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Additional Crossing of the Clarence River at Grafton: Flood Impact, Levee Upgrade, and Structural Considerations

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Abstract: *The Clarence River catchment, on the far north coast of New South Wales (NSW), is one of the largest catchments on the east coast of Australia, with an area of approximately 20,000km^2. The lower Clarence River floodplain spans 500km^2, within which lie the towns of Grafton and Maclean. These towns are home to over 20,000 residents collectively and serve as a rural centre for the surrounding agricultural lands. Both Grafton and Maclean are protected by levee systems which have been developed over time as a response to previous floods in the region. Roads and Maritime Services (RMS) is currently investigating options for an additional crossing of the Clarence River at Grafton to address short-term and long-term transport needs. All upgrade options for an additional crossing of the Clarence River will increase flood levels. RMS intends to maintain the current level of immunity and mitigate any adverse impact from piers and structures within the Clarence River by raising current levees. This paper draws upon and consolidates some of the findings from the options analysis to investigate considerations associated with spanning a 600m section of the Clarence River, mitigation of flood impacts, and modifications proposed to the existing levee systems.*

Keywords: *Clarence River, Levee, Grafton, South Grafton.*

1. INTRODUCTION

Grafton and South Grafton are currently protected by a series of levees that, in addition to naturally high ground and an elevated railway line, surround the town. Construction of these levee banks and drainage improvements have been undertaken progressively over time to help reduce the frequency and severity of flooding in residential and commercial areas.

Figure 1 shows the Grafton and South Grafton levee system. Both the Grafton and South Grafton levee systems are made up a combination of embankment levees, structural retaining walls (concrete, brick or block walls).

1.1. Grafton Levee

The first levees in Grafton were constructed during the 1890's along the riverbank. These levee banks provided only limited flood protection up to approximately a 3½ year Average Recurrence Interval (ARI) flood (SL&M, 1980). Subsequent flood mitigation works began in the 1960s, when a major program of levee construction was initiated in response to major floods that inundated the town. The riverbank levees were initially raised to provide a level of protection that was thought to be similar to a 20 year ARI flood. From 1969 these levees were further extended and raised. Protection from backwater flooding was also provided by continuing the riverbank levees back around the north of the town, effectively forming a ring levee enclosing the town.

As the levees have been progressively constructed, extended and raised over time, there is no single report or other documentation that clearly states the design criteria for the complete levee system. Some reports have quoted the levee system providing protection against the record flood of 1890, or

the 100 year ARI flood, whilst other advice is that the riverfront levees were designed on the basis of recorded levels from the 1967 flood with an additional freeboard. Regardless of the actual design specifications, there was a belief that the levee system provided the town with protection up to the 100 year ARI flood.

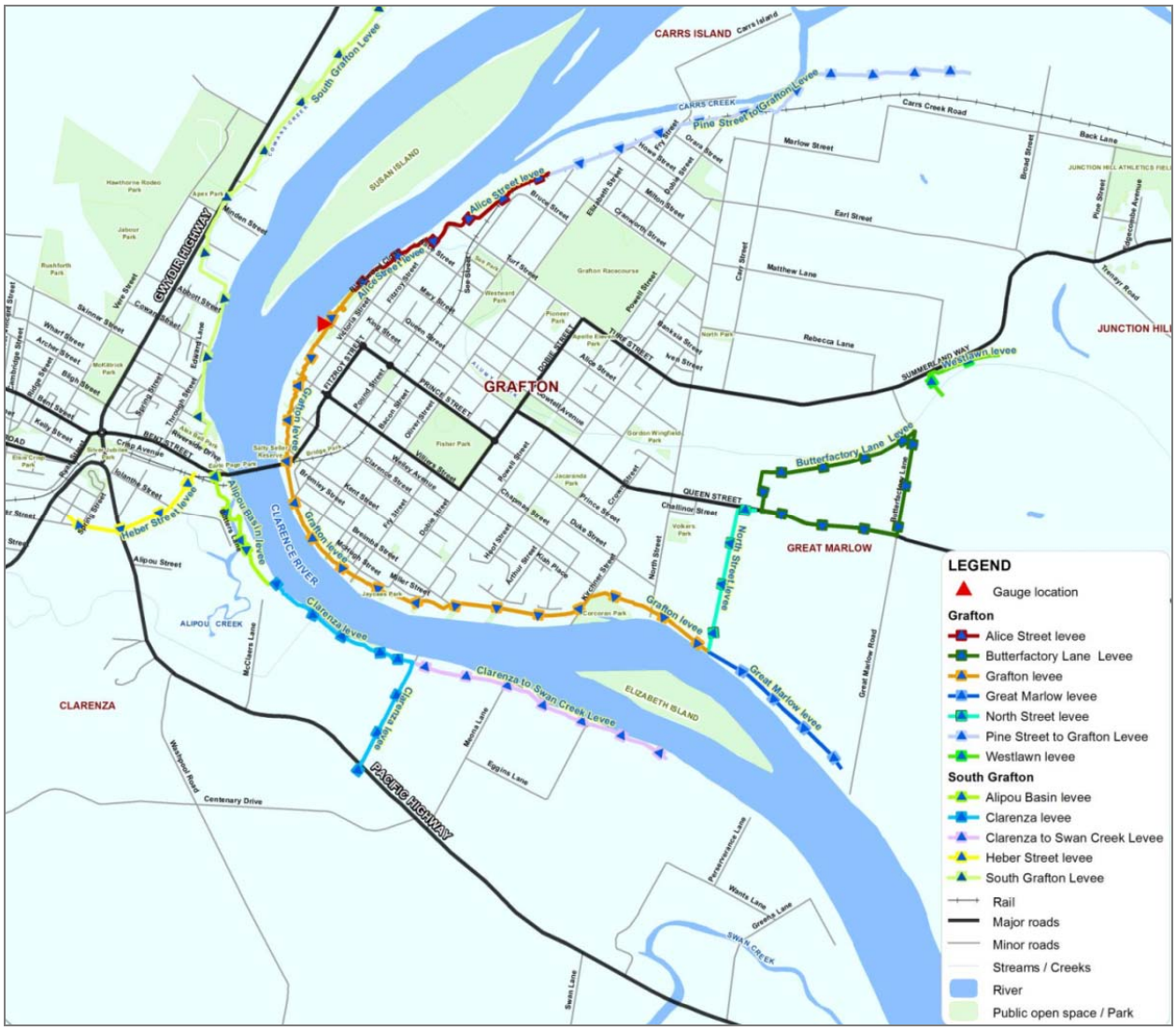

Figure 1 - Grafton and South Grafton Levee system

Subsequent investigations by WBM (2004, 2013) have shown that the levee system has an approximate 5% AEP event flood immunity (≈20 year ARI event), with overtopping of the levee initiating in Dovedale, between Bacon and Powell Streets. Following the initial overtopping and depending on the magnitude of the flood event, extensive overtopping occurs in numerous locations.

1.2. South Grafton Levee

Construction of the first flood mitigation works in South Grafton commenced in the 1960's, with drainage improvements and flood-gating of various drains, levees at Waterview and South Grafton, and other levees downstream of the railway line to prevent backwater flooding into the town. By the 1980's it was recognised that the levee scheme provided protection from river flooding to the 20 year ARI flood, and backwater flooding to the 8 year ARI flood (Paterson Consultants, 1993).

In 1985, Clarence River County Council commissioned investigations to examine increasing the level of protection up to the 100 year ARI flood. Various levee height standards were subsequently adopted for different sections of the levee system to minimise adverse flooding impacts elsewhere in the floodplain. These standards ranged from 0.1m below the 100 year flood; the 100 year flood (with no freeboard); and the 100 year flood with either 0.25m or 0.5m freeboard. Upgrade of the levee system was completed over the period 1990 to 1996.

The level of protection provided by the upgraded levee system was questioned following the March 2001 flood. Further investigations by WBM (2004, 2013) have shown that the levee system has an approximate flood immunity of between a 5% and 2% AEP event (20 to 50 year ARI event), with overtopping initiating west of the Gwydir Highway, along a section of the Waterview levee between the Waterview and Seeland Drain floodgates. Depending on the magnitude of the flood event, extensive overtopping occurs in numerous locations following initial overtopping.

2. HISTORIC FLOODING

Historically, flood exceeding a moderate classification (defined as greater than 3.6 m at the Prince Street gauge) of the Clarence Valley has occurred 73 times since 1839 within Grafton and South Grafton (Clarence Valley Council, 2013).

From the first European settlers in approximately 1830, to the commencement of sugar farming in 1868, only relatively small floods overtopped the natural river banks near the early settlements. The effects of floods on the new settlements before 1876 have not been ascertained but the flood heights that were recorded suggest that only two floods, those in 1863 and 1864, would have overtopped the banks near the settlements.

Over the following seventeen years, however, the security of the floodplain was seriously questioned. During this time seven floods would have overtopped the banks and among these was the flood of 1890, which achieved a height of 8.19mAHD. This spate of flooding subsided during the next three decades as the next major flood did not occur until 1921, followed by another major flood in 1928.
Since 1945, the incidences of major flooding have been much higher, with major floods occurring in 1945, 1946, 1948, 1950, 1954, 1956, 1959, 1963, 1967, 1974 and 1976. The 1950 flood approached the height of the 1890 flood and caused widespread damage in the valley. The frequent major flooding from 1946 to 1956 had major effects on the economy of the valley and aroused public interest in measures to reduce those effects.

The most recent floods have occurred in 2001, 2009, 2011 and the record breaking 2013, and have reached levels of 7.70mAHD, 7.33m AHD, 7.64m AHD and 8.09mAHD respectively (Clarence Valley Council, 2013).

3. ADDITIONAL CROSSING OF THE CLARENCE RIVER AT GRAFTON

Roads and Maritime Services (RMS) has undertaken investigations and community consultation to identify the preferred route for an additional crossing of the Clarence River at Grafton to address short-term and long-term transport needs (Arup, 2013).

In June 2011 twenty-five preliminary route options in five corridors were identified for engineering and environmental investigation and in January 2012 six route options were selected for further investigation. Design refinements and further field and technical investigations were undertaken on the six route options (Arup, 2012).

The six route options were also subject to an assessment process in October and November 2012 to identify a recommended preferred location for the additional crossing. The assessment process was based on community feedback, technical investigations undertaken to date, the outcomes of a value management workshop and RMS review of the options. The assessment process resulted in a preferred option shown in Figure 2 (Arup, 2012).

Figure 2 - Preferred option for an additional crossing of the Clarence River at Grafton.

Members of the public and other stakeholders were engaged within the decision process. A number of supporting consultation activities were undertaken and community feedback sought via varying methods of communication (staffed displays, mail or hand delivery, email and telephone). Community responses raised flood questions and concerns which were all addressed by RMS within Arup (2013).

4. FLOOD IMPACT CONSIDERATIONS

4.1. Potential Adverse Flood Impacts

Flood levels within Grafton and South Grafton are largely dictated by the volume of floodwater overtopping the respective levee systems. Upstream of the existing Grafton Bridge, the Grafton and South Grafton levees extend for approximately 10km before tying into naturally high ground. Due to the long length of these levees, slight changes in flood level within the main Clarence River have the potential to considerably alter the volume of water overtopping the levee, possibly resulting in significant variations in flood level behind the levee systems. This has the potential to adversely affect the populations of Grafton and South Grafton, increasing their flood risk exposure.

All upgrade options for an additional crossing of the Clarence will increase flood levels. Public concern of this was evident through submissions received during community consultation.

4.2. Possible Mitigation Measures

Mitigation options vary from design of a cable stayed bridge option, which will have not impacts on flood levels, or a pier bridge type combined with an upgrade to the levee system upstream of the

bridge duplication. These may also be combined with non-structural measures, such as flood awareness schemes.

The option exists to construct a cable stayed bridge form that spans the extent of the floodplain with no piers, avoiding the need for flood mitigation. Consideration would need to be given to technical viability, aesthetics, and cost of such an option. It is likely that the cost would be prohibitive to the project, given the upfront cost and ongoing maintenance associated with such a structure.

Alternatively, duplication of the existing bridge with a design which includes piers within the river may be viable with appropriate additional mitigation measures. Measures associated with the bridge structure include; the type of piers, number, configuration, alignment with the existing upstream bridge, skew, blockage area and structure soffit level.

Accounting for these design features, the proposed bridge design will result in less than 0.05m afflux within the river upstream of the bridge. This additional bridge afflux results in up to 0.5m increase in flood level within the leveed areas of Grafton and South Grafton. Due to this, upgrade of the levee system upstream of the duplicated bridge will be required to maintain the existing level of flood immunity in Grafton/South Grafton and mitigate the flood impacts associated with this design. It is estimated that approximately 18km of levee will require upgrade under this design scenario. This design and associated mitigation measure is currently the preferred option, as the costs associated with this option are significantly less than that of the cable stayed option.

4.3. Appropriate Design Standards

In line with RMS requirements for major bridges, and consistent with Austroads Road Design Guidelines and the associated RTA Supplements, the crossing had a minimum design requirement to achieve 100yr ARI flood immunity. Notwithstanding this, while the design flood is the 1 in 100 year ARI flood event, flood modelling was conducted that considered a range of flood events including peak flood levels, velocities and flows for the 5, 20 and 100 year ARI flood events, and the probable maximum flood (PMF) event. Due to river navigation requirements, bridge soffit levels greater than PMF event peak flood level are proposed. This design far exceeds the RMS flood immunity design standard.

4.4. Flood Evacuation Impacts

The Clarence Valley Local Flood Plan (SES, 2007) defines three main evacuation routes out of Grafton. Two routes north, to Junction Hill, and one route across the existing Grafton Bridge to South Grafton. During a flood event, following overtopping of the Grafton levees, backwater inundation and ponding within the floodplain between Grafton and Junction Hill cuts the evacuation routes to the north. When this occurs, the only flood free route available for evacuation is via the existing Grafton Bridge to South Grafton. The efficiency of flood evacuation within Grafton is therefore largely constrained by traffic movement across the bridge.

An additional crossing of the Clarence River would benefit flood evacuation within Grafton as it would increase the efficiency of mass evacuation of Grafton during a major flood event regardless of the location. Consequently, the proposed route will have significant flood evacuation benefits.

4.5. Levee Upgrade Design, Construction and Maintenance Guidance

Existing guidance on the assessment, design, construction, and maintenance of levees is variable in detail and scattered through numerous and often obscure documents within different countries driven by different engineering disciplines. Current Australian guidance is limited. A summary of the most relevant guidance is listed below and would provide the best point of reference when considering modifications/upgrades to Grafton and South Grafton levee systems:

- *Dam and Levee Safety and Community Resilience: A Vision for Future Practice*. National Research Council 2012
- *Design and Construction of Levees*. US Army Engineer Manual EM-1110-2-1913, 30 April 2000.
- *Levee/Floodwall Freeboard Design For An Urban Flood Control Project.* US Army Research
- *Levee Design Construction and Maintenance*. Department of Natural Resources and Environment, Victoria, 2002.
- *Guidelines for the construction of earth-fill dams*. Water Resources Policy #2008/1, Department of Primary Industries and Water, Tasmania.

Subsequent to the above, six nations (USA, France, Netherlands Germany, UK/Ireland) have been working together for the past three years to deliver a comprehensive International Levee Handbook, collating international practises and knowledge to spread consistent standards and approaches widely. Due to be released in October 2013 this Handbook should be a point of reference for future Grafton flood levee works.

4.6. Levee Upgrade Design Standard

Levee design standards largely come down to site constraints and the level of protection that can be practically achieved. In many instances it will be a limiting height control that dictates the design standard, either due to aesthetic concerns or cost implications. It is essentially a balancing act between costs, benefits, aesthetic issues, and community attitudes (Maddocks et al., 2007).

Consideration should be given to selecting an appropriate level of protection for public safety, health, and welfare in comparison to cost (inclusive of maintenance cost also). High level estimates predict a cost to increase the 15.7km of levee upstream of the proposed second Clarence River crossing by 0.1m and 0.5m of $14.2 million and $23.1 million respectively.

4.7. Flood Risk Considerations

A problem often experienced by communities protected by levees is complacency regards the likelihood and associated consequences of flooding. When a levee is constructed, the frequency of flooding is reduced, resulting in residents forming the option that the levee has eliminated the flood threat completely. This complacency increases the flood risk within leveed communities.

Maddocks et al. (2007) reported that the March 2011 flood was predicted to overtop the levees in Grafton and consequently an attempt was made to evacuate some 12,000 residents. The evacuation was unsuccessful, with only approximately 10% of the people actually evacuating the town. Pfister (2002) stated "*the residents of Grafton, having experienced few direct effects of flooding since the construction of the levees, are likely to have developed a low consciousness of the flood threat, and are therefore less ready to act*." Consequently, it appears that although a high levee will provide a high level of protection, it is likely to also induce a high level of community complacency, and when the levee does finally overtop evacuation procedures can be severely hampered and consequences of flooding may be amplified.

Community flood education is therefore critical in leveed towns. Flood education aims to increase flood awareness. In times of flood, a flood aware community will be more likely to respond appropriately during an emergency situation. As such, community flood education is an effective means of reducing flood hazard.

4.8. Freeboard Considerations

Freeboard is the 'contingency' part of the levee between the design height and the levee crest. The purpose of freeboard is to provide a reasonable certainty that the risk exposure associated with a particular design flood is actually provided. There are no formal freeboard standards adopted in Australia. Similar to the levee design standard elements, freeboard consideration should account for a

range of issues, including aesthetic concerns, cost implications and the potential flood risks associated with overtopping of the proposed levee structure. For example, increased freeboard allowances in locations which protect critical evacuation routes may be considered in some instances.

Additionally, it is also worth noting that flood level estimates will inevitably change over time, and potentially several times during the life of the levee, as modelling techniques change and additional flood data becomes available. This may potentially also be exacerbated by the impacts of future climate change. Adoption of a conservative freeboard may be cost beneficial in the long term, avoiding constant adjustment of the levee to mitigate these future uncertainties.

4.9. Land Use Controls

Development controls for the area 'protected' by the levee are considered an important component of any levee system, and minimum floor levels controls can help when the levee overtops. Currently conditions exist whereby residential dwellings within the flood levee system in Grafton are to be built to a level greater than 6.4mAHD. Outside of Grafton, landuse controls are defined based on the 100 year ARI flood event. In both instances these landuse controls are resulting in new residential subdivisions being constructed on what is essentially a large earthworks pad.

Council have also tried to place the majority of the levee system into an access easement, to instate it as a Council asset. Much of it used to be under the private ownership due to crossing private residential or farm land. It is understood that apart from a few land owners, the majority of the flood levee is now within the easement.

There is an area that sits outside of the levee system on Carrs Island. Properties on Carrs Island were impacted by Council's recent upgrading of the South Grafton levee system. As a result, Council has paid to lift several dwelling to place the floor level above the 100yr ARI flood level, as well as building some flood mounds for stock. As such, consideration also needs to be given to the fact that with raising the levee wall, properties sitting just outside of this system have greater impacts during floods. If upgrade of the Grafton and South Grafton levees is proposed as part of the bridge duplication project, further consideration of mitigation measures for the residents of Carrs Island will be necessary.

5. SUMMARY

Roads and Maritime Services (RMS) is currently investigating options for an additional crossing of the Clarence River at Grafton. Without mitigation an additional crossing of the Clarence River will increase upstream flood levels, with adverse impacts to the communities of Grafton and South. RMS intends to maintain the current level of immunity and mitigate any adverse impact from piers and structures within the Clarence River by raising current levees.

Although the primary objective of the additional crossing aims to address short-term and long-term transport needs, secondary flood risk management benefits will be an outcome of the project. The additional crossing will significantly improve the flood evacuation situation in Grafton. Furthermore, potential opportunities exist to further reduce flood risk within the respective townships as part of the levee raising exercise which is proposed to mitigate the flood impacts associated with the bridge design. These issues are currently being considered as part of the design process.

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