12 June 2024

Wairoa Flood Protection Stakeholder Group

Digital Flood Modelling - Wairoa

Dear Members of the Stakeholder Group,

Please find below information on the use of digital flood modelling and the application of the modelling for the Wairoa project.

What is a digital flood model?

Digital flood models, such as the model developed for the Wairoa River, are used widely across New Zealand and the rest of the world for assessing flood risk. The simplest explanation is that a digital flood model is a virtual representation of the river and its flood plain. Their use is standard industry practice around the world. They allow us to simulate flood events quickly and efficiently at low cost. These types of digital model are extremely useful, as they can quickly and easily be modified, and many scenarios or flood events can be simulated over a short time-period with reduced labour.

Modern computing power means that we can build these large, detailed 2-dimentional flood models. In the past when computer power was more limited, physical models or 1-dimensional digital flood models were more commonly used.

1-dimensional digital flood models represent flow in only one axis and are therefore not very well suited to rivers with complex flood plains where water can flow in multiple directions. They are best suited to situations where the flow is in one direction only. The benefit of 1-dimensional models is they do not require a lot of computational effort. 1-dimensional digital flood models are still used; however, they are not well suited to catchments like Wairoa. Physical models are a scaled physical representation of the catchment where the results are transposed to equivalent full-scale values. Physical models are still occasionally used to model complex situations, especially where it is important to understand complex flow behaviour or sediment interaction. They are normally developed in research institutes[1]) as they require large flumes and specialist equipment.

The disadvantage of physical models is that they are more expensive and slower to develop, especially if wanting to test lots of different mitigation options at short notice. This is why physical modelling globally is not commonly used and is generally reserved for academic research or specific situations which are beyond the limits of modern software or computing.

[1] Total Environment Simulator (hull.ac.uk)

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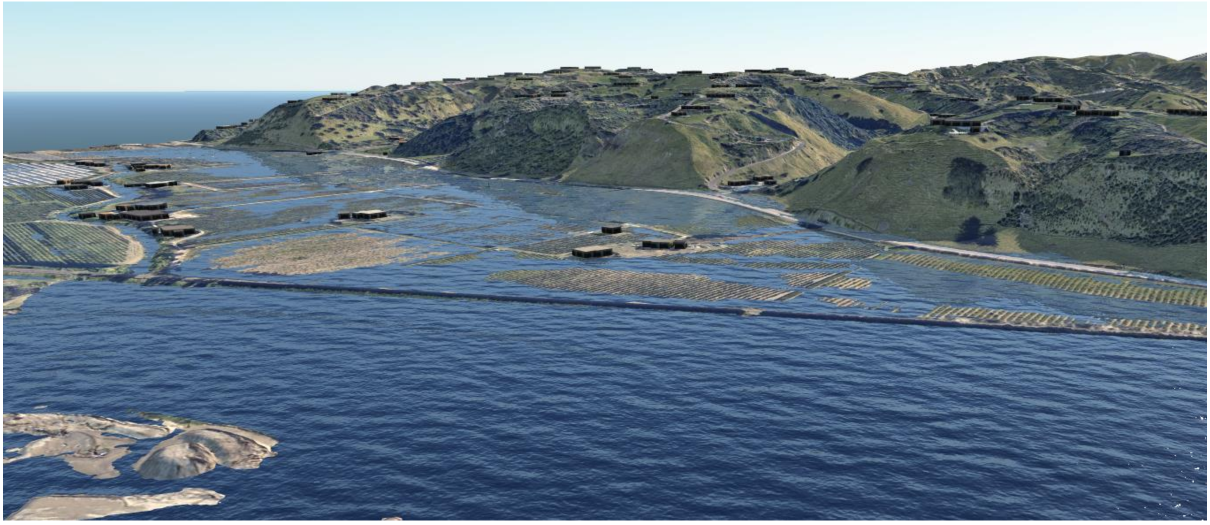

Figure 1 – 3D visualisation of a flood model showing the terrain (DEM) and the predicted flood extent.

What information does a Digital Flood Model use?

Digital flood models combine multiple information sets to simulate floods. These include:

- Digital Elevation Models (DEMs) – these are developed using LiDAR and survey to represent the form of the landscape digitally (a 'digital twin').
- Flow inputs – for Wairoa these are estimated using statistical procedures from data measured at flow gauges and historic flood events.
- Rainfall – run-off from land that contribute flows to the main river are simulated using the High Intensity Design Rainfall System (HIRDS) which was developed by NIWA. HIRDS rainfall values are based on statistical analysis of historic rainfall.
- Spatial Roughness – representation spatially of different surface roughness's. Roughness is important as influences the speed at which water flows with higher roughness resulting in slower flowing and deeper water.
- Tidal boundary – the bottom end of the Wairoa model is governed by the coastal mouth, as represented in the DEM and the level of the tide, which is calculated through statistical analysis of tide gauges along the coastline. The Wairoa flood model assumes that the design flow events coincide with a high tide.

What are Digital Model Limitations?

Whilst flood models are based on well established principles of physics, such as Newton's laws of motion, they are also subject to some limitations. These come in two forms, data uncertainty (information used by the model and how accurate it is) and model uncertainty (computational limitations, or simplification).

Common limitations include:

- Hydrology – hydrology is commonly the largest area of uncertainty in a hydraulic model. In many catchments the flood flow needs to be estimated from rainfall which is harder to get right. In the Wairoa catchment there are flow gauges that allow for more robust assessment of flood flows using statistical methods. However, even with gauged flow data, there is still uncertainty over which flood frequency distribution is used, how it is fitted to the observed data and the length of the record (its sensitivity to the effects of 'randomness' or outlier flood events).

- Stationarity – models represent a snapshot in time. However, some things are not stationary in practice and can change over time (non-stationary). Examples are land use, fences, building and ground elevation (such as the Wairoa River's mouth). During Cyclone Gabrielle there was deposition of sediment through the event some of which may have since been removed through natural and mechanical processes. These changes that can occur through a flood or over decades are complex, hard to predict and hence are not simulated as changing. Instead, the models are periodically updated to capture these changes over time and to provide updated outputs.

- Accuracy of validation information – sometimes water levels are recorded after the fact (for example using debris marks) which can shift as the flood recedes or is influenced by other factors such as vehicle bow waves. Photos of the flooding may not be taken at the true peak of the flood which may give a false impression. People's accounts of flood depths can also sometimes be inaccurate when recorded many months after an event, or they may overstate or understate the flooding where it might affect them personally.

- The level of model detail – there is a trade-off between computational cost and model accuracy. Urban structures such as fences can have local effects on flooding and are non-stationary but would require significant computational effort to simulate explicitly. Complex areas such as these are often represented implicitly rather than explicitly for computational efficiency. This means the overall effect is represented as an average, rather than specifically modelling each building, wall, and fence in detail.

- Flood plain and channel hydraulic roughness is simulated as being constant, but in practice can vary seasonally, over time, and under different flow conditions.

- Flow parameters – information on the amount of entrained sediment or the waters temperature is not normally recorded and available for use. These have a small effect on how 'viscous' the water behaves, but generally the effect is small enough that it can be discounted or compensated for through modification of the hydraulic roughness applied.

- Flow is simulated as 2-dimensional (it can travel on the X and Y axis, but not vertically in the Z axis) – in practice flow is 3-dimensional, but 3-dimensional flow analysis (termed Computational Fluid Dynamics) requires significant computational effort and cannot be deployed at this scale for practical applications. The model instead represents velocity on the Z axis as being averaged over the water's depth. This means that eddies/turbulence cannot be explicitly simulated and must be accounted for implicitly by the water's effective viscosity.

- Sediment transport – sediment transport occurs during large flood events and involves both erosion and deposition of sediment. This means that the DEM is effectively non-stationary. However, to account for sediment transport a lot of historic data is needed and much higher computational effort is needed. This adds significant additional cost and time delays to a project and, without good data to validate results, may not add value to a project. In the case of the Wairoa model, the terrain (DEM) is treated as static, and the main river channels bed is lowered to represent the level of scour that likely occurred during the peak of the flood which is the most important time-period.

- Instability – some model situations can result in instabilities where results can either be erroneous or erratic due to the way the software is trying to resolve the situation. When the model is being developed, we look out for such issues and try and resolve them.

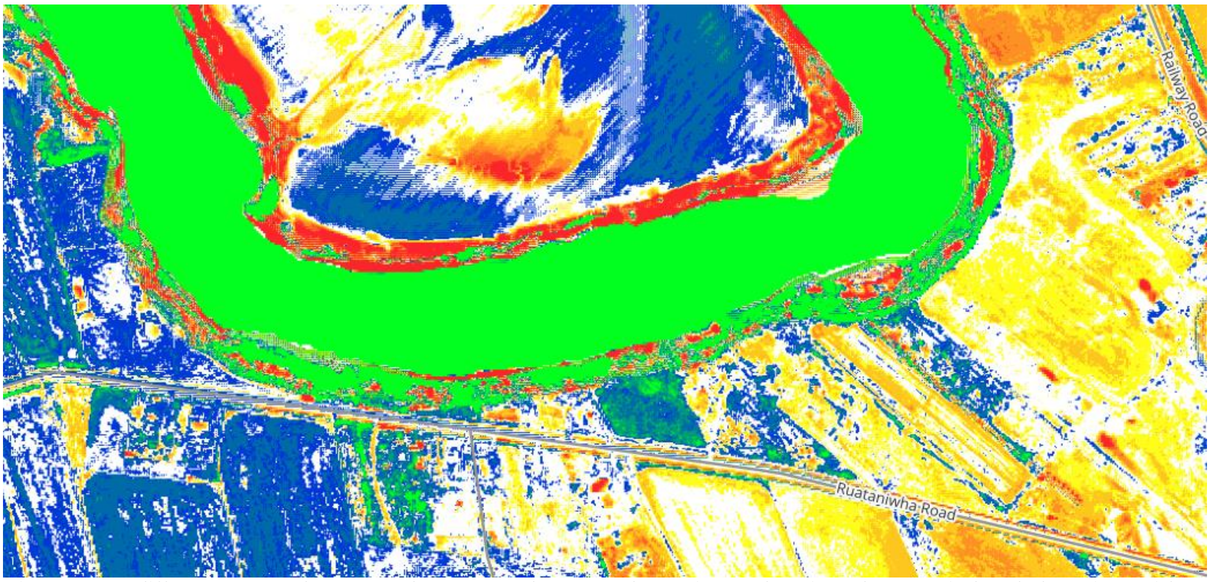

Figure 2 – A difference map between the pre- and post-cyclone LiDAR showing changes in land elevation, with green to blue being land that is now lower, white being unchanged, and yellow through to red being higher (areas of sediment deposition). The lower areas occur either from erosion or changes in crop cover which the earlier LiDAR has removed effectively. Such changes represent data uncertainty but translate to model uncertainty.

How are these limitations accounted for?

Within the field of hydraulic modelling these limitations are well understood, and standard practice has development around them. Ways that these are managed include:

- Industry standard software – we only use software programs for hydraulic modelling that are accepted by the industry and best practice and tried and tested. For the Wairoa model we have used both MIKE+ and TUFLOW software.
- Best practice – we follow best practice guidance on how to build digital flood models which includes, for example, how things should be schematised to avoid model instability or significant errors.
- Resolution – the resolution of the model can be tested at different scales to find the optimum computational time step and resolution that balances accuracy with computational effort.
- Model testing – digital flood models are tested when first built to look for any telltale signs of issues, such as instabilities (erratic values) or time varying values under equilibrium conditions.
- Volume balance (conservation of mass) – the software checks for errors at each model timestep and provides an overall summary of the total volume balance at the end of the simulation. This is to ensure that the volume of water entering the model matches the volume leaving accounting for the volume still in the model. The volume balance checks are reviewed for any signs of an issue and are carried out to ensure conservation of mass is achieved.
- Validation of the model against historic flood events – testing to see how well the model can recreate a historic flood event compared to observational data.
- Sensitivity testing – adjusting different parameters that are tuneable or have an error margin to look at their effect on the results. This provides us with an idea if a parameter

is important or not and which limitations / areas of uncertainty really matter. For example, WSP tested the effect of the flood waters viscosity (due to sediment entrainment) and found it had only a minor effect.
- Experience – consultants such as WSP employ experienced staff who understand hydraulic modelling and best practice. All outputs are internally reviewed by a peer for quality and error prior to being released.
- Peer review – important flood models are commonly peer reviewed by an independent organisation to ensure that they appropriately balance accuracy, computational effort and follow industry practice. The Wairoa model has been peer reviewed by DHI (Danish Hydrological Institute) New Zealand.
- Freeboard / Factors of Safety – engineers understand the limitations of hydraulic models and other factors such as construction tolerances, or post construction settlement and apply freeboard (spare capacity) or 'factors of safety' to their designs to account for it. The same process is applied when a Council sets the floor level of a building or structural engineers design a bridge. These freeboards or factors of safety means there is less of a reliance on the model being highly accurate and manages any residual risks.

Are all floods the same?

No, not all floods are the same. There are a number of factors that influence the scale of a flood which includes:

- How wet or dry the catchments soils are and how elevated groundwater is at the start of the rainfall event
- The direction and speed the rainfall travels over the rivers catchment
- The how the rainfall varies spatially and over time
- The time of year and land use (such as the status of crops)
- The amount of surface failures / slips and woody debris mobilised
- The form of the river's mouth
- Tide level

Whilst scientists and engineers try to predict the 'shape' of the flood and its peak flow, there are always other factors that influence the outcome.

Some flood flows are estimated by modelling rainfall run-off processes. Using this approach, it is much more difficult to predict a flood flow as the way rainfall is translated to river flow is complex and influenced by groundwater and soil conditions.

Peak flood flows for the Wairoa River have been estimated using statistical methods based on measured flow. With this method we can be more confident over the peak flow rate expected for a given Annual Exceedance Probability (AEP) as it's based on flood flows rather than rainfall.

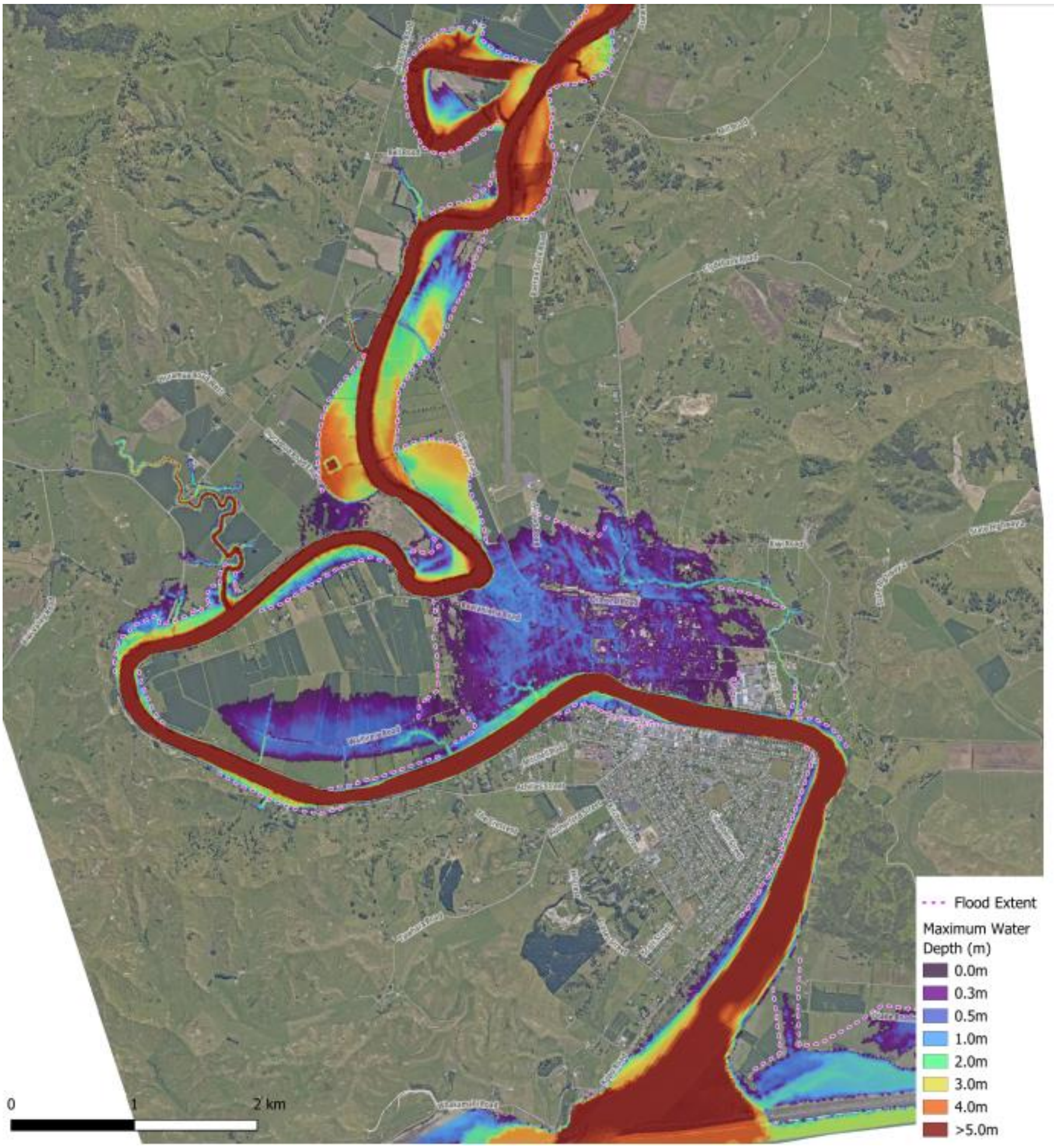

Figure 3 – Comparison of the model flood extents with the observed Cyclone Gabrielle flood extent (dashed pink line) used to assess model performance.

How well does the Wairoa model perform?

The Wairoa flood model developed by WSP has been validated against information from several sources. This includes:

- Verbal accounts
- Sediment deposition (post cyclone aerials)
- Debris marks
- Photographs of flooding

We found that the model performs well in the focus area of North Clyde, despite the complexities of an urban flood plain. The model also visually fits well against the extents of the post Cyclone Gabrielle sediment deposition. Other locations reviewed specifically with landowners recently were Turiroa Station (off SH2), Huramua Road East and adjacent to the Wairoa Substation.

We found the model matched the reported flood elevation at Turiroa almost exactly when we included a debris breach on the PNGL rail bridge and was otherwise very close, though slightly lower. Images of flooding on SH2 also match the model results closely.

At Huramua Road East the model matched the reported flood level almost exactly. This is a key area to get right, as it governs the amount of flow that spills into North Clyde.

At the Wairoa substation, the model under-estimated the flood elevation by around 300 mm. This location is further upstream toward Frasertown and therefore doesn't have much bearing on the model performance in North Clyde or through Wairoa. We believe the difference at this location is due to differences in the LiDAR data sets used. Between the pre-cyclone and post-cyclone LiDAR the road levels changes by up to 300 mm. Given the uncertainty over the road elevation it has hard to compare it with the reported depth. Such differences can occur where LiDAR point density, benchmarks and ground cover vary, where the landform changes post flood, or due to sediment deposition during the flood (of which there a significant amount north of the substation).

One known area of deficiency in the model is an area of ponding predicted west of North Clyde along Waihirere Road. Whilst this area has little impact on the flooding in North Clyde or the assessment of options, we believe that there is likely some form of structure to stop the Wairoa River back flooding this area. However, we haven't explored this further as it has no bearing on the goals of the project.

Generally, we found that the model performed well overall and specifically in the key areas. Given any subsequent option design will include allowances for uncertainty, such as freeboards or factors of safety, this is considered accurate enough for decision making purposes. This view is supported by the Regional Council and the peer reviewer. We also understand that Gary Williams has raised no concerns over the modelling aspects either and considers it in line with best practice.

It is not uncommon for communities or councils in New Zealand to make decisions of this nature using models with greater uncertainty, as not all rivers are gauged for flow. Fortunately for the Wairoa community we have higher confidence over the flood flows (generally the highest area of uncertainty) due to the gauges as well as a model that performs well when validated against Cyclone Gabrielle. Further to this, appropriate design can manage any residual risks associated with modelling or data uncertainty, with the freeboard applied proportional to the level of uncertainty.

Kind Regards

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