Gerringong to Bomaderry
Princes Highway Upgrade

Preliminary Flooding and Drainage Report

The Roads and Traffic Authority NSW
October 2007
Quality Information

Document  Preliminary Flooding and Drainage Report
Ref  DEV06/04-EN-MA-Prelim Flooding and Drainage
Date  28 October 2007
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Revision History

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| 1        | 28/10/2007    | For issue| Richard Merrett
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RTA acceptance

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<td>Project No.</td>
<td>DEV06/04</td>
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1.0 Background

Maunsell was engaged by the RTA in December 2006 to carry out an Options and Route Selection Study, Concept Development and Environmental Assessment (EA) for upgrading the Princes Highway between 42.6 km to 74.6 km south of Wollongong. Maunsell has engaged a number of prominent sub-consultants to contribute to the delivery of this project.

The work includes development of route options and concept development based on the identified preferred route, environmental assessment, public displays and handover period to allow for finalisation of all activities and reports following the announcement and display of the Preferred Route, the Environmental Assessment and the Conditions of Approval.

The project will provide a bypass of Berry. The northern extremity of the project is in the vicinity of the Mount Pleasant Lookout (north of Gerringong at the termination of the four lane configuration) and the southern extremity of the project is the intersection (roundabout) of the Princes Highway with Cambewarra and Moss Vale Roads at Bomaderry.

Community involvement is a key aspect of this project and will afford the broader community the opportunity to make a demonstrable input to the process and to ensure that the requirements and aspirations of the community will be adequately and appropriately addressed. This is particularly relevant to:

a) Any potential impacts on rural and residential areas within the study area;
b) Social and economic impacts;
c) Accessibility of the road network for local and through traffic;
d) Potential impacts on water quality;
e) Potential impacts on wetlands;
f) Potential impact on flooding;
g) Potential impacts on land uses;
h) Threatened flora and fauna species;
i) Indigenous and non-indigenous heritage;
j) Visual impact;
k) Noise; and
l) Air quality.

Several studies have been undertaken since the early 1990s to identify a preferred route to upgrade sections of the Princes Highway between Kiama and Nowra including a bypass around the town of Berry. These studies include:

m) Lower Shoalhaven River Flood Study (Public Works, 1990)
n) Gerringong to Berry Route Selection Study (GHD, 1991);
o) North Street Berry Bypass EIS (ERM, 1997);
p) Gerringong Gerroa Sewerage Scheme Report on Flood Study (GHD, 1999);
q) Broughton Creek Flood Study (SMEC 2004); and
r) 2004/05 Quantm Study from Kiama to Nowra.

Sections of the highway between Gerringong and Bomaderry have a poor accident record and limited safe overtaking opportunities.
Due to the significant changes in traffic, land use and population since 1991, the NSW state government, in March 2006 committed to investigating an area where it is likely a preferred route would be located to upgrade the Princes Highway between Mount Pleasant at Gerringong and Moss Vale/Cambewarra Road at Bomaderry to meet current road standards.
2.0 Objective of report

2.1 General

As part of the route options development process for upgrading the Princes Highway from Gerringong to Bomaderry, it is necessary to carry out a preliminary investigation of the existing flooding and drainage conditions within the study area.

This report is one of a series of supporting studies that will assist the RTA in developing a short list of route options and later a preferred route from Gerringong to Bomaderry.

Figure 2.1: Study area between Gerringong and Bomaderry
2.2 Scope

The flooding and drainage assessment includes both surface water and groundwater. The surface water assessment includes an investigation of the preliminary drainage impacts and implications of possible routes in regard to floodwater extent and water depths and to identify potential flood impacts and constraints associated with route options. The groundwater assessment will assess the impacts of possible routes on local and regional hydrogeology, including groundwater abstraction and identify constraints and risks of groundwater conditions on road construction and long term stability.

This report does not cover surface water and groundwater quality impacts. These assessments are included as part of the Preliminary Biological Report – Aquatic Ecology and Water Quality Management.

The details contained herein provide sufficient input to the route options development process only. More detailed assessment such as flood inundation periods and velocities will be undertaken for the concept design of the preferred route.
3.0 Existing flooding and drainage review

3.1 General

The proposed upgrade will include the crossing of both minor and major watercourse and floodplains. There is a need for flooding and drainage assessment of the existing conditions and new route recommendations.

The study area incorporates part of the expansive floodplain of the Lower Shoalhaven River and Broughton Creek, Crooked River, Ooaree Creek (Omega Flat) as well as other minor watercourses. Some route corridors, which cross e.g. as Lower Crooked River and Omega Flat would require construction across floodplain, resulting in the requirement for embankments and structures to provide flood immunity. The waterway area to be provided via structure or culverts needs to be determined to minimise impacts on flood levels, the distribution of flows, inundation times and flood velocities.

The proposed Princes Highway upgrade will require additional crossings of Broughton Creek, which is the major creek system that transverses the study area. These works could potentially impact flood levels, the distribution of flows, inundation times and velocities. Such impacts will need to be mitigated or minimised as part of an economically viable design, especially in populated areas and in areas of environmental significance.

The proposed upgrade may require excavation in areas with shallow groundwater, soft soils and acid sulphate soils. Any construction in these regions will require consideration of construction methodology to avoid or minimise potential impacts on groundwater flows and quality. Alternative routes may incorporate deep cuttings through topographically high regions. Consideration will need to be given to groundwater inflow into excavations, impacts on local water table and impacts on local bores.

3.2 Surface drainage

There are several main drainage watercourses and floodplain areas within the study area as follows:

a) Omega Flat;
b) Crooked River floodplain;
c) Broughton Creek (upper catchment);
d) Berry Township floodplain area; and
e) Shoalhaven River (upper catchment).

The surface drainage associated with these areas is further described below.

Omega Flat

Omega Flat is located north of the Gerringong near Werri beach. Ooaree Creek crosses Omega Flat and the Princes Highway before discharging into the ocean via Werri Lagoon. The Princes Highway flood immunity is influenced by Ooaree Creek hydrology as well as the Werri Lagoon levels caused by tidal effects.

A flood study of Ooaree Creek at Omega Flat was undertaken by GHD in 1999 for Sydney Water. The study comprised modelling using XP-RAFTS and one-dimensional flood level modelling using HEC-RAS. The creek’s total catchment area is approximately 16.4 km$^2$. Design flows in Ooaree Creek at the Princes Highway crossing for a 20 and 100 year Average Recurrence Interval (ARI) are approximately 152 m$^3$/s and 204 m$^3$/s respectively.
The resultant 20 and 100 year ARI flood levels upstream of the existing Princes Highway are approximately 2.9 m AHD and 3.03 m AHD respectively. Both the 20 and 100 year ARI floods overtop the Princes Highway significantly, with inundation along approximately 1.8 km of the roadway and adjacent railway line.

**Crooked River floodplain**

The routes cross the Crooked River and several minor tributaries of the Crooked River. The Crooked River broadens substantially in the lower 2.5 km to form a sheltered creek. The river enters the ocean at the northern end of Seven Mile Beach adjacent to Black Head and Gerroa. In the lower reaches south of the railway line, floodwaters would most likely spread out across the low lying area between Beach Road, Gerroa Road and the railway line.

Potential connectivity between the river and the low lying swamp area during large floods is likely to occur resulting in significant floodplain storage adjacent to the existing railway line. Other issues that may influence flooding in the area are the entrance conditions at the estuary mouth and the operation of tidal flood gates on Blue Angel Creek, installed to prevent inundation of low-lying land.

A flood study of Crooked River was undertaken by GHD in 1999, as part of the Gerringong Gerroa Sewerage Scheme Report. The study involved modelling using XP-RAFTS and one-dimensional flood level modelling using HEC-RAS of Crooked River downstream of the existing railway embankment only. The river's total catchment area is 32.4 km$^2$ including the Blue Angel creek catchment. The subcatchment area just upstream of the existing railway embankment is approximately 13 km$^2$. Design flows are not defined at the existing railway crossing, however, based on the estimated flows approximately 600 m downstream, the estimated 20 and 100 year ARI discharges are approximately 90 m$^3$/s and 130 m$^3$/s respectively. The resultant 20 and 100 year ARI flood levels approximately 600 m downstream of the existing railway embankment are approximately 3.0 m AHD and 3.24 m AHD respectively.

**Broughton Creek (upper catchment)**

Broughton Creek (upper catchment) upstream of Berry township, transverses the study area in a southerly then westerly direction. The catchment consists predominately of rural pastures below steeper forested hillsides. The dominating land-use is agriculture. The creek’s catchment area upstream of Berry is approximately 30 km$^2$ which is predicted to produce a 1 in 100 year ARI discharge of approximately 760 m$^3$/s.

There is currently no detailed flood study for this upper portion of the Broughton Creek catchment. Therefore additional flooding and drainage modelling of the creek system would be appropriate to describe the flooding characteristics in this area. **Section 5** provides a summary of the flooding and drainage assessment of this area.

**Berry township floodplain area**

Berry is located on floodplain land adjacent to the confluence of two major creek systems, comprising Broughton Mill Creek and Bundewallah Creek, which run south and south east respectively. The catchment consists predominately of rural pastures below steeper forested hillsides. The dominating land-use is agriculture.

Bundewallah Creek located to the north of Berry township flows eastwards under a bridge at Woodhill Mountain Rd to join Broughton Mill Creek. From its confluence with Bundewallah Creek, Broughton Mill Creek flows southwards under an existing bridge at the Princes Highway, then under a further bridge at the railway line which runs to the south of Berry. Downstream and to the east of the township, Broughton Mill Creek flows into Broughton Creek, which in turn flows southward into the Shoalhaven River.
Connollys Creek enters Bundewallah Creek upstream of the confluence with Broughton Mill Creek. Bundewallah Creek and Connollys Creek have catchments of approximately 1500 ha and 630 ha respectively. Broughton Mill Creek has a catchment of approximately 2000 ha immediately upstream of the confluence with Bundewallah Creek. At the railway bridge, approximately 500 m downstream of the Princes Highway, the total catchment is 4400 ha. The predicted 1 in 100 year ARI discharge at the Broughton Mill Creek and Bundewallah Creek confluence is approximately 1100 m$^3$/s. Broughton Creek at the railway bridge has a predicted 1 in 100 year ARI discharge of approximately 1880 m$^3$/s.

Two unnamed creeks flow through Berry, before joining Broughton Mill Creek. Princess Creek is the name associated with the watercourse which meanders eastwards through the Berry town centre, adjacent to Princess St, before joining Broughton Mill Creek. At the north of the township Princess Creek has a catchment of approximately 68 ha, which increases to 116 ha at the confluence with Broughton Mill Creek. Albert Creek is the name associated with the creek which flows adjacent to Albert Street.

A number of flood studies have been recently undertaken in the vicinity of the Berry area. These have included the following:

f) Flood study undertaken for the Environmental Impact Study for the proposed North Street Berry Bypass for the RTA in 1997 (prepared by ERM Mitchell McCotter); and

g) Broughton Creek Flood Study for Shoalhaven City Council (prepared by SMEC Australia Pty Ltd.).

The flood history, study results and findings from these flood studies are summarised below:

**North Street Berry Bypass EIS (ERM, 1997)**

The Berry township area has experienced localised flooding, predominantly from Bundewallah Creek and Princess Creek floodwaters originating from the north of the township. The largest flood event (at the time of the study) was during February 1971.

During large floods, Bundewallah Creek and Broughton Mill Creek overtop banks near the confluence. When flood levels are sufficiently high at this location, floodwaters follow an overland flow path that passes by the bowling club and a number of houses at the eastern extremity of the town. To the south of the town, Broughton Mill Creek has overtopped the railway bridge prior to its replacement. Flooding of Princess Creek also occurs through the township.

The EIS proposed bypass alignment was to follow North Street and cross Woodhill Mountain Road and Broughton Mill Creek at the north eastern limits of the township. Mike 11 modelling of the proposed bypass identified the following flooding impacts and results:

h) The proposed bypass bridge over Broughton Mill creek was to consist of 8 x 33 m spans, located upstream (north) of the existing Princes highway bridge;

i) The proposed bypass alignment adjacent to North Street becomes a weir between Woodhill Mountain Road and the Bowling Club;

j) The proposed bypass roadway embankment represents an opportunity to contribute to mitigation of the existing flood problems with Berry township in the vicinity of the bowling green; and

k) Flooding across Woodhill Mountain Road will increase due to the proposed bypass, however the road is already overtopped in the 100 year ARI flood event.

**Broughton Creek Flood Study (SMEC, 2004)**

The Berry township floodplain has an elevation generally between 1m and 2m AHD. Tidal influence extends approximately 12 km upstream to the Broughton Creek / Shoalhaven River confluence in the vicinity of the Coolangatta Road Bridge.
HEC-RAS and Mike 11 modelling of the study area identified the following flooding impacts and results:

1) A severe flood event in July 2005 caused severe damage to parts of Berry and its surroundings. The existing railway embankment was also overtopped and damaged during this event; and

m) The area upstream of the railway line at Broughton Creek and parts of Broughton Mill Creek and lower Bundewallah Creek are high hazard flood storage (in accordance with NSW Floodplain Development Manual);

The floodplain downstream of the railway line is also primarily high hazard flood storage.

Shoalhaven River

The section between Berry and Nowra follows the existing Princes Highway alignment which is outside of the floodplain of the Shoalhaven River in this region. Existing flooding characteristics in the southern part of the study area are defined in the Lower Shoalhaven River Flood Study (April 1990).

Shoalhaven City Council still utilises this document for the determination of flood planning levels for development in the Lower Shoalhaven River floodplain. This study covers the lower section of the Shoalhaven River from approximately 10 km upstream of Nowra to the Pacific Ocean outlets, and includes the section of Broughton Creek downstream of Coolangatta Road. Modelling was undertaken using WBNM for flooding and the quasi two-dimensional CELL model for drainage.

3.3 Hydrogeology

3.3.1 Summary of geology of the study area

A preliminary geotechnical investigation of the study area was undertaken by Coffey Geotechnics as part of the route selection study and documented in the Preliminary Geotechnical Report. This included a review of the regional geology and local stratigraphy of the study area and the installation of piezometers in eleven boreholes to assess current groundwater levels in the study area and enable ongoing monitoring.

The geology of the study area comprises stratigraphy corresponding to the Permian Shoalhaven Group. Two subgroups are present within the study area, the Gerringong volcanics and the Berry Formation. The Berry formation comprises sandstone, siltstone and shale and is the most extensive geological unit within the study area. The Berry formation occurs mainly along the undulating hills and associated foothills to the north west of the railway line and south of the Crooked River. Gerringong volcanics present include Trachyte tuff and Tuffaceous sandstone and occur in the north eastern section of the study area, at Mt Pleasant ridge and along ridgelines of Toolijooa Hill and Harley Hill.

Alluvial soils cover most of the floodplain and valley floor areas within the study area, including the Broughton Creek and Shoalhaven River floodplains. These soils mainly consist of clay soils overlying residual soils. Estuarine deposits occur in the vicinity of Omega Flat and are likely to also occur on the floodplains of Crooked River, Flying Fox Creek and Jaspers Creek. These deposits are generally dark clays and silts. Acid sulphate soils may be present in this unit.

3.3.2 Groundwater monitoring (refer Section 7 for detailed discussion)

As part of the geotechnical investigation undertaken for this study, standpipe piezometers were installed in eleven of the boreholes within various geotechnical units throughout the study area. The piezometer installation depths ranged from 4.2m to 16.2m. The locations of boreholes and test pits are detailed within the Preliminary Geotechnical Report.
Piezometers located on elevated ridges had standing groundwater at depths between approximately 3.3m and 7m. These bores were observed to have slow recharge rates. Groundwater identified at the bores north of the existing highway and north east of Berry were considered to be possible perched water tables.

Piezometers on lower ridges had standing groundwater occurring at depths between approximately 3.5m to 4.5m. These bores had continuous recharge and were located either in the Broughton Creek floodplain or close to the existing Princes Highway alignment south of Berry. The boreholes indicated sandy clays, siltstone or fractured claystone.

Piezometers located within the alluvial floodplains and low lying estuarine floodplains had very shallow standing groundwater levels of between approximately 0.4m to 2.5m. These mainly exhibited continuous recharge indicating high groundwater conductivity.

3.3.3 Groundwater abstraction

A review of Department of Natural Resources registered bores within the study area was undertaken. Over 80 licensed bores were identified within the study area, with the majority located between Toolijooa and Gerringong. These bores are used for domestic uses, stock and irrigation. The locations of most of these licensed bores are detailed in the Preliminary Acid Sulphate Soil Assessment Report (Appendix H of Preliminary Geotechnical Report). There was limited information available for these bores in regard to groundwater flow, standing water levels and groundwater quality. However, information provided for the majority of bores included the depths to, and stratigraphy of the water bearing zones. The majority of bores access groundwater from deep fractured rock aquifers, at depths commonly in excess of 20m. Mostly these water bearing zones are overlain by clays or hard rock.
4.0 Flooding immunity criteria

4.1 General

The preferred route design must ensure that the appropriate level of flood immunity is provided. During the design flood event part of the road could be flooded but a certain number of lanes must be available for traffic above the high water level.

4.2 RTA flooding immunity criteria

The project design parameters require the following protections:

a) A target of 1 in 100 year ARI flood event for new alignment; and
b) A minimum target of at least a 1 in 20 year ARI flood event for upgrades of existing alignment;

It is understood that the difference of flood immunity event for new and existing alignments provides an opportunity to consider a reduction in cost if there is potential to retain existing structures on the existing alignment. Also, the RTA has provided the following definitions related to the above:

c) Upgrade of existing alignment; is that which is directly connected to the existing roadway. It could be a duplication to provide dual carriageway generally along the existing alignment, a widening of the existing formation and/or change in level of the existing highway with some horizontal alignment correction. Or from another perspective when the existing highway is not abandoned or given to a local council to maintain as a local or regional road.

d) Flood immunity; a minimum of two (2) lanes must be available for traffic (usually on one carriageway), however water can be tolerated over the shoulder up to the edge line of the available lanes.

Based on the above criteria, preliminary flooding and drainage assessments were undertaken for the critical 1 in 100 year ARI event for the major watercourse crossings within the study area (refer Section 5). As a result, the 1 in 20 year ARI flood extents/levels were not assessed as part of this preliminary assessment to identify potential flood impacts and constraints associated with route options.
5.0 Flooding and drainage assessment

5.1 General

The study area incorporates part of the expansive floodplain of the Lower Shoalhaven River and Broughton Creek, Crooked River, Ooaree Creek (Omega Flat) as well as other minor watercourses. Some route corridors, such as those crossing lower Crooked River and Omega Flat, would require construction across floodplain, resulting in the requirement for embankments / structures to provide flood immunity. The waterway area to be provided via structure or culverts was determined to minimise impacts on increased flood levels, redistribution of flows, increases in inundation times and increases in flood velocities.

Flooding and drainage investigation of the existing historical flood patterns and assessment of the proposed routes has been undertaken to develop an understanding of the potential impact of the project. The investigations involved the following:

a) A review of the existing flood modelling and historical studies of the major surface drainage systems within the study area; and
b) Additional flood modelling (using the one-dimensional steady HEC-RAS model program) where required within the study area that require flood data to complete the study.

5.2 Peak flow determination

Within areas covered by the North Street Berry Bypass EIS (ERM, 1997), the Broughton Creek Flood Study (SMEC 2004), and the Gerringong Gerroa Sewerage Scheme Report on Flood Study (GHD, 1999), peak flows for the 100 year ARI storm event were taken from these studies where possible. The flows were checked against the Probabilistic Rational Method (PRM) calculation using estimation procedures outlined in Australian Rainfall and Runoff (AR&R, 1999).

For areas not included in the above studies, peak flows were calculated using the PRM. PRM hydrology is generally recommended and accepted for applications up to 25 km$^2$ and does not reflect physical factors such as the storages and temporal and spatial patterns of rainfall intensity. Intensity-Frequency-Duration (IFD) parameters for Berry, Bomaderry / Nowra and Gerringong were taken from AR&R (Vol 2) and used to calculate the flows.

5.3 Flood level determination

Flood levels for the 100 year ARI event were obtained from the Broughton Creek Flood Study (SMEC 2004) where possible. MIKE 11 quasi 2-dimensional unsteady flood modelling software was used for simulating the flow behaviour as well as for assessing the characteristics of the road crossings. For other creek crossing locations not covered in this flood study, HEC-RAS steady flow simulation was used to estimate the indicative flood level.

The HEC-RAS steady models were set up to simulate Crooked River and it’s tributary flood behaviour. The PRM (in AR&R) was used to estimate peak flows for use in a steady flow HEC-RAS analysis. The geometry for the models representing the site, including cross sections and reach length, were extracted using 12D, a 3 dimensional CAD computer program utilising DTM survey information. No existing drainage structures, neither at the highway nor railway line, were included in this modelling. Several HEC-RAS models have been created and design flood levels were calculated.

5.4 Flooding results

Based on the flooding and drainage assessment, the preliminary flood extent and levels within the study area associated with the 1 in 100 year ARI event are provided in Appendix A.
6.0 Preliminary crossing requirements

6.1 General

The proposed routes cross numerous watercourses and floodplains. This provides an opportunity to control the flow during flood events with the provision of drainage structures (such as culvert and bridges) within the road embankment to ensure upstream water levels (afflux) are mitigated to acceptable levels. For some minor tributaries, there may be opportunity to mitigate downstream water levels by redirection of the tributary.

HEC-RAS steady flow analysis was utilised to assess all preliminary drainage crossing structures details as well as the water levels upstream and downstream of those road crossings. Bridges and culverts were included in existing HEC-RAS models and limited optimisation techniques were used to determine the preliminary crossing opening requirements and to determine indicative road embankment levels.

The following design assumptions were adopted for determining preliminary road embankment level and watercourses crossing requirements for the route options:

a) Road pavement levels were determined with a 500 mm minimum freeboard height above the 100 year ARI flood level;

b) Due to the relative flatness of the floodplain at the Crooked River lower area, the existing railway line embankment level was assumed to act as a flow control with the road embankment levels set approximately 300 mm above the railway line along this route; and

c) The road embankment through Omega Flat was set at the existing Princes Highway level plus an additional 1500 mm.

At the time of writing this report, a review of industry wide practices and developments is underway to ascertain what allowances if any, should be made for global warming and climate change. In this regard, changes in sea level and rainfall frequency and intensity may be received.
7.0 Groundwater assessment

7.1 Data limitations

Due to the large size of the study area, a limited number of piezometers were installed to provide some data for conceptual groundwater modelling. The large size of the study area, and the variability of local stratigraphy and topography, will require additional boreholes, piezometers and monitoring once the preferred route is selected to better define groundwater conditions.

The piezometers were installed following a relatively dry period which has been experienced throughout the area over the last two to three years. Therefore observed groundwater levels may be lower than the long term average. Insufficient data is available to interpret the impacts of climatic variability on groundwater levels. On-going monitoring will enable assessment of any potential variability.

The piezometers are of limited depth and are generally located within the unconfined water table and potentially monitor standing water levels in separate sub-basins due to subsurface groundwater divides. Licensed bore details indicate that there are deeper confined or semi-confined water bearing zones which may have piezometric levels lower or higher than the observed standing water levels, depending on their location.

7.2 Groundwater characteristics of the study area

From the limited piezometric data and variable stratigraphy of the study area it is not possible to accurately determine groundwater divides and aquifer geometry. However, based on the available borehole data and geological mapping, it can be assumed that study area is characterised by relatively shallow unconfined groundwater which would be expected to closely mimic the natural topography. Due to undulating terrain, a number of sub-basins would be expected, superimposed on the regional system. This unconfined water table may include some areas of perched water table. Several boreholes indicate possibly confining layers below the unconfined aquifers comprising clays or hard sandstones.

Below this are several different confined or semi-confined water bearing layers, mainly within fractured shales and sandstones within areas of the Berry Formation, and within fractured tuff and basalt in areas characterised by Gerringong volcanics. These deeper aquifers are accessed by the majority of licensed bores within the study area generally at depths ranging between 15 m and up to 50 m below ground level.

The undulating hills and foothills are expected to represent recharge areas. Discharge areas are expected to be concentrated in the Broughton Creek, Crooked River and Ooaree Creek floodplains where the regional water table is more uniform.

The deep aquifers may act as conduits transmitting water to principal discharge areas such as Broughton Creek.

The unconfined water table levels may fluctuate due to climatic conditions, however there is currently insufficient data to assess this.
7.3 Areas of soft soils and acid sulphate soils

Areas mapped as high probability of acid sulphate soils are also indicative of areas of soft soils to depths generally in excess of 3m. These areas include the Ooaree Creek floodplain, Crooked River floodplain, Broughton Creek floodplain south of Berry and areas south of the existing railway line between Berry and Nowra.

Zones identified as low probability of acid sulphate soils generally correlate with zones of soft soils to depths less than three metres. These areas comprise a strip parallel to the railway line south east of the ridge between Toolijooa Hill and Harley Hill, Broughton Creek floodplain east of Berry and areas south of the railway line between Berry and Nowra.

The Preliminary Geotechnical Report details the approximated extent of soft soil zones while Appendix H of the Preliminary Geotechnical Report details the extent of acid sulphate soils risk zones.

Several route options traverse these acid sulphate soil risk zones. These areas are typically located within floodplains and therefore will require significant fill embankments to provide serviceability above designated flood levels and significant drainage works at creek crossings. Potential impacts associated with these zones may include the following:

a) Construction of drainage structures requiring excavation below the groundwater table in zones with high acid sulphate soil hazard. This may have adverse impacts on surface and groundwater quality. Measures to mitigate this impact would be required and may include cut-off walls or re-injection to reduce the risk of lowering the groundwater table in these areas.

b) Some construction options suggested in the Preliminary Geotechnical Report include consolidation of the soft soils, replacement of material, and wick drains. Wick drains in these zones would result in localised lowering of the water table which may expose acid sulphate soils. Consolidation of embankment foundation material may impact on the lateral flow of superficial groundwater, potentially raising groundwater levels on the upslope side of the embankment.

7.4 Areas of shallow groundwater

Areas of shallow groundwater identified from the piezometer monitoring data generally coincide with the occurrence of soft soils. However, shallow groundwater was also identified further upstream in the Broughton Creek floodplain and in the area immediately north of Berry, where a number of watercourses converge. In these areas, groundwater levels are typically between approximately 0.37m and 2.5m below ground level.

For the zones coinciding with soft soils and acid sulphate soils the potential impacts are as described in Section 7.3 above.

In the areas north of Berry, and in the upper reaches of the Broughton Creek floodplain road construction in cutting would need to provide adequate cut off drains to collect any groundwater seepage.

7.5 Potential road cuttings

Route options may include some sections of significantly deep cutting or tunnels to traverse some of the elevated ridgelines and hills. Tunnels of approximately 40 m depth below ground level may be required to negotiate the ridgeline between Toolijooa Hill and Hartley Hill. Other route options located closer to the foothills of the undulating hills on the western side of the study area may require cuttings ranging between 10 m to 30 m depth.
Based on the piezometer data and licensed borehole data, the cuttings are unlikely to intersect the deep water bearing zones that the majority of bores access. They will however, intersect the shallow unconfined water table and will require adequate cut off drains to collect any groundwater seepage.

The exception to this is the area to the north and north east of Berry where a small number of licensed bores access water bearing zones over a wide range of depths including shallow fractured rock layers. If these bores are located close to the preferred route, further investigations would be made into potential impacts on the bores in this area as a result of localised lowering of the water table at any proposed cuttings.

Possible tunnel locations are along the ridgeline between Toolijooa and Harley Hill and from Toolijooa north towards Foxground. Existing licensed bores between Toolijooa and Harley Hill are located in the foothills and access deep fractured rock aquifers, therefore a tunnel in this area is unlikely to impact on bore yields. To the north of Toolijooa, there are two licensed bores located close to the ridge. There are no details available for these bores. If these bores are located close to the preferred route, further investigations will be made to confirm that any tunnelling in this vicinity will not impact these bores.
8.0 Discussion of results

8.1 Surface water issues

Based on the above criteria and on the preliminary flooding and drainage assessments undertaken, the following preliminary comments and conclusions are provided with respect to potential flood impacts and constraints (only) of potential highway route options within the study area.

Omega Flat

All proposed highway routes pass through the Omega Flat floodplain area. A route located in the upper portion of the study area would encounter reduced flood extent / depth / flow, however given the flatness of the area this is likely to be minimal. An upgrade of the existing Princes Highway would be subject to a reduced flood immunity criterion (1 in 20 year ARI flood event), and may be able to make use of existing drainage infrastructure.

Crooked River floodplain

Proposed highway routes passing through the Crooked River floodplain (i.e. adjacent to the existing railway alignment) require at least three major watercourse crossings due to flatness of the area, and likely to consist of a combination of bridge structures and shallow culverts.

Broughton Creek (upper catchment)

Within the central portion of the study area, proposed highway routes require crossing of Broughton Creek. These crossings would consist of bridge structure(s) varying in length depending on the crossing location. Bridge structures aligned approximately perpendicular to the creek channel would reduce structure lengths. In the upper reaches (i.e. to the north of Toolijooa Ridge) Broughton Creek channel is relatively narrow and well defined, requiring bridge lengths typically between 100 m and 200 m. Towards Berry, Broughton Creek expands to a wider channel and floodplain requiring bridge structures greater than 350 m in length.

Berry floodplain area

Berry is located on floodplain land adjacent to the confluence of two major creek systems, comprising Broughton Mill Creek and Bundewallah Creek, located to the north-east of Berry. This system then joins Broughton Creek to the south with the 1 in 100 year ARI floodplain extending up to 2.5 km in width. Therefore crossing Broughton Creek to the south of Berry would require bridge structures and culverts between 600 and 2500 m in length, depending on the crossing location. To the north of Berry, Broughton Mill Creek and Bundewallah Creek are relatively narrow and well defined, requiring bridge lengths typically between 60 m and 120 m, and/or culverts.

Shoalhaven River (upper catchment)

The 1 in 100 year ARI flood extent for the Shoalhaven River extends only to the southern portion of the study area (i.e. typically south of the existing railway). Therefore a route located to the north of the railway and along the existing Princes Highway would be located outside the Shoalhaven River catchment.
8.2 Groundwater issues

Omega Flat

All routes pass through the Omega Flat floodplain area which includes Ooaree Creek. This area is generally low lying and is characterised by deep soft soils, high probability of acid sulphate soils and shallow groundwater. The construction of drainage structures such as culverts and storage basins in this area may require excavation below the water table and may intersect zones of acid sulphate soils. Mitigation measures such as cut-off walls or re-injection may be required in this area to reduce the risk of lowering the water table. Construction methods adopted in these estuarine soft soils should avoid creating barriers to the lateral flow of shallow groundwater. These measures all increase the costs of construction.

Crooked River floodplain

Proposed route options adjacent to the existing railway line would pass through the Crooked River floodplain. This area is similar to that of Omega Flat and is characterised by deep soft soils, high probability of acid sulphate soils and shallow groundwater. The groundwater issues that relate to this area are the same as those for Omega Flat.

Broughton Creek upper catchment

Route options in this area may include short sections of significantly deep cuttings or tunnels to traverse some of the elevated ridgelines and hills. Tunnels of approximately 40 m depth below ground level may be required to negotiate the ridgelines between Toolijooa Hill and Hartley Hill and Toolijooa and Foxground. Other route options located closer to the foothills of the undulating hills on the western side of the study area may require cuttings ranging between 10 m to 30 m depth below ground level.

The cuttings are unlikely to intersect the deep water bearing zones that the majority of licensed bores access. However, mitigation measures, such as cut-off drains, will need to address seepage from the shallow unconfined water table.

Existing licensed bores between Toolijooa and Harley Hill are located in the foothills and access deep fractured rock aquifers, therefore a tunnel in this area is unlikely to impact on bore yields. To the north of Toolijooa, there are two licensed bores located close to the ridge. There are no details available for these bores, therefore further investigations should be made to confirm that any tunnelling in this vicinity will not impact these bores should a route option here progress further.

Berry Township floodplain area

Some route options may cross the low lying floodplain area directly to the east of Berry. Alternatively, some options could approach Berry from the northern side of Broughton Creek and may require cuttings of between 10 m to 30 m depth.

Low probability acid sulphate soils and soft soils occur to the south and east of Berry and follow the southern floodplain of Broughton Creek. This area also has a relatively shallow water table. Based on topography, these areas are likely to be groundwater discharge areas. The groundwater issues that relate to this area are the same as those for Omega Flat, however, the lower probability of occurrence of acid sulphate soils should be taken into account.

In the areas to the north and north east of Berry, a small number of bores access water bearing zones over a wide range of depths including shallow fractured rock layers. Further investigations should be made into potential impacts on the bores in this area a result of localised lowering of the water table at any proposed cuttings.
Shoalhaven River upper catchment

Areas of soft soils and acid sulphate soils and shallow groundwater occur mainly to the south of the existing railway line.

The existing highway alignment is located to the north of the existing railway. An upgrade of this section of highway is not likely to introduce significant cut or fill. Therefore there are no likely significant impacts on or from groundwater in this area.
9.0 References

Lower Shoalhaven River Flood Study (April 1990)
Gerringong to Berry Route Selection Study (GHD, 1991)
Gerringong to Bomaderry Princes Highway Upgrade, Preliminary Geotechnical Report (Maunsell in association with Coffey Geotechnics, 2007)
North Street Berry Bypass EIS (ERM, 1997)
Gerringong Gerroa Sewerage Scheme Report on Flood Study (GHD, 1999)
Broughton Creek Flood Study (SMEC 2004)
2004/05 Quantm Study from Kiama to Nowra
RTA-Princes Highway Gerringong to Bomaderry Ground Survey (Hard & Forester Pty Ltd., 2006);
Australian Rainfall and Runoff, Volume 1 & 2 (Engineers Australia).
Appendix A  1 on 100 year ARI flood map