WISE SCENARIO MODELLING – COASTAL INUNDATION

EXPLORING IMPLICATIONS OF PROJECTED COASTAL INUNDATION AND FLOODING ON THE REGION

Assessment of Hauraki Plans Inundation – Final Report July 2018

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SUMMARY

The assessment of regional hazards and approaches to adaptive management could be informed by using the WISE model to explore a range of future scenarios. Understanding the risk and consequences from flooding and coastal inundation in the Waikato based on a range of climate and future land use scenarios would help to identify future areas of risk, potential impacts and consequences and opportunities for alternate land uses.

Analysis Undertaken:

- Inundation layers for a range of Reduced Levels (18000 – 5000 mm in 200 mm increments) for analysis to represent a range of possible outcomes from sea level rise and storm surge events.
- The extent and location of land use in Hauraki basin impacted by these levels were assessed both at 2013 and at end of WISE Reference scenario (2064) which includes the Healthy River policy applied to the Waikato catchment. Analysis was undertaken using a 10m grid size.
- The distinction is made between areas that are 'inundated' (land is below the Reduced Level [RL] and directly connected to sea – i.e. would require additional stop bank / flood protection infrastructure to maintain land use) and 'saturated' (land is at or below the RL and NOT directly connected to sea – i.e. would require drainage infrastructure to maintain land use).
- Assessment of extent of inundation impact on infrastructure (Roads) and regional economic activity (Value Add) were also made.

Key Findings:

- As water levels increase the area of land use impacted increases from 22,500ha at 1800 mm to 58,400ha at 5000 mm.
- Under the WISE Reference scenario there is minimal change in the rural land use types in the inundated area. There is some urban land use change around key settlements in line with projected economic growth and population change.
- The key 'tipping point' for extensive inundation is when existing flood protection infrastructure is exceeded. This analysis assumes that only the current level of flood protection is provided in future.
- Dairying is the major land use in the inundated areas (with ~18,800 ha impacted at 1800 mm and ~44,000 ha impacted at 5000 mm). Sheep and beef is the next largest land use impact by area (with ~2,300 ha impacted at 1800 mm and ~5,000 ha impacted at 5000 mm). The regional economic of these area if they became unusable for current land use (and assuming they would not relocated to other parts of region) would for Dairying be 5.4% of regional Value Add at 3000 mm and 6.8% at 5000 mm. For sheep and beef it is significantly less (0.65% of regional Value Add at 3000 mm and 0.78% at 5000 mm).
- Impact on urban land uses is smaller in special extent but significant in terms of potential disruption and community cost. Potential impact of projected 2060 land use include:

Land use (at 2060)	Area impacted at 3000 mm (ha)	Area impacted at 3600 mm (ha)	Area impacted at 5000 mm (ha)
Lifestyle	415	472	569
Low Density Residential	126	157	231
Commercial	49	50	64
Manufacturing	65	82	119
Community services	70	90	115
Airport	30	30	30

- Most of this urban land use impact occurs in the Thames area, Ngatea and Kerepehi, with issues emerging in parts of Paeroa at the highest levels
- The economic impact on urban land uses is not available directly from WISE outputs, but would be considered significant and should be part of any further assessment.
- The extent of inundation impact on the Road network is 150km at 1800 mm up to 440km at 5000 mm.

Next Steps:

- The real power of WISE as a scenario tool would come from modelling possible adaptation strategies. WISE could model a number of adaptation strategies to help better understand the requirements and options for more resilient land use in these areas.

BACKGROUND

The assessment of regional hazards and approaches to adaptive management could be informed by using WISE to explore a range of future scenarios. Understanding the risk and consequences from flooding and coastal inundation in the Waikato based on a range of climate and future land use scenarios would help to identify future areas of risk, potential impacts and consequences and opportunities for alternate land uses.

This scenario exploration process could be used to inform both current discussions and future policy development. The use of WISE would also align well with the need to build community resilience and improve their understanding of risk to achieve WRC’s key strategic directions.

The initial work brief for this project was developed to look at the impacts of different inundation scenarios, generated from the Waikato Regional Councils (WRC) Coastal Inundation Model, on current and projected future land use in the Hauraki plains. This could then be followed up with development of adaptive management approaches that could be tested to minimise negative outcomes from inundation.

This report only covers the assessment of increasing inundation levels on current and projected land use under the WISE Reference scenario[1]. Work on adaptation strategies was not undertaken at this stage.

[1] The WISE Reference scenario is set up to represent the modelled projections of population and economic growth for the Region and the current policies and plans that influence growth and land use development (http://www.creatingfutures.org.nz/reference-scenario/).

As a first step an initial assessment of impacts of coastal inundation on the Hauraki Plains was undertaken. This assessed the following Inundation scenarios:

- Current state 1% AEP 3.1 m Reduced Level [RL] (Moturiki VD)
- Climate change scenario 1 (1 % AEP + 0.5 m Sea Level Rise) = 3.6 m (Moturiki VD)
- Climate change scenario 1 (1 % AEP + 1.0 m Sea Level Rise) = 4.1 m (Moturiki VD)

The WRC 'Inundation' model was run at for 3.0 m RL, 3.4 m RL and 4.0 m RL to provide three raster layers for this initial analysis. These were slight different but still considered representative of current and future inundation scenarios.

The outcomes of this initial assessment were assessed and decision was made to run several more inundation levels to increase the understanding of incremental impact. The results discussion in this report is based on the Inundation Model outputs from RL 1800mm to RL 5000mm at 200mm increments.

DATA SET-UP

The following processing of the inundation data layers was then undertaken:

Simplifying inundation data:

- The inundation raster data was provided with specific levels of inundation. The 99 values represent areas that are at or below the specific RL water level, but are not 'connected' to the sea, based on the DEM used.
- The other values are showing water depths (at 200 mm increments), however to keep the raster small in size, these are integers where:
    - 2 = 200 mm
    - 4 = 400 mm
    - 6 = 600 mm
    - ……. Etc
- For this initial raster analysis the inundation raster layers were simplified into two groups - inundated levels connected to sea [represented by 1] and 'saturated' at or below water level but not connected to sea (99's) [represented by 2]

Re-sampling of data:

- The Inundation raster layer data was provided at 2m grid size and the WISE land use data was to 100m grid size. Processing of such a small 2m grid is time consuming, but resampling to 100m would cause significant over estimation of areas.
- It was decided to process both layer to 10m grid size. This was a simple re sample (downscaling) for WISE land use data. The inundation raster's were resampled (upscaling) using a 'majority' setting
- An analysis of areas under the 2m grid size and resulting 10m grid size for inundation data was undertaken to assess effect of increasing grid size. The 10m grid cells tend to slightly overestimate the areas of impact. At 3000 RL this is about 5.6% overall (7% for inundated area & 5.1% of "saturated" area), for 3400 RL this is about 3.9% overall (3.5% for inundated area & 4.3% of "saturated" area), and at 4000 RL this is about 2.8% overall (1.9%% for inundated area & 12.7% of "saturated" area [small scattered areas]) . As expected this shows the 'edge effect of re-gridding data and as the overall impacted area gets larger and more contiguous the bias effect is less. For efficiency of processing it was decided to use the 10m grid for this analysis.

ANALYSIS METHODOLOGY

In GIS a cross tabulate function was used to quantify the land use types impacted under the range of modelled levels. These cross tabulations results compared the range of modelled levels with land use projections from three time steps of the WISE model (2013 [actual land use], 2040, 2060).

IMPACTS OF INUNDATION LEVELS

The spatial results for land use impacts are presented as:

- 'Saturated' - areas at or below water level but not connected to sea,
- 'Inundated' – areas at or below water level levels and directly connected to sea , and
- Total - sum of Saturated and Inundated.

SCALE AND SPATIAL IMPACTS

The total areas affected by modelled increases in coastal water levels increases from 22,500 ha at 1800 mm to 58,400 ha at 5000 mm (Figure 1). At 1800mm most of the impacted area is 'saturated' so not directly at risk of coastal inundation, but might require some form of active drainage to remain useable for productive land uses. As modelled sea level increases the area impacted as 'saturated' increases to a peak of 35,400 ha at 3000mm (Figures 1 & 2).

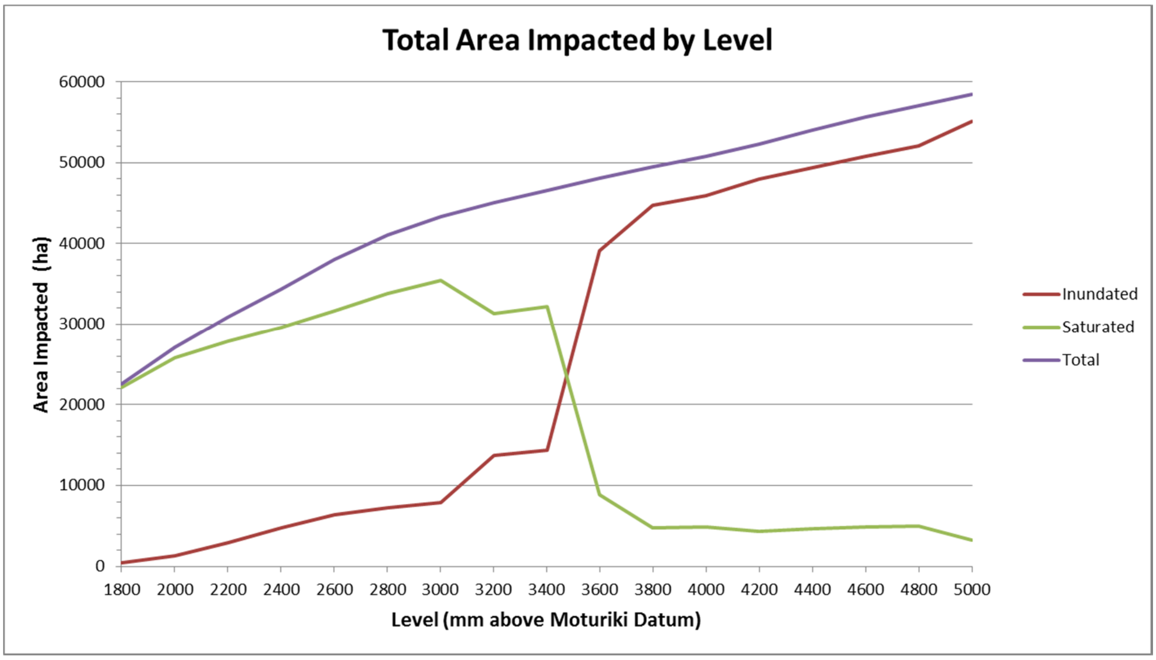

Figure 1: Scale of land area impacted by increasing sea level

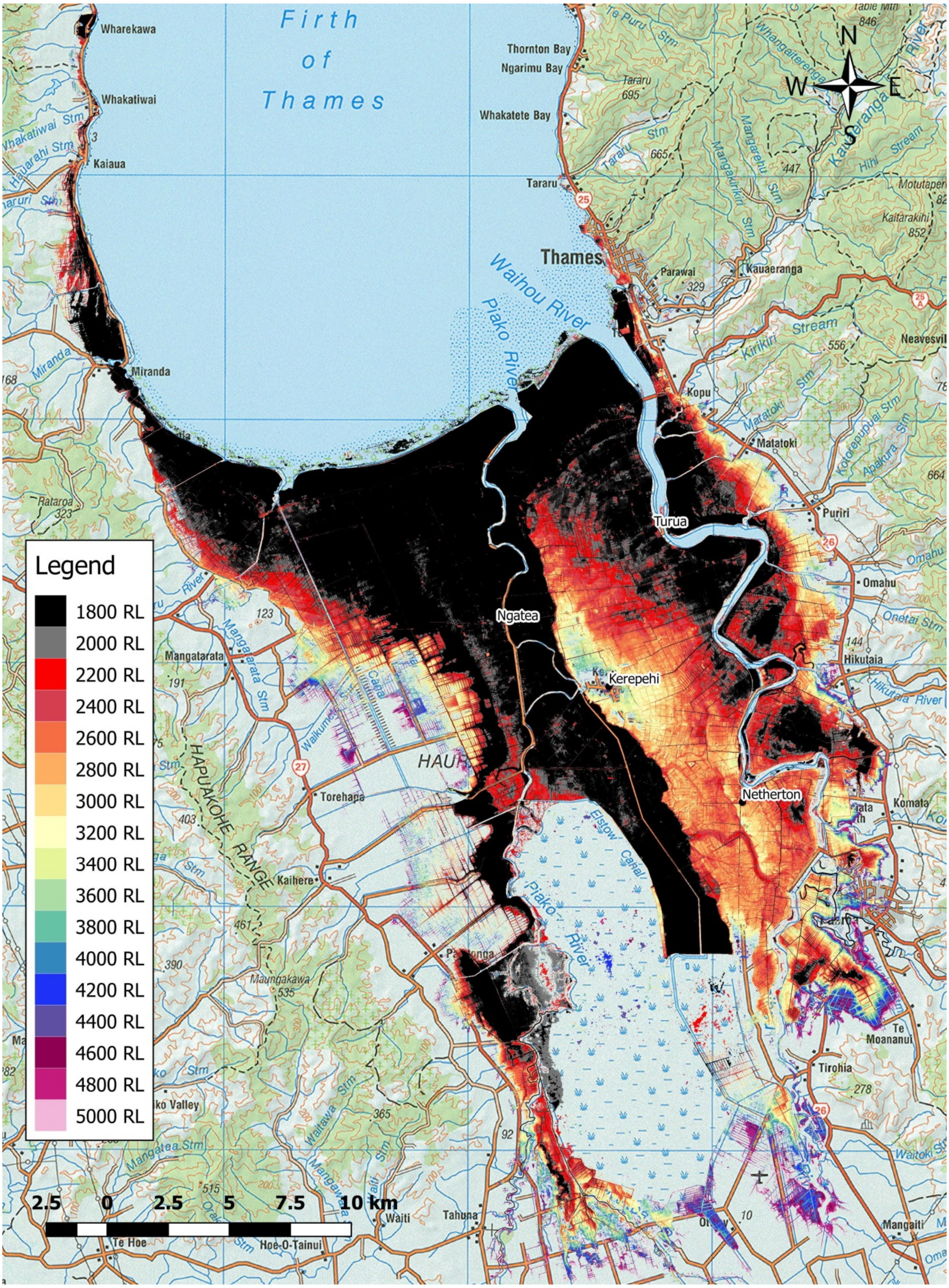

Figure 2: Spatial pattern of 'Saturated' areas within increasing sea levels

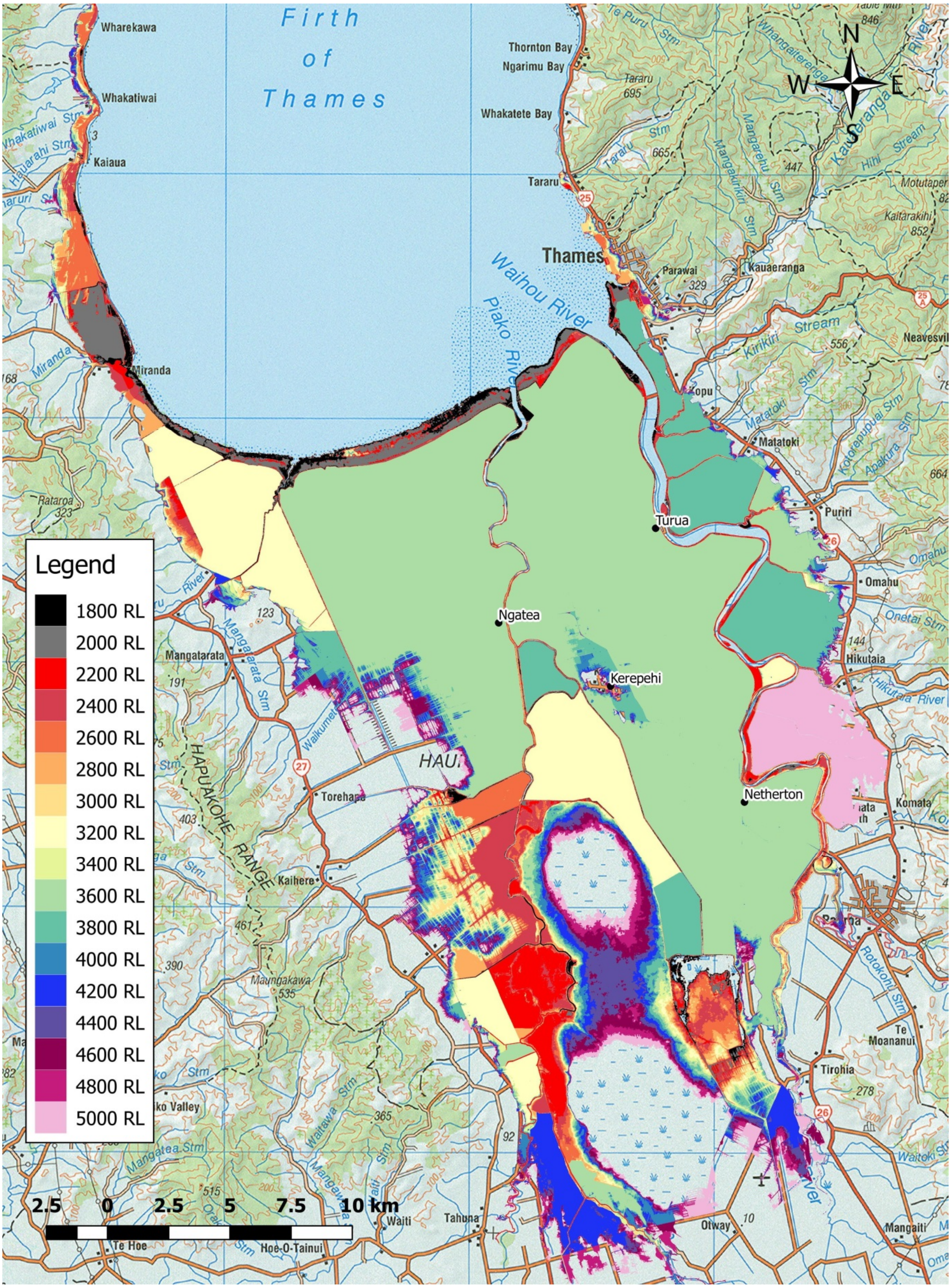

Figure 3: Spatial pattern of 'Inundated' areas within increasing sea levels

At higher levels significant flood protection infrastructure is breached (~3100mm for HDC stop banks around Waitakaruru and 3600mm for WRC stop banks on Piako River) and large areas of land that were classed as 'saturated' then become 'inundated' (Figures 1, 2 & 3).

With increasing sea level the area of 'Inundated' land increases by about 10,000 ha between levels 3800 mm to 5000 mm (Figure 1 & 3). The area of 'saturated' land remains relatively constant at ~4000-5000 ha across these levels.

The results of the WRC Coastal inundation modelling which shows the progressive impact of rising sea levels and depths of inundation that could occur based on current flood/drainage infrastructure is shown in the animation in Figure 4.

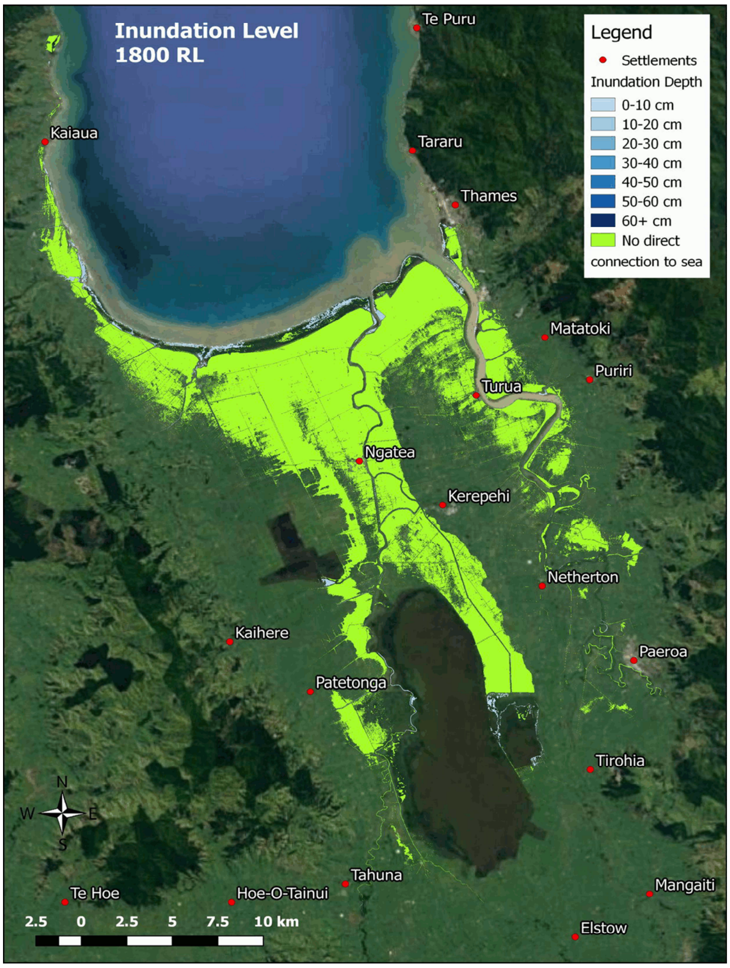

Figure 4: Animation of Inundation within increasing sea levels (Double Click to run)[2]

IMPACT ON LAND USE TYPES

Based on the WISE Reference scenario the rural land uses in the area, potentially impacted by modelled increases in sea level, are not projected to change significantly out to 2060. For example the area of dairying land use is projected to increase by only 1% (~500 ha) by 2060 as most suitable land is already in dairying. Sheep and beef land use is projected to decrease slightly by 0.4% (~20 ha).

[2] These outputs were produced by WRC Hazards Team using their Coastal Inundation Model

Due to these minor changes in projected rural land use a comparison of impacts on rural land uses over time is not provided and the following results are based only on the 2013 land use.

There are some changes in the projected urban land uses over time as a result of changes in population and economic activity. The relevance of these changes over time is presented in the results below.

IMPACTS ON RURAL LAND USES

The lower Hauraki plains is a flat highly productive landscape which is dominated by dairy farming so not surprisingly the largest land use impact by area from increase sea levels would be dairying. Based on 2013 land uses the impacted area would increase from 18,800 ha at 1800 mm to 44,000 ha at 5000 mm (Figure 5). The rate of increasing impact is highest initially (1800-2800 mm) being driven mainly by an increase in 'saturated' areas.

The overall pattern of impact and pattern between 'saturated' and 'inundated' land is the same as for total land use impacts (Figure 1) because dairying makes up 83% of affected area at 1800 mm level lowering to 75% at 5000 mm level. The major consequences for dairying would also occur as current flood protection infrastructure is breached and large areas of land that were classed as 'saturated' then become 'inundated' (Figures 5).

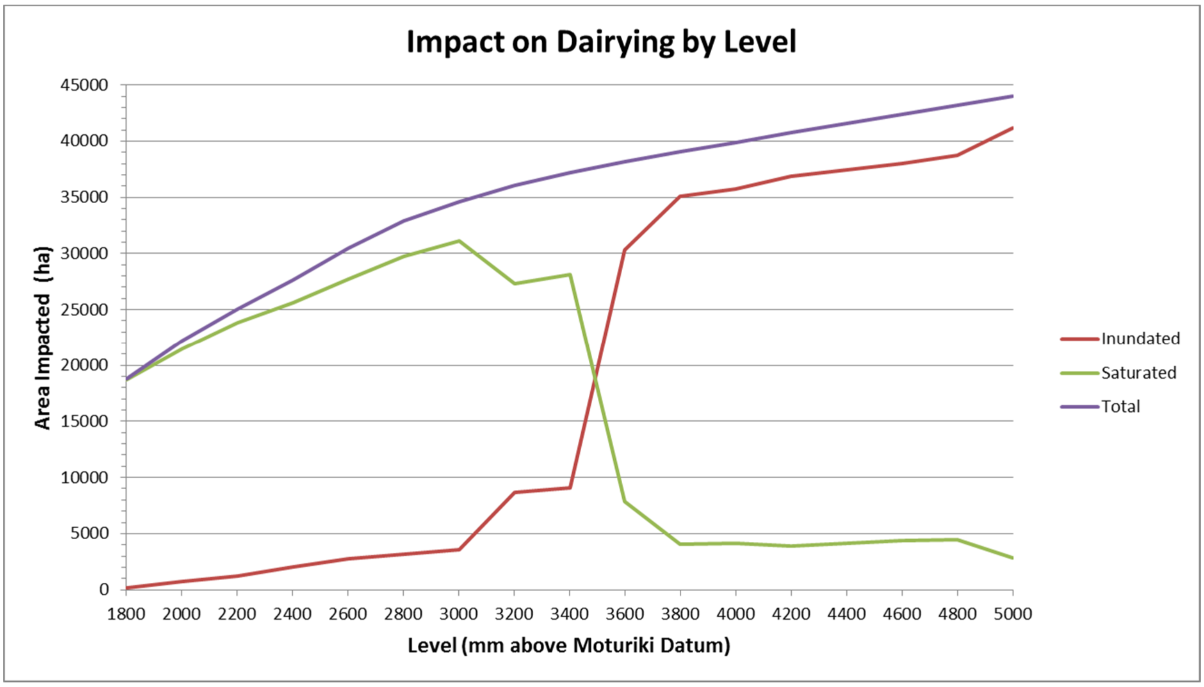

Figure 5: Scale of Dairying land use (2013) impacted by increasing sea level

The second largest rural land use in the impacted area is sheep and beef. At only a tenth of the scale of dairying the area affected is only 2300 ha at 1800 mm increasing to 5000 ha at 5000 mm (Figure 6). These results show that sheep and beef land use is more impacted by being inundated by rising levels and the extent of 'saturated' land remains relatively constant until the large flood infrastructure is breached. The progressive increase in inundated sheep and beef land use tends to occurring in two main areas before the large scale inundation occurs at 3600 mm, these are along the coastal areas between Miranda and Kaiaua, and around the Piako River near Patetonga.

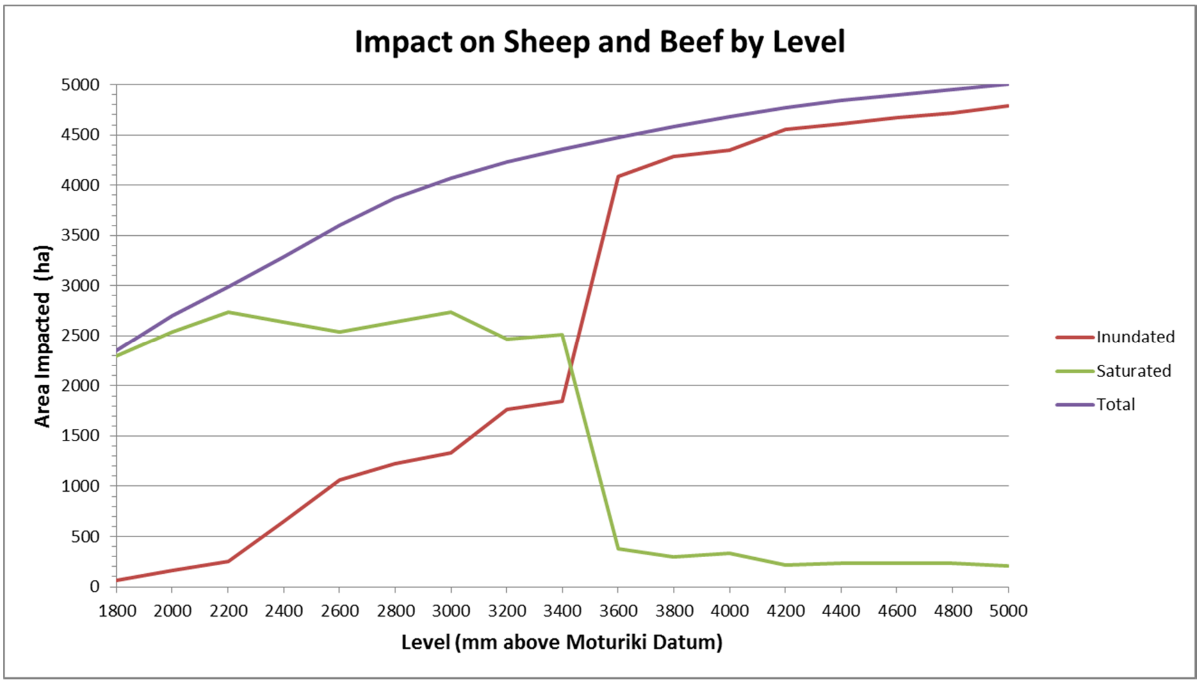

Figure 6: Scale of Sheep and Beef land use (2013) impacted by increasing sea level

Impacts on other rural land uses are smaller with respect to area impacted, with 'other agriculture' land use with ~400 ha, horticulture ~45 ha, other cropping ~35 ha and forestry with 10 ha impacted.

IMPACTS ON URBAN LAND USES

The potential impact of increasing sea inundation levels on urban land uses, although smaller in spatial scale than those in rural areas, it would be significant for the communities involved. At a level of 3000 mm there is projected to be 168 ha of low density residential land impacted (Figure 7: 96 ha saturated and 72 ha inundated – based on 2013 land use) most of this occurs at Thames and around the settlements of Kaiaua and Whakatiwai on the coast. At 3600 mm with the 'over-topping' of existing flood infrastructure additional areas of low density residential around Ngatea and Turua are inundated and additional inundation around areas of Thames , Kaiaua and Whakatiwai (Total impacted low density residential is 200 ha - 24 ha saturated and 176 ha inundated – based on 2013 land use). At 5000 mm low density residential at Kerepehi and South Thames/Totara are being impacted with total impact for this land use type being 268 ha based on 2013 land use (Figure 7).

The current population projections[3] for the Thames-Coromandel and Hauraki Districts projects a decline in populations from mid-late 2030's after a period of only modest population growth from 2013 (Figure 8). This projection of population change is used within the WISE Reference scenario and therefore will influence the growth and location of residential land uses within these districts and the area modelled here for potential coastal inundation. For the Hauraki Districts this results in a

[3] Based on the Waikato Projections Project that used University of Waikato to develop Waikato specific projections - http://www.creatingfutures.org.nz/waikato-projections-demographic-and-economic/

projected 1.4% reduction in low density residential land area and for Thames-Coromandel a 1.3% reduction by 2060.

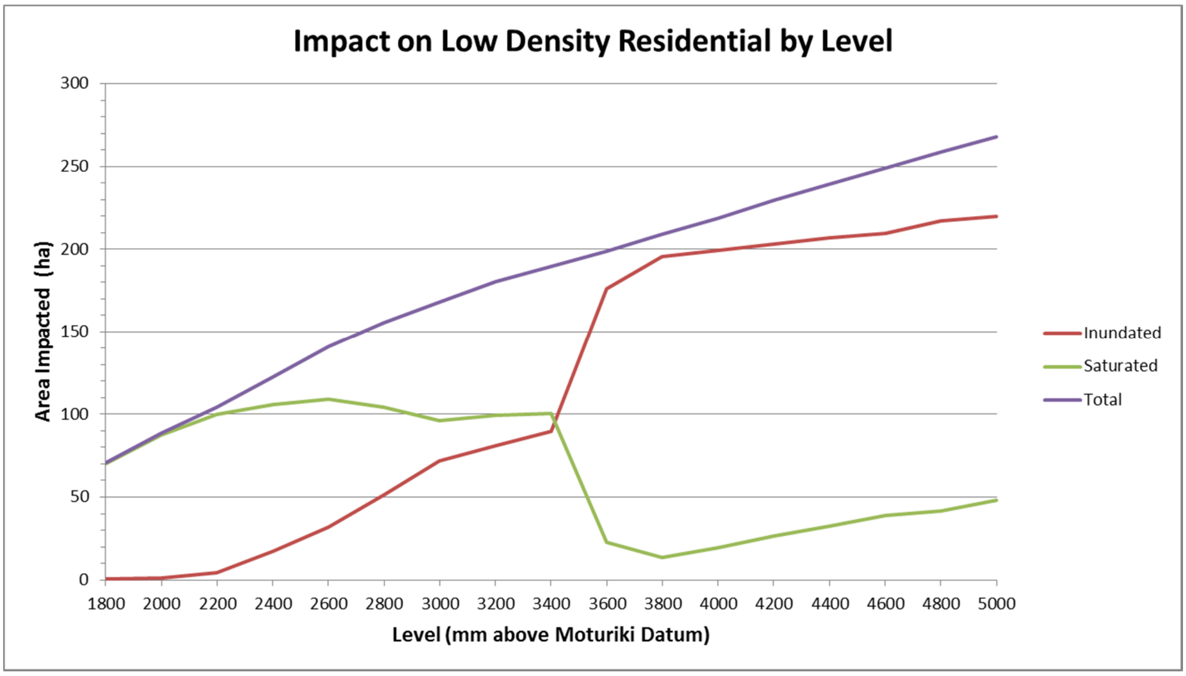

Figure 7: Scale of Low Density Residential land use (2013) impacted by increasing sea level

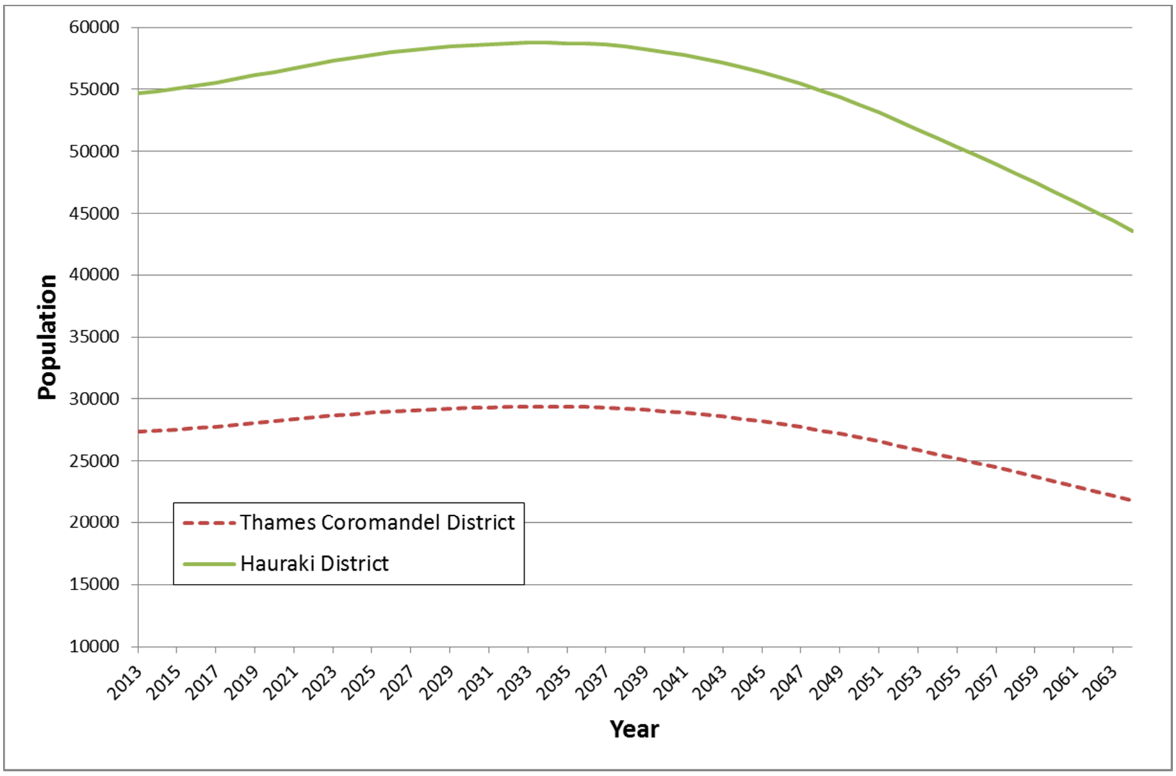

Figure 8: Projected population growth used in WISE Model[3]

The implications of this population change against the risk of coastal inundation from increasing levels are shown in Table 1. This shows a modest decrease in impacted area particularly in the period 2040-2060. Also at the high water levels most of the impact is ‘inundation’ of this land use type and most of the population driven reduction appears to be occurring in these areas.

Level	Year	2013	2040	2060
3000 mm	Inundated	72	72	71
	Saturated	96	91	55
	Total (ha)	168	163	126
		2013	2040	2060
3600 mm	Inundated	176	168	132
	Saturated	24	26	25
	Total (ha)	200	194	157
		2013	2040	2060
5000 mm	Inundated	220	215	177
	Saturated	48	54	53
	Total (ha)	268	268	231

Table 1: Areas of projected low density residential land at risk with increasing coastal water level.

The commercial and manufacturing land use types are allocated in WISE based on a regional economic model. Future projections of these land use types are driven by projected economic growth, increases in productivity and changes in household consumption. They are not directly related to population changes over time.

The extent of commercial land use impacted , based on 2013 land use, increases from about 6 ha at the 1800mm level to 40 ha at the 5000 mm level. Most of the initial impact from rising levels, up to 2600 mm is represented as ‘saturated’ areas (Figure 9) which occur around coastal edge of Thames and at Kopu and Ngatea. After 2600 mmm level there is a rapid increase in inundation of commercial land. Most of this occurs in the coastal margin along the Thames Township.

There is a projected increase in the total impacted area of commercial land use, based on initial 2013 land use, of 18 % by area to 2040 (additional 7 ha) and 59 % increase by 2060 (up 24 ha).

The extent of this projected impact needs to be kept in context with the spatial limits of the input data. Although the WRC Coastal inundation model operates at a very fine scale using accurate Lidar data (inundation data was provided at 2 x 2m cell size) the WISE model operates at a regional scale using a 100 x 100m cell size (1 ha). This creates a ‘margin of error’ when trying to accurately locate specific land uses at a small scale. This scale issues is not a problem when considering large scale land uses such as dairying (1000’s ha change), but it could over or under represent projected land use impacts when land use areas and change are small (few 10’s of ha) as is the case for commercial and manufacturing land uses in this area.

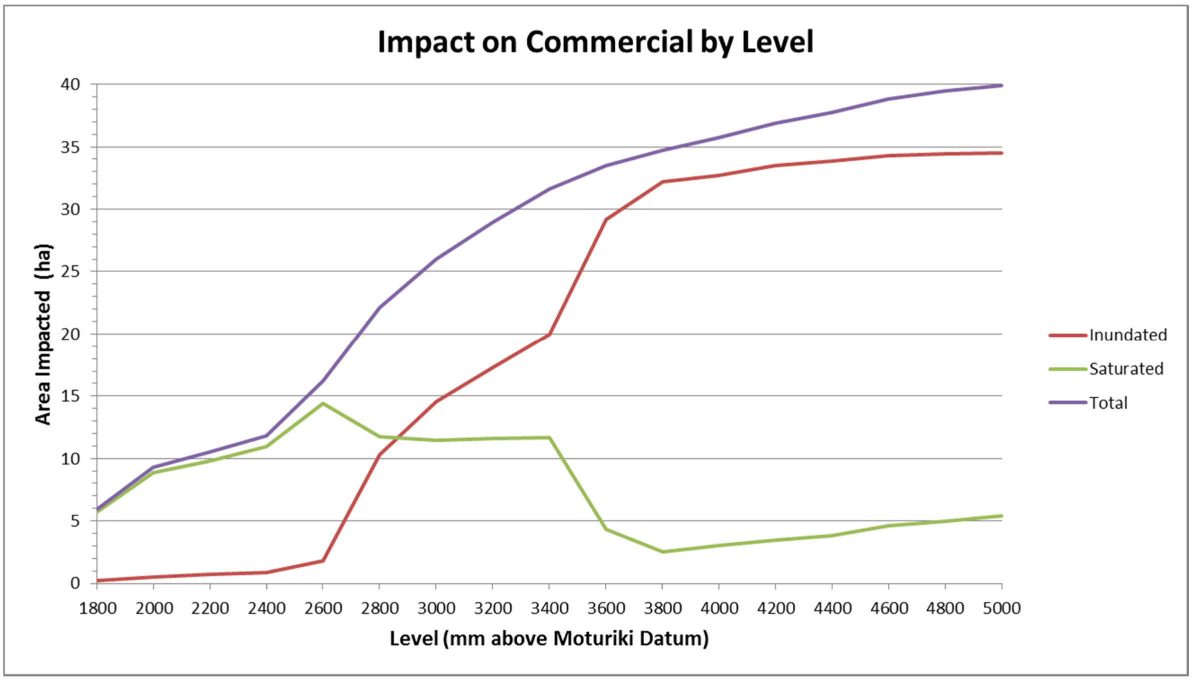

Figure 9: Scale of commercial land use (2013) impacted by increasing sea level

The extent of manufacturing land use impacted , based on 2013 land use, increases from about 10 ha at the 1800mm level to 100 ha at the 5000 mm level. Most of the initial impact from rising levels, up to 2600 mm is represented as 'saturated' areas (Figure 10) which occurs mainly at Kopu with smaller areas in south Thames and at Ngatea. After 2600 mmm level the areas around the Thames Township become inundated and higher than 3600mm level the areas at Kopu and Ngatea are inundated. There is a projected increase in the total impacted area of manufacturing land use, based on initial 2013 land use, of 10 % by area to 2040 (additional 10 ha) and 19 % increase by 2060 (up 24 ha).

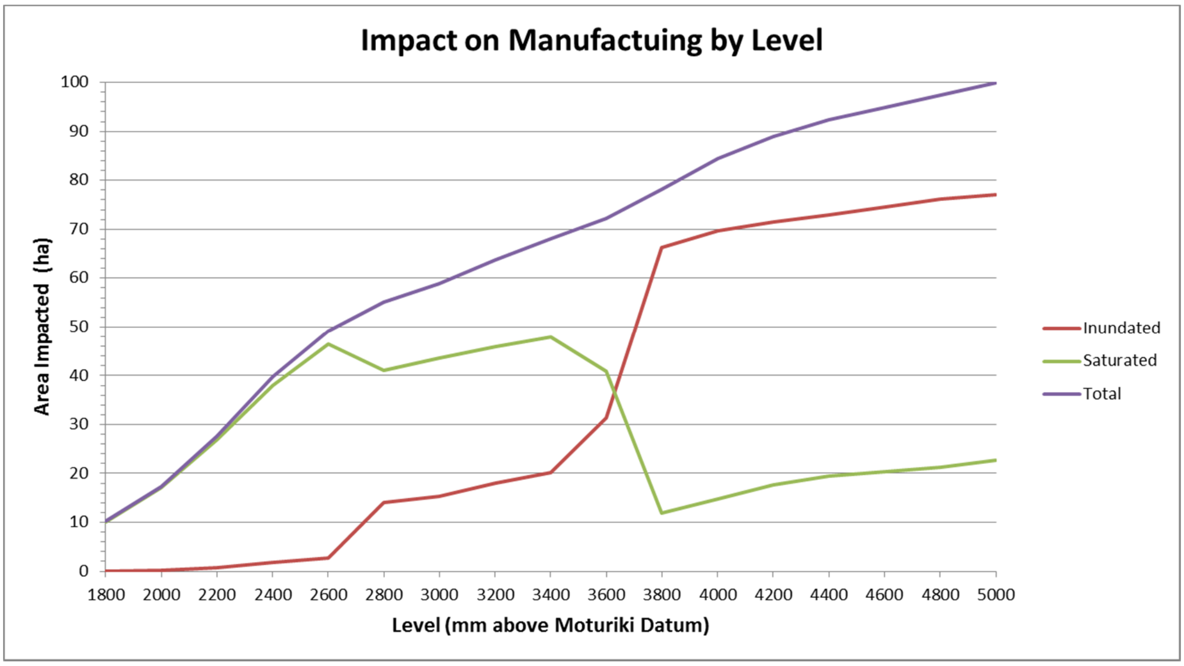

Figure 10: Scale manufacturing land use (2013) impacted by increasing sea level

There is a reduction in risk to lifestyle residential land use over time as it is projected that this land will occur more in the rolling/hill country around Paeroa, Waihi and Coromandel range. On the flatter areas prone to inundation the zoning and competition from other land uses sees a significant movement of this land use out of these areas. Overall the projected extent of lifestyle residential land use only drops about 5% in the Hauraki district and this is a function of projected decline in population.

Based on the 'tipping-point' level of 3600 mm for 2013 land use about 870 ha of lifestyle would be impacted (120 ha saturated and 750 ha inundated), the projected land use for 2040 see a reduction in the risk to 615 ha (115 ha saturated and 500 ha inundated) and a further reduction in risk by 2060 to 470 ha (100 ha saturated and 370 ha inundated).

IMPACT ON INFRASTRUCTURE

Using the Infrastructure layer in WISE (Road and Rail networks) an analysis of the extent of this infrastructure affected was undertaken based on the increasing RL inundation layers used in this analysis.

The results show that the total length of roads affected increases from about 150 km at 1800mm to about 300 km at 2600mm, and then continues to increase more slowly to ~440 km at 4800 mm (Figure 11).

Similar to the impacts on land use the extent of inundated roads increases quickly as the RL levels exceed the current major flood protection infrastructure around the 3600 mm. Prior to this 'tipping point' there is about 250 km of road network that would need some form of drainage support to maintain their function. Above the 3600 mm level there would be 350-400 km of road network that would be under threat of inundation based on the current flood protection infrastructure.

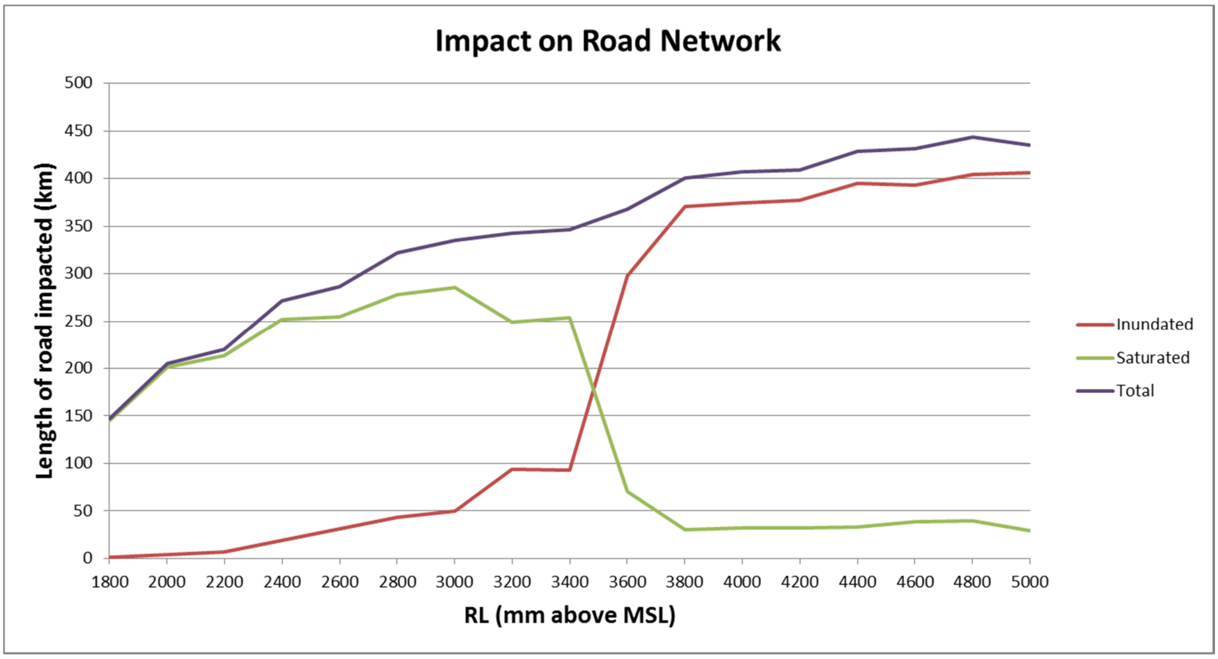

Figure11: Impact of increasing inundation levels of road infrastructure.

ECONOMIC EFFECT OF INUNDATION

As an indicator of the potential economic impact from inundation/saturation the WISE Value Add output from WISE is used to assess impacts in regional context

For Dairying the WISE value add output for Dairy farming is $881m ($2007) and for Dairy product manufacturing is $548m in 2013. Given there is 647200 ha of dairying in the region in 2013 this equates to $2210/ha[4] value add. This value is used to derive Figures in Table 2.

	3000 mm		3600 mm		5000 mm	
	Value Add "Loss"	% of Reg. Value Add	Value Add "Loss"	% of Reg. Value Add	Value Add "Loss"	% of Reg. Value Add
Inundated	$8m	0.6%	$67m	4.7%	$92m	6.4%
Saturated	$69m	4.8%	$17m	0.9%	$5m	0.4%
Total	$77m	5.4%	$84m	5.8%	$97m	6.8%

Table 2: Economic output (Value Add - $2007) at risk from inundation – Dairy land use (2013).

The results show that total value add from dairying at risk increases from $77m at 3000 mm to $97m at 5000 mm. This however only represents 5.4% to 6.8% respectively of the regional dairy value add.

For the Sheep and Beef land use the WISE value add for Meat and meat product manufacturing sector is $356m ($2007). Given there is 637,600 ha of Sheep and Beef land use in the region in 2013 this would equate to $560/ha value add. This value is used to derive figures for Table 3.

	3000 mm		3600 mm		5000 mm	
	Value Add "Loss"	% of Reg. Value Add	Value Add "Loss"	% of Reg. Value Add	Value Add "Loss"	% of Reg. Value Add
Inundated	$0.8m	0.23%	$2.3m	0.64%	$2.7m	0.76%
Saturated	$1.5m	0.42%	$0.2m	0.06%	$0.1m	0.02%
Total	$2.3m	0.65%	$2.5m	0.70%	$2.8m	0.78%

Table 3: Economic output (Value Add - $2007) at risk from inundation – Sheep and Beef land use.

Even though this is the second largest area affected by these inundation scenarios the impact on the regional Sheep and Beef sector would be minimal. Potentially only affecting less than 1% of the regional sector.

The other land uses impacted by these scenarios, although small in area, that would have significant economic implication are the urban land uses particularly those around the Thames township area.

[4] This assumes that any reduction in land area would cause a relative reduction in product manufacturing value add.

DISCUSSION

This analysis outlines the extent of land use impacts from increasing coastal water levels as a potential result of increased sea level and storm surge outcomes. A 'semi-artificial' separation is made between the impact of projected inundation where ground levels are at or below the water level and the area is directly connected to the sea and 'saturated' area which are at or below water level but not connected to sea. In practical terms the 'saturated' areas would potentially require additional drainage actions to remain useable as a land use and for any existing 'barriers' to the sea to be maintained, and inundated areas would require new or improved 'barriers' (stop banks) and increased drainage to maintain their viability at these levels. The potential impacts outlined in this report are based on the key assumption that only the existing flood protection and drainage infrastructure was in place to provide protection or mitigate impacts of increasing coastal water levels.

The range of increasing coastal water levels analysed shows spatially the implications for land use in the area and in particular the significant impact when the current flood protection infrastructure is exceeded. Based on area the highest rate of impact occurs during the first 1000mm of increased water level. However the severity of impact is greatest when the current flood protection infrastructure is breached at 3600 mm. After this point there is then a steady rate of further inundation with increasing water level and the extent of 'saturated' land remains relatively constant.

The current WISE Reference scenario does not project much change in the type and extent of rural land uses in the affected area over the next 45 years. In any future development of adaptation strategies to minimise the impact of future risk it may be difficult to 'move' the affected land uses to other parts of the Region, especially with respect to dairying, as recent expansion of dairying has meant most suitable land is already under this use within the Region. Therefore options to offset land use from impacted areas to other parts of the Region may be limited.

For urban land uses there is projected to be some reduction in population and this has some effect at reducing the future level of risk from increasing coastal water inundation. However, if the future population growth was different then there is the potential for additional growth in low lying areas to increase the risk and impacts of increased coastal water levels in future.

Although relatively small in area the potential impact on urban land uses would be costly and disruptive for the community. Most of the impacts for low density residential land occur around Thames, Ngatea and coastal communities of Miranda and Kaiaua. The impacts for commercial and manufacturing land use are mainly at Thames and Kopu, with a small area in Ngatea. This analysis of urban land uses is only high level due to the grid size (100 x 100m cells) used to project land use in WISE and the relatively small well defined areas impacted by increasing water levels. Spatially the analysis of applying the land use projections has a higher margin of error than analysis of large scale rural land uses.

These results represent the potential outcomes of 'status-quo' . The real opportunity is to use further scenario planning with WISE to develop and explore different adaptation options to prepare for and mitigate the potential effects from increased sea levels and storm surges in future. This would support wider community engagement and development of future strategies and policies.