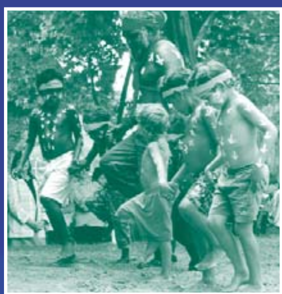
Environmental Health

The Journal of the Australian Institute of Environmental Health



...linking the science and practice of Environmental Health

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Environmental Health
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Special Issue

Climate Change and Health

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Call for Papers

The Journal is seeking papers for publication.

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.

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 encourage contributions from students

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

Guest Editorials

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.

Research and Theory

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.

Practice, Policy and Law

Articles and reports should be approximately 3000 words in length and can include articles and reports on successful practice interventions, discussion of practice initiatives and applications, and case studies; changes in policy, analyses, and implications; changes in laws and regulations and their implications, and global influences in environmental health. Up to six key words should be included. Name/s and affiliation/s of author/s should be included at start of paper and contact details including email address at the end.

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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New Minister for Health and Ageing

The Journal welcomes the appointment of Dr Kay Patterson as the new Minister for Health and Ageing and gratefully acknowledges the support of the previous Minister for Health, Dr Michael Wooldridge.

Dr Patterson's careers have prepared her well for this ministry and particularly for the part she will play in environmental and public health. As a principal lecturer in health sciences with a focus on healthy ageing and head of a large academic department, she has a multidisciplinary approach to health. Her parliamentary career, while supposedly little known, has given her an intricate knowledge of the importance of a regulatory framework if environmental health is to be promoted and maintained. She has passion combined with an immense capacity for attention to detail. She enjoyed her membership of the Senate Regulations and Ordinances Committee and was keenly aware of the importance of regulations and the need for their careful scrutiny.

She has been a campaigner for being 'sunsmart' long before that approach was invented, for public education and for opportunistic screening for skin cancer. Her interest and support for immunisation, for healthy nutrition, for child health, and for education has had practical application in Papua New Guinea, Samoa, and Cambodia among others, in her position as Parliamentary Secretary to the Minister for Foreign Affairs.

Her professional knowledge, her management skills with a strong emphasis on negotiation to achieve consensus, her extensive experience of the parliamentary process, and above all her enthusiasm and determination will make her a valuable and effective Minister in the environmental health area.

Heather Gardner
Editor.

Global Climate Change and Health: Research Challenges, Ecological Concepts and Sustainability

There is accruing evidence that humans, in aggregate, are now overloading several of the Earth's biogeochemical systems, including the climate system (Vitousek et al. 1997). This is a remarkable crossroads in the quarter-million year career of the human species – and it has been reached in our lifetimes (McMichael 2001). For the first time, the weight of human economic activity is great enough to perturb the planet's life-support systems at a global level.

This novel development necessarily extends the environmental health research agenda. Therefore, the recent commissioning by the Australian government of an assessment of the health risks due to climate change in Australia and environs is welcome. Indeed, it signifies a recognition that research on the social and environmental impacts of climate change is now a necessary complement to the science of climate change per se.

The body of scientific evidence in relation to human-induced global climate change, present and future, has now become compelling. The Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), the international scientific body established within the UN system to advise governments on the processes and impacts of climate change, was published in mid-2001. That report makes the following three things very clear (IPCC 2001).

First, human-induced warming has begun. Global average temperature is rising faster than at any time in the last 10 000 years. The IPCC report concludes that "there is new and stronger evidence to indicate that most of the warming observed over the last fifty years is due to human activities". The particular pattern of temperature increase over the past quarter-century displays unequivocal human "finger-prints". For example, the recent rise in global average temperatures has been due principally to an increase in minimum daily (i.e. nighttime) temperatures, and hence diurnal temperature variation has decreased (Easterling et al. 2000). This differs from the warming trends of earlier decades, which were driven predominantly by solar forces and were characterised by an increase in maximum daytime temperatures (Easterling 1997). Further, the recently observed warming has been greatest at high latitudes, and has been accompanied by more frequent, intense precipitation. These are features that climatologists would expect to see in a "greenhouse"-warmed climate.

Second, a coherent, worldwide pattern of climate-attributable changes in simple physical and biological systems has become evident. This includes the retreat of glaciers, melting of sea-ice, thawing of permafrost, earlier nesting and egg laying by birds, polewards extension of insect and plant species, and earlier flowering of plants. These are all changes in natural systems or processes that are unprotected by the sorts of cultural and technological buffering that is available to human societies; buffering that might obscure or defer the occurrence, or at least the detectability, of climate-induced impacts in human populations.

Third, climate scientists now foresee an average surface-temperature rise this century within the range of 2-6°C. This is a faster increase than was predicted in the IPCC's Second Assessment Report, in 1996, and is much faster than any climate change experienced by human societies since the onset of agrarianism 10 000 years ago. In view of the great inertia in the climate system, it has now become apparent that, even if a reinforced Kyoto Protocol were implemented, Earth is committed to experiencing human-induced warming over the coming century. Indeed, even if we managed, with Herculean international effort, to eliminate excess greenhouse gas emissions within the coming half-century, the world's oceans would continue to rise for up to a thousand years as heating gradually extends through and expands the ocean's layers.

The general public and their policy-makers are now aware that climate change, over coming decades, will cause adverse health impacts. Environmental health researchers should therefore expect to make an important contribution to the policy discussion around this great contemporary issue. To do so, however, will require a widening of our professional field of vision.

Because of the unfamiliar nature, and the recency, of rapid human-induced climate change as an environmental "exposure", much of the initial research effort has gone into estimating – and where possible, mathematically modelling – the likely future health impacts. There has been little direct empirical evidence available, in contrast to the abovementioned observations on physical and biological systems. That, though, is beginning to change. For example, there is evidence that tick-borne encephalitis has moved northwards in Sweden following a trend of warmer winters over the past two decades (Lindgren & Gustafsen 2001). In Africa similar changes in the occurrence of malaria, including a move to higher altitude, have been observed. These changes are unlikely to be due to non-climate factors such as altered land-use patterns, increasing drug resistance, or reduced effectiveness of health services (Tulu 1996).

There is an important challenge here for epidemiologists and others: that is, to seek out situations in which evidence of climate-attributable impacts on human health is likely. Is the seasonal summer peak of salmonellosis and campylobacteriosis widening, as critical temperature thresholds are passed earlier and later in the year? Is the pattern of heat-attributable mortality in urban populations changing as the frequency of very hot days gradually increases? Can we discern a trend in injuries and deaths due to extreme weather events?

This adducing of empirical evidence of health impacts will be an important input to the public debate on climate change. Indeed, it will help us to see the wider ecological dimension; to understand that we humans are beginning to alter the conditions of life on Earth. This, inevitably, has potential consequences for patterns of health and disease in populations everywhere. In the meantime, as empirical evidence accrues, we must also engage more energetically in applying current knowledge and theory to the modelling-based forecasting of the range of future health impacts. Useful and valid models will require interdisciplinary collaborations.

Ratification of the now-precarious Kyoto protocol would have committed nations to an overall reduction in greenhouse gas emissions of 5% of their 1990 levels. Note, however, that such a reduction would fall seriously short of the 60% cut needed to stabilise atmospheric carbon dioxide levels (McMichael & Powles 1999). The talks have so far failed primarily because the United States has remained unwilling to curb its domestic consumption of fossil fuels, and would prefer to buy out its obligations in an international market of tradeable emission permits. Australia and New Zealand have been part of the "umbrella group" that supported the US position on carbon sinks and trading credits. There may well be a place on the margins for these strategies, since many countries do not have the "luxury" of imploding economies and cancelled coal industries which enable East and West Europe, respectively, to meet their Kyoto greenhouse targets relatively comfortably. However, the central issue cannot be ducked: curbing the impact of human activities on the world's climate will require fundamental changes in the ways modern states extract and consume natural resources.

Finally, environmental health scientists should appreciate that global climate change is one of a larger set of large-scale environmental changes now underway, each reflecting the increasing human domination of the ecosphere (Vitousek et al. 1997). All of these changes – stratospheric ozone depletion, biodiversity loss, worldwide land degradation, freshwater depletion, disruption of the elemental cycles of nitrogen and sulphur, and the global dissemination of persistent organic pollutants – have huge consequences for the sustainability of ecological systems, for food production, for human economic activities and therefore for human population health (McMichael 2001).

It is becoming evident that the sustainability of population health must be a central consideration in the overall discourse on the Sustainability Transition (McMichael, Smith & Corvalan 2000). "Sustainability" is, at core, about maintaining functional ecological and other biophysical life-support systems on Earth. If these systems decline, then eventually population health indices will also begin to turn down. We can buy time with technology, we can insulate ourselves against immediate impacts, but we cannot evade nature's bottom-line accounting: the health of populations depends on the environment's carrying capacity. For this reason, public, policymakers and other scientists are increasingly interested in hearing from environmental health researchers about these matters. There is a nascent understanding that population health is, in many ways, an ecological entity; an index of the success of our longer-term management of the social and natural environments.

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Global Climate Change and Health: The Challenges Facing Policy Makers

Climate change adaptation is a new and complex issue. It is an issue that is becoming increasingly significant for public and private sector decision-makers. Incorporating climate change into risk assessments and sustainability plans is an increasing need.

The IPCC Third Assessment report concludes that the impacts of climate change will become increasingly negative for more of the world's regions and systems as the extent of global warming increases. The report also concludes that adaptation is a necessary strategy at all scales to reduce the negative impacts of climate change and to maximise the opportunities that may arise.

As with many emerging policy areas, there is some uncertainty regarding the issues of science, economics, and social effects of climate change and the potential to mitigate these effects through adaptation. However, many of the human systems that are in place or are being planned now, will exist long enough to be affected by the projected climate change. These include transport, urban and coastal developments, water supply and long-lived crops. It is therefore appropriate to consider climate change as one factor in shaping the design and location of infrastructure and development of regional growth and environmental strategies.

The Government recognises that adaptation to the impacts of climate change would be necessary at national and local scales in combination with emissions mitigation efforts. A national Adaptation Working Group has been established to progress work in this area. The Group has agreed a number of adaptation principles and criteria for decision makers in assessing the need, the form and the timing of planned adaptation actions that aim to achieve one or more of the following:

- Increase the robustness of infrastructure and long-term investments (either physically or by reducing potential economic loss)
- Increase the flexibility of vulnerable managed systems (enable change of use or consideration of value)
- Enhance the natural adaptability (by reducing other stresses or removing barriers to adaptation)
- Avoid increasing vulnerability (by preventing activities that will increase future risk)
- Improve awareness and preparedness (through education, risk assessment and early warning systems).

The Working Group also provides a strategic forum to address national priorities in the development of sectoral and regional climate change adaptation strategies. Work is currently underway, for example, in investigating the costs of climate change on major sectors of grazing, wheat and barrier reef tourism. These case studies will inform policy and highlight areas where further research is required.

Environmental health is a cornerstone of public health and the Commonwealth Department of Health and Ageing is providing national leadership and coordinating strategic action to improve environmental health in Australia. The Department is progressing the development of a health adaptation framework to climate change. As a first step a systematic risk assessment of the human health impacts of climate change is being undertaken, including identification and analysis of gaps in health related climate change research. This project will strengthen the national response to global environmental health matters. It is part of the Department's role in contributing to the implementation of the National Greenhouse Strategy.

Many challenges remain in addressing gaps in our understanding, in developing capacity to assess costs and benefits, in raising awareness and in incorporating climate change into decision making. Studies such as these will help us all, in partnership, to find a way forward.

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Thinking Globally and Acting Locally: Climate Change and Environmental Health Practice - A Discussion Paper

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The interactions between social and environmental sustainability at the local and global scales, and between the two scales, are complex and difficult to evaluate. Yet this is the very field in which environmental health practitioners have their day-to-day practice. Nowhere is this complexity more apparent than in responding to the effects of global climate change. This review of the context in which these practitioners must deal with the issues concludes that there is discontinuity between decision making within globalisation-from-above (the national and supra-national scale) and globalisation-from-below (the sum of the local responses worldwide). To address issues of global governance such as climate change in any effective manner, globalisation-from-above needs sustainable regulatory mechanisms, and the links between globalisation from above and below need to be established or reinforced. Meanwhile, environmental health practitioners get on with the job, building on local knowledge of place, collaborative networks and cooperative alliances.

Key words: *Global Change, Climate Change, Local Governance, Environmental Health*

Global to Local and Local to Global

Environmental health practitioners are facing many unprecedented challenges at the start of the twenty-first century, among them those arising from the local effects of global environmental change, particularly the far-reaching effects of global climate change. Yet concerns about global climate change can seem very distant from the day-to-day concerns of environmental health practice. The time scales are different, the geographic scale is different, and the responsibilities for response appear to lie in different areas. However, it is the local environmental health practitioner who has inherited the task of making local decisions on matters arising from the multiple connections between local health impacts and global climate change. Every global climate change has, by definition, a local effect, however unpredictable that may be. Even slight rises in temperature and rainfall affect almost every aspect of environmental health, from the spread of infectious diseases to increased risks for food safety, from higher rates of respiratory disease through to an increased rate of destruction of the ozone layer (McMichael 1993, 2001; World Resources Institute, United Nations Environment Program, United Nations Development Program & the World Bank 2000).

What is certain is that there is no longer a question of whether, but of when, these effects will eventuate. We now know they will be with us for centuries. World temperature has increased by 0.6% (a greater rate of increase than in the last 10 000 years). This increase cannot be reversed this century, since the concentration of greenhouse gases will inevitably double before any restraining programs are in place. The production of greenhouse gases, carbon dioxide from fossil fuels, methane from agriculture, and halocarbons from industrial processes, is increasing. With the rise in temperature, rise in sea levels, special storm events, and associated effects, such as the increase in ultraviolet radiation starting to take effect, the prediction is that sea levels will continue to rise slowly for another 1000 years, whatever remedial action is taken (Intergovernmental Panel on Climate Change 2000).

The impact of these global changes is difficult, if not impossible, to predict with certainty for any one particular place. Rainfall patterns are expected to change, with higher rainfall in high rainfall areas and lower rainfall in low rainfall areas, but little is understood about what would happen in between. Unprecedented storm events are consistently higher in all parts of the world, but as yet with no discernible patterns. In the lead up to stringent global controls over energy use and vehicle emissions, there has been extensive negotiation over standards and controls. At the global level of debate, there are as yet no discussions on appropriate responses at the local scale. The potential is high for confusion between global and local perceptions of the issues and hence for conflicts in decision making. Yet globally it is each individual locality which provides the premier site of the action in response to those predictions. Local knowledge is required to adapt to the changes at the local scale.

Falk (1999) offers a direction for sorting out this confusion. An expert in international relations from Princeton in the United States, he argues that globalisation is not one, but two, decision making systems governing (or not governing) the global flows of information, finance, people and natural systems. One, globalisation-from-above, consists of vast flows of unconnected and ungoverned resources. No one is in charge of the information in cyberspace, where the information flows at an unprecedented speed and at low cost. There is no longer a limit to access to information, but a very restrictive limit on who constructs and posts the information. Finance flows are quite unregulated across national borders without contributing taxes or resources to any country. Never in human history have people been so migratory, tourism so large scale, and refugees turned from their national soil in such large numbers.

Table 1: Attributes of globalisation

	Globalisation-from-above	Globalisation-from-below
Area	Unregulated flows	Locally organised flows
Information	Information technologies	Networking, local knowledge
Finance	Globalised corporations	Regional economies
Governance	United Nations, World Health Organization, World Trade Organisation, International Labour Organisation	Local community, services and government
People	Tourists, immigrants, refugees	Settled neighbourhoods, sense of place
Natural systems	Billion-year-old natural cycles —disrupted	Local ecosystems —degraded

Source: adapted from Falk 1999

In concert with globalisation-from-above is a counterbalancing flow of globalisation-from-below, a mirror image of the former involving:

- increased respect for the reliability and validity of local knowledge
- enhanced importance of each community's power of self-determination
- recognition of local sense of place and social capital as a key to social sustainability
- establishment of shared governance between residents, councils and civil society organisations, and
- strengthened regional and global networks of localities helping each other manage a shared sustainable environment.

The decision making system of governance that regulates resources and social priorities is tightly structured at national, state and local scales, with laws, regulations and customs. At a global scale there is as yet no agreed or formalised system of control. The United Nations has formal procedures, but has insufficient funds or workforce for its Commission for Sustainable Development to be an effective regulator. The World Trade Organisation and the World Bank come closest to that role, but only through international consensus, a consensus difficult to achieve or maintain. With respect to the global systems of natural resources, that is, the self-regenerating cycles of air, water, soil and living things, the basic issues of environmental health, these were self-regulating until the industrial revolution brought the human power to disrupt them. As the Kyoto protocol discussions demonstrate only too clearly, there is no tradition of global governance to supervise the negotiation of sustainable outcomes.

Globalisation-from-below is reflected in the increasing tendency for localities to link together in associations and networks, regionally and eventually globally, for different purposes and on different issues. Australian Landcare has not only linked farming families Australia-wide, but is now spreading to South Africa, South America and even France (Marriott 1999). Community service organisations such as World Vision and the Red Cross are taken for granted as global emergency response organisations, but their funds and their workforce are generated from a worldwide network of localities. Global conservation groups, such as Greenpeace and Friends of the Earth are equally locally based, as are the influential Councils of Social Service of almost all democratic countries. Any or all of these can be natural allies of the environmental health practitioner.

Major global decision making organisations, recognising their lack of regulatory authority when faced with global environmental and health issues, proceed to nominate networks of cities and local government authorities to bring about global change. In public health, the World Health Organization established the global network of Healthy Cities in 1985. The United Nations Conference on Environment and Development in 1992 launched the Local Agenda 21 Plans, intended for every local government authority on the planet to implement the principles of sustainable development. These principles, protecting inter- and intra-generational equity, ecological integrity and biodiversity, valuing natural resources and practising precautionary management, overlapped considerably with the traditional responsibilities of environmental health practice. Devolving responsibility in this way returned decision making to the local level, where the day-to-day experiences of communities and their governments were more formally organised (Table 1). Local knowledge and local practice is an essential basis for any action on issues of globalisation-from-above, because it is:

- grounded in place and time – things actually happen there
- the original source of baseline data for other branches of knowledge
- the outcome of lived experience, where you can tell if things are or are not working
- the testing ground for new ideas and practices, and
- the unit of regional, national and global action.

Renewed respect for the local by specialists and government strategists – for local action, local knowledge, local solutions and local autonomy – is a phenomenon of our time, and the key to linking globalisation from below and from above (see Table 1). The burden of the future delegated to the responsibility of the local scale from the global scale is impressive, but without those links is wildly unrealistic. The key questions for environmental health practitioners working at the interface between globalisation from above and below is: 'How are we managing and what supports do we have for the task?'

The size of the task

Not only are global issues managed differently at the local scale, but also the form of the impact of global change also differs. While locally some changes in climate and changes in health risks can be linked directly as cause and effect (Ewan, Bryant & Calvert 1990), others such as the increase in melanomas, the loss of mammalian species, and transport emissions, are not so clearly connected and can and do take decades to identify. Table 2 documents the ways in which all the major areas of traditional environmental health concern, air, water, land and people, are already affected by global change. Some of these effects are directly related and some only indirectly related to climate change, but since the world's life support systems are interconnected, the results are cumulative. Increased erosion alters rainfall patterns that can add to the climatic effects and to changes in energy use – and the downward cycle continues.

A great deal of the burden of responding to the local environmental effects of climate change seems to have been passed to the field of environmental health, through its traditional responsibilities for local air, water and food quality, for environmental monitoring and regulatory powers for waste management and urban and rural zoning. This is history repeating itself, since it was the "too-hard" management of the exploding cities of the nineteenth-century industrial era that gave birth to the professional field of environmental health (Ashton & Seymour 1988). In responding to this era's pressures on environment and health, the local environmental health workforce has broadened to include the community itself in its everyday uses of the environment, along with urban and rural planners, environmental law and environmental accounting (Brown et al. 2001).

Table 2: Local effects of global environmental change

Area	Global changes	Australian local effects
Air	Ozone depletion	Melanomas world highest level, Tasmania (Australian Institute of Health & Welfare 1998)
	Global warming	Floods, droughts, changed pollination patterns (CSIRO 1996)
Water	Irrigation	Salting, acidification of soils (Department of Environment, Sport & Territories 1996)
	Forest clearances	Increased erosion, drop in rainfall (White 1997)
Land	Productive land	Reduced 10% every year, 60% degraded (Beale & Fray 1990)
Life	Biodiversity (Aust.)	More mammals extinct than any other continent (Flannery 1994)
People	Population	Waste production per head second in OECD (Western Sydney Waste Board 1997)
Energy	Energy use	Greenhouse gases increasing by 16% (8% allowed by 2008 in the Kyoto Agreement)

Source: Brown 2001.

It seems there have been, and still are, a wide range of differing opinions about who is concerned with local global change, who is responsible, and what to expect. The first educational campaign alerting Australia to the impact of climate change was a community education campaign during 1987–88, arising from the then Commission for the Future. The first review of health implications, sponsored by the National Health and Medical Research Council in 1990, made the following recommendations, which can hardly be said to have been adopted (Ewan, Bryant & Calvert 1990, p. 6):

- to reduce the emissions of greenhouse gases and other pollutants affecting climate, and to establish priorities for action to achieve this reduction;

- to develop federal strategies which support a global approach;
- to develop guidelines to assist government and non-government bodies in formulating strategies to protect the environment.

As early as 1991 a survey of over 900 Australian local government authorities found that "greenhouse-related concerns" were among the top four environmental issues of concern (Brown, Orr & Smith 1992). In the same survey, the councils reported federal policies as one of the most needed and least available resources. A decade later, concerns have greatly increased, but the requests for help from those responsible at the wider scales remain largely unanswered. Local environmental health still seems to be largely "going it alone", as shown by research nearly a decade later.

A study of the environmental health concerns of the Australian public in 1999 show increasing pollution and global environmental change at the top of their list (Starr, Langley & Taylor 2000). Of 2008 respondents, 83% agreed that the greenhouse effect is a serious problem that could lead to harmful changes in the environment and in people's health. A survey of environmental health practitioners, on the other hand, did not nominate global concerns as a present concern, but did expect they would need more help to combat increasing environmental risks in the future (Cruickshank 2001).

In the first survey, community members agreed they should respond to increasing environmental health risks themselves, but overwhelmingly (80% of the sample of 2008) considered that response is a government responsibility. In the second survey, the highest priority for assistance for environmental health practitioners was community education (53% of the 307 respondents), with community development and community partnerships not far behind. It would seem the two groups need each other. The National Environmental Health Strategy Implementation Plan shares responsibility for action on environmental health issues between individuals and communities, business and industry and government, confirming the links for these multiple alliances. However, while the plan acknowledges global environmental change in one of its nine principles, that "Environmental health programs need to take into account that global environmental protection requires local action and that local actions impact globally" (enHealth Council 2000, p. 5), it is difficult to find mention of either responsibilities or actions on global environmental change anywhere in the plan.

A paragraph from the first formal Australian document on the health implications of long-term climate change sums up the situation facing environmental health in every locality:

In addressing the health effects of the global environmental problem we must recognise the hazards of taking a problem-by-problem approach. Climate change, air and water pollution, food production, ozone depletion, soil erosion and salination act synergistically in bringing about environmental degradation. Deterioration in one area may accelerate decline in other areas and multiply the effects on health and ecology in ways that cannot be predicted. Similarly, adopting a disease-by-disease approach to minimising health effects may result in a trivialising or complacent outlook because each identified problem can, in itself, be either dismissed for lack of data or apparently dealt with effectively (Ewan, Bryant & Calvert 1990, p. 7).

Box 1: Councils' incorporation of sustainable development principles

Baulkham Hills	Whole-of-council staff development process, developing sustainability indicators for the work of all departments.
Blacktown	Internal interdepartmental environment committee meets regularly to discuss ecologically sustainable development issues throughout Blacktown, and has developed an environment management framework.
Blue Mountains	Education sessions for policy-makers; inclusion in business plans; seeking World Heritage classification.
Fairfield	Council facilitates community environmental strategy groups and restoration projects.
Hawkesbury	Hawkesbury Agricultural Sustainable Development Scheme, Healthy Cities Healthy Food Project.
Liverpool	Corporate plan reviewed in 1999 to include sustainable development in corporate plan, management plan and structure plans.
Parramatta	The 'Parramatta REP' contains an action plan for sustainability; ecologically sustainable development principles underpin the draft 'Comprehensive LEP' and the draft 'City Centre DCP'.
Penrith	Sustainable Penrith has a program to continue collaborative partnerships with key environmental, social and economic organisations; investigate emerging approaches, including greenhouse credits and environmental accounting; and require development to be designed and managed on ecologically sustainable development principles.

Source: Council Environmental Health Officers

A new wave of environmental health, working in the broader field of managing for local social and environmental sustainability, is rising to this challenge (Box 1). While there are still specialists in environmental matters who contend that "lay" (for lay, read local community) perceptions of risks and solutions have never been validated against expert assessments (for example, Margolis 1996), a great deal of evidence suggests otherwise (Brown, Griffith & Ohlin 1998; Wynne 1996). Although government policies and strategies in this area continue to be accused of lacking implementation mechanisms (Harding & Institute of Environmental Studies 1996; Lowe 2000; Worldwatch Institute 2000), at the local scale, local governments, their communities and their industries have been getting on with the job (Box 2).

Box 2: Local reduction of greenhouse gases: Cities for Climate Change

The use of fossil fuels generates the gas carbon dioxide (CO_2). Once in the atmosphere, CO_2 acts like the glass in a greenhouse and raises the earth's temperature. Cities for Climate Protection (CCP) is an international program that enlists city councils in a plan to reduce greenhouse gases in their locality. Funded by the National Greenhouse Office, the Cities for Climate Change project can be contacted through their Melbourne office.

There are five very practical milestones to be completed within three years as part of the CCP program:

Milestone 1	involves establishing a greenhouse gas emissions baseline for the shire by undertaking an inventory of current corporate and community emissions. It also involves forecasting emissions to the year 2010. Answers the question 'Where are we at?'
Milestone 2	requires the council to agree on a greenhouse emissions reduction target for both the community and corporate sectors. Answers the question 'What do we want to achieve?'
Milestone 3	involves the development of a local action plan based on the information provided by the Milestone 1 inventory and forecast, and the target adopted in Milestone 2. Answers the question 'How will we get from where we are – the baseline – to where we want to go – the target?'
Milestone 4	involves implementing the local action plan. Answers the question 'What did we do?'
Milestone 5	comprises an ongoing process to monitor the implementation of the local action plan. Answers the question 'Did we achieve what we set out to do?'

Source: Cities for Climate Change Office, Melbourne, 2000

The range of locally initiated responses goes beyond the well-regarded Landcare groups to community education groups such as OzGreen and Household Options for Protecting the Environment; community monitoring (Alexandra, Higgins & White 1998); and community sustainability indicators (Australia Institute & Newcastle City Council 2000; Western Sydney Regional Organisation of Councils & University of Western Sydney 2001). More broadly, there are the environmental health units of public health services and the approximately 600 Australian local government authorities, each of which has environmental health officers. Environment education centres with environmental health information can be found in every sizeable community. In Sydney these range from the specialised Lead Information Centre to the Total Environment Centre, which conducts its own respected research programs.

Nor is there a shortage of state-level programs supporting local action. In New South Wales (and proposed for Victoria) annual environmental monitoring is legislated as compulsory for every local government authority. Queensland has the integrated environmental management legislation, although this has been criticised for lack of implementation (Brown et al. 2001). Some of the strongest emissions reduction programs of the Australian National Greenhouse Office are conducted through local governments (Cities for Climate Change, see Box 2) and local industries (The Greenhouse Challenge), both cases where there is national and local scale cooperation.

While Healthy Cities and Local Agenda 21 could both be said to have failed to be taken up widely in Australia, their influence permeates the environmental health practices of regional public health units and councils (Whitaker 1995). A national program for integrating environmental, economic and social services at the local scale, Integrated Local Area Planning, has met the same fate (Australian Local Government Association 1995). A national review of local environmental and health planning found five reasons why such locally integrative programs are at the same time so influential and so short-lived. There is abundant evidence that councils and their communities are taking coordinated steps towards implementing sustainable development principles (see Box 3.)

But local responses are not without problems. A review of the practice of environmental health through the experiences of 40 environmental health practitioners from the community, the profession, government and coordinating agency bodies, and a review of mandatory and voluntary planning frameworks in environment and in health, revealed some basic changes needed for effective, long-term responses to global environmental change:

Box 3: Regional integrated sustainability monitoring

An 18-month consultation and visioning process was used to determine the sustainability indicators for the Western Sydney region. Community members were more interested in knowing that the whole environment was safe, rather than evaluating by separate measures for air, water and noise. They wanted a composite index, like the Consumer Price Index or the Dow Jones Index on finance. While the New South Wales Environmental Protection Authority (EPA) gives daily bulletins on the separate measures that are widely accessed, the only major composite index is the Regional Pollution Index (RPI) measuring fine particles, ozone, nitric oxide and nitrogen dioxide levels in the air. The air chemistry measured by the RPI reflects the air impact of industry, transport and ultraviolet light levels.

Residents recommended strongly using their own senses as the most direct index: the scent of gums in the early morning, birds in chorus, trees rustling leaves, clear long-distance views. But they accepted that more objective measures were also necessary.

Problem:	While there were known regional ill-health effects from polluted air, water and soil, there were no joint human health/environmental quality standards; and no compliance levels to RPI index warnings.
Solution:	Improve the status of the RPI as a reliable warning; public re-fuelling stations offering alternative fuels; Protection of Environment Operations Act 1997.
Sustainability goal:	Air, water and soil meet EPA standards 100% of days.
Indicator:	Improved RPI, taken from an adequate spread of local sites with well-publicised warning levels.
Action	
by community:	Become familiar with the current trends in RPI readings, and the point sources that contribute to high readings.
by council:	Publicise RPI trends and pollution sources through radio, newsletter and local media; finalise local air quality management plans.
by state EPA:	Expand air monitoring sites to be representative of risk to Western Sydney residents (eg, near main roads, extractive industries).

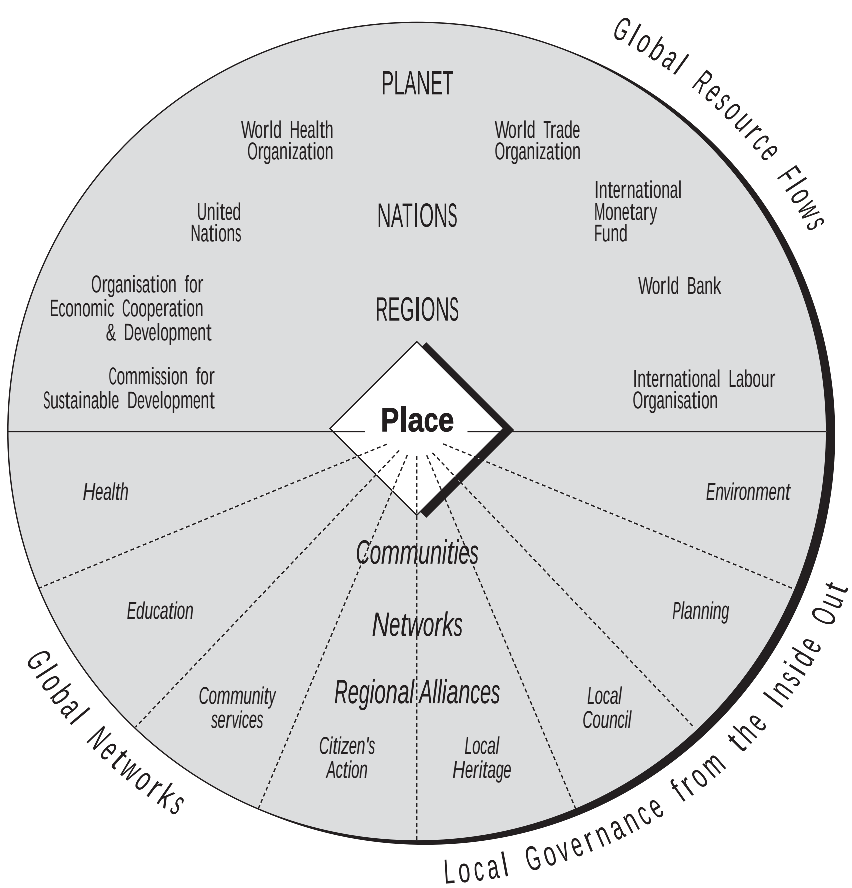
Source: Western Sydney Regional Organisation of Councils & University of Western Sydney 2001

- Voluntary and mandatory health and environment planning frameworks need to be redesigned so as to reinforce each other. Currently, they are conflicting. Voluntary frameworks such as Healthy Cities are designed to foster diversity and change, while mandatory frameworks such as Local Environment Plans are based on uniformity and certainty. Each needs to be linked to the other to allow effective response to globalisation-from-above.

- Health and environment services need to be linked through strong collaborative mechanisms. In almost all regions and localities they are sharply divided into inwardly focused specialisms often categorised as "silos", and working to different priorities. Synergistic action becomes difficult or even impossible.
- Local community groups have vastly insufficient funds or membership even to do what they are doing now, much less manage the continual devolution of practical action from higher scales of responsibility.
- Integrative programs and agencies report lack of support, recognition, or resources from the community groups, specialised services and government agencies they are established to coordinate (Brown et al. 2001).

Globalisation-from-above and from-below are useful ideas, which help to position local environmental health practice within the context of global change. Although it makes the weaknesses, or rather the non-existence of global environmental governance apparent, it also highlights the strengths of the local practices of environmental health,

Figure 1. Globalisation from above and below



locally and globally. Acting with the local in mind, a more useful perspective is to examine the strengths and weaknesses of local environmental governance from inside out and outside in (Figure 1). Place-centred governance of the effects of global change works from a focus on that place and its community outwards through networks and alliances. The global approach to climate change, as to other disruptions of global natural systems, is piecemeal and subsidiary to other interests and priorities.

The Core of Sustainable Living

There is no longer any serious disagreement with the proposition that climate change is now occurring, and that it brings with it unknown and unprecedented pressures on human settlements and thus on human health. There is also agreement that we can no longer prevent the change, but only slow it down. In the meantime, every locality must live with the effects of this and other global environmental change. Although most of the public and political discussion and debate is concerned with the impacts of globalisation-from-above, the impact of the change and, in the end the remedy, is at the local scale.

To respond to a global change at the local scale requires the cooperation of globalisation-from-below; the linking of localities in effective responses worldwide. Such responses need to have been confirmed as effective by the appropriate experts, but must be delivered through local knowledge and local experience at the local scale. These initiatives are increasingly gaining local community and government support, in principle and in practice. The gap in effective responses appears to lie in the actions of globalisation-from-above. Support for action at the global scale and for coordinated action taken at the local scale are both responsibilities of the nation-state and of the organisations taking responsibility for global governance.

These tensions between global and local action impact directly on environmental health practice, since air, water, soil and living conditions are the core of the environmental health role. The challenges to environmental health at the local scale have spread far beyond the capacities of the local formally qualified environmental health profession, requiring legislation, strategic planning, community cooperation and political will. It seems that traditional environmental health has broadened in response, so that cooperation within local environmental health practice has many effective examples throughout Australia, with links to the local governance sector worldwide. A useful framework for local response to climate change is to consider the response as working from the inside out. The place and the community remain the core of sustainable living, and provide the unit of response from both a global and a local perspective. It is the links between globalisation-from-above and globalisation-from-below that now need attention, both from above and from below.

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West Nile Virus

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In July 1999, the first case in the Western Hemisphere of West Nile Virus (WNV) was identified in Queens, New York, a suburb of New York City (CDC 1999; Lanciotti et al. 1999). A cluster of human cases, appearing at the same time as an alarming die off of native birds and some exotics in local zoos, announced the arrival of the pathogen. Subsequently, the virus has spread throughout the eastern United States.

Key words: *West Nile Virus, New York City, Avian and Human Pathogen*

West Nile Virus is a flavivirus first recognised in conjunction with an outbreak in Uganda in l937 (Smithburn et al. 1940). In recent years it has caused significant numbers of human cases in Israel and in Armenia. It is closely related to other flaviviruses such as St. Louis Encephalitis, for which the outbreak in New York was initially mistaken, and to Kunjin and Murray Valley viruses, which have caused outbreaks in Australia.

The US West Nile Virus isolates are virtually identical to a goose isolate from Israel in 1998. Polymerase chain reaction (PCR) analysis suggests the present epizootic is the result of a single introduction of WNV to the United States (US) (Giladi et al. 2001). Speculation on how West Nile Virus could become a New World pathogen from European sources centres on the following scenarios:

1. Transport of an infected bird to the US either through legal or illegal means.

2. Migration of an infected bird across the Atlantic (directed, inadvertent, or storm blown). The New York City area is located on a major nexus of both north/south and east/west bird migration routes (Rappole, Derrickson & Hubálek 2001).

3. Infected human traveller being bitten by a mosquito subsequent to arrival in the US.

4. Infected mosquito arriving by ship or more likely by air.

Scenarios 1 and 2 are most likely. Since humans are usually “dead-end” hosts for arboviruses (Tyler 2001), three is much less likely.

Disease in Humans

The clinical course of WNV disease in humans is clearly age dependent. Young persons appear to have a milder clinical illness, marked by mild upper respiratory symptoms, if any symptoms at all. Routine laboratory findings are often nonspecific. Typical presenting symptoms are fever, stiff neck, headache, or altered mental status (Weiss et al. 2001). At advanced age, and particularly at age greater than 75 years, illness can be quite severe, with meningitis and/or encephalitis, often preceded by muscle weakness. Death occurs in roughly

Table 1: Human WNV cases, North East USA

Cases		Deaths	
1999	62	1999	7
2000	12	2000	0
2001	24	2001	2

12% of cases (Nash et al. 2001). Age greater than 75 years and diabetes mellitus are independent risk factors for death, with relative risks of 8.5 (95%CI 1.2-59.1) and 5.1 (CI 1.5-17.3) respectively (Nash et al. 2001). Pancreatitis and hepatitis have been seen as rare sequellae elsewhere (Tsai 2000), but have not been reported thus far in the US epidemic.

Table 1 summarises human infections and deaths for the 1999-2001 seasons. The decrease in human cases is more likely due to as yet undefined epidemic dynamics driving spillover from the epizootic into humans, such as has been documented in European outbreaks, than from effective means of vector control measures (Marfin et al. 2001).

Random cluster household serosurveys of asymptomatic adults were carried out in October and November, 2000 in areas of observed WNV epizootic in the 1999 and 2000 summer seasons. These have revealed scant evidence of inapparent infection in humans. Positive IgM titres for WNV were found in five of 2436 persons tested in New York and Connecticut in October and November 2000 (CDC 2001). It thus appears evident that the reproductive rate, R_0, of WNV in humans is very low.

Endemic regional WNV activity will be maintained through reservoirs of susceptible avian species. There are some reports of WNV activity in areas of Israel virtually devoid of mosquitoes, implicating the existence of additional competent vectors. Ticks have been suggested as an additional vector (Marfin & Gubler 2001).

Epizootic Dynamics

WNV is primarily an avian pathogen. High levels of infectivity in birds without spread to humans in a geographic area is common. High levels of viral activity in birds (without die offs) without associated human disease has been the typical pattern for WNV as seen in the recent European and Middle Eastern outbreaks. Singular in the Northeast US manifestation of West Nile Virus activity has been the high degree of pathogenicity in certain bird species, particularly North American Crows (*Corvus brachyrhynchos*). This appears to be a true virgin soil outbreak. Researchers in New York State identified 14 infected species in 1999 and 63 in 2000 (Bernard et al. 2001)

Mammals, primarily horses and humans, are secondary hosts. Spillover to secondary hosts is probably facilitated by high viremia in an amplifying host, proximity of vector and secondary host habitat (e.g., pools of stagnant water, perfect for breeding sites, in inner city environments apparently favoured by Culex sp.). and presence of a vector, which feeds on both birds and humans.

The US Geological Survey, Center for Integration of National Disaster Information, maintains a website that presents data on the extent of the WNV epidemic, human, avian, and veterinary, across the US.

Vector Dynamics

The principal vectors for West Nile Virus in the Northeastern US are *Culex pipiens* and *Culex restuans* mosquitoes. *C. pipiens* is primarily a bird feeding species which breeds in stagnant water. There is evidence that two distinct patterns of vector activity are involved, one a woodland (sylvatic) pattern of Culex activity, the other an urban one. The distinctions appear to be that sylvatic Culex mosquitoes bite birds preferentially (perhaps exclusively) and thus serve the role of amplifying viral infection of bird populations, but contribute little to human infections. In urban areas, where Culex species favour the catch basins of storm drainage systems as breeding environments, they may play a larger role in transmitting disease to humans (Anderson, Vossbrinck & Andreadis 2001). The relatively warm ecological niches of the catch basins (i.e., warm relative to ambient temperatures) might also enable infected mosquitoes to over winter (Anderson, Vossbrinck & Andreadis 2001). The winters of 1999/2000 and 2000/2001 also were warmer than average.

It has been verified that WNV survived the winters of 1999-2000 and 2000-2001 (December through March in the Northern Hemisphere); it is likely that this was through transovarial transmission by infected female mosquitoes (Nasci et al. 2001). Reverse transcription-polymerase chain reaction (RT-PCR) analysis of the envelope gene of WNV collected in New York in 1999, and again in 2000, provides further evidence that the 2000 outbreak was a continuation of the infection cycle introduced in 1999 and not a reintroduction (Ebel et al. 2001).

C. restuans is more common in Connecticut and feeds on birds only, which may partially explain the dichotomy seen in the epidemic profile with more human cases in New York than Connecticut and a larger bird die-off in Connecticut than elsewhere in the region.

Since WNV is now endemic in the continental US, WNV disease in humans will probably continue to be sporadic and episodic. Variability seen in human infection terms will be driven by fluctuations in temperature, humidity, rainfall, and availability of habitat, such as discarded tyres and untreated storm sewer catch basins in urban environments. Eradication of the virus or the competent vectors does not appear feasible by any presently available methodology. A vaccine for humans would be welcome by public health and the public, although decision criteria for whom to vaccinate might be problematic.

Ecological Dynamics

This outbreak is far more of an emerging infectious disease problem in wildlife than in humans. It is best considered as part of an increasing pattern of emerging infectious diseases in wildlife paralleling the increase in emerging and reemerging infectious diseases in humans, and disruption of the environment, particularly through global warming, and facilitation of pathogen migration due to human activity (Epstein 2000).

Complete understanding of the dynamics of emergent WNV in the US, like many other emerging infectious disease problems worldwide, will demand a systems approach.

Epidemiological and ecological factors driving a regional epidemic of WNV include:

- competence/susceptibility of primary and secondary host species and vectors
- virus dynamics (viral load, generation frequency) in amplifying host(s)
- presence and abundance of competent transmitting vectors
- species-specific infectivity and virulence factors
- weather and climate patterns
- conducive vector habitat.

The summer drought pattern witnessed in the northeastern US over the past several years benefits mosquitoes by resulting in less flushing of their stagnant breeding pools. This is especially so in storm drain catch basins that incorporate a sump, which will remain filled with stagnant water between storms. Drought also contributes to decrease in mosquito predator populations such as amphibians (Epstein 2001).

Most of these factors still require further elucidation before quantification or qualification can be achieved. As with any emerging infection, the history so far of West Nile Virus in the US has been marked by an evolution in the knowledge base and an appreciation of gaps that need to be filled by further research.

Control Measures

Control measures attempted to date have included:

- ecological alteration - altering habitats by eliminating standing water to reduce and eliminate where possible mosquito breeding

- personal protection eliminating possibility of mosquito bites by use of screens, protective clothing, mosquito repellents, and particularly avoiding being out of doors at dawn and dusk when most mosquito species in this region bite

- larviciding – elimination of mosquitoes in the larval stage particularly with biological controls such as *Bacillus thuringiensis*.

- adulticiding by using pyrethrin sprays (and malathion in New York City), either from truck mounted or airplane mounted sprayers.

Control measures in the northeastern states have focused on reducing the risk in humans, not eliminating viral activity or vector populations.

The approach adopted in most regions of Connecticut and New York generally followed CDC guidelines, although there was much variation as different townships and suburbs were still free to exercise their own judgment and adopt their own (usually reactive rather than proactive) control plans. In most places, larviciding was initiated following identification of WNV in dead crows. Adulticide spraying, from aircraft in New York State and from truck mounted sprayers in neighbouring Connecticut, was initiated when evidence of WNV infection was discovered in human biting mosquito pools or infection of secondary hosts, horses or humans.

Adulticiding with pyrethrin-based products appears to pose little health risk, but also only minimal effect at controlling mosquito populations. Mosquitoes have to fly through a cloud of the spray in order to be affected, and truck mounted spraying is limited to areas in close proximity to roads, but not into interiors of marshland areas where mosquitoes are breeding. Even at its most effective, spraying only controls available adult mosquitoes, and so when the next larval generation hatches, an area is repopulated (Thier 2001).

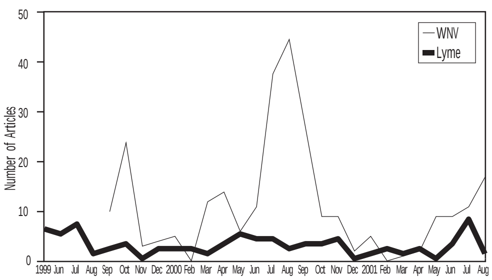
Public Response

West Nile Virus is a classic example of an issue with a high outrage factor. It is new, it is exotic, it has the potential to kill, and exposure is difficult to avoid (Sandman 1989). Ambient spraying of adulticides also possesses a high outrage factor in that it is imposed on a populace by political and professional decision makers, controlled by others, affects children, contains its own additional unknown risks and has questionable effectiveness (Sandman 1989). At best it is control, not prevention.

Of particular interest in observing the public health response to this emerging disease has been the public response to West Nile Virus. The northeast region of the US is not unfamiliar to vector borne disease, being at the epicentre of Lyme Disease, an arbovirus spread by ixodid ticks first recognised in the town of Lyme, Connecticut in 1975 (Steere et al. 1977).

Coverage of West Nile Virus has eclipsed that of Lyme Disease in the popular press (Figure 1), to the dismay of public health practitioners, as Lyme Disease certainly has at present and can be expected in the future to provide a much greater burden of human morbidity and mortality. The level of concern on the part of the public was also huge in the first two years of the epidemic. This concern was twofold, on the one hand certain segments of the populous were concerned with human risk for infection by and death from the pathogen itself, others feared control measures implemented to control mosquito populations.

Figure 1: News coverage of WNV and Lyme Disease, 1999-2001



Source: New York Times

An absence of hard data on the human health effects of these products and also the notable lack of data proving efficacy as a control measure have fuelled critics of spraying as a public health approach. It does not help that the brand name of the product generally used is Scourge.® Coupled with the growing appreciation that risk to humans from WNV was generally low, spraying in the 2000 and 2001 seasons (summer months of July through October in particular in this region) was greatly diminished from spraying levels of the 1999 season (McCally 2001).

Broadcast spraying faced less public hostility in shoreline communities, as it was not only a more familiar activity, but was also generally considered desirable, since it had been continually carried out for decades to control salt marsh mosquitoes. Salt marsh mosquitoes are a particular nuisance in coastal areas of Connecticut since their bite is painful and they bite during the day. Mosquito control activities in inland areas had long since been terminated due to budget cuts and public apathy.

The US National Association of County and City Health Officials (NACCHO) published a guidance document on West Nile Virus, based on conclusions reached at a workshop held in early 2000 to discuss the issue and review lessons learned (NACCHO 2000). This document provides a valuable source of information, not only for West Nile Virus, but also for other emergent mosquito borne pathogens.

As a result of terrorist attacks of 11 September 2001, a focus on West Nile Virus both from a public perspective, and as a focus of major activity on the part of public health professionals has been necessarily diverted to potentially more threatening issues.

A Cautionary Tale

Public health risk communication and disease control efforts sometimes yield unintended consequences. One evening in late summer 2000, a woman in the Connecticut shoreline town of Milford was cooking hamburgers for her family on the barbecue when she saw the spraying truck coming up her street. She decided the burgers were done enough and brought the meal inside, serving it to her family. Unfortunately, the ground beef she was cooking was contaminated with E. coli 0157:H7. Her two-year-old daughter became infected, with the illness progressing over the next week to haemolytic uremic syndrome. The child recovered after a long hospitalisation (England pers. comm. 2001).

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Environmental Change, Global Warming and Infectious Diseases in Northern Australia

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We are increasing our clinical surveillance for new and increasing infectious diseases that may relate to environmental changes occurring in the short term and global warming over the longer term. It is predicted that with global warming the tropical north of Australia will become both hotter and wetter. This is likely to expand the receptive area within Australia for mosquito-borne diseases such as malaria and the arboviruses, Murray Valley encephalitis (MVE), Japanese encephalitis, and dengue. Melioidosis has recently been diagnosed in two people in Central Australia (below the "normal" endemic area of the Top End). Changing weather, together with environmental change from agricultural practices may well result in melioidosis becoming more common in parts of Australia other than the Top End. Leptospirosis has been increasingly diagnosed in north Queensland and the Top End, with several people critically ill. The crisis in East Timor has increased the movement of people and cargo between East Timor and Darwin and there has been the predicted increase in imported cases of malaria and dengue. The introduction of Japanese encephalitis to the Torres Strait and subsequently the Australian mainland is of great concern. The large numbers of feral pigs across northern Australia provide a potential amplifying host for this virus, which can result in destructive and fatal neurological disease (very similar to MVE virus disease). A new focus of scrub typhus has emerged in Litchfield Park south of Darwin, probably reflecting tourist exposure to bacteria present for millennia in a rodent-mite cycle.

Key Words: *Global Warming, Tropical Infections, Melioidosis, Murray Valley Encephalitis Virus, Japanese Encephalitis Virus, Dengue, Malaria, Leptospirosis, Scrub Typhus*

Climate, Environment and Infections

Both environmental change and climatic factors can influence the emergence and reemergence of infectious diseases. In addition there are important human determinants such as population changes, and in particular large movements of people during times of political instability, war and famine. Mosquito-borne diseases such as malaria, dengue and viral encephalitides are currently considered the most likely to be affected by both climate variations and potential climate change (Patz et al. 1996). Changes in temperature, total rainfall and rainfall patterns will change the geographic range of disease carrying mosquitoes and increase mosquito longevity, reproduction and biting rates. Increased temperature and humidity will also decrease the time for the pathogens to develop to an infectious stage within the mosquito (the extrinsic incubation period) (Githeko et al. 2000; Patz et al. 1996; Rogers & Packer 1993).

The combinations of increased temperature, increased rainfall and environmental changes with destruction of natural vegetation are likely to extend the range and increase the incidence of various environmental pathogens such as *Burkholderia pseudomallei*, the causative agent of melioidosis, and leptospirosis (Currie 2000). A rise in sea surface temperature and sea levels is predicted to increase a number of important water-borne diseases that are associated with temperature-sensitive marine ecosystems (Kovats 2000; Patz et al. 1996). These include cholera, which has been found to be widely distributed in marine environments, often associated with zooplankton and sometimes entering a viable but nonculturable state (Colwell 1996). Warmer water favours the growth of dinoflagellates, which are associated with coastal algal blooms such as red tides, and with toxic shellfish poisoning.

Stratospheric ozone depletion permits an increased amount of harmful ultraviolet (UV) radiation to enter the biosphere. The effect of UV radiation on DNA and proteins is thought to account for its effect on human health (Tong 2000). In addition to increased skin cancers such as melanoma and increased cataracts, potential effects of UV radiation on the immune system are of concern. These include decreased antigen processing at the skin and mucosal level and altered immune cell populations and cytokine production. It has been proposed that associated with this there may be a reduction in vaccine efficacy (Tong 2000).

There has recently been interest in the potential for microorganisms, including human pathogens, to survive in dust particles and travel thousands of kilometers within clouds (McCarthy 2001). It has been noted that the amount of African dust crossing the Atlantic and arriving in the Caribbean has been related to weather conditions, with a substantial increase during past severe droughts in Africa. Whether this weather-related phenomenon is resulting in the spread of infectious diseases currently remains speculative.

Natural Climate Variability

There is an important distinction between current climate variability and potential climate change. The most important global climate system correlating with year-to-year variations in weather is the El Niño Southern Oscillation (ENSO). ENSO is a cycle of warming and cooling of the sea surface. Its two extremes are El Niño (warm event for the Peruvian coast) and La Niña (cool event) (Kovats 2000). The changes in sea temperature in the Pacific Ocean are paralleled by changes in atmospheric pressure across the Pacific basin (the Southern Oscillation). El Niño events occur every 2-7 years and last for 1-2 years. They are associated with extreme weather conditions, including floods in some countries such as in South America, and droughts in others such as Australia, Indonesia and Papua New Guinea (Kovats 2000; Nicholls 1993). There has been a strong association between ENSO and natural disasters globally such as floods, droughts, cyclones, hurricanes and volcanic eruptions (Bouma et al. 1997). In general the effects are more marked during El Niño years than La Niña years, with the rate of persons affected by natural disasters worldwide being greatest in the two years after each El Niño commences. However, there are important regional differences, with those parts of the world which usually receive less rain during El Niño events (such as Australia, Indonesia and Papua New Guinea) tending to become wetter during La Niña events (Githeko et al. 2000; Kovats 2000). Regional variations also occur in the likelihood of tropical storms and cyclones (Bouma et al. 1997). Similarly, disease risk variations are also evident. While some areas have an increased risk of malaria epidemics during a typical El Niño year, others have decreased malaria (Githeko et al. 2000; Loevinsohn 1994).

Climate Change

While the link between variation in climate as evidenced by ENSO and natural disasters and disease is clearly established, the potential magnitude of the additional impact of predicted global climate change remains to be quantified. However, there has recently been consensus amongst most climatologists that climate changes resulting from human activities and separate from natural climate variations have already begun (Githeko et al. 2000; Patz et al. 1996). This is due to large-scale pollution of the lower atmosphere with greenhouse gases, of which carbon dioxide related to both fossil fuel use and deforestation is the major contributor (Patz et al. 1996). There is now general agreement that anthropogenic greenhouse gas emissions are significantly accelerating current global trends in warming. It was estimated that by 2100 the average temperature increase would be 2.0°C with a range of 1.0°C to 3.5°C (Githeko et al. 2000). However, the most recent estimates which include carbon-cycle feedbacks in the modelling now predict an average rise of 5.5°C by 2100 (Cox et al. 2000). It is also estimated that sea levels may rise by approximately 0.5m by the year 2100 (Patz et al. 1996). The earlier more conservative estimated rises in temperature and sea level represent five-fold and three-fold faster rates respectively than those which have occurred over the last 100 years. Of concern is that in addition to the direct effects of global warming it is predicted that ENSO events such as severe storms and weather conditions causing floods and droughts may become more frequent with global warming (Kovats 2000; Nicholls 1993; Patz et al. 1996).

In addition to the direct effect of increased temperature and rainfall on vector-borne diseases, climate variability and natural disasters can result in extensive human migration, damage to health system infrastructure and crop failure with resulting malnutrition and economic instability. There is therefore the potential for catastrophic multifactorial health impacts from global warming when combined with population pressures and environmental destruction such as deforestation and desertification.

Specific Diseases in Australia

For Australia, it was predicted that by 2030 temperatures will rise by 0.3-1.4°C, and there may be an overall decrease in rainfall, although this has not been evident in recent analyses (Githeko et al. 2000). The most recent CSIRO prediction is for a 0.4-2.0°C rise over most of Australia by 2030 (CSIRO 2001). Furthermore, although rainfall may decrease in southern Australia the overall rainfall in the tropical north may well increase and in particular be associated with heavier monsoonal rainfall (Nicholls 1993). A study from the Top End of the Northern Territory showed a slight overall increase in annual total rainfall over the last 50 years with an increase in the strength of the Australian summer monsoon during that period (Butterworth & Arthur 1993).

Malaria

Malaria was an important cause of morbidity and mortality during early European settlement of northern Australia (Currie 1993). The decline of malaria in the north resulted from a combination of case treatment, surveillance and drug eradication programs, together with vector mosquito control measures around population centres. The last indigenous case of malaria in Australia (not imported or from an introduced case) was from Roper River, Northern Territory in 1962. However, the continuing presence of certain Anopheles mosquito species makes tropical Australia north of latitude 19°S (north of a line connecting Broome and Townsville) considered to be receptive for malaria reintroduction (Currie 2000). There has been no malaria transmission in the Northern Territory since 1962, but in north Queensland there have been occasional local cycles of transmission called “introduced malaria”, which involved local mosquitoes being infected from an imported case (Brookes et al. 1997). A case of “airport malaria” was reported from Cairns in 1996 and was presumed to be caused by importation of an infected mosquito (Jenkin et al. 1997).

With the close geographical and cultural links to Papua New Guinea, the Torres Strait Islands are particularly vulnerable to introduced malaria and the potential for reestablishment of indigenous disease. Deaths from *Plasmodium falciparum* malaria occurred in the Torres Strait Islands in 1990 and 1992, and in 2000 a brief local transmission cycle was implicated in a reported case of introduced *P. falciparum* malaria (Harley et al. 2001). Since the events of late 1999 leading to independence for East Timor, there has been a substantial increase in numbers of malaria cases imported to Darwin and the Northern Territory, with several severe cases and one fatality (Blum & Stephens 2001). Potential future population migrations from malaria endemic areas to receptive northern Australia make ongoing malaria control measures essential. These include entomological surveillance with larval and adult mosquito control where indicated; longer term physical control measures to prevent vector mosquito breeding sites around urban areas; supervised therapy and follow up of cases to confirm parasite clearance; and active case detection in selected situations for high-risk groups, such as boat people and refugees from highly endemic areas.

Cycles of climate variation and potential global warming both have important implications for malaria. Malaria epidemics have occurred in South America after heavy rain and flooding associated with El Niño (Kovats 2000). However while malaria epidemics are more likely during and following an El Niño event in the Punjab and Sri Lanka, in the Punjab these epidemics are associated with above-normal rainfall while in Sri Lanka they are associated with below-normal rainfall (Githeko et al. 2000). The Sri Lankan situation is attributed to increased mosquito breeding in stagnant pools of water in the drier conditions. It has been predicted that the most dramatic impact on malaria with global warming will be in regions near the altitude or latitude limits of the disease, where there is unstable transmission and a large non-immune population (Githeko et al. 2000; Loevinsohn 1994; Patz et al. 1996).

Climate modeling for the Australian situation has suggested that global warming will enlarge the potential range of the main malaria vector in Australia, *Anopheles farauti*. With a model incorporating a 1.5°C increase in temperature and a 10% increase in summer rainfall in southern Australia by the year 2030, it was estimated that *A. farauti* could extend along the Queensland coast as far south as Gladstone, which is 800km south of the present limit of *A. farauti* (Bryan, Foley & Sutherst 1996).

Dengue

Since the 1880s dengue and its main mosquito vector *Aedes aegypti* have periodically invaded north Australia. Initial epidemics spread south as far as northern New South Wales. As *A. aegypti* breeds in water receptacles, it is thought that the replacement of open rainwater tanks with reticulated water has substantially contributed to the dramatic decline of *A. aegypti* which resulted in eradication of dengue in 1955 (Currie 1993). However, in the 1980s there was a resurgence of dengue in north Queensland, with seven outbreaks documented between 1990 and 1998 (Hanna et al. 1998). *A. aegypti* remains present in north Queensland and dengue continues to be introduced, with extensive surveillance and public health measures required, such as the Dengue Fever Management Plan for imported dengue cases and when local transmission occurs (Hanna et al. 2001). *A. aegypti* and therefore dengue remain eradicated from the Northern Territory and Western Australia, but imported mosquitoes and/or larvae are occasionally detected, most recently in boats arriving from East Timor. In addition, since late 1999 there has been a substantial increase in the numbers of dengue cases arriving in Darwin, mostly from East Timor. Continued surveillance is therefore essential to prevent reestablishment of dengue in the Top End of the Northern Territory.

Increased rainfall can affect *A. aegypti* density in some locations and high rates of dengue and dengue haemorrhagic fever in 1998 in parts of Asia were attributed to weather conditions related to El Niño (Kovats 2000). Epidemics of dengue in some South Pacific islands have been linked to La Niña events, which were associated with more rainfall and a higher temperature than normal (Kovats 2000). However, in Indonesia dengue fever epidemics have occurred in drought conditions following El Niño (Kovats 2000). This may in part reflect the importance in urban settings of *A. aegypti* breeding in peri-domestic receptacles.

The increases in dengue in many tropical regions over the last 20 years have been attributed to a combination of urbanisation, population migration, absence of closed water systems and inadequate mosquito control (Kovats 2000; Patz et al. 1996). In addition, there has been a clear association of increased rates of dengue during warmer years. With slightly higher temperatures the extrinsic incubation period of the virus in the mosquito decreases, resulting in a higher proportion of mosquitoes becoming infectious at a given time (Patz et al. 1996). It has also been shown that at high temperatures *A. aegypti* bite more frequently. Therefore global warming is likely to result in both an increased distribution of dengue to higher latitudes and altitudes as well as an increased incidence in endemic areas.

Murray Valley Encephalitis

The Murray Valley encephalitis (MVE) virus is a mosquito-borne flavivirus of the West-Nile Japanese encephalitis antigenic complex. MVE virus usually causes asymptomatic infection, but for those with encephalitis the mortality from the destructive neurological disease is 20% (Currie 2000). MVE is endemic in the Kimberley region of Western Australia and the adjacent Northern Territory. MVE virus has caused epidemics of encephalitis in southeastern Australia, particularly in the Murray Darling River system. The last epidemic was in 1974, which involved 58 cases, with 13 deaths (Mackenzie 1999). The virus survives in zoonotic transmission cycles involving various vertebrate reservoir hosts of which wild birds and in particular wading water birds such as the Nankeen (Rufous) night heron are believed to be most important. The main mosquito vector is Culex annulirostris. The infrequent epidemics in temperate south-eastern Australia occur between January and May, usually following several seasons of high rainfall and flooding with large increases in vector populations (Mackenzie 1999; Spencer et al. 2001). This flooding is generally associated with La Niña events (Nicholls 1993). Cases of MVE also occur occasionally in Queensland and in Papua New Guinea (Spencer et al. 2001). MVE has been rare in Central Australia but after exceptionally heavy rainfall accompanied by flooding in early 2000 there was a cluster of cases confirmed in the region (Brown 2000).

It is thought likely that the virus is sporadically re-introduced into southern locations by birds from the north of Australia following periods of extreme rainfall and flooding. It has been proposed that environmental and ecological changes as a result of damming the Ord River to establish the irrigation area within the Kimberley region of northern Western Australia have been responsible for an increase in MVE virus activity and endemicity (Mackenzie 1999). In addition, predicted increases in temperature and intensity and frequency of tropical storms and extreme weather events associated with global warming may result in an extension of the current MVE virus endemic area and more frequent epidemics in central and southern Australia.

Japanese Encephalitis

Japanese encephalitis (JE) virus is a mosquito-borne flavivirus similar to MVE virus. The first outbreak of JE in Australia occurred in the Torres Strait in 1995 (Hanna et al. 1996). Two of the three cases were fatal. The cases occurred on Badu Island but seroepidemiological studies of sentinel pigs showed evidence of widespread infection within the Torres Strait Islands. As viral isolates were virtually identical, it was thought that the outbreak originated from a single source (Mackenzie 1999; Van Den Hurk et al. 2001). One human case of JE was reported from the Mitchell River area in south-west Cape York from March 1998 (Hanna et al. 1999). Extensive serological studies showed no evidence of other human infections in Cape York communities but domestic pigs seroconverted to JE virus in several regions. Sentinel pigs in the Torres Strait have shown JE virus activity during most wet seasons subsequent to 1995. However, sentinel pigs on Cape York have remained negative since 1998, suggesting only the single incursion of JE virus into the Australian mainland to date (Mackenzie 1999).

It has now been shown that JE virus is also established in Papua New Guinea and in particular in the Western Province (Mackenzie 1999). JE virus isolates from Papua New Guinea, the Torres Strait Islands and the Australian mainland have all been nearly identical (Van Den Hurk et al. 2001). This has led to speculation that the introduction of JE virus to Australia is through infected mosquitoes transported down from Papua New Guinea by winds associated with monsoonal weather systems (Mackenzie 1999; Van Den Hurk et al. 2001). However, further studies are necessary to definitively elucidate the mechanisms of incursion of JE virus into Australia and the roles of potential vertebrate hosts such as domestic and feral pigs and birds and the relative importance of the various potential vector mosquito species. JE has recently been confirmed also from East Timor (Hueston et al. 2001).

There is also a relationship between JE and weather patterns. Epidemics have occurred in India following heavy rainfall (La Niña effect) (Nicholls 1993). Increased temperatures and increased extremes of weather involving Papua New Guinea and northern Australia have the potential to increase the likelihood of further JE incursions into Australia. In addition, environmental factors may be important in cycles of JE virus transmission. In particular the increasing numbers of feral pigs across northern Australia have the potential to act as amplifying hosts for the virus. Authorities have estimated the numbers of feral pigs to now be in the millions in both the Top End of the Northern Territory and in Cape York, with substantial populations near many remote Aboriginal communities (Savannah Links 1999).

Melioidosis

Burkholderia pseudomallei is a soil and water saprophytic bacterium which infects humans and animals to cause melioidosis. Melioidosis is the most common cause of fatal community-acquired bacteraemic pneumonia in the tropical Top End of the Northern Territory (Currie et al. 2000a). Melioidosis is also important in north Queensland, including the Torres Strait Islands and in the Kimberley (Currie et al. 2000b). Two small outbreaks have been documented in remote Aboriginal communities associated with contamination of the water supply (Currie et al. 2001; Inglis et al. 2000). Other cases in Australia have also occurred following heavy rains and flooding in areas not normally considered endemic for melioidosis. These have included cases in the Brisbane River Valley at Ipswich (27.5°S) (Munckhof et al. 2001) and Tennant Creek (19.5°S) (Hassell et al. 2001).

Melioidosis is closely linked with rainfall. In the Top End of the Northern Territory 85% of cases occur during the six months of the monsoonal wet season (November through April) (Currie et al. 2000a).

Heavier rainfall is associated with more cases and in particular extreme weather events have resulted in clusters of cases within the endemic region. For example, subsequent to the Katherine floods on Australia Day, 26 January 1998, there were 11 cases of melioidosis with one death. Following Cyclone Thelma, a category 5 severe tropical cyclone that struck the Tiwi Islands on December 7, 1998, there were seven cases of melioidosis from the Islands, with one death. Prior to this melioidosis had been extremely uncommon on the Tiwi Islands, possibly because of the predominance of sandy soil layers rather than the clay seen across much of the mainland Top End. In addition to high rainfall predicting melioidosis cases, environmental factors are also important. Disturbance of surface soil with engineering works has been associated with animal and human case clusters in Australia (Currie et al. 2000b; Inglis et al. 2000). It is thought that these disturbances result in an increasing presence of *B. pseudomallei* at the surface, resulting in an increased likelihood of percutaneous inoculation or possibly inhalation of the bacteria. Agricultural practices have also been implicated in changes in the microbial ecology of the soil environment in certain regions. In particular it is postulated that widespread rice farming in Thailand may be implicated in a greater presence of *B. pseudomallei* in the soil and surface water (Dance 2000). In parts of northeastern Thailand melioidosis is the most important cause of community-acquired septicaemia (Chaowagul et al. 1989). Recent molecular genetic studies of the microbial ecology of soils from virgin forest and cleared areas of the Big Island in Hawaii showed a dramatic change of soil organisms within the cleared location towards *Burkholderia pseudomallei* and related species (Nusslein & Tiedje 1999). The use of pesticides and herbicides may also be relevant to the presence of *B. pseudomallei*. Elucidating the association of *B. pseudomallei* with specific vegetation and its interaction with the rhizosphere and with other soil microflora has important implications for the epidemiology of melioidosis.

It is therefore likely that potential global warming and more severe weather conditions, in particular more heavy rain and flooding, will extend the current melioidosis endemic locations. In addition, various environmental factors such as disturbances of surface soils and alterations in soil microbial ecology may result in an increase in melioidosis.

Leptospirosis

Leptospirosis is a zoonotic disease of worldwide distribution. *Leptospira* hosts include rodents, livestock, marsupials and dogs. Animals may have asymptomatic infection and harbour the spirochaete for months in their kidneys, with urinary excretion resulting in environmental contamination (Centers for Disease Control and Prevention 2001). Heavy rainfall and high temperatures increase the survival of the organism in the environment. Transmission to humans usually follows contact of skin (especially abraded skin) with contaminated water or wet soil or vegetation. Ingestion of contaminated water is also a mode of transmission. Leptospirosis is therefore an occupational hazard for those working on the land or with animals as well as being a recreational hazard to bathers, campers and most recently those involved with sporting events such as white water rafting and the recent Eco-Challenge-Sabah 2000 in Borneo, Malaysia (Centers for Disease Control and Prevention 2001).

In South America most cases occur during the rainy season (Lomar, Diament, & Torres 2000). Over the last few years leptospirosis has been increasingly diagnosed in north Queensland and the Top End of the Northern Territory (Krause 2001; Smythe et al. 2000). This is in part attributed to increasing numbers of people with recreational exposure and contrasts with the long known association of leptospirosis with sugar cane cutters exposed to rat urine. It is also possible that the *Leptospira* organisms are becoming more widespread, associated with changes in the environment with increased numbers of animal reservoirs and possibly also associated with changes in rainfall patterns. As well as increasing numbers of cases in northern Australia there has been an increase in severity of cases in both north Queensland and the Northern Territory, with patients requiring intensive care management for multiple organ damage and fatalities from severe pulmonary haemorrhage (Simpson et al. 1998).

Scrub Typhus

Scrub typhus is caused by the bacterium *Orientia tsutsugamushi*, which is transmitted to humans by the bite of a larval trombiculid mite. The mite is an ectoparasite of small mammals such as rodents and native marsupials. The bacterium is maintained in the environment through a rodent-mite cycle. Scrub typhus has long been recognised as endemic in coastal Far North Queensland as well as in Asia, Southeast Asia and some Pacific islands (McBride et al. 1999). The geographic distribution of scrub typhus vectors and disease are characteristically patchy and in north Queensland most of the circumscribed foci (mite islands) have been rainforest areas of high humidity and annual rainfall exceeding 1500mm (Currie, O'Connor & Dwyer 1993). Scrub typhus cases in humans have occurred when virgin rainforest (formerly called "scrub" in Queensland) was cleared for human settlement or activities. In Asia scrub typhus has had a monsoonal relationship.

Since 1990, nine cases of scrub typhus have been diagnosed in people visiting Litchfield Park, an area of rainforest 140km south of Darwin in the Northern Territory (Currie, O'Connor & Dwyer 1993). This region was opened to the public as Litchfield National Park in 1986 and cases have only become evident since the area became accessible to tourists. A genetic analysis of the Litchfield strain of *O. tsutsugamushi* shows it to be substantially different from strains from the East Coast of Australia and from overseas (Odorico et al. 1998). It is therefore likely that *O. tsutsugamushi* has been present in the mites and native mammals of northern Australia for millennia. There may well be other circumscribed foci of vectors, endemic rodents and *O. tsutsugamushi* in the discrete rainforest habitats across northern Australia where humans have to date rarely intruded (Currie, O'Connor & Dwyer 1993). These may become evident as tourism to the "outback" increases. It is also possible that changes in weather patterns with increasing rainfall in some regions will result in *O. tsutsugamushi* being introduced into new locations. In contrast, it has been noted that tick-borne diseases often favour temperate climates with cooler temperatures because of higher tick mortality at higher temperatures (Githeko et al. 2000). Therefore, Australian Tick Typhus, which is caused by *Rickettsia australis*, may have a diminished northern range with global warming, although higher humidity would favour tick survival.

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Effects of Climate Variation on the Transmission of Ross River Virus in Queensland, Australia

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The spatial and temporal variations of Ross River virus (RRv) infections reported in Queensland, Australia, between 1985 and 1996 were investigated by using the geographic information system. The function of cross-correlations was used to assess the correlations between climate variables (rainfall, maximum temperature, minimum temperature, relative humidity and high tide) and the monthly incidence of RRv disease over a range of time lags. The autoregressive integrated moving average (ARIMA) model was used to perform a time-series analysis. The notified cases of RRv infection came from 489 localities between 1985 and 1988, 805 between 1989 and 1992, and 1157 between 1993 and 1996 ($p < 0.001$*). There was a marked increase in the number of localities where the cases were reported by 65% for the period of 1989-1992 and 137 % for 1993-1996, compared with that for 1985-1988. The cross-correlation function shows rainfall, maximum temperature, minimum temperature and relative humidity at a lag of 1-2 months and high tide in the current month were significantly associated with the monthly incidence of RRv. The results of this study indicate that the geographic distribution of the notified RRv cases has expanded in Queensland over recent years and climate variability may have played a role in the transmission of RRv within the context of socio-ecological changes.*

Key words: *Autoregression Integrated Moving Average, Climate Variation, Geographic Information Systems, Geographic Variation, Ross River Virus*

The incidence of many arbovirus diseases has been linked to climatic factors, particularly rainfall, high tide and temperature (Lindsay, Mackenzie & Condon 1993; McMichael, Haines & Slooff 1996; Philip 1997). However, the quantitative relationship between climate variation and the transmission of arboviruses remains unclear.

Ross River virus (RRv) infection is the most prevalent vector-borne disease in Australia. Over the last 10 years (1991-2000), a total of more than 53 347 laboratory confirmed RRv cases have been reported to the Commonwealth Department of Health and Aged Care (Australian Department of Health and Aged Care 2000). In general terms, RRv activity appears to have increased in Australia in the past decade (Curran et al. 1997; Tong et al. 2001), but causes for this increase remain largely unknown (Russell 1994). A number of studies have examined the relationship between climate variation and arboviral disease (Lindsay et al. 1993; McMichael, Haines & Slooff 1996; Tong et al. 1998). Several models have been developed to assess the potential impact of such future climatic changes on health (Derek et al. 1999; Martens et al. 1995; Patz et al. 1998).

RRv, an alphavirus, causes a syndrome known as epidemic polyarthritis or RRv disease (Kay & Aaskov 1988; Mackenzie et al. 1994). Epidemic polyarthritis is a debilitating and frequently persistent disease characterised by arthritis, fever, rash, and fatigue. It is the most prevalent vector-borne disease in Australia and many cases are reported annually (Curran et al. 1997; Mackenzie et al. 1994). The economic impact of this disease is thought to be costing a minimum of tens of millions of dollars annually in direct and indirect health costs nationally (Boughton 1994; Russell 1994, 1998).

Methodologies for assessing the relationship between environmental exposures and health outcomes have been evolving rapidly over the last two decades. Geographic Information System (GIS) is a useful tool for studying associations between location, environment, and disease because of its spatial analysis and display capabilities (Gesler et al. 1986). Recently GIS has been used in the surveillance and monitoring of vector-borne diseases (Kitron & Kazmierczak 1997; Hightower et al. 1998; Morrison et al. 1998), waterborne diseases (Clarke et al. 1991), sexually transmitted diseases (Becker et al. 1998), in environmental health (Reeves et al. 1994; Vine et al. 1997), injury control and prevention (Braddock et al. 1994), and in the analysis of disease control policy and planning (Gordon & Womersley 1997). It is envisaged that GIS will play an increasingly important role in medical and public health research.

Time series analysis has a long history of application in econometrics, particularly in the domain of forecasting. Recently, it has been used extensively to study the public health effects of environmental exposures such as the impact of air pollution on mortality and morbidity (Bowie & Prothero 1981; Catalano & Serxner 1987; Helfenstein 1986; Helfenstein 1991).

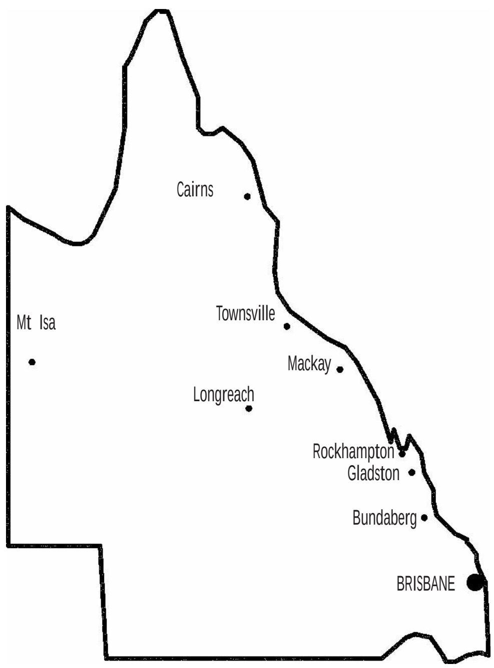
Using GIS, we attempted to examine the geographic distribution of notified cases of the RRv infection. Additionally we used time series analytic techniques to assess the potential impact of climate variability on the transmission of RRv infection in Queensland between 1985 and 1996.

Methods

Queensland is the second largest state (behind Western Australia), but has the largest habitable area in Australia. It occupies the northeastern quarter of the continent (Figure 1) and covers approximately 1 727 000 km^2, with 7400 km of mainland coastline (9800 km including islands). Lying generally between 10° and 29° south of the equator, it ranges from the temperate and densely populated southeast to the tropical, sparsely populated Cape York Peninsula in the north. There were 3 566 357 residents in Queensland on 30 June 2000 (Australian Bureau of Statistics 2000).The computerised data set on the notified RRv cases in Queensland for the period of 1985 to 1996 and their key sociodemographic information was obtained from the Queensland Department of Health. This data set was also used by the National Notifiable Diseases Surveillance System (NNDSS) which is conducted under the auspices of the Communicable Diseases Network Australia New Zealand. The reported place of onset for each case was used to characterise the geographic distribution of the RRv infection within Queensland.

The MapInfo Professional software (MapInfo professional version 4.5 1998) was used to display the spatial and temporal distributions of RRv cases. The digital base map data sets used for constructing the GIS were obtained primarily from the Queensland Department of Natural Resources. These data were manipulated to facilitate the accurate identification of the spatial locations of suburbs, townships and their linkages with the other data layers. Therefore, according to the digital base map data sets provided by the Queensland

Figure 1: Map of Queensland



Department of Natural Resources, the location in this study is defined as the locality of a suburb (e.g., in Brisbane and other major cities) or a township. The onset places in the data set were geo-coded to the digital base maps of localities utilising MapInfo and Microsoft Access software. The location for each notified case of the RRv virus infection was then obtained by overlaying the database of the onset places of notified RRv infections with the digital base maps. The software automatically links the onset places of the notified RRv virus cases from the data set to the digital base-map database if there is an exact locality match. Places that could not be automatically geo-coded were matched interactivity, using postcode as a secondary search criterion to reduce potential assignment errors. Cases that could not be geo-coded (< 1%) were excluded from the spatial analysis. The basic premise underlying the geographical mapping is the localities where the cases were notified.

In order to visualise the temporal and spatial distributions of notified RRv infections, the Chi-square test of homogeneity was performed to examine whether the differences in the localities where RRv cases were notified in different years were the random variation (Tong et al 2001). We examined annual variation of localities where RRv cases were notified and then classified them into three categories (each for a four-year period).

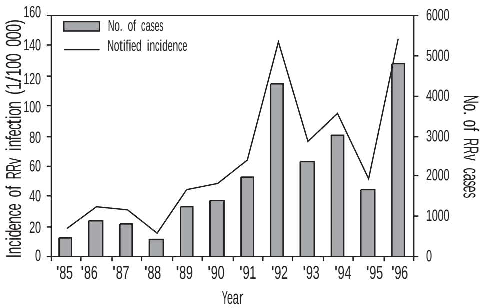
We also attempted to explore possible determinants of the RRv transmission. As the first step, the quantitative relationship between climate variability and monthly incidence of RRv was assessed. The function of cross-correlations was used to assess the associations between climate variables and the incidence of RRv disease over a range of time lags (Chatfield 1975). A pilot study was conducted to assess the association between climate variation and the RRv transmission. The autoregressive integrated moving average (ARIMA) models were developed and validated using the data from Cairns (Tong & Hu 2001). ARIMA models were fitted with the time series of the monthly incidence of RRv (Box & Jenkins 1970). The goodness-of-fit of the models was checked for adequacy using both time series (residual autocorrelation functions) and classical tools (the normality of residuals). The data file was divided into two data sets: a model building (January 1985-December 1994); and a validation (January 1995-December 1996). The former was used for the construction of the ARIMA model and the latter for the validation of the model.

Results

The number of notified RRv cases in Queensland varied between 1985 and 1996, and reached a record high (4815 cases) in 1996. The incidence of the RRv infection ranged from 15.0 per 100 000 in 1988 to 144.2 per 100 000 in 1996 (Figure 2).

Over the period 1985-96, there was a remarkable increase in the number of

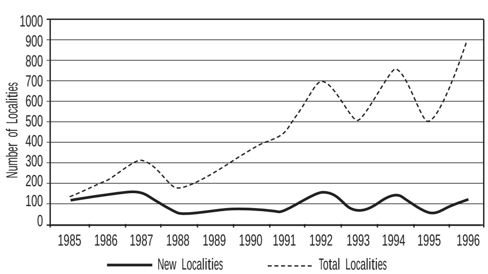
Figure 2: Incidence of notified Ross River virus infections in Queensland, 1985-1996



localities where RRv infections were reported. It is worth noting that, in the meantime, the number of "new" sites of notified RRv cases on more than one occasion increased steadily since 1988 (Figure 3).

The spatial analyses show that the cases came from 489 locations between 1985 and 1988, 805 between 1989 and 1992, and 1157 between 1993 and 1996. Clearly, there was a statistically significant increase in the number of localities where RRv cases were notified ($\chi^2_{(df=2)} = 680.9$; $p < 0.001$). The increase of the number of localities was also seen across the majority of categories (Table 1). The total number of locations where the RRv cases were reported increased by 65% for the period of 1989-1992 and 137% for 1993-1996, compared with that for 1985-1988.

Figure 3: Number of localities by type and year



In order to examine the impact of climate variability on the transmission of RRv, further analysis was conducted using the data from Cairns. The results of the cross-correlations show that most climate variables were significantly associated with the monthly incidence of RRv (Table 2). The maximum temperature in the current month, and rainfall and relative humidity at 3pm at lag of two months were significantly associated with the incidence of RRv. However, the relative humidity at lag of five months was inversely associated with the RRv incidence. The ARIMA model was built with the 10-year data (January 1985 to December 1994) on monthly incidences of RRv and climate variation, and then validated using the data between January 1995 and December 1996. The results show the relative humidity at a lag of five months ($p<0.001$) and rainfall at lag of 2 months ($p<0.05$) were statistically significantly associated with the transmission of RRv

Table 1. Number of localities where the Ross River virus cases were notified in Queensland, Australia, 1985-1996

Time	Number of cases				*p*
	1-49	50-99	100-	Total	
1985-1988	482	3	4	489	
1989-1992	777	19	9	805	<0.001
1993-1996	1126	23	8	1157	

Table 2. Cross correlation coefficients between climate variables and monthly incidence of Ross River virus in Cairns, Queensland*

Cairns	MaxT	MinT	Rainfall	Rh9am	Rh3pm	HT
Lag 0	0.214†	-0.080	0.101	-0.064	-0.146	0.191
Lag 1	0.169	0.042	-0.019	0.053	0.117	0.064
Lag 2	-0.002	0.007	0.223†	0.195	0.206†	0.177
Lag 3	0.140	-0.030	0.181	0.067	0.079	0.123
Lag 4	0.183	0.056	-0.122	-0.177	-0.074	-0.165
Lag 5	0.065	0.128	-0.165	-0.293†	-0.224†	-0.018

*MaxT: Maximum temperature; MinT: Minimum temperature; RH9am: Relative humidity at 9am; Rh3pm: Relative humidity at 3pm;

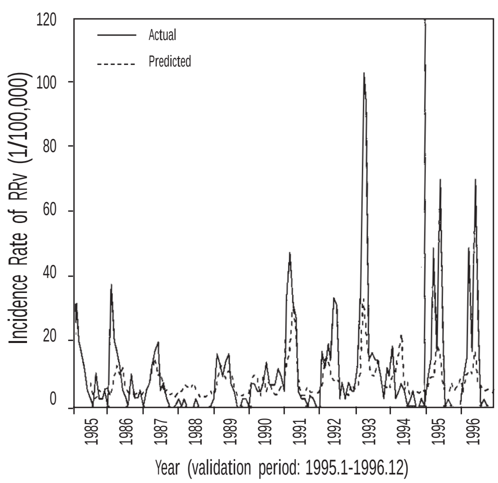
HT: High tide, - data unavailable

Lx =the lagged months

† Significant at the 0.05 level (2-tailed)

disease in Cairns. The regressive forecast chart in Cairns indicates that the predicted values and the actual incidence rates of RRv matched considerably well (Figure 4).

Figure 4: Regressive forecasts or RRv in Cairns, 1985-1996



Discussion

Geographic distribution of notified RRv cases appears to have expanded in Queensland over recent years. This finding is consistent with the geographic variation observed in South Australia (Selden & Cameron 1996). However, determinants of the spatial and temporal variation of RRv remain unclear. Temperature, humidity, virus strain, mosquito population densities and survival, human behaviour, urban development and housing characteristics may all contribute and interact in determining RRv transmission.

Changes in climate and the environment may influence the abundance and distribution of vectors and intermediate hosts (Lindsay, Mackenzie & Condon 1993; McMichael, Haines & Slooff 1996). Warmer temperatures may allow vectors to survive winters that normally would have limited their populations and to reach maturity much faster than lower temperatures (Lindsay, Mackenzie & Condon 1993). For example, within the temperature range that a mosquito species can breed, larvae reared at high temperature has a dramatic effect on length and efficiency of the extrinsic incubation periods (EIPs) of arboviruses in their vectors. The EIPs are inversely related to the temperature of incubation, within the temperature ranges that allow virus replication to occur. In other words, mosquitoes exposed to higher temperatures after ingestion of virus become "infectious" more rapidly than mosquitoes of the same species exposed to lower temperatures (McMichael, Haines & Slooff 1996). Transmission of an arbovirus may therefore be enhanced under warmer conditions because more vector mosquitoes become infectious within their life span.

High tides and rise in sea level have been implicated as important precursors of outbreaks of RRv (Lindsay, Mackenzie & Condon 1993; McManus, Russell & Wells 1992; Phillips et al. 1992). Tidal inundation of saltmarshes is a major source of water for breeding of the important arbovirus vectors *Ae.vigilas* and *Ae.camptorhynchus*. Adult females of both species lay their eggs on soil, mud substrate and the plants around the margins of their breeding sites. The eggs hatch when high tides subsequently inundate sites. Large populations of adult mosquitoes can emerge as quickly as eight days after a series of spring tides (Lindsay, Mackenzie & Condon 1993). There is good evidence that a rise in sea level may contribute to a major outbreak of RRv. For example, in an outbreak of RRv in south-western Australia during the summer of 1988-1989, a rise in sea-level of 5.5 cm (above the long-term mean), exacerbated by a pattern of strong north and south-westerly winds, led to more frequent and widespread inundation of coastal saltmarshes in the region than is normally recorded. This subsequently increased the populations of *Ae.camptorhynchus* mosquitoes and as a result, an outbreak of RRv infection occurred (Lindsay & Mackenzie 1997). The results of this study corroborate the previous findings, indicating that sea level is an important factor in the transmission of RRv in the coastal region.

Relative humidity influences longevity, mating, dispersal, feeding behaviour and oviposition of mosquitoes (McMichael, Haines & Condon 1993). Under suitable humidity, mosquitoes generally survive for longer and disperse further. They have a greater chance of feeding on an infecting animal and surviving to transmit a virus to humans or other animals. Relative humidity also directly affects evaporation rates from vector breeding sites. Clearly, humidity is another contribution factor to outbreaks of RRv disease, particularly in normally arid regions (Lindsay & Mackenzie 1997). In our pilot study, we found that the incidence of RRv disease was significantly and inversely associated with relative humidity at a log of five months. It might be because the decrease in relative humidity can lead to a reduction in the flow of water in streams, resulting in the establishment of series of stagnant pools, often high in organic matter, making perfect breeding sites for a number of mosquito species. Added to this, such reduced water sources are likely to become central to animal and bird drinking requirements, thus increasing the potential for vertebrate host-insect transmission cycles.

The geographic distribution of RRv can also be affected by many other factors, such as population growth, urbanisation, increased travel, environmental or ecological change. For example, the Queensland population increased by approximately 30% from 2 625 000 to 3 390 000 between 1986 and 1996 (Australian Bureau of Statistics 2000), and more people might have moved into endemic areas or into areas with increased potential for exposure to RRv infection. It is likely that an increase in the potential for exposure to the virus is partly due to urban expansion into areas close to wetlands and saltmarshes or through the establishment of canal developments, leading to either increased mosquito populations, or to increased contact between humans and existing vector populations (Mackenzie et al. 1994; Russell 1994). The possible variation in the quality of the NNDSS data (e.g., notification rates) might also affect the assessment of the geographic distribution of RRv. For example, arboviral infections were primarily reported by medical practitioners before the end of 1991. From 1992, RRv infections became notifiable by confirming laboratories (Russell 1994). However, the national guidelines for testing and reporting, was not available until 1993 (Mackenzie et al. 1993). Further, both under-reporting and over-diagnosis are possible in the NNDSS data. Under-reporting is likely to occur when most of the people infected by RRv were not clinically apparent; patients who had infections did not attend physicians because they knew there was no specific treatment for RRv; and some patients might be misdiagnosed as having other diseases if they did not have typical clinical symptoms. Over-diagnosis is also possible in endemic situations because an IgM response was usually based on a single serum specimen, and it may represent past infection in a person who currently has another disease (Mackenzie et al. 1998).

The limitations of this study must be acknowledged. First, the premise underlying the geographical mapping in this study is the place of onset, that is, the locality where the RRv case was notified. The place of onset is presumed as the place of acquisition of infection under the NDDSS. Although some studies indicate that the geographical distribution of cases reflects fairly accurately the locations in which RRv infections actually occur (Lindsay & Mackenzie 1997; Selden & Cameron 1996); there may be differences between these two places, particularly in holiday seasons. Second, climate variation is possibly one of the many factors that determine the RRv transmission, and the availability of the socio-ecological data (eg., mosquito species and density, scale of urbanisation and human behaviour) is limited. Finally, there was an epidemic outbreak of RRv across

Queensland in 1996, and it may have a significant impact on the assessment of the geographic distribution of RRv. It remains to be determined whether the geographic expansion of RRv has continued since 1996.

There has been global resurgence of arboviral diseases (Gubler 1996). Ecologic changes and human behaviour are important in the spread of these diseases (Ansari & Shope 1994). As the geographic expansion of RRv transmission is likely to continue, with a concomitant increase in disease incidence, it is essential that public health resources are directed into these areas. In the meantime, epidemiologists, public health physicians, microbiologists, ecologists and environmental health practitioners need to work together to assess major determinants of RRv transmission.

Conclusion

The results of this study indicate that the geographic distribution of the notified Ross River virus cases has expanded in Queensland over recent years and climate variability may have played an important role in the transmission of RRv within the context of socio-ecological changes. RRv disease is a serious public health problem accounting for significant morbidity in Australia and therefore concerted efforts are needed to control and prevent this disease. In order to develop effective disease control and preventive strategies, it is necessary to improve our understanding of the impact of environmental change and ecosystem stress on the transmission of RRv. The following strategies may be useful. First, the current disease surveillance system must continue but its effectiveness may need to be improved to increase the accuracy of the surveillance data. Second, more research is clearly warranted better to understand the ecology of RRv transmission and more funding is required. Third, systematic and integrated training might be necessary for medical practitioners and public health professionals. Finally, computer models need to be developed on the basis of in-depth research to predict possible epidemic activity under different environmental conditions, and as a means of predicting future consequences of environmental change.

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Climate Variability and the Dengue Outbreak in Townsville, Queensland, 1992-93

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Although Australia is free of local dengue transmission, there have been several outbreaks of dengue in Queensland since 1981 because of importation of dengue cases. This study was conducted on monthly time-series data of the dengue outbreak in Townsville in 1992 and 1993. It used graphic assessment, Spearman correlation, AutoRegressive Integrated Moving Average and Generalised Least Square regression analyses. The results showed that the annual mean minimum temperature in the outbreak years was 0.6°C higher than that in non-outbreak years. Monthly mean maximum and minimum temperatures, total amounts of precipitation and relative humidity four months earlier were significantly correlated with the monthly attack rate of the disease. The regression analysis suggested that monthly mean minimum temperature with a four-month lagged effect was the strongest climatic predictor of the dengue fever outbreak and indicated that it was important in dengue transmission. However, the relationship between climatic variables and dengue fever needs to be viewed within a wider context of other social and environmental factors, such as population growth, human behaviour, house conditions and vector control programs. Vigilance in control and prevention of dengue fever may need to be increased in Australia because of possible climate change with temperature increases.

Keywords: *Climate, Dengue Fever, Outbreaks, Queensland*

Dengue fever is a mosquito-borne disease caused by dengue viruses, transmitted mainly by *Aedes aegypti*, a domestic, day-biting mosquito that prefers to feed on humans. It has been regarded as the most important mosquito-borne viral disease in the world, and tens of millions of cases of dengue fever occur every year (Gubler & Clark 1995). There are between 250 000 and 500 000 Dengue Hemorrhagic Fever/ Dengue Shock Syndrome cases throughout the world annually, and the case fatality rate approaches 40% to 50% if untreated (Patz et al. 1996).

Australia was considered to be free of local dengue transmission following 1953-55, when there was a large outbreak (15 000 cases) in Townsville, northern Queensland (Doherty 1957). However, several dengue outbreaks have been reported in the last two decades, such as that in northern Queensland in 1981 (Kay et al. 1984), Cairns and the Torres Strait during 1990-91 (Mackenzie et al. 1994) and 1996-98 (Hanna et al. 1998), in Townsville and Charters Towers in 1992-93 (Phillips et al. 1992; Row et al 1993), and in far north Queensland in 1997-99 (Hanna et al. 2001).

The importation of viruses from Fiji, Papua New Guinea, Thailand and Indonesia, and their transmission have been a significant public health problem in Australia, particular in Queensland, because *Aedes aegypti* is widespread (Hanna et al 2001; Russell 1995).

Climate variability may impact on the transmission of dengue fever because it could influence the growth of the virus and mosquito, as well as people's behaviour. It has been shown that temperatures can affect the replication of dengue II virus within *Aedes aegypti* (Koopman et al. 1991; Nimmannitya et al. 1969; Watts et al. 1987).

According to the predictions of the Commonwealth Scientific & Industrial Research Organisation (CSIRO), temperature is expected to increase 1-3°C and there could be more irregular rainfall in Australia by the end of the 21st century (CSIRO 1996). It is important to study the impact of climate variability on the transmission of dengue in Australia, especially in dengue receptive areas such as north Queensland. However, few data are available in this field. Hence, an empirical analysis was conducted of the dengue fever outbreak in Townsville during 1992-93, to examine the relationship between climate variables and the attack rate of the disease, to determine possible risk factors and to set up a predictive model on the basis of the empirical data.

Methods

Background information

Situated in the tropics of North Queensland, Townsville is located approximately 1380 kilometres north of Brisbane, and 350 kilometres south of Cairns. With a population exceeding 130 000 in 1996, it is the largest population centre in northern Queensland. Townsville has been a particular area for dengue fever, with large-scale outbreaks. In 1897, for example, approximately 75% of the town's population was infected, and in the 1953-55 outbreak, it was 40% (Doherty 1957; Hare 1898).

Study population

All the residents in Townsville over the period 1990-94 were treated as the study population (as denominator). Locally infected dengue cases during this period were treated as numerator.

Data collection

Monthly disease data were obtained from the Queensland Department of Health. All dengue cases in Townsville over the study period were confirmed by laboratory test according to Australian laboratory criteria. The Australian Bureau of Statistics provided population data. Monthly meteorological data were retrieved from the Australian Bureau of Meteorology.

Data analysis

Data analysis was performed using the Statistical Package for Social Sciences (SPSS) (Coakes & Steed 1996). Monthly averages of climatic variables were calculated as the arithmetic average of the daily observations for each climatic variable. Spearman's rank correlation analysis was conducted between monthly attack rate of dengue fever and monthly average climatic variables such as temperature, precipitation, and relative humidity. To examine any lagged effect of climate variables on the transmission of dengue fever, correlations were performed between the monthly attack rate of dengue fever and climatic variables in the current month, and with lags of one, two, three and four months. The month that had the largest correlation coefficient was chosen as a lag period in subsequent analysis.

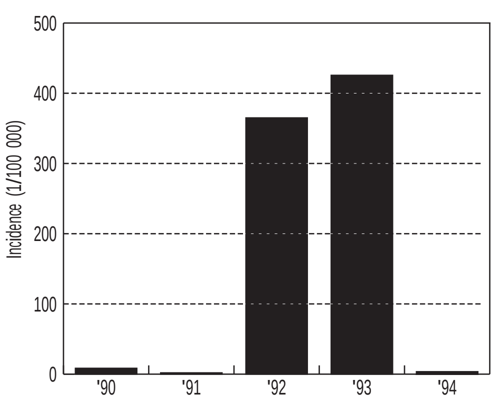
Since there might be correlations among both dependent and independent variables over time, AutoRegressive Integrated Moving Average (ARIMA) and Generalised Least Squares (GLS) regression analyses were performed, the purpose was to control for possible autocorrelation in the time-series data. A model was developed after the effect of autocorrelation had been removed by the ARIMA procedures, and GLS regression analysis was conducted to assess the independent effects of each climatic variable (Box & Jenkins 1976).

Results

Annual distribution of dengue cases in Townsville, 1990-94

Figure 1 showed the annual distribution of dengue cases in Townsville, 1990-94. There was a clear outbreak in 1992 and 1993.

Figure 1: Annual distribution of dengue in Townsville, 1990-94



The distribution of monthly attack rate of dengue fever and mean minimum temperatures in Townsville from 1990 to 1994

Figure 2 indicated the distribution of monthly attack rates of dengue fever and mean minimum temperatures in Townsville, 1990-94.

The relationship between annual attack rate of dengue fever and annual mean minimum temperature in Townsville from 1990 to 1994

Figure 3 showed that the annual mean minimum temperatures in 1992 and 1993, when the outbreak occurred, were about 0.6 °C higher than the minimum temperatures in other years over the period 1990-1994. However, there was no apparent change in other climatic variables during these years (e.g., the annual average rainfall is 547mm: 556mm between the outbreak <92-93> and non-outbreak years <90, 91, and 94> in Townsville). It seemed that mean minimum temperature could be worthy of investigation as a possible contributor to the progress of the dengue fever outbreak in Townsville.

Correlation analyses among monthly climatic variables and monthly attack rate of dengue fever in Townsville, 1992-93

As shown in Table 1, four climatic variables, lagged four months, were statistically significantly correlated with the monthly attack rate of dengue fever.

Table 1: Correlations between climatic variables and monthly attack rate of dengue in Townsville, 1992-93

Climatic variables	Monthly incidence	P value
MaxTP4	0.742	0.000
MinTP4	0.796	0.000
RainP4	0.621	0.001
RHP4	0.581	0.003

MaxTP4 = monthly mean maximum temperatures four months earlier,
MinTP4 = monthly mean minimum temperatures four months earlier,
RHP4 = monthly mean relative humidity four month previously,
RainP4 = total amounts of monthly precipitation four months earlier.

Climatic variables and monthly attack rate of dengue fever in Townsville, 1992-93—regression analysis

To further quantify the relationship between climatic variables and monthly attack rate of dengue, regression analysis was performed. Table 2 showed that there was a significant

Figure 2: The distribution of monthly dengue fever attack rate and minimum temperatures in Townsville, 1990-94

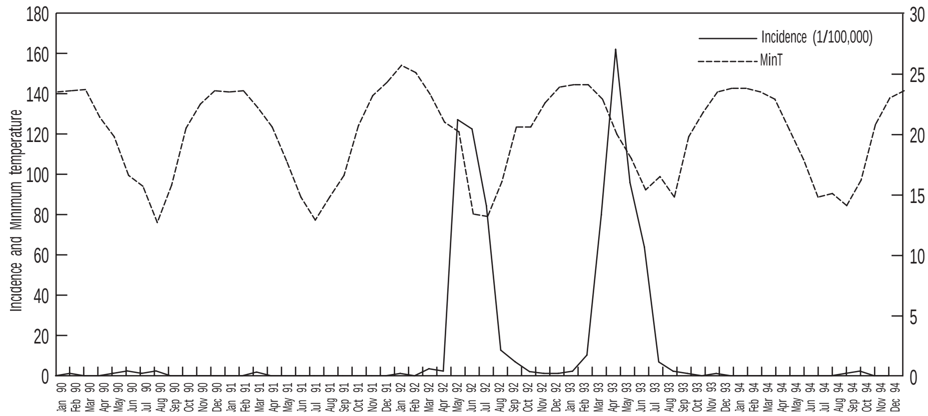


Figure 3: Annual attack rates of dengue and minimum temperatures, 1990-94

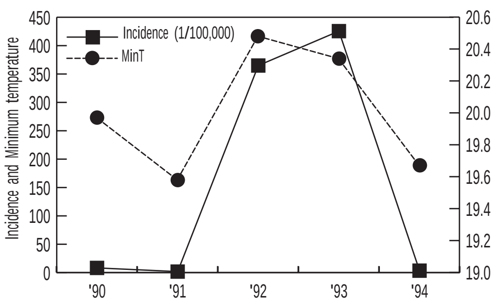


Table 2: Regression analysis between climatic variables and monthly attack rate of dengue in Townsville, 1992-93

Explanatory variables	*B*	*SE*	*P* value
Model 1			
MinTP4 (0C)	0.6957	0.1912	0.013
RAINP4 (mm)	-0.0007	0.0019	0.725
RHP4 (%)	0.0052	0.0281	0.855
CONSTANT	-7.4589	1.2929	0.000
	R^2=0.42		
Model 2			
MaxTP4 (0C)	0.6450	0.1908	0.019
RAINP4 (mm)	-0.0012	0.0019	0.534
RHP4 (%)	0.0369	0.0246	0.153
CONSTANT	-11.8738	2.3719	0.000
	R^2=0.38		

relationship between the monthly attack rate of dengue and monthly mean minimum temperature four months earlier, after taking into account the effects of rainfall and relative humidity. However, there was no significant association between monthly attack rate of dengue and either rainfall or relative humidity. The results also indicate that monthly mean minimum temperature seems to play a more important role in the transmission of dengue fever than monthly mean maximum temperature.

Discussion

Dengue is not endemic in Australia, outbreaks are the result of importations (Mackenzie et al. 1998). Most importations probably do not lead to significant local transmission. However, outbreaks do occur when conditions suit. Types of viruses, vector populations, temperature, unscreened houses and human behaviour, and an immunologically naïve human population are possible risk factors (Koopman et al. 1991; McBride et al. 1998; Murray-Smith et al. 1996).

There are four types of dengue viruses. The dengue virus type in the Townsville outbreak in 1992-93 was dengue type II (Phillips et al. 1992; Row et al. 1993). An outbreak of dengue fever is complicated. Many factors, such as the timing of introduction of an infected traveller (with dengue virus) coinciding with the presence of a receptive vector population, the number of viraemic travellers, human activities, increased abundance of vectors, as well as climatic variables, may contribute to the outbreak. Unfortunately, data on most potential risk factors were not available in this study.

Climatic variables could be expected to play a certain role in the transmission of vector-borne diseases including dengue fever (Lindsay & Mackenzie 1997). Temperatures influence the aspects of *Aedes aegypti*'s life cycle, including growth rate and survival of the immature stage, time to first blood meal, and the length of gonotrophic cycles (Lindsay & Mackenzie 1997). They also play a key role in determining the Extrinsic Incubation Period (EIP), the period of viral replication within mosquitoes (Lindsay & Mackenzie 1997). For dengue II virus, for example, the EIP is about 12 days at 30°C, but at 32-35°C, it is seven days (Watts et al. 1987). A field study in Mexico found that communities with a mean temperature of 36°C during the rainy season had a four-fold increased risk of infection when compared with communities with a mean rainy season temperature of 17°C (Koopman et al. 1991). Correlation and regression analyses in this study showed that temperatures were significantly associated with the attack rate of dengue fever. The increase of temperatures, especially the rise of mean minimum temperatures, would probably have a positive impact on the development of the mosquito and virus replication within the mosquitoes, then on the transmission of dengue fever. This might also be important in maintenance of dengue foci. In this study, it was found that monthly mean minimum temperatures impact on the transmission of dengue fever through a four-month lagged effect. This includes the periods of the replication and development of the mosquito, the EIP of the virus to replicate in the mosquito and the incubation period of the virus within the host, as well as the time of creation of breeding sites by increased use of sprinklers and pot plant watering.

Temperature is one of the potential risk factors in the transmission of dengue fever. Combining the importation of dengue fever cases with abundance of an "effective" vector population and a lower population immunity in Townsville (its previous outbreak occurred in 1981), higher minimum temperatures could have increased the likelihood of an outbreak in 1992-93. Although dengue is not endemic in Townsville, there were cases every year over the period 1990-94, which seemed to be the result of its introduction by infected travellers in the presence of a receptive vector population. The 0.6°C higher minimum temperature in 1992-93 was probably one of the driving forces of the vector population.

Although there is a correlation between total monthly amounts of precipitation and the monthly attack rate of dengue fever, the variable is not significant in this regression model. *Aedes aegypti* is predominantly a day-biting mosquito whose larvae may be found almost exclusively in clean water in man-made containers such as water-barrels, rainwater tanks, wells, vases, tyres, bottles, tins and most other water-holding containers found in the domestic environment (Kay et al. 1987; Lindsay & Mackenzie 1997). This is particularly important because these breeding sites are often maintained by human activity and are largely independent of precipitation. It suggests that precipitation may not make a significant contribution to the generation of a dengue fever outbreak (Herrera-Basto et al. 1992). In the outbreak of dengue fever in Townsville in 1981, for example, 40-80% of infestations were associated with indoor plants and the water-containing saucers beneath them, as well as with other garden accessories (Kay et al. 1984). Rainfall could increase relative humidity and create a suitable environment for the growth and development of the mosquitoes, and hence its impact on *Aedes aegypti* might be indirect. The context of epidemic triggering within seasonal rainfall may not be an important factor; this does not relate to the relative magnitude of local precipitation.

If man-made containers are favoured, there should be more mosquito potential breeding during dry (i.e., lower rainfall) periods, but actually there is not such a trend in Townsville. This might be because in Northern Queensland, the dry periods are in winter, and low temperatures during this period have a negative impact on the development of the mosquitoes.

Because *Aedes aegypti* is not a tidal-breeding mosquito, high tides should not influence its development. There are many variables influencing the transmission system of dengue, and it would be a useful next step to examine further their separate impacts. For example, our understanding of the relationship between climate variables and the attack rate of dengue would be enhanced by field data showing increased breeding and abundance of adult *Aedes aegypti* prior to and during the outbreak combined with laboratory data showing effect of temperature on development rate, vector competence and survival of Aedes aegypti. Our arguments would be stronger if similar results could be obtained from other dengue outbreaks in Townsville. Unfortunately, this information is not available and other studies are needed to consider these aspects.

While human behaviour, house-screening, and active vector control are probably key elements of dengue control (Gubler & Clark 1995; Herrera-Basto et al. 1992; Kay et al. 1987; McBride et al. 1998; Murray-Smith et al. 1996), it is important to recognise that climatic factors might change the background risk against which these control measures operate.

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Laboratory Evaluation of an Aerosol Insecticide Surface Spray Against the Mosquito *Aedes aegypti*

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Dengue is the most important arboviral disease in humans, with increasing activity in the tropics including north Queensland. Current control strategies, traditionally dominated by government-based vector control, have increasingly employed community participation to empower the public to control "their mosquitoes". The use of surface sprays to kill adult mosquitoes could be used as part of a community-based dengue control strategy. We conducted laboratory studies to measure the efficacy of a residual surface spray (Mortein's Odourless Low Irritant Surface Spray®), containing the synthetic pyrethroids permethrin and tetramethrin, against the mosquito Aedes aegypti. *Adult female mosquitoes were exposed to treated wood by a) holding them in contact with the wood using forceps or by b) placing treated wood inside a small cage of mosquitoes. Mean knockdown of mosquitoes touched down one and three times to treated wood was 4.4 and 40%, respectively. Mean mortality of caged mosquitoes exposed for 1 to 24 hours increased from 0 to 34%, respectively. The results suggest that to be effective, repeated or prolonged exposure to pyrethroid-based surface spray is required.*

Key Words: *Dengue,* Aedes aegypti*, Synthetic Pyrethroid, Community Participation*

Dengue virus infections have become the most important arbovirus disease of humans in terms of morbidity, mortality and economic burden for the affected community (Gratz 1991; Kuno 1995). Dengue is rapidly expanding in the tropical regions of the world, with an estimated 50 to 100 million cases and 2.5+ billion people at risk of infection (Gubler 1997). Increased international air travel has enhanced its spread, providing an ideal mechanism for importation of dengue between population centres in the tropics via viraemic humans (Gubler 1989).

This later phenomenon has led to a re-emergence of dengue in north Queensland since 1990. In this time, there have been four major outbreaks of dengue in north Queensland (Hanna et al. 2001), although, fortunately, no deaths have been reported. The difficulty experienced in preventing and controlling outbreaks of dengue suggest new and existing methods of controlling mosquitoes need to be developed and assessed. Interior spraying of houses with residual pyrethroid insecticides in dengue outbreak areas has been adopted recently as a control measure by the Tropical Public Health Unit in north Queensland. Interior spraying, in conjunction with source reduction and larval control, resulted in marked declines in local dengue transmission when implemented during epidemics (Hanna et al. 1998, 2001; Ritchie et al. 2001a).

The mosquito vector of dengue, *Aedes aegypti*, is a highly domesticated species (Tabachnick 1991), breeding in artificial containers such as tyres and buckets while adults frequently harbour in houses and buildings. Clearly, this domestic behaviour suggests that the public can play an important role in controlling *Ae. aegypti*. While community participation campaigns typically promote "source reduction" to remove larval breeding sites to control *Ae. aegypti* (Gubler 1989, Gubler & Clark 1996), the public can also use commercial aerosol sprays to control adult mosquitoes. Osaka et al. (1999) report that a public intervention using aerosol space sprays resulted in a significant reduction in dengue cases in southern Vietnam. The most effective adulticiding product for the homeowner would be easy to use, readily available, inexpensive, effective at killing *Ae. aegypti* when used in a typical home environment and not have any adverse health effects on the user or non-target organisms. This study investigated the efficacy of a commercially available residual pyrethroid surface spray against adult female *Ae. aegypti* under laboratory conditions.

Methods

The product tested was Mortein's Odourless Low Irritant Surface Spray®, (active constituent 2.79g/kg permethrin, 1.38g/kg tetramethrin) and is available to the public from general retailers. Test mosquitoes were from a colony of *Ae. aegypti*, maintained by Queensland Institute of Medical Research, with no known resistance to insecticides. Mosquitoes were reared in Cairns and maintained at 28°C with access to 10% sucrose until tested.

Two different experimental designs were used to assess the efficacy of the surface spray against *Ae. aegypti*. Direct contact experiments involved holding individual female *Ae. aegypti* against a treated substrate for a fixed period of time. Experiments were also conducted by exposing caged mosquitoes to a treated surface for 24 hr.

Direct contact exposure

The objective of this experiment was to determine the knockdown rate of female *Ae. aegypti* held in contact with a surface treated with the residual surface spray for three standard exposure times. The treated surfaces were 100 cm^2 pieces of timber painted with red acrylic paint. A grid consisting of 100 1- cm^2 cells was drawn onto the board to assist evenly distributing the points of contact on the board. The square was sprayed with Mortein's Odourless Low Irritant Surface Spray®, to the point of run off then allowed to air dry for at least 1hour. Each treated board was weighed before and immediately after spraying to determine the dosages. The average amount of spray was 370 + 20 mg per board or 37 g/m^2 (n = 3). This equates to a dose of approximately 100 mg/m^2 of permethrin and 50 mg/m^2 of tetramethrin. The "control" boards were not sprayed.

A few mosquitoes were anaesthetised with carbon dioxide gas then placed on a refrigerated cold table (5-10°C) to prevent escape. Individual females were gently picked up with fine forceps by the wings. While held with the forceps, all six tarsi were placed in contact with the board as follows:

- touched once on the treated surface;
- touched 3 times on the treated surface;
- held for 10 seconds on the treated surface; or
- touched once on an untreated surface (control).

After exposure, mosquitoes were placed in a 250-ml holding cup and observed for 24 hours post-treatment. A mosquito was defined as being "knocked down" if it was incapable of righting itself or flying.

Three trials, each with three replicates using 10 (trial 1-2) or 20 (trial 3) mosquitoes, were conducted for each of the doses. The percentage of knocked down mosquitoes was determined for each trial and the treatment and control means were compared using a One-way Analysis of

Variance using SPSS for Microsoft Windows, Release 6.1.

Cage exposure

One of the objectives of the project was to conduct the trials in a "real life" situation to simulate how the product works in a normal home environment. The pyramid cage design was based on the WHO bioassay cone with some modifications. The plastic cone was replaced by a mesh pyramid that allowed airflow and provided an untreated, alternative landing surface. This was important as in the field mosquitoes may selectively avoid landing or resting on treated surfaces if the residual surface spray has a repellent effect.

The treated surface was a 100 cm^2 square piece of timber painted with red acrylic paint. The red colour was chosen to increase the attraction of the surface to mosquitoes (Service 1993). The timber was sprayed with residual surface spray (Mortein's Odourless Low Irritant Surface Spray®) to the point of run off and allowed to dry. The squares were weighed pre- and post-spraying to confirm equal amounts of residual surface spray were applied to the squares. The average amount of spray was 370 mg per board or 3.7 g/m^2, the same as used in the direct contact experiment. The "control" boards were not sprayed.

Ten mosquitoes were placed in each cage, and then the boards were inserted into the cage forming a square base. The cages were placed with a mesh side down so that the treated side formed one of the upright walls of the cage. Each cage was provided with 10% sucrose and kept at 28°C and ca. 80% RH. The control and treatment trials (n = 10) were conducted at the same time and counts of knocked down mosquitoes were taken at 1, 4, 18 and 24 hr. The mean number of mosquitoes knocked down in the treatment and control populations was compared using a one-way ANOVA.

Results

Direct contact exposure

The percentage of female *Ae. aegypti* knocked down 24 hours after being touched three times or held down for 10 seconds on treated timber was significantly greater ($p < 0.05$) than for mosquitoes touched down on untreated timber (Table 1). However, touching the treated timber once did not have a significant ($p > 0.05$) impact upon the mean percentage of *Ae. aegypti* knocked down. This suggests that *Ae. aegypti* must either remain on the treated surface for some time or land on the surface a number of times in order to sustain a significant knockdown effect. While Reiter and Gubler (1997) state that transient contact with surfaces treated with residual surface spray can be sufficient to kill particular insects, they do not quantify the amount of this transient contact necessary to produce mortality with respect to *Ae. aegypti*.

Table 1: Mean (± SE; n= 3) percentage knockdown (24 hr post exposure) of 10 (trial 1-2) or 20 (trial 3) female Ae. aegypti held in contact to a painted timber treated with Mortein's Odourless Low Irritant Surface Spray® (active ingredients 2.79g/kg permethrin, 1.38g/kg tetramethrin).

	Touched once	Touched 3 times	Held down 10 sec.	Control
Trial				
1	0.0 ± 0.0	23.3 ± 23.3	6.7 ± 6.7	0.0 ± 0.0
2	3.3 ± 3.3	80.0 ± 20.0*	86.7 ± 13.3**	3.3 ± 3.3
3	10.0 ± 2.9*	16.7 ± 7.3	23.3 ± 16.4	0.0 ± 0.0
Mean	4.4 ± 1.9	40.0 ± 13.6**	38.9 ± 13.8**	1.1 ± 1.1

* *statistically significant at 0.05 level by ANOVA*

** *statistically significant at 0.01 level by ANOVA*

Cage exposure

Ae. aegypti placed in the pyramid cages containing timber treated with residual surface spray exhibited significant knockdown that increased with exposure (Table 2). Presumably, this increase is due to more mosquitoes making contact with the surface over time. No knockdown was observed until four hours' post-exposure, indicating that the spray is not fast acting. We observed mosquitoes resting on the treated surfaces for some time, although generally mosquitoes chose the untreated screen walls to rest on rather than the treated boards. This suggests that while the surface spray might have some repellency, it did not prevent some of the mosquitoes from resting on the treated timber.

Table 2: Mean percentage of female Ae. aegypti (10/cage) knocked down in pyramid test cages (n = 10) after exposure to painted timber treated with Mortein's Odourless Low Irritant Surface Spray, (active ingredients 2.79g/kg permethrin, 1.38g/kg tetramethrin).

Exposure Time	Treatment Mean ± S.E.	Control Mean ± S.E.
1 hour	0.0 ± 0.0	0.0 ± 0.0
4 hours	4.0 ± 1.6*	0.0 ± 0.0
18 hours	9.0 ± 4.3***	0.0 ± 0.0
24 hours	34.0 ± 4.0***	0.0 ± 0.0

** statistically significant at 0.05 level by ANOVA*

*** statistically significant at 0.001 level by ANOVA*

Discussion

The residual surface spray treatment did not produce mean knockdowns close to 100%, even in trials involving placement of the mosquitoes directly onto the treated surface for short periods of time. The highest mean 24-hour knockdown was 39% in *Ae. aegypti* held for 10 seconds on the treated surface (Table 1). A large degree of variability was seen between each of the "direct contact" trials (Table 1). This may be due to an uneven distribution of the insecticide in the applied spray, leading to exposure variability among test mosquitoes. In trial 2, although higher mortalities were recorded, it should be noted that there was some mortality in control mosquitoes and this group may have been more susceptible as a result of some unknown experimental condition. Results also indicate that a mosquito will not be killed if it briefly lands on the treated surface. Thus, for surface sprays to be effective, a mosquito must make either repeated or prolonged contact with the treated surface. The latter may be difficult to achieve using synthetic pyrethroids, which can be repellent to mosquitoes (Arredondo-Jimenez et al. 1997). Nonetheless, it would be useful to expand the direct exposure trials to include longer periods and more touchdowns on a treated surface.

In caged mosquitoes exposed for 24 hours to the treated surface, the mean knockdown was only 34%. The low knockdown rate was surprising considering the use of synthetic pyrethroid surface sprays in two recent dengue outbreaks (Hanna et al. 1998; Ritchie et al. 2001a). The observations made during the pyramid cage trials suggest that mosquitoes did rest on the treated surface for some time. Perhaps, in resting on rather than crawling over the surface, mosquitoes failed to pick up a lethal dose of the microencapsulated insecticide. It should be noted that the manufacturer's label recommends the product be used against crawling insects, not mosquitoes. The product, therefore, may be primarily designed to work after repeated or prolonged exposure to a treated surface. Additionally, the concentrations of insecticide used (0.28% and 0.14% permethrin and tetramethrin, respectively) might have been insufficient to kill mosquitoes. Ping et al. (2001) report a LC95 of 1.66% w/w for permethrin against a colony strain of *Ae. aegypti*.

Nonetheless, the surface spray did result in significant knockdown of female *Ae. aegypti* in both trials. This suggests that surface sprays containing synthetic pyrethroids such as tetramethrin, permethrin and deltamethrin could be used by the public to control *Ae. aegypti*. The Pan American Health Organization (1994) describes a method of perifocal treatment of breeding sites for *Ae. aegypti* using residual insecticides. The insecticide is applied with a hand or power sprayer to any water (non-potable) inside the container to kill larvae and pupae, and to the internal and external walls of the container and any walls within

60 cm of the container to kill adult mosquitoes resting on these surfaces. Treatment of terracotta plant pots and tyres with an aerosol surface spray containing imiprothrin and cypermethrin prevented *Aedes* breeding for four and five months, respectively (Ritchie et al. 2001b). If a similar method was applied to a target highly attractive to *Ae. aegypti*, such as the "enhanced ovitrap" (a wide-mouth pint-sized glass jar, painted black on the outside, with a paddle clipped vertically to the inside, partially filled with water and containing an olfactory attractant) (Reiter et al. 1991), the method could be successful at reducing numbers of adult *Ae. aegypti*. During dengue outbreaks, householders could be encouraged to spray suitable containers, such as pot plant bases, or resting sites such as the undersides of tables, with commercially available surface spray to control *Ae. aegypti*. Further study into applications of surface sprays and, especially, methods to improve exposure of mosquitoes to treated surfaces, are desirable. Human behavioural studies to examine how the public would use retail surface sprays in a dengue outbreak situation should be conducted.

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Vaccine Storage and Handling: Maintaining the Cold Chain under Global Warming

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The requirement for most vaccines to be kept within a temperature range of 2-8°C has led to the development of detailed guidelines for maintaining the cold chain. It is known, however, that compliance with such guidelines is often difficult in developing countries, while in developed countries research has highlighted many instances of non-compliance with guidelines. Although some vaccines can tolerate limited exposure to extreme temperatures, many experience loss of potency under such conditions, therefore placing their efficacy at risk. Although much has been written on vaccine storage, handling and thermostability, no study to date has identified the potential impacts of global climate change on these factors, and therefore on immunisation programs around the world. This paper does so. It also identifies a number of adaptive strategies such as the development of more thermostable vaccines and better, low cost, packaging procedures.

Key words: *Climate Change, Temperature, Vaccine, Medication, Cold Chain, Human Health*

Numerous studies on vaccine storage and handling, and the so-called "cold chain", have been published. These studies often focus on the importance of storing vaccines at the recommended temperature (2-8°C). As a result of these studies it has become clear that significant problems and inadequacies exist in the storage of vaccines in both developing and developed countries. The efficacy of vaccines can be diminished when they are exposed to temperatures outside the recommended range and a number of studies have found vaccines stored by doctors and others responsible for immunisation have diminished potency (e.g., Finnegan & Howell 1996; Oliveira et al. 1993). Indeed, it has been suggested that cases of disease have been the result of inadequate vaccination procedures (Gago García et al. 1990; Hill 1992; Lipp 1992; Miles & Merrell 1992; Prevots et al. 1998).

Wilson, Fineberg and Colditz (1995) examined the relation between geographic latitude and the efficacy of bacillus Calmette-Guérin (BCG) vaccine for preventing tuberculosis. They found that efficacy increased with distance from the equator and that factors such as climate and storage of the vaccine were influential in this variance. The tropical climate of many African countries, coupled with poor storage and transportation facilities, has been identified as a major factor leading to reduced potency of the measles vaccine (Abdurrahman & Taqi 1981). A study of the measles vaccine in the Canary Islands attributed a diminished efficacy of this vaccine to a break in the cooling system or to a smaller seroconversion index in the subtropical climate (Gago García et al.

1990).

Although it is clear that inadequate vaccine storage and handling is widespread and that vaccines are sometimes influenced by ambient temperatures, no study to date has examined the potential for this problem to be augmented in the future by the increased ambient temperatures expected with global climate change. This paper reviews the standard climate-related storage and handling procedures for vaccines as well as the common inadequacies in this area. It also examines the potential implications of global climate change and discusses a number of adaptive strategies that could be established in response to such implications.

Vaccine Storage and the Cold Chain

Health authorities require vaccines to be stored within the temperature range 2-8°C. Vaccines such as Diphtheria-Tetanus-Pertussis (DTP), Diphtheria-Tetanus (Td or ADT and DT or CDT), tetanus, pertussis, Hib, influenza, hepatitis A, hepatitis B and pneumococcal vaccines are inactivated if they are frozen, while others have a shortened shelf-life if exposed to temperatures higher than 8°C (NHMRC 1997; Reimer & Lewis 1998). Vaccines that are most unstable at room temperature are poliomyelitis vaccine (OPV), reconstituted measles vaccine, and reconstituted BCG vaccine (NHMRC 1997). For example, reconstituted measles vaccine undergoes a 50% loss of potency after exposure to temperatures of 22°C - 25°C for only 1 hour. Exposure of this vaccine to temperatures above 37°C leads to inactivation within 1 hour (NHMRC 1997). Detailed guidelines on the maintenance of an effective cold chain have been developed by the World Health Organization's Expanded Programme on Immunization (EPI). These guidelines address:

- use of cold chain monitors and freeze indicators;
- transporting vaccines in insulated containers;
- unpacking vaccines after transport;
- maintaining and monitoring refrigerator temperatures, including
  - use of a maximum/minimum thermometer;
  - recording of temperatures daily (at the same time); and
  - minimisation of door openings;
- maintenance of the vaccine refrigerator; and
- modifying a domestic refrigerator for safe vaccine storage, including
  - storage only in appropriate locations in the refrigerator (i.e. the middle and upper shelves);
  - stabilisation of temperature with bottles of salt water; and
  - adequate spacing of vaccines.

Compliance with these guidelines depends on many factors, ranging from provision and reliability of power supplies and access to refrigeration facilities, to knowledge of such guidelines and establishment of and adherence to compatible procedures. Unfortunately, compliance with guidelines has been inadequate in many instances. This is discussed further in the following section.

Present Standards of Vaccine Storage and Cold Chain Maintenance

It has been known for many years that the ability to maintain the cold chain, and therefore vaccine efficacy, in many developing and tropical regions is limited and transportation and storage facilities are often poor (Abdurrahman & Taqi 1981; Kumar 1998; Senanayake, Perera & de Silva 1997). These and other factors can result in the journey from manufacturer to end user taking considerable time, in some situations many months (Lipp 1992). Recent studies (see Table 1) have demonstrated that vaccine storage and handling in developed countries is also poor in many cases. Breaches of the guidelines outlined in the previous section include:

- not storing vaccines in a refrigerator;
- not using a maximum/minimum thermometer to monitor refrigerator temperature;
- not recording refrigerator temperature twice daily;
- not maintaining correct temperature range in refrigerator;
- not maintaining refrigerator (e.g., broken seals);
- storing vaccines on refrigerator door shelves; and
- inadequate defrosting procedures.

All these breaches make vaccines more vulnerable to ambient environmental conditions. It follows that when such breaches occur in very hot (or very cold) environments, the risks of vaccine damage are greater. As such, any climate warming over time has the potential to place vaccines at greater risk, leading to a range of undesirable outcomes including costly replacement of vaccines (Gold, Kemp & Osbourne 1998) or cases of preventable disease.

Potential Impacts of Global Climate Change

It is now widely believed that increases in greenhouse gas concentrations have led to a warming of the Earth's surface and other changes in climate. Over the last century, global average surface temperature increased by 0.6 ± 0.2°C. Importantly, this human influence on global climate is expected to continue in the future (Houghton et al. 2001). The Intergovernmental Panel on Climate Change (IPCC) has produced a range of scenarios of future emissions of greenhouse gases and aerosols, which have been used to develop projections of future climate. The best estimate is for global average surface temperature to increase by 1.4 to 5.8°C over the period 1990 to 2100 (Houghton et al. 2001). This generally means a poleward and altitudinal shift of present isotherms such that, for example, "tropical climates" would expand northward in the Northern Hemisphere and southward in the Southern Hemisphere. Though these increases in temperature may seem small and insignificant, it is important to note that:

i) the average rate of warming would probably be greater than any seen in the last 10 000 years;

ii) nearly all land areas will warm more rapidly than the global average;

iii) regional temperature changes would often differ substantially from the global mean value; and

iv) a general warming is expected to lead to an increase in the occurrence of extremely hot days and a decrease of extremely cold days (Houghton et al. 2001).

Recent analyses have highlighted the projected changes in temperature over the land and on a regional basis (Giorgi et al. 2001). For example, Giorgi and Francisco (2000) have shown a number of regions are projected to experience a warming much greater than (i.e., > 40% above) the global average warming, in both summer and winter. These include what they defined as the Alaska, Greenland, Sahara, Central Asia, Tibet, and Northern Asia regions. Under some emissions scenarios, it was found that warming by 2071 to 2100 of a number of regions at high northern latitude in winter (including Alaska, Greenland, and

Table 1. Summary of selected studies of vaccine storage and cold chain procedures. Studies are in chronological order.

Location	Focus	Use of refrigerator	Correct positioning of vaccine in refrigerator	Record of refrigerator temperature	Study results of refrigerator temperature	Source
State of Rio de Janeiro, Brazil	Public health units	Not stated (assumed to be 100%)	60%	54.5% adequate control of temperature	Not assessed	Oliveira et al. (1991)
Los Angeles, USA	Pediatric offices and clinics	Assumed 100% possessed refrigerators but 16% routinely stored vaccines outside during the day	Not assessed	20% checked thermometers at least weekly	22% > 8°C	Bishai et al. (1992)
Central Manchester and Bradford, United Kingdom	General practices and child health clinics	Not stated (assumed to be 100%)	Not assessed	20% had maximum and minimum thermometers 2.5% monitored daily	37.5% went below 0°C (to -4°C); 37.5% went above 8°C (up to 16°C)	Thakker and Woods (1992)
State of Rio de Janeiro, Brazil	Public health units	100%	100%	64.7% presented 'adequate' storage conditions	Not assessed	Oliveira et al. (1993)
Northern Territory, Australia	Cold chain	Not stated (assumed to be 100%)	Not assessed	Not assessed	23% of sabin oral poliomyelitis vaccine vials were exposed to 48 hours or more to > 10°C; 47.5% of recombinant hepatitis-B vaccine vials were exposed to -3°C or less	Miller and Harris (1994)
Sydney, Australia	General practitioners	Not stated (assumed to be 100%)	Not assessed	30% used 'temperature monitors'	Not assessed	Rixon, March and Holt (1994)
South-western Sydney, Australia	General practitioners	Not stated (assumed to be 100%)	82%	5% kept a record of temperature 16% had a means of measuring temperature	70% within recommended range	Liddle and Harris (1995)
Ontario, Canada	General and pediatric practices	Not stated (assumed to be 100%)	47.5%	10% had thermometers	33% outside recommended range	Yuan et al. (1995)
Ireland	Family doctors	98.6%	81.1%	8.1% had thermometers	37.8% outside recommended range	Finnegan and Howell (1996)
Central Coast of New South Wales, Australia	Pharmacies	100%	Not assessed	2% had thermometer and checked temperature regularly	19% within recommended range 29% 0.1 to 11.9°C 23% -5 to 0°C 29% > 8°C	Reimer and Lewis (1998)
Taiwan	Primary care physicians' offices	Not stated (assumed to be 100%)	Not assessed	47.6% used 'simple' thermometer; 46% used 'recording' thermometers to produce temperature charts	22% > 8°C	Pai and Ko (1999)
Adelaide, Australia	General practices	Not stated (assumed to be 100%)	Not assessed	Not assessed	41% had more than 20% of storage time either < 2°C or > 8°C	Gold et al. (1999)
Central Italy	Primary vaccine offices	76.5%	71%	None used maximum and minimum thermometer None monitored temperature	14% had > 8°C 29% had 8°C	Grasso et al. (1999)
Ethiopia	Immunisation centres/health institutions	95.5%	26.6%	57.8% had complete record 6.3% had no thermometer	1.7% had < 0°C 88.3% had 0-8°C 10% had > 8°C	Berhane and Demissie (2000)
Georgia, USA	Private physicians' offices	Not stated (assumed to be 100%)	Not assessed	6.9% had no thermometer	4.5% had ≥ 9°C 14.9% had ≤ 1°C 30.2% had ≤ 2°C	Bell et al. (2001)

Northern Asia) could be as much as 5 to 11°C above the 1961 to 1990 average.

Hennessy and Pittock (1995) examined extreme temperature events in southeastern Australia using a range of warming scenarios for the year 2030. Even a low warming scenario of about 0.5°C resulted in at least 25% more days over 35°C in summer and spring, and at least 25% fewer winter days below 0°C. Similar changes are expected in other regions.

It is clear that ambient temperature is a significant factor in vaccine inactivation. It is not only transport and storage of vaccines in developing regions that are of concern as the studies described in the previous section and in Table 1 have shown that even in developed countries, the standard of vaccine storage and handling can be suboptimal. Given this, and given the anticipated warming expected as a result of increasing greenhouse gases, there is a need to review vaccine handling procedures.

It should also be noted that regions experiencing freezing temperatures will be reduced and the frequency of freezing temperatures will also decrease. As such, the problem of keeping vaccines above freezing temperatures will be lessened in some areas.

Prospects for Adaptation

Based on existing evidence, some degree of climate change over the coming decades is inevitable. It would be wise, therefore, to reinforce current guidelines as well as focus on further strategies to maintain the cold chain in a warmer world. A number of strategies are discussed below.

Some vaccines have been demonstrated to have good thermal stability and can withstand short periods at high temperatures. For example, Wiedermann and Ambrosch (1994) demonstrated that the immunogenicity and reactogenicity of inactivated hepatitis A vaccine stored at 37°C for 1 week were similar to that stored at the recommended temperature of 2-8°C. Similar results have been found with tetanus toxoid and hepatitis B vaccine (Sutanto et al. 1999), and Fuenzalida & Palacios type antirabies vaccine (Albas et al. 1992). A number of studies have identified compounds that can be added in the production of vaccines to make them more thermostable. For example, deuterium oxide (D_2O) and magnesium chloride ($MgCl_2$) have been found to significantly improve the thermostability of oral poliovirus vaccine (Chen et al. 1997; Melnick 1996; Milstien, Lemon & Wright 1997). Sutanto et al. (1999) documented successful home delivery of heat-stable vaccines in Indonesia (in an area where average temperature is 26°C). Further development of thermostable vaccines would be clearly advantageous.

Development and improvement of packing methods for vaccine distribution is another strategy that could help maintain the cold chain in present and future deleterious thermal environments. For example, Kendal, Snyder and Garrison (1997) have recently examined packing procedures in the United States of America and provided recommendations for use of both frozen and non-frozen water-based cold packs for vaccine distribution. The cost of packing procedures is a major consideration in developing countries and development of low cost packing procedures is a high priority. There have been recent calls for clearer labelling of storage requirements for a range of medications, including vaccines (e.g., Arya 2000). Distinctive symbols, analogous to those currently used for poisons, inflammables, and radioactive substances, could be used for this purpose.

Certain existing procedures have proven very effective. For example, the vaccine monitor card and freeze watch is an excellent means by which cumulative exposure of vaccine to both low and high temperatures can be checked during transportation and storage in developing countries (Lipp 1992). More recently, the Vaccine Vial Monitor (VVM) has proven to be perhaps the most important piece of new technology for ensuring effective immunisation programs (Zaffran 1996). VVMs can be attached to each vial of vaccine and indicate whether or not the vaccine has been thermally inactivated. They can also be tailored to the thermostability of different vaccines and of vaccine produced by each individual manufacturer (Milstien, Lemon & Wright 1997). The World Health Organization (2001) has stated that "in 1992, almost 60% of [Oral Polio] vaccines were thrown away because of doubts about their potency after breaks in the cold chain and possible damage from exposure to high temperatures". The introduction of VVMs is expected to significantly reduce such wastage (Milstien, Lemon & Wright 1997). These are standard techniques that must be used in developed countries as well, particularly given the likelihood of more extreme heat episodes in the future.

Wider use of specifically designed vaccine refrigerators would also aid in the maintenance of the cold chain. Such refrigerators are able to maintain an ideal internal temperature (5 ± 2°C) in ambient temperatures up to and including 43°C (tropical standard), including rapid recovery after door opening. They also possess a range of other features including external temperature display, continuous monitoring of minimum/maximum temperature, alarms to signal excessive temperature deviations, and automatic defrosting, which removes the need to find alternative storage for vaccines during refrigerator defrosting. An in-built back-up power facility in vaccine refrigerators would further ensure adequate storage of vaccines in the event of power failure. Such failures are common in some parts of the world (Kumar 1998; Senanayake, Perera & de Silva 1997). Although implementation of these recommendations would be costly, at least in the short term, the additional expenditure is justifiable on the basis of a reduction in the costs associated with poor storage of vaccines. It has also been suggested that the cost to individual health providers could be partly offset by purchasing bulk orders through associated health agencies or organisations (Liddle & Harris 1995).

Adequate training of staff responsible for the handling of vaccine and maintaining the cold chain will be of even greater importance than it already is. It is concerning to see that deficiencies can persist even in developed countries for some time after they have been identified. For example, deficiencies persist in Australia even after a number of studies in the mid-1990s highlighted such deficiencies (Table 1). There is scope for health authorities to take a leading role in facilitating the use of adequate practices. One example of such an initiative has taken place in the United Kingdom, where general practices and clinics were sent a set of guidelines and an A3 sized laminated chart and pen for recording daily refrigerator maximum and minimum temperature (Lewis 1992).

Conclusion

Vaccines are a particularly temperature-sensitive group of medications. Although detailed guidelines have been developed to maintain adequate vaccine storage and handling, compliance with these guidelines has been shown to be poor in some cases, making vaccines vulnerable to ambient temperatures and at risk of reduced potency. There is the potential for the increased temperatures expected with global climate change to increase the risks of vaccine inactivation when guidelines are poorly complied with. As such, increased efforts are required to reinforce the importance of vaccine storage and handling guidelines, as well as focus on development of more thermostable vaccines and other adaptive responses.

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The Predicted Impact of Climate Change on Toxic Algal (Cyanobacterial) Blooms and Toxin Production in Queensland

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Research on proposed global climate change in Australia has highlighted changes that will influence both the human and natural environments. To date, however, no estimates of the effects of climate change on public health aspects of toxic freshwater algae have been performed. The aim of this article is to review and discuss the proposed outcomes of climate change and how they might affect cyanobacterial (blue-green algal) proliferation and toxin production in Queensland. Factors such as increased temperatures, the trend towards more El-Niño like conditions, and increased intensity of the heaviest rainfall events have been interpreted in terms of effects on cyanobacteria in water reservoirs. This information has then been evaluated in terms of potential public health effects. It is predicted that changes in climatic factors might enhance the levels of cyanobacteria, extend their season, and cause a change in distribution to favour the more tropical species, Cylindrospermopsis raciborskii *on a state and nation-wide basis. Public health implications exist both for drinking water containing cyanotoxins and recreational exposure to cyanobacteria in water reservoirs. The toxins produced by the cyanobacteria considered in this study are hepatotoxins and neurotoxins and in some cases these might be present at levels that are well in excess of proposed guideline values.*

Keywords: Cylindrospermopsis raciborskii, Microcystis aeruginosa, Anabaena circinalis, *Climate Change, Toxic Cyanobacteria, Blue-Green Algae*

Debate surrounds the issue of climate change and its potential impacts on natural and man-made environments. The National Health and Medical Research Council (NHMRC) Report (Ewan 1990), *Health Implications of Long Term Climate Change*, identified some environmental health implications of global climate change. These included higher incidence of heat stress, and increases in the incidence and distribution of water and vector borne diseases. Additionally, changes in overall climate or local weather patterns could result in changes in agricultural productivity in certain regions. These factors might affect the distribution of natural vegetation. These changes might have environmental health consequences as well as an effect on the ecological sustainability of our current lifestyle. More recently, research undertaken by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) Atmospheric Research has highlighted a number of predicted impacts related to increases in temperature and increases in the intensity of heaviest rainfall events (Walsh et al. 2001). Of these, a number could result in public health effects and include less vulnerability to cold weather diseases, and greater vulnerability to warm weather/ tropical diseases. Recent predictions for the United States (Rose et al. 2001) on potential impacts of climate change and variability have highlighted the potential for future deficiencies in watershed protection and infrastructure. This in turn relates to links between climate variability and occurrence of microbial agents and phytoplankton in water.

Current research by the authors focuses on the effects of climate change on toxic cyanobacteria. Cyanobacteria are prokaryotic, photosynthetic microorganisms with the majority of species demonstrating the capacity to fix atmospheric nitrogen. They are found in terrestrial and aquatic environments including freshwater, brackish and marine waters and can exist in free-living or symbiotic forms. It has been postulated that cyanobacterial photosynthesis was central in the establishment of earth's atmosphere. Some of these organisms have the capacity to produce toxins and both freshwater and marine species have been known to form "blooms", (Mur, Skulberg & Utkilen 1999) which when associated with toxin production can result in detrimental environmental health effects.

In Australia, as the driest inhabited continent, the importance of water as a resource cannot be over emphasised. In comparison to other continents, Australia has the lowest proportion of precipitation becoming run-off. As a result of these climatic characteristics, Australia has the largest amount of water storage per capita, and not surprisingly surface water provides the domestic supply for more than 90% of the population (State of the Environment Advisory Council 1996). Cyanobacterial blooms have been an issue affecting surface water quality in Australia since the first bloom was recorded in 1877 in Lake Alexandrina, South Australia (Francis 1878). In that instance *Nodularia spumigena*, was observed forming a scum that resulted in death of livestock upon ingestion of the scum.

The potential environmental and public health consequences from cyanobacterial blooms arise not only from ingestion of toxins in drinking water, but also from aesthetic problems, incorporating taste and odour compounds and recreational exposure. These issues need to be recognised and addressed by the appropriate health and water management authorities.

Ecologically Sustainable Development for Australia has been defined as: "…using, conserving and enhancing the community's resources so that ecological processes, on which life depends, are maintained and the total quality of life, now and in the future, can be increased" (Commonwealth of Australia 1992). Additionally, the National Environmental Health Strategy (Commonwealth of Australia 1999) emphasises the necessity for integrated management of catchment and storage areas in conjunction with effective water treatment systems to ensure water quality. It is obvious that any impacts global climate change might have on cyanobacterial blooms or toxin production need to be determined to minimise adverse effects on water quality and environmental health, and allow water resources to be managed in an ecologically sustainable way.

The aims of this article are to:

- initially assess the impact of global climate change on the growth of and toxin production by three potentially toxic species of cyanobacteria
- examine the potential for changes in geographical distribution of these cyanobacteria
- determine the likely public health consequences of any changes in proliferation and toxin production by cyanobacteria
- suggest possible adaptation responses to climate changes.

The three species emphasised in this article are *Microcystis aeruginosa*, *Cylindrospermopsis raciborskii* and *Anabaena circinalis*. The research has been designed such that outcomes from the CSIRO climate prediction modelling will be incorporated into a range of experiments. The range includes laboratory culturing experiments to determine effects of various parameters related to climate change on growth and toxin production. Field-based mesocosm research is also included, where environmental conditions inside the mesocosms are modified in order to determine response by the cyanobacteria and interpretation of field data collected from around Queensland of phytoplankton abundance and toxin levels compared with meteorological parameters.

These data will then be evaluated in terms of climate change scenarios. Field-work and historical field data acquisition have been facilitated with collaboration from the Department of Natural Resources, South East Queensland Water Corporation, various local governments and Queensland Health.

Cyanobacteria and their Toxins

There are three basic categories of freshwater cyanotoxins classified according to their mechanism of toxicity. These include:

(i) hepatotoxins, comprising the cyclic peptides microcystin and nodularin, plus the alkaloid cylindrospermopsin.

(ii) neurotoxins, such as the anatoxins and saxitoxins often called Paralytic Shellfish Poisons (PSPs).

(iii) dermatotoxins, including the cell membrane bound lipopolysaccharide endotoxins and some primary toxins produced by the genera *Lyngbya*, *Oscillatoria* and *Schizothrix*, (Sivonen & Jones 1999). See Table 1 for a summary of selected cyanotoxins.

The cyclic peptides (protein phosphatase inhibitors) are the most commonly found cyanotoxins globally. In Australia, *Nodularia spumigena* a brackish water species produces nodularin and *M. aeruginosa* produces the microcystins. *M. aeruginosa* has world-wide distribution and is common in Australia where it is often found to be present in high cell densities and can be associated with eutrophic conditions (Sivonen & Jones 1999).

Table 1: Toxicity of Selected Cyanotoxins

Toxin	Structure/Type	LD_{50} (intraperitoneal, mouse)	Reference
Cylindrospermopsin	Alkaloid/ Hepatotoxin	200 μg kg^{-1}	(Seawright et al. 1999)
Microcystin- LR	Cyclic Heptapeptide/ Hepatotoxin	50-60 μg kg^{-1}	(Kuiper-Goodman, Falconer & Fitzgerald 1999)
Saxitoxin (PSP)	Alkaloid/ Neurotoxin	10μg kg^{-1}	(Sivonen 1996)

More than 60 different variants of microcystin have been isolated, from a variety of different cyanobacteria including *M. aeruginosa*, *M. viridis*, *Anabaena spp. A. flos-aquae*, *Planktothrix (Oscillatoria) agardii* and *Nostoc* species (Sivonen 1996). Microcystin-LR is the most commonly reported and the most potent of the microcystins.

The genus *Anabaena* has a worldwide distribution in temperate fresh waters, and has been associated with the production of anatoxin-a, a post-synaptic neuromuscular blocking agent (Falconer 1996). In contrast, Australian *Anabaena* species have been shown to produce PSPs including saxitoxin, neosaxitoxin, and a series of gonyautoxins, all of which are potent sodium channel blocking alkaloids (Falconer 1996). The production of PSPs (normally associated with dinoflagellate “red tides”) by cyanobacteria was first observed in New Hampshire from *Aphanizomenon flos-aquae* (Gentile et al. 1969) in (Sivonen 1996)) and has also been identified from the same species in Portuguese and Danish bloom samples. *C. raciborskii* in Brazil has also been found to produce saxitoxin and neosaxitoxin (Sivonen & Jones 1999).

Cylindrospermopsin is an alkaloid hepatotoxin and potential genotoxin, which has been isolated in Australia from *C. raciborskii* and recently *Aphanizomenon ovalisporum* (Shaw et al. 1999). Internationally this toxin has been isolated from *A. ovalisporum* (Israel) and has also been found in *Umezakia natans* (Japan). In Australia, four species of potentially toxic cyanobacteria are known to produce blooms: *M. aeruginosa*, *Anabaena circinalis*, *C. raciborskii* and *Nodularia spumigena*. The first three are common in Queensland, with *C. raciborskii* being very common in central and northern Queensland.

A challenging feature of cyanobacterial research, however, is that not all blooms of potentially toxic cyanobacteria produce toxins. Environmental factors have been shown to affect toxin content of cyanobacteria, usually within an order of magnitude (Sivonen & Jones 1999). The presence of any of these cyanotoxins in drinking water supplies often mean that special water treatment processes must be employed if potable end use is desired.

Recent work has shown that the genetic characteristics of a bloom are the major determining factors in its toxicity. Over the lifetime of a bloom the toxin content in the field can vary from below detection to three orders of magnitude greater, depending on which strains dominate (Blackburn et al. 1997). Additionally, it was found that Australian strains of the same species of cyanobacteria are genetically quite different from the same organisms isolated from different countries. This emphasises the necessity for research with local strains in local conditions to determine the environmental health consequences for Queensland in relation to cyanobacterial blooms under enhanced greenhouse conditions.

Effects of Predicted Climate Change on Toxic Cyanobacteria

The natural "Greenhouse effect" is a well-established atmospheric phenomenon that allows the earth's surface to be heated by the trapping of radiative energy by certain trace gases in the atmosphere, for example, water vapour (H_2O), carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and ozone (O_3). It is the magnitude, timing and consequences of the anthropogenic component of the greenhouse effect, that is, global warming, that is widely debated. The issue is hampered by the difficulty in identifying a "signal" of global warming against the background "noise" of natural climatic variation, which can exist on a multi-decadal time scale.

The consensus so far, based on global climate models (GCMs) is that if the CO_2 (or its greenhouse gas equivalent) levels were to double, the resultant global mean surface air temperature increase would be 1.5-4.5°C (Intergovernmental Panel on Climate Change [IPCC] 1996). Climate change in Queensland has been modelled by the CSIRO's, atmospheric research group and the predictions based on these models are outlined in Table 2 (Walsh et al. 2001). These results are determined using the IPCC IS92a scenario which describes a moderate greenhouse gas increase and give the temperature change between now and 2050. Hot days are defined as > 40°C in the North and Central region and > 35°C in the South East region and cold days as < 10°C in the North and < 5°C in the Central and South East regions of Queensland.

Table 2: Climate changes predicted for Queensland

Winter (April – September)			
South - East	Central	North	
Ave Max Temp.°C	↑ 0.4-1.9	↑ 0.6-2.1	↑ 0.7-2.2
Ave Min Temp. °C	↑ 0.7-2.1	↑ 0.8-2.3	↑ 0.7-2.3
No. of hot days (% change)	↑ 30- 162%	↑ 92 - 411%	↑ 62-216%
No. of cold days (% change)	↓ 18-56%	↓ 20-58%	↓ 27-61%
Summer (October- March)			
South - East	Central	North	
Ave Max Temp.°C	↑ 0.7-2.2	↑ 1.0-2.5	↑ 0.8-2.2
Ave Min Temp. °C	↑ 0.7-2.2	↑ 0.9-2.4	↑ 0.7-2.1
No. of hot days (% change)	↑ 16-46%	↑ 49-128%	↑ 35-83%
No. of cold days (% change)	↓ 72-89%	↓ 75-93%	↓ 100%

Source: Based on Walsh et al. 2001

Since Australia has the lowest mean annual run-off (11%) and the highest variability in stream flow of any continent in the world (Harris & Baxter 1996), hydrological events as well as ambient temperatures strongly influence phytoplankton dynamics and community structure. Simulations using the GCMs demonstrate that in the northern parts of Australia, the increase in temperature alone has little effect on run-off and soil moisture (Chiew et al. 1995). To be useful for determining the impacts of climate change on cyanobacteria, changes in rainfall and surface hydrology need to be predicted. The current climate models can only do this to a much lower level of confidence than that for temperature, but some changes that have been predicted include no significant change in mean rainfall but an increase in the number of rain days and the intensity of the 1 in 40 year rainfall event.

Additionally, the South East Queensland region is characterised by strong inter-annual variability in rainfall linked to the El Niño Southern Oscillation (ENSO). At the current time, predictive climate models are unable to represent these mechanisms completely, so it is difficult to assess the climate change impacts on the hydrological systems. Generally, however, the balance of evidence suggests a trend towards an average climate that is more El Niño-like, resulting in more droughts for Queensland. It remains controversial whether the more frequent El Niños of the 1990s are an early sign of global warming or are a result of the natural oscillations in the climate system (Walsh et al. 2001).

Model simulated changes in summer rainfall over Queensland continue to be tentative due to uncertainty regarding the correct response of the surrounding oceans to global warming, winter rainfall has been simulated to decrease over the next 80 years. The latest CSIRO model generally predicts reduced rainfall in the next century and beyond (Walsh et al. 2001). This might favour the formation of blooms, which are common under calm, stratified conditions that result from the absence of water inflows to reservoirs. Additionally, summer blooms might exist for extended periods of time if the winter rainfall is later than normal or without sufficient intensity to disrupt the stability of the water column. The reliability of any estimation of the impact of climate change on surface hydrology is always questionable due to the limitations of hydrologic models and the capacity of the GCMs to adequately simulate planet scale processes (Chiew et al. 1995).

The inland areas of Australia, which are water limited and drought prone, have been identified as vulnerable to changes in climate (IPCC 1999). In these areas, increases in rainfall can induce percentage changes in run-off that can be a factor of five greater than the initial percentage change in rainfall (Chiew et al. 1995). Due to the greater proportion of Australia being arid or semi-arid and the concomitant dependence on surface water, Australia's water resources are very vulnerable to any compromise of water quality, which results from cyanobacterial blooms. Therefore, any deleterious effects of climate change on either availability or quality of our water resources need to be determined and examined.

El-Niño: The trend towards more El Niño-like conditions

Findings of our research relate to specific predicted outcomes of the CSIRO climate change modelling (Walsh et al. 2001). In particular, the trend towards more El Niño-like conditions with enhanced drought frequency and severity produces longer retention times of water in reservoirs. The main consequence being that cyanobacteria are favoured under these conditions, as with short retention times it is more likely that diatoms will dominate the phytoplankton assemblage (Paerl et al. 2001). With established cyanobacterial populations, however, it appears that isolated rain events with consequent input of nutrients will favour enhancement of cyanobacterial growth and toxin production.

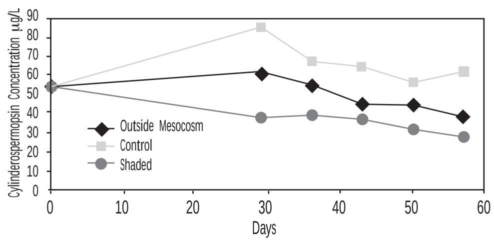
El Niño-like conditions also favour development and maintenance of stratification in water bodies during the dryer late Winter/Spring. Stratification favours cyanobacteria over other phytoplankton (Jones & Poplawski 1998). This is due to calm conditions and the fact that enhanced release of soluble phosphorus and ammonium occurs from the sediments in the anoxic lower layer of the water body (Chorus & Mur 1999). Following consideration of field distributions of cyanobacteria, enhanced periods of sunlight in Winter/Spring may result in increased growth of *A. circinalis* and *M. aeruginosa* in some selected reservoirs in Southern Queensland.

Longer periods without rain can lead to decreased turbidity in the water reservoirs and result in greater light penetration through the water column. Culture experiments have shown that increased light intensity can cause increased production of microcystins by *M. aeruginosa* and enhanced transport of this toxin out of the cells into the surrounding water (Hesse & Kohl 2001).

Preliminary data also suggests that increased production of cylindrospermopsin by *C. raciborskii* occurs with higher light levels. In field experiments in Far North Queensland (Coen) it has been observed that following shading of duplicate experimental mesocosms (1000 L polyethylene bags) to approximately 50% ambient level, the cylindrospermopsin concentration was significantly reduced ($p<0.05$) compared to the control mesocosm. This occurred despite the fact that *C. raciborskii* cell numbers showed no significant difference between treatments (Garnett et al. 2001). This is demonstrated in Figure 1.

C. raciborskii maximal photosynthetic activity has been shown to occur between 11.0 am and 3.0 pm suggesting it has an ability to efficiently use the higher intensity light present at this time of the day. Additionally, depth samples of *C. raciborskii*

Figure 1: Coen Dam - Cylindrospermopsin Concentration



have shown that maximum photosynthesis occurs at 20-40% of surface light, highlighting its ability to photosynthesise over large depth ranges in the water column (Dyble, Neilan & Paerl 2001). *C. raciborskii* is also found in a range of colours with yellow/brown/red observed in tropical regions and green dominating in the sub-tropical/temperate regions of Queensland (Fabbro, pers. comm.). These colours relate to photosynthetic pigment composition, which is a consequence of genetic factors and the intensity and spectral range of ambient light.

Rainfall: The trend towards increased intensity of heaviest rainfall events

The climate change modelling (Walsh et al. 2001) predicts an increase in the intensity of heaviest rainfall events, which will most likely occur during the warmer months of the year. The increase in rainfall intensity can result in elevated levels of nutrients entering water storages. One typical rainfall event in a reservoir in Queensland has been shown to contribute 80% and 400% of the average annual in-lake nitrogen and phosphorous pools respectively (Jones & Poplawski 1998).

In reservoirs with established cyanobacterial dominance, high levels of nutrients may favour rapid growth of cyanobacteria. It has been shown that this situation can result in blooms of *C. raciborksii* in smaller Queensland impoundments with such elevated toxin levels that cattle drinking the water have died from hepatotoxicity. In one instance investigated, it was found that cylindrospermopsin concentration in the water was over 1000 µg/L. As a comparison, from preliminary toxicological studies, a proposed provisional guideline value for cylindrospermopsin in human drinking water has been suggested as 10µg/L (Shaw, Seawright & Moore 2001). Guideline values are discussed further in the Public Health Implications section.

We have shown that cyanobacteria, especially *C. raciborskii* have a rapid response to added nutrients and under certain conditions can produce large blooms in a matter of days. It has been demonstrated that *C. raciborskii* has a requirement for both nitrogen and phosphorous for bloom formation. Therefore, both nitrogen and phosphorous management are important aspects to consider in dealing with enhanced run-off events associated with global climate change. The cyanobacterium of most relevance to Queensland, *C. raciborskii*, requires approximately 8 µg/L/day of phosphorous at 100 000 cells/mL in exponential growth phase. This demonstrates the high potential for blooms of this organism resulting from run-off events containing elevated levels of nutrients. In addition, ammonium nitrogen is more readily assimilated by *C. raciborskii* than nitrogen in the form of nitrate (Paerl et al. 2001). This finding is also applicable to green algae, but to a much lesser extent. Thus the source of nitrogen entering reservoirs from catchments is important in determining whether cyanobacteria have a competitive advantage, with ammonium from sources such as cattle faeces being more problematical than nitrate from fertilizers.

In addition, intense rainfall events can produce run-off that contains herbicides from catchment areas, which eventually end up in the reservoirs. Preliminary results indicate that cyanobacteria have great adaptability to a range of light conditions made possible by high flexibility of their photosynthetic apparatus. This means that cyanobacteria may be more resistant than other phytoplankton, to inhibition by common herbicides which are photosystem II inhibitors such as atrazine and diuron.

A key prediction of the climate change modelling is an increase in intensity of cyclones along the Queensland coastline (Walsh et al. 2001). This again is predicted to result in increased run-off containing nutrients and herbicides. Also higher wind speeds can affect the thermocline in stratified water bodies and transfer nutrient-rich bottom water to the photic zone, thereby increasing its availability for the growth of phytoplankton including cyanobacteria. It has been shown that intermittent strong winds can drive this enhanced nutrient transfer sufficiently to sustain growth for up to three months (Bormans, Ford & Fabbro 2001).

Temperature: The trend towards increased temperatures

A gradual increase in temperature is predicted under enhanced greenhouse conditions, on a time scale as short as 40 years. Temperature can affect the growth of cyanobacteria and as temperature increases, a succession of different groups of phytoplankton are observed, with the optimum growth rates changing from diatoms to green algae and then to cyanobacteria, which usually dominate at warmer water temperatures over 20°C (Robarts & Zohary 1987). Based on this information, in the absence of nutrient limiting conditions, it can be assumed that the dominance of cyanobacteria in freshwater ecosystems will become more pronounced.

The proposed increase in maximum and minimum temperatures (Walsh et al. 2001) is predicted to favour the proliferation of *C. raciborskii* in Queensland. There are likely increases in the distribution of this toxic cyanobacterium to lower latitudes in Queensland. There is also likely to be an extension of the bloom season for this organism. During the winter of 2001, there have been extensive blooms of *C. raciborskii* in Central to Southern Queensland. This has been ascribed to earlier than usual stratification in some smaller water bodies which can be a result of warmer weather conditions (Fabbro, pers. comm.).

Recruitment: The effects of climate change on cyanobacterial recruitment

Climate change induced effects on differentiation and germination of some cyanobacterial akinetes are also being determined. Akinetes are reproductive spores produced by cyanobacteria (Mur, Skulberg & Utkilen 1999), and it is important to determine which factors control these processes and whether these factors are likely to be affected by enhanced greenhouse conditions. The two main environmental parameters commonly associated with akinete germination are temperature and light (Yamamoto 1976). Additionally, laboratory experiments show that stable water conditions as opposed to mixing promotes akinete differentiation (Fay, Lynn & Majer 1984). If future climatic predictions are proven to favour the increased recruitment of cyanobacteria it is predicted that cyanobacterial blooms will form earlier and persist longer.

Overall predicted effects of climate change on toxic cyanobacteria in Queensland

The outcomes with respect to the effect of climate change on toxic cyanobacteria are likely to be beneficial for these organisms following change towards a warmer world. In particular, we have shown that there is a rapid uptake of nutrients by cyanobacteria, resulting in benefits for these organisms following run-off events, especially if substantial destratification does not occur following rain events. Cyanobacteria are able to utilise a wide range of wavelengths and intensity of light. A temperate reservoir in Queensland, exhibits a succession of *A. circinalis* in late winter/early spring, is followed by *M. aeruginosa*, similar population dynamics may be observed under enhanced greenhouse situations. In the sub-tropical to tropical regions it is predicted that *C. raciborskii* will dominate and reach higher cell concentrations for longer periods than has currently been observed. Global warming thus is expected to produce seasonally earlier blooms of *A. circinalis* and *M. aeruginosa* and the potential southward distribution and/or earlier population maximum of *C. raciborskii*. Current research indicates that toxin concentrations will increase in conjunction with cyanobacterial proliferation.

Public Health Implications

The health consequences of cyanotoxins may result from a range of toxic mechanisms but all have the potential to cause deleterious health outcomes and for certain routes of exposure to contaminated water, for example, renal dialysis, death might result. Microcystins are hepatotoxins and tumour promoters and are produced in Queensland by *M. aeruginosa*. Cylindrospermopsin is also a hepatotoxin and possible genotoxin produced by *C. raciborskii*. The final group of cyanobacterial toxins of relevance to Queensland are the saxitoxins produced by *A. circinalis*. These toxins are neurotoxins and in acute poisonings, death can result from respiratory arrest.

The predicted effects of global climate change with respect to cyanobacterial proliferation and toxin production are an increase in cyanotoxin concentration in water reservoirs and the presence of cyanotoxins for a greater proportion of the year. In particular, there is potential for an increase in neurotoxins in Southern Queensland during winter. Microcystins are likely to be present in reservoirs in Southern Queensland for an extended time period. On a State basis, it is forecast that cylindrospermopsin is likely to be found in more reservoirs, for longer periods and at higher concentrations.

Effects of chronic human exposure to cyanotoxins are difficult to measure, however, a retrospective study in the

Armidale region of New South Wales has been undertaken. It was noted that people drinking water from a reservoir that contained a bloom of *M. aeruginosa* had elevated levels of the enzyme γ-glutamyltranspeptidase, which is characteristically released following alcohol or toxin damage to liver cell membranes. This was when compared to a population who obtained their reticulated water supply from another reservoir (Falconer, Beresford & Runnegar 1983). It was concluded by the authors, that this indicated an increase in liver damage among members of the population who received their water from a reservoir containing a bloom of *M. aeruginosa*.

Acute toxicity of cyanotoxins, although more commonly recorded for livestock, has also been observed in humans. One example of a hepato-enteritis outbreak has been observed in a Palm Island Aboriginal community in 1979. Symptoms including vomiting, headache, painful liver enlargement and dehydration were observed. Urinary analysis showed compounds indicative of severe kidney damage. Following appropriate treatment all the 140 children and 10 adults exposed to this source of drinking water, recovered. Analyses at the time eliminated a range of infectious organisms and toxins, hence the symptoms were attributed to a “Mystery Disease” (Byth 1980). Prior to the outbreak, an algal bloom occurred in the local water supply, Solomon Dam, which resulted in disagreeable tastes and odours. This bloom was treated with copper sulfate one week prior to the appearance of symptoms in the community (Bourke et al. 1983). Subsequently, the cyanobacterium *C. raciborskii* was identified in the reservoir and has since been found to produce cylindrospermopsin, which produces symptoms in mice consistent with the hepato-enteritis observed.

Currently the World Health Organization (WHO) has adopted a provisional guideline value for microcystin (based on microcystin-LR) in drinking water of 1µg/L. This guideline value is not mandatory and is intended for use as a basis for development of national standards, which if properly implemented would ensure the safety of drinking water supplies (Falconer et al. 1999). It is calculated by using a Tolerable Daily Intake (TDI), which is the amount of a potentially harmful substance that can be consumed daily over a lifetime with negligible risk of adverse health effects. To date this is the only cyanotoxin guideline value to be endorsed by the WHO. A preliminary human health risk assessment using cylindrospermopsin, based on daily dosing experiments using mice, suggests that a guideline value of less than 10µg/L should be applied (Shaw, Seawright & Moore 2001). For cyanotoxins, both the animal and human toxicity data are incomplete, which makes the determination of guideline values for safe drinking water difficult.

Blooms whether toxigenic or not can result in a range of environmental problems. Aesthetic problems are caused by unsightly and odiferous scums forming in recreational water bodies. Characteristic earthy taste and odour compounds, such as geosmin and 2-methyl-isoborneol produced by cyanobacteria, are considered a nuisance within the drinking water industry (Falconer 1999). The presence of these compounds can indicate cyanobacterial growth, which might also indicate the presence of toxins, but unfortunately the converse is not the case, since toxins might be present in the water in the absence of any taste or odour compounds. The potential chronic health effects of exposure to these taste and odour compounds have not been investigated.

A recreational exposure study undertaken in Australia, demonstrated increasing symptom occurrence with increasing duration of water contact and increasing cyanobacterial cell density. The symptoms recorded included diarrhoea, vomiting, flu-like symptoms, skin rashes, mouth ulcers, fevers and eye or ear irritation. However, there was no correlation between symptom occurrence and the presence of hepatotoxins. This suggests that the symptoms are related to the allergenic effects of the cyanobacterial cells themselves (Pilotto, Douglas & Burch 1997), and probably due to the lipopolysaccharides in the cell wall of the bacteria.

Obviously blooms of cyanobacteria can provide a significant public health risk through a range of mechanisms, so knowledge of the factors contributing to bloom formation now and in the future is critical. However, the principles of ecological sustainability requires consideration of the economic, social and environmental implications in an integrated way.

Management Strategies

Given the predicted increase in cyanobacteria and their toxins in Queensland reservoirs, management of these issues will be important in the future. To achieve this, a number of preliminary recommendations for suitable adaptation responses include the following:

- monitoring programs for cyanobacteria and their toxins. Monitoring programs are currently in place in many reservoirs in Queensland;
- early warning systems for bloom events with a predictive modelling tool for cyanobacterial blooms;
- integrated catchment management. This can include maintenance of riparian vegetation and strategies to reduce nutrient run-off following intense rainfall events. These strategies could incorporate reduction of human activities in catchments and reservoirs and re-evaluation of grazing activities;
- artificial destratification may be of use in some reservoirs to reduce the intensity of toxic cyanobacterial blooms;
- treatment of reservoirs to reduce nutrient release from sediments using products such as finely divided clay;
- biomanipulation using plants and/or animals;
- development of treatment methodologies to remove cyanobacteria from reservoirs. Chemical treatments are currently seen as problematical due to undesirable ecological effects;
- treatments to remove toxins from water including: activated carbon; chlorination; ozone/biologically activated carbon; ultraviolet light with titanium dioxide catalysis; and microbial decomposition of toxins with the possibility of incorporating degrading microbes into water treatment such as water detention facilities and slow sand filtration.

Conclusion

Cyanobacteria are a ubiquitous element of freshwater ecosystems in Australia and many places around the world, and their potential to produce toxins results in public and environmental health issues. Under enhanced greenhouse conditions a number of changes to the climatic mean state are predicted. These include increased temperatures, increased intensity of heaviest rainfall events and a change towards more El-Niño-like conditions. All these features have the potential to increase cyanobacterial cell numbers and also cyanotoxin concentrations in water reservoirs, including those used for domestic supply.

This toxic cyanobacterial increase as a result of proposed climate change could be achieved by one or all of the following mechanisms: extending the growth season, expanding distribution of species, and increasing the population maxima.

Uncertainty still surrounds future climate under enhanced greenhouse conditions, but it is important to be aware of potential consequences so that any public health risk due to cyanotoxins can be effectively assessed and managed. Research is continuing into whether toxic or non-toxic strains of cyanobacteria have the potential to be selectively favoured as a result of environmental factors that can be affected by climate change.

Cyanobacteria are highly adaptable and have the ability to colonise rapidly after changed environmental conditions. They have been persistent at the geological time scale and need to be managed effectively in the future in an environment affected by climate change.

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Despite Awareness Programs Residents of the Sunshine Coast, Australia, Are Not Prepared for Natural Disasters

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It is critical to establish baseline levels of community awareness of, and preparedness for, natural disasters in an environment of global climatic change and uncertainty. Stakeholder interviews, expert workshops, and a survey of 800 residents of the Sunshine Coast exposed gaps between residents' awareness of advised precautions, and their preparedness for natural hazards likely to affect the area. For instance, only 4.5% of respondents knew of a disaster management plan for their area and possessed an emergency preparedness kit. Even in instances where responses concerning awareness and preparedness criteria were aligned, the majority of residents were ill prepared for natural disasters. Further, although those who identified themselves as members of emergency services were more inclined than others to know of disaster management plans, 70% of these emergency service members did not know of a disaster management plan for their area. Other issues covered here include media sources, safe storage of documents, and how relatives could be found if separated during a natural disaster. Although these findings are of local relevance they may be reflected in many communities internationally, therefore signifying that part of any management regime should be to assess the level of effectiveness of communication and education programs in local and regional communities.

Key Words: *Natural Disaster, Awareness, Preparedness, Participatory Research*

The impacts of global climate change on human health have been a key focus of the work of the Intergovernmental Panel on Climate Change (IPCC). There is emerging evidence that increased frequency and magnitude of extreme climatic events do impact on social and economic systems (IPCC, 2001a). "Developing a response to climate change is characterised by decision-making under uncertainty and risk" (IPCCb, 2001, p. 3). In the context of natural disasters, risk has the dimensions of magnitude, vulnerability, and probability (McEntire 2000; Young 1998). The vulnerability of a community is related to the extent to which it is aware and prepared for such extreme events. Those responsible for disaster management, including environmental health professionals, need to be mindful of the current status of awareness and preparedness in their communities. The purpose of this paper is to report on the levels of awareness and preparedness for natural disaster on the Sunshine Coast.

The natural disasters most likely to eventuate on the Sunshine Coast (Figure 1) according to the Maroochy Shire Counter Disaster Plan (24 April 1997), are those recognised as Australia's major natural hazards: bushfires; storms and cyclones; and floods (Bell 1989). Disasters identified as having the highest risk factor, that is, most likely to cause the greatest human and property damage, are earthquake and cyclone, although earthquakes on the Sunshine Coast have a relatively low level of probability. Small steep catchments set within an escarpment setting on the

Sunshine Coast promote high rainfall and flash flooding. The 1999 Floods in the Gympie and Mary River regions, for example, took seven lives. Cyclonic rains, though less frequent, are nonetheless a serious concern both from a flooding and a coastal damage perspective. In addition to these, the steeper, more densely vegetated escarpment type catchments promote a bushfire hazard.

Figure 1: Location of the Sunshine Coast, Queensland

Smith (1996) identifies the four stages of emergency risk management as pre-disaster planning; preparedness; response; and recovery and reconstruction. He infers that management strategies are wanting in the preparedness stage and recommends that "education of people, both victims and managers at all levels, is essential" (Smith 1996, p. 75). Media, though an effective educative resource, can nonetheless exaggerate disaster associated with natural hazards (Smith 1996). Further, inaccurate predictions tend to exacerbate problems, false alarms result in skepticism and lack of appropriate response, and panic might ensue from ill-conceived awareness programs (Burby 1998; Smith 1996). Human action or inaction depends on recognition of hazard types and available options, and choosing appropriately from those available options (Burton et al. 1993). Of relevance in this research is the level of preparedness of individuals within the community; the inference being that the level of preparedness of individuals will influence the type and degree of community response required.

"Preparing for every scenario can become overwhelming, so the public deals with those hazards (if any) that seem the most immediate and discounts the rest" (Ryland 2000, p. 48). Awareness levels increase with a greater frequency of events, and "with the magnitude of the most recent events" (Burton et al. 1993, p. 114). Smith warns that people are inclined to believe that services such as communications, electricity and water, and infrastructure will be available at all times thus "programmes designed to improve the hazard-prone reliability…are widely perceived to be unnecessary" (Smith 1996, p. 25). Accordingly, risk assessment and management should incorporate individual and community perception (Smith 1996) and recognise the underlying complexity of social and physical causation in order to reduce vulnerability "rather than dealing with the physical hazards as the starting point" (Blaikie et al. 1994, p. 6).

Further, exposure to hazards is an ethical and equity issue so community participation and collaboration "… must extend beyond government to embrace professional groups, non-governmental citizens' groups, and most importantly, private citizens" (Burby 1998, p. 291). Moreover, unsafe areas might be economically attractive, and/or offer aesthetically pleasing locations with concomitant lifestyles, thus attracting large populations to areas of risk such as low lying coastal areas or bushland settings.

Although the media is "an excellent source of information" on natural hazards, especially in disaster situations (Dolan 1994, p. 13), media sources tend to reflect preferences for over simplified local events with an emphasis on sensationalism. Also conflicting advice and awareness about individual rights in emergency situations can be compounded by insufficient or inferred information. For example, Le Grand et al. (Weekend Australian 20-21 December 1997) stated that while in some states residents might choose to stay in their homes during a bushfire, in others including Queensland, "fire authorities and police also command the power to evict people from their homes". They continue to suggest that there is a growing consensus "...among firefighters that if residents take the necessary precautions, home is a safe place to be during even the most destructive fires". This type of information when conveyed nationally through television programs such as the series "Hazards, Disasters and Survival", screened in 1998 by the Australian Broadcasting Commission, without the additional information concerning different legislation with differential powers between states, can cause confusion.

"Unless education efforts can impart a sense of personal responsibility and motivation to the public", instead of "comprehensive natural disaster mitigation" there will be "only natural disaster welfare" (Ryland 2000, p. 48). Chapman (1999) warns that people must accept the consequences of their locational decisions. Substantial resources, including much professional and volunteer time are directed towards fostering community awareness re preparedness for natural disasters. However, little is known about the actual effectiveness or benefits of these expenditures.

This paper establishes levels of community awareness of, and preparedness for, natural disasters on the Sunshine Coast. From the outset, the research was intended to be highly participatory, being relevant to and influenced by those responsible for natural disaster management on the Sunshine Coast. Therefore, multiple research strategies were combined to gather both qualitative and quantitative data in a sequence that allowed key stakeholders to help to identify relevant issues to be targeted in the most appropriate way. The specific research questions were formulated after reviewing the qualitative data from the initial phases of the research and the background literature. Thus the research objectives were to explore:

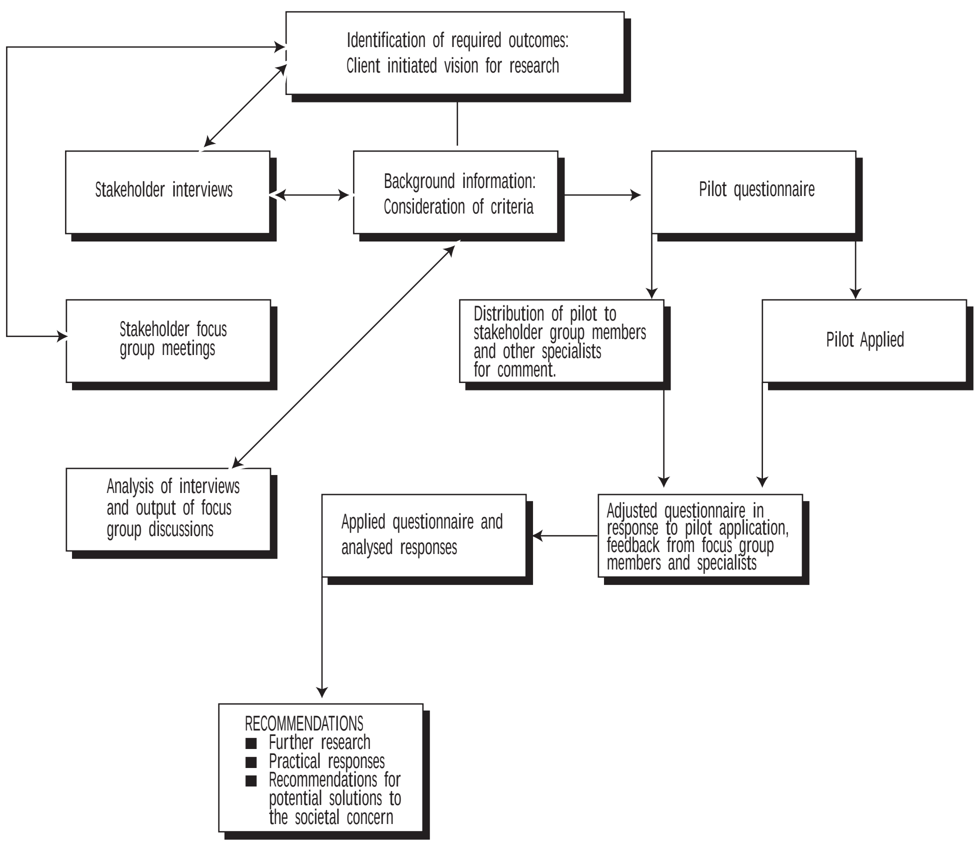
- levels of perception of awareness of, and actual knowledge about, natural disasters and what to do in the event of a disaster;
- relationships between perceived knowledge and actual knowledge;
- levels of perception of preparedness for, and actual preparedness for, a disaster should it eventuate on the Sunshine Coast;
- relationships between perceived preparedness and actual preparedness; and
- whether or not awareness eventuates in action resulting in higher levels of preparedness for a natural disaster.

This research was commissioned in response to a need expressed by a community service group with a broad-based membership. It was not the intention of the research to evaluate current local government or State Emergency Service programs. Rather, there was a more fundamental need to establish the baseline levels of community awareness and preparedness and to provide a foundation for more focused evaluations across the sector.

Methods

An integrated research strategy as advocated by DePoy and Gitlin (1998) and Baum (1998), utilised both qualitative inquiry and quantitative survey approaches, with several stages of data collection. This strategy included preliminary interviews with key stakeholders, focus groups constituting specialist disaster response personnel, followed by a comprehensive telephone survey of the broader community. Each stage informed the next. The participatory methods for defining awareness of and preparedness for natural disasters, as used in this research, were in keeping with those subsequently recommended by Enders (2000). The various stages of data collection and analysis are described below and are depicted in Figure 2.

Figure 2: Acquisition and Analysis Process



Interviews with key informants

Initially, key individuals involved in disaster risk management were interviewed in depth. These individuals were identified by the Regional Director of the State Emergency Service and through relevant documentation such as local disaster management plans. The purpose of these interviews was to scope the issues surrounding disaster awareness and preparedness and to identify other stakeholders (individuals and organisations) who should be contacted. These initial interviews also facilitated access to important, unpublished documentation pertinent to local disaster risk management.

Focus groups with key stakeholders

The aims of the focus groups held in 1998 were:

- to scope the issues of shared concern, and to foster lively discussion between experts and practitioners involved in planning for and responding to natural disasters; and

- to gain insight into desired levels of awareness of and preparedness for natural disasters for residents of the Sunshine Coast according to those responsible for responding to natural disasters.

Participants (51) involved members of response team organisations such as the police, rural and urban fire brigade, ambulance, local councils, State Emergency Service, and Red Cross among others. The research team briefed the entire group before four smaller sub-groups with cross-sectoral representation participated in structured group discussions which were directed by trained facilitators.

The initial workshop was based on a number of open-ended questions (see Box 1)

Box 1

Awareness:

- How would you define "awareness" in the context of being prepared for a natural disaster?
- Can individuals have too much awareness that could lead to alarm and/or complacency?
- In your opinion, what do people need to know to be sufficiently aware in the event of a natural disaster?
- Does what people need to know differ between coastal and hinterland areas?

Preparedness:

- Can you identify different levels of preparedness and if so what would they be?
- What would you put on a preparedness checklist?
- Would your preparedness checklist be different for coastal and hinterland areas?
- In your opinion what would be a schedule to conduct routine activities to ensure preparedness for a natural disaster?

An integrated summary of the findings from the focus groups was mailed to all participants for confirmation, feedback and further comment. At this stage the project was redefined.

Survey of the Sunshine Coast community

Focus group participants and other experts commented critically on the draft pilot questionnaire that was based on essential themes as identified by the focus group discussions. The questionnaire was piloted. The final questionnaire, originally planned for early 1999, was delayed until mid-year because of the potential for bias due to extensive flooding within Cooloola shire.

In the telephone survey two lines of inquiry were considered essential. First, people's levels of awareness about natural disasters and what to do in order to prepare for them were targeted. Second, questions that would elicit descriptions of actual experiences, actions and behaviours related to natural disaster preparation were needed.

A stratified random sample of potential respondents was selected using telephone prefixes to identify each local government area. All adults were assumed to have significant responsibility in disaster situations hence any adult member of a household was accepted as a valid respondent by the telephone interviewers.

Through consultation with the stakeholders, the target population for this survey was broadly defined as the Sunshine Coast community. This comprised residents of the four local shires: Caloundra (66 000); Maroochy (108 070); Noosa (36 400); and Cooloola (32 070) (Cook et al. 1998). The target number of completed survey questionnaires was 800, which was approximately 200 from each area.

Respondents, 37% of whom were male and 63% female, lived in local government areas in the following proportions: Caloundra 207 (26%); Maroochy 191 (24%); Noosa 188 (23.6%); and Cooloola 211 (26.4%). They had lived on the Sunshine Coast for varying lengths of time from less than a year to more than 20 years. The majority, 76.8% of respondents owned their residence, 20.7% lived in rented accommodation, and 2.5% had other arrangements.

Descriptive analyses utilising percentages and Chi Square analyses to explore relationships between key parameters were used to identify areas of concern. Only significant relationships ($p \leq 0.05$) and those non-significant results that raise concern are reported here.

Results

Focus group workshops

It was imperative that the status quo pertaining to awareness and preparedness was identified. The output and foci of the open ended discussions uncovered unrealistic expectations pertaining to the potential for temporal, spatial, and sectoral subsets of the research. For example, it was deemed important to understand, among others, the influence of hinterland/lowland, workplace/resident, rural/urban strata, and demographics on levels of awareness of, and preparedness for, likely disaster situations. Another important issue involved identification of information gaps (spatial, temporal, and contextual) and to recommend ways of closing those gaps. Key findings from the focus groups included:

- identification and prioritisation of natural hazards as a threat to the Sunshine Coast;
- clarification of what constitutes awareness and preparedness from the stakeholders' view;
- distinction between generic and specific information and response;
- the relevance of zones (geographical and sectoral); and
- clarification of risk terminology.

A matter of debate was the difference between appropriate levels of awareness and preparedness between individuals and authorities. At the individual level stakeholders agreed that what people needed to know varied according to an individual's particular situation and their geographical location at the time of the disaster, however, there was no consensus on the suggested stratum of coastal and hinterland areas. Workforce personnel and tourists move freely about the Sunshine Coast region and those in either stratum may need to be ready to assist in the event of a natural disaster affecting the other.

The focus group workshops highlighted a number of deficiencies with respect to coordination in the event of a natural disaster:

- while the chain of command and the level of involvement of the various decision makers was reasonably clear, there was no consensus about who was responsible for coordinating levels of response as the magnitude of the disaster increased.
- stakeholders were not fully aware of resources developed by, or available to, other stakeholders.
- communication between the authorities was an ongoing point of contention. Although a central command van had been purchased, participants were concerned about the refusal by the police department to fit it with a police radio for security reasons. The advice provided by the police present at the focus group meeting was that one could be installed when a natural disaster was declared.

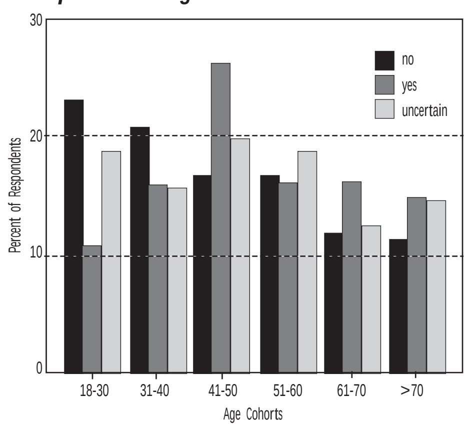
Although these issues were not an intended component of the current research, these and other results provided a timely warning for the re-examination of inter-authority relationships within the region.

Community survey

Perceived awareness of respondents

Two thirds of respondents felt that they were aware of how to prepare for a natural disaster, 21.5% stated that they were not aware and 12.1% were uncertain about their level of awareness. The 41-50 age cohort members of emergency services and those who owned a home were more likely to perceive themselves as aware than others (Figure 3). This perceived awareness was lower than expected in the city, and higher than expected in the shires. Even though respondents may perceive themselves to be appropriately aware, they may not, in fact, be so.

Figure 3: Perception of awareness according to respondents' age.



Actual awareness of respondents

Upon providing a description of natural disasters as "naturally occurring events that threaten and damage people and their surroundings" respondents were asked to identify the three natural disasters most likely to occur in the Sunshine Coast region. Of interest was the degree to which the residents were aware of the prevalence of bushfire, flood, and cyclone on the Sunshine Coast. In 6.1% of cases none of these disaster types was recognised whereas 25.1% of respondents identified one, 45.4% two, and 23.3% identified all three. Flooding was identified by 75.4% of respondents, followed by cyclone (64.5%), and bushfire (45.7%). Female respondents whose house and contents were insured and those who identified themselves as members of emergency services (N=54) were more likely to identify disasters most likely to occur on the Sunshine Coast. The young and the old were least likely to identify all three of these natural disasters

A high proportion of respondents (85.6%) did not know that a disaster management plan for their area existed. Knowledge of such a plan was aligned with higher levels of formal education, shire and age. The 41-50 and 51-60 age cohorts represented 54.7% of those who knew of disaster management plans. Similarly, 17.4%, 19.1%, 23.5% and 40% of respondents from Caloundra, Maroochy, Noosa and Cooloola respectively, had such knowledge. Members of an emergency service were more inclined to know of a disaster management plan for their area, nevertheless, 38 of the 54 (i.e., 70%) emergency service respondents were not aware of such a plan.

When asked how to obtain the most up to date information on what to do in a disaster situation if power had been cut, 18.5% of respondents identified battery operated radios as their information source. A further 9.9% identified a radio. Assuming that this response inferred that the radio would be battery operated, over a quarter of respondents (28.4%) would use the preferred information source. The majority of the respondents simply did not know, or were uncertain.

In the event that telephones were down, only 2.3% of respondents recognised the Red Cross as the organisation that reunited families in disaster situations. A further 7.5% mentioned evacuation centres, and as the Red Cross operates through evacuation centres, approximately 10% would eventually utilise this channel. More problematic were the 17.2% of respondents who mentioned emergency services as a means of reuniting families and the 14.2% who would try to use mobile phones. A further 13.2% would seek family members in person. Other means of finding out about family members such as approaching neighbours and agreed meeting places in the event of separation were identified by 44.7% of respondents, though many simply did not know.

The majority, 59.7% of respondents,

recognised that they should take pets with them in the event of a natural disaster. A further 7.5% of respondents would set them free. Included in other anticipated behaviours concerning pets was uncertainty, and locking them in the house or shed, not caring whether they were looked after (13.6% of respondents).

The majority of respondents (45.7%) recognised the police as the authority they were obliged by law to follow in the event of a natural disaster, but other organisations such as the State Emergency Service (21.5%), the fire brigade (1.4%) and the army (2.0%) were also identified. Minor mention was made of landlords, body corporates, radio announcements, and council authorities, but no specific mention was made of environment or environmental health officers.

Responses to the questions about the three most important items to have in a household, and the three most important things to do, in the event of a natural disaster, varied, as indicated in Tables 1 and 2 respectively. Relatively few appeared to be aware of the importance of torches and radios, but a majority realised the importance of water storage and food supplies (Table 1). Again, relatively few appeared to realise the importance of locking up to guard against looting, turning off utilities, and of taking precious items and important papers such as insurance documents with them when evacuating (Table 2).

Table 1: Respondents' identification of the three most important items to have in a household in the event of a natural disaster.

Items Mentioned	1st mentioned (%)	2nd mentioned (%)	3rd mentioned (%)
Battery Torch	11.6	11.2	7.6
Battery Radio	10.1	8.0	8.3
Water Storage	25.7	25.0	13.9
Food	25.4	23.4	21.5
Other light	7.6	10.4	9.9
Other	18.6	20.0	35.8
Total	100.0	100.0	100.0
N	794.0	751.0	685.0

Table 2: Respondents' identification of the three most important things to do in the event of a natural disaster.

Items Mentioned	1st mentioned (%)	2nd mentioned (%)	3rd mentioned (%)
Take Important Papers	4.0	4.4	4.3
Lock Up	9.9	10.1	9.3
Take Precious Items	8.2	13.8	14.6
Look After Pets	3.9	5.4	4.3
Turn Off Utilities	11.2	7.4	6.0
Leave Quickly	14.5	9.4	15.9
Other	47.3	47.5	42.6
Total	100	100	100
N	794	596	397

Only 14.1% of respondents knew of the location of the nearest evacuation centre. When asked when it was safe to leave their premises after a bushfire, cyclone, or flood, approximately 30% in each case noted that it was safe to leave when advised by authorities. In the case of bushfire, 35.3% of respondents stated it would be safe to leave once the fire had passed; 45.9% of respondents stated it would be safe to leave once a cyclone had passed; and 28.3% of respondents stated it would be safe to leave after flood waters had receded.

It was considered important to ascertain sources of information accessed by residents if levels of awareness are to be improved. Table 3 presents information sources and the degree to which these informed respondents about natural hazards. Table 4 shows the probability of relationships between demographic data and information sources from which respondents gained such information. More respondents with associate diplomas (undergraduate) than expected accessed information through pamphlets or brochures. Gender appeared to influence listening to relevant radio programs, but to a relatively small degree; 32.7% of females and 38.8% of males gained information concerning disasters in this way. The significant influence according to Local Government Area and information source focused around Cooloola for radio, and those shires other than Noosa for television advertisements.

Table 3: Sources of information and proportions of respondents who gained information concerning natural hazards from those sources.

Information Source	Obtained	*N*
An Information Session	5.6%	791
A Television Documentary	52.6%	793
A Television Advertisement	59.8%	796
Pamphlets/Brochures	32.7%	794
Newspapers/Periodicals/Magazines	44.3%	793
A Radio Program	32.5%	793
Information Centre (Council, SES)	17.5%	790
Other	12.8%	759

likely to threaten the Sunshine Coast. Of those who did not identify any of the three types of disaster, 14.3% were uncertain about their level of awareness, 46.9% recognised their low level of awareness, but 38.8% felt that they were aware of how to prepare for a natural disaster.

Those who considered themselves appropriately aware were also more inclined to know of a disaster management plan for their local area, and those who identified all three disaster types, were more inclined to be aware of the fact that there is a disaster management plan for their area. Even so, 77.3% of those who considered themselves appropriately aware were unaware of the existence of a disaster management plan for their area. It appears that television advertising influenced respondents' knowledge concerning awareness of the types of potential disaster (Table 5), yet, this relationship did not extend to their perceived awareness or knowledge of a disaster management plan.

Table 4: Relationships between demographics and information sources from which respondents gained information concerning natural hazards.

	Information Session	TV Documentary	TV Advertisement	Pamphlets Brochures	Papers Magazines Periodicals	Radio Program	Information Centre
Age	$P = 0.692$	$P = 0.798$	$P = 0.004$	$P = 0.205$	$P = 0.128$	$P = 0.077$	$P = 0.201$
Gender	$P = 0.438$	$P = 0.429$	$P = 0.232$	$P = 0.299$	$P = 0.306$	$P = 0.024$	$P = 0.979$
Education	$P = 0.077$	$P = 0.440$	$P = 0.251$	$P = 0.016$	$P = 0.699$	$P = 0.490$	$P = 0.340$
Length of Residence on Coast	$P = 0.526$	$P = 0.163$	$P = 0.866$	$P = 0.070$	$P = 0.037$	$P = 0.031$	$P = 0.850$
Member of Emergency Service	$P = 0.000$	$P = 0.352$	$P = 0.199$	$P = 0.331$	$P = 0.523$	$P = 0.772$	$P = 0.021$
Home Ownership	$P = 0.539$	$P = 0.381$	$P = 0.723$	$P = 0.206$	$P = 0.030$	$P = 0.624$	$P = 0.460$
Insurance	$P = 0.496$	$P = 0.919$	$P = 0.270$	$P = 0.820$	$P = 0.067$	$P = 0.956$	$P = 0.427$
LGA	$P = 0.958$	$P = 0.894$	$P = 0.006$	$P = 0.064$	$P = 0.215$	$P = 0.004$	$P = 0.810$

Note: Bolded cell entries indicate significant relationships at $p < 0.05$.

Relationship between perceived awareness and actual awareness

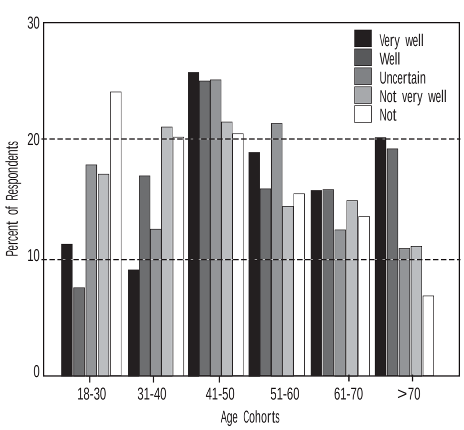
Chi-square tests were used to establish any relationship between perceived awareness and the knowledge based variables. A significant relationship existed between respondents' perception of their level of awareness and the degree to which they identified the types of natural disasters most

A consistent alignment between the different modes of gaining information suggested that those who gained information concerning natural disasters were likely to do so from various sources. The only exception to this was in the case of those seeking information by attending an information session. This minority was more likely to gain information from a narrower range of sources: information centres, popular press (papers, magazines, periodicals), and brochures and/or pamphlets.

Perceived preparedness of respondents

When questioned about their perceived level of preparedness, 11.3% and 32.7% of respondents considered themselves to be very well or well prepared for a natural disaster (i.e., a total of 44% prepared), whereas 41.8% considered themselves not very well (28.6%), or not (13.2%) prepared. A further 14.2% were uncertain about their level of preparedness. Noteworthy here, was the fact that 55.9% of respondents recognised their lack of preparedness for a natural disaster. Males who owned their residence; respondents who identified themselves as members of emergency services; and residents of Cooloola; were more inclined to consider themselves to be prepared for a natural disaster. Of particular concern was the influence of age (Figure 4), with the younger age cohort less inclined to consider they were prepared for a natural disaster.

Figure 4: Perception of preparedness according to respondents' age.



Actual preparedness of respondents

Given the possible need for evacuation in a situation where power and communication systems failed, it was assumed that those who had a ready supply of fuel in their cars could be more prepared for an emergency than those who did not. Table 6 reflects the refuelling habits of respondents. The younger cohorts were more likely to leave refueling their tanks until they were almost empty whereas those aged over 50 were less likely to do so. It was anticipated that membership of an emergency service would have influenced refuelling habits, but this was not the case. Fewer homeowners than tenants left refueling their tanks until they were almost empty.

Possession of an emergency kit, used as a measure of actual preparedness, exposed an overall lack of preparedness. Only 19.8% of respondents had an emergency preparedness kit in their home, 79.4% did not, and 0.8% were uncertain. Further, it was evident that at least 17.9% of those who claimed to have an emergency preparedness kit mistook this for a first aid kit.

Most respondents (74.2%) owned a battery operated radio with those who owned their homes and were covered by house and contents insurance, more inclined to own battery operated radios. Again, membership of an emergency service was not significantly aligned with ownership of a battery-operated radio. Almost 60% of respondents checked their radio batteries within a month prior to interview and the likelihood of this increased with age, home ownership, and insurance coverage.

Only 31.2% of respondents had their important papers stored in a place that would survive both fire and flood. Even though the elderly were more inclined to do so, less than half (44.6%) of the > 70 year old cohort did so. Fewer in the 31-40 (21.9%) and 41-50 (26.9%) age cohorts stored their documents in an appropriately safe place. Those with insurance coverage were also more inclined to have their important papers stored safely. Appropriate storage of documents was not significantly influenced by membership of an emergency service.

Table 5: Significance of chi square results showing associations between level of awareness indicators and information sources.

	Information Session	TV Documentary	TV Advertisement	Pamphlets Brochures	Papers Magazines Periodicals	Radio Program	Information Centre
Knowledge of disaster types	P = 0.782	P = 0.465	P = 0.018	P = 0.077	P = 0.142	P = 0.715	P = 0.812
Perception of awareness	P = 0.000	P = 0.002	P = 0.131	P = 0.000	P = 0.005	P = 0.001	P = 0.002
Knowledge of disaster management plan	P = 0.000	P = 0.057	P = 0.546	P = 0.000	P = 0.027	P = 0.015	P = 0.000

Note: Bolded cell entries indicate significant relationships at $p < 0.05$.

Relationship between perceived preparedness and actual preparedness

Those who considered themselves prepared for a natural disaster were more inclined to refuel their petrol tanks when it was half or three quarters full. They were also more likely to have an "emergency preparedness kit" and a battery operated radio. However, while 75.2% of respondents had a battery operated radio and 95.6% a battery operated torch, only 19.8% of respondents had an emergency kit. Even though these respondents were more likely to have their important papers stored such that they "would survive both fire and flood", 54 % of those who considered themselves prepared, did not.

Responses for measures designed to establish actual preparedness levels, were tested against each other. It was found that refuelling habits were aligned with the possession of an emergency preparedness kit and possession of a battery-operated radio. Given that a battery-operated radio is an essential component of an emergency preparedness kit, it was gratifying to find a significant alignment between these two measures. Safe storage of important papers was significantly related to ownership of an emergency kit, but 22.1% of those who stored their papers in a safe place did not possess a battery-operated radio. This reinforces the fact that many do not understand the nature of an emergency kit.

Relationship between awareness and preparedness

Respondents' awareness of disaster types most likely to occur on the Sunshine Coast was neither related to respondents' perception of their preparedness for, nor their actual preparedness for, a natural disaster (Table 7). The probability for the relationship between respondents' ability to identify disaster types, and their perception of how prepared they were for natural disasters was almost indistinguishable from that which would be found under perfectly random conditions. Yet, respondents' perception of their awareness was strongly aligned with their perceived and actual preparedness (Table 7). Thus the ability to identify disaster types likely to occur on the Sunshine Coast appeared not to impede respondents' preparations for them.

Table 6 Stated levels at which respondents usually add fuel to their cars.

Fuel Levels	Proportion of respondents (N=759)
Nearly empty	25.8%
1/4 full	27.1%
1/2 full	22.8%
3/4 full	8.0%
Cheap	5.0%
Other	11.2%

Even though perception of awareness and refueling habits were aligned (Table 7), 58.7% of those who normally left refuelling their cars until their tanks were almost empty considered themselves to be aware of how to prepare for a disaster. Also, although perceived awareness was aligned with possession of an emergency kit (Table 7), 76% of these "aware" respondents had no emergency kit, 19.8% did not have a battery-operated radio, and 58.5% did not have their documents stored appropriately.

Table 7: Significance of chi square results for the analysis of relationships between awareness and preparedness indicators.

	Perception of preparedness	Car refuelling habits	Possession of emergency preparedness kit	Possession of battery operated radio	Possession of battery operated torch	Storage of important papers
Knowledge of Disaster Types	$p = 0.993$	$p = 0.616$	$p = 0.759$	$p = 0.146$	$p = 0.230$	$p = 0.077$
Perception of awareness of how to prepare	$p = 0.000$	$p = 0.031$	$p = 0.003$	$p = 0.000$	$p = 0.005$	$p = 0.001$
Awareness of disaster management plan	$p = 0.000$	$p = 0.002$	$p = 0.000$	$p = 0.094$	$p = 0.527$	$p = 0.247$

Note: Bolded cell entries indicate significant relationships at $p < 0.05$.

Respondents who were aware of a disaster management plan for their area were more likely to possess an emergency preparedness kit, but only 4.5% of respondents had a kit and knew of a disaster management plan. Also, 17.1% of those who refuelled their cars before tanks were less than half full knew of a disaster management plan, whereas only 7.1% of those who left refuelling of their tanks until they were almost empty did so.

All sources of information considered except television advertisements were significantly related to respondents' perceptions of their preparedness for a natural disaster (Table 8). It appears that the most effective means of communicating information pertaining to preparedness for a natural disaster so that it actually influences people's behaviour, is television (Table 8). Television appeared not to have a significant influence on the possession of emergency kits whereas safe storage of important papers was significantly related to television documentaries but not television advertisements.

The information provided at information centres such as State Emergency Service or Council offices appeared to be more effective in promoting actual preparedness (with respect to the two key preparedness measures: possession of an emergency kit, and safe storage of important papers) among those who accessed it. However, the majority of respondents (79.6%) had not accessed information in this way. Television may be the more efficient means of communicating information since 52.6% and 59.8% of respondents gained information pertaining to natural disasters from television advertisements and documentaries respectively, but information sessions may be more effective. The popular print media and radio programs appeared to be the least effective means of conveying messages such that they influenced actual preparedness for natural disasters (Table 8).

Table 8: Significance of chi square results for analyses of information sources and indicators for respondents' perception of their preparedness, and actual preparedness, for a natural disaster.

	Information Session	TV Documentary	TV Advertisement	Pamphlets Brochures Periodicals	Papers Magazines	Radio Program	Information Centre
Perception of preparedness	$p = 0.000$	$p = 0.030$	$p = 0.066$	$p = 0.001$	$p = 0.002$	$p = 0.017$	$p = 0.012$
Car refuelling habits	$p = 0.070$	$p = 0.015$	$p = 0.038$	$p = 0.346$	$p = 0.521$	$p = 0.331$	$p = 0.134$
Possession of emergency preparedness kit	$p = 0.021$	$p = 0.142$	$p = 0.606$	$p = 0.004$	$p = 0.205$	$p = 0.284$	$p = 0.002$
Possession of battery operated radio	$p = 0.533$	$p = 0.028$	$p = 0.017$	$p = 0.085$	$p = 0.132$	$p = 0.035$	$p = 0.008$
Possession of battery operated torch	$p = 0.958$	$p = 0.000$	$p = 0.018$	$p = 0.754$	$p = 0.472$	$p = 0.368$	$p = 0.899$
Storage of important papers	$p = 0.015$	$p = 0.021$	$p = 0.157$	$p = 0.030$	$p = 0.027$	$p = 0.586$	$p = 0.004$

Note: Shaded cell entries indicate significant relationships at $p < 0.05$.

Discussion

The timeline of the project was determined by the outcome of the focus groups, the level of community exposure to State Emergency Service community programs, and exposure to natural hazards. It was considered that a reasonable amount of time should elapse after flooding in the area early in 1999 and prior to media warnings for the ensuing cyclone season. Thus interviews were held at a time when any immediate influence of focused publicity concerning disaster preparedness or a disaster situation was minimised. Nevertheless there appeared to be some residual impact aligned with flooding in Cooloola.

Focus group workshops

One of the more interesting outcomes of the focus group was confusion about the term "risk" amongst practitioners and professionals. It is important to clarify the definition of risk as it pertains to natural hazards, and to establish consistent terminology across all disaster management sectors and regional, and national documentation. It would be preferable if international consistency were also realised. Most international guideline documents on risk assessment distinguish between hazard and risk. Further, in their definitions of "risk" they link the likelihood of occurrence of an event or process with the potential of that event or process to cause harm (e.g., Omenn et al. 1997). The Sunshine Coast Disaster District Plan (1997), however, separates "risk" from "probability" when identifying "threats with the most potential of impacting within the Sunshine Coast Disaster District". This plan appears to relate "risk" to the likely degree of damage to humans and property, whereas "probability" appears to relate to the likelihood of occurrence.

In addition the workshop exposed confusion as to whether emergency plans should focus on a geographical (i.e., rural/urban or hinterland/coastal) or sectoral (i.e., business/government/tourist/community) level. Another example of confusion was the perception by some stakeholders that the location of the coordination centre in Maroochydore was itself at risk yet others claimed it was not. If the location is actually "safe" (i.e., beyond the risk of flooding) this fact should be relayed to stakeholders and community members alike. The focus group workshops clearly identified a number of areas of concern, inconsistency, and more importantly, inappropriate beliefs held by practitioners and specialists.

Community survey

Awareness of respondents

Levels of awareness of how to prepare for a natural disaster among respondents were not always matched by responses to actual awareness measures. The major concerns of this anomaly include the lack of understanding of process as expressed in disaster management plans for specific areas. In addition, likely responses by residents could severely impinge on communication strategies by unnecessarily clogging or jamming phone and mobile phone networks, rendering them inaccessible to emergency response teams and those experiencing life threatening or extreme situations. There was a low level of recognition that if the electricity was unavailable, many phones (phone/facsimiles) could be inoperable.

Few respondents recognised the Red Cross as the appropriate organisation to approach for locating missing persons and few knew that there was a designated evacuation centre for their area. Further, a high proportion of respondents would seek information on family members via the emergency services reflecting inappropriate levels of awareness that could hamper critical or urgent response activities.

Although members of emergency services were more likely to be appropriately aware and prepared in relation to some variables they were no more aware or prepared than other residents on others. This is of particular concern because these people are likely to be called upon to advise and assist others. If members of response teams are not better informed in pertinent matters than the general public, there is a real challenge ahead in stimulating others to improve their levels of awareness and preparedness. This flags the need to review training of emergency personnel and various agencies.

Respondents recognised the need to have food and water readily available, but few recognised torches, battery operated radios, and important papers as essential items that should be readily available in each household for use during or immediately after a natural disaster. Similarly, there was little recognition that utilities should be turned off. Fewer than 20% of respondents had obtained information on natural disasters from the relevant authorities, or directly from the State Emergency Service or local government.

In response to the question regarding whose instructions respondents were obliged to follow in the event of a natural disaster, almost 50% recognised the police as the main authority, but there was some confusion about following the instructions of others. This is not surprising given the different requirements in different states according to different types of emergency. It would appear that consistent and complementary legislative requirements would be beneficial in a nation such as Australia where there is a high level of internal migration.

Briefly, those who considered themselves to be aware of how to prepare for a natural disaster were more likely to be so, but even so, this research has identified crucial gaps in awareness levels in the community. Those who received relevant information through the media were likely to do so from several sources. Further research into the variety of media sources for conveying particular types of information to particular cohorts of the community is warranted. By identifying these gaps and the means by which particular cohorts of the community are likely to access this type of information public education programs can more directly target these inadequacies.

Two thirds of the respondents felt that they were aware of how to prepare for a natural disaster, but half of those could identify only one or none of the three most likely natural disasters to occur on the Sunshine Coast. Thus there is a major gap in the community's knowledge base concerning natural hazards and likely disaster situations and this raises questions about appropriate preparation for them.

Preparedness of respondents

Over half the respondents admitted that they had done nothing or little to prepare for a natural hazard. This should be a major concern for relevant authorities, because the large amount of readily available information concerning how to prepare for a natural disaster, is either not getting to, or not being acted upon by, the community. The influence of home ownership on perceptions of preparedness for a natural hazard is understandable given the higher level of investment involved in the ownership of residential property. The higher perception of preparedness in the Cooloola Shire could reflect the recency of exposure to flooding though it could reflect the fact that those in rural settings are more likely to be informed regarding natural hazards (Burton et al. 1993).

Given the importance that agencies place on having an emergency kit prepared for an emergency situation, it was of concern that only about 20% of respondents had an emergency kit. Further, many were unaware that a first aid kit did not constitute an emergency kit, but rather was a component of one. Also, some who claimed to have an emergency preparedness kit had no battery-operated radio, an essential item in such a kit.

For several of the variables, there was no significant influence aligned with membership of an emergency service. This included having emergency kits in homes, possession of battery operated radios, checking of batteries for both radios and torches, and the safe storage of important papers. Again, this complicates response issues. If those responsible in the event of an emergency are not better prepared than others, complacency may be insurmountable.

Although most in the community were prepared in terms of having a battery operated radio to hand, when it came to more specifically directed behaviour to prepare for such a situation the community was wanting. A large majority of respondents (>80%) claimed they had checked their radio batteries within the last month. The question is raised whether respondents actually tested the batteries or whether they assumed that, because the radio was working, the batteries were sufficiently charged. This area of public education needs clarification.

People's preparedness with respect to document storage tended to improve with age but even so, fewer than half those over 50 years of age had papers appropriately stored. Also, appropriate insurance coverage is essential and can relieve unnecessary anxiety after the event. Many may be ill informed as to the actual coverage of their insurance or do not have their important papers stored in such a way as to easily access support after a disaster. Anticipation of post disaster needs is an important part of preparation for a natural disaster. According to these criteria almost two thirds of the community is insufficiently prepared.

Relationship between awareness and preparedness

First, a lack of awareness of the specific natural disaster types pertinent to the Sunshine Coast region did not necessarily prevent some respondents from being prepared for such disasters. This might reflect an underlying caution among some respondents towards their physical and social world. Second, while respondents who considered themselves to be aware of how to prepare for a disaster took more precautions than those who recognised they were not aware, the majority of respondents who perceived themselves to be appropriately aware had in fact not prepared their households for such an eventuality. Thus lack of awareness did not prevent preparedness, but on the other hand, awareness did not result in preparedness for the majority of respondents, thus resulting in an overall lack of preparedness for natural disasters amongst residents.

The importance of education

The preceding discussion on levels of awareness, preparedness and the relationship between the two raises a central and foundational concern on information dissemination. In this case, all forms of media impacted upon respondents' levels of preparedness, though each in its own way. The type of message relayed by television, the medium identified as the most accessed for relevant information, needs further consideration. Public education programs could be more successful if emphasis is placed on key criteria such as storage of important papers and possession of an emergency kit. The non-significant results for media types could indicate that these are ineffective means for relaying particular types of information concerning precautionary behaviour, or that they currently do not provide this type of information at all.

In light of the above results regarding the relationship between levels of awareness and preparedness it is strongly recommended that the underlying features of this difference and the various media impacts be thoroughly investigated, addressing the issue of just what is involved in changing people's behaviour patterns (Rohrmann 2000). Health promotion theories such as the social learning theory that 'addresses both the underlying determinants of health behaviour, and methods of promoting change' (Nutbeam & Harris 1998, p. 30), should be considered if sustained behavioural change is the desired outcome of future initiatives. Boughton (1998) suggests active community participation throughout risk identification and management as a way of deriving the best solution regarding community response to emergency situations including natural disasters. This could be considered in the broader context of the multiple strategies prescribed by the Ottawa Charter for Health Promotion (WHO 1986).

Conclusion

"Disaster preparedness needs attention from all governments but blaming it all on global warming does not seem to be warranted at this point in time" (Adams 1999 p. 5). To establish the implications for specific stakeholders in disaster management it is recommended that the findings of this research be discussed with representatives of various organisations in directed integrated focus group workshops on a regional basis. Specific matters that warrant further consideration include:

- assessment of the location of the Disaster District Control Group and Communication Headquarters;
- uniformity of information via the provision of a single information booklet pertaining to all regional natural disasters and associated risks consistently available from various outlets;
- investigation of the effectiveness of conveying information via different media outlets for specific information and target audiences;
- in depth study of ways to overcome apathy, complacency and ignorance concerning natural hazards and disasters;
- clarification and coordination of policy and process; and
- sector-based groups (Boughton 1998) through geographical and social strata.

Perhaps of greatest concern is the fact that, although the emergency service sub-group was small, this research suggests some shortfall in awareness and preparedness levels of emergency response personnel. The effectiveness of emergency service training programs should be assessed and adjustments made if necessary. The shortfall identified between awareness of what respondents believed and what they had actually done to prepare for such a disaster, should be addressed in preparing for a natural disaster. Future research should aim to provide managers with information that will help to close this gap. Cooperation, coordination and continuity between governments and non-government organisations should be linked at the local level through appropriate and effective public education (Stanissis 1985).

While recent world attention has focused on human initiated disasters such as acts of terrorism, threats of natural disasters associated with climatic conditions or climate change can be overlooked. The research clearly suggests that, because of the doubts raised about their effectiveness, there is an urgent need to evaluate existing public education programs regarding natural hazards.

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Indoor Air Influences on Total Personal Exposure to Nitrogen Dioxide: A Pilot Study

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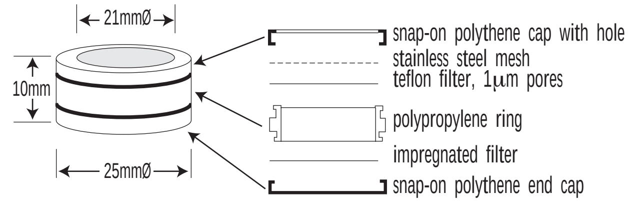
The weekly concentration of nitrogen dioxide (NO_2) was measured over 22 weeks in one individual's car, kitchen, office and outdoors at home and work. The lowest concentrations were measured in the car (mean ± sd. 6.8±1.6 ppbv) and office (9.0±4.6 ppbv). The highest concentration was measured in the kitchen (22.4±7.4 ppbv), where a gas stove was used. Outdoors at work and at home, mean NO_2 concentrations were similar, being lower than the kitchen value but greater than the office and car concentrations. The lower concentrations measured indoors in the individual's office can be attributed to the slow deposition of NO_2 to surfaces. The low ratio measured in the car (compared to outdoors) also points to this explanation. This was confirmed by deploying samplers in the individual's car and in the vehicles of a group of volunteers for 1 week, and exposing one for the entire week and another only when the engine was running. These results supported the surface uptake hypothesis and showed that the concentration measured by those devices exposed only while the car engine was running was from three to 10 times greater than the concentrations measured by the devices exposed in the car for the entire week.

Keywords: *Exposure Assessment, Personal Exposure, Passive Gas Samplers, Indoor Air Quality*

Passive samplers are suitable for personal exposure monitoring because they are unobtrusive. They are quiet, rugged and do not require auxiliary power. They provide time-integrated measurements and are less expensive than continuous monitoring devices so that large sample numbers can be utilised. Passive gas samplers operate on the principle of molecular diffusion, so that the gas of interest is collected on a filter coated with a sorbent species, and the amount of gas collected is integrated over the time of exposure. Figure 1 shows the Ferm-type (Ferm 1991; Ferm & Svanberg 1998) passive samplers used by CSIRO Atmospheric Research. Further details may be found in Keywood et al. (1998) and Ayers et al. (1998).

Atmospheric nitrogen dioxide (NO_2) is produced from nitric oxide (NO) via photochemical oxidation processes involving ozone (O_3), peroxy radicals and odd hydrogen species. Anthropogenic sources of NO and some NO_2 include vehicle exhaust and stationary sources such as fossil fuel-fired power stations, industrial boilers and incinerators. Indoors, the primary source of NO_2 is from gas cooking stoves and heaters. When such appliances are poorly ventilated the NO_2

Figure 1. The passive gas sampler used by CSIRO Atmospheric Research



concentrations indoors can build to high levels (Brown 1997).

The health effects of NO_2 are reviewed in the National Environment Protection Measure and Impact Statement for Ambient Air Quality (National Environment Protection Centre [NEPC], 1998). The health effects of NO_2 at low concentrations are uncertain. However, within Australia, studies have shown an association between hospital admissions for respiratory and cardiac conditions and ambient NO_2 levels (Environment Protection Authority Victoria [EPAV] 2000; Morgan 2000). Upon examination of multiple pollutant models, increases in NO_2 were found to be primarily responsible for increases in admissions for childhood asthma and for heart disease in the elderly (Morgan et al., 1996)

Methods

The aim of the study was to determine whether the low readings for NO_2 in cars found by Keywood et al. (1998) are attributable to the slow deposition of NO_2 to surfaces.

The study consisted of two components:

- integrated weekly exposure of an individual over 22 weeks, along with the integrated concentration of NO_2 in the individual's kitchen, office, car, and home and work outdoor environments, and

- One week integrated in-vehicle exposure for seven individuals.

In the first, one of the authors (TB) continuously wore an NO_2 passive gas sampler over 22 weeks from August 1996 to February 1997. The sampler was changed every seven days. Passive gas samplers were also placed in his workplace (office), in his kitchen, in his car, and outdoors at his work place (Aspendale) and home (Balwyn) for the same weekly periods. In the second part of the study, seven volunteers deployed two NO_2 passive gas samplers in their vehicles for one week. One sampler was deployed continuously. The other sampler was deployed only when the motor was switched on.

After exposure the passive gas samplers were dismantled and the impregnated filter placed into a polyethylene bag. The filter extraction method is described in Keywood et al. (1998). The concentration of NO_2 was then calculated on the basis of the total resistance of the sampler, time of exposure in the field and the diffusion coefficient of NO_2 at ambient temperature. Duplicate NO_2 samplers enabled an assessment of the reproducibility of the measurement during the sampling and analytical stages of the process. The overall mean difference between duplicates was 5%.

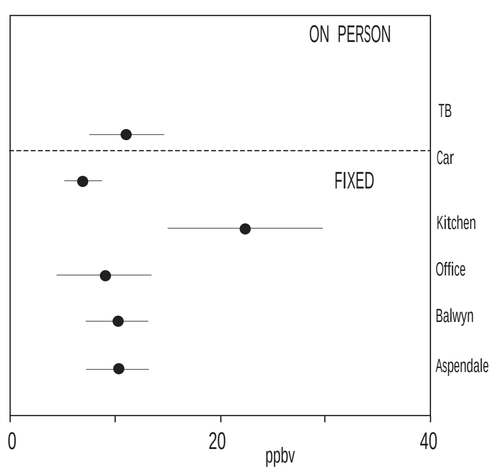
Results

Figure 2 compares TB's individual mean exposure over 22 weeks with the mean concentration of NO_2 measured in his car, kitchen, office and outdoors at Balwyn (home) and Aspendale (workplace). The lowest concentrations were measured in his car (mean ± sd 6.8±1.6 ppbv) and office (9.0±4.6 ppbv). The highest concentration was measured in his kitchen (22.4±7.4 ppbv), where a gas stove is used. Outdoors at Aspendale and Balwyn, mean NO_2 concentrations were similar (10.3±3 ppbv and 10.2±3 ppbv respectively), and were lower than the kitchen value but greater than the office and car concentrations. TB's mean personal exposure (11.1±3.6 ppbv) was greater than the concentration measured in his office and outdoors and was much lower than the level measured in his kitchen. The readings in the car are significantly lower (t=5.5, df = 21) at 99% confidence levels.

TB's personal exposure levels of NO_2 decreased from August (winter) to February (summer), in accordance with the decrease in outdoor concentrations of NO_2 measured by the passive gas samplers at Balwyn and Aspendale, and measured by chemiluminescence active sampling at the Victorian Environment Protection Authority monitoring sites at Brighton (18 km north of Aspendale) and Box Hill (10 km east of Balwyn), as shown in Figure 3. This seasonal cycle is well documented for Melbourne Air Quality stations (Lorimer, Whillans & Kinhill Engineers 1992). Lower ambient NO_2 concentrations have been noted in summer elsewhere, for example in Seoul Korea, (Baek, Yoon-Shin & Perry 1997) and attributed to strong winds (i.e., ventilation) and reduced use of combustion for heating in summer.

Figure 2. The mean (and standard deviation) NO_2 concentrations for TB's personal exposure

TB's car, kitchen, office, outside of TB's workplace (Aspendale) and

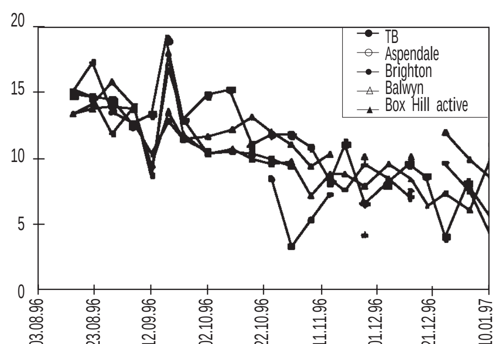


home (Balwyn) over 22 weeks and the group's mean personal exposure

TB's personal exposure to NO_2 (Figure 4) and the concentrations measured in his kitchen, office, and outdoors at Aspendale and Balwyn are lower in summer than in winter. T test analyses show this is so at the 95% confidence level. The concentrations measured in his car were not significantly different from winter to summer. A striking peak for all sites can be seen on the week of the 19th September which can be attributed to a meteorological event involving low wind speeds during that week. The peak in the office at 26 September represents a shift in the position of the sampler in TB's office to under the air conditioning vent for a period of three weeks. The elevated NO_2 concentrations most probably record the influence of greater airspeeds directly beneath the airconditioner, which affect the laminar boundary layer (LBL). While the LBL of 1.5 mm used for the outdoor samplers was used for the periods when the sampler was located beneath the air conditioner vent, the elevated NO_2 concentrations suggest that this LBL might be overestimated.

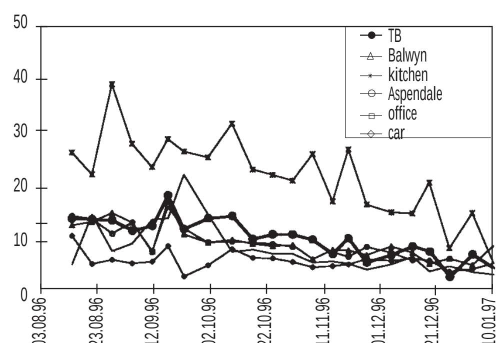
Figure 3. Time series of TB's personal exposure and ambient concentration

Measured at Aspendale and Balwyn (measured by passive gas) and



Brighton and Box Hill (measured at the Victorian Environment Protection Authority; "active") by instrumental chemiluminescence.

Figure 4. Time series of TB's personal exposure, ambient concentrations



Measured at Aspendale and Balwyn, concentrations in TB's office, kitchen and car.

In the absence of nearby point sources the ratio of indoor/outdoor NO_2 has been measured elsewhere to be less than unity (Baek, Yoon-Shin & Perry 1997; Gillett et al., 1994; Godish, 1991). This is also the case in the present investigation. TB's office indoor/outdoor ratio is (mean±s.e.) 0.93±0.07, while his kitchen indoor/outdoor ratio is 2.3±0.15. The lower concentrations measured indoors in his office can be attributed to the slow deposition of NO_2 to surfaces. The low ratio measured in TB's car (compared to outdoors at both Aspendale and Balwyn) also points to this explanation. The surface area to volume ratio is much larger in a car than in an office so that NO_2 will be lost relatively rapidly to the internal surfaces of the car, yielding low concentrations of NO_2. Further, NO_2 entering the car while in use may have been almost completely lost to the car surfaces in the sealed car in the lengthy periods while the car was stationary. This was tested by deploying samplers in TB's car for 1 week, and exposing one for the entire week, and one only when the engine was running. The respective results were 4.2 ppbv and 32.5 ppbv NO_2. In this case the concentration measured by the samplers exposed only while the car engine was running was seven times greater than the samplers exposed for the entire week, clearly supporting the surface uptake hypothesis. The representativeness of this result was further examined by placing two samplers in the cars of seven volunteers for a one-week period in the first week of December 1998. The results are given in Table 1 and confirm that a ratio of seven is a representative average value that describes the ratio between concentrations of NO_2 in a car with the motor on, to the long-term average concentration of NO_2 in the car.

Table 1: Results of one-week exposure of NO_2 passive samplers for seven vehicles

Motor on (ppbv)	Continuous (ppbv)	Ratio	Age of Car (years)	Mileage (km)	Av. Speed (km/hr)
24.2	2.3	10.7	1	479	40
31.0	4.8	6.5	10	528	38
16.6	3.7	4.5	8	524	34
42.2	5.1	8.4	15	261	44
32.5	3.6	9.1	4	167	38
29.4	4.4	6.6	16	181	39
27.7	6.4	4.3	12	388	32
Average					
29.1	4.3	7.2			

Discussion

An estimate of TB's weekly personal exposure based upon the time spent in different environments of known NO_2 concentrations can be calculated from the following relationship (Keywood et al. 1998):

$$Estimate = \sum \left[\frac{hours}{168}\right] * [NO_2\,concentration].$$

The number of hours TB spent in each environment is assumed as listed in Table 2.

The value used for the outdoors NO_2 concentration is the mean of the outdoors concentration measured at Aspendale and Balwyn. The value used for the car NO_2 concentration is that measured while the car engine was running. As the concentration of NO_2 was not measured regularly in TB's home (except the kitchen where the level is elevated due to the point source), the concentration for the home was calculated by weighting the Balwyn levels with the ratio of indoor to outdoor NO_2 concentrations at Aspendale.

Taking the mean over 22 weeks, TB's mean estimated exposure listed in Table 2 is 11.3±4.0 ppbv, which compares well with his mean measured exposure of 11.1±3.4 ppbv, with a difference of 2% overestimation. Considering that TB's estimated movements during the measurement program were only approximated (i.e., a detailed diary was not kept), this result is reasonable.

Table 2. Estimated hours spent in each monitored environment.

Environment	Hours	Mean Concentration (ppbv)	Weighted Concentration (ppbv)
outdoors	8.5	10.2	0.5
car	10.0	32.5	1.9
kitchen	7.0	22.4	0.9
home	97.5	9.5	5.5
office	45.0	9.0	2.4
sum	168.0	Estimated exposure	11.3

Conclusion

We have shown that the passive gas sampler can be used to monitor indoor, outdoor, and mobile personal exposure to NO_2. The fact that a volunteer could wear one for 22 weeks, and that they could be deployed in cars indicates that they are convenient. The passive gas samplers are sensitive enough to measure average concentrations of NO_2 expected in different environments. The concentration of NO_2 in a kitchen with a gas stove is greater than that measured outdoors. In the absence of a point source, levels of NO_2 measured indoors are less than outdoors, reflecting a slow loss of NO_2 to surfaces indoors. This is most evident in motor vehicles, in which there is a high surface area to volume ratio, so that despite the presence of an NO_2 source in the form of an internal combustion engine, the long term average concentrations of NO_2 in a car are lower than those measured in other indoor environments.

We have also shown that passive gas samplers can be used to indirectly estimate an individual's personal exposure to atmospheric pollutants, provided that information about environmental concentrations and the time spent in each environment is available. This can be achieved by monitoring the most frequented environments of an individual with passive gas samplers only for the duration that the individual is in the environment and carefully recording the time spent in each environment.

Acknowledgments

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Human Frontiers, Environments and Disease: Past Patterns, Uncertain Futures

Tony McMichael

Cambridge University Press, 2001, 424pp. $49.95 paperback, $130.00 hardback

This is a must-read book for all environmental health practitioners. The Australian author, Tony McMichael, has just moved from the prestigious Chair of Epidemiology at the London School of Hygiene and Tropical Medicine to take up the directorship of the Centre for Epidemiology and Population Health at the Australian National University. He has, among other things, worked on the national diet at the Adelaide CSIRO Division of Human Nutrition and for the World Health Organization as one of its key advisers on international aspects of environmental health. He currently sits on the Intergovernmental Panel on Climate Change.

It is not new for Tony's work to act as an early warning system. He has published ground-breaking findings on the connections between dietary fats and heart disease, low incomes and heightened health risks, passive smoking and lung cancer, lead in the air and children's intellectual development, and climate change and the spread of insect borne diseases. As one of the early major public health researchers to take the local health impacts of global environmental change seriously, he published *Planetary Overload: Global Environmental Change and the Health of the Human Species* in 1993. The present book is far from a mere sequel. While *Planetary Overload* warns of the mistakes of the past and the risks of the present, *Human Frontiers, Environments and Disease* takes a broader view, looking at how humans have lived in the past, are living now, and could live in the future.

It is this aspect of the book that leads to the recommendation that it should be on the shelf of everyone contributing to environmental health, who include government administrators, local government Environmental Health Officers, public health practitioners, and the concerned community. Such a strong recommendation might seem surprising, in view of the highly expert technical detail on which the book is based, its presentation in a tightly packed format, and its somewhat formidable title. But once the readers get past all that, they will find that here is another example of Tony McMichael's capacity to be ahead of the game. This time he throws a searchlight onto the complexities of past, present and future relationships between global and local environments and health.

While the book will undoubtedly be widely used as a textbook, it offers much more than that to the everyday practitioner. The statistics, the expert references and the footnotes are all there, but the book itself is easy to read, with some intriguing section headings such as " A polar bear for a bishop" and "Mouths versus meals". Two helpful and intriguing threads bringing together the immense detail of the book, the first being the familiar public health demons, the four horsemen of the biblical Apocalypse: "We have partially reined in *Famine* and *Pestilence* on their black and pale horses.... Meanwhile, the other two horsemen, *War* and *Conquest*, still roam menacingly on their red and white steeds"(p.xi). McMichael connects these classical threats to the conditions of the 21st Century, the globalised population and the damaged planet. He goes further, offering a fifth horseman that did not exist in biblical times, *Industrialisation*. Or, he asks, is this another manifestation of Conquest, only this time it is the world's natural systems not other human beings that have been enslaved? (p. 153).

The second theme of the book tracks human footprints over time. First, the footprints in the mud of the African grasslands, our earliest evidence of recognisably human upright movement, with toes still clawed to cling to branches. Slowly these almost-human people's molecular footprint adapted to fit the African environment and global natural systems of their era, with our molecular programming today still not very different from theirs, but with radically altered global systems. As the social tools of speech and culture developed, so did the shape of the footprints they left behind in the shape of pottery, stone tools, permanent settlements and permanently modified local environments. While these feet trod fairly gently on the earth, the next set of footprints, the global overlay of technology, are heavy enough to breach the limits. "...we must find a way of living within this essentially closed system, Planet Earth. The trail cannot continue with footprints like these" (p. xvi).

As well as being a good read, the book makes two further contributions to environmental health practice. It interweaves environmental themes and social processes in discussing environmental issues, linking health risks to their related social behaviours through the devices of the Apocalyptic horsemen (the risks) and the changing footprints (the human social practices). This helps to resolve the everyday dilemma of the environmental health professional: whether to give priority to treating the environmental degradation or to trying to change the human behaviour that caused it. From the evidence presented in this book, there is no contest. It has to be the point of interaction between the two, as Figure 10.1 with its multiple interacting pathways makes clear.

The third use of the book is as a practical reference work. The writing de-mystifies many of the newly emerging environmental health risks that are still matters of scientific and political debate. Climate change, Mad Cow Disease, genetically modified foods, food safety and persistent organic chlorines are subjects of community mythology and scientific uncertainty, yet it is environmental health practitioners who are often asked to produce the right answers at the local scale. Looking up these issues in the index of this well-based book is likely to be more rewarding than ploughing through purely technical material. There is even the odd laugh on the side.

There will surely be a second edition, which would benefit from a better laid out text, more illustrations, and perhaps even a punchier title, in order to reach the wide audience that needs and deserves this book.

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Air Pollution and Health Risk

Tom Beer (Editor)

CSIRO & The Clean Air Society of Australia and New Zealand, 2000, $55.00, paperback, ISBN 0643 065024

Air Pollution and Health Risk is based on the proceedings of a one-day workshop on air pollution and health risk, held in October 1998. The book is organised around the presentations of the invited speakers who participated in that workshop. The introductory chapter, "*Exposure assessment and health risk assessment: the Australian context*", by the editor, Tom Beer, is an excellent, concise and relevant entry point to the area of health risk assessment. This chapter describes the background and rationale for the development and implementation of the National Environment Protection Measure (NEPM) for ambient air quality. This focuses on the role of air quality data available in Australia, the assessment of exposure (including the comparison of Australian and US exposure models), the fundamental principles of health risk assessment, dose-response modelling and a discussion of environmental standard setting. The chapter specifically uses ozone as an example of dose-response modelling, although reference is made to other published material for those who wish to study in further detail.

The third chapter also provides examples of how data may be manipulated and analysed in order to assist the risk assessment process. These approaches are the use of physiologically-based pharmacokinetic models as a means of estimating internal doses of pollutants, and Bayesian networks as an improved tool for interpreting epidemiological data. This, and the first chapter, would together act as templates for those studying or working in the area of health risk assessment of airborne pollutants, providing sufficient detail to enable the process to be applied to field data and model situations.

Although, in my opinion, a little out of sequence, chapters two and four represent useful background information on emerging issues in air quality risk assessment and a review of the health effects of particles respectively. The emerging issues that have been identified include:

- definitions of risk assessment within the context of risk management
- newly introduced regulations that will require or encourage health risk assessments
- changes in public perceptions of risks
- validation of risk assessment process and its elements
- cost-benefit analysis of risk management strategies adopted or recommended following risk-assessment
- technology based standards.

Other identified emerging issues are the definition of acceptable risk, endocrine disruptors, indoor air, and natural pollution sources. Some of these have been examined quite superficially, whereas others will become dated with time. However, they do provide useful starting points for discussion in teaching environments. The review of health effects and particles, is reasonably comprehensive, but would have benefited from a health risk assessment example based on the presentation.

The remaining three chapters describe air quality studies in Brisbane, Adelaide and Sydney. These studies differ in their approach to health risk assessment, and can represent alternative paradigms for research, depending on the aims and outcomes that are desired. They also provide reference material, for others planning research in Australian cities, but which might otherwise be seen as too specific to be of a wider interest.

It is unfortunate that many of the innovative ideas and analytical tools presented in chapters one and three were not applied to the data in the final chapters and the chapter on particles, as this would have demonstrated the strength and general utility of these approaches to risk. That is, examples of the applicability of these tools, in a format that can be readily adopted by researchers examining other pollutants and/or situations, would have rounded off the book perfectly.

I have found the book to be an excellent addition to my library, and I intend to use it in teaching at undergraduate and postgraduate levels. It is not overly complex, and the mathematical treatments in particular are reasonably easy to follow. In short, it is readable, relevant, and affordable.

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