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FRAMEWORK TO INSPECT FLOODWAYS TOWARDS ESTIMATING DAMAGE

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ABSTRACT

Floodways provide economic and environmental friendly alternative solution over bridges and culverts for roads with low traffic volumes in rural road networks. They connect regional communities, farmlands and agricultural areas to city centers and hence play a vital role in the economy of a country. Design and operational condition of floodways differ from major road infrastructures because the floodway design process allows a certain degree of submergence for floods with high annual exceedance probability (AEP). Nevertheless, natural hazards can cause damage to floodways as evident from the 2011 and 2013 Queensland flood events. 58% of floodway structures in the Lockyer Valley Regional Council area in Queensland, Australia, were damaged during the 2013 Queensland flood event leading to operational failures in rural road networks and isolating regional communities. Damage assessment during the post-disaster event is a difficult but significant step to enhance the resilience of regional communities. A lack of a proper method to estimate the extent of damage can cause significant delays to repair/reconstruction activities and also can lead to errors in the decision-making process on prioritizing the repair/reconstruction works. Such delays can have a detrimental effect on the resilience of the regional communities. In general, floodways are infrequently being inspected or assessed its capacity only after a natural disaster. This irregularity can cause difficulties during the inspection and assessment process, as information on the previous state of the floodway can easily be unknown. Unavailability of a widely accepted inspection framework is the main cause of this problem. Having identified this gap in knowledge, this paper aims to develop a floodway inspection framework. This framework is designed to extend its capability to help the decision makers to quantify the damage and estimate the repair/reconstruction needs. This framework, therefore, contributes to enhancing the resilience of regional communities who are served by floodways.

INTRODUCTION

Bridges, culverts, and floodways are vital road infrastructures for the operation of a road network. Their application may vary based on geographic and demographic features of the territory. Floodways are common in rural road networks as they provide economic and environmental friendly solutions over bridges and culverts. Floodways play a significant role in the economy of a country by connecting regional communities, farmlands and agricultural areas to city centers. For an example, 48% of total agricultural production in Australia in 2006 had been produced from regional council areas, those covering only about 6.9% of Australia's population, 11% of total Australian land mass and 24% of roads in length [1]. Floodways are common in most of these rural road networks and, hence, play a vital role to distribute agricultural and farming products to highly populated city centers. Therefore, healthy operational levels of floodways are of paramount importance to maintain the continuous supply of essential commodities and the economic balance of Australia.

Floodways are different from bridges and culverts in the design and operational aspects. By definition, floodways are sections of roads which have been designed to be overtopped by floodwater during relatively low average recurrence interval (ARI) floods and are expected to return to fully serviceable level after the flood water recedes [2]. They are also known as causeways in some regions [3]. Although, floodways are designed to withstand at low flood levels, extreme natural disasters can damage these vital road infrastructures as evident from the 2011 and 2013 Queensland flood events. 58% of floodway structures in the Lockyer Valley Regional Council (LVRC) area in Queensland, Australia, were damaged during the 2013 Queensland flood event leading to operational failures in rural road networks. Floodway damage leads to isolating regional communities and hindering the supply of agricultural products to other regions. In a post-disaster period, the long-term impacts on the community and the economy of the country depend on the speed of re-establishing the fully operational level of those floodways.

BACKGROUND

The rehabilitation process of floodways during the post-disaster period includes several steps such as preliminary assessment, detailed evaluation, design and tendering process and reconstruction activities, similar to any other infrastructure. It is obvious that the preliminary and detailed assessment steps can cause an enormous impact on the subsequent operations. Underestimation of the extent of the damage often leads to subsequent failures of floodways during floods with lower recurrence intervals than that they are designed for. This situation can result in frequent repair and/or reconstruction activities causing operational failures in terms of extended travel times and/or distances. On the other hand, overestimation of damage results in overdesigning the structure and hence higher repair/reconstruction costs. In these situations, financial constraints should be thoroughly investigated, particularly in case of widespread natural disasters such as in the 2011 and 2013 Queensland flood events. In such cases, regional councils and government bodies can extend the time frame for the repair/reconstruction period, after prioritization of all activities through a detailed budget evaluation. Correct identification of the extent of the damage will avoid both situations highlighted above and will lead to right decision making in terms of prioritization and reconstruction of damaged floodways. Development of a method to estimate the extent of damage in terms of monetary requirements will assist the regional councils by enhancing the decision making and prioritization processes, considering both short term and long term benefits. Damage index method defined below evaluates repair and reconstruction needs in monetary terms.

DAMAGE INDEX

Nishijima and Faber [4] presented a damage index that is the ratio of the repair cost to the estimated replacement cost. This index measures the severity of damage in terms of the cost for the repair/reconstruction activities. Wahalathantri et al. [5] extended this method to quantify the extent of floodway damage. They divided the reconstruction work of a floodway into eight gross activities, namely: construction of temporary road; demolishing and removing existing structures; reconstruction of concrete roadway crossing; reconstruction of apron; placing geotextile fabric in conjunction with rock fill; construction of rock protection; replacing sign posts and clearing debris material. This categorization is based on the inspections reports for damaged floodways in Lockyer Valley region during 2013 flood event. For each of above eight activities, contribution factors were defined using Equation 1, in which, 'i' represents the ith category from the above list.

$$\text{Contributing Factor for item 'i'} = \frac{\text{Repair Cost for item 'i'}}{\text{Estimated replacement cost}} \qquad \text{Equation (1)}$$

The damage index is then calculated using Equation 2 as given below.

$$\text{DI} = \sum \text{Contributing Factors for items 'i'} \qquad \text{Equation (2)}$$

Wahalathantri et al. [5] defined maximum contributing factors for these eight elements based on cost estimations for 27 floodways across the Left Hand Branch

Road in the LVRC. The extent of the damage is classified into five categories based on the calculated damage indices as below.

1. Complete damage – when the calculated damage index becomes 1 or above. Full replacement can be warranted based on site investigations.
2. Extreme damage – when the damage index is between 0.8 and 1. It is advisable to consider the long-term benefits of the full replacement, rather considering repair works only.
3. Major damage – when the damage index is between 0.5-0.8. It is advisable to assess the vulnerability of areas that are severely damaged against possible extreme flood event in near future.
4. Moderate damage – when the damage index is between 0.1 and 0.5. Floodways with moderate damage can be easily rectified.
5. Minor damage – when the damage index is less than 0.1. Such incidents may have an insignificant impact on the operational level of the floodway.

The above method estimates the maximum damage index using maximum contributing factors. However, actual damage index can vary if the floodway components are not fully damaged. This discrepancy often leads to overestimation of the repair cost that may result in an extended time frame for reconstruction of damaged floodways. Extended time will cause partial operation for long periods of times, which will reduce the resilience of the community. Therefore, an accurate method to estimate the extent of the damage is an important field of study. Such a detailed method should include a detail inspection report to improve the quality of the assessment.

Although bridges do have an inspection framework/protocol to follow, same is not applicable for floodways. For an example, Queensland Transport and Main Roads do have the bridge inspection manual [6] which outlines inspection procedures, key components of bridges and general format of inspection forms for Queensland. Floodway inspection details received from the LVRC for the 2011 and 2013 flood events do not indicate the existence of such a detailed inspection report or framework for floodways. Similarly, other regional councils may also do not utilize standard forms to inspect floodways. If any regional council has a standard framework to assess damage, it is worthwhile to bring this matter into a common discussion forum so that regional councils who own floodways can further discuss and improve the framework towards developing a locally, regionally and nationally accepted framework. Therefore, developing a floodway inspection framework is a timely topic for investigation.

FLOODWAY INSPECTION FRAMEWORK

The proposed floodway inspection framework consists of following key elements:

A. Basic information about floodway
B. Notes from previous inspection or repair/maintenance work
C. Basic details of current inspection
D. Inspection records
E. Condition report

A. BASIC INFORMATION

Contrasts to the other major road infrastructures, floodways do not require regular inspections, and, hence, they are often inspected infrequently or only after a major natural disaster. This inspection practice leads towards making assumptions about the floodway performance prior to a natural disaster. Also, it makes it difficult to distinguish between deterioration due to aging and damage due to a natural disaster. These factors can lead to more uncertainties in judgement or may require re-inspection after referring to the previous condition. The inclusion of basic information minimizes those uncertainties and any needs for re-inspections.

Basic information should facilitate asset identification, location, some design and construction details with suitable sketches or drawings as shown in Table 1. A01-A03 supports floodway identification in terms of asset number, suburb and road name. Type of floodway should be specified under A04. It is recommended to adopt the Austroads Guide [7] to define the floodway type. Austroads guide defines five types of floodways [7]. However, alternative floodway types or slightly modified versions from above five types have been attempted and constructed by regional councils in Australia. For an example, Allen and Rickards [8] presented alternative floodway types with the utilization of soil stabilization methods. Some of those types are being constructed and tested in the Central Local Government Region of South Australia. In such situations, a clear explanation should be given to the type of floodway with the correct reference. Alternatively, a comprehensive study should be performed to include those floodway types in a nationally accepted guideline such as Austroads guide [7]. A05-A11 provides design details of the floodway.

A. Basic Information	
A01. ID	
A02. Suburb & Road Name	
A03. Local Authority	
A04. Type	
A05. Constructed year	

A06. Design Life				
A07. Number of lanes and load limit				
A08. Construction material				
A09. Design Flood (AEP)	Trafficable		Maximum	
A10. Chainages/Coordinates	Start chainage (Latitude, Longitude)		End chainage (Latitude, Longitude)	
A11. Drawings & Details (dimensions, material)				

Table 1: Section A of the Floodway Inspection Framework

B. NOTES FROM PREVIOUS INSPECTION, REPAIR OR MAINTENANCE WORK

Summary of previous inspection reports, repair/reconstruction work will also be important in the decision-making process. This section can include pictures from last inspection to demonstrate the latest status of the floodway. Table 2 shows a general format for this task.

B. **Notes from previous inspection, repair or maintenance work**	
B01. Date of last inspection	
B02. Inspected by	
B03. Reason	
B04. Recommendations	
B05. Repair/reconstruction work	
B06. Pictures/sketches	

Table 2: Section B of the Floodway Inspection Framework

C. BASIC DETAILS OF CURRENT INSPECTION

Section C is to record current inspection records such as date, time, person/s inspecting and the reason for the inspection. The reason for the inspection can be due to regular inspection procedures, maintenance work or to assess the structure due to the damage caused by a natural disaster or an accident. In the latter case, the nature of the incident should also be included. For an example, flood level, period and annual exceedance probability can be included in the event of a flood event. Table 3 shows the general format for the element C.

C. Basic details of current inspection	
C01. Date of current inspection	
C02. Time	
C03. Inspected by	
C04. Reason	
C05. Nature of the incident (E.g., flood level, period, AEP in case of flood)	
C06. Pictures/sketches	

Table 3: Section C of the Floodway Inspection Framework

D. INSPECTION RECORDS

This section should include a detailed and methodological approach outlining each component of a floodway, failure mechanisms and extent of the damage. This step is the most important step to estimate the magnitude of the damage and hence decisions on repair/reconstruction needs. Therefore, attempts should be made to quantify the damage at all possible instances. A qualitative assessment can be performed if it is hard to undertake a quantitative evaluation.

Table 4 presents the framework to record inspection details according to floodway zones and elements in each of the four zones. Four floodway zones proposed by Allen and Rickards [8] are used in this table. Wahalathantri et al. [5] presented common floodway failure mechanisms and elements based on the inspection records from the LVRC area following the 2013 QLD flood event. These floodway zones and elements are therefore listed in Table 4.

D. Inspection records					
Element		Quantitative Assessement[1]		Qualitative assessment (See notes below)[2]	Notes (such as failure mode, source of damage, etc..) & reference to photos/sketches
		Location/ Dimension	Damage extent (%)	Quality Index	Notes
D01. Upstream Zone					
	Apron				
	Rock Protection				

	Cut-off Wall					
	Culvert entry					
	Stream banks					
D02. Downstream Zone						
	Apron					
	Rock Protection					
	Cut-off Wall					
	Culvert exit					
	Stream banks					
D03. Roadway Zone						
	Road crossing					
	Sub-base					
	Sub-grade					
	Culvert					
	Road signs					
	Flood level indicators					
D04. Peripheral Zone						
	Approaches					
	Approach signs					
	Flooded area beyond floodway extent					
	Vegetation - upstream					
	Vegetation - downstream					
	Evidence on creek changes					
D05. Photos						
Notes:	[1] Report extent and dimension, if the damage extent significantly varies at different sections for a given element					
	[2] Qualitative Assessment					
	Value	5	4	3	2	1
	Condition	Critical	Poor	Fair	Satisfactory	Good

Table 4: Section D of the Floodway Inspection Framework

Table 4 has a provision for both quantitative and qualitative assessments and a column to record any other notes or sketches or reference for photos. The qualitative assessment assigns a value to each element based on the state of the floodway at the time of inspection [9]. The value of 1 indicates that the element is In excellent condition with no significant damage or deficiency. Satisfactory condition means that the floodway is only subjected to minor damage, deterioration and/or misalignment with insignificant effect on the performance. Moderate damage/deterioration levels can be classified as the fair condition. Elements with major or multiple defects that can cause significant impact on the serviceability or the integrity of the floodway should be rated as poor condition. Any element that has failed or failure is imminent should be rated as in critical condition.

E. CONDITION REPORT

Last section includes a condition report prepared and signed by the person/s who inspect the floodway. Judgement on the extent of damage, repair/reconstruction needs should be outlined here. The method developed by Wahalathantri et al. [5] can be used to rank the repair/reconstruction needs. Maximum contributing factors defined by Wahalathantri et al. [5] should be modified based on the estimated percentage damage for each component.

E. Condition Report					
E01. Damage Index			Repair need as a fraction	Maximum factor for item	Adjusted Contribution factor
Need for temporary access				0.05	
Demolishing existing structures				0.10	
Reconstruction of roadway crossing				0.25	
Reconstruction of apron				0.50	
Placing Geo-textile				0.01	
Reconstruction of Rock Protection				0.05	
Replacing sign posts				0.02	
Cleaning and debris removal				0.02	
DI = Σ(Adjusted contribution factors)					
E02. Level of Damage	Complete DI =1	Extreme DI: 0.8 -1.0	Major DI: 0.5 – 0.8	Moderate DI: 0.1 – 0.5	Minor DI < 0.1
E03. Recommendation based on DI	Replace the structure	Perform a detail analysis considering design life	Critically assess components subject to major damage	Repair activities should perform as quickly as possible	Rectify the problem at the earliest possible time
E04. Other recommendations					
E05. Asset Number:					
E06. Date of inspection:					
E07. Prepared by (Name, Signature and Date):					

Table 5: Section E of the Floodway Inspection Framework

CONCLUSION

Damage assessment during the post-disaster event is a difficult but significant step to enhance the resilience of regional communities. A lack of proper method to inspect floodways and quantify the extent of damage can cause huge delays to repair/reconstruction activities and also can lead to errors in making correct decisions and prioritizing the repair/reconstruction works. Such delays can have a detrimental effect on the resilience of the regional communities. This paper, therefore, developed a f loodway inspection framework that can be easily extended to estimate the extent of the damage using a damage index method. Hence, this framework will enable making correct decisions in terms of repair/reconstruction activities and prioritizing them. This approach, therefore, contributes to enhancing the resilience of regional communities who are served by floodways.

The developed floodway inspection framework consists of five key elements, labelled as A-E: A -basic information; B - details of previous inspection report and recommendation; C - basic details of current inspection; D - inspection report and E - condition report. Elements A and B provide the basic information about the floodway and its last known condition to assess the damage or the state of the floodway at the current state. Element C and D provide the details of the person/s inspecting the floodway, reason for inspection and the inspection records. The last element, E, provides the condition of the floodway based on the current inspection and state of the structure in terms of repair/reconstruction needs.

WAY FORWARD

Although every effort has made to include all the aspects with respect to floodway inspection process, this framework should be attempted by councils who own floodways towards developing a nationally accepted framework. Future studies should also be conducted to derive contributing factors for each element of the floodway based on the extent of the damage or the qualitative assessment. Department of Transport and Main Roads has observed approach damage as another failure mechanisms. This failure mechanism should be further studied to identify associated cost components. Such studies require details from multiple case studies across Australia. Also, it is identified that new floodway types are being attempted by some regional councils in Australia. A detailed study on those new floodways is recommended to update floodway types given in the Austroads Guide.

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