Moorland to Herons Creek EIS

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Hydrology and Flooding

Pacific Highway Upgrade
Moorland to Herons Creek
Preferred Option
Working Paper –
Hydrology/Hydraulics Report

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LIST OF ABBREVIATION

1D/2D	One dimensional/two dimensional
AHD	Australian Height Datum
ARI	Average Recurrence Interval
DEM	Digital Elevation Model
DIPNR	Department of Infrastructure, Planning and Natural Resources
DLWC	Department of Land and Water Conservation
PMF	Probable Maximum Flood
PWD	Public Works Department

1 INTRODUCTION

Ove Arup & Partners has commissioned WBM Oceanics Australia to carry out hydrological and hydraulic assessments as part of the Route Selection, EIS and preliminary design of the upgrade of the Pacific Highway between Moorland and Herons Creek. The route selection report was submitted in September 2001.

This report forms part of Ove Arup & Partners' EIS and preliminary design of the upgrade of the Pacific Highway between Moorland and Herons Creek. It addresses the detailed flooding analysis of the major watercourses across the Highway (eg, Stewarts River, Camden Haven River and Herons Creek) using both one-dimensional (1D) and two-dimensional (2D) hydraulic models.

The purpose of this report is to document the detailed hydraulic analysis of the major watercourses crossed by the previously selected route as well as the preliminary hydraulic design of the waterway structures under the Highway to achieve the design standard flooding criteria.

The proposed dual carriageway, four lane upgrade is to provide a minimum of one lane trafficable in each direction for the 20 year Average Recurrence Interval (ARI) flood event south of Kew. North of Kew, the upgrade is to provide a minimum of one lane trafficable in each direction for the 100 year ARI flood event.

In addition, the proposed upgrade should not cause any unacceptable increase in flood levels, velocities or times of flood inundation. Where unacceptable flood levels, velocities or times of flood inundation occur as a result of deficiencies in the existing highway, it is anticipated that it may be necessary to consider improvements in existing drainage provisions.

2 HYDRAULIC ANALYSIS OF MAJOR WATERCOURSES

2.1 Overview

Previously two major watercourses were identified along the proposed highway upgrade corridor, namely Stewarts River and Camden Haven River (WBM, 2001). Herons Creek was also found to be of significant importance due to the potential overtopping of the Highway during a moderate to a large flood event in Herons Creek. This section outlines the following aspects of the three major watercourses:

- Existing flooding behaviour;
- Hydraulic modelling (1D and 2D) of the existing watercourses incorporating the Pacific Highway and the waterway structures (eg, bridges, and culverts);
- Analysis of the discharge capacity of the existing waterway structures; and
- Recommended upgrading of the waterway structures

Where any existing waterway structures were found to have inadequate capacity to meet the design flooding criteria preliminary design of these structures has been outlined in Section 4.

2.2 Stewarts River

2.2.1 Existing Flooding Behaviour

The Stewarts River has a catchment of 103 km^2 upstream of the Pacific Highway crossing near the town of Johns River as shown in Figure 2-1. This river flows into Watson Taylors Lake approximately 5 km downstream of the Pacific Highway. The catchment extends westward to include parts of the Lansdowne State Forest. The major tributaries of the Stewarts River are Starrs Creek and Deep Creek.

The Camden Haven Flood Study (1989) included estimation of Stewarts River inflows into Watson Taylors Lake in order to derive appropriate flood levels in the lake. However, this modelling of Stewarts River was limited to hydrologic modelling (ie. deriving flows from rainfall) and did not include any hydraulic modelling (ie. deriving flood levels from flows) of Stewarts River.

Based on the hydrologic modelling of the Camden Haven River, which included Stewarts River catchment, the critical duration for flooding was found to be 36 hours (PWD, 1989). Hence, it is expected that flood events would result in elevated river levels for similar periods.

The Pacific Highway crossing of the Stewarts River was re-constructed in 1982. The existing bridge has a minimum road level of 8.5 mAHD. The highest recorded flood level over the last 70 years is 5.7 mAHD (in the 1929 flood event).

2.2.2 Hydraulic Modelling

The flooding pattern of Stewarts River in the vicinity of the Pacific Highway is considerably one-dimensional in nature, except when the river overtops its right bank on the upstream of the Pacific Highway. A MIKE11 1D model was developed in quasi 2D form to analyse the flow along the river, floodplain and between the river banks and the floodplain. The river network represented by the MIKE11 model is shown in Figure 2-2.

The total length of the river that has been modelled is 7.2 km. The upstream end of the MIKE11 model is approximately 2.5 km upstream of the Pacific Highway Bridge and the downstream extent of the model is the Watson Taylor Lake.

Six cross-sections of the river were surveyed at locations shown in Figure 2-2. Additional cross-sections of the river and adjacent flood plains were obtained from a digital elevation model (DEM). The DEM was derived using the data from the aerial photogrammetric survey of approximately 1 km strip along the proposed Pacific Highway upgrade. The cross-sections of the floodplain outside the DEM area were estimated from bank levels and the 10 m contours shown on the 1:25,000 scale topographic maps of the area.

Roughness of the cross-sections was estimated based on the aerial ortho and/or aerial perspective photographs. Most of the floodplain was either cleared pasture land or estuarine swamp. Manning's roughness coefficient n-value for the floodplain was assumed to be 0.04. However, higher roughness coefficient of up to n = 0.08 was assumed along the riparian zone of the river where thick vegetation was found.

The electronic version of the previous RAFTS model (PWD, 1989) was not available. However the model was reproduced based on the information available from the study report to obtain the design flow boundary at the upstream end. The estimated 100 year ARI discharge from the Stewarts River catchment was approximately 10% more than the value in the report.

The downstream end boundary at the Watson Taylor Lake was obtained from the Camden-Haven River hydraulic model (Section 2.3). Two different combinations of the downstream end boundary were selected depending on whether the assessment was for the purpose of impact assessment of the bridge duplication or for the estimation of the design road levels. The higher water level in the Watson Taylor Lake would result in the higher flood level at the Pacific Highway and vice versa. Therefore, the constant peak flood level of the same frequency flood event was considered for determining the waterway area and road level of the proposed duplication. Conversely, the impact of the duplication of the Pacific Highway Bridge is expected to be more sensitive to the low water level in the Watson Taylor Lake. Therefore, lower water level at the Lake was considered for the impact analysis.

The adopted downstream boundary conditions are shown in Table 2-1.

The existing and the proposed bridge deck levels (approximately 8.5 mAHD) are above the predicted 100 year ARI peak flood level at the bridge site (approximately 3.5 mAHD). The width of the flow opening area is approximately 290 m, which is adequate width for the floodwater not to experience any considerable constriction. Therefore, the energy losses through the bridge are predicted to be small.

Table 2-1 Downstream Boundary Condition of Stewarts River Model

Design Flood Event in Stewarts River (year ARI)	Downstream Water Level in Watson Taylor Lake (assumed constant peak flood level from Camden Haven River model)	
	Impact Assessment of Bridge Duplication	Assessment of Design Road Level
5	Constant water level of 0.5 mAHD	5 year ARI peak flood level (2.3 mAHD)
20	5 year ARI peak flood level (2.3 mAHD)	20 year ARI peak flood level (2.7 mAHD)
100	20 year ARI peak flood level (2.7 mAHD)	100 year ARI peak flood level (3.3 mAHD)
PMF	100 year ARI peak flood level (3.3 mAHD)	100 year ARI peak flood level (3.3 mAHD)

2.2.3 Analysis of Design Flood Events

The peak flood levels for 5, 20, 100 year ARI and PMF along the Stewarts River are shown in Figure 2-3. These peak flood levels were estimated using the downstream boundary condition mentioned in the far right column of Table 2-1. The peak flood levels for the 20 year ARI and 100 year ARI would provide guidelines for determining the crest level of the Pacific Highway duplication.

It is not anticipated that any houses would be inundated during a predicted 5, 20 and 100 year ARI flood events in Stewarts River in the vicinity of the Highway.

2.2.4 Impact of Duplication of Highway

The impact of duplication of the Pacific Highway on the design flood levels has been assessed using the downstream boundary condition mentioned in the second column of Table 2-1, and is shown in Figure 2-4.

The bridge deck, piers and abutment for the duplicated highway are similar to those of the existing bridge. Duplication of the bridge in the close proximity (within 20m) of the existing bridge would not increase the flow constriction significantly. The duplicated bridge was modelled as a parallel bridge according to the AUSTROADS (1994) guideline and the bridge loss coefficients were increased by 40% in comparison to the existing bridge. Nevertheless, the impact of the duplication of the Pacific Highway Bridge at Stewarts River on 5, 20, 100 year ARI and PMF peak flood levels are predicted to be negligible.

The time of inundation for the Stewarts River floodplain will also not change to any discernible degree as a result of the upgrade as demonstrated in Figure 2-5.

2.3 Camden Haven River

2.3.1 Existing Flooding Behaviour

The Camden Haven River is the largest river crossed by the route with a catchment of 257 km^2 (upstream of the Pacific Highway) as shown in Figure 2-1. The catchment extends westward to the Broken Bago Range and includes large areas of State Forest (eg. Broken Bago, Lorne, Kerewong, Comboyne and Upsalls Creek State Forests). The major tributaries of the Camden Haven River are Black Creek (north-west) and Upsalls Creek (west), McLeod's Creek (west) and Gills Creek (south-west).

The highway upgrade corridor crosses the floodplain near the settlement of Rossglen immediately upstream of the existing Pacific Highway bridge over the Camden Haven River and approximately 5 km upstream of the junction of the Camden Haven River and Watson Taylors Lake. As well, the highway upgrade corridor crosses the eastern edge of the Camden Haven River floodplain north-west of Kew.

A flood study was carried out for the Camden Haven River in 1989 by Willing and Partners Pty Ltd for Hastings Shire Council. The study included the development of a numerical model of the river and its floodplain using the modelling system WILLCELL (a 1D hydrodynamic flood modelling program). The study derived the flood behaviour for a range of design flood events (eg. 100 year ARI, 50 year ARI and 20 year ARI).

The flood behaviour of the Camden Haven River is influenced by a range of factors including:

- the intensity of rainfall on the catchment;
- the duration of rainfall on the catchment;
- the timing of the catchment runoff in relation to runoff from other tributaries of Watson Taylors Lake (eg. Stewarts River);
- the magnitude of elevated ocean levels occurring due to effects such as storm surge; and
- the timing of the flood runoff in relation to the peak ocean levels (eg, tide and storm surge).

The flood study concluded that peak flood levels at the Pacific Highway and other parts of the study area are influenced by the above factors. The highest peak flood levels at the Pacific Highway occurred with an ocean storm surge occurring 24 hours after the start of a 36 hour rainfall event.

This design flood results in long duration flooding at the Pacific Highway with elevated river levels occurring for more than 24 hours.

The existing bridge is 164m long and was constructed in 1984. There is also a culvert on the floodplain to the south of the bridge consisting of four cells of 1.8m x 1.8m Reinforced Concrete Box Culverts (ie. RCBC's) with a total flow area of 13m^2. There is also a culvert to the north of the bridge (1/2.6m wide x 2.0m RCBC). However, this culvert is non functioning as it appears to have sunk.

Hastings Council has made the following comments on the issues to be considered in planning stage of project:

"Flood studies undertaken on Council's behalf during 1989 identified that the existing Pacific Highway that traverses the Camden Haven River floodplain between Ross Glen and Kew imposes a constraint on the movement of flood waters. Council requests that concept designs and subsequent detailed designs ensure the safe passage of flood waters and that the objective of the NSW Governments Floodplain Development Manual is addressed in so far as that any works proposed should not result in any net increases in flood levels and flood costs to the community".

The concept design for the upgrade across the Camden Haven River floodplain will require consideration of the impact of the additional structure proposed for the western side of the existing bridge and embankment across the floodplain.

During the Route Selection stage of the project (WBM, 2001), it became apparent that the Camden Haven River flooding issues are relatively complex and would benefit from a 2D approach. Therefore, a 2D model for an area encompassing upstream and downstream of the Pacific Highway, particularly for the floodplain area was developed using the TUFLOW software (WBM, 2003).

2.3.2 Hydraulic Modelling

The electronic version of the previous hydraulic model for the Camden Haven Flood Study (PWD, 1989) using WILLCELL model was not available. However, a MIKE11 model of Camden Haven River was obtained from DLWC (currently DIPNR), which was prepared for for the estuary study of the lower part of the river. The MIKE11 model was developed based on the information in the WILLCELL model.

It was decided to use the 2D model TUFLOW (WBM, 2003) for the area adjacent to the Pacific Highway Bridge, which required linking to a broad scale 1D model of the Camden Haven River. Therefore, a 1D ESTRY (WBM, 2002) model was used for broad scale modelling of Camden Haven River due to its ability to be dynamically linked with the TUFLOW model. The existing and the proposed duplicated bridges across the Camden Haven River were also modelled in the 1D model.

The 2D modelling area is 920 hectares (Figure 2-6). The modelling area is approximately 3.0 km in the east-west and 3.9 km in the north-south directions. The size of the 2D grid is 10 m. This results in approximately 97,000 cells representing the topography of all flowpaths and storage areas in the 2D domain. Approximately 48,000 cells were used during the 100 year ARI flood event.

Detailed topographic information required for the above-mentioned hydraulic modelling was obtained from the following sources:

- topographic survey data comprised of an aerial photogrammetric survey of the study area and limited detailed ground survey of the study area; and
- survey of six cross-sections of 5.5 km reach of the Camden Haven River in the vicinity of the Pacific Highway Bridge across the River.

The boundary conditions for the 2D model were applied through the 1D hydraulic model and transferred to the 2D modelling domain via 1D/2D dynamic links. The main inflow hydrograph was entered at the upstream extent of the 1D model of Camden Haven River at Kendall. The inflow from the residual catchment between Kendall and Watson Taylor Lake was also included on the upstream side of the Pacific Highway Bridge. Other inflows (eg. inflows from Stewarts River and Herons Creek and local catchments) were included downstream side of the 1D model. The ocean boundary was based on the previous study (PWD, 1989).

The roughness of the potential flowpaths has been processed in the model using the Manning roughness coefficient, n. The roughness was estimated based on the vegetation, meandering of the channel and roughness of the bed materials. The values of n were obtained from the previous study (PWD, 1989).

2.3.3 Analysis of Design Flood Events

Four design flood events were analysed for the existing scenario, namely 5, 20, 100 year ARI's and the PMF. The extents of flooding for these flood events are shown in Figure 2-7.

Figure 2-8 shows the contours for the peak 100 year ARI flood levels and the velocities for the existing scenario. The Pacific Highway would be overtopped during a predicted 100 year ARI flood event approximately 500 m north of the bridge across the Camden Haven River. The peak flood level difference upstream and downstream of the existing highway is approximately 0.3 m for this flood event at this location (ie. 500 m north of river). The maximum overtopping depth and velocity during the 100 year ARI flood event are predicted to be 0.3 m and 1.5 m/sec respectively. The peak 100 year ARI flood level difference upstream and downstream of the bridge (ie. at the river) is approximately 0.04 m, which is approximately the afflux for the existing Pacific Highway.

The 20 year ARI flood levels and the velocities for the existing scenario are shown in Figure 2-9. The Pacific Highway would not be overtopped during the predicted 20 year ARI flood event. The 20 year ARI peak flood level difference upstream and downstream of the Pacific Highway bridge (ie. at the river) is approximately 0.03 m, which is approximately equal to the afflux for the existing Pacific Highway. The peak flood level difference upstream and downstream of the existing highway at 500 m north of the river is approximately 0.28 m for this flood event.

The peak velocities (depth and width averaged) for the 100 and 20 year ARIs flood events are predicted to be 2.2 and 1.8 m/sec respectively in the Camden Haven River under the bridge for the existing highway.

2.3.4 Impact of Duplication of Highway

The following criteria are to be fulfilled for the proposed duplication of the Pacific Highway south of Kew:

1) At least one carriageway must be free from inundation during the predicted 20 year ARI flood event; and

2) The proposed duplication must not worsen the flooding of existing properties on the floodplain.

The proposed duplicated highway will be a new north bound bridge on the western side of the existing Pacific Highway Bridge across the Camden Haven River. The proposed bridge would be identical in span arrangement to the existing one and approximately 16 m (between centrelines of the bridges) on the upstream side. The design drawings of the proposed bridge indicates that the new bridge would be very similar to the existing bridge in terms of pier locations, pier sizes and abutment locations. The parameters for analysing the proposed bridge along with the existing bridge were adopted from the Waterway Design (AUSTROADS, 1994) guidelines considering the combination as a dual bridge.

The increase in the 100 year ARI peak flood level (afflux) on the upstream side of the proposed duplication is 16 to 17 mm as shown in Figure 2-10. The afflux of duplication on the 20 year ARI flood peak would be approximately 12 mm upstream of the Highway.

The predicted afflux is small for the duplication of the Pacific Highway across Camden Haven River. Therefore, no amelioration measures would be required. However, the highway would be overtopped by approximately 0.3 m deep floodwater during the 100 year ARI flood event at about 500 m north of the river.

Based on the above mentioned analysis, particularly overtopping of the highway during the 100 year ARI flood event (Q100), flood assessments for the new northbound carriageway with road level above the Q100 peak flood level were carried out. This road level with Q100 immunity would result in cumulative afflux of 22 mm during the 100 year ARI flood. It is recommended to provide 2/ 3.3m x 2.1m RCBC culverts near the existing sunken underpass, which would reduce the overall afflux for the proposed highway upgrade including the proposed carriageway above the 100 year ARI flood level (13 to 15 mm). The cumulative afflux due to the proposed duplication at a level above the 100 year ARI can be reduced to almost nil by increasing the number of box culverts to five.

The box culverts recommended in the previous paragraph has environmental significance. There is anecdotal evidence that the sunken underpass flows east to west during a heavy rainfall in the catchment feeding the SEPP14 wetland on the east side of the highway. However, this may only occur because of the tidal gates on the SEPP14 outlet to the river on the east side of the highway are closed. The recommended culverts are expected to assist in reinstating the hydrological regime of the wetland.

The stage hydrographs of a location approximately 500 m upstream of the Pacific Highway Bridge are shown in Figure 2-11 for the existing scenario and after the duplication of the Pacific Highway Bridge. This figure demonstrates that the proposed upgrade will have a negligible impact on the time of flood inundation on the Camden River floodplain.

The peak velocities (depth and width averaged) in the Camden Haven River under the bridge for the duplicated highway are predicted to be similar to the existing highway (ie. V_{100} = 2.2 m/sec and V_{20} = 1.8 m/sec).

2.4 Herons Creek

2.4.1 Existing Flooding Behaviour

The Herons Creek catchment (area 59.3 km^2) was previously modelled as a part of the entire Camden Haven River catchment (PWD, 1989). Refinement of the Herons Creek catchment model, especially on the upstream side of the Pacific Highway was required to estimate the design discharges more accurately. The sub-catchment layout and RAFTS network is shown in Figure 2-12. The catchment parameters for hydrologic modelling are shown in Table 2-2.

The rainfall intensities for the design storms were derived for 18 and 36 hours in the previous Camden Haven Flood Study (PWD, 1989). The Intensity-Frequency-Duration table for Herons Creek catchment was derived using the methodology in Australian Rainfall and Runoff (Institution of Engineers, 1987). Estimation of the design flows for a range of standard storm durations (ie. 1, 2, 3, 6, 12, 24, 36, 48 and 72 hours) was undertaken. The 36 hour storm duration was found to be the critical duration which resulted in the highest peak flow through Herons Creek at the Pacific Highway Bridge.

Table 2-2 Herons Creek Sub-catchment Parameter for Hydrologic Modelling

Sub-catchment	Total Area (Ha)	Impervious-ness (%)	Slope (%)	Roughness Pern	Time lag to downstream Sub-catchment (mins)
3A	2021	0	2.03	0.050	93.3
3B	1093	5	0.40	0.045	18.8
3C	1280	0	2.60	0.050	62.7
3D	791	5	0.60	0.045	14.3
3E	107	5	2.05	0.050	6.5
3F	37	3	0.70	0.040	11.0
3G	37	5	1.40	0.045	7.1
3H	133	3	1.80	0.050	14.8
3I	53	5	1.10	0.040	13.4
3J	76	10	1.85	0.050	8.4
3K	78	5	1.25	0.045	11.5
3L	131	5	1.10	0.060	15.9
3M	90	5	1.10	0.050	0

The estimated peak discharges of Herons Creek at the Pacific Highway are shown in Table 2-3.

Table 2-3 Herons Creek Peak Discharges

Design Flood Events (year ARI)	Current Study (Pacific Hwy Bridge, CA* = 59.3 km2)		Previous Study (PWD, 1989) (Queens Lake, CA* = 80 km2)	
	Critical Duration (hours)	Discharge (m3/s)	Critical Duration (hours)	Discharge (m3/s)
5	36	305	Not Available	Not Available
20	36	430	36	460
100	36	560	36	610
PMF#	36	1680	Not Available	Not Available

CA* - Catchment area # - PMF is assumed to be three times the 100 year ARI discharge

A detailed analysis for estimating the probable maximum flood (PMF) is an expensive exercise, which was not warranted for the Herons Creek catchment. The PMF was assumed to be three times the 100 year ARI discharge. This assumption is based on practical experience of catchments with similar characteristics and studies of similar nature.

The proposed route of the Pacific Highway crosses Herons Creek at the same location as the existing Pacific Highway crossing, but on the upstream side. The highest recorded flood level at the bridges is 5.18 mAHD (drawing RL 117 feet). This is 1.75 m lower than the road crest at 6.93 mAHD. The reduced level shown in imperial unit on the bridge drawing (ref required) was converted to Australian Height Datum using the following conversion formula:

RL in AHD = (RL in the bridge drawing in feet – 100 ft)/3.281

Preliminary estimates during the route selection study (WBM, 2001) indicated that the velocity through the bridge would be very high during a large flood event. This would result in a significant head drop across the bridge and would result in scour if all flow was contained within the bridge opening. It was supposed that the bridges would not have the capacity to pass the 100 year ARI flood event and that flooding would occur over the highway further to the south of the bridges and closer to the turn off to the township of Herons Creek. This is supported by the anecdotal evidence provided in the RTA's Strategic Concept Report of overtopping of the highway in this vicinity.

The existing bridge over the main Herons Creek waterway has two spans of 12m (ie. 24m span bridge). Replacement of this existing 24m span bridge is required in any case due to the age of the bridge. It was proposed in the route selection report (WBM, 2001) that the replacement bridge should have a total length of 32m and a minimum bridge level matching the level of the existing bridge. Another 32m long bridge crosses a flood channel 100m south of the main creek. This flood channel bridge replaced an originally smaller sized (12.2 m span) bridge. The existing Pacific Highway bridges cross Herons Creek 150m downstream of the railway bridges. There are numerous buildings (eg. houses) on the Herons Creek floodplain upstream of the Pacific Highway.

2.4.2 Hydraulic Modelling

During the Route Selection stage of the project (WBM, 2001), it was apparent that the Herons Creek flooding issues are relatively complex and would benefit from a 2D approach. The 2D model TUFLOW (WBM, 2003) was used for analysing the flooding characteristics and to design the required waterway structures for Herons Creek crossing the proposed Pacific Highway upgrade.

The 2D modelling area is 202 hectares (Figure 2-13). The modelling area is approximately 1.5 km in the east-west and 1.9 km in the north-south directions. The size of the 2D grid is 5 m. This results in approximately 80,000 cells representing the topography of all flowpaths and storage areas in the 2D domain. Approximately 26,000 cells were used during the 100 year ARI flood event for the existing scenario.

Detailed topographic information was obtained for an area of approximately 6 km^2 encompassing Herons Creek upstream and downstream of the Pacific Highway, lower part of Herons Creek village and all the waterway structures in the vicinity of the Herons Creek crossing of the Pacific Highway. The topographic data in the 2D model was obtained from a digital elevation model (DEM), which was produced using the topographic survey data supplied by Roger Dwyer & Associates. The survey data comprised of an aerial photogrammetric survey of the study area and some limited detailed ground survey of the study area.

The boundary conditions for the 2D model were applied through the 1D hydraulic model and transferred to the 2D modelling domain via 1D/2D dynamic links. There were two upstream inflow boundaries, namely Herons Creek main inflow and its tributary (location 1 and 2 respectively in Figure 2-13). The downstream was located approximately 1.5 kms from the Pacific Highway. A fixed water level of 3 mAHD was assumed to be the downstream boundary, which is the 100 year ARI peak flood level in Queens Lake (PWD, 1989).

The roughness of the potential flowpaths has been processed in the model using the Manning roughness coefficient, n. The roughness was estimated based on the vegetation, meandering of the channel and roughness of the bed materials. The values of n were obtained from values for similar land-uses in other calibrated 2D hydraulic models. The riparian zone of Herons Creek has a considerable cover of trees. However, the main channel does not have much vegetation at the centre of the creek. The land between the riparian zone and adjacent high ground is predominantly pasture without many trees. The high ground has significant cover of native vegetation. However, this area is mostly above the highest flood level considered in this study.

The values of n adopted for this study are as follows:

- Floodplain and grassland (pasture) 0.04;
- Riparian zone on creek bank 0.10; and
- Creek bed 0.04.

There are four waterway structures across the existing Pacific Highway in the vicinity of Herons Creek as listed below:

1) An existing 24 m wide old bridge across the main Herons Creek (Arup structure No. 28);
2) A reconstructed 32 m bridge along the right flood channel (No. 28);
3) A 450 mm diameter pipe culvert at 200 m south of the floodplain bridge (No. 26A); and
4) A 2m x 2m RCBC at 90 m south of Herons Creek Road (No. 26).

Modelling of the above mentioned bridges were undertaken in the 2D TUFLOW model. However, the culverts were modelled as 1D structures, which were dynamically nested inside the 2D modelling domain.

2.4.3 Analysis of Design Flood Events

Four design flood events were analysed for the existing scenario, namely 5, 20 and 100 year ARI's and the PMF. The extents of flooding during these flood events are shown in Figure 2-14.

Figure 2-15 shows the contours for the peak 100 year ARI flood levels and the velocity vectors and magnitudes. A 170 m section of the Pacific Highway south of the Herons Creek bridges would be overtopped by the predicted 100 year ARI flood. The overtopping depth is predicted to be approximately 1.0 m at the lowest point of the highway.

The peak 100 year ARI flood level difference upstream and downstream of the northern bridge (ie. at the creek) is approximately 0.57 m, which is approximately the afflux for the existing Pacific Highway. The existing afflux at the southern flood channel is approximately 0.75 m. The maximum peak flood level difference at the above mentioned location of overtopping is predicted to be approximately 2.0 m during the 100 year ARI flood event.

The peak velocities (V_p) during the 100 year ARI flood event in Herons Creek under the existing Pacific Highway bridge would be 1.7, 2.0 and 2.1 m/sec on the left bank, centre and right bank of the creek respectively. The V_p would be 0.6, 3.0 and 1.6 on the left bank, centre and right bank of the flood channel respectively under the existing bridge. The maximum peak overtopping velocity would be approximately 2.7 m/sec.

2.4.4 Impact of Duplication of Highway

The following criteria are to be fulfilled for the proposed duplication of the Pacific Highway north of Kew:

1) At least one carriageway must be free from inundation during the 100 year ARI event; and
2) The proposed duplication must not worsen the flooding of existing properties.

The proposed northbound carriageway was considered to be set above the predicted 100 year ARI flood levels. Figure 2-16 shows the impact on the 100 year ARI peak flood levels of the raised carriageway assuming only duplication of the existing waterway structures. If only duplication of the existing waterway structures is assumed, the 100 year ARI peak flood levels would increase by the following margins:

- 280 mm between the Pacific Highway and the Railway line;
- 200 mm upstream of the Railway line;
- 930 mm at the southwest corner of the Pacific Highway and Herons Creek Road; and
- 150 mm immediately downstream of the Pacific Highway Bridges.

No houses are predicted to be flooded in the 100 year ARI event even after the above-mentioned considerable additional afflux resulting from the proposed duplication. The increase in flood levels immediately downstream of the Pacific Highway bridges is due to the increase in headwater for bridge waterway discharge. This would result in high erosion potential at the bridge abutments and adjacent areas.

2.4.5 Preliminary Design to Ameliorate Adverse Impacts

The high additional afflux due to the proposed duplication of the Pacific Highway can be reduced by increasing the capacity of the waterway structures across the proposed duplicated highway. Among the four waterway structures, which are discussed in Section 2.4.2, the culvert 200m south of the floodway bridge (Culvert No. 26A) is considered to be undersized. The significant increase in flood levels upstream of the culvert beside Herons Creek Road (Culvert No. 26) is due to the afflux upstream of the Railway line, which results in Herons Creek flows moving southward and then across the Herons Creek Road underpass under the railway. Amelioration of the flooding impact was analysed in a number of options.

The proposed option involves replacing the existing 450 mm diameter pipe culvert 200m south of the floodway bridge (No 26A) with three RCBC cells of 3.0 m x 2.1 m under both the proposed northbound and existing southbound carriageways. The affluxes reduced to the following figures:

- 45 mm between the Pacific Highway and the Railway line;
- 30 mm upstream of the Railway line;
- 180 mm at the southwest corner of the Pacific Highway and Herons Creek Road; and
- 20 mm immediately downstream of the Pacific Highway Bridges.

The estimated afflux for this option is shown in Figure 2-17.

There would be no significant increase in the 100 year ARI peak velocities in Herons Creek and southern flood channel for the above mentioned upgraded case. The outlet peak velocity of the upgraded culvert 26A is predicted to be approximately 2.6 m/sec. Outlet protection measures may be required for this upgraded culvert.

3 ANALYSIS OF MINOR WATERCOURSES

3.1 Flow Estimation

There are three minor watercourses that cross the proposed corridor generally flowing west to east:

- Passionfruit Gully (2.2 km^2);
- Stony Creek (12 km^2); and
- Walkers Creek (3 km^2).

Minor watercourses have been defined for the purposes of this assessment as those with a catchment area of less than 50 km^2.

As well, there are approximately 23 other small un-named catchments (less than 2 km^2 in area) crossed by the existing Pacific Highway routes and the upgrade options being considered. The catchment areas of all of the minor and small watercourses are shown in Figure 3-1 and Figure 3-2. Table 3-1 presents the catchment areas for each of these minor watercourses and the peak 20 year and 100 year ARI flows. The design flows have been estimated using the Rational Method according to the recommended design method for eastern New South Wales in the Australian Rainfall and Runoff (Institution of Engineers Australia, 1987).

Table 3-1 Minor Watercourse Catchment Areas and Flows

Catchment Number*	Area (km^2)	Time of Concentration** (min)	20y ARI Flow (m^3/s)	100y ARI Flow (m^3/s)
1.1	0.22	25	2.2	3.7
2	0.11	20	1.2	2.1
3A	0.22	26	2.2	3.8
4	0.30	29	2.8	4.8
5A	0.17	23	1.8	3.0
5B	0.81	42	6.4	11.0
5C	0.13	21	1.5	2.5
6	0.37	31	3.4	5.7
8B	0.24	26	2.4	4.0
8C	0.19	24	1.9	3.3
9.1 (Passionfruit Ck)	2.18	61	13.9	23.9
9.3	0.17	23	1.8	3.0
10.2	0.61	38	5.1	8.6
11.2	0.45	34	4.0	6.7
12.1 (Stony Ck)	11.89	172	53.0	90.0
13.2	0.42	33	3.7	6.4
14.1	0.35	31	3.2	5.5
15.1	0.78	41	6.2	10.6
16.1	0.49	35	4.2	7.2

<table>
<tr><th>Catchment Number*</th><th>Area (km^2)</th><th>Time of Concentration** (min)</th><th>20y ARI Flow (m^3/s)</th><th>100y ARI Flow (m^3/s)</th></tr>
<tr><td>18
(old sunken culverts)</td><td>0.68</td><td>39</td><td>5.6</td><td>9.5</td></tr>
<tr><td>20
(old sunken cattle grid)</td><td colspan="4">Local catchment is not well defined. Section 2.3.4 discusses about the importance of upgrading this culvert.</td></tr>
<tr><td>21</td><td>0.31</td><td>29</td><td>3.0</td><td>5.0</td></tr>
<tr><td>22A</td><td>0.14</td><td>21</td><td>1.5</td><td>2.5</td></tr>
<tr><td>24.1</td><td>0.11</td><td>20</td><td>1.3</td><td>2.1</td></tr>
<tr><td>25.1
(Walkers Ck)</td><td>2.94</td><td>69</td><td>16.1</td><td>30.2</td></tr>
<tr><td>26</td><td>0.74</td><td>41</td><td>5.9</td><td>10.1</td></tr>
<tr><td>26A
(0.45dia to be upgraded)</td><td colspan="4">Local catchment is small but takes overflow from Herons Creek. Required to upgrade to reduce afflux after the Pacific Highway upgrade. Refer to Section 2.4.5.</td></tr>
</table>

* Refer to Figure 3-1 and Figure 3-2.

** Time of concentration is an indication of the storm duration that would result in peak flows for that catchment.

3.2 Adopted Tide Level

The Australian National Tide Tables (Australian Government Publishing Service, 1992) list the following for the Camden Haven River (assuming MSL = 0.0 mAHD):

- Mean of High Water Springs = 0.5 mAHD; and
- Mean of High Water Neaps = 0.3 mAHD

It is recommended to use the tide level of 0.5mAHD for any minor drainage design. The Highest Astronomical Tide level (occurring once every 11years), which is approximately 1.1m AHD, can be used for very conservative approach.

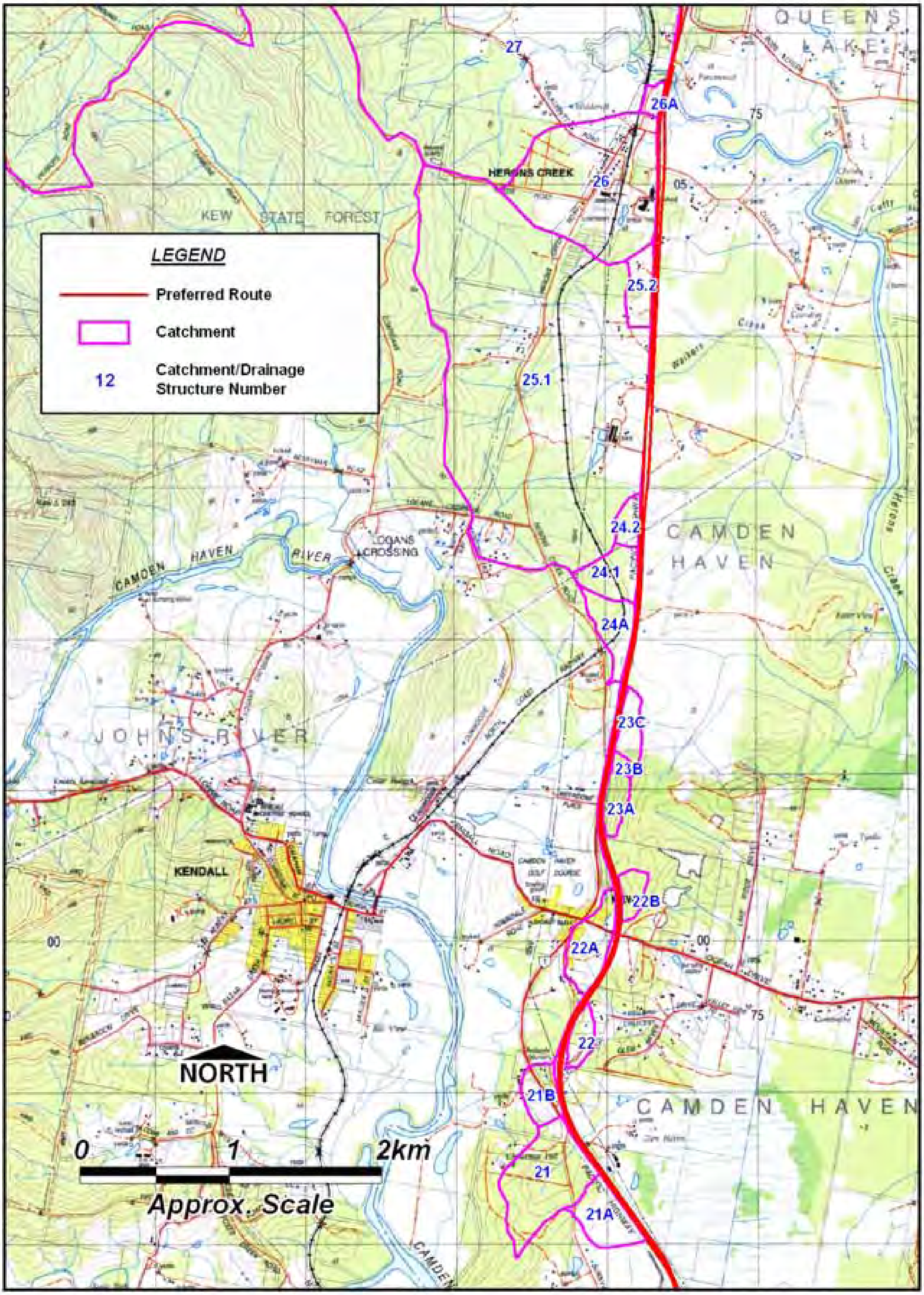

Figure 3-1 Minor Catchments – Northern Section

Figure 3-2 Minor Catchments – Southern Section

4 REQUIRED UPGRADING OF WATERWAY STRUCTURES

Preliminary assessments of the required waterway structures for the watercourses crossed by the upgraded highway are presented in Table 4-1 below. The capacities of existing and proposed waterway structure for the minor watercourses have been based on an assumption of inlet control.

The outlet velocities of the culverts depend on a number of factors including whether the culvert would function in outlet or inlet control, headwater level, tailwater level, length of the culverts and longitudinal grade. Estimation of the outlet velocities is required to determine the scour protection measures. The preliminary design in Table 4-1 is based on the assumption of culverts flowing full and the maximum outlet velocities of 2 m/sec. The detailed analysis for estimating the outlet velocities should be undertaken during the design phase of the project.

It was assumed that the waterway structures would required to be the 100 year ARI discharge capacity. The format of the dimension of the box culvert is Number x Width x Height.

Table 4-1 Watercourse Catchment Areas, Flows and Required Structures

Catchment No. (refer Figs 3.1 & 3.2)	20y ARI Flow (m^3/s)	100y ARI Flow (m^3/s)	Waterway Structure
1.1	2.2	3.7	Existing structure of 1 x 2.4m x 1.2m RCBC can accommodate 7.7 m^3/s. Hence, only **lengthening** of existing structure required.
2	1.2	2.1	Existing structure of 2 x 0.75m dia. pipe can accommodate 2.1 m^3/s. Hence, only **lengthening** of existing structure required.
3A	2.2	3.8	Existing structure of 1 x 2.4m x 1.2m RCBC can accommodate 7.7 m^3/s. Hence, only **lengthening** of existing structure required
4	2.8	4.8	A new structure of 1 x 2.4m x 1.2m RCBC.
5A	1.8	3.0	A new structure of 1 x 1.5m dia RCP.
5B	6.4	11.0	A new structure of 2 x 2.44m x 1.2m RCBC.
5C	1.5	2.5	A new structure of 1 x 1.5m dia RCP.
6	3.4	5.7	A new structure of 1 x 2.4m x 1.2m RCBC.
Stewarts River			295m bridge (ie. **duplication** of existing bridge) is only required as the maximum afflux is only 10-12 mm.
8B	2.4	4.0	Existing culvert is 2 x 1.2dia RCP, adequate to discharge the 100 year ARI event.
8C	1.9	3.3	Existing culvert – size unknown. Required flow area is approximately 1.7 m^2.
9.1 (Passionfruit Ck)	13.9	23.9	Existing structure of 3 x 3.0m x 3.0m RCBC can accommodate 100 year ARI flow. Hence, only **lengthening** of existing structure required.
9.3	1.8	3.0	Existing culvert is 0.45dia RCP, which has **inadequate** capacity for the 100 year ARI design flow. Replacement with a 0.75 m dia RCP is required.

Catchment No. (refer Figs 3.1 & 3.2)	20y ARI Flow (m^3/s)	100y ARI Flow (m^3/s)	Waterway Structure
10.2	5.1	8.6	Existing structure of 3 x 900mm RCP's is **inadequate**. Crossing needs to be **replaced** by a 2 x 2.4m x 1.2m RCBC which would accommodate the 100 year ARI flow.
11.2	4.0	6.7	Existing structure of 2 x 1050mm RCP's is **inadequate**. Crossing needs to be **replaced** by a 2 x 1.8m x 1.2m RCBC which would accommodate the 100 year ARI flow.
12.1 (Stony Ck)	53.0	90.0	15.2m bridge (ie. **duplication** of existing bridge)
13.2	3.7	6.4	Existing structure of 1 x 1200mm RCP's (unconfirm) is **inadequate**. Crossing needs to be **replaced** by a 2 x 1.8m x 1.2m RCBC which would accommodate the 100 year ARI flow.
14.1	3.2	5.5	Existing structure of 1 x 1200mm RCP's is **inadequate**. Crossing needs to be **replaced** by a 1 x 2.4m x 1.2m RCBC which would accommodate the 100 year ARI flow.
15.1	6.2	10.6	Existing structure of 2 x 0.6m RCP's is **inadequate**. Crossing needs to be **replaced** by a 2 x 2.4m x 1.2m RCBC which would accommodate the 100 year ARI flow.
16.1	4.2	7.2	Existing structure of 2 x 450mm RCP's is inadequate. Crossing needs to be **replaced** by a 2 x 1.8m x 1.2m RCBC which would accommodate the 100 year ARI flow.
18	5.6	9.5	Existing 4 No 1.8x1.8m RCBC (sunken). Replacement with the same sized structure is recommended.
Camden Haven River			163m existing bridge would be sufficient to discharge the 20 year ARI flood without overtopping the Pacific Highway. Therefore, duplication of the existing bridge would be adequate.
20			Existing sunken cattle grid. It is strongly recommended to replace the existing 1 x 2.6m x 2.0m RCBC with 2 Nos 3.3m x 2.1m culverts (refer to Section 2.3.4).
21	3.0	5.0	Existing structure of 2 x 1500mm RCP can accommodate approximately 9.0 m^3/s. Hence, only **extension** of existing structure required.
22A	1.5	2.5	This culvert is on the Kew Bypass so requires a completely new culvert 1 x 1.5m dia. RCP
24.1	1.3	2.1	Existing structure of 1 x 750mm RCP is **inadequate**. Crossing needs to be **replaced** by a 1 x 1.2m dia RCP which would accommodate the 100 year ARI flow.
25.1 (Walkers Ck)	16.1	30.2	Existing structure of 2 x 4.0m x 3.5m RCBC's can accommodate 100 year ARI flow. Hence, only **extension** of the existing structure is required
26	5.9	10.1	The existing 2m x 2m RCBC structure forms a part of the total Herons Creek floodplain management structures. This structure would be adequate provided that the

Catchment No. (refer Figs 3.1 & 3.2)	20y ARI Flow (m^3/s)	100y ARI Flow (m^3/s)	Waterway Structure
			structure no 26A is upgraded as a part of the overall Herons Creek floodplain management strategy.
26A	Part of Herons Creek overland flow		Existing 1 x 450mm RCP is extremely inadequate. It is recommended to replace this pipe with 3 x 3.0m x 2.1m under both carriageways.
Herons Creek	450	580	Existing floodplain bridge (southern) is adequate and, hence, only requires duplication. The existing 24m northern bridge is likely to be replaced because of its age. Increasing the waterway opening of the replacement bridge would worsen the flooding immediately downstream and would not provide any overall benefit. However, replacing the culvert No. 26A (see above) would provide a better design. The replacement Southbound bridge and the new northbound bridge should both have 24m opening between abutments.

5 CONCLUSIONS

The conclusions drawn from the hydraulic impact assessment for the Moorland to Herons Creek Pacific Highway Upgrade are as follows:

- There are a number of structures along the existing Pacific Highway route that would require upgrading to meet the relevant design criteria of the project in relation to flood immunity.
- The additional afflux created by the duplication of the Camden Haven River and Stewarts River bridges will result in negligible impacts.
- Duplication only of the Herons Creek bridges would result in unacceptable impacts. It is proposed to supplement the existing bridges (duplicated in the new northbound carriageway) with 3 x 3.0m x 2.1m RCBC's in both carriageways at the location of the existing 450mm diameter pipe.
- The majority of the waterway structures for minor catchments will require upgrading to meet the design flood standards.

6 REFERENCES

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