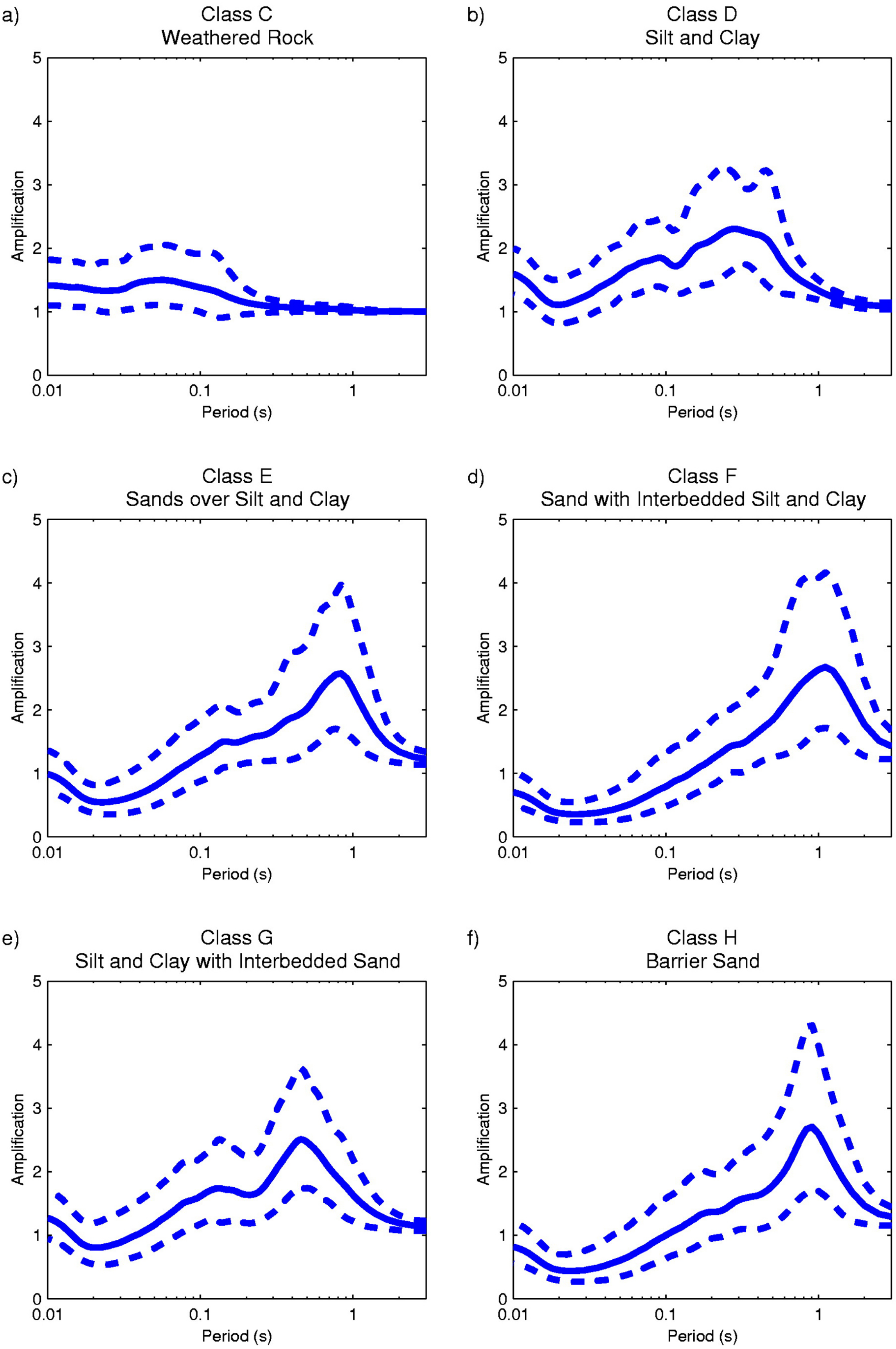

*Figure 4.12: Amplification factors for Newcastle site classes, based on an input rock motion from a moment magnitude 5.5 event with PGA of 0.25g. The solid line is the median amplification factor calculated from 50 randomly generated soil models, and the dashed lines represent the 16th and 84th percentiles (ie ± the variability parameter in log space)*

A comparison of the amplification factors for an earthquake of moment magnitude 5.5 and a PGA of 0.25 g with those suggested by the Australian Standard for earthquake loading (AS1170.4, 1993) highlights the significance of the new amplification factors (Figure 4.13). Figure 4.13 (a) compares site class C with the weak rock class from the standard. Generally these two sets of amplification factors are very similar. However, the amplification factors for site class C are greater than those for weak rock at periods less than 0.3 s.

Figure 4.13 (b) compares the amplification factors for site classes D, E, F and G with the factors from the Australian earthquake loading standard for soils containing 6-12 m of silt. The amplification factors from the loading standard do not accurately match the calculated amplification factors for any of the site classes displayed here. For periods less than 0.6 s, the factors from the standard are smaller than the amplification factors calculated for any of the Newcastle and Lake Macquarie site classes.

Figure 4.13 (c) compares site class H with the soil class from the Australian earthquake loading standard containing greater than 12 m of silt. The factors from the standard are generally less than those calculated for site class H. This difference is greatest near a period 0.9 s which is where site class H has its maximum amplification.

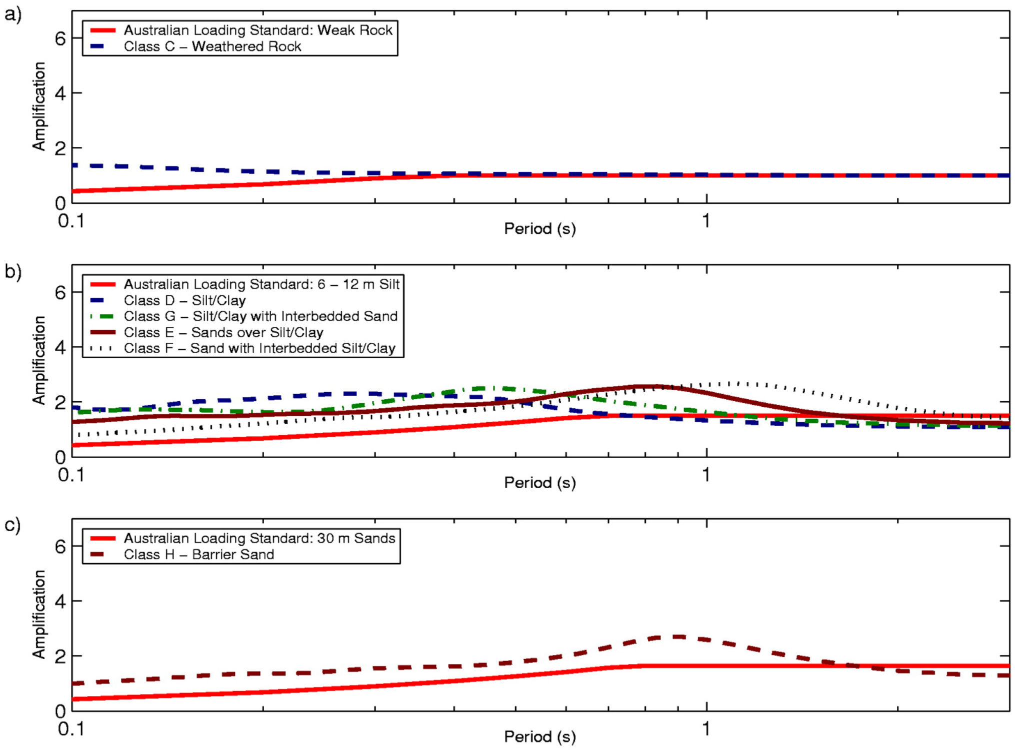

*Figure 4.13: Comparison of amplification factors calculated for the Newcastle and Lake Macquarie site classes with the amplification factors suggested by the Australian standard for earthquake loading (AS1170.4, 1993)[15].*

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[15] *The Australian earthquake loading standard presents a single number, known as the site factor (S), for each soil class. In practice, this number is limited to be the minimum of S or $2T^{2/3}$, where T is period in seconds, to create the period dependent amplification factors presented in Figure 4.13.*

# 4.6 Earthquake Hazard

## 4.6.1 Introduction

As mentioned at the start of this Chapter, earthquake hazard is typically measured in terms of the level of ground shaking that has a certain chance of being exceeded in a given time period. This Section presents two levels of earthquake hazard for the study region, specifically the hazard that has a 10% chance of being exceeded in 50 years and the hazard that has a 2% chance of being exceeded in 50 years. These levels of hazard correspond to impacts with return periods of approximately 500 years and 2,500 years respectively. We have used PGA and spectral acceleration as our indicators of earthquake hazard. The reader should note that other parameters such as spectral displacement and spectral velocity are also important, especially for medium-rise and high-rise buildings and other large structures.

## 4.6.2 Calculation of Earthquake Hazard

The previous four Sections described the source, attenuation and site response models that have been developed for the Newcastle and Lake Macquarie region. In order to calculate the earthquake hazard in the region, it is necessary to amalgamate these models. The approach taken in this study is outlined below:

1. A spacing of 250 m was used to create a uniformly spaced grid of sample points at which the hazard was calculated.
2. Earthquakes were simulated using the method described in Section 4.3.
3. For each earthquake - sample point combination the following procedure was carried out:
   - An attenuation function was selected by choosing a random variation from the median attenuation model[16];
   - The attenuation function was used to determine the rock RSA at the sample point;
   - The appropriate median amplification factor was selected based on the sample point’s site classification, the magnitude of the earthquake and the level of the rock RSA, and;
   - A random variation of the amplification factor was selected[16] and used to amplify the rock RSA to produce a regolith RSA.
4. Each regolith RSA had a likelihood of occurrence the same as its causative earthquake (Section 4.3).
5. For a given level of hazard identify the maximum regolith RSA that has at least that chance of being exceeded in the given time frame. For example, given a hazard level of 10% probability of exceedance in 50 years, the hazard at a sample point is defined as the maximum RSA that has at least a 10% chance of being exceeded in 50 years.

## 4.6.3 10% Chance of Exceedance in 50 Years (approx. 500 year return period)

The Australian earthquake loading standard, AS1170.4-1993, presents earthquake hazard in terms of an ‘acceleration coefficient’ that has a 10% chance of being exceeded in 50 years. This acceleration coefficient is considered equivalent to peak ground acceleration (PGA). Figure 4.14 and Figure 4.15 allow a comparison of the earthquake hazard from AS1170.4-1993 with the equivalent hazard calculated in this study. Both maps have the same trend of increasing hazard towards the north-east of the study region. However, the hazard calculated within this study is typically greater than the hazard suggested by the Australian earthquake loading standard.

The hazard maps presented in Figure 4.14 and Figure 4.15 were calculated using the *peak ground acceleration* or acceleration coefficient that would be experienced on a rock outcrop. However, the buildings in Newcastle and Lake Macquarie are not built on rock, but on varying thicknesses of regolith (Section 4.5.2). Figure 4.16 presents the earthquake hazard on regolith in the study region. This figure demonstrates that the

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[16] *Random variations for both the attenuation function and the amplification factors were selected by randomly choosing a scaling variable from a normal distribution with a zero mean and a standard deviation of one. This scaling variable was multiplied against the appropriate variability parameter and then added to either the attenuation function of the amplification factors.*

presence of regolith increases the earthquake hazard in the study region compared to hard rock. All of the regolith site classes have a similar, amplifying effect on PGA values.

The damage that is experienced by buildings is often influenced not only by the peak ground acceleration, but also the level of ground shaking at a specific period of vibration. For example, low- to medium-rise structures are typically more vulnerable to ground shaking that has a *period of vibration of approximately 0.3 s* than they are to PGA. Figure 4.17 and Figure 4.18 present maps of earthquake hazard for both outcropping rock and regolith, based on the response of idealised low- to medium-rise structures. The hazard at 0.3 s on rock is very similar to the PGA hazard on rock presented in Figure 4.15. Both figures indicate a similar level of hazard, as well as a trend of increasing hazard to the north-east. A comparison of Figure 4.17 and Figure 4.18 demonstrates that the regolith causes an increase in the earthquake hazard. Moreover, unlike the PGA hazard presented in Figure 4.16, variations in the regolith material cause significant variations in the hazard across the study region, with areas of deeper regolith generally corresponding to regions of higher hazard. The regions of highest hazard are generally located on the silts and clays of site class D.

Medium- to high-rise structures are typically more vulnerable to ground shaking that has a *period of vibration of approximately 1 s*. Figure 4.19 and Figure 4.20 present maps of earthquake hazard for both outcropping rock and regolith, based on the response of idealised medium- to high-rise structures. The spectral acceleration at 1 s on rock is less than either the PGA on rock or the spectral acceleration at 0.3 s on rock. Similarly, the spectral acceleration at 1 s on regolith is less than either the PGA on regolith or the spectral acceleration at 0.3 s on regolith.

A comparison of Figure 4.19 and Figure 4.20 demonstrates that the regolith causes an increase in the earthquake hazard as compared to the hazard on rock. As with the hazard at 0.3 s on regolith, variations in the regolith material cause significant variations in the hazard across the study region. However, unlike the hazard at 0.3 s on regolith, the silts and clays of site class D do not vary the hazard at 1 s from the hazard experienced on the weathered rock of site class C.

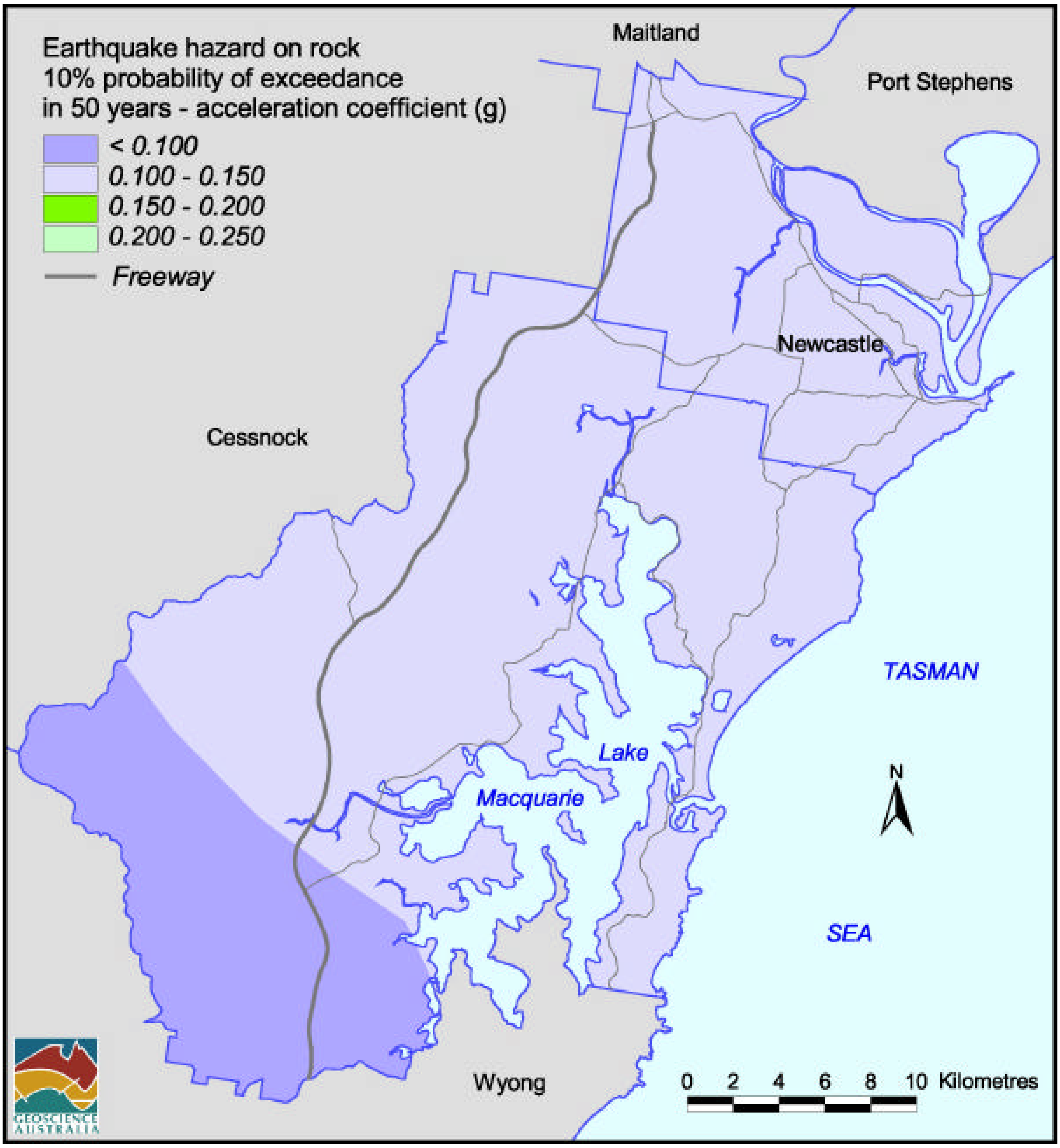

*Figure 4.14: Earthquake hazard on rock in Newcastle and Lake Macquarie as suggested by the Australian earthquake loading standard, AS1170.4-1993. Earthquake hazard is defined as the acceleration coefficient (considered equivalent to peak ground acceleration) that has a 10% chance of being exceeded in 50 years*

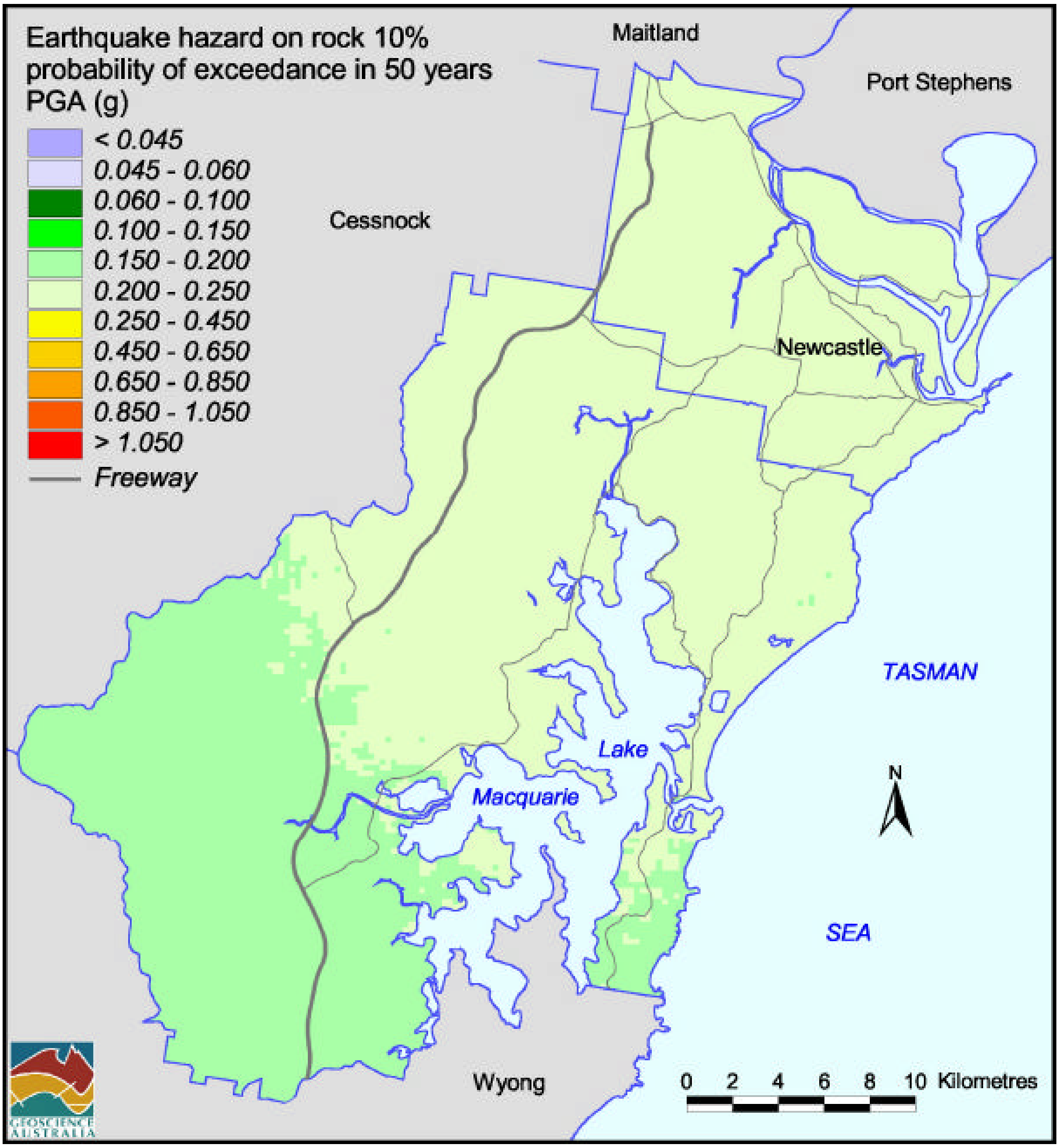

*Figure 4.15: Earthquake hazard on rock in Newcastle and Lake Macquarie as suggested by the hazard assessment conducted for this study. Earthquake hazard is defined as the peak ground acceleration that has a 10% chance of being exceeded in 50 years*

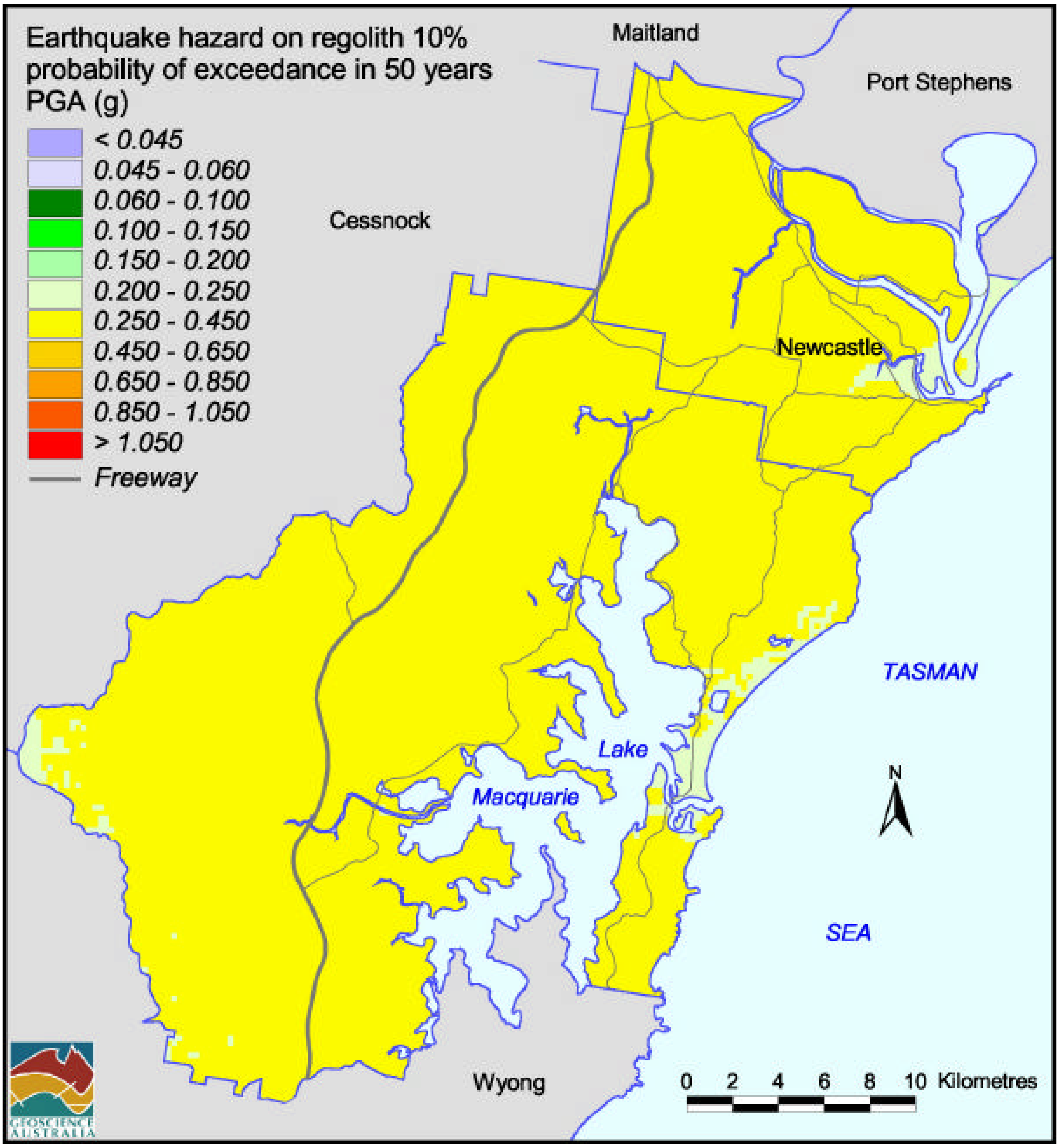

*Figure 4.16: Earthquake hazard on regolith in Newcastle and Lake Macquarie as suggested by the hazard assessment conducted for this study. Earthquake hazard is defined as the peak ground acceleration that has a 10% chance of being exceeded in 50 years*

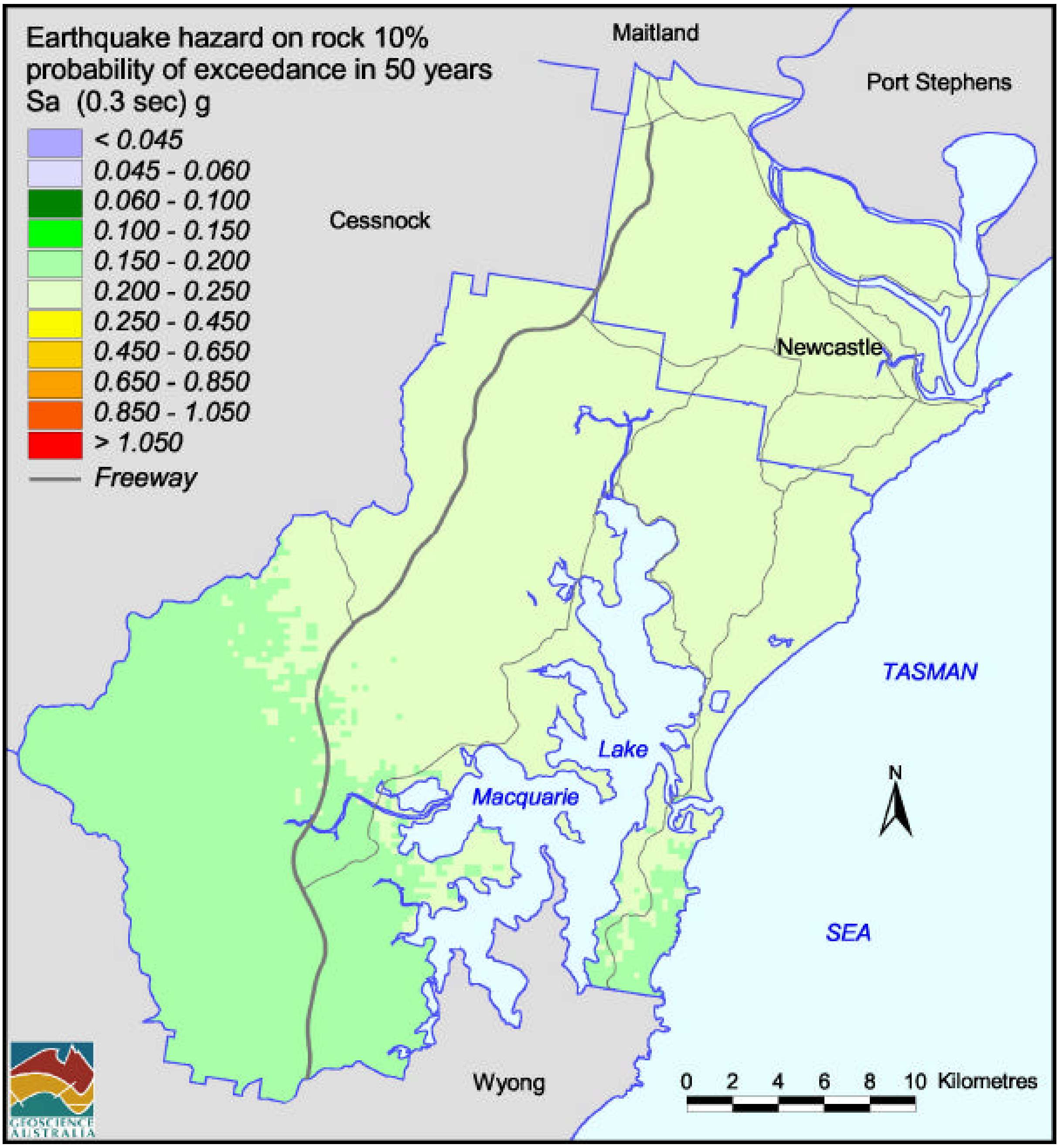

*Figure 4.17: Earthquake hazard map on rock with a 10% chance of being exceeded in 50 years. Hazard is defined by the response of idealised low- to medium-rise buildings with a natural period of 0.3 s*

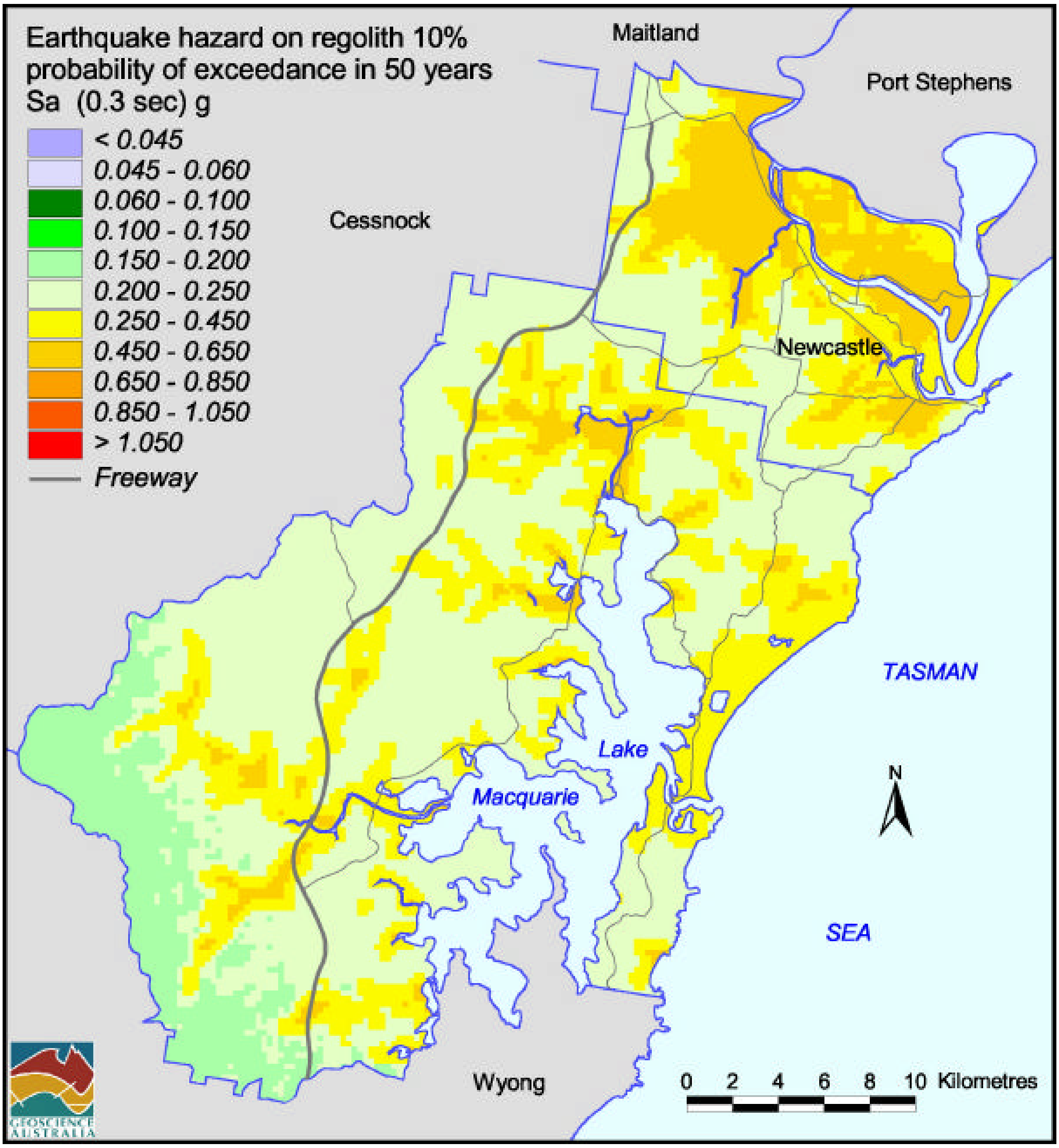

*Figure 4.18: Earthquake hazard map on regolith with a 10% chance of being exceeded in 50 years. Hazard is defined by the response of idealised low- to medium-rise buildings with a natural period of 0.3 s*

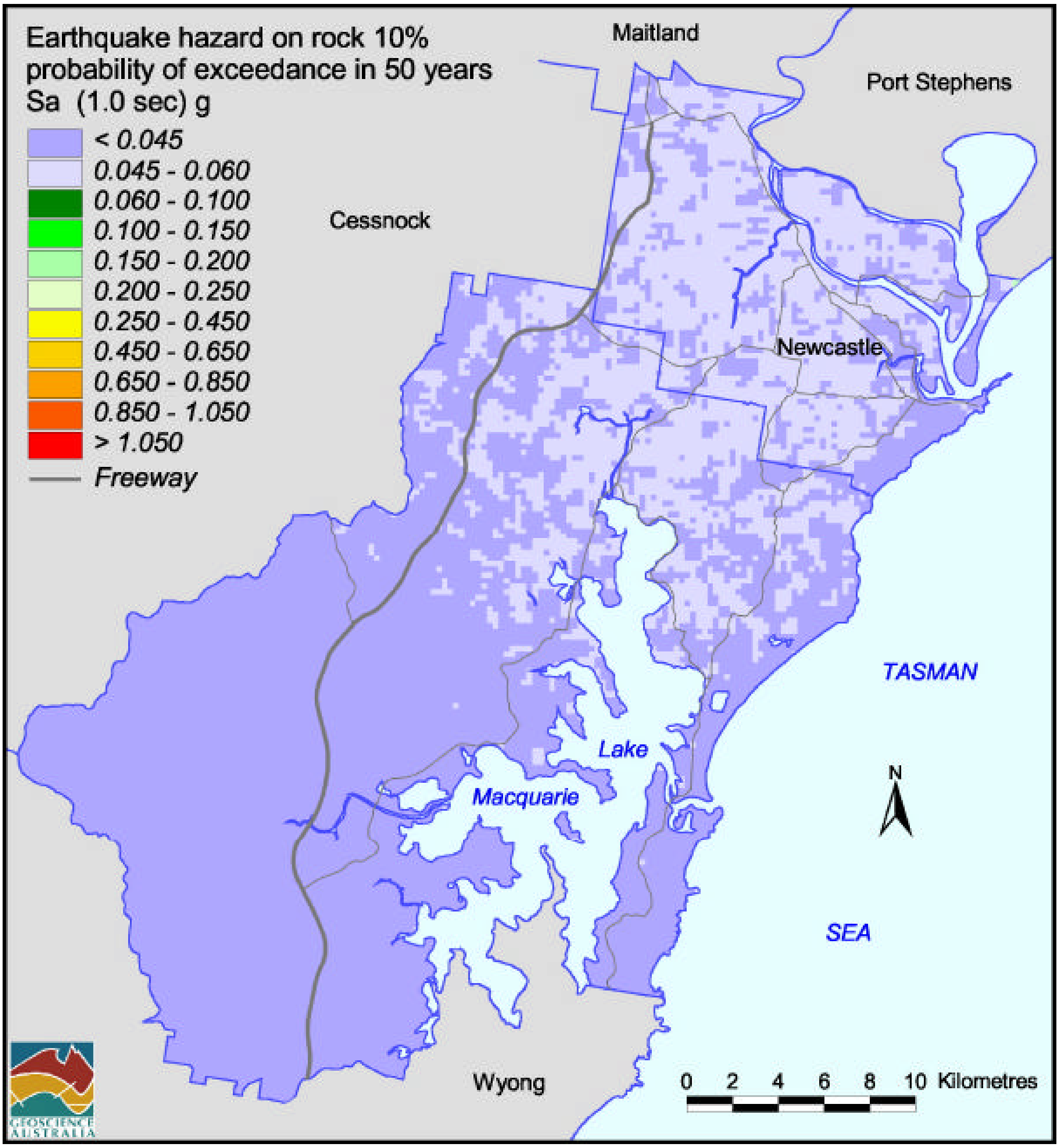

*Figure 4.19: Earthquake hazard map on rock with a 10% chance of being exceeded in 50 years. Hazard is defined by the response of idealised medium- to high-rise buildings with a natural period of 1 s*

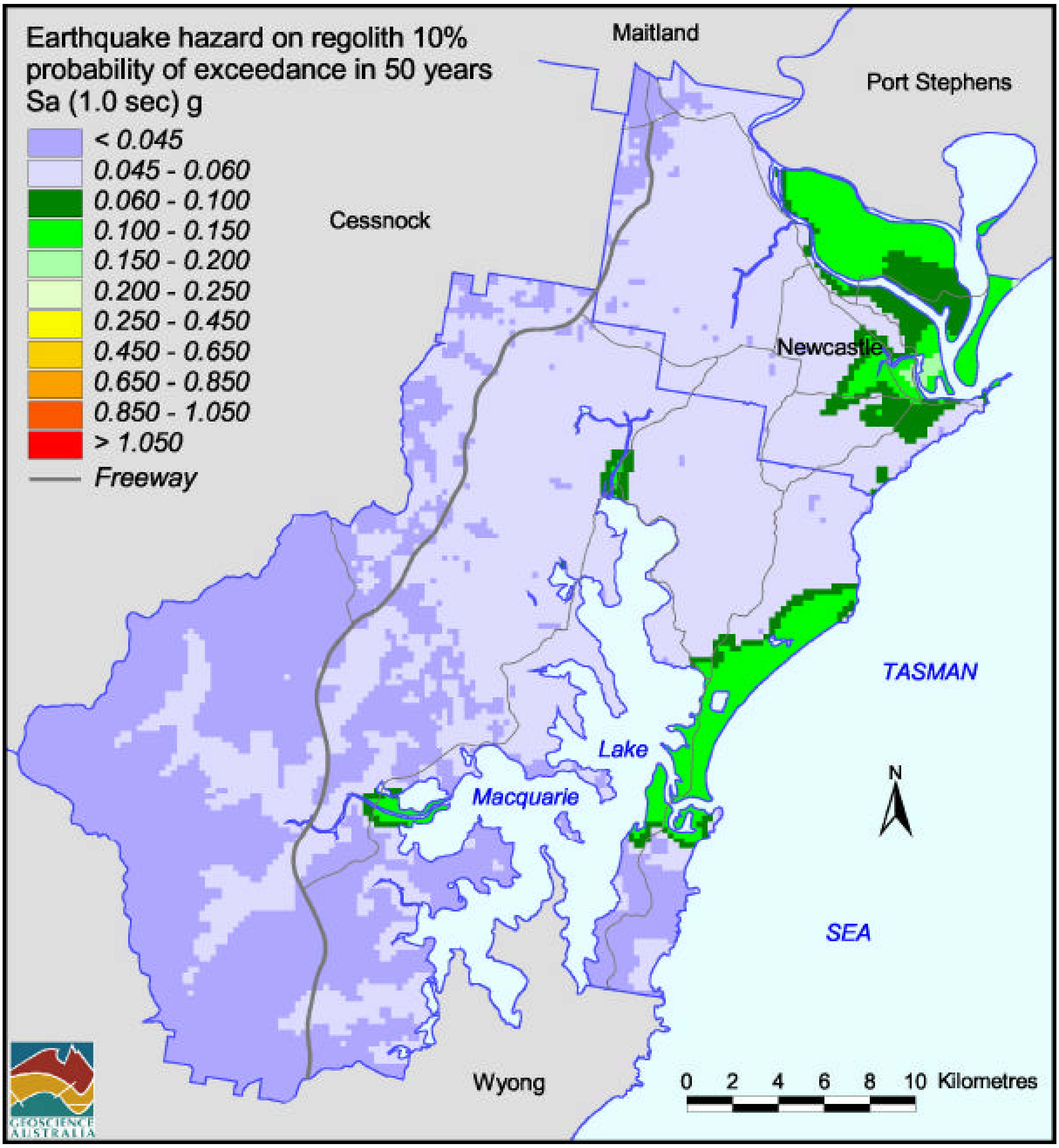

*Figure 4.20: Earthquake hazard map on regolith with a 10% chance of being exceeded in 50 years. Hazard is defined by the response of idealised medium- to high-rise buildings with a natural period of 1 s*

### 4.6.4 2% Chance of Exceedance in 50 Years (approx. 2,500 year return period)

Whilst the Australian earthquake loading code describes hazard in terms of the level of ground shaking that has a 10% chance of being exceeded in 50 years, it is often important to consider the possible effect of less likely but more damaging events. Consequently, this study has also determined the earthquake hazard that has a 2% chance of being exceeded in 50 years. This probability of being exceeded corresponds to events with a return period of approximately 2,500 years.

Earthquake hazard with a 2% chance of being exceeded in 50 years, on rock and regolith for PGA, 0.3 s and 1 s is presented in Figure 4.21 - Figure 4.26. The earthquake hazard presented in these figures is significantly greater than the corresponding hazard that has a 10% chance of being exceeded in 50 years. Despite the increase in the level of hazard, the same general trends are present in these maps of hazard as in the maps of hazard with a 10% chance of being exceeded in 50 years, specifically:

- The hazard on rock demonstrates a trend of increasing hazard to the north-east of the study region for hazard at PGA, 0.3 s and 1 s;
- The hazard on rock at PGA and 0.3 s is very similar across the entire study region, however the hazard at 1 s is significantly lower than either of these;
- The presence of regolith causes a significant increase in hazard across the study region for hazard at PGA, 0.3 s and 1 s;
- Variations in the regolith material cause variations in the hazard across the study region, especially for the hazard at 0.3 s and 1 s;
- The hazard at 0.3 s on regolith is greatest on the silts and clays of site class D, and;
- The hazard at 1 s on the silts and clays of site class D and the hazard at 1 s on the weathered rock of site class C tends to be very similar and noticeably lower than the hazard at 1 s on any of the other site classes.

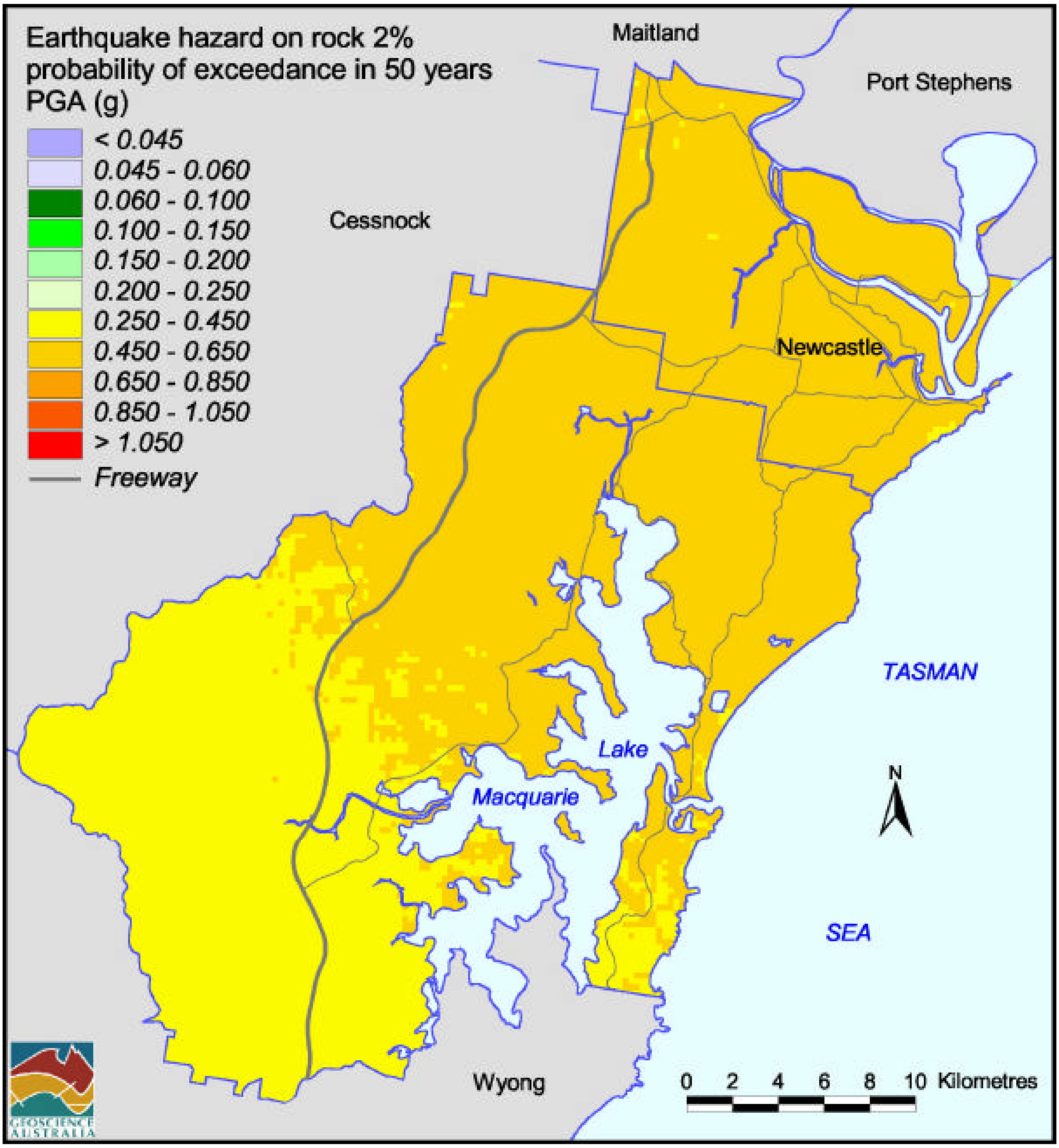

*Figure 4.21: Earthquake hazard on rock in Newcastle and Lake Macquarie as suggested by the hazard assessment conducted for this study. Earthquake hazard is defined as the peak ground acceleration that has a 2% chance of being exceeded in 50 years*

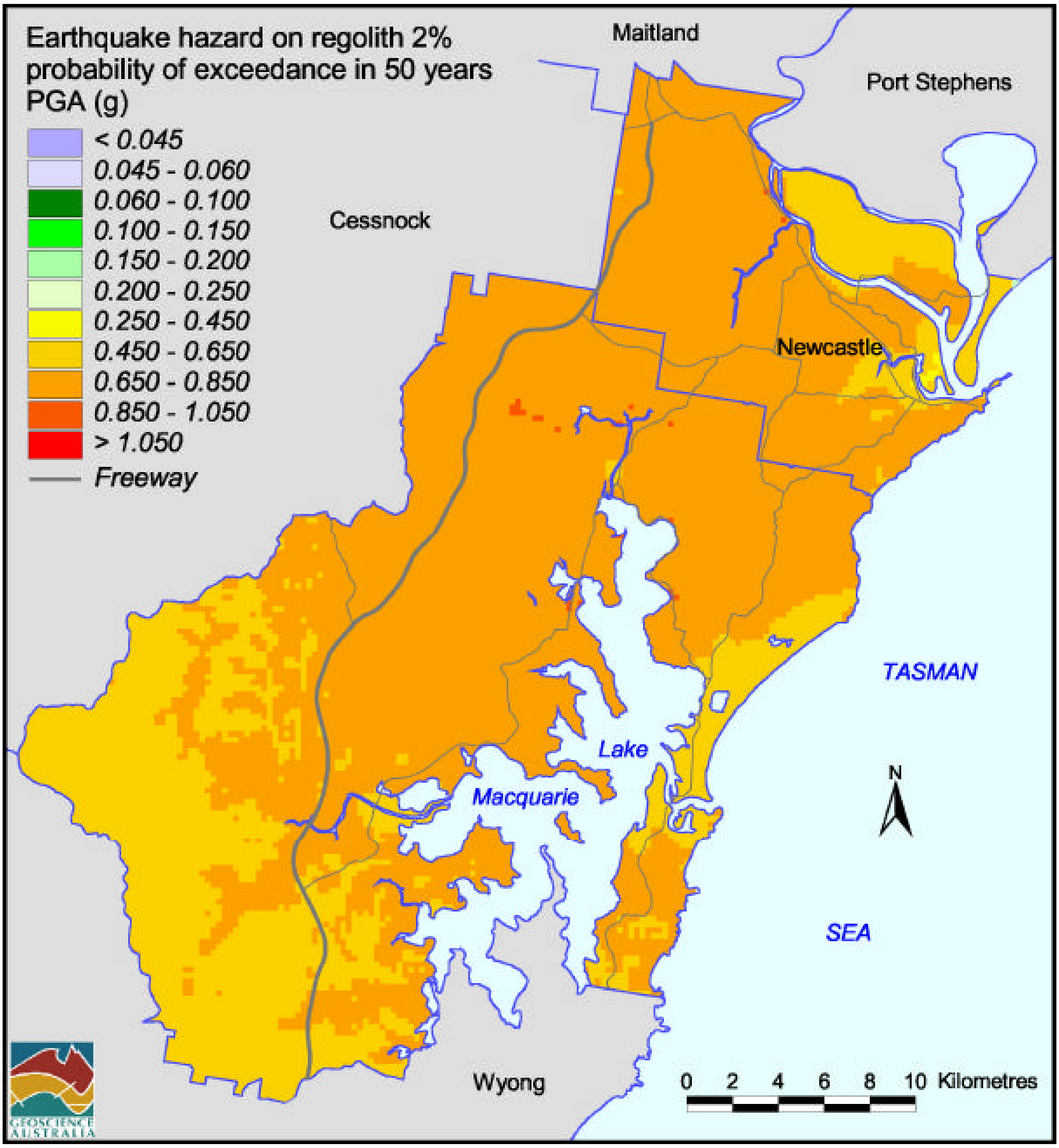

*Figure 4.22: Earthquake hazard on regolith in Newcastle and Lake Macquarie as suggested by the hazard assessment conducted for this study. Earthquake hazard is defined as the peak ground acceleration that has a 2% chance of being exceeded in 50 years*

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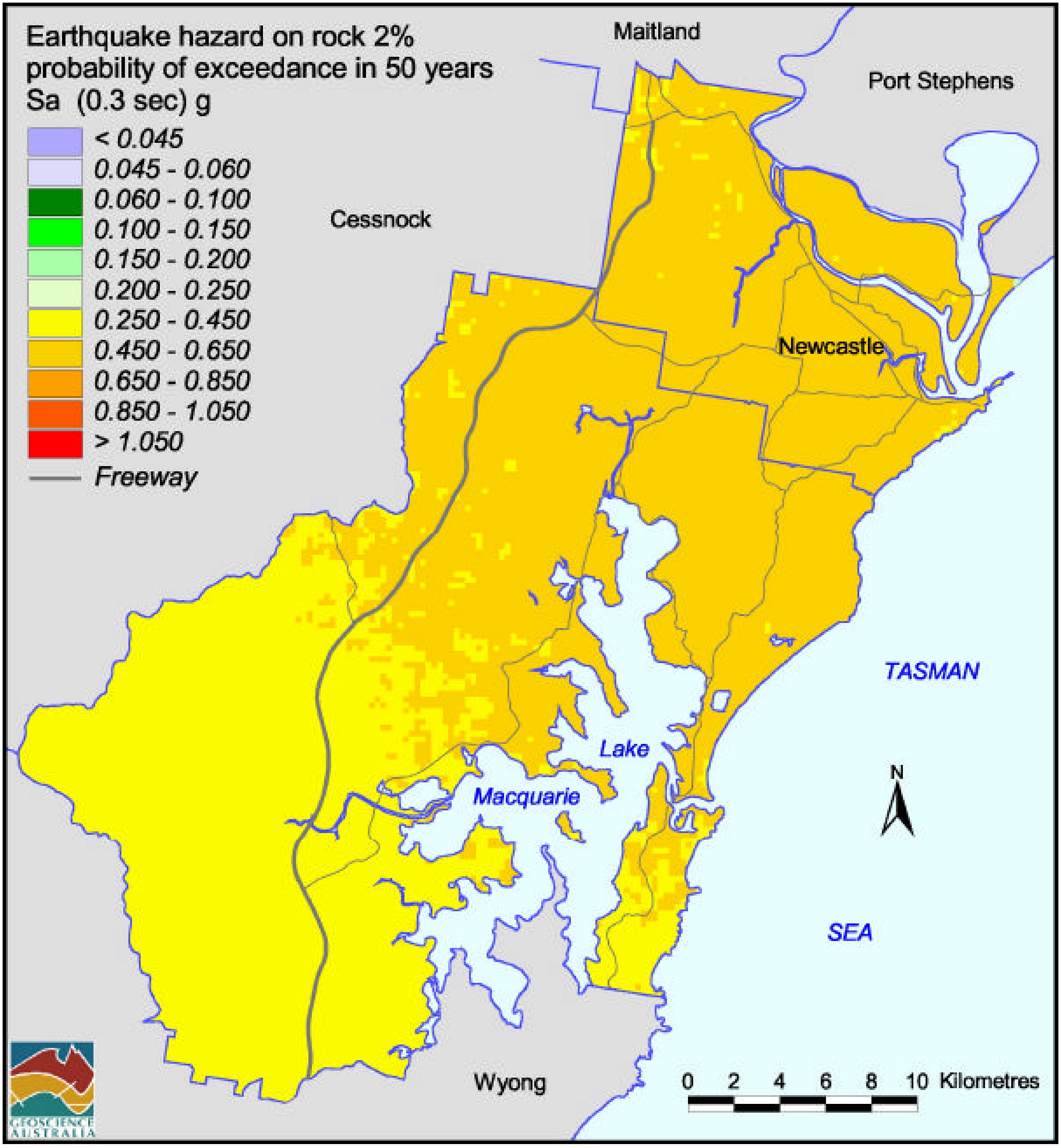

*Figure 4.23: Earthquake hazard map on rock with a 2% chance of being exceeded in 50 years. Hazard is defined by the response of idealised low- to medium-rise buildings with a natural period of 0.3 s*

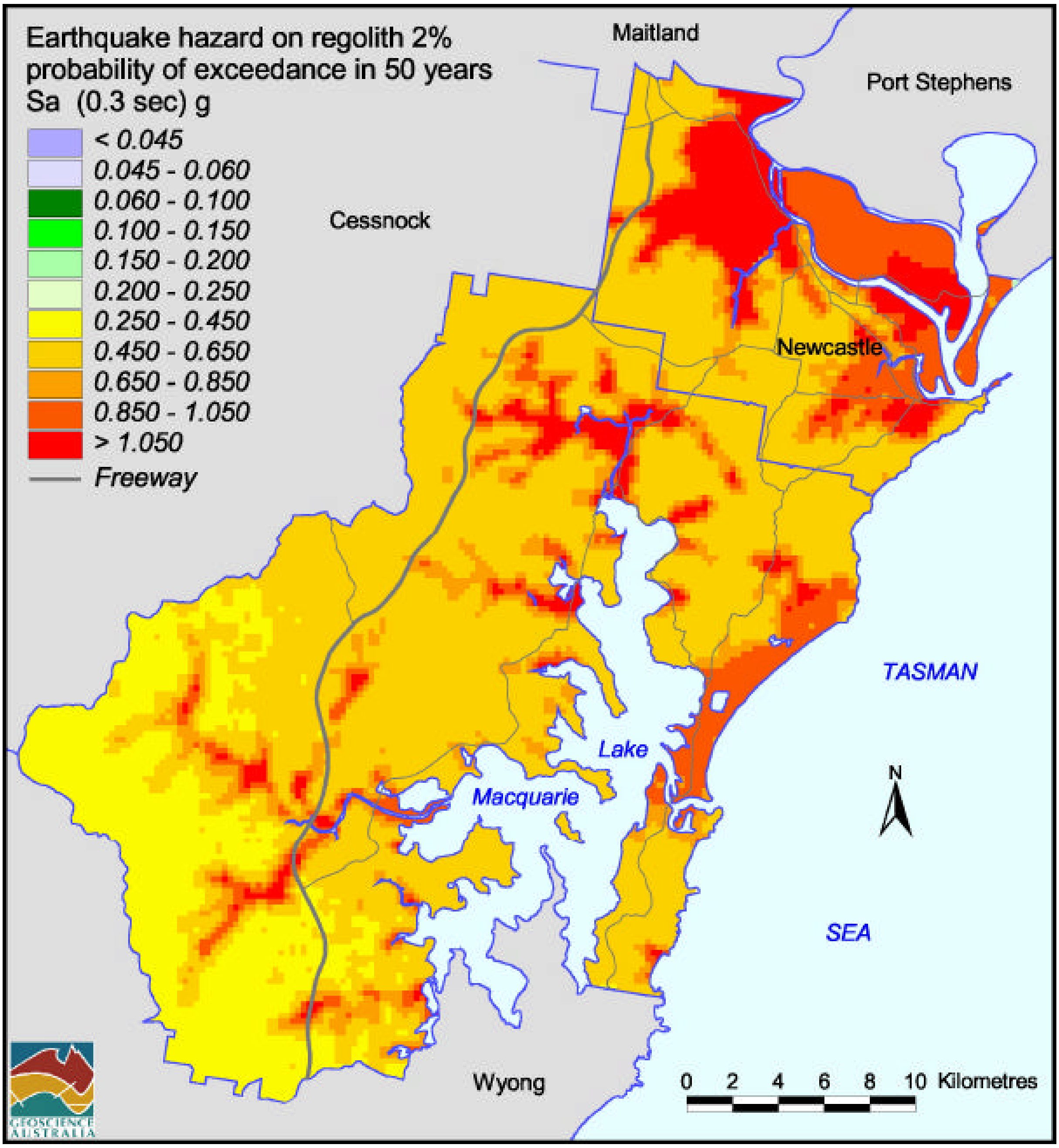

*Figure 4.24: Earthquake hazard map on regolith with a 2% chance of being exceeded in 50 years. Hazard is defined by the response of idealised low- to medium-rise buildings with a natural period of 0.3 s*

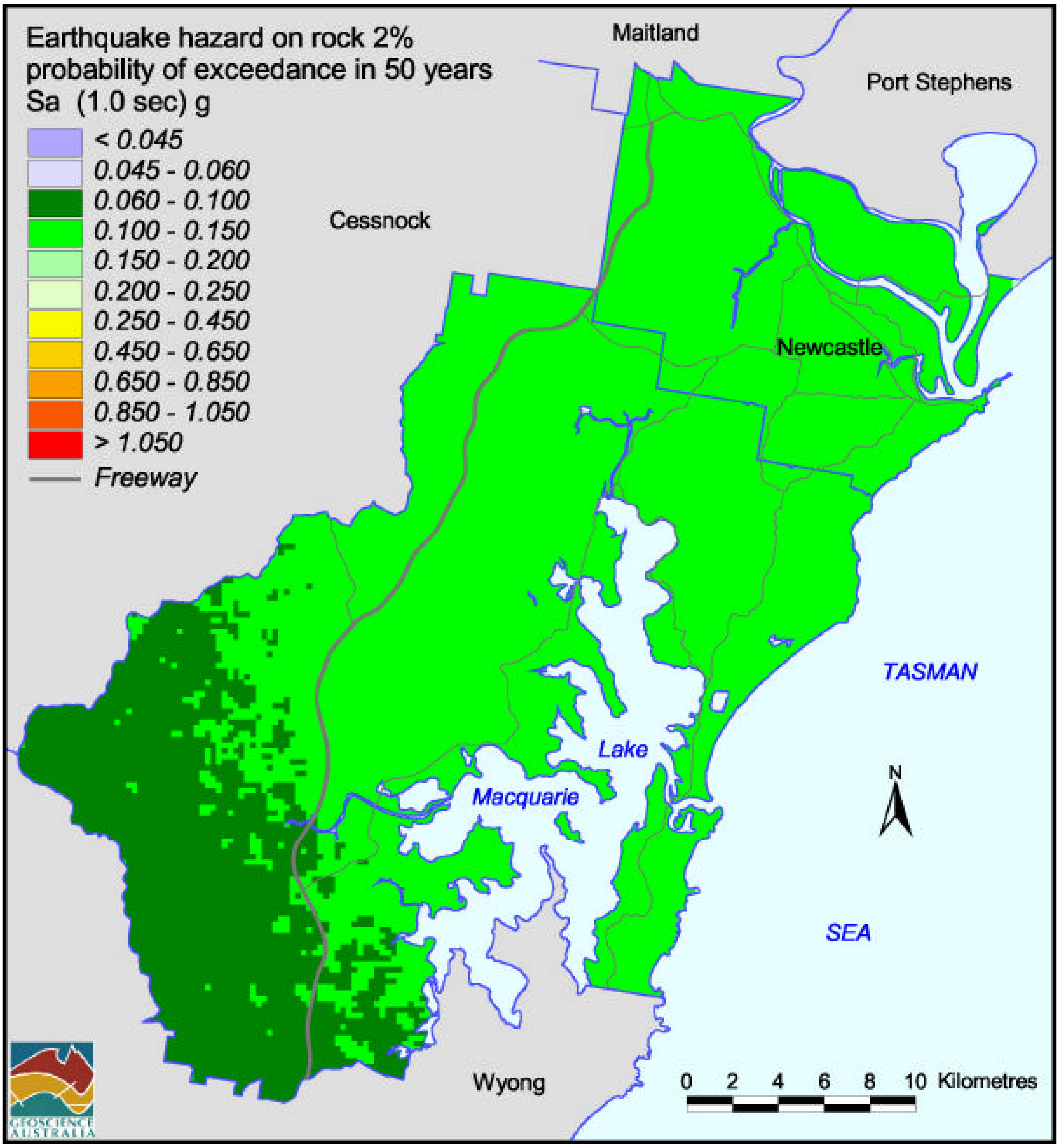

*Figure 4.25: Earthquake hazard map on rock with a 2% chance of being exceeded in 50 years. Hazard is defined by the response of idealised medium- to high-rise buildings with a natural period of 1 s*

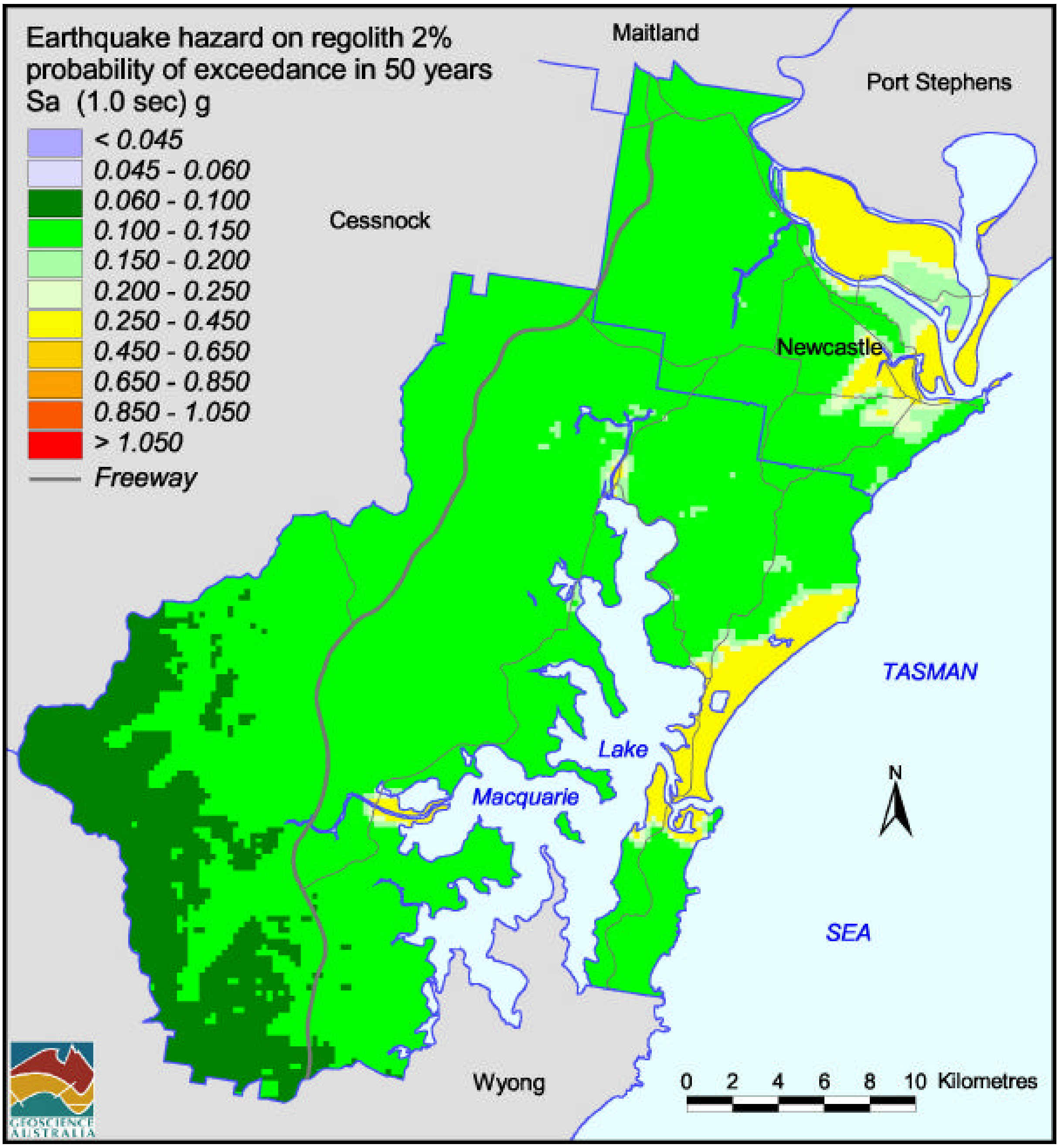

*Figure 4.26: Earthquake hazard map on regolith with a 2% chance of being exceeded in 50 years. Hazard is defined by the response of idealised medium- to high-rise buildings with a natural period of 1 s*

## 4.7 Assumptions and Uncertainties of the Earthquake Hazard Models

The earthquake hazard results in this work are based on numerous assumptions and idealisations ranging from the empirical relationships used to determine rupture dimension through to the use of an equivalent-linear methodology for modelling site response. The majority of these are thought to have minimal impact on the results presented in this Chapter. However, there are some assumptions and uncertainties that are thought to strongly influence the results that have been presented, and these are discussed below.

### 4.7.1 Earthquake Source Model – Assumptions and Uncertainties

There are two key issues relating to the earthquake source zones that have had a significant impact on the earthquake hazard results, specifically:

1. The Gutenberg-Richter (GR) relationships defined for the Newcastle Triangle and Newcastle Fault zones are based on datasets that have a great deal of uncertainty associated with them. The GR relationship for the Newcastle Triangle Zone is based on a historical record of seismicity that is very short and generally incomplete. The GR relationship for the Newcastle Fault Zone is based on poorly constrained estimates of rupture age and total slip for faults that may or may not be currently active. Variations in the GR relationships for either of these source zones would have a significant affect on the estimated hazard.
2. The definition of the source zones in the region has been based partly on an interpretation of the local structural geology. Variations in this interpretation would influence the GR relationships defined in the region and consequently would change the estimated earthquake hazard.

### 4.7.2 Attenuation Model – Assumptions and Uncertainties

The attenuation model used in this study is one of the most important inputs to the earthquake hazard analysis. Every estimate of earthquake ground shaking is based on this model's prediction of earthquake attenuation. Consequently, a change in the attenuation model could potentially cause a significant change in the estimated hazard. As mentioned previously, the attenuation model of Toro et al. (1997) is based on the tectonic and geological conditions of central and eastern North America. To date there has been no detailed analysis of the applicability of this model to Australian conditions, and consequently there is still some question as to the appropriateness of this attenuation model.