Investigating the performance of floodway in an extreme flood event

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ABSTRACT

Resilience of critical infrastructure such as roads, telecommunications and power is vital in support activities for disaster response and recovery. In the event of natural disasters such as the Queensland floods, resilient roads were critical to survival and safety, as well as to the health and security of the region. Disaster damage to road structures such as bridges, culverts and floodway significantly increases the vulnerability of communities.

This research paper investigates the damage caused by the recent floods in Queensland on the floodway. Floodway in Lockyer Valley Regional council (LVRC) area in Queensland has been selected as a case study. LVRC has identified a major need to re-examine the design of flood-ways, which have to be designed to be submerged during a flood and return to complete functionality after the flood water subsides. In 2011 flood, about 58% of the floodway were damaged in LVRC area. Many of the flood-ways were damaged during the period of submergence and are currently the weakest links in Lockyer valley roads after a flood. There are no standard design guidelines for these structures accepted at national level.

In this case study, data such as the dimensions, materials used (concrete, gravel with concrete overlay), culvert details and the type of road where the floodway are situated will be collected. Inspection of damaged floodway revealed that the damage due to the floods was mainly due to the excessive debris load and impact load. This paper aims at developing a strategy for flood-way design considering impact loading and debris loading by using a detailed analysis of flood-ways in this region.

KEYWORDS: Disaster, Resilience, Vulnerability, Flood-ways

1.0 INTRODUCTION

Hoping for the best but preparing for the worst is a good planning strategy that the normal population adopt in their everyday activities. However defining this worst case scenario is extremely difficult for mega scale projects with no exception to planning a city that will be resilient in an extreme natural disaster event. Resilience of a city/region depends on the resilience of the infrastructures and the community. The predicted 9 billion world population by 2050 (Hudson et al., 2012) will increase the natural and manmade hazards as well as the effects of such uncertainties. The importance of the resilience of infrastructure in a disaster has been discussed previously by many researchers (Nishijima and Faber, 2009; Pritchard, 2013). Although this concept has been overlooked due to resource shortages and other immediate priorities, it is emphasized that resilient infrastructures are of paramount importance for a resilient society in a disaster situation. Resilience of critical infrastructure such as roads, bridges, culverts and floodway is vital in evacuation support activities for disaster response and recovery (Oh et al., 2010). During an emergency event, community relies heavily on road infrastructure to enable them to evacuate the area fast. During the re-building period after a disaster, resilient road infrastructure plays a major role in ensuring access to the affected areas. Floodway are located mainly in rural areas and have a huge impact on the community resilience. Therefore, understanding the influencing factors which affect resilience of the road infrastructures such as floodway is extremely important to ensure that they can be properly designed or maintained so that the community resilience can be improved significantly.

Floods will have significant adverse effect on the Australian economy in addition to the world products and agricultural commodity prices. Australia is the world's largest coal exporter and Queensland is the highest contributor for that. IBISWorld (Queensland floods: The economic impact Special Report, 2011) reported that the floods reduce 0.6% from the previous GDP forecast for the third quarter of 2010-11, $2 billion in lost coking coal production and $1.6 billion damage to agriculture. Although the revenue from tourism industry was forecast to be $84.2 billion (Queensland floods: The economic impact Special Report, 2011), the floods reduced this by 0.7%.

The recent flood events in Queensland, Australia had an adverse effect on the country's social and economic growth. Queensland state controlled road network included 33337 km of roads and 6500 bridges and culverts (Flooding on roads in Queensland, 2010). 2011-2012 flood in Queensland produced record flood levels in southwest Queensland and above average rainfall over the rest of the state (Pritchard, 2013). Frequency of flood events in Queensland, during the past decade appears to have increased. In 2009 March flood in North West Queensland covered 62% of the state with water costing $234 million damage to infrastructure (Increasing Queensland's resilience to inland flooding in a changing climate, 2010). Theodore in Queensland was flooded three times within 12 months in 2010 and it was the first town, which had to be completely evacuated in Queensland. 2010-2011 floods in Queensland had a huge impact particularly on central and southern Queensland resulting in the state owned properties such as 9170 road network, 4748 rail network, 89 severely damaged bridges and culverts, 411 schools and 138 national parks (Rebuilding a stronger, more resilient Queensland, 2012). Approximately 18000 residential and commercial properties were significantly affected in Brisbane and Ipswich (Queensland floods: The economic impact Special Report, 2011) during this time. More than $42 million was paid for individual, families and households while more than $121 million in grants has been paid to small businesses, primary producers and not-for-profit organisations and more than $12 million in concessional loans to small businesses and primary producers (Rebuilding a stronger, more resilient Queensland 2012). The Australian and Queensland governments have committed $6.8 billion to rebuilding the state.

During the 2011 floods in Queensland, hundreds of families were evacuated from their homes in the middle of the night leaving very little time to gather their personal valuables and with a very unstable physiological status. Psychologists who are specialized in management of people's emotional response to disasters say that it takes a very long time to get their lives back on track. 2011 floods in Queensland have devastated the landscape, many rivers and creeks became unhealthy as they were eroded, contaminated and littered with debris. Erosion of river banks was detrimental for the freshwater turtles. During the floods only 15% of the coal mines in Queensland were operational and it is reported that Government had to drop environmental regulations and allow 44 mines to pump millions of litres of contaminated water into creeks and rivers (*Environmental impacts of floods-Febriary 2011*, 2011). This contaminated water is a huge threat to marine environment and the nation's most notable tourist attraction, coral reef. In order to reduce these detrimental impacts on the economy and the community it is necessary to investigate the effect of robustness of critical road infrastructures on these impacts.

This research paper aims to understand the factors influencing the resilience and vulnerability of floodway in the most recent extreme flood event in Queensland.

2.0 DESIGN GUIDELINES

There are no nationally accepted design standards for floodway design. However, Road Drainage manual of Queensland Department of Main Roads devotes one chapter for floodway design (Roads, 2010) and Main Roads Western Australia has developed a floodway design guide (Australia, 2006). Department of Main Roads, Queensland recommends the use of 5 types of floodway which are varying as per the protection type used (concrete, rock mattress, bitumen sealed and dumped rock-RipRap) and hence the the associated cost. Floodway Design Guide by Main Roads Western Australia recommends three types of floodway suitable for low, medium and high velocities of water. Both of these design guidelines are based on the hydraulic design side of the floodway although there are variations in the recommended types by the two organisations. Recent extreme flood events in Queensland revealed that the floodway are damaged due to high debris loads and impact loads. Hence investigating the factors that affect the vulnerability of floodway and incooporating the structural design side into the floodway design guidelines is a timely concern.

3.0 RESEARCH METHODOLOGY

Resilience can be defined as the ability to maintain functionality and return to normality following an extreme event making sure that the damage is tolerable and affordable (Hudson et al., 2012; Lamond and Proverbs, 2009). It was defined as the ability of a system to reduce the chances of a shock, to absorb a shock if it occurs and to recover quickly after a shock (Cimellaro et al., 2010). According to the definition a resilient system should have low probability of failure, even if it fails, very low impact on the society in terms of loss of lives, damage and negative economic and social consequences and most importantly low recovery time. Vulnerability and resilience is represented in Figure 1 (Lokuge and Setunge, 2013).

(a)

(b)

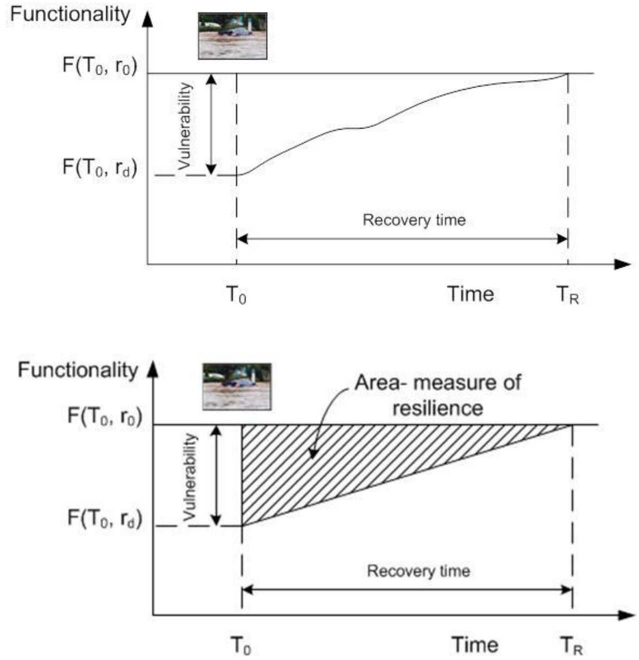


Figure 1: Representation of resilience and vulnerability (Lokuge and Setunge, 2013)

Figure 1 shows how an infrastructure will function when it is subjected to an extreme event. At time T_0, the system was fully functioning [$F(T_0, r_0)$] when the extreme event occurred. Functionality was reduced to $F(T_0, r_d)$ due to the damage to the infrastructure system. At time T_R, the system completely recovered and started functioning as it was at time T_0. From Figure 1 (b) it can be concluded that resilience of an infrastructure can be improved if the shaded area can be reduced. Either damage to the infrastructure should be reduced or recovery time should be minimized in order to achieve a resilient system.

Delivering resilience is a cycle of identification, assessment, addressing and reviewing (Hudson et al., 2012). This research paper aims at the identification stage of this cycle as shown in Figure 2. At the identification stage, a case study should be selected to analyse the parameters that are affecting the functionality of the infrastructure and to find the impact of the element failure towards the overall performance of the infrastructure. Although resilience and vulnerability are widely accepted terms to decide the performance of a structure, the authors have investigated the use of damage index instead. Nishijima and Faber (2009) used a damage index to evaluate the performance of buildings and it relies on the construction cost per square metre and a replacement ratio which is approximately equal to the costs relative to the cost of replacing a median-sized family home. In this research damage index for the infrastructure is defined as:

$$\text{Damage index} = \frac{\text{Cost for repair}}{\text{Cost of replacement}}$$

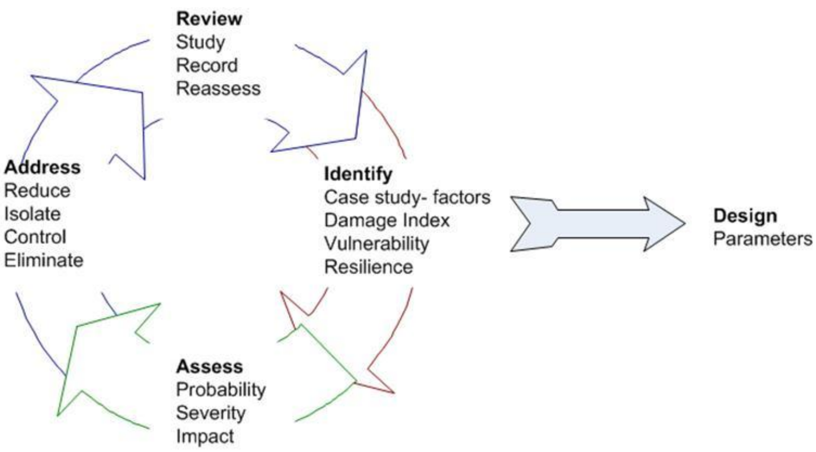
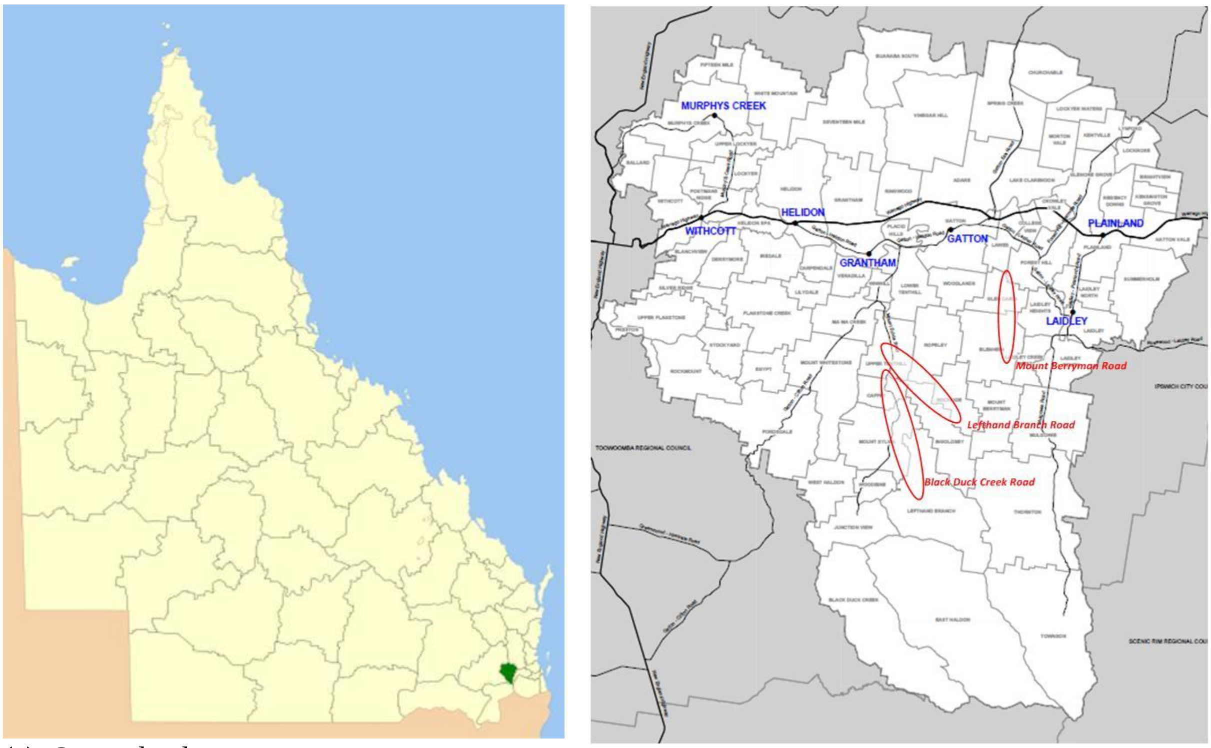


Figure 2: Delivering resilience

Evaluating or re-evaluating resilience can be related to the aftermath of an event, a near miss, or event affecting a similar infrastructure elsewhere. Using a case study, it is aimed to investigate the factors that affect the vulnerability of a floodway in an extreme event.

4.0 CASE STUDY

The floodway in Lockyer Valley Regional Council (LVRC) area (Figure 3) were selected in this case study. Lockyer Valley is situated to the west of state's capital, Brisbane and is one of the most fertile farming areas in the world. The valley is enclosed on either side by the Great Dividing Range. Lockyer creek and its tributaries drain the valley and through Brisbane River empty into Morten bay. The importance of resilience and maintenance of road, rail and all infrastructure has been identified by LVRC in order to remain as the key supplier of vegetables for Brisbane markets, transport truckloads of vegetables all over Australia, and to be a thoroughfare for coal from the Darling Downs and also recently developed CSG industry (Underwood and Teece, 2013). The selected floodway from Lockyer Valley are situated on the roads shown in Figure 3 (b).



(a). Queensland state (b). Lockyer Valley Regional Council area

Figure 3: Locality map of Lockyer Valley

Lockyer Valley in Queensland suffered two nationally prominent extreme flood disasters in the recent past, one in 2011 and the other in 2013. In 2011 some areas of Lockyer Valley region were severely affected by the surge created by the flash flooding in the higher grounds of the Lockyer creek. Lockyer Valley region has been selected for the case study because 2011 and 2013 floods had a huge impact on the community in this region.

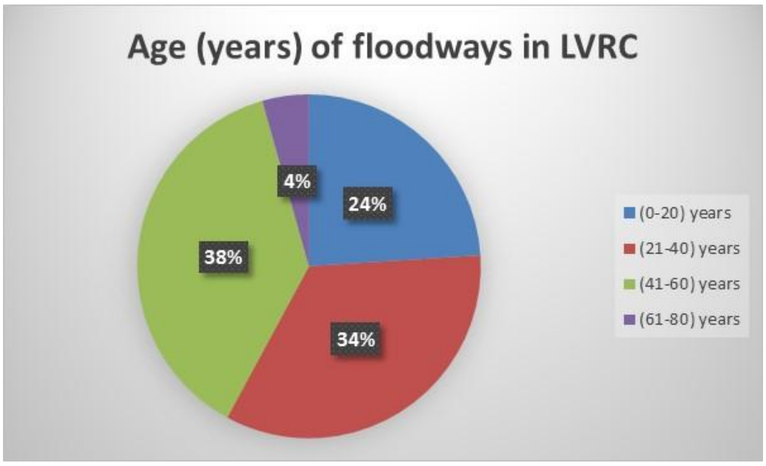


Figure 4: Age of floodway in LVRC area

There were 347 floodway all together in the Lockyer Valley Regional Council area and 64 of them were completely damaged and needed repair due to the 2013 floods. Majority of the floodway in the region are 20-60 years old (Figure 4).

4.1 Damaged floodway

The damaged floodway were assessed by LVRC and it was found out that the damage to asset was due to various reasons as shown in Figure 5. Worst case scenario was that the floodway was completely washed away without leaving any information to judge the type of infrastructure. Common failure type was the damage on upstream or downstream rock structure. Sometimes the surface of the floodway was undermined and cracks could be visible.

Undermined and cracked

Rock protection structure damaged

Unsure of road alignment and what infrastructure was there before

Damaged at upstream

Figure 5: Damaged floodway

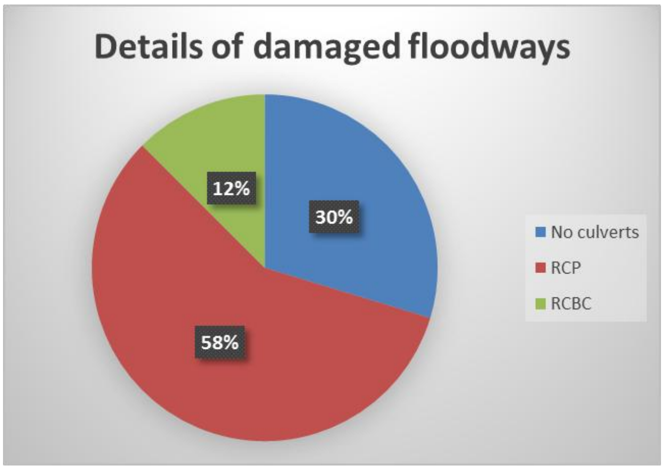


Figure 6: Culvert details for damaged floodway

Available inspection data for the completely damaged floodway were analysed to identify a general trend for the failure. These floodway either did not have culverts or they had Reinforced Concrete Pipe culverts (RCP) or Reinforced Concrete Box Culverts (RCBC). It can be seen from Figure 6 that most of the completely damaged floodway had RCP culverts.

4.2 Damage index

LVRC has estimated the repair/replace cost for some of the completely damaged floodway. Detailed cost calculation for a selected floodway is shown in Table 1.

Table 1: Detailed cost estimate for replacement of a floodway

No	Labour/Plant	Quantity	Unit	Base Rate	Value
1	Temporary road (lump sum)	1			10000
2	Demolish and remove existing - culvert/pipes Demolish and remove existing concrete structures	36	m3	436	15696
3	Reconstruct - Fully reconstruct concrete floodway	270	m2	217.59	58749
4	Reconstruct Apron - Reconstruct concrete floodway apron	360	m2	335.03	120610
5	Geotextile Fabric - Geotextile fabric to be used in conjunction with rock fill	180	m2	5.14	925.2
6	Rock Protection - Bulk fill or armour washout areas with rock/boulder protection	100	m3	131.79	13179
7	Replace Post - Replace sign post	1	each	349.9	349.9
8	Replace - standard - Replace standard road sign. Excludes post	1	each	168	168
9	Replace - Replace guide posts or markers	12	each	89.9	1078
10	Heavy clearing - Embankment/floodway Heavy clearing of dense/mixed debris material (remove from site)	20	m3	65.54	1310
11	Raise pavement approach on northern end by approx. 500mm and tie in with existing pavement	135	m2	130	17550
12	Provide rock to table drains on floodway approaches	40	m2	120	4800
	Total				**234417**

Details of a selection of damaged floodway are given in Table 2. Some of the floodway are suggested to be repaired and some are to be completely replaced. Replacement costs included not only replacing the previous floodway slab but extending it further and hence included the associated costs for the apron. Repair costs normally included the costs to rehabilitate the apron/floodway or approaches.

In Table *2* the authors do not have the data for both repair cost and replace cost for a particular floodway to calculate the damage index. However this will be conducted in the next stage of this research project.

4.3 Element failure of floodway

Damage to the floodway can be classified based on the damage to the elements.

Table 2: Details of selected floodway

Floodway	Slab width (*m*)	Slab length (*m*)	Culvert size (*mm*)	Number of cells	Age (years)	Repair cost ($)	Replace cost ($)
1	4.2	15			77		290840
2	3.6	15.5			45		256245
3	3.5	21	375	1	45		169996
4	3.5	15.5			45		389160
5	3.6	16.4	375	1	45		152902
6	3.7	18			45		310586
7	3.7	28			45		220867
8	3.9	34.5	1200x300	1	45		234417
9	4.3	20			45	376208	
10	4	115			45	21725	
11	3.5	7	375	1	45		208363
12	4	32	300	1	49	113301	
13	4	26	300	1	49		141095
14	3.6	8	375	2	9	67547	
15	4	16.1	300	2	9	91535	
16	4	47	375	2	52	91592	
17	6.2	28.3	375	2	30		187566

Analysis of the failure of floodway in the region revealed that the failure mechanisms can be categorised as follows:

- Floodway washout/moved – For most of the floodway in this category, original assessments were unsure of damage to floodway as they were still under water. Subsequent inspections have revealed that the floodway to be seriously undermined and cracked. Partial or complete replacement of floodway is required and sometimes floodway needs to be extended. Apron is normally damaged and needs to be repaired/replaced.
- Floodway approaches are susceptible for damage due to high water velocities and they may be scoured or undermined. These approaches need to be repaired or replaced (Provide rock to table drains on floodway approaches).
- Floodway slabs are susceptible for damage due to high water velocities and they may be scoured or undermined. Erosion around floodway has damaged the slab. It is necessary to strengthen the slab or replace the slab and sometimes extend the length of the slab.
- Aprons in both the upstream and downstream sides of floodway were damaged/washed away due to the heavy debris load and high water velocities. In order to repair these, Rock Protection (Bulk fill or armour washout areas with rock/boulder protection) was used in conjunction with geotextile fabric.

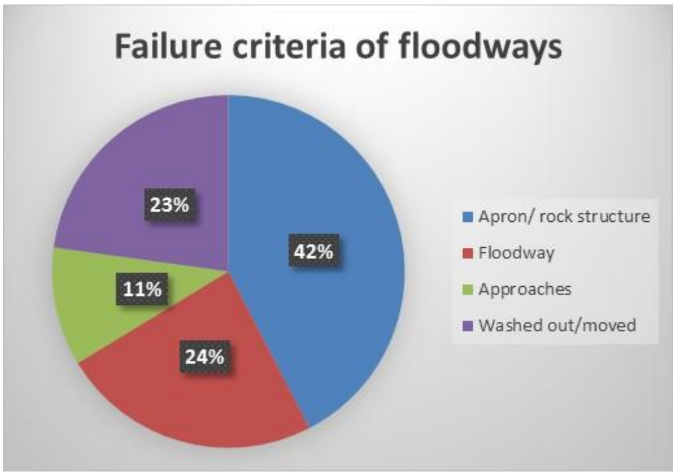


Figure 7: Floodway damaged due to different failure mechanisms

Inspection data records for all the damaged floodway were analysed to identify the element failure towards the overall performance of that particular floodway (Figure 7). It can be seen that the majority of the floodway were damaged due to the failure of the aprons.

5.0 DISCUSSION

Almost all the floodway in the LVRC area are located in the rural access roads while a very few are located in the rural collector roads. Road infrastructure becomes extremely important in enhancing the resilience of a community during the event of disaster as well as during the recovery time. Based on the functional classes of roads of Austroads Bridge Design Code (1992), rural access roads and rural collector roads are classified as Class 4 (Roads whose main function is to provide access to property within a town in rural area). Although the roads in urban areas (classified as class 6 and 8 in Austroads Bridge Design Code) will survive in the extreme flood events, they become redundant as the roads in rural areas are damaged. As a result, floodway being small road structures in rural roads play an important role in the community resilience during and after an extreme flood event. Importance of incorporating community impact in classifying the roads was identified by the authors in another research paper on bridges (Lokuge and Setunge, 2013).

When the failure mechanisms are analysed for the damaged floodway in LVRC area, it can be seen that majority of them were damaged due to the heavy impact loads experienced due to large boulders came with the flood and also excessive debris has damaged the floodway aprons which is the most expensive element to be replaced/ repaired. Therefore it is important to include the structural design aspect together with the hydraulic design aspect when formulating design guidelines for floodway.

6.0 CONCLUSIONS

The paper presents the importance of floodway in enhancing community resilience during an extreme flood event. Based on the analysis of a case study from Lockyer Valley Regional Council for the performance of floodway during floods in Queensland, Australia in 2013, following early conclusions are drawn:

- Most of the completely damaged floodway in the region are more than 60 years old. This possibly is related to a number of factors which require further research such as: construction practices adopted during the construction of the aging bridges, possible strengthening after a previous disaster event etc.
- At the moment there is no nationally accepted design standard for floodway. Including the higher debris load and impact loads in the design of floodway might give extra strength for these vulnerable small road structures.
- These comparatively small road structures are normally located in rural areas on rural access roads or rural collector roads. During the flood and in the recovery stage of it, these rural access and collector roads may be the only access to a community. Therefore the vulnerability of these floodway will have an impact on the resilience of the community in these rural areas. This aspect of community impact requires further consideration in designing floodway.

A current research project is examining further the definition of damage index and the associated cost estimations for partially and completely damaged floodway.

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