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The Journal of the Australian Institute of Environmental Health

...linking the science and practice of Environmental Health

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Environmental Health is a quarterly, international, peer-reviewed journal designed to publish articles on a range of issues influencing environmental health. The Journal aims to provide a link between the science and practice of environmental health, with a particular emphasis on Australia and the Asia-Pacific Region.

The Journal publishes articles on research and theory, policy reports and analyses, case studies of professional practice initiatives, changes in legislation and regulations and their implications, global influences in environmental health, and book reviews. Special Issues of Conference Proceedings or on themes of particular interest, and review articles will also be published.

The Journal recognises the diversity of issues addressed in the environmental health field, and seeks to provide a forum for scientists and practitioners from a range of disciplines. *Environmental Health* covers the interaction between the natural, built and social environment and human health, including ecosystem health and sustainable development, the identification, assessment and control of occupational hazards, communicable disease control and prevention, and the general risk assessment and management of environmental health hazards.

Environmental Health is indexed in Ulrich's Periodicals Directory, the Australasian Medical Index, PANDORA and APAIS

Aims

- To provide a link between the science and practice of environmental health, with a particular emphasis on Australia and the Asia-Pacific Region
- To promote the standing and visibility of environmental health
- To provide a forum for discussion and information exchange
- To support and inform critical discussion on environmental health in relation to Australia's diverse society
- To support and inform critical discussion on environmental health in relation to Australia's Aboriginal and Torres Strait Islander communities
- To promote quality improvement and best practice in all areas of environmental health
- To facilitate the continuing professional development of environmental health practitioners
- To encourage contributions from students

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Call for Papers

The Journal is seeking papers for publication.

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Papers can be published under any of the following content areas:

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Guest Editorials address topics of current interest. These may include Reports on current research, policy or practice issues, or on Symposia or Conferences. Editorials should be approximately 700 words in length.

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Articles under Research and Theory should be 3000-5000 words in length and can include either quantitative or qualitative research and theoretical articles. Up to six key words should be included. Name/s and affiliation/s of author/s to be included at start of paper and contact details including email address at the end.

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Reports and Reviews

Short reports of topical interest should be approximately 1500 words. Book reviews should be approximately 700 words and Review Articles should not exceed 3000 words in length.

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The Declining Environmental Health Workforce: An International Perspective on Doing Things Smarter

The International Federation of Environmental Health (IFEH) World Congress was held in Dublin in June 2006. Linked to this biennial event is an international faculty forum (IFF) where educators meet as a satellite of the Congress. The IFF convened for the first time in Scotland in the late eighties and with the exception of the Kuala Lumpur meeting, they have continued to meet at each world congress to share views and exchange information about the state of environmental Health (EH) education in the world. This year, the forum was held in the Dublin Institute of Technology (DIT) on 18 June.

The forum was extremely well organised by the host team from DIT led by Barbara Delaney and chaired by Koos Engelbricht from South Africa. The team are to be congratulated for their very professional yet friendly approach and for their legendary Irish hospitality.

There was representation from academics around the globe with particularly strong attendance from South Africa, Europe, Australasia and North America. It was particularly encouraging to see no fewer than five faculty members from Australia, perhaps reflecting an interest in the upcoming forum in Queensland in 2008.

About fifty delegates had registered interest in attending the forum and almost all came for at least part of the day-long event which combined formal presentations with a rather too brief opportunity to engage in debate on issues of current relevance to educators internationally. One item worth consideration for the Australian team who will have the task of overseeing the forum in 2008 is to consider scheduling less 'formal' individual sessions and to concentrate more on group discussion and sharing through facilitated workshops and discussion. Indeed, the informal content of the Dublin forum was so useful that a number of the group adjourned and met over lunch the following day to progress issues of interest.

Papers were given on a range of topics including meeting workforce needs, quality assurance, and educational issues such as paradigms of teaching and learning styles. Within the informal session one of the recurring themes was linking accreditation by any EH professional body to a notion of 'eligibility to practice' rather than tying it to a specific undergraduate or postgraduate qualification. It was agreed by the international educational community that a range of offerings should be acceptable for accreditation provided they meet the end point of suitability for practice as determined by the professional body. The forum then went on to discuss whether it was feasible or desirable to develop an internationally accepted accreditation process. The IFEH is keen to explore this for a range of reasons, primarily to increase mobility of graduates worldwide. This has the obvious benefit of taking qualified professionals from places of excess demand to places of greater need.

Members of the forum who were present at the discussion on the second day decided to move forward the task of determining whether it was legitimate to progress the notion of an international accreditation process by:

1. determining whether the notion was indeed educationally valid or sound;

2. summarising existing models of accreditation, including the recently developed Australian model;

3. determining whether there exist commonalities between the models which might form the basis from which to proceed.

Professor Charles (Chuck) Treser from University of Washington agreed to collate existing accreditation models around the globe and is currently progressing with this task.

The issue of workforce needs and specifically the shortage of environmental health graduates was a major focus of international debate among the academic community. Chuck Treser described the situation in the United States where 11 of 37 States currently have reported shortages of environmental health graduates; the vacancy rate for positions is 11%, turnover is at 12%, and about 1 in 4 of the current EH profession are eligible for retirement. The situation in Australia is potentially even bleaker: a recent survey by the Department of Human Services in South Australia (SA) determined that 39% of current metropolitan EHOs believed they would be working in the profession for less than five years. The survey did not determine whether this was solely due to retirement or staff moving out of the profession, however, the reasoning is largely irrelevant, the important concern is that many of these positions are not being filled due to shortages of EH graduates. The situation is even more depressing in regional areas where 46% of staff stated that they would not be working as Environmental Health Officers (EHOs) within the next five year period. The demographic of staff in rural areas might highlight part of the problem, but not the solution - 13% of staff currently employed in regional SA are over 60 and 58% are over 50 years. The 'rectangularisation' of the demographic pyramid by the baby-boomer generation is impacting on the environmental health profession in a way which might have serious longer term implications for public and environmental health, unless we are able to reverse the trend of the shortage of EH graduates very quickly.

Professor Treser from the University of Washington believes they might be beginning to develop a solution to this problem of staff shortage in the United States. In his paper at the Dublin forum he outlined a model whereby the Centers for Disease Control & Prevention, National Center for Environmental Health have recently joined with the US National Environmental Health Accreditation Council (EHAC) to promote the establishment of new organisation, the Association of Environmental Health Academic Programs (AEHAP). This organisation has been working over the past five years to:

1. increase numbers of entrants to programs
2. increase number of programs
3. expand ethnic diversity within the student body and within teaching staff
4. promote the development of staff with practical experience
5. support curriculum development.

Professor Treser claims the initial success from the CDC-funded project in that they are seeing larger numbers of students enrolling in programs, new programs are being accredited, and they have witnessed an increase in the ethnic diversity of students. Professor Treser ended his session with the comment that the: "shared vision between academics and practitioners is proving successful".

It is a model we would do well to emulate here in Australia, perhaps with financial support from the Commonwealth Department of Health and Ageing and effective strategic partnerships between state and local government health organisations and academic institutions offering accredited programs.

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Sheppeard, Morgan and Corbett contribute a trilogy of papers to this issue of *Environmental Health*, describing the outcomes of a two-phase cross-sectional survey undertaken in 1999 to identify the prevalence of principal sources of indoor air pollutants in New South Wales (NSW) homes. Methods included an initial telephone survey, and a subsequent field survey of 140 homes. Part I in this series of three papers describes the variation in potential indoor sources of pollution by region and provides summary data for indoor pollutant monitoring. Part II provides a detailed analysis of nitrogen dioxide concentrations. Part III quantifies the contribution of both common indoor and outdoor sources of particulate matter to indoor concentrations. This interesting set of papers reveals the relationship between indoor smoking, wood heaters and unflued gas appliances with levels of air pollution that might exceed established health-based air quality standards.

Nunn and Ross conducted a survey of effluent quality from Aerated Wastewater Treatment Systems (AWTS) in a rural Victorian municipality to explore compliance with permit requirements. Only one of the 21 systems sampled was compliant with EPA permit effluent water quality requirements. Findings included discovering that the presence of chlorine tablets was a major determinant of compliance with both chlorine residual and E. coli levels, and a relationship between the number of non-compliances and the number of residents in the household. It was also found that many residents had little knowledge about their AWTS and its maintenance, indicating appropriate and effective educational material is needed.

Talbot and Kent explore how an Evidence-driven Audit Cycle Model can be used to assist Quality Assurance in Environmental Health Education. This paper describes the development and pilot testing of a continuous, evidence-driven audit cycle of university course quality assurance (QA) activities for the Bachelor of Public Health (Environmental Health) program. The main outcome of this project was an evaluated, conceptual model that streamlines quality processes, and a reflective checklist that ensures the ongoing QA cycle process is continued in a timely manner regardless of staff changes or structural reorganisation. The authors recommend that other universities consider the use of such a cycle to help ensure the quality of environmental health education.

Hendrie and Bishop undertake an economic analysis of the Food Safety Program of a local Council in Western Australia. The City of Swan's food safety program was analysed, reviewing the cost of the program, revenue raised through licensing and service fees, and the cost per case of foodborne disease. The analysis also revealed a 1.2% decrease in the total annual number of cases of foodborne illness in the City of Swan. This paper reveals reasonable evidence that the food safety program in this study is a cost-effective program that provides net benefits to the community.

Monaghan et al. present a fascinating account of an integrated public health response to a major elemental mercury incident in a boarding house in Newcastle. Eighteen people were potentially exposed to elemental mercury vapour, with one individual showing blood mercury levels of 1012 nMol/L (acceptable range 0-50 nM/L). Three sites required an environmental health risk assessment including a 12 room boarding house, a private residential dwelling, and an abandoned industrial site. This served to initiate an interagency response including Hunter New England Population Health (HNEPH), Hunter New England Toxicology Service (HNETS), local government, NSW Fire Brigade Hazardous Materials Unit (HAZMAT), police, the local hospital Emergency Department, and the Ambulance Service. The HAZMAT unit also attended the site with a Public Health Physician and an Environmental Health Officer from HNEPH, and Newcastle City

Council's Environmental Protection Officer. This paper also explores the many issues faced by the public health team, including time delays, dispersion of residents, intoxication with recreational substances, apprehension towards authorities and non-compliance with treatment for exposure. The authors call for specific public health, non-occupational response protocols for responding to such incidents in Australia.

I hope you enjoy the current issue of *Environmental Health*. If you have any comments on articles published in this issue of the Journal, or on a particular environmental health issue, don't keep them to yourself, send a Letter to the Editor and let your views make a difference. We would love to hear from you! Please email your letters to journal@aieh.org.au.

For those of you who enjoyed reading Monaghan et al.'s response to a mercury incident, why not consider publishing a report on issues you have faced in the environmental health field? Help others learn from your experiences to improve the practice of environmental health. For more information on preparing articles for the Journal, please contact Jaclyn Huntley, Assistant Editor at journal@aieh.org.au.

Jim Smith
Editor

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New South Wales Indoor Air Survey: Part I Sources and Concentrations of Pollutants in Homes in New South Wales

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The three parts of this paper describe the outcomes of a two-phase cross-sectional survey undertaken in 1999 to identify the prevalence of the principal sources of indoor air pollutants in homes in New South Wales (NSW) and to quantify typical indoor pollutant concentrations. An initial telephone survey of 2036 home occupants throughout the state determined prevalence of house characteristics and indoor air pollution sources. A subsequent field survey of 140 homes drawn from ten of the 17 health regions in NSW collected particulate matter (PM_{10}), nitrogen dioxide, nicotine and formaldehyde over one week. Part I describes the variation in potential indoor sources of pollution by region and provides summary data for indoor pollutant monitoring. PM_{10} concentrations ranged from 5 - 144 μg/m^3, and were highly correlated with nicotine levels. Nitrogen dioxide ranged from 1 - 97 ppb. Formaldehyde ranged from 0.1 - 46 ppb. Part II provides a detailed analysis of nitrogen dioxide concentrations and uses multivariate regression modelling to predict indoor nitrogen dioxide concentrations based on number and use of sources, and outdoor nitrogen dioxide concentrations. Unflued gas appliances were associated with elevated levels of nitrogen dioxide in homes. Part III uses multivariate regression modelling to quantify the contribution of common indoor and outdoor sources of particulate matter to indoor PM_{10} concentrations. The main contributors to the elevated indoor particulate matter levels were smoking and wood heaters. The presence of indoor smoking, wood heaters or unflued gas appliances is associated with levels of air pollution that might exceed established health-based air quality standards. Indoor air quality also varies with local conditions.

Key words: *Indoor Air Pollution; Particulate Matter, Formaldehyde; Nitrogen Dioxide; Wood Heaters; Environmental Tobacco Smoke; Gas Appliances*

Surveys of community attitudes in New South Wales (NSW) consistently rank air pollution as one of the most important environmental issues (NSW EPA 2000). While levels of outdoor pollutants are modest by international standards, studies in the urban conurbation around Sydney have demonstrated impacts of air pollution on mortality, hospital admissions, respiratory symptoms and lung function (Jalaludin et al. 2000; Lewis et al. 1998; Morgan, Corbett & Wlodarcyzk 1998; Morgan et al. 1998).

However, residents of industrialised countries spend over 80% of their time indoors, mostly in their own homes (Lewtas 1989), and exposure to air pollutants in homes has not been assessed systematically in NSW.

Recent advances in technology have made available inexpensive, sensitive, reliable monitors for gaseous and particulate air pollutants (Ayers et al. 1999; Keywood et al. 1998). This paper describes the methods used in a population-based survey of indoor air pollutants in urban and rural NSW, and the general findings of the survey. The particular focus is on concentrations of nitrogen dioxide, formaldehyde, nicotine, and particulate matter pollution in homes, and on estimating the contribution of potential sources, such as environmental tobacco smoke, heating and cooking fuels, outdoor pollutant levels, and recent building activity, to indoor pollutant levels. The effect of potential ameliorating factors such as natural and mechanical ventilation is examined

Methods

The survey was conducted in two phases. In the first phase, telephone interviews were undertaken to determine the prevalence of potential indoor sources of pollutants. In the second phase, using a stratified sample of telephone respondents, concentrations of pollutants were measured in homes.

Phase I

Phase 1 was completed in May 1999 over a three-week period, using a computer-assisted telephone (CATI) survey of residents of New South Wales who were 18 years or older. To ensure a sufficient sample size from regional areas was available for phase 2, the sample was selected by urban and rural strata. Subjects within each stratum were selected by random digit dialling. Six hundred subjects (29%) in the sample were drawn from five rural or regional centres across NSW: Armidale (a city in the northern tablelands with cold winters), Lismore (a far north coast city with mild winters), Lithgow (a midwest city with cold winters), Tumut (a southern highlands town with cold winters), and Central Coast (a semi-rural/suburban region with temperate winters). The remaining 1436 subjects (71%), in the sample were drawn from the remainder of NSW, including Sydney.

The administered questionnaire sought details of housing type and structure, types of floor coverings, heating and cooking fuels, smoking practices, the presence of pets, and basic demographic information. Respondents were interviewed from each of the identified areas until the sample size target for that area was met.

Phase 2

Sample selection

Three hundred and three of 2036 (15%) respondents in phase 1 consented to have air quality testing performed in their homes. These subjects were stratified according to the type and number of potential pollution sources in their home.

Homes were selected for inclusion so that a range of potential pollution sources could be measured, distributed over ten areas: five regional areas and five in Sydney. Testing was undertaken between June and September 1999, which are all cold months. All homes in an area were sampled over the same week.

Indoor air sampling

Active sampling

Particulate matter with a mean aerodynamic diameter less than ten microns (PM_{10}), and gas phase nicotine were measured using a Micro-Vol© low volume aerosol sampler with a PM_{10} size selective inlet and active flow control of 3 litres/minute. Active sampling operated for one week in each home (7 days x 24 hours). Details of the active sampling method are provided in Part III.

Passive sampling

We used passive samplers based upon the well-characterised design of Ferm (Ferm 1991) to measure indoor nitrogen dioxide (NO_2) and formaldehyde. Passive gas samplers operate on the principle of molecular diffusion of a gas onto a filter coated with a sorbent species, integrated over the time of exposure. These methodologies have been previously described (Ayers et al. 1998; Gillett, Kreibich & Ayers 2000; Keywood et al. 1998). Passive sampling integrates pollutant concentrations over the time of exposure, and is usually undertaken over periods of several hours to several days. While passive sampling is a cost-effective means to obtain quite precise measurements of pollutant concentrations, the longer averaging periods do not allow direct comparison of the results to established health guideline values.

Home visits

In each home one active monitor (Micro-Vol) and four passive monitors were deployed. The Micro-Vol was placed in the living area of the house. Passive samplers for nitrogen dioxide and formaldehyde were placed on a horizontal surface 0.5 - 2 metres above the floor in the living room. One nitrogen dioxide sampler was also placed in a bedroom, and one was placed immediately outside the home in a suitable location protected from rain.

During the initial home visit details of house structure and appliances were recorded. The participants were asked to complete a daily diary of times when heating and cooking appliances were used, cleaning activities undertaken, and time spent in the home. The proximity to major roads was also recorded. Road traffic volumes were obtained from the Roads and Traffic Authority (RTA 1996) in Sydney or from local councils in regional areas. At the return home visit, one week later, evidence of any power disruption to the Micro-Vol was noted, and all filters were collected and sealed in individual containers.

All filters were analysed by the CSIRO Division of Atmospheric Research. The exposure characteristics of the homes were not provided to CSIRO with the filters so that they were tested blind.

In some homes, further testing was undertaken to demonstrate the repeatability of the sampling method. This included repeat deployment of filters in a subsequent week in six homes.

Analysis

Prevalence rates of sources and household characteristics reported in the telephone survey are reported as unadjusted percentages from the sample.

To investigate the role of house age and changes in building practices over time on indoor air quality, the house age was categorised as built before 1920, 1920 - 1949, 1950 - 1969, 1970 - 1989, and from 1990 on. The quantity of cigarettes smoked was calculated for each house from the daily number of cigarettes reported smoked by residents, adjusted by waking hours spent in the house. Proximity to a busy road was tested for both self-reported and investigator-confirmed location of the home within 50 metres of a road with over 20,000 vehicles per day.

The data were log transformed to normalise the distribution of variables, and geometric means were calculated when appropriate. Rates of housing characteristics were compared by the chi-squared test. Differences in pollution levels between exposure categories were assessed by t-test or ANOVA. Multiple regression analysis was undertaken to model the relationships between pollution sources and housing characteristics and measured levels of air pollution. Explanatory variables were retained in a model if significant ($P < 0.05$) or if their inclusion improved the predictive accuracy of the model. Data were analysed using Microsoft©Excel 97 and SAS v6.12 for Windows (SAS Institute, Cary NC).

Australian Bureau of Meteorology data were obtained from the nearest station. Australian Bureau of Statistics 1996 Census data were accessed via HOIST (Churches, Indig & Lim 1998).

Results

Telephone survey

Residents of 2036 homes were interviewed, a 25% response rate. Reasons for not being included in the telephone interview were refusals (37%), no answer, or answering machine only after five calls (17%), disconnection or suitable respondent not available (12%), business or fax number (2%), and no English spoken (1%). There was no significant difference in the response rates between regions.

There were some important differences between regions: house age varied significantly, from 6% prevalence of pre-1950 dwellings in the Central Coast to 56% in Lithgow ($P < 0.001$). Homes were mainly built with double brick in Lithgow (40%), brick veneer in the Central Coast (54%), Armidale (43%) and Tumut (35%), and timber in Lismore (55%) ($P < 0.01$). Rates of home ownership and type of residence were similar from region to region.

The subset of homes selected for indoor air monitoring was of a similar age to the full sample, but less likely to be freestanding. More of these homes were constructed of double brick (39%), and had wood window frames (36%) than in the complete telephone sample (23% and 24% respectively), though the rate of fixed ventilation in the walls was similar (53%).

Prevalence of potential indoor air pollution sources

The prevalence of indoor air pollution sources is shown in Table 1 for NSW as a whole, and according to the five regions targeted outside Sydney. The number of households in these sampling regions is estimated from Australian Bureau of Statistics 1996 census data.

Long term climate summaries for each location are also reported in Table 1 (Bureau of Meteorology). During the monitoring week, daily temperature ranges varied from 2 - 12 °C in Armidale to 9 - 16 °C in Sydney and the Central Coast. Rainfall was minimal except for 56mm in Lismore and 89mm on the Central Coast.

Validation of telephone survey

Some questions in the telephone survey were repeated in the home visit. Responses to these questions were compared to obtain a measure of validity of the telephone questionnaire. Questions about cooking and heating fuel, house structure, and smoking

Table 1: Prevalence of indoor pollution sources by region, NSW 1999 (with 95% CI for NSW and significantly different regions)

	New South Wales	Armidale	Central Coast	Lismore	Lithgow	Tumut
Households in region:	2,174,919	8,204	100,323	16 372	5 575	918
Sample N=	2036	110	160	110	110	110
Smoking indoors[1]	24% (22 - 26%)	19% (12 - 26%)	25%	13% (7 - 19%)	34% (25 - 42%)	28%
Gas cooking	25% (23 - 27%)	16%	23%	19%	49% (40 - 58%)	15%
Gas heating[2]	27% (25 - 29%)	20%	26%	15% (8 - 21%)	54%[4] (45 - 64%)	28%
Unflued gas heating[2]	19% (17 - 20%)	15%	23%	11%	16%	21%
Solid fuel heating[2]	27% (25 - 29%)	54% (45 - 64%)	9% (5 - 14%)	17%	15%[4]	48%
Wall-to-wall carpet - living areas	82% (80 - 84%)	85%	84%	86%	92%	84%
New furnishings[3]	61% (59 - 63%)	66%	63%	52%	59%	65%
Pets indoors	40% (38 - 42%)	42%	42%	23%	45%	36%
temperature range July (°C)		0.4 - 12	4 - 17	6.5 - 20	0.6 - 10	0.8 - 12.5
July rainfall (mm)		43	54	53	55	91

Notes:

1. Reported as "people occasionally, or frequently smoke in the house".

2. Reported as "usual way to heat the living area".

3. Reported as either renovating kitchen or bathroom, house extension, purchase of new upholstered furniture, new furniture from wood products, or new carpet within last 2 years.

4. The unexpected heating preference for flued gas over slow combustion/open fires in Lithgow was investigated by follow-up discussions with Lithgow Council. Most Lithgow homes were previously heated centrally by external coal boilers. Programs to reduce pollution from coal boilers have converted many of these units to gas or wood burning.

in the house, had a high sensitivity (80 - 98%). Questions related to the means of exhausting air from the kitchen and the practice of opening windows when heating had lower sensitivity (71% and 78% respectively). In homes where gas was the primary source of heating, only 67% of those reporting flued appliances in the telephone survey had a flued appliance.

Activity patterns

Hours spent in the house were reported for 359 people from 130 of the 140 houses surveyed. Number of occupants in homes ranged from 1 - 6, with an average of 2.8 residents per home. Averaged over a week the mean time spent in the home was 15.7 hours per day, with a minimum of 8.2 hours, and a maximum of 23 hours.

The use of heating and cooking appliances varied by region, with the highest use in Armidale (median of 0.5 hours each for cooktop and oven, 9.6 hours for primary heater), and the lowest use in Lismore (0.3 hours for cooktop, 0.0 hours for oven, and 1.7 hours for heating). In the homes where smoking occurred, the median number of cigarettes smoked indoors in the week was 110. Details of the range of time spent in home activities are given in Table 2.

Cleaning activities were reported in 132 homes. The most frequent pattern for dusting or vacuuming and sweeping was weekly (79 and 31 homes), with 8 homes reporting daily dusting or vacuuming, and 8 homes reporting no dusting or vacuuming during the study week.

Table 2: Range of reported activities from daily diary, NSW 1999

	Minimum	1st quartile	Median	3rd quartile	Maximum
Cooktop (hours/day)	0	0.2	0.4	0.7	2
Oven (hours/day)	0	0	0.3	0.5	1.5
Primary heater (hours/day)	0	1.7	4.3	6.6	24
Number of cigarettes smoked in house/week*	4	54	110	208	406

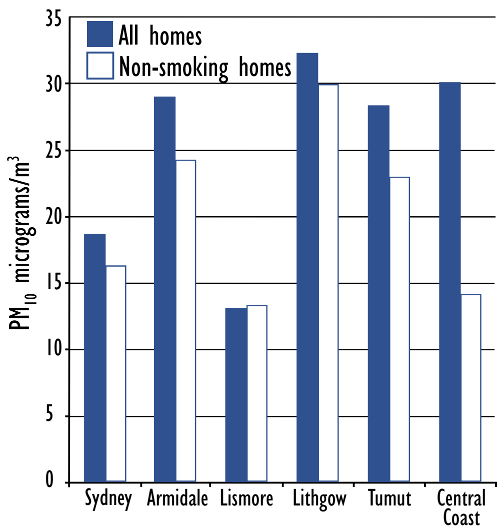
Note: * in houses where smoking occurred.

Air pollution monitoring

PM_{10} levels

PM_{10} levels were measured in 136 homes. Missing results were due to filter or equipment malfunction. The median weekly PM_{10} level was 24.3 µg/m³ with a range from 5.4 - 143.8 µg/m³. In homes without smoking indoors the median PM_{10} was 22.7 µg/m³, with a range from 5.4 to 68.4 µg/m³. Levels varied significantly between regions, with the highest PM_{10} concentrations measured in regions where the use of solid fuel heaters was most prevalent (Figure 1). Fine particle concentrations were highest in Lithgow, where coal is still used for heating some homes. Homes where smoking occurred indoors had the highest PM_{10} concentrations, ranging from 11.3 - 143.8 µg/m³, with a median of 70.1 µg/m³. In Lismore there was only one home where the respondent reported that people usually smoked indoors. This home had PM_{10} levels very similar to other Lismore homes. Other measures of smoking in this home, such as nicotine levels and reported number of cigarettes indicated that very little smoking had occurred indoors.

Figure 1: Mean winter indoor PM_{10} concentrations by region, NSW 1999



Nitrogen dioxide levels

Nitrogen dioxide was measured in 140 living areas, 139 bedrooms and 137 outdoor locations. Locations with missing results were due to loss of the filters. The geometric mean for all living area samples was 9.1 ppb, with a range from 1.04 to 96.5 ppb. The geometric mean in bedrooms was 8.0 ppb, and was 9.3 ppb outdoors. Nitrogen dioxide levels measured in living areas of homes where a gas appliance was used were significantly higher than where no gas appliance was used (15.5 ppb compared to 5.6 ppb). In homes where no gas appliances were used, there was no significant difference between living area and bedroom measurements (5.6 ppb and 5.4 ppb respectively), and both were around 60% of the average outdoor level of 8.5 ppb (Table 3). In univariate analysis, neither the presence of smoking nor solid fuel heaters had an impact on indoor nitrogen dioxide levels.

Outdoor concentrations of nitrogen dioxide measured at each home varied significantly by region, with the highest levels found in Central and Northern Sydney (geometric mean 16.4 and 15.5 ppb respectively) and the lowest found in Tumut and Lismore (geometric mean 2.6 and 3.5 ppb respectively).

Formaldehyde

Results of formaldehyde levels were available from 139 living areas. The median level was 3.35 ppb (range 0.13 to 46.17ppb).

Table 3: Geometric mean winter nitrogen dioxide (ppb) by location and indoor source, NSW 1999

	Living area (ppb)	Bedroom (ppb)	Outdoors (ppb)
All homes (N=140)	9.1	8.0	9.3
Homes with no gas use (N = 73)	5.6[2]	5.4	8.5[3]
Homes with gas use (N = 67)	15.5[1,2]	12.2[1]	10.3[3]

1. P < 0.01 for paired t-test. For homes with no gas use, there was no difference between living area and bedroom levels (P>0.3).
2. P = 0.0001
3. P = 0.09

Geometric mean levels of formaldehyde varied significantly between regions, with house age and type of construction, and type of heating (Table 4). There was also a significant difference in formaldehyde levels between homes with fixed vents in the walls and those without (geometric means 2.78ppb and 4.18ppb respectively, P = 0.02). Homes that reported "usually opening windows when heating" had lower mean formaldehyde levels (2.18ppb) than those reporting "sometimes opening windows" (2.74ppb) and than those reporting "never opening windows" (4.39ppb) (ANOVA p = 0.009).

In univariate analysis the following variables did not have a significant effect on formaldehyde: painting within the last year, purchase of new furniture within the past two years, renovations to the house within the past two years, quantity of cigarettes smoked, or type of dwelling.

In multivariate analysis, 36% of the variability in formaldehyde concentration was explained by the duration of exposure to unflued gas heating, age of the house, type of construction, presence of wall vents, habit of opening windows when using heater, geographic region, painting in the past year and quantity of cigarettes smoked, with heating, ventilation and type of construction being the main determinants. The duration of exposure to wood heaters was not significant in predicting formaldehyde concentrations.

Nicotine levels

Nicotine levels were detected in 89 living areas. Levels in the remaining homes were below the detection limit. The geometric mean was 0.065μg/m^3 (range 0.001μg/m^3 to 11.38μg/m^3). Nicotine levels varied significantly with all measures of smoking used (see Table 5). Nicotine levels also varied with PM_{10} levels measured in the home.

Repeatability

In the six homes where repeat monitoring was undertaken, there was no significant difference between the results for the two

Table 4: Selected geometric mean formaldehyde concentrations (ppb), NSW 1999

Construction		House Age		Region		Primary heater type	
Full brick	2.64	Pre 1920	2.16	Tumut	5.37	Unflued gas	5.78
Brick veneer	4.62	1920 - 1950	3.92	Armidale	3.72	Electric	2.94
Timber	2.08	1970 - 1990	3.32	Lismore	1.70	Wood	3.15
Asbestos cement	3.95	Post 1990	4.70	Central Sydney	2.17		
				South West Sydney	4.23		

Table 5: Geometric mean nicotine concentrations (μg/m³ with 10 & 90%ile) by smoking indicators, NSW 1999

Telephone response re indoor smoking:		Number of indoor smokers reported:		Reported quantity of cigarettes smoked indoors:	
Never	0.015 (0 - 0.053)	0	0.015 (0 - 0.032)	0	0.019 (0 - 0.064)
Occasional	0.48 (0 - 2.73)	1	0.80 (0.074 - 4.14)	1-69	0.94 (0.086 - 4.14)
Frequent	1.43 (0.12 - 9.79)	2	3.53 (1.10 - 5.73)	70-139	1.68 (0.074 - 5.42)
		3	10.25 (8.75 - 11.38)	140	1.92 (0.016 - 11.38)

weeks by paired t-test, with a high correlation between the two sets of results (PM_{10} R = 0.72, nitrogen dioxide R = 0.86, 0.94 and 0.96, formaldehyde R= 0.93, nicotine R = 0.8).

Discussion

The prevalence of common indoor air pollution sources in New South Wales' homes has been estimated and quantified for the impact on indoor air quality. The prevalence of pollution sources in our study has been affected by the sampling frame used, and by limiting 30% of the survey to targeted regions. The representativeness of the findings for NSW as a whole is also limited by the relatively low response rate in the initial telephone survey. However, the prevalence of the use of heating and cooking fuel reported in the study is not significantly different from that reported in a large recent random telephone survey of NSW residents (Centre for Epidemiology and Research, 2003). ABS data also demonstrate similar rates for NSW (Australian Bureau of Statistics, 2002). Further, it is probably more appropriate to consider prevalence rates of indoor pollutants on a regional basis, as they differ significantly between regions, depending on climatic and other local determinants. Regions could undertake further studies to characterise local risks to indoor air quality.

With the exception of occupants being able to distinguish between flued and unflued gas heating, and the means of venting air from cooking, most house characteristics and pollutant sources were reported validly by occupants during the telephone interview as confirmed by observations in their homes.

The study sample of NSW residents spent 65% of the week in their own homes. This is higher than previously published data reported by residents in the United States (Lewtas 1989), which indicated that they spent 47% of their time indoors at home, with a total proportion of time spent indoors of 82%. This might be explained by seasonal variation, as this study only considered the winter months or might arise from bias in the population sample selected. However, it is likely that Australians might also have different time-activity patterns than US residents. To estimate better the risk of exposure to indoor air pollution, further studies are required to determine where Australians spend their time.

This study demonstrated that indoor air quality can be measured reliably with inexpensive monitors, given that the measurements were repeatable in different weeks, and small gradients in indoor concentrations were detected, such as between living areas and bedrooms in homes using gas appliances. The rate of equipment failure or loss was very low, and no residents withdrew from the study because of disruption or inconvenience from the monitors.

Many studies have shown health effects associated with increases in ambient PM_{10} levels (Dockery & Pope 1994; Morgan et al. 1998), with no minimum threshold for this effect. We have demonstrated that the presence of smoking in a home is associated with increased PM_{10} levels. We have also demonstrated that an increased prevalence of the use of solid fuel heaters in a region is associated with elevated mean indoor levels of PM_{10} in that region, even for houses without solid fuel heaters. This is consistent with the ready penetration of ambient particulate matter indoors.

Nitrogen dioxide is associated with increased respiratory morbidity, especially among people with asthma (Morgan, Corbett & Wlodarcyzk 1998). Pilotto et al. demonstrated that children exposed to levels of nitrogen dioxide over 40 ppb averaged over periods of the use of gas appliances (several hours) had increased respiratory symptoms and days absent from school (Pilotto et al. 1997). The study averaged nitrogen dioxide levels over one week. The weekly mean averages out higher levels of nitrogen dioxide that may have been present during the time that gas appliances were in use. In homes where there were no gas appliances, ambient nitrogen dioxide was the predominant determinant of indoor nitrogen dioxide exposure.

The study detected significant changes in formaldehyde levels related to the age of the home, amount of cigarettes smoked, ventilation and use of unflued gas heating. Overall, however, formaldehyde concentrations appear to have decreased from the levels detected using a similar method averaged over 24 hours in homes in 1988 (28.9 ppb down to 3.8 ppb) (McPhail 1991). The decrease in formaldehyde levels might be attributable to changes in manufacturing processes to result in lower formaldehyde emissions from products since McPhail's study. Our study also reproduced the findings of a UK study by showing an inverse relationship between formaldehyde and home age (CRC 1996).

The study has demonstrated that active sampling is able to detect nicotine down to levels attributable to degassing from clothing in homes where smoking does not occur. The levels detected in some non-smoking homes are comparable to the 7.5 nanograms (8-hr time-weighted-average) level proposed by Repace as corresponding to a 1 in 1,000,000 increased risk of lung cancer due to exposure to environmental tobacco smoke (Repace & Lowrey 1993).

Australia does not currently have indoor standards for air pollutants. The World Health Organization (WHO) provides some guidelines, however, none of the pollutants studied have a weekly averaged guideline value for comparison (WHO 2000). Thus while the sampling methods we used were suitable for comparing the impact of sources on indoor air pollution in a large sample of homes, they are not as useful for undertaking health risk assessment of the pollutants measured.

Conclusion

The study measured several common indoor air pollutants in homes with inexpensive monitoring devices. Homes where these pollutants are likely to be elevated can be predicted by assessing the location of the home and the presence of indoor sources. It is concluded that the use of unflued gas appliances, solid fuel heating, or smoking cigarettes indoors, results in significant elevations of pollutant levels in some New South Wales homes.

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References

Australian Bureau of Statistics (ABS) 2002, *Australia Now - Environmental Issues: People's Views and Practices*, Cat. No. 4602.0 Canberra, ACT, Australian Bureau of Statistics, <http://www.abs.gov.au> July 2004.

Ayers, G.P., Keywood, M.D., Gillett, R.W., Manins, P.C., Malfroy, H. & Bardsley, T. 1998, 'Validation of passive diffusion samplers for SO_2 and NO_2', *Atmospheric Environment*, vol. 32, pp. 3587-92.

Ayers, G.P., Baruch, R., Keywood, M.D. & Gillett, R.W. 1999, 'Indoor air quality: A pilot study employing low-technology methods', *Clean Air*, vol. 33, pp. 29-33.

Bureau of Meteorology, Climate Averages for Australian Sites, <http://www.bom.gov.au/climate/averages/tables/ca_nsw_names.shtml>

Centre for Epidemiology and Research, NSW Department of Health 2003, 'New South Wales Adult Health Survey 2002', *NSW Public Health Bulletin*; vol. 14, Suppl. 4.

Churches, T., Indig, D., Lim, K. 1998, *Health Outcomes and Statistical Information Toolkit (HOIST)*, Epidemiology Branch, NSW Department of Health, Sydney.

CRC Ltd 1996, *Indoor Air Quality in Homes 1996*, The BRE indoor environment study, CRC Ltd, London.

Dockery, D.W. & Pope, C.A. 1994, 'Acute respiratory effects of particulate air pollution', *Annual Review of Public Health*, vol. 15, pp. 107-132.

Ferm, M. 1991, 'A sensitive diffusional sampler', Report to the Swedish Environmental Research Institute B-1020, Stockholm.

Gillett, R.W., Kreibich, H. & Ayers, G.P. 2000, 'Measurement of indoor formaldehyde concentrations with a passive sampler', *Environment Science and Technology*, vol. 34, pp. 2051-56.

Jalaludin, B., Chey, T., O'Toole, B., Smith, W. & Leeder, S. 2000, 'Acute effects of bushfires on peak expiratory flow rates in children with wheeze: A time series analysis', *Australian & New Zealand Journal of Public Health*, vol. 24, pp. 174-7.

Keywood, M.D., Beer, T., Ayers, G.P., Gillett, R.W. & Kreibich, H. 1998, 'The use of passive gas samplers to monitor personal exposure', *Clean Air*, vol. 32, pp. 32-36.

Lewis, P.R., Hensley, M.J., Wlodarcyzk, J., Toneguzzi, R.C., Westley-Wise, V.J., Dunn, T. & Calvert, D. 1998, 'Outdoor air pollution and children's respiratory symptoms in the steel cities of New South Wales', *Medical Journal of Australia*, vol. 169, pp. 459-63.

Lewtas, J. 1989, 'Toxicology of complex mixtures of indoor pollutants', *Annual Review of Pharmacology & Toxicology*, vol. 29, pp. 415-39.

McPhail, S. 'Formaldehyde in homes', *Journal of Occupational Health and Safety*, vol. 7, pp. 139-44.

Morgan, G., Corbett, C., Wlodarcyzk, J. & Lewis, P. 1998, 'Air pollution and daily mortality in Sydney, Australia, 1989 through 1993', *American Journal of Public Health*, vol. 88, pp. 759-64.

Morgan, G., Corbett, C. & Wlodarcyzk, J. 1998, 'Air Pollution and hospital admissions in Sydney, Australia, 1990 to 1994', *American Journal of Public Health*, vol. 88, pp.1761-66.

NSW EPA 2000, *Who Cares About the Environment?* New South Wales Environment Protection Authority, Social Research Series, Sydney South, NSW.

Pilotto, L.S., Douglas, R.M., Attewell, R.G. & Wilson, S.R. 1997, 'Respiratory effects associated with indoor nitrogen dioxide exposure in children', *International Journal of Epidemiology*, vol. 26, pp. 788-96.

Repace, J.L., Lowrey, A.H. 1993, 'An enforceable indoor air quality standard for environmental tobacco smoke in the workplace', *Risk Analysis*, vol. 13, pp. 463-75.

RTA 1996, *Traffic Volume Data for Sydney Region 1996*, Roads and Traffic Authority of NSW, Roseberry, NSW.

World Health Organization 2000, *WHO Air Quality Guidelines*, Copenhagen, DK, WHO-Regional Office for Europe.

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New South Wales Indoor Air Survey: Part II Concentrations of Nitrogen Dioxide in Homes in New South Wales

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The three parts of this paper describe the outcomes of a two-phase cross-sectional survey undertaken in 1999 to identify the prevalence of the principal sources of indoor air pollutants in homes in New South Wales (NSW) and to quantify typical indoor pollutant concentrations. An initial telephone survey of 2036 home occupants throughout the state determined the prevalence of house characteristics and indoor air pollution sources. A subsequent field survey of 140 homes drawn from ten of the 17 health regions in NSW collected particulate matter (PM_{10}), nitrogen dioxide, nicotine and formaldehyde over one week. Part II provides a detailed analysis of nitrogen dioxide concentrations and uses multivariate regression modelling to predict indoor nitrogen dioxide concentrations based on number and use of sources, and outdoor nitrogen dioxide concentrations. Unflued gas appliances were associated with elevated levels of nitrogen dioxide in homes.

Key words: *Indoor Air Pollution; Nitrogen Dioxide; Gas Appliances*

Exposure to nitrogen dioxide is associated with increased respiratory symptoms, particularly in children (Neas et al. 1991; Pilotto et al. 1997). Ecological studies linking nitrogen dioxide with respiratory disease have been based on measurements of ambient nitrogen dioxide (Brauer et al. 2002; Hajat et al. 1999; Morgan, Corbett & Wlodarczyk 1998; Morgan et al. 1998). However, in homes where gas appliances are used, nitrogen dioxide levels can be much higher than ambient levels of nitrogen dioxide (Garrett et al. 1999; Levy et al. 1998). Recently, it has been demonstrated that nitrogen dioxide levels in homes where unflued gas heaters were operating averaged ten times the levels recorded outdoors (AWN Consultants and Team Ferrari 2004).

As part of the New South Wales Indoor Air Survey nitrogen dioxide levels were measured inside and outside 140 homes. Appliance use, and other household factors potentially affecting indoor air pollution, were recorded. This paper details findings of nitrogen dioxide levels in New South Wales' homes measured during winter 1999, and provides a method to estimate exposure to nitrogen dioxide based on level of use of indoor sources and ambient levels.

Methods

The methodology of the New South Wales Indoor Air Survey is reported in detail in Part I in this issue of *Environmental Health* (Sheppeard, Morgan & Corbett 2006). Briefly, a telephone survey of 2036 randomly selected households assessed the prevalence of housing types and indoor sources of various air pollutants. One hundred and forty homes were selected for indoor monitoring of pollutants, 90 in the five Sydney health regions and 50 in five of the twelve other health regions of the state. Each home had air pollutants sampled for one week during winter 1999. Residents also completed daily diaries of use of heating and cooking appliances, and questionnaires related to practices of smoking, opening windows, use of kitchen exhausts, and house structure.

Home monitoring

Three nitrogen dioxide (NO_2) passive samplers were deployed at each home, one in the living area, one in a bedroom and one immediately outside the front door, or in a similar protected outdoor position. The samplers were left in place for one week.

The NO_2 passive samplers used are based upon the well-characterised design of Ferm (Ferm 1991) as discussed in detail by Keywood et al. and Ayers et al. (Ayers et al. 1998; Keywood et al. 1998). Passive gas samplers operate on the principle of molecular diffusion, the gas of interest being collected on a filter coated with a sorbent species, integrated over the time of exposure. The passive samplers consist of a short squat tube with a collection medium (chemically impregnated filter) at one end. The other end is exposed to the atmosphere, with a porous cover that ensures a well-defined diffusion length.

Quantitative operation of these samplers for NO_2 under Australian conditions is shown in Ayers et al. (Ayers et al. 1998). The use of NO_2 passive samplers in the indoor environment is demonstrated in Keywood et al. and Ayers et al. (Ayers et al. 1999; Keywood et al. 1998). Filters were analysed using a UV-VIS Varian Techtron Spectrophotometer (Model 635) at 540 nm, and the concentration of NO_2 determined.

The reproducibility of the NO_2 passive sampler measurement is 5-10% (Ayers et al. 1998) and blank concentrations of 3% ± 0.5 % of average values measured in this study were determined by subjecting passive samplers to all filter handling procedures and exposing for one minute. The NO_2 concentrations reported are corrected for the blank contribution.

Ambient monitoring

The New South Wales Department of Environment and Conservation (DEC) routinely records hourly levels of NO_2 using chemiluminescent monitoring at 18 sites located around Sydney (NSW DEC 2004). The DEC provided these routine measurements, which were converted to mean weekly levels corresponding to the monitoring weeks of the survey. Households were allocated the level of nitrogen dioxide measured at their closest station, or in the case of houses located midway between stations, a mean of the applicable levels. The nearest monitoring site was required to have valid readings for at least 80% of the time over at least four days of the corresponding indoor monitoring period for an ambient weekly mean to be calculated.

Weather data

Meteorological observations were obtained from the Bureau of Meteorology automatic weather station at Homebush, a location geographically near the centre of Sydney. Three-hourly measures of temperature, humidity, wind speed, wind direction and rainfall were available for all except one of the monitoring days during the two months that home monitoring occurred in Sydney. Daily minimum, maximum and mean were calculated, and then weekly minima, maxima and means were calculated for each starting date of monitoring.

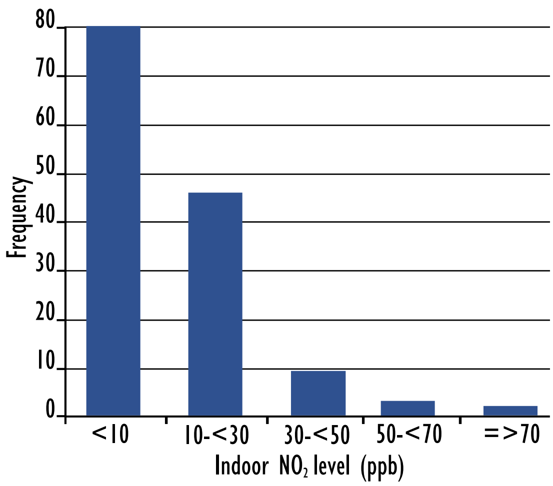
Analysis

Variables were log transformed to normalise their distribution when appropriate, and geometric means were calculated. Differences in nitrogen dioxide levels between exposure categories were assessed by ANOVA or t-test. Multiple regression analysis with stepwise elimination was used to model the relationships between pollution sources and indoor nitrogen dioxide levels. When examining the effect of ambient NO_2 and weather on indoor NO_2 only the subset of 90 homes from Sydney was used. Data were analysed using SASv6.12 (SAS Institute, Cary NC) for Windows.

Results

Nitrogen dioxide levels were measured in the living areas of all 140 homes studied, 139 of the bedrooms and 137 outdoor locations. Missing results were due to loss of some filters during the week of exposure. Nitrogen dioxide averaged over one week ranged from 1 -97ppb. Due to the skewed distribution of indoor levels, geometric means were calculated. The week-averaged geometric mean was 9.1 ppb for all living area samples, 8.0 ppb for bedrooms and 9.3 ppb outdoors. In homes where no gas appliances were used, there was no significant difference between living area and bedroom levels (5.65 and 5.45 ppb respectively, $P > 0.3$). The distribution of homes by NO_2 measured in living areas is shown in Figure 1.

Figure 1: Number of homes by average weekly indoor nitrogen dioxide level (ppb), NSW 1999



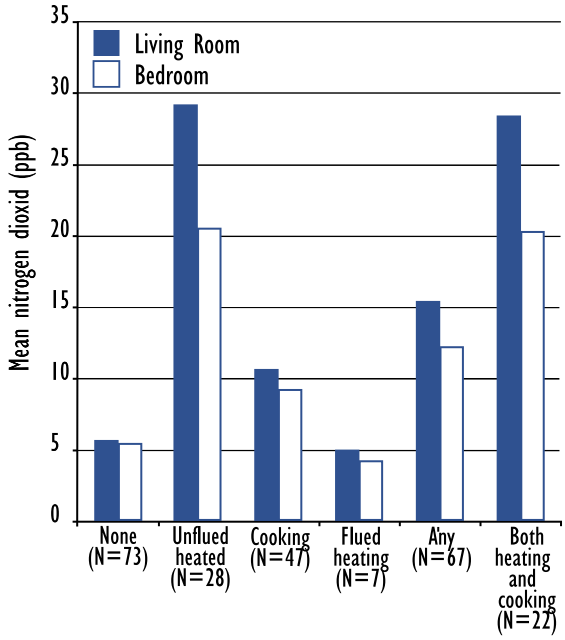
Indoor nitrogen dioxide levels

Homes where gas appliances were not used had indoor living area levels of NO_2 significantly lower than those where gas appliances were used (5.6 and 15.5 ppb in living areas respectively, P=0.0001). The presence of smoking indoors or the use of solid fuel heaters did not affect mean indoor NO_2 levels.

The average weekly NO_2 level by use of gas appliances is shown in Figure 2. The use of any gas appliance except for flued heating alone resulted in a significant increase in average weekly NO_2 compared to homes with no use of gas appliances. Homes that used unflued gas heating were recontacted to determine the age and brand of the heater. There was no correlation between these factors and NO_2 level.

In univariate analysis, the following variables were also significantly related to indoor living area NO_2 levels: living within 50 metres of a road with more than 20,000 vehicles per day, the region where the house is located, and measured level of outside nitrogen dioxide.

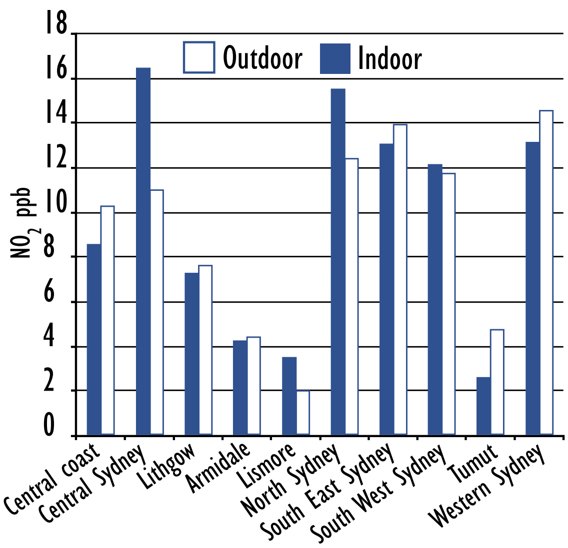
Figure 2: Unadjusted weekly indoor nitrogen dioxide by gas appliance use, NSW 1999



Outdoor and ambient nitrogen dioxide

Outdoor NO_2 concentrations measured immediately outside each home also varied significantly by region, ranging from 2 - 26ppb averaged over a week. Generally, levels were higher in Sydney areas than in regional centres (Figure 3). For homes within 50 metres of a busy road, the outdoor NO_2 was significantly higher than those further away, even when only homes in Sydney were considered (15.8 and 13.4ppb respectively, P=0.04). Outdoor levels also varied significantly by the assigned DEC monitoring site.

Figure 3: Mean nitrogen dioxide levels by region, NSW 1999



Ambient levels of NO_2 (measured at a DEC site) were available for 86 of the 87 Sydney homes in the study. Ambient levels varied from 8.9ppb to 23.6ppb, with a mean of 16.4ppb. Assigned ambient levels were correlated with actual outdoor measurements (R = 0.54, P=0.0001). In univariate analysis, assigned ambient levels predicted 29% of outdoor measures. In multivariate analysis, 42% of outdoor concentration was predicted using assigned ambient NO_2 level, self-reported proximity to a busy road, and average weekly minimum temperature (Table 1).

Weather effects

Minimum temperatures were inversely correlated with indoor measures of NO_2, but this correlation did not persist when homes using unflued gas heating were excluded. Maximum and mean temperatures were inversely correlated with outdoor levels of NO_2. All measures of temperature were inversely correlated with the reported hours of using heating.

Winds from the north or northwest tended to be associated with lower levels of ambient NO_2. Winds from the south were correlated with increased heater use, increased outdoor NO_2, and lower temperatures. Wind speed, humidity and rainfall were not correlated with any measures of NO_2.

Table 1: Multiple regression model predicting outdoor nitrogen dioxide (ppb) levels at Sydney homes, 1999

	Parameter Estimate	SE	P
Intercept	11.25	2.41	
Ambient NO_2 (pphm)	5.42	0.84	0.0001
Proximity to a busy road	1.14	0.62	0.07
Average min temperature (°C)	-0.68	0.25	0.007

Multiple regression modelling of indoor nitrogen dioxide

Several models predicting indoor levels of NO_2 were developed. The best model explained 87% of the variability of living area NO_2 levels and included both Sydney and regional home data. Only variables that were significant were retained in the model, except for type of kitchen exhaust, which was of borderline significance (p= 0.08), but when excluded, increased the standard error of the model. The other variables retained were: outdoor NO_2 level, hours of use gas cooking per day, hours of use unflued gas heating per day, quantity of cigarettes smoked indoors during the week, type of heater, region, type of oven, and age group of home, as well as the interaction variable of gas heating and house age. Variables accounting for type of water heater, presence of wall vents, reported habit of opening windows, housing type and structure or proximity to busy roads were not significant in predicting living area NO_2 levels.

Table 2: Predicted indoor nitrogen dioxide (ppb) by outdoor concentration and use of gas appliances

Outdoor NO_2	No gas appliance	1 hr unflued heating	4 hrs unflued heating	4 hrs flued heating	1 hr cooking	4 hrs unflued heating + 1 hr cooking	4 hrs unflued heating + 1 hr cooking + 1 hr oven
10	6.78	8.16	14.19	8.12	10.71	22.39	32.09
20	11.28	13.57	23.59	13.48	17.79	37.21	53.34
30	15.18	18.26	31.75	18.16	23.95	50.01	71.79

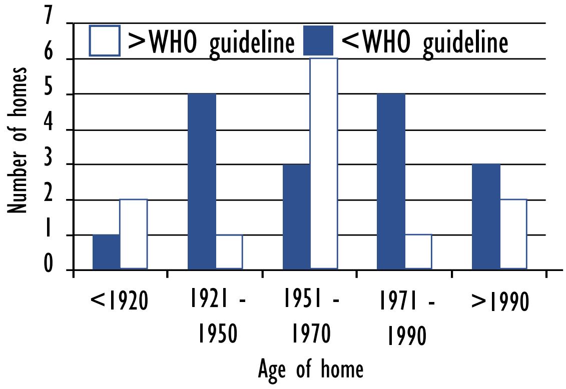
The addition of three significant meteorological variables (rainfall, wind direction and wind speed) to the subset of homes in metropolitan Sydney increased the predictive value of the model in this subset by around 4% to 84%.

A simpler predictive model for weekly average indoor nitrogen dioxide levels based on known outdoor levels and presence of significant indoor sources was also developed.[1] This resulted in a model explaining 72% of the variability of living area NO_2 levels. Table 2 shows predicted living area nitrogen dioxide levels by outdoor level and use of gas appliances, where no cigarettes are smoked.

Estimation of NO_2 concentrations during heater use

The best model was used to estimate the contribution of gas heating to indoor weekly average NO_2 concentrations by calculating the difference between living area NO_2 levels for the homes using gas heating and living area NO_2 level for these homes by substituting model-derived values for electric heating (values for six homes could not be derived due to missing values). A one-hour averaged NO_2 level during appliance use was calculated by correcting this contribution for the reported time that gas heating was used, and adding it to the predicted electric heating level. From these calculations the number of homes that may have exceeded the WHO 1-hour guideline for nitrogen dioxide exposure (WHO 2000) during gas heater use was estimated (Figure 4). Among the homes using unflued gas heating, 50% were predicted to have NO_2 levels above the WHO guideline. The calculated 1-hour levels of NO_2 varied from 5.5 - 44.9ppb for flued gas heating, and 19.6 - 291ppb for unflued gas heating, with median values of 24 and 112ppb respectively.

Figure 4: Estimated peak nitrogen dioxide levels in homes with gas heating by age of home, NSW 1999



Discussion

In general, levels of nitrogen dioxide in New South Wales' homes were low. This exposure varies principally with known indoor sources of nitrogen dioxide, and this paper presents several models that are highly predictive of this variability. The weekly averaged levels are consistent with another passive monitoring study conducted in Australia where concentrations were averaged over four days on five occasions during a year (Garrett et al. 1999). Garrett et al. found an average concentration of 3.5 ppb in homes with no sources of nitrogen dioxide and 13.5 ppb in homes with multiple sources of nitrogen dioxide in Victorian homes (compared to 5.6 ppb and 15.5 ppb in this study). In the Northern hemisphere Cyrys et al. monitored nitrogen dioxide concentrations in German homes averaged over two days and found an average concentration of 8ppb, and that homes with gas cooking had substantially higher concentrations (41%) (Cyrys et al. 2000). Levy et al. found that indoor nitrogen dioxide concentrations in 'gas intensive cities' of the northern hemisphere were considerably higher than found in Australia at 31.3 ppb averaged over seven days (Levy et al.1998). The lower concentration found in Australian homes using gas appliances might reflect the relatively high ventilation rate of Australian homes.

In Australia the National Environment Protection Council has set hourly and annual standards (120 and 30ppb respectively) for NO_2 in ambient air (NEPC 1998). The measures in this study cannot be compared directly with these goals. The World Health Organization (WHO 1987) previously set an indoor air quality guideline for exposure averaged over 24-hours at 70ppb. Adjusted for the different averaging period[2], this predicts a weekly goal in the range of 47 - 49ppb, a level exceeded by 14% of homes using unflued gas heating.

The predicted 1-hour NO_2 levels during unflued gas heating use are similar to recent monitoring undertaken in 116 homes with unflued gas heating in Sydney, Melbourne and Canberra by Ferrari and AWN Consultants (AWN Consultants & Team Ferrari 2004). In the Ferrari/AWN study, monitored 1-hour average NO_2 levels exceeded the WHO guideline in 67% of homes, whereas the model estimated that 50% of the homes with unflued gas heating in this study would have exceeded this level. The model assumed constant emission rates of NO_2 during the operating hours of the heater. This probably resulted in an underestimate of peak levels, as emission rates tend to be highest during the first hour of operation. The Ferrari/AWN study also demonstrated that high levels of NO_2 could be found even with very new heaters, which is confirmed in this study. It is not clear why heaters manufactured in compliance with the Australian Standard NO_2 emission rates of 5ng/J, which have been in place since 1991, demonstrate such a wide range of performance with respect to indoor NO_2 levels (Standards Australia 2000). Taken together, these studies highlight a problem in at least three jurisdictions in Australia of nitrogen dioxide concentrations in homes using unflued gas heaters exceeding WHO guidelines. No 'low nox' emission heaters were represented in the sample so this study is unable to assess the emission performance of this type of unflued gas heater.

The study by Neas et al. assessed children's respiratory symptoms based on average levels measured over two weeks in three seasons of a year (Neas et al. 1991). The Neas et al. study detected an odds ratio of 1.4 for lower respiratory tract symptoms for each 15 ppb increase in nitrogen dioxide over the levels in homes without major sources (8.6 ppb). In this study 11% of homes were in the range 15 -30 ppb above homes with no sources, and 3.6% in both the range 30-45 ppb above and over 45 ppb above homes with no sources.

Pilotto et al. and Garrett et al. prospectively studied symptoms in relation to measured nitrogen dioxide levels in Australian homes and schools (Garrett et al.1998; Pilotto et al.1997). Pilotto et al. assessed exposure to nitrogen dioxide averaged over time exposed to unflued heating and found increased respiratory symptoms in children exposed to over 40 ppb. Garrett et al. averaged nitrogen dioxide measures over four days and found a weak association with symptoms and measured levels. The presence of gas cooking, however, was a stronger indicator of symptoms, and perhaps represents a peak exposure that was diluted in the four-day measure.

The simplest predictive model developed in this study is easily applicable to assess indoor exposure to nitrogen dioxide in homes. Most of the variability in nitrogen dioxide is accounted for by a few factors, including hours of use of unflued gas heating, gas cooking, and outdoor level of nitrogen dioxide, which can be approximated by ambient levels measured on a regional basis. This provides an improvement to a previously developed model by Lee et al. that was only able to predict 42% of winter indoor variation (Lee et al. 1998). Lee's model included only the presence of gas appliances, not hours of use.

Some factors that might have been expected to affect indoor levels of nitrogen dioxide were found to have little or no significant effect in multivariate analysis. In the case of smoking indoors, this is probably because the production of nitrogen dioxide from combustion of a cigarette is small relative to other sources. Housing construction, fixed ventilation, or the practice of opening windows possibly have little affect due to average weekly ventilation rates being similar between houses. Alternately, relying on reporting of practice of opening windows or doors during heating might not be a good measure of actual practice. A quantitative evaluation of the effect of passively increasing room ventilation by opening widows during heating is warranted as this advice is part of risk reduction strategies for unflued gas heating. Interestingly, the age of the house was important in predicting indoor nitrogen dioxide. This might relate to aspects of house construction that were not well measured by the questionnaire, or to the age of the appliances in the home.

While proximity to a busy road was not independently significant in predicting indoor levels of nitrogen dioxide, it was highly significant in predicting measured outdoor levels. Thus the use of measured outdoor nitrogen dioxide in the predictive model for indoor levels probably accounted for the proximity of the house to a busy road.

Region where the home was located was independently important in predicting indoor levels of nitrogen dioxide, even after outside nitrogen dioxide was controlled for. As each region was studied over a different week, variables for ambient nitrogen dioxide and weather conditions were included in the model instead of outdoor nitrogen dioxide to test if this accounted for regional differences. The predictive ability of the model improved by the addition of these factors, but the region remained significant. Thus region might be accounting for differences in housing construction or appliance brand or model, not measured by the questionnaire. A similar effect of region was found by Cyrys et al. in Germany (Cyrys et al. 2000).

Conclusion

This study shows that indoor levels of nitrogen dioxide are significantly increased in homes using unflued gas heating or cooking appliances. As increases of this magnitude are associated with health impacts, further investigation of the relationship between appliance brand, age, maintenance and ventilation factors and nitrogen dioxide peak exposure is needed. The current management strategies for unflued gas appliances might need reviewing, however, any changes in the regulatory approach to gas appliances needs to be viewed in the context of regulation of nitrogen dioxide in ambient air, and economic, environmental and greenhouse costs of alternate fuel sources for heating and cooking.

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This study was funded by NSW Health. The study concept and design was developed by Rona Baruch. The cooperation and efforts of Public Health Unit Directors and Environmental Health Officers from Central Coast, Central Sydney, Northern Rivers, Western Sydney, New England, South East Sydney, Greater Murray, South West Sydney and Mid West was vital to the successful collection of air samples. We wish to thank the NSW Department of Environment and Conservation, Atmospheric Science Branch for technical advice, equipment and ambient monitoring data, and Drs Greg Ayers and Melita Keywood formerly of CSIRO Division of Atmospheric Research who provided extensive technical advice.

Endnotes

1. log (living area NO_2) = 0.23 + 0.73*log (outdoor NO_2) + 0.18*av daily hours of unflued gas heating + 0.46*av daily hours of gas stove top + 0.36*av daily hours of gas oven + 0.04*av daily hours of flued gas heating + 0.06*log (number of cigarettes smoked in house/week).
2. Goal adjusted for averaging period by the formula: goal2 = goal1*$(t1/t2)^{0.2 \text{ or } 0.18}$.

References

AWN Consultants and Team Ferrari Environmental 2004, *Technical Report No. 9: Unflued Gas Appliances and Air Quality in Australian Homes*, Australian Department of Environment and Heritage, Canberra.

Ayers, G.P., Keywood, M.D., Gillett, R.W., Manins, P.C., Malfroy, H. & Bardsley, T. 1998, 'Validation of passive diffusion samplers for SO_2 and NO_2', *Atmospheric Environment*, vol. 32, pp. 3587-92.

Ayers, G.P., Baruch, R., Keywood, M.D. & Gillett, R.W. 1999, 'Indoor air quality: A pilot study employing low-technology methods', *Clean Air*, vol. 33, pp. 29-33.

Brauer, M., Hoek, G., van Vliet, P., Meliefste, K., Fischer, P.H., Wijga, A., Koopman, L.P., Neijens, H.J., Gerritsen, J., Kerkhof, M., Heinrich, J., Bellander, T. & Brunekreef, B 2002, 'Air pollution from traffic and the development of respiratory infections and asthmatic and allergic symptoms in children', *American Journal of Respiratory & Critical Care Medicine*, vol. 166, pp. 1092-98.

Cyrys, J., Heinrich, J., Richter, K., Wolke, G. & Wichmann, H.E. 2000, 'Sources and concentrations of indoor nitrogen dioxide in Hamburg (west Germany) and Erfurt (east Germany)', *Science of the Total Environment*, vol. 250, pp. 51-62.

Ferm, M.A. 1991, *A Sensitive Diffusional Sampler,* Report to the Swedish Environmental Research Institute, B-1020, Stockholm.

Garrett, M.H., Hooper, M.A., Hooper, B.M. & Abramson, M.J. 1998, 'Respiratory symptoms in children and indoor exposure to nitrogen dioxide and gas stoves', *American Journal of Respiratory & Critical Care Medicine*, vol. 158, pp. 891-5.

Garrett, M.H., Hooper, M.A. & Hooper, B.M. 1999, 'Nitrogen dioxide in Australian homes: Levels and sources', *Journal of Air & Waste Management Association*, vol. 49, pp. 76-81.

Hajat, S., Haines, A., Goubet, S.A., Atkinson, R.W. & Anderson, H.R. 1999, 'Association of air pollution with daily GP consultations for asthma and other lower respiratory conditions in London', *Thorax*, vol. 54, pp. 597-605.

Keywood, M.D., Beer, T., Ayers, G.P., Gillett, R.W. & Kreibich, H. 1998, 'The use of passive gas samplers to monitor personal exposure', *Clean Air*, vol. 32, pp. 32-6.

Levy, J.I., Lee, K., Spengler, J.D. & Yanagisawa, Y. 1998, 'Impact of residential nitrogen dioxide exposure on personal exposure: an international study', *Journal of Air & Waste Management Association*, vol. 48, pp. 553-60.

Lee, K., Levy, J.I., Yanagisawa, Y., Spengler, J.D. & Billick, I.H. 1998, 'The Boston residential nitrogen dioxide characterization study: Classification and prediction of indoor NO_2 exposure', *Journal of Air & Waste Management Association*, vol. 48, pp. 736-42.

Morgan, G., Corbett, S. & Wlodarczyk, J. 1998, 'Air pollution and hospital admissions in Sydney, Australia, 1990 to 1994', *American Journal of Public Health*, vol. 88, pp. 1761-6.

Morgan, G., Corbett, S., Wlodarczyk, J. & Lewis, P.R. 1998, ' Air pollution and daily mortality in Sydney, Australia, 1989 to 1993', *American Journal of Public Health*, vol. 88, pp. 759-64.

Neas, L.M., Dockery, D.W., Ware, J.H., Spengler, J.D., Speizer, F.E. & Ferris, B.G. Jr. 1991, 'Association of indoor nitrogen dioxide with respiratory function and pulmonary function in children', *American Journal of Epidemiology*, vol. 134, pp. 204-19.

NEPC 1998, *National Environment Protection Measure and Revised Impact Statement for Ambient Air Quality*, Adelaide SA, National Environment Protection Council.

NSW DEC 2004, *Sydney Air Quality Monitoring Sites*, New South Wales Department of Environment and Conservation, Available at: http://www.epa.nsw.gov.au/air/sydney3.htm. Accessed August 2004

Pilotto, L.S., Douglas, R.M., Attewell, R.G. & Wilson, S.R. 1997, 'Respiratory effects associated with indoor nitrogen dioxide exposure in children', *International Journal of Epidemiology*, vol. 26, pp. 788-96.

Standards Australia 2000, AS 4553-2000 Gas Space Heating Appliances, SAI Global, Sydney.
World Health Organization 1987, *Air Quality Guidelines for Europe*, WHO-Regional Publications European Series No. 23/1987, WHO, Copenhagen.
World Health Organization 2000, *WHO Air Quality Guidelines*, WHO-Regional Office for Europe, Copenhagen.

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New South Wales Indoor Air Survey: Part III Particulate Matter Concentrations in Homes in New South Wales

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The three parts of this paper describe the outcomes of a two-phase cross-sectional survey undertaken in 1999 to identify the prevalence of the principal sources of indoor air pollutants in homes in New South Wales (NSW) and to quantify typical indoor pollutant concentrations. An initial telephone survey of 2036 home occupants throughout the state determined prevalence of house characteristics and indoor air pollution sources. A subsequent field survey of 140 homes drawn from ten of the 17 health regions in NSW collected particulate matter (PM_{10}), nitrogen dioxide, nicotine and formaldehyde over one week. Part III uses multivariate regression modelling to quantify the contribution of common indoor and outdoor sources of particulate matter to indoor PM_{10} concentrations. The main contributors to the elevated indoor particulate matter levels were smoking and wood heaters. The presence of indoor smoking, wood heaters or unflued gas appliances is associated with levels of air pollution that might exceed established health-based air quality standards. Indoor air quality also varies with local conditions.

Key words: *Indoor Air Pollution; Particulate Matter; Nitrogen Dioxide; Wood Heaters; Environmental Tobacco Smoke;*

Concentrations of particulate matter air pollution are linked to indices of cardiac and respiratory morbidity and mortality (Morgan et al. 1998; Morgan, Corbett & Wlodarcyzk 1998; Peters et al. 2000; Samet et al. 2000). Indoor sources are known to contribute to total exposure (Janssen et al. 1998). The relative contributions of these sources to indoor air pollution have not been previously documented in Australia.

As part of the New South Wales Indoor Air Survey particulate matter concentrations were measured inside 140 homes along with a record of appliance use, and other household factors potentially affecting indoor air pollution. This paper reports detailed findings of particulate matter concentrations in New South Wales' homes, and identifies the sources of increased indoor exposure to particulate matter.

Methods

The methodology of the New South Wales Indoor Air Survey is reported in detail elsewhere (Paper I). Briefly, it comprised a telephone survey of 2036 randomly selected households to assess prevalence of house types and potential indoor sources of various air pollutants. One hundred and forty homes were selected for indoor monitoring of pollutants, 90 in the five Sydney health regions and 50 in five of the twelve other health regions of the state. Each home was monitored using active low volume sampling for particulate matter and nicotine, and passive sampling for nitrogen dioxide and formaldehyde, for one week during winter 1999. Residents also completed daily diaries of use of heating and cooking appliances, and questionnaires related to practices of smoking, opening windows, use of exhausts, and house structure.

Active sampling

Micro-Vol

The Micro-Vol© was used to collect aerosol samples for the determination of particulate matter with a mean aerodynamic diameter less than ten microns (PM_{10}) and gas-phase nicotine. The Micro-Vol is a low volume aerosol sampler, with a PM_{10} size selective inlet and active flow control that maintains a constant flow of three litres per minute as mass on the filter increases during sampling. This constant flow is very important for maintaining the cut-size of the size selective inlet. The flow rate at the beginning and end of the sampling week was recorded, and found to be stable in most homes. Particle size selection within the inlet is achieved by a simple flat plate impactor, designed and calibrated by the Commonwealth Scientific and Industrial Research Organisation (CSIRO). The Micro-Vol was operated with a dual filter pack. Aerosol mass was collected on the first filter (stretched teflon) after the impaction plate, while nicotine was collected on the back-up filter (quartz fibre).

Gravimetric mass

Gravimetric mass was collected on a stretched teflon filter (47 mm in diameter; 2 µm pore size). Mass was determined using a Mettler UMT2 ultra-microbalance with a speciality filter pan. Electrostatic charging was reduced by the presence of radioactive static discharge sources within the balance chamber. The resolution of the balance is 0.1 µg. Filters were weighed at constant humidity (relative humidity (RH) < 20%) both before and after exposure after drying in a desiccator (RH <20%) for 24 hours. The reproducibility of the mass measurement (± 6 µg or 0.6% of the average mass of 978 µg measured during this study) was determined by repeated weighing of a standard blank teflon filter over several months. Sampling blanks (i.e. mass introduced by the filter handling procedures) were determined by subjecting a blank filter to all filter handling procedures and drawing air through the filter for one minute. The blank mass was 8 ± 2 µg per filter, or 1% of the average mass.

Nicotine

Nicotine was collected on a glass fibre filter coated with a solution of sodium bisulfate. The filters were soaked in coating solution and dried under clean conditions prior to use. After exposure, the collected nicotine was obtained as an aqueous solution by extracting each filter in 5 ml of Milli-Q grade water in polythene bags. Extraction was for one hour with periodic shaking. The nicotine concentration in the aqueous solution was determined by gradient ion chromatography as described in Ayers et al. (Ayers et al. 1998). Blank concentrations were determined by subjecting filters to all filter handling procedures and drawing air through the filter for one minute. These were found to be negligible (0 ± 0 µg per filter). Houses in the study that did not have active smoking were also used to assess blank artefacts, particularly degassing of nicotine from surfaces. This artefact was found to be 0.026 ± 0.004 µg m^{-3}, or 1% of the average nicotine concentration measured in smoking houses during this study.

Ambient monitoring

The New South Wales Department of Environment and Conservation (DEC) routinely records particulate matter using nephelometry (11 sites), high volume 6-day gravimetric sampling with size-selective inlet (6 sites) and tapered element oscillating balance (TEOM) (14 sites) in representative locations across Sydney. In Lithgow the DEC monitored particles with a nephelometer and a high volume sampler during the study period. The DEC provided these routine measurements, which were converted to mean weekly concentrations corresponding to the monitoring weeks of the survey. High volume sampler results were either averaged between consecutive samples, or utilised directly from a single sample, depending on how the starting date of indoor monitoring corresponded with 6-day sampling cycles. Households were allocated the concentration of particulate matter measured at their closest station, or in the case of houses located midway between stations, a mean of the concentrations. The nearest monitoring site was required to have valid readings for at least 80% of the time over at least four days of the corresponding indoor monitoring period for an ambient weekly mean to be calculated.

Armidale City Council monitors particulate matter concentrations with nephelometry and these results were also obtained for the week of the study and converted to a weekly mean concentration.

Meteorological data

Meteorological observations were obtained from the Bureau of Meteorology automatic weather station at Homebush, a location geographically near the centre of Sydney. Three-hourly measures of temperature, humidity, wind speed, wind direction and rainfall were available for all except one of the monitoring days during the two months that home monitoring occurred in Sydney. Weekly minimum and maximum and mean temperatures, and maximum and geometric mean wind speed and wind direction mode were calculated from each starting date of monitoring.

In regional areas Bureau of Meteorology data were obtained from the nearest automatic weather station, usually in the same town. Weekly values were calculated as for the Sydney data.

Analysis

The distribution of variables was normalised using a log transformation when appropriate, and geometric means calculated. Differences in PM_{10} concentrations between exposure categories were assessed by ANOVA or t-test. Multiple regression analysis with stepwise elimination was used to model the relationships between pollution sources and indoor PM_{10} or nicotine concentrations. Data were analysed using SASv6.12 (SAS Institute, Cary NC) for Windows.

Results

PM_{10} concentrations were collected in the living areas of 136 homes. In two homes improper assembly of the filter pack meant that no particles were collected, and in two others the pump malfunctioned. Due to the skewed distribution of PM_{10} concentrations a winter weekly geometric mean was calculated, which was 26.2 μg/m^3 with a range from 5.4 - 143.8 μg/m^3.

Nicotine concentrations were detected in the living areas of 89 homes. Concentrations from the remaining homes, all non-smoking, were below the detection limit. The geometric mean of the 89 samples was 0.065μg/m^3, with a range from 0.001 - 11.38 μg/m^3 averaged over the week of the study.

Univariate analysis

PM_{10} concentrations varied significantly by region, with the highest mean concentrations found in regional centres where solid fuel heaters are more prevalent (see Part 1). Mean weekly indoor PM_{10} concentrations also varied significantly with presence and number of smokers indoors, and main heater type (Table 1).

Weekly indoor PM_{10} concentrations were significantly positively correlated with weekly nicotine concentrations (R=0.72), number of cigarettes reported smoked inside (R=0.55), hours of use of main heater (R=0.3), and hours of stovetop cooking (R=0.18).

Type of secondary heater, the type or use of kitchen exhaust, the presence of wall vents, practice of opening windows, main building material and proximity to a busy road, all showed no effect on variation of weekly averaged PM_{10} concentrations.

The variation in PM_{10} with reported cleaning practices differed significantly between reported frequencies of dusting and vacuuming and PM_{10} concentrations. However, no trend in association between PM_{10} and cleaning frequency was apparent. Further, cleaning frequency was not significant in predicting PM_{10} concentrations, even in the subset of non-smoking homes.

Even when homes with smoking and wood heaters were excluded, indoor PM_{10} concentrations were higher in regions where wood heater use is more prevalent (mean in Tumut 23.04µg/m³, compared to Sydney 20.7µg/m³, compared to Lismore 17.0µg/m³).

Weekly nicotine concentrations also varied significantly with the number of smokers and reported number of cigarettes smoked. Other variables were not significantly related to nicotine in univariate analysis.

Table 1: Geometric mean indoor PM_{10} concentrations (µg/m³) by significant univariate predictors, NSW 1999

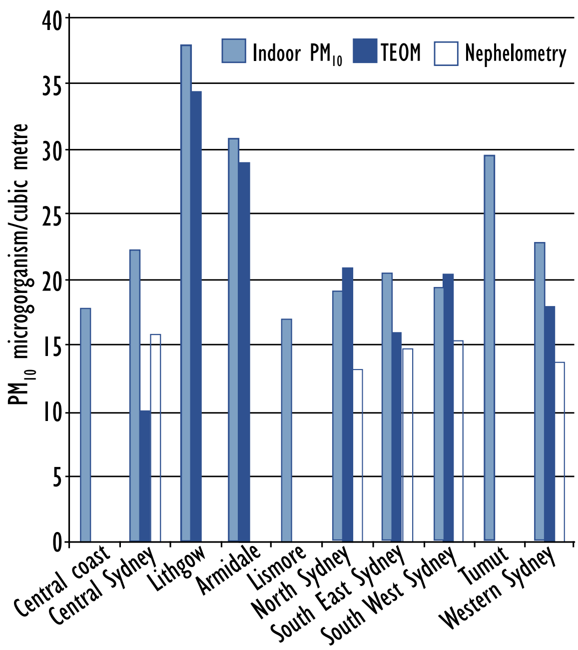
	N	Mean	SD
Region			
Lithgow	10	40.8	1.9
Armidale	10	36.7	1.9
Tumut	10	35.9	2.2
Central Coast	13	31.9	2.3
Sydney Central	15	25.3	1.5
Sydney South West	17	19.8	1.4
Lismore	10	16.4	1.4
Number of smokers			
none	112	22.4	1.6
one	14	47.6	2.1
two	7	66.6	1.2
three	3	115.0	1.2
Main heater type			
Air conditioned	21	16.2	1.8
Electric	51	25.5	1.8
Gas	35	29.3	1.8
Wood	25	37.3	1.8

Ambient particulate matter

Ambient weekly geometric mean PM_{10} concentrations by TEOM in Sydney varied from 11.0 - 20.1 µg/m³ (median 14.9µg/m³). The mean PM_{10} by high volume sampler was 17.8 µg/m³, and mean weekly nephelometry concentration was 0.196 bscat. In Lithgow, the PM_{10} by high volume sampler during the study week was 27.8 µg/m³ and the mean nephelometry reading was 0.387 bscat. In Armidale, the mean nephelometry reading was 0.347 bscat. In locations where both monitoring types were present, there was good correlation between average weekly nephelometry concentrations and high volume sampler results ($R = 0.71$). Correlation of weekly TEOM concentrations with nephelometry and high volume sampler varied by monitoring site.

For homes where outdoor particulate matter measures were available, the mean weekly TEOM measurement was a significant predictor of weekly indoor PM_{10} concentrations in univariate analysis. When homes where smoking occurred were excluded, ambient nephelometry and high volume sampler results were also significant in predicting indoor PM_{10} concentrations. The relationship between ambient and indoor PM_{10} concentrations is illustrated in Figure 1.

Figure 1: Comparison of indoor PM_{10} in non-smoking homes with ambient measures of particulate matter, NSW 1999



Meteorological data

Weekly minimum, maximum and mean temperatures were inversely correlated with weekly indoor PM_{10} in homes where there was no smoking (R=0.45, 0.31, 0.3 respectively). All measures of temperature were also inversely correlated with the reported hours of using heating (R=0.42, 0.43 and 0.39). Wind speed and weekly rainfall were not correlated with indoor PM_{10}.

Multiple regression modelling of indoor PM_{10}

Homes where cigarettes were smoked were modelled separately from those where no smoking occurred, as the predictive relationships varied between the two groups. Variables that predicted indoor PM_{10} concentrations in non-smoking homes were non-significant in smoking homes.

In the homes where smoking did not occur, the region, type of heater, minutes of cooking and hours of use of a wood heater explained 44% of the variability of weekly indoor PM_{10} concentrations. The use of a kitchen exhaust significantly decreased the concentration of PM_{10}. If the primary heater type was air conditioning, PM_{10} concentrations were also significantly decreased. Table 2 provides predicted PM_{10} concentrations by region and heater type by this model.

Variables such as proximity to a busy road, opening windows, age or structure of the home were not significant in predicting indoor PM_{10}. When region was included in the model, ambient measures of particulate matter became non-significant. Region was also a better predictor of indoor PM_{10} than meteorological observations. When region was excluded from the model, the weekly minimum temperature was the only significant meteorological observation to predict indoor PM_{10}.

In homes where smoking occurred, weekly indoor PM_{10} was best predicted by weekly nicotine concentration (R-squared = 63%). Nicotine concentration was superior to number of smokers or number of cigarettes smoked in predicting PM_{10}. The addition of reported practice of opening windows or use of a kitchen exhaust improved the predictive value of the model as assessed by adjusted R-squared (overall R-squared = 71%), and resulted in a decrease in PM_{10} concentrations. In the case of these homes where smoking occurred, variables such as region, heater type or use, cooking time, ambient particles or meteorological factors were insignificant in predicting PM_{10}.

Table 2: Predicted weekly indoor PM_{10} concentrations in non-smoking homes with one hour of cooking per day

	Lithgow		SW Sydney		Lismore	
Use Kitchen Exhaust?	No	Yes	No	Yes	No	Yes
Air conditioning	35.9	26.8	21.2	15.8	17.8	13.3
Wood heater	50.0	37.33	29.5	22.0	24.8	18.5

Multiple regression modelling of nicotine

Smoking is a source of both PM_{10} and nicotine concentrations in the home, so weekly nicotine concentrations were also modelled. In homes where cigarettes were smoked 76% of variability in nicotine was accounted for by weekly indoor PM_{10} and number of smokers. In homes with two smokers an increase in PM_{10} from 20 to 43μg/m^3 was associated with a 1μg/m^3 increase in nicotine. In the homes where there was no smoking reported, no variables were significant in predicting nicotine concentrations, including number of occupants, presence of carpet, presence of vents or opening of windows.

Discussion

This study has demonstrated that active low-volume sampling is an effective means of measuring exposure to indoor particulate matter. A wide range of particle exposure was detected, and varied as expected with predicted indoor and outdoor sources of particulate matter and with nicotine concentrations. Previously, Repace has shown that for each 1μg/m^3 increase in nicotine, respirable suspended particles (RSP [particles less than 3.5μg/m^3]) concentrations would increase by 10μg/m^3 (Repace & Lowrey 1993). In this study, a 20μg/m^3 increase in PM_{10} associated with a 1μg/m^3 increase in nicotine. Assuming an RSP:PM_{10} ratio of 0.5, this result is similar to that predicted by Repace.

It is clear from this study that during winter the predominant source of fine particle pollution exposure in homes for around 25% of the population is environmental tobacco smoke. In homes where smoking occurs, concentrations of particulate matter pollution exceed by several times the concentration found in homes where there is no smoking. The contribution of all other indoor or outdoor sources is dwarfed by the contribution from cigarettes.

In homes free from tobacco smoke, the contribution of wood heaters, both operating in the home and in the region is the predominant influence on particulate matter exposure. Three regional centres - Tumut, Lithgow and Armidale - had higher indoor and outdoor concentrations of particle pollution during winter than in Sydney, even in homes that did not use a wood heater. Part I reports that the usual way to heat the living area was solid fuel heating for 48% of Tumut residents and 54% of those living in Armidale, compared to 9% of homes in a region such as the Central Coast. The evidence of the impact of neighbourhood wood heaters on the indoor air of homes using cleaner forms of heating provides support to recent NSW government initiatives to decrease pollution from this source (NSW DEC 2004).

In 1998, the National Environment Protection Council set a standard for PM_{10} in ambient air of 50μg/m^3, averaged over 24-hours (NEPC 1998). This standard acknowledges that a threshold for the health effects of particulate matter has not been identified, and that health impacts increase with particulate matter concentrations. There is no recognised indoor particulate matter standard, in part due to the lack of data on the relationship between indoor particulate matter concentrations and associated health effects. However, as in most homes indoor concentrations are shown to be very similar to outdoor concentrations, it is likely that the ambient exposure studies upon which health standards are based actually incorporated similar effects from unmeasured indoor particle exposure.

In this study PM_{10} was collected for one week. This tends to underestimate peak daily exposures, but provides a reasonable estimate of long-term winter season exposure. Four of the 112 homes with no smoking, and eighteen of the 24 homes with smoking exceeded 50μg/m^3 averaged over the week.

Epidemiological studies of health effects due to fluctuations in ambient PM_{10} concentrations have identified dose response relationships between increases in PM_{10} and several health endpoints. In Sydney, Morgan found that for each 10μg/m^3 increase in PM_{10}, mortality increased by around 1% (Morgan et al. 1998). If the relationship between indoor PM_{10} and health effects is the same as for ambient air, the use of a wood heater on any day would be associated with approximately a 1% increase in risk of mortality compared to homes where air-conditioning is used. Considered across the state, this increment in risk is a population health concern, especially as sensitive groups such as the elderly and infants tend to be inside for large periods of the day (Glinianaia et al. 2004; Morgan et al. 1998).

Region was a better predictor of indoor PM_{10} than ambient pollution or meteorological factors. There are several limitations to the generalisation of this finding. First, the regions used in Sydney were based on health service regions, rather than on any geographical, socio-economic or cultural factors. Second, homes in each region were tested in the same week, and each region was tested in a different week. Thus some, or all, of the variability between regions might reflect the net result of variations in ambient pollution and weather from week to week, rather than any inherent difference between regions. Further, as ambient measures were sourced from a variety of instruments (nephelometry, high volume sampler and TEOM) and as no one instrument's results were available for the majority of homes, the use of ambient measures in multiple regression modelling resulted in reduced sample size and a loss of power. An additional limitation was the difficulty of assigning homes to the most representative monitoring station.

Surprisingly, housing construction, fixed ventilation, or the practice of opening windows has little effect on particle concentrations. In contrast to the findings for gaseous pollutants, proximity to a busy road was not significant in predicting indoor concentrations of particulate matter. This is consistent with the finding by Janssen that indoor concentrations of PM_{10} were not higher in homes along busy streets (Janssen et al. 1998).

This study also replicated findings of studies from the northern hemisphere in demonstrating that cooking adds significantly to indoor particle concentrations (about 4µg/m^3 per hour) but cleaning activities do not (Janssen et al. 1998; Ozkaynak et al. 1996; Wallace 1996). The population exposure to particulate matter in NSW from cooking is likely to be small, however, as the average time spent cooking per day was only 24 minutes in this sample. Further, particle concentrations were significantly reduced with the use of a kitchen exhaust.

The significantly lower concentrations of particulate matter detected in homes using air-conditioning suggests that this might be a means to lower indoor exposure to particulate matter in areas where ambient particle concentrations are high. The study did not collect information on the type of unit, or have a large enough sample to examine the interaction between housing type and use of air-conditioners to provide a recommendation on using air-conditioners to lower indoor particle concentrations.

Using active sampling allowed detection of nicotine in homes where smoking did not occur. It is not surprising that the variables measured were unable to predict nicotine concentrations in non-smoking homes as the source of this nicotine is determined by factors outside the home such as time spent in an environment where smoking is permitted, such as a bar.

Conclusion

In homes where smoking occurs, residents are likely to be exposed to concentrations of particulate matter that exceed ambient health-based standards. The other main source of particle exposure in homes in winter was wood heater use, both in the home and from neighbouring homes. Based on the known health effects of particulate matter, this finding provides support for increased controls on emissions from wood heaters.

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This study was funded by NSW Health. The study concept and design was developed by Rona Baruch. The cooperation and efforts of Public Health Unit Directors and Environmental Health Officers from Central Coast, Central Sydney, Northern Rivers, Western Sydney, New England, South East Sydney, Greater Murray, South West Sydney and Mid West were vital to the successful collection of air samples. We wish to thank the NSW Department of Environment and Conservation, Atmospheric Science Branch for technical advice, equipment and ambient monitoring data, and Drs Greg Ayers and Melita Keywood formerly of CSIRO Division of Atmospheric Research who provided extensive technical advice. We would also like to thank Professor Geoffrey Berry for advice on statistical methods and Professor John Beard for assistance with the manuscript.

References

Ayers, G.P., Selleck, P.W., Gillett, R.W. & Keywood, M.D. 1998, 'Determination of nicotine in water by gradient ion chromatography', *Journal of Chromatography A*, vol. 824, pp. 241-5.

Glinianaia, S.V., Rankin, J., Bell, R., Pless-Mulloli, T. & Howel, D. 2004, 'Does particulate air pollution contribute to infant death? A systematic review', *Environmental Health Perspectives*, vol. 12, no. 14, pp. 1365-71.

Janssen, N.A.H., Hoek, G., Brunekreef, B., Harssema, H., Mensink, I. & Zuidhof, A. 1998, 'Personal sampling of particles in adults: Relation among personal, indoor and outdoor air concentrations', *American Journal of Epidemiology*, vol. 147, pp. 537-47.

Morgan, G., Corbett, C., Wlodarcyzk, J. & Lewis, P. 1998, 'Air Pollution and Daily Mortality in Sydney, Australia, 1989 through 1993', *American Journal of Public Health*, vol. 88, pp. 759-64.

Morgan, G., Corbett, C. & Wlodarcyzk, J. 1998, 'Air Pollution and hospital admissions in Sydney, Australia, 1990 to 1994', *American Journal of Public Health*, vol. 88, pp. 1761-66.

NEPC 1998, *National Environment Protection Measure and Revised Impact Statement for Ambient Air Quality*, National Environment Protection Council, Adelaide.

NSW DEC 2004, *Woodsmoke Reduction Program*, NSW Department of Environment & Conservation, Sydney, <http://www.epa.nsw.gov.au/woodsmoke/incentives.htm> August 2004.

Ozkaynak, H., Xue, J., Spengler, J., Wallace, L., Pellizzari, E. & Jenkins, P. 1996, 'Personal exposure to airborne particles and metals: Results from the Particle TEAM study in Riverside, California', *Journal of Exposure Analysis & Environmental Epidemiology*, vol. 6, pp. 57-78.

Peters, A., Liu, E., Verrier, R.L., Schwartz, J., Gold, D.R., Mittleman, M., Baliff, J., Oh, J.A., Allen, G., Monahan, K. & Dockery, D.W. 2000, 'Air pollution and incidence of cardiac arrhythmia', *Epidemiology*, vol. 11, pp. 11-17.

Repace, J.L. & Lowrey, A.H. 1993, 'An enforceable indoor air quality standard for environmental tobacco smoke in the workplace', *Risk Analysis*, vol. 13, pp. 463-75.

Samet, J.M., Dominici, F., Curriero, F.C., Coursac, I. & Zeger, S.L. 2000, 'Fine particulate air pollution and mortality in 20 US cities, 1987 - 1994', *New England Journal of Medicine*, vol. 343, pp. 1742-9.

Wallace, L. 1996, 'Indoor particles: A review', *Journal of the Air and Waste Management Association*, vol. 46, pp. 98-126.

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Compliance of Aerated Wastewater Treatment Systems: A Quantitative and Qualitative Analysis

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A survey was conducted of the compliance with permit requirements of effluent quality of Aerated Wastewater Treatment Systems (AWTS) located in a rural municipality in Victoria. The study was prompted by anecdotal reports of high levels of non-compliance, concerns about performance after installation of the systems, and a lack of information about the factors affecting non-compliance. Twenty one of the 45 AWTS identified in the municipality were sampled to investigate their compliance with the Victorian EPA effluent water quality requirements (EPA Victoria 2002). Only one of the 21 systems was compliant with EPA permit effluent water quality requirements. Eighty six percent (86%) of systems were found to have a chlorine residual below the minimum requirement of 0.5 mg/L and 67% of the systems had Escherichia coli *levels above the EPA prescribed limit. Fifty two percent (52%) and 33% of the systems were above the BOD and suspended solids prescribed limits, respectively. The presence of chlorine tablets was a major determinant of compliance with both chlorine residual and* E. coli *levels. A relationship between the number of non-compliances and the number of residents in the household was found, as was a relationship between the number of residents and Biochemical Oxygen Demand (BOD). A survey assessing household knowledge of their system indicated that many residents had little knowledge about their AWTS and its maintenance. A need for accessible, understandable educational material to inform the owners about their system was identified.*

Key words: *Aerated Wastewater Treatment Systems; Onsite Wastewater Disposal; Chlorine; Compliance; Owner Knowledge*

Untreated domestic wastewater is a complex mixture that may contain particles of organic matter, nutrients and chemical and microbial contaminants, varying widely in hydraulic load and composition over the space of a day. In remote locations onsite treatment options such as Aerated Wastewater Treatment Systems (AWTS) are often employed to remove components harmful to human or animal health, or detrimental to the receiving environment by settling solids and reducing organic content and microbial load (Khalife & Dharmappa 1996; Martens & Correy 1992). However, failure of decentralised wastewater treatment systems has been identified as a potential source of human pathogens in the environment (Gerba & Smith 2005). These authors report studies indicating that pathogens can be transported in surface waters or groundwater, and that discharge from malfunctioning systems can be a major contributor to contamination problems in shellfish growing areas. Gerba and Smith (2005) also report a study linking density of septic tanks to possible illness in children. Geary and Whitehead (2001) report that onsite system failure, and subsequent contamination by wastewater, was considered to be a potential factor in both the outbreak of Hepatitis A linked to oysters at Wallis Lakes, and the 1998 occurrence of

Cryptosporidium and *Giardia* in Sydney drinking water supplies. The authors also cite a number of cases of onsite wastewater treatment failure linked to bacterial, viral and nitrate contamination of groundwater and wells (Geary & Whitehead 2001).

Aerated Onsite Wastewater Treatment Systems

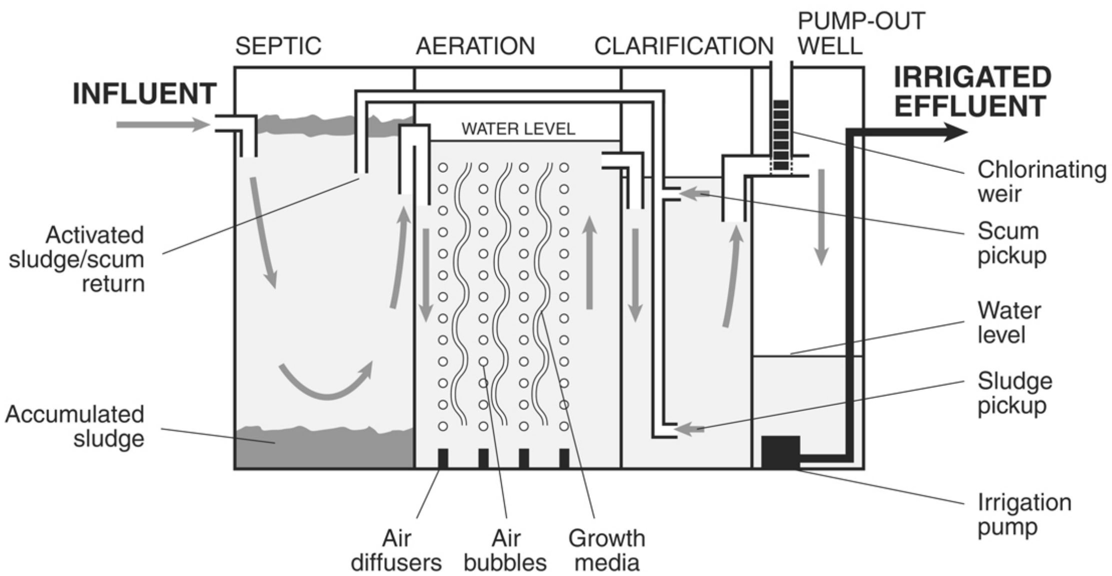
Aerated Wastewater Treatment Systems are defined in the Australian Standard AS 1546.3 as systems for biological treatment of wastewater using an aeration process, followed by clarification to produce an effluent appropriate to the land application system (Figure 1). The provision of an oxygen rich environment for biological treatment allows aerobic organisms to reduce the organic portion of the wastewater to carbon dioxide and water. This is achieved using either suspended growth, where microorganisms are maintained in a suspension in the effluent stream, or fixed film, where microorganisms attached as biofilm on an inert medium (Department of Local Government NSW [DLGNSW] 1998; United States Environmental Protection Agency [USEPA] 2000).

Aerated systems are commonly used in situations considered unsuitable for septic tanks, such as locations close to dams and waterways, or where soil is unsuitable for subsurface (trench or deep soil) disposal. AWTS have the capacity to treat to secondary level and are considered to produce effluent with lower Biochemical Oxygen Demand (BOD), suspended solids and pathogen levels, making them more suitable for surface irrigation (DLGNSW 1998).

Correctly maintained and managed, an AWTS should produce a clear odourless effluent that meets regulatory or permit requirements (Geary 1998). However, anecdotal evidence is emerging that many AWTS are not performing to expected standards and the findings of a number of recent investigations support this opinion.

An audit of 1168 onsite wastewater systems at Colac Otway Shire (Colac Otway 2002) revealed that at least 30% of sand-filters and aerated wastewater systems were discharging effluent off-site. It was suggested that lack of regular checks and maintenance was leading to the defective state of these systems. A NSW study analysed samples

Figure 1: Diagram of aerated wastewater treatment system (adapted from Petrozzi and Martens 1995)



from 27 randomly chosen AWTS. Samples were assessed against the NSW Department of Health standard limits of 20mg/L for BOD5, 30mg/L for suspended solids, 30 colony forming units (cfu) per 100ml for faecal coliforms and residual chlorine between 0.5 and 2.0 mg/L. It was found that few samples met these requirements, with average values of 39 mg/L for BOD, 180 mg/L for suspended solids, 18,000 cfu/100ml for faecal coliforms, and residual chlorine levels below 0.5mg/L in all but two samples. Some systems also failed to comply with the guidelines for land application of effluent, with reduced or poorly maintained irrigation areas, often used for other purposes, or too close to dwellings or swimming pools (Khalife & Dharmappa 1996).

Beal et al. (2005) report that in a Queensland study of 216 aerobic systems, only 30% of the systems met effluent quality criteria for BOD, suspended solids and faecal coliforms.

This study was undertaken to determine the extent of non-compliance with effluent water quality requirements (EPA Victoria 2002) of AWTS in a rural area in Victoria, Australia, and to identify factors that determine non-compliance.

Materials and Methods

Council records and reports from maintenance contractors were used to identify the location of all known AWTS in the municipality. Forty-three systems were identified and an introductory letter sent to all owners of AWTS. Twenty-one residents volunteered to participate, and at the time of sampling they were asked to complete a survey to determine their familiarity with system operation and maintenance and a water usage log to estimate approximate water flow into each system. Location, type, model and age of the system and details of maintenance records received were collected from council files.

Effluent sampling and testing

Samples were collected from the pump-well chamber (Figure 1) of 21 of the 43 AWTS in the municipality. Five different system types were sampled. This included seven Supertreat, eight Envirosep SP2000, two Biocycle, two Taylex Clearwater, and two Septech Turbojet systems. Each system was checked to ascertain presence or absence of chlorine tablets. All samples were transported in an esky with ice blocks until being placed into a refrigerator or freezer, and were delivered to the laboratory within 24 hours.

BOD and suspended solids were analysed using methods described in APHA-AWWA-WEF (1998). Levels of *Escherichia coli* were determined using methods described in Water Microbiology Method 7: Thermotolerant Coliforms and *Escherichia coli* - Membrane Filtration Method (Standards Australia 1995). Free chlorine, total chlorine and pH were tested using a Lovibond® Tintometer PC Checkit Photometer. The free chlorine reading was recorded as residual chlorine.

A qualitative assessment was undertaken of the household awareness about correct usage of the treatment system, and care taken to use appropriate household products and minimise hydraulic loading. Awareness and care were designated as low, medium or high.

A water usage log was used to group the systems into estimated daily water usage categories, again using low (<600 L) medium (600-1199 L) or high (1200+L) to assess any differences resulting from hydraulic loading. Figures for average water usage of different activities and appliances (Brisbane City Council 2005) were used in conjunction with the log.

Statistical analysis

Data were analysed using GraphPad Prism Version 4. Tests for normality were conducted on all data, and median values rather than means have been used for non-normal data to avoid bias by extreme values.

The 90% confidence interval (alpha = 0.1) was used in all analyses. T tests and one-way ANOVA were used to analyse sets of normal data. Mann Whitney U and Kruskal-Wallis tests were used to detect significant differences in non-normal data sets. Strength of relationships between variables was determined by calculating a Spearman or Pearson correlation coefficient. Where values were below the limit of quantification of analytical equipment (reported as 'less than' or LO), half the reported value or the limit of detection were used as the value for statistical analysis.

One system was not required to meet the criteria for *E. coli* or residual chlorine as effluent disposal was by subsurface trenches. To maintain confidentiality this system has not been identified, as it was the only one in the municipality with subsurface disposal. Where the *E. coli* and residual chlorine criteria were not relevant to compliance the results have been omitted from the data during statistical analysis.

Zero water usage estimates (owners away for the weekend) were also excluded from analyses that compared water use with compliance levels.

Results

Effluent sample test results

A summary of the effluent testing results is presented in Table 1. Of the 21 systems sampled, only one complied with all four water quality compliance criteria investigated, with four systems failing on all four criteria, 12 on three, and one on one criterion.

Chlorine residual results were grouped according to the presence or absence of chlorine tablets. Only two systems had chlorine levels above the minimum compliance level, and it was found that the residual chlorine levels were significantly higher (p=0.0126) in systems where the presence of chlorine tablets was observed (median value 0.16mg/L) compared with systems where chlorine tablets were absent (median value 0.025mg/L) (Figure 2). Presence or absence of chlorine tablets also resulted in a significant difference in *E. coli* levels (p=0.0004) (A median value of 4.0 cfu/100ml for systems with tablets, compared with a median value of 5650 cfu/100ml for those without chlorine tablets) (Figure 3).

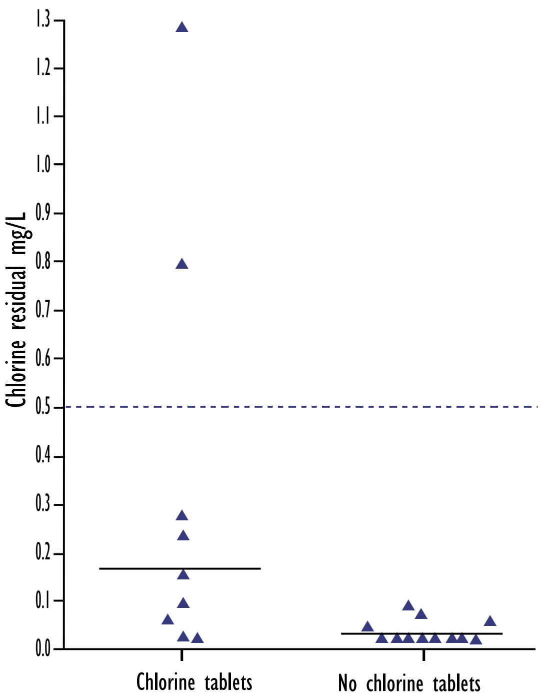
Table 1: Summary of effluent test results

	Range	Mean[a]	Criteria limits[b]	Number of systems failing to meet criteria (%)
Residual Chlorine (mg/L)	0.05-1.29	0.05	0.5 - 2.0	18 (86%)
BOD (mg/L)	4-97	20	Below 20	11 (52%)
Suspended Solids (mg/L)	2-74	28.6	Below 30	7 (33%)
E. coli (cfu/100mL)	<2-380,000	700	Below 10 org/100ml	14 (67%)

a. or median where appropriate

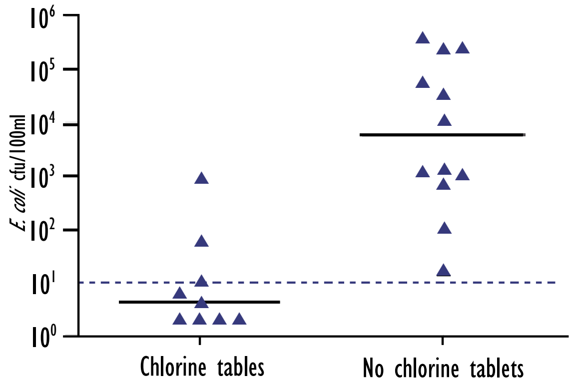
b. reference for compliance

Figure 2: Chlorine residual in systems with and without chlorine tablets present at the time of sampling



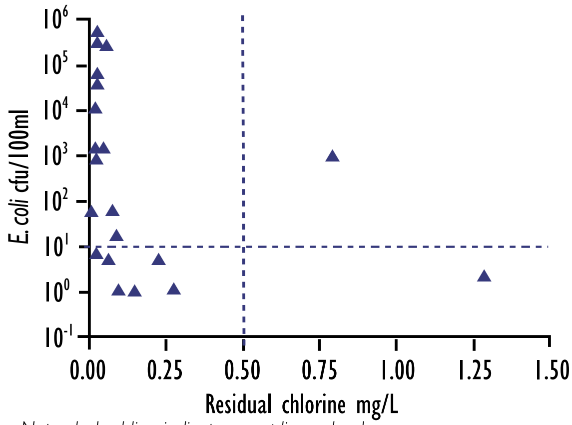
Note: bold line indicates median, dashed line indicates minimum compliance level

Figure 3: Relationship between total chlorine and E. coli



Note: bold line indicates median, dashed line indicates minimum compliance level

The relationship between *E. coli* and chlorine residual is shown in Figure 4. A relatively small decrease in chlorine residual corresponds to a large increase in the numbers of *E. coli* (p = 0.0006). 68% of the variation in *E. coli* levels can be attributed to residual chlorine. As indicated in Figure 4, six systems complied with *E. coli* criteria despite noncompliant chlorine residual. All six of these systems had chlorine tablets present and all but one having total chlorine readings well above 0.5mg/L (indicating that contact with the chlorine tablets had provided adequate disinfection when initially present but had subsequently combined with organic matter). One system was noncompliant with respect to *E. coli* despite the presence of chlorine tablets and a chlorine residual of 0.8mg/L. This system had a high suspended solid level, which may have resulted in ineffective disinfection.



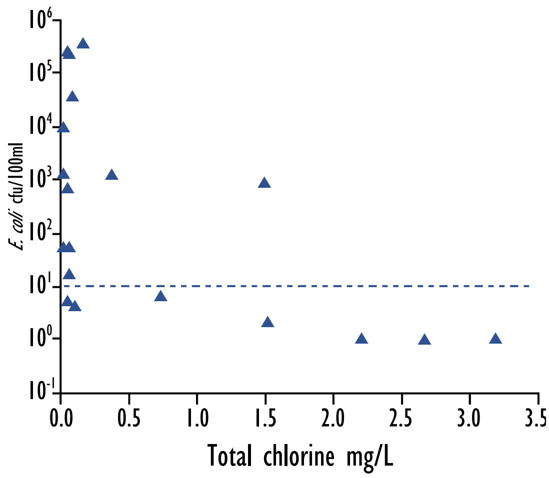
Note: dashed line indicates compliance levels

Figure 4: Relationship between E. coli and residual chlorine

As mentioned above, seven of the systems failed to meet residual chlorine criteria despite presence of chlorine tablets (Figure 2). This is likely to have been due to reaction of the chlorine with organic matter remaining in the effluent. However, of these seven, only one failed on *E. coli* with a relatively low result of only 54 cfu/100ml. This suggests that free chlorine had been present initially, providing some disinfecting effect before it combined with organic matter present in the effluent.

As shown in Figure 5, a relationship was also found between total chlorine and *E. coli* results (p = 0.0247). This indicates that total chlorine might prove to be a useful indicator of the initial presence and disinfection effect of chlorine residual (free chlorine). Systems that had no chlorine tablets for extended periods of time had the lowest total chlorine levels - also corresponding with the highest *E. coli* levels.

Figure 5: Relationship between total chlorine and E. coli



Note: dashed line indicates compliance levels

Visual inspection

No obvious problems were identified in terms of effluent appearance, foaming, solids or odours. Effluent was generally slightly turbid and light brown to grey in colour with an earthy odour. Irrigation systems were observed to be in a varied state of repair. While some were well maintained and irrigating appropriate areas, others were in poor repair with damaged sprinkler heads (usually damaged by whippersnippers or mowers) resulting in a fountain of effluent with potential to reach eye or mouth level. Two participants were irrigating fruit trees; one in winter months and one all year round. One participant reported knowledge of another owner irrigating vegetables with treated effluent.

Owner knowledge and attitudes

Householder knowledge of the systems varied widely. Some owners were unclear about the location, type and operation of the system, while others were actively involved in maintenance of their systems. Conversations with owners revealed that many did not understand what was done during maintenance visits, and several did not know that chlorine tablets were used in their system. Notably, most owners were under the impression that if there was no odour and the effluent had a clean appearance their system was working well. Several owners remarked that when initially choosing a system, they gained the impression that the water would be treated to a standard that was almost safe enough to drink. All owners were unaware that their permit conditions required an annual laboratory analysis of the effluent when using surface irrigation. The ongoing expense of operating the system was identified as an issue for most owners, particularly unexpected expenses such as replacement of pumps. Some indicated that they had not been informed of the life expectancy of mechanical parts and replacement costs.

Survey results compared with compliance criteria

Twenty of the 21 surveys were returned, although some owners did not fill out all sections. A summary of the results is presented in Table 2. Approximations of water use ranged from no use at all where residents were away for the weekend, to just above 1500 litres. Zero values for residents who were away for the weekend were excluded from the data sets. The estimated 24-hour water usage for households with mains water supply was compared with that of tank water supply with no significant difference found between the two groups.

Table 2: Summary of survey results

	Responses	Result
Number of residents	19 responses	ranged from 2 to 7 residents in house
Loads of washing/week	12 responses	ranged form 2 to 14 loads per week
Dishwasher in kitchen	18 responses	Of these 11 households had dishwashers
Water supply	19 responses	8 on rainwater 10 on town supply
Household cleaning	Many households using antimicrobial products	
Details of wastewater treatment system	Most didn't know	
Maintenance history	Few knew last service of desludge	
Problems with system	One reported problem with blocked overflow	
Other Comments	One mentioned poor service and follow up - only 2 services done when it should have had 4	

No significant relationship between 24-hour water usage estimates or householder chemical awareness categories and compliance criteria (*E. coli*, suspended solids and BOD) was found. Nor was any significant difference found between householder chemical awareness and the number of non-compliances. No significant difference in compliance was found between households with or without a dishwasher.

No significant relationship was detected between the number of residents and suspended solids, *E. coli* and chlorine residual criteria compliance. However, a relationship between number of residents and the number of non-compliances and number of residents and BOD was detected (Table 3).

Age of system and time interval from last service or desludge

As the data on date of commissioning of the systems in the council files were found to be unreliable in some cases it could not be used for analysis. Reliable data on the most recent service were also difficult to obtain, as reports were not always lodged after services, and owners rarely kept records of service dates. Many systems in the municipality were too recently installed to have required desludging so these data were also unable to be used for analysis.

There were no detectable differences between brands of AWTS. However, this might be an artefact of the small numbers of each system were sampled. A larger data set could result in a statistically significant result.

Table 3: Relationship between number of residents and compliance criteria

	BOD	SS	*E coli*	Chlorine	Failed criteria
Spearman r	0.6509	0.2960	0.006443	0.2641	0.6463
P value (two-tailed)	0.0025	0.2185	0.9791	0.2746	0.0028
Significance of relationship[a]	Yes	No	No	No	Yes

[a]*alpha=0.05*

Discussion

The use of reclaimed water in agriculture is highly regulated, recognising the potential risk to humans, livestock, and the environment from residual pathogens (EPA Victoria 2003). While guidelines for reclaimed water usage are generally developed with larger scale reuse in mind, potential exposure routes and types of pathogens are likely to be similar in domestic systems. It is, therefore, possible that similar risk may be posed by surface disposal of effluent from AWTS if they are not closely monitored to ensure sufficient reduction in microbial load. While analysis of an isolated grab sample of effluent from an AWTS cannot give a meaningful measure of overall performance and compliance with permit conditions, it gives an indication of the potential risk to residents of the household. With this in mind the results of this survey raise concerns given that two thirds of the systems failed to comply with microbial quality as indicated by *E. coli* levels.

The major finding of this survey was the significant effect the absence of chlorine tablets had on compliance with the residual chlorine requirement, and on the microbial quality of the effluent. The negative correlation between residual chlorine and *E. coli* level reflects the disinfection effect of the chlorine and the fact that effluent reaching irrigation systems without this disinfection might pose a health risk to the residents. Khalife and Dharmappa (1996) report 10^6 cfu/100ml as the level expected of *E coli* in untreated domestic wastewater. In comparison, the highest *E coli* level was estimated to be 3.8 x 10^5 cfu/100ml, indicating that there had been relatively little reduction in bacterial levels and raising concerns about the health risk posed by contact with the effluent from some systems.

The majority of AWTS that failed to meet the *E. coli* requirement had very low residual chlorine levels, and in most of these systems the chlorine tablets had been used up or were not initially installed. The presence of chlorine tablets effectively reduced the median *E. coli* levels by a factor of 10^3.

Total chlorine is a measure of both the available residual chlorine and the chlorine that is no longer available for disinfection after combining with organic matter. Systems with no chlorine tablets for extended periods of time had the lowest total chlorine readings in addition to noncompliant residual chlorine levels. Systems with low levels of both total and residual chlorine generally corresponded to the highest *E. coli* levels. This also indicates that the initial presence of chlorine tablets provides some measure of protection, even if the tablets become exhausted before the scheduled maintenance. If chlorine tablets had only been depleted recently it could also explain how six systems failing to comply with the chlorine residual limit still complied with *E. coli* limit. These findings indicate that the most effective risk management strategy for AWTS would entail informing owners of the requirement for consistent chlorination in all AWTS utilising surface irrigation, and for maintenance to be conducted at the scheduled three-monthly intervals.

While the levels of remaining BOD and suspended solids in the treated effluent indicate removal of organic load, and therefore by default some pathogens and nutrients, they also act as a predictor for the effectiveness of disinfection. High combined chlorine levels measured in some systems suggested that remaining organic matter had reacted with free chlorine provided by the chlorine tablets, rendering it unavailable for disinfection, and showing that no particular factor should be investigated in isolation. Seven systems where chlorine tablets were present still failed to meet residual chlorine criteria, which could have been explained by high levels of organic matter reacting with the chlorine.

Of the 21 systems sampled (20 with surface irrigation and one with subsurface disposal), only one complied totally with EPA requirements, and only seven systems passed on microbiological quality. This suggests the need for urgent action to ensure regular maintenance and adequate disinfection. None of the owners appeared to be aware that there might be a problem with their systems, and most were confident that they were performing well based on lack of odour. This highlights the need for further owner education about the compliance requirements and maintenance of their AWTS.

It is difficult to make direct comparisons with the findings of other investigations, as specific results are not always quoted. Larger sample sizes are more likely to yield a normal distribution allowing means to be calculated. However, a comparison with the results of the NSW study by Khalife and Dharmappa (1996) is presented in Table 4 showing a general similarity of the findings. It should be noted that factors such as the timing and method of sampling might also affect the results.

Survey responses indicated that many owners had little knowledge about their systems, or frequency and type of maintenance, and few owners kept records or knew when maintenance was due. The survey results reinforced the impression from conversations with owners that maintenance was left in the hands of contractors. It would not be surprising if owners omitted to remind the contractor of overdue maintenance as the cost was frequently mentioned as an issue.

Table 4: Comparison of average results with NSW study by Khalife and Dharmappa (1996)

	Khalife and Dharmappa, (1996)	This study
Residual chlorine	92.6% below 0.5mg/L	90% below 0.5mg/L
BOD average value	39 mg/L	20mg/L (median value)
Suspended solids average value	180mg/L	28.6mg/L (mean)
E. coli average value	18,000 cfu/100ml	700cfu/100ml (median value)

Few owners knew what the contractor did when the system was maintained, and after seeing the contractor conduct pH tests some thought that microbiological safety of the effluent used for irrigation was tested each visit. Consequently, the owners were not concerned about where they were irrigating. This potentially posed a high risk to the residents if the system was not performing well; particularly where irrigation areas were not fenced or, as seen in one case, the effluent was being used to irrigate fruit trees.

None of the owners were aware of the permit requirement for an annual laboratory report. The lack of awareness of permit conditions highlights the need for dissemination of some user-friendly information following purchase of an AWTS or purchase of a property with an existing AWTS. This should ideally occur after residents settle into a new house, as there is often little time for reading during building or moving and it is easy to mislay documentation.

The only household characteristic that showed a statistically significant relationship with compliance results was the number of residents in the household. The

BOD results increased with the number of residents, which reflects the increased hydraulic and organic load on the system. The number of non-compliances also increased with number of residents. This might reflect the fact that raised BOD levels caused by increased hydraulic and organic loading inevitably impact on the residual chlorine level and disinfection of the system. Increased hydraulic load also decreases retention time for treatment of the effluent and settling of solids. Increased usage of household products, such as washing powders, cleaning agents and personal hygiene products, might also affect the microbial ecology of the system resulting in poor performance.

Increased water usage (hydraulic load) decreases the contact time with chlorine tablets, which might also impact on disinfection of the effluent. Fearnley et al. (2004) discussed the factors known to impact on household water consumption. These included number, age and habits of household inhabitants, type of property, season, and type of appliances in the dwelling. However, the volume of wastewater gives no indication of the quality of the wastewater generated. Although Geary (1998) comments that households with limited water supply generally use less water and generate lower wastewater volume, there was no significant difference found between the estimates for water usage for town water supply and rainwater tanks. The method of estimation was not necessarily accurate and this could be assessed more precisely using a flow meter.

The data on water usage were limited to the period 24 hours before sampling. However, these data do not indicate how the water was used and what types of sudden impacts the system was subjected to. By sampling on, or just after the weekend, the survey also potentially targeted the time period impacted by maximum flows, but without more detailed monitoring it is difficult to assess the impact of water usage on the systems.

Patterson (2004a) expresses the opinion that a water conservation mentality is important in households with onsite wastewater treatment, to minimise the area of land required to apply the hydraulic load. He suggests using strategies, such as pressure limiting devices, but comments that the installation of water saving devices or appliances often cost more money than they save. This highlights a need for careful thought at the design stage to ensure that a new house is water efficient when onsite disposal is utilised. Installation of water efficient appliances and care in placing the hot water service close to the taps is significantly cheaper during the initial construction of a dwelling.

Sudden increases in hydraulic load on the system can be minimised by more even distribution of high water usage activities, such as laundry, baths and showers, throughout the day or week. A better understanding of onsite wastewater systems and the effect of these impacts would help engender better household habits. The Municipal Association of Victoria (MAV) recently launched its 'Smart Septics' initiative to help address some of these problems. The program includes a community education package to assist Environmental Health Officers in raising community awareness of correct use of onsite wastewater treatment systems.

The installation of a reliable, low risk system can easily be undone at household level through ignorance (Patterson 2004b). Chemical usage in the household will inevitably impact on the quality and quantity of effluent produced by the system. However, there is currently little information displayed on the packaging of household cleaning, laundry and personal care products about their suitability for use in households with onsite wastewater treatment systems. Few residents were aware of which products are suitable and indicated that they had not been provided with this information. A definitive need for easily readable information was identified.

The findings were affected to a degree by the small sample size, as one or two very high or low results could affect the ability to find a significant difference or correlation. The nature of the subjective groupings (high, medium or low) might also have affected the results and more detailed analysis of the results might have shown other relationships between factors investigated and compliance.

Other factors such as resuspension of sediments when sampling from the smaller pump-out chambers of the Supertreat systems might also have impacted on the results. Beal et al. (2005) question how failure is defined for AWTS, and whether a single sample result is a true indication of performance, given the variability of effluent quality over time and possibility of sampling errors. Consequently, the results of the survey should only be seen as an initial snapshot. It also became apparent that further study is necessary to eliminate the overwhelming effect of the presence or absence of chlorine tablets before clear results could be gained on the effect of household habits.

Ideally, a multifaceted approach to management of AWTS would take into account the various aspects of risk. In a report on wastewater issues in Gippsland, Smith (2004) recommends that principles such as the waste hierarchy (where avoidance and reuse are preferred over treatment), the precautionary principle, intergenerational equity, conservation of biological diversity, and ecological integrity should be adopted in the management of wastewater issues in line with the Victorian *Environment Protection Act 1970*. Patterson (2004b) also espouses avoidance and reduction as the key rather than relying solely on treatment.

In terms of monitoring of AWTS it might be necessary to re-think the aims of assessment. The results of the study suggest that assessment of the household water and chemical usage, and quality of maintenance of these systems, might prove to be more useful than relying solely on an annual laboratory report from a single grab sample. While it might be difficult to monitor and measure the raw effluent quality and quantity households produce, a self-assessment tool could be developed that allows residents to assist them in management of risk factors.

There has been a recent shift from a prescriptive to a performance-based approach to wastewater management, reflected in changes to Australian Standards and state guidelines for on-site sewage management (Whitehead et al. 1999). However, Blumenthal et al. (1989) suggest that measures for health protection need not rely on total pathogen removal by waste treatment processes. Utilising a multi-barrier risk management approach requires prevention of exposure to wastewater pathogens by exclusion of access to irrigation areas, handwashing, and use of gloves in the garden.

Conclusion

The results of this study of aerated wastewater treatment systems clearly identified a problem revealing very high rates of non-compliance. While some failures to meet BOD and suspended solids compliance limits occurred in the AWTS investigated, the major finding of this study was the effect of the presence or absence of chlorine tablets in the systems. A key finding in the survey was the crucial role that residents could potentially play in improved management of the risks associated with AWTS. A well-informed owner could not only modify household behaviour, but also prompt service contractors and suppliers to provide more effective maintenance of the systems. This strongly suggests that the provision of material that is easily accessible and understood to AWTS owners is likely to be the most effective method in increasing compliance levels.

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References

American Public Health Association, American Water Works Association, and Water Environment Federation (APHA-AWWA-WEF) 1998, *Standard Methods of the Examination of Water and Wastewater*, 20th edn, Washington DC.

Beal, C., Gardner, E., Christiansen, C. & Beavers, P. 2005, 'A review of on-site wastewater practices in South-East Queensland', *Water*, June, pp. 69-74.

Blumenthal, U.J., Strauss, M., Dara, D.D. & Cairncross, S. 1989, 'Generalised model of the effect of different control measures in reducing health risks from waste reuse', *Water Science and Technology*, vol. 21, pp. 567 - 77.

Brisbane City Council 2005, Water Wise Fact Sheet: Average Domestic Water Usage Chart, <http://www.thisplace.com.au/eco/tt_waterusage.htm> 3rd September 2005.

Colac Otway Shire 2002, *Draft Wastewater Management Strategy*, <http://www.colacotway.vic.gov.au/files/wwms_draft.pdf > 2nd July 2005.

Department of Local Government NSW (DLG NSW) 1998, *Environment and Health Protection Guidelines: On-site Sewage Management for Single Households Part 5: Onsite Sewage Management System Options*, <http://www.dlg.nsw.gov.au/Files/Information/onsite.pdf > 19th May 2005.

Environment Protection Authority (EPA) Victoria 2002, *Guidelines for Aerated Onsite Wastewater Treatment Systems*, EPA Publication No. 760, January, Victoria, <http//:www.epa.vic.gov.au>

Environment Protection Act 1970 (Victoria)

Environment Protection Authority (EPA) Victoria, 2003, *Guidelines for the Use of Reclaimed Water*, EPA Publication No. 464.2, June.

Fearnley, E.J., Thomas, K.D. Luscombe, A. & Cromar, N.J. 2004, 'Determination of water usage rates and water usage patterns in a residential recycling initiative in South Australia', *Environmental Health*, vol. 4, no. 2, pp. 72-81.

Geary, P.M. 1998, *Environment Design Guide: Domestic Wastewater-Treatment and Re-use*, The Royal Australian Institute of Architects.

Geary P.M. & Whitehead, J.H. 2001, 'Groundwater Contamination from On-site Domestic Wastewater Management Systems in a Coastal Catchment', *9th National Symposium on Individual and Small Community Sewage systems Proceedings*, American Society of Agricultural Engineers, St. Joseph, Michigan, pp. 479-87.

Gerba, C.P. & Smith, J.L. 2005, 'Sources of pathogenic microorganisms and their fate during land application of wastes', *Journal of Environmental Quality*, vol. 34, no. 1, pp. 42-8

Khalife, M.A. & Dharmappa, H.B. 1996, 'Aerated septic tank systems: Field survey of performance', *Water*, vol. 23, no. 5, pp. 25-8.

Martens, D.M. & Correy, B. 1992, *On-site Domestic Aerobic Wastewater Treatment: Process and Design*, Martens & Associates, Integrated Environmental Management and Planning, November, <www.martens.com.au> 17th September 2005.

Patterson, R.A. 2004a, 'Water efficiency, domestic appliances and hydraulic design for on-site systems', *Proceedings of 1st International Conference on Onsite Wastewater Treatment and Recycling*, Environmental Technology Centre, Murdoch University, Perth 11-13 February 2004, <http://www.lanfaxlabs.com.au> 12th September 2005.

Patterson, R.A. 2004b, 'A resident's role in minimising nitrogen, phosphorous and salt in domestic wastewater', in *Tenth National Symposium on Individual and Small Community Sewage Systems Proceedings*, ed. K.R. Mankin, Sacramento, California 21-24 March, American Society of Agricultural Engineers, <http://www.lanfaxlabs.com.au> 12th September 2005.

Petrozzi, M. & Martens, D.M. 1995, *On-site Sewage Treatment Options: A Discussion Paper on the Environmental and Health Ramifications of On-Site Domestic Wastewater Treatment and Disposal Options*', Martens & Associates, Integrated Environmental Management and Planning, January, <www.martens.com.au> 17th September 2005.

Smith, J. 2004, Report on Waste Water Management Issues in Gippsland, <http://www.wastewatersolutions.com.au> 19th May 2005.

Standards Australia 1995, AS 4276.7 Water Microbiology Method 7: Thermotolerant Coliforms and *Escherichia coli* - Membrane Filtration Method.

United States Environmental Protection Agency (USEPA) 2000, *Decentralised Systems Technology Fact Sheet: Aerobic Treatment*, USEPA Office of Water, Publication No. 832-F-00-031, December, USEPA.

Whitehead, J.H., Geary, P.M., Linich, M. & Patterson, R. 1999, 'Responding to the changing training needs of on-site wastewater management professionals', *Proceedings of Onsite '99 Armidale*, <http://www.lanfaxlabs.com.au> 3rd June 2005.

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Graduate Certificate in Environmental Health (Risk Assessment)

ARE YOU:

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Graduates will be able to demonstrate:

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- ability to use risk assessment to form successful risk management strategies;
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Program of Study

The course commences in Semester 2 each year and is designed to be completed in one semester. It comprises three core topics:

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- ENVH8003 Principles of Risk Assessment, Management and Effective Communication (6 units)

Full details of these topics can be found at: http://www.som.flinders.edu.au/FUSA/EnvHealth/Default.htm

Admission Requirements

See website for details. http://www.flinders.edu.au/courses/postgrad/risk.htm

Course Fees

The course is available on a fee-paying basis. Fee details can be found on the University's website at:

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Application forms are available from:

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Further Information

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Administrative officer (08) 8204 5674

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How an Evidence-driven Audit Cycle Model Can Be Used to Assist Quality Assurance in Environmental Health Education

Erica James, Lyn Talbot and Margaret Kent

School of Public Health, La Trobe University, Bendigo

In Australia, there is a wide range of undergraduate and postgraduate courses that address environmental health issues. Universities are responsible for delivering programs of sound quality to students, and employers of university graduates have expectations of the competency of those graduates to meet professional standards. In addition to these QA activities, the Australian Institute of Environmental Health (AIEH) accredits courses whose graduates are eligible to apply for membership of AIEH and practice as environmental health officers. This paper describes the development and pilot testing of a continuous, evidence-driven audit cycle of university course quality assurance (QA) activities for the Bachelor of Public Health (Environmental Health) program at La Trobe University. When implemented, this cycle can reduce the peaks in University QA activity to a more even and continuous process, while ensuring that all reporting requirements are met, including external and internal QA requirements and AIEH accreditation requirements. The main outcome of this project was an evaluated, conceptual model that streamlines quality processes, and a reflective checklist that ensures the ongoing QA cycle process is continued in a timely manner regardless of staff changes or structural reorganisation. Other universities might consider using this form of cycle to help ensure the quality of Environmental Health education.

Key words: *Curriculum; Quality Assurance; Environmental Health*

To meet current and emerging needs of environmental health professionals in Australia there is a wide range of undergraduate and postgraduate courses that address environmental health issues. There are eight environmental health undergraduate courses in Australia at present and all are at various stages of accreditation with the Australian Institute of Environmental Health ([AIEH] 2006). As recognised in the Environmental Health Symposium on Education, Research and Workforce:

> *Education, research and workforce are inter-related and development in each of these areas needs to build on existing links in order to strengthen environmental health education, research and workforce capacity. Workforce needs and information gathering through research will assist in guiding the direction for educational development. Appropriate and responsive education and research will in turn support workforce development* (Commonwealth Department of Health and Aged Care 2000).

This quote illustrates the importance of designing vocationally based university courses to meet workforce competency requirements.

Universities are responsible for delivering programs of sound quality to students and are required to report the results of their Quality Assurance (QA) processes through the Australian Universities Quality Assurance (AUQA) audit process. Quality Assurance is a:

> *formal and systematic exercise in identifying problems in delivery, designing activities to overcome the problems and carrying out follow-up monitoring to ensure that no new problems have been introduced and that corrective steps have been effective* (Lapsley 2000).

Both institutional accreditation (for example, accreditation of a hospital) and course accreditation (for example, accreditation of a program of study such as in teaching) are recognised and accepted components of QA (Lapsley 2000). In addition to university QA processes, some courses, which lead directly to professional practice, undergo accreditation with outside bodies, to ensure practitioners meet certain essential competencies for practice. This is often necessary in order for graduates of that program to gain professional recognition by the professional body representative of their discipline, for example, the role played by the AIEH in accrediting university programs whose graduates can gain professional recognition as Environmental Health Officers in Australia.

The university, industry and the wider community benefit from offering well designed and well structured courses, which directly meet the needs of new practitioners in the field. Well designed, high quality courses reduce the likelihood of student discontent or litigation. Students benefit because, upon graduation, they make a smooth and successful transition into professional practice, possessing the essential prerequisites in their field.

Academic and university administration staff need to be aware constantly of the parallel processes of university QA and external accreditation, to ensure that they have documented evidence of their ability to meet the requirements of each agency. Also, it is important to ensure that any alterations made to a course do not reduce their ability to meet quality and accreditation requirements. However, from an academic and course administration point of view, QA and course accreditation processes can be quite onerous to undertake, especially in terms of the preparation of documentation and the logistics of consulting with community and external experts in the field.

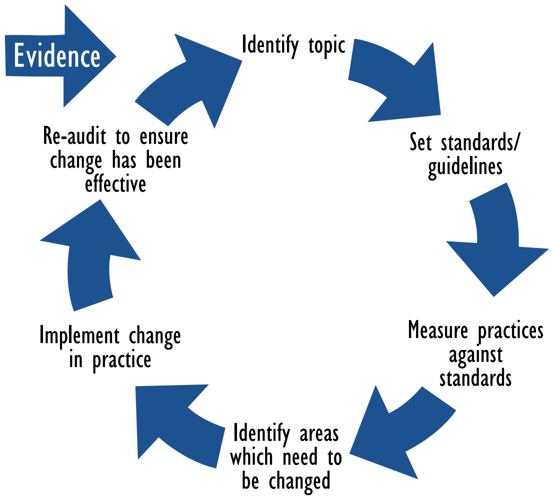
The introduction of a continuous evidence-driven audit cycle was considered to have the potential to reduce the peaks in QA and accreditation activity to a more even and continuous process. It was also seen to be of benefit in clearly documenting the requirements and stages of QA that need to be undertaken, even if there are personnel changes in course administrators and academic course coordinators, or university restructures. It allows for documentation and tracking of changes that are made to course content and delivery, such as changes made in response to an external accreditation review. In recognition of these challenges, and the recent focus on evidence based curriculum development that ensures that research evidence informs course development and forms an important part of quality processes (Greenhalgh et. al 2003), this project was designed to develop and pilot test an evidence-driven audit cycle model. The model was developed and based on published research evidence from the well respected and validated quality cycle proposed by Gray (2001) as shown in Figure 1.

This cycle was applied to the Environmental Health Stream of the Bachelor of Public Health as a case study, incorporating re-accreditation of the BPH(EH) by the AIEH in 2005. This paper deals with mapping and ordering the procedures of the cycle rather than reporting the specific details of data gathered or changes recommended by the AIEH. This article describes how the Quality Cycle was used to incorporate more order into existing QA procedures, to identify duplication and gaps in data collection procedures or types of data, and as a framework for deciding on the best sequence of activities to inform future planning. Thus the cycle can be adapted to any practice-based course offered by any Australian university.

The specific objectives of this project were to:

1. Identify the full range of relevant QA reporting requirements of the BPH, including those both internal and external to the University.

Figure 1: Evidenced based medicine quality cycle



Source: Gray 2001

2. Map the requirements of varying review processes to identify common data needs.

3. Measure existing data gathering processes against the needs identified in phase 2.

4. Identify the changes required to current data collection procedures.

5. Initiate revised data collection strategies.

6. Re-audit to see if the change has been successful.

7. Develop a reflective checklist to assist future users to identify their ongoing needs.

The objectives were designed to correspond with Gray's validated quality cycle (2001), and were achieved sequentially. They provided an effective development framework for each phase of a new quality data collection cycle.

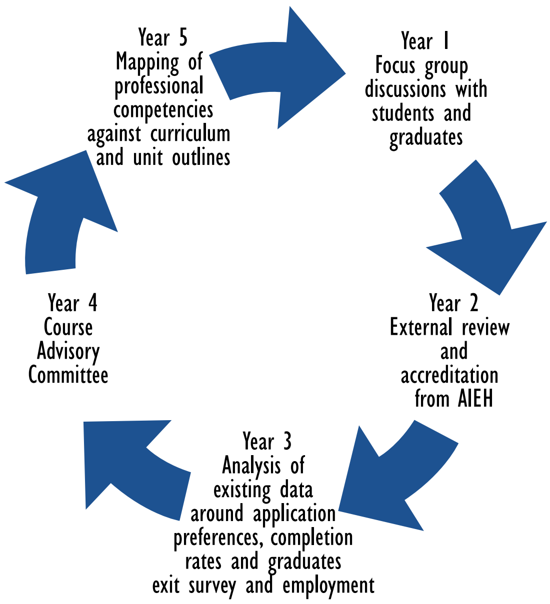
At La Trobe University a program of study such as the Bachelor of Public Health is referred to as a *course* that is made of major *streams* (such as Environmental Health or Health Promotion) and comprising a program of separate *units*.

QA Reporting Requirements of the BPH (EH)

This phase identified the parallel quality improvement processes and reporting requirements related to Course Reviews both internal and external, QA of individual units, and reaccreditation by the AIEH. In this phase, documentation from the University and external organisations was scrutinised to determine the range of QA reporting requirements.

The cycle of QA data collection procedures previously implemented by the Department of Health and Environment, the administrative level in the University which is responsible for collecting and reporting on QA data, was a five yearly cycle that enabled continuous quality improvements to be made to the course. Figure 2 outlines the data collection activities undertaken by the Department in each year of the cycle.

Figure 2: Department of Health and Environment QA data collection cycle



In addition to the activities undertaken in this five-year data collection cycle, the Department had also been involved in the following University quality activities:

- Australian Universities Quality Agency (AUQA) Audit

- University Accreditation Process for New Courses
- Course Reviews
- Course Advisory Committee
- Unit Evaluation (Quality Assurance of Subjects - QAS)
- Unit Outline and Exam Moderation
- Student Evaluations of Teaching

Set standards and guidelines

For each of the quality activities listed above, there are a variety of data gathering systems and sources of information. The aim of this phase of the project was to map the various review processes and identify common (or overlapping) data needs, along with the optimal timing for information gathering.

There were some sources of data required for only one quality activity, for example, graduation and attrition rates were required only for internal course advisory committees. Other data collection needs were duplicated in a number of activities. For example, the AUQA audit, internal University course advisory committees and AIEH required documentation that demonstrated EH literacies and skills of graduates against the curriculum. AIEH accreditation, internal course advisory committees and course review procedures all required interviews with and/or written feedback from Alumni or Employer Groups. This phase of the project allowed us to identify all the data and documentation required to meet the needs of all quality activities.

Measuring practice against standards

During this phase, the actual practices, in terms of quality data collection procedures were tabled against the required QA standards/procedures for each type of review or audit (as identified in phase 2 of the project). Tables were compiled to indicate common areas of data collection between the QA processes, and document any gaps in data collection procedures.

Identification of areas that need to be changed

This phase analysed, in terms of the content of the course as well as the steps in the current QA processes and their sequencing, those areas that needed to be changed to streamline the QA process, avoid duplication, and to ensure a more even spread of data gathering over the cycle. In the development of this model, this phase was informed by internal and external data collection. As a result, a number of gaps in processes or accrued information were identified, the most significant being that although Health Promotion competencies were mapped against course content for the Bachelor of Public Health in 2004, it became evident that the AIEH literacies (competencies) also needed to be mapped against the Environmental Health stream content to measure practice against standards. Table 1 shows a sample unit map showing the unit objectives along with the corresponding health promotion competencies and environmental health literacies.

This phase also identified the invaluable capacity building that occurred within the Department as a result of having all staff (including administrative staff) involved in the mapping processes for this project. It facilitated information sharing, and raised awareness of the need to enable ongoing access to, and documentation of, the wealth of corporate knowledge into the one place.

Implementation of changes in practice

This phase involved the implementation of changed QA and data recording processes identified as deficient in the previous phase. In the pilot test of this model, the AIEH re-accreditation of the Bachelor of Public Health (EH) in 2005 was incorporated into the implementation phase. It involved, for example, revision of individual unit

Table 1: A sample unit map showing the unit objectives along with the corresponding health promotion competencies and environmental health literacies

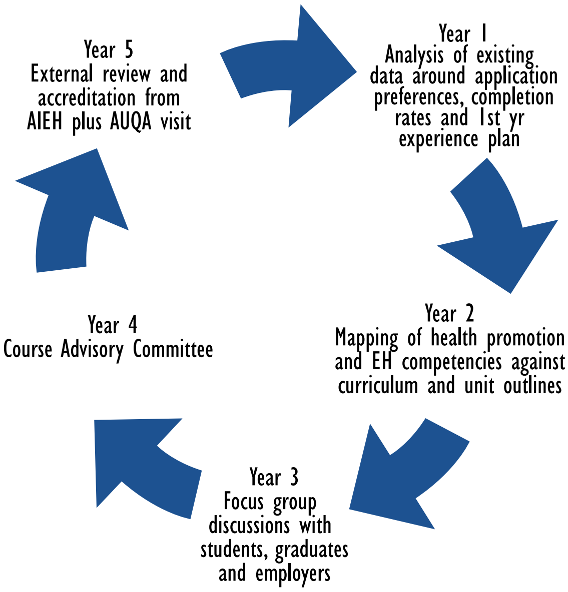
UNIT TITLE	AIMS:	OBJECTIVES:	ASSESSMENT:	HP	ENVIRONMENTAL HEALTH LITERACIES AND CORE CONCEPTS
Environmental Health HLT21EH	The aim of this subject is to provide the opportunity for students to develop a greater understanding of the interrelationship between the physical environment and human health in preparation for public health practice.	Upon successful completion of the subject, students will be able to: 1. Discuss the interdependence of humans and their physical environment. 2. Discuss the relationship between some of the content themes and health. 3. Develop an understanding and outline some of the theoretical and action frameworks that public health practitioners can use to promote, protect and restore the health of the planet and consequently human health. 4. Discuss the interrelationship between environmental health and social justice. 5. Critically appraise the environmental health literature. 6. Develop skills in communicating environmental health issues to a wide range of audiences through report writing.	Assessment 1 - 2,000 - 2,500 word assignment (50%) Assessment 2 - One 2-hour examination (50%) Assessment 1 Literature review focusing on a theme of significant environmental importance such as climate change, ozone depletion, soil quality, water quality and scarcity, air quality, population increases and consumption patterns or biodiversity. A. Thinking globally provide an overview of the global environmental health issues relating to the theme you have identified. Discuss the actual or potential long and short-term impacts for the world. B. Thinking globally identify actual or potential health risks to members of a local community that have developed because of the factors associated with global conditions of change discussed in Part A. These will be local public health issues which also have relevance for people everywhere. Assessment 2 One 2-hour examination (50%) Comprising: short answer questions (15%), multiple choice (15%), discussion - short essay (15%)	Competencies N2 P1 K1 K6 I10	Public health principles • International public health issues and initiatives eg. Health for All, Ottawa Charter. • The interaction between human lifestyles, consumption patterns, urbanisation and health. • Social inequalities in health. Sustainable development and environmental health principles • The historical development and current paradigms pertaining to the discipline of environmental health in Australia and overseas; • Links between good health and the state of the environment • Principles of environmental health justice and equity • Promoting healthy environments through sustainable development thinking • The complexity of population change, resource management and climate change • The links between environment and society, economics and environment, politics and environment, and environmental health development • Principles of environmental protection, ecologically sustainable development and the precautionary principle • Impacts of global and local pollution and environmental degradation * Resource depletion and consumption and environmental protection Foundation sciences Basic environmental toxicology

objectives, revisions of course content and structure, revision of student assessment profiles, and mapping of Environmental Health literacies against unit outlines. This process identified the 'ideal' sequence for data collection and therefore also resulted in a revision in the order of activities in the Department's QA data collection cycle.

Re-audit to ensure change has been effective

Re-auditing systematically reviewed the required changes to assess the quality and scope of implemented changes. All of the suggested changes from the previous phase had been incorporated or actioned. Recommended changes to the course were documented and if, for example, changes were required to unit objectives to match better with required literacies or competencies, or workforce expectations, this would be audited to ensure that the changes were implemented in the unit outlines, on the subject database, in the handbook, and in the actual content of the teaching program. The revised QA data collection cycle is shown in Figure 3.

Figure 3: Bachelor of Public Health revised data collection cycle



Identify new aspects for audit if necessary

To ensure the ongoing QA cycle process is continued regardless of staff changes or structural reorganisation within the wider University, a reflective checklist and recommended quality cycle was developed (see Figure 3 for the revised data collection cycle). The reflective checklist for data gathering for the course /Department quality cycle is comprehensive and ensures that staff are aware of all aspects of data collection for external and internal review processes. If external reporting or reaccreditation requirements change then suitable amendments can be made to the Quality Cycle processes. For example, some of the questions on the reflective checklist from this project are provided in Box 1.

Box 1: Reflective checklist

Reflective checklist for data gathering for a course/Department quality cycle

AUQA -When planning a Quality Cycle work backwards from this date. Are you prepared in advance?

Do you:

- Know the review date?
- Know what data will be required and how it will be collated?
- Need to brief the staff to engage them in the process?

Do the course documents and course aims reflect the objectives of the strategic plan?

COURSE REVIEW COMMITTEE (INTERNAL)

Have you

- Implemented the changes identified in previous reviews?
- Documented any changes in appropriate places, such as Course Document master copy, Unit data-base, Handbook and Unit Outlines?

RE-ACCREDITATION

Is it necessary? - check with the external registering authority, such as the AIEH

** complete the processes for an external reaccreditation in the year before the AUQA Audit because the data will serve multiple purposes.

Are you aware of:

- The data requirements necessary to meet their terms of reference?
- What data has already been collected for other quality processes and can be assembled?
- What additional data is required?

COURSE ADVISORY COMMITTEE

** complete the processes for a CAC in the year before the external re-accreditation in required because the data will serve both purposes.

Do you know:

- The data requirements necessary to meet their requirements?
- What data has already been collected for other quality processes and can be assembled for this?
- What additional data is required? Qualitative or quantitative?
- What data can be multi-used? (Can meetings with experts from the field, current and former students inform quality revisions in course focus, structure and content, and ALSO meet the requirements of the re-accreditation authority at the same time? Are there common themes?

Does each unit grid:

- State the aims and objectives and record content and separate literacies/competencies?
- Get updated to reflect review recommendations and literacy/competency updates?

DEPARTMENT REVIEW PROCESSES

Does Course recruitment and information material record the graduate attributes?

Does the Department maintain a data file of:

- A Quality Assurance (QA) plan indicating the frequency of QA for each unit?
- A Quality Assurance report for each unit to advise unit and course changes?
- A spreadsheet, updated annually with ENTER scores for enrolled students?
- Popularity Polls for the course, and completion rates?
- Course Completion data relevant to the course?

Are QA reports available to students (such via the WWW)?

Conclusion

The need for QA evidence is well accepted and is a requirement for all University courses. This project has linked with the University Strategic Plan and the Unit Level Planning and Review processes, which identify that the external professional and stakeholder expectations (such as AIEH registration requirements) must be integrated into the quality cycle. The main outcome is an evaluated conceptual model that streamlines quality processes, and can be adapted to a range of undergraduate courses across the University sector, regardless of discipline base. Use of the model has delivered an improvement in management processes because all staff in the Department are familiar with the expectations and purpose of various forms of data gathering, the tasks are spread more evenly across the five-year cycle, the processes are undertaken collaboratively, and the existing documentation is updated in a systematic manner. The model enhances recognition of the importance of professional competencies for universities and accrediting bodies, and of all stakeholders internal and external to the University.

The introduction of a continuous evidence-driven audit cycle such as this has the potential to reduce the peaks in QA activity to a more even and continuous process, and provide a systematic and comprehensive approach that is sustainable regardless of staff changes or organisational restructures. In addition, the process provides a useful orientation for staff new to the university sector (and for new Course Coordinators) for whom the processes and requirements can be very confusing, and seem overwhelming. In addition, the clear and definite purpose for each type of data collection reinforces the continuing cycle of feedback, reflection and change. Importantly, the implementation of a continuous evidence-driven audit cycle model means that the costs of QA processes, both financial and in terms of staff time, are more evenly spread across the five-year cycle, and the cycle ensures greater efficiency in data gathering because it can be used for multiple purposes. Other universities might consider using this form of cycle to help ensure the quality of Environmental Health education.

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References

Australian Institute of Environmental Health (AIEH) 2004, *Course Accreditation Policy 2005*, Australian Institute of Environmental Health, Brisbane.

Australian Institute of Environmental Health (AIEH) 2006, *AIEH Course Accreditation*, <http://accreditation.aieh.org.au/accred_uni.php> 31 march 2006.

Commonwealth Department of Health and Aged Care 2000, *Proceedings of the Environmental Health Symposium on Education, Research and Workforce*, 17 and 18 July 2000, Canberra.

Gray, J.M. 2001, *Evidence Based Healthcare: How to Make Health Policy and Management Decisions*, 2nd edn, Churchill Livingstone, London.

Greenhalgh, T., Toon, P., Russell, J., Wong, G., Plumb, L. & Macfarlane, F. 2003, 'Transferability of principles of evidence based medicine to improve educational quality: Systematic review and case study of an online course in primary health care', *British Medical Journal*, vol. 326, pp. 142-5.

Lapsley, H. 2000, 'Quality measures in Australian healthcare', in *Health Reform in Australia and New Zealand*, ed. A. Bloom, Oxford University Press, Melbourne.

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An Economic Analysis of the Food Safety Program of a Local Government in Western Australia

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The objective of this study was to conduct a break-even analysis of the food safety program of the City of Swan, a local government authority in Western Australia. Costs of the local government food safety program were calculated from its costs to the agencies involved in its implementation. Cost savings generated by the program were based on an estimate of the cost per case of foodborne illness calculated by Food Standards Australia and New Zealand. The break-even point of the program was determined by calculating the number of cases needed to be prevented in order for the food safety program to be cost neutral. The total cost of the City of Swan's food safety program in 2003/04 was A$234,680, with a net cost of A$142,643 after allowing for revenue raised through licensing and service fees. Under the assumption of a cost per case of foodborne disease of A$630, the break-even number of cases that would need to have been prevented by the activities of the food safety program so that its costs were exactly equal to the cost savings generated from prevented cases was 226. Using higher and lower estimates of the cost per case, provided lower and upper break-even points of 118 and 453 respectively. An annual reduction of 226 cases represented an estimated 1.2% decrease in the total number of cases of foodborne illness in the City of Swan. A program effectiveness of this low order of magnitude appears credible, particularly given evidence suggesting the City of Swan has a relatively effective food safety program. Foodborne illness is a serious public health problem. This study shows it is reasonable to argue that the food safety program of the City of Swan is likely to be a cost-effective program that provides net benefits to the community.

Key words: *Foodborne Illness; Food Safety Inspection Program; Break-even Analysis; Economic Evaluation*

Foodborne contamination and illness can be caused by microbiological, chemical or physical hazards (Engel & MacDonald 2001). The consequences of foodborne illness range from mild gastroenteritis to life threatening conditions, such as neurological, liver and kidney conditions. While the familiar symptoms of food poisoning include vomiting, abdominal pain, diarrhoea and fever, there are also potential longer term symptoms such as arthritis, meningitis, haemolytic-uraemic syndrome, septicaemia, cancer and spontaneous abortion (Engel & MacDonald 2001).

In Australia, routine surveillance of foodborne disease relies on reports from doctors or clinical laboratories relating to people diagnosed with gastrointestinal or foodborne infections. Several microbiological infections are specifically notifiable to state and territory health departments. In Western Australia there were 1681 notifications of locally acquired enteric disease in 2003/04, with the most common being campylobacteriosis (Department of Health Western Australia 2004). At a national level, data on communicable diseases including foodborne illnesses are collected by the National Notifiable Disease Surveillance System (Department of Health and Ageing 2006).

Reliable data on the incidence of foodborne disease are not available for numerous reasons in Australia or elsewhere.

These include the fact that many microbiological infections are not notifiable, such as those caused by viruses that have been estimated to cause between 30 and 40% of all cases (Food Standards Australia and New Zealand 2004). Further, foodborne illnesses caused by chemical or physical contamination are not notifiable and individuals do not always go to a doctor or hospital for treatment of foodborne illness, so these cases are not captured either. Further compounding the issue is that for many suspected cases the potential causes are not available for testing so the cause of the illness cannot be established conclusively.

Estimates of the incidence of foodborne disease must thus be extrapolated from a range of sources including notifiable disease registers, community surveys, laboratory records and clinical studies. Food Standards Australia and New Zealand (FSANZ) is the principal bi-national independent statutory authority for maintaining a safe food supply in Australia. Based on a variety of sources, Food Standards Australia and New Zealand (2004) estimated an annual 4.2 million individual cases of food-related illness in Australia. This figure represented the average across four estimates produced from different sources, with the estimates ranging from 2.7 to 5.4 million. Different views have been expressed about the accuracy of the FSANZ figure of 4.2 million cases of foodborne illnesses, especially with regard to its underlying assumptions. Based on different assumptions, Sumner, Ross and McMeekin (The Allen Consulting Group 2002, p. 20) have suggested an incidence of foodborne illness in the range of 1.0 to 2.3 million cases per annum.

Despite debate about the number of cases, foodborne disease caused by contaminated food is unquestionably a serious public health problem in Australia. Responsibility for programs to reduce the risk to public health from contamination in the food supply is primarily the responsibility of state, territory and local governments. Food safety programs include the investigation of cases of foodborne illness, monitoring food hygiene in food premises, food sampling and ensuring compliance to food hygiene and food safety legislation. In Australia, most of this work is delegated in legislation to local governments.

From an economic perspective, very little is known regarding the benefits and costs of programs to reduce the risk to public health from food contamination. The objective of this study was to explore this question in relation to a food safety program of a local government authority. The chosen local government authority was the City of Swan, a large local government in the outer metropolitan area of Perth, Western Australia. It has a population of approximately 90,000 people in an area covering 1042 square kilometres in the north east of the metropolitan area. The approach adopted for the study was a break-even analysis, in which the costs of operating the food safety program were compared with the cost per incident of foodborne illness, to determine the number of cases needed to be prevented for the food safety program to be cost neutral. In addition, the likelihood of this number of cases being prevented was considered. Break-even analysis was used, rather than other more widely used methods of economic evaluation of health programs, such as cost-effectiveness analysis or cost-benefit analysis, because of the limited reliable data on the effectiveness of food safety programs in preventing foodborne illness. Other methods of economic evaluation require these effectiveness data.

Method

Costs of the food safety program

The total costs of the local government food safety program were calculated based on its costs to the two agencies involved in its implementation, the City of Swan and the WA Department of Health. At a local government level, the main components of the food safety program consist of the routine risk assessment inspection of food premises within the local government boundary, food sampling, investigation of food complaints and incidents of foodborne disease, and general monitoring of food safety standards. The Food Safety Branch at the WA Department of Health plays a key supporting role primarily in relation to policy regarding food safety, development of legislation, food safety monitoring and education.

In calculating costs, the costs of each activity of the food safety program at the City of Swan were separately identified. Where possible, exact costs of activities were calculated. Where this was not possible, the hours spent on the activities were estimated and the cost of the activities were calculated based on an hourly cost plus any additional fixed costs. In the case of the WA Department of Health, a percentage of the annual budget for its Food Safety Branch was allocated to the City of Swan's food safety program, based on the size of the population of the City of Swan relative to the total population of Western Australia. Since the Food Safety Branch accounts for such a small share of the WA Department of Health's overall budget, no share of corporate overheads of the Department of Health was allocated to the cost of the City of Swan's food safety program.

The food safety program at the City of Swan raises revenue through annual licensing fees that are paid by certain categories of food service organisations and by charging a service fee for approving plans for new food businesses. This income provides some cost recovery to the local authority for activities carried out in the food safety program. Net costs of the food safety program were calculated by subtracting this revenue from the cost of implementing the food safety program.

Cost savings generated by the food safety program

Each case of foodborne illness prevented by the food safety program will result in cost savings to society equal to the cost per incident of an episode of foodborne disease. In broad terms, the types of cost resulting from foodborne illness include treatment costs, regulatory and response costs, the cost of legal action, costs to affected persons and their families, employer costs from loss of productivity and losses to food companies (Table 1).

Table 1: Cost factors associated with foodborne illness

Cost category	Types of cost
Health system	Treatment costs including for GP consultations, emergency department presentations, hospital admissions, pharmaceuticals, other miscellaneous
	Food safety program costs including investigation of episodes of foodborne illness
Other government costs	Court and other legal costs
Affected persons and their families	Travel, out of pocket expenses for health care and other items, loss of earnings, long-term health consequences, loss of quality of life, legal costs
Employers of affected persons or their families	Productivity losses
Loss to food companies supplying offending food	Loss of sales, recall and destruction of food, loss of reputation, fines, legal costs

Source: FSANZ 2004

Several countries have attempted to measure and value the cost of an incident of foodborne disease. In the US, a recent report (United States Department of Agriculture 2004) estimated the average cost of cases of selected foodborne illness for five specific pathogens: *Campylobacter* (all serotypes), *Salmonella* (non-typhoidal), *E. coli* O157, *E. coli* non-O157 STEC, and *Listeria monocytogenes*. These costs ranged from US$612 (A$820, yr. 2000 dollars) for *Campylobacter* (all serotypes) to US$922,583 (A$1.237m.) for *Listeria monocytogenes*, with the overall cost per case across the five selected pathogens being US$2029 (A$2720). These cost estimates included medical costs, productivity losses from missed work, and an estimate of the value of premature death. Mayers and Couture (cited in Food Standards Australia and New Zealand 2004, p. 15) estimated the average cost per case of foodborne disease in Canada at around CAD$1000 (A$1210, yr. 1999 dollars), which was considerably lower than an earlier estimate by Todd (1989) of an average cost of foodborne disease for 12 pathogens of CAD$6220 (A$7,526, yr. 1989 dollars). In the UK, the Food Standards Agency (FSA) (2000) calculated an average cost of infectious intestinal disease. While foodborne disease does not map perfectly onto this category, there is a strong relationship. For all types of pathogens, the average cost per case was GBP£79 (A$198, yr. 1995 dollars), with the cost rising to GBP£250 per case ($A627) where the affected person sought assistance from a general practitioner (GP).

In Australia, FSANZ (2004) has produced a figure for the cost per case of foodborne illness based on an analysis by Access Economics. Using various assumptions relating to loss of productivity for people directly affected by foodborne illness and those caring for them, the use of health system resources, and costs to affected persons and their families (excluding quality of life loss), the average cost per incident of foodborne illness was calculated at A$315. Drawing on international studies, FSANZ then doubled this figure to A$630 to account for other costs including losses to food companies supplying the offending food, the cost of the government's regulatory response, loss of quality of life and the multiplier impact to the rest of the economy due to the productivity losses caused by foodborne illness.

FSANZ's estimate of the average cost of an incident of foodborne disease is of the same order of magnitude as the FSA's estimates for the UK for cases visiting a GP and below estimates for the US and Canada. As this was the only estimate for Australia, and it appears conservative compared with estimates produced in international studies other than the UK, this study accepted FSANZ's figure of A$630 as the average cost of an incident of foodborne disease. In a sensitivity analysis, a lower and higher figure of A$315 and A$1210 were used, which were based respectively on the direct cost estimate calculated by FSANZ and the Canadian estimate adjusted to 2004 Australian dollars.

Break-even analysis of the food safety program

The number of cases needed to be prevented for the food safety program to be cost neutral was calculated based on the net costs of the program and the cost per case of foodborne illness. The likelihood of this number of cases being prevented was examined.

Results

The total cost of the City of Swan's food safety program in 2003/04 was A$234,680, with the City of Swan's share of the budget of the Food Safety Branch in the WA Department of Health accounting for A$105,600 (45%) of this expenditure (Table 2). Other major cost components were the risk assessment inspection of food premises (A$65,000) and food sampling (A$30,980). In 2003/04, licensing income amounted to A$92,037, thus resulting in a net cost of the food safety program of A$142,643 (Table 3).

Under the assumption that each case of foodborne disease costs A$630, the break even number of cases that would need to have been prevented by the activities of the food safety program, so that its costs were equal to the cost savings generated from prevented cases, was 226 (Table 3). To test the sensitivity of this break even number of cases, a higher and lower cost per case were also tested. If a higher cost of foodborne illness of A$1210 per case was used then the break even number of cases was 118, and if a lower cost of A$315 was used then the break even number increased to 453.

The question of whether or not the food safety program at the City of Swan would have prevented 226 cases of foodborne illness is a difficult one, with no available data relating to the effectiveness of local

Table 2: Costs of the food safety program to the City of Swan, 2003/04

Item	Description	Details	Source	Total Cost[1]
Routine risk assessment (inspection)	Risk assessment inspection of food premises	City of Swan contract of $65000 with private service provider	(2)	$65,000
	Administrative costs associated with routine risk assessment contract	(i) 1718 risk assessment inspections	(3)	$8,590
		(ii) 6 minutes of officer time per risk assessment inspection	(4)	
		(iii) $50 per hr for admin officer time	(5)	
	Follow up compliance/risk management/administrative work in response to non-compliances identified in routine risk assessment	(i) 70 to 100 non-compliance improvement orders issued p.a.	(3)	$14,000
		(ii) 2 hrs of officer time per non-compliance improvement order issued	(4)	
		(iii) $70 per hr for EHO officer time	(6)	
	Food recalls	(i) 42 food recall follow up/checks p.a. Note cost absorbed in the routine risk assessment contract	(3)	-
Promotional and preventative work	City of Swan - food safety training/education/ promotional material /newsletters	(i) 100 hours p.a.	(3)	$7,000
		(ii) $70 per hr for officer time Note: negligible cost of consumables/cost of printing newsletters	(4)	
Food sampling	Response to complaints	(i) 16 food samples submitted for analysis	(3)	$2,240
		(ii) 2 hrs of officer time per sample	(4)	
		(iii) $70 per hr for officer time Note: laboratory analysis of food samples included in costs for general monitoring (see below)	(5)	
Food sampling	General monitoring	(i) 107 food samples submitted for analysis	(3)	$30,980
		(ii) 2 hrs of officer time per sample	(4)	
		(iii) $70 per hr of officer time	(5)	
		(iv) Laboratory analysis of food samples, cost of $16,000 p.a. to City of Swan	(2)	
Annual licensing of 'eating houses' (food premises)	Administrative costs of processing licences for eating houses	(i) 305 eating houses	(3)	$1,270
		(ii) 5 mins of officer time per premise	(4)	
		(iii) $50 per hr of officer time	(5)	
Statewide monitoring and surveillance	Costs to WA Health Department of Health in providing food safety services within the City of Swan	Total budget of $2.4m. p.a for Food Safety Branch. Allocation to City of Swan based on its share of the WA population (4.4%)	(7)	$105,600
TOTAL				$234,680

Notes:

(1) All values expressed in Australian dollars.

(2) City of Swan financial records.

(3) City of Swan Health Services Branch Annual Report 2003/04.

(4) Estimate made by Program Manager Health Services - City of Swan.

(5) Hourly charge rate (including overheads) of administrative officer (Health Services) at the City of Swan.

(6) Hourly charge rate (including overheads) of Environmental Health Officers at the City of Swan.

(7) WA Health Department financial records.

government food safety programs in Australia. A search of the literature suggested these data were also not available internationally for a comparable food safety program.

What is known, is that the food safety program at the City of Swan during the 2003/04 financial year resulted in the risk assessment inspection of 597 food businesses, totalling 1718 inspections and

Table 3: Break-even point of the City of Swan's food safety program, 2003/04

Program costs[1]	
Expenditure ($)	234 680
Revenue from licences ($)	92 037
Net costs ($)	142 643
Cost per case of foodborne illness ($)	630
Break even number of prevented cases	
Base case analysis	
Cost of foodborne illness of A$630	226
Number of cases of foodborne illness of 4.2 million	
Sensitivity analysis	
Low cost of foodborne illness of A$315	453
High cost of foodborne illness of A$1179	121

Note: 1. All values expressed in Australian dollars

averaging 2.9 inspections per premises per year (City of Swan 2004). A process of risk rating of registered food businesses has recently been introduced, which is based on a priority classification system for food safety published by the Australia New Zealand Food Authority (ANZFA), the forerunner to FSANZ. Under this system, food businesses are allocated into one of the three categories of 'High', 'Medium' and 'Low' on the basis of the type of food, activity of the business, method of processing and customer base (Australia New Zealand Food Authority n.d.). While the risk levels for food businesses were only applied in the year following the study year, the breakdown of premises by risk category has remained relatively steady and data for 2004/05 would therefore provide a reliable indicator of the risk levels of food businesses monitored during the study year and the potential risk to patrons. In addition, consideration of the risk factors identified while inspecting food businesses and the enforcement action taken provides further evidence of the risks identified by the City of Swan's food program and the corrective action taken.

Eighty-four percent of the food businesses inspected in 2004/05 were in the medium risk level category, with high risk businesses comprising 9% (Table 4). Significant incidences of poor hygienic practice were noted, and the most frequently occurring risk factors in 2003/04 provide evidence that good hygienic practice was not always being followed (Table 5).

Table 4: Risk categories of registered food premises in the City of Swan, 2004/05

Risk category	Registered food premises	
	Number	Percentage (%)
High Risk	57	9
Medium Risk	529	84
Low Risk	45	7
TOTAL	631	100

Source: City of Swan 2005

Table 5: Food hygiene non-compliances in the City of Swan, 2003/04

Top Five Risk Factors Identified	Percentage of risk assessment inspections found to be non-compliant (%)
Premises not being kept clean and tidy	30
Premises not being maintained in a good state of repair and maintenance	23
Cross-contamination not being prevented	14
Single use towels and soap not being provided	11
Cold food (potentially hazardous) not being held at below 5 degrees Celsius	11

Source: City of Swan (2004).

Enforcement activity in that year provides further evidence that, in the absence of a food safety program, customers of these food businesses would have been exposed to the risk of contracting a foodborne illness (Table 6).

Table 6: Food hygiene enforcement activity in the City of Swan, 2003/04

Enforcement Activity	Description
Food seizures	6 seizures of food consignments after being declared unfit for human consumption, 5 from lack of temperature control and 1 from fire damage
Non-compliant food samples	8 samples found to be non-compliant with standards (Australian Food Standards Code)
Consumer food complaints investigated	16 complaints, 10 for food containing foreign matter and 6 for alleged food poisoning cases
Food recalls	42 recalls
Legal notices	7 notices served for food hygiene contraventions
	73 food hygiene improvement orders issued
Prosecutions	2 prosecutions for a business selling food contaminated with maggots and a premise trading unlicensed

Source: City of Swan 2004

While it is reasonable to argue on the basis of these data that the food safety program would most likely have reduced the incidence of foodborne illness, it is not possible to argue as to whether it would have been effective in preventing 226 cases or more. An alternative means of assessing the likelihood of this number of cases being prevented is to determine the magnitude of this decrease in relation to the total number of cases of foodborne illness in the City of Swan.

Given FSANZ's estimate of an annual number of 4.2 million cases of foodborne illness in Australia, and assuming the incidence of cases is the same in all Australian states and territories, the annual number of cases of foodborne illness in Western Australia can be estimated as 414,400. If all local authorities in Western Australia were assumed to have the same incidence of foodborne disease, then the annual number of cases of foodborne illness in the City of Swan would be around 19,170.

A reduction of 226 cases of foodborne illness in a year thus represents a 1.2% decrease. If FSANZ's higher estimate (5.4 million) and lower estimate (2.7 million) of the incidence of foodborne illness in Australia are used, the annual reduction of 226 cases represents a 0.9% and 2.2% decrease respectively. A program effectiveness of the food safety program of the City of Swan of this low order of magnitude appears credible, especially if consideration is also given to the risk level of food businesses involved and the corrective interventions made. An examination of the variation within metropolitan local authorities in the rate of locally acquired enteric disease notifications shows considerable variation between local authorities in the rate of disease notifications per population.

The mean number of locally acquired enteric disease notifications across all metropolitan local authorities was 11.6 per 10,000 population, with this number varying between 5.8 per 10,000 population and 29.8 per 10,000 population (50% to 257% of the mean respectively). While a variety of factors would contribute to these differences, it is possible that the food safety programs in the different local authorities would be responsible for a share of the differences. Local authorities with effective food safety programs would be expected to have lower rates of foodborne illness overall, including locally acquired enteric diseases that are notifiable. Compared with other local authorities, the City of Swan had a rate of locally acquired enteric disease notification of 8.3 per 10,000 population, 72% of the mean for metropolitan local authorities for the study year, which suggests a relatively effective food safety program that could likely have reduced the rate of foodborne illness by at least 1.2%.

Discussion

The break-even analysis of the food safety program at the City of Swan suggested it would be cost-effective if it reduced foodborne illness by 1.2%. Although no relevant data regarding the effectiveness of food safety programs are available, it seems credible that the City of Swan's food safety programs could affect the incidence of foodborne illness by this amount.

While no studies were found that quantified the impact of food safety programs, studies reviewing the effectiveness of specific public health interventions in food safety have found some programs to be effective. A systematic review of published and unpublished studies (Campbell et al. 1998) suggested routine inspections (at least once per year) of food premises was effective in reducing the risk of foodborne illness, food handler training could improve knowledge and practice of food handlers, and selected community based education programs could increase public knowledge of food safety. Similar studies (Mann et al. 2001; Ribens et al.1994) evaluating food safety programs also concluded that inspection, education and training could be effective. At the City of Swan all registered food premises are inspected several times per year on average, with educational material provided and incentive schemes used to encourage good hygienic practice and the adoption of food safety programs. From a review of the risk factors identified during inspections in the study year and the enforcement actions taken, poor hygienic practice is occurring in food businesses and being corrected.

The main limitation of this study is its reliance on previously published estimates of (i) the number of cases of foodborne disease in Australia and (ii) the cost per case of foodborne illness. The number of cases of foodborne illness used in the study, which was calculated by FSANZ, has been argued to be too high. However, even if FSANZ's lower bound figure was used, the food safety program would be cost-effective if it reduced foodborne illness by 2.2%. The cost per case of foodborne illness was also estimated by FSANZ, based on many assumptions. In comparison to estimates for overseas countries, the FSANZ figure of the cost per case of foodborne illness is low, which makes the results of the study conservative. If the cost per case of foodborne illness was higher, the break-even point would be lower and fewer cases of foodborne illness would need to have been prevented for the cost savings to offset the costs of the food safety program.

Another factor in relation to the FSANZ estimate of the cost per case of foodborne illness (A$630), is the method used to calculate this cost. The estimated cost was calculated using the human capital approach, which is a method that measures cost of illness based on the loss of productivity associated with the condition. An alternative approach is the willingness to pay method, which assigns a value to the willingness to pay for a reduction in risk of acquiring the illness. In general, willingness to pay estimates of what risk reduction is worth to individuals whose health might benefit are higher than estimates based on the human capital approach. Thus the use of a cost per case based on the willingness to pay method would result in a lower break-even point than obtained using a cost per case based on the human capital approach.

A more rigorous investigation of the cost-effectiveness of the food safety program of a local government would require improved data relating to the benefits of food safety programs. More specifically, additional data are required on the effectiveness of food safety programs in preventing foodborne illness and the cost savings associated with fewer cases of foodborne illness. Future research needs to be undertaken to fill these information gaps if local governments are to be able to determine with more certainty whether their food safety programs represent value for money, not withstanding the broader social rationale for providing such services

Conclusion

Foodborne illness is a serious public health problem and local governments have a key responsibility to protect their communities from this threat to their health. However, given constrained resources, local governments are not able to eliminate all risks in their communities and must select which to control. Determining which programs deliver value for money is one factor that must be considered in making decisions regarding which programs should be implemented. This study shows that it is reasonable to argue that the food safety program of the City of Swan is likely to be a cost-effective program that provides net benefits to the community.

References

The Allen Consulting Group 2002, *Food Safety Management Systems Costs, Benefits and Alternatives*, Final Report to the Commonwealth Department of Health and Ageing, The Allen Consulting Group, Melbourne.

Australia New Zealand Food Authority undated, *Food Safety: The priority classification system for food businesses*, <http://www.foodstandards.gov.au/_srcfiles/ANZFA_1578_Info_Paper__final.pdf> June 2006.

Campbell, M.E., Gardner, C.E., Dwyer, J.J., Isaacs, S.M., Krueger, P.D. & Ying, J.Y. 1998, 'Effectiveness of public health interventions in food safety: A systematic review', *Canadian Journal of Public Health*, vol. 89, no. 3, pp. 197-202.

City of Swan 2004, *Health Services Annual Report 2003-04*, City of Swan, Perth.

City of Swan 2005, *Health Services Annual Report 2004-05*, City of Swan, Perth.

Department of Health and Ageing 2006, '*National notifiable diseases surveillance system*', <http://www1.health.gov.au/cda/Source/CDA-index.cfm> 3 April 2006.

Department of Health Western Australia 2004, *Local Government Enteric Disease Report 2003-04*, Perth, WA.

Engel, D. & MacDonald, D. 2001, *Managing Food Safety*, Chadwick House, London.

Food Standards Agency 2000, *Putting the Consumer First: Food Standards Agency to Reduce Food Poisoning by 20%*, <http://www.food.gov.uk/news/pressreleases/2000/jul/reducefoodpoisoningers.usda.gov/briefing/FoodborneDisease/features.htm> 5 May 2006.

Food Standards Australia and New Zealand 2004, *Incidence of foodborne illness*, <http://www.foodstandards.gov.au/mediareleasespublications/publications/foodsafetystandardscostsandbenefits/incidenceoffoodborne633.cfm> 22 October 2004.

Mann, V., DeWolfe, J., Hart, R., Hollands, H., LaFreance, R., Lee, M. & Ying, J. 2001, The effectiveness of food safety interventions, *Health-evidence.ca* <http://health-evidence.ca/article.aspx?id=16155> 20 October 2005.

Riben, P.D., Mathias, R.G., Campbell, E. & Wiens. M. 1994, 'The evaluation of the effectiveness of routine inspections and education of food handlers: Critical appraisal of the literature', *Canadian Journal of Public Health*, vol. 85, no. 1, pp. 56-60.

Todd, E.C.D. 1989, 'Preliminary estimates of costs of foodborne disease in Canada and costs to reduce salmonellosis', *Journal of Food Protection*, vol. 52, no. 8, pp. 586-94.

United States Department of Agriculture 2004, *Economics of Foodborne Disease: Estimating the Benefits of Reducing Foodborne Disease*, <http://www.ers.usda.gov/briefing/FoodborneDisease/features.htm> April 2004.

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Mercury Incident in a Boarding House: An Integrated Public Health Response in Newcastle, Australia

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This paper describes an integrated public health response to a major elemental mercury exposure incident that occurred in Newcastle, New South Wales, Australia. Eighteen people were potentially exposed to elemental mercury vapour with two cases receiving chelation treatment. Three sites required an environmental health risk assessment for potential mercury contamination: a 12 room boarding house, a private residential dwelling and an abandoned industrial site. Several issues complicated the investigation including the time delay in accessing a mercury vapour analyser, closure of the boarding house late at night with dispersion of residents. Residents were intoxicated with recreational substances, apprehensive of authorities, and non-compliant with treatment. Careful exposure histories correlated well with the biometric mercury measurements. Although such incidents are uncommon the acute and chronic health effects of elemental mercury exposure can be devastating and there is clearly a need for specific public health, non-occupational protocols for responding to such incidents in Australia.

Key words: *Elemental Mercury; Public Health; Newcastle; Risk Assessment*

There are three classes of mercury: elemental (also known as metallic or pure form mercury), inorganic and organic mercury. At room temperature, metallic mercury is a heavy, shiny, silver-white, odourless liquid, which is slightly volatile and releases toxic, odourless vapour, especially when heated (Agency for Toxic Substances and Disease Registry 1999). At 24°C, mercury vapour saturates the air at 13 to 18 μg/m^3 (Dart & Sullivan 2004). Mercury vapour is heavier than air and might collect in poorly ventilated and lower lying areas. Inhalation of mercury vapour is the primary route of exposure to elemental mercury and inhaled vapour is almost completely absorbed by the lungs. Elemental mercury is only slowly absorbed through the skin, but causes irritation to both skin and eyes. When ingested, elemental mercury is essentially non-toxic as less than 0.01% is absorbed. Children are more sensitive to elemental mercury than adults, due to greater lung surface to body weight ratio, greater permeability of their blood-brain barrier, higher respiratory rate and the developing nature of their nervous systems (Agency for Toxic Substances and Disease Registry 2004).

Health effects are associated with acute and chronic exposure to metallic mercury. Respiratory symptoms include bronchial irritation and chemical pneumonitis with fever chills and dyspnea, which can progress to pulmonary oedema or fibrosis (Agency for Toxic Substances and Disease Registry 1999). Abdominal cramps, diarrhoea, renal dysfunction, visual disturbances and central nervous system damage leading to neuropsychiatric disturbances and tremors may also occur. Dermal reactions and acrodynia, particularly in children or adolescents, with discoloration of the soles and palms can also result. Ongoing low level exposure to metallic mercury can result in accumulation in the body and permanent damage to the nervous system and kidneys (Baughman 2006).

The Situation

On 6 July 2005, two teenagers trespassing within secure premises on an abandoned industrial site in Newcastle, Australia found approximately 200 mL of metallic mercury. After vigorously playing with it for several hours at the site they transported approximately 100 mL to an inner-city boarding house where they were resident. A total of approximately 20 mL was spilt in the boarding house that evening; 1mL was spilt in the kitchen and a further 19 mL in the bedroom of one of the teenagers. Approximately 1 mL of mercury beads were collected by the resident cleaner and kept in a small glass container in his bedroom after he removed it from the linoleum kitchen floor. The boarding house had 12 bedrooms, a shared kitchen, a shared shower and an unoccupied shed at the rear of the property. The remainder of the metallic mercury was hidden in two closed glass containers behind the shed by the teenagers. In addition to the two teenagers, 11 other predominantly young people were resident in the boarding house at the time of the incident, with on average 30 additional visitors occasionally sleeping at the boarding house each week. There were also a number of short-term visitors, including children.

On the evening of 14 July 2005, the toxicologist on call for the Hunter New England Toxicology Service (IW) alerted the Population Health Unit that a 16 year old male (Index Case 1) had been referred to the service by a general practitioner concerned that he had a blood mercury level of 1012 nM/L (acceptable range: 0-50 nM/L). The teenager initially refused treatment but advised the toxicologist that his friend (Index Case 2) and others had been exposed to mercury in his bedroom at the boarding house where he resided. This served to initiate an interagency response that included Hunter New England Population Health (HNEPH), Hunter New England Toxicology Service (HNETS), local government, NSW Fire Brigade Hazardous Materials Unit (HAZMAT), Police, the local hospital Emergency Department, and the Ambulance Service. The HAZMAT unit attended the site with a Public Health Physician and Environmental Health Officer from HNEPH, and Newcastle City Council's Environmental Protection Officer. With cooperation of boarding house management, HAZMAT identified visually contaminated areas, and conducted an initial cleanup of contamination at both the boarding house and at the abandoned industrial site (the source). Both properties were closed until they were decontaminated and acceptable mercury vapour levels confirmed.

The Public Health Response

Hunter New England Population Health has an integrated public health team, comprising public health physicians, environmental health officers, public health nurses and epidemiologists. The team was also assisted by an experienced local clinical toxicologist. During the on-site response on the 14 July 2005, a public health physician and environmental health officer collected the names of potentially exposed people who were resident at the boarding house, or who had spent periods of four hours or more in the boarding house since the metallic mercury had been introduced on the site. The following day the public health team members commenced contacting residents and visitors to the boarding house to confirm potential exposure, provide advice and recommend free mercury blood and urine testing. Several people were difficult to contact. Telephone messages and letter drops urged all known contacts to report to the HNEPH. The messages emphasised the need for testing. Team members held twice daily briefings during the five days of response.

Clinical and laboratory testing

All persons who were known to have entered the bedroom in the boarding house where the spill occurred or the room where mercury was stored, handled clothing of the index case, and individuals who reported attempting to clean up the elemental mercury in the house were referred to the HNETS for mercury blood and urine testing. This included the two index teenagers (Case 1 and Case 2), 11 residents, a visiting partner and three children of one of the index cases who had all slept at the boarding house in the room where the spill occurred and who were considered at high risk of exposure (Table 1). Blood mercury concentrations were also determined on the responding public health physician and environmental health officer who entered the house after HAZMAT had bagged obviously contaminated articles, stood at the door of the room where the spill had occurred and spent approximately 45 minutes inspecting the house without respiratory protection.

An elevated blood mercury concentration confirms recent exposure while urine mercury concentrations are a better indicator of total mercury body burden. In individuals with no occupational exposure, urine concentrations are reported to be in the range of 0.004-0.012 µM/L (Queensland Health 2002). Acceptable ranges of blood and urine mercury are 0-50 nM/L and 0-6 nM/mM of creatinine, respectively (Dart & Sullivan 2004). The two index cases who obtained and transported the mercury to the boarding house had substantially elevated blood mercury concentrations. Case 1 (peak blood mercury 1015 nMol/L, urine Hg 228 nM/mM creatinine) complained of mild respiratory symptoms, decreased appetite and vague abdominal pain, while on examination he had a generalised skin rash, especially truncal, which was erythematous and blanching, with early desquamation of his hands. The latter is known as acrodynia or Pink's disease. Case 2 had significantly elevated blood mercury (peak blood mercury 402 nM/L) but refused a urine test. He was asymptomatic. Case 7 had a blood mercury of 43 nM/L and a urine mercury of 4 nM/mM creatinine, and although these concentrations did not exceed the acceptable limits they were consistent with some exposure, probably due to cleaning up the spilled liquid 'beads' in the kitchen and from the 1 mL of mercury collected in an open glass jar and stored in his poorly ventilated, heated bedroom.

Table 1: Results of blood mercury levels and exposure

Case Number	Potential and type of exposure during known exposure period	Blood mercury nmol/L	Urine mercury nmol/mM creatinine
1	Handled mercury and slept in contaminated room for 7 days. Window open.	1012	228
2	Handled mercury and slept in contaminated room for 5 days.	402	not tested
3	Held bottle of mercury.	25	4
4	Caretaker of the property.	12	not tested
5	Resident of boarding house.	4	
6	Resident who cleaned up initial mercury spill in kitchen with rag	32	3
7	Resident and cleaner. Assisted with cleaning kitchen. Kept 1 mL of mercury in glass jar in room that was heated with window permanently closed.	43	4
8	Assistant caretaker.	10	1
9	Visited Case 1 up to 4 times each day during exposure period.	17	2
10	Handled Case 1's clothes.	<4	1
11	Handled Case 1's clothes.	<4	not tested
12	Overnight visitor - partner to Case 1.	26	not tested
13	Overnight visitor - child 1 of Case 1.	29	not tested
14	Overnight visitor - child 2 of Case 1.	32	not tested
15	Overnight visitor - child 3 of Case 1.	38	not tested
16	Homeless overnight visitor on the night of mercury spill	13	not tested
17	Public health officer 1 - one hour exposure	<4	not tested
18	Public health officer 2 - one hour exposure	<4	not tested

Cases 1 and 2 were offered chelation therapy using 2,3- dimercaptosuccinic acid (DMSA) to bind the systemic mercury and increase excretion. Limited availability of DMSA in Australia required sourcing of additional supplies from the United States. While awaiting delivery, oral penicillamine 250mg four times daily was used for 24 hours. The DMSA was administered orally at 10 mg/kg three times daily for 5 days, followed by 10mg/kg twice per day for 14 days (Dart & Sullivan 2004). Case 1 was followed up and his blood mercury on 24 May 2006 was 4 nM/L (RR 0 - 50 nM/L) and he reported feeling well.

Environmental investigation

An environmental and public health risk assessment was required at the boarding house and the abandoned industrial site. The Council required the boarding house manager to engage a suitable organisation to perform mercury vapour testing in the boarding house and conduct environmental decontamination. Through the investigation, an additional potentially contaminated site requiring a risk assessment was identified. This was a nearby residence where Case 1 visited on several occasions during the exposure period to visit family and have clothing washed. The same organisation was used to assess, test and report on potential mercury contamination at the residential premises. A Mercury Vapour Analyser (Bacharach MV2) was used to determine the extent of contamination at the boarding house and residential property and then again to validate the decontamination process. The detection capacity of the analyser was 0.01 mg/m^3 and was calibrated and tested for mercury response using a test sample of known metallic mercury.

The boarding house

The following day, 15 July 2005, an on-site assessment identified the further two containers containing 50 mL and 30 mL of metallic mercury behind the shed at the rear of the property. In addition, nineteen 'spot samples' were collected to detect the presence of metallic mercury in the boarding house including samples taken in 12 bedrooms, the kitchen, hallway and floor drain.

Mercury was detected in 6 of the 19 samples. Mercury was detected in room 1 (bike handle), room 6 (carpet), room 11 (on items used to collect a small amount of mercury from the kitchen floor spill into a glass and the shelf on which the open glass was stored) and on the kitchen floor (Table 2). These environmental mercury detections were consistent with the blood mercury levels of residents in the boarding house: 402 nM/L (occupant of room 1), 1012 nM/L (occupant of room 6) and 43 nM/L (occupant room 11), respectively.

Table 2: Results of environmental mercury sampling

Location of sample	16/7/05 Mercury Vapour Results mg/m^3	Environmental decontamination action	19/7/05 Validation Vapour Results mg/m^3
Room 1	0.05 (bike handle)	Cleaned and released	Nd
Room 2	Nd	-	-
Room 3	Nd	-	-
Room 4	Nd	-	-
Room 5	Nd	-	-
Room 6	0.1 (carpet)	Carpet removed	Nd
Room 7	Nd	-	-
Room 8	Nd	-	-
Room 9	Nd	-	-
Room 10	Nd	-	-
Room 11	0.3 (shelving) 0.3 (small brush) 0.03 (container)	Items removed and disposed	Nd Nd Nd
Room 12	Nd	-	-
Hallway	Nd	-	-
Kitchen floor	0.03	Sulphur bomb and vacuumed	Nd
Kitchen floor waste	Nd	-	-
Bathroom floor waste	Nd	-	-
Outside ORG**	Nd	-	-

* Nd = Not detected ** Overflow relief gully

Environmental decontamination to achieve occupational mercury vapour standards was implemented and included the removal and disposal of contaminated carpet and personal effects, clothing and shoes by double bagging, and the application of sulphur powder ('sulphur bomb') to bind mercury on the kitchen floor. Metallic mercury and vapours are extremely difficult to remove from clothes, furniture, carpet, floors, walls and other items. If these items are not property cleaned, the mercury can remain for months or years, and continue to be a source of exposure (Agency for Toxic Substances and Disease Registry 2004). Spilled mercury forms small beads that easily spread, making a thorough clean up difficult and making removal from porous material, such as carpeting and clothing, almost impossible. Validation of the success of decontamination was conducted on 19 July 2005 at which time no mercury vapour was detected and boarding house management and residents were notified.

Residential premise for laundry

Table 3: Environmental mercury measurements at residential property

Location of Sample	16/7/05 mercury vapour mg/m3
Exposed occupants bed	Not detected
Bedroom floor	Not detected
Exposed occupants jeans	Not detected
Exposed occupants shoes	Not detected
Exposed person bag	Not detected
Denim jacket	Not detected
Lounge seat 1	Not detected
Lounge floor at seat 1	Not detected
Lounge seat 2	Not detected
Lounge floor at seat 2	Not detected
Lounge sofa	Not detected
Lounge sofa at floor	Not detected
Laundry washing machine	Not detected
Laundry Sink	Not detected
Laundry floor	Not detected
Laundry clothes basket	Not detected
Shower	Not detected

Over the two week exposure period, case 1 visited a nearby residential property on several occasions to have his clothes washed and thus it was decided to extend environmental mercury sampling to this property. There have been a number of documented instances where shoes and clothing have contaminated other areas (Baughman 2006). On 16 July 2005, 19 mercury measurements were taken from the residential property, including from the bed where case 1 had sat and slept, and from the laundry area where his contaminated clothing had been stored and washed. No detectable levels of mercury were found at this residence (Table 3).

Abandoned industrial site

On 15 July 2005, the abandoned industrial site was inspected by the local council who identified and removed a further 100 mL sealed container of metallic mercury. It is unknown if past industrial practices led to the mercury being left on the site or whether it was later dumped on site. Environmental mercury samples were not taken as the site was well ventilated, already listed on Council's contaminated sites register and classified as unused. Council directed the owner of the property to increase security at the property to prevent future public access.

Discussion

No previous reports of a public health response to mercury exposure in a non-occupational workplace setting have been published in Australia. The local emergency management response to this incident was considered effective as the time from initial incident notification to tracing of all potentially exposed residents, completion of environmental sampling, cleanup and validation, and initiating of appropriate patient therapy, spanned only five days.

While the response was considered effective, several issues complicated this investigation particularly the lack of standards and limited testing capability. Residents of the boarding house were of low socio-economic status and on the edge of homelessness. When the response team first arrived at the boarding house many residents appeared intoxicated or were suffering from the effects of mind-altering substances. This complicated the collection of accurate information and necessitated checking of information over subsequent days. In addition, residents appeared to be apprehensive about providing information and this may be explained by the presence of multiple authorities.

The closing of the boarding house on the night of the incident at 10 p.m. appeared to exacerbate the situation, with people rapidly dispersing in search of alternative accommodation before accommodation closed for the night. Residents were nervous and uncertain as to whether they would be able to access their personal belongings, such as money, keys and clothing, which increased their anxiety. There was a 36-hour delay in accessing a mercury vapour analyser as its availability and appropriate specifications were not included in any existing protocol, but an analyser was eventually traced and transported from Sydney (2.5 hours away). This delay in identifying contaminated areas and personal effects increased residents' frustration. While it is acknowledged that other mercury vapour analysers have greater detection and sensitivity capabilities, such as the Lumex RA915 (detection capacity 2ng/m^3), the Bacharach MV2 was the only analyser available at the time in NSW to respond to such an incident. The Bacharach MV2 is usually used to assess workplace mercury spills. The limited detection capacity might have compromised detection of lower level contamination. The instrument detection capability is crucial in ensuring accurate identification of areas of contamination and in particular validation of the clean up.

Tracing people who might have been exposed relied on using the loose 'network' of associates. Although some residents had prepaid mobile phones, some phones had no credit and were not in use. Only two residents were successful in finding alternative accommodation immediately, several residents were able to stay with other friends, while the remainder were effectively homeless. It would have been beneficial to ensure community services emergency response personnel were included in the initial response, as this would not only have provided necessary social support to those directly affected but also simplified public health follow-up.

There was initial non-disclosure of the mercury concealed behind the shed, due to its perceived value to Case 1 who thought that the mercury could be sold for a considerable sum to someone 'for making a bomb'. This perception of the value of this heavy metal despite it being nearly worthless has previously attracted comment (Baugham 2006).

Once adequate therapy was accessed there were issues with treatment compliance due to the extended period required for effective therapy (19 days). Patients feeling generally well once exposure ceased possibly became non-compliant due to other life priorities, including accommodation, employment and food security. Only limited DMSA was available in Australia and the national toxicology network should review the need for larger supplies as a large mercury exposure incident could rapidly deplete available stock.

While we are unaware of similar incidents in Australia, it is likely that they might have occurred but not been published. A national system to document and share lessons from toxicological incidents would be useful and the ATSDR's Hazardous Substances Emergency Events Surveillance system might be a useful model for Australia to explore.

In Australia, while there are mercury standards for food (Australian New Zealand Food Standards Code), drinking water (Australian Drinking Water Guidelines 2004) and occupational exposure limits (National Exposure Standards Source A Updates 2005), there are no non-occupational or environmental exposure standards relating to mercury vapour exposure. In an industrial or workplace contamination incident environmental samples are usually collected and averaged over an 8 hour period to assess the time weighted average (TWA) using the occupational exposure standards. However, due to the nature of the incident (in a public residential boarding house) and the potential long exposure period (longer than an 8-hour working period) the time weighted average exposure limits were not appropriate for assessing risk. Suitable Australian standards are required for non-occupational exposures such as those published by the World Health Organization (WHO) and ATSDR. The WHO (Air Quality Guidelines for Europe 2000) has an established guideline level for mercury in air of 1 μg/m^3. This value includes a 10-fold safety factor to take account of 'uncertainties due to variable sensitivities in higher risk populations'. This value is an annual average, which means that continuous exposure to that level in indoor air for a year is expected to have no ill effects. Similarly, with ATSDR (Minimal Risk Levels for Hazardous Substances 2005) the minimal risk level of 0.2 μg/m^3 is an estimate of the daily human inhalational exposure (24 h a day, 7 days a week, for 70 years) that is likely to be without appreciable risk.

Public health officers at the investigation site followed advice from HAZMAT and the toxicologist regarding entry into the 'hot zone'. However, during a subsequent debrief it was resolved that officers needed to be more informed on the toxic nature of elemental mercury and have readily available reference resources at hand in the field. Additional personal protection equipment for public health response staff should include disposable foot covers to cover footwear and a personal data storage device for immediate access to relevant technical information.

Conclusion

As the acute and chronic health effects of elemental mercury exposure can be devastating there is clearly a need for specific public health, non-occupational protocols for responding to such incidents in Australia. These should involve consideration of suitable exposure standards to assist public health practitioners such as those published by the World Health Organization and the Agency for Toxic Substances and Disease Registry. Our experience suggests that such protocols should emphasise the involvement of community services early where marginalised groups are affected to ensure an appropriate response. They should also stipulate the need for access to appropriate mercury vapour analysers, effective chelating agents, and adequate personal protective equipment for public health response teams.

References

Agency for Toxic Substances and Disease Registry (ATSDR) 1999, '*Toxicological profile for mercury*', Department of Health and Human Services, Public Health Service, Atlanta, GA: U.S. <www.atsdr.cdc.gov>

Agency for Toxic Substances and Disease Registry (ATSDR) 2004, '*Toxicological profile for mercury*', Department of Health and Human Services, Public Health Service, Atlanta, GA: US <www.atsdr.cdc.gov>

Agency for Toxic Substances and Disease Registry (ATSDR) 2005, *Minimal Risk Levels (MRLs) for Hazardous Substances*, Department of Health and Human Services, Public Health Service, Atlanta, GA: US <www.atsdr.cdc.gov/mrls.html>

Australian Government Department of Employment and Workplace Relations 2005, '*Amendments to the Adopted National Exposure Standards for Atmospheric Contaminants in the Occupational Environment* [nohsc:1003(1995)] Source A updates 2005', <http://www.nohsc.gov.au/ohslegalobligations/hazsubstancesanddnggoods/nes/natexpstand.htm>

Australian Government, National Health and Medical Research Council and the Natural Resource Management Ministerial Council, *National Water Quality Management Strategy: Australian Drinking Water Guidelines 2004*, National Health and Medical Research Council, Canberra.

Baughman, T.A. 2006, 'Elementary mercury spills', *Environmental Health Perspectives*, vol. 114, no. 2, pp.147-52.

Centers for Disease Control and Prevention (CDC), 2005, 'Measuring exposure to an elemental mercury spill: Dakota County, Minnesota, 2004', *Morbidity & Mortality Weekly Report*, vol. 54, no 6, pp.146-9.

Centers for Disease Control and Prevention (CDC) 2005, 'Mercury exposure: Kentucky, 2004', *Morbidity & Mortality Weekly Report*, vol. 54, no. 32, pp. 797-9.

Dart, R.C & Sullivan, J.B. 2004, Mercury, in *Medical Toxicology*, 3rd edn, Lippincott, ed. R.C. Dart, Williams & Wilkins, Philadelphia.

Food Standards Australia and New Zealand 2006, *Australia New Zealand Food Standards Code: Standard 1.4.1*, Commonwealth Australia, Aanstat Pty Ltd, <http://www.foodstandards.gov.au/_srcfiles/fsc_1_4_1_Contaminants_v78.doc>

MacLehose, R. et al. 2001, 'Mercury contamination incident', *Journal of Public Health Medicine*, vol. 23, no.1, pp. 18-22.

Queensland Government, Queensland Health March 2002, *Public Health Guidance Note: Mercury*, <http://www.health.qld.gov.au/phs/Documents/ehu/2666.pdf>

World Health Organization, 2000, *Air Quality Guidelines for Europe*, 2nd edn. World Health Organization, Geneva.

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