Reducing Critical Service Loss through Coordinated Resilience Planning

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Abstract: In the modern economy, the drive to manage assets efficiently and effectively is stronger than ever. Recent catastrophic events affecting people and assets have resulted in a surge of Business Continuity Planning requirements on the boardroom agenda. This paper outlines a process to identify potentially vulnerable critical infrastructure during emergency events that would require detailed response plans. It summarizes observations from traditional disaster planning methods and compares outputs from vulnerability analysis and Geographical Information Systems modelling undertaken for a Local Authority in New Zealand. These outputs illustrate the benefits of coordinated analysis across local roads, water services and wastewater services.

KEYWORDS: Critical Vulnerability, Resilience Planning, Business Continuity, Cross-Network Infrastructure, Rena

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1. Introduction

Requirements to undertake risk and analysis for lifelines and critical infrastructure protection have been in place and publicized for many years as seen in Crimp (2008). Likewise, recognized concepts of Plan-Do-Check-Act (PDCA) have been embedded in asset management standards like BSI PAS-55 (2008) and Optimized Renewal Decision Making (ODRM) is part of our everyday manuals such as the International Infrastructure Management Manual (2011). Why then, is resilience planning focussed on protection of a single asset class and so easily overlooked for a set of crossing but unconnected networks? Possibly because ODRM is only applied on assets that custodians have direct influence on. Possibly because there are no agreed guidelines that outline the scope of impact analysis that should be undertaken. This paper does not seek to recommend modelling of every scenario, however it demonstrates how a broader planning approach can identify mitigation options for unaccounted for eventualities, such as the Rena (2011) oil spill that was not a considered scenario however benefited from an accelerated emergency response, therefore improving resilience.

1.1 The Compounding Impact

Recent catastrophic events, exhibit compounding effects of disasters that impact simultaneously on multiple services. These include mobility, electricity, potable water, haulage of goods and availability of community centres. These compounding effects can have devastating impacts on the economy, driving communities and businesses out of city centres, causing lasting changes to regions. A recent report on climate change by the Commonwealth of Australia (2009) stated "even if the cost of protection was AUD$10 billion for Melbourne alone, it would still be a lower cost alternative to losing low-lying infrastructure, building assets and the cost of disruption to the local economy and society". Business Continuity Planning (BCP) assists in dealing with the ensuing aftermath from events like these however they do not address the ability to build resilience into the infrastructure to standard procedures.

1.1 Local Research Review

Several lifelines studies have been completed in the Bay of Plenty region in New Zealand. These generally focus on one location at a time, or one scenario at a time. The Chapel Street Treatment Plant was investigated by Dowrick, Johnston and Perrin (2000) for seismic, volcanic, flooding or fire damage but only looks at the localized network issues. The region was studied by the Western Bay of Plenty Lifelines Group (2002) to model different scenarios of earthquake or volcanic eruption but does not include analysis of built assets that may affect the localized consequence. The region also has tsunami evacuation zone maps developed by the Bay of Plenty Regional Council (2008) but these do not consider routes for accessing other critical infrastructure. A national study by Gordon and Matheson (2008) was completed on improving transport asset management. This report starts to show improvements in taking a wider approach to analysing resilience but still only covers highway assets. The local research, although thorough, does not illustrate an optimum level of coordination.

1.2 Research with Insufficient Scope

Many international studies have been undertaken that focus on one aspect of emergency response at a time. Evacuation routes by Cova and Church (1997) look at micro models of road connectivity and assume there is no other infrastructure that may impact on a route. Identifying optimum penetration of highway or rail networks by Jha and Manoj (2008) are modelled in GIS, however focuses on commuting or demographics and not resilience from a community perspective. There are detailed studies outlining transportation routes to mitigate damage from hurricanes by Campbell, Thomas, Hunter and Levesque (2006), but again only cover one type of natural disaster allowing potential vulnerabilities under different scenarios.

1.3 Aspects to Combine

A paper on lifecycle analysis of existing infrastructure by Magnuson and Amador (2010) looks at coordinating renewals and reducing the long term cost of replacing essential services. This methodology aligns with good practice asset management however only considers time of optimized renewal, not optimising the replaced asset. Another promising paper by Bruneau et al. (2003) looks at performance indicators to identify resilient communities and has a conceptual framework that could be applied in a regulatory context. This model would work best for measuring resilience using a coordinated approach. It does not utilize the feedback cycle ORDM to build resilience into core infrastructure. The International Standard on Business Continuity ISO/PAS-22399 (2007) covers multidisciplinary resilience planning. However this is only for one organisation and it is not designed to set procedures for post disaster recovery.

2. Case Study: Cross Asset Vulnerability Analysis

Tauranga City Council (TCC) engaged GHD New Zealand Ltd. to lead the development of a vulnerability assessment for City Transportation and City Waters to be delivered to the Bay of Plenty Lifelines Advisory Group (BOPLAG), a member of the New Zealand Engineering Lifeline Groups. During the project it was identified that different results were captured if analysis was undertaken on a single network than when undertaken in a combined spatial environment. Therefore the results of the individual studies have been combined to illustrate a more complete output.

The purpose was to identify potential high risk areas within communities that are susceptible to damage during natural disaster events or service outages, in order to capture region-wide mitigation planning. The objective was to review asset criticality in the transportation, water and wastewater networks, assess their vulnerability under 27 different severe climate scenarios and deliver optimum outputs to the BOPLAG as set out in Table 1.

Table 1. Natural Event Scenarios

Code	Scenario	Event
FL	Flooding	Flash Flood
		Inundation
		Landslide
GE	Geothermal	Chemical Action
		Ground Settlement
		Ground Shaking
IL	Infrastructure Local Authority	Sewerage
		Stormwater
		Water
IP	Infrastructure Private	Electricity
		Gas
		Telecoms
SE	Seismic	Fault Displacement
		Ground Settlement
		Ground Shaking
		Landslide
		Liquefaction
SS	Storm Surge	Coastal Erosion
		Inundation
TS	Tsunami	Coastal Erosion
		Inundation
		Velocity Damage
VO	Volcanic	Ash Fall
		Lahar
		Water
WF	Wind Fire	Fire
		Wind

The locations of critical assets across different networks were modelled in a Geographical Information System (GIS), ESRI ArcGIS. This assisted in identifying areas of high risk with a dependency on other infrastructure networks. Critical assets were overlaid with soil maps to identify drainage issues, contour maps to identify tsunami impacts and liquefaction maps to identify earthquake-prone areas. Under each scenario, assets identified as 'vulnerable' had potential risk mitigation techniques documented so that these actions could be combined where vulnerable hot-spots emerged.

2.1 Process Undertaken

Critical assets were defined through meetings with Transportation, Water and Wastewater network managers and asset managers. The process used to identify the vulnerable assets was explained and is illustrated in Figure 1.

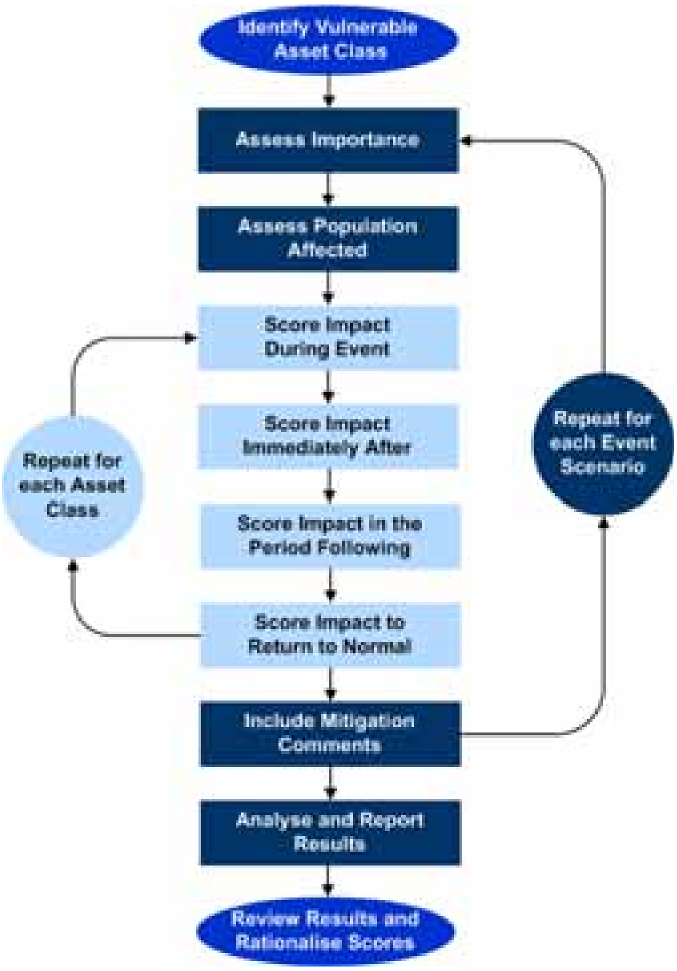

Figure 1. Process to Assess Vulnerability

Under each scenario, critical assets were scored on three dimensions; importance to the network, population affected if service was disrupted and likelihood of being affected by the scenario. The impact or consequence was then scored at four stages during the event. This resulted in an understanding of when an asset becomes vulnerable and aids prioritisation.
This process allowed all critical assets to be ranked by vulnerability across the entire city.

2.2 Risk Score Definitions

Asset classes were scored across three dimensions using definitions provided by BOPLAG (Table 2):

Table 2. Risk Definitions

Ranking	Importance (population or people served)	Vulnerability (likelihood)	Impact (consequence)
5	Extremely important	Almost certain	Catastrophic
4	Very important	Likely	Major
3	Important	Possible	Moderate
2	Some importance	Unlikely	Minor
1	Not important	Rare	Insignificant

2.3 Risk Time Factor

Each event's impact is scored with a time factor to indicate when the most severe damage would occur. The descriptions below are used to define each time period that should be scored.

Table 3. Chronological Assessment of Impact Codes

Chronological Code	Description
DE	During Event
IA	Immediately After
PF	Period Following
RN	Return to Normal
RT	Return Time (Weeks)

2.4 Data Sources Utilized to Define Asset Classes

The Transportation (RAMM), Water and Wastewater (Hansen) Asset Management Systems (AMS), and GIS databases were reviewed to collate the set of asset classes. The soil maps were sourced from the Western Bay of Plenty Lifelines Study : Microzoning for Earthquake Hazards (2002) report. The asset classes identified are as follows:

Table 4. Asset Classes Reviewed

Network	Type
Transportation	Bridges
	Retaining Walls
	Embankments
	Arterial Pavements
Wastewater	Pump Stations
	Reticulation - Gravity
	Rising Mains
	Treatment Plant
Water Supply	Booster Pump Stations
	Intakes
	Interchange
	Pipe Bridges
	Processing Plants
	Reservoirs
	Reticulation - Distribution
	Reticulation - Raw

2.5 GIS Features Used to Map the Asset Classes

The asset attributes from TCC were filtered to extract only the critical assets that are essential for the network to operate. The resulting GIS layers are as follows.

Table 5. GIS Features Utilized

Feature	Description
TCC Road Centreline	All local roads used as a basis for selecting critical linear assets
State Highways	Define NZTA responsibility
Critical Asset Point	Roads that are potentially vulnerable
Critical Asset Line	Bridges, Embankments and Retaining Walls that are potentially vulnerable
NZ Power Transmission Lines	High Voltage Lines
NZ Railways	Rail network for critical access
Relic Slips Database	Slips database maintained since 2004
Contour and TIN	20m contours used to define low lying areas
Liquefaction ground damage	Based on soil maps
Soil Drainage	Based on soil maps
Earthquakes in 2009	NZ Earthquakes for 12 month period in 2009
Treatment Plants	Location of wastewater treatment facilities
Reticulation - Rising	Extent of pumped rising mains to treatment facilities
Reticulation - Gravity	Extent of gravity fed mains to treatment facilities
Processing Plants	Location of water processing plants
Raw Water Intakes	Location of raw water intakes
Reticulation - Distribution	Extent of trunk distribution of treated water
Reticulation - Raw	Extent of raw water trunk lines to processing plants
Eastern Boundary	Area assumed for defining assets in Tauranga East
Western Boundary	Area assumed for defining assets in Tauranga West

2.6 Resulting Map Outputs of Vulnerable Assets

The maps, Figure 2 to Figure 10, show how the identified critical assets in the Transportation and Waters networks are affected by the surrounding environment.

This extent shows the entire road network by hierarchy. It also notes railway lines and high voltage power lines. All state highways are considered critical however were excluded as assessed by the New Zealand Transport Agency (NZTA).

Figure 2. Extent of Study

The extent below shows the critical assets only. This includes the point assets (bridges, embankments and retaining walls) and the line assets (pavement).

Figure 3. Critical Transportation Assets

This extent shows critical water assets with treatments plants, pump stations, reservoirs and intakes.

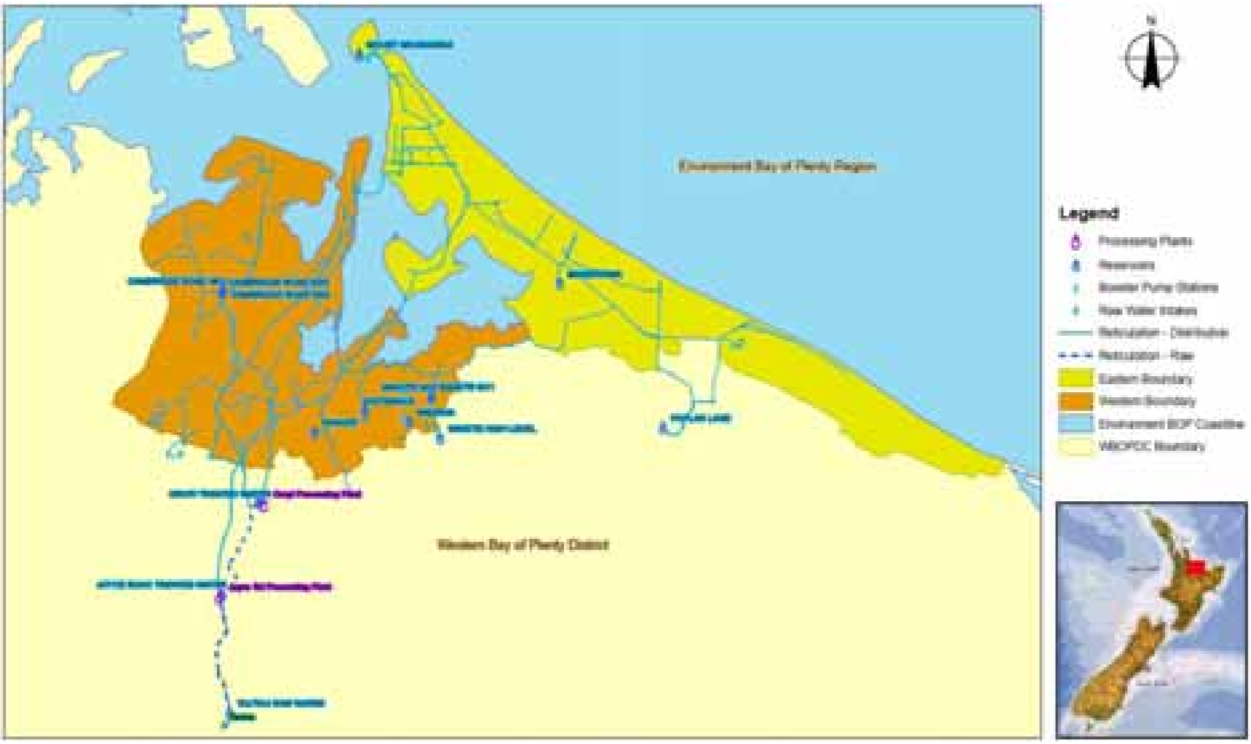

Figure 4. Critical Water Assets

This extent shows critical wastewater assets with treatments plants, pump stations and ocean outfalls.

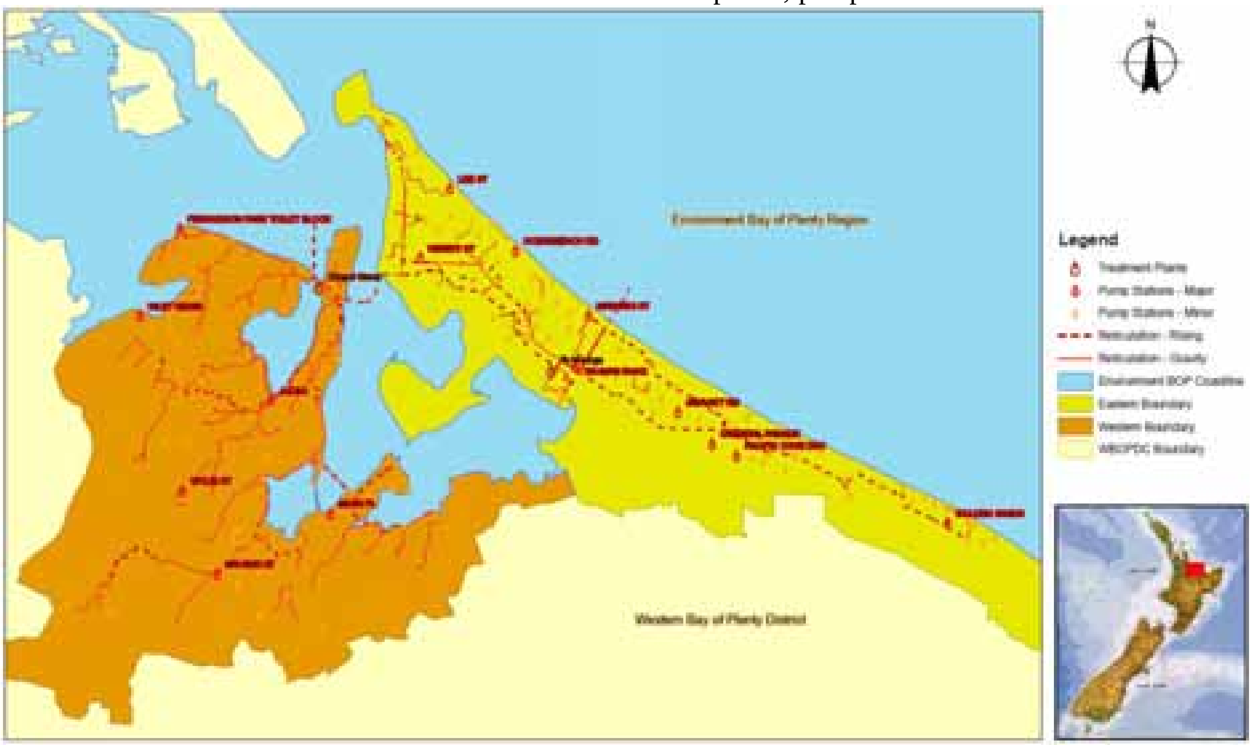

Figure 5. Critical Wastewater Assets

This extent illustrates the ground shaking events recorded in the previous year. It shows that the Bay of Plenty is on a fault band, however TCC is not as active as Matata to the southeast.

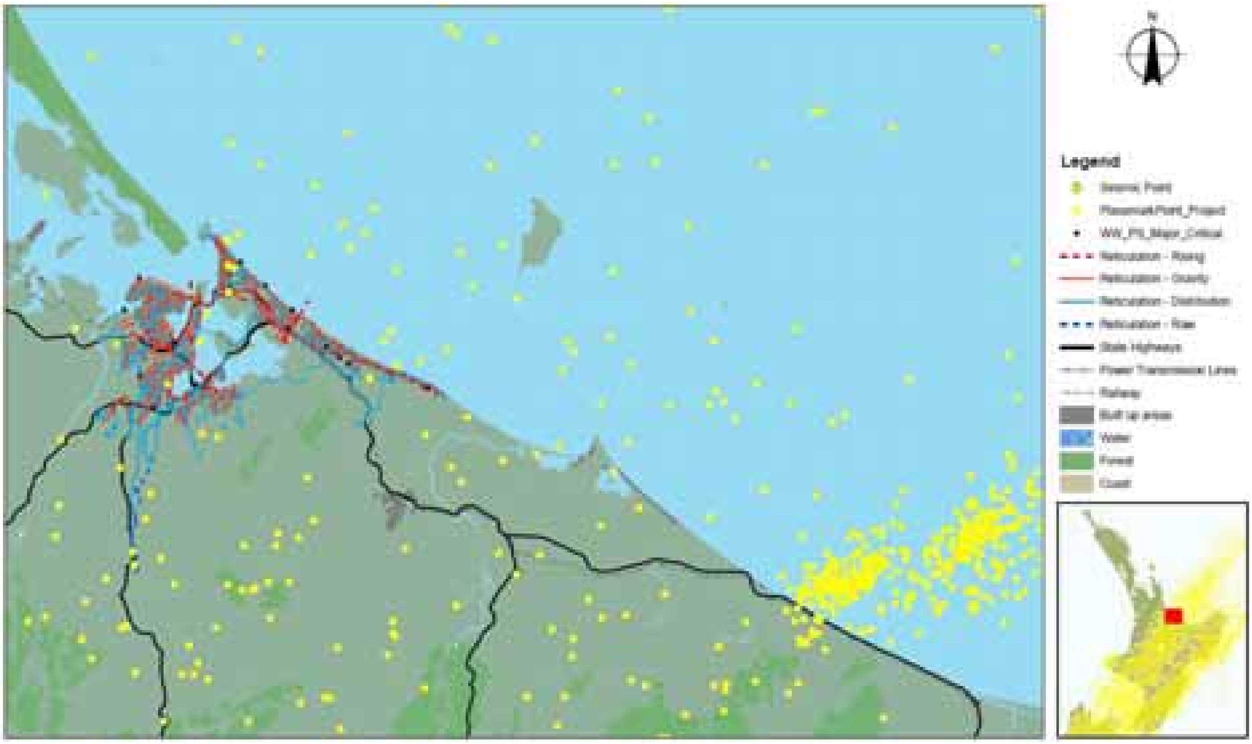

Figure 6. Seismic Activity across 12 Months

This extent shows the soils that are susceptible to flooding and ponding. This has an impact on surface runoff, damage to road basecourse and debris lodging in drains.

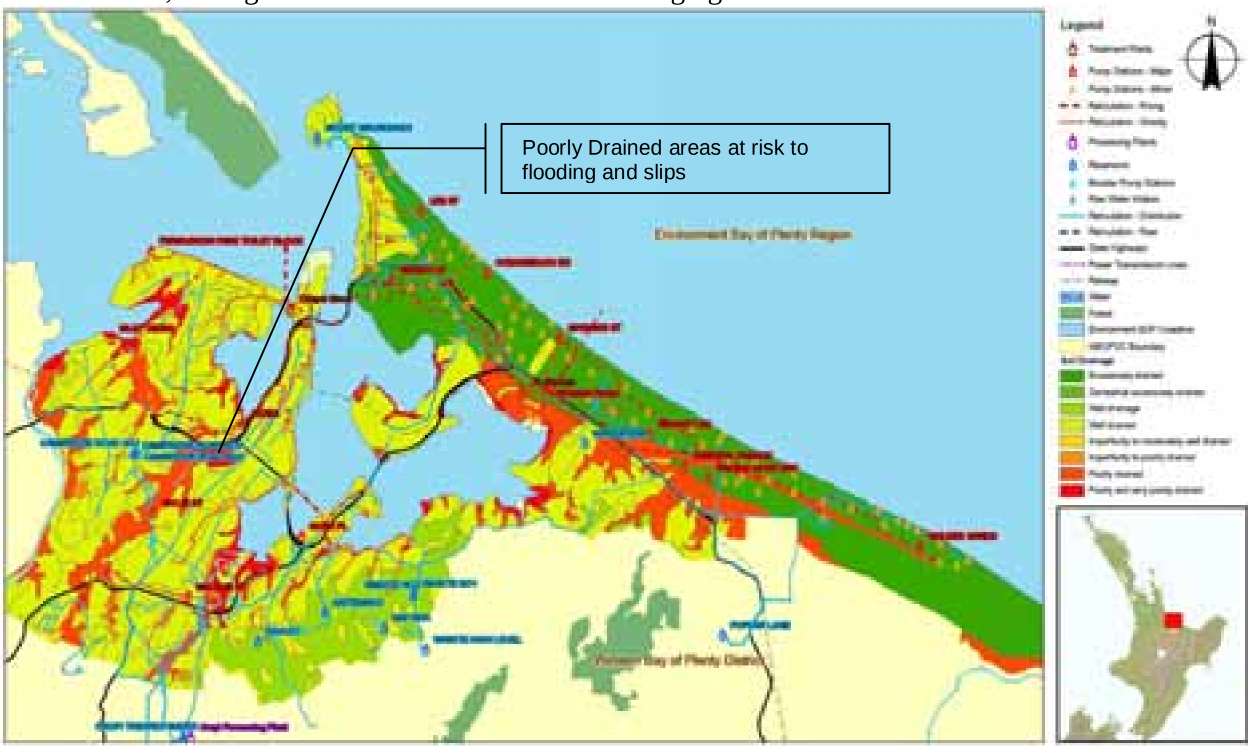

Figure 7. Soil Drainage

This extent shows the soils that are susceptible to liquefaction. It also uses a colour coded scale to illustrate which areas are affected by this.

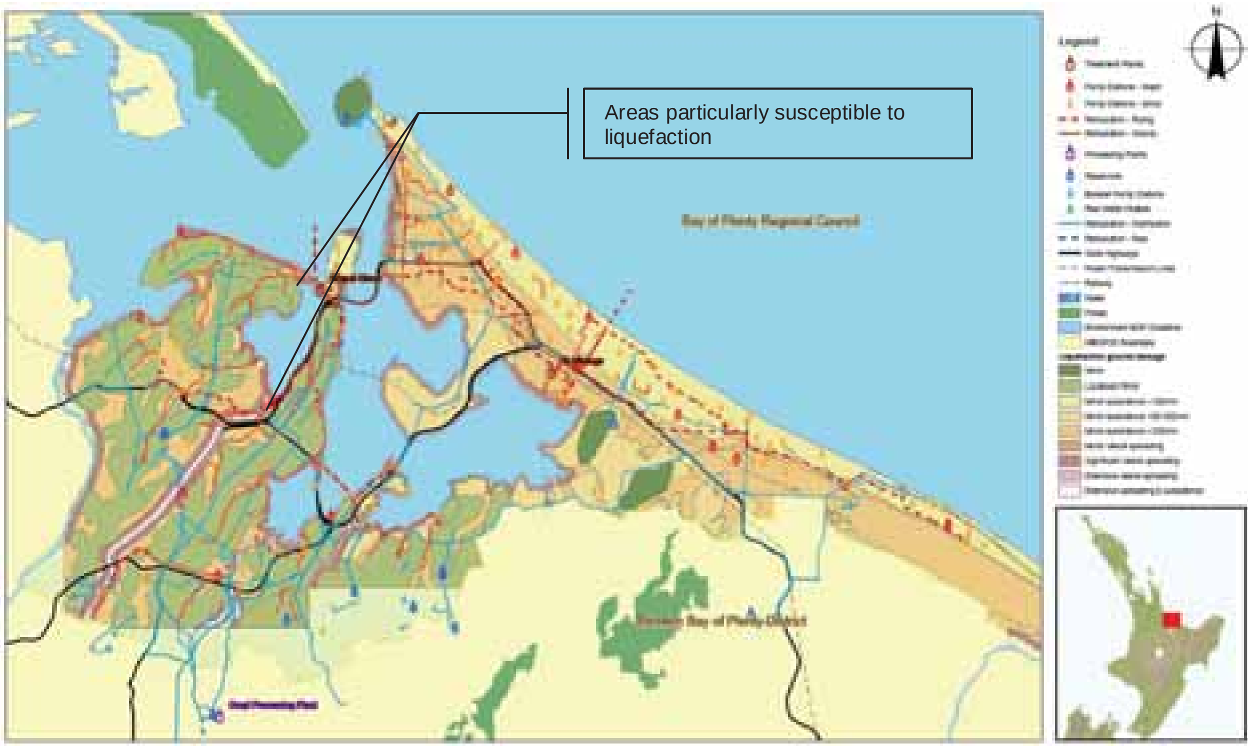

Figure 8. Liquefaction Ground Damage

This extent shows the topology of the coastal region and the risk of tsunami impact. It also shows where water naturally drains from the hill sides.

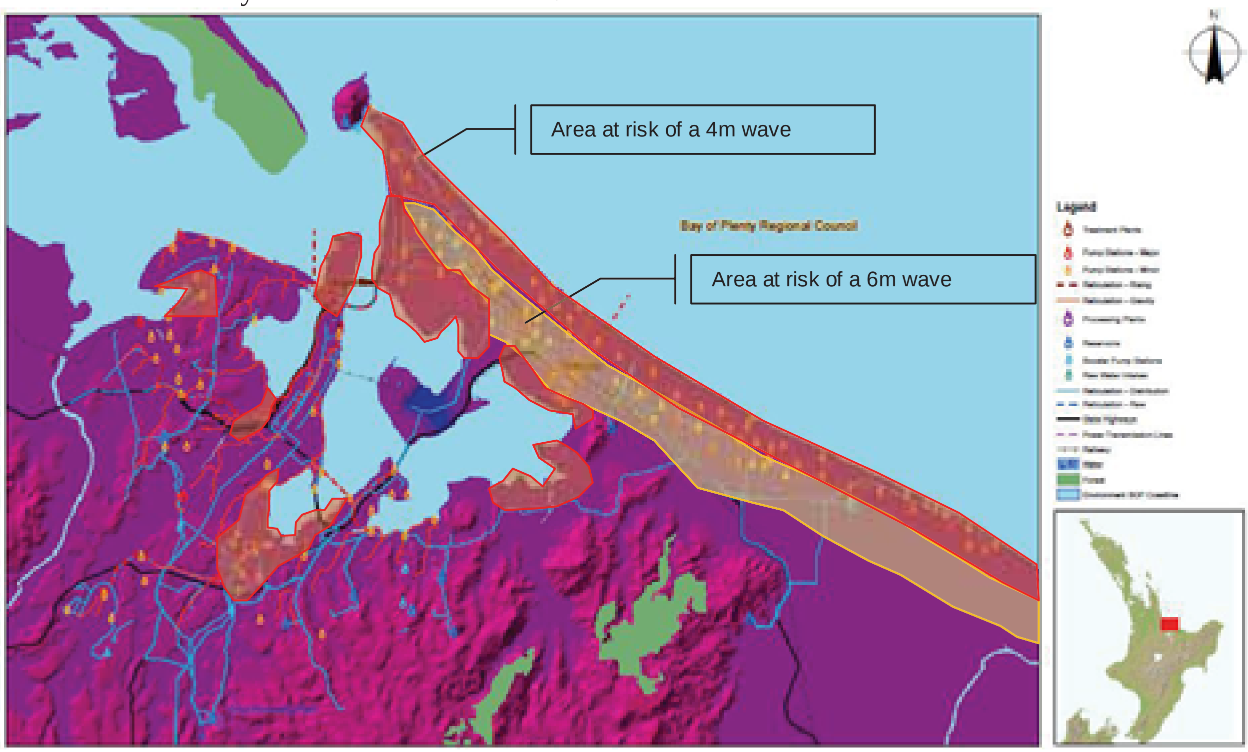

Figure 9. Elevation and Tsunami Impact

This extent shows the intersections between critical roads, water and wastewater mains. It utilized proximity and intersection analysis tools to highlight the critical areas in pink of (A) the Chapel St bridge and the Chapel St treatment plant and (B) the Welcome Bay bridge as a bottleneck access to critical reservoirs and pump stations.

"We are now realizing benefits through increased funding to improve infrastructure for the highest ranking critical assets."
Transportation Planning Manager

2.7 Overall Summary of Impact Scores

All asset classes were scored against the vulnerability criteria and populated into a risk resilience framework. This enabled further analysis of the results for the purpose of rationalising the scores and identifying the most critical assets. Table 6 below ranks the top 10 asset classes from most critical by the sum of each score given for each event. This method does not follow the traditional risk matrix. Currently the model sums all scenarios for the asset impact (consequence) score and vulnerability (likelihood). It also shows which critical assets remain critical for longer indicated by having a larger score in the Period Following and Return to Normal columns.

Table 6. Critical Asset Class Impact Ranking

Network	Type	Component	During Event	Immediately After	Period Following	Return to Normal	Total Score
Transportation	Arterial Pavements	Welcome Bay Rd	82	60	44	34	220
Transportation	Arterial Pavements	Chapel Street	73	54	43	34	204
Transportation	Arterial Pavements	Papamoa Beach Road 2	66	49	39	32	186
Wastewater	Treatment Plant	Chapel St - Overload	57	49	44	33	183
Wastewater	Reticulation - Gravity	Trunk Main Overload	53	54	45	30	182
Wastewater	Treatment Plant	Te Manga - Overload	56	49	44	33	182
Transportation	Bridges	Chapel Street Bridge	61	51	39	30	181
Transportation	Arterial Pavements	Papamoa Beach Road 1	64	47	37	31	179
Wastewater	Pump Stations	Pump Stations - Western Major L	61	47	40	29	177
Transportation	Arterial Pavements	Maunganui Road	62	45	35	30	172
Etc							

2.8 Limitations in Identifying Disaster Event Scenarios

Since the study above it has been noted that although a coordinated analysis of site vulnerability has taken place and critical response plans have been identified, there are still events that have not been planned for. This is evident in the event of 5 October 2011 where the container ship, Rena, ran aground on the Astrolabe Reef in the Bay of Plenty posing a threat of spilling its cargo including 1,700 tonnes of oil.

Although this event was not part of the vulnerability analysis, the resulting emergency response plans provided the thought processes for organising clean-up and support teams. At the height of the response approximately 600–800 people were involved in the oil spill response team including those that produced refreshable GIS maps of the disaster location and hazard areas as seen below.

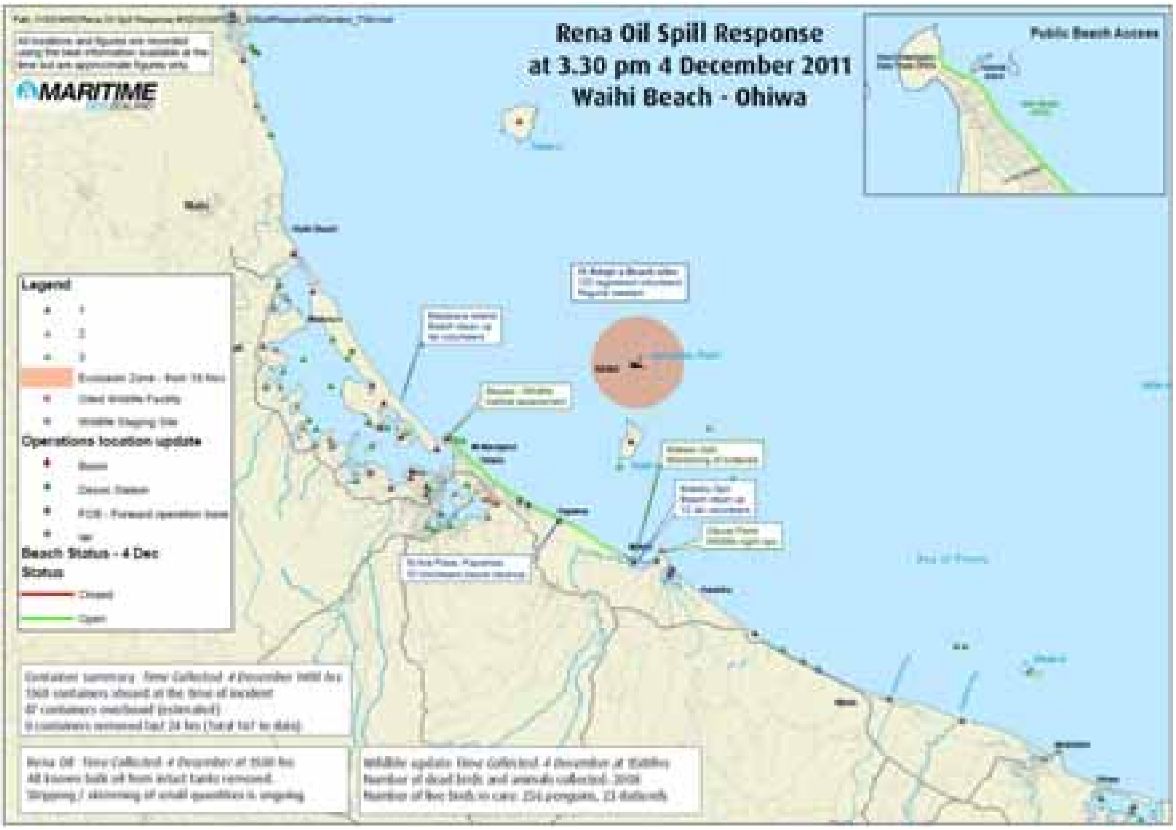

Figure 11. Rena Oil Spill Disaster Location (source: Maritime New Zealand)

3. Conclusion

With the majority of the world's population living in urban environments dependency on our built infrastructure will continue to escalate, along with the consequences of major failures. In order to meet this challenge, there needs to be a new approach and new responsibilities to address the resilience of the integrated infrastructure.

This represents a major change over current autonomy practices in that resilience should be a combined assessment across all types of infrastructure. Nor is this confined to the provision of new infrastructure but needs to address the ongoing maintenance and replacement of existing infrastructure, such that fundamental weaknesses from an integrated perspective are not perpetuated simply because they are inherited.

It is evident that a collective responsibility will have to be applied and possibly achieved through an overseeing authority, one that can regulate the interests of the stakeholders with the sustainability imperatives for the community.

4. Acknowledgements

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6. Biography

Julian moved to the UK from GHD New Zealand with 10 years spatial sciences experience and eight years focused on holistic asset management across multiple portfolios. Julian's emphasis is on improvement planning to link strategy to people, knowledge, data and system enablers, optimising service delivery processes and cross-network geospatial modelling.