pitt&sherry

UTAS Inveresk Development

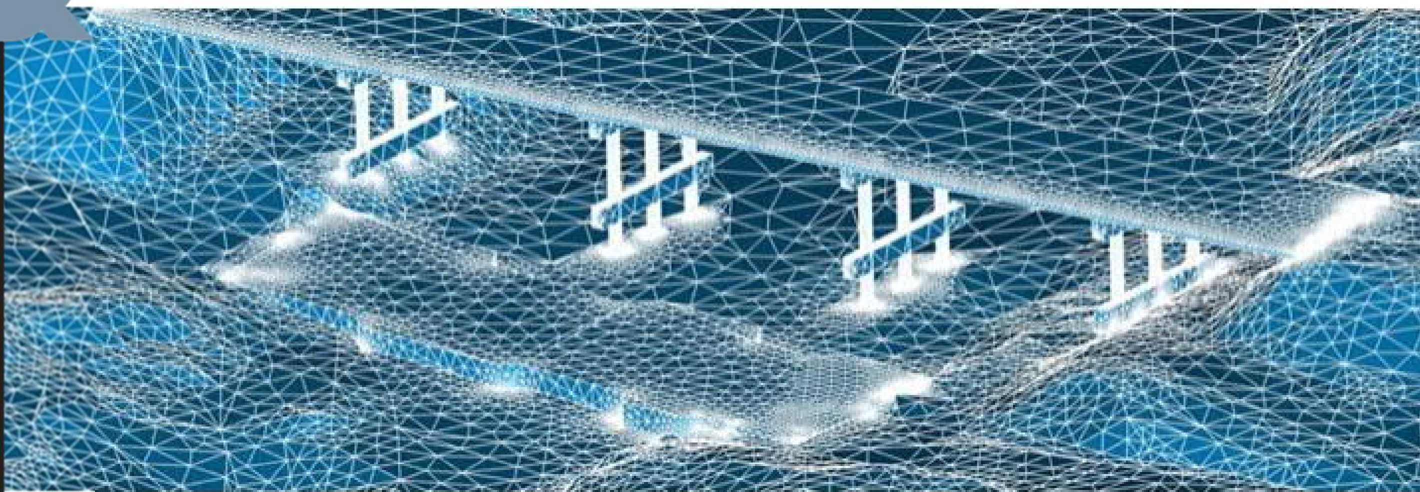
Building 3 flood study report

Prepared for
Ireneinc Pty Ltd

Client representative
Irene Duckett

Date
27 June 2019

Rev 01



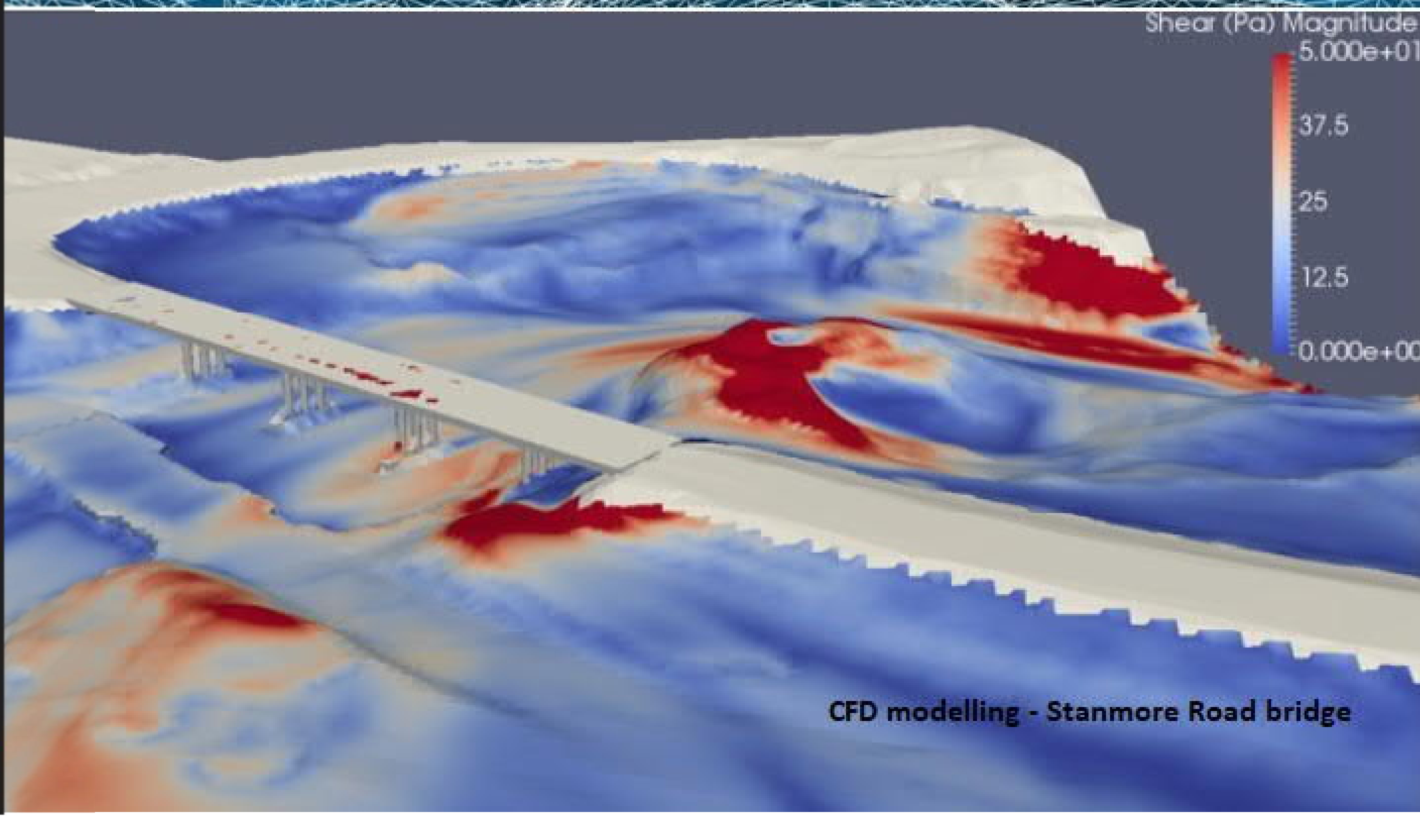


Table of Contents

List of figures

List of tables

Appendices

Appendix A — Risk Register
Appendix B — Seismic evaluation

Prepared by — Haydn Betts		**Date — 27/06/2019**
Reviewed by — Joshua Coates		**Date — 27/06/2019**
Authorised by — Haydn Betts		**Date — 27/06/2019**

Revision History

Rev No.	Description	Prepared by	Reviewed by	Authorised by	Date
00	Issued for use	H Betts	J Coates	H Betts	30/05/2019
01	Updated to reflect additional information	H Betts	A Turner	H Betts	27/06/2019

Executive Summary

This Planning Report – Flooding supports a development application for a three-story building known as Building 3 within the University of Tasmania's (UTAS) site at Inveresk, Launceston. The development is subject to the requirements of the City of Launceston's Interim Planning Scheme 2015 and in particular, the Code provisions set out in Section E16.7.2 Flood Impact Performance Criteria P3.

Building 3 will host the library and student services together with a retail and food beverage tenancy and an expected building population of up to 500 persons.

The Inveresk site is located on the former Tasmanian Railway Workshops area between the North Esk River, Invermay Road and UTAS Stadium (formerly York Park). The Inveresk site is relatively low lying and is contained within the polder formed by the flood levees of the Launceston Flood Protection System.

This report explores the flood risk profile for the Inveresk area. It provides relevant background, an overview of the riverine flood risk, an overview of the existing flood risk controls, documents the known residual risks and proposes risk management options that can be incorporated into the development approval.

This report relies on the existing flood risks that have been determined for the City of Launceston and set out in a report prepared by BMT consulting engineers in November 2018.

The report will be accompanied by a Flood Emergency Management Plan that can be incorporated into the UTAS Inveresk site emergency management plan.

Glossary and acronyms

AEP	Annual Exceedance Probability The likelihood of the occurrence of a flood of a given or larger size occurring in any one year, usually expressed as a percentage (Handbook 7). The terminology to be used for events less frequent than a 10% AEP event is % AEP as outlined by the Geoscience Australia at http://arr.ga.gov.au/__data/assets/pdf_file/0006/40398/New-ARR-Probability-Terminology_final.pdf
AHD	Australian Height Datum (approximates mean sea level where it is set to zero) and provides a vertical control for elevation comparisons.
ANCOLD	Australian National Committee On Large Dams
CoL	City of Launceston
DEM	Digital Elevation Model (expressed as a series of grid cells where the elevation of each cell is the average height of the cell area)
DFE	Designated Flood Event: the flood event selected for the management of flood hazard for the location of specific development as determined by the appropriate authority (NCC 2016 Building Code of Australia Volume 1). It is used for land use planning purposes and usually expressed in terms of Annual Exceedance Probability (AEP)
DFL	Defined Flood Level: the flood level associated with a defined flood event relative to a specified datum (NCC 2016 Building Code of Australia Volume 1)
DPAC	Department of Premier and Cabinet
DPIPWE	Department of Primary Industries, Parks, Water and Environment
Existing flood risk	The risk a community is exposed to as a result of its location on the floodplain (Handbook 7)
Flood prone	Land that would be inundated in the event of the Probable Maximum Flood (PMF)
Freeboard	A factor of safety above design flood levels, typically used in relation to the setting of floor levels, and levee crest heights. It is usually expressed as a height above the design flood level. Freeboard tends to compensate for flood prediction uncertainties and for factors which increase flood levels, such as a wave action, localised hydraulic effects, settlement of levees. It should not be relied upon to provide protection for events larger than the design flood.
Future flood risk	The risk that new development within a community is exposed to as a result of developing on the floodplain (Handbook 7).
Habitable room	A room used for domestic activities, and Includes a bedroom, living room, lounge room, music room, television room, kitchen, dining room, sewing room, study, playroom, family room, home theatre and sunroom, but excludes a bathroom, laundry, water closet, pantry, walk-in wardrobe, corridor, hallway, lobby, photographic darkroom, clothes-drying room, and other spaces of a specialised nature occupied neither frequently nor for extended periods. (NCC 2016 Building Code of Australia Volume 1)

The Guide to the NCC 2016 applies the term ‘habitable room’ *to Class 2 and Class 3 buildings and Class 4 parts of buildings*. It is intended this definition applies to student accommodation where there are privately habitable or commonly known as sole occupancy units as defined in the National Construction Code.

Left bank	The side of a river when looking downstream (see ‘right bank’)
LiDAR	Light imaging, detection, and ranging: A surveying method that measures distance to a target by illuminating the target with pulsed laser light
LIPS	Launceston Interim Planning Scheme 2015
LFPS	Launceston Flood Protection Scheme (includes the flood levees)
MEMP	City of Launceston Municipal Emergency Management Plan
NERAG	National Emergency Risk Assessment Guideline
PMF	Probable Maximum Flood, a flood that would result from Probable Maximum Rainfall (PMP)

Polder	A low-lying tract of land that forms an artificial hydrologic entity, enclosed by levees
PSA	Planning Scheme Amendment
QVMAG	Queen Victoria Museum and Art Gallery
Residual flood risk	The risk a community is exposed to that is not remedied through established risk treatment processes. In simple terms, for a community, it is the total risk to that community, less any measure in place to reduce that risk (Handbook 7).
Right Bank	The right side of a rive when looking downstream (see ‘left bank)
RL	Reduced Level – a height of a point relative to AHD
TheList	Land Information System Tasmania – on-line database managed by the Department of Primary Industries, Parks, Water and Environment
TUFLOW	Australian developed two-dimensional hydraulic modelling software used internationally https://www.tuflow.com/Tuflow.aspx
Right bank	The side of a river when looking downstream (see also left bank)
UTAS	University of Tasmania

Many of the definitions provided above and other definitions are available from the on-line Australia Disaster Resilience Glossary (The Glossary) available at https://knowledge.aidr.org.au/glossary/?wordOfTheDayId=&keywords=&alpha=&page=1&results=50&order=AZ

1. Introduction

This report has been prepared to support a development application to the City of Launceston (CoL) for a building known as Building 3 to be constructed on the University of Tasmania's (UTAS) transformation site at Inveresk on land depicted with a red outline on Figure 1.

1.1 Location

The site is located as indicated by the red polygon in Figure 1 and is currently the site of an asphalt carpark between two existing building clusters.

Figure 1 Building 3 development site, Inveresk

1.2 Purpose

The intent of this report is to assess the proposed Building 3 against the Code provisions set out in Section E16.7.2 Flood Impact Performance Criteria P3. The report explores the risk profile associated potential developments on the Invermay/Inveresk floodplain, and proposes risk management options that reduce the residual risks to the intended uses.

Specifically, the report:

- Provides relevant background information
- Provides an overview of the riverine flood risk
- Provides an overview of the existing flood risk controls
- Documents those residual risks
- Proposes risk management options that can be incorporated in to the planning scheme amendment to reduce the residual risks associated with the intended use to acceptable levels.

Appended to this report is a memorandum that considers the risks of geotechnical induced failure as discussed in

Section 5.5 below and a tabulation of the residual risks.

This report should be read in conjunction with a draft Flood Emergency Management Plan as specified in the Planning Scheme Code requirements set out in Section 1.4.

1.3 Building description

It is understood Building 3 will be a three-story building and will hold a Library and Student Services and have a gross floor area of 3,360 m^2. It will contain the following spaces:

- Student study spaces
- Library book collection
- Staff office spaces
- Student services spaces
- Plant/ back of house, etc.
- Retail tenancy most likely food and beverage.

Potential building populations are

- 450 students and staff in the library and student services areas
- 30 – 50 patrons in the food and beverage area.

This proposal forms part of a broader masterplan which will be subject to a future planning application and scheme amendment.

1.4 Planning requirements

The report addresses the requirements of the Inveresk/Invermay Flood Inundation Area Code of the City of Launceston's Interim Planning Scheme 2015 (LIPS). The planning requirements for the City Park side of the North Esk River are not so stringent.

The Invermay/Inveresk Code provisions are set out in Section E16.7.2 Flood Impact Performance Criteria P3:

> *Buildings not in the Residential use class must be sited and designed in accordance with a hydrological report and an emergency management plan prepared by a suitably qualified engineer. The report and plan must:*
>
> *(a) detail:*
>
> *(i) the risks to life;*
>
> *(ii) the likely impact on the use or development; and*
>
> *(iii) how the use or development will manage the risk to tolerable levels;*
> *during either an overtopping of the levee or a levee breach at the closest point in the levee during a 5% AEP, 2% AEP or a 1% AEP flood event; and*
>
> *(b) consider the following:*
>
> *(i) the likely velocity and depth of flood waters;*
>
> *(ii) the need to locate electrical equipment and other fittings above the 1% AEP flood level;*
>
> *(iii) the likely effect of the use or development on flood characteristics;*

(iv) the development and incorporation of evacuation plans into emergency management procedures for the precinct; and

(v) the ability of the use or development to withstand flood inundation and debris damage and the necessity for the incorporation of any flood proofing measures in the development.

1.5 UTAS Objectives

UTAS seeks to achieve:

- Modern, fit-for-purpose teaching and learning spaces a short walk to the Central Business District
- High-tech research facilities that focus on distinctive fields of academic endeavour, driving better education and economic outcomes in northern Tasmania
- An inviting and accessible environment that is attractive to the community, including new, exciting spaces for cultural and community events; and
- A precinct that acknowledges the previous and current history of the site including Aboriginal and industrial heritage.

2. Background

2.1 Site context

The Inveresk site is located on the former Tasmanian Railway Workshops area between the North Esk River, Invermay Road and UTAS Stadium (formerly York Park). The Inveresk site is relatively low lying and is contained within the polder formed by the flood levees of the Launceston Flood Protection System (refer Section 2.2.2 below).

Peak flood levels in the North Esk River apply to both sides of the river although they are marginally higher at the northern (Forster Street) end of the Inveresk area than closer to Tamar Street.

2.2 Flooding

2.2.1 Flood history

Launceston is located at the confluence of the North and South Esk Rivers where they form the River Tamar. The Tamar Estuary catchment makes up approximately 15% of Tasmania's land area at approximately 10,000 square kilometres. The South Esk catchment accounts for approximately 9,000 square kilometres of the Tamar catchment and flood behaviour on the Launceston floodplain is dominated by the South Esk River due to its dominant catchment size. Flooding can be exacerbated by high tide levels and storm surge in the River Tamar.

Flood records have been collated since European settlement and significant flooding on the South Esk has been recorded in Launceston in 1828, July and August 1852, 1863, 1929, 1969 (Tasmania, 2000) and most recently in 2016. Whilst the 1852 and 1863 floods are reported to have been greater in magnitude than the 1929 flood, the consequence of flooding was greater in 1929 due to the increase in floodplain development between the 1800's and 1929. One thousand homes and buildings were damaged in Invermay in 1929, prompting the development of the Launceston Flood Protection Scheme (LFPS).

2.2.2 Flood levee system

The LFPS was designed to protect Invermay and low-lying areas of Launceston City from riverine flooding equal in magnitude to that experienced in 1929 and construction of the LFPS began in the 1960's. The 1960 iteration of the LFPS was deemed not fit-for-purpose in 2005 due to the structural degradation of the formed levee system.

An agreement to fund the levee rebuild was made between the CoL and The Crown in Right of Tasmania (Tasmanian State Government) in 2008. The Launceston Flood Risk Management Deed outlines the terms and conditions of the funding arrangement. Section 4.2 of the deed agreement states:

> *(a) The Council must prepare amendments to the Launceston Planning Scheme and submit those amendments to the Resource Planning and Development Commission. The amendments are to constrain increases in potential future flood damage to property in the 1:100 year flooding overlay areas in Invermay and must address the flood hazard by introducing measures that:*
>
> *iii. Prohibit new schools and other educational facilities, aged care homes and any essential services premises or similar premises;*

The more recent Launceston City Deal commits the relocation of the UTAS campus to the Inveresk Precinct and the Greater Launceston Plan identifies the rejuvenation of the Inveresk Precinct as a priority. In contrast; the Launceston Flood Risk Management Deed required the prohibition of educational facilities in Invermay. These documents can be reconciled by aligning modern floodplain management and strategic directions and achieved by strengthening the risk management measures that will need to encompass floodplain planning, risk management and ongoing commitments to maintain or improve the level of protection provided by the levees in perpetuity. This must recognise that the consequences of a changing climate include increases in flood levels through increased storm surge, sea level rise and increased rainfall intensities and possibly rainfall volume.

2.2.3 Flood risk

Treating risk involves developing an effective management plan. This relies upon a detailed understanding of the local flood situation and its potential to impact the community, and an understanding of the treatment options available and their limitations. There is no single treatment or set of treatments to manage the full range of flood risks that are valid for all communities. In addition, flood risk does not necessarily remain constant. Unless effectively managed, flood risk can change significantly with alterations to catchment and floodplain development, the geomorphology and topography of the river systems and their floodplains, catchment and floodplain vegetation, and infrastructure on the floodplain. Risk can also vary with a changing climate. The growth of risk can be managed by limiting risks to new development and avoiding permanent occupation in a floodplain. Reducing risk to existing development also needs to consider the efficient and effective use of scarce resources. Residual risks need to be understood and managed or accepted (Australia 2017a).

Flood risk is a product of the likelihood and the consequence of flooding that occurs on lands that are usually dry. Flood risk is not considered static, *i.e.* as the likelihood and consequence of flooding change, as does the risk profile of the floodplain. Prior to the development of the floodplain in Launceston, the consequence of flooding would have been considered insignificant. However, as development of the floodplain occurred, the consequence of flooding became more severe. This changing risk profile continues, and several risk management strategies are used to decrease this risk profile.

Typically, flood risk is categorised in terms of environmental, economic and social implications and its governance. The prime criterion is the safety of people and, if people are not exposed to flood risk, there should be no impediment to development. The next criterion is, as far as it is practicable or reasonable to do so, to ensure the structure and fabric of buildings constructed in flood prone areas are flood resilient. Exceptions might be where the design life of the building is comparatively short in which case exposure to floodwaters should not cause collapse and/or disintegration with resulting debris worsening flood damage to proximate development. Further decisions on infrastructure should consider whether activities can be relocated, and materials, equipment and furniture are readily relocatable to as to minimise financial losses.

3. BMT Flood Risk Summary

As part of its continual improvement to floodplain management, CoL engaged consulting hydrologists and hydraulic engineers BMT in 2017 to update the North Esk, South Esk Rivers and River Tamar flood model and produce new flood mapping outputs. The subject site/s of the UTAS campus relocation is contained within flood prone land included in this flood model.

The key updates for this model and mapping update are:

- An updated flood frequency analysis which estimates the 1% AEP flood event flow rate(s)
- A joint probability analysis in accordance with Australian Rainfall and Runoff 2016 (Ball *et al*) which considers the interaction between North Esk and South Esk Rivers flooding, and tidal influences, storm surge and climate change consequences
- New hazard mapping in accordance with the Australian Institute of Disaster Resilience Handbook 7 (Australia 2017a).

The flood frequency analysis was revised through the examination of the history of flood data of the South Esk River at Trevallyn and estimation of the likely magnitudes of events of a given return period, commonly expressed as Annual Exceedance Probability (AEP).

The South Esk River at Trevallyn (upstream of Launceston) has a long gauge history that allows for a flood frequency analysis to be used as the primary method adopted for estimating peak flows, and hence peak water levels in the hydraulic model. It also benefits from written records dating to 1828 which were used to inform the flood frequency analysis.

The last flood frequency analysis was undertaken in 2008 by Hydro Consulting. The key changes from this analysis to the present analysis include:

- An additional 10 years of data, including the 2016 flood event
- The inclusion of two very large flood events from the 1800's. These events were previously excluded as they were believed to be unreliable and skewed the result. Ball *et al* (2016) now allows for the inclusion historic data as 'censored data'.

The result of the updated flood frequency analysis presents a larger than previously estimated flow rate for the 1% AEP flood event.

This information has been released publicly and the analysis and results of the study are finalised and are not subject to change in the immediate future. Due to the significance of the UTAS relocation, it is prudent to consider this newly available information as it shifts the risk profile of the UTAS relocation site.

The increase in flow rate can be directly attributed to the inclusion of pre-1900 observations in the flood frequency analysis, which is now permitted by Australian Rainfall and Runoff (Ball *et al*, 2016). These increases in peak flows contribute to increased water levels for each design flood event. The design water levels at Black Bridge for each design flood event are shown in Table 1. Black Bridge is the former railway bridge that provides some hydraulic control to the floodplains upstream to Hoblers Bridge Road.

The water levels depicted in Table 1 are sourced from BMT (2018) and identify the impacts of climate change in these river systems.

Table 1: Peak water levels at Black Bridge from North and South Esk Rivers Flood Modelling and Mapping Update Volume 1: Technical Report (BMT, 2018)

AEP	Peak Flood Level (m AHD) @ Black Bridge		
	Existing conditions	2050 conditions	2090 conditions
20%	2.45	2.79	3.34
10%	2.68	3.07	3.65
5%	3.16	3.56	4.10
2%	3.92	4.37	5.04
1%	4.58	5.04	5.45
1 in 200 (95% confidence)	5.20	5.58	5.93
1 in 500	6.01	6.34	6.74
1 in 1000	6.75	7.08	7.54
1 in 2000	7.51	7.94	8.45

The above table includes climate change assessments undertaken to determine likely changes in flood level and flood behaviour at the years 2050 and 2090 in conjunction with the updated flood study. To define the flood risk over the expected life of the development (and future proof subsequent general planning amendments), BMT assessed the climate change scenarios presented in Table 2. As recommended in Ball *et al* (ARR 2016), the sea level rise scenarios have been sourced from Sea-Level Rise and Allowances for Tasmania based on the Fifth Assessment Report (IPCC 2014) and increased rainfall intensity from the Australian Rainfall & Runoff Data Hub[1].

Table 2: Climate Change Scenarios

	RCP 8.5
2050	2.3
2100 (2090 rainfall)	2.7

From a planning, economic and social perspective, it is unclear what the makeup of Invermay and Inveresk will be over the next 80 years. Furthermore, it is unclear how a university and associated uses will be operated over this time scale.

A 30-year planning horizon is generally considered an appropriate timescale to foresee likely planning, development and uses within the Launceston region. Therefore, consideration must be given to the use of likely changes to flood levels and flood behaviour over time, particularly if a proposed development is intended to operate over an extended period.

3.1 Flood Levee Overtopping

A flood levee is almost never designed to exclude the PMF (probable maximum flood) and as such, will be overtopped at some stage. (Handbook 7, page 56). As discussed above, the latest flood study has demonstrated the perceived level of service if the flood levee system is reduced. This means any proposed development must consider the risk of flood levee overtopping, even if the event that may cause overtopping is rare and infrequent.

The BMT flood risk study draft report includes flood maps for the 5%, 2%, 1%, 1 in 200, 1 in 500-year and 1 in 2,000 year AEP events. The 1% AEP event is a common flood design flood event used in Australia for planning and development controls for flood prone communities. It provides a reasonable balance for reducing damage associated with flooding whilst also allowing land to be developed where it is appropriate to do so, and where the flood risk is understood and quantified. Flood maps are provided in the BMT report. The 1 in 2000 year AEP event is used as a design parameter in the structural design of bridges.

[1] http://data.arr-software.org/

3.2 Flood Levee Failure

Flood modelling was extended by BMT to determine the likely impact of flooding due to flood levee failure. The levee failure mode examined was a simulated instantaneous removal of a 40m long section of flood levee. Flood levee failures under the (updated) 5%, 2% and 1% AEP events were modelled at six breach locations, selected to represent worst case levee failure points (based on proximity to development) near the proposed UTAS sites, a breach at a single location being modelled at any one time.

The flood hazard associated with flood levee failure can be classified using the *Australian Institute for Disaster Resilience Guideline 7-3: Technical flood risk management guideline (Australia 2017b): Flood hazard*. Flood hazard is quantified as a relationship between flood velocity and depth, *i.e.* generally speaking, the deeper the flood waters and the faster the waters are travelling, the more hazardous the classification of the flood waters. Table 3 summarises flood hazard classifications.

Table 3: Hazard classifications

Hazard Vulnerability Classification	Description
H1	Generally safe for vehicles, people and buildings *
H2	Unsafe for small vehicles
H3	Unsafe for vehicles, children and the elderly
H4	Unsafe for people and vehicles
H5	Unsafe for vehicles and people. All buildings vulnerable to structural damage. Some less robust building types vulnerable to failure
H6	Unsafe for vehicles and people. All building types considered vulnerable to failure

* Some small vehicles have been observed to float at a depth of 150mm.

Observation points were scattered through and beyond the UTAS site to record simulated depths and velocities that resulted from the levee failures.

As indicted in Figure 3, the results of the modelled levee failure events relevant to the UTAS site (Inveresk and Willis Street) indicate that in the event of a levee failure, a hazard classification of H3 is noted in the UTAS Inveresk area in the immediate vicinity of the levee in a 5% AEP event. As expected, as the distance increases away from the levee breach, the hazard class reduces in severity to between H2 and H1. The number to the lower right of the report point dot is the equivalent flood depth.

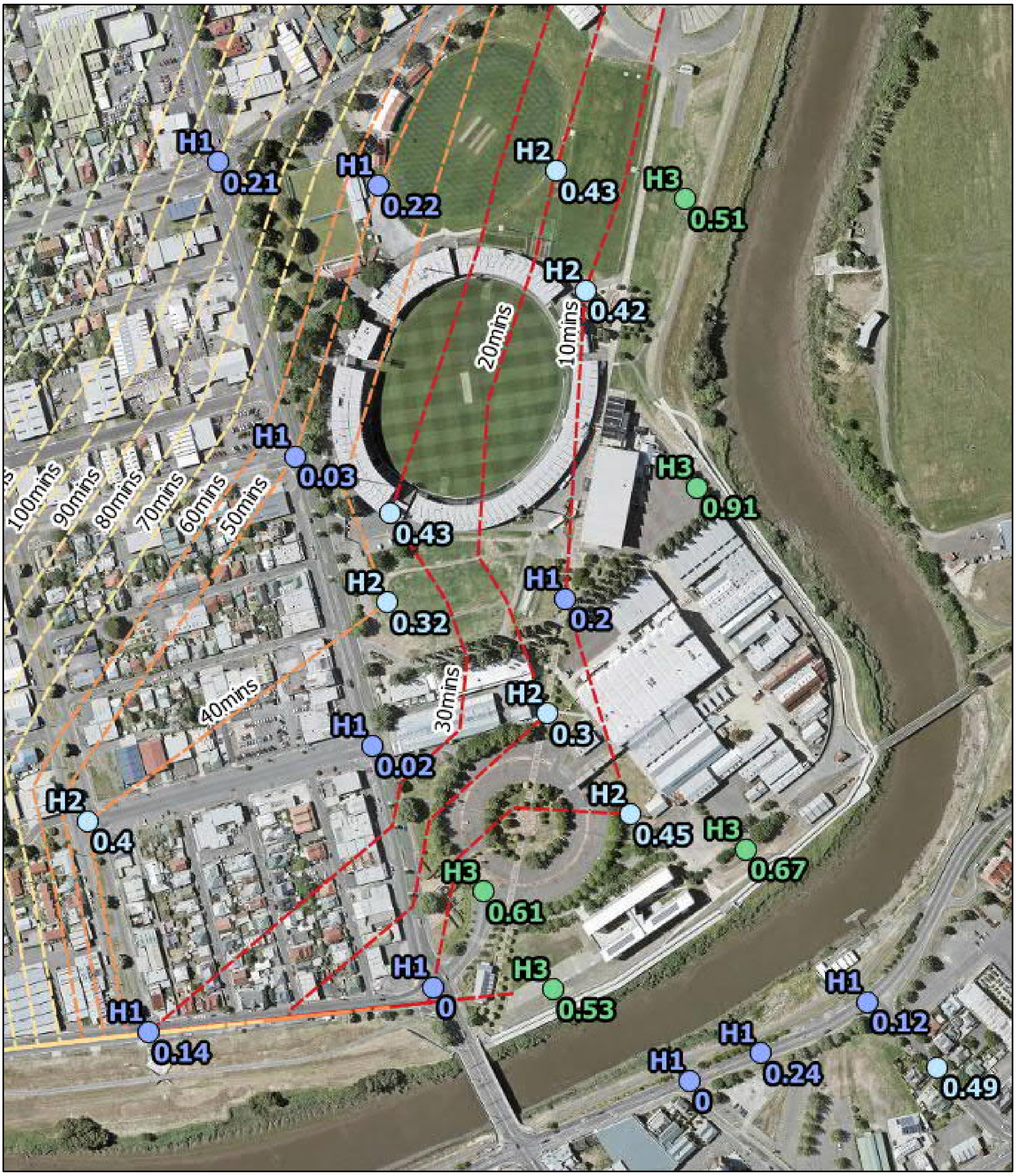


Figure 2 Hazard classification 5% AEP event levee failure

Figure 2 also displays the time to inundation (as isochrones) of the land as a result of the simulated levee failures. Most of the UTAS Inveresk Precinct in general will be completely inundated within 30 minutes.

The modelled hazard classifications for both modelled flood events greater in magnitude than the 5% AEP (2% and 1% AEP flood events) show that the resultant simulated flood behaviour generally corresponds to a hazard classification of H4 across the UTAS relocation site.

4. Existing controls

This section presents an overview of existing flood management controls relevant to the UTAS relocation site. These controls have been developed over many years to help mitigate the risks associated with the flooding of the Invermay/Inveresk and Launceston City floodplains. The controls include educational awareness and preparedness programs, physical works and emergency management procedures.

Before discussing the floodplain management controls that are in place, it is prudent to appreciate how the topography of a floodplain can be classified in terms of potential emergency response strategies.

4.1 Flood Emergency Response Classification

Floodplain areas can be classified regarding isolation and access considerations in a way that informs emergency response management Australian Disaster Resilience Guideline 7-2 Flood Emergency Response Classification of the Floodplain (Australia 2017c).

Table 4 describes the flood emergency response classifications that relate to land subject to flooding in the event of the Probable Maximum Flood (PMF):

Table 4: Australian Disaster Resilience Guideline 7-2 Flood Emergency Response Classification of the Floodplain

Primary Classification	Secondary Classification	Tertiary Classification	Description
Flooded (F) – The area is flooded in the PMF	Isolated (I)	Submerged (FIS)	Where all land in the isolated area will be fully submerged in a PMF after becoming isolated.
		Elevated (FIE)	Where there is a substantial amount of land in isolated areas elevated above the PMF.
	Exit Route (E)	Overland Escape (FEO)	Evacuation from the area relies upon overland escape routes that rise out of the floodplain.
		Rising Road (FER)	Evacuation routes from the area follows roads that rise out of the floodplain
Not Flooded (N) - The area is not flooded in the PMF		Indirect Consequence (NIC)	Areas that are not flooded but may lose electricity, gas, water, sewerage, telecommunications and transport links due to flooding.
		Flood free	Areas that are not affected flood affected and are not affected by indirect consequences of flooding.

Invermay/Inveresk would be described as Category FIS. This is considered as the most dangerous isolation scenario if members of the community wait to observe flooding themselves, there will be no option for evacuation other than rescue.

The following figure is an excerpt from (Australia 2017c) provides a pictorial representation of FIS.

Figure 7: Example of area protected from the river by a levee designed for the 1% AEP event. In larger floods, including the PMF, the levee will overtop and fully submerge the entire area. access to the Area will be lost before overtopping. Category (FIS).

Figure 3: Flooded, Isolated and Submerged (FIS)

4.2 Education and floodplain preparedness

Avoidance of personal flood risk is preferable to evacuation and both are preferable to rescue.

To avoid a rescue scenario, residents and occupiers of floodplains need to be made aware of their flood risks and how they should react to a flood threat when advised to do so. Timely and effective community response occurs when facilitated by community education, emergency management planning, evacuation infrastructure, flood warning, and through to assistance with community recovery.

Residents and occupiers of Invermay and Inveresk are generally aware of that flooding can occur, are aware that flood levels provide then with a level of protection, and there may be further risks of flooding, but they may not yet appreciate the nature and magnitude of those risks. Their communities are exposed to annual testing of the flood siren and responded quickly to the June 2016 flood event. Early last century, Inveresk residents responded to continual chiming of the Town Clock. Nevertheless, there are imperatives for new occupiers to be similarly informed by CoL generally and UTAS in particular with respect to developments within ifs precincts.

4.3 Levee system

The levee system (which forms the major part of the CoL’s flood defense) is the most recognised flood risk control measure in Launceston. Levees are present on the banks of the North and South Esk Rivers and the Tamar Estuary between Hoblers Bridge Road and the Mowbray Connector, refer to Figure 4 below.

This section presents the regulatory obligations of the levee owner (CoL), the design and construction undertaken, the operation and maintenance activities and the flood response requirements related to the levee system.

4.3.1 Regulation of Flood Levee System

The *Water Management Act 1999* ('the Act') and the *Water Management (Safety of Dams) Regulations 2015* ('the Regulations') ensure that owners of existing dams (and levees) meet their dam safety responsibilities. The Regulations set out the ongoing activities and reporting requirements for dam safety and incorporates the requirements of the Australian National Committee on Large Dams (ANCOLD) for dam safety. The identified regulator in Tasmania is the Department of Primary Industries, Parks, Water and Environment (DPIPWE). The CoL work closely with DPIPWE to satisfy those conditions relevant to the levee system.

The CoL was issued a permit by DPIPWE: The *Permit to Construct a Dam Under Section 157* (Water Management Act 199) provided several conditions relating to the construction of the flood levees and ongoing management of the flood levees.

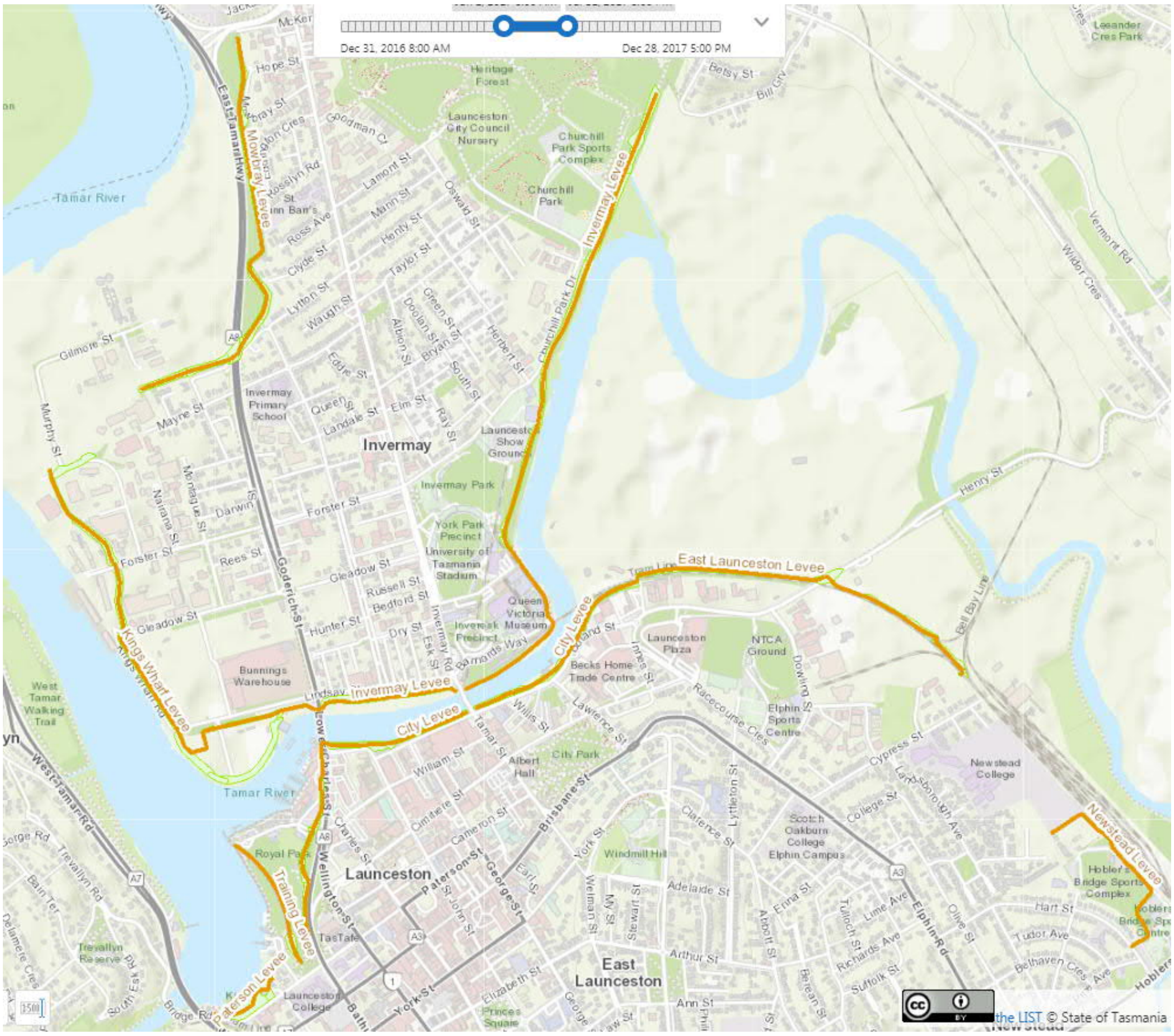


Figure 4: Launceston flood levees

4.3.2 Flood Levee Asset Management and Ongoing Funding

The current CoL flood management strategy intends the levee system provide its design level of protection in perpetuity, not only in the context of the UTAS campus relocation but for all residents and businesses located within the LFPS polders. The CoL (draft) Strategic Asset Management Plan 2018 - 2038 states "The whole of life sustainability analysis via the Strategic Asset Management Plan (SAMP) and the Long Term Financial Plan (LTFP) shows we (CoL) have the financial capacity to achieve very acceptable renewal ratios".

The SAMP indicates the LFPS is funded to its horizon of 2038. Recognising the criticality of the LFPS in the protection it provides to not just the Inveresk and Willis Street sites but the whole of the Invermay/Inveresk and Launceston City floodplains, it is not possible to foresee a future Launceston without some iteration of the LFPS.

4.3.3 Flood Levee Operations and Maintenance

Upon completion of the flood levee system, the Launceston flood Authority submitted a works as executed report (a requirement of the permit to construct) and an operations and maintenance manual. The flood levee system is classified as a High A dam.

In addition to comprehensive inspections (currently being compiled), the CoL undertakes routine levee inspections on an annual and quarterly basis in addition to ad-hoc inspections. This is consistent with the operations and maintenance manual submitted as part of the permit to construct the levee. This aims to identify any issues that would reduce the level of service or compromise the structural integrity of the flood level system. Any identified issues are then recorded and prioritised for remediation.

Further to the scheduled inspections and corresponding maintenance works, regular routine activities are undertaken such as vegetation management (mowing and unwanted vegetation removal) as required.

The flood levee system comprises several types of infrastructure that are required to be operated effectively to ensure the flood levee system operates as intended. Regular operational activities include:

- Closure of penstocks prior to a flood event to ensure flood water does not enter the underground drainage system
- Closure of flood gates prior to a flood event to ensure the flood levee system operates at the intended level of service
- Monitoring of flood levee system during a flood event to ensure flood levees and gates are operating as intended.

To support the operation of the flood levee system, the following maintenance activities are undertaken:

- Inspections and maintenance are performed on the penstocks, flood gates and tide flaps (every 6 months) to ensure they are operational when required
- Tests of gate closures.

4.4 Emergency Management

The purpose of the flood levee system is to protect communities that reside on developed floodplains from flooding up to a defined level of service or flood magnitude. Although flood levees do manage most flooding events, it is not practical to protect communities from all floods. Flood levees should not be relied upon to mitigate the risk to life caused by floodwaters so emergency management plans are usually developed to guide those actions required to mitigate the residual risks associated with flooding.

In the event of flood producing rain, the Bureau of Meteorology issues a series of flood warnings. These warnings are based on the information provided from a significant hydro-meteorological warning system that utilizes automatic rain gauges in the catchments, automatic water level recorders along the rivers and meteorological modelling. The Bureau enters into agreements with local authorities and provides a Service Level Specification for Flood Forecasting and Warning Services for Tasmania Version 2 that is published on the Bureau's website.

This service level agreement provides for a warning time of 12 hours for Launceston for a North Esk River flood event and 24 hours for a South Esk River flood event, considered as generating the more severe flood. In practice, heavy rain forecasts are now possible for several days before rain begins to fall and generates sufficient runoff for by the Bureau of Meteorology to issue Flood Watch, or Minor, Major and Severe flood warnings. The respective catchments are sufficiently large there is ample time to enact the City of Launceston Municipal Emergency Management Plan (MEMP) that identifies various hazards and how they are managed.

It should also be noted that occupation of the UTAS Inveresk site and Building 3 is controlled by Tasmania Police acting upon advice from the State Emergency Service (SES) and CoL. Access to the site will be prevent should a flood above a nominated threshold occur or forecast to occur. Occupants of the site and Building 3 will be instructed to evacuate should it be considered a flood levee is at risk of failure. These protocols and thresholds are described below.

Table 5 contains an excerpt from the MEMP relating to flooding. The plan specifically details CoL as a response management authority for flooding interacting with the Launceston Flood Protection Scheme (geographically bound).

Table 5: Hazard Management Summary – Excerpt from MEMP (Table 3)

Row	Hazard	Response Management Authority	Council Support
10	Flood-rivers	SES	Property Identification Road Closures Local operations centres Public information in close consultation with State Emergency Service (SES) Providing plant and machinery Recovery/evacuation centres
11	Launceston Flood Protection Scheme	CoL TasWater SES TASPOL	Flood Warning. (within area of Trevallyn Dam (South Esk River) to the Tamar River and Corra Lynn (North Esk River) to the Tamar River). Response – flood gate and penstock closure Public information in close consultation with SES Levee Patrol Assist Tasmania Police with road closures Recovery/ evacuation centres

Flood evacuation is the responsibility of Tasmanian Police, although SES and CoL provide advice. The Police Regional Commander (RC) ultimately decides if evacuation is necessary. Councils are often the most well-equipped authority to provide this advice through their knowledge of the flood levee system and associated flood protection infrastructure.

The *Launceston Flood Evacuation Plan – Issue 2 2011* sets out the roles and responsibilities for flood evacuation in Launceston.

The circumstances under which evacuation would normally occur are:

- The trigger point for placing Invermay residents on evacuation standby is when flooding in the South Esk River is expected to reach 2000 m^3/s, (corresponding to an approximate flood level of RL 3.0m)
- If rising flood waters in the South Esk River are expected to breach the Launceston levee system causing significant inundation to the Invermay and Inveresk areas (a flood approaching 2330 m^3/s and corresponding to an approximate flood level of RL 3.3m)
- If the combined discharge values in the South and North Esk Rivers approach a 2330 m^3/s flood; and
- Or at any other time deemed appropriate by the Police Regional Commander North.

These flows and levels reflect the current hydraulic conveyance of the river system (as modelled by BMT) and do not reflect climate change per se.

4.4.1 Evacuation Timeline

The *NSW SES Timeline Evacuation Model* has been the de facto standard for evacuation calculations in NSW since it was first developed for evacuation planning in the Hawkesbury Nepean Valley. The Hawkesbury Nepean Valley is a very large river system, so the evacuation planning method used for this catchment is likely to be robust and applicable for Launceston to a degree. The following presents the concepts as presented in the paper Molino *et al* (2013). The evacuation model can be described as:

Surplus Time = Time Available – Time Required.

Time available is the time from a flood warning issued from the Bureau of Meteorology that would trigger evacuation to the point at which flood evacuation routes are cut or entering the flood plain becomes unsafe. The latter is the likely scenario for Launceston as Inveresk will flood before any flood evacuation route is cut.

Based on previous flood events: it estimated that the time available from the South Esk River flood is approximately **24 hours**, although it is recognised that this could be greater or lesser depending on catchment conditions, rainfall intensity and the ability to issue warnings within a reasonable confidence limit.

The SES evacuation timeline model uses the following equation to calculate Time Required:

Time Required = *Warning Dissemination (WD)* + Warning Acceptance Factor (WAF) +

Warning Lag Time (WLT) + Travel Time (TT) + Travel Safety Factor (TSF)

It is estimated under current development conditions that the time required to evacuate Inveresk is approximately **10 hours**, although it is recognised that this is highly variable. This indicates it is possible to evacuate all persons from Inveresk/Invermay with an appropriate factor of safety.

'All persons' means the current population and the anticipated increase of less than 1,000 people that would occupy the UTAS Inveresk campus site at any one time (pers. comm. UTAS Project Manager December 2018). A traffic impact assessment (Midson Traffic, 2019) suggests that a much higher aspirational campus population would generate a maximum additional 1,521 vehicle movements per hour that could be 'adequately absorbed in the surrounding road network' (p32). This report is based on a more traditional student FTE ratio while the advice from the University is that the larger proportion of the increase is expected to come from students who have intermittent and/or very low campus utilisation. This is consistent with higher education trends.

4.5 Existing land use planning controls

Flood related development controls are specified in Section E16.7.2 of the *Launceston Interim Planning Scheme 2015 for the Invermay/Inveresk Flood Inundation Code*. The controls are based on previous flood modelling and do not reflect the results of the most recent flood modelling (BMT 2018). The current controls for non-residential development in Invermay includes Acceptable Solution A3 that states:

A3 All buildings not in the Residential use class must have a floor level of at least 3.4m AHD

The associated Performance Criteria P3 requires:

Buildings not in the Residential use class must be sited and designed in accordance with a hydrological report and an emergency management plan prepared by a suitably qualified engineer. The report and plan must detail:

- The risks to life
- The likely impact on the use or development
- How the use or development will manage the risk to tolerable levels; and
- During either an overtopping of the levee or a levee breach at the closest point in the levee during a 5% AEP, 2% AEP or a 1% AEP flood event.

The current scheme and proposal is influenced by consideration of the area's development by the Department of Premier and Cabinet (DPAC in 2014). A letter from the Office of Security and Emergency Management within the Department of Premier and Cabinet (DPAC 2014) to Launceston Council attached correspondence to the Tasmanian Planning Commission. Significant matters identified within the letter include:

- S9.1.1 Allow residential development to support educational facilities
- S9.1.1 Allow intensification of non-residential development
- S9.2.1 Development and building controls consider the impacts of levee breaks …
- S9.2.3 Proponents of new development work with COL, Tasmania Police and the State Emergency Service to develop and implement educational packages; and

- S9.2.4 Consideration of thresholds for evacuation.

Other statements included:

- Successful development applications were to be subject to the completion of a hydrological report and emergency management plan
- Controls and interventions offered included emergency management, building control and land use planning; and
- The application of the principle to the assessment of planning controls is provided in the letter's Table 1 based on revised National Emergency Risk Assessment Guidelines (Australia 2015). It considered deaths and injury directly from the emergency event were core components; risks to the environment were not considered relevant for this assessment; and risks to the economic activity of the region due to a natural disaster.

In its conclusions, DPAC recommended:

Risk to Life: *Where non-residential development is intensified in close proximity to the levee, consideration should be given to arrangements to evacuate those facilities as an additional precaution during significant flood events.*

Risks to operation of emergency and other critical services: *Effective building design and emergency management plans …*

Economic risk: DPAC noted

The economic risk to the city of Launceston will inevitably increases with the size of the new non—residential development in the area. Costs would be incurred where significant proportions of economic activity are either temporarily interrupted or are not replaced after a major flood. The recommendations relating to the treatment of large non-residential development for 'risks to life' would also contribute to managing economic risks.

Moral Hazard: The Moral Hazard associated with Non-residential development is significantly lower than the Moral Hazard associated with residential development. It recognizes that non-residential development is generally more resilient to disasters.

The phrase 'Moral Hazard', used by DPAC, is quoted in economics literature and refers to the concept that one party to an agreement may engage in risky behavior or may fail to act in a risky event knowing that it is protected against the risk, and that the other party will incur the cost.

5. Residual risks and proposed mitigation

Residual risk is the risk that remains after the implementation of risk control measures that are in place at the time of the emergency. It recognises that it is impossible to remove all risk in an absolute sense, and that elements of risk will always remain.

The movement of the University to the floodplain will significantly change the risk profile associated with the Invermay/Inveresk and Launceston City floodplain.

The existing controls outlined in Section 4 will ensure that people are not exposed to flooding in floods up to the 1% AEP design event. Controls are currently in place to ensure that areas protected by the LFPS are not occupied should potential vulnerabilities become apparent.

However, there are residual risks that need to be recognised, planned for and reacted to, if those residual risks occur. Appendix A presents a tabulation of identified hazards, current controls and the residual risk. These residual risks are categorised as follows:

- Local stormwater flooding
- Functional risks
- Structural risk
- Population increases
- Geotechnical risk
- Anthropogenic risk
- A failure of the levee system
- The occurrence of floods larger than the 1% AEP event that might lead to levee overtopping or failure; and
- Transitional risk as climate changes.

The management of residual risks is described below.

5.1 Local stormwater flooding

Ground floor levels of non-habitable buildings are required to be of sufficient height to prevent 1% AEP flood flows from entering the building and includes estimated local stormwater flood events. The site is considered by CoL not to be affected by local stormwater events assuming: local stormwater systems including stormwater inlets, pipes and pump stations operate and any residual overflows can drain to the river. pitt&sherry has modelled local stormwater more conservatively by assuming the underground stormwater system is inoperable and riverine flooding prevents free draining of the polder area.

The Building 3 ground level varies between 2.3m AHD and 2.5m AHD at the eastern corner.

The ground floor level should be set approximately 300mm above the highest 1% AEP flood level including an allowance for climate change at year 2050 or higher in accordance with UTAS's accepted risk profile.

The 1% AEP flood level under existing climate conditions varies between 2.34mAHD to the north of the building and 2.53mAHD to the south of the building. If climate change allowances for increased rainfall to year 2090 are included, the peak water level is 2.35 at the north of the building and 2.57mAHD to the south of the building. The 2050 climate change water levels were not modelled but are close enough they can be interpolated.

These would suggest a flood level should be 2.65m AHD at the front of the building if there are no openings in the south-eastern and north-eastern walls of the building for 2090 conditions. If there are to be openings in those eastern walls, the flood level should be 2.87mAHD under 2090 conditions. If the design is to be to 2050 conditions, the floor level should be 2.64mAHD if there are no openings in the eastern walls. If there are to be openings, the floor level should be 2.85mAHD.

Stormwater modelling shows a small overflow path from the east onto the building site that affects the floor level discussion based on whether that eastern side of the building has a solid wall or an opening. As we do not know what other buildings or land level changes are contemplated to the south-east, a flood level of 2.87mAHD is recommended.

5.2 Building 3 functional risks

Building 3 will have three stories.

With a ground floor level at say 2.87 m AHD and a requirement the main functional parts of the building are 500mm above the 1% AEP flood level at the year 2050 (5.04mAHD, or higher if required), the first floor will have a minimal level of 5.54m AHD. However, there will likely be a floor to floor level dimension of 4m providing a first-floor level at 6.87m and an upper floor level of 10.87m AHD. This upper flood level is higher than the 1:2000 AEP event at year 2090.

The building will host the library and student support services, include retail food outlets but will exclude a creche. To support the long-term function of a library, archival material and data servers should be located as high as possible within the building. Some local authorities require their and government archives to be located above the level of the probable maximum flood (water level not available), but other authorities are less restrictive.

The LIPS Code requirement is for electrical equipment to be above the 1% AEP flood level (i.e. 5.04m AHD at 2050), plus freeboard. By comparison, the Queensland Reconstruction Authority advice is to locate electrical switchboards and controls above the 1:200 AEP flood event plus freeboard. Brisbane City's Flood code requires substations to be above the 1:200 AEP flood level and major substations to be above the 1:500 AEP flood level.

BMT (2018) reports1:200 AEP flood level is 5.58m AHD.

Inundation of Invermay, Inveresk and other polder areas may result in an extended period, perhaps up to three months (CoL advice), when electricity, sewage and water supply services are inoperable. These pose an operational risk to UTAS facilities.

A safety provision could be included if UTAS ever installs a PV solar generating system. Although the Aurora electrical reticulation system may be lost during a flood, a PV array will still be generating electricity in which case an isolation switch should be provided at a height above the 1:200 AEP flood level.

5.3 Building 3 structural risk

The structure of the building and its fabric should be constructed to withstand inundation and impact of moving water and be constructed of flood resistant material to a level above the 1% AEP flood level at the year 2050 plus an additional 500mm allowance for freeboard.

5.4 Population increase and the impact on evacuation

Section 4.4 describes the current emergency management system under which the CoL operates for riverine events. Under existing conditions, the CoL has sufficient time to effectively evacuate Invermay based on the existing population and trigger levels.

At the time of the 2016 Census, 3061 people resided in Invermay and approximately 800 businesses were also located in Invermay. UTAS has advised the likely population of Building 3 could be slightly less than 500 people at any one time. This quantum of population increase has the potential to add to the evacuation burden (but not overly) of Invermay in the lead up to a flood event if not included in UTAS emergency management plans and only if the building is populated during a flood emergency.

It is unlikely Building 3 will be populated given the CoL's flood emergency management strategy.

The evacuation timeline assessment documented in Section 4.4.1 suggests sufficient time for regional evacuation. Evacuation has been successfully undertaken in the past and is the most appropriate residual risk management measure (for preservation of life) given emergency response classification of the affected community (FIS, Section 4.1).

In the event of a flood event of magnitude that requires evacuation, it will be an imperative not only to evacuate the floodplain but also to prevent people from entering the floodplain and accessing those facilities. This accords with current CoL strategies as outlined in Section 5.7 below.

5.5 Geotechnical induced failure

Geotechnical factors that might induce failure of levees can be classified as being initiated by:

- Hydraulic slumps of the river bank sufficient to undermine the levees
- Piping failures where hydrostatic forces along weaknesses beneath the levees can create subsurface flow paths into the area protected by the levees (generally counteracted by cut-off walls built into the design); and
- Seismic events (earthquakes) that can initiate ruptures within the levee, that cause or exacerbate hydraulic slumps or piping mechanisms.

Hydraulic slumps can occur at any time but are more likely after high water levels and at low tide. Regular inspections and specific inspections prior to the onset of heavy rain should identify any potential weaknesses. This would be triggered within the CoL Municipal Disaster Management Plan. The potential for piping failure is reduced by the construction of cut off walls built into the design or constructed as fail-safe sheet piling walls behind the levees.

Seismic risk has been examined and reported in a memorandum to Council by pitt&sherry dated 15 July 2010 (refer Appendix B). The safe exceedance probability for various ground accelerations (aground) is tabulated as Table 5 of that memorandum, which is reproduced here in Table 6.

Table 6: Earthquake risk for LFPS

Scenario	Exceedance Probability	a_{ground}
Levee – Immediately after construction	1:170	0.026
Levee – long term with strength increase due to consolidation	1:500	0.04
Levee during a flood	1:1000	0.06

Given the levees were reconstructed prior to 2016, the probability of failure of during an earthquake is less than immediately after construction. Additionally, the probability of a seismic event occurring during a flood event, having sufficient flow to cause rapid flooding within the SAP Concept area, is 1:1000 AEP. This combined probability reflects the occurrence of two statistically independent events where a severe earthquake occurs at the same time as a severe flood. The combined probability of an earthquake occurring during a flood having the impact depicted in Figure 2 (a 5% AEP levee breach) is probably closer to (1:500 x 1:20) = 1:10,000 AEP.

5.6 Anthropogenic

The levee could be damaged by human actions, such as:

- Sabotage, for example undermining by sappers (unlikely during a flood as the levees are under regular and nearly continuous inspection)
- Vehicle impact on concrete levee walls during a flood (can be prevented/mitigated by the design speeds available and or bollards at key locations, and restricted access); and
- Vehicle impact on flood gates during a flood (can be prevented/mitigated by the design speeds available and or bollards at key locations, and restricted access).

None of the above are likely during a flood as the levees are under regular and nearly continuous inspection. No additional residual risk mitigation measures other than those presented in Flood Levee Failure / Flood Levee Overtopping.

5.7 Flood Levee failure / Overtopping

Flood levees also increase the time available for communities to evacuate from an impending flood. Unless a flood levee is constructed to the PMF level plus uncertainty allowances, levees will ultimately be overtopped.

The decision to use a flood levee as a flood mitigation measure means the community, by default, has accepted that they will live in flood prone land and one day that land, and the homes they live in, will flood. At the time when it does flood, the impact is likely to be major or even catastrophic.

When a flood occurs within a polder, persons are removed from the floodplain to reduce the risk to life or injury and may be undertaken through a compulsory evacuation.

The CoL's current trigger levels for evacuation are set at a predicted flow rate of 2,330 m^3/s in the South Esk River (Section 4.). This corresponds to approximately the peak 5% AEP flow rate expected in 2050. With a reasonable level of confidence, provided the emergency management system operates as intended, it can be assumed that persons would be evacuated from the floodplain at a flow rate of 2,330 m^3/s.

In flood events less than 2,330m^3/s, it is likely that persons may be present within the floodplain. Flood levee breach modelling at the current 5% AEP shows flood hazard categories of H1 and H2 throughout much of the site with H3 hazard categories at locations close the flood levees (Figure 3).

As described in Section 4.3, CoL monitors flood levees prior to and during a flood event. The CoL incident management committee would be established at this point and would be able to rapidly disseminate a message to affected community members.

A flood levee failure will also impact buildings and services in the floodplain resulting in an economic loss. Similar impacts would be experienced for a flood levee overtopping with the magnitude depending on the duration and volume overtopped.

A review of the flood velocity resulting from a flood levee overtopping or failure is generally low and it is expected that a structure or buildings would be constructed to appropriately withstand hydrodynamic flood forces.

Notwithstanding, a flood levee overtopping or flood levee failure will cause hazardous flood water to enter subject site. Any proposed buildings in the floodplain must be constructed from flood compatible materials and be able to withstand flood forces. The following residual risk management measures are required to minimise the economic loss associated with flooding:

As the proposed use will likely exist in the floodplain for many years. It is appropriate to consider the impact a changing climate may have upon the flood levels. It is considered appropriate for this site that the DFE be the 1% AEP 2050 climate change scenario. From the modelling presented by BMT, the 1 AEP flood level in 2050 is expected to be RL 5.04m to which an addition 0.5m freeboard is to be applied.

As Invermay is protected by a flood levee, these standard planning controls do not immediately apply without further interrogation. Therefore, planning and development controls within Invermay should consider the following key facts.

- Land behind the flood levee (within the polder) is not affected by a 1% AEP riverine flood while the levee functions as intended
- Land behind the flood levee is still considered as flood prone land
- At some point in the future, the levee will overtop. Under this scenario evacuation will take place and buildings will be inundated by flood water.

Flood levee breach modelling under the 1% AEP, 2050 scenario suggests peak flood levels within the subject site would be similar to those for a 1% AEP 2050 scenario flood level outside the flood levee. Therefore, from a building resilience point of view, the minimum 'building resilience' level should reflect flood levels outside of the flood levee.

Uses below the minimum 'building resilience' level must not comprise core uses that must be in operation a short period following a flood event. In this context, core uses are defined as those that are essential to the operation of the University.

The following residual risk management measures relating to building resilience and flood damage reduction are proposed.

5.8 Limitation of Educational and Occasional Care

Under the Tasmanian Planning Scheme, the use class *Educational and Occasional Care* is described as use of land for educational or short-term care purposes. Examples include a childcare centre, day respite centre, employment training centre, kindergarten, primary school, secondary school and tertiary institution. Each of these uses has a distinct and varied risk profile associated due to population make-up.

Most tertiary students are unlikely to be reliant on others to retrieve them from the floodplain in the event of an evacuation. The potential reduction in these retrieval trips reduces the strain on the transport system and so facilitates evacuation of others.

As noted above, it is an imperative in a flood response situation to not only evacuate the floodplain but to prohibit others from entering the floodplain. It is foreseeable, if educational use is not restricted to only include tertiary, that the remaining uses listed in the Tasmanian Planning Scheme (childcare centre, day respite centre, employment training centre, kindergarten, primary school and secondary school) will draw other members of the public to the floodplain in the event of an evacuation.

A conservative recommendation is that the educational and ancillary uses are restricted to tertiary.

6. Conclusions and Recommendations

The University is to submit a development application for Building 3 to be located as marked on Figure 1. The building will be for library and student support services and retail flood outlets.

The building will be able to meet the Code provisions are set out in Section E16.7.2 Flood Impact Performance Criteria P3as tabled below.

Planning requirement	Is satisfied by
Buildings not in the Residential use class must be sited and designed in accordance with a hydrological report and an emergency management plan prepared by a suitably qualified engineer. The report and plan must:	This report is presented together with an emergency management plan that is developed in accordance with AS3745-2010.
Detail *The risks to life*	Risks to life are prevented by CoL's flood emergency management plan that prevents entry to the inundation area when peak flows are predicted to reach a nominated threshold. In the event Building 3 is occupied and flood flows in the North Esk reach 2,000 m3/s and are forecast to rise, Building 3 is to be evacuated and occupants are to remove themselves from the Inveresk/Invermay area. In the event a levee breach occurs, occupants are to evacuate to Invermay Road, and thence to Launceston CBD along the route(s) marked on the Evacuation Management Plan
The likely impact on the use or development; and	The Emergency Management Plan must enable the operator to rapidly respond to a flood levee failure event. This plan is to be prepared and will accompany this flood report. The plan should include the establishment of trained flood wardens (akin to Fire Wardens). A response plan should allow for earlier evacuation of disabled or not physically active persons.
How the use or development will manage the risk to tolerable levels during either an overtopping of the levee or a levee breach at the closest point in the levee during a 5% AEP, 2% AEP or a 1% AEP flood event; and	The building will not be affected by stormwater inundation or riverine flooding for floods that do not exceed the 1%AEP threshold. Risks are managed to a level greater than the 1% AEP flood levels and velocities. The Building will not be occupied when flood flows are predicted to reach the threshold nominated in the CoL Emergency Management Plan In the event of a sudden levee breach, Building 3 occupants will need to pass through H1 and H2

Planning requirement	Is satisfied by
the likely velocity and depth of flood waters the need to locate electrical equipment and other fittings above the 1% AEP flood level the likely effect of the use or development on flood characteristics the development and incorporation of evacuation plans into emergency management procedures for the precinct; and the ability of the use or development to withstand flood inundation and debris damage and the necessity for the incorporation of any flood proofing measures in the development.	hazard areas. This is considered an acceptable hazard for pedestrians, even though access to Inveresk will be prevented. Electrical equipment is located on or above first floor level. The building is in the polder area protected by levees of the Launceston Flood Protection Scheme and will not influence flood behaviour. A Flood Emergency Management Plan is presented with this report and aligns with the UTAS Emergency Management Plan. The plan must include an action to suspend regular University activity if a flood threat is imminent until the flood threat has passed. Building 3 is to be constructed of flood resilient materials to 500mm above the 1% AEP flood level as predicted to year 2050. The following forces are to be considered: • Hydrostatic pressure • Hydrodynamic pressure • Impact of debris • Buoyancy forces.
Requirements recommended as part of this report: Local stormwater flooding	The ground floor level is recommended to be 300mm above the 1% AEP local stormwater flooding event that assumes the existing stormwater system fails and gravity drainage to the river system is prevented by riverine flood levels.
Archival and data services	Archival and data service equipment is recommended to be as high as possible within the building. The likely floor level of the upper floor is more than the predicted 1 in 2000 AEP flood level at year 2090.
Earthquake induced failure	The combined probability of an earthquake occurring during a 5% AEP flood (levee breach scenario), is likely to be 1in 10,000 AEP.
Anthropogenic induced failure	Failure caused by sabotage or vehicle impact are considered likely during a flood as the levees are under regular and nearly continuous inspection.
Levee overtopping	The CoL Municipal Emergency Management Plan requires Inveresk to be evacuated and access prevented if peak flood flows (and levels) reach a certain threshold that is less than the levee overtopping threshold.
Limitation of education and occasional care as defined in the Tasmanian Planning scheme	A conservative recommendation is that the educational and ancillary uses are restricted to tertiary. However acceptable educational use should exclude permanent infant, primary and secondary schooling.

7. References

Australian Institute for Disaster Resilience, Australia Disaster Resilience Glossary available at https://knowledge.aidr.org.au/glossary/?wordOfTheDayId=&keywords=&alpha=&page=1&results=50&order=AZ

Ball J, Babister M, Nathan R, Weeks W, Weinmann E, Retallick M, Testoni I, (Editors), 2016, *Australian Rainfall and Runoff: A Guide to Flood Estimation*, Commonwealth of Australia.

BMT (2018), *North and South Esk Rivers Flood Modelling and Mapping Update –Final Report,* November 2018.

Bureau of Meteorology*, Service Level Specification for Flood Forecasting and Warning Services for Tasmania (Version 2.)* is published on the Bureau's website at http://www.bom.gov.au/tas/flood/SLS-2014-15-TAS-signed.pdf

Commonwealth of Australia, Department of the Prime Minister and Cabinet*, Launceston City Deal* 2017

Government of Australia (Australia 2015), *Australian Disaster Resilience Handbook 10: National Emergency Risk Assessment Guidelines, 2015*, Australian Institute for Disaster Resilience, 2015.

Government of Australia (Australia 2017a), Australian Disaster Resilience *Handbook 7 Managing the Floodplain: A Guide to Best Practice in Flood Risk Management in Australia* (2017).

Government of Australia (GoA 2017b*),* Australian Disaster Resilience Handbook Collection, *Guideline 7-3 Flood Hazard* (AIDR 2017).

Government of Australia (Australia 2017c*),* Australian Disaster Resilience Handbook Collection, *Guideline 7-2 Flood Emergency Response Classification of the Floodplain,* 2017.

Midson Traffic Pty Ltd (Midson 2019), *University of Tasmania Inveresk Specific Area Plan Traffic Impact Assessment,* June 2019.

IPCC, 2014: *Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp.

Maqsood T, Wehner M, Mohanty I, Corby N and Edwards M (Maqsood *et al* 2017), Launceston Flood Risk Mitigation – June 2016, Bushfire and Natural Hazards CRC, Melbourne, Australia (October 2017.

Molino. S., Morrison, T., Howard, M., and Opper, S., (2013), *Technical Guideline for SES Timeline Evacuation Model*, 2013.

Risk Register

Appendix A

HB18185 Risk Register

Ratings applicable to SAP Concept area only

Risk ID	Risk statement	Risk source	Hazard	Impact area	Existing controls	Controls strength	Controls expediency	Control effectiveness	AEP	Consequence Level	Likelihood level	Risk Priority	Treatment options	Residual Risk Rating
1	That rain falling directly on the polder area of the SPA Concept area will pond	Severe rainfall	Flood	People	Early warning system Flood information kits Evacuation plan	High	Medium	Medium	> 1% AEP	Mortality Insignificant Injury Insignificant Economy Insignificant Governance Insignificant Social setting Insignificant	Likely	Very low	Building flood levels have freeboard	Very Low
2	That heavy rain in the South Esk and North Esk River catchments will cause flooding	Severe rainfall	Flood	People	LFPS Levees and CoL Operational Plans and MEMP	High	High	High	> 5% AEP	Mortality Insignificant Injury Insignificant Economy Insignificant Governance Insignificant Social setting Insignificant	Unlikely	Low	Evacuation if forecast flow rates exceed the evacuation trigger	Low
3	That heavy rain in the South Esk and North Esk River catchments will cause flooding	Severe rainfall	Flood	People	LFPS Levees and CoL Operational Plans and MEMP	High	High	High	< 2% AEP	Mortality Insignificant Injury Insignificant Economy Insignificant Governance Insignificant Social setting Insignificant	Unlikely	Low	Evacuation and limiting entry to the polder area	Low
4	That heavy rain in the South Esk River and North Esk River catchment will cause flooding	Severe rainfall	Flooding and overtopping levees	People and property	Early warning system Flood information kits Evacuation plan Flood levees	High	Medium	Medium	> 1% AEP	Mortality Minor Injury Minor Economy Moderate Governance Low Social setting Moderate	Rare	High	Increased levee inspections Flood Emergency Management Plan, Communications Flood warning and evacuation	Medium
5	That high flood levels in combination with flood levee failure will cause plodder flooding	Structural failure	Flood	People and property	Early warning system Flood information kits Evacuation plan Flood levees Levee inspection regime	High	Medium	Medium	> 1% AEP	Mortality Minor Injury Minor Economy Moderate Governance Low Social setting Moderate	Very Rare	Medium	Increased levee inspections Flood Emergency Management Plan, Communications Flood warning and evacuation	Low
6	That high flood levels in combination with flood levee failure will cause polder flooding	Piping failure	Flood	People Facilities	Early warning system Flood information kits Evacuation plan Flood levees Levee inspection regime	High	Medium	Medium	< 1% AEP	Mortality Minor Injury Minor Economy Moderate Governance Low Social setting Moderate	Very Rare	Medium	Included cut off walls below levees Increased levee inspections Flood Emergency Management Plan, Communications Flood warning and evacuation Buildings are flood resilient	Low

Risk ID	Risk statement	Risk source	Hazard	Impact area	Existing controls	Controls strength	Controls expediency	Control effectiveness	AEP	Consequence Level	Likelihood level	Risk Priority	Treatment options	Residual Risk Rating
7	That heavy rain in the South Esk and North Esk River catchments will cause flooding	Electrocution	Live PV Solar array	People	A PV solar array may be installed in the future that remains live even though Inveresk power distribution is out of service	Low	Low	Low	> 1% AEP	Mortality High Injury High Economy Moderate Governance Moderate Social setting High	Low	High	Provide electrical isolation above the design flood level.	Medium
8	That high flood levels in combination with flood levee failure will cause polder flooding	River bank sump	Flood	People Facilities	Early warning system Flood information kits Evacuation plan Flood levees Levee inspection regime	High	Medium	Medium	< 1:200 AEP	Mortality Minor Injury Minor Economy Moderate Governance Low Social setting Moderate	Very Rare	Medium	Included cut off walls below levees Increased levee inspections Flood Emergency Management Plan, Communications Flood warning and evacuation Buildings are flood resilient	Low
9	That high flood levels in combination with flood levee failure will cause plodder flooding	Seismic	Flood	People Facilities	Early warning system Flood information kits Evacuation plan Flood levees Levee inspection regime	Medium	Very low	Low	< 1:200 AEP	Mortality Minor Injury Minor Economy Moderate Governance Low Social setting Moderate	Extremely Rare	Low	Included cut off walls below levees Increased levee inspections Flood Emergency Management Plan, Communications Flood warning and evacuation Buildings are flood resilient	Low
10	That high flood levels in combination with flood levee failure will cause plodder flooding	Anthropogenic (Undermining Impact Explosive)	Flood	People Facilities	Early warning system Flood information kits Evacuation plan Flood levees Levee inspection regime Design elements and bollards	Medium	Very low	Low	< 1:200 AEP	Mortality Minor Injury Minor Economy Moderate Governance Low Social setting Moderate	Extremely Rare	Low	Included cut off walls below levees Increased levee inspections Flood Emergency Management Plan, Communications Flood warning and evacuation Design elements and bollards Buildings are flood resilient	Low

Seismic evaluation

Appendix B

pitt&sherry

Launceston Flood Protection Scheme
Factor of Safety Analysis for River Edge

Memo

pitt&sherry
sustainablethinking®

To: Steve Ratcliffe (Launceston City Council, LCC)

From: Andy Turner (**pitt&sherry**)

Date: 15 July 2010

Re: **Stability of Earth Levees during Earthquake Events**
Request for Direction

1. Introduction

Recent design calculations for stability of the flood levee at Scottsdale Levee has shown that the factor of Safety (FoS) during earthquake events is marginal to unacceptable (design FoS = 1.1). The issue is particularly relevant where the soft sediments extend beyond 10m below ground level (eg Charles Street Bridge area).

A discussion was held with Mr S Ratcliffe and Dr O Ingles at which the issue was presented. As no formal conclusion could be reached at the time, we hereby request that Launceston Flood Authority (LFA) provides direction in relation to the stability of the earth levee with respect to earthquake loading.

Several analysis cases are presented to show how the Factor of Safety, which is an indication of the stability, varies for different conditions.

2. Ground Acceleration Coefficient

Council uses the Levee Design Guide and has advised **pitt&sherry** that design for earthquake resistance for a probability of 1:200 years is acceptable for the period immediately following construction of the levee (ie prior to consolidation). In the long term the levees should withstand an earthquake with 1:1000 year probability.

The Levee Design Guide was based on AS1170.4-1993. The Guide states that "*For the purposes of design, the Hazard Factor (Z)… can be taken as 0.06 for the Launceston area. This is equivalent to an acceleration coefficient of 0.06 with an annual exceedance probability of 1/500*".

The current issue of AS1170.4-2007 has changed the acceleration coefficient and hazard factor formula. Formula 8.2(2), the peak ground acceleration for an object mounted on the ground can be calculated from:

$$a_{ground} = K_p Z C_h(0) \qquad (1)$$

Where Z= hazard factor from AS1170.4 Table 3.2 = 0.04 for Launceston
K_p = probability factor (and depends on annual probability) and
$C_h(0)$ is the spectral shape factor for a period of 0 seconds (= 1.1 for soft soils)

Table 1 summarises the acceleration coefficient for various exceedance probabilities used in this memo.

Table 1. Ground acceleration coefficients for Launceston from AS1170.4 - 2007

Annual Exceedance Probability	K_p	a_{ground}
1:200 year	0.7	0.03
1:500 year	1.0	0.04
1:1000 year	1.3	0.06

3. Stability Modelling

The impact of earthquakes on the Factor of Safety (FoS) of an earth levee depends on a number of factors, such as the peak ground acceleration (a_g), the thickness of the soft sediments below the foundation, and the shear strength of the sediments. Two cross sections are presented below which show that deep silt deposits are more susceptible to instability during an earthquake event than shallow deposits.

3.1 Deep Silt Deposits

The cross section at Scottsdale Levee, CH50m is used for the stability assessment with deep silt deposits. At Ch50m, the silts extend to RL -19m. The centreline of the earth levee was modelled 20m behind the existing concrete levee. Geometry and strength of materials are consistent with the models presented in our design reports.

A number of simulation models were run in order to assess the impact of various parameters. The situation of "no levee" is also presented for comparison. The presence of any river edge piles (foreshore protection) and piles under the existing concrete levee has been ignored in the analysis.

The simulation models and the FoS results are summarised in Table 2 for various ground accelerations. Graphical results for a_g = 0.06 are attached.

Table 2. Deep Sediments: Simulation Models and Minimum FoS Results

Simulation Model	Minimum FoS			
	$a_g = 0$	0.03	0.04	0.06
		1:200 yr	1:500 yr	1:1000 yr
1. No levee	1.671	1.314	1.222	1.071
2. Earth levee, no effect of consolidation	1.374	1.086	1.012	0.887
3. Earth levee, no effect of consolidation, river in flood	-	-	-	1.268
4. Earth levee, strength increase under levee (due to consolidation)	1.502	1.187	1.110	0.982
5. Earth levee, strength increase and lime piles to RL -3m	1.503	1.207	1.129	0.999
6. Earth levee, strength increase and lime piles to RL -6m	1.547	1.241	1.164	1.034

Model 3 was included to show that the effect of a flood is to increase the overall FoS during an earthquake event.

To achieve a FoS = 1.1 in Model 2, the required acceleration coefficient is 0.028. This is equivalent to a 1:170 year exceedance probability.

The lime piles were assumed to extend 9m toward the landside of the levee, to force the circle with minimum FoS through the levee. The undrained shear strength of the lime piles was assumed to be c_u = 70kPa, which is a 4-fold increase in strength of the silt (70kPa/16kPa). A 5-fold increase has been reported following lime pile trials by Ingles (May 1991). An undrained shear strength of 70kPa was adopted for the earth levee and existing fill.

The 1:1000 year event has FoS's that are less than the design value in all models (except Model 3), while the 1:500 and 1:200 year events are generally at or above the design value.

The common factor in the location of the calculated slip circles is their large radius: passing from the rear of the levee, almost to the base of the soft sediments (at RL -19m) and terminating in the middle of the river. This leads to 3 observations:

i) The slip is so large it would be challenging and very expensive, to design and implement mitigation measures to increase the FoS to the design value. Models 5 and 6 show how the FoS increases only marginally by installing lime piles 3m and 6m, respectively, into the silt.

ii) Moving the levee further away from the river will improve the overall FoS. The proposed levee centreline is about 40m from the river edge. However, physical constraints (ie Lindsay St) prevent greater offset.

iii) The FoS will increase as the thickness of the soft sediments decreases. At CH300m, the base of the soft sediments is at RL -5m and the levee centreline is about 45m from the river edge. The FoS results, presented in section 3.2, are generally > 2. Thus, the area around Charles Street bridge is particularly susceptible to earthquake induced slip failures.

Although the lime pile option presented above provides an acceptable FoS up to $a_g = 0.04$, it is based on the assumption that the silt is amenable to lime treatment and that a uniform c_u of at least 70kPa can be achieved.

To increase the FoS for Model 6 (and $a_g = 0.06$) to above 1.1, an undrained shear strength of at least 90kPa is required for the lime stabilised silt. This represents a 5-fold increase in undrained shear strength of the silt (90kPa/16kPa).

Other options, such as the use of light weight fill, stone columns, deep soil mixing or other ground improvement techniques, have not been investigated at this stage. Deep mixing of the soil with cement will make it possible to ensure a more homogeneous strength increase in the silt.

The order of cost for undertaking the strengthening works is likely to be in the range of $500,000 to achieve the design for FoS for a 1:1000 year event.

3.2 Shallow Silt Deposits

To show the effect of shallow silt deposits, stability analyses were carried out using the cross section at Scottsdale Levee CH300m. At this location, the silt deposits extend to RL -5m and are underlain by stiff clay (c_u = 35kPa) to RL -10m. The presence of any river edge piles (foreshore protection) has been ignored in the analysis.

Selected models were analysed. The models have been numbered to remain consistent with those reported in Table 2:

- Model 1, no levee.
- Model 2, earth levee with no effect of consolidation (ie short term).
- Model 4, earth levee with strength increase (ie long-term).

Graphical results for $a_g = 0.06$ are attached.

Table 3. Shallow Sediments: Simulation Models and Minimum FoS Results

Simulation Model	Minimum FoS	
	a_g = 0.03	**0.06**
	1:200yr	1:1000yr
1. No levee	2.06	1.77
2. Earth levee, no effect of consolidation	2.35	1.89
4. Earth levee, strength increase under levee due to consolidation	2.46	2.00

The FoS for each model and ground acceleration is greater than the design value. Thus, an earth levee constructed on sediments that extend to RL -5m has an acceptable FoS during a 1:1000 year earthquake event (a_g = 0.06).

4. Discussion

The following quote is taken from Fell et al (2005, p 484): "*Earthquake intensity is a qualitative value based on the response of people and objects to the earthquake. The intensity depends on distance from the earthquake, ground conditions and topography, so there will be a range of intensity values for any earthquake. The most commonly used scale is the modified Mercalli Scale..*".

For design of structures, the acceleration induced by the earthquake is usually required. Such information is best obtained from actual measurements of acceleration. In the absence of such information, we have obtained an approximate correlation between ground acceleration, Richter Scale and the modified Mercalli equivalent (www.geography-site.co.uk/pages/physical/earth/richt.hmtl), which is attached.

Thus, a ground acceleration a_g of about 0.05 (the 1:1000yr event), corresponds to an earthquake event of Richter magnitude 5.4. The effects of such an event are that trees sway, it is felt by all, some walk unsteadily and there is some damage from overturning and falling objects (books off shelves, pictures off walls).

Similarly, an event with ground acceleration, a_g, of about 0.02 (a 1:85yr event), corresponds to an earthquake of Richter magnitude 4.8. The effects of such an event are that sleepers awake, liquids are disturbed, small unstable objects are displaced or upset, doors swing or close or open and pendulum clocks stop or start or change rate.

5. Conclusion

The present Levee Design Guide recommends that the minimum FoS under earthquake conditions is 1.1 for a 1:500 year exceedance probability, while LFA has advised that in the long term the levees should withstand an earthquake with 1:1000 year probability.

The FoS of the existing riverbank is variable and may be less than the design value: 1.07 at Ch50m without a levee, and 1.77 at Ch300m without a levee.

The FoS of the proposed earth levee depends to a large extent on the thickness of sediments below the foundation. It is likely that an acceptable FoS exists for (soft) sediments that extend to RL -10m. Table 4 summarises the exceedance probability for the two depths of sediments modelled such that FoS is greater than 1.1.

Table 4. Annual Exceedance Probability for FoS > 1.1 at Analysed Cross Sections

Scenario	Shallow Sediments Silt RL = -5m	Deep Sediments Silt RL = -19m
No levee	>1:1000	1:500
Levee – soon after construction	>1:1000	<1:200
Levee – long term strength increase due to consolidation	>1:1000	1:500
Levee – long term with ground improvement	>1:1000	>1:1000

Where sediments extend beyond RL -10m, ground improvement is required to achieve a FoS greater than 1.1 for the proposed levee for a 1:1000 year earthquake event. No ground improvement is required for a 1:500 year event after the silts have consolidated.

In the unlikely occurrence of a 1:1000 year earthquake during a flood event, the presence of the flood water would increase the FoS (to 1.27), rather than lowering it.

The installation of ground improvement works is likely to be in the order of $500,000 for a 200m long section.

Based on the above conclusions, it is recommended that consideration is given to revise the Levee Design Guide for earth levee construction with respect to earthquake loads as follows:

Table 5. Annual Exceedance Probability for New Earth Levees

Scenario	**Exceedance Probability**	a_{ground}
Levee – immediately after construction	1:170	0.026
Levee – long term with strength increase due to consolidation	1:500	0.04
Levee during a flood	1:1000	0.06

The exceedance probability immediately after construction is close to 1:200 years. The actual FoS calculated would depend on the geometry of the riverbank as well as the depth of sediments.

Due to the long drainage paths (half the sediment thickness), we estimate that the undrained shear strength in the area with 18m of soft sediments, will increase sufficiently after 15 years to withstand a 1:200 year earthquake event. The actual time may be less, if there are sand layers that shorten the drainage path and increase the consolidation rate.

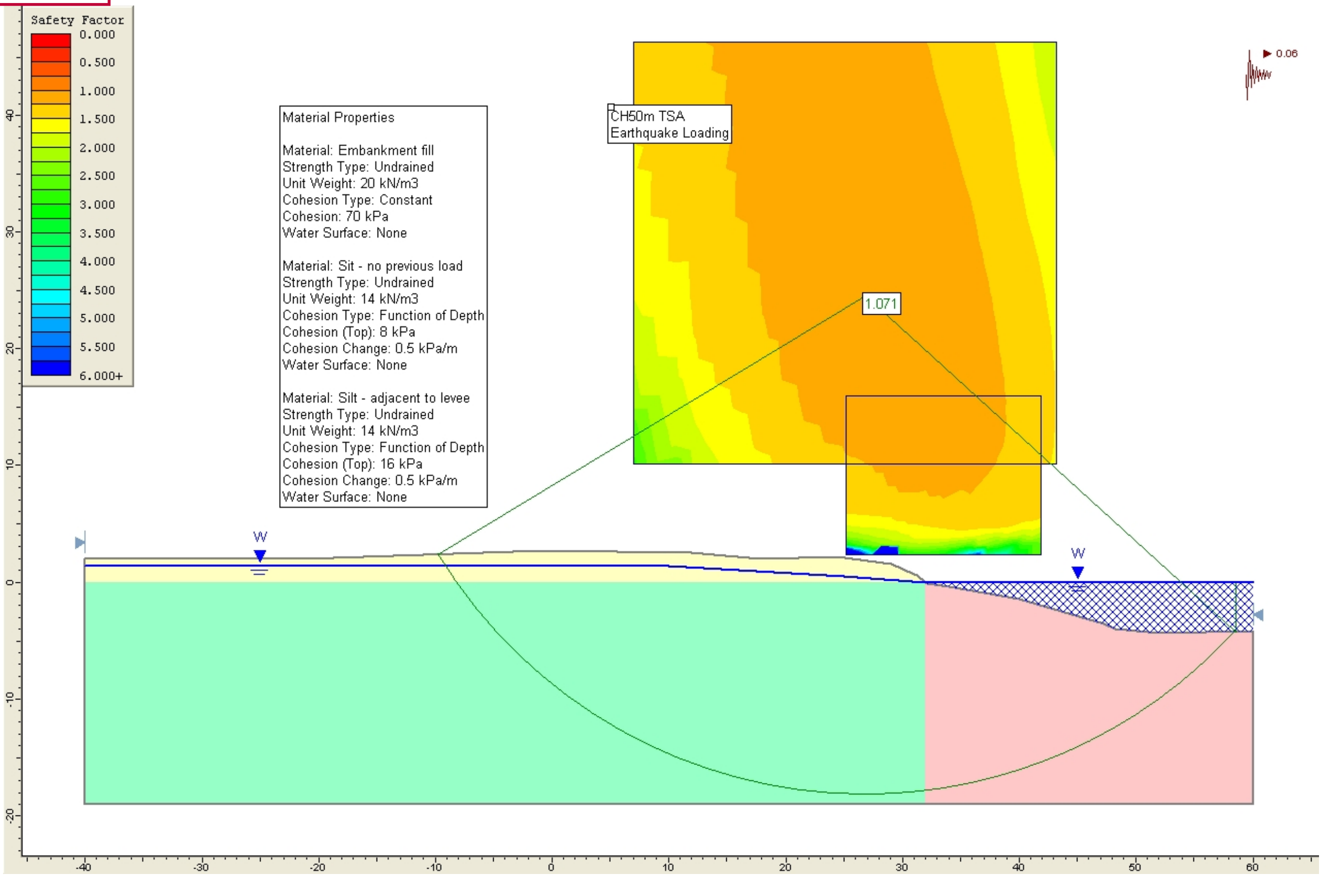
The combined likelihood of a 1:500 year earthquake at the same time as a 1:100 year or 1:200 year flood is very low (1:50,000 to 1:100,000).

Prepared by

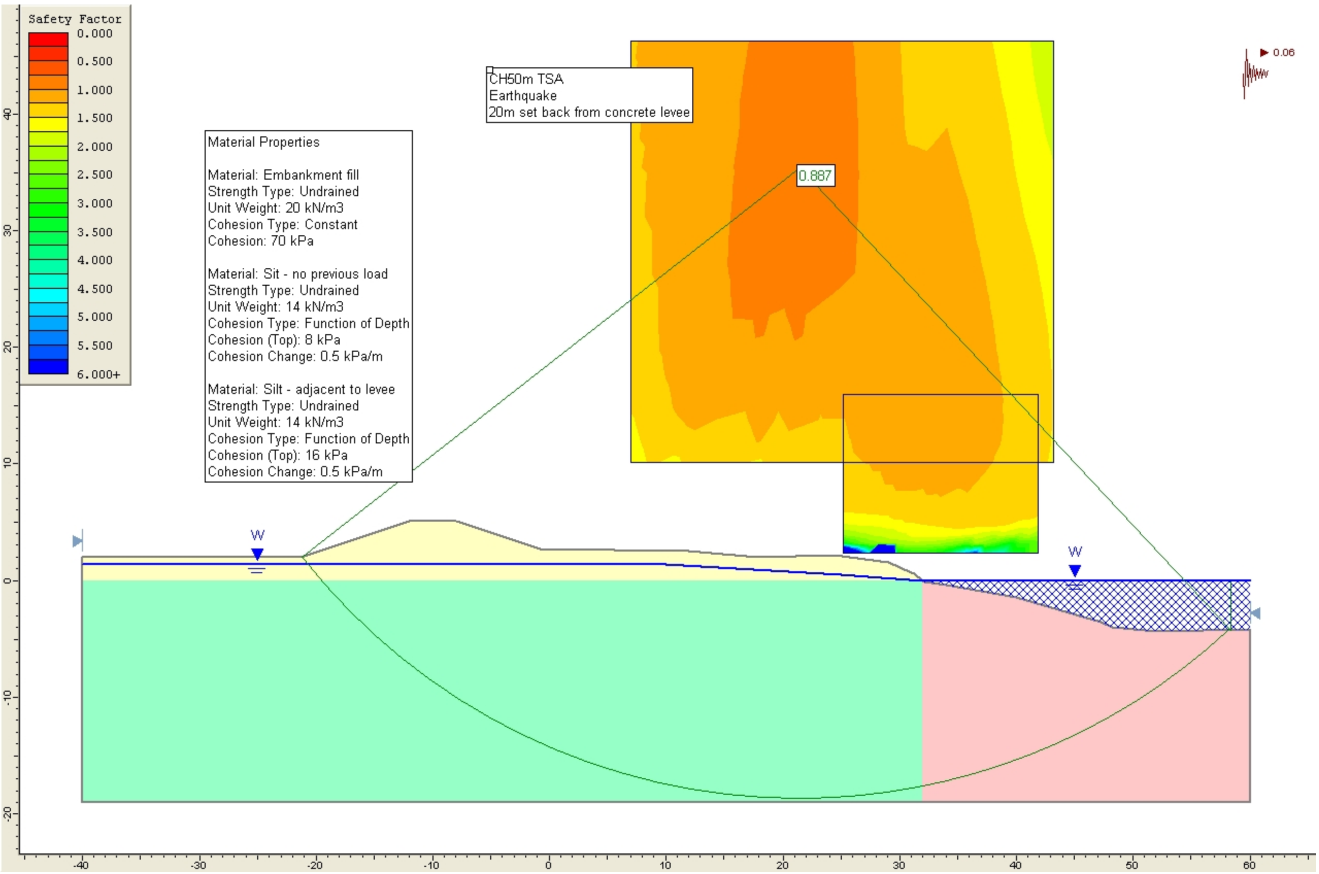
Wayne Griffioen
pitt&sherry

Attachments: Graphical stability outputs (4 pages)
Comparison between Richter Scale, Ground Acceleration and Modified Mercalli intensity (1 page)

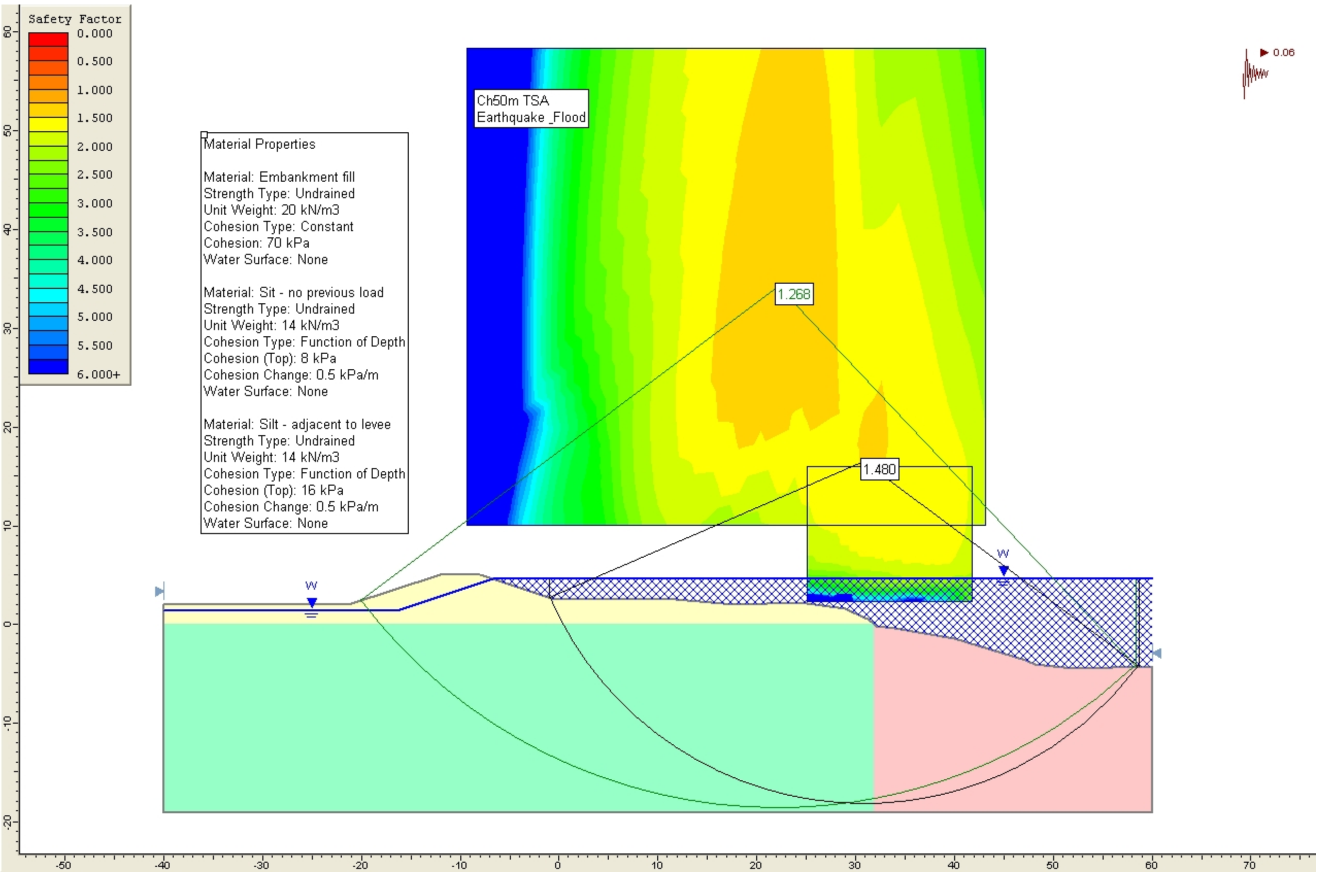
sustainablethinking®



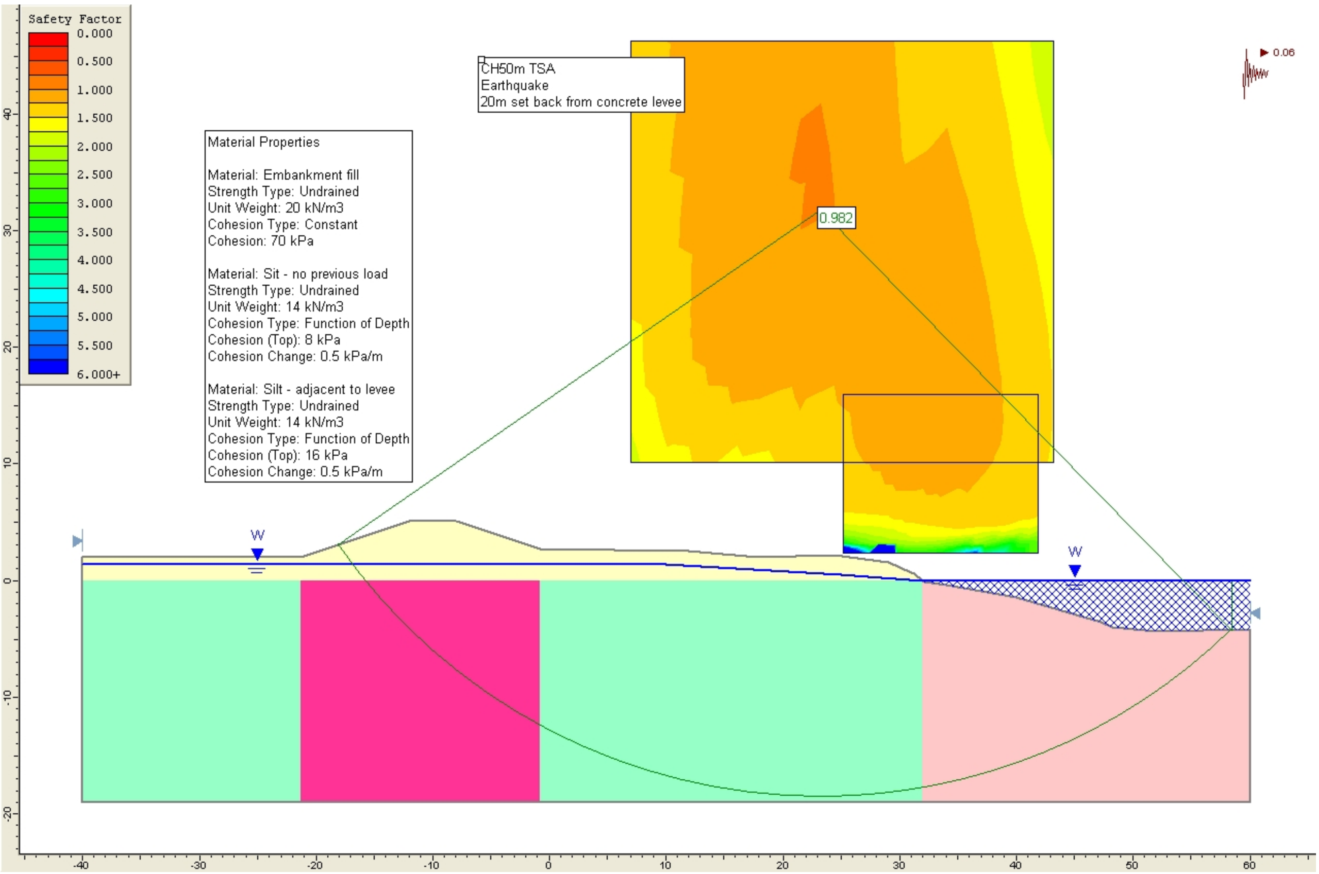
Deep Silt Model 1. No levee



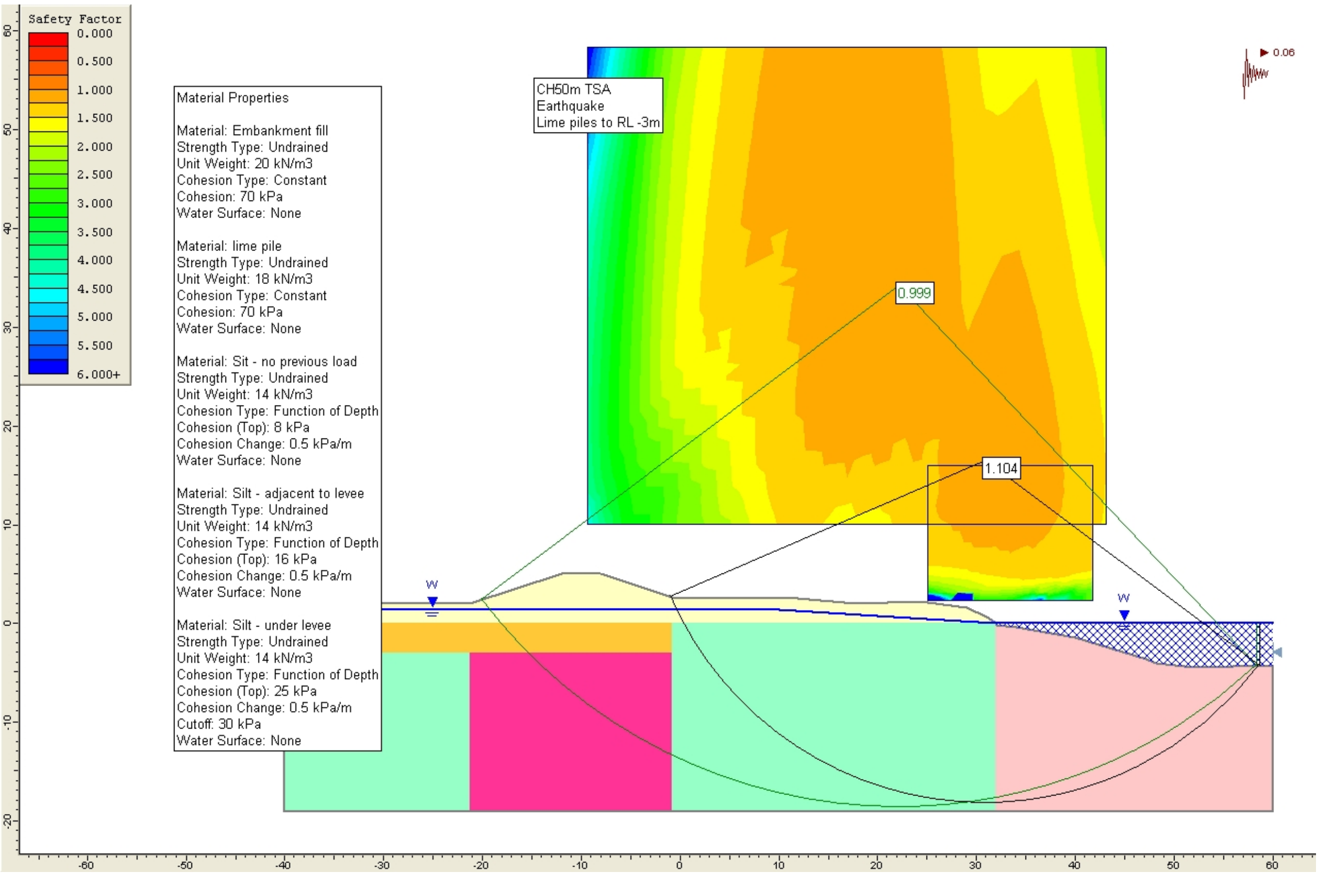
Deep Silt Model 2. Earth levee, no effect of consolidation



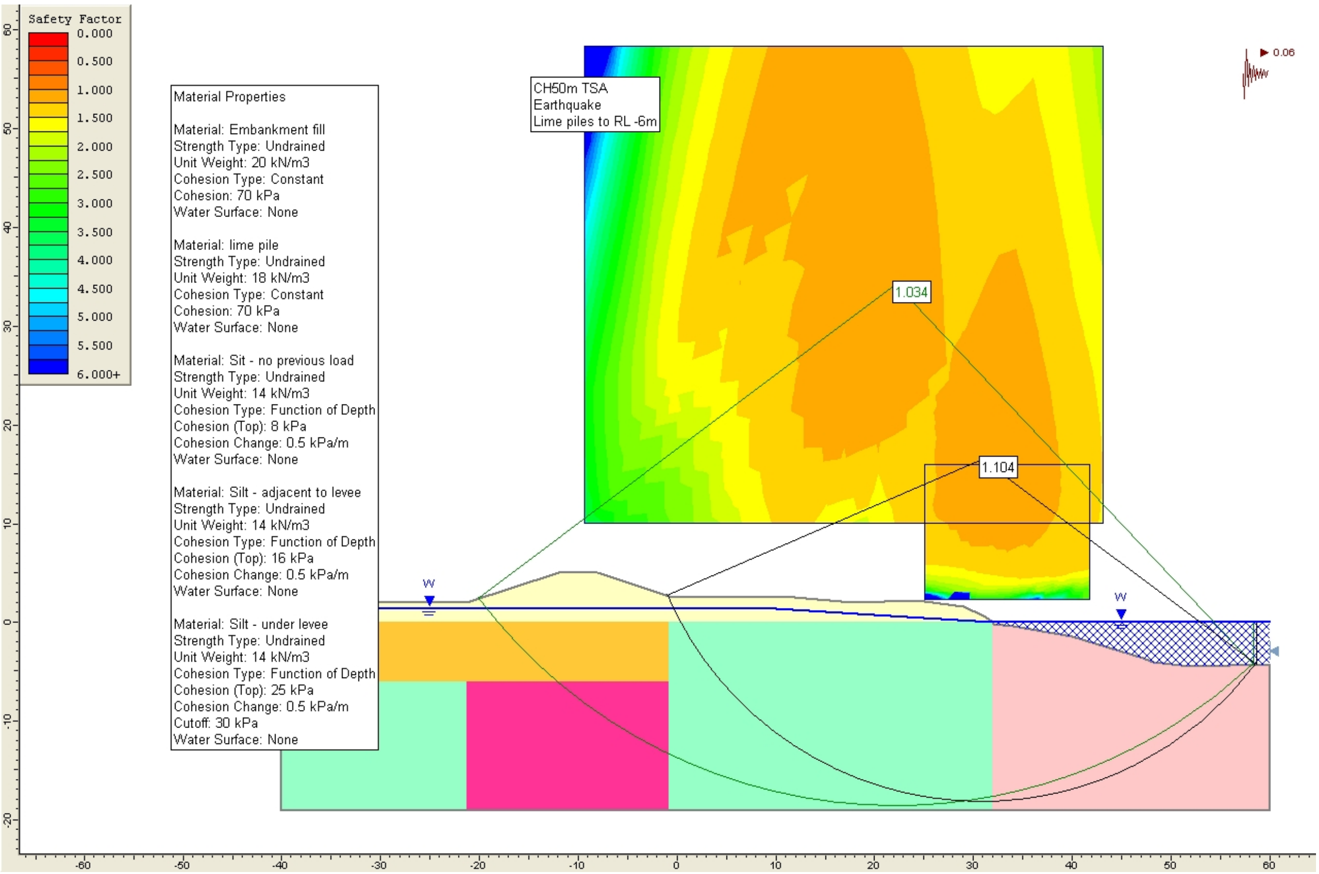
Deep Silt Model 3. Earth levee, no effect of consolidation and river in flood



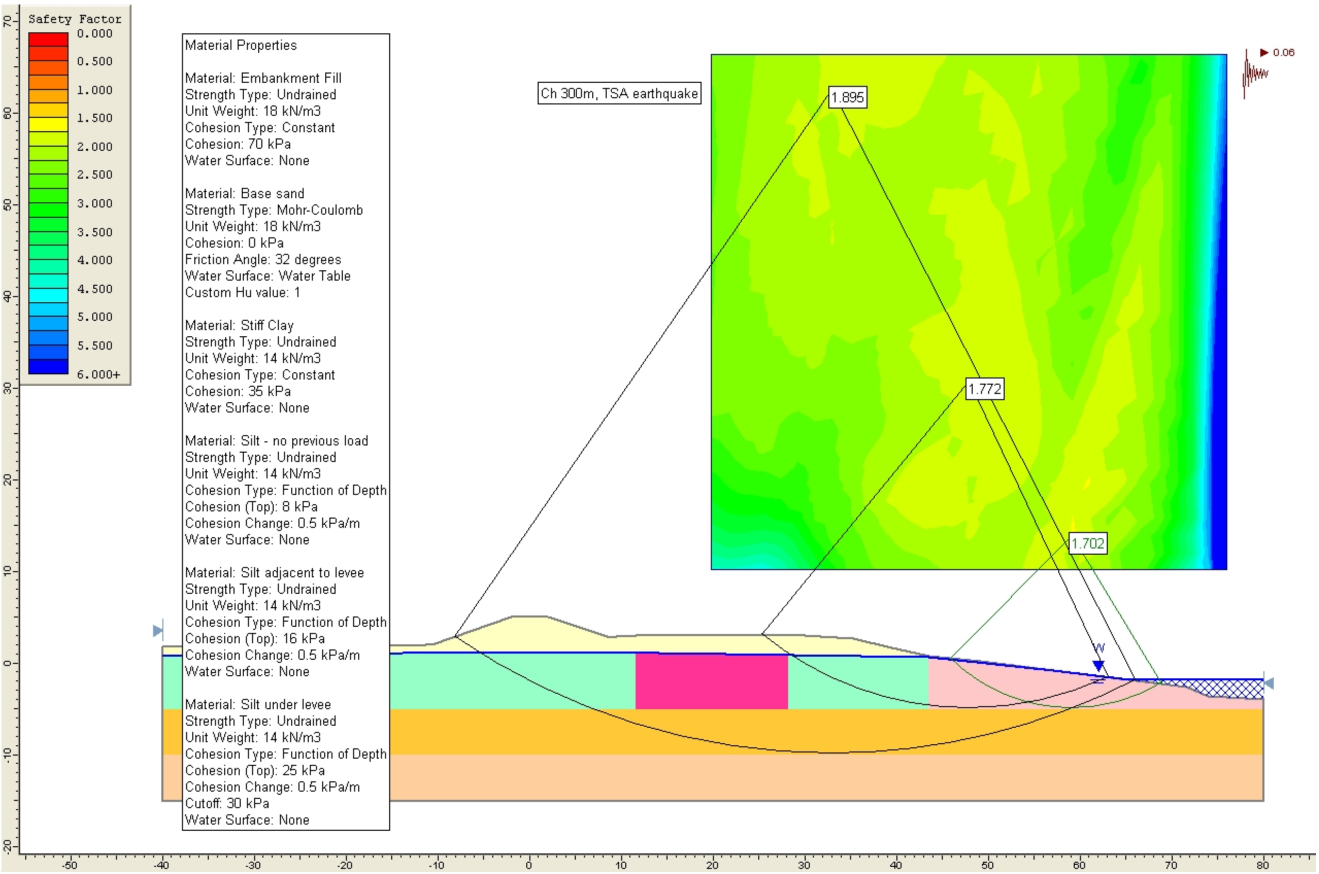
Deep Silt Model 4. Earth levee, strength increase under levee



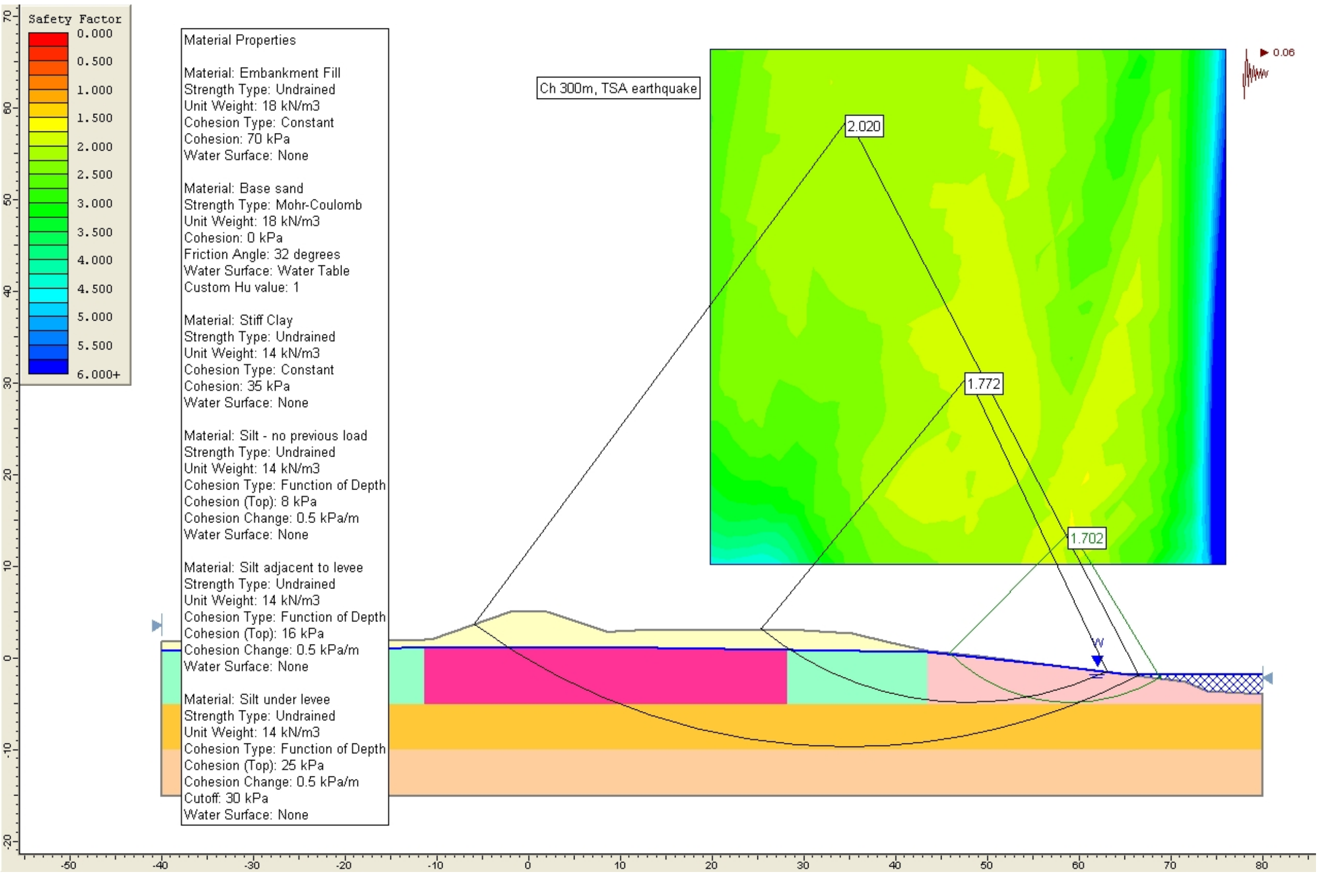
Deep Silt Model 5. Earth levee, strength increase under levee and lime piles to RL -3m



Deep Silt Model 6. Earth levee, strength increase under levee and lime piles to RL -6m



Shallow Silt Model 2. Earth levee, no effect of consolidation



Shallow Silt Model 4. Earth levee, strength increase under levee

Modified Mercalli Scale

Richter Scale	Approximate Acceleration, a_g	Approximate Mercalli equivalent	Effects
<3.5	<0.001	I	Not felt
3.5	0.002	II	Felt by persons at rest, on upper floors or favourably placed.
4.2		III	Felt indoors. Hanging objects swing. Vibration like passing of light trucks. May not be recognised as earthquake.
4.5	0.01	IV	Hanging objects swing. Vibration felt like passing of heavy trucks. Stadning cars rock. Windows, dishes, doors rattle. Crockery clashes.
4.8	0.02	V	Felt outdoors. Duration estimated. Sleepers wakened. Lkiquid disturbed, some spilled. Small unstable objects displaced or upset. Doors swing, close, open. Shutters, pictures move. Pendulum clocks stop, start, change rate.
5.4	0.05	VI	Felt by all. Many frightened and run outdoors. People walk unsteadily. Windows, dishes, glassware broken. Knickknacks, books etc off shelves. Pictures off walls. Furniture moved or overturned. Weak plaster cracked. Trees, bushes shaken.
6.1	0.10	VII	Difficult to stand. Noticed by drivers of cars. Hanging objects quiver. Furniture broken. Damage to poor quality masonry. Weak chimneys broken at roof line. Some cracks in ordinary quality masonry work. Waves in ponds. Small slides and caving along sand or gravel banks. Fall of plaster, loose bricks, stones and tiles.
6.5		VIII	Steering of cars affected. Damage to ordinary quality masonry, partial collapse. Twisting, fall of chimneys, factory stacks, monuments, towers, elevated tanks. Branches broken from trees. Cracks in wet ground and on steep slopes.
6.9	0.25	IX	General panic. Low quality masonry destroyed. Ordinary quality masonry heavily damaged, sometimes with complete collapse. Serious damage to reservoirs. Underground pipes broken. Conspicuous cracks in ground. In alluvial areas sand and mud ejected, earthquake fountains, sand craters.
7.3	0.51	X	Most masonry and frame structures destroyed with their foundations. Serious damage to dams, dikes, embankments. Large landslides. Water thrown on banks of canals, river, lakes etc. Rails bent slightly.
8.1	0.76	XI	Rails bent greatly. Underground pipelines completely out of service.
>8.1	1	XII	Damage nearly total. Large rock masses displaced. Lines of sight and level distorted. Objects thrown into the air.

UTAS Inveresk Development

Building 3 flood study report

Contact

Haydn Betts
6210 1400
hbetts@pittsh.com.au

Pitt & Sherry (Operations) Pty Ltd
ABN 67 140 184 309

Phone 1300 748 874
info@pittsh.com.au
pittsh.com.au

Located nationally —
Melbourne
Sydney
Brisbane
Hobart
Launceston
Newcastle
Devonport
Wagga Wagga