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Mandalong Transmission Line 24 Relocation Project

EMF Assessment

Centennial Mandalong

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Contents

Figures

Tables

Executive Summary

Centennial Mandalong is seeking to modify its existing development consent for the Mandalong Transmission Line 24 Relocation Project. To achieve optimum coal extraction and limit subsidence effects on surface infrastructure, Mandalong Mine proposes to arrange for the relocation of a 2.4 kilometre section of TransGrid's 330kV Transmission Line (TL) 24, which currently represents a significant constraint to the mine layout as approved under the Mandalong Southern Extension Project (SSD-5144). As part of this project, it is proposed to remove 12 existing steel lattice towers and establish eight new tension and suspension steel lattice towers.

Centennial Mandalong is conducting an Environmental Assessment for the TL24 Relocation Project and in this context, Aurecon has been engaged by Centennial Mandalong to assess the electric and magnetic fields (EMF) associated with the proposal. In summary, Aurecon's findings are:

Magnetic Fields

- The highest magnetic field contribution directly below the proposed relocated Line 24 is predicted to be 124mG under 85th percentile loads upon commissioning and 168mG under ultimate 85th percentile loads. Both occur at the low point of the span which has the greatest conductor sag, between Towers 32 and 33X. The higher of these is equivalent to 8.4% of the ICNIRP general public exposure reference level. At the edge of the easement, the predicted field contribution is approximately 26mG and 35mG under 85th percentile commissioning and ultimate loads respectively. The higher of these is equivalent to 1.8% of the ICNIRP general public exposure reference level.
- The typical magnetic field contribution at 1m above ground level is lower overall for the new section of Line 24 than for the existing, primarily due to the fact that it has been designed with greater conductor clearance to ground level. At the crossing of Line 25/26, the new line will now cross over the top of it instead of under it.
- Even under peak or emergency load conditions, the magnetic fields are still predicted to remain well within the relevant guideline reference level.

Electric Fields

- The highest electric field contribution directly below the proposed Line 24 deviation is predicted to be 4.5kV/m, occurring at the low point of the span which has the greatest conductor sag, between Towers 32 and 33X. This is equivalent to 90% of the ICNIRP general public exposure reference level. At the edge of the easement, the predicted field contribution is approximately 1kV/m, or 20% of the ICNIRP general public exposure reference level.
- The typical electric field contribution at 1m above ground level is lower overall for the new section of Line 24 than for the existing as it has been designed with greater conductor clearance to ground level. This is particularly evident at the crossing of Line 25/26, where the new line will now cross over the top of it instead of under it.
- Even if the line were to be operated at a voltage 10% greater than the nominal voltage, the electric field contribution of the proposed line deviation is still predicted to remain well within the relevant guideline reference level.

Prudent Avoidance Measures

- Consistent with the notion of prudent avoidance, Centennial Mandalong and/or TransGrid have:
  - Sited the electrical infrastructure within the mine property, well away from residences, such that the EMF contribution at residential properties is expected to be negligible.

  - Designed the line such that the clearance of the conductors above ground level is greater than that of the existing line, thereby reducing the EMF contribution at the relevant height of 1m above ground level.
- While it cannot be said with certainty that these measures are beneficial, they are certainly consistent with the notion of prudent avoidance.

1 Introduction

1.1 Site and Project Description

Centennial Mandalong is seeking to modify its existing development consent for the Mandalong Transmission Line 24 Relocation Project. To achieve optimum coal extraction and limit subsidence effects on surface infrastructure, Mandalong Mine proposes to arrange for the relocation of a 2.4 kilometre section of TransGrid's 330kV Transmission Line (TL) 24. As part of this project, it is proposed to remove 12 existing steel lattice towers and establish eight new tension and suspension steel lattice towers.

TransGrid's 330kV electricity transmission line in EL6317 represents a significant constraint to the mine layout, approved under the Mandalong Southern Extension Project (SSD-5144). Suspension towers, which are those where the line passes through without changing direction, can withstand a certain amount of tilt and strain and can be protected from subsidence to a certain extent. Tension towers, where the line is fixed to the towers, are installed where there is a change of direction or a clearance issue and these towers have very low tolerance to tilt and strain due to the line being tightened or slackened and instability of the structure due to the change in line angle. Impact to TransGrid's infrastructure has been minimised by the mine layout, however it was not possible to avoid the lines altogether. As such, a feasibility study has been undertaken by TransGrid which has determined that the best option is to relocate a section of Line 24 to avoid undermining of the tension towers.

Approximately 8.5 hectares of vegetation clearing is required for the new section of TL24 which includes a 60 metre wide easement entirely on freehold land owned by Centennial Fassifern Pty. Ltd. Following the establishment of the eight new towers and relocation of the transmission line, the redundant 12 towers will be decommissioned, dismantled and removed in consultation with key stakeholders. The location of the existing and proposed TL24 is illustrated on Figure 1. Upon completion of the line, the easement for the redundant section of TL24 will be relinquished and a new easement will be created over the new section of TL24.

The Project is summarised into the following key stages:

- Establishment of access tracks and clearing of required 60m wide easement;
- Construction of proposed tower foundations and establishment of towers for new section of TL24;
- Stringing and cutting in of lines on new section of TL24; and
- Removal and remediation of redundant TL24 structures

Upon completion of the Project, TransGrid will continue to operate and maintain the transmission line and easement.

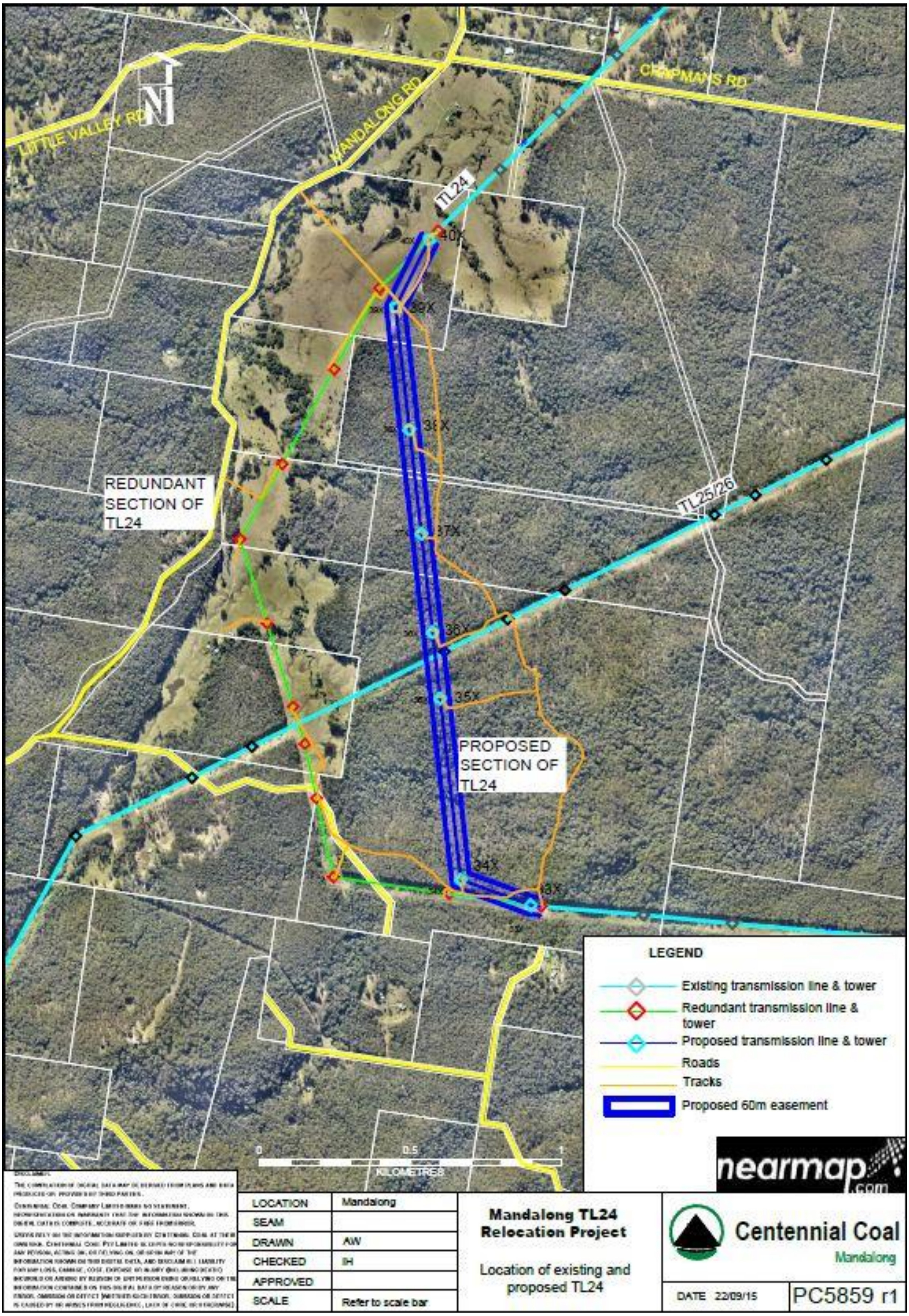

Figure 1 – Location of the Existing and Proposed TL24

1.2 Scope of Assignment

Centennial Mandalong is conducting an Environmental Assessment for the TL24 Relocation Project and in this context, Aurecon has been engaged by Centennial Mandalong to assess the electric and magnetic fields (EMF) associated with the proposal. Specific content of this assessment is to include:

- A brief description of the EMF health issue
- Reasonable predictions of the EMFs associated with the proposed relocated line at 1m above ground level, under 85th percentile and time-weighted-average (TWA) loads, both upon commissioning and in the ultimate condition
- An assessment of compliance of the proposal against relevant national and international EMF guidelines
- An assessment of the proposal against precautionary and prudent avoidance principles as defined by the relevant guidelines
- Provide advice regarding further magnetic field mitigation, if appropriate

1.3 Structure of Report

Section 2 provides background information on the EMF and human health issue and Section 3 documents the relevant information supplied by Centennial Mandalong. Section 4 contains predictions of the EMF levels associated with the line, both in its existing scenario and the proposed new locations. Section 5 addresses the proposed design in the context of compliance with EMF guidelines and precautionary/prudent avoidance principles. Conclusions are presented in Section 6 and a list of reference documents is contained in Section 7.

1.4 List of Abbreviations/Acronyms

A	ampere
ACSR/GZ	Aluminium Conductor, Galvanised Steel Reinforced
ARPANSA	Australian Radiation Protection and Nuclear Safety Agency
ELF	Extremely Low Frequency
EMF	Electric and Magnetic Field
ENA	Energy Networks Association
IARC	International Agency for Research on Cancer
ICNIRP	International Commission on Non-Ionizing Radiation Protection
IEEE	Institute of Electrical and Electronics Engineers
km	kilometre
kV	kilovolt
kV/m	kilovolts per metre
m	metre
mG	milliGauss
MVA	mega-volt ampere
NHMRC	National Health and Medical Research Council
NIEHS	National Institute of Environmental and Health Sciences (US)

NRPB	National Radiological Protection Board (UK)
SC/AC	Aluminium-Clad Steel Conductor
SCA	Steel Cored Aluminium Conductor
SES	Safe Engineering Services & Technologies Ltd
TL	Transmission Line
WHO	World Health Organization

2 Overview of Electric and Magnetic Fields

2.1 General Description

The electric and magnetic fields associated with electrical equipment are essentially independent of one another. The electric field is associated with the voltage of the equipment and the magnetic field is associated with the current (amperage). In combination, these fields cause energy to be transferred along electric wires.

An **electric field** is a region where electric charges experience an invisible force. The strength of this force is related to the voltage, or pressure, which forces electricity along wires. Electric fields are strongest close to their source, and their strength diminishes rapidly with distance from the source, in much the same way as the warmth of a fire decreases with distance. Many common materials – such as brickwork or metal – block electric fields, so they are readily shielded and, for all practical purposes, do not penetrate buildings. They are also shielded by human skin, such that the electric field inside a human body will be at least 100,000 times less than the external field (Ref. 1).

Being related to voltage, the electric fields associated with transmission lines remain relatively constant over time, except where the operating voltage changes.

A **magnetic field** is a region where magnetic materials experience an invisible force produced by the flow of electricity (known as the electric current and measured in Amperes). As magnetic fields are related to the current rather than the voltage, high voltage equipment is not the only source of magnetic fields encountered in everyday life. Modern life involves frequent contact with magnetic fields from a variety of sources such as appliances in the home and workplace and electrical machinery.

The strength of a magnetic field depends on the size of the current (measured in amps), and decreases with distance from the source. While electric fields are blocked by many common materials, this is not the case with magnetic fields. This is why locating equipment in enclosures or underground will eliminate any external electric field but not the magnetic fields.

The magnetic field strength resulting from an electrical installation varies continually with time and is affected by a number of factors including:

- The total electric load
- The size and nature of the equipment
- The design of the equipment
- The layout and electrical configuration of the equipment and its interaction with other equipment

2.2 Overview of EMF and Human Health

The possibility of adverse health effects due to the EMFs associated with electrical equipment has been the subject of extensive research throughout the world. To date, adverse health effects have not been established, but the possibility that they may exist has not been ruled out.

While EMFs involve both electric and magnetic components, electric fields are relatively constant over time, are readily shielded and, in the health context, are generally no longer associated with the same level of interest as magnetic fields.

Research into EMFs and health is a complex area involving many scientific disciplines – from biology, physics and chemistry to medicine, biophysics and epidemiology. Many of the health issues of interest to researchers are quite rare. In this context, it is well accepted by scientists that no study considered in isolation will provide a meaningful answer to the question of whether or not EMFs can contribute to adverse health effects. In order to make an informed conclusion from all of the research, it is necessary to consider the science in its totality. Over the years, governments and regulatory agencies around the world have commissioned independent scientific review panels to provide such overall assessments.

The most recent scientific reviews by authoritative bodies are reassuring for most potential health issues. However, statistical associations[1] between prolonged exposure to elevated magnetic fields and childhood leukaemia have persisted. This led the International Agency for Research on Cancer (IARC) (Ref. 2) in 2001 to classify magnetic fields as a "possible carcinogen".[2]

The fact that, despite over 20 years' laboratory research, no mechanism for an effect has been established, lends weight to the possibility that the observed statistical associations reflect some factor other than a causal relationship. This point is made in the 2001 report of the UK National Radiological Protection Board's (NRPB) Advisory Group, chaired by eminent epidemiologist, the late Sir Richard Doll (Ref. 3)

> *"in the absence of clear evidence of a carcinogenic effect in adults, or of a plausible explanation from experiments on animals or isolated cells, the evidence is currently not strong enough to justify a firm conclusion that such fields cause leukaemia in children" (page 164)*

2.3 Health Guidelines/Standards

Until about 15 years ago, the relevant Australian health guideline was the document called 'Interim Guidelines on Exposure to 50/60 Hz Electric and Magnetic Fields' (1989) (Ref. 4), issued by the National Health and Medical Research Council (NHMRC) and based on international guidelines[3]. As the NHMRC has not updated its guidelines since their original issue, they have lapsed and the relevant Australian regulator (now ARPANSA) has been developing a new standard for many years[4]. In December, 2006, ARPANSA issued a Draft Standard on "Exposure Limits for Electric and Magnetic Fields (0Hz to 3kHz)" for public comment (Ref. 5). The Draft Standard proposed a magnetic field exposure limit (Reference Level) for the general public of 1000 milligauss (mG), which is numerically identical[5] to the previous (Australian) NHMRC Guidelines but only 50% of the current (2010) version of the international (ICNIRP) guidelines (Ref. 6), upon which they were based. It is

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[1] *It should be noted that that a statistical association does not necessarily reflect a cause and effect relationship.*

[2] *IARC publishes authoritative independent assessment by international experts of the carcinogenic risks posed to humans by a variety of agents, mixtures and exposures. These agents, mixtures and exposures are categorised into 5 groups, namely:*

- *Group 1 - the agent is carcinogenic to humans - 117 agents are included in the group, including asbestos, diesel engine exhaust, tobacco and ultraviolet radiation;*
- *Group 2A - the agent is probably carcinogenic - 74 agents have been included in this group, including creosotes, lead compounds and petroleum refining (occupational exposures);*
- *Group 2B - the agent is possibly carcinogenic to humans - 287 agents have been included in this group, including coffee, gasoline, lead, nickel, petrol engine exhaust and extremely low frequency magnetic fields;*
- *Group 3 - the agent is not classifiable as to carcinogenicity - 503 agents have been included in this group, including caffeine, coal dust and extremely low frequency electric fields;*
- *Group 4 - the agent is probably not carcinogenic to humans - only 1 agent (caprolactam) has been included in this group.*

[3] *The relevant international guidelines upon which the NHMRC Guidelines were based are those issued by the International Commission on Non-ionising radiation Protection (ICNIRP). These were first issued in 1988, have been regularly updated since, and were most recently re-issued in 2010. The World Health Organisation currently recognises two international standards, the ICNIRP Guidelines and the IEEE Standard for Safety Levels with Respect to Human Exposure to Electromagnetic Fields, 0–3kHz.*

[4] *Pending finalisation of the new Standard, ARPANSA currently advises that the 1989 NHMRC Guidelines remain suitable for use in Australia.*

[5] *In line with the international guidelines, this limit is now independent of duration of exposure. Previous relaxations for shorter term exposures no longer apply.*

understood that, as a result of submissions received in response to the 2006 Draft, the Australian Government Radiation Health Committee, at its meeting of 18th July, 2007 (Ref. 7), resolved, inter alia, to revise the magnetic field limit for the general public upwards to 3000mG. It is also understood that, more recently (9th November, 2011), following the release of the 2010 ICNIRP Guidelines, the Committee agreed that the Draft Australian Guidelines be reviewed to adopt as much of the ICNIRP 2010 Guidelines as possible (Ref. 8). ARPANSA is still in the process of developing their new Guideline and there is no indication that it will be finished soon.

In the absence of a current Australian standard, while noting the possible adoption of a 3000 mG limit in a future ARPANSA Standard, Aurecon have favoured the current international (ICNIRP) guideline level of 2000mG[6] for this assessment.

In applying the ICNIRP Guideline, it is important to recognise that the numerical limits, e.g. 2000mG, are based on established health effects. In ICNIRP's fact sheet on the guidelines (Ref. 9), it notes that:

> *"It is the view of ICNIRP that the currently existing scientific evidence that prolonged exposure to low frequency magnetic fields is causally related with an increased risk of childhood leukaemia is too weak to form the basis for exposure guidelines. Thus, the perception of surface electric charge, the direct stimulation of nerve and muscle tissue and the induction of retinal phosphenes are the only well established adverse effects and serve as the basis for guidance."*

The limits for both electric and magnetic fields contained in the various health guidelines are summarised in Table 1.

[6] *The corresponding occupational guideline level is 10000mG.*

Table 1 – Health Guideline Reference Levels

Parameter	NHMRC (1989)	ARPANSA 2006 Draft	ARPANSA 2007 Revised Draft	ICNIRP 2010	IEEE 2002 (Reaffirmed 2007)
Electric Fields – General Public	5kV/m	5kV/m	5kV/m	5kV/m	5kV/m[7]
Electric Fields – General Public: Controlled Circumstances (a) or Short Term (b)	10kV/m (b)	10kV/m (a)	10kV/m (a)	N/A	N/A
Electric Fields – Occupational	10kV/m	10kV/m	10kV/m	10kV/m	20kV/m
Electric Fields – Occupational Short Term	10-30kV/m	N/A	N/A	N/A	N/A
Magnetic Fields – General Public	1000mG	1000mG	3000mG	2000mG	9040mG
Magnetic Fields – General Public: Controlled Circumstances (a) or Short Term (b)	10000mG (b)	3000mG (a)	N/A	N/A	N/A
Magnetic Fields – Occupational	5000mG	5000mG	5000mG	10000mG	27100mG
Magnetic Fields – Occupational Short Term	Up to 50000mG	N/A	N/A	N/A	N/A

Being based on established biological effects (which occur at field levels much higher than those normally encountered in the vicinity of electrical equipment), the (numerical) exposure limits in the guidelines and standards cannot be said to define safe limits for possible health effects, should these exist, from fields at levels normally encountered in the vicinity of electrical equipment. Nevertheless, in the Foreword to the ARPANSA Draft Standard, the CEO of ARPANSA, Dr John Loy notes that

> *"the incorporation of arbitrary additional safety factors beyond the limits of the Standard is not supported".*

It is in this context that precautionary measures such as "Prudent Avoidance" have arisen.

2.4 Prudent Avoidance

With regard to the potential health effects from magnetic fields, while compliance with the relevant guideline is important in protecting people from established health effects, it does not necessarily address possible health effects, should they exist, from fields at levels normally encountered in the vicinity of electrical equipment. The possibility of such effects has been comprehensively studied over

[7] *Within power line easements, the guideline limit for the general public is 10kV/m under normal load conditions.*

several decades worldwide but, to this day, there is no clear understanding of whether or not electric or magnetic fields at low levels can pose a threat to human health.

Since the late 1980s, many reviews of the scientific literature have been published by authoritative bodies. There have also been a number of Inquiries such as those by Sir Harry Gibbs in NSW (Ref. 10) and Professor Hedley Peach in Victoria (Ref. 11). These reviews and inquiries have consistently found that:

- Adverse health effects have not been established
- The possibility cannot be ruled out
- If there is a risk, it is more likely to be associated with the magnetic field than the electric field

Both Sir Harry Gibbs and Professor Peach recommended a policy of prudence or prudent avoidance, which Sir Harry Gibbs described in the following terms:

> *"…. [doing] whatever can be done without undue inconvenience and at modest expense to avert the possible risk …"*

In 1999, the (US) National Institute of Environmental and Health Sciences (NIEHS) (Ref. 12) found:

> *"In summary, the NIEHS believes that there is weak evidence for possible health effects from ELF-EMF exposures, and until stronger evidence changes this opinion, inexpensive and safe reductions in exposure should be encouraged." (page 38)*

The practice of 'prudent avoidance' has been adopted by the (Australian) Energy Networks Association (ENA), of which TransGrid is a member.

In the Australian context, the (2006) Draft ARPANSA Standard addresses the matter of prudent avoidance in an Annex entitled "A Public Health Precautionary Approach to ELF Fields". The Annex states:

> *"[Prudent avoidance] does not imply setting exposure limits at an arbitrarily low level, and requiring that they be achieved regardless of cost, but rather adopting measures to reduce public exposure to ELF fields at modest cost."*

Section 5.7 of the Draft addresses "Protection of the General Public" and relevantly stipulates:

> *"Measures for the protection of the general public who may be exposed to ELF and/or static fields due to their proximity to high ELF and/or static sources must include the following: …… Minimising, as appropriate, ELF and/or static electric and magnetic field exposure, provided this can be readily achieved without undue inconvenience and at reasonable expense. Any such precautionary measures should follow good engineering and risk minimisation practice. ……………The incorporation of arbitrary additional prescriptive safety factors beyond the exposure limits of this Standard is not supported."*

Internationally, the World Health Organisation has also addressed the notion of prudence or precaution on several occasions, including in its 2007 publication Extremely low frequency fields. Environmental Health Criteria, Vol 238 (Ref. 1), which states:

> *"…..the use of precautionary approaches is warranted. However, it is not recommended that the limit values in exposure guidelines be reduced to some arbitrary level in the name of precaution. Such practice undermines the scientific foundation on which the limits are based and is likely to be an expensive and not necessarily effective way of providing protection."*

It also states:

"Provided that the health, social and economic benefits of electric power are not compromised, implementing very low-cost precautionary procedures to reduce exposure is reasonable and warranted."

Given the inconclusive nature of the science, it is considered that a prudent approach continues to be the most appropriate response in the circumstances. Under this approach, subject to modest cost and reasonable convenience, power utilities should design their facilities to reduce the intensity of the fields they generate, and locate them to minimise the fields that people, especially children, encounter over prolonged periods. While these measures are prudent, it cannot be said that they are essential or that they will result in any benefit.

3 Input Information and Aspects of Field Predictions

3.1 Information Provided by Centennial Mandalong

Centennial Mandalong has provided the following information on the proposed overhead line to serve as a basis for this assessment:

- Drawing showing the existing route of Line 24, and proposed route of the deviation
- Drawing showing the route of Lines 25/26
- Dimensioned drawings showing:
  - Existing single circuit tower configurations on Line 24 as shown in Figure 2 and Figure 3
  - Existing double circuit tower configurations on Line 25/26 as shown in Figure 4 and Figure 5
  - Proposed new single circuit tower configurations on Line 24 as shown in Figure 6, Figure 7 and Figure 8
- Advice that the conductor for the new section of Line 24 is to be twin Olive ACSR/GZ
- Advice that earthwires for the new section of Line 24 are 7/3.25 SC/AC and OPGW Type A
- Advice that the existing conductor for Line 24, and on Lines 25/26, is twin Moose 0.5 SCA
- Advice that the existing earthwires for Line 24 are 7/.144 SC/AC and OPGW Type A
- Advice that the earthwires on Lines 25/26 are 7/.162 SC/AC
- Advice that the maximum conductor design temperature of Lines 24 and 25/26 is 120ºC. Since the conductor is unlikely to reach (or even approach) this temperature under 85th percentile and TWA load conditions, Aurecon has been instructed to use a conductor temperature of 60ºC for this assessment
- The phasing arrangement of Line 24 as shown in Figure 9
- The phasing arrangement for the double circuit Lines 25/26 is 'low reactance phasing' as shown in Figure 10
- Existing loading information, including the 85th percentile and TWA loads for Lines 24, 25 and 26 as shown in Table 2
- Advice to use the existing loads as the loads upon commissioning on Line 24
- Advice that the ultimate maximum loading on Line 24 predicted for the year 2024/2025 is 833MVA, and to assume that the 85th percentile and TWA loads for Line 24, and the loads for Lines 25 and 26 are to increase by the same ratio. These are listed in Table 3

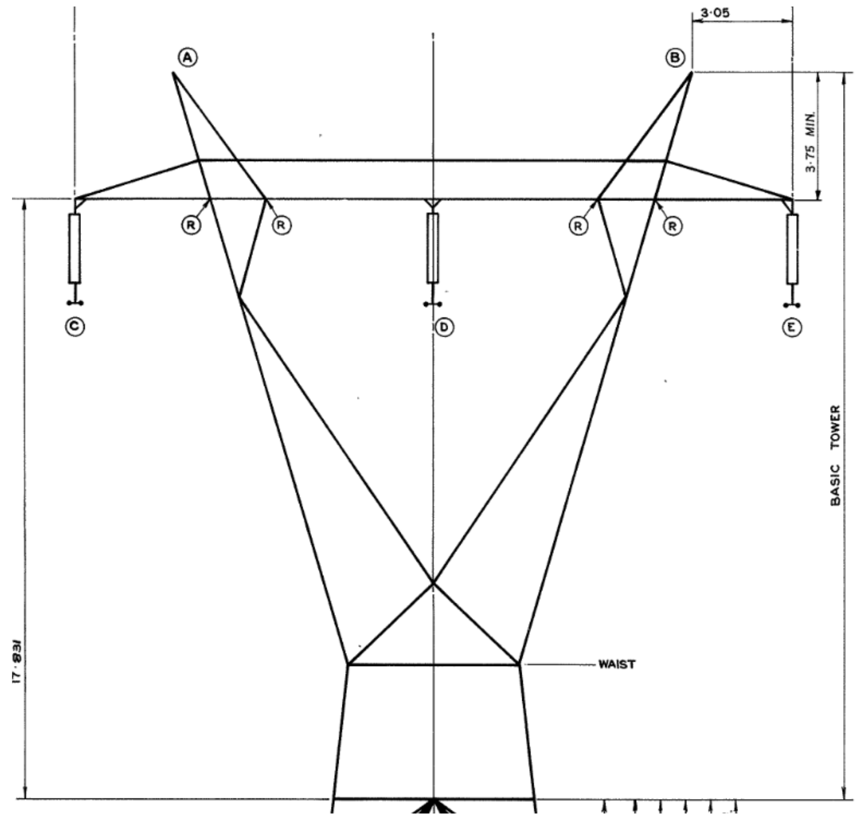

Figure 2 – Line 24 Existing 330kV Single Circuit Suspension Tower SP

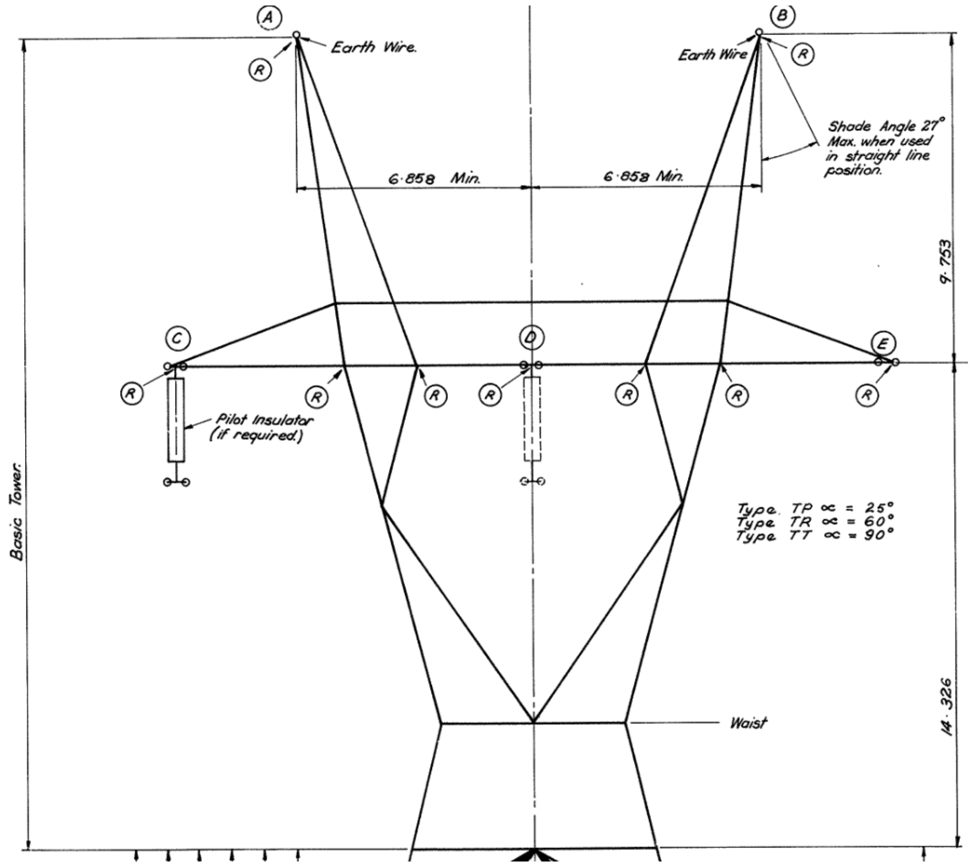

Figure 3 – Line 24 Existing 330kV Single Circuit Tension Tower TP TR TT

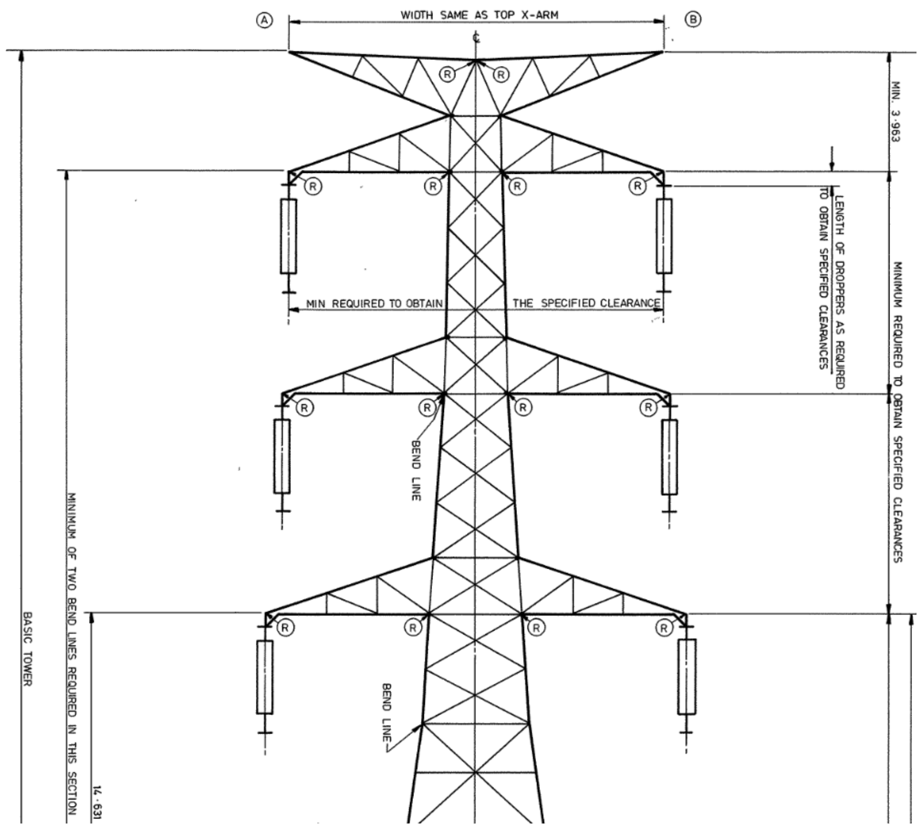

Figure 4 – Line 25/26 Existing 330kV Double Circuit Suspension Tower DSP DSR

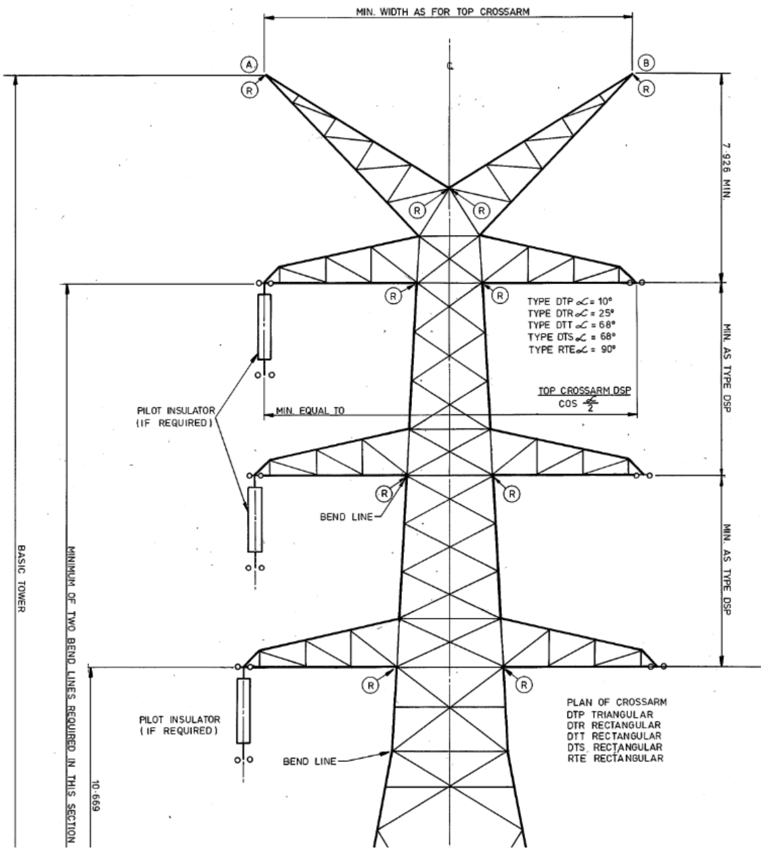

Figure 5 – Line 25/26 Existing 330kV Double Circuit Tension Tower DTP DTT

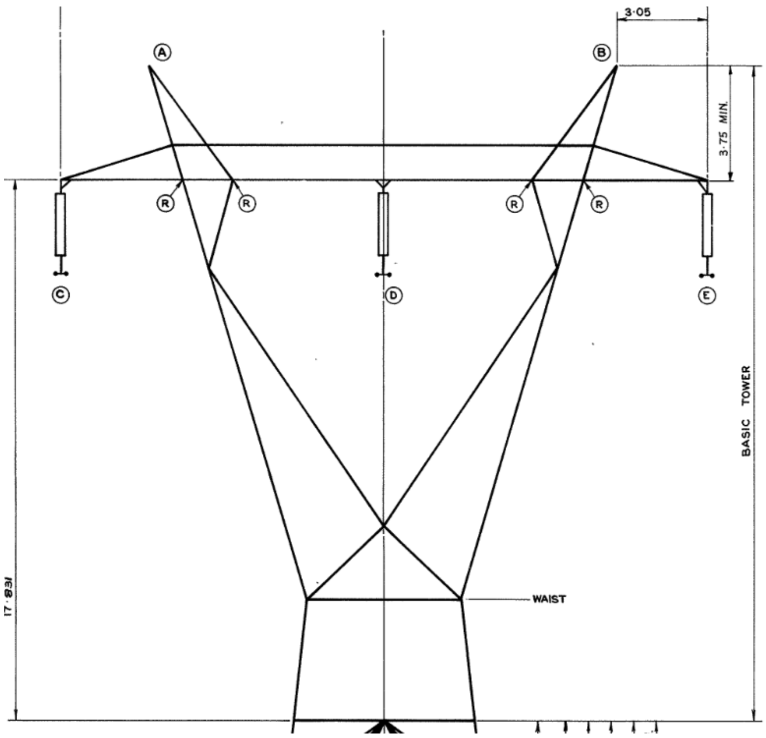

Figure 6 – Line 24 Proposed 330kV Single Circuit Suspension Tower SP SR

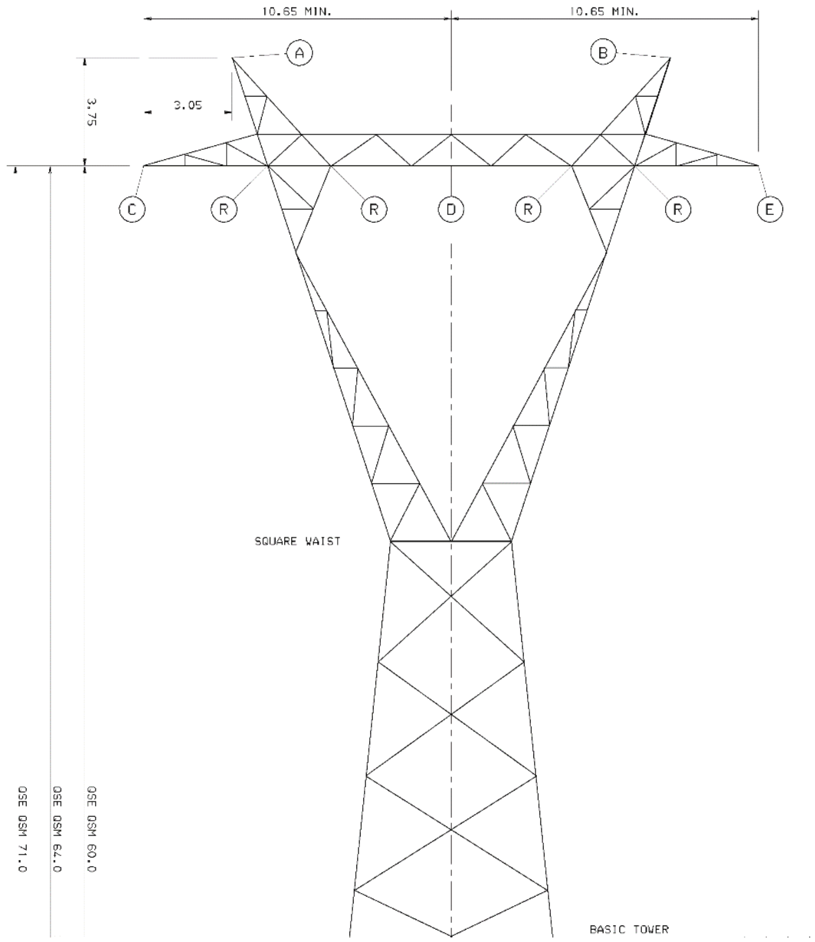

Figure 7 – Line 24 Proposed 330kV Single Circuit Suspension Tower QSM

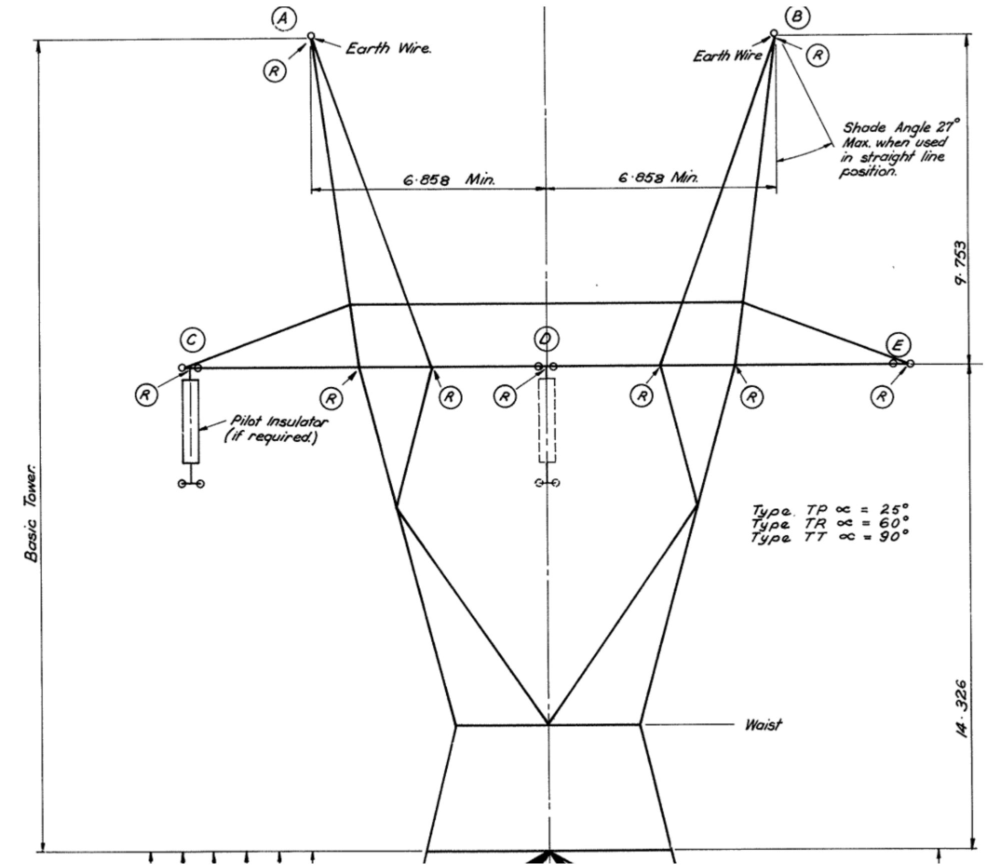

Figure 8 – Line 24 Proposed 330kV Single Circuit Tension Tower TP TR TT

Figure 9 – Line 24 Phasing Arrangement – Looking Toward Newcastle

Figure 10 – Line 25/26 Phasing Arrangement – Looking Toward Eraring/Munmorah

Table 2 – Loading Details: Existing

Lines	TWA Load	85^{th} Percentile Load	Maximum Load
Line 24	186MVA	365MVA	615MVA
Line 25	256MVA	348MVA	2042MVA
Line 26	157MVA	230MVA	2279MVA

Table 3 – Loading Details: Ultimate

Lines	TWA Load	85th Percentile Load	Maximum Load
Line 24	252MVA	494MVA	833MVA
Line 25	347MVA	471MVA	-
Line 26	213MVA	312MVA	-

3.2 Assumptions and Exclusions for Modelling

In undertaking this EMF assessment, Aurecon has made the following assumptions:

- All loads are balanced and all circuits are in-phase
- The modelling has assumed that Lines 25/26 are under the normal mode of operations, where both circuits are in service. The case where one of the circuits is out of service, and the other circuit is loaded to its maximum capacity has not been considered and is beyond the scope of this report

In accordance with Aurecon's brief, the magnetic field contribution associated with the existing and proposed configuration of 330kV Line 24 has been modelled, including the region where Line 24 crosses Lines 25/26. The characterisation of the EMF levels associated with other existing sources which may be found along the routes of the proposed new line is beyond the scope of this report. It should be noted that the overall magnetic field level would be the total vector sum of the contributions from the various different sources.

3.3 Magnetic Field Dependence on Load

The magnetic fields from electrical equipment depend on the loadings at that particular time. When various pieces of electrical equipment, including transmission lines, are located in proximity to each other, their interaction will influence the resulting fields. Accordingly, in characterising the magnetic fields from an item of electricity infrastructure, it is necessary to make practical assumptions regarding the loadings on the equipment at these sites.

During a typical day, the amount of load current passing through a transmission line will vary substantially between a daily minimum, generally in the early hours of the morning and a daily maximum at times of peak demand. Loadings may also vary seasonally during the year, generally reaching a peak[8] in either summer or winter. Loads may also grow slowly over time, due to a wide variety of factors. It is these various actual loadings which are relevant in the health context, rather than the maximum capacity of the transmission line, which may only be required for very short periods, under emergency conditions[9], a few times over its service life.

Given that the epidemiological associations which underpin community interest regarding magnetic fields tend to relate to elevated "average" magnetic fields, of the various hypothetical conditions one could select for magnetic field characterisation, the most meaningful is to take conservative estimates of the long term average annual load and link this to reasonable assumptions regarding other factors. The magnetic fields derived under these conditions are appropriate for consideration in the context of the magnetic field/health literature.

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[8] *The peak load is the highest load expected to occur on a piece of equipment under normal operation of the network.*

[9] *This is the maximum (worst-case) load expected to occur on a piece of equipment (i.e. line, cable, switchgear or transformer). It takes into account emergency circumstances where certain parts of the network are out of service, and the remaining connected equipment is required to pick-up additional load.*

This approach has been followed in our modelling calculations, where two measures of the transmission line loadings have been employed:

- 85th percentile loading levels (i.e. that level which is exceeded for only 15% of the time) as stipulated in the relevant industry guideline (Ref. 13)
- Time-weighted-average[10] loads (the TWA magnetic field is a common metric which has been used in major epidemiological studies)

It should be noted that, following completion of the proposed section of transmission line, the magnetic fields associated with it at any particular time would be dependent on the actual loadings rather than those used for calculation purposes.

Figure 11 shows a typical load duration curve, with the peak, 85th percentile and TWA loads indicated.

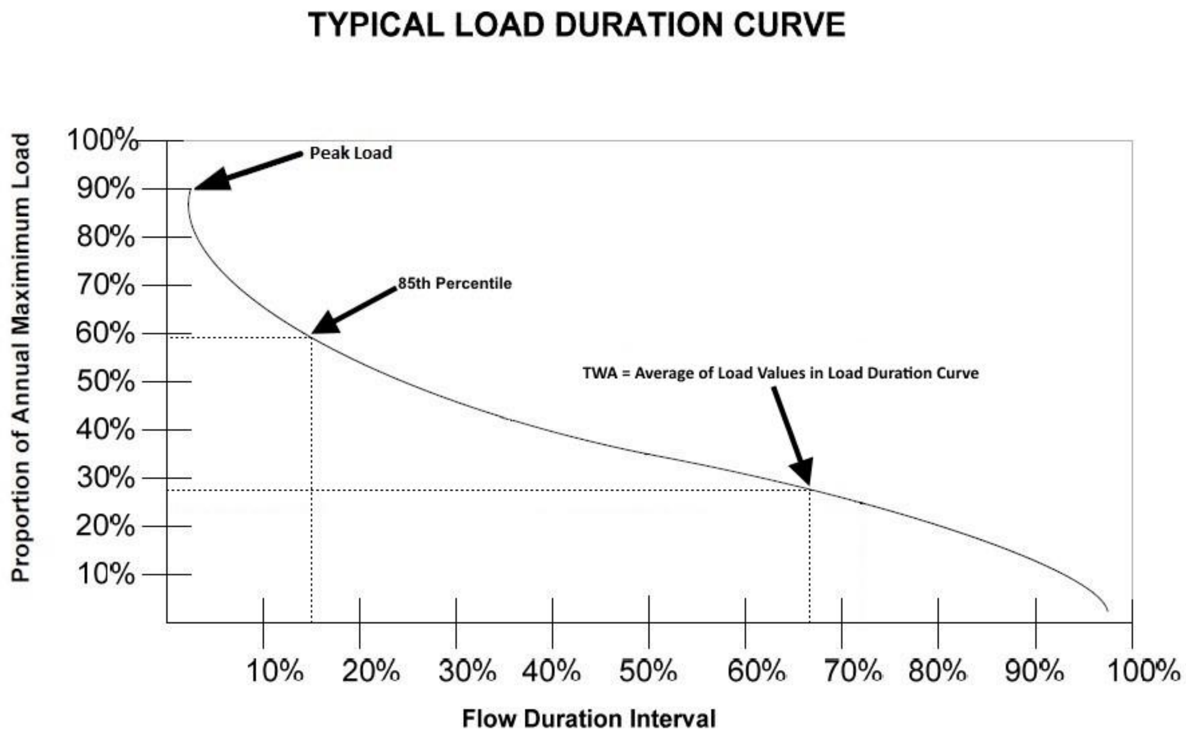

Figure 11 – Typical Load Duration Curve

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[10] *The time-weighted-average load is the average load of the equipment, calculated under normal network operation, over a period of time, usually on an annual basis.*

4 Field Characterisation

4.1 General

Based on the available design and loading information, provided by Centennial Mandalong, the magnetic field contribution expected from the proposal has been modelled using the CDEGS software package. CDEGS is an internationally recognised software package pioneered by Safe Engineering Services & Technologies (SES) to provide grounding, electromagnetic and conductive interference analysis involving electrical networks. The software has undergone extensive scientific validation using field tests and comparisons with analytical or published results for over twenty years (Ref. 14).

Aurecon has modelled the existing transmission line configurations and the proposed line deviation and calculated the EMF contribution associated with each, to allow for comparison between the existing field levels of the line and those expected with the proposed new line section. In addition, Aurecon has modelled the section where Line 24 crosses Line 25/26 in order to assess the cumulative EMF levels in this area. It is noted that the assessment of the cumulative fields is confined to the area within the Line 24 easement only – an evaluation of the EMF contribution associated with Line 25/26 elsewhere is beyond the scope of this report. The results of this modelling are presented in Sections 4.2 and 4.5.

The electric and magnetic fields have been calculated at a height of 1m above ground level in accordance with international practice. All calculations have been undertaken using the 85th percentile and TWA forecast loads provided by Centennial Mandalong, as listed in Table 2 and Table 3. As previously noted, following completion of the proposed works, the magnetic fields associated with the transmission lines would be dependent on the actual loading rather than that used for calculation purposes.

4.2 Magnetic Field Modelling

4.2.1 Existing Line 24

A screenshot of the CDEGS model showing the relevant sections of the existing Lines 24 and 25/26 is shown in Figure 12. The results obtained from the EMF modelling are presented in the form of surface contour plots underneath and around the transmission line, and as profiles extending 30m either side of the centreline of the transmission line across the width of the easement.

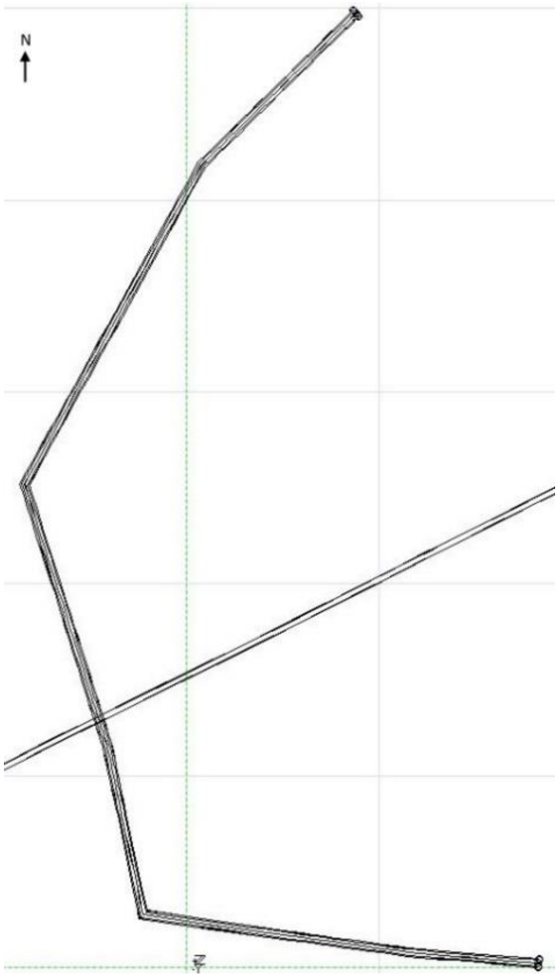

Figure 12 – CDEGS Model of Existing Lines 24 and 25/26

Figure 13 and Figure 14 show the magnetic field contribution of the existing 330kV Line 24, calculated under 85th percentile and TWA loading conditions respectively.

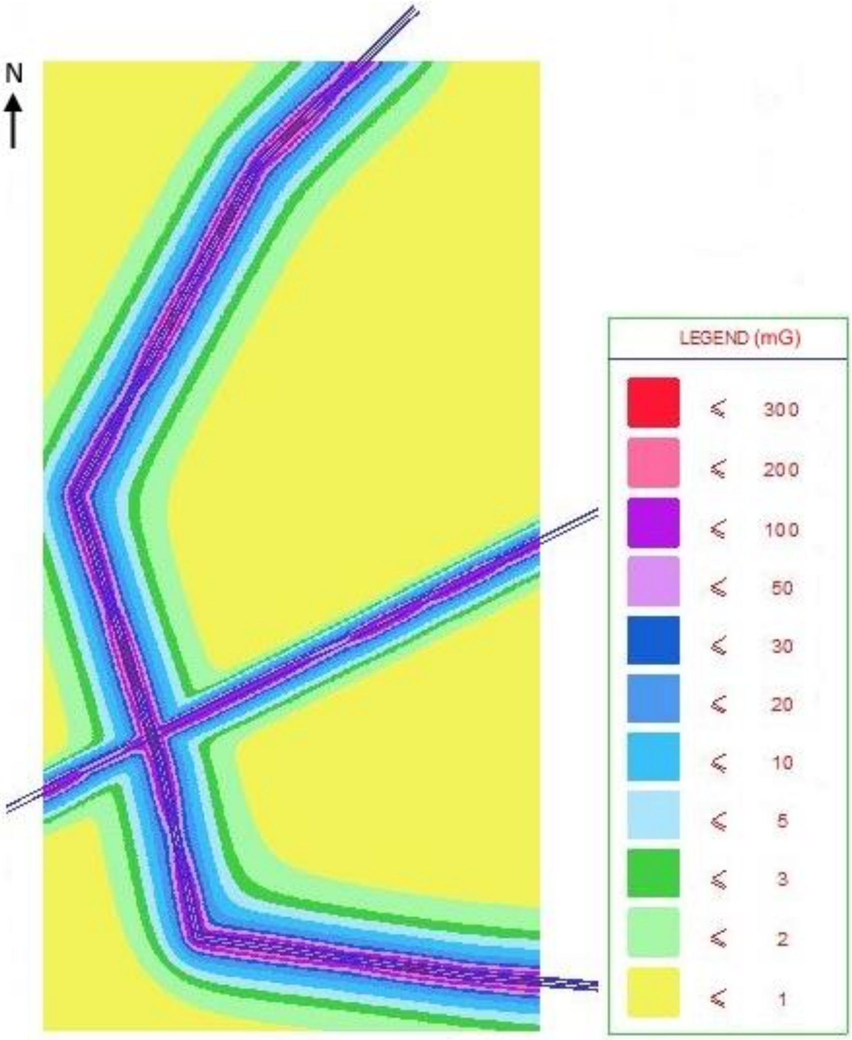

Figure 13 – Calculated Magnetic Field Contribution of Line 24: Existing 85th Percentile Loads

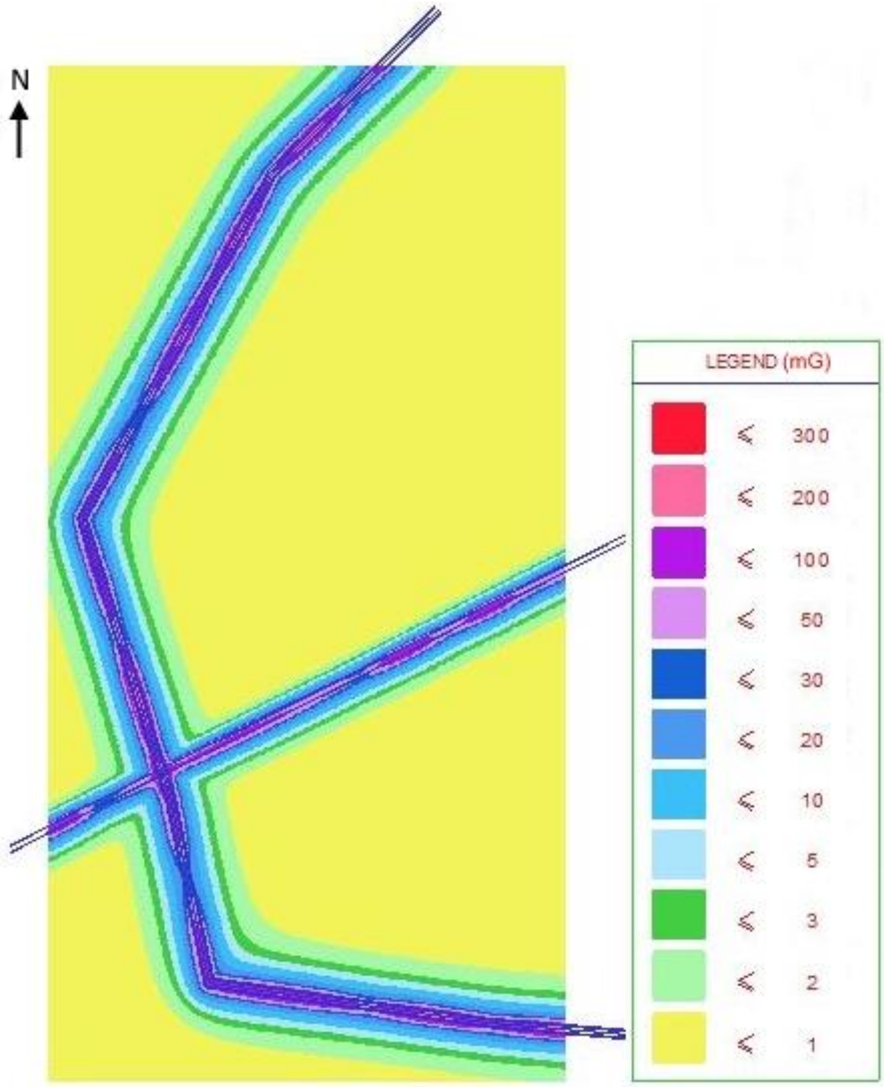

Figure 14 – Calculated Magnetic Field Contribution of Line 24: Existing TWA Loads

It can be seen that the highest magnetic fields associated with the existing Line 24 have been calculated to be between 200mG and 300mG under 85th percentile loading conditions, and between 100mG and 200mG under TWA loading conditions. The highest fields occur directly beneath the line at the point of lowest conductor sag in the span between Towers 38 and 39 to the northern side of the line crossing with 25/26. At the undercrossing of Line 25/26, fields are predicted to be of similar levels.

The magnetic fields decrease as one moves away from the route centreline, and at the edge of the easement, fields are predicted to be less than 50mG and 30mG under 85th percentile and TWA loads respectively. At a distance of 100m from the route centreline, the magnetic field contribution is 3mG or less.

A profile across the width of the easement showing the magnetic field contribution of the line at the low point of the span between Towers 38 and 39 can be found in Figure 15.

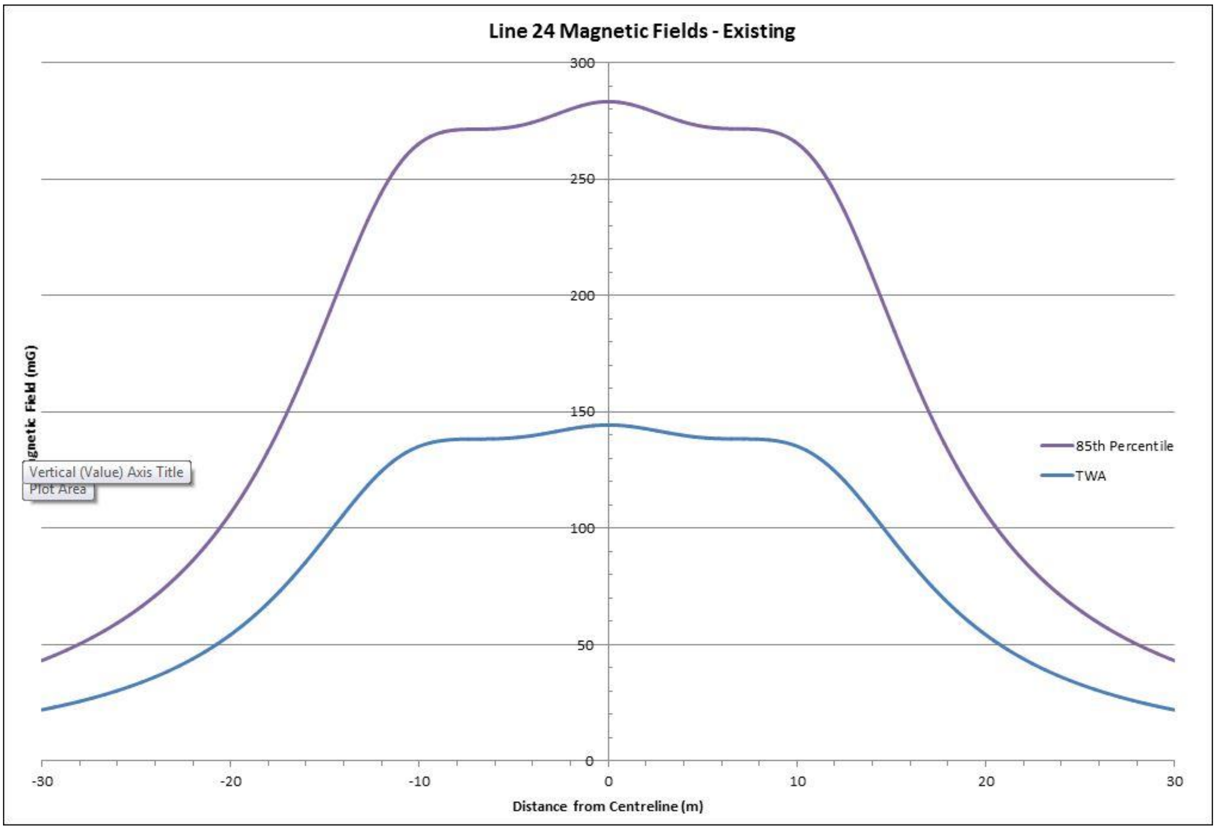

Figure 15 – Calculated Magnetic Field Contribution of Line 24 across Easement: Existing Loads

As shown, the highest calculated magnetic field levels associated with the existing line are approximately 283mG and 145mG under 85th percentile and TWA loading conditions respectively, occurring directly below the transmission line. At the edge of the easement, at a distance of 30m from the route centreline, the magnetic fields are predicted to reduce to approximately 43mG under 85th percentile loads and 22mG under TWA loads.

4.2.2 Proposed Line 24 Deviation

A screenshot of the CDEGS model showing the route deviation of Line 24 and the relevant sections of Line 25/26 is shown in Figure 16. Again the results are presented as surface contour plots and as a profile across the width of the transmission line easement.

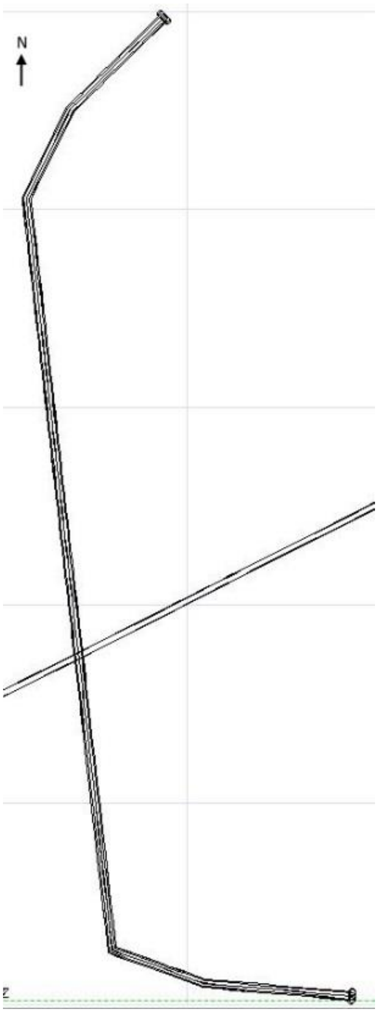

Figure 16 – CDEGS Model of Lines 24 and 25/26 with the Proposed Line 24 Route Deviation

Upon Commissioning

Figure 17 and Figure 18 show the magnetic field contribution associated with the proposed Line 24 deviation, calculated under 85th percentile and TWA commissioning loading conditions respectively.

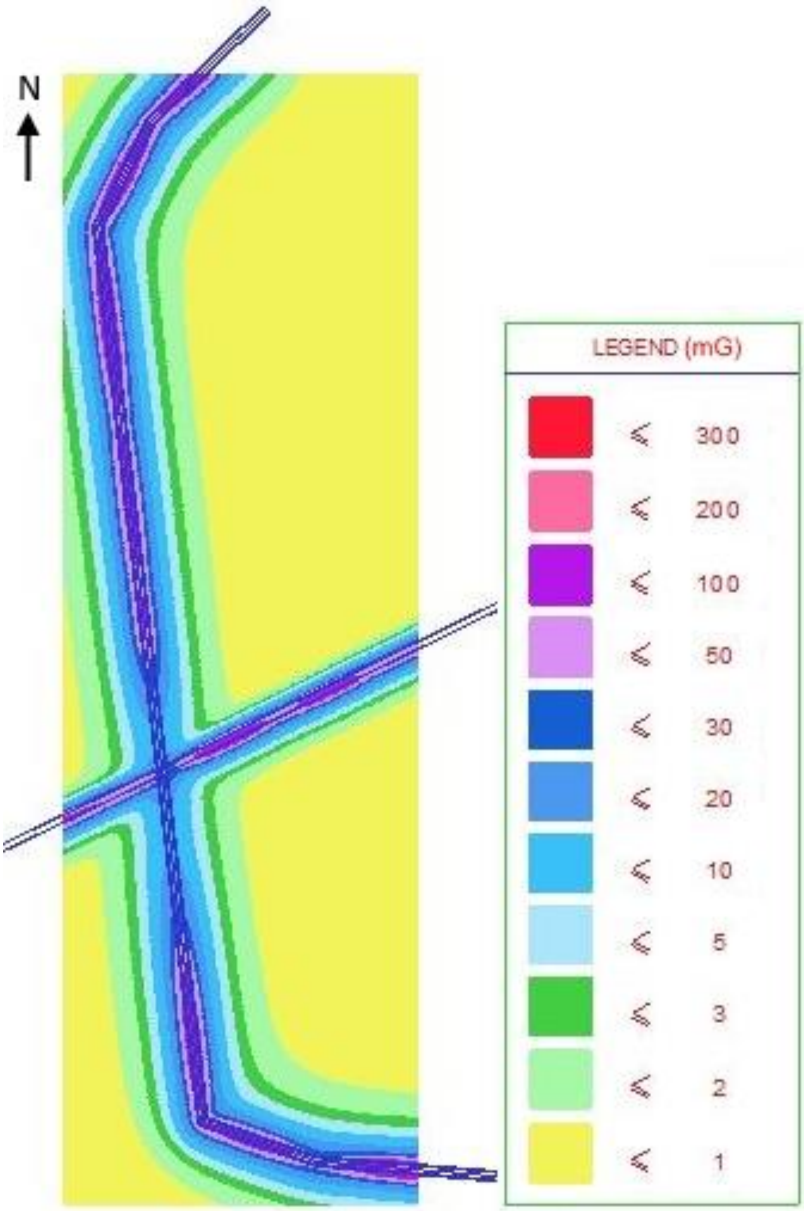

Figure 17 – Predicted Magnetic Field Contribution of Line 24: Commissioning 85th Percentile Loads

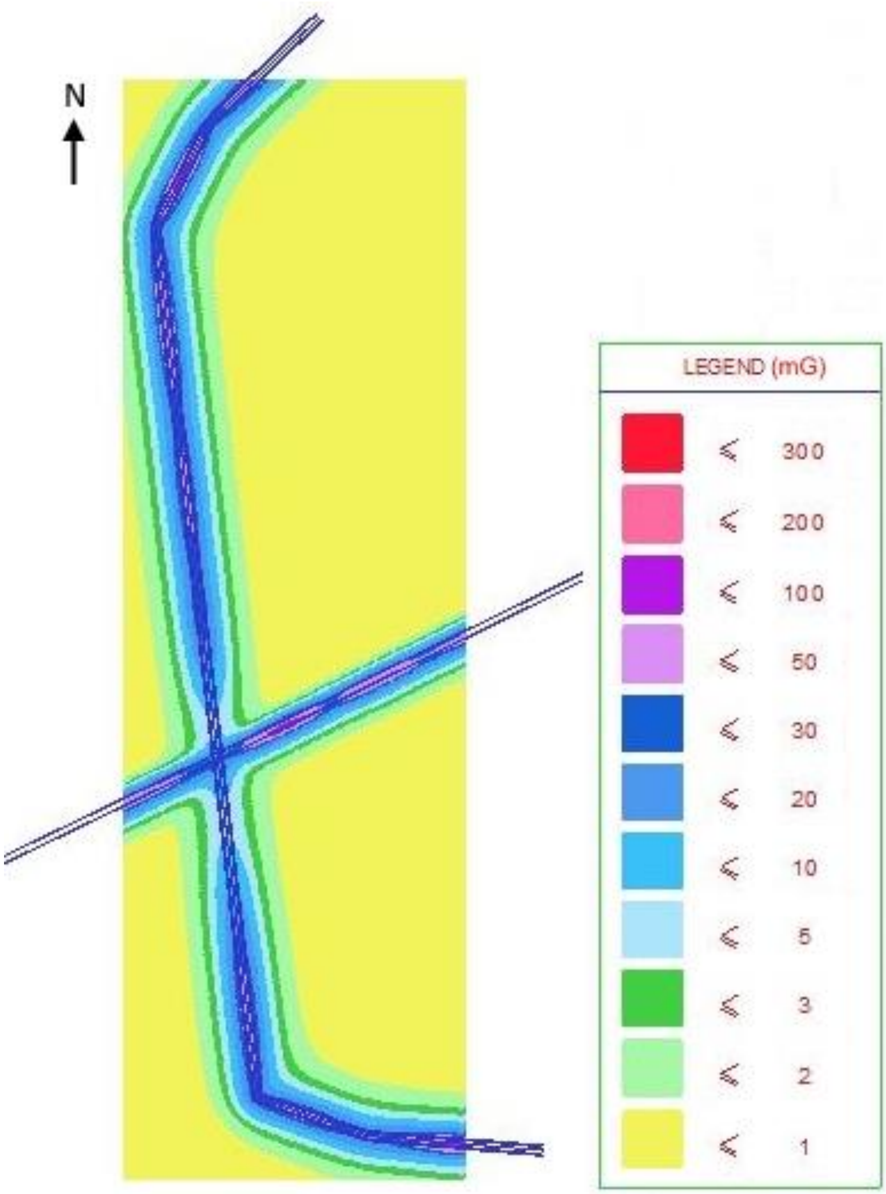

Figure 18 – Predicted Magnetic Field Contribution of Line 24: Commissioning TWA Loads

With the relocated section of Line 24, it can be seen that the highest magnetic field contribution under 85th percentile commissioning loads is now predicted to be between 100mG and 200mG, and between 50mG and 100mG under TWA commissioning loads. The highest fields occur directly beneath the line at the point of lowest conductor sag in the span between Towers 32 and 33X.

Elsewhere along the line, the typical field contribution levels predicted are between 50mG and 100mG under 85th percentile loads and between 30mG and 50mG under TWA loads. The levels here are less than those calculated for the existing line due to the greater clearance of the conductors to ground in the proposed line section. At the crossing of Line 25/26, fields are predicted to be less than 50mG and 30mG under 85th percentile and TWA loads respectively. These are primarily influenced by Line 25/26, as Line 24 will now cross over it.

The magnetic fields decrease as one moves away from the route centreline, and at the edge of the easement, fields are predicted to be less than 30mG and 20mG under 85th percentile and TWA loads respectively. At a distance of 100m from the route centreline, the magnetic field contribution is 2mG or less.

A profile across the width of the easement showing the magnetic field contribution of the line at the low point of the span between Towers 32 and 33X can be found in Figure 19.

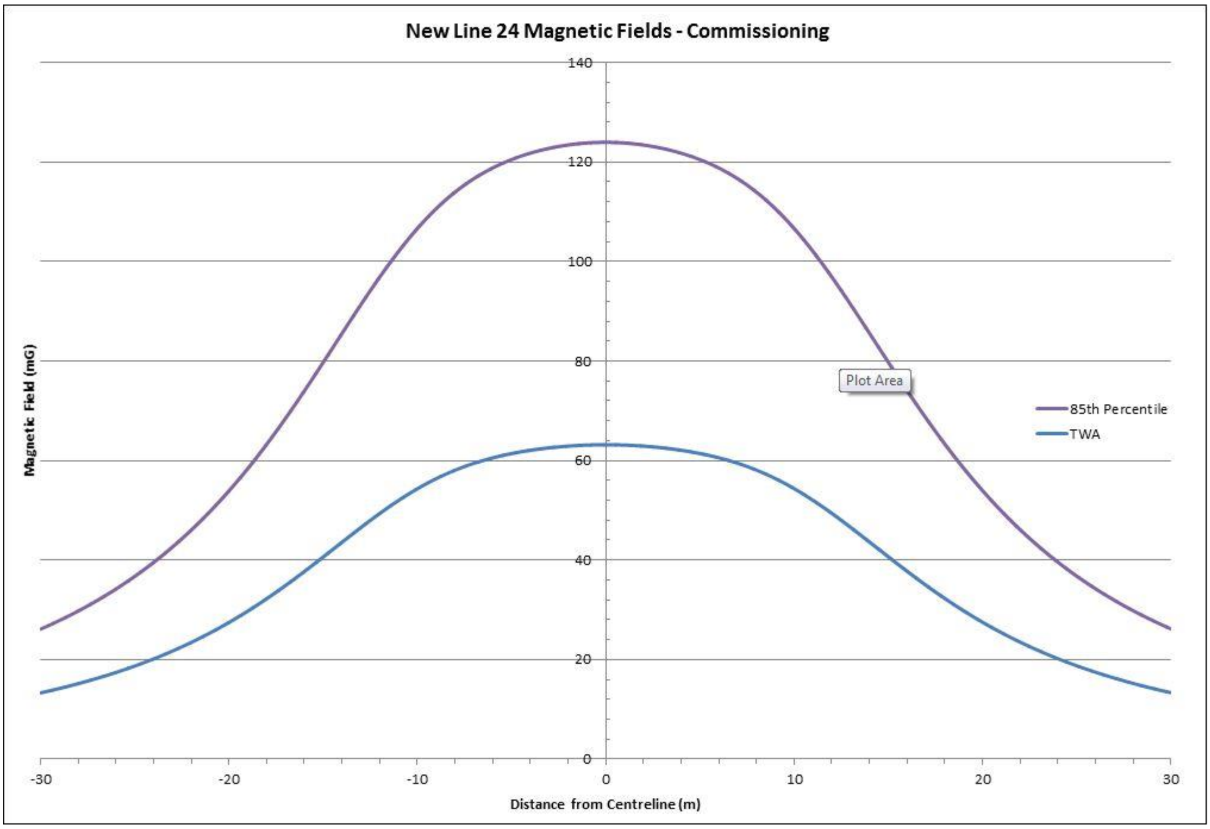

Figure 19 – Predicted Magnetic Field Contribution of Line 24 across Easement: Commissioning Loads

As shown, the highest predicted magnetic field contribution associated with the new line section is approximately 124mG and 64mG under 85th percentile and TWA loads upon commissioning respectively. Again, both peaks occur directly below the transmission line. At the edge of the easement, at a distance of 30m from the centreline of the route, the magnetic fields are predicted to reduce to approximately 26mG under 85th percentile loads and 13mG under TWA loads.

Under Ultimate Scenario

Figure 20 and Figure 21 show the magnetic field contribution associated with the proposed Line 24 deviation, calculated under 85th percentile and TWA ultimate loading conditions respectively.

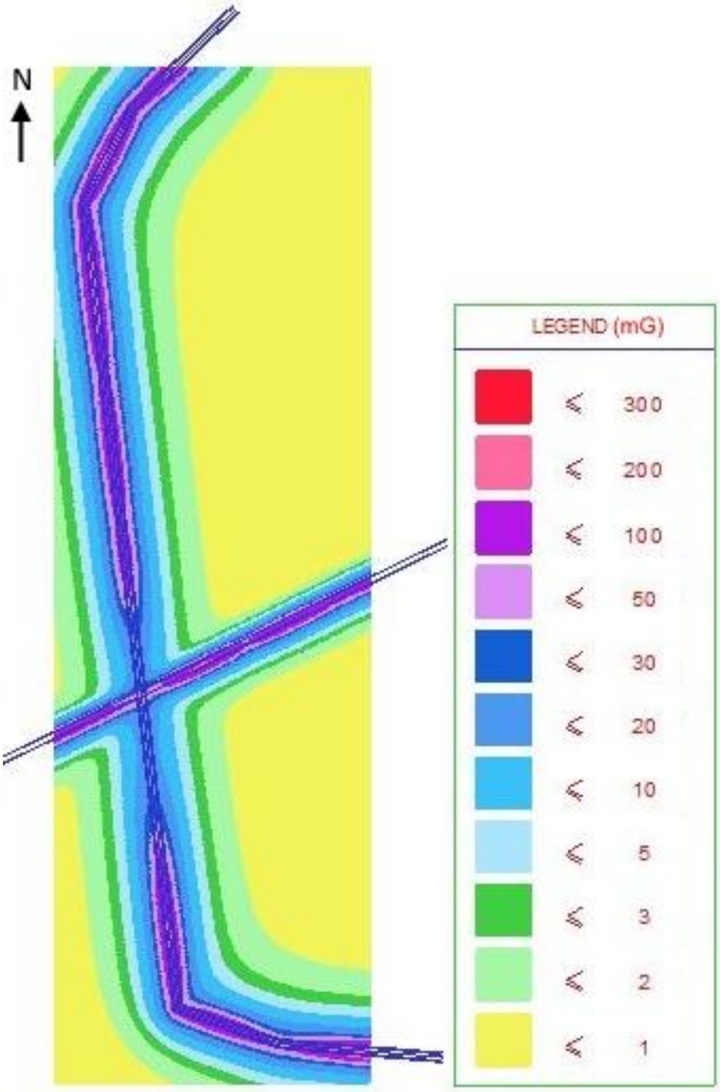

Figure 20 – Predicted Magnetic Field Contribution of Line 24: Ultimate 85th Percentile Loads

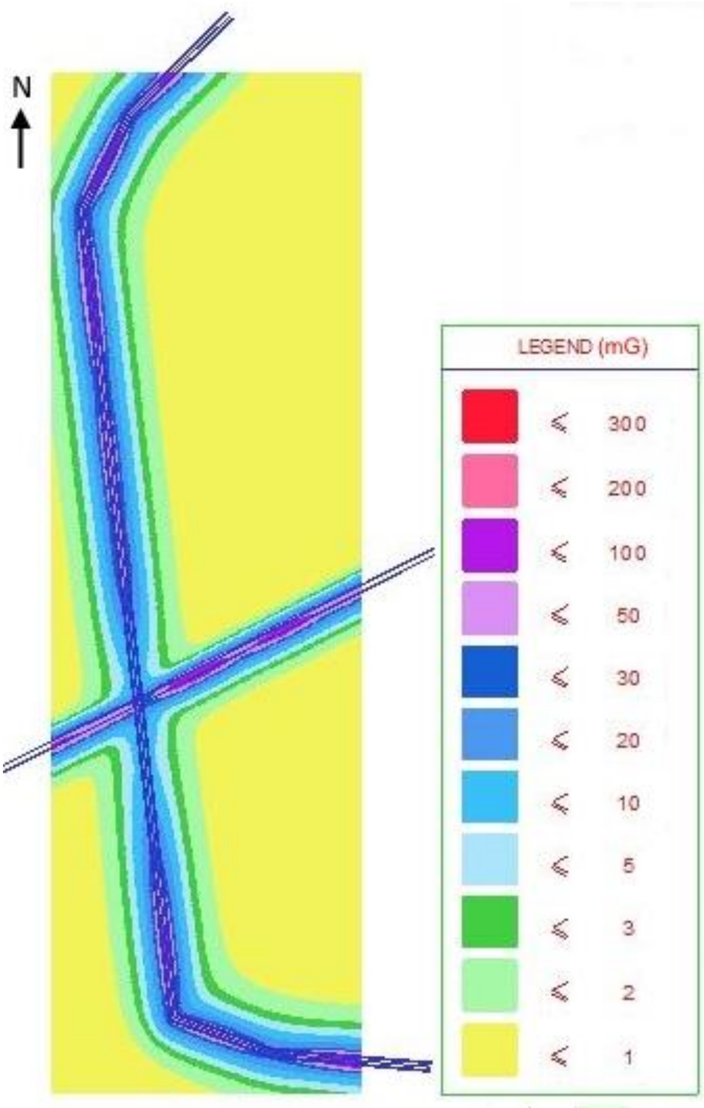

Figure 21 – Predicted Magnetic Field Contribution of Line 24: Ultimate TWA Loads

Under 85th percentile ultimate loads, it can be seen that the area where the magnetic field contribution is between 100mG and 200mG in the span between Towers 32 and 33X is now predicted to be greater than that under commissioning loads. Under TWA ultimate loads, fields are again predicted to be in the range of 50mG to 100mG.

Typical magnetic field contribution levels along the line are now predicted to be in excess of 100mG under 85th percentile ultimate loads and 50mG under TWA loads. Despite the increase in the load, the field levels under the ultimate conditions are still less than those calculated for the existing line. At the crossing of Line 25/26, fields are still predicted to be less than 50mG under both 85th percentile and TWA loads and are primarily influenced by Line 25/26.

The magnetic fields decrease as one moves away from the route centreline, and at the edge of the easement, fields are predicted to be less than 50mG and 20mG under 85th percentile and TWA loads respectively. At a distance of 100m from the route centreline, the magnetic field contribution is 2mG or less.

A profile across the width of the easement showing the magnetic field contribution of the line under ultimate loading conditions at the same point of the span between Towers 32 and 33X can be found in Figure 22.

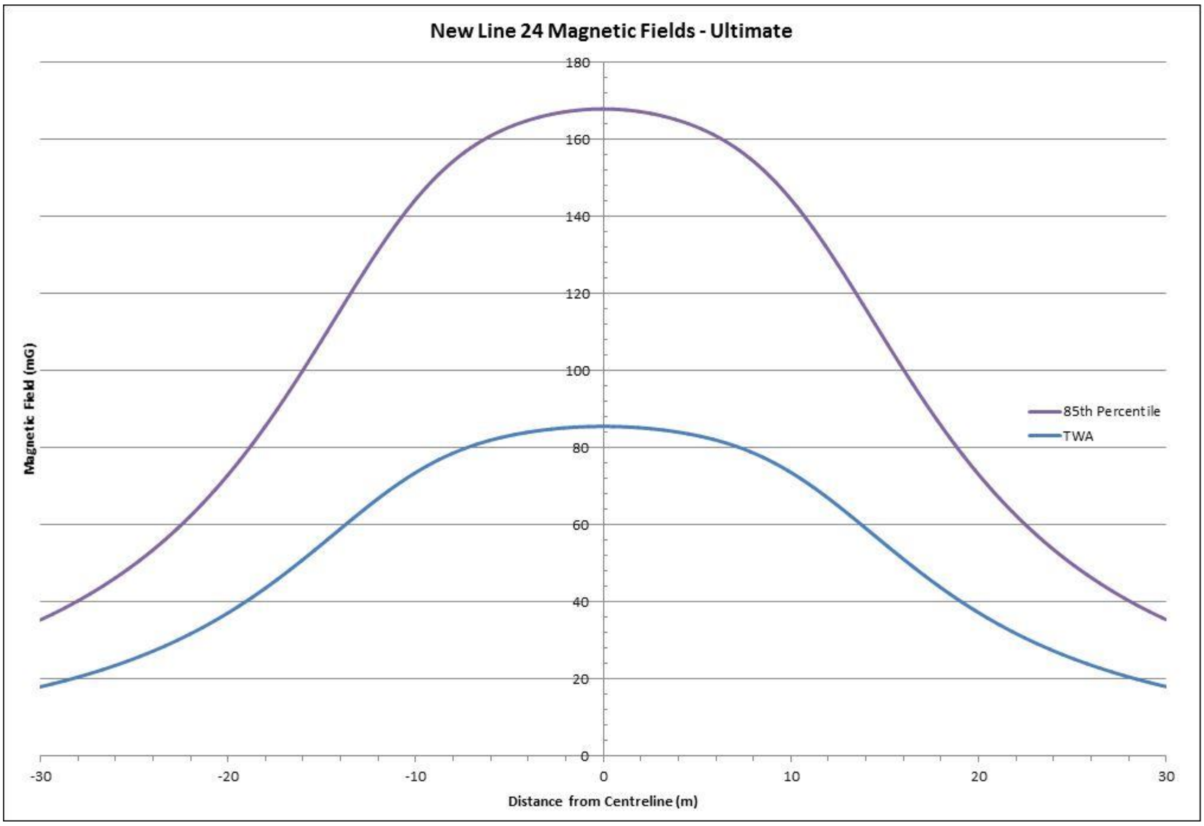

Figure 22 – Predicted Magnetic Field Contribution of Line 24 across Easement: Ultimate Loads

As shown, the highest predicted magnetic fields associated with the new line are approximately 168mG and 85mG under 85th percentile and TWA ultimate loads respectively, with the peaks occurring directly below the line. At the edge of the easement, at a distance of 30m from the centreline of the route, the magnetic fields are predicted to reduce to approximately 35mG under 85th percentile loads and 18mG under TWA loads.

4.2.3 Further Remarks

Even under ultimate loadings, the predicted magnetic field contribution of the new relocated section of Line 24 is predicted to be less than those associated with the existing line. This is primarily due to the design of the new section, which has made allowance for greater clearance of the conductors to ground. It is noted that the profiles have been taken at the low point of the span to indicate that highest predicted field contribution levels, which will be lower at other points along the span where the conductors are higher above from ground level.

4.3 Magnetic Fields Experienced Intermittently

Whilst the field levels presented in Section 4.2 are the most relevant in the health context, in the broader context of an environmental assessment, it is also appropriate to recognise that, in the longer term, under emergency conditions, higher magnetic field contributions up to twice those reported for 85th percentile conditions could be experienced in some places for short periods over the life of the feeders. Such situations are only expected to arise rarely, and would not be expected to be of prolonged duration.

4.4 Magnetic Fields Experienced in Everyday Life

In considering the fact that the predicted field levels associated with the proposed new section of Line 24 are localised to the area beneath it and will vary intermittently depending on the actual loadings on the line, it is important to recognise that life in the modern world involves moving from one source of magnetic fields to another. To put the magnitude of the predicted magnetic fields into perspective, it is worth considering the range of typical magnetic field levels associated with common household appliances at normal user distances and utility infrastructure, shown in Table 4. This table is sourced from the Energy Networks Association (Ref. 15).

Table 4 – Magnetic Field Levels Associated with Appliances and Utility Infrastructure

Source	Typical Measurement (mG)	Range of Measurements (mG)
Stove	6	2-30
PC	5	2-20
TV	1	0.2-2
Electric Blanket	20	5-30
Hair Dryer	25	1-70
Refrigerator	2	2-5
Toaster	3	2-10
Kettle	3	2-10
Fan	1	0.2-2
Overhead Distribution Line - Under Line	10	2-20
Overhead Transmission Line - Under Line - Edge of Easement	20 10	10-200 2-50

From the above range of field levels, it can be seen that the magnetic field contributions associated with the proposed section of 330kV Line 24, even in the ultimate scenario, are within the range of fields commonly associated with transmission infrastructure, both underneath the line and at the edge of the easement. At this location, some 30m from the route centreline, the magnetic field contribution of the proposed line is similar in level to those associated with common appliances. Beyond 100m from the route centreline, the field contribution of the proposed line is expected toward the lower end of the range normally encountered in everyday life.

4.5 Electric Fields

4.5.1 Existing Line 24

The electric fields associated with the existing configuration of Line 24 have been calculated based on its normal mode of operation. Figure 23 shows the electric field contribution of the existing 330kV Line 24.

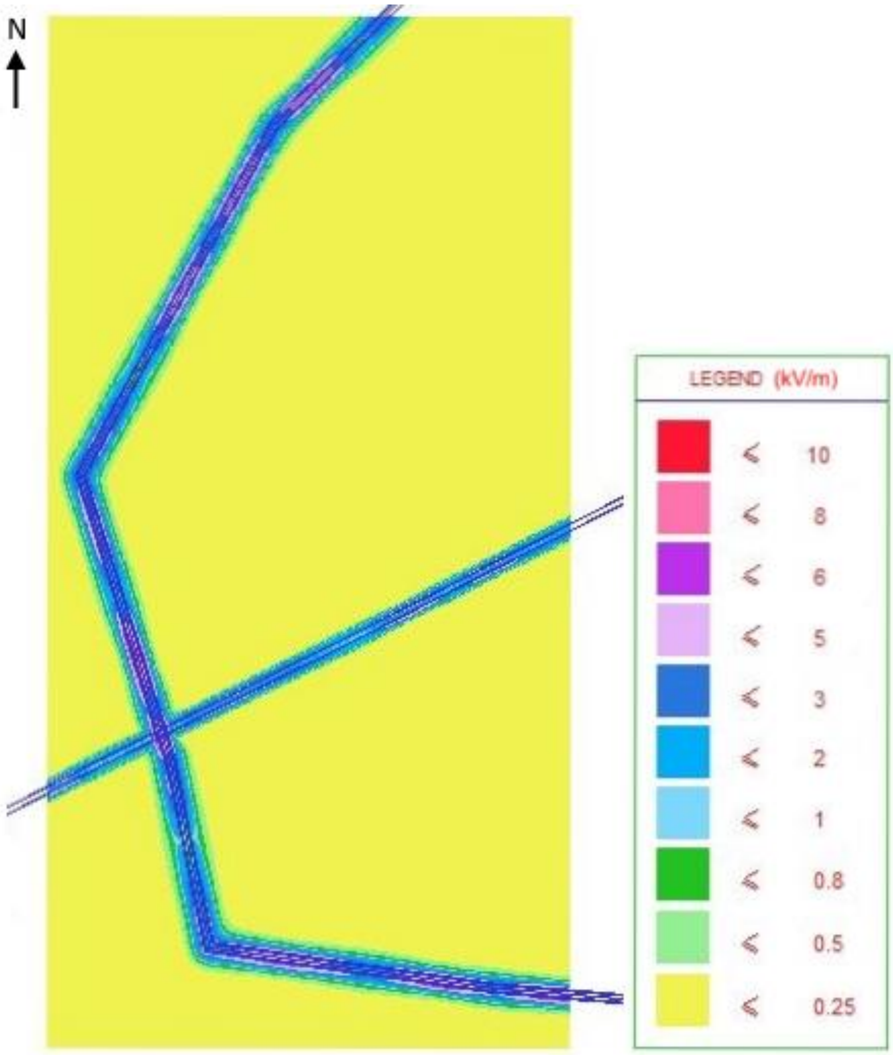

Figure 23 – Calculated Electric Field Contribution of Existing Line 24: Normal Operating Conditions

It can be seen that the electric field contribution of the existing Line 24 is predicted to be highest directly underneath the line at the low points of the span, generally in the range of 6kV/m to 8kV/m, even at the undercrossing of Line 25/26.

At the edge of the easement, a distance of 30m from the route centreline, the electric field contribution is predicted to be approximately 1kV/m or less, and reduces rapidly with distance beyond this point.

A profile across the width of the easement showing the electric field contribution of the line at the low point of the span between Towers 38 and 39 can be found in Figure 24.

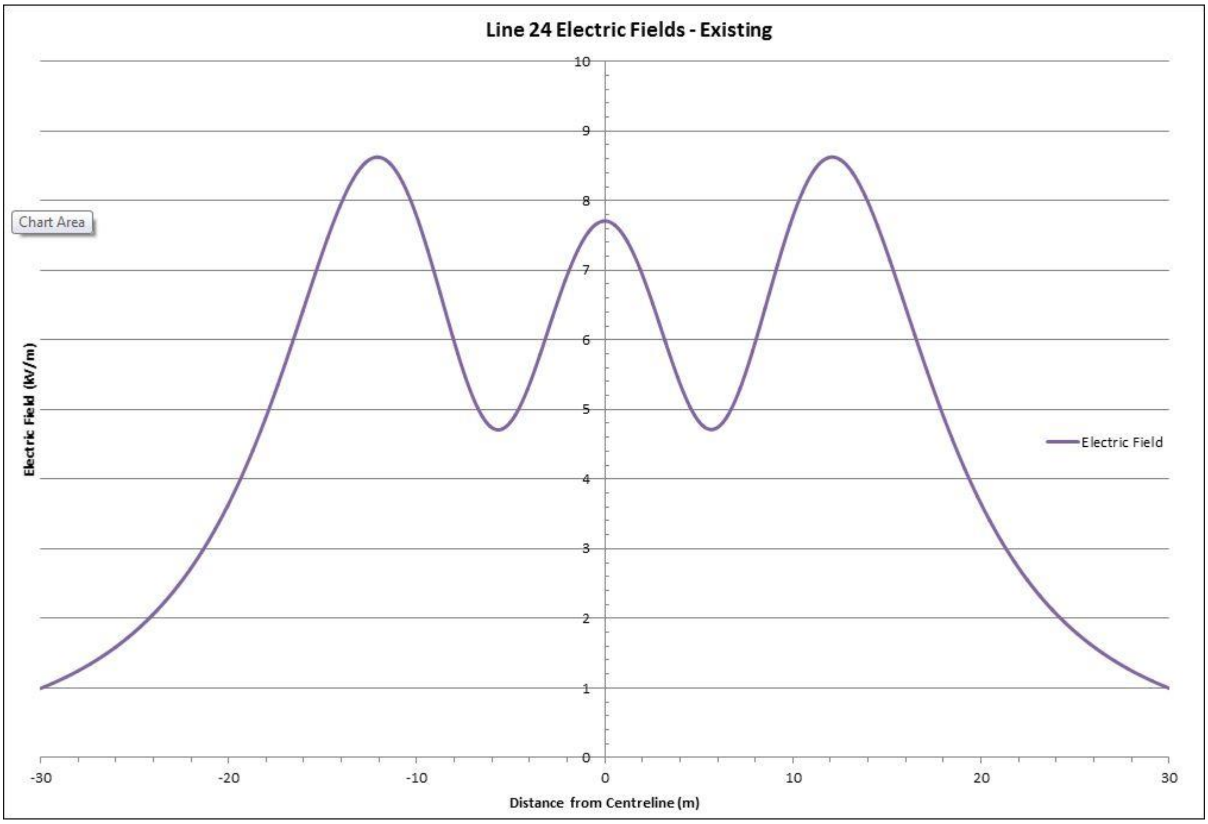

Figure 24 – Calculated Electric Field Contribution of Existing Line 24 across Easement: Normal Operating Conditions

As shown, the highest calculated electric field levels are approximately 8.6kV/m directly underneath outer conductors of the existing line. At the edge of the easement, the field levels are predicted to reduce to approximately 1kV/m.

4.5.2 Proposed Line 24 Deviation

Again, the electric fields associated with the proposed Line 24 deviation have been calculated based on its normal mode of operation. Figure 25 shows the electric field contribution of the new section of 330kV Line 24.

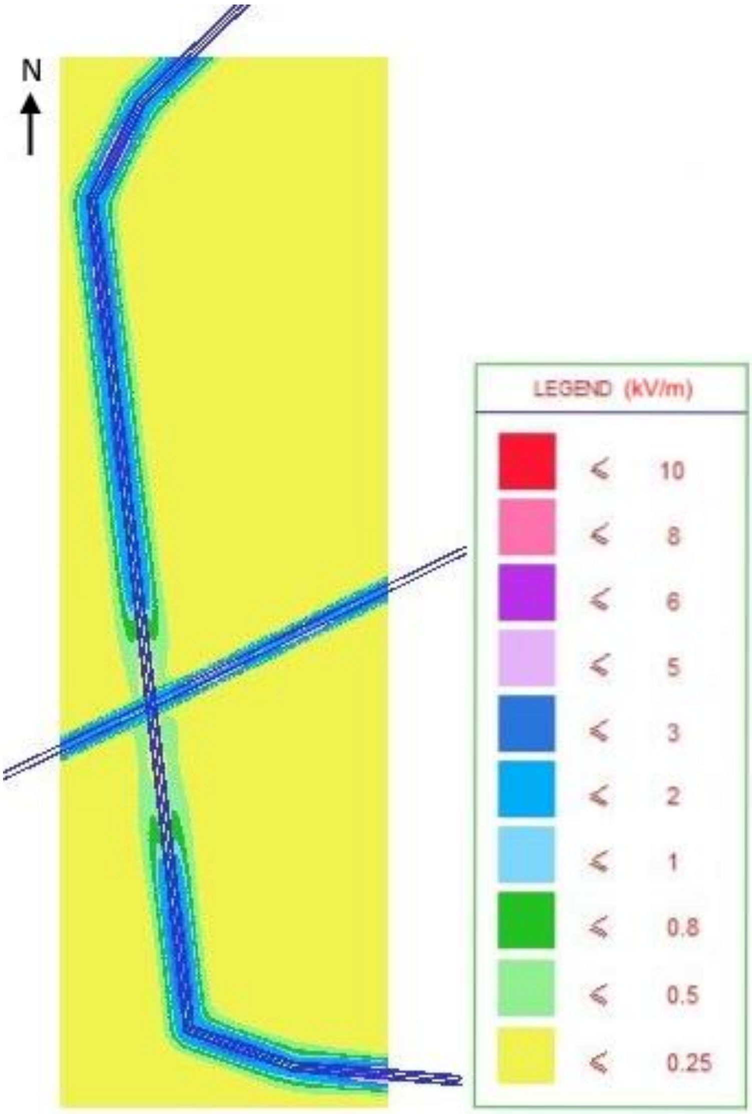

Figure 25 – Predicted Electric Field Contribution of Proposed New Line 24: Normal Operating Conditions

With the proposed Line 24 deviation, the highest predicted electric fields are now in the range of 3kV/m to 5kV/m, with the fields underneath those spans with greater ground clearance being generally in the range of 2kV/m to 3kV/m. At the crossing of Line 25/26, fields are now predicted to be 2kV/m to 3kV/m and is primarily influenced by Line 25/26, as Line 24 will now cross over it.

Again, at the edge of the easement, a distance of 30m from the route centreline, the electric field contribution is predicted to be approximately 1kV/m or less, and reduces rapidly with distance beyond this point.

A profile across the width of the easement showing the electric field contribution of the line at the low point of the span between Towers 32 and 33X can be found in Figure 26.

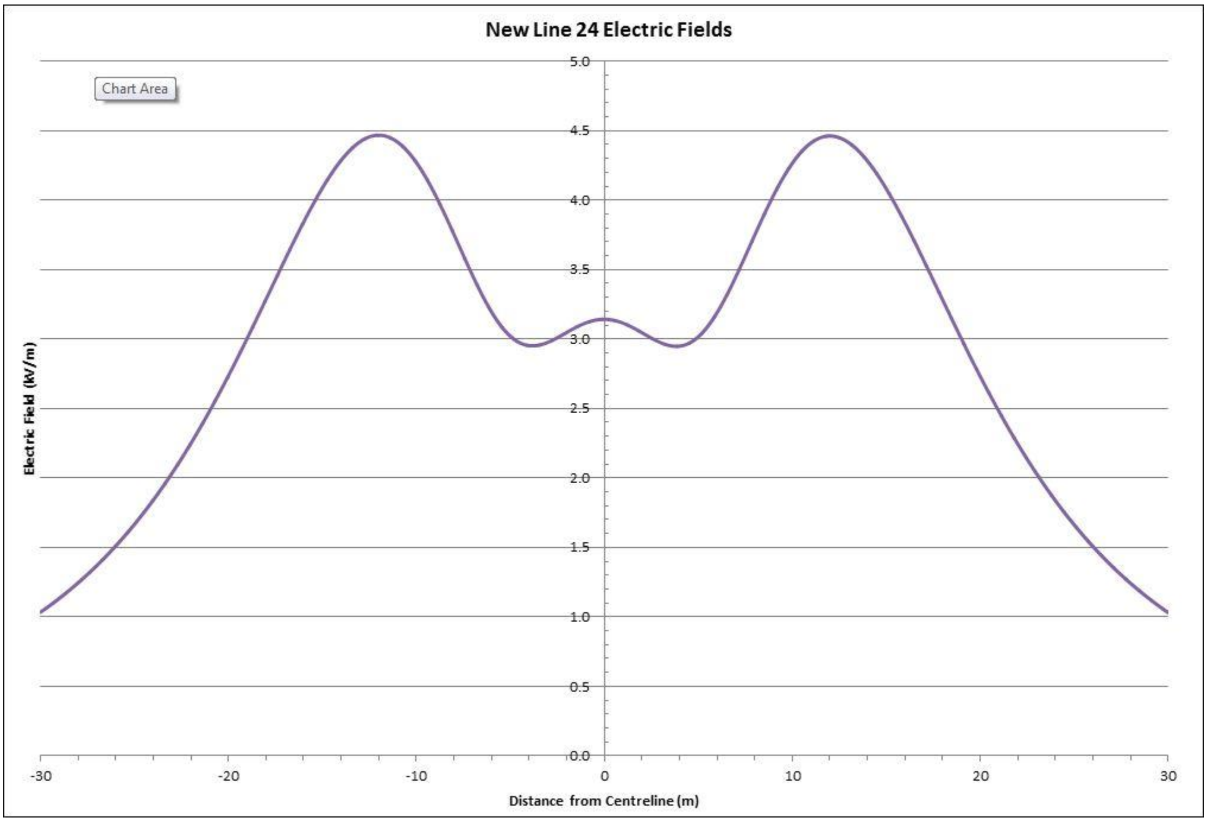

Figure 26 – Predicted Electric Field Contribution of Proposed New Line 24 across Easement: Normal Operating Conditions

As shown, the highest predicted electric field levels are approximately 4.5kV/m directly underneath the outer conductors of the line. At the edge of the easement, the field levels are predicted to reduce to approximately 1kV/m.

4.6 Perspective of Electric Fields

As the electric field levels are related to the voltage of the line, they are relatively constant over time and, accordingly, the levels shown in Section 4.5.2 can be taken to represent the long term situation also.

It is noted that the highest electric field levels underneath the existing Line 24 exceed the ICNIRP general public exposure reference level of 5kV/m. In order to put this into perspective, it is important to note that, while the guideline reference levels are easy to measure, they are not the actual guideline limits[11]. The actual guideline limits are not easily measured, but are likely to be somewhat higher than the 5kV/m reference level. As an example, electric fields under high voltage lines in the UK in the order of 7kV/m have been demonstrated by detailed modelling to comply with the actual guideline restriction. In Australia, electric fields exceeding 5kV/m are not uncommon under major transmission lines, partly because the earlier NHMRC guidelines allowed general public exposure of 10kV/m for up

[11] *The actual limits in the guidelines are expressed in terms of an* ***induced electric field strength*** *within a human body, which is virtually impossible to measure and extremely complex to calculate. Accordingly, for practical reasons, the guidelines contain reference levels, which relate to the actual fields in the environment and are convenient to apply. However they are extremely conservative. If a scenario meets the reference levels, it will undoubtly comply with the guidelines, but if it does not meet the reference levels, it does not necessarily mean that it is non-compliant. In this case, compliance with the guidelines is more difficult to demonstrate..*

to a few hours a day. The draft ARPANSA standard also allows fields up to 10kV/m in “controlled circumstances”. It is also worth noting that the IEEE Standard (Ref. 16), which is the second of the two international guidelines recognised by the World Health Organisation, allows fields up to 10kV/m on transmission line easements.

For the new section of the Line 24 deviation, the electric field contributions are not predicted to exceed the ICNIRP general public exposure reference level of 5kV/m and are considerably less than those associated with the existing line. As with the magnetic fields, this is due to the design of the new section, which has made allowance for greater clearance of the conductors to ground. It should be noted that, at times during its operation, the 330kV Line 24 may operate at voltages up to 10% higher than its nominal stated voltage. Even under these conditions, the field levels for the proposed new section of Line 24 are still predicted to remain within the ICNIRP general public exposure reference level.

In practice, the electric field contribution from the proposed section of line is likely to be even lower than that indicated in Section 4.5.2. This is due to the effect of shielding from a variety of sources including vegetation and buildings.

5 Compliance with EMF Health Standards and Prudent Avoidance Principles

5.1 Compliance with Health Guidelines

5.1.1 Magnetic Fields

As noted in Section 4.2, the highest magnetic field contribution associated with the proposed new line section is predicted to be approximately 168mG under 85th percentile ultimate loads. This occurs directly below the line at its lowest point of sag, and corresponds to 8.4% of the ICNIRP general public exposure reference level of 2000mG.

Even under peak or emergency load conditions where the field levels could be up to twice those reported under 85th percentile loading conditions, the magnetic fields are still predicted to remain within the relevant guideline reference level.

5.1.2 Electric Fields

As noted in Section 4.5, the highest calculated electric field contribution associated with the proposed new line section is predicted to be approximately 4.5kV/m. Again this occurs directly below the line at its lowest point of sag, and is within the ICNIRP general public exposure reference level of 5kV/m.

Even if the 330kV line were to be operating at voltages up to 10% higher than its nominal voltage, the fields associated with the proposed new line are predicted to remain within the general public exposure reference level of 5kV/m.

5.2 Assessment against Prudent Avoidance Principles

As noted in Section 2.4, given the inconclusive nature of the science, it is considered that a prudent/precautionary approach continues to be the most appropriate response in the circumstances. Under this approach, power infrastructure asset owners should design their facilities to reduce the intensity of the fields they generate, and locate them to minimise the fields that people, especially children, encounter over prolonged periods, provided this can be readily achieved without undue inconvenience and at reasonable expense, and are consistent with good engineering and risk minimisation practice.

It is understood that, along with other members of ENA, TransGrid, which is the owner of the asset, has adopted the policy of prudent avoidance, which Centennial Mandalong is complying with. Based on the design information received thus far, there is evidence that the principles of prudent avoidance has been applied to this project. In this context, Centennial Mandalong and/or TransGrid have, over the course of the project:

- Sited the electrical infrastructure within the mine property, well away from residences, such that the EMF contribution at residential properties is expected to be negligible
- Designed the line such that the clearance of the conductors above ground level is greater than that of the existing line, thereby reducing the EMF contribution at the relevant height of 1m above ground level

While it cannot be said with certainty that these measures are beneficial, they are certainly consistent with the notion of prudent avoidance.

6 Conclusions

Based on the design information currently available, Aurecon has assessed the electric and magnetic field contributions associated with the proposed 330kV Transmission Line 24 deviation against the relevant health guidelines and the principles of prudent avoidance. In summary, Aurecon's findings are:

Magnetic Fields

- The highest magnetic field contribution directly below the proposed Line 24 deviation is predicted to be 124mG under 85th percentile loads upon commissioning and 168mG under ultimate 85th percentile loads. Both occur at the low point of the span which has the greatest conductor sag, between Towers 32 and 33X. The higher of these is equivalent to 8.4% of the ICNIRP general public exposure reference level. At the edge of the easement, the predicted field contribution is approximately 26mG and 35mG under 85th percentile commissioning and ultimate loads respectively. The higher of these is equivalent to 1.8% of the ICNIRP general public exposure reference level.
- The typical magnetic field contribution at 1m above ground level is lower overall for the new section of Line 24 than for the existing, primarily due to the fact that it has been designed with greater conductor clearance to ground level. At the crossing of Line 25/26, the new line will now cross over the top of it instead of under it.
- Even under peak or emergency load conditions, the magnetic fields are still predicted to remain well within the relevant guideline reference level.
- A summary of the magnetic field contribution levels predicted for the existing and proposed new section of 330kV Line 24, including those calculated using TWA loads, is shown in Table 5.

Table 5 – Summary of Predicted Magnetic Field Contribution Levels for 330kV Line 24

Configuration	Highest Contribution Underneath Line	% of ICNIRP General Public Exposure Reference Level	Edge of Easement	% of ICNIRP General Public Exposure Reference Level
Existing Line 24 - 85th Percentile - TWA	 283mG 145mG	 14.2% 7.3%	 43mG 22mG	 2.2% 1.1%
Proposed Line 24 Deviation - 85th Percentile Commissioning - TWA Commissioning - 85th Percentile Ultimate - TWA Ultimate	 124mG 64mG 168mG 85mG	 6.2% 3.2% 8.4% 4.3%	 26mG 13mG 35mG 18mG	 1.3% 0.7% 1.8% 0.9%

Electric Fields

- The highest electric field contribution directly below the proposed Line 24 deviation is predicted to be 4.5kV/m, occurring at the low point of the span which has the greatest conductor sag, between Towers 32 and 33X. This is equivalent to 90% of the ICNIRP general public exposure reference level. At the edge of the easement, the predicted field contribution is approximately 1kV/m, or 20% of the ICNIRP general public exposure reference level.
- The typical electric field contribution at 1m above ground level is lower overall for the new section of Line 24 than for the existing as it has been designed with greater conductor clearance to ground level. This is particularly evident at the crossing of Line 25/26, where the new line will now cross over the top of it instead of under it.

- Even if the line were to be operated at a voltage 10% greater than the nominal voltage, the electric field contribution of the proposed line deviation is still predicted to remain well within the relevant guideline reference level.
- A summary of the magnetic field contribution levels predicted for the existing and proposed new section of 330kV Line 24 is shown in Table 6.

Table 6 – Summary of Predicted Electric Field Contribution Levels for 330kV Line 24

Configuration	Highest Contribution Underneath Line	% of ICNIRP General Public Exposure Reference Level	Edge of Easement	% of ICNIRP General Public Exposure Reference Level
Existing Line 24 - Nominal Voltage	8.6kV/m	> 100%	1kV/m	20%
Proposed Line 24 Deviation - Nominal Voltage	4.5kV/m	90%	1kV/m	20%

Prudent Avoidance Measures

- Consistent with the notion of prudent avoidance, Centennial Mandalong and/or TransGrid have:
  - Sited the electrical infrastructure within the mine property, well away from residences, such that the EMF contribution at residential properties is expected to be negligible.
  - Designed the line such that the clearance of the conductors above ground level is greater than that of the existing line, thereby reducing the EMF contribution at the relevant height of 1m above ground level.
- While it cannot be said with certainty that these measures are beneficial, they are certainly consistent with the notion of prudent avoidance.

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