

Bridging on the Alice Springs to Darwin Railway

Ken Ross, BE, MEngSc, MIEAust

Principal Engineer, Kellogg, Brown and Root, Brisbane;

Scott Ashdown, BE, MIEAust

Senior Engineer, Kellogg, Brown and Root, Brisbane;

Tony Dawson, ME, FIEAust, CPEng

Chief Engineer, Kellogg, Brown and Root, Melbourne

SYNOPSIS

The ADrail Design & Construct Joint Venture was responsible for the design and construction of the Alice Springs – Darwin Railway project. The 1420km project required 93 bridges to be constructed in remote locations, many where the readily available workforce was unskilled, and the infrastructure to support construction projects was minimal. Emphasis was thus needed to be placed on appropriate constructability, minimising site activity, and maximising prefabricated steel and precast concrete components. The result is an economical portfolio of bridges.

1 INTRODUCTION

The Alice Springs to Darwin Railway Project has been constructed under a 50-year Build, Own, Operate and Transfer (BOOT) concession. In 1998, the AustralAsia Railway Corporation, acting for the Governments of the Northern Territory and South Australia, invited BOOT bids from interested parties for the concession. The concession was awarded to the Kellogg, Brown and Root led Asia Pacific Transport Company in 2001 and construction of the \$1300 million project was completed in October, 2003.

The new line to Darwin is an extension of the existing rail line from Tarcoola in South Australia to Alice Springs. The extension is 1420 km long with track gauge of 1435mm. The route of the line is shown on Figure 1.

For most of the route between Alice Springs and Katherine, it passes over relatively flat arid country, with characteristically sheet flow streams that only flow during the wet season. Between Katherine and Darwin, the topography is more undulating, and the rivers and streams are better defined, with several flowing all year round.

The bridge design work commenced in 1998 as part of the Bid by the Asia Pacific Transport Company. Various studies had been carried out up to that time and made available to the Bidding Consortia. These showed basic levels of detail, including a centreline survey, some preliminary hydrological analysis, and details of the original North Australia Railway (NAR) alignment north of Katherine along which some of the route followed.

When Financial Close was achieved in April 2001, a separate entity, ADrail was formed to design and construct the railway for the Asia Pacific Transport Consortium. Detailed design

commenced at that time utilising KBR's bridge design personnel, and was completed in June 2002.

Bridge construction was completed in mid 2003, and Practical Completion for the Project was granted in October 2003.

93 bridges have been designed and constructed for the project, of which 6 are grade separations with roads, while the remaining bridges span across waterways.

2 DESIGN CRITERIA

The Design Brief specified that the bridges had to meet the following significant criteria:

- Design in accordance with the Australian Bridge Design Code (SAA HB77);
- Railway design loading 300-A-12;
- 220 million tonnes cumulative loading (in 40,000 trains);
- Flood immunity -
 - 100 year average recurrence interval to bridge soffit for 9 specified waterways, and
 - 50 year average recurrence interval for bridge overtopping for the remaining bridges.
- 100 years bridge design life.

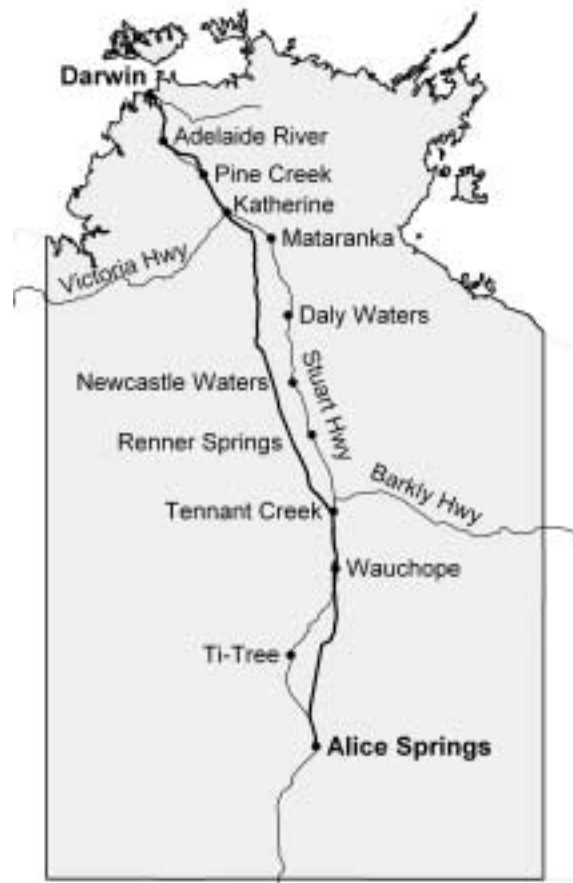


Figure 1 – Alice Springs to Darwin Route

3 HYDROLOGY

Flood frequency analysis is a difficult problem for the remote regions of the Northern Territory. The major river systems have recorded stream flow data for use in the design flood analysis, but most catchments are ungauged.

The stream flow data was collected and reviewed by ADrial's hydrologists, and the records analysed for stations with more than 15 years data. While it was recognised that this is a relatively short period of record for the longer recurrence interval design floods and the highly variable hydrology of the Northern Territory, there are few stations with long records. This period of record was therefore accepted as a compromise to ensure an adequate number of stations. Regional flood frequency procedures were applied to this data.

The hydrological analysis for the project is described in detail elsewhere (1). Hydraulic analysis generally followed Manning's criteria, although on some catchments, HEC2 modelling was deemed necessary. Ultimate limit state flood forces were applied to bridges as

the effect of the 100 year flood increased by 50%, and nearly all bridges were designed as submerged structures.

4 GEOTECHNICAL

Geotechnical investigations were primarily a borehole program at every bridge site and possible bridge site. Typically, a minimum of two holes were drilled at a bridge site, the number increasing for the longer bridge sites where holes were drilled at maximum spacings of 30 metres, or occasionally closer if conditions were variable.

The great majority of sites revealed over the top 10 metres either medium dense sands and gravels suitable for founding driven piles, or sedimentary rocks of varying degrees of weathering suitable for drilling socketed piles. Foundations rarely needed to go deeper than 10 metres. Only three bridge sites, all near Alice Springs, revealed sufficiently hard surface rock to require footings instead of piles.

5 BRIDGE STUDIES

The development of the bridge designs for the Project went through a number of evolutionary phases, starting in 1998 with the issue of the Invitation to Bid documents by the AustralAsia Railway Corporation, and continuing beyond Financial Close in April 2001, to overlap with the first 12 months of the construction. These four years allowed an uncommonly extensive period of interaction between the designers, the key construction personnel and the project cost planners. The result was an ongoing refinement of the bridge design, both in the context of the bridging and in the interface with the overall project constraints. Many of the key design decisions were equally owned by the designers and constructors.

The Bid documentation included advice of earlier studies related to bridging, hydrology and geotechnical studies. It identified 7 ‘major’ bridges (Elizabeth, Adelaide, Cullen, Fergusson, Edith, Katherine and Charles Rivers), 91 ‘minor’ rail bridge sites, and eight road over rail bridges at major road crossings. At all bridges locations, the rail design speed was 115km/hr. The major bridges were proposed in multiples of 30m span lengths, while the minor rail bridges were proposed in a range of six span lengths between 10m and 30m. The total length of identified bridging was 5916m, potentially representing about 10% of the Project cost.

Early in the Bid phase, these span lengths were rationalised down to 3 span lengths viz. 30m, 18m and 12m. The 12m span was selected as this length could be transported around the Territory without transport restrictions. The 30m span length was necessary as it matched the span lengths already existing on the adjacent 17-span road bridge at Elizabeth River. 18m was adopted as a suitable intermediate span length. It was also important to adopt ballasted decks as far as possible, to allow efficient track laying. Ballasted bridge decks were 4m width between kerbs.

All likely bridge configurations were examined as thoroughly as the available data would allow. This data was limited to the surveyed long sections, photogrammetric survey at a few sites, geotechnical data extrapolated from adjacent road bridge sites, and visual inspection of a good number of sites by experienced personnel.

Bridge costs in remote regions are heavily influenced by unavailability of an experienced workforce, the cost of that workforce, and the lack of supporting infrastructure, such as piling and concrete suppliers. Cost effectiveness was thus achieved from minimising site activity, and maximising prefabricated steel and precast concrete components.

For the 12m spans, the superstructure types considered included twin prestressed concrete voided slabs placed side by side, and steel girders with either composite deck slab or non-composite steel trough deck. Both reinforced concrete and steel substructures were considered. Costings of the options showed that the twin prestressed concrete slabs supported on steel piers was clearly the cost effective solution for these minor bridge sites.

For the 18m and 30m spans, superstructure forms developed included steel girders with composite deck, tee-roff style pretensioned concrete beams with composite deck, and incrementally launched superstructures in both steel and concrete. The substructures were single columns on footings or piled foundations. Cost comparisons of these options showed that the tee-roff beams with composite deck were more cost effective at sites between Darwin and Katherine, whilst the steel beams with composite deck was more cost effective at the Charles River site near Alice Springs, due to transport costs of concrete girders.

At that stage in the bid process, eighteen bridges were identified as comprising 18m spans, and six bridges were identified with 30m spans.

After Contract award, when detailed hydrological and geotechnical data became available, it unfolded that all new bridges other than the six major bridges at Katherine, Edith, Fergusson, Cullen, Adelaide and Elizabeth were more cost effective with the short span twin prestressed concrete slab design, generally on steel piers.

In its assessment of the initial Bids, the AustralAsia Railway Corporation identified that the financial viability of the project could be improved by relaxation of the design criteria in the original Project Brief. The Asia Pacific Transport Company sought to identify appropriate relaxation in these criteria for a revised Bid. The most significant relaxations that impacted on the bridge design were:

- Reduction of design load from 300-A-12 to 230-A-12;
- Reduction of design speed to 80 kph between Katherine and Adelaide River thus enabling significant reuse of the bridging on the former NAR alignment;
- Reduction in ballasted deck width to 3.5m between kerbs.

The reduced loading is justified as the bridges on the line south of Alice Springs were also designed for AREA Coopers E50 loading, which approximates HB77 230-A-12.

The reuse of the NAR alignment also allowed the recycling of the existing substructures along that alignment through modification of those substructures.

6 MAJOR BRIDGES

The five new bridges across the largest waterways have been designated major bridges. They are characterised by being constructed in simply supported 30m spans, comprising two 1500mm deep pretensioned tee-roff beams and a composite deck slab.

At Katherine, Edith, Cullen and Adelaide Rivers, piers up to 17m high of single circular section support the superstructure. They comprise a steel tube of 1000mm top diameter and constant (1 in 28) taper connected to in-situ concrete stub columns of 2m to 3m height. This configuration provided maximum uniformity for the jointing of prefabricated components whilst allowing flexibility in pier heights via the site constructed base joint. This pier form has resulted in remarkably short construction times and great economy.

The typical form of these four bridges is shown in Fig. 2, whilst a photograph of the near complete Katherine River Bridge is shown in Fig. 3.

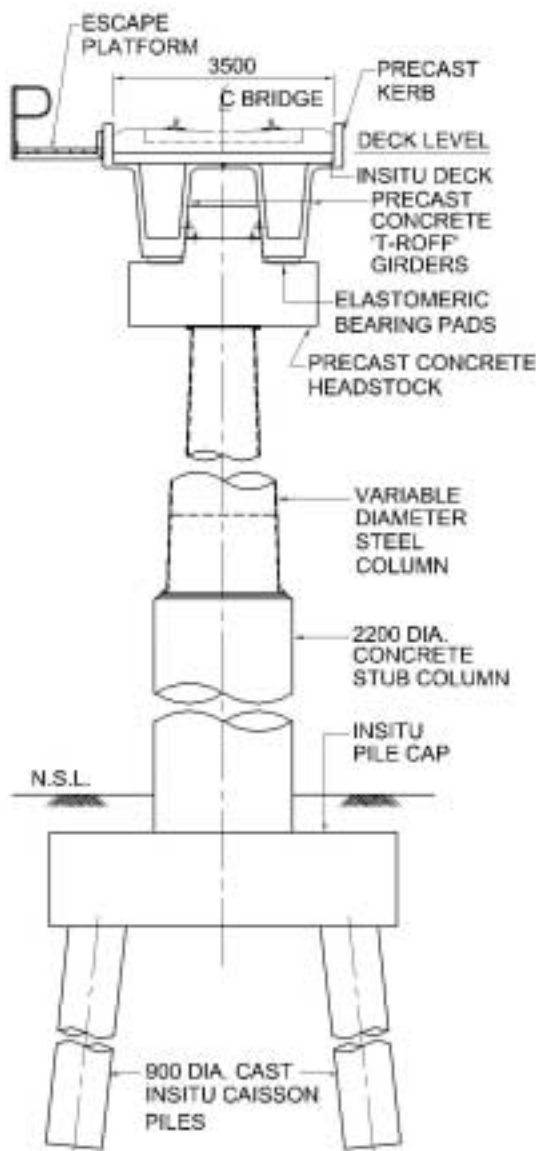


Figure 2 – Typical Major Bridge Section



Figure 3 – Katherine River Bridge

The other major bridge is located at Elizabeth River. This bridge comprises seventeen 30m spans and is the longest bridge in the Project.

The rail bridge is unusual in that it has been positioned adjacent to an existing 17-span bridge along the road from Darwin to Channel Island and attached to that bridge. The attachment detail between the road and rail bridges is shown in Fig 4. The attachment comprises a yoke fixed to the edge of the rail bridge headstock, and clamped around the tops of the road bridge piers. The yoke is designed to carry all lateral and longitudinal loads in the rail bridge superstructure to the road bridge piers. Those road bridge piers have adequate reserve capacity to carry the imposed horizontal rail bridge loadings.

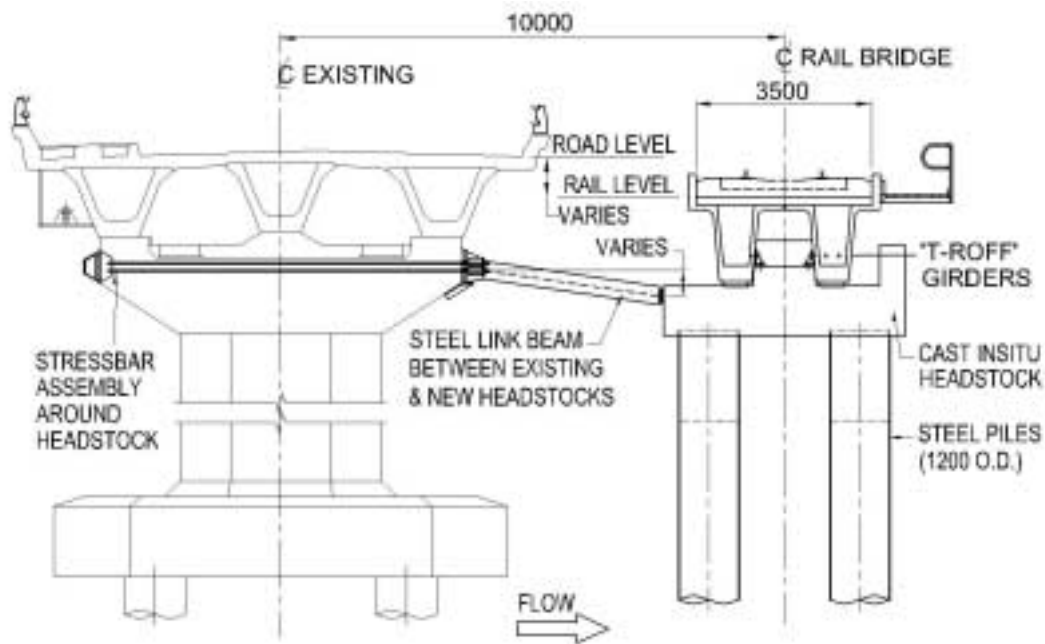


Figure 4 – Elizabeth River Bridge

The Elizabeth River is a saltwater estuary with an eight metre tidal range. To avoid cofferdams and to minimise the number of work operations, each pier sub-structure consists of a pair of tubular steel piles driven to 7000kN ultimate geotechnical load, and cut off below a cast-in-situ headstock. The critical lateral loading on the piles was the impact of a drifting vessel. The piles were filled with mass concrete to resist local deformation under impact.

Following the recent discovery of microbiological influenced corrosion of some Arnhem Highway bridge piles, including a notable pile collapse on the Adelaide River Bridge, particular attention was paid to the corrosion protection system. After considerable study, the Dulux Steelshield system to 3 mm thickness, augmented by a sacrificial aluminium anode cathodic protection system was adopted. This was selected in preference to an impressed current system due to maintenance and vandalism considerations and because no permanent power supply was available at the site.

7 MINOR BRIDGES

There are 84 other new railway bridges on the Project. One bridge carries the rail over the Crater Lakes road from the Stuart Highway to Bachelor. The other bridges all cross waterways. The great majority of these waterways only flow during the wet season, and thus the bridges can be constructed in dry conditions.

17 bridges along the old NAR alignment between Katherine River and Adelaide River reuse the existing bridge abutments. All the other bridges are completely new, and are designed in a modular form of design in multiples of 12m spans. Piers for minor bridges usually comprise two tubular steel piles and a box shaped headstock with radiussed soffit butt welded into a slot cut through the top of the piles. The headstock was 300mm narrower than the piles.

Typical cross sections for these bridges are shown in Fig 5, while one of the 371 typical piers is shown in Fig 6.

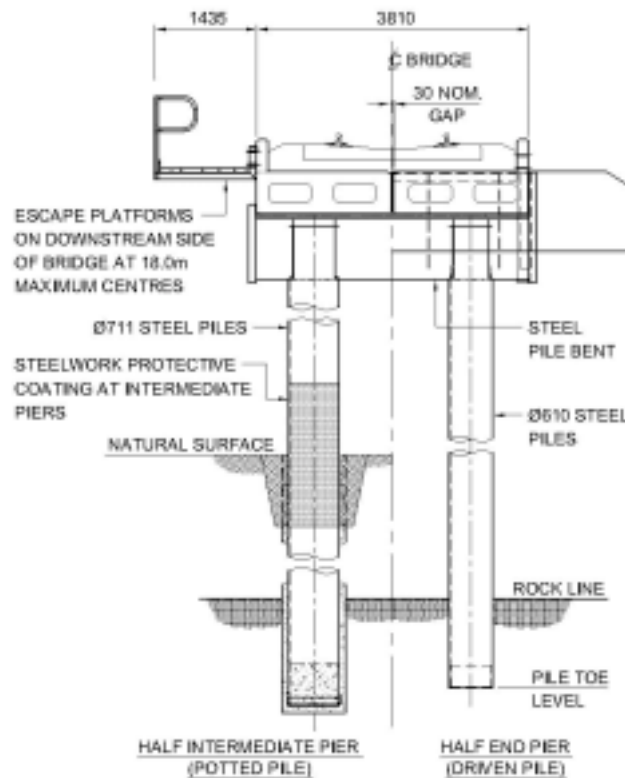


Figure 5 – Typical Minor Bridge Section

Potted piles have a predrilled oversize hole of sufficient depth to develop flexural fixity and pullout capacity where required. After the pile is stood up to correct line and level above the base of the pile, high slump concrete is poured around the bottom of the pile to at least 2m depth. The piling crew was equipped to construct both forms of pile.

Intermediate pier piles are 711mm dia with wall thickness varying between 12mm and 16mm depending on the level of design lateral loads, mainly flood and debris load. Not all piles and headstocks received protective coatings, with sites south of Katherine being designed for a corrosion allowance except where they have a protective coating at river bed level. Abutment piles are 610 dia and 12mm wall thickness.



Figure 6 – Typical Minor Bridge Pier

Piles are either driven steel tubes where the upper layers of the ground are penetrable, or potted where the upper layers are too hard for adequate pile driving penetration.

The most critical aspect of the pier design is the fatigue behaviour of the pile/headstock connection. The connection was modelled using thin plate shell bending elements. The connection was analysed in a series of models that allowed for piles up to 75mm out of position, variations in internal stiffener locations, and headstock shape. The specified 620Mt freight tonnage over the design life was disaggregated to realistic train axle loading sets. The fatigue design procedure followed the American Petroleum Institute (API) document “Recommended Practice for Planning, Designing and Constructing Fixed Offshore Platforms - Working Stress Design”. This method of fatigue analysis looks at local stress concentration for connections through published tables of Stress Concentration Factors based on finite element analyses. It requires the calculation of stress history as the design train passes over the pier, the application of the Rainfall Counting method to the stress history to obtain the breakdown of stress cycles over the history, and evaluation of fatigue damage based on breakdown of stress cycles.

The cost effectiveness of the design was derived from mass production and the minimisation of site works. Three stages were involved in the construction of these bridges. The piling crew typically installed the piles over two to three days and then moved to the next site. At a later time, the headstock crew cut the slots in the piles and welded in the prefabricated steel headstock pieces, again over a 2-3 day period. When a number of adjacent sites were available to receive their superstructures, the prestressed slabs were transported down from the casting yard in Darwin and erected typically in less than one day for an entire bridge. A separate earthworks crew installed precast wingwalls where required to complete the bridge.

The prestressed concrete girders for the 12m spans were 600mm deep. Virtually all prestressed slabs were identical end for end, including ballast kerbs, and were not ‘handed’. They were thus ideally suited to mass production and ease of distribution. The voids were full length of the slabs and were formed with collapsible internal steel forms.

Five bridges departed from the standard bridge substructure design. This occurred where there was shallow depth to strong rock, plus relative proximity to the ready mix concrete plants at Katherine and Alice Springs which influenced the cost balance. At these sites concrete piers were used, consisting of twin insitu columns with precast headstocks attached via post tensioned bars

8 RECYCLED BRIDGES

Some 156 kilometres of the NAR alignment north of Katherine was reused. This allowed, where possible, the recycling of some bridges along that alignment. These bridges had been built in stages, with the line from Darwin to Pine Creek completed in 1888 to carry Coopers E30 loading, and extended in stages to Katherine in 1926, to carry Coopers E50 loading.

The decision granted during the Bid period allowing the reduction in bridge design load to HB77 230-A-12 - which approximates Coopers E50 loading - permitted the reuse of the existing heritage listed transom deck railway bridge over the Fergusson River.

That bridge completed in 1923, was a steel plate girder superstructure in five spans of 30.5m or 18.3m, with piers over 20m high. Its design load was AREA Coopers E50, which approximates 230-A-12. It is shown in Fig. 7.



Figure 7 –Recycled Fergusson River Bridge

This bridge was constructed in the 1920s to carry Coopers E50 loading. It only needed some minor strengthening, mainly to the bracing between the girder pairs, to meet the current code standards. Corroded rivets were replaced with friction grip bolts, new walkways and steel transoms were fixed, and some of the steel roller bearings were replaced.

All NAR bridges available for reuse were originally steel stringer transom deck structures. Their lengths were typically made up from multiples of 4.0m, 4.6m, 6.7m, 12.2m and 18.3m spans. The abutments of these bridges were unreinforced concrete gravity structures with concrete strengths of the order of 10MPa to 15MPa. None had been undermined by flood flows, despite lack of maintenance since the line was closed in 1976, although there was occasional abrasion of concrete from water flow at bed level.

The existing abutments of these bridges have been reused by keying a new reinforced concrete seating to the top to suit higher railway formation levels, and placing twin prestressed concrete slabs on that seating.

Where the bridge length between existing abutments was greater than 12m, new intermediate piers of the standard minor bridge structural steel design were provided at equal spacings. This led to the design of a range of shorter spans of 4.6m, 6.7m, 8.1m, 9.1m, 10.3m, 11.1m and 11.5m. 17 bridge sites were reused in this way.

A typical example of one of the NAR bridges showing two intermediate steel piers and one reused mass concrete abutment is shown in Fig. 8.

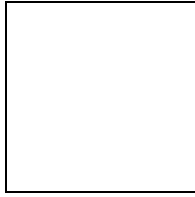


Figure 8 – Typical Recycled Minor Bridge

9 CONCLUSION

The Alice Springs to Darwin BOOT railway is by far the largest new railway constructed in Australia in recent decades. The 93 bridges of 5700m total length were a major component of the cost. As such, the bridges provided a unique opportunity to explore construction economy in modern railway bridge engineering and optimise the whole-of-life costs.

The adopted bridging solutions with their use of off-site precast and prefabricated components have realised outstanding program and cost outcomes, particularly for a remote location. The result demonstrated the value of extensive interaction between the designers and key construction staff.

9 ACKNOWLEDGEMENTS

The authors thank Asia Pacific Transport Company and ADrail, for permission to publish this paper. The authors wish to acknowledge the cooperative engagement of the ADrail Project Director, Al Volpe, Design & Construction Manager, Jock Chudacek, Design Manager, Charles Duncan, and Construction Managers Kevyn Brown and Tony Tanna.

10 REFERENCES

- 1 Weeks, W.D., Teakle, I.A.L., Gondinoudis, S. and Doherty, H. M. (2002). “Alice Springs - Darwin Railway Regional Flood Frequency Assessment” *National Hydrology and Water Resources Symposium*, Published on CD-ROM by IEAust., Melbourne, May 2002.