HOW MUCH RISK SHOULD WE TAKE? DEVELOPING A FRAMEWORK FOR HOLISTIC RISK BASED FLOODPLAIN PLANNING

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Abstract

While a merits based approach has been the cornerstone of floodplain management in NSW for the past 25 years, it can be argued that only some flood risks are fully considered in floodplain management plans. This paper draws on some recent work undertaken by the authors as part of the development of a larger floodplain management framework for Moreton Bay Regional Council in Queensland to present an approach to flood risk evaluation and mitigation which could have universal application.

The methodology first recognises that there are a multitude of flood risks which need to be managed. These include risks that have been considered for decades such as over floor flooding and risk to life, but also others which have been less explicitly dealt with such as isolation, roads being cut, infrastructure shutdown and building failure.

It then considers all of the factors which contribute to the consequences of flooding for the specific risk which is being assessed across the full range of floods. This will include hydraulic hazard, rate of rise, duration, vulnerability, criticality and population size.

A set of risk matrices are then developed and thresholds of acceptable, tolerable and unacceptable risk suggested. Using these matrices, a suite of potential risk mitigation options are then presented which are more objective based than prescriptive. This allows floodplain managers to design the means of managing the flood risks in whatever way is practical, affordable and acceptable providing that the risk reduction objectives have been met for all types of risks across the full range of floods.

This work is currently in its early stages and the purpose of presenting this paper is to receive industry feedback on the methodology as well as opinions on appropriate thresholds of risk tolerance.

Background

It is common to define risk as being a function of both probability and consequence. When it comes to floodplain management, risk assessments often reduce the probability to that of a particular flood event occurring and the consequence to a particularly clearly defined threshold being exceeded. For example the probability of above floor flooding occurring. This allows simple lines to be drawn on maps for town planning purposes but overlooks what needs to be considered when fully evaluating risk (Molino, 2010). Furthermore, while there has been a widely accepted

threshold of a 1 in 100 probability for above floor flooding there is no industry norm for the acceptability of other flood risks.
As part of Moreton Bay Regional Council's development of comprehensive, consistent floodplain management across its local government area, GHD and Molino Stewart were engaged to develop a framework for floodplain risk management. The following outlines the approach being taken.

A Flood Risk Assessment Approach

The basic approach was to develop a set of risk tables which show what combinations of hazard and probability are acceptable, tolerable and unacceptable. The following is a generalised table in which "acceptable risk", "tolerable risk" and "unacceptable risk", have the following definitions:

Acceptable risk – individuals and society can live with this risk without feeling the necessity to reduce the risks any further. This is coloured green in the table

Tolerable risk - –society can live with this risk but believe that as much as is reasonably practical should be done to reduce the risks further. Note that individuals may find this risk unacceptable and choose to take their own steps, within reason, to make this risk tolerable. This is coloured yellow.

Unacceptable risk – individuals and society will not accept this risk and measures must be put in place to bring them down to at least a tolerable level. This is coloured red.

	Low Hazard	Medium Hazard	High Hazard
Low Probability			
Medium Probability			
High Probability			

This generalised table was expanded both horizontally and vertically for each type of risk which was considered. Vertically, various probability thresholds were inserted while horizontally a range of hazard categories were created which reflected the particular risk in question.

The following risk categories were considered:

- Risk of isolation
- Risk to road access
- Risk to life in residential buildings
- Risk to life in non-residential buildings
- Risk to residential property
- Risk to non-residential property
- Risk to critical infrastructure

Determination of Flood Hazard Categories

The starting point for flood risk assessments is determining the flood hazard. The flood hazard relates to how dangerous a site on a floodplain can be (HNFMSC, 2006). It depends on the behaviour of the flood at that location and changes with the probability of the event, generally the rarer the flood the greater the hazard.

Many aspects of hazard relate to the behaviour of the floodwaters themselves but other influences of hazard relate to the topography, development and the people.

The following factors can all have an influence on the true flood hazard categories:

- Depth and Velocity of Floodwaters
- Rate of Rise and Duration of Flooding
- Topography
- Effective Flood Access
- Evacuation Problems
- Effective Warning Time / Rate of Rise of Floodwaters
- Flood Preparedness
- Obstruction and Blockages
- Type of Development
- Vulnerability
- Critical and Cumulative Consequences
- Water Entering Buildings

Most of these are being considered in the MBRC project but the point at which they are considered in the risk assessment process varies. The following sections explain the logic and process which is being applied.

Hydraulic Hazard

Hydraulic hazard is a major contributor to flood hazard and is independent of what is placed in the floodplain yet it is only meaningful when compared to how depth and velocity would impact on what is placed in the floodplain.

It is recognised that there are thresholds of hydraulic hazard which have different consequences for different things placed in the floodplain. An accepted practice has been to develop hazard category tables or graphs, and though there are variants on where the thresholds are drawn, they all work on the idea that a certain combination of depth and velocity will have certain consequences for different things exposed to that flood hazard.

Floodplain Management in Australia (CSIRO, 2000) and the NSW Floodplain Development Manual (NSW Government, 2005) each have their own hydraulic threshold behaviour diagrams which have three hazard categories. Figure 2, which has five hydraulic hazard categories, was used for this project as its thresholds are related to different types of hazards which one might be interested in although it can be argued where the actual lines between hazard categories are drawn (Shand et al, 2010).

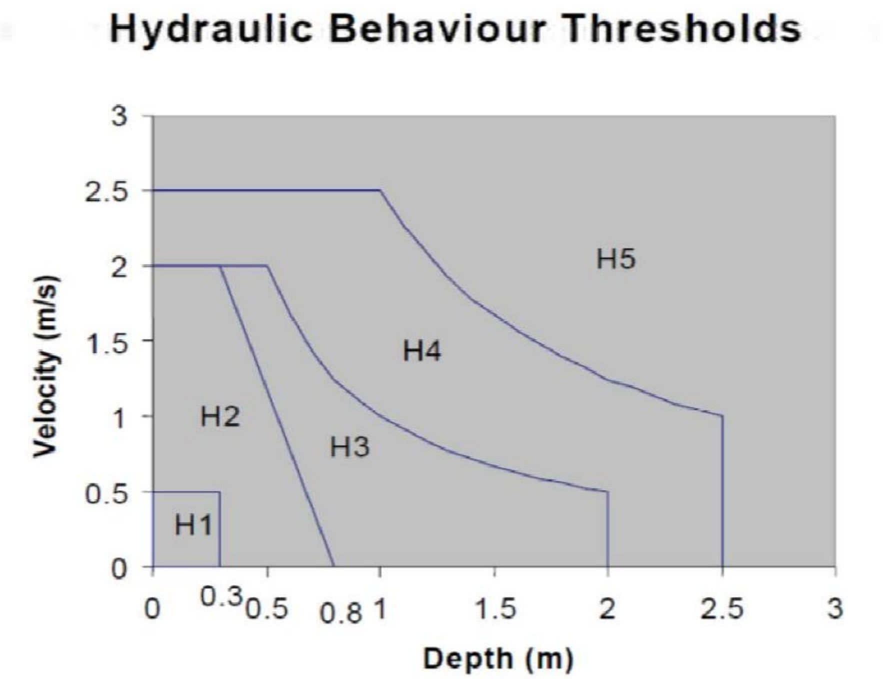

Figure 2 - Hydraulic Behaviour Thresholds for Newcastle LGA (BMT WBM, 2008)

The hydraulic hazard thresholds in this diagram are very similar to the hazard categories which are embedded in WaterRIDE which is the program being used by MBRC.

Using WaterRIDE it would be very straightforward to map for a design event of a given probability the extent of the various hydraulic hazard areas which can then be used to help with decision making.

The hydraulic hazard categories in the diagram are summarised in the Table 1.

Table 1 Revised Hydraulic Hazard Categories

Low Risk to Life and property		High Risk to Life and property		
H1	**H2**	**H3**	**H4**	**H5**
No significant life risk Property risk only to items which come in direct contact with floodwaters such as building contents	Low life risk. Able bodied adults can walk safely. Cars can float and precautions must be followed to keep them out of floodwaters	Able bodied adults cannot safely walk Only large vehicles (trucks) can safely travel.	Major life risk Light frame buildings (e.g. houses) can fail structurally	Extreme life risk Majority of buildings could fail

The following set of tables has been developed for each type of flood risk which needs to be considered for any type of flooding in MBRC. The hazard is defined using both the hydraulic hazard category and, where relevant for that particular type of risk, the other hazards which contribute to the overall hazard rating.

A more comprehensive analysis than the hydraulic hazard categorisation alone is also needed to establish the risks which need to be managed and this can only be made from within the strategic framework of a floodplain management plan. The determination of the risks requires the detailed results of a flood study and the hydraulic hazard categorisation along with an assessment of all the hazard factors.

Duration of Flooding

The duration of flooding or length of time a community, town or single dwelling (for example, a farmhouse) is cut off by floodwaters can have a significant impact on the costs and disruption associated with flooding. For example:

- An extended period of isolation in stressful situations can exacerbate post-event anxiety and trauma-related disorders;
- Shortages of water and food may occur thereby placing high demands on limited emergency services; and
- Medical emergencies may occur with treatment delayed or at worst prevented.

Flood duration is not relevant to all risks but is taken into when determining the hazards for some risk assessments.

Vulnerability

Another consideration in assessing consequences is vulnerability. This is taken into account to some extent in the hazards diagram which recognises that there are thresholds above which all people are vulnerable to flooding or all timber framed buildings are vulnerable to flooding. But all people and all timber framed buildings are not the same.

Children, the elderly or people with a disability will be more vulnerable than an able bodied adult which is what the hazard diagram is based upon. Isolation through flooding will be more of an issue for those with medical conditions which may require emergency access than those in good health. Likewise, a light framed building which has plywood as frame bracing (as occurs in many modern brick veneer homes) will be more vulnerable to structural failure than one with a water resistant bracing system (HNFMSC, 2006, EAA, 2011). Furthermore, some building contents are less vulnerable to flood damage than others and the depth of flooding within a building may also have an impact on whether the contents will be damaged.

Critical and Cumulative Consequences

The consequences will also differ depending on the use to which an asset is put. For example, the consequences for a community will be different if the hospital is closed due to flood damage than if a commercial operation is closed, at least in the short term. Furthermore the closure of a regional hospital will be of greater consequence than the closure of a local hospital and the closure of a large business employing many locals will be of greater consequence than the closure of a small shop.

Finally, the issue of cumulative consequences must also be taken into consideration. If one home is flooded during a major storm event, the consequences are different at a societal level than if 1,000 buildings are flooded even if the chance of them being flooded were the same. If the 1,000 flooded buildings are scattered along the Qld coast the consequences at the local level are likely to be tolerable because by and large local communities and facilities would continue to function and with some external resources would be able to help those affected recover. If however the flooded buildings were all at the one location resources would be more stretched, particularly if 1,000 buildings constituted the majority of a single town. The flooding of a business which employs 200 people could have similar consequences to the closure of 100 businesses which each employ two people.

Determination of Probability Thresholds

Apart from the 1 in 100 event being widely used as a threshold for above floor flooding, there is little guidance available on what would be appropriate for other flood consequences. Wind loading codes generally require buildings to be structurally sound in events up to something equivalent to a 1 in 500 or 1 in 1,000 event depending on their use. Something similar could be applied with regard to flooding. A recent survey, however, suggests that the community finds these probabilities too frequent for these consequences (Molino, 2012).

Creating Risk Tables

Taking into consideration the hazard and probability issues discussed in the preceding sections, the following risk tables were created. It needs to be stressed that these are draft tables and both the hazard categories and probability thresholds presented in them are presented as a starting point for discussion rather than recommendations for adoption.

Risk of Isolation

Event range (1 in X)	Maximum hazard category of surrounding floodwater						
	H1	H2		H3-H5			
		<24 hrs	>24 hrs	<24 hrs		>24 hrs	
				Non vulnerable population	Vulnerable population	< 1,000people	> 1,000people
1,000 - PMF							
100-1,000							
50 to <100							
>10 to <50							
10							

Risk to Road Access*

Event Range (1 in X)	Road Type >H1 flooding						
	Collector Road	Distributor Road	Sub Arterial	Arterial	Highway	Motorway	Critical Evacuation Route
1,000 - PMF							
100-1,000							
50 to <100							
>10 to <50							
10							

Risk to Life - all residential buildings in the floodplain

Event range (1 in X)	Maximum hazard category of floodwater surrounding residential building								
	H1	H2		H3			H4		H5
		<24hrs	>24hrs	<2hrs	>2hrs but <24hrs	>24hrs	<24hrs	>24hrs	
1,000 - PMF									
100-1,000									
50 to <100									
>10 to <50									
10									

Risk to Life - all commercial buildings in the floodplain

Event range (1 in X)	Maximum hazard category of floodwater surrounding commercial building								
	H1	H2		H3			H4		H5
		<24hrs	>24hrs	<2hrs	>2hrs but <24hrs	>24hrs	<24hrs	>24hrs	
1,000 - PMF									
100-1,000									
50 to <100									
>10 to <50									
10									

Risk to Property - applies to all residential property

Event Range (1 in X)	Above Floor Flooding	Ground floor ceiling depth flooding		H4		H5
		Two storey dwelling or second floor and above in unit block	Single storey dwelling or ground floor in unit block	Multistorey flood resistant unit block	All other dwellings	
1,000 - PMF						
100-1,000						
50 to <100						
>10 to <50						
10						

Risk to Property - applies to all commercial and industrial property

Event Range (1 in X)	Vehicle parking and flood resistant materials/stock storage	Above floor flooding – ground floor		H4	H5
		multi storey building	Single storey building		
1,000 - PMF					
100-1,000					
50 to <100					
>10 to <50					
10					

Risk to Critical Infrastructure

Infrastructure Type	**Within infrastructure categorisation**						
Water Supply	Local water supply network	Trunk mains	Reservoirs/Towers	Water Treatment Plant processing infrastructure	Water Treatment Plant throughput pumps and pipes and mains leading out of WTP		Source (e.g. Dam) and main trunk
Electricity	11 kV distribution system	33 kV power cables	33/11 kV substation	110 kV power cables	110/33 kV substation		275/110 kV substation & 275kV and higher voltage power cables
Telecommunications	Cables connecting mini exchanges	Mini exchanges	Other mobile phone towers cables connecting terminal exchanges and mobile phone towers to switching centres and each other	Terminal Exchanges And critical mobile phone (cellular) transmission towers	intercity cables and cables between switching centres		Radio transmission infrastructure used by emergency services. Telephone switching centres
Emergency Services				Minor Evacuation Centre	Station (Police/Fire brigade/Ambulance/SES)		Major Evacuation Centre or Control Centre (Police/Fire brigade/Ambulance/SES)
Sewage and waste			Gravity Pipes	Sewage pumps and waste tips or landfill	Sewage Water Treatment Plant		
Health services			Medical Centres	Private Hospitals and aged care facilities	Local Public Hospitals		Regional Public Hospitals
Duration / **Event Range**					<24hrs	>24hrs	
1,000 - PMF							
100-1,000							
50 to <100							
>10 to <50							
10							

Risk Management Measures

The preceding tables are intended to provide broad guidance on the acceptability or otherwise of various flood risks. Those risks which are identified as unacceptable must be managed and it is also desirable to manage those which are tolerable. Risk management actions should have the objective of making otherwise unacceptable risks at least tolerable and tolerable risks more tolerable, if not acceptable.

It is also possible that implementation of a single measure alone will not reduce the risks sufficiently and an additional measure will be required to deal with the residual risk. The treatment of residual risk needs to be considered until the residual risk is acceptable or tolerable, a worthwhile treatment is not available or the treatment is not affordable.

Any risk management process also needs to be able to deal with existing risk as well as future risk, particularly future risk created by future development.

The process proposed for MBRC is that the preceding risk tables be populated with risk management measures which are appropriate to the level of unmitigated risks. These tables can then serve two purposes.

1. Existing risks can be assessed to determine whether additional risk management measures are required
2. Future risks can be managed through planning controls or approval conditions to ensure that the required risk management measures are implemented.

Once again the following tables are provided as a starting point for discussion rather than recommended risk management measures. Nevertheless, they do reflect considerable experience with risk assessments for floodplains and developments in Queensland, NSW and Victoria and discussions Steven Molino has had with state and local government planners and engineers and emergency service personnel in those states.

It should be noted that most of the risk management measures are objective based rather than prescriptive. In other words they set out what needs to be achieved by the risk management measure rather than specifying what exactly needs to be done. This allows the methodology to have wide application and the adopted measures to be designed to suit local conditions.

It should also be noted that in some cases only one means of mitigation is considered appropriate and in other cases there is a choice of measures. For some of the more extreme risks it is necessary to have more than one measure because a single risk management measure alone would not be sufficient and there would be an unacceptable residual risk.

The Next Steps

GHD is currently trialling the methodology for storm tide flooding in MBRC local government area. We are also seeking feedback from the floodplain management profession on the methodology as a whole as well as appropriate hazard categories, acceptability thresholds and mitigation measures.

Risk of Isolation

Event range	Maximum hazard category of surrounding floodwater						
	H1	H2		H3-H5			
		<24 hrs	>24 hrs	<24 hrs		>24 hrs	
				Non vulnerable population	Vulnerable population	< 1,000people	> 1,000people
1,000 - PMF					1,2,3 or 4	1,2,3 or 4	1,2,3 or 4
100-1,000					1,2,3 or 4	1,2,3 or 4	1,2,3 or 4
50 to <100			1,2 or 3	1,2 or 3	1,2 or 3	1,2 or 3	1 or 2
>10 to <50			1,2 or 3	1 or 2	nil	1 or 2	1 or 2
10			1,2 or 3	1 or 2	nil	1	1

Potential Risk Mitigation Options

1. Ability for entire population to be accommodated until road access is restored in buildings which are not flooded. Emergency power supply, food fresh drinking water supplies and road access to hospital grade medical facilities be available for full duration of the flood
2. Warning system, community education program and evacuation plan which can be demonstrated to evacuate all people to a location outside of the flood affected area before evacuation routes are cut by H2 flooding.
3. Ability to use large vehicles to access through H3 floodwaters for essential supplies and medical evacuations
4. Ability to use fixed wing or rotary aircraft for essential supplies and medical evacuations

Risk to Road Access*

Event Range	Road Type						
	Collector Road	Distributor Road	Sub Arterial	Arterial	Highway	Motorway	Critical Evacuation Route
1,000 - PMF						4 or 5	2 or 3
100-1,000					4 or 5	4 or 5	2 or 3
50 to <100				4 or 5	4 or 5	4 and 5	1 or 2
>10 to <50			4 or 5	4 or 5	4 and 5	1, 4 and 5	1 or 2
10		4 or 5	4 or 5	4 and 5	1	1, 4 and 5	1 and 2

Potential Risk Mitigation Options

1. Route raising to ensure its probability of flooding is at least tolerable
2. Route capacity and warning time are sufficient for all to evacuate before road is cut
3. Route raising to ensure its probability of flooding is acceptable
4. Alternative route is available which is not flooded at this probability and is no more than two categories lower on the road hierarchy
5. Route is cut for no more than 24 hours

Risk to Life - all residential buildings in the floodplain

Event range	Maximum hazard category of floodwater surrounding residential building								
	H1	H2		H3			H4		H5
		<24hrs	>24hrs	<2hrs	>2hrs but <24hrs	>24hrs	<24hrs	>24hrs	
1,000 - PMF					1,2,3,5 or 6	1,2,3 or 4	1,2,3,5 or 6	1,2,3 or 4	1,2,3 or 4
100-1,000					1 and (2,3,5 or 6)	(1 and 3), 2 or 4	1 and (2,3,5 or 6)	(1 and 3), 2 or 4	(1 and 3), 2 or 4
50 to <100			1,2,3 or 5		(1 and 5), (2 and 5), or 4	(1 and 2), or 4	4	4	4
>10 to <50	1,2,3 or 5	1,2,3 or 5	1,2 or 3	1,2,3 or 5	(1 and 5), (2 and 5) or 4	(1 and 2) or 4	4	4	4
10	1,2,3 or 5	1,2,3 or 5	1,2 or 3	1,2,3 or 5	(1 and 5), (2 and 5) or 4	4	4	4	4

Potential Risk Mitigation Options

1. Warning system, community education program and evacuation plan which can be demonstrated to evacuate all people to a location outside of the flood affected area before evacuation routes are cut by H2 flooding.
2. Able bodied occupants are able to walk to a flood free location ahead of rising floodwaters should they not evacuate until floodwaters enter the premises
3. The building is flood resistant, there is a flood free refuge within the building and there is sufficient clean water, food and emergency power supply for the duration of the flood and there is a practical means of medical evacuation
4. Voluntary purchase of building
5. The building is flood resistant and ground floor level is above peak flood level
6. The building is flood resistant and there is a flood free refuge within the building

Risk to Life - all commercial buildings in the floodplain

Event range	Maximum hazard category of floodwater surrounding commercial building								
	H1	H2		H3			H4		H5
		<24hrs	>24hrs	<2hrs	>2hrs but <24hrs	>24hrs	<24hrs	>24hrs	
1,000 - PMF					1 or 2	1, 2 or 3	1, 2 or 3	1, 2 or 3	1, 2 or 3
100-1,000					1 or 2	1, 2 or 3	1, 2 or 3	(1 and 2) or 3	(1 and 2) or 3
50 to <100					1, 2 or 3	(1 and 2) or 3	(1 and 2) or 3	(1 and 2) or 3	(1 and 2) or 3
>10 to <50				1 and 2	(1 and 2) or 3	(1 and 2) or 3	3	(1 and 2) or 3	3
10			1 or 2	1 and 2	(1 and 2) or 3	3	3	3	3

Potential Risk Mitigation Options

1. Warning system, community education program and evacuation plan which can be demonstrated to evacuate all people to a location outside of the flood affected area before evacuation routes are cut by H2 flooding.
2. The building is flood resistant and there is a flood free refuge within the building
3. Voluntary purchase of building

Risk to Property - applies to all residential property

Event Range	Above Floor Flooding	Ground floor ceiling depth flooding		H4		H5
		Two storey dwelling or second floor and above in unit block	Single storey dwelling or ground floor in unit block	Multistorey flood resistant unit block	All other dwellings	
1,000 - PMF				3	2 or 3	3
100-1,000			1 or 3	3	2 or 3	3
50 to <100	1		1 or 3	3	2 or 3	3
>10 to <50	1	3	1 or 3	3	3	3
10	1 or 3	3	3	3	3	3

Potential Risk Mitigation Options

1. Voluntary house raising of single storey dwellings of suitable construction
2. Building reinforcement for flood resistance
3. Voluntary purchase

Risk to Property - applies to all commercial and industrial property

Event Range	Vehicle parking and flood resistant materials/stock storage	Above floor flooding – ground floor		H4	H5
		multi storey building	Single storey building		
1,000 - PMF				3	3
100-1,000				3	3 or 4
50 to <100	1		2	3	4
>10 to <50	1	4	4	4	4
10	4	4	4	4	4

Potential Risk Mitigation Options

1. Barriers to prevent vehicles, stock or equipment from leaving the site
2. Storage area for stock and equipment above 1 in 100 level in areas where there is sufficient warning time to relocate stock
3. Building reinforcement for flood resistance
4. Voluntary purchase

Risk to Critical Infrastructure

Infrastructure Type	**Within infrastructure categorisation**						
Water Supply	Local water supply network	Trunk mains	Reservoirs/Towers	Water Treatment Plant processing infrastructure	Water Treatment Plant throughput pumps and pipes and mains leading out of WTP		Source (e.g. Dam) and main trunk
Electricity	11 kV distribution system	33 kV power cables	33/11 kV substation	110 kV power cables	110/33 kV substation		275/110 kV substation & 275kV and higher voltage power cables
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Emergency Services				Minor Evacuation Centre	Station (Police/Fire brigade/Ambulance/SES)		Major Evacuation Centre or Control Centre (Police/Fire brigade/Ambulance/SES)
Sewage and waste			Gravity Pipes	Sewage pumps and waste tips or landfill	Sewage Water Treatment Plant		
Health services			Medical Centres	Private Hospitals and aged care facilities	Local Public Hospitals		Regional Public Hospitals
Duration / **Event Range**					<24hrs	>24hrs	
1,000 - PMF					2 or 3	2 or 3	2 and 3
100-1,000				2 or 3	2 or 3	3	2 and 3
50 to <100		1, 2 or 3	2 or 3	2 or 3	3	3	2 and 3
>10 to <50	1 or 3	2 or 3	3	3	3	3	2 and 3
10	1 or 3	3	3	3	3	3	2 and 3

Potential Risk Mitigation Options for Infrastructure

1. Means of restoring basic service within 48 hours.

2. Provide backup/alternative system/service to provide adequate service for more than 48hrs. This includes power, telecommunications, access and consumables required to provide critical services

3. Relocation of infrastructure.

Conclusions

Flood risk assessment needs to consider a wider range of risks than has been traditionally considered in the past and these need to be considered in a transparent and repeatable way. It would be preferable if there were nationally adopted standards for acceptable risks to guide developers, planners, regulators and the courts.

The methodology presented in this paper proposes a methodology which would achieve those objectives but more discussion would be needed within the floodplain management profession to better define acceptable and tolerable risk threshold.

The advantage of the proposed methodology are that it is suitable for existing and future development, it considers existing and residual risk and it is outcomes focussed rather than prescribing risk management measures.

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