Department of Science, Information Technology, Innovation and the Arts

Tsunami Modelling along the East Queensland Coast

Report 2: Sunshine Coast

Coastal Impacts Unit

Great state. Great opportunity.

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Executive Summary

Following the 2004 Indian Ocean tsunami that devastated Indonesia, Thailand and Sri Lanka, the Australian Government through Geoscience Australia (GA) undertook a probabilistic assessment of tsunami hazard along the Australian coastline in terms of tsunami amplitude (water level height above mean sea level) at the 100m depth contour. GA supplemented this with a national nearshore modelling study to examine the relative amplification of tsunami at 20m depth compared to the 100m depth contour for select locations. However that study did not include some locations such as the Sunshine Coast.

Stage 1 of this project built upon the earlier work of GA by utilising DHI's hydrodynamic modelling software to examine the nearshore amplification at 10m depth along the entire east Queensland coast from Cooktown to the NSW border. Stage 1 identified that south-east Queensland was at higher risk to larger tsunami propagation than the rest of the east Queensland coast. Subsequent discussions with the project Study Advisory Group indicated that the Sunshine Coast was of particular interest.

This report summarises the results of tsunami inundation modelling for the Sunshine Coast to examine the potential risk for emergency management purposes. Hydrodynamic modelling was undertaken using DHI’s Mike21 flexible mesh software with boundary conditions provided by GA’s TsuDAT tool. Three hypothetical events were considered originating from the New Hebrides Trench, and representing an average recurrence interval of 750, 3000, and 10000 years at Mean Sea Level (MSL). Each scenario was also modelled at Highest Astronomical Tide to represent a worse case.

Overall, 65km of coastline as well as waterways were modelled between Teewah and Caloundra. Detailed LiDAR bathymetry collected in 2011 by the Queensland Government, CRC for Spatial Information and the Department of Climate Change and Energy Efficiency, was available for the Sunshine Coast out to 30m depth. This was supplemented with a combination of James Cook University’s gbr100 digital elevation model (DEM), a 5m topographic DEM developed from the Sunshine Coast Level 2 classified LiDAR, and a hydrologically enforced and conditioned DEM for the Maroochy catchment.

The modelling undertaken indicates that a 1 in 10,000 year event will produce a maximum amplitude of about 4m near the coast (in 10m depth), whereas a 1 in 750 year event will only be about 1m. Along the open coast, the extensive dune system prevents the tsunami from encroaching urban development (assuming the dune system in not eroded). Instead, the tsunami propagates into the numerous waterways, inundating adjacent low lying areas.

For a more probable event (scenario 1), the community is mostly protected provided they remain away from the beach and waterways. Even under the extreme scenario 3 (HAT), the communities along the open coast are mostly protected, with inundation of areas adjacent to waterways.

The regions identified in this study to be the most at risk are Noosa, Maroochydore, Mooloolaba, Kawana Waters, Caloundra, and Golden Beach.

There are some limitations as to the accuracy of inundation depths close to the waterways due to the steep bank gradients that are not fully captured within the model. Finer mesh resolution of particular areas of interest (such as Kawana Waters) together with rigorous analysis of crest level position may enhance the assessment of risk of inundation in these locations.

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Glossary

AEST	Australian Eastern Standard Time
ARI	Average Recurrence Interval
ATWS	Australian Tsunami Warning System
BoM	Bureau of Meteorology
BPA	Queensland Beach Protection Authority
C	Chézy Coefficient
CRCSI	CRC for Spatial Information
DEM	Digital Elevation Model
DHI	Danish Hydraulic Institute
EMA	Emergency Management Australia
GA	Geoscience Australia
GBR	Great Barrier Reef
HAT	Highest Astronomical Tide
MSL	Mean Sea Level
n	Manning's roughness
NSW	New South Wales
NTHA	Nearshore Tsunami Hazard Assessment of Australia
PTHA	Probabilistic Tsunami Hazard Assessment of Australia
SAG	Study Advisory Group
SEQ	South-east Queensland
TsuDAT	Tsunami Data Access Tool

1. Introduction

Following the 2004 Indian Ocean tsunami that devastated Indonesia, Thailand and Sri Lanka, the Australian Government through Geoscience Australia (GA), the Bureau of Meteorology (BoM) and Emergency Management Australia (EMA) developed the Australian Tsunami Warning System (ATWS) to provide independent advice of potential tsunami events.

To support the end-to-end warning system, GA undertook a probabilistic assessment of tsunami hazard along the Australian coastline in terms of tsunami amplitude (water level height above MSL) at the 100m depth contour (Burbidge et al, 2008). This study was funded by EMA as part of the community awareness and capacity building component of the ATWS. The study was intended to assist the relevant state government departments to assess the tsunami risk along the coast and to prioritise regions that require further detailed assessment. However the study was limited in that for Queensland, the 100m depth contour is offshore of the continental shelf and the Great Barrier Reef (GBR). Therefore, the influence of these significant features on tsunami propagation was uncertain.

To better understand the impact of the complex bathymetric features across the Australian continental shelf on tsunami propagation, GA undertook a national nearshore modelling study to examine the relative amplification of tsunami at 20m depth compared to the 100m depth contour for select locations (Fountain et al, 2009). However that study did not include some locations such as the Sunshine Coast.

Stage 1 of this project built upon the earlier work of GA by utilising DHI's hydrodynamic modelling software to examine the nearshore amplification at 10m depth along the entire east Queensland coast from Cooktown to the NSW border. Stage 1 identified that South-east Queensland (SEQ) was at higher risk to larger tsunami propagation than the rest of the east Queensland coast. Subsequent discussions with the project SAG indicated that the Sunshine Coast was of particular interest.

This report summarises the results of tsunami inundation modelling of the Sunshine Coast for three scenarios each at MSL and HAT.

2. Scope

This study comprises two main stages:

- Stage 1: Develop, calibrate and validate hydrodynamic models of the east coast of Queensland for tsunami propagation modelling and determine amplification factors in the nearshore compared to the 100m depth contour.
- Stage 2: Undertake inundation modelling at one location to be determined from Stage 1 in consultation with the Study Advisory Group (SAG).

This report details the results for Stage 2 of the study.

3. Locality

The Sunshine Coast is located in South-east Queensland approximately 100km north of Brisbane. With a population of over 300,000 the Sunshine Coast has the third highest population in

Queensland behind the Gold Coast and Brisbane. The economy is focused on three main sectors being tourism, retail and construction, but also has a strong agricultural sector. The coastline stretches approximately 65km from Caloundra in the south to Noosa in the north.

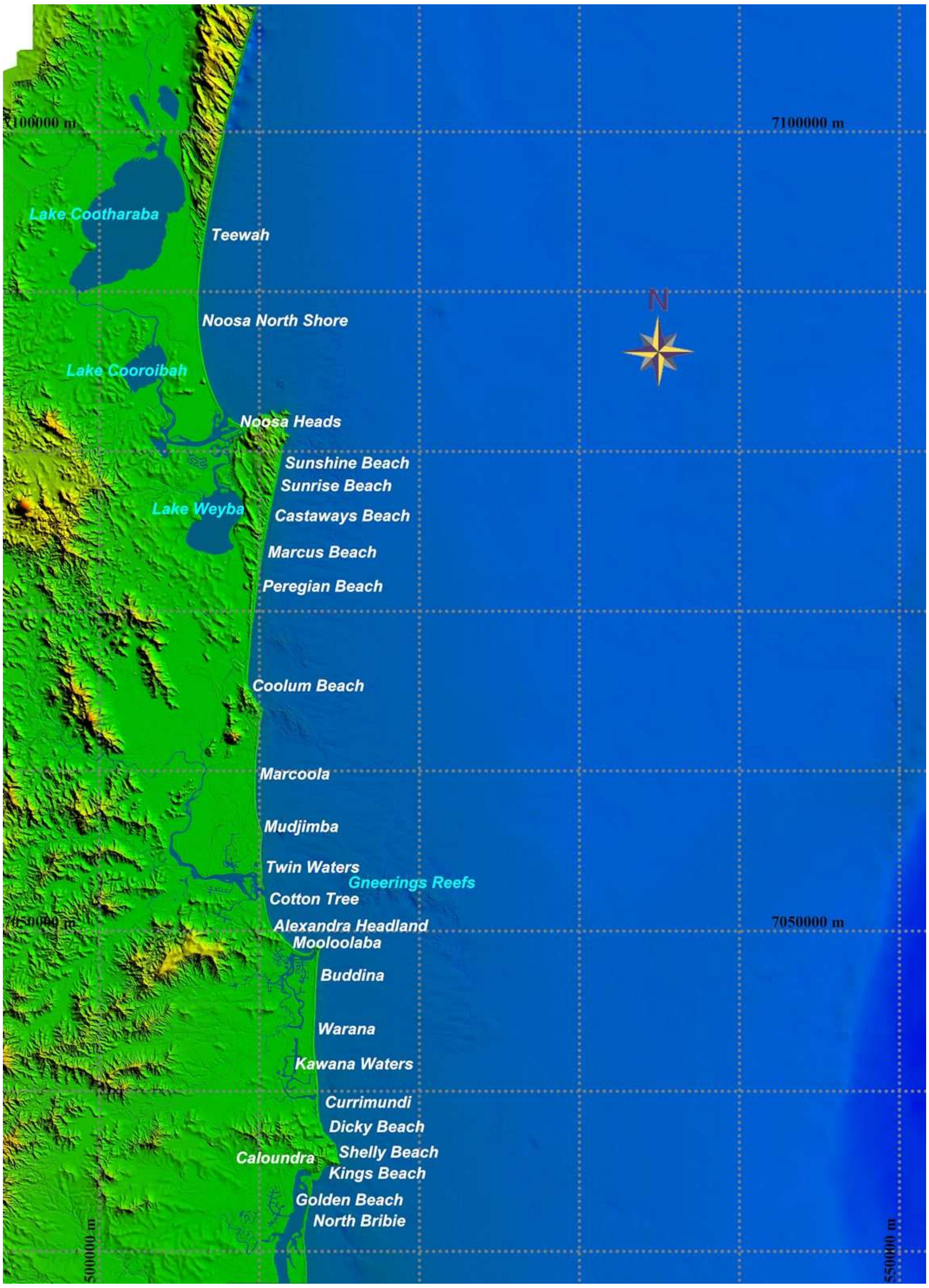


Figure 1 - Sunshine Coast

The Sunshine Coast was chosen based on a number of factors:

- It was an area identified in Stage 1 as being at higher risk
- The nearshore modelling undertaken by GA excluded the Sunshine Coast.
- The region has a high population.
- Both detailed topographic and bathymetric LiDAR was available for this region.

4. Digital Elevation Model

A tsunami is a long wave that is felt through the whole water column, even in relatively deep water. As such, the propagation of the tsunami will be sensitive to the underlying bathymetric data used in the model. Considerable effort was therefore directed towards producing a Digital Elevation Model (DEM) that best represented the inland, nearshore and deep water bathymetry within the model domain based on the most complete set of available data.

The bathymetry used in the regional model (Stage 1 – Boswood, 2013) was based on a high resolution 0.001 arc degrees (approximately 100m) DEM of the GBR and Coral Sea (known as the gbr100 DEM) developed by James Cook University (Beaman, 2010). The gbr100 DEM incorporated all available bathymetric data including ship-based multibeam and singlebeam echosounder surveys, airborne LiDAR bathymetric surveys, and satellite data, together with GA's 0.0025-arc degree (about 250 m) Australian Bathymetry and Topography Grid (Webster and Petkovic, 2005). The gbr100 DEM was further supplemented with available beach survey profiles collected by the Qld Beach Protection Authority (BPA) from the early 1970s to the mid-1990s. (Boswood, 2013).

A pilot study was conducted on the Sunshine Coast as a collaboration between the Queensland Government, CRC for Spatial Information (CRCSI) and the Department of Climate Change and Energy Efficiency (DCCEE) to examine the benefit of collecting bathymetric LiDAR for vulnerability modelling and mapping (Queensland Government, 2012). As part of that study, a 5m DEM was produced from high-resolution near-shore bathymetry captured over the period 27 October to 07 November 2011 out to 30m depth between Warana and Noosa (Fugro LADS Corporation Pty Ltd, 2011) (this data is available to download from the Queensland Government Spatial Data Portal http://www.information.qld.gov.au/).

Figure 2 demonstrates the differences between the DEM used for Stage 1 and the bathymetric LiDAR. To compare the two, the Stage 1 DEM was re-gridded to a 10m DEM using triangulation with linear interpolation. As can be seen, the bathymetric LiDAR is able to provide higher resolution of many coastal features such as the numerous offshore reefs and the nearshore bars along the coast that are not represented fully with the gbr100 DEM. The differences between the two meshes range between -25m and 68m, with a mean of 0.06m and a 95 percentile of 2.5m. The greatest differences occur north of Noosa Heads where the gbr100 DEM incorrectly shows holes in the nearshore up to 70m deep.

The LiDAR bathymetry was supplemented with the gbr100 DEM developed for Stage 1, as well as a 5m topographic DEM developed from the Sunshine Coast Level 2 classified LiDAR (Schlencker Mapping Pty Ltd, 2009) and a hydrologically enforced and conditioned DEM for the Maroochy catchment (SKM, 2012). The accuracy of this data is detailed in Table 1.

The bathymetric LiDAR acquisition was very successful in the near-shore areas but much less effective in the onshore waterways due to turbidity, low seabed reflectivity and very shallow water (Queensland Government, 2012). Therefore, the data was supplemented with hydrographic survey data for the Mooloolah River entrance (MSQ, 2012). However assumptions were made of bed levels within a number of inland waterways and lakes based on the available data in surrounding areas. Although there is doubt as to the accuracy of these assumptions, the main focus of this study is directed more towards the coastal strip and not the inland waterways.

The developed overland DEM is a bare earth model in that only ground points have been included, thereby removing all structures and vegetation. The influence of these features on inland inundation is introduced implicitly by the introduction of roughness factors. The DEM is also assumed to be static and non-erodible. Should a tsunami cause erosion of the dune system along the Sunshine Coast, then the extent of inundation will differ to these model results.

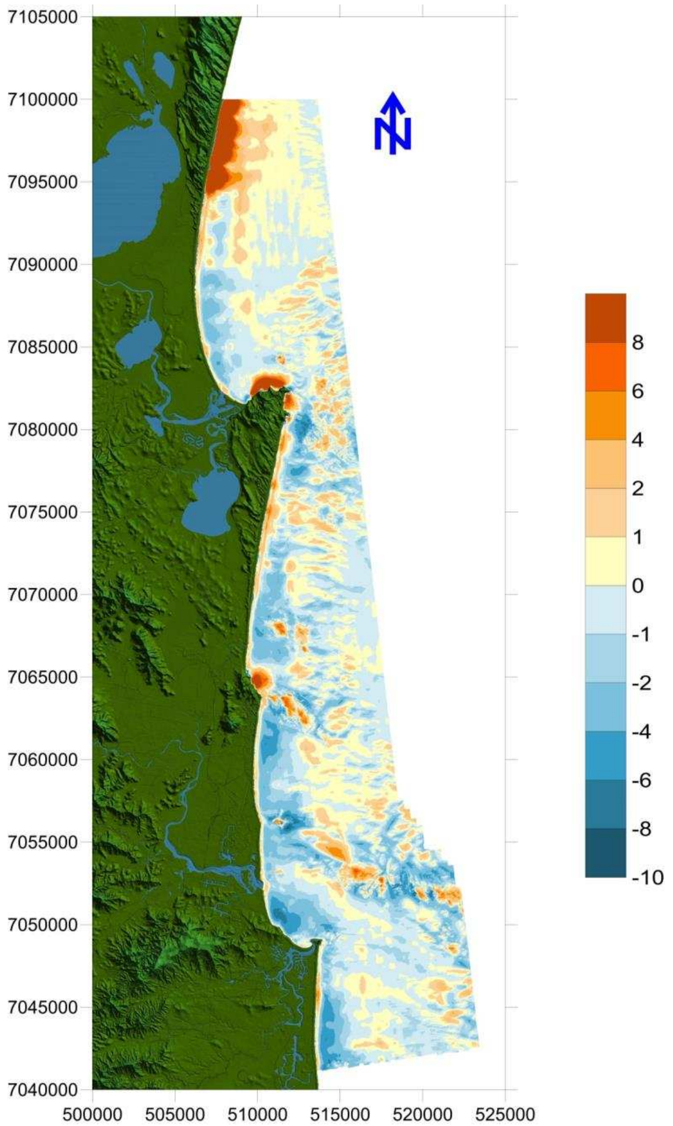


Figure 2 - Differences between bathymetric LiDAR DEM and gbr100 (LiDAR - gbr100)

Table 1 - Accuracy of the various data sets.

Data	Horizontal Accuracy	Vertical Accuracy
BPA Surveys	Unknown	Unknown
Geoscience Australia 1km Digital Terrain Model	Variable	Variable
Mooloolaba Boat Harbour Hydrographic Survey	±1.5m	±0.2m
Sunshine Coast Topographic LiDAR	±0.20 @ 1 standard deviation	±0.15 @ 1 standard deviation
Sunshine Coast Bathymetric LiDAR	± 2.39 m (95% confidence)	± 0.50 m (95% confidence)

5. Model Implementation

The modelling was undertaken using DHI's MIKE21 flexible mesh hydrodynamic model. The hydrodynamic model is based on the numerical solution of the two-dimensional (depth averaged) shallow water equations (DHI, 2012). The model solves the continuity and momentum equations using a cell-centred finite volume method. Unstructured meshes can be generated comprising both triangular and quadrilateral elements in either cartesian or spherical coordinate systems. An explicit scheme is adopted for time integration.

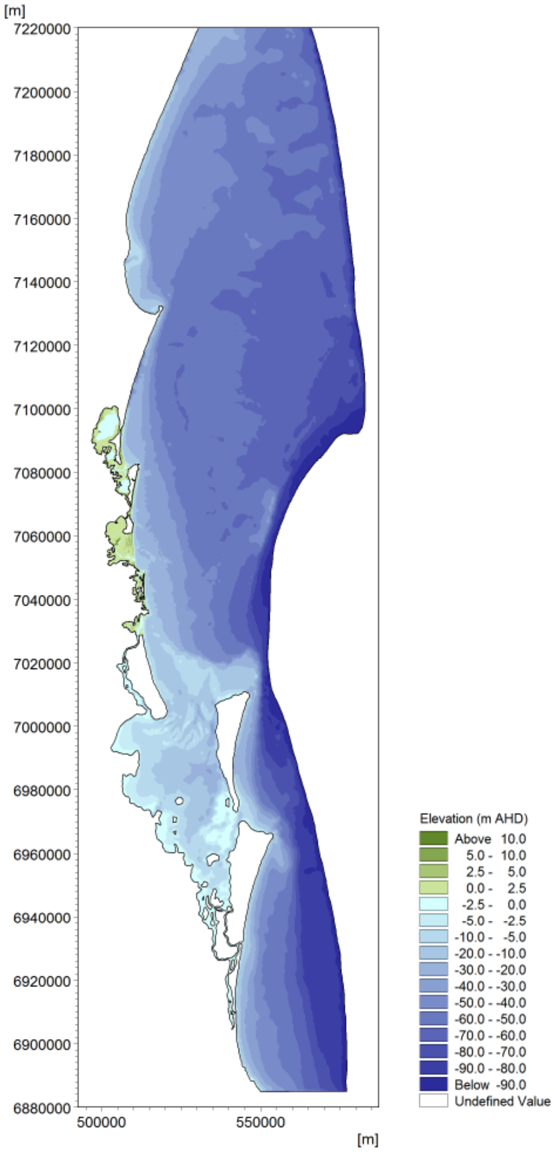


Figure 3 - Model Domain.

The model domain was developed from the SEQ model from Stage 1 (Boswood, 2013). A number of model runs with scenario 3 (refer below for details of the scenarios) were undertaken to optimise the inland extent of the model and mesh resolution in the offshore (i.e. depths > 10m) to maintain feasible computation times whilst reducing numerical dispersion and adequately representing key geomorphological features within the bathymetry. An initial mesh resolution of 200,000 m^2 in the offshore to 75,000m^2 at 10m depth was compared to a mesh with an offshore mesh resolution of 35,000m^2 and 10,000m^2 at 10m depth. The reduction in the equivalent spatial resolution by about half (630m to 265m in the offshore and 390m to 140m in the nearshore) resulted in over a two fold increase in computation time for an average 3% increase in maximum amplitude. A 9% increase was observed at Mooloolaba suggesting this location to be more sensitive to mesh resolution and the underlying bathymetry. The finer mesh provided greater localised variations as finer detail was represented in the bathymetry, but added little to the general inundation when compared against the large increase in computation time. The final mesh over the water was therefore a compromise between the two tested resolutions.

Given the large land extent to cover (a coastline length of over 65km), mesh resolution over the dry land was set to a maximum of 500m^2 (or 30m) in built up areas, and up to 1500m^2 (or 55m) in low lying pastoral or wetland areas. The differences in maximum amplitudes between this and the fine mesh detailed above were less than 1%.

The final mesh comprises 661,240 triangular elements, extends from Fraser Island to the Gold Coast with higher detail within the study area. Mesh resolution in the Sunshine Coast area varies from a maximum of 75,000m^2 offshore to 500m^2 inland or an equivalent spatial resolution of 390m to 30m. Although a 5m high resolution topographic DEM was available, the inland mesh size of 500m^2 (spatial resolution of about 30m) was considered adequate for emergency management purposes as it approximately represents a block of land but is not too fine to cause memory problems or unreasonable simulation times.

The mesh assumes a linear slope in elevation within each triangular element. For land elements adjacent to waterway polylines (defined by 0m AHD), the actual bank gradient may be much steeper than portrayed within the model. Figure 4 demonstrates the canal bank slope for a canal estate at Noosa. Here the bank gradient is quite steep, climbing from 0m AHD to 2m AHD within a horizontal distance of 5m. The model resolution required for acceptable run times does not allow these steep slopes to be captured within the model. Better representation of the bank crests could be achieved by setting the polylines to the crest of the bank. However there is considerable variation in crest elevation, especially along the natural waterways.

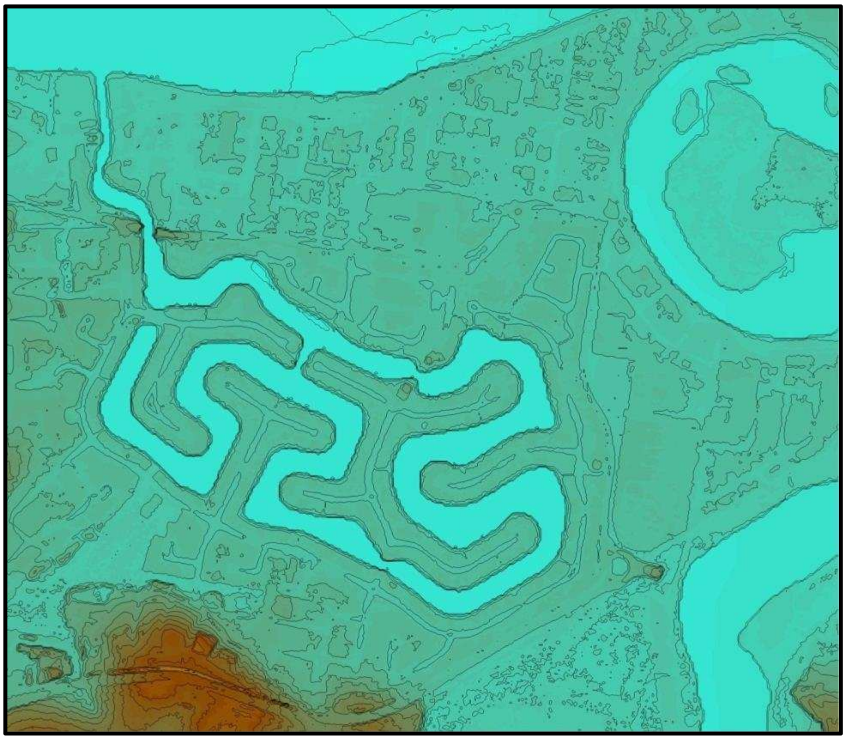


Figure 4 - Detailed contours for LiDAR data at Noosa Heads.

The model results will therefore overestimate the depth and extent of inundation for conditions where the inundation is within one mesh element of the waterways polylines. This is the case for the majority of inundation calculations along the many artificial waterways.

For the small tsunami amplitudes within the canals, the buildings will also assist in blocking tsunami propagation over land. The results of this study can therefore be considered to be conservative immediately adjacent to inland waterways.

The offshore boundary was set along the continental shelf at 100m depth to correspond to the output locations for the deep-water PTHA by GA (Burbidge et al, 2008a). Boundary conditions are defined by the Flather (1976) condition (i.e. water elevations and velocities) for three scenarios from the PTHA using TsuDAT (GA, 2010). The land boundary provides for flooding and drying associated with inundation.

Bed roughness within the model was defined by manning's number (n) based on the range of values suggested in Aida (1977) and Kotani et al (1998) as presented in FAO (2007). For residential areas, Kotani et al (1998) suggested 0.04 (low density) to 0.08 (high density) and 0.025 for water areas. For relatively dense vegetation, Aida (1977) suggested 0.05. A recent NSW tsunami modelling study undertaken by Cardno (Garber et al, 2011), adopted roughness values of 0.02 (water and roads), 0.03 (open grassland), 0.07 (parkland and forest), and 0.10 (residential) based on high resolution modelling of a section of coastline with buildings included and then matching the inundation for a bare earth model.

Given that the adopted resolution can distinguish between residential lots but not individual buildings and roads, a constant value of roughness was adopted for built-up areas to represent the combined effect of buildings and roads. Preliminary sensitivity testing indicated that for the region of interest, the model is not very sensitive to roughness as the inundation is very limited. The lower end of the recommended values was used to be on the conservative side given no validation of inland flooding was possible. For this study, three roughness values were adopted: n=0.025 for offshore and waterways; n=0.033 for the beach and dune system; and n=0.05 for built up and vegetated areas.

6. Model Validation

Model validation was undertaken against Stage 1 scenario 3 model results (Boswood, 2013). Testing of the original Stage 1 model using a bed roughness defined by manning's number, n=0.025, resulted in tsunami amplitudes comparable to the original model results using a Chézy coefficient, C=60.

The tsunami time series from Stage 1 (refer Figure 5) was applied constantly along the offshore boundary of the Sunshine Coast model. As with Stage 1, the maximum amplitudes within the model domain were normalised against the maximum amplitude of the boundary time series. The resulting amplification factor map is provided in Figure 6 along with the Stage 1 map. Both maps are very similar with the amplification factors from the Sunshine Coast model varying between 0.79 and 1.99. The original Stage 1 results varied between 0.81 and 1.91.

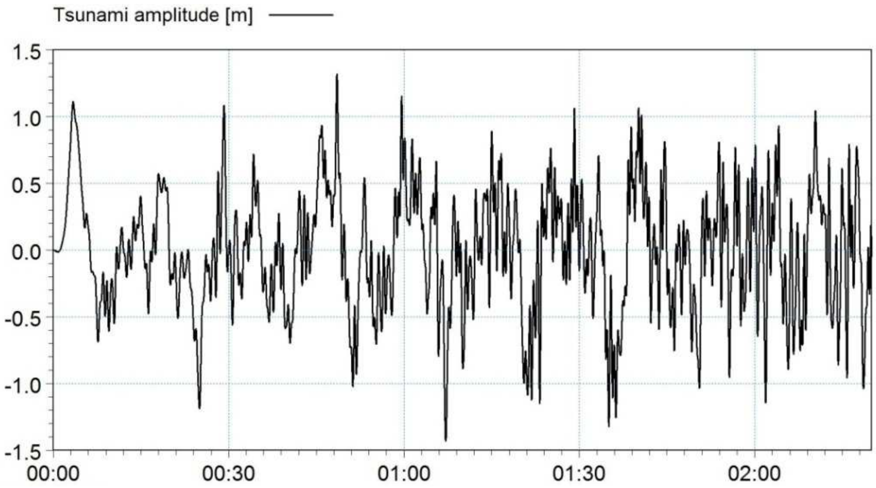
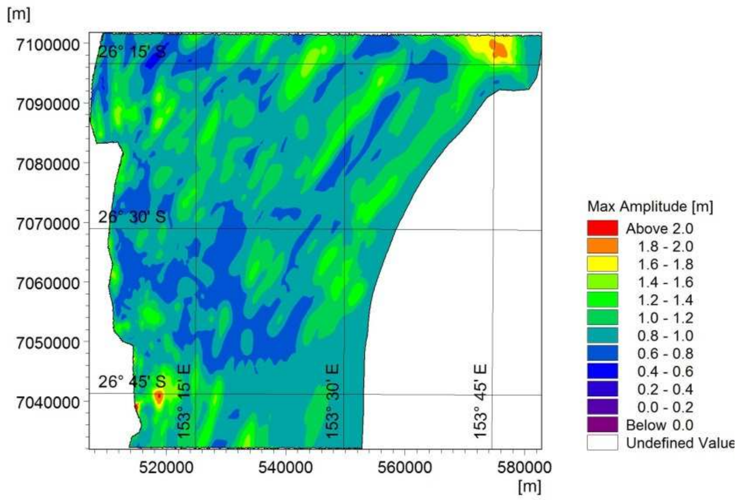
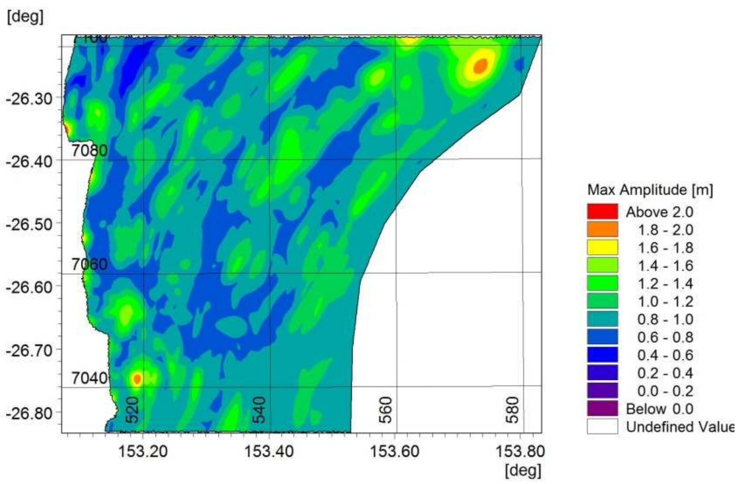


Figure 5 - Scenario 3 from Stage 1.



(a) Sunshine Coast model.



(b) Stage 1 model.

Figure 6 - Comparison between Sunshine Coast model (a) and Stage 1 model (b).

7. Scenarios

According to Fountain et al (2009), the most important sources of tsunami hazard at the 100 m depth contour off southern Queensland are, in order of importance: the New Hebrides Trench, South East Solomons Trench, Kermadec Trench and Puysegur Trench. These are illustrated in Figure 7.

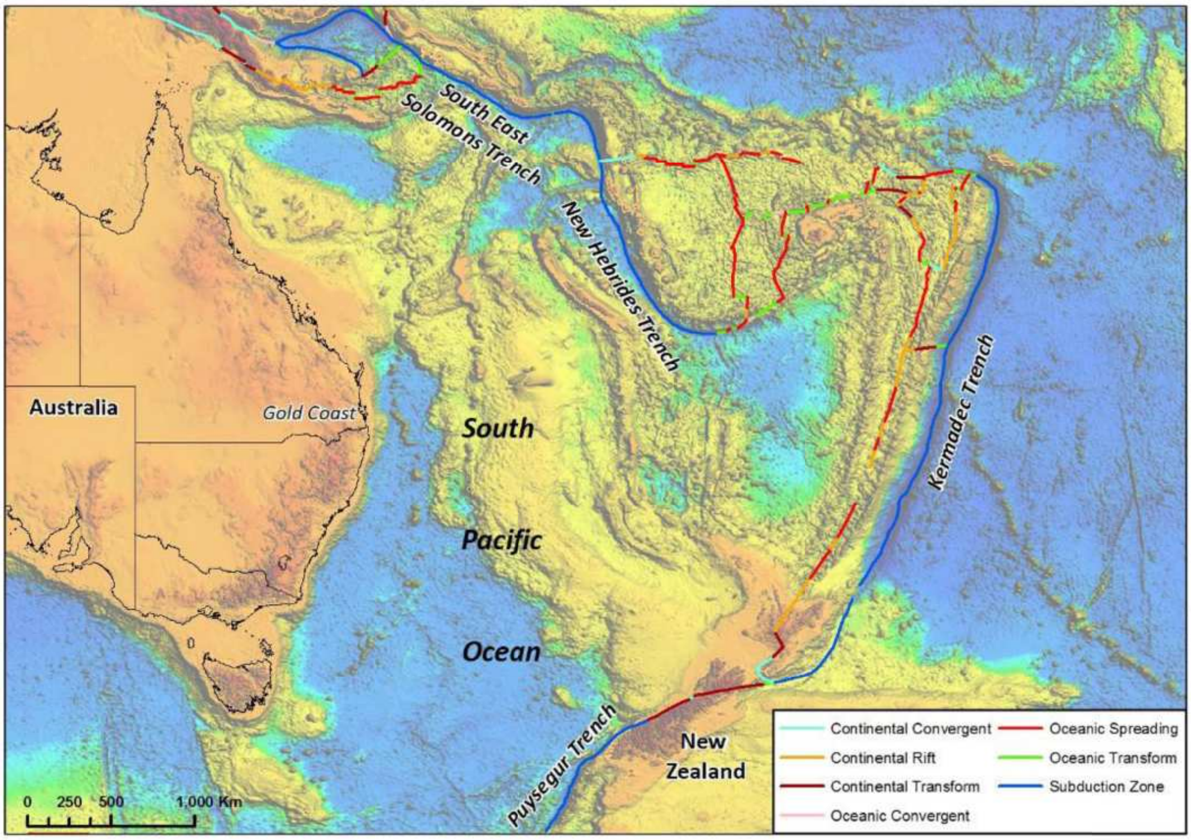


Figure 7 - Subduction zones influencing the tsunami hazard along Southern Queensland as identified in the PTHA (Burbidge et al, 2008).

The scenarios were determined from TsuDAT, a tool created by GA (2010) to allow for the extraction of events from the PTHA at defined hazard points along the 100m depth contour based on user defined criteria of area of interest, average recurrence interval (ARI), and subduction zone. The model domain can be defined within TsuDAT so that the time series extraction is specific to the area of interest. As the probabilistic assessment varies for each hazard point, one hazard point within the area of interest is selected to define the return period statistics for event selection. For this study, a hazard point offshore from Maroochydore was selected (longitude 153.567° east, latitude 26.6° south) being approximately at the midpoint of the study area.

Examination of TsuDAT showed that the pre-defined sub-faults along the New Hebrides Trench have the highest contribution to the hazard offshore of the Sunshine Coast. Three events were selected from TsuDAT, representing the range of credible events that could affect the Sunshine Coast. These events are detailed in Table 2. TsuDAT provides a time series of water level and momentum along the two major axes (uh and vh) at defined points along the 100m contour. An example of TsuDAT for scenario 3 is shown in Figure 8 and the return period plot for the selected hazard point is shown in Figure 9

The tsunami return periods provided in Table 2 are based on the given maximum amplitude at MSL. The model was also run for each scenario at HAT to provide a worse case event. HAT was set to 1.18m above MSL as defined in the 2012 tide tables for Mooloolaba (MSQ, 2012b). Although modelling based on HAT has also been undertaken, the return periods would be much greater than that detailed in Table 2.

Table 2 - Scenarios chosen for modelling.

Scenario	ARI (yrs)	Max Amplitude (m)	Event ID	Earthquake Magnitude	Slip	Source Zone
Sunshine1	750	0.48	49501	8.3	9.314	New Hebrides
Sunshine2	3,000	0.94	49907	8.8	16.948	New Hebrides
Sunshine3	10,000	1.53	50127	9.2	12.316	New Hebrides

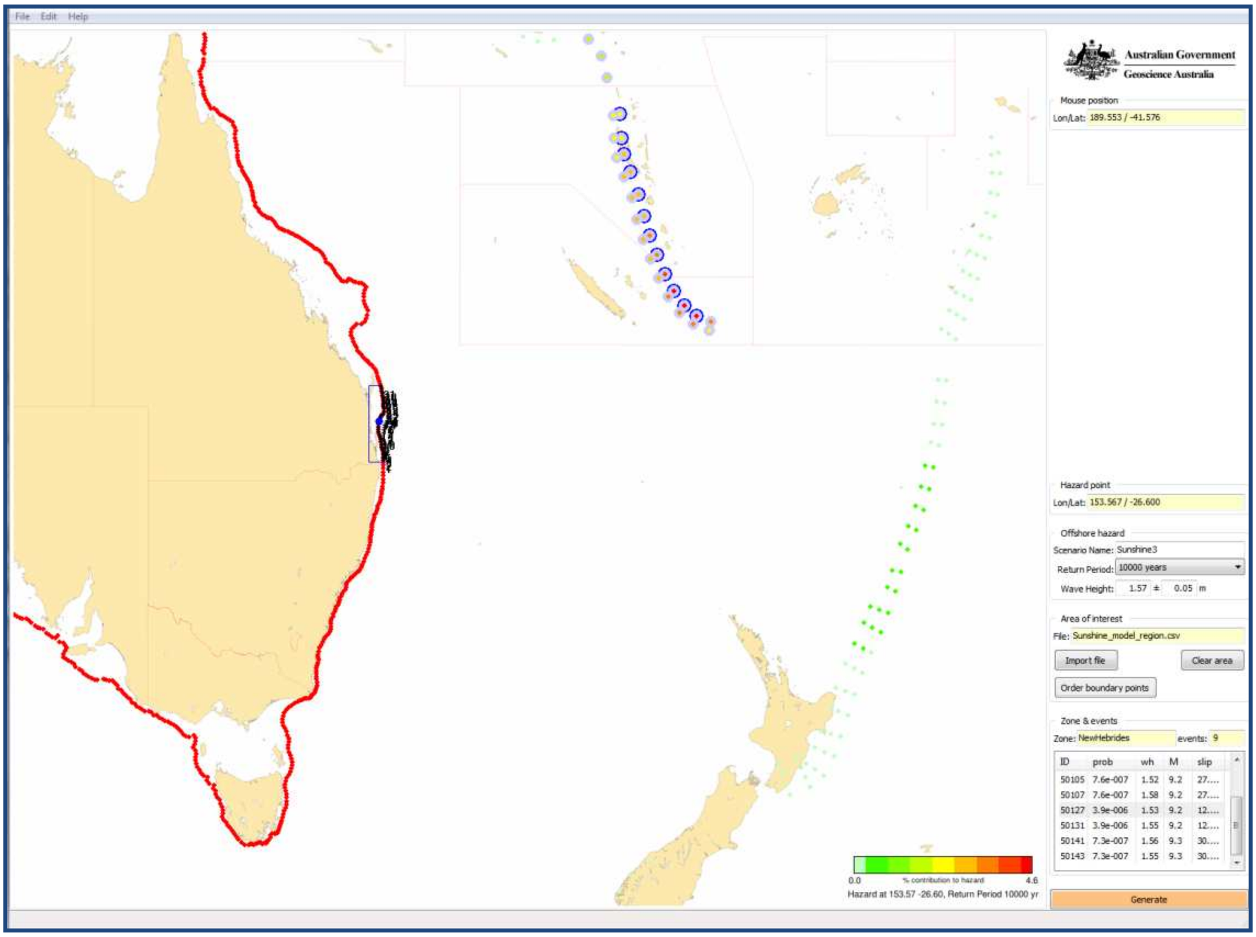


Figure 8 - TsuDAT for scenario 3.

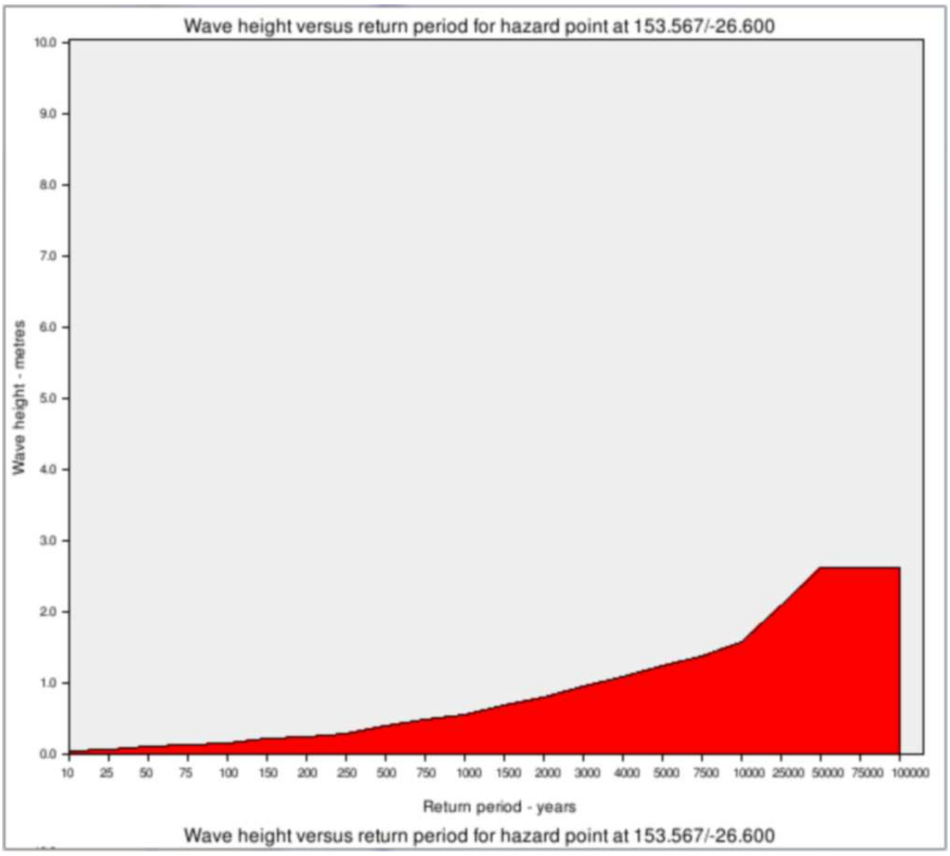


Figure 9 - Return Period of tsunami amplitude for TsuDAT hazard point offshore of Maroochydore.

8. Sensitivity to Bathymetry

To examine the sensitivity of the model to nearshore bathymetry, scenario 3 (HAT) was modelled using both the Stage 2 mesh defined in section 5, and the same mesh interpolated using the gbr100 DEM from Stage 1. Figure 10 shows the differences between the two meshes. As described in section 4, the differences between the two DEMs are as much as 60m north of Noosa due to the gbr100 DEM incorrectly showing deep holes in the nearshore.

Figure 11 shows the differences in maximum amplitude resulting from the two meshes for scenario 3 (HAT). Despite the variations in bathymetry for the two meshes, the differences in maximum amplitude are within ±0.1m or less than 2.5% of the peak amplitude within the model domain. The difference in inundation depth over the domain is less than 0.05m, and there are no obvious differences in inundation extent. It is possible that a finer mesh at particular locations where the bathymetry is the most complex may influence the resulting inundation for specific locations.

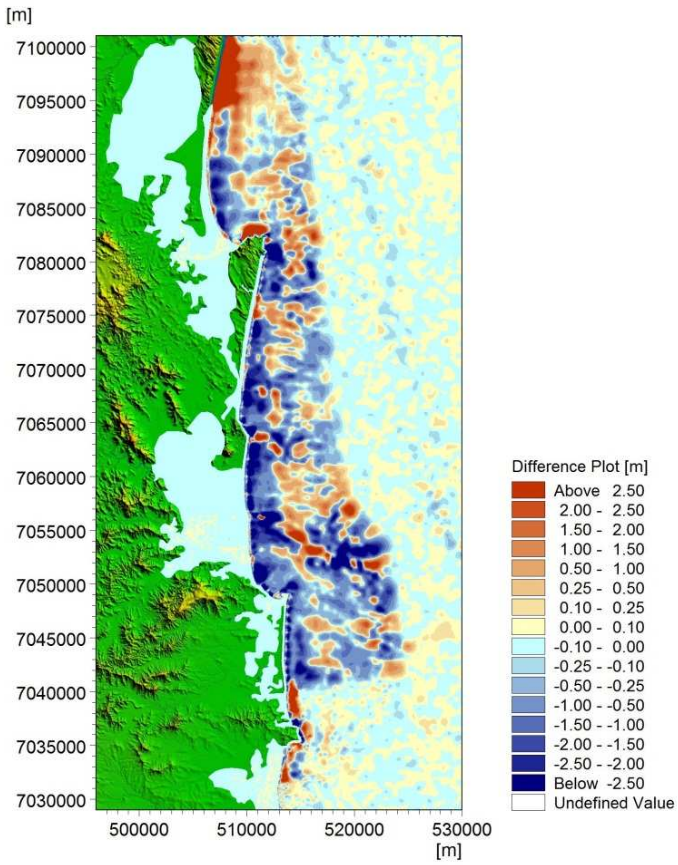


Figure 10 - Difference between LiDAR and gbr100 meshes (LiDAR – gbr100).

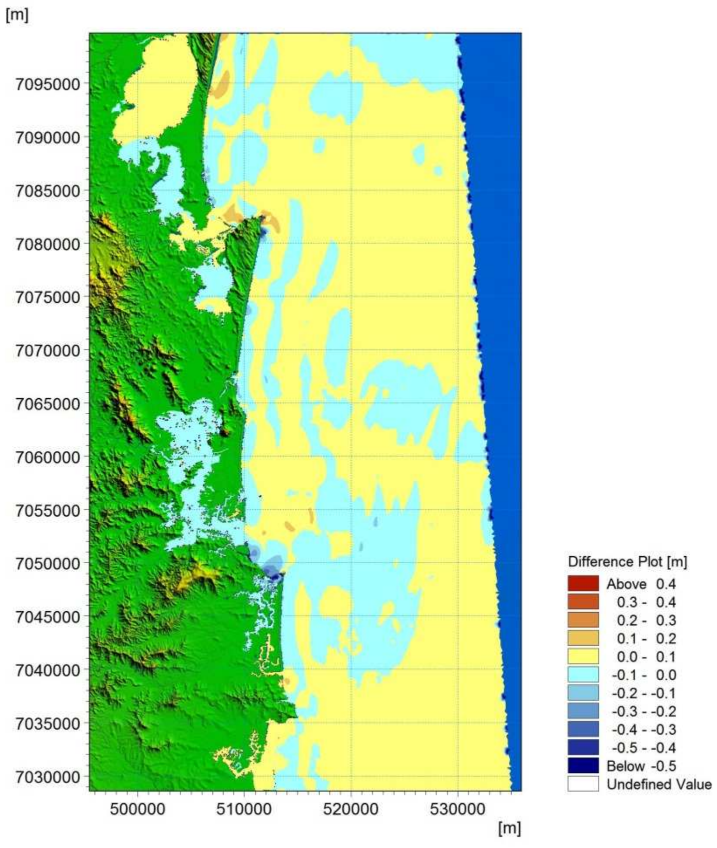


Figure 11 - Difference in maximum amplitude (LiDAR - gbr100 mesh).

9. Model Results

Inundation and velocity plots for the six model runs are provided in Appendix A. Figure 12 to Figure 14 demonstrate the tsunami time series at the coast for each scenario. For Scenarios 1 and 2 the leading edge of the tsunami (defined by a deviation of 1cm from MSL for the MSL cases) arrives 3:52 hours after the earthquake. There is a time difference of about 10 minutes between the southern (Dicky Beach) and northern (Noosa) locations (refer Table 3). Scenario 3 in general arrives 10 minutes earlier than the other two scenarios.

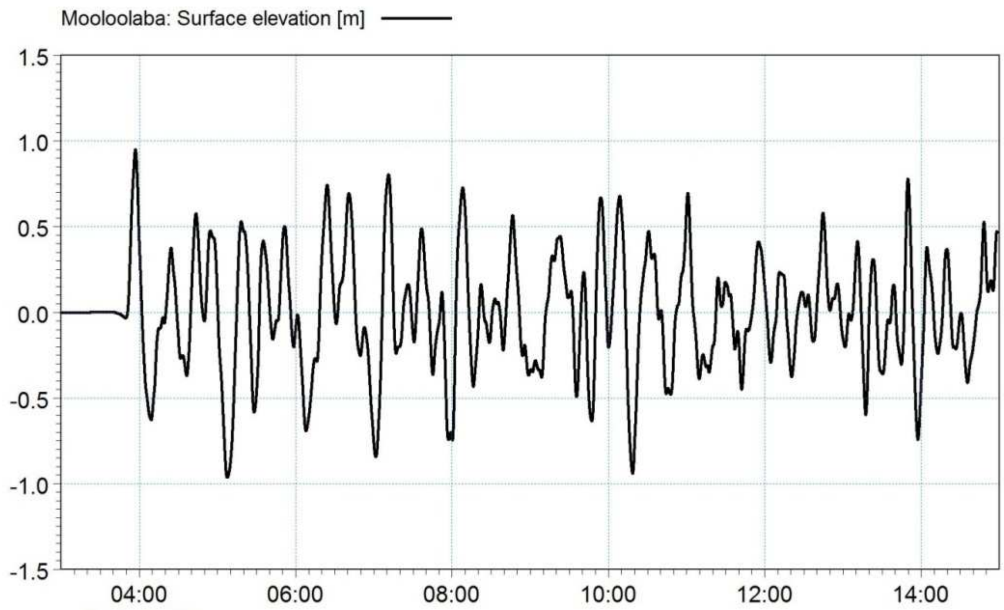


Figure 12 - Scenario 1 in 10m depth off Mooloolaba.

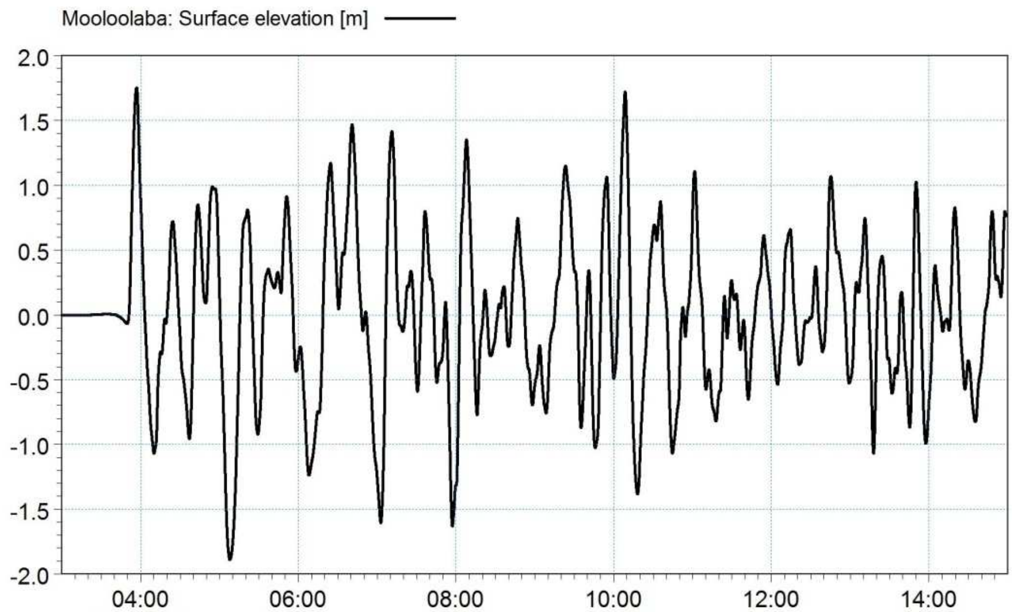


Figure 13 - Scenario 2 in 10m depth off Mooloolaba.

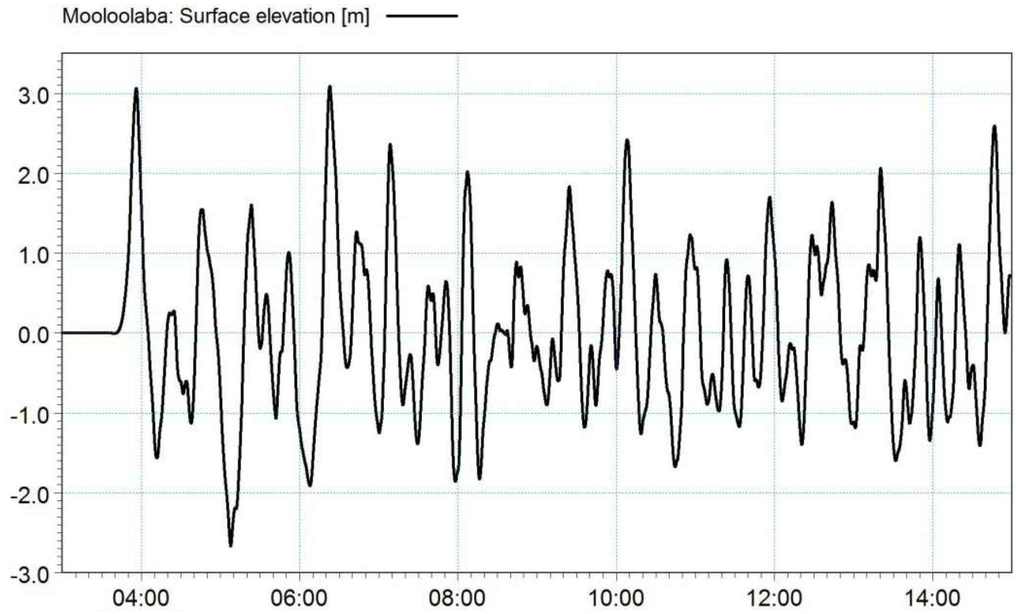


Figure 14 - Scenario 3 in 10m depth off Mooloolaba.

Table 3 - Arrival Times (hours:minutes after earthquake) at locations in 5m water depth.

Location	Scenario 1	Scenario 2	Scenario 3
Noosa	3:59	3:59	3:48
Peregian	3:53	3:53	3:42
Coolum	3:53	3:53	3:43
Twin Waters	3:52	3:52	3:42
Mooloolaba	3:51	3:51	3:41
Dicky Beach	3:48	3:48	3:39

The tsunami amplitude close to the coast was up to 1.4m for scenario 1 (MSL) and 4m for scenario 3 (MSL). In all three cases the largest wave was the leading wave. It is noted thought that this is not always the case as it is possible that the largest wave during a tsunami event may be from a subsequent wave. The time series for Mooloolaba for each event demonstrates that subsequent waves of similar magnitudes as the leading wave can be observed quite some time after the first. This pattern is consistent with the boundary time series for scenarios 1 and 2, but not as prominent for scenario 3. The large subsequent waves for scenario 3 at Mooloolaba could be contributable to interactions with the complex bathymetry and wave interactions due to the varying wave periods within the time series. There is considerable wave attenuation at the entrances to the main waterways such that the tsunami amplitudes within the main rivers are typically under 0.3m for scenario 1 (MSL) and 1m for scenario 3 (MSL).

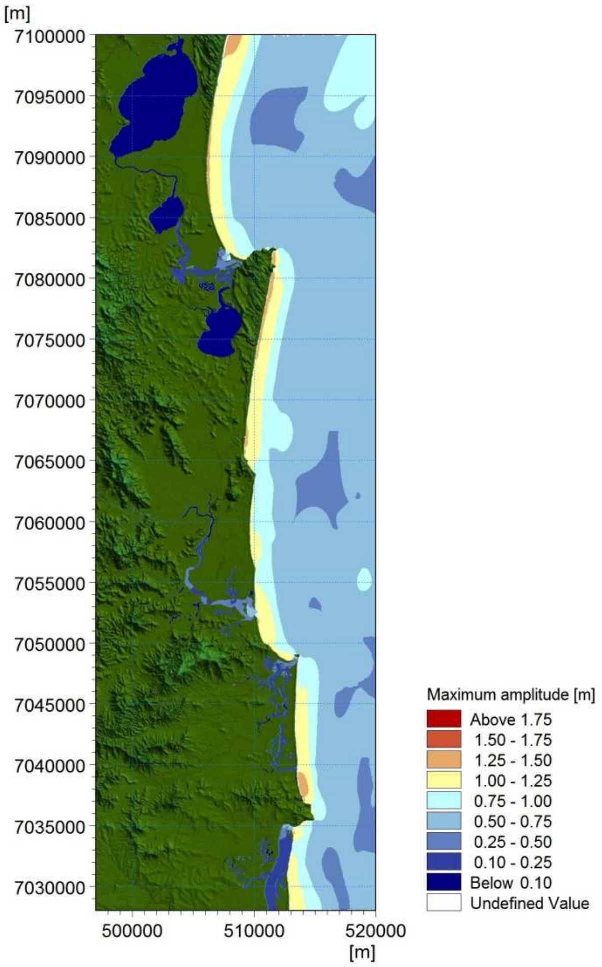


Figure 15 - Maximum amplitude for scenario 1 (MSL)

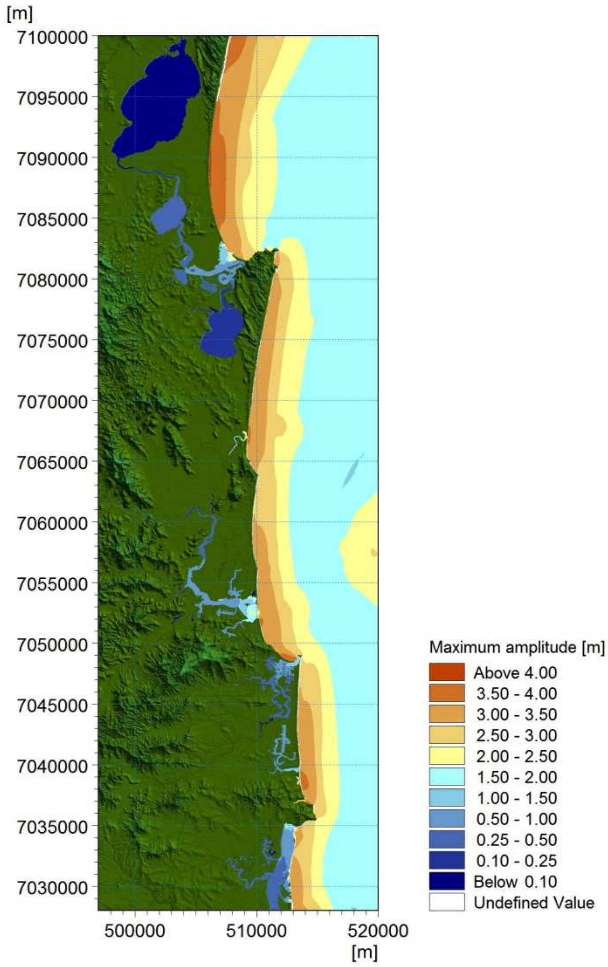


Figure 16 - Maximum amplitude for scenario 3 (MSL)

A summary of the modelled inundation for each scenario are provided below.

Teewah to Noosa

For all scenarios, Teewah was not inundated but access via the beach was cut off. Boreen Point on Lake Cootharaba was not inundated by any of the MSL cases. There was minor inundation of up to 0.3m for houses closest to the Lake for scenarios 2 and 3 with HAT. For Noosa North Shore the inundation was contained to the beach for Scenarios 1 and 2 (MSL). The camping grounds on the North Shore was compromised for Scenario 3 (MSL) and scenario 2 and 3 (HAT).

Inundation of Noosa is predominantly caused by the tsunami propagating up the Noosa River. Scenario 1 (MSL) does not cause inundation beyond the beach adjacent to Hastings Street, and only minor inundation for scenarios 2 and 3 (MSL). For all scenarios, there is inundation of Noosa Parade, and the first row of houses along the river bank and canals. Scenario 3 (HAT) shows extensive inundation along the river bank and of Hasting St. Inundation within the canal estates is contained within the first row of buildings and is typically less than 0.2m for scenario 1 (MSL) and up to 2m for scenario 3 (HAT).

Sunshine Beach to Mudjimba

The beaches from Sunshine Beach to Mudjimba have a continuous dune system at around 4.5 to 10m AHD, which is broken by small creeks. This dune system protects houses along this stretch of coastline such that the tsunami is contained to the beach for scenarios 1 (MSL and HAT) and 2 (MSL). There is inundation of David Low Way near Coolum Beach Surf Club for scenario 2 (HAT) and scenario 3. For all the HAT scenarios and scenario 3 (MSL) there is inundation of some houses along Stumers Creek.

The Sunshine Coast Airport was not inundated under any cases modelled. Mudjimba became inundated four blocks back from the beach to Conebush Street for scenario 3 (HAT) only.

Maroochydore and Twin Waters

As with Noosa, all scenarios caused inundation along the river and canal banks affecting the first row of buildings, as well as inundation of buildings on Chambers Island. The HAT scenarios also produce wide spread inundation of the low rural areas in the upper catchment. Scenario 1 (HAT), and scenarios 2 and 3 cause inundation of Cotton Tree park and the Cotton Tree caravan park. Scenario 3 (HAT) inundates up to four blocks back from the river and into Horton Park Golf Club, as well as Beach Parade and Sea Breeze Caravan Park from inundation on the ocean side.

Inundation within the canal estates is typically less than 0.3m for scenario 1 (MSL) and up to 2.9m for scenario 3 (HAT).

Alexandra Headlands

There is no inundation beyond the beach for Scenario 1(MSL and HAT). Scenario 2 and 3 inundates Alexandra Parade between Mary and Mayfield Streets. For scenario 3 (HAT) the inundation extends to Alex Beach Caravan Park.

Mooloolaba

All scenarios cause inundation of the buildings along the river and canal banks as well as inundation of River Esplanade and Harbour Parade. Scenario 1 (HAT) and scenarios 2 and 3 inundate the caravan park on the Mooloolaba Esplanade as well as the Spit. Inundation of the River Esplanade extends to Brisbane Road for Scenario 3 (HAT).

Inundation within the canal estates is typically less than 0.3m for scenario 1 (MSL) and up to 2.9m for scenario 3 (HAT).

Buddina to Shelly Beach

The dune system protects Buddina and Warana for all scenarios. The vulnerable locations along this stretch of coast are the waterways of Currumundi Lake, Kawana Waters, and Tooway Creek. Properties adjacent to these waterways experience inundation for all scenarios, including Kawana Nursing Centre, Blue Care, Kawana Private Hospital, and Currimundi Lake Villas.

Scenario 3 (HAT) also inundates Currimundi Recreation Camp, Currimundi Primary School and Dicky Beach Surf Club and caravan park.

Kings Beach to Pelican Waters

Tsunami inundation for scenario 1 (MSL) is limited to the beach for all locations except Caloundra and Lamerough Canal. Scenario 1 (HAT), scenario 2 and scenario 3 cause some degree of inundation at all locations. At Caloundra, the caravan park is inundated for scenario 2, extending to the Westfield complex for scenario 3 (HAT) with 1.6m depth over the caravan park. Scenario 2 also inundates the Esplanade at Golden Beach (typically 0.3m for scenario 1 (HAT) and 2 (MSL and HAT)), and the Caloundra Power Boat Club becomes inundated for Scenario 3 (MSL) and all HAT cases. Scenario 3 (HAT) also inundates parts of Pelican Waters by as much as 0.5m.

The northern end of Bribie Island is overtopped for scenario 1 (HAT) and scenarios 2 and 3.

Velocities

Depth averaged velocities associated with the tsunami are a maximum at entrances to waterways and near headlands. For scenario 1 (MSL) the velocities reach 3.5m/s. Along the open coast the velocities are typically under 1.5m/s.

The most extreme scenario produces velocities at the entrances and headlands of the order of 5 to 8m/s, and 1 to 1.5m/s along the open coast.

10. Conclusions and Recommendations

The modelling undertaken indicates that a 1 in 10,000 year event will produce a maximum amplitude of about 4m near the coast (in 10m depth), whereas a 1 in 750 year event will only be about 1m. Along the open coast, the extensive dune system prevents the tsunami from encroaching urban development (assuming the dune system in not eroded). Instead, the tsunami propagates into the numerous waterways, inundating adjacent low lying areas.

For a more probable event (scenario 1), the community is mostly protected provided they remain away from the beach and waterways. Even under the extreme scenario 3 (HAT), the communities along the open coast are mostly protected, with inundation of areas adjacent to waterways.

The regions identified in this study to be the most at risk are:

- Noosa (Hastings St region and adjacent Noosa River and canal estates);
- Maroochydore (adjacent Maroochy River and canal estates);
- Mooloolaba (caravan park on the Esplanade, the Spit, and adjacent Mooloolah River and the canal estates);
- Kawana Waters adjacent the waterways;
- Caloundra (caravan park and Tay Ave);
- Golden Beach (the esplanade); and
- Areas adjacent to other waterways (Stumers Ck, Tooway Ck, and Lamerough Canal).

As detailed in the discussion, there are some limitations as to the accuracy of inundation depths close to the waterways due to the steep bank gradients that are not fully captured within the model. Finer mesh resolution of particular areas of interest (such as Kawana Waters) together with rigorous analysis of crest level position may enhance the assessment of risk of inundation in these locations.

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Appendix A - Model Results

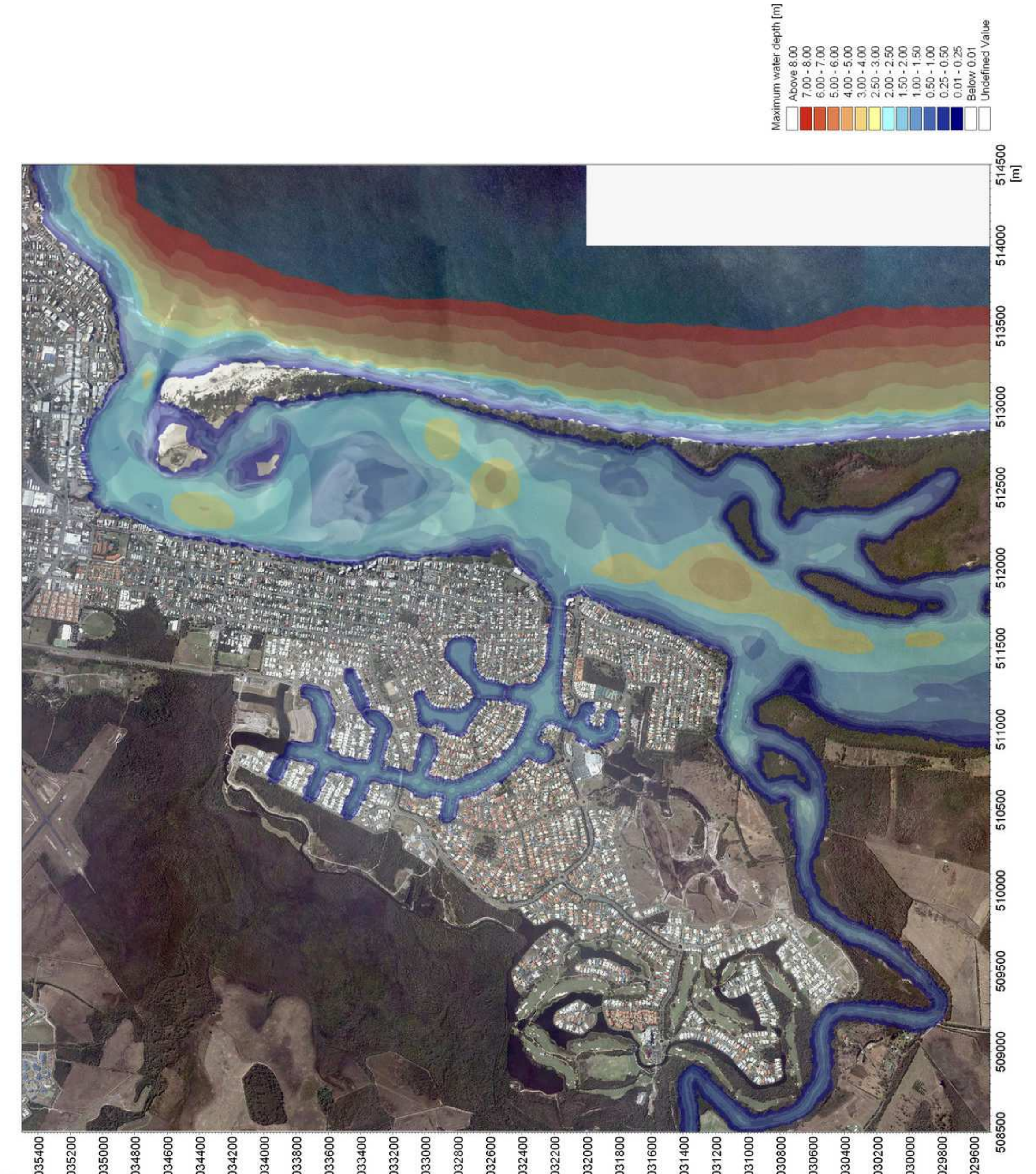

Figure A - 1 Scenario 1 inundation at Golden Beach (MSL).

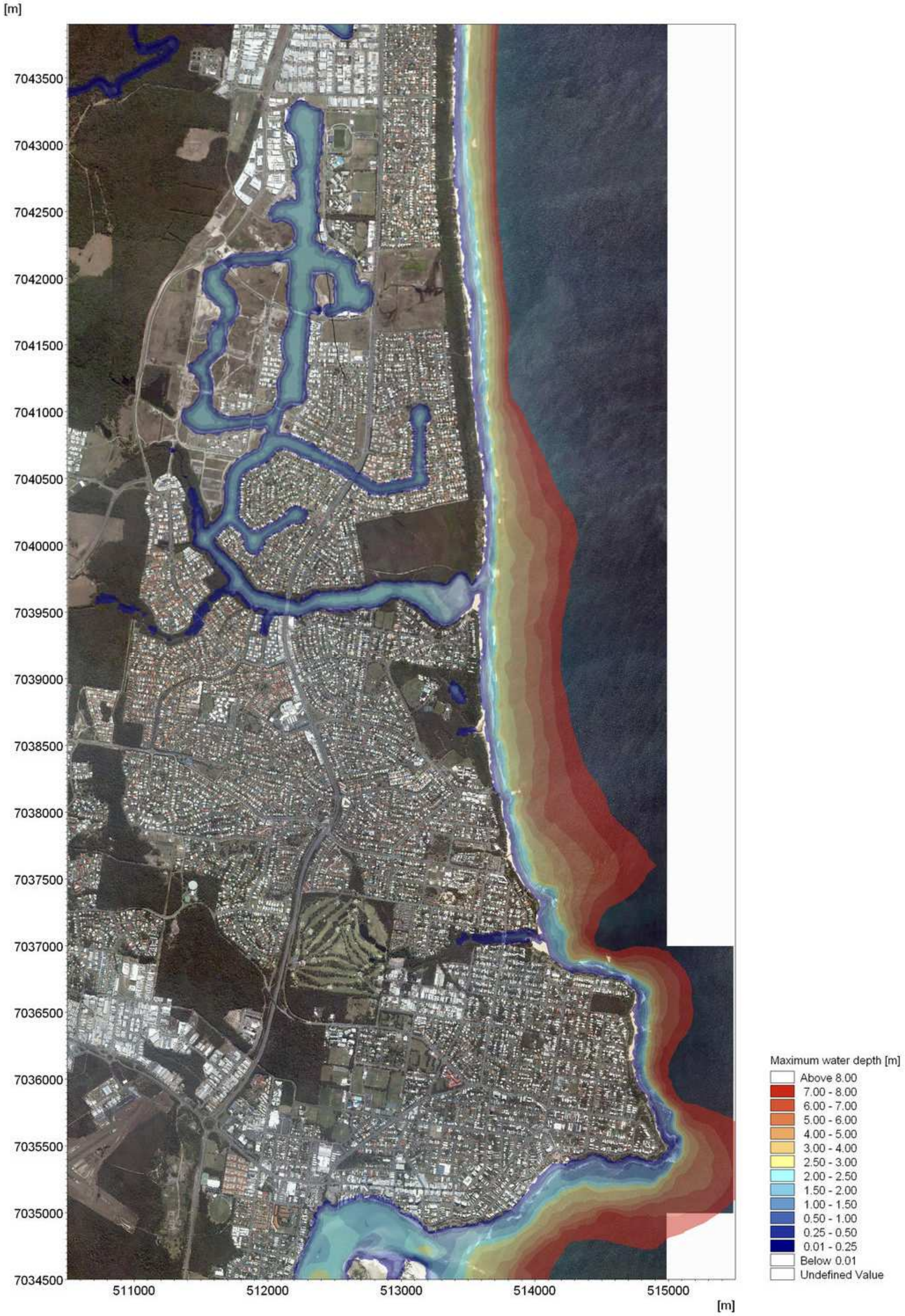

Figure A - 2 Scenario 1 inundation at Warana to Caloundra, Scenario 1 (MSL).

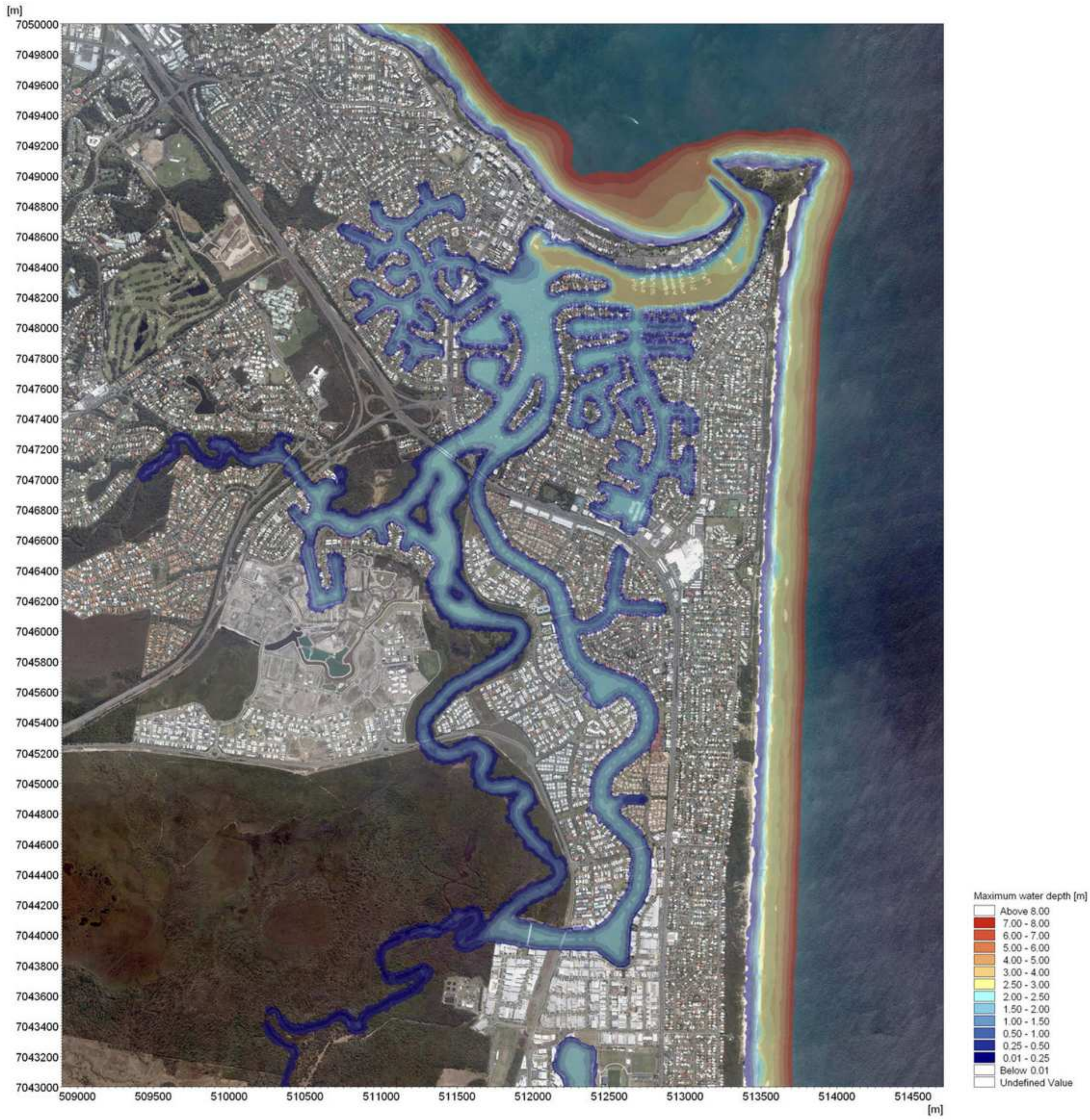

Figure A - 3 Scenario 1 inundation at Mooloolaba (MSL).

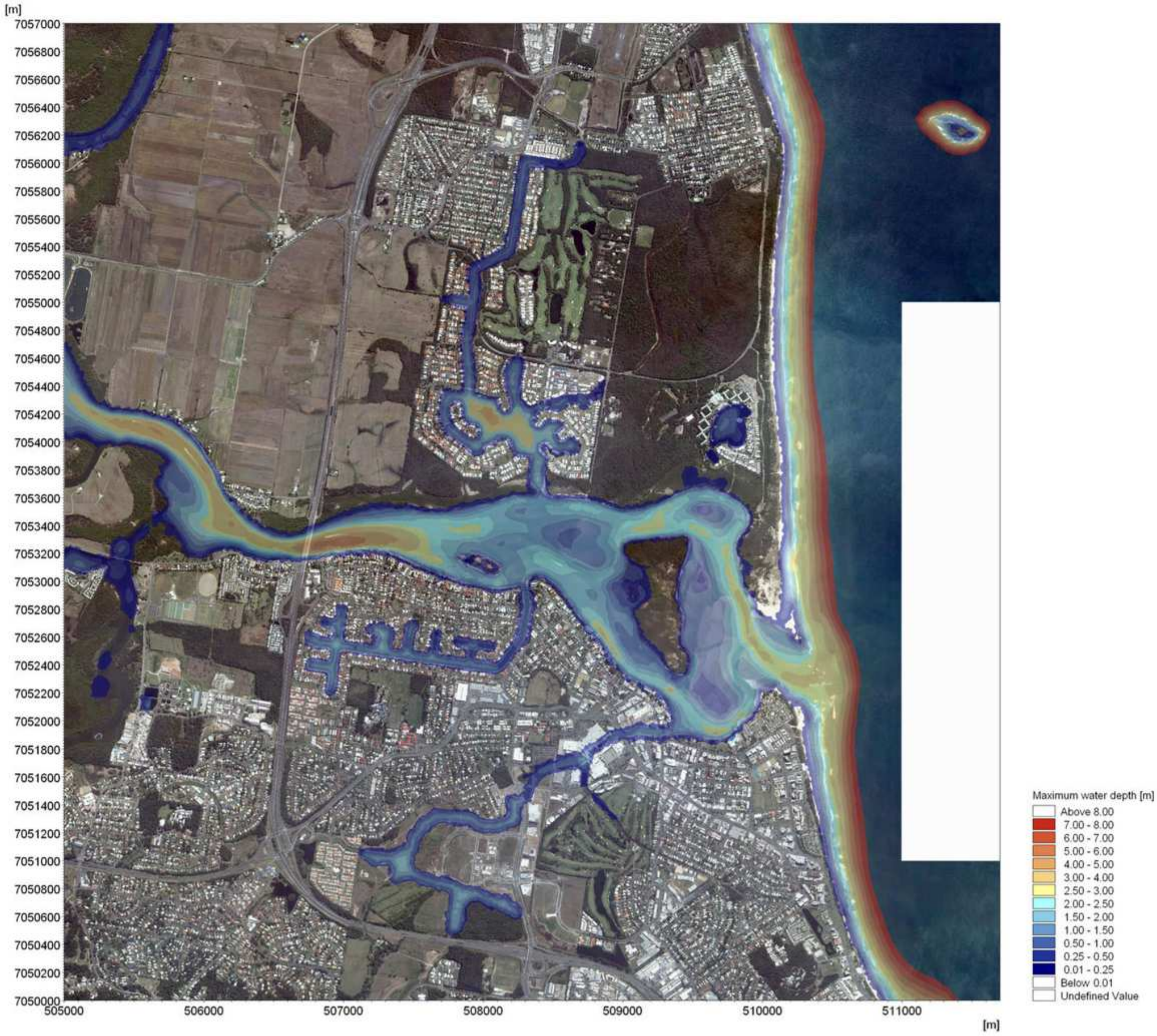

Figure A - 4 Scenario 1 inundation at Maroochydore (MSL).

Figure A - 5 Scenario 1 inundation at Mooloolaba to Coolum (MSL).

Figure A - 6 Scenario 1 inundation at Coolum to Sunshine Beach (MSL).

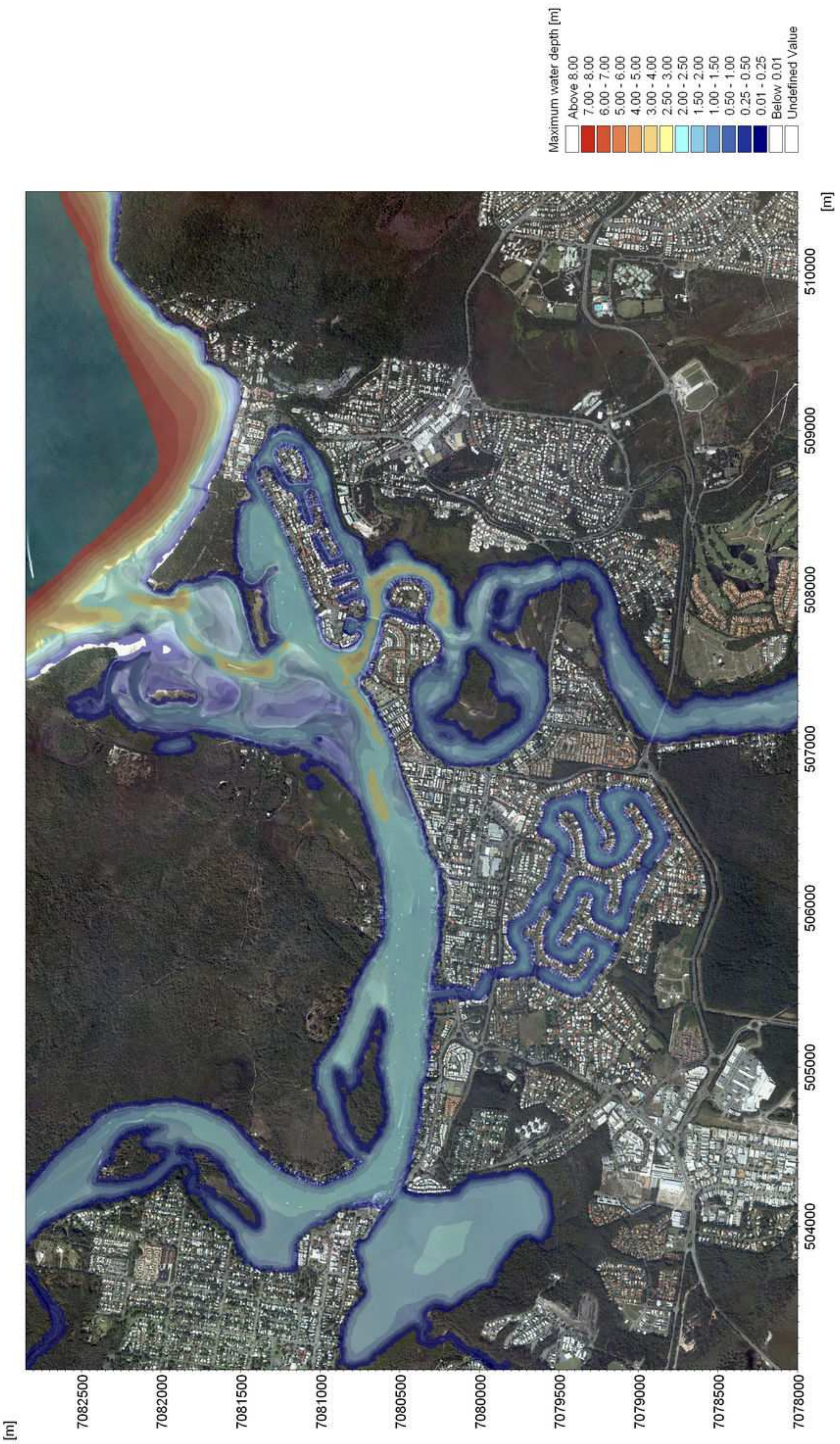

Figure A - 7 Scenario 1 inundation at Noosa Heads (MSL).

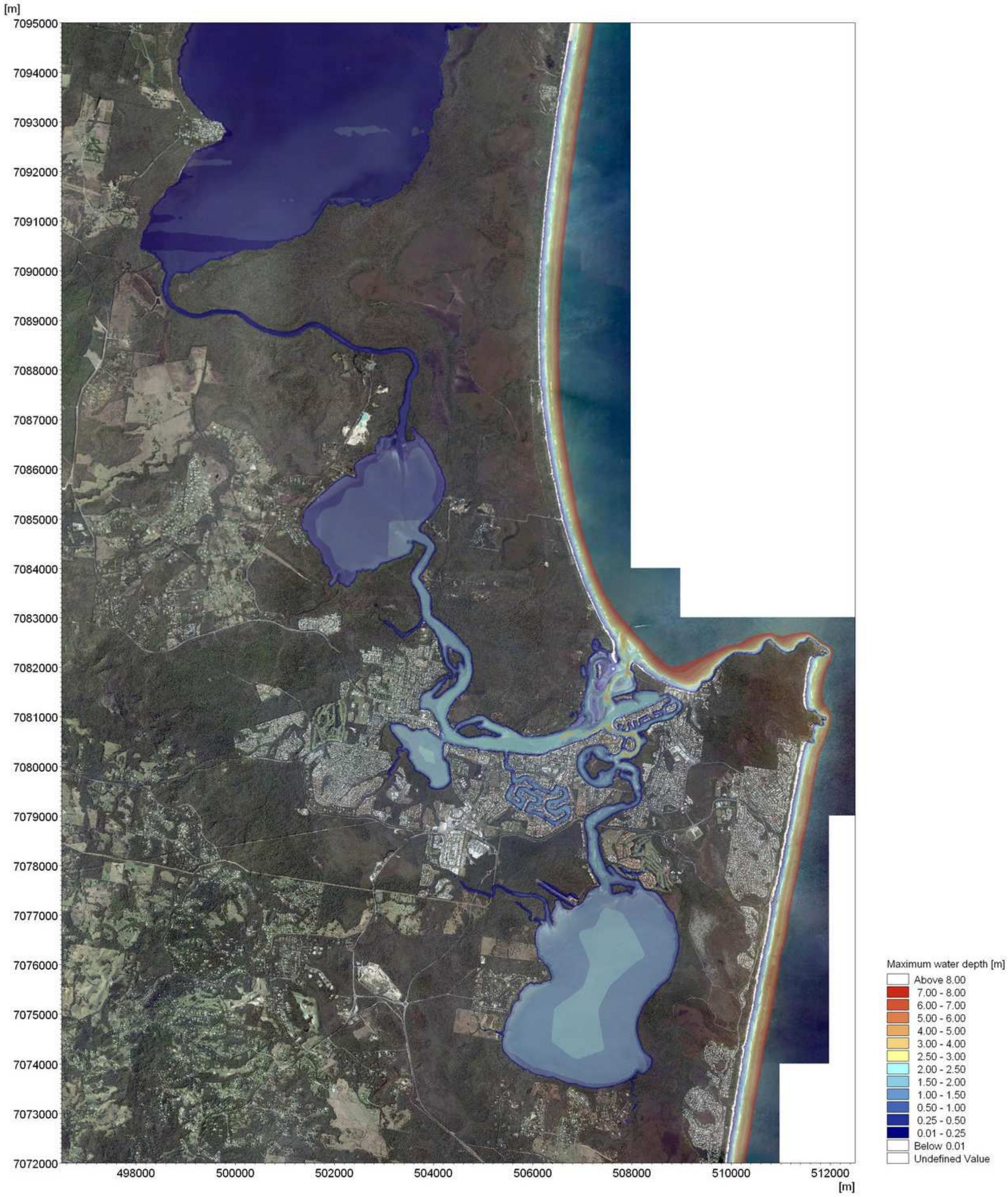

Figure A - 8 Scenario 1 inundation at Noosa to Teewah (MSL).

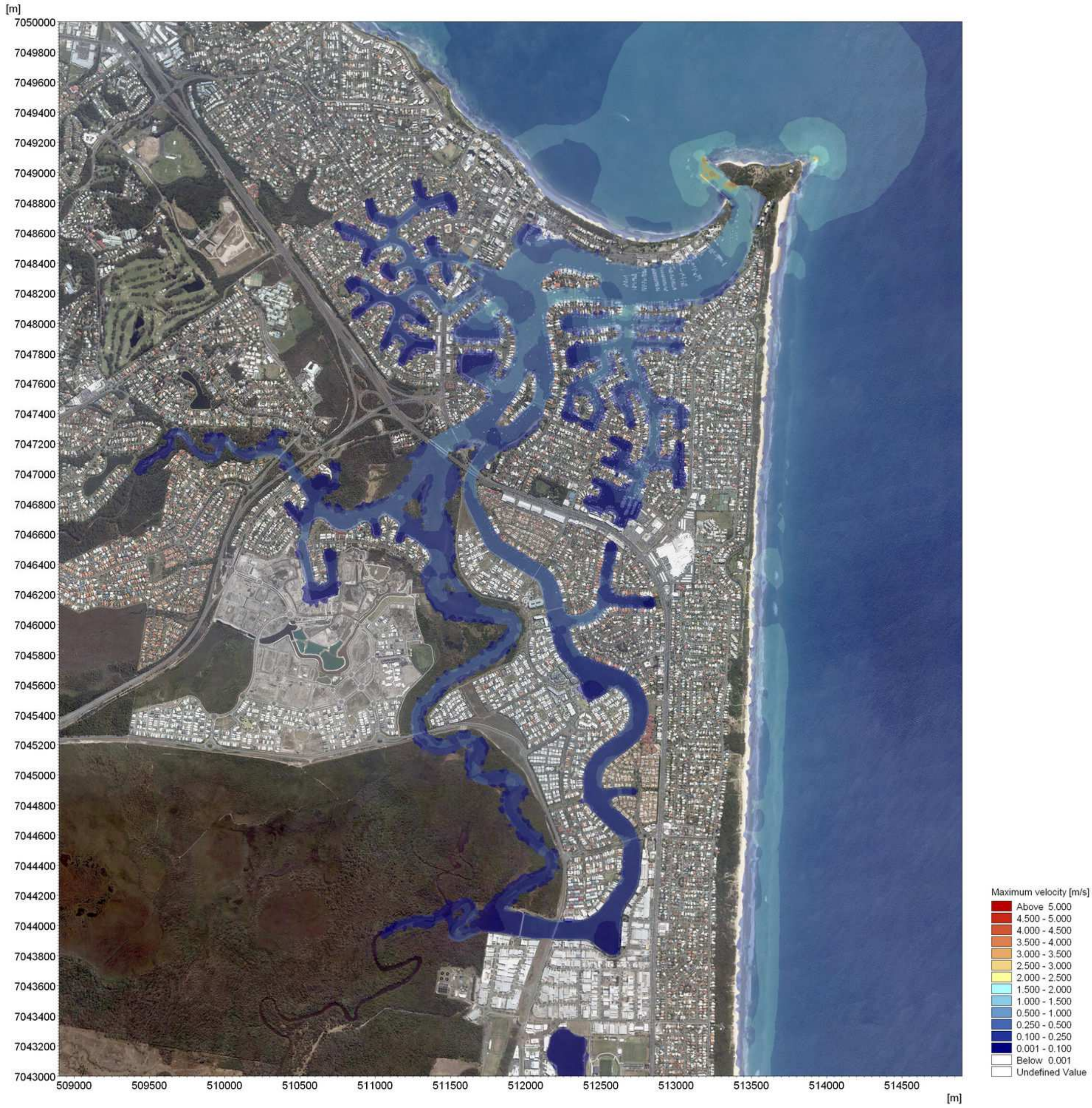

Figure A - 9 Scenario 1 maximum velocities at Mooloolaba (MSL).

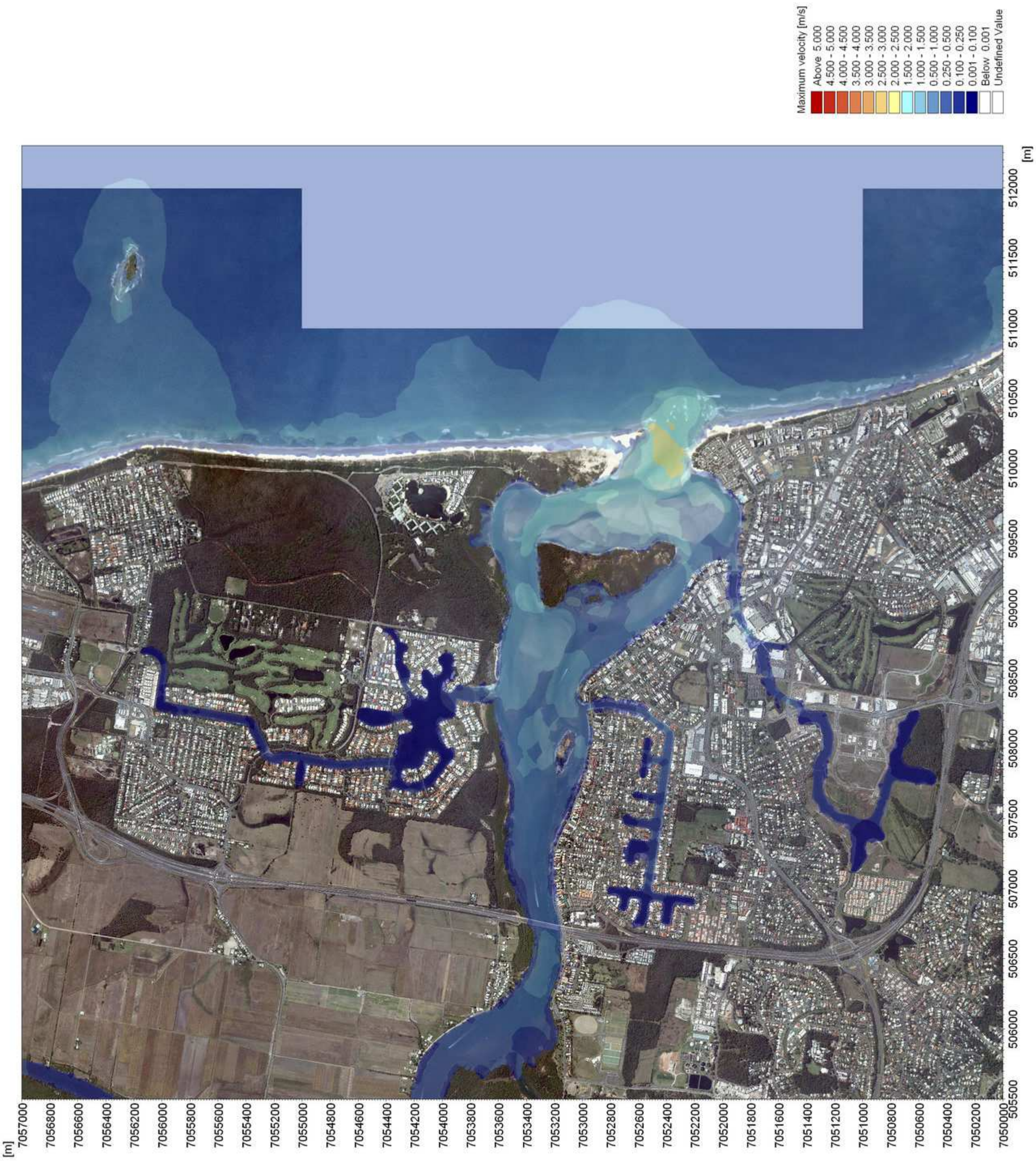

Figure A - 10 Scenario 1 maximum velocities at Maroochydore (MSL).

Figure A - 11 Scenario 1 maximum velocities at Noosa Heads (MSL).

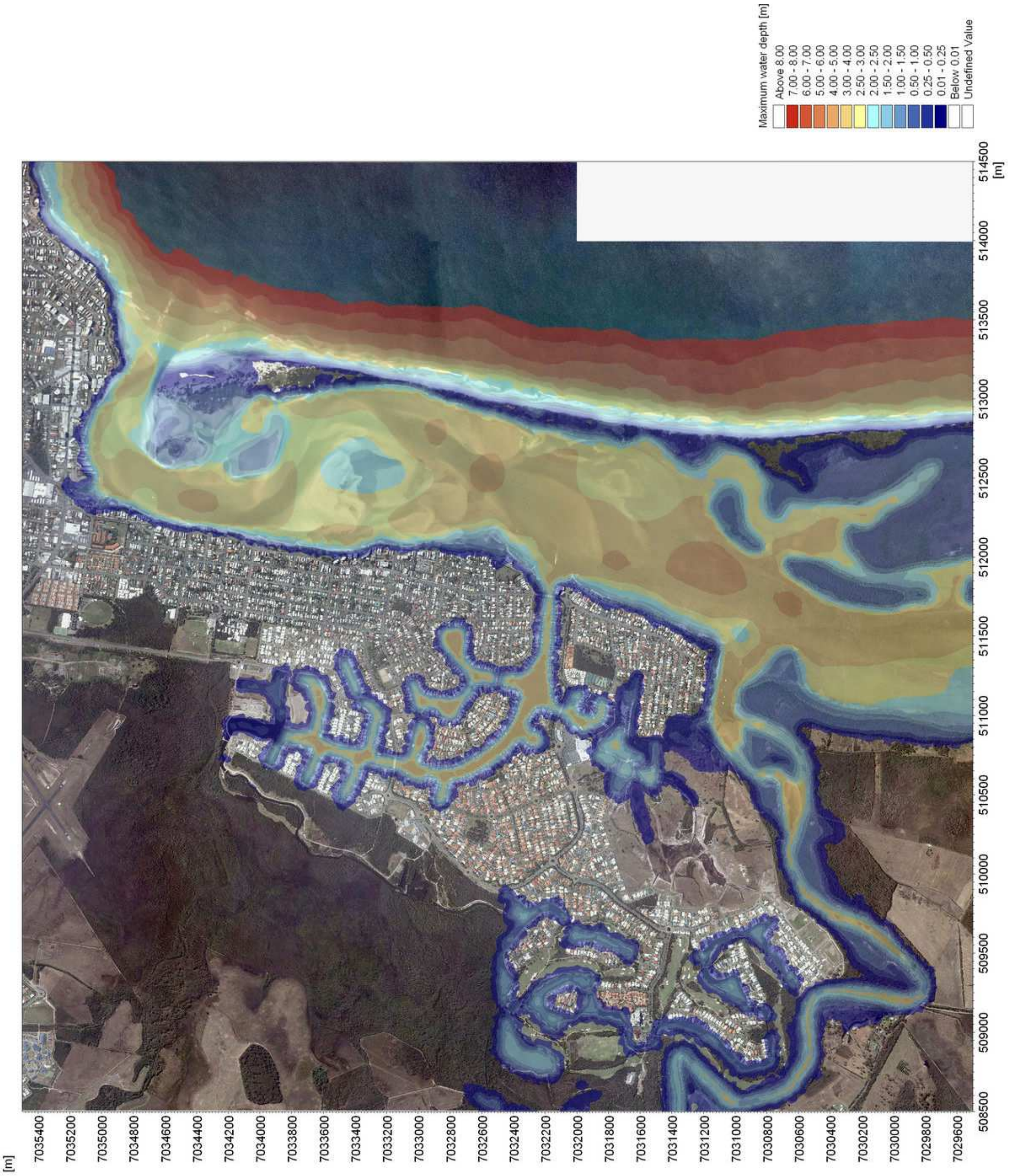

Figure A - 12 Scenario 1 inundation at Golden Beach (HAT).

Figure A - 13 Scenario 1 inundation at Warana to Caloundra, Scenario 1 (HAT).

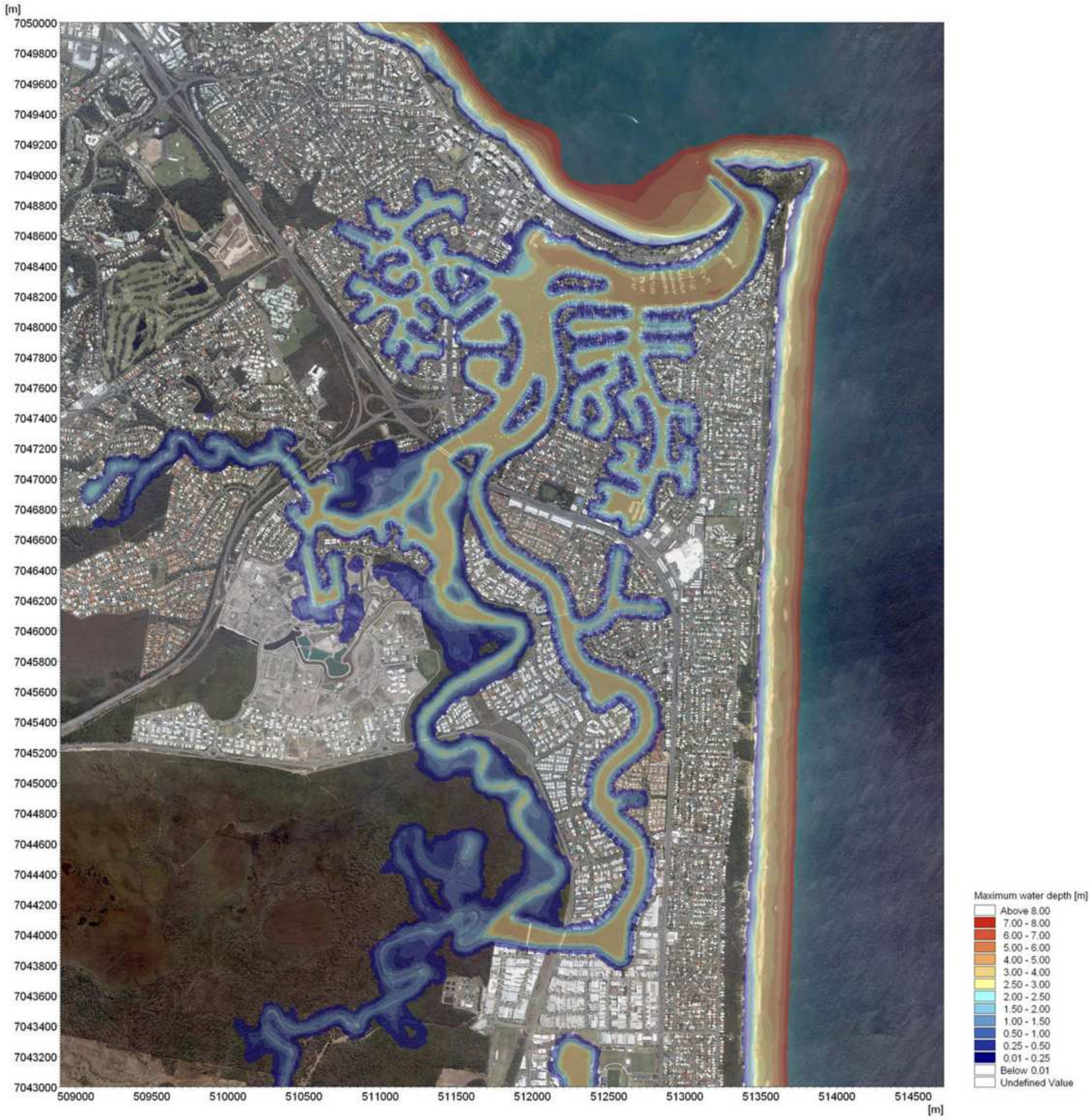

Figure A - 14 Scenario 1 inundation at Mooloolaba (HAT).

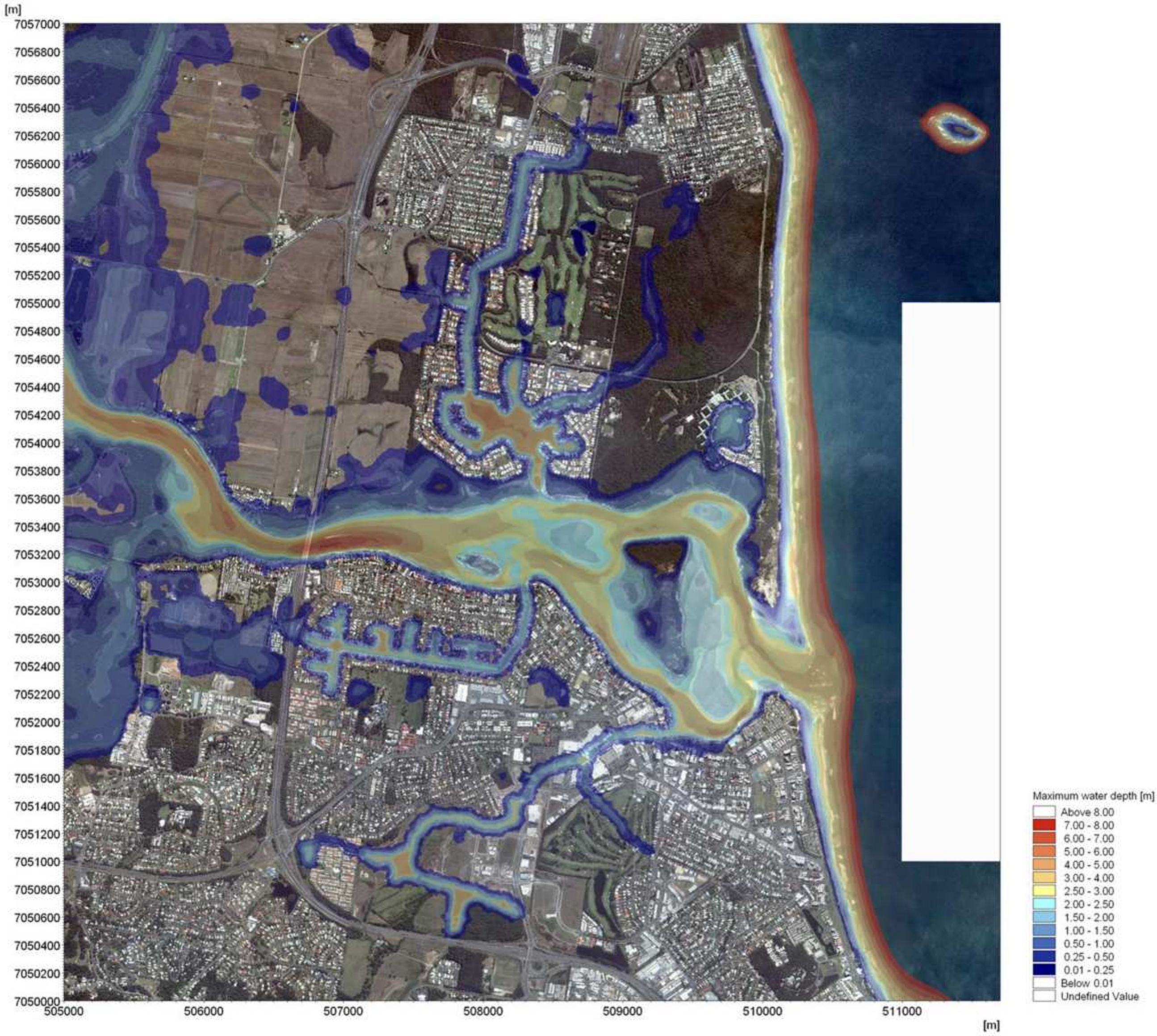

Figure A - 15 Scenario 1 inundation at Maroochydore (HAT).

Figure A - 16 Scenario 1 inundation at Mooloolaba to Coolum (HAT).

Figure A - 17 Scenario 1 inundation at Coolum to Sunshine Beach (HAT).

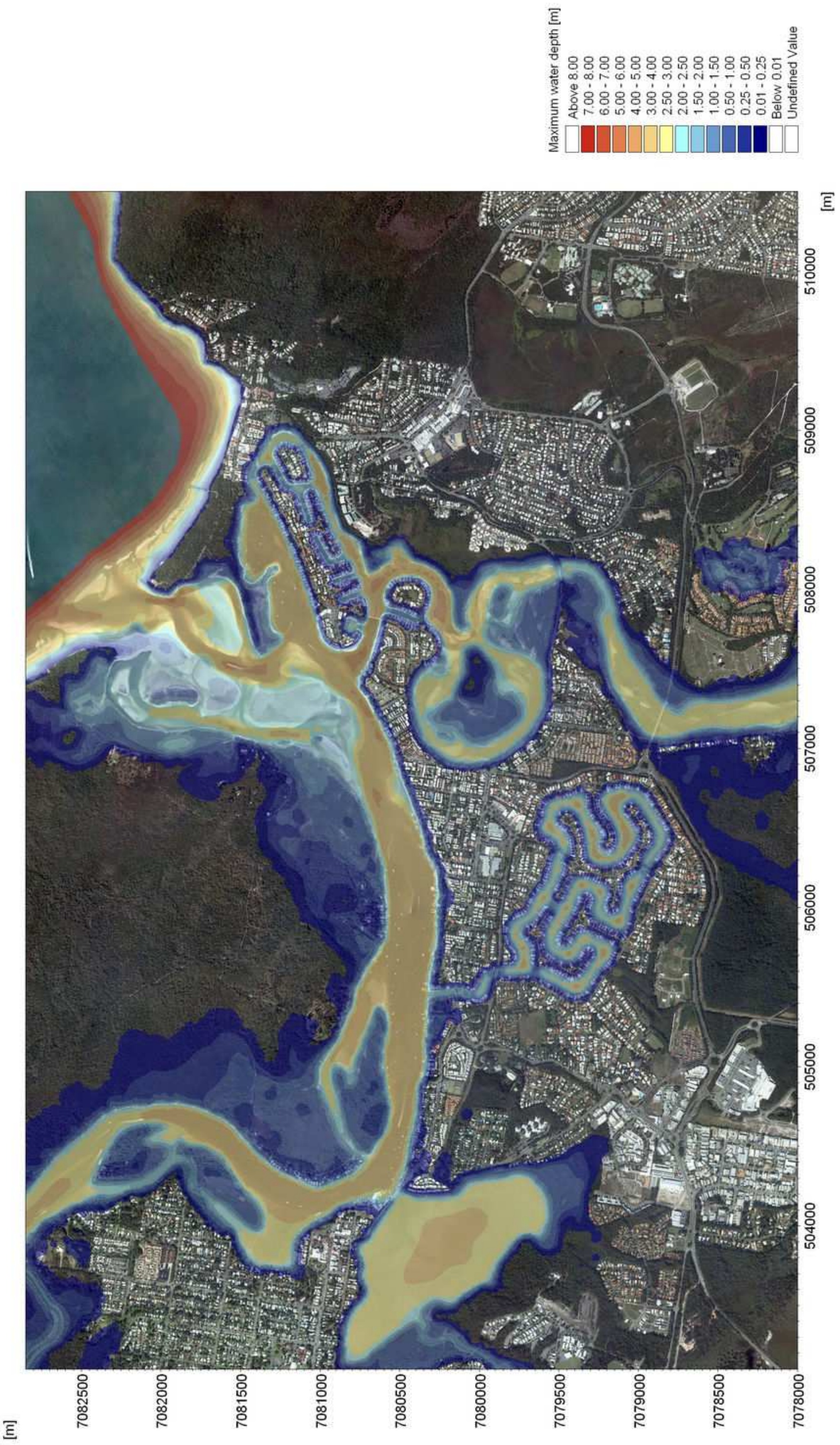

Figure A - 18 Scenario 1 inundation at Noosa Heads (HAT).

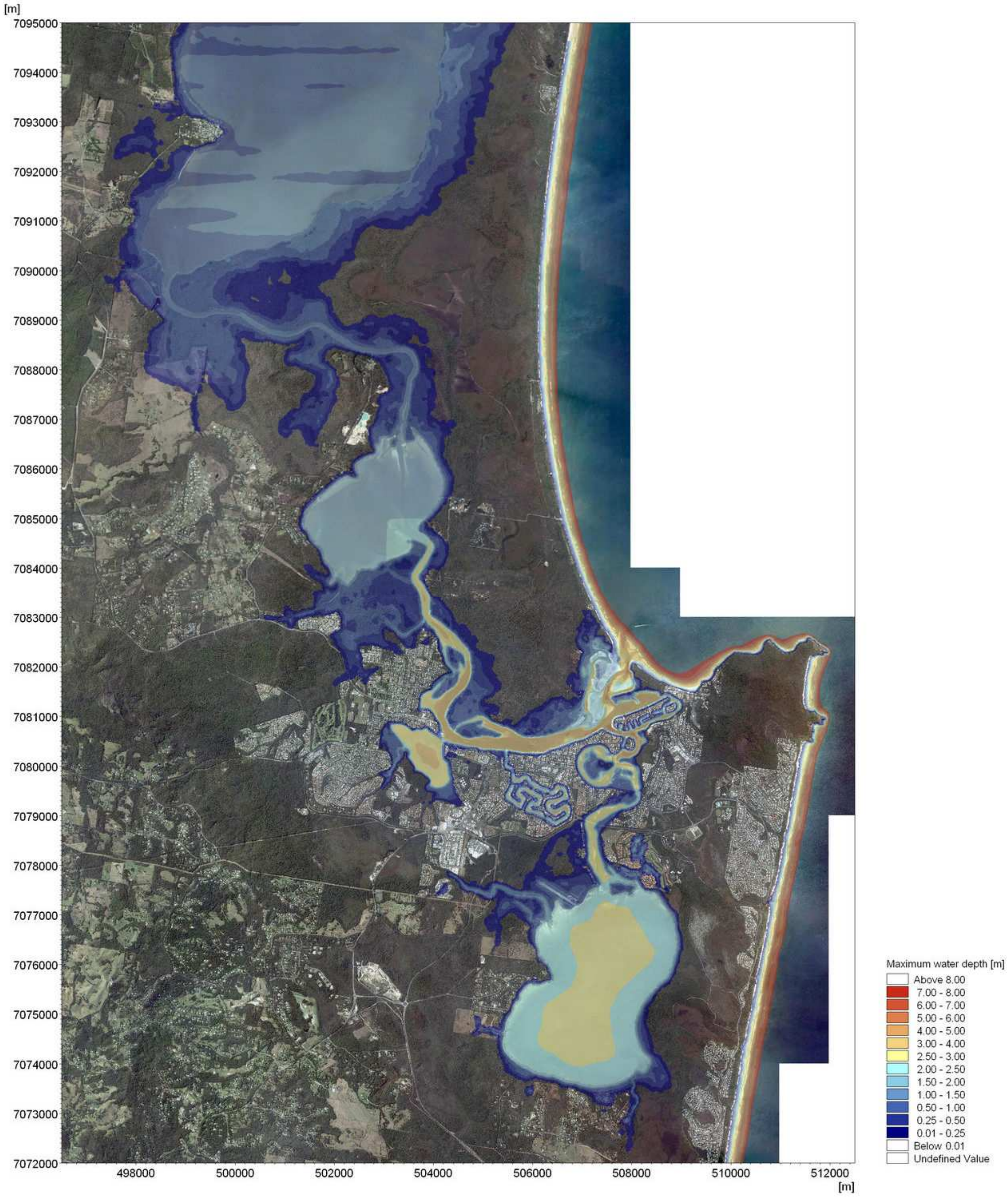

Figure A - 19 Scenario 1 inundation at Noosa to Teewah (HAT).

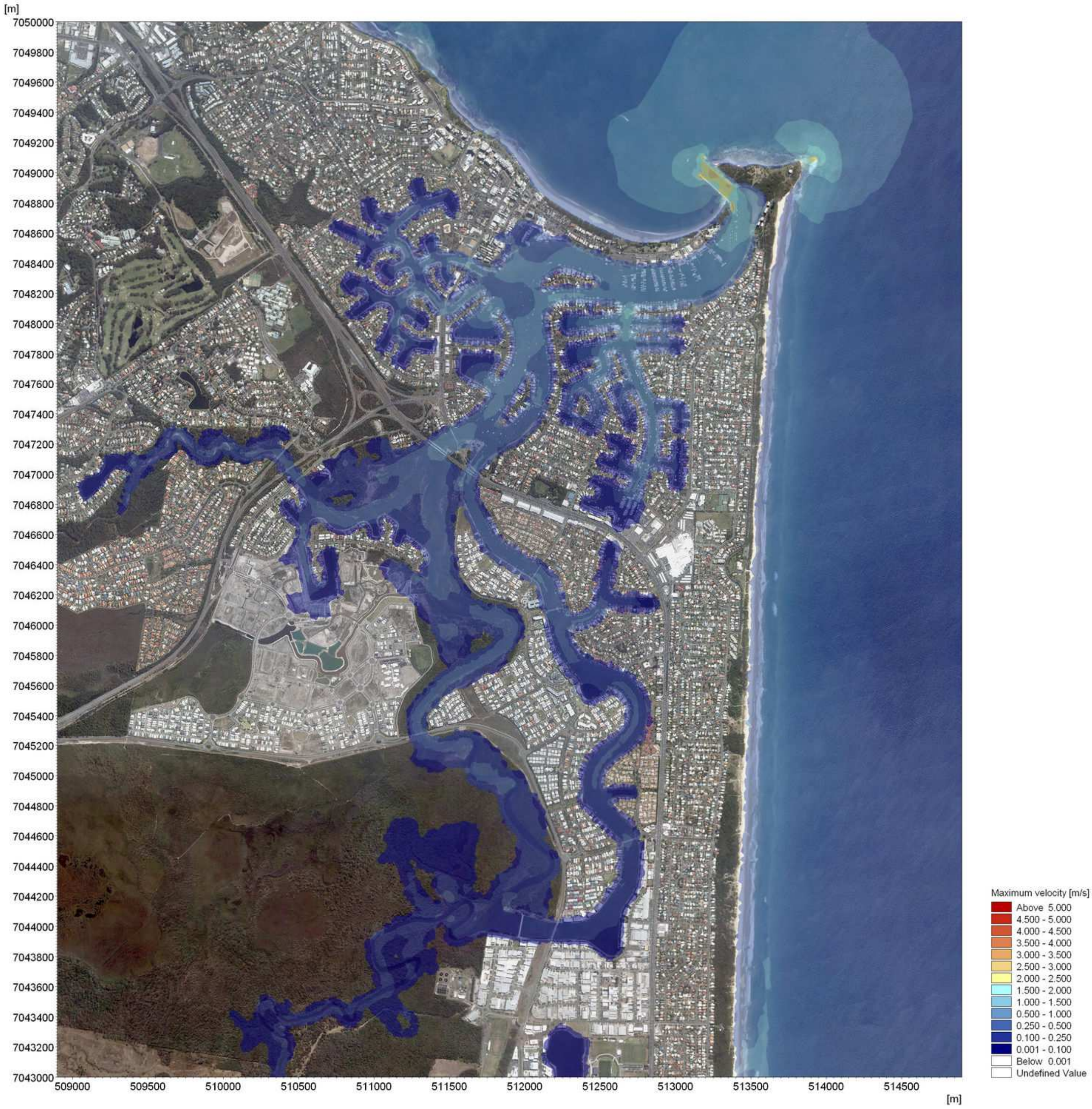

Figure A - 20 Scenario 1 maximum velocities at Mooloolaba (HAT).

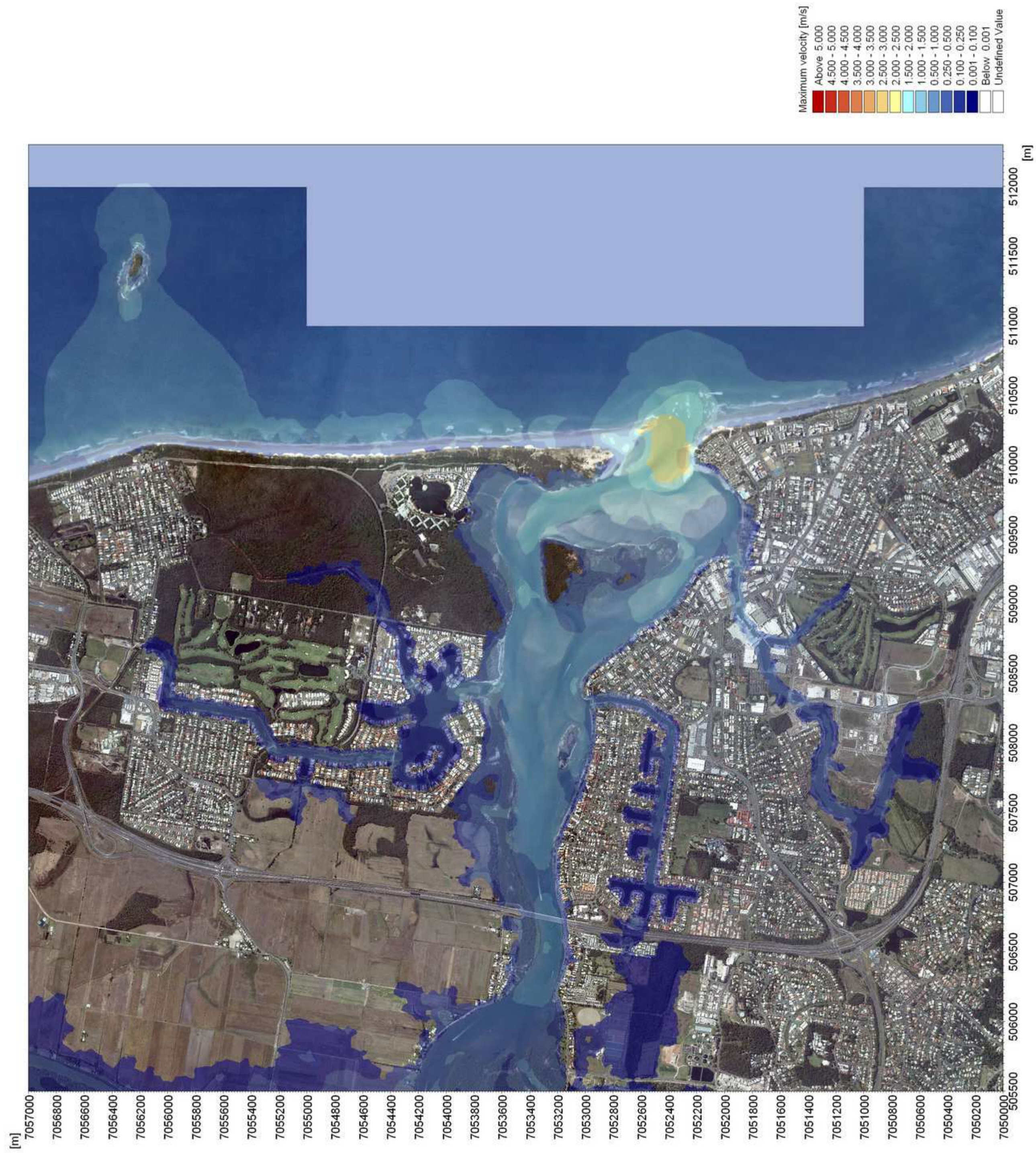

Figure A - 21 Scenario 1 maximum velocities at Maroochydore (HAT).

Figure A - 22 Scenario 1 maximum velocities at Noosa Heads (HAT).

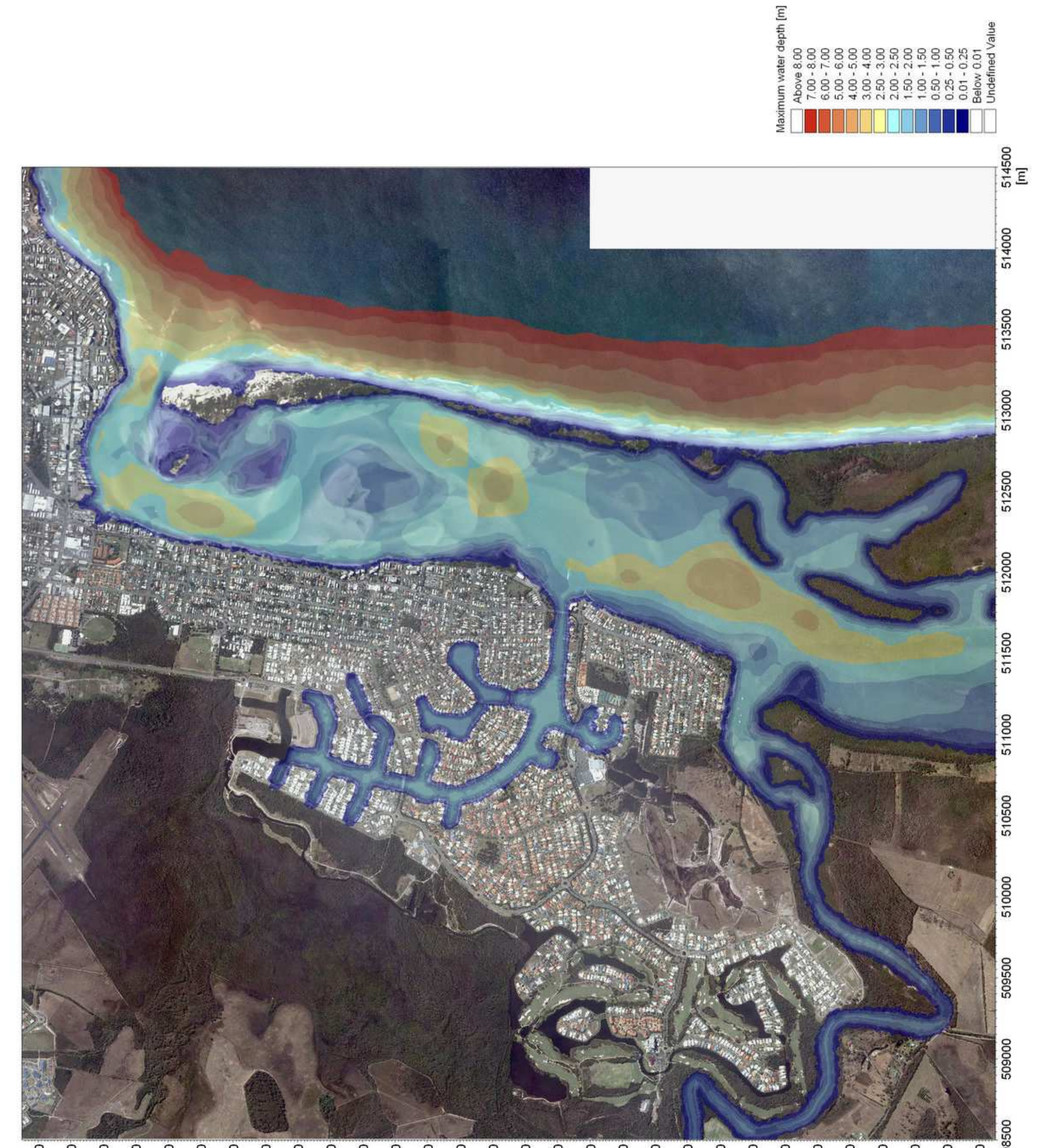

Figure A - 23 Scenario 2 inundation at Golden Beach (MSL).

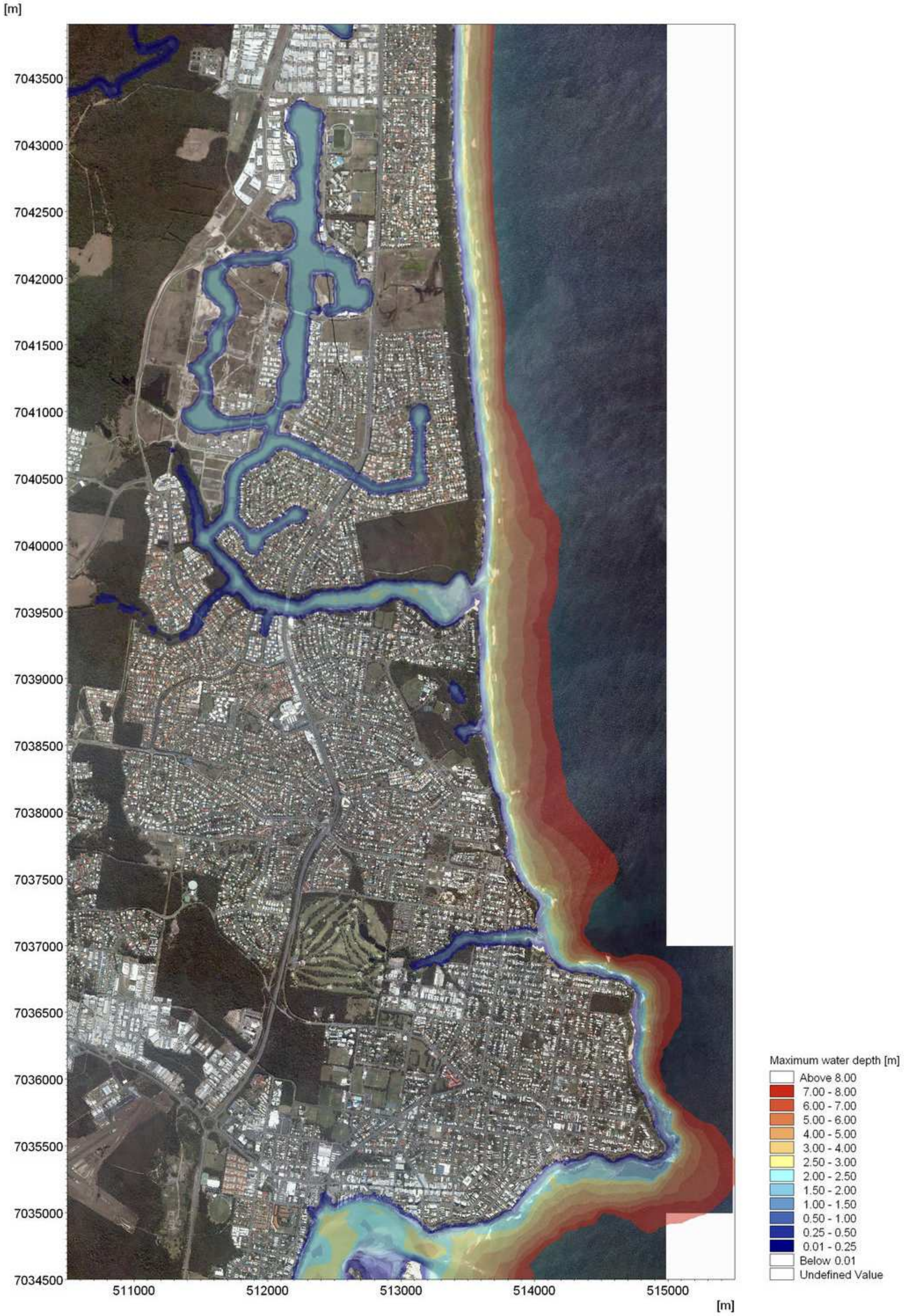

Figure A - 24 Scenario 2 inundation at Warana to Caloundra, Scenario 1 (MSL).

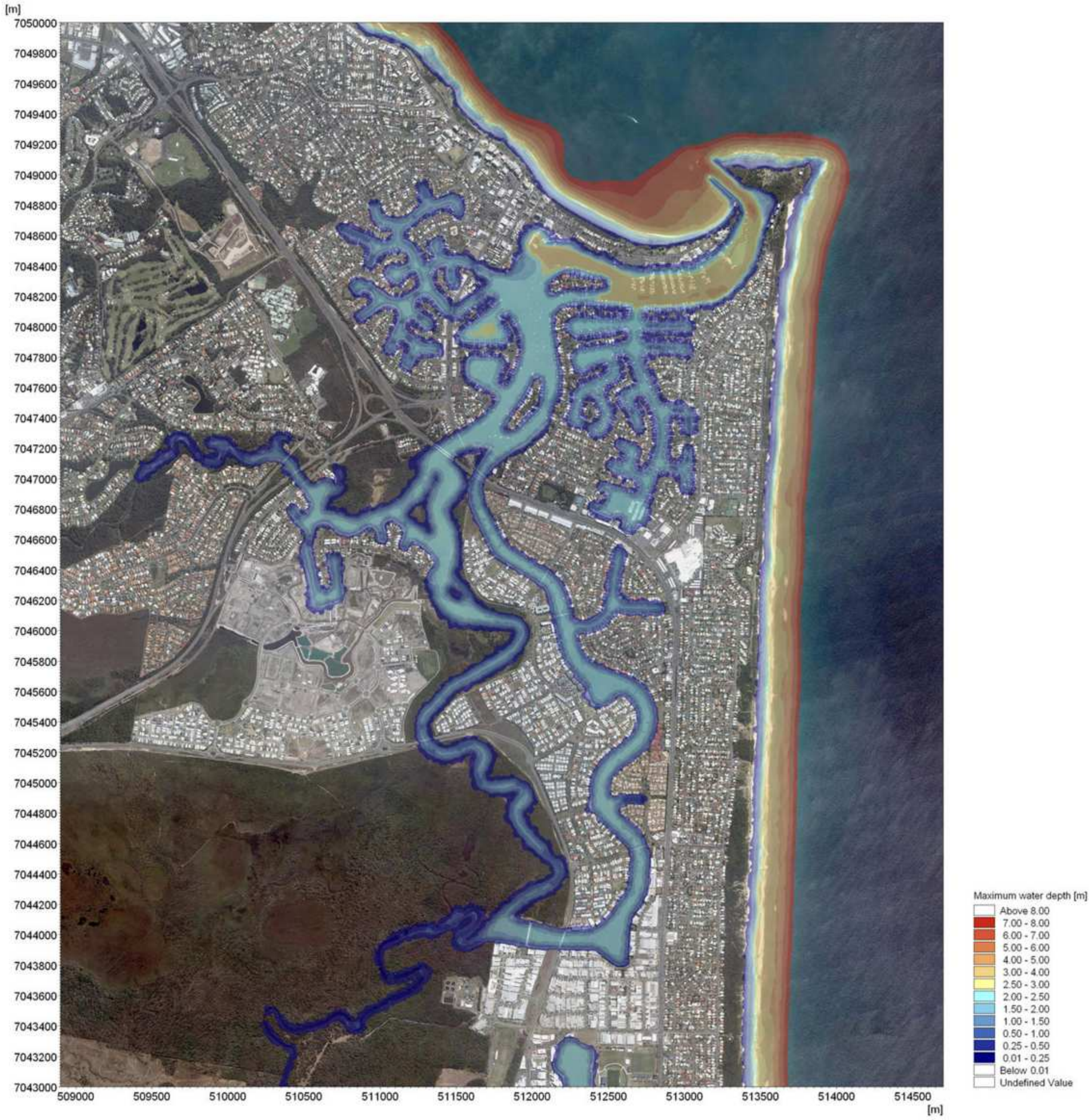

Figure A - 25 Scenario 2 inundation at Mooloolaba (MSL).

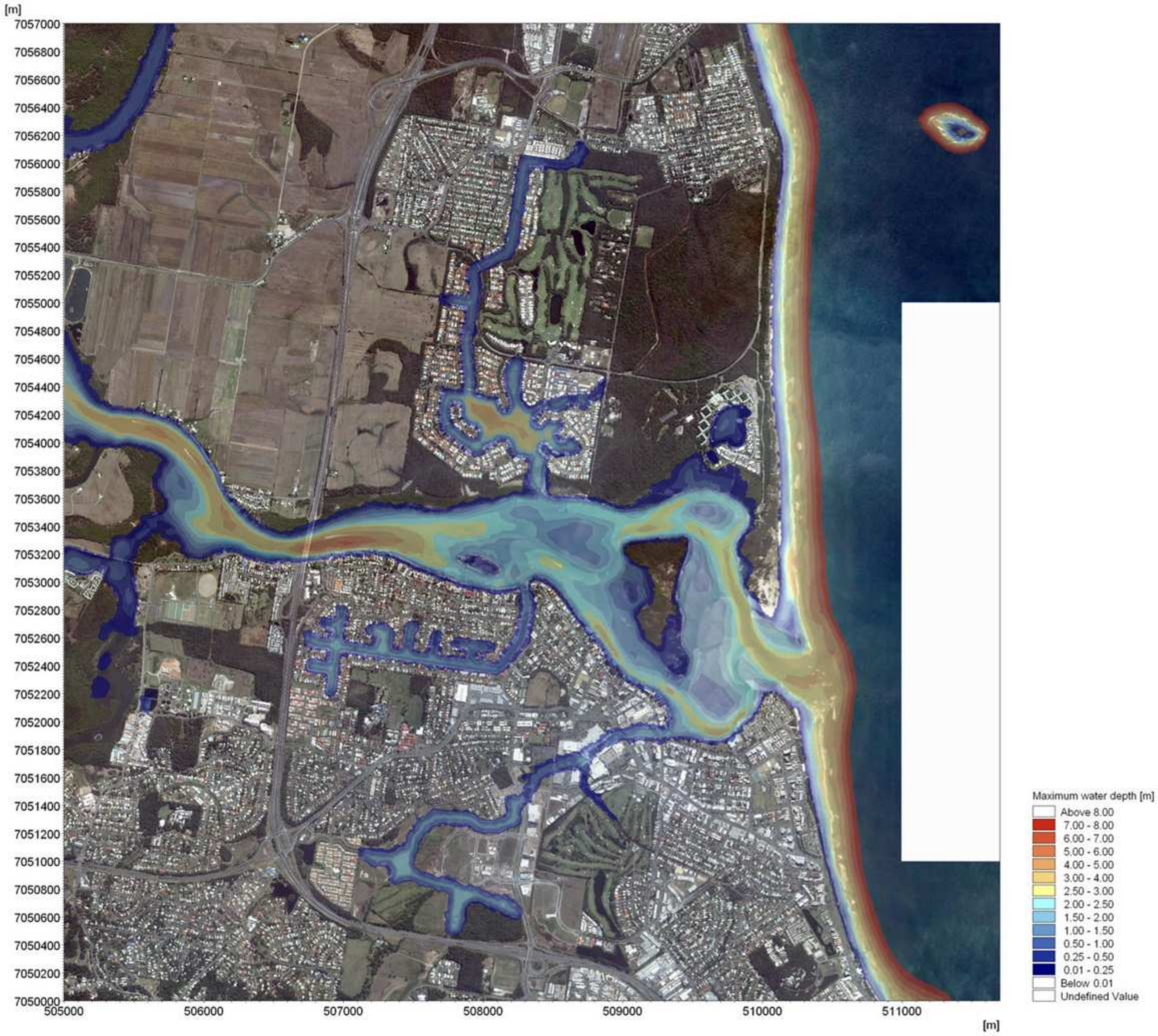

Figure A - 26 Scenario 2 inundation at Maroochydore (MSL).

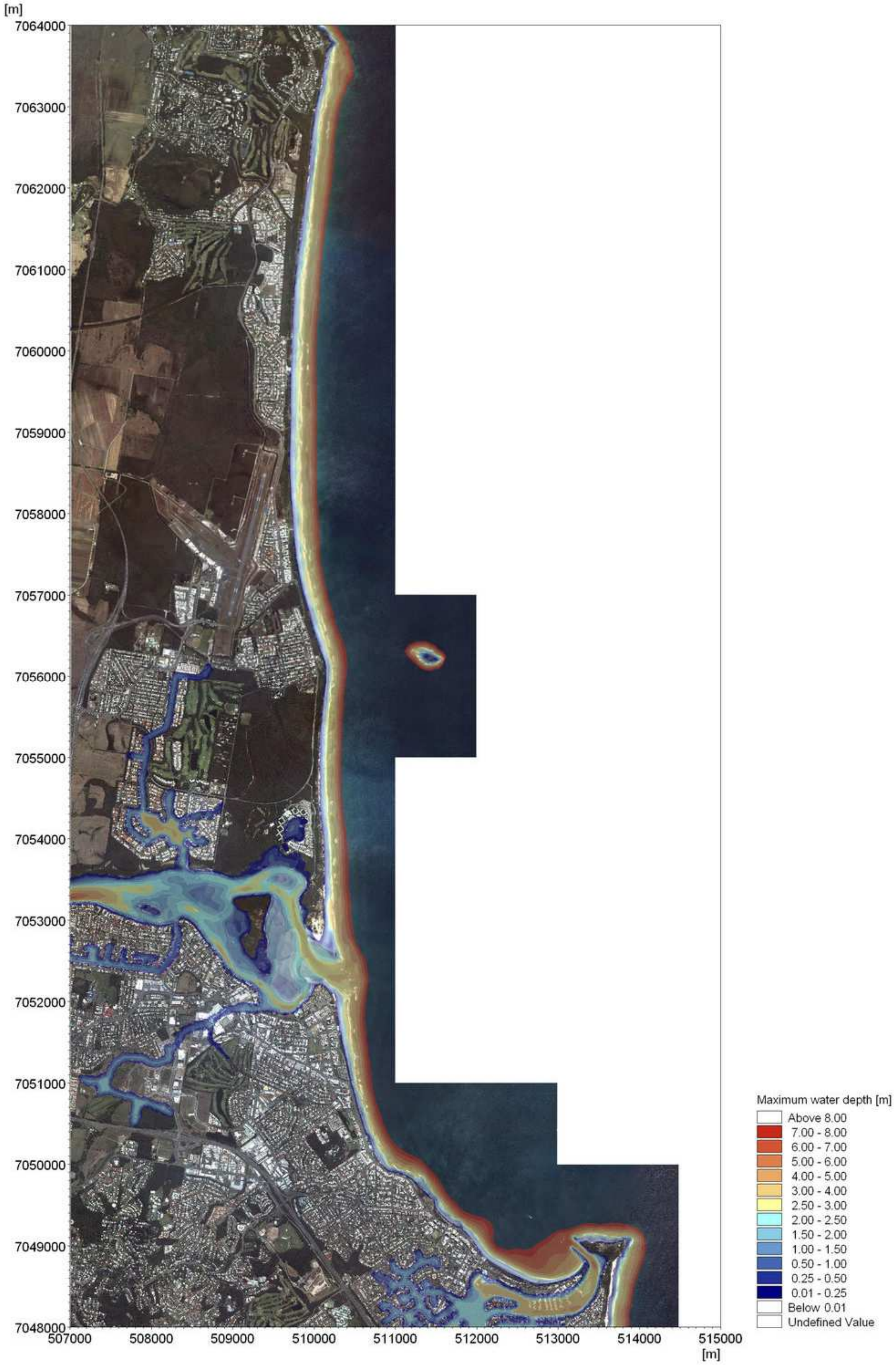

Figure A - 27 Scenario 2 inundation at Mooloolaba to Coolum (MSL).

Figure A - 28 Scenario 2 inundation at Coolum to Sunshine Beach (MSL).

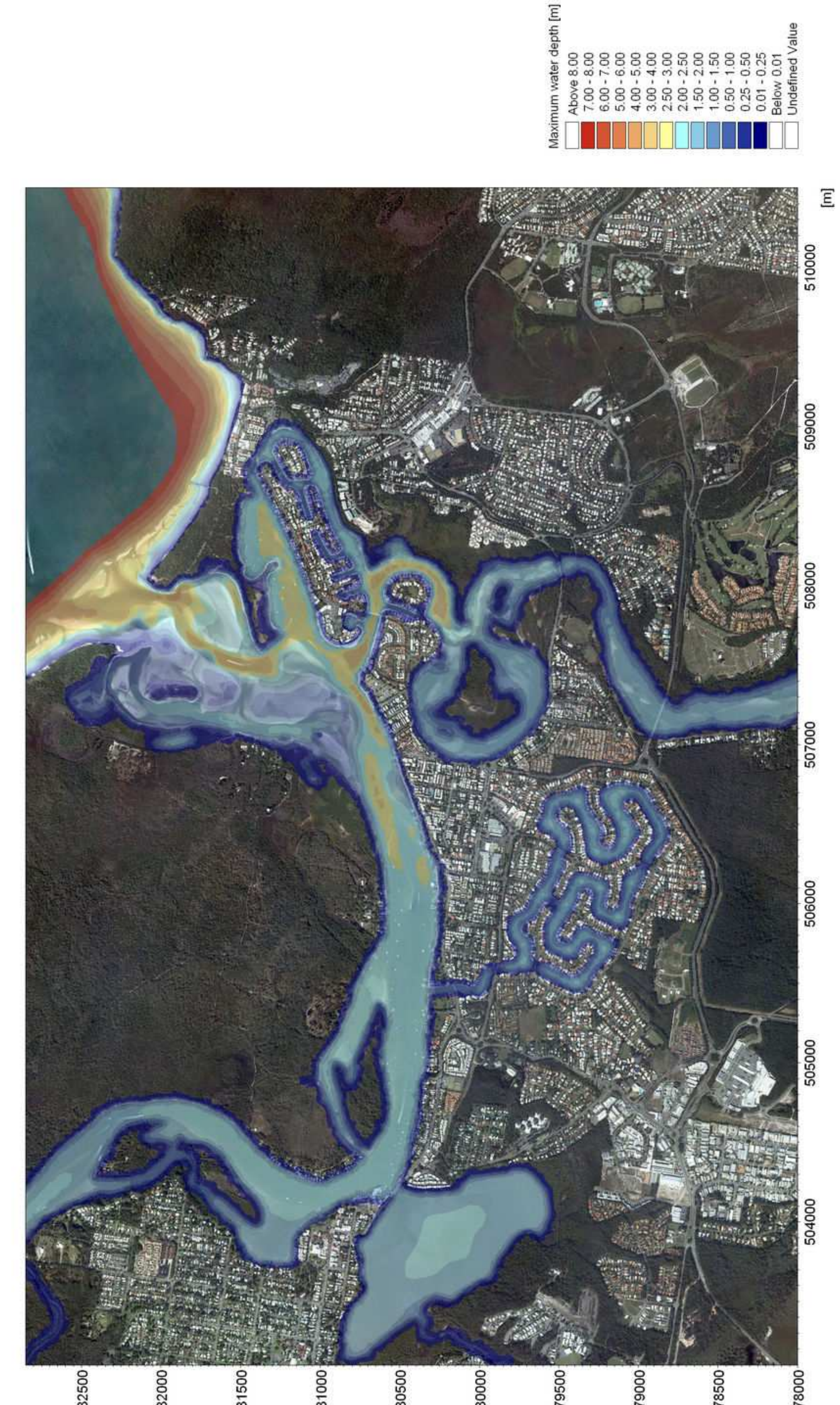

Figure A - 29 Scenario 2 inundation at Noosa Heads (MSL).

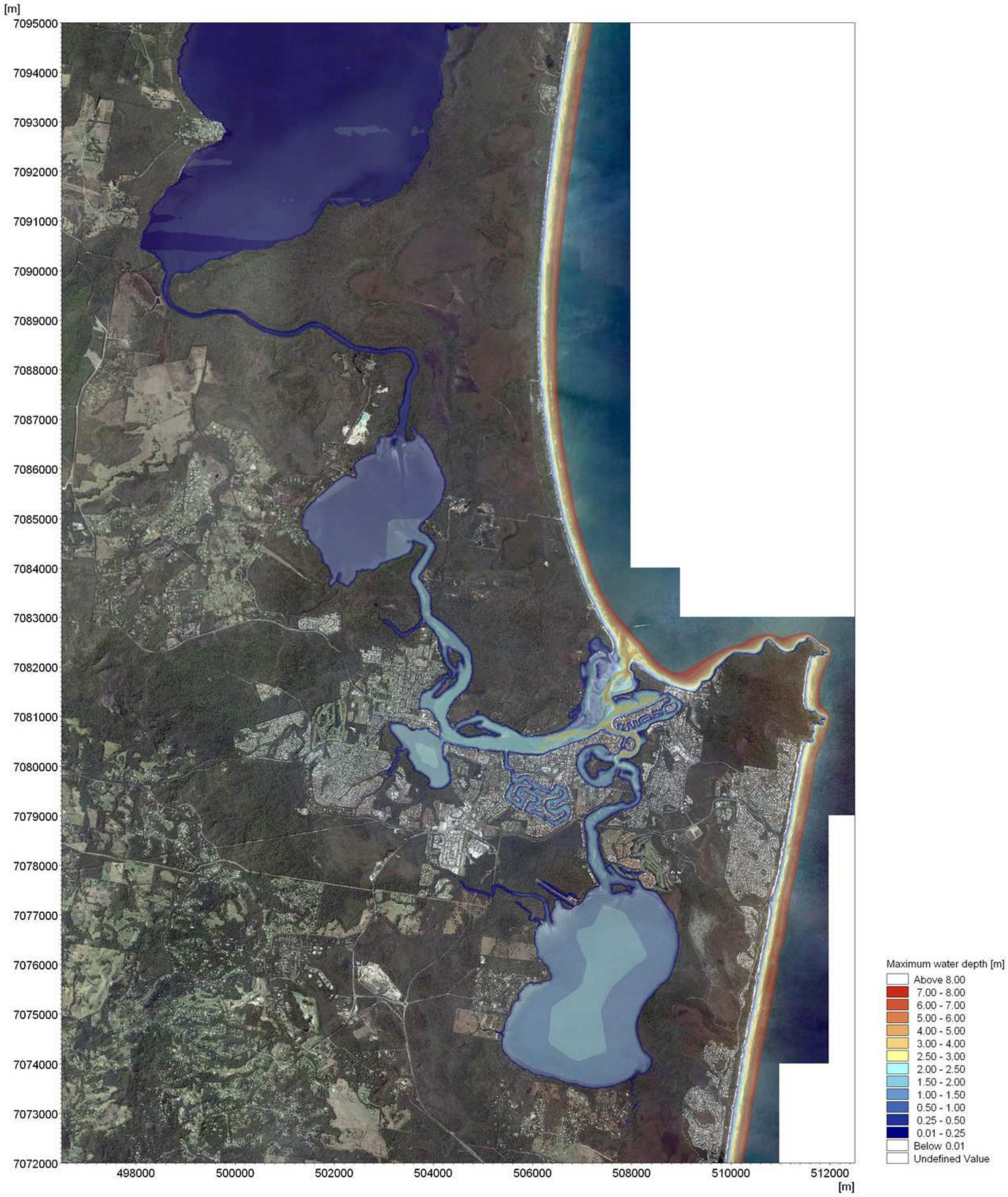

Figure A - 30 Scenario 2 inundation at Noosa to Teewah (MSL).

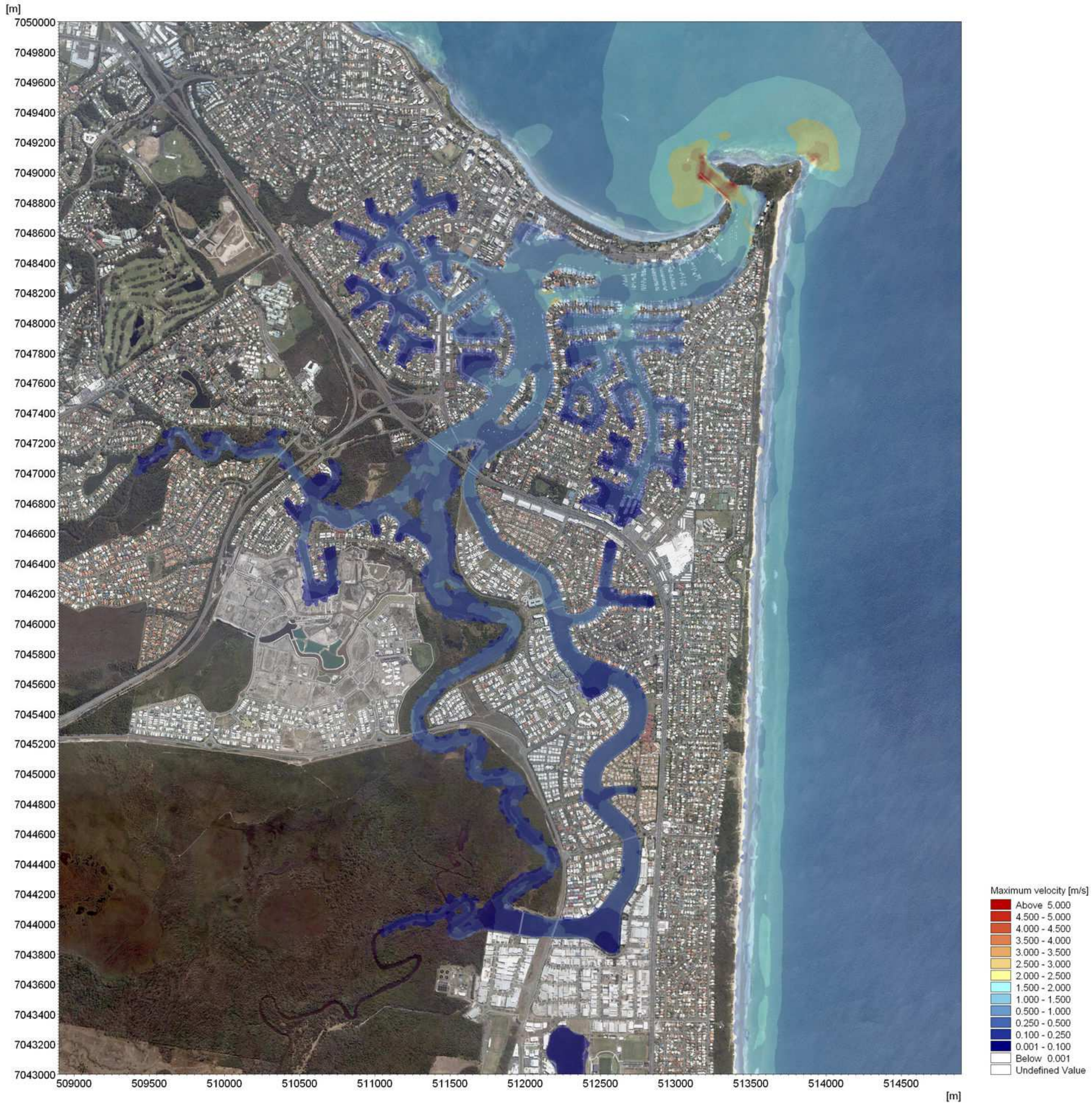

Figure A - 31 Scenario 2 maximum velocities at Mooloolaba (MSL).

Figure A - 32 Scenario 2 maximum velocities at Maroochydore (MSL).

Figure A - 33 Scenario 2 maximum velocities at Noosa Heads (MSL).

Figure A - 34 Scenario 2 inundation at Golden Beach (HAT).

Figure A - 35 Scenario 2 inundation at Warana to Caloundra, Scenario 1 (HAT).

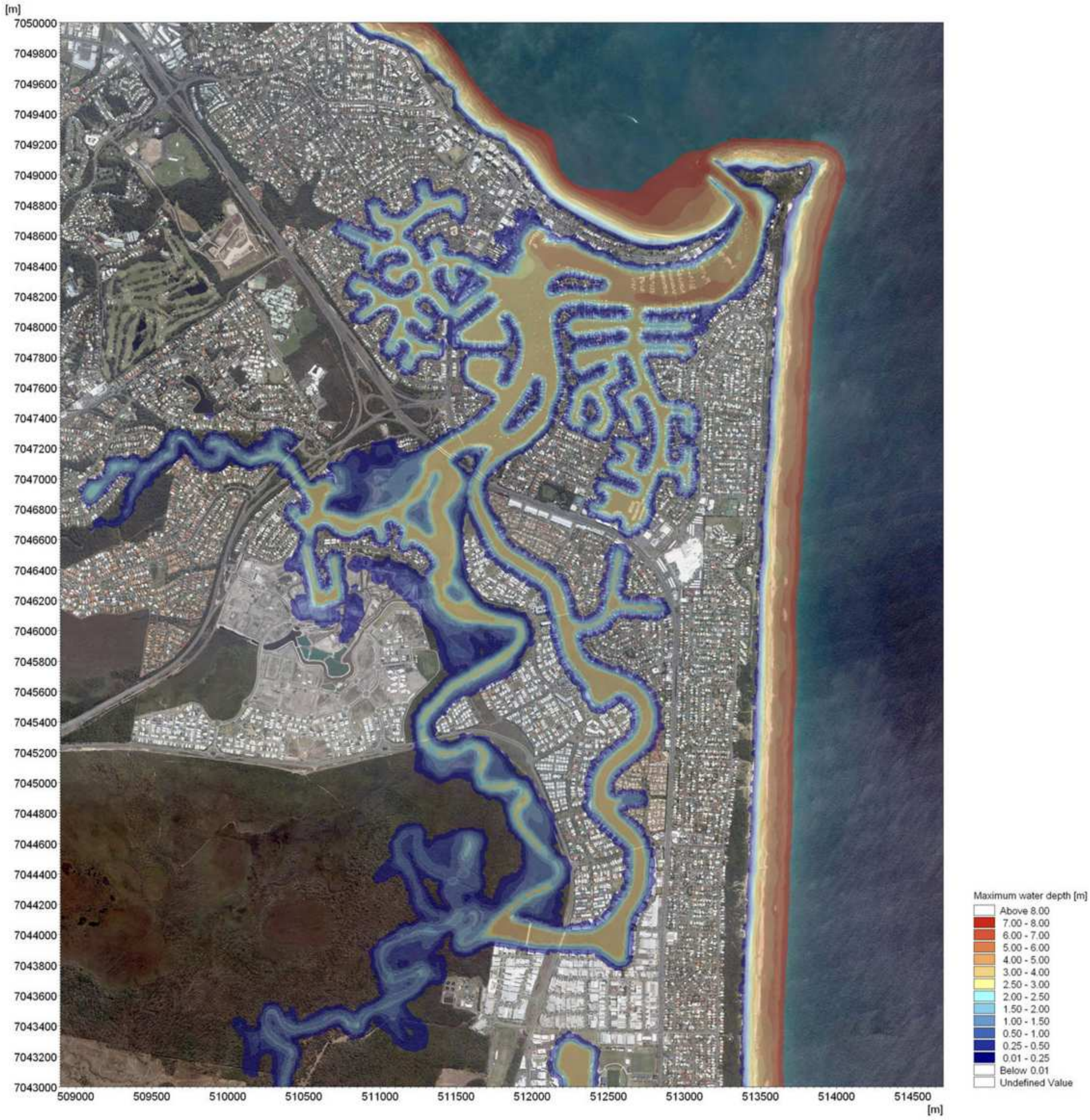

Figure A - 36 Scenario 2 inundation at Mooloolaba (HAT).

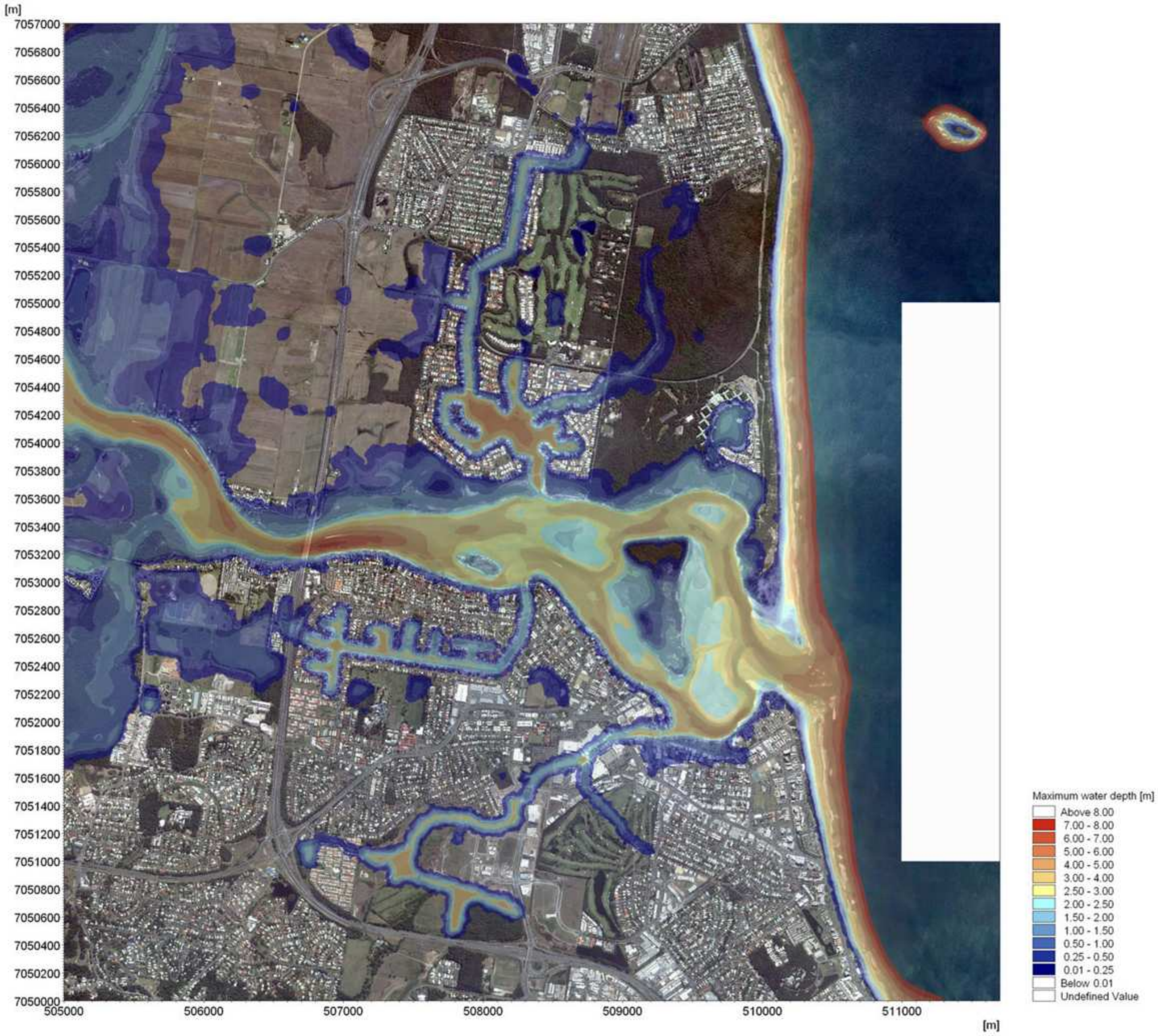

Figure A - 37 Scenario 2 inundation at Maroochydore (HAT).

Figure A - 38 Scenario 2 inundation at Mooloolaba to Coolum (HAT).

Figure A - 39 Scenario 2 inundation at Coolum to Sunshine Beach (HAT).

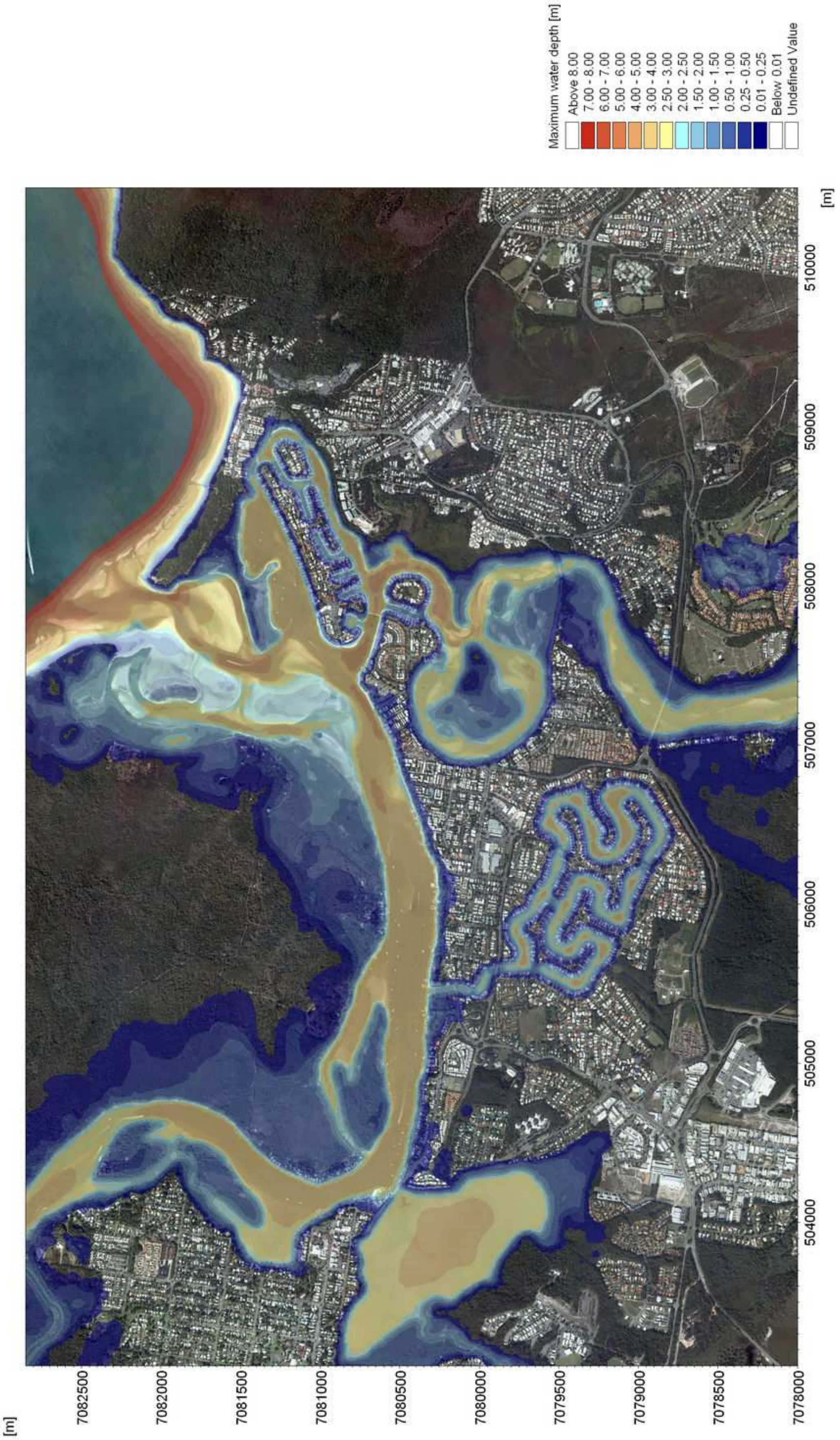

Figure A - 40 Scenario 2 inundation at Noosa Heads (HAT).

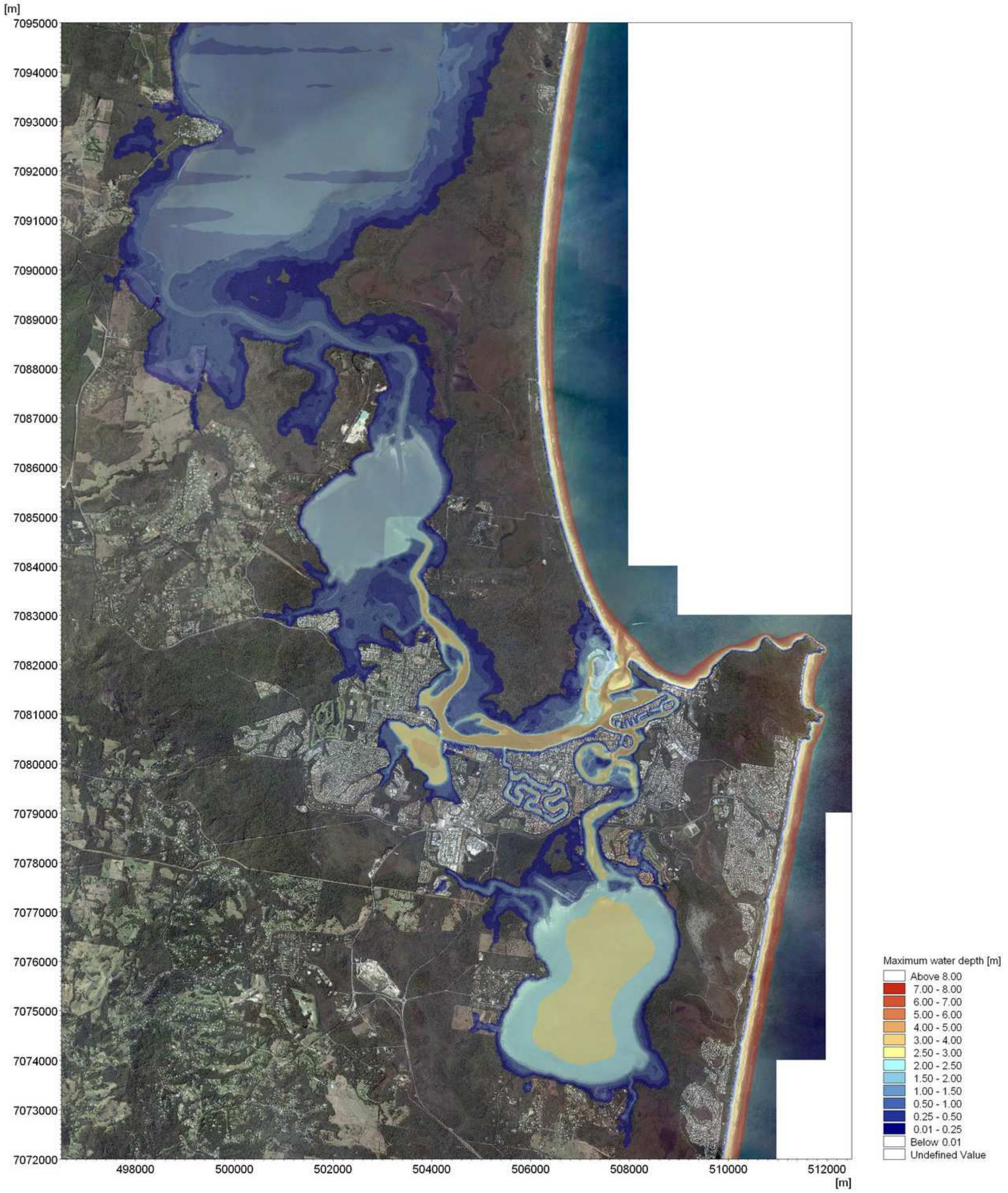

Figure A - 41 Scenario 2 inundation at Noosa to Teewah (HAT).

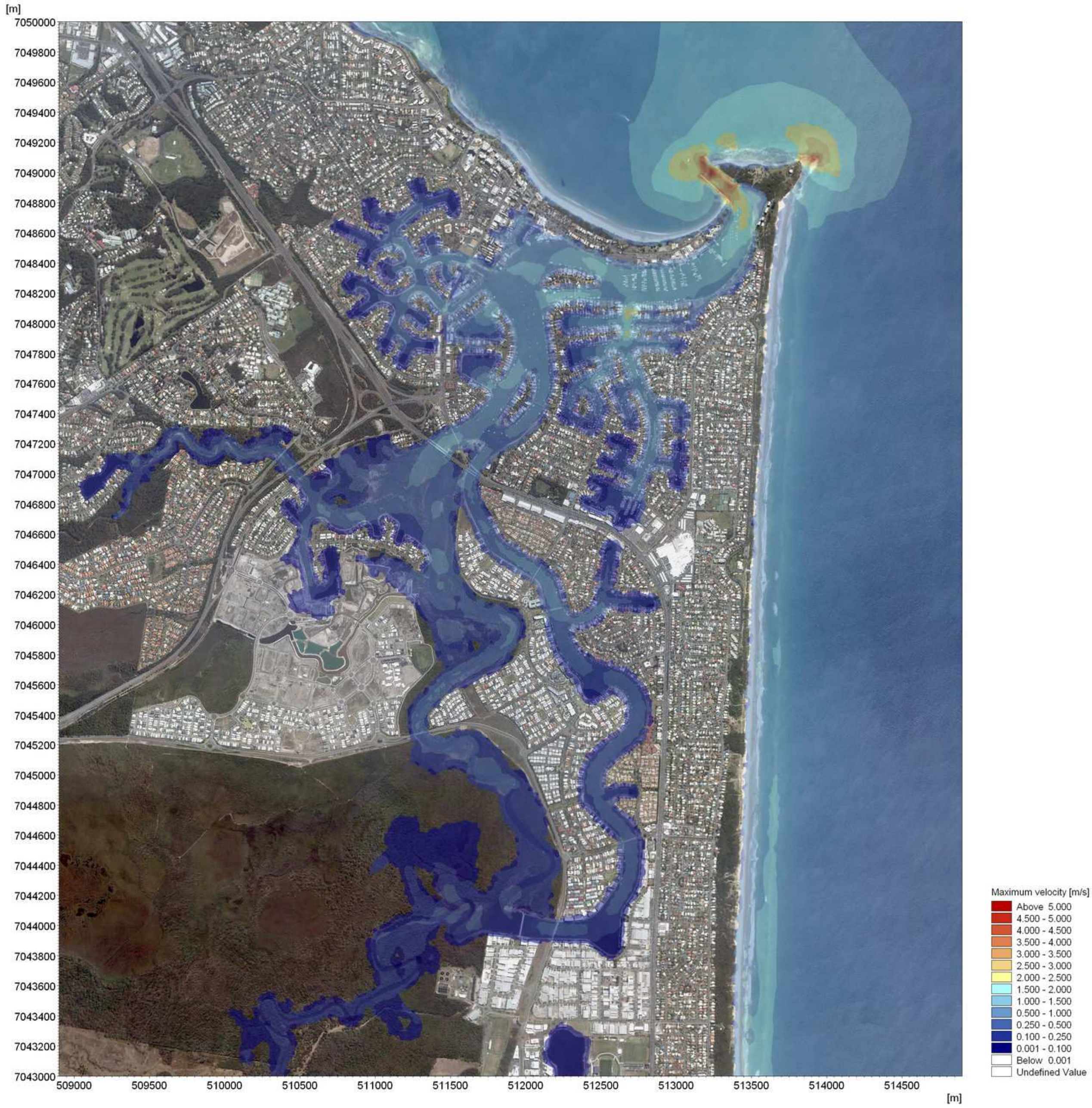

Figure A - 42 Scenario 2 maximum velocities at Mooloolaba (HAT).

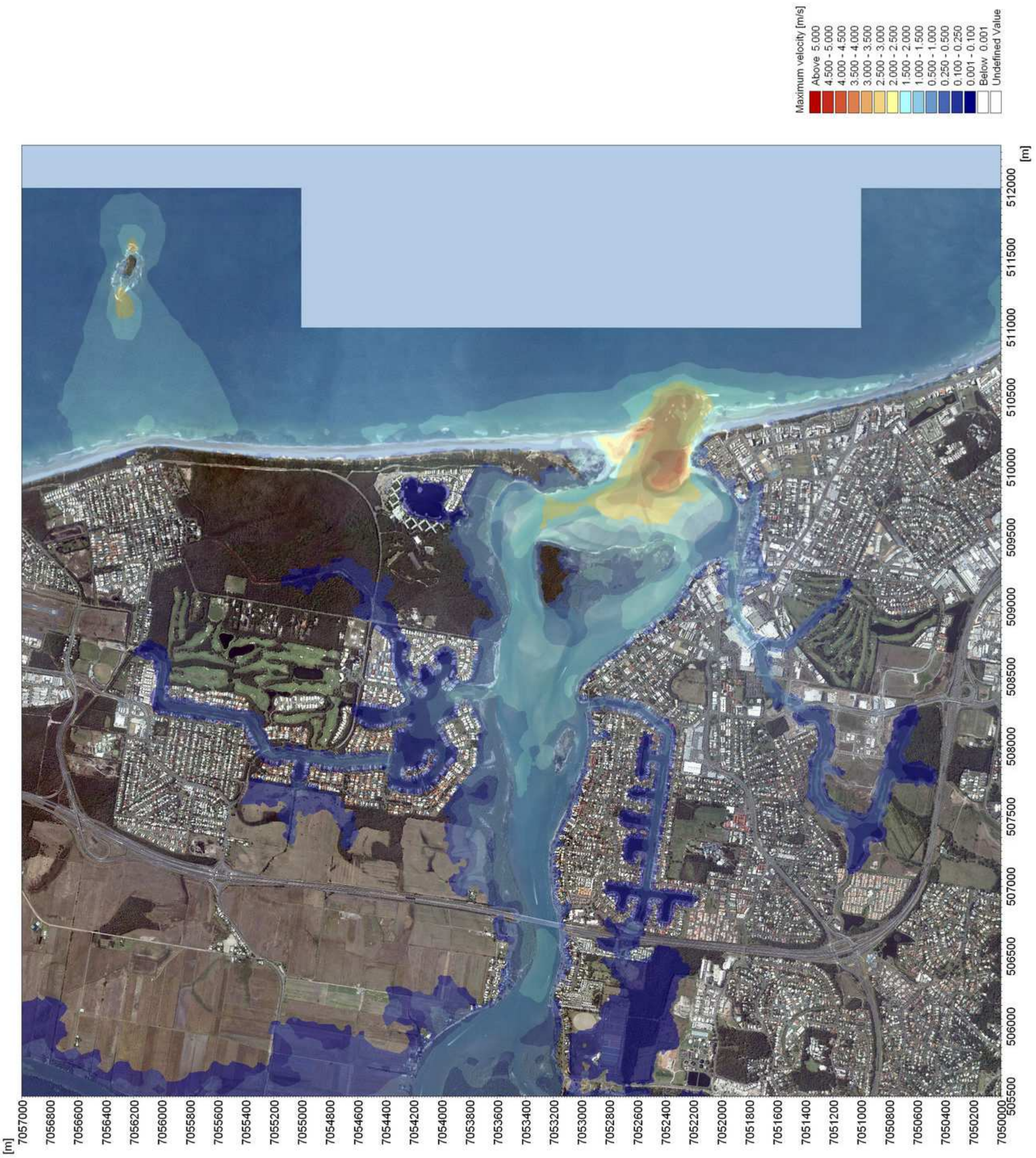

Figure A - 43 Scenario 2 maximum velocities at Maroochydore (HAT).

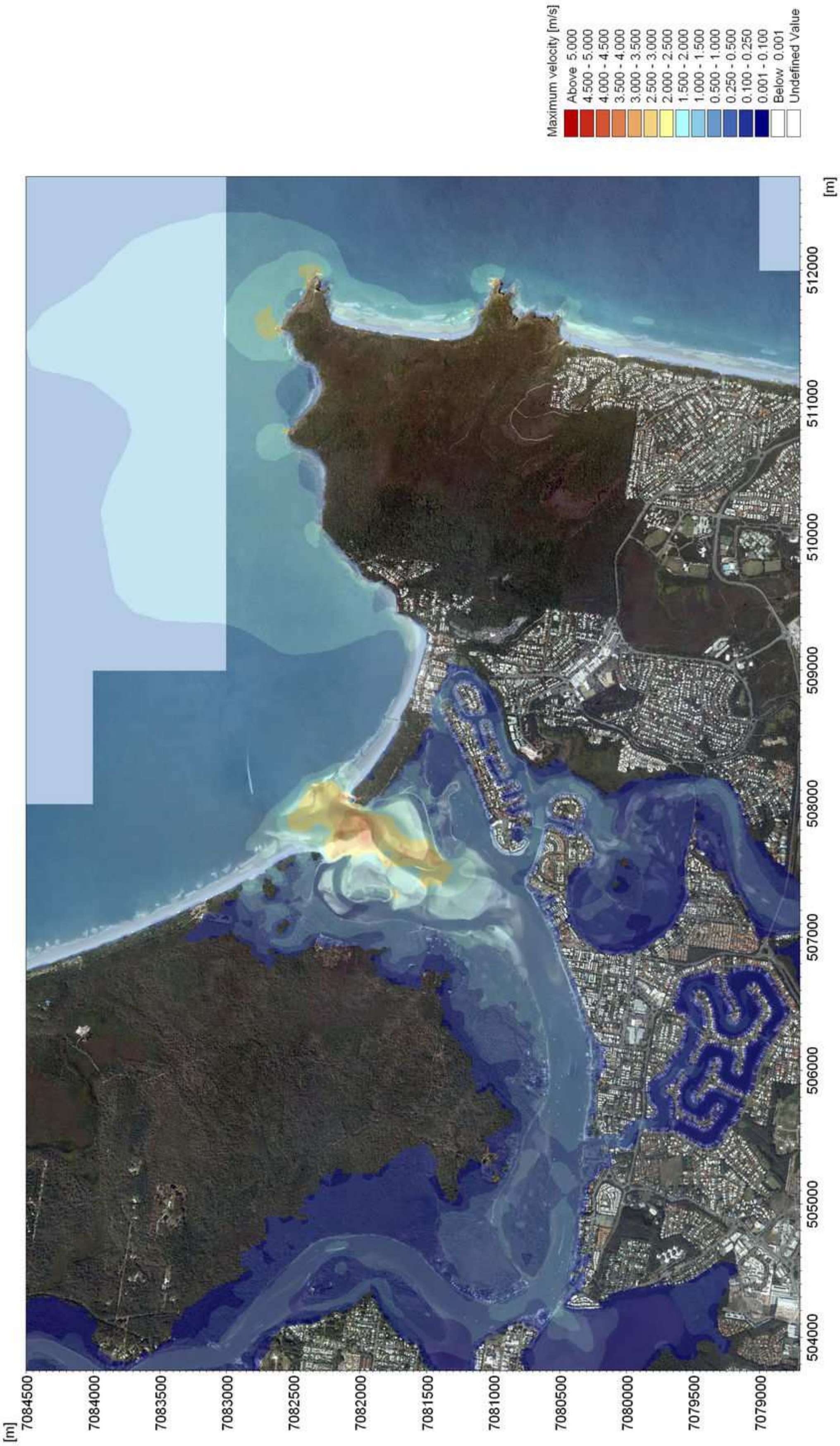

Figure A - 44 Scenario 2 maximum velocities at Noosa Heads (HAT).

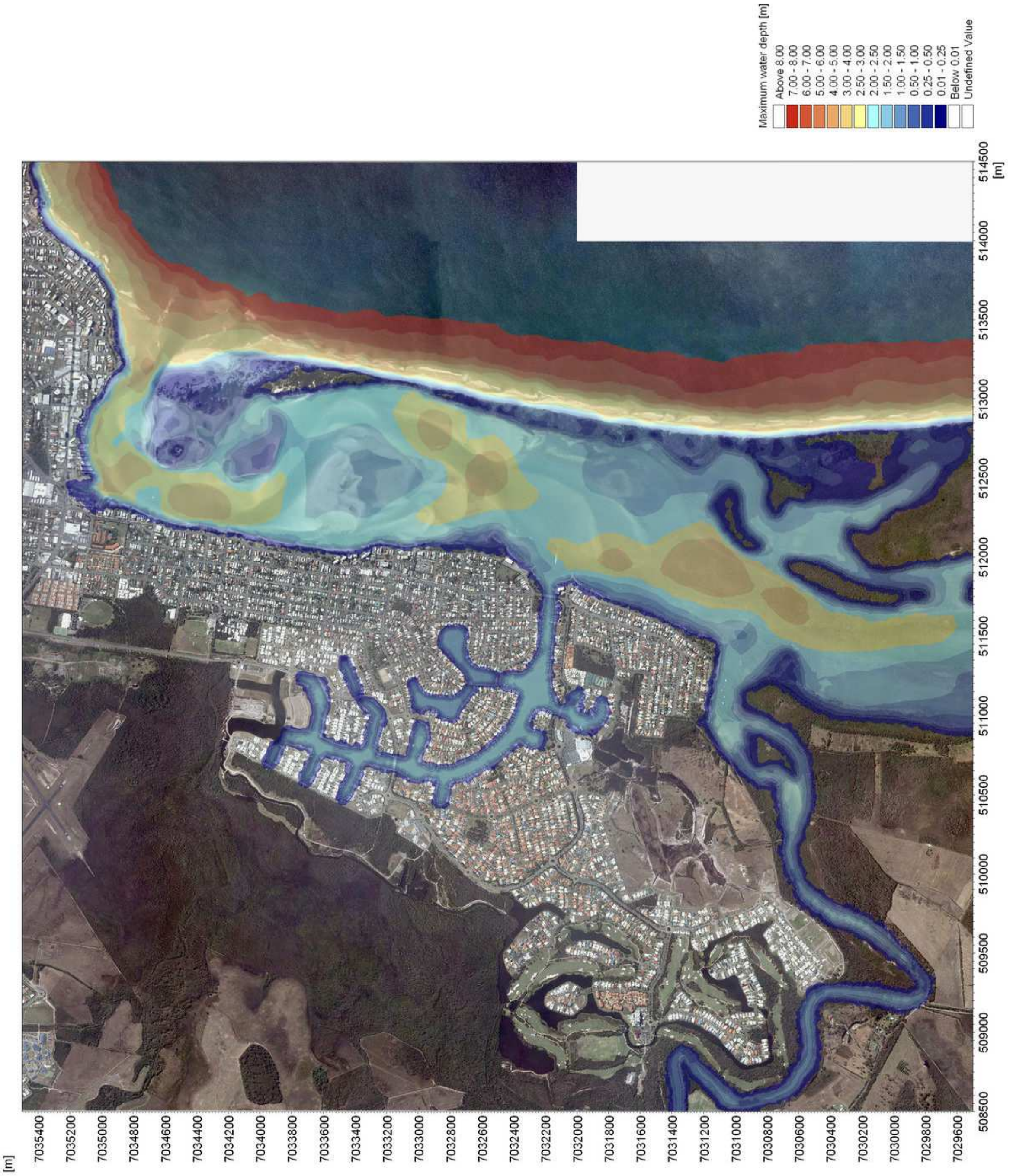

Figure A - 45 Scenario 3 inundation at Golden Beach (MSL).

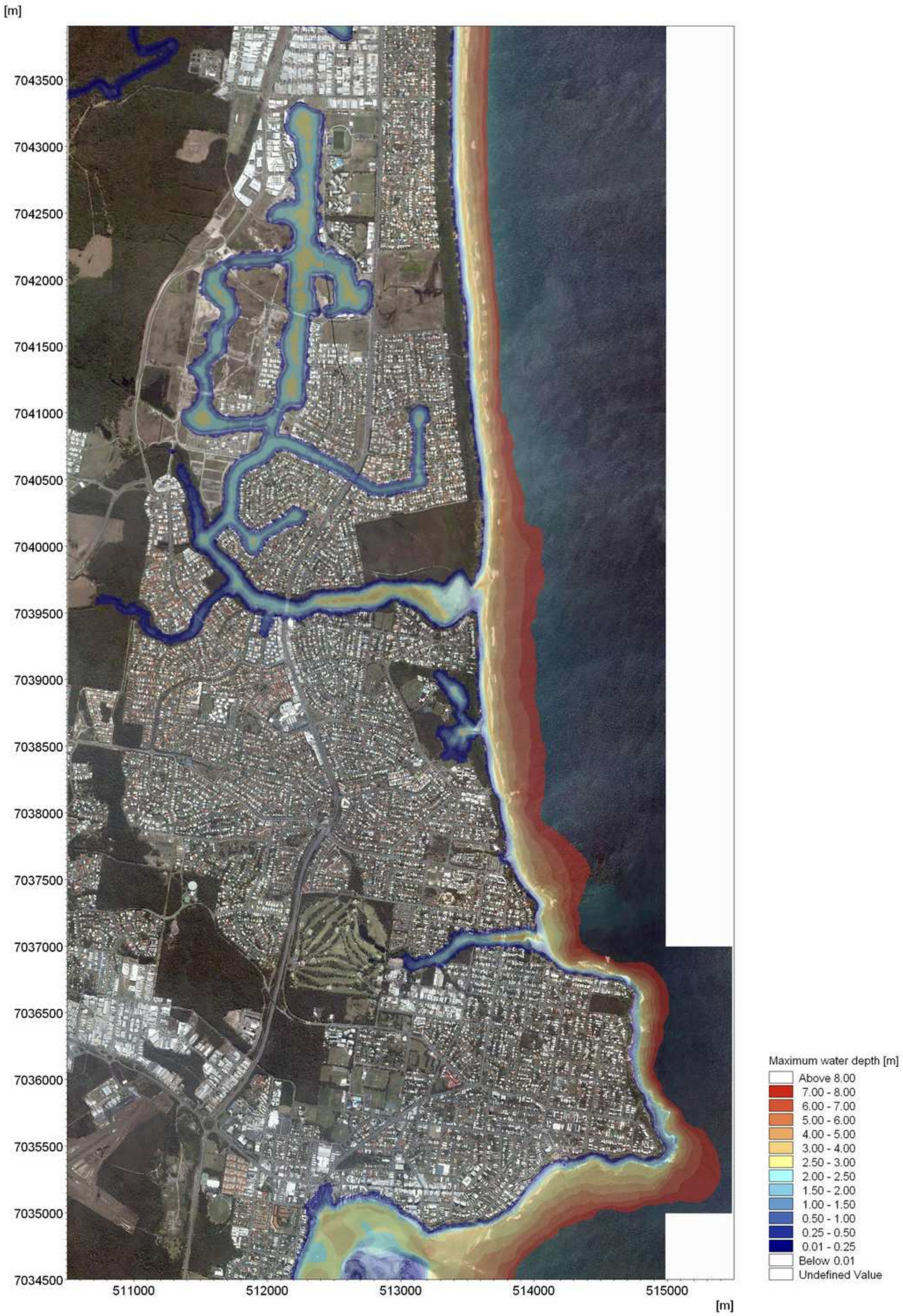

Figure A - 46 Scenario 3 inundation at Warana to Caloundra, Scenario 1 (MSL).

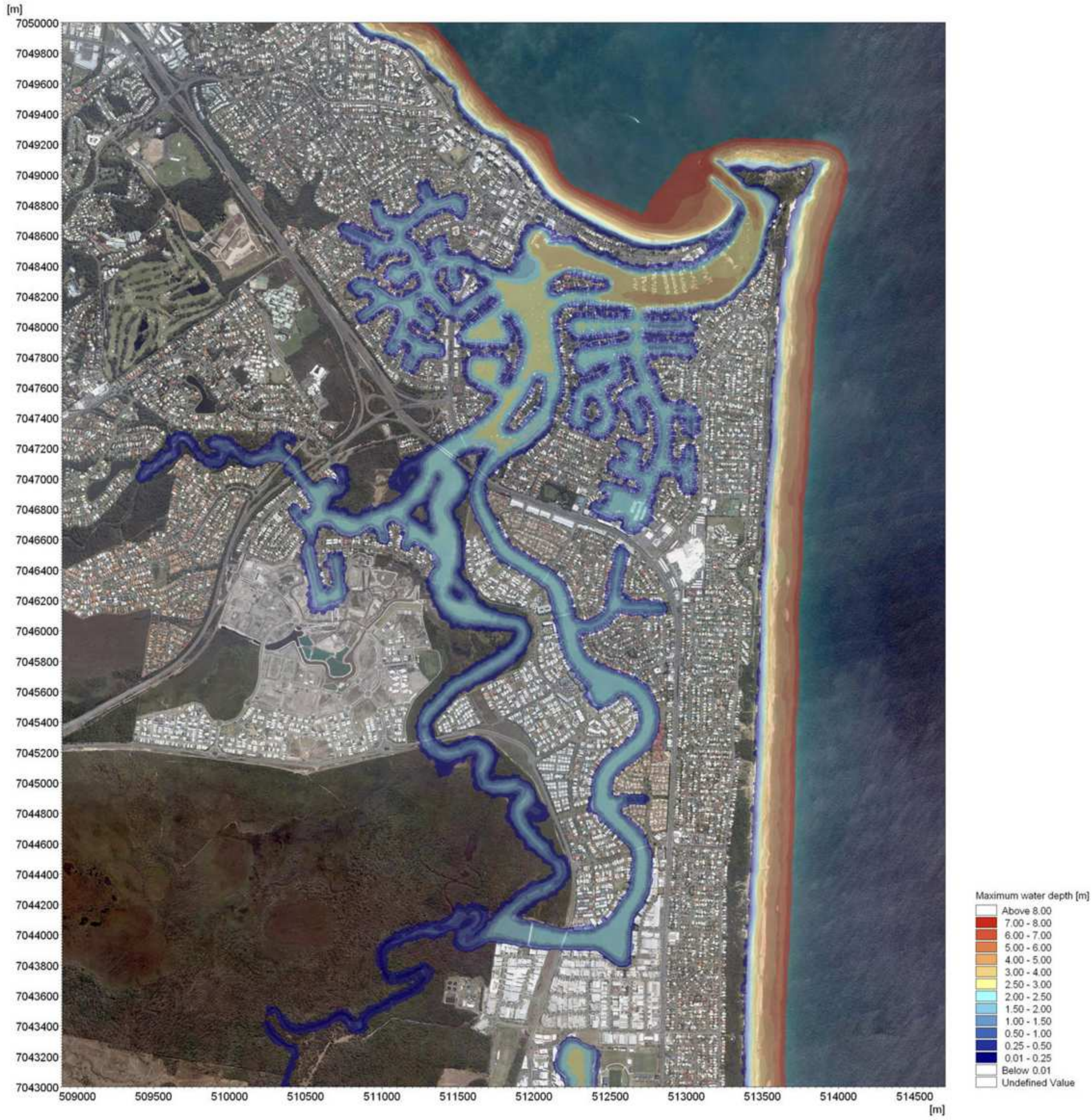

Figure A - 47 Scenario 3 inundation at Mooloolaba (MSL).

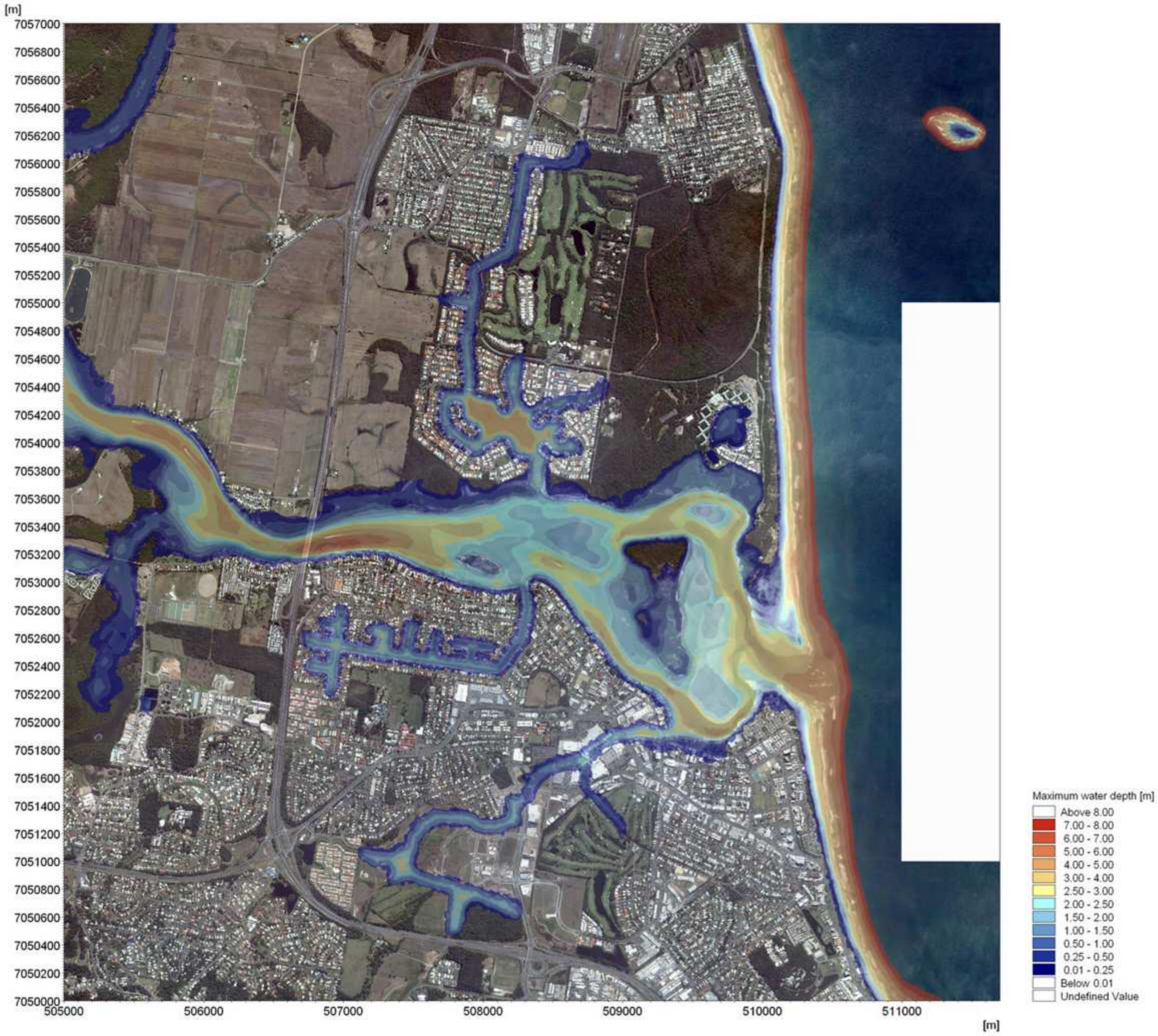

Figure A - 48 Scenario 3 inundation at Maroochydore (MSL).

Figure A - 49 Scenario 3 inundation at Mooloolaba to Coolum (MSL).

Figure A - 50 Scenario 3 inundation at Coolum to Sunshine Beach (MSL).

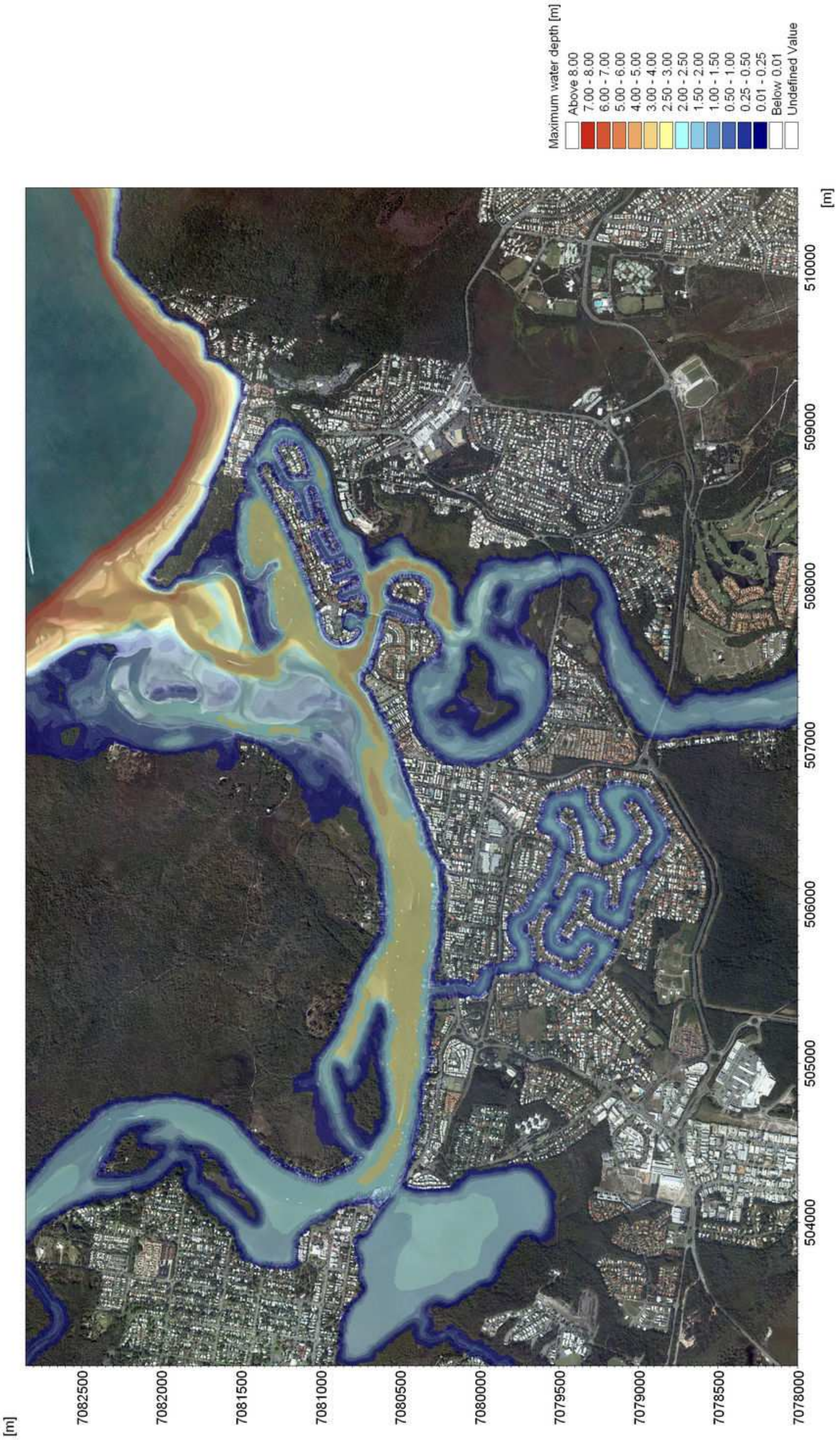

Figure A - 51 Scenario 3 inundation at Noosa Heads (MSL).

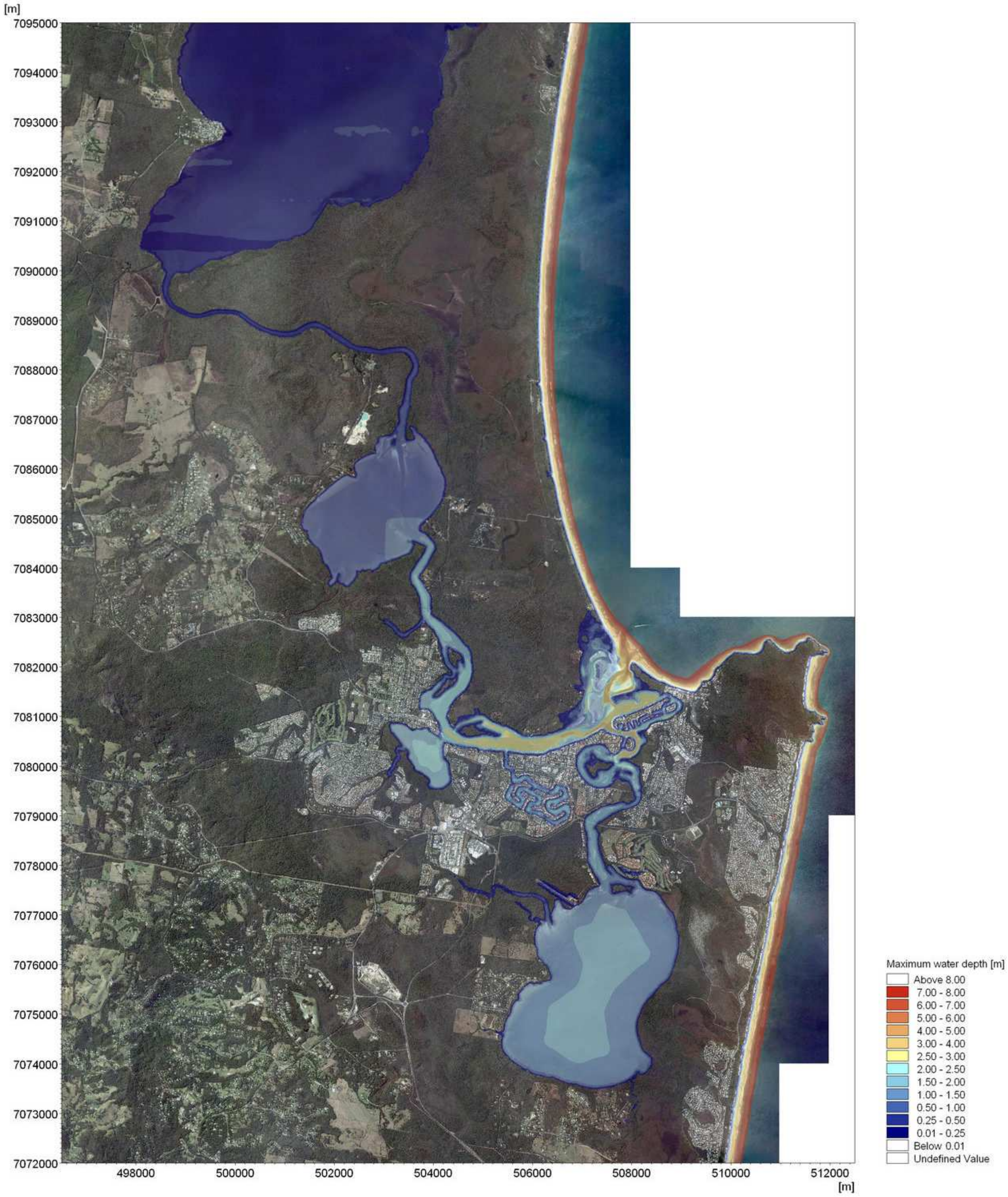

Figure A - 52 Scenario 3 inundation at Noosa to Teewah (MSL).

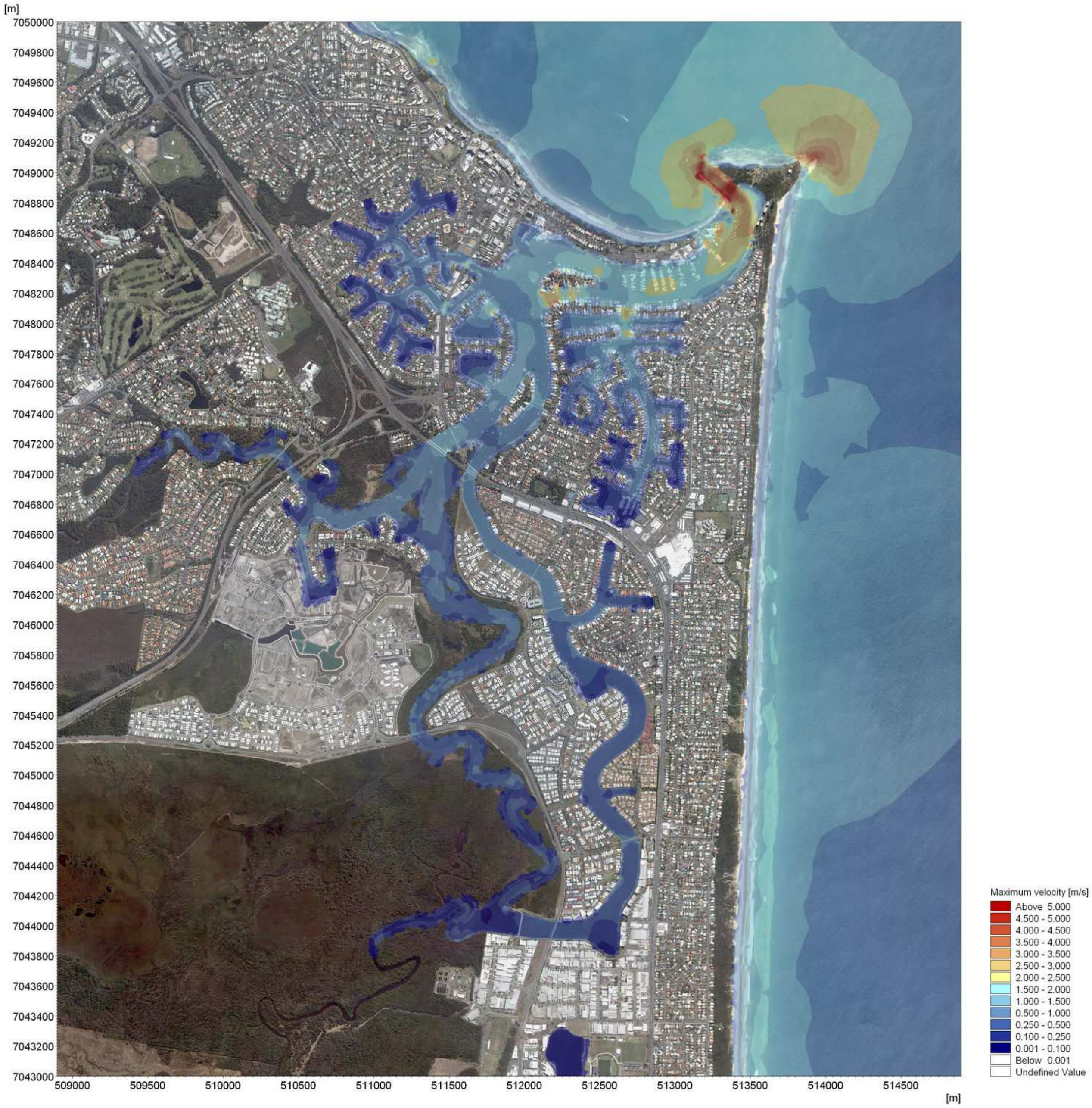

Figure A - 53 Scenario 3 maximum velocities at Mooloolaba (MSL).

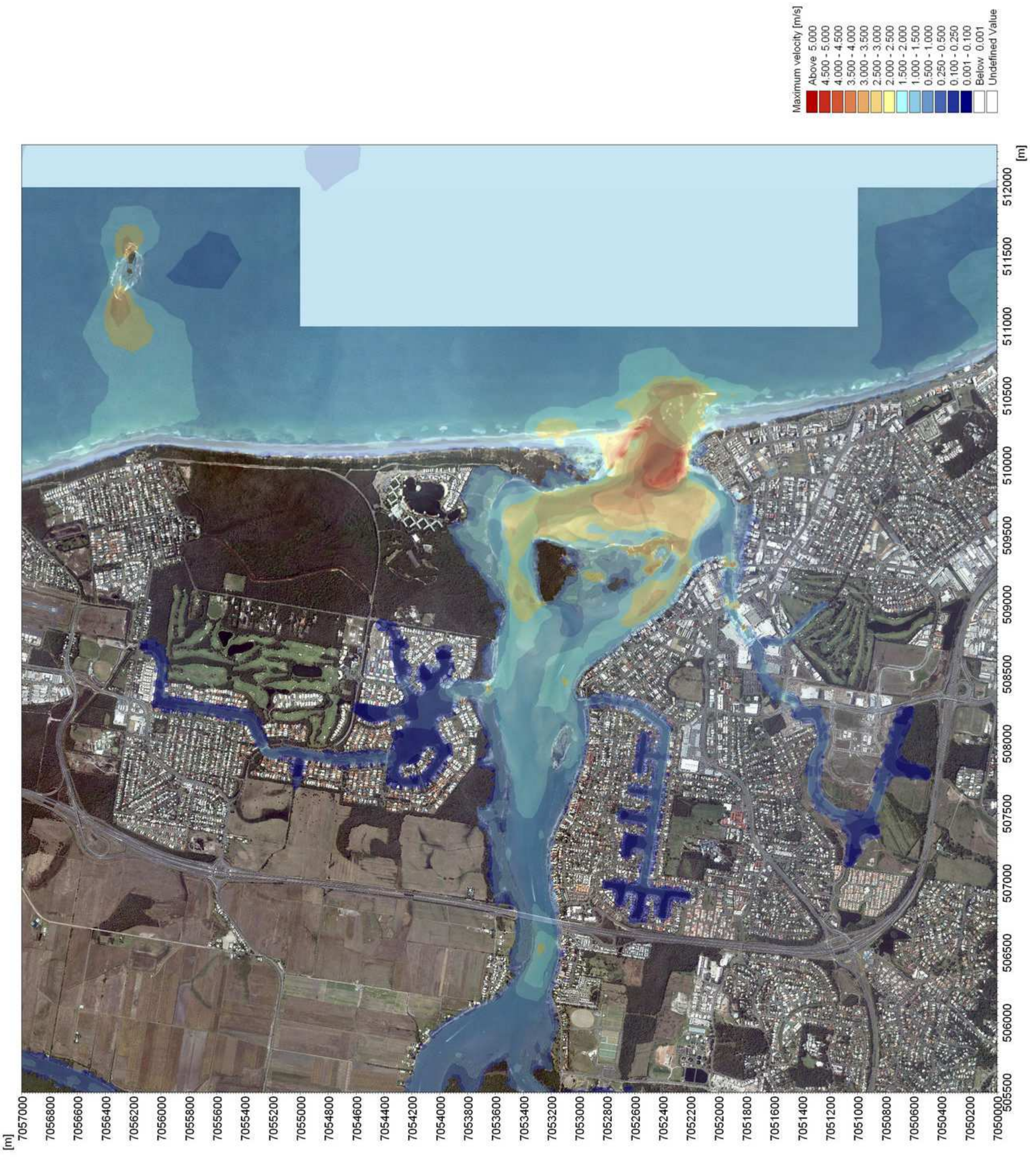

Figure A - 54 Scenario 3 maximum velocities at Maroochydore (MSL).

Figure A - 55 Scenario 3 maximum velocities at Noosa Heads (MSL).

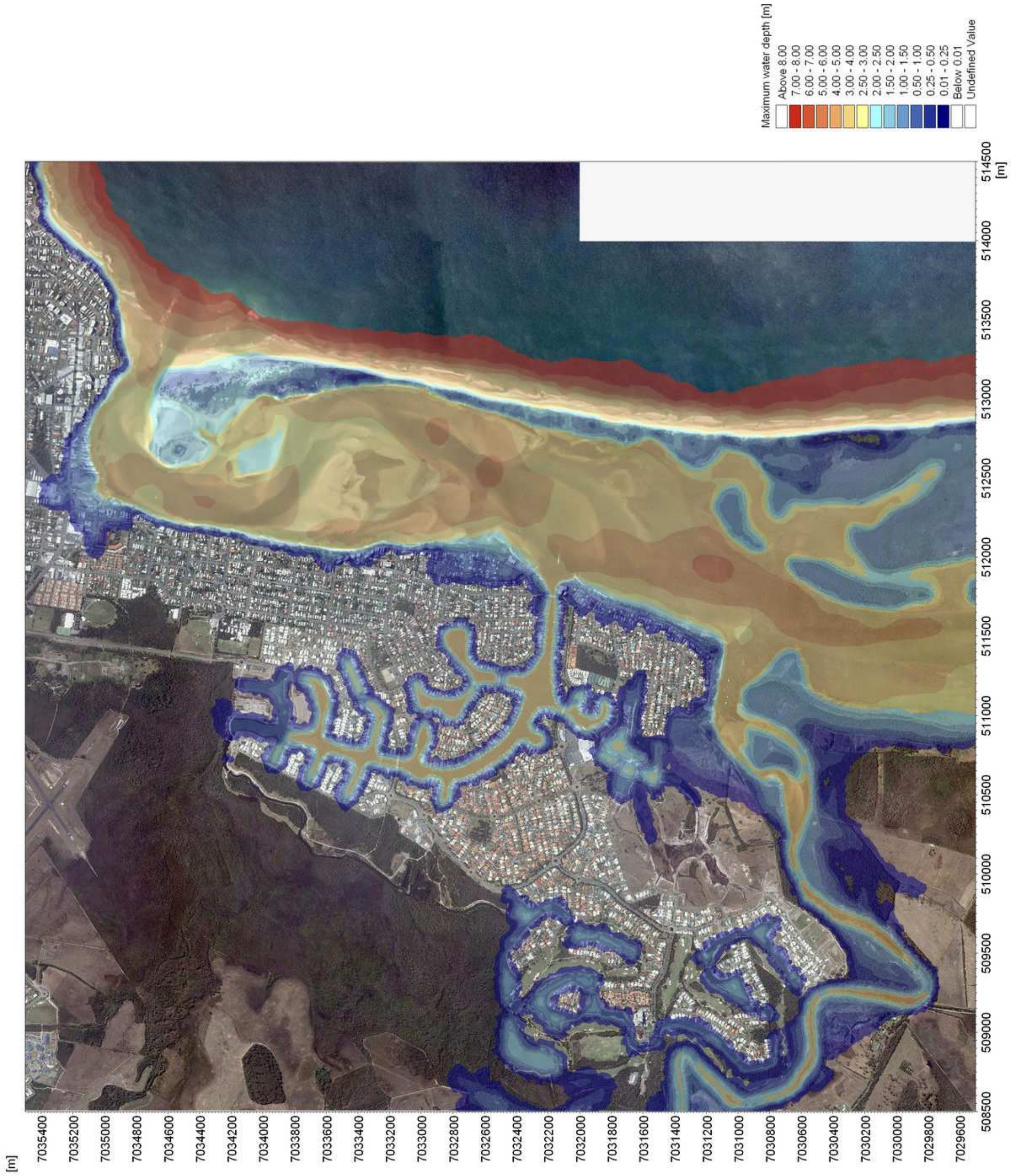

Figure A - 56 Scenario 3 inundation at Golden Beach (HAT).

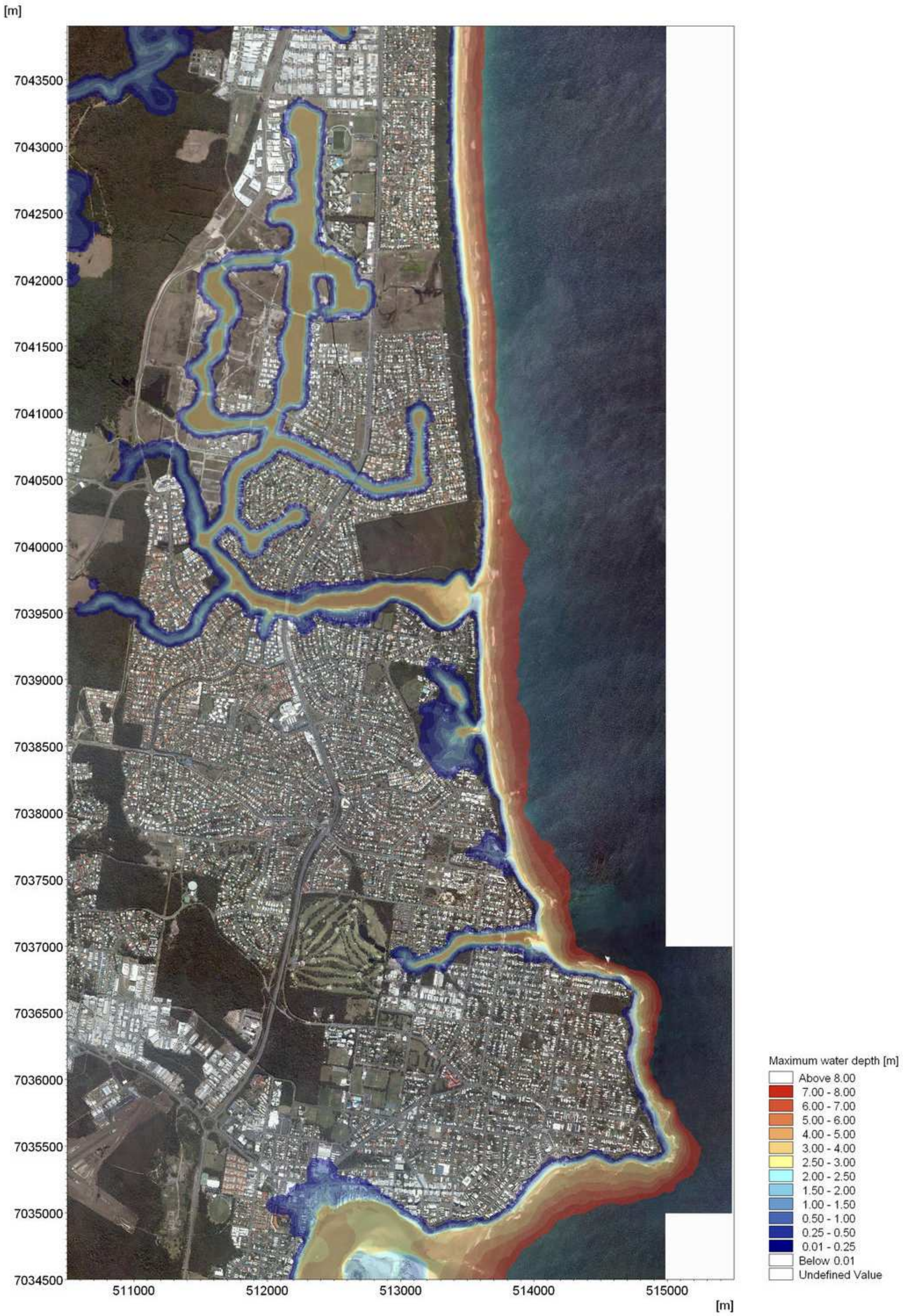

Figure A - 57 Scenario 3 inundation at Warana to Caloundra, Scenario 1 (HAT).

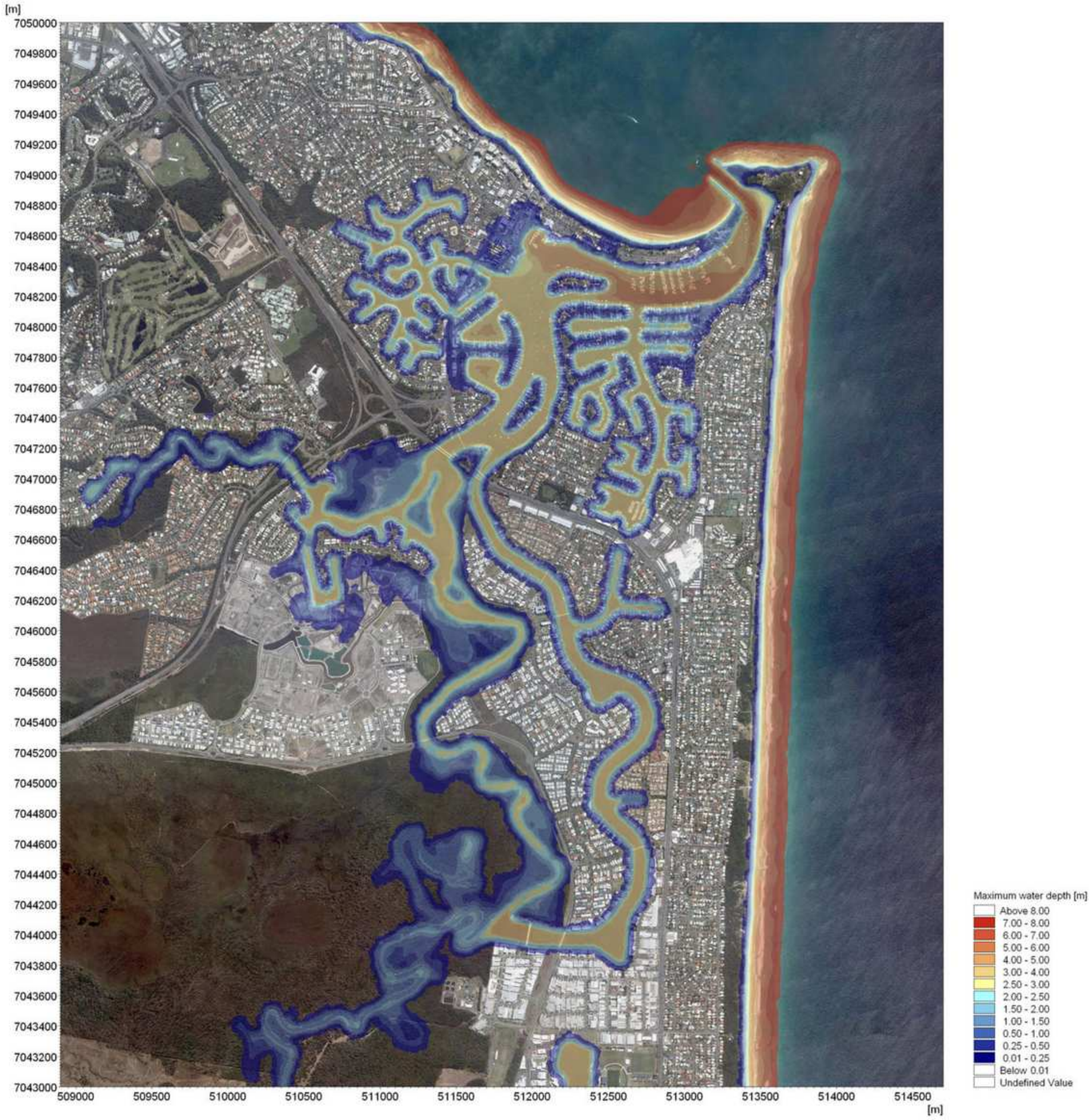

Figure A - 58 Scenario 3 inundation at Mooloolaba (HAT).

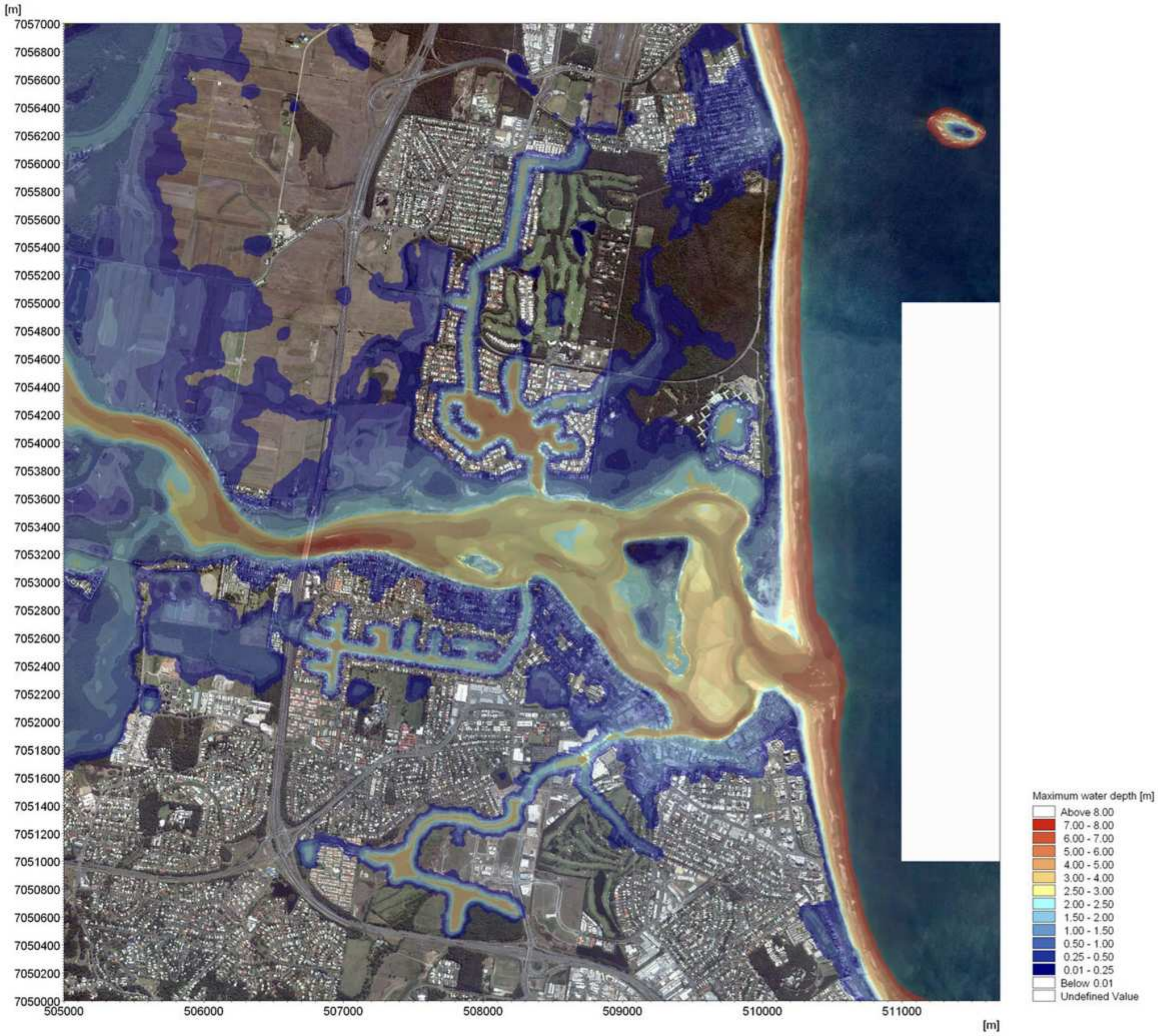

Figure A - 59 Scenario 3 inundation at Maroochydore (HAT).

Figure A - 60 Scenario 3 inundation at Mooloolaba to Coolum (HAT).

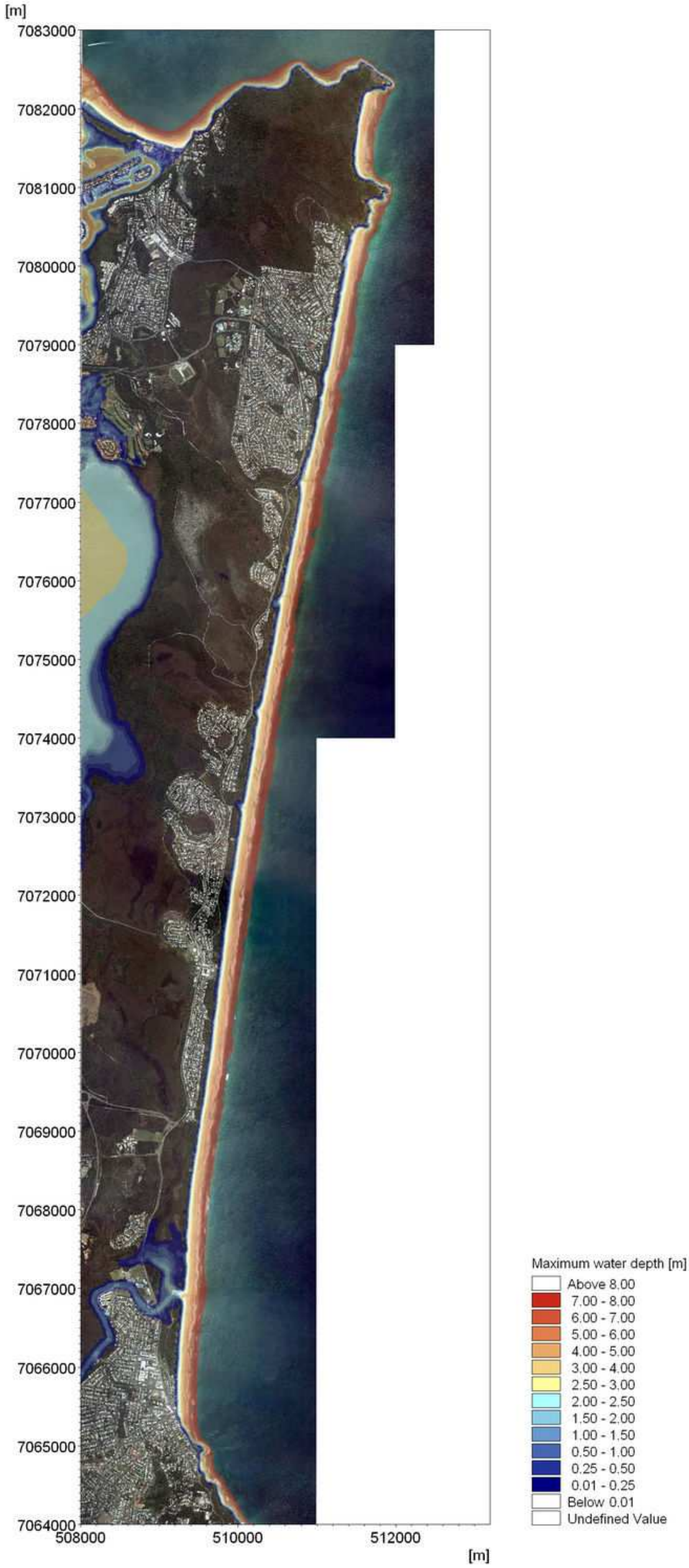

Figure A - 61 Scenario 3 inundation at Coolum to Sunshine Beach (HAT).

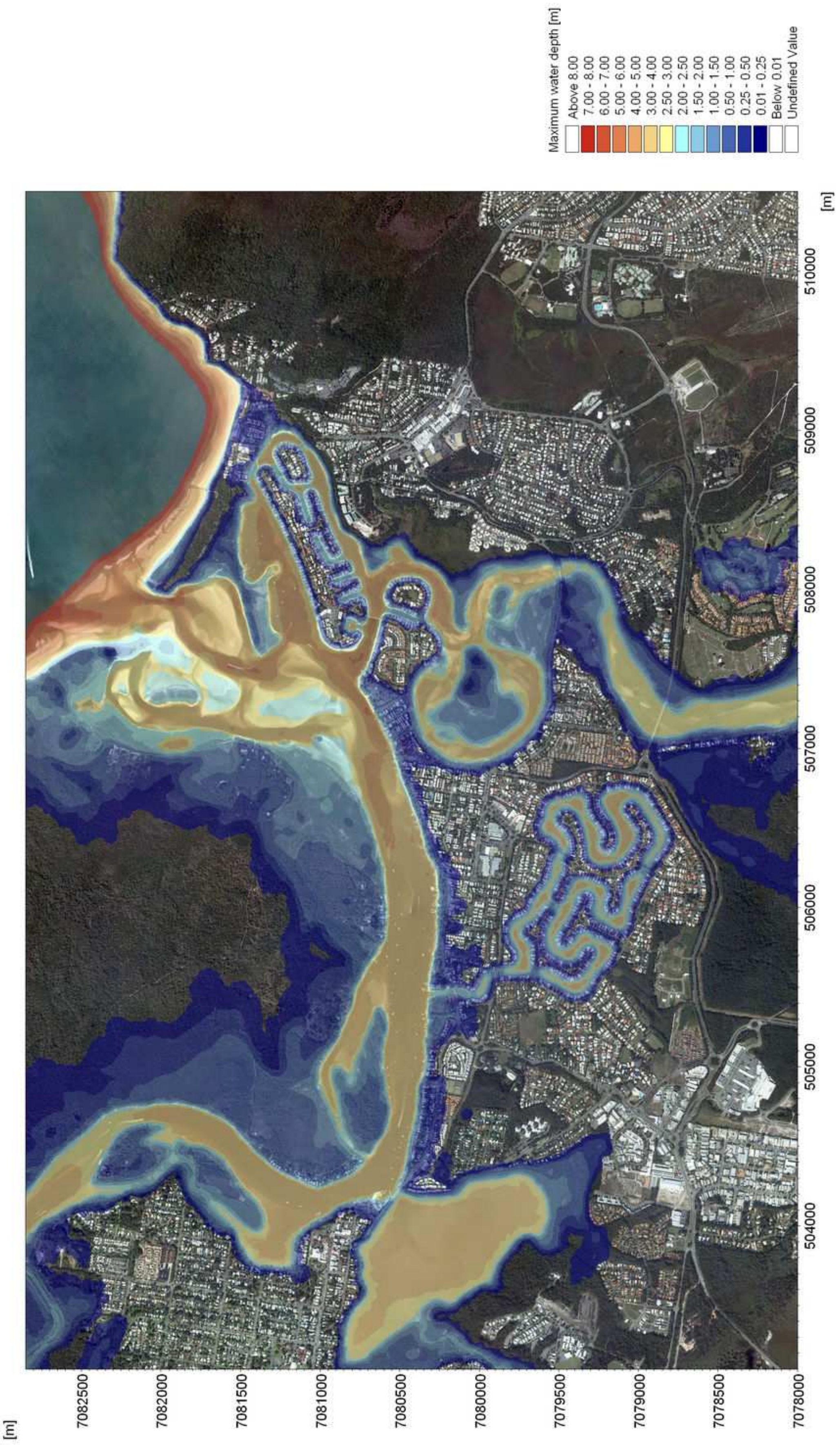

Figure A - 62 Scenario 3 inundation at Noosa Heads (HAT).

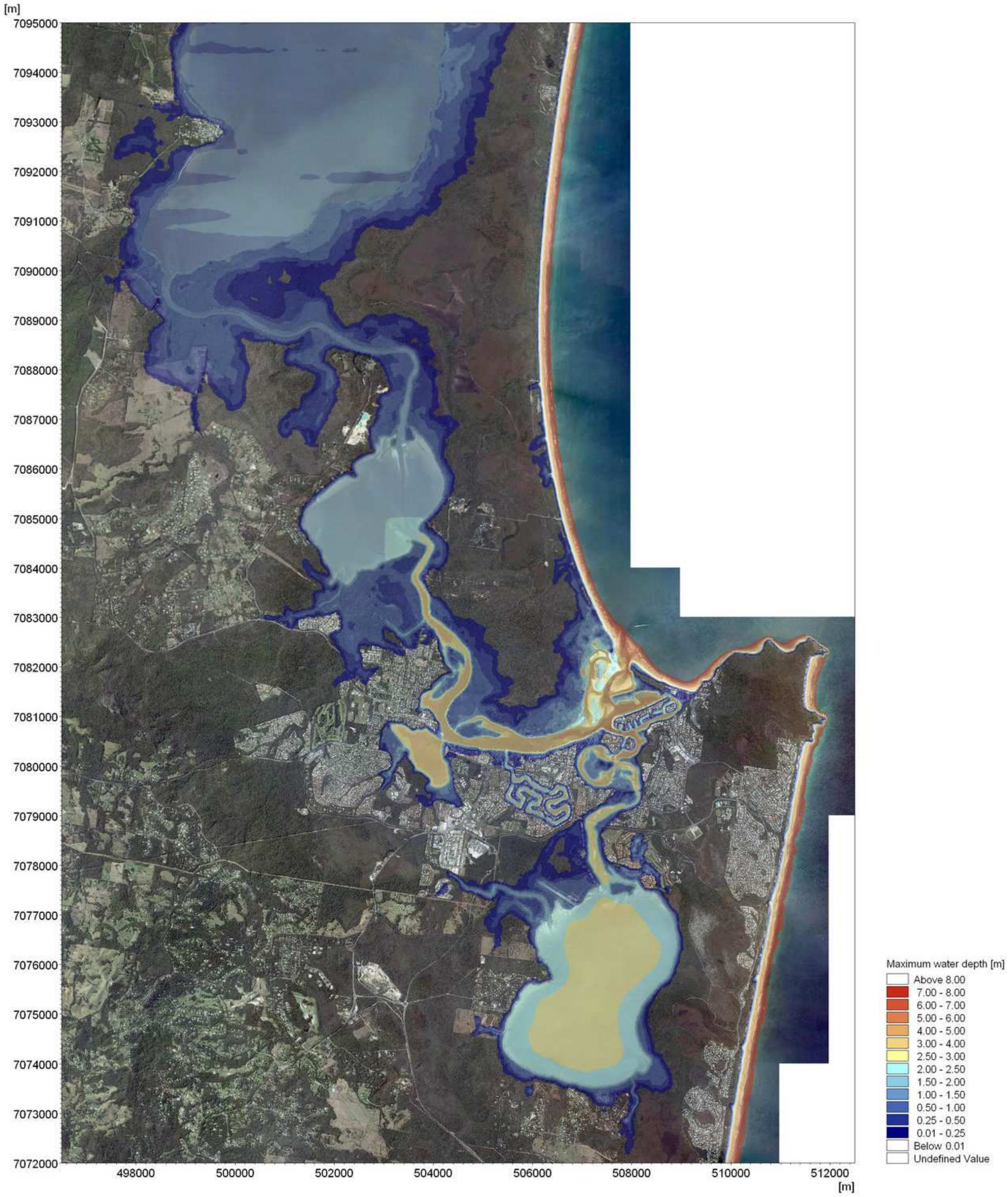

Figure A - 63 Scenario 3 inundation at Noosa to Teewah (HAT).

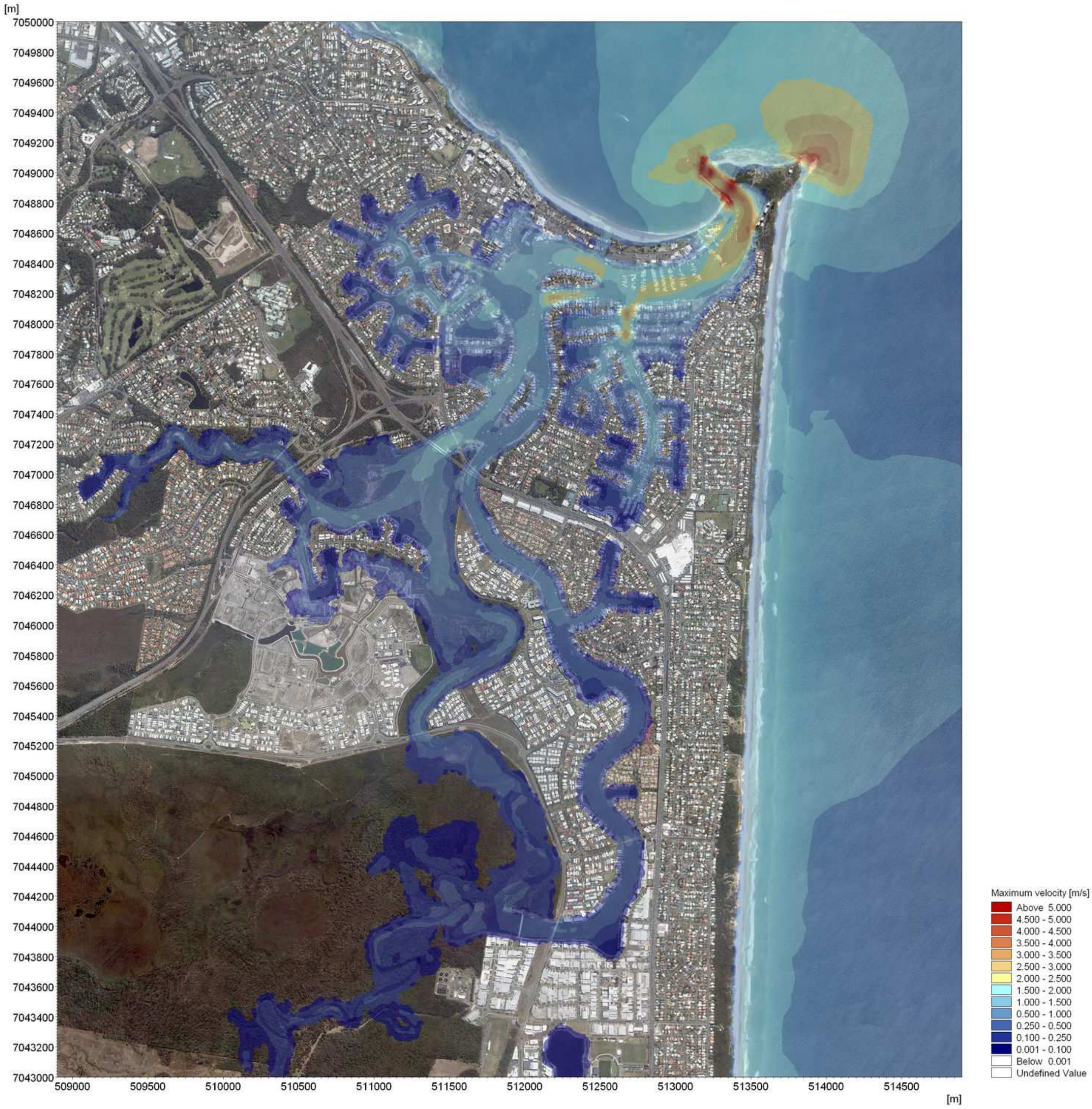

Figure A - 64 Scenario 3 maximum velocities at Mooloolaba (HAT).

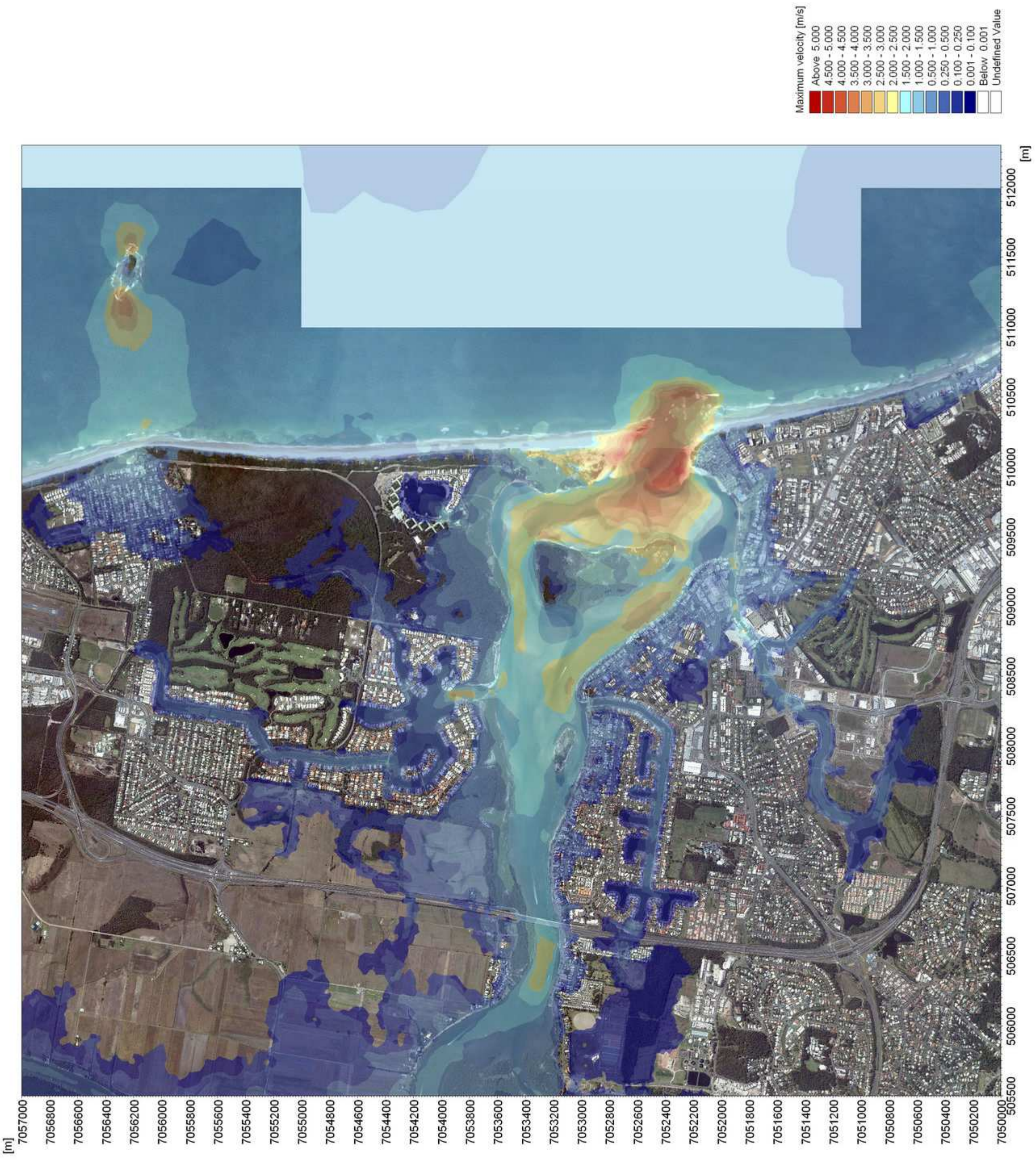

Figure A - 65 Scenario 3 maximum velocities at Maroochydore (HAT).

Figure A - 66 Scenario 3 maximum velocities at Noosa Heads (HAT).