UPPER SOUTH ISLAND RELIABILITY STAGE 1

ATTACHMENT E
ISLINGTON SUBSTATION HILP EVENT STUDY

Transpower New Zealand Limited

May 2012

Keeping the energy flowing

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Executive summary

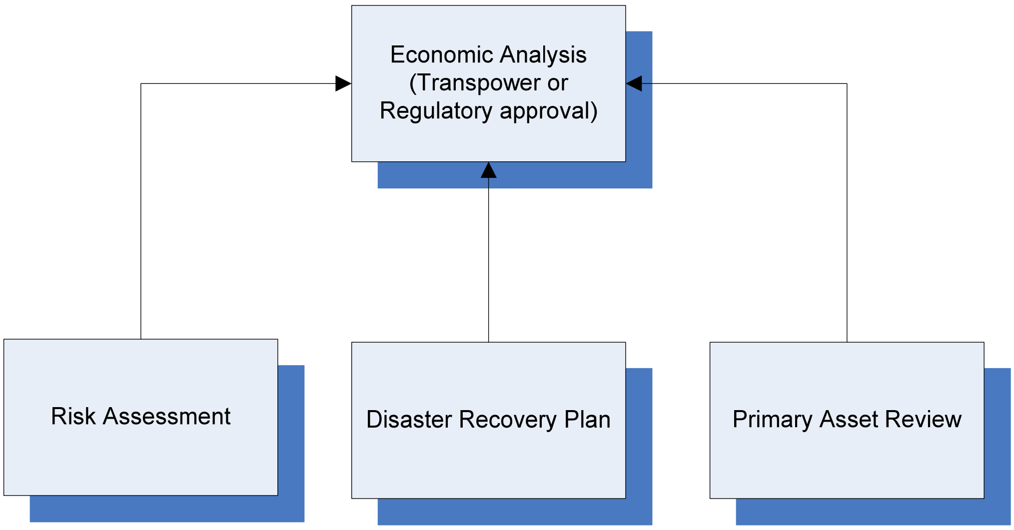
This report presents the findings of a High Impact Low Probability (HILP) event study for the Islington (ISL) substation site. The study identified HILP risks, proposed mitigations, and made recommendations to carry out works or to progress further investigations. The recommended works will quantifiably improve ISL site reliability.

The study aims to bring together a number of various independent reports (see Figure 1) that look at HILP exposure from different perspectives. While this study could not be considered to be a fully exhaustive risk analysis, it has significantly improved our understanding of the major HILP related issues at Islington.

This report includes summaries and recommendations from the following sources:

- A report that assesses the Islington site from an insurance perspective for such events as earthquake, flood, fire etc. This report will be used to ascertain the return period for the various identified HILP exposures (carried out by Marsh Insurance).
- Seismic assessment reports of the various buildings on the ISL site that ties into the insurance review, namely at the control, condenser and oil filter/compressor buildings to understand if they are designed to meet our current essential building design standards (Opus Consulting).
- A power system disaster recovery plan should certain major outage events occur. This report will be used to indicate, at a high level, the time it may take for the emergency restoration of supply (at reduced security for an extended period) using temporary towers or re-locatable spare transformers for example. This analysis is used to give some indication of lost load implications for the HILP events in question (TLM Consulting).
- A primary asset and control room assessment. This report investigates such things as maintenance issues in the switchyard itself, transformer proximity and fire risk, control building fire risk and high voltage cable issues (Transpower).
- Preliminary economic analysis to demonstrate that the mitigation measures of the highest risk HILP exposures are economic (Transpower).

Summary Figure 1: HILP framework



Islington substation – a key site in the New Zealand power system

Islington substation is considered to be one the key substation sites in the New Zealand power system. It is a large 220 kV/66 kV/33 kV/ 11 kV substation; one of the top 5 sites in terms of asset value[1] and the 6th in terms of incoming transmission line capacity. This is a strategically important site not only in terms of supply to Christchurch but also to North Canterbury, Nelson/Marlborough and the West Coast of the South Island.

The Upper South Island peak demand which includes the aforementioned regions is predicted to be approximately 1200MW in 2011 rising to 1450MW by 2021[2]. All of this demand is serviced either directly or indirectly by the Islington substation site (see Figure 1).

Marsh Insurance reports

Marsh Insurance was engaged to carry out a study of the ISL site HILP event exposure to such things as earthquakes, floods and fires for example, and estimate event probabilities (the return periods) based on international insurance data.

Marsh used a quantitative analysis to firstly ascertain probable HILP events of interest, then used a qualitative analysis to estimate asset vulnerability and the mechanisms of this vulnerability. Marsh then used internationally available data for such events to estimate event probabilities.

It was concluded that a clear risk involves a fire and fire spread in the Control Building and surrounds. With a 265 year return period[3] for such events and the clear lack of fire detection and suppression strategy at such a key site, this was identified as a high risk HILP exposure.

The Marsh analysis also suggests that site flood and earthquake exposures may also be prevalent, with mitigation measures requiring further investigation. However, regarding site earthquake exposure, Marsh concluded with the following:

"Certainly not only has the ISL equipment proved very resilient to events since September 2010 but similar installations at Bromley exposed to very much higher (severe) forces during the February event also sustained limited damage.[4]"

Finally, Marsh identified that site water pressure may be an issue if any significant fire fighting duties were necessary. This issue is presently being investigated.

Opus Seismic Reports

As part of an ongoing program of work, we are conducting reviews of all suspect or potentially vulnerable site building assets in order to assess whether they, firstly comply with the Building Act 2004, and secondly, our seismic policy.

The Opus Seismic reports identified that the ISL site Control and Condenser buildings are not up to the required 75% New Building Standard (NBS) required by our policy and in fact appear to be well short of this. This is a clear risk as the Control Building in particular is a difficult to replace asset at a key site.

Mitigations necessary to bring the ISL Control and Condenser Building up to 75% NBS have also been costed at $1.4m. It is still undecided whether the Condenser building will remain on site and this is presently being investigated.

TLM reports

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[1] From the Marsh Insurance Islington Substation Property Underwriting Report 2008.

[2] From the Transpower 2011 Annual Planning Report.

[3] When presenting risk data like this, the return period relates to the probabilistic exposure to risk at that site, based on accumulated historical data for similar sites.

[4] The conclusions from the Opus report (discussed in Section 5) illustrate that, despite the ISL site being relatively unscathed by recent events, the control and condenser buildings are still a major earthquake related HILP exposure.

We engaged TLM Consulting to identify lost load implications and time to restore supply at a high level, should a catastrophic loss of switchyard or control building occur. This may involve temporary site transmission line re-configurations, temporary equipment installations, and an indication of the power restoration capabilities and staging.

On the basis of the estimated TLM report Stage 1 restoration period alone, it appears that all of the fire detection and mitigation options discussed by Marsh are economic to implement.

Asset Risk Review

A preliminary site inspection was carried out by our staff to identify potential causes of high impact events. This was a visual inspection and did not include a formal review of the design or asset condition. However the review included input reporting from an asset condition report prepared by the maintenance contractor, and a risk survey undertaken by ELMAC.

A number of issues were identified that need to be investigated further with appropriate mitigations put in place. The main items of relevance are:

- Risk associated with the cable basement generally;
- Risk associated with the 110 V dc, 48 V dc and 24 V dc power supplies located in the cable basement;
- Risk associated with the 415 V local service system, and the switchboard in the cable basement; and
- Risk of damage to critically important cables in cable trenches close to the main control block building.

Economic Analysis

The preliminary economic analysis was carried out internally and has demonstrated that the HILP events with the greatest potential for disruption, namely control building fire events, site wide flood and earthquake damage events all generate substantial enough HILP event reliability benefits to justify mitigation measures.

In the case of the control building fire mitigation, the analysis demonstrates that all of the fire mitigation options identified by Marsh are economic to implement.

The earthquake mitigation measures by Opus, to bring the control and condenser buildings up to our 75% NBS standard, are also economic to implement.

While we need to confirm what standard the ISL switchyard equipment has been designed to, equipment resilience to recent earthquake events indicate that it is likely that the Islington switchyard has substantial earthquake mitigation measures already in place.

Additionally the Bromley substation site has been largely undamaged since the Christchurch earthquake sequence began, and this site was located in one of the worst affected regions in Christchurch; we can take some significant comfort that its switchyard earthquake design standards are effective.

The HILP economic analysis indicates that the implementation of flood mitigation measures, particularly in the cable basement is a reasonable expenditure given the relatively low return period for such events noted in the Marsh report.

Study recommendations

In summary it is recommended that the following planned works and further investigations are carried out:

Further investigate whether flood mitigation measures are necessary at the Islington site. This may require a report to discuss the impact of various water levels at the site and perhaps lead to the removal of some key equipment from the cable basement. This area would likely become inundated even for a low level flood event. Preliminary economic analysis suggests that there may be value in pursuing mitigations for this type of event;

Upon commissioning of the upgraded LVAC system as per the SSR option 3 investigate re-locating the 110 V dc, 48 V dc and 24 V dc power supplies presently located in the cable basement. There are two issues here. The first is the fire risk and the second is that if there was a significant flood event, the cable basement may be partially submerged. This could mean the loss of these power supplies and subsequent ability of the control room to function.

Investigate the cost and design of a re-configurable mobile control and protection unit for use at other substation sites, should a HILP event remove a substation control building from service for any significant length of time.

1| Purpose

The objectives of this investigation are to:

- Identify potential HILP risk at the Islington substation site;
- Identify potential HILP risk mitigation measures at the Islington substation site;
- Carry out economic analysis to ascertain if the identified mitigations are justified.

This report contains a lot of detail regarding the analysis framework. It is proposed that this framework be used as a template to carry out HILP studies at other major substation sites in our network.

2| Attachments

A number of external and internal reports are used in this HILP study and these are noted below:

Appendix A – ISL HILP Study (Marsh Insurance 16 Jun 2011)

Appendix B – ISL Fire Protection (Marsh Insurance 4 Aug 2011)

Appendix C – Initial Seismic Assessment Report – Islington Control, Condenser and Oil Filter/Compressor Buildings (Opus Consulting 2011)

Appendix D – Detailed Seismic Assessment Report – Islington substation (Opus Consulting Aug 2011)

Appendix E – ISL SVIP Seismic Hazard Assessment (Maunsell Consulting May 2004)

Appendix F – ISL Disaster Recovery Plan (TLM Consulting Jun 2009)

Appendix G – ISL Control Room Fire Recovery Plan (TLM Consulting Aug 2011)

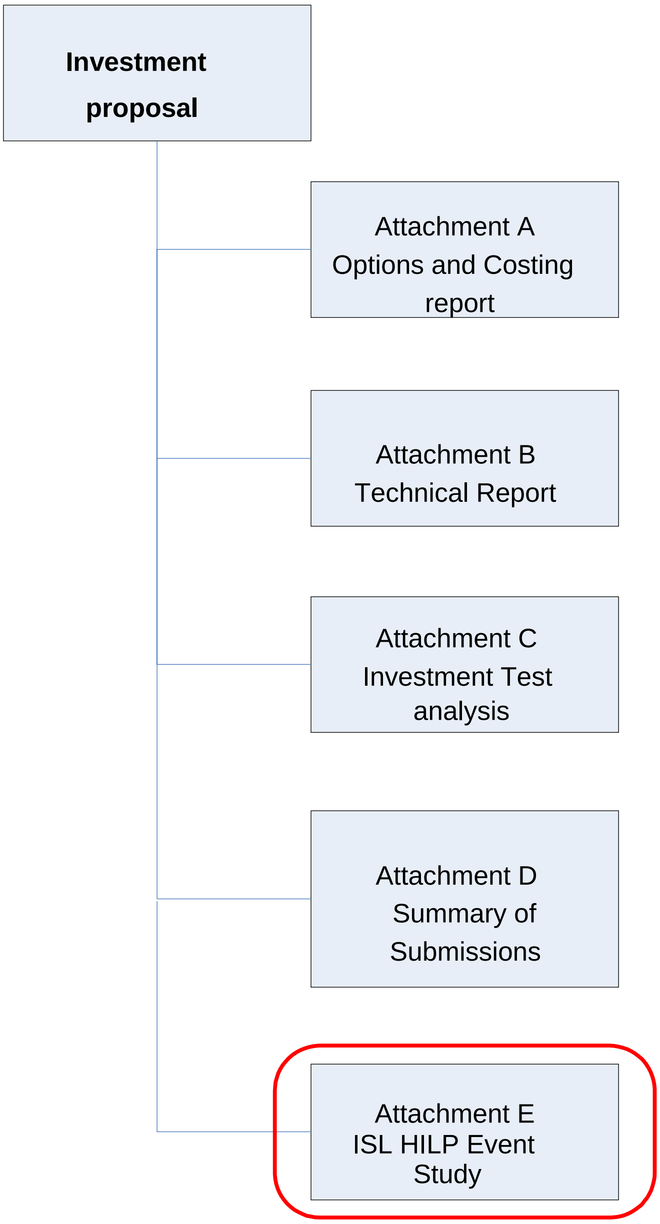
Appendix H – ISL Substation LVAC Upgrade Options Report

Appendix I – Preliminary Economic Analysis

3| Introduction

3.1 Document Structure

This report forms part of the Upper South Island Reliability Investment Proposal, as set out in the diagram below:

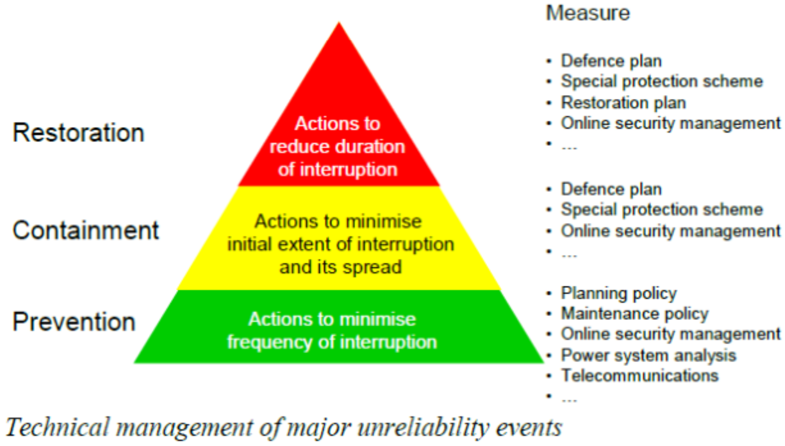


3.2 Background

Exposure to High Impact Low Probability (HILP) events has been discussed for many years at Transpower and at other transmission asset owners overseas.

The recent CIGRE brochure 433: “Planning to Manage Power interruption Events” by Working Group C1.17 in October 2010, discusses some industry thinking around this issue of HILP and its mitigation. The general strategic approach is summarised in Figure 3.1 below, reproduced from the CIGRE report.

Figure 3-1: CIGRE Brochure 433 view of generalised power system HILP strategy



With reference to Figure 3.1, HILP strategies are generally approached by firstly understanding the HILP events you may be exposed to. Once you understand these then the engineer can design relevant mitigations to reduce, and manage exposure to the extent practicable.

All HILP events can never be fully protected against, but sometimes there are some very cost effective means to reduce exposure and permit rapid supply restoration, if certain HILP events were to occur.

There are many instances of HILP mitigations already in place in the New Zealand power system such as the substation switchyard earthquake mitigation designs; Automatic Under-Frequency Load Shed (AUFLS) blocks to defend against frequency collapse events; and the HVDC runback facility for N-2, N-3 and N-4 AC transmission equipment outage events. These are well known HILP mitigations that have been implemented as necessity to maintain power system stability and asset integrity.

To date it has generally been considered problematic to quantify substation risk exposure and then use this to economically justify mitigations prior to event occurrence at key sites. Seismic mitigations are carried out as a matter of policy and sometimes fire deluge systems have been installed for high value transformers (such as the DC converter transformers).

Sometimes HILP mitigations are carried out after significant events often because they are so difficult to predict. The Otahuhu June 2006 overhead earth wire (OHEW) incident is an example of a *post-facto* HILP analysis, which was used to assist in the justification of an additional GIS substation at the Otahuhu site. This June 2006 incident where the substation OHEW failed and landed on the 110kV buswork caused a large outage in the Auckland region. This event was considered to be a 1-in-100 year event and estimated to have a lost load cost of $100m.

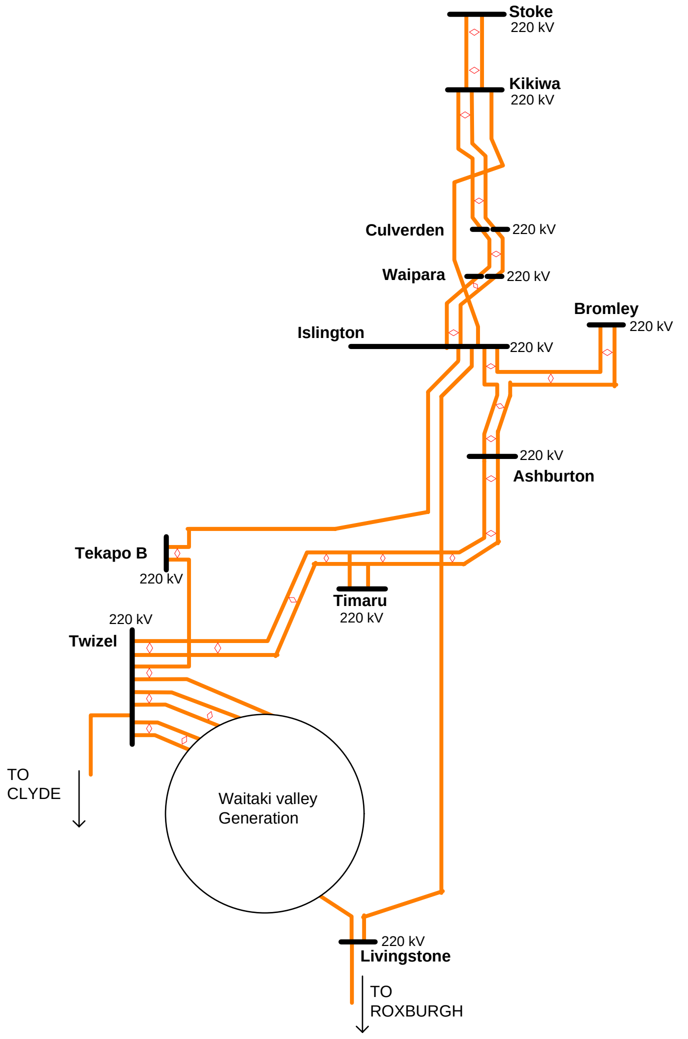
In general, a strategy of implementing HILP mitigations only after significant events have occurred should be avoided as a matter of policy.

3.3 Islington substation

Islington substation is considered to be one the key substation sites in the New Zealand power system. It is a large 220 kV/66 kV/33 kV/ 11 kV substation; one of the top 5 sites in terms of asset value[5] and the 6th in terms of incoming transmission line capacity. This is a strategically important site not only in terms of supply to Christchurch but also to North Canterbury, Nelson/Marlborough and the West Coast of the South Island.

The Upper South Island peak demand which includes the aforementioned regions is predicted to be approximately 1200MW in 2011 rising to 1450MW by 2021[6]. All of this demand is serviced either directly or indirectly by Islington.

Figure 3-2: The Upper South Island (USI) transmission 220 kV network from the Waitaki Valley and Livingstone north as at April 2011



3.4 Scope of the investigation

Included in the scope

This study aims to bring together a number of various independent reports (see Figure 3.3) that look at HILP exposure from different perspectives. While this study could not be considered to be a fully exhaustive risk analysis, it should provide some degree of

[5] From the Marsh Insurance Islington Substation Property Underwriting Report 2008.

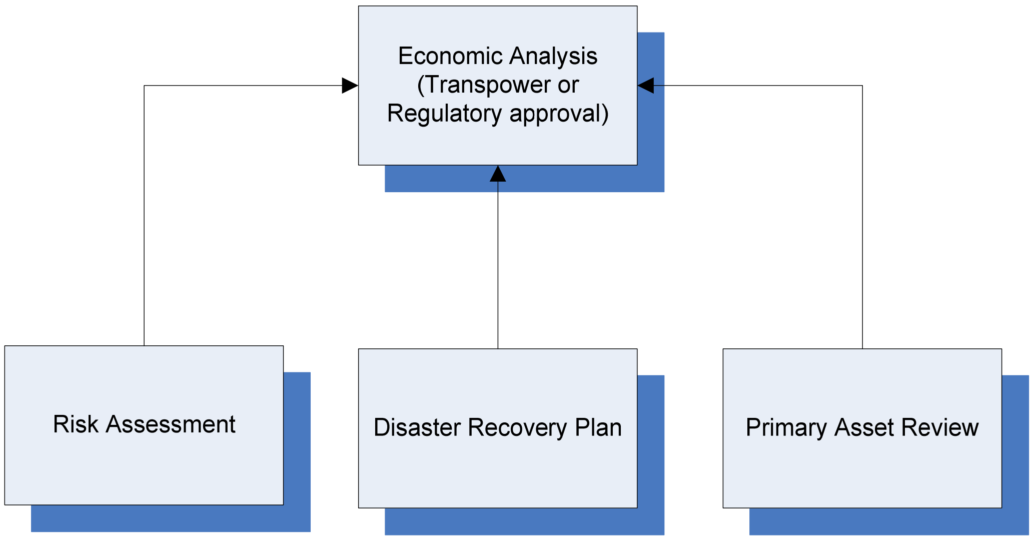
[6] From the Transpower 2011 Annual Planning Report.

reasonable confidence to Transpower that it understands the major HILP related issues at Islington.

This report includes summaries and recommendations from the following sources:

- A report that assesses the Islington site from an insurance perspective for such events as earthquake, flood, fire etc. This report will be used to ascertain the return period for the various identified HILP exposures.
- Seismic assessment reports of the various buildings on the ISL site that ties into the insurance review, namely at the control, condenser and oil filter/compressor buildings to understand if they are designed to meet our current essential building design standards.
- A power system disaster recovery plan should certain major outage events occur. This report indicates, at a high level, the time it may take for the emergency restoration of supply (at reduced security for an extended period) using temporary towers or re-locatable spare transformers for example. This analysis is used to give some indication of lost load implications for the HILP events in question.
- A primary asset and control room assessment. This report investigates such things as issues during maintenance in the switchyard itself, any issues with such things as transformer proximity and fire risk, control building fire risk, high voltage cable issues etc.
- Economic analysis to demonstrate if the mitigation measures of the highest risk HILP exposures are economic to implement.

Figure 3-3: The proposed HILP framework



Excluded from scope

The investigation does not consider the following:

Switchyard busbar or asset arrangement. It will be assumed that the ISL buswork, now and in the future, will be consistent with the current Grid Reliability Standards (GRS)[7] in that a bus section fault is classed as a *single credible contingent event* and does not result in any lost load and that the power system remains in a satisfactory operational state following the event.

[7] Electricity Industry Participation Code (EIPC) 2010 Part 12 Clauses 12.55 to 12.58 and Schedule 12.2

Diversity. This study is not about the justification for diversification of assets away from the ISL site itself. Fully geographic substation diversification of existing substation sites is unlikely to be justified on HILP based reliability benefits alone. It is more likely that diversification, unless decreed to be based on some deterministic standard (which is not supported in the present investment rules framework), will be based on such inputs as local lines company investment costs being higher than if the diversification didn't proceed, another GXP was to accept large load growth or perhaps that voltage stability equipment was more efficiently placed elsewhere.

3.5 Outline of the document

In this report:

Chapter 4 discusses the analytical approach and some key findings of two reports carried out by Marsh, an insurance company who specialise in infrastructure based insurance assessments. The first report is concerned with the ISL site wide exposure to HILP events and the second, more specifically investigates the fire risk in and around the ISL control building.

Chapter 5 discusses recent Opus Consulting reports regarding the earthquake resilience of the ISL site control, condenser and oil/compressor buildings, along with some predicted mitigation costs to bring these up to the Transpower standard for essential buildings.

Chapter 6 discusses two Disaster Recovery Reports carried out by TLM Consulting, the first related to the loss of the ISL switchyard itself and the second to do with the loss of the ISL control building. Loss of load implications and time to restore estimates are made in these reports.

Chapter 7 presents our internal review of issues surrounding the ISL switchyard primary assets and control room. This review was carried out to identify easily rectifiable issues that may be prevalent during maintenance or for such things as control and HV cables in close proximity that, in the event of an HV cable issue may result in control or protection outages.

Chapter 8 then presents preliminary economic analysis carried out to ascertain whether identified mitigations defined in the external reports may be economic.

Chapter 9 outlines the main recommendations from this study.

4| Marsh reports

4.1 Introduction

Marsh Insurance was engaged to carry out a study of the ISL site HILP event exposure to such things as earthquakes, floods and fires for example, and estimate event probabilities (the return periods) based on international insurance data.

The useful aspect of looking at HILP risk from an insurance perspective is that the insurance industry generally has access to extensive data for damage related events to large scale infrastructure, such as substations.

With this data, insurance companies perform actuarial studies to identify risk profiles for assets to set insurance premiums. It is the event probabilities that this study is most interested in as in conjunction with the Disaster Recovery Reports from TLM Consulting; an indication of lost load costs on an annualised basis may be determined. The avoidance of these lost load costs can then be balanced against the capital cost of any identified mitigation measures.

Two reports were commissioned with the second commissioned after the findings of the first. The main findings and key comments from each are summarised in the following sections. The two March reports were:

- Islington HILP Study – 16 June 2011
- Islington Fire Protection Study – 4 August 2011

4.2 Islington HILP Study – 16 June 2011

4.2.1 ISL site qualitative analysis

Marsh investigated the following probable HILP initiating events of interest at the ISL substation site and made the following qualitative assessment of each (Table 4.1).

Table 4-1: Marsh initial qualitative HILP exposure analysis

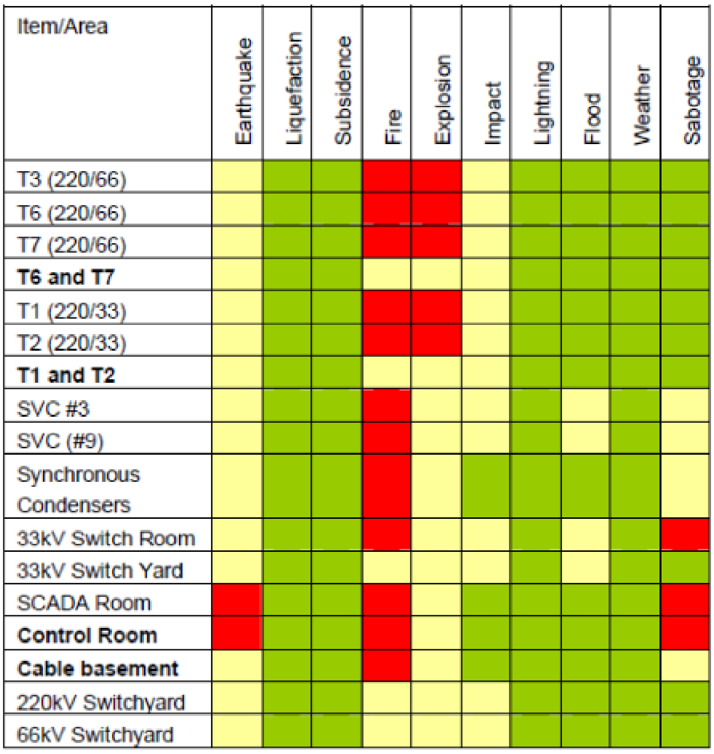
Event	Risk	Existing mitigation measures
Earthquake	MCE of MM 8.62. Soft deep soils in Christchurch can cause an amplification effect of up to +1MM.	Bracing and anchoring of equipment in accordance with Transpower's Seismic Design policy and standards. Main control building and condenser buildings reviewed by Opus (2008). Initial review noted further investigation required.
Liquefaction	Potential exists however no evidence of significant liquefaction in February event.	No mitigation identified in UIR.
Subsidence	Potential exists however no evidence of significant subsidence in February event.	No mitigation identified in UIR.
Tsunami	No credible exposure.	Not applicable.
Volcanic Activity	No credible exposure.	Not applicable.
Bush Fire	No credible exposure.	Not applicable.
Fire	Potential for electrical fires, transformer oil fires, condenser oil fires and building fires.	Non or low combustible construction. Limited fuel loads (except transformer oil). Separation by distance and construction. CO2 gas flooding of condensers. Thermal detection

	Workshop operations.	and smoke detection including aspirating detection. Tank water supplies and street hydrants.
Explosion	Potential for explosive transformer failure.	None identified in UIR
Impact	In proximity to Christchurch International Airport (4.3km) but not on normal flight path for descent and ascent stages. However still some potential for off path impact from commercial aircraft or light aircraft. No credible potential for road impact.	No mitigation identified in UIR. Flat, exposed area so no protection from surrounding landforms or structures.
Flood	Moderate flood risk. Potential for low likelihood (1 in 500 year) event from Waimakariri River.	None identified in UIR
Lightning	Modest risk (5 thunder days per year).	Lightning protection installed on site.
Windstorm (tornado)	Potential exists. No reported damage in life of station.	No mitigation identified in UIR.
Snow loading	Potential exists. No reported damage in life of station.	Not covered in UIR.
Sabotage	Potential exists. No reported damage in life of station.	Not covered in UIR.
3rd Party Exposures	No significant risk from neighbouring activities. Potential for sabotage or malicious action.	Frequently (but not permanently) manned. Site access through one gate (proximity reader and PIN). Building entry by proximity reader and PIN and key lock. Intruder alarms (PIR) inside buildings.

Note: UIR refers to the 2008 Marsh Underwriting Insurance Report for the Islington site

The Marsh analysis then extended the qualitative assessment to assess asset vulnerability to the events that were considered to be most relevant to the ISL site. Green indicates low vulnerability, yellow moderate vulnerability and red indicates high vulnerability. The assets considered to have the highest HILP exposures were bolded (Table 4.2).

Table 4-2: Marsh view of ISL asset HILP vulnerability



Marsh then defined what it considered to be the most likely High Impact scenarios and the potential mechanisms of each:

Simultaneous loss of T6 and T7

A. Pool fire in one transformer spreading to the other.

B. Explosive failure in one transformer damaging the neighbouring transformer

Simultaneous loss of T1 and T2[8]

A. Pool fire in one transformer spreading to the other.

B. Explosive failure in one transformer damaging the neighbouring transformer

Fire causing loss of the control room

A. Fire in the control room spreading through the room.

B. Fire in the control room producing large smoke volumes and damaging equipment

C. Fire in a neighbouring area spreading into the control room.

D. Fire in a neighbouring area spreading smoke into the control room.

[8] The firewall between T1 and T2 is to be installed by the end of 2011.

Fire causing destruction of the cable basement

A. Fire in the cable basement spreading through the area.

Site wide event

A. Severe earthquake damaging (partial or full collapse) control room building or damaging multiple field equipment items leading to an HI event.

B. Large aircraft impact on site with physical damage and fire.

C. Severe flood on site causing water damage and direct physical impact damage to equipment on site.

D. Severe weather event (windstorm or snowstorm) leading to destruction of multiple equipment items on site.

E. Destructive tornado event leading to destruction of multiple equipment items on site.

F. Sabotage (e.g. destruction of equipment, fire starting)

Using the Risk Matrix from the ISO 31000 Risk Management Standard, Marsh then summarised the most likely High Impact events with critical and catastrophic consequences, which were to be carried through to the quantitative analysis. These are summarised in Table 4.3.

Table 4-3: Marsh HILP event risk ranking after quantitative analysis

Event	Likelihood	Consequences	Risk
Spreading Transformer Fire Event	1 (remote)	5 (critical)	Moderate
Control Building Fire Event	3 (unlikely)	6 (catastrophic)	Severe
Severe Earthquake	1 (remote)	6 (catastrophic)	High
Volcanic	No credible risk		
Aircraft impact	1 (remote)	6 (catastrophic)	High
Severe Flood	2 (highly unlikely)	5 (critical)	Moderate
Wind Storm	4 (possible)	3 (serious)	Moderate
Snow Storm	3 (unlikely)	2 (moderate)	Moderate
Tornado	1 (remote)	6 (catastrophic)	High
Sabotage	1 (remote)	5 (critical)	Moderate

ISL site quantitative analysis summary

Marsh then used international data for events such as transformer fires (from other transmission asset owners and agencies worldwide such as the IEEE, Statnett, UKAEA and CIGRE) and fire risk data from Electric Power Research Institute[9] (EPRI) to estimate the High Impact event probabilities. These are summarised in Table 4.4.

[9] Data from the EPRI report TR-1000370, Fire Induced Vulnerability Evaluation

Table 4-4: Marsh quantitative analysis HILP event return periods

Event	Expected Probability [yr^{-1}]	Return Period [years]
Fire spread involving T1 and T2	0.00004	25,000
Fire spread involving T6 and T7	<0.00001	>100,000
Transformer Fire Spread Event	*0.00005*	*20,000*
Control Room Fire	0.0016	625
Equipment Room Fire	0.0010	1,000
Communications Room Fire	0.00005	20,000
Cable Gallery Fire	0.00032	3,125
Other area fire	0.0008	1,250
Any Major Control Building Fire (assuming all fires have HI potential)	*0.00377*	*265*
Any Major Control Building Fire (assuming 10% of fires have HI potential)	*0.000377*	*2,650*
Earthquake	0.0001	10,000
Aircraft Impact	0.000003	330,000
Severe Flood	0.0002	5,000
Severe Wind Storm (Tornado)	4×10^{-7}	>2,000,000
Sabotage	0.00013	7,700
Any HILP Event	***0.0043***	***230***

Site wide events – Earthquake resilience

A number of site wide events were assessed using the quantitative analysis. Particular attention was given to earthquake risk considering that the Canterbury region has experienced significant recent earthquake activity.

Despite this though, and since the 4 September 2010 Magnitude 7.1 earthquake (the Darfield earthquake), there has been no significant damage to Transpower assets in the region or at the ISL site since. Regarding the ISL site itself this is possibly due to the implementation of Transpower seismic design standards for substation switchyards over the years.

The Marsh HILP report analysed the earthquake exposure issue in considerable depth (Section 4 pg 19-29) and some interesting observations were made:

"Analysis of all recordings (main and aftershocks) from 4 September 2010 to 30 April 2011 reveals:

- *Within a 30 km radius of the Islington site there have been over 200 earthquakes with a magnitude greater than MW 4 and < 15 km deep.*
- *Within a 10 km radius of the Islington site there have been 56 earthquakes with a magnitude greater than MW 4 and < 15 km deep.*
- *Within a 2.5 km radius of the Islington site there have been only 13 earthquakes with a magnitude greater than MW 2 and < 15 km deep. It is notable that none of the earthquakes close to the site have been greater than MW 3.5. The earthquake centred closest to the site was the 6 September event which was located 1.07 km to the north.*

From the above it is evident that the Islington site has experienced the effects of a large number of earthquakes in the period since early September 2010. While no site specific ground acceleration or shaking intensity data is available it is likely (using data from nearby monitoring stations and the February event map overleaf) that the site may have experienced PGA's of about 0.5g (H) and 0.15g (V) in the September event and about 0.3g (H) and 0.14g (V) in the February event with shaking intensities of possibly MM 7.5+.

The site has sustained remarkably little damage and only minor service disruption."

Marsh concluded that the majority of the damage sustained in Christchurch from the recent earthquake sequence, particularly the 22 February 2011 earthquake (considered to be an aftershock) was due to:

"...the deep and soft alluvial structures that are a feature of the Canterbury Plains and Christchurch urban area. This combined with a relatively high water table and some of the 'unique' effects of the February event in particular, have resulted in amplified ground shaking and sometimes extreme liquefaction events."

The examination of the ISL site geology concluded that there was little risk of liquefaction there and that since the September earthquake none had been observed. However as with much of the Christchurch urban area the site was still classed as Zone 3 with sediment levels at the ISL site between 50-800m deep. This means that there is still potential for "amplification of base level ground shaking intensity"[10].

However Marsh concluded with the following:

"Certainly not only has the ISL equipment proved very resilient to events since September 2010 but similar installations at Bromley exposed to very much higher (severe) forces during the February event also sustained limited damage."

Marsh further conclude that, despite the recent earthquakes and considerable damage evident in the region, that the site risk of an earthquake event causing site wide damage had a return period of 10,000 years[11].

Finally, one issue that has warranted further investigation in this HILP study (and has been the focus of an ongoing program of investigations) has been the ISL control and condenser buildings and their resilience to earthquake events. This issue will be discussed in more depth in Section 6 and Section 8.

This issue surrounding the Canterbury region earthquake exposure return period is still being investigated as the recent earthquake sequence has yet to end. However what can be said is that the preliminary economic analysis in Section 8 will demonstrate that even with a 1 in 10,000 site wide event probability with 10% of those leading to the site buildings being significantly damaged, the building earthquake mitigation costs identified by Opus will be justifiable.

Other site wide events

Other site wide event possibilities were also analysed such as severe weather events (a tornado for example), volcanic activity and aircraft impact. However, the conclusion was that the return periods were so large that they would not lead to any significant HILP benefits in the economic analysis to support any mitigations.

The one exception may be flood exposure though, with a return period of 5,000 years. Marsh reproduced a diagram (Figure 17 page 34) from the "Christchurch Engineering Lifelines Project 1994" which shows that in the event of a severe flood of the Waimakariri River, that the ISL site was predicted to be on the edge of what is termed the inundation zone.

[10] The conclusions from the Opus report (discussed in Section 5) illustrate that, despite the ISL site being relatively unscathed by recent events, the control and condenser buildings are still a major earthquake related HILP exposure.

[11] When presenting risk data like this, the return period relates to the probabilistic exposure to risk at that site, based on accumulated historical data for similar sites.

However Marsh concluded that flood risk may only be critical if flood levels exceeded 1 metre, and that Transpower substations have not been critically damaged for flood events up to this level, quoting the Melling flood event in October 2008.

Despite this though high level economic suggests (see Section 8) that there may be some value in considering flood event mitigations at ISL, especially for the high value hard to quickly replace assets the Outdoor Junction Boxes (ODJB's), and the AC and DC power supplies located in the cable entry basement[12].

Transformer fire events

The Marsh report determined that two transformer fire spread events warranted a quantitative analysis, namely fire spread between units T6 and T7, and between T1 and T2.

T6 and T7 are 220/66/11kV units with continuous ratings of 250MVA and 200MVA respectively. T7 comprises single phase units while T6 is a three phase unit. The T6 11kV winding is connected to the soon to be decommissioned synchronous condensers which is likely to be replaced at some stage by either a STATCOM or SVC device. They both supply the 66kV load along with another 220/66/11 kV unit T3.

For events such as the spreading of transformer fires between the T6 and T7 units, Marsh concluded that these units were sufficiently spaced apart (20-25 metres) to render the risk of a catastrophic fire spreading almost negligible (a return period of greater than 100,000 years). The assumption was made that even if the wind direction meant fire spread was more likely, that Fire Service intervention to permit cooling of the unaffected transformer was possible.

Table 4-5: Marsh quantitative T6/T7 fire spread analysis results

Event	Expected Probability [yr^{-1}]	Return Period [years]
Fire in T6 or T7	0.002 (0.001 per Tx)	500
Potential Spread to T7	<0.0001	>10,000
Damage to T7	<0.00001	>100,000

T1 and T2 are 220/33kV three phase units with continuous ratings of 100MVA. Marsh concluded that the risk of fire spreading between the T1 and T2 was again considered negligible due to the impending fire wall installation between the units by the end of 2011. It was assumed in the Marsh analysis that this fire wall will be suitably rated for such an event.

Table 4-6: Marsh quantitative T1/T2 fire spread analysis results

Event	Expected Probability [yr^{-1}]	Return Period [years]
Fire in T1 or T2	0.002	500
Fire spread to neighbour	0.00004	25,000

With these very large return periods it is considered that further mitigations for transformer fire spread events are unlikely to generate any significant HILP reliability benefits. However one issue that will be discussed later in this report regards the site water supply and whether this is suitable for enable the Fire Service to carry out fire spread avoidance.

Control building fire event

What is immediately noticeable from the Marsh quantitative analysis is the low return period for fire events particularly in the ISL control room building and other areas of the ISL

[12] The cable basement elevation is to be checked as an aspect of the assessment of whether these should be moved due to fire and flood damage risk.

substation building spreading to other areas. This was considered to be a clearly identified risk.

On page 16 of the Marsh HILP report it notes that:

"Critical areas of the Control Building, ie; Cable Basement, Relay/Protection Room and Communications Room are fully exposed (no-adequate FFR[13] *or suppression) to fire risk presented by non-essential areas such as utility areas of the building and the Transformer Workshop (leased to TP contractor for this purpose). Exposure includes fuels such as transformer oils and other in drums in the workshop (transformers are supposedly drained before being taken into the building) and external fire exposure risk from transformer oil tanks outside the building."*

Further Marsh state on page 17 that

"Overall fire detection / alarm philosophy of ISL control/condenser building based on early detection and manual intervention, i.e.; designed when site was attended 24/7. No recognition of changing requirements when site de-manned. ***ISL as a highly strategic site lacks the fire suppression / controls now being introduced to other critical sites****; notably Haywards and Benmore HVDC."*

Basically the conclusion from the Marsh HILP report is that the fire detection and suppression within the ISL Control and Condenser buildings is less than desirable for such a strategic site. Given the low return period for such events (estimated at 265 years[14] for any control building fire event) this is an issue that warrants further investigation with a likely conclusion that mitigation measures need to be put in place[15].

This conclusion also resulted in Transpower commissioning an extension to the existing ISL site Disaster Recovery Plan report by TLM Consulting to assess the impact of actually losing part or all of the ISL control building. This study was to be used to attempt to place some boundaries on the prospective lost load implications for such an event.

Marsh also highlighted another site issue involving the fire risk and that was the provision of water supply to fight any major incidents. On pages 17 and 18 the following was observed:

"Historically the site had a yard hydrant system, large water storage reservoir and fire pump. Hydrants were removed (in line with all sites) and the pump removed some years ago. Status of reservoir appears to be that it is not maintained. Site now relies on a single hydrant point off city main located inside the main gate/near control building. This is via a assumed 100mm connection to the 150mm main in Moffet Street. There is also a 150mm main and public hydrant's in Roberts Road at the opposite (north) end of the site.

NZFS has no flow information. Test flows (visual only) at the single on site hydrant in past year indicate marginal flow/pressure available. This means hose runs of about 100m from on site hydrant, > 200m from Moffet Street and over 300m from Roberts Street to 'reach' general area of transformers with marginal/unknown

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[13] FFR - Fire Fighting Response

[14] From the Marsh HILP report. Underlying risk of this event is taken as 0.0095 (based on EPRI data). A nominal 95% probability of successful detection is assumed (based upon conventional smoke detection biased to high performance given context). Assumes a 40% probability of rapid response (personnel on site) with a 95% success rate, and an 80% probability of fire brigade being able to mount a successful operation.

[15] As the economic analysis in Section 8 demonstrates, even if 10% of these events proved to be catastrophic events (a 1 in 2650 year return period), all of the mitigation options discussed by Marsh are likely to be economic propositions.

delivery. If tanks/pumps installed for any suggested suppression system; size to include (say) a hose/header arrangement to provide adequate fire fighting water."

There are some serious issues noted in this passage from the report.

Fire fighting capability for any major fire incident on the ISL site may not be possible at all, or at best, marginal.

On the basis of these Marsh report conclusions a second report was commissioned to look at this issue more closely and provide Transpower with some recommendations. This report is discussed in the next section.

4.3 Islington Fire Protection Study – 4 August 2011

On the basis of the June 2011 Marsh HILP report conclusions, a second more focussed fire protection report was commissioned. This report was to build on the earlier HILP work and tasked with specifically looking at the following:

- Develop fire protection concept design options for the control building,
- Consider protection of and against a fire in the adjoining condenser crane hall building, with costs and options detailed.
- Develop detailed budget estimates for design alternatives
- Select preferred approach from alternatives based upon costs and benefits.
- Develop performance specification for preferred option at a level of detail suitable for competitive tender of the required work.

Early conclusions from Marsh included that:

- Fire separation between areas is generally incomplete with concrete walls but no formal fire doors or doors which have been sealed by dry-wall construction.
- Doors generally on closures but latching of these not always correct.
- Doors are solid core but not tagged as fire rated doors.
- Service/cable penetrations would also require sealing in some locations.
- Some potential for exposure through windows to the control building. Including building to building from the condenser hall and also from external fire loads notably transformers and diesel oil storage. Glazing is generally Georgian wired but there are a number of opening windows.
- Some potential for link bridges to act as a conduit for fire spread.
- Fire load is highest in the condenser hall which is partially separated from the control building.
- External exposure from service transformers and oil storage for emergency diesel.

On page 10 of their report Marsh summarise 7 fire start scenarios based on location, discuss the immediate effects and spread potential. For each scenario Marsh developed fire control options such as sprinklers, fire doors and gas flood systems. As an example the Cable Basement start location options are shown in Table 4.7.

Table 4-7: Options for cable basement fire start location from Marsh Fire Protection report.

#	Start Location	Additional Controls	Comment
1	Cable Basement	Sprinkler Protection	High effectiveness. Deals with all fire types and limits both damage and spread potential
		Check and upgrade cable penetration seals	Should be undertaken as a maintenance activity
		Replace doors with fire doors (and upgrade dry wall)	Limited benefit if sprinklers installed.
		Provide Intumescant coating on cables.	Limits involvement of cables. Not regarded as reliable as sprinkler protection. May affect the rating of cables.
		Gas flood	Given volume of space and nature of fire load then gas flood is not considered a practical alternative to sprinklers. It could be used in the battery rooms if these were considered to be critical.

Marsh conclude with 10 mitigation options for the ISL control and condenser building (page 17) with costs ranging from $152,000 for cable basement sprinklers and fire doors to $642,000 for sprinkler protection throughout the control and condenser building, and a gas flood system in critical areas.

However, this issue of fire protection will require further investigation. There are many views regarding what is considered good practice in this regard.

For example, water sprinkler systems in the control building relay room may cause significant damage and loss of integrity of the various protection relays there. It may be that a gas deluge system for each cabinet is more appropriate in this case.

In summary it is clear that there are numerous fire mitigation measures that can be implemented to improve fire safety at the ISL buildings. The best mitigation strategy is yet to be identified for ISL and other key sites[16].

Finally, the issue of water mains pressure for the sprinklers, and should the Fire Service be required to attend an issue on site, has yet to be resolved. This small investigation is currently being carried out.

4.4 Summary

The Marsh reports have been used to determine the most probable ISL site HILP exposures. After using a quantitative analysis to ascertain probable HILP events of interest, a qualitative analysis was then performed to estimate asset vulnerability and the mechanisms of this vulnerability. Marsh then used internationally available data for such events to estimate event return periods at the ISL site.

It was concluded that a clear risk involves a fire and fire spread in the Control Building and surrounds. With a 265 year return period for such events and the clear lack of fire detection and suppression strategy at such a key site, this was identified as a high risk HILP exposure at such a key site.

Further analysis suggests that flood and earthquake related HILP exposures may also be prevalent, with mitigation measures likely needing further investigation.

[16] A fire mitigation strategy for substations is currently being investigated by Transpower's Asset Development group.

5| Seismic Assessments – Opus Consulting

5.1.1 Introduction

As part of an ongoing program of work, we are conducting reviews of all suspect or potentially vulnerable site building assets in order to assess whether they, firstly comply with the Building Act 2004, and secondly, the Transpower seismic policy[17].

This policy takes into account the requirements for earthquake prone buildings prescribed in the Building Act 2004 and the requirements for lifeline facilities prescribed in the Civil Defence and Emergency Management Act 2002. The policy also incorporates the recommendations of the New Zealand Society for Earthquake Engineering (NZSEE) to mitigate the risk to buildings that are essential to the functioning of the National Grid.

The minimum seismic standards of Territorial Authorities are deemed acceptable for buildings of importance level 1, 2, and 3. These minimum requirements generally correspond to the Building Act requirements. For buildings of importance level 4, such as at Islington, a higher seismic standard has been set to meet Emergency Management Act 2002 legal requirements and NZSEE recommendations. This requires that all existing substation structures are at or near 75% of what is classed as a New Building Standard (NBS).

5.1.2 Initial seismic assessment report

The ISL control building was built in the 1950s with an extension added of unknown age. Opus state that in general:

“The buildings that make up the Islington Substation facility have generally performed well in all of the recent seismic activity in the Canterbury region. Various minor areas of damage have been noted throughout the buildings. The main area of damage that has been observed is at the joints between the control room building and the condenser building. At both the main link and the bridge, damage to the concrete structures is evident.”

The initial Opus assessment (Appendix C) was based on a high level review of the three building construction drawings and a preliminary risk review. Opus concluded that based on this high level review:

- The control room building rating is 5% of the NBS;
- The condenser building rating is 8% of the NBS; and
- The oil filter/compressor building rating is 7% of the NBS.
- The conclusion of the initial assessment was that a further detailed assessment should be carried out for all three buildings as they were all considered below the 75% NBS requirement for essential buildings.

5.1.3 Detailed seismic assessment report

The detailed Opus seismic assessment report is provided in Appendix D.

The report contains a cursory review of the recent Christchurch earthquake events. However for a more in depth analysis of site exposure to recent earthquake events the Marsh HILP report (Appendix A) is more useful.

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17 Seismic Policy TP.GG 61.02 Issue 2 April 2009.

Opus state in their report that there is no geotechnical data available for the site however a Maunsell report exists from 2004, which provides some data regarding site geology (Appendix E).

While the conclusions of the Maunsell report are largely out of date, particularly regarding the earthquake return periods which will currently be under review, it does provide site geology information from a drilling program.

The Maunsell report concluded that:

- There was minimal liquefaction potential at the ISL site (page 4)
- There was no detectable slope instability (page 5)

Their conclusions regarding geology, despite being out of date for recent events, and coupled with the fact that minimal damage has been noted at the ISL site itself since the September 2010 earthquake, demonstrates that the Marsh conclusions regarding site earthquake exposure are likely to be sound.

The Opus conclusions regarding the detailed ISL building assessments and possible costs to bring these up to the 75% NBS are presented in Table 5.1.

Table 5-1: Summary of the Opus detailed assessment for the three reviewed buildings at ISL

Building	Importance Level	Seismic Policy Minimum Standard	Detailed Assessment Standard	Improvements Required
Oil Filter/ Compressor House	4	75% NBS	100%NBS	Nil
Condenser Building	4	75% NBS	38%NBS	Yes
Control Block	4	75% NBS	28%NBS	Yes

The approximated cost to bring the Control Building up to 75% NBS was estimated to be $370,000, while doing the same to the condenser building would cost about $1.04m. No mitigations were considered to be necessary for the Oil filter/ Compressor building.

Presently we are preparing to retire the synchronous condensers at ISL due to costs associated with their maintenance. It is looking increasingly likely that these units will be replaced with either an SVC or STATCOM device(s) which would be located in the switchyard itself.

However we have identified that retaining the condenser hall may not be necessary at all, and presently this is being investigated. Unless it is required for some other purpose such as transformer maintenance then it may be more economically prudent to have it removed and concentrate on upgrading the Control Building to meet the 75% NBS. This investigation is ongoing.

5.2 Summary

The Opus Seismic reports have identified that the ISL site Control and Condenser buildings are not up to the required 75% New Building Standard (NBS) required by Transpower policy and in fact appear to fall well short of this.

Mitigations necessary to bring the ISL Control and Condenser Building up to 75% NBS which is the Transpower policy for what are considered essential buildings have also been costed. It is still undecided whether the Condenser building will remain on site so earthquake mitigations for this building may not be necessary.

6| Disaster Recovery Reports – TLM Consulting

6.1 Introduction

In June 2009 we engaged TLM Consulting to develop a study that was to form the basis of what are called Disaster Recovery Plans (DRP) for key substation sites should there be some catastrophic switchyard failure there. The first of these plans was to assess disaster recovery at the Islington site.

A Disaster Recovery Plan is meant to be a high level identification of what transmission line configurations may be changed, what temporary equipment may be installed and where, and an indication of the power restoration capabilities and stages. It is only an indicative view though about what may be possible.

The usefulness of a report like this in the context of a HILP study is that it gives some high level indication of HILP event lost load implications and time to restore. This in conjunction with the Marsh reports and their view of HILP event return periods can be used in an economic analysis[18] to perhaps justify a suite of forward looking HILP mitigations.

Interestingly this DRP work was timely as it was carried out prior to the September 2010 earthquake and subsequent aftershock sequence. As it turns out the Islington substation has proven remarkably resilient to what has been a significant period of earthquake activity.

6.2 Islington Substation Disaster Recovery Plan – June 2009

The first Islington Substation DRP focused solely on the Islington substation switchyard assets and their catastrophic loss for whatever reason. The Marsh HILP report identified that the return periods for site wide events such as earthquake (1 in 10,000 years[19]) and flood (1 in 5000 years) at ISL were possibly significant.

The DRP report provides some indication of lost load potential for these events and may place a sanity check on what is perceived to be a credible expenditure on benefits to avoid these events.

As an example of what economic analysis may indicate, a catastrophic flood event at ISL was explored. Marsh identified that a site wide Waimakariri flood event (with a possible 1 metre high water inundation at the ISL site) had a 1 in 5000 year event probability. If we assume that 10% of those floods are such that they affect the switchyard assets to the extent that they are no longer immediately usable, and that a 50 day full outage block of the entire USI region results, then an NPV HILP reliability benefit of approximately $3.5m[20] can be generated (see Section 8).

Even if this outage duration and loss of USI load were true, these HILP reliability benefits will only be sufficient for mitigation measures at the ISL site. What these mitigations may be is another matter entirely, but the point of HILP analysis and the general conclusions in published literature is that the HILP benefits themselves, if they can be quantified, are

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[18] Outage probabilities and lost load implications form the basis of reliability benefit calculations.

[19] This is likely to change in the near future once a full geological re-assessment of the region is completed.

[20] Additional assumptions include that the USI region MWh unserved per day is approximately 13,000, the value of lost load is $20,000/MWh and no load is restored at all in that 50 day period.

generally only ever sufficient to justify mitigation measures, not as some would argue, as a basis for redundancy.

However, despite the preliminary analysis in Section 8, the question is does the DRP report conclude that a full 50 day outage in the USI region is a reasonable assumption?

The TLM supply restoration conclusions indicate that a full 50 day outage block may in fact be a credible scenario, albeit as an analytical means to model the staged restoration and partial supply that would likely occur post-event over the ensuing months and beyond. TLM concluded the following:

a) Central Canterbury and much of Christchurch City will, after initial system stabilisation, will lose supply. Eastern suburbs supply will be maintained by via BRY, with a load capacity of approx 220 MVA.

b) The areas of Christchurch City which cannot be supplied from BRY will be without supply for one to two weeks and then on a staged reduced supply until full capacity can be reinstated.

c) North and Central Canterbury and the Kaikoura coast will be without supply for one to two weeks.

d) The West Coast and the top of the South Island will be on a considerably limited supply sourced from Coleridge, West Coast and upper SI local generation, for up to one week.

e) This recovery plan aims to restore the main 220 kV transmission network north of Christchurch using emergency towers to by-pass ISL and then provide limited supply into Christchurch by back-feeding from SBK and using emergency transformers at ISL.

f) If all the recovery Stages are implemented, the plan indicates that the power supply to Christchurch will be restored to approx 67% of normal load, West Coast and top of South Island to 100% and North Canterbury to 45%.

g) Further recovery would require additional transformers and reactive support.

Following an event that removes the entire ISL substation from service, the indicative staged recovery discussed by TLM concluded that some spare assets may be necessary for the 5 identified recovery stages. It also estimated staged recovery MW supplied and the time taken to restore. The following are the possible temporary augmentations in stages:

Stage 1 – TIM, ASB and BRY re-livened and possibly some of Nelson region if Cobb can operate islanded[21]. Approximately 320MW of USI load restored within 24 hours. No spare equipment required.

Stage 2 – Connect ISL-TKB 220kV circuit to ISL-WPR-CUL-KIK circuit 3 at tower 3 near the ISL site. This then supplies some of the BRY group, ADD, MLN, the WPR group and the Nelson/West Coast region. Approximately 500MW of USI load restored within one week assuming it is immediately possible to carry out the works. Two spare 220kV towers and 200m of 1000A conductor required.

Stage 3 – Install temporary 66kV pole line to energise PAP 66kV bus from the SBK 66kV bus via the ISL-SBK 66kV circuit 2. No additional load restoration above Stage 2, taking possibly one to two weeks to carry out. Can be carried out in parallel with Stage 2. Two spare 66kV pole lines and 200m of 800A rated conductor required.

Stage 4 – ISL-LIV 220kV bypass and connect into ISL-WPR-CUL-KIK 2 creating LIV-KIK 2 circuit. Install spare 220/66kV transformer (or use one of the WPR transformers) north of

[21] This may not be possible and this will need to be confirmed as a possibility. TLM also assumed that some of the West Coast region may be supplied islanded from Coleridge power station. This also needs to be confirmed. Whether or not these assumptions are true though won't significantly impact the overall conclusions as the event return period and restoration stages are so indicative and therefore dominate the HILP analysis results.

ISL substation next to the ISL-LIV 220kV circuit and connect, with the LV connecting to the temporary 66kV pole line extension to supply PAP 66kV from Stage 3. Approximately 600MW of USI load able to be supplied. Possible that works could be complete within 10 days although doubtful transformer could be suitably located within this time. Three 66kV poles and 3 220kV spare towers, conductor and a 220/66kV transformer with CB etc.

Stage 5 – Under ASB-ISL circuit 1 install and connect a spare 220/66kV transformer (including controls, power supplies and protection etc), and connect into the ISL-SPN 66kV 1 and 2 circuits energizing the SPN 66kV. At this point approximately 650MW USI load may be supplied. This last stage may take 14 days or even longer depending on site difficulties.

This high level restoration plan indicates that possibly within 4-6 weeks, depending on transformer availability and the time taken to suitably site equipment, upwards of 60% of USI peak demand may be restored, albeit at N-security[22].

It has highlighted that spare transformers are needed for such a plan while the ISL substation switchyard is restored to service. This may take weeks or months, and will of course include the time taken to source transformers possibly from other sites that may be on N-1 security while the existing units are possibly repaired.

In short, the high level economic analysis detailed before may not be as unrealistic as first thought, as the rebuild time for a full site wide disaster, while improbable, may have significant medium term lost load implications, particularly due to transformer issues if they are damaged.

It may be that in the case of flood mitigations, at risk equipment is suitably raised above the 1m flood level discussed by Marsh. Equipment can also be designed to ensure that they can withstand significant earthquake events. Additionally, the HILP benefits may be used to help justify some aspect of the spare transformer policy that could be used nationally. While the ISL site wide HILP event reliability benefits may not be sufficient to justify a dedicated spare, these benefits may, in conjunction with the HILP benefits at other sites, be used to defend the necessity for their purchase instead of having to argue that this is considered good engineering practice to do so.

Finally the numerous spare towers and poles noted in the TLM report, along with control cabling in switchyard for example may also be able to be reasonably justified on this analytical basis.

6.3 Islington Substation Control Room Fire Recovery Plan

The Marsh HILP report indicated that the ISL site Control Room building may have a fire risk return period of 265 years. This return period is an order, or orders, of magnitude greater than many of the other ISL site HILP exposures. However no DRP analysis was carried out in the first ISL DRP for the loss of the Control Building, and assumed that only the switchyard primary assets were affected by the HILP event in question.

With this in mind we commissioned TLM to extend the original DRP study to ascertain the impact of an Islington Control Building partial and full loss, due to a high impact fire event.

Immediately following the fire incident TLM conclude that a similar scenario exists as for the loss of the entire switchyard in that the entire USI region would have a loss of supply for 24 hours. TLM estimate that approximately 320MW of USI load may be restored within

[22] Internal discussions at Transpower following a review of this report indicate that it is not entirely accurate. However it has to be noted that it these types of reports were never intended to be exact plans. The ISL DRP report does serve the purpose of this HILP study which is to provide some high level view of lost load implications and time to restore supply.

24 hours, much the same as the Stage 1 restoration in the original ISL DRP, and mostly at the TIM, ASB and BRY GXP's.

At this point the restoration activities change as the switchyard is assumed to remain undamaged by the Control Building fire event, and it is assumed that only the ISL protection, control and communication equipment is inoperable. TLM state that:

> This approach is not relevant here as the physical structure of the network would be intact with only the protection, control & communications equipment inoperable. For the control room fire scenario covered in this report it is more appropriate to identify what limited protection equipment would be required to regain network capacity in the shortest possible time. In this emergency situation, the principal role of the protection equipment would be to isolate faults and limit/prevent subsequent damage to primary plant with security of supply being a secondary issue.

The next stage of supply restoration becomes quite speculative and is less easily carried out. This is due to the protections for the transformers, bus zones and connected transmission lines being inoperable. Without some form of protection further power restoration will not be possible at all. There is also the issue of the 33kV and 66kV switchgear and its integrity post-event.

TLM state that some of Transpower's normal protections could be dispensed with in this emergency scenario such as complex bus zone protection, utilization of distance protection from other remote substations to act as fault clearance at the expense of fault clearance times and possible bus shutdowns, and additionally implementing minimal transformer protections.

However, exactly how these protections could be configured and how long it would take, has not been elaborated on sufficiently by TLM to be considered a robust plan. If such an investigation was sufficiently robust it may be used as a basis for Transpower to consider the possibility that a mobile control room may be economically justifiable, or spare switchgear and control cabling may be held in storage. A mobile protection unit could be configured to be usable on most Transpower sites should a major control room event happen anywhere.

Section 8.2 presents a high level economic analysis of the Marsh control building fire mitigation options which demonstrate that all appear to be economic, even on the basis of the first 24 hour period following the HILP event in question.

6.4 Summary

In summary and on the basis of the estimated TLM Stage 1 restoration period alone, it appears that all of the fire detection and mitigation options discussed by Marsh may be economic to implement. This analysis needs to be extended to include the cost of upgrading the water supply to the site once water flow rates are determined and reported on.

At this point there are many questions that the TLM report has not been able to answer and that Transpower needs to investigate further in order that some form of mobile re-configurable protection unit may be justified for use at all Transpower sites. Additionally site flood exposure needs to be further looked into and it may be that flood mitigation measures can be implemented to protect high value assets. This will be discussed later in this report in the Economic section.

7| Primary Asset Issues – observations from site inspection

7.1 Introduction

A preliminary site inspection was carried out in July 2011 to identify potential causes of high impact events with specific reference to the switchyard primary assets and control building.

The visit was a visual inspection only, and did not include a formal review of the design or asset condition. Supplementary risk information in this section has also been obtained from an asset condition report prepared by the maintenance contractor[23] (May 2011), and photographs from a risk survey undertaken by ELMAC in 2010[24].

7.2 Cable Basement

The consequences of a major fire in the cable basement could be catastrophic, potentially leading to loss of supply or severe rationing of supply to large parts of Christchurch and the upper South Island.

Even allowing for emergency measures and temporary bypasses of the main substation following such an event, it is likely that restoration of transmission services to some areas could take several weeks or even months depending on the severity of the damage.

ISL cable basement – general view

Main 415 V LVAC switchboard

The main risk factors identified in the cable basement are that:

[23] From "Annual Report on Asset Condition - ISL - Rev01 - May 11.doc" by Transfield Services.

[24] From "Islington Substation ELMAC survey 2010 Photographs.pdf"

- there are high energy sources present. The presence of a heavy power 415V switchboard in the cable basement is considered undesirable because it is a possible source of ignition[25];
- there is a large concentration of critical equipment in the cable basement;
- there is no fire separation between any of the critical equipment;
- physical access for fire fighting will be difficult, and there is only one point of entry/exit;
- there would be a lengthy fire-fighting response time to any fire alarm, because of safety access control requirements;
- smoke detection is present, but the coverage in the basement seems incomplete; and
- there is no fire suppression installed at all.

7.3 Critical facilities in cable basement

In addition to the cables carrying all protection, control and indication circuits for all switchyard equipment, the cable basement room also contains the following critical facilities:

- main 110 V dc, battery, charger and distribution systems for the entire station;
- main 48 V dc battery, charger and distribution systems for the entire station;
- main 24 V dc battery, charger and distribution systems for the entire station; and
- main 415 V switchboard.

[25] There is an investigation presently underway for the major replacement of the main LVAC systems. This includes the local service power transformers, standby generators and fuel tanks that are currently co-located outside the control building, with what is considered to be inadequate fire separation.

Main 110 V dc distribution panel

Loss of any of these facilities would have major implications.

The most critical of these is the 110 V dc system, because failure would immediately disable all switchgear protection and control. Transpower has no standard procedure for dealing with total loss of 110 V dc, and response would be slow and difficult.

7.3.1 Risk of damage to cables in switchyard trenches

The site inspection indicated that there is some risk to the integrity of the station from damage to cables in trenches in the switchyard. Two main sources of risk have been identified:

fire risk – spread from burning oil from a transformer, or from a burning heavy power cable; and
impact damage from above – collapse of cable trench covers under vehicle load for example.

	
All control and protection cables, from the 220 kV switchyard, are installed in these trenches beneath the main access route into the switchyard. There is a further crossing at the apron in front of the control building.	All control and protection cables, from the 220 kV switchyard, appear to cross 11 kV heavy power cable runs at this point. Details of cross-over to be photographed separately.

The cable trenches crossing the main vehicle access route into the switchyard are densely packed with cables, and appear vulnerable to impact damage from above.

The crossovers of control and 11 kV power cables represent a potential point of major failure in the event of a power cable fire. Details of the crossover have not yet been obtained.

7.4 Summary

The main items of relevance to this report identified from the site visit and the other two sources are:

- risk associated with the cable basement generally;
- risk associated with the 110 V dc, 48 V dc and 24 V dc power supplies located in the cable basement;
- risk associated with the 415 V local service system, and the switchboard in the cable basement;

- risk of damage to critically important cables in cable trenches close to the main control block building.

8| Economic Analysis

8.1 Introduction

This section outlines the economic analysis has been used to determine that the HILP events identified by Marsh Insurance are economic to mitigate. It is intended that these mitigations will significantly increase HILP event return periods and improve reliability at the ISL site.

8.2 Economic analysis – Control Room Fire Event

The initial Marsh HILP report concluded that the fire detection and suppression within the ISL Control and Condenser buildings is less than desirable for such a strategic site. Given their estimated return period for such events (estimated at 265 years for any major substation building fire event) this was considered an issue that warranted further investigation with a likely conclusion that mitigation measures needed to be put in place.

In the second Marsh report which focused on fire protection, 10 separate mitigation options for the ISL control and condenser building were presented with capital costs ranging from $152,000 for cable basement sprinklers and fire doors, to $642,000 for sprinkler protection throughout the control and condenser building, and a gas flood system in critical areas.

The second TLM Consulting report concluded that a control building fire event would have the same lost load and outage duration implications as the loss of the switchyard. TLM suggest that within 24 hours of the loss of the control building due to a catastrophic fire event that upwards of 320MW USI demand could be restored within 24 hours.

An indicative economic analysis was performed on this outage duration alone to illustrate that all fire mitigation measures identified by Marsh were easily justifiable.

Marsh estimated that the return period for a control building fire event was 265 years. If 10% of these fires are assumed to destroy the control building to the extent that ISL substation is immediately inoperable then the entire USI demand will not be served as noted by TLM.

Using a daily USI load curve for a typical winter peak period, the MWh lost is estimated at 13,000 MWh. Given the unserved energy value of $20,000/MWh[26] and 24 hour outage duration before full Stage 1 restoration, noted by TLM, results in an annualized HILP reliability benefit of approximately $100,000 (see Table H.1 in Appendix H).

On an NPV basis this is a benefit of $1.3m in $2011. If fire mitigation costs were to be implemented at a cost $642,000 (most costly option) in say 2014, this is an NPV cost of $522,000 in $2011. So clearly even on the basis of the likely Stage 1 restoration period alone, all of the Marsh fire mitigation measures are economic to implement.

In summary it is clear that there are numerous fire mitigation measures that can be implemented to improve fire safety at the ISL buildings.

8.3 Economic analysis – site wide events (flood and earthquake)

Marsh identified that a site wide Waimakariri flood event may have a 1 in 5,000 year event probability. If we assume that 10% of those floods are such that they affect the switchyard

[26] Until the new CAPEX Input Methodology is finalised the value of unserved energy is referenced in the Electricity Governance Rules (EGR's) Part F Section III Schedule F4 Rule 8.3.4.

assets to the extent that some are no longer usable, and that a 10 day full outage block of the entire USI region results, then an NPV HILP reliability benefit of approximately $0.7m in $2011 may be possible. This NPV analysis is presented in Table H.2 Appendix H.

Similarly, Marsh identified that a site wide earthquake may be a 1 in 10,000 year event. If 10% of those earthquakes were sufficiently severe to destroy the primary switchyard (if it wasn't already designed to Transpower standards) and control and condenser buildings and that the assumption is that the outage MW and duration is modeled by a full 50 day USI outage block, then an NPV HILP reliability benefit of approximately $1.7m in $2011 may be possible. This NPV analysis is presented in Table H.3 Appendix H.

The earthquake mitigation costs noted by Opus Consulting for the two building that didn't meet the 75% NBS were approximately $1.4m ($1.15m in $2011). On the basis of the assumptions made it seems that strengthening both buildings may be justified. However, given that substation building earthquake proofing is required to meet the statutory requirements of the Emergency Management Act 2002, this reliability benefit calculation is superfluous. What it does demonstrate though is that mitigation measures can be analytically shown to be economic based on the HILP event return periods.

Both flood and earthquake exposure may generate significant HILP related reliability benefits if the modeled post-24 hour lost load implications are considered reasonable.

The TLM supply restoration conclusions indicate that a full 50 day outage block may in fact be a credible scenario, albeit as an analytical means to model the staged restoration and partial supply that would likely occur post-event over the ensuing months and possibly beyond.

This high level restoration plan indicates that possibly within 4-6 weeks, depending on transformer availability and the time taken to suitably site the spare transformer units, upwards of 60% of USI peak demand may be restored, albeit at N-security. This means that there is still a significant lost load on an ongoing basis post-event.

It may be that in the case of flood mitigations, at risk equipment is suitably raised above the 1m flood inundation level discussed by Marsh. Equipment can also be designed to ensure that it can withstand earthquake events, however at the ISL site switchyard equipment earthquake design levels haven't been fully confirmed yet. Even if transformer spares are available, there are still significant lost load implications as noted by TLM as the spares are likely to be sited elsewhere.

8.4 Economic analysis – HILP analysis to justify national spares strategy

One aspect of this HILP analysis that has become clear is that the HILP benefits that can be analytically demonstrated in the economic analysis appear, at the very least, sufficient to justify the mitigations to reduce the risk and increase HILP event return periods. The analysis has also demonstrated that it may also be used to help justify some aspect of the national spares strategy.

While the ISL site wide HILP event reliability benefits may not be sufficient to justify a dedicated spare, these benefits, in conjunction with the HILP benefits at other sites, may be used to defend the necessity for their purchase instead of having to argue that this is considered good engineering practice to do so.

The numerous spare towers and poles noted in the TLM report, along with control cabling in switchyard for example may also be able to be reasonably justified on this analytical basis. Finally it will be recommended that we investigate the development of a mobile control room that can be relocated to any Transpower substation site.

8.5 Summary

The economic analysis demonstrates that the HILP events with the greatest potential for disruption, namely control building fire events, site wide flood and earthquake damage events, all generate substantial HILP reliability benefits that can justify mitigation measures.

In the case of the control building fire exposure the analysis demonstrates that all of the fire mitigation options identified by Marsh are economic to implement. However we are yet to determine the final fire suppression technology strategy.

The earthquake mitigation measures also noted by Opus, to bring the control and condenser buildings up to the Transpower 75% NBS standard, are economic to carry out. However given that this will be necessary to meet statutory requirements this analysis is largely superfluous.

It is unknown to what standard the switchyard equipment has been designed to at this stage. Given equipment resilience to recent earthquake events though, it is likely that the ISL switchyard has substantial earthquake mitigation measures already in place. This needs to be confirmed though.

The HILP economic analysis also indicated that the implementation of flood mitigation measures is a reasonable expenditure given the relatively low return period for such events noted in the Marsh report.

Finally the economic analysis, while demonstrating that some identified HILP mitigation measures are economic, could also be used to assist in the justification of a national spares strategy for high value items such as transformers. Also it is possible that we could investigate the possibility of developing a mobile control room with protection and communication abilities, in the event of a substation control building event of significance. We have 174 substation sites all reliant on their own dedicated control building, the loss of which would take months to resolve, and in many cases, have significant lost load implications.

9| Recommendations

In this section the main recommendations for further investigation or mitigation works that need to be carried out at the Islington site are made.

It is recommended that the following planned works and further investigations are carried out:

Further investigate whether flood mitigation measures are necessary at the Islington site. This may require a report to discuss the impact of various water levels at the site and perhaps lead to the removal of some key equipment from the cable basement. This area would likely become inundated even for a low level flood event. Preliminary economic analysis suggests that there may be value in pursuing mitigations for this type of event;

Upon commissioning of the upgraded LVAC system as per the SSR option 3 investigate re-locating the 110 V dc, 48 V dc and 24 V dc power supplies presently located in the cable basement. There are two issues here. The first is the fire risk and the second is that if there was a significant flood event, the cable basement may be partially submerged. This could mean the loss of these power supplies and subsequent ability of the control room to function.

Investigate the cost and design of a re-configurable mobile control and protection unit for use at other Transpower substation sites, should a HILP event remove a substation control building from service for any significant length of time. It is possible that this will require Transpower to retain suitable spare cable to connect to switchyard equipment.

Appendix A ISL HILP Study - Marsh 16 Jun 2011

Appendix B ISL Fire Protection - Marsh 4 Aug 2011

Appendix C ISL Initial Seismic Assessment (Opus 2011)

Appendix D ISL Detailed Seismic Assessment (Opus – Aug 2011)

Appendix E ISL SVIP Seismic Hazard Assessment (Maunsell - May 2004)

Appendix F ISL Disaster Recovery Plan (TLM – June 2009)

Appendix G ISL Control Room Fire Recovery Plan (TLM - Aug 2011)

Appendix H ISL Substation LVAC Upgrade Options Report

Appendix I Economic Analysis

Table H.1: Economic analysis demonstrating fire mitigation HILP reliability benefits (note that analysis extends beyond 2025)

Control Room															
control room fire return period (years)	2,650														
Value of Lost Load ($/MWh)	$20,000														
Energy Unserved in 24 hours (MWh)	13,000														
LOL cost for HI control room fire event ($m)	$260														
Fire mitigation cost ($000's)	$640														
	NPV ($000's)	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**
Fire mitigation CAPEX cost	**$522**	$0	$0	$640	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
HILP benefit	**$1,308**	$98	$98	$98	$98	$98	$98	$98	$98	$98	$98	$98	$98	$98	$98

Table H.2: Economic analysis demonstrating flood mitigation HILP reliability benefits (note that analysis extends beyond 2025)

Site wide flood event														
catastrophic flood return period (years)	50,000													
Value of Lost Load ($/MWh)	$20,000													
USI energy unserved per day (MWh)	13,000													
Outage days	10													
	NPV ($000's)	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**
HILP benefit	**$693**	$52	$52	$52	$52	$52	$52	$52	$52	$52	$52	$52	$52	$52

Table H.3: Economic analysis demonstrating earthquake mitigation HILP reliability benefits (note that analysis extends beyond 2025)

Control and condenser building														
catastrophic earthquake return period (years)	100,000													
Value of Lost Load ($/MWh)	$20,000													
USI energy unserved per day (MWh)	13,000													
Outage days	50													
	NPV ($000's)	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**
HILP benefit	**$1,733**	$130	$130	$130	$130	$130	$130	$130	$130	$130	$130	$130	$130	$130
Earthquake mitigation costs	**$1,151**	$0	$0	$1,410	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0

