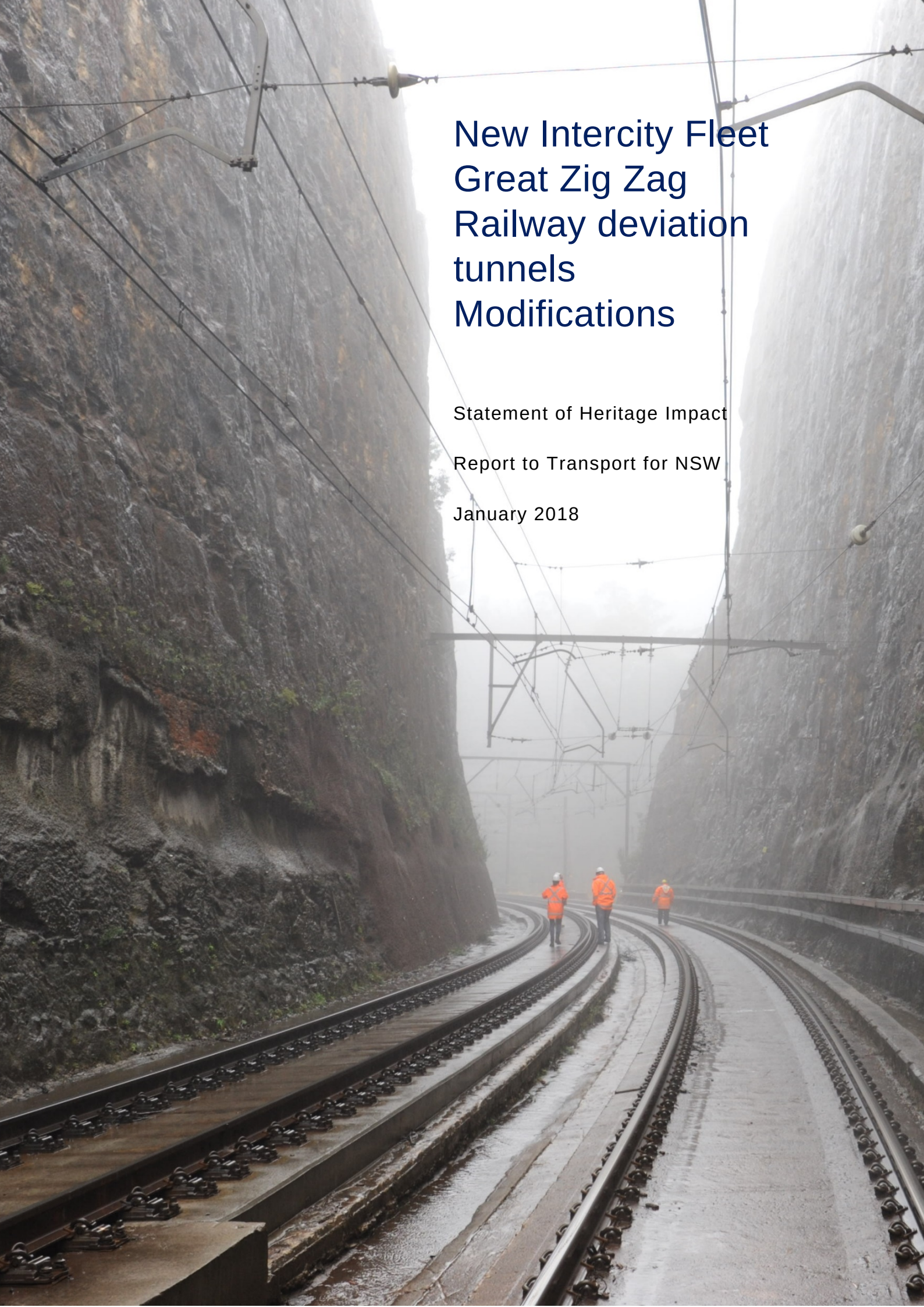

New Intercity Fleet Great Zig Zag Railway deviation tunnels Modifications

Statement of Heritage Impact

Report to Transport for NSW

January 2018

Document history and status

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EXECUTIVE SUMMARY

Overview

Transport for NSW (TfNSW) is the government agency responsible for the delivery of major transport infrastructure projects in NSW and is the proponent for the Great Zig Zag Railway deviation tunnels Great Zig Zag Railway deviation tunnels Modifications (the Project).

In May 2014, the NSW Government announced delivery of the New Intercity Fleet, to replace trains carrying customers from Sydney to the Central Coast, Newcastle, Blue Mountains and the South Coast. The introduction of the New Intercity Fleet would allow for the replacement of the older electric train fleets currently used to provide intercity services.

The Project involves modifications to the tunnel lining of the State Heritage Register (SHR) listed Great Zig Zag Railway deviation tunnels (or Great Zig Zag Railway deviation tunnels) and associated infrastructure to accommodate the wider New Intercity Fleet. Subject to approval, construction is expected to commence in 2018 and take around two years to complete.

The Project fulfils the program objectives by carrying out essential enabling works that would facilitate the safe and reliable operation of the New Intercity Fleet through the Ten Tunnels Deviation on the Blue Mountains Line. This would provide a better experience for public transport customers by delivering an accessible, modern, safe and comfortable travel experience.

Conclusions

The Project would result in a moderate physical impact and a minor visual impact to the State heritage listed Great Zig Zag Railway deviation tunnels (SHR# 01037). The Project would result in a neutral physical impact and a negligible visual impact to the State heritage listed Great Zig Zag Railway and Reserves (SHR# 00542). The recommendations set out below would aid in mitigating the impact of the Project on the Great Zig Zag Railway deviation tunnels and nearby heritage items.

Recommendations & mitigation measures

Development	Discussion
Approvals	A Section 60 permit under the NSW *Heritage Act 1977* would be required prior to works occurring within the Great Zig Zag Railway deviation tunnels SHR curtilage. The permit would cover the works described in Section 7.1 of this report. This assessment would be provided to the NSW Heritage Council in support of a Section 60 application. As the Project has been assessed as potentially resulting in a moderate physical impact to the LEP listed Great Zig Zag Railway and deviation tunnels item, TfNSW should consult with Lithgow City Council to provide information on the Project.
Archival resources	Prior to commencement of the Project, a Photographic Archival Recording (PAR) should be prepared, recording areas to be affected by the Project. The PAR should include photographs of the portal entrances and existing cable route and trough within Tunnel 3 prior to commencement of works, and include a record of views that would be modified by the Project. The recording would be undertaken in accordance with the guidelines for *Photographic Recording of Heritage Items Using Film or Digital Capture* prepared by the NSW Office of Environment & Heritage. The PAR would be submitted to Lithgow City Council, and copies retained as per the standards.

Development	Discussion
	A 3D model prepared for the Great Zig Zag Railway deviation tunnels using detailed scanning technology should be made available as an archival resource for the heritage item once the format of the file is appropriate for access. Consideration should be given to making this resource available on relevant online catalogues and databases including the Lithgow Library, Blue Mountains Library, State Library New South Wales and the National Library of Australia. Prior to commencement of works, consideration should be given to exploring options of conducting a video recording of the Great Zig Zag Railway deviation tunnels. This should be from the point of view of the driver, and could be achieved by mounting a camera to the front of a train or work vehicle.
Geotechnical investigations	Geotechnical investigation of tunnel fabric may be required during detailed design. The scope of these investigations may be consistent with the scope of geotechnical investigations conducted in 2017 during preparation of the concept design. That investigation included concrete and brick coring, brick and mortar sampling, and brickwork stress testing. Geotechnical investigations must only take place in areas where notching is proposed, and adhere to the following principles: • Structural investigation work which involves the removal or damaging of tunnel fabric should ensure it is located in the interior areas of the tunnel, away from the openly visible tunnel portals and brick arches, to reduce the potential for visual heritage impacts • The removal of bricks for brick and mortar sampling should involve the replacement of similar bricks to infill voids in the brick lining, where the removal of significant fabric will be visible following completion of notching works • Following the removal of concrete and brick cores, the exposed holes should be refilled with non-shrink grout A Heritage Consultant should be consulted once details of the scope of geotechnical investigations are known in order to ensure consistency with these recommendations.
Selection of sympathetic materials and finishes	The selection of new materials and finishes used for the proposed reconstruction of sections of tunnel lining within the Great Zig Zag Railway deviation tunnels should be as sympathetic as possible to the existing character, with the aim of minimising visual impacts. Where new concrete is used for minor repairs, this should be selected to closely match the colour and texture of the existing concrete lining, so as to avoid potential visual impact in small localised areas of new work. Where new concrete is required for major repairs and involves new work across larger areas, i.e. more than one metre, the colour and texture of new concrete should be visually recessive and complement the existing concrete lining, while being identifiably new in order to distinguish itself from the original design and fabric of the tunnels. Consideration should be given to the type of material used to infill any holes left by the removal of the existing Galvanised Steel Trough (GST) on the down track of Tunnel 3. Materials used to support or grout affected concrete would be sympathetic to existing

Development	Discussion
	grouting on the tunnel walls. Adequate allowance should be made for any variance in the physical properties of new surfacing fabric in terms of thermal expansion and contraction, to avoid cracking and physical impacts on underlying heritage significant fabric.
Appropriate cleaning methodology	In areas where infringement is minimal and requires cleaning as opposed to notching, hand cleaning should be carried out wherever safe and practicable to do so. Blasting with a high-pressure hose should be avoided where possible to avoid inadvertent impact or damage to mortar and bricks within the tunnel.
Protection of overhead wiring structures	For the duration of the proposed work, protective measures and machine spotting would be utilised to avoid inadvertent impact or damage to overhead wiring structures within the Great Zig Zag Railway deviation tunnels. In the event that inadvertent impact to overhead wiring structures occurs during the proposed work, efforts should be made to source replacement parts rather than replacing the overhead wiring structure. Where replacement is the only option, efforts should be made to ensure that the replacement part does not involve any removal of significant brick fabric.
Gradient/ radius/ survey markers	Where it is identified that any gradient/ radius/ survey markers are located within proposed notching areas, those markers should be included in the PAR. Photographic recording should take place prior to commencement of works. The location of the recorded markers should be recorded by a surveyor and included in the PAR.
Treatment of modified rock bolts	Where a portion of rock bolt is removed prior to commencement of proposed notching works, advice from a specialist (structural engineer and/ or contamination specialist) would be required to ensure the remaining section of rock bolt does not corrode and expand, which would potentially damage and undermine the integrity of original significant fabric.
Vegetation management and maintenance	Some vegetation on sandstone cuttings adjacent to tunnel portals would be trimmed during the New Intercity Fleet works. This work would not involve any works that would impact the cutting face. A Heritage Consultant should be consulted where works would include removal of vegetation and potential impacts to the sandstone cutting face.
Culverts and drainage	The construction contractor would be required to assess culverts and drainage prior to placement of temporary hi-rail access points, and ensure that these will not be impacted by the Project. For the duration of the project, drainage infrastructure within the Great Zig Zag Railway deviation tunnels curtilage would be protected to avoid inadvertent damage and prevent blockage by way of debris/spoil. It is noted the Project would be carried out within and adjacent to the ongoing Sydney Trains project for the repair and replacement of culverts at 147.165km and 148.707km.
Vibration monitoring	During the proposed construction work, careful ongoing monitoring would be required for potential risk of vibration to the tunnel structures. This is particularly associated with notching of tunnel lining, which could potentially loosen bricks or impact the concrete lining. The proposed works would be undertaken in accordance with the safe work distances outlined in the Noise and Vibration Assessment prepared for the Project, and attended vibration monitoring or vibration trials would be undertaken prior to tunnel notching.

Development	Discussion
	To minimise potential vibration impacts during works to significant fabric, regular inspections of the construction activities and work areas wold be undertaken by structural engineers to monitor and review the construction methodology and confirm the integrity of the tunnel lining. Where it is identified that levels of vibration are causing damage to the tunnel lining, works would stop and the construction methodology reviewed for its appropriateness in consultation with a Heritage Consultant.
Removed fabric	Detailed design should consider the appropriateness and potential locations for keeping all removed original fabric within the SHR curtilage of the Great Zig Zag Railway deviation tunnels. It is assumed that the removed fabric will be highly fragmented ceramic building material. Sydney Trains heritage advisors should be consulted during this process with regards to potential long-term locations within the curtilage for removed fabric.
Sealant	To maintain the visual appearance of the original brick and concrete fabric, no sealant has been recommended for application to notched areas. Where it is determined through detailed design that sealant will be required on some or all notched surfaces, further advice from a Heritage Consultant would be required on the appearance and type of sealant used.
New signage	Detailed design should consider placing new signage proposed for the Lithgow end of Tunnel 10 adjacent to the up track and not attached to the brick portal.
Ongoing heritage specialist advice	A Heritage Consultant should provide ongoing heritage advice during the detailed design and construction phases of the Project, and should ensure that the above material and design options advice is enacted. A heritage induction should be provided to all on-site staff and contractors involved in the project. The induction should clearly describe the heritage constraints of the site.
Unexpected finds procedure	During proposed ground disturbing and construction works, the Transport for NSW *Unexpected Finds Procedure* would be adhered to.
SHR curtilage	The Great Zig Zag Railway deviation tunnels SHR curtilage as gazetted is incorrect and does not match the description of the item. Heritage Division should be advised of the discrepancy, in order to commence the process of gazetting the correct curtilage.

Acronyms

Acronym	Definition
Down track	The Blue Mountains line consists of two tracks, the down track is the rail track which carries trains in the direction of Lithgow from Sydney.
EP&A Act	*Environmental Planning and Assessment Act 1979*
GST	Galvanised steel trough
Haunch	The upper section of the tunnel wall
ISEPP	*State Environmental Planning Policy (Infrastructure) 2007*
LEP	Local Environmental Plan
LGA	Local Government Area
OEH	Office of Environment and Heritage
REF	Review of Environmental Factors
SHR	State Heritage Register
SoHI	Statement of Heritage Impact
TfNSW	Transport for New South Wales
Toe	The lower section of the tunnel wall
Up track	The Blue Mountains line consists of two tracks, the up track is the rail track which carries trains in the direction of Sydney from Lithgow

CONTENTS

FIGURES

TABLES

1.0 INTRODUCTION

1.1 Background

Transport for NSW (TfNSW) is the government agency responsible for the delivery of major transport infrastructure projects in NSW and is the proponent for the Ten Tunnel Deviation Modifications (the Project).

In May 2014, the NSW Government announced delivery of the New Intercity Fleet, to replace trains carrying customers from Sydney to the Central Coast, Newcastle, Blue Mountains and the South Coast. The introduction of the New Intercity Fleet would allow for the replacement of the older electric train fleets currently used to provide intercity services.

The Project involves modifications to the tunnel lining of the State Heritage Register (SHR) listed Great Zig Zag Railway deviation tunnels (or Ten Tunnel Deviation) and associated infrastructure to accommodate the wider New Intercity Fleet. Subject to approval, construction is expected to commence in 2018 and take around two years to complete.

The Project fulfils the program objectives by carrying out essential enabling works that would facilitate the safe and reliable operation of the New Intercity Fleet through the Ten Tunnel Deviation on the Blue Mountains Line. This would provide a better experience for public transport customers by delivering an accessible, modern, safe and comfortable travel experience.

AECOM, on behalf of TfNSW, has engaged Artefact Heritage to provide a Statement of Heritage Impact (SoHI) for the Project. This report assesses the heritage significance of the Ten Tunnel Deviation and nearby heritage items, evaluates potential heritage impacts and outlines heritage management and mitigation measures where appropriate.

1.2 Overview of the project

The Project comprises minor modifications to sections of the lining of eight tunnels in the Great Zig Zag Railway deviation tunnels and minor modifications to ancillary infrastructure extending from the eastern portal of Tunnel 1 (Sydney end) to the western portal of Tunnel 10 (Lithgow end) to accommodate the operation of the New Intercity Fleet which is marginally wider and longer than the existing trains. No modifications are planned for the rail line between the tunnels as part of this Project.

A detailed description of the Project is provided in Section 7.1.

1.3 Design development

To assess the capacity of the Ten Tunnels Deviation to accommodate the New Intercity Fleet, a 3D laser survey was undertaken along the length of the tunnels to confirm the existing dimensions. Figure 1 shows an example image of the tunnels from the laser survey.

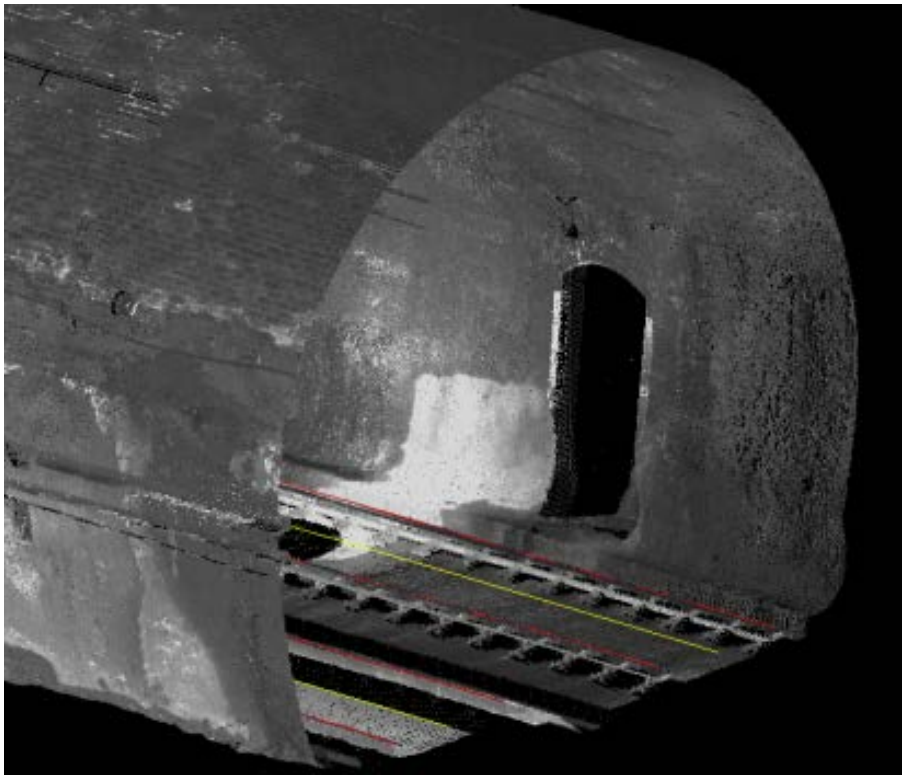


Figure 1: Image from the 3D tunnel survey

Survey information was then used to model the potential infringements against the sub-medium electric standard (which the New Intercity Fleet trains comply with). The modelling calculated which sections of the up track (towards Sydney) and down track (towards Lithgow) tunnel lining (i.e. the lower 'toe' or upper 'haunch') would require treatment ('notching') and to what depths to achieve the necessary kinematic envelope clearances at 10 metre intervals.

The kinematic envelope of a train is the outline of the space around it when in motion, and takes into account its tilt and sway. The TfNSW Assets Standards Authority (ASA) establishes and maintains standard with requirements around the minimum clearances between the kinematic envelope of a train and the surrounding environment, to ensure it operates safely and does not infringe on structures in the rail corridor.

Currently only two types of trains have a kinematic envelope that meet the standard and can safely operate through the Ten Tunnels Deviation, these include the narrow electric passenger trains (V-Sets) and the narrow non-electric freight and passenger trains (e.g. XPTs and the Bathurst Bullet).The New Intercity Fleet is wider than the existing V-Sets with a different kinematic envelope.

Notching refers to the process of cutting back or milling the tunnel lining. This is typically achieved through the use of road headers, jackhammers or hand tools. The notching treatment types are classified by letter ('H' for haunch and 'T' for toe) to indicate the area of the tunnel that requires notching, along with a number to describe the modelled depth of notching required. These are summarised below:

- Haunch
    - H0: 0-20 millimetres
    - H1: 20-60 millimetres
- Toe
    - T1: 0-100 millimetres

- T2: 100-160 millimetres
- T3: 160-215 millimetres
- T4: 215-265 millimetres.

The notching depth is measured from a virtual tunnel 'design line', which approximately correlates with the original tunnel lining position. This means that where there is existing notching, the maximum depth of proposed notching is measured from the design line, rather than from the existing notched depth. Much of the toe sections of the tunnels have been notched in the past to allow for the V-sets.

The implications of this are that although the deepest proposed notching measures up to 265 millimetres depth (T4 treatment type), the deepest notching from the existing tunnel lining (i.e. actual notching undertaken) would be no greater than approximately 100 millimetres (subject to construction tolerance of 25 millimetres).

During detailed design, the treatments would be refined to provide minimum required clearances. Figure 2 provides a typical cross section which shows the infringement.

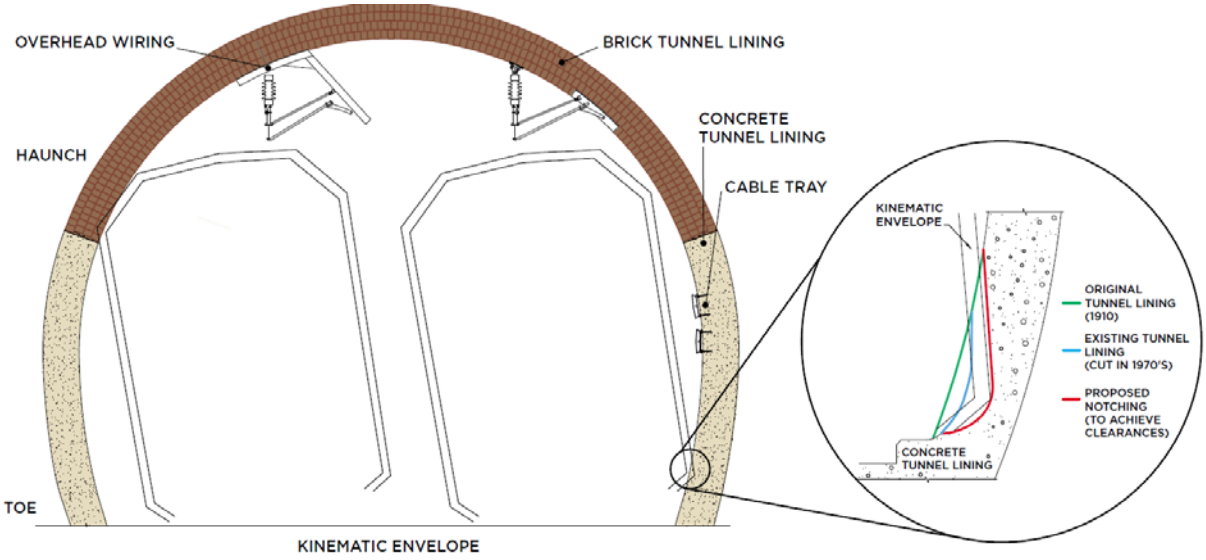


Figure 2: Typical tunnel cross section which shows the infringement

1.4 Site location

The Project is located to the east of Lithgow on the western escarpment of the Blue Mountains, across the localities of Clarence, Hartley and Dargan NSW. The Project is in close proximity to the UNESCO World Heritage protected Blue Mountains National Park.

1.5 Report methodology

This SoHI has been prepared using the document *Statement of Heritage Impact* (2002), prepared by the NSW Heritage Office, contained within the *NSW Heritage Manual,* as a guideline and includes:

- Desktop searches of relevant heritage registers
- Review of Project drawings and concept design reports
- Review of the following key documents:
  - heritage register listings for the Great Zig Zag Railway deviation tunnels

  - historic plans for the Great Zig Zag Railway deviation tunnels held by the Sydney Trains Plan Room
  - previous reports and other relevant documentation provided by Transport for NSW
- Background research into the historical development of the Great Zig Zag Railway deviation tunnels using the historic plans, historical photographs, newspapers and other primary and secondary historical sources as relevant as referenced
- Site inspections were conducted by Artefact Heritage staff in May and September 2016 and April 2017. Note: all photographs within this report were taken by Artefact during these site inspections unless otherwise stated
- Assessment of the Project against the heritage significance of the Great Zig Zag Railway deviation tunnels. The assessment has been undertaken in light of the conservation processes and principles found in *The Burra Charter: The Australian ICOMOS Charter for Places of Cultural Significance* (2013). *The Burra Charter* is considered to be the pre-eminent guidance document for the management of change for places of heritage significance within Australia.

1.5.1 Significance grading

This report includes an assessment of the relative contributions of individual components of the Great Zig Zag Railway deviation tunnels to its overall heritage value. Components are assessed according to the grading in Table 1.

Table 1: Standard grades of significance

Grading	Justification	Status
Exceptional (E)	Rare or outstanding element directly contributing to an item's local and state significance.	Fulfils criteria for local or state listing
High (H)	High degree of original fabric. Demonstrates a key element of the item's significance. Alterations do not detract from significance.	Fulfils criteria for local or state listing
Moderate (M)	Altered or modified elements. Elements with little heritage value, but which contribute to the overall significance of the item.	Fulfils criteria for local or state listing
Low (L)	Alterations detract from significance. Difficult to interpret.	Does not fulfil criteria for local or state listing
Intrusive (I)	Damaging to the item's heritage significance.	Does not fulfil criteria for local or state listing

1.5.2 Impact assessment

In order to consistently identify the potential impact of the Project, the terminology contained in Table 2 has been referenced throughout this document.

Table 2: Terminology for assessing the magnitude of heritage impact

Grading	Definition
Major	Actions that would have a long-term and substantial impact on the significance of a heritage item. Actions that would remove key historic building elements, key historic landscape features, or significant archaeological materials, thereby resulting in a change of historic character, or altering of a historical resource. These actions cannot be fully mitigated.
Moderate	Actions involving the modification of a heritage item, including altering the setting of a heritage item or landscape, partially removing archaeological resources, or the alteration of significant elements of fabric from historic structures. The impacts arising from such actions may be able to be partially mitigated.
Minor	Actions that would result in the slight alteration of heritage buildings, archaeological resources, or the setting of an historical item. The impacts arising from such actions can usually be mitigated.
Negligible	Actions that would result in very minor changes to heritage items and no significant alteration of its heritage values.
Neutral	Actions that would have no heritage impact.

1.5.3 Report authorship and acknowledgements

This report has been prepared by Josh Symons (Principal) and Charlotte Simons (Heritage Consultant). Dr Sandra Wallace (Director) reviewed the report.

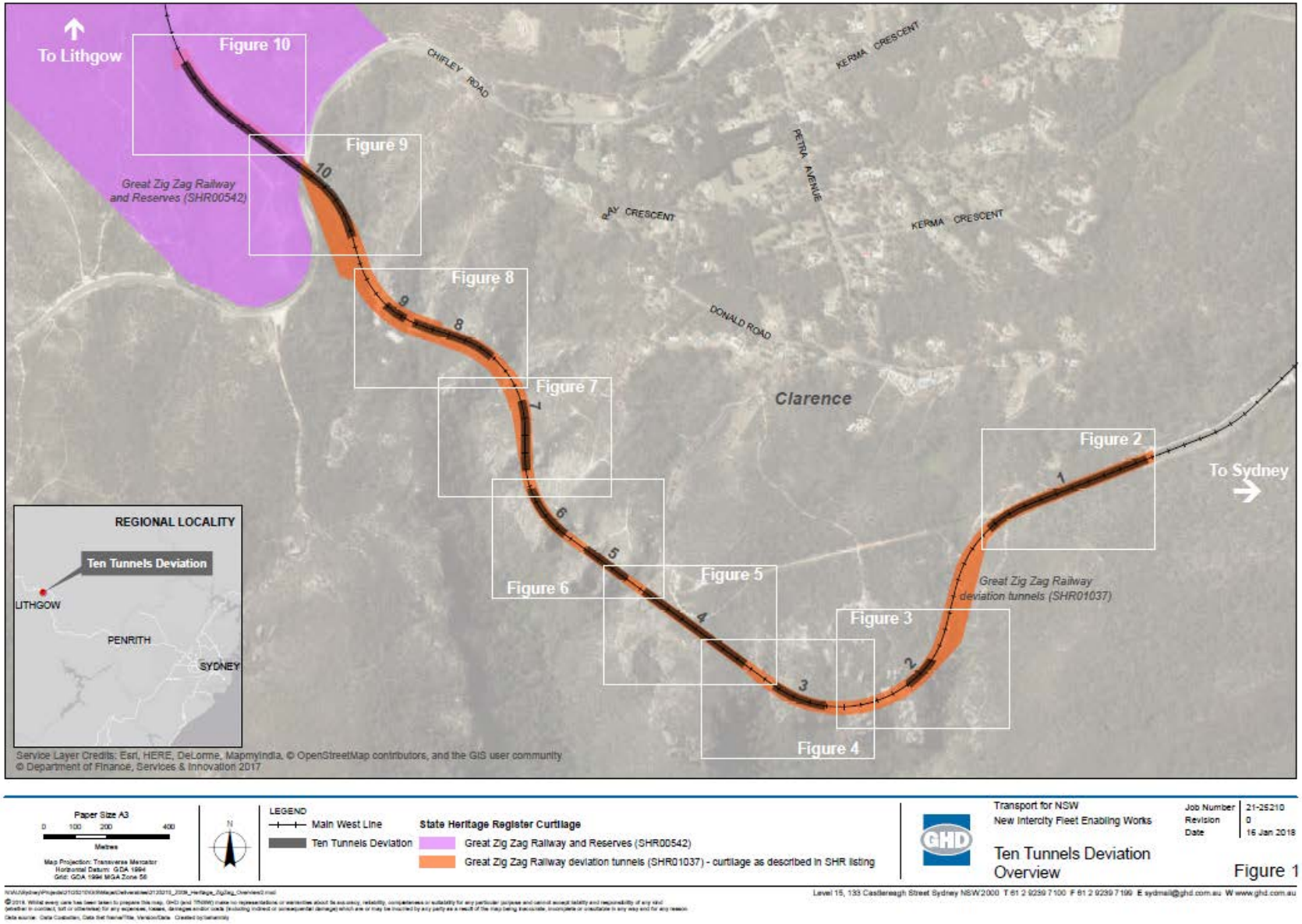


Figure 3: Location of Great Zig Zag Railway deviation tunnels (supplied by GHD)

2.0 STATUTORY CONTEXT

2.1 Commonwealth legislation

2.1.1 Environment Protection and Biodiversity Conservation Act 1999

The *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) provides a legislative framework for the protection and management of matters of national environmental significance, that is, flora, fauna, ecological communities and heritage places of national and international importance. Heritage items are protected through their inscription on the World Heritage List, National Heritage List or the Commonwealth Heritage List.

The EPBC Act stipulates that a person who has proposed an action that will, or is likely to have; a significant impact on a World, National or Commonwealth Heritage site must refer the action to the Minister for the Environment (hereafter the Minister). The Minister would then determine if the action requires approval under the EPBC Act. If approval is required, an environmental assessment would need to be prepared. The Minister would approve or decline the action based on this assessment.

As the Great Zig Zag Railway deviation tunnels are not registered on the World, National or Commonwealth Heritage Lists, the heritage provisions of this act do not apply and works for the Project would not require referral to the Minister.

2.2 State legislation

2.2.1 Heritage Act 1977

The NSW *Heritage Act 1977* (Heritage Act) is the primary piece of State legislation affording protection to heritage items (natural and cultural) in NSW. Under the Heritage Act, 'items of environmental heritage' include places, buildings, works, relics, moveable objects and precincts identified as significant. Significance is based on historical, scientific, cultural, social, archaeological, architectural, natural or aesthetic values. State significant items can be listed on the NSW SHR and are given automatic protection under the Heritage Act against any activities that may damage an item or affect its heritage significance. The Heritage Act also protects 'relics', which can include archaeological material, features and deposits.

Under the Heritage Act, all government agencies are required to identify, conserve and manage heritage items in their ownership or control. Section 170 of the Act requires all government agencies to maintain a Heritage and Conservation Register that lists all heritage assets and an assessment of the significance of each asset. They must also ensure that all items inscribed on its list are maintained with due diligence in accordance with State Owned Heritage Management Principles approved by the Government on advice of the NSW Heritage Council. These principles serve to protect and conserve the heritage significance of items and are based on NSW heritage legislation and guidelines.

The Heritage Act also provides protection for 'relics', which includes archaeological material or deposits. Section 4 (1) of the Heritage Act (as amended in 2009) defines a relic as:

> *"...any deposit, artefact, object or material evidence that:*
>
> *(a) relates to the settlement of the area that comprises New South Wales, not being Aboriginal settlement, and*

> *(b) is of State or local heritage significance"*

Sections 139 to 145 of the Heritage Act prevent the excavation or disturbance of land known or likely to contain relics, unless under an excavation permit. Section 139 (1) states:

> *A person must not disturb or excavate any land knowingly or having reasonable cause to suspect that the disturbance or excavation will or is likely to result in a relic being discovered, exposed, damaged or destroyed unless the disturbance is carried out in accordance with an excavation permit.*

Excavation permits are issued by the Heritage Council of NSW, or it's Delegate, under Section 140 of the Heritage Act for relics not within SHR curtilages, or under Section 60 for significant archaeological remains within SHR curtilages.

The Great Zig Zag Railway deviation tunnels are listed on the State Heritage Register (SHR #01037).

The Great Zig Zag Railway deviation tunnels overlap with the SHR curtilage of the Great Zig Zag Railway and Reserves (SHR #00542).

2.2.2 Environmental Planning and Assessment Act 1979

The *Environmental Planning and Assessment Act 1979* (EP&A Act) establishes the framework for cultural heritage values to be formally assessed in the land use planning and development consent process. The EP&A Act requires that environmental impacts are considered prior to land development; this includes impacts on cultural heritage items and places as well as archaeological sites and deposits. The project is subject to assessment under Part 5 of the EP&A Act.

The EP&A Act also requires that local governments prepare planning instruments (such as Local Environmental Plans [LEPs] and Development Control Plans [DCPs]) in accordance with the EP&A Act to provide guidance on the level of environmental assessment required. The Great Zig Zag Railway deviation tunnels fall within the boundaries of the City of Lithgow local government area (LGA). Schedule 5 of the Lithgow LEP 2014 includes a list of items/sites of heritage significance within this LGA.

2.2.3 State Environmental Planning Policy (Infrastructure) [ISEPP] 2007

State Environmental Planning Policy (Infrastructure) 2007 (ISEPP) aims to facilitate the effective delivery of infrastructure across the state. ISEPP clarifies the consent arrangements for certain infrastructure projects.

As the Project meets the definitions of 'rail infrastructure facilities' provided for by clause 78, and is being carried out by TfNSW, it is permissible without consent under ISEPP. As a result, it can be assessed under Part 5 of the EP&A Act. Development consent from Lithgow City Council is not required. Part 2 of the ISEPP contains provisions for public authorities to consult with local councils and other public authorities before the commencement of certain types of development.

2.3 Local government

2.3.1 Lithgow Local Environmental Plan 2014

Part 5, Section 5.10 of the Lithgow LEP deals with heritage conservation within the area covered by this LEP. All heritage items listed on the LEP are included in Schedule 5. The Lithgow LEP states:

(1) *The objectives of this clause are as follows:*

a. to conserve the environmental heritage of Lithgow

b. to conserve the heritage significance of heritage items and heritage conservation areas, including associated fabric, settings and views,

c. to conserve archaeological sites,

d. to conserve Aboriginal objects and Aboriginal places of heritage significance.

(2) Development consent is required for any of the following:

a. demolishing or moving any of the following or altering the exterior of any of the following (including, in the case of a building, making changes to its detail, fabric, finish or appearance):

i. a heritage item,

ii. an Aboriginal object,

iii. a building, work, relic or tree within a heritage conservation area,

b. altering a heritage item that is a building by making structural changes to its interior or by making changes to anything inside the item that is specified in Schedule 5 in relation to the item,

c. disturbing or excavating an archaeological site while knowing, or having reasonable cause to suspect, that the disturbance or excavation would or is likely to result in a relic being discovered, exposed, moved, damaged or destroyed,

d. disturbing or excavating an Aboriginal place of heritage significance,

e. erecting a building on land:

i. on which a heritage item is located or that is within a heritage conservation area, or

ii. on which an Aboriginal object is located or that is within an Aboriginal place of heritage significance,

f. subdividing land:

i. on which a heritage item is located or that is within a heritage conservation area, or

ii. on which an Aboriginal object is located or that is within an Aboriginal place of heritage significance.

The Great Zig Zag Railway deviation tunnels are listed as an item of environmental heritage on Schedule 5 of the Lithgow LEP 2014.

2.4 Heritage curtilages

The curtilage of the Great Zig Zag Railway deviation tunnels is described on the SHR register as 'the extent of the ten tunnels from the start of tunnel portal 1 to the end of tunnel portal 10, including the rock cliff faces at the portals at each tunnel'.[1] The gazetted map of the SHR curtilage is not correct, however, in that it does not extent to the start of tunnel portal 1 as outlined in the curtilage description.

[1] SHR #01037: http://www.environment.nsw.gov.au/heritageapp/ViewHeritageItemDetails.aspx?ID=5012082

There are additionally potential inaccuracies with the borders of the mapped curtilage. For the purpose of this SoHI, all maps showing the curtilage of Great Zig Zag Railway deviation tunnels show a curtilage boundary modified to extend from the Sydney end of Tunnel 1 to the Lithgow end of Tunnel 2, and encapsulating the breadth of the rail corridor cadastre in-between.

The 'Great Zig Zag Railway and Reserves' (SHR #00542) item is a separate listing but includes a portion of Great Zig Zag Railway deviation tunnels which overlaps with the railway track of the former Zig Zag bottom point (lowest elevation portion of the Zig Zag track). Due to the aesthetic significance of the SHR item, the curtilage of the item extends over the sandstone escarpment on either side of the Zig Zag Railway in order to ensure that the visual heritage setting of the item is protected. The curtilage extends west to Chifley Road, which approximately correlates with the midway point of Tunnel 10. The Project is entirely constrained to causing small physical impacts inside the tunnels of the Great Zig Zag Railway deviation tunnels, and would therefore not be visible from outside of the tunnels or within views of the Zig Zag.

The 'Railway Culvert of Ida Falls Creek', or 'Oakey Park (Ida Falls Creek) Railway Culvert' has a listed curtilage on the Lithgow LEP 2014 comprising the railway corridor from approximately half-way through Tunnel No. 10 and extending west to a point approximately in line with Bragg Street, Oaky Park. However, the State Heritage Inventory (SHI) gives the following description of the item's boundaries:

> *North: a line projecting approximately 5 metres north of the face of the sandstone culvert, projecting from the rail embankment in a northerly direction into the natural riparian course of Ida Falls Creek. South: a line projecting approximately 5 metres south of the face of the sandstone culvert, projecting from the rail embankment in a southerly direction into Ida Falls Gully. East: the hard-built edge of the sandstone culvert West: the hard-built edge of the sandstone culvert. Note: This item falls within the SHR listed curtilage for Great Zig Zag Railway and Reserves (#00542).*

A location map of this item is also provided on the SHI listing page which is reproduced in Figure **4**. As the item is significantly smaller than its listed curtilage, this item would not be impacted by the Project. Consequently, its heritage significance will not be assessed in this report.

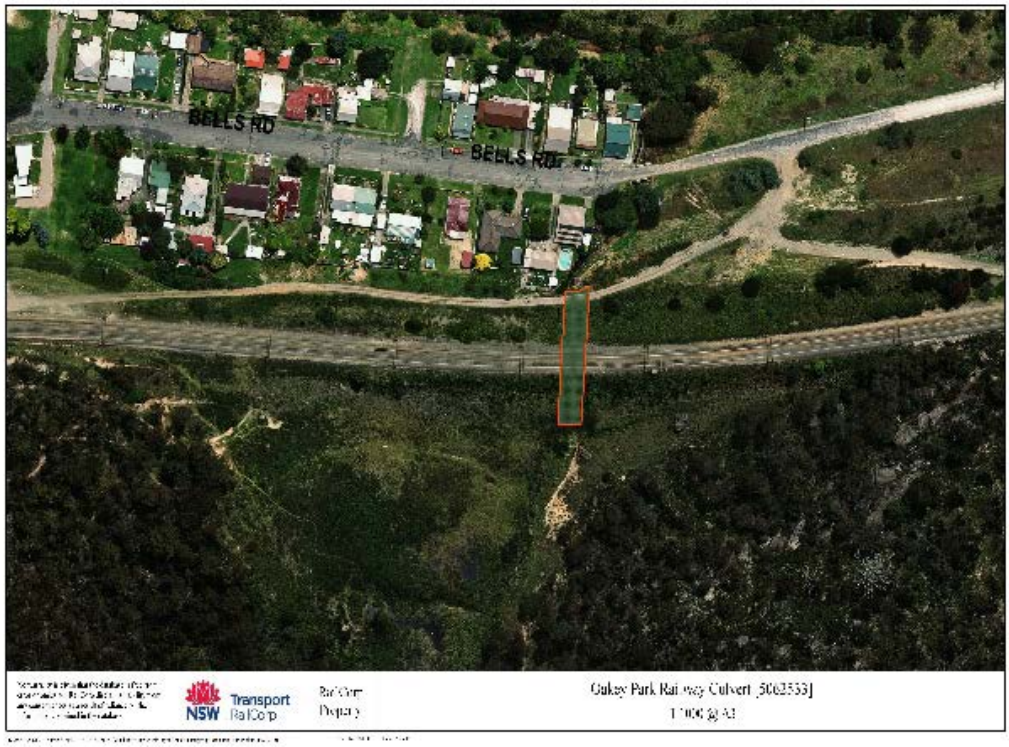


Figure 4: Location and curtilage map of the Railway Culvert of Ida Falls Creek (Lithgow LEP A133)

2.4.1 Summary of heritage listings and curtilage

The Great Zig Zag Railway deviation tunnels is listed on several heritage registers, summarised in Table 3 below. The curtilages of these items are illustrated in Figure 5.

Table 3: Results of register search for Great Zig Zag Railway deviation tunnels

Register	Listing
World Heritage List	Great Zig Zag Railway deviation tunnels **is not registered** on the World Heritage List
National Heritage List	Great Zig Zag Railway deviation tunnels **is not registered** on the National Heritage List
Commonwealth Heritage List	Great Zig Zag Railway deviation tunnels **is not registered** on the Commonwealth Heritage List
State Heritage Register	Great Zig Zag Railway deviation tunnels **is registered** on the State Heritage Register as 'Great Zig Zag Railway deviation tunnels', SHR# 01037 Great Zig Zag Railway deviation tunnels curtilage is **partly within** the State Heritage Register curtilage of the 'Great Zig Zag Railway and Reserves', SHR# 00542
Section 170 Registers	Great Zig Zag Railway deviation tunnels **is registered** on the RailCorp s170 Register as 'Bell to Zig Zag Ten Tunnel Railway Deviation and Zig Zag Rail Corridor', SHI# 4800183
Lithgow Local Environmental; Plan 2014	Great Zig Zag Railway deviation tunnels **is registered** on the Lithgow LEP 2014 as 'Great Zig Zag Railway and deviation tunnels', LEP# I443 Great Zig Zag Railway deviation tunnels **is partly within** the Lithgow LEP 2014 listing for 'Railway Culvert of Ida Falls Creek', A133 *[Note: as outlined in Section 2.4.1, this curtilage does not overlap with the Great Zig Zag Railway deviation tunnels]*

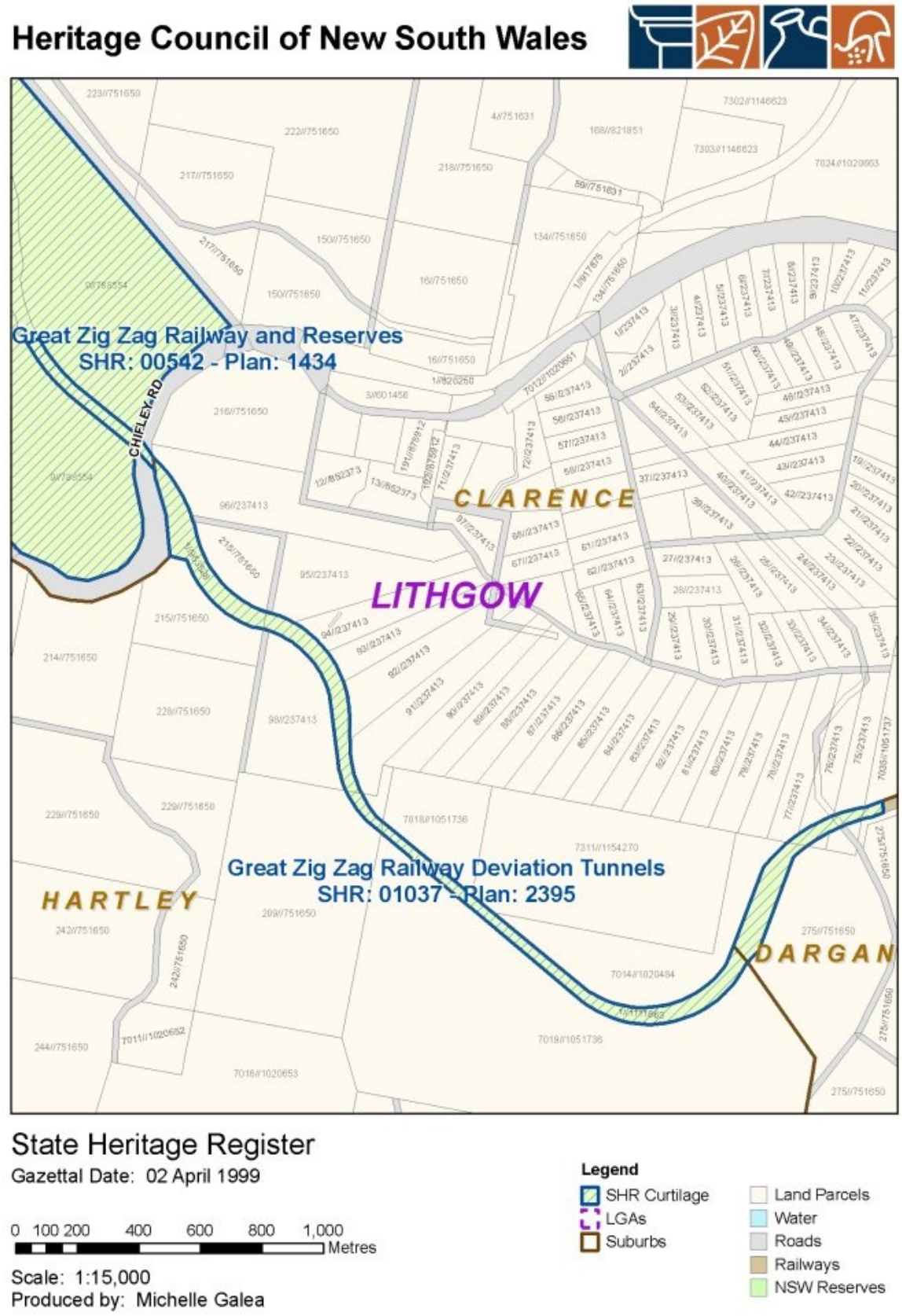


Figure 5: Great Zig Zag Railway deviation tunnels SHR Curtilage (SHR# 01037)

3.0 HISTORICAL CONTEXT

3.1 The Main Western Railway Line

In 1848, the *Sydney Railway Company* announced proposals to establish a railway line to Bathurst. The original 1869 single line headed north from Mount Victoria along the ridge known as the Darling Causeway. After turning west, it then entered the Dargan's Creek valley. From this point, the railway reached a steep escarpment, the crossing of which had resulted in numerous proposals being put forward. These alternatives, including a three kilometre tunnel, were disregarded due to budget and material constraints, and limitations in tunnel construction technologies at the time.[2]

3.1.1 Establishment of the Great Zig Zag

Constructed between 1866 and 1869, the Great (Lithgow) Zig Zag (Figure 6) climbed the western flank of the Great Dividing Range in the shape of a 'Z', and allowed the land west of the Blue Mountains to be accessed by rail.[3] Completion of the Great Zig Zag resulted in the relocation of the Western railway's terminus from Mount Victoria to the newly created station at Bowenfels.

The requirement for trains to continually change directions along the Great Zig Zag and short reversing stations limited the length of trains able to use the line, and prevented locomotives from being heavily laden with carriages.[4] This ultimately restricted the volume of goods that could be transferred on the Main Western Railway Line at any one time. This, in conjunction with increased rail traffic, undermined the viability of transporting goods to coastal markets and created an increasingly inefficient bottleneck on the Main Western Railway Line. Several accidents occurred on the railway, with runaway trains at reversing points. The restrictions imposed by the Great Zig Zag prompted numerous attempts to realign the track and to relocate and extend reversing stations. Despite these developments, problems associated with the efficiency and safety of the Great Zig Zag continued. The combination of these pressures resulted in consideration to its replacement as early as 1885.[5]

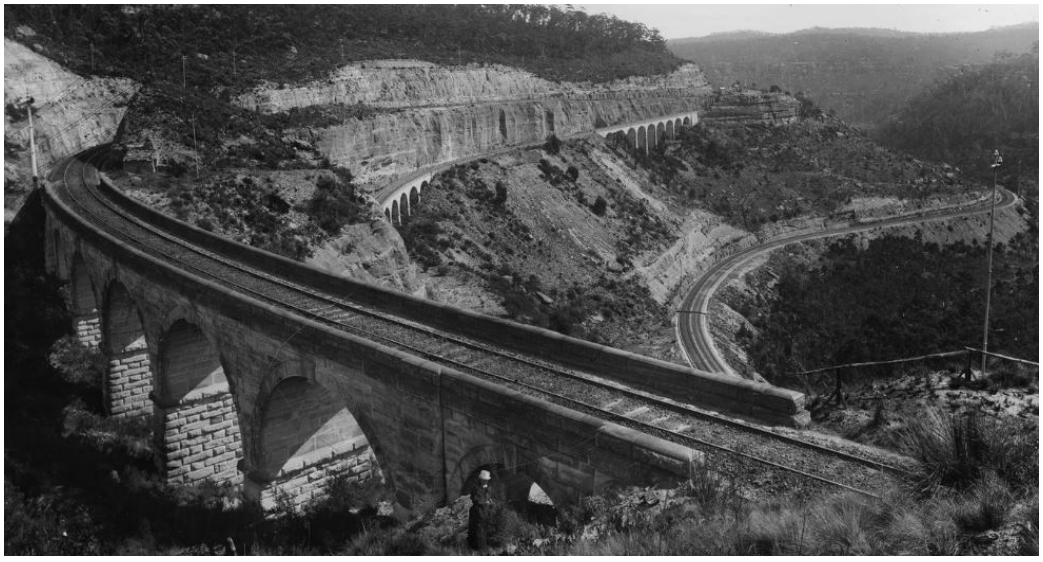


Figure 6: The Great Zig Zag Railway, c1880-1923
(Source: Museum of Applied Arts & Sciences. Object Number: 85/1286-207)

[2] Bayley, William, *'Lithgow Zig Zag Railway'* Third Edition, Austrail Publications. 1973, p6
[3] Bayley 1973, p1
[4] Bayley 1973: 28
[5] Bayley 1973: 28

3.1.2 Early deviations and modifications to the Zig Zag

During the 1880s and 1890s, numerous proposals were put forward for the suggested deviation routes from the Zig Zag Railway. These proposals encompassed a tunnel from Dargan's Creek to Bottom Points, a tunnel further north from Dargan's Creek to Farmer's Creek to be crossed on a viaduct, a spiral with three tunnels from near Top Points to Bottom Points, a line from Bottom Points tunnelling through spurs and ridges up to Dargan's Creek, a scheme to drop down Mount York and traverse Hartley Vale, and a scheme from Eskbank to Clarence Tunnel higher above the line heading to Dargan's Creek. These alternative proposals for the deviation of the Great Zig Zag were rejected.[6]

In April 1897, a deviation three miles in length (4.8 kilometres) was constructed heading to Dargan's Creek and re-joining the original line at then Clarence Station. This deviation, which remained in use for the next thirteen years, avoided the steep grades to and from Dargan's Creek.

The turn of the twentieth century witnessed increased traffic on the Main Western Railway Line, and several further modifications were carried out at the Zig Zag Railway in order to increase rate of movement of freight trains to and from the west. In October 1901, the Edgecombe Loop along the top road above Bottom Points was constructed to allow trains to pass between Clarence and Bottom Points.

In December 1906, the passing of the *Great Western Railway Deviation (Lithgow Zigzag) Act 1906* by the New South Wales Parliament approved construction of the Great Zig Zag Railway deviation tunnels.[7] This double line deviation formed part of the duplication of the Main Western Railway Line between Penrith and Lithgow.[8] On 4 January 1907, the *Daily Telegraph* announced the proposal to replace the Zig Zag with a total deviation:

> *"The Great Zig Zag, that feat in engineering which for so many years stood out as the greatest achievement in connection with the New South Wales railway system, will be discarded for all practical purposes. But notwithstanding its abandonment by the locomotive, the side of the mountain will continue through the ages to bear mute testimony to the ingenuity and the indomitable pluck of the early railway administrators of the state."*[9]

Due to pressures of traffic, the passing loops for trains at the Top and Bottom Points of the Zig Zag were prioritised over construction of the Great Zig Zag Railway deviation tunnels. In 1908, modifications to Top Points included abandonment of the original dead end and construction of a new, longer, double track dead end to cater for more frequent, and longer, trains. The change-over at Bottom Points involved an extension of the dead endwith crossing for passenger trains, and provision for long goods trains with engines on both ends. These modifications permitted more rapid movement of freight in the two years pending construction of the Great Zig Zag Railway deviation tunnels.

3.2 Great Zig Zag Railway deviation tunnels

3.2.1 Construction of the Great Zig Zag Railway deviation tunnels

On 1 June 1908, construction of the tunnels commenced near the former Oakey Park Colliery on the 1 in 42 Bottom Road, which had been duplicated in 1880. The route of the Ten Tunnel Deviation started at Newnes Junction and finished at the Zig Zag Bottom Points. The original plans for the four-and-a-half-mile deviation consisted of eleven tunnels. Discovery of rock faults, however, undermined

[6] Bayley 1973: 28
[7] NSW State Archives & Records, *Great Western Railway Deviation (Lithgow Zigzag) Act, 1906*, Western Sydney Records Centre, Kingswood. Item No. 130.
[8] NSW State Archives & Records, *Great Western Railway Deviation (Lithgow Zigzag) Act, 1906*, Western Sydney Records Centre, Kingswood. Item No. 130.
[9] Bayley 1973: 38

the structurally stability of one tunnel that was converted into an open cutting over 60 metres deep between Tunnel 2 and Tunnel 3.[10] The tunnels varied in length from 50 metres to 800 metres.

Opened with explosives to remove masses of rock, tunnels were then chiselled out and constructed with brick lined elliptical arches and concrete sidewalls cast in situ. Tunnel 9 was of all-brick construction. Construction of the deviation involved some 1,500 day employees (Figure 8 to Figure 10). For the duration of the project, a camp was established at Clarence Siding to accommodate workmen and their families.[11] A power house was established near Newnes Junction to supply electric light and fans to the tunnels, and electricity for rock drills, compressors and water pumps.[12]

In 1909, construction of the Ten Tunnel Deviation accounted for 74 per cent of bricks sold by the pottery and brickworks that operated as a subsidiary of the Lithgow Valley Colliery Company.[13] Supplies to the line during construction were provided by a funicular railway that descended 350 feet from the main ridge line adjacent to the Great Zig Zag Railway to a location near the Lithgow end of Tunnel 9 (Figure 7). Vast quantities of material were transported down the funicular railway during construction works including approximately 3,500,000 bricks, 12,000 tonnes of gravel, 4,000 tonnes of cement and various other items.[14]

Figure 7: Funicular used to carry materials in the construction of the Great Zig Zag Railway deviation tunnels to the Lithgow end of Tunnel 9
(Source: NSW Railway and Tramway Magazine)

[10] Bayley 1973: 41
[11] Bayley 1973: 41
[12] Bayley 1973: 42
[13] Higginbotham 1982, 'Lithgow Valley Colliery Co. Ltd., and its Pottery, Brick and Pipeworks: Report on the Excavation of Part of the Brick and Pipeworks': 3.
[14] Bayley 1973:38, 42

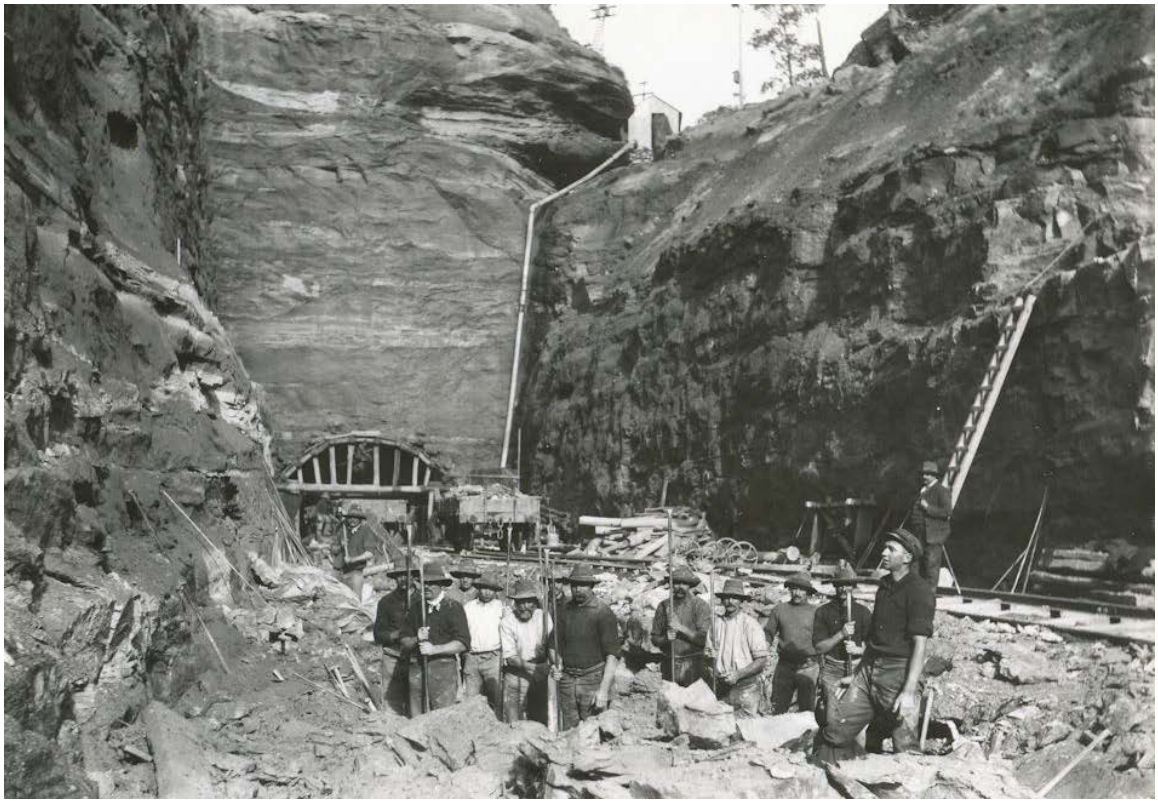


Figure 8: Workers during construction of the Great Zig Zag Railway deviation tunnels (Source: Lithgow Library Learning Centre)

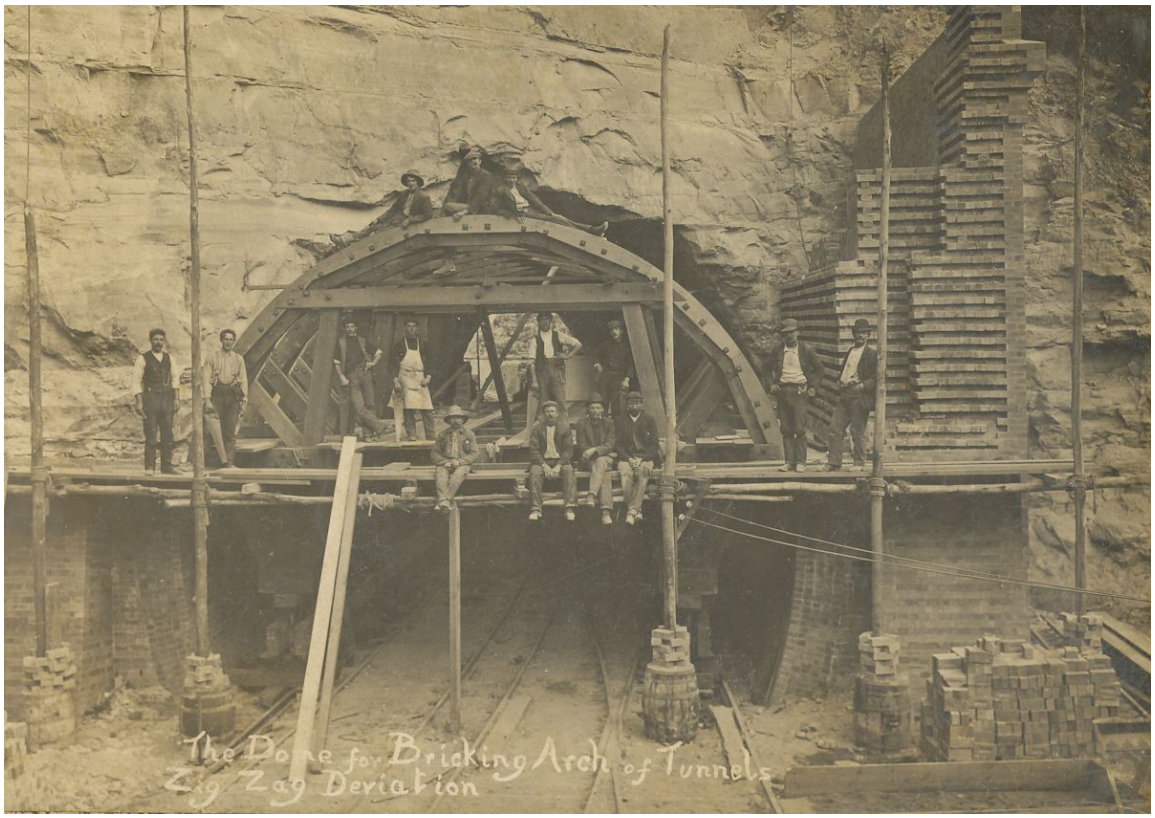


Figure 9: Workers during construction of the Great Zig Zag Railway deviation tunnels showing building of portal (Source: Lithgow Library Learning Centre)

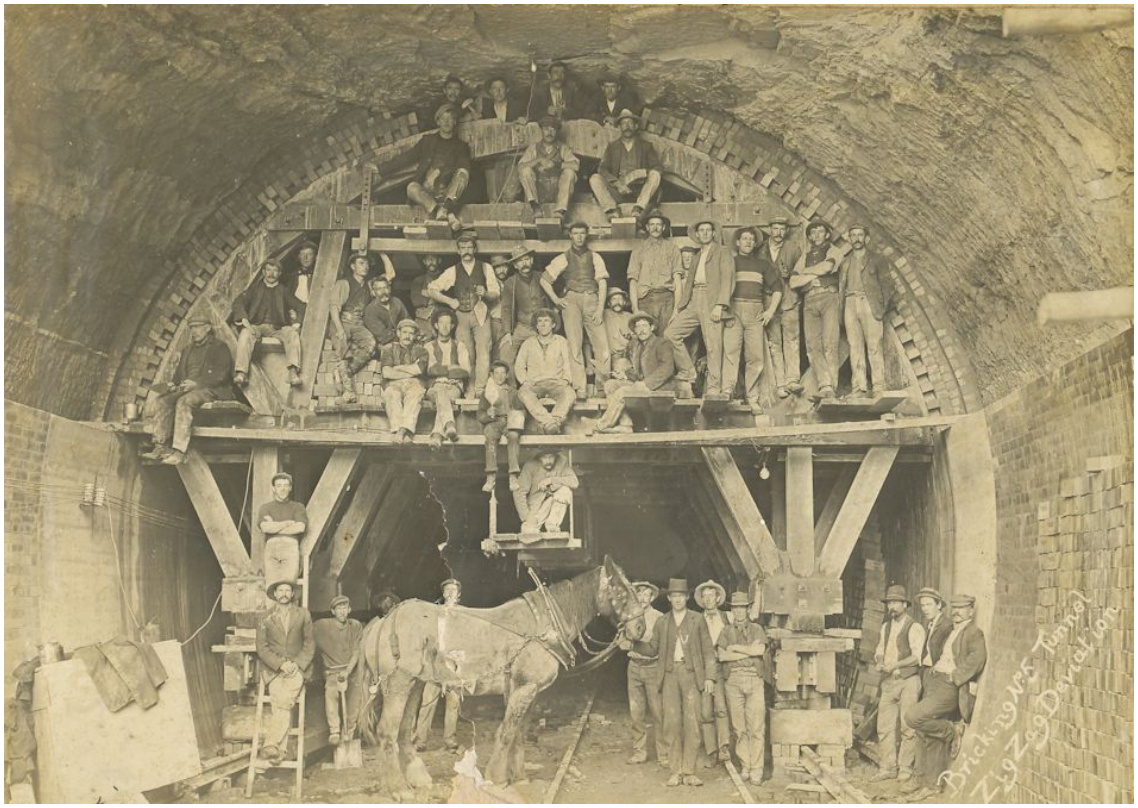


Figure 10: Workers during construction of Great Zig Zag Railway deviation tunnels (Source: Lithgow Library Learning Centre)

Accessibility to worksites at the tunnels and in the short open sections between cliffs was challenging. At some locations horses were craned down to the worksites, where they were used to move rubble and bricks. Brick construction materials were sourced from the nearby Lithgow Valley Colliery and Pottery Works, utilising up to 70 per cent of the brick output at that time. Meanwhile, the Great Zig Zag Railway continued to operate for the duration of the construction of the deviation. A newspaper article published in 1909 provides a description of the project's progression and terrain faced by the construction workers:[15]

> *Good progress continues to be made with the Zig-Zag deviation, and a fair indication of its route is now seen as the work is pushed on. At the bottom of the present Zig-Zag, known as Bottom Points, a new cutting is being driven through a mass of rock, and already it has been excavated many feet below the old line. A large number of men are employed, and the work of driving the tunnels, of which there will be ten, continues. When completed, the deviation will probably form as unique a piece of railway engineering as the present Zig-Zag. .*

On 16 October 1910, the Great Zig Zag Railway deviation tunnels was opened. Old stations at Bell, Newnes Junction, Clarence and Zig Zag were closed following completion of the deviation and new stations opened at Bell, Newnes Junction and Clarence.

An engineering feat enabling the Main Western Railway Line to come into the twentieth century, the double tracked Ten Tunnel Deviation reduced the route mileage by approximately five miles and reduced journey times by between 20 and 30 minutes. Reduction in gradient from 1 in 42 to 1 in 90

[15] "The Zig-Zag Deviation" *The Bathurst Daily Argus (NSW: 1909)* 20 February 1909. Retrieved from: http://nla.gov.au/nla.news-article130885100

provided for doubling in the loads of trains. Construction works had removed over 570,000 cubic metres of earth and rock from the cuttings and over 180,000 cubic metres of rock from the tunnels.[16]

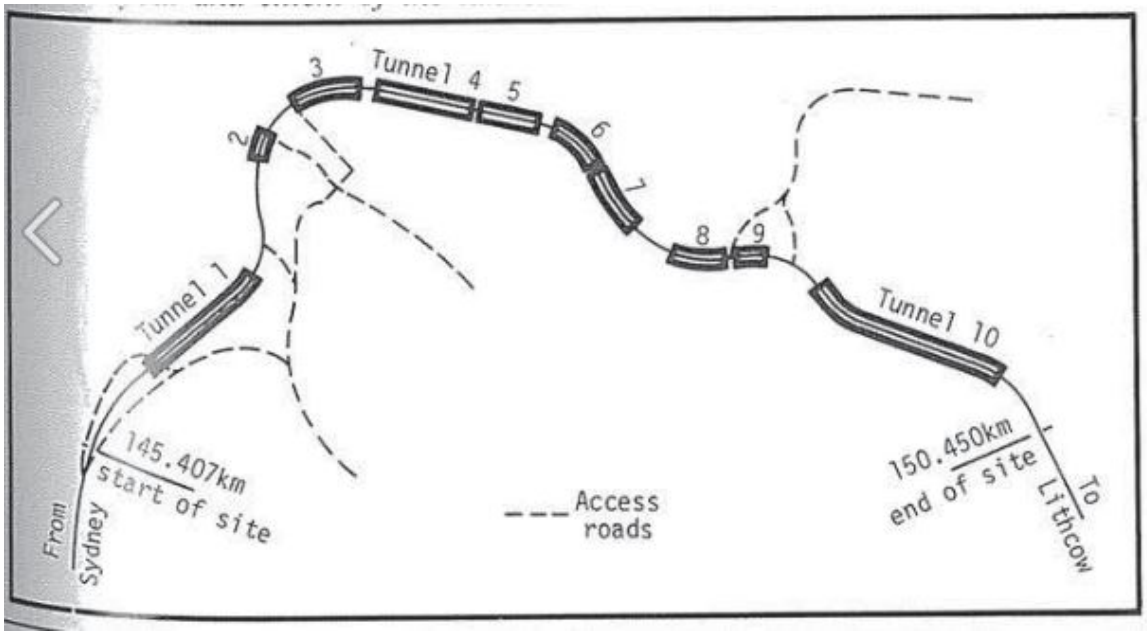


Figure 11: Map showing route of Great Zig Zag Railway deviation tunnels, 1980 (Source: Duncan, S.D. 'Paved track for Australia's Blue Mountains Zig Zag tunnels' *Tunnels & Tunnelling,* May 1980, p31)

3.2.2 Modifications to Great Zig Zag Railway deviation tunnels

In 1951, plans were announced to electrify the Main Western Railway Line between Parramatta and Lithgow at an estimated cost of £3 million. Estimates indicated that electrification of the railway line would reduce journey times by up to 30 minutes. The scheme was envisaged as the first stage of a twelve year project covering 940 single track miles of NSW railway lines.[17]

In 1957, the Ten Tunnel Deviation was electrified, along with the rest of the Main Western Railway Line. This resulted in the installation of overhead wiring structures along the roof and sides of the tunnels.

Between 1977 and 1978, works were undertaken to alter the tunnels in response to difficulties experienced in maintenance operations. The project involved upgrading the line with a new paved concrete track. The requirement for the upgraded line to accommodate double-deck 'V-set' trains resulted in works that lowered the tracks by 650 millimetres (Figure 12). Works undertaken during the project included removal of old tracks, installation of two metre long rock bolts, excavation and lowering of rock foundations, cleaning, formation and installation of underslab drains, casting base slab, and installation of new tracks.[18] The works also required portions of the tunnel lining to be graded back where the tunnels curved.[19] Upon completion of works, a formal opening ceremony was held on 13 November 1978.

[16] 'Passing of the Zig Zag: The New Deviation' *Sydney Morning Herald,* 17 October 1910
[17] 'Sydney Lithgow Railway Electrification' *Construction (Sydney, NSW: 1938-1954)*, 2 May 1951. Accessed online at: http://nla.gov.au/nla.news-article222885435
[18] Duncan, S.D. 1980, 'Paved track for Australia's Blue Mountains Zig Zag tunnels' in Tunnels & Tunnelling May 1980, p31
[19] Upgrading the Zig Zag Tunnels, Railways of Australia Network, April 1978, pp7-11

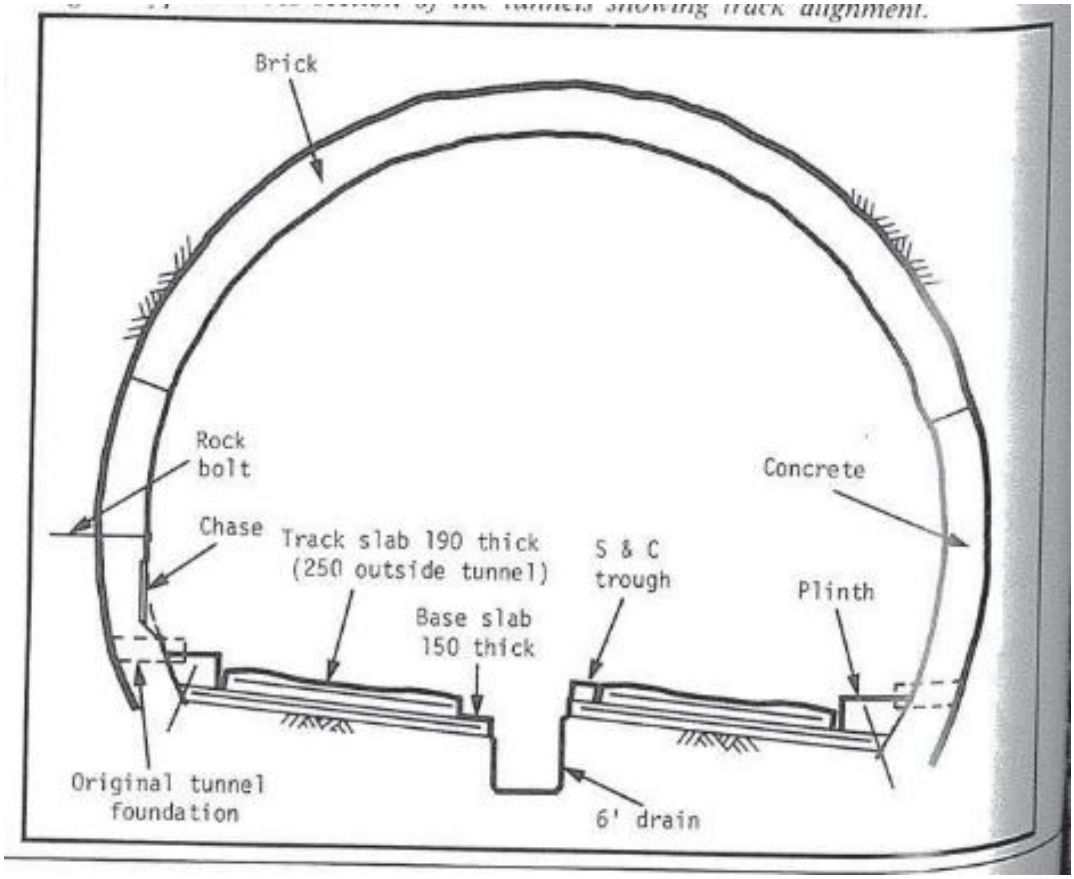


Figure 12: Section showing upgrade works to tunnels including lowering works, 1980 (Source: Duncan, S.D. 'Paved track for Australia's Blue Mountains Zig Zag tunnels' *Tunnels & Tunnelling,* May 1980, p32)

4.0 PHYSICAL DESCRIPTION

4.1 Introduction

Site inspections of the Great Zig Zag Railway deviation tunnels were conducted by Josh Symons (Principal) on 14 and 15 May 2016, and on 2 September 2016. A subsequent inspection of the Great Zig Zag Railway deviation tunnels was conducted by Josh Symons and Duncan Jones (Heritage Consultant) on 23 April 2017. The aim of these site inspections was to provide constraints advice and preliminary assessment of the condition of the tunnels to TfNSW, and to inform an assessment of significant fabric, during preparation of the Concept Design. All site inspections were undertaken on foot and a photographic record was made. A number of photographs taken during the site inspection are provided in Appendix A.

4.2 Great Zig Zag Railway deviation tunnels

The Great Zig Zag Railway deviation tunnels are located through undulating and precipitous sandstone terrain between Dargan and Clarence. Tunnel 1 is located at the Sydney end of the Great Zig Zag Railway deviation tunnels, and approximately 2.5 kilometres down track from the Chifley Road overbridge.

Tunnels 1 through 10 consist of a sequence of differing length tunnels cut through the southern perimeter of a sandstone escarpment overlooking Reedy Creek. Tunnel 10, the longest tunnel, extends beneath Chifley Road and a prominent sandstone ridge. The Lithgow end of Tunnel 10 emerges adjacent to, and below, Bottom Points on the Great Zig Zag Railway and Reserves (SHR#00542). The track then merges with the former alignment of the Great Zig Zag Railway approximately one kilometre down track from Tunnel 10.

The Great Zig Zag Railway deviation tunnels were constructed between 1908-1910, with the main modifications since construction to accommodate the V-set trains in the 1970s.

Physical characteristics common to each tunnel, such as overhead wiring structures and concrete track bed are outlined in Section 4.2.1 below. Physical characteristics unique to each tunnel, such as extent of existing notching and condition of original fabric, are outlined in Table 4.

4.2.1 Tunnels 1 – 10

Each tunnel consists of a brick lined elliptical arch approximately six metres in height. The tunnels were excavated through the sandstone and shale bedrock, and lined with four courses of dry pressed bricks (Figure 12). The portals to each tunnel are large elliptical archways with a sandstone keystone, bordered by a rectangular brick entrance façade.

Bricks

Bricks used throughout the Great Zig Zag Railway deviation tunnels were sourced from the Lithgow Valley Colliery. The bricks are reddish brown dry pressed bricks measuring approximately 230mm x 110mm x 80mm (see Figures 12 and 13). The bricks include frequent fine (less than two millimetres) gravel inclusions. The bricks are bonded with concrete, with the sandy mix including frequent fine gravel inclusions (less than two millimetres). Bricks are laid in English Cross bond around the tunnel portals, and stretcher bond for the tunnel lining.

Recesses, or ‘safe places’, were built into the tunnel fabric in Tunnels 1, 4 and 10 during original construction. These recesses are brick lined and comprise a brick arch within the concrete lined

section of those tunnels. Recesses were added to the remaining tunnels later in the 20th century – these later additions do not have a brick arch, or the same type of brick lining as the original recesses in Tunnels 1, 4 and 10.

The brickwork appears generally in excellent condition. The excellent condition of the brickwork was demonstrated during recent geotechnical investigation commissioned by TfNSW, where bricks were to be removed for testing.[20] Only two whole bricks could be removed, with the remaining attempts failing due to the binding at the back of the bricks being strongly cemented. Areas of water seepage in Tunnel 1 appear to have resulted in some mortar flushing and subsequent brick removal or bricks falling from the tunnel vault.

Concrete

With the exception of Tunnel 9, the lower part of each tunnel wall is lined with concrete (Figures 10 and 15). The concrete commences approximately six metres in from the tunnel portal and extends to approximately 2.5 metres in height. The concrete is not reinforced, and includes frequent large (<10 centimetre) locally derived water rolled gravels as part of the concrete mixture (Figure 15). Tunnel 9 is the exception to this construction methodology, and is lined entirely with brick.

The concrete appears weathered in some areas, particularly due to water seepage in Tunnel 1 and Tunnel 10. Areas of significant weathering have resulted in small cavities appearing at the base and top of the concrete. This seems to be a significant issue where the cavity occurs beneath the upper brick vault, leaving some small sections of brick exposed. In the remaining tunnels, the concrete appears generally in good condition.

Overhead wiring structures

The section of the Blue Mountains Line that includes the Great Zig Zag Railway deviation tunnels was electrified in the 1950s. Electrical wiring infrastructure installed within the tunnels consists of two different types of overhead wiring structures: one type installed into the arch that involved removal of some brick for installation; whilst the second type consists of a more elaborate supporting structure that is affixed to the brick arch (Figure 16). At each overhead wiring structures point throughout each tunnel there is generally one type on the up track and the other type on the down track. The orientation of each type between the up and down track alternates throughout each tunnel.

Modifications to accommodate the V-set Trains in the 1970s

The floor of each tunnel was lowered in the 1970s and replaced with a concrete track bed (Figure 11). In addition to lowering the tunnel floor, certain toe sections of the tunnels were notched to at least one metre in height. This work was conducted to accommodate the 'V-set' double deck trains that still service the Blue Mountains Line to Lithgow. The notching included removal of both brick and concrete tunnel lining fabric, as well as a section of the original concrete foundation beneath the tunnel lining.

The site inspection observed evidence of different techniques applied to this phase of notching and finishing. Some sections of tunnel exhibit evidence of jack-hammering to remove tunnel fabric (see Figure 11), whilst others have a rough, uneven finish, and no clear indication of fabric removal technique. Some sections of notching have been rendered with shotcrete or similar, whilst others are left as cut back original fabric. Further detail on the extent of existing notching in each tunnel is outlined in Table 4.

[20] GHD, 2017. *New Intercity Fleet Enabling Works TA, ISD-15-4794 Item T4.4 Appendix F3, Geotechnical Report – Tunnel Lining Investigation Blue Mountains Line, Route Clearance, Great Zig Zag Railway deviation tunnels*. Report prepared for TfNSW

Galvanised Steel Trough (GST) and cabling

Galvanised Steel Trough (GST) is located adjacent to the down track through the Great Zig Zag Railway deviation tunnels. The GST is generally attached to, or supported on steel columns adjacent to, sandstone cuttings next to each tunnel portal. The GST is then attached to the down track tunnel lining, generally situated at the mid-point between the toe and haunch. Exceptions to this include Tunnel 4, where the GST is situated towards the toe of the tunnel lining, and Tunnel 5, where the GST it situated at the toe of the tunnel lining.

In addition to cabling housed in the GST, other cabling is attached to tunnel portals and tunnel lining. This includes communications cabling and antennas attached to the portal face, sandstone keystone, and brick vault lining of Tunnel 1, Tunnel 3, Tunnel 4, Tunnel 5, Tunnel 6 (Sydney end portal only), Tunnel 7 (Lithgow end portal only), Tunnel 8, Tunnel 9 (Sydney end portal only), and Tunnel 10. Other cabling or pipes of unknown use are attached to the Sydney end portal face of Tunnel 1.

Existing rock bolts

Rock bolts are located throughout the Great Zig Zag Railway deviation tunnels for structural support. The first plans showing the location of rock bolts within the Great Zig Zag Railway deviation tunnels were produced in 1980, suggesting that rock bolt introduction relates to the modifications made to the tunnel lining in the 1970s for the introduction of the V-set trains.

A second plan, from March 2000, shows rock bolt installation as part of works to the concrete track slab. Information from that plan indicates that the rock bolts were installed at least 2.5 metres into the bedrock behind the tunnel lining, and only required where no existing ‘tunnel wall anchors’ are present. The physical appearance of the rock bolts includes a steel anchor plate, small section of exposed threadbar and metal nut (see Figure 125).

Tunnel features

Other features observed intermittently throughout the Great Zig Zag Railway deviation tunnels include the following:

- Possible former light fixtures (see Figures 17 and 18). These are located at approximately two metres height, and may have consisted of a circular metal light frame with hinge opening for access. The salient features of these items were difficult to discern due to their generally very poor condition. Many of these fittings were barely discernible from the tunnel lining. These fittings were observed in Tunnel 1, with verification of their former distribution not possible either due to their generally poor condition or removal during later works
- Gradient/ radius/ survey markers (see Figures 19 and 20). These were observed predominantly in Tunnel 1 and Tunnel 10, including the up track cutting face adjacent to the Lithgow end of Tunnel 1. The markers consist of a small cement fixture with abbreviations and imperial measurements. The purpose and meaning of the measurements provided on these plaques has not been established, and it is assumed that they may provide information on gradient and track radius, or were used as survey markers (or a combination). The plaques are located on both the up track and down track, and their condition is generally poor. Sections of plaques have been removed or knocked off, and some plaques or sections of plaques have been covered with soot and particulate and are barely discernible on the tunnel lining.

Graffiti and other modern text on tunnel lining

Graffiti and spray painted text for works/ surveying is present throughout the Great Zig Zag Railway deviation tunnels. The frequency of graffiti and other spray painted text is relatively infrequent. One example of chiselled graffiti from 1917 was observed in the brickwork at the Lithgow end portal of Tunnel 10 (see Figure 115). The remaining graffiti and spray painted text appears to be modern and predominantly related to works during track possession.

Figure 13: Country end of Tunnel 1, showing brick tunnel portal and transition to concrete across the lower tunnel wall approximately six metres from the portal (red line placed adjacent to change from brick to concrete to highlight the interface)

Figure 14: View up track within Tunnel 9, showing concrete track bed and notching at the toe of the tunnel wall from track bed lowering in the 1970s. Tunnel 9 is the only tunnel that is wholly lined with bricks (red arrow indicates previous notching).

Figure 15: Example of English Cross bond from the country end portal of Tunnel 8

Figure 16: Example of English Cross bond from the city end portal of Tunnel 1, showing where water has removed some of the concrete bonding

Figure 17: Example of stretcher bond within tunnel lining, this example from Tunnel 1

Figure 18: Water damage to tunnel lining in Tunnel 10 emphasises the locally sourced water rolled gravels that form part of the aggregate

Figure 19: Overhead wiring structures on the brick vault of Tunnel 1, Lithgow end portal

Figure 20: Example of former light fitting, Tunnel 1 down track

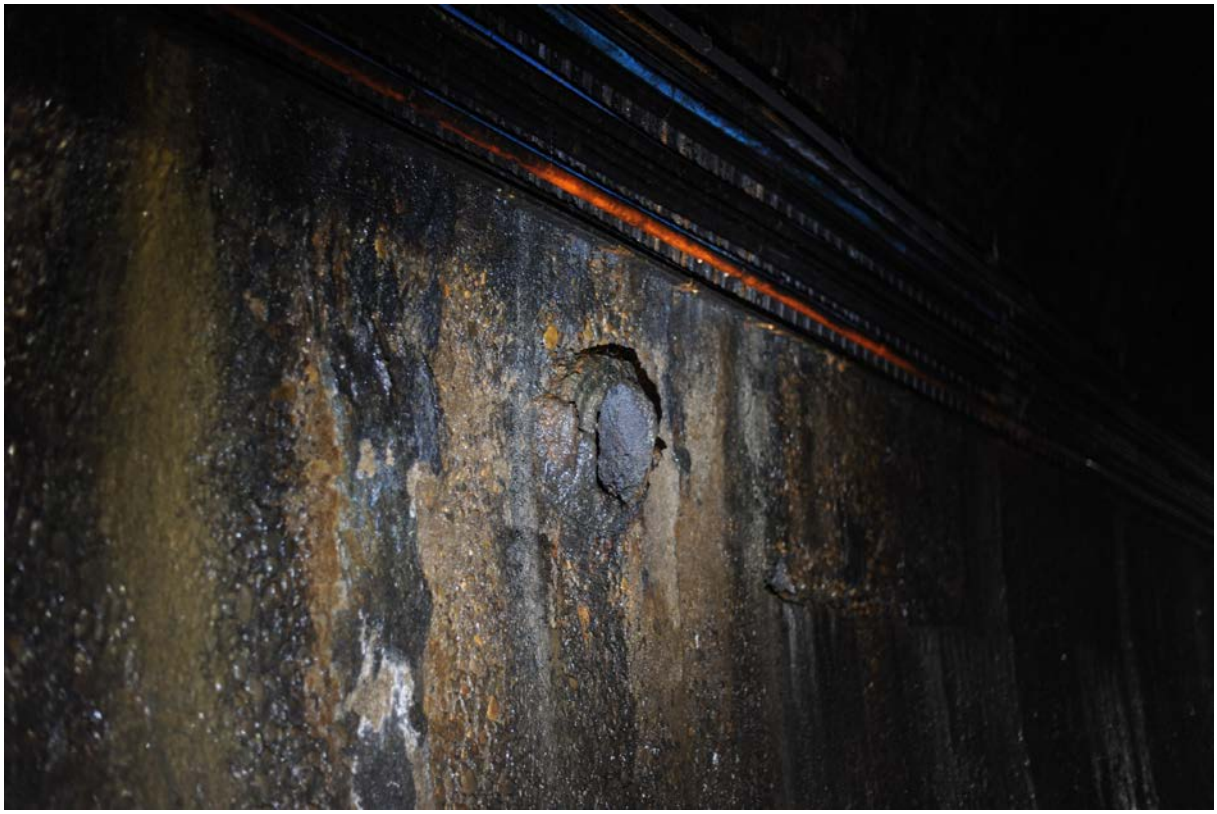


Figure 21: Example of former light fitting, Tunnel 1 down track

Figure 22: Example of gradient/ radius/ survey marker, Tunnel 10 down track

Figure 23: Example of gradient/ radius/ survey marker, down track cutting face adjacent Tunnel 1 Lithgow end portal

Table 4 – Physical description of Tunnels 1 – 10

Tunnel	Physical Description
1	Tunnel 1 consists of a brick barrel vaulted tunnel 551 metres in length and approximately six metres high. The brick barrel vault, sandstone keystone and concrete tunnel lining abutments are original fabric. The portals are partially occluded by high-visibility signage and GST routing along the down track side of the portal and tunnel lining. The GST is attached behind a flat metal protective sheet, which may function to stop water ingress. Communications cabling and antenna are attached to the brick face of both the Sydney and Lithgow end portals. Additional piping of unknown function is attached to the Sydney end portal face, adjacent to the down track. Rock bolts are present throughout the tunnel. The rock bolts are not original fabric. Notching from the 1970s works to accommodate the V-set trains is present on up track tunnel lining from the Lithgow end portal to approximately 146.260 kilometrage. The notching is limited to the toe of the tunnel lining only, and has been finished with a concrete rendering. Tunnel 1 is in a deteriorating condition compared with the other nine tunnels due to water seepage through the overlying sandstone into the concrete lining and brick vault. Water damage has caused the erosion of aggregate concrete in some parts of the inner wall. Water seepage also appears to have resulted in the loss of several bricks from the vault lining.
2	Tunnel 2 consists of a brick barrel vaulted tunnel 107 metres in length and approximately six metres high. The brick barrel vault, sandstone keystone and concrete tunnel lining abutments are original fabric. The portals are partially occluded by high-visibility signage and GST routing attached to the down track side of the portal and tunnel lining. Rock bolts are present throughout the tunnel. The rock bolts are not original fabric. Notching from the 1970s works to accommodate the V-set trains is present on the down track tunnel lining for the entire tunnel length of Tunnel 2. The notching is limited to the toe of the tunnel lining only. Notching is up to at least one metre height from the concrete track bed. The regular, parallel indentations along the notching indicates that a jack-hammer may have been used for this work. The notching has been finished with a shotcrete (or similar) rendering. The existing notching is visible on each portal. The fabric of Tunnel 2 is in largely excellent condition, with a minimal amount of water seepage and consequent damage. However, the existing notching is intrusive and unsympathetic, while other intrusive elements are visible, such as overhead wiring structures, numerous rock bolts, and signage.
3	Tunnel 3 consists of a brick barrel vaulted tunnel 176 metres in length and approximately six metres high. The brick barrel vault, sandstone keystone and concrete tunnel lining abutments are original fabric. The portals are partially occluded by high-visibility signage and GST routing along the down side of the portal and tunnel lining. Communications cabling and antenna, are attached to the brick face of both the Sydney and Lithgow end portals. Rock bolts are present throughout the tunnel. The rock bolts are not original fabric. Notching from the 1970s works to accommodate the V-set trains is present on the down track tunnel lining for the entire tunnel length of Tunnel 3. The notching is limited to the toe of the tunnel lining only. Notching is up to at least one metre height from the concrete track bed. The regular, parallel indentations along the notching indicates that a jack-

Tunnel	Physical Description
	hammer may have been used for this work. The notching has not been finished with concrete or shotcrete rendering. The existing notching is visible on each portal. The fabric of Tunnel 3 is in largely excellent condition, with a minimal amount of water seepage and consequent damage. However, the existing notching is intrusive and unsympathetic, while other intrusive elements are visible, such as overhead wiring structures, numerous rock bolts, and signage.
4	Tunnel 4 consists of a brick barrel vaulted tunnel 404 metres in length and approximately six metres high. The brick barrel vault, sandstone keystone and concrete tunnel lining abutments are original fabric. The portals are partially occluded by high-visibility signage and GST routing attached to the down track side of the portal and tunnel lining. The GST is attached to the lower toe portion of the down track tunnel lining. Communications cabling and antenna are attached to the brick face of both the Sydney and Lithgow end portals. Communications cabling on each portal is partly covered by metal sheeting, increasing the visibility of the unsympathetic addition to the brick fabric. No rock bolts or notching were observed in Tunnel 4. The fabric of Tunnel 4 is in largely excellent condition, with a minimal amount of water seepage and consequent damage. Tunnel 4 strongly exhibits the structural features and engineering methods of its construction, particular the brick arched portal and surrounding sandstone cuttings. Despite some later intrusive elements, the tunnel fabric and setting is largely intact.
5	Tunnel 5 consists of a brick barrel vaulted tunnel 161 metres in length and approximately six metres high. The brick barrel vault, sandstone keystone and concrete tunnel lining abutments are original fabric. The portals are partially occluded by high-visibility signage and GST routing attached to the down track side of the portal and tunnel lining. The GST through Tunnel 5 is attached to the base on the toe on the down track tunnel lining. Communications cabling and antenna are attached to the brick face of both the Sydney and Lithgow end portals. Communications cabling on the Sydney end portal is partly covered by metal sheeting, increasing the visibility of the unsympathetic addition to the brick fabric. Rock bolts are present on both the up track and down track tunnel lining. The rock bolts are not original fabric. Minor notching from the 1970s works to accommodate the V-set trains is present on both the up track and down track tunnel lining. The notching is predominantly visible at the Lithgow end of Tunnel 3, where it is between 200 and 330 millimetres high. The notching diminishes in height to approximately 100 millimetres towards the Sydney end of Tunnel 3. The notching is limited to the toe of the tunnel lining only. The existing notching is visible on the Lithgow end portal only. The fabric of Tunnel 5 is in largely excellent condition, with a minimal amount of water seepage and consequent damage. Tunnel 5 strongly exhibits the structural features and engineering methods of its construction, particular the brick arched portal and surrounding sandstone cuttings. Despite some later intrusive elements, the tunnel fabric and setting is largely intact.
6	Tunnel 6 consists of a brick barrel vaulted tunnel 183 metres in length and approximately six metres high. The brick barrel vault, sandstone keystone and concrete tunnel lining

Tunnel	Physical Description
	abutments are original fabric. The portals are partially occluded by high-visibility signage and GST routing attached to the down track side of the portal and tunnel lining. Communications cabling is attached to the brick face of the Sydney end portal, including an antenna attached to the sandstone keystone. Rock bolts are present on the up track tunnel lining. The rock bolts are not original fabric. Notching from the 1970s works to accommodate the V-set trains is present on both the up track and down track tunnel lining. The notching is limited to the toe of the tunnel lining only. The notching is more pronounced on the down track, with the height of notching increasing from 50 millimetres high at the Sydney end portal to over one metre at the Lithgow end. Notching on the up track tunnel lining is approximately 300 millimetres high at the Sydney end portal, with no notching visible on the Lithgow end portal. However, concrete rendering along the toe of the tunnel lining at the Lithgow end on the up side may cover minor notching. The fabric of Tunnel 6 is in largely excellent condition, with a minimal amount of water seepage and consequent damage. Tunnel 6 strongly exhibits the structural features and engineering methods of its construction, particular the brick arched portal and surrounding sandstone cuttings. Despite some later intrusive elements, the tunnel fabric and setting is largely intact.
7	Tunnel 7 consists of a brick barrel vaulted tunnel 224 metres in length and approximately six metres high. The brick barrel vault, sandstone keystone and concrete tunnel lining abutments are original fabric. The portals are partially occluded by high-visibility signage and GST routing attached to the down track side of the portal and tunnel lining. The GST through Tunnel 7 is attached to the tunnel lining on the down side. Communications cabling and antenna are attached to the brick face of the Sydney end portal. Rock bolts are present on the up track tunnel lining. The rock bolts are not original fabric. Notching from the 1970s works to accommodate the V-set trains is present on both the up track and down track tunnel lining. The notching is limited to the toe of the tunnel lining only. The notching is more pronounced on the down track, with the height of notching decreasing from one metre high at the Sydney end portal to over 400 millimetres at the Lithgow end. Notching on the up track tunnel lining is approximately 300 millimetres high at the Sydney end portal, increasing to 600 millimetres at the Lithgow end portal. Notching on the down track tunnel lining has been finished with concrete rendering. The fabric of Tunnel 7 is in largely excellent condition, with a minimal amount of water seepage and consequent damage. While intrusive elements such as overhead wiring structures and signage are present, these are limited in size, scale and extent.
8	Tunnel 8 consists of a brick barrel vaulted tunnel 171 metres in length and approximately six metres high. The brick barrel vault, sandstone keystone and concrete tunnel lining abutments are original fabric. The portals are partially occluded by high-visibility signage and GST routing attached to the down track side of the portal and tunnel lining. Communications cabling and antenna are attached to the brick face of both the Sydney and Lithgow end portals. Rock bolts are present on the up track tunnel lining. The rock bolts are not original fabric. Notching from the 1970s works to accommodate the V-set trains is present on both the up track and down track tunnel lining. The notching is limited to the toe of the tunnel lining

Tunnel	Physical Description
	only, and only visible at the Sydney end portal. On the down track tunnel lining at the Sydney end portal, notching is approximately 400 millimetres high, whilst on the up track side of the portal, notching is approximately 600 millimetres high. Notching on the up track tunnel lining has been finished with concrete rendering. The fabric of Tunnel 8 is in largely excellent condition, with a minimal amount of water seepage and consequent damage. While intrusive elements such as overhead wiring structures and signage are present, these are limited in size, scale and extent.
9	Tunnel 9 consists of a brick barrel vaulted tunnel 79 metres in length and approximately six metres high. The brick tunnel lining and sandstone keystone are original fabric. Tunnel 9 is the shortest tunnel of the Great Zig Zag Railway deviation tunnels, and also the only tunnel lined entirely with brick. The portals are partially occluded by high-visibility signage and GST routing attached to the down track side of the portal and tunnel lining. Communications cabling is attached to the brick face of the Sydney end portal, including an antenna attached to the sandstone keystone. Rock bolts are present on both the up track and down track tunnel lining. The rock bolts are not original fabric. Notching from the 1970s works to accommodate the V-set trains is present on both the up track and down track tunnel lining. The notching is limited to the toe of the tunnel lining only. Significant notching to a height of approximately 1.3 metres is present on the down track tunnel lining for the entirety of Tunnel 9. This notching has been finished with concrete rendering. Notching on the up track tunnel lining appears to be limited to the lower 200-300 millimetres of the toe, and possibly likely demonstrative of tunnel lowering into the concrete foundation of the brick lining and subsequent notching of the exposed foundation to accommodate the V-set trains. The fabric of Tunnel 9 is in largely excellent condition, with a minimal amount of water seepage and consequent damage. While intrusive elements such as overhead wiring structures and signage are present, these are limited in size, scale and extent.
10	Tunnel 10 consists of a brick barrel vaulted tunnel 790 metres in length and approximately six metres high. The brick barrel vault, sandstone keystone and concrete tunnel lining abutments are original fabric. Tunnel 10 is the longest tunnel of the Great Zig Zag Railway deviation tunnels. The portals are partially occluded by high-visibility signage and GST routing attached to the down track side of the portal and tunnel lining. Down track from the Lithgow portal of Tunnel 10 the GST is located adjacent to both the up track and down track. In order to pass the GST from the up track to down track tunnel lining, the GST is attached to the portal face brickwork and directed over the tunnel entrance to the down track. Rock bolts are present throughout the tunnel. The rock bolts are not original fabric. Notching from the 1970s works to accommodate the V-set trains is present on the up track tunnel lining. The notching is limited to the toe of the tunnel lining only and is visible at the Sydney end portal only. The notching on the up track tunnel lining extends approximately 300 metres from the Sydney end portal to approximately 149.760 kilometrage. The notching height increases from approximately 500 millimetres at the Sydney end portal, to approximately one metre at approximately149.760 kilometrage. This notching has been finished with concrete rendering. Tunnel 10 has evidence of water seepage and subsequent concrete degradation. Thin layers of ash deposits have accumulated on the inner surface of the brick lining from steam and diesel train traffic. Portions of the brick in the tunnel vault appear to have been removed, and in some areas partially replaced with modern, non-matching brick.

Tunnel	Physical Description
	Tunnel 10 strongly exhibits the structural features and engineering methods of its construction, particular the brick arched portal and surrounding sandstone cuttings. Elements of intrusive fabric and encroaching water damage are relatively minor compared with the overall size of the tunnel.

5.0 ASSESSMENT OF SIGNIFICANCE

5.1 Assessment of significance for the 'Great Zig Zag Railway deviation tunnels' (SHR# 01037)

The following assessment of significance included as Table 5 has been adapted from the SHR entry for the 'Great Zig Zag Railway deviation tunnels'.

Table 5: Assessment of significance for the Great Zig Zag Railway deviation tunnels

Criterion	Explanation
A – Historical Significance	The Great Zig Zag Railway deviation tunnels are historically significant as the second phase of the Great Dividing Range railway crossing. The project was one of the great railway deviations and is still in use today more than one hundred years since its construction. The tunnels form part of a larger railway landscape in the Lithgow area and across the Blue Mountains including the Zig Zag railway, Dargan's Creek Deviation, Eskbank Goods Yard and the State Mine Colliery railway, and remains a critical component of the Main Western Line. **The Great Zig Zag Railway deviation tunnels are classified as State significant under this criterion.**
B – Associative Significance	The construction of the Ten Tunnels sourced bricks and labour for its construction from the Lithgow Valley Colliery and Pottery works. During the construction of the tunnels, up to 70 percent of the brick output of the colliery and pottery works were utilised for the deviation works. This had a significant effect on the local economy of the Lithgow region at that time. **The Great Zig Zag Railway deviation tunnels are classified as locally significant under this criterion.**
C – Aesthetic or Technical Significance	The Great Zig Zag Railway deviation tunnels illustrate high level technical achievement for tunnelling, engineering and railway building practices. The work included excavation of the deepest cutting on the NSW rail system. The construction involved up to 1500 employees per day. It resulted in journey times reduced by 30 minutes and the track gradient reduced from 1 in 41 to 1 in 90 which allowed a doubling in the load of trains. **The Great Zig Zag Railway deviation tunnels are classified as State significant under this criterion.**
D – Social Significance	The Great Zig Zag Railway deviation tunnels significantly improved transportation access to the Lithgow Valley and wider interior NSW region. While the tunnels were not the first rail line to cross the Blue Mountains, the deviation provided reliable two-track rail access to the interior of NSW via the Main Western Railway Line, significantly improving economic growth in the early 20th century. **The Great Zig Zag Railway deviation tunnels are classified as locally significant under this criterion.**
E – Research Potential	The Great Zig Zag Railway deviation tunnels have research significance in providing evidence on the techniques of tunnel construction in the first decade of the 1900s. **The Great Zig Zag Railway deviation tunnels are classified as State significant under this criterion.**

Criterion	Explanation
F – Rarity	The Great Zig Zag Railway deviation tunnels are a major engineering achievement within New South Wales dating from the early 1900s and are rare in this regard. **The Great Zig Zag Railway deviation tunnels are classified as State significant under this criterion.**
G - Representativeness	The Great Zig Zag Railway deviation tunnels are representative of brick-arch construction used for tunnelling during the early 20th century railway construction in NSW. **The Great Zig Zag Railway deviation tunnels are classified as State significant under this criterion.**

5.2 Statement of significance

The Great Zig Zag Railway deviation tunnels are of State heritage significance.

The following statement of significance has been sourced from the SHR entry for the 'Great Zig Zag Railway deviation tunnels':

> *The Great Zig Zag Railway deviation tunnels are of state significance due to its historical associations with the second phase of railway crossing across the Great Dividing Range. It is of a high level of technical significance as a large-scale engineering achievement of the early 20th century including excavation of the deepest cutting on the NSW rail system. The project was one of the great railway deviations constructed throughout NSW, and was a success in reducing both journey time and track gradient, and continues to be in use today. The tunnels form part of a larger railway landscape in the Lithgow area and across the Blue Mountains including the Zig Zag railway, Dargan's Creek Deviation, Eskbank Goods Yard and the State Mine Colliery railway.*

5.3 Great Zig Zag Railway deviation tunnels components

Table 6 summarises the heritage significance of the components of the Great Zig Zag Railway deviation tunnels, which has been prepared for the purposes of this report.

Table 6: Grades of significance for components of the Great Zig Zag Railway deviation tunnels

Component	Description	Grading
Tunnel 1	Tunnel 1 consists of a brick barrel vaulted tunnel 551 metres in length and approximately six metres high. The brick barrel vault, sandstone keystone and concrete tunnel lining abutments are original fabric. Tunnel 1 strongly exhibits the structural features and engineering methods of its construction, particularly the brick arched portal and surrounding sandstone cuttings. However, the deteriorating intactness of the fabric combined with the occluding intrusive elements reduces the tunnel's significance from exceptional to high.	**High**
Tunnel 2	Tunnel 2 consists of a brick barrel vaulted tunnel 107 metres in length and approximately six metres high. The brick barrel vault, sandstone keystone and concrete tunnel lining abutments are original fabric. Tunnel 2 strongly exhibits the structural features and engineering methods of its construction, particular the brick arched portal and surrounding sandstone cuttings. The notching conducted in the 1970s is intrusive and unsympathetic. The existing notching combined with the occluding intrusive elements reduces the tunnels significance from exceptional to high. Despite some later intrusive elements, the tunnel fabric and setting is largely intact.	**High**
Tunnel 3	Tunnel 3 consists of a brick barrel vaulted tunnel 176 metres in length and approximately six metres high. The brick barrel vault, sandstone keystone and concrete tunnel lining abutments are original fabric. Tunnel 3 strongly exhibits the structural features and engineering methods of its construction, particular the brick arched portal and surrounding sandstone cuttings. However, the notching conducted in the 1970s is intrusive and unsympathetic. The existing notching combined with the occluding intrusive elements reduces the tunnels significance from exceptional to high. Despite some later intrusive elements, the tunnel fabric and setting is largely intact.	**High**
Tunnel 4	Tunnel 4 consists of a brick barrel vaulted tunnel 404 metres in length and approximately six metres high. The brick barrel vault, sandstone keystone and concrete tunnel lining abutments are original fabric. Tunnel 4 strongly exhibits the structural features and engineering methods of its construction, particular the brick arched portal and surrounding sandstone cuttings. Despite some later intrusive elements, the tunnel fabric and setting is largely intact, and demonstrates exceptional significance.	**Exceptional**

Component	Description	Grading
Tunnel 5	Tunnel 5 consists of a brick barrel vaulted tunnel 161 metres in length and approximately six metres high. The brick barrel vault, sandstone keystone and concrete tunnel lining abutments are original fabric. Tunnel 5 strongly exhibits the structural features and engineering methods of its construction, particular the brick arched portal and surrounding sandstone cuttings. Despite some later intrusive elements, the tunnel fabric and setting is largely intact, and demonstrates exceptional significance.	**Exceptional**
Tunnel 6	Tunnel 6 consists of a brick barrel vaulted tunnel 183 metres in length and approximately six metres high. The brick barrel vault, sandstone keystone and concrete tunnel lining abutments are original fabric. Tunnel 6 strongly exhibits the structural features and engineering methods of its construction, particular the brick arched portal and surrounding sandstone cuttings. Despite some later intrusive elements, the tunnel fabric and setting is largely intact, and demonstrates exceptional significance.	**Exceptional**
Tunnel 7	Tunnel 7 consists of a brick barrel vaulted tunnel 224 metres in length and approximately six metres high. The brick barrel vault, sandstone keystone and concrete tunnel lining abutments are original fabric. Tunnel 7 strongly exhibits the structural features and engineering methods of its construction, particular the brick arched portal and surrounding sandstone cuttings. Despite some later intrusive elements, the tunnel fabric and setting is largely intact, and demonstrates exceptional significance.	**Exceptional**
Tunnel 8	Tunnel 8 consists of a brick barrel vaulted tunnel 171 metres in length and approximately six metres high. The brick barrel vault, sandstone keystone and concrete tunnel lining abutments are original fabric. Tunnel 8 strongly exhibits the structural features and engineering methods of its construction, particular the brick arched portal and surrounding sandstone cuttings. Despite some later intrusive elements, the tunnel fabric and setting is largely intact, and demonstrates exceptional significance.	**Exceptional**
Tunnel 9	Tunnel 9 consists of a brick barrel vaulted tunnel 79 metres in length and approximately six metres high. The entirety of Tunnel 9 is brick-lined. The brick tunnel lining and sandstone keystone are original fabric. Tunnel 9 is the shortest tunnel of the Great Zig Zag Railway deviation tunnels, and also the only tunnel lined entirely with brick. Tunnel 9 strongly exhibits the structural features and engineering methods of its construction, particular the brick arched portal and surrounding sandstone cuttings, as well as being the only tunnel lined entirely with brick. Despite some later intrusive elements, the tunnel fabric and setting is largely intact, and demonstrates exceptional significance.	**Exceptional**

Component	Description	Grading
Tunnel 10	Tunnel 10 consists of a brick barrel vaulted tunnel 790 metres in length and approximately six metres high. The brick barrel vault, sandstone keystone and concrete tunnel lining abutments are original fabric. Tunnel 10 is the longest tunnel of the Great Zig Zag Railway deviation tunnels. Tunnel No. 10 strongly exhibits the structural features and engineering methods of its construction, particular the brick arched portal and surrounding sandstone cuttings. Tunnel No. 10 is also the longest of the ten tunnels. Elements of intrusive fabric and encroaching water damage are relatively minor compared with the overall size of the tunnel. Despite the water degradation and some later intrusive elements, the tunnel fabric and setting is largely intact, and demonstrates exceptional significance.	**Exceptional**
Rock bolts and GST	Although the rock bolts and GST are integral to the safe operation of the Great Zig Zag Railway deviation tunnels for both structural and signalling purposes, there are unsympathetic additions to the original fabric.	**Intrusive**
Overhead wiring structures	Overhead wiring was introduced to the Great Zig Zag Railway deviation tunnels in the 1950s. The electrification of the Blue Mountains (Main West) Line to Lithgow represented and adaptation of existing rail infrastructure to service evolving railway technology, maintain the Great Zig Zag Railway deviation tunnels as a relevant component of the rail network to this day. Additionally, the adaptation of the Great Zig Zag Railway deviation tunnels to accommodate overhead wiring represents a technical achievement.	**Moderate**
Former light fittings and gradient/ radius/ survey markers	The phasing of the former light fittings and gradient/ radius/ survey markers has not been established. However, it is assumed based on their generally poor physical condition (light fittings and markers) and imperial measurements (markers) that they are likely to be associated either with the original construction of the Great Zig Zag Railway deviation tunnels or during the early 20th century. Although these components are, with exceptions, both generally in poor condition, they have the potential to contribute to an understanding of the early operations of the Great Zig Zag Railway deviation tunnels.	**Moderate**

5.4 Assessment of heritage significance for the 'Great Zig Zag Railway and Reserves' (SHR# 00542)

The statement of significance from the SHR listing for the Great Zig Zag Railway and Reserves is included below:

> *"The Great Zig Zag Railway had a profound influence upon the development and economy of western New South Wales. At the time it was the greatest civil engineering work in Australia and was considered worldwide as an engineering marvel. It reflects the difficulty experienced in crossing the Blue Mountains and engineering compromises enforced by economics. The reserve is a fine scenic attraction and the sandstone escarpments and viaducts provide a dramatic juxtaposition to the urban development of nearby Lithgow"*

The assessment of heritage significance for the Great Zig Zag Railway and Reserves has been adapted from the SHR listing, which is included in Table 7 below.

Table 7: Assessment of Heritage Significance for the Great Zig Zag Railway and Reserves using information from the SHR listing

Criterion	Explanation
A – Historical Significance	The Great Zig Zag Railway and Reserves is of historical significance because upon completion it triggered extensive development and had a profound influence on the economy of western New South Wales. It contributed to the economy of western New South Wales to such an extent that it could not handle the volume of traffic and was replaced by the Great Zig Zag Railway deviation tunnels (SHR 01037) **The Great Zig Zag Railway reaches the threshold for State significance under this criterion.**
B – Associative Significance	The Great Zig Zag Railway and Reserves is associated with John Whitton, Engineer-in-Charge for New South Wales between 1856 and 1899. Whitton was integral not only to overseeing planning and construction of the Great Zig Zag Railway and Reserves, but also an extensive railway network across NSW. **The Great Zig Zag Railway and Reserves reaches the threshold for State significance under this criterion.**
C – Aesthetic or Technical Significance	The Great Zig Zag Railway and Reserves is a fine scenic attraction in itself, offering superb views of the rugged sandstone valleys and escarpments leading to the western plains. It serves to provide a dramatic juxtaposition to the urban development of nearby Lithgow suburbs. The three main viaducts are particularly pleasing structures. **The Great Zig Zag Railway and Reserves reaches the threshold for State significance under this criterion.**
D – Social Significance	The Great Zig Zag Railway and Reserves reflects the difficulty experienced in crossing the Blue Mountains and engineering compromises enforced by economics. **The Great Zig Zag Railway and Reserves reaches the threshold for State significance under this criterion.**
E – Research Potential	The Great Zig Zag Railway and Reserves was regarded as the greatest civil engineering work in Australia at the time it was constructed and attracted worldwide interest as an engineering marvel. **The Great Zig Zag Railway and Reserves reaches the threshold for State significance under this criterion.**
F - Rarity	The Great Zig Zag Railway and Reserves was a major engineering achievement in the late 19th Century and is rare in this regard. A smaller scale zig zag railway was utilised to ascend and descend the railway eastern margin of the Blue Mountains to Emu Plains at Lapstone. That example is does not have the same integrity or scale as the Great Zig Zag and does not meet the threshold for State significance. As such the Great Zig Zag railway is a unique and largely intact example of zig zag railway construction in NSW. **The Great Zig Zag Railway and Reserves reaches the threshold for State significance under this criterion.**
G – Representative Significance	The Great Zig Zag Railway and Reserves is representative of railway engineering solutions to steep gradients in late 19th Century NSW. **The Great Zig Zag Railway and Reserves reaches the threshold for local significance under this criterion.**

6.0 ARCHAEOLOGICAL ASSESSMENT

The Project is confined to the tunnel lining of Tunnels 1, 2, 3, 6, 7, 8, 9 and 10. The tunnel lining consists of either brick or concrete overlying sandstone and shale bedrock. The tunnel lining is not considered to be an element of the Great Zig Zag Railway deviation tunnels with archaeological potential. As such, the proposed notching and GST relocation works (Tunnel 3) are in areas that demonstrate **nil** archaeological potential.

Proposed site compounds near the Lithgow end of Tunnel 2, the Lithgow end of Tunnel 9, and up track of the Edgecombe signal hut are in already established compound and stockpile areas. No ground-penetrating works are associated with establishing site compounds for the Project.

Proposed hi-rail access points are located on the existing concrete track bed. Temporary high-rail access pads will be placed on the concrete track bed during works to assist hi-rail vehicles on and off the tracks. No ground-penetrating works are associated with hi-rail access for the Project.

7.0 HERITAGE IMPACT ASSESSMENT

7.1 Proposed works

7.1.1 Overview

The Project comprises minor modifications to sections of the lining of eight tunnels in the Great Zig Zag Railway deviation tunnels and minor modifications to ancillary infrastructure extending from the eastern portal of Tunnel 1 (Sydney end) to the western portal of Tunnel 10 (Lithgow end) to accommodate the operation of the New Intercity Fleet which is marginally wider and longer than the existing trains. No modifications are planned for the rail line between the tunnels as part of this Project.

The Project has been designed as far as possible to reduce potential impacts to the heritage significance of the tunnels, by way of using the existing alignments of the tracks from Edgecombe Station to Zig Zag Station, avoiding modification to the overhead wiring structures, minimising works required to the existing cable route and other tunnel infrastructure such as lighting, and minimising works to the fabric of the tunnel lining.

7.1.2 Proposed work activities

The site-based scope of works to be completed includes:

- Notching the tunnel lining:
    - Haunch section – total length of infringement is 77 metres in masonry (excluding tunnel light infringements)
    - Toe section – total length 939 metres in mixture of masonry and variable strength concrete
    - Typically, treatments require removal of tunnel wall using rail mounted excavators with road header attachments.

- Rock bolt replacement / installation:
    - Placement of new rock bolts in the tunnel lining at locations where toe section notching is required. Existing rock bolts will either be left in situ, or the removal of the outer portion of the rock bolt and treatment with corrosion prevention sealant, or removed entirely. Entire removal is unlikely, as it requires coring around the existing rock bolt prior to removal.
    - Installation of Double Corrosion Protected (DCP) rock bolts adjacent to the existing, redundant ones
    - Where required toe notching fouls the existing rock bolts, these bolts will need to be physically removed. Depending on exact position of rock bolt and notching, this may require the removal of just the anchor plate, but possibly a certain length of bolt as well and protection of the end to prevent rusting.

- Wall reconstruction:

  - T4 type treatment in poor quality concrete may require removal of the existing wall to be replaced with new mass concrete.

- Tunnel infrastructure:
  - Modification / replacement of five tunnel lighting moisture protection shields within Tunnels 1 and 10 to ensure they are outside of the Sub-Medium kinematic envelope and therefore are slimmer than the existing by approximately 50 millimetres.

- Rail infrastructure:
  - Install temporary protection to overhead wiring structures, e.g. 'Tiger Tails' or similar. To be installed prior to works commencing and after power outage is confirmed, and must be removed following completion of the works, prior to the overhead wiring structures being re-energised
  - Installation of a new cable tray under the existing trough on the down track of Tunnel 3 and relocation of the existing cables and recovery of the existing route. This shall ensure the cable route is outside of the kinematic envelope.

- Trackside infrastructure:
  - Install trackside signs to indicate to the driver the operational restrictions associated with Great Zig Zag Railway deviation tunnels approved rolling stock and recovery of existing signs which no longer apply.

7.1.3 Tunnel notching treatments

To incorporate the New Intercity Fleet trains, sections of the existing tunnel lining of Tunnels 1, 2, 3, 6, 7, 8, 9 and 10 would be modified to ensure compliance with relevant rail standards. Within the Great Zig Zag Railway deviation tunnels, these modifications would consist of notching to both the haunch and toe of the sections of those sections of each tunnel that will be modified to ensure compliance standards. A summary of the notching treatment depths is outlined below, and location of notching treatment types across the Great Zig Zag Railway deviation tunnels is shown in Figure 24 to Figure 33.

Haunch treatment categories:

- Self-supporting treatment:
  - Type H0 (max 20 millimetres)
  - Type H1 (max 60 millimetres).
- Note: no haunch treatment required for approximately 5.6 kilometres of 5.692 kilometres (length including up and down track).

Toe treatment categories:

- Self-supporting treatment:
  - Type T1 (max 100 millimetres deep)
  - Type T2 (max 160 millimetres deep)

  - Type T3 (max 215 millimetres deep)
  - Type T4 (max 265 millimetres deep).
- Note: no toe treatment required for approximately 4.76 kilometres of 5.692 kilometres (length including up and down track).

The notching depth is measured from a virtual tunnel 'design line', which approximately correlates with the original tunnel lining position. This means that where there is existing notching, the maximum depth of proposed notching is measured from the design line, rather than from the existing notched depth. The implications of this are that although the deepest proposed notching measures up to 265 millimetres depth (T4 treatment type), the deepest notching from the existing tunnel lining will be no greater than approximately 127 millimetres (subject to construction tolerance of 25 millimetres).

The proposed height of notching will vary depending upon the determined infringement in each tunnel. The height of notching will extend up to approximately one metre.

Haunch infringements are minimal and predominantly associated with existing tunnel lights or minor build-up of soot or other diesel particulates. In both of these circumstances, notching will not be required. Either cleaning of the tunnel haunch or replacement of tunnel light fittings will suffice instead of notching in both circumstances. Infringement charts show that notching of the brick vault in Tunnel 10 may be required to a depth of up to 60 millimetres for a section of tunnel approximately 40 metres in length.

The majority of the notching works would be completed by mechanical device fitted to a hi-rail excavator or similar machine. The mechanical device would likely consist of a cutter head with a spiral head and picks rotating parallel to the cutter boom axis. The size of the excavator can be varied by the contractor depending on the height and access restrictions at any given location. The depth, height, and extent of notching would be programmed into the machine before commencing notching. Cutting tool monitoring equipment, including a laser guidance system and real time monitoring, will guide the notching works. A surveyor would be engaged prior to commencement of works to mark on the tunnel lining sections of tunnel lining to be notched.

Where the degree of notching is minimal, or where a finer finish than that offered by a machine is required, handheld tools will be utilised. This includes works for cable route modifications and any required lighting works.

Use of a cutter head attached to a machine will provide a more uniform and smoother finish, as well providing more control over notching, than that offered by jack-hammering. Jack-hammering appears to have been utilised for large sections of the existing notching within the Great Zig Zag Railway deviation tunnels, with a resulting rough and uneven finish. Use of machine also provides greater safety for workers undertaking the works, eliminating vibration syndromes from extensive use of a jack-hammer.

For T4 treatment types where rock bolts do not provide suitable tunnel lining support, such as where the thickness of the remaining concrete or because of the low strength of the concrete, reconstruction works may be required. Concrete reconstruction works would involve removing the existing concrete lining and some depth of bedrock behind the tunnel lining, before replacing with new concrete. Concrete replacement works would take place in one metre long sections. The method of extraction and nature of replacement concrete will be determined during detailed design prior to commencement of works.

A series of tunnel recesses are located throughout Tunnels 1 through 10. The original function of these recesses was to provide refuge to workers from passing trains. However, existing tunnel lining modifications and other factors such as overlapping GST, mean that the Worksite Protection

Hazardous Location Register does not identify any of the recesses within the Great Zig Zag Railway deviation tunnels as a ‘safe place’. Where these recesses overlap with the proposed notching, the amount of space provided in each recess will be reduced further.

As noted in Section 4, the majority of the recesses throughout the Great Zig Zag Railway deviation tunnels are unsympathetic additions to the tunnel lining. Only the longest three tunnels (Tunnels 1, 4 and 10) have brick-arched and lined recesses, whilst the recesses in the remaining tunnels are later additions.

No rendering or sealant is proposed to be applied following completion of notching works.

7.1.4 Rock bolts

The rock bolts installed throughout the Great Zig Zag Railway deviation tunnels assist in reducing the later load on the tunnel lining, as well as increasing the lining capacity by tying the concrete lining and rock mass together. The existing rock bolts will continue to assist with supporting the tunnel lining following proposed notching works. However, some of the rock bolts were installed when the tunnel lining was modified in the 1970s prior to introduction of the V-set trains, and will be nearing the end of their design life. As such, installation of new rock bolts will be required as part of the current scope of works. Load distribution changes from the proposed notching will be determined during detailed design. An indicative total of 830 rock bolts may be required during works, however, the location and number of required rock bolts cannot be determined at this stage, and will be confirmed during detailed design or on site by the contractor during works. No rock bolts will be required for haunch works.

Existing rock bolts will either be removed and/ or supplemented with new rock bolts. New rock bolts will be similar in appearance to existing rock bolts, with a metal anchor plate, exposed section of threadbar with domed nut. The new rock bolts will likely have a plastic cap covering the exposed section of threadbar and domed nut. The rock bolt will pass through the tunnel lining fabric and into bedrock.

Existing rock bolts will need to be removed where they overlap with proposed areas for notching. Removal of existing rock bolts may involve removal of the anchor plate only, or a certain length of the rock bolt.

Complete removal of rock bolts, where required, would involve coring around the rock bolt and removal of the rock bolt and a small section of surrounding fabric and bedrock.

7.1.5 Galvanised Steel Troughing (GST)

There is an identified infringement on existing GST within Tunnel 3 on the down track side. Renewal / relocation of GST within Tunnel 3 will be required as part of the proposed notching works. The existing GST will be replaced with a cable ladder mounted to the wall. The cable route will be a lower profile for greater clearance, and will be raised slightly off the tunnel lining to allow ground water leaching through the tunnel lining to pass without affecting the cable route. The cable route will be fixed to the tunnel walls with the use of chemical anchors and stainless steel bolts at a minimum depth of 110 millimetres.

The new cable route within Tunnel 3 will be placed at least 200 millimetres beneath the existing GST alignment on the down track side. The existing GST will be left in place whilst cabling is transferred to the new cable route. The existing GST will then be removed.

No other replacement of existing GST is proposed under the current scope of works.

7.1.6 Protection of existing overhead wiring structures during works

Existing overhead wiring structures attached to the brick vault of each tunnel will be visually highlighted and physically protected during works by utilising a combination of 'Tiger Tails', polycarbonate sheet or other appropriate protective measures. These would be variously placed on overhead wiring, steady arms, and catenary support insulators during works. These methods of protection and high visibility marking will not have a physical impact on the brick fabric of the tunnel vault. The exact nature of protective measures for overhead wiring structures during works will be confirmed during detailed design or on site by the contractor during works.

7.1.7 Trackside signage

To facilitate the change of operation to accommodate the Sub-Medium rolling stock, some signage on the Blue Mountains (Main West) Line requires updating.

New 'Medium rolling stock must not pass this point' signs will be installed at the Lithgow end of Tunnel 10.

7.1.8 Culverts and drainage

A number of brick culverts, brick and concrete drains, and chiselled sandstone drains, are located throughout the Great Zig Zag Railway deviation tunnels. All of these items are located outside the tunnels, and are responsible for diverting water through the precipitous sandstone terrain away from the tunnel entrances. No impacts to any drains outside the tunnels have been identified as part of the current scope of works.

The construction contractor will be responsible for ensuring that culverts and drains are not impacted by placement of temporary hi-rail access points, or blocked by debris and spoil.

7.1.9 Site compounds, rail access points, and miscellaneous plant and equipment required for works

Three locations are proposed for site compounds to support notching works:

- Approximately 850 metres east of the Sydney end of Tunnel 1, near the existing Edgecombe Section Hut and existing hi-rail access point. This location is outside the SHR curtilage of the Great Zig Zag Railway deviation tunnels, and will be located in an existing cleared area adjacent to the down track
- Existing rail access point adjacent to the up track, and located at the Lithgow end of Tunnel 2 and the Sydney end of the large cutting that is located between Tunnel 2 and Tunnel 3. The site compound location is an existing cleared and raised area with concrete access ramp to the up track and down track. A temporary track-infill would be placed on the concrete track slab for hi-rail access
- Existing site compound facility at the Lithgow end of Tunnel 9. An existing Sydney Train compound facility, stockpile area, and vehicle parking area is located at the Lithgow end of Tunnel 9. This location is proposed for a temporary compound facility during notching works. The area is generally clear and flat to allow for existing Sydney Trains activities, but is bordered to the west beneath the steeper sandstone terrain by open drainage dating to the construction of the

Great Zig Zag Railway deviation tunnels. No compound facilities are proposed that would overlap with the existing drainage infrastructure. A temporary track-infill would be placed on the concrete track slab for hi-rail access.

Access to proposed site compound facilities near Tunnel 2 and Tunnel 9, and up track from Edgecombe is by established vehicle access tracks, much of which has been bituminised by Sydney Trains.

Miscellaneous equipment that may be required to complete the works include:

- Water cartage for dust suppression. This could be either:
    - A road rail mounted bowser located next to the cutting machinery
    - Water pumped from temporary holding tanks located in the cuttings between the tunnels. To avoid down-time these tanks would need to be placed and filled prior to the possession and removed after. (It is noted that the position of water pumps etc. will have to be agreed to signalling maintainer).
- Generators and lighting systems
- Road rail crew vehicles
- Road rail suction trucks for spoil removal
- Rail mounted trolleys for material delivery, such as rock bolts, reinforcing bars, formwork, and associated equipment
- Road rail concrete trucks for and or concrete pumping equipment for wall reconstruction
- Rail mounted elevated work platforms / scissor lifts
- Fans, air scrubbers and filters
- Miscellaneous small equipment, such as survey equipment.

[Note: the final methods for notching would be confirmed during detailed design, and will include a construction tolerance of 25 millimetres]

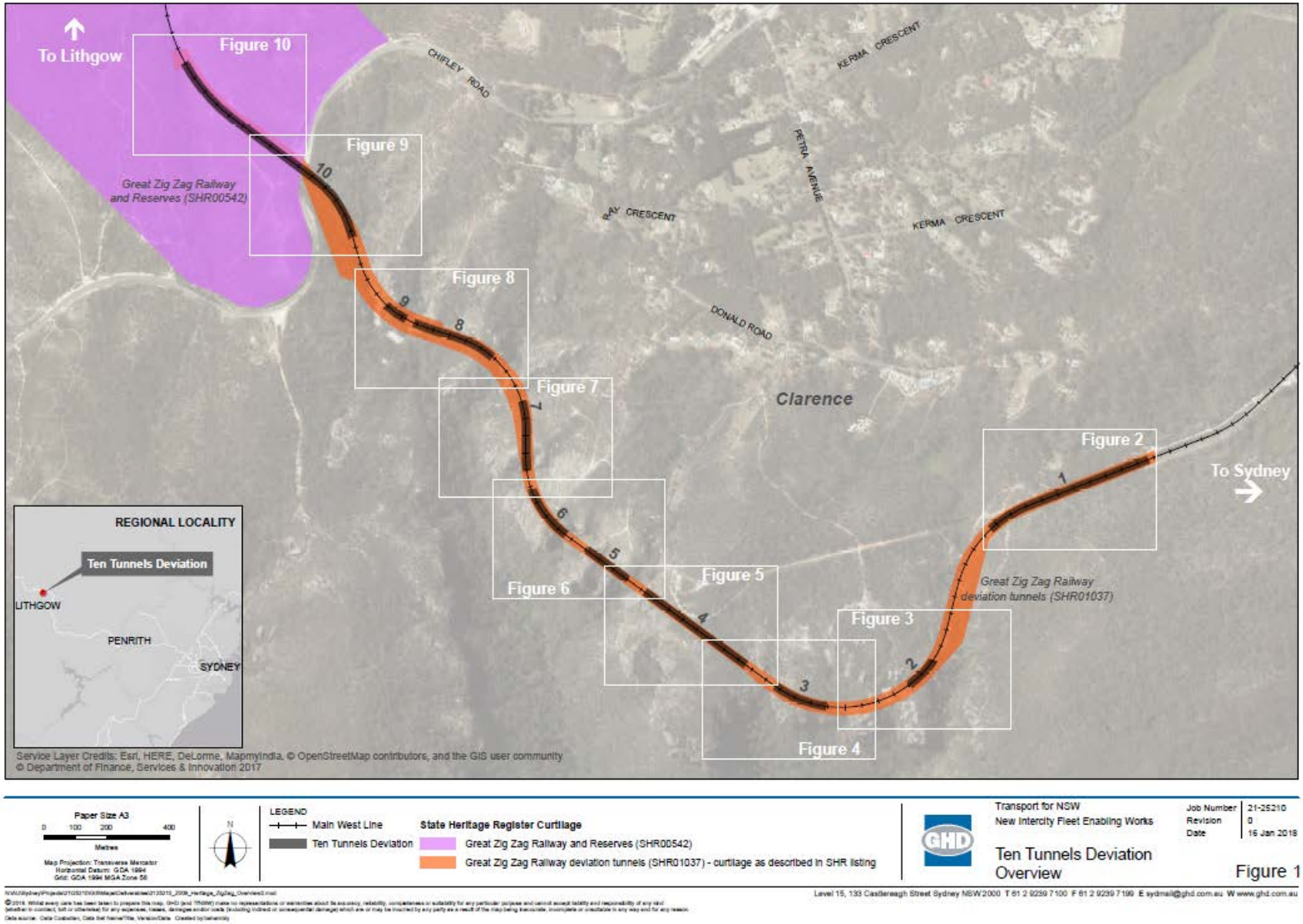


Figure 24: Overview plan showing tunnel locations (GHD Great Zig Zag Railway deviation tunnels Heritage Design Summary 2018)

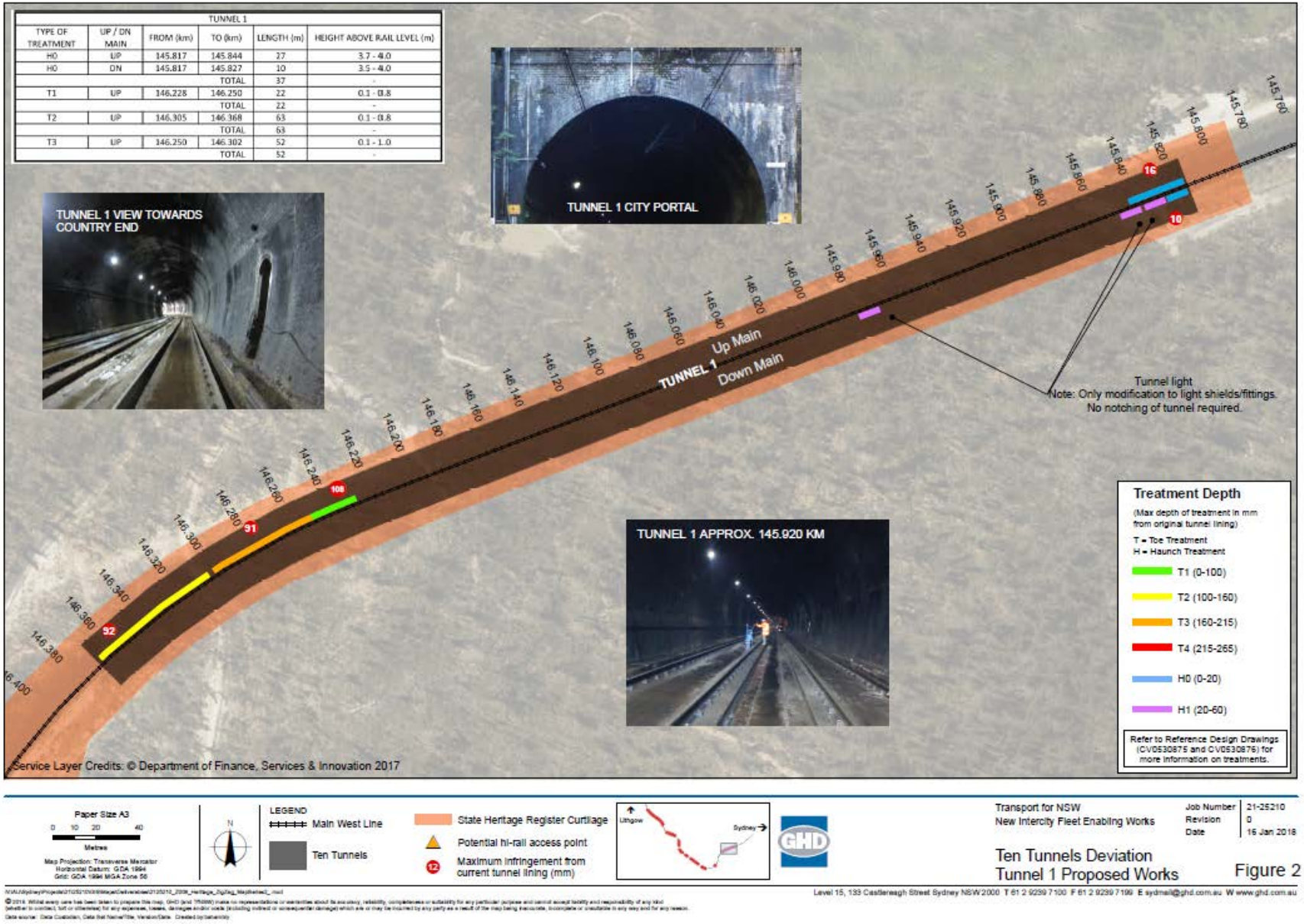


Figure 25: Proposed treatment overview for Tunnel 1 (GHD Great Zig Zag Railway deviation tunnels Heritage Design Summary 2018)

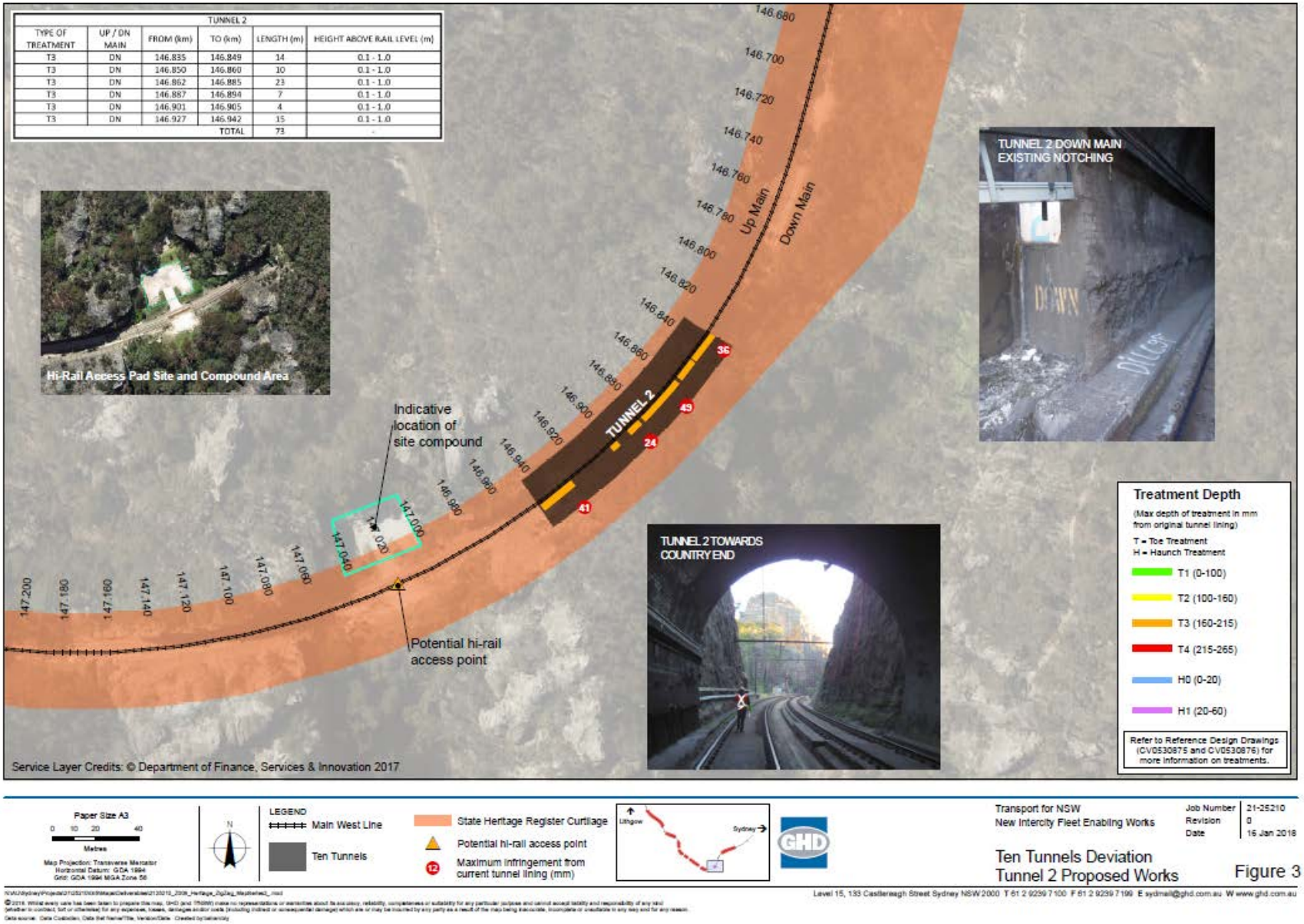
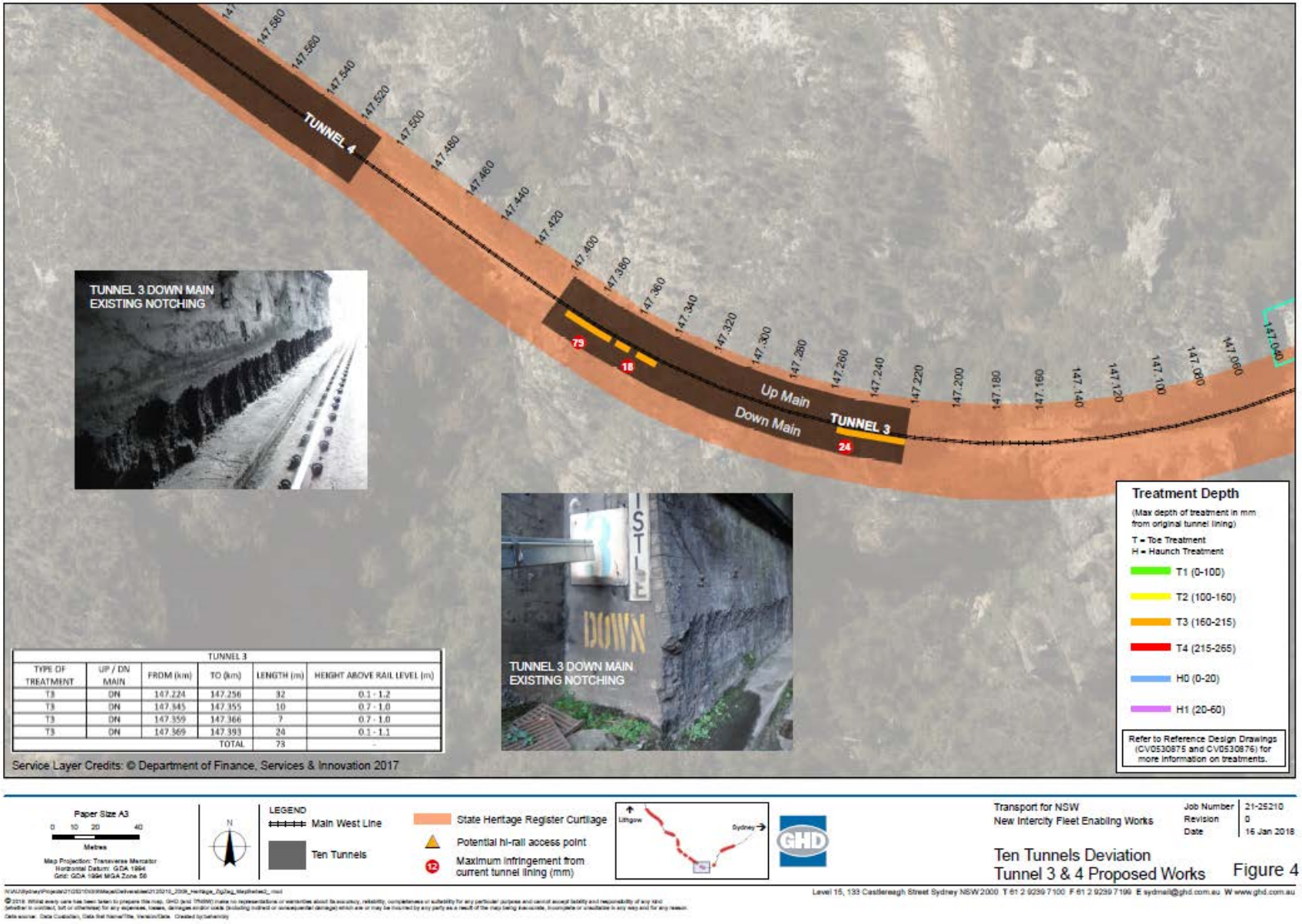


Figure 26: Proposed treatment overview for Tunnel 2 (GHD Great Zig Zag Railway deviation tunnels Heritage Design Summary 2018)



TUNNEL 3					
TYPE OF TREATMENT	UP / DN MAIN	FROM (km)	TO (km)	LENGTH (m)	HEIGHT ABOVE RAIL LEVEL (m)
T3	DN	147.224	147.256	32	0.1 - 1.2
T3	DN	147.345	147.355	10	0.7 - 1.0
T3	DN	147.359	147.366	7	0.7 - 1.0
T3	DN	147.369	147.393	24	0.1 - 1.1
			TOTAL	73	

Figure 27: Proposed treatment overview for Tunnel 3 and Tunnel 4 (GHD Great Zig Zag Railway deviation tunnels Heritage Design Summary 2018)

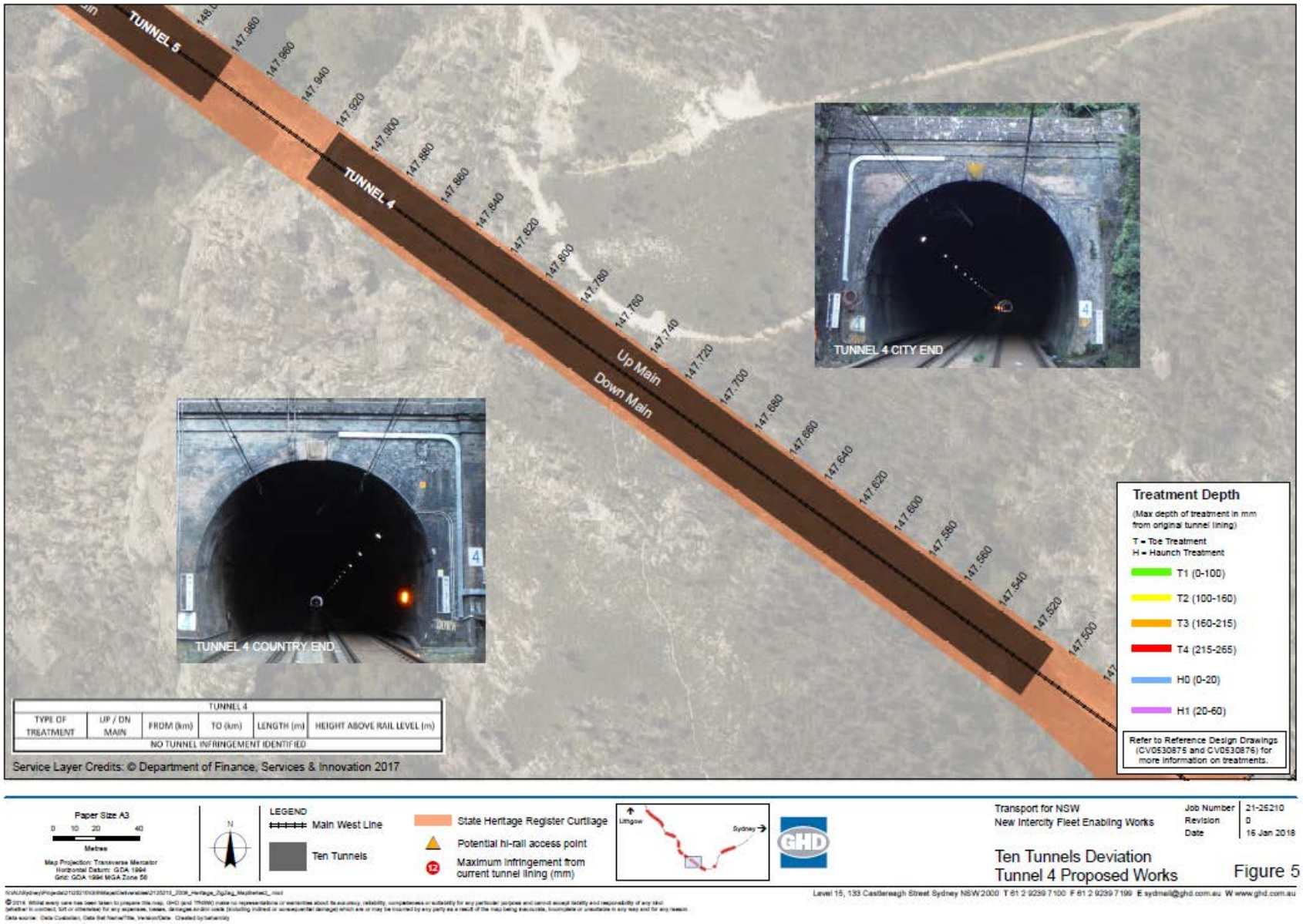
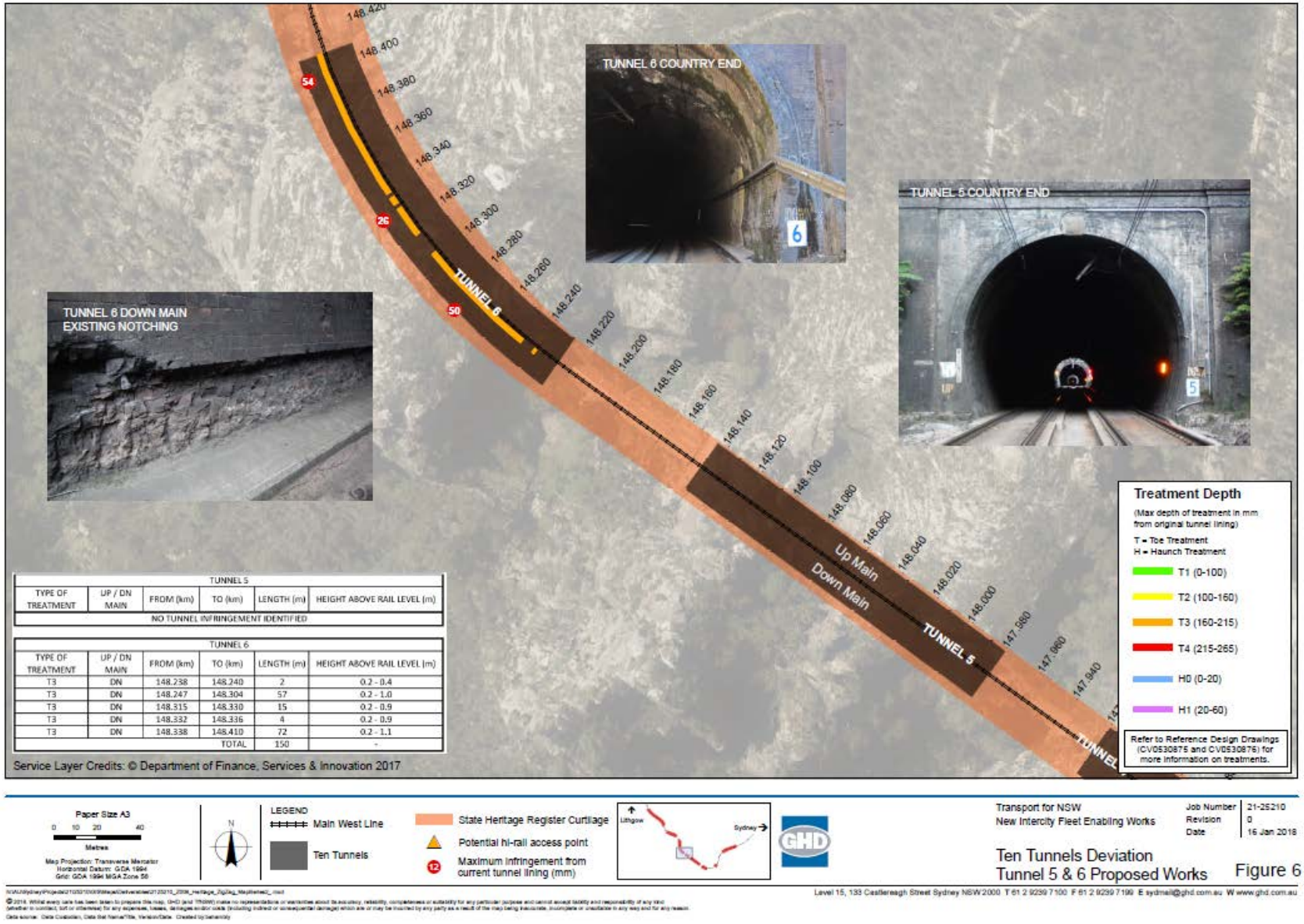


Figure 28: Proposed treatment overview for Tunnel 4 and Tunnel 5 (GHD Great Zig Zag Railway deviation tunnels Heritage Design Summary 2018)



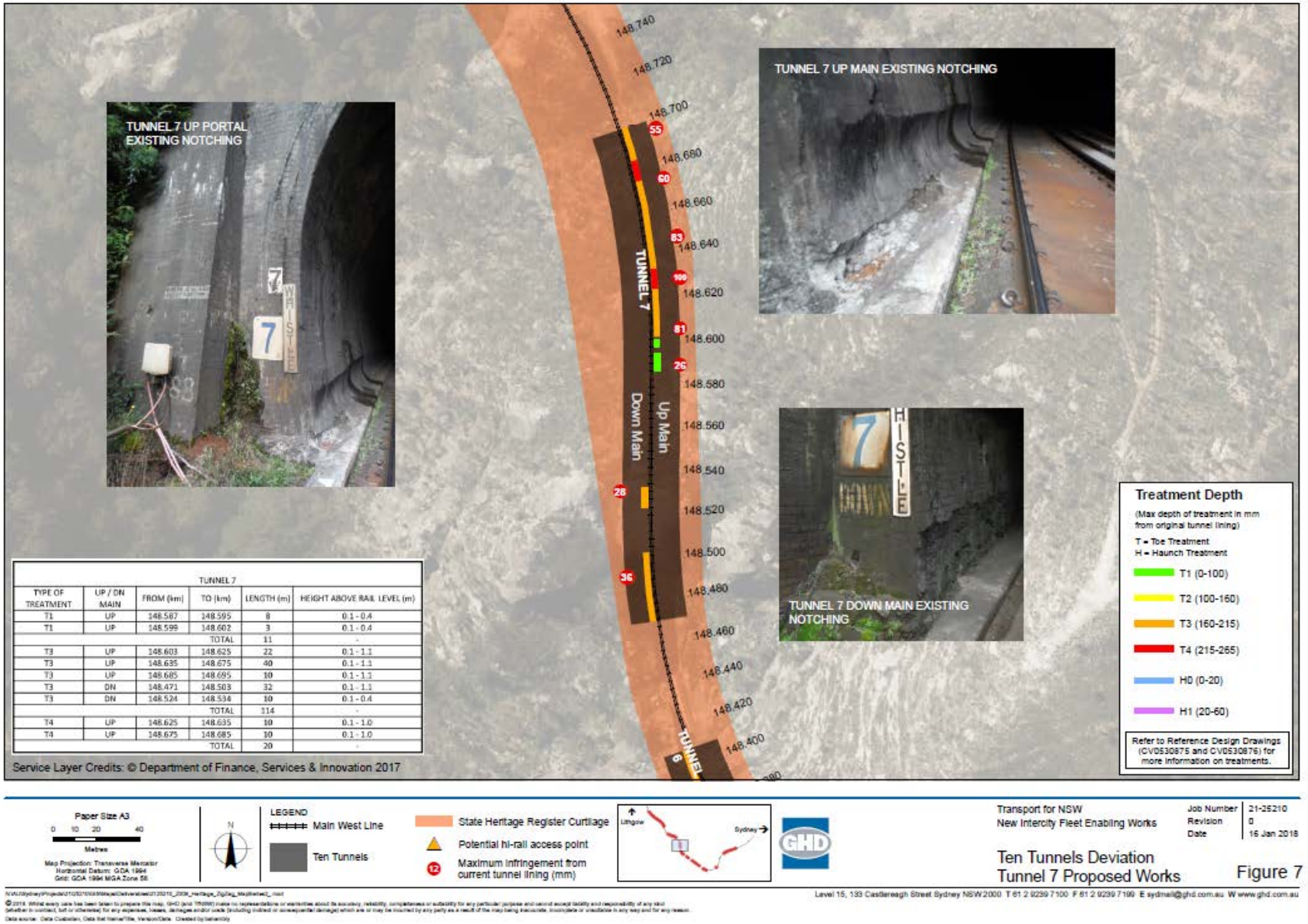
TUNNEL 5

TYPE OF TREATMENT	UP / DN MAIN	FROM (km)	TO (km)	LENGTH (m)	HEIGHT ABOVE RAIL LEVEL (m)
NO TUNNEL INFRINGEMENT IDENTIFIED					

TUNNEL 6

TYPE OF TREATMENT	UP / DN MAIN	FROM (km)	TO (km)	LENGTH (m)	HEIGHT ABOVE RAIL LEVEL (m)
T3	DN	148.238	148.240	2	0.2 - 0.4
T3	DN	148.247	148.304	57	0.2 - 1.0
T3	DN	148.315	148.330	15	0.2 - 0.9
T3	DN	148.332	148.336	4	0.2 - 0.9
T3	DN	148.338	148.410	72	0.2 - 1.1
			TOTAL	150	-

Figure 29: Proposed treatment overview for Tunnel 5 and Tunnel 6 (GHD Great Zig Zag Railway deviation tunnels Heritage Design Summary 2018)



TUNNEL 7					
TYPE OF TREATMENT	UP / DN MAIN	FROM (km)	TO (km)	LENGTH (m)	HEIGHT ABOVE RAIL LEVEL (m)
T1	UP	148.587	148.595	8	0.1 - 0.4
T1	UP	148.599	148.602	3	0.1 - 0.4
			TOTAL	11	-
T3	UP	148.603	148.625	22	0.1 - 1.1
T3	UP	148.635	148.675	40	0.1 - 1.1
T3	UP	148.685	148.695	10	0.1 - 1.1
T3	DN	148.471	148.503	32	0.1 - 1.1
T3	DN	148.524	148.534	10	0.1 - 0.4
			TOTAL	114	-
T4	UP	148.625	148.635	10	0.1 - 1.0
T4	UP	148.675	148.685	10	0.1 - 1.0
			TOTAL	20	-

Figure 30: Proposed treatment overview for Tunnel 6 and Tunnel 7 (GHD Great Zig Zag Railway deviation tunnels Heritage Design Summary 2018)

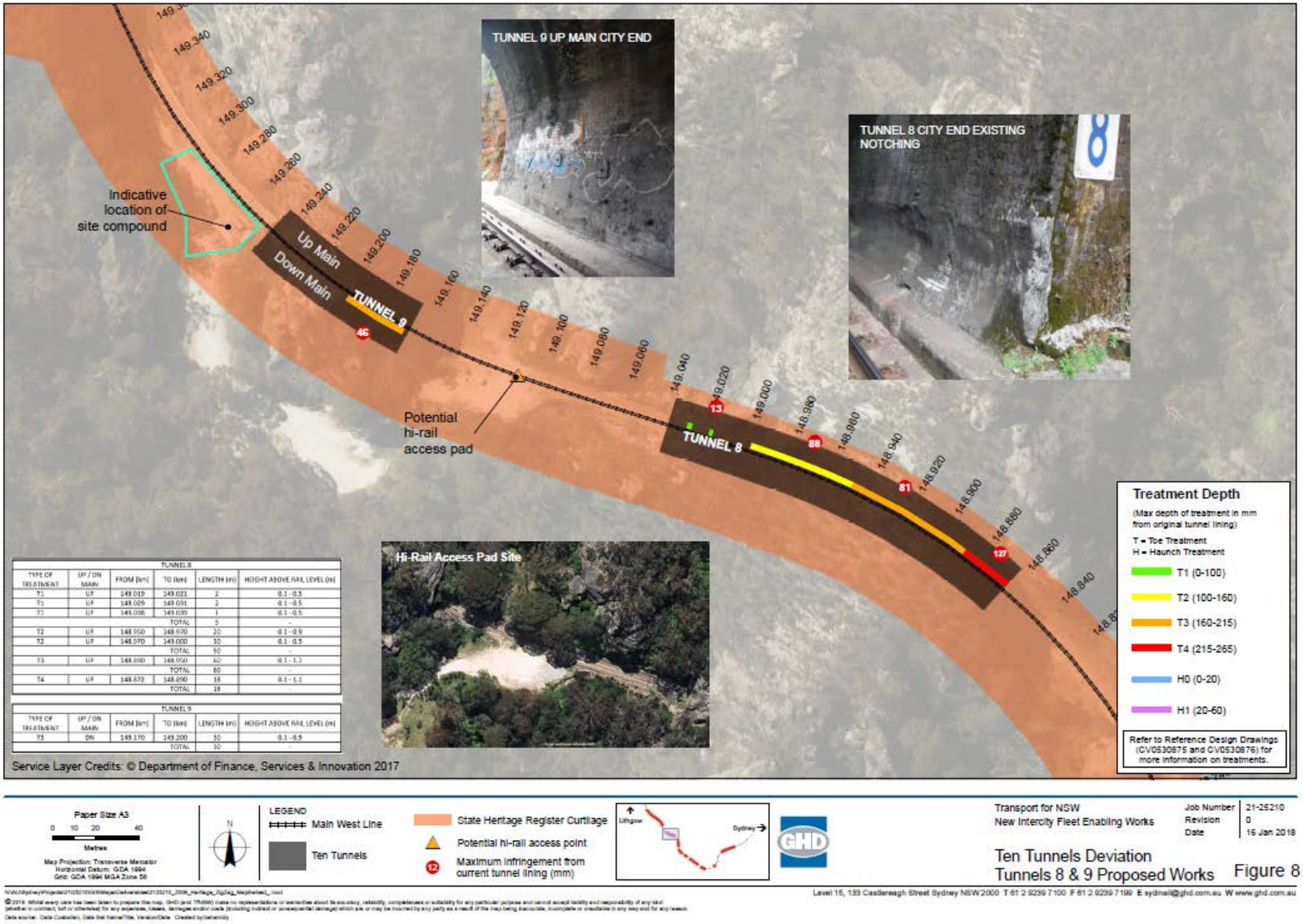
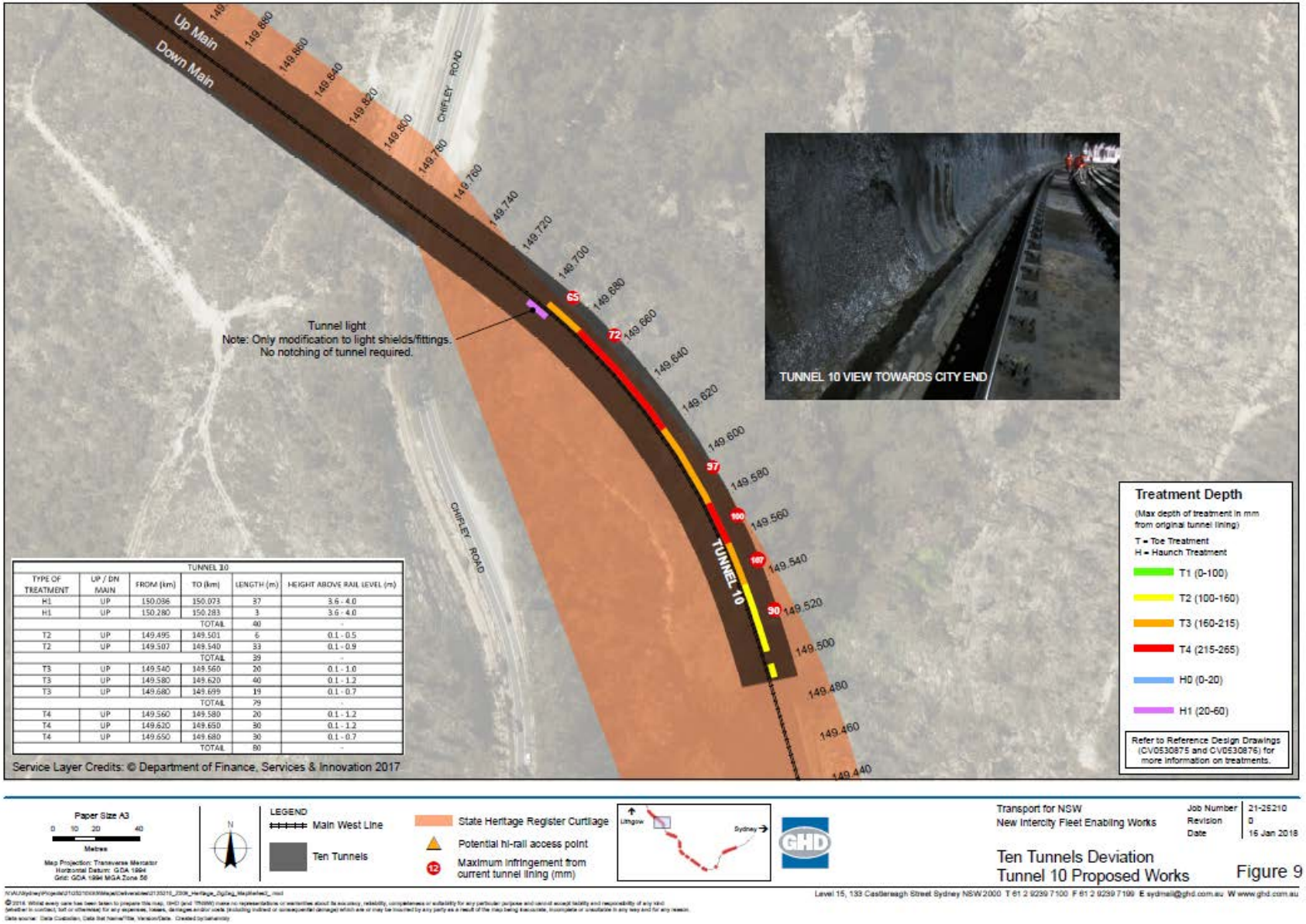
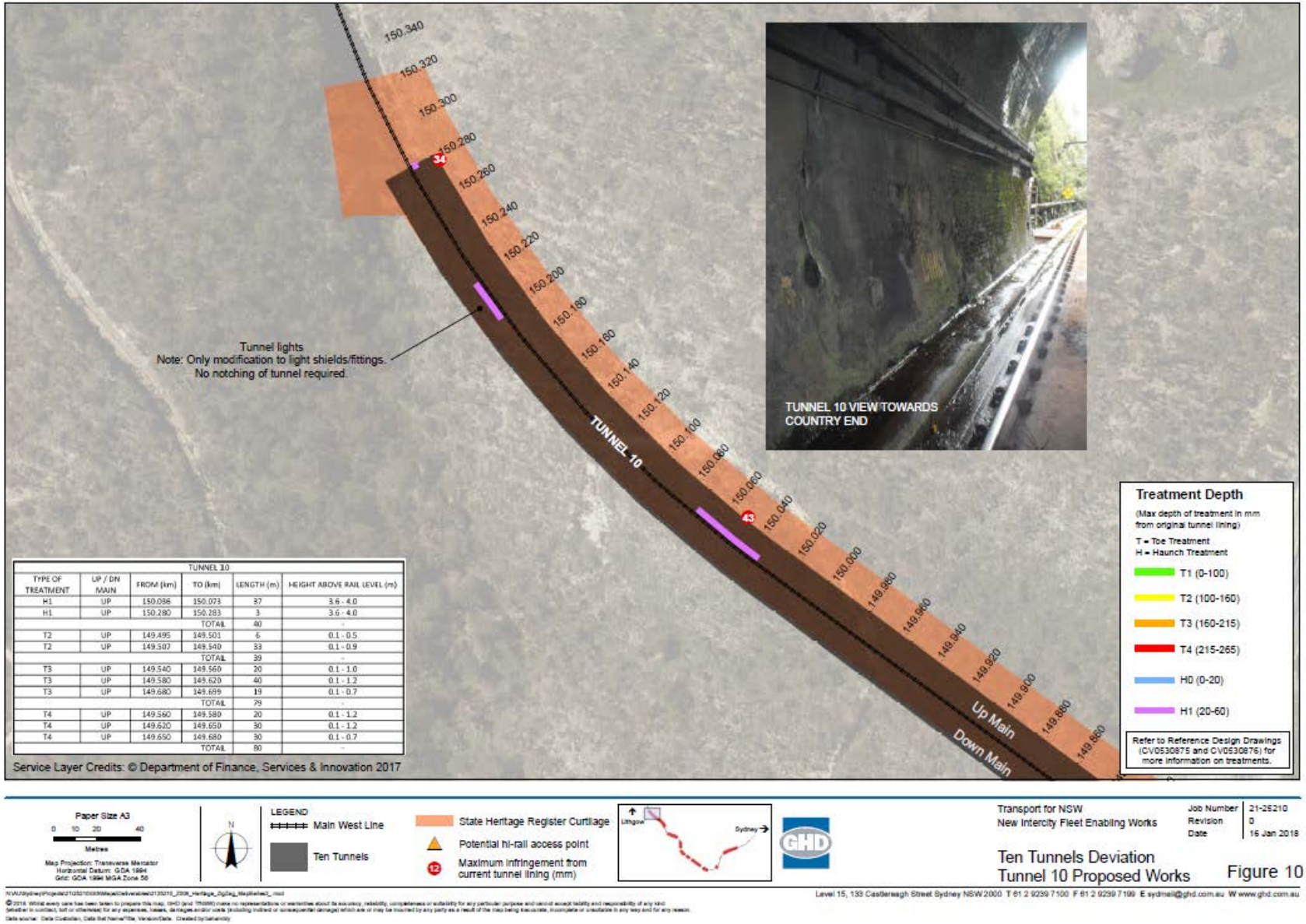


Figure 31: Proposed treatment overview for Tunnel 8 and Tunnel 9 (GHD Great Zig Zag Railway deviation tunnels Heritage Design Summary 2018)



TUNNEL 10					
TYPE OF TREATMENT	UP / DN MAIN	FROM (km)	TO (km)	LENGTH (m)	HEIGHT ABOVE RAIL LEVEL (m)
H1	UP	150.036	150.073	37	3.6 - 4.0
H1	UP	150.280	150.283	3	3.6 - 4.0
			TOTAL	40	-
T2	UP	149.495	149.501	6	0.1 - 0.5
T2	UP	149.507	149.540	33	0.1 - 0.9
			TOTAL	39	-
T3	UP	149.540	149.560	20	0.1 - 1.0
T3	UP	149.580	149.620	40	0.1 - 1.2
T3	UP	149.680	149.699	19	0.1 - 0.7
			TOTAL	79	-
T4	UP	149.560	149.580	20	0.1 - 1.2
T4	UP	149.620	149.650	30	0.1 - 1.2
T4	UP	149.650	149.680	30	0.1 - 0.7
			TOTAL	80	-

Figure 32: Proposed treatment overview for Tunnel 10 (GHD Great Zig Zag Railway deviation tunnels Heritage Design Summary 2018)



TUNNEL 10					
TYPE OF TREATMENT	UP / DN MAIN	FROM (km)	TO (km)	LENGTH (m)	HEIGHT ABOVE RAIL LEVEL (m)
H1	UP	150.086	150.073	87	3.6 - 4.0
H1	UP	150.280	150.283	3	3.6 - 4.0
			TOTAL	40	-
T2	UP	149.495	149.501	6	0.1 - 0.5
T2	UP	149.507	149.540	33	0.1 - 0.9
			TOTAL	39	-
T3	UP	149.540	149.560	20	0.1 - 1.0
T3	UP	149.580	149.620	40	0.1 - 1.2
T3	UP	149.680	149.699	19	0.1 - 0.7
			TOTAL	79	-
T4	UP	149.560	149.580	20	0.1 - 1.2
T4	UP	149.620	149.650	30	0.1 - 1.2
T4	UP	149.650	149.680	30	0.1 - 0.7
			TOTAL	80	-

Figure 33: Proposed treatment overview for Tunnel 10 (GHD Great Zig Zag Railway deviation tunnels Heritage Design Summary 2018)

7.2 Options assessment

The New Intercity Fleet is wider than the existing V-Sets with a different kinematic envelope. Options for the operation of the trains (e.g. on a single line or both lines), and associated modifications to achieve the necessary clearances through the tunnels are discussed in the sections below.

The kinematic envelope of a train is the outline of the space around it when in motion, and takes into account its tilt and sway. The TfNSW Assets Standards Authority (ASA) establishes and maintains standard with requirements around the minimum clearances between the kinematic envelope of a train and the surrounding environment, to ensure it operates safely and does not infringe on structures in the rail corridor.

Currently only two types of trains have a kinematic envelope that meet the standard and can safely operate through the Ten Tunnels Deviation, these include the narrow electric passenger trains (V-Sets) and the narrow non-electric freight and passenger trains (e.g. XPTs and the Bathurst Bullet).

7.2.1 Options to achieve necessary width clearances

Do Nothing

Under a ‘do nothing’ option, the tunnels would not be modified. This option was not progressed, as without modifications to the tunnels, the New Intercity Fleet would not meet the necessary clearances to safely travel through the Great Zig Zag Railway deviation tunnels. This would not meet the objectives of the Project to provide a new passenger train service through to Lithgow, and so was discounted.

Dual line running

To achieve the necessary clearances for the New Intercity Fleet so that trains could travel on both lines and pass each other, a rebuild option was initially proposed which would involve notching the tunnel walls, repositioning of the track and a rebuild of the track slab.

This option was discounted as it would not meet the Project objectives, and in particular would likely have major impacts to the heritage values of the tunnels as well as adverse impacts to freight and passenger services during construction, due to the need for a tunnel closure which would likely extend for several months.

Single line running

This option would involve notching of the tunnel walls on one side only so that the New Intercity Fleet trains could travel bi-directionally on the same line. Modifications to both the up track only and the down track only options were considered. The benefits of single running options would be fewer construction impacts and cost; along with less impact to heritage fabric than the dual line running options.

The main disadvantage of single running would be that trains could not pass in the tunnel which would have a long-term impact on timetabling on both the New Intercity Fleet and regional passenger services, and for this reason was discounted.

Dual line running with new sub-medium electric standard

A third option was then progressed which included the development of a new standard for a sub-medium electric train (which the New Intercity Fleet complies with) that would allow the New Intercity Fleet to operate on both lines and pass each other, and therefore ensure better longer term operational outcomes, while also minimising heritage impacts.

The new standard takes into account the kinematic envelope of the train and also that the tilt of a train is typically more stable when on a concrete slab track rather than ballast. Therefore, when the infringements are modelled it would reduce the amount of notching required in the tunnel walls, and minimise impacts to heritage fabric (when compared to the options above).

The dual line running with new sub-medium electric standard is the preferred option and is described in more detail in Section 7.1.

7.3 Heritage impacts to the Great Zig Zag Railway deviation tunnels (SHR# 01037)

7.3.1 Impacts to heritage significant fabric

Notching of tunnel lining

The Project has been developed to minimise, as far as possible, the depth and extent of required notching of tunnel lining. This primarily relates to changes in the kinematic envelope in order to reduce infringements on the tunnel lining, whilst still maintaining safe operation of rolling stock through the tunnels. Minimisation of treatment depth and length required high definition static laser scans of each tunnel to be carried out to create a more accurate representation of the tunnel wall lining. This resulted in modifications to track and rolling stock parameters and resulted in a dramatic reduction in the required works.

The proposed work activities would involve removal of portions of tunnel lining in localised haunch and toe sections in order to increase the cross-sectional area of the tunnels to eliminate identified infringements associated with the operation of the New Intercity Fleet. This includes removal of sections of original brick masonry and concrete by way of rail mounted excavators with cutter head attachments. Notching of tunnel lining would result in the removal of significant fabric that is representative of early-20th century rail engineering practices, and the economic and construction methods employed to build the tunnels.

The Project would not involve notching of tunnel lining in Tunnel 4 and Tunnel 5, the exceptionally significant fabric and setting of which remain largely intact. Tunnel 4 has not been subject to notching previously, with the main modification including lowering of the tunnel floor in the 1970s to accommodate the V-set trains.

It is noted that in localised areas, the lining of tunnel toe sections in most of the other tunnels has already been significantly impacted by intrusive notching that was carried out in the 1970s. This includes existing notching of tunnel lining primarily at the bottom parts of the tunnels, and installation of rock bolts along the length of tunnels to provide structural support. Background information suggests that installation of rock bolts within the Great Zig Zag Railway deviation tunnels has continued since the 1970s work prior to introduction of the V-set trains.

The affected portions of tunnel lining fabric vary from tunnel to tunnel in relation to treatment length, depth and proximity to the masonry portal entrances. The combined length of the tunnels within the Great Zig Zag Railway deviation tunnels is 2,846 metres. Overall, approximately 77 metres of haunch treatment and 939 metres of toe treatment would be required under the Project. It is also noted that portions of the haunch section infringement is associated with lighting only and will not impact the brick arch. Haunch section treatments of 0 to 20 millimetres (H0) would affect the up track of Tunnel 1, while haunch section treatments of 20 to 60 millimetres (H1) would affect the down track of Tunnel 1 and the down track and up track of Tunnel 10, impacting the brick vault in these areas.

In areas where the infringement treatments are deeper, the anticipated levels of impact to the significant fabric of the Great Zig Zag Railway deviation tunnels would also be greater. For example,

the toe section treatments of 215 to 265 millimetres (T4) which is the deepest treatment would affect the up track of Tunnel 7, the up track of Tunnel 8, and the up track of Tunnel 10.

It is noted, however, that the depth of treatment type is measured from the design line of the tunnel, not from existing notched surfaces. The depth of notching treatment will include already notched areas, as shown in Figure 25 to Figure 33.

Although the notching treatment will include some previously notched areas, the project will involve removal of original brick and concrete fabric which are integral to the technical and aesthetic significance of the Great Zig Zag Railway deviation tunnels. Additionally, areas of T4 treatment may involve removal and replacement of sections of significant concrete fabric due to the depth of impact. A summary of proposed treatment types and lengths of impacted fabric in each tunnel is provided in Appendix B.

Portals

The level of impact would be increased in areas where treatments would involve alterations to the brick portal entrances, which would also be associated with increased visual impacts as discussed in the sections below. Affected portal entrances include:

- Tunnel 1 Sydney end, both sides
- Tunnel 1 Lithgow end, up track (already existing portal notching)
- Tunnel 2 Sydney end, down track (already existing portal notching)
- Tunnel 2 Lithgow end, down track (already existing portal notching)
- Tunnel 3 Sydney end, down track (already existing portal notching)
- Tunnel 6 Lithgow end, down track (already existing portal notching)
- Tunnel 7 Lithgow end, up track (already existing portal notching)
- Tunnel 7 Sydney end, down track (already existing portal notching)
- Tunnel 8 Lithgow end, up track
- Tunnel 8 Sydney end, up track (already existing portal notching)
- Tunnel 10 Lithgow end, up track
- Tunnel 10 Sydney end, up track.

Overhead wiring and other fittings / markers

Notching would not impact overhead wiring structures, and protective measures would be put in place to ensure that this infrastructure is not inadvertently impacted during works (see Section 6.1.6).

Notching is not likely to impact former light fittings, due to the fact that these features are situated above the level of toe notching, and below the level of haunch notching (Tunnel 10). There is potential for works to impact some of the gradient/ radius/ survey markers, due to those components being located below one metre above the concrete track bed. Several gradient/ radius/ survey markers identified towards on the down track tunnel lining towards the Lithgow end of Tunnel 10, for example, will not be impacted.

Overall, considering the dimensions and locations of the proposed notching it is considered that the removal of tunnel lining in areas of infringement would result in a **moderate** physical impact to the Great Zig Zag Railway deviation tunnels. The impact of the Project on individual tunnels is outlined in Table 9.

Alterations to rock bolts

The Project would require alterations, removal and replacement of the rock bolts within the tunnels in several locations. This includes removal and/or replacement of existing rock bolts in the side walls at locations where toe section notching is required, as well as installation of rock bolts adjacent to existing reductant bolts in several locations. In some instances, only a section of the rock bolt would be removed, and the remainder of the bolt retained in situ.

The installation of rock bolts into the lower portions of the tunnel walls commenced in the 1970s as part of the upgrade works to accommodate double-deck 'V-set' trains, and appears to have continued since then. The large metal bolts are present along the brick inner walls of the tunnels. While the bolts are not part of the original fabric of the Great Zig Zag Railway deviation tunnels, nor are they significant components in themselves, they play an important role in supporting the structural integrity and condition of the tunnels and overall heritage item. Care should therefore be taken to ensure the continued role of the supporting bolts.

Overall, the proposed alterations of existing rock bolts, and installation of new rock bolts within the tunnels would result in a **minor** physical impact to the Great Zig Zag Railway deviation tunnels. The impact of the Project on individual tunnels is included in Table 9.

Wall reconstruction

For T4 treatment types where rock bolts do not provide suitable tunnel lining support, such as where the thickness of the remaining concrete or because of the low strength of the concrete, reconstruction works may be required. The method of extraction and nature of replacement concrete will be determined during detailed design prior to commencement of works.

T4 reconstruction works would be limited to the concrete lined portions of the respective tunnels only. No reconstruction works or T4 treatment is proposed within the brick portal sections of any tunnel.

Overall, the possible concrete reconstruction works associated with the T4 treatment type would have a **moderate** physical impact to the Great Zig Zag Railway deviation tunnels.

Modifications to tunnel, rail & trackside infrastructure

The Project would require modifications to fabric associated with tunnel, rail and trackside infrastructure within the Great Zig Zag Railway deviation tunnels in order to achieve compliance with the required kinematic envelope. This includes modification and replacement of several tunnel lighting moisture protection shields within Tunnel 1 and Tunnel 10, installation of temporary protection to the overhead wiring structures prior to commencement of works, installation of a new cable tray under the existing GST on the down track of Tunnel 3 and relocation of the existing cables, and installation of new trackside signs.

These features, which are associated with tunnel, rail and trackside infrastructure, are not original components of the Great Zig Zag Railway deviation tunnels nor do they constitute significant fabric. Overall, the modifications to this infrastructure would have a **minor** impact to the Great Zig Zag Railway deviation tunnels.

Site compound & potential hi-rail access pad

The Project would involve establishment of two temporary site compounds and hi-rail access pads within the Great Zig Zag Railway deviation tunnels SHR curtilage. These include one site compound and hi-rail access pad located south west of the Lithgow End of Tunnel 2, a hi-rail access pad located between the Lithgow End of Tunnel 8 and Sydney End of Tunnel 9, and a site compound located north west of the Lithgow End of Tunnel 9. The use of each area for a temporary compound would be

away from the tunnel structures themselves, and would likely involve the stockpiling of construction equipment, materials and temporary office structures. Further assessment would be required where it is determined that the temporary construction compounds and hi-rail access pads would involve ground-penetrating impacts.

Overall, the proposed site compounds and hi-rail access pads would result in a **negligible** temporary physical impact to the Great Zig Zag Railway deviation tunnels.

7.3.2 Impacts to the heritage views and setting

Notching of tunnel lining

The proposed work activities would involve removal of tunnel lining in localised haunch and toe sections, including portions of significant brick masonry and concrete. Removal of brick and concrete material would primarily occur inside the tunnels, in areas of low light that are not clearly visible to bushwalkers, rail workers in the vicinity of the tunnels, or train commuters. Notching work inside the tunnels would primarily be visible to rail workers working inside, or passing through, each tunnel during rail possessions. The aesthetic values of the item, as such, are largely associated with the masonry portal entrances and external sandstone cuttings.

The proposed removal of tunnel lining would be located in areas near several tunnel portal entrances. Affected portal entrances include:

- Tunnel 1 Sydney end, both sides
- Tunnel 1 Lithgow end, up track (already existing portal notching)
- Tunnel 2 Sydney end, down track (already existing portal notching)
- Tunnel 2 Lithgow end, down track (already existing portal notching)
- Tunnel 3 Sydney end, down track (already existing portal notching)
- Tunnel 6 Lithgow end, down track (already existing portal notching)
- Tunnel 7 Lithgow end, up track (already existing portal notching)
- Tunnel 7 Sydney end, down track (already existing portal notching)
- Tunnel 8 Lithgow end, up track
- Tunnel 8 Sydney end, up track (already existing portal notching)
- Tunnel 10 Lithgow end, up track
- Tunnel 10 Sydney end, up track.

Notching of tunnel portals would be between 100 to 160 millimetres at Tunnel 1 and Tunnel 10, between 160 to 215 millimetres at Tunnel 2, Tunnel 3, Tunnel 6 and Tunnel 7, and between 215 to 265 millimetres at Tunnel 8. It is noted that the depth of treatment type is measured from the design line of the tunnel, not from existing notched surfaces. As such, the depth of notching treatment will include already notched areas.

While these impacts would be relatively inconspicuous for train commuters and train drivers approaching and travelling through the tunnels at high speed, the proposed modifications to the tunnel portals would be visible for rail workers and also bushwalkers on access roads and bush trails adjacent to the Great Zig Zag Railway deviation tunnels. It is noted, however, that the proposed removal of fabric is relatively small in relation to the overall height and configuration of the portal entrances.

There would be temporary minor visual impacts to overhead wiring structures during works as temporary protective linings are placed on this infrastructure to ensure there is no inadvertent impact during works. Overall visual impacts to overhead wiring structures from the Project would be neutral.

There will be neutral visual impact to former light fittings, as these fittings are generally in poor physical condition, and they will not be impacted by the Project. There is the potential for minor visual impacts to the gradient/ radius/ survey markers where individual markers are removed during works.

Overall, the proposed removal of tunnel lining in areas of infringement would result in a **minor** visual impact to the Great Zig Zag Railway deviation tunnels, with **minor-moderate** visual impacts where there will be notching to portals that have not been notched previously (Tunnels 1, 8 and 10). The impact of the Project on individual tunnels is included in Table 9. It is noted that the infringement on the Lithgow end portal of Tunnel 8 is less than 5mm, and could potentially be moss/grit that could be removed by cleaning.

Alterations to rock bolts

The Project would involve modifications and alterations to the existing rock bolts that are present on the lower inner walls of the tunnels, and replacement with new in several locations. The rock bolts have been a visual component of the tunnels since the upgrading works that were undertaken in the 1970s, and the addition of new rock bolts, therefore, would not result in any immediately discernible changes to the overall appearance of the tunnels. The rock bolts are relatively small in the context of the overall tunnel structures, and it is noted this aspect of the Project would occur in areas of low light that are not clearly visible to pedestrians or train commuters.

Overall, the proposed alterations to rock bolts within the tunnels would result in a **negligible** visual impact to the Great Zig Zag Railway deviation tunnels. The impact of the Project on individual tunnels is included in Table 9.

Wall reconstruction

The Project may involve the reconstruction of concrete in T4 treatment areas, such as where the thickness of the remaining concrete or because of the low strength of the concrete. The concrete is original fabric, and as such has been a component of the Great Zig Zag Railway deviation tunnels since construction in 1908 to 1910.

The concrete sections of tunnel lining are all displaced at least six metres from the tunnel portal, meaning that concrete reconstruction works would not result in any immediately discernible changes to the overall appearance of the tunnels. Concrete reconstruction works would not be visible to train passengers, and would not likely be visible to train drivers. Concrete reconstruction works would primarily be visible to site workers walking through the tunnels during rail possessions, however, due to the generally dark lighting in most of the tunnels, it is likely that some concrete reconstruction works may not be clearly visible.

Overall, potential concrete reconstruction works within the tunnels would result in a **minor** visual impact to the Great Zig Zag Railway deviation tunnels. The impact of the Project on individual tunnels is included in Table 9.

Modifications to tunnel, rail & trackside infrastructure

The Project involves modifications to tunnel, rail and trackside infrastructure, including tunnel lighting moisture protection shields within Tunnel 1 and Tunnel 10, temporary protection to the overhead wiring structures, installation of a new cable tray under the existing trough on the down track of Tunnel 3 and relocation of existing cables, and modifications to trackside signage. These items have been visual components of the tunnels since the upgrading works that were undertaken in the 1970s.

Alteration to these elements, and introduction of new associated infrastructure would not result in any immediately discernible changes to the overall appearance of the tunnels. It is noted this aspect of the Project would primarily occur in areas of low light that are not clearly visible to pedestrians or train commuters.

Overall, the proposed modifications to tunnel, rail and trackside infrastructure would result in a **negligible** visual impact to the Great Zig Zag Railway deviation tunnels. The impact of the Project on individual tunnels is included in Table 9.

Site compound & potential hi-rail access pad

The establishment of temporary construction compounds and hi-rail access pads, including one site compound and hi-rail access pad located south west of the Lithgow End of Tunnel 2, a hi-rail access pad located between the Lithgow End of Tunnel 8 and Sydney End of Tunnel 9, and a site compound located north west of the Lithgow End of Tunnel 9, would involve setting up demountable buildings and stockpiling of machine plant and material. These facilities would be removed following the completion of the construction phase of the Project.

The temporary site compounds could potentially partially impinge on sight lines to the adjacent portal entrances at Tunnel 2, Tunnel 8 and Tunnel 9, and surrounding stone cuttings. These impacts, however, would be temporary in nature and primarily affect views for site workers.

Overall, the proposed site compounds and hi-rail access pads would result in a temporary negligible temporary visual impact to the Great Zig Zag Railway deviation tunnels. The impact of the Project on individual tunnels is included in Table 9.

7.3.3 Impacts to archaeological resources

No archaeological resources would be impacted by the proposed removal of tunnel lining fabric within Tunnels 1, 2, 3, 6, 7, 8, 9 and 10.

No ground-penetrating works are associated with the establishment of site compounds up track of the Edgecombe signal hut, near the Lithgow end of Tunnel 2, or the Lithgow end of Tunnel 9. Both areas are also established Sydney Trains compound and stockpile areas. No ground-penetrating works are associated with the proposed hi-rail access points near the Lithgow end of Tunnel 2, or the Sydney end of Tunnel 9. No archaeological resources would be impacted by the proposed establishment of site compounds and hi-rail access points.

7.4 Heritage impacts to Great Zig Zag Railway and Reserves (SHR# 00542)

The Project falls within the curtilage of the Great Zig Zag Railway and Reserves (SHR# 00542). The curtilage for this item is established as the physical fabric of the original Zig Zag Railway and sidings, and a wider visual catchment which has been allowed to ensure that the form and heritage character of the item is not impacted by works within that curtilage.

The Project would primarily occur within the Great Zig Zag Railway deviation tunnels (SHR# 01037), up to 80 metres below the existing ground surface. As such, much of the works would not be visible within the visual catchment of the item. The proposed notching of tunnel lining near the portal entrances, however, would result in a visual impact. The scale of this aspect of the Project in relation to the overall scale of the Great Zig Zag Railway and Reserves would be relatively inconspicuous, and would not impact on the visual qualities or setting of this SHR item. The ten tunnels themselves are not a physical component of the fabric of the Great Zig Zag Railway and Reserves, and the Project therefore would not impact the fabric of the SHR item.

The Project would result in a neutral physical impact and a negligible visual impact to the Great Zig Zag Railway and Reserves (SHR# 00542).

7.5 Cumulative impacts

The Project has been assessed as likely to result in a neutral physical impact and negligible visual impact to the Great Zig Zag Railway and Reserves. The Project has not been identified as likely to have an impact on any other listed heritage items in the local area. The cumulative impacts to listed heritage items in the area surrounding the Great Zig Zag Railway deviation tunnels is considered to be neutral physical impact and negligible visual impact.

The Project has been assessed as likely to result in an overall moderate physical impact and minor visual impact to the Great Zig Zag Railway deviation tunnels. The Great Zig Zag Railway deviation tunnels were subject to modification in the 1970s when the tunnel floor was lowered and the toe section of several tunnels notched in order to accommodate the V-set trains. The proposed notching works will in include application of notching treatments to sections of tunnel that have been notched previously, and will result in an increase in notching depth in those areas, as well as application of notching treatment to toe sections that have not been notched previously. The Project will also involve notching treatments to small haunch sections of Tunnel 1 and Tunnel 10. No previous works within the Great Zig Zag Railway deviation tunnels have involved notching the brick vault. Existing works have also involved application of GST to tunnel lining, and other cables and pipes to brick portals.

Overall, the Project will involve an increase in physical impact to the Great Zig Zag Railway deviation tunnels. The existing extent of notching will generally be increased, and haunch notching (Tunnel 1 and Tunnel 10) is a new impact. The Project has been assessed as likely to result in moderate physical cumulative impacts to the Great Zig Zag Railway deviation tunnels.

The Project will involve an increase in notching to several tunnel portals. With regards to the overall size and extent of the Great Zig Zag Railway deviation tunnels, the proposed impacts to those tunnel portals would be relatively inconspicuous. Considering the relatively small visual impacts in relation to the overall height and configuration of the portal entrances, the Project has been assessed as likely to result in minor visual cumulative impacts to the Great Zig Zag Railway deviation tunnels.

Table 8: Summary of cumulative heritage impacts

Heritage item	Cumulative impact from works
Great Zig Zag Railway deviation tunnels (SHR# 01037)	Moderate physical and minor visual impacts
Great Zig Zag Railway and Reserves (SHR# 00542)	Neutral physical and negligible visual impacts

7.6 Summary overview of heritage impacts

A summary of impacts to individual tunnels within the Great Zig Zag Railway deviation tunnels is provided in Table 9.

Table 9: Summary of impacts to the Great Zig Zag Railway deviation tunnels (SHR# 01037)

Tunnel No.	Proposed work	Impact to fabric	Visual impact
1	Notching of tunnel lining	Moderate	Minor-moderate
	Alterations to rock bolts	Minor	Negligible
	Wall reconstruction	Moderate	Minor
	Modifications to tunnel, rail & trackside infrastructure	Minor	Negligible
	Site compound and hi-rail access pad	Neutral	Neutral
2	Notching of tunnel lining	Moderate	Minor
	Alterations to rock bolts	Minor	Negligible
	Wall reconstruction	Moderate	Minor
	Modifications to tunnel, rail & trackside infrastructure	Negligible	Negligible
	Site compound and hi-rail access pad	Neutral	Minor (temporary)
3	Notching of tunnel lining	Moderate	Minor
	Alterations to rock bolts	Minor	Negligible
	Wall reconstruction	Moderate	Minor
	Modifications to tunnel, rail & trackside infrastructure	Minor	Negligible
	Site compound and hi-rail access pad	Neutral	Neutral
4*	Notching of tunnel lining	Neutral	Neutral
	Alterations to rock bolts	Neutral	Neutral
	Wall reconstruction	Neutral	Neutral
	Modifications to tunnel, rail & trackside infrastructure	Negligible	Negligible
	Site compound and hi-rail access pad	Neutral	Neutral
	*notching not required		

Tunnel No.	Proposed work	Impact to fabric	Visual impact
5*	Notching of tunnel lining	Neutral	Neutral
	Alterations to rock bolts	Neutral	Neutral
	Wall reconstruction	Neutral	Neutral
	Modifications to tunnel, rail & trackside infrastructure	Negligible	Negligible
	Site compound and hi-rail access pad	Neutral	Neutral
	*notching not required		
6	Notching of tunnel lining	Moderate	Minor
	Alterations to rock bolts	Minor	Negligible
	Wall reconstruction	Moderate	Minor
	Modifications to tunnel, rail & trackside infrastructure	Negligible	Negligible
	Site compound and hi-rail access pad	Neutral	Neutral
7	Notching of tunnel lining	Moderate	Minor
	Alterations to rock bolts	Minor	Negligible
	Wall reconstruction	Moderate	Minor
	Modifications to tunnel, rail & trackside infrastructure	Negligible	Negligible
	Site compound and hi-rail access pad	Neutral	Neutral
8*	Notching of tunnel lining	Moderate	Minor-moderate
	Alterations to rock bolts	Minor	Negligible
	Wall reconstruction	Moderate	Minor
	Modifications to tunnel, rail & trackside infrastructure	Negligible	Negligible
	Site compound and hi-rail access pad	Neutral	Minor (temporary)
	* Infringement on Lithgow end of Tunnel 8 is less than 5mm, and is assumed to be build-up of moss or grit that could be removed from cleaning		

Tunnel No.	Proposed work	Impact to fabric	Visual impact
9	Notching of tunnel lining	Moderate	Minor
	Alterations to rock bolts	Minor	Negligible
	Wall reconstruction	Moderate	Minor
	Modifications to tunnel, rail & trackside infrastructure	Minor	Negligible
	Site compound and hi-rail access pad	Neutral	Minor (temporary)
10	Notching of tunnel lining	Moderate	Minor-moderate
	Alterations to rock bolts	Minor	Negligible
	Wall reconstruction	Moderate	Minor
	Modifications to tunnel, rail & trackside infrastructure	Minor	Negligible
	Site compound and hi-rail access pad	Neutral	Neutral
Overhead wiring structures	Notching of tunnel lining	Neutral	Minor (temporary) Neutral (overall)
Former light fittings	Notching of tunnel lining	Neutral	Neutral
Gradient/ radius/ survey markers	Notching of tunnel lining	Minor – potential	Minor – potential
Great Zig Zag Railway deviation tunnels Overall Impact		**Moderate**	**Minor**

8.0 STATEMENT OF HERITAGE IMPACT

A statement of heritage impact for the Great Zig Zag Railway deviation tunnels is provided in Table 10.

Table 10: Statement of heritage impact for the Great Zig Zag Railway deviation tunnels (SHR# 01037)

Development	Discussion
What aspects of the Project respect or enhance the heritage significance of the study area?	The Project would result in improving and modernising the rail infrastructure of the wider NSW rail network. The ongoing use of the Great Zig Zag Railway deviation tunnels with the development of the rail network over time is consistent with the site's history as a major transportation route since its construction more than one century ago. The improvement of the rail service to the Great Zig Zag Railway deviation tunnels is consistent with its heritage significance, and would allow for the continuation of its historic use. The Project has been sensitively designed and developed to minimise as far as possible impacts to the fabric and setting of the Great Zig Zag Railway deviation tunnels. Development of a new sub-medium standard that takes into account the inherent stability of the concrete base track slab has resulted in reduced tunnel infringements, particularly in haunch areas i.e. the upper portions of the tunnel walls. The methodology of the Project development, which utilised high definition static laser scans of each tunnel to create a more accurate representation of the tunnel wall lining, has resulted in minimisation of treatment depth and length and dramatically reduced the scope of required works. As such, the Project would assist in maintaining the significant fabric of the Great Zig Zag Railway deviation tunnels and allow for its ongoing use. It is noted the Project, by involving changes to the kinematic envelope, would not require any work to Tunnel 4 and Tunnel 5, the exceptional fabric and setting of which remain largely intact. Large sections of lining in most tunnels have previously been altered by way of intrusive and roughly executed notching that was carried out in the 1970s. The Project may potentially provide an opportunity to improve the appearance and finishing of notching in these parts of the tunnels.
What aspects of the Project could have a detrimental impact on the heritage significance of the study area?	The Project would involve works that would have a detrimental impact on the significance of the Great Zig Zag Railway deviation tunnels. This primarily relates to the proposed notching of original brick masonry and concrete tunnel lining. Removal of tunnel lining, by way of rail mounted excavators with road header attachments, would result in the removal of significant original fabric that is representative of 19th and early-20th century rail engineering practices and methodologies of tunnel construction at the time. The aesthetic values of the Great Zig Zag Railway deviation tunnels are largely associated with the masonry portal entrances and external sandstone cuttings. While potential visual impacts of the Project would be essentially minimised given the works would be largely carried out in low light areas that are not clearly visible to pedestrian or train commuters, the proposed works to the portal entrances would result in a minor visual impact on tunnels with existing portal notching, and a minor-moderate visual impact on tunnels without existing portal notching. Potential visual impact associated with notching of the lower and upper sections of tunnel lining near several portal entrances would affect Tunnel 1, Tunnel 2, Tunnel 3, Tunnel 6, Tunnel 7,

Development	Discussion
	Tunnel 8 and Tunnel 10. While the proposed notching near portal entrances would be relatively inconspicuous for train commuters and train drivers approaching the tunnels at high speed, the modifications would be visible for pedestrians on bush trails and for site workers. It is noted, however, that the proposed removal of fabric is relatively small in relation to the overall height and configuration of the tunnel portals. It is noted that the lining of the tunnel toe sections in most tunnels has already been significantly impacted by notching that was undertaken in the 1970s, which removed portions of lining at the bottom parts of the tunnels and installation of supporting rock bolts along the length of the tunnels. The Project may potentially provide an opportunity to improve the appearance and finishing of notching in these parts of the tunnels.
Have more sympathetic options been considered and discounted?	Development of the Project considered several options, including do nothing, single line running and dual line running options. The issues associated with these options and reasons for being discounted are described below. The 'do-nothing' option would not involve any work to the tunnel lining, tracks and electrical along the Great Zig Zag Railway deviation tunnels. This option, while respecting the significant fabric of the Great Zig Zag Railway deviation tunnels, would not meet compliance and prevent the New Intercity Fleet from operating on the line. This would be inconsistent with NSW Government objectives of enhancing rail passenger services for long distance rural travel, would not improve public transport from Sydney to the Blue Mountains and would not meet the needs of the local community. This option was therefore discounted. The dual line running option initially proposed notching the tunnel walls, repositioning of track and a rebuild of the track slab to achieve necessary clearances for the New Intercity Fleet to allow trains to travel on both lines and pass each other. This option would require major impacts to the heritage values of the tunnels as well as adverse impacts to freight and passenger services during construction. The option did not meet the project objectives and was therefore discounted. The single line running option would involve notching of the tunnel walls on one side only to allow New Intercity Fleet trains to travel bi-directionally on the same line. While this option would result in less impact to heritage fabric than a dual line running option and involve fewer construction costs, this option would prevent trains from passing in the tunnel. The long-term timetabling impact of this option on timetabling for passenger and freight services resulted in it being discounted. The proposed option was found to meet the project objectives while also resulting in lowered heritage impacts by way of a reduced kinematic envelope and subsequent reduction in notching impacts. This option was selected as the preferred option on this basis and represents a more balanced outcome.

9.0 CONCLUSIONS AND RECOMMENDATIONS

9.1 Conclusion

The Project would result in a moderate physical impact and a minor visual impact to the State heritage listed Great Zig Zag Railway deviation tunnels (SHR# 01037). The Project would result in a neutral physical impact and a negligible visual impact to the State heritage listed Great Zig Zag Railway and Reserves (SHR# 00542). The recommendations set out below will aid in mitigating the impact of the Project on the Great Zig Zag Railway deviation tunnels and nearby heritage items.

9.2 Recommendations & mitigation measures

Table 11: Overview of recommendations and mitigation measures.

Development	Discussion
Approvals	A Section 60 permit under the NSW *Heritage Act 1977* would be required prior to works occurring within the Great Zig Zag Railway deviation tunnels SHR curtilage. The permit would cover the works described in Section 7.1 of this report. This assessment would be provided to the NSW Heritage Council in support of a Section 60 application. As the Project has been assessed as potentially resulting in a moderate physical impact to the LEP listed Great Zig Zag Railway and deviation tunnels item, TfNSW should consult with Lithgow City Council to provide information on the Project.
Archival resources	Prior to commencement of the Project, a Photographic Archival Recording (PAR) should be prepared, recording areas to be affected by the Project. The PAR should include photographs of the portal entrances, and existing cable route and trough within Tunnel 3 prior to commencement of works, and include a record of views that would be modified by the Project. The recording would be undertaken in accordance with the guidelines for *Photographic Recording of Heritage Items Using Film or Digital Capture* prepared by the NSW Office of Environment & Heritage. The PAR would be submitted to Lithgow City Council, and copies retained as per the standards. A 3D model prepared for the Great Zig Zag Railway deviation tunnels using detailed scanning technology should be made available as an archival resource for the heritage item once the format of the file is appropriate for access. Consideration should be given to making this resource available on relevant online catalogues and databases including the Lithgow Library, Blue Mountains Library, State Library New South Wales and the National Library of Australia. Prior to commencement of works, consideration should be given to exploring options of conducting a video recording of the Great Zig Zag Railway deviation tunnels. This should be from the point of view of the driver, and could be achieved by mounting a camera to the front of a train or work vehicle.
Geotechnical investigations	Geotechnical investigation of tunnel fabric may be required during detailed design. The scope of these investigations may be consistent with the scope of geotechnical investigations conducted in 2017 during preparation of the concept design. That investigation included concrete and brick coring, brick

Development	Discussion
	and mortar sampling, and brickwork stress testing. Geotechnical investigations must only take place in areas where notching is proposed, and adhere to the following principles: • Structural investigation work which involves the removal or damaging of tunnel fabric should ensure it is located in the interior areas of the tunnel, away from the openly visible tunnel portals and brick arches, to reduce the potential for visual heritage impacts • The removal of bricks for brick and mortar sampling should involve the replacement of similar bricks to infill voids in the brick lining, where the removal of significant fabric will be visible following completion of notching works • Following the removal of concrete and brick cores, the exposed holes should be refilled with non-shrink grout A Heritage Consultant should be consulted once details of the scope of geotechnical investigations are known in order to ensure consistency with these recommendations.
Selection of sympathetic materials and finishes	The selection of new materials and finishes used for the proposed reconstruction of sections of tunnel lining within the Great Zig Zag Railway deviation tunnels should be as sympathetic as possible to the existing character, with the aim of minimising visual impacts. Where new concrete is used for minor repairs, this should be selected to closely match the colour and texture of the existing concrete lining, so as to avoid potential visual impact in small localised areas of new work. Where new concrete is required for major repairs and involves new work across larger areas, i.e. more than one metre, the colour and texture of new concrete should be visually recessive and complement the existing concrete lining, while being identifiably new in order to distinguish itself from the original design and fabric of the tunnels. Consideration should be given to the type of material used to infill any holes left by the removal of the existing GST on the down track of Tunnel 3. Materials used to support or grout affected concrete would be sympathetic to existing grouting on the tunnel walls. Adequate allowance should be made for any variance in the physical properties of new surfacing fabric in terms of thermal expansion and contraction, to avoid cracking and physical impacts on underlying heritage significant fabric.
Appropriate cleaning methodology	In areas where infringement is minimal and requires cleaning as opposed to notching, hand cleaning should be carried out wherever safe and practicable to do so. Blasting with a high-pressure hose should be avoided where possible to avoid inadvertent impact or damage to mortar and bricks within the tunnel.
Protection of overhead wiring structures	For the duration of the proposed work, protective measures and machine spotting would be utilised to avoid inadvertent impact or damage to overhead

Development	Discussion
	wiring structures within the Great Zig Zag Railway deviation tunnels. In the event that inadvertent impact to overhead wiring structures occurs during the proposed work, efforts should be made to source replacement parts rather than replacing the overhead wiring structure. Where replacement is the only option, efforts should be made to ensure that the replacement part does not involve any removal of significant brick fabric.
Gradient/ radius/ survey markers	Where it is identified that any gradient/ radius/ survey markers are located within proposed notching areas, those markers should be included in the PAR. Photographic recording should take place prior to commencement of works. The location of the recorded markers should be recorded by a surveyor and included in the PAR.
Treatment of modified rock bolts	Where a portion of rock bolt is removed prior to commencement of proposed notching works, advice from a specialist (structural engineer and/ or contamination specialist) would be required to ensure the remaining section of rock bolt does not corrode and expand, which would potentially damage and undermine the integrity of original significant fabric.
Vegetation management and maintenance	Some vegetation on sandstone cuttings adjacent to tunnel portals would be trimmed during the New Intercity Fleet works. This work would not involve any works that would impact the cutting face. A Heritage Consultant should be consulted where works would include removal of vegetation and potential impacts to the sandstone cutting face.
Culverts and drainage	The construction contractor would be required to assess culverts and drainage prior to placement of temporary hi-rail access points, and ensure that these will not be impacted by the Project. For the duration of the project, drainage infrastructure within the Great Zig Zag Railway deviation tunnels curtilage would be protected to avoid inadvertent damage and prevent blockage by way of debris/spoil. It is noted the Project would be carried out within and adjacent to the ongoing Sydney Trains project for the repair and replacement of culverts at 147.165km and 148.707km.
Vibration monitoring	During the proposed construction work, careful ongoing monitoring would be required for potential risk of vibration to the tunnel structures. This is particularly associated with notching of tunnel lining, which could potentially loosen bricks or impact the concrete lining. The proposed works would be undertaken in accordance with the safe work distances outlined in the Noise and Vibration Assessment prepared for the Project, and attended vibration monitoring or vibration trials would be undertaken prior to tunnel notching. To minimise potential vibration impacts during works to significant fabric, regular inspections of the construction activities and work areas wold be undertaken by structural engineers to monitor and review the construction methodology and confirm the integrity of the tunnel lining. Where it is identified that levels of vibration are causing damage to the tunnel lining, works would stop and the construction methodology reviewed for its appropriateness in consultation with a Heritage Consultant.

Development	Discussion
Removed fabric	Detailed design should consider the appropriateness and potential locations for keeping all removed original fabric within the SHR curtilage of the Great Zig Zag Railway deviation tunnels. It is assumed that the removed fabric will be highly fragmented ceramic building material. Sydney Trains heritage advisors should be consulted during this process with regards to potential long-term locations within the curtilage for removed fabric.
Sealant	To maintain the visual appearance of the original brick and concrete fabric, no sealant has been recommended for application to notched areas. Where it is determined through detailed design that sealant will be required on some or all notched surfaces, further advice from a Heritage Consultant would be required on the appearance and type of sealant used.
New signage	Detailed design should consider placing new signage proposed for the Lithgow end of Tunnel 10 adjacent to the up track and not attached to the brick portal.
Ongoing heritage specialist advice	A Heritage Consultant should provide ongoing heritage advice during the detailed design and construction phases of the Project, and should ensure that the above material and design options advice is enacted. A heritage induction should be provided to all on-site staff and contractors involved in the project. The induction should clearly describe the heritage constraints of the site.
Unexpected finds procedure	During proposed ground disturbing and construction works, the Transport for NSW *Unexpected Finds Procedure* would be adhered to.
SHR curtilage	The Great Zig Zag Railway deviation tunnels SHR curtilage as gazetted is incorrect and does not match the description of the item. Heritage Division should be advised of the discrepancy, in order to commence the process of gazetting the correct curtilage.

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11.0 APPENDIX A

11.1 Photos

Photographs taken during site inspection of the Great Zig Zag deviation tunnels are provided below in Table 12 to Table 21.

Table 12: Photos of Tunnel 1

Tunnel 1		
		
Figure 34: Sydney end portal, Tunnel 1	**Figure 35: Lithgow end portal, Tunnel 1**	**Figure 36: Detail of existing notching, up track Lithgow End**
		
Figure 37: Former light fitting in poor condition	**Figure 38: Detail of water seepage through brick vault**	**Figure 39: Tunnel Engineers documenting condition of original concrete fabric**

Tunnel 1

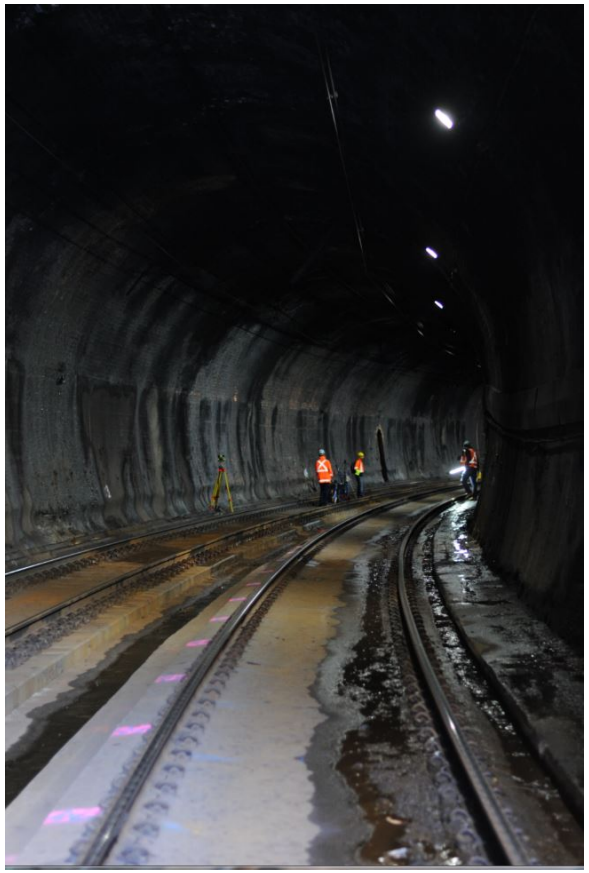

Figure 40: Tunnel 1, showing existing toe notching on the up track tunnel lining

Figure 41: Brick lined ‘recess’ in tunnel wall

Figure 42: Locations on brick vault where bricks have either fallen out, or been taken out

Table 13: Photos of Tunnel 2

Tunnel 2		
		
Figure 43: Sydney end portal, Tunnel 2	**Figure 44: Lithgow end portal, Tunnel 2**	**Figure 45: Internal view of Tunnel 2 showing existing toe notching on down track**
		
Figure 46: Detail photo of GST and existing notching, down track Sydney end portal	**Figure 47: Detail photo of existing notching, down track Sydney end portal**	**Figure 48: Existing toe notching on down track showing internal 'recess' in tunnel wall**

Tunnel 2

Figure 49: Lithgow end portal of Tunnel 2

Figure 50: Recess – later addition

Figure 51: Sydney end portal of Tunnel 2

Table 14: Photos of Tunnel 3

Tunnel 3		
		
Figure 52: Sydney end portal, Tunnel 3	**Figure 53: Lithgow end portal, Tunnel 3**	**Figure 54: Detail photo of GST and existing notching, down track Sydney end portal**
		
Figure 55: Internal shot of Tunnel 3 showing existing toe notching	**Figure 56: Recess – later addition**	**Figure 57: up track tunnel lining, Tunnel 3**

Tunnel 3

Figure 58: GST attached to sandstone cutting, down track, adjacent to Sydney end portal

Figure 59: View of portal entrance to Tunnel 3 and sandstone cliff overhead

Table 15: Photos of Tunnel 4

Tunnel 4		
		
Figure 60: Sydney end portal, Tunnel 4	**Figure 61: Lithgow end portal, Tunnel 4**	**Figure 62: View of Tunnel 4 interior showing tunnel lining**
		
Figure 63: Brick arched and lined ‘recess’ in tunnel wall	**Figure 64: Detail shot of brick vault within Tunnel 4**	**Figure 65: Internal view within Tunnel 4, looking down track to Tunnel 5 and Tunnel 6**

Tunnel 4

Figure 66: Sydney end portal, Tunnel 4

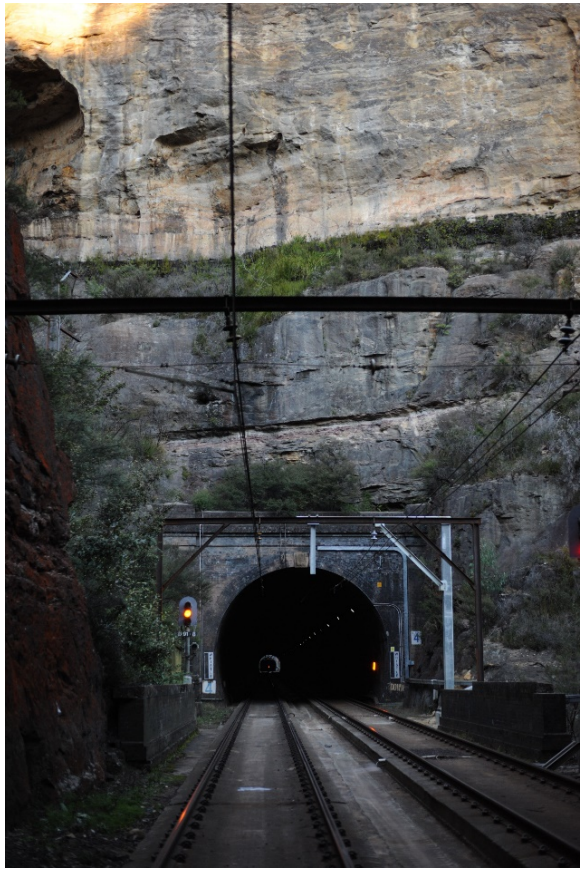

Figure 67: Lithgow end portal, Tunnel 4

Figure 68: Brick lined ‘recess’ in tunnel lining

Table 16: Photos of Tunnel 5

Tunnel 5		
		
Figure 69: Sydney end portal, Tunnel 5	**Figure 70: Lithgow end portal, Tunnel 5**	**Figure 71: Detail of brick lining, up track**
		
Figure 72: View from Lithgow end portal looking towards Sydney end portal of Tunnel 6	**Figure 73: Brick lined ‘recess’ in tunnel lining**	**Figure 74: View from Sydney end portal of Tunnel 5 towards of Tunnel 4**

Tunnel 5

Figure 75: Detail shot showing communication cabling and GST on Sydney end portal, down track

Figure 76: Sydney end portal, Tunnel 5

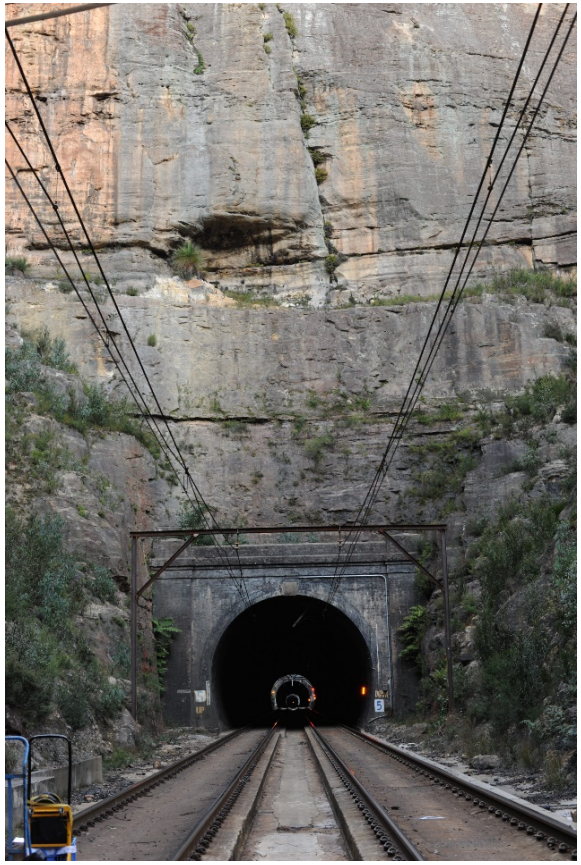

Figure 77: Lithgow end portal, Tunnel 5

Table 17: Photos of Tunnel 6

Tunnel 6		
		
Figure 78: Sydney end portal, Tunnel 6	**Figure 79: Lithgow end portal, Tunnel 6**	**Figure 80: Detail of existing toe notching and rock bolts, down track, Lithgow end portal**
		
Figure 81: Detail of existing toe notching and rock bolts, showing original concrete (left) and brick (right) fabric	**Figure 82: Internal view of Tunnel 6 towards Tunnel 7**	**Figure 83: View from Lithgow end portal of Tunnel 6 towards Sydney end portal of Tunnel 7**

Tunnel 6

Figure 84: ‘Recess’ in tunnel lining

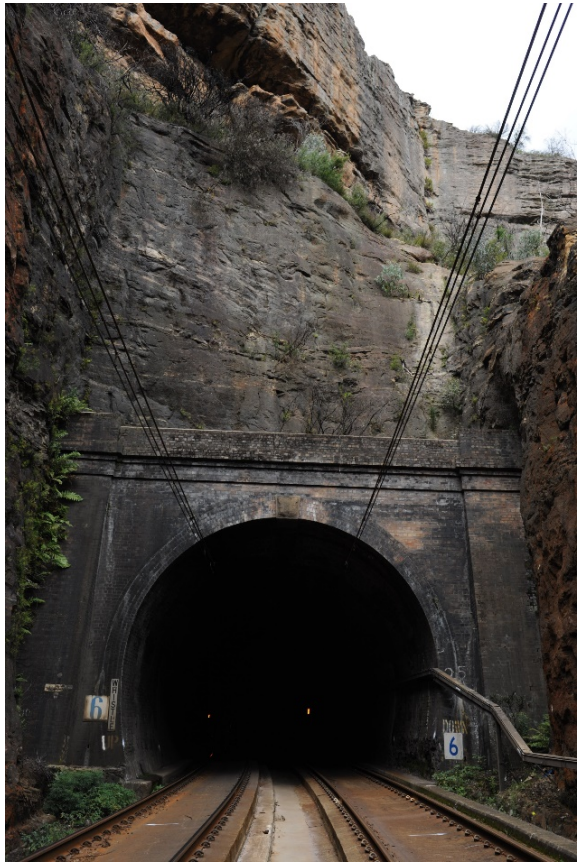

Figure 85: Lithgow end portal, Tunnel 6

Table 18: Photos of Tunnel 7

Tunnel 7		
		
Figure 86: Lithgow end portal, Tunnel 7	**Figure 87: Sydney end portal, Tunnel 7**	**Figure 88: Detail photo of GST and existing notching, down track Sydney end portal**
		
Figure 89: Internal view of Tunnel 7 showing existing toe notching and lighting, down track	**Figure 90: Detail of existing toe notching and gradient/ radius/ survey markers within Tunnel 7**	**Figure 91: Internal view of Tunnel 7, overhead wiring structures seen at top of image**

Tunnel 7

Figure 92: Lithgow end portal, Tunnel 7

Figure 93: Detail shot of original drainage features near Sydney end portal of Tunnel 7

Figure 94: ‘Recess’ in tunnel lining

Table 19: Photos of Tunnel 8

Tunnel 8		
		
Figure 95: Sydney end portal, Tunnel 8	**Figure 96: Lithgow end portal, Tunnel 8**	**Figure 97: Internal view within Tunnel 8 towards Sydney end portal of Tunnel 9**
		
Figure 98: Detail shot of toe section of Tunnel 8 showing absence of notching, down track	**Figure 99: Detail shot of toe section of Tunnel 8 showing existing notching, down track**	**Figure 100: Detail of overhead wiring structures at Tunnel 8**

Tunnel 8

Figure 101: Brick lined ‘recess’ in tunnel lining

Figure 102: Brick lined ‘recess’ in tunnel lining

Figure 103: Detail shot of brick lined toe section of Tunnel 8, down track

Table 20: Photos of Tunnel 9

Tunnel 9		
		
Figure 104: Sydney end portal, Tunnel 9	**Figure 105: Lithgow end portal, Tunnel 9 showing adjacent compound area**	**Figure 106: Detail of rock bolts and toe notching, Sydney end portal, down track**
		
Figure 107: Detail shot of existing toe notching and rock bolts, Lithgow end portal, down track	**Figure 108: up track tunnel lining showing existing notching and rock bolts**	**Figure 109: View out from Tunnel 9 towards country end portal and compound area beyond**

Tunnel 9

Figure 110: Sydney end portal, Tunnel 9

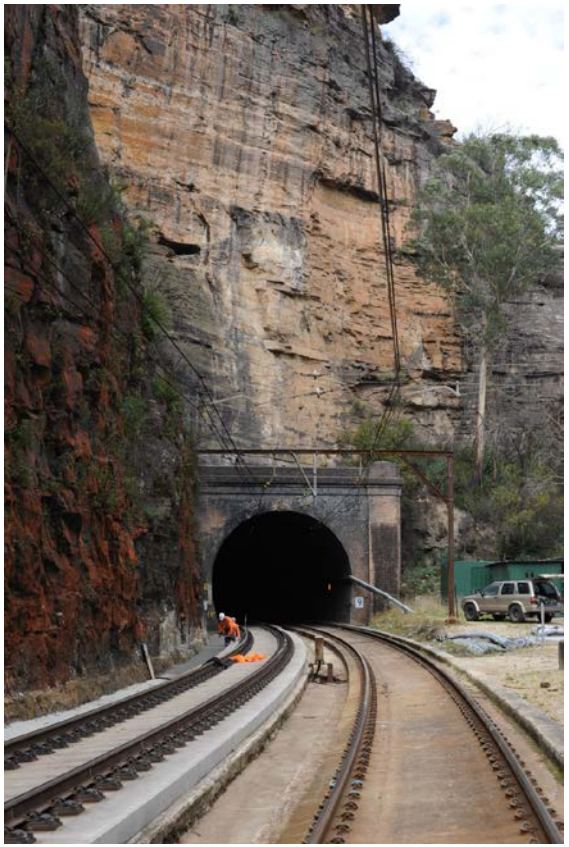

Figure 111: Lithgow end portal, Tunnel 9

Figure 112: Lithgow end portal, down track, showing removal of up to three courses of brick during previous notching of tunnel lining

Table 21: Photos of Tunnel 10

Tunnel 10		
		
Figure 113: Sydney end portal, Tunnel 10	Figure 114: Lithgow end portal, Tunnel 10	Figure 115: Internal view within Tunnel 10 showing rock bolts and existing notching
		
Figure 116: Internal view within Tunnel 10 showing existing lighting	Figure 117: Detail shot of Tunnel 10 Lithgow end up track portal entrance showing engraving in brickwork	Figure 118: Detail shot of Tunnel 10 Lithgow end down track portal entrance showing gradient/ radius/ survey marker

Tunnel 10

Figure 119: Detail shot showing graffiti and existing rock bolts within Tunnel 10

Figure 120: Brick lined ‘recess’ in tunnel lining, showing existing notching

Figure 121: Brick lined ‘recess’ in tunnel lining

12.0 APPENDIX B

12.1 Design plans and works information for New Intercity Fleet Enabling works at the Great Zig Zag Railway deviation tunnels

12.1.1 Overview of infringements

The following table summarises the proposed haunch and toe treatment works within the ten tunnels.

Table 22: Summary of treatment works (GHD Great Zig Zag Railway deviation tunnels Heritage Design Summary 2018)

Tunnel	Tunnel Length (m)	Up/Down	Treatment Type	Treatment Length (m)
1	551	Down	H0	10
		Up	H0	27
			T1	22
			T2	63
			T3	52
2	107	Down	T3	73
3	176	Down	T3	73
6	183	Down	T3	150
7	224	Down	T3	42
		Up	T1	11
			T3	72
			T4	20
8	171	Up	T1	5
			T2	50
			T3	60
			T4	18
9	79	Down	T3	30
10	790	Up	H1	40
			T2	39
			T3	79
			T4	80

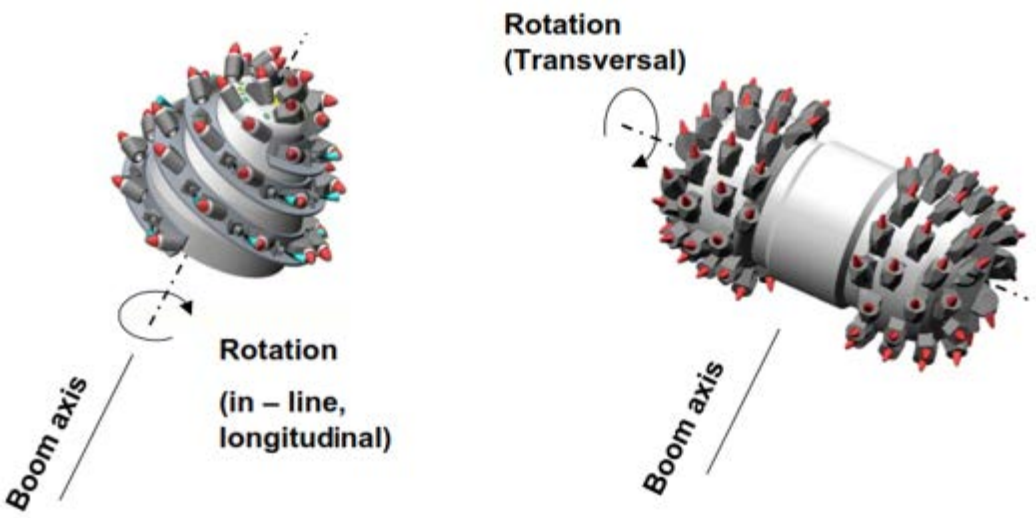

Figure 122: Example of longitudinal and transversal cutter heads

Figure 123: Example of excavator machinery with cutter head attachment

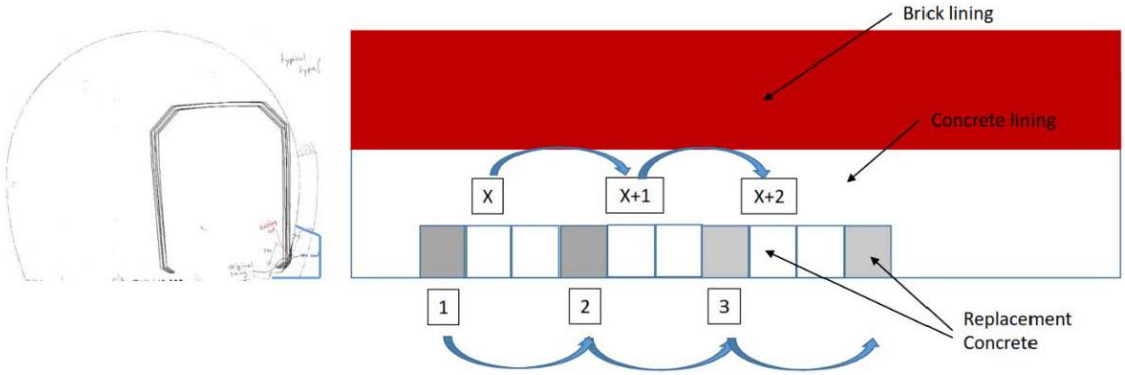

Figure 124: Example construction sequence for concrete wall reconstruction, where required

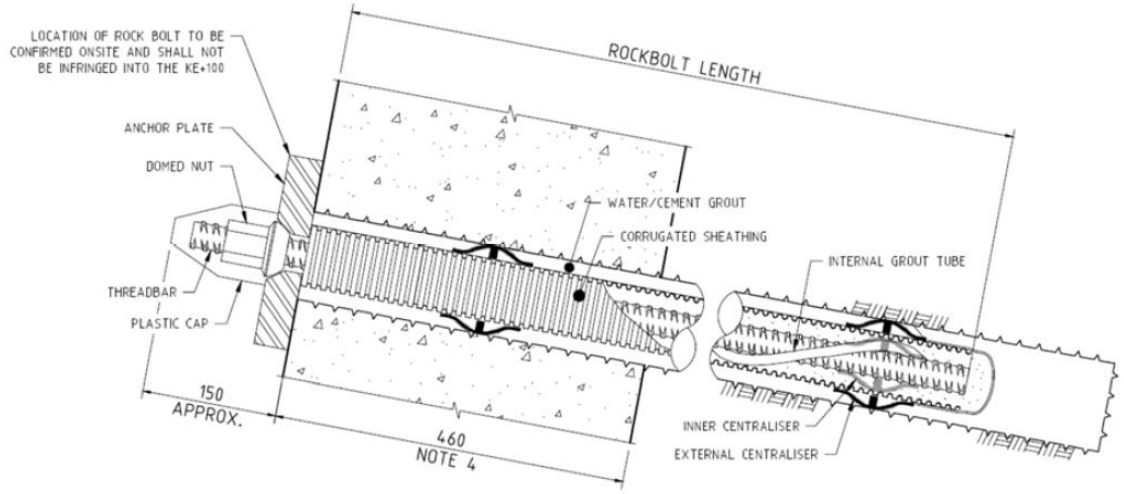

Figure 125: Example rock bolt cross-section

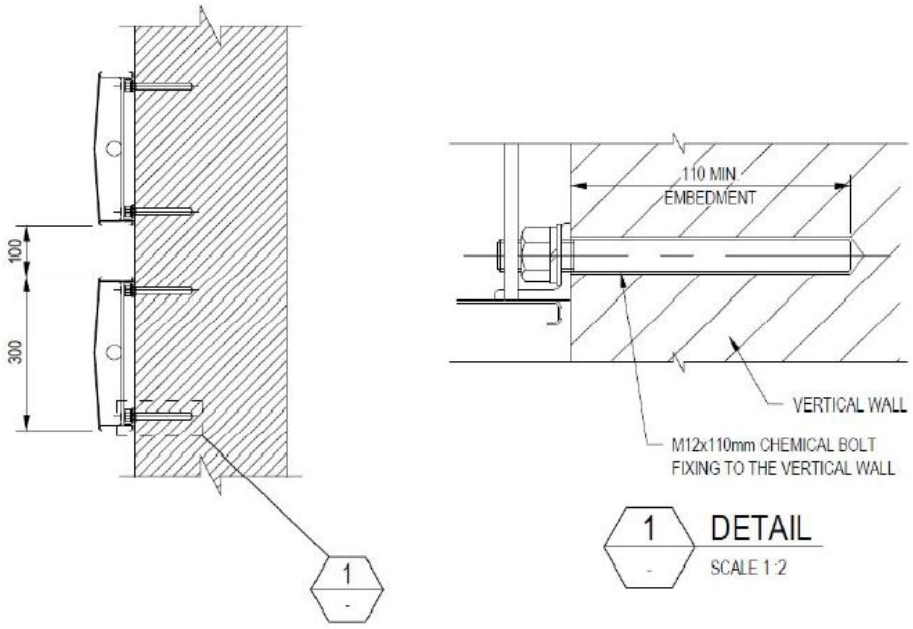

Figure 126: Cable ladder and chemical anchor general arrangement to replace GST in Tunnel 3

Figure 127: Example of Tiger Tail protection installed on a transmission line

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