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Managing the health risks of extreme weather events by managing hospital infrastructure

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Abstract

Purpose – A predicted increase in climate change-related extreme weather events will present hospitals with new health-related and physical risks which were not originally anticipated in building and infrastructure designs. Markus *et al.*'s building systems model is used to analyse a range of adaptive strategies to cope with such events. The paper aims to discuss these issues.

Design/methodology/approach – Focus group interviews were conducted with a wide range of hospital stakeholders across three case study hospitals in Australia and New Zealand which have experienced extreme weather events.

Findings – It is concluded that effective adaptive strategies must balance responses across different organisational sub-systems. Contrary to previous research, the findings indicate that hospital managers do see hospital infrastructure as an important component of disaster response. However, it is the least adaptable of all response subsystems, making other options more attractive in the heat of a crisis.

Research limitations/implications – A focus on three case studies allowed the researchers to explore in-depth the experiences of stakeholders who had experienced extreme weather events. While producing highly valid results, the inherent limitation of this approach is the lack of breath. So further case studies are needed to generalise from the results.

Practical implications – Recommendations are made to improve the adaptive capacity of healthcare facilities to cope with the future health challenges of climate change risk.

Originality/value – By acknowledging that no one group holds all the knowledge to deal with extreme weather events, this paper capture the collective knowledge of all key stakeholders who have a stake in the process of responding effectively to such an event. It shows that hospital adaptation strategies cannot be considered in isolation from the surrounding emergency management systems in which a hospital is imbedded.

Keywords Hospitals, Risk, Climate change, Systems, Adaptive capacity, Extreme weather

Paper type Research paper

Introduction

Extreme weather events are caused when an individual climate variable such as wind speed temperature or rainfall "exceeds a particular threshold and deviates significantly from mean climate conditions" (Linnenluecke and Griffiths, 2010, p. 2). In recent years there has been accumulating evidence of an increased incidence of such events (such as temperature extremes, floods and storms) and one of the most

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concerning impacts is anticipated to be on human health (Hennessy and Fitzharris, 2007; Stern, 2009). For example, in Australia, heatwaves kill more people than any other natural disaster and are associated with increased incidence of Malaria and Dengue fever, respiratory diseases and heatstroke and exhaustion (McMichael and Woodruff, 2007; Luber and McGeehin, 2008; PWC, 2011). These health impacts affect the most vulnerable in our communities and are anticipated to increase into the future as populations in many countries age, grow and urbanise.

Given the implications of extreme weather events for human health, it is widely acknowledged that there is a need to better understand how to protect and improve the resilience of public health systems to such events (DEWR, 2007; PCI, 2011). This includes hospital buildings which have long been an undervalued resource in the health sector (Valins and Salter, 1996; McGregor and Then, 1999; Georgoulis, 2008). While new hospitals are relatively resilient to extreme weather events, existing building stock is less resilient and there is a pressing need to develop new adaptation strategies to address any new risks posed which were not envisaged in original designs (DEWR, 2007). For example, recent extreme weather events have illustrated that many hospitals are built on floodplains; that floods can exert pressure on structures that can cause them to collapse; and that water infiltration can damage equipment and services (often located in basements which are prone to flooding). Moving flood water is also a major problem during extreme weather and can undermine roads and foundations (FEMA, 2010, 2012; Helman *et al.*, 2010). The high winds which normally accompany storms can strip roof and wall coverings and blow whole structures down. Equipment on the roof is especially vulnerable to wind and once loosened, flying debris may cause further danger to people and damage property (Mason and Haynes, 2010; Verdon-Kidd, 2010). In contrast, during heatwaves, extreme temperatures can exceed the temperature tolerances of many existing construction materials, designs and heat management technologies, causing them to break down and under-perform. As many patients' health depends on precisely controlled temperature and humidity conditions, this can be a serious risk. Finally, hospital dependency on critical infrastructure such as electricity, gas and water has been found to be a major risk during extreme weather events since they are also likely to suffer serious outages (Hiete *et al.*, 2011; AIHA, 2010; Hampton, 2011; WHO, 2009).

Within this context the aim of this paper is to explore the types of adaptive strategies that can be put in place to deal with these new risks.

Adaptive strategies to cope with extreme weather events

Given growing international concern about the resilience of health facilities in the face of climate change, many countries have strengthened and developed legal frameworks, research and funding schemes for disaster reduction and climate change adaptation. For example, the Pan-American Health Organisation has published extensively on the structural integrity of hospitals, with special attention to high winds and earthquakes, including guides on how to construct, maintain and retrofit hospitals (PAHO, 2008; WHO, 2010). The United Nations International Strategy for Disaster Reduction (UNISDR) and the Hyogo Framework for Action are also addressing the broader task of global disaster reduction, which includes the safety and continual operability of health services (ISDR, 2008; Shaw *et al.*, 2010). Outside the UN, individual countries are also producing their own research and guidance. For example, in Australia, BRANZ produced a climate change adaptation report for the Australian Greenhouse Office (BRANZ Ltd, 2007), which addressed climate change impacts on buildings and adaptation options. The National Climate Change Adaptation Research Facility (NCCARF) has produced several extreme weather case studies (Kiern, 2010), which take various approaches, and the Australian Building Codes Board has produced two recent drafts on flood mitigation (ABCB, 2011). In the USA, the Federal Emergency Management Agency's Building Science Branch develops and produces multi-hazard mitigation publications that aim to create disaster-resilient communities and reduce loss of life and property. These publications mainly focus on floods, high winds and earthquakes. FEMA's design guide for improving hospital safety provides important insights into multi-hazard mitigation for health facilities (FEMA, 2007b) and is complemented by their design guide for improving critical facility safety (FEMA, 2007a). In the UK the FloodProBE project aims to provide cost-effective solutions for flood risk reduction in urban areas. FloodProBE develop and test adaptation technologies and research ways of integrating flood protection into urban planning (Van Ree *et al.*, 2011). A review of the literature in this area (which includes the above) indicates the adaptive strategies in Table I are widely recommended for different types of extreme weather events.

Having listed some of the common adaptation strategies recommended to mitigate the impacts of extreme weather events, it is important to point out that multi-hazard mitigation is considered best practice. While it can be very costly to protect a building from one particular hazard, it is far more cost-effective to protect a building from multiple hazards (FEMA, 2007b). Research has shown that different mitigation measures may reinforce or counter each other and FEMA provides a multi-hazard design matrix, which illustrates this. For example, shatter-proof thermochromic windows can withstand earthquakes and flying debris, and can also improve the thermal adaptive capacity of the building. Similarly, seals on doors can withstand

Table I.
Examples of extreme weather event adaptive strategies

Extreme weather event	Common adaptation strategies
Floods	Elevation – raise building above expected flood levels
	Floodwalls and levees – to deny flood waters entry to an area
	Dry flood proofing – to prevent water intrusion
	Wet flood proofing – allows water to enter buildings in a controlled way
Storms	Building design – use smooth, regular and rounded shapes and materials. Avoid exterior-mounted equipment. Use a vestibule
	Urban design – Adjacent buildings can produce a wind tunnel effect and tall trees may fall and damage buildings and harm people
	Materials and specifications – Avoid unfixed materials, protect fragile materials like glass or use impact resistant materials particularly at lower levels. Use *in-situ* concrete structures and weather stripping
Heatwaves	Air-conditioning – use HVAC systems keep internal environments at a constant temperature
	Natural ventilation – HVAC systems are vulnerable to electrical outages. Hence, incorporate advanced natural ventilation combined with good passive design with sensor controlled mechanical apertures and fans
	Thermal insulation – thermal insulation to keep indoor temperature constant with minimal heating and cooling
	Shading – external shading can be provided by orientation, vegetation, other buildings and external panels. Also use shutters, curtains, blinds, window tinting and solar reflective coatings and chromogenic technology

both floodwaters and wind pressure. But the ultimate multi-hazard mitigation strategy is the concept of building autonomy which is a completely self-sustained hospital capable of providing all the services that are needed in the building, including electricity, heating, cooling, ventilation, water collection, conservation and treatment, sewage and waste treatment, recycling and food production. However, while completely self-sustained buildings are possible, they are virtually non-existent, due to the high cost of implementing such designs. This is particularly the case for hospitals as they rely on more services than most building types (Achour and Price, 2010). It is therefore very difficult to make a hospital completely self-sustained. However, it is possible to ensure that a hospital can keep functioning at least for a few days by incorporating more built-in redundancies.

Method

To investigate the types of adaptive strategies which may be suitable in practice and their relative impacts on extreme weather event impacts, this research employed a multiple case study approach. This is important in the context of this research because understanding the operation of hospitals requires more than a simple appreciation of building related issues. As Becker and Carthey (2007) point out, a hospital is a complex organisation with many diverse stakeholders and functions which need to interact in the delivery of appropriate health services to a community. Responses to extreme weather events are similarly complex and given their scale are likely to require many parts of these systems working together. They are also likely to involve an interplay of many economic, social, organisational, political and cultural forces which can only be explored fully using a case study approach. Other approaches to data collection, such as a large survey/questionnaire of people who have been involved in responding to such events, would have failed to provide the depth of insight we needed to fully understand the social and organisational issues in this complex adaptive system.

Hammersley *et al.* (2000) acknowledge that case study research has often been criticised on the grounds that its findings are not generalisable, especially by comparison with those of survey research. However, they point out that much case study research has in fact put forward rigorous empirical generalisations and they argue that in at least one respect this is unavoidable. Supporting this argument, Flyvbjerg (2011) has sought to dispel five common myths about case-study research which are used to present a cautionary view of case studies in the conventional philosophy of science. These are that:

(1) general, theoretical knowledge is more valuable than concrete, practical knowledge;

(2) one cannot generalise on the basis of an individual case and, therefore, the case study cannot contribute to scientific development;

(3) the case study is most useful for generating hypotheses, whereas other methods are more suitable for hypotheses testing and theory building;

(4) the case study contains a bias towards verification, i.e., a tendency to confirm the researcher's preconceived notions; and

(5) it is often difficult to summarise and develop general propositions and theories on the basis of specific case studies.

Flyvbjerg (2011, p. 310) argued that "while it is correct that the case study is a detailed examination of a single example, it is not true that a case study cannot provide reliable information about the broader class. It is also correct that a case study can be used "in the preliminary stages of an investigation" to generate hypotheses, but it is misleading to see the case study as a pilot method to be used only in preparing the real study's larger surveys, systematic hypotheses testing, and theory building".

Specifically, in response to the above points, he argued that since universal truths are problematic in the study of human affairs, context-dependent knowledge gained through case study research is arguably more valuable than the search for predictive theories. Furthermore, formal generalisation is overvalued as a source of scientific development, whereas "the force of example" is underestimated. Flyvbjerg also argues that case studies are useful for both generating and testing of hypotheses and, when done well, contain no greater bias towards verification of the researcher's preconceived notions than other methods of inquiry. Indeed, according to Flyvbjerg, experience indicates that the case study contains a greater bias towards falsification of preconceived notions than towards verification. Finally, it is important to recognise that it is not always desirable to generalise case studies and that good studies are of enormous value as highly valid narratives in themselves. While the advantage of large samples is breadth, the advantage of case studies is depth. Both approaches have their advantages and disadvantages are equally generalisable. In reality, good research needs both approaches, even if they are not done in one single research project.

The case studies are described below. The first step in identifying suitable case studies was to develop detailed climate change prediction models with our partner (the UNSW Climate Research Centre). These allowed us to identify areas in Australia and New Zealand that were particularly vulnerable to extreme weather event risks. These initial samples were presented to our partners (health services in New South Wales, South Australia and New Zealand) who, in turn, conducted an analysis of population dependency, hospital size and past experience of extreme weather events at each hospital. Past experience was important because the risk and opportunities management system (ROMS) method for collecting data (described below) depends on harnessing user experience for the identification of risks and opportunities using its multi-stakeholder approach. Population dependency was important to ensure the results had maximum impact and hospital size was important to ensure we could access a wide range of stakeholder perspectives in understanding the risks and opportunities these events presented. Having identified a shortlist of hospitals we then had detailed discussions with key stakeholders in each hospital and selected the three hospitals below based on their willingness and ability to participate. Given this was a three-year project, "buy-in" was essential to maintain the quality of data over this timeframe. Furthermore, importantly, each of these facilities had also been subjected to a severe weather event, namely flash floods; floods caused by storm surges; and heatwaves, respectively.

Coffs Harbour Base Hospital

Situated on the mid North Coast of NSW, Coffs Harbour Base Hospital serves a population of 100,000. Coffs Harbour is a humid, sub-tropical area which means that flooding and storms are relatively common. While Coffs Harbour Base Hospital is relatively new, being operational only since 2001, the hospital suffers from its location adjacent to a creek and on a flood plain, and is one of the first areas in town to be inundated in a flooding event. Flood events have increased in frequency and intensity in recent years, with the region experiencing six major flooding events in 2009 alone.

Whangarei Hospital

Whangarei serves a district of 78,000 and is located in the North Island of New Zealand. The hospital is situated on a hill, and accessed by only one road which can be cut off during floods and storms. A major renovation was undertaken in 2001, but many of the buildings date from the 1950s to 1960s. The NZ Ministry for the Environment warns that due to climate change, Northland's temperature is expected to raise by 3°C over the next century and the frequency of floods could increase fourfold by 2090 (Ministry for the Environment, 2009).

Ceduna District Health Services

Ceduna is located in the remote northwest corner of the Eyre Peninsula, South Australia and is approximately ten hours by road from Adelaide. Out of its small population of 3,731, 25.5 per cent of the population in 2006 identified themselves as indigenous i.e. of Aboriginal or Torres Strait Islander origin. Located within an arid zone, the town is exposed to hot, dry summers with limited rainfall, during which time the daytime temperatures can reach up to 47°C for a week or longer. In early 2009, when Adelaide reported up to six days over 40°C, Ceduna recorded a temperature of 46.2°C. Ceduna District Health Services offers a mix of 25 acute care beds and ten beds for high level aged care, with a further 29 beds for low level aged care located on another site.

Data collection

Data collection was by means of a series of focus group sessions using a proprietary risk and opportunities management system called ROMS (ROMS, 2011). ROMS was used for a number of important reasons. First, it provides a multi-stakeholder approach to risk management which brings together perspectives from a range of stakeholders. Given the complexity of hospitals and the large diversity and numbers of stakeholders involved in responding to extreme weather events, the involvement and buy-in of key hospital stakeholders is crucial to an actionable outcome. Second, ROMS had been tested and refined in a hospital context in a previous pilot study project in New South Wales Health which looked at the risks to hospital infrastructure posed by climate change (see Carthey *et al.*, 2009).

ROMS uses multimedia technology to provide a structured approach to help health sector stakeholders from varied backgrounds identify, assess and control the risks and opportunities associated with a nominated problem. In this case the problem posed was how to respond effectively to an extreme weather event scenario provided by the research team. Scenarios are a widely used method for helping stakeholders to think about risks and opportunities and in this research the scenarios were generated from scientific advice and statistical evidence from the UNSW Climate Change Research Centre (a partner in this research). Given the different location of each case study hospital, three different scenarios were used which were relevant to each case study hospital's unique context. Namely, a flood scenario was posed for Coffs Harbour Hospital, a heatwave for Ceduna Hospital and a storm and flood for Whangarei Hospital.

By acknowledging that no one group holds all the knowledge to deal with extreme weather events, ROMS provides an interactive, inclusive and constructive process which is able to harness and capture the collective knowledge of all key stakeholders who have a stake in the process of responding effectively to such an event (Loosemore, 2010). ROMS uses focus groups as the mechanism to collect this information since they are widely recognised as an effective way to promote interaction and self-disclosure among a carefully structured group of respondents who can share their perspectives about a specific topic in a non-judgemental environment (Morgan, 1997).

ROMS focus groups were run in two stages in each case study hospital with key stakeholders. The focus group samples included: clinicians, emergency department staff, facility managers, nurses, technical staff, healthcare specialists and health service representatives. They were identified as "key" stakeholders in a detailed stakeholder analysis which was conducted using Freeman's (1984) well-known method. Stage one focus groups involved a one-day workshop to agree collective objectives in responding to an extreme weather event (i.e. what resilience means for the stakeholders) and to identify and assess the risks and opportunities against these objectives. Stage two focus groups involved another one-day workshop with the same stakeholders to consider the controls which could reduce these risks to an acceptable level and maximise the opportunities which had been identified in the stage one focus groups.

Discussion of results

Although each case study faced a different scenario, we have sought here to present the results as one combined analysis in line with the efficient multi-hazard philosophy described above. To this end, the common organisational objectives across all case studies which emerged were:

(1) continuity of service delivery;

(2) preserving the building structure's integrity along with its building services;

(3) having effective communication both externally and internally;

(4) maintaining access to and from the site; and

(5) ensuring availability and safety of relevant staff on hand to respond to the crises.

Across the three case studies a total of 90 risks were identified, assessed and ranked and 158 adaptive strategies were identified which if implemented, would reduce the risk profile to acceptable levels for the focus group stakeholders (see Appendix for full list of adaptive strategies). It became evident during the analysis that the hospital is part of a much larger system and that it cannot be treated in isolation from that system. Traditional linear risk analysis methodologies ignore subsystem interdependencies and wrongly assume that risks arise linearly and in isolation and that there is always some root cause to be searched for (Forrester, 1994). To overcome these inherent limitations, the risks and controls were then represented as rich picture diagrams (RPD) to show the health sub system interdependencies which determine the health system's entire response to an extreme weather event (McGeorge *et al.*, 2011) (see Figure 1). In simple terms, a RPD is a pictorial multi-layered representation of the real world using symbols to represent sub-systems and their relationships (of different types – communications, dependencies, etc.) within a defined system boundary (Patching, 1990). The number of arrows surrounding a particular node (risk) on the RPD gives some measure of the overall level it poses to the system as a whole.

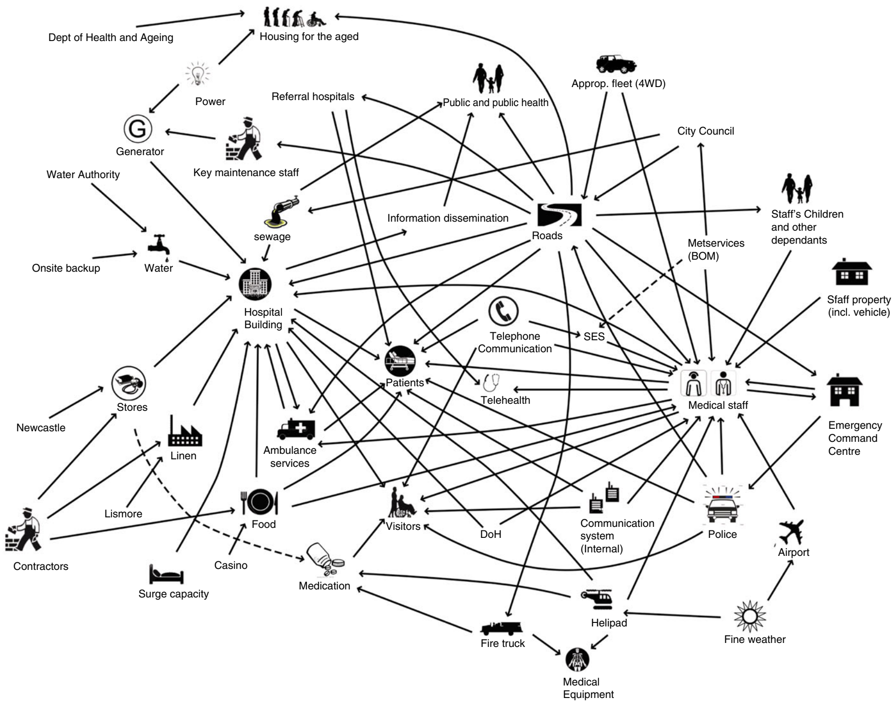

Figure 1.
Rich Picture diagram of case study 1

In selecting additional controls to mitigate risk and maximise opportunity in a commercial setting, it is normal in risk management practice to select them on the basis of a cost/benefit comparison. The control which yields the greatest improvement (risk reduction) for the least cost will normally be chosen. However, in the context of health facilities, the stakeholders had a number of other considerations to make in addition to monetary costs. These included existing government policies (which are continually changing in the realm of healthcare), their own power within the organisation (health care is extremely hierarchical and political), and the unpredictability and severity of extreme weather events (we can only predict extreme weather events with a low level of granularity). These additional considerations added to the complexity of selecting appropriate controls. It also showed that their implementation would require the resilience of the whole system and thus necessitate hospital emergency managers to undertake a wide range of actions, from lobbying governments to moving equipment to different parts of the building to maximise its function or prevent damage, etc. Furthermore, while this research was focused on hospital infrastructure, it became evident that it is not possible to isolate this from the wider health system in which it is imbedded and that only some of the controls were building related. Potential controls often act together to have an effect which is greater than the sum of the parts, or conversely be cancelled out by a competing parameter or control in the wider health system. Finally, not all controls are completely within the influence of the health organisation in question (i.e. lobbying the state government a good example).

In order to better understand the nature of possible controls the data to emerge from the ROMS workshop was to categorise possible strategies to compare like-with-like and to identify any patterns that could be used towards formulating an adaptive strategy. Each item coded was checked against the others to establish analytical categories, in a process referred to as "constant comparison" (Pope and Ziebland, 2000). Patterns were identified by examining co-occurrences such as correlation between "themes, respondents or events" (Guest and McLennan, 2003, p. 188).

This analysis was, in essence, an exploration of "spheres of influence" (Pettigrew and McNulty, 1995). To this end, the identified controls were separated into endogenous and exogenous categories and were then further broken down into "within sphere of influence", "partially within sphere of influence" and "outside sphere of influence". These categories reflect the nature of the healthcare systems which are characterised by a complex hierarchical structure of decision takers and governance regimes with varying spheres of influence. The term "endogenous" refers to adaptive strategies that relied only on decision takers within the case study hospitals to be implemented; whereas "exogenous" refers to adaptive strategies that relied on other government departments or private organisations for their implementation. As workshop participants were specifically asked to identify actions they could take themselves (as a group) to mitigate risks, it is useful to investigate which types of risks they found most difficult to control internally.

It was clear from the second workshop that the likelihood of a control being proposed and, in turn, implemented is directly correlated to the degree of influence or authority which a stakeholder is able to exert over other actors in the health system. For example, in the case of Ceduna hospital, when faced with the challenge of needing to accommodate staff on site during a heatwave event, ideas of appealing to a higher authority for funding quickly turned inwards, with participants noting "I think we can do some of that ourselves […] we could publically raise funds [from the local community] for couches and the like". Examples of endogenous and exogenous controls are provided in Table II although in practice the boundary between them is fuzzy.

When analysing respondents' controls we also noted that many were not only related to the physical building but to other activities that occurred within it. To understand this further we used a model produced by Markus *et al.* (1972) to analysis the results. Despite being 40 years old, Markus' model is still as relevant and as useful today to show how the building sub-system relates to other sub-systems in an organisation. According to Markus *et al*, a building facility and its stakeholders can be seen as an "adaptive system" which comprises five key elements (sub-systems): the building system; the environmental system; the activity system; the objectives system; and the resources system. The building system comprises the external envelope; the structure; the division of internal spaces, services and contents. The environmental system refers to the internal building environment created by the building system. The activity system represents what happens within the facility and the resources system represents the external environment from which the other sub systems draw from to enable them to function effectively. This includes the supply of physical, financial and human resources. In simple terms, the building system creates the environmental system which people inhabit and use to perform activities in order to achieve defined organisational objectives.

Combining Markus *et al*'s ideas with the concept of endogenous and exogenous controls, a coding exercise was conducted to classify each adaptive strategy identified into the categories of building, environment, activity and objective systems. The resources system is recognised in our analysis as an "applied system", since each

	Categories	Definition	Example (extracted from ROMS workshop transcripts)
Endogenous (En)	Within sphere of influence (W)	Actions that can easily be implemented using existing resources and associations within the hospital organisation	Set up a pseudo pharmacy service for visitors
	Partially within sphere of influence (P)	Actions that will require collaboration or assistance from other health departments	Develop support system amongst local hospitals
	Outside sphere of influence (O)	Strategic decisions relating to the hospital that its organisation does not have the authority to make	Build a new hospital
Exogenous (Ex)	Within sphere of influence (W)	Actions involving or dealing with outside bodies but which the hospital organisation can easily manage and control	Educate public about extreme weather event risks
	Partially within sphere of influence (P)	Actions involving or dealing with outside bodies but which the hospital organisation can manage and control somewhat	Negotiate with nearby mining company to share their helicopter services for flying patients in and out
	Outside sphere of influence (O)	Actions involving or dealing with outside bodies and which the hospital organisation has little scope or likelihood of management and control	Lobby commonwealth government to change the building requirements for aged care facilities

Table II.
Endogenous and exogenous controls

sub-system has a series of actions or resources that needs to be put in place to allow them to function. In this sense, all the adaptive strategies identified are explorations of the resources system. Table III shows an example of the typical types of activities that were classified into each of the categories.

Table IV shows the results of categorising all 158 adaptive strategies identified by the respondents using this coding framework.

Table IV shows that adaptive strategies in dealing with the risks of extreme weather events in hospitals are quite evenly spread across the building (41), environmental (30), activity (47) and objectives (40) systems. This indicates that any response to an extreme weather event must be a balanced one across these different sub systems. Given that stakeholders in the ROMS focus groups were evenly balanced across all functional groups in the hospital system (clinicians, managers, administrators, nurses, facility managers, asset managers, emergency services, etc.), this would also seem to contradict the literature in facilities management which claims that the relationship between health service outcomes and hospital performance is neglected in the health sector and that infrastructure is an under-appreciated and under-utilised resource (McGregor and Then, 1999; Valins and Salter, 1996). If this were the case then one would have expected to have seen the controls focused into the three other "non building" categories. Furthermore, Table III shows that most of the controls were endogenous (109) rather than exogenous (49). That is, they were generally

Table III.
Examples of adaptive strategies in each coding category

		Sphere of influence	Building	Environment	Activity	Objectives
Endogenous (En)	W(En)	Within sphere of influence	Program to replace defective steel windows to aluminium ones	Set up e.g. a pseudo pharmacy/food service for visitors	Improve internal communications relating to early warning e.g. give staff time to move cars	Develop a policy to call in staff when early warning received
	P(En)	Partially within sphere of influence	Avoid flat roof when next replacing it (e.g. during an extension)	Temporarily move ED up to day procedures unit	Develop telehealth links to tertiary centres	Provide policy to support other hospitals
	O(En)	Outside sphere of influence	Build a new hospital	Lobby Council to address maintenance of road as a top priority	(none recorded)	(none recorded)
Exogenous (Ex)	W(Ex)	Within sphere of influence	Look at other accommodation near hospital to house additional patients/visitors – hotel is community owned so negotiation is easy	Use alternative sites such as local school ground to land helicopter in event of high wind	Set up automated early warning system	Develop a community welfare/disaster plan to consider issues such as accommodation, food, etc.
	P(Ex)	Partially within sphere of influence	Talk to power company about using hospital as a test bed for solar generation	Liaise with other Council agencies to use their fleet during an event	Negotiate with private developer to build car park	Work together with Council and SES to develop mitigation strategy
	O(Ex)	Outside sphere of influence	Lobby RTA (road and traffic authority) to upgrade road	Lobby council to fix their services	Help aged-care facilities secure funding to develop risk management controls	Lobby government to make risk management part of aged care facility accreditation process

	Building	Environment	Activity	Objectives	Totals W	P	O	All
Endogenous (En)	30	22	28	29				109
W(En)	20	18	25	25	88			
P(En)	5	3	3	4		15		
O(En)	5	1	0	0			6	
Exogenous (Ex)	11	8	19	11				49
W(Ex)	2	2	13	4	21			
P(Ex)	5	3	5	2		15		
O(Ex)	4	3	1	5			13	
Total	41	30	47	40	109	30	19	158

Table IV. Adaptive strategies by sphere of influence

independent of external stakeholders' cooperation. Nevertheless, it is also clear that wider exogenous governance structures and factors at state and federal levels have an important bearing on a hospital's ability to respond to an extreme weather event.

Referring to Table III, it is also interesting to note that most of the adaptive strategies to extreme weather events are within the sphere of influence ($W = 109$) of the stakeholders in the focus groups and that the building system has the highest proportion of endogenous controls (30), followed by the objectives (29), activity (28) and environmental (22) systems. This suggests that the building itself is a source of adaptive capacity which can be changed without recourse to external (and therefore relatively uncontrollable) powers. However, when one looks at the relative W, P and O totals for each sub-system, then the building system has the greatest O score ($5+4=9$) compared to the environmental system ($1+3=4$), activity system ($0+1=1$) and objectives system ($0+5=5$). As a proportion of total controls ($9/44 = 20.45$ per cent) this represents the highest proportion of O scores of any sub system (environment $4/22 = 18.18$ per cent; activity $1/28 = 3.57$ per cent; objectives $5/29 = 17.24$ per cent). This indicates that while the building system is an important source of adaptive strategies to cope with extreme weather events, the controls associated with the building system were, relatively speaking, outside the sphere of influence of the stakeholder group. Managers might therefore be tempted to look first at changing the activity and objectives system since these contained by far the largest proportion of controllable strategies – thereby enabling a faster response to an extreme weather event scenario. This may help explain why previous research has shown that hospital buildings are undervalued in healthcare management.

Conclusion

The aim of this paper was to explore the range of controls that hospital organisations can put in place to mitigate the impact of extreme weather events. Because of the case study approach adopted, the qualitative nature of this research and the complexity and variety of hospital facilities and stakeholders involved, significant benefits are likely to be derived from further case studies in this area, particularly in terms of the generalisability of the findings. Nevertheless, within this limitation, the findings indicate that hospital buildings and the facility managers that manage them are an important part of a much larger open system which must work in an integrated way if any response is to be effective. The RPD analysis shows that one part of the system cannot be considered in isolation and the analysis here shows that the controls identified fall under the control of many organisations (often external to a hospital).

This raises important governance issues for facility managers which should be explored in future research. The findings also show that it is important for hospital facility managers to work cooperatively with other external authorities such as public infrastructure, aged care and government organisations in developing effective responses.

There are clearly a wide range of adaptive strategies which can be used to respond to an extreme weather event that span across hospital building, environment, activity and objectives systems. However, it is also clear that while some building system strategies are within the control of healthcare organisations (without recourse to external agencies) they are often among the least controllable strategies that can be enacted. The building sub-system may be relatively uncontrollable compared to other sub-systems in hospitals because once constructed, building elements takes a relatively long time to change. This research suggests that it may be related to the inflexibility of hospital designs and the dispersed internal governance structures that control these resources. This research also supports Haigh and Amaratunga's (2010) view that more focus needs to be given to the built environment in the context of disaster prevention and management.

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Appendix

Table AI. ROMS results showing all 158 adaptive strategies

	Risks and opportunities	Adaptive strategies
COFFS Harbour Base Hospital		
Objectives	To ensure staff and patient safety (including vulnerable patients within the community)	
Risks	Roads being cut	Lobby RTA/Council to upgrade roads from hospital to bypass – as part of Pacific Highway upgrade and Coffs Harbour bypass to ensure all weather access
		Further develop support provided to local hospitals
		Developing a process of when we receive early warning that those on call physically come into the facility so we have them on site (intensivist, O&G, anaesthetist, general surgeon, etc.)
	Adequacy of community age care facilities BCM plans and capacity to implement those plans	Help age care providers to secure funding to develop risk management/emergency/BCM plans
		Lobby commonwealth to make risk management plans/BCM part of age care facility accreditation process
		Lobby local government planners to make location of age care facilities in DA approval consider risk of where they are building
	Inability to respond to speed of event	Improve internal communications relating to early warning – give staff time to move cars, etc.
		We need real-time data about levels of creeks (currently a critical lag of 15 minutes) –linked to triggers which commence activation of plans
		Automated early warning system is needed to ensure that alarms ring if rate of creek flooding rises above a certain rate – currently manual
	Lack of disaster procedures for vulnerable patients	Build closer relationships and better communication systems with GPs to service communities that cannot get to hospital (create a network of health providers we can draw on – to service a different type of demand – external in community)
		Set up a pseudo pharmacy/food, etc. service for visitors (who may also need health care)
		Filter out non-critical communications which clog the response system (such as insurance questions, child care, etc.)

(*continued*)

Table AI.

	Risks and opportunities	Adaptive strategies
	Not having leadership available onsite causing poor coordination during event	Develop an online education and training facility to ensure people know what to do during an event
	Flooding into clinical areas	Move ED up into day procedures unit (temporary)
	Lack of disaster procedures for vulnerable patients	None
	Unpredictability of pattern of event (intensity, nature/pattern/location of impact, etc.)	None
Opportunities	Develop and implement flood mitigation strategy for the site (e.g. Coffs Harbour bypass may present opportunity, engage with urban planning controls)	Work together with council and SES to develop mitigation strategy – document procedures
	Build a multistorey car park	Private medical centre developer wants to build one – negotiate with them as a JV to build one
Objectives	Maintain essential services and physical fabric (water, electricity, gas, communications (IT) communications, sewerage and sufficient supplies) (weighting 20%)	
Risks	Not having an adequate minimum level of supplies maintained (fuel, food, etc.)	Decentralise services centres in Newcastle and bring them closer to Coffs Harbour Increase local storage capabilities on site Better defining the essential supplies needed for unusual events and how long needed
	Just-in-time models for logistics resulting in reduced onsite stock levels	None
	External service providers – cessation of services such as food, linen, waste, etc.	None
	Inability of key maintenance staff to get to work	None
	No back-up essential services (due to cost savings, etc.)	Onsite water storage Portable toilets for sewerage outage Use roof space to collect water and sun
	Capacity of emergency services to get necessary resources to site	None

(*continued*)

	Risks and opportunities	Adaptive strategies
	Inadequate building design (e.g. low pitch roof design, drains, essential services located in flood-prone areas – at low levels, etc.)	Design new buildings and major upgrades for expected extreme weather events
		Council building should comply with DA laws
		Develop flood mitigation strategy for existing buildings – e.g. elevated modular temporary walkways, etc.
	Flooding into essential services (usually in the basement)	None
Opportunities	Revise HFG and other regulations and guidelines re: design and planning of critical infrastructure	Feed flood mitigation strategies into the regular review cycle of HFG guidelines, etc. with x% compliance on existing buildings (timing of upgrade related to risk level)
	Increase self-sufficiency (utilise roof space for water collection, solar – use of new technologies, etc.)	None
Objectives	To ensure continuity of service delivery (core clinical services – theatres, emergency, maternity, ICU and ensuring adequate staff resources to deliver health services – senior management and health staff (weighting 20%)	
Risks	Specialist staff themselves being affected by the flood (cannot get to work – their priority will be their family and property)	None
	Being regional we have a limited pool of casual staff and specialised staff to draw on and no back-up supply of staff (e.g. intensive care nurses)	None
	Lack of availability of staff over an extended period – replacement of fatigued staff	None
	Lack of new growing population's knowledge of flood events	Develop emergency education programmes with council, SES, etc.
		Information packs for vulnerable outpatient client-base, new staff and populations (at front desk, etc.)
	Timing of the event – if occurs after hours increased risk	None

(*continued*)

Table AI.

Table AI.

	Risks and opportunities	Adaptive strategies
Opportunities	Adapting other facilities to accommodate staff during an emergency	None
Objectives	To ensure timely access in and out of facilities for staff, patients and emergency vehicles (to ensure we maintain adequate resources and staff available to cope, patients can get treatment, etc.) – including wider access in catchment area (weighting 10%)	
Risks	Singular access to the site and potential secondary access is also flood-prone	For future development there should always be two points of access
	Hub and spoke model of service delivery can be compromised by loss of access in wider catchment area	None
	Inability to air lift critically ill patients to tertiary care – rotary unable to fly	Tele-health connection to Sydney
	Availability of appropriate vehicles to cross flooded areas (e.g. water police, boats, large 4WD, etc.	Ensure in fleet stock we have appropriate vehicles – or identify staff that have such vehicles
	Co-location of ambulance means cannot get out during a flood	Set up early warning procedure for ambulance services to enable them to move vehicles off site before event
Opportunities	Further develop our telehealth facilities	Develop tele-health communication links to tertiary centres
	Create a flood-free access to the hospital	None
Objectives	Effective internal and external communications (external horizontal – SES, police, council, community services, power/energy – all LEMC members; vertical – Department of health, HSFAC) internal – onsite services, staff, etc. (weighting 10%)	
Risks	Location of emergency operating centre in town preventing management staff working there	Make sure health is represented at town's emergency command centre – make it as part of our escalation plan
	Inadequate phone access – swamping of mobile and landlines and control centres	None
	Inadequacy of communication system for campus population – staff and public (e.g. PA system, etc.)	Emergency take over PA and TV system
	Inadequate early warning system	None

(*continued*)

	Risks and opportunities	Adaptive strategies
	Inadequate numbers of senior staff to attend to all areas and other staff stepping in inappropriately	Better manage communications with public stranded at hospital (we managed other communications well – staff/public/ED)
	Clarity of communications – to ensure people respond appropriately – needs to withstand scrutiny	Making sure we maintain consistency with other emergency services
	Controlling large volumes of conflicting information from numerous sources to avoid misunderstanding	None
	People not following protocols/directions	None
Opportunities	Coffs Council can make their emergency operating centre flood free	None
	Ability to control from one single source all communications to entire campus via designated screens/TV system override/emergency channel, etc.)	None
Whangarei Hospital		
Objectives	Maintain physical integrity of building fabric (leaking roof, windows, flooded basements, etc.)	
Risks	Windows fall out (steel frame windows in particular) and lack of materials to repair them	Build a new hospital
		Screw a proportion of the windows shut (at risk windows at first)
		Programme to replace all steel windows with aluminium (at risk first)
	Plant rooms become flooded (most infrastructure is located in basements or in ceiling space which can become flooded)	Flood detection technology
		Install pumps
	Water ingress through roof (flat roof collects water)	New roofs (focus on susceptible areas) – during expansion perhaps
		Replace/install extra guttering and downpipes
		Install drains on inside of door to roof or pump to drain water away if its collect

(*continued*)

Table AI.

Table AI.

	Risks and opportunities	Adaptive strategies
	Emergency services not being available to pump out basements	Install pumps – as above
		Put critical services above flood levels (i.e. new hospital)
	Waste system can become flooded (because its under buildings)	Good public health management to deal with sewerage Pump it to swimming pool or first town drain Install new sewerage pipes/lines into town system
	Local authority system floods (if this floods then our system is affected)	Lobby council to address this problem
		As above – public health management Lobby council to address hospital road as a priority
	Getting contractors to site to undertake repairs (after the event due in particular due to their capacity constraints)	Employ more contractors on site (less reliance on external contractors particularly plumbers and electricians)
Opportunities	Working with supply chain to develop products that are fit for future purpose (R&D programme)	Build a demonstration hospital for testing/promotion of new products/technologies – university research testing, etc.
	Increase energy efficiency of the asset with any interventions	Comes down to money – no financial return/incentives for being green star rated – use demonstration projects at hospital with new projects to prove viability of new technologies Talk to North Power about using hospital as a test bed for solar generation
	Self-sufficiency (rainwater harvesting, solar, change roof structure, etc.)	Lobby EECA and other programs to fund energy efficiency programs
		Create a sustainability team to champion sustainability initiatives
Objectives	Ensure adequate access (staff, patients, emergency services, contractors, suppliers, etc.)	
Risks	Communication system overload affecting ability to contact staff and dependants (mobile included)	Vodaphone creates a separate circuit for use in emergencies
		Protocols during an incident to use system less – automated ideally Explore local control network – North Power (lines company)
	Staff and patient dependents need support so staff cannot attend work or may need to leave to support family members	Resilience induction programs to help staff increase their personal resilience – improve to current staff not just new staff
	Patients cannot leave site leading to capacity overload	None – just deal with it

(*continued*)

	Risks and opportunities	Adaptive strategies
	Main access road is flooded (there are only two – once basin floods only one access route) – will prevent ambulance and emergency services getting access since located other side of town	Localise an ambulance/fire engines base – which could be used to locate ambulances, etc. in advance of an incident, ready for use during an incident
		Talk to ambulance/fire services about their emergency plans
	High winds stops helicopter landing, prevents access to helicopter or damages building (landing pad is top of building) and lack of secondary landing sites (currently subject to flooding)	Use car park – empty car park (think about how to move cars during an event – use PA system)
		Use other sites like local school (Norton House) – predetermine some sites – talk to helicopter services about this
Opportunities	Expand strategic partnership with Vodaphone to cover disaster response resilience	We have an account manager – do it regionally with Auckland DHBs services
	Work with local authorities to re-design roads to eliminate potential access problems (be part of the infrastructure group)	Discussion with minister – talk to local member who is big on roads (particularly Manu road)
	On-site childcare facilities and accommodation for staff)	Already addressed
	Strategic partnership with local hotels to accommodate staff	Already addressed
	Strategic partnership with NZ meteorological society to get priority access to information to protect our hospital	Already addressed
Objectives	Ensure appropriate access resources to maintain service delivery (staff, food, essential services such as power, IT, water, etc.)	
Risks	Over reliance on key individuals (limited back up if absent)	Better succession planning – knowledge transfer – cut in hard copy – keep simple
	Ineffective communication about unexpected events such as power black-outs during the event	Document recently developed emergency procedures and training people to understand them

(*continued*)

Table AI.

Table AI.

	Risks and opportunities	Adaptive strategies
	Staff do not get clear and advanced planning information about appropriate level of threat, response action and support to ensure staff can plan attendance at hospital	Improve text messaging system (including database of every person's numbers, etc.) and annual testing
	Ineffective information on staff about their personal property risk	Encourage staff to use council web site
Opportunities	Grow our own food – operating veg garden (self-sufficiency) – also benefits for rehabilitation, mental health, etc.)	None
Objectives	Adequate surge capacity to cope with influx of patients during an event	
Risks	ED is not big enough to handle influx	Build bigger ED Better management of code red declarations – expand into other areas, etc. Better messages to primary care and community to prevent patients coming and liaise with emergency services to divert patients to other providers – Auckland, etc.
	Lack of plan for re-distributing patients to other locations during an event	None
	We run at a high occupancy rate (95%) plus patients cannot be discharged (see reasons above)	Looking at other accommodation option on sites – lots of houses on site which could be used school Rigorously implement code red controls
	Limited accommodation for staff during an event	None
	Poor communication from public health services about health risks associated with flood (drinking water, etc.) increasing admissions	None
Opportunities	Temporary change to model of care during an event (possible bigger opportunity to change permanently via discussions with primary care)	Liaise with key stakeholders such as media and primary care to better broadcast what is happening and what model of care it is being applied after agreeing with primary care first Set community-based assessment centres

(*continued*)

	Risks and opportunities	Adaptive strategies
	Develop partnerships with other health facilities to take discharge sub-acute patients	Develop MOU with Rest homes, Kensington, etc.
	Community-based assessment centre to direct patients to appropriate health facilities	None
Objectives	Maintaining communications with key stakeholders (staff, minister, public, emergency services, etc.)	
Risks	Cell phone coverage drops out	None
	Escalation risk (not determining to initiate CIMS structure early enough)	A lot has been done since last workshop to reduce risk – better communication, reinforced process, clarity of leadership, escalation process has been accepted by SMG – now good in asset management and FM but could be pockets in clinical services, etc. Integrate the BCPs and IS and payrole plan, etc.
	Confusion over communication protocols (especially before CIMS initiated)	As above – improved now
	PABX system drops out	When goes down some people do not get notified – so better communications when it goes down When contractors get on site they can interfere with it – lock at isolating system Need an audit – has not been done since installed
	Phone systems are flooded (volume capacity problems)	None
	Intercom fails	None
Opportunities	Have an emergency operating/command centre for use in any incident large or small (especially before CIMS is initiated) – we are vulnerable in period before CIMS initiated – could be mobile	Already have several – need written procedures to know how to set them up
	Separate phone system for use in emergency situations supported by 24/7 desk	Look at Canterbury's system as a starting point to explore this opportunity
	Have our own radio transmitter	None
	Our own radio/TV station/system	Talk to IT about using computers to override screen savers Open up the PA

(*continued*)

Table AI.

Table AI.

	Risks and opportunities	Adaptive strategies
Ceduna Hospital		
Objectives	To ensure essential services/utility supplies continue to be delivered during the event (ICT, air conditioning, fridges, water supply, power, etc.)	
Risk	Electricity supplies failing	Self-sufficient (wind, photovoltaics, etc.)
		BCM plan
	(Likely, extraordinary, exceptional)	Back-up generators and increased fuel storage as above
	If our emergency generator/transformer fails (its new but we only have one) – we cannot get a replacement quickly and our remoteness means our maintenance response time is very long	Install a second generator and increase fuel storage as above
		Reduce reliance on electricity such as buildings with lower demand for energy
	(Possible, extraordinary, very high)	Train up a locally based maintenance resource
	If PABX fail (Telstra switch off without telling us as they did recently, power spikes, lightning strikes, etc.)	BCM plan as above – back up systems, mobiles, intercom, satellite, use media services to communicate with community, etc.
		Talk to ICT services for SA health to manage this problem
	Town's water supply fails	Further increase storage and catchment of water
		Build desalination plant
		Cancel elective surgery, transfer dialysis patients and higher ware use patients out of town (manage services to reduce water usage)
	If we do not regularly test and maintain our essential services/infrastructure to identify and address vulnerability	Identify additional resources available within the district
		New facility will have new infrastructure and better monitoring equipment
	If we do not keep our air conditioning plant cool over a long period (it will overheat) – kitchens are particularly vulnerable to over heating, staff cant work here if AC fails threatening food supply for patients	Control influx of people to hospital who arrive to keep cool

(*continued*)

	Risks and opportunities	Adaptive strategies
		Manual fans available if system drops out
		Limit time staff are in areas which can get overheated (such as kitchens, etc.)
Opportunity	Become self sustainable in power generation (photovoltaics, windmills, etc.) – use our natural resources	Look at all viable opportunities to fund solar power (funding, lobbying, etc.)
		As cost/benefit of technology reduces over time – revisit viability of solar, etc.
		Explore viability of wind/tidal power as supplement to solar
	Have everything underground	None
	We use the ocean to assist with cooling strategies	Explore viability of cooling via sea
Objectives	To ensure we have enough staff (nursing, medical, ancillary, etc.) available for work even if on leave) (weighting 30%)	
Risk	Poor communications with staff about staff needs before an event	Adjust job descriptions to include duties during extreme weather events
		Personal resilience training for staff to reduce likelihood of staff not turning up
		Add onto country health SA OHS policies around extreme weather
	If essential services fail then staff cannot come to work	Multi-skilling and willingness to multi task during an event
		Set up facilities/environment to allow staff to bring families to work – may even alleviate stress if families are close
		Use lists of volunteers to go to staff homes to help look after families
	Staff will stay home to protect their own facilities/ families/business, etc. and not present to work	Reduce demand on health services by cancelling elective surgery, etc. – focus on core and emergency services only
	Not having an attractive work environment (provide housing, etc.)	Addressed
	Increase in transient population who do not travel-on through Nullabor during a heat wave – presenting over whelming facility in terms of needing treatment	Extreme heat warnings on routes to Ceduna, TV, web, community radio, etc. re: no health services, etc. – talk to DTEI

(*continued*)

Table AI.

Table AI.

	Risks and opportunities	Adaptive strategies
	Inability to communicate with staff on days off, leave, etc.	As above
	Loss of key staff expertise and knowledge of infrastructure/equipment (no redundancy in human resources in small communities like Ceduna)	Succession planning with country health workforce services
Opportunity	Recreation areas to enable staff to remain in work (get out of work environment, swimming pool to cool down, etc.)	Talk to SA asset services/commonwealth, etc. to support staff welfare – insert staff facilities such as cafe into new hospital to enable them to relax and de-stress Use parts of the old building as a relaxation area for staff – raise from public Talk to council about locating safe swimming area near hospital to make hospital a community place this would attract cafe and walkway, etc.
Objectives	To ensure we can manage a large influx of patients (heat strokes, dehydration, etc.) – adequate supplies, flexible space, adequate service capacity, pumps, etc.)	
Risk	Inadequate car parking	Solved with new car park
	Not having enough beds	Look for alternative facilities in advance – negotiate local hotels, footy clubs, etc. Only provide essential services and use those areas – use offices and consulting rooms for patient accommodation
	Not being able to manage additional extended family members who accompany patients	Use de-commissioned old existing buildings which are no longer used Develop a community welfare/disaster plan to consider issues such as accommodation, food, health, etc.
	Poor security	New facility has electronic security and one point of entry, etc. Employ security workforce
	We run out of supplies/consumables	Nominate a person to monitor weather and better pre-warnings need to be issued that a heat wave is coming

(*continued*)

	Risks and opportunities	Adaptive strategies
	Not having sufficient specialist equipment for vulnerable patients who are more likely to admit (bariatric, elderly, young, chronic diseased, etc.)	None
	Insufficient equipment (beds, biomedical, etc.) to manage excess demand	None
	Not having flexible space – change of use	New building has addressed this
Opportunity	Strategic agreements with local hotels, etc. to use their facilities during an event	Talk to community hotel about using vacant rooms during these events
	Build in redundancy to cope – just in case (equipment, staff, stock, etc.)	None
Objectives	To coordinate with other health services, emergency services such as SES, fire services, etc. to enable coordinated response (to fires, other events when we are ready over loaded – in 200 km radius)	
Risk	Communications failing (phones, e-mail, etc.) – PABX drop out, our reliance on GRN (which us run on power)	PUT BCM in place
		Build communication strategy into community contingency plan
	Inability to evacuate/transport patients out of Ceduna – FDS, capacity of Medstar (we are outside range of helicopter)	Better early warning system as above
		Building early warning for community into community contingency plan
		Liaise with Country Health SA and SA ambulance about how they are going to evacuate outlying/rural health services patient
	If we lose emergency power –everything depends on this during a crisis	Addressed above
	If other health services are over whelmed – they are coping with their needs – do they have sufficient resources to help us	As above
	Not having sufficient morgue space	Been addressed in new building

(*continued*)

Table AI.

	Risks and opportunities	Adaptive strategies
Opportunity	Strategic relationship with mining companies to use their resources in event of disaster	Need to liaise with mining companies – develop MOU
	Own satellite-based wireless communication systems (no reliability on GRN – spots where it does not work)	As above – talk to mining companies
	Owning our own plane and pilot – so not reliant on others to come to us	Undertake a cost/benefit analysis of our plane usage it's not unfeasible – could share plane/helicopter
Objectives	To ensure we can transport supplies/patients, etc. to and from community (especially Aboriginal communities)	
Risk	Insufficient SAAS capacity to transport patients – they have two vehicles only (we do not have a FWD to assist)	Purchase our own ambulance
		Liaise with ambulance, SES, police services, etc. about resources available during an event
		Build up lists of suitable people in community who could use their vehicles (sourcing local transport)
	Roads are closed due to extreme rain fall/bush fire (only one road into Ceduna and one out)	See above – plane or ocean (Ceduna has a commercial transport facility)
	Insufficient vehicle fleet to meet the increased need	See above – expand fleet into community
		Liaise with other local government agencies with fleets to utilise during an event (central depot in Ceduna for all government vehicles accessible to hospital during an event)
Opportunity	Strategic relationship with other agencies to share resources during an event	As above
	Use boats to assist with transport to coastal communities (use our natural resources)	None

Table AI.

This article has been cited by:

1. Anumitra Mirti Chand Department of the Built Environment , University of New South Wales, Sydney, Australia Martin Loosemore Department of the Built Environment, University of New South Wales, Sydney, Australia . 2016. Hospital disaster management's understanding of built environment impacts on healthcare services during extreme weather events. *Engineering, Construction and Architectural Management* **23**:3, 385-402. [Abstract] [Full Text] [PDF]
2. Anumitra Mirti Chand, Martin Loosemore. 2015. A socio-ecological analysis of hospital resilience to extreme weather events. *Construction Management and Economics* **33**:11-12, 907-920. [CrossRef]
3. Wenbo Wang, Hong Chen, Jibiao ZhouStrategies for the Safety Management of Road Transportation Infrastructure under Severe Weather Conditions in China 2905-2914. [CrossRef]