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25 February 2016

Waimakariri District Council
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Dear Kirsten

Waimakariri District Council (WDC) Kaiapoi Red Zone Engineering Feasibility Peer Review
Our Ref: 250806

1 Executive Summary

Waimakariri District Council (WDC) is proposing to redevelop the Kaiapoi Residential Red Zone land which includes five areas earmarked for regeneration; Kaiapoi North residential development, Courtenay Drive residential development, Kaiapoi West commercial development, Kaiapoi North commercial development, and Kaiapoi Southeast commercial development. Tonkin and Taylor Limited (T&T), working for WDC, have completed an initial engineering feasibility study to assess the redevelopment potential from a technical perspective. The assessment and findings are presented in their report, "Kaiapoi Red Zones – Engineering Feasibility of Potential Land Uses, Stage 1 Report", Report Ref 52082.030.v3, dated January 2016:

WDC has engaged Aurecon to undertake a high level technical review of the T&T (2016) report with particular regard to input assumptions, key findings, and recommendations for each of the five regeneration areas.

Based on our review, we consider the T&T (2016) assessment to be reasonable and highlights the main project risks and uncertainties. We agree with T&T conclusions, that from an engineering perspective, it is feasible to undertake the proposed redevelopment in the different areas using readily available construction techniques around Christchurch. However, we believe that some items need to be clarified and explored to help WDC better understand the economic feasibility of the redevelopment. The main items to be explored prior to finalising cost estimates are:

- Flood level requirements and site wide flood management strategy.
- Extent of land contamination and associated construction risks. We believe that costs associated with remediation or disposal of contaminated fill should be added to the 'over and above' costs.
- Acceptable degree of damage where no ground improvement (including lateral spreading mitigation) is proposed by T&T such as under yard based commercial or rural/residential development. We also note that some yard-based commercial uses may not be suitable in areas where flood inundation, lateral spreading, and liquefaction induced land damage can occur on a semi-regular basis.

- The use of dynamic compaction for ground improvement near residential areas should be very carefully considered due to its disruptive nature, expected vibration and noise levels, and lower effectiveness in silty soils with high groundwater table.
- The effectiveness of relatively thin gravel fill (without ground improvement) in Area A to create a target TC2 building platform will need to be further supported. This is based on our understanding that SLS level settlements are up to 140mm in places and occur in the upper 6m to 8m depth.
- The potential for compounding traffic volumes should development on several Areas occur in parallel. We suggest to determine the impact onto the roading network and the effect of high traffic volumes on the wider community.
- Where no ground improvement is proposed, the areas are likely to experience similar post-earthquake settlement under a moderate earthquake to those experienced during the Canterbury Earthquake Sequence and we recommend that this settlement is allowed for when assessing final building platform levels.
- WDC should review the implications of adopting gravity systems in rural residential areas without ground improvement. Alternative solutions such as onsite site effluent disposal systems with drip irrigation may be more resilient and cost effective to build and maintain.
- We have reviewed the development costs and believe that they provide representative values and are in line with good industry practice.
- T&T mention further work streams to reduce uncertainties and to provide further surety around cost. We believe that the suggested approach is reasonable.

In summary, we believe that the T&T report presents a well thought through technical analysis of the concept and the scope covered is well suited for a feasibility study.

2 Introduction

Waimakariri District Council (WDC) has prepared a Draft Recovery Plan for the Residential Red Zone in the Waimakariri District focused on Kaiapoi, Pines Beach, and Kairaki. Tonkin and Taylor Limited (T&T), working for WDC, undertook an initial engineering feasibility assessment of the development of the residential red zones around Kaiapoi. Details of T&T assessment is included in their report, "Kaiapoi Red Zones – Engineering Feasibility of Potential Land Uses, Stage 1 Report", Report Ref 52082.030.v3, dated January 2016.

Waimakariri District Council (WDC), via their project managers Beca, have engaged Aurecon to undertake a high level technical review of the T&T (2016) engineering feasibility study with particular regard to the following:

- Input assumptions
- Key findings and recommendations for each of the five regeneration areas

The detailed scope of our work is included in our engagement letter dated 10 February 2016. Approval to proceed was given via signed Short Form Agreement from WDC dated 12 February 2016. This report letter summarises the peer review of the engineering feasibility study undertaken by T&T (2016). Our limitations are attached as Section 14 of this report and the report shall be read as a whole.

3 Information Provided

The following reports and information has been provided by WDC and T&T for the peer review:

- Tonkin and Taylor (2016), Kaiapoi Red Zones Engineering Feasibility of Potential Land Uses – Stage 1 Report, Report Ref 52082.030.v3, dated January 2016.
- ECan (2008), Waimakariri District Flood Hazard Management Strategy Ashley River Floodplain Investigation – Figures 4, 5, 7, 8, 9, 11, 12, 17, and 18, dated June 2008.
- Waimakariri District Council Flood Maps for Kaiapoi – 100 year ARI, 200 year ARI, and 500 year ARI, dated 11 February 2015.

We have also accessed readily available information on the Canterbury Geotechnical Database (CGD) and Environment Canterbury (ECan) online database for the peer review.

4 Extent of Development Zones Considered

The five regeneration areas considered in this report are the development Zones A to E as identified in Figure 3.1 of T&T (2016) report. We also understand the following based on T&T (2016) report:

- Residential development is proposed for Areas A and B.
- Commercial development is proposed for Areas C, D, and E.

We understand that the two unlabelled red zones on Figure 3.1 are reserved for stormwater and floodplain management purposes to offset effect of placing fill in the red zone development areas.

5 Background Geotechnical Review and Analysis

We have reviewed readily available geotechnical information on the Canterbury Geotechnical Database and undertaken liquefaction assessment of selected CPT data to gain a better understanding of ground conditions in the various development zones, site performance to date, and liquefaction potential in future SLS, ILS and ULS level earthquakes. Our review is summarised in the sections below.

5.2 Level of shaking in previous earthquakes

The CGD indicates the following levels of shaking have been experienced at the site to date:

		Area A	Area B	Area C	Area D	Area E
4 Sept 2010 EQ (M_w7.1)	Distance from epicentre	~43km NE	~43km NE	~42km NE	~43km NE	~43km NE
	Median PGA on site	0.21g – 0.25g	0.20g – 0.22g	0.22g – 0.23g	0.22g – 0.24g	0.22g
	Equivalent PGA for M_w7.5	0.19g – 0.22g	0.18g – 0.20g	0.20g – 0.21g	0.20g – 0.22g	0.20g
22 Feb 2011 EQ (M_w6.2)	Distance from epicentre	~22km N	~22km N	~22km N	~22km N	~22km N
	Median PGA on site	0.18g – 0.19g	0.18g – 0.19g	0.18g – 0.19g	0.18g – 0.19g	0.18g – 0.19g
	Equivalent PGA for M_w7.5	0.13g – 0.14g	0.13g – 0.14g	0.13g – 0.14g	0.13g – 0.14g	0.13g – 0.14g
13 Jun 2011 major aftershock (M_w6.0)	Distance from epicentre	~22km NW	~21km NW	~22km NW	~22km NW	~21km NW
	Median PGA on site	0.10g	0.10g	0.10g	0.10g	0.10g
	Equivalent PGA for M_w7.5	0.07g	0.07g	0.07g	0.07g	0.07g
23 Dec 2011 major aftershock (M_w5.9)	Distance from epicentre	~17km NW	~17km NW	~18km NW	~17km NW	~17km NW
	Median PGA on site	0.15g – 0.16g	0.15g – 0.16g	0.15g – 0.16g	0.15g – 0.16g	0.15g – 0.16g
	Equivalent PGA for M_w7.5	0.10g – 0.11g	0.10g – 0.11g	0.10g – 0.11g	0.10g – 0.11g	0.10g – 0.11g

Notes:

- PGA on site based on median values of the study by Bradley Seismic Limited as published on the CGD. It is possible that the model underestimates PGA experienced at the site.
- Equivalent PGA for Mw7.5 event based on method of Idriss and Boulanger (Idriss, I.M and Boulanger R.W, 2008)

The site has therefore only experienced above SLS level earthquake shaking, potentially equivalent to an ILS (Intermediate Level State) event. The levels of shaking experienced to date are not close to an ULS level earthquake.

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5.3 Ground Conditions

The following ground conditions have been assessed for each development zone.

Development Zone	Ground Conditions	General Comments
A	Interbedded layers of loose to medium dense silt, sand and sandy gravel/gravelly sands to approximate 6m depth across majority of the site. The interbedded sand/silt/gravelly sand layers are underlain by medium dense to dense sand and gravel to minimum 10m depth.	Recorded SPT N values generally greater than 25 below 6m/8m.
B	Stratigraphy similar to Area A. Groundwater table generally measured below 1m depth	Historical river channels likely present beneath the area in places (e.g. Wotherspoon et al, 2013).
C	Interbedded layers of loose to medium dense silt, sand and gravelly sands to approximate 9m depth. The interbedded sand/silt/gravelly sand layers are underlain by medium dense to dense sand and gravel to minimum 15m depth investigated.	Silt is generally soft between 7m and 9m with recorded SPT N values of 0.
D	Ground conditions are similar to Area A. We note from large ground improvement works nearby that the subsoil layers are variable in both vertical and horizontal extent.	Recorded SPT N values generally greater than 25 below 6m.
E	Interbedded layers of loose to medium dense silt, sand and sandy gravel/gravelly sands to approximate 6m depth across majority of the site. The interbedded sand/silt/gravelly sand layers are underlain by medium dense to dense sand and gravel to minimum 10m depth.	Recorded SPT N values generally greater than 25 below 5m/8m.

Groundwater was generally measured between 0.5m to 1.5m across the sites from 2011 to 2015. We note that there are both seasonal fluctuations and tidal influence from the nearby Kaiapoi River.

5.4 Nature of land damage in previous earthquakes

All areas experienced significant vertical settlement and lateral spreading manifesting as numerous large cracks across the sites. An aerial view of the crack patterns indicates that damage was heavily influenced by significant lateral spreading and in case of Area E, there are signs of incipient significant lateral spreading of the entire block. As noted above, the level of shaking was just above an SLS level earthquake but significantly less than ULS level shaking. We infer that the ground damage in all affected areas will be worse should stronger and prolonged shaking occur. We also note that Kaiapoi was affected by significant land damage from past earthquakes.

5.5 Degree of Liquefaction Induced Settlement

Our review of liquefaction induced settlement (in absence of further settlement due to lateral spreading) for the different development zones under both SLS and ULS level earthquake shaking is presented below. We have undertaken analysis based on randomly selected CPT data from the areas to assess accuracy of the CGD information.

Development Zone	SLS level EQ settlement	ULS level EQ settlement
A	30mm to 140mm	50mm to 200mm
B	20mm to 90mm (less than 5mm in one location)	40mm to 120mm (less than 5mm in one location)
C	70mm to 160mm	140mm to 170mm
D	40mm to 90mm (locally up to 140mm along river edge)	70mm to 150mm
E	20mm to 140mm (locally less than 5mm)	60mm to 170mm (locally less than 20mm)

Notes:

- *The liquefaction generally occurs in the loose to medium dense sand and silt layers in the upper 8m profile.*
- *Degree of differential settlement could be similar to total settlement due to variability of depth and strength of intermediate gravel layers, and/or presence of historical river channels.*

Based on the above results, we believe that the sites are all highly susceptible to liquefaction induced settlement which in turn will cause land damage. We understand that T&T have found similar results which in part led to red zoning of the land by the Central Government.

6 Review – Key Technical Assumptions (Section 2; T&T, 2016 report)

6.1 Residential Development Scenarios

T&T (2016) assumes two residential development scenarios; Rural-residential and Urban-residential. We consider the key features assumed for each development scenario to be reasonable but recommend WDC reviews the assumption that rural-residential land will predominantly remain at existing ground level with predicted flood recurrence intervals less than 100 years. There is an implicit assumption that such level of flooding is acceptable for rural/residential development. We recommend WDC reviews the implications of allowing new residential development where flood risk is considered to be high without appropriate flood protection measures. We note that T&T assumes that the actual dwellings will be on an elevated platform above flood level which provides a sanctuary for the residents in case of flooding and also provides amenity around dwellings.

6.2 Commercial Development Scenarios

T&T (2016) assumes two commercial development scenarios; Yard-based commercial and Large-format retail. We consider that key features assumed in each scenario to be reasonable provided WDC reviews the implication of allowing re-development without flood management measures in case of Yard-based commercial where T&T is proposing redevelopment without raising existing ground levels.

We note that some yard based commercial uses may not be suitable in areas where flood inundation, lateral spreading and liquefaction induced land damage can occur on semi-regular basis.

6.3 Target Land Performance (Earthquake Damage)

6.3.1 Residential Lots

- MBIE TC2 type land performance target is considered reasonable for residential developments.
- Area wide ground improvement, as proposed by T&T, is likely to be the most practical and cost effective approach to manage liquefaction for urban-residential areas due to the high density of proposed development. In rural-residential areas, localised ground improvement and setting dwelling as far back as possible from the lateral spreading free faces is also considered reasonable.

6.3.2 Commercial Developments

- T&T (2016) target land performance for Yard-based commercial scenarios and carpark areas for large format retail scenario is to provide only suitable static bearing capacity with no regard to future liquefaction susceptibility and/or damage. Noting that the areas underwent significant damage during previous earthquakes that were generally similar to an SLS level earthquake, we recommend WDC to consider whether this is reasonable due to the expected frequency of damage. We also note that post-earthquake consolidation settlement is likely to worsen the already high flooding risk.
- T&T (2016) target performance for building footprints in the large-format retail scenario is acceptable.

6.3.3 Underground Service Corridors

T&T (2016) assumptions are reasonable but we recommend WDC reviews implication of adopting gravity systems without ground improvement where proposed in rural-residential areas. As noted in T&T (2016) report, WDC may wish to consider alternatives to the gravity sewer system to minimise required level of ground improvement. Alternative solutions such as onsite effluent disposal systems with drip irrigation may be more resilient and cost effective to build and maintain.

6.4 Infrastructure

T&T (2016) assumptions are reasonable but recommend WDC notes likelihood of increased stormwater discharge to surrounding green zones where new land is raised and adjacent roads/land is not raised. We acknowledge T&T (2016) assumption that all stormwater will drain to new stormwater management system as part of sitewide development.

6.5 Flooding

With the exception of flood maps provided to Aurecon, we have not reviewed existing flood management studies and/or reports to better understand effectiveness of the existing flood management strategies around Kaiapoi such as existing stop banks particularly as the stop banks are likely to have settled following the earthquakes of the Canterbury Earthquake Sequence.

T&T (2016) have indicated that implementation of engineering measures (Section 2.5.1 of the report) is likely to be less effective and they have therefore assumed that flood management is likely to comprise a combination of raising the land to above level of frequent flood events (e.g. 50 year event) and constructing buildings with floor levels above extreme flood events (e.g. 200 year event), and/or adopting land uses that are more tolerable to impacts of flooding such as sports fields or market gardens. While we have no objections to the assumption since the land may require raising to create a non-liquefiable crust, we recommend review of adopting engineering measures to minimise flooding risk for areas where no fill is proposed.

T&T(2016) has adopted the WDC flood model results for the *'200-year ARI event South Ashley 2015 scenario"* to estimate fill level required to meet consenting requirements for flood and dwellings. Our review of the supplied flood map indicates average depths of at least 1m across the development areas. While we consider this to be a reasonable assumption for the initial high level study, consideration could be given to adopting less stringent land requirements outside of high density residential or commercial zones.

We note that no consideration was given for land settlement arising from future earthquake shaking. In areas where lateral spreading mitigation measures would be implemented this may reduce the magnitude of settlement but areas with no ground improvement are likely to experience very similar post-earthquake settlement to those values noted from the Canterbury Earthquake Sequence.

6.6 Coastal Erosion and Inundation, Tsunami

We consider T&T (2016) assumption that coastal erosion and inundation or tsunami is unlikely to be the governing case for setting minimum ground and floor levels for the new residential or commercial developments to be reasonable. This is because the risk, if any, is not unique to the red zones but include adjacent green zones based on review of surrounding ground levels and river systems. We assume that the effects of coastal erosion and inundation or tsunami if any for the wider Kaiapoi area will be reviewed in the future and note that Environment Canterbury has several research studies on this topic.

6.7 Construction Cost Estimates

6.7.1 Costs "over and above" normal construction work

We consider T&T (2016) assumption in which providing development costs that are over and above the normal land development construction work as acceptable. These costs show a comparison of additional costs which could potentially be incurred for raising land to deal with geotechnical and flooding issues, which other land development projects may not necessarily need to consider.

However, given that all of the proposed development sites can be considered 'brown field' sites due to past land use, we suggest to add the environmental land management costs to the 'over and above' construction costs. We note that T&T have considered contaminated land management cost elsewhere, but were unable (and justly so) to quantify the magnitude of costs due to lack of field testing.

We suggest that WDC consider environmental land management (contaminated land) costs alongside costs for mitigation measures to reduce the impact from seismic shaking.

6.7.2 Confidence Range

The use of "Confidence Range" is an acceptable measure of quantifying risk given that the report is of a broad nature to give WDC initial insight to conditions which should be considered in the land development of areas within Stage 1.

However, we caution against using optimistic scenario cost estimates after a prolonged period following the issue of the report as construction cost can rapidly escalate. Further we note that geotechnical engineering projects have the tendency to uncover unforeseen ground conditions, are affected by plant and equipment failures or delays and can be affected by adverse weather. This in many instances impacts on the project programme and cost.

7 Review – Kaiapoi North Residential Development (Area A).

7.1 Preliminary general land use outline plan

The land use outline plan (Figure 4.1) shows the land to the south of Cass Street including majority of development zone D reserved for stormwater and floodplain management. This assumption may be in conflict with designation of Zone D as commercial land as set out elsewhere in the report. We therefore recommend clarification with T&T.

7.2 Key technical considerations

7.2.1 Geotechnical

We consider T&T assessment and considerations for land to the north of Cass Street is reasonable.

T&T assessment for the south of Cass Street is reasonable provided WDC appreciates that repair works will likely be required for all events not too dissimilar to shaking that occurred during the 4 September 2010 earthquake and 22 February 2011 earthquake. WDC should also accept that in such events not too dissimilar to an SLS level earthquake, level of damage is likely to be similar to what occurred during the 4 September 2010 earthquake or 22 February 2011 earthquake is to be expected.

7.2.2 Flooding

T&T (2016) indicates that there is still considerable uncertainty regarding consentable minimum land and floor levels. The latest modelling by WDC shows flooding covering the entire Area A red zone with flood depths ranging between 0.5m to greater than 1.0m. We therefore recommend that WDC confirms consentable land and floor levels level to reduce the uncertainty which follows through engineering solutions and costings. T&T has currently assumed fill levels ranging between 2.0mRL to 2.8mRL which we consider reasonable based on available flood modelling and in absence of specific guidance from WDC. Fill levels up to 2.8mRL (Lyttelton Vertical Datum) assume up to 1.8m fill based on LiDAR levels around the site of between 1.0mRL and 1.5mRL.

We suggest to consider land settlement arising from future earthquake events to be added to the flood level inundation minimum reduced levels. The magnitude of this shall be discussed with T&T and based on best estimate over say 50 years (defined as the lifetime of residential buildings as per NZ Building Code).

7.2.3 Ground Contamination

T&T (2016) has raised the potential risk of ground contaminations particularly from asbestos contaminated demolition fill. This risk has however not been quantified at this stage and there does not appear to be a basis for assumptions regarding extent of contaminated ground adopted for the study. We recommend, as a minimum, an environmental desktop study to qualify the likely extent of contamination assumed in the current report. We note that the degree of contamination is likely to influence cost and therefore the re-development strategy. As noted earlier we suggest that cost dealing with contamination is considered as part of the ‘over and above‘.

7.3 Preliminary land improvement outline plan

We make the following comments regarding proposed improvement outline plan and proposals there in:

- Based on our understanding that SLS liquefaction induced vertical settlement can be up to 140mm in places, liquefaction occurring in the upper 6m to 8m depth, and up to 200mm ground cracks were recorded in previous SLS level earthquake, the proposed sitewide engineered fill (up to 1.75m thick) for the urban-residential scenario may not result in an MBIE

TC2 equivalent building platform. The engineered fill is however expected to significantly reduce expected differential settlements resulting in more cost effective specifically engineered foundation systems. We recommend that the wider design team explores incorporating a geogrid raft across the base of the entire platform if the fill is thin, say less than 1.5m, to minimise cracking migrating to the top of engineered fill and affecting the building foundations. To create a TC2 building platform, we believe the thickness of fill may need to be increased and/or some form of ground improvement similar to that proposed for rural residential scenario adopted. We note that either alternatives may have their challenges as higher fill may lead to slope instability along the edge that needs to be mitigated while ground improvement beneath the fill may add to costs.

- For rural-residential scenario, proposed solutions comprising stone columns with an overlying gravel raft are expected to result in a TC2 equivalent performing building platform.
- We do not consider the use of biaxial geogrid along slopes (Figure 52082.0300-F3) to be effective in preventing slope movement (surficial slip failure or deep failure). The slope is relatively shallow with slope gradients of 1:5 to 1:10. If steeper slopes are considered such as 1:2 we would recommend uniaxial geogrids are adopted for design or biaxial geogrid with the principal strength being in cross-machine direction. At this stage, we consider that biaxial geogrids are unlikely to be required for such shallow slopes provided the basal geogrid reinforcement is appropriately designed and specified.
- It is not clear whether there has been allowance for detailing required between transition of underground services supported on proposed ground improved soils and services into which they connect in the green zone which are not supported on ground improved soils.

7.4 Potential civil engineering effects on neighbouring areas

We consider that Table 4.1 generally summarises the main impacts due to the new development. Specific comments to subsections 4.4.1 and 4.4.2 of T&T report are presented below.

7.4.1 Exacerbation of flooding elsewhere

Aurecon has not sighted all the information upon which conclusions in Section 4.4.1 of T&T (2016) report are based to help comment on findings/conclusions. We note that the overall philosophy adopted by T&T is based on sound engineering principles.

7.4.2 Construction Traffic

Construction traffic is estimated to be between 20-40 truck movements per day over a three to five year period. We consider this number of movements to be realistic but we note that T&T have assumed that some site won fill will be used and this is not accounted in the traffic volumes above. T&T have assumed that fill will be won from the Waimakariri River and is a suitable source of gravel, however, this may not be the only source due to demand.

The assumption of construction traffic preferring Smith Street as the access route to the site is highly likely. Given this, whichever route is used, the additional heavy vehicles will significantly increase road maintenance requirements and WDC need to consider these costs which have not been quantified in T&T report. We also note that further heavy traffic (say 4 truck and trailer movements per hour for several years) will decrease amenity for the community.

7.4.3 Dynamic Compaction for Ground Improvement

We note that T&T suggest to use dynamic compaction plant near current residential areas. Based on our experience with ground improvement in the Canterbury area over the past five years, we caution

against the use of dynamic compaction as this will have a significant effect on the adjacent community. Our work at Prestons Road subdivision also indicated that silty soils may only marginally benefit from dynamic compaction such as square roller compaction plant.

It should therefore be noted that while dynamic compaction may be effective to reduce the liquefaction susceptibility, it is a greatly disruptive process and it will affect the community.

7.5 Preliminary estimate of land improvement costs and timeframe

We have considered the quantities and associated costs used in the T&T (2016) report. This report is at feasibility stage and several assumptions have been made which are typical at this early stage of investigations. The earthwork volumes are shown in a broad range which has a direct impact on the costs being reported. The broad range used is to encompass the risk of an undetermined safe flood level.

Assessment of earthwork volumes are appropriate for the assumed estimated cut to fill volume and estimated cut to waste volume.

We consider T&T's cost estimates to be slightly elevated by approximately 20%. However, we did not consider any potential cost which may be necessary for ensuring that the civil infrastructure such as stormwater and sewer pipes are robust enough for the geology of the area. These costs could potentially be quite substantial if it is deemed suitable to protect the infrastructure from future seismic events.

Overall we believe the volumes and costs given in the report are a fair representation of the proposed development plan given the report is an initial assessment of engineering feasibility.

7.6 Discussion

We agree with T&T conclusions that, from an engineering perspective, it is feasible to undertake land improvement works to enable residential development in Zone A using readily available construction techniques around Christchurch. However, we believe that some items need to be clarified and further explored to help WDC better understand the economic feasibility of the project. The main items to explore include degree of land contamination from past use and potential remediation costs, flood level requirements including an understanding of whether existing stop banks have been included in the current model, resilience considerations to account for future land settlement following strong seismic shaking, and extent of ground improvement across the site and along the edges to create a TC2 platform as proposed under assumptions.

7.7 Next steps

T&T (2016) have identified five areas of further investigation:

i) Flood level requirements
ii) Contaminated soil quantities
iii) Cut to fill quantities from basin constructions
iv) Dynamic compaction use in semi urban environment
v) Providing further details for rural residential foundation costs

We believe that T&T have identified the five important aspects which would require further investigations as to establish a more conclusive construction cost estimate.

8 Review - Courtenay Drive residential development (Area B)

8.1 Preliminary general land use outline plan

Ground improvement using deep stone columns to the east and north of Courtenay Drive is considered reasonable noting that significant damage in this area was due to lateral spreading. We consider that T&T's pessimistic option is likely to be the most likely option based on observed damage in previous earthquakes of the Canterbury Earthquake Sequence.

We also note that there are historical river channels across the site (e.g. Wotherspoon et al, 2013) and we recommend that T&T carefully considers the appropriateness of the proposed shallow gravel raft to mitigate effects of differential settlements without having basal geogrid extending across the entire footprint of the proposed earthworks area (as we understood the concept from the supplied drawings).

8.2 Key technical considerations

8.2.1 Geotechnical

We consider overall T&T assessments to be reasonable but the potential impact of historical river channels within the area should be well qualified/quantified/addressed to minimise potential differential settlement in future large earthquakes and propagation of cracks to the surface.

8.2.2 Flooding

T&T (2016) indicates that there is still considerable uncertainty regarding consentable minimum land and floor levels. The latest modelling by WDC shows flooding covering the entire Area B red zone with flood depths ranging between 0.5m to greater than 1.0m. We therefore recommend that WDC confirms consentable land and floor levels to reduce the uncertainty which follows through engineering solutions and costings. T&T has currently assumed fill levels ranging between 2.6mRL to 3.5mRL which we consider reasonable based on available flood modelling and in absence of specific guidance from WDC. Fill levels up to 3.5mRL (Lyttelton Vertical Datum) assume up 2m fill based on LiDAR levels around the site of between 1.5mRL and 2.3mRL.

8.2.3 Ground Contamination

Based on our understanding that the Courtenay Drive was developed relatively recently including placement of fill across the site, we consider T&T preliminary assessment of likelihood of contamination to be appropriate. Nevertheless, we recommend WDC to allow high level contamination assessment to inform subsequent stages and potential risks.

8.3 Preliminary land improvement outline plan

We make the following comments regarding proposed improvement outline plan and proposals there in:

- There are historical river channels across proposed development zone and we recommend that the wider design team explores incorporating a geogrid across the base of the entire platform to minimise differential settlement and potential cracks migrating to the top of engineered fill.
- For rural-residential scenario, proposed solution comprising stone columns with an overlying gravel raft is expected to result in a TC2 equivalent platform. The stone columns are however unlikely to extend to 8m depth due to presence of dense intermediate gravel layer at approximate depth of 6m below ground level.
- We do not consider the use of biaxial geogrid along slopes (Figure 52082.0300-F3) to be effective in preventing slope movement (surficial slip failure or deep failure) and we

recommend that uniaxial geogrids are adopted if considered necessary for design. It could though be argued that the biaxial geogrids are probably not required for such shallow slopes provided the basal geogrid is appropriately designed and specified.

- Due to presence of intermediate dense gravel layers, we recommend that any costs of stone column installation to 8m allow for potential increase in installation time than on a normal site.

8.4 Potential Civil Engineering effects on neighbouring areas

We consider that Table 5.1 generally summarises the main impacts due to the new development. Specific comments to subsections 5.4.1 and 5.4.2 of T&T report are presented below.

8.4.1 Exacerbation of flooding elsewhere

Aurecon has not sighted all the information upon which conclusions in Section 5.4.1 of T&T (2016) report are based to help comment on findings/conclusions. We note that the overall philosophy adopted by T&T is based on sound engineering principles.

8.4.2 Construction Traffic

Construction traffic is estimated to be between 6 - 13 truck movements per day over a two to three year period. We consider this number of movements to be a realistic view. T&T have assumed that fill will be won from the Waimakariri River and is a suitable source of gravel, however, this may not be the only source due to demand.

The assumption of construction traffic preferring Ohoka Road as the main access route to the site is highly likely. Given this, whichever route is used, the additional heavy vehicles will significantly increase road maintenance requirements and WDC need to consider these costs which have not been quantified in T&T's report.

8.5 Preliminary estimate of land improvement costs and timeframe

We have considered the quantities and associated costs used in T&T (2016) report. Due to the degree to which the report is commissioned, several assumptions have been made which are typical at this early stage of investigations. The earthworks and ground improvement costs are shown in a broad range, to assimilate the unknown extent and intensity of deep ground improvements required to mitigate lateral spreading of the land.

Our assessment of earthwork volumes and assumed ground improvement are appropriate for the area of land.

We consider T&T's cost estimates to be slightly elevated by approximately 15%. However, it is difficult to determine the cost involved with deep ground improvements as it is not a widely used system in the Canterbury region.

Overall we believe the volumes and costs given in the report are a fair representation of the proposed development plan given the report is an initial assessment of engineering feasibility.

8.6 Discussion

We agree with T&T conclusions that, from an engineering perspective, it is feasible to undertake land improvement works to enable residential development within Zone B using readily available construction techniques around Christchurch. However, we believe that some items need to be clarified and/or explored to help WDC better understand the economic feasibility. The main items to explore include flood level requirements including an understanding of whether existing stop banks have been included in the current model, effect of historical river channels to proposed development, resilience considerations to account for future land settlement following strong seismic shaking, and

added construction time/cost of installed stone columns through intermediate dense gravel layer to intended design depth.

8.7 Next steps

T&T (2016) have identified further areas for investigation if WDC were to establish a more conclusive cost of construction. They are briefly described below:

As deep ground improvements are required to mitigate lateral spreading of land, and these are seen as significant costs, T&T has recommended that further geotechnical investigations be undertaken to determine a more precise ground improvement requirement, and consequently a more precise cost is derived. We agree with this approach and suggest that laboratory data is also collected.

Flood levels and flood paths have not been definitively defined. This influences flood paths and the amount of imported fill required. Therefore T&T have recommended that the modelling of flood waters be undertaken to define fill level and flood paths, which will in turn define the amount of fill required and consequently the cost involved.

Contaminated soils for the site have not been quantified and this will influence the overall construction cost. T&T have recommended further investigation to quantify the amount of contaminated soil for cost estimation, which we see as beneficial for WDC.

9 Review – Kaiapoi West commercial development (Area C)

9.1 Preliminary general land use outline plan

We consider the general concepts and outline to be reasonable provided WDC accepts that level of damage similar to that which occurred during 4 September 2010 and 22 February 2011 earthquake will be expected in earthquake levels not to dissimilar to SLS level event and repairs will be required to the areas that are not improved.

9.2 Key technical considerations

9.2.1 Geotechnical

T&T has highlighted the key technical considerations and proposed engineering works are reasonable.

9.2.2 Flooding

T&T (2016) indicates that there is still considerable uncertainty regarding consentable minimum land and floor levels. The latest modelling by WDC shows flooding covering the entire Area C red zone with flood depths greater than 1.0m. We therefore recommend that WDC confirms consentable land and floor levels to reduce the uncertainty which follows through engineering solutions and costings. T&T has currently assumed fill levels ranging between 3.45mRL to 3.7mRL which we consider reasonable based on available flood modelling and in absence of specific guidance from WDC. Fill levels up to 3.7mRL (Lyttelton Vertical Datum) assume up 2m fill based on LiDAR levels around the site of between 1.7mRL and 2.0mRL.

9.2.3 Ground Contamination

T&T (2016) has raised the potential risk of ground contaminations particularly from asbestos contaminated demolition fill. This risk has however not been quantified at this stage and there does not appear to be a basis for assumptions regarding extent of contaminated ground adopted for the study. We recommend, as a minimum, an environmental desktop study to qualify the likely extent of contamination assumed in the current report. We note that the degree of contamination is likely to significantly influence cost and the re-development strategy.

9.3 Preliminary land improvement outline plan

We consider T&T (2016) land improvement proposals for the large-format retail to be reasonable and ground improvement if implemented across the length of the river front is likely to minimise damage from lateral spreading which was one of the main failure mechanisms for the block. We note that the lateral spreading ground improvement works may need to extend across Rich Street and Black Street to minimise potential for recurrence of wider block failure identified in the earthquakes of the Canterbury Earthquake Sequence. We also note that the ground improvement may need additional shear resistance to be able to retain the large soil block and Deep Soil Mixing columns may be preferred to simple stone columns.

In terms of yard-based commercial scenario, WDC should note that if no ground improvement is undertaken including measures to minimise lateral spreading potential, damage similar to that which occurred in the Canterbury Earthquake Sequence is to be expected in earthquakes not too dissimilar to SLS level.

We also note our previous comments regarding geogrid detailing for proposed shallow embankment slopes where adopted.

9.4 Potential civil engineering effects on neighbouring areas

We consider that Table 6.2 generally summarises the main impacts due to the new development. Specific comments to Subsections 6.4.1 and 6.4.2 of T&T report are presented below.

9.4.1 Exacerbation of flooding elsewhere

Aurecon has not sighted all the information upon which conclusions in Section 6.4.1 of T&T (2016) report are based to help comment on findings/conclusions. We note that the overall philosophy adopted by T&T is based on sound engineering principles.

9.4.2 Construction Traffic

Construction traffic is estimated to be 10 truck movements per day over a nine month period. We consider this number of movements to be a realistic view. T&T have assumed that fill will be won from the Waimakariri River and is a suitable source of gravel, however, this may not be the only source due to demand.

The assumption of construction traffic preferring Ohoka Road as the main access route to the site is highly likely. Given this, whichever route is used, the additional heavy vehicles will increase road maintenance requirements and WDC need to consider these costs which have not been quantified in T&T's report.

9.5 Preliminary estimate of land improvement costs and timeframe

A large portion of construction cost is the proposed deep ground improvements. Given it is not yet precisely ascertained the exact requirements for deep ground improvements to mitigate lateral spreading, it is difficult to state that the figures given in the T&T report are a reasonable representation of the work required for land development. However, the report does give an "over and above" construction cost range between $5.0M and $7.2M (Large-format retail) which is a spectrum we believe is broad enough to accommodate for the majority of uncertainties.

Construction duration for land improvements (over and above), depending on scenario, should be able to be completed in 12 months.

9.6 Discussion

We agree with T&T conclusions that, from an engineering perspective, it is feasible to undertake land improvement works to enable commercial development within Zone C using readily available construction techniques around Christchurch. However, as highlighted by T&T, we believe that some items need to be clarified and explored to help WDC better understand the economic feasibility. The main items to explore include flood level requirements including an understanding of whether existing stop banks have been included in the current model, whether damage levels are acceptable for yard-based commercial where no ground improvement and/or lateral spreading measures are undertaken, and extent/degree of contamination.

9.7 Next steps

T&T (2016) have identified further areas for investigation if WDC were to establish a more conclusive cost of construction. They are briefly described below:

As deep ground improvements are required to mitigate lateral spreading and differential settlement of land, and these are seen as significant potential costs, T&T has recommended that further geotechnical investigations are undertaken to determine a more precise ground improvement requirement and consequently derive a more precise cost.

Flood levels and flood paths have not been definitively defined. This influences flood paths and the amount of imported fill required. Therefore T&T have recommended that the modelling of flood waters be undertaken to define fill level and flood paths, which will in turn define the amount of fill required and consequently the cost involved.

Contaminated soils for the site have not been quantified. This will influence the overall construction cost. T&T have recommended further investigation to quantify the amount of contaminated soil for cost estimation, which we see as beneficial for WDC.

10 Review – Kaiapoi North commercial development (Area D)

10.1 Preliminary general land use outline plan

We consider the general concepts and outline to be reasonable provided WDC accepts that level of damage similar to that which occurred during 4 September 2010 and 22 February 2011 earthquake will be expected in earthquake levels not to dissimilar to SLS level event and repairs will be required to the areas that are not improved.

10.2 Key technical considerations

10.2.1 Geotechnical

T&T has highlighted the key technical considerations and proposed engineering works are reasonable.

10.2.2 Flooding

T&T (2016) indicates that there is still considerable uncertainty regarding consentable minimum land and floor levels. The latest modelling by WDC shows flooding covering the entire Area D red zone with flood depths between 0.1m to greater than 1.0m. We therefore recommend that WDC confirms consentable land and floor levels level to reduce the uncertainty which follows through engineering solutions and costings. T&T has currently assumed fill levels ranging between 2.0mRL to 2.8mRL which we consider reasonable based on available flood modelling and in absence of specific guidance from WDC. Fill levels up to 2.8mRL (Lyttelton Vertical Datum) assume up 1m fill based on LiDAR levels around the site of between 1.2mRL and 1.9mRL.

10.2.3 Ground Contamination

T&T (2016) has raised the potential risk of ground contamination particularly from asbestos contaminated demolition fill. This risk has however not been quantified at this stage and there does not appear to be a basis for assumptions regarding extent of contaminated ground adopted for the study. We recommend, as a minimum, an environmental desktop study to qualify the likely extent of contamination assumed in the current report. We note that the degree of contamination is likely to influence cost effective re-development strategy.

10.3 Preliminary land improvement outline plan

We consider T&T (2016) land improvement proposals for the large-format retail to be reasonable but note the following:

- We do not consider the use of biaxial geogrid along slopes (Figure 52082.0300-F3) to be effective in preventing slope movement (surficial slip failure or deep failure) and we recommend that uniaxial geogrids are adopted if considered necessary for design. It could though be argued that the biaxial geogrids are probably not required for such shallow slopes provided the basal geogrid is appropriately designed and specified.
- The thickness of fill proposed is limited and such fill thickness even when reinforced are not likely to provide significant mitigation to lateral spreading risk highlighted. We recommend the wider team explores the benefits of undertaking lateral mitigation measures along Charles Street.
- For the yard-based commercial scenario, WDC should note that if no ground improvement is undertaken including measures to minimise lateral spreading potential, damage similar to that which occurred in Canterbury Earthquake Sequence is to be expected in earthquakes not too dissimilar to SLS level.

10.4 Potential civil engineering effects on neighbouring areas

We consider that Table 7.2 generally summarises the main impacts due to the new development. Specific comments to subsections 7.4.1 and 7.4.2 of T&T report are presented below.

10.4.1 Exacerbation of flooding elsewhere

Aurecon has not sighted all the information upon which conclusions in Section 7.4.1 of T&T (2016) report are based to help comment on findings/conclusions. We note that the overall philosophy adopted by T&T is based on sound engineering principles.

10.4.2 Construction Traffic

Construction traffic is estimated to be between 8 and 13 truck movements per day over a 3 to 24 month period. We consider this number of movements to be a realistic view. T&T have assumed that fill will be won from the Waimakariri River and is a suitable source of gravel, however, this may not be the only source due to demand.

The assumption of construction traffic preferring Smith Street as the main access route to the site is highly likely. Given this, whichever route is used, the additional heavy vehicles will increase road maintenance requirements and WDC need to consider these costs which have not been quantified in T&T's report.

10.5 Preliminary estimate of land improvement costs and timeframe

Preliminary estimates are based on sized scenarios based on either yard based commercial or large format retail. Each scenario has its own implications for both construction costs and assumptions.

T&T have quantified both commercial and retail “over and above” costs for each proposed size ranging from $0.9M - $4.2M for yard based commercial and $3.4M - $22.8M for large format retail.

As pointed out by T&T, the uncertainty of construction costs, preferred design option, foundation designs, and flood/fill levels has meant a broad costing estimates are presented.

We believe that given the above uncertainties as well as the limited deep ground improvement design, it is difficult to state that the figures given in the T&T report are a reasonable representation of the work required for land development. However, the spectrum is broad enough to accommodate for the majority of uncertainties.

Depending on size and scenario, construction duration for land improvements (over and above) should be able to be completed between 3 and 32 months.

10.6 Discussion

We agree with T&T conclusions that, from an engineering perspective, it is feasible to undertake land improvement works to enable commercial development within Zone D using readily available construction techniques around Christchurch. However, as highlighted by T&T, we believe that some items need to be clarified and/or explored to help WDC better understand the economic feasibility. The main items to explore include flood level requirements including an understanding of whether existing stop banks have been included in the current model, whether damage levels are acceptable for yard-based commercial where no ground improvement and/or lateral spreading measures are undertaken, and extent/degree of contamination.

10.7 Next steps

T&T (2016) have identified further areas for investigation if WDC were to establish a more conclusive cost of construction. We believe that these suggestions are appropriate for a more concise construction cost estimate.

11 Review – Kaiapoi Southeast commercial development (Area E)

11.1 Preliminary general land use outline plan

We consider the general concepts and outline to be reasonable provided WDC accepts that the level of damage similar to that which occurred during 4 September 2010 and 22 February 2011 earthquake will be expected in earthquake levels not to dissimilar to SLS level event and repairs will be required to the areas that are not improved.

11.2 Key technical considerations

11.2.1 Geotechnical

T&T has highlighted the key technical considerations and proposed engineering works are reasonable. Observations of crack patterns indicate that there was potential onset of ‘global’ lateral spreading at the site in the previous earthquakes and it is possible that area-wide lateral spreading could occur at return periods less than the 500 years assumed in T&T report.

11.2.2 Flooding

T&T (2016) indicates that there is still considerable uncertainty regarding consentable minimum land and floor levels. The latest modelling by WDC shows flooding covering the entire Area D red zone with flood depths greater than 1.0m. We therefore recommend that WDC confirms consentable land and floor levels to reduce the uncertainty which follows through engineering solutions and costings. T&T has currently assumed fill levels ranging between 3.45mRL to 3.7mRL which we consider reasonable based on available flood modelling and in absence of specific guidance from WDC. Fill levels up to

3.7mRL (Lyttelton Vertical Datum) assume up 2.5m fill based on LiDAR levels around the site of between 1.3mRL and 2.0mRL.

11.2.3 Ground Contamination

T&T (2016) has raised the potential risk of ground contaminations particularly from asbestos contaminated demolition fill. This risk has however not been quantified at this stage and there does not appear to be a basis for assumptions regarding extent of contaminated ground adopted for the study. We recommend, as a minimum, an environmental desktop study to qualify the likely extent of contamination assumed in the current report. We note that the degree of contamination is likely to influence cost effective re-development strategy.

11.3 Preliminary land improvement outline plan

We consider T&T (2016) land improvement proposals for the large-format retail to be reasonable and ground improvement if implemented across the length of the river front is likely to minimise damage from lateral spreading which is likely to cause significant damage in a moderate to large earthquake. We note that the lateral spreading ground improvement works may need to extend beyond the site to the north to minimise potential for recurrence of wider block failure identified in the earthquakes of the Canterbury Earthquake Sequence.

In terms of yard-based commercial scenario, WDC should note that if no ground improvement is undertaken including measures to minimise lateral spreading potential, damage similar to that which occurred in Canterbury earthquake sequence is to be expected in earthquakes not too dissimilar to SLS level.

We also note our previous comments regarding geogrid detailing for proposed shallow embankment slopes where adopted.

11.4 Potential civil engineering effects on neighbouring areas

We consider that Table 8.2 generally summarises the main impacts due to the new development. Specific comments to subsections 8.4.1 and 8.4.2 of T&T report are presented below.

11.4.1 Exacerbation of flooding elsewhere

Aurecon has not sighted all the information upon which conclusions in Section 6.4.1 of T&T (2016) report are based to help comment on findings/conclusions. We note that the overall philosophy adopted by T&T is based on sound engineering principles.

11.4.2 Construction Traffic

Construction traffic is estimated to be 10 truck movements per day over a 12 to 24 month period. We consider this number of movements to be a realistic view. T&T have assumed that fill will be won from the Waimakariri River and is a suitable source of gravel, however, this may not be the only source due to demand and / or contractor back-loading.

The assumption of construction traffic preferring Ohoka Road as the main access route to the site is highly likely. Given this, whichever route is used, the additional heavy vehicles will increase road maintenance requirements and WDC need to consider these cost which have not been quantified in T&T's report.

11.5 Preliminary estimate of land improvement costs and timeframe

Preliminary estimates are based on two scenarios, either yard based commercial or large format retail with two proposed development areas. Each scenario has its own implications for both construction costs and assumptions. T&T have quantified both commercial and retail "over and above" costs for

each proposed size ranging from $0.8M - $2.2M for yard based commercial and $3.3M - $11.4M for large format retail.

As pointed out by T&T, the uncertainty of construction costs, preferred design option, foundation designs, and flood/fill levels has meant a broad costing estimate presented in the report.

We believe that given the above uncertainties as well as the limited deep ground improvement design, it is difficult to state that the figures given in the T&T report are a reasonable representation of the work required for land development. However, the spectrum is broad enough to accommodate for the majority of uncertainties.

Depending on size and scenario, construction duration for land improvements (over and above) should be able to be completed between 6 and 18 months.

11.6 Discussion

We agree with T&T conclusions that, from an engineering perspective, it is feasible to undertake land improvement works to enable commercial development within Zone E using readily available construction techniques around Christchurch. However, as highlighted by T&T, we believe that some items need to be clarified and explored to help WDC better understand the economic feasibility. The main items to explore include flood level requirements and wider impact from red zone developments, whether damage levels are acceptable for yard-based commercial where no ground improvement and/or lateral spreading measures are undertaken, and extent/degree of contamination.

11.7 Next steps

T&T (2016) have identified further areas for investigation if WDC were to establish a more conclusive cost of construction. We believe that these suggestions are appropriate for a more concise construction cost estimate.

12 Conceptual Options for Alternative Residential Building approaches

T&T proposed alternative options are considered to be technically feasible.

13 Concluding Remarks

We generally consider T&T (2016) assessment to be reasonable and recommend that the following main items are explored prior to finalising cost estimates:

- Flood level requirements and site wide management strategy.
- Extent of land contamination and associated construction risks; cost associated with remediation or disposal of impacted land should be added to the ‘over and above’ costs.
- Acceptable degree of damage particularly where no ground improvement including lateral spreading mitigation is proposed.
- Compounding traffic volumes should some development areas be developed in parallel and the impact on roading network and the community.

We believe that the feasibility report prepared by T&T is sufficiently detailed to capture the main project issues. The report provides an assessment of project risks and associated uncertainties are well detailed.

As peer reviewers we broadly agree with the outcomes of the T&T feasibility study.

14 Limitations

We have prepared this report in accordance with the brief as provided. The contents of the report are for the sole use of the Client and no responsibility or liability will be accepted to any third party. Data or opinions contained within the report may not be used in other contexts or for any other purposes without our prior review and agreement.

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If you have any questions regarding the details of this report letter, please contact the undersigned

Yours sincerely

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