Memorandum

29 September 2021

To	New Zealand Aluminium Smelters Ltd		
Subject	**NZAS Closure Preliminary Study** Sea Level Rise Impact Assessment	Job no.	12533899 / CAL.11
Document No.	12533899-3100-HY-MEM-00001 CAL.11-3100-H-MMO-00001	Rev.	0

1 Introduction

1.1 Background

New Zealand Aluminium Smelters (NZAS) owned by Rio Tinto (RT) engaged GHD Pty Ltd (GHD) to undertake a Closure Preliminary Study for the Tiwai Point Aluminium Smelter ('the Smelter') located on Tiwai Road, Invercargill, New Zealand.

The smelter site is in a coastal environment and the topography is low and broadly close to sea levels. Sea level rise has the potential to result in inundation of the NZAS site over time, which presents a risk to ongoing management of residual buried waste (e.g. existing landfill and the SCL pad) and site contamination. An understanding of the rate of sea level rise and extent of inundation over time will be important in the closure options trade-off process when evaluating options for the existing landfill and SCL pad. RT agreed the need to include a high-level sea level inundation assessment in the Preliminary Study.

The purpose of this assessment was to complete a preliminary evaluation of the risks of land inundation from high sea levels, considering both the present-day sea levels and plausible future sea levels and based on future predictions of sea level rise. This memo first presents an evaluation of a range of potential sea levels and then illustrates (maps) how those levels would affect the site based on the existing topography.

1.2 Assumptions

The evaluation is preliminary and relatively simple, with inundation mapping limited to bathtub methodology. There are accordingly some assumptions in the analysis as follows:

- no change in future surge risks, wave climate or tidal range (this is probably unconservative, but an immaterial consideration for now, in comparison to much larger uncertainty on the rate of future SLR)
- wave setup allowance is conservatively based on open ocean wave conditions and ignores the expected lesser wave setup within the estuary to the north of the site (noting that the transmission of wave setup through the harbour throat into Bluff Harbour is uncertain and complex to assess. It is expected to be dependent on harbour throat bathymetry, sea level/depth and wave conditions at the time).
- wind setup is not assessed but will be minor in comparison to sea level rise and wave setup magnitudes. Wind setup can be positive or negative but is reasonably expected to contribute a negligible increase to site inundation risks.

- we rely on data, analyses and advice from others without independent verification (such data is described herein when we introduce it)
- sea level data from Bluff Harbour and Dog Island is equivalent to sea levels at Tiwai Point
- topography is assumed to be static throughout the considered future period (possible future topographic changes, impacts of coastal erosion or accumulation or tectonic plate movements are not considered)
- additional inundation risk caused by wave run-up is not considered. This is based on advice from MetOcean (ref 1) that wave run-up is not expected to contribute materially to inundation of the site and for the site as a whole it is appropriate therefore to have zero allowance for wave run-up.

1.3 Acronyms And Terminology

There are several acronyms and terminology, which are useful to introduce:

- SLR: Sea Level Rise. Increase in the sea level over a decades and centuries, typically associated with climate change.
- MSL: Mean Sea Level. The average level of the sea surface over a long period or the average level which would exist in the absence of tides. Measured at a specific location, over a specified time period.
- MHWN: Mean High Water Neaps. The average of the lowest high tide sea levels - during the period of about 24 hours in each semi-lunation period (approximately every 14 days), when the range of the tide is least (Neap Range). Determined directly from measurements of neap high tides or derived from a harmonic analysis of the full measured tidal sinusoid. Measured at a specific location, over a specified time period.
- MWHS: Mean High Water Springs. The average of highest high tide sea levels - during the period of about 24 hours in each semi-lunation period (approximately every 14 days), when the range of the tide is greatest (Spring Range). Determined directly from measurements of neap high tides or derived from a harmonic analysis of the full measured tidal sinusoid. Measured at a specific location, over a specified time period.
- Storm surge: is the sum of all factors that can disturb the regular periodic tidal variations in sea level associated with astronomical bodies. Such factors include barometric pressure and wind. Storm surge is measured within short periods of time (hours and days) and excludes long period sea level changes such as sea level rise from climate change. Storm surge is measured as a distance from what would be the normal astronomical sea levels and is measured in still water or averaged over periods long enough to exclude wave impacts.
- Storm tide: is similar to storm surge but is measured as a sea level rather than a vertical distance. Storm tide at any instant equals astronomical tide level plus storm surge at that instant. Storm tide annual recurrence interval describes how many years, on average over a long period of observations, between successive sea level is exceedances.
- NZVD2016: New Zealand Vertical Datum 2016. The official vertical datum for New Zealand and its offshore islands as defined in the LINZ standard LINZS25009.

- Wave setup: is the effect of wave the increase in mean water level due to the presence of breaking waves.
- Wave run-up: the maximum onshore elevation reached by waves (ie: “wet toes at the beach”). In typical beach situations wave run-up goes higher up the beach than wave setup and covers areas of the beach which have no water depth in between wave peaks.
- Disconnected inundation: When low lying land is separated from the inundation source (in this case the ocean), by intermediate high ground, then it is often the case that this land will remain dry and not actually be inundated. Exceptions often occur in developed sites though through drainage system connections including underground pipes which will convey flooding to the low-lying ground. Such separated areas are considered to be disconnected flooding. This is discussed further in section 3.2.

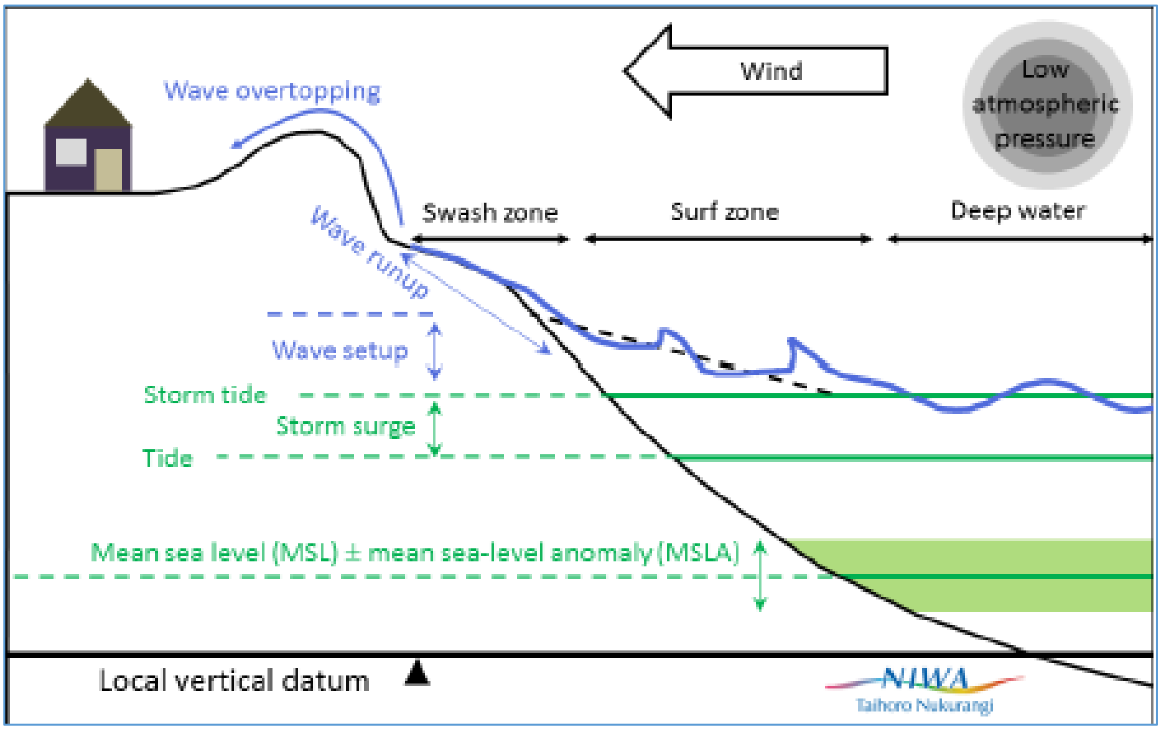

Figure 1 Terminology Diagram[1]

[1] Figure taken from Waikato Regional Council publication https://www.waikatoregion.govt.nz/assets/Coastal-Inundation-Tool-V2-User-Guide.pdf (therein Fig 3)

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1.4 Disclaimer

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1.5 Summary of Revision Changes

The previous Rev B version of this memo was peer reviewed. Key feedback and resulting changes in this revision 0 of the memo is described below.

Storm tide: The recommendation to change from Adams storm surge (taken from ref 1) to Stephens storm tide (ref 5) is adopted herein. This makes the reported sea levels better quantified in term of frequency of exceedance (i.e. this improves confidence in the sea level exceedance frequency).

Wave setup: The recommendation to allow for wave setup is adopted herein. This increases the sea inundation levels used for mapping and removes a known source of bias in the previous revision.

Wave run-up: The recommendation to allow for wave run-up is not adopted. This decision is based on advice from MetOcean (ref 1) that wave run-up is not expected to contribute materially to inundation of the site and that for the site as a whole, with bathtub inundation method, it is appropriate to set an allowance of zero for wave run-up as any wave run-up effect is limited to a small area close to the beach.

Disconnected inundation: The recommendation to differentiate disconnected inundation is not adopted for reasons given in section 3.2. In order to better illustrate potential for connectedness, the maps now show the underground pipe network with diameter symbolised so the reader can better appreciate that connectedness.

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2 Sea Levels

2.1 Input data sources

This assessment relies on evaluations of sea level measurements taken at Bluff Harbour (approx. 5 km west of the smelter) and Dog Island (approx. 7 km south of Dog Island).

Measurements of MSL, MHWN and MWHS are taken from LINZ at Bluff Harbor as reported by MetOcean (ref 1).

Estimates of storm tide are taken from Stephens 2020,(ref 5) using median data from Dog Island[2] .

Site topography is as defined from by a LiDAR survey carried out on 3/11/2020 by LandPro and then supplied to GHD by Rio Tinto.

2.2 Datum relationships

The LINZ published sea level statistics for Bluff are published in terms of Bluff Chart Datum. MetOcean (ref 1) have found that in order to convert these levels into NZVD2016, a subtraction of 1.928 m is required (this being the difference between the levels of LINZ benchmark code “ABCC” in the two datums, namely 8.620 and 6.692 m). All levels presented in this memo are presented in terms of NZVD2016.

2.3 Current sea levels

Table 1: Current sea levels

Level specification	Level (m) NZVD2016	Qualitative exceedance frequency
MSL	-0.178	Half of every tide cycle (12 hrs)
MHWN	0.492	Every 12 hours
MHWS	0.882	Fortnightly
1yr storm tide	1.412[3]	Yearly
10yr storm tide	1.542	10 years
100yr storm tide	1.642	100 years
1000yr storm tide	1.722	1000 years

Because the range of levels from 1 – 1000 year ARI is modest, the yearly and 100 yearly levels are selected for later mapping.

[2] Stephens supplement, table S7, site # 19.

[3] Storm tide levels from Stephens (ref 5) are understood to use MSL as the datum. We convert them to NZVD2016 using MSL = 0.178

2.4 Wave setup estimates

Wave setup has been estimated following advice from MetOcean and is added onto the sea levels presented in Table 1.

Table 2: Wave setup and current inundation level

Level specification	Wave Height (m)	Wave setup (m) [4,5]	Current inundation level including sea surge and wave setup (m) NZVD2016
MSL	1.0	0.2	0.022
MHWN	1.5	0.3	0.792
MHWS	2.0	0.4	1.282
1yr storm tide	2.48	0.496	1.908
100yr storm tide	2.94	0.588	2.230

2.5 MfE SLR predictions

Predicted sea level rise in New Zealand through to the year 2150 has been reported by the Ministry for Environment (MfE) (2017[6]) by modifying the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (AR5) projections of sea level rise under four different representative concentration pathway (RCP) scenarios. The RCP scenarios estimate varying future climate outcomes based on predicted global emissions and population.

For the purposes of this assessment, the RCP scenario trajectories have been extrapolated to predict potential sea level rise for up to 500 years (Figure 2).

[4] Annual and 100 yr wave setup allowance is taken from Alexis@MetOcean email "NZAS Coastal Model update" 20210917_1250. This wave setup is based on omnidirectional wave heights from their table 5-2 (Ref 1) for their O3 location. Wave setup is then estimated as 20% of wave heights (from ref 1, section 2.1.2) and wave setup added to storm tide (above mean sea level) from assumption that wave height probability will be well correlated with sea-level probability (eg: 100yr storm tide level occurs coincident with a 100yr wave height).

[5] Sub-annual wave setups (MSL, MHWN and MHWS) are estimated by the author as reasonable for illustration but without any scientific rigour. Other factors of uncertainty are greatly more significant in this assessment than the nearest 0.1m of wave setup in the normal tidal range.

[6] Ministry for Environment, 2017. Coastal hazards and climate change. Guidance for local government.

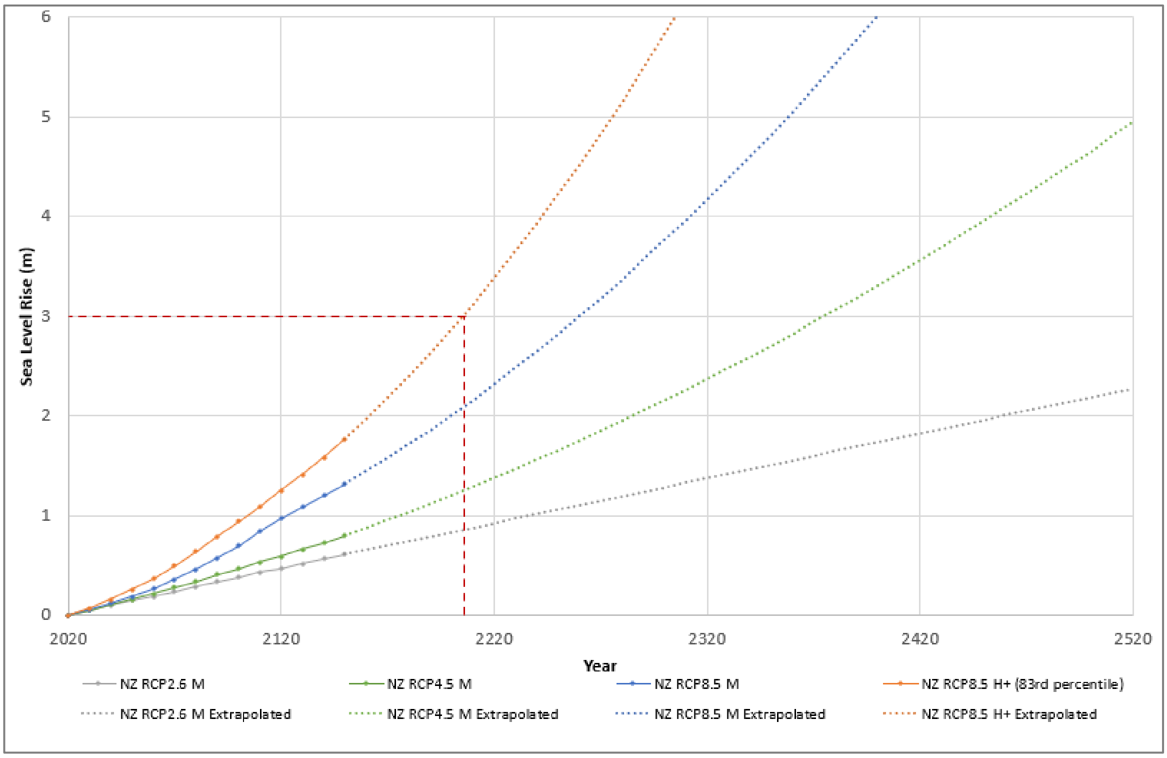


Figure 2: RCP sea level rise to 2150 (MfE, 2017) and extrapolated to 2520. 3 m sea level rise outlined using red dashed line for RCP8.5 H+

Table 3: Approximate number of years until specific sea level rise increments could be reached

Sea Level Rise (m)	Early (RCP8.5 H+)	Late (RCP2.6 M)	Description (years from now)
1	80	210	100-200 years
2	140	410	150-400 years
3	180	>500	200-1000 years
4	220	>>500	>250 years

Table 4: Approximate decade when specific sea level rise increments could be reached

Sea Level Rise (m)	Early (RCP8.5 H+)	Late (RCP2.6 M)
1	2100	2230
2	2160	2430
3	2200	>2520
4	2240	>>2520

2.6 Future inundation levels

Future inundation levels are calculated by the simple addition of the current sea levels (Table 1), and wave setup estimates (Table 2) plus the sea level rise increments shown. For convenience in this memo, and for mapping titles, we approximate the sea level rise timeframes presented in Table 3, as shown below in Table 5.

Table 5: Future Inundation Levels (NZVD2016)

Level specification	Current (2020)	100-200 years from now (1 m SLR)	150-400 years from now (2 m SLR)	200-1000 years from now (3 m SLR)	>250 years from now (4 m SLR)
MSL	0.022	1.022	2.022	3.022	4.022
MHWN	0.792	1.792	2.792	3.792	4.792
MHWS	1.282	2.282	3.282	4.282	5.282
Annual storm tide level	1.908	2.908	3.908	4.908	5.908
100 yr storm tide level	2.230	3.230	4.230	5.230	6.230

These inundation levels are shown on the attached site inundation maps.

2.7 Vertical Land Movement

Bevan et al (ref 7) 2012, reports that Bluff continuous GPS land level monitoring between 2004-2009 show the land as being stable (having a slow upward annual velocity of 0.4mm/year - table 2). Upward land movement would reduce the frequency of future sea level inundation with sea level rise, however at Bluff the rate of expected New Zealand sea level rise (circa 5-10mm/yr) massively dominates the estimated slow upward land movement.

There is a significant risk of sudden tectonic action (earthquake) causing significant land movement either up or down. This is intrinsically unpredictable and the risks are generally unknown. Downward land movement from an earthquake would immediately increase the risk of sea inundation. This risk is not quantified or otherwise considered in this memo.

3 Inundation

The typical flat ground level around the NZAS developed site has a relative level (RL) of around 3.5 – 4.5 m.

With 2 m of SLR, circa 150-400 years from now (attached Figure 3), more than half of the ground in this level range would experience inundation by an annual storm event (annual storm tide plus 0.5m of wave setup).

With 3 m of SLR, circa 200-1000 years from now, some of this ground would be begin to experience inundation every day (even during neap tides) and almost all of this ground would be inundated fortnightly by MHWS plus 0.4m wave setup.

With 4 m of SLR, all of this ground would experience twice daily inundation every day (even during neap tides plus 0.3m wave setup), and half of the ground in this range would be inundated by mean sea level plus 0.2m of wave setup..

3.1 Site features of interest

Key features of interest on the site such as the landfills and the SCL repository are typically on higher ground predominantly above RL 5 m and so would be less susceptible to sea level inundation than the main site at 3.5 – 4.5 m.

Key features which are shown on the following mapping are listed below in Table 6 including their lowest ground level and comment on what future sea level would begin to cause inundation of this ground level.

Table 6: Key features of interest

Feature	Indicative low ground level (m)	Future sea level inundating (approx.)
Liquid storage area	2.9	Annual storm, 1m SLR
Landfills	4.7	Less than annual storm, 3m SLR
Haysoms Dross Waste Pile	4.7	as above
WWTP discharge are	4.7	as above
Spent cell liner storage	4.8	as above
Area for potential future facilities	4.8	as above
Spent cell liner pad	5.7	Less than annual storm, 4m SLR

The above ground levels have been taken from the NZAS supplied LiDAR at reference elevation locations as shown on the inundation maps. At this preliminary stage, features of interest in relation to sea level inundation are not well defined nor their sensitivities understood, so the features identified here should be improved in subsequent work.

3.2 Inundation maps

Maps showing the inundation extents at the site for the four sea level conditions and four sea level rise scenarios illustrated in Table 5 are attached to this memo.

Areas of disconnected inundation can readily be discerned through careful inspection on the maps as presented. We have not highlighted connected flooding or differentiated disconnected flooding because of substantial shades of grey in the realities of connectedness. These shades of grey result from ;

1. In many of the disconnected areas, there are underground pipes which make a connection, so some inundation is expected to occur, but likely not to the full bathtub level.
2. In many areas of connected flooding, the depth and breadth of connection is modest in relation to the volume of water needed to inundate the low-lying area to bathtub levels, within the typically short duration of a tidal peak. In this instance again some inundation is expected to occur, but likely not to the full bathtub level.
3. In the long timescales considered in the mapping here, coastal erosion is likely to alter landforms and change which areas are connected or disconnected. Similarly anthropogenic changes such as removal of drainage culverts and reinstatement of open drains would make similar changes.

In general, the concept of disconnected flooding is not an important consideration for preliminary closure planning. It cannot be more usefully understood until (and if) hydraulic modelling is undertaken. Hydraulic modelling would not be recommended until a reasonably firm closure concept is selected and then only if significant sensitivities to sea level inundation were left onsite.

4 Conclusions

From this preliminary assessment, sea levels are relevant to the distant but foreseeable future planning at Tiwai Point. While the risks of sea level inundation are reasonably low at present, in future with plausibly higher sea levels (SLR), sea level inundation can reasonably be expected to become common over much of the site. Annual inundation of half of the existing developed flat land could become typical within 150-400 years (2 m of SLR). Within the site, the lowest feature of apparent interest is the existing liquid storage area.

Sea level inundation may result in adverse impacts from ground salinity and coastal erosion. These factors will influence flora and fauna and could disrupt any residual human infrastructure on the site, such as landfills, roading access, concrete pipes and foundations. The importance of such impacts will depend on the post-closure approach selected, future land-use and ownership. For some types of future land-use and ownership, sensitivity to such impacts may motivate a more thorough assessment of effects from sea level rise risks at the site. Isolated low-lying topography (if any) should be considered with respect to whether ecological outcomes with increasing salt-water inundation frequency are likely to be positive or perhaps better avoided through change to the post closure topography.

For any features to remain long-term onsite, post closure sensitivities to future inundation should be evaluated in parallel with closure and future land use planning. In the immediate term, prior to further closure plan development, sensitivities of all existing site features to future inundation could be evaluated.

If closure planning proposes to leave significant features sensitive to sea level inundation based on a wait and see approach to sea level rise and deferral of possibly action to protect or remove sensitive features, then more sophisticated modelling of inundation scenarios may be warranted to better understand risk thresholds and define under what future conditions risks might be considered to justify further action of protection or removal, if those conditions do arise.

5 References

1. MetOcean: Coastal Assessment Study - Tiwai Peninsula, for NZAS/GHD, Feb 2021, Rev 0.5
2. Rio Tinto / NZAS: Supplied LiDAR and aerial photos surveyed by LandPro 3/11/2020
3. MfE “Coastal hazards and climate change: Guidance for local government” 2017, refer table 10
4. MfE “Update to 2018 of the annual MSL series and trends around New Zealand” 2018
5. Hannah and Bell “Regional sea level trends in New Zealand”, Journal of Geophysical Research Vol 117, Jan 2012
6. Stephens 2020: “Spatial and temporal analysis of extreme storm-tide and skew-surge events around the coastline of New Zealand”, Nat. Hazards Earth Syst. Sci., 20, 783–796, 2020, Scott Stephens, Robert Bell, and Ivan Haigh
7. Beavan RJ, Litchfield NJ. 2012. Vertical land movement around the New Zealand coastline: Implications for sea-level rise. Lower Hutt: GNS Science. www.gns.cri.nz/static/pubs/2012/SR%202012-029.pdf

Kind regards

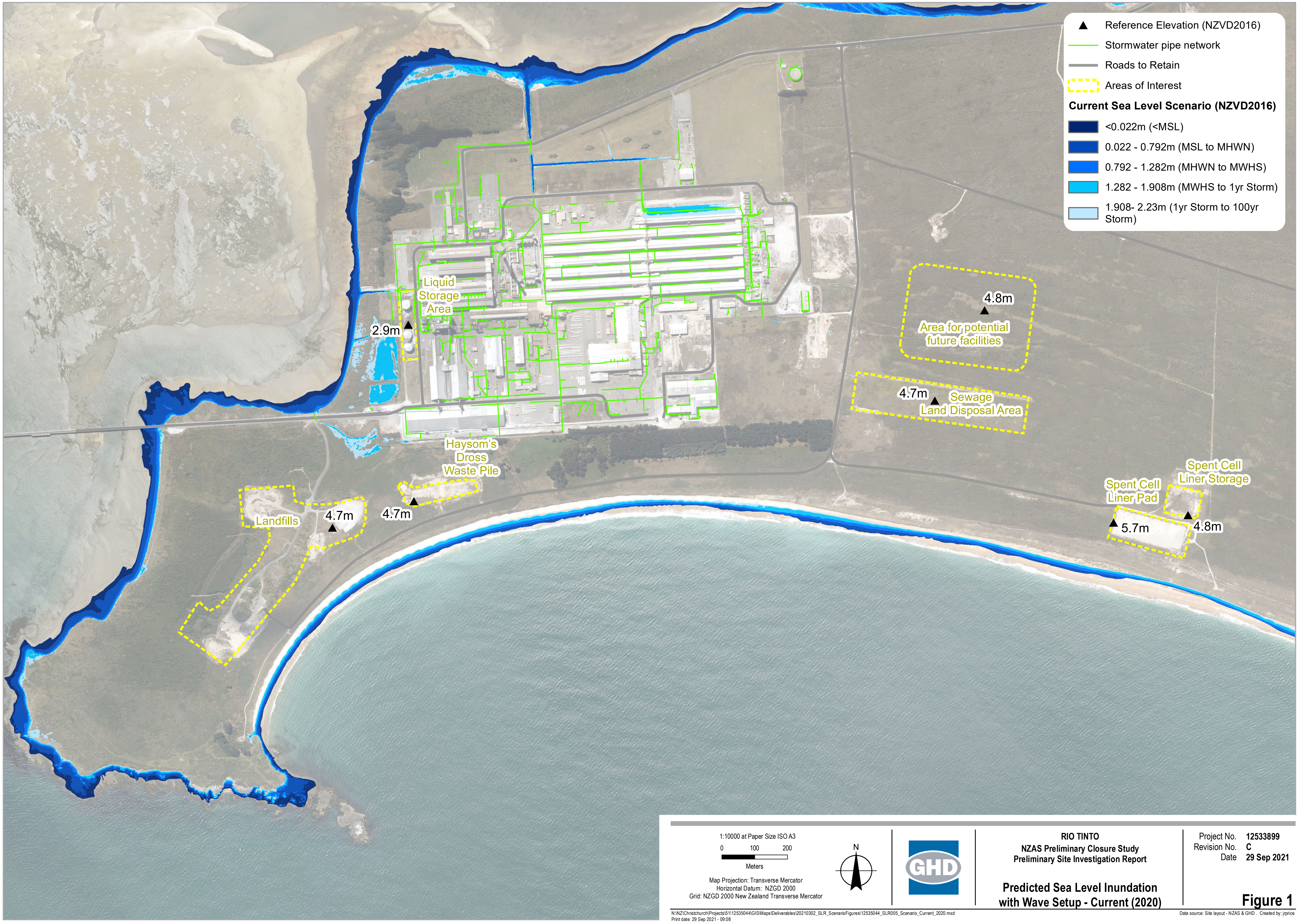
Tim Preston
Senior Water Engineer

Daniel Todd
Project Manager

Memorandum

Attachments:

1. Figure 1 – Predicted Sea Level Inundation Current (2020)
2. Figure 2 – Predicted Sea Level Inundation 100-200 years from now (1 m SLR)
3. Figure 3 – Predicted Sea Level Inundation 150-400 years from now (2 m SLR)
4. Figure 4 – Predicted Sea Level Inundation 200-1000 years from now (3 m SLR)
5. Figure 5 – Predicted Sea Level Inundation >250 years from now (4 m SLR)



Map Projection: Transverse Mercator
Horizontal Datum: NZGD 2000
Grid: NZGD 2000 New Zealand Transverse Mercator

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NZAS Preliminary Closure Study
Preliminary Site Investigation Report

Predicted Sea Level Inundation with Wave Setup - Current (2020)

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Figure 1

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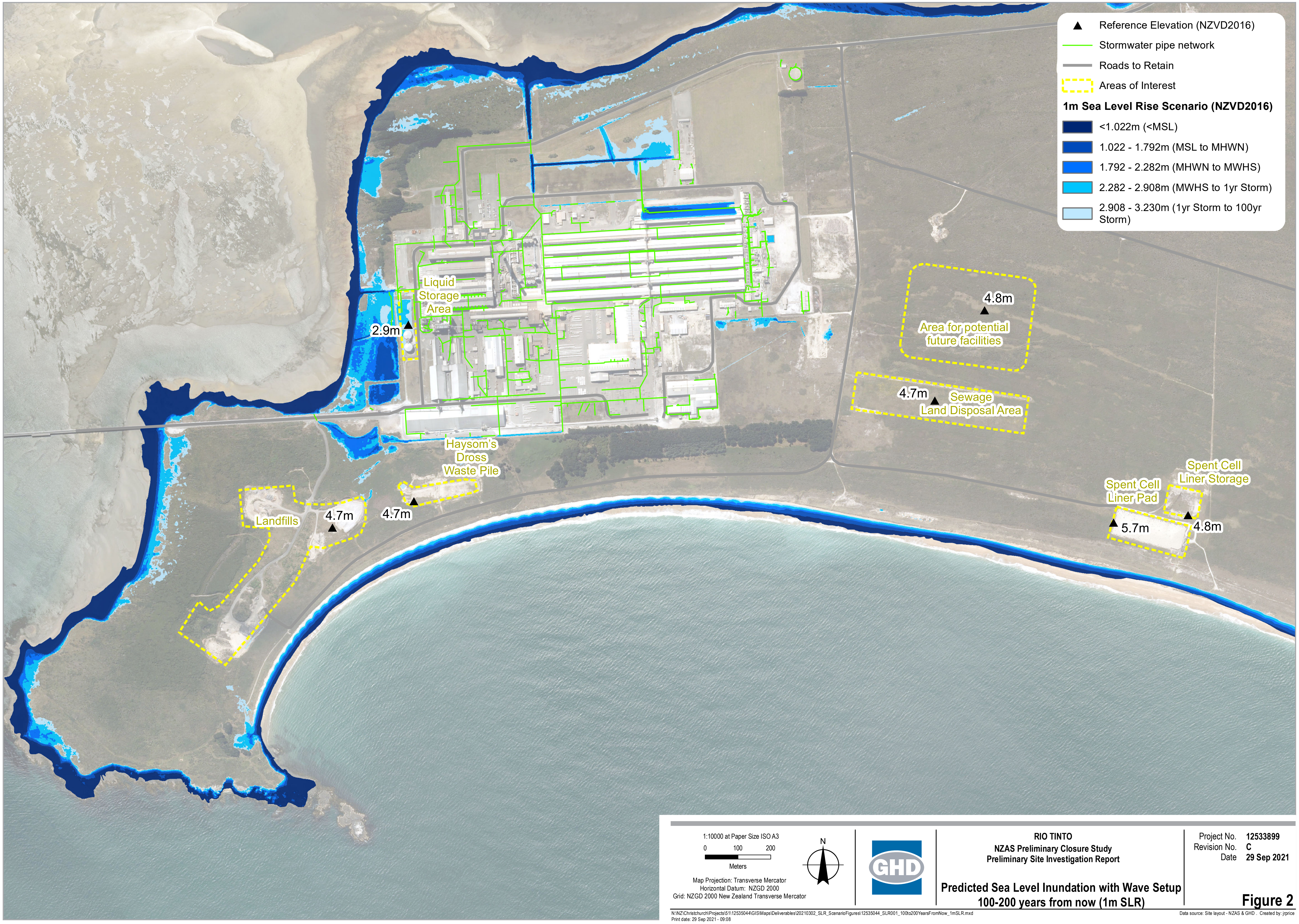

Map Projection: Transverse Mercator
Horizontal Datum: NZGD 2000
Grid: NZGD 2000 New Zealand Transverse Mercator

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Predicted Sea Level Inundation with Wave Setup 100-200 years from now (1m SLR)

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Figure 2

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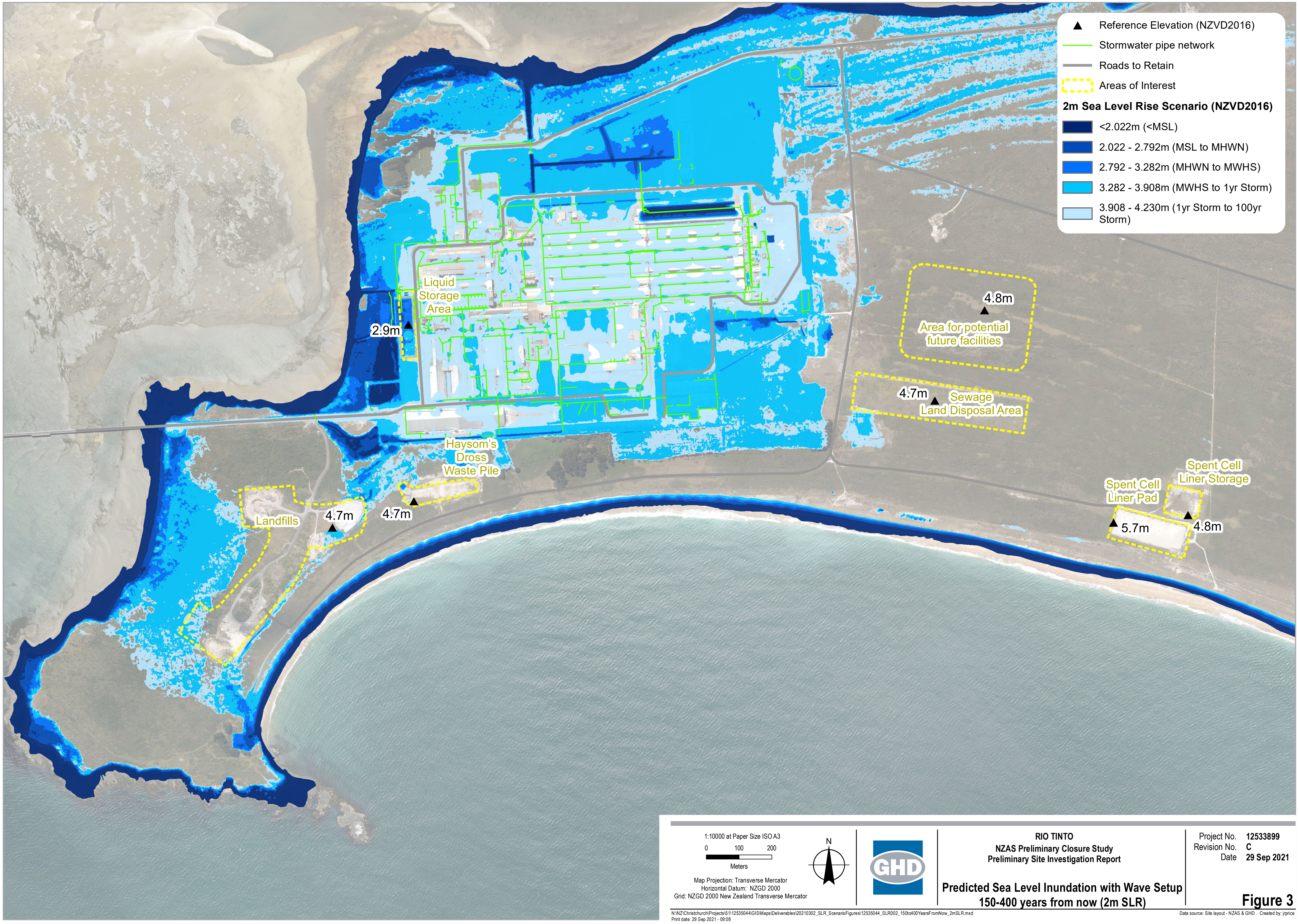

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Predicted Sea Level Inundation with Wave Setup 150-400 years from now (2m SLR)

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Figure 3

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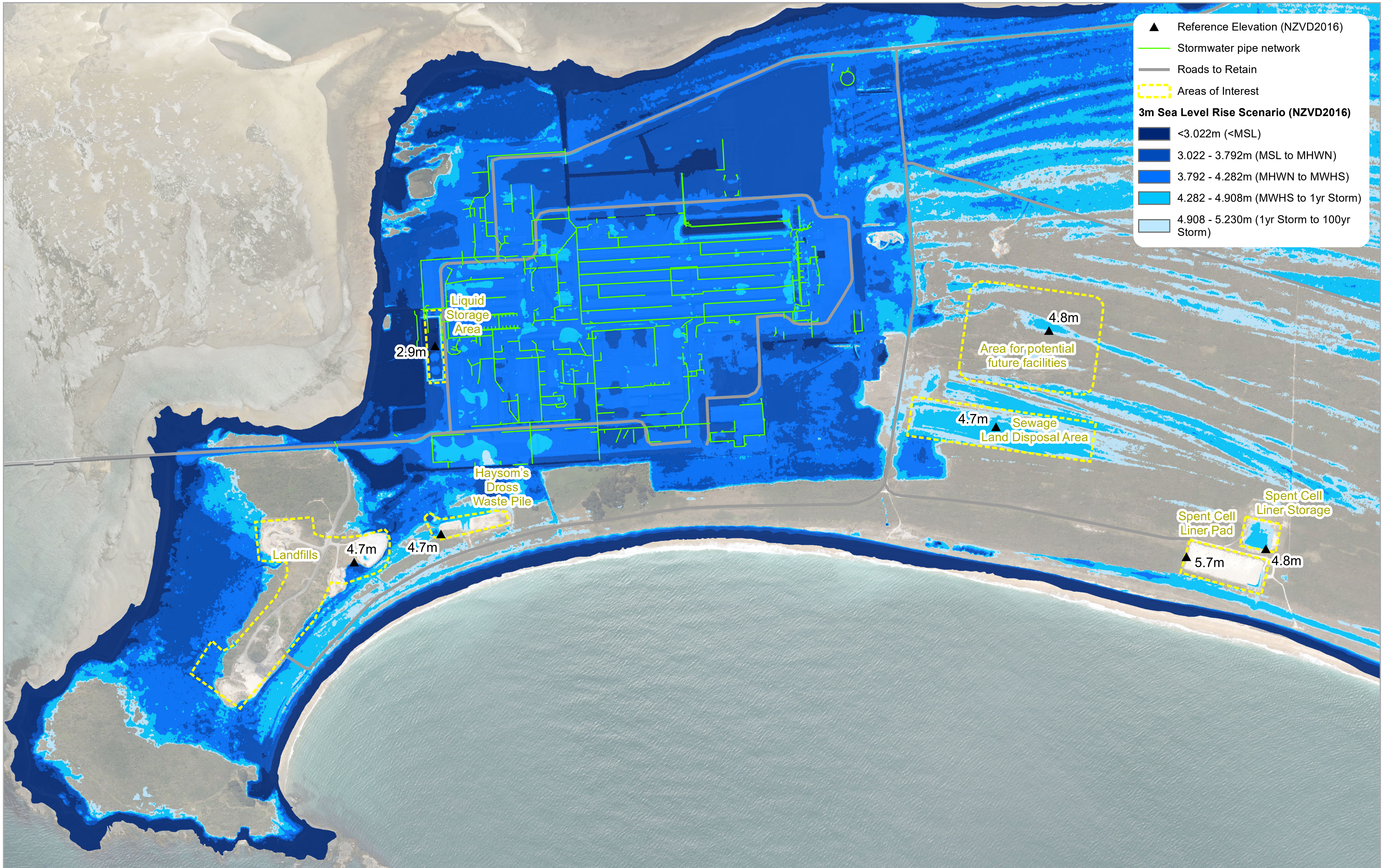

Map Projection: Transverse Mercator
Horizontal Datum: NZGD 2000
Grid: NZGD 2000 New Zealand Transverse Mercator

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Predicted Sea Level Inundation with Wave Setup 200-1000 years from now (3m SLR)

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Figure 4

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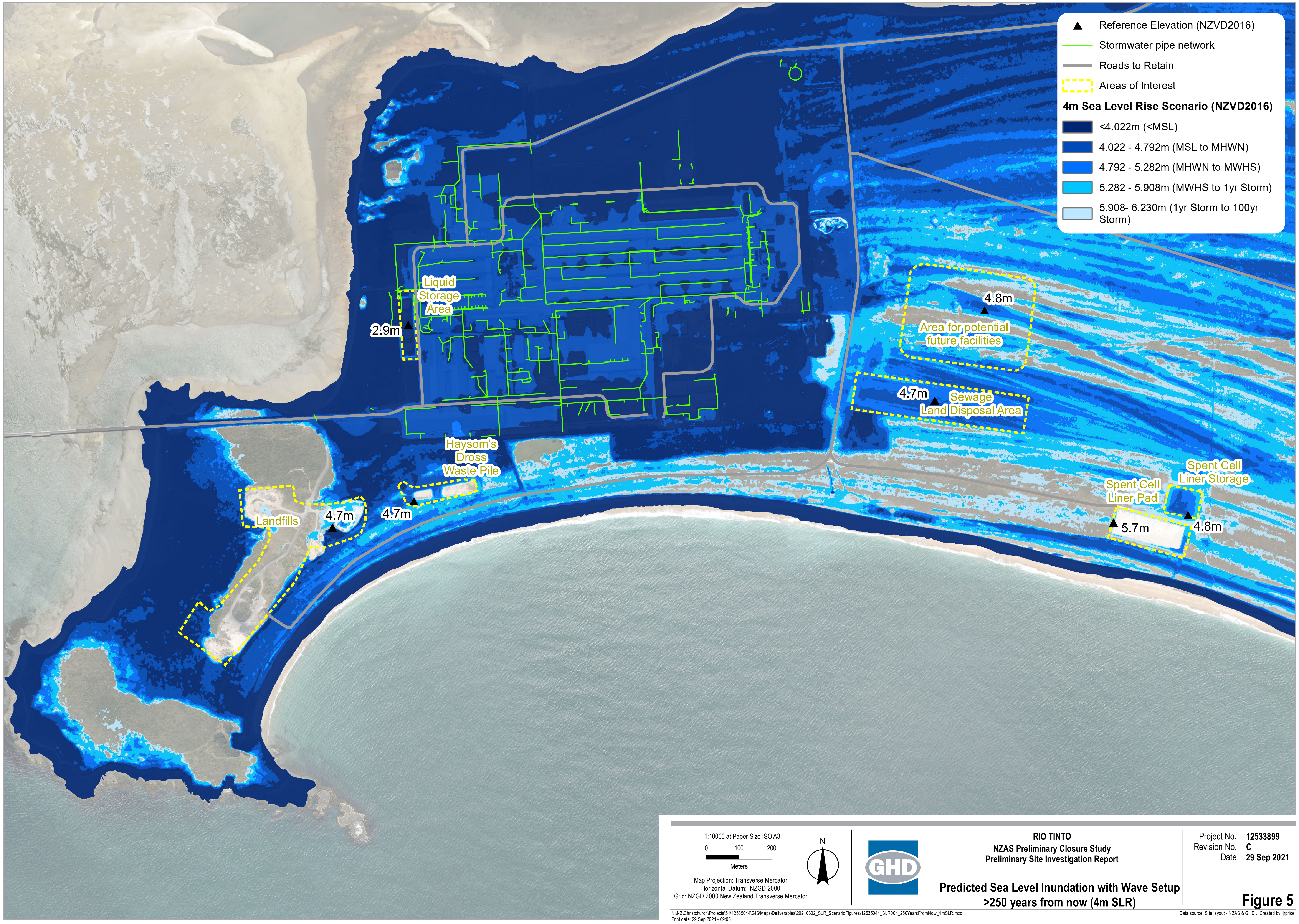

Map Projection: Transverse Mercator
Horizontal Datum: NZGD 2000
Grid: NZGD 2000 New Zealand Transverse Mercator

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Predicted Sea Level Inundation with Wave Setup >250 years from now (4m SLR)

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Figure 5

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