From: li82303@bigpond.net.au
Sent: Sat, 18 Sep 2021 23:56:39 +1000
To: "Contact Us" <contactus@launceston.tas.gov.au>;"Michael Stretton" <michael.stretton@launceston.tas.gov.au>
Subject: Representation LPS SPC 17 September 2021
Attachments: TRA Inc Representation LPS SPC 17 September 2021 #1.pdf

Please see attached Representation
Tasmanian Ratepayers Association Inc.

Tasmanian Ratepayers' Association Inc.
P.O. Box 1035,
LAUNCESTON TAS 7250
Tel. 03 6331 6144 email li82303@bigpond.net.au

17 September 2021

General Manager
City of Launceston Council
Town Hall
St John Street
LAUNCESTON TAS 7250 by email to contactus.tas.gov.au

Dear Mr Stretton,

Re: Draft Launceston Local Provisions Schedule (LPS) exhibited under section 35B of the Land Use Planning and Approvals Act 1993 until Saturday 18th September 2021

We refer to the relative advertisements published in The Examiner Newspaper. This is our representation.

LEVEL OF CONSULTATION WITH CITIZENS

The State Planning Scheme (SPC), and now the Draft Launceston Local Provisions Schedule (LPS), is an extremely lengthy and complex set of documents, and with the 35 separate Supporting Reports, presents a completely overwhelming amount of information that is completely daunting to any 'average observer' citizen of Launceston to navigate and gain an understanding of the implications that these documents will have, not only on individual properties, but in context of the many natural and cultural heritage overlays upon which the ordinary citizen expects to enjoy in their protection of public amenity, and appreciation of their liveability more generally, of the City.

It will not be realised or recognised until a future development proposal threatens amenity and liveability values, that the degree to which the SPS and LPS is left wanting and fails to protect the citizens and public more broadly, that the 'average observer' will be shocked and seriously aggrieved.

That realisation will, sadly, come too late.

It is Council's duty and obligation to develop these local provisions, respecting matters that are important to our community, as the essential complement to the Tasmanian Planning Scheme, and fundamental to making sure the LPS achieves:

- Zones, specific area plans and codes for particular purposes that are not provided for in the Tasmanian Planning Scheme;
- Code lists such as the local heritage listed places; and
- Site specific qualifications for exceptional circumstances.

We are not at all confident that these elements of this task have been completed adequately, comprehensively or being effectively assessed or included.

Regardless of superficial and relatively flippant social media promotions undertaken, and face-to-face promotional campaigns by ill-equipped and untrained junior staff engaged by Council in public malls etc., we believe that whether it has been the method used or failure of the community to engage, that the community views have not been elicited accurately or effectively.

In an environment where social media gives 'everyone' a voice and public sentiment is of empowerment, independence and even defiance, it has never been more important to be completely transparent and involve stakeholders and those in the community who consider they have a 'community of ownership and interest' (COI), in the future protection, and also the advancement of Launceston, than now.

- Yes, it is true that over the 6-week period there were 4 'drop-in' sessions across the city (Town Hall 10-2 30 July, Suburban Bowls Club 10-2 3 August, Suburban Community Club 10-2 6 August and Town Hall 6-9 19 August) These were all during business hours, which excludes workers, and only one in the evening in the city centre. We have no idea about the attendance at these sessions, but the total number of 8 hrs in group consultations, hardly seems adequate for around 55,000 adult citizens of Launceston.

- Yes, it is true that an individual appointment could be booked at Town Hall 10-4 weekdays. Again, only probably really practical for City Centre workers in their limited lunch-break periods or retirees/unemployed citizens.

Recognising the hesitancy of many citizens to attend any public or face-to-face interviews during the COVID19 pandemic emergency, few citizens would be willing or be prepared to participate.

- Yes, it is true that telephone enquiries could be made, but only one officer was delegated to receive telephone calls 10-4 weekdays. Again, practical only if one's employer allowed calls to be made during working hours, or retirees/unemployed citizens.

- Yes, it is true email communications were invited, again only if an interested person had access to, or could operate a computer. The digital divide for Launceston citizens in this regard, would be significant.

Accordingly, the response level, the validity and reliability, of any information surveys or consultations that may have been undertaken in relation to the SPS and LAC in particular, is unknown, but under-coverage (in Launceston's adult population of around 55,000) is very likely to have been high.

SCENIC PROTECTION OVERLAYS

As an example, the Central Hills area of Launceston (Windmill Hill, extends in length from Brisbane Street to Wentworth Street, along the High Street ridge) and has traditionally been recognised as a principle area of scenic importance, and these values been recognised with a Scenic Protection overlay, albeit with boundaries significantly curtailed in more-recent Planning Maps. This Scenic Protection overlay has now been deleted altogether, with the short statement following an observation that because the area includes several public parks, some with heritage status, that:
"It is determined that the Central Hills Precinct can be excluded from the SPC."
No community consultation within the Central Hills Precinct citizens was undertaken and accordingly TRA Inc. cannot support that determination, being an example of how inadequate this SPC research and preparation process has been.
Not only should a Scenic Protection overlay be reinstated for this precinct, but its boundaries should be extensively extended to fully cover the hill, and so as to protect the now-threatened scenic values.

Whilst time and resource limitations prevent us from further investigations of the extent of Scenic Protection overlays being included/developed for other areas of Launceston, we note that at Trevallyn, a similar Planning Officer approach has been taken in an important hilltop area where Scenic Protection overlay is already in place (albeit only as high as a questionable contour apparently defining a 'military crest'), to simply declare that "*the Trevallyn Precinct can be excluded from the SPC."*
Once again, the citizens of Trevallyn have not been specifically consulted or even had this exclusion of an overlay drawn clearly to their attention.
Trevallyn is the most viewed area of the city, immediately flanking the northern side of Cataract Gorge Reserve, and from the most popular tourist viewpoints at Kings Park, Royal Park, Home Point, Seaport and Silo's Hotel, not to mention the panorama viewed from Victoria Square (Windmill Hill Reserve) and the Central Hills Precinct itself. It will be a failure of Council if a Scenic Protection Overlay is not included for Trevallyn Precinct.

CULTURAL HERITAGE PROTECTION

Cultural Heritage Protection, for a city that is acknowledged as Australia's third oldest city with valuable cultural amenity and tourism values, has been grossly neglected during the preparation of this Planning Scheme and more-over the SPC's. Since preparation of the 1996 Planning Scheme, the responsible Planning Officers, having admitted this neglect in better-defining the identification of existing heritage places, completing heritage surveys, and defining heritage areas or precincts, and where at that Scheme's Planning

Commission Hearing, the Manager of Planning was called upon and agreed to complete this task within the subsequent 6 months period and return to the Commission with a subsequent amendment for their consideration and adoption, but in spite of reminders, has utterly failed to deliver.

The basis of the “Heritage List” in the preceding versions of the Launceston Planning Scheme, was the **REGISTER of the National Trust of Australia (Tasmania), last reviewed in May 1997.** All of the research and work undertaken in the preparation of the REGISTER and presented to Launceston City Council, was done gratis by the National Trust’s Expert Committee, and this was also the basis of all entries to the then REGISTER OF THE NATIONAL ESTATE.

The basis of the TASMANIAN HERITAGE REGISTER gazetted in 2002, was by legislative provision formed automatically from the NATIONAL TRUST’S REGISTER and the REGISTER OF THE NATIONAL ESTATE (see above for its basis).

In spite of Council’s commissioning (firstly prior to 2002) of consultant PAUL DAVIES PTY LTD to present ***THE LAUNCESTON HERITAGE STUDY*** –

- The preparation of a thematic history of the Launceston area;
- Field survey work to identify potential heritage items and conservation areas and;
- The preparation of a final report inventory of the properties and conservation areas being recommended for inclusion as items of heritage significance to Launceston;

nothing has been completed, concluded or now included in the Planning Scheme or SPC.

That means that virtually nothing new has been considered for entry onto the Schedule since 1997, a period of almost 25 years.
During this 25-year period, countless unrecognised, non-considered heritage places have been lost, destroyed or disfigured, all due principally to these places not being afforded heritage “protection” triggered for consideration as a discretionary matter when Development Approvals were being sought.

Resources and time constraints are preventing TRA Inc. from furthering this issue here at present, in the hope and expectation that other representors will be able to expand on this task.

LAND CAPABILITY

Various hazards, risks and areas of unstable land within the Launceston Planning Scheme area, are disregarded and ignored, and with important questions of Land Capability unanswered. During recent years and particularly during Council’s preparation of these SPC’s and contributing to the preparation of the State-wide provisions, our Association and others of like mind, have made many, many representations concerning advertised Development Applications and Scheme Amendments, to draw Council’s attention to the risks of developments on the flood plain, the inevitability of

sea level rises, and the added impacts of seismic risks to such flood-prone developments and the integrity of the Launceston flood levee systems.
The regularity of representations is only matched by Council's regularity of contemptuously ignoring the arguments and evidence presented. Elsewhere, as already reported, enlightened communities and their statutory planning authorities, are taking progressive action to withdraw from floodplain developments and occupation of such, in favour of developments and occupation of higher ground.

The objectives of the LUPA Act includes for sustainable development whereby in Part 1 ***sustainable development*** is defined as managing the use, development and protection of natural and physical resources in a way, or at a rate, which enables people and communities to provide for their social, economic and cultural well-being and for their health and safety while-

2(c) avoiding, remedying or mitigating any adverse effects of activities on the environment.

And in Part 2

(f) to promote the health and wellbeing of all Tasmanians and visitors to Tasmania by ensuring a pleasant, efficient and safe environment for working, living and recreation, and

(i) to provide a planning framework which fully considers land capability.

It is our general submission that CoL will fail its ratepayers, citizens and visitors to Tasmania should it allow unstable, flood prone and undesirable land to be further developed with buildings and tall buildings constructed to heights of 43m and beyond, when prudent and feasible alternatives are available, elsewhere within the Central Launceston area, and land that does not suffer from an inability to be evacuated in the event of flooding, inundation by sea level rises or climate change or such dangers and risks being compounded by seismic activity.

MANAGEMENT OF RISK

"Hazard consideration at the strategic planning level is critical to determining whether the benefits of allowing consideration of development in certain areas subject, or likely to be subject, to a natural hazard outweigh the costs to the community and individuals required to mitigate that hazard in the short, medium and long term. Other strategic planning issues need to be considered alongside the natural hazard issue to enable an informed judgement that is based on holistic planning and balancing social, economic and environmental benefits and costs. The strategic consideration of natural hazards could result in decisions about settlement planning, zoning, and the articulation of hazard layers through land use strategies. It can also provide an indication of the need to establish buffers, or areas of hazard expansion, over longer time frames than are expressed in planning schemes, which are generally focussed on a five to ten-year time frame. As the controls at this

stage represent a 'first cut' of limitation on use and development, they can be seen as a trigger for more detailed assessment of the hazard risk, which can be more directly translated into use and development controls."

GUIDE TO CONSIDERING NATURAL HAZARD RISKS IN LAND USE PLANNING AND BUILDING CONTROL – Aug 2013 TRIM Ref 12/11/11634

Department Premier and Cabinet, Tasmania

PDF
Guide_to_consideri
ng_natural_hazards.

The management of risk-

- probable flood events
- land stability/seismic risk

importantly must take a precautionary approach.

A Sobering example of which to be reminded from overseas.

Why does a modern 12-storey building suddenly collapse – pancake ?

Photo courtesy AFP, Joe Raedle

On June 24, 2021, at about 1.30am EDT, Champlain Towers South, a 12-storey beachfront condominium in the Miami Florida USA, partially collapsed. [ABC reports that as at 1 June, 18 people are confirmed dead and the number of residents still unaccounted for stands at 147 people].

It will be some time before experts can access the site and investigate why this building suddenly collapsed and **pancaked.**

"There's no reason for this building to go down like that," *Surfside Mayor Charles Burkett told reporters* ***"Unless someone literally pulls the supports from underneath, or they get washed out, or there's a <u>sinkhole</u> or something like that because it just went down."***

Surfside lies on a stretch of coast where severe tropical storms form, so Florida has some of the strictest building codes in the USA. Because of the marine exposure, additionally, local authorities require buildings more than 40 years old to undergo mandatory structural testing, and that process was underway. But there are concerns that these inspections do not take sufficient account of subterranean damage caused by ***<u>rising sea levels</u>*** and the ***<u>state of the bedrock.</u>*** Reports say that the building was built on ***<u>reclaimed wetlands</u>*** which were native to the area prior to development.

Authorities say that it could be months, maybe years before they have the answers.

<u>Could this happen in Launceston, where by example a current Scheme Amendment (SF 7233 Amendment 66) and where the subject site bounded by Paterson, Margaret and Brisbane Streets, is on a former wetlands where seismic action has caused a very deep hole to form, with at least 2 rift valleys 150m – 230m deep, and later be filled by soft silts and alluvial clays?</u>

This subject land fronting Paterson, Margaret and Brisbane Streets is on a tidal flood plain and is subject to certain seismic activity risks. Not only does the seismic risk endanger the safety of any infrastructure that may exist or is proposed to be constructed there, but it also endangers the stability and durability of the Flood Levee system which allegedly is intended to make-safe from inundation, the land area in question.

Accordingly, the limitation on building heights for any constructions located within the land area of this LPS Scheme amendment Ref SF7233 Amendment 66 Planning Scheme, must take these risks into account, and accordingly the limitation on building height must not exceed 12-14M.

TIDAL FLOOD PLAINS AND RISING SEA LEVELS.

A mapping tool created by a group of climate scientists called *Surging Seas Mapping Choices* and published in The Sunday Examiner Newspaper September 15, 2019 shows the effects of rising sea levels (The Tamar is the longest estuary in Australia, with a normal rising tide of 3.5M) on Launceston from the year 2100 onwards at two points of possibility.

- The first is if the Earth heats by four degrees, and
- the second is if the Earth heats by only 2 degrees.

20210918_003202.PDF

"Warming of two degrees Celsius is a long-standing international target, and corresponds to what many would consider successful global efforts to control greenhouse gas emissions". The authors of the map write. choices.climatecentral.org

Climate Emergency

City of Launceston declared "climate emergency' on August 9 2019,

City of Launceston declares 'climate emergency' - City of Launceston

And, whilst there was much trumpeting of name of the policy and political chest-beating by Councillors that Launceston was leading Local Government by its actions, the resolutions fell completely short of applying any policy to its statutory duties as a Planning Authority.

Flood Modelling

City of Launceston commissioned consultants BMT Eastern Australia Pty Ltd to provide an update of its earlier work in 2008, the 2-volume ***North and South Esk Rivers Flood Modelling and Mapping Update*** published November 2018.

https://www.launceston.tas.gov.au/files/assets/public/r.m20921.002.01.final_lowres.pdf

https://www.launceston.tas.gov.au/files/assets/public/r.m20921.003.00.mapping_lowres.pdf

As a result of the improved and updated analysis, Council announced a significant REDUCTION in the protection of the low-lying levels of the City by the flood levee system.

State View on Climate

At a Tasmanian State level, The Department of Premier and Cabinet released their prediction on changes to Tasmania's climate, with a warning the spatial pattern of the trend in daily maximum temperature..... is for greater change in the north-east and the interior", whereas sea level rise ....could lead to a 1-in-100 year storm tide event as frequently as once every 50 years by 2030.

[Department of Premier and Cabinet (dpac.tas.gov.au)]

Independent View on Flood Plain Developments Researched

In February/March 2019 an independent self-funded group **NORTHERN TASMANIAN NETWORK PARTNERS & ASSOCIATES** commissioned expert academic researcher Chris Penna, to undertake an analytical review/assessment and investigate currently published reports and publicly-available material, including flooding reports and seismic risk investigations, culminating in publication and broad distribution of the ***EVALUATIVE REVIEW of the UNIVERSITY OF TASMANIA INVERESK PRECINCT REDEVELOPMENT PROJECT.***

Evaluative-Review_
UTas-Inveresk_V3-M

This comprehensive and peer-reviewed report was published electronically, and distributed in both hard copy and electronically, to University of Tasmania and its Vice Chancellor; City of Launceston Council and individual Councillors; State Government, the Premier and Ministers, all Upper and Lower House Members; Commonwealth Government, Prime Minister and particular Ministers, all Tasmanian Senators and Lower House Members; and all media outlets.

The banner of RETREAT from building and retaining developments of flood plains that will be further impacted by climate change and rising sea levels and furthermore with seismic risks, could not be more solemn. The spectre of liability should developments be allowed to occur on these already identified areas of Launceston, but not regulated by present SPC proposals, if not addressed, will become forever a dark cloud over the heads of Councillors and other Statutory Approval Authorities.

The potential liability to statutory authorities who approve inappropriate developments on flood plains and further impacted by seismic risk and damage is of concern. When former Head of State Treasury Don Challen, insisted on planning restrictions at Invermay/Inveresk, it was out of concern that should development here be damaged or compromised by flooding, then huge compensation payout could result.

The Australian Local Government Association has published this warning and report to Local Government and cites the Committee for Sydney accordingly –

AUSTRALIAN LOCAL GOVERNMENT ASSOCIATION

Call for retreat on floodplain development in Sydney

The NSW government should offer to buy back thousands of homes in flood-prone areas of Sydney's west to reduce disaster response and recovery costs, the Committee for Sydney has said.
The urban policy think tank said scaling back development in the floodplain would move people out of harm's way and reduce growing pressure on our emergency services agencies.
Insurance costs associated with last month's flooding in western Sydney are forecast to rise to as much as $2 billion.
"As residents, businesses and governments face the stark reality of rebuilding and re-establishing homes, farms and businesses in this increasingly hazard-prone location, we have an opportunity to use that money differently to support [them] for the long term," the Committee said.
A voluntary purchasing scheme funded and set up by the state government would provide a mechanism for residents to sell flood-risk properties at market rates.
Any land bought back by the government would have its ownership transferred to Landcom or Western Sydney Parklands Authority to be managed consistent with designated land uses, the Committee said.
In a statement "Building back better may mean building back somewhere else", the committee said that after the 2011 Brisbane floods, the Brisbane City Council had introduced a voluntary home purchase scheme to break the cycle of disaster and recovery.
Seventy-three flood-affected private properties across Brisbane had been bought for $35 million and transformed into parklands, green space, conservation areas, or green links to bikeways.
"It's time for Sydney to look at a long-term plan to reduce the cycle of disaster, response and recovery that continues to test the safety and resilience of at-risk communities and stretch the resources of our emergency management agencies," the committee said.

SEISMIC RISK

Seismic microzonation in Australia

Jensen, V, Seismic microzonation in Australia, Journal of Asian Earth Sciences, 18, (1) pp. 3-15. ISSN 1367-9120 (2000) [Refereed Article]
DOI: doi:10.1016/S1367-9120(99)00048-6

Abstract

Since the 1980s seismic microzonation studies have been undertaken in Australia to assess the likely effects of earthquakes on urban centres built on unconsolidated sediments. Presently the Nakamura method is used for processing data. So far parts of Perth, Adelaide, Cairns, Gladstone, Rockhampton, Newcastle, Sydney and Launceston have been zoned. The Launceston, Tasmania, study was the pilot study for many of these as it refined the methodology used and the data obtained were incorporated into a

GIS database. Building heights and site factor zoning maps were produced for the Launceston City Council. One of the major activities, of the new initiative by the Australian Geological Survey Organisation (AGSO), popularly known as the 'Cities Project', is coordinating seismic microzonation throughout Australia. Microzonation data have been included in AGSO's geohazards GIS database. This is helping local councils zone land for seismic hazards. State Emergency Services use the information to plan for emergencies resulting from the effects of earthquakes. These practical applications of seismic microzonation data will help mitigate the destructive effects of any future large earthquakes occurring near major urban centres. In the Launceston case it was found that there is a variable risk dependant on epicentral distance and the nature of relatively unconsolidated sediments in various parts of the city. Disastrous amplification could occur at some sites.

Following scientific study, measuring and assessment, the Launceston microtremor analysis does not hold to the conventional assumption of a 1-dimensional homogeneous geology. In scientific hypothecation of Launceston's geology, due to the presence of the Tamar Rift Valley, amplification of seismic waves is thought to occur due to patterns of earthquake damage that occurred in the past during historic earthquakes. This results in a suspicion that 2-dimensional effects occur on this site.

Earthquake Engineering in Australia, Canberra 24-26 November 2006

169-Claprood-Asten.pdf

Use of Microtremors for Site Hazard Studies in the 2D Tamar Rift Valley, Launceston, Tasmania

Maxime Claprood and Michael W. Asten Monash University

Abstract

Analysis of microtremor for risk zonation is conventionally interpreted in terms of sub-horizontal layered geology. This assumption not being valid in some cases, there is a need to take into account the impact of 2D/3D geology for analysis of more complicated models. Bard and Bouchon (1980a, 1980b, 1985) intensively studied SH, SV and P waves motions in sediment-filled valleys. Identification of 2D and 3D effects has been analyzed by Field (1996), Steimen et al (2003), and Roten et al (2006) using spectral amplification and phase behavior. Modeling and interpretation of 2D microtremor data is the next challenge, and several methods have been developed to do so. A finite difference code was developed by Moczo and Kristek (2002) within the European SESAME project. Tessmer et al (1992) and Faccioli et al (1997) present the basis of a pseudo spectral approach combined to domain decomposition techniques for modeling of propagating waves. The research

group led by Komatitsch and Tromp developed a spectral element code for 2D and 3D seismic wave propagation (Tromp3D), using a combination of finite-elements method with spectral analysis. Assessment of the different methods available for detecting, modelling and interpreting 2D and 3D effects is the main objective of this project, using both H/V and SPAC data. Modelling methods will be compared with microtremor data acquired over a 2D rift valley (the Tamar Valley in Launceston, Tasmania) where there is a history of earthquake damage associated with site effects.

Introduction

Figure 1 shows the location of Launceston in Tasmania, south of the Australian mainland. Even if Launceston is not located in a very seismically active zone, damage has occurred in the past from earthquakes. Epicentres of earthquakes are located in two seismic zones:

• West Tasman Sea Zone,

• Western Tasmanian Zone.

Earthquake damage in Launceston is thought to be caused by site amplification response due to 2D geology effects. Figure 2 presents the results of the microzonation project at Launceston (Michael-Leiba, 1995). Profiles are obtained from a gravity survey (Leaman, 1994). Bedrock is Jurassic dolerite, which presents low seismic risk when outcropping. The survey outlines the presence of at least 2 deep NNW-SSE trending valleys filled with Tertiary and Quaternary sediments:

• along Tamar Valley axis, maximum sediment thickness of 250m,

• along North Esk Valley (floodplain), maximum sediment thickness of 130m.

Microtremor survey has previously been done in Launceston, using the H/V spectrum ratio (Nakamura, 1989) to estimate the natural site period of site amplification at 56 sites, and to create zoning maps of Launceston. Periods calculated present a large range of values from 0.1 to 1.5 sec. These variations in the calculated periods over the 56 sites do not appear to fit known geological depth; hence they may be explained by 2D effects generated by the presence of deep and narrow valleys. More data will be obtained with SPAC processing of array data as well as H/V data, with the aim being to identify and model 2D effects in the Tamar rift valley.

Figure 1. [see link 169-Claprood-Asten.pdf]

Location of Launceston, Tasmania. Epicenters of earthquakes with Richter magnitudes of 4.0 or more around Tasmania from 1884-1994 (from Michael-Leiba, 1995)

Figure 2. [see link 169-Claprood-Asten.pdf]

Microzonation of Launceston (Michael-Leiba, 1995). Sites where microtremor data have been obtained with H/V spectrum ratio. Geological profiles obtained from a gravity survey (Leaman, 1994)

Review of the problem

Interpretation of single-station H/V microtremor data has traditionally used the hypothesis of a layered geology, where waves of fundamental modes are assumed to dominate the signal. From Nakamura's technique, natural period of a layered site is calculated as:

$$T = 4H/V,$$

where H is the layer thickness and V is the shear wave velocity in the layer. Developments have been made analyzing variations of H/V spectral ratios and reference site method (RSM) along a profile over a valley to detect and analyze 2D effects.

The SPAC method measures the covariance at different frequencies between the signals observed at different stations. Phase velocities are determined by averaging signal coherency between the different points of observation in an array of receivers. Depending on the components of the signal analyzed, Rayleigh and Love waves can be analyzed to determine a 1D shear velocity depth profile.

Bard and Bouchon (1980a, 1980b and 1985) studied the variation in spectral amplitude of SH, SV and P waves along a profile over 2D geology. Trying to extend the H/V spectrum ratio technique to more complex geology, Field (1996) found that the method did not fit the sediment to bedrock ratio over a 2D geology. He recognized that H/V spectral ratio could be used to detect 2D effects. He observed shifting in the peak frequency along a profile over a valley. Data obtained with SPAC method in Launceston will be of interest to see if the use of H/V ratio and SPAC data simultaneously is of interest to better detect and analyze 2D effects in microtremor data.

Working hypotheses

Measurement of Vs depth profile using array methods will provide quantitative shear velocities to use in models.

H/V spectral ratios are an efficient tool to detect and analyze 2D effect in microtremor data.

Array methods (SPAC) applied over a basin edge will give perturbed microtremor phase velocities; these types of perturbations can be studied using 2D or 3D models.

Information deduced from SPAC data will help improve the detection and interpretation of 2D effects in microtremor data.

Methodology

The first step is to obtain H/V spectral ratio and SPAC microtremor measurements on a profile crossing the Tamar Valley in Launceston. H/V spectral ratio data should then be analyzed using 2D effect developed by Bard and Bouchon (1985) and Roten et al (2006). Modeling should then be used to represent Launceston area, using both 1D and 2D geology models. Comparison between SPAC data modeled from 1D and 2D geology would better assess the type of data recorded at Launceston. Recognition of 2D effects from SPAC data is the final step in the project, using both modeled and field data. Few programs can be used to model complex geology. Two approaches will be assessed in this study; the spectral element method, and the joint mode-summation and finite difference method.

Spectral Element Method (SEM)

• Work with Tromp3D program using SEM method (Komatitsch and Tromp, 1999)

• Weak formulation: integral formulation of seismic equations of motion. The weak formulation naturally satisfies the stress-free surface boundary condition.

• Hexahedra elements (quadrangles in 2D)

• Lagrange high-order polynomial representation of elements

• Gauss-Lobatto-Legendre approximation used for integration of equations of motion • Mass matrix diagonal by construction in SEM: reduces cost of calculations. Mode-summation and finite-difference modeling

• 3D fourth-order staggered grid finite-difference for modeling seismic motion and seismic wave propagation (Moczo et al, 2002)

• Mode-summation method is used to model wave propagation from source position to local 2D/3D irregularity. Path from source to irregularity is assumed to be flat, homogeneous layers.

• Finite-difference method is used in the laterally heterogeneous part of the model (Tamar rift valley). Spurious effects might be created due to the need to impose artificial boundaries to the model to save on CPU time and memory.

Conclusion

Analysis of microtremor data conventionally assumes a 1D homogeneous geology. This hypothesis does not hold in Launceston, Tasmania, due to the presence of the Tamar rift valley. Amplification of seismic waves is thought to occur at Launceston due to patterns of earthquake damage in historic quakes. 2D site effects are suspected.

The expected pattern in H/V spectrum ratio can be used to identify these 2D effects in the Launceston area. SPAC measurements will be used to complete the study. Microtremor data acquired over Launceston will be used to assess modelling over 2D and 3D effects, using the SEM method and the joint mode-summation and finite-difference method.

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SEISMIC MICROZONATION INVESTIGATION

Michael L. Turnbull, publishing in ***Journal of Earth System Science***, May 2009, supports the methodology of site responsiveness to earthquakes with a adaptation of the ***Nakamura horizontal to vertical spectral ratio method***, and gives credit to such work as was done by Michael-Leiba M and Jensen V 1999 **Seismic Microzonation of Launceston, Tasmania.**

Turnbull says *"The resulting microzonation maps indicate the relative seismic shaking vulnerability for built structures of different height categories within adjacent zones, with a resolution of approximately 1 km."*

Combining HVSR microtremor observations with the SPAC method for site resonance study of the Tamar Valley in Launceston (Tasmania, Australia)

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Author Notes

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Summary

The presence of the deep and narrow Tamar Valley in the City of Launceston (Tasmania, Australia), in-filled with soft sediments above hard dolerite bedrock, induces a complex pattern of resonance across the city. Horizontal to vertical spectrum ratio (HVSR) microtremor observations are combined with 1-D shear wave velocity (SWV) profiles evaluated from spatially averaged coherency spectra (SPAC) observations of the vertical component of the microtremor wavefield to complete a site resonance study in a valley environment such as the Tamar Valley. Using the methodology developed in a previous paper, 1-D SWV profiles are interpreted from observed coherency spectra (axial-COH) above the deepest point of the Tamar Valley, using pairs of sensors spatially separated parallel to the valley axis. The 1-D SWV profiles interpreted at five sites suggest the depth to bedrock interface varies from approximately z= 25 m north of the city, to z= 250 m above the deepest point of the valley. Numerical simulations of the propagation of surface waves in a 2-D model representation of the Tamar Valley compare well with HVSR observations recorded on two profiles transverse to the valley axis. HVSR observations can identify the in-plane shear (SV) frequency of resonance above the deepest part of the valley on two separate profiles transverse to the valley axis. By computing the ellipticity curves from the preferred SWV profiles interpreted by the SPAC method, the antiplane shear (SH) modes of resonance expected to develop in the Tamar Valley are identified; modes which HVSR observations alone fail to locate with precision. HVSR observations suggest a complex mix of 1-D and 2-D patterns of resonance develops across the valley. The results from this paper suggest that HVSR microtremor observations can be combined with SPAC microtremor method to characterize the geology and the pattern of resonance in a 2-D narrow structure such as the Tamar Valley.

Numerical solutions, Surface waves and free oscillations, Site effects, Wave propagation, Australia

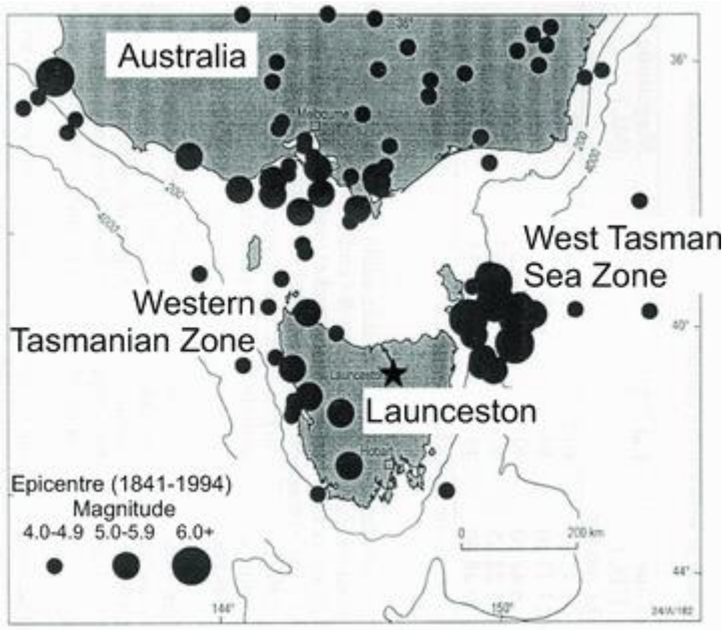
Issue Section: Seismology

1 Introduction

The presence of low velocity sediments slows down the propagation of seismic waves generated by earthquake. It also induces amplification of the surface motion at a frequency of resonance proportional to the velocity and thickness of soft sediments above hard bedrock. Abrupt lateral variations of geology further amplify the surface motion and shift the frequency of resonance, generating a different pattern of resonance than expected above a layered earth. These local geology effects have significant importance when evaluating seismic hazard and seismic risk at specific sites (Horike 1985).

The situation of the City of Launceston (Tasmania, Australia) is an interesting example where such local geology effects are observed. While Launceston is not located in highly seismically active region (Fig. 1), damage has occurred to some buildings in the city from past earthquakes, which epicentres were located at more than 200 km from the city centre. Several hypotheses may explain the damages, including high vulnerability of the structure and complex pattern of resonance generated by abrupt changes in the near surface geology across the City of Launceston. While we do not discard the hypothesis of structure vulnerability, our study investigates the site resonance pattern expected to develop in the Tamar Valley.

Figure 1



Location of Launceston in Tasmania, Australia. Epicentres of earthquakes with Richter magnitude of 4.0+ around Tasmania from 1884–1994 (modified from Michael-Leiba 1995).

The recording of ambient ground vibrations, or microtremors, has proven to provide a good estimation of the frequency of resonance and shear wave velocity (SWV) structure to complete such hazard zonation studies (Horike 1985; Field 1996; Kudo *et al.* 2002). For the purpose of this study, we use the term microtremor for ambient vibrations of any sources, from low frequency natural phenomena to high frequency human activities.

Single station microtremor methods, such as the horizontal to vertical spectrum ratio (HVSR) and the standard spectral ratio (SSR), are commonly used to estimate the frequency of resonance of layered earth geology, and to generate earthquake hazard or expected ground motion zonation maps (Ibs-von Seht & Wohlenberg 1999; Parolai *et al.* 2002; Fäh *et al.* 2003; Mirzaoglu & Dýkmen 2003; Tanimoto & Alvizuri 2006). The efficiency and low cost of HVSR field survey make that method a popular choice for resonance and microzonation studies (Lachet & Bard 1994). The interpretation of HVSR observations gives an accurate estimate of the fundamental frequency of resonance of soft sediments over hard bedrock (Field & Jacob 1995).

Different patterns of resonance develop above complex geologies such as 2-D and 3-D valleys in-filled with soft sediments. Several studies were completed to analyse the generation and propagation of the different components of surface waves induced in valleys of various dimensions (Bard & Bouchon 1980a,b, 1985; Kawase & Aki 1989; Frischknecht & Wagner 2004).

Many authors have demonstrated the potential of single station microtremor methods to detect a 2-D pattern of resonance, and to identify the frequencies of resonance expected to develop in a valley environment. Steimen *et al.* (2003) used the SSR method to analyse the resonance effects from the St Jakob-Tüllingen and Vetroz valleys in Switzerland. Results from the Vetroz Valley were studied in further detail by Roten *et al.* (2006) to better distinguish between laterally propagating surface waves induced by a 1-D pattern of resonance and vertically propagating standing waves generated by a 2-D pattern of resonance. Uebayashi (2003) used HVSR observations to constrain the modelling of 3-D basin structures; comparing modelled HVSR, observed HVSR and theoretical Rayleigh wave ellipticity curves to analyse the complex geology across the Osaka Basin (Japan). Hinzen *et al.* (2004) used HVSR observations to map the changes in sediments thickness across the normal fault Lower Rhine Embayment (Germany). Cara *et al.* (2008) noted significant variations in HVSR measurements from 90 sites above alluvial sediments in riverbeds in the city of Palermo (Italy). Recently, Lenti *et al.* (2009) analysed 2-D site amplification in the Nera River alluvial valley (Italy), using SSR and HVSR observations from microtremor and earthquake weak ground motion. Barnaba *et al.* (2010) used HVSR observations to estimate sediment thickness (assuming 1-D geology) in irregular shape valley in the Friuli region (Italy), comparing with gravity interpretation and seismic refraction velocity profiles.

We record HVSR observations in Launceston to analyse the frequencies of resonance in and around the Tamar Valley in Launceston. The choice of the HVSR method rather than SSR was justified on the basis that HVSR observations do not require the use of a reference station on hard bedrock, whereas the distant location for a reference station relative to the other stations can violate the hypothesis of spatial stationarity of the microtremor wavefield.

Single station microtremor observations do not provide good estimates of the SWV structure of a soil (Asten *et al.* 2002; Chávez-García *et al.* 2007), an important parameter to evaluate for site hazard study. Several authors demonstrated that the reliability of site resonance studies is greatly improved by combining array based and single station microtremor observations to evaluate the SWV structure and the pattern of resonance. For example, Satoh *et al.* (2001) used HVSR observations at 48 sites to constrain SWV profiles evaluated by array based FK method at four sites in the Taichung Basin (Taiwan). Scherbaum *et al.* (2003) used the FK method to evaluate dispersion curves to constrain the velocity to depth dependence, and HVSR observations to constrain the layer thickness in the Lower Rhine Embayment (Germany). Parolai *et al.* (2005) proposed a joint inversion of HVSR and velocity dispersion curves, using fundamental and higher modes of propagation to determine the SWV structure by a genetic algorithm at a test site in the Cologne area (Germany). Similarly, using microtremor observations at four sites in the cities of Kushiro, Odawara, and Tokyo

(Japan), Arai & Tokimatsu (2005) demonstrated that a joint iterative non-linear inversion of HVSR spectra and array derived velocity dispersion curves gives better results at evaluating SWV profiles than using velocity dispersion curves alone. Di Giulio *et al.* (2006) combined HVSR and FK observations in the Colfiorito Basin (Italy) to derive SWV profiles. Chávez-García *et al.* (2007) conducted a microzonation study of the city of Colima (Mexico) by combining HVSR observations at 315 sites with array based ReMi and spatially averaged coherency spectra (SPAC) microtremor methods at eight sites for improved resolution. Roten & Fäh (2007) concluded that the combined inversion of velocity dispersion curves obtained from the FK method, with 2-D frequencies of resonance evaluated from SSR observations, was a reliable method to evaluate SWV profile to bedrock interface in the Rhône Valley.

Several authors have analysed the use of array based microtremor methods in complex geology. For example, Cornou *et al.* (2003a,b) used the MUSIC algorithm with HVSR observations to identify the wavefield associated with site amplification in the Grenoble Valley (France), using an extensive array of 29 three-component seismometers with a total array aperture of 1 km. Hartzell *et al.* (2003) used the FK and MUSIC methods to detect edge generated surface waves with a dense array of 52 sensors in the Santa Clara Valley (USA), using site response spectra from earthquake generated motion to evaluate the SWV profile. Roten *et al.* (2006, 2008) used the FK method to identify the modes of resonance expected to develop in the Rhône Valley (Switzerland). Seismic noise tomography was used by Picozzi *et al.* (2009) to image shallow structural heterogeneities with an array of 21 geophones at the Nauen test site in Germany.

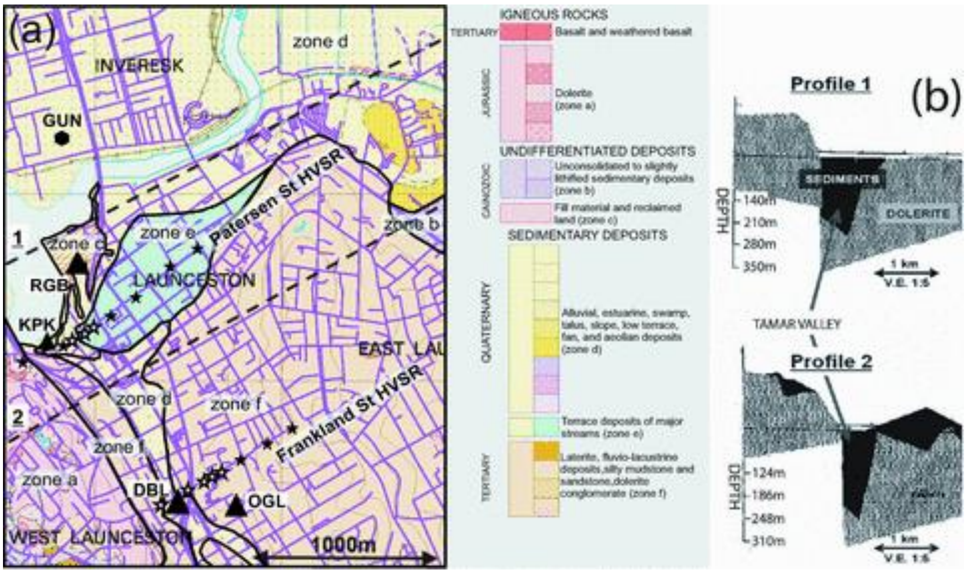
In this study, we present the results of a site resonance study conducted in and at the edge of the Tamar Valley in Launceston, combining the results obtained from HVSR and SPAC observations at separate sites. Until recently, the use of SPAC method was restricted to regions where the geology could be approximated by a layered earth geology. A methodology was developed in Claprood *et al.* (2011), paper subsequently referred to as CAK1, to permit the use of temporally averaged coherency spectra observations to evaluate SWV profile above the deepest point of a valley. Building on the results obtained in CAK1 at two sites DBL and RGB, we complete the site resonance study in Launceston by analysing SPAC observations at three additional sites (GUN, OGL, and KPK) to evaluate 1-D SWV profiles in and outside the valley. HVSR observations at all five sites are analysed to constrain SPAC observations and to evaluate the frequencies of resonance at separate sites in Launceston. Additional HVSR observations are recorded on two profiles transverse to the valley axis to identify the different modes of resonance which develop in the Tamar Valley.

2 Geophysical Settings

While other causes such as structure vulnerability are not excluded, we investigate the possibility that site amplification response due to local geology effects could induce the earthquake damages observed in Launceston.

Information on the geology of Launceston is available from unpublished maps from Mineral Resources Tasmania, borehole logs held by the Launceston City Council, and a gravity survey completed by Leaman (1994). The geological map of Launceston presented in Fig. 2 outlines the rapid changes in surface geology in the Central Business District of Launceston, with the geological interpretation of two gravity profiles recorded across the valley.

Figure 2



(a) Map of surface geology of Launceston (modified from Mineral Resources Tasmania), divided into six zones by thick black lines. Triangles and hexagons are location of SPAC microtremor observations at sites GUN, RGB, KPK, DBL and OGL. Black stars: stations for HVSR profiles. White stars: projected stations for HVSR profiles. Dashed lines: location of two gravity profiles from Leaman (1994) which geological interpretation is presented on panel (b).

The area covered by this survey is topographically flat. The bedrock comprises dense, fractured and weathered Jurassic dolerite; which provides reduced seismic risk and excellent foundation conditions (Leaman 1994). It is covered by poorly consolidated materials, i.e. clays, sands, conglomerates, silts and fills which can be compressible, water saturated, plastic, and of low density. Quaternary alluvial sediments (silts, gravels, fills) were deposited in valleys floor and other marshy areas near sea level. These sediments have poor cohesion, negligible strength, and may be thixotropic. The ancient valley systems beneath Launceston are Tertiary rift valleys, filled with low density Tertiary sands and clays. A gravity interpretation (Leaman 1994) identified two palaeo-valley systems, i.e. the Trevallyn-Tamar lineament referred as the Tamar Valley in this paper, and the North Esk Palaeovalley, both trending in a NNW-SSE direction. The Tamar Valley is the focus of our research for it is more continuous and better defined than the North Esk Valley. Interpretation of the gravity survey indicates that the Tamar Valley has a width of 700 to 1000 m and an approximate maximum depth of 250 m.

Borehole logs, located at proximity to site DBL and in the northern part of Launceston (Inveresk, Fig. 2), are drilled to a maximum depth of 20 m, hitting hard dolerite bedrock in Inveresk only. The boreholes drilled at site DBL were terminated, for unknown reason, at depth less than 10 m in silty sand, interpreted to be the interface between Quaternary and Tertiary sediments. The interpretation of borehole logs gives little information about the geology inside the Tamar Valley. While the interpretation of the gravity survey from Leaman (1994) provides some knowledge about the extent of the soft sediments filling the Tamar Valley, it adds little information about the shear wave velocity inside the valley.

3 Geophysics Surveys

Prior to the first microtremor field survey completed in October 2006, some geophysical surveys have been completed to characterize the geology and to identify the frequency of resonance at several sites in Launceston. We briefly present the main conclusions interpreted from a gravity survey (Leaman 1994) and a microzonation project (Michael-Leiba 1995), which results suggested the need of acquiring additional microtremor observations in Launceston.

3.1 Gravity survey

The geological interpretation of two gravity profiles recorded across the city is presented in Fig. 2(b). The survey provided some evaluation of the geometry of the valley systems, and outlined the importance to complete a microzonation study in the city of Launceston to evaluate the frequency of resonance at separate sites in the city. We use this interpretation to constrain some SWV profiles recorded in Launceston, and to constrain the geometry of the Tamar Valley during the numerical simulations.

3.2 Microzonation project

The microzonation study was completed by Michael-Leiba (1995), by recording HVSR observations to estimate the natural period of resonance at 56 sites in Launceston. The observations were used to create two zoning maps of the city, depicting site soil factors and building height groups which may be affected by resonance.

The periods of resonance evaluated during this microzonation project present a large range of values (0.1–1.5 s), variations which do not always appear to fit the interpreted bedrock interface from gravity data (Leaman 1994). The hypothesis of multiple layering of sediments, non-uniformity of the layer with respect to shear-wave velocity, or departure from simplified layered earth geology were advanced by Michael-Leiba (1995) to explain these disagreements. We further investigate the hypothesis that 2-D effects generated by the presence of soft sediments in the Tamar Valley could explain some of these contradictory observations.

4 Site Resonance Study

We recorded array-based SPAC and single station HVSR microtremor observations in and around the Tamar Valley to increase our knowledge of the pattern of resonance which develops in Launceston.

Two HVSR profiles transverse to the valley axis are used to identify the frequencies of resonance which are induced in the Tamar Valley. The SPAC method is used to evaluate the SWV structure above the deepest point of the valley, which is used to compute the Rayleigh wave ellipticity curve. The peak of the ellipticity curve is an estimation of the expected frequency of resonance fh when assuming a layered earth geology. Using a model developed by Bard & Bouchon (1985), we compute the frequencies of all expected modes of resonance in the Tamar Valley using the SWV information from SPAC interpretation and the frequencies of resonance observed from the HVSR profiles. Both sets of observations (SPAC and HVSR) are needed to complete the site resonance study of the Tamar Valley because: (1) HVSR observations can not resolve for all modes of resonance, and (2) the modes of resonance computed from the SWV determined by the SPAC method need validation from HVSR profiles at different points across the valley. Numerical simulations of the propagation of surface waves in a 2-D model representation of the Tamar Valley are completed to confirm the interpretation of microtremor observations recorded in Launceston, and to better define the geometry, geology, and modes of resonance of the valley.

4.1 SPAC method

The SPAC method was introduced by Aki (1957) under the name spatial autocorrelation method. Assuming the spatial and temporal stationarity of microtremors, coherency spectra are evaluated between all pairs of sensors in an array. The spatially averaged coherency spectrum $C(f)$ is computed for multiple inter-station separations as:

where J_0 is the Bessel function of first kind and zero order, k is the spatial wavenumber at frequency f, r is the interstation separation, and $V(f)$ is the S-wave velocity dispersion function of a layered earth model, which SWV profile is evaluated (Aki 1957; Okada 2003; Asten 2006a). While Aki (1957), Fäh *et al.* (2007), and Köhler *et al.* (2007) demonstrated the potential of using vertical and horizontal components of the microtremor wavefield (method referred as the 3cSPAC), the vertical component alone is used in this project for its simpler processing. Observed coherency spectra are directly fit to theoretical coherency spectrum (COH) by least-square optimization (Herrmann 2002) to evaluate the SWV to depth profile, as proposed by Asten *et al.* (2004). The domain of validity of the frequency interval to interpret SPAC observations with an array of sensors is still debated in the literature (Henstridge 1979; Okada 2006; Asten 2006a,b; Ekström *et al.* 2009). We select the interval of valid frequencies on a case-by-case scenario from the analysis of the microtremor wavefield. The valid frequency range is identified on each selected sites on the coherency spectra.

When the hypothesis of a layered earth is not valid, suggesting the presence of 2-D effects from the valley, we use the methodology developed in CAK1 to identify the patterns of resonance and evaluate 1-D SWV profiles from microtremor observations recorded in a valley environment. The coherency spectra observed with pairs of sensors with separation parallel to the valley (axial-COH) of the vertical component alone is fit to the theoretical coherency spectrum to evaluate the depth to bedrock interface above the deepest point of the valley. The use of single pair of sensors to evaluate the coherency spectrum, replacing the spatial averaging by temporal averaging and increasing the length of the microtremor time series, has been validated by different studies (Aki 1957; Capon 1973; Morikawa *et al.* 2004; Chávez-García *et al.* 2005; Claprood & Asten 2010).

4.2 HVSR method

The HVSR, introduced by Nogoshi & Igarashi (1971) and popularized by Nakamura (1989), provides a good estimate of the natural frequency of resonance of soft sediments over hard bedrock (*fh*). In a layered earth geology, the HVSR peak is empirically found to be a reliable estimation of the Rayleigh wave ellipticity R_0 (Lachet & Bard 1994; Tokimatsu 1997; Scherbaum *et al.* 2003), where the shape of the elliptical motion is determined by the shear wave frequency of resonance in particular, and more generally by the elastic parameters of the earth. In a typical interpretation sequence, Rayleigh wave ellipticity curves are computed from the SWV profiles evaluated by the SPAC method. At the shear wave frequency of resonance of an assumed layered earth, the Rayleigh wave's elliptical motion tends to degenerate into a dominantly horizontal motion (Asten *et al.* 2002), showing a peak on the ellipticity curve.

An intricate pattern of resonance develops across a valley in-filled with low velocity sediments. Surface waves bounce back and forth from the edges of the valley, creating interference and inducing a pattern of resonance different than that expected over a layered geology. A 2-D pattern of resonance develops in deep and narrow valleys. A critical shape ratio was expressed by Bard & Bouchon (1985) to better define the conditions of formation of 1-D and 2-D patterns of resonance with respect to the dimensions of the valley. The shape ratio of a valley is defined as the ratio between the maximum thickness of sediments H to the half-width w of the basin (the length over which the local sediments thickness is greater than half the maximum thickness H).

Different modes of resonance develop in a valley, shifting the frequency of resonance to higher frequencies when compared to its equivalent layered geology. Bard & Bouchon (1985) recognized the SH mode of resonance excited by the axial component of horizontal motion (parallel to the valley axis), and the SV and P modes of resonance excited by the transverse component of horizontal motion (perpendicular to the valley axis) and the vertical component of motion. The theoretical SH and SV modes of resonance are expected at frequencies:

where *fh* is the frequency of resonance of an equivalent layered earth, *m* and *n* are the number of nodes in the vertical and horizontal standing modes, respectively. By decomposing the horizontal microtremor time series into its axial and transverse components of motion relative to the valley axis, we seek to detect these theoretical frequencies of resonance on HVSR observations recorded in the Tamar Valley in Launceston. At a qualitative level, a difference in observed HVSR frequency maxima for axial and transverse components of motion can be an indicator of 2-D effects in the geology. Where the different frequency maxima are resolvable, we are able to make quantitative conclusions on the nature of a 2-D valley.

5 Microtremor Observations

Microtremor observations were recorded in October 2006 and 2007 in the city centre of Launceston. We used seven vertical component Mark L28—4.5 Hz cut-off frequency sensors to record SPAC observations; and one three-component Mark L4C—1 Hz cut-off frequency geophone to record HVSR observations at the centre of each array during the 2006 field survey. Two 5 min time series were recorded at each site. To gain sensitivity at depth, we used four three-component Guralp CMG-3ESP—30 and 60 s period geophones to record SPAC and HVSR observations in 2007. Observations were recorded with time series of 20 to 30 min, sufficient to ensure reliability in the observed coherency spectra computed with a limited number of sensors (Chávez-García & Rogríguez 2007; Chávez-García *et al.* 2007; Claprood & Asten 2010) and to significantly reduce the statistical variability of microtremor observations (Picozzi *et al.* 2005).

The time series are divided into 80-s time segments, with 50 per cent overlap, weighted with a Hanning bell, and fast-Fourier transformed in the frequency domain to obtain the raw spectra $Si(f)$ of microtremor energy at every sensor i. HVSR or SPAC processing were then computed on every time segment, from which the temporal average over all time segments was evaluated.

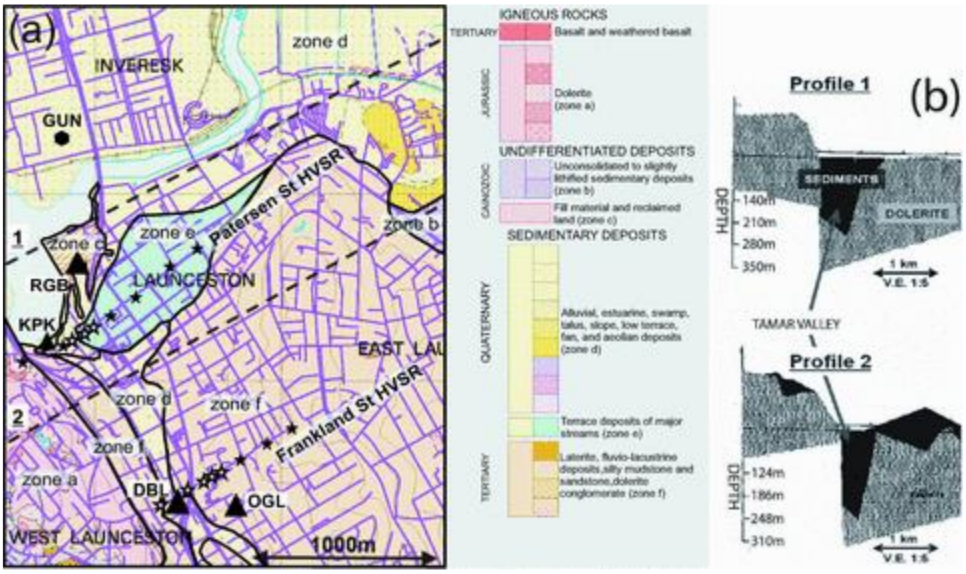
The SPAC results for sites DBL and RGB have been used in CAK1 to develop the methodology permitting the use of the SPAC method in valley environment. We now include three additional sites (KPK, GUN, OGL), integrating HVSR data with the SPAC data for identifying perturbations attributable to the 2-D geology. The location of the sites GUN, RGB, KPK, DBL and OGL is presented in Fig. 2(a). Two HVSR profiles are also recorded transverse the Tamar Valley along Paterson and Frankland Streets to analyse the frequencies of resonance across the valley.

5.1 SPAC observations

The complex coherency spectrum $Cij\ (f)$ between each pair of sensors (i, j) is computed using the equation:

where * denotes complex conjugate. Complex coherency spectra are averaged over all time segments to yield the temporally averaged coherency spectrum at each pair of sensors. The abbreviation COH is used for coherency spectrum throughout this paper. SPAC are computed by averaging over azimuth for all interstation separations possible from the array geometry. We used centred hexagonal arrays of n= 6 sensors during the 2006 field survey and centred triangular arrays of n= 3 sensors during the 2007 field survey. The geometry of both arrays is presented in Fig. 3.

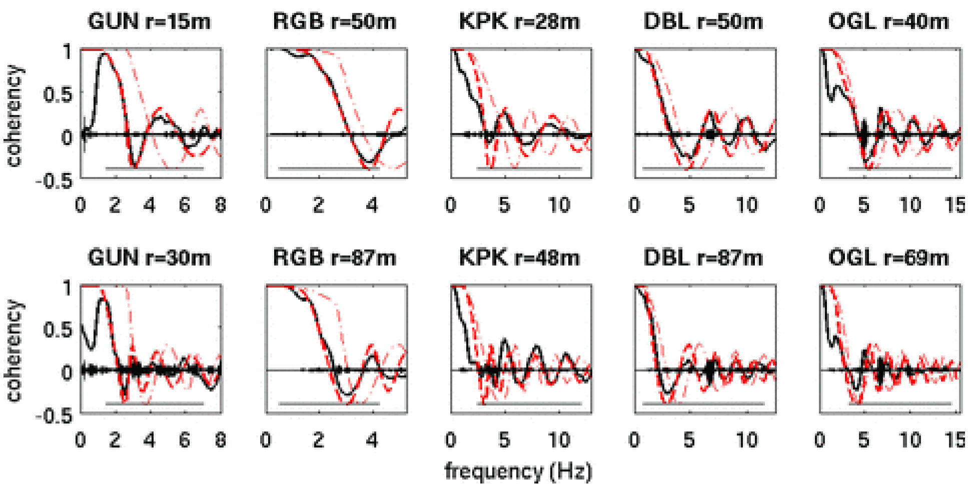
Figure3



Common SPAC array geometries. (a) Centred hexagonal array of six stations with four interstation separations r_1, r_2, r_3 and r_4. (b) Centred triangular array of three stations with two interstation separations r_1, r_2.

The coherency spectra observed at all five sites in Launceston are presented in Fig. 4 for all pairs of sensors of selected interstation separations, along with the spatially averaged coherency spectra recorded at five sites in Launceston and the theoretical coherency spectrum computed from the preferred SWV profile at each site.

Figure 4



Best-fit coherency models at five sites for selected interstation separations. Hexagonal arrays used at sites GUN and KPK, sum of two triangle arrays with pair of sensors XA oriented axial and transverse to valley axis used at sites RGB, DBL and OGL. Thick black curve is real component of observed spatially averaged coherency spectrum (COH). Bars are roughened imaginary component of observed COH. Thick dashed red curve is the theoretical COH for the fundamental mode Rayleigh wave, for the preferred SWV layered earth model. Dash–dotted red curve is the theoretical COH for the 1st higher mode Rayleigh wave. Straight line at bottom of each graph shows the frequency interval over which the theoretical COH is fitted to the observed COH.

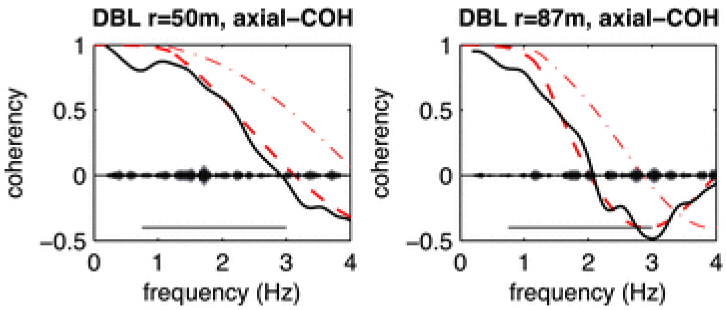
Coherency spectra were recorded with two centred hexagonal arrays of 15 and 30 m radius at site GUN. The SWV profile was evaluated by fitting the theoretical coherency spectra to the observed SPAC for frequencies $1.5 \leq f \leq 7.0$ Hz. The observed SPAC agree well with the theoretical coherency spectra, and the SWV profile evaluated compares well with the borehole logs obtained from the Launceston City Council.

The site RGB is located above the eastern flank of the Tamar Valley. Previous analysis of SPAC observations at site RGB in CAK1 suggested a directionality of the microtremor wavefield (Claprood & Asten 2010), which was not induced by 2-D resonance from the Tamar Valley (CAK1).

The site KPK is assumed to be located above the deepest point of the valley (Leaman 1994). Observed coherency spectra at site KPK are analysed over an extended frequency interval ($2.5 \leq f \leq 12.0$ Hz) with a 28 m radius centred hexagonal array in 2006 and two 28 m radius centred triangular arrays in 2007. The bedrock interface is not detected with SPAC observations alone due to the small array size; HVSR and gravity interpretation were used as constraints to fix the depth to bedrock interface at site KPK.

The site DBL is assumed to be located above the deepest point of the Tamar Valley at approximately 1 km southeast of site KPK. A 20 m radius centred hexagonal array was used in 2006 to resolve the shallow layers (Claprood & Asten 2008a). This site was revisited in 2007 with two 50 m radius centred triangular arrays for improved resolution at depth. As outlined in CAK1, different behaviours were detected on the coherency spectra observed at low frequencies with the 50 m radius array with respect to azimuth. Following the methodology developed in CAK1 concerning the use of the SPAC method in a valley environment, only the axial-COH was used to evaluate the depth to bedrock interface at site DBL. The coherency spectra observed on other pairs of sensors are affected by the 2-D resonance pattern, and could not be used to interpret a 1-D SWV profile at site DBL. Fig. 5 presents the fit between the theoretical coherency spectra and observed axial-COH at site DBL for interstation separations $r_1 = 50$ m and $r_2 = 87$ m on the frequency interval $0.75 \leq f \leq 3.0$ Hz.

Figure 5

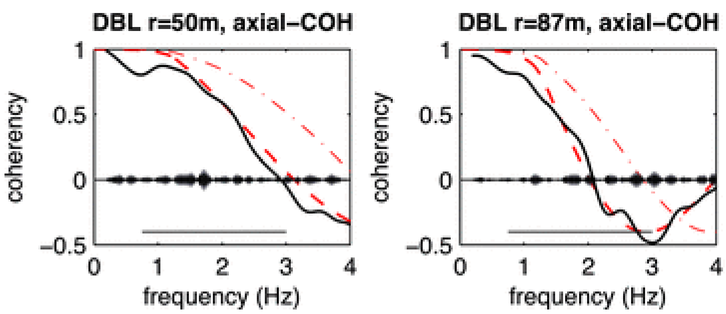


Best-fit coherency model at site DBL between theoretical coherency spectrum (thick dashed red curve for fundamental mode, dash–dotted red curve for 1st higher mode) and observed axial-COH (thick black curve) for interstation separations r_1= 50 m and r_2= 87 m on frequency interval 0.75 $\leq f \leq$ 3.0 Hz.

Observed coherency spectra at site OGL, located on the eastern flank of the Tamar Valley, show poor resolution at low frequency, and were used in combination with HVSR observations to resolve the bedrock interface at this site. The depth to bedrock of the SWV profile was adjusted so the peak of the ellipticity curve, computed from SPAC observations, would match the frequency of resonance observed on HVSR data.

Conversely to Di Giulio *et al.* (2012) who explored the whole model space by ranking the best classes of models for the inversion of surface-wave dispersion inversion, we only present the preferred SWV profiles (thick lines) and the 20 per cent lower and upper bounds in sediments thickness (dashed lines) evaluated at all five sites (Fig. 6). We believe our approach is sufficient to analyse and differentiate the impact of the complex geology such as the Tamar Valley on SPAC and HVSR observations. Fig. 6 outlines the variability in the shear wave velocity structures interpreted at different locations within the city of Launceston. The bedrock interface is interpreted to be at $z \simeq$ 25 m at site GUN, and deeper than 200 m at sites KPK and DBL (Fig. 6). This explains the large range of periods of resonance recorded by Michael-Leiba (1995) over the city. The interpreted 1-D SWV profiles are used to compute the expected frequencies of resonance at these five separate sites in Launceston.

Figure 6



Thick lines: preferred SWV profiles evaluated at at sites GUN, RGB, KPK, DBL and OGL from SPAC observations. Dashed lines: lower and upper bounds on sediment thickness of preferred SWV profiles by adjusting layers thickness by ±20 per cent.

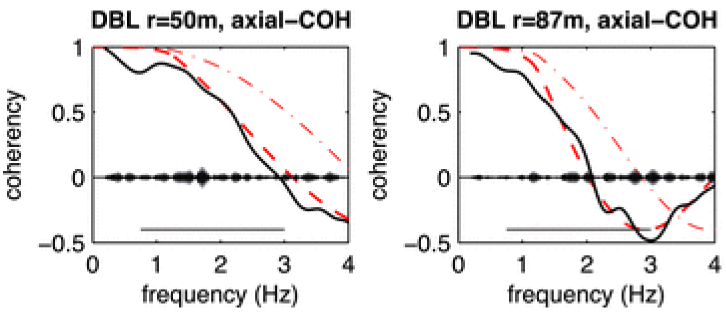
5.2 HVSR observations

Horizontal to vertical spectrum ratios are computed to estimate the frequency of resonance at separate sites in Launceston. The sensors are oriented to record the horizontal components parallel and perpendicular to the valley axis to identify the and frequencies of resonance which develop in a valley (Bard & Bouchon 1985; Steimen *et al.* 2003; Roten *et al.* 2006). We use the term axial-HVSR for HVSR computed with the axial horizontal component to the valley axis, and to the term transverse-HVSR for HVSR computed with the transverse horizontal component. For the example of a valley striking north-south, we compute HVSR as:

where is the north-south (axial in Launceston) component of horizontal power spectrum, is the east-west (transverse in Launceston) component of horizontal power spectrum, and is the vertical microtremor power spectrum.

We present HVSR observations recorded at the centre sensor of all SPAC arrays in Fig. 7. HVSR observations are compared to the Rayleigh wave ellipticity computed from the 1-D SWV profiles evaluated at all sites (Fig. 6).

Figure 7



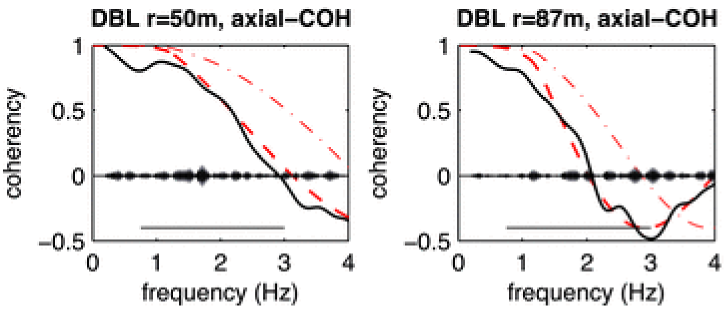
HVSR observations at all five sites. Thick black solid line is conventional HVSR; blue line is axial-HVSR; green line is transverse-HVSR; thick red and yellow lines are Rayleigh wave ellipticity curve of fundamental mode R_0 and first higher mode R_1 from the preferred SWV profile at each site; thin red and yellow lines are R_0 and R_1 from the lower and upper bounds of SWV profiles.

Different behaviours are observed on the HVSR curves depending on the site analysed. Conventional, axial and transverse-HVSR all agree well with the Rayleigh wave ellipticity curves computed at sites GUN, RGB and OGL. A sharp peak is recognized on HVSR observations at fh= 1.18 Hz at site GUN, and at fh= 1.31 Hz at site RGB. It is interesting to note the frequency of resonance is lower at site GUN than at site RGB, despite a much shallower bedrock interface (SWV profiles, Fig. 6). Sediments of very low velocity at site

GUN are thought to be the main cause of such a low frequency of resonance. The frequency of resonance is estimated at *fh*= 0.87 Hz from HVSR observations at site OGL.

Despite the fact that the sites RGB and OGL are assumed to be located within the Tamar Valley, they do not show 2-D frequencies of resonance. We propose the hypothesis that the east flank of the valley is dipping at such low angle that the geology can be approximated by a layered earth for microtremor studies at these sites. This hypothesis of a layered earth does not hold true above the deepest point of the valley, where a separation of the modes of resonance is observed at sites KPK and DBL. At both sites, the peaks are located at different frequencies on axial-HVSR and transverse-HVSR; at higher frequency than the expected frequency of resonance *fh* computed from the ellipticity curve from SPAC observations by considering a layered earth. Fig. 8 better expresses that difference by zooming on the HVSR curves at sites KPK and DBL around their frequencies of resonance.

Figure 8



HVSR observations at sites KPK and DBL around the frequencies of resonance. Same legend as Fig. 7.

The difference in behaviour observed on the axial and transverse-HVSR is typical of the separation of modes of resonance expected in deep and narrow valleys. The frequencies of resonance on the axial-HVSR and Hz on the transverse-HVSR at site KPK; and Hz and Hz on the axial-HVSR, and Hz on the transverse-HVSR at site DBL were identified in Claprood & Asten (2008b).

We observe that the uncertainty in the 1-D SWV profiles can not explain the discrepancy observed between the ellipticity curves and HVSR observations at sites KPK and DBL. A significant change in the sediment thickness can not explain the separation in the frequency of resonance regarding to the orientation of the horizontal components. Similar analysis is also true concerning the higher modes of propagation, which affect both horizontal components by the same amount. This is not observed on HVSR curves, where the horizontal components are shifted differently depending on their orientation.

6 Tamar Valley Characterization

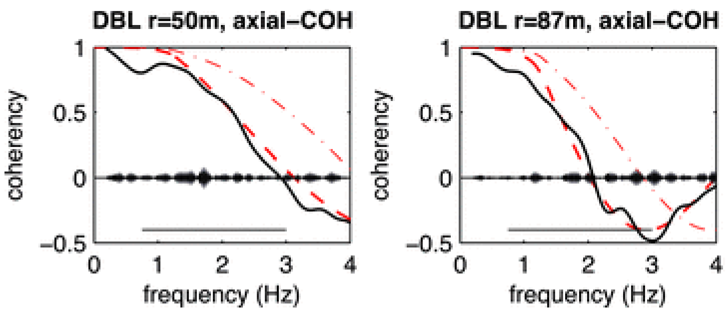
Building on the SPAC and HVSR results obtained at five separate sites, we complete the site characterization study of the Tamar Valley by recording two HVSR profiles transverse to the valley axis. The first profile runs along Paterson Street, at proximity to the sites KPK and RGB, while the second profile runs along Frankland Street at proximity to the sites DBL and OGL (Fig. 2a).

Axial- and transverse-HVSR profiles are constructed by presenting the observed HVSR curves side by side with respect to the distance from the western edge of the valley. A grey tone contour map is generated from the traditional HVSR observations. Each HVSR curve is normalized so its peak is fixed to a value of 1. This normalization was completed to present a smoother map of HVSR observations, and to better observe the variations in the pattern of resonance across the Tamar Valley. It is commonly accepted that, while HVSR observations are reliable to evaluate the frequency of resonance, their amplitude does not give an accurate estimation of the actual site amplification (Lachet & Bard 1994; Dravinski *et al.* 1996), which justifies the normalization process.

6.1 Paterson Street HVSR profile

The Paterson Street profile is formed from HVSR observations recorded at different sensors at site KPK and additional stations along Paterson Street. The axial-HVSR and transverse-HVSR profiles on Paterson Street are presented in Figs 9 and 10.

Figure 9



Observed axial-HVSR profile recorded across the Tamar Valley along Paterson Street. The contour map shows amplitude of HVSR (white is maximum) as a function of position and frequency. Expected frequencies of resonance *fh* from Rayleigh wave ellipticity at site KPK, and , , and computed from Bard and Bouchon's model (eq. 2) are shown as vertical dashed lines. Circles on the right are the location of HVSR observations along the profile. Left: model representation of the Tamar Valley along Paterson Street used in the numerical simulations.

Observed transverse-HVSR profile recorded across the Tamar Valley along Paterson Street. Expected frequencies of resonance *fh* from Rayleigh wave ellipticity at site KPK, and computed from Bard and Bouchon's model (eq. 3) are presented. Left: model representation of the Tamar Valley along Paterson Street used in the numerical simulations.

Combining all geophysical information (gravity interpretation, SPAC and HVSR), we evaluate the geometry of the valley along Paterson Street profile. The maximum depth to the bedrock interface is fixed at H= 230 m from gravity interpretation (Leaman 1994). The width at half-depth is evaluated at w= 500 m to match most observed HVSR peaks to the expected frequencies of resonance of modes SH and SV. These expected frequencies of resonance are computed by the Bard and Bouchon's model using the ellipticity curve from SPAC observations. A shape ratio of SR= 0.46 is computed for the Tamar Valley along Paterson Street. The expected frequencies of resonance of modes SH and SV are annotated on Figs 9 and 10.

The peak on the axial-HVSR profile on Paterson Street is located at f= 0.90 Hz. This is significantly higher than the expected frequency of resonance for an equivalent layered earth (fh= 0.74 Hz), and is located between the expected Hz and Hz frequencies of resonance. A double peak feature is observed at f= 1.27 Hz on axial-HVSR and on the transverse-HVSR profile (Fig. 10). We suggest this peak corresponds to a 1-D frequency of resonance above the flank of the valley. A 1-D frequency of resonance was identified at fh= 1.31 Hz from HVSR observations at site RGB which is located at similar distance to the edge of the valley, supporting this hypothesis. Such complex spectral resonance in a valley environment, including a mix of 1-D and 2-D patterns of resonance, has been recognized by Lenti *et al.* (2009). The peak located at f= 1.16 Hz above the deepest point of the valley at x= 250–300 m on the transverse-HVSR profile on Paterson Street (Fig. 10) agrees well with the expected Hz computed from Bard and Bouchon's model.

6.2 Frankland Street HVSR profile

HVSR observations recorded at selected sensors from the SPAC arrays at sites DBL and OGL and additional stations are used to construct this HVSR profile across the Tamar Valley, located approximately 1 km southeast of the Paterson Street profile. The HVSR stations from the site OGL are projected parallel to the valley axis to correctly evaluate the distance from each station perpendicular to the edge of the valley. The profile contains a total of ten stations, unequally spaced. Figs 11 and 12 present the Frankland Street axial-HVSR and transverse-HVSR profiles. An expected 1-D frequency of resonance of fh= 0.61 Hz is evaluated on the ellipticity curve computed from SPAC observations at site DBL. The peaks identified on HVSR profiles in Figs 11 and 12 are clearly located at higher frequencies.

Observed axial-HVSR profile recorded across the Tamar Valley along Frankland Street. Left: model representation of the Tamar Valley used in numerical simulations.

Combining the SWV profiles obtained by the SPAC method and observed frequencies of resonance observed on HVSR data is necessary to evaluate the geometry of the valley along this profile. The maximum sediments thickness is evaluated at H= 250 m from axial-COH interpretation at site DBL while the numerical simulations of the valley presented in the Section 6.3 allows to determine the width at half-depth (w= 421 m) by fitting the expected and observed frequencies of resonance from HVSR profiles.

We observe a peak at f= 0.90 Hz on the axial-HVSR profile above the deepest point of the valley in Fig. 11. This frequency approximately equals that of the computed Hz. SH modes of resonance of higher order could not be detected on the axial-HVSR profile.

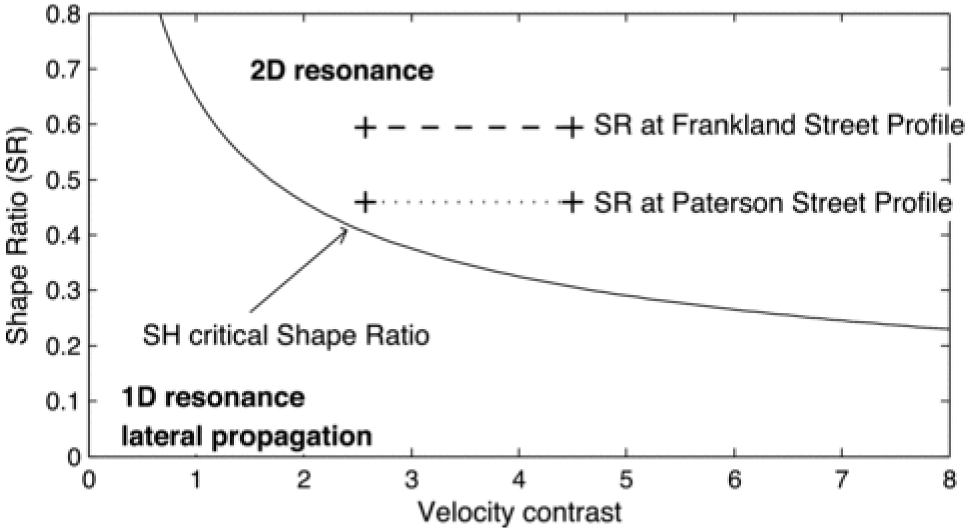
On the transverse-HVSR profile (Fig. 12), a clear peak is identified at frequency f= 1.18 Hz above the deepest point of the valley, which corresponds to the expected frequency of resonance Hz. This peak, along with the peak observed on axial-HVSR at f= 0.90 Hz (Fig. 11), suggests the presence of a 2-D pattern of resonance above the deepest part of the Tamar Valley.

A peak is also identified at location x= 450 m above the gently dipping flank of the valley, which location corresponds to the site OGL. A 1-D frequency of resonance was previously identified at fh= 0.87 Hz on HVSR observations and the ellipticity curve computed from the preferred SWV profile at site OGL. This suggests the resonance behaviour above this side of the valley reacts as a layered earth geology; in a similar pattern than was previously observed on the HVSR profile along Paterson Street.

We note a significant change in the pattern and frequencies of resonance on the axial- and transverse-HVSR profiles at $x \simeq$ 500 m. HVSR data show a peak at constant frequency $f \simeq$ 3.5 Hz on both profiles for x > 550 m. This suggests the geology east of the Tamar Valley can be approximated by a layered earth.

Fig. 13 presents the shape ratio of the valley computed along Paterson and Frankland Street profiles. The shape ratios computed on both profiles are plotted against the critical shape ratio of the SH mode of resonance in Fig. 13. It shows that a 2-D pattern of resonance is expected to develop in the Tamar Valley along both profiles when considering the SH mode of resonance, which confirms the results obtained with HVSR observations. The velocity contrast was computed for a dolerite bedrock shear wave velocity estimated at 1800 m s^{-1}, and Tertiary sediments shear wave velocity of 400 to 700 m s^{-1}, evaluated on the 1-D SWV profiles at sites KPK and DBL.

Figure 13



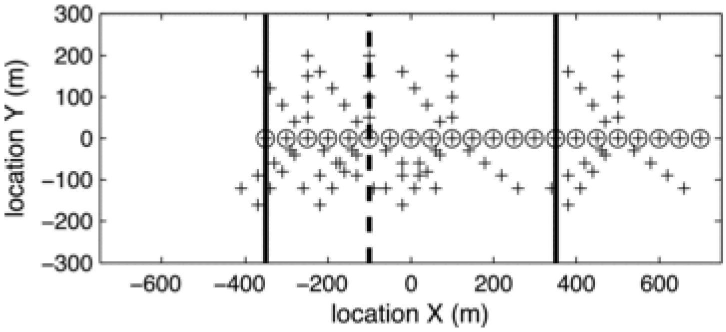
Shape ratio (SR) computed for the Tamar Valley in function of velocity contrast along Frankland Street Profile (dashed line with crosses, *H*= 250 m, *w*= 421 m, for *SR*= 0.59), and along Paterson Street Profile (dotted line with crosses, *H*= 230 m, *w*= 500 m, for *SR*= 0.46). Velocity contrast is computed between bedrock velocity (1800 m s^{-1}) and minimum (400 m s^{-1}) and maximum (700 m s^{-1}) Tertiary sediments velocity from the SWV profiles evaluated at site DBL and KPK. Solid curve is the critical shape ratio of SH mode of resonance in function of velocity contrast (from Bard & Bouchon 1985).

6.3 Numerical simulations

We simulate the propagation of surface waves in complex geology to constrain the geometry and geology of the Tamar Valley. We use the program package NOISE developed within the European 5FP project 'Site Effects Assessment using Ambient Excitations (SESAME)' to complete the numerical simulations (Moczo & Kristek 2002). NOISE is designed to compute the propagation of seismic noise (microtremors) in 3-D heterogeneous geological structures with a planar free surface, from surface and near-surface random sources (Moczo & Kristek 2002). The package is divided in two main programs: Ransource for the random space-time generation of microtremor point sources and Fdsim for the computation of seismic wavefields in 3-D heterogeneous geological structures based on the finite-difference method (Moczo *et al.* 2002; Kristek *et al.* 2002, 2006; Moczo *et al.* 2007).

The 2-D model representation of the Tamar Valley is described in CAK1, to which the reader is referred to for additional information concerning the initial parameters used in the numerical simulations. We only model the Frankland Street profile because SPAC observations recorded above the deepest point of the valley along the Paterson Street profile (site KPK) do not offer adequate resolution of the depth to bedrock interface, an important constraint in the numerical simulations. Simulated three-component microtremor time series are recorded at a series of receivers positioned at 50 m spacing to construct a HVSR profile across the model representation of the valley (circles in Fig. 14). Additional simulated receivers were also positioned to record simulated SPAC data used in CAK1 (crosses in Fig. 14).

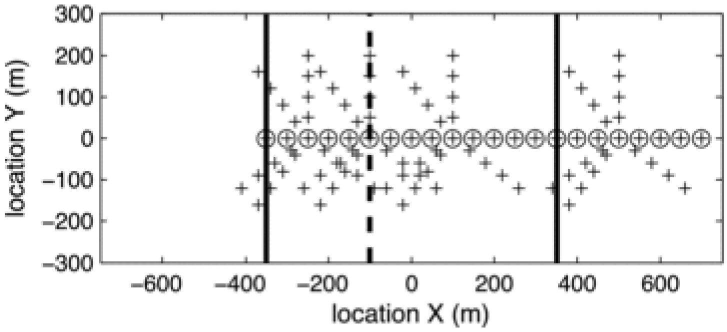
Figure 14



Location of all simulated receivers across the Tamar Valley. Crosses: receivers forming SPAC arrays. Circles: receivers for HVSR profile across the valley. Thick vertical solid lines are the edges of the valley. Thick vertical dashed line is the axis of the valley, at its deepest point.

The parameters of the model representation of the Tamar Valley are determined to fit HVSR and SPAC microtremor observations recorded along the Frankland Street profile. The SWV profile used in the simulations above the deepest point of the valley is an approximation of the SWV profile evaluated by the axial-COH method at site DBL (Fig. 15b). The geometry of the right flank of the valley is constrained by simulating HVSR measurements over a layered earth model, varying the depth to bedrock interface to fit SPAC and HVSR observations at site OGL, and HVSR observations at different stations on the Frankland Street profile. The SWV profile interpreted at site OGL, and its approximation used in the numerical simulations are presented in Fig. 15(c). The assumption of a layered earth on this flank of the valley is postulated by the behaviour of HVSR observations presented in Section 6.2.

Figure 15



(a) Bedrock interface of model representation of the Tamar Valley (vertical exaggeration of 2). Circles are locations of HVSR receivers. Dash–dotted line is bedrock interface interpreted from gravity survey by Leaman (1994) (Fig. 2b, Profile #2). Dashed lines are the location of SWV profiles presented in

(b) for site DBL, and (c) for site OGL. Solid lines on SWV profiles are preferred SWV profiles from SPAC observations; dashed lines are SWV approximation used for the numerical simulations of the Tamar Valley.

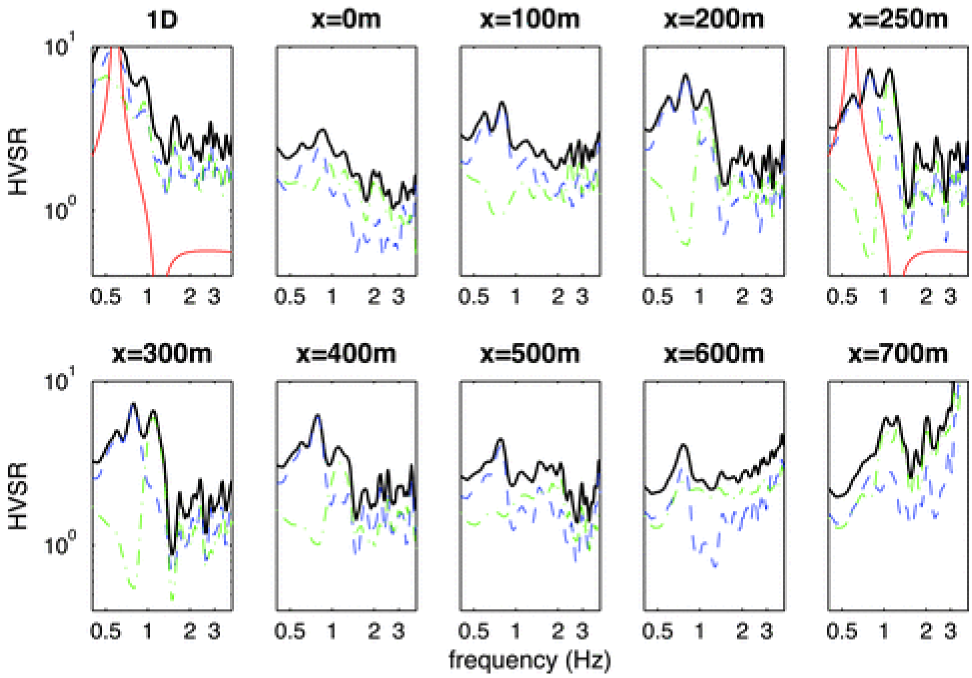
The 2-D model representation of the valley (Fig. 15a) is simulated by an exponential analytical expression inspired from Paolucci (1999), which parameters are described in CAK1. A layered earth with depth to bedrock *z*= 25 m is interpreted right of the valley from the HVSR profiles presented in Figs 11 and 12. The propagation of surface waves in a layered earth geology using the SWV profile above the deepest point of the Tamar Valley model (Fig. 15b) is also simulated to better understand the differences between HVSR observations in a layered earth and in a 2-D valley.

6.4 Simulated HVSR

Simulated HVSR curves are computed at all points across the valley. These are used to validate the frequencies of resonance which develop within the valley, and the variations of HVSR observations along the Frankland Street profile.

HVSR simulated at ten receivers are presented in Fig. 16. The top left panel presents the HVSR curves simulated for the equivalent layered earth, with the Rayleigh wave ellipticity curve computed from the SWV profile of Fig. 15(b). HVSR simulated at different locations across the valley are presented in the other panels with respect to the distance *x* to the left edge of the valley. The deepest point of the valley is located at *x*= 250 m.

Figure 16



Simulated HVSR above layered earth model (top left) of SWV profile from Fig. 15(b); and at distance *x* from the left edge of the 2-D model representation of the Tamar Valley. Thick solid black line is conventional HVSR; dashed blue line is axial-HVSR; dash–dotted green line is transverse-HVSR. Solid red line is the Rayleigh wave ellipticity computed assuming a layered earth model of SWV profile from Fig. 15(b). Rayleigh wave ellipticity is presented for location where the depth to bedrock interface is simulated at H= 250 m.

We observe some variability in the HSVR curves simulated above a layered earth and those simulated at different locations across the 2-D model representation of the Tamar Valley. HVSR peaks from all components (HVSR, axial-HVSR and transverse-HVSR) agree well with the peak on the ellipticity curve above a layered earth (Fig. 16, top left). We observe a separation of the peaks on simulated axial-HVSR and transverse-HVSR, indication of a 2-D pattern of resonance at distance 200 $\leq x \leq$ 400 m from the edge of the valley. The peaks on simulated HVSR above the deepest point of the valley (Fig. 16, top right) are shifted to higher frequencies when compared to the peak on the ellipticity curve computed for an equivalent layered earth. A change in the pattern of resonance, similar to what was observed on the HVSR profiles recorded in Launceston, is observed between x= 400 m and x= 500 m, where the peak is unclear on simulated HVSR curves.

Simulated axial-HVSR and transverse-HVSR profiles are presented in Figs 17 and 18 to better identify the pattern of resonance which develops in the 2-D model representation of the Tamar Valley. The expected 1-D frequency of resonance for the equivalent layered earth (SWV profile from Fig. 15b) is computed at fh= 0.59 Hz. No peak is detected at this frequency on the simulated axial- or transverse-HVSR profiles. Using Bard and Bouchon's model with a shape ratio 'SR = 0.59 (H= 250 m, w= 421 m), we seek to identify 2-D frequencies of resonance on the simulated HVSR profiles.

Simulated axial-HVSR profile across a 2-D model representation of the Tamar Valley (left). Expected frequencies of resonance fh from Rayleigh wave ellipticity from SWV profile presented in Fig. 15(b), and , and computed from Bard and Bouchon's model are presented. Circles on the right are the location of HVSR observations along the profile.

Simulated transverse-HVSR profile across a 2-D model representation of the Tamar Valley (left). Expected frequencies of resonance fh from Rayleigh wave ellipticity from SWV profile in Fig. 15(b), and computed from Bard and Bouchon's model are presented. Circles on the right are location of HVSR observations along the profile.

A broad peak is observed on the axial-HVSR profile at frequency f= 0.81 Hz, between the expected frequencies of resonance and Hz. Similar difficulties in precisely separating the multiple SH modes of resonance were recognized on the Paterson and Frankland Streets HVSR profiles. While simulated HVSR data fails to provide accurate detection of the different SH modes of resonance, it is effective in the recognition of a 2-D pattern of resonance; the peak on the axial-HVSR is located at frequency significantly higher than that of the equivalent layered earth.

The fundamental SV mode of resonance is accurately identified on the simulated transverse-HVSR profile (Fig. 18). The peak is observed at f= 1.11 Hz, approximately equal to the computed SV frequency of resonance Hz (eq. 3). This confirms the capability of the transverse-HVSR to identify the SV mode of resonance across a deep and narrow valley such as the Tamar Valley.

The peak on the transverse-HVSR is not well defined at locations $x \geq 450$ m, for which location the peak seems to follow more closely the shape of the valley. The results of the numerical simulations agree well with SPAC and HVSR observations recorded across the Tamar Valley in Launceston, and confirm the results of Lenti *et al.* (2009) concerning the possibility of developing a mixture of 1-D and 2-D patterns of resonance in a valley environment such as the Tamar Valley.

6.5 Frequencies of resonance

The site resonance study of Launceston is summarized in Table 1. The table lists the expected (from Bard and Bouchon's model), observed, and simulated frequencies of resonance at all five sites. The expected 1-D frequencies of resonance fh are interpreted from the peaks in the Rayleigh wave ellipticity curves computed from the preferred SWV profiles evaluated by the SPAC method. The expected SH and SV frequencies of resonance are computed from the eqs (2) and (3) of Bard and Bouchon's model, using the shape ratios evaluated on Paterson Street and Frankland Street profiles. The frequencies of resonance identified on HVSR observations at all five sites in Launceston are indicated in brackets. The frequencies of resonance computed and identified from the numerical simulations of the Tamar Valley model are presented in the right column of the table.

Table 1

Mode	GUN	RGB	KPK	DBL	OGL	Tamar
f_h	1.16 (1.18)	1.24 (1.31)	0.74 (–)	0.61 (–)	0.95 (0.87)	0.59 (–)
SH_{00}	–	–	0.83 (–)	0.71 (–)	–	0.68 (–)
SH_{01}	–	–	1.01 (0.90)	0.94 (0.90)	–	0.91 (0.81)
SH_{02}	–	–	1.27 (1.25?)	1.24 (1.20?)	–	1.20 (–)
SV_{fund}	–	–	1.24 (1.16)	1.21 (1.18)	–	1.17 (1.11)

Expected 1-D frequencies of resonance f_h computed on the Rayleigh wave ellipticity curves from the preferred SWV profiles, and SH and SV frequencies of resonance computed at separate sites in Launceston. Frequencies of resonance identified on HVSR observations at five sites in Launceston, and above the deepest part of model representation of the Tamar Valley are presented in brackets (frequency in Hz). The question mark '?' indicates these values are identified with low confidence on HVSR observations.

The site resonance study completed in Launceston verifies the existence of a complex pattern of resonance across the city of Launceston. A 1-D pattern of resonance is recognised at sites GUN, RGB and OGL where the peaks identified on HVSR observations agree well with the peaks on Rayleigh wave ellipticity curves. This result was expected at site GUN, which was assumed to be located above a layered earth, however it is a surprising result at sites RGB and OGL which are located within the limits of the Tamar Valley. As initially expressed by Bard & Bouchon (1985) and later observed by Lenti *et al.* (2009), certain valleys simultaneously develop 1-D and 2-D patterns of resonance. We suggest this is the case in the Tamar Valley, where a 2-D pattern of resonance is clearly recognized at sites KPK and DBL, located above the deepest point of the valley.

We observe from Table 1 that HVSR observations are adequate to identify the expected frequency of resonance in a layered earth, and the expected frequency of resonance in valley environment. Good fits are obtained between expected and observed at sites KPK and DBL above the deepest point of the valley. While HVSR observations can detect the shift in frequency induced by the SH mode of resonance, they fail to identify the expected SH frequencies with adequate precision. The frequencies of resonance of the SH mode can be estimated by using the peak of the ellipticity curve determined from SPAC observations, and computing the shifts to higher frequencies from Bard and Bouchon's model. Combining the results from SPAC and HVSR methods permits to get the complete picture of the site resonance study across the Tamar Valley.

7 Conclusions

We conducted a site resonance study at five separate sites in and around the deep and narrow Tamar Valley in the City of Launceston (Tasmania, Australia). We combine the use of the array based SPAC microtremor method to evaluate SWV profiles with single station HVSR microtremor observations to evaluate the frequency of all modes of resonance.

The SPAC method is conventionally applied to reliably evaluate the SWV profile at site GUN, located above an assumed layered earth. The frequency of resonance is identified at fh= 1.18 Hz from HVSR observations; frequency which agrees well with the expected frequency of resonance above a layered earth from the Rayleigh wave ellipticity curve computed at site GUN.

The interpretation of SPAC observations at sites RGB and OGL provides credible SWV profiles at both sites. While the gravity survey from Leaman (1994) suggests these sites are located in an area having 2-D geology, the similar behaviour of the observed coherency spectra when comparing different orientations suggests the geology can be approximated by a layered earth at both sites. This is confirmed by HVSR observations which peaks, identified at the same frequency on the axial and transverse components, agree well with the peaks on the Rayleigh wave ellipticity curves computed from the SWV profiles interpreted by SPAC method. HVSR measurements simulated in a 2-D model representation of the Tamar Valley confirm the presence of a 1-D pattern of resonance above the flank of the valley. The frequency of resonance identified on HVSR observations is estimated at fh= 1.31 Hz at site RGB, and at fh= 0.87 Hz at site OGL.

A 2-D pattern of resonance is detected above the deepest part of the Tamar Valley on two HVSR profiles recorded transverse to the valley axis along Paterson and Frankland Streets, as judged from the separation of SH and SV modes of resonance at sites KPK and DBL. The fundamental SV frequency of resonance is identified on the transverse-HVSR component at f= 1.16 Hz along Paterson Street profile and at f= 1.18 Hz along Frankland Street profile. While a shift to higher frequencies is clearly recognized on both axial-HVSR profiles, HVSR observations fail to identify with precision the SH frequencies of resonance expected to develop in the Tamar Valley.

SPAC observations recorded above the deepest point of the valley are used to constrain the SWV structure and geometry of the Tamar Valley, and to evaluate the different SH modes of resonance expected to develop in the valley. As originally proposed in CAK1, coherency spectra recorded with pairs of sensors oriented parallel to the valley axis (axial-COH) are used to evaluate the SWV profile above the deepest point of the valley at site DBL.

From Bard and Bouchon's model, we can evaluate the expected SH and SV frequencies of resonance in the Tamar Valley by computing the Rayleigh wave ellipticity curve from the SWV profile evaluated by axial-COH above the deepest point of the valley. The frequencies of resonance expected to develop across the Tamar Valley along Frankland Street are Hz, Hz, Hz and Hz.

We suggest the frequencies of resonance are shifted to slightly higher frequencies along the Paterson Street profile, but lack of resolution of the bedrock interface with SPAC observations limits the conclusions. Observations with larger SPAC arrays would be necessary to gain resolution at depth. Deployment of such arrays was made difficult by the layout of the streets of Launceston. The best estimates of the expected frequencies of resonance along Paterson Street profile are Hz, Hz, Hz and Hz.

The results demonstrate a successful application of combined SPAC and HVSR observations recorded at separate sites to conduct a site resonance study in a 2-D valley environment, where the use of both methods allows identification of the complex pattern of resonance (modes and frequencies of resonance) which develops in this narrow deep valley.

Acknowledgments

Maxime Claprood is supported by a Monash Graduate Scholarship, an International Postgraduate Research Scholarship, and a Québec's Funds for Nature and Technology Scholarship. Seismometers used in this project were loaned to Monash University by the Australian National Seismic Imaging Resource (ANSIR). We are grateful to the City Council of Launceston, for their assistance during field survey. Geological maps of Launceston were provided by Mineral Resources Tasmania. We would like to recognize the help of Miss Janett Steiner for her assistance during the field survey. Thanks are due to the editor Prof. Jean Virieux and Matteo Picozzi whose constructive suggestions helped improving the quality of the manuscript and our research in general.

NOTE : The test site denote KPK Figures 2 & 3 is the area of the subject land Amendment 66 Current Planning Scheme Amendment for the land fronting Paterson,

Margaret and Brisbane Streets.

Environmental hazards and constraints have not been properly identified nor addressed by the proponent. The proposed development site is situated on a narrow seismic plate between to seismic fault lines (one running parallel beside the abutments of Paterson Bridge, immediately on the east side of Ritchie's Mill along. Bourke Street via Glen Dhu St and beyond the former Coates Paton's building, and the other passing midway between Park and Margaret Streets and extending beyond the junction of Melbourne and Leslie Street in South Launceston. These particular fault lines are two of quite a number of faults crossing the Launceston area and accurately displayed on the Geological Survey of Launceston (part of the survey of Tasmania) conducted by Department of Mines, Tasmania Ref. 8315 S1 1 & 111 Zone 7 Sheet No.39). This seismic plate has dropped approximately 3OOm from the adjoining Trevallyn plate, and then the next eastern plate has dropped approximately a further 300m. We interpret this as showing the development siie being founded on a differing geological base of at least 300m compared.to adjacent foundation and with well-documented evidence of building damage having occurred in recent times (geologically speaking) along the course of Margaret Street. A copy of this reference is readily available and can be found in Council's own files.

PATERSON BRIDGE DESIGN/CONSTRUCTION ASSESSMENT

By example, in 1965, as part of due diligence by engineers designing the Paterson Bridge, a Geophysical Survey of the bridge site was undertaken by the National Bureau of Mineral Resources, Geology and Geophysics for the Commonwealth's Department of National Development (Ref Record No. 1965/153), pinpointing the location of the western-side fault line crossing the South Esk River at a point about 35m downstream of the old Kings Bridge. The decision was made to particularly position the new bridge abutments on just one side of the fault line, so as to attempt as much as possible to minimise the risk of a structural collapse.

EARLY SEISMIC RISK ASSESSMENTS

Dr Owen Ingles

In 1990 and with historical awareness from earlier studies and seismic events, the then LCC City Engineer commissioned Dr Owen lngles to carry out a seismic risk assessment for the Launceston Municipality, his report being submitted in March 1991. lngles considered four risk factors from potential earthquakes: fault displacement; landslide/landslip; sediment liquefaction; and fill settlement.

GHD Consultants

The more recent 2006 GHD study notes the presence of fill and the potential for ongoing settlements" when undertaking an assessment of the stability of Launceston's flood levee system.

Dr Marion Leiba

In December 1995, Dr Marion Leiba, Geologist, Geophysicist, Seismologist and much more, authored a report on behalf of Australian Geological Survey Organisation to Launceston City Council titled **Survey and Seismic Microzonation, Launceston Tasmania**. ln this report, she pointed out that Launceston had been damaged by 5 earthquakes arising in the West Tasman Sea (1884, 1885, 1992, 1929 and 1946). The damage was thought to be caused by amplified earthquake shaking because of sediments and possibly other aspects of geology and topography in certain parts of Launceston.

Consequently, zoning maps were prepared using microtremor measurements at 53 sites, a soils map by Steve Forsyth of Mineral Resources Tasmania, a gravity interpretation by David- Leaman, and unpublished drillhole data.

These maps showed areas of Launceston where amplified earthquake shaking may occur because of the presence of underlying sediments. Also resonance effects may increase the destructiveness of the earthquake. She explains in relation to the period of vibration of the ground, if matching that of a building above it, to be like a person pushing a swing higher and higher by matching the push to the moving swing. This resonance effect increases the likelihood of a building being damaged by an earthquake. She advises that one can lessen the chance of Earthquake Damage by avoiding erecting a building with a certain resonant period on a site within the same period.

Three groups of buildings were considered for the map: low rise (1-3 storeys), medium rise (4-9 storeys) and high rise (10+ storeys). Certain soil characteristics can give a more sophisticated method for computing the "period" of the building (when the natural 'period' of the ground matches the period of the building, probable maximum damage to the building occurs.

Seven zones on the **building heights earthquake zoning map** are:

ZONE 0. No resonance, but for other geological reasons, a response would be unknown.

ZONE 1-3 Possible resonance for 1-3 storeys (low rise buildings).

ZONE 1-5 Possible resonance for .1-5 storey buildings (a narrow NNW -SSE trending zone along the eastern side of the Tamar axis valley.

ZONE 1-9 Possible resonance for 1-9 storeys (low and medium rise buildings (Small zones on Windmill Hill and near Coronation Park).

ZONE ALL Possible resonance all buildings. (Tertiary sediment areas and in particular NE part of the North Esk axis and floodplain.....

ZONE 4+ Possible resonance for 4 or more storeys (high rise) buildings - mainly deep sediment fill in the Tamar and North Esk axis valleys and the Norwood area. Also on shallow floodplain sediments, including most of the old railyards……what a wonderful choice as the site for a new University….

ZONE 10+ Possible resonance for 10 or more stories (high rise) buildings - from gravity and soils map, to the east of the old rail yards.

The ongoing studies and assessments of various works and reports by Dr Ingles warned against building structures in Launceston higher than **4 storeys**.

It is part of our representation, that the assessment of the environmental hazards and constraints for proposed and 'at risk' development sites must be adequately investigated along with any associated risks such as (say) the Paterson St earth levee being breached by the combination of rising sea and silt levels (most recent advice to LCC is that even the 'newly reconstructed' levees are now only 1:100 yr not 'l: 200 yr as proclaimed at the end of the reconstuction project in 2017) and the potential for a seismic event destabilising one of the levees as well as a proposed building, is in combination or singlely, sufficient to potentially cause great public risk, notwithstanding potentially damaging other adjacent structures as well as endangering lives.

We thank you for this opportunity to make this representation and encourage further communication with us before the proposal is finalised.

Yours faithfully

Lionel Morrell

President, for and on behalf of
Tasmanian Ratepayers Association Inc.

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Guide to considering natural hazard risks in land use planning and building control

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Tasmanian Government

Version control

Edition	Comments received	Actioned	Approved
1.10	Tony McMullen – on version dated the 13/10/2011	LR	MH
1.11	Landslide hazard reference group comments – 18/10/2011	LR	MH
1.12	MH and LR	LR	MH
1.13	MH and LR	LR	MH
1.14	Liza Fallon – risk tolerance	LR	MH
1.15	MH	MH	MH
1.16	LR	LR	MH
1.17	MH	LR	MH
1.18	Simon Roberts	LR	MH
2	LR/MH	LR	MH
2.1	Comments from Steering Committee,	LR	MH
2.2	External reviewers - Clive Attwater SGS Economics	LR	MH
2.3	TPC	LF/LR	MH
3/ 3.1	Regional Workshops	LR	MH
3.2	Comments from project steering committee	LR	MH

CONTENTS

1 RISK – THE CONTEXT

Natural hazards can impact significantly on the social, environmental, and economic costs associated with the use and development of land. Events such as flooding, bushfires, storms and landslides impose costs on individuals in terms of life or private property loss, or for the community by way of environmental damage, infrastructure loss, reduced wealth, or loss of social confidence. Mitigating the consequences of a natural hazard event requires a range of treatment options, including emergency management, emergency response, construction standards and land use planning.

This guide outlines how to manage the risk presented by natural hazards within the land use planning system in Tasmania. It applies a 'hazard treatment approach' to land use planning as a tool to mitigate the risk presented by natural hazards. Land use planning is one of the tools available to government that can increase community resilience against the impacts of natural hazards. Other tools include emergency response and recovery, the building standards, and community awareness. Land use planning allows governments to strategically consider the hazard when planning settlements, and set policy on acceptable risk and controls that increase the ability of individuals and the community to resist and recover from a hazard event.

Planning can be defined as "…*the process of making decisions to guide future action*" (PIA 2010). This planning process is one part of a broader system that also includes emergency management and building standards. In this context, this guide sets out a structured method for making decisions on exposure to a natural hazards event (***likelihood***), to understand what these assumptions may mean for planning and development (***consequence***), and provide a method for identifying when avoidance should occur and when appropriate controls on use and development are required (***tolerance***).

Through the development of the guide, it is expected that the Tasmanian Government will be in a stronger position to:

- promote a broad understanding of the existence of hazards and risks in any given location;
- provide certainty through strategic planning as to where development can achieve appropriate levels of tolerance;
- provide certainty in the development process including what information is required of developers and when;
- provide guidance on what is considered to be a tolerable level of residual risk to the community; and
- impose planning controls that are proportional to the level of exposure to a natural hazard and the type of development.

The guide contains four sections:

- **Section one:** reviews the approaches to the risk management of natural hazards.
- **Section two:** outlines the risk tools that are used as part of a hazard treatment approach. This approach seeks to use a combination of elements associated with risk assessment, precautionary and emergency response approaches.
- **Section three:** provides details of the tools used in the hazard treatment approach.
- **Section four:** outlines the steps involved in implementing the hazard treatment approach.

1.1 *Balancing Costs and Benefits*

Mitigating risks from natural hazards is not about totally avoiding or eliminating the risk. Natural hazards are a feature of our environment and, in most instances, the potential impacts of natural hazards can be managed. Individuals, developers, communities and governments must balance the costs associated with managing the impacts of natural hazards against the benefits arising from development. In some cases, the costs (including the costs of mitigation) may outweigh the benefits and the community may determine that it is prudent to avoid development.

The background paper titled: "The overarching principles for the consideration of natural hazards in the planning system" (DPAC 2011) broadly sets out the current policy context for natural hazards and suggests a set of foundation principles for the Government's intervention in land use planning and development for the purposes of managing risks from natural hazards (a summary of the principles is included at Appendix A). This guide is consistent with the principles detailed in the background paper in that it:

- promotes ownership of private risks by an individual or business;
- ensures that the impact of a natural hazard is identified very early in the planning process to avoid encouraging development where the risk is so high that mitigation is problematic and the costs outweigh the benefits;
- advocates a structured decision-making process when considering a development (and potentially in the transfer of land);
- helps governments (at all levels) to inform/educate the community, industry, and government officials about natural hazards;
- clarifies the approach to managing both public and private risks;
- assists in the prioritisation for investment in research and mitigation of natural hazards by individuals, businesses and governments; and
- enables governments (at all levels) to identify and avoid actions that give rise to unacceptable public and private risks to individuals or the community.

1.2 *Risk Management*

The risk management process is a suite of tools that helps to focus the attention of decision-makers on the potential costs of unpredictable events and, in the context of natural hazards, ensure that public exposure to a known natural hazard is within tolerable limits (Saunders and Glassey 2009).

Risk management processes for natural hazards are broadly outlined in the *National Emergency Risk Assessment Guidelines* (NERAG) and the *Australian Standard for Risk Management* (AS/NZS 31000 2009). The risk management process is shown in Figure 1.

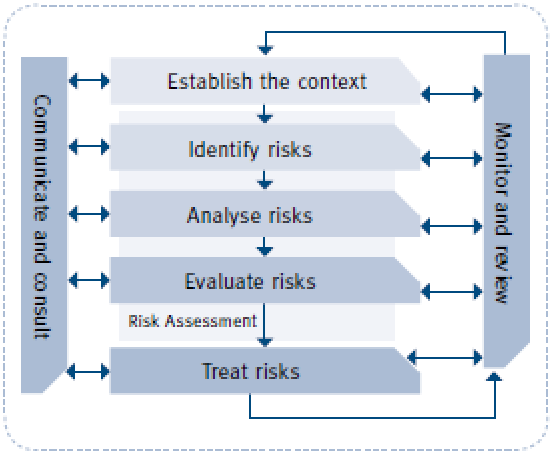

Figure 1: Risk management process (NERAG 2009)

The Australian Standard AS/NZS 31000 (2009) expresses risk in its simplest form as "*the effect of uncertainty on objectives*". In the context of natural hazards, risk can be described as the product of the chance of a hazard occurring (**likelihood)** and the impact of an event **(consequence)**, in which:

- **Likelihood:** relates to the uncertainty surrounding "... the chance of something happening ..." at a location, or conversely, how often a use or development is likely to be impacted by a natural hazard in any given location.

- **Consequence:** relates to the "... outcome(s) of an event affecting objectives…" or how the intended use of land may be impacted by any given natural hazard event.

There is no universal truth on when the likelihood of an event is too high or the consequence too great. Rather, communities and governments make judgements that inform an appropriate ***risk tolerance***. Here, risk tolerance is the judgement regarding when the combination of likelihood and consequence of a natural hazard becomes unacceptable in terms of potential costs to the community (public risks) or to an individual (private risks). Risk tolerance is further discussed in Section 2.3.

There are a number of methods[1] available for making judgements regarding tolerance to risk and the treatment of potentially intolerable risk, these are outlined in Appendix B – Approaches to the Management of Risk. The preferred approach to risk is the **hazard treatment approach**.

The hazard treatment approach seeks to use a combination of tools associated with risk assessment, and precautionary and emergency response methods. The approach seeks to meet the challenge of balancing short-term costs (additional studies or building works) with the long-term costs (loss of property, annual insurance, or emergency response and recovery) that are associated with natural hazard exposure.

This hybrid risk method encourages the use of detailed evidence where it is available, but also allows policy judgements to be made in the absence of clear evidence. The approach focuses the attention of governments on areas where risks are deemed intolerable, but also accommodates judgements that the risk in other areas is acceptable and in these circumstances, it is appropriate to rely only on an emergency response if required.

The hazard treatment approach relies on mapping 'hazard bands' based on the likelihood of a hazard occurring. The mapping of hazard bands is based on available information. The collection of further data by the public or private sector can be prioritised in areas of high development demand to support their objectives. Proxies for hazard likelihood are used in areas where detailed hazard modelling has not been (and may never be) undertaken.

The adoption of the hazard treatment approach recognises, in part, that a legitimate role of governments is to protect public value by making judgements regarding risk, even in the absence of detailed risk information. Policy judgements regarding both hazard likelihood and appropriate control measures can be developed through active engagement with stakeholders to ensure that they reflect community attitudes towards risk and tolerance to risks.

[1] This builds on the work completed by Klinke and Renn 2002, who identified three approaches to managing risk (risk assessment, applying the precautionary principle, and managing through hazard treatment) by adding emergency response as a method to manage risk in land use planning.

2 HAZARD TREATMENT – TOOLS

Applying the **hazard treatment** approach requires a capacity to assess or make judgements on likelihood, consequence and risk tolerances in strategic land use planning, and use and development control.

2.1 *Likelihood*

Likelihood is "...used to refer to the chance of something happening, whether defined, measured ... qualitatively or quantitatively..." (ISO Guide 73-2009, Risk management - vocabulary). For natural hazards, it is the chance of a natural hazard event happening or how often a natural hazard impacts something of public or private value.

Likelihood has two components: magnitude (extent or severity) and recurrence (probability or how often).

The 2010 National Emergency Risk Assessment Guideline (NERAG) provides guidance on describing likelihood levels for a hazard event occurring from **almost certain** to **almost incredible** with the associated frequency and annual exceedance probabilities (AEP) shown in Table 1 below.

Table 1: Likelihood table (NERAG 2009)

Likelihood level	Frequency	Average recurrence interval	Annual exceedance probability[2]
Almost certain	Once or more per year	<3 years	>0.3
Likely	Once per ten years	3 – 30 years	0.031 – 0.3
Possible	Once per hundred years	31 – 300 years	0.0031 – 0.03
Unlikely	Once per thousand years	301 – 3,000 years	0.00031 – 0.003
Rare	Once per ten thousand years	3,001 – 30,000 years	0.000031 – 0.0003
Very rare	Once per hundred thousand years	30,001 – 300,000 years	0.0000031 – 0.00003
Almost incredible	Less than once per million years	>300,000 years	<0.0000031

Likelihood expressed in terms such as AEP can be used to make planning assumptions regarding both *magnitude* and *recurrence* (see Box 1). It is not, however, always possible to express likelihood (recurrence and magnitude) in such clear terms. The capacity to make assumptions regarding magnitude and recurrence relate very strongly to:

[2] Annual exceedance probability is expressed in this table as a proportion of one.

- the ability to predict triggers that lead to a natural hazard event;
- the ability to make assumptions regarding the linkages between a trigger and the natural hazard event; and
- the complexity between the preconditions for an event, the trigger, and a resulting hazard occurrence and magnitude.

Table 2 below, outlines how the understanding of triggers and the linkage to a hazard event drives different approaches to judging likelihood. In general, the following approaches can be used for assessing likelihood:

- *Modelled event* calculated as an AEP or similar measure (outlined in Appendix C) can be used where the trigger event can be predicted for a given location and where there is a relatively direct link between the trigger event and the hazard (eg flood, storm, coastal inundation).

  These measures can be used to model both recurrence and magnitude for planning purposes.

- *Areas of hazard susceptibility* can be used where the preconditions for a hazard event are reasonably well known, but the linkage to a trigger event and the resulting hazard is difficult to model without a full site assessment. In these areas neither recurrence nor magnitude can be modelled on a regional or statewide basis.

  For example, the preconditions for landslide are reasonably well known; the land needs to be sloped, and have a certain geology prone to failure (generally speaking). The risk of land sliding during heavy rain, however, will depend upon many inter-related factors that cannot be assumed and can only be evaluated by a site assessment.

- *Exposure to a reference event* should be used where the preconditions for a hazard event are

Box 1: Example of assessing recurrence and magnitude using AEP

Assume that it is assessed (through modelling or the recording of historical events) that there is, on average, a 1 per cent chance every year that a flood will reach, for example, three metres above the natural surface of the riverbed. Generally speaking, this measure allows planners and developers to make the following judgements for planning purposes:

- In any 100-year period, it should be assumed that land below this point will be inundated more than once (recurrence); and
- In any 100-year period, it should be assumed that floodwaters will rise three metres above the riverbed (magnitude).

Similar calculations can be modelled for other recurrence levels (eg 5%, 20%, 50% AEP) or for other magnitudes (ie four metres relates to 0.5% AEP and two metres relates to 5% AEP).

either not known or relatively dynamic (eg vegetation condition or dryness) and where trigger events cannot be reasonably predicted for a given location.

For example, the preconditions for a bushfire (eg soil and vegetation dryness, and weather conditions) are reasonably predictable within a seven-day period but can be difficult to judge on timeframes appropriate for planning purposes where consideration may be required over the lifetime of a development (eg 30, 50 or 100-year periods). Similarly, predicting the frequency of a trigger event (eg lightning strike or intentional ignition) is almost impossible to predict with any accuracy.

Table 2: Examples of approaches to assuming likelihood

Hazard	Trigger event predictability	Predictability of preconditions to an event	Linkage between preconditions, trigger, and the hazard	Approach to likelihood
Flood	Can be predicted. Largely triggered by rainfall that can be accessed through historic records and modelled for future events.	Reasonably predictable around soil dryness, river morphology or vegetation condition.	Relatively direct linkage between preconditions, rainfall and flooding events.	Can be expressed in terms of annual probability (eg ARI[3] or AEP[4] – see Appendix C).
Landslide	Moderate capacity to predict the trigger event. The trigger event can include rainfall, loading, and leaking pipes. In general, rainfall events can be accessed through historic records and modelled for future events. Other triggers are unable to be modelled.	Can be made based on broad assumptions around slope, geology, soil depth, land use, vegetation coverage, and construction at the toe/top of the slope.	Large uncertainties regarding the linkages between triggers and a landslide event.	Can be assessed by identifying areas of hazard susceptibility. Measures cannot be used to assume magnitude or frequency without a detailed site assessment.

[3] Annual recurrence interval

[4] Annual exceedance probability

Bushfire	Difficult to predict. Many possible triggers including accidental or deliberate man-made ignition, lightning strikes or industrial cases (eg electricity arching).	Able to be modelled although bushfires are highly dynamic due to changes in soil and vegetation dryness, fuel load, etc.	Large uncertainties regarding the linkage between the trigger and preconditions. Linkages include weather conditions, availability of fire suppression assets, topography downwind of the point of ignition, fuel reduction measures, etc.	Likelihood can be judged through an assessment of the potential exposure to a reference event. (eg exposure to a fire of defined character in the area).

Choosing an appropriate measure of likelihood is a critical part of the successful implementation of the hazard treatment approach. The choice of likelihood measure will significantly impact on the ability to define natural hazard bands (see Chapter 3) and the successful implementation of the hazard treatment approach will help to build confidence that controls are reasonably well aligned to the threat from the natural hazard. The measures and level likelihood will also heavily influence the nature of controls that will need to be imposed in the band.

2.2 *Consequence*

Consequence is the "...outcome of an event affecting objectives" (AS31000 2009). For the purposes of this guideline, 'event' relates to a natural hazard and 'objectives' relates to the intended use or development of land.

As detailed in Table 3, NERAG provides a tool for assessing consequences in terms of people, environment, economy, public administration, social setting and infrastructure.

Table 3: Exposure impact category definitions

Impact category definitions	
People	Relates to the direct impacts of the emergency on the physical health of people/individuals and emergency services' (ie health system) ability to manage. Mortality defined as the ratio of deaths in an area of the population of that area (expressed per 1 000 per year).
Environment	Relates to the impacts of the emergency and its effects on the ecosystem of the area (including fauna and flora).
Economy	Relates to the economic impact of the emergency on the governing body as reported in the annual operating statement for the relevant jurisdiction and industry sectors as defined by the Australian Bureau of Statistics.
Public administration	Relates to the impacts of the emergency on the governing body's ability to govern.
Social setting	Relates to the impacts of the emergency on society and its social fabric, including its cultural heritage, and the resilience of the community.
Infrastructure	Relates to the impacts of the emergency on the area's infrastructure/lifelines/utilities and their ability to service the community.

The challenge for assessing the likely consequences for development from exposure to a natural hazard is that they will depend very heavily on circumstances that cannot be predicted accurately, such as the time of day, the day of the week, the response to the event (eg emergency mitigation measures) and the behaviour of individuals. Assumptions must be made, therefore, based on the nature of the use or development, and how it relates to the impact categories identified by NERAG.

Considering consequence in the hazard approach requires the development of consequence statements, which describe the assumed impacts on different types of use. Generally, consequence statements are considered separately for categories of use classified as 'hazardous' (such as chemical storage facilities) and 'vulnerable' (such as schools and hospitals). As outlined at Appendix D, Asset Classes 3 to 5 are considered vulnerable and hazardous.

Consequence statements are not accurate assessments of the actual consequence for a type of use. Rather, they are policy judgements regarding how to assume consequence for the purposes of assessing the appropriate use of land through the land use planning system. At particular levels of risk, the State may require a more detailed analysis of the actual consequence inherent in a particular development. Flexibility is often built into the planning system to allow the assumptions regarding consequences to be tested for individual development applications, if warranted.

2.3 *Risk Tolerance*

Risk tolerance is defined as the "...readiness to bear the risk after risk treatment in order to achieve its objectives" (ISO Guide 73 2009). In the hazard treatment approach, acceptable risk tolerance is the point at which the State judges that it is no longer necessary to intervene in the use of land to mitigate risk, but relies on response and recovery. All other areas of land would be judged to have an intolerable exposure to the hazard unless the use and development is treated to make the residual risk tolerable.[5]

Judging when an acceptable risk becomes intolerable is a 'wicked problem' (Rittel and Webber 1973). It is the boundary point at which the State intervenes in the normal regulation of use of land because the benefit of a use or development to either a private individual or the broad community may not outweigh the cost that development places on the community or the environment.

The hazard method seeks to set the boundary between acceptable and intolerable risk. Figure 2 illustrates zones of acceptable, tolerable and intolerable risk while having regard to likelihood and consequence. Of note is the spectrum between acceptable, tolerable and intolerable risk that exists because both the quantification of risk is very difficult and controls placed on the risk may change it from being intolerable to tolerable for different types of use.

[5] Judgements regarding residual risk should consider the impact of treatment options beyond land use planning (eg the action of landowners, capacity of emergency responders, or regard to building standards).

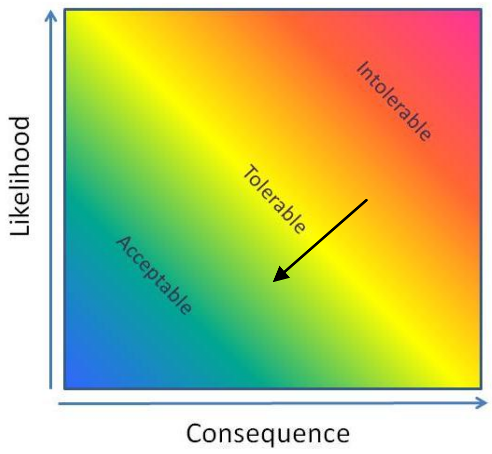

Figure 2: The range of risk tolerance

Acceptable risk (or negligible risk), as defined by the Australian Geomechanics Society (AGS), is "...a risk, for the purposes of life or work, society is prepared to accept as it is with no regards to its management. Society does not generally consider expenditure in further reducing such risks justifiable" (AGS 2007a).

Acceptable risk can be assumed for each of the categories outlined in Table 4. For example, the AGS and Keey (2000) define acceptable risk for loss of life as a risk of less than 1 in 100,000 deaths in society. Complexities arise, however, when attempts are made to align measures of acceptable risk across all areas outlined in Table 4 for each development application.

For the purpose of the hazard approach, acceptable risk is defined as the area outside the tolerable and intolerable risk zones, in which no hazard specific controls are placed on development. The boundary of acceptable and intolerable/tolerable risk is identified through a process of consultation with relevant stakeholders.

In areas of acceptable risk, non-planning measures will be used to mitigate the impacts of natural hazards (eg building controls, emergency response).

Box 2: Tolerable risk in bushfire prone areas

As an example of applying the As Low As is Reasonably Possible (ALARP) principle in Tasmania, it has been judged that in a Bushfire Prone Area, the risk can be made tolerable if:

- a development can meet a minimum separation distance from bushland for new or existing parcels of land; or
- a development is able to demonstrate through a hazard management plan how it will mitigate the impact of a bushfire through improved building standards, evacuation controls, access to water, and maintenance actions.

This is not to say that a building will not be impacted by bushfire, but that society is prepared to accept that the actions taken will reduce the risk to 'as low as reasonably practical', and will not place an unreasonable impact on society.

Intolerable risks are those risks that are considered unreasonable with regard to the likely costs to the public and to the individual. Theoretically, everywhere outside of areas of acceptable risk are areas of intolerable risk.

However, when controls on use and development are appropriate, governments judge that where the risk is moderate (defined in Chapter 3 as 'low' and 'medium' risk), routine measures can be employed to reduce intolerable risks to within tolerable limits. In this context, the AGS defines **tolerable risk** as "...a risk within a range that society can live with so as to secure certain net benefits. It is a range of risk regarded as non-negligible and needing to be kept under review and reduced further if possible" (AGS 2007a). In defining areas of tolerable risk, judgements are made that:

- use and development in the area is likely to provide net benefits to landholders and the general community; and
- while society cannot regard the risk as negligible, or as something we might ignore, society accepts that the risks can be properly managed through routine measures, including development control measures (such as siting of buildings and access requirements), building control and engineering, or emergency planning.

It is in the tolerable risk range that controls are placed on developments to mitigate the risk to As Low As is Reasonably Practicable (ALARP) (see Figure 3). Here, society is prepared to tolerate certain risks in order to secure the benefits of land use. This tolerance may change depending on the proposed use.

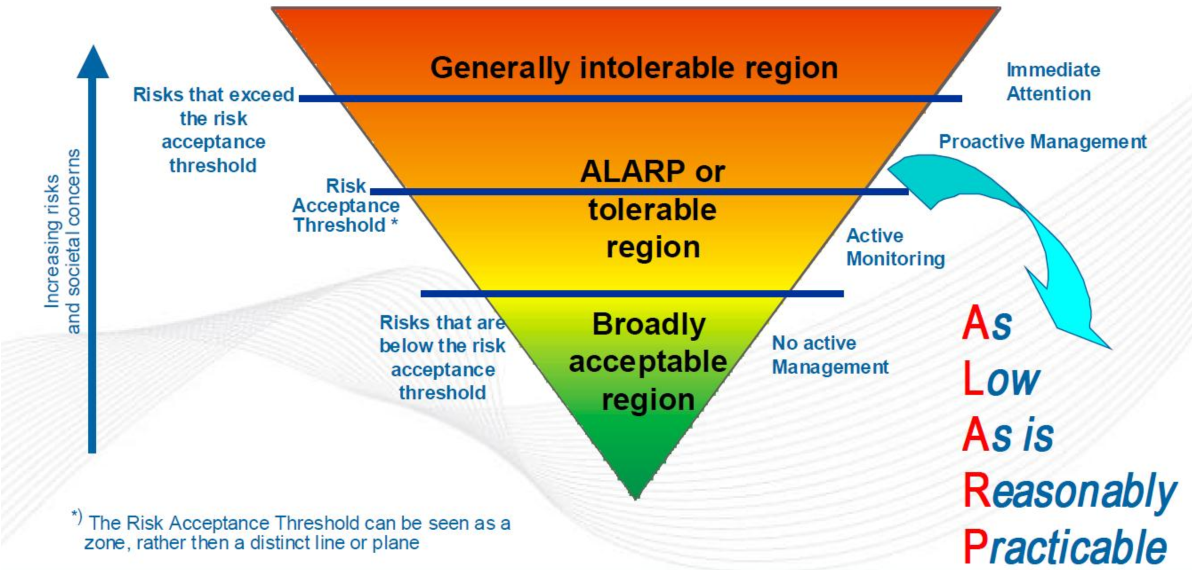

Figure 3: Illustrates how the As Low As is Reasonably Practicable (ALARP) principle applies to the hazard treatment approach (NERAG 2009)

Areas may remain where the risks are so high that they cannot be reasonably mitigated for most use and development (defined in Chapter 3 as 'high'). The starting assumption in these areas is that the cost to society outweighs the benefits of development in the area. These areas will generally be identified through strategic planning and zoned in a way that avoids most forms of use and development. In these areas, planning controls will generally prohibit development, especially for sensitive uses such as residential, educational, health, aged care, and hazardous. Where flexibility is provided to allow some use and development, the onus will be shifted to the developer to demonstrate that reasonable mitigation measures are available to reduce intolerable risks to within tolerable limits. The employment of experts to develop hazard management plans that prescribe the appropriate structural and behavioural risk mitigation measures required to reduce residual risk to within tolerable limits is likely to feature prominently in controls imposed on development and use.

To this point, it has been implicitly assumed that the underlying natural hazard does not change over time, except perhaps, if it is explicitly modified. However, a number of natural hazards are likely to unpredictably or systematically change over time. Examples include the following:

- the natural hazard caused by coastal erosion and inundation is likely to increase with rising sea levels, as a consequence of climate change;
- changes in vegetation due to changing land use, plantations, different agricultural practices or climate change may affect bushfire risks; and
- changes in extreme weather events, such as the intensity of rainfall, may affect landslip.

Particularly where natural hazards are changing systematically over time (eg due to sea level rise), a location that has an acceptable risk today may be faced with a tolerable risk in the medium term and an intolerable risk in the long term. Assets established in these locations will face a changing risk profile over the asset's lifetime. Where this occurs, it becomes necessary to consider the lifetime risks faced by the asset in this location, which, in part, depends on the expected lifetime of the asset. In these circumstances, decision-makers should employ the precautionary principle, where the risk level over time is uncertain. Additionally, the overriding balance of issues might support development but, given the nature of the changing risk profile, there may be a need to create buffers that protect the development over the long term even though the buffers might not be required in the short to medium term.

Climate change is the most significant, but not only, example of this dynamic natural hazard issue.

<u>Defining risk tolerance</u>

Generally, communities with low tolerance for risk will place significant controls in areas of low exposure to a hazard, while communities with high tolerance for risk will impose few (if any) controls on development in area of low exposure to a hazard. The proposed hazard treatment approach seeks to provide a baseline for this assessment by setting policy judgements regarding risk tolerance that can be applied on a statewide basis.

Under the hazard treatment approach, these judgements are made through the development of the Hazard Matrix. The Matrix contains a series of bands that provide a range of controls that increase proportionally as the hazard exposure rises. The purpose of each band is described in Section 3.

The underlying assumptions in setting controls for natural hazards have been detailed in the National Emergency Risk Assessment Guidelines (NERAG 2009), which suggest that high magnitude events have a very low frequency (such as a tsunami occurring in Tasmania), while low magnitude events have a high frequency of occurring (such as a daily high tide). The second assumption applies the precautionary principle and assumes that a hazard will affect all land susceptible to the hazard at some point in time. The assumptions enable the classification of hazards into hazard bands. The composition of the controls in each hazard band defines the risk tolerance to the hazard.

Controls and interventions include:

- Emergency management: is controlled through the Emergency Management Act 2006, with roles and responsibilities set out in the Tasmanian Emergency Management Plan 2006 (TEMP). The TEMP sets out the management arrangements for each hazard, including Prevention, Preparedness, Response, and Recovery.

- Building control: provides the minimum necessary standard for safety and amenity of buildings for the occupants. This can be achieved through the requirement to meet an Australian Standard (eg building in bushfire prone areas) or providing design guidance by identifying a site as being susceptible to a hazard.

- Land use planning: including strategic planning, use and development controls. Strategic planning includes placement of defences such as flood barriers, and avoidance of the hazard, such as not building on active landslides. Use controls include modifications to the zoning of land to guide vulnerable development away from hazards. Development controls focus on the form of the development, such as identifying a residential house envelope on a new parcel of land, or requiring a minimum level of services, such as water pressure in a mains water supply.

Figure 4 is a visualisation of the relationship between emergency management, building control, and land use planning (strategic settlement and use control). The vertical axis represents the benefit each type of control represents, while the bottom axis represents the intervention as composite of the controls. The colouring on the graph represents the hazard changing from low likelihood – high magnitude events to high likelihood – low magnitude events.

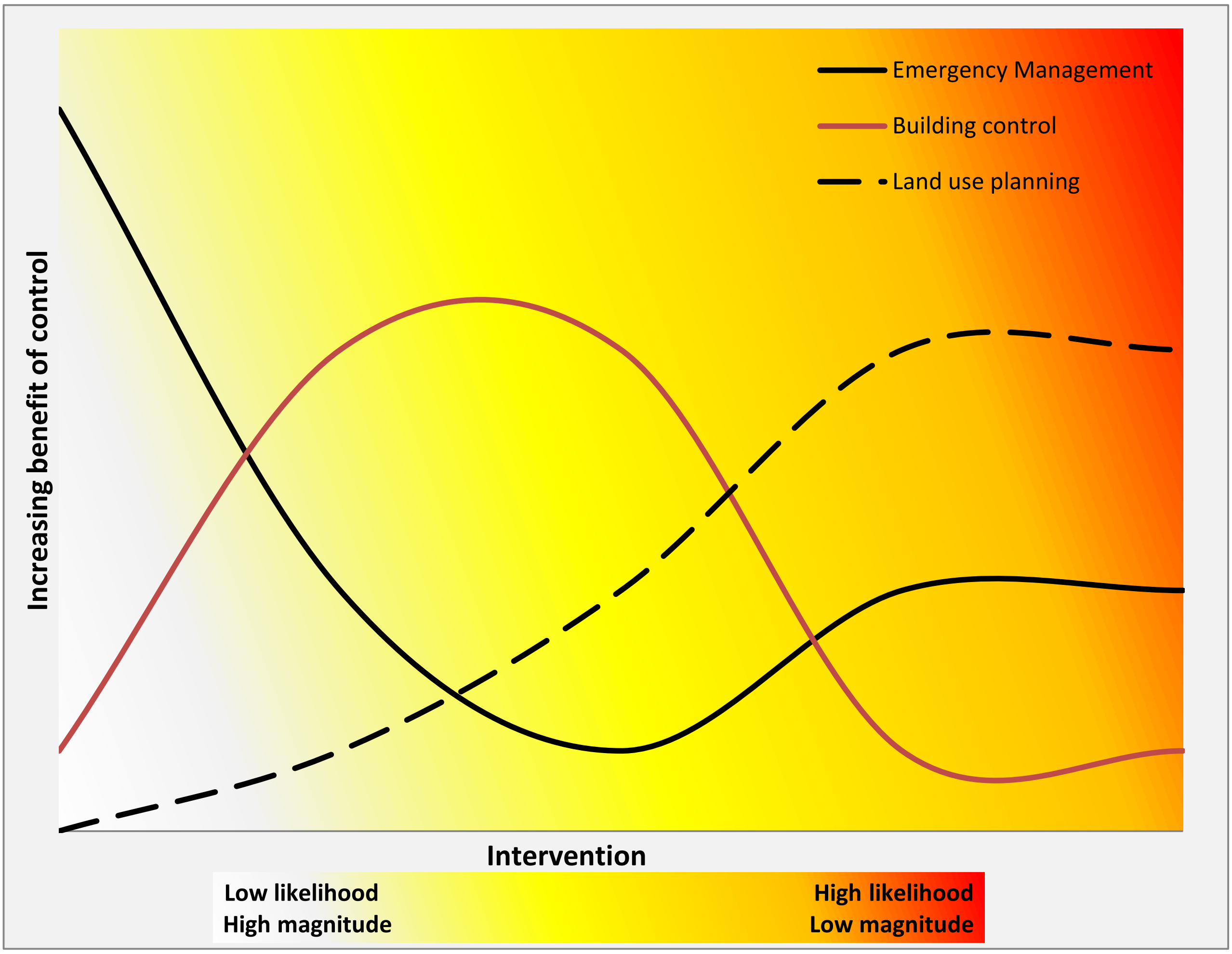

Figure 4: Visualisation of the type of intervention

The hazard treatment approach provides the framework with which to make judgments on the controls and assumptions regarding the threat posed by a natural hazard. In defining this balance through the hazard treatment approach, the State provides a clear 'statement of tolerance to risk in any given location. The process for implementing the hazard treatment approach is outlined in Chapter 3.

3 HAZARD TREATMENT

This chapter outlines how assumptions of hazard likelihood, consequence, and risk tolerance are brought together in a form that can be used to directly inform land use planning decisions at both the strategic and development control stages. It introduces the concept of hazard controls and describes how controls can be used to populate a hazard matrix, which describes the hazard likelihood, consequence and controls.

3.1 *Purpose of Hazard Treatment*

All land use planning in Tasmania is based on objectives outlined in the *Land Use Planning and Approvals Act 1993* (LUPAA). The relevant Resource Management and Planning System (RMPS) objectives for the mitigation of natural hazards in LUPAA are:

- *to provide for the fair, orderly and sustainable use and development of air, land and water; and*
- *to promote the sharing of responsibility for resource management and planning between the different spheres of government, the community and industry in the State.*

Under the RMPS, sustainable development is defined as:

> Managing the use, development and protection of natural and physical resources in a way, or at a rate, which enables people and communities to provide for their social, economic and cultural wellbeing and for their health and safety while:
>
> (a) sustaining the potential of natural and physical resources to meet the reasonably foreseeable needs of future generations;
>
> (b) safeguarding the life-supporting capacity of air, water, soil and ecosystems; and
>
> (c) avoiding, remedying or mitigating any adverse effects of activities on the environment.

Objectives of the Planning Process under LUPPA also include the following:

- to provide sound strategic planning and coordinated action by State and local government;
- to establish a system of planning instruments to be the principal method of setting objectives, policies, and controls for the use, development and protection of land;
- to secure a pleasant, efficient and safe working, living and recreational environment for all Tasmanians and visitors to Tasmania;
- to protect public infrastructure and other assets and enable the orderly provision and coordination of public utilities and other facilities for the benefit of the community; and
- to provide a planning framework that fully considers land capability.

These objectives provide a foundation for the purpose of intervening in the use of land to both avoid and mitigate the impacts of an individual hazard. The hazard treatment approach seeks to further the objectives of the RMPS and the planning process by ensuring a consistent approach to the management of the risks from natural hazards for (new) land use and development. This purpose can be summarised as:

> …to ensure that use and development is appropriately located, designed, serviced and constructed to reduce the risk to human life and property and the cost to the community caused by [hazard].

The above purpose intentionally includes consideration of both the location of the use (considered through settlement planning, zoning and infrastructure development) and the nature of the development (through development control and building standards). The hazard treatment approach should be used to guide decision-making at both the strategic planning level and the mitigation level, where conditions are placed on individual developments.

3.2 *Implementing the Hazard Treatment Approach*

As noted in Section 2, risk tolerance is set by making judgements (policy decisions) regarding the level of controls that are to be placed on use and development that would be exposed to different risks. Under the hazard treatment approach, these judgements are made through the development of a Hazard Matrix.

A completed Hazard Matrix can be used to inform current planning processes. It can also be employed as the basis for the development of specific planning instruments at State, regional or local levels.

To construct a Hazard Matrix, it is necessary to define:

- *Hazard bands (likelihood)*: regions where it is presumed that natural hazards exist at a relative high, medium, low or acceptable level.
- *Control level*: agreement to generalised statements regarding the presumed consequences associated with natural hazard bands.
- *Strategic planning level*: agreed measures that should be employed through the strategic planning stage to determine whether the benefits to the community of allowing consideration of development in certain areas subject, or likely to be subject, to a natural hazard, outweigh the costs to the community and individuals required to mitigate that natural hazard in the short, medium and long term.
- *Use or development controls*: agreed measures that should be imposed on use or development for the purpose of reducing risks in each hazard band; and

- *Life controls*: additional factors that should be considered with regard to the expected life of the development and the chances that the nature of the hazard will change over that period.

An example of the Hazard Matrix is provided at the end of this chapter.

3.3 *Defining Hazard Bands (likelihood)*

Under the hazard treatment approach, likelihood (as defined in Section 2.1) is summarised through the creation of hazard bands. The primary purpose of hazard bands is to provide a 'graded' base that enables decision-makers to consider strategic settlement planning, apply policy, and guide controls on development and use. Controls may not be appropriate in all bands.

As a starting point, four levels of hazard banding are described (the actual number of bands may vary for different natural hazards) that group the likelihood of an event occurrence. These hazard bands are:

1. Acceptable: it is presumed that the risk in the area is acceptable, as either the natural hazard does not apply at all to the area, or occurs with such low frequency that it is not considered a matter that needs to be addressed. Normal building controls and emergency management responses are considered adequate to address any residual risk.
2. Low: the hazard occurs in the area but the frequency is low enough, or the magnitude when it does occur is low enough, that it might be experienced by a significant portion of the community without concern. Also, where there is a reasonable expectation that a natural hazard may be present, based on the characteristics of the land and our understanding of the hazard. Precautionary controls that are proportional to the importance of the use and development may be appropriate, including requirements for further site assessment or building standards.
3. Medium: our knowledge of the hazard demonstrates that the likelihood is such that when it does occur the impact could be regarded as significant. Mitigation measures should be required to discourage vulnerable and hazardous uses from being located in these areas, or discretionary planning controls should be imposed on the form of a use or development through assessment against performance standards.
4. High: the hazard is frequent or severe, in that it creates conditions not normally considered manageable or tolerable without exceptional measures employed to respond to the natural hazard. It is to be presumed that most use and development would be unacceptable in this area. Any exceptional development would need to be considered on a case-by-case basis against rigorous tests and by demonstrating a need for, and community benefit of, locating in the area.

The number of hazard bands used depends upon the nature of the hazard and the need to differentiate the level of controls. The number of hazard bands may also depend on the ability to differentiate between degrees of likelihood based on the available evidence.

Clearly, defining hazard bands is critical to the hazard treatment approach and will heavily influence decisions regarding settlement planning and zoning. It is important, therefore, that hazard bands are defined in a way that is suitable for decision-making at both the strategic and development control levels.

The challenge: is to identify and define natural hazards in a way that can be related systematically to the likelihood of consequences.

Action: hold workshops that include emergency managers, local government, hazard experts, and policy officers to explore the risks posed by natural hazards and the range (and merits) of possible government and non-government interventions (see Section 4 of the Implementation Guide).

3.3.1 Setting the boundaries of the hazard bands

How the boundaries between hazard bands are defined will depend upon the nature of the hazard and the current state of evidence. When setting boundaries between hazard bands, consideration needs to be given to the consistency with the treatment of likehood across all natural hazards (known as Boundary Application Criteria).

The defined boundary between hazard bands should be set in consultation with relevant stakeholders and in parallel with an assessment of the impact on communities throughout Tasmania. However, guidance for setting boundaries is:

- Acceptable to low: point at which risks can no longer be managed solely through non-planning measures (eg emergency response, recovery and building controls);
- Low to medium: point at which development controls (eg siting and building controls) are not adequate to mitigate risks, and controls on types of use (particularly for vulnerable and hazardous uses) become increasingly important; and
- Medium to high: point at which it can be presumed that use and development should not be located in the area due to the likely costs arising from natural hazards.

In many non-urban areas, use or development demand is unlikely to justify the collection of detailed evidence required to measure hazard likelihood and accurately define hazard band boundaries. To ensure that hazard bands can be drawn throughout Tasmania, boundary definitions may include two elements:

- an actual measure of likelihood relevant to the natural hazard; or
- an assumed proxy for likelihood where the evidence base is not available.

The challenge: is to define hazard bands that allow best known modelled evidence on hazard likelihood to map alongside proxies for the existence of a natural hazard (that use available data) where evidence is not available, or is insufficient. In considering how to set the boundaries between the bands, the following factors could be considered:

- The current pattern of impact from the natural hazard: where does the hazard currently impact? Likelihood.
- Our current response to the natural hazard: where, when and how often do we respond to this hazard? Response.
- The predicted change in the natural hazard and exposure from land use and climate change: change in likelihood.
- Current planning policy, strategies and controls: governance.
- Where will insurance companies insure for the natural hazard? Consequence.
- Current and projected settlement patterns: consequence.

Action: hold workshops that include emergency managers, local government, hazard experts, and policy developers to define the boundaries between bands of hazard likelihood (see Section 4 of the Implementation Guide) and the change in risks that may apply as natural hazards increase.

3.4 *Control Level*

At a broad level, the consequence of a natural hazard event on future use and developments is unknown. Therefore, governments must assume a level of consequence and make judgements on how to intervene in the use and development of land to avoid intolerable consequences.

The 'control level' column of the Hazard Matrix provides guidance on the nature of the controls that are required to bring risks from the natural hazard to within tolerable limits. The consequence statement should be broad; highlighting the differences in the level of intervention considered that will later inform the appropriate level of control for each hazard band. The column will indicate the type of work required to make the residual risk tolerable within the area, including strategic, statutory and non-planning tools. Mitigation measures may vary depending on whether the proposed development is a hazardous or vulnerable use, the level of likelihood, or the requirement for further research.

Consequence statements should have regard to the likelihood of the natural hazard within the band, the type and mix of government interventions required, and the types of development and controls required for each type of development. Table 4 provides guidance on the types of statements that may be considered for each hazard band.

Table 4: Guidance for the development of consequence statements for hazard bands

Hazard band	Consequence statements
Acceptable hazard band	No damage is likely to occur from the hazard in this area, or the likelihood of any damage is negligible and manageable in the normal course of events. Controls should not influence the use of land, with no planning or development controls required in this area due to the low level of 'hazard' for the natural hazard.
Low hazard band	Relatively minor damage may occur from the natural hazard, and relatively infrequently. Simple measures are available to keep the likely level of damage to acceptable levels. The likelihood or lack of knowledge of the natural hazard is such that the residual risk to most types of development is *most likely tolerable* but some caution is required. The following advice is provided to ensure that residual risk is tolerable: – routine site assessment is required to identify the existence of natural hazards and to inform any consideration of the need for controls; and – vulnerable and hazardous use should be allowed where it can be demonstrated that the residual risk is tolerable. Controls in place in the low hazard band should improve the ability of residents to resist the impact of a natural hazard event, and increase the resilience of the community.
Medium hazard band	Structures exposed to this level of natural hazard are likely to sustain repeated minor damage or infrequent major damage during their service life, unless significant mitigating measures are used. The following guidance is provided on the mitigation: – detailed site assessments are required to describe the nature of the natural hazard; to make recommendations regarding the controls required to respond to the hazard; and to provide the development with a greater ability to resist a hazard event. – Vulnerable and hazardous use should be avoided unless it can demonstrate it is in the public interest and needs to be located in this area, and the residual risk can be reduced to a tolerable level through a combination of use and development controls. Controls in place in the medium band should discourage inappropriate development that is likely to significantly increase the costs of mitigating the natural hazards for the community; seek to improve the ability of residents to resist the impact of a natural hazard event; and increase the resilience of the community.
High hazard band	Without taking extraordinary measures, structures exposed to this level of natural hazard are likely to sustain repeated damage during the period they are in use. Development should generally be prohibited unless evidence can be supplied that an exceptional departure from the controls is warranted. Significant control and assessment would be required, including the following: – residential, vulnerable, and hazardous uses should be treated as prohibited, and allowed only where the need for the location can be justified. There is a requirement to demonstrate a suite of controls, including behavioural, physical and procedural, that will make the residual risk tolerable, and not be a burden on the community. – minor developments should be allowed only where they can demonstrate appropriate levels of performance.

Consequence statements will inform strategic and statutory planning instruments. The consequence statements should be in plain English and in a form that is understood without a comprehensive knowledge of planning law or language. The consequence statements speak to intent, or Government policy, and assist in the drafting of planning instruments.

For more information, Table 5 provides an example of consequence statements for each hazard band.

The challenge: is to translate the potential impact of the natural hazard into broad actions that are able to deliver a tolerable risk for different types of use.

Action: develop, in consultation with key stakeholders, a consequence summary statement for each hazard band that summarises the actions required for the different types of uses or developments.

3.5 *Strategic Planning Level*

Hazard consideration at the strategic planning level is critical to determining whether the benefits of allowing consideration of development in certain areas subject, or likely to be subject, to a natural hazard outweigh the costs to the community and individuals required to mitigate that hazard in the short, medium and long term.

Other strategic planning issues need to be considered alongside the natural hazard issue to enable an informed judgement that is based on holistic planning and balancing social, economic and environmental benefits and costs.

The strategic consideration of natural hazards could result in decisions about settlement planning, zoning, and the articulation of hazard layers through land use strategies. It can also provide an indication of the need to establish buffers, or areas of hazard expansion, over longer time frames than are expressed in planning schemes, which are generally focussed on a five to ten-year time frame.

As the controls at this stage represent a 'first cut' of limitation on use and development, they can be seen as a trigger for more detailed assessment of the hazard risk, which can be more directly translated into use and development controls.

The challenge: is to provide an adequate consideration of the range of natural hazards as part of a broad land use strategy, where determinations about overall community benefits can be made.

Action: determine the level of hazard information and consequence statements required for regional and local strategic planning exercises in consultation with key stakeholders.

3.6 *Use or Development Control*

Natural hazard controls are measures that are imposed on use or development for the purposes of reducing risk. The controls must always align with the consequence statement, as they are a more detailed expression of the actions that are considered necessary to reduce intolerable risks to within tolerable levels. It should be possible to directly translate these controls into standards that would be included with a statewide code or local government planning scheme (although some slight adjustment may be required during the drafting of, and public consultation on, a planning instrument).

The nature of the controls included in this column will directly impact on the likely cost to governments, industry and the community. Therefore, it is critical to consider the impact of the controls, while having regard to the coverage of the hazard band. Some adjustment of the hazard band boundary definitions and/or controls within each band may be necessary to strike the correct balance between the cost of intervention and the risk. In essence, this process is how the State established an agreed risk tolerance.

The challenge: is to translate consequence statements into clearly articulated development and use controls that can be adopted within planning and building instruments.

Action: prescribe appropriate development and use controls in consultation with key stakeholders.

3.7 *Use and Development Life Controls*

Climate change will impact on the nature and distribution of threats from natural hazards. This change should be considered if, during the expected design life of the development, the threat is considered significantly greater than the current threat.

Where available, maps of hazard banding should be used at the point in time that is closest (but after) the end of the development's expected life. For example, for a residential development with a presumed life of 75 years, the hazard banding relevant for the closest known point beyond 75 years should be used.

The Tasmanian Government will provide advice on the likely consequences of climate change on natural hazard profiles throughout the State.

The challenge: is to reasonably understand the future threat based on the best available science and ensure that guidance is available for planning purposes.

Action: the Tasmanian Government is to provide guidance on the likely impacts of climate change on natural hazard profiles throughout the State.

The Hazard Matrix, detailed below in Table 5, provides an example of how the three components (likelihood, consequence and control) of hazard mitigation can be linked to mitigate risks from natural hazards.

Table 5: Hazard matrix – Landslide (example for illustration only)

Hazard band	Hazard exposure (Likelihood of an event)	Control level (Consequence)	Strategic planning level	Use or development controls (Control)
Acceptable	Rare to almost incredible – a landslide is rare to almost incredible to occur in this area based on current understanding of the hazard, but it may occur in some circumstances. Defined as: Less than 0.3% AEP; or Site is outside of Low, Medium, and High hazard bands or has been assessed by MRT[6] regional (1:25 000 scale) mapping as having very low to no susceptibility to landslides.	Development and use is not subject to landslide controls.	No impacts on land use strategies or change to zoning required.	No hazard specific controls. No controls are required to bring the development into an acceptable hazard level.
Low	Possible to unlikely – this area has no known landslides, and has not been assessed by MRT regional (1:25 000 scale) landslide susceptibility mapping, but may be prone to the hazard occurring. Defined as: 0.3 – 1% AEP; or Slopes greater than 9 degrees; or A position within a 12 degree shadow angle at the foot of a steep slope (greater than 25 degrees).	Planning controls may be necessary to reduce the risks associated with vulnerable and hazardous uses to ensure that risks are tolerable (as recommended by AGS). No non-construction requirements necessary for residential or minor use or development.	Where broader planning considerations support the development of the area, some use (particularly for vulnerable and hazardous uses) and development controls may be required to qualify the general planning regulations.	Minor use and development (Asset Class 1) (except swimming pools) are permitted. Residential use and development (Asset Class 2) generally permitted in planning regulations but may be subject to additional building controls. Vulnerable and hazardous use and development (Asset Class 3-5) and swimming pools will require a landslide risk assessment and hazard management plan prepared by a geotechnical practitioner with expertise in landslide risk management,

[6] Mineral Resources Tasmania (MRT)

				to demonstrate that the development can achieve and maintain a tolerable level of risk (as recommended by AGS).
Medium	Likely – the area has known landslide features, or is within an identified regional (1:25 000 scale) landslide susceptibility zone, or has legislated controls to limit disturbance of adjacent unstable areas. <u>Defined as:</u> 1 – 3% AEP; or Site is outside of the high band, and has: A declared Landslip B area; or Mapped landslide features identified by MRT; or An MRT regional (1:25 000 scale) landslide susceptibility zone. A 'Landslide', 'Landslip', or 'Unstable Land' zone identified in a planning scheme.	Planning controls are necessary for all use and development to ensure that risks are tolerable (as recommended by AGS). Any vulnerable or hazardous use, including swimming pools, will only be allowed in exceptional circumstances.	Areas rated as medium should be considered in terms of other planning issues, and where there is no compelling reason for including these in areas earmarked for future development, they should be zoned for rural, open space or environmental purposes. In these circumstances, zoning that clearly acknowledges the natural hazard in the zone purpose statement should be applied.	Development in declared Landslip B areas is controlled under Part 10, Division 1 of the *Building Act 2000* and by Part 2, Division 1 of the *Building Regulations 2004*. Minor use and development (Asset Class 1) (except swimming pools) are permitted subject to a site assessment prepared by a geotechnical practitioner with expertise in landslide risk management. Residential and all vulnerable or hazardous use and development (Asset Class 2-4) can be considered on a site-specific basis that justifies its location and is subject to a landslide risk assessment and hazard management plan prepared by a geotechnical practitioner with expertise in landslide risk management, demonstrating that a tolerable level of risk (as recommended by AGS) can be achieved and maintained. Asset Class 5 use and developments are generally prohibited; however, if there is an overriding community benefit, an exceptional circumstance and performance-based solution may be appropriate.

High	Almost certain – the site is within a declared Landslip A area, or there is potential danger from a recently active or currently active landslide. <u>Defined as:</u> Greater than 3% AEP; or A declared Landslip A area; or A recent or active landslide identified by MRT; or Slopes greater than 42 degrees.	All use and development would require significant investigation and an engineered solution to mitigate the natural hazard and enable the development to achieve and maintain a tolerable level of risk, however, the mitigation measures may never achieve comprehensive levels of security and safety.	Strategies should discourage all development except vital community infrastructure in these areas. Strategies must indicate appropriate zoning and overlays to provide a clear message to the public and the drafters of local government planning schemes to ensure use and development is generally prohibited except under special circumstances.	Minor use and development (Asset Class 1) (except swimming pools) are discretionary subject to a landslide risk assessment and a hazard management plan prepared by a geotechnical practitioner with expertise in landslide risk management, demonstrating that a tolerable level of risk (as recommended by AGS) can be achieved and maintained. Other use and development (Asset Classes 2-5) are generally prohibited; however, if there is an overriding community benefit, an exceptional circumstance and performance-based solution may be appropriate. Most development is prohibited in declared Landslip A areas and is controlled under Part 10, Division 1 of the *Building Act 2000* and by Part 2, Division 1 of the *Building Regulations 2004*.

4 GUIDANCE TO IMPLEMENTATION

A resource for the implementation of this guide is available and provides detailed support for the development of hazard matrices through a series of stakeholder workshops. In summary, it is recommended that hazard matrices are developed through the following sequence of actions:

1 Pre-workshop

1.1 Develop a preliminary definition for the natural hazard and identify how to map the hazard.

1.2 Develop preliminary hazard bands, including the thresholds and consequence statements.

2 Workshop one

2.1 Review and discussion of the definition of the natural hazard.

2.2 Agree on draft hazard boundaries (or options) and consequence statements.

3 Post-workshop

3.1 Assess the coverage of hazard bands in each local government area (LGA) and summarise the nature of existing development and use, as well as known areas of development demand in hazard bands (for each option is necessary).

4 Workshop two

4.1 Review the hazard boundaries and coverage of hazard bands.

4.2 Review the consequence statements.

4.3 Consider controls.

4.4 Agree to natural hazard definitions and HAZARD Matrix.

5 Develop supporting material

APPENDIX A – PRINCIPLES

Foundation Principles

The following set of principles is proposed for the purpose of defining the role of governments in intervening in the use of land for the purposes of reducing risks and increasing the shared responsibility associated with natural hazards.

1. **Private risks associated with natural hazards are the responsibility of individuals and business.**

   The role of governments is largely limited to building and defending 'public value'. Individuals and business must take responsibility for the choices they make and for the risks they knowingly expose themselves to.

2. **Governments should encourage public and private risks to be factored into investment decisions.**

   Clear pricing of the risk from natural hazards in the purchase and ongoing maintenance of property can be an effective mechanism for mitigating risk. Governments should continue to work towards ways of ensuring that the long-term costs of natural hazards are factored into both the purchase price of property and/or the costs associated with the maintenance of property.

3. **Governments can support individuals and business to understand and manage private risks through the collection of evidence, provision of information, and facilitation of collective action.**

   Information is a powerful tool for ensuring that people understand the costs associated with natural hazards. In many instances, governments are in the best position to collectively invest in an improved understanding of natural hazards and risks and inform the community about the consequences of them.

   In many cases, collective work to manage natural hazards may be more cost effective and technically effective than individual action. In some cases, individual action may be totally inappropriate. Governments should provide frameworks to support the implementation of collective action by individuals or business.

4. **Governments should ensure that private investment minimises unacceptable public risk.**

   It is rare that private sector investment decisions are made in a way that is completely disassociated from public risk. Governments should ensure that private investment does not give rise to unacceptable risks in terms of costs for the broader community.

   Governments should signal their tolerance to public risk from natural hazards as early as possible in the private sector investment cycle to maximise public value. Governments are well placed to provide the signals on when the potential public burden from a private investment decision is becoming too great by giving guidance on the type and composition of government intervention, ie emergency management, building control, or land use planning.

5. **Governments should avoid investment, regulation, or policy that gives rise to unacceptable public or private risks.**

   The development of government policy, regulation (or investment) should have regard to the risks from natural hazards and their impact on sustainable development, current or future private risks.

6. **Governments should have regard to, and support individuals and business to consider, how natural hazards may change in the future, including through climate change.**

   Arrangements for the mitigation of natural hazards need to be flexible to respond to climate change, improvements in evidence, the development of better mitigation options and tools, or changes to vulnerability.

APPENDIX B – APPROACHES TO THE MANAGEMENT OF RISK

Risk Assessment Approach

The **risk assessment** approach is evidence based, relying on the quantification of exposure, likelihood, design and safety (Saunders et al 2011). Under this approach, the state or local government has responsibility to undertake a risk-based assessment of land use and development opportunities to provide a baseline for decision-making. This approach relies on five steps including: objectives, information, alternatives, impact assessment and evaluation (see Randolph 2004). This is consistent with the complete application of the National Emergency Risk Assessment Guide (NERAG) to natural hazards and the risk assessment guide developed by the Australian Geomechanics Society (AGS 2007a).

The risk assessment approach is suitable for considering the risks generally from natural hazards (eg State Risk Assessment) or for assessing the risks associated with individual assets. The process delivers a rigorous and transparent understanding of the risks, potential mitigation measures, and judgements regarding residual risk.

The advantage of the risk assessment approach is that it provides high levels of certainty with regard to the adequacy of measures employed to treat risks. The process is highly transparent.

However, disadvantages of the risk assessment approach include the following:

- all inputs to the risk assessment must be measurable;
- the potentially high cost of evidence collection where current information is inadequate to carry out a full risk assessment; and
- a shortage of hazard specialists who are able to assess risk in government, industry and private sectors.

Precautionary Approach

The **precautionary** approach[7] is also evidence-based planning. However, it differs from the comprehensive risk assessment approach as it passes the responsibility for the assessment of risk from the government to the individual. The incentive for the private sector to invest in risk management processes is provided by an assumption that (within reason) a risk exists unless it can be shown otherwise.

The advantage of this approach is that it comprehensively addresses the risks from natural hazards, allows risks to be considered at a local level, and transfers the costs of any additional investigations from the community (government) to those that are likely to directly benefit from the improved information.

The disadvantages of adopting the precautionary approach include that it:

- requires everybody, on a case-by-case basis, to consider risks from natural hazards even when the risks are likely to be low;
- places a greater responsibility on individuals to quantify and argue the relative levels of risk through the development application process, and on the planning authority to make judgements on tolerance to risk because the level of risk has not been previously documented by public authorities;
- reduces the ability to strategically plan for natural hazards through settlement planning because a hazard assessment has not been conducted on a broad scale;
- increases the potential for inconsistent responses between and within planning authorities as a consequence of multiple case-by case assessments that produce a 'mosaic' of decision-making outcomes on risk for a particular hazard;
- reduces confidence and transparency for the developer or the planning authority because there is no prior knowledge available on the natural hazard;
- externalises the cost of risk assessment to the applicant, reducing the potential for economies of scale to be achieved through a community assessment (ie economically inefficient); and
- promotes a greater perception of 'red tape' in the planning process because an additional assessment 'test' has been placed in the development application process.

[7] The Intergovernmental Agreement on the Environment, 1992, defines the 'precautionary principle' as meaning where there are threats of serious or irreversible environmental damage, lack of full scientific certainty should not be used as a reason for postponing measures to prevent environmental degradation.

Emergency Response

Emergency response focuses on managing natural hazards as and when they arise. This approach relies very heavily on awareness and acceptance of risks, and the capacity to respond to and recover from an event.

Emergency response can be an appropriate approach in some circumstances. For example, it may be more cost effective in some areas to rely on 'just in time' flood protection measures (such as sand bags) to protect property from minor, low-frequency flooding events. This approach may be most cost effective for existing development in relatively low risk areas, where retrofitting reasonable engineering solutions is cost-prohibitive.

While appropriate in the situations cited above, disadvantages of the emergency response approach include:

- nobody responds to the natural hazard until during or after the event;
- it removes the consideration of natural hazards in strategic land use planning or when assessing land capacity;
- it relies on emergency services and governments to have the capacity to both respond to the event and, in many instances, assist with recovery; and
- it relies on a capacity to price the costs of natural hazards so that market forces 'steer' development away from areas of high risk.

The Council of Australian Governments (COAG) report on natural hazards and the National Disaster Resilience Strategy encourage governments to move away from a strong reliance on emergency response approaches (see for example, Middelmann 2007).

Hazard Treatment Approach

The **hazard treatment** approach seeks to use a combination of elements associated with *risk assessment, precautionary* and *emergency response* methods. The approach seeks to meet the challenge of balancing short-term costs (additional studies or building works) with long-term costs (loss of property or annual insurance) associated with natural hazard exposure.

This hybrid risk method encourages the use of detailed evidence where it is available, but also allows policy judgements to be made in the absence of clear evidence. The approach focuses the attention of governments on areas where risks are deemed to be intolerable, but also accommodates judgements that the risk in areas is acceptable and that it is appropriate to rely on an emergency response.

The hazard treatment approach relies on the mapping of 'hazard bands' based on the likelihood of a hazard occurring. The mapping of hazard bands is based on available information and the collection of further data can be prioritised in areas of high development demand or when it can be justified by the private sector. In areas where detailed hazard modelling has not (and may never be) undertaken, proxies for hazard likelihood could be used.

Policy judgements regarding both hazard likelihood and appropriate control measures can be developed through active engagement with stakeholders to ensure that they reflect community attitudes towards risk and tolerance to risks.

Summary of Hazard Approaches

Table 6 summarises each of the risk approaches, providing a brief outline of each and the relative costs and benefits.

Table 6: Risk approaches (after Saunders 2011)

Risk Approaches	Summary	Cost	Benefit
Risk assessment	Government defines risk tolerance. Development considered on the basis of government risk assessments at regional or local level.	High cost for government in the collection of evidence.	Comprehensive, with high levels of confidence. High level of certainty. Consistency.
Precautionary principle	Government presumes that all properties within defined areas are at risk from a hazard. Assessment of development in defined areas required to include an assessment of the risks at the cost of the developer.	High cost to the private sector, which may be unreasonable in some areas. Uneven risk decision 'mosaic'.	Comprehensive with high levels of confidence. High level of certainty.
Emergency response	Relies on an emergency response or mechanism to assist individuals to recover from an event.	High cost for Government and community.	Low level of confidence. High levels of uncertainty.
Hazard treatment	Draws on elements of the risk approach, precautionary approach, and emergency response. Development controls based on agreed 'banding' of hazard likelihood based on best available knowledge. Process involves consultation, multi-agency participation in developing policy. Graduated imposition of assessment and control requirements.	Moderate cost for government and private sector.	Policy driven, high transparency, reasonable confidence, joint responsibility.

APPENDIX C – MEASURES OF LIKELIHOOD

Modelling the likelihood of a natural hazard involves a range of likelihood indicators. Below is an extract from the report prepared by Clive Attwater (SGS Economics 2011) into the information and evidence required to address coastal hazards through statewide planning instruments. The extract provides an overview of measures of likelihood that are a result of modelling. It summarises and discusses annual exceedance probability (AEP), average return interval (ARI), lifetime exceedance probability (LEP), probable lifetime count of flood events (PLCFE), integrated lifetime flood severity (ILFS), and net present value of lifetime flood damage (NPV-LFD).

Methods of specifying likelihood by reference to an acceptable level of risk as determined by a number of different indicators are as follows:

- Annual exceedance probability (AEP): the probability that a particular level will be exceeded in any year (eg an elevation or level that has a 1 per cent AEP has a 1 per cent chance of being exceeded in a given year). This would have reference to the conditions in that year. Therefore, this may be expressed as an AEP under current conditions, for some specified future sea level rise (0.8 m) or for some specified future time where the sea level rise has a distribution of possibilities or a specified expected level.

  Annual exceedance probability works intuitively for most people for relatively low frequency events but less well for events that happen more frequently, say, several times per year or even several times per decade.

  AEPs are static – that is, they apply for the year and conditions specified but would change (slightly) each year as sea levels change and so a single AEP number does not express well what the risk for an asset would be over its lifetime.

- Average return interval (ARI): The average number of years between occurrences of an event of a particular severity (as specified by a level or elevation) or greater. Non-hazard or risk specialists are prone to interpreting this to mean that if an event (ie 100-year return interval or one in 100-year event) has occurred recently that it will not happen again for that many years, which is not the case.

  ARI is static, like AEP, so does not easily respond to a moving hazard baseline.

- Lifetime exceedance probability (LEP): This builds on the concept of AEP but can allow for the fact that the AEP changes each year. It combines the series of (increasing) annual probabilities into a single number reflecting the probability that the level will be exceeded over a period of time (ie the expected lifetime of an asset) allowing for a rising sea level. This enables a lifetime risk estimate to be provided with a moving hazard baseline. To be calculated, the starting year, the starting sea level, the life of the asset (or end year) and the rate of sea level rise (or final sea level) need to be specified. The answer will be different if any one of these elements changes.

LEP is relatively easy to understand for low likelihood events where the probability is significantly less than one but is less easily comprehended if an event is likely to occur multiple times over the life of the asset. While giving the total probability of flood events, it does not make evident that with a rising hazard baseline, the probability is low in the early years and relatively high in the later years.

- Probable lifetime count of flood events (PLCFE): This is the estimated likely number of events that the asset may face above the specified level in its lifetime. It is an easier statistic to generate and work with for some purposes and is effective over a wide range (from less than one up to quite large numbers of events). It requires the same four parameters to be specified as with LEP. Similar to LEP, it can also be calculated over a moving natural hazard baseline. However, the single combined number does not indicate that events are far more likely in the later years.

- Integrated lifetime flood severity (ILFS) or integrated lifetime flood damage (ILFD): While the previous two specifications can show the frequency or probability of a flood exceeding a certain level and affecting an asset over its lifetime with a moving hazard baseline, they do not show that all exceedances are not equal. What they are tracking is how often an inundation exceeds a certain height, but not by how much. A deep flood is of more consequence than a shallow one. It would be possible to track not only the exceedance frequency/probability, but also how many were minor, moderate or severe to give a lifetime index of the overall flood severity. If the response of the asset to flooding was also considered, this severity could be translated into damage. However, this latter calculation would depend on the characteristics of the asset and its vulnerability to flooding and ceases to be just a characteristic of the location.

  At this time, there is no agreed way of aggregating floods of different severity into an index. However, the lifetime probability or count for floods of different severity ranges could be tabulated easily enough into a series of three or four numbers.

- Net present value of lifetime flood damage (NPV-LFD): This measure moves well away from the characteristics of the location to considering the characteristics of the asset. This calculated value considers not only the likelihood of flooding and its severity but also its timing. If an asset is severely flooded when new, a large portion of its construction cost may be written off and have to be rebuilt before it has had much use. Alternatively, if an asset is destroyed by flooding in the last year of its expected service life, relatively little value is lost. Further, allowing for financial discounting, losses in the near future are more costly than losses in the distant future, as indicated in financial calculations by using a discount rate. Whereas with a static hazard this timing is entirely unpredictable, for a rising baseline it is strongly skewed toward the later years.

The NPV-LFD calculates the NPV of the cost of expected future flood events in annual (or to simplify, perhaps five-yearly) steps, recognising increasing risk over time from rising sea level, decreasing asset value and the financial discounting of events further into the future. In addition to the costs of damage to the asset, the calculation should also include cost of consequential losses (ie disruption to business, need for alternative accommodation, etc, until reoccupying a home) and cost allowance for injury or deaths arising from the event. Unlike a depreciating asset, these costs would not decline over time. This calculation provides the most realistic assessment of lifetime risks incorporating not only a moving hazard baseline but also the time effects of when the events are most likely to be experienced.

The NPV-LFD may be cumbersome and hard to communicate and is not recommended for general use. However, understanding how it varies with other simpler indicators, such as PLCFE or LEP, can be highly desirable in selecting appropriate levels when using these other simpler measures; for impacts on different uses (eg dwellings, schools, hospitals, etc); and for acceptable responses to hazard exposure – ie where an asset is regularly exposed but has some form of accommodation to deal with the hazard (eg is 'flood proof' to some degree).

Once an acceptable present day elevation under static risk and associated probabilities is established and an agreed scenario for future sea level rise is adopted, any of these indicators can be calculated relatively easily, with the exception of ILFD and NPV-LFD, which would also need to identify asset characteristics, their corresponding flood stage damage curves, and associated expected consequential losses.

APPENDIX D – ASSET CLASSES

Table 7 is drawn from AS/NZS 1170.02002 – structural design actions. While only applicable in New Zealand, the table describes the relative importance of building based on community importance and the risk to life if structural failure occurs during or after a natural hazard event. The table would need to be modified to be appropriate to the Tasmanian context based on the consequence of failure tables in the standard and the Tasmanian Planning Schemes.

Table 7: Building importance levels

Importance level	Comment	Examples
1	Structures presenting a low degree of hazard to life and other property.	Structures with a total floor area of <30 m2. Farm buildings, isolated structures, towers in rural situations. Fences, masts, walls, in-ground swimming pools.
2	Normal structures and structures not in other importance levels.	Buildings not included in Importance Levels 1, 3 or 4. Single family dwellings. Car parking buildings.
3	Structures that as a whole may contain people in crowds or contents of high value to the community or pose risks to people in crowds.	Buildings and facilities as follows: a) Where more than 300 people can congregate in one area. b) Day care facilities with a capacity greater than 150. c) Primary school or secondary school facilities with a capacity greater than 250. d) Colleges or adult education facilities with a capacity greater than 500. e) Health care facilities with a capacity of 50 or more resident patients but not having surgery or emergency treatment facilities. f) Airport terminals and principal railway stations with a capacity greater than 250. g) Correctional institutions. h) Multi-occupancy residential, commercial (including shops), industrial, office and retailing buildings designed to accommodate more than 5000 people and with a gross area greater than 10 000 m2. i) Public assembly buildings, theatres and cinemas of greater than 1 000 m2.Emergency medical and other emergency facilities not designated as post-disaster. j) Power-generating facilities, water treatment and waste water treatment facilities and other public utilities not designated as post-disaster. k) Buildings and facilities not designated as post-disaster containing hazardous materials capable of causing hazardous conditions that do not extend beyond the property boundaries.
4	Structures with special post-disaster functions.	Buildings and facilities designated as essential facilities. Buildings and facilities with special post-disaster functions. Medical emergency or surgical facilities. Emergency service facilities such as fire, police stations and emergency vehicle garages. Utilities or emergency supplies or installations required as backup for buildings and facilities of Importance Level 4. Designated emergency shelters, designated emergency centres and ancillary facilities. Buildings and facilities containing hazardous materials capable of causing hazardous conditions that extend beyond the property boundaries.
5	Special structures (outside the scope of this Standard – acceptable probability of failure to be determined by special study).	Structures that have special functions or whose failure poses catastrophic risk to a large area (eg 100 km2) or a large number of people (eg 100 000). Major dams, extreme hazard facilities.

APPENDIX E – REFERENCES

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