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# Port Phillip Bay Coastal Hazard Assessment Follow Up Inundation Project Technical Note

## Methodology for applying inundation heights to rasters of inundation extent that combines hydrodynamically-modelled stormtide and empirically-modelled wave setup

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# 1 Background

The Port Phillip Bay Coastal Hazard Assessment (PPBCHA) was a project undertaken by CSIRO for DELWP to provide a coastal hazard around Port Phillip Bay (PPB). The methodology for the PPBCHA is laid out in the technical report for that project. This note is an addendum to the method for the inundation hazard assessment, which is provided in Chapter 5 of the PPBCHA technical report. It addresses an inconsistency between the inundation height data and the inundation extents in which the spatial coverage of the inundation height data did not extend as far inland as the inundation extent data. The cause of this mismatch was that the inundation height data were based solely on the CSIRO City Flood Adaptation Solutions Tool (CFAST) model. Since CFAST does not simulate the action of waves on a beach, CFAST inundation extents do not include a wave setup component, which is the elevation in the mean sea level due to wave action averaged over the time scale of a storm surge. During the PPBCHA, DELWP requested that the inundation extent layers modelled by CFAST be combined with separately modelled wave setup extents calculated using empirical wave setup equations to account for the wave setup component. However, since the wave setup equations do not provide an associated inundation height, no adjustment to the inundation height layers were made in areas of the coast where the combined CFAST and wave setup extents exceeded those of CFAST alone. This meant that the data layers providing inundation height did not cover the same area as layers for inundation extent based on the combination of the modelled CFAST inundation and wave setup.

DELWP has subsequently identified a need to have the maximum-inundation-height (MIH) raster layers provided by CSIRO in the PPBCHA project to coincide precisely with the inundation extent data. This note documents the method by which this adjustment has been undertaken. DELWP also requested permanent inundation layers, which have been developed at 0.1 m intervals from 0.0 to 2.0 m AHD.

# 2 Methodology

The Maximum Inundation Height (MIH) is the modelled water level height minus the surface elevation provided by the Digital Elevation Model (DEM). The modelled water level includes the Still Water Level (SWL) in the context used here, which accounts for the stormtide plus a sea-level rise (SLR) scenario and represents a time-mean water level on the time scale of the storm surge.

Examples of where CFAST inundation heights did not extend to areas where inundation due to wave setup occurs are shown at four different beach locations in Figure 1. The left-most column of Figure 1 shows the CFAST MIH rasters (for 5% likely peak SWL), the middle column shows the probabilistic wave setup extents, and the right most column shows the CFAST MIH overlaid on the wave setup extents. The difference in flood extents is highlighted in the visibility of the wave setup extent polygons (coloured magenta, blue and aqua) behind the CFAST MIH raster layers (coloured white to blue) in the right most column of Figure 1.

CFAST modelled the MIH associated with storm-tide and mean sea level changes but does not model wave setup behaviour. Instead, wave setup was captured in the PPBCHA project by an empirical formulation, which extends the inundation layers further up the beaches.

The method by which inundation extents with missing height data were amended is as follows. First, the union of the two extent layers was calculated. The MIH from the CFAST layer at its inland-most extent was used to provide a nominal threshold at the shoreline extent. The maximum-height data was calculated cell-by-cell for the following conditions:

- Use CFAST maximum inundation height (MIH) data if it is available.
- Else if within Zone 1 (95% likely) or Zone 2 (50% likely) of the wave setup extent then use the nearest available CFAST MIH data.

- Else if within Zone 3 (5% likely) of the wave setup extent and surrounded by CFAST MIH data, Zone 1 data or Zone 2 data, then use the nearest available CFAST MIH data.
- Else if within Zone 3 (5% likely) of the wave setup extent then use the nominal threshold flooding value of 0.1 m.

This method assigned a value for the inundation height to all missing values in the combined layer that includes the wave setup extent. A diagram explaining how the nearest CFAST value was applied to the wave setup layer is shown in Figure 2.

# 3 Results and Discussion

Figure 3 shows inundation height results before and after combining layers for four coastal locations for the baseline sea level cases. Note that the left column of Figure 3 is the same data representation as the right most column of Figure 1. The new combined raster on the right most column of Figure 3, has MIH for the entire extent of the union of the two original datasets. Additionally, there is a seamless continuous connection of the maximum-height data in both the landward and seaward directions. Manual inspection along the whole coastline reveals that this procedure produces satisfactory results around Port Phillip Bay (PPB). This procedure was applied to the data from all stormtide Annual Exceedance Probabilities (AEPs) and SLR scenarios. Figure 4 shows the same kind of comparisons but for the 0.8 m SLR case, which do not show any unrealistic or unexpected results.

While the procedure applied in this note provides consistent inundation extents and heights from the combination of stormtides and wave setup, several differences in the underpinning processes of both, as well as limitations in the modelling of wave setup are noted here. For instance, stormtide heights change on the order of minutes to hours, whereas, wave setup includes the time-averaged swash motion of individual waves surging up a beach and can change dramatically on the order of seconds. Wave setup is estimated from a surveyed range of historical beach slopes and since there are no direct measured observations of wave setup in Port Phillip Bay, estimates used for deriving empirical models are from international studies. Beaches are highly dynamic, and sand can be eroded from the shore face during a storm, which will change the beach slope and hence the wave setup during an event. In the PPBCHA, since there is no long-term consistent monitoring of how beach profiles change as a result of storms, beach slopes are assumed not to change throughout a storm or with future sea level rise. This results in significant uncertainty in inundation height.

| | CFAST Maximum-Inundation Height Raster | Probabilistic Wave Setup Extents | CFAST MIH Overlaid on top of Probabilistic Wave Setup Extents |
|---|---|---|---|
| (a) | | | |
| (b) | | | |
| (c) | | | |
| (d) | | | |

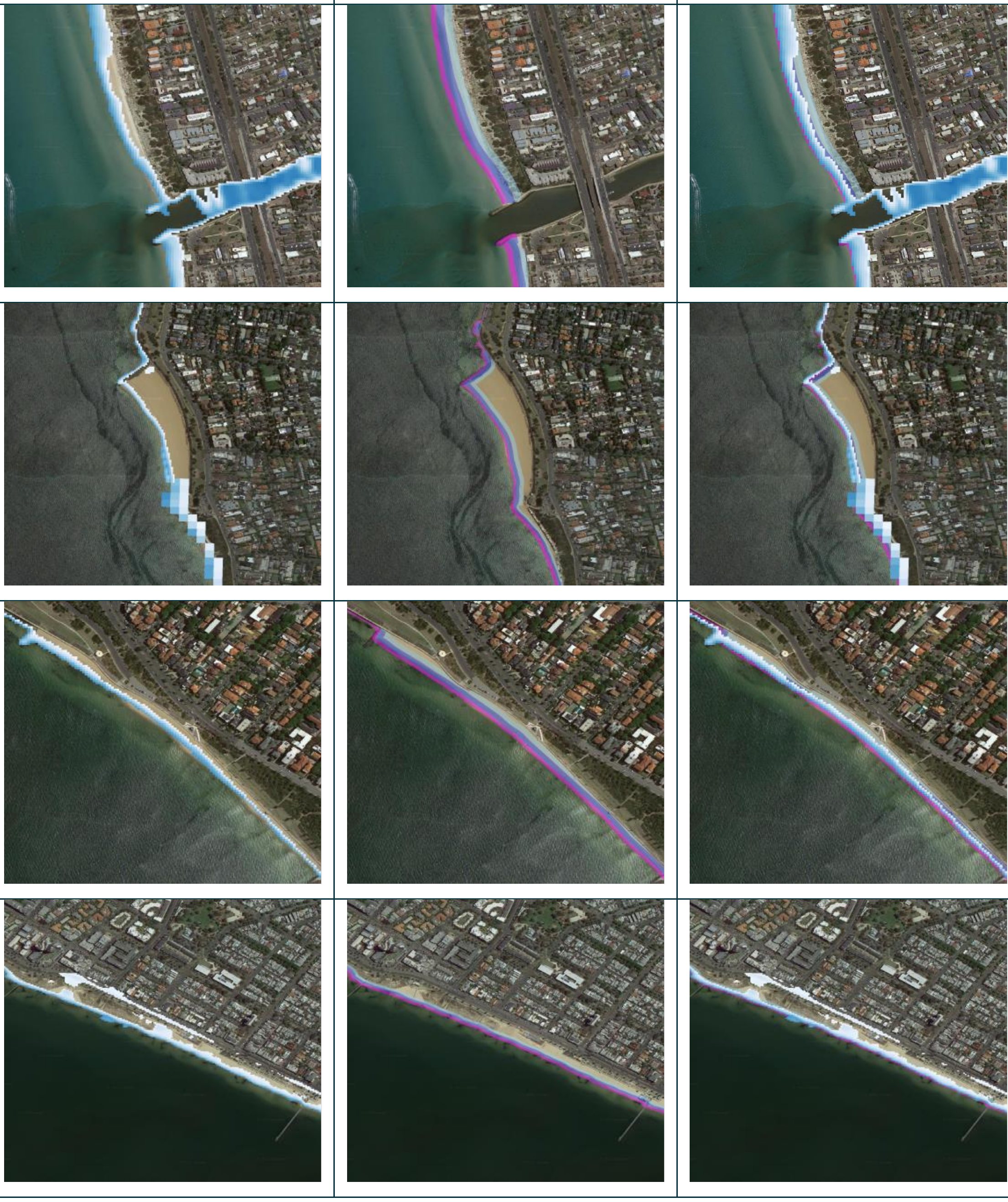


**Figure 1**: Examples of inundation extents from CFAST Maximum-Inundation Height Raster (dark blue is 2.0 m and white is 0.0 m), Probabilistic wave setup extents (Zones 1, 2 and 3 coloured magenta, blue and aqua respectively), and both datasets overlaid at (a) Patterson River, (b) Brighton Beach, (c) Elwood, and (d) Port Melbourne. This is for the case of baseline sea level, 1% AEP storm surge and no rainfall.

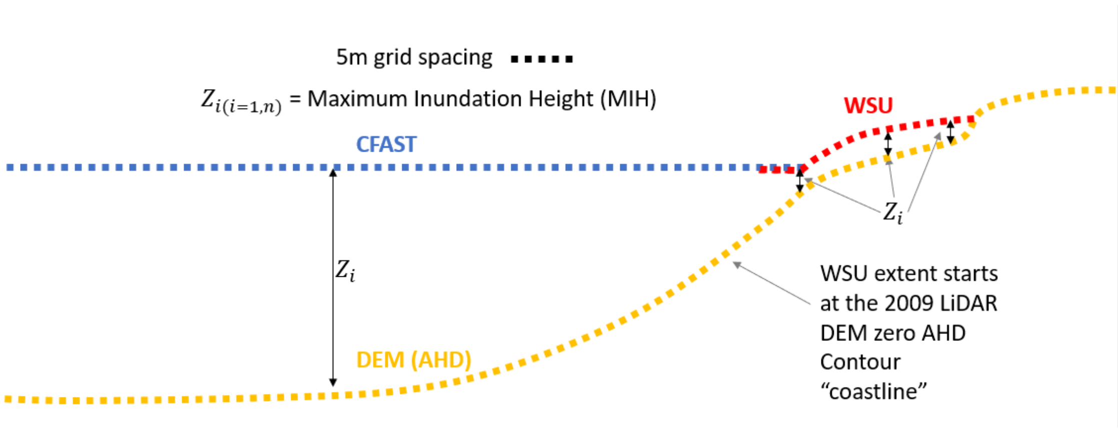



**Figure 2**: Conceptual diagram showing the Maximum Inundation Height (MIH = $Z_i$), Digital Elevation model (DEM), the CFAST modelling water surface and the wave setup (WSU) zones.

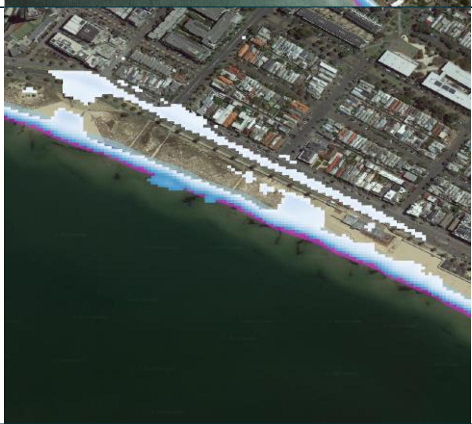
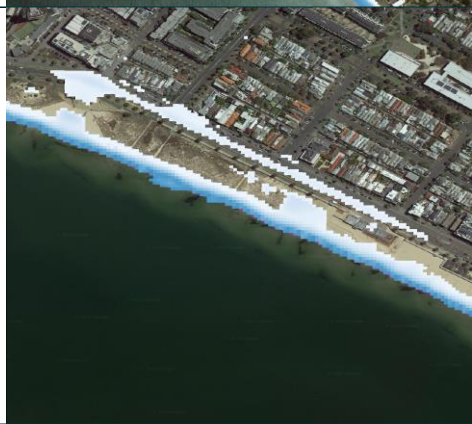
| | CFAST MIH Overlaid on top of Probabilistic Wave Setup Extents | New Combined CFAST/Wave Setup Maximum-Inundation Height Raster |
|---|---|---|
| (a) |  |  |
| (b) |  |  |
| (c) |  |  |
| (d) |  |  |

**Figure 3:** Examples of the original data overlaid and the new combined maximum-height raster for the case of baseline sea level, 1% AEP storm surge and no rainfall at the locations of (a) Patterson River, (b) Mordialloc, (c) Port Melbourne, and (d) Queenscliff.


**Figure 4**: Examples of the original data overlaid and the new combined maximum-height raster for the case of 0.8 m SLR, 1% AEP storm surge and no rainfall at the locations of (a) Patterson River, (b) Mordialloc, (c) Port Melbourne, and (d) Queenscliff.

# 4 Permanent inundation layers

This addendum details the methodology used to generate the permanent inundation (bathtub-fill) layers provided as a deliverable for this project. Typically, bathtub inundation layers would identify flooding as all land below a given water level. Here we describe a bathtub-fill method which only allows a single connected region below a given water level to be flooded. Isolated inland low-lying regions behind dunes or high-land are not flooded.

## 4.1 Inputs

The Digital Elevation Model (DEM) of Port Phillip Bay was created using Vic Coasts 2017 DEMs. Specifically this was done by overlaying “Updated HighRes 2.5m DEM” with the “Continuous Seamless 10m DEM”. This created a DEM at 10 m spatial resolution for a projection of “EPSG:28355 – GDA94 / MGA zone 55” and a vertical level datum of "m AHD".

## 4.2 Fill methodology

To generate each permanent inundation layer, the DEM was filled from a central point within Port Phillip Bay to a given vertical water level, $H$ (e.g. 0.5 m AHD). The algorithm starts from the initial cell and neighbouring cells are flooded if their base DEM level, $B$, is less than $H$. Each time a new cell is flooded, then its neighbours are subsequently checked if they too should be flooded. This algorithm proceeded until there were no more cells needed to be flooded. This flood filling methodology only allows a single connected region to be flooded. Isolated inland low-lying cells ($B<H$) behind high dunes or coastal structures ($B>H$) were not flooded. This process was repeated for a series of different fill levels, starting at 0.0 m AHD and increasing in 0.1 m increments up to 2.0 m AHD.

## 4.3 Limitations

The limitations of any typical bathtub or this bathtub-fill approach include that flow is considered instantaneous (unrestricted flow).  While this bathtub-fill approach is designed to limit the total amount of flow due to the flood protection of dunes and high land, narrow flow-restricted channels/gaps in the DEM can allow unrestricted instantaneous inland flooding, as the temporal effects of the flow dynamics are not considered. Also not considered in the bathtub-fill approach are the flows through drainage networks and under bridges. In reality, tidal peaks are of short duration and may not allow major coastal inundation before the tide subsides. Consequently, these bathtub-fill layers predict less coastal flooding than a typical bathtub method would, due to the consideration of coastal protection. The Port Phillip Bay Coastal Hazard Assessment project (McInnes et al., 2022) included an Inundation Hazard assessment which used dynamic hydrodynamic flow simulations with parametric representation of flow over vertical protection structure and through drainage networks with rainfall on grid, which resolves these stated limitations of any bathtub modelling.

# 5 Conclusion

This note documents the method by which inundation heights are applied to inundation extents formed by combining modelled SWL and wave setup. The inundation heights are calculated in the CFAST model for SWL. However, the empirical formulations used to provide wave setup extents do not provide an associated water height. Therefore, the method adopted here assigns an inundation value to all missing values in the combined layer that includes the wave setup extent. Layers of permanent inundation were also provided to complement the CFAST modelled layers. These layers were generated using a bathtub infill technique for levels from 0.0 m AHD to 2.0 m AHD in 0.1 m increments. It is noted that these layers do not capture features and processes associated with actual storm surge events, such as the temporal component of the tides which influences how much inundation will occur.

# References

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