Urban flood damage under greenhouse conditions: what does it mean for policy

by D. I. Smith, Centre for Resource and Environmental Studies, Australian National University

Introduction

There is little doubt that the study of greenhouse-induced climates has concentrated upon the modelling of atmosphere-land-ocean interactions in order to improve our understanding of what is still a very uncertain hydrological future. The last few years have seen the first tentative steps to use these scientific scenarios to assess the socio-economic impacts on communities. The proceedings of the two organised symposia, held in 1987 and 1994 (Pearman, 1988 and Bouma et al. 1996), rank highly as early studies of this kind. However, even these seminal publications tend to address the topic in a manner that is heavy on science and light on policy. There are many reasons why greenhouse climate scenarios have yet to receive any rigorous link to policy. Three major handicaps are:

- That the scenarios are surrounded by uncertainty and focus on what happens under double CO_2 conditions, the date for which is also uncertain but for convenience in this account will be taken as about 2070. This is a long time horizon when compared to that usually considered by decision-makers charged with policy formulation
- The implementation of environmental policies formulated by Commonwealth and State governments falls upon local government authorities, their resource base (technical and financial) is often inadequate to meet such demands.
- Even if the scenarios had less uncertainty the socio-economic impacts have a complexity that is just as great as that facing climate modellers. However, the research funds available to assess the socio-economic impacts are paltry in comparison. Australia has no greenhouse research institutions for such studies with a funding base comparable to that available to, say, CSIRO and the Bureau of Meteorology.

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The problem is similar at international level. The IPCC has only recently produced a background volume devoted to *'the economic and social dimensions of climate change'*(Bruce et al. 1996), this covers both costs of abatement as well as impacts. As we shall see, the volume has relatively little to say about greenhouse climate impacts on specific facets of the socio-economic world. In addition, the IPCC has published a technical report of climate change and adaptations which provides *'guidelines for assessing climate change impacts and adaptations'*(Carter et al. 1994). This is useful in giving an outline to possible methodologies but lacks specific illustrative examples.

The account that follows is limited to a consideration of the possible effects and possible policy responses to the most recent IPCC (1996) climate change scenarios for urban flood losses in Australia. This, it can be correctly argued, is a narrow topic but it does provide an example of the complex nature of policy responses to greenhouse climate impacts. It is also of interest because the effects of climate change on extreme meteorological-linked natural hazards have been highlighted, mainly by GCM modellers, as of special concern. A useful background to this subject is given in *Climate change and extreme events — altered risk, socio-economic impacts and policy response* by Downing et al. (1996). However, with minor exceptions, that study is lacking in detailed case studies of the impact of extreme events that can form a solid base on which to consider policy responses other than in the most general way.

Greenhouse urban flooding: Australian case studies

This account uses the results of a recent research project, funded by the Commonwealth Department of Environment, Sport and Territories, as background against which to comment on the policy implications of potential changes to urban flooding under greenhouse climate induced scenarios. Neither the modelling of the flood hydrology nor their conversion to urban flood damages under greenhouse conditions will be discussed in detail in this account, other than to report that the hydrology combined the use of conceptual rain/runoff model (IHACRES) with a stochastic weather generator and that the flood damages were assessed using an established computer package (ANUFLOOD). The technical aspects and detail of the results are described in Smith et al. (1997). Immodestly, the authors of the report consider that the methodologies used are the equal of any elsewhere!

Background to methodology

The climate scenarios employed were those given in CIG (1996) which are based on IPCC (1996) but modified for application in Australia. The modelling was undertaken for three catchments that contain existing flood prone urban communities. The case study urban locations were for Queanbeyan and Canberra (essentially in the same catchment), for the Hawkesbury-Nepean corridor (that includes Penrith, Richmond and Windsor) and for the highly urbanised Upper Parramatta River catchment. It is pertinent to note that all these fall within a region for which the CIG (1996) climate scenarios are identical. The modelling concentrated upon 'the most wet' and 'most dry' extremes for the year 2070, assumed to be close to double present CO_2 concentrations.

The estimation of direct flood damage (resulting from the impact of flood waters, sediment etc) was undertaken using widely accepted techniques. It gained from the availability of pre-existing data bases that contained information on every individual building in the urban areas at risk. The data bases were unusual in that they extended well beyond the level of the probable maximum flood (the theoretical worst case) under current climates. The analysis of damage also allowed for building failure from extreme flood events when the combination of velocity of depth of the flood waters exceeded the critical limits for lightweight structures. The databases for Queanbeyan, Canberra and the Hawkesbury-Nepean were collected in the late 1980s to assist with the estimation of upstream dam failure. As a minor point, the data bases for these locations were not updated but all damage estimates are expressed in terms of mid-1996 prices. Unfortunately it has not yet proved possible to provide comparable damage estimates for the Upper Parramatta, although the hydrological modelling is complete and the changes under greenhouse scenarios have been estimated.

The results

The simplest single statistic to demonstrate the impact of greenhouse change is that for average annual damage (AAD). This integrates losses and probability of flood occurrence across the whole range of flood frequencies. It can be equated with annual flood insurance premium that would charged to provide flood cover for all buildings and contents (without allowance for administrative charges, profit etc). It is pertinent to note that members of the Insurance Council of Australia have never offered flood cover for dwellings or small businesses. The results for the case study locations are presented in Table 1, the losses are restricted to those for direct damage i.e. due to the contact of flood waters with building fabric and contents. For flood prone Toongabbie in the Upper Parramatta River catchment, current losses would increase, under worst case greenhouse 2070 scenario, by a factor of about 2.5

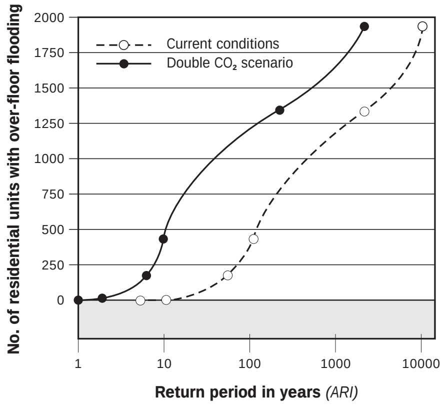

Figure 1: Number of residential buildings in Queanbeyan at risk from over–floor inundation, under present and for most wet 2070 greenhouse climate scenario

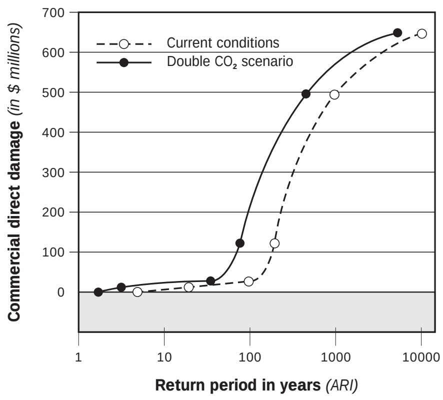

Figure 2: Direct flood damage to commercial buildings in the Hawkesbury-Nepean corridor, under present conditions and for the most wet 2070 greenhouse climate scenario.

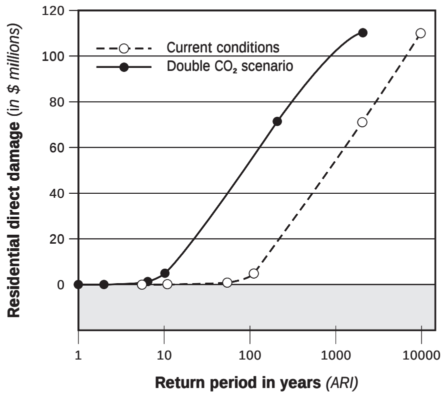

Figure 3: Direct flood damage to residential buildings in Queanbeyan, under present conditions and for the most wet 2070 greenhouse climate scenario

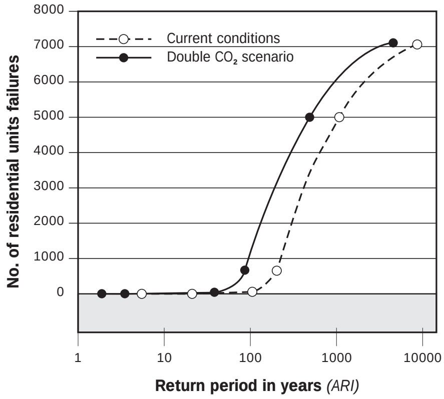

Figure 4: Residential buildings at risk from failure in the Hawkesbury-Nepean corridor, under present conditions and for the most wet 2070 greenhouse climate scenario

although direct damages values are not yet available.

The significance of *Table 1* is that even for locations within the same regional greenhouse climate scenario the adverse effects are markedly different. This reflects both the different hydrological responses for the catchments and the type and height distribution of buildings.

Figures 1 to 4 compare, in graphical form, other aspects of the most wet double CO_2 climate scenario for 2070 with those for present flood hydrology. These are selected on from a range of similar graphs that can be presented for the case studies. They show the effect that double CO_2 has, for floods of differing recurrence interval, on the numbers of buildings at risk, for direct damage and the implications for building failure under extreme flood conditions. For each locality comparable graphs can be produced for the residential, commercial and industrial sectors; for ease of presentation the latter two have been combined. The flood damages presented are restricted to those for direct flood damage i.e. contact of flood waters and their contents to building fabric and

Average annual direct flood damage

	Present conditions			Worst case double CO_2		
	Residential	Commercial/ Industrial	Total	Residential	Commercial/ Industrial	Total
Queanbeyan	0.55	0.69	1.24	5.40	6.75	12.15
Canberra	<0.001	0.007	0.007	0.001	0.07	0.07
Hawkesbury-Nepean	3.76	2.34	6.10	14.29	8.91	23.20

All figures in $m at mid-1996 values

Table 1: Average annual direct flood damage for Queanbeyan, Canberra and the Hawkesbury-Nepean corridor under present day and most wet double CO_2 (2070) climates

contents. In *Figure 1* the number of buildings illustrated are those that would experience over-floor inundation, although the direct damage data incorporates the losses from over-ground flooding i.e. limited to building grounds.

To obtain estimates of total urban flood damage it is necessary to add indirect and intangible flood losses to direct flood damage. Indirect losses are essentially due to disruption and would include the costs of alternative residential accommodation and loss of profit for the commercial–industrial sector. These are not specifically considered in this account since the normal manner to estimate indirect losses is as a proportion of direct losses. Intangible losses (not easily or sensibly expressed in monetary terms) are an additional loss and in cost benefit analysis are usually expressed qualitatively. One category of intangible flood losses is the stress-related effects on health, another is the potential for fatalities associated with building collapse under extreme flood conditions.

Notwithstanding the unique features of each and every urban flood prone location, the salient feature of the illustrative material is that there is a sharp increase in number of flood prone buildings (and therefore in flood damages) at around the level of the 1-in-100 year ARI flood under present conditions. This has a form similar to that of a step function. Any increase in flood frequency therefore, causes developments positioned just above the level of the current 1-in-100 year flood line to become exposed to significantly greater risk. For the case study areas, this 1-in-100 year 'step' corresponds to the annual recurrence interval level used as 'the designated flood line'. The designated flood line is the level at which land use controls are placed on new developments. This is the case for New South Wales and the Australian Capital Territory, in which the case studies are located. The 1-in-100 year designated flood line is also commonly used worldwide as the designated flood line, albeit often without any sound hydrological or reasoning.

Figure 4, which shows changes to residential building failures for the Hawkesbury-Nepean corridor, requires some additional explanation. The majority of the potential failures are to single storey, detached, weatherboard dwellings that are a relatively common house type in older urban areas in Australia. Under present conditions a 1-in-100 year flood event would likely cause the failure of about 70 such dwellings in the Hawkesbury-Nepean corridor. For the equivalent worst case 2070 flood, this increases to about 1200. It is not suggested that this result should be extrapolated to other flood prone urban areas, this is because the flood height range for the Hawkesbury-Nepean is exceptionally high. The increase in flood height from the 1-in-20 to the 1-in-100 year at Windsor is in excess of 10 metres with a comparable rise between the 1-in-100 and the probable maximum flood. It does, however, represent a significant factor for urban floodplain and emergency management under both current and greenhouse flood regimes. Queanbeyan exhibits similar, but less dramatic, changes in the potential for building collapse. In contrast, many inland locations in both New South Wales and Queensland experience flood height ranges of only a metre or so and greenhouse change would have insignificant effects on failure potential.

The socio-economic scenarios and response

The uncertainty of the scenarios and the hydrological modelling apart, the information given in *Table 1* and *Figures 1 to 4* provides a basis on which to consider how urban floodplain managers and policy makers may respond. These can be considered as socio-economic impact scenarios comparable to the climate scenarios of GCM modellers. In summary the scenario for impacts is:

- there are differences in the estimates of future flood loss even between catchments in the same greenhouse climate region
- under worst case 2070 conditions there are major increases in the numbers of buildings at risk and therefore in damage
- under the most dry option all forms of flood damage would be similar to, or slightly less than, those experienced with present day flood frequencies
- for some existing flood prone urban developments the risk of building failure under the most wet scenarios is unacceptable
- the hydrological analysis suggest that even under the worst case the major changes are likely to occur after the year 2030 i.e. before 2070.

Current Australian urban floodplain management and policy

The policy response to socio-economic scenarios for greenhouse urban flooding require an understanding of current policy. A recent detailed review for Australia is available in Smith et al. (1996) and an extensive international comparison of policy style in May et al. (1996). For Australia the starting point is that water resources, including floodplain management, are constitutionally the responsibility of the States. Although each State government takes a different stance to floodplain management, the role of local government authorities (LGAs) in all States is of major importance. There are about 900 LGAs in Australia and likely about half of these would have an urban flood problem of some kind. It could be argued therefore, that there are several hundred different versions of floodplain management and policy in the Commonwealth, each of which has an unique blend of flood hydrology and damage profiles!

Discussion can, however, gain by focussing on New South Wales and Queensland, if only because those two States have approximately equal shares in the 85% or so of existing flood prone buildings in Australia, the national situation is reviewed in Smith (1996). This review serves to highlight the policy differences between States. New South Wales has State guidelines for urban floodplain management that match world best practice, it has steadfastly promoted these policies for some twenty years. There are incentives for LGAs to prepare and implement locally-based floodplain management usually incorporated into local planning controls, invariably based on the 1-in-100 year designated flood. In addition, flood mitigation measures have often been introduced at LGA level to reduce flood losses to existing flood prone developments. However, the attainment of this high standard of urban floodplain management has required the provision of considerable financial and technical resources and, at times, prompted fierce political confrontation between State government and LGAs. It is often said that there are no votes in the introduction of locally-based planning controls to limit flood-prone development.

In contrast, Queensland has no State policy or guidelines for urban floodplain management. It is solely a matter for individual LGAs, some have excellent locally-based management but the majority have only the most skeletal framework. This leads to an escalating problem in vulnerability and damage potential. For instance, the Gold Coast has several thousand dwellings at risk, virtually all of which have been built since the major flood of 1974, for which good quality maps of the limits of inundation are available.

Thus, theoretically NSW could modify its State policy guidelines to take account of greenhouse effects and encourage LGAs to incorporate such future change into their local controls. In Queensland this is still a matter for LGAs, most of which see the imposition of floodplain management controls as a barrier to local development. It is possible that Queensland may introduce state guidelines and policy, if this were the case consideration might be given to including potential greenhouse effects.

Even if there were much improved certainty of change to the designated 1-in-100 year flood line under greenhouse conditions, the response is not a simple matter of 'changing the line'. Designated flood lines were the result of major and fierce argument and, having agreed to a line, any further change would cause major distortions to the prevailing property market. Certainly the present degree of uncertainty makes any such response most unlikely. It is the LGAs that need to be persuaded of the need for change, although in NSW the State government has some leverage in part due to its willingness to assist with the funding of flood studies and mitigation measures for the LGAs that adopted State guidelines for sound floodplain management. These are described in the NSW *Floodplain Development Manual* (1986).

Local Government response

The only detailed survey of which I am aware that considers the response of LGAs for planning and greenhouse is by Zehner (1991). In 1990, he conducted a postal questionnaire survey (addressed to the 'Chief Town Planner') of all LGAs in Australia (some 900) and obtained a response rate of about 75%. The two most important environmental issues for LGAs, regardless of any greenhouse change, were 'drainage/water runoff' and 'flooding', mentioned by 75% and 62% of respondents respectively. Approximately half of the responses indicated that greenhouse climate effects are expected in Australia. However, 50% of LGAs had no interest in 'long term changes in climate', 39% had 'some interest' and only 11% had taken action to provide discussion papers, to propose or implement policy changes. Only 15 out of 671 responses were in the category of 'actual policy change'. Intuitively, it is unlikely that these responses have changed much since the early 1990s.

The survey suggested that most respondents considered that the federal government should take the responsibility for greenhouse policy planning. Understandable though this may be, the responsibility for implementing policy would remain with the LGAs.

Scientific and media reporting of potential greenhouse effects continues without any sign of diminishing. However, the scientific community should understand that the frequency with which the climate scenarios change does not instil confidence or act as a spur to action at LGA level. To take a simple illustration: the CIG (1992) range in winter rainfall change for 2070 is given is –20 to +20% of present, CIG (1996) gives this as –10 to +10%, the corresponding summer changes are 0 to +40% (1992) to –10 to +10% (1996). These illustrations all refer to the region in which the case studies are located. The 1987 scenario (used in Pearman, 1988) suggested 'higher spring, summer and autumn rainfalls by up to 50% in those regions deriving such rain from southern penetration of tropic–subtropical air during the Australian monsoon season' and 'winters will be generally 20% drier'.

LGAs have many urgent priorities that clamour for their attention. For those who practice sound floodplain management, modifications to match the continually changing greenhouse science scenarios targets are understandably accorded a low priority. Those LGAs with only minimal regulations under current conditions are even more unlikely to change their practices in the light of current greenhouse scenarios.

Undoubtedly the translation of greenhouse climate to socio-economic scenarios should be supported by federal agencies but, even with increased certainty of possible adverse effects, policy change at LGA level is difficult to implement. It should be remembered that probably half of all LGAs in Australia are lucky to have a single professional on their council staff — invariably a harassed engineer who doubles as the 'planner'.

'No regrets' and the 'Precautionary Principle'

'No regrets' and the 'Precautionary Principle' are two policy stances that have emerged as key words in the greenhouse policy literature. They apply both to strategies to reduce emissions and how to cope with potential impacts. Bruce et al. (1996) contains simple definitions:

- the 'no regrets option can be regarded as 'measures worth doing anyway' (p. 15)
- the 'precautionary principle' 'can be stated as a means 'to invest more than would otherwise have been invested' in order to '… enhance the economy's ability to adapt should climate change damages occur'(p.26).

These two policy approaches to possible greenhouse changes to urban flood damage provide more scope that the pessimistic background to response outlined above. The precautionary principle accords with Australia's overarching environment policy of 'ecologically sustainable development'. This is a policy accepted by all tiers of government i.e. at Commonwealth, State and local government levels.

As postulated, the general approach of LGAs to planning for the future of flood prone urban developments is not one of enthusiasm for change. There are however, exceptions and these are often where the professional staff are concerned over duty of care and persuade the elected representatives that this a shared responsibility. For such LGAs future adverse greenhouse effects provide additional information to implement changes that represent sound and effective floodplain management under present climate conditions, the effects on uncertain greenhouse futures would be a bonus.

The most likely response is to improve the current flood warning system in order to lessen the effects of floods on the community at risk. This has the advantage that it is likely to have a favourable cost–benefit ratio regardless of the inclusion of greenhouse effects. This however, is not an easy task as a 'flood warning system' includes not only the hardware and forecast of flood heights but requires improvements in community awareness and response. Such improvements to flood warning systems are a prime example of the no regrets policy style, they would be advantageous to all the case studies described.

The potential for building failure with its associated risk to life, clearly demonstrated for the Hawkesbury–Nepean, requires a different policy response. In the author's opinion, the risk of such failure under extreme current conditions is unacceptable, it is a question not of if such failure will occur but when. If it were to be tomorrow, there is no question that much more severe building regulations would be immediately implemented, in the worst event from the Coroner's Court. The worst-case failure with the 2070 greenhouse scenario is completely unacceptable. In this case, judicious use of the 'precautionary principle' represents the favoured path, this could take the form of changes to building regulations in flood prone areas.

Greenhouse flooding studies: the literature

There are very few accounts in the literature that provide hydrological and socio-economic information on urban flooding under greenhouse conditions that can be compared to those described here. The IPCC study on economic and social dimensions succinctly comments (Bruce et al., p. 202, 1996) that:

'... little information is currently available regarding the socioeconomic impact change in the frequency and intensity of river floods' (see Arnell and Dubourg, 1994).

A study based on similar procedures to those described here, for Limburg on the River Meuse in the southern Netherlands, is reported by Penning-Rowsell et al. (1996). The changes to urban flood damages by the year 2070 are estimated to be 2.2 larger than under present conditions. The Dutch study however, does not give the range for 'most dry' and 'most wet' climate scenarios.

Robinson (1988) used earlier, and 'wetter scenarios' than used in this report, to indicate the potential for major changes to flood frequency for a variety of Australian catchments. These were not directly converted to flood damage. Smith (1993) outlined methodologies to assess urban flood damage but declined to provide quantitative estimates as the scenarios at that time were inadequate for such prognostications. That methodology was used in Minnery and Smith (1995) and forms the basis for the results presented in this account.

Minnery and Smith based their tentative assessment of greenhouse changes to urban flood loss on the scenarios for changes to rainfall intensity reported in Fowler and Hennessy (1995). The hydrological analysis used by Minnery and Smith is inferior to those reported here. The changes, based on rainfall scenarios for the year 2070 resulted in a four-fold regional increase in AAD; there was no attempt to consider separately the most wet and most dry cases.

Despite differences in the climate scenarios used, all these earlier studies indicate that urban flood losses are likely to increase under greenhouse climates.

Conclusions and recommendations

The methodology to investigate the impact of future greenhouse climate change on urban flood damages outlined in Section 1 is put forward as the best currently available. However, the uncertainties and lack of local detail in the greenhouse scenarios and the problems of estimating the frequency of extreme events, question whether the figures for changes in flood loss are adequate to form a basis for future policy change.

Even discounting these formidable limitations, any modification to current urban floodplain management and policy is likely to be incremental. Policy changes based on the no regrets and precautionary principle are therefore, recommended. These are also the most likely to be undertaken.

The good news at national level is that even the worst case scenarios represent only a tiny fraction of gross national product although there may be much trauma at local level for those directly affected by future adverse changes to river flooding. The bad news is that this study has been confined to the changes in flood frequency to rivers and possible effects on damage to urban buildings and their contents: adverse changes to flood frequencies have much wider implications. These range from problems for urban drainage surcharge to the question of safety for hazardous dams.

Acknowledgements

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Book review

Flood Warning: Issues and Practice in Total System Design

John Handmer (ed), Flood Hazard Research Centre, Middlesex University, 1997.

By Dingle Smith, Centre for Resource and Environmental Studies Australian National University, Canberra

The hazard of flood and the establishment of effective warning systems are key concerns to emergency managers worldwide. The search for an optimal solution is one of the many 'golden fleeces' of emergency management. An unending quest for the perfect system is renewed with vigour after the occurrence after each major devastating flood event. In September 1990, AEMI sponsored a workshop at Mt Macedon to yet again consider the problem. This workshop assembled a wide range of stakeholders drawn from all three levels of government, from a range of governmental agencies and with a sprinkling of researchers from academia. The meeting was seminal to the formation of a committee charged with producing a publication to promote better flood warning procedures in Australia. The outcome was the publication, in 1995, of *Flood Warnings: an Australia Guide.* (This publication can be obtained from the Information Centre at the Australian Emergency Management Institute, it is a free publication).

Thus for the first time there was a clear national statement of the path to be followed. As with all the golden fleeces that together form the totality of emergency management, it does not give all the answers and it is certain that the management of future flood events will be far from perfect and EMA will convene meetings to see where the flood warning systems went wrong. However, it is an invaluable guide to the overall principles that should be followed.

Flood Warning: Issues and Practice in Total System Design, edited by John Handmer and published by the Flood Hazard Research Centre at Middlesex University in 1997 continues the theme initiated at Mt Macedon but within an international context. It is based upon a Workshop held in September 1995 and attended by some twenty flood warning experts drawn from six countries. The publication includes 16 papers presented by those present and gives a background to flood warning systems from a variety of countries. The Workshop used as its centre piece the EMA flood warning guide, with major contributions from John Handmer, Jim Elliott and Chas Keys who were members of the committee that wrote and edited the EMA publication. Thus Australian emergency management and EMA can be justifiably proud of the role they played in forwarding the adoption of better flood warning systems.

It is critical to understand that to attain effective flood warnings for communities, that the provision of the forecast is only the first step in a long chain of actions and feedback loops that comprise the 'system'. Technological expertise based on the sciences of meteorology and hydrology are necessary but could, in my opinion, be regarded as the easy part of the system. Such expertise exists, the barrier is the provision of resources (human and financial) to install, maintain and interpret the information. Indeed, this technocratic bias has for too long been regarded as the cutting edge of emergency management. For decades the assumption, from the scientists involved, was that if the community were given the information that they would then respond in an appropriate manner.

Thus, if the extent of flood-prone lands were defined and forecasts of river height and time were available that the battle for effective emergency management was virtually over. That this is false is clear to anyone involved in emergency management. Once the basic, and clearly important, scientific information is available the problem really starts! No longer can those involved at the sharp end of the process shelter behind the shield of 'we don't have the information', the task has becomes how can the information best be used? The Australian guide stresses these aspects and classifies the steps into translation of the technical forecast into terms that are appropriate for those at risk, followed by how to efficiently disseminate the warning to those at risk, and then to give guidance as to what the appropriate response should be. These issues form the core of the Australian guide and were the starting point for the international meeting at Middlesex University.

Several of the papers describe flood warning practice in the United Kingdom while others outline practice in other countries. I have sympathy for the authors of these papers, as in each case it is necessary to describe the institutional arrangements in which the flood warning system operates. This does not make for easy reading, it is difficult enough to try and comprehend the multi-organisational arrangements that operate in Australia. The overall impression is that the Australian pattern is comparable to those elsewhere and