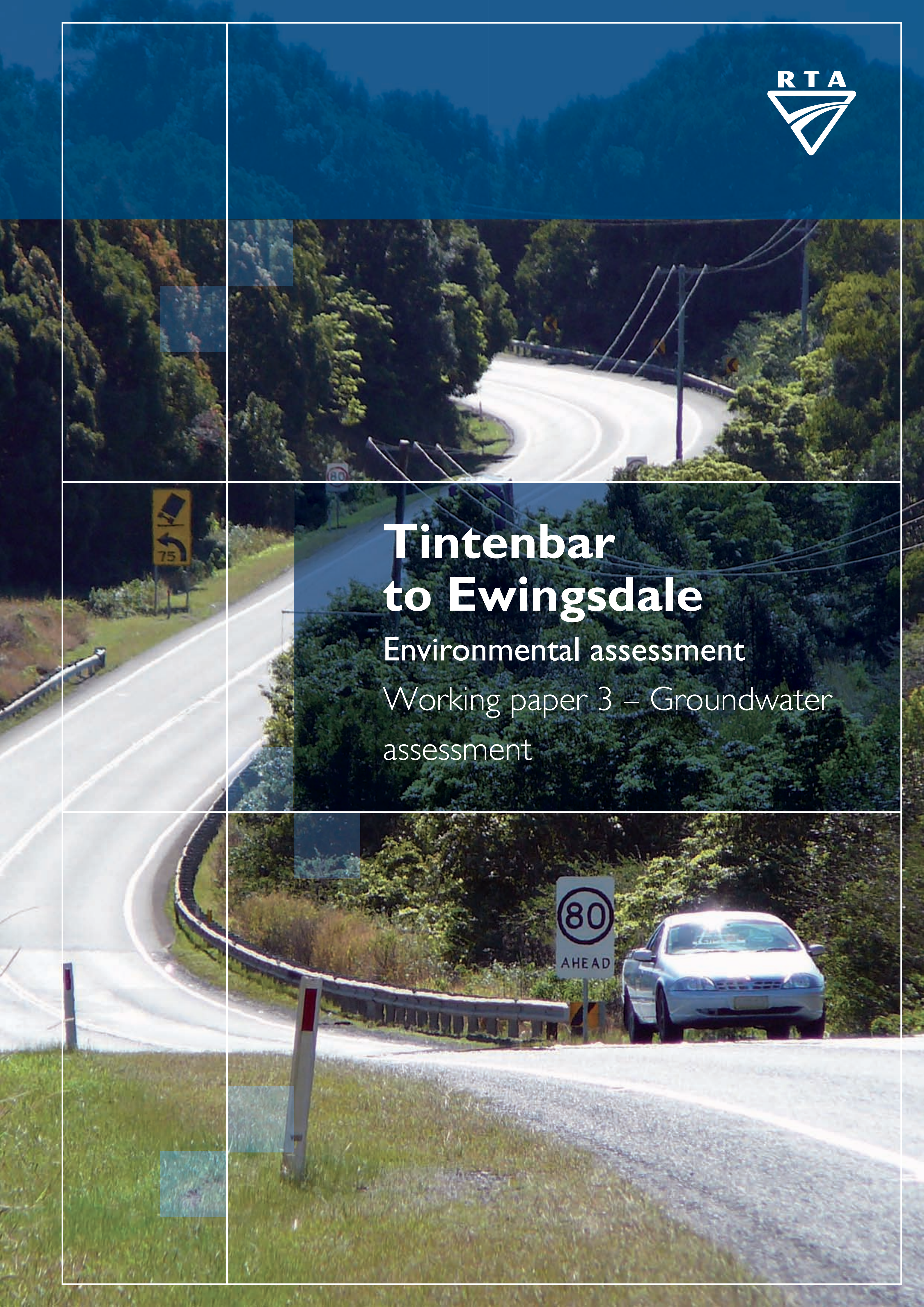
RTA

Tintenbar to Ewingsdale

Environmental assessment

Working paper 3 – Groundwater assessment



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REPORT ON

PACIFIC HIGHWAY UPGRADE PROGRAM

TINTENBAR TO EWINGSDALE ENVIRONMENTAL ASSESSMENT

GROUNDWATER ASSESSMENT

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EXECUTIVE SUMMARY

This report presents the results of a hydrogeological and groundwater impacts study carried out by Golder Associates Pty Ltd along and adjacent to the proposed upgrade of the Pacific Highway between Tintenbar and Ewingsdale (T2E), referred to as the “Pacific Highway Upgrade Program” (PHUP, or more simply, the proposed upgrade).

The objective of this study of groundwater impacts arising from the proposed upgrade works (road cuttings and the proposed tunnel under St. Helena Hill) is to address *key issues* raised in the Director-General’s requirements for the *Environmental Assessment* of the project (NSW Roads and Traffic Authority, 22 May 2007).

The Director-General’s requirements addressed by this study concern groundwater impacts, including the local impacts at each proposed deep road cuttings and the tunnel (Figures 2 to 8), and their cumulative impacts on the hydrogeology of the eastern Alstonville Plateau, and has considered:

- The extent of drawdown;
- Impacts to groundwater quality;
- Discharge requirements;
- Implications for groundwater-dependent surface flows (including springs, drainages, creeks and drinking water catchments);
- Implications for groundwater-dependent ecological (GDE) communities; and
- Implications for groundwater users, including the Alstonville Basalt Groundwater Source Water Sharing Plan.

The report has provides a description of the pertinent geological and hydrogeological environments studied, and which can be broadly represented as two groundwater systems, a shallow and deeper aquifer systems, having a likelihood of impact. These are underlain by a regional groundwater systems which extends across the entire Alstonville Plateau. The assessment has categorised the different road cuts (and tunnel), with respect to defined criteria, into three cut categories, namely *Type A*, *Type B*, and *Type C*.

Two typical examples of the first two categories (Cut 19 and Cut 6, representing *Type A*, and *Type B* cuts – Figures 9 and 10), assessed most likely to impact groundwater conditions were selected for field testing and modelling.

A third category, *Type C*, are not expected to impact groundwater conditions at all because they do not penetrate the groundwater table nor have a significant footprint.

As an outcome of the study it has been estimated that *Type A* cuts *may* impact the groundwater systems and GDEs by depriving the local shallow aquifer (perched systems mainly) of up to approximately 25% of recharge water (rainfall and diversion groundwater infiltration); the impact on local groundwater systems in the vicinity of *Type B* cuts is expected to be *low to negligible* or potentially not measurable (here regarded as a ‘minor’ impact); and local groundwater systems in the vicinity of *Type C* cuts are not expected to be impacted at all (impacts not measurable).

The proposed upgrade traverses Bangalow Zone 3 *Groundwater Source Zone*, Alstonville Zone 1 *Groundwater Source Zone* and is slightly overlying Lennox Zone 6 *Groundwater Source Zone* as defined by the DWE in the local Water Sharing Plan. The WSP prescribes protection of the high priority GDEs from "water supply work (bore)" and provides buffer zones around such GDEs and streams. These are covered by this study and will be impacted as detailed in Table ES-1 and will be managed as described in Table ES-2.

Whilst local groundwater and surface water impacts are predictable, the impact of the upgrade upon the regional groundwater resource is regarded as negligible to not measurable. This is primarily due to the insignificant footprint area of the alignment when compared with the total area of the aquifer system recharge for the Alstonville Plateau (limitation of recharge infiltration and diversion of run-off are insignificant on the scale of the aquifer system.

The following table summarises the estimated impact outcomes:

Table ES-1: Summary Table of Potential Impacts (refer to Figure 2 and Figures 4 to 8,)

Cut No.	Chainage	Type	Potential Impact before Mitigation
0	134750 - 135050	**B**	Minor reduction of groundwater to creek and potential spring C1-2 and local water resource within approximately 100m of cutting. Water course related GDE's present in the vicinity of cut (no groundwater-reliant rainforest or wetlands are present in the area of potential impact.
1	135090 - 135430	**B**	Minor reduction of groundwater to creek and potential springs C1-2 and C1-1, and local water resource within approximately 100m of cutting. Potential impact to water course related GDE's present in the vicinity of cut (no groundwater-reliant rainforest or wetlands are present in the area of potential impact).
2	135920 - 136150	**C**	No measurable impact on local or regional groundwater systems or resources anticipated. No groundwater-reliant rainforest clusters or wetlands are present in the vicinity of the cut.
3	136530 - 136750	**C**	No measurable impact on local or regional groundwater systems or resources anticipated. No groundwater-reliant rainforest clusters or wetlands are present in the vicinity of the cut.
4a+b	137365 - 138280	**A**	Reduction of groundwater to local creeks and streams, and local water resource in the southern portion of the cut, i.e. within approximately 100m of cutting. Potential impact to water course related GDE's present in the vicinity of cut (no springs or groundwater-reliant rainforest or wetlands are present in the area of potential impact, i.e. within 200m of cutting).

Cut No.	Chainage	Type	Potential Impact before Mitigation
5	138990 - 139270	**A**	Reduction of groundwater to local creeks and streams, and local water resource in the southern portion of the cut, i.e. within approximately 100m of cutting. Potential impact to water course related GDE's present in the vicinity of cut (no springs or groundwater-reliant rainforest or wetlands are present in the area of potential impact, i.e. within 200m of cutting).
6	140090 – 140520 (investigated and modelled)	**B**	Minor reduction of groundwater to creek and 4 potential springs, C6-1 to C6-4, and SP-13, and local water resources within approximately 100m of cutting. Potential impact to water course related GDE's and groundwater-reliant rainforest (north of cutting) present in the vicinity of cut (no groundwater-reliant wetlands are present in the area of potential impact).
7	140760 - 140925	**C**	No measurable impact on local or regional groundwater systems or resources anticipated. No groundwater-reliant rainforest clusters or wetlands are present in the vicinity of the cut.
8	141140 - 141340	**B**	Minor reduction of groundwater to creek and potential spring C8-2 and water resource within approximately 100m of cutting. Potential impact to water course related GDE's present in the vicinity of cut (no groundwater-reliant rainforest or wetlands are present in the area of potential impact).
9	141715 - 142020	**B**	Minor reduction of groundwater to creek and potential spring C8-1 and water resource within approximately 100m of cutting. Potential impact to water course related GDE's present in the vicinity of cut (no groundwater-reliant rainforest or wetlands are present in the area of potential impact).
10	142265 - 142325	**C**	No measurable impact on local or regional groundwater systems or resources anticipated. No groundwater-reliant rainforest clusters or wetlands are present in the vicinity of the cut.
11	142680 - 142975	**B**	Minor reduction of groundwater to creek and water resource within approximately 100m of cutting. Potential impact to water course related GDE's present in the vicinity of cut (no groundwater-reliant rainforest or wetlands are present in the area of potential impact).
12	143130 - 143340	**C**	No measurable impact on local or regional groundwater systems or resources anticipated. No groundwater-reliant rainforest clusters or wetlands are present in the vicinity of the cut.
14	143960 - 144215	**C**	No measurable impact on local or regional groundwater systems or resources anticipated. No groundwater-reliant rainforest clusters or wetlands are present in the vicinity of the cut.

Cut No.	Chainage	Type	Potential Impact before Mitigation
15	144530 - 144950	**B**	Minor reduction of groundwater to creek and potentially to springs C15-1 to C15-4, and SP 22 (C15-5 and C15-6, and SP17 to SP-21 negligible risk of impact), and local water resources within approximately 100m of cutting. Potential impact to water course related GDE's present in the vicinity of cut (no groundwater-reliant rainforest or wetlands are present in the area of potential impact).
16	146230 - 146310	**C**	No measurable impact on local or regional groundwater systems or resources anticipated. No groundwater-reliant rainforest clusters or wetlands are present in the vicinity of the cut.
18a	147050 - 147250	**C**	No measurable impact on local or regional groundwater systems or resources anticipated. No groundwater-reliant rainforest clusters or wetlands are present in the vicinity of the cut.
18b	147345 - 147580	**C**	No measurable impact on local or regional groundwater systems or resources anticipated, there groundwater-reliant rainforest cluster (south) unlikely to be impacted. No wetlands are present in the vicinity of the cut.
19	147950 – 148335 (investigated and modelled)	**A**	Reduction of groundwater to local creeks, streams, springs (C19-2 and C19-3) and local water resource in the vicinity of the cut - within approximately 100m of cutting. Likely impact to water course related GDE's present in the vicinity of cut (no groundwater-reliant rainforest or wetlands are present in the area of potential impact).
20	148600 - 148815	**B**	Minor reduction of groundwater to creek and potential spring C20-1 to C20-3 and local water resources within approximately 100m of road cutting. Potential impact to water course related GDE's present in the vicinity of cut (no groundwater-reliant rainforest or wetlands are present in the area of potential impact).
St Helena Hill Tunnel Area			
21	Cut on southbound carriageway only	**C**	No measurable impact on local or regional groundwater systems or resources anticipated. A cluster of groundwater-reliant rainforest may exist of the west and east of the Cut 21 but these are not likely to be impacted. No springs or groundwater-reliant wetlands are present in the vicinity of the cut.
22	149525 - 149705	**B**	Minor reduction of groundwater to creek and potential spring C22-1 and C22-2 and local water resource within approximately 100m of cutting. Potential impact to water course related GDE's present in the vicinity of cut (no groundwater-reliant rainforest or wetlands are present in the area of potential impact).

Cut No.	Chainage	Type	Potential Impact before Mitigation
23	149970 – 150086 [tunnel south portal]	**B**	Minor reduction of groundwater to spring, creek and local water resource (groundwater well/s and dams) within approximately 100m of excavation. Potential impact to water course related GDE's present in the vicinity of cut (no springs, groundwater-reliant wetlands are present in the area of potential impact). Groundwater-reliant rainforest present around potentially likely to be impacted by portal cut.
Tunnel	150086 - 150426	**C**	Tunnel tanked, therefore no impact anticipated (leakage to tunnel essentially not measurable) within approximately 100m of excavation. No measurable impact on local or regional groundwater systems or resources anticipated. Groundwater-reliant rainforest clusters may be are present in the vicinity of the tunnel (over and east/west) but are unlikely to be impacted. No groundwater-reliant wetlands are present in the vicinity of the tunnel.
24	150426 – 150560 [tunnel north portal]	**B**	Minor reduction of groundwater to spring and associated creek leading to local water resource dam (and possible groundwater well/s). Minor local potential impact to water course related GDE's present in the vicinity of cut anticipated (no groundwater-reliant wetlands are present in the area of potential impact). Potential groundwater-reliant rainforest present around portal - potential minor impact anticipated.
25	150970 - 151260	**C**	No measurable impact on local or regional groundwater systems or resources anticipated. No groundwater-reliant rainforest clusters or wetlands are present in the vicinity of the cut.
26	151410 - 151810	**C**	No measurable impact on local or regional groundwater systems or resources anticipated. No groundwater-reliant rainforest clusters or wetlands are present in the vicinity of the cut.

The management strategy for these predicted impacts has been to pursue the following three-pronged approach:

(a) ***Assessment*** – this study, involving the investigations carried out and predictions made;

(b) ***Monitoring*** – to assess that the investigation and its predictions are accurate and to permit earlier intervention in the unlikely case/s that the actual outcomes deviate from predictions; and

(c) ***Mitigation*** – implement mitigation measures where predictions and/or monitoring measures suggest that these are required.

Management solutions have been proposed to mitigate and/or limit groundwater impacts through implementation of engineering measures that would require monitoring to assess any predicted (and unpredicted) impacts and the effectiveness of the mitigation measures. *Type A* cuts will require mitigation measures, likely to involve artificial recharge of captured surface water to the shallow groundwater system. *Type B* cuts are unlikely to require engineering mitigation, and this will need to be verified through further monitoring before, during and following construction.

Two categories of engineering management/mitigation measures could be considered at *Type A* cuts, and at *Type B* cuts, if monitoring indicates that engineering mitigation is required:

Option a) Engineering mitigation measures that transfer the seepage water downstream. Standard practice would be to collect the seepage from the cut face in the drainage system for the highway, which would be diverted into water quality ponds before being released back into the creek or natural drainage system at some point downstream.

Option b) Engineering mitigation measures that transfer the seepage water (where present) into the groundwater ecosystem immediately down-slope of the cut. These may involve collecting the seepage water from the cut face just above the level of the road, and piping it under the cut/fill platform to the down-slope side of the highway. This collection and piping system would also likely include seepage collected from the drainage blanket under the highway pavement. The collected water could then be returned to the ground through absorption trenches or discharged directly to the surface water system.

From the perspective of risk to GDEs and the local groundwater flow patterns, *Option b),* above, would provide the better solution for both *Type A* and *Type B* cuts, although a system combining both may need to be applied in some circumstances (depending on monitoring outcomes). The preferred method and exact form of the mitigation measures would be the subject of ongoing development of the concept design and environmental assessment process.

In summary, Golder Associates propose the following approach:

- ***Type A Cuts***: There is a higher likelihood that Type A cuts would impact on groundwater regimes. The implementation of engineering measures are likely to be required as part of construction to mitigate groundwater impacts. Long-term monitoring of the groundwater regime in the vicinity of Type A cuts should be commenced well in advance of the road construction. Depending on the results of the monitoring, before and during road construction, it may be that engineering mitigation would not be required at some (or all) of the Type A cuts. After road construction, the monitoring should continue to verify the effectiveness of the engineering mitigation, so that modifications can be made, if required.
- ***Type B Cuts***: It is less likely that Type B cuts would adversely impact on groundwater regimes. Engineering mitigation measures will probably not be required at Type B cuts. However, we propose long-term monitoring, commencing prior to construction, and observation of groundwater behaviour and impact during construction to verify impacts. As an outcome of the monitoring and observations, it may be necessary to implement engineering mitigation at some of the Type B cuts.
- ***Type C Cuts***: These cuts are expected to have no or negligible groundwater impacts. Monitoring and engineering mitigation measures are not required.

These recommendations are summarised in Table 3, which indicates the type of management and mitigation at each cut.

Table ES-2 Recommended Monitoring and Risk Management Strategies

	Location	Water Table penetration*	Monitoring Required	Impact Mitigation Measures Required
	TYPE A **CUTS AND TUNNEL**			
a	**Cut 4a**, Ch137365 - 138280	yes	yes	likely
b	**Cut 5**, Ch. 138990 - 139270	yes	yes	likely
c	**Cut 19**, Ch. 147950 - 148335	yes	yes	likely
	TYPE B **CUTS**			
d	**Cut 0**, Ch. 134750 - 135050	probable	yes	unlikely
e	**Cut 1,** Ch. 135090 - 135430	yes	yes	unlikely
f	**Cut 6,** Ch. 140090 - 140520	yes	yes	unlikely
g	**Cut 8**, Ch. 141140 - 141340	yes	yes	unlikely
h	**Cut 9**, Ch. 141715 - 142020	possible	yes	unlikely
i	**Cut 11**, Ch. 142680 - 142975	possible	yes	unlikely
j	**Cut 15,** Ch. 144530 - 144950	no	yes	unlikely
k	**Cut 20**, Ch. 148600 - 148815	yes	yes	unlikely
l	**Cut 22**, Ch. 149525 - 149705	yes	yes	unlikely
m	**Cut 23**, Ch. 149970 - 150086	yes	yes	unlikely
n	**Cut 24**, Ch. 150426 - 150560	yes	yes	unlikely
	TYPE C **CUTS**			
	All other cuts (13)	no	no	Not required

Notes: * based on groundwater table measured during the investigations in 2006 and 2007, and current cut design dated 3 August 2007; and

** tunnel is to be 'tanked' (fully lined with a low leakage concrete liner).

This strategy would be further detailed in a *Water Management Plan* to be prepared for both the project construction *and* operation phases.

GLOSSARY - DEFINITIONS

Item	Definition
adsorption	The attraction and adhesion of ions from an aqueous solution to the surface of solids.
AHD	Australian Height Datum
analytical model	A mathematical model that provides an exact or approximate solution of a differential equation (and the associated initial and boundary conditions) for subsurface water movement or transport.
anisotropy	The conditions under which one or more of the hydraulic properties of an aquifer vary with direction. (See also isotropy).
aquiclude	A geologic formation which may contain water (sometimes in appreciable quantities), but is incapable of transmitting significant quantities under ordinary field conditions.
aquifer	A consolidated or unconsolidated geologic unit (material, stratum, or formation) or set of connected units that yields a significant quantity of water of suitable quality to wells or springs in economically usable amounts. • confined (or artesian) - an aquifer that that is immediately overlain by a low-permeability unit (confining layer). A confined aquifer does not have a water table. • leaky / semi-confined - an aquifer that receives recharge via cross-formational flow through confining layers. The aquifer displays characteristics of both confined and unconfined aquifers. • perched - a local, unconfined aquifer at a higher elevation than the regional unconfined aquifer. An unsaturated zone is present between the two unconfined aquifers. • unconfined (or water-table) - the upper surface of the aquifer is the water table under atmospheric pressure. Water-table aquifers are directly overlain by an unsaturated zone of a surface water body.
aquitard	A semi-pervious geologic formation which can store water but transmits water at a low rate compared to the aquifer.
base flow	Part of the discharge which enters a stream channel mainly from groundwater (but also from lakes and glaciers) during long periods when no precipitation (or snowmelt) occurs.
bgl	Below Ground Level.
flow model	A digital computer model that calculates a hydraulic head field for the modelling domain using numerical methods to arrive at an approximate solution to the differential equation of groundwater flow.
GDE	Groundwater Dependent Ecosystem.
groundwater flow	The movement of water through openings in sediment and rock that occurs in the zone of saturation.

Item	Definition
groundwater model	A simplified conceptual or mathematical image of a groundwater system, describing the features essential to the purpose for which the model was developed and including various assumptions pertinent to the system. Mathematical groundwater models can include numerical and analytical models.
hydraulic conductivity (K)	The volume of fluid that flows through a unit area of porous medium for a unit hydraulic gradient normal to that area.
infiltration rate	Rate at which soil or rock under specified conditions absorbs falling rain, melting snow, or surface water; expressed in depth of water per unit time. Also, the maximum rate at which water can enter soil or rock under specific conditions, including the presence of an excess of water; expressed in units of velocity.
NMLC	Diamond Coring – drilling method.
piezometer	A tube or pipe, open to the atmosphere at the top and to water at the bottom, and sealed along its length, used to measure the hydraulic head in a geologic unit.
Piper diagram	A graphical means of displaying the ratios of the principal ionic constituents in water.
sorption	The general process by which solutes, ions, and colloids become attached (sorbed) to solid matter in a porous medium. Sorption includes absorption and adsorption.
well screen	A filtering device used to permit the flow of liquid or air but prevents the passage of sediments or backfill particles.

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1.0 INTRODUCTION

1.1 Objectives

This report presents the results of a groundwater impacts study carried out by Golder Associates Pty Ltd (Golder Associates) along the proposed upgrade of the Pacific Highway between Tintenbar and Ewingsdale (T2E), referred to as the "Pacific Highway Upgrade Program[1]" (PHUP).

The objective of this study of groundwater impacts arising from the proposed upgrade works was to address key issues raised in the Director-General's requirements (DGRs) for the Environmental Assessment (EA) of the project. The DGRs were set out in a letter from the NSW Government Department of Planning to the NSW Roads and Traffic Authority dated 22 May 2007, together with the formal project description, copies of which are provided in Appendix A. The DGRs addressed by this study are groundwater impacts, including the local impacts at each proposed deep cut and cumulative impacts on the hydrogeology, considering:

- The extent of drawdown;
- Impacts to groundwater quality;
- Discharge requirements;
- Implications for groundwater-dependent surface flows (including springs, drainages, creeks and drinking water catchments);
- Implications for groundwater-dependent ecological (GDE) communities; and
- Implications for groundwater users, including the Alstonville Basalt Groundwater Source Water Sharing Plan.

This report *also* considers the potential groundwater impacts of the proposed tunnel under St. Helena Hill.

The potential environmental impacts on the existing groundwater regime, springs and GDE's needs to be understood (through appropriate investigation) so that, if required, appropriate monitoring and mitigation measures can be implemented. The proposed road cuts and the tunnel *could* impact local surface water features by modifying groundwater recharge to the local groundwater system(s). This is because road cuts locally divert incident rainfall to a constructed drainage system reducing the potential for infiltration to the subsurface (reducing recharge) downgradient of the cut.

Further, some of the cuts and the tunnel penetrate below the existing groundwater table that are likely to capture local groundwater flow. This groundwater flow may be diverted to the surface water drainage system associated with each cut and out of the local groundwater system which may otherwise feed local springs and creeks.

[1] The alignment of the proposed upgrade is simply referred to in this report as the "proposed upgrade".

Specifically, the proposed upgrade has the potential to impact on the groundwater regime and springs, including groundwater dependent ecosystems (GDEs) and drinking water resources, as follows:

- The construction of cuts/tunnel below the groundwater table may locally draw the groundwater table down, particularly where the base of the structure is deeper than the local groundwater table. Therefore, there is the potential for the drawdown to impact on the rate of flow and flow duration/frequency of local springs and/or creek flow outside of the cut footprint. Spring flow rates could decline and, possibly, periodically or permanently dry up if there is strong hydraulic connection between the spring and cut.
- The cut and tunnel portals may capture and divert potential recharge water (by restricting rainwater infiltration to the groundwater systems) to local surface water drainages. This has the potential to detrimentally impact the prevailing natural water balance in the immediate vicinity of the structures. Typically this captured water is redirected by the roadside drains to nearby creeks or other natural drainages and is therefore less likely to recharge the groundwater systems immediately beneath the cut footprint.
- Cuts (including for the tunnel portals) may encroach over known (and some currently unknown) springs and/or cause spring flows to decline and/or intermittently or permanently cease flowing.
- Unless the rate of groundwater recharge by surface infiltration is greater than the rate of recharge to upgradient spring recharge areas or seepage into the tunnel, the groundwater table will be locally drawn down.
- An unlined tunnel excavation will behave like a drain and cause the groundwater above the tunnel invert to seep into the open excavation. Unless the rate of surface infiltration is greater than the rate of seepage into the tunnel, the groundwater table will be locally drawn down. Where the tunnel is lined ("tanked"), as proposed, this effect is negligible or non-existent.
- Local GDEs have the potential to be impacted if rainfall water destined for recharge to groundwater and GDEs is diverted to nearby surface water flow systems.
- Similarly, Local GDEs have the potential to be impacted if groundwater seepage occurs from a cut embankment and is diverted away from local downgradient GDEs to neighbouring surface water flow systems; and
- Potential groundwater resource aquifers discussed in the Water Sharing Plan for the Alstonville Plateau Groundwater Sources (DIPNR 2004) that may be deprived of some recharge waters in the immediate vicinity of the cuts and tunnel.

1.2 The Proposed Upgrade

The proposed upgrade extends from a starting at Ross Lane in Tintenbar in the south to the existing Ewingsdale interchange, near the settlement of Ewingsdale, in the north (refer to "The Project Description" in Appendix A, and Figure 1). At Ross Lane, the proposed upgrade would connect to the north end of the Ballina bypass. Generally the alignment of the proposed upgrade lies in close proximity to existing Pacific Highway corridor from Ross Lane to the Bangalow bypass. The existing highway would be maintained for local and regional traffic. The length of the proposed upgrade would be approximately 17 km.

From Bangalow, the proposed upgrade would diverge away from the Bangalow bypass to the northeast through Tinderbox valley. From there, the proposed upgrade would avoid the steep grades of St Helena Hill by way of a tunnel approximately 340 m long and 45 m below the ridge line. North of the tunnel, the proposed upgrade alignment is located immediately to the east of the existing highway before tying into the Ewingsdale interchange.

1.3 Previous Investigations

This groundwater impacts study supplements earlier geotechnical investigations along the preferred route carried out by Golder Associates between 1997 and 2007. Reports for these previous investigations provide important background information about the proposed upgrade, site conditions (topographic characteristics, land use, drainage and climate), geology and hydrogeology along the alignment and a preliminary conceptual groundwater model.

The groundwater impacts investigation program carried out for the proposed upgrade included a preliminary assessment of the hydrogeological conditions and groundwater levels at each cut. The hydrogeology along the proposed upgrade alignment is complex because of the interlayered nature of the underlying basalt geology. Golder Associates' interpretative geotechnical reports included preliminary assessments of the likely groundwater impacts from the cuts and the tunnel (Golder Associates 2007a and 2007b). The preliminary groundwater assessments were based on broad-based data that had the primary aim of establishing, as a first pass, the geological and hydrogeological conditions and level of groundwater within the cuts. Addressing the DGRs was not part of the scope of work for the earlier reports.

1.4 Physical and Environmental Setting

The proposed upgrade alignment traverses an elevated rural region of low rolling hills and deeply incised valleys known as the Alstonville Plateau (typically at 70 to 190 m Australian Height Datum). The dominant land use along the proposed upgrade is agricultural, which includes grazing, poultry, banana, coffee, stone fruit and macadamia plantations. Rural residential development is present at localities along the route.

The predominant creek systems (and their tributaries) that lie within the proposed upgrade corridor (from south to north) are as follows:

- *Emigrant Creek* (part of the catchment for Emigrant Creek dam, which is a potable water supply for the area);
- *Skinners Creek*;
- *Byron Creek*; and
- *Tinderbox Creek.*

Rainfall during the four months preceding the groundwater impact study (April to July 2007) was lower than average, with two months about 50% lower than average. However, heavy rainfall occurred during the late August 2007 field activities, with 102 millimetres (mm) of rainfall recorded at Byron Bay weather station (and, for reference, 160 mm and 170 mm was recorded at Murwillumbah and Ballina weather stations, respectively).

1.5 Regional Geology and Hydrogeology

The regional geology in the area traversed by the proposed upgrade is illustrated on the 1:100,000 Lismore-Ballina Sheet 9640. The Alstonville Plateau is underlain by the *Lismore Basalt* of the Lamington Volcanics (Morand, 1994, Brodie and Green, 2002; and the Geological Survey of NSW) and have the following features pertinent to this groundwater impacts study:

- The Lismore Basalt typically consists of sub-aerially extruded basalt (lava flows) and is thought to be up to 150 m thick at the top of St Helena Hill;
- Time lapses between lava flows created the formation of interlayered soils and weathering zones. Clay layers or fossil soils are typically about 1 m to 5 m thick, and interbeds of high and low strength basalt vary from about 5 m to 25 m thick;
- The lava flows are commonly vesicular (containing air voids, typically less than about 10 mm in diameter) and, more rarely, amygdaloidal (almond-shaped minerals);
- The basalts are highly variable, laterally and vertically; and
- The regional dip of the individual lava flows is generally 0 to 5 degrees to the *north west*.

The generalised basalt geology and stratigraphy encountered during previous investigations by Golder Associates along the proposed upgrade can be described as residual soils (basalt derived) of mainly high plasticity to variable depths, typically between 3 m and 5 m depth, overlying extremely weathered basalt (exhibiting soil-like properties) to depths to at least 15 m with discrete layers of basalt bedrock ranging in strength from very low to extremely high and highly weathered to fresh bedrock (Golder Associates 2007a and 2007b).

In addition to the residual soil and basalt rock units described above, the steep slopes and escarpment are frequently draped with landslide debris and colluvium derived from the basalt. These features are noteworthy because they have a strong influence on the local shallow groundwater behaviour.

Before presenting a more simplified groundwater setting it is necessary to consider the following geological and groundwater characteristics that are pertinent to this groundwater impacts study:

- The local residual weathering profiles and regional layered geological sequences within the Lismore Basalt govern the nature of the ‘shallower’ and ‘deeper’ (respectively) groundwater systems in the studied profiles within/along the proposed upgrade alignment.
- Intermittent and perennial perched groundwater tables can be present within the shallow soil and residual profile studied. Groundwater tables may also be present locally, within the underlying weathered or fractured basalt sequences. These are either continuous or discontinuous extent forming a complex, largely layered, cascading[2] groundwater flow system.

[2] ‘Cascading’ here is intended to convey the notion of groundwater flow which moves horizontally until a vertical flow zone (say at a thinning of a perched aquifer system, a discontinuity arising from a weathering, a fault or fracture conduit zone, or a combination of the above) is reached, whence vertical flow continues down to an impermeable zone and horizontal flow resumes and is visualised by considering a waterfall or cascading rapid system.

- Deeper groundwater systems exist within the more permeable fractured or weathered layers of basalt studied (immediately beneath the shallow groundwater system/s referred to above) that can be confined or semi-confined between the relatively massive and competent high strength, and less permeable, basalt layers, as shown in the diagram below (from Brodie and Green, 2002). With depth this transitions into the Regional Aquifer System (on a scale of 10s to 100s kilometres)
- Superimposed on this bedrock sequence is a surficial profile arising from the weathering of the bedrock sequence, that generally mimics (follows) the topography.
- Each of the above systems has its own unique influence on the way recharge water (rainfall) runs off or infiltrates into the subsurface, thus creating two dominant individual but hydrogeologically connected groundwater systems. There is likely to be a zone where the two systems overlap and where groundwater flow will be affected in part by each layering system. This zone produces a complex groundwater flow pattern, and one which is extremely difficult to interpret, predict and model.
- Regional groundwater flow in the Lismore Basalt generally follows the regional dip of the lava beds, that is, to the north west. Local flow directions will be largely governed by the local topography, geology, hydrogeology and the highly variable weathering profile.
- Each groundwater system has the potential to give rise to spring flow occurrences at the surface, largely where zones/layers of lower permeability 'daylight' (outcrop) at the ground surface.

For the purpose of this groundwater impacts study, and based on our understanding gained from the previous geotechnical investigations (Golder Associates 2007a and 2007b) and this study, the groundwater regimes in the area of the proposed upgrade can be represented as three types of aquifers:

- ***Shallow Aquifer/s***: A local shallow (or upper) aquifer that is present within the weathered or residual soil horizon generally at a depth of between 10 to 15 m bgl. This aquifer is unconfined and is likely to be discontinuous over the length of the proposed upgrade;
- ***Deeper Aquifer/s***: A local semi-confined deep (or intermediate depth) aquifer present within the layered basalt bedrock. Similarly to the shallow aquifer, the deep aquifer is likely to be discontinuous over the length of the proposed upgrade;
- ***Regional Aquifer***: The regional deep 'aquifer' that is present at depths greater than the extent of our investigations (including previous geotechnical investigations and this groundwater impacts study), deeper than the proposed cuts and tunnel, and has a lateral extent covering tens to hundreds of square kilometres, and is the subject of the Water Sharing Plan (DIPNR 2004). The cuts and tunnel were assessed to have zero or negligible impact on the regional aquifer (due to the immense scale difference between the two[3]) and consequently further assessment of the regional aquifer is not warranted.

[3] the Regional Aquifer was not further due to its scale (>100km) relative to the local scale of each of the cutting (<100m); any groundwater diverted from the local aquifer systems is typically largely reintroduced at locations (streams, creeks) immediately adjacent to the cutting/s considered with respect to their impacts.

2.0 SCOPE OF STUDY AND METHODOLOGY

2.1 Study Approach

The approach to addressing the DGRs was to assess the sensitivity of groundwater systems and the associated springs to the proposed highway construction. This approach has required field testing, data collection, review of published information, and numerical groundwater modelling to be undertaken.

As a basis of this assessment, the proposed road cuttings (and tunnel) were separated into one of three categories. This initial categorisation was primarily based on the depth of penetration into the local water table and the length and area of the cutting or tunnel, since these are the dominant physical features which are most likely to generate impacts to the local and regional groundwater systems. These categories are:

- ***Type A Cuts*** – where the proposed cut has a significant depth of excavation into the topography, a large length and area of extent, a deep penetration into the groundwater table. This is the case for Cut 4a (southern portion of Cut 4), 5 and 19 (refer Table 1 and Figures 2 to 8).
- ***Type B Cuts*** – where the proposed cut has a relatively moderate depth of excavation into the topography, a small to moderate length and area of extent, limited penetration below the groundwater table (nominally, less than about 4 m). This is the case for Cuts 0, 1, 6, 8, 9, 11, 15, 20, 22, 23 and 24 (refer Table 1 and Figures 2 to 8).
- ***Type C Cuts –*** where the proposed cut is expected to be above the groundwater table or penetrate less than 1 m below the groundwater table. This is the case for Cuts 2, 3, 4b (northern portion of Cut 4), 7, 10, 12, 14, 16, 18a, 18b, 21, 24, 25 and 26 (refer Table 1 and Figures 2 to 8). Type C cuts are not expected to impact on the groundwater regime due the fact that they do not penetrate to the groundwater table, and, therefore, no further discussion is provided in this report. The St Helena Tunnel is considered to reside in this category since it is proposed to be fully tanked (negligible leakage inferred) and would not give rise to measurable impacts to the local and regional groundwater systems even though it penetrates up to 19m below the measured water table.

Information about the groundwater conditions at the twenty seven road cuts and the tunnel is shown in Table 1 and includes current knowledge about the expected depth of excavation and the depth of the groundwater table in relation to the proposed base of the excavation. This information is based on groundwater levels in piezometers installed as part of the proposed upgrade geotechnical investigations (Golder Associates 2007a and 2007b) supplemented with additional piezometers installed at two of the cuts specifically as a part of this study, as discussed later in this report.

Table 1: Groundwater Conditions and GDEs at Cuts and Tunnel (refer to Figure 2 and Figures 4 to 8)

Cut No.	Chainage	Cut Depth (m)	Approx. Area Covered (m^2)	Approx. Penetration into groundwater table (m, max)	Type
0	134750 - 135050	8	23,010	1 - 2	**B**
1	135090 - 135430	12	42,000	2 - 3	**B**
2	135920 - 136150	1	16,740	-	**C**
3	136530 - 136750	13	19,200	-	**C**
4a+b	137365 - 138280	9	32,200	3	**A**
5	138990 - 139270	13	19,800	4 - 5	**A**
6	140090 - 140520	17	36,000	<1	**B**
7	140760 - 140925	14	14,410	-	**C**
8	141140 - 141340	9	25,740	<2	**B**
9	141715 - 142020	5	24,500	9 - 12	**B**
10	142265 - 142325	2	5,320	-	**C**
11	142680 - 142975	13	27,950	<3	**B**
12	143130 - 143340	7	16,830	-	**C**
14	143960 - 144215	10	17,480	-	**C**
15	144530 - 144950	28	57,550	<3	**B**
16	146230 - 146310	1	15,738	-	**C**
18a	147050 - 147250	13	14,900	-	**C**
18b	147345 - 147580	4	23,838	-	**C**
19	147950 - 148335	19	54,890	9	**A**
20	148600 - 148815	13	14,000	4	**B**
St Helena Hill Tunnel Area					
21	cut on southbound carriageway only		1100	-	**C**
22	149525 - 149705	7	11,250	<3	**B**
23	149970 - 150086	11	5795	Yes (portal)	**B**
Tunnel	150086 - 150426	?	7500	12 – 19 (tanked)	**C**
24	150426 - 150560	15	7500	Yes (portal)	**B**
25	150970 - 151260	13	13800	-	**C**
26	151410 - 151810	4	16000	-	**C**

Notes: Cut depth refers to the maximum excavation of the road cut below natural ground surface at the deepest point of penetration;

Area refers to the total area of the cut excavation;

Penetration into the groundwater table refers to the deepest vertical depth the cut excavation penetrates into the prevailing groundwater system/s present at the location in 2007;

Groundwater levels were collected for this study and those data from previous Golder Associates' investigation (Golder Associates 1997 through 2007);

A dash ("-") means not present or not affected; and

Chainage Information is based on the vertical and horizontal alignment for the proposed upgrade provided by ARUP in March 2008.

"tanked: refers to the fact that the tunnel will have a sealed concrete liner (impermeable liner will not permit measurable groundwater flows into the tunnel void).

The previous geotechnical investigations (Golder Associates 2007a and 2007b) for the preferred route report included developing a preliminary understanding of groundwater conditions and possible impacts. As an outcome of this initial work, it was established that further work was required to provide a more rigorous response to the DGRs. For that reason, additional investigations and analyses have been undertaken. The study approach was to select a typical Type A and Type B cut where penetration of the cut excavation into the groundwater table was proposed, make a rigorous assessment of the potential groundwater impacts at those two cuts, and extrapolate the results to the other Type A and B cuts. This work included carrying out supplementary field investigations at the selected Type A and B cuts, including additional boreholes, installation of monitoring wells, groundwater infiltration tests, and groundwater monitoring, as discussed in Section 3.0 of this report. This work was required to develop a more rigorous geological and hydrogeological model for use in the predictive modelling and groundwater impacts assessment.

The third cut category, Cut Type C, was assigned to cuts where the depth of cut is expected to be shallower than the level of the groundwater table and is likely to remain above the groundwater table even if groundwater levels rise above present level during wetter seasonal conditions. Type C cuts are therefore not expected to impact on the groundwater regime nor are there any vulnerable creeks, springs, wells or GDE’s within 100m of the cuts, and, therefore, no further discussion is provided in this report.

The two cuts selected for the study were:

- ***Type A*:** *Cut 19*, located at approximately Ch 147,950 to Ch. 148,335, was selected as this was the deepest proposed cut when this groundwater impact study commenced. The proposed cut base was up to about 12 m below the highest measured groundwater level. Even though the cut depth was revised to limit potential groundwater impacts (see below) the groundwater level has been measured about 9 m above the new proposed base level and is still the deepest proposed penetration into the groundwater table on the alignment, within the Tinderbox Creek catchment.
- ***Type B*:** *Cut 6*, located from about Ch. 140,090 to Ch. 140,520, is within the Emigrant Creek catchment and was initially selected because when this groundwater impact study commenced the proposed base of this cut would have been about 4 to 5 m below the highest measured groundwater level. During the data acquisition phase the cut depth was revised by Arup. The expected groundwater level is now at or just below the proposed cut base which is considered typical of several cuts.

Cut 19 is on the side of a steeply sloping hill used as grazing land. The slopes at Cut 6 are not as steep as at Cut 19, and the land is used for a variety of purposes including grazing, the existing Pacific Highway road corridor, orchards and residential.

It is important to highlight that subsequent to the commencement of this groundwater impact study, the vertical alignment of the proposed upgrade was altered at these cuts to reduce the potential impacts on groundwater. As a result, the base of Cut 19 is now about 9 m below the highest measured groundwater table, and Cut 6 no longer penetrates below the measured level of the groundwater table. The alignment of the proposed upgrade used for this groundwater impact study is based on Arup data dated 3 August 2007. The results presented in this report for Types A and B cuts are based on site-specific geological conditions at Cuts 6 and 19.

2.2 Scope of Work

The scope of work for the groundwater studies involved the following activities:

- Spring identification;
- Drilling boreholes;
- Installation of monitoring wells;
- Groundwater quality testing;
- Hydraulic conductivity testing including borehole and surface water infiltration testing;
- Review of existing data, including the applicable Water Sharing Plan (DIPNR 2004) and GDE assessments (Brodie and Green, 2002, *and* Biosis Research report, 2008);
- Development of geological and hydrogeological models;
- Numerical groundwater modelling; and
- Assessment of potential groundwater impacts and engineering mitigation measures.

The methodology for each of the field investigation tasks is presented in Appendix B. The fieldwork for this study was carried out in July and August 2007. The study been based on groundwater levels monitored at the cuts from late 2006 to January 2008.

3.0 RESULTS OF SUPPLEMENTARY FIELD INVESTIGATIONS AND DATA ASSESSMENT

3.1 Spring Identification

Brodie and Green, from the Bureau of Rural Sciences (BRS) in 2002 identified the location of Groundwater Dependant Ecosystems (GDE) and the location of springs on the Alstonville Plateau using aerial photography extending from the 1940s to recent. These springs locations, together with an assessment of current aerial photographs (circa 2005) for this study, established the location of potential[4] springs along the proposed upgrade especially in the vicinity of Cut 6 and Cut 19. These springs were subsequently verified by a visual inspection at each identified location.

Figure 4 to Figure 8 illustrate the location of identified springs and GDEs along the proposed upgrade, whilst Figures 9 and 10 show the presence of springs and GDEs proximal to Cut 6, and Cut 19, respectively.

It was not possible to verify the location of all identified springs due to the lack of access on some private properties.

Only one of the seven potential springs proximal to Cut 6 or Cut 19 identified by our assessment was verified as a location where groundwater emerges from the shallow aquifer to the ground surface such as a spring, seep, or creek. No other springs were observed during our walkover inspections of Cut 6 and Cut 19.

A summary of the spring verification task is provided as Table 2 with further information provided in Appendix B.

[4] Referred to as “potential” here since they pinpointed using observations made from available aerial photographs, and as such, may not be actual springs until verified on the ground.

Table 2: Results of Spring Verification

Verification of Springs at Cut 6		Verification of Springs at Cut 19	
C6-1 (high priority)	No spring present at this location. The lusher vegetation is due to the very close proximity of the creek (alluvial flood plain), note the creek is misplaced on the map.	**C19-1** (not of interest)	Not checked (outside likely area of influence)
SP13	Spring exists at this location and is flowing.	**C19-2** (not of interest)	No spring present at this location
C6-2 (high priority)	Access to property not permitted	**C19-3** (high priority)	No spring present at this location. Subsurface water flow discharge observed during heavy rain.
C6-3 (low priority)	No spring present at this location. Drainage feature.		
C6-4 (high priority)	Access to property not permitted. Assessment from nearby property. No springs present in the vicinity of location C6-4. The cluster of vegetation seems to be due to a water hole feature. No water flowing after heavy rains.		

3.2 Boreholes and Well Installation

The geotechnical investigations for *preferred route* report included drilling boreholes at each cut and the installation of standpipe piezometers to monitor water levels. For the specific purpose of the groundwater impacts study, additional boreholes were drilled at Cuts 6 and 19. This work was carried out in July and August 2007 (Golder 2007a, 2007b). The additional boreholes were drilled along “transects,” near perpendicular to the proposed road alignment, and extending from the nearest groundwater divide (up gradient of the cut) to the creek below, and part-way up the adjacent slope. These additional boreholes that were installed for this groundwater impacts study are shown on Figures 9 and 10.

The investigation of the groundwater system along each transect was intended to develop a hydrogeological model on which to base the predictive numerical modelling and assess the groundwater and surface water systems and their interactions. Drilling data obtained from each transect included:

- The geological conditions along the transect;

- Water levels in the various water systems along the profile; and
- Possible hydrogeological conduits (preferential flow pathways) based on inferred rates of drilling water loss to the surrounding rock mass.

Five pairs of groundwater monitoring wells were drilled and constructed at approximately equal spacing along each transect. At each of the five locations a ‘deep’ groundwater piezometer was installed within the bedrock (up to about 25 m depth), together with a shallow piezometer within the weathered rock (about 10 m depth). The standpipe piezometers were completed as groundwater monitoring wells, to permit ongoing measurement of local groundwater levels (piezometric head) in each of the shallow and deep aquifers. Samples were obtained from the monitoring wells for water quality testing.

The borehole reports and well installation reports are presented in Appendix C.

3.3 Hydraulic Tests

To improve the rigour of the predictive numerical groundwater models, hydraulic testing was carried out, as follows:

- *Falling head test* (or slug test) methods were used in each of the newly installed groundwater monitoring wells, to estimate the hydraulic conductivity (permeability) of the basalt layers.
- *Talsma infiltration tests* (also called ring infiltrometer tests) were carried out to assess the permeability of the surficial soil. The test was carried out at each of the piezometer locations along each transect. The test provides an estimate of the rate of rainfall infiltration which is used to estimate the rate of groundwater recharge. The rate of infiltration at the surface is typically influenced by the presence of worm holes, roots and other soil features and defects.

The falling head test data was analysed using AQTESOLV v3.5 software to calculate hydraulic conductivity, storativity and other aquifer properties. Analysis reports for each test are provided in Appendix D.

Estimated hydraulic conductivities for the shallow and deep aquifers at Cuts 6 and 19, measured using the falling head test methods, are within the following ranges:

Shallow aquifer:	Cut 6	3.1E-07 to 3.6E-05 m/s
	Cut 19	2.5E-07 to 9.9E-07 m/s
Deep aquifer:	Cut 6	4.5E-08 to 3.2E-06 m/s
	Cut 19	1.8E-09 to 1.1E-07 m/s

Soil permeability testing to assess the vertical saturated hydraulic conductivity for the surface soils (infiltration tests) provided the following results:

Top of Transect	Cut 6	5.0E-06 to 1.7E-05 m/s
	Cut 19	1.0E-04 m/s
Middle of Transect	Cut 6	1.0E-04 m/s
	Cut 19	3.7E-05 m/s
Base of Transect	Cut 6	4.1E-05 to 1.3E-04 m/s
	Cut 19	5.2E-05 m/s

The values given above may vary by as much as a full order of magnitude from the true value.

The data presented above was used in the numerical seepage analysis presented in Section 4.3 (and Appendix G).

3.4 Water Quality Testing Results

The laboratory analysis for the water samples collected from groundwater monitoring wells and the creeks and springs (i.e. BH2003 to BH2007, and BH1021, Cut 19 creek and spring SP-13) are summarised in Appendix B. The laboratory certificates are presented in Appendix E.

The chemistry results were plotted on a Piper diagram (Appendix B, Figure B-2) to categorise the 'water types' according to the relative major ion composition of the water, namely, chloride, sulphate, bicarbonates, potassium, calcium, magnesium and sodium concentrations. Water samples from different origins often have different water types.

The Piper diagrams reveal the following:

- Groundwater samples from the deep aquifer plot separately from groundwater samples from the shallow aquifer and the creeks and springs;
- The shallow aquifer groundwaters and surface water creek samples are Na-Cl-SO_4 type and are similar in general water type, and are 'young' and more typical of rainfall recharge waters. This is generally typical of shallow groundwater systems which are readily recharged and drain rapidly to the surface drainage system (creeks and springs); and
- The deep aquifer groundwater samples are Na-Cl-HCO_3-SO_4 type waters, again reflecting rainfall recharge (normally Na-Cl dominant), however, influenced by longer residence time within the aquifer (mineral leaching is more pronounced). These deeper groundwaters are distinct from the more dynamic shallow water flows. They are also dissimilar to the creek and spring water quality, suggesting they do not contribute significantly to the local creek and spring flows.

On this basis it can be inferred that the baseflow to the creeks is provided largely by the shallow aquifer or local and intermediate groundwater flow systems. It is also inferred that the deep aquifer does not contribute significantly to creek baseflow. These points imply that any cut that significantly diverts potential rainfall recharge away from the local shallow groundwater system (even though they are largely intermittent) is likely to locally diminish water discharges to the creeks and springs. This hypothesis was tested by the predictive numerical modelling described in Section 4.0 (and Appendix G). The exception to this is in the specific case of the tunnel which penetrates deeper into the various aquifer systems (by 12 m to 19 m), namely the top portion of the deep aquifer system, and is less likely to directly impact local springs and creeks.

3.5 Water Level Measurements

The results of depth to groundwater measurements are provided in Appendix B. Copies of the borehole reports showing monitoring well construction information are provided in Appendix C.

The following inferences are considered pertinent to the study objectives:

- The groundwater systems, both shallower and deeper, on the Cut 6 transect are generally in full hydraulic connectivity. Cut 19 water levels patterns are not clear cut as for Cut 6, confirming the heterogeneity[5] of the aquifer systems;
- Groundwater in the shallow aquifer system at the crest of the hills (groundwater divides) is intermittent or absent;
- At mid-slope, the deep and shallow aquifer systems are largely independent (lack significant vertical hydraulic connectivity);
- groundwater piezometric levels in the deeper groundwater systems (semi-confined and confined) were generally deeper than the groundwater level in the shallow aquifer confirming the presence of at least two fully or partially independent groundwater systems and inferring a general downward groundwater flow pattern over most of the transect length (exception being at the creek alignment where flow directions reverse).

3.6 Groundwater Dependant Ecosystem Assessment (GDE)

Two studies have been referenced in assessing the likely impact of the proposed upgrade on local ecosystems in the vicinity of the alignment, these include:

(1) Bureau of Rural Sciences (BRS) - Brodie and Green, 2002 identified the location of Groundwater Dependant Ecosystems (GDE); and

(2) Biosis Research, 2008 - "Tintenbar to Ewingsdale Pacific Highway Upgrade: Environmental Assessment - Terrestrial Flora and Fauna Report", referred to as "Working Paper 4" in the EA.

Brodie and Green, BRS, 2002, conducted an aerial photograph mapping study of the hydrogeology and groundwater dependent ecosystems (GDEs) of the Alstonville Plateau fractured basalt aquifers. Their GDE assessment included mapping potential wetlands, river base-flow systems and terrestrial vegetation communities. This mapping used aerial

[5] Heterogeneous, meaning, highly variable vertically and horizontally, and comprising different rock-types, with variable fracture density and hydraulic properties.

photographs available from the 1940s onwards and was refined using information collected from flora and fauna studies to define significant remnants of freshwater wetlands, riparian, and rainforest vegetation communities. Brodie and Green identified three types of GDEs on the Alstonville Plateau. The GDE they identified and mapped are described as:

- *Wetlands* – aquatic communities and fringing vegetation dependent on groundwater fed lakes and wetlands. These are lands permanently or temporarily under water or water logged, and include groundwater springs and seepage areas;
- *River base flow systems* – aquatic and riparian ecosystems that exist in or adjacent to streams that are fed by groundwater base flow. Groundwater may be a significant contributor to flows in coastal streams supporting riparian forests, "sedgelands" and grasslands, as well as in stream flora and fauna; and
- *Terrestrial vegetation* – vegetation communities and dependant fauna that have seasonal or episodic dependence on groundwater. These include trees and shrubs that require the water table to be at least episodically or periodically within their root zone.

Biosis Research, 2008, has completed detailed vegetation on-the-ground mapping *along* the proposed upgrade and *within 50 m* on each of the proposed upgrade alignments (Figure 3 to 8). Greater emphasis has been placed on this work in the assessment of impacts of GDE's. Of note is the fact that groundwater dependant wetlands were not identified along or adjacent to the proposed upgrade during the vegetation mapping. Rainforests which rely mostly on rainfall water and groundwater from the *shallow aquifer* were identified along and within 50m of the proposed upgrade (refer to Figures 2 to 8). A detailed description of the vegetation species encountered during the vegetation mapping can be found in the Biosis Research report (2008).

Note: the Brodie and Green (BRS, 2002) study used aerial photography study methods and was *not* verified on the ground using direct observations, and are therefore highly conservative. As such, this study has put greater emphasis on the results of the Biosis Research study and lesser emphasis on the Brodie and Green outcomes (but acknowledges that the information, whilst conservative, does extend of the entire area (more than the 50m wide corridors on each side of the alignment). It is worthy of note that the Biosis Research observations showed that there are some inaccuracies in the locations and extents of the Brodie and Green GDE boundaries, with many not being present at all.

Golder Associates has assessed which of those GDEs may be affected by the proposed cuts and tunnel. This assessment has considered:

- The geometry of the proposed cut such as proposed depth and horizontal planar area. Some cuts do not intersect the water table and have been classified as having no impact on GDEs. Cuts which intersect (or could potentially intersect) the water table are assessed on the importance of the cut being under the water table and the geographical extent of the cut;
- The distance from each GDE to the nearest proposed cut. GDEs located directly adjacent to a proposed cut are more likely to be impacted than a GDE located >200 m away from the cut;

- The groundwater flow direction and hydraulic gradient. Cuts intersecting the water table but for which the inferred groundwater flow direction is not directed towards a GDE are not considered to impact the GDE; and
- The outcome of the predictive groundwater modelling (numerical simulations). The groundwater modelling has identified the impact of the cuts on local seepage to creeks and springs. The results of the modelling are used in the assessment of impact to any GDE.

Figures 4 to 8 illustrate the location of the springs, creeks, vegetation and pertinent GDEs in relation to the road cuts and tunnel.

3.7 Review of the Local Water Sharing Plan and the Region Resource Issue

A *Water Sharing Plan for the Alstonville Plateau Groundwater Sources* (DIPNR, 2004) was prepared in February 2003 by NSW Department of Water and Energy (DWE) in accordance with the *Water Management Act (2000)*. The purpose of the water sharing plan was to sustainably allocate groundwater from the Alstonville Plateau source to environmental flows and other uses (including groundwater extraction from water bores and storages). The Alstonville Plateau groundwater source covers an area of about 391 square kilometres (km^2), some of which is located in the study area, and comprises a Tertiary Basalt plateau overlying Clarence Moreton basin sediments.

The annual average recharge of the aquifer was reported to be 44,472 megalitres per year (ML/yr), of which 80% or 35,578 ML/yr is allocated to environmental flows. Water allocated to *environmental flows* is to support river and stream base flows, as well as, groundwater dependent ecosystems. The WSP provides conditions for the protection of GDEs in Section 39 of the Water Sharing Plan.

The proposed upgrade traverses Bangalow Zone 3 *Groundwater Source Zone*, Alstonville Zone 1 *Groundwater Source Zone* and is slightly overlying Lennox Zone 6 *Groundwater Source Zone* as defined by the DWE. Those high priority GDEs requiring protection listed in the WSP that are present along the proposed upgrade include: terrestrial vegetation such as remnant rainforest, wetlands, and river baseflow (Section 3.6). The conditions of the Water Sharing Plan to protect these high priority GDEs specifically relate to “water supply work (bore)” and provides buffer zones around such GDEs and streams. The buffer zones to protect high priority GDEs do not apply to the proposed upgrade.

The impact on local and regional water users is discussed further in Section 4.

3.8 Numerical Groundwater Model

Two-dimensional *Conceptual Groundwater Models* (CGMs) illustrating the geological and groundwater conditions were developed to conceptualise the potential impacts of road construction on the groundwater systems and were based on Cut 6 and Cut 19. The models were used as the basis for subsequent numerical groundwater modelling to predict the impact of the cuts on local and regional groundwater seepage, spring and creek flows in the areas of the proposed road cuts. The details of these modelling assessments are presented in summary in Section 4 and in detail in Appendices F and G.

4.0 GROUNDWATER IMPACT ASSESSMENT

4.1 Conceptual Groundwater Model

Golder Associates (2007a) developed a preliminary *conceptual groundwater model* (CGM) as a means visualising the groundwater system and how the springs and creeks might be linked with the groundwater system (refer to Appendix F for a detailed description) to provide a simplified representation of the key physical features and their expected behaviour. The CGM forms the precursor to a numerical groundwater model which is a predictive tool used to estimate the likely future effects that may arise after the road cuts are excavated and constructed.

The preliminary CGM identified data required to provide a more robust and credible predictive groundwater model of the groundwater systems. This data included water table and deep confined aquifer water level profile, geological and hydrogeological boundaries, rainfall recharge rate information and hydraulic gradients. The data collected from the field investigation allowed a more complete CGM to be prepared (for typical road cuts, Cut 6 and Cut 19, i.e., representative of Type B and Type A cuts, respectively) and hence allowed more reliable predictive numerical model outcomes to be achieved. The St Helena Hill tunnel is here considered to fall into a Type A 'cut' category because of its deep penetration into one or more local groundwater systems, in a way similar to Cut 19.

4.2 Conceptual Hydrogeological Setting and Model Components

Separate CGMs were developed for Cut 6 and Cut 19 using Figures 9 and 10 that show spring and GDE locations along the proposed upgrade. These CGMs represent the two local groundwater systems, shallow and deeper, as follows (refer to Section 1.5 and Appendix F for details):

- *Shallow Groundwater Flow System:* A local shallow (or upper) groundwater aquifer within the weathered soil and rock (the regolith). The investigation borehole cores show that this shallow system comprises a sequence of variably weathered bedrock material within which remnant layers of less weathered rock are interspersed. By virtue of the geological variability (extremely to moderately weathered and laterally variable zones) of this sequence, it is likely to host numerous localised perched subsystems (largely unconfined). Groundwater flow within this complex geological system will be equally complex, with flow being dominantly horizontal in one areal location and dominantly vertical in an adjacent location. An analogy would be that the groundwater 'cascades' from one perched system to another, eventually reaching the deeper bedrock system below. Superimposed of this groundwater flow system is a moderately to densely spaced fracture pattern which is also likely to influence groundwater flow; and
- *Deeper Groundwater Flow System/s:* A local deeper groundwater system investigated, largely within the fractured porosity, is pervasively developed within moderately weathered to fresher basaltic lava flow sequences present at depth. Present within this stacked lava flow sequence are rare interbedded zones of moderately to highly weathered basalts, and some amygdaloidal, scoriaceous and fossil soil horizons. These interbeds are laterally variable, thickening and thinning out with lateral extent. Groundwater flow is dominated by the fracture plane porosity/permeability, and to a lesser extent the interbed

layers. On a macroscopic scale the groundwater flow is likely to behave in a porous media fashion (anisotropic, and controlled by the more dominant horizontal fracture and bedding planar features). On a mesoscopic (1m – 10m width) and microscopic scale flow is likely to be tortuous and highly variable. The deep aquifer behaves as a confined or semi-confined aquifer system.

Note: the *Regional Aquifer* was not considered in the numerical modelling due to its scale (>100km) relative to the local scale of each of the cutting (<250m). Any groundwater diverted from the local aquifer systems is typically largely reintroduced at locations (streams, creeks) immediately adjacent to the cutting/s considered with respect to their impacts.

Each system is characterised by different but variable hydraulic properties. The rainfall recharge (infiltration) to the two systems is complex and dependant on the topographic situation, thickness and density of the interbedded layers, vertical and horizontal hydraulic conductivity (permeability) contrasts and the overprint of a moderate to dense, tight fracture pattern of preferential flow pathways. As a consequence of these features, groundwater flow, both horizontal and vertical, is similarly controlled by low or moderate locally contrasting permeability and, hence, similarly characterised tortuous pathways. The mechanism and magnitude of the contribution that these groundwater systems (particularly the shallow flow system) make to the local springs or creeks is consequentially inferred to be highly variable, locally specific and largely seasonally controlled.

This dual groundwater system has a number of important characteristics which greatly affect the estimation of the nature and magnitude of the impact of the cuts on spring and creek flow, as follows:

- Groundwater flow within the shallow flow system ('aquifer') is largely responsible for the creek baseflow and springs, and it is likely that this is a local effect (not regional).
- The shallow aquifer system/s are intermittently to fully saturated (flow may be perennial, intermittent or may cease periodically), particularly in the upper sections of the topography (the hill top areas).
- A consistently downward groundwater flow gradient between the shallow and the deep flow systems is generally present along the transects. The exception to this general rule is noted adjacent to and beneath the creek lines.
- Moderate to strong hydraulic connectivity between the shallow and deep aquifer systems is evident along the creek alignments. This is particularly evident across the valley flat areas of Cut 6 suggesting that the creek down-gradient of Cut 6 is a 'making' creek environment (where the groundwater system discharges and supplements the creek flow).
- Spring occurrences, away from the creek alignments, whilst rare, are largely due to hydrogeologically differing rock layers (having contrasting hydraulic conductivities) daylighting at the ground surface.

Note: Groundwater level measurements collected during this stage of investigations occurred immediately after a period of above average rainfall. As a consequence, the CGM interpretation may be skewed towards an abnormally wet case-study condition. A further round of sampling would be required during dry weather conditions to confirm the relationship between the creek and springs, and the shallow aquifer.

4.3 Assessment of Potential Impact on Seepage using Numerical Groundwater Modelling

A cross-sectional seepage analysis model (two dimensional) was developed for each of the two type examples of the proposed cut configurations using Seep/W software. The models were constructed based on the CGM presented in Section 4.2 for Type A and B cuts.

The details for the models and the results of the predictive numerical modelling are presented in Appendix G and Figures G-1 to G-8.

Once the models had been calibrated to simulate the observed natural condition (pre-roadworks), they were then modified to represent the proposed cut geometry at both Cut 6 and Cut 19. Model prediction simulations were then undertaken to assess the likely impacts of the cut excavations. Figure G-7 present the results of prediction model simulations for proposed Cut 6 and Cut 19, being representative of Type B and Type A cuts, respectively.

In summary, the predictive model simulations suggest that:

- In the case of Cut 6 (Figure 5) a groundwater seepage face[6] on the up-gradient cut face of the cut is not expected to develop or be sustained (if present) because the dry season water table level is at or just below the invert of the cut (see Figure 9). Under normal or wetter rainfall conditions the cut may intersect the water table. Type B cuts are predicted to follow this behaviour;
- In the case of Cut 19 (Figure 7), predictive model simulations suggest that a seepage face on the up-gradient cut face of the cut may initially develop. Dewatering of the local up-gradient aquifer will reduce (and possibly eliminate) the seepage into the cut (see Figure 10). The degree of seepage into the road cut is likely to be heavily influenced by the local seasonal conditions. This is largely due to the dynamic behaviour of the shallow water flow system which is rapidly influenced by rainfall events. Such events will recharge the shallow aquifer more rapidly and consequentially raise the water table in that aquifer. Type A cut are predicted to follow this behaviour;
- The predicted extent of change in the water table profile in the proposed Type B cuts is limited to the near vicinity of the proposed cut (<100m), and does not cause extensive impacts on the flow conditions or magnitude of flow rate or flow volumes in the shallow flow system (regarded as minor). The deeper flow system is largely unaffected by the construction of the Type B road cuts;
- The predicted extent of change in the local water table profile surface in the vicinity of the more conservative-case Type A road cuts is potentially significant;
- The impact of the Type A (Cut 19) cut configuration is greatest at the mid-slope on the profile (beneath the cut footprint) where the impact on the local groundwater flow system is to lower the water table by up to 2 to 3 m;
- Further, the impact of the Type A (Cut 19) cut configuration on the groundwater flow volumes (or flux) which may locally contribute to spring and/or creek flow is predicted to

[6] groundwater seepage face – is that portion to the cut excavation slope (normally on the upgradient side) which is fully saturated with groundwater, and which water seeps out of and trickles down the slope to a collection drain.

be up to approximately 25% less than it would otherwise be (measured over the linear length of creek down-slope of the same linear length of the cut).

- By comparison, the predicted relative change to groundwater flow volumes to creeks and springs down-gradient of Type B cuts is *low to negligible* or not measurable (regarded as 'minor');
- In the case of Type C cuts which are above the local water table, relative change to predicted groundwater flow volumes to creeks, springs and GDEs down-gradient of these cuts is negligible or non-existent (not measurable); and
- The predictive modelling on Cut 19 suggests that the extent of drawdown of the shallow groundwater in the vicinity of Type A cuts will be to the invert level of the cut. This effect will potentially cause a reduction in recharge to the local groundwater systems of up to approximately 25% of their normal groundwater recharge. The lateral extent of the drawdown impacts for Type A cuts could be up to 100m. With Cut 6, and by extrapolation, Type B cuts, the impact is low to negligible, with impact being largely un-measurable. The Type C road cuts, those which do not penetrate into any identified local groundwater system are estimated to have negligible to no impact on the supply of water to surface water and groundwater systems.

4.4 Risk of Impact to Spring Flow and Groundwater Flow

In summary, from the predictive modelling undertaken (described above), there is little evidence to suggest that there are groundwater springs at the representative transects (Cut 6 and Cut 19). The only verified spring is at Cut 6 (SP13 on Figure 9), which is on the opposing side of the groundwater divide and is therefore not likely to be influenced by the proposed cut. The water table profile presented in Figure G1 for Cut 6 and Figure F5 for Cut 19 indicates that the water table does not intersect the current ground surface at or in the vicinity of Cut 6 or Cut 19 and therefore springs are unlikely to form. This conclusion is supported by site inspection works presented in Section 3.1.

The southern portal cut along the tunnel alignment encroaches over the mapped location of a spring (not verified in the field) that is located in the side of the gully. After excavation of the portal cut, seepage due to the perched groundwater flow to the original position of the potential spring will occur from the excavated cut face. There is also a spring to the east of the northern portal feeding a small dam in that vicinity. The groundwater supply to this spring will potentially diminished as a consequence of tunnel construction. For these reasons, the tunnel portals areas are regarded as a Type B "cut". The tunnel itself is planned to be fully tanked and as a consequence leakage of water from the local groundwater systems will be negligible. The tunnel itself is regarded as a Type C "cut".

Predictive numerical modelling, however, suggests that there is likely to be an impact to the contribution which groundwater makes to the creeks and spring (if present) where the cut penetrates into the water table zone (in excess of 3-4m), such as in Cut 19 (Type A cuts). By contrast, where the cut does not penetrate into the water table zone impacts to the contribution which groundwater makes to the creeks and spring are likely to be negligible (Type A cuts). *As such, at locations other than those studied where cuts extend below the water table, there remains a potential to affect nearby groundwater springs and creek flows.*

Due to the prevailing below average rainfall conditions experienced during this groundwater impacts study, it was found that groundwater was *not* discharging directly to surface waterways at neither Cut 6 (representative of 'Type B cuts') nor Cut 19 (representative of 'Type A cut's) since the water table levels were below the creek bed level. However, the groundwater system is contributing to the hyporheic zone associated with the spring wetlands and creek waterways (and the GDE's) down-gradient of the proposed road cuts (Type A cuts, and to a much lesser extent Type B cuts). This condition has arisen out of a relatively dry weather period and therefore may vary under different short and long term seasonal circumstances.

The outcome of the predictive modelling carried out for this groundwater impacts study, suggests that impacts are likely in the case of cuts which penetrate into the water table zone upgradient of springs and creeks. As a consequence, consideration of methods to minimise or mitigate these impacts may be required. Possible mitigation measures are discussed in the sections which follow.

4.5 Risk of Impact on Groundwater Dependent Ecosystems

River based flow systems and terrestrial vegetation systems (namely rainforest along and within 50m of the proposed upgrade) are the only groundwater dependent ecosystems identified along the proposed upgrade.

Type A cuts *may* be affected by a reduction in groundwater contribution to any local ecosystem/s (flora and fauna) which inhabit the hyporheic[7] zone in the creek or spring immediately down-gradient of this type of road cut. The GDE's may have a strong reliance on sustained perennial or periodic groundwater flow from the shallow groundwater systems (particularly where these are 'making' creeks).

As a consequence, the GDEs in the vicinity of Type A, and potentially Type B (but not Type C), cuts may have the potential to be impacted if rainfall water destined for recharge of GDEs is diverted from the local surface and groundwater systems to more distant surface water flow systems.

4.6 Impacts on the Regional Groundwater Resource and WSP Issues

As discussed in Section 3.7, the proposed upgrade traverses Bangalow Zone 3 *Groundwater Source Zone*, Alstonville Zone 1 *Groundwater Source Zone* and is slightly overlying Lennox Zone 6 *Groundwater Source Zone* as defined by the DWE. Those high priority GDEs present along the proposed upgrade alignment and which require protection include remnant rainforest, wetlands, and river baseflow. The WSP describes protection of these high priority

[7] The hyporheic zone is a region beneath and lateral to a stream bed, where there is mixing of shallow groundwater and surface water. The flow dynamics and behaviour in this zone (termed hyporheic flow) is recognized to be important for surface water/groundwater interactions, as well as fish spawning, among other processes.

GDEs from "water supply work (bore)" and provides buffer zones around such GDEs and streams. The buffer zones to protect high priority GDEs do not apply to the proposed upgrade. The GDE's prescribed are, where they apply, those covered by this study and will be impacted as detailed in Section 4.7 and will be managed as described in Section 5 (Table 4).

Whilst local groundwater and surface water impacts are predictable, the impact of the upgrade upon the regional groundwater resource is regarded as negligible to not measurable. This is primarily due to the insignificant footprint area of the alignment when compared with the total area of the aquifer system recharge for the Alstonville Plateau (limitation of recharge infiltration and diversion of run-off are insignificant on the scale of the aquifer system.

4.7 Summary of Potential Impacts

The following table summarises the assessment outcomes:

Table 3: Summary Table of Potential Impacts (refer to Figure 2 and Figures 4 to 8,)

Cut No.	Chainage	Type	Potential Impact before Mitigation
0	134750 - 135050	**B**	Minor reduction of groundwater to creek and potential spring C1-2 and local water resource within approximately 100m of cutting. Water course related GDE's present in the vicinity of cut (no groundwater-reliant rainforest or wetlands are present in the area of potential impact.
1	135090 - 135430	**B**	Minor reduction of groundwater to creek and potential springs C1-2 and C1-1, and local water resource within approximately 100m of cutting. Potential impact to water course related GDE's present in the vicinity of cut (no groundwater-reliant rainforest or wetlands are present in the area of potential impact).
2	135920 - 136150	**C**	No measurable impact on local or regional groundwater systems or resources anticipated. No groundwater-reliant rainforest clusters or wetlands are present in the vicinity of the cut.
3	136530 - 136750	**C**	No measurable impact on local or regional groundwater systems or resources anticipated. No groundwater-reliant rainforest clusters or wetlands are present in the vicinity of the cut.
4a+b	137365 - 138280	**A**	Reduction of groundwater to local creeks and streams, and local water resource in the southern portion of the cut, i.e. within approximately 100m of cutting. Potential impact to water course related GDE's present in the vicinity of cut (no springs or groundwater-reliant rainforest or wetlands are present in the area of potential impact, i.e. within 200m of cutting).

Cut No.	Chainage	Type	Potential Impact before Mitigation
5	138990 - 139270	**A**	Reduction of groundwater to local creeks and streams, and local water resource in the southern portion of the cut, i.e. within approximately 100m of cutting. Potential impact to water course related GDE's present in the vicinity of cut (no springs or groundwater-reliant rainforest or wetlands are present in the area of potential impact, i.e. within 200m of cutting).
6	140090 - 140520	**B**	Minor reduction of groundwater to creek and 4 potential springs, C6-1 to C6-4, and SP-13, and local water resources within approximately 100m of cutting. Potential impact to water course related GDE's and groundwater-reliant rainforest (north of cutting) present in the vicinity of cut (no groundwater-reliant wetlands are present in the area of potential impact).
7	140760 - 140925	**C**	No measurable impact on local or regional groundwater systems or resources anticipated. No groundwater-reliant rainforest clusters or wetlands are present in the vicinity of the cut.
8	141140 - 141340	**B**	Minor reduction of groundwater to creek and potential spring C8-2 and water resource within approximately 100m of cutting. Potential impact to water course related GDE's present in the vicinity of cut (no groundwater-reliant rainforest or wetlands are present in the area of potential impact).
9	141715 - 142020	**B**	Minor reduction of groundwater to creek and potential spring C8-1 and water resource within approximately 100m of cutting. Potential impact to water course related GDE's present in the vicinity of cut (no groundwater-reliant rainforest or wetlands are present in the area of potential impact).
10	142265 - 142325	**C**	No measurable impact on local or regional groundwater systems or resources anticipated. No groundwater-reliant rainforest clusters or wetlands are present in the vicinity of the cut.
11	142680 - 142975	**B**	Minor reduction of groundwater to creek and water resource within approximately 100m of cutting. Potential impact to water course related GDE's present in the vicinity of cut (no groundwater-reliant rainforest or wetlands are present in the area of potential impact).
12	143130 - 143340	**C**	No measurable impact on local or regional groundwater systems or resources anticipated. No groundwater-reliant rainforest clusters or wetlands are present in the vicinity of the cut.
14	143960 - 144215	**C**	No measurable impact on local or regional groundwater systems or resources anticipated. No groundwater-reliant rainforest clusters or wetlands are present in the vicinity of the cut.

Cut No.	Chainage	Type	Potential Impact before Mitigation
15	144530 - 144950	**B**	Minor reduction of groundwater to creek and potentially to springs C15-1 to C15-4, and SP 22 (C15-5 and C15-6, and SP17 to SP-21 negligible risk of impact), and local water resources within approximately 100m of cutting. Potential impact to water course related GDE's present in the vicinity of cut (no groundwater-reliant rainforest or wetlands are present in the area of potential impact).
16	146230 - 146310	**C**	No measurable impact on local or regional groundwater systems or resources anticipated. No groundwater-reliant rainforest clusters or wetlands are present in the vicinity of the cut.
18a	147050 - 147250	**C**	No measurable impact on local or regional groundwater systems or resources anticipated. No groundwater-reliant rainforest clusters or wetlands are present in the vicinity of the cut.
18b	147345 - 147580	**C**	No measurable impact on local or regional groundwater systems or resources anticipated, there groundwater-reliant rainforest cluster (south) unlikely to be impacted. No wetlands are present in the vicinity of the cut.
19	147950 - 148335	**A**	Reduction of groundwater to local creeks, streams, springs (C19-2 and C19-3) and local water resource in the vicinity of the cut - within approximately 100m of cutting. Likely impact to water course related GDE's present in the vicinity of cut (no groundwater-reliant rainforest or wetlands are present in the area of potential impact).
20	148600 - 148815	**B**	Minor reduction of groundwater to creek and potential spring C20-1 to C20-3 and local water resources within approximately 100m of road cutting. Potential impact to water course related GDE's present in the vicinity of cut (no groundwater-reliant rainforest or wetlands are present in the area of potential impact).
St Helena Hill Tunnel Area			
21	Cut on southbound carriageway only	**C**	No measurable impact on local or regional groundwater systems or resources anticipated. A cluster of groundwater-reliant rainforest may exist of the west and east of the Cut 21 but these are not likely to be impacted. No springs or groundwater-reliant wetlands are present in the vicinity of the cut.
22	149525 - 149705	**B**	Minor reduction of groundwater to creek and potential spring C22-1 and C22-2 and local water resource within approximately 100m of cutting. Potential impact to water course related GDE's present in the vicinity of cut (no groundwater-reliant rainforest or wetlands are present in the area of potential impact).

Cut No.	Chainage	Type	Potential Impact before Mitigation
23	149970 – 150086 [tunnel south portal]	**B**	Minor reduction of groundwater to spring, creek and local water resource (groundwater well/s and dams) expected within approximately 100m of portal excavation. Consequentially, mininal impact to water course related GDE's present in the vicinity of cut (no springs, groundwater-reliant wetlands are present in the area of potential impact). Groundwater-reliant rainforest present around potentially likely to be impacted by portal cut.
Tunnel	150086 - 150426	**C**	The tunnel is planned to be fully tanked (negligible leakage to tunnel), and therefore no impact anticipated (leakage to tunnel essentially not measurable) within approximately 100m of excavation. No measurable impact on local or regional groundwater systems or resources anticipated. Groundwater-reliant rainforest clusters may be are present in the vicinity of the tunnel (over and east/west) but are unlikely to be impacted. No groundwater-reliant wetlands are present in the vicinity of the tunnel.
24	150426 – 150560 [tunnel north portal]	**B**	Minor reduction of groundwater to spring and associated creek leading to local water resource dam (and possible groundwater well/s) expected within approximately 100m of excavation. Minimal local potential impact to water course related GDE's present in the vicinity of cut anticipated (no groundwater-reliant wetlands are present in the area of potential impact). Potential groundwater-reliant rainforest present around portal - potential minor impact anticipated.
25	150970 - 151260	**C**	No measurable impact on local or regional groundwater systems or resources anticipated. No groundwater-reliant rainforest clusters or wetlands are present in the vicinity of the cut.
26	151410 - 151810	**C**	No measurable impact on local or regional groundwater systems or resources anticipated. No groundwater-reliant rainforest clusters or wetlands are present in the vicinity of the cut.

5.0 POTENTIAL MANAGEMENT MEASURES

5.1 Management Timing : Construction Phase and Operational Phase

Impact to groundwater and management strategies needs to address the timing of the road upgrade. The impact to groundwater and surface water systems will vary during the two phases of the project: the construction phase and the operational phase.

Management strategies, described below, need to apply to be in place for the construction phase of the upgrade, especially monitoring and management strategies addressing the tunnel portals areas and deeper cuts as identified on Table 3.

5.2 Management Strategy

Cut Types A and B are expected to penetrate to and below the water table (Type A and B), and hence have the potential to impact on downstream groundwater patterns, spring, creeks and their associated GDEs.

The management strategy has been to follow the following three-pronged approach:

(d) ***Assessment*** – this study, involving the investigation carried out and predictions made;

(e) ***Monitoring*** – to assess that the investigation and its predictions are accurate and to permit earlier intervention in the unlikely case/s that the actual outcomes deviate from predictions; and

(f) ***Mitigation*** – implement mitigation measures where predictions and/or monitoring measures suggest that these are required.

This is on the basis that the approach to assessing groundwater impacts and requirements for management and mitigation has been to investigate a single cut from each of the two types of cut and assume that there would be similar impacts at the other Type A and B cuts. However, the actual groundwater impacts may differ from our predictions. This is because geological conditions are highly variable and can change away from the locations at which our investigations were performed. In addition, groundwater conditions change over time, depending on climatic conditions.

To effectively manage and mitigate groundwater impacts, and potential uncertainties about the actual impacts, we propose the following approach:

- ***Type A cuts***: There is a higher likelihood that Type A cuts would impact on groundwater regimes and GDEs. The implementation of engineering measures are likely to be required as part of construction to mitigate groundwater impacts. Long-term monitoring of the groundwater regime in the vicinity of Type A cuts should be commenced well in advance of the road construction. Depending on the results of the monitoring, before and during road construction, it may be that engineering mitigation would not be required at some (or all) of the Type A cuts. After road construction, the monitoring should continue to verify the effectiveness of the engineering mitigation, so that modifications can be made, if required.

- ***Type B cuts***: It is lesser likely that Type B cuts would adversely impact on groundwater regimes and GDEs. Engineering mitigation measures will probably not be required at Type B cuts. However, we propose long-term monitoring, commencing prior to construction, and observation of groundwater behaviour and impact during construction to verify impacts. As an outcome of the monitoring and observations, it may be necessary to implement engineering mitigation at some of the Type B cuts.
- ***Type C cuts***: These cuts are expected to have no or negligible groundwater impacts. Monitoring and engineering mitigation measures are not required.

These recommendations are summarised in Table 3, which indicates the type of management and mitigation at each cut.

Table 4 Recommended Monitoring and Risk Management Strategies

	Location	Water Table penetration*	Monitoring Required	Impact Mitigation Measures Required
	TYPE A **CUTS AND TUNNEL**			
a	**Cut 4a**, Ch137365 - 138280	yes	yes	likely
b	**Cut 5**, Ch. 138990 - 139270	yes	yes	likely
c	**Cut 19**, Ch. 147950 - 148335	yes	yes	likely
	TYPE B **CUTS**			
d	**Cut 0**, Ch. 134750 - 135050	probable	yes	unlikely
e	**Cut 1,** Ch. 135090 - 135430	yes	yes	unlikely
f	**Cut 6,** Ch. 140090 - 140520	yes	yes	unlikely
g	**Cut 8**, Ch. 141140 - 141340	yes	yes	unlikely
h	**Cut 9**, Ch. 141715 - 142020	possible	yes	unlikely
i	**Cut 11**, Ch. 142680 - 142975	possible	yes	unlikely
j	**Cut 15,** Ch. 144530 - 144950	no	yes	unlikely
k	**Cut 20**, Ch. 148600 - 148815	yes	yes	unlikely
l	**Cut 22**, Ch. 149525 - 149705	yes	yes	unlikely
m	**Cut 23**, Ch. 149970 - 150086	yes	yes	unlikely
n	**Cut 24**, Ch. 150426 - 150560	yes	yes	unlikely
	TYPE C **CUTS**			
	All other cuts (13)	no	no	Not required

Notes: * based on groundwater table measured during the investigations in 2006 and 2007, and current cut design dated 3 August 2007; and

** tunnel is to be 'tanked' (fully lined with a low leakage concrete liner).

This strategy would be further detailed in a *Water Management Plan* to be prepared for both the project construction *and* operation phases.

Surface water captured by the constructed road is likely to have a degraded chemical quality compared to rain fall. Typically elevated suspended solids and increased concentrations of metals can be expected. The water captured by a drainage system at each cut could need to be managed before being reintroduced into the natural groundwater system. Groundwater quality monitoring would be required.

5.3 Monitoring

Monitoring of both groundwater level and chemical quality is proposed as an essential measure to mitigate uncertainty in predictions of groundwater behaviour, which have been based largely on groundwater observations over a relatively short period of time. The monitoring would comprise:

- Installation and monitoring of wells.
- Groundwater sampling and analyses for suspended solids and metals.
- Visual observations of surface water flows at springs and creeks.
- An assessment of GDE healthiness.

Long-term monitoring of the existing monitoring wells should be continued up to, during and following construction of the cuts. The monitoring would be initiated prior to construction (background data collection), during construction and during the early years of operation, at a frequency to be determined (potentially quarterly for the first 5 years of operation, with a review of data to determine whether further monitoring is required).

New monitoring wells will need to be installed at Type A and B cuts where there are currently no monitoring wells installed. Additional monitoring wells may also be required at Cuts 6 and 19 where wells were previously installed for the purpose of this study.

The objective of long-term monitoring will be to:

- Obtain baseline groundwater data over a longer period than for this groundwater study and verify the validity of groundwater levels at the two cuts investigated during the study and at the other Type A and B cuts, verify long-term and adverse trends.
- For cuts at which engineering mitigation measures are implemented, permit an early assessment of groundwater behaviour in response to engineering mitigation measures and verify the effective functioning of the mitigation measures.
- At cuts where mitigation measures are not planned (Type B) verify that there are no adverse impacts as a result of the construction.

5.4 Potential Engineering Mitigation Measures

Two categories of engineering mitigation measures could be considered at Type A cuts, and at Type B cuts, if monitoring indicates that engineering mitigation is required:

Option a) Engineering mitigation measures that transfer the seepage water downstream. Standard practice would be to collect the seepage from the cut face in the drainage system for the highway, which would be diverted into water quality ponds before being released back into the creek or natural drainage system at some point downstream.

Option b) Engineering mitigation measures that transfer the seepage water (where present) into the groundwater ecosystem immediately down-slope of the cut. These may involve collecting the seepage water from the cut face just above the level of the road, and piping it under the cut/fill platform to the down-slope side of the highway. This collection and piping system would also likely include seepage collected from the drainage blanket under the highway pavement. The collected water could then be returned to the ground through absorption trenches or discharged directly to the surface water system.

From the perspective of risk to GDEs and the local groundwater flow patterns, *Option b),* above, would provide the better solution for both Type A and Type B cuts, although a system combining both may need to be applied in some circumstances (depending on monitoring outcomes). The preferred method and exact form of the mitigation measures would be the subject of ongoing development of the concept design and environmental assessment process.

6.0 CONCLUSIONS

Golder Associates has performed an assessment of the potential groundwater impacts relating to the different cut types and propose to manage and monitor the expected impacts, as discussed in this groundwater impacts study, to address the objectives of the study and, hence, the general requirements of the key groundwater issues identified by the DGR.

This report has provides a description of the geological and hydrogeological environment studied, and which can be broadly represented as two groundwater systems, a shallow and deeper aquifer, having a likelihood of impact. The assessment has categorised the different road cuts with respect to defined criteria into three cut categories, namely *Type A*, *Type B*, and *Type C*. As an outcome of the study it has been estimated that *Type A* cuts *may* impact the groundwater systems and GDEs by depriving the local shallow aquifer (perched systems mainly) of up to approximately 25% of recharge water (rainfall and diversion groundwater infiltration); the impact on local groundwater systems in the vicinity of *Type B* cuts is expected to be *low to negligible* or potentially not measurable (here regarded as a ‘minor’ impact); and local groundwater systems in the vicinity of *Type C* cuts are not expected to be impacted at all (impacts not measurable).

Management solutions have been proposed (see Section 5) to mitigate and/or limit groundwater impacts through implementation of engineering measures that would require monitoring to assess any predicted (and unpredicted) impacts and the effectiveness of the mitigation measures. Type A cuts will require mitigation measures, likely to involve artificial recharge of captured surface water to the shallow groundwater system. Type B cuts are unlikely to require engineering mitigation, and this will need to be verified through further monitoring before, during and following construction.

The key issues, identified in the DGRs, are addressed by this groundwater impact study through targeted investigations of local hydrogeological conditions and subsequent numerical modelling. These key issues to be addressed were extent of drawdown, impacts to groundwater quality, discharge requirements and implications for groundwater dependent surface flows and GDEs, and groundwater users, including the key requirements enunciated in the *Water Sharing Plan*.

The specific components of the groundwater key issues in the DGRs have been addressed by this groundwater impacts study. In summary, the geometry and groundwater setting of each proposed cut (see Sections 2 and 3) have been considered and numerical groundwater modelling predictions performed (see Sections 2 and 4) to estimate the potential for and magnitude of groundwater impacts. This assessment and modelling identified that the extent of drawdown would be a reduction in recharge to the localised shallow aquifers of up to about 25% due to some of the cuts (Type A, possibly Type B). There is also the potential for groundwater chemistry changes, namely an increase in suspended sediments (see Sections 3 and 4). A consequence of the deprivation of the shallow aquifers of surface water recharge potentially impacts on groundwater dependent surface flows and GDEs.

Management solutions are proposed to mitigate and/or limit these potential impacts (see Section 5). The impact on groundwater users (separate from the environmental flows and identified GDEs) identified in Water Sharing Plan (see Section 3) is expected to be negligible because the Water Sharing Plan refers largely to the regional aquifer that will have negligible impact from the cuts.

7.0 IMPORTANT INFORMATION

Your attention is drawn to the document - “Important Information About Your Geotechnical Engineering Report”, which is included in Appendix H of this report. This document has been prepared by the ASFE *(Professional Firms Practicing in the Geosciences),* of which Golder Associates is a member. The statements presented in this document are intended to advise you of what your realistic expectations of this report should be, and to present you with recommendations on how to minimise the risks associated with the ground-works for this project. The document is not intended to reduce the level of responsibility accepted by Golder Associates, but rather to ensure that all parties who may rely on this report are aware of the responsibilities each assumes in so doing.

We would be pleased to answer any questions about this important information from the reader of this report.

GOLDER ASSOCIATES PTY LTD

Ray Hatley
Principal Hydrogeologist

FH,JRB,RH/RH,CSC/fh,jrb,rh,csc
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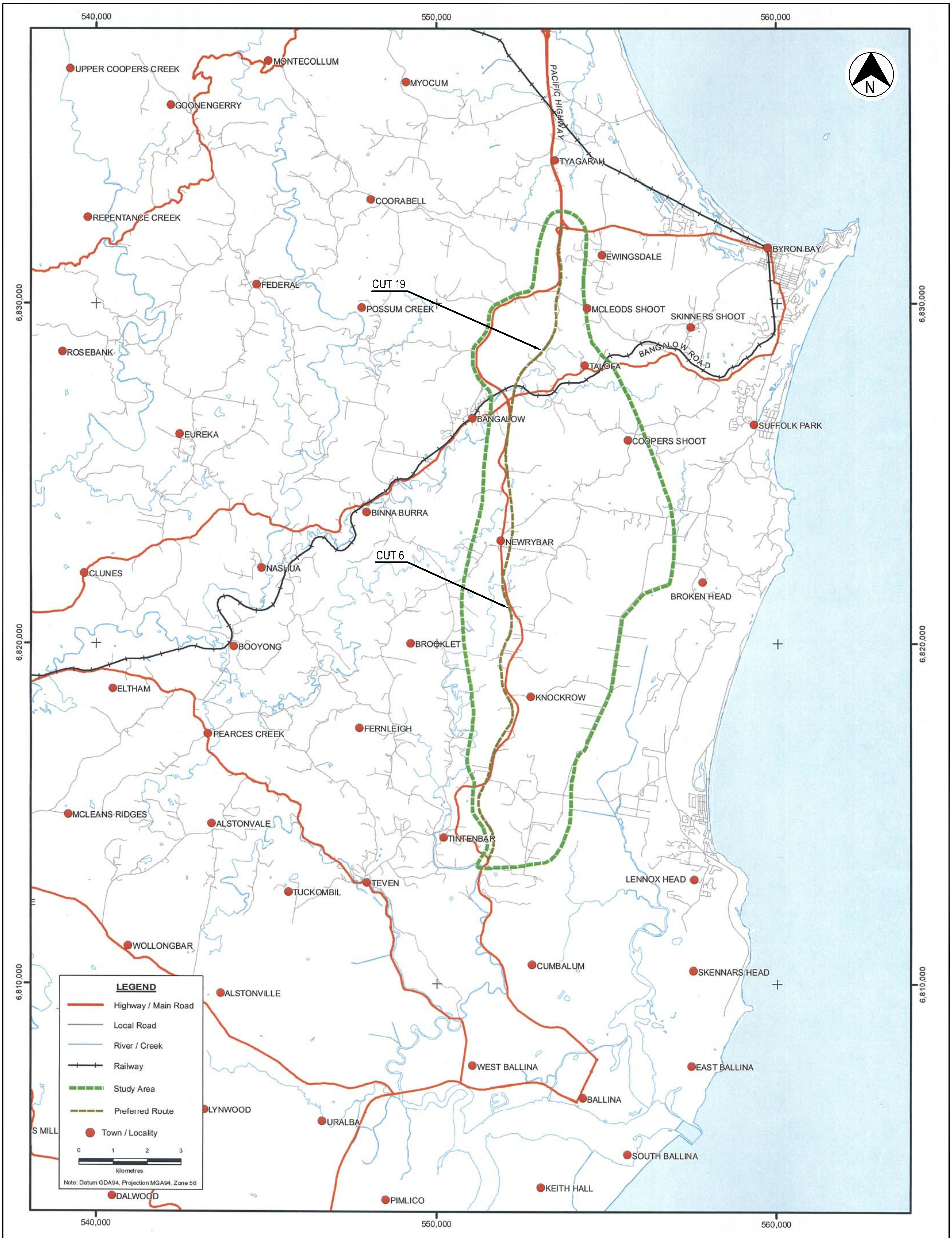
Figures



DRAWING TAKEN FROM MAPINFO AUSTRALIA PTY LTD DRG. No. BASE MAP

Golder Associates 124 PACIFIC HIGHWAY ST. LEONARDS, N.S.W. 2065 Telephone (02) 9478 3900 Facsimile (02) 9478 3901	CLIENT ARUP	PROJECT PACIFIC HIGHWAY UPGRADE - TINTENBAR TO EWINGSDALE	
	DRAWN H.C. 13.06.2008	TITLE SITE LOCATION PLAN	
	CHECKED F.H. 13.06.2008		
	SCALE AS SHOWN A3	PROJECT No 06622140-D0002	FIGURE No FIGURE 1 REVISION 6

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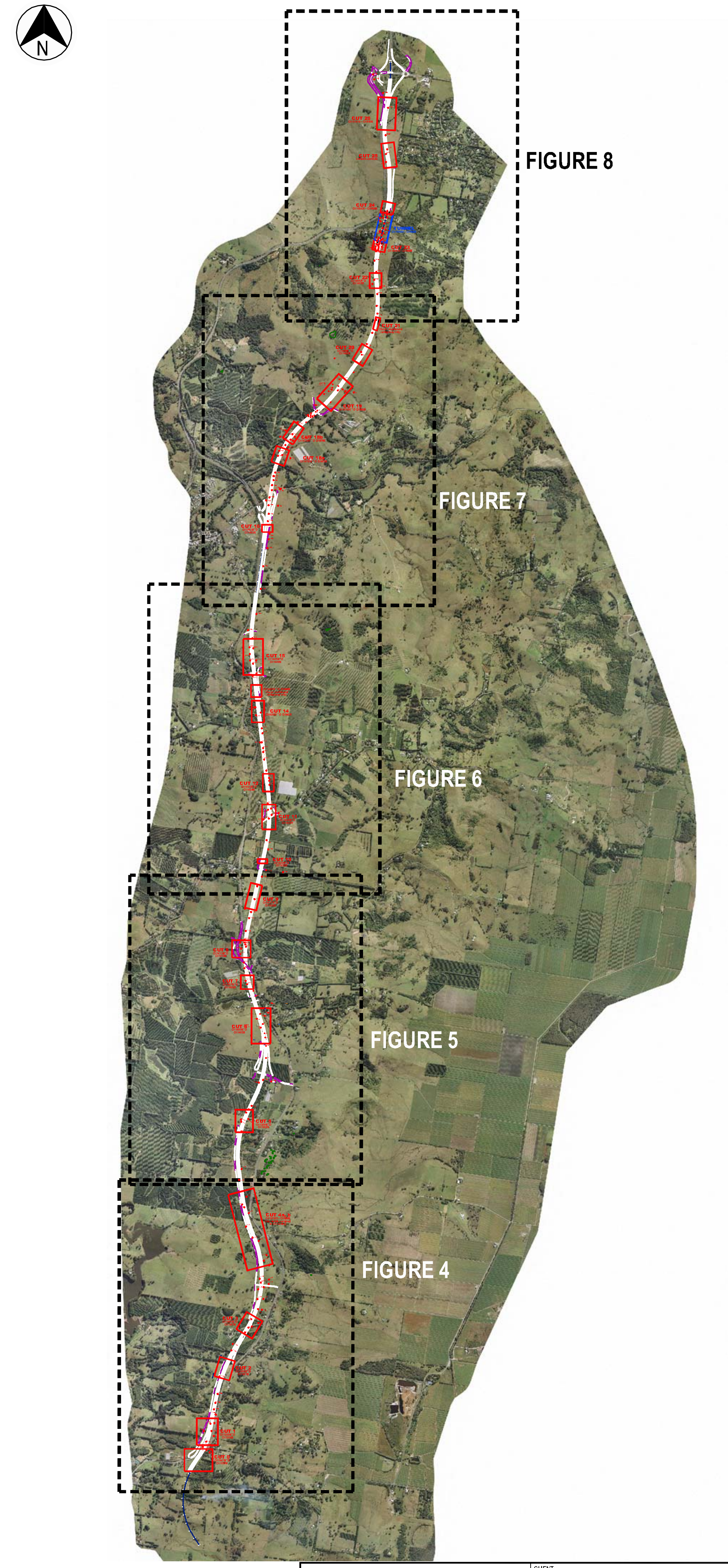

NOTES:

1. Alignment of road supplied by Arup , Preferred Route V7
2. mga grid, Zone 56
3. Extracted from "Tintenbar to Ewingsdale Pacific Highway Upgrade Environmental Assessment: Terrestrial Flora and Fauna Report".

Golder Associates 124 PACIFIC HIGHWAY ST. LEONARDS, N.S.W. 2065 Telephone (02) 9478 3900 Facsimile (02) 9478 3901	CLIENT: ARUP		PROJECT: PACIFIC HIGHWAY UPGRADE - TINTENBAR TO EWINGSDALE	
	DRAWN: H.C. 13.06.2008		TITLE: CUTS LOCATION	
	CHECKED: F.H. 13.06.2008			
	SCALE: 1:50000	A3	PROJECT No: 06622140-D0001	FIGURE No: FIGURE 2 — REVISION: 6

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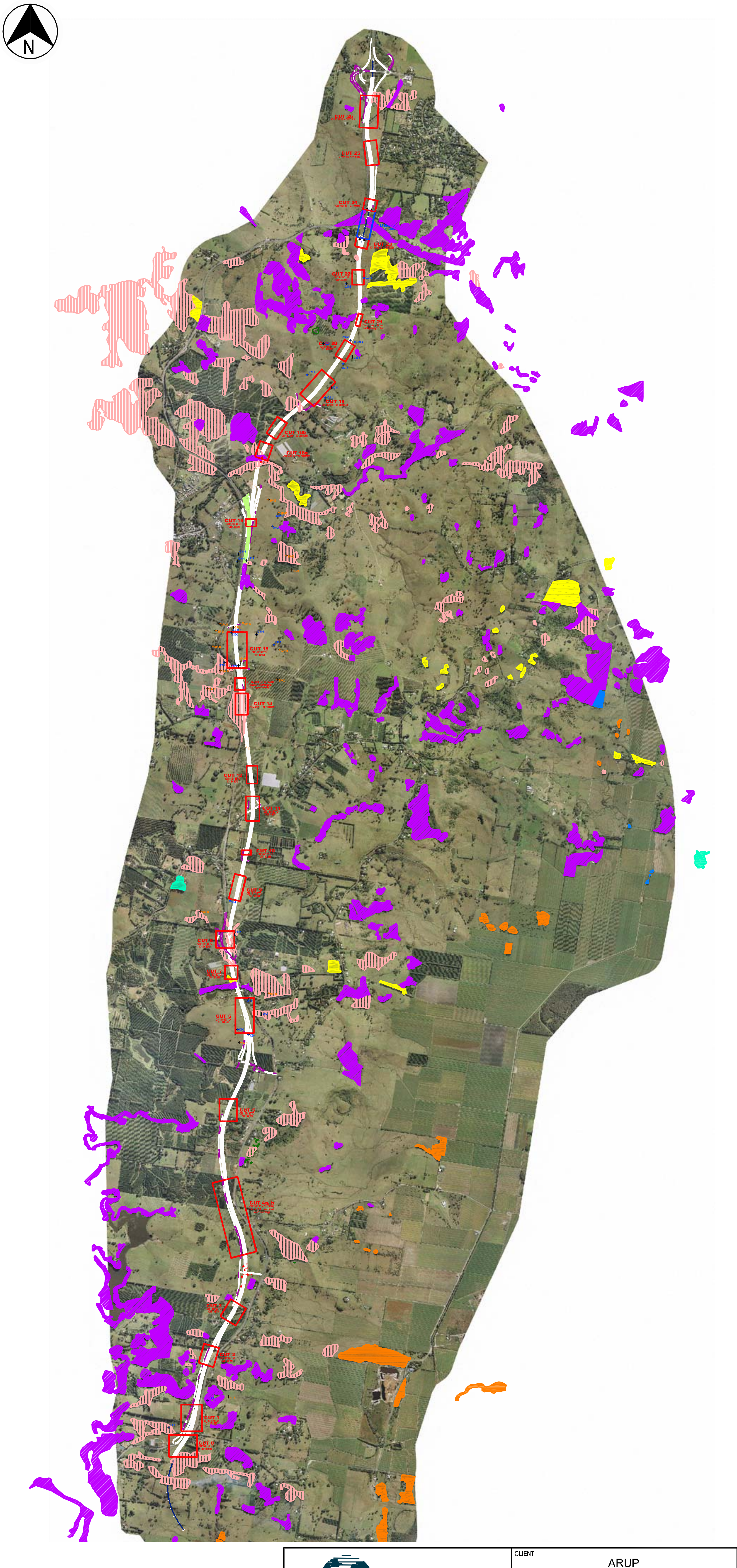

LEGEND

VEGETATION MAPPING

- *Camphor Laurel**
- *Lowland Rainforest**
- *Lowland Rainforest on Floodplain**
- *Moist Sclerophyll Forest**
- *Plantation**
- *Revegetation* (refer note 3)
- *Swamp Sclerophyll Forest**

* **Biosis Research Pty Ltd**, "Constraints Mapping, showing plant communities and locations of threatened species", File No. S4071, 21.12.2007

NOTES:

1. Alignment of road supplied by Arup , Preferred Route V7
2. mga grid, Zone 56
3. Extracted from "Tintenbar to Ewingsdale Pacific Highway Upgrade Environmental Assessment: Terrestrial Flora and Fauna Report".

1:50000 0 0.5 1 1.5 2 2.5km

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CLIENT: ARUP		PROJECT: PACIFIC HIGHWAY UPGRADE - TINTENBAR TO EWINGSDALE	
DRAWN: H.C.	13.06.2008	TITLE: VEGETATION MAPPING ALONG PROPOSED UPGRADE	
CHECKED: F.H.	13.06.2008		
SCALE: 1:50000	A3	PROJECT No: 06622140-D0001	FIGURE No: FIGURE 3 — REVISION: 6

xref:-
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1:10000 0 100 200 300 400 500m

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124 PACIFIC HIGHWAY ST. LEONARDS, N.S.W. 2065 Telephone (02) 9478 3900 Facsimile (02) 9478 3901

CLIENT	ARUP	PROJECT	PACIFIC HIGHWAY UPGRADE - TINTENBAR TO EWINGSDALE
DRAWN	H.C. 13.06.2008	TITLE	LOCATION OF GDE, SPRINGS AND CUTS CUT 0 TO CUT 4a,b
CHECKED	F.H. 13.06.2008		
SCALE	1:1000 A3	PROJECT No 06622140-D0001	FIGURE No FIGURE 4 REVISION 6

xref:-
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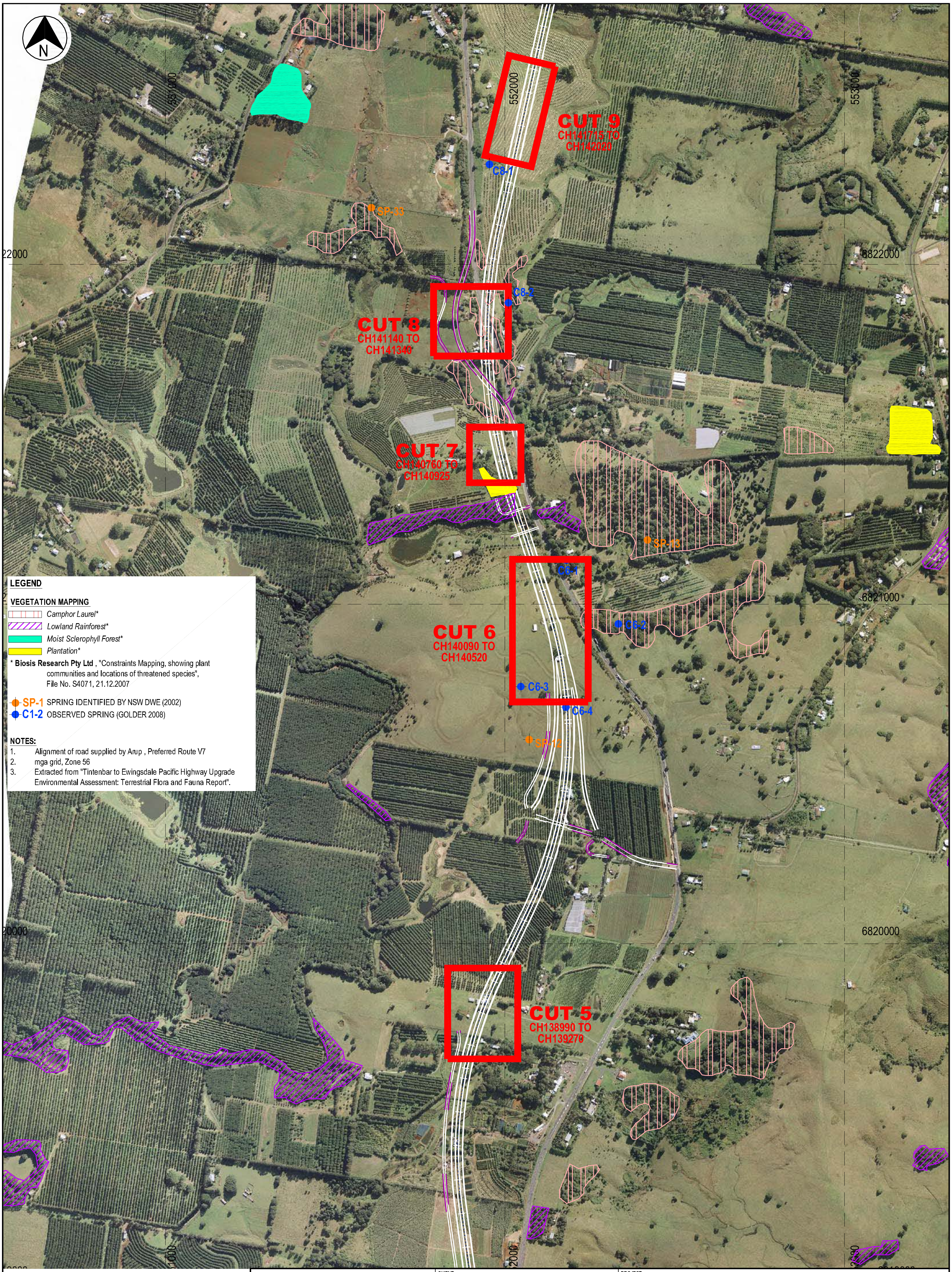

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124 PACIFIC HIGHWAY ST. LEONARDS, N.S.W. 2065 Telephone (02) 9478 3900 Facsimile (02) 9478 3901

CLIENT	ARUP	PROJECT	PACIFIC HIGHWAY UPGRADE - TINTENBAR TO EWINGSDALE
DRAWN	H.C. 13.06.2008	TITLE	LOCATION OF GDE, SPRINGS AND CUTS CUT 5 TO CUT 9
CHECKED	F.H. 13.06.2008		
SCALE	1:1000 A3	PROJECT No 06622140-D0001	FIGURE No FIGURE 5 — REVISION 6

xref:-
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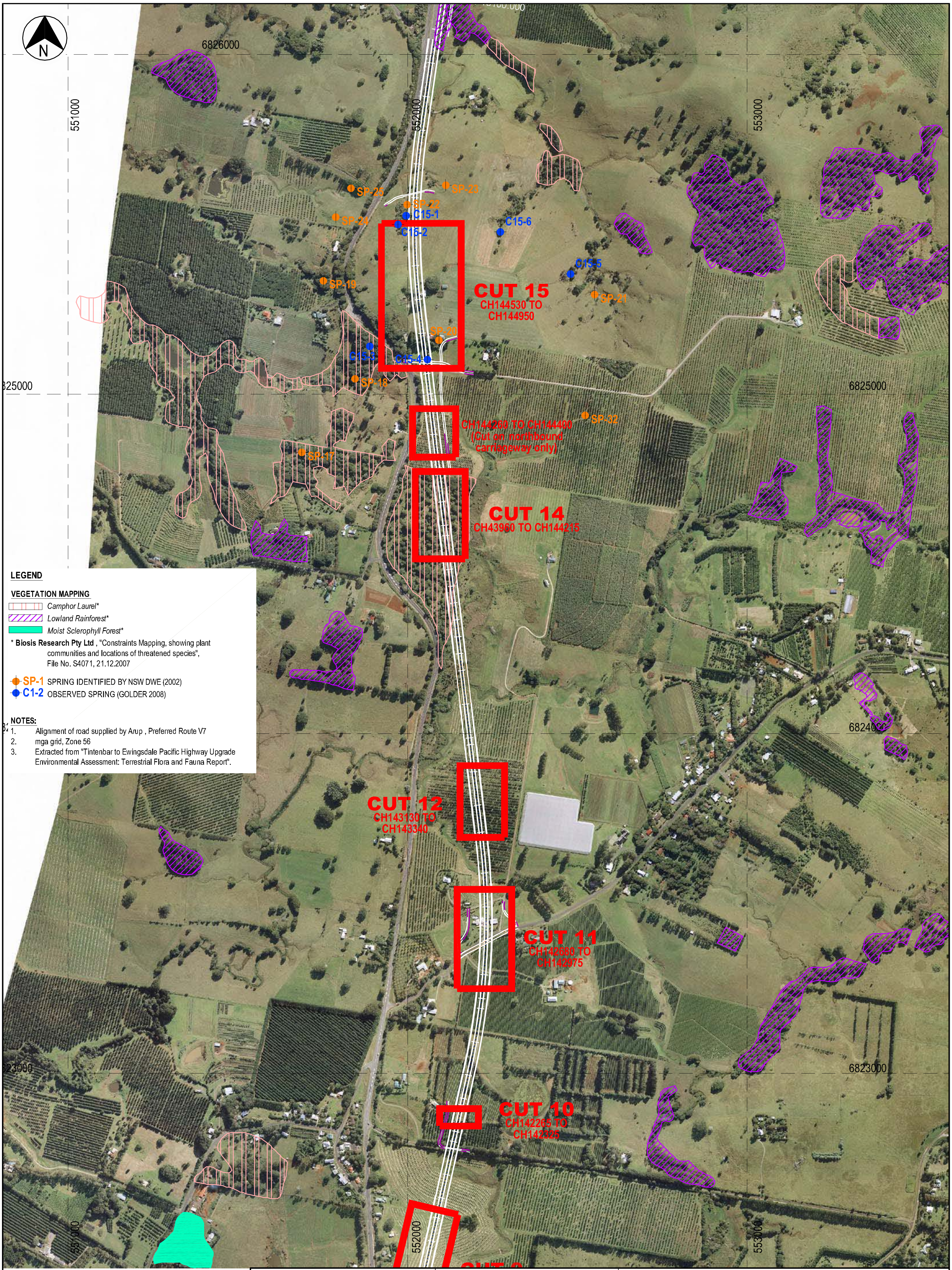

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Telephone (02) 9478 3900
Facsimile (02) 9478 3901

CLIENT	ARUP		PROJECT	PACIFIC HIGHWAY UPGRADE - TINTENBAR TO EWINGSDALE
DRAWN	H.C.	13.06.2008	TITLE	LOCATION OF GDE, SPRINGS AND CUTS CUT 10 TO CUT 15
CHECKED	F.H.	13.06.2008		
SCALE	1:1000	A3	PROJECT No 06622140-D0001	FIGURE No FIGURE 6 / REVISION 6

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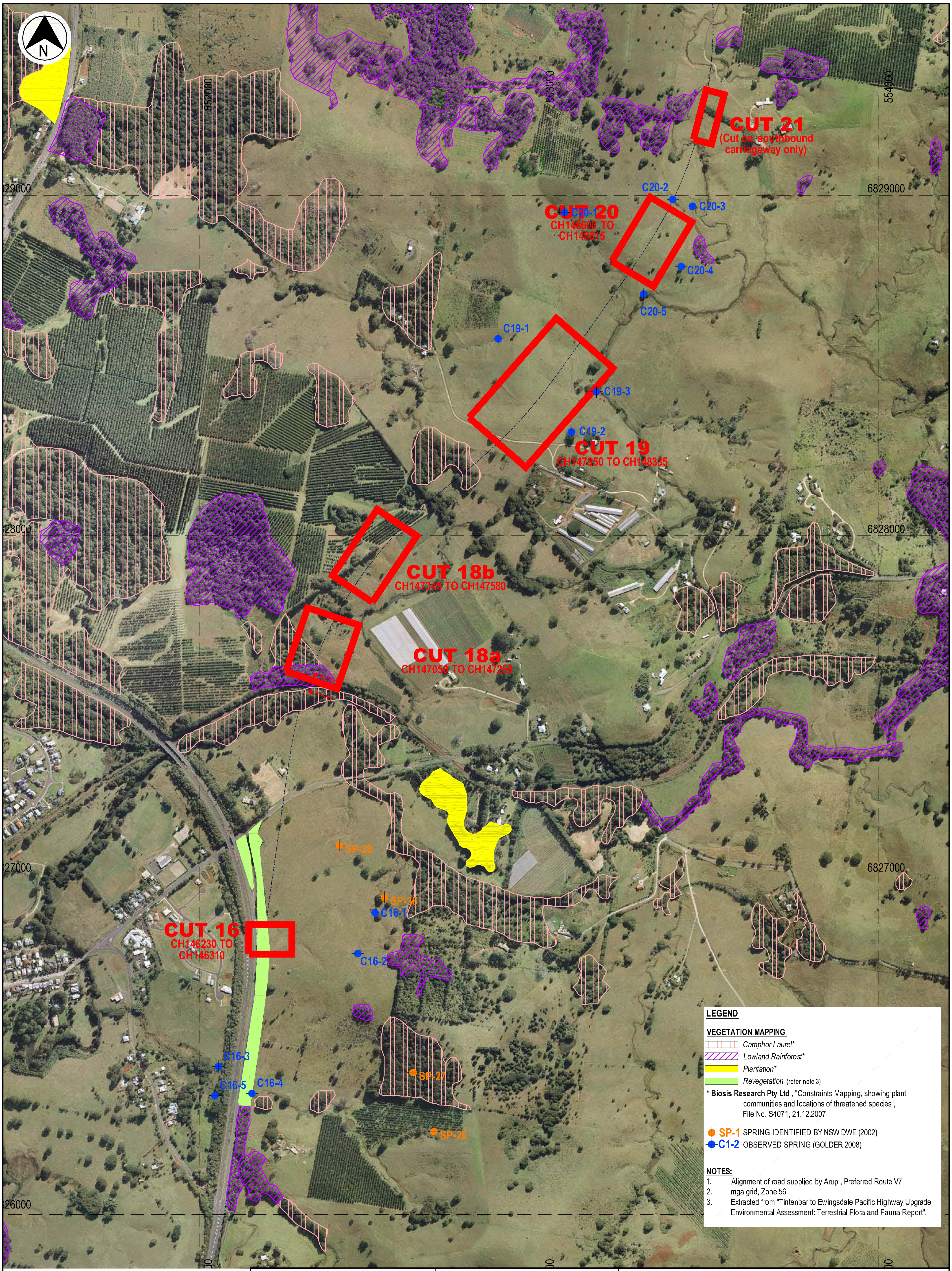

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124 PACIFIC HIGHWAY ST. LEONARDS, N.S.W. 2065 Telephone (02) 9478 3900 Facsimile (02) 9478 3901

CLIENT	ARUP	PROJECT	PACIFIC HIGHWAY UPGRADE - TINTENBAR TO EWINGSDALE
DRAWN	H.C. 13.06.2008	TITLE	LOCATION OFGDE, SPRINGS AND CUTS CUT 16 TO CUT 21
CHECKED	F.H. 13.06.2008		
SCALE	1:1000 A3	PROJECT No 06622140-D0001	FIGURE No FIGURE 7 / REVISION 6

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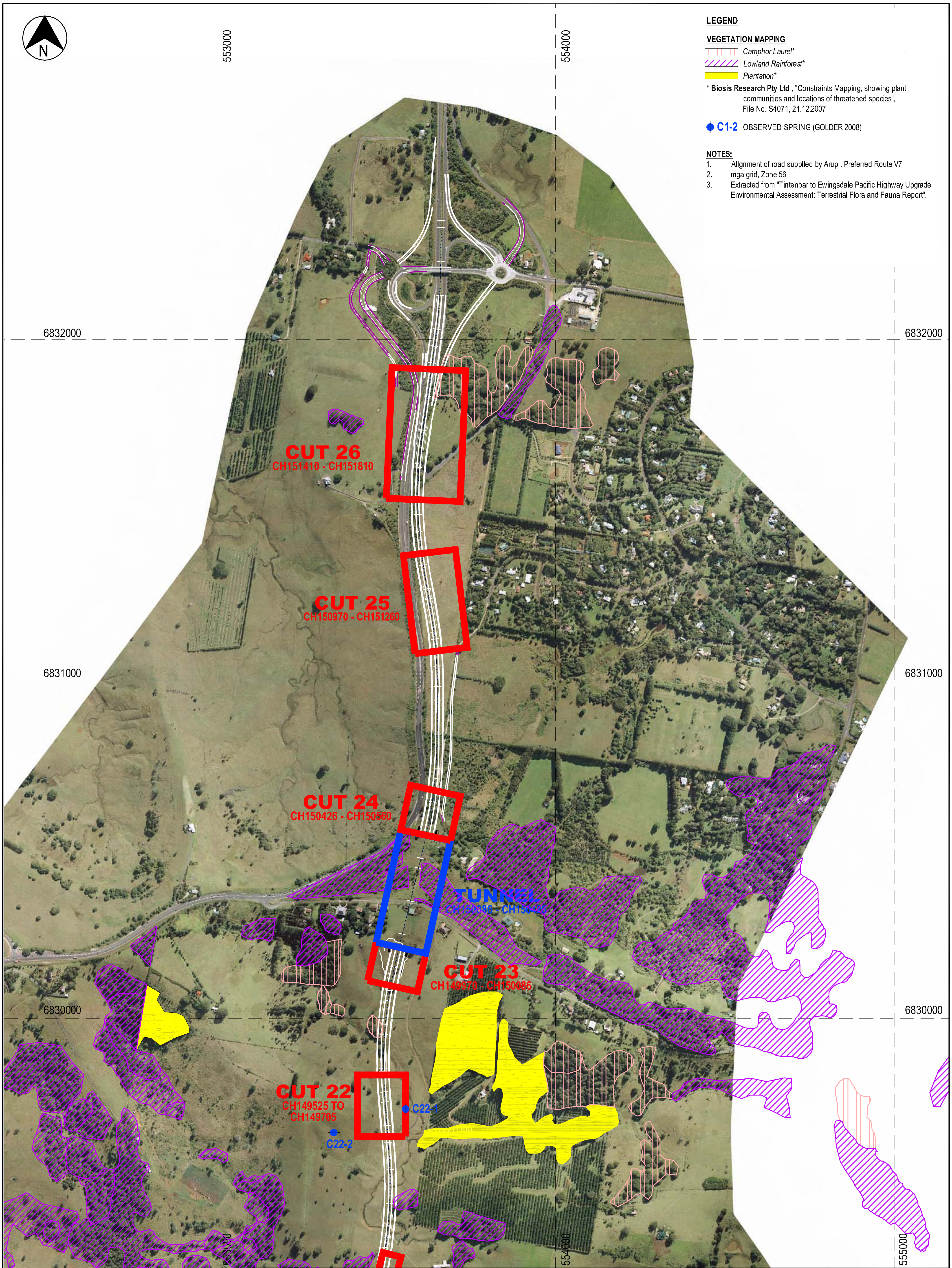

1:10000 0 100 200 300 400 500m

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Telephone (02) 9478 3900
Facsimile (02) 9478 3901

CLIENT	ARUP	PROJECT	PACIFIC HIGHWAY UPGRADE - TINTENBAR TO EWINGSDALE
DRAWN	H.C. 13.06.2008	TITLE	LOCATION OF GDE, SPRINGS AND CUTS CUT 22 TO CUT 26, (INCLUDING ST HELENA TUNNEL)
CHECKED	F.H. 13.06.2008		
SCALE	1:1000 A3	PROJECT No	06622140-D0001
FIGURE No	FIGURE 8	REVISION	6

xref:-
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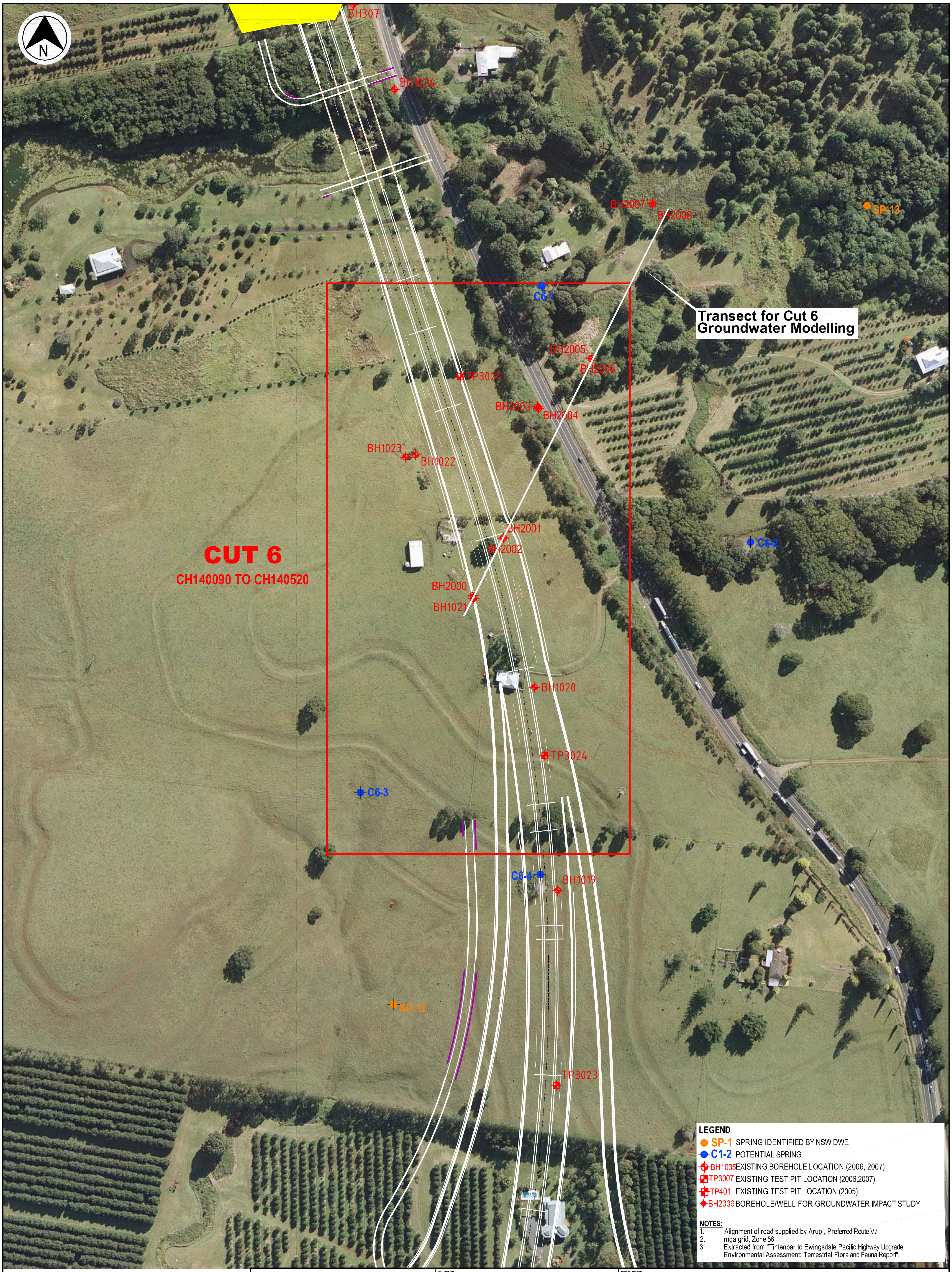

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124 PACIFIC HIGHWAY ST. LEONARDS, N.S.W. 2065 Telephone (02) 9478 3900 Facsimile (02) 9478 3901

CLIENT: ARUP		PROJECT: PACIFIC HIGHWAY UPGRADE - TINTENBAR TO EWINGSDALE	
DRAWN: H.C. 13.06.2008		TITLE: SITE LAYOUT AND BOREHOLE LOCATION PLAN FOR PROPOSED CUT 6	
CHECKED: F.H. 13.06.2008			
SCALE: 1:1000	A3	PROJECT No: 06622140-D0001	FIGURE No: FIGURE 9 — REVISION: 6

xref:-
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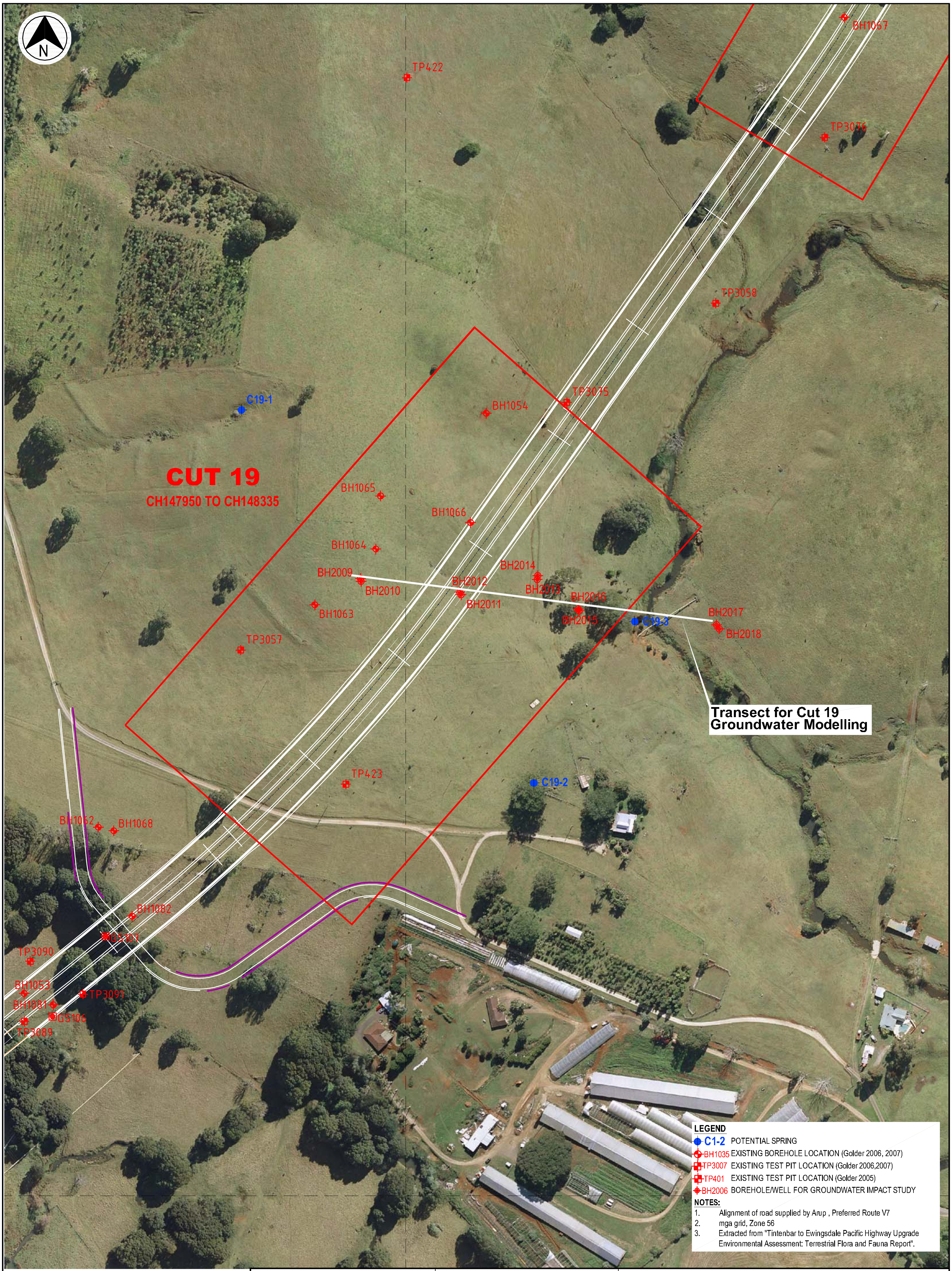

1:2500 0 25 50 75 100 125m

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124 PACIFIC HIGHWAY ST. LEONARDS, N.S.W. 2065 Telephone (02) 9478 3900 Facsimile (02) 9478 3901

CLIENT	ARUP	PROJECT	PACIFIC HIGHWAY UPGRADE - TINTENBAR TO EWINGSDALE
DRAWN	H.C. 13.06.2008	TITLE	SITE LAYOUT & BOREHOLE LOCATION PLAN FOR PROPOSED CUT 19
CHECKED	F.H. 13.06.2008		
SCALE	1:1000 A3	PROJECT No 06622140-D0001	FIGURE No FIGURE 10 — REVISION 6

xref:-
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