Tonkin+Taylor

Job No: 1012360.2000
29 September 2020

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Attention: Matt de Boar

Dear Matt

Review of DHI hydrodynamic model for inundation assessment within the Kaipara Harbour

1 Introduction

The Northland Regional Council (NRC) engaged the Danish Hydraulic Institute (DHI) to develop a hydrodynamic model for the Northern Kaipara Harbour to assess and map coastal inundation around the harbour margins. This has been undertaken for a range of scenarios from present day mean high water spring and 1% AEP storm events to future 1% AEP event with up to 1.5 m sea level rise.

NRC have subsequently engaged Tonkin & Taylor Ltd (T+T) to undertake a review of the modelling and the resultant levels and inundation extents.

1.1 Scope of review

This review has included the following scope of works:

- An Initial meeting (teleconference on 5 August) with Matt de Boer from NRC and Ben Tuckey from DHI to discuss the scope of DHI's assessment, methods and findings
- A review of the modelling methods and resultant levels as presented within the DHI (2020) Draft 0.2 report and the inundation layers
- Teleconference with DHI and NRC (15/9/20) to discuss preliminary findings
- Presentation of review within in a concise letter to NRC

2 Review

2.1 Overview of DHI brief

We understand DHI's brief from NRC (3/12/19) includes the following:

- Extension of the hydrodynamic model for the southern part of the Kaipara Harbour to include the entire Kaipara harbour using new LiDAR data
- Following a prescribed methodology to

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- develop the model including stop banks and roughness
- Utilising previously developed extreme levels to develop boundary conditions
- Sensitivity testing to determine the necessary size of domain and cells
- Modelling of three inundation scenarios

- A summary report detailing method, technical issues addressed, and results
- Mapping and provision of GIS data including

  a) GIS Rasters (Arc Map 10.4.1 compatible) for maximum flow depth, velocity and flood elevation for each site and each event assessed (CFHZ 0, CFHZ 1, CFHZ 2)

  b) GIS polygon shapefiles for each event assessed, mapped to DEM, based on maximum flood elevation raster file.

We understand from DHI (Tuckey pers. Comm. 29/07/20) that certain assumptions, limitations and approaches have been agreed with NRC during the course of modelling including:

- How stopbank breeches should be infilled to prevent unrealistic present day flooding
- Where extreme levels should be matched (initially Ruawai B)
- An alternative approach to deriving extreme levels

2.2 Overview of assessment

Our understanding of the assessment is as follows. DHI have extended an existing Kaipara Harbour model to include the northern Kaipara Harbour and have utilised LiDAR data provided by NRC as a 1 m DEM to define the intertidal areas and floodplains within the NRC region. A flexible mesh model has been used with higher resolution (around 10 x 10 m) around narrow rivers and stopbanks and larger mesh used on flood plains or the wider harbour. Stop banks and main highways have been generally represented by dikes with levels based on LiDAR or council survey in the case of a wooden stopbank south of Dargaville. Some additional gaps in the stopbank were identified and closed with crest levels set based on surrounding stopbank crest levels. Varying roughness was defined across the domain based on land use. Sensitivity testing was undertaken on bed roughness, model resolution and effect of catchment flooding and extreme coastal level coincidence.

The tidal boundary across the mouth of the harbour has been established and for the purposes of calibration, this is set based on Pouto Point gauge. Model calibration has been undertaken using water level gauges at Dargaville and Helensville for a typical tidal cycle and two storm tide/surge events with low river flows. A constant, flow from the Wairoa River of 80 m^3/s (reported as the mean flow) and an adjustment to the boundary condition of +0.08 m and -55 minutes was found necessary to achieve calibration at Dargaville and applied across all modelled scenarios. Additionally, some channel depths were increased from the hydrographic charts to improve calibration.

NRC requested that the following scenarios to be modelled:

1. MHWS – Present day mean high water spring
2. CFHZ0 - Present day 1% Annual Exceedance Probability (AEP) storm event with wave set up
3. CFHZ1 - 2% AEP storm event with wave setup and 0.6 m sea level rise
4. CFHZ2 - 1% AEP storm event with wave set up and 1.2 m sea level rise
5. CFHZ3 - 1% AEP storm event with wave set up and 1.5 m sea level rise.

This was undertaken by adding a synthetic storm surge to a tidal timeseries at the boundary with coinciding peaks to match 1% AEP and 2% AEP values for Pouto Point. Then adding 0.18 m to account for wave set up (based on value for Ruawai B in T+T, 2017) and sea level rise as required for the three future scenarios. Values were compared to T+T (2017) (adjusted to NZVD and 0.2 m SLR differences) with generally lower values found which is attributed to volume lost into the flood plain compared to the static 'bathtub' level assumed by T+T.

Sensitivity testing was undertaken around roughness (levels typically -10 cm for change in roughness of +25%), grid size (slight increase in flooded area using finer grid) and the additional of a 50 year ARI flood flow (peak flow of 1700 m^3/s coincided with the storm tide peak) which indicated less than 5 cm difference on the Ruawai flood plain, 5-10 south of Dargaville, 10-20 cm across the river from Dargaville and greater differences further up the Wairoa River.

Results were presented as 10 m x 10 m raster files of maximum water depth, maximum water level and maximum current speed with GIS polygons of maximum flood elevation mapped from the 10 m rasters to a 1 m DEM.

2.3 Detailed review

Specific review comments are marked up within the Draft Technical Report with comments summarised below.

2.3.1 Assessment brief

The assessment brief provided to DHI prescribed the events, the levels to match and the sea level rise scenarios to adopt.

It is unsurprising that a level match was difficult to achieve given the levels were originally based on empirical assessment and a static, bathtub approach. A modified approach is presented in the DHI report utilising an extreme boundary condition based on Poutu Point gauge data and then allowing the (calibrated) model to inform the inundation levels. This is a reasonable approach and is further discussed below.

The sea level rise values were also prescribed at +0.6, 1.2 And 1. which is in agreement with the values to be used within the remainder of Northland Inundation assessment (T+T, In Draft).

2.3.2 Background information and data

Background information and data appears up to date and fit for purpose, although some dates and references to LINZ hydrographic chart numbers could be provided along with quoted accuracy on the LiDAR used.

We note that the lack of stopbank information in some locations required infilling by interpolation, which is reasonable, but could be followed up with topographic survey or at least inspection where possible.

2.3.3 Model development

The model development appears reasonable with the domain resolution selected to balance accuracy and computational time given the very large size of the area being modelled. Given the resolution, the inclusion of stopbanks as dikes is essential with elevation either taken from LiDAR or from NRC survey south of Dargaville. An additional stop bank survey dataset is mentioned by eCoast (2017) at Ruawai, though their plots indicates that LiDAR appropriately resolves this bank (within 0.1 m) so inclusion is unlikely necessary.

The extents of the domain are shown within Figure 3-1. However, it is likely that inundation will extend beyond this in some locations (i.e. up the Wairoa River) and where inundation reaches, and is constrained by, a model boundary this should be clearly indicated within results.

Finally structures such as culverts are not included. This should be noted with NRC giving consideration to where such structure may exist and whether their inclusion could affect results. We note the Banett & MacMurray (2016) report mention inclusions of such structures into the Tuflow model at that time, though detail is not provided within their report.

2.3.4 Modelling calibration and validation

Model calibration appears reasonable. Figure 4.1 shows slight over-prediction at Helensville but better agreement at Dargaville which is more important. Calibration and validation for significant storm tide events on 6 June 2012 and 9 September 2006 show good agreement with peak levels observed.

The calibration approaches of deepening the channels, adjusting the boundary by +0.08 m and adding 80 m^3/s river flow (mean flow) appear reasonable.

2.3.5 Sensitivity testing

Sensitivity testing has been undertaken to test the effect of a coincident 50yr ARI flood event, the effect of roughness and the effect of grid size. The modelling results find that addition of the flood event results in differences of less than 0.05 m at Ruawai, increasing with distance upstream. DHI appropriately conclude that the coincidence of flood flows should be considered upstream of Ruawai. We agree with this statement and that this work lies outside of the present study scope.

The influence of a higher resolution grid in increasing flooding in some discrete locations is interesting and not well explained. This could be due to the higher resolution grid exposing a flow path not resolved at lower resolution? We also note that only the lower CFHZ0 has been modelled using the higher resolution. Given the reduced levels and inundation extents achieved under the hydrodynamic modelling compared to the previous bathtub, there needs to be confidence that the potential inundation is not now being under-predicted due to effects of resolution.

2.3.6 Scenarios simulated

We understand that specific scenarios were requested by NRC including combinations of 1% and 2% AEP scenarios (including wave set up) combined with sea level rise values of 0.6, 1.2 and 1.5 m. A recent reassessment of the Poutu Point gauge has been undertaken by NIWA (2020), though 1% AEP results are within 3 cm. As noted above, the levels developed by T+T (2017) were based on an empirical building block approach and matching specific values at different locations within a hydrodynamic model would be difficult. The revised method of utilising an extreme level at the boundary and using the (calibrated) model to determine levels is more appropriate.

The main comments here are that a single value for wave set up is added directly to the boundary rather than added to the storm tide level within the harbour. This may therefore result in slightly over-estimated levels in sheltered locations where wave set up is unlikely to occur and under-estimated levels in exposed locations. However, to resolve this would require use of an additional wave model, combination of multiple datasets and likely some form of extrapolation to determine final inundation extents. Therefore, the inclusion of 0.1 to 0.2 m for wave set up across the model as has been undertaken is reasonable and likely results in inundation levels ±0.2 m for sheltered and exposed locations.

2.3.7 08 m Resultant levels

The resultant levels appear reasonable, although it is noted that the simulated CFHZ0 level (and the T+T level) for Dargaville are lower than shown in Table 5.2. 2D HI have suggested (B. Tuckey pers. Comm. 4/9/20) that inundation flows over the stopbanks will result in lower water levels which the extreme value analysis may not be accounting for and additionally the extreme value analysis may include river flood events. This difference is therefore reasonable, although it is noted that river flood events may elevate water levels higher than shown here.

2.3.8 Mapping

DHI have confirmed (B. Tuckey pers. Comm. 4/9/20) that the MHWS mapping has been based on hydrodynamic modelling and have clarified this in the report, although the specific definition of the MHWS (MHWS-10) should be defined as well as a comparison to the MHWS level at Pouto Point (given in NIWA, 2020 at 1.51 m NZVD2016).

The remainder of the mapping appears reasonable, although the description of how the 10 m x 10 m raster values are mapped to a 1 m DEM is light on detail and a figure or some additional text describing the process would assist. The shapefiles have ended up quite fragmented (e.g. Figure 1) with many disconnected parts and may need some cleaning prior to use. We understand that this has been outside of DHI's scope of works but may need to be considered by NRC prior to use. Additionally, there are locations (e.g. Figure *2*) where the raster appears to extend further landward than the 1 m shapefiles. DHI have indicated (B. Tuckey pers. Comm. 4/9/20) that this is due to the resolution of the raster, which is reasonable.

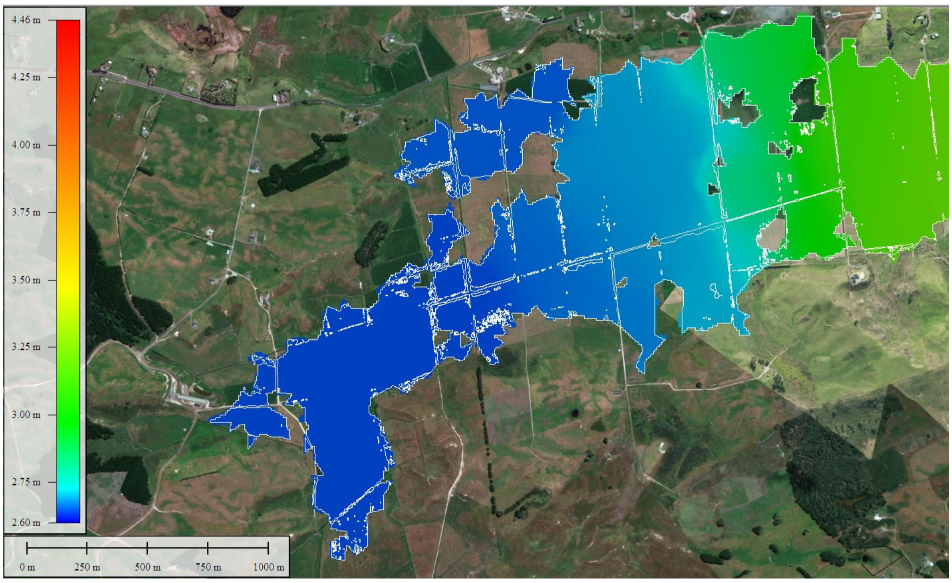

Figure 1 Example of 1 m shapefile (white) overlying 10 m raster image for CFHZ3

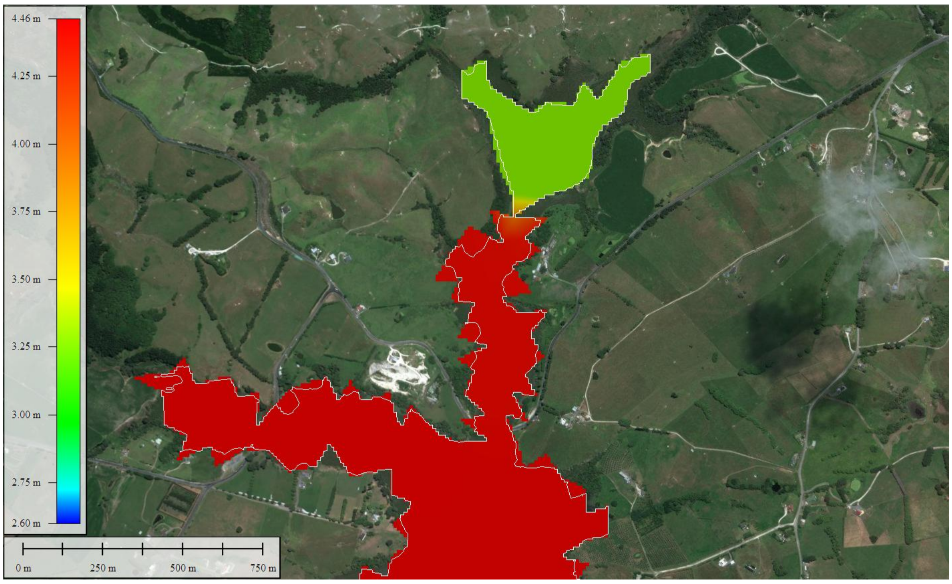

Figure 2 Example of 1 m shapefile (white) overlying 10 m raster image for CFHZ3 with the raster extending further landward

2.4 Conclusions

We have reviewed the DHI (2020) Draft 0.2 and Final 1.1 reports describing the model development and the resulting inundation layers. Based on our review we find that DHI have undertaken the modelling tasks requested of them using generally best practice methods. The method of incorporating wave set up is relatively blunt but effective and likely results in inundation levels ±0.2 m for sheltered and exposed locations.

We have queried some aspects of the modelling such as whether calibration adjustments have been carried through into the scenario modelling and reasons for the difference in modelled extreme level at Dargaville from statistical values. And also of the mapping such as the MHWS definition and whether hydrodynamic modelling has been used to establish the mapped polyline the methods used to map the 1m   polygon and reasons for slight differences in inundation extent between the raster and polygon layers. DHI have provided responses to these which are acceptable and generally clarified their approach in their report.

Overall we conclude that this model is suitable for defining areas susceptible to coastal inundation, and while we note that the adopted resolution means that spatial extents may be under-predicted in some locations (i.e. as shown in Figure 6-2 of DHI, 2020), the bulk addition of a wave set up allowance to the boundary condition likely balances this.

3 Recommendations

Recommendations for additional works or improvements during subsequent updates include:

- Better understanding and incorporation of stop-bank crest levels in locations of uncertainty. This may include topographic or higher resolution aerial survey.
- Understanding of stop bank condition and the effects of failure of stop banks in poor condition (also recommended in Barnett & MacMurray (2016)
- Identifying other structures (culverts etc) that may connect the harbour to low lying land or modify the flow conditions (i.e. roads)
- Additional sensitivity using a higher resolution domain to confirm inundation extent or areas that would benefit from use of a higher resolution domain.

- Consideration of open coast storm tide (astronomical tide and storm surge) separately from intra-harbour effects such as wind and wave set up. We understand this can be problematic due to the joint occurrence and dependence between these processes but either joint analysis of scenario-based assessment could be considered.

4 Further consideration of the joint occurrence of elevated coastal levels with river flows to better understand the potential combined flood hazard.References

Barnett & MacMurray Ltd (2016) Coastal flood hazard zone modelling for Kaihu valley, Dargaville and Awakino floodplain. Report prepared for Northland Regional Council.

DHI (June 2020 Draft 0.2) Technical Report: Coastal Inundation Modelling for Northern Kaipara Harbour Numerical Modelling. Report prepared for Northland Regional Council.

eCoast (2017) Coastal Flood Modelling of Ruawai, Kaihu-Dargaville and Awanui. Report prepared for Northland Regional Council.

NIWA (2020). Extreme sea-level plots for Northland gauges. Prepared for Tonkin & Taylor Ltd.

Tonkin and Taylor (2017). Coastal Flood Hazard Zones for Select Northland Sites 2017 Update. Report prepared for Northland Regional Council.

5 Applicability

This report has been prepared for the exclusive use of our client Northland Regional Council, with respect to the particular brief given to us and it may not be relied upon in other contexts or for any other purpose, or by any person other than our client, without our prior written agreement.

Tonkin & Taylor Ltd

Environmental and Engineering Consultants

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Appendix A: DHI (2020) Draft 0.2 including T+T comments and DHI responses