Application of the Holistic Risk Based Framework in Floodplain Planning

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Abstract

At the 2012 Floodplain Management Conference, Molino *et al* (2012) presented a new framework for risk assessment in floodplain planning. Since this publication, the framework has been applied within the 14 Catchments in Moreton Bay Regional Council Local Government Area.

The resulting product of the risk assessment is broad scale mapping of the entire floodplain in terms of acceptable, tolerable and unacceptable risks for each risk category. The risks assessed include the risk to personal safety, property, isolation, road access and critical infrastructure. Each risk was assessed against the 10, 50, 100, 1000 ARI and PMF design events.

These risk maps are considered a 'first' in floodplain planning and have a wide range of applications both in managing existing risk and in planning future development. They can be effectively overlaid with one another to determine the most critical areas as well as identify the most effective infrastructure improvements in terms of a risk reduction.

A key part of the risk assessment process was undertaking topographic categorisation across the whole catchment. This was undertaken down to the property scale. Again, it is believed that this is a 'first' fine scale application across a wide area of the methodology set out in DECC (2007) with some minor modifications to the categories.

The methodology has been undertaken such that it would be transferable to other catchments with common property and infrastructure data and flood modelling.

Background

Moreton Bay Regional Council (MBRC) has developed a Regional Floodplain Database (RFD) (Roso *et al*, 2012), which creates a common spatial database of topographic, landuse and flood modelling data across the 14 catchments in its local government area which cover a total of 2,000km^2.

To compliment and build upon its library of flood model data it is creating products that will support Council's future floodplain management decisions. This has led to the development of the Moreton Bay Regional River and Creek Floodplain Risk Management Study – Phase 1.

MBRC commissioned Molino Stewart to undertake this study and produce a set of outputs to identify and classify flood risks throughout the local government area (LGA) in a way which will assist floodplain management planning and decision making. This work applied the first part of the holistic risk based floodplain planning methodology described in detail in Molino *et al* (2012). The results presented in this paper are preliminary and should not be used for drawing conclusions about flood risks in Moreton Bay LGA.

The Framework

The basic approach was to develop a set of risk tables which show what combinations of hazard and probability are acceptable, tolerable and unacceptable. Table 1 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			

Table 1: Generalised Risk Assessment Table

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

General Methodology

GIS analysis was used to undertake the risk assessments. It is not possible to go into detail in this paper as to how the assessment was done for each type of risk, however most of the analyses were able to be automated and undertaken across the whole LGA at the same time.

The major exception to this was the risk of isolation where it was necessary, as one of the interim steps, to undertake a visual analysis of road routes and contours to determine whether or not there was rising road access or an overland escape route from flooded areas.

Risks to existing buildings and infrastructure were assessed to guide the targeting and prioritization of flood modification, building modification and/or response modification to mitigate existing risks. The risk profile of every part of the LGA was also mapped to inform future development planning.

Many of the risk assessments were based on the hydraulic hazard classification in the full range of flood events, although other considerations such as duration, population size and vulnerability etc. were also considered. Hydraulic hazard classification for each event was undertaken using the thresholds illustrated in Figure 1.

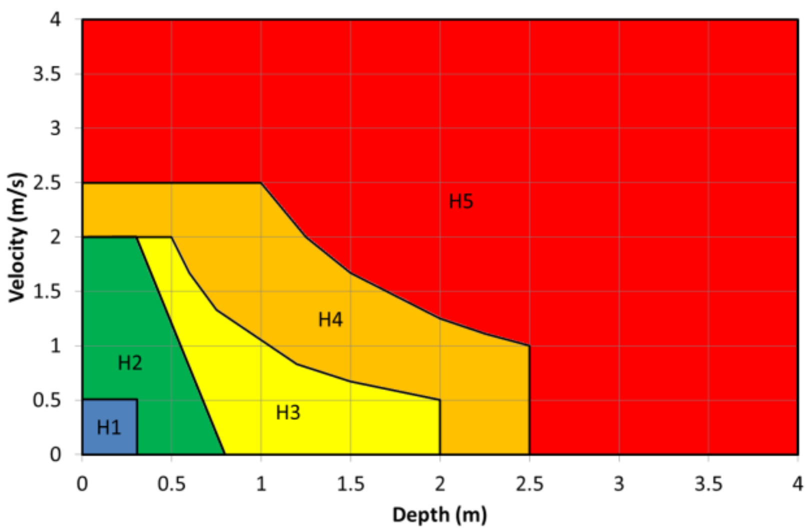

Figure 1: Hydraulic Hazard Categories (after BMTWBM 2009)

Risk of Isolation

The first step in this process was to undertake a topographic classification, a process first proposed by the NSW SES (DECC, 2007) in order to better understand the personal safety risks within a catchment.

Topographic categorisation involves defining an area based on two questions. Firstly, is it within the floodplain (defined by the extent of the PMF) and secondly, can it be isolated by floodwater. Further complexity is then introduced by examining how those within the floodplain can escape (by road or foot) to areas outside the floodplain.

Consideration was given to using the NSW State Emergency Service categories (DECC, 2007) but these were considered to make some unnecessary distinctions and miss some important other distinctions.

The following describes the categories which are illustrated in tabular form in Table 2.

Connected Flood Free (CFF) - Above the PMF and connected by road to outside of the catchment.

Isolated Flood Free (IFF) - Above the PMF but not connected by road to outside of the catchment.

Low Flood Island (LFI) - Area below the PMF which has all evacuation routes cut prior to the area becoming inundated.

Rising Road Access (RRA) to IFF - There are road evacuation routes to isolated flood free areas.

		Does it Flood?			
		Flooded			Flood Free
		Escape Route			
		Road	Overland	None	
Is it Isolated?	Isolated	RRA (IFF)	OER (IFF)	LFI	IFF
	Not Isolated	RRA (CFF)	OER (CFF)	N/A	CFF

RRA: Rising Road Access
OER: Overland Escape Route
LFI: Low Flood Island
IFF: Isolated Flood Free
CFF: Connected Flood Free

Table 2: Topographic Classification

Rising Road Access to CFF - There are road evacuation routes to connected flood free areas.
Overland Escape Route (OER) to IFF - There is no road access to isolated flood free land but it can be reached by walking across rising terrain.

Overland Escape Route to CFF - There is no road access to connected flood free land but it can be reached by walking across rising terrain.

Figure 2 shows the results of the topographic categorisation for part of the MBRC LGA.

For mapping clarity, the RRA and OER have been shown without further categorising them as to whether they connect to CFF or IFF land. It is clear from looking at the maps which category they connect to as they are adjacent to either CFF or IFF.

The trend of the categorisation follows an expected pattern, where:

- Connected Flood Free (CFF) areas form a ring around the upper parts of the catchments and reflect areas connect via roads which generally follow the ridges
- Isolated Flood Free (IFF) areas occur along the ridges between tributaries where the road network crosses, rather than follows these ridges. Additional IFF land is found in what can be called high flood islands that are enclosed by floodplain.
- The rural areas at the upstream ends of the catchments tended to be OER as they have little access to roads (or no development) and the floodplain is relatively narrow and few islands are formed).
- The RRA and OER areas are more likely to provide escape to IFF areas rather than CFF areas.
- In the downstream reaches, there is generally more development and the areas are a mix of RRA, OER and LFI.

Overall, 36% of the LGA falls within the connected flood free category and 40% in the isolated flood free category. Only 7% of the LGA has rising road access and 4% consists of low flood islands. Table 3 summarises the number of buildings within each of the flood affected topographic classifications. Building numbers were not available for areas above the PMF.

Category	Residences	Commercial and Industrial Buildings
RRA	20,609	1,515
OER	1,867	207
LFI	5,503	817
Total	**27,979**	**2,539**

Table 3: Buildings in Each Flood Affected Topographic Classification

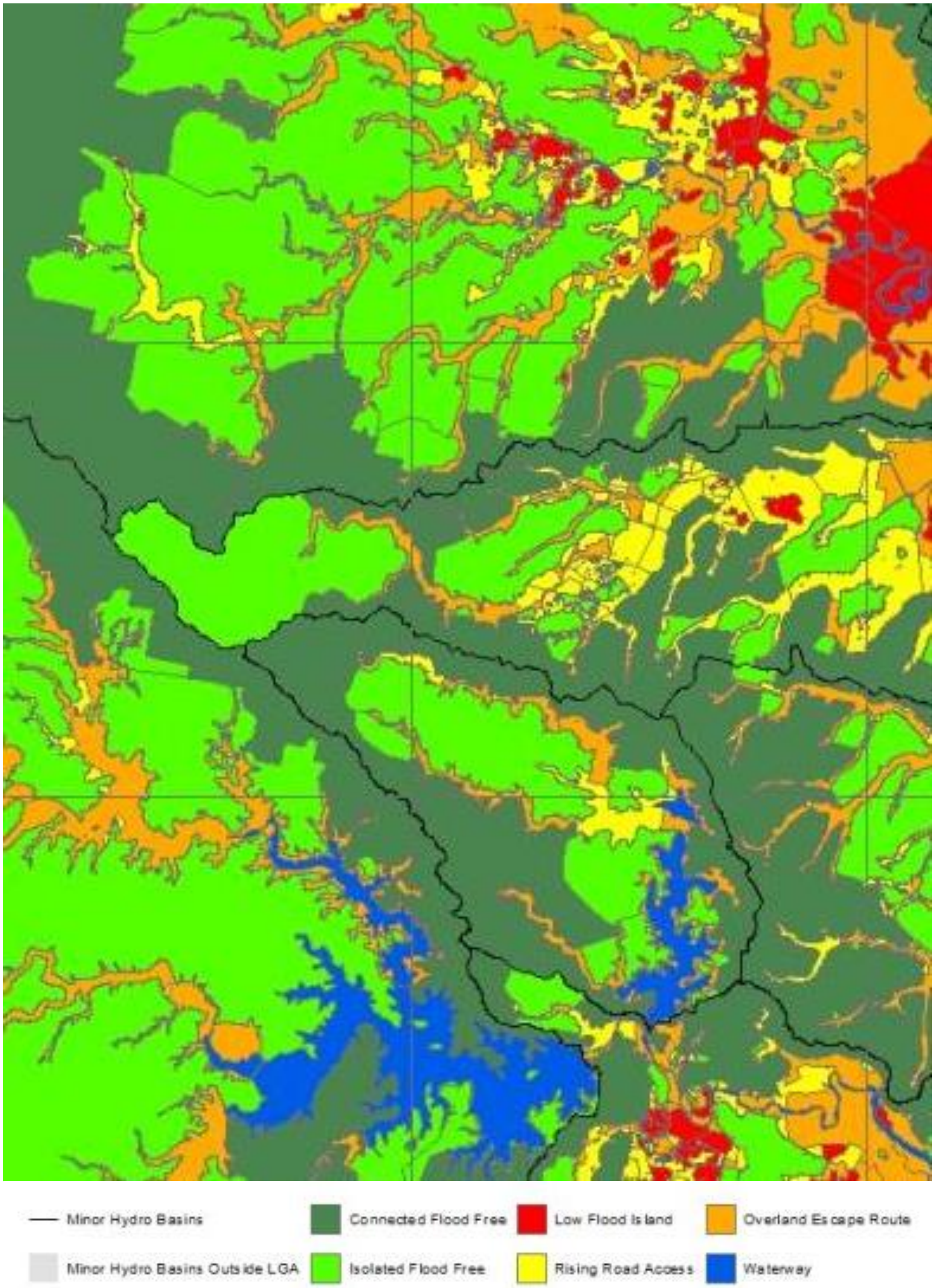

Figure 2: Topographic Classification for Part of the MBRC LGA

However, to determine whether the risk of isolation was acceptable or not, the hazard category of the isolating floodwaters and the probability of isolation had to be taken into account as illustrated in Table 4. Information was not available on the vulnerability of the populations nor the number of people who would be isolated above the PMF, therefore these subcategories within the table were not applied.

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	< 1,000 people	> 1,000 people
1,000 - PMF							
100-1,000							
50 to <100							
>10 to <50							
10							

Table 4: Risk of Isolation Assessment Table

The results of is analysis (Figure 3) show very large areas which have an unacceptable risk of isolation. However, these are raw risks which do not take into account mitigation measures which may already be in place. For example, most of these areas have sparse rural populations and consideration needs to be given as to whether existing mitigation measures they currently have in place to deal with this isolation (tank water, emergency power supplies, access to local medical facilities) makes the probability and duration of isolation tolerable. Nevertheless, there are significant areas of dense urban development which have no appreciable mitigation measures and therefore an unacceptable risk of isolation.

Figure 3 also shows which road segments contribute to the unacceptable isolation risk.

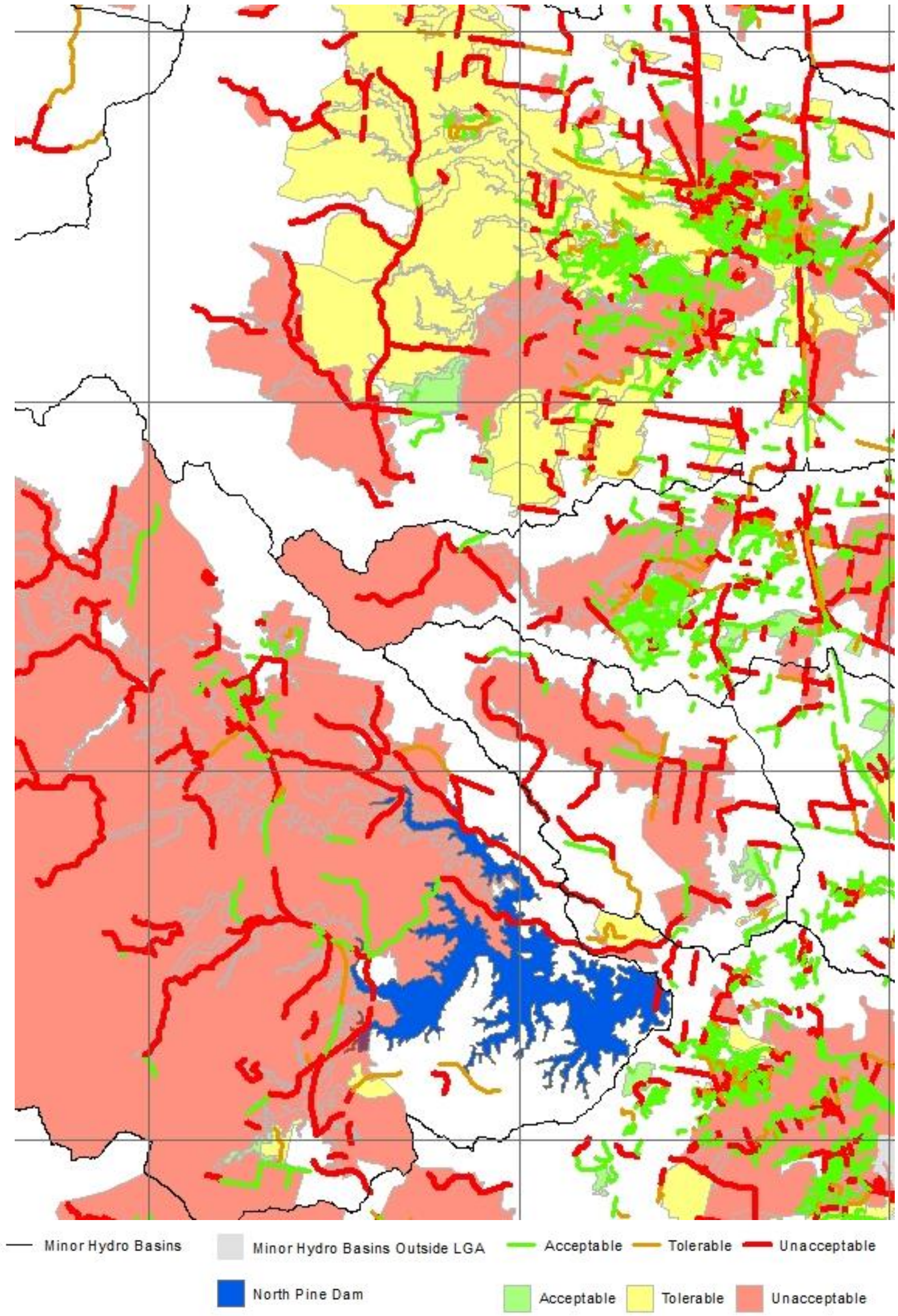

Figure 3: Risk of Isolation in Part of LGA

Risk to Personal Safety

This risk assessment for residential development was undertaken as per the risk table in Table 5 and the results are shown in Figure 4. In the riverine catchments, the majority of the floodplain represents an unacceptable risk to personal safety. This is fringed by areas of tolerable and acceptable risk. In the smaller, overland flow catchments (e.g. Redcliffe) there is a much larger ratio of acceptable and tolerable risk to unacceptable risk. This is because these floodplains have few areas of high hazard flooding even in the more extreme events.

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	<24 hrs	>24hrs	
1,000 - PMF									
100-1,000									
50 to <100									
>10 to <50									
10									

Table 5: Risk to Residential Personal Safety Assessment Table

A similar method was applied for commercial development but with different thresholds of tolerability.

Risk to Property Damage

The risk to residential property damage took into account the probability of above floor flooding, the probability of flooding above typical bench top level in single storey and two storey dwellings and the probability of flood depth and velocity combinations which could cause structural damage. That is summarised in Table 6. Table 7 shows the matrix which was proposed to determine risk to commercial property. While these were able to be used for mapping areas suitable for different types of residential and commercial development, they were not able to be used to map existing development to his level of detail because only floor level information was available for existing commercial buildings and not all two storey residential buildings had been catalogued as such.

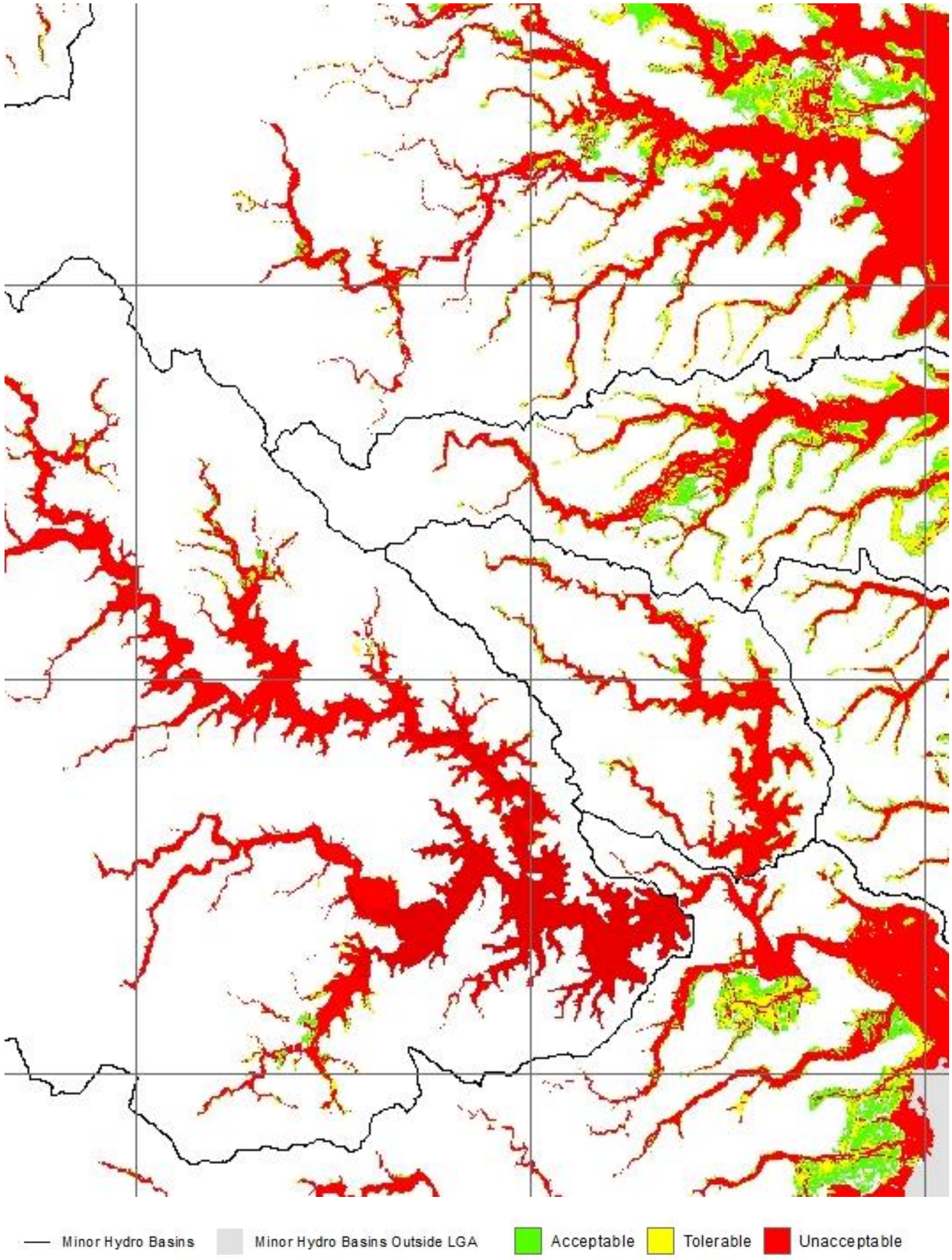

Figure 4: Risk to Residential Personal Safety

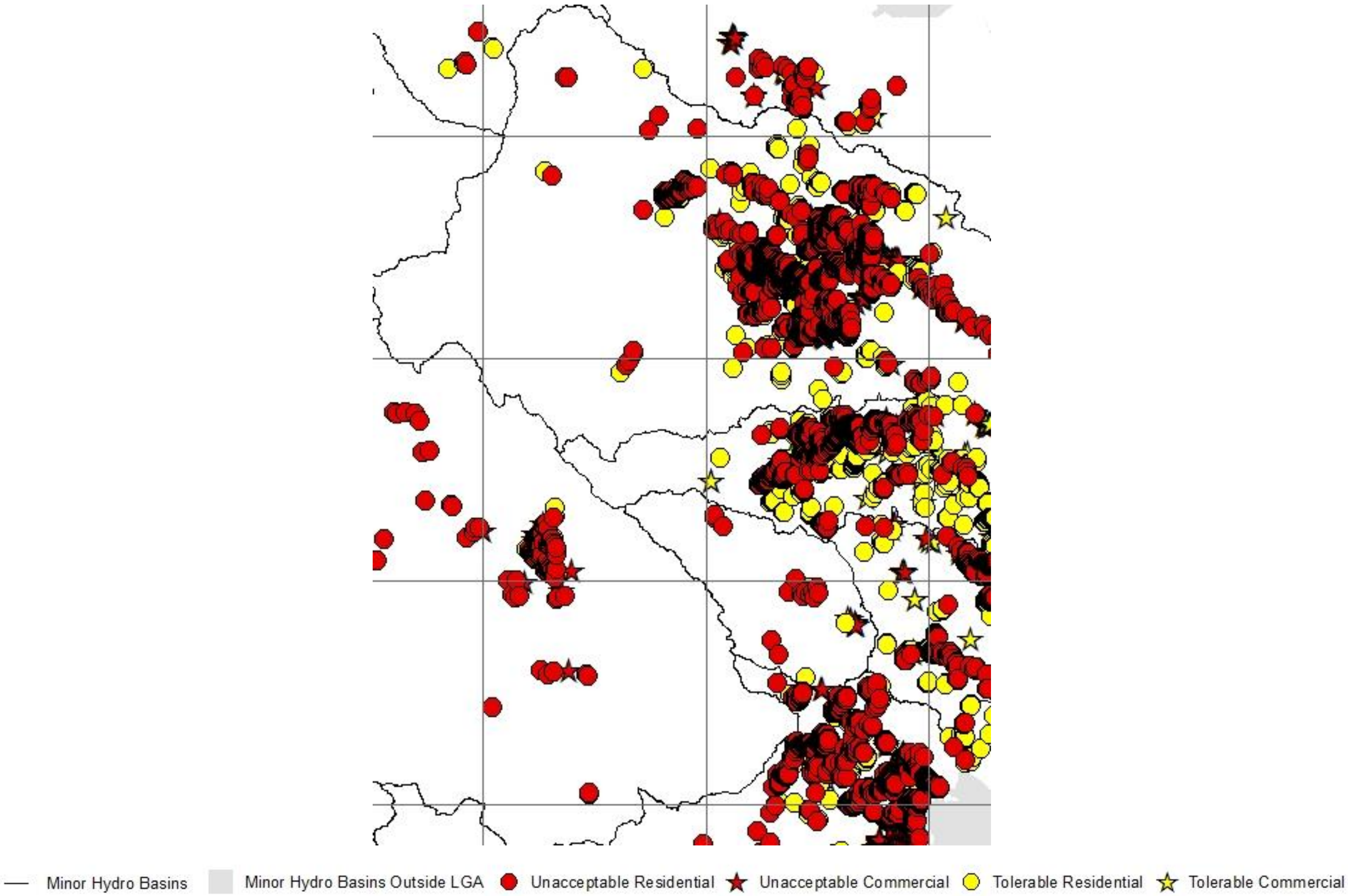

Figure 5: Existing Residential and Commercial Buildings with a Risk to Personal Safety

Event Range (1 in X)	Above Floor Flooding	Typical Table/Bench level 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						

Table 6: Risk to Residential Property Assessment Table

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					

Table 7: Risk to Commercial Property Assessment Table

These analyses showed that there are about 1,500 existing residential buildings and 350 commercial buildings with an unacceptable risk to property damage. Interestingly, Redcliffe and Bribie Island show up as being the catchments with the most number of residential properties with unacceptable risk to property damage yet these have few areas with unacceptable risk to life. Closer examination reveals that these have numerous properties which can be frequently flooded but even in extreme events the flood waters do not become hazardous. This observation highlights that consideration of different risk types is important in understanding the risk profile of an area and the need to tailor floodplain management options to the specific risk which needs to be managed.

Combined Risks

While Redcliffe and Bribie Island are two cases where risk to personal safety and risk to property are at opposite ends of the spectrum, there are other locations with buildings which have an unacceptable risk to personal safety, unacceptable risk of isolation and unacceptable risk to property. A map was produced which highlighted all of the buildings (residential and commercial) with an unacceptable risk across all three categories and those with an unacceptable risk in only one or two categories (Figure 6). This type of mapping helps prioritise those areas which have the greatest need to mitigate flood impacts.

Similarly, maps were produced showing areas which have unacceptable risk to residential development across all three categories, those which have an unacceptable risk in only one or two, those which have at least one tolerable risk and those where all risks are acceptable. This was done for residential and commercial development and is shown in Figure 7 for residential development. This highlights those areas which are unsuitable for future development, those which are suitable and those which may be suitable with appropriate development controls to change the risk profile.

A further map (Figure 8) was produced for use with these other maps which shows the low flood islands and the probability of their isolation. This highlights those flood islands which have the greatest risk of being isolated and therefore are the highest priority for emergency response to existing development and the least suitable areas for future development.

Infrastructure Risks

In addition to residential and commercial buildings, flooding causes significant direct and indirect damages to public infrastructure. These losses can result in further indirect and intangible impacts on communities, including those that have not been directly impacted by flooding.

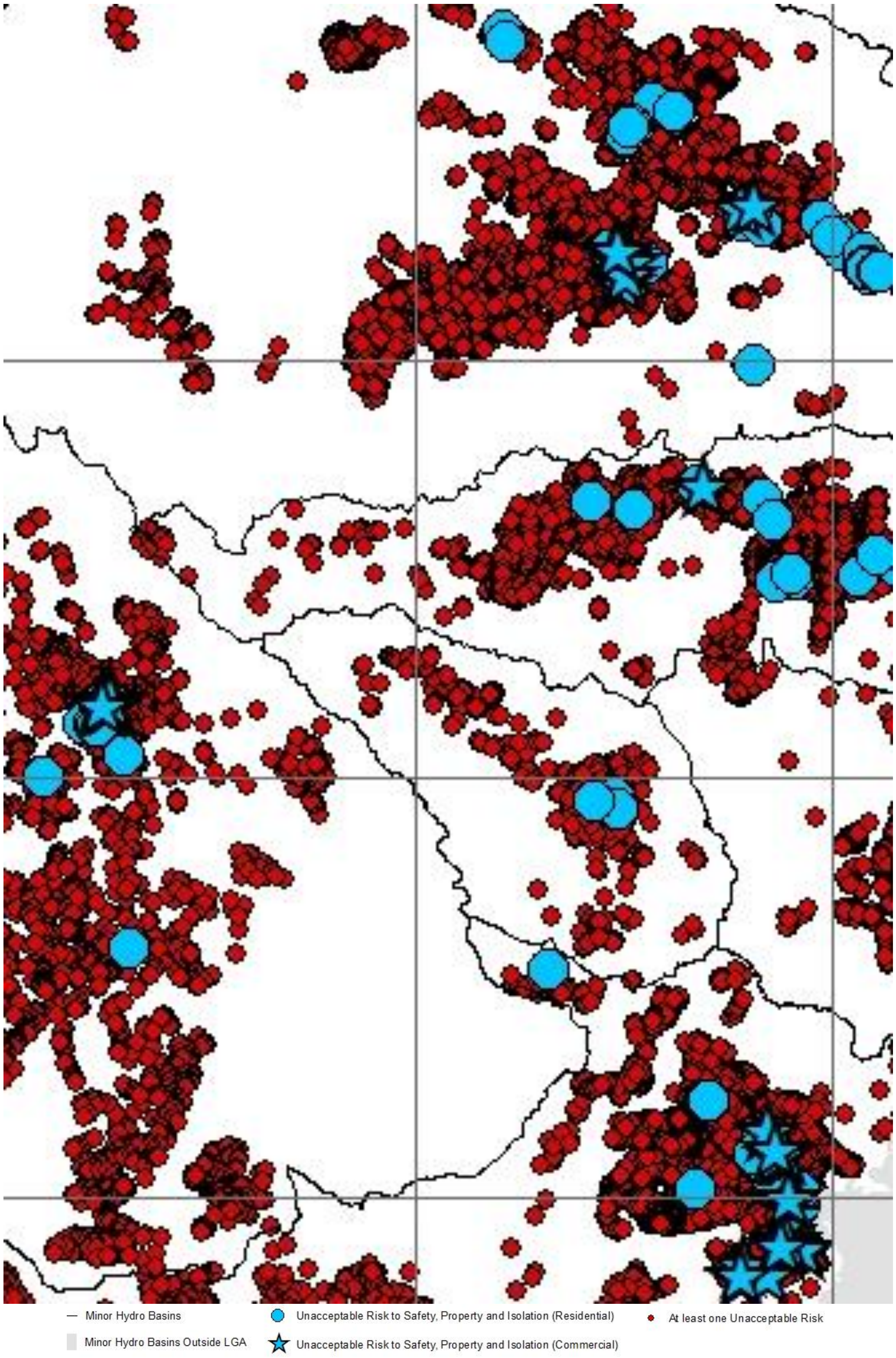

Figure 6: Unacceptable Combined Risks for Existing Residential and Commercial Development

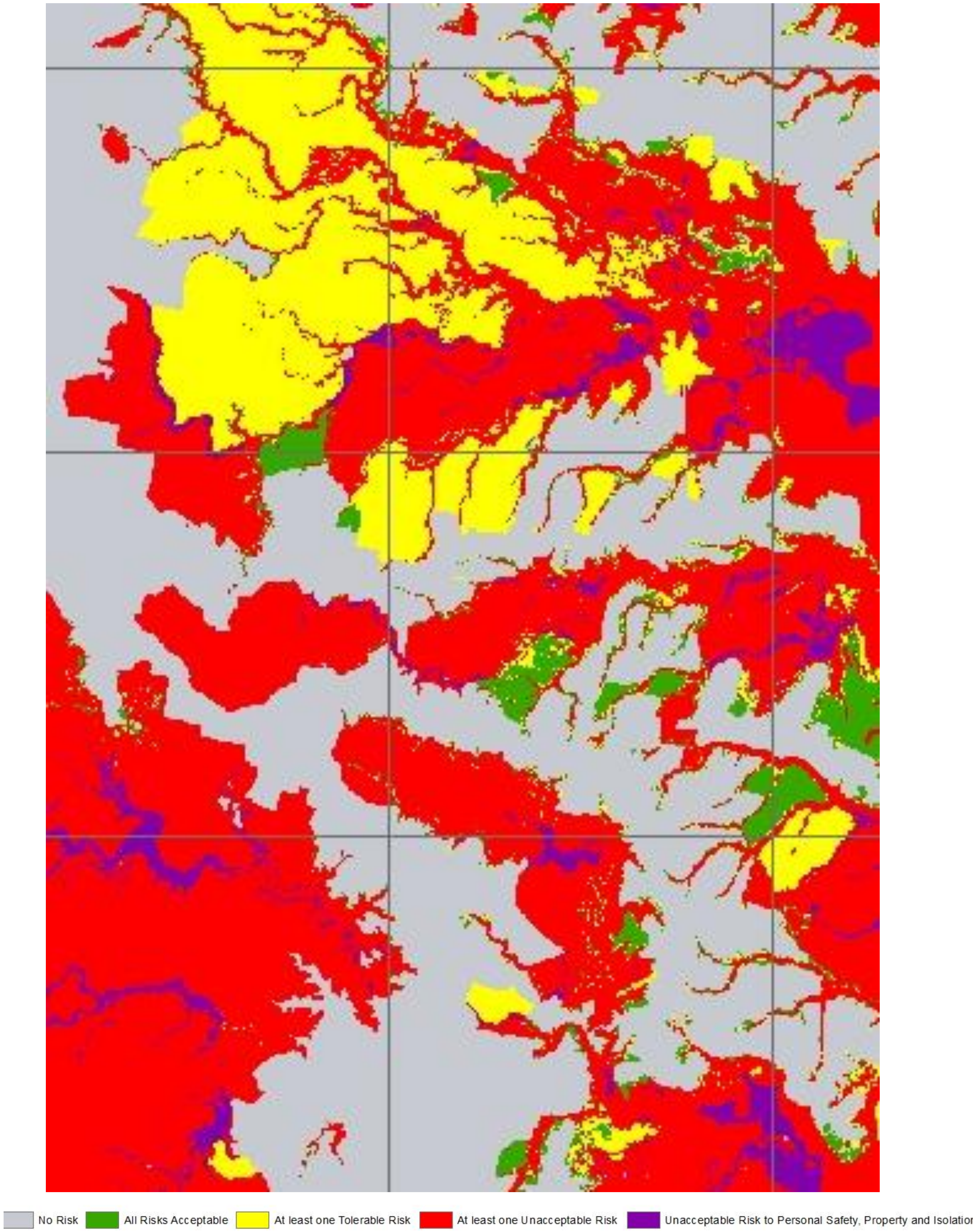

Figure 7: Unacceptable Combined Risks for Future Residential and Commercial Development

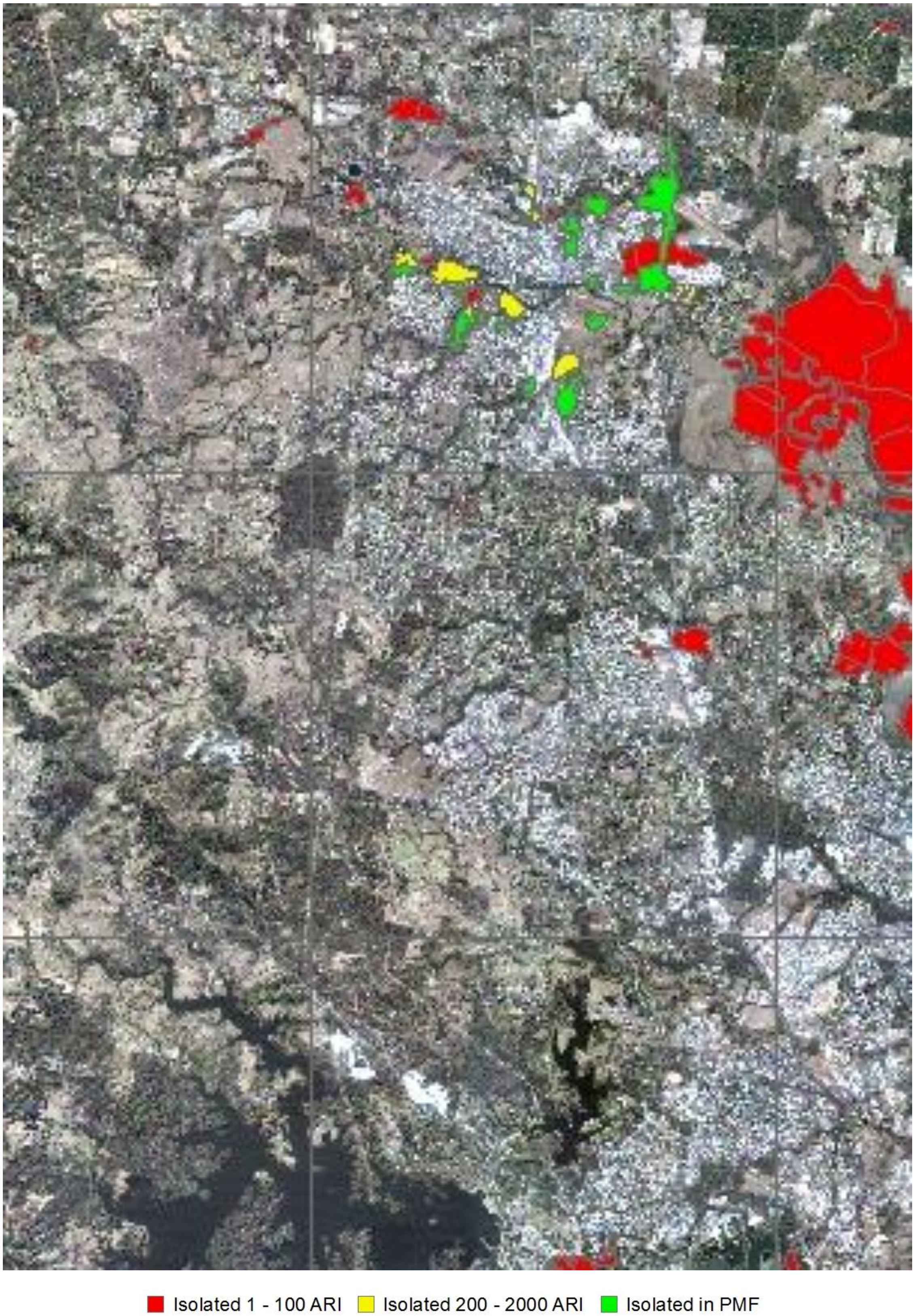

Figure 8: Low Flood Island Isolation Frequency

A similar approach was taken when assessing the risks posed to infrastructure by flooding. Table 8 shows the risk assessment table used to evaluate risks to roads and Table 9 the table used for other infrastructure. Cells in the table which are grey indicate that information was not available at the time of analysis for that category of infrastructure.

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							

Table 8: Risk to Road Assessment Matrix

Examples of the resultant maps are provided in Figures 9, 10 and 11. There is not space here to discuss some of the ambiguities with the road and electricity infrastructure data, suffice to say that it was given the most conservative interpretation in terms of how these assets might be impacted by flooding. Where these maps show an unacceptable risk it highlights areas where Council needs to work with the infrastructure owners to more precisely define the flood impacts and determine whether the impacts are in fact unacceptable.

Flood Damages

In addition to using the flood database to undertake the risk assessments described in the preceding sections, the database was used with standard stage damage curves to assess direct and indirect damages at each residential and commercial building for all events up to the PMF. This work was still being quality checked at the time of writing and was not able to be published.

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	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	
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							

Table 9: Risk to Infrastructure Assessment Table

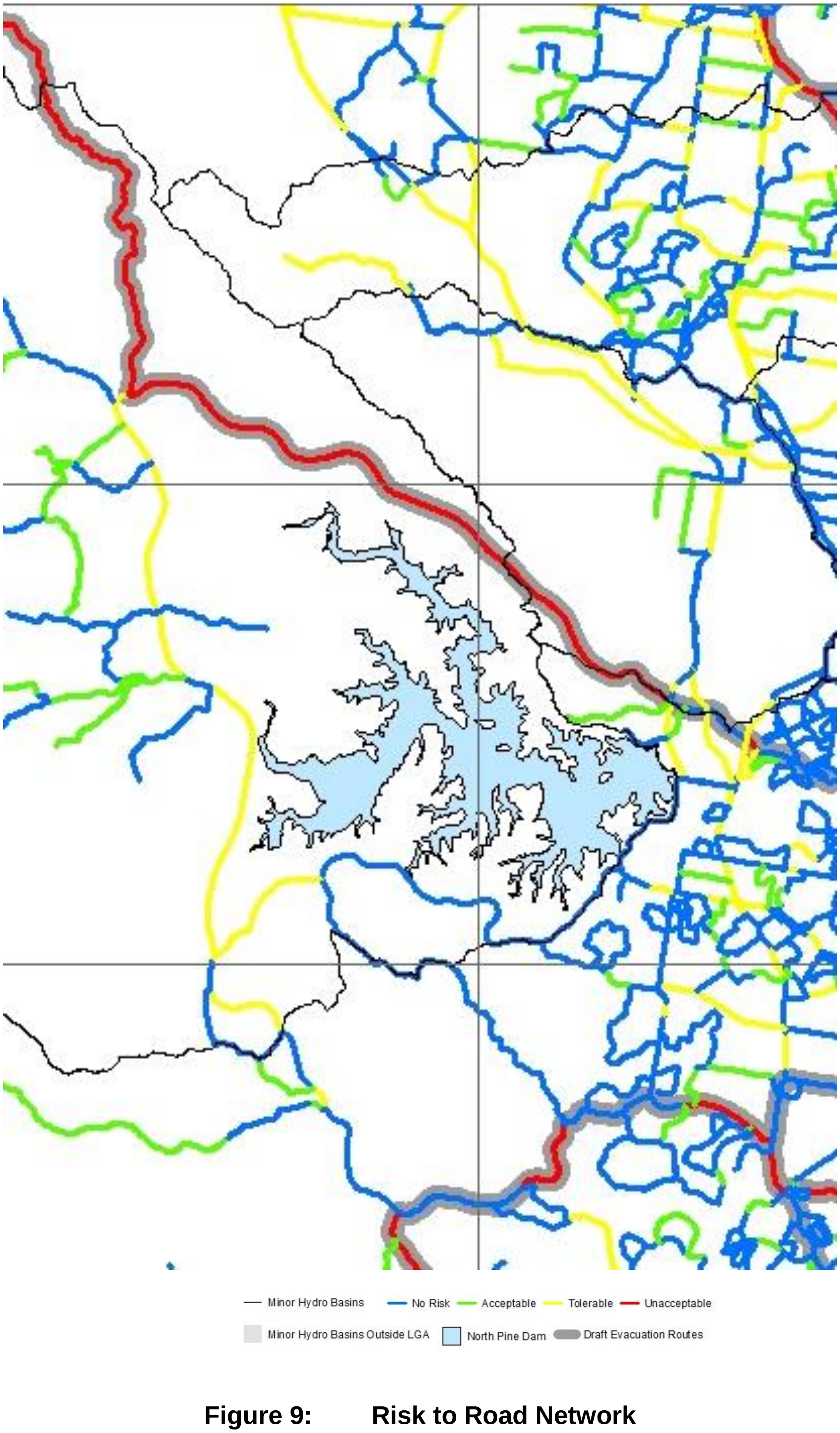

Figure 9: Risk to Road Network

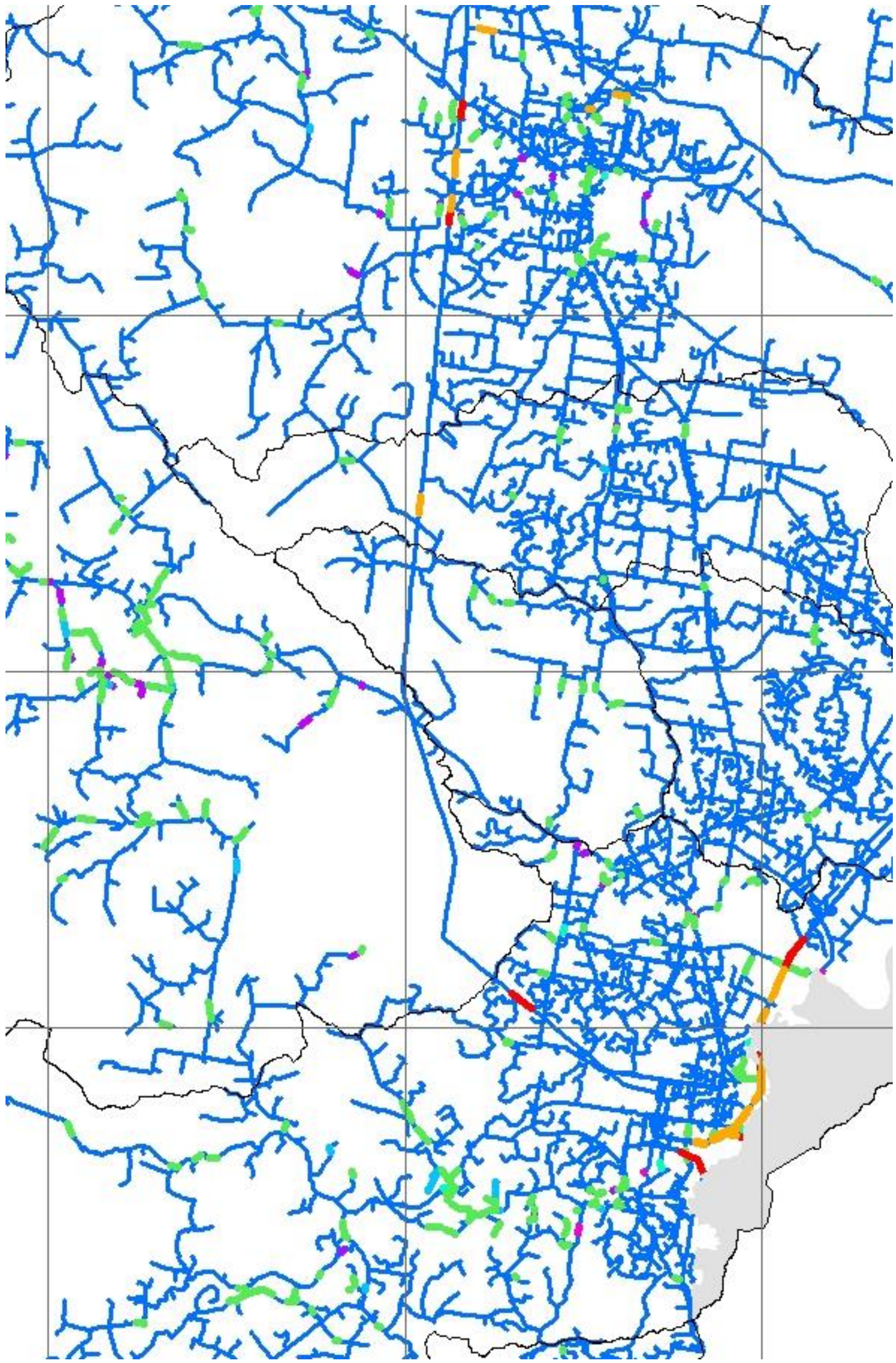

Figure 10: Risk to Electricity Transmission Lines

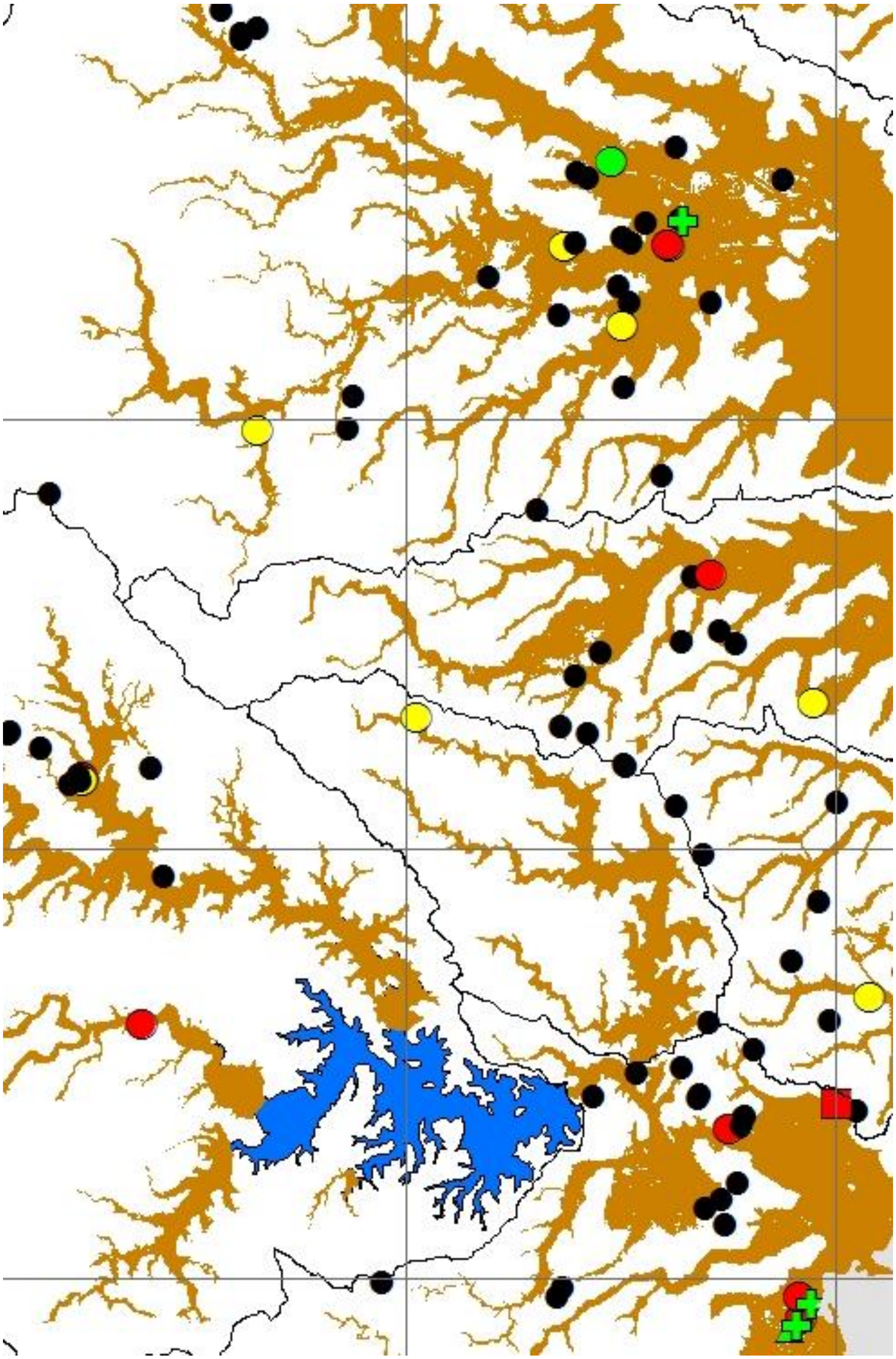

Figure 11: Risk to Other Infrastructure

Using the Results

The results of the analyses can be used in three ways.

Emergency Planning

The mapping at a broad scale can be used to prioritise areas for emergency management, with the highest priority to areas with the largest numbers of premises with an unacceptable risk to life and which are low flood islands cut of in the most frequent events.

The database can be used to identify why the risk to life is high which in turn helps identify the most appropriate options to improve an area's risk profile. This might be as simple as raising an evacuation route at a low point or changing resource allocations or response actions in the flood emergency plan.

It also highlights where critical infrastructure impacts may compound the indirect impacts. Emergency planners can work with infrastructure owners to home in on apparently vulnerable assets and determine whether there are ways to reduce the risks to an acceptable level.

It also provides precise spatial information which enables emergency planners to work more effectively with communities to develop warning systems and community education plans.

Town Planning

By highlighting areas which have multiple unacceptable risks, it clearly delineates those areas which are least suitable for development and should be avoided. Where only one risk is unacceptable it helps focus attention on what development features would be required to make development acceptable or tolerable. This then aids in the development of planning controls which are appropriate to the risks which need to be managed.

Mitigation Works

The mapping of the various risk types assists with the prioritisation of locations for flood mitigation or property modification works investigations. It also helps in shortlisting options for detailed investigations. For example, a location with an unacceptable risk of isolation and unacceptable risk to life may best be improved by an upgrade to the road access while an area with an unacceptable risk to property only may be more suited to a levee or house raising scheme. In addition to the quantified reduction in damages which can be calculated for particular mitigation works, the intangible benefits can be quantified by calculating the number of premises with an improved risk profile with regard to risk to personal safety and risk of isolation.

Conclusions

While the work to date has only been the first step in the process of implementing the holistic risk management framework, it is demonstrating that:

- it can be applied consistently over a large area using conventional GIS tools
- different areas can have different flood risks which need different solutions
- by mapping combinations of flood risks it helps highlight priority areas for mitigating existing flood risks including improvements to infrastructure, flood modification works, property modification measures and response modification measures
- it is a useful tool for identifying areas for future development which are not constrained by flood risk, those which have multiple flood risks and are probably not suited to development and those areas where development controls may be able to mitigate specific flood risks to a level which makes development appropriate. Development controls can be tailored to the specific risk which needs to be managed
- it provides a means of quantifying some of the less tangible benefits of floodplain management options such as reducing risk to personal safety and reducing risk of isolation.

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