ENVIRONMENTAL AND COMMUNICABLE DISEASE EPIDEMIOLOGY IN QUEENSLAND

Thesis for the degree of Master of Philosophy (Applied Epidemiology)

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Queensland Health

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Originality statement

I hereby declare that this submission is my own work and to the best of my knowledge it contains no materials previously published or written by another person, or substantial proportions of material which have been accepted for the award of any other degree or diploma at Australian National University or any other educational institution, except where due acknowledgement is made in the text. Any contribution made to the research by others, with whom I have worked is explicitly acknowledged in the thesis. I also declare that the intellectual content of this thesis is the product of my own work, except to the extent that assistance from others in the project's design and conception or in style, presentation or linguistic expression is acknowledged.

Cushla Mary Coffey

08 November 2018

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Abbreviations

ABS	Australian Bureau of Statistics
AIDS	Acquired immunodeficiency syndrome
BLL	Blood lead level
CDB	Communicable Diseases Branch
CDC	Centers for Disease Control and Prevention (Atlanta, GA, United States of America)
CRF	Case report form
CI	Confidence interval
DNRM	Department of Natural Resources and Mines
ED	Emergency Department
EDSSS	Emergency Department Syndromic Surveillance System
EHO	Environmental health officers
ELSS	Excessive lead surveillance system
ESL	English as a second language
GCPHU	Gold Coast Public Health Unit
GI	Gastrointestinal
GIS	Geographic information systems
GP	General practitioners
HAV	Hepatitis A
HHS	Hospital and Health Service
HPB	Health Protection Branch
IQ	Intelligence quotient
IRR	Incidence rate ratio
LRJ	Lead risk job
mg/L	Micrograms per litre
MAE	Master of Philosophy in Applied Epidemiology
MLVA	Multi-locus number tandem repeat analysis
NAAT	Nucleic acid amplification test
NAT	Nucleic acid test
NHMRC	National Health and Medical Research Council
NNDSS	National Notifiable Disease Surveillance System
NTM	Nontuberculosis mycobacteria
NOCS	Notifiable Conditions Register

OCT	Outbreak Control Team
OFN	OzFoodNet
OR	Odds ratio
PPV	Positive predictive value
PHMO	Public Health Medical Officer
PHU	Public health unit
RR	Risk ratio
ug/dL	Micrograms per decilitre
umol/L	Micromoles per litre
US	United States of America
WGS	Whole genome sequencing
WHO	World Health Organization
WHS	Workplace health and safety
WHSQ	Workplace Health and Safety Queensland

Abstract

I undertook a field placement with the Health Protection Branch, Queensland Health from February 2017 to December 2018. This thesis contains the projects undertaken. My outbreak project, provided in chapter two, describes the enhanced surveillance of gastroenteritis to detect outbreaks at the Gold Coast 2018 Commonwealth Games, including description of two outbreaks investigated. Chapter three describes an analysis of *Giardia* trends in the United States and project undertaken with the Centers for Disease Control and Prevention. Chapter four describes an evaluation of the blood lead surveillance system in Queensland, including capillary screening program implemented in a mining town. Chapter five is my epidemiology project which explored the epidemiology of nontuberculosis mycobacteria and association with areas of low water disinfection in southeast Queensland. The final chapter in this thesis includes other public health experiences gained during the placement, including my role in teaching. These projects and experiences fulfil the core requirements of the Master of Philosophy (Applied Epidemiology) Program at the Australian National University.

Chapter 1 Introduction to field placement and summary of experience

Field placement overview

1.1. My placement for the duration of the Master of Philosophy in Applied Epidemiology (MAE) Program was at the Health Protection Branch (HPB), Prevention Division of Queensland Health. The HPB aims to “safeguard the community from potential harm or illness caused by exposure to environmental hazards, diseases and harmful practices”. Seven areas exist within the HPB: Environmental Health Regulation and Standards (Environmental Hazards), Water Quality, Food Safety Standards and Regulation, Radiation Health, Health Protection Licensing, Public Health Incidence Management and the Public Health Regulation Systems Unit.

My primary role was within Environmental Hazards and Water Quality, although I worked with other units as required. In January 2018, I undertook a research visit with the Waterborne Disease Prevention Branch at the Centers for Disease Control and Prevention (CDC) in Atlanta, United States (US). From March until May 2018, I assisted with the surveillance and outbreak response at the Gold Coast Public Health Unit (GCPHU) in the lead up, during and following the Gold Coast 2018 Commonwealth Games (the Games).

1.2.

Summary of degree requirements

Investigate an acute public health event

I investigated the ability of the enhanced surveillance system established during the Games to identify and characterise clusters and outbreaks for public health investigation. I focused on two unique systems including the intensified surveillance and advanced reporting of notifiable communicable disease data, and Emergency Department Syndromic Surveillance System (EDSSS). Two community gastroenteritis outbreaks were detected and investigated through the surveillance systems. As part of the investigations, I developed self-administered electronic questionnaires, interviewed cases and conducted descriptive and analytical studies as part of the GCPHU team. A key recommendation for health agencies is to establish enhanced surveillance systems during mass gathering events.

Other outbreak activities

I assisted with other cluster and outbreak investigations through the Metro North Public Health Unit (MNPHU), Metro South Public Health Unit, GCPHU and Queensland OzFoodNet. In Queensland, the Public Health Microbiology Laboratory routinely subtypes all *Salmonella* Typhimurium strains using the molecular technique multi-locus number tandem repeat analysis (MLVA). I followed up two separate clusters of *Salmonella* with the same MLVA profiles, interviewed study controls as part of the multijurisdictional hepatitis A (HAV) outbreak associated with pomegranates, and assisted with the data management of an overseas acquired HAV outbreak in a family. I regularly attended the Communicable Diseases Branch surveillance meetings and I supported the daily surveillance functions undertaken by the Queensland OzFoodNet team for a period.

Data analysis

Giardiasis is the most common intestinal parasitic disease of humans identified in the US and an important waterborne disease. Jurisdictions in the US voluntarily report giardiasis cases to the CDC. I described the epidemiology of giardiasis cases from 1995–2016 using data obtained from National Notifiable Disease Surveillance System. I found that the annual incidence of reported giardiasis decreased across all age groups, consistent with previous reports. Incidence rates in males and older age groups have not decreased to the same extent as incidence rates in females and children, and may reflect either changes in surveillance methods or changes in exposures. Further investigation into the risk factors of populations with higher rates of giardiasis will support prevention and control efforts.

Evaluate a public health surveillance system

I conducted the first evaluation of the Queensland excessive blood lead surveillance system. Lead exposure remains an ongoing public health issue in Queensland largely due to historical contamination. Recent decreases in the levels required to be notified increase the importance of strong surveillance systems and clear lead management practices. Evidence was obtained using semi-structured interviews with selected stakeholders, via extraction and analysis of lead notification data and following a review of the system protocols and documents.

From 2000–2017, there were 2,549 individuals notified with elevated blood lead, of which 40.1% were attributed to occupational exposure reflecting regular biological screening required by legislation. The evaluation revealed the system was acceptable to users, conceptually simple, flexible and integrated within an existing system. An absence of clearly documented aims and objectives, incomplete surveillance data, absence of regular data reviews, and a lack of analysis or dissemination translated to limited usefulness for stakeholders and for public health action.

Plan and conduct an epidemiological study

Nontuberculosis mycobacteria (NTM) are opportunistic pathogens associated with environmental sources, such as municipal and recreational water sources. NTM is a notifiable condition in Queensland, Australia and cases reported have increased in recent years. As some NTM occur in treated drinking water supplies, I mapped cases of NTM species potentially associated with water and water quality results for chloramine disinfectant to identify potential sources of infection and areas of higher risk in southeast Queensland. I observed increasing trends of NTM in Queensland including species potentially associated with water. The clustering of these environmental species were largely identified in southeast Queensland, the significance of which is unclear. I did not observe an association between notification rates of water-associated NTM and total chlorine results. It may be important to examine potential transmission of NTM to humans from the environmental using whole genome sequencing.

Prepare a scientific manuscript for a peer-reviewed journal

I prepared the following manuscript:

- Evolving epidemiology of reported giardiasis cases in the United States, 1995–2016, submitted for publication (Chapter 3).

I contributed to the following perspective piece with fellow MAE scholars:

- Perspectives from a mass gathering deployment—Field Epidemiology Trainees at the Gold Coast 2018 Commonwealth Games, published by Global Biosecurity.

Communication to a lay audience

I compiled a summary report and fact sheet on blood lead and pre-eclampsia for stakeholders at Queensland Health and in Mount Isa (Chapter 4).

Conference Presentations

I gave the following oral presentations at scientific conferences:

- OzFoodNet face-to-face meeting, Alice Springs, Northern Territory, June 2018
- Environmental Health Australia 77th Annual State Conference 2018, Surfers Paradise, Queensland, September 2018
- The Annual Scientific Meeting of the Australasian Epidemiological Association, Fremantle, Western Australia, October 2018

I presented two posters at the following conference:

- CDC International Conference on Emerging Infectious Diseases, Atlanta, US, August 2018

Lessons from the field

I prepared a teaching exercise titled “Preventative screening of excessive lead exposure in a mining town” (Chapter 6). I attended Lessons from the Field exercises, prepared by fellow MAE scholars.

Teaching

I participated in a teaching activity titled “Evaluating complex public health interventions” with fellow MAE scholars Bobby Maher and Jana Sisnowski for first-year MAE scholars (Chapter 6).

Coursework

I successfully completed the required coursework subjects of the MAE Program:

- POPH8316—Outbreak Investigation

- POPH8317—Public Health Surveillance
- POPH8315—Research Design and Methods
- POPH8315—Analysis of Public Health Data
- POPH8914—Issues in Applied Epidemiology.

Table 1 provides a summary of core competencies delivered by chapter as required by the MAE Program.

Table 1 Summary of projects and degree requirements

Degree requirements	Chapter					
	1	2	3	4	5	6
Outbreak investigation		✓				
Data analysis			✓			
Evaluate a surveillance system				✓		
Epidemiological study					✓	
Teaching activities						✓
Conference presentation		✓	✓		✓	
Communication with a lay audience				✓		
Late draft of a peer review publication			✓			

Chapter 2 Enhanced surveillance of gastroenteritis to detect outbreaks at the Gold Coast 2018 Commonwealth Games

2.1. Prologue

This chapter describes the enhanced communicable disease surveillance system established for the Gold Coast 2018 Commonwealth Games (the Games). I investigated the ability of the enhanced surveillance system to identify and characterise clusters and outbreaks for further public health action, with a focus on two different systems including the:

- intensified surveillance and advanced reporting of notifiable disease data; and
- Emergency Department Syndromic Surveillance System (EDSSS) and electronic questionnaire.

The enhanced surveillance system detected two gastroenteritis outbreaks; these were investigated to determine the cause and instigate appropriate public health action.

Project role

My role with the Gold Coast Public Health Unit (GCPHU) Epidemiology and Data team commenced in November 2017. I assisted with surveillance and outbreak functions in the lead up, during and following the Games. In addition, I evaluated the validity and reliability of the gastrointestinal (GI) syndrome definition, established as part of the EDSSS. During March and April 2018, I was based at the GCPHU where I attended planning meetings during the development phase, team meetings throughout and debriefing sessions following the Games. I assisted in multiple cluster and outbreak investigations in the Gold Coast region, including during the Games period and in the months following.

I gained broad experience at GCPHU including: questionnaire design; interviewing and contact tracing; data entry, management, analysis and reporting; compiling the epidemiology sections of the daily situational reports; monitoring syndromic surveillance trend data; and following up sentinel surveillance sites. I had the opportunity to attend several environmental site inspections. This developed my understanding of inspection procedures and sampling techniques. I provided input

in the final summary report written by the GCPHU and presented key findings relating to the EDSSS at multiple conferences on behalf of the GCPHU.

I played a key role assisting with both outbreak investigations described in this chapter. I contacted the referring clinicians and potential secondary cases (i.e. childcare centres), interviewed cryptosporidiosis cases, assisted with data entry into Epi Info™ software, the daily surveillance of food and water venues, and data management, and participated in Outbreak Control Team (OCT) meetings. During the norovirus outbreak, I developed a self-administered questionnaire to be completed by student volunteers and academic staff as part of the immediate investigation and cohort study, completed the data management, statistical analysis, and final summary report under supervision.

Lessons Learned

The placement at the GCPHU was invaluable in the development of my field epidemiology skills. I gained experience in cluster and outbreak detection, investigation and response. I was encouraged to participate in all regular meetings during the Games, including those attended by high-level stakeholders. This enabled me to see and understand the importance of clear leadership during the public health response to mass gatherings, the decision-making processes, risk assessment, political considerations, how to implement and evaluate control measures, and when to commence and conclude public health investigations. By assisting with a variety of public health responses, I learnt about the epidemiology of different communicable diseases and the multidisciplinary roles undertaken during an outbreak. I also learnt how to use Epi Info™ software to create questionnaires, extract, manage and analyse data.

Working with the newly developed EDSSS, I gained a comprehensive understanding of syndromic surveillance as a system, including advantages, disadvantages and potential to enhance traditional surveillance systems. The project allowed me to learn about public health considerations in mass gathering events, importance of planning, communication challenges, rumour mitigation, and consideration of political sensitivities. Importantly, I learnt that despite the increased potential for adverse public health events, outbreaks do not always occur during mass gathering events as one might expect.

Public health impact

The chapter was presented to the GCPHU Medical Director and the Epidemiology and Data team. The recommendations are intended to inform an evaluation of the EDSSS, electronic questionnaire and assist with future cluster and outbreak detection on the Gold Coast. I presented the findings at multiple meetings and conferences, adding to the body of work on surveillance strategies during mass gatherings.

Communication

Oral presentations were conducted at the following conferences and meetings:

- OzFoodNet face-to-face meeting, Alice Springs, Northern Territory, June 2018
- Environmental Health Australia (Qld) INC 77th Annual State Conference 2018, Surfers Paradise, Queensland, September 2018
- Annual Scientific Meeting of the Australasian Epidemiological Association 2018, Fremantle, Western Australia, October 2018

Core MAE requirements addressed

- Investigation of an acute public health event
- Literature review (Appendix A)
- Data analysis
- Presentation at a national conference (Appendix B)

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In addition to my field and academic supervisors, key GCPHU individuals important to my field-based training included Dr Satyamurthy Anuradha, Ian Hunter, Deena Seesaengnom, Sharon Jurd, Fiona Vosti, as well as many other communicable disease, environmental health and administration staff. I acknowledge the invaluable opportunity to participate in epidemiological investigations provided by

the GCPHU. I am also grateful to Queensland OzFoodNet epidemiologists Russell Stafford and Robert Bell, who provided ongoing technical guidance, education and support during these outbreaks.

Abstract

Background

During mass gathering events, including large international sporting events, existing surveillance systems may be inadequate to detect clusters or outbreaks, requiring temporary enhancement. An enhanced communicable disease surveillance system was established during the Gold Coast 2018 Commonwealth Games (the Games), including intensified surveillance and advanced reporting of selected notifiable disease data, and establishment of the Emergency Department Syndromic Surveillance System (EDSSS) and electronic exposure questionnaire.

Aim

To examine the role of the enhanced surveillance system in improving public health surveillance during the Games period, 20 March–18 April 2018; determine if the advanced reporting of notifiable disease data, and EDSSS and electronic questionnaire were able to detect gastrointestinal (GI) clusters and outbreaks; and provide recommendations for public health action.

Methods

Intensified surveillance and advanced reporting of notifiable disease data were conducted for selected GI pathogens including *Cryptosporidium*, *Salmonella* and *Shigella*. Telephone interviews were conducted with the notified cryptosporidiosis cases using the standard Queensland Health Cryptosporidiosis case report form (CRF); bi-weekly monitoring of case counts occurred only for the other GI pathogens. The EDSSS received, aggregated and displayed GI syndrome case data from two Gold Coast public hospital EDs, through a secure information management platform. Eight physician assigned diagnoses were aggregated to categorise the gastroenteritis (gastro) syndrome. Real-time data were aggregated and displayed on a visual dashboard, which was monitored daily for unexpected signals. Signal alert thresholds were based on historical ED GI presentation data and a statistical algorithm. A SMS text message was manually sent to gastro patients by the GCPHU containing a link to an electronic questionnaire, aimed at identifying food or water exposures within the three days prior to illness. Responses were extracted and analysed daily for common food and water venues in the Gold Coast to guide public health investigation.

Results

One small outbreak of four cryptosporidiosis cases was detected through the advanced reporting of notifiable disease data during the Games period. Three of the four cases notified were linked to a common recreational swimming venue; one case was a household contact. *Giardia intestinalis* cysts and *Cryptosporidium* oocysts were detected in samples collected from one of the three pools at the recreational swimming venue. Following the Games, an outbreak of suspected norovirus was detected through the EDSSS and electronic questionnaire, which was linked to the consumption of complimentary food items served during a university open day. A cohort study found limited evidence of an association between some meat items consumed and GI illness.

Conclusion

The enhanced surveillance systems improved detection of GI illness and potential outbreaks. The cryptosporidiosis outbreak demonstrated system sensitivity for outbreak detection through enhanced collection of routinely reported data. The norovirus outbreak demonstrated the ability of the EDSSS and electronic exposure questionnaire to detect outbreaks, provided a surveillance tool to monitor GI trends in the Gold Coast community at any point and with little demand on staff time, and reassurance that an outbreak was not occurring during a mass gathering event. The EDSSS and electronic questionnaire have been embedded in the GCPHU surveillance as a legacy of the Games. A key recommendation for health agencies is to establish these systems to allow early and improved GI outbreak detection through better surveillance capacity and appropriate public health action if required.

2.3. Introduction

The World Health Organization (WHO) defines a mass gathering as an event attended by a sufficient number of people to strain the planning and response resources of a community, state or nation.[1] The complexity and workload of surveillance is increased during mass gathering events due to changes in population and population density, increased numbers of potentially diseased persons, population migration and introduction of new services and behaviours.[2] Mass gatherings may compromise the health system of the city or country in which they are held[3] and existing surveillance systems may be inadequate to detect clusters, unexpected or emerging health threats, requiring temporary enhancement.[4] Such enhanced systems may be achieved by modifying routine notifiable disease reporting and establishing additional data systems, such as syndromic surveillance.

Syndromic surveillance is the collection, analysis, interpretation and dissemination of health-related data to enable to early identification of the impact (or absence of) potential health threats, leading to effective public health action.[5] Clinical case features (preceding definitive laboratory diagnosis) are classified into a ‘syndrome’ of illness and aggregated data reviewed for early outbreak warnings or signals (when there is a statistically significant increase in the value of an indicator above expected values).[1] Syndromic surveillance systems monitoring emergency department (ED) data are commonly used during mass gathering events. There are several strengths of syndromic surveillance including improved sensitivity and timeliness, and the ability to demonstrate an absence of observed illness increases which can be reassuring that an outbreak is not occurring, a negative finding not easily or readily available from traditional surveillance systems.[1, 3] In particular, syndromic systems can use available data streams from hospitals and health services to capture data on acute illness in the community, with limited effort to public health agencies.

The evidence for the risk of disease transmission at international sporting events and ability of syndromic surveillance systems to detect outbreaks is not clear.[3] Syndromic surveillance can detect public health threats and support an epidemiologic investigation. Early warning of increased gastroenteritis cases linked

to an outbreak of *Salmonella* spp. was provided during the Athens 2004 Olympic Games.[6] Outbreak simulation data used to evaluate the London 2012 Olympic and Paralympic Games (the London 2012 Games) public health surveillance system hypothesised potential detection for small localised food poisoning incidents via ED syndromic surveillance.[5] Syndromic surveillance identified a GI cluster at a mass youth 10-day camping event in the United States (US) state of Virginia.[7] Criticisms of syndromic surveillance include uncertainty regarding their ability for timely and sensitive detection of emerging diseases,[8] ability to detect local GI outbreaks with few, mild or dispersed cases,[9] potential to miss outbreaks due to their rare occurrence, and before well established and effective surveillance systems which already exist in developed countries.[2, 10]

The Gold Coast 2018 Commonwealth Games (the Games) was held from 5 to 14 April 2018. The 10-day event hosted 71 nations at 17 sporting venues across four event cities. The event was attended by an estimated 6,600 athletes and team officials, and 591,000 domestic and international visitors in Queensland.[11] The duration of stay and presence of a large numbers of visitors increased the potential for the spread of communicable diseases in Queensland during the Games, and globally as visitors returned to their country of residence. The Gold Coast Public Health Unit (GCPHU) was the local agency responsible for providing enhanced public health surveillance and outbreak response. The enhanced Games surveillance period (the Games period) operated over 30 days starting two weeks before the opening ceremony and finishing three days after the closing ceremony (20 March–18 April 2018).

Enhanced surveillance was geared towards detecting food-related and waterborne gastrointestinal (GI) illnesses. GI outbreaks have been reported from mass gatherings such as festivals[12] and sports events.[13-15] They are a serious public health threat as the responsible agents may be highly infectious, transmit rapidly and cause severe clinical illness. Outbreaks may be prevented or mitigated, although detection and control is challenged by the significant heterogeneity in the etiology, clinical severity and transmission of GI infections.[16] In Queensland, only a select number of GI pathogens are notifiable under the *Public Health Act 2005*[17]; illness reported may be delayed or missed by the existing passive surveillance system. The enhanced surveillance system consisted of strategies established for

the event, and several enhancements to existing routine surveillance systems (Figure 1). New developments included the establishment of the Emergency Department Syndromic Surveillance System (EDSSS) and electronic exposure questionnaire. Enhancements to existing systems included the intensified surveillance and advanced notifiable disease reporting to the GCPHU for investigation.

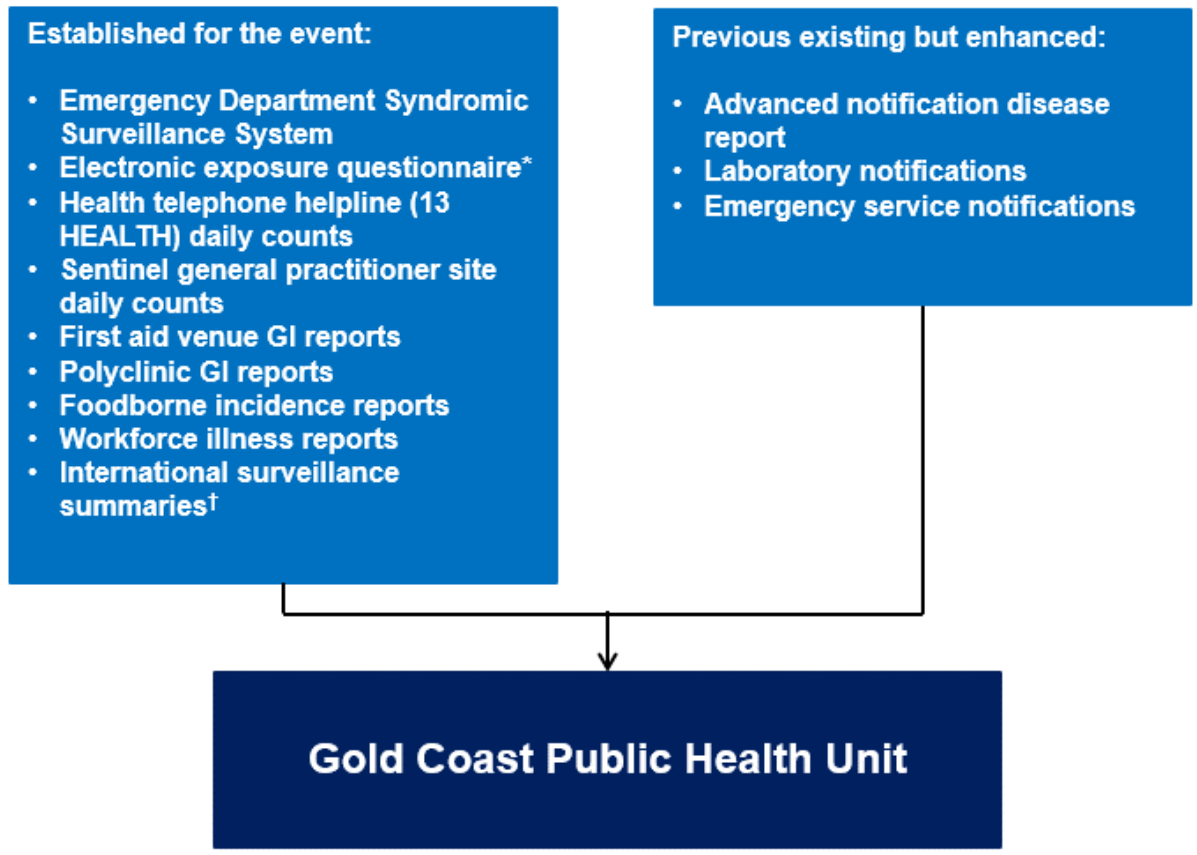

Figure 1 Surveillance systems for gastrointestinal illness used by the Gold Coast Public Health Unit, 20 March–18 April 2018

Abbreviations GI = Gastrointestinal

* Electronic exposure questionnaire was accessed through a SMS invitation sent to individuals who presented to EDs, via a verbal invitation for those accessing the telehealth service (13 HEALTH) and pamphlets available at sentinel surveillance sites.

† International surveillance summaries were compiled by the Commonwealth Government staff based in the Australian Capital Territory.

Objectives

2.4. Focusing on the enhanced communicable disease surveillance system established during the Games, I aimed to see if two individual surveillance components were able to detect outbreaks. My objectives were to:

- Determine if the intensified surveillance and advanced reporting of notifiable disease data, and EDSSS and electronic exposure questionnaire were able to detect outbreaks
- Investigate each outbreak to determine the cause
- Provide public health recommendations.

2.5. Methods

2.5.1. Design and setting

The method section will describe the GI presentations detected through the EDSSS during the Games, as well as the general investigation steps for the two outbreaks. The advanced reporting of notifiable disease data, and EDSSS and electronic exposure questionnaire each identified one outbreak. The first outbreak detected by the advanced reporting of notifiable disease data occurred during the Games period and involved four cryptosporidiosis cases. The second outbreak was detected after the Games period by the EDSSS through two cases who attended University X Open Day, presented to the ED with GI illness and completed the electronic exposure questionnaire.

2.5.2. Enhanced surveillance systems

Intensified surveillance and advanced reporting of notifiable disease data were conducted for GI pathogens *Cryptosporidium*, *Salmonella* (all serotypes) and *Shigella*. Line-listed data of GI pathogen laboratory tests requested by Gold Coast general practitioners (GPs) were sent to the GCPHU Epidemiology and Research team for investigation (daily for cryptosporidiosis and biweekly for *Salmonella* and *Shigella*). Each cryptosporidiosis case was followed up using the standard Queensland Health case report form (CRF).[18] Responses were entered at the time

of telephone interview into Epi Info™ and analysed daily for common food and water venues attended by cryptosporidiosis cases within their exposure period (onset date – 12 days).

The GCPHU established syndromic surveillance using data entered into electronic ED patient management information systems from the two public EDs in the Gold Coast. Patient data were transmitted to a computerised patient management information system at 15-minute intervals. The focus of syndromic surveillance was GI illness due to resource constraints, season and the potential for GI outbreaks to occur. The gastro syndrome was based on aggregated ED provisional four-hour diagnoses including: gastroenteritis, viral gastroenteritis, dysentery, protozoal intestinal infection, food poisoning, pseudomembranous colitis, and nausea and vomiting. Data obtained included patients' age, sex, locality, presenting complaint, nurse assigned urgency of treatment (triage category), diagnosis, date and time of visit and hospital name. Data were available on an automated virtual dashboard in real-time and reported once daily in the situational report, using data extracted from the dashboard.

Statistical control charts were used to automatically detect increases in GI activity, using three years of historical baseline data to establish a moving threshold and standard deviations (SD) of counts. Patient presentation counts were examined daily and compared with trends in the day-of-the-week upper and lower intervals (mean ± 1.5 SD). A signal for further investigation was defined as any daily count that exceeded 1.5 SD above the baseline mean on two consecutive days.

Patient data were manually extracted from the management information system and stored in an Excel spreadsheet. Patients discharged were sent an SMS requesting they complete the electronic exposure questionnaire in the hyperlink, created using Epi Info™ software. The questionnaire was a new tool developed using the Centers for Disease Control and Prevention (CDC) online software, Epi Info™ (Appendix C). The questionnaire captured clinical presentation details, healthcare sites visited, date of illness onset, if other individuals were known to be unwell, and food and water venues attended within three days prior to illness onset. The aim was to rapidly scan if a food or water venue in the Gold Coast was linked to two or more cases of GI illness within a seven-day reporting period for further

public health investigation. Questionnaires submitted were extracted daily, and analysed using Microsoft Excel and Stata, version 14.1 (StataCorp, College Station, TX, USA) for common venues. Common food or water venues were reported in the daily sitrep for further review by the communicable disease and environmental health teams.

2.5.3. Case finding and definition

Cryptosporidium, *Salmonella* and *Shigella* are notifiable diseases under legislation in Queensland and laboratories must report confirmed cases to public health authorities. When a cryptosporidiosis case was notified, the referring GP was contacted, and a telephone interview conducted with the case using the standard Queensland Health CRF. A confirmed case of cryptosporidiosis is defined as a person with laboratory definitive evidence including detection of detection of *Cryptosporidium* oocysts in a faecal sample; detection of *Cryptosporidium* specific antigen; or detection of *Cryptosporidium* by nucleic acid testing.[19] *Salmonella* and *Shigella* notifications received biweekly were reviewed for unusual patterns and trends; no case follow-up occurred. Outbreak 1 was detected through follow-up of line lists of individuals who were recently tested sent daily to the GCPHU

Outbreak 2 was detected through two individuals who presented to the ED with GI illness, completed an electronic questionnaire and indicated they ate food items from Venue X, served at University X Open Day. Case finding occurred through an electronic self-completed questionnaire administered to student volunteers and staff present at University X Open Day, provided by the university management. The questionnaire was developed using Epi Info™ with questions including demographic characteristics, clinical history of GI illness, food items consumed on the day and other relevant risk factors (Appendix D). The questionnaire was emailed and a reminder sent three days later. A confirmed case was defined as a person who consumed food items from Venue X at University X Open Day on Sunday 12 August 2018, developed symptoms of gastroenteritis (diarrhoea [three or more loose bowel motions within 24 hours] and/or nausea/vomiting) within five days of consumption, and was diagnosed with a gastroenteritis-causing organism in their stool sample. A probable case was defined as a person who consumed food items from Venue X at University X Open Day on Sunday 12 August 2018,

developed symptoms of gastroenteritis (diarrhoea [three or more loose bowel motions within 24 hours] and/or nausea/vomiting) within five days of consumption.

2.5.4. Environmental investigation

Cryptosporidiosis case follow-up identified a common recreational swimming venue in the Gold Coast had been attended by multiple cases during their incubation period. This prompted public health actions including: notifying the venue operators/managers, conducting a site visit, collection of water samples, laboratory testing, review of maintenance records (i.e. chlorination and filtration records), and mobilising control measures. The norovirus outbreak detected initiated an environmental investigation at the food premise where food was prepared. This included collecting a list of the food items, checking for illness among staff, collecting information on the preparation, storage and distribution of food, and consulting local government. A site visit of University X was also performed, and rooms examined where the food was stored, prepared and those surrounding including the bathrooms.

2.5.5. Data analysis

Information collected were collated, cleaned and analysed. I described data using numbers and proportions. Where appropriate, I calculated crude risk ratios (RR) with 95% confidence intervals (CI), to determine statistical associations between individual food items and illness. I also completed univariate analyses on aggregated food items. Fisher's exact p-values (where expected cell frequencies were less than 5) were calculated for RRs, with $p<0.1$ considered significant for inclusion in the multivariate analyses. For multivariate analyses, I calculated adjusted odds ratios (ORs) with 95% CIs using stepwise logistic regression on all significant food items and $p<0.05$ considered significant in the final model. I analysed data using Stata, version 14.1 (StataCorp, College Station, TX, USA), Microsoft Excel™ and Epi Info™.

2.5.6. Microbiological analysis

Real-time reverse transcription polymerase chain reaction (RT-PCR) testing of one faecal specimen was conducted using GeneXpert at the Gold Coast University Pathology laboratory.

2.5.7. Ethics approval

Ethics approval for this evaluation was granted by the Australian National University Human Research Ethics Committee (HREC 2018/437) and Gold Coast Hospital and Health Service Human Research Ethics Committee (LNR/2018/QGC/45911).

2.6. Results

2.6.1. Enhanced surveillance system overview

During the Games period, 15 cryptosporidiosis cases were notified to the GCPHU and 13 cases able to be interviewed. One outbreak was detected, linked to a recreational swimming venue involving four cases. Nine cases were classified as sporadic and two unknown.

There were 338 presentations for GI illness detected through the EDSSS during the Games period, compared to a four-year average of 323 and an increase of 4.6% (Figure 2). The majority of individuals were aged less than five years and 15–34 years (26.9% each). The most frequent four-hour diagnoses were gastroenteritis (36.1%), nausea and vomiting (30.2%) and viral gastroenteritis (29.6%). Of the 338 ED GI presentations, a mobile number was available for 90.1% (307/338) individuals. A SMS follow-up invitation was sent to 307 individuals, of whom 88 (28.7%) completed an exposure questionnaire. The number of daily GI presentations exceeded the threshold once on 3 April 2018. The GI cases were investigated by age group, sex, clinical presentation (four-hour diagnoses) and locality; no clustering was identified. As the daily count did not exceed the threshold on two consecutive days no further public health action was taken. The exposure questionnaires did not identify any common food and water venues for further public health investigation.

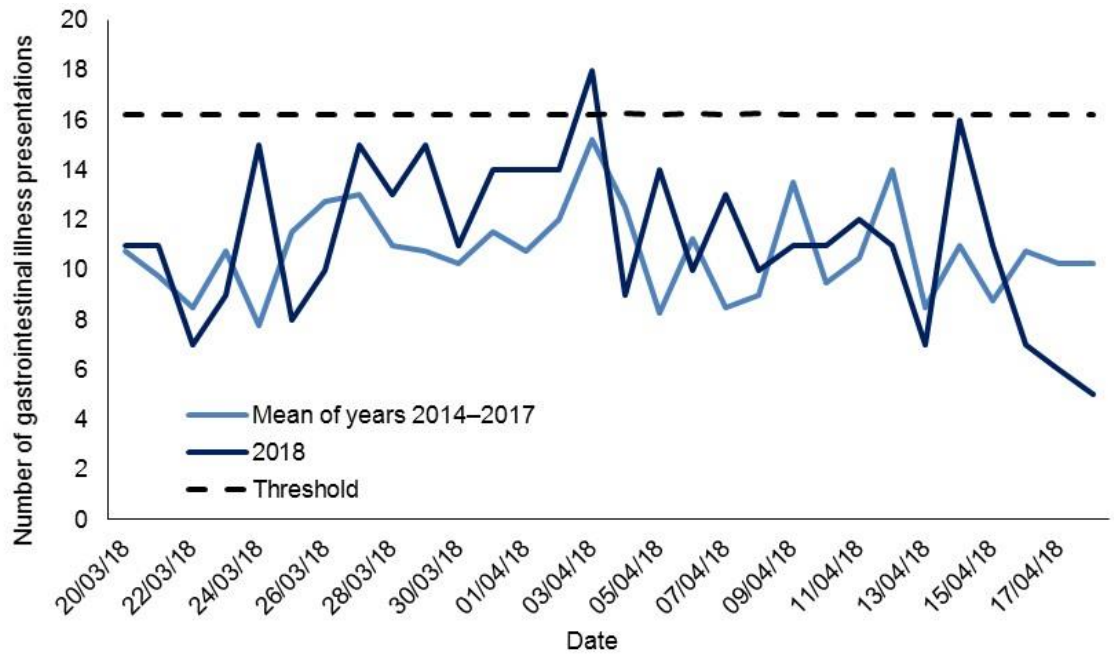

Figure 2 Emergency Department Syndromic Surveillance System gastrointestinal presentations during the Games period, Gold Coast, 20 March–18 April 2018

2.6.2. Outbreak 1 – Cryptosporidiosis detected in the Gold Coast through the advanced notifiable disease surveillance

On 1 April 2018, three cryptosporidiosis cases aged less than five years reported swimming at recreational swimming venue X during their incubation period (Figure 3). The cases were notified to Queensland Health between 27 and 29 March 2018. A fourth related case came to attention through the follow-up of a sibling (case 3) and was notified on 5 April 2018 following testing.

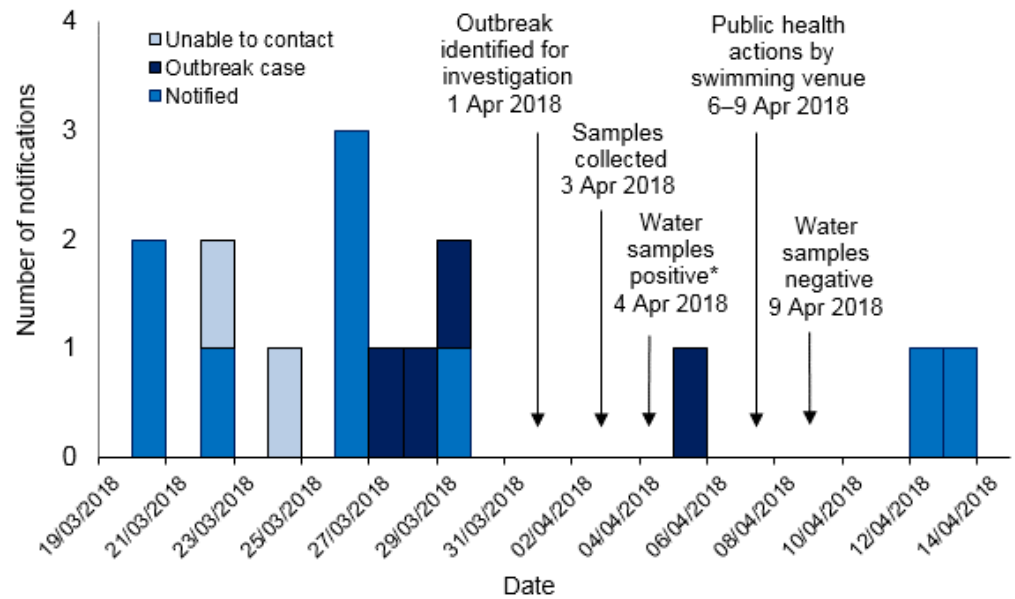

Figure 3 Timeline of cryptosporidiosis cases† by notification date and outbreak response, Gold Coast, 20 March–18 April 2018

***** *Giardia intestinalis* cysts and *Cryptosporidium* oocysts were detected in one of the three swimming pools

† n=15

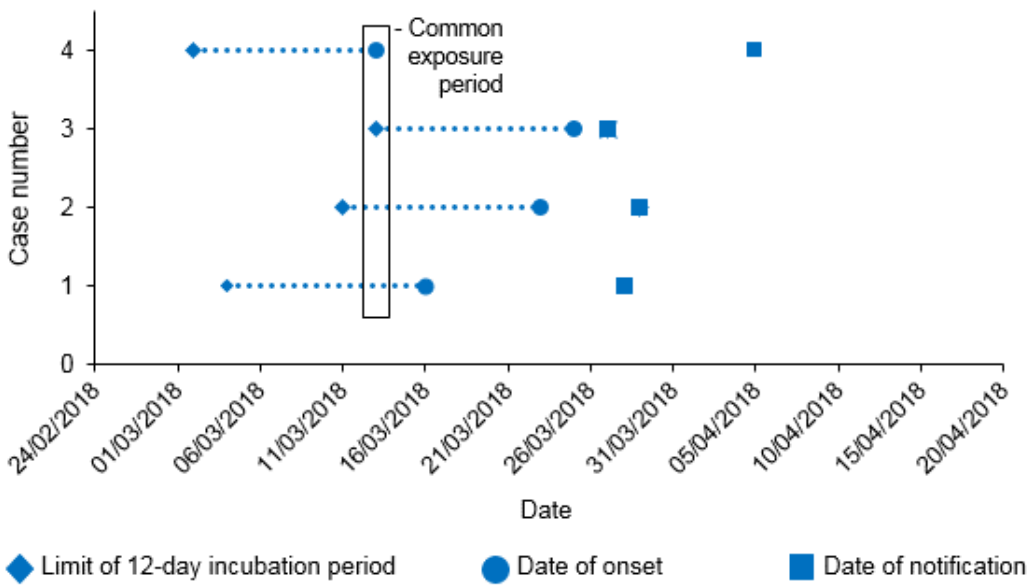

Figure 4 Exposure periods for cases* of cryptosporidiosis during a community outbreak, Gold Coast, 20 March–18 April 2018

* n=4

Four cases were identified with illness onset dates from 13 March to 25 March 2018 (Figure 4). Of the four cases, symptoms included diarrhoea (100%), vomiting (75%), fever (50%), stomach cramping (50%), and loss of appetite (50%). Two (50%) cases reported unresolved diarrhea at the time of interview. All three (75%) initial cases reported weekly or bi-weekly swimming lessons at recreational swimming venue X, during their incubation period. The fourth case did not swim at recreational swimming venue X, although was a household contact (sibling) of one of the other cases and could be explained by potential person-to-person transmission of *Cryptosporidium*. One case reported swimming on the day of symptom onset, although not following. The father of one case who regularly attended the swimming lessons with his child also had unresolved GI symptoms according to his spouse, although was unable to be contacted. Two children attended different childcare centres, where other unwell children were reported. Both childcare centres were contacted; however, there were no reports of GI illness by management. No exposures to other water sources (e.g., water park, drinking untreated or tank water) were reported. All four cases reported exposure to domestic pets, although none demonstrated any GI symptoms.

In total, 15 cryptosporidiosis cases were notified during the Games period and 13 were able to be interviewed. Of the 15 cases, the median age was 13 years (range 1–77 years); 66.7% were female. Of 13 cases interviewed, diarrhoea (84.6%) was the most frequently reported symptom, followed by stomach cramps (76.9%), loss of appetite/weight (69.2%), vomiting (38.5%) and fever (38.5%). Four individuals (26.7%) reported ongoing diarrhoea at the time of interview. The median incubation period was 12 days (range 5–18 days); one case reported reoccurring symptoms and was excluded from the calculations of the median incubation period. No cases were hospitalised. Potential risk factors reported by cases included swimming in recreational public pools (53.8%), contact with children in childcare centres (46.2%), contact with domestic pets (46.2%) and contact with a person with diarrhoea (53.8%).

Environmental health investigation

Giardia intestinalis cysts and *Cryptosporidium* oocysts were reported in samples collected from one of the three pools at recreational swimming venue X on 3 April

2018, despite superchlorination[a] occurring within the previous week. Records on the days the cases attended the pool showed chlorine levels were lower than required (2 mg/L, ppm).[20] Management were advised of the water quality results, a notice was served to recreational swimming venue X requiring the water quality comply with microbial standards and chemical parameters (including maintaining appropriate free residual chlorine) and corrective actions be undertaken including drainage of the affected pool, steam cleaning of pool components, replacement of filters and all replaceable parts. A subsequent inspection on 5 April 2018 found the required pool had been drained. Resampling on 9 April 2018 found no evidence of *Giardia intestinalis* cysts and *Cryptosporidium* oocysts.

2.6.3. Outbreak 2 – Gastrointestinal illness detected through the Emergency Department Syndromic Surveillance System and electronic questionnaire

Of the 78 students and staff volunteers contacted during this outbreak investigation, 61 questionnaires were completed. Responses were excluded if they were duplicates (1/61), not on the original contact list (3/61) or did not eat the food items (7/61). The response rate was calculated as 70.4% (50/71), where those that did not eat the food items were considered unexposed and removed from the total denominator of at-risk persons.

Of the 50 study participants, 36 were female (72%). One symptomatic patient submitted a faecal sample and RT-PCR testing was undertaken for bacterial (*Salmonella* spp*, Shigella* spp, *Campylobacter* spp*, Yersinia entercolitica, Vibrio cholerase* and *Vibro parahaemolytics*) and viral pathogens (adenovirus, norovirus and rotavirus). The specimen was positive for norovirus. There were 33 cases of GI illness associated with this outbreak (one confirmed, 32 probable). Five (15.2%) of the 33 cases presented to an ED, 11 (33.3%) presented to a GP only, and two (6.1%) presented to both the GP and ED. No cases were hospitalised.

[a] Superchlorination refers to the addition of two to four times the normal daily dose of chlorine to pool water to eliminate chloramines and other impurities.

The median age of outbreak cases was 21 years (range 18–63 years); 69.7% were female. The median incubation period for 31 of the 33 cases able to be calculated was 29 hours (range 8–73 hours), based on the time respondents indicated food items were consumed, or the time food was first served (1100hrs) if no time was recorded in the questionnaire.

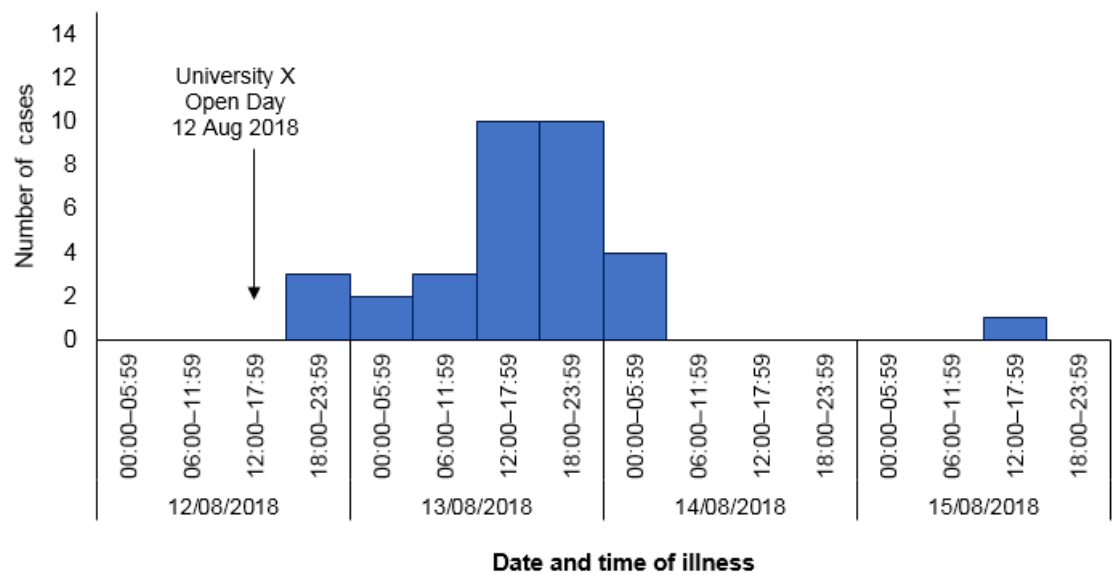

Figure 5 Epidemiology curve of reported cases, by date and time of onset of illness*, 12–15 August 2018

* Food was served until 1400hrs in a separate room to the auditorium where University X Open Day was held.

The median duration of illness for those who recovered was 2 days (range <1–5 days; 30/33). Nausea/vomiting (100%; 33/33), stomach cramping/abdominal pain (87.9%; 29/33), aches and pains (87.9%; 29/33) and diarrhoea (69.7%; 23/33) were more frequently reported, followed by other[b] symptoms (30.3%; 10/33) and blood in stools (6.1%; 2/33).

Analytic epidemiology

Cases were more likely to have eaten a turkey (RR 1.7, 95% CI 1.3–2.2) and Italian BMT (Bigger Meatier Tastier) sub (RR 1.5, 95% CI 1.1–2.2) (Table 2). Eating a vegetarian sub (RR 0.4, 95% CI 0.1–0.9) or wrap (RR 0.5, 95% CI 0.2–1.2) was

[b] Other reported symptoms included headache, fever, anorexia, migraine, dizziness and generalised weakness

protective. Six food items reported non-corresponding CIs and p-values which may be explained by small values in the cells, leading to nonsensical data and poor performance in the model. Attending any group events within the previous 12 hours was not associated with increased illness (RR 1.1, 95% CI 0.7–1.7). No cases reported being ill prior or had any ill family members.

After aggregating meat and vegetarian subs and wraps, eating a chicken (RR 1.6, 95% CI 1.1–2.2), turkey (RR 1.6, 95% CI 1.2–2.2), roast beef (RR 1.6, 95% CI 1.2–2.2) and BMT item (RR 1.7, 95% CI 1.2–2.4) remained the food items associated with the highest risk of illness, and vegetarian items least likely (RR 0.4, 95% CI 0.2–0.9). Multivariate regression analysis was constructed using the aggregated chicken, turkey, roast beef, BMT and vegetarian sub or wrap (p-value<0.1). Eating the chicken (OR 9.8, 95% CI 1.2–55.4) or BMT sub or wrap (OR 20.0, 95% CI 2.2–181.7) remained significantly associated with illness only, although results questionable due to small numbers.

Table 2 Attack rates and risk ratios for food exposures of gastrointestinal illness (confirmed and probable) and non-cases during an outbreak at a university in the Gold Coast, 12 August 2018

Food exposure	Ill exposed			Non-ill exposed			Risk Ratio	95% CI	p-value*
	No.	Total	AR%	No.	Total	AR%			
Subs									
Chicken	9	11	81.8	24	39	61.5	1.3	0.9–1.9	0.210
Ham	12	15	80.0	21	35	60.0	1.3	0.9–1.9	0.171
Turkey	9	9	100.0	24	41	58.5	1.7	1.3–2.2	0.017
Roast beef†	8	9	88.9	25	41	61.0	1.5	1.0–2.0	0.109
BMT	10	11	90.9	23	39	59.0	1.5	1.1–2.1	0.048
Vegetarian	3	11	27.3	30	39	76.9	0.4	0.1–0.9	0.002
Wraps									
Chicken†	6	6	100.0	27	44	61.4	1.6	1.3–2.1	0.061
Ham	10	13	76.9	23	37	62.2	1.2	0.8–1.8	0.334
Turkey	4	5	80.0	29	45	64.4	1.2	0.8–2.0	0.486
Roast beef†	5	5	100.0	28	45	62.2	1.6	1.3–2.0	0.091
BMT†	5	5	100.0	28	45	62.2	1.6	1.3–2.0	0.091
Vegetarian†	3	9	33.3	30	41	73.2	0.5	0.2–1.2	0.022
Salad bowl†	3	3	100.0	28	45	62.2	1.6	1.3–2.0	0.185
Subs or wraps combined									
Chicken	14	16	87.5	19	34	55.9	1.6	1.1–2.2	0.028
Ham	18	23	78.3	15	27	55.6	1.4	0.9–2.1	0.091
Turkey	12	13	92.3	21	37	56.8	1.6	1.2–2.2	0.020
Roast beef	12	13	92.3	21	37	56.8	1.6	1.2–2.2	0.020
BMT	14	15	93.3	19	35	54.3	1.7	1.2–2.4	0.008
Vegetarian	4	13	30.8	29	37	78.4	0.4	0.2–0.9	0.002

Abbreviations AR = Attack Rate; CI = Confidence Interval; BMT = Bigger Meatier Tastier

* p-value statistically significant at α=0.05 (Fisher exact two-tailed).

† Non-corresponding p-values and confidence intervals.

Environmental health investigation results

An environmental site inspection occurred on 17 August 2018. No leftover food items from the complimentary lunch were available for microbiological testing and there was no evidence of illness among the food handlers from Venue X. Venue X also provided subs and wraps to another school during the open day; there were no reports of GI illness. A vomit odour was reported during site inspection from the

bathroom facilities closest to the room where food was served. Viral gastroenteritis information and infectious control advice were provided to university management.

Discussion

2.7. The enhanced communicable disease surveillance established for the Games identified one small outbreak through the enhancement of the routine notifiable diseases reporting, and one outbreak through the establishment of the EDSSS and electronic questionnaire. Intensified surveillance and advanced reporting of cryptosporidiosis detected a small outbreak at a recreational swimming venue, which otherwise would have been unidentified. During the Games, the largely automated syndromic surveillance system and electronic questionnaire provided a timely and sensitive surveillance tool to monitor GI trends in the Gold Coast community at any point in time, increased the availability of food and water exposure data from large numbers of individuals and provided reassurance a large-scale outbreak was not occurring, with limited burden to the GCPHU. The identification of a norovirus outbreak following the Games period demonstrated the ability of this surveillance system to increase the sensitivity and timeliness of outbreak detection, contribute to epidemiological surveillance by supplementing traditional surveillance and providing an additional measure of infectious disease activity.

The findings indicate that no significant outbreaks of GI illness occurred during the Gold Coast 2018 Commonwealth Games. No major public health incidents were reported through syndromic surveillance, similar to the London 2012,[3] Beijing 2008,[21] Athens 2004[6] and Sydney 2000 Olympic Games.[22] Only a few small outbreaks of GI infections were recorded at the London 2012 Games, although not considered a risk or important to the event. Infectious disease reports were also typical for mass gatherings.[3] At the Beijing 2008 Games, the number of GI infections decreased, no outbreaks were reported and syndromic surveillance identified that recorded diarrhoea events were largely caused by contaminated food.[21] During the Sydney 2000 Olympics, a syndromic surveillance network in 15 EDs across New South Wales detected non-GI clusters, including injuries and drug overdoses.[22] Preventative efforts, such as food safety management measures were hypothesised as contributing to the absence of GI illness outbreaks during the Sydney 2000 Olympics.[21]

There were limited public implications from the two outbreaks. One outbreak was detected through the intensified surveillance and advanced reporting of notifiable diseases data, not involving Games participants and spectators. The outbreak demonstrated the sensitivity of the system and ability to show patterns of disease through enhancements and changes to routine notifiable surveillance. Epidemiological and microbiological evidence of cryptosporidiosis promoted public health control measures in a recreational swimming centre, potentially preventing additional cases in the community. Limitations of passive surveillance in detecting outbreaks were highlighted. Cryptosporidiosis notifications are not routinely investigated by all PHUs and it is likely that outbreaks are under-recognised in Queensland. Routine follow-up of cryptosporidiosis notifications in at-risk individuals and maintenance of intensified investigations by Queensland PHUs is recommended to identify community outbreaks, guide research priorities, prevention and control efforts.

The norovirus outbreak detected at a university highlighted the ability of the EDSSS and electronic questionnaire to detect outbreaks in a region. In contrast, in the US state of Florida, a statewide survey over a one-year period aiming to characterise norovirus activity found syndromic surveillance did not contribute to detecting GI outbreaks. Furthermore, no counties reported first learning of a norovirus outbreak through the use of this system.[23] Findings were attributed to the relative infrequency of hospitalisations or ED visits for norovirus gastroenteritis and self-limiting symptoms.[23] Outbreaks of GI disease often go unrecognised, unreported, are not investigated or investigated poorly due to a lack of epidemiological expertise, resource constraints and competing priorities.[24] This outbreak would have gone undetected had the two initial cases detected by the EDSSS developed a milder clinical illness and not presented to the public EDs.

Norovirus outbreaks are a regular and ongoing public health issue faced by PHUs, currently captured only through the mandatory reporting of institutional outbreaks (residential aged care facilities and child care centres); no passive surveillance or national register exists in Queensland. The EDSSS and electronic questionnaire demonstrated a clear ability to detect GI outbreaks. The systems continue to be used as legacy for public health surveillance, resulting in a sustainable benefit for

the Gold Coast population. Additional data surveillance systems, such as syndromic surveillance systems may help facilitate faster detection, timely investigation and response to these types of outbreaks.

The enhanced surveillance systems improved sensitivity compared to existing systems alone, although with GI illness there is always the possibility of under counting cases and potentially missing outbreaks. Detection of cryptosporidiosis and follow-up was limited to individuals who presented for healthcare, underwent diagnostic testing and had laboratory evidence of infection. The clinical presentation of GI illness includes a broad spectrum of symptoms and outcomes, ranging from asymptomatic presentation to hospitalisation and even death. The EDSSS is more likely to reflect severe illness rather than those who are asymptomatic, have mild or subclinical cases not reported to ED, or are treated for milder symptoms at other healthcare facilities.[25] Additional surveillance data, including telephone helpline, pharmacy sales and GP out-of-hours attendances for GI illness were collected during the Games and may have addressed this gap in surveillance. Ongoing collection and monitoring of these other available data sources should be considered to facilitate detection of GI outbreaks during routine surveillance.

Syndromic surveillance may also not be the best system for detecting epidemics over a large geographical area, rather small localised incidents due to events such as food poisoning.[5, 6] During the Games, outbreaks may have been missed by syndromic surveillance, as local residents moved out of the area covered by the mass gathering surveillance, reducing the reported cases and accuracy of the threshold used to trigger a public health response.[3] Games-related outbreaks may have been missed as cases could have obtained medical care from team doctors, although these would have potentially captured through other surveillance sources such as polyclinic reports. Cluster identification is subjective and unusual patterns and clusters may have been missed, including age-specific trends due to the aggregated data. The classification of the GI syndrome using four-hour diagnoses may be less effective than other methods, such as use of triage free-text. Naive Bayes classifier of free-text triage diagnosis data has shown utility in providing a more sensitive and earlier detection of cases of acute GI syndrome than other methods.[26]

Both surveillance systems required varying public health input. The intensified notifiable disease surveillance for cryptosporidiosis was more labour intensive, requiring manual extraction of cases, contact with GPs and telephone interviews with cases. The intensive work raises questions surrounding system sustainability and net benefit gained. The EDSSS and electronic questionnaire was largely automated with little impact on the PHU, although required the sending of SMS texts manually and ongoing data interpretation. Electronic questionnaire responses are affected by uptake of mobile technology, excluding those who did not record a mobile number at ED and some age groups less likely to respond (older and younger individuals). Electronic questionnaire response trends and reasons for incompletion requires further investigation. Recommendations for the EDSSS include review of the diagnoses used to classify the gastro syndrome, monitoring of age specific trends (<5 years and ≥5 years), development of protocols to guide epidemiologists and prioritise actions in deciding whether to pursue an investigation.

There were several limitations in our outbreak investigations. The cryptosporidiosis outbreak was relatively small with only four cases and unable to be investigated through an analytical study. The norovirus investigation was limited by the lack of RT-PCR testing on samples from other student volunteers and staff reporting GI illness, resulting in potential misclassification of asymptomatic cases. The testing may have provided additional evidence to support the conclusion of a norovirus outbreak or identified additional GI pathogens. There is also potential selection bias introduced through non-responders, as those who completed the questionnaire are likely to differ in many ways from those who preferred not to. However, efforts were made to ensure a high-level of follow-up occurred to minimise this bias. The study may have also benefited from a higher response rate which would have increased the statistical power, potentially strengthened the measures of association and provided additional evidence of a suspected foodborne source.

Mass gathering surveillance is recommended due to the inherent characteristics that place them at higher risk of adverse health events.[1] Significant public health expenditure is invested through the establishment of new processes and systems, with planning commencing over years. However, evidence suggests mass

gatherings in high-income countries, such as Australia, have a small impact on the health of the local population and systems. The likelihood of disease importation is reduced through the health and wealth of visitors to these events. There are also limited opportunities for infection with the local endemic community because visitors spend most of the time in hotels and event venues.[22] Although the risk of infectious diseases at sporting mass gatherings is low, the need for reassurance of the absence of public health problems to multiple stakeholders (e.g., organising committee, government and media) is higher than has been previously considered, and this could challenge conventional public health surveillance systems.[1, 3] In addition, there is also a need to challenge rumours and false stories, which was shown to take up significant time at the London 2012 Olympics.[1] The importance of this reassurance is only beginning to be described in mass gathering publications.[3] Surveillance systems are generally not designed to demonstrate an absence of an outbreak and future mass gathering organisers need to be aware of this important component.[3]

2.8.

Conclusion

Early detection of outbreaks and rapid implementation of prevention and control measures is important to minimise potential morbidity and mortality. In this chapter I highlight two outbreaks detected through the enhanced surveillance system that would have been unrecognised through traditional surveillance methods. The systems showed value for public health surveillance and monitoring, adding to existing evidence on the usefulness of these systems during mass gathering events and following during routine epidemiological surveillance.[27] Linkages between EDs and public health agencies can provide rapid information that enhance outbreak detection and response during mass gathering events and routine surveillance. The EDSSS developed specifically for the Games demonstrated multiple functions during and post-Games including monitoring GI illness, assisting in the early detection of clusters and outbreaks, filling stakeholder information needs and providing reassurance, and helping the GCPHU to protect community health. The system will continue to operate in the Gold Coast as part of the Games' legacy. A key recommendation for public health agencies during mass gathering events is to have these enhanced surveillance systems in place to allow early identification of

the presence or absence of outbreaks and appropriate public health action if required.

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Appendix A–Literature review outline

Introduction

2.10. In this literature review I focused on GI outbreaks and the role of the ED in population health surveillance and outbreak detection, although other sources of surveillance data and types of outbreaks were examined. Studies which evaluated and examined the reliability and validity of syndromes categorised were also reviewed.

Methods

The research questions selected for this literature review were:

1. Can syndromic surveillance detect clusters or outbreaks during a mass gathering event?
2. How are GI syndromes categorised and thresholds established?
3. How can the GI syndromes categorised be validated?

The focused literature search was conducted primarily using PubMed Health, although other databases were also used to locate articles. The top search terms are described in Table 3. The search date included publications between 1980 and 2018, English language publications and syndromic surveillance systems used both in Australia and internationally.

Table 3 Literature search terms

Top search terms	Search terms
Target disease	Gastrointestinal illness
Index test	Syndromic surveillance
Important terms	Outbreak detection Outbreaks Disease outbreaks Disease Detection
Relevant patient or population characteristics	Mass gathering events Emergency Department
Gold standard	Laboratory techniques
Validation	Validation

Table 4 Focused literature review search terms and resulting number of articles

History	Search terms	Article results
#1	Search ((((("Gastrointestinal Diseases"[Mesh]) OR gastrointestinal diseases) OR ((Diagnosis/Broad[filter]) AND (gastrointestinal)))) AND (("Sentinel Surveillance"[Mesh]) OR syndromic surveillance)	398
#2	Search (((((("Gastrointestinal Diseases"[Mesh]) OR gastrointestinal diseases) OR ((Diagnosis/Broad[filter]) AND (gastrointestinal)))) AND (("Sentinel Surveillance"[Mesh]) OR syndromic surveillance)) AND ((("Disease Outbreaks"[Mesh]) OR outbreaks) OR detection)	355
#3	Search ((((((("Gastrointestinal Diseases"[Mesh]) OR gastrointestinal diseases) OR ((Diagnosis/Broad[filter]) AND (gastrointestinal)))) AND (("Sentinel Surveillance"[Mesh]) OR syndromic surveillance)) AND ((("Disease Outbreaks"[Mesh]) OR outbreaks) OR detection)) AND ((mass gathering) OR (("Emergency Service, Hospital"[Mesh]) OR emergency department))	32
#4	Search (((((((("Gastrointestinal Diseases"[Mesh]) OR gastrointestinal diseases) OR ((Diagnosis/Broad[filter]) AND (gastrointestinal)))) AND (("Sentinel Surveillance"[Mesh]) OR syndromic surveillance)) AND ((("Disease Outbreaks"[Mesh]) OR outbreaks) OR detection)) AND ((mass gathering) OR (("Emergency Service, Hospital"[Mesh]) OR emergency department)))) AND (("Laboratories"[Mesh]) OR laboratory disease detection)	4
#5	Search (((((((("Gastrointestinal Diseases"[Mesh]) OR gastrointestinal diseases) OR ((Diagnosis/Broad[filter]) AND (gastrointestinal)))) AND (("Sentinel Surveillance"[Mesh]) OR syndromic surveillance)) AND ((("Disease Outbreaks"[Mesh]) OR outbreaks) OR detection)) AND ((mass gathering) OR (("Emergency Service, Hospital"[Mesh]) OR emergency department)))) AND (("Validation Studies" [Publication Type]) OR Validation)	2
#6	Search (((((("Sentinel Surveillance"[Mesh]) OR syndromic surveillance)) AND ((("Disease Outbreaks"[Mesh]) OR outbreaks) OR detection)) AND (("Emergency Service, Hospital"[Mesh]) OR emergency department)) AND (("Validation Studies" [Publication Type]) OR Validation)	19

Abstracts were scanned for relevance from search number three and six. Full-text versions of relevant articles were located and their reference lists were manually searched to identify any additional relevant manuscripts. For selected studies, the following data were recorded: authors and year of publication; setting/system/event; syndromes; outcome/results; validation measure/statistical measure (if relevant); and additional comments.

Gastrointestinal syndrome categorisation

Available ED-related data include ambulance presentations, nurse triage free-text, triage presenting complaint (chief complaint), outpatient and hospital admission, four-hour diagnoses and ICD-coded diagnoses. The use of free-text in nursing assessments or ED discharge notes contain vital signs and symptom information and may increase the sensitivity and specificity of case classification. However additional software is required including the application of language processing techniques to extract information from transcribed reports.[10, 28]

There was considerable heterogeneity in the categorisation of the GI syndrome across system examined. GI syndromes are frequently categorised using triage data, ICD-coded diagnoses, data stored in triage free-text, or a combination of these methods. The use of different datasets requires an understanding of the data limitations. The triage presenting complaint are the earliest clinical data, entered in the ED system shortly after patient's arrival and available immediately, although may not represent the clinical state of the patient.[10, 28] Diagnoses are commonly used and can be more specific than automatically classified syndromes; however, may be entered by busy ED physicians with varying accuracy or not entered at all.[2, 10] As only one diagnosis code may be entered in the system for each patient presenting, a limited part of the presenting syndrome is available.[10] Studies have validated the use of GI chief complaint and discharge diagnosis showing a high correlation for some syndromes.[28] Nursing free-text may often a fuller picture of the presenting syndrome as can assign multiple categories.[10] Naive Bayes classifier of free-text triage diagnosis data has shown utility in providing a more sensitive and earlier detection of cases of acute GI syndrome than ICD-coded diagnoses.[29]

Thresholds

Statistical alarms should include effective and automatic visual data for the manual investigation stage not to hinder the real-time data analysis process. Thresholds for the system should be simple, sensitive and ideally, provide a high positive predictive value. There are multiple aberration detection methods to identify increases in syndromes. The challenge for outbreak detection is to identify a signal

corresponding to an outbreak or cluster amid background ‘noise’ in the data. Localised and more granular data are usually characterised by increased variability in daily presentations and this makes the identification of real events among the background ‘noise’ challenging’.[30] Signal detection methods have not yet been standardised.[27] The methods used range from simple mathematical functions to complex statistical simulation models and are summarised in Table 5.

Table 5 Summary of statistical thresholds applied in syndromic surveillance systems

Statistical method	Description
Line graphs	Line graphs of time series data offer a simple and effective way to review data and undertake exploratory analysis.
Moving averages	Moving averages include appropriate smoothing method to distinguish the expected changes in consultation numbers due to the day of the week, public holiday and influx of individuals; 7-day, working day moving average and extended working day moving average.
Counts	Weekly counts compared to the same week in the previous five years (seasonal comparison) Daily counts compared to the same day in the previous five years (seasonal comparison) Weekly counts compared to the previous 51 weeks Daily counts compared to the previous 51 same day of the week Daily index of increase (an indication of the sustained increase in a syndrome). An index value of 15 is used to trigger signals and as an indicator of the start of the influenza season.
Proportion	Proportion of syndrome against total utilisation.
Cumulative sum (cusum)	Statistical quality control method operates by accumulating deviations between observations and expectations. Advantage includes detecting smaller shifts from the mean, similar shifts in the mean more quickly and less advanced computation.
Standard deviation (SD)	Variable levels of standard deviation (against historical data) may be considered including tiered systems. The NSW ED and ambulance public health surveillance system PHREDSS uses 5 SD above the mean as the cut off to indicate when counts are significantly elevated, including specific age groups and locations. The CDC uses 3 SD above the mean for some surveillance monitoring.

Poisson regression model	Calculated the expected number of cases based on national gastro survey (circa 2010), estimated number of episodes per person per year, per week and Poisson probability. Establishes an alert based on the probability being statistically significant ($p<0.05$) and warrant further investigation.

Validation methods

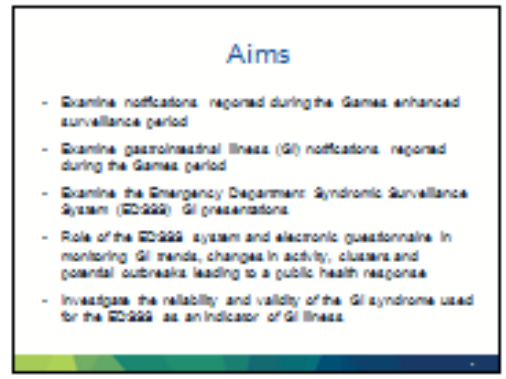
There were two main validation methods identified in the literature. Existing data sources used to evaluate GI outbreaks include ambulatory care diagnoses,[31] emergency room records,[32] ED chief complaints,[33, 34] telephone helplines[35] and medication sales, as well as the same patient population to evaluate multiple electronic medical records.[16] Proxy and historical outbreaks covering a range of public health scenarios have been used to evaluate syndromic data.[36]

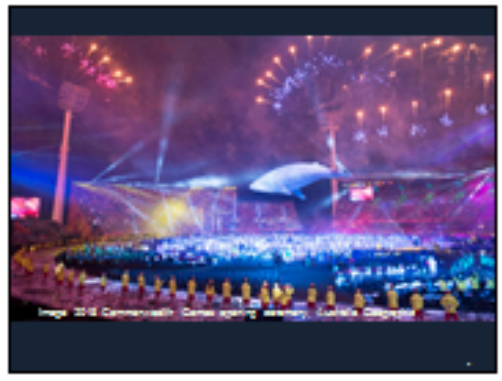
Summary

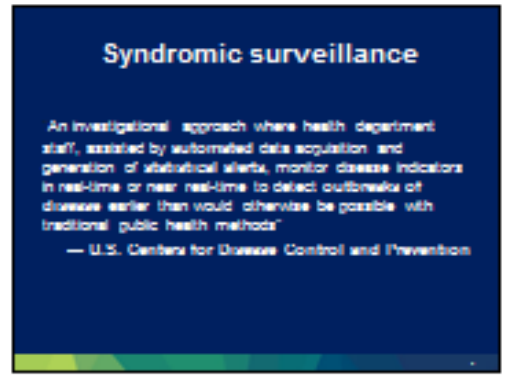
From the analysis of the selected publications, there is conflicting evidence for of the utility of syndromic surveillance in outbreak detection and during mass gatherings. Identifying and assigning syndromes trends to specific causes remains a challenge, there is considerable heterogeneity between systems, no clearly defined guidelines how this surveillance should be conducted and the types of syndromes which should be reported.[37] It is difficult to initiate a public health response following an increase in the incidence of a symptom or clinical sign that in most cases represents a naturally occurring and self-limiting illness.[10] The role of syndromic surveillance during mass gathering events requires further evaluation.

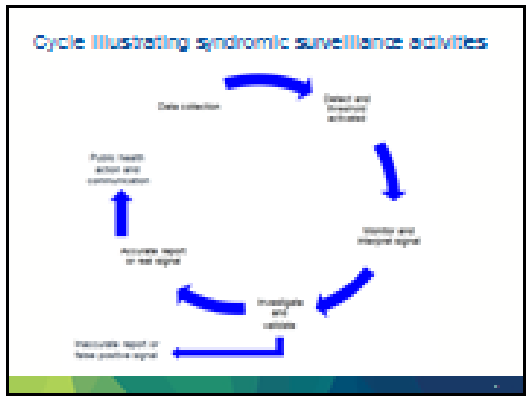
Appendix B–Presentation at the Environmental Health Australia Annual State Conference, Gold Coast, September 2018

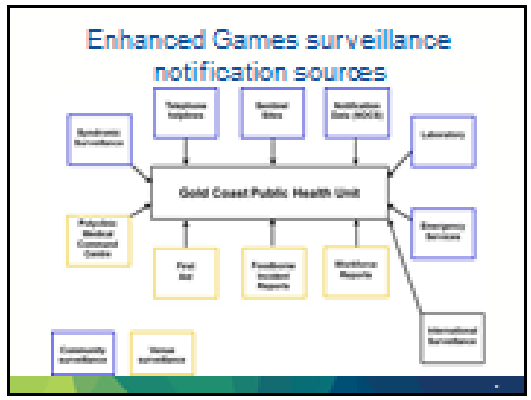
2.11.

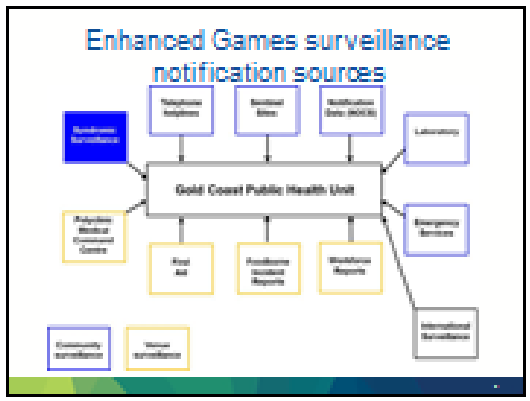




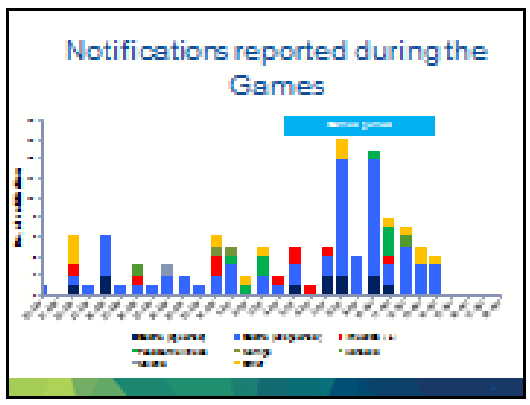


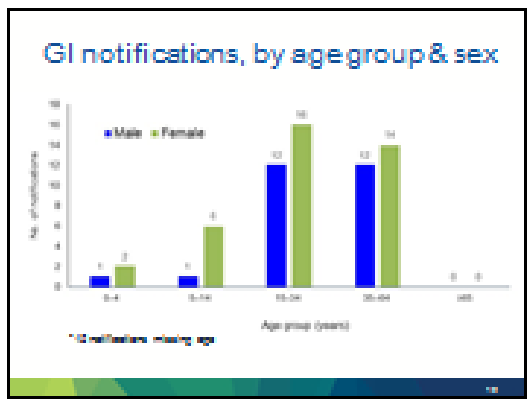

Cycle illustrating syndromic surveillance activities

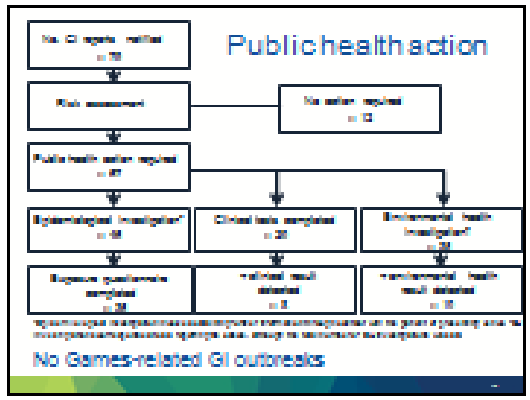

Enhanced Games surveillance notification sources
Gold Coast Public Health Unit

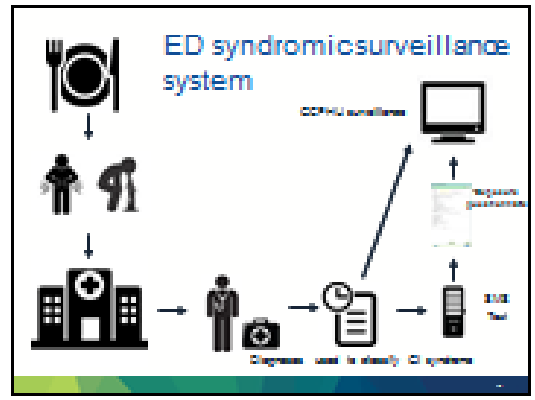

Enhanced Games surveillance notification sources
Gold Coast Public Health Unit

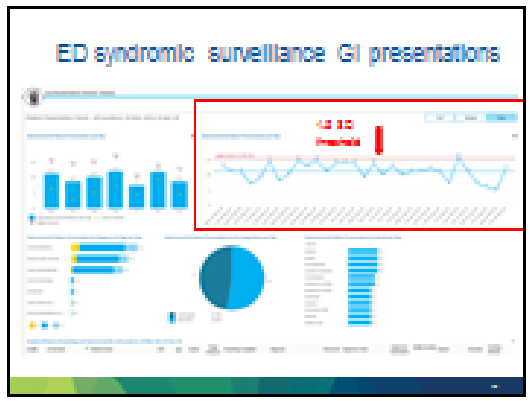

A virus has spread among Olympic staff workers ahead of the Games
London 2012: 30 people fall ill after norovirus hits athletics event

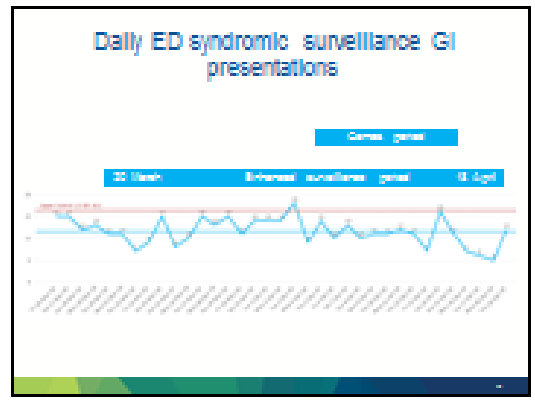

Notifications reported during the Games

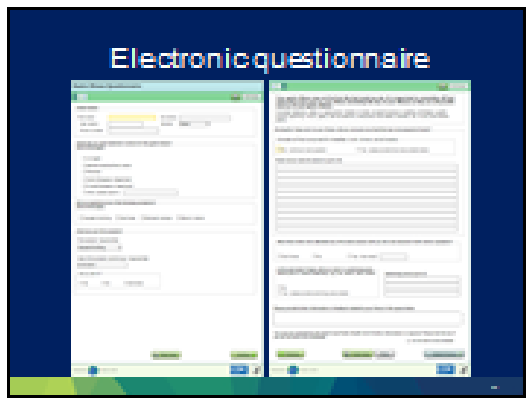

GI notifications, by age group & sex
Male
Female
Age group (years)

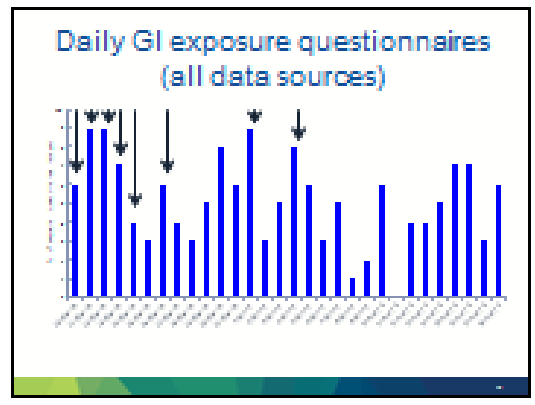

Public health action
No Games-related GI outbreaks


ED syndromic surveillance system

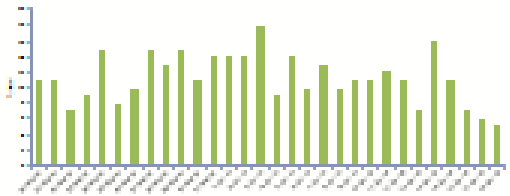

ED syndromic surveillance GI presentations


Daily ED syndromic surveillance GI presentations

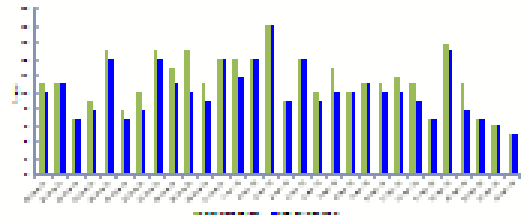

Electronic questionnaire


Daily GI exposure questionnaires
(all data sources)

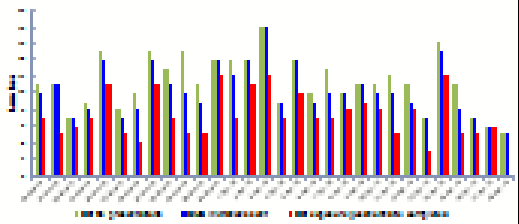
Daily ED GI presentations & questionnaire response



Daily ED GI presentations & questionnaire response



Daily ED GI presentations & questionnaire response



Validation of GI syndrome

- Identified different data streams (e.g., GI notifications, telephone helplines) & analyzed weekly counts → poor correlation
- Outbreak register → not all generated a signal
- True increases in GI activity identified across different data sources → no gold standard
- Context of limitations
  - Selected notifiable pathogens captured
  - Broad spectrum of gastrointestinal pathogen
  - Outbreaks compared
  - Absence identifiable data
  - Healthcare seeking behaviour

Key challenges to enhanced Games surveillance

- Integrated many data sources
- Notifications queryable
- Follow up resource intensive
- Timeliness of notifications by stakeholders variable

Discussion enhanced Games surveillance

- Timely analysis and sharing of results critical
- Sensitive system
- Presence of GCPHU clinical staff facilitated GI notifications
- Political factors
- System processes to facilitate data capture and transfer
- No outbreaks detected

Key challenges to ED syndromic surveillance

- Establishment of threshold for public health action
- Selection bias
- Delays in receiving exposure information through questionnaires & lower response rate
- Localised daily data variable & presentations influenced by many factors (e.g., day, public holidays)
- Role of epidemiologist
- Limited geographic area

Discussion ED syndromic surveillance

- Enhanced real-near time data
- Rapidly collect information on large numbers of individuals
- Cost effective
- Validation of GI syndrome challenging
- Evidence of usefulness post-Games

Conclusion

- Viability of syndromic surveillance system demonstrated
- Syndromic surveillance complement to existing traditional surveillance systems – not replacement
- Effective situational awareness
- Reassurance to public & stakeholders
- Opportunity to create a legacy system

Conclusion (continued)

- Additional work to prospectively assess ability of syndromic surveillance to identify known outbreaks
- Exposure questionnaire response rate
- Explore other potential syndromic surveillance data sources
- Development of response mechanisms & protocols

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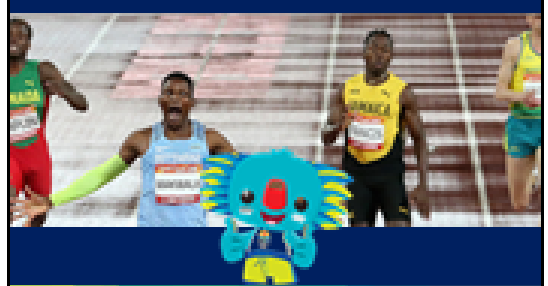
Public Health Nurses

Environmental Health Officers
Data Analysis Team

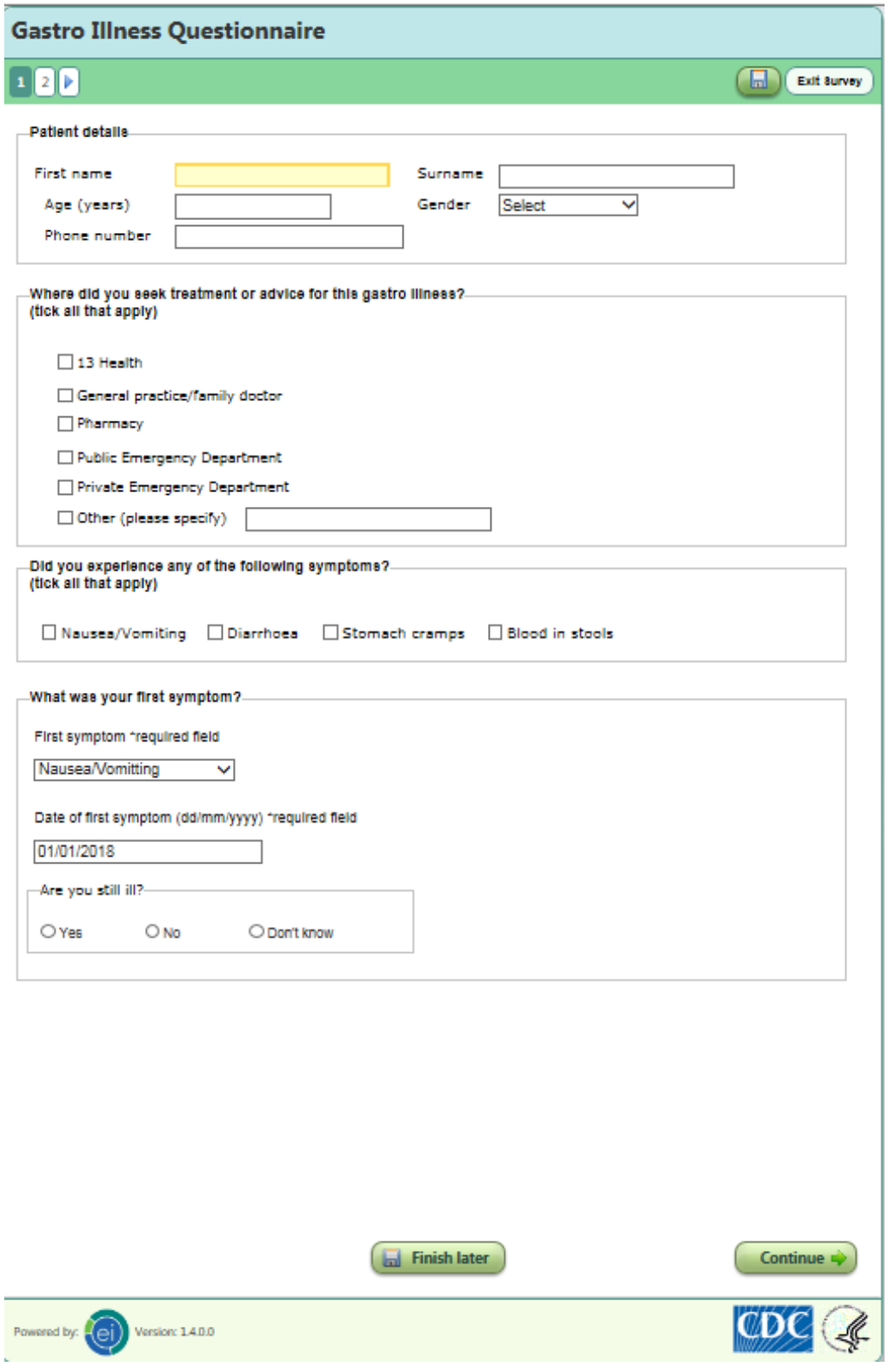
MAC
Martyn Kirk
Suzanne Huxley
Kelley Meder
Kaitlyn Vass
Brigita Osterberger

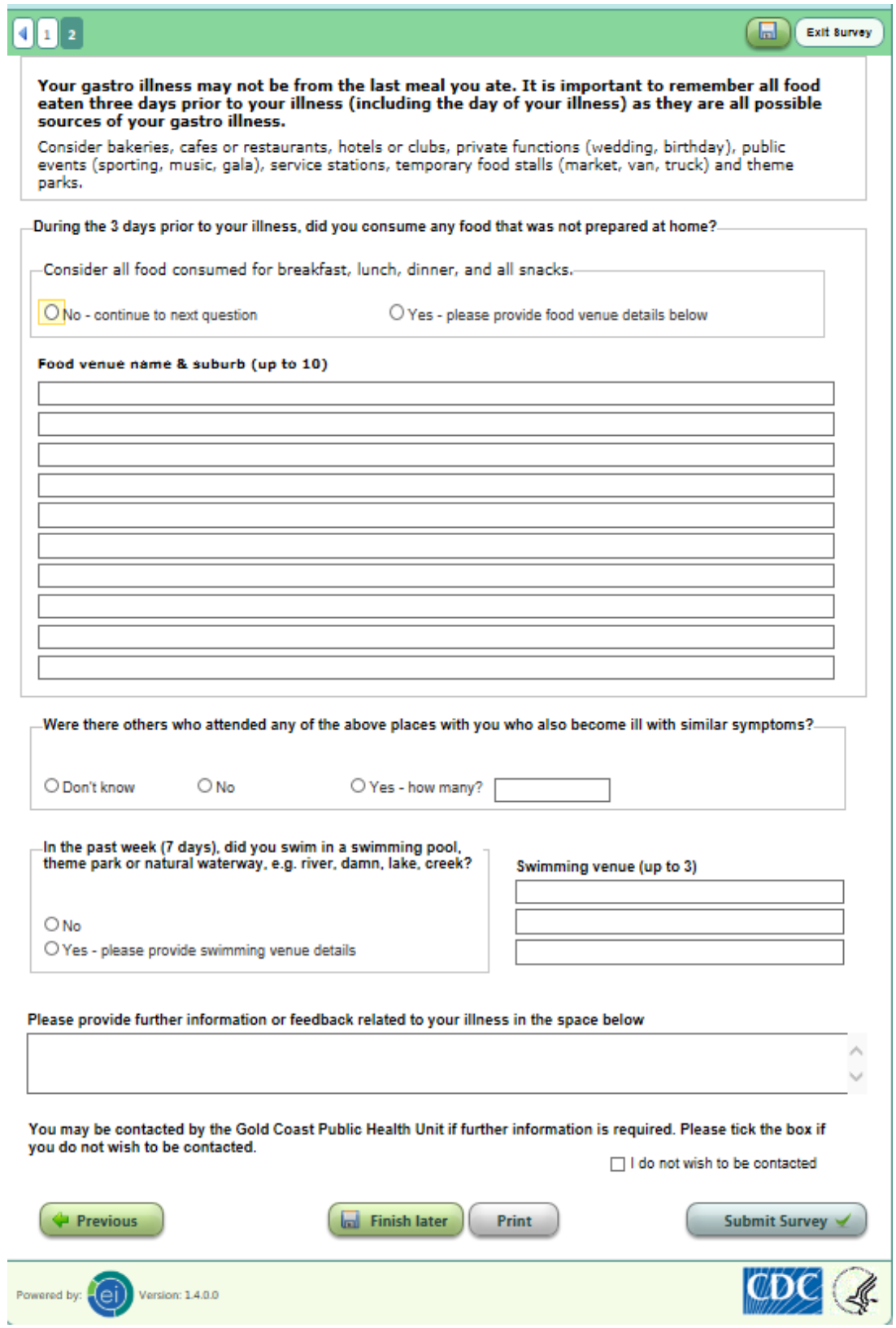
Thank you



Appendix C–Gastrointestinal illness electronic exposure questionnaire

2.12.




1
2
Exit Survey
Your gastro illness may not be from the last meal you ate. It is important to remember all food eaten three days prior to your illness (including the day of your illness) as they are all possible sources of your gastro illness.
Consider bakeries, cafes or restaurants, hotels or clubs, private functions (wedding, birthday), public events (sporting, music, gala), service stations, temporary food stalls (market, van, truck) and theme parks.
During the 3 days prior to your illness, did you consume any food that was not prepared at home?
Consider all food consumed for breakfast, lunch, dinner, and all snacks.
No - continue to next question
Yes - please provide food venue details below
Food venue name & suburb (up to 10)
Were there others who attended any of the above places with you who also become ill with similar symptoms?
Don't know
No
Yes - how many?
In the past week (7 days), did you swim in a swimming pool, theme park or natural waterway, e.g. river, damn, lake, creek?
No
Yes - please provide swimming venue details
Swimming venue (up to 3)
Please provide further information or feedback related to your illness in the space below
You may be contacted by the Gold Coast Public Health Unit if further information is required. Please tick the box if you do not wish to be contacted.
I do not wish to be contacted
Previous
Finish later
Print
Submit Survey
Powered by:
Version: 1.4.0.0
CDC

Appendix D–Norovirus electronic exposure questionnaire

2.13.

Griffith University Open Day Questionnaire

Patient details

First name | Surname | Date of birth | Age (years) | Gender

Phone number | Questionnaire self-completed? | Other (please specify)

Street address | Suburb | State | Postcode | Country

Since Sunday 12 August 2018, have you had an illness with diarrhoea (three loose motions in 24 hours) or any other gastroenteritis symptoms?

○ No ○ Yes ○ Unknown

Are you still unwell?

○ No ○ Yes ○ Unknown

Did you experience any of the following symptoms? (tick all that apply)

☐ Nausea/vomiting
☐ Diarrhoea
☐ Stomach cramping/abdominal pain
☐ Blood in stools
☐ General aches and pains
☐ Other symptoms (please describe)

What was your first symptom?

○ Nausea/vomiting ○ Blood in stools
○ Diarrhoea ○ General aches and pains
○ Stomach cramping/abdominal pain ○ Other (please describe)

Time of first symptom

Date of first symptom (DD/MM/YYYY)

How long did your gastrointestinal illness last? (hours, days) (e.g., nausea/vomiting, diarrhoea)

Did you experience any gastrointestinal symptoms prior to Sunday 12 August 2018

Did you consult a GP for your illness? Did you attend an emergency department for your illness?

Do you have any pre-existing medical conditions?

What time did you eat at the Griffith University Open Day?

Did you consume any of the following options from the SUB platter? (tick all that apply)

- Chicken strips
- Ham
- Turkey
- Roast beef
- BMT (salami, pepperoni, ham)
- Vegetarian

No. of total subs consumed?

Did you consume any of the following options from the WRAP platter? (tick all that apply)

- Chicken strips
- Ham
- Turkey
- Roast beef
- BMT (salami, pepperoni, ham)
- Vegetarian

No. of total wraps consumed?

Did you consume a salad bowl?

Did you use utensils to pick up the food items?

Between Saturday 11 August 2018 and the open day on Sunday 12 August 2018, did you attend any other group events, parties, special functions, receptions etc.?

Have any members of your family or people you are living with been unwell with the same or similar symptoms since Sunday 12 August 2018?

Are you aware of any other people who may be unwell with the same or similar symptoms since Sunday 12 August 2018?

Please provide any other information you may believe if relevant relating to your illness in the space below (if required)

Thank you for your time. You may be contacted by the Queensland Health Gold Coast Public Health Unit if further information is required.

Chapter 3 Evolving epidemiology of giardiasis cases in the United States,1995–2016

3.1. Prologue

Project role

During January and February 2018, I undertook a research opportunity for four weeks with the Centers for Disease Control and Prevention (CDC), Waterborne Disease Prevention Branch, Domestic WASH Epidemiology Team in Atlanta, United States (US). The primary aim of the research visit was to work on an analytic project related to waterborne disease and outbreaks. During the visit with the assistance of key CDC researchers and epidemiologists, we identified and developed a research project to explore the evolving epidemiology of giardiasis in the US using 17 years of giardiasis case report data.

I was the principal researcher for this data analysis project responsible for liaising with CDC staff to obtain the dataset and other information as required during the analysis. I negotiated access to the data; determined the appropriate methodology; liaised and worked with other CDC researchers to undertake the analysis and progress the paper. I conducted the analyses from data cleaning through to the regression models using statistical software Stata, version 14.1 (StataCorp, College Station, TX, USA) and Microsoft Excel™. I generated all tables and graphs, interpreted and summarised the results. I conducted the literature review for the introduction and drafted the journal article for publication.

Lessons learned

As part of the Waterborne Disease Prevention Branch duplication policy, the analyses were required to be replicated by a CDC researcher using another statistical software. I learnt how to conduct data analysis using a structured and detailed approach, meticulously document each step using log files to provide a detailed record including the location of data sources, working files and records of file manipulations for the audit trail. I refined my skills in data cleaning, descriptive analyses, generating and verifying variables, calculation of crude rates and application of regression models. The project facilitated the revision of basic statistical tests and learning of new tests for trends. This project highlighted the importance of going back to basic principles and how data management may take up substantial time and resources (and is often underestimated).

The subject matter of the project provided an opportunity to enhance my knowledge about a neglected waterborne disease and frequently identified human protozoan in both developed and developing countries. Working with the National Notifiable Disease Surveillance System (NNDSS) used to monitor US infectious diseases, I gained an additional understanding of the limitations of surveillance data and how these can impact observed trends. Through my research visit at the CDC headquarters, I had the chance to understand the mandate and activities of the agency, meet staff from varying backgrounds including the US Epidemic Intelligence Service Officers, attend technical and program meetings and gain a thorough perceptive of a federal agency that conducts and supports variable health promotion and response activities in the US and globally.

Public health impact

The NNDSS giardiasis data had not been updated since 2011–2012, despite significant changes occurring in transmission patterns and available diagnostics. The paper compiled described the epidemiology of US giardiasis cases for the period 1995–2016 and updated state-level data reported to the NNDSS. Examining current trends is the first step in understanding disease prevalence and transmission demographics and how these may be changing over time. The analyses identified important emerging trends and transmission pathways for further investigation and public health response. The paper will be published and findings used by federal, state and local public health agencies to guide and implement targeted evidence-based disease prevention strategies and research priorities for *Giardia* and other waterborne pathogens.

Communication

- International Conference on Emerging Infectious Disease, Atlanta, 28 August 2018 (Appendix A)

Core MAE requirements addressed

- Analysis project
- Presentation at international conferences

Acknowledgements

Thank you to Martyn Kirk for facilitating the CDC research visit, supporting the giardiasis project, ongoing guidance, waterborne disease education and valuable feedback. I would like to acknowledge the multiple CDC staff I worked with during my research visit including Katie Fullerton, Kathy Benedict, Sarah Collier, Jonathan Yoder and other members of the Waterborne Disease Prevention Branch team. It was a wonderful opportunity to collaborate with such inspiring and talented people. I am grateful to all those who took the time to discuss their projects and answer my many questions and in particular, members of the *Giardia* project team who were unwavering with their patience, flexibility and support.

This following chapter is presented as an article. It represents work by the *Giardia* project team including Sarah Collier, Michelle Gleason, Jonathan Yoder, Martyn Kirk, Alice Richardson, Kathleen Fullerton and Katharine Benedict. This chapter is formatted for publication in the US and differs from other chapters. The final article may have changed due to reviewer feedback.

3.2. Abstract

Background

Giardiasis is the most common intestinal parasitic disease of humans identified in the United States and an important waterborne disease. In the United States, giardiasis has been variably reportable since 1992 and was made a nationally notifiable disease in 2002. Our objective was to describe the epidemiology of US giardiasis cases from 1995–2016 using National Notifiable Disease Surveillance System data.

Aim

Negative binomial regression models were used to compare incidence rates by age groups (0–4, 5–9, 10–19, 20–29, 30–39, 40–49, 50–64 and ≥65 years) during three time periods (1995–2001, 2002–2010 and 2011–2016).

Methods

From 1995–2016, the average number of reported cases were 19 781 per year (range 14 623–27 778 cases). The annual incidence of reported giardiasis in the US decreased across all age groups. This decrease differs by age group and sex and may reflect either changes in surveillance methods (for example changes to case definitions or reporting practices) or changes in exposure. Incidence rates in males and older age groups did not decrease to the same extent as rates in females and children.

Results

The annual incidence of reported giardiasis in the US decreased from 13.8 per 100 000 in 1995 to 6.4 per 100 000 in 2016. Compared to 1995–2001, incidence rates were lower in 2002–2010 and 2011–2016 across all age groups.

Conclusion

Trends suggest that differences in exposures by sex and age group are important to the epidemiology of giardiasis. Further investigation into the risk factors of populations with higher rates of giardiasis will support prevention and control efforts.

3.3. Introduction

Giardia duodenalis (also known as *G. lamblia* and *G. intestinalis*) is one of the most common intestinal parasites in humans, with one million estimated giardiasis cases annually in the United States [1, 2]. Giardiasis is typically characterized by acute gastrointestinal illness presenting as diarrhea with or without abdominal cramping and bloating, flatulence, malabsorption and weight loss. Symptoms can persist for weeks and are highly variable depending on the susceptibility of the host, strain genotype and pathogen virulence. Infected individuals can be asymptomatic or experience a mild, self-limiting illness. Less frequently, in adults, severe illness and/or chronic sequelae occur, including irritable bowel syndrome [3], chronic fatigue [4], post-infectious arthritis or joint pain [5, 6]. Chronic sequelae in infants and children can include failure to thrive and malnutrition [7, 8]. Giardiasis can be successfully and simply treated with a number or combination of anti-giardial drugs if identified early minimizing post-infectious and long-term sequelae [9].

Transmission of giardiasis occurs through waterborne, person-to-person and foodborne sources. Infection occurs indirectly or directly via ingestion of contaminated water and food, or through person-to-person contact via the fecal-oral route [10]. This range of transmission pathways can make identification of the exposure source of individual cases or outbreaks challenging. At-risk individuals include those in close contact with infected persons, such as other children in child care settings, their family members and caregivers [11, 12]. Giardiasis is frequently diagnosed in international travellers returning from endemic countries [13] and in internationally adopted children [14]. There is growing evidence of giardiasis transmission among men who have sex with men (MSM) through fecal-oral contact during sexual activity [15, 16]. Improvements in molecular technology for characterization of *Giardia* suggest that zoonotic transmission, including from household pets, is less common than other transmission pathways [17].

Giardiasis is a common cause of outbreaks of waterborne gastrointestinal illness associated with drinking water and treated and untreated recreational water sources [18-21]. Transmission of giardiasis via water is facilitated by several factors, including the chlorine-tolerance of *Giardia* cysts, their immediate infectiousness, protracted and intermittent shedding of *Giardia* protozoa by individuals who may be asymptomatic or experience a mild infection, and the low

dose required for infection [22, 23]. Foodborne outbreaks of giardiasis caused by contamination from food handlers, animals, or irrigation practices are less common [24, 25].

Giardiasis has been reported to the Centers for Disease Control and Prevention (CDC) since 1992; in 2002 it became nationally notifiable. The most recent published summary data from the National Notifiable Disease Surveillance System (NNDSS) demonstrated a slight decline in giardiasis rates from 2011–2012 across all US regions, compared with relatively steady rates from 2005–2010 [26]. This paper describes the epidemiology of US giardiasis cases for the period 1995–2016 by analyzing 22 years of state-level giardiasis case data reported to NNDSS. Identification of changing patterns and transmission pathways is essential to inform the public health response to giardiasis.

3.4. Methods

3.4.1. Data

State-level giardiasis case data were obtained from the NNDSS for the period 1995–2016. The number of health departments submitting can vary from year to year depending on which states have designated giardiasis as reportable in their jurisdictions. National giardiasis reporting by states varied with several not reportable each year and therefore not notified to CDC (annual range 4–9). Giardiasis was not reportable in Texas and North Carolina during the study period. NNDSS case data include year of report; whether the case was reported as associated with an outbreak; case-patient's state of residence; race; ethnicity; sex; age; and classified case status (i.e. whether the case met criteria of the national case definition for confirmed or non-confirmed classification (https://wwwn.cdc.gov/nndss/conditions/giardiasis/case-definition/2011/) [27]. Case status was dichotomized into confirmed and non-confirmed cases (probable, suspect and unknown). Age was categorized into eight groups: 0–4, 5–9, 10–19, 20–29, 30–39, 40–49, 50–64 and ≥65 years. Case counts were examined by year and aggregated into three time periods (1995–2001, 2002–2009 and 2011–2016) to simplify analysis and presentation, guided by changes to giardiasis surveillance.

3.4.2. Analysis

NNDSS data for 1995–2016 were analyzed using Stata, version 14.1 (StataCorp, College Station, TX, USA). Initial descriptive analysis included calculation of crude annual incidence rates (cases per 100 000 population) using each year's mid-year census estimate as denominators. Rates were examined by year, age group, sex, US state, and census region (Northeast, Midwest, South and West). Maps were created to display rates of giardiasis by state across three time periods (1995–2001, 2002–2010 and 2011–2016), using ArcGIS version 10.3 (ESRI, USA). Average reported giardiasis incidence rates per 100 000 population for these three time periods were calculated by combining case counts and mid-year census estimates. There were nine states that did not report for at least one year between 1995 and 2016. Non-reporting states were removed from census estimates for the non-reporting year only.

To examine trends in binomial proportions of case status, sex, race and ethnicity over time, a test for trend was used. The hypothesis was that there were no changes in proportion of non-confirmed, male, white or non-Hispanic cases over time. We then used count response models to examine changes in giardiasis rates during the time period, overall and by age group and sex. Negative binomial regression was used to model counts because the data were over-dispersed. Model results were summarized as predicted incidence rate ratios (IRR) and 95% confidence intervals (CI) to compare modelled rates across the time periods. Multivariable models were constructed with selected variables to assess possible interactions as well as the independent effects. The base regression model included age group, sex and year period. The full model added interactions between age group and year period, age group and sex, and sex and year period. The difference between the base and full models were evaluated using a likelihood ratio test.

3.5. Ethics approval

Ethics approval for this evaluation was granted by the Australian National University Human Research Ethics Committee (HREC 2018/424).

3.6. Results

A total of 435 186 cases of giardiasis were reported to NNDSS in the time period 1995–2016 (annual range 14 623–27 778) (Table 6). From 1995–2016, 5.1% of reported cases were reported as outbreak-associated. From 1995–2002, the proportion of outbreak-associated cases ranged between 7.7% and 13.1%, except for 2001 where it was considerably lower (1.6%). From 2003, the proportion remained relatively stable and less than 2.5% of all giardiasis cases reported.

Table 6 Number of reported giardiasis cases by reported outbreak-associated status and year, United States, 1995–2016 (N = 435 186).

	Outbreak-associated status		
Year	Yes, n (%)	No/unknown[a], n (%)	Total, n (%)
1995	3321 (13.0)	22250 (87.0)	25571 (100)
1996	3136 (11.3)	24642 (88.7)	27778 (100)
1997	3337 (13.1)	22052 (86.9)	25389 (100)
1998	2645 (10.9)	21559 (89.1)	24204 (100)
1999	2460 (10.6)	20785 (89.4)	23245 (100)
2000	1980 (9.1)	19792 (90.9)	21772 (100)
2001	316 (1.6)	19339 (98.4)	19655 (100)
2002	1500 (7.7)	18037 (92.3)	19537 (100)
2003	439 (2.4)	17843 (97.6)	18282 (100)
2004	285 (1.4)	20359 (98.6)	20644 (100)
2005	221 (1.1)	19566 (98.9)	19787 (100)
2006	393 (2.1)	18564 (97.9)	18957 (100)
2007	345 (1.8)	19074 (98.2)	19419 (100)
2008	188 (1)	18736 (99)	18924 (100)
2009	152 (0.8)	19251 (99.2)	19403 (100)
2010	189 (1)	19699 (99.1)	19888 (100)
2011	251 (1.5)	16533 (98.5)	16784 (100)
2012	200 (1.3)	14997 (98.7)	15197 (100)
2013	243 (1.6)	15024 (98.4)	15267 (100)
2014	224 (1.5)	14400 (98.5)	14624 (100)
2015	202 (1.4)	14421 (98.6)	14623 (100)
2016	180 (1.1)	16056 (98.9)	16236 (100)
Total	22207 (5.1)	412979 (94.9)	435186 (100)

[a] No/unknown outbreak-associated status included 205 335 (47.2%) cases reported as not to be associated with an outbreak, 207 517 (47.7%) unknown outbreak status and 127 (0.03%) missing outbreak status.

There was a clear decreasing trend in the crude incidence of giardiasis over the time period with the highest annual rate seen in 1995 (13.8 per 100 000), decreasing to 6.4 per 100 000 in 2016 (Figure 6). Crude incidence rates varied over time, decreasing from 1995–2003 before remaining relatively stable until 2010. Rates again decreased from 2010–2012, before stabilizing until 2015 and

increasing in 2016. Across the time period 1995–2016, the majority (n = 406 723; 93.5%) of reported giardiasis cases were classified as confirmed. Although the total number of confirmed cases decreased over the time period, there was marked variation in the proportion of confirmed cases from 1995–2016. Higher rates of confirmed cases were reported during 1997–2001 (range 10.0–12.9 per 100 000) and 2013–2016 (range 5.7–6.3 per 100 000) (Figure 6).

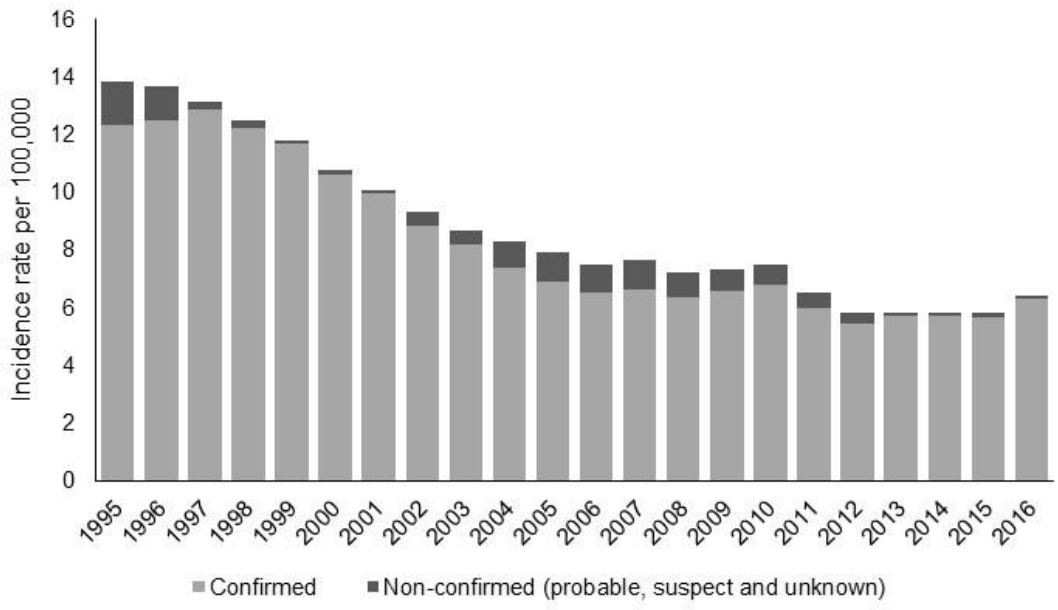


Figure 6 Incidence rate of reported giardiasis cases per 100 000 population, by case status and year, United States, 1995–2016.

Crude incidence rates also varied over the time period of reporting by individual US states. In 1995, the annual rate of giardiasis ranged from 0.7 cases to as high as 53.5 cases per 100 000; however, by 2016, the range had reduced from 1.8 cases to 14.1 cases per 100 000 (Figure 7). Over the time period, the highest numbers of giardiasis cases were reported by northern US states. Rates were consistently highest in the Northeast (10.9 cases per 100 000) and lowest in the South (6.1 cases per 100 000). The greatest reduction per region was observed in the West, which fell from 13.6 cases per 100 000 in 1995–2001 to 5.8 cases per 100 000 in 2011–2016. By state, rates were lowest in Louisiana (2.7 cases per 100 000) and highest in Vermont (35.1 cases per 100 000). In 1995, 32 US jurisdictions reported

giardiasis rates higher than 10 cases per 100 000; however, by 2016, this number had reduced to 17 jurisdictions.

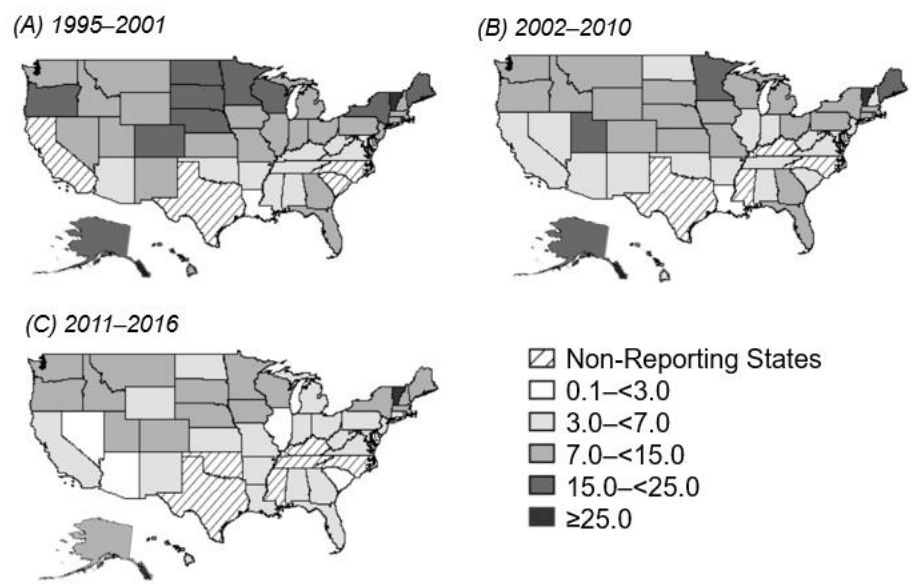


Figure 7 Incidence rate of reported giardiasis cases per 100 000 population, by state, United States, 1995–2016 (A) 1995–2001 (B) 2002–2010 (C) 2011–2016.

During the time period 1995–2016, the majority were reported in white (n = 205 198; 47.2%) and non-Hispanic giardiasis cases (n = 191 933; 44.1%); however, over half of case reports were missing race and ethnicity data. Nationally changing trends in sex distribution were observed. In 1995, 12 951 cases were male (51.3%) and 12 298 cases were female (48.7%). By 2016, the proportion of male cases (60.1%) was significantly higher than female cases (39.9%) ($X^2 = 1362.077$, $p < 0.0001$) (Figure 8).

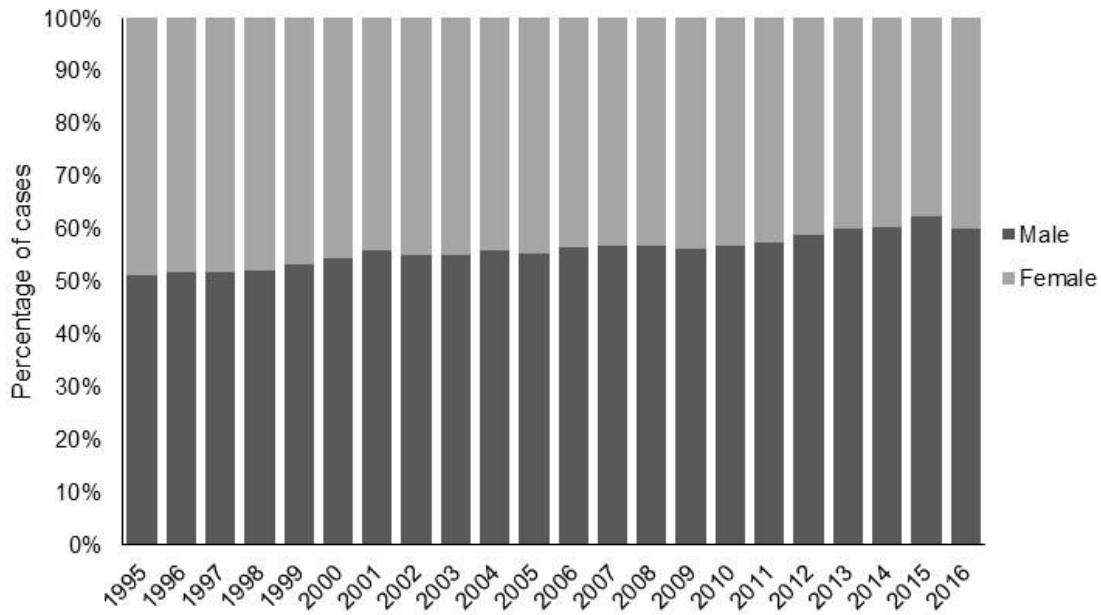


Figure 8 Percentage[a] of reported male giardiasis cases, by sex and year, United States, 1995–2016. [a] N = 427 337 male and female cases; missing sex data for n = 7 849 (1.8%) cases.

The highest giardiasis rates throughout the study period were observed in children aged 0–4 years and 5–9 years compared to other age groups (Figure 9). From 1995–2001, higher rates were seen in adults aged 30–39 years; however, by 2011–2016 the rate had decreased to become comparable to other adult age groups. Rates in those aged 10–19 and ≥65 years remained consistently lower than rates observed in all age groups during the time period.

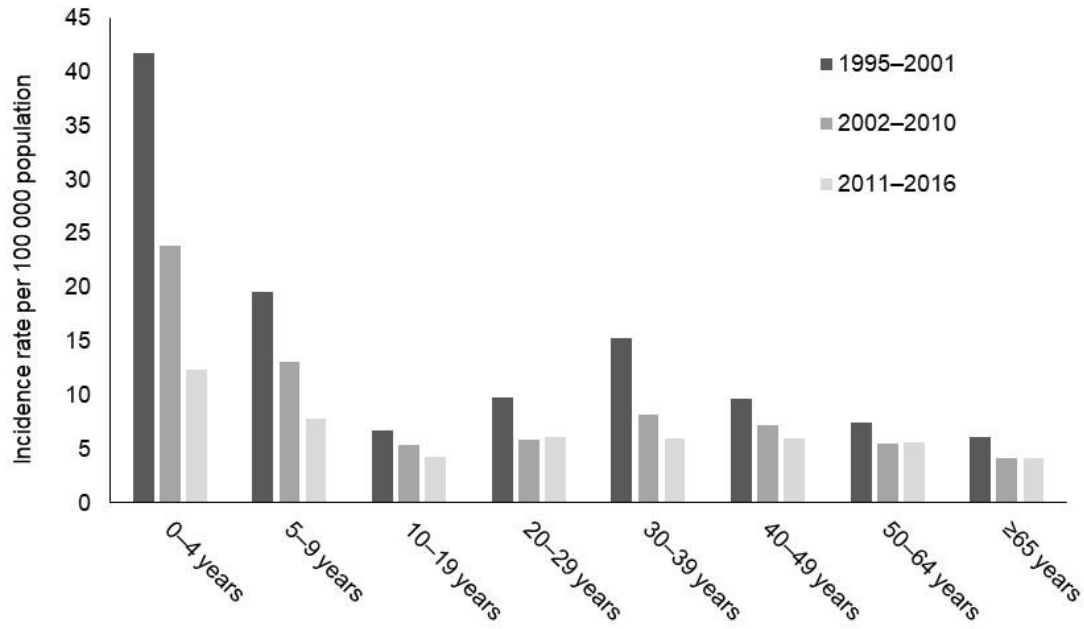


Figure 9 Average incidence rate[a] of giardiasis cases per 100 000 population, by age group and year period, United States, 1995–2016. a N = 429 417 cases: missing age data for n = 5 770 (1.3%) cases.

Using count response models, the rate of decrease over time differed by age group (Supplementary Table S1). Compared with 1995–2001, significant declines in 2002–2010 and 2011–2016 occurred across all age groups. The largest decrease from the referent period was observed in children aged 0–4 years (IRR 0.30, 95% CI 0.20–0.44) and smallest decrease among adults aged 50–64 years (IRR 0.80, 95% CI 0.70–0.92). During 2002–2010 and 2011–2016, rates significantly decreased in all age groups except in adults aged 20–29 years, 50–64 years and ≥65 years.

Examination of the interaction between age group and year period ($X^2 = 105.42$, df = 14, $p<0.0001$), age group and sex ($X^2 = 42.39$, df = 14, $p<0.0001$), and sex and year period ($X^2 = 37.61$, df = 14, $p< 0.0001$) showed significant differences. In females relative to males, predicted IRRs were lower in persons aged 10–49 years, notably in the 40–49 age group (IRR 0.73, 95% CI 0.67–0.79). No difference between sex was observed in cases aged 0–9 years and ≥50 years (Figure 10). Compared with males, females had lower predicted rates of incidence in 2002–2010 (IRR 0.86, 95% CI 0.78–0.93) and lower further in 2011–2016 (IRR 0.74, 95% CI 0.68–0.81).

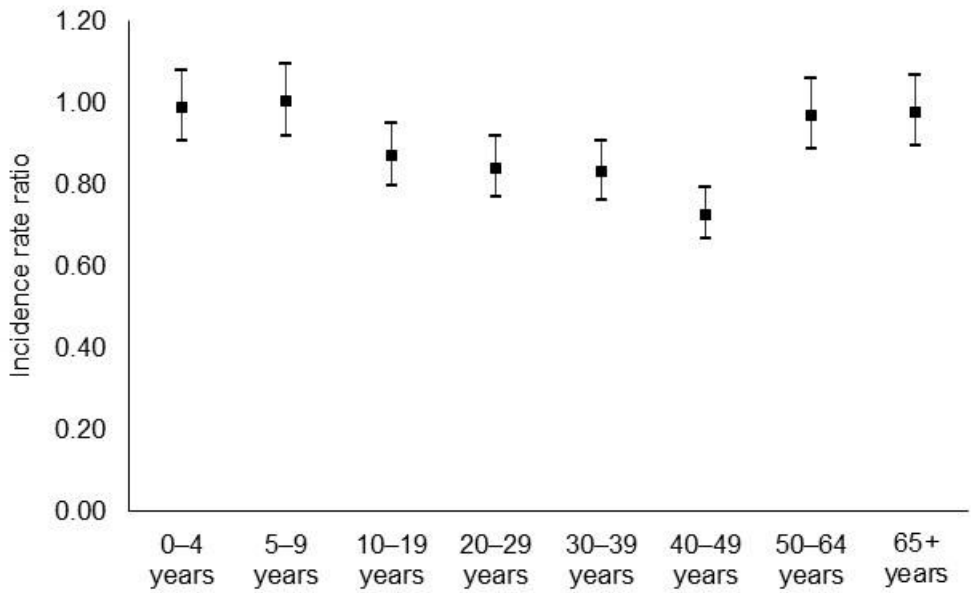


Figure 10 Predicted incidence rate ratio for females versus males, by age group, United States, 1995–2016

3.7. Discussion

We describe significant declines in the rates of reported giardiasis in the United States during 1995–2016. We observed considerable variations in the incidence of reported giardiasis cases between age groups, sex and among US states and jurisdictions. The higher incidence rates seen in children aged 0–4 years compared with other age groups might reflect minimal toileting skills, attendance at child care centers and greater immunologic susceptibility [28]. Persistently higher rates highlight the continued challenges of preventing and controlling giardiasis in young children. Children may transmit infection to household contacts or other children in crowded environments such as child care settings, and represent an important source of community infection [29]. Increased risk of giardiasis infection associated with children in diapers has been reported in the United States, and likely represents an important and frequently encountered risk factor [16]. Good diaper-handling hygiene in the home and child care settings may limit disease spread. Additionally, in child care settings, maintenance of infection control principles as well as support of ongoing staff training may limit disease spread [28, 30].

We found that males had significantly higher rates of illness, particularly later in the surveillance period. From 1995–2001, the distribution among males and females was relatively equal; however, during 2002–2010 and 2011–2016 the proportion of giardiasis cases in males was significantly higher. The higher incidence rates in males aged 10–49 years may reflect differing patterns of exposures to activities although this is difficult to assess, as standardized exposure data is not required to be reported by US states. The difference between males and females was most significant in individuals aged 40–49 years, followed by 30–39 years and 20–29 years. Enteric infections such as giardiasis can be transmitted during sexual activity where there is exposure to fecal material [15, 31-33]. *Giardia* has been documented among MSM and significant association between male-male sexual behavior reported [15, 16]. The potential contribution of this person-to-person transmission route to the differences observed between sexes needs to be further explored. Furthermore, understanding how different sexual behaviors influence transmission would inform prevention interventions and facilitate individual-level changes in behavior through targeted messaging. Increased clinician awareness of risk factors in addition to contaminated water and travel to endemic locations may raise consideration of other high-risk individuals with prolonged diarrhea. Pairing this clinical attention of high-risk individuals with the appropriate laboratory examinations may improve detection and reduce transmission in the United States.

It is known that giardiasis can be transmitted through untreated surface water. The implementation of national drinking water regulations for surface and ground water sources, changes in public water system management and practice, and general improvements to drinking water infrastructure may have contributed to a decrease in giardiasis outbreaks [26, 34]. These changes include revisions to the US Environmental Protection Agency management practices under the Safe Drinking Water Act to address parasite contamination of surface water and improved water quality and safety following large waterborne outbreaks of chlorine-tolerant pathogens [35, 36]. Plateauing rates of giardiasis may indicate that private, unregulated water supplies could be an important route of transmission; evidence indicates US counties with high private-well reliance have higher giardiasis rates [37]. In most situations, private well owners are not legally compelled to test, treat or maintain their drinking water systems to any standard. The standardized

collection of exposure information by US states on all giardiasis cases would increase information on risk factors and disease prediction.

Our analysis found higher rates were reported in the Northeast region. Explanations may include regional differences in giardiasis transmission [26, 38]. Other explanations for the variation across states and regions include differences in laboratory detection practice and surveillance capacity. As noted previously, the number of US states who report giardiasis cases fluctuated over the period. There are many reasons states may decide not to include giardiasis on their list of reportable diseases including resource considerations, perceived lack of severity and relative importance with other enteric infections, and lack of diagnostic capabilities. Non-reporting states were dominated by those from the US southern region. Declining and plateauing rates across the time period may also be influenced by changing case definition criteria. Prior to the case definition change in 2011, all cases with laboratory evidence of giardiasis were classified as confirmed, regardless if the case met the clinical description [27]. The overall decrease in giardiasis rates, including in non-confirmed cases, may be due to the more precise case definition for national surveillance.

Despite declining rates, giardiasis continues to be the most commonly reported intestinal parasite identified in the US. There are an estimated 1 459 emergency department visits and 2 833 hospitalizations of giardiasis annually, costing approximately $65 million [2]. In 2016, giardiasis rates increased for the first time since 2010 coinciding with the introduction of molecular diagnostics for rapid and simultaneous detection of enteric pathogens; however, diagnostic testing data is unavailable to validate these trends. Accurate identification and diagnosis of enteric pathogens is required to appropriately manage and treat case symptoms, minimize long-term sequelae and in combination with accurate exposure information, control the spread of disease. Molecular diagnostics have provided new tools for detecting *Giardia* and have the potential to improve timeliness and detection of sporadic infections. Improved technologies can impact the number of cases identified and public health response [29]. Future research priorities will include investigating the impact of these changing diagnostic techniques on surveillance for giardiasis in the United States.

Our analysis is subject to some limitations, including under-reporting of infections due to asymptomatic presentation and carriage, failure by infected individuals to seek medical care, failure of medical staff to include giardiasis diagnostic testing in their evaluation and incomplete case report or laboratory reports forwarded to public health officials. Surveillance data used in this analysis was incomplete for race and ethnicity data which limits our information on different population subgroups [30]. Public health agencies report whether giardiasis cases are outbreak-associated without connection to separate outbreak reporting systems, which may under-capture the true proportion of outbreak-associated cases. Variability in surveillance capacity, reporting requirements and the number of reporting states may limit comparison of rates over time and between US states.

3.8. Conclusion

Giardiasis has declined significantly in the United States and the age and sex groups at highest risk have changed. Our findings should be used by federal, state and local public health agencies to guide and implement targeted evidence-based disease prevention strategies and research priorities for giardiasis. Further investigation is needed to explain the apparent plateau in rates between 2012 and 2015, if the increase in 2016 continues thereafter, higher and increasing reporting in males especially among certain age groups, variability in geographical distribution and how the increasing use of molecular diagnostics will influence the future notification and surveillance of giardiasis in the United States.

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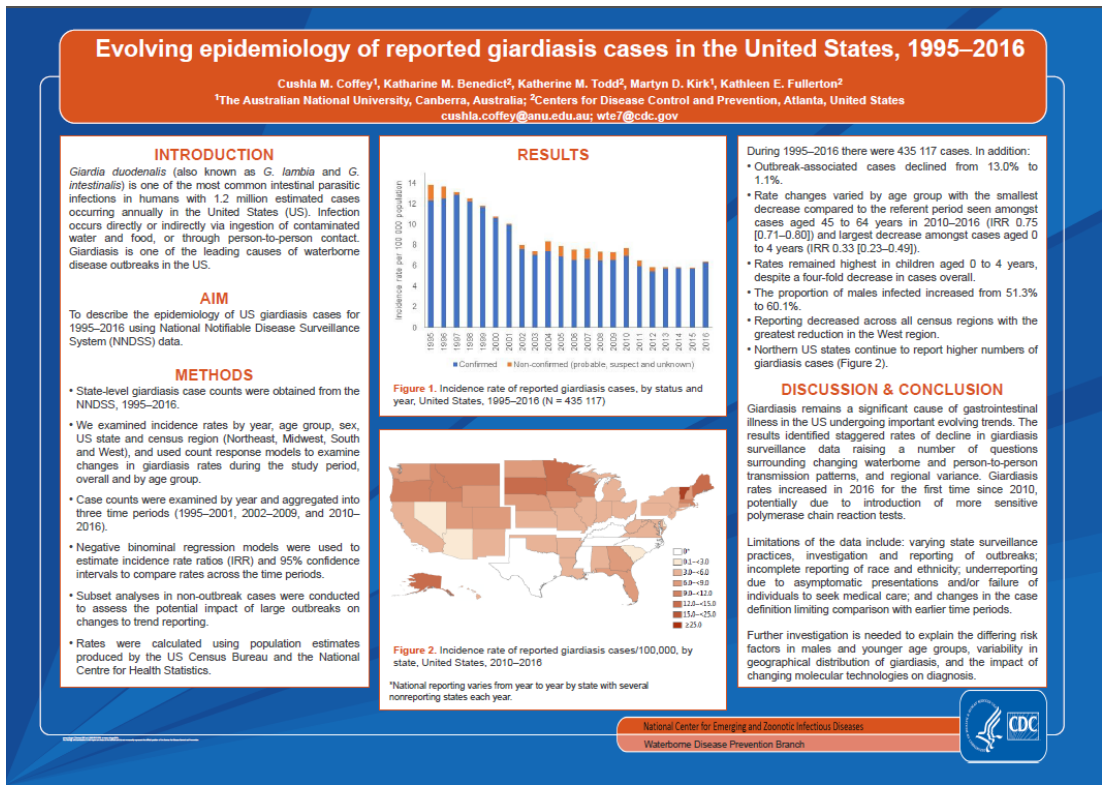
Supplementary Table 1. Giardiasis incidence rates and predicted incidence rate ratios from negative binomial regression models, by age group and year period, United States, 1995–2016

Age group (years)	Year group	Rate/100 000 population	IRR (95% CI) (*vs.*1995–2001)	IRR (95% CI) (*vs.*2002–2010)
All ages	1995–2001	12.2	1.00	
	2002–2010	7.7	0.65 (0.57–0.73)	1.00
	2011–2016	5.9	0.47 (0.41–0.55)	0.74 (0.65–0.83)
0–4	1995–2001	41.7	1.00	
	2002–2010	23.8	0.59 (0.42–0.84)	1.00
	2011–2016	12.3	0.30 (0.20–0.44)	0.5 (0.35–0.71)
5–9	1995–2001	19.6	1.00	
	2002–2010	13.1	0.67 (0.60–0.74)	1.00
	2011–2016	7.9	0.40 (0.36–0.45)	0.6 (0.55–0.65)
10–19	1995–2001	6.7	1.00	
	2002–2010	5.4	0.80 (0.70–0.92)	1.00
	2011–2016	4.3	0.64 (0.55–0.74)	0.79 (0.71–0.89)
20–29	1995–2001	9.8	1.00	
	2002–2010	5.9	0.60 (0.55–0.67)	1.00
	2011–2016	6.1	0.62 (0.56–0.7)	1.03 (0.97–1.10)
30–39	1995–2001	15.3	1.00	
	2002–2010	8.2	0.54 (0.49–0.59)	1.00
	2011–2016	5.9	0.39 (0.35–0.43)	0.72 (0.64–0.80)
40–49	1995–2001	9.6	1.00	
	2002–2010	7.2	0.75 (0.70–0.81)	1.00
	2011–2016	6.0	0.63 (0.58–0.68)	0.84 (0.78–0.89)
50–64	1995–2001	7.4	1.00	
	2002–2010	5.5	0.75 (0.71–0.80)	1.00
	2011–2016	5.6	0.76 (0.71–0.80)	1 (0.95–1.06)
≥65	1995–2001	6.1	1.00	
	2002–2010	4.2	0.68 (0.61–0.77)	1.00
	2011–2016	4.2	0.68 (0.60–0.77)	1 (0.90–1.10)

IRR, Incidence rate ratio; CI, confidence interval

3.10. Appendix A—International conference presentation



Evolving epidemiology of reported giardiasis cases in the United States, 1995–2016

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INTRODUCTION

Giardia duodenalis (also known as *G. lambia* and *G. intestinalis*) is one of the most common intestinal parasitic infections in humans with 1.2 million estimated cases occurring annually in the United States (US). Infection occurs directly or indirectly via ingestion of contaminated water and food, or through person-to-person contact. Giardiasis is one of the leading causes of waterborne disease outbreaks in the US.

AIM

To describe the epidemiology of US giardiasis cases for 1995–2016 using National Notifiable Disease Surveillance System (NNDSS) data.

METHODS

- State-level giardiasis case counts were obtained from the NNDSS, 1995–2016.
- We examined incidence rates by year, age group, sex, US state and census region (Northeast, Midwest, South and West), and used count response models to examine changes in giardiasis rates during the study period, overall and by age group.
- Case counts were examined by year and aggregated into three time periods (1995–2001, 2002–2009, and 2010–2016).
- Negative binominal regression models were used to estimate incidence rate ratios (IRR) and 95% confidence intervals to compare rates across the time periods.
- Subset analyses in non-outbreak cases were conducted to assess the potential impact of large outbreaks on changes to trend reporting.
- Rates were calculated using population estimates produced by the US Census Bureau and the National Centre for Health Statistics.

RESULTS

Figure 1. Incidence rate of reported giardiasis cases, by status and year, United States, 1995–2016 (N = 435 117)

Figure 2. Incidence rate of reported giardiasis cases/100,000, by state, United States, 2010–2016

*National reporting varies from year to year by state with several nonreporting states each year.

During 1995–2016 there were 435 117 cases. In addition:

- Outbreak-associated cases declined from 13.0% to 1.1%.
- Rate changes varied by age group with the smallest decrease compared to the referent period seen amongst cases aged 45 to 64 years in 2010–2016 (IRR 0.75 [0.71–0.80]) and largest decrease amongst cases aged 0 to 4 years (IRR 0.33 [0.23–0.49]).
- Rates remained highest in children aged 0 to 4 years, despite a four-fold decrease in cases overall.
- The proportion of males infected increased from 51.3% to 60.1%.
- Reporting decreased across all census regions with the greatest reduction in the West region.
- Northern US states continue to report higher numbers of giardiasis cases (Figure 2).

DISCUSSION & CONCLUSION

Giardiasis remains a significant cause of gastrointestinal illness in the US undergoing important evolving trends. The results identified staggered rates of decline in giardiasis surveillance data raising a number of questions surrounding changing waterborne and person-to-person transmission patterns, and regional variance. Giardiasis rates increased in 2016 for the first time since 2010, potentially due to introduction of more sensitive polymerase chain reaction tests.

Limitations of the data include: varying state surveillance practices, investigation and reporting of outbreaks; incomplete reporting of race and ethnicity; underreporting due to asymptomatic presentations and/or failure of individuals to seek medical care; and changes in the case definition limiting comparison with earlier time periods.

Further investigation is needed to explain the differing risk factors in males and younger age groups, variability in geographical distribution of giardiasis, and the impact of changing molecular technologies on diagnosis.

National Center for Emerging and Zoonotic Infectious Diseases
Waterborne Disease Prevention Branch

Chapter 4 Evaluation of the blood lead surveillance system in Queensland

4.1. Prologue

My role

I was responsible for the design of the evaluation, including liaising with Queensland Health stakeholders involved in the surveillance system to determine the scope. I conducted stakeholder interviews and analysed their responses for key themes. I analysed surveillance data to evaluate data quality, surveillance trends and selected attributes of the surveillance system. I conducted an additional evaluation of the Mount Isa Capillary Blood Lead Screening Program, presented as an executive summary (Appendix A). I also assisted in cleaning of the surveillance data and compiling the lead surveillance annual reports from 2012–2015. I developed an updated surveillance form which will inform the revision of enhanced surveillance form. Other work I was involved in included sample size estimates during a public health investigation of lead solder in domestic water fixtures. I drafted a report summarising the current evidence of elevated blood lead and pre-eclampsia in pregnant women and revised the summary as a fact sheet (Appendix B). Finally, I presented a critical appraisal of a pilot study examining children's blood lead in Mount Isa to a journal club.

Lessons learned

This was my first experience with a state notifiable disease surveillance system. Examining surveillance data of lead broadened my understanding of the focus of public health surveillance due to the many areas it involves including public health determinants (e.g., risk behaviours, health care services and socioeconomic factors), occupational and environmental health. I gained an understanding of the functions of surveillance systems, data flow and management. I learned that there are many factors that may influence reporting, observed trends and interpretation of the data. A key lesson for me was the importance of ongoing engagement with stakeholders involved in the system and dissemination of data to encourage its use. Feedback allows for recognition of their involvement to provide a sense of ownership and purpose.

I gained an understanding of the epidemiology of lead globally and burden of disease. Excessive lead is a challenging condition; acute poisoning may demonstrate similar attributes to infectious diseases and lower, chronic exposure due to environmental or workplace sources may be missed or difficult to manage. I learnt how different surveillance systems may be prioritised. Lead is the only chemical hazard under surveillance by the Health Protection Branch (HPB) and is managed separately to other notifiable infectious diseases and conditions. However, lead continues to be an important potential hazard and topical area, as seen in recent public health incidents involving contaminated water supplies in the United States city of Flint, Perth Children's Hospital and hot water systems in some Queensland homes.

I gained further experience in project management through the capillary screening evaluation and Mount Isa field visit, including the ability to identify important players, develop and maintain stakeholder relationships. I gained important experience in qualitative research and evaluation, an understanding how to develop robust methodology, and analyze a research question in different ways. I learned how to interview effectively and obtain the best responses from individuals, record and analyse information. The importance of adequate preparation, organisation and rehearsal was highlighted, as well as the time and resource intensive nature of interviewing. My data collation and analysis skills in Microsoft ExcelTM were reinforced by working with the Environmental Hazards Unit staff on the annual summary reports.

Public health impact

The evaluation was presented to the HPB Executive Director and Environmental Hazards Director. The report contains recommendations to improve the surveillance of lead in Queensland, as well as the capillary screening program currently operating in the town of Mount Isa.

MAE core activity requirements addressed

- Evaluate a surveillance system(s)
- Communication to a lay audience (Appendix B)

Acknowledgments

I would like to acknowledge the support of the HPB and my supervisors Dr Suzanne Huxley and Martyn Kirk. In particular, I would like to thank David Ward, Clive Paige, and Uma Rajappa. I acknowledge multiple field stakeholders, including from the Data Services team and public health units (PHUs) who volunteered their time to be interviewed and share their extensive experience; without their efforts, this evaluation would tell only half the story of blood lead surveillance in Queensland.

4.2. Abstract

Introduction

Excessive blood lead has been a notifiable condition in Queensland since 1995. Venous blood lead results greater than or equal to 5 micrograms per decilitre are required to be notifiable by laboratories to Queensland Health. Occupational and environmental exposure to lead remains a serious public health problem due to the irreversible neurological, cognitive and behavioural health effects that can occur from lead exposure.[1-3] This is the first evaluation of the Queensland blood lead surveillance system. This evaluation examined the lead surveillance system in Queensland from 2000–2017 with a focus on selected attributes, the changes to the case definition on notification rates and made recommendations for improvement.

Methods

The evaluation was guided by the Centers for Disease Control and Prevention Updated Guidelines for Evaluating Public Health Surveillance Systems and World Health Organization Communicable Disease Surveillance and Response Systems: Guide to Monitoring and Evaluating. A mixed research methodology was employed. Evidence was obtained using semi-structured interviews with selected stakeholders, via analysis of extracted all lead notification data, and following a review of the system protocols and documents.

Results

There were 2,549 individuals notified with elevated blood lead; 40.1% were occupational. The majority were male adults employed in the lead mining industry reflecting regular biological screening required by legislation. Of all non-occupational lead notifications, exposure occurred predominately in males (73.5%) with approximately one-fifth of notifications in children aged less than 5 years. Lead-based paint was responsible for the highest proportion of non-occupational elevated blood lead levels (34.3%) followed by exposure at shooting ranges (15.7%), residence in Mount Isa (11.3%) and making of lead objects, such as fishing sinkers and toys (8.9%). The evaluation revealed the system was acceptable to users, conceptually simple, flexible and integrated within an existing system. An absence of clearly documented aims and objectives, incomplete

surveillance data, absence of regular data reviews, and a lack of analysis or dissemination translated to limited usefulness for stakeholders and for public health action.

Summary

There are gaps in our understanding of lead exposure in some subgroups in Queensland. Estimates of rates of elevated blood lead in Queensland should be considered as a minimum, as not all exposed individuals are tested and until July - 2017, lead notifications from occupational sources were considerably higher than non-occupational levels. Lead exposure remains an ongoing public health issue in Queensland and recent changes in notification levels increase the importance of strong surveillance and clear lead management practices. Some of the key recommendations to improve the system include: a review of the surveillance system objectives; updating and disseminating of lead surveillance data; improvements in data quality; and timely trend reporting through various information channels.

4.3. Introduction

The World Health Organization (WHO) classifies lead as one of 10 chemicals of major public health significance.[4] It is a potential environmental hazard and cumulative toxin affecting multiple body systems. The widespread use of lead in petrol, paint, consumer goods, and lead emissions from mining and metal manufacturing has resulted in extensive distribution and persistence in the environment. Exposure to lead is ubiquitous, although likely to be higher in low- and middle-income countries where there have been less efforts to remove lead from several sources.[5]

In Australia, lead poisoning among children was first reported in 1892 in Queensland, with the discovery of lead pigments affecting children's health approximately 11 years later.[6] Evidence eventually uncovered an epidemic of lead poisoning worldwide and in 1922, resulted in the introduction of state legislation regulating the use of household lead in Queensland. In Australia, public health campaigns and legislation have decreased the amount of lead introduced into the environment. Significant interventions include regulating the quantity of lead in house paints from 1965 to 1997 (from 1 to 0.1%), introduction of unleaded petrol in 1986, phase-out of leaded fuel since 2003[7] and restricting or preventing the use of lead in consumer goods, medicines and imported products (e.g., jewellery, cosmetics, toys with lead-based paint).[8]

Lead poisoning can occur from chronic or acute exposure. Acute exposure and very high lead levels are now rare in Australia. Ongoing exposure to lower levels of lead remains a public health issue disproportionally affecting communities with large industrial point sources (e.g., lead smelters) and individuals undertaking workplace activities, soil contamination from industrial processes and building work and renovations. The historical use of lead mean traces may be present in drinking water, air, paint, dust, soil and consumer products. The Queensland Government Department of Health (Queensland Health) designated excessive blood lead as a notifiable non-infectious condition in 1995, although surveillance data of varying quality have been collected since 1984. Monitoring and reducing lead exposure remains an important public health issue in Queensland.

Public health surveillance and prevention

Public health surveillance is the ongoing “systematic collection, collation, analysis and interpretation of health data for the planning, implementation and evaluation of public health action”.[5] Surveillance systems are a critical component of epidemiology and public health to serve as an early warning system for public health emergencies, inform immediate disease prevention and control measures, monitor and verify the epidemiology of health problems and guide public health decision-making, policy and strategy. Health-related events under surveillance range from communicable diseases to occupational and environmental hazards, such as lead exposure. The decision to prioritise excessive blood lead as a notifiable condition is due to its preventability, adverse health outcomes, public and political concern, ability to collect surveillance data and vulnerability within particular subgroups.[9] Surveillance systems should be reviewed regularly to ensure problems of public health importance are being monitored efficiently and effectively and the system continues to meet its objectives.

In the case of lead poisoning, preventative measures are undertaken by federal and state agencies. Primary prevention includes efforts to prevent the introduction of lead into the environment, such as legislation limiting lead in paint and lead air emissions limits.[10] Secondary prevention includes early detection and intervention with the aim of reversing, halting or at least slowing the progress of a condition, such as passive surveillance systems and screening programs, education and environmental interventions. Tertiary prevention minimises the effect of disease, including chelation therapy for lead poisoning.[10, 11] In Queensland, passive population-based surveillance and active surveillance of lead occurs in a mining town. The measurement of blood lead concentrations is undertaken as part of the routine monitoring of workers active in the lead industry or other work involving lead.

Public health importance of lead

Lead has no essential role in the human body and exposure is entirely preventable.[12] It may be absorbed into the body by breathing (e.g., using leaded gasoline, generated from burning materials containing lead during smelting and recycling), swallowing lead-contaminated particles (e.g., water from leaded pipes, food from lead-soldered containers), through the placenta during pregnancy and dermal exposure (e.g., lead-containing cosmetics, jewellery).[13] The ability of lead to inhibit and mimic the actions of calcium within the human body results in lead toxicity. Multiple organs are affected by lead toxicity and health effects vary for adults and children.[13]

Higher concentrations of lead in blood can cause abnormal kidney function, neurological effects and blood abnormalities. At high levels (≥100 micrograms per decilitre [µg/dL]) there is most likely to be no organ unaffected. Encephalopathy may occur at blood lead levels (BLLs) of 100 to 120 µg/dL in adults and 70 to 100 µg/dL in children, and death at these levels in some cases.[14] Lead is a cumulative toxicant able to be stored in the bones (range 3–20 years) and re-released into the bloodstream and soft tissues years after the exposure ceases.[15] Individuals who are pregnant and breast feeding, experiencing menopause, prolonged bed rest or osteoporosis are at particular risk, due to the higher bone turnover and calcium mobilisation.[16] Chronic low-level exposure is also associated with non-specific health outcomes including high blood pressure, behavioural changes and hearing and cognitive effects.[13, 17] More recently, low-level environmental lead exposure has been demonstrated in the United States (US) as a largely overlooked risk factor for cardiovascular disease mortality.[17]

Lead absorption is influenced by age, sex, diet (e.g., malnutrition resulting in iron and calcium deficiencies increases absorption), exposure route, quantity or duration and the presence of co-morbidities. Lower BLLs may present asymptomatically delaying diagnosis and the identification of a source.[2] Unborn babies, infants and children are at higher risk of exposure. Young children, especially those aged younger than 2 years are particularly susceptible due their higher intestinal absorption than adults (40–50% compared with 3–10%) and intake per unit body weight, their rapid development and increased sensitivity of their growing organs, in particular developing neurological system.[18, 19] Children also

absorb more lead through their environment through exploratory hand-to-mouth activity, ingestion of non-food substances and exposure to ground materials (e.g., soil containing lead). Pregnant women exposed to high lead levels can result in miscarriage, stillbirth, premature birth and low birth weight, as well as minor malformations.[10] The increased risk of adverse outcomes highlights the importance of targeting infants, children and pregnant women through lead poisoning prevention programs.

The causal pathway between lead exposure and health effects at BLLs greater than 10 µg/dL is well established. Scientific evidence for health effects occurring as a result of low blood lead (5–<10 µg/dL) is less clear. The definition of low exposure, what constitutes an 'elevated' BLL and 'safe' threshold has been lowered multiple times. There are differing statements on the health effects of lead by peak bodies. The most recent statement and information paper undertaken by the Australian National Health and Medical Research Council (NHMRC) found an association between low BLLs (5–<10 µg/dL) and reduced intelligence quotient (IQ), academic achievement and behavioural problems in children; increased blood pressure in adults (including pregnant women) and a delay in sexual maturation or puberty onset in adolescent boys and girls. There was insufficient evidence to conclude that lead at this level *caused* any of the health effects observed, due to other factors including socioeconomic status, education, parenting style, or exposure to other substances.[13] In May 2015, the NHMRC updated its recommendation indicating that "if a person has a BLL greater than 5 µg/dL, the source of exposure should be investigated and reduced, particularly if the person is a child or pregnant woman".[13] In contrast, the Centers for Disease Control and Prevention (CDC) maintains there is no safe level of blood and even low levels (≤5 µg/dL) have been shown to affect IQ, attention and academic achievement.[20] Since 2012, the CDC has used a reference level of 5 µg/dL to identify children with BLLs that are higher than most children's levels. The current value for public health reporting is based on the 97.5th percentile of the distribution of lead in US children aged 1–5 years, as reported by the National Health and Nutritional Examination

Survey. Scientific research currently focuses on low to very low exposure and defining the limits for safe exposure. Exposure to low levels of environmental lead remains a concern with non-occupational lead poisoning in children a key focus.[21]

Blood lead surveillance in Australia

The purpose of lead surveillance is to detect elevated BLLs that may cause potential health effects for investigation and management. Elevated blood lead is a notifiable condition in six Australian jurisdictions, with differences in data collection, notification methods and timeliness (Table 7).[13] Additional lead management in communities at risk of lead exposure from nearby lead mines, smelters or other lead industries may exist and linked to community based screening, education and community wide engagement activities.

Table 7 Notifiable blood lead levels and existing screening programs, by Australian jurisdiction

Jurisdiction	Notifiable	Notifiable blood lead level*	Other blood lead program	Details
Queensland	Yes	≥5 µg/dL	Yes	Capillary screening for children aged 1–4 years, Mount Isa
Australian Capital Territory	No	N/A	No	N/A
New South Wales	Yes	≥5 µg/dL	Yes	Capillary screening for children aged 1–4 years, Broken Hill
Northern Territory	Yes	≥5 µg/dL	No	N/A
South Australia	No	N/A	Yes	Capillary screening for children aged 0–4 years and pregnant women, Port Pirie
Victoria	Yes	≥5 µg/dL	No	N/A
Western Australia†	Yes	High-risk ≥5 µg/dL Remaining public ≥10 µg/dL	No	N/A
Tasmania	Yes	≥5 µg/dL	No	N/A

* Blood lead levels are collected using a venous technique and notifiable via laboratories unless otherwise stated.

† In Western Australia medical practitioners must notify health authorities if they make a diagnosis of 'lead poisoning'.[13]

In Queensland, pathology laboratories are mandated to report elevated venous blood lead results. Notifiable cases are reported to Queensland Health through the Notifiable Conditions Register, NOCS. In Queensland until mid-2017, there was a two-tiered notification threshold for elevated blood lead based on exposure source. From 2000 to July 2017, the criteria for occupational notification were demonstration of a BLL ≥50 µg/dL in any person known to be occupationally exposed to lead. The occupational notification thresholds were guided by Queensland Government's occupational health and safety body, Workplace Health and Safety Queensland (Table 8).

Table 8 Occupational blood lead notification thresholds, by sex

Action	Male	Female		
		Reproductive capacity		Not of reproductive capacity
		Not pregnant or breastfeeding	Pregnant or breastfeeding	
Lead risk work	30 µg/dL	10 µg/dL		30 µg/dL
Removal of worker required	50 µg/dL	20 µg/dL	15 µg/dL	50 µg/dL

In July 2017, occupational notification levels were aligned with the existing non-occupational levels (5 µg/dL) (Figure 11). Non-occupational notification thresholds have been reduced two times since 2000.

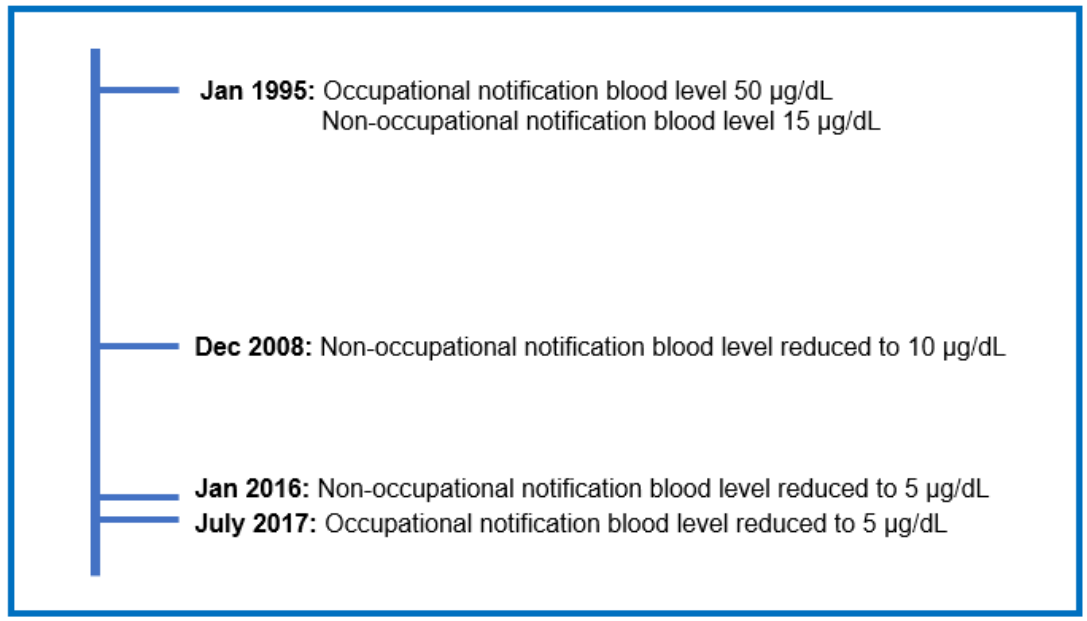

Figure 11 Timeline of blood lead notification levels in Queensland, 1995–2018

Blood lead surveillance for children in Mount Isa, Queensland

Exposure to lead fumes and dust can place individuals working or living near lead smelters and mines at risk of elevated BLL. There are four mines in Queensland where the output currently or previously contained significant quantities of lead:

- Mount Isa Mines, Mount Isa, northwest Queensland
- Cannington Silver and Lead Mine, northwest Queensland
- Sun Metals Townsville, Townsville, north Queensland
- Century Mines, northwest Queensland.

Mount Isa Mines has operated since 1931 and contains one of the biggest lead mining operations in Australia—Xstrata Mount Isa Mines Limited.[22] Two active surveillance programs for children aged less than 5 years operate through Queensland Health to detect elevated BLLs, through venous and capillary blood testing. Since August 2014, opportunistic diagnostic testing of lead in routinely collected venous or arterial blood specimens has occurred in children presenting to Mount Isa Hospital. Venous blood is obtained via a direct puncture to a vein, commonly from the arm or hand. The results are reported to and monitored by the Townsville Public Health Unit in northwest Queensland. The Mount Isa Capillary Blood Lead Screening Program commenced in September 2016 at the Mount Isa Child Youth and Family Health Service. The purpose of screening asymptomatic children is to detect early evidence of an abnormal BLLs. Capillary blood is collected via a finger prick during routine immunisation visit and results available within a few minutes. Capillary results are not considered diagnostic and a blood result above the reference range must be confirmed via venous testing to be notifiable. The Mount Isa Capillary Blood Lead Screening Program will also be analysed in this evaluation separately (Appendix A).

Legal authority for data collection

Public health legislation and associated regulations provide the regulatory framework for the implementation of surveillance and response systems.[23] Queensland Health is responsible for non-occupational lead exposure to safeguard the public from any potential harm of illness caused by exposure to environmental hazards, diseases and harmful practices. Management of elevated BLLs involves investigating and controlling the source of lead (non-occupational or occupational), through interventions to reduce exposure to individuals and the community. Public health services in Queensland are provided through 16 Hospital and Health Services (HHS) governed by a Hospital and Health Board. Each HHS is served by one public health unit (PHU) responsible for responding to notifiable diseases and conditions.

The *Public Health Act 2005* (the *Act*) is the legal mechanism under which elevated lead exposure must be notified.[24] Lead exposure is listed as a "pathological diagnosis notifiable condition" (Section 72) in the *Public Health Regulation 2005,* which contains implementation details and as subsidiary legislation guidelines, dictate how provisions of the *Act* are applied.[25] Workplace Health and Safety Queensland (WHSQ) regulate occupational lead exposure under the *Work Health and Safety Act 2011,* supported by the *Work Health and Safety Regulation 2011*.[27] Workplace Health and Safety (WHS) legislation, health and safety requirements are largely consistent across Australia; Queensland legislation is based on the national standards. The WHS legislation stipulate businesses do what is reasonably practicable to ensure the health and safety of their workers. This requires them to eliminate or minimise risks associated with workers exposed to lead in occupations so far as is reasonably practical with regards to lead-risk jobs, or work carried out in a lead process that is likely to cause the blood lead to be elevated. The *Occupational Health & Safety Regulations 2011* outline employer and employee responsibilities at workplaces where lead-risk work is undertaken including:

- regular monitoring of workers classified 'at risk'
- worker suspension or removal if prescribed BLLs are exceeded
- case referral to Workplace Health and Safety Queensland.[28]

Treating doctors and/or employers are responsible for case management.

Lead surveillance involves multiple stakeholders increasing the surveillance and case management complexity. Stakeholders include Queensland Health, Department of Natural Resources and Mines, WHSQ, public health medical officers (PHMO), general practitioners (GP), other health care providers, academia and members of affected communities. Occupational lead exposure is also discussed in this evaluation for several reasons. From 2012, lead test results <50 µg/dL were sent from selected occupational workplaces, following a change in reporting practices by some pathology laboratories undertaking workplace lead testing. Since October 2018, all occupational lead tests results ≥5 µg/dL were notified to Queensland Health. Notifications are not immediately classified as occupational or non-occupational, they require triage and work by the Data Services staff and occasionally investigation by environmental health officers (EHOs) to further confirm the occupational source and clarify the cause. Low-level environmental exposure may be caused by occupational and non-occupational sources and pathways. Occupational workplace exposure is a public issue, as lead dust may be present on clothes or vehicles that leave the workplace, potentially exposing spouses and children of individuals in lead-risk jobs. Exposure may also occur in para-occupational employment or through hobbies in unregulated private residences (e.g., production of jewellery, sinkers or lead shot). Effective working relationships with different departments involved in lead surveillance is essential to identify all those at risk and prevent exposure.

Evaluation objectives and rationale

Public health systems should be evaluated periodically to ensure they serve a useful public health function, to promote the best use of public resources and monitored routinely to ensure they continue to meet their objectives.[11, 29] Upcoming and recent changes to the surveillance system provide an opportunity to inform areas for improvement. The aims of this evaluation were to systematically and objectively evaluate the usefulness and selected attributes of the excessive lead surveillance system (ELSS) and provide recommendations for improvement.

The specific objectives of this evaluation were to:

1. Describe the surveillance system in Queensland
2. Describe the purpose and operation of the surveillance system
3. Analyse surveillance data to understand trends in the epidemiology of elevated BLL notifications in Queensland
4. Assess surveillance system attributes including acceptability, data quality, flexibility, representiveness, sensitivity, stability, timeliness and usefulness
5. Determine if the objectives of the surveillance system are being met
6. Use the results to provide evidence-based recommendations to alter and/or improve the existing surveillance system.

4.4. Methods

I used the Updated Guidelines for Evaluating Public Health Surveillance Systems developed by the CDC to undertake the evaluation. The WHO Communicable disease surveillance and response systems: Guide to monitoring and evaluating was also used as a complementary resource. The steps outlined by the CDC are described in Figure 12.

Figure 12 Evaluation steps established by the Centers for Disease Control and Prevention

Qualitative and quantitative data were used to construct a balanced and reliable description of the surveillance system and assess the eight selected attributes. Three primary attributes were selected based on the condition under surveillance: simplicity, representativeness and acceptability. Five other secondary attributes were also selected to facilitate a comprehensive evaluation and investigate the relationships between the different attributes (Table 9).

Table 9 Summary of public health surveillance system attributes for the excessive lead surveillance system evaluation and their measurement*

Attribute	Definition	Measurement considerations
Acceptability	Willingness of persons or organisations to participate in the surveillance system. This may include the participation rate of data providers, completeness of case report data, timeliness and frequency of data reporting, or responsiveness to request for supplemental information.	Semi-structured interviews. Analysis of surveillance data, including timeliness of enhanced surveillance investigations undertaken and the simplicity of the surveillance system.
Data quality	Completeness and validity of data in the surveillance system.	Semi-structured interviews. Analysis of surveillance data, including completeness of data fields and data errors.
Flexibility	The ability of the system to be adapted to changing needs. Flexible systems can accommodate new health-related events, changes in case definitions or technology, variations in funding or reporting sources, modification of the reporting frequency and data requirement needs. Retrospectively evaluated by observing how the system has responded to recent changes in the surveillance processes.	Semi-structured interviews.
Simplicity	Structure and ease of implementation, including the simplicity of information flow from its point of generation to the end users. Aspects including (a) amount and type of information collected, (b) ease of collection, (c) compilation, (d) analysis, (e) reporting and (f) ease of using the reporting format should be considered.	Semi-structured interviews. Review of multiple internal Queensland Health documents.
Representat-iveness	Ability of the system to accurately describe the occurrence of a health condition under surveillance over time and its distribution the population by person and place. Assessed by comparing the reported cases or events to actual cases/events and based on the understanding of the epidemiology of the health conditions in the population.	Semi-structured interviews. Analysis of elevated surveillance data. Analysis of Mount Isa capillary screening data. Review of the surveillance protocol.
Sensitivity	Sensitivity to a surveillance system to (a) case detection (proportion of individuals who have the condition of interest), (b) outbreak detection (probability that the surveillance system will detect a significant increase in a health condition in	Semi-structured interviews.

	time or space) and (c) case definition (ability of the case definition to critically represent the health condition of interest and clarify the cases to which it is applied).	
Stability	The stability of the system refers to the reliability (function without failure) and availability (operational when required) of the public health system.	Semi-structured interviews. Review of the surveillance protocol.
Timeliness	A public health system that is representative accurately describes the occurrence of a health-related event over time and its distribution in the population by place and person. It refers to the degree in which the reported cases reflect the occurrence and distribution of all the cases in the population under surveillance.	Semi-structured interviews Analysis of surveillance data, including timeliness of investigations undertaken and cases closed. Review of the surveillance protocol.

* Table adapted from references [11, 23, 30]

4.4.1. Notification data

I performed descriptive analyses using Stata, version 14.1 (StataCorp, College Station, TX, USA) and Microsoft Excel™. Data were extracted from the NOCS system on 17 November 2017 for all cases of elevated blood lead notified between 1 January 2000 and 31 December 2017 in Queensland. The analysis was re-run in September 2018 (data extracted 9 September 2018) to obtain up-to-date estimates in 2017. The data ranges examined were selected due to reduced data quality prior to 2000. I analysed non-occupational and occupational exposure data separately due to the two-tiered notification system.

Numbers percentages and incidence rates (cases per 100,000) of elevated blood lead were calculated in aggregate and separately between 2000 and 2017. Rates were calculated by dividing the number of reported new cases by the mid-year estimated resident population estimates and multiplying by 100,000. Data were also analysed by demographics (age and sex), health region as defined by Queensland health areas, HHS. To examine reporting over time, annual rates per 100,000 population were calculated between 2000 and 2017. Rates could not be calculated for some variables (e.g., Indigenous status) because a significant percentage of notifications were missing from this data field. The highest blood lead test result is reported in the analysis if multiple test results were conducted within a 12-month period. Individuals residing interstate or overseas are excluded.

4.4.2. Ethics approval

Ethics approval for this evaluation was granted by the Australian National University Human Research Ethics Committee (HREC 2017/909) and Townsville Hospital and Health Service Human Research Ethics Committee (HREC 17/QTHS/269).

4.5. Results

4.5.1. Objectives of the excessive lead surveillance system

The purpose of the surveillance system describes why the system exists and objectives relate to how the data are used for public health action.[29] I was unable to identify any documented purposes or objectives for the system. Based on interviews of stakeholders, potential objectives for the system are:

- To monitor the epidemiology of lead exposure in Queensland
- To identify novel exposures so that appropriate public health action can be taken

4.5.2. Semi-structured interviews

Stakeholders were interviewed if they had one or more of the following roles in the lead surveillance system including:

- data collection
- data entry
- data analysis or reporting
- enhanced surveillance and case investigation
- general management of the surveillance system.

Two primary stakeholder groups included system operators and data users. System operators included individuals responsible for the database, which houses the notification data. I interviewed three members of the Data Services team. Fourteen PHU directors were approached and asked to nominate an appropriate staff member for interviewing. Thirteen PHUs responded (92.9%). I conducted a total of 18 interviews with stakeholders including EHOs, environmental health team leaders, managers, and one public health registrar. Informed verbal consent was obtained from all participants. Stakeholders had been involved with the lead surveillance system between less than 1 to 24 years. Interviews with Queensland Health employees involved in different areas of the surveillance system enabled triangulation and varying perspectives, facilitating a more comprehensive understanding and evaluation.

I developed a semi-structured questionnaire guided by selected system attributes (Appendix C). I piloted the questionnaire with a colleague experienced in qualitative research and improvements were made to the structure, questions, sampling frame and recruitment process. Interviews occurred until the field of interest was saturated and no additional information was being obtained. The interviews were audio-recorded and notes taken with the participant's permission. I later manually coded and classified the notes. A second checking of themes occurred through the re-reading the interview notes and re-listening of selected sections to review and transcribe quotes. This enabled the earlier system of classification to evolve into a more sophisticated system and development of themes, concepts, ideas and recommendations.[31]

During the placement, I had multiple informal discussions with members from the Environmental Hazards team as I assisted with the lead surveillance system tasks and activities. These discussions and activities informed the evaluation and enabled me to be familiar with critical elements of the surveillance system. Other sources of information were reviewed including system documents, legislation, internal correspondence and emails identified as relevant to the historical context, operations, input, output and management. I also contacted other Australian states and territories for information relating to their lead surveillance system processes for comparison.

Population

The population under lead surveillance includes Queensland residents. In June 2016, the estimated resident population was 4,844,473 people.[22]

4.5.3. Excessive lead surveillance data

From 2000–2017, there were 2,549 persons notified with elevated blood lead notified to Queensland Health. Occupational cases represented 40.1% (1,022/2,549) reflecting regular testing required by workplaces at risk of lead exposure. In 2017, the reduced notification level increased the proportion of occupational notifications to 69.4% (846/1,219).

4.5.3.1. Occupational lead exposure

From 2000–2017, annual occupational blood lead notifications ranged from 1 to 846 notifications and were predominately in males (998/1,022).

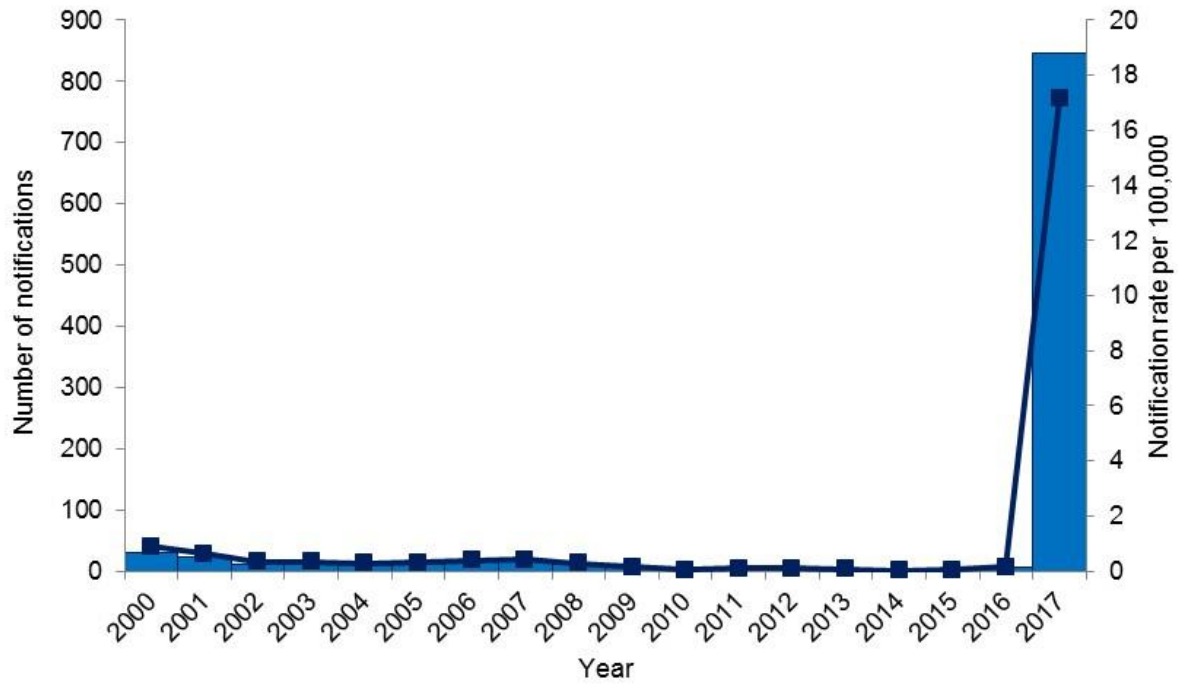

Figure 13 Occupational blood lead notifications and notification rate per 100,000 population, Queensland, 2000–2017*

* In July 2017, the occupational notification threshold decreased from 50 µg/dL to 5 µg/dL aligning with the non-occupational notification threshold

The median age was 40 years (range 19–68 years). From 2000–2016 when the occupational notification level was 50 µg/dL, 91.5% of lead levels were between 45 and 69 µg/dL (161/176). In 2017, 47.9% of blood levels were between 5 and <10 µg/dL (405/846), impacted by the change in BLL notification level in July 2017. From 2000–2017, the highest notification rate was seen in Townsville HHS (202.0 per 100,000), due to the presence of several mining sites and regular workforce residing in this area (Table 10).

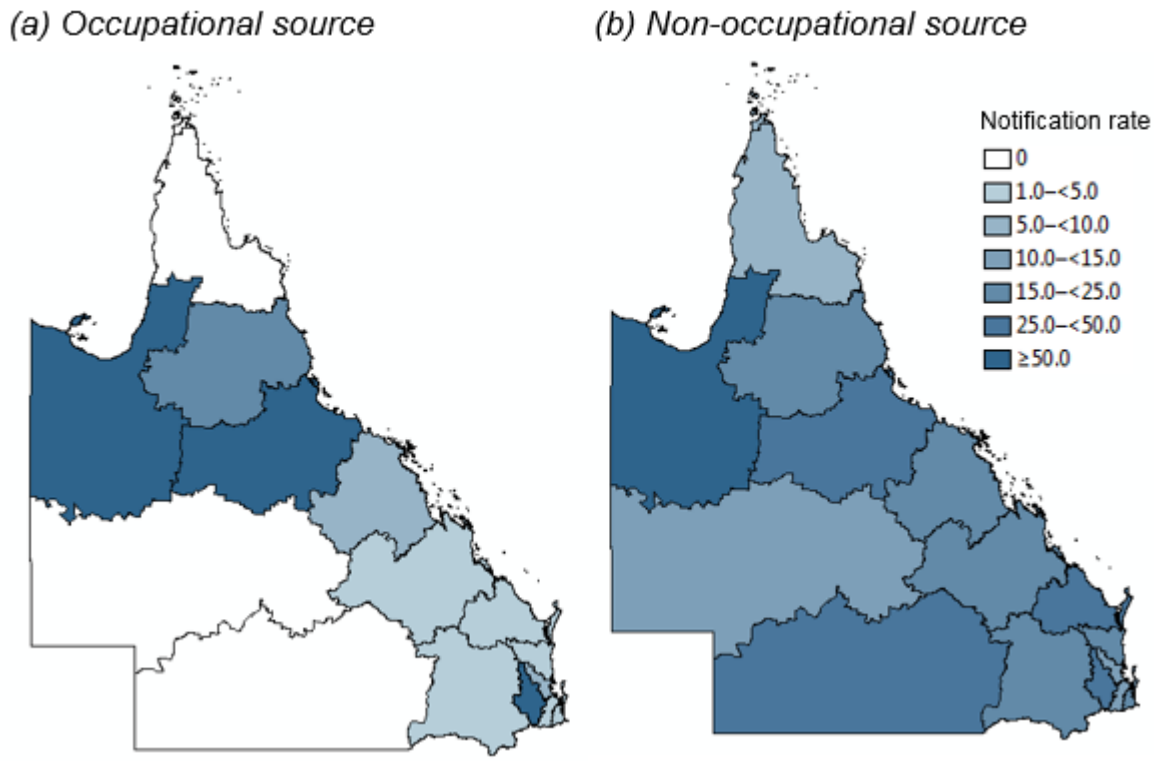

Figure 14 Lead notification rate per 100,000 population, by source and Hospital and Health Service, 2000–2017

* Notification rates were calculated using Hospital and Health Service estimated resident population estimates. Population estimates were unavailable for years 2000, 2001 and 2016. For these years, population estimates were substituted from the closest available year.

In Queensland, mining accounted for 51.4% (525/1,022) of all occupational exposures, followed by battery manufacturing (17.7%) and exposure to lead concentrate (9.2%).

Table 10 Number and proportion of occupational causes of elevated lead exposure, Queensland, 2000–2017

Cause	No.	%
Battery breaking	8	0.8
Exposure at indoor/outdoor rifle range	25	2.4
Lead-based paint from structures	16	1.6
Lead exposure during maintenance or demolition	13	1.3
Removal lead-based paint domestic	45	4.4
Making lead-based objects*	1	0.1
Weld, braze or solder lead	8	0.8
Scrap metal recycling	2	0.2
Exposure at mine sites	525	51.4
Exposure at foundry	15	1.5
Use/exposure ceramic glaze	3	0.3
Battery manufacturing	181	17.7
Exposure lead concentrate†	94	9.2
Plastics manufacture	9	0.9
Radiator manufacture, repair or maintenance	10	1.0
Vehicle work	2	0.2
Manufacture/lead cutting	2	0.2
Fire assay laboratory	7	0.7
Not answered	5	0.5
Other	45	4.4
Unknown cause	6	0.6
Total	1,022	100.0

* Lead-based objects include lead items such as sinkers, toy soldiers and lead shot.

† Excluded exposure at Mount Isa Mines.

4.5.4. Non-occupational lead exposure

From 2000–2017, there were 1,042 non-occupational blood lead notifications (annual range 13–187); 26.5% were female (276/1,042). The notification rate remained stable (0.3–1.6 per 100,000 population) until changes were made to the case definition from 2016 (3.8–3.9 per 100,000 population) (Figure 15). From 2000–2017, the median age was 45 years (range <1–83 years) and children aged less than 5 years represented 20.9% of notifications (218/1,042).

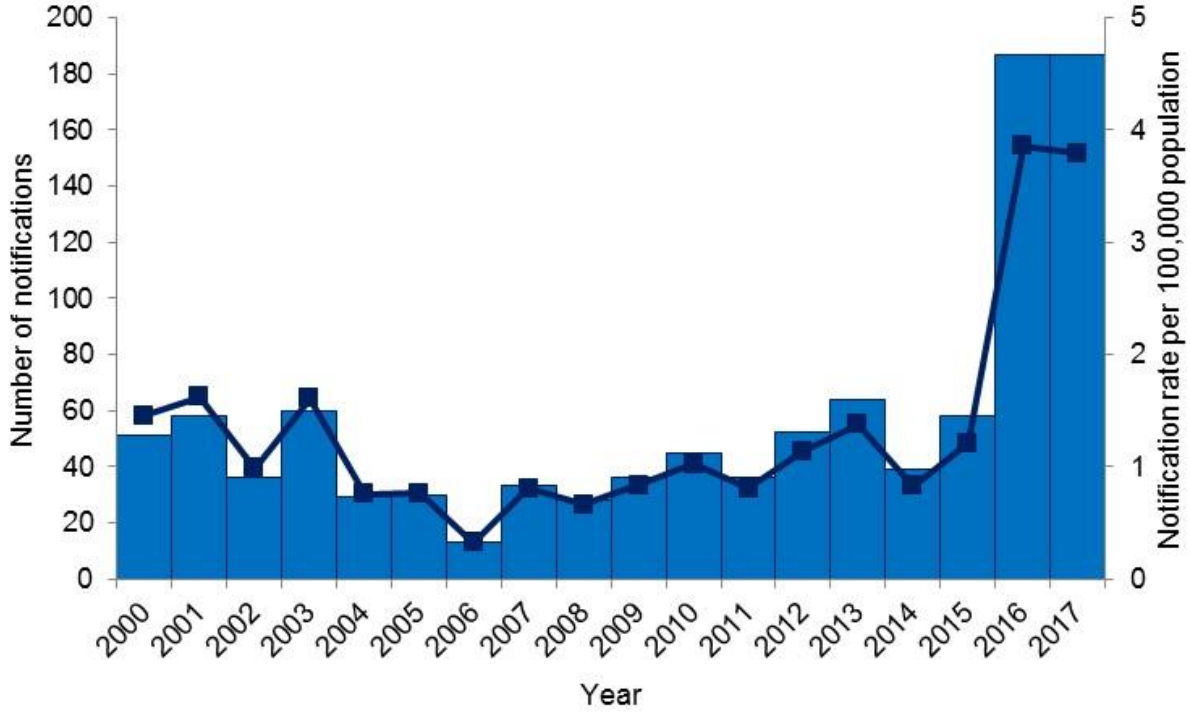

Figure 15 Non-occupational blood lead notifications and notification rate per 100,000 population, Queensland, 2000–2017

Blood lead levels decreased from 2000 to 2017; the notification rate for blood lead ≥15 µg/dL decreased from 1.5 to 0.8 per 100,000 population (Figure 16). From 2000–2008, the highest proportion of blood lead results notified were within 20–<45 µg/dL (49.6%). From 2009–2015, the highest proportion were within 10–<20 µg/dL (66.7%) and from 2016–2017, 61.5% of blood lead results were within 5–<10 µg/dL.

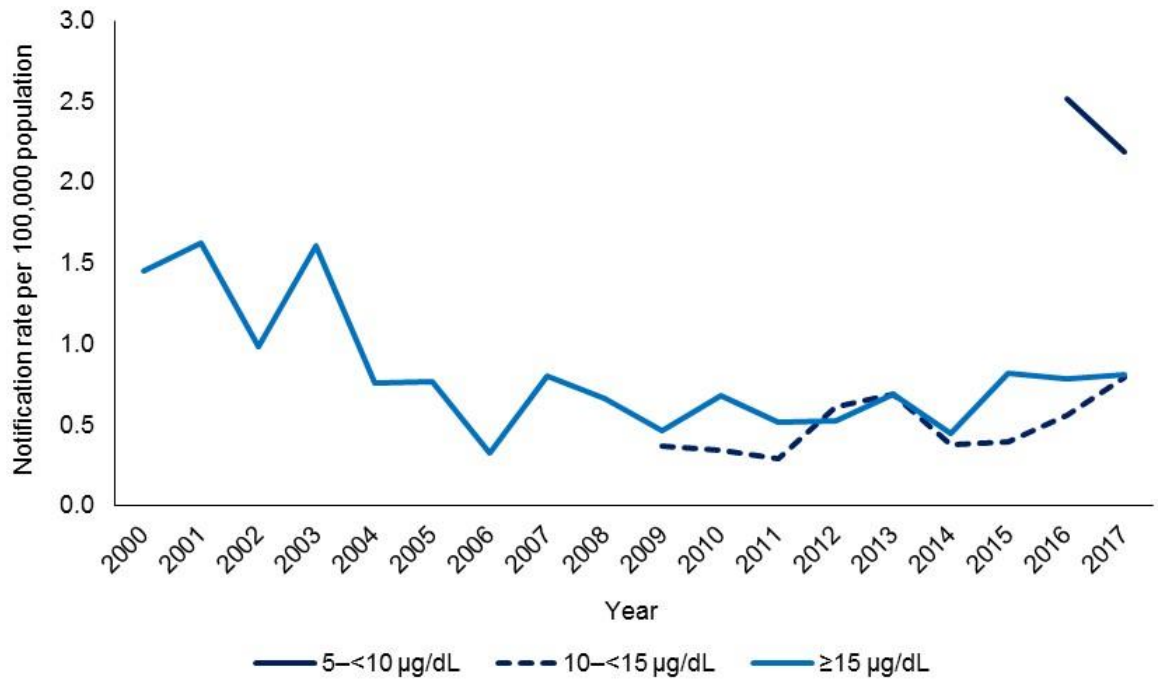

Figure 16 Non-occupational blood lead notification rate per 100,000 population, by lead category, Queensland, 2000–2017

In individuals aged 5 years and above, the most common causes of elevated blood lead were exposure during lead-based paint removal in domestic environments (35.9%), firing ranges (19.9%) and making of lead objects (i.e. sinkers, toy soldiers) (10.8%). In children aged less than 5 years, the most common causes of elevated blood lead were Mount Isa residence (32.1%), lead-based paint removal in domestic environments (28%) and pica (hand to mouth exposure) (18.3%). Of all non-occupational notifications, 9.2% were unable to have a cause determined (Table 11).

Table 11 Number and proportion of non-occupational lead notifications, by cause of exposure and age group, Queensland, 2000–2017

Cause	Age group					
	<5 years		≥5 years		Total	
	No.	%	No.	%	No.	%
Battery breaking	0	0.0	3	0.4	3	0.3
Exposure at firing range	0	0.0	164	19.9	164	15.7
Lead-based material (soil, sinkers)	0	0.0	3	0.4	3	0.3
Lead-based paint removal (domestic)	61	28.0	296	35.9	357	34.3
Lead-based paint removal (structures)	1	0.5	9	1.1	10	1.0
Maintenance or demolition exposure	2	0.9	16	1.9	18	1.7
Lead lighting manufacture	1	0.5	3	0.4	4	0.4
Exposure to leaded petrol* (incl. petrol sniffing)	1	0.5	8	1.0	9	0.9
Making lead-based objects†	4	1.8	89	10.8	93	8.9
Mount Isa resident	70	32.1	48	5.8	118	11.3
Skin penetration by lead object	0	0.0	4	0.5	4	0.4
Welding, brazing or soldering	0	0.0	6	0.7	6	0.6
Pica (intentional)	40	18.3	18	2.2	58	5.6
Lead medicines	0	0.0	15	1.8	15	1.4
Scrap metal recycling	0	0.0	2	0.2	2	0.2
Secondary exposure	3	1.4	3	0.4	6	0.6
Burning wood with lead	0	0.0	1	0.1	1	0.1
Furniture restoration	0	0.0	4	0.5	4	0.4
Exposure at mine sites	0	0.0	1	0.1	1	0.1
Exposure at foundry	0	0.0	1	0.1	1	0.1
Use/exposure ceramic glaze	0	0.0	2	0.2	2	0.2
Not answered	0	0.0	2	0.2	1	0.1
Other	15	6.9	47	5.7	62	6.0
Unknown cause	20	9.2	79	9.6	99	9.5
Total	218	100.0	824	100.0	1,042	100.0

* Exposure to leaded petrol includes petrol sniffing.

† Lead-based objects include items such as fishing sinkers, toy soldiers and lead shot.

The first step in reducing elevated blood lead in individuals is to identify the source of exposure for investigation and further management.[13] Occupational notifications significantly increased in 2017, following alignment with non-occupational notification levels and a reduction in notification threshold (from 50 to 5 µg/dL). Workplace exposure remains a serious and underestimated issue in Queensland. Increased occupational blood lead notifications will require clear management of processes and designation of PHU responsibilities. There is also an important opportunity for surveillance of individuals at risk of secondary exposure. Exposure to lead-based paint reported the highest number of non-occupational notifications, although confirmatory testing of suspected lead-based paint is not standard practice. Historical lead-based paint may be found on window frames, doors, skirting boards, cupboards, exterior and interior walls, gutters, metal surfaces and other structures built prior to 1970 and may be covered by more recent coatings of paint. Renewed interest in historical property renovation may lead to a new group at risk of lead exposure, including children living in homes where renovations occur.

There are a wide range of potential exposure pathways. The current system does not enable multiple sources of lead to be recorded potentially under-representing other important risk factors. The changing notification levels mean trends are difficult to interpret, although the notification rate decreased over the time period suggesting declining lead exposure. From 2016–2017, the highest proportion of notifications were 5–<10 µg/dL. At this level health effects may not be noticeable and supportive advice and education is provided only.

It is important to recognise some of the limitations of blood lead surveillance data. Individuals may be asymptomatic, not seek healthcare and all those who seek healthcare may not be referred or have further diagnostic blood lead testing. The changing notification levels means that an individual with a ‘normal’ BLL previously may now be considered to have a high BLL based on updated evidence and notification levels. Previous years may underestimate individuals with elevated blood lead results. Occupational numbers were under-representative of elevated blood lead in the community, capturing very high lead levels only. Although changes may reflect the changing epidemiology, notifications may be also affected by an increased emphasis on lead surveillance for example, targeted community surveys. Queensland Health undertook a blood lead screening program of Mount

Isa children aged 1–4 years from 2006–2007 and follow-up survey in 2010. Data from 2016–2017 were not considered finalised, with a number of notifications with an ‘unanswered’ source. Total estimates for 2016–2017 are likely to change as data is updated and investigations complete.

Monitoring the epidemiology of excessive lead exposure provides useful information to identify novel exposures and clusters, inform the development of better risk reduction strategies, control measures, guide future research and develop policies in Queensland. Laboratory testing data including lead tests <5 µg/dL would be useful in interpreting notification data to determine whether trends were a result of a change in diagnostic practices or true reflection of a change in the epidemiology of lead exposure. The absence of available data reduces the ability to identify emerging risk factors, clusters and respond accordingly.

4.5.5. Resources used to operate the surveillance system

Resources used to operate the system include funding sources, personnel requirements, data management systems (NOCS) and other components such as travel, laboratory support and software maintenance. An estimate of the costs is beyond the scope of this evaluation. Stakeholders contributing to the operation of the ELSS are listed in Table 13.

Table 12 Stakeholders responsible for the Queensland excessive blood lead surveillance system

Stakeholder	Role
Queensland Health	
Communicable Diseases Branch, Prevention Division	Establishment, maintenance, accuracy and integrity of the notifiable conditions register (NOCS). Initial notification triage. Notification to the PHU following an elevated blood lead result. Receipt of enhanced notification data and entry into NOCS.
Health Protection Branch, Prevention Division	Monitoring of NOCS to ensure requirements of the Management of Blood Lead Levels Protocol are being met. Identifying emerging sources and trends of lead exposure across Queensland and initiating any necessary action. Ongoing review of the notification system to enhance lead notification management. Publication of an annual notifiable blood lead report within six months from the end of the calendar year.
Environmental Health, PHUs	Undertaking enhanced case surveillance and investigation. Identification of lead exposure source. Provision of advice to the affected individual, family member and/or other relevant individual on reducing lead exposure. Return of the completed enhanced surveillance form to CDB (Appendix D).
External stakeholders	
Pathology laboratories	Blood lead specimen analysis. Notification of elevated blood lead results to Queensland Health.
General practitioners, specialists (e.g., paediatricians) and other health professionals	Identification of possible cases of lead exposure in the community. Referral of cases for blood lead testing if suspected lead exposure has occurred. Assisting with enhanced surveillance investigations including identifying exposure source and cause.

Source: Adapted from Queensland Health[3]

4.5.6. Flow of data through the system

The flow of data is described in Figure 17.

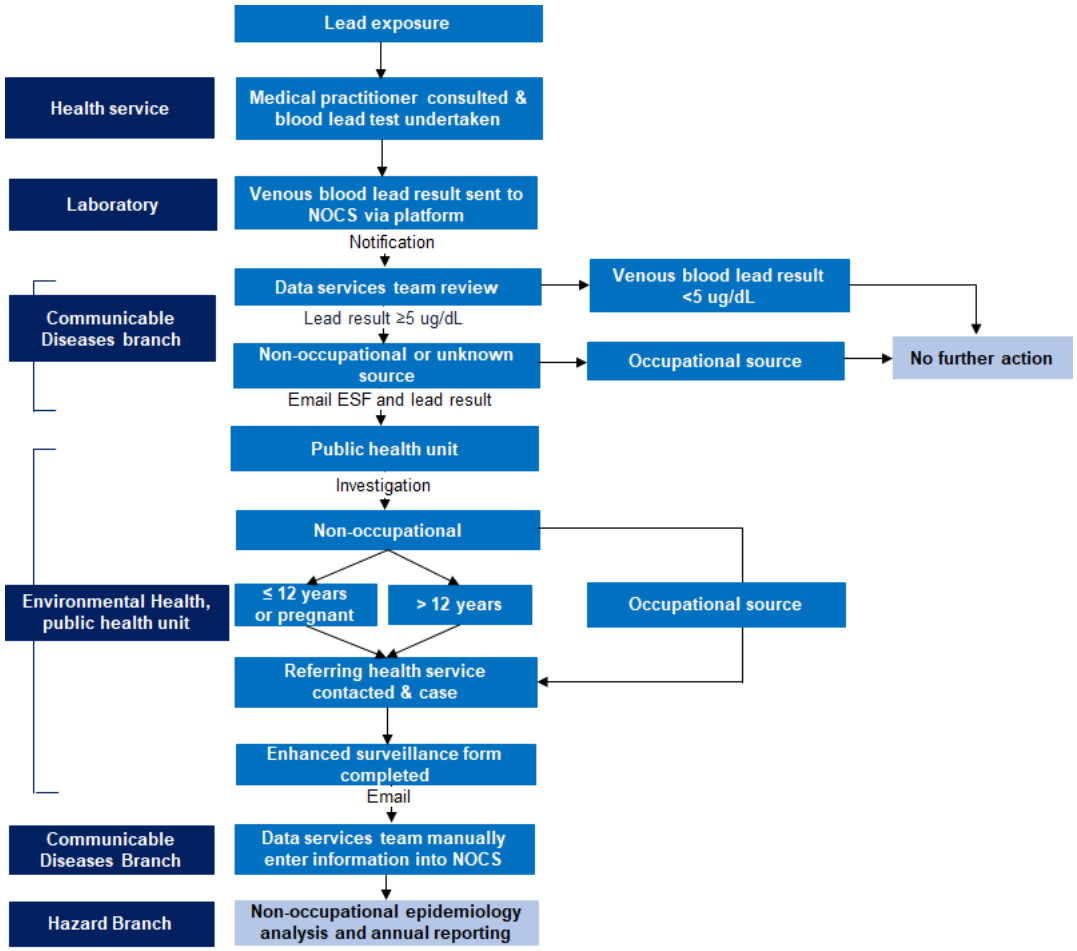

Figure 17 Flow of information through the lead surveillance system

Lead surveillance data is received via secure web-based portal from laboratories, managed and stored in NOCS. The Data Services team play an important role in facilitating the data flow and triaging notifications. If result is identified as occupational by the referring laboratory, the source field is changed in NOCS manually and no further action is taken by Queensland Health. At the time of writing, occupational lead exposure data were not reviewed, analysed or reported to other agencies, although an agreement had been signed enabling the sharing of information. Non-occupational or unknown lead notifications are reviewed to determine if a new notification or repeat test. The following documentation will be printed, scanned and emailed to the appropriate PHU:

- cover letter
- enhanced surveillance form
- scanned blood lead pathology report
- historical BLL tests (if re-test).

The Environmental Health team per PHU is responsible for case investigation. Public health management is undertaken by PHUs guided by the blood lead result, Management of Notifiable Blood Lead Levels protocol and existing documents released by other agencies, for example US Environmental Protection Agency and Health Safety Executive. Clinical management is undertaken by clinicians. Investigation results are emailed to the Data Services team where they are entered manually into NOCS. At the PHU, the results are stored as a paper file and entered into the state register and records system (Monitoring, Applications, Permits and Licensing Events [MAPLE]).

4.5.7. Security

Notification data are highly protected. All access to NOCS is through named accounts, each account has a limited set of permissions to view and edit appropriate subsets and NOCS can only be accessed from inside the Queensland Health information technology network. The lead data is located within the same registry as sensitive communicable diseases data, which translates to a high level of security.

4.6. Evaluation of system attributes

4.6.1. Simplicity

The simplicity of the ELSS, including structure and ease of operation is variable. Integrating lead surveillance within the communicable disease data management system facilitates uniform structures, processes and personnel. It avoids a lack of standardisation arising from independent systems and additional resources (e.g., staff training requirements, system maintenance). In 2008, the transition from

manual to automated pathology reporting of lead results improved the timeliness and efficiency of data transfer.[32]

Managing the lead notification is highly manual due to the existing data transfer process. Each blood lead result is manually reviewed by the Data Services team to determine if it is above the notifiable BLL, is a new notification or repeat test and has an occupational source. A member of the Data Services team will email the following documentation to the relevant PHU:

- cover letter
- enhanced surveillance form
- scanned blood lead pathology report
- previous BLL tests if relevant.

Upon investigation completion, the completed enhanced surveillance form is then scanned, emailed to the Data Services team where the data manually entered into NOCS. The same process will occur if it is a re-test. The paper-based data flow is administratively burdensome and time consuming.

"I think we need to simplify the process and make it more automated"

Data entry occurs at the PHU into Queensland Health's monitoring and record storage platform (MAPLE) and stored as a paper record.

In theory, lead investigations are simple. The majority are completed by contacting the referring health service clinician or other healthcare staff (nurse manager or practitioner), and sometimes the case via telephone. Challenges may occur trying to obtain case contact details or in contacting the case.

"…filling in the enhanced surveillance form isn't difficult but there is a lot of background work that goes on before you work out what it is that is causing the problem"

Demographic information (age, sex, Indigenous status, locality) are captured automatically from the pathology notification. The system may be improved by capturing exposure data during the process of laboratory referral.

"I think this [determining the source] could be done at the time of taking the blood lead test, finding out where the person works or they work in the lead industry…we're just doubling up in phoning up and finding this information out, it could all be received at the time of the doctor either requesting the test or taking the actual sample"

The Management of Notifiable Blood Lead Levels protocol is relatively clear for non-occupational notifications. Environmental health management actions are aligned with lead level categories, age (≤12 years and >12 years) and pregnancy status. Less straightforward is the level of investigation required for occupational and repeat non-occupational exposures, translating to variability in follow-up by PHUs. There are conflicting guidelines in the protocol:

"A lead exposure notification which is linked to an occupation is to be confirmed for cause and source of lead exposure for Register recording. However, educational/public health interventions are not undertaken as this responsibility falls under the jurisdiction of Workplace Health and Safety Queensland or the Department of Natural Resources and Mines"

This is contradicted by a following suggestion for consideration of education to be given to the occupationally exposed person and recommendation they consult with a medical practitioner. Stakeholders described two examples of uncertainty in the investigation process:

- Notification of re-test and elevated BLL due to workplace testing and below levels required for workplace suspension or removal (Table 8).
- Notification of a re-test following non-occupational blood test and elevated BLL in an individual considered not at risk where the original cause is clearly outlined.

There is a lack of clear direction regarding the role of Queensland Health in occupational exposure case investigation, sharing data and communicating with WHS.

“The interface with Workplace Health and Safety is always a bit fuzzy…we’re not entirely sure what they’re doing”

“How do Workplace Health and Safety do their job is they don’t get the information from Queensland Health? How does Queensland Health do their job if we can’t give the information to the regulatory body that can improve the situation?”

“We need be either talk to Workplace Health and Safety or some sort of structure involved where we can assist them in their role with regards to this…I believe there is an avenue for improvement”

Concerns were highlighted that Queensland Health has access to occupational surveillance data, while little to no follow-up actions occur for either the cases, or secondary exposed individuals. In 2017, discussions with stakeholders including Mount Isa Mines and WHSQ commenced to facilitate sharing of data through a Memorandum of Understanding, which would overcome the current confidentiality barriers. At the time of writing, the agreement and data sharing processes were finalised and first stages of data transfer to commence. Lead notifications deemed to be from an occupational source require a clear management and streamlined process. This is especially important with the decreased notification threshold in 2017 and increase in notifications.

Limited risk factor information is captured on the enhanced surveillance form simplifying the investigation:

- occupational source
- occupation
- cause of lead exposure
- case validity.

There are 29 potential attributable on the enhanced surveillance form. A review is required to refine and expand possible causes to identify potential risk factors, as

well as capture demographic information which may be missed. For example, there are two categories for pica (intentional ingestion) and multiple categories for exposure to lead-based paint. Pregnancy, multiple causes, reason for testing, household contacts and individuals at risk of secondary exposure are not captured through the current surveillance processes. One PHU adapted the surveillance form to improve data capture and common risk factors observed.

Extraction of the data from NOCS is simple although requires a specific program (SQL developer) not available to PHUs. The data are extracted as a line listing onto a Microsoft Excel™ spreadsheet by the Data Services team. Algorithms may be tailored to the PHU needs for example, data extracted using the highest BLL notification per individual within the reporting period (<12 months), or all BLL tests received per individual. Data fields are largely drop down and non-text. Basic summary analyses can be undertaken using available programs such as Microsoft Excel™. Advanced data analysis requires a more advanced statistical package for example, identification of data entry errors and time-series analysis. At a state level the review, analysis and dissemination of the data is straightforward, although knowledge of the surveillance system, basic data cleaning and management is required. A data cleaning and analysis protocol would be useful to facilitate consistency of annual reporting.

PHUs have access to elevated BLL data in their health area only obtained through notifications they receive from the Data Services team. The data is not regularly reviewed and information is stored across three systems. A simpler data management and transfer system is required. At the time of writing, proposed changes were for EHOs to have direct access to NOCS to monitor elevated lead notifications within their HHS and enter investigation information directly into the system. Alternatively, for the Data Services team to send a regular Excel spreadsheet of aggregated current and outstanding elevated BLL notifications to PHUs for action.

In conclusion, the simplicity of the surveillance system varied. Input of information into the system was simple from laboratories and surveillance data easy to extract via the Data Services team. However, the data transfer processes and multiple management systems did not facilitate the dissemination and use of information.

4.6.2. Acceptability

The investigation of elevated blood lead was viewed as important by stakeholders due to the irreversible and preventable adverse effects. Higher importance was placed on at-risk populations including children and individuals residing in mining areas.

"On the non-occupational side, I think it's [investigation of lead exposure] important that it continues to happen because there is a lot of concern in lead mining areas that there could be things happening that they don't know about"

Delays in the return of the enhanced surveillance form by PHUs suggested the investigation and/or reporting were not prioritised. Ad hoc dissemination of lead surveillance data by the Environmental Hazards Unit also occurred, which meant that users of the system could not see clear public health outcomes from their actions and therefore were not engaged in the system.

"I don't think the way it's [surveillance data] utilised at the moment makes it very important…If it's not being analysed in any whatsoever way then I don't see why we would do all the extra work"

Five respondents were unaware annual reports existed prior to 2012. In contrast, other select communicable disease data are publicly reported weekly, by year-to-date and annually on the Queensland Health website. A weekly communicable disease update report is also released, containing comments on conditions for notifications of public health interest. Dissemination of surveillance data may improve acceptance of the system through the perceived benefits, acknowledge PHU efforts and facilitate an understanding of lead exposure trends.

"I think that we should have that feedback loop report so we can better identify and educate the community for these risks…I don't know [trends] because we haven't got the data coming back"

“Only anecdotally [understand lead surveillance trends] because we never get the data back…Maybe at the end of the year it would be good to see a report”

4.6.3. Flexibility

Flexibility is assessed in line with the changes to the blood lead notification level and Queensland Health reporting policies. The reduction of the non-occupational blood lead level in 2009 and 2016 translated to a higher number of notifications. From July 2017, the case definition included all occupational notifications submitted to Queensland Health ≥5 ug/dL. Reports indicate the additional system demands were well-absorbed by system recorders. These included increased triaging by the Data Services team and number of investigations undertaken by PHUs.

“We had fair notice that the change was coming through…the system and the unit coped well with it”

Facilitators include an integrated electronic notification system (NOCS), experienced personnel (Data Services team and EHOs), stable funding and automated reporting. Simpler systems are more flexible as fewer components require modification.

“It’s not a system that’s overly complicated and the surveillance isn’t overly complicated…I think it would be adaptable”

“I think it can change with the changing environment just sometimes the timeliness of that change may not be as quick as we’d like it to be”.

The flexibility of the system at a management or field level must also be considered in addition to the internal flexibility. Absent data sharing agreements between key stakeholders prevent sharing of surveillance data historically. Agreements enabling the sharing of data were significantly delayed, highlighting the variable flexibility within the system.

4.6.4. Sensitivity

A true estimate of the sensitivity of the system is difficult to assess because available lead data are limited, there are no national or state blood screening programs, little available evidence of lead exposure in low-risk areas confined to a

few research studies[13] and no recent population prevalence studies.[33, 34] Detecting elevated lead exposure is complicated as exposure may occur over a long time, clinical presentation is variable and there is a dose-response relationship. Asymptomatic and non-specific symptoms mean the sensitivity is likely to be low, except in workplaces undertaking regular monitoring of blood lead and Mount Isa due to the active lead screening program in children.

"It's [lead surveillance system] not going to give you full coverage…unless you're aware that you've been exposed to lead-based products or you're exhibiting some form of symptoms that triggers a doctor to test you for lead then we may never pick up on the fact that you have an elevated blood lead level…the notification process is great when tests are being taken but we've got no way of knowing what we don't know"

Within lead workplaces, variability was reported in exposure awareness, blood monitoring and protection practices undertaken. There are potential gaps in the surveillance system, for example smaller and informal employers such as renovators and painters, or part-time or voluntary work undertaken, such as in shooting ranges.

Sensitivity is affected by GP awareness of lead exposure, who are responsible for facilitating lead testing. Variable knowledge by GPs was reported, reflected by higher lead notifications linked to individual health services. Identical medical history and presentation may generate a referral for the same individual by a GP in one area, whereas a GP in another area may not recognise the risk or request blood lead testing. This may translate to non-uniform case detection and under-diagnosis.

"I'm not convinced that we're actually capturing all the information from the community because the doctors aren't ordering the tests…energy could be invested in that first initial critical step"

Clinical judgement and GP awareness are clearly important in promoting lead testing and preventing disease. Sensitivity may also be considered by the ability of the surveillance system to detect clusters and monitor trends over time.

"They've found out about the people in southeast Queensland who were at the rifle ranges so they've identified an outbreak there"

Smaller and/or informal businesses may be unaware of their obligations for employees undertaking lead process activities, promote less robust practices to avoid lead exposure (e.g., protective clothing and equipment) and less diligence in monitoring that their employees have their blood lead checked by a registered medical practitioner. The willingness of cases to present for testing and/or answer investigation questions affects sensitivity. Stakeholders cited examples where cases were hesitant about responding to public health investigations due to the personal implications or consequences for their workplaces.

The case definition for excessive blood lead is based on laboratory definitive evidence (BLL ≥5 µg/dL) in any individual. Using a laboratory case definition means the case definition is more specific[3] reducing the number of 'false positive' lead notifications. Laboratory testing is widely available and accredited to national standards in Australia. As with any laboratory test, no test is totally accurate (with 100% sensitivity and specificity). There may be variation in accuracy between laboratories even when strict protocols are adhered to, it may be more difficult to accurately measure samples in which the concentration of lead is less than 10 µg/dL and a margin of error when interpreting results.[2, 11]

A public health surveillance system that does not have high sensitivity and/or detect all cases may still be useful in gaining sufficient information to monitor current and future trends, if specificity and positive predictive value (PPV)[4] remain constant. Changes to improve the sensitivity (e.g., parallel physician and laboratory reporting, state screening programs) must be carefully weighed with the increased GP workload, cost, reduction in population BLL and overall public health impact. False

[3] Specificity refers to the proportion of persons without the disease that are considered by the surveillance system as not having the disease.
[4] The PPV refers to the proportion of cases that meet the cases definition who actually have the condition.

positives may also result in the poor allocation of time and resources by health services and have unintended harmful effects for the population.

4.6.5. Representativeness

The representativeness of the lead surveillance system varied between populations in Queensland. Lead exposure disproportionally affects selected workplaces, hobbies which use lead-based materials and communities where lead mining and smelting occur. Those who come into closest contact with lead in production processes are over-represented in the surveillance system due to routine blood lead monitoring, indicated by the high number of elevated blood lead notifications from mining workplaces.

Children residing in Mount Isa are well represented due to the opportunistic testing at Mount Isa Hospital and capillary screening program. However, there is varying representativeness within this at-risk group and concern Aboriginal and Torres Strait Islander (Aboriginal) children are not being tested due to acceptability and accessibility barriers. Furthermore, Aboriginal children may be at higher risk of elevated BLLs. In an analysis of capillary screening data from September 2016 to February 2018, Aboriginal children in Mount Isa were shown to have higher BLLs than non-Aboriginal children (Appendix A). Higher BLLs were also reported in Mount Isa Aboriginal children in a pilot study.[35]

Stakeholders drew upon their experiences to identify other potential subgroups under-represented or systemically excluded:

- shooting range participants (see Case Study 1)
- culturally and linguistically diverse families
- casual or para-occupational employment in lead exposed workplaces.

Several stakeholders raised concerns regarding secondary lead exposure and the importance of GPs in detecting elevated blood lead in patients.

> *"I think the secondary exposures that are coming out of workplaces and again, I don't know if it's broadly all workplaces it's probably not by the nature of the work…certainly we've seen it in the battery manufacturing setting and it wouldn't surprise me if there are others. Often what we're finding is the secondary exposure stuff is not always front of mind for the doctors either when we talk to the doctors. So, awareness from the doctors that they're not just dealing with an individual client whose had an elevated exposure from a workplace for a while…often the lack of knowledge that that could also be contributing to an unknown secondary exposure in the household"*

Case Study 1 – Increased notifications of elevated blood lead linked to a shooting range in Brisbane, Queensland

In late 2015, an employee at a shooting range in metropolitan Brisbane reported a high BLL. Safety concerns surrounding the shooting range were reported to WHSQ and Queensland Health. The original employee and regulators encouraged other employees and/or shooting range members to have blood lead testing. From 2015 to 2016, the number of BLL notifications attributed to shooting increased from 1 to 8 in Metro North HHS, and from 11 to 42 in Queensland. Strict safety controls and improvements in industrial practices have assisted in ensuring occupational lead poisoning is monitored in larger occupational settings. The investigation indicated that cases of lead exposure from shooting ranges may not be well captured and may be under-represented in the surveillance data.

In 2014, the highest non-occupational lead notification was attributed to the use of imported lead-based medicine. Lead may be present in certain types of unregulated cosmetics and medicines used in countries such as India, China and Viet Nam.[1] Families from culturally and linguistically diverse backgrounds and who purchase unregulated items containing high lead levels (e.g., consuming lead-based medicines, kolh make-up or jewellery) may be under-represented.

An assessment of the system representativeness is challenged by poor data completeness in some fields, limited risk factor data captured and high notification levels for occupational lead notifications, prior to 2017. It is unlikely all elevated lead exposure cases are being captured in Queensland. A surveillance system

does not have to be representative to be useful if under-represented populations are identified and actions taken to reduce exposure. The WHO recommends increased testing in children, pregnant women and adults known to be exposed to lead, testing in individuals where someone in their household has been exposed, in individuals where severe health problems which may be attributed to lead and other persistent and unexplained health problems.[12] Strengthening detection efforts in at-risk populations to reduce exposure is an important public health priority.

4.6.6. Timeliness

Timeliness is influenced by the asymptomatic or non-specific clinical presentation, latency period, diagnosis by a GP and laboratory reporting to Queensland Health (Figure 18).

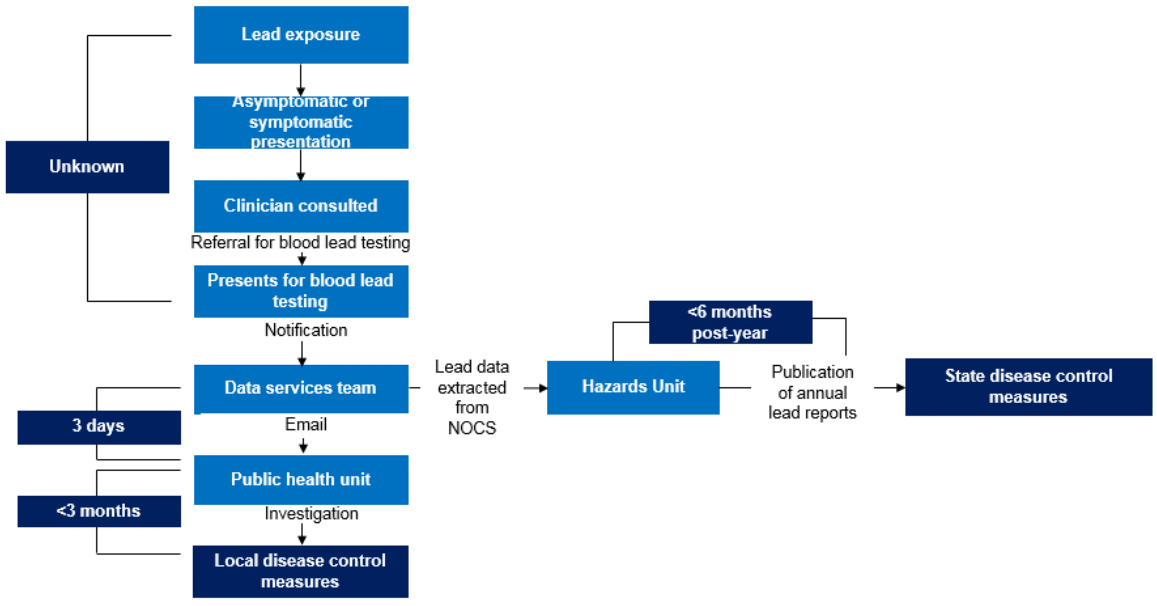

Figure 18 Operational characteristics in the lead notification process and time between steps

The exact time between exposure to the lead source and seeking of medical attention is unknown due to key information that was not captured in NOCS, including onset of symptoms and the date of investigation. In September 2018, a review of the surveillance data from 2016 to 2017 demonstrated approximately one

third of notifications were unfinalised and had an unanswered or undetermined source. This may reflect delayed public health investigation and perceived low severity or sending of the enhanced surveillance form to the Data Services team for entry into NOCS.

Several factors affecting the timeliness of follow-up were cited including existing system processes, competing workloads and inability to contact the GP or other relevant healthcare personnel and/or case.

"The delays would generally be potentially just as simple as an email gets missed you know the notification comes through to a generic email box and for whatever reason it gets missed…it has happened again rarely but it has happened"

"Occasionally it [delays] may be work priorities that are happening at the time"

Some PHUs reported a risk-based assessment and prioritisation of at-risk groups including:

- children aged less than 5 years
- pregnant women
- significantly elevated BLLs.

"If we do get notifications in that are involving children we tend to jump on those pretty quickly"

"We tend to try to screen the notifications well and I don't know whether that might be something that could be better reflected in the protocol…at the moment all notifications have to be actioned within a certain time frame to me that's not really risk based"

The timely reporting of surveillance data is important for wider stakeholders to understand and respond to changing trends. As mentioned previously, annual surveillance reports have not been published since 2011 limiting an understanding of lead exposure trends.

4.6.7. Stability

Since 2001, NOCS has been managing lead notification data as part of an integrated disease surveillance system. The single database means there is internal expertise to complete minor changes. Staff turnover is limited reducing the need for orientation of new staff and important regarding the role of the Data Services team in managing notifications (e.g., triaging). Funding has remained consistent for the surveillance system.

In 2013, 2017 and 2018, there were three documented occasions of unexpected system performance resulting in some lead notifications not received from laboratories. Approximately 400 blood lead results during 2016–2017 were not sent to Queensland Health resulting in delayed public health action. In 2018 there was an unscheduled outage of one pathology information system. This translated to an increased workload by the Data Services team as reports needed to be manually monitored and delays in notification processing. The events highlight the influence of information technology on system performance and fragility of surveillance systems with one notification source. The notification system undergoes regular and random auditing of notifiable diseases; however, auditing of the lead surveillance system does not occur regularly due to resource constraints. A retrospective audit may identify issues with the transmission of notification data by laboratories.

Other factors that may have reduced the stability of the system include changing of the case definition and lack of enhancements to the lead surveillance system, despite the additional workload. Finally, there is an absence of dedicated resources to collate, analyse and disseminate lead surveillance data.

4.6.8. Data quality

Data quality is high, as assessed through two main collection points of information, including notifying laboratory lead results and enhanced surveillance forms submitted by PHUs.

Surveillance data are available from 1984 until 2018. From 1984–1999, blood lead results were not recorded in NOCS. From 2000, an improvement in data quality occurred and blood lead results recorded for over 99% of notifications. Investigation by PHUs will result in the notifications being allocated to one of four potential sources and 28 attributable causes. From 2000–2015, 2% of data had an unanswered source category and less than 1% undetermined (Figure 19). In 2016 and 2017, there were a higher number of ‘not determined’ (114/345 and 128/1,219) and ‘undetermined’ (37/345 and 58/1,219) sources, indicating incomplete data.

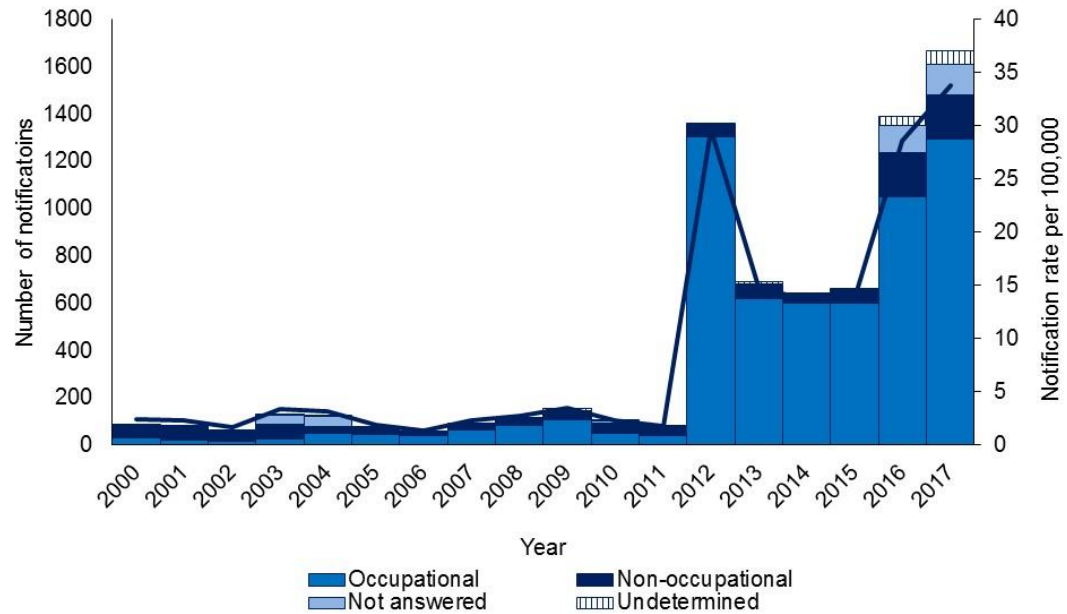

Figure 19 Number of elevated blood lead notifications and notification rate per 100,000, by source, Queensland, 2000–2017

Data fields captured are limited. Name, age, sex, HHS, locality, onset, notification and collection date reported 100% completeness. On the rare occasion demographic data is missing, a member of the Data Services team will source the information from another available dataset (e.g., Medicare, Australian Immunisation Register). In contrast, Indigenous status remained largely incomplete and proportion with the annual recorded Indigenous status ranged between 29% and

69% during the surveillance period. The occupation field was completed in 84.4% (867/1,022) of all occupational notifications, although the category ‘other’ represented a significant number (289/867).

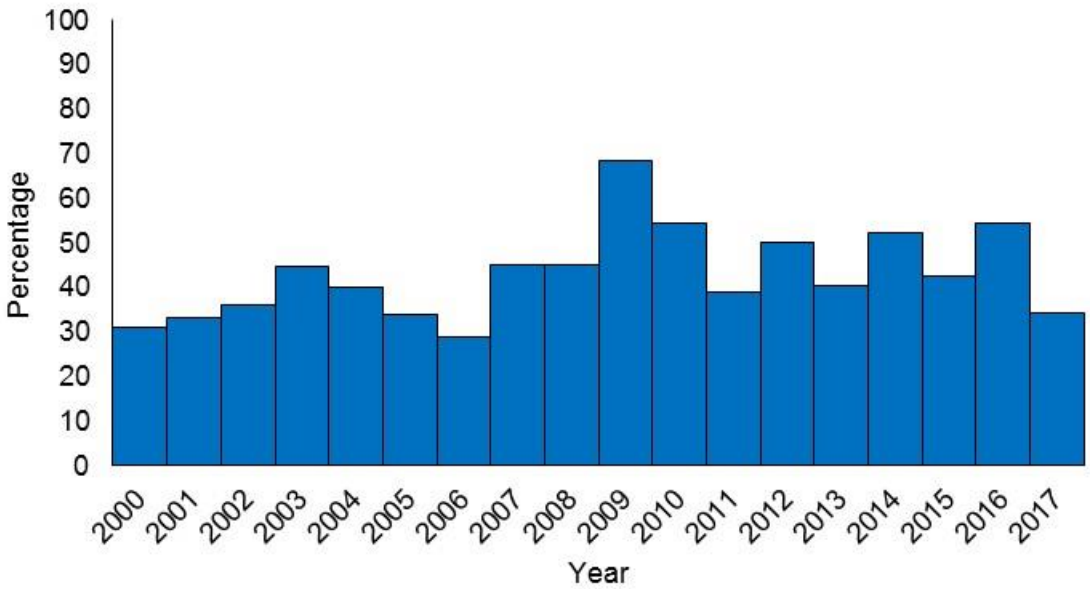

Figure 20 Proportion of elevated blood lead notifications with Indigenous status recorded, Queensland, 2000–2017

From 2000–2017, a source (occupational, non-occupational, unknown) was recorded for 89.5% of all notifications (range 47.1–100%). No cause was specified for 14.5% of notifications (Figure 21).

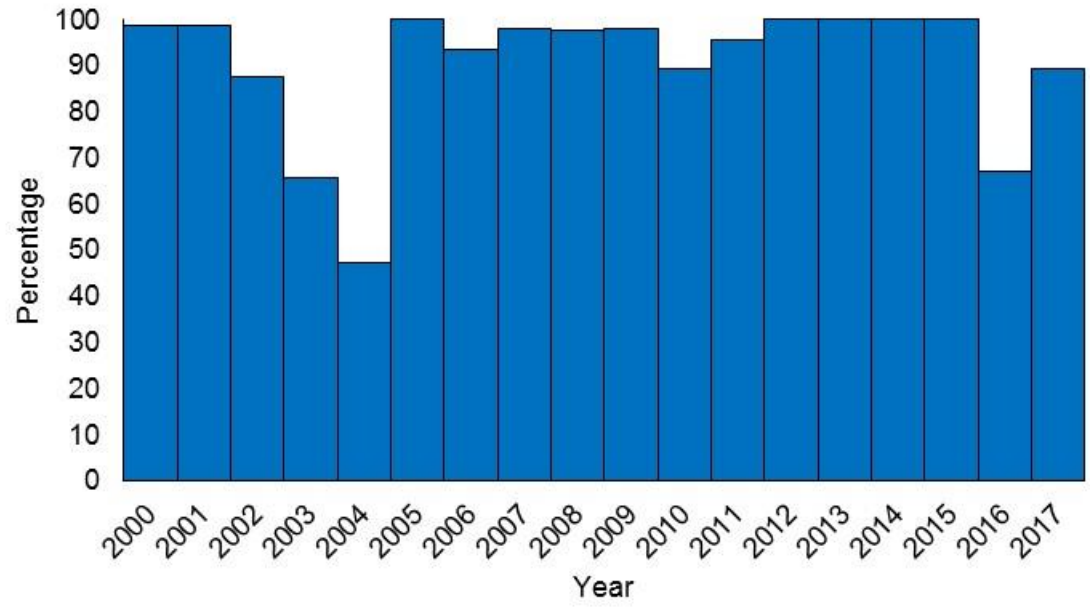

Figure 21 Proportion of elevated blood lead notifications with a source recorded, Queensland, 2000–2017

Quality is influenced by training and supervision of individuals involved, and care exercised in data entry and management. Investigations are undertaken by environmental health officers who undergo tertiary- and work-based training, guided by a standardised protocol. Two experienced Data Services team members are primarily responsible for entering the data into NOCS. Data quality checks occur at various stages facilitating consistency and quality. The Environmental Health Manager per PHU will review and approve the investigation findings prior to submission to the Data Services team. The PHMO may also be consulted for case management. Periodic data quality checks occur within the Data Services team.

Data quality is increased through laboratory notifications, centralised data entry and collection of limited variables. Other important risk factors would be valuable to increase the quality of the risk factor data collected. For example, duration of residence, other individuals residing in the same household, pregnancy status, country of origin, language other than English, reason for testing, among others (Appendix D). Additional data may be used in efforts to identify high-risk groups, target and evaluate interventions.

4.7. Discussion

In this evaluation, I have systematically assessed the blood lead surveillance system in Queensland. The eight attributes assessed were guided by the health outcome and their relationship with one another. The system is acceptable, conceptually simple and flexible. The lack of clearly documented aims and objectives, delayed investigations, failure to disseminate epidemiological information means that the data are not helping users to identify novel exposures, detect clusters and changes in trends. It also means that it is difficult to assess control measures and inform public health action.

Elevated blood lead clearly has public health importance warranting long-term surveillance in Queensland. Occupational lead exposure remains the major exposure route. The risk of lead exposure and contribution of sources differs between areas and population groups in Queensland. Surveillance of occupational lead exposure is required as a safeguard for at-risk groups to be identified, for example those in para-occupational roles, unregulated or unidentified occupations, and other individuals through secondary exposure. For the population at large, which is not occupationally exposed, lead-based paint, soil and atmospheric lead remains an important public health risk. Reservoirs of lead still exist in these environments and these sources will continue to affect populations for years. Lead exposure is preventable, associated with disparities and inequalities, may result in long-term disability, is of public health interest and there are actionable public health measures to control exposure. Some exposed and at-risk subgroups are under-represented. The cost of screening the Queensland population for elevated blood lead is not justifiable or recommended and identifying at-risk groups who have been exposed to more lead than the trace ‘background’ amounts remains the recommended strategy.

The epidemiology of elevated blood lead in Queensland is not completely understood, although likely to be decreasing in line with exposure to lead in

Australian homes and communities.[13] There are several challenges in lead surveillance. Patients with elevated blood lead may present asymptomatically or non-specifically. Additionally, chronic exposure may occur over long-periods before being identified such that the connection between the primary exposure source is difficult to trace with certainty.[36] The fundamental difference in managing lead exposure compared with an infectious disease is that the removal of lead from an individual's environment is required, rather than medical treatment. These prevention methods may be difficult or impossible to implement due to cost or acceptability.[36] Ultimately, public health policies to reduce lead in the ambient environment will achieve the strongest gains

Screening, monitoring, intervention and evaluation are critical for the development of cost-effective and evidence-based public health policies aiming at achieving these goals.[21] Identification and prevention of lead exposure requires targeting at-risk persons, such as children residing in mining communities, families living in older houses and those belonging to minority groups. The wide range of government and industry stakeholders involved in the management of lead exposure in Queensland mean that ongoing dialogue and communication are required. The siloed management of non-occupational and occupational notifications precludes identification of all lead-exposed individuals, as well as clusters resulting from occupational sources impacting on community members from secondary transmission. Engagement and education of GPs and frontline primary health care staff regarding lead exposure trends is important for case detection. In workplaces with lead production or contact, industry standards and controls need to be enforced and improved upon. Facilitating sharing of surveillance data between Queensland Health and WHS will achieve strong gains in identifying and addressing lead exposure.

This evaluation has attempted to use a systematic framework, data collection methodology and analysis. It provides a better understanding of the ELSS and opportunity for improvements to be made. It recommends a review of the surveillance system objectives, improvements in data quality and timely reporting at various levels. The results of this evaluation may provide the framework to enhance and improve the Queensland Health ELSS.

4.8. Recommendations

Below are areas that require strengthening to enhance the usefulness, acceptability, efficiency and effectiveness of the excessive blood lead surveillance system.

Recommendations for priority actions

1. The HPB specifically define, outline and publish ELSS objectives.
2. Routine meetings between the HPB and PHUs to discuss evaluation and system improvements.
3. Publication of a surveillance report by HPB examining trends, 2000–2017.
4. HPB to oversee auditing of lead notifications between the CDB Data Services team, laboratories and PHUs to identify any outstanding lead notifications to improve the stability of the notification process.

Recommendations for secondary actions

5. Designate a surveillance role within the Environmental Hazards Unit to regularly review and analyse lead notifications and follow-up of enhanced surveillance investigations. Responsibilities would include having access to notifications (SQL developer, NOCS), notifying PHUs of lead results and timely follow-up, confirming cases, data quality, examining novel trends and clusters, and completing annual reports. Occupational exposures would also be periodically reviewed and analysed for changes in trends.
6. Simplify data entry by investigating EHOs within PHUs entering investigation data directly into NOCS (and upcoming NOCS replacement in 2019).
7. Develop data extraction algorithms to develop triggers for outstanding enhanced surveillance investigations (>3 months) and priority notifications, including high BLLs (as per NHMRC guidelines) and in children aged less than 5 years.

8. Improve identification of Indigenous status through a review of pathology test submission practices and collection of Indigenous status on all pathology tests and/or enhanced surveillance forms.
9. Review of the enhanced surveillance form and collection of additional data fields including: pregnancy status, language other than English, reason for blood lead testing, onset of symptoms (if applicable), case residence (e.g., number of people living in the house, time residing at current address), primary cause and multiple cause category options (Appendix D).
10. Continue to acknowledge and strengthen existing formal and informal partnerships between Queensland Health and relevant stakeholders including WHSQ, Department of Natural Resources and Mines and other government agencies. Establish Queensland Health as the lead agency for lead surveillance and conduct annual meetings to provide education about blood lead. Establish clear standard operating procedures highlighting testing, notification and investigation responsibilities and data sharing. Continue to work in partnership with those who have a vested interest in the exposure pathways and/or health outcomes through improving data accessibility, communication channels and reporting (i.e. quarterly sharing of data).
11. Disseminate regular surveillance reports through formal and informal channels including quarterly and annual surveillance reports published online, trend surveillance reports and submissions in health bulletins. This includes information on occupational exposure to provide industry information on current trends.
12. Quarterly teleconferences with Queensland Health departments involved in the ELSS to share and evaluate the latest information and developments in lead surveillance.
13. Develop non-technical lead exposure education materials for the community including Queensland Health fact sheets for other important exposures (e.g., lead-based paint, pre-eclampsia, lead shooting, home renovators). Disseminate public health messages about the potential risks using targeted media and communication channels for at-risk communities.

14. Continue to engage GPs, paediatricians and frontline primary healthcare workers to be aware of sources of lead exposure and high-risk groups.

15. Conduct applied epidemiological projects surrounding lead exposure in Queensland:

a) Evaluation of lead surveillance practices across Australia, including Queensland, New South Wales and Victoria.

b) Mixed methods study examining the knowledge and attributes surrounding lead exposure and blood lead testing in workplaces where lead process activities occur.

c) Mixed methods study examining the acceptability and accessibility of blood lead screening in Mount Isa. The study would examine facilitators and barriers of blood lead screening in a mining community by interviewing healthcare workers and community members who do and do not participate in screening for their children.

d) Case reports of lead exposure clusters and outbreaks.

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4.10. Appendix A–Evaluation of the capillary blood lead screening program in Mount Isa

Image: Mount Isa Mines infrastructure, Mount Isa, Queensland

Executive Summary

Introduction

Lead is an environmental toxicant and potential health hazard.[13] Children aged less than 5 years are at greatest risk of poor health outcomes due the increased sensitivity of their developing nervous system and organs, and higher intestinal absorption than adults.[18, 19] High levels of lead exposure are associated with brain damage and impaired intellectual development.[3] At lower levels, less obvious health effects may include hearing and cognitive impairment, behavioural changes (hyperactivity, depression, anxiety) and blood abnormalities.[2] Lead exposure, as defined as a blood lead level of greater than or equal to 5 micrograms per decilitre [µg/dL] is a notifiable condition under the *Public Health Act 2005*.[24, 25]

The proportion of individuals exposed to additional sources of lead is very small in the general community. Individuals working or living near lead smelters and mines may be exposed to higher levels of lead due to air pollution contaminating local dust and soil over time.[13] Mount Isa in northwest Queensland, Australia contains one of the biggest lead mining operations operating since 1931—Xstrata Mount Isa Mines Limited.[22] Capillary blood lead screening was introduced 8 September 2016 as part of a wider community lead reduction strategy for children aged less than 5 years. Capillary screening is currently available only at the Mount Isa Maternal Child Youth and Family Health Service and offered at the same time children present for immunisations (6, 12, 18 and 42 months). Screening refers to the application of a test to a population which has no overt signs or symptoms of the disease, to determine the presence or absence of a disease.[37] Screening at-risk populations including mining communities for elevated blood lead is a recommended approach by the National Health Medical Research Council (NHMRC) and World Health Organization (WHO).

Capillary screening detects and measures the concentration of lead in a small sample (50 microliter of blood) obtained through a finger prick. The aim of capillary screening is to identify individuals who may benefit from advice and interventions to minimise or avert future exposure, monitor the effectiveness of community-wide efforts to reduce blood lead levels (BLL) and advocate for resources to reduce community exposure.[38] The characteristics of capillary testing mean lead may be measured quickly, it is less invasive test than venous blood testing, simple to

perform, does not require skilled laboratory personnel, has low purchase and operational costs and a reasonably good detection limit (range 3.3–65.0 µg/dL).[39] However, the capillary test may report a higher level of lead due to the test being harder to perform accurately, easy contamination of samples and test margin of error.[13] Further action is guided by the blood lead result. Follow-up management is recommended for results ≥5 µg/dL and referral for venous testing ≥10 µg/dL. In Mount Isa, active lead surveillance also occurs through opportunistic testing of lead in routinely collected blood specimens for children presenting to Mount Isa Hospital for other purposes, monitored by the Queensland Health Townsville Public Health Unit since 2014. Since 2010, free blood lead testing at Queensland Medical Laboratory (QML) has been available for all Mount Isa residents.

Regular monitoring and evaluation of screening programs is important to ensure they continue to be effective, and improved where possible to promote the best use of public health resources.[37] Further research should be undertaken when participation is suboptimal, in close co-operation with the community or subgroups with lower participation.[38] The objectives of this study were to: (1) provide reliable evidence on the number of children utilising the service in Mount Isa, (2) assess the prevalence of children with elevated blood lead levels, (3) understand the accessibility and acceptability of the capillary screening program and (4) identify factors which facilitate or hinder the uptake of capillary screening. The research will inform future recommendations of the Mount Isa capillary screening program.

Methods

Identifiable capillary blood lead data were received from the Mount Isa Child Youth and Family Health Service. Amounts of lead were measured using capillary blood tested with the Magellan LeadCare II Blood Lead Analyzer. Data variables provided included name, date of birth, Indigenous status, date of test, test result, iron level, place of birth and suburb of residence. Indigeneity was based on an ever-Indigenous algorithm, where an individual was recorded as Aboriginal and Torres Strait Islander (Aboriginal) if ever assigned an Indigenous status in the clinical data.

Names were examined using set duplicate checks and corrected for misspellings to enable the total number of individual children to be analysed. Duplicate entries and children aged 5 years and above were excluded. In the event multiple lead tests occurred on the same day or different lead results recorded, the highest test result was used. Age was calculated using the first date children presented for screening.

Concentration of lead are assessed both as a continuous variable and categorically, guided by groupings of health effects outlined by the NHMRC.[2] The geometric mean was calculated for the continuous data as considered a better representation of the average value when the data is highly skewed. For lead results below the level of detection of 3.3 µg/dL (36/1,032), an amount of 1.41 µg/dL was imputed, which is the level of detection divided by the square root of two.[40] Sensitivity analyses were undertaken using presentations with and without missing names, and missing Indigenous status. In September 2017, a preliminary site visit was conducted and informal discussions held with 18 individuals involved in lead surveillance and/or child health in Mount Isa. The executive summary represents the findings from the preliminary discussions and quantitative data as of October 2018.

Results

During 8 September 2016 to 13 February 2018, there were 1,032 capillary tests. The number per month ranged from 16 to 91 tests. This represented 730 individual children, including 593 (81.2%) non-Aboriginal children, 118 (16.2%) Aboriginal children and 19 (2.6%) children without Indigenous status recorded.

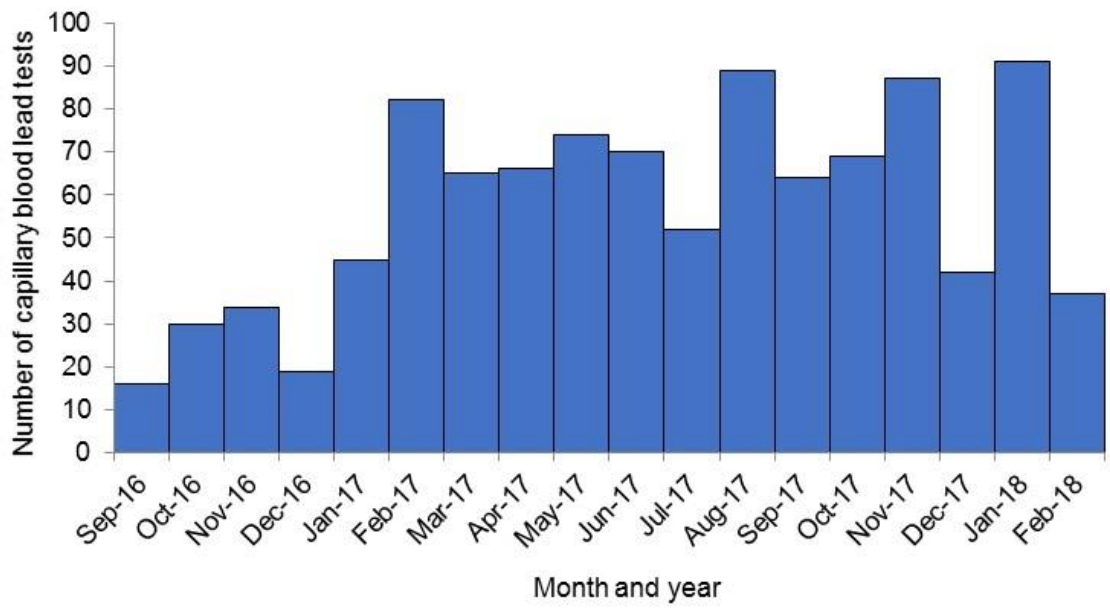


Figure 22 Number* of Mount Isa children who presented to the health clinic aged <5 years and had a capillary blood lead test performed, 8 September 2016–13 February 2018

***** n = 1,032

Children aged less than 1 year and non-Aboriginal children represented the highest number of children who presented for testing.

Table 13 Characteristics of individual Mount Isa children* aged less than five years of age who presented for capillary blood lead testing, by age†, lead result and Indigenous status, 8 September 2016–13 February 2018

Characteristic	Indigenous status			
	non-Aboriginal	Aboriginal	Not stated	Total
	No. (%)	No. (%)	No. (%)	No. (%)
Total	593 (81.2)	118 (16.2%)	19 (2.6%)	730 (100)
Age group				
<1 year	216 (36.4)	34 (28.8)	3 (15.8)	253 (34.7)
1 year	196 (33.1)	40 (33.9)	11 (57.9)	247 (33.8)
2 years	44 (7.4)	13 (11.0)	2 (10.5)	59 (8.1)
3 years	40 (7.0)	11 (9.3)	1 (5.3)	53 (7.3)
4 years	97 (16.4)	20 (16.9)	2 (10.5)	118 (16.2)
Lead level				
<5 µg/dL	436 (73.5)	72 (61.0)	17 (89.5)	525 (71.9)
5–9.9 µg/dL	133 (22.4)	39 (33.1)	1 (5.3)	173 (24.0)
≥10 µg/dL	24 (4.0)	7 (5.9)	1 (5.3)	32 (4.4)

* n = 730

† Age group is based on first presentation.

There were 205 children (157 non-Aboriginal, 46 Aboriginal and 2 not stated) who reported their highest blood lead result ≥5 µg/dL. The proportion of all children, non-Aboriginal and Aboriginal with blood lead levels above the current benchmark of 5 µg/dL was 28.1%, 26.5% and 39%.

Of these 205 children, 32 reported their highest blood lead result ≥10 µg/dL. The highest blood lead level recorded was 19 µg/dL. There was a significant difference between blood lead results and Indigenous status ($p<0.01$). Aboriginal children were more likely to report their highest blood lead result 5 µg/dL or above (39%) compared with non-Aboriginal children (25.5%).

Overall the geometric mean lead level was 4.2 µg/dL (95% CI 4.1–4.3) and higher for Indigenous children (4.7 µg/dL; 95% CI 4.4–5.1) compared with non-Aboriginal children (4.2 µg/dL; 95% CI 4.0–4.3). Sensitivity analysis of missing Indigenous status did not significantly alter the results.

Discussion

There were 730 individual children who presented for capillary blood lead testing in Mount Isa over the 18-month period. This represents approximately 42.6% of the Mount Isa population aged 0–4 years (730/1,712)[5].[41] Capillary screening showed approximately three out of 10 children screened had an elevated blood lead result, a rate higher than previously reported. There were 118 Aboriginal children who presented for capillary testing; 38.9% (46/118) were above the notifiable level. The data suggests Aboriginal children may be at higher risk of lead exposure. A collaborative partnership with Aboriginal Community Controlled Health Services Gidgee Healing is recommended to understand lead awareness in Aboriginal populations, improve the acceptability and undertaking of capillary screening. At the time of writing, capillary screening was not available as a continued screening service at the two Gidgee Healing clinics.

For screening to be effective it needs to be acceptable to the community at risk (i.e. they are willing to come) and accessible (i.e. the service exists and is easily accessed by the community at risk).[38] The lower participation suggests variable acceptability to different Mount Isa population subgroups, was less available and/or not considered a priority. The evaluation indicated there may be various community- and family-level factors which influence the decision by parents and carers to have their children undertake BLL screening.[42] Reported facilitators included the integration of the program into a local health service and childhood immunisation schedule; opt-out screening system; presence of long-standing community education, awareness and lead management programs; and characteristics of the capillary test itself. Reported barriers include low perception of risk especially lower lead levels; stigma and shame surrounding having a child with an elevated BLL; loyalty to the mines; absence of public transport in Mount Isa; unavailability of capillary screening at Aboriginal health services; ongoing migration of both non-Aboriginal and Aboriginal people; lack of awareness of the screening

[55] In the 2016 Census, there were 18,6791 people in Mount Isa (C) (Local Government Areas). Of these 1,712 were aged 0–4 years and 431 Aboriginal and aged 0–4 years.

program, alternate available testing services in Mount Isa and apathy by community members, including healthcare providers.

The purpose of lead screening in an asymptomatic individual is early detection of elevated lead exposure, in order to recommend preventative strategies or treatment that will provide a better health outcome than if the disease were diagnosed at a later stage.[37] The WHO principles and practices for the screening of disease may be used to provide support for or against screening in Mount Isa. Lead exposure is an important health issue for high-risk groups, there is a recognised latent period, the natural history of the condition is understood, agreed policy on whom to treat as patients, suitable test available with a moderate degree of accuracy and available facilities for diagnosis.

Several criteria are not or partially fulfilled. For screening to be introduced, there should be an accepted treatment. Most children with elevated blood lead reported levels between 5 and <10 ug/dL. The management for these children include education, an assessment and identification of risk factors, and follow-up capillary screening within a three-month time frame. It also cannot be assumed that a person with a screen-detected elevated blood lead will benefit from the diagnosis.[37] There is insufficient scientific evidence that the early detection of lower BLLs at these levels improves health outcomes through education[43] or environmental interventions such as dust control.[44] Compared with the treatment of an infectious disease, only lead removal from the environment will reduce risk to others.[36] This requires broader interventions and ongoing political commitment by the government and mining companies.

The screening test must be acceptable to the population, or participation will be low.[37] The participation over an 18-month period questions the acceptability and accessibility by some members of the Mount Isa community. It is likely that some high-risk groups are missed. There were 1,032 capillary samples undertaken on 730 children over the 18-month period. Several children with a BLLs below the threshold were rescreened within a 12-month period. Clear and refined protocols may ensure low-risk children are not unnecessarily screened wasting resources and high-risk children targeted, including Aboriginal children, those of a lower

socio-economic status and children of lead workers. Finally, screening should be viewed as a continuing process and not a ‘once off’ project. Ongoing investment and additional funding will be required.

There are important ethical considerations surrounding screening programs. There is a risk that children who receive false negative results may experience delays in diagnosis, parents develop a false sense of security, ignore warning signs or public health messaging. False positives may mean children without elevated BLL undergo follow-up and unnecessary and uncomfortable venous blood lead testing, lowering community confidence in the program.[37] Parents and carers should be informed prior to the testing or potential adverse effects as well as potential benefits.[37] Ongoing communication and clear messaging is required for the Mount Isa community regarding lead as a potential hazard.

There are several limitations in this analysis. Data quality was variable and missing important fields such as some names, sex, residence and length of time in Mount Isa. The analysis included the results of 27 unidentified children potentially over-estimating the number of individual children who presented for capillary screening during the period. An ever-Indigenous algorithm was applied to enhance Indigenous identification which may over-estimate Indigenous status. Although a sensitivity analysis did not alter the results. Misclassification of Indigenous status may still have occurred under-estimating true BLLs in Aboriginal children. Accurate data is required to monitor changes in blood lead and access to services. The results represent less than 40% of the Mount Isa population aged 0–4 years. Using the 2016 ABS Census data as the denominator may result in inaccurate estimates of service utilisation. The sample size and screening at one health service in Mount Isa means results cannot be interpreted to represent the whole community and is potentially affected by selection bias, including low-risk individuals. Blood lead accuracy and reliability is affected by environmental lead contamination during sample collection (e.g., collecting equipment and skin cleanliness) and some day-to-day biological variability. In lead endemic areas it may be easy to contaminate

blood samples, collection tubes and test kit items resulting in inaccurate blood lead test results. There is a small margin of error with blood lead tests (±2 µg/dL) and in combination with the risk of contamination, capillary samples may report higher concentrations of lead than venous samples.[13] Measurement error should be considered when interpreting the results.

Summary

This evaluation found the benefits of capillary screening outweighs potential negative outcomes; however, ongoing and additional efforts are required. Prospective monitoring of the screening program is necessary to ensure the screening program remains effective. Additional data will facilitate an understanding of the burden of blood lead among Mount Isa children. This preliminary study provided insight of the how the social environment in Mount Isa influences uptake of capillary screening, facilitators of and barriers to capillary screening in a mining community, as well as potential strategies to encourage screening in Mount Isa. Future challenges for managing blood lead in Mount Isa include ensuring the community continues to engage in preventative lead activities and maintaining the long-term momentum in the community to support childhood screening.

There are several recommendations below which may be considered to strengthen the existing capillary screening program and increase participation.

Recommendations

1. Expand surveillance risk factor data, including sex and length of Mount Isa residence.
2. Improve data quality, reduce the need for extensive cleaning and improve accessibility of data long-term through a standardised Excel spreadsheet template and data management tools such as Microsoft Access.
3. Facilitate robust and clear communication messaging regarding the capillary screening program, including the recommencement 14 May 2018.
4. Ongoing messaging surrounding potential hazards of lead exposure and health effects at lower lead levels (5–<10 ug/dL).

5. Regular monitoring and evaluation of the screening program to ensure effectiveness is maintained and improved where possible.
6. Regular publishing of the annual screening results to members of the Mount Isa community and relevant stakeholders.
7. Targeting of at-risk individuals including Aboriginal children, lower socio-economic groups and those of mining workers.
8. Expansion of screening at Gidgee Healing Aboriginal Community Controlled Health Service.
9. Review the lead testing undertaken by different Queensland Health departments in Mount Isa. This includes the opportunistic testing undertaken at Mount Isa Hospital, capillary screening program at Maternal and Child Health Services and testing at QML pathologies. While the existing programs are likely to identify different subgroups, some overlap will occur resulting in duplicated efforts. Triangulation of the data may highlight the effectiveness of different service.
10. Continue to focus on primary prevention strategies in addition to secondary prevention.

4.11. Appendix B–Communication to a lay audience

Fact Sheet: Elevated blood lead level and risk of pre-eclampsia

Introduction

Pre-eclampsia is a condition that occurs during pregnancy and has effects on both the mother and baby. The key signs and symptoms of pre-eclampsia include new onset of high blood pressure after 20 weeks of pregnancy, protein in the urine, and problems with the function of the placenta. The Society of Obstetric Medicine of Australia and New Zealand define pre-eclampsia as a hypertensive (high blood pressure) disorder.

Pre-existing high blood pressure is a strong risk factor for the developing pre-eclampsia. Certain women appear to be more at risk than others, including women who have a family history of the condition, are having their first pregnancy, have diabetes, are pregnant with more than one baby in the womb, are older (aged 40 years and above), obese or have some immune or organ conditions. Women who have one or more of these health conditions are at increased risk.
About three to five per cent of pregnancies are affected by pre-eclampsia. In low- and middle-income countries, it is one of the main causes of death of the mother and baby. In Australia, pre-eclampsia is uncommon; however, pre-eclampsia and its complications can lead to serious problems and death if untreated.

What is the main evidence?

Blood lead at low levels (from five to nine micrograms per decilitre) is associated with high blood pressure in adults. Some medical evidence suggests there is also a link between blood lead and high blood pressure during pregnancy, including at lower lead levels. The National Health and Medical Research Council recommends a person who has a blood lead level greater than five micrograms per decilitre should be investigated. The health complications for lead-exposure pregnant women may be higher than in non-pregnant women. In adults, lead is stored in the bones. During pregnancy, more calcium is needed and lead may also be released from the mother’s bones into the blood affecting the baby. Lead can also be found in breast milk. These findings are important in Queensland, which contains some areas with lead, such as Mount Isa.

What is the evidence of pre-eclampsia in Queensland?

- The percentage of women in Mount Isa with preclampsia was 6%, compared with 3.4% across Queensland.
- These estimates support the medical evidence linking higher blood lead levels with preclampsia.
- More research may be needed to understand and reduce the risks for mothers and their babies.

Summary

Pregnant women with blood lead levels greater than four micrograms per decilitre should be investigated. Pre-eclampsia should be monitored in pregnant women with higher blood lead levels. In addition, pregnant women who develop pre-eclampsia should be tested for lead exposure. In at-risk women and women with low calcium in their diets, calcium supplements may protect against the development of pre-eclampsia.

4.12. Appendix C–Excessive lead surveillance system stakeholder questionnaire

Australian National University

Queensland Government

Department of Health

LEAD EXPOSURE SURVEILLANCE QUESTIONNAIRE

PARTICIPANT INFORMATION

Name:

Date of completion (DD/MM/YYYY): / /

Job title:

INTERVIEWEE BACKGROUND

What is your role with the elevated lead level surveillance system in Queensland?

_____

How long have you been involved with the surveillance system? (Years)

_____

1. SUPPORT FUNCTIONS

Are you aware of any documents which help you fulfil your role with the surveillance system?

- ☐ Yes
- ☐ No
- ☐ Partially
- ☐ Not applicable

Describe the documents that describe or guide what information is entered into the system.

_____

Describe the documents that direct how the surveillance system is managed.

_____

Do you believe there are sufficient resources to support the core functions of the surveillance system?

- ☐ Yes
- ☐ No
- ☐ Partially
- ☐ Not applicable

2. SIMPLICITY

Can you describe the ELSS?

_____

In your experience/judgement, do you believe any part of the surveillance system is unnecessarily complicated?

- ☐ Yes
- ☐ No
- ☐ Partially
- ☐ Not applicable

If yes, what changes would you make to make it easier to implement while still achieving its purpose?

_____

Do you enter data onto the electronic notifiable conditions register?

- ☐ Yes
- ☐ No
- ☐ Partially
- ☐ Not applicable

If yes, is the notifiable conditions register user friendly?

_____

How easy is it to complete the enhanced surveillance form?

_____

3. USEFULNESS

The following questions relate to the objectives of the surveillance system.

Does the surveillance system assist in monitoring lead exposure trends?

- ☐ Yes
- ☐ No
- ☐ Partially
- ☐ Not applicable

If yes, what were the trends?

_____

Does the surveillance system assist in investigating sources of lead exposure?

- ☐ Yes
- ☐ No
- ☐ Partially
- ☐ Not applicable

Specify details _____

Has information from the surveillance system assisted in changing practices or policies to reduce lead exposure in Queensland?

- ☐ Yes
- ☐ No
- ☐ Partially
- ☐ Not applicable

Specify details _____

Are there any important variables that the dataset does not currently cover?

- ☐ Yes
- ☐ No
- ☐ Partially
- ☐ Not applicable

Specify details _____

4. ACCEPTABILITY

Do you believe the state surveillance of non-occupational exposure to lead in Queensland is important?

- ☐ Yes
- ☐ No
- ☐ Partially
- ☐ Not applicable

Specify details _____

Do you believe there may be more effective surveillance systems to identify non-occupational lead exposure in Queensland?

- ☐ Yes
- ☐ No
- ☐ Partially
- ☐ Not applicable

Specify details _____

5. FLEXIBILITY

Is the surveillance system able to adapt to changing needs over time?

- ☐ Yes
- ☐ No
- ☐ Partially
- ☐ Not applicable

Specify details _____

Can you provide an example of a change in the surveillance system?

- ☐ Yes
- ☐ No
- ☐ Partially
- ☐ Not applicable

Specify details _____

Have there been any disruptions to the system which may have impacted data flow?

- ☐ Yes
- ☐ No
- ☐ Partially
- ☐ Not applicable

Specify details _____

Has there been an occasion when the surveillance system was not able to adapt to a required change?

- ☐ Yes
- ☐ No
- ☐ Partially
- ☐ Not applicable

Specify details _____

6. TIMELINESS

Are there any issues with the timeliness of obtaining data from laboratories?

- ☐ Yes
- ☐ No
- ☐ Partially
- ☐ Not applicable

Specify details _____

Are there any issues with sending the test results (e.g., ESF, laboratory results) to the relevant public health unit?

- ☐ Yes
- ☐ No
- ☐ Partially
- ☐ Not applicable

Specify details _____

Are there any issues with the timeliness of the undertaking of the investigation by the Public Health Unit and return of the investigation documentation (e.g., enhanced surveillance form) to the Communicable Diseases Branch?

- ☐ Yes
- ☐ No
- ☐ Partially
- ☐ Not applicable

Specify details _____

7. ACCESSIBILITY

Can you describe how the data is available?

- ☐ Yes

☐ No

☐ Partially

☐ Not applicable

Specify details _____

Is the data available for research?

☐ Yes

☐ No

☐ Partially

☐ Not applicable

Specify details _____

Have you used the annual reports for any purpose?

☐ Yes

☐ No

☐ Partially

☐ Not applicable

Specify details _____

8. REPRESENTIVENESS

Are there any population subgroups with elevated lead levels that may not be detected in Queensland?

☐ Yes

☐ No

☐ Partially

☐ Not applicable

Specify details _____

9. DATA QUALITY

Do you believe the data is accurate?

☐ Yes

☐ No

☐ Partially

☐ Not applicable

Specify details _____

Have you identified any issues with the quality of the data?

☐ Yes

☐ No

☐ Partially

☐ Not applicable

Specify details _____

Are there processes to ensure data quality?

☐ Yes

☐ No

☐ Partially

☐ Not applicable

Specify details _____

10. COHERENCE

Are there any datasets which are similar to your dataset which are held by you or another organisation?

☐ Yes

☐ No

☐ Partially

☐ Not applicable

Specify details _____

11. OTHER

Do you have any comments regarding the usefulness or qualities of the surveillance system?

Specify details _____

INTERVIEW COMPLETED

4.13. Appendix D–Existing enhanced surveillance form

EHS: _____ Case Name: _____

NOCS NID#: _____

(To be completed by Environmental Health)

Excessive Lead Exposure (Notifiable)

ENHANCED SURVEILLANCE FORM (ESF) ***October 2014***

1. Exposure source was: [ ] **Occupational (Current)** [ ] **Non-occupational** [ ] **Undetermined**
   [ ] **Occupational (Former)**

2. Occupation: _____

3. Most likely cause of lead exposure was from undertaking or present during **(please tick one box only):**
   [ ] Battery breaking
   [ ] Battery manufacturing (except Century-Yuasa Batteries)
   [ ] Exposure at Century-Yuasa Batteries
   [ ] Exposure at BHP Cannington Mine
   [ ] Exposure at MIM
   [ ] Exposure from lead concentrate (except MIM, or BHP Cannington)
   [ ] Exposure at Foundry
   [ ] Plastics manufacture
   [ ] Vehicle work including motor body restoration
   [ ] Radiator manufacture, repair or maintenance
   [ ] Welding, brazing or soldering with lead
   [ ] Manufacture or cutting lead sheeting (eg. lead flashing)
   [ ] Lead exposure during maintenance or demolition work
   [ ] Scrap metal recycling
   [ ] Furniture restoration
   [ ] Exposure at fire assay laboratory
   [ ] Exposure at Indoor/outdoor rifle range
   [ ] Removal of lead-based paint from domestic buildings
   [ ] Removal of lead-based paint from other structures (eg. boats, bridges)
   [ ] Making lead sinkers, lead toy soldiers, etc.
   [ ] Use of, or exposure to, lead-based ceramic glazes
   [ ] Use of complementary medicines and dietary supplements
   [ ] Mount Isa resident – general non-specific environmental lead exposure
   [ ] Pica (Intentional Ingestion) of lead based paint chips or flakes
   [ ] Pica (Intentional Ingestion) of lead based material soil
   [ ] Exposure Overseas
   [ ] Secondary exposure from living with lead worker
   [ ] Unknown cause of exposure
   [ ] Other (if does not fit above please describe): _____
   _____

4. Case validity: **[ ] Valid** **[ ] Invalid** **[ ] Unsure** (supply reason) **[ ] Probable** (supply reason)

Reason for recording validity as Unsure or Probable: _____

_____

MEH Name and signature :_____

- Completed Enhanced Surveillance Form (ESF) to be signed by Manager Environmental Health Services (MEHS).
- Changes to the validity status of the case or entry of the source and cause of exposure into the enhanced surveillance section of NOCS to be completed by the 'CDIS (NOCS) Data Entry team.
- Completed ESF to be emailed to CDIS-NOCS-Support at CDIS-NOCS-Support@health.qld.gov.au for entry onto NOCS.
- Please do not return associated pathology reports to NOCS.
- ESF and associated pathology report to be kept by each Environmental Health Service.

4.14. Appendix E–Updated enhanced surveillance form

EXCESSIVE LEAD EXPOSURE ENHANCED SURVEILLANCE FORM

INVESTIGATION DETAILS

Investigator name _____

Date investigation commenced (DD/MM/YYYY) / /

Date investigation completed (DD/MM/YYYY) / /

Public health unit _____

PART A DEMOGRAPHIC INFORMATION
CASE DETAILS

First name	Surname
Address	Home phone / Mobile number Email
Others residing in the same house (please include relationship and contact number if appropriate)	
1.	3.
2.	4.
5.	6.

Sex

- ☐ Male
- ☐ Female
- ☐ Unknown

If the case is female, is she

- ☐ Pregnant
- ☐ Breastfeeding
- ☐ Neither pregnant nor breastfeeding
- ☐ Unknown

Indigenous status

- ☐ Neither Aboriginal nor Torres Strait Islander
- ☐ Aboriginal
- ☐ Torres Strait Islander
- ☐ Both Aboriginal and Torres Strait Islander
- ☐ Unknown

Country of origin

- ☐ Australia
- ☐ Overseas
- ☐ Unknown

Previous history of lead exposure

- ☐ Yes
- ☐ No
- ☐ Unknown

If previous exposure, blood lead level (µg/dL)

Number tests	Date (DD/MM/YYYY)	Blood lead level (µg/dL) (2 decimal places)
1.		
2.		
3.		

Reason for testing

- ☐ Workplace biological monitoring
- ☐ Re-testing
- ☐ Case presented with clinical signs and symptoms of lead exposure
- ☐ Mount Isa resident
- ☐ Lead exposure reported in the same household
- ☐ Other, specify
- ☐ Unknown _____

Did the exposure occur interstate or overseas?

- ☐ Queensland
- ☐ Interstate, specify state _____
- ☐ Overseas, specify country _____
- ☐ Other, specify _____
- ☐ Unknown _____

PART B SOURCE AND CAUSE OF LEAD EXPOSURE

B1. Likely source of source

- ☐ Occupational (current)
- ☐ Occupational (former)
- ☐ Non-occupational
- ☐ Undetermined

B2. Cause of lead exposure

Primary cause identified

- ☐ Yes, please state _____
- ☐ No

Multiple causes of lead exposure may be considered. Please tick all relevant causes.

If occupational source, please state your workplace

- ☐ Mount Isa Mines
- ☐ BHP Cannington Silver and Lead Mine
- ☐ Sun Metals Townsville
- ☐ Century Mine
- ☐ Other mining site
- ☐ Foundry
- ☐ Shooting range
- ☐ Battery manufacturing (Century-Yuasa Batteries)
- ☐ Battery manufacturing (other than Century-Yuasa Batteries)
- ☐ Vehicle repair or restoration industry (including radiator repair)
- ☐ Painting or house renovating industry
- ☐ Scrap metal recycling
- ☐ Other

If yes or other, please specify role and location _____

Lead exposure in or around the home

- ☐ Resides in house built before 1970
- ☐ Lives in home current undergoing repairs or renovations
- ☐ Discarded or stored batteries
- ☐ Imported toys containing lead or coated with lead-based paints
- ☐ Imported traditional jewellery
- ☐ Natural medicines (dietary supplements)
- ☐ Imported cosmetics
- ☐ Soil contaminated with lead
- ☐ Ingestion of lead-based paint or flakes (pica)

☐ Other, specify _____

Lead exposure activities

☐ Restoring homes, bridges, boats, cars and furniture coated with lead-based paint

☐ Demolition

☐ Glazing and firing pottery (ceramics)

☐ Soldering (radiators, stained glass, electronics)

☐ Welding

☐ Burning of lead-stabilised plastics

☐ Eating animals hunted using lead shot

☐ Exposure to lead dust at shooting ranges

☐ Scrap metal recycling

☐ Exposure at fire assay laboratory

☐ Exposure to fuels (aviation gasoline, racing fuels)

☐ Other, specify _____

Secondary exposure

Does the case live with anyone who works in the following workplaces?

☐ Mining

☐ Battery recycling plant

☐ Paint manufacture

☐ Shooting ranges

☐ Scrap metal recycling

☐ Painting or house renovating industry

☐ Other, specify _____

PART C RESIDENCE in MOUNT ISA

Does the case live in Mount Isa, Queensland?

☐ Yes

If yes, how long has the case resided in Mount Isa? Years _____ Months _____

☐ No

Chapter 5 Epidemiology of nontuberculosis mycobacteria and association with areas of low water disinfectant in southeast Queensland, Australia, 2002–2017

5.1. Prologue

Nontuberculosis mycobacteria (NTM) are opportunistic pathogens causing infections associated with environmental sources, including those from drinking water distribution systems. NTM is a notifiable condition in Queensland and cases have increased in recent years. Water distribution system vulnerabilities such as low disinfectant levels may facilitate the survival of microbes. To investigate the epidemiology of NTM, I mapped notifications of NTM potentially associated with water (water-associated) and water quality results for chloramines to identify possible sources of infection and geographic areas of higher risk. This chapter describes trends in NTM notifications in Queensland from 2002–2017, water quality and association between potentially water-associated NTM notifications and water quality in selected Brisbane reservoir zones from 2012–2016.

Project role

I worked with the Queensland Health Communicable Diseases Branch (CDB) and Health Protection Branch (HPB) Water Unit to plan and conduct the project. I was involved in all steps including: developing the hypothesis; defining and selecting the units to be compared; obtaining notification and water monitoring data; determining an appropriate analytical approach; and analysing the data. This included liaising with the water utility company. I connected with other researchers investigating NTM epidemiology and assisted them with their concurrent projects. This included compiling a geospatial database of environmental and climatic variables to examine the association between other environmental exposures and the notification of NTM. I attended ongoing project meetings which facilitated my knowledge in geospatial epidemiology.

Lessons Learned

This was my first opportunity to be involved in an environmental health project and first experience of using ArcGIS. I found this project the most challenging of all projects due to the complexity in investigating health outcomes associated with social, environmental and host-related factors. Environmental epidemiology attempts to determine whether a hazard is causing disease, and the assessment of the exposure is a crucial feature. A key challenge in this project was assessing low

levels of water disinfectant as an exposure, which was complicated by the wide variability of total chlorine results observed across different sampled areas and during the different months. A secondary challenge was assessing and categorising water disinfectant levels as “sufficient” or “insufficient”. It highlighted the difficulties in estimating exposure in relation to health effects. During the process, I learnt about important considerations in environmental epidemiology including the judgement of safety—or what is an acceptable level and tolerable burden of disease. I also learnt about the Queensland Health notifiable disease condition register (NOCS) and how surveillance data practices, policies and resources may change over time impacting trends. NTM uses notification date (compared with onset date) to monitor trends. This prompted me to explore how dates are used in surveillance and how this may impact the ability to link exposures and disease.

I used the project as an opportunity to develop basic skills in geographic information systems (GIS) as an additional tool to traditional epidemiological techniques. I learnt about how to approach spatial analysis and mapping in ArcGIS, how to categorise data into different forms (points or aggregated polygons), format maps, geocode large numbers of addresses, sources of available environmental and population data and appropriate spatial tests to use to investigate potential disease clusters. I learnt about the advantages and limitations of analysing environmental data, including challenges in linking exposures and outcomes, potential confounders and lag periods. Importantly, I learnt that geospatial analysis is a one tool in the investigation of disease patterns and clusters. The proficiency I gained in ArcGIS was applied to other projects.

Through this project I was initiated into the world of waterborne disease, principles and complexities involved in effective water management and regulation. I learnt about the multiple factors facilitating the growth of microorganisms (other than low levels of disinfectant). This project gave me the opportunity to meet water utility personnel and understand current issues in water management. In public health we are dealing with real people and complex exposures that are difficult to measure and almost impossible to control adequately. Multiple stakeholders including technical experts, implementers, industry policy makers and public health need to be involved to develop effective and long-term solutions. If I had to undertake this project again, I would change the methodology to a prospective case-control study allowing for the collection of clinical data, water usage and exposures, individual

activity information and environmental samples from different areas (household, workplace) to examine risk factors in the acquisition of NTM. Irrespective of the project outcome, through the process of trial and error, I gained important knowledge surrounding waterborne pathogens, water quality and spatial analysis of epidemiological data.

Public health impact

I presented the findings as a poster at the International Conference on Emerging Infectious Diseases in Atlanta, August 2018. The results were used as an opportunity to discuss the challenges of opportunistic pathogens and water quality in general in Brisbane. Findings from this research will contribute to the increasing growing body of work on environmental factors involved in NTM transmission.

Communication

- International Conference on Emerging Infectious Diseases, Atlanta, 28 August 2018 (Appendix A)

Core MAE requirements addressed

- Design and conduct an epidemiology project
- Presentation at an international conference

Acknowledgements

Martyn Kirk and Suzanne Huxley took the lead supervisory roles during the project. I gratefully acknowledge the contributions of the Water Unit in this epidemiology project for providing expertise around water quality. I particularly would like to acknowledge the Director of the Water Unit Greg Jackson for facilitating the opportunity to work with water utility stakeholders. I would also like to thank Dr Chris Coulter and Bridget O'Connor from the CDB for their NTM expertise and ongoing epidemiological support, and Dr Kinley Wangdi for the GIS and geospatial analysis input.

5.2. Abstract

Background

Nontuberculosis mycobacteria (NTM) are opportunistic pathogens associated with environmental sources such as municipal and recreational water sources. NTM is a notifiable condition in Queensland, Australia and cases have increased in recent years. As some NTM occur in treated drinking water supplies, we mapped cases of NTM species potentially associated with water (water-associated) and water quality results for chloramine disinfectant to identify potential sources of infection and areas of higher risk.

Methods

We mapped data from the notifiable condition register to the water monitoring database. Incidence rate ratios (IRR) were estimated using negative binominal regression models to compare three-time periods (2002–2006, 2007–2011, 2012–2017). Local Moran's I was used to identify spatial clusters for water-associated species across Queensland 2012–2017. Water-associated species examined included *Mycobacteria abscesses, M. avium, M. lentiflavum* and *M. kansasii*. Water disinfectant levels per sampling points were aggregated across selected supply zones in southeast Queensland and the proportion of total chlorine results <0.2 mg/L calculated overall and per year, 2012–2016. Poisson regression models were used to compare disinfectant trends per year and reservoir zone. Negative binominal regression models were used to explore the association between rates of water-associated NTM and proportion of total chlorine samples <0.2 mg/L overall and by reservoir zones.

Results

Rates of all NTM and water-associated NTM increased over time. Compared to 2002–2006, adjusted NTM rates were significantly higher in 2007–2011 (IRR 1.47, 95% CI 1.38–1.56) and 2012–2017 (IRR 1.55, 95% CI 1.46–1.65). Water-associated NTM increased to a lesser extent. *M. intracellulare* predominated over the period. During 2012–2017, Local Moran's I identified 48 statistically significantly clusters of water-associated NTM, the majority of which were in Brisbane. Overall, the proportion of water samples with insufficient disinfectant levels increased across all reservoir zones in southeast Queensland, 2012–2016 ($p<0.01$). Between reservoir zones, the proportion of samples reporting a total chlorine result <0.2

mg/L per year increased significantly in five of the 11 individual reservoir zones ($p<0.05$). We did not observe an association between notification rates of water-associated NTM and total chlorine results.

Conclusions

We observed increasing trends of NTM in Queensland including species potentially associated with water. The clustering of these environmental species were largely identified in southeast Queensland, the significance of which is unclear. In this type of descriptive study, it is difficult to adequately relate the place of residence to exposure and water quality results. It may be important to examine potential transmission of NTM to humans from the environmental using whole genome sequencing (WGS). Better insights into the spatiotemporal clustering of NTM notifications and water-associated NTM species, role of individual risk factors, drinking water use and activities on NTM acquisition, impact of using different disinfection methods and control strategies on NTM survival and growth in biofilms may be useful in increasing understanding of NTM epidemiology in Queensland.

5.3. Introduction

Nontuberculosis mycobacteria (NTM), also known as environmental mycobacteria, atypical mycobacteria and mycobacteria other than *Mycobacterium* tuberculosis complex, are human pathogens of the Mycobacteria. The genus includes over 200 distinct species, of which approximately 25 pathogenic species cause clinical diseases in humans.[1, 2] Most exposures to NTM do not cause disease. Persons vulnerable to infection include: the elderly, those with cystic fibrosis, chronic obstructive pulmonary disease, undergoing immunosuppressive therapy or those with acquired immunodeficiency syndrome (AIDS).[2] Colonisation of healthy individuals or individuals with no known predisposing factors may occur, for example *M. scrofulaceum* and *M. kansasii* has been documented in otherwise healthy young children and *M. ulcerans* causing Buruli ulcer (chronic ulcer with necrotic centres) affects all age groups.

In Queensland, cases of NTM are required to be notified by pathology laboratories under *the Public Health Act 2005*[3] and considered an important group of bacteria with increasing public health importance.[4-7] Infection can result in significant morbidity and mortality if left untreated. Illness is characterised primarily by pulmonary infections followed by lymphadenitis, although NTM can cause a range of diseases involving the skeleton, lymph nodes, skin and soft tissues as well as gastrointestinal and genitourinary tracts.[1] There are no vaccines, treatment may require combination antibiotic therapy of prolonged duration with potential side effects and re-infection is common.[2, 8, 9] Evidence indicates the incidence and prevalence of NTM is increasing worldwide and in Australia, including NTM associated with waterborne transmission.[10, 11] In Queensland, NTM notification rates have been rising steadily with an increase from 17.0 per 100,000 population in 2012 to 27.5 per 100,000 population in 2016.[12] As clinical presentation associated with NTM is highly variable, not all people would seek medical attention or get tested. This means notification data is likely to underestimate the true incidence of NTM.

The epidemiology of NTM is complex due to the large number of distinct species, heterogeneity in pathogenicity, widely varying growth rates between different species and growth environment.[13, 14] The reasons for the increasing trends and burden of disease are unclear. Possible factors include increased awareness among clinicians of mycobacteria as a pulmonary pathogen, improvements in

detection and molecular diagnostics, an aging population, increased numbers of immunosuppressed individuals due to disease or treatment, increased mycobacterial infection sources and increased number of individuals undertaking activities where they may be exposed including gardening, hiking and swimming in untreated water sources.[15]

M. tuberculosis complex, which include *M. tuberculosis* and closely related species (*M. bovis, M. africanum* and *M. microti*) have only human or animal reservoirs.[1] Principal NTM transmission routes include contact with soil, inhalation (via aerosols), ingestion of and contact with contaminated water.[1, 16] NTM are ubiquitous in diverse natural and human-influenced aquatic environments such as surface water, natural fresh ecosystems, public drinking water distribution and hospital water systems. It is likely that NTM found in households plumbing systems come from public water utility sources and distribution systems.[17] Circumstantial evidence of a causal relationship between the occurrence of mycobacteria in drinking water and human disease exists.[1] An investigation into the frequent isolation of *M. kansasii* from clinical specimens demonstrated the presence of the same strains in Rotterdam, the Netherlands. In Massachusetts, United States (US), *M. avium* complex has been attributed to their incidence in drinking water.[1] Factors that help sustain NTM in water supplies include the ability to grow in low nutrient concentrations, form biofilms, resist high temperatures and complex cell wall structure contributing to chlorine resistance.[18, 19] Environmental mycobacteria have gained importance from high profile outbreaks in hospital settings including: *M. chimaera* infections from cardiac cooling units, *M. abscess* from surgical devices and *M. avium* from disinfection units causing infections in Australia and other countries.[20, 21] NTM have also been recovered in ice machines and heated nebulisers, hot tubs and spas, as well as biofilms which form in these aquatic environments.[7, 11, 22]

In Queensland, *M. intracellulare* is the predominant species, followed by *M. avium.* There is geographic variability in NTM species identified across Queensland. *M. ulcerans* infections are frequently reported from the northeast Daintree region and less commonly the Capricorn Coast.[16] Distinct spatial clusters of *M. kansasii* and *M. intracellulare* have been identified in the central region of Queensland and *M.*

abscessus in the Whitsunday region, associated with areas of high agricultural, mining and tourism activity.[14] The exact environmental reservoir and mode of transmission to humans remain unclear. Case reports and series worldwide have linked genetically identical NTM in patients to their home environments. Increasing evidence indicate biofilms in showerheads, are a common environmental niche that may result in transmission when aerosolised.[10, 17, 23] Biofilms are layers of microorganisms contained in a matrix (slime layer) which form on surfaces in contact with water and enable the growth of mycobacteria.[1] A Brisbane study found pathogenic NTM strain types identical to environmental ones from household water, biofilms, and aerosols in a small subgroup of patients.[15] The evidence was strongest for *M. abscessus, M. avium, M. lentiflavum,* and *M. kansasii.*[15, 24] The identified routes of transmission, isolation of clinical samples and detections of NTM in drinking water suggest drinking water supplies are a plausible source of infection.[1]

The supply of safe and reliable drinking water in Queensland is regulated by state legislation. The city of Brisbane in southeast Queensland has one of the largest water supply systems in Queensland, Australia. In the Brisbane supply, water is provided from 32 reservoir zones, which differ in their water quality. To provide safe high-quality drinking water, the water authority manages water catchments, protects sources waters, tests the supply zones, treats using coagulation and filtration, and disinfection and maintains the distribution system.[25] Brisbane drinking water is disinfected using a chloramination[6] process at the treatment plants and at points of entry into the system, with the goal to eliminate pathogens responsible for waterborne disease.[25] The advantages compared with traditional chlorination, are that chloramination results in a long lasting residual effect that persists for longer in water distribution systems.

Drinking water monitoring is the assessment of the water quality in the distribution system that is supplied to the consumer.[25] It includes the regular sampling and testing performed for assessing compliance with guidelines, regulatory requirements and agreed levels of service.[25] The objective of any water quality monitoring is to ensure that the source water is suitable for its intended purpose, to monitor long-term trends, identify rapid changes and ensure the water available to

[6] Chloramines are form when chlorine and ammonia are added to water.

consumers meets requirements.[26] The location and number of sampling points within a distribution system are determined by the complexity of the system and design of the sampling program.[25] Sampling points are normally selected from within the distribution system to be representative of the what most consumers receive, system performance and control, and spread geographically to give coverage to a zone.[25, 27] Routine sampling includes the measurement of physical-chemical parameters, such as total and free chlorine residual, temperature and electrical conductivity and microbiological indicators, such as the presence of *Escherichia coli (E. coli)*.

Water disinfectant in distribution systems has the purpose of controlling microbial load, minimising biofilm development.[1] Typical chloramine concentrations of 0.5 to 2.0 mg/L are found in drinking water supplies, where chloramine is used as a primary disinfectant.[28] As a minimum, detectable monochloramine should be present at the end of chloraminated distribution networks (≥0.2 mg/L).[29] Although higher concentrations are needed to control biofilm growth (2 mg/L minimum), odour and taste will be detected at concentrations of 1.5 mg/L and over.[1, 29] No specific guidelines have been established for mycobacteria in drinking water and routine monitoring for mycobacteria is not recommended.[25] Monitoring disinfectant residual is necessary to verify there is an effective disinfection to control microbial load, minimise biofilm development and reduce public health risk.[27] The World Health Organization (WHO) states that while drinking-water treatment may not eliminate mycobacteria, persistent residual disinfectant if operating satisfactory should reduce the number of mycobacteria to a level that represents a negligible risk to the general population by reducing mycobacteria in the water column, although unlikely to be effective against mycobacteria present in biofilms.[1,25] The presence of biofilms may be responsible for water quality and operational problems.[30]

When disinfectants are added to water, they gradually decrease as they travel through a distribution system.[18] Ideally, water from drinking water suppliers should contain a persistent disinfectant residual although it can be difficult, if not impossible to maintain effective disinfectant residuals at all times.[27] There is no regulation of disinfection residuals in Queensland drinking water supplies.[27] Areas

of lower disinfectant residual may be at higher risk of NTM growth. Thomson *et al.* found a positive association between the distance of sampling points from the main treatment plant and isolation of pathogenic NTM in Brisbane water distribution systems.[8] Higher mycobacterial concentrations at distal sites compared with those immediately downstream from treatment facilities have also been reported in studies from the US and Finland.[13] [31]

5.4. Objectives

This study investigated the following research questions:

- What are the trends in NTM notification in Queensland, 2002–2017?
- What are the trends in disinfectant residual in selected water supply zones in Brisbane, 2012–2016?
- Do areas with lower disinfectant residuals have higher rates of NTM potentially associated with water?

5.5. Methods

I investigated whether NTM notifications are higher in areas where lower disinfectant residuals were more common using geographic and traditional epidemiologic methodology. I designed this study as a pilot examining one area in southeast Queensland for potentially water-associated NTM species.[15] Low disinfectant levels associated with the presence of NTM may be significant as it could signify potential for other opportunistic waterborne pathogens to cause disease. Results may provide insight regarding water-associated NTM which are less well examined in the literature and could guide future policy decisions of water regulators and research around water-related hazards.

I conducted descriptive analysis on NTM and water quality data separately before examining potential associations between NTM notification rates and water disinfectant. Firstly, I examined trends of all NTM notifications and aggregated water-associated NTM species in Queensland. Separately, I examined water-associated NTM species in a metropolitan Brisbane area (Figure 23c). Secondly, I examined trends in water disinfectant in the same metropolitan Brisbane area.

Finally, I overlapped the two datasets to determine if higher notification rates of potentially water-associated NTM species were seen in areas with lower disinfectant levels.

The metropolitan Brisbane area selected for investigation had higher population density, uniform drinking water supplies and disinfectant and available water quality data. The population represented approximately 28.3% of all persons residing in Brisbane (Australian Bureau of Statistics [ABS] estimated resident population 2016).[32] NTM notification data were available from 2012–2017 and water quality data from 2002–mid-2017. The period 2012–2016 was selected to examine water quality data and the association between NTM notification rates and water data. Data cleaning and analysis was performed in Stata, version 14.1 (StataCorp, College Station, TX, USA. Mapping and spatial analysis was undertaken using ArcGIS (Esri, USA).

5.5.1. Trends in nontuberculosis mycobacteria

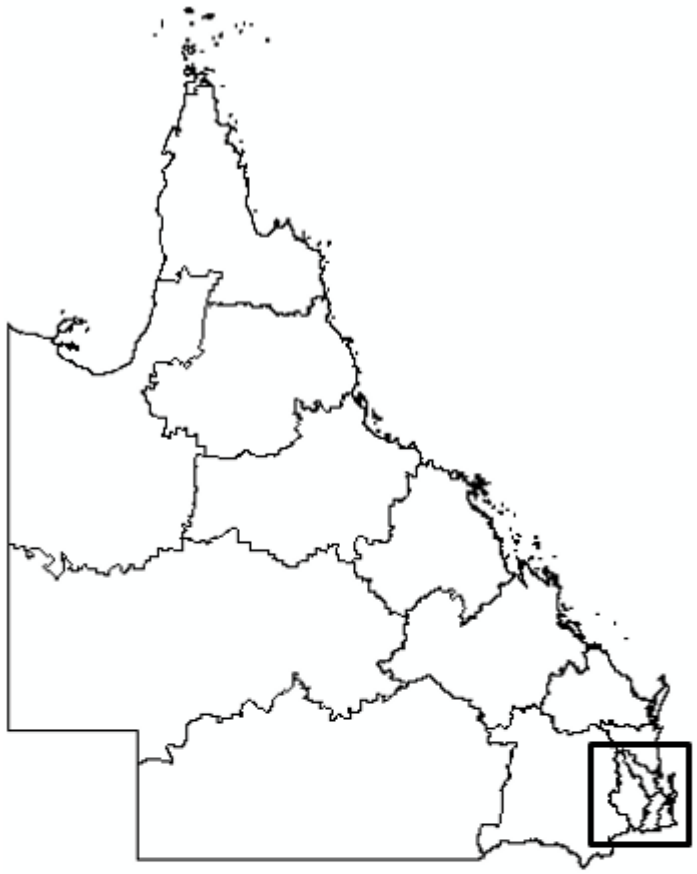
Case definition and surveillance

In Queensland, NTM has been a notifiable disease since 1988. The case definition (1 January 2012 onwards) required: isolation or detection by nucleic acid amplification tests (NAAT) of *M. ulcerans* from any site; isolation or detection by NAAT of other NTM from any site other than sputum or urine; isolation of any NTM from multiple samples of sputum or urine; or detection of acid fast bacilli by histology.[33] There is a 12-month reinfection period for NTM notifications. Cases reported with a second notified report of NTM within 12 months were considered a reinfection, unless the second species was different to the initial notification. Multiple notifications could be linked to the same individual within 12 months. The case definition excluded mycobacteria from the *M. tuberculosis* complex.

Data extraction

Queensland notification records were stored in the Notifiable Conditions System (NOCS) and water quality data in records maintained by the water utility company. Notifications of NTM with onset date from 1 January 2002 to 31 December 2017

were extracted from NOCS (14 February 2018). Notification records included patient identification (ID), notification ID, age, sex, Indigenous status, notification date, onset date, address, specimen type and source and species of mycobacteria identified. One isolate per individual per year was included, unless multiple species were identified. Cases were excluded from the analysis if they had an interstate or international address, or were duplicates. Water quality data included sampling location, date of sample, total chlorine, free chlorine, temperature, pH and turbidity (NTU) for 11 selected water reservoir zones within the Brisbane water supply.



(a) Queensland, Australia

(b) Southeast Queensland

(c) Selected water reservoir zones, Brisbane, Queensland

Figure 23 Selected water zones reservoirs within southeast Queensland, 2012–2016 (a) Queensland (b) Southeast Queensland (c) Selected water reservoir zones, Brisbane, Queensland

Descriptive analysis

Age was categorised into four groups: <20 years, 20–44 years, 45–64 years and ≥65 years. We calculated annual notification rates (cases per 100,000 persons) by dividing the number of reported notifications by Queensland mid-year estimated resident populations and multiplying by 100,000.[34] The population distribution of the total 2001 Australian population was used as the standardisation weights. Age-standardised rates were calculated by year for NTM notifications. I also calculated rates of selected water-associated NTM species, including *M. abscessus, M. avium, M. lentiflavum* and *M. kansasii*. Count response models were used to examine trends in the NTM rates during the study period, overall and by age group. Case counts were aggregated into three-time periods. I used negative binominal regression, as the data were over dispersed. Model results were summarised as average notification rates per 100,000 and as incidence rate ratios (IRR) and 95% confidence intervals (CI) to compare modelled rates across time periods. A multivariate analysis model was constructed using age groups, sex and time period, as well as subset analyses with water-associated NTM notification category.

Geospatial analysis

Maps were created using ArcGIS to display notification rates of NTM by postcode over three-time periods (2002–2006, 2007–2011, 2012–2017). I calculated average annual NTM notification rates per 100,000 population for these time periods by summing each postcode counts over the given years, diving this sum by mid-year estimates using the 2006, 2011 and 2016 ABS census data. The counts were aggregated within time periods to increase stability of the trends. Notifications were excluded if the postcode of residence of an individual who had been tested did not correspond to a residential area (postcode represented a post office box).

Local spatial clusters of NTM infections were examined using the Local Moran's I statistic to identify local water-associated NTM clusters from 2012–2017. This statistic identifies hotspots (high-high), coldspots (low-low) and spatial outliers (high-low and low-high). A positive Local Moran's I value indicates that the target postcode is surrounded by postcodes with similar notification rates. This may include high-high clusters where a postcode with a high notification rate is surrounded by postcodes with high rates and low-low clusters, where a postcode with a low rate is surrounded by postcodes with low rates. The assignment of

postcodes to these four classes (high-high, low-low, high-low, low-high) depends on the results of a statistical test.[35, 36] The test performs random comparisons along the target postcodes and its neighbours Moran's I values to all postcode Moran's I values within the state of Queensland. The observed Moran's I value is compared to the value corresponding to the random permutations (expected Moran's I). If the test is significant ($p<0.05$) indicating spatial dependence, the observed Moran's I value is significantly larger (or smaller in the case of a negative relationship) than the expected Moran's I value. The postcode will remain in a neutral class (no spatial dependence) if the test is not significant.[35, 36]

5.5.2. Trends in water quality data

I obtained data on water sample testing from 11 reservoir zones within the Brisbane supply area and examined disinfectant trends during 2012–2016. There were 136 sampling points across all combined reservoir zones and annual variation in the number of sampling points from which data were available. Total chlorine results were summarised as a categorical variable: <0.2 mg/L and ≥0.2 mg/L. The proportion of total chlorine results <0.2 mg/L were calculated by reservoir zone and year. A Poisson regression model was used to examine trends in the proportion of sample total chlorine <0.2 mg/L over time.

5.5.3. Association between NTM notifications and disinfectant residual

Individual postcodes were manually assigned to reservoir zones by visual inspection using ArcGIS. Postcodes were used rather than geocoded individual residential addresses due to a large proportion of cases without a complete address and high accuracy of the allocated postcode field. Postcode boundaries did not perfectly align with the reservoir zones. Two models were examined: postcodes of which ≥75% of the boundaries lay within the reservoir zone (Model 1) and postcodes where ≥50% of the boundaries lay within the reservoir zone (Model 2) (Appendix B). Annual notification rates were calculated by summing all NTM notifications within the postcodes assigned to the reservoir zones per year, dividing the number by the estimated ABS population and multiplying by 100,000 per

population. The reservoir zone population was calculated using the 2016 ABS postcode estimates; ABS postcode estimates were not publicly available during 2012–2015. The association between NTM notification rates and proportion of positive total chlorine samples <0.2 mg/L were determined by negative binominal regression stratified by reservoir zone and year. The null hypothesis was that there was no relationship between NTM notification rates and proportion of total chlorine <0.2 mg/L.

5.6. Ethics approval

Ethics approval for this evaluation was granted by the Australian National University Human Research Ethics Committee (HREC 2017/689) and *Public Health Act* Application to Queensland Health (QCOS/029817/RD007137).

5.7. Results

The number of NTM notifications per analyses are summarised in Figure 24.

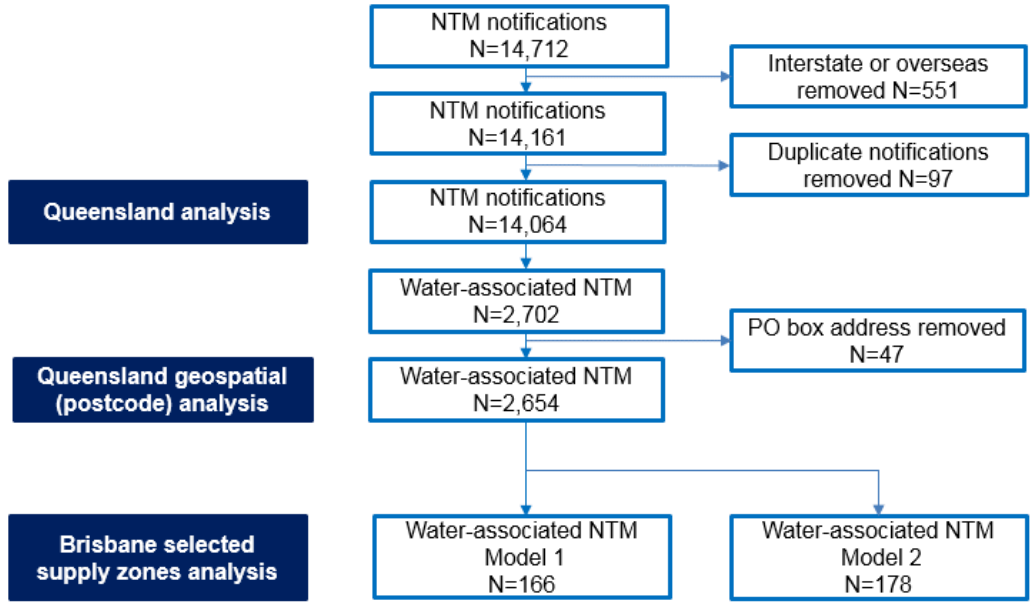


Figure 24 Nontuberculosis mycobacteria notifications included in different analysis: flow chart

Trends in nontuberculosis mycobacteria

From 2002–2017, there were 14,064 NTM notifications in Queensland and increasing trends over time. Characteristics of all NTM and selected waterborne species are shown in Table 14.

Table 14 Characteristics of notified cases of nontuberculosis mycobacteria and selected water-associated species, Queensland, 2002–2017

Characteristic	All NTM species	*M. abscessus*	*M. avium*	*M. kansasii*	*M. lentiflavum*
	No. (%)	No. (%)	No. (%)	No. (%)	No. (%)
Total	14,064 (100.0)	1,061 (7.5)	1,229 (8.7)	280 (1)	133 (0.9)
Sex					
Male	6,985 (49.7)	506 (47.7)	500 (40.7)	148 (52)	70 (52.6)
Female	7,078 (50.3)	555 (52.3)	729 (59.3)	132 (47)	63 (47.4)
Age group (years)					
<20	738 (5.2)	136 (12.8)	59 (4.8)	9 (3)	11 (8.3)
20–44	1,786 (12.7)	257 (24.2)	68 (5.5)	40 (14)	16 (12.0)
45–64	4,075 (29.0)	280 (26.4)	327 (42.2)	75 (26)	36 (27.1)
≥65+	7,464 (53.1)	388 (36.6)	775 (63.1)	156 (55)	70 (52.6)
Year					
2002–2006	2,726 (19.4)	179 (16.9)	307 (25.0)	71 (25)	20 (15.0)
2007–2011	4,542 (32.3)	313 (29.5)	369 (30.0)	99 (35)	45 (33.8)
2012–2017	6,796 (48.3)	569 (53.6)	552 (45.0)	110 (39)	68 (51.1)

Abbreviations NTM = nontuberculosis mycobacteria.

* Of the 14,064 cases, age and sex for one case was unknown.

Among all NTM notifications, the most frequently notified were *M. intracellulare* (34.4%), followed by *M. avium* (8.7%) and *M. abscessus* (7.5%). There were 21.7% of NTM notifications without a species reported. Annually the median proportion of NTM isolates speciated was 78.2% (range 58.6–92.1%). Aggregated NTM water-associated species accounted for 2,703 (19.2%) of all notifications with *M. avium* (8.7%) the most commonly reported. For all NTM notifications combined, the male to female ratio was approximately equal. A higher proportion in females was reported for *M. abscessus* and *M. avium*. In contrast, a higher proportion of males

was reported for *M. kansasii* and *M. lentiflavum* infections. A higher proportion of *M. abscessus* were aged less than 45 years compared to the other species, the significance of which is unclear.

Overall for all NTM, the age-standardised notification rates ranged from a low of 10.1 per 100,000 persons in 2002 to a high of 28.3 per 100,000 persons in 2017 (Figure 25). Rates increased from 2002–2007, before declining from 2008–2012 overall, and increasing from 2013–2017. For potentially water-associated NTM species, the notification rate increased from 2.5 per 100,000 population in 2002 to 5.1 per 100,000 population in 2017 over the same period. Stratifying by water-associated species showed age-standardised rates increased for *M. abscessus* and *M. avium* only (Figure 26).

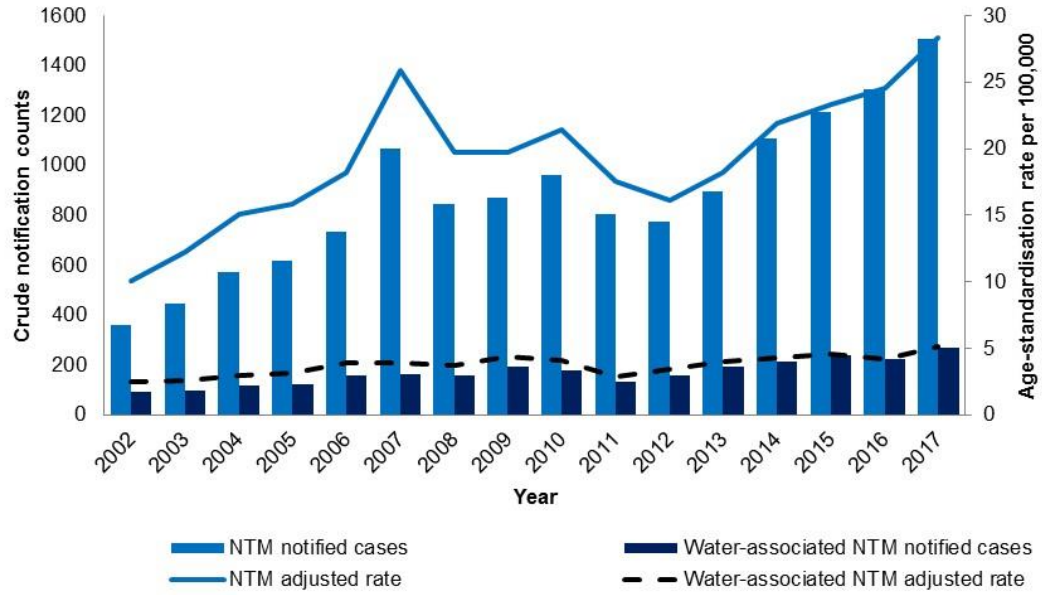


Figure 25 Crude notification counts and age-standardised rates (per 100,000) of all nontuberculosis mycobacteria and water-associated notifications, Queensland, 2002–2017

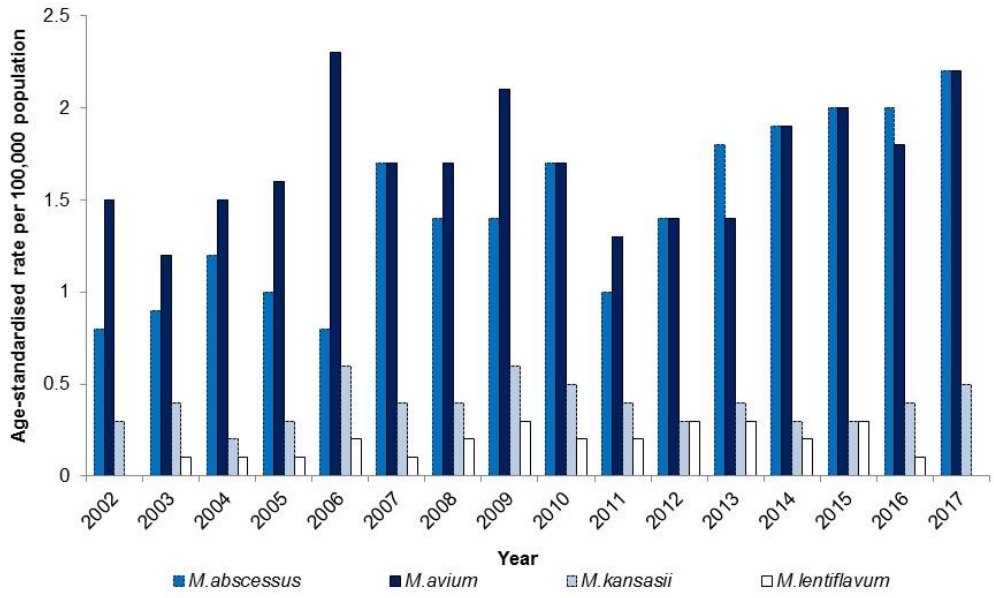


Figure 26 Age-standardised rate (per 100,000 population) of water-associated nontuberculosis mycobacteria species, by specie, Queensland, 2002–2017

Rates were highest in adults aged ≥65 years, followed by persons aged 45–64 years for all NTM and aggregated water-associated species (Figure 27). Rates in adults aged ≥65 years increased from 2002–2007, before declining from 2008–2012 and increasing until 2017.

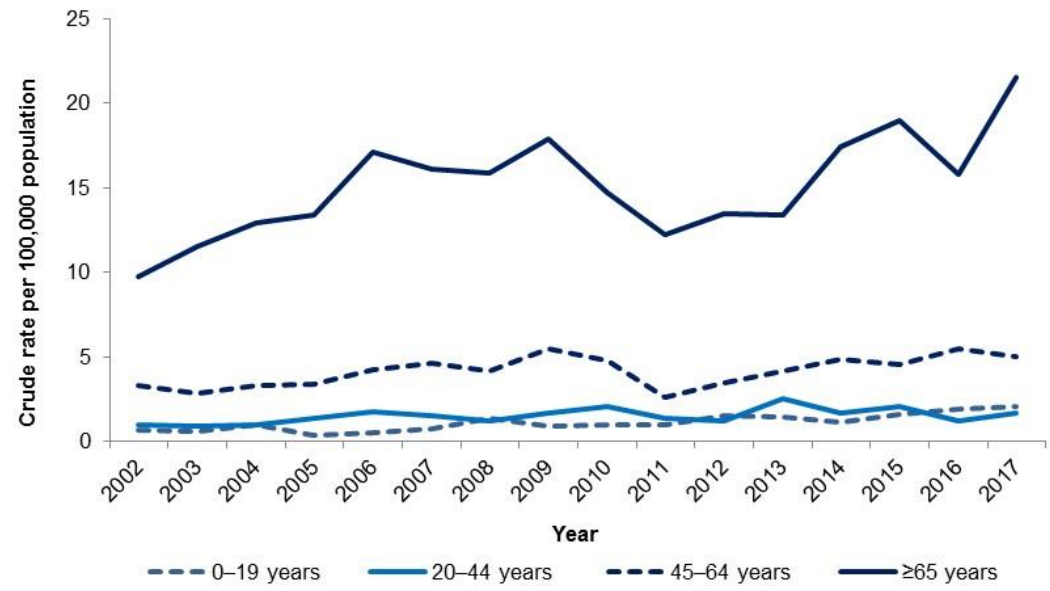


Figure 27 Notification rate of aggregated water-associated nontuberculosis mycobacteria notifications, by age group, 2002–2017

Multivariate analysis for all NTM found that notification rates increased by 47% in 2007–2011 and 55% in 2012–2017, when compared with 2002–2006 (Table 15). An increase was observed across all age groups. Compared with males, females reported lower rates for all NTM. Examining water-associated NTM species only showed similar trends, although increasing trends were less pronounced. In contrast to all NTM notifications, water-associated NTM notifications increased by 12% in females between 2002 and 2017.

Table 15 Nontuberculosis mycobacteria incidence rate ratios, by risk factors and species, Queensland, 2002–2017

Characteristic	All NTM		Water-associated NTM	
	IRR (95% CI)	p-value	IRR (95% CI)	p-value
Age group (years)				
0–19	1.0		1.0	
20–44	1.8 (1.6–2.0)	p<0.001	1.3 (1.1–1.6)	p<0.001
45–64	6.2 (5.7–6.8)		3.6 (3.1–4.3)	
≥65	20.5 (18.8–22.3)		12.9 (11.1–15.0)	
Sex	1.0		1.0	
Female (c/w male)	0.9 (0.9–0.9)	p<0.001	1.1 (1.0–1.2)	p=0.001
Year				
2002–2006	1.0		1.0	
2007–2011	1.5 (1.4–1.6)	p<0.001	1.2 (1.1–1.4)	p<0.001
2012–2017	1.6 (1.5–1.6)		1.4 (1.3–1.6)	

Abbreviations NTM = nontuberculous mycobacteria, IRR = incidence rate ratio, CI = confidence interval.

Water-associated NTM notification rates varied per postcode (Figure 28). The proportion of Queensland postcodes containing one or more water-associated NTM cases increased from 40% in 2002–2006 to 54% in 2012–2017. Per individual postcode, during 2002–2006 the median NTM notification rate was 2.8 per 100,000 population (range 0–9.1 per 100,000) (Figure 28a). During 2012–2017, the median was 3.3 per 100,000 (range 0–32.9 per 100,000) (Figure 28c). In all three-time periods, higher notification rates of water-associated NTM species occurred in southeast Queensland, coinciding with urban areas (Figure 29. In the selected Brisbane area, a high proportion of water-associated NTM was found.

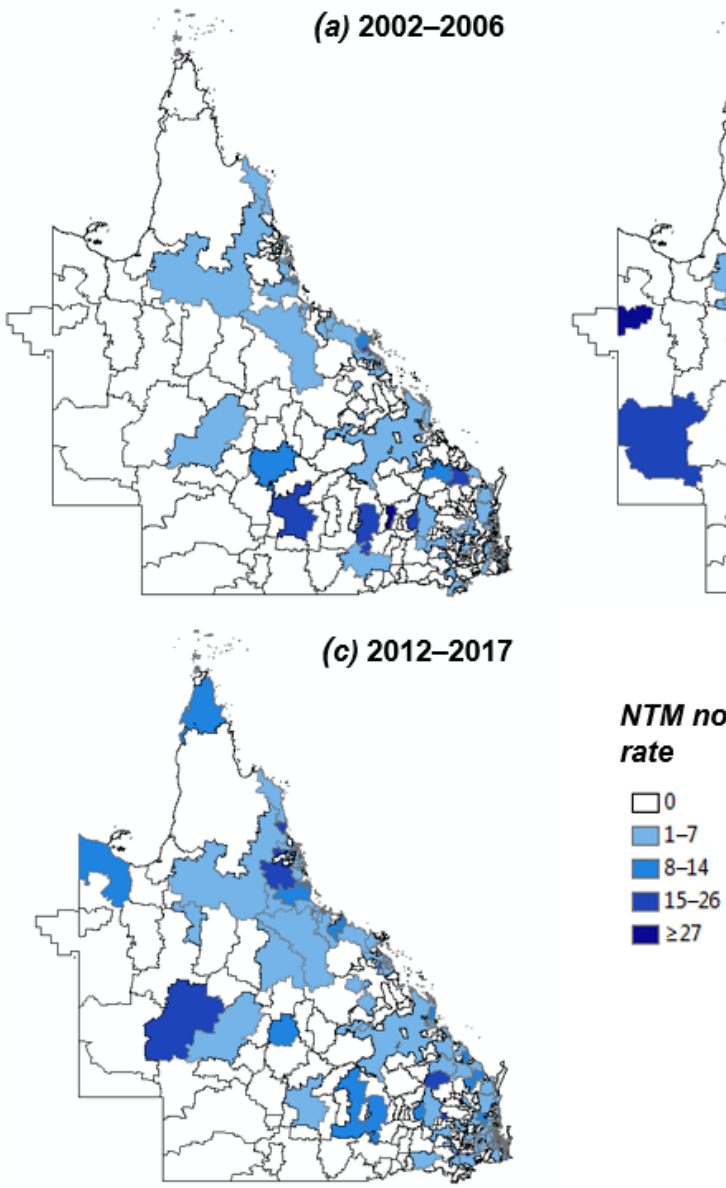


Figure 28 Notification rate of aggregated water-associated nontuberculosis mycobacteria per 100,000, by postcode, Queensland, 2002–2017 (a) 2002–2006, (b) 2007–2011, (c) 2012–2017

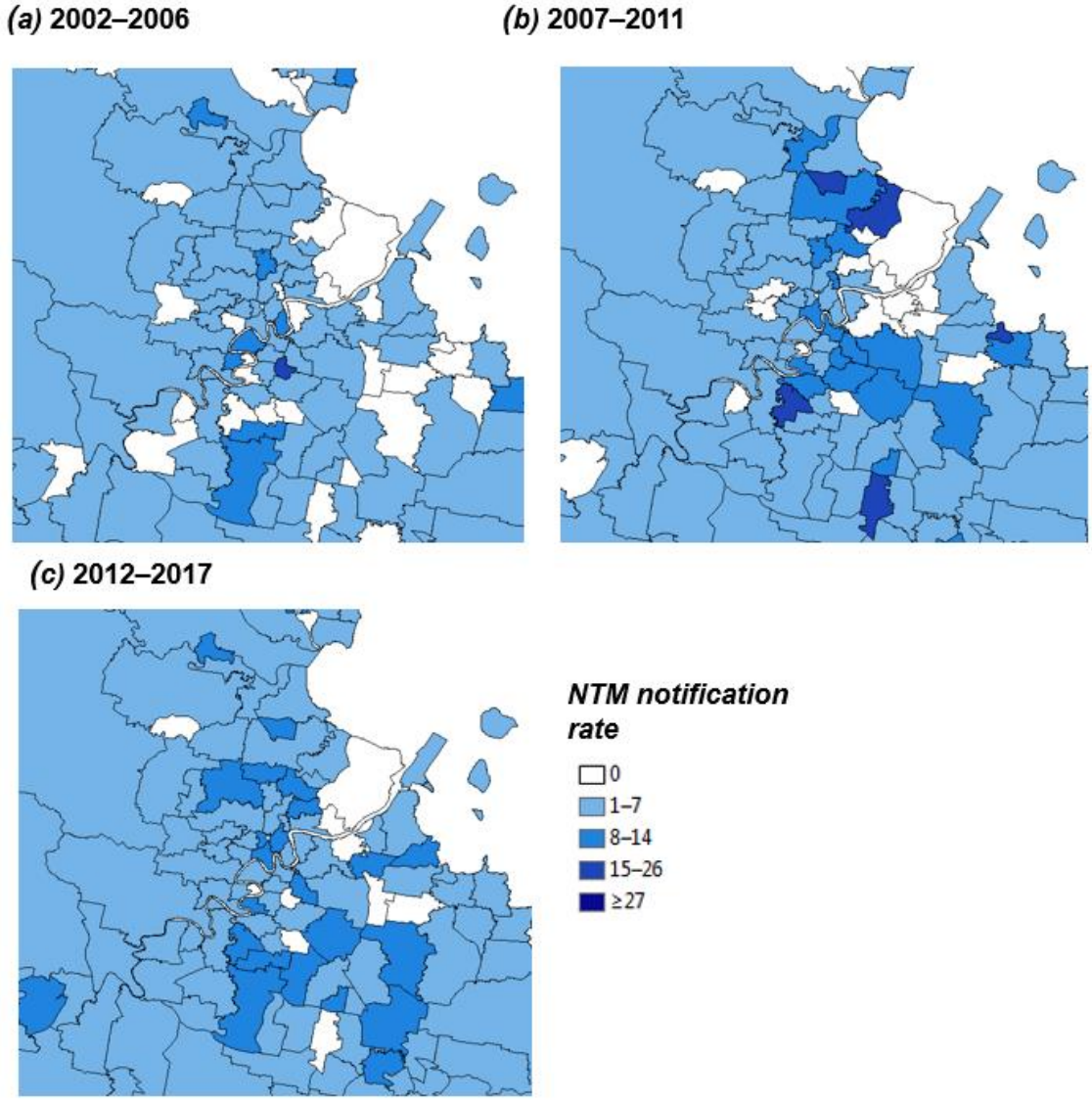


Figure 29 Notification rate of water-associated nontuberculosis mycobacteria per 100,000, by postcode, Brisbane, 2002–2017. (a) 2002–2006, (b) 2007–2011, (c) 2012–2017

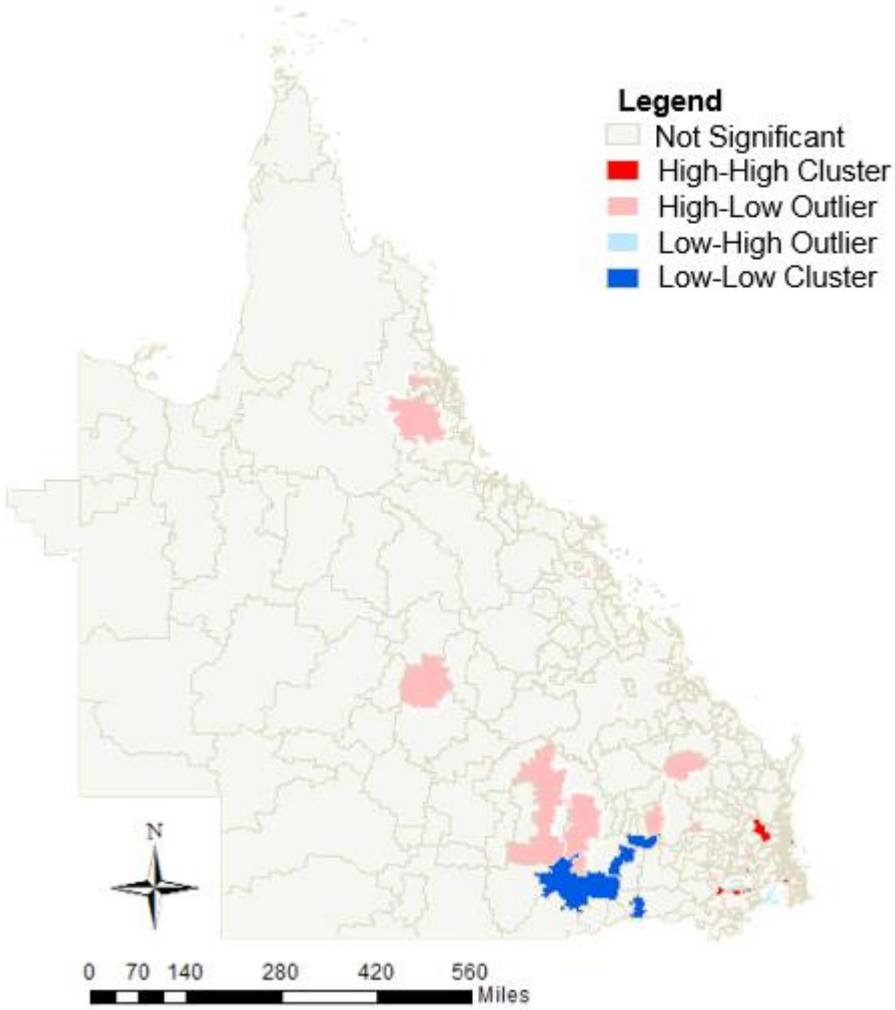
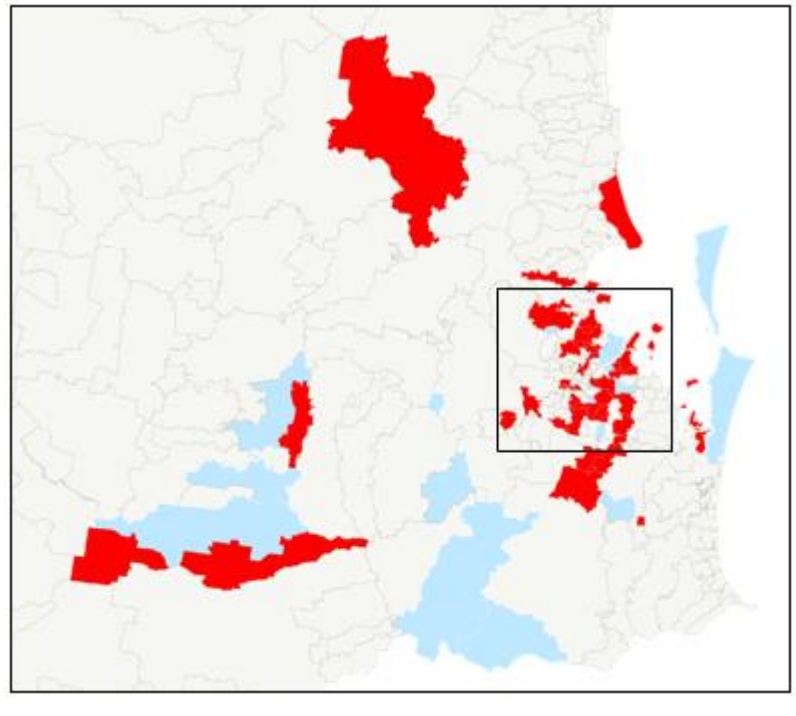


Figure 30 Water-associated NTM notification rate clusters and outlier map (using Anselin's Local Moran's I method), Queensland, 2012–2017

The Anselin's Local Moran's I technique for cluster and outlier analysis found significant hotspots largely in southeast Queensland, and one in Townsville (Figure 30). A limited number of coldspots (low-low) were found in the southwest. There were 48 high-high clusters, 4 low-low clusters, 10 high-low outliers, 21 low-high outliers and 356 postcodes not statistically significant. Of the 48 statistically significant high-high clusters, a large number fell within the southeast Brisbane area indicating areas with unexpectedly high rates of NTM.

(a) **Southeast Queensland**



(b) **Brisbane, Queensland**

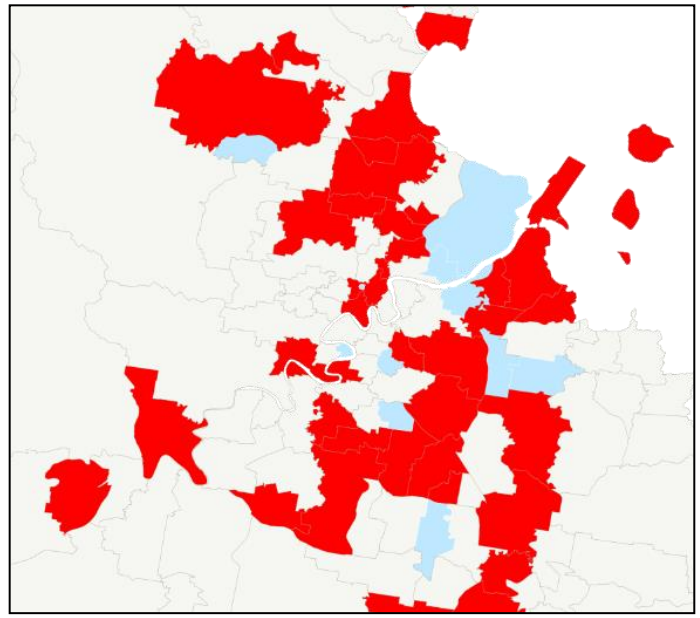


Figure 31 Water-associated nontuberculosis mycobacteria notification rate clusters and outlier map (using Anselin's Local Moran's I method), Brisbane, 2012–2017

Trends in water quality

The number of total chlorine samples included in the analyses are summarised in Figure 32.

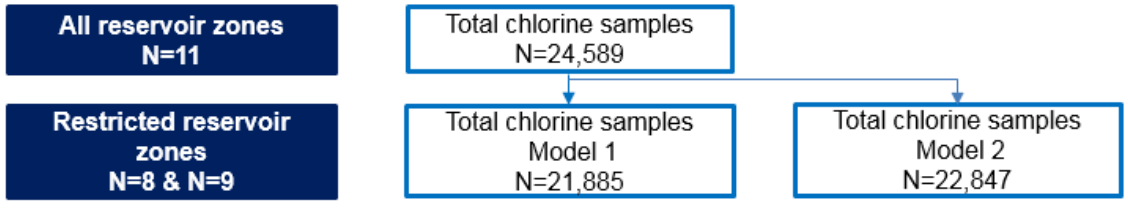


Figure 32 Total chlorine samples included in different analysis of water quality: flow chart

From 2012–2016, there were 24,589 total chlorine samples collected across 11 reservoir zones and 136 sampling points. Per reservoir zone, the median number of sampling points was 9 (range 4–38 per sampling point). Approximately one chlorine sample per sampling point was recorded per week. The median number of annual samples per sampling point was 51 (range 1–54). The number of sample points monitored varied over the period as the sampling locations were altered (e.g., re-located) or ceased (Appendix C). Total chlorine results were available for 91 (66.9%) of the 136 sample points annually during 2012–2016; 45 (33.1%) of the sample points were missing total chlorine results for one or more years during this time period.

From 2012–2016, when examined as a categorical variable, 5,202 (21.2%) samples had total chlorine <0.2 mg/L. Between reservoir zones, the proportion of annual samples with a total chlorine result <0.2 mg/L ranged between 4.6% and 72% (Table 16). There was a significant difference among reservoir zones regarding the proportion of samples with total chlorine <0.2 mg/L ($p<0.01$).

From 2012–2016, the proportion of total chlorine results <0.2 mg/L increased from 16.4% in 2012 to 23.0%. The increase found to be statistically significant ($p<0.001$).

Table 16 Total number of chlorine samples and proportion with a result <0.2 mg/L, by reservoir zone, 2012–2016

Zone	No. SP	Year									
		2012		2013		2014		2015		2016	
		No.*	% <0.2 mg/L	No.*	% <0.2 mg/L	No.*	% <0.2 mg/L	No.*	% <0.2 mg/L	No.*	% <0.2 mg/L
1	9	347	4.6	339	11.2	330	40.6	258	46.1	248	29.4
2	8	234	10.7	233	10.7	204	25.0	146	26.7	118	15.3
3	5	261	31.8	259	56.8	258	55.0	210	67.6	156	65.4
4	14	565	2.8	576	3.8	573	2.8	529	3.8	518	10.4
5	4	209	25.4	208	26.9	207	33.3	182	34.1	155	31.6
6	4	209	61.2	207	98.1	208	80.3	183	68.9	155	44.5
7	38	1541	7.0	1480	6.4	1477	3.7	1134	3.9	808	3.2
8	4	156	63.5	156	92.3	154	79.9	159	73.6	156	69.9
9	9	465	18.3	465	21.5	412	29.1	329	41.0	216	42.6
10	11	517	9.5	511	1.8	479	4.8	440	8.4	364	1.4
11	28	1305	22.2	1239	25.7	1165	29.4	765	32.7	411	39.9

Abbreviation No = Number; SP = Sampling point

* Number of total chlorine samples per year

Five of the 11 reservoir zones reported a significant increase ($p<0.05$) in the proportion of total chlorine samples <0.2 mg/L, one reported a significant decrease and five reservoir zones were unchanged (Table 16). In 2016, two reservoir zones reported greater than 60% of their annual total chlorine samples were <0.2 mg/L.

Association between NTM notifications and disinfectant residual

The notification rates of water-associated NTM and proportion of total chlorine <0.2 mg/L were examined across selected reservoir zones in metropolitan Brisbane. Of the 11 reservoir zones for which total chlorine data were available, eight (Model 1) and nine (Model 2) contained one or more postcodes within their zone boundaries and were able to be matched for analysis. From 2012–2016, there were 166 NTM notifications within the examined reservoir zones, representing 16.1% notifications of water-associated NTM in Queensland (Model 1). The median annual NTM notification rate per reservoir zone was 5 per 100,000 population (range 0–12).

Negative binominal regression indicated there was no relationship between proportion of total chlorine samples <0.2 mg/L within a reservoir zone and the NTM notification rate overall and per year. The same result was found when Model 2 was used in the regression analysis.

5.8. Discussion

In this study I demonstrated that notification rates of NTM increased over 16 years, including for water-associated NTM species *M. abscesses* and *M. avium*. In addition, I demonstrated that the proportion of water samples containing sufficient total chlorine decreased significantly in selected Brisbane reservoir areas. On a spatial level, I did not observe an association between increased rates of water-associated NTM and lower total chlorine, although the results need to be discussed in the context of several important limitations.

Trends in nontuberculosis mycobacteria

NTM notification rates, including those potentially associated with water continued to increase in Queensland consistent with previous reports.[12,14] Increasing trends from 2002–2006 culminated in a large peak in 2007 before declining until 2012, and increasing steadily until 2017. The reasons for the increasing overall rates overall, including peak in 2007 and during 2012–2017 are not entirely clear. It has been suggested that the incidence of NTM disease is increasing, along with improvements in laboratory testing. Trends may also be influenced by increasing disease awareness, availability of diagnostic services and improvements in diagnostic capabilities. The development of molecular techniques enabling the detection of differences in the 16S rRNA gene greatly improved species differentiation, although would not have impacted total case counts. In Queensland, *M. avium* complex isolates are now identified as *M. avium* or *M. intracellulare* through multiplex PCR.[8] Changes in diagnostic capabilities mean comparing rates across time must be undertaken cautiously.

Rate changes did not occur uniformly across age groups, sex or geographic area. Individuals notified with NTM were consistently older (≥ 65 years). When adjusted for age and time period, there were lower rates of all NTM in women than men,

although there were higher rates of water-associated NTM in women than men. Examining differing behavioural or individual exposures between men and women may be valuable in informing transmission patterns for selected species.

I identified 48 geospatial clusters and outliers of water-associated species during 2012–2017 across Queensland, indicating areas with unexpectedly higher rates of water-associated NTM. Most hotspots were in the southeast region of Queensland and approximately one third were in the selected Brisbane metropolitan areas examined. Studies have suggested that greater proximity to environment and unique conditions are associated with increased concentrations of mycobacteria in water.[13, 37, 38] The presence of piped networks of municipal systems compared with well-water systems used in rural areas have also been suggested to increase NTM exposure.[13] Alternately, individuals living remotely may be less likely to seek medical care and therefore have NTM diagnosed. Clusters may be caused by differences in environmental factors that increase the risk of disease, or individual differences in risk factors. The presence of the water-associated NTM hotspots in urban Brisbane require further investigation to determine if they are real small area clusters, or caused by other reasons including smaller numbers occurring by chance.

Trends in water disinfectant levels

There were differences in aggregated total chlorine levels between reservoir zones from 2012–2016. Eight of the 11 reservoir zones reported increases in the proportion of total chlorine <0.2 mg/L over the period, with statistically significant increases in five of reservoir zones. The efficiency of disinfection depends on the quality of the source of the treated water and may be strongly impacted by factors such the pH, turbidity, organic contact of the water and chemical contact time. Some areas in southeast Queensland have longer distribution systems and water travel times translating to reduced levels of disinfectant at the point of consumer. The variable and lower disinfection levels observed in some reservoir zones may represent a public health risk.

NTM notifications and disinfectant residuals

No association was found between NTM notification rates and disinfectant levels in selected reservoir zones in Brisbane. There are several reasons that may explain a lack of association. Small numbers of aggregated NTM water-associated species

matched to reservoir zones may have produced unstable and unreliable notification rates for comparison. The analyses examined four potentially water-associated NTM species in Brisbane. The NTM species were selected from one study showing identical species identified in the home matched that found in the patient. This is circumstantial evidence of a relationship between the occurrence of bacteria in water supplies and human disease only. Furthermore, other NTM species may also be potentially water-associated which may be relevant and were not examined.[1, 39] Aggregated NTM water-associated species may have masked trends. Separate analyses of species did not occur due to small numbers and time constraints and may be important to examine in future studies.

NTM have demonstrated varying levels of resistance to disinfectants. Although monochloramine has shown greater effectiveness than other disinfectants (chlorine, ozone), the ability of NTM to grow in biofilms reduces the disinfectant effectiveness.[1] Biofilms are present on the surfaces of piping material in all water distribution systems and mycobacteria may be found after events that dislodge biofilms, such as flushing or flow reversals.[1] Persistent residual disinfectant should reduce the number of mycobacteria in reticulated water. A combination of control measures including residual disinfectant, restriction of the residence time of water in distribution systems and treatment to optimise organic carbon removal may minimise biofilm growth.

This analysis is subject to several limitations. Firstly, while the data I used were considered the most complete and included all laboratory-confirmed notifications, some NTM cases may have remained undetected where the patient were not diagnosed or if they were unable to provide an appropriate specimen for identification (incomplete ascertainment). This type of misclassification would lead to an underestimate of case count and rate, leading the estimates representing a minimum estimate of the true value. NTM cases may present asymptomatically and notified cases were likely to represent more severe clinical presentation. The real burden of NTM is expected to be much higher than the one based on notifications and is a typical limitation of passive surveillance data.

Secondly, we were unable to accurately link total chlorine results to the water a case was actually exposed to. Mapping the nearest sample point to the notified NTM residence to calculate direct exposure may have determined more accurately if a potential association between NTM disease and lower disinfectant levels existed. However, we attempted to measure the average disinfectant level in the postcode, which would have provided a reasonable measure of exposure. Any misclassification would have likely biased results toward the null, indicating no association when an association may have been present. Uncertainty also remains surrounding the threshold and level of disinfection (or absence of) that would enable potential transmission of NTM.

It is very difficult quantify environmental exposures, such as determining what level of total chlorine constituted an inadequate or effective disinfectant residual and time period for it to constitute a risk for acquiring NTM. Measuring exposure to low-chlorine for individuals with NTM infection was very challenging. A one-year lag time was examined based on reasoned judgement of the context, plausibility and previously published estimates. Although the evidence surrounding the incubation period between NTM exposure and disease is poorly defined and has been estimated to be between a few months to years. A more advanced statistical approach may be required to examine variable lag times, which were beyond the scope of the project.

Thirdly, important clinical and behavioural risk factor information were unavailable. It was not feasible for me to collect, individual exposure data due the retrospective nature of the data collection, along with resource and time constraints. Nearly everyone is presumed exposed to NTM, although most individuals do not develop clinical signs of infection.[40] Some population subgroups are vulnerable to developing NTM illness and important potential confounders may include age, pre-existing comorbidities (chronic obstructive pulmonary disease) and those undergoing immunosuppressive therapy. Persons may spend significant time at locations other than their residences (e.g., workplaces, outdoors) and transmission may occur through other routes such as aerosols and soil. The risk of acquiring NTM has been shown to be high in communities engaged in occupations which generate aerosols and are exposed to soil for a longer time (e.g., agriculture, landscaping).[41]

Fourthly, factors predisposing individuals to infection are not well understood; however, likely due to an interaction between host defence mechanisms, exposure dose and environmental exposures. The sufficient number of NTM organisms required to produce infection are unknown. Individual water source and dose measurement (e.g., daily water use, distance from site of disinfection and duration of residence) were unavailable. Looking at one exposure such as water transmission is limited in comparison with total-exposure assessment, consisting of all possible exposures (water, aerosols, soil) and all routes of entry (inhalation, dermal contact, ingestion) to assessing the combined effects of multiple exposures on human health. In the future, whole genome sequencing in well-designed epidemiological studies will provide important understanding about the transmission of NTM to individuals from the environment and establish the role of water exposure in transmission.

Finally, postcodes were aggregated and mapped to reservoir zones. The non-overlapping boundaries between the notification (i.e. postcodes) and water quality data (i.e. reservoir zones) may have led to inaccurate estimation of exposure.

5.9. Conclusion

In this study, I used routinely collected data to answer the research question—do areas with lower disinfectant residuals have higher rates of NTM potentially associated with water? The study design was restricted in one area in southeast Queensland with the aim of exploring hypotheses about the aetiology of selected water-associated NTM species. Analyses showed that NTM continues to increase in Queensland and that there were higher rates of water-associated species in urban areas. I found no association between NTM notification rates and lower disinfectant levels, although we were limited in drawing firm conclusions due to potential for misclassification of exposure. The findings relating to water quality and lower disinfectant levels in Brisbane are important as many of the environmental factors conductive to NTM also allow for growth of other opportunistic pathogens. This study highlighted complexities in investigating a pathogen with a broad spectrum of clinical manifestations and transmission sources, quantifying

environmental exposures across time periods and areas, and identifying potential associations using spatial data and geographical epidemiology.

Specific risk factors for NTM infection are poorly understood. Current research is focusing on associations between environmental variables including rainfall, temperature, flooding and dust, and NTM infection. Whole genome sequencing may prove important to improve our understanding of transmission of NTM to individuals from the environment. Further examination of the spatiotemporal clustering of NTM notifications in urban areas and other environmental exposures may increase our understanding of factors that help NTM grow and survive in the environment in Queensland.

5.10. References

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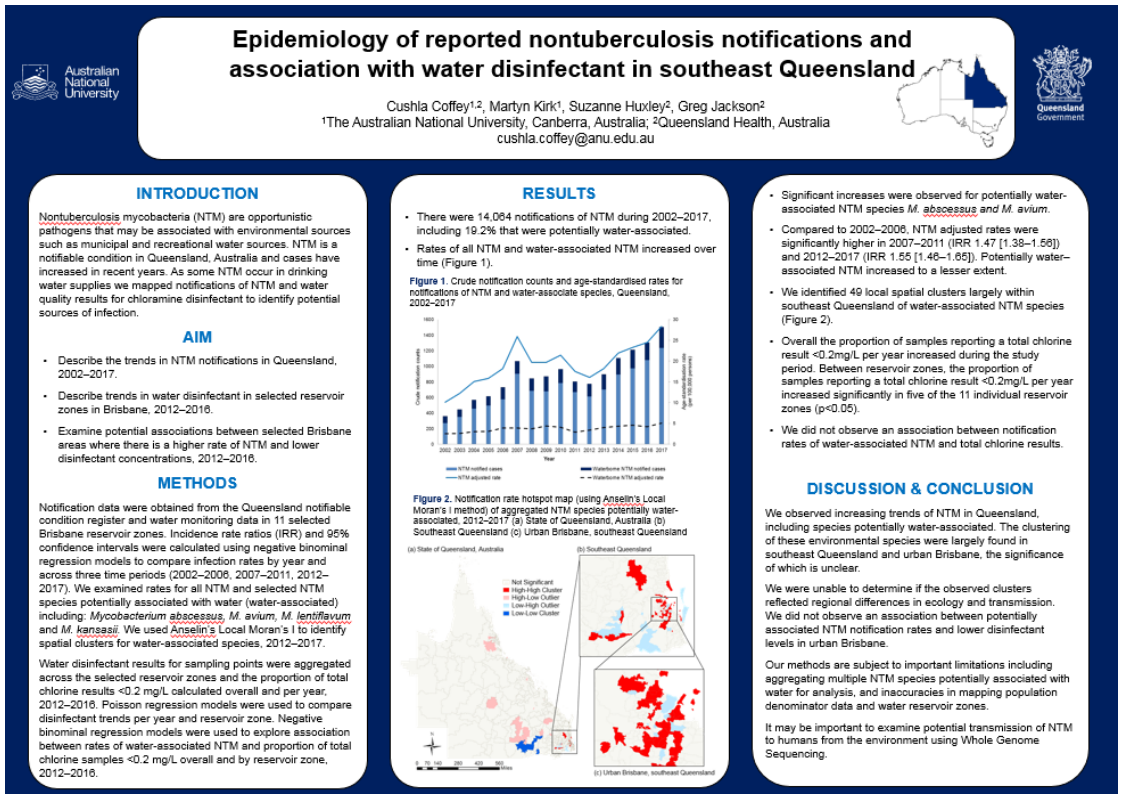
5.11. Appendix A—International conference presentation



Epidemiology of reported nontuberculosis notifications and association with water disinfectant in southeast Queensland

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INTRODUCTION

Nontuberculosis mycobacteria (NTM) are opportunistic pathogens that may be associated with environmental sources such as municipal and recreational water sources. NTM is a notifiable condition in Queensland, Australia and cases have increased in recent years. As some NTM occur in drinking water supplies we mapped notifications of NTM and water quality results for chloramine disinfectant to identify potential sources of infection.

AIM

- Describe the trends in NTM notifications in Queensland, 2002–2017.
- Describe trends in water disinfectant in selected reservoir zones in Brisbane, 2012–2016.
- Examine potential associations between selected Brisbane areas where there is a higher rate of NTM and lower disinfectant concentrations, 2012–2016.

METHODS

Notification data were obtained from the Queensland notifiable condition register and water monitoring data in 11 selected Brisbane reservoir zones. Incidence rate ratios (IRR) and 95% confidence intervals were calculated using negative binominal regression models to compare infection rates by year and across three time periods (2002–2006, 2007–2011, 2012–2017). We examined rates for all NTM and selected NTM species potentially associated with water (water-associated) including: *Mycobacterium abscessus, M. avium, M. lentiflavum* and *M. kansasii*. We used Anselin's Local Moran's I to identify spatial clusters for water-associated species, 2012–2017.

Water disinfectant results for sampling points were aggregated across the selected reservoir zones and the proportion of total chlorine results <0.2 mg/L calculated overall and per year, 2012–2016. Poisson regression models were used to compare disinfectant trends per year and reservoir zone. Negative binominal regression models were used to explore association between rates of water-associated NTM and proportion of total chlorine samples <0.2 mg/L overall and by reservoir zone, 2012–2016.

RESULTS

- There were 14,064 notifications of NTM during 2002–2017, including 19.2% that were potentially water-associated.
- Rates of all NTM and water-associated NTM increased over time (Figure 1).

Figure 1. Crude notification counts and age-standardised rates for notifications of NTM and water-associate species, Queensland, 2002–2017

Figure 2. Notification rate hotspot map (using Anselin's Local Moran's I method) of aggregated NTM species potentially water-associated, 2012–2017 (a) State of Queensland, Australia (b) Southeast Queensland (c) Urban Brisbane, southeast Queensland

- Significant increases were observed for potentially water-associated NTM species *M. abscessus and M. avium*.
- Compared to 2002–2006, NTM adjusted rates were significantly higher in 2007–2011 (IRR 1.47 [1.38–1.56]) and 2012–2017 (IRR 1.55 [1.46–1.65]). Potentially water–associated NTM increased to a lesser extent.
- We identified 49 local spatial clusters largely within southeast Queensland of water-associated NTM species (Figure 2).
- Overall the proportion of samples reporting a total chlorine result <0.2mg/L per year increased during the study period. Between reservoir zones, the proportion of samples reporting a total chlorine result <0.2mg/L per year increased significantly in five of the 11 individual reservoir zones ($p<0.05$).
- We did not observe an association between notification rates of water-associated NTM and total chlorine results.

DISCUSSION & CONCLUSION

We observed increasing trends of NTM in Queensland, including species potentially water-associated. The clustering of these environmental species were largely found in southeast Queensland and urban Brisbane, the significance of which is unclear.

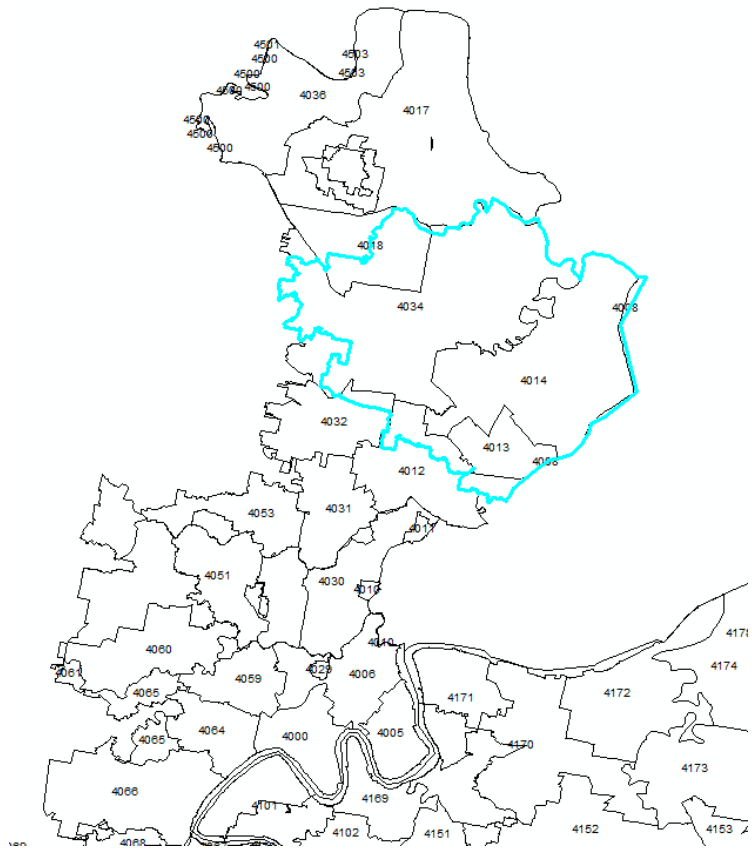
We were unable to determine if the observed clusters reflected regional differences in ecology and transmission. We did not observe an association between potentially associated NTM notification rates and lower disinfectant levels in urban Brisbane.

Our methods are subject to important limitations including aggregating multiple NTM species potentially associated with water for analysis, and inaccuracies in mapping population denominator data and water reservoir zones.

It may be important to examine potential transmission of NTM to humans from the environment using Whole Genome Sequencing.

5.12. Appendix B—Allocation of postcodes to reservoir zones

Individual postcodes were manually assigned to reservoir zones by visual inspection using ArcGIS. Postcodes that were predominately in the reservoir zone (>50%) were assigned into Model 1 (>75%) or Model 2 (>50%) based on the proportion of the postcode which fell within the zone. In the above example, postcodes 4014, 4034 and 4013 were assigned into Model 1 and 4013, 4014, 4034 and 4018 into Model 2.



5.13. Appendix C—Number of sampling points and total chlorine samples per reservoir zones

Reservoir zone	Sampling points	Number of annual total chlorine samples				
		2012	**2013**	**2014**	**2015**	**2016**
Reservoir zone 1 (n=9)	SP063	39	29	41	45	52
	SP121	52	51	53	29	39
	SP129	51	52	30	-	-
	SP185	51	52	50	53	52
	SP219	52	51	53	39	26
	SP268	51	52	51	39	26
	SP311	51	52	52	40	26
	SP332	-	-	-	13	26
	SP369	-	-	-	-	1
	Total	**347**	**339**	**330**	**258**	**248**
Reservoir zone 2 (n=8)	SP029	51	52	52	39	26
	SP030	-	-	-	32	44
	SP031	52	51	53	12	-
	SP032	28	27	20	23	14
	SP033	52	51	28	-	-
	SP263	51	52	51	40	25
	SP367	-	-	-	-	6
	SP370	-	-	-	-	3
	Total	**234**	**233**	**204**	**146**	**118**
Reservoir zone 3 (n=5)	SP048	52	51	51	40	26
	SP050	52	52	52	52	52
	SP137	52	52	52	26	-
	SP174	52	52	51	53	52
	SP179	53	52	52	39	26
	Total	**261**	**259**	**258**	**210**	**156**
Reservoir zone 4 (n=14)	SP017	51	52	53	12	-
	SP039	52	53	52	26	-
	SP049	52	52	52	51	52
	SP066	52	51	53	51	52
	SP083	52	53	51	26	-
	SP130	51	52	52	53	39
	SP144	52	53	52	51	52

	SP182	48	53	52	52	52
	SP210	52	53	52	52	52
	SP216	51	52	52	53	52
	SP225	-	-	-	18	52
	SP316	52	52	52	26	12
	SP360	-	-	-	32	52
	SP361	-	-	-	26	51
	Total	**565**	**576**	**573**	**529**	**518**
Reservoir zone 5 (n=5)	SP018	52	52	51	39	26
	SP019	52	52	52	39	26
	SP021	52	52	52	39	26
	SP060	53	52	52	52	51
	SP355	-	-	-	13	26
	Total	**209**	**208**	**207**	**182**	**155**
Reservoir zone 6 (n=4)	SP089	52	51	53	52	51
	SP165	53	52	53	52	52
	SP321	52	52	51	26	-
	SP323	52	52	51	53	52
	Total	**209**	**207**	**208**	**183**	**155**
Reservoir zone 7 (n=38)	SP002	50	-	-	-	-
	SP025	51	52	53	39	26
	SP052	51	52	53	33	13
	SP054	53	51	52	33	13
	SP057	54	53	52	52	52
	SP058	53	52	52	52	52
	SP102	51	52	52	32	13
	SP103	51	52	53	39	26
	SP104	53	51	53	33	13
	SP110	51	51	53	32	12
	SP148	1	-	-	-	-
	SP160	51	51	53	39	26
	SP162	52	51	53	32	13
	SP164	53	51	52	38	26
	SP198	49	51	53	49	52
	SP214	52	51	53	33	13
	SP222	51	52	53	52	52
	SP224	52	51	53	39	26
	SP238	52	51	53	22	6
	SP242	52	51	53	32	13
	SP244	53	52	52	39	26

	SP246	53	52	52	32	13
	SP253	51	51	53	32	13
	SP254	53	51	53	33	13
	SP255	52	52	48	51	52
	SP261	53	45	27	33	10
	SP299	52	51	52	32	13
	SP308	52	51	50	26	-
	SP319	51	51	53	31	26
	SP344	-	-	-	13	26
	SP345	-	-	-	7	13
	SP401	25	28	25	39	52
	SP408	25	28	25	13	-
	SP415	25	27	25	20	13
	SP435	13	15	13	14	13
	SP806	-	-	-	26	52
	SP808	-	-	-	6	13
	SP816	-	-	-	6	13
	Total	**1541**	**1480**	**1477**	**1134**	**808**
Reservoir zone 8 (n=4)	SP088	52	52	52	41	26
	SP124	52	52	51	52	52
	SP150	52	52	51	53	52
	SP333	-	-	-	13	26
	Total	**156**	**156**	**154**	**159**	**156**
Reservoir zone 9 (n=10)	SP139	52	53	52	26	-
	SP061	52	52	51	40	26
	SP064	52	52	51	40	26
	SP175	52	51	51	38	26
	SP176	51	52	52	40	26
	SP177	52	52	52	54	52
	SP276	51	48	-	-	-
	SP287	52	53	52	51	34
	SP318	51	52	51	34	13
	SP352	-	-	-	6	13
	Total	**465**	**465**	**412**	**329**	**216**
Reservoir zone 10 (n=11)	SP010	53	49	30	26	-
	SP020	52	52	52	52	52
	SP022	51	52	53	26	-

	SP023	51	52	53	52	52
	SP024	51	52	53	39	26
	SP101	51	52	53	39	26
	SP111	52	52	52	52	52
	SP125	52	46	28	51	52
	SP215	51	52	53	39	26
	SP218	53	52	52	39	26
	SP362	-	-	-	25	52
	Total	**517**	**511**	**479**	**440**	**364**
Reservoir zone 11 (n=28)	SP037	53	52	52	33	13
	SP038	52	52	52	33	13
	SP042	52	52	52	32	13
	SP076	52	52	51	33	25
	SP084	51	41	24	24	17
	SP090	52	50	53	32	26
	SP091	-	-	-	-	25
	SP092	1	-	-	2	-
	SP093	51	51	53	32	26
	SP094	53	52	52	39	26
	SP100	53	52	51	39	26
	SP117	53	52	52	25	-
	SP154	52	52	51	27	-
	SP155	52	52	51	27	-
	SP167	53	52	51	32	13
	SP169	52	52	51	40	26
	SP170	52	52	50	27	-
	SP171	53	51	52	26	-
	SP172	51	52	53	52	52
	SP180	53	52	52	26	-
	SP190	52	52	52	26	-
	SP192	52	51	53	39	26
	SP217	52	23	-	-	-
	SP221	52	38	-	-	-
	SP250	52	51	53	32	6
	SP251	52	51	53	33	13
	SP328	52	52	51	53	52
	SP358	-	-	-	1	13
	Total	**1305**	**1239**	**1165**	**765**	**411**

Chapter 6 Teaching

6.1. Prologue

Core MAE requirements addressed

- Prepare at least one (and participate in all) “Lessons from the field” (LFFs)
- Prepare and conduct a case study for first year MAE students (or another epidemiology training program), as part the second-year subject POPH8914 Issues in Applied Epidemiology

My role and lessons learnt

The topic I chose for my LFF related to clinical research and health screening (Appendix A). In an evaluation of the Mount Isa Capillary Screening Program, a key question remains whether capillary point-of-care testing for elevated blood lead is acceptable as a reasonable diagnostic alternative, compared with venous blood sampling (gold standard). Through this real public health issue, I used the LFF as an opportunity to re-examine important indices to evaluate the validity of a test (sensitivity, specificity, positive predictive value, negative predictive value), expand my colleague’s knowledge of important concepts relating to diagnostic testing (reproducibility, agreement and reliability), introduce two potential statistical tests for categorical data (proportion of agreement and Cohen’s kappa) and discuss important considerations in screening. Health programs rely on multiple people to collect data and undertake research, and different measurement tools to generate the same result. I thoroughly enjoyed planning the LFF around this hypothetical scenario and show how statistical methods may be used to address questions surrounding the accuracy and reproducibility of the health effect. Cohen’s kappa statistic may be broadly applied in different epidemiology work from measuring the effectiveness of healthcare workers undertaking nutrition surveys to accurately identify malnutrition to assessing the TB status of children after treatment using two different measurement methods. Commonly held beliefs that an ‘early diagnosis’ of a disease and screening everyone if effective in improving health outcomes exist. There are principles and important considerations in population screening which require consideration. The process of developing the lesson and feedback gained will be extremely useful during future opportunities for learning. I also found

participating in LFF's very valuable in expanding my epidemiological knowledge and having the opportunity to regularly connect with my colleagues.

I worked with MAE scholars, Jana Sisnowski and Bobby Maher, to create and teach a training session on evaluating complex public health interventions. Evaluation is an extremely important component of the MAE, extending beyond the competency, evaluation or establishing a surveillance system. We introduced logic models for planning and evaluation of public health interventions. We developed the session using our experiences and examples of successful and less successful public health interventions. We hope first-year MAEs understanding of evaluation was broadened by the information. Teaching is an extremely important skill that consolidates your knowledge and experience. I gained an appreciation of positive attributes which facilitate teaching, appreciation of the time required to prepare and undertake learning sessions and importance of clearly identifying objectives.

6.2. Lessons from the field

Preventative screening of excessive lead exposure in a mining town

The LFF Skype conference is scheduled for **Wednesday 20 December 6.00pm EST** The answers are due back on **Wednesday 20th December 2017 12.00pm EST.**

Instructions

In this lesson from the field (LFF), we will explore concepts in clinical epidemiology, screening and diagnostic testing. The case study is based on environmental lead exposure and current public health issue in a mining town in Queensland. The details and numbers have been made up for this exercise. There are several recommended and suggested readings for this LFF.

Recommended readings

Kottner J, Audigé L, Brorson S, Donner A, Gajewski BJ, Hróbjartsson A, et al. Guidelines for reporting reliability and agreement studies (GRRAS) were proposed. Int J Nurs Stud. 2011;48(6):661-71

Ribgy AS. Statistical methods in epidemiology. v. Towards an understanding of the kappa coefficient. Disabil Rehabil. 2000;22(8):339-44.

Cancer Council Australia. 2018. Principles of screening [Internet]. 2018 [cited 2018 May 1]. Available from https://wiki.cancer.org.au/policy/Principles_of_screening

Andermann A, Blancquaert I, Beauchamp S, Déry V. *Revisiting Wilson and Jungner in the genomic age: a review of screening criteria over the past 40 years*. Bull World Health Organ. 2008;86:317–319.

David S, Hughes AM. Minimising Bias. Methods in Applied Epidemiological Research. (Canberra, Australian National University, 29 August 2018)

Additional resources

National Health and Medical Research Council. Managing individual exposure to lead in Australia – A guide for health professionals [Internet]. Canberra: National Health and Medical Research Council, 2016. Available from: http://www.leadalliance.com.au/wp-content/uploads/2016/09/16200_nhmrc_managing_individual_exposure_to_lead_in_australia_web.pdf

Learning objectives

By the end of this LFF students should be able to:

- Improve their understanding of clinical epidemiology.
- Understand the concept of reproducibility and measures of agreement and reliability for categorical data.
- Understand the kappa statistic and know when to apply it in the field.
- Understand broader considerations and issues related to health screening.

Part 1 – Background

You are the new Master of Philosophy (Applied Epidemiology) (MAE) scholar working in a public health unit (PHU) in a mining town. Mining of lead has been undertaken in the area for over 70 years. The mine is an important source of employment and the town was built adjacent to the mine. Lead is endemic in the community and although there are available voluntary lead testing services, reports indicate there is limited uptake of this testing service.

There have been increased concerns regarding lead exposure for children aged less than five years, particularly as the recommended blood lead level (BLL) has been lowered from 10 micrograms per decilitre (µg/dL) to 5 µg/dL The Department of Health tasked your PHU with implementing a capillary lead screening program, including validation study in the first month of the program. Unfortunately, due to staffing issues no evaluation or analysis has been undertaken. The program is now one-year-old and the Department of Health wants immediate information.

Part 2 – Learning about lead

Lead is a naturally occurring metal found in the earth's crust and has a wide variety of use in manufacturing. Lead compounds are not beneficial for human health. Individuals absorb lead into the body by breathing lead-contaminated air,

swallowing lead-contaminated particles or dermal exposure.[42] Sources of lead exposure in Australia include workplaces in the lead industry such as mining sites, exposure to lead-based paint during maintenance or demolition, hobbies (e.g., restoring boats, soldering, casting objects, shooting) and lesser extent imported products containing lead (i.e. complimentary medicines, jewellery).

The adverse health effects of lead are well-established at BLLs greater than 10µg/dL.[43] A recent review undertaken by the National health and Medical Research Council also found an association between BLLs less than 10 µg/dL and health effects, including reduced Intelligence Quotient and academic achievement in children, behavioural problems in children, increased blood pressure in adults and a delay in sexual maturation in adolescent boys and girls.[43] Evidence about the human health effects of lead with BLLs between 5 and 9 µg/dL is inconclusive. A BLL greater than 5µg/dL suggests that a person has been, or continues to be exposed to lead at a level that is above what is considered the average 'background' exposure in Australia and should be investigated and reduced, particularly if the person is a child or pregnant woman. Investigating the source of exposure where BLLs are 5µg/dL and greater will reduce the risk of harm to the individual and others in the community, including vulnerable populations. Elevated blood lead is a notifiable condition in Australia except in South Australia and the Australian Capital Territory. In Queensland, diagnosis of BLL 5 µg/dL and greater in any person must be notified to the Department of Health by pathology laboratories.

Part 3 – Capillary blood lead screening

The capillary screening program commenced 1 October 2016 targeting children aged less than five years. Children aged less than five years of age are at increased risk of elevated blood lead and poorer health outcomes due the increased sensitivity of their developing organs and higher intestinal absorption (from 40 to 50%) compared with adults (from 3 to 10%).[44, 45] Risk of exposure to environmental lead is also increased through the behaviour of children such increased exploratory hand-to-mouth activity, ability to reach potentially contaminated surfaces and ingestion of non-food substances and materials such as soil.[43] BLLs are indicators of circulating lead that captures variation in recent lead exposure as well as lead that has been mobilised from tissue stores.[46] BLLs may be measured using venous and capillary blood. Venous blood is obtained via a direct puncture to a vein often location on the arm or hand. Capillary blood is collected via a finger prick on site with results available within a few minutes. Capillary results are not considered diagnostic and a blood result above the reference range must be confirmed via venous testing to be notifiable.

Image: LeadCare II Blood Lead testing System is a point-of-care device that tests children at risk of lead exposure providing a BLL within 3 minutes

The characteristics of capillary testing mean lead may be measured quickly, it is less invasive test than venous blood testing, simple to perform, does not require skilled laboratory personnel, has low purchase and operational costs and a reasonably good detection limit (3.3–65.0 ug/dL).[47] However, the capillary test may report a higher level of lead due to the test being harder to perform accurately, easy contamination of samples and test margin of error.[42]

The accuracy of capillary blood lead testing as a screening tool was extensively debated by those implementing the program. It is important to evaluate the validity

of diagnostic tests to measure the exposure (i.e. does the test measure what it needs to measure) and potential for measurement error. An important question was raised:

Is capillary screening accurate and reliable enough to detect elevated BLLs in a lead endemic area?

The accuracy and reliability of point-of-care capillary testing for the detection of elevated BLLs has also been questioned by lead prevention programs in other areas. It is known there is a small margin of error ±2 µg/dL which needs to be considered when interpreting results.[43] For example, a blood lead reading of 10 µg/dL may actually be from 8 µg/dL to 12 µg/dL. The level of precision is allegedly further reduced for BLLs <10 µg/dL.

This validation study tested the first 100 children aged less than five years who present to the clinic for lead exposure using concurrent capillary blood specimens and venous blood specimens. Before an analysis of the blood lead data over the year is undertaken, the Department of Health wants information regarding the accuracy and reliability of the capillary screening tool (LeadCare II).

Part 4 – Clinical Epidemiology

Clinical epidemiology focuses on groups of patients or population groups seen in the clinical setting. The emphasis is placed on health-seeking behaviour, referral of patients, diagnostic approaches, treatment choices and outcomes and technology assessment. The main objectives are the optimisation of diagnosis and treatment of disease and health-resource allocation. Similarities exist with classic epidemiology, including shared reliance on comparative approaches to the study of health and illness, strong concerns about the misclassification and the biases that can lead to erroneous conclusions limiting the generalisability of the study results.

The project plan states as part of the validation study the statistical analysis includes an estimation of agreement and reliability.[48] Concepts including measurement error, validity and reliability were explored during the previous course block (Review Minimising Bias lecture).

Read documents in listed under the readings and answer the following questions.

1. What is measurement error?

Measurement (or observational) error is the difference between the measured value and true value, occurring at the stage of data collection. Misclassification of exposure and/or outcome is the main source of error and has the potential to bias the measure of association. It may be systematic or random, and caused if measurements are not valid or reliable.

2. What is reproducibility?

Reproducibility is the degree to which repeated measurements provide similar results. This may be if two persons using the same method of measurement separately obtain the same result (between-observer), or if two techniques used to measure a particular variable, under ideal circumstances, produce the same result (between method). Do we get the same measurement each time? There are two concepts involved including agreement and reliability. Both provide information regarding measurement error and whether measurements are reproducible in test re-test situations.[49]

3. What is the difference between agreement and reliability?

Reliability and agreement studies provide important evidence regarding measurement error. Often terms are used interchangeably, however, the concepts are conceptually distinct. These are measures which relate to whether test reproducible.[48]

Agreement relates to how close are the scores for repeated measurements and degree to which scores or ratings are identical. [48]

Reliability relates to how well patients can be distinguished from each other, despite the measurement errors or objects. It is the ability to differentiate between subjects or objects. [48] *It is highly dependent on the variation in the population sample and generalisable to samples with a similar variation. It is the characteristic of the performance of an instrument in a certain population.*[49]

Results of reliability and agreement studies are intended to provide information about the amount of error inherent in any diagnosis, score or measurement. These are fixed properties of measurement tools, rather the products of interactions between the tools. [48]

4. What may be sources of variation in repeated measurements of blood lead?

Sources of variation may be:

- *Biological variation within persons*
- *Different observers and raters taking the measurements (e.g., varying levels of clinical skills/training)*
- *Different blood collection technique*
- *Different diagnostic test (finger prick, capillary point-of-care versus venous blood test)*
- *Different technique to analyse the sample in the laboratory*
- *Circumstances which the measures takes place (e.g., room selection, hygiene, temperature).*[49]

Part 5 – Testing agreement and reliability

There are several statistical approaches that may be used in the measurement of agreement and reliability based on the type of data. We are only going to review two statistical tests for agreement (proportion of agreement) and reliability (kappa coefficient) measures for categorical data[50]

Venous blood tests are considered an independent gold standard to diagnose elevated BLLs. Another colleague has emailed you a 2x2 table compiled by the previous epidemiologist. The first 100 blood lead result were compared against the same blood samples using venous testing. Fortunately, all lead test results were <10 µg/dL allowing us to examine agreement and reliability with lower BLLs.

Table 1 Agreement between two observers for determining the presence/absence of a disease

		Target disorder (lead exposure) as indicated by venous testing		Totals
		Present ≥5µg/dL	Absent <5µg/dL	
Screening test (capillary)	Positive (≥5µg/dL)	a	b	a+b
	Negative (<5µg/dL)	c	d	c+d
		a+c	b+d	a+b+c+d

Table 2 Variation between two observers classifying lead exposure using venous and capillary blood

		Target disorder (lead exposure) as indicated by venous testing		Totals
		Present ≥5µg/dL	Absent <5µg/dL	
Screening test (capillary)	Positive (≥5µg/dL)	17	4	21
	Negative (<5µg/dL)	3	76	79
		20	80	**100**

5. Calculate the proportion of agreement between the two tests (cells which the capillary and venous test result agrees)

Observed agreement = (a+d)/(a+b+c+d)

Observed agreement = *(17+76)/(22+2+6+70)*

Observed agreement = *0.93 (93%)*

The observed agreement is high since there are only 7 discordant pairs.

6. Calculate the proportion of reliability between the two tests

We have calculated the observed agreement using the proportion of agreement calculation. However, some degree of agreement can always occur by chance. The statistic kappa coefficient (k) corrects the percent agreement (observed agreement) for the amount of agreement due to chance (expected agreement). The equation is:

$$\text{kappa (k)} = \frac{\text{Observed agreement – Chance agreement}}{\text{Maximum agreement – chance agreement}}$$

Let's now calculate the chance agreement. You see the previous epidemiologist commenced the calculations.

		Target disorder (lead exposure) as indicated by venous testing		Totals
		Present ≥5µg/dL	Absent <5µg/dL	
Screening test (capillary)	Positive (≥5µg/dL)	21*20/100	21*80/100	21
	Negative (<5µg/dL)	79*20/100	79*80/100	79
		20	80	**100**

Chance agreement = ((21*20/100)+ (79*80/100))/100

Chance agreement = *((21*20/100)+ (79*80/100))/100*

Chance agreement = *0.67 (67%)*

Finally calculate the kappa coefficient (k)

$$\text{kappa (k)} = \frac{\text{Observed agreement – Chance agreement}}{\text{Maximum agreement – Chance agreement}}$$

k = *(0.93 – 0.67) / (1 – 0.67)*

k = *0.7853*

k = *0.79*

You find an interpretation table* among the notes of the previous epidemiologist:

Table 3 Interpretation of the kappa coefficient

Kappa coefficient	Agreement
>0.80	almost perfect
0.61 ≤ k ≤ 0.80	substantial
0.41 ≤ k ≤ 0.60	moderate
0.21 ≤ k ≤ 0.40	fair
0.00 ≤ k ≤ 0.20	slight
<0.0	poor

*

7. According to the kappa coefficient, what was the level of reliability between the capillary screening test and the venous test?

The level of reliability is classified as substantial (0.61 ≤ k ≤ 0.80). Although there was some disagreement between the capillary and diagnostic testing, capillary screening for elevated blood lead is a suitable alternative to direct venous testing within the mining town, provided care is taken to avoid specimen contamination.

The advantages of kappa test are that it corrects for chance, is not affected by zeros in cells, can be easy to calculate, indicates the size and direction of the agreement; and is not restricted to two levels or agreement between two observers. The disadvantages of the kappa test is that sample sizes need to be large enough, not entirely clear what is a 'good' agreement (depends on the setting).

Part 6 – Test characteristics

Carrying out a diagnostic test is useful if the information adds more certainty for determining a health exposure such as elevated blood lead. Obtaining venous samples as a gold standard test allows us to assess the properties of the lead capillary screening test such as sensitivity, specificity and positive and negative predictive values.

8. What is sensitivity?

a / (a+c) true positive / total disorder present

Proportion of patients with positive test results among those infected. How good is the test at identifying people with the disease?

9. What is specificity?

d / (d+b) (true negative / total disorder absent)

Proportion of patients with negative test results among those infected. How good is the test at identifying people without the disease?

10. What is positive predictive value?

a / (a+b) (true positive / total test positive)

Probability a positive test is correct. The PPV depends on the sensitivity and

specificity of the test, and whether the condition is common or rare in the population being screened.

11. What is negative predictive value?

d / (c+d) (true negative / total test negative)

Probability a negative test is correct.

12. Calculate the following and then express as a percentage:

e) Sensitivity: *85%*

f) Specificity: *95%*

g) Positive predictive value: *81%*

h) Negative predictive value: *96%*

Comment on the results

There is higher specificity than sensitivity meaning this test is better at identifying people without disease / lead exposure. Preventative screening is generally carried out under conditions of low prevalence. In these settings, lower sensitivity is often more tolerated (i.e. accept a higher number of false negative or missed cases) compared with a more severe disease and health outcome such as acute myocardial infarction, where higher sensitivity would be desired due to potential mortality.

13. What are some of the inherent challenges in screening programs?

Challenges in screening programs, including those for lead exposure include:

- *Test accuracy and potential harms. Capillary and venous blood tests may yield false-positive and false-negative results.*
- *Cut-off. The recent 5 ug/dL was selected by the CDC based on population epidemiology. 97th percentile. Epidemiological tools are fairly blunt at*

detecting threshold levels. Not on powerful epidemiological or toxicological method. Dichotomising outcomes establishes a cut off to distinguish between negative from positive tests.

- *Difficulty determining the benefit of screening for an individual.*
- *The validation of instruments should occur in a new setting (i.e. laboratory), even when the instrument/test has been validated elsewhere. It should be validated especially in settings with additional uncertainty (i.e. lead endemic settings).*
- *Testing is neither universal nor randomly sampled therefore the data are not generalisable and cannot be used to interpret the prevalence or incidence for the overall population of community.*
- *Under-representation in vulnerable subgroups. Voluntary screening programs may encourage certain subgroups in the community to attend. Barriers including transport, health knowledge etc. may discourage individuals to attend.*
- *A positive screening test means little except more testing is required. This strategy can be easily used (and abused) as a screening tool for everyone becoming costly and highly inefficient.*
- *Economic issues where resources allocated to a screening program may lower resources for other health needs.*
- *A BLL reflects recent lead exposure (i.e. over weeks to months) from environmental or occupational sources only. Previous exposure is not captured.*[51]

14. Discuss the possible consequences if an erroneous lead result is received?

A distinct advantage of this investigation is that many children who initially tested negative on the screening test were immediately confirmed to be free of lead poisoning and, therefore, true negatives. A false positive can mean people without the disease undergo follow-up testing that may be uncomfortable, lead to psychological consequences such as anxiety. False negatives may mean people with the disease experience are not subject to confirmatory venous blood tests, delays in diagnosis, develop a false sense of security and ignore warming symptoms.[51] False confidence might also alter individuals and parents subsequent health-related behaviour.

Acknowledgment

This LFF acknowledges Associate Professor Isabel Ferreira, School of Public Health, Queensland University, whose passion and skills in teaching inspired me to examine diagnostic tests surrounding lead exposure further and pass on important epidemiological concepts to my colleagues.

6.3. Evaluating complex public health interventions

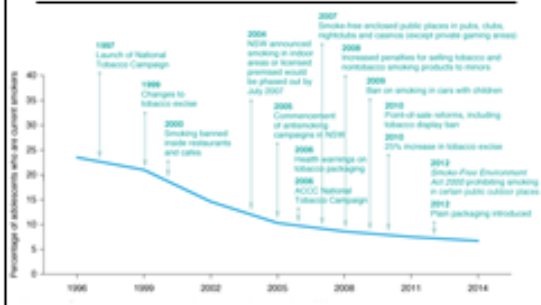
Evaluating complex public health interventions

Cushla Coffey, Bobby Maher & Jana Sisnowski (MAE '17)

Learning objectives

- Describe the components of a logic model
- Apply a logic model to a given public health intervention
- Explain the challenges of capturing different aspects of complex public health interventions

Public health interventions creating impact...



... and having unintended consequences

Articles

Efficacy of infant simulator programmes to prevent teenage pregnancy: a school-based cluster randomised controlled trial in Western Australia

"The infant simulator-based VIP programme did not achieve its aim of reducing teenage pregnancy. Girls in the intervention group were more likely to experience a birth or an induced abortion than those in the control group before they reached 20 years of age."

Challenges of public health interventions

- Beholden to policy cycles
- Often not trialled first
- Choice of evaluation types:
  - Formative evaluation
  - Process evaluation
  - Outcome evaluation
  - Impact evaluation
  - (Health) economic evaluation
  - Realist evaluation

Logic Model

Impact
Long-term, sustained benefits

Logic Model

Impact
Long-term, sustained benefits

Inputs
Resources required

Logic Model

Impact
Long-term, sustained benefits

Inputs
Resources required

Activities
Actions taken

Logic Model

Impact
Long-term, sustained benefits

Inputs
Resources required

Activities
Actions taken

Outputs
Results of activities

Logic Model

Impact
Long-term, sustained benefits

Inputs
Resources required

Activities
Actions taken

Outputs
Results of activities

Outcomes
Immediate benefits

Logic Model

Impact
Long-term, sustained benefits

Inputs
Resources required

Activities
Actions taken

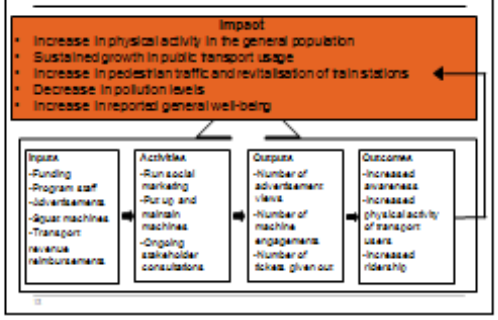
Outputs
Results of activities

Outcomes
Immediate benefits

Group activity: building a logic model

In Russia, 30 squats get you a subway ticket

Logic Model



Additional Resources

1. US Centers for Disease Control and Prevention. (2011) Introduction to Program Evaluation for Public Health Programs: A Self-Study Guide. Available from: https://www.cdc.gov/eval/guide/
2. Bamberger, M. et. al. (2004) Shoestring Evaluation: Designing Impact Evaluations under Budget, Time and Data Constraints. American Journal of Evaluation; 25(1):5-37.
3. Johns Hopkins University. (2006) Fundamentals of Program Evaluation. Available from: http://ocw.jhsph.edu/index.cfm/go/viewCourse/course/FundamentalsProgramEvaluation/coursePage/Index/