Isles of Scilly Coastal Flood Modelling

Draft Main Report

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Manley House

Kestrel Way

EXETER

Devon, EX2 7LQ

JBA Project Manager

Matthew Hird
JBA Consulting
1 Belle Vue Square
Broughton Road
SKIPTON
North Yorkshire
BD23 1FJ

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This report describes work commissioned by the Environment Agency. The Environment Agencies representative for the contract was Roger Quinn. Fay Fishford, Harriett Twohig-Howell, Rachel Perks and Callum Rowett of JBA Consulting carried out this work.

Prepared by .....Fay Fishford BSc MSc
Senior Analyst

Harriett Twohig-Howell BSc MSc

Analyst

Rachel Perks BSc MSc

Analyst

Callum Rowett BSc (Hons) MSc

Assistant Analyst

Reviewed by .....Matthew Hird BSc MCIWEM C.WEM CEnv CSci
Principal Analyst

Purpose

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Abbreviations

CCO..... Channel Coastal Observatory

CFBD..... Coastal Flood Boundary Data

FAA..... Flood Alert Area

FWA..... Flood Warning Area

FPTF..... First Property to Flood

FA..... Flood Alert

FW..... Flood Warning

mODK..... metres above St. Mary's Ordnance Datum

SoN..... State of the Nation

WW3..... WAVEWATCHIII

1 Introduction

1.1 Study site and aim

The Isles of Scilly are a flooded landscape of over 200 low lying islands and rocks located 45 kilometres south west of Cornwall.

There are five inhabited islands, 78% of the population live on St Mary's (2011 census) and the remainder of the population live on Bryher, St. Agnes, St. Martin's and Tresco.

The Isles of Scilly has one of the largest oceanic fetches in the world, extending over thousands of miles to the south west. High energy waves and storms arriving from the Atlantic can cause physical damage to defences and property. The significant challenges surrounding coastal flood risk in the South West have been clearly demonstrated over the last few years with significant storms affecting the coast in 2013 and 2014, and these need to be understood for the Islands.

This report will specifically assess the risk associated with long range, long period Atlantic swells, recognising the that the highest impacts are generally caused by the extremes in the wave climate.

Although 30% of the land on the islands is at or below 5m elevation, most of the low-lying areas are protected by large dunes, and the present day still water flooding is of limited concern. Inundation risks are associated with the high energy waves causing wave run-up and overtopping of the limited coastal defences, and it is these risks that need to be understood through this commission.

Figure 1-1: An aerial view of St. Mary's with Tresco and St. Martin's in the background, illustrating the low-lying nature of the islands (photo courtesy of Visit Isles of Scilly)

1.2 Study aims

The overall aim of the project was to improve understanding of the area's exposure to coastal flood risk. To this end, the specific objectives were:

- To build new 2D hydrodynamic models suitable for assessing flood risk for the Isles of Scilly;
- Replace the State of the Nation offshore multivariate analysis using water level data appropriate to the datum of the islands;
- Create a wave transformation model to assess how the offshore waves transform into the nearshore;
- Calculate wave overtopping to assess the flood risk from waves around the islands;
- Create a series of flood inundation models to map the flood risk on the islands;
- To estimate flood levels for the 50%, 20% 10%, 5%, 4%, 3.33%, 2%, 1.33%, 1%, 0.5%, and 0.1% Annual Exceedance Probability (AEP) flood events;
- To estimate flood levels for the 1%, 0.5% and 0.1% AEP events plus climate change based on the medium emission 95th percentile UKCP09 scenario projected to the year 2065 and 2115;

- To estimate flood levels for the 0.5% AEP event plus climate change based on the NPPF scenario projected to the year 2115;
- Use the models to map coastal flood risk and produce a variety of outputs including flood depths, velocities, extents, and hazards;
- To derive new Flood Map components;
- Evaluate the current Standard of Protection (SoP) of local defences;
- Review of the current Flood Warning Areas and criteria/procedures for flood incident management;

1.3 Flood history

Historical flooding was reviewed and used to calibrate and verify the modelling. Information was collected during the site visit from Julian Pearce from the Isles of Scilly Council. Other important data sources were Council of the Isles of Scilly (2017) Isles of Scilly Local Flood Risk Management Strategy, Jan Petzold (2017) Social Capital, Resilience and Adaptation on Small Islands: Climate Change on the Isles of Scilly and www.scillytoday.com which usefully also contained some information on large events which did not lead to flooding.

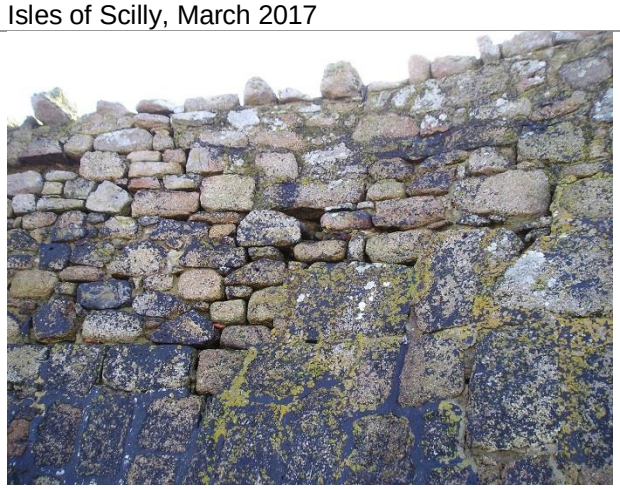
Documentary evidence of storm impacts is variable, significant events resulting in extensive damage and significant levels of flooding having been recorded during the “Great Storm of 1744”, December 1771, March 1962, the winter of 1989/90 in particular the storm of 16/17th December 1989, Easter 1994, early 1995, October 2004 and the winter of 2013/14 culminating in the storm on 14th February 2014.

The following review concentrates on the flood history from 1994 onwards. From 1994 onwards, water level records are available from St Mary's allowing hindcasting of the modelling to be performed.

Videos of wave overtopping1 show that the wind significantly increases the wave overtopping. Wind is not accounted for in the neural network calculations of overtopping rates.

Date	Flooding
Easter 1994	Popplestone Brow, Bryher eroded 0.5m in storms. The old seawall at Great Popplestones cracked (now replaced) Source: Coastal defences and structures 1997 Council of the Isles of Scilly Shoreline Management Plan
Early 1995	10m of old seawall at Great Popplestones, Bryher was lost Source: Coastal defences and structures 1997 Council of the Isles of Scilly Shoreline Management Plan

1 https://www.youtube.com/watch?v=gl3_2bkYfOQ
https://www.youtube.com/watch?v=-VvYRY_EGVQ

Date	Flooding
October 2004	 Wave impact and flooding at Old Town, 2004 (above) source: Isles of Scilly Local Flood Risk Management Strategy, Council of the Isles of Scilly, March 2017
17-18 October 2012	 Figure 1-2: Sea wall damage in front of Mermaid Inn, St. Mary's This event caused recorded flooding in St. Mary's along the north coast of Hugh Town, in Porthloo, around Spray View and behind Watermill Cove.
2 November 2013	Overtopping at the Mermaid Inn, St Mary's. source: http://www.scillytoday.com/2014/01/02/urgent-warning-issued-of-possible-coastal-flooding-in-scilly/

Date	Flooding
3 January 2014	Limited flooding reported on St Mary's. Worst affected area was Hugh Street with a few inches of water between the Paper Shop and the Co-Op, caused by tide locking. On St Agnes large rocks were thrown over sea defences into the quay. Figure 1-3: Atlantic Inn, St Marys, tide locking Figure 1-4: Hugh Street, St Marys, impact of tide locking Source: http://www.scillytoday.com/2014/01/03/scilly-experiences-limited-flooding-as-high-tide-and-storm-combines/ Isles of Scilly Local Flood Risk Management Strategy, Council of the Isles of Scilly, March 2017
14 February 2014	**St Mary's** Huge amounts of sand were carried into Hugh Town, the main street was covered in sand. (http://geographical.co.uk/nature/climate/item/1481-scilly-s-changing-climate) Flooding of the slipway at Porth Mellon from 2014 (photo courtesy of the Barefoot Photographer)

Date	Flooding
	 Erosion of Porthloo bank following 2014 storms (photo courtesy of Duchy of Cornwall) Overtopping of Mermaid Sea Wall, 2014 (photo courtesy of the Duchy of Cornwall) source: Isles of Scilly Local Flood Risk Management Strategy, Council of the Isles of Scilly, March 2017 Atlantic hotel flooded **Fig. 5.6** Storm surge hitting Porthcressa on February 14, 2014 (*left*), and overtopping sea wall (*right*) (*Source* both, A. Martin, private photograph, 14/02/2014)

Date	Flooding
	 Fig. 5.7 Damaged sea wall and slipway at Porthcressa, February 15, 2014 (*Source* both, A. Martin, private photograph, 15/02/2014) source: Jan Petzold (2017) Social Capital, Resilience and Adaptation on Small Islands: Climate Change on the Isles of Scilly. Springer Publishing. **St Martin's** Extensive erosion of the coast. (http://geographical.co.uk/nature/climate/item/1481-scilly-s-changing-climate) **St Agnes** Campsite was completely inundated, after 120m of dry wall was knocked over. (http://geographical.co.uk/nature/climate/item/1481-scilly-s-changing-climate) **Tresco** No descriptions of flooding found **Bryher** Overtopping caused flooding of the lowland behind Great Porth as shown below. Flooding of the lowland behind Great Porth, 2014 (photo courtesy of Gareth Tibbs) source: Isles of Scilly Local Flood Risk Management Strategy, Council of the Isles of Scilly, March 2017

1.4 Additional document and deliverables

A model development report is to be read in conjunction with this summary report. The model development report provides an overview of the model development and verification and provides detailed technical information on the modelling. It covers, in greater detail, the model construction process and provides detailed information on the model validation and sensitivity testing undertaken.

Digital deliverables were supplied on a hard drive.

2 Modelling approach

2.1 Introduction

Previous tidal flood maps for the study area were based on projecting still water levels and did not consider the importance of wave action. However, a significant risk for the Isles of Scilly comes from waves overtopping defences, as occurred on the 14 February 2014. The flood modelling that has been undertaken for this study includes the effects of still water flooding and wave overtopping. This section describes the key drivers of coastal flooding and the method used to simulate them in this study.

2.2 Background to coastal flooding

Prior to undertaking any modelling, it is important to first consider the drivers of coastal risk for the islands. Coastal flooding is a complicated process, affected by a number of dependant and independent variables. Figure 2-1 illustrates the main components of sea level variation that can contribute to coastal flooding during a storm event. The base sea level, often referred to as either the still water sea level or total sea level, is comprised of the underlying astronomical tide and the passage of a large-scale storm surge. These two components determine the average sea level for a specific location at a particular time. Whilst this variable is very important in terms of coastal flooding, still water induced flooding is normally limited to sheltered locations such as tidal rivers and harbours. Not surprisingly, the sea is not still during a storm event and for more exposed locations such as on the open coastline, most flooding occurs through wave action rather than still water flooding.

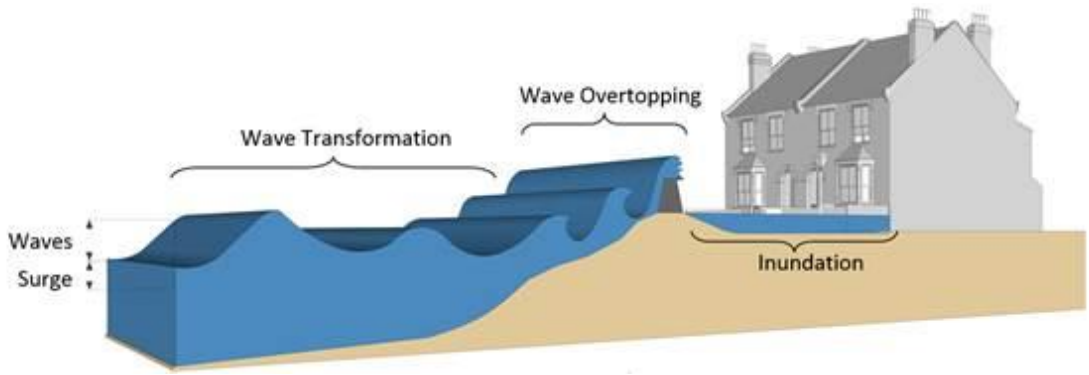


Figure 2-1: Components of sea level variation that lead to typical coastal flooding

Wave action is a complex process controlled by a number of factors. The manner in which these factors combine determines the magnitude of any wave induced flood impacts. Waves generate in deep water and then propagate towards land. As they do so, they enter shallower bathymetry where wave transformation processes occur, including shoaling, diffraction, refraction, depth limitation and breaking. These waves are also subject to additional influence from wind. The consequence of these processes is that the waves' properties, when they reach the base of flood defences, are quite different to the waves in deep water. It is these nearshore waves that are of most importance because they interact with beaches and defences and lead to wave overtopping.

Wave overtopping itself is also a complicated process controlled by the state of the sea (depth and wave properties), the geometry of the beach and local flood defences. The impact of all the above flood risk drivers during a particular storm is also heavily dependent upon the location and orientation of the defences with respect to the sea.

This means that while one location may be flooded during a storm event, another location, just a short distance away, may be impacted to a lesser extent due to its orientation with respect to the dominant wind/wave direction.

2.3 Modelling method

The method for calculating wave overtopping is a multistage process within the coastal flood modelling system (Figure 2-2). The wave overtopping calculations can be broken down into five key stages; offshore data and extremes analysis, defence schematisation, wave transformation modelling, emulation and wave overtopping calculations.

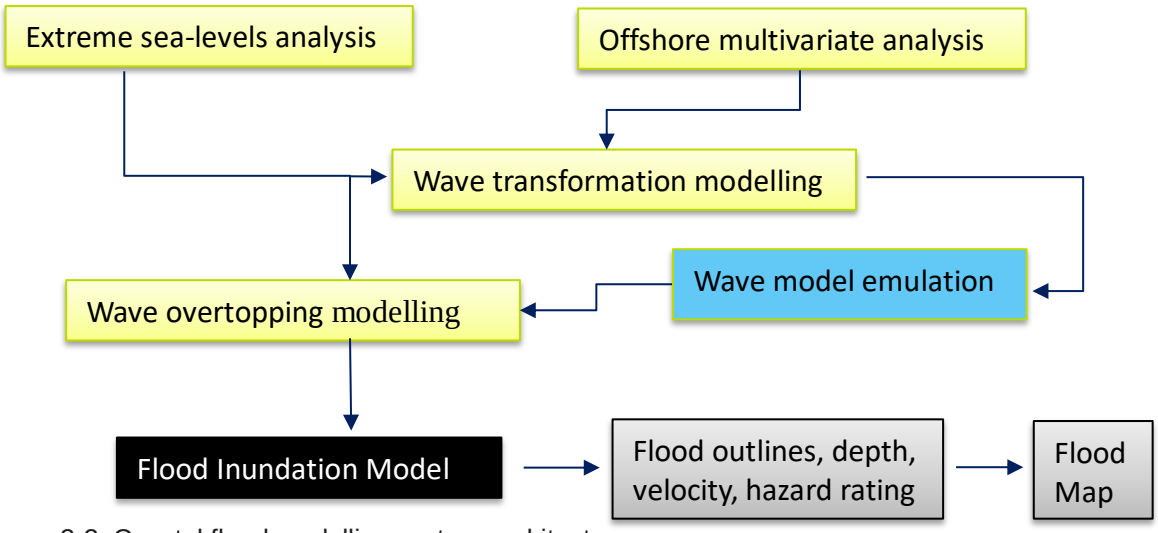


Figure 2-2: Coastal flood modelling system architecture

To help understand this flood risk, several modelling tools were used. Offshore events were determined through multivariate analysis of the available tide gauge data and hindcast wave data. Offshore waves were transformed into the nearshore using a high-resolution wave transformation model. Wave overtopping modelling was undertaken to calculate volumes of wave overtopping based on the nearshore wave heights, and flood inundation modelling was applied to simulate flood inundation from both extreme still water level flooding and wave overtopping volumes.

No single model is capable of simulating the wave transformation, wave overtopping and flood inundation, so each process was modelled separately with the wave and still water inputs combined in the flood inundation models. Offshore boundary conditions were defined through the multivariate dependence modelling and combined with sea-level extremes calculated by the Coastal Flood Boundary Data Study (2011). The outputs from the wave models were used to calculate the wave overtopping volumes at each defence. Additional details about the modelling methods are included in the accompanying model development report.

The following chapters describe the model data used and the methods applied to calculate the flood risk.

3 Model data

3.1 Data used

The models developed for this study required a wide range of data sources. These can be categorised as ground data, flood defence data and inflow boundary data. The nature of these data and their sources is summarised below.

3.2 Ground data

3.2.1 Terrain data

Terrain data across the Isles of Scilly was required to represent the surface upon which the progression of the flood wave moves across and interacts within the study area.

LIDAR data was provided by the Environment Agency. LIDAR data was provided in both surface (unfiltered) and bare earth (filtered) formats at 1.00m and 2.00m horizontal resolution.

LIDAR data was also obtained from the Channel Coastal Observatory (CCO) at 1m resolution, flown in 2015.

3.2.2 Bathymetric data

Bathymetric data was required to be incorporated into the wave transformation and the flood inundation model. Offshore bathymetry data for the islands was based on four sources of data:

- CCO LIDAR bathymetry and topography (1m resolution)
- SeaZone NW54950065 (~26m resolution)
- Cornwall State of the Nation SWAN model mesh grid (200m resolution)
- UKHO tile 10,404 (217m resolution)

Datasets were converted to Ordnance Datum St. Mary's (ODK) from chart datum using a spatially uniform value of 2.91m, based on St. Mary's tide gauge. The CCO LIDAR bathymetry data was collected using the OSTN02 geoid which is less accurate than the new OSGM15 geoid. There is an approximately constant difference of 0.36m between data collected with the new and old geoids over the isles[2], therefore, the CCO LIDAR was uniformly decreased by 0.36m. Comparisons of the adjusted CCO LIDAR to survey data collected by JBA (2017) at control points, indicate the data is accurate to around 0.10m.

The Isles of Scilly sit on a seamount. The surrounding sea floor is at a depth of around 80m, the seamount platform is roughly delimited by the -25m contour: the islands then raise up from this platform. At the edge of the seamount the bathymetry rises steeply from around -80m to -25m. The UKHO, SoN and SeaZone bathymetry were merged together with the most accurate data used in areas of overlap. Whilst the SeaZone data is the most accurate data source covering the edge of the seamount, interpolation errors were clearly visible in the dataset over the steep slope. For the islands and the shallow water around the islands, the CCO LIDAR bathymetry was the most accurate dataset.

3.2.3 Land use data

The rate and extent to which floodwater will flow across a floodplain is controlled partly by the topography roughness, which varies as a function of land cover type (for example, a woodland will offer more resistance to floodwater flow than short grassland).

OS MasterMap data contains a highly-detailed topography layer where individual features detail land objects and uses. This dataset was used to generate a polygon dataset of different land uses in the study area. Each of these different land uses was then assigned a roughness value, based on the commonly used Manning's *n* parameter. The assignment of the roughness values was based on standard values given in Chow (1959)[3] and professional judgement. Further information on the roughness coefficients used in the model are provided in the model development report.

[2] https://www.ordnancesurvey.co.uk/gps/transformation/updateOSTN

3 Chow, V.T. (1959). Open-Channel Hydraulics. McGraw-Hill: Auckland.

3.2.4 Flood defence data

There are relatively few formal defences around the islands. The basis of the defence dataset used for this modelling was from the Environment Agency's Asset Information Management System (AIMS) dataset. The AIMS database has 44 defences, mainly consisting of walls, embankments and areas of high ground. In addition to the AIMS data, a survey team were commissioned to collect additional beach profiles and defence crest data as part of this project. Additional topographic survey data from around the islands was provided by the Isles of Scilly Council.

In addition to the survey data, some defences were extracted from high resolution (1.00m and 2.00m) LIDAR data.

3.2.5 Extreme sea-level data

The extreme sea-levels used in this study came from the Coastal Flood Boundary Data (CFBD)[4] project. The CFB data has a base year of 2008, this was updated to a new base year of 2017 using sea-level rise adjustments from UKCP09. The extreme sea-level data used in this study is summarised in Table 3-1.

Table 3-1. Extreme sea-level data used in this study

Site CFB Chainage	Extreme still water level for the year 2017 per AEP (mAOD)										
	50%	20%	10%	5%	4%	3.33%	2%	1.33%	1%	0.5%	0.1%
ESL 0	3.51	3.59	3.64	3.69	3.71	3.72	3.75	3.78	3.80	3.84	3.95

3.3 Inflow boundary data

Figure 3-1 shows an example of the different hydraulic boundaries required for the inundation model. These boundaries include:

1. a still water boundary, located offshore around the circumference of the island, which allows propagation of the tide and surge into the model domain; and
2. wave overtopping boundaries along the coastal frontage, which inject wave water into the model to the rear of the flood defences to account for the water that is calculated to get over and behind the defences.

4 Environment Agency (2011), 'Coastal flood boundary conditions for UK mainalnd and islands - SC060064

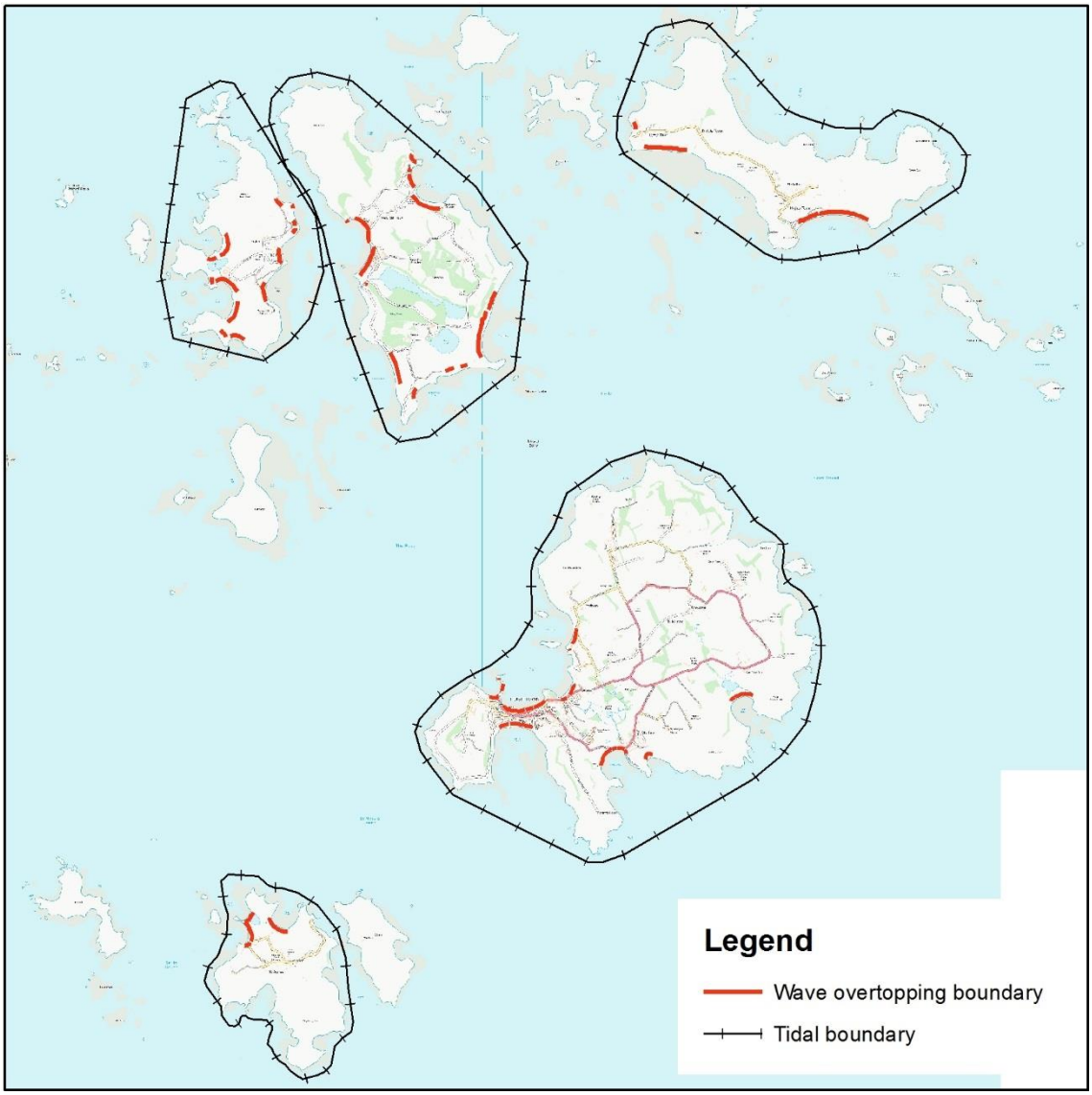


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Figure 3-1: Hydraulic boundaries for the five TUFLOW models

It is important to note that the sources of fluvial inputs were not considered in this project. This study was focused and coastal and tidal flood risk and did not consider the joint probability with fluvial events. For the watercourses on the islands, within the tidal limit, the volume of water and the levels reached from tidal events far exceed those of fluvial events, therefore, it is the tidal events that pose the dominant flood risk in these locations.

Modelling the input of the tide and surge wave into the model domain required the derivation of design tidal-graphs. Tidal graphs are a time-series data that quantify how sea-levels are expected to change through time during an extreme event. It is these design tidal-graphs that are used to drive the still water component of a flood inundation model at its offshore boundaries.

Derivation of the design tidal-graphs required three principal sources of information:

(1) extreme still water sea-level estimates taken from the CFBD for the AEPs of interest;

(2) a design surge shape taken from the CFBD guidance, and

(3) a design astronomical tide taken from a gauge local to the site.

Table 3-2 shows the source of the tide curve data applied to the offshore tidal boundary for all five models. An example of the sea-level time-series data input generated for the 0.5% AEP event is presented in Figure 4-19.

Table 3-2. Tide curve data

Boundary Name	Extreme Sea Level	Astronomical Tide	Surge Shape Location
ESL_0	CFB Chainage Point 0	St Mary's HAT	St Mary's Class A Gauge

During the creation of the tidal-graphs the surge is aligned with the trough prior to the peak tide as can be seen in Figure 3-2. As the peak is always scaled to the CFB extreme sea level, by aligning the surge to the trough before the peak it generates a larger volume when compared to aligning the peak of the tide and the surge.

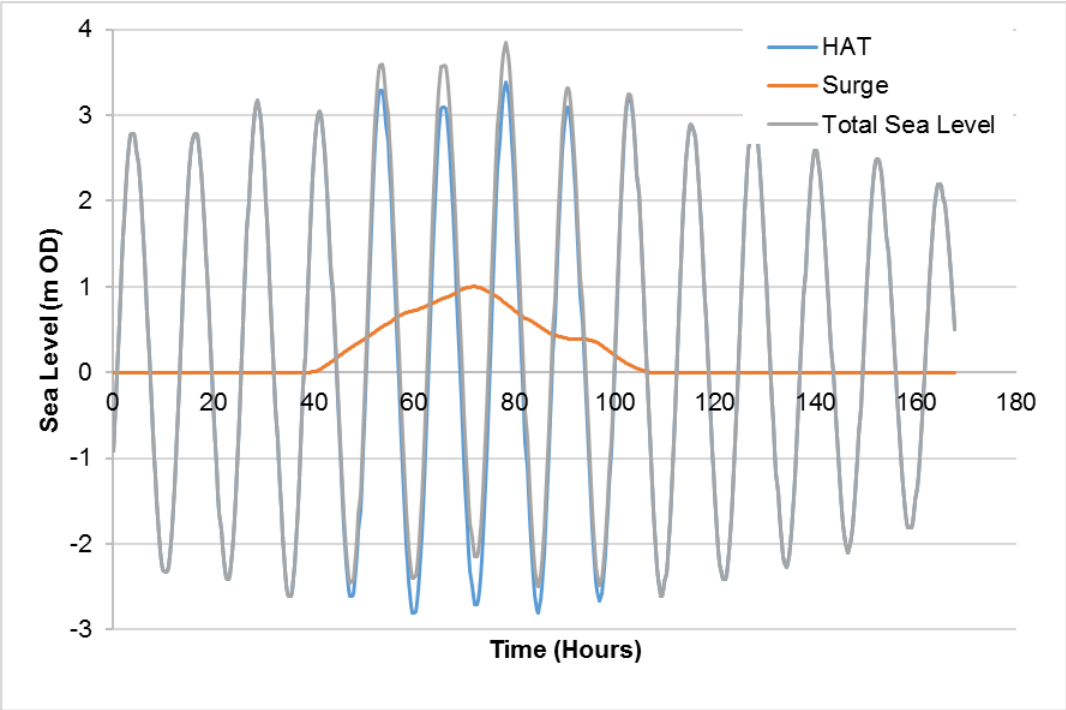


Figure 3-2: Design tidal-graph for a 0.5% AEP event (2017) based on CFB chainage point 0 at St Mary's.

The wave overtopping boundaries were based on a nearshore wave climate generated using the multivariate probability analysis. The multivariate offshore data was based on wave and wind data from Met Office WAVEWATCHIII (WW3) hindcast and the CFBD sea level extremes. The offshore data was used to provide boundary data for the wave models and these gave the nearshore wave data required to calculate wave overtopping at each defence. The development of the wave overtopping inflows are discussed further in the following chapter.

Climate change

In addition to present day extreme still water level events, a 1%, 0.5% and 0.1% AEP climate change scenario projected to 2067 and 2117 was modelled based on Adapting to the Climate Change: Advice for FCERM Authorities 2016 guidance.

Sea level rise estimates were based on the latest UKCP09 sea-level change guidance[5] using the medium emission 95th percentile scenario. The increases for sea level rise are shown in Table 3-3.

Table 3-3. UKCP09 medium emissions scenario sea level rise estimates, metres per year (2017 base year).

Base year	SLR projected to 2065	SLR projected to 2115
2008	0.386	0.844

Base year	SLR projected to 2065	SLR projected to 2115
2017	0.334	0.792

Linked with the changes in predicted sea levels, increases in offshore wind speed and wave height allowances are provided within the UKCP09 guidance for two epochs which are noted below:

- 2056 to 2115 +10%.

An increase of 10% to both offshore wind speed and wave height was applied for this study.

The latest National Planning and Policy Framework (NPPF) guidance was also used, the same wind and wave increases were applied but the sea-level rise figures were higher, as set out in Table 3-4.

Table 3-4. NPPF sea level rise estimates, metres per year (2017 base year).

Base year	SLR projected to 2065	SLR projected to 2115
2008	0.418	1.093
2017	0.387	1.062

4 Statistical and numerical modelling

Although still water levels provide the background conditions resulting in a flood event, a significant proportion of the flooding in coastal areas can be attributed to the overtopping of defences due to wave overtopping. An accurate representation of the effects of wave overtopping is crucial because if defences are overtopped, the impact on the flood extents may be significant.

Wave overtopping must be calculated separately as there is no one model capable of simulating both still water flooding and wave overtopping. The method outlined in the State of the Nation (SoN) National Flood Risk Assessment (NaFRA) 2014[6] project was used to calculate the wave overtopping volumes. The Isles of Scilly are covered by SoN joint probability region 7 (JP7) but this data could not be used directly in this study due to the datum difference between the water levels at St Mary's and those used from Newlyn for JP7. The first step to calculate the wave overtopping was to determine new offshore wave boundary conditions using multivariate statistical analysis.

4.1 Multivariate statistical analysis

When considering extreme coastal events, it is important to assess the likelihood of conditions occurring simultaneously. Coastal surges, winds and waves are generated by the same atmospheric processes, as such there are relationships between these variables. Extreme waves occurring during a high sea level, pose a far greater coastal flood risk than if they occurred during lower sea levels. The probability of concurrent processes needs to be carefully assessed through dependence relationships between each variable, in addition to independent process, such as astronomical tides.

A statistical multivariate probability analysis was undertaken to determine coincident wave (height, period, direction and spread), sea level (surge and tide) and wind conditions. This was undertaken using hindcast model data from WWIII point number 49 (49.7970 -6.5410). The methodology comprises of the following steps:

1. Coincident wave and sea level time series records were obtained over a 22-year period from 1994 to 2015. The full WW3 hindcast period back to 1980 could not be used due to coincident data from St Mary's tide gauge only being available from 1994.
2. Each time series was declustered to identify independent storm events.
3. A Generalised Pareto Distribution was fitted to the declustered storm events for the variables: wave height, wave period, wind speed and skew surge, in a process called marginal modelling.
4. The Heffernan and Tawn dependence model was fitted to the declustered data to assess the dependence between each variable.
5. The Monte Carlo sampling technique was used to produce a dataset with storm events that could be observed over 10,000 years. What is classified as a storm is defined by the declustering performed in step 2. The length of the Monte Carlo dataset equals 10,000 (number of years) times the average number of storms which occur each year in the observed dataset. The simulated storms have the same relationship between the variables as in the observed dataset.
6. For each storm in the dataset an astronomical high tide value was added to the skew surge value to obtain total sea level.
7. A maximum dissimilarity algorithm was used to select the 2,000 most dis-similar events from the dataset to use in the generation of the wave emulators. Initially 500 events were selected as this was the number used in the SoN study. This was found to be inadequate for the Islands due to the complex nature of the coastline and the 360° exposure to storms approaching from any direction.

4.1.1 Coincident wave and sea level records

Sea level data from the class A tide gauge at St Mary's was used. The data from the primary tide gauge was supplemented with data from either the secondary or MSL gauge as appropriate to reduce the data gaps. The data was de-trended to a baseline of 1st January 2017, using a rate of

6 Environment Agency 2015 'State of the Nation Flood Risk Analysis, Coastal Boundary Conditions' MCR5289-RT025-R02-00

1.37mm/yr taken from the CFBD study. The de-trended sea level data were separated into two components; astronomical tide and skew surge. By way of definition:

- The term ‘astronomical tide’ refers to the sea level component that is attributable to the gravitational forces of the moon and sun.
- The term 'surge' typically refers to the residual sea level components that is attributable to meteorological or storm affects; e.g. wind and pressure changes associated with storms can raise or lower the sea level above or below the predicted astronomical tide. A coastal surge can be estimated through two parameters; surge residual and skew surge. Surge residual is equal to the actual, or observed sea level, minus the predicted astronomical tidal level at a particular point in time. The use of surge residual can often be misleading due to its dependence on discrete time-based calculations. Due to tide-surge interaction processes, there is sometimes a tendency for tides to arrive earlier than predicted, which can lead to the illusion of surge during the rising limb of a tide. For coastal assessments this phenomenon can lead to increased uncertainty with respect to the peak sea levels, and as such, the parameter skew surge is favoured. Skew surge is calculated as the absolute difference between the maximum recorded sea level during a tidal cycle and the predicted maximum astronomical tidal level, irrespective of their timing. As a result, this is favoured for coastal risk assessments, as the skew surge plus the peak astronomic tide level results in the maximum sea level.

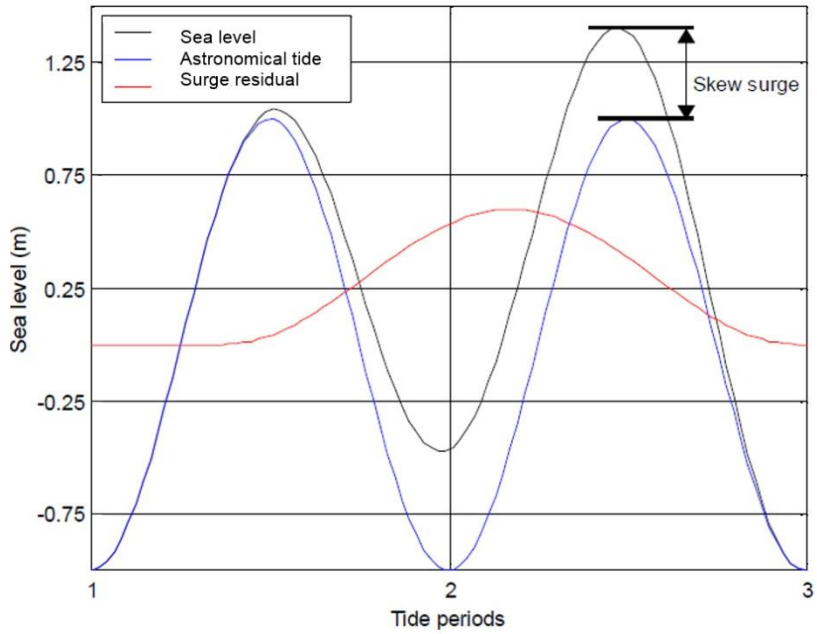


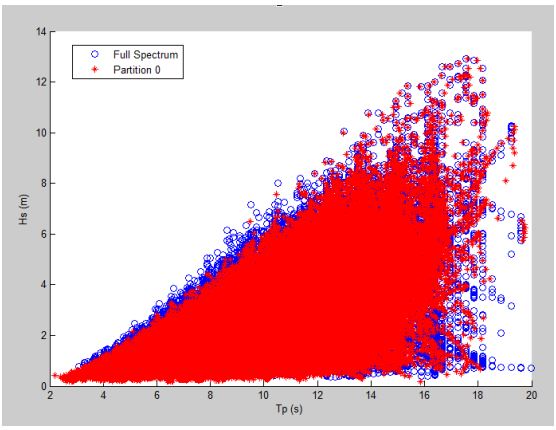
Figure 4-1: Sea level components: total sea level, astronomical tide, surge residual and skew surge

Wave and wind data were obtained from the Met Office WW3 point 49. Variability in the storm wind climate across the island chain was assessed and found to be uniform, hence point 49 is a suitable choice. This wind and wave data are referred to as empirical data herein to distinguish them from the values sampled from the statistical models.

4.1.2 Multi-modal wave spectrums

As part of the study it was investigated whether different aspects of the wave spectrum should be included in the multivariate analysis. The Isles of Scilly are exposed to large swells from the Atlantic as well as locally generated waves, hence the spectrum is often multi-modal. The statistics need to correctly represent the parts of the wave spectrum that pose a flood risk. Hence firstly, to decide if the statistical method needed developing for multi-modal distributions, the structure of the wave climate was examined concentrating on storm events capable of inducing flooding. The WW3 data is provided with short-term statistics (Hs, Tp, peak direction, spread) calculated based on the total / full spectrum and also in four energy partitions 0-3 with 0 containing the most energy and 3 the least.

a) Total sea and partition 0



b) Total sea and partitions 0 and 1

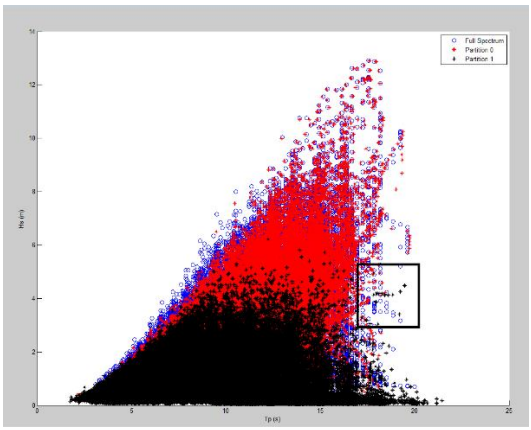


Figure 4-2: Significant Wave height (y axis) plotted against peak period (x axis) for the full spectrum (blue), partition 0 (red) and partition 1 (black)

Figure 4-2 shows the WW3 total spectrum Hs against Tp (blue) and partitions 0 (red) and 1 (black). It can be seen that the most damaging events (large waves and long period) are uni-modal events and well represented by the total spectrum statistics. The uni-modal nature of the largest events is shown more clearly in Figure 4-3 which plots Hs against Tp, where Hs is greater than 10m for the total spectrum, along with the values in partition 0 at the corresponding times.

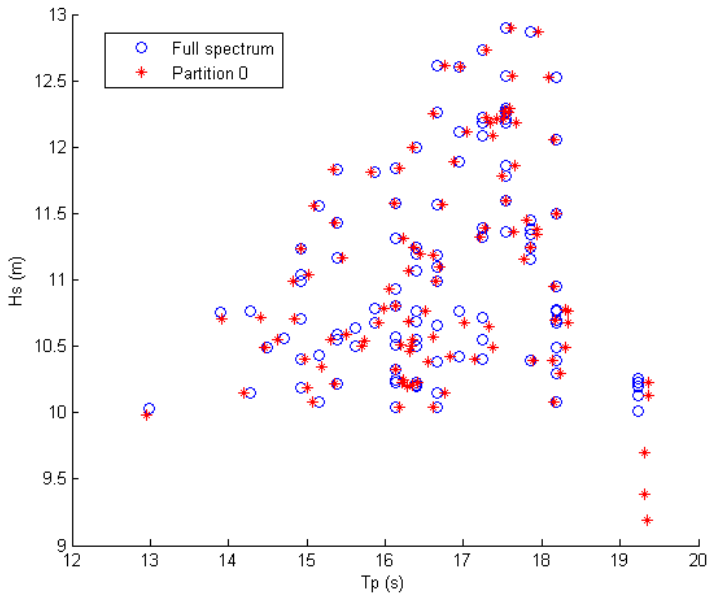


Figure 4-3: Total spectrum and partition 0, Hs v Tp, for wave heights above 10m

The wave conditions in partition 1 are not of interest for a flood risk study. The worst-case conditions are shown within a black box in Figure 4-2b. These points all correspond to an event on 10th – 11th December 2014: which had a bi-modal spectrum with both modes having similar energy levels but partition 0 has a mean period around 8s and partition 1 has a mean period around 18s. This event did not cause flooding.

Flood risk in the Isles of Scilly is caused by large, long period waves, all of which are well represented by the total sea statistics or the first partition and hence there is no need to modify the

statistics to accommodate multi-modal spectrums. It was decided to perform the statistical analysis on wave data in partition 0. This is preferable to using the total spectrum statistics, as it confirms a genuine relationship between the variables for the dependence modelling: this relationship may not be preserved using the total sea statistics of a multi-modal spectrum. Additionally, as shown in Figure 4-2a, partition 0 does not include long period, low wave height events which are not of interest in a flood risk assessment.

4.1.3 Monte Carlo sample of offshore sea conditions

The statistical multivariate probability analysis steps of declustering, marginal analysis and dependence modelling were completed, more details on each stage of the analysis, the thresholds and fittings, are provided in the model development report. The Monte Carlo method creates a sample of simulated data which maintains the same relationship between the variables as found in the observed dataset. It was used to produce a representative 10,000-year storm dataset from the dependence models. Values of wind direction, wave direction and wave spread are associated with the sampled data based on their empirical distributions.

4.1.4 Calculation of total sea level

The Monte Carlo sample data accounts for the observed relationship between storm surge, waves and winds. These conditions have a degree of dependence because they are caused by the same atmospheric storm conditions.

However, to consider the risk at the shoreline, the total sea level is required, so that it can be applied in the subsequent wave transformation modelling. The total sea level for each member of the Monte Carlo sample was calculated by adding a randomly sampled high tide value, drawn from an 18.6-year dataset, to each surge value. The high tide value is randomly selected to replicate the real world, where the co-occurrence of a storm event and a specific astronomical tide (e.g. HAT) is random due to their different causes (weather opposed to the sun and moon). However, the value is selected from the observed distribution of astronomical tides. Hence the astronomical high tides assigned to the Monte Carlo sample have the same properties (mean value, maximum value etc) as the observed astronomical tides. This technique of calculation the total sea level was validated by comparing the water level return periods which would be calculated from the Monte Carlo sample to the Coastal Flood Boundary Dataset. All return periods were found to be within 0.10m of each other which is within the accuracy of the Coastal Flood Boundary Dataset.

The final offshore sample of water levels, wind and wave data contained just over 1 million individual events in the 10,000-year record.

4.2 Wave transformation modelling

Wave transformation modelling was required to transform the offshore waves into the nearshore. The SoN wave model was not suitable for use due to the close proximity of the offshore boundary to the islands and the resolution of the model, which at 200m (fixed grid) would not properly account for the complexity of the islands and rocky outcrops in and around the islands.

Wave transformation modelling was undertaken using the SWAN (Simulating Waves Nearshore) wave model. This is consistent with the SoN project. SWAN is a third-generation wave model incorporating complex physics for the description of nearshore processes. It is an open source package (no licence required) used widely for research and commercial applications, developed by internationally recognised experts at the Delft University of Technology[7].

A new unstructured wave transformation model was created for this study. The wave model was used to transform a subset of waves from the offshore statistical event set to nearshore points at the five inhabited islands. These results were used to fit emulators, which were used to transform the rest of the offshore sample to the nearshore. The nearshore wave conditions were then used as inputs to calculate wave overtopping. The model was developed with a flexible mesh to enable more detailed to be added around the important features that impact upon the waves and around the model output points, where the data is extracted for use in the wave overtopping calculations.

The model mesh contains 21 islands. Some of these islands represent one actual island, such as St Mary's but some of them represent groups of smaller islands. For example, the Eastern Isles have been grouped into five islands in the mesh: this allows the model to represent their blocking

7 SWAN User Manual, SWAN Cycle III version 40.81, Delft University of Technology, 2010

effect on the far field, wave field whilst avoiding the numerical problems created by modelling these islands in low or high resolution. The wave model mesh is shown in Figure 4-4.

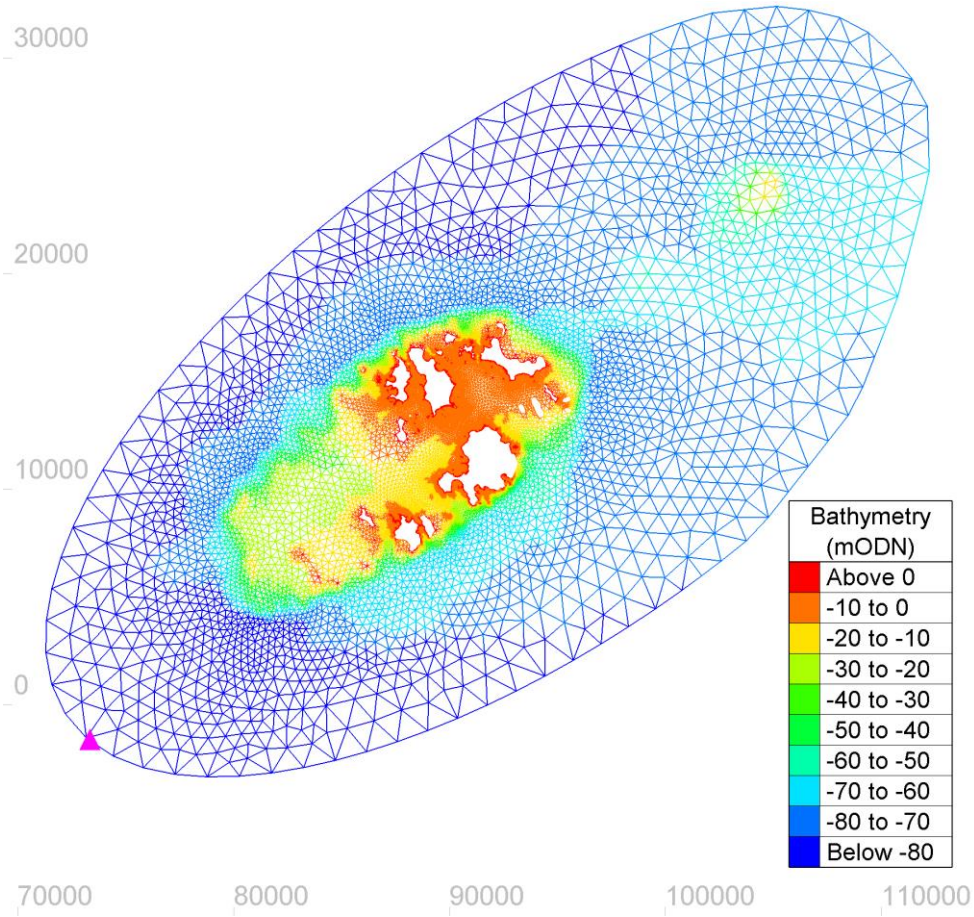


Figure 4-4: Wave model mesh and bathymetry and WAVEWATCH III point 49 (pink triangle)

4.2.1 Wave model calibration

The wave transformation model was calibrated against nine extreme wave events. Sensitivity testing was performed on the choice of wind parameterisation, the choice of bottom friction model, the bottom friction coefficient and the boundary conditions. This testing was used to select the most appropriate model setup, based on comparisons at the three wave observation locations and used to quantify the uncertainty at the model output locations where observations are unavailable. triangle) and the model boundary (black line)

Three wave observation locations were used to calibrate the model: St. Mary's Sound wave buoy (available 2014 - 2016), SW Isles of Scilly wave buoy (2014 - 2016) and SevenStones Light Vessel (available 1995-2016). The length of observations at St Mary's Sound and the SW Isles of Scilly are very small and do not include any very large events, therefore, most of the events were selected based on the largest waves recorded at SevenStones. The locations of the wave observation points are shown in Figure 4-5.

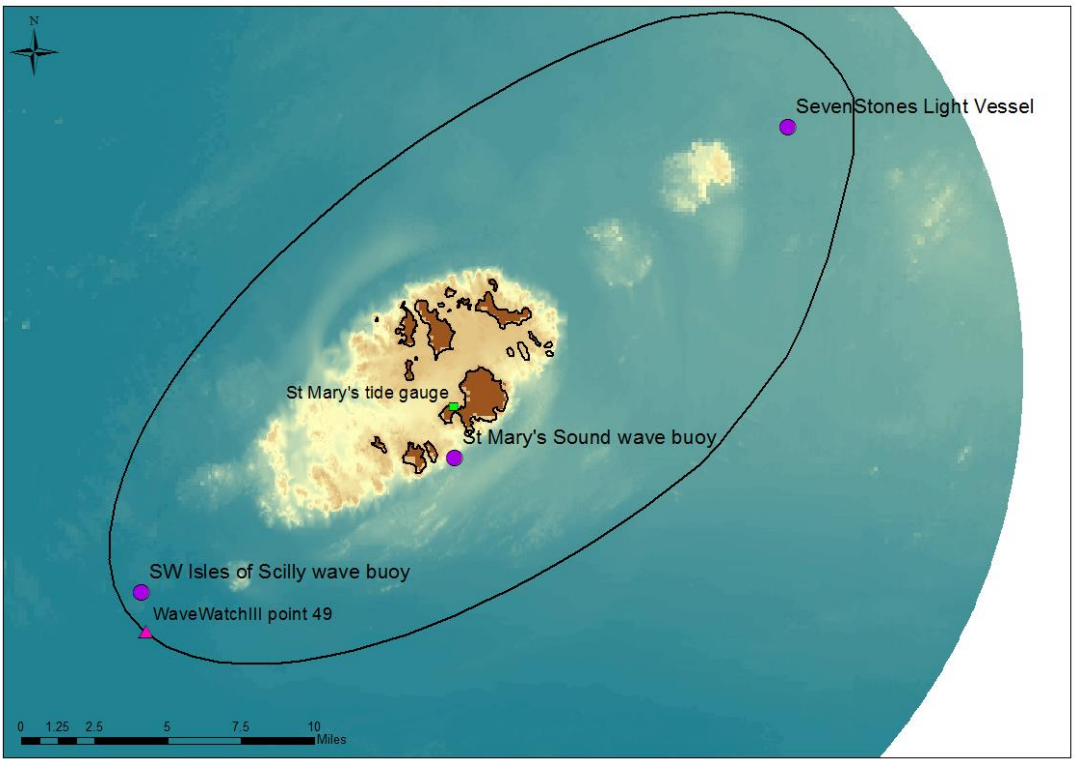


Figure 4-5: Locations of wave (purple circles) and water level (green square) observations, WWIII point 49 (pink

Two calibration events were selected where observations are available at all three buoys. Model calibration was performed based on south-westerly events based on the flood history and fetch limitation of waves from other directions.

Wave and wind boundary conditions come from WW3 point 49 as used in the statistical analysis. Water levels were taken from St Mary's tide gauge as used in the statistical analysis, when data was not available from this gauge, values were taken from the Newlyn tide gauge. Water levels are similar but slightly lower at Newlyn, for example HAT at St. Mary's is 6.31m compared to 6.13m at Newlyn. The calibration boundary conditions are shown in **Error! Reference source not found.**.

The most appropriate events and boundary forcing was selected, however, there is still uncertainty. It was noted that the boundary data for calibration events six and eight looks improbable as the waves are higher at Seven Stones than they are at the WW3 point further east. We would not expect any growth in the wave heights across the domain, as they are fully developed conditions coming from the North Atlantic.

After testing all of the model setups for the nine calibration events, the error statistics were compared to find the best performing setup. The Janssen wind model and Jonswap bottom friction model produce the lowest RMSE for wave heights at 0.57m (6% relative error). However, using the Janssen wind model led to poor model convergence for some of the events. Therefore, the Komen wind model and Jonswap bottom friction scheme was selected. Using this set up, the model replicates wave heights with negligible bias, and a small relative error 7% (RMSE of 0.63m on wave height) and wave periods are also well modelled with a relative error of 11% and a bias under 1s. Validation was then performed on a further nine validation events, the results of which are summarised in the model development report.

4.2.2 Wave model sensibility

The model results were checked visually over the full domain, to confirm that the wave parameters vary in a physically realistic way. Figure 4-6, show an example of the wave field and Table 4-1 summarises the offshore data applied. In the figure, isobars of the model bathymetry are plotted at 10m intervals and the output locations are shown as black triangles.

The figure shows high waves propagating from the south west and breaking as they travel over the seamount. Wave heights reduce with decreasing water depth as expected. Wave periods also

decrease as the waves travel through shallower water between the islands. The wave direction field shows offshore waves approaching from the south west and turning as they propagate around the islands.

Table 4-1: Offshore event conditions simulated

Hs (m)	Wave direction (°)	Tp (s)	Water level (mAODK)	Wind speed (m/s)	Wind direction (°)
10.41	214	15	3.13	17.56	240

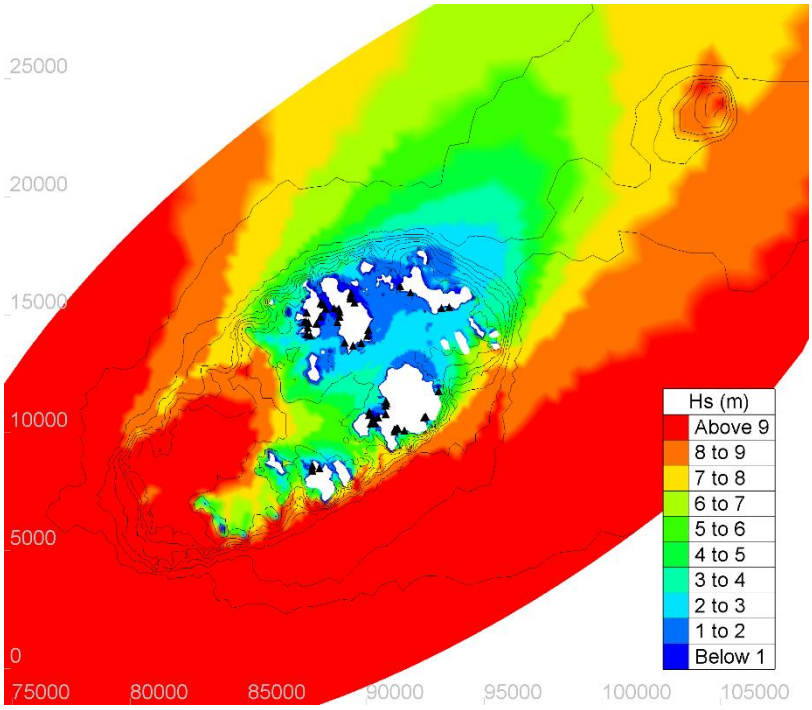


Figure 4-6: Significant wave height across the domain

Further details of the wave model setup, sensitivity testing, calibration and validation are summarised in the model development report.

4.3 Emulation

To translate the offshore extreme event dataset to nearshore, an emulator approach has been used. This is consistent with the SoN project. In principle, it is necessary to transform all the offshore extreme event dataset (comprising of over 1,000,000 individual events) through to the nearshore. Simulating all the events is not feasible in the SWAN wave model as this is computationally time consuming. Instead, an emulator approach was used.

Fundamentally, an emulator is similar in concept to a "look-up" table, using a representative sample to derive results for the complete dataset. A maximum dissimilarity algorithm (MDA) was applied to the offshore event set to derive a representative sample of 2,000 events. These 2,000 events were then run through the SWAN 2D wave transformation model to derive the nearshore conditions at the toe of the defences on the five main Islands of the Isles of Scilly. These nearshore conditions formed the base data on which the emulators were trained to be able to derive data for all events in the offshore dataset. The simulation results were divided, 90% of the results were used to create the emulators (training data), and the remaining 10% of the results were used for validation (validation data).

Interpolation techniques were applied to the training data, selecting the empirical functions that best describes the relationship between the offshore and nearshore wave conditions, specifically the wave height, period and direction. These empirical functions form the emulator, with a separate emulator required for each defence toe. Once the emulators functions were selected, they were tested using the validation data. The emulators were used to derive the wave conditions at the 51-

defence output for each validation event. The resulting wave conditions were then compared against the validation data. In cases where there were significant differences between the wave conditions derived from the emulator and the SWAN wave model, the emulator was revised, and this process repeated.

Figure 4-7 shows a graphical comparison of the SWAN and emulated significant wave heights for the validation results at a selection of the defence toes. The graphs show that the emulators predict the significant wave heights with a high degree of accuracy and very little scatter.

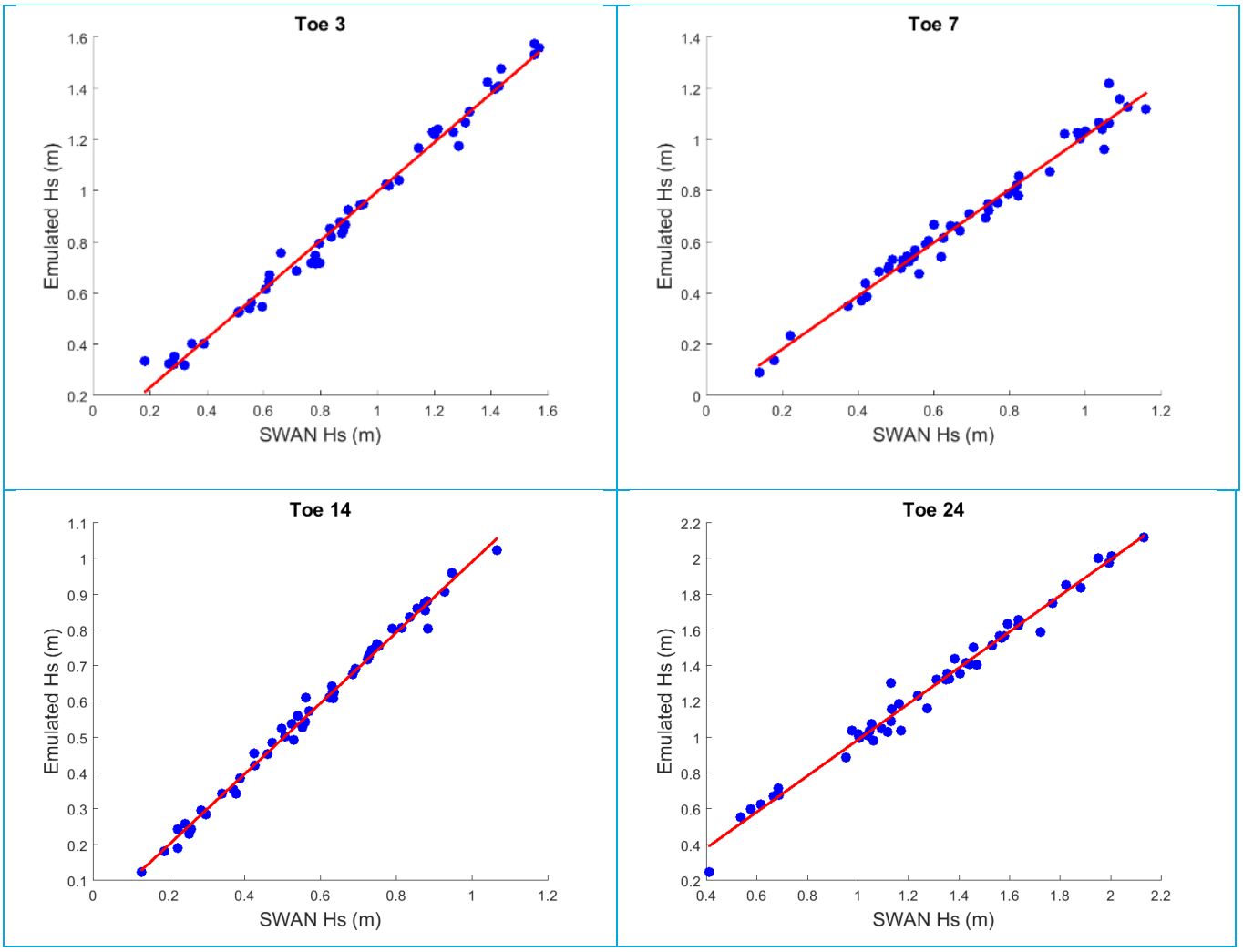


Figure 4-7: Comparison of the SWAN significant wave height and the emulated significant wave height at a selection defence toes

Once the emulators were finalised, they were used to calculate the wave conditions at each of the separate defence toes for each of the 1 million plus events in the offshore dataset.

4.4 Wave overtopping modelling

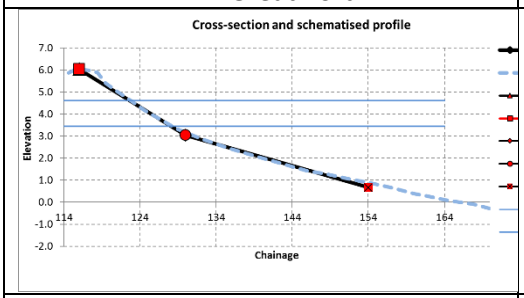
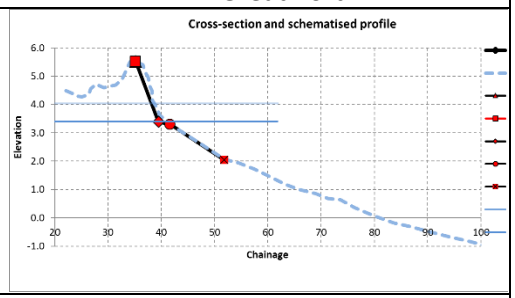
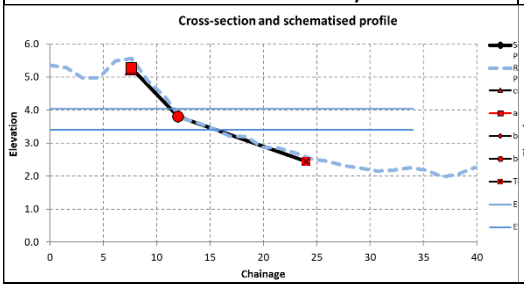
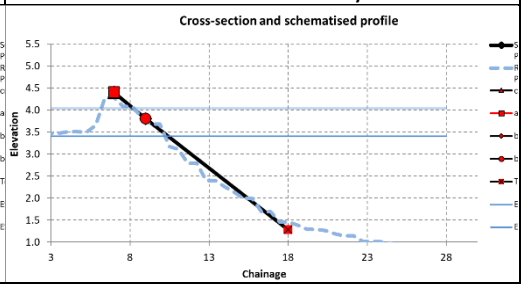
4.4.1 Defence schematisation

Flood defence structures along the coastline of the five main islands of the Isles of Scilly were analysed. These defences were divided into 51 separate stretches that were theorised as having a specific wave overtopping risk. Schematisation of the defence profile is principally required for calculating the wave overtopping discharge rate during the wave overtopping calculations stage. However, it is also used at the wave transformation and emulation stage, as it defines the locations of where the nearshore wave conditions are required.

Wave overtopping volumes have been calculated at 51 key sites, these were, 11 on Bryher, 14 on Tresco, 4 on St Agnes, 18 on St Mary's and 4 on St Martin's. The study has applied the Neural

Network methodology to calculate the wave overtopping discharge rates, the details of which are outlined in the European Overtopping Manual (EurOtop). The Neural Network tool in EurOtop was developed by the European CLASH programme. EurOtop uses a large database of results from physical modelling tests to derive a solution based on complex defence profiles. The schematisations of the 51 defences describe the components of the profile using the parameters required by the Neural Network tool. A total of 18 parameters are used to describe the defence structure, the defence toe level, defence crest, defence slope, roughness and orientation. Schematisations were produced for the defended models and for the undefended situation with the raised defences removed. Examples of the defence schematisations are shown in Table 4-2.

Table 4-2: Neural Network Schematisations

Great Porth 1	Great Porth 2
	
Great Pool Bryher 1	**Great Pool Bryher 2**
	

Maps of the defence profile locations across the five islands are provided in Figure 4-8 to Figure 4-13.

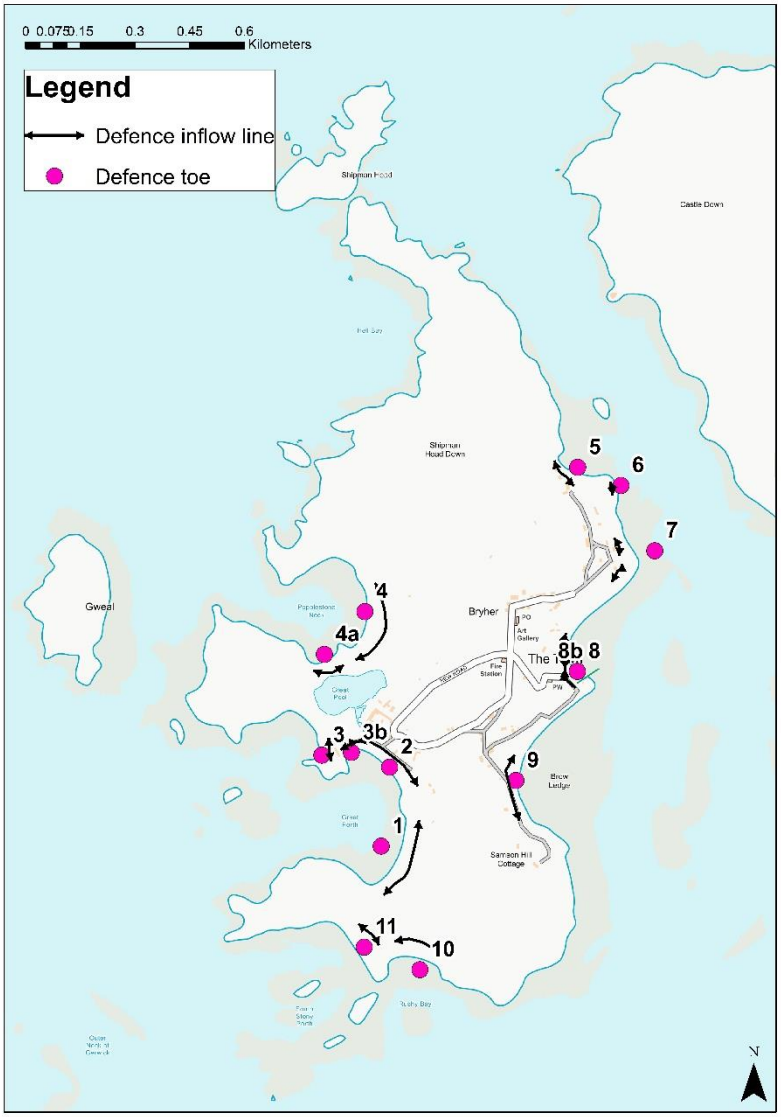


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Figure 4-8: Overtopping inflow lines, Bryher

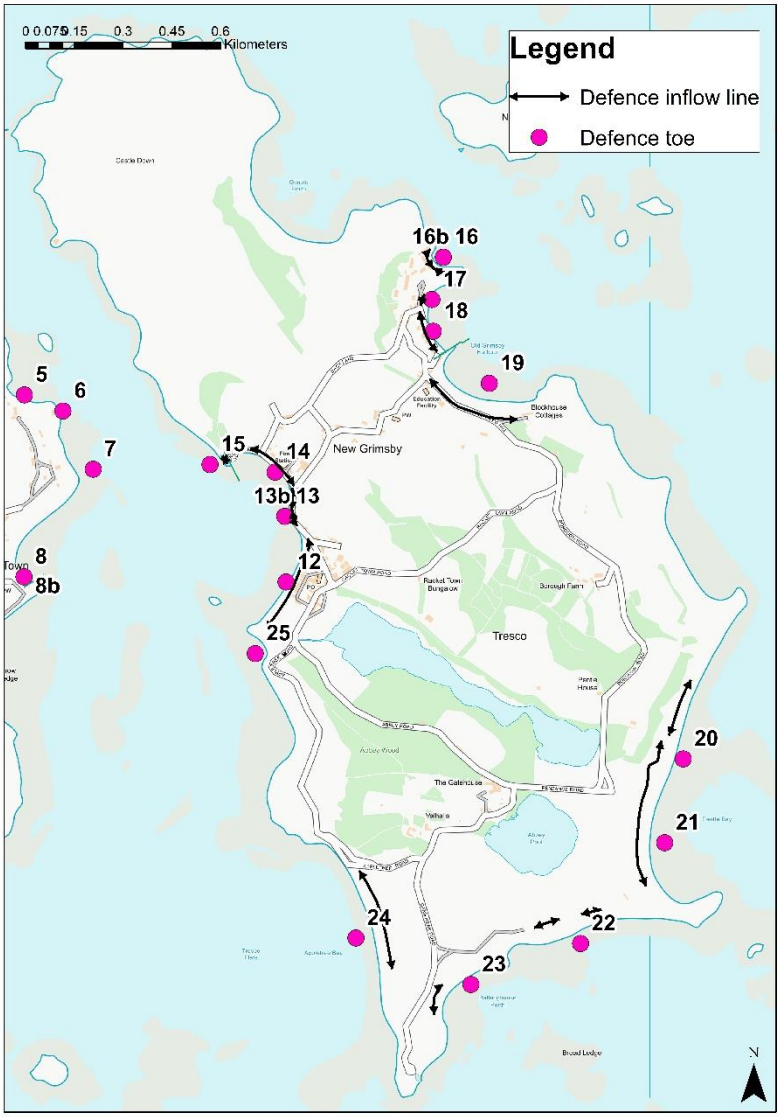

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Figure 4-9: Overtopping inflow lines, Tresco

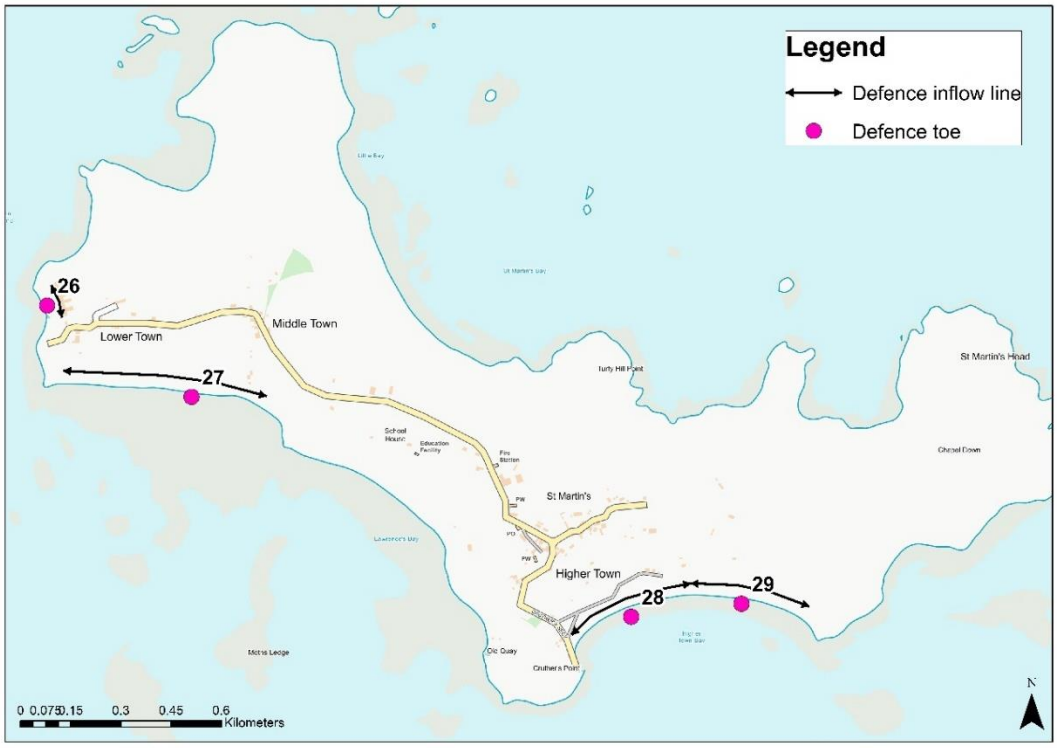

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Figure 4-10: Overtopping inflow lines, St. Martin's

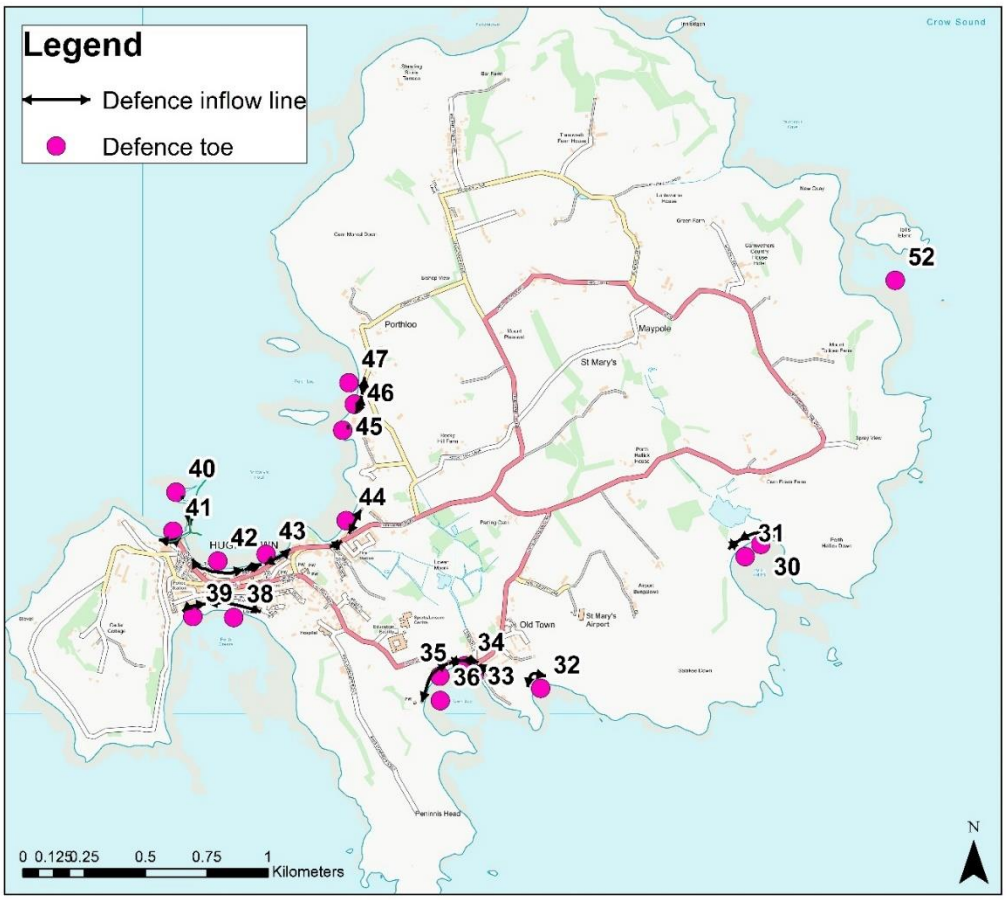

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Figure 4-11: Overtopping inflow lines, St. Mary's

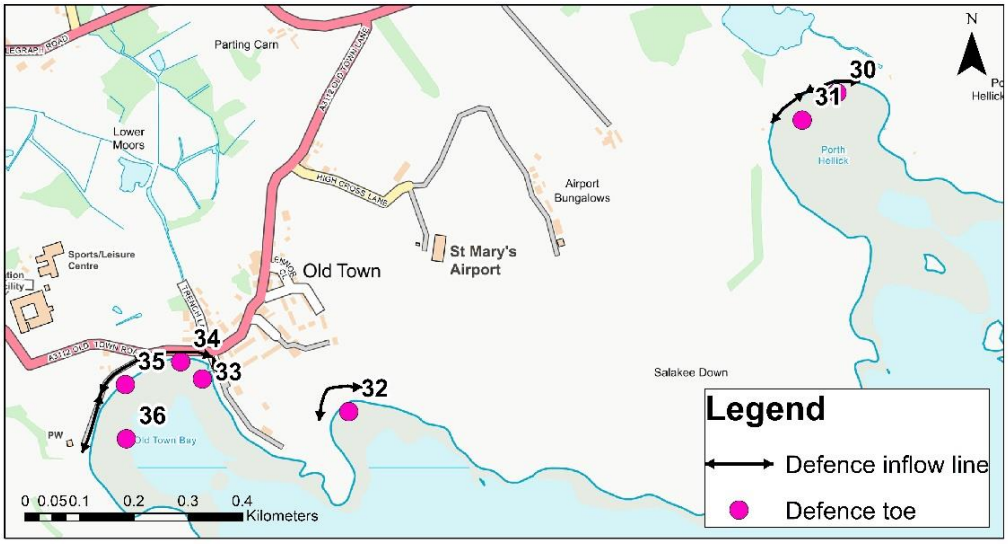

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Figure 4-12: Overtopping inflow lines, south St. Mary's

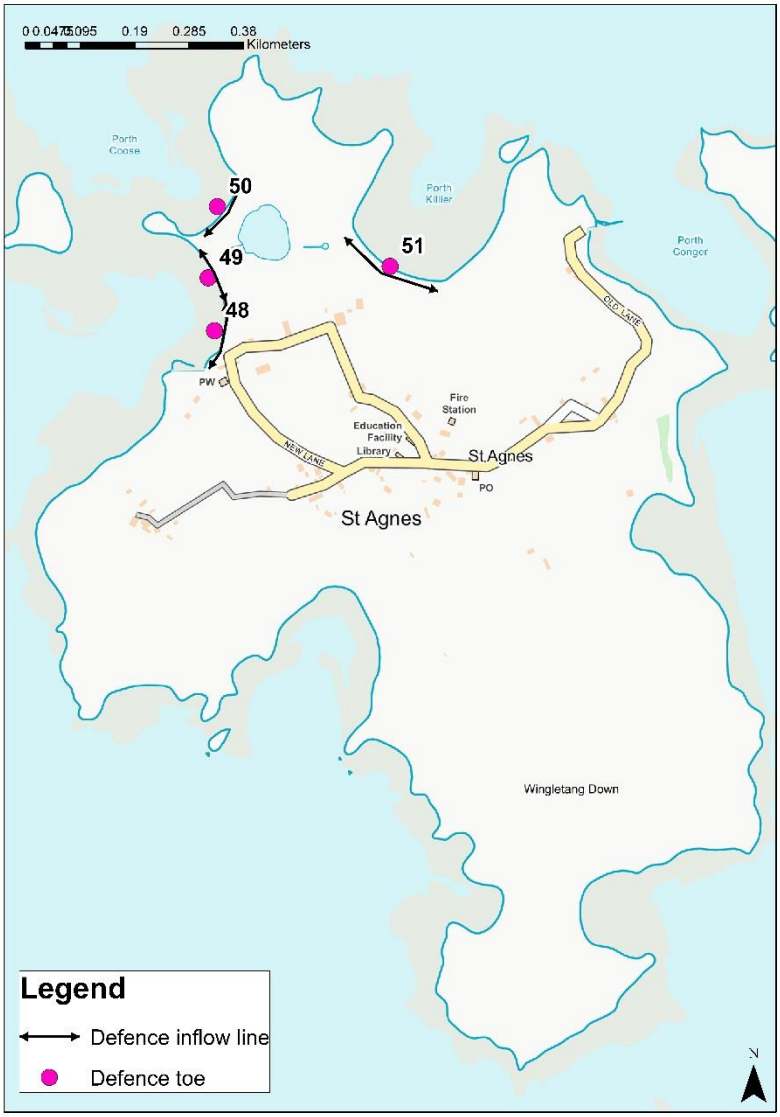

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Figure 4-13: Overtopping inflow lines, St. Agnes

Details of the defence schematisations, and the data used are summarised in the schematisation summary sheets.

4.4.2 Wave overtopping calculations

The wave overtopping method calculates a wave overtopping discharge, quantified by the parameter 'q', in $m^3/s/m$. The Neural Network approach requires a set of input parameters for the calculations which comprise the still water level at the defence toe (including wave set-up), the incident wave conditions, and the defence profile schematisation. The nearshore wave conditions for each event in the full offshore extreme event dataset, derived using the emulator approach, are run using the Neural Network method. The resulting wave overtopping discharges were analysed and assigned an event probability. A time series of wave overtopping volumes for each event, 50%, 20%, 10%, 5%, 4%, 3.33%, 2%, 1.33%, 1%, 0.5%, 0.1% AEP events were then derived. Wave overtopping volumes were also calculated for climate change events for the 1%, 0.5% and 0.1% AEP for 2065 and 2115 per UKCP09 estimation for change for the defended scenarios. For the undefended scenarios only the 0.5% AEP for 2065 and 2115 volumes were calculated per UKCP09. Additionally, for the 0.5% AEP NPPF guidance was used to calculate overtopping volumes for both the defended and undefended scenarios.

The emulator process derived the wave conditions at the defence toe for each event in the 10,000-year offshore dataset. These wave conditions were run through the Neural Network tool to derive a wave overtopping discharge for each event in offshore dataset. The overtopping rates were then

ranked, the largest being the overtopping rate associated with the 0.01% AEP event. Once ranked, the wave and water level conditions could then be extracted for each desired AEP event and run through the Neural Network using a full tidal water level time-series; this generates the wave overtopping discharges that vary through time for each AEP. A list of the wave condition parameters calculated at each defence toe for the 0.5% AEP event can been seen in Table 4-3. Profile 8, 19 and 21 do not have any water level parameters as there is no overtopping predicted at this AEP.

Table 4-3: 0.5% AEP event parameters for each defence toe.

Defence	Wave Conditions			
	Wave Height (m)	Wave Period (s)	Wave Direction (º)	Water Level (mODK)
1	1.03	8.83	282	3.76
2	0.91	9.84	235	3.68
3	1.15	8.71	263	3.84
3b	0.63	7.99	180	3.81
4	0.81	8.98	278	3.63
4a	0.75	9.26	278	3.7
5	1.66	12.02	14	3.52
6	0.98	9.69	33	3.87
7	1.2	8.23	136	3.45
8	-	-	-	-
8b	0.29	8.28	69	3.7
9	0.71	5.72	119	3.92
10	1.44	10	203	3.72
11	1.66	8.05	229	3.75
12	0.89	6.63	266	3.63
13	0.76	5.66	238	3.72
13b	0.84	4.42	231	3.77
14	0.76	5.66	221	3.72
15	0.77	10.57	238	3.56
16	0.79	10.08	41	3.66
16b	0.75	10.41	40	3.72
17	0.59	10.52	95	3.45
18	0.85	11.72	58	3.54
19	-	-	-	-
20	1.8	6.65	109	3.47
21	-	-	-	-
22	1.67	9.84	181	3.61
23	1.87	9.48	163	3.66
24	1.86	8.34	237	3.64
25	0.78	8.26	220	3.79
26	1.08	10.09	273	3.56
27	2.24	10.27	162	3.21
28	2.24	10.27	162	3.21
29	1.99	9.12	185	3.3
30	1.22	10.12	158	3.51
31	0.66	8.69	145	3.53
32	1.74	10.42	146	3.65
33	1.25	8.04	190	3.65

Defence	Wave Conditions			
	Wave Height (m)	Wave Period (s)	Wave Direction (°)	Water Level (mODK)
34	1.24	11.03	171	3.61
35	1.43	9.5	142	3.62
36	1.81	8.03	126	3.72
38	2.11	8.99	190	3.52
39	1.72	9.81	166	3.51
40	2.64	10.16	292	3.79
40b	2.67	10.56	291	3.6
41	2.31	10.05	318	3.64
42	0.67	6.81	348	3.64
43	0.74	8.29	323	3.79
43b	0.84	9.12	324	3.74
44	1.09	9.56	301	3.61
45	1.27	10.42	248	3.49
46	0.99	11.57	281	3.71
47	2.09	10.6	271	3.66
48	1.46	8.7	263	3.93
49	1.41	11.91	251	3.54
50	1.4	10.01	303	3.56
51	1.17	10.04	19	3.63

Time series of wave overtopping volumes, representing the wave conditions for each annual exceedance probability event were then derived. In cases where the still water level is at or above the defence crest, resulting in a zero or negative freeboard, the wave overtopping volumes were adjusted to avoid double counting the volume of water overtopping the defence from wave action with that from still water flooding. The volume of water overtopping the defence from still water flooding in TUFLOW is subtracted from the wave overtopping volumes. Figure 4-14 shows the wave overtopping discharge profile for the 0.5% and 0.1% AEP events using UKCP09 predictions for the year 2117 which exemplify the modifications to account of negative freeboard, which is accounted for in TUFLOW via the still-water flooding.

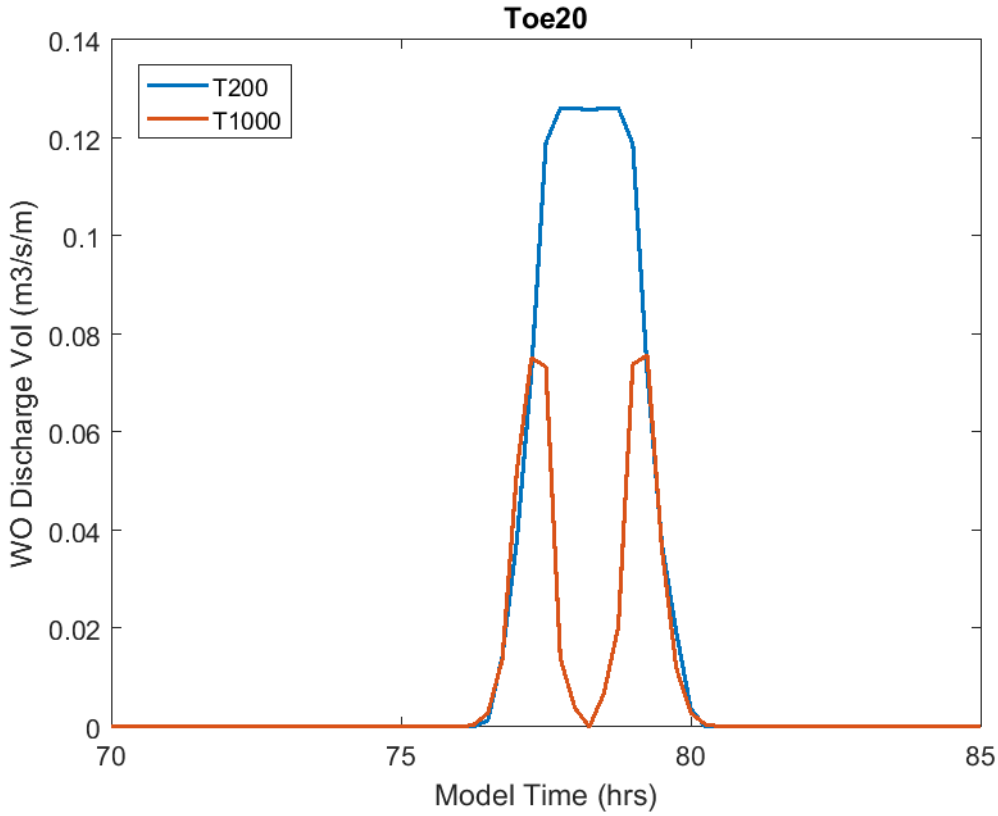

Figure 4-14: Wave overtopping profile at defence 18 (Old Grimsby 4) using toe 20 wave conditions

4.4.3 Validation with hindcast data

The accuracy of the overtopping calculations was assessed through sensitivity testing and by performing a hindcast of wave overtopping between 1994 and 2015. The hindcast was driven by wave and wind data from WW3 point 49 and water levels from St. Mary's gauge: the same data used to derive the statistical dataset. The hindcast analysis enables the identification of the largest events to have caused wave overtopping in the recent past and a comparison against the historical flood records, to confirm that overtopping is being predicted for the events where overtopping was reported. Finally, the hindcast analysis allows a frequency analysis check to provide further information on whether the defences as overtopping as frequently or in-frequently compared against local evidence.

A succession of storms hit the Isles of Scilly between January and March 2014. At the majority of toes, the largest overtopping rate in the hindcast is from one of these storms. Specifically, the largest events occur on the following dates in 2014: 3rd January, 1st, 3rd, 5th and 14th February and 3rd and 31st March. The exceptions are at WO_28, WO_36 and WO_39 the highest overtopping occurred on October 2004; at WO_20 the highest overtopping occurred in January 2001 and at WO_9 highest overtopping occurred 2015. The second largest overtopping rate for all of these toes was in 2014.

4.4.3.1 Replication of historical flooding

To analyse the historical flooding, the ten largest overtopping events from the hindcast data at each defence were extracted along with the dates that these events occurred. These extracted dates were then compared to the known dates of flooding on the islands.

Three events are very common within the extracted dataset, these being the 17/10/2012, 01/01/2014-04/01/2014 and 14/02/2014. The islands are known to have flooded at these times, with the 17/10/2012 and 14/02/2014 being the events chosen to calibrate the flood models with.

4.4.3.2 Frequency analysis

The modelled historical frequency with which overtopping exceeded tolerable discharges was calculated at each defence. The tolerable discharge limits were taken from the EurOtop manual[8]. The thresholds for unaware pedestrian (0.03 l/s/m), aware pedestrian (0.1 l/s/m) and trained staff (l l/s/m) were used. The annual frequencies of exceedance are shown in Table 4-4. The frequency was calculated as the average number of events with an overtopping rate equal or above the threshold per year. Events where selected from a three-hourly interval and hence a single storm maybe represented by more than one 'event'.

Table 4-4: Annual overtopping frequency above safety thresholds for each defence

Defence		Annual overtopping frequency		
		> 0.03 l/s/m	> 0.10 l/s/m	> 1.00 l/s/m
1	Great Porth 1	6.2	1.1	0.1
2	Great Porth 2	2.4	0.6	0.0
3	Great Pool Bryher 1	1.0	0.1	0.0
3b	Great Pool Bryher 2	3.5	1.3	0.0
4	Popplestone	0.0	0.0	0.0
4a	Popplestone A	1.9	0.5	0.0
5	The Town 1	24.2	14.1	4.2
6	The Town 2	12.6	6.7	1.1
7	The Town 3	0.1	0.0	0.0
8	The Town 4	0.0	0.0	0.0
8b	The Town 5	0.1	0.1	0.0
9	Brow Ledge	7.0	3.4	0.5
10	Rushy Bay	3.6	1.0	0.0
11	SW Bryher	191.8	141.4	35.6
12	New Grimsby 1	0.9	0.1	0.0
13	New Grimsby 2	0.4	0.2	0.0
13b	New Grimsby 2b	1.9	1.1	0.3
14	New Grimsby 3	8.1	2.8	0.3
15	New Grimsby 4	33.9	19.1	3.6
16	Old Grimsby 1	8.9	2.5	0.2
16b	Old Grimsby 2	2.2	0.5	0.0
17	Old Grimsby 3	2.4	0.4	0.1
18	Old Grimsby 4	6.9	3.2	0.3
19	Old Grimsby 5	0.0	0.0	0.0
20	Pentle Bay 1	0.2	0.0	0.0
21	Pentle Bay 2	0	0.0	0.0
22	South Tresco	0.4	0.0	0.0
23	Bathinghouse Porth	60.1	33.0	6.9
24	Appletree Bay	0.8	0.1	0.0
25	Great Pool Tresco	2.4	0.7	0.0
26	Karma Hotel	0.2	0.1	0.0
27	Lower Town	1.0	0.3	0.0
28	Higher Town Bay	1.6	0.4	0.2

[8] EurOtop (2007) Wave overtopping of Sea Defences and Related Structures: Assessment Manual. Die Kuste.

Defence		Annual overtopping frequency		
		> 0.03 l/s/m	> 0.10 l/s/m	> 1.00 l/s/m
	West			
29	Higher Town Bay East	0.3	0.1	0.0
30	Porth Hellick 1	21.9	12.0	2.3
31	Porth Hellick 2	0.1	0.0	0.0
32	Porth Minnick	6.6	2.3	0.1
33	Old Town Bay 1	101	3.5	0.3
34	Old Town Bay 2	23.3	16.5	3.4
35	Old Town Bay 3	3.0	1.3	0.1
36	Old Town Bay 4	30.3	18.9	4.9
38	Porthcressa 1	11.9	3.5	0.3
39	Porthcressa 2	5.2	2.4	0.1
40	Hugh Town Pier	56.6	24.3	2.2
40b	Hugh Town Pier B	187.6	126.5	44.4
41	The Mermaid Inn	220.8	151.3	42.3
42	Hugh Town West	211.1	182.2	125.1
43	Hugh Town East	25.7	11.6	1.0
43b	Hugh Town East B	0.4	0.1	0.0
44	Porthmellon Beach	0.1	0.0	0.0
45	Porth Loo 1	0.5	0.1	0.0
46	Porth Loo 2	0.4	0.1	0.0
47	Porth Loo 3	56.6	29.5	5.8
48	Agnes Pool 1	30.1	12.5	0.8
49	Agnes Pool 2	13.1	5.2	0.4
50	Porth Coose	11.5	3.8	0.2
51	Porth Killier	0.2	0.1	0.0

Profiles identified with the most frequent overtopping were profiles 11 on Bryher and profiles 40b to 42 in Hugh Town. Each of these profiles had annual frequencies of over 30 events per year that were exceeding the 'trained staff' threshold of 1.00l/s/m. Profile 11 is in an exposed location on the south west corner of Bryher in Stony Porth. The area is unpopulated, but overtopping contributes to flooding further in land. A low point in the sand dunes was used for the defence crest height and the combination of the low crest and exposed position leads to frequent overtopping. As this area is unpopulated there is no evidence to confirm whether the frequency is correct, but given the location, it appears reasonable. On St Mary's, profiles 40b and 41 are the pier and the wall behind the Mermaid Inn in Hugh Town, this location is known to be regularly overtopped and there are many photographs of this occurring. Profiles 42 is the beach in Hugh Town, as shown in Figure 4-15; this profile has a very low crest level, below the level of the 100% AEP extreme sea-level. The crest was taken at the foot of the houses at the back of the beach. Given the low crest, the frequency of overtopping is reasonable.

Figure 4-15: Profile 42, beach at Hugh Town

4.5 TUFLOW flood inundation modelling

Five new 1D-2D ESTRY-TUFLOW flood inundation models were constructed to model the flood risk on the five main islands of the Isles of Scilly; Bryher, Tresco, St Agnes, St Mary's and St Martins. The models were used to simulate a range of design AEP present day and climate change events, incorporating both still water conditions and wave overtopping conditions. This output is intended to update Flood Warning Areas and flood intelligence files. A model development report providing a detailed technical summary for the new 1D-2D ESTRY-TUFLOW flood inundation model is provided alongside this summary report. This section provides an overview of the flood inundation modelling carried out for this study.

4.5.1 Model Setup

A single TUFLOW control file (tcf) was used for each model. This tcf specifies all the event scenarios required for this study reducing the likelihood of typographical errors in the control file set up, as well as reducing the number of model run files required.

4.5.1.1 Active area

With a 5m grid resolution, a single model covering the full area of the Isles of Scilly was considered too large to be workable due to the large number of wet cells. There is only one extreme water level available in the Coastal Flood Boundary dataset for the Isles of Scilly, and as such, modelling the five main islands separately would not compromise model accuracy.

The TUFLOW domains for each model cover the whole circumference of the five modelled islands. The total area of the TUFLOW model domains range in size from 2.4km^2 for St Agnes to 9.7km^2 for St Mary's. The model domain extents are summarised in Figure 4-16.

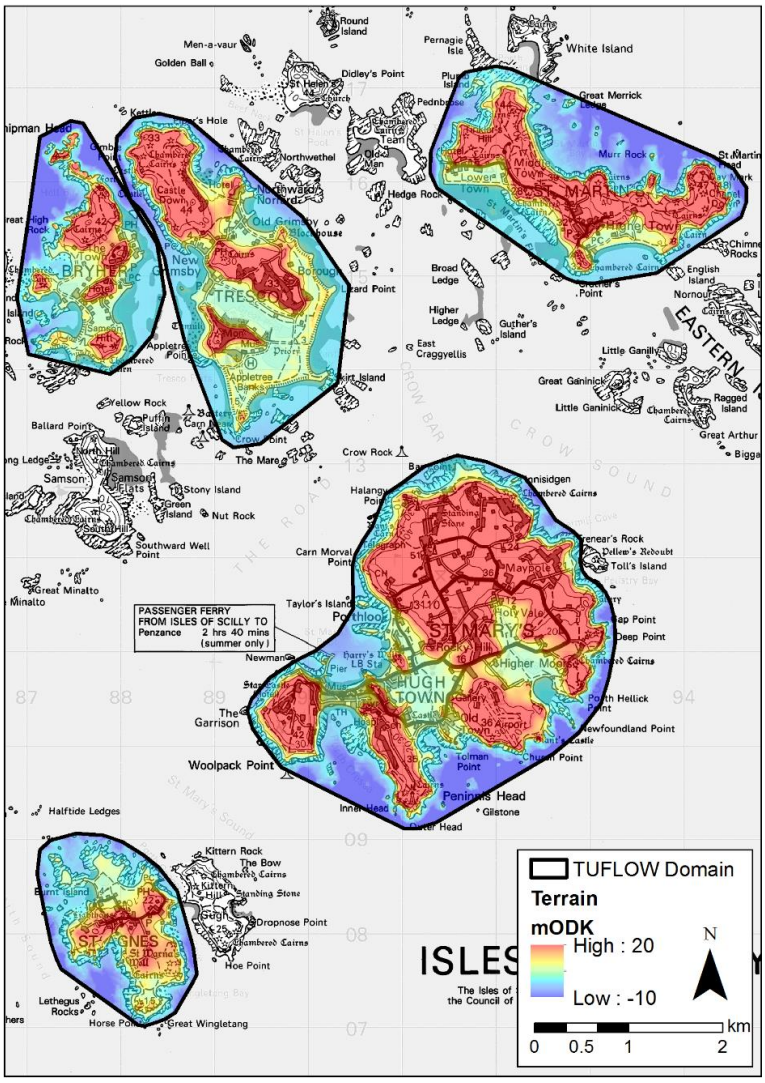

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Figure 4-16: The five Isles of Scilly model domains

4.5.1.2 Model Orientation

The grid orientation of the models are aligned to the dominant flow paths for the key communities on each island.

4.5.1.3 Model grid cell size

A 5m model grid cell size was adopted for all five models. A 5m grid size is detailed enough that important flow paths across the floodplains will be represented. As is often the case with 2D modelling, greater detailed could be achieved using a finer grid resolution, but this would risk longer model simulation times and larger model results files.

4.5.1.4 Model DTM

The five TUFLOW models DTM comprises three separate sources of data:

- LIDAR data for the Isles of Scilly, 1m resolution, supplied by the Environment Agency through Open Source, flow in 2015. Provides the detailed depiction of the land environment.
- Channel Coastal Observatory singlebeam bathymetry data, 1m resolution, downloaded from the CCO website December 2016. Provides the detailed depiction of the nearshore bathymetry.
- Coarse resolution SeaZone bathymetry survey data for offshore areas only. TruDepth Grids 25m resolution.

The three datasets were required because no single dataset provided complete coverage of the model area. GIS interpolation techniques were utilised to merge the three separate datasets together, using ztin polygons. GIS interpolation techniques were also used in situations where the coverage of incomplete datasets. All datasets are in Ordnance Datum K (ODK), the vertical datum used in this project.

4.5.1.5 Model roughness

Roughness values have been defined based on OS MasterMap data. This model has used eight separate categories to define roughness values for the model domain.

Table 4-5. Bed and floodplain roughness values for the TUFLOW model

Manning's n	Topography Category	Land Type
0.300	1	Buildings
0.100	2	Structures
0.030	3	Inland and Coastal Water
0.070	4	Natural Surface and Gardens
0.025	5	Manmade Surface Roads and Paths
0.100	6	Trees, Roughland and Scrub
0.046	7	Marsh, reeds or saltmarsh
0.030	10	Default floodplain value

4.6 Topographical modifications

4.6.1 Defence representation

The coastline of the five modelled islands has very few hard defence structures. It is dominated by beaches, embankments, sand dunes and cliff faces. Topographical modifications were used to incorporate the crest heights of the various defence types in place on the five islands. The model development report provides technical information of the approach used to model these defences and the origin of the data used for each defence. Table 4-6 summarises the defence represented in the five TUFLOW models.

Table 4-6. The defence representation on Bryher, Tresco, St Agnes, St Mary's and St Martins

Island	Location	Defence
Bryher	Great Porth	The raised defence lining the back of Great Porth beach
	Great Pool	The channel connecting Great Pool lake to the culvert (linking the channel to Great Porth bay)
	The Town	Bryher to St Mary's/Tresco Ferry Terminal
Tresco	New Grimsby	Wall lining New Grimsby Quay and the dock
	Old Grimsby	Dock at Old Grimsby Harbour
	Carn Near Road	Tresco to St Mary's/Bryher Ferry Terminal
St Agnes	Porth Coose	Embankment lining back of beach (north and south of rocky outcrop)
	Porth Killier	Embankment lining back of beach
	Porth Conger	St Agnes to St Mary's Ferry Terminal
St Mary's	Hugh Town	St Mary's Isles of Scilly Terminal. The wall lining the north-west edge of the terminal dockside. The raised walkway lining the back of the beach.
	Porthmellon Beach	The walls, embankment/sand dune lining the back of Porthmellon beach. The walkways through these embankments.
	Porth Loo	Raised embankment at the back of Porth Loo beach.
	Porth Hellick	Raised embankment/sand dune lining the back of

Island	Location	Defence
		Porth Hellick beach. Channel connecting the lake to the culvert (linking the channel to Porth Hellick bay.
	Old Town Bay	Wall lining Old Town Road
	Porth Cressa	Promenade lining the back of Porth Cressa beach (east of the rock outcrop). Wall lining the back of Porth Cressa beach (west of rock outcrop).
St Martin's	Lower Town	Karma St. Martin's Hotel, raised defence demarking the line between the hotel gardens and the beach.
	Higher Town Bay	St Martin's to St Mary's Ferry terminal

4.6.2 Undefended representation

For the undefended scenarios, defences with a raised elevation compared to the base terrain level and/or were considered to prevent or hinder the movement of still water levels were removed. Figure 4-17 show the lower base topography used when the defence has been removed from the model.

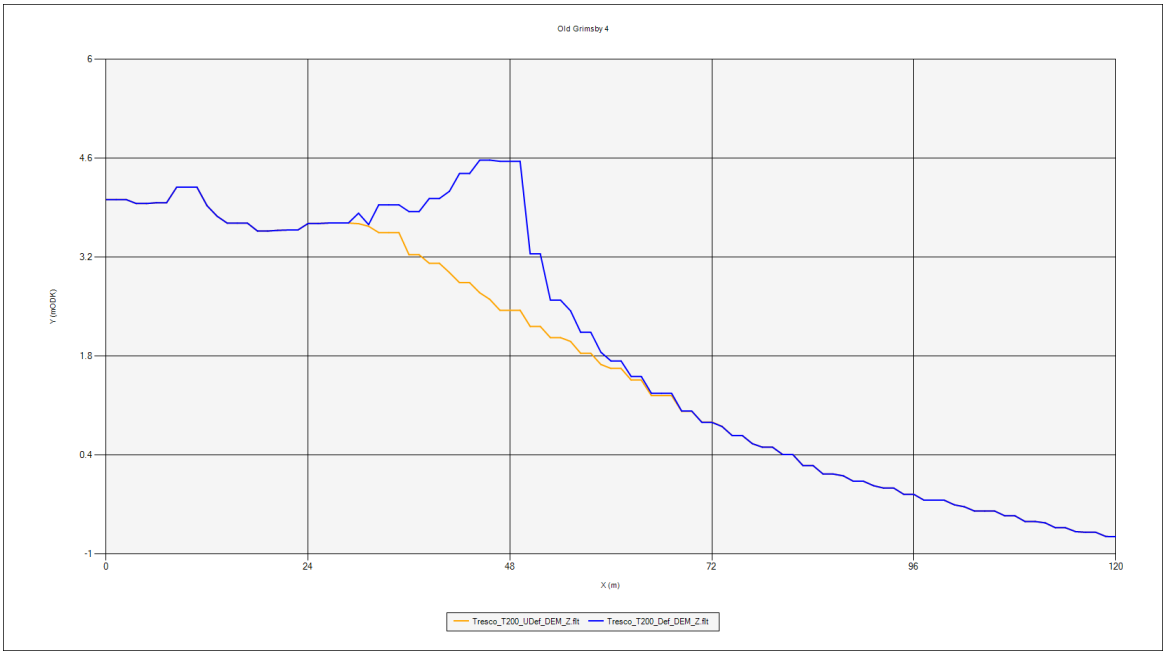


Figure 4-17: Comparison of defended and undefended modelled DTM at New Grimsby 4

In addition to the removal of defences represented in the TUFLOW model, defences were also altered for the wave overtopping calculation process, to derive new wave overtopping volumes for lowered or altered defences. Table 4-7 shows the defence altered for the wave overtopping calculation process for the undefended scenario.

Table 4-7. The defences altered in the WO calculation process for the undefended scenario

Island	WO profile	Defence	Alteration
Bryher	7	The Town 3	Reduced bank level to level behind bank
Bryher	8	The Town 4	Reduced to ground levels behind defence
Tresco	12	New Grimsby 1	Removed defence wall and armour crest width
Tresco	14	New Grimsby 3	Crest level reduced to height of road
Tresco	15	New Grimsby 4	Crest level reduced by height of defensive wall

Island	WO profile	Defence	Alteration
Tresco	17	Old Grimsby 3	Wall removed from schematisation and crest set to base of wall
St Marys	33	Old Town Bay 1	Reduced crest level by height of defensive wall
St Marys	34	Old Town Bay 2	Reduced crest to match road level
St Marys	35	Old Town Bay 3	Reduced crest to armour crest level
St Marys	36	Old Town Bay 4	Reduced crest by height of wall
St Marys	38	Porth Cressa 2	Removed armour crest width
St Marys	41	The Mermaid Inn	Reduced crest by height of wall
St Marys	42	Hugh Town West	Lowered crest level
St Marys	43b	Hugh Town East B	Reduced wall height to road level
St Marys	45	Porthloo 1	Reduced crest to match armour crest
St Marys	46	Porthloo 2	Removed raised bank
St Agnes	51	Porth Killier	Removed embankment

4.6.3 Building representation

To represent buildings within the model the following options are available to TUFLOW modellers, as discussed in Engineers Australia, 2012[9]:

- Increased model roughness for building footprints;
- Blocking out of model elements;
- Modelling of exterior walls partially or in full;
- Using energy loss coefficients within the footprint; and
- Modelling buildings as porous elements.

For this project buildings were given an increased Manning's n roughness value of 0.30 to account for the tortuous flow path taken by water through these features. The building footprints were also increased by 0.3m.

The 2012 paper by Engineers Australia states that whichever method of building representation is used, the impact of flow volume stored within buildings is insignificant. It concludes any of the methods above, if applied correctly, are adequate for estimating peak water levels when the grid resolution is below 10m. A grid size of 2m or less is required for accurately representing flow vectors around each building. For the current project the model is required to estimate peak design levels for the five main islands of the Isles of Scilly and as such the use of a 5m grid is appropriate.

4.6.4 Culvert Data

Culverts were included in two of the five models, one rectangular culvert on St Mary's and two rectangular culverts on Bryher. The culvert on St Mary's Island is at Porth Hellick Bay, running through the embankment lining the back of the beach connecting Porth Hellick Bay to a channel leading to an inland lake. The two culverts on Bryher are at Great Porth and Brow Ledge. The culvert at Great Porth runs under the raised embankment at the back of the beach connecting Great

9 Engineers Australia (2012). Revision Project 15: Two dimensional simulations in urban areas; representation of buildings in 2D numerical flood models. *Australian Rainfall and Runoff.*

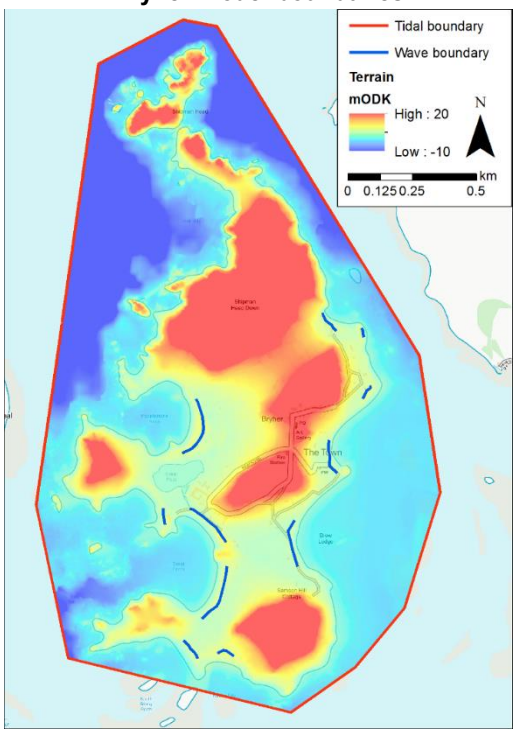
Porth bay to a channel leading Great Pool lake. The culvert at Brow Ledge runs under the sand dune at the back of the beach connecting Brow Ledge bay to an inland drain.

4.6.5 Model Boundaries

Two types of hydraulic boundaries were required for the numerical modelling for the Isles of Scilly modelling study (Figure 4-18). These boundaries include:

- One still water boundary, located offshore encircling the full circumference of the modelled island, allowing propagation of the tide and surge into the model domain.
- Wave overtopping boundaries along the coastal frontage, which inject wave water into the model at the location of the flood defences.

Bryher model boundaries



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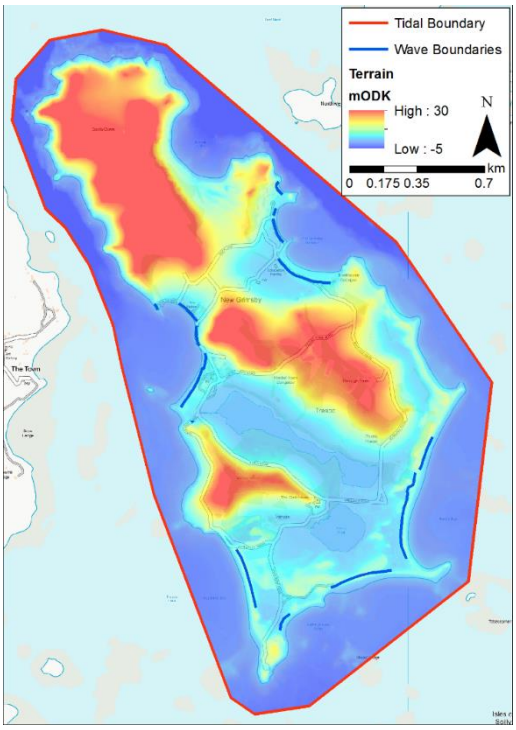
Tresco model boundaries



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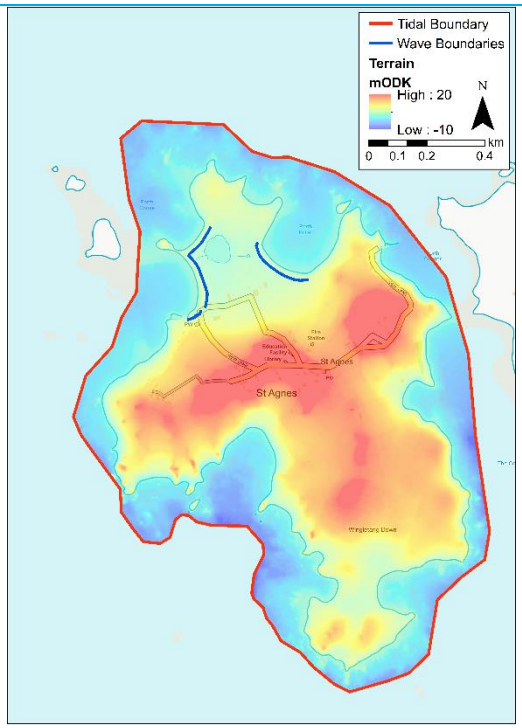
St Agnes model boundaries



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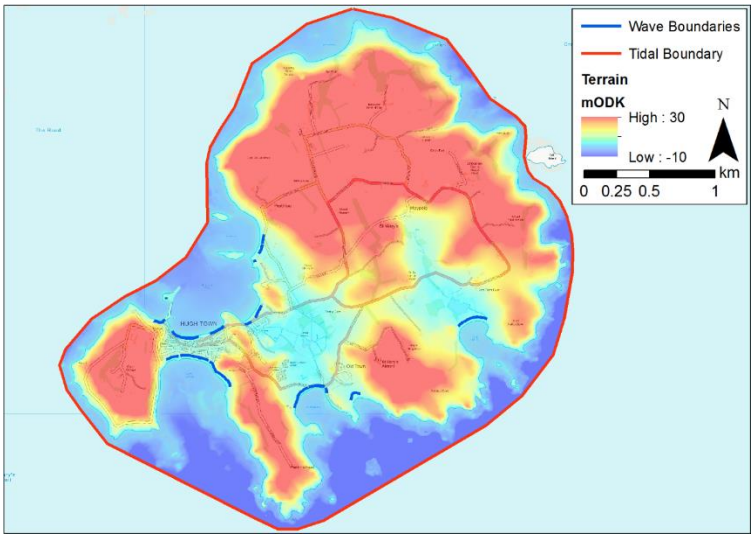
St Mary's model boundaries



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St Martin's model boundaries

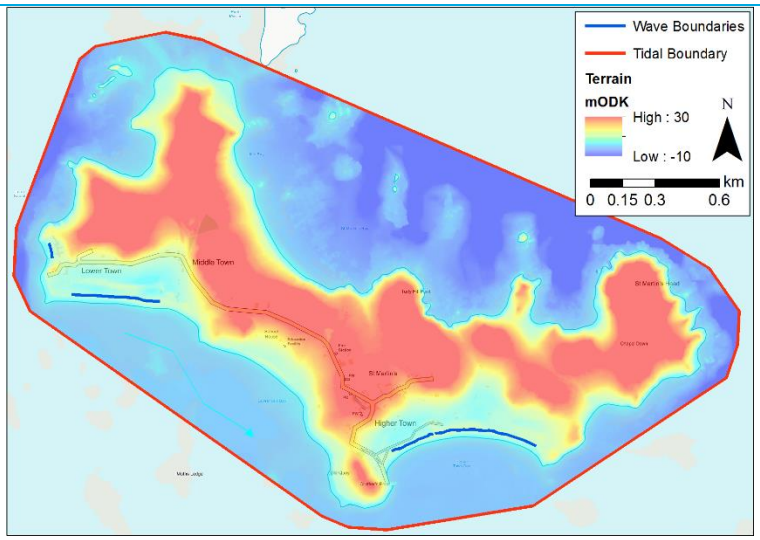

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Figure 4-18: Isles of Scilly model boundaries

4.6.5.1 Tidal Boundary

The tidal boundaries are located offshore, encircling the full circumference of the modelled island, orientated to the main direction of flow for the key island communities. The tidal boundary does not need to tie into high ground because it is fully encircling the island, and as such will not experience the glass walling effect.

Design tide curves were generated for 11 Annual Exceedance Probability (AEP) present day 2017 events and the AEP climate change events for EPOCs 2067 and 2117. There is only one dataset of tide levels available for the Isles of Scilly and as such, all models use the same tide data at the tidal boundary (Table 4-8). This process of generating design tide curves used information from three principal sources.

- Extreme still water sea-level estimates. Extreme still water sea-level estimates were obtained from the Coastal Flood Boundary Dataset (CFBD) [10] at the Isles of Scilly (Chainage ELS 0). These estimates are provided for a baseline year of 2008, updated to account for sea-level rise to the year of project start (2017) using the UKCP09 95 percentile medium emission scenario data. The sea level estimates for 2067 and 2117 were calculated using UKCP09 allowances[11], increasing by 0.351m (2017 - 2067) and 0.812m (2017 - 2117). NPPF allowances increased water levels by 1.04m (2017-2117).
- A design astronomical tide. For this, a Highest Astronomical Tide (HAT) at St Mary's Class-A Tide Gauge was extracted from the Admiralty Tide software and corrected from Chart Datum (CD) to Ordnance Datum (m OD): -2.91m).
- A design surge shape. This study has used the latest coastal extreme guidance for the UK, from the CFBD project. Surge profile number 18 (St Mary's) was selected to derive tidal curves for this study.

Table 4-8. Extreme sea-level estimates for the Isles of Scilly

AEP (%)	RP	Site CFB Chainage ESL0 - Extreme still water level (mOD)			
		2015	UKCP09 2067	UKCP09 2117	NPPF 2117
50	2	3.51	-	-	-
20	5	3.59	-	-	-
10	10	3.64	-	-	-
5	20	3.69	-	-	-
4	25	3.71	-	-	-

10 Environment Agency (2011) 'Coastal flood boundary conditions for UK mainland and islands - SC060064

11 Department for Communities and Local Government (2012) 'Technical Guidance to the National Planning Policy Framework'

AEP (%)	RP	Site CFB Chainage ESL0 - Extreme still water level (mOD)			
		2015	UKCP09 2067	UKCP09 2117	NPPF 2117
3.33	30	3.72	-	-	-
2	50	3.75	-	-	-
1.33	75	3.78	-	-	-
1	100	3.80	4.15	4.61	-
0.5	200	3.84	4.19	4.65	4.88
0.1	1000	3.95	4.30	4.76	-

Environment Agency guidance[12] was followed to develop tidal curves for the Isles of Scilly. The peak of the design surge profile was aligned to coincide with the low tide level before the maximum peak of the HAT to generate the tidal profile. The design surge profile was multiplied by a growth factor and added to the HAT to form a new tide curve for each event. An example plot of a generated tide curve, for the 0.5% AEP 2017 tidal event, showing the surge profile and the influence of surge on the HAT tide is provided in Figure 4-19. The CFB guidance allows the placement of the surge peak at any point from low to high tide. In this instance, aligning the peak surge with the trough increases the overall volume of the tide graph by a greater volume than aligning the peak surge with the peak tide. Alignment with the trough was therefore chosen as it was the more conservative option.

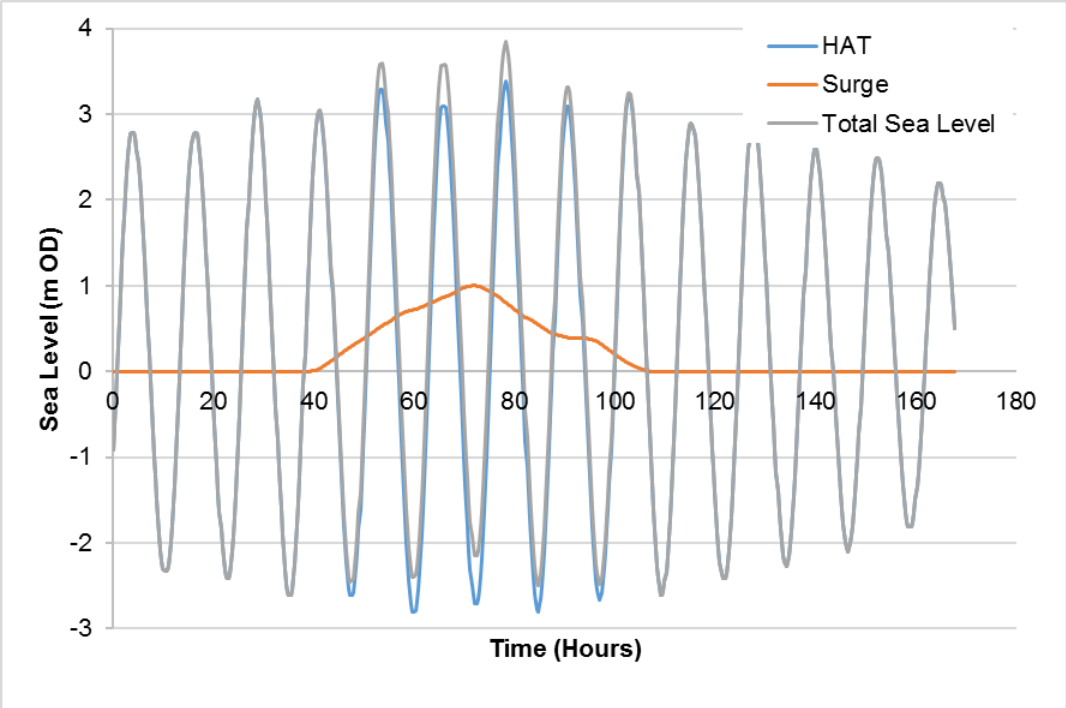

Figure 4-19: Design tidal-graph for a 0.5% AEP event (2017) based on CFB chainage point 0 at St Mary's.

The best practice guidance recommends that three tidal cycles are modelled for tidal inundation studies, with the tidal peak occurring during the second cycle. This practice has been followed in the model update.

4.6.5.2 Fluvial boundaries

No fluvial boundaries were included in this model.

12 Environment Agency (2011) 'Using the national coastal flood boundary data for the coasts of England and Wales: Operational Instruction 490_11'.

4.6.5.3 Wave overtopping boundaries

A total of 51 separate wave overtopping boundaries have been included over five models, 11 on Bryher, 14 on Tresco, 4 on St Agnes, 18 on St Mary's and 4 on St Martin's. The wave overtopping boundaries were placed on the landward side of the flood defences to allow the flow propagation inland.

4.6.6 Model verification

It was originally planned that the modelling would be verified against three historical flooding events. Tide gauge data at St. Mary's is only available between 23 June 1994 and 11 May 2015. Tide gauge data is required along with the WW3 hindcast data to provide boundary conditions for the modelling. Hence the historical events must occur between 1994 and 2015 to be modelled. The Council of the Isles of Scilly only have data on the impacts of two flood events in this period: 14 February 2014 and 17-18 October 2012. Therefore, as agreed with the Environment Agency, two instead of three historical flooding events were simulated.

Breaching of defences is common on the Isles of Scilly as most of the defences are natural sand banks and this is a significant source of flood risk. The location of breaches is highly variable for example over the last few years there have been several breaches on St. Agnes but each has occurred at a different location. Due to unpredictability of breaching and the lack of information on breach locations, dimensions and the period of time over which the defence failed, it has not been modelled. The modelling was calibrated against the flooding that occurred on 14 February 2014. Breaching occurred on three islands: St. Mary's, St Agnes and Bryher during this event. These breaches have not been included in the modelling and the underestimation of flooding serves as an example of the underestimation in the design events due to the absence of this important but unpredictable process.

4.6.6.1 Model Calibration: 14 February 2014

The model was calibrated against the coastal flooding that occurred on the 14th February 2014. The storm event caused flooding on each of the five inhabited islands, it also caused coastal erosion. The majority of flooding was from overtopping but in some locations sea defences were breached. Breaches occurred on St. Mary's at Porth Mellon (beach access), Wheelhouse slipway at Porthcressa and Porthloo bank. Defences were also breached at Periglis on St. Agnes and Great Porth and Brow Ledge on Bryher. On Bryher, still water flooding also occurred. No observational wave overtopping volume data is available to compare the modelled wave overtopping results against. Instead the wave overtopping schematisations and TUFLOW model setup were calibrated against photographs and anecdotal information on the flood extents and depths.

4.6.6.2 Calibration results Bryher

In February 2014, flooding on Bryher was caused by wave overtopping and still water flooding through breached defences in Great Porth and Brow Ledge. The maximum modelled flood depths across Bryher are shown in Figure 4-20.

Figure 4-21 shows the observed flooding of the lowland behind Great Porth and Figure 4-22 shows the model results in this area. Behind Great Porth, the maximum modelled flood depth was 0.8m in the low-lying areas, which is lower than observed. This is to be expected as the breaches that occurred during 2014 were not included in the simulation due to a lack of information on the breach dimensions and the period over which the defence failed. The results give an example of the underestimation of flood risk in the design events due to the absence of breaching, which is common on the Isles of Scilly. Where a breach occurs, these are usually repaired by local residents and information on the actual number of breaches is hard to obtain.

The bi-directional culvert between Great Pool and Great Porth allowed seawater to flow into Great Pool during the event. Water which overtopped the defences along the south coast ran back to sea in the modelling.

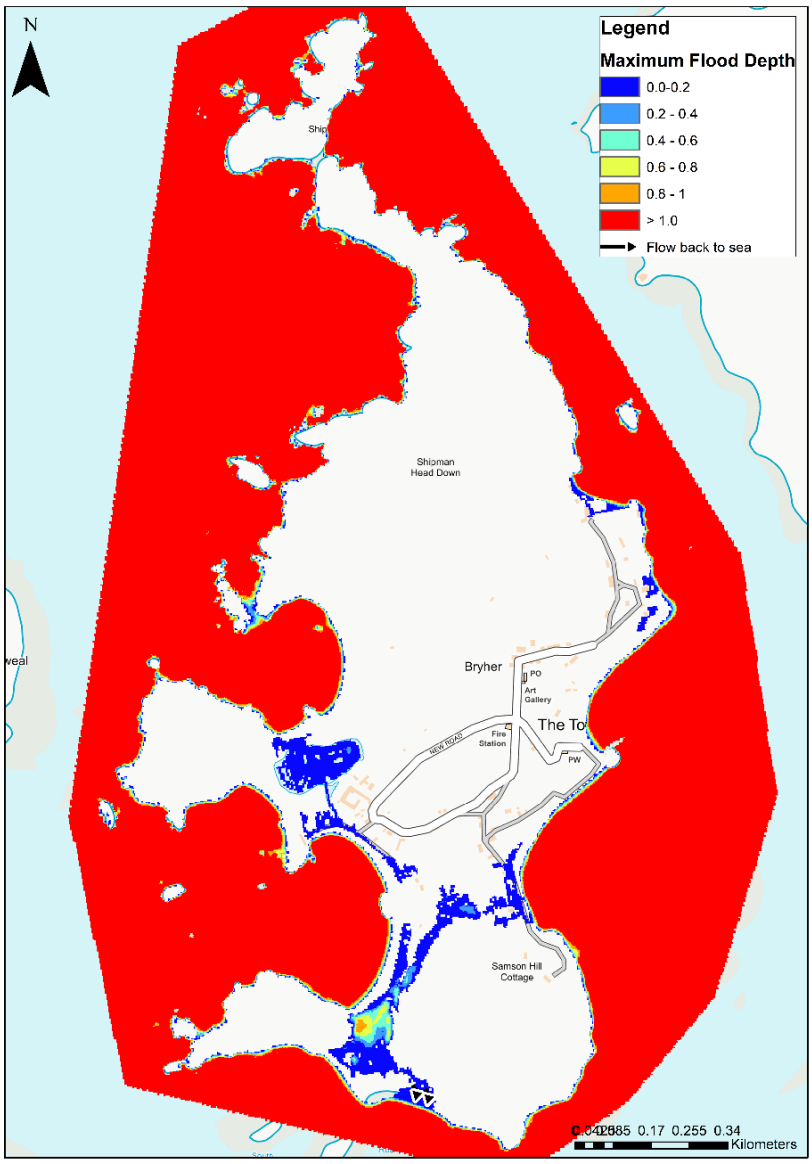

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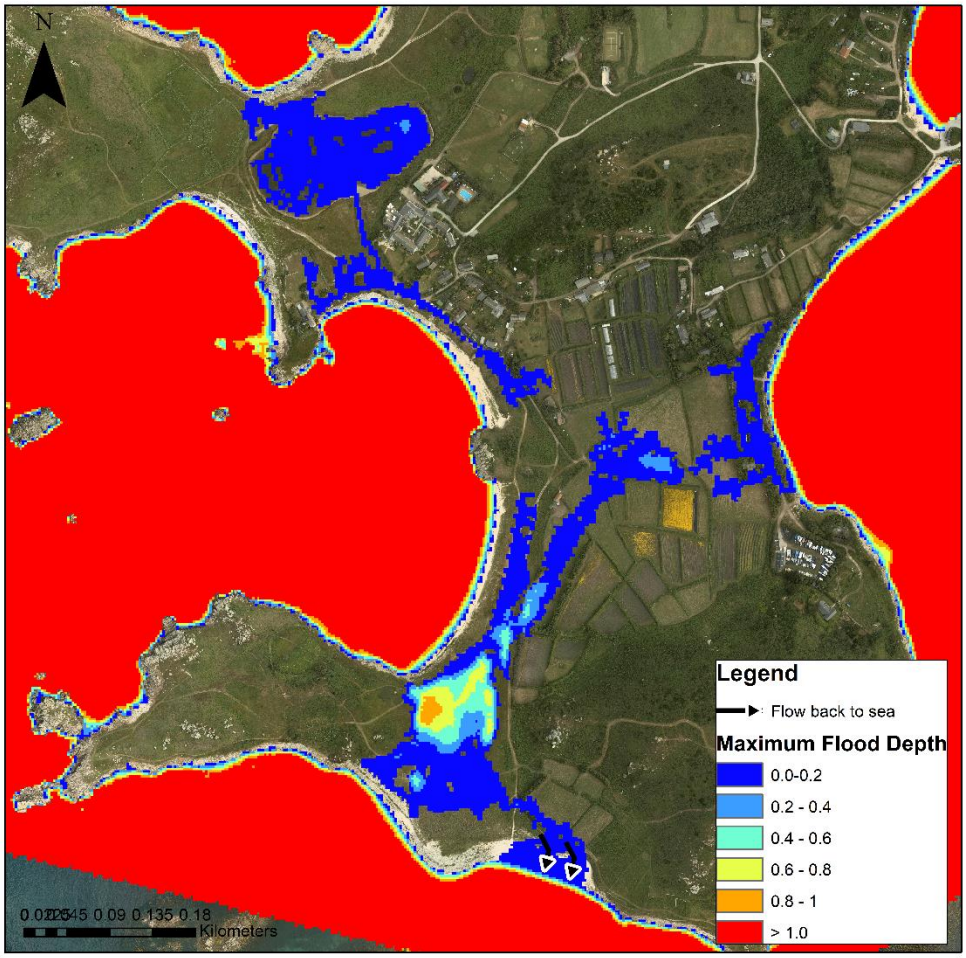
Figure 4-20: Maximum flood depths across Bryher

Figure 4-21: Photograph of the flooding of the lowland behind Great Porth (courtesy of Gareth Tibbs)



Aerial image courtesy of Channel Coastal Observatory

Figure 4-22: Maximum modelled flood depths in South Bryher

4.6.7 Calibration results St. Agnes

In February 2014, flooding resulted from breaching of the defences at Periglis on St. Agnes. This breach was not included in the modelling and consequently the flood depths around this area are underestimated. The results give an example of the underestimation of flood risk in the design events due to the absence of breaching, which is common on the Isles of Scilly.

In February 2014, Troytown Farm campsite was completely inundated after 120m of dry wall was knocked over[13]. Overtopping is not being calculated for this location and no breach was included in the modelling therefore in the model results (shown in Figure 4-23) this area is dry. Wave overtopping was calculated at four locations along the north coast: Porth Cosse, Porth Killier and two profiles around Agnes Pool. The modelling shows overtopping at every defence during the 14 February 2014 as recorded in the flood history. The maximum overtopping rates were 0.242 l/s/m, 0.041 l/s/m, 0.065 l/s/m and 0.012 l/s/m respectively. The inundation modelling shows this overtopping running into Agnes Pool. As overtopping volumes are very small they lead to model flood depths of around 0.01m, which would likely be absorbed by the grass coverage and thus not flow into the lake.

[13] http://geographical.co.uk/nature/climate/item/1481-scilly-s-changing-climate

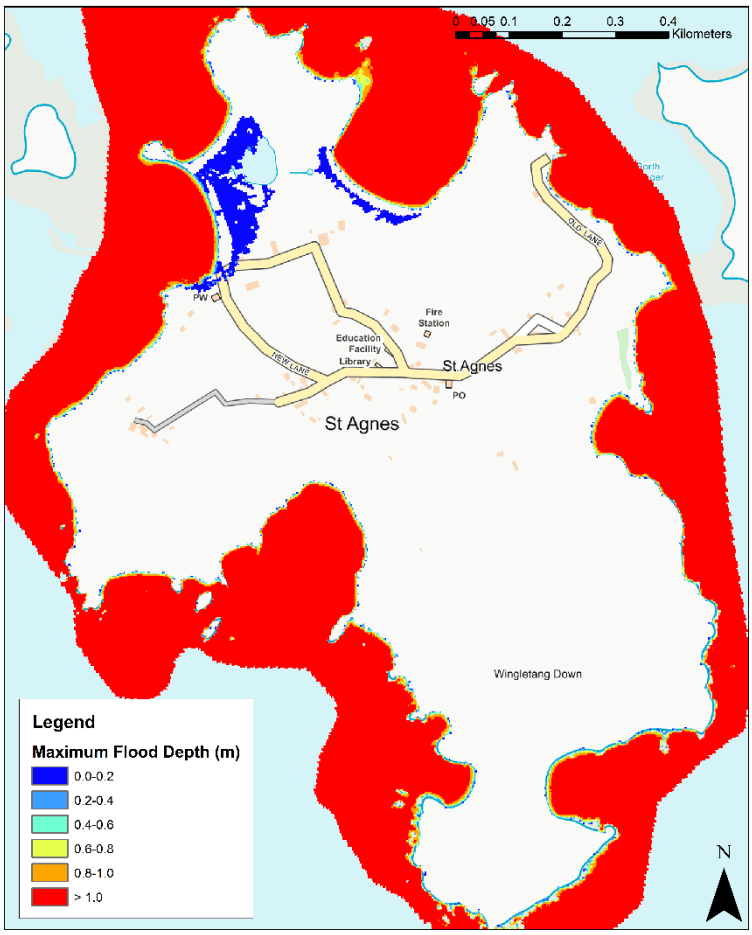


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Figure 4-23: Maximum flood depths across St. Agnes

4.6.8 Calibration results St. Martins

In February 2014, wave overtopping caused significant erosion of St. Martin's[14] coastline but no flooding was reported[15]. Wave overtopping was calculated for four locations in St. Martin's: Karma Hotel, Lower Town Beach and two profiles for Higher Town Bay. The wave overtopping was calculated based on a static beach profile and thus does not represent flooding caused by coastal erosion. The maximum modelled flood depths are shown in Figure 4-24.

Zero wave overtopping was predicted at the Karma Hotel. All model flooding was caused by wave overtopping and flood depths are generally very shallow. The maximum flood depth in Lower Town is 0.05m. Generally, flood depths in Higher Town are also less than 0.05m, however, water does pool behind the western side of the Bay leading to deeper flood depths.

The maximum wave overtopping rates were 0.022 l/s/m, 1.164 l/s/m and 0.107 l/s/m for Lower Town, Higher Town West and Higher Town East respectively and were associated with wave heights of 1-2m. According to the guidance on overtopping thresholds[16] higher overtopping rates (above 5 l/s/m) would be required with these wave heights, to cause structural damage on grass covered crests were the grass is maintained. However, if the grass is not maintained and there are open spots, moss or bare patches, then overtopping rates of 0.1 l/s/m upwards can cause structural damage, with these wave heights. Hence the modelling results are consistent with erosion on the western side of Lower Town Bay.

[14] http://geographical.co.uk/nature/climate/item/1481-scilly-s-changing-climate
[15] Julian Pearce, Council of the Isles of Scilly.
[16] EurOtop, 2016. Manual on wave overtopping of sea defences and related structures. An overtopping manual largely based on European research, but for worldwide application. Van der Meer, J.W., Allsop, N.W.H., Bruce, T., De Rouck, J., Kortenhaus, A., Pullen, T., Schüttrumpf, H., Troch, P. and Zanuttigh, B., www.overtopping-manual.com.

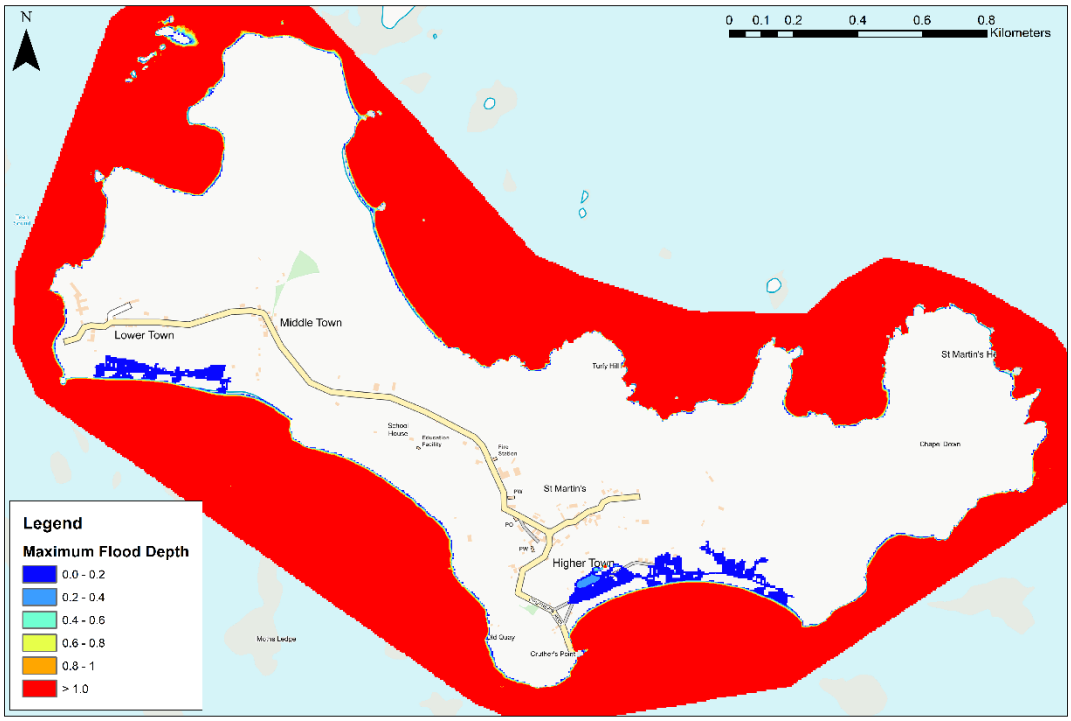

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Figure 4-24: Maximum flood depths across St. Martin's

4.6.9 Calibration results St. Marys

Several areas in St. Mary's were affected by the storm on 14 February 2014. Wave overtopping was modelled in Porthloo, Porthmellon, Hugh Town, Porthcressa, Old Town Bay, Porth Minnick and Porth Hellick, the resulting maximum flood depths are shown in Figure 4-25.

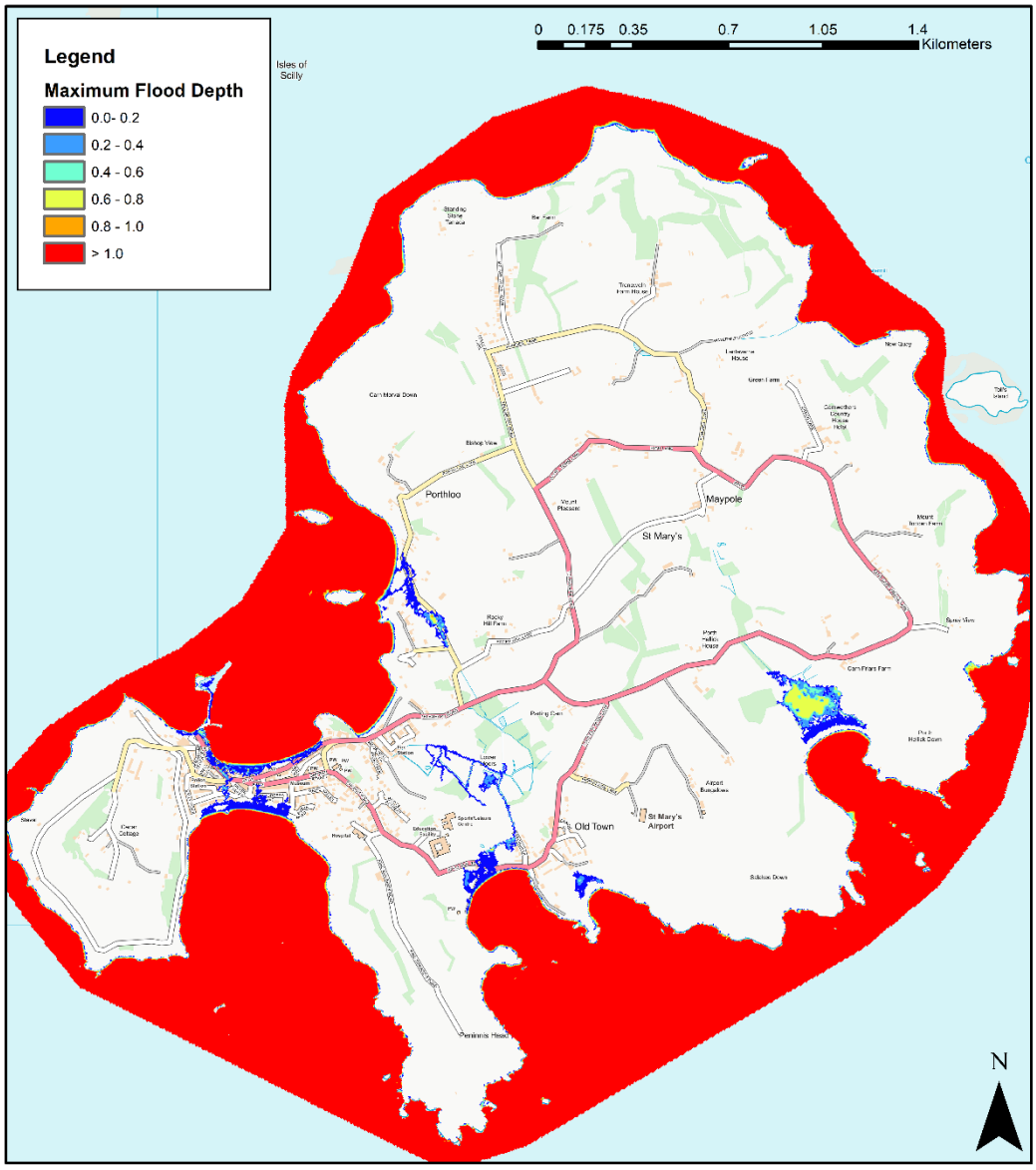

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Figure 4-25: Maximum flood depths across St. Mary's

In Porthloo, the bank was eroded by overtopping as shown in Figure 4-26. The modelling correctly predicted wave overtopping in the centre of the Bay. The maximum wave overtopping rate was 3.6 l/s/m associated with a nearshore significant wave height of 1.77m. This wave height and overtopping rate are consistent with the damage caused[17], assuming the grass was not in perfect condition.

[17] EurOtop, 2016. Manual on wave overtopping of sea defences and related structures. An overtopping manual largely based on European research, but for worldwide application. Van der Meer, J.W., Allsop, N.W.H., Bruce, T., De Rouck, J., Kortenhaus, A., Pullen, T., Schüttrumpf, H., Troch, P. and Zanuttigh, B., www.overtopping-manual.com.

Figure 4-26: Erosion of Porthloo bank following 2014 storms (photo courtesy of Duchy of Cornwall)

The modelling shows flooding in the south of Porthloo from overtopping (Figure 4-27), with depths up to 0.86m, this agrees with observations of quite significant overtopping in this location[18]. There were also breaches in the defence at Porthloo and Porth Mellon which resulted in additional (more substantial) flooding in those areas. The observed flood waters at Porthloo drained to both the north west, into the sea and to the south east across to the Lower Moors and into the sea at Old Town. Modelled flood waters do make their way inland towards the Lower Moors however, there is insufficient flood water to flow all the way to Old Town. This difference is caused by the breaches at Porthloo not being included and hence less water is able to make its way beyond the defence.

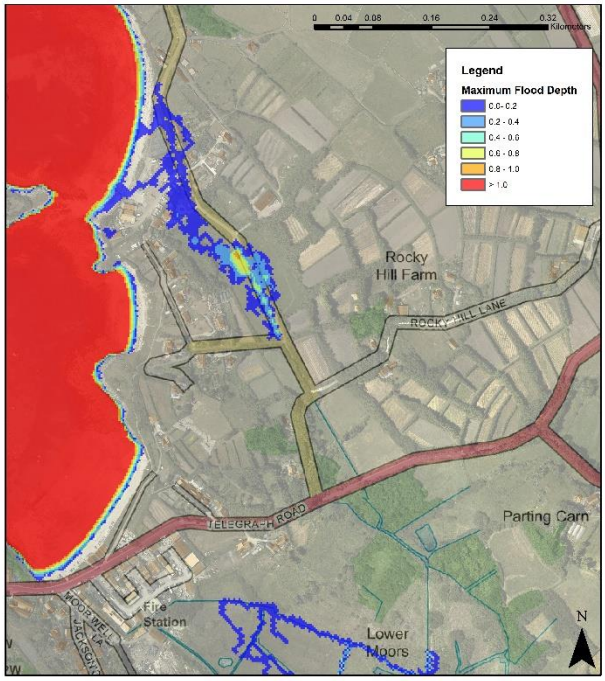

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Figure 4-27: Maximum flood depths in Porthloo

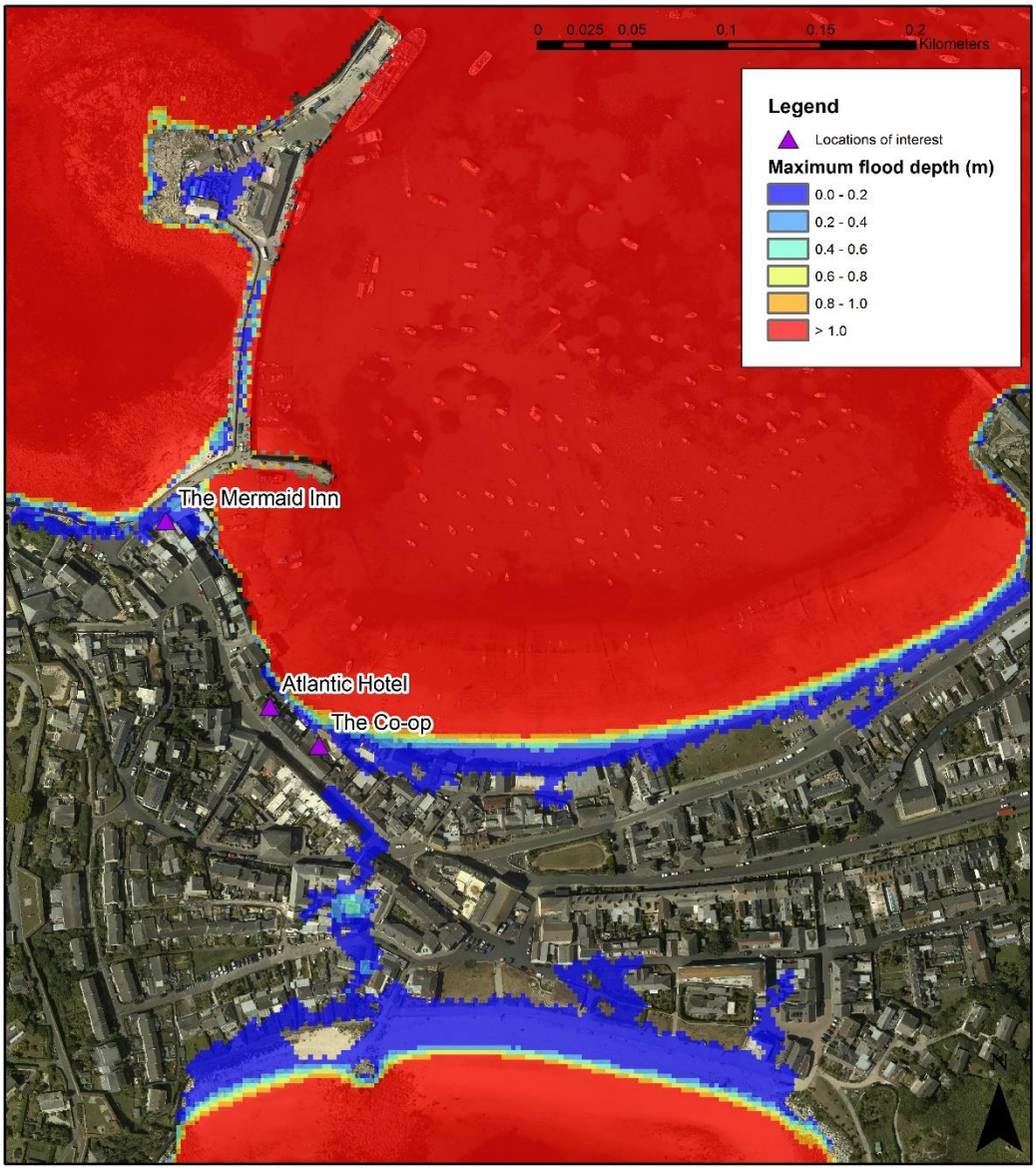
Flooding was recorded on the slipway at Porthmellon, the modelling here does not match the flood history, zero wave overtopping was calculated and the still water level does not appear to reach the back of the beach (as shown in Figure 4-28). This may be due to differences in the beach levels during the storm compared to the model. The model overtopping is based on surveyed beach levels from September 2015, the TUFLOW model beach (affecting the still water line) is based on 2015 CCO LIDAR.

[18] Source: Julian Pearce, The Council of the Isles of Scilly.

Figure 4-28: Flooding of the slipway at Porthmellon (photo courtesy of Barefoot Photographer)

Significant overtopping was photographed at the Mermaid Inn (shown in Figure 4-29) and the Atlantic hotel flooded. Figure 4-30 shows the modelled flooding in Hugh Town. Overtopping occurs over the sea wall beside the Mermaid Inn, in agreement with the observations. The Atlantic hotel was also flooded as were several other properties in the centre of the bay including the rear of the Co-op.

Figure 4-29: Overtopping of Mermaid Sea Wall (photo courtesy of the Duchy of Cornwall)



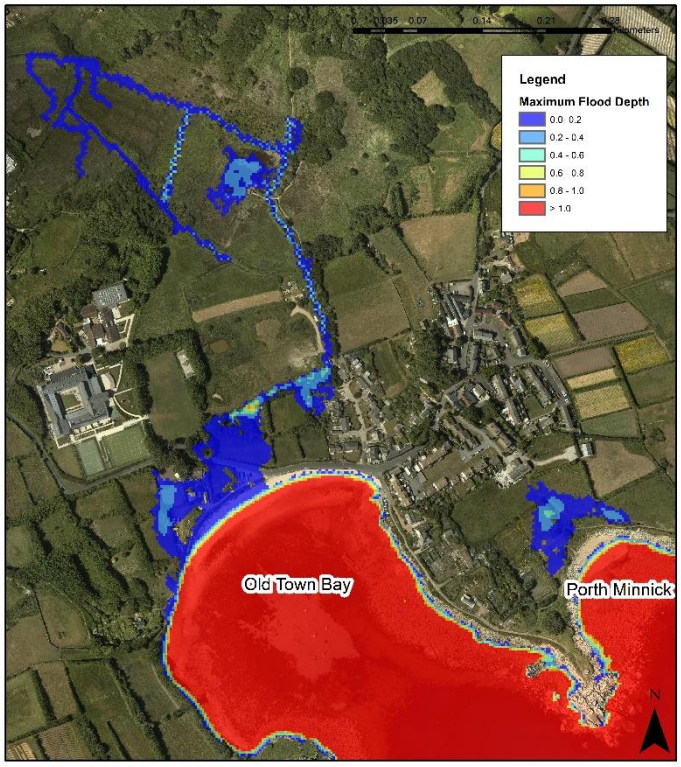
Aerial image courtesy of Channel Coastal Observatory

Figure 4-30: Maximum flood depths in Hugh Town and Porthcressa

Photographs (Figure 4-31) show waves overtopping the sea wall in Porthcressa and inundating the land behind. Photographs after the event show the damage caused to the seawall and slipway. The wave overtopping and inundation is reproduced by the modelling, as shown in Figure 4-30. Overtopped water from Porthcressa flows through the network of streets and onto Hugh Street where the flood depths are 0.1m. This modelled flow path may be unrealistic as water is shown flowing through buildings to reach Hugh Street. This is one of the limitations of TUFLOW with the buildings only being simulated as 0.3m high which allows water to pass over them, as is seen in this case.

Figure 4-31: Wave overtopping Porthcressa (left) and inundation (right) source: A. Martin private photograph 14/02/2014

No flood history was found for Old Town Bay or Porth Minnick, the modelled flooding is shown below in Figure 4-32. The modelled flood depths are shallow. The model does not take account of the local draining systems or infiltration and is these processes were modelled, there may have been no flood risk shown for this location.

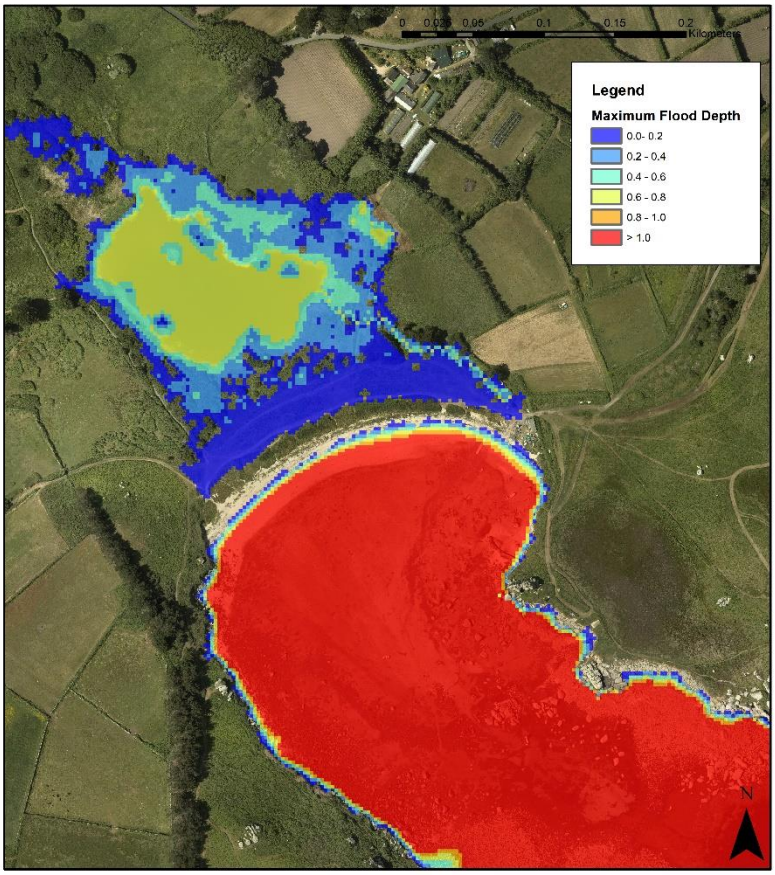


Aerial image courtesy of Channel Coastal Observatory

Figure 4-32: Maximum flood depths in Old Town Bay and Porth Minnick

In 2014, water which overtopped the dunes at Porth Hellick, flowed into the fresh water lake[19] the modelled flooding agrees with the flood history and is shown in Figure 4-33.

[19] Julian Pearce, Council of the Isles of Scilly.



Aerial image courtesy of Channel Coastal Observatory

Figure 4-33: Maximum flood depths around Porth Hellick

4.6.10 Calibration results Tresco

No historical flood data was found for the impacts of the February 2014 storm on Tresco. The model results are shown in Figure 4-34 and Figure 4-35.

The modelling shows a small amount of water overtopping the path on Appletree road and running into the lake. Waves overtopped the southern beach but the overtopping rate is low and the flood outline shown below Abbey Pool represents flood depths of less than 0.02m, which was probably absorbed into the sand dunes and grass. Waves overtopped the defences in the north of Appletree Bay and in Bathinghouse Porth, pooling in the low-lying land behind.

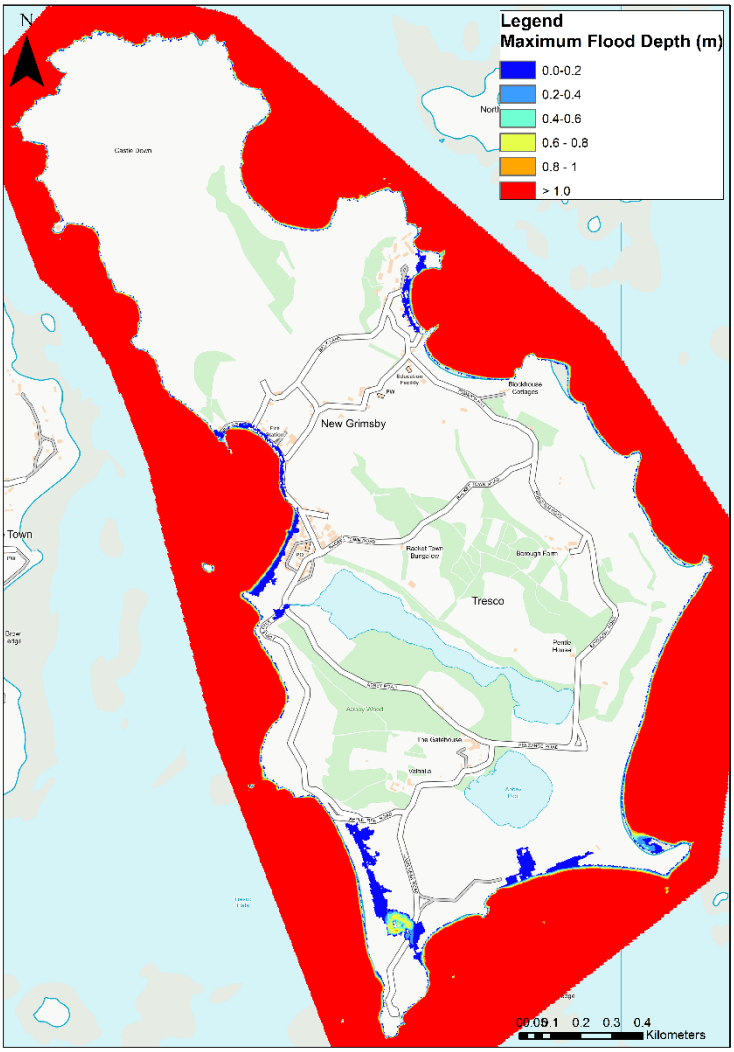


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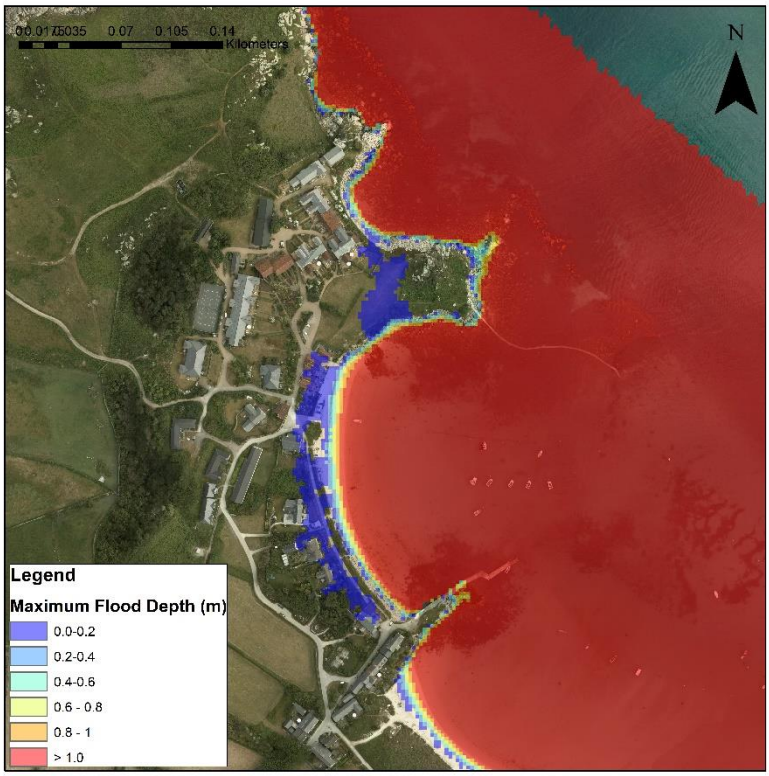
Figure 4-34: Maximum flood depths across Tresco

Figure 4-35 shows the maximum flood depths around Old Grimsby, the maximum depth is 0.01m. The modelling shows water overtopping the gardens to the east of Seagarden Cottages and flowing back to sea in Old Grimsby Bay.



Aerial image courtesy of Channel Coastal Observatory

Figure 4-35: Maximum flood depths in Old Grimsby

4.7 Model Validation: 17-18 October 2012

The modelling was validated against the coastal flooding that occurred on the 17th and 18th October 2012. This event caused flooding in St. Mary's along the north coast of Hugh Town, in Porthloo, around Spray View and behind Watermill Cove. This flooding was the result of wave overtopping and not still water inundation. No observational wave overtopping volume data is available to compare the modelled wave overtopping results against. Instead, wave overtopping schematisations and the TUFLOW model setups were validated against photographs and anecdotal information on the flood extents and depths.

No data is available regarding flooding on the other islands. It is noted that these are resilient communities and that a lack of flood reports does not indicate a lack of flooding. Since there is no data for the off-islands, only St. Mary's was modelled.

Flooding in Hugh Town from the Town Beach side was greater than 2014, extending up to 0.30m deep in the main street[20]. It is suspected that the flooding recorded at Spray View, Watermill and Porthmellon, would have been surface water flooding and not from overtopping[21]. Flooding occurred at Porthloo due to overtopping[22]. The flooding caused damage to the sea wall in front of the Mermaid Inn as shown in Figure 4-36.

[20] Julian Pearce, Council of the Isles of Scilly.
[21] Julian Pearce, Council of the Isles of Scilly.
[22] Julian Pearce, Council of the Isles of Scilly.

Figure 4-36: Sea wall damage in front of Mermaid Inn, St. Mary's

The modelled 2012 results across St. Mary's are displayed in Figure 4-37. Figure 4-38 shows significant flood depths around the Mermaid Inn, which is consistent with the damage the occurred to sea wall. Flooding in the west of Hugh Town is extensive with water overtopping the defences to the north and flowing into the town.

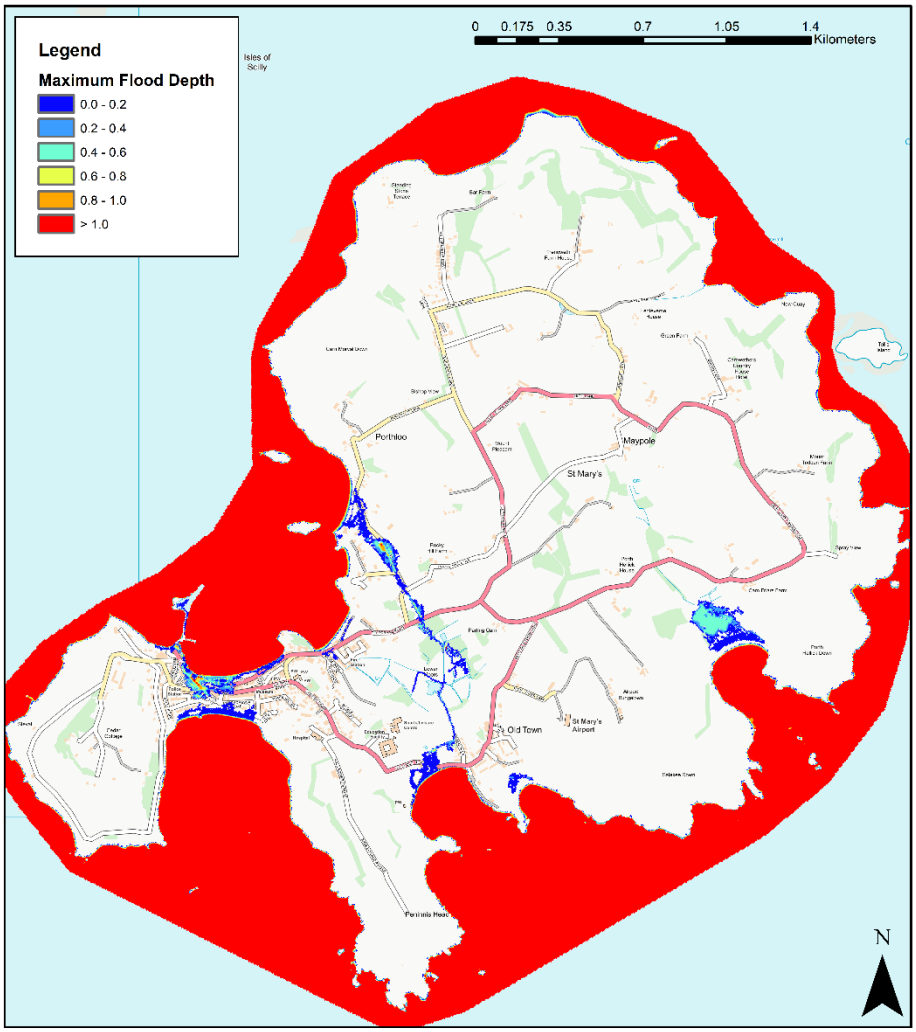


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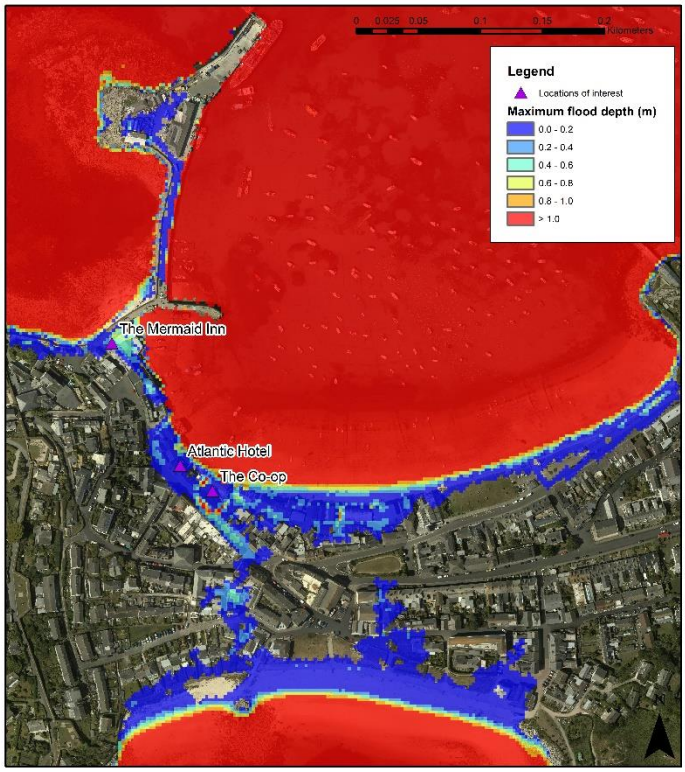
Figure 4-37: St Mary's maximum flood depths



Aerial image courtesy of Channel Coastal Observatory

Figure 4-38: Maximum flood depths for Hugh Town and Porthcressa

Figure 4-38 shows high flood depths around the Co-op store on Hugh Street. In the west of Hugh Town Bay the buildings are located at the top of the beach. Thus it has been necessary to apply the overtopping directly on top of the buildings, as shown in Figure 4-39. As the buildings also act as a barrier between Hugh Street and the sea, along this section they have been stamped onto the model domain at their surveyed height. Please note, everywhere else buildings have been represented as stubby buildings using a 0.3m threshold. This combination has led to the isolated deep-water levels around the Co-op seen in Figure 4-38.

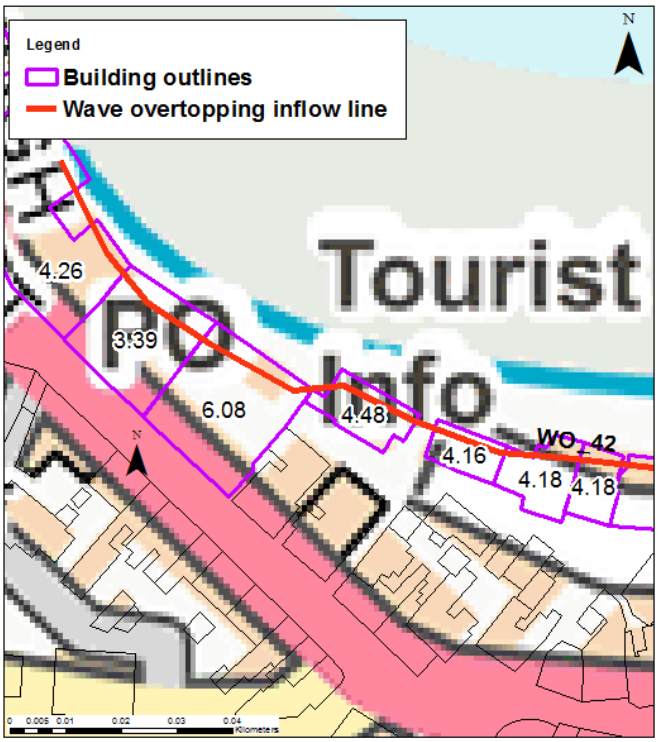


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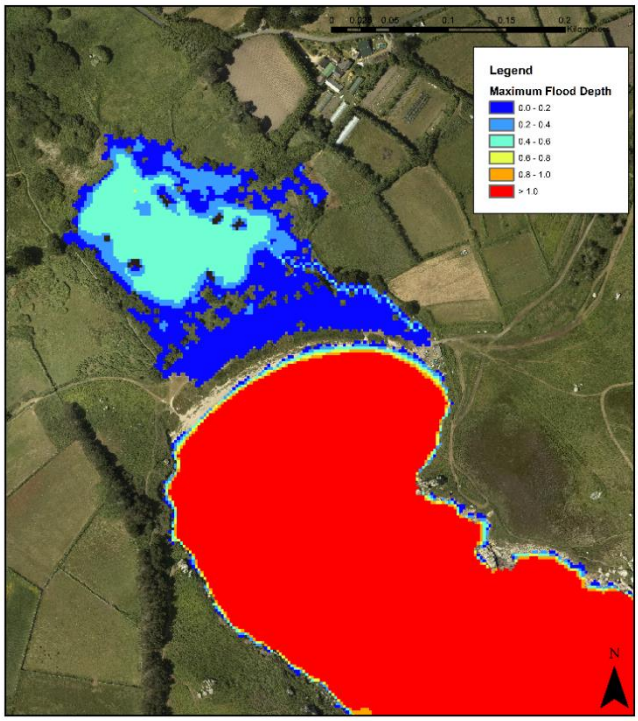
Figure 4-39: Building outlines and wave overtopping inflows around the Co-op, Hugh Town

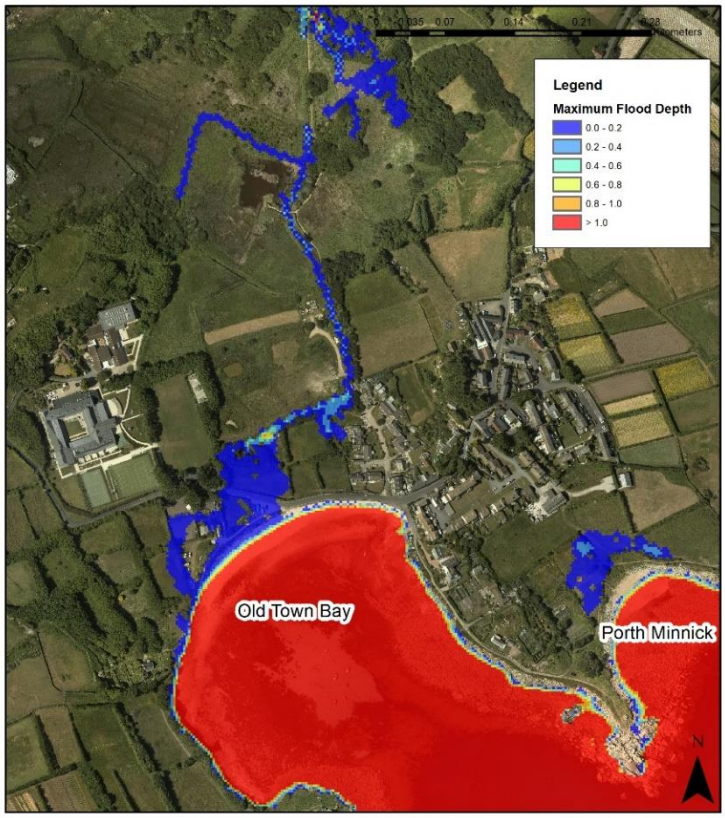
The flooding at Porth Hellick is very similar to the 2014 event where wave overtopping fills the freshwater lake, as shown in Figure 4-40. However, in the 2012 event the extents and depths are slightly smaller, a maximum flood depth of 0.46m compared to 0.65m.



Aerial image courtesy of Channel Coastal Observatory

Figure 4-40: Maximum flood depths for Porth Hellick

Old Town also sees a reduction in flooding between the 2012 and 2014 events. Flooding from overtopping is less extensive with less water passing through the town and onto the Lower Moors, as shown in Figure 4-41.



Aerial image courtesy of Channel Coastal Observatory

Figure 4-41: Maximum flood depths for Old Town

The 2012 flooding at Porthloo is more extensive than 2014, with water passing under Telegraph Road and down onto the Lower Moors, as shown in Figure 4-42.

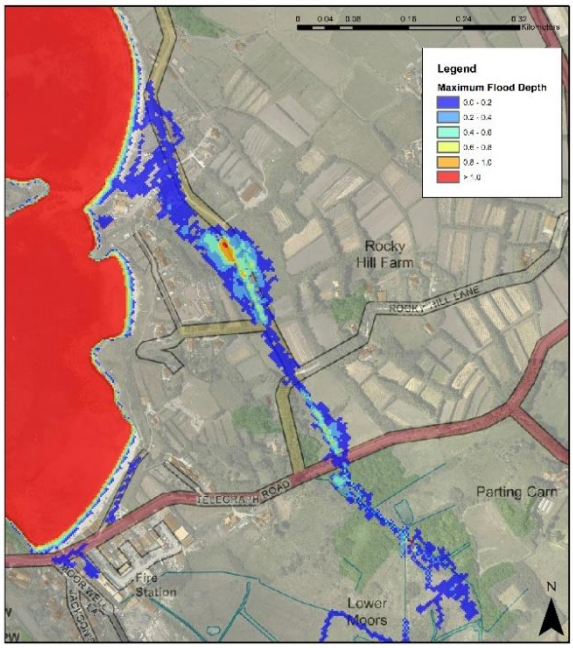


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Figure 4-42: Maximum flood depths at Porthloo

5 Model Results

The five TUFLOW 1D-2D flood inundation models have been used to simulate a range of extreme events to assess the present day and future flood risk for the Isles of Scilly. The results from these simulations are intended to be used to update the current Isle of Scilly tidal procedures.

5.1 Scenarios

Defended and undefended scenarios were simulated using the newly built TUFLOW models. All AEP events were simulated through both scenarios (Table 5-1). The defended scenario represents the current set up of the defences around the islands. The results from these scenarios can be used to assess the present day and future flood risk from a coastal event. The undefended scenario represents the situation with all defences removed. All defences with a raised elevation compared to the base terrain level and/or were considered to hinder the movement of still water levels were removed. New wave overtopping rates were calculated for location were the defences were removed.

Table 5-1. Model scenarios simulated using the five TUFLOW flood inundation models for the Isles for Scilly

Scenario	AEP event			
	Present day 2017	Climate Change 2067 (UKCP09)	Climate Change 2117 (UKCP09)	Climate Change 2117 (NPPF)
Defended	50%, 20%, 10%, 5%, 4%, 3.33%, 2%, 1.33%, 1%, 0.5%, 0.1%	1%, 0.5%, 0.1%	1%, 0.5%, 0.1%	0.5%
Undefended	50%, 20%, 10%, 5%, 4%, 3.33%, 2%, 1.33%, 1%, 0.5%, 0.1%	1%, 0.5%, 0.1%	1%, 0.5%, 0.1%	0.5%

5.2 Scenario results

Model results for the five islands are described in the following chapter. There are no undefended results for St Martin's as the island was not deemed to have any maintained defences, therefore the results from the two scenarios would have been identical.

5.2.1 Bryher

Present day defended scenarios for Bryher show that the island is cut into several smaller islands during all flood events, Figure 5-1. Most notably the area of low-lying land between Great Porth and Brow Ledge is completely cut of at the 50% AEP event with water pooling up to a depth of 0.25m. A further increase in AEP events sees the same low-lying area become increasingly inundated to greater depths. Additional overtopping, at the southern edge of the island at Rushy Bay and the freshwater lake at Great Pool causes more sections of the island to become cut off at the 50% AEP event.

The eastern side of the island around The Town does not see such a great level of inundation due to its more sheltered position, as well as the slightly steeper topography of the area. Flood extents on this side of the island are limited to a narrow coastal strip with few properties inundation even at the largest 0.1% AEP event.

Present day undefended scenarios show slightly less inundation than the defended scenarios, Figure 5-2. Flooding around The Town is largely unchanged between the defended and undefended scenarios with the same area's flooding. The freshwater lake at Great Pool still floods at the 50% AEP event, however, the inundation of the higher return periods does flood to a greater depth in this area. The low-lying area between Great Porth and Brow Ledge is again flooded in the undefended scenarios but to a lesser extent and a smaller depth. This reduction in flood extent is as a result of the overtopping at both Great Porth and Brow Ledge in the undefended scenario flowing back to sea with the removal of the defences.

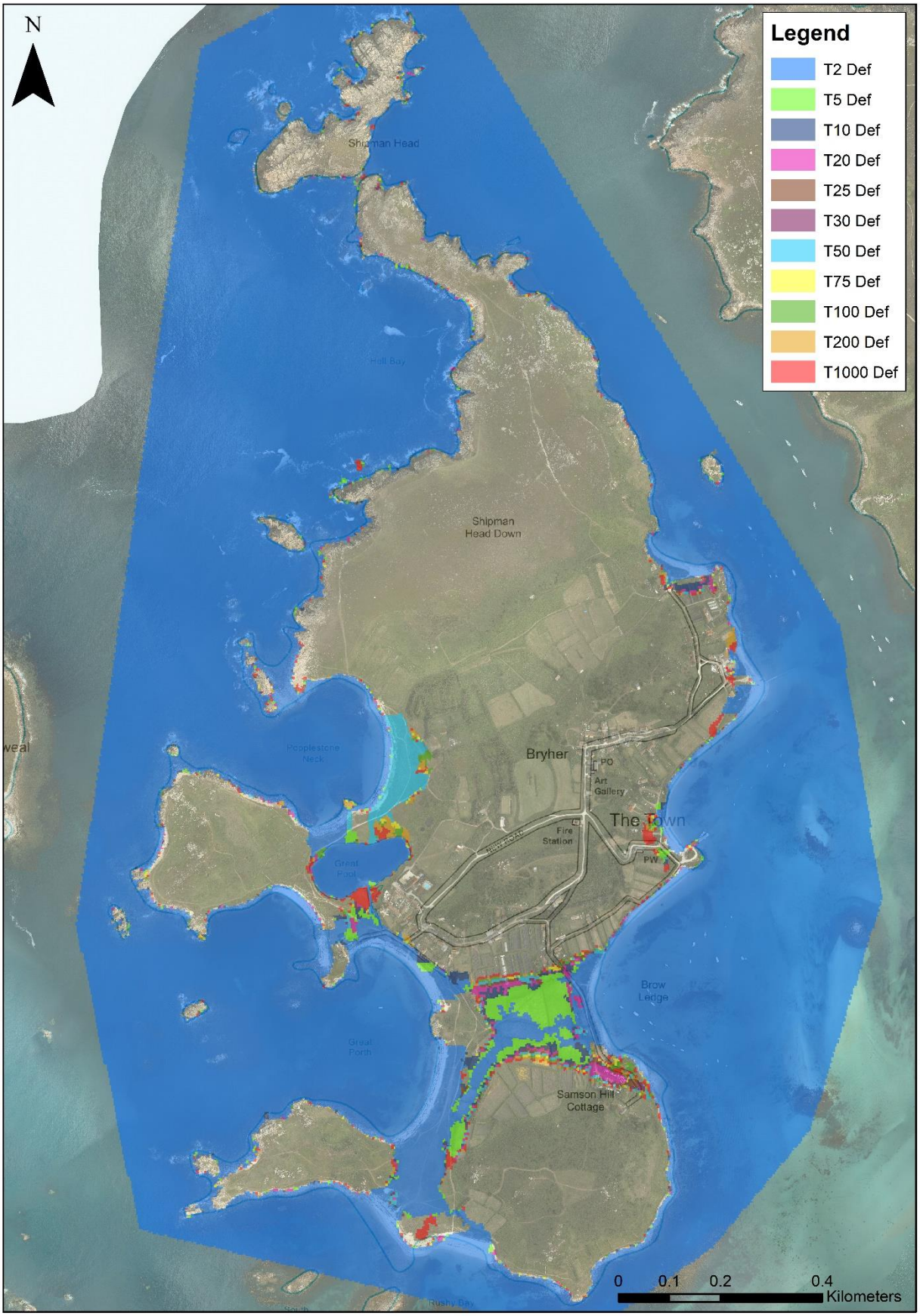
Flood outlines for the climate change runs, for both defended and undefended, are shown in Figure 5-3-Figure 5-8. In all climate change scenarios, the modelled the area between Great Porth and Brow Ledge is inundated along with the freshwater lake and Great Pool.

Flood extents for the defended scenarios in 2067 using UKCP09 projections show only small increases from the 1% AEP event apart from the area to the east of Great Pool where flooding increases for the larger AEP events. Areas along the east coast of the island also see increased inundation when compared to the present-day scenarios with more overtopping of the defences resulting in larger flood depths and extents.

Increasing climate projects to 2117 using UKCP09 guidance shows little change across much of Bryher, when compared to the 2067 model results. The Town and the area of low-lying land at Great Porth and Brow Ledge, see almost identical flooding with only the depths increasing slightly. However, when moving from 2067 to 2117, the area around Popplestone Neck sees a large increase in flood extents and depths. But, this increase in flooding does not flood any additional properties around Great Pool.

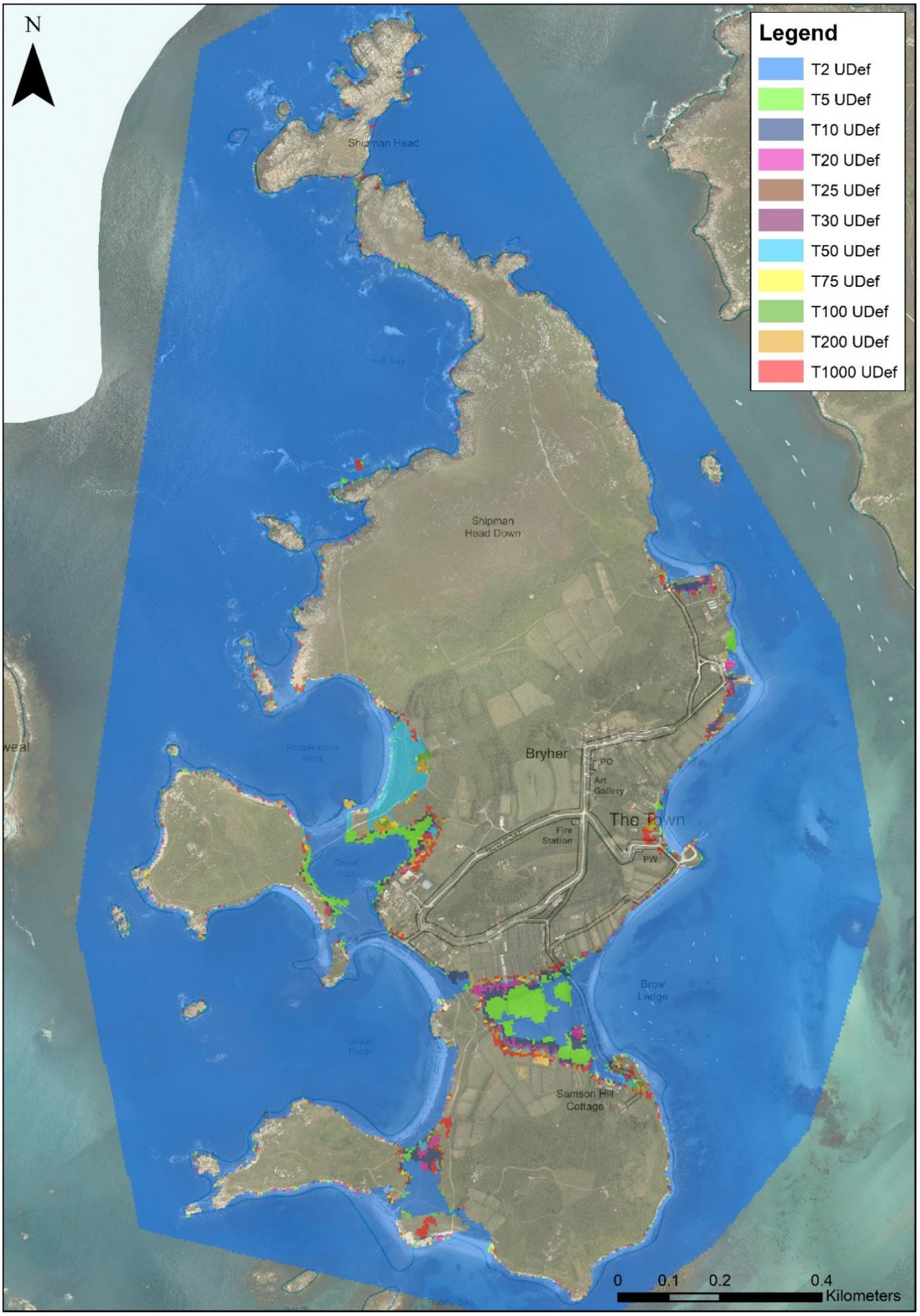
Undefended climate change runs in both 2067 and 2117 using UKCP09 projections show little changes in the extent of flooding as flood water is constrained by the topography of the island. However, the flood depths around Great Pool and the area between Great Porth and Brow Ledge do increase as AEP increases.

For the undefended and defended scenarios using NPPF guidance, for the year 2117, the flood outlines show very little variation for the 0.5% AEP. The one exception is at Great Porth where slightly less water comes over the defence here in the undefended scenario. But the land behind is inundated by water from neighbouring profiles and as such the flood extent and depths only show a slight variation.



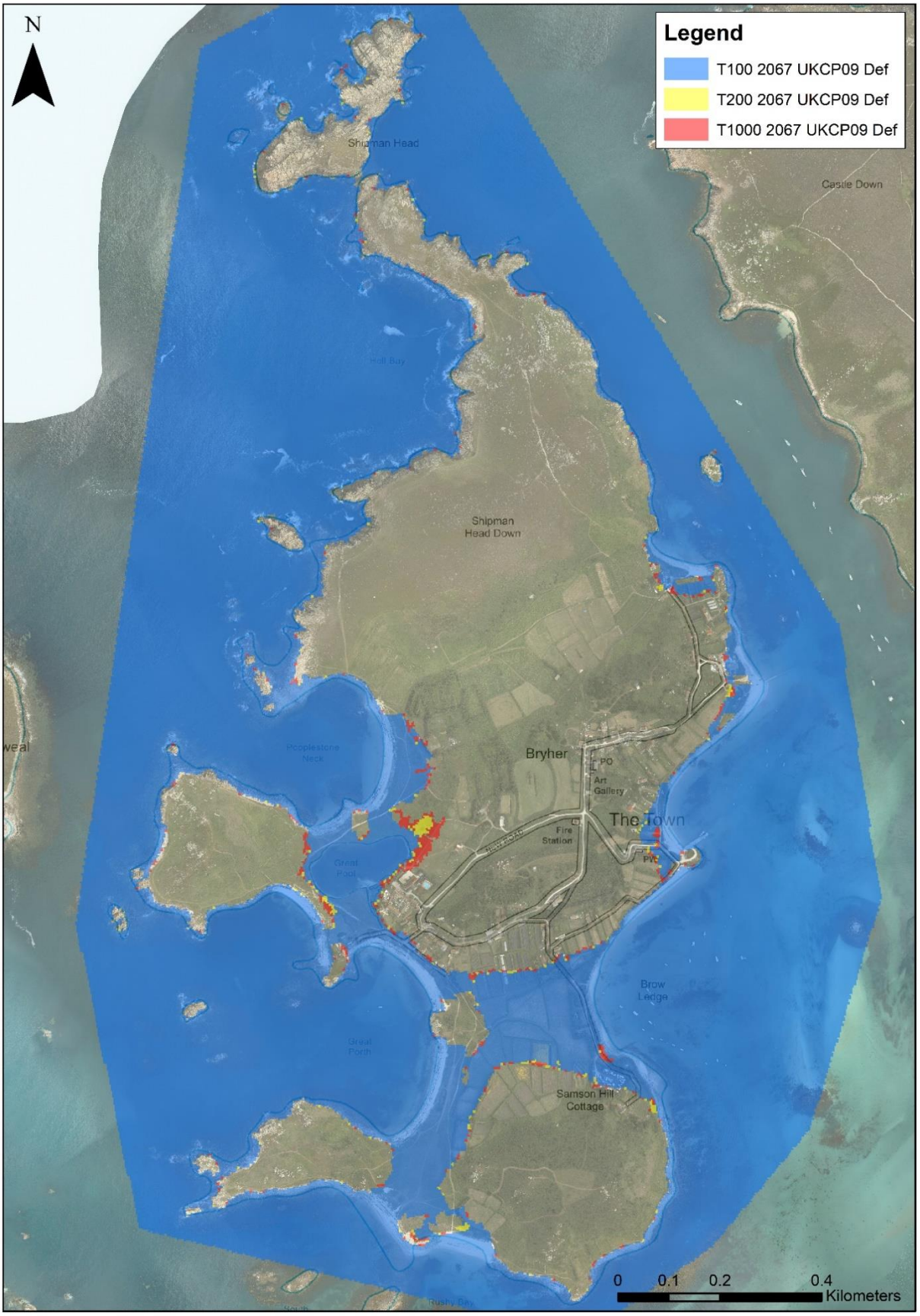
Aerial image courtesy of Channel Coastal Observatory

Figure 5-1: Model flood extents Bryher Defended present day



Aerial image courtesy of Channel Coastal Observatory

Figure 5-2: Model flood extents Bryher Undefended present day



Aerial image courtesy of Channel Coastal Observatory

Figure 5-3: Model flood extents Bryher Defended 2067 UKCP09

Aerial image courtesy of Channel Coastal Observatory

Figure 5-4: Model flood extents Bryher Defended 2117 UKCP09

Aerial image courtesy of Channel Coastal Observatory

Figure 5-5: Model flood extents Bryher Defended 2117 NPPF

Aerial image courtesy of Channel Coastal Observatory

Figure 5-6: Model flood extents Bryher Undefended 2067 UKCP09

Aerial image courtesy of Channel Coastal Observatory

Figure 5-7: Model flood extents Bryher Undefended 2117 UKCP09

Aerial image courtesy of Channel Coastal Observatory

Figure 5-8: Model flood extents Bryher Undefended 2117 NPPF

5.2.2 Tresco

Present day flood outlines for Tresco are shown in Figure 5-9. The southern edge of the island sees flooding from overtopping with water coming from Appletree Bay and Bathinghouse Porth which cuts off the jetty at the south of the island at the 50% AEP event and above. Flood depths at this location for the 2% AEP event are around 0.30m. Pentle Bay at the south east of the island also sees some inundation but only significant flooding is seen at the 0.1% AEP event, however, no properties flood at this location. The western side of Tresco is well protected with only the 0.1% AEP event flooding any properties in the east of New Grimsby. Additionally, in the 0.1% AEP event flood water reaches the freshwater lake at Great Pool. On the eastern side of the island, the area around Old Grimsby Harbour sees inundation with flood water coming over the defence north of the jetty and flowing down behind the defences and flooding the school at the 5% AEP event and above, Figure 5-17.

Undefended present-day outlines show a general reduction in flooding across the island. This comes as a result of flood water from undefended overtopping being allowed to flow back to sea by the removal of defences. This is most notable at Old Grimsby Harbour where flood water in the undefended scenario flows back to sea instead of inundating the school and the surrounding properties (Figure 5-18). There is also a slight reduction in flood extents at the southern edge of the island, however, the jetty is still cut off from the rest of the island.

Defended results for 2067 using UKCP09 projections are shown in Figure 5-11. All the defended AEP events in 2067 reach the freshwater lake at Great Pool with the 0.1% AEP event reaching Abbey Pool. On the western side of the island at New Grimsby, some of the shorefront properties are flooded from wave overtopping. At Old Grimsby Harbour the flooding from overtopping increases in both size and depth for the 2067 AEP events with flood water inundating further inland to St Nicholas's Church. For the events in 2117, both Great Pool and Abbey Pool are flooded in the 1% AEP events with the flood depths increasing across both areas in the south of the island. New Grimsby also sees an increase in flooding from overtopping with yet more properties flooded along the shorefront. Old Grimsby Harbour does not see a great increase in flood extents with the water still reaching the church, but being constrained well by the topography, Figure 5-20. However, the flood depths around the school do increase as more water passes over the defences.

Undefended results for Tresco using UKCP09 are shown in Figure 5-14 and Figure 5-15. Again, on Tresco, the undefended flood extents are less than the defended flood extents due to overtopped water flowing back to sea. This is most notable at Old Grimsby Harbour where both the depths and flood extents for the 2067 and 2117 AEP events are much less than the defended scenarios, Figure 5-22 and Figure 5-23. New Grimsby does not see any increases in flooding during any undefended scenario with the flood water here well constrained by the topography. Both the freshwater lakes at Great Pool and Abbey Pool are still inundated during the undefended scenarios.

NPPF results for both the defended and undefended are shown in Figure 5-13 and Figure 5-16. There is almost no variation between the defended and undefended outlines on Tresco. This is demonstrated well at Old Grimsby Harbour (Figure 5-21 and Figure 5-24) where both flood outlines are identical suggesting that flooding here is not controlled by the overtopping rate over the defences.

Aerial image courtesy of Channel Coastal Observatory

Figure 5-9: Model flood extents Tresco Defended present day

Aerial image courtesy of Channel Coastal Observatory

Figure 5-10: Model flood extents Tresco Undefended present day

Aerial image courtesy of Channel Coastal Observatory

Figure 5-11: Model flood extents Tresco Defended 2067 UKCP09

Aerial image courtesy of Channel Coastal Observatory

Figure 5-12: Model flood extents Tresco Defended 2117 UKCP09

Aerial image courtesy of Channel Coastal Observatory

Figure 5-13: Model flood extents Tresco Defended 2117 NPPF

Aerial image courtesy of Channel Coastal Observatory

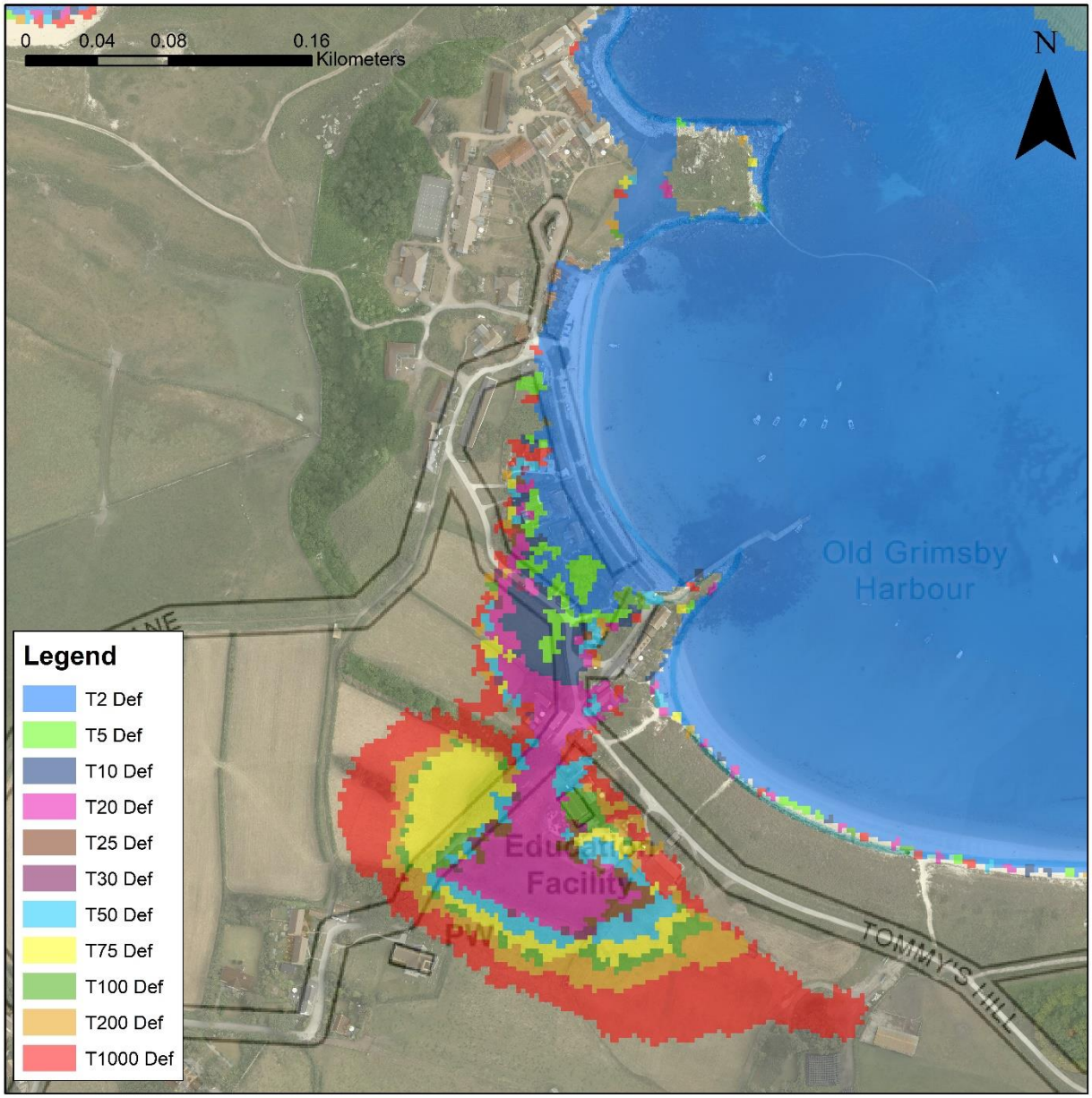
Figure 5-14: Model flood extents Tresco Undefended 2067 UKCP09

Aerial image courtesy of Channel Coastal Observatory

Figure 5-15: Model flood extents Tresco Undefended 2117 UKCP09

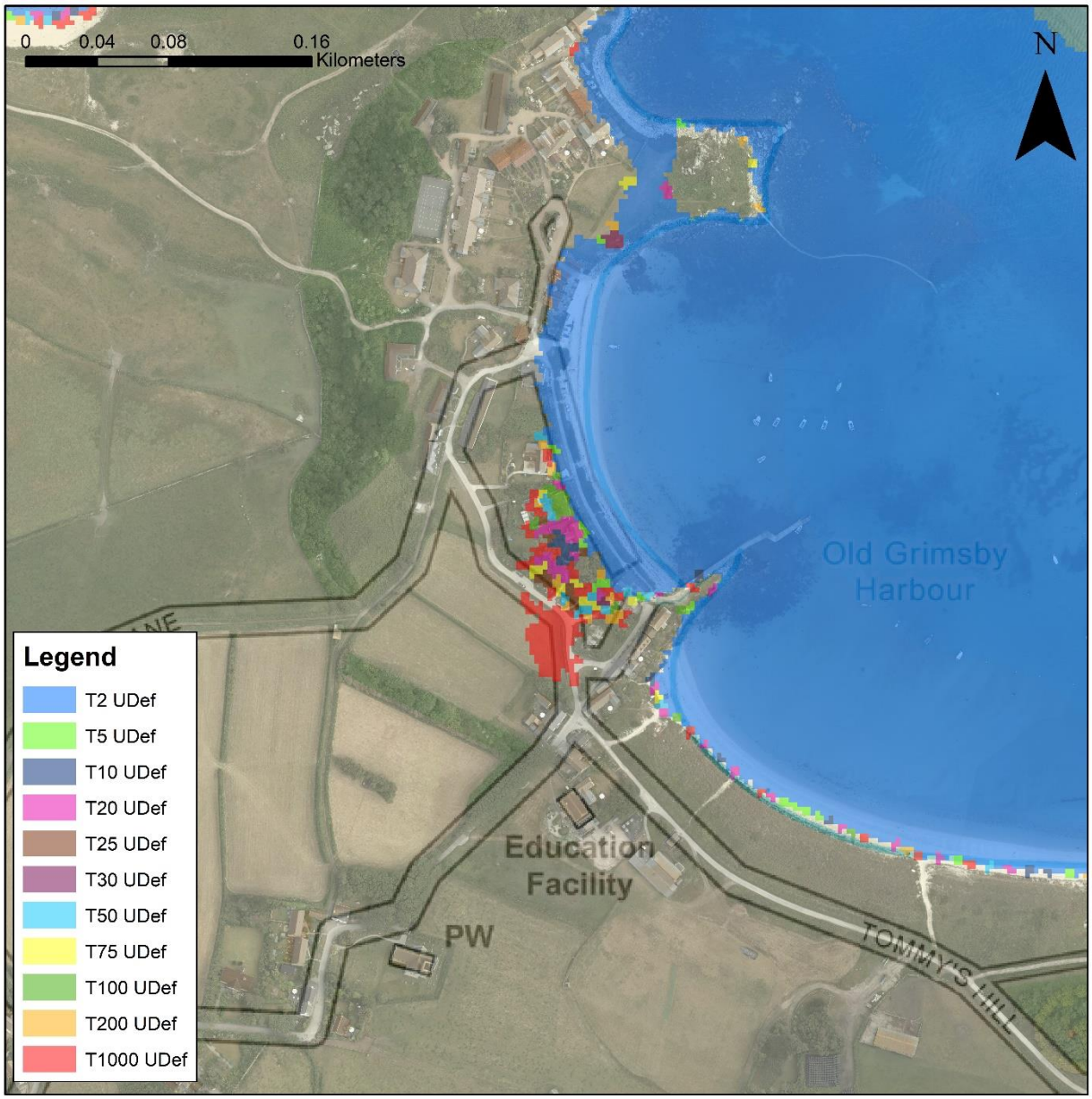
Aerial image courtesy of Channel Coastal Observatory

Figure 5-16: Model flood extents Tresco Undefended 2117 NPPF



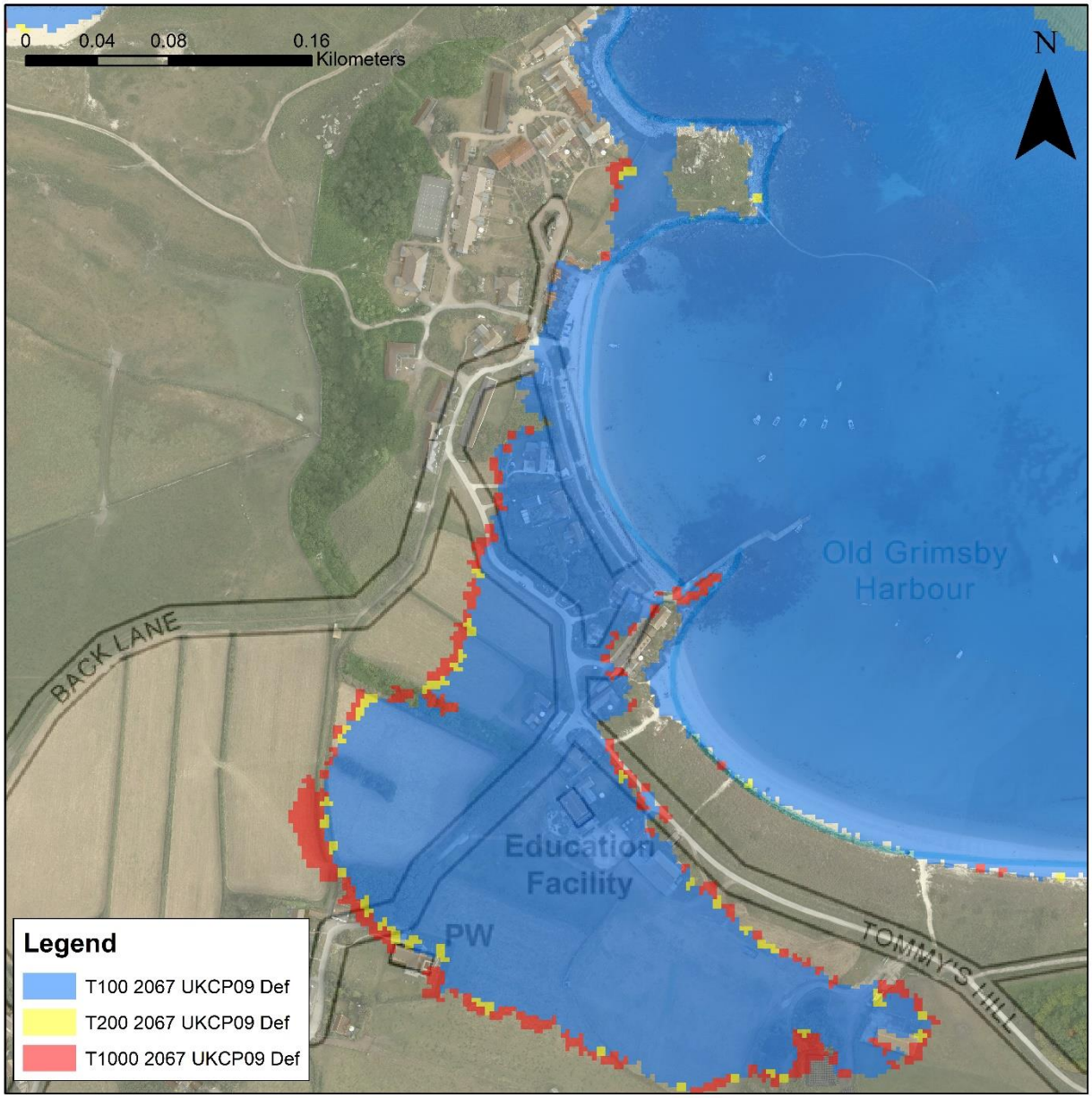
Aerial image courtesy of Channel Coastal Observatory

Figure 5-17: Model flood extents Tresco Old Grimsby Defended present day



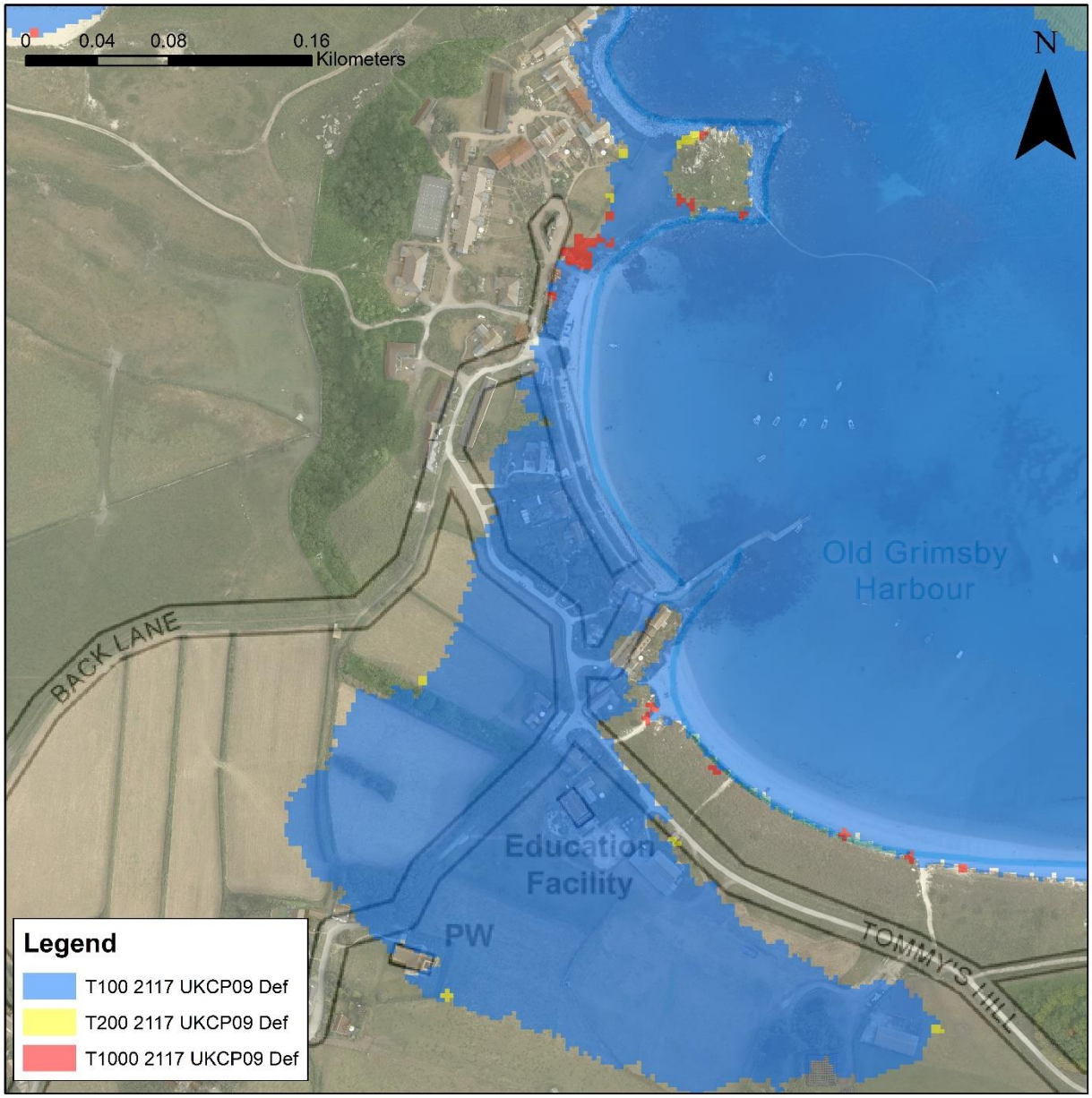
Aerial image courtesy of Channel Coastal Observatory

Figure 5-18: Model flood extents Tresco Old Grimsby Undefended present day



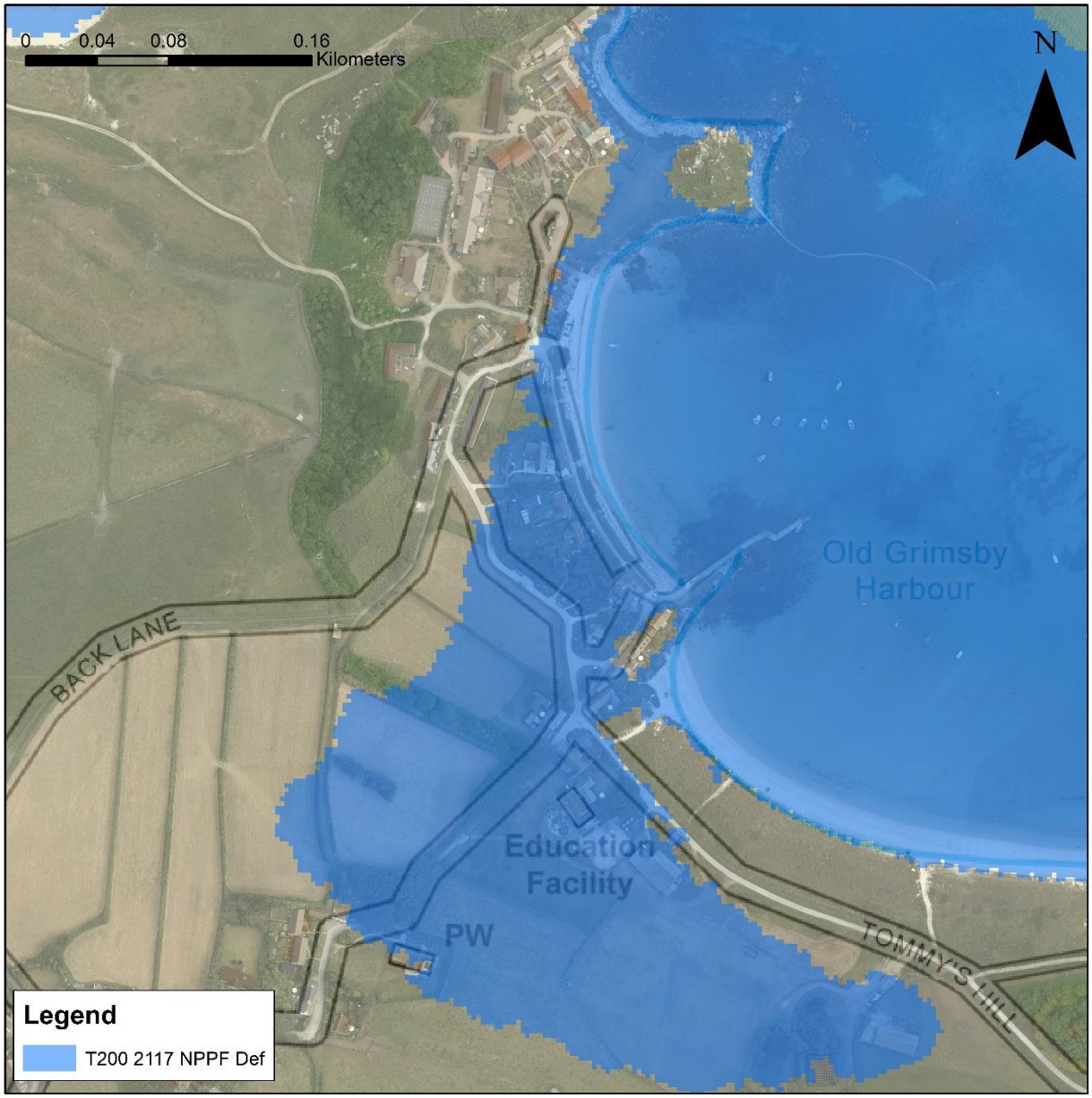
Aerial image courtesy of Channel Coastal Observatory

Figure 5-19: Model flood extents Tresco Old Grimsby Defended 2067 UKCP09



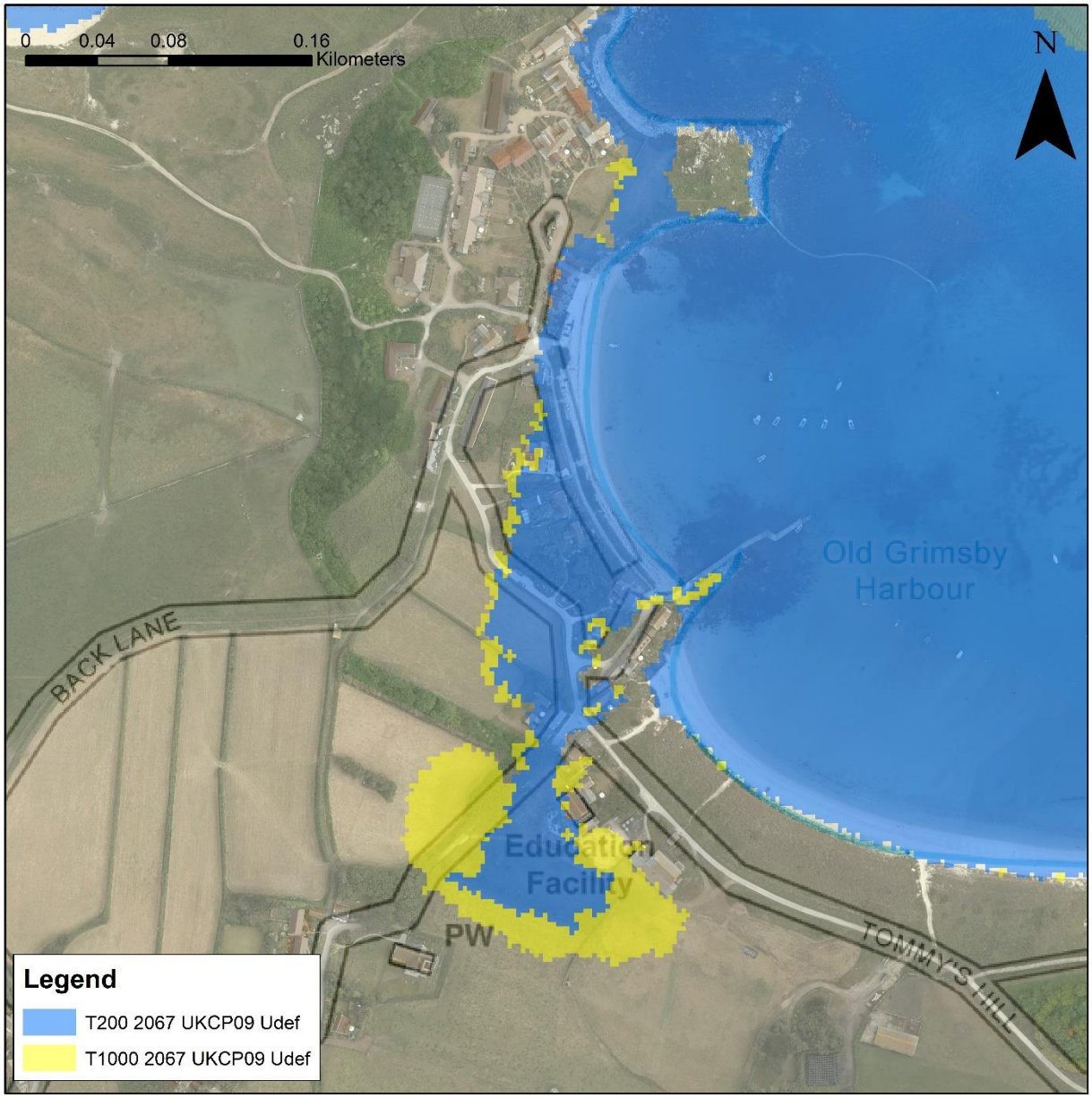
Aerial image courtesy of Channel Coastal Observatory

Figure 5-20: Model flood extents Tresco Old Grimsby Defended 2117 UKCP09



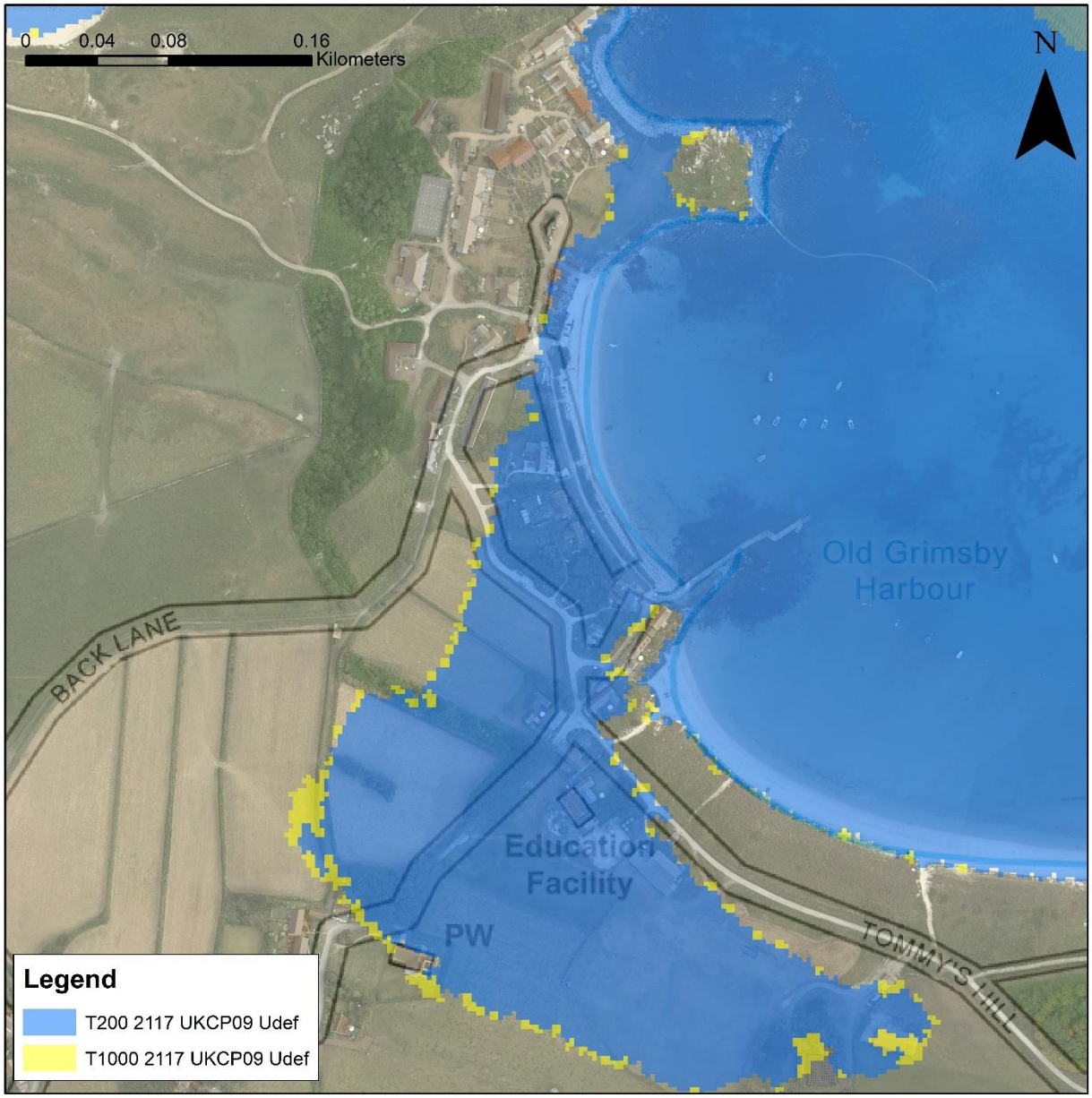
Aerial image courtesy of Channel Coastal Observatory

Figure 5-21: Model flood extents Tresco Old Grimsby Defended 2117 NPPF



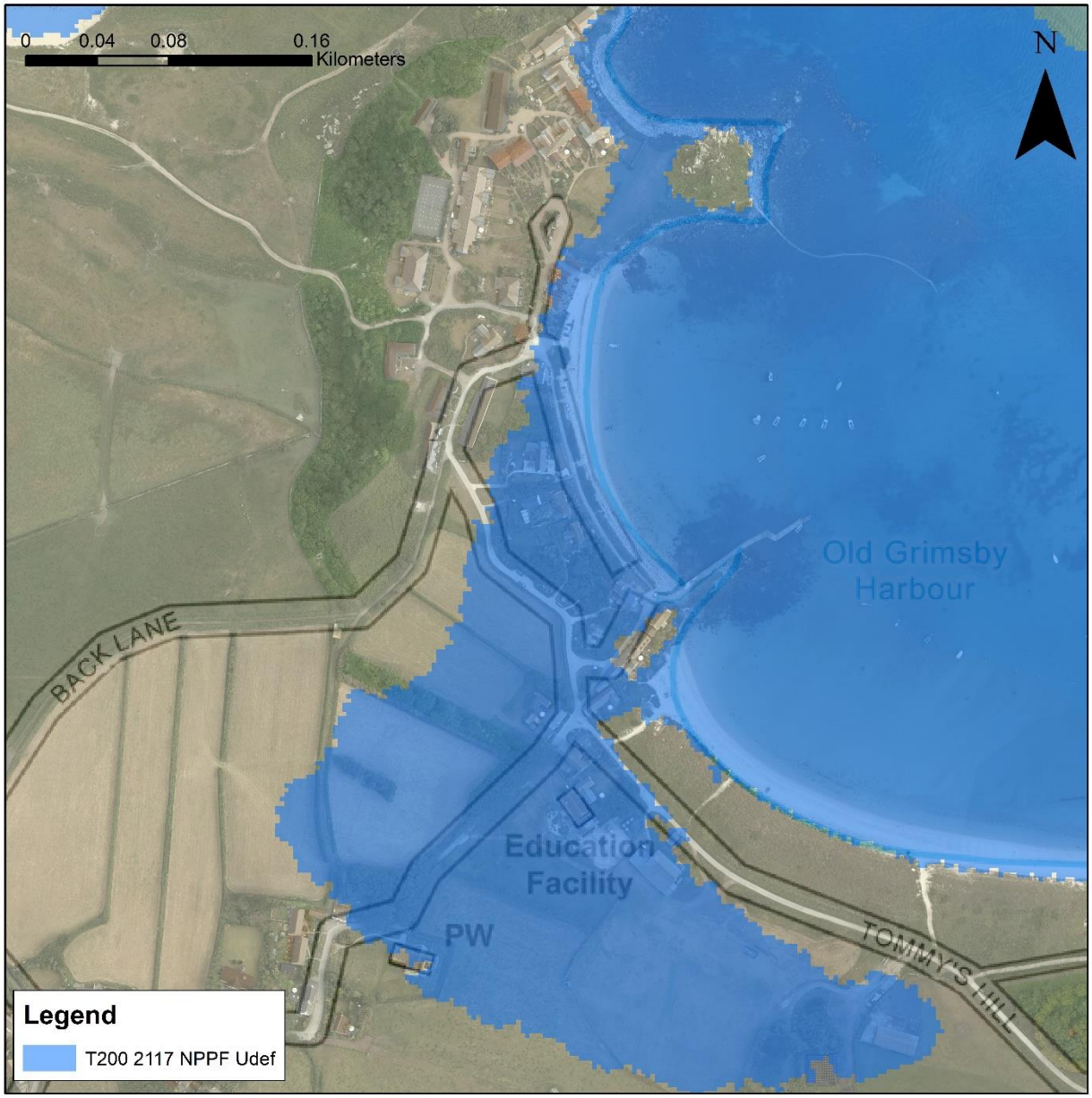
Aerial image courtesy of Channel Coastal Observatory

Figure 5-22: Model flood extents Tresco Old Grimsby Undefended 2067 UKCP09



Aerial image courtesy of Channel Coastal Observatory

Figure 5-23: Model flood extents Tresco Old Grimsby Undefended 2117 UKCP09



Aerial image courtesy of Channel Coastal Observatory

Figure 5-24: Model flood extents Tresco Old Grimsby Undefended 2117 NPPF

5.2.3 St Agnes

Present day defended results for St Agnes are shown in Figure 5-25. Only the northern edge of the island around Lower Town sees any flooding. The main volume of water from overtopping comes from both Periglis and Porth Coose with the freshwater lake at the north of the island flooding at the 50% AEP event. All the properties that flood during the defended scenarios flood at the 50% AEP event, these are situated to the south of the bay at Periglis. Higher AEP events flood further inland at the north of the island however no further properties are flooded. The 0.1% AEP event floods from both the eastern and western bays and cuts the northern tip of the island off, however, there are no properties on this part of the island.

Flood outlines for the undefended scenarios for the present day are shown in Figure 5-26. Undefended outlines on St Agnes do show more flooding than the defended outlines apart from at the 50% and 20% AEP events which are slightly smaller and have lower depths. The northern edge of the island is cut off at the 10% AEP event in the undefended scenario. It should be noted that no additional properties flood when comparing the undefended and defended outlines.

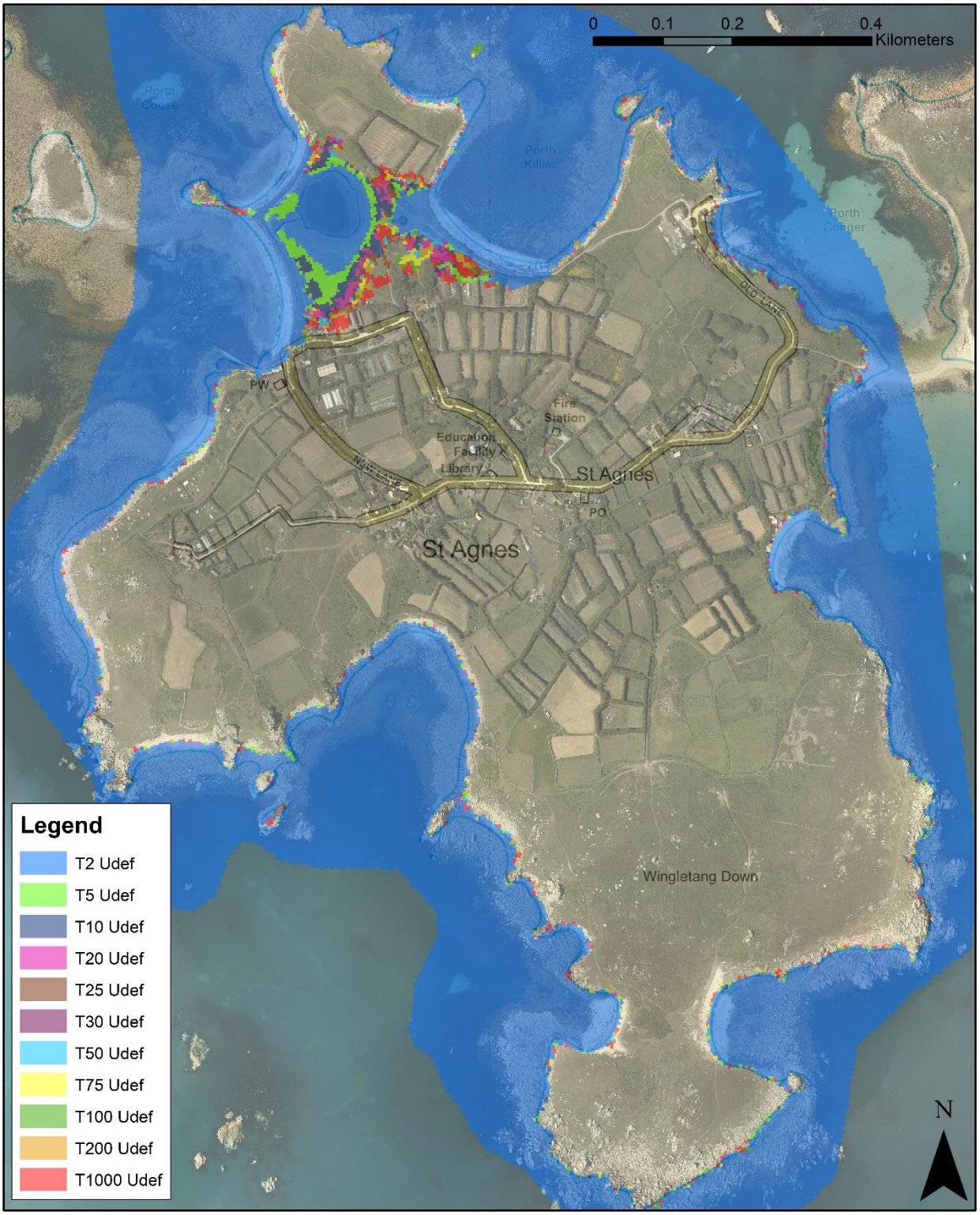
The defended result outlines for both 2067 and 2117 using UKCP09 projection for St Agnes are shown in Figure 5-27 and Figure 5-28. Defended climate change outlines are larger than the present-day ones and flood the area to a greater depth, however it is only the 0.1% AEP event in 2117 that floods any additional properties. Again, during climate change events the northern tip of the island is cut off.

The undefended results for St Agnes using UKCP09 projections for 2067 and 2117 are shown in Figure 5-30 and Figure 5-31. The undefended model outlines on St Agnes are smaller than the defended outlines for the same scenarios across all AEP events. The reason for this is that during the undefended inundation, water from overtopping can flow back to sea and as such, less water is retained on land. This reduction in flood water only results in only a couple of properties not to be flooded during the undefended scenarios.

NPPF climate change results for the defended and undefended results on St Agnes are shown in Figure 5-29 and Figure 5-32. Results for the 0.5% AEP event show that the northern tip of the island is cut off and the freshwater lake inundated for both defended and undefended scenarios. The undefended scenario does however flood less properties than the defended scenario with water being allowed to flow back to sea in the undefended scenario.

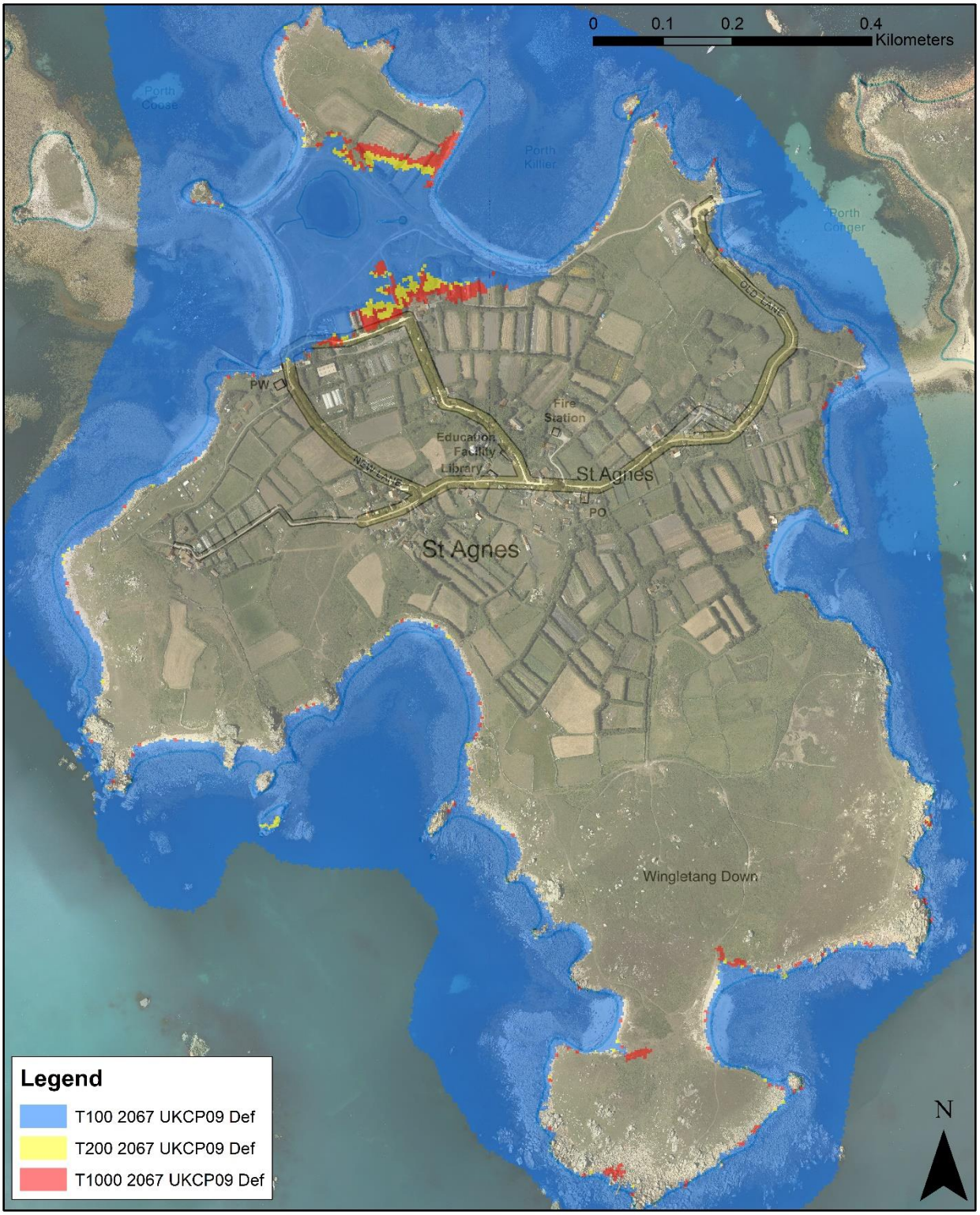
Aerial image courtesy of Channel Coastal Observatory

Figure 5-25: Model flood extents St Agnes Defended present day



Aerial image courtesy of Channel Coastal Observatory

Figure 5-26: Model flood extents St Agnes Undefended present day



Aerial image courtesy of Channel Coastal Observatory

Figure 5-27: Model flood extents St Agnes Defended 2067 UKCP09

Aerial image courtesy of Channel Coastal Observatory

Figure 5-28: Model flood extents St Agnes Defended 2117 UKCP09

Aerial image courtesy of Channel Coastal Observatory

Figure 5-29: Model flood extents St Agnes Defended 2117 NPPF

Aerial image courtesy of Channel Coastal Observatory

Figure 5-30: Model flood extents St Agnes Undefended 2067 UKCP09

Aerial image courtesy of Channel Coastal Observatory

Figure 5-31: Model flood extents St Agnes Undefended 2117 UKCP09

Aerial image courtesy of Channel Coastal Observatory

Figure 5-32: Model flood extents St Agnes Undefended 2117 NPPF

5.2.4 St Mary's

Present day defended results for St Mary's are shown in Figure 5-33. The main areas to flood on St Mary's are Porth Hellick, Old Town, Hugh Town and Porthloo. At Porth Hellick the freshwater lake is inundated at the 50% AEP event and water floods the road during the 0.5% AEP event to a depth of 0.20m. At Old Town, Old Town Lane floods at the 50% AEP event with water flowing down onto Lower Moors for all scenarios modelled, Figure 5-49. Additionally, at Porth Minnick the 0.1% AEP event floods several properties on Launceston Road. At Hugh Town, flooding comes from both the north and south bays with the 4% AEP event cutting the town in two with water reaching a depth of 0.30m on Hugh Street at the 4% AEP event, Figure 5-57. Furthermore, in Hugh Town, the Mermaid Inn and the quay are flooded at the 50% AEP event with access to the Duchy of Cornwall cut off. At Porthloo floodwaters overtop the defences and flow down Porthloo Lane inundating the properties adjacent to the beach and lane, Figure 5-65. Flood water from Porthloo also passes through the culvert under Telegraph Road during the 10% AEP event. Flood waters from both Porthloo and Old Town Bay cut the island in half during the 5% AEP event with both Old Town Road and Telegraph Road flooded.

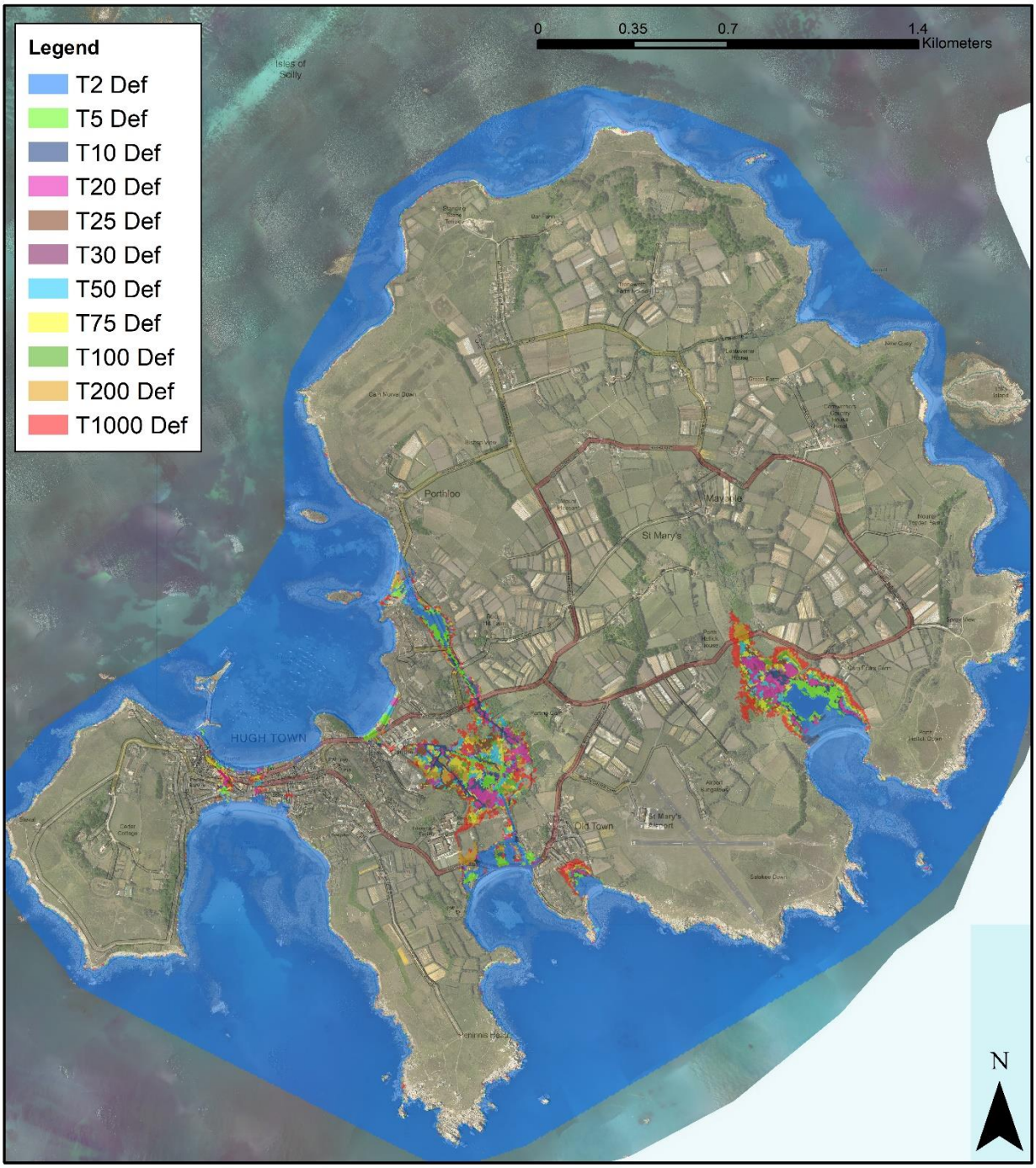
Undefended present-day results for St Mary's are shown in Figure 5-34. Flooding is still seen at Porth Hellick, Old Town, Hugh Town and Porthloo, however flooding during the undefended scenarios is reduced at some locations. At Porth Hellick, inundation is increased by removing the defence with flood outlines at the lower return periods increased resulting in the road flooding during the 4% AEP event. At Porth Minnick and Old Town Bay flood extents and depths decrease when compared to the defended scenarios as much of the undefended overtopping flows back to sea instead of inland, Figure 5-50. Flood water at Porth Minnick fails to flood any properties and the flood depths at Old Town Bay are reduced and as such, less water flows onto Lower Moors. At Hugh Town flood depths again decrease when compared to the defended scenarios with the town eventually becoming split in two during the 1.33% AEP event with flood depths on Hugh Street reach 0.50m in depth for the 1.33% AEP event, Figure 5-58. At Porthloo removing defences results in less water passing over the defences with much of the flood water flowing back to sea. As such, only the 0.5% and 0.1% AEP events flood any properties here, Figure 5-66.

The defended results for 2067 and 2117 using UKCP09 guidance are shown in Figure 5-35 and Figure 5-36. At Porth Hellick the 1% AEP event in 2067 inundates the road to a depth of 0.55m with the same AEP event in 2117 flooding the road to a depth of 1.3m (Figure 5-43 and Figure 5-44). At Old Town Bay and Porth Minnick, large volumes of water overtop the defences in both 2067 and 2117 with Old Town Road completely flooded with the flood water flowing overland to inundate Lower Moors (Figure 5-51 and Figure 5-52). Additionally, flood waters from Porth Minnick are able to flow through the town and connect up with flood water from Old Town Bay cutting off the properties on the seafront. At Hugh Town, the town is completely cut in two during the 1% AEP event in 2067 with subsequent return periods increasing the inundation in the town, Figure 5-59. Furthermore, during flood events in 2117 more flooding occurs at the northern edge of Hugh Town with extra water passing over the defences and inundating further inland, Figure 5-52. At Porthloo the 1% AEP event in 2067 flows down the road and floods Lower Moors, additionally, water floods Lower Moors from Porth Mellon through still water flooding, Figure 5-67. The same occurs during the 2117 events however more water passes over the defences and floods a larger area of Lower Moors, Figure 5-68.

Undefended results for 2067 and 2117 using UKCP09 projections are shown in Figure 5-38 and Figure 5-39. Again, the undefended outlines are almost always smaller when compared to the defended climate change outlines. At Porth Hellick the undefended outlines are larger than the defended outlines with the road well flooded in the 0.5% AEP event in both 2067 and 2117 (Figure 5-46 and Figure 5-47). At Old Town, the extents for 2067 decrease in both extent and depth as much of the flood water is allowed to flow back to sea, Figure 5-54. However, during the events in 2117, the water levels are high enough to allow some of the overtopped water to flow inland and inundate Lower Moors, Figure 5-55. At Hugh Town the 2067 and 2117 undefended outlines are larger than the defended outlines for the same AEP events, this is as a result of removing the defence to the north of Hugh Town allowing water to penetrate further into the town, Figure 5-63 and Figure 5-64. At Porthloo all the undefended outlines are much small than the defended outlines as water again flows back to sea, most of the water that passes onto Lower Moors comes from still water flooding from Porth Mellon, Figure 5-70 and Figure 5-71.

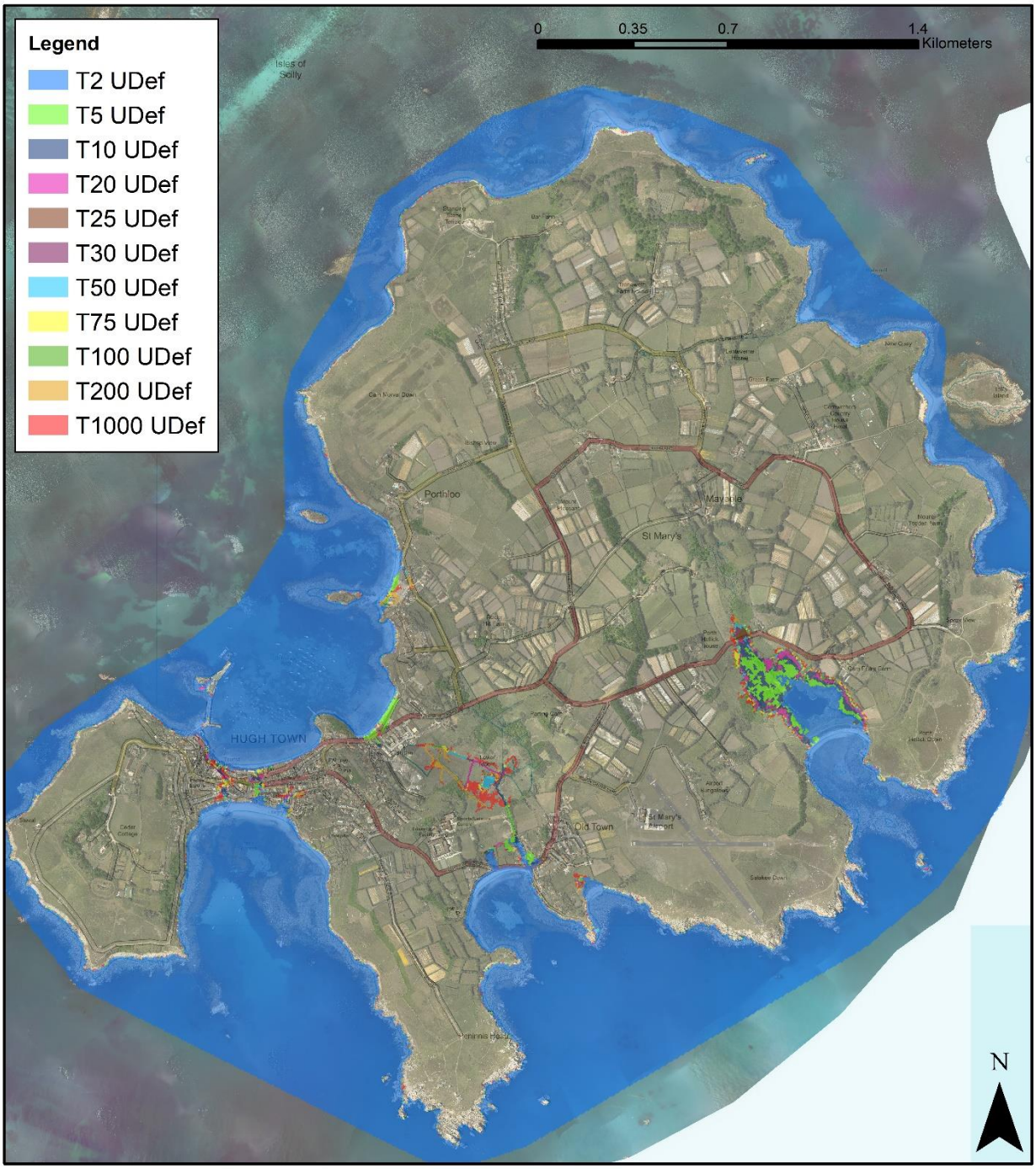
Results for the 0.5% AEP event in 2117 using NPPF guidance for both defended and undefended are shown in Figure 5-37 and Figure 5-40. At Porth Hellick both the undefended and defended outlines are the same as the flood water has reached the maximum extent that it can as it is

constrained by the topography and can't flow any further, Figure 5-45 and Figure 5-48. At Old Town Bay and Porth Minnick, the defended outline is larger than the undefended outline as a result of flood water flowing back to sea during the undefended runs. This results in less inundation of Old Town during the undefended run, Figure 5-53 and Figure 5-56. At Hugh Town, the undefended and defended outlines show little variation with the majority of flood water coming from the north, cutting the town in half. The only slight difference is the area around Porthcressa Road which sees more inundation during the 2117 event, Figure 5-61 and Figure 5-64. Finally, at Porthloo the undefended outlines are smaller than the defended outlines with water flowing back to sea instead of inland. Much of the flooding that inundates Lower Moors come from still water flooding at Porth Mellon, Figure 5-69 and Figure 5-72.



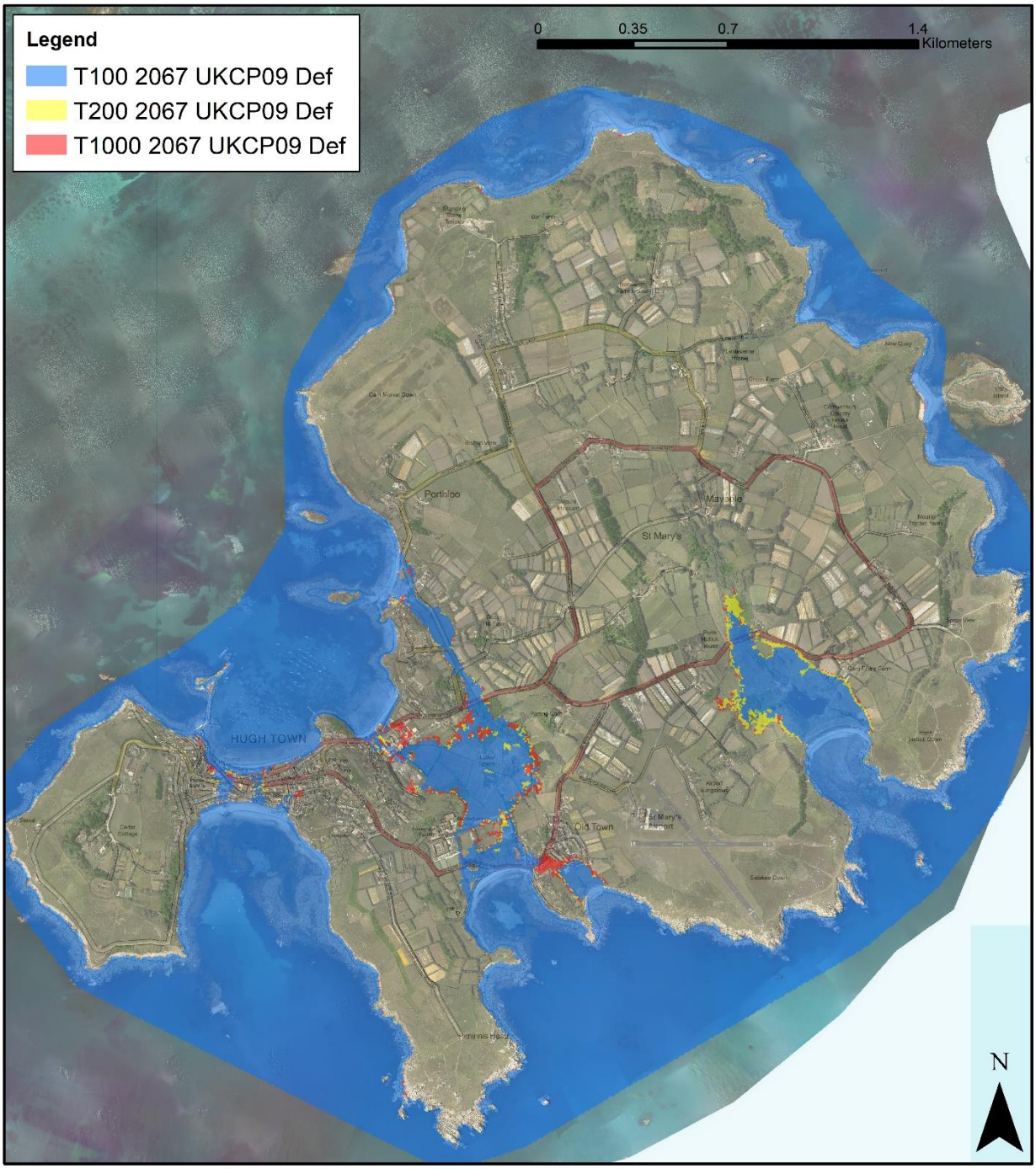
Aerial image courtesy of Channel Coastal Observatory

Figure 5-33: Model flood extents St Mary's Defended present day



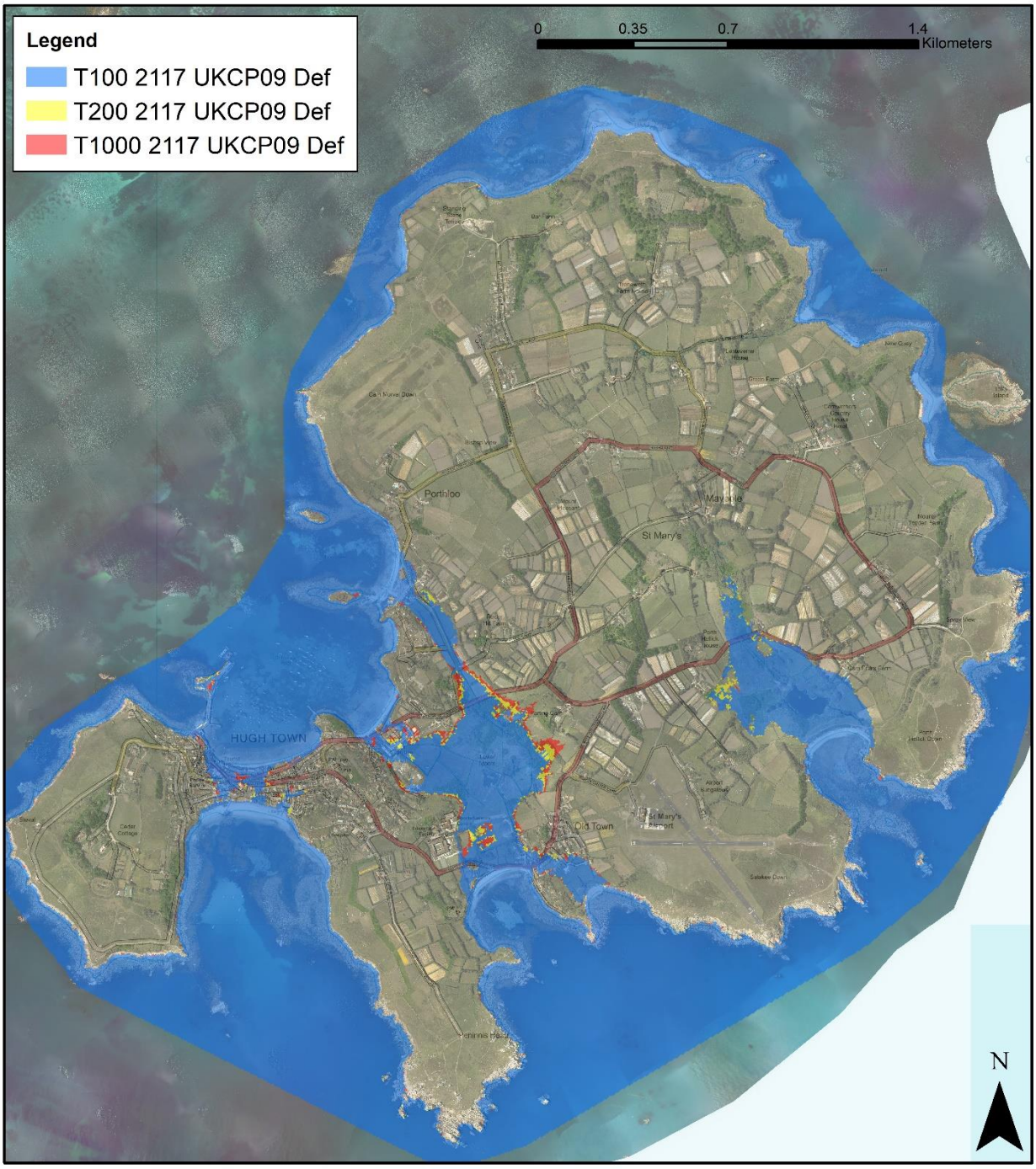
Aerial image courtesy of Channel Coastal Observatory

Figure 5-34: Model flood extents St Mary's Undefended present day



Aerial image courtesy of Channel Coastal Observatory

Figure 5-35: Model flood extents St Mary's Defended 2067 UKCP09



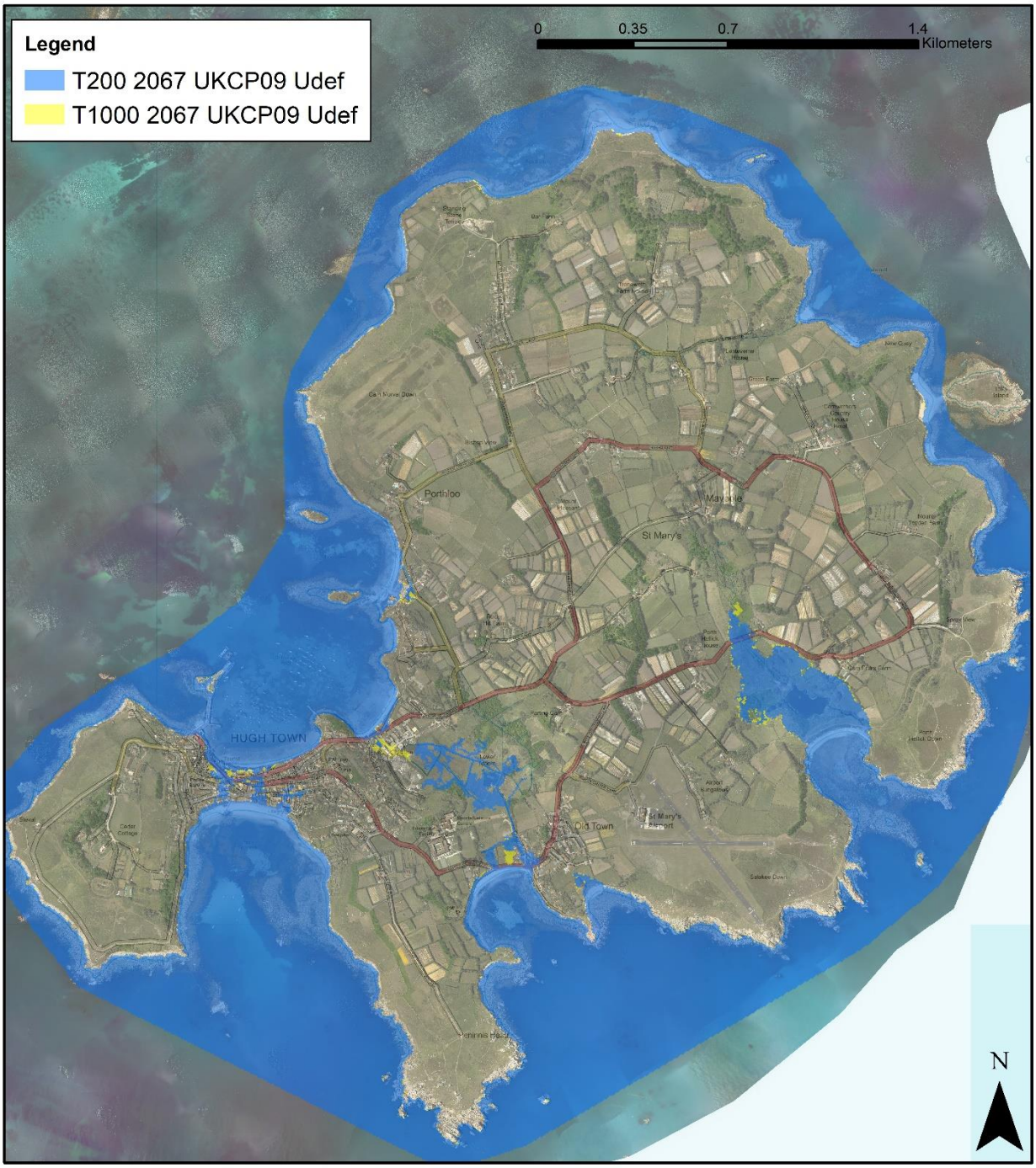
Aerial image courtesy of Channel Coastal Observatory

Figure 5-36: Model flood extents St Mary's Defended 2117 UKCP09

Aerial image courtesy of Channel Coastal Observatory

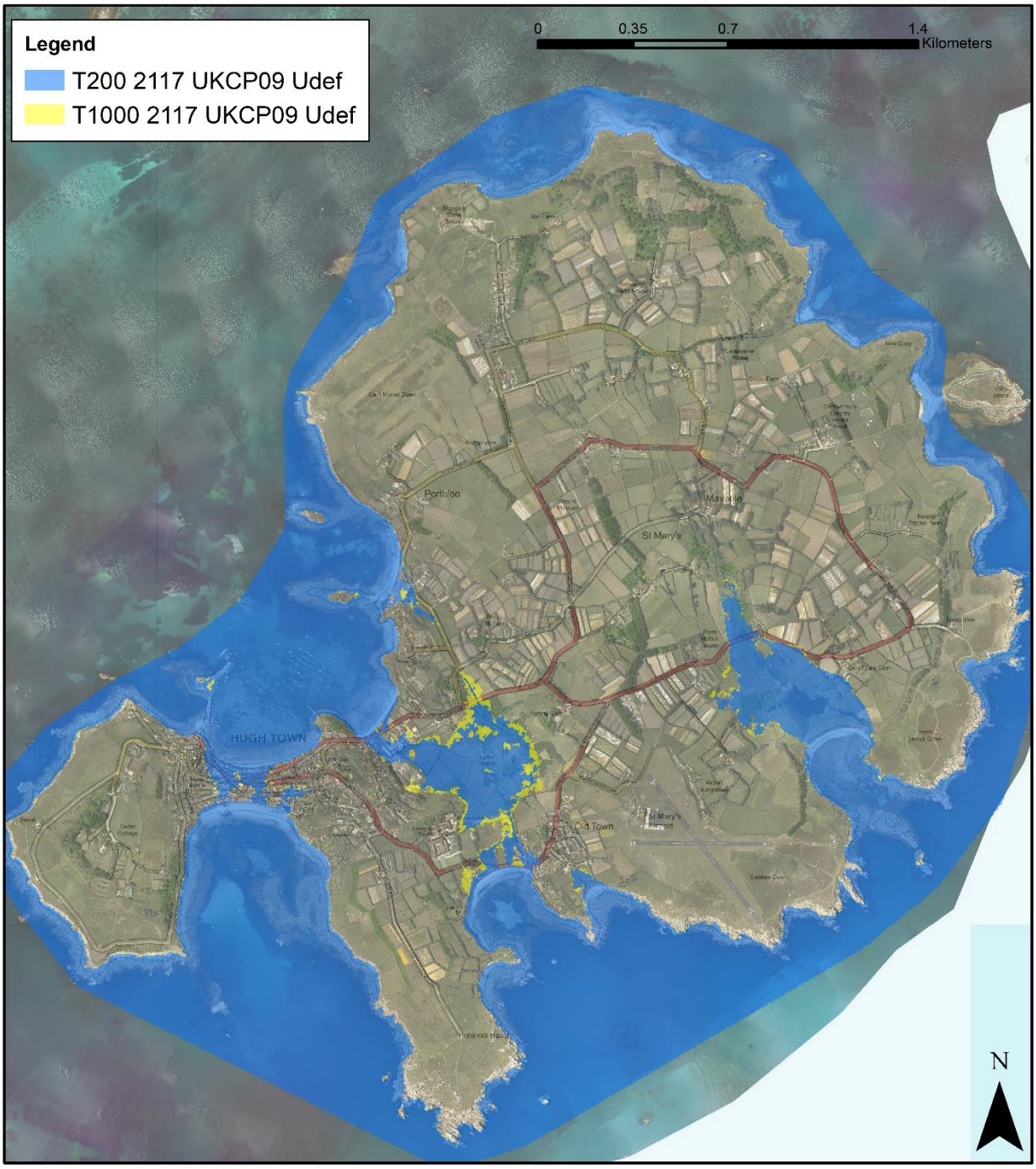
Aerial image courtesy of Channel Coastal Observatory

Figure 5-37: Model flood extents St Mary's Defended 2117 NPPF



Aerial image courtesy of Channel Coastal Observatory

Figure 5-38: Model flood extents St Mary's Undefended 2067 UKCP09

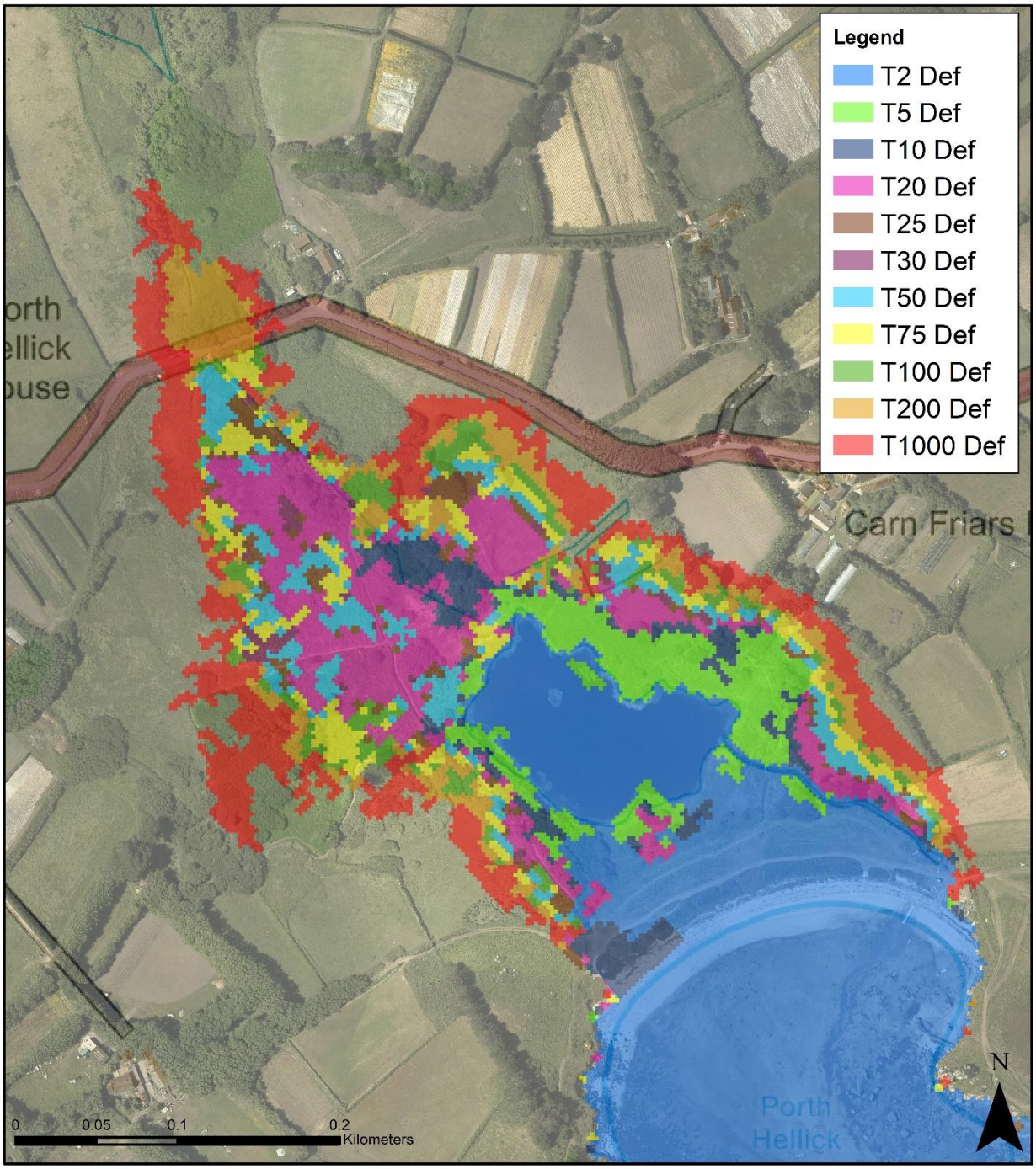


Aerial image courtesy of Channel Coastal Observatory

Figure 5-39: Model flood extents St Mary's Undefended 2117 UKCP09

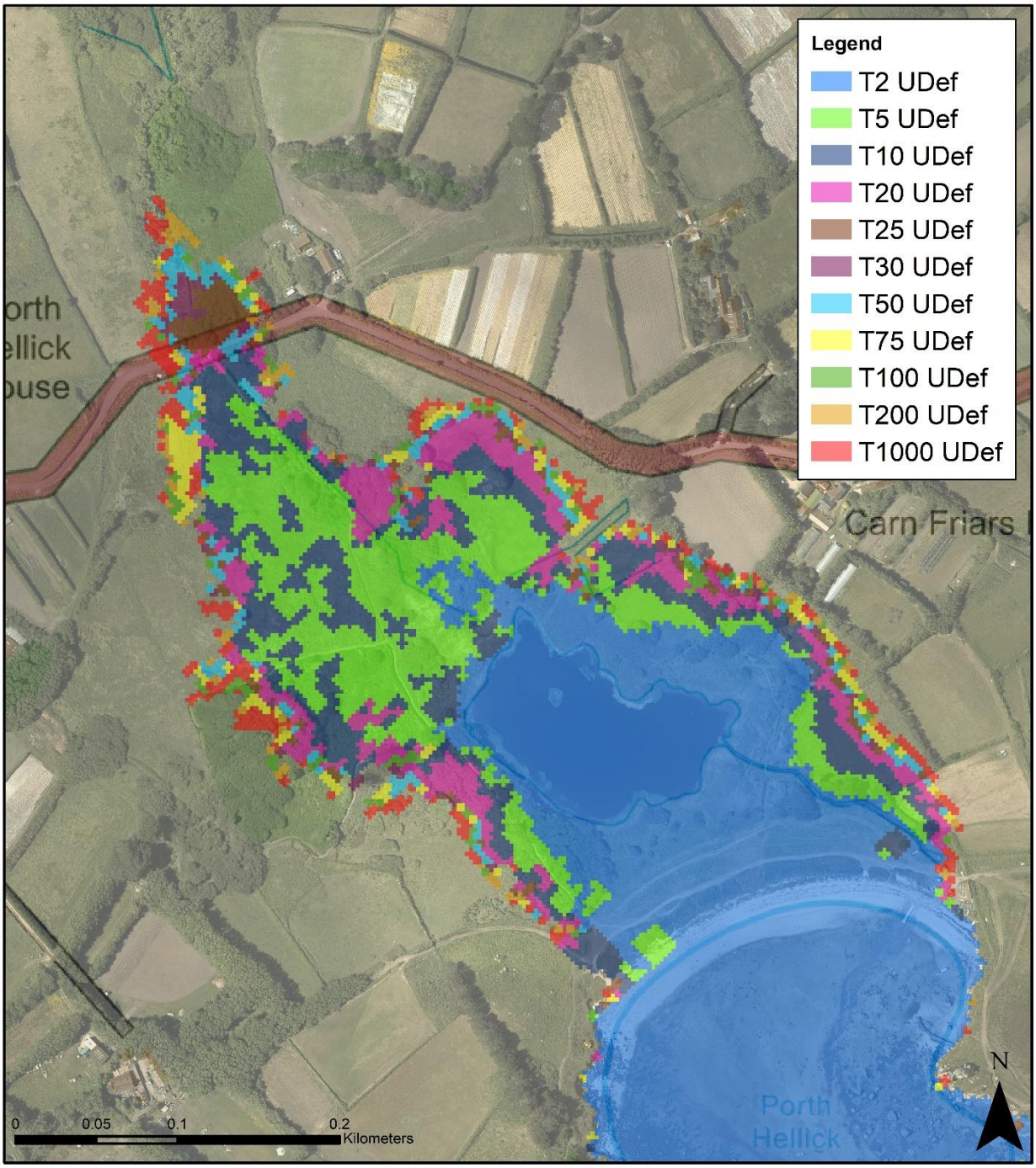
Aerial image courtesy of Channel Coastal Observatory

Figure 5-40: Model flood extents St Mary's Undefended 2117 NPPF



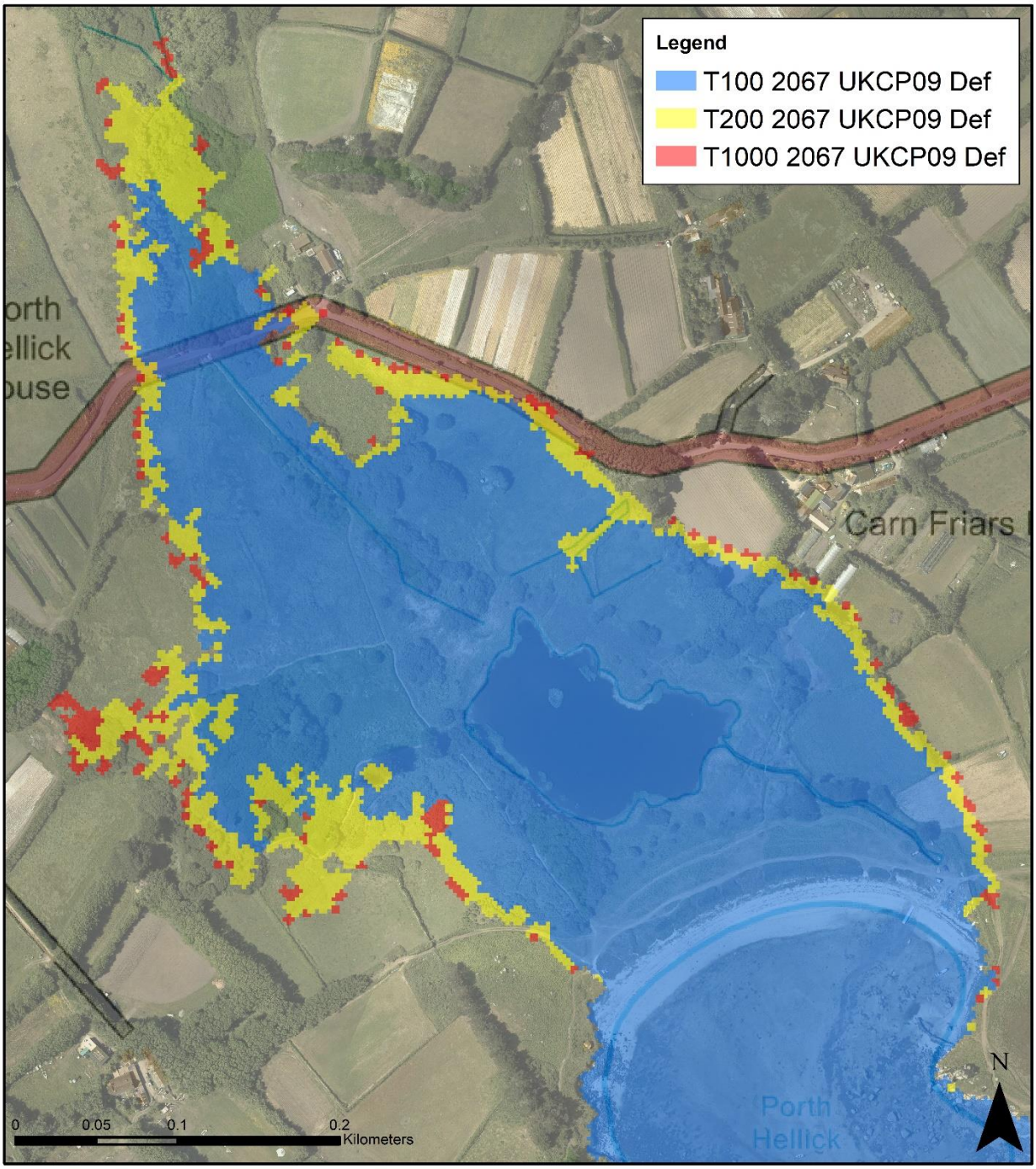
Aerial image courtesy of Channel Coastal Observatory

Figure 5-41: Model flood extents St Mary's Porth Hellick Defended present day



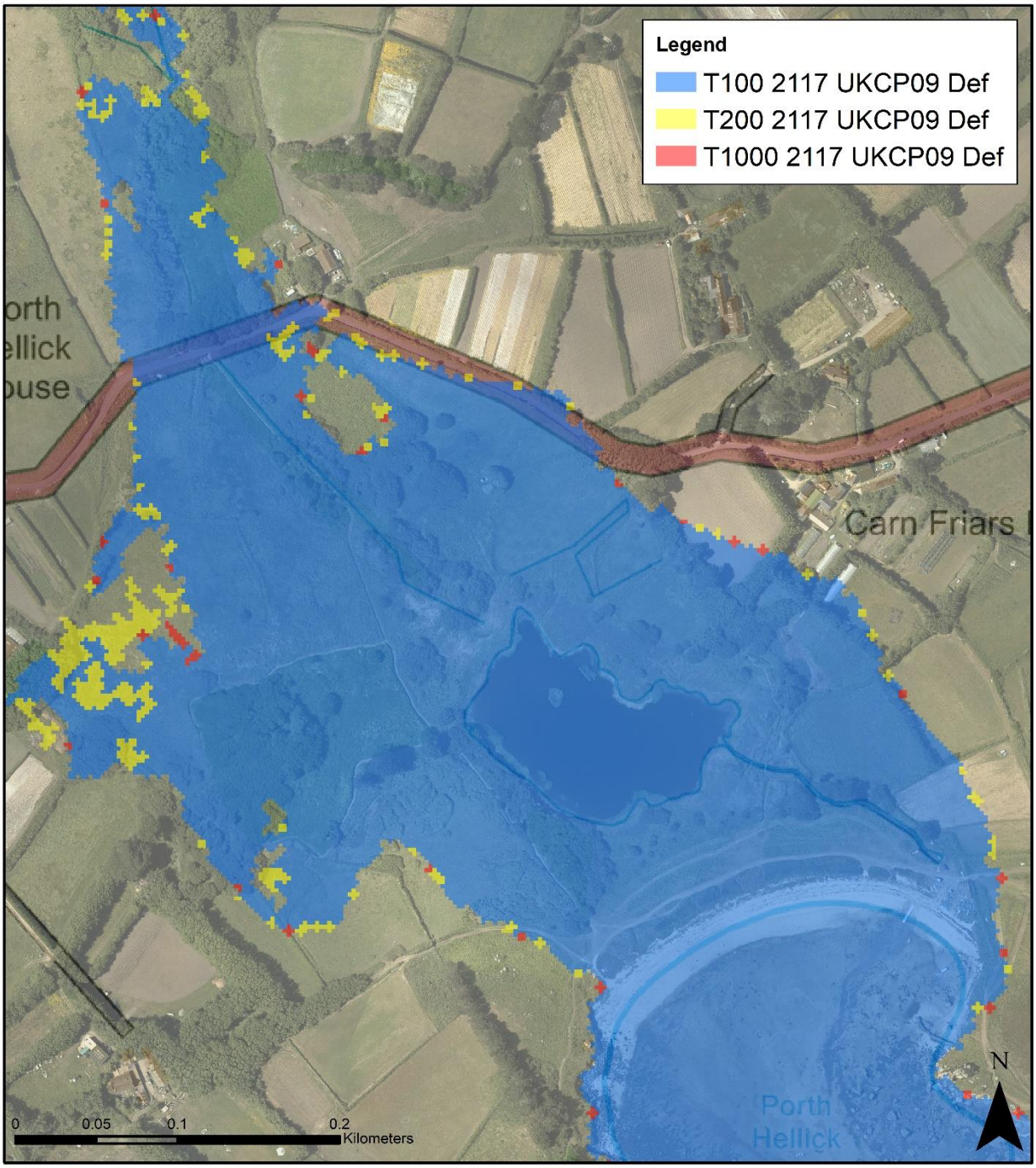
Aerial image courtesy of Channel Coastal Observatory

Figure 5-42: Model flood extents St Mary's Porth Hellick Undefended present day



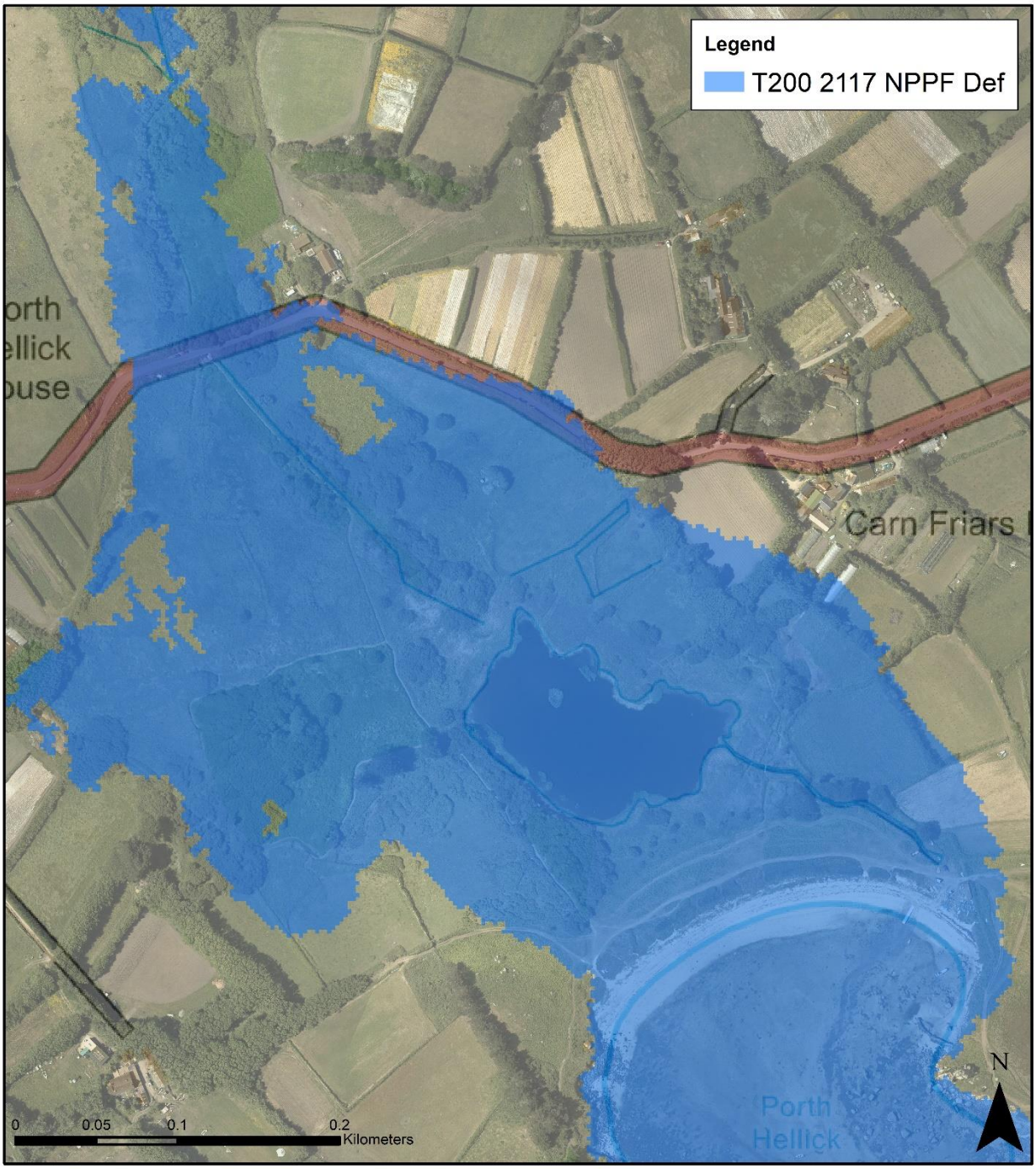
Aerial image courtesy of Channel Coastal Observatory

Figure 5-43: Model flood extents St Mary's Porth Hellick Defended 2067 UKCP09



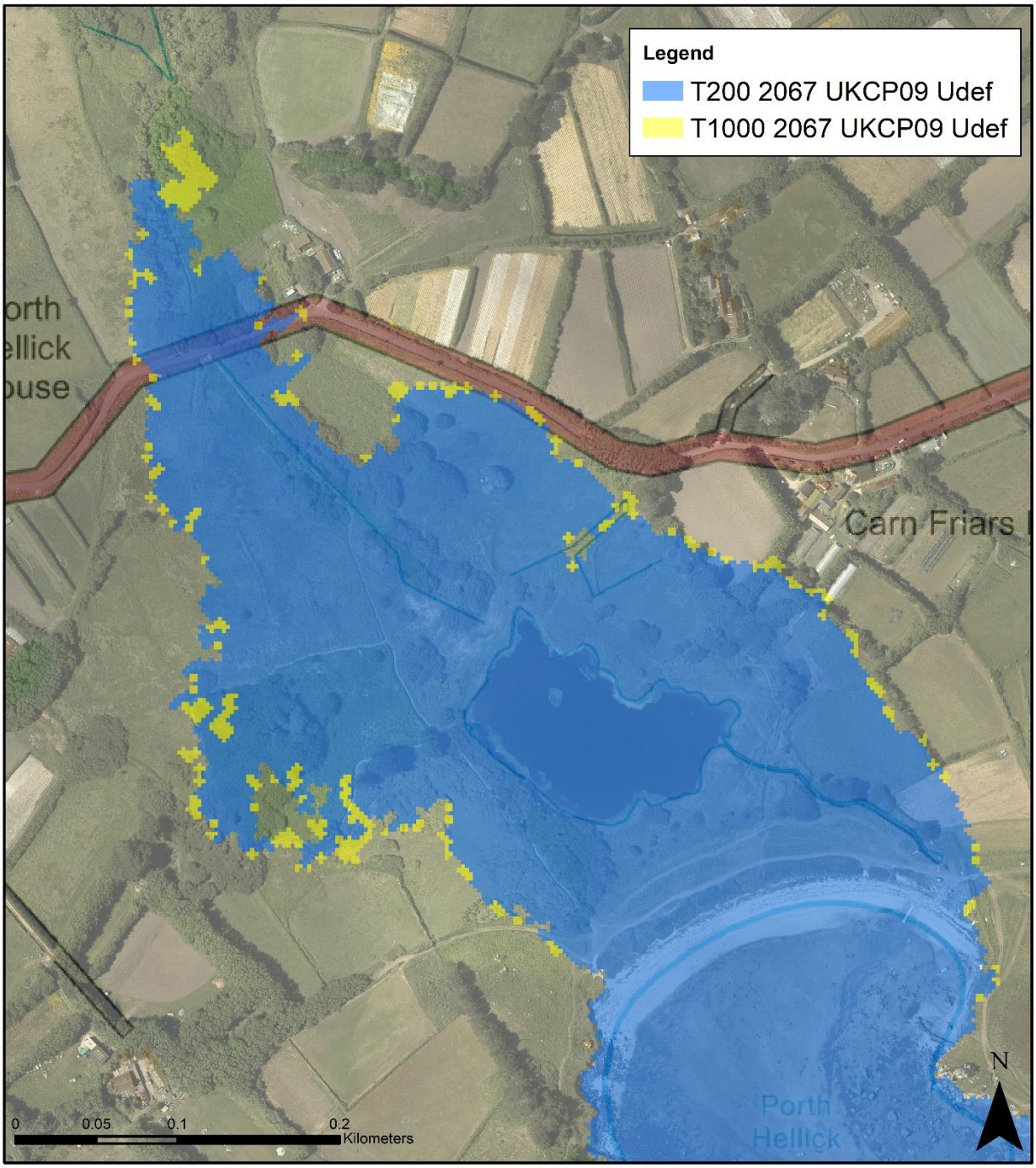
Aerial image courtesy of Channel Coastal Observatory

Figure 5-44: Model flood extents St Mary's Porth Hellick Defended 2117 UKCP09



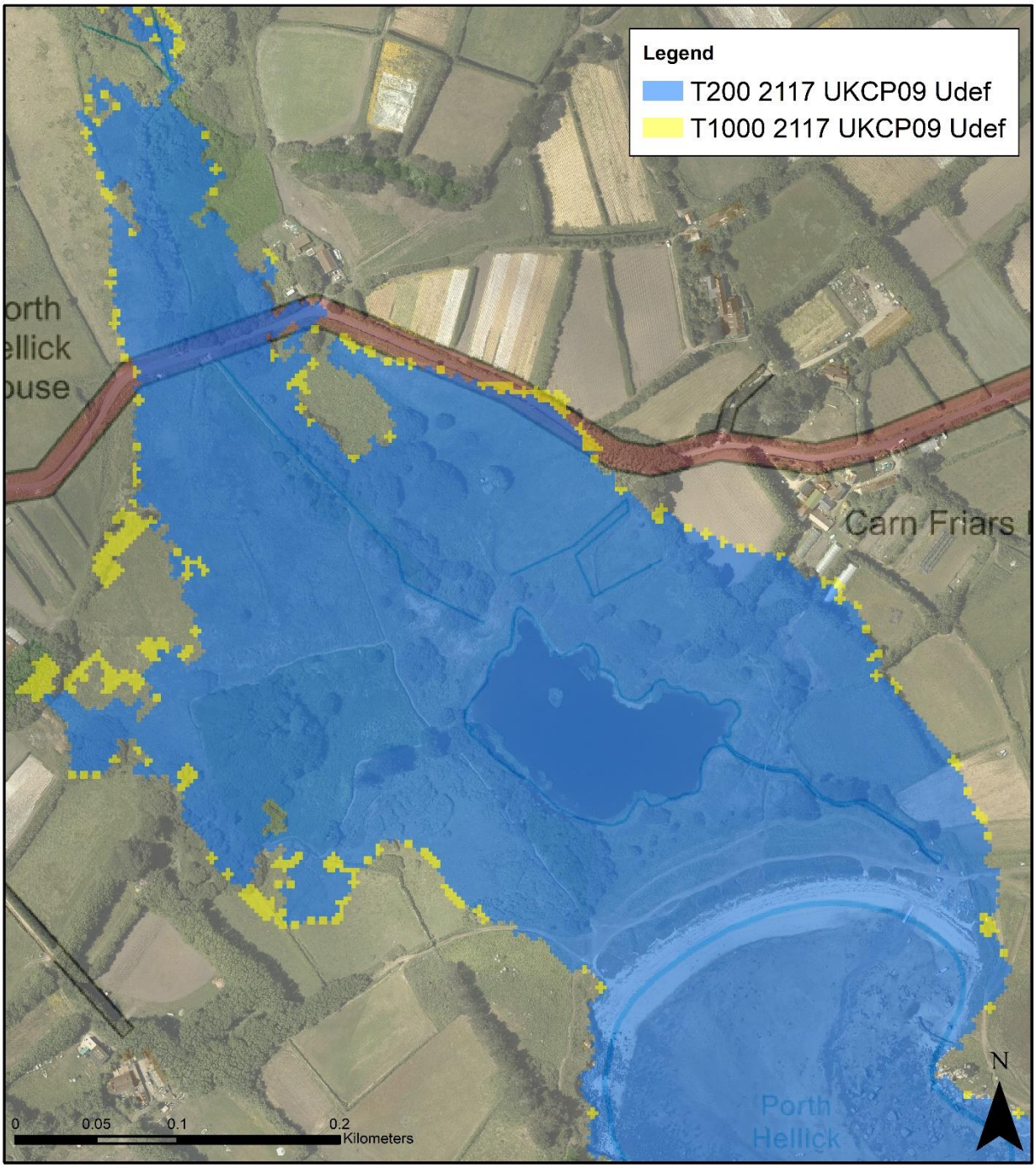
Aerial image courtesy of Channel Coastal Observatory

Figure 5-45: Model flood extents St Mary's Porth Hellick Defended 2117 NPPF



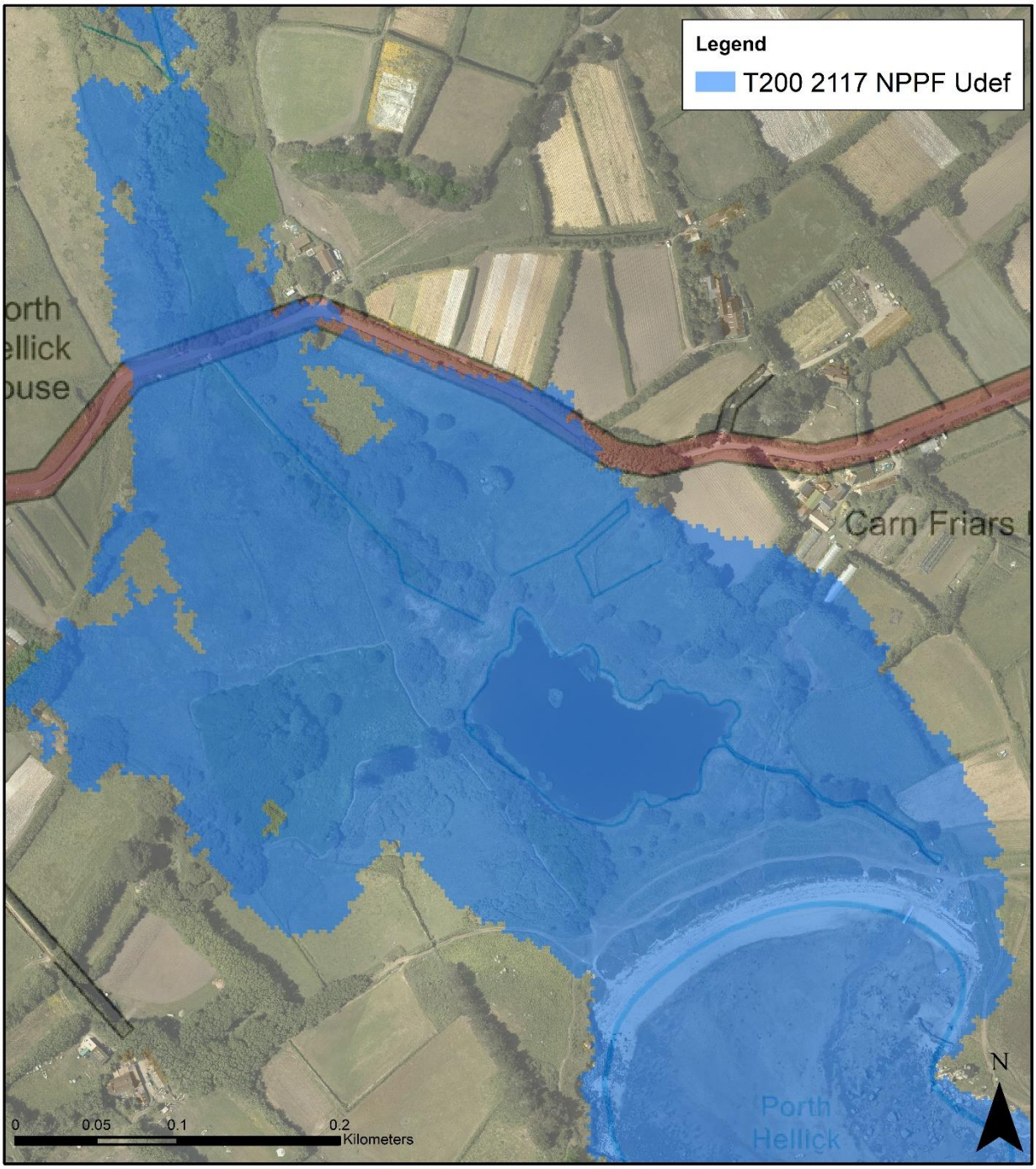
Aerial image courtesy of Channel Coastal Observatory

Figure 5-46: Model flood extents St Mary's Porth Hellick Undefended 2067 UKCP09



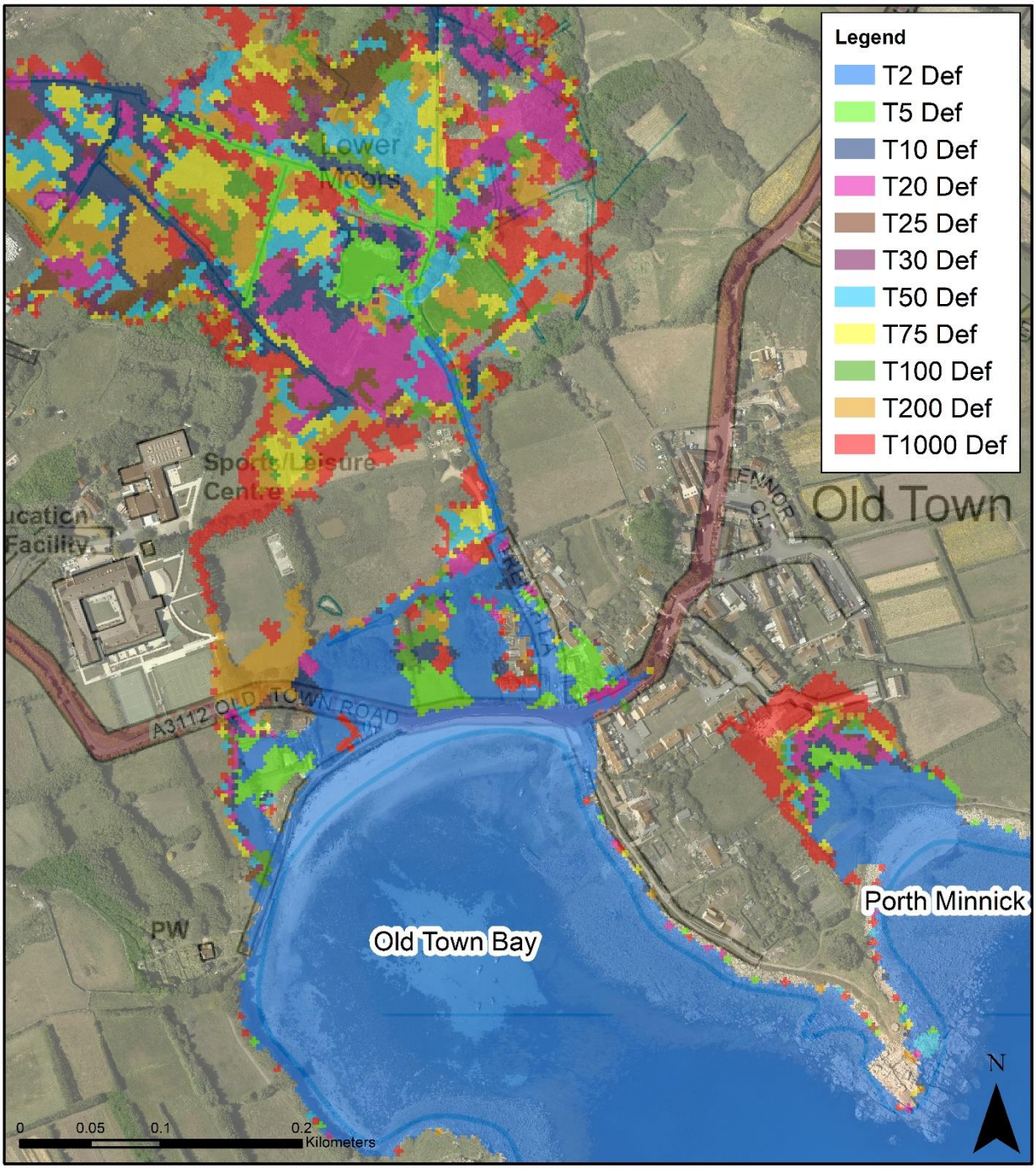
Aerial image courtesy of Channel Coastal Observatory

Figure 5-47: Model flood extents St Mary's Porth Hellick Undefended 2117 UKCP09



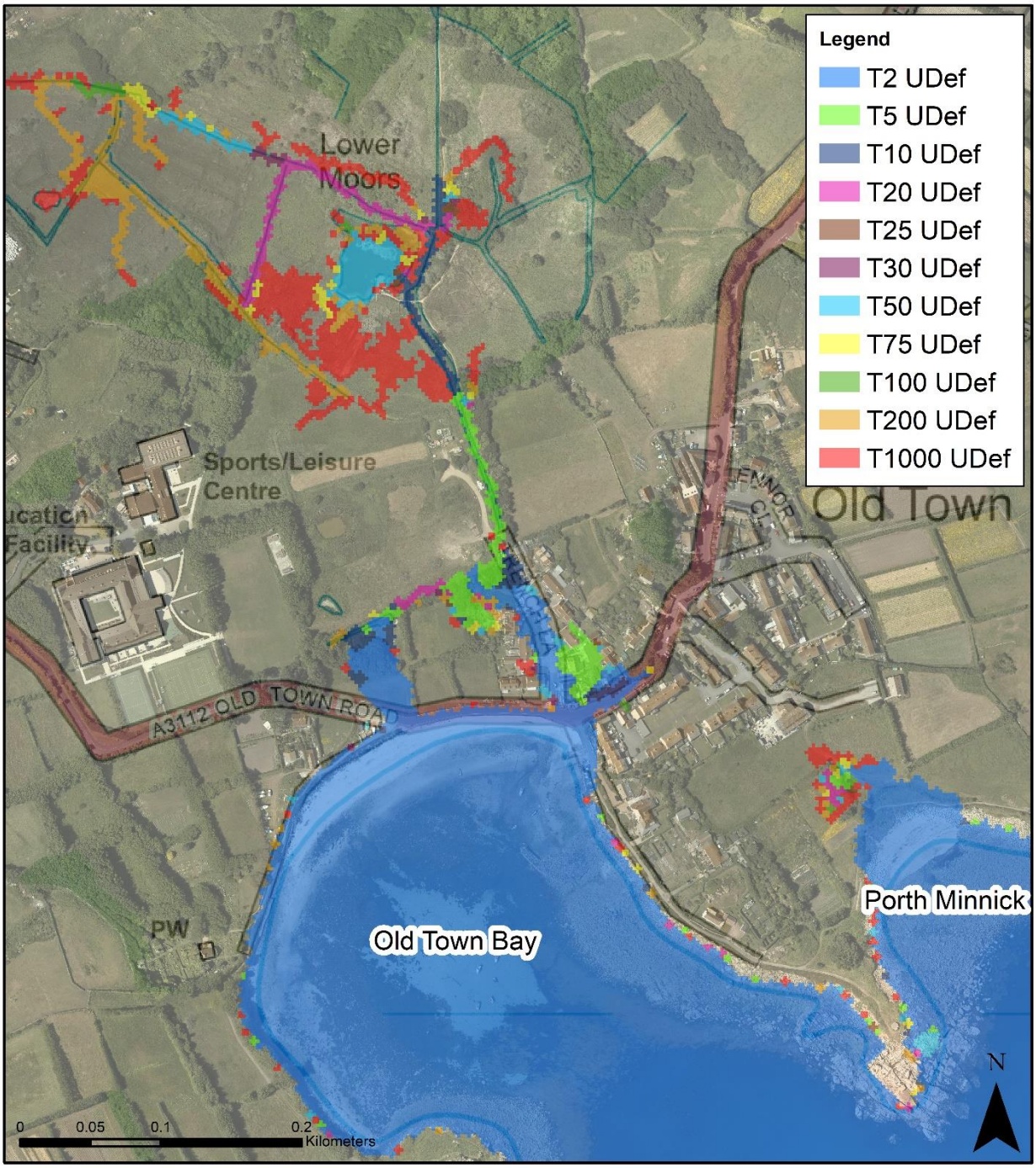
Aerial image courtesy of Channel Coastal Observatory

Figure 5-48: Model flood extents St Mary's Porth Hellick Undefended 2117 NPPF



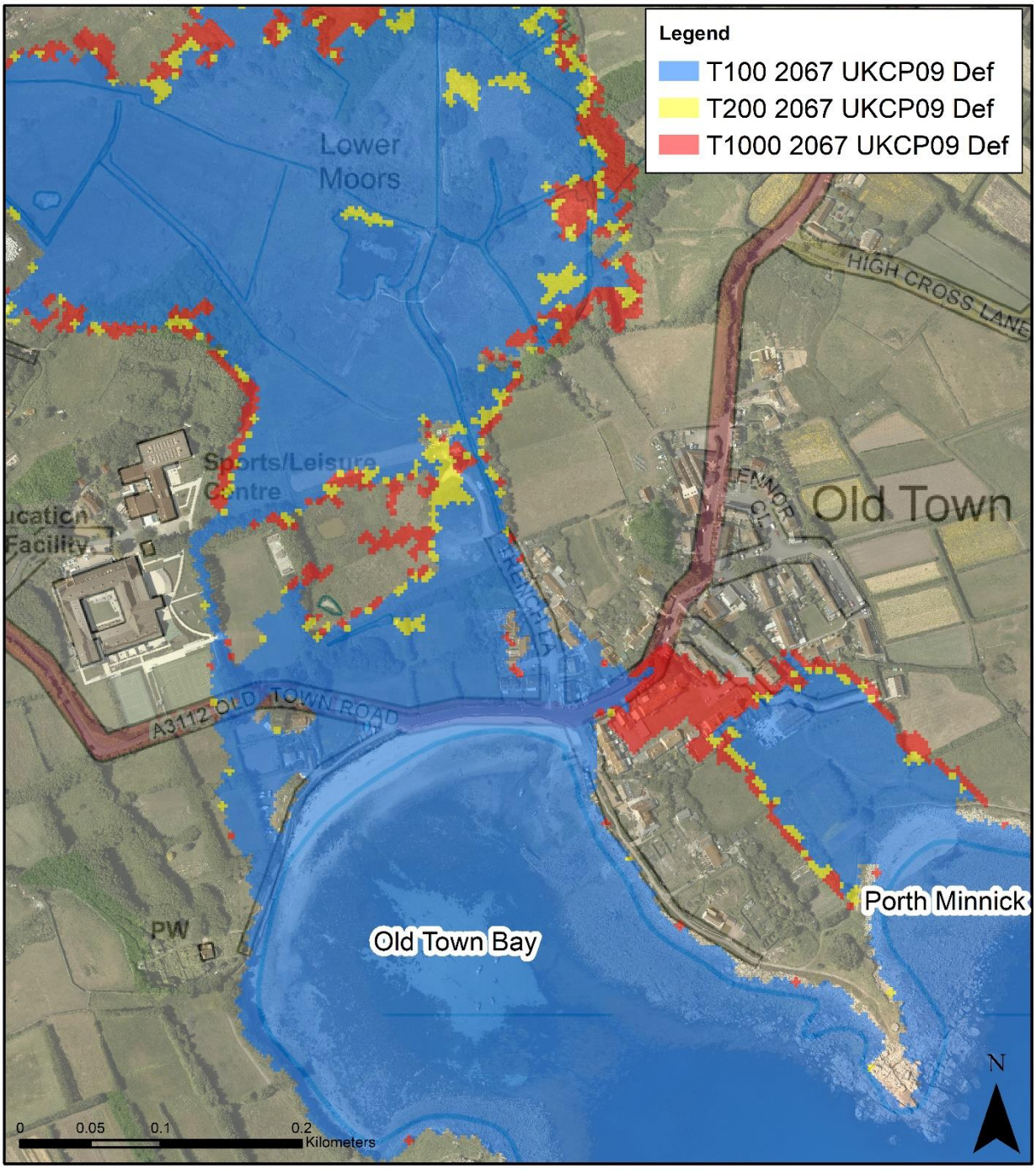
Aerial image courtesy of Channel Coastal Observatory

Figure 5-49: Model flood extents St Mary's Old Town Bay Defended present day



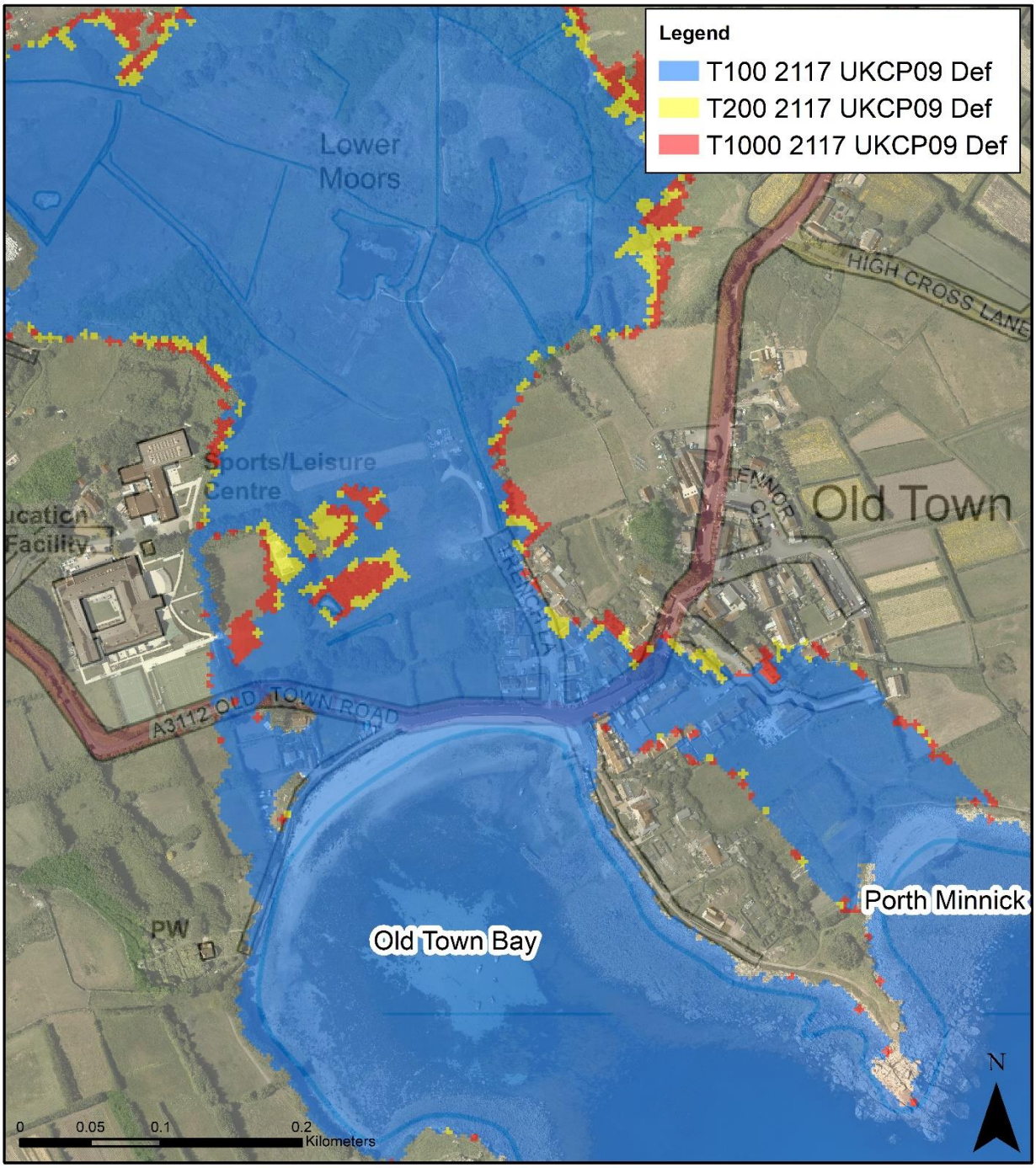
Aerial image courtesy of Channel Coastal Observatory

Figure 5-50: Model flood extents St Mary's Old Town Bay Undefended present day



Aerial image courtesy of Channel Coastal Observatory

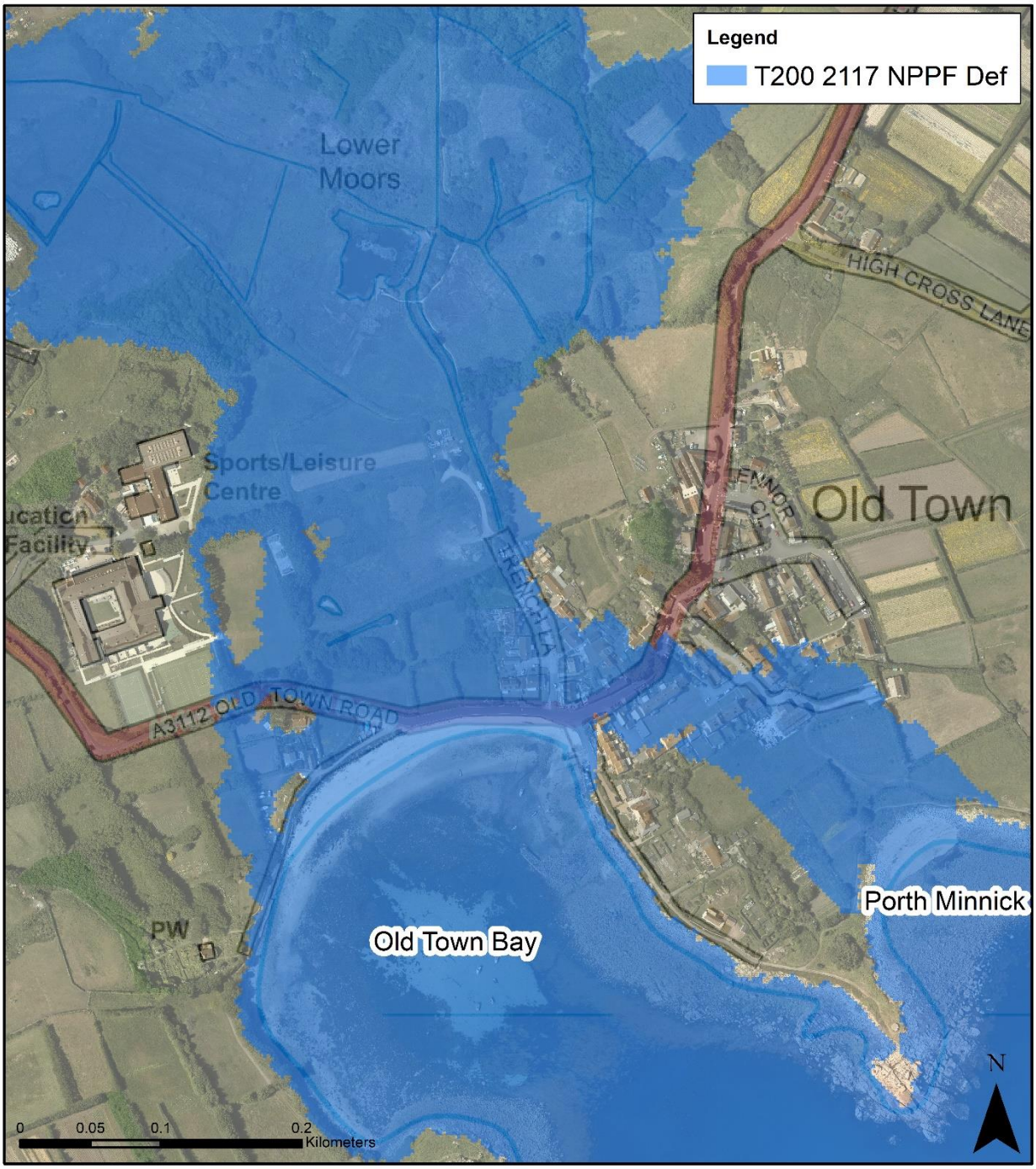
Figure 5-51: Model flood extents St Mary's Old Town Bay Defended 2067 UKCP09



Aerial image courtesy of Channel Coastal Observatory

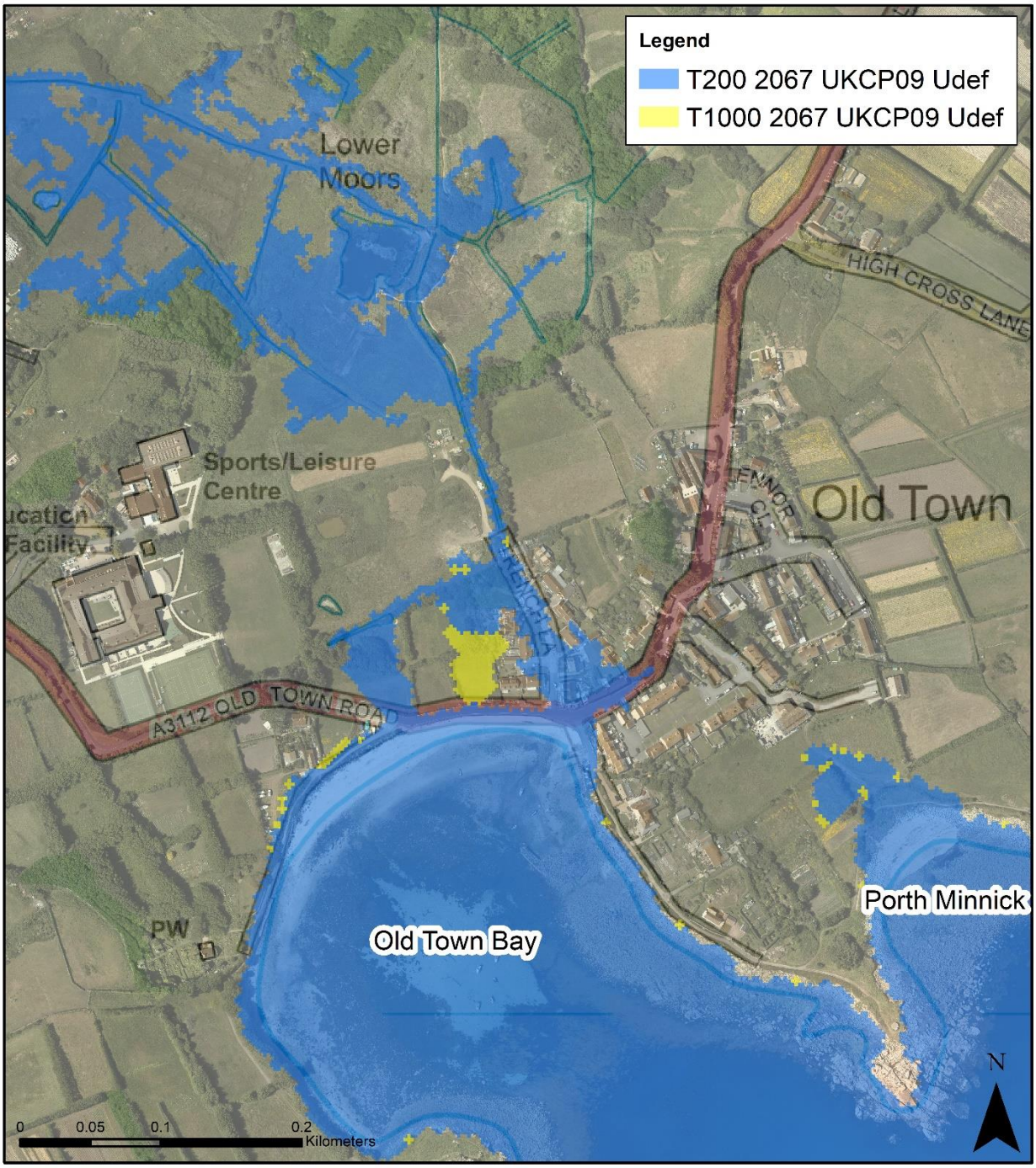
Figure 5-52: Model flood extents St Mary's Old Town Bay Defended 2117 UKCP09

Aerial image courtesy of Channel Coastal Observatory



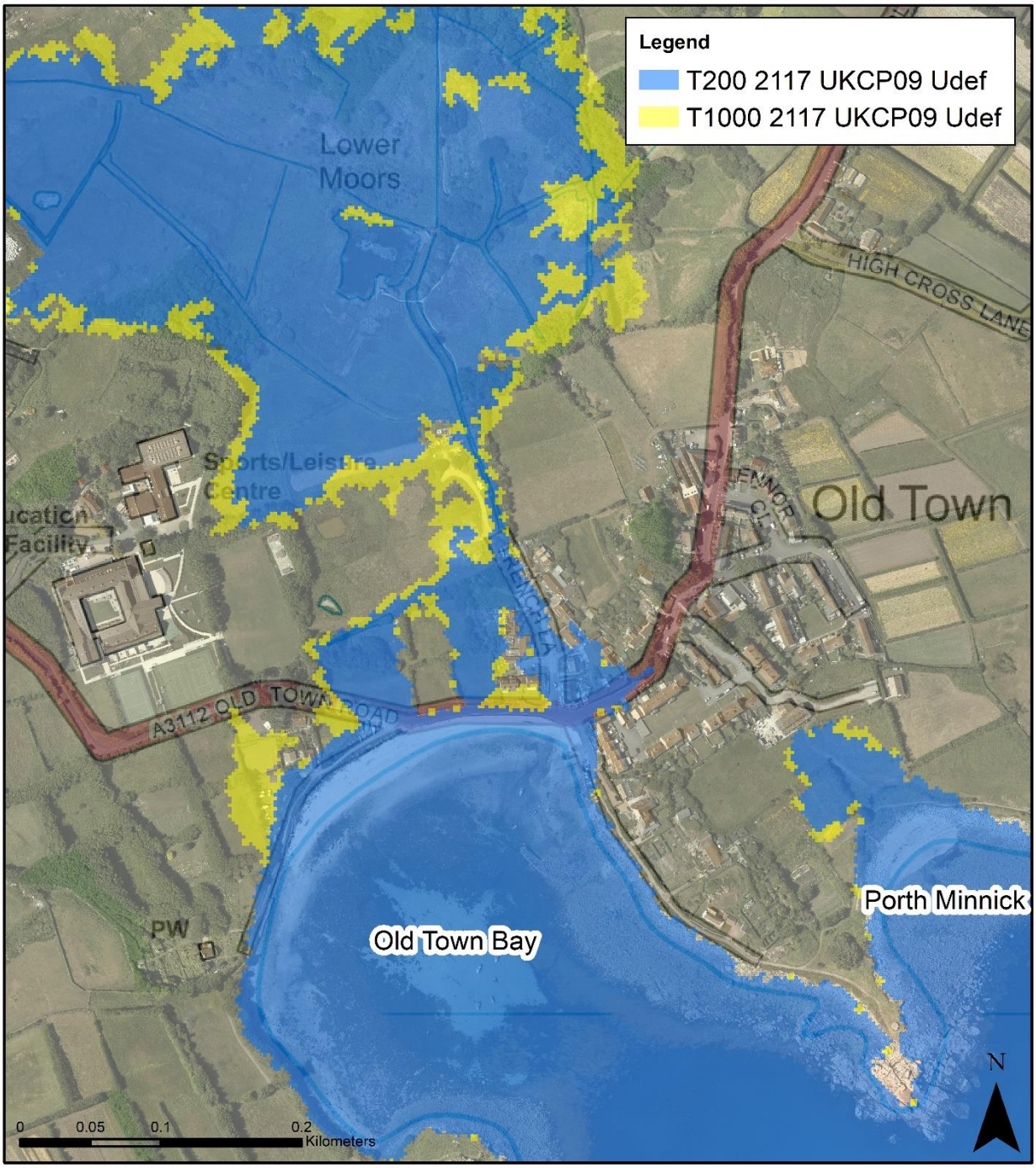
Aerial image courtesy of Channel Coastal Observatory

Figure 5-53: Model flood extents St Mary's Old Town Bay Defended 2117 NPPF



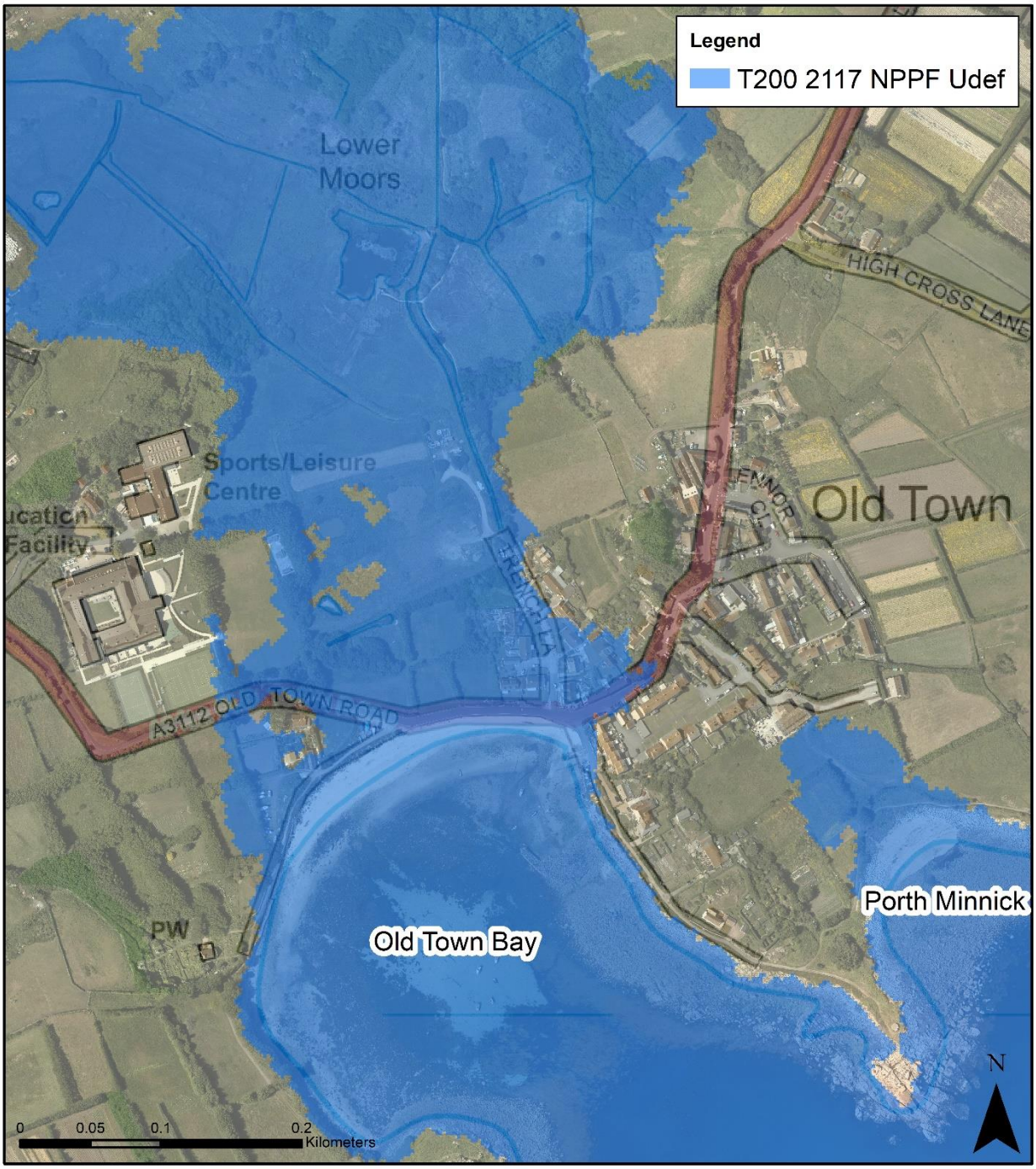
Aerial image courtesy of Channel Coastal Observatory

Figure 5-54: Model flood extents St Mary's Old Town Bay Undefended 2067 UKCP09



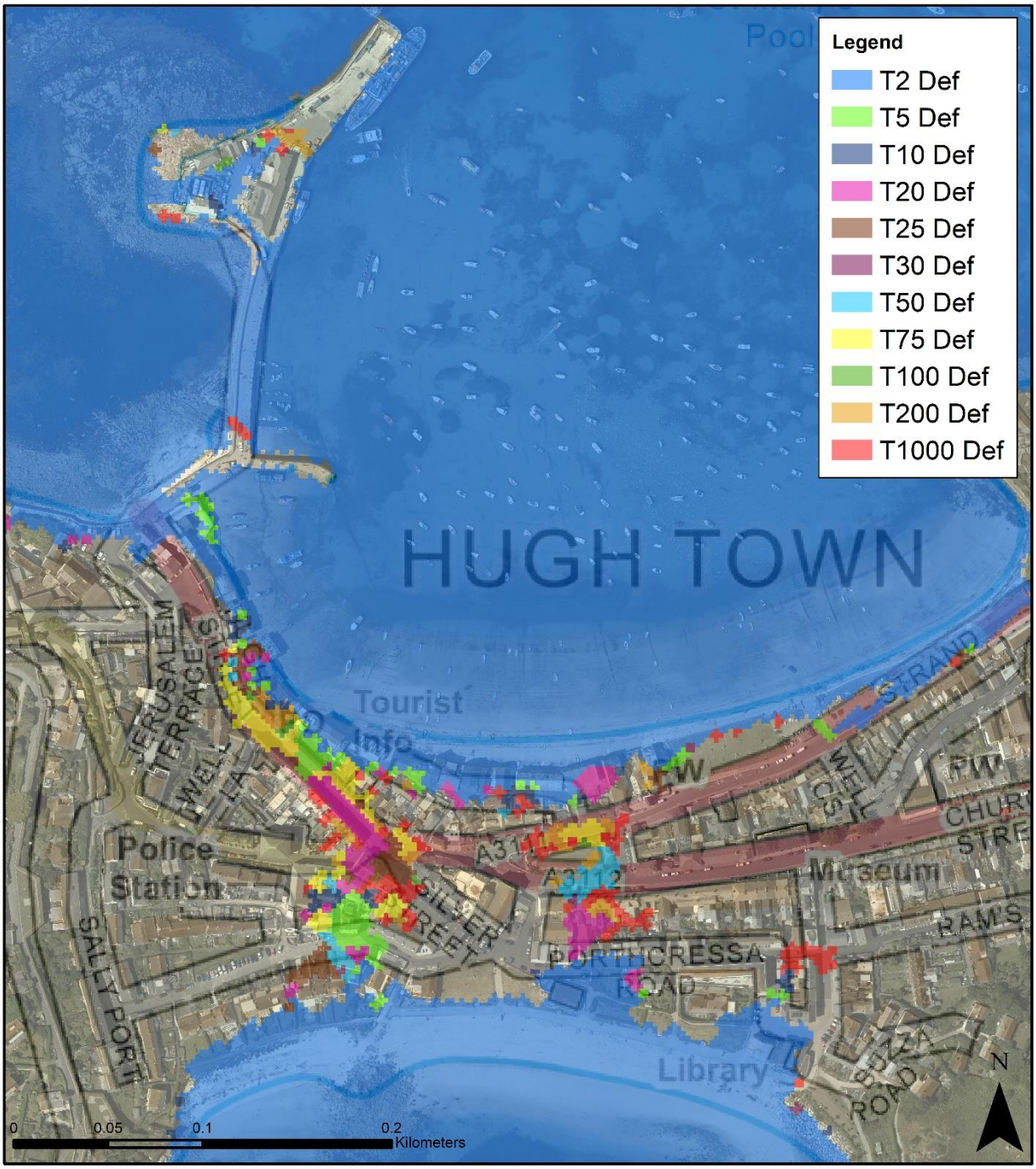
Aerial image courtesy of Channel Coastal Observatory

Figure 5-55: Model flood extents St Mary's Old Town Bay Undefended 2117 UKCP09



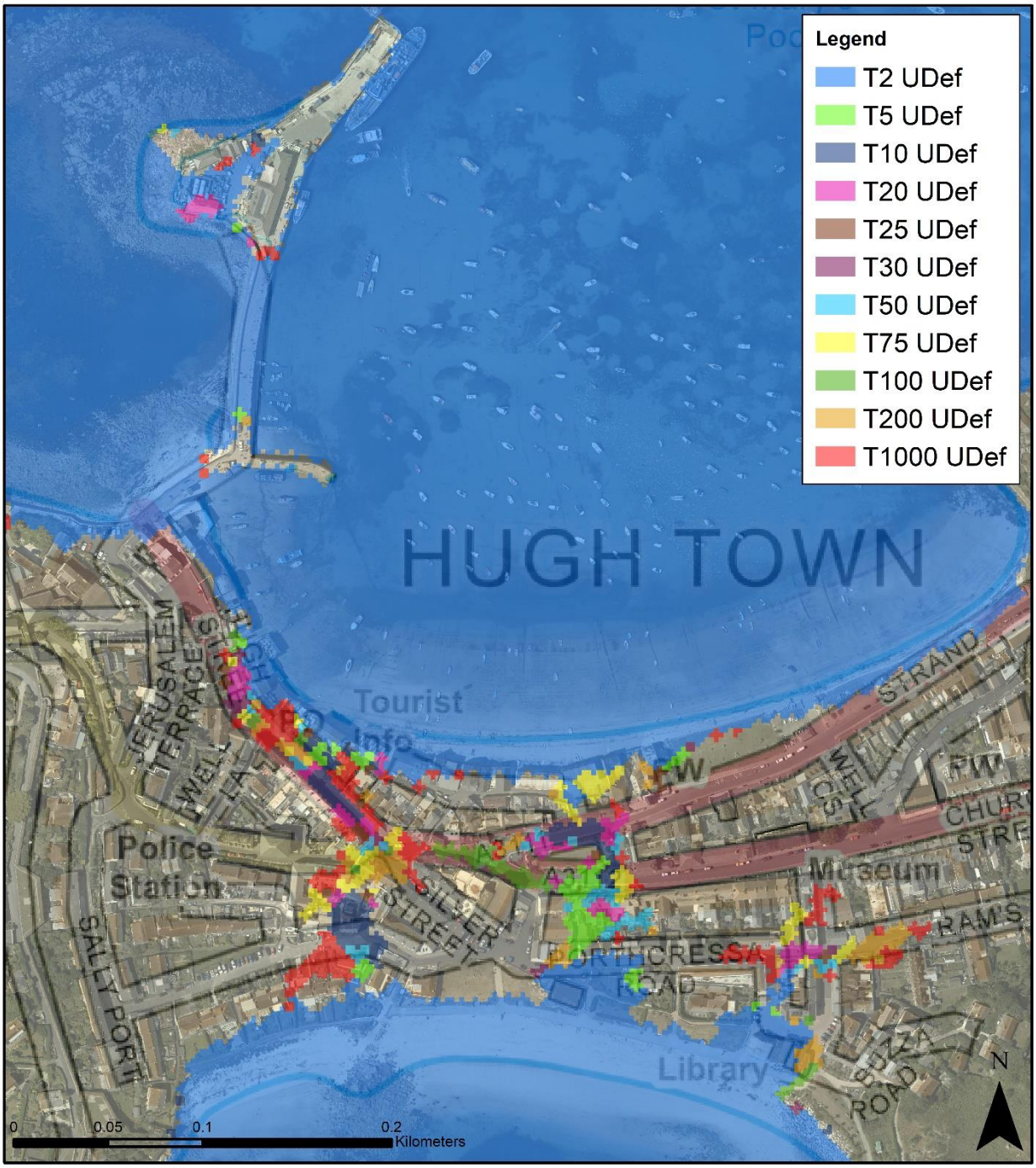
Aerial image courtesy of Channel Coastal Observatory

Figure 5-56: Model flood extents St Mary's Old Town Bay Undefended 2117 NPPF



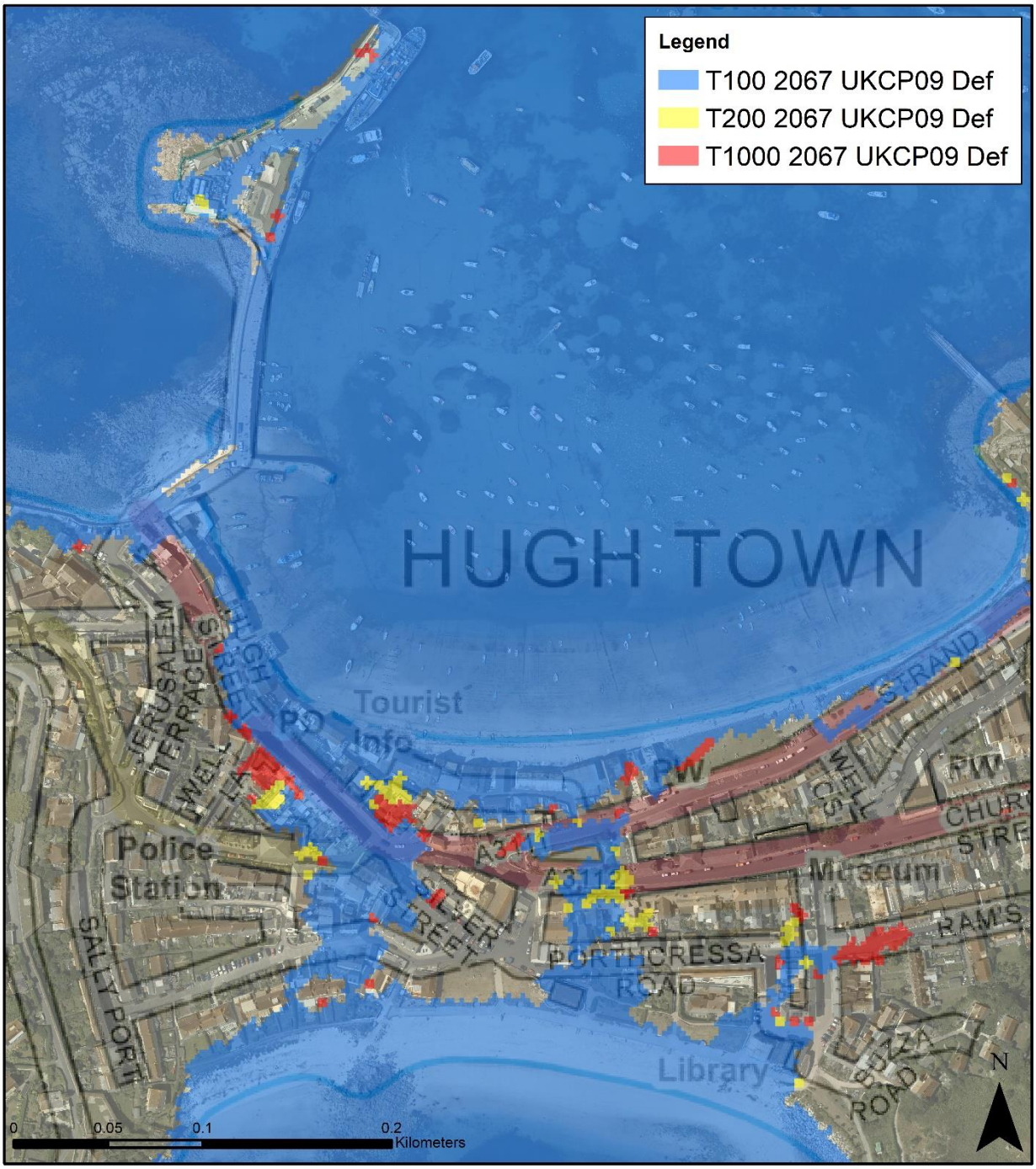
Aerial image courtesy of Channel Coastal Observatory

Figure 5-57: Model flood extents St Mary's Hugh Town Defended present day



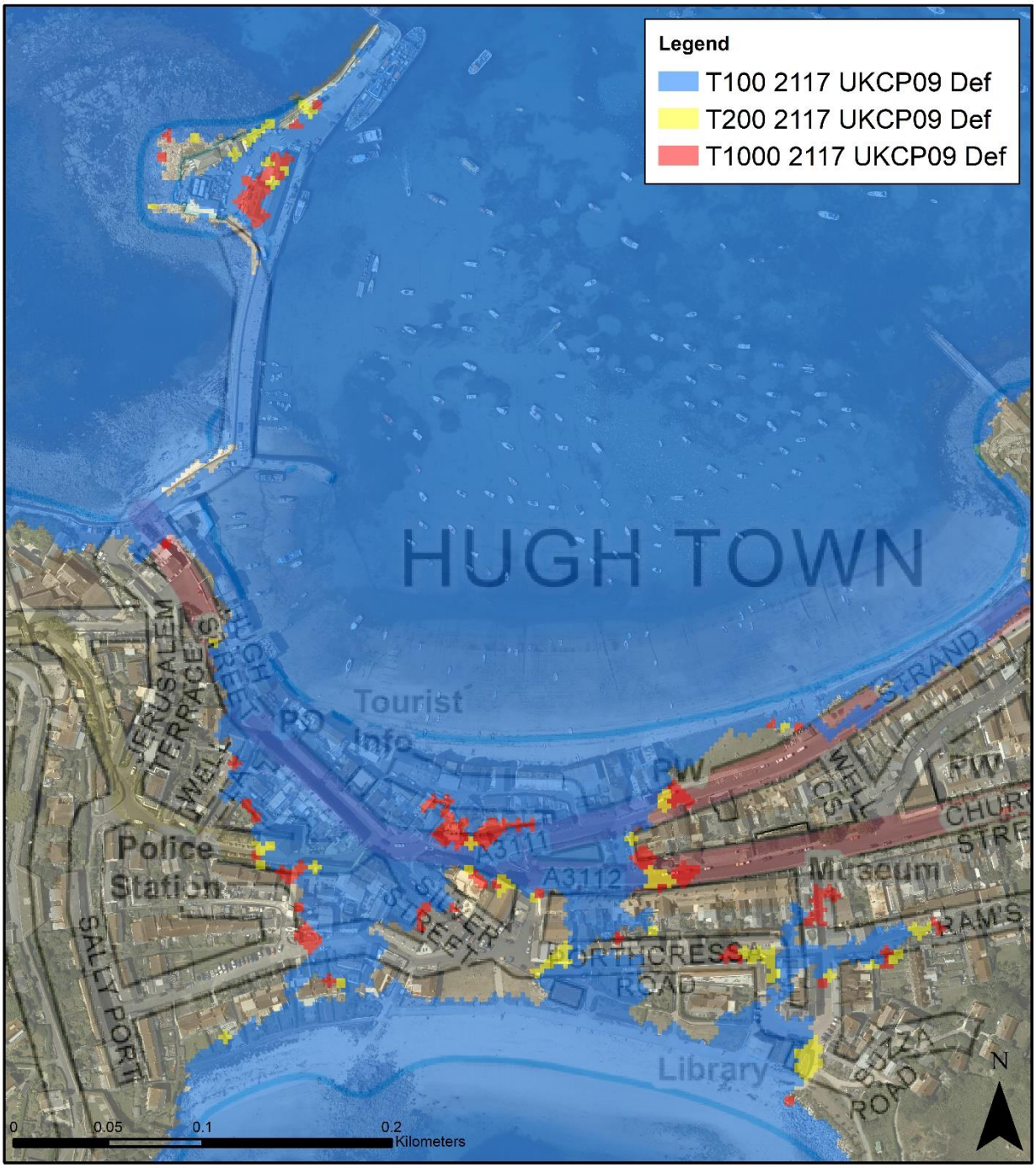
Aerial image courtesy of Channel Coastal Observatory

Figure 5-58: Model flood extents St Mary's Hugh Town Undefended present day



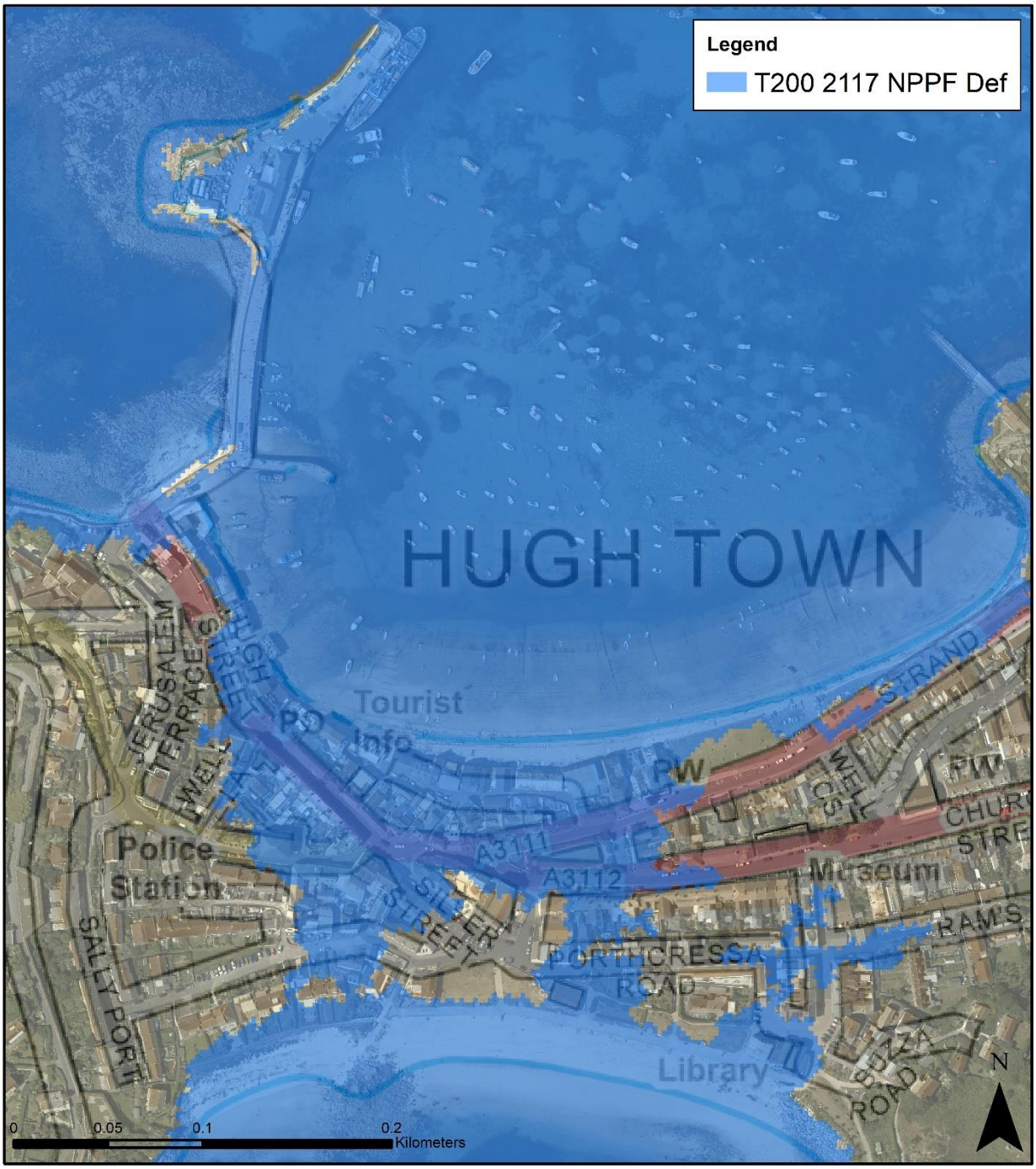
Aerial image courtesy of Channel Coastal Observatory

Figure 5-59: Model flood extents St Mary's Hugh Town Defended 2067 UKCP09



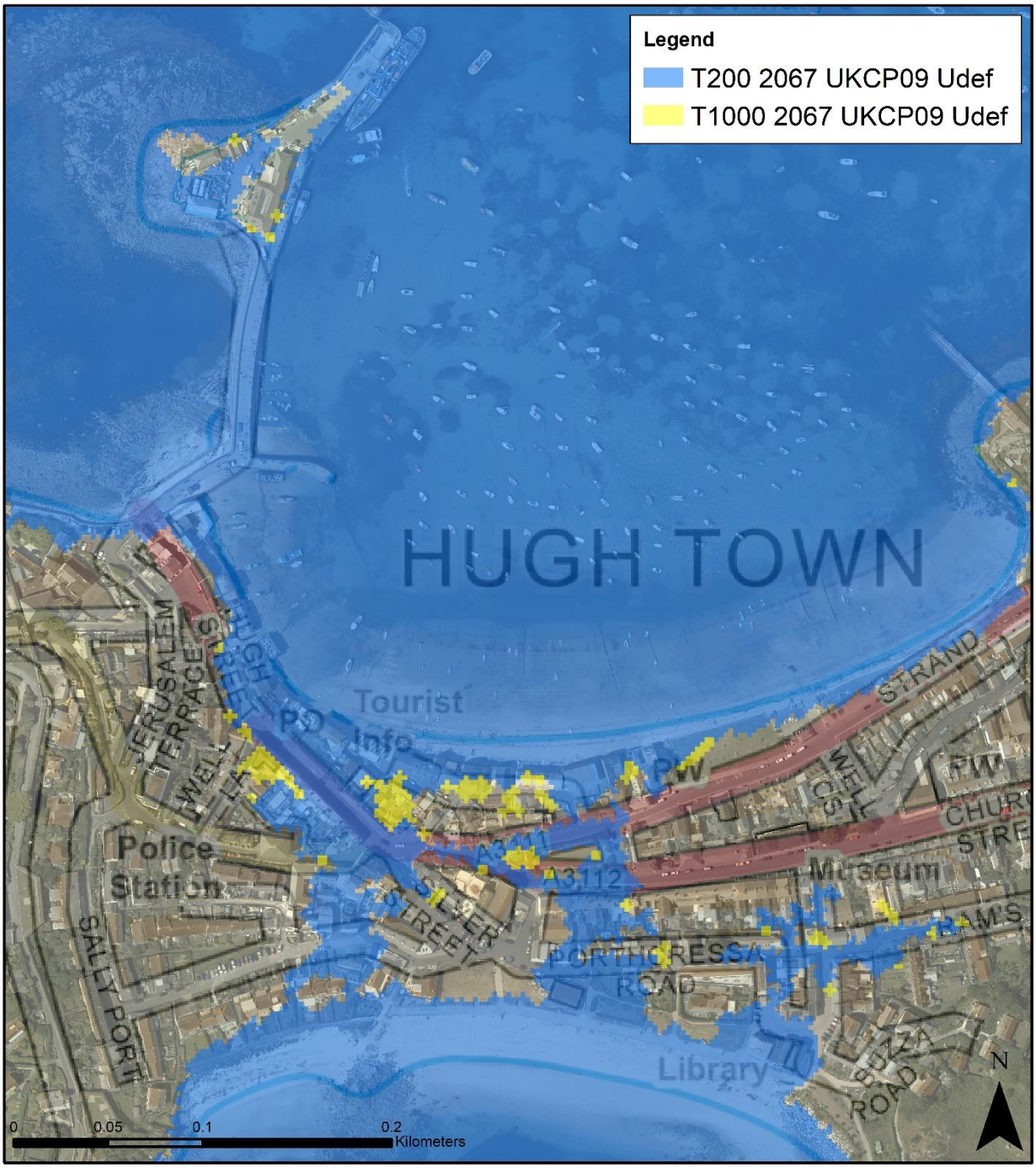
Aerial image courtesy of Channel Coastal Observatory

Figure 5-60: Model flood extents St Mary's Hugh Town Defended 2117 UKCP09



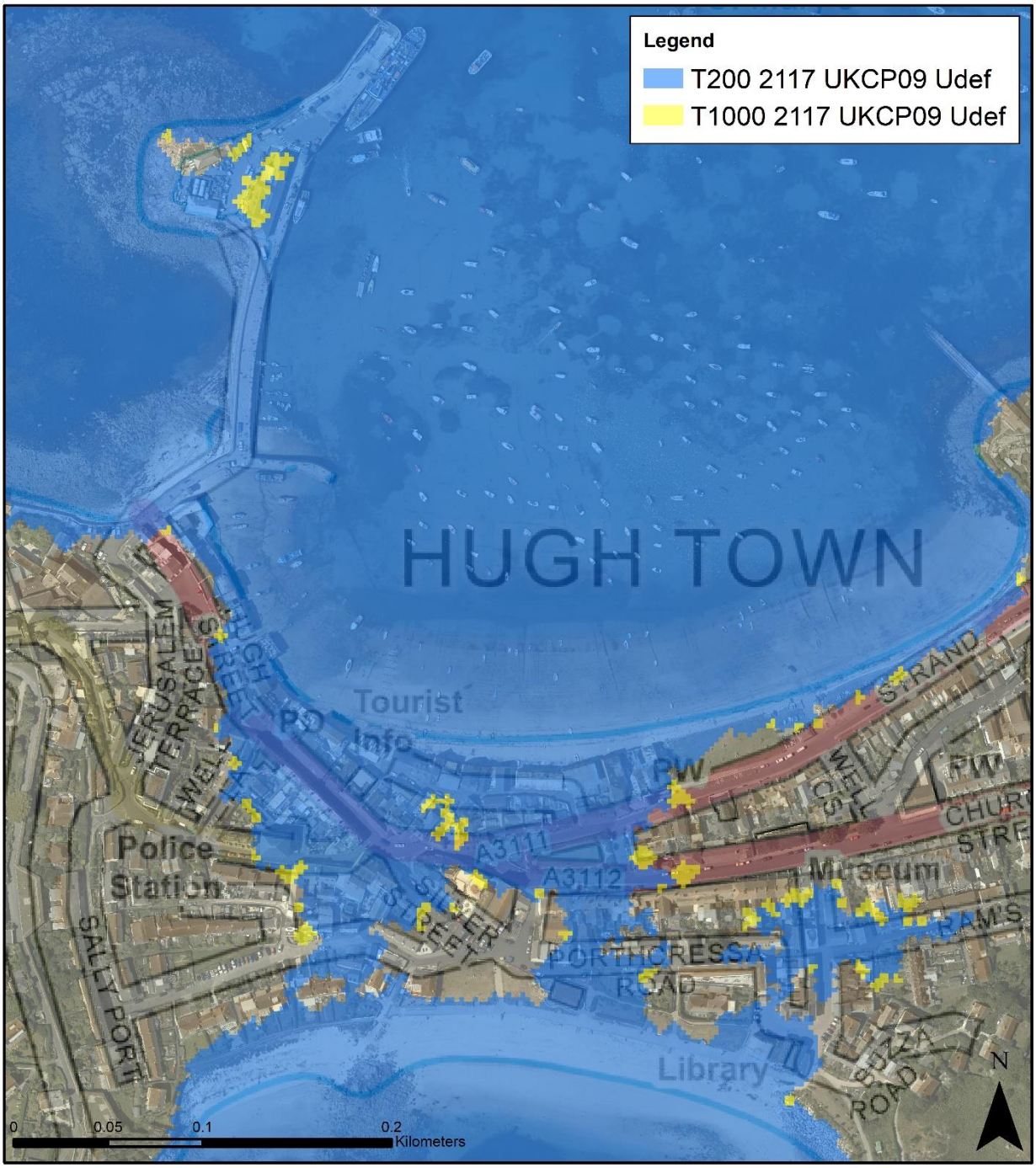
Aerial image courtesy of Channel Coastal Observatory

Figure 5-61: Model flood extents St Mary's Hugh Town Defended 2117 NPPF



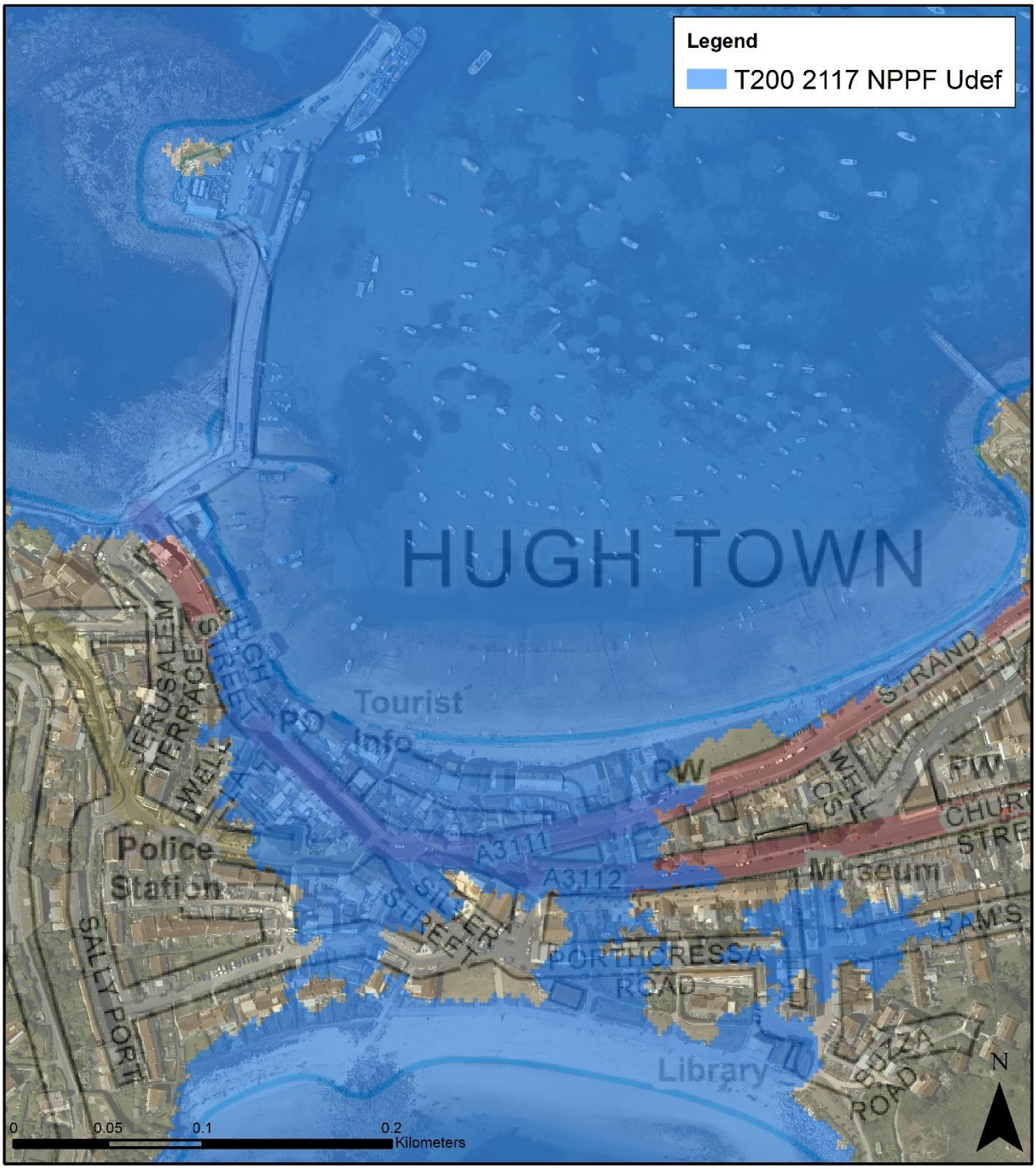
Aerial image courtesy of Channel Coastal Observatory

Figure 5-62: Model flood extents St Mary's Hugh Town Undefended 2067 UKCP09



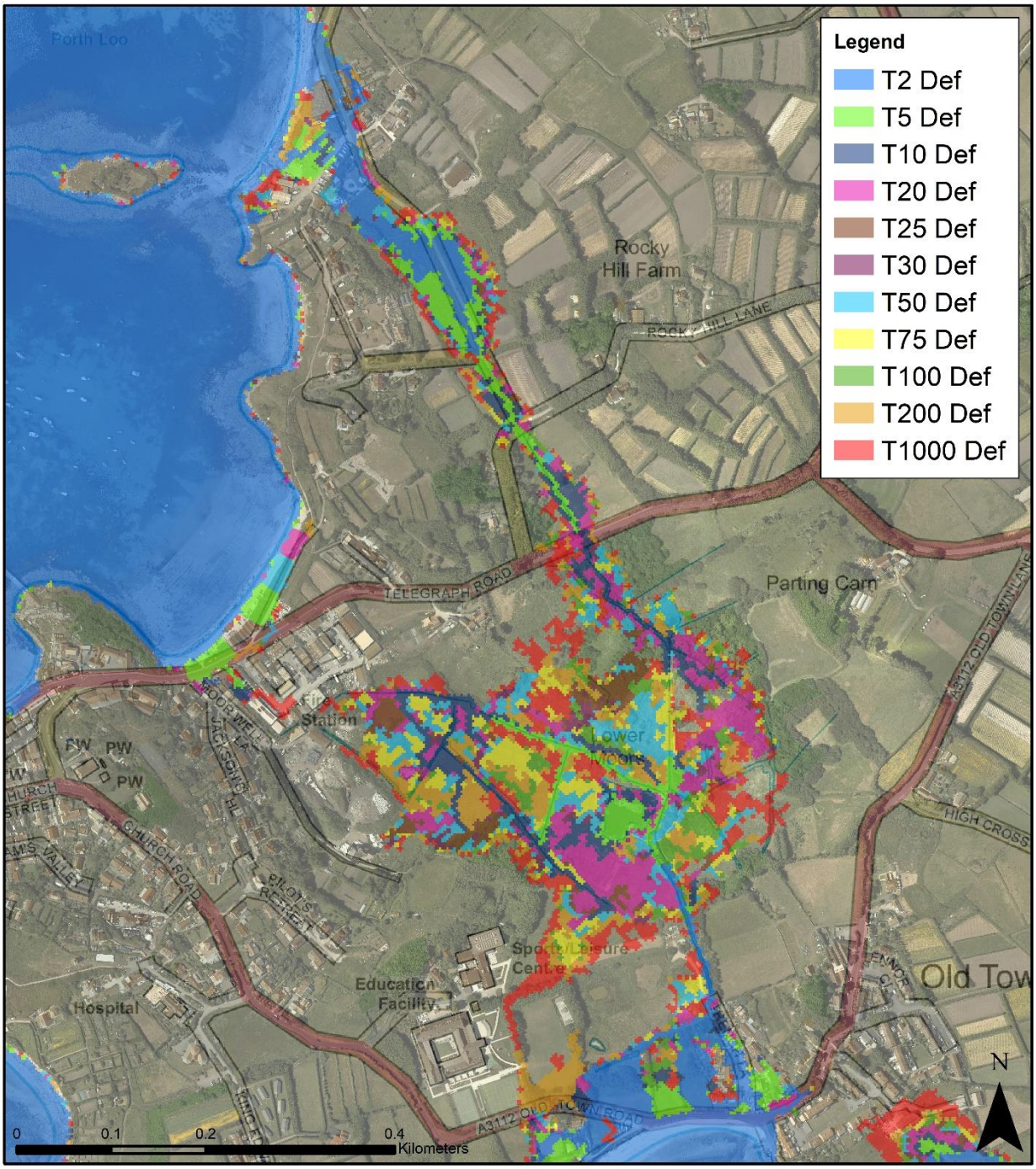
Aerial image courtesy of Channel Coastal Observatory

Figure 5-63: Model flood extents St Mary's Hugh Town Undefended 2117 UKCP09



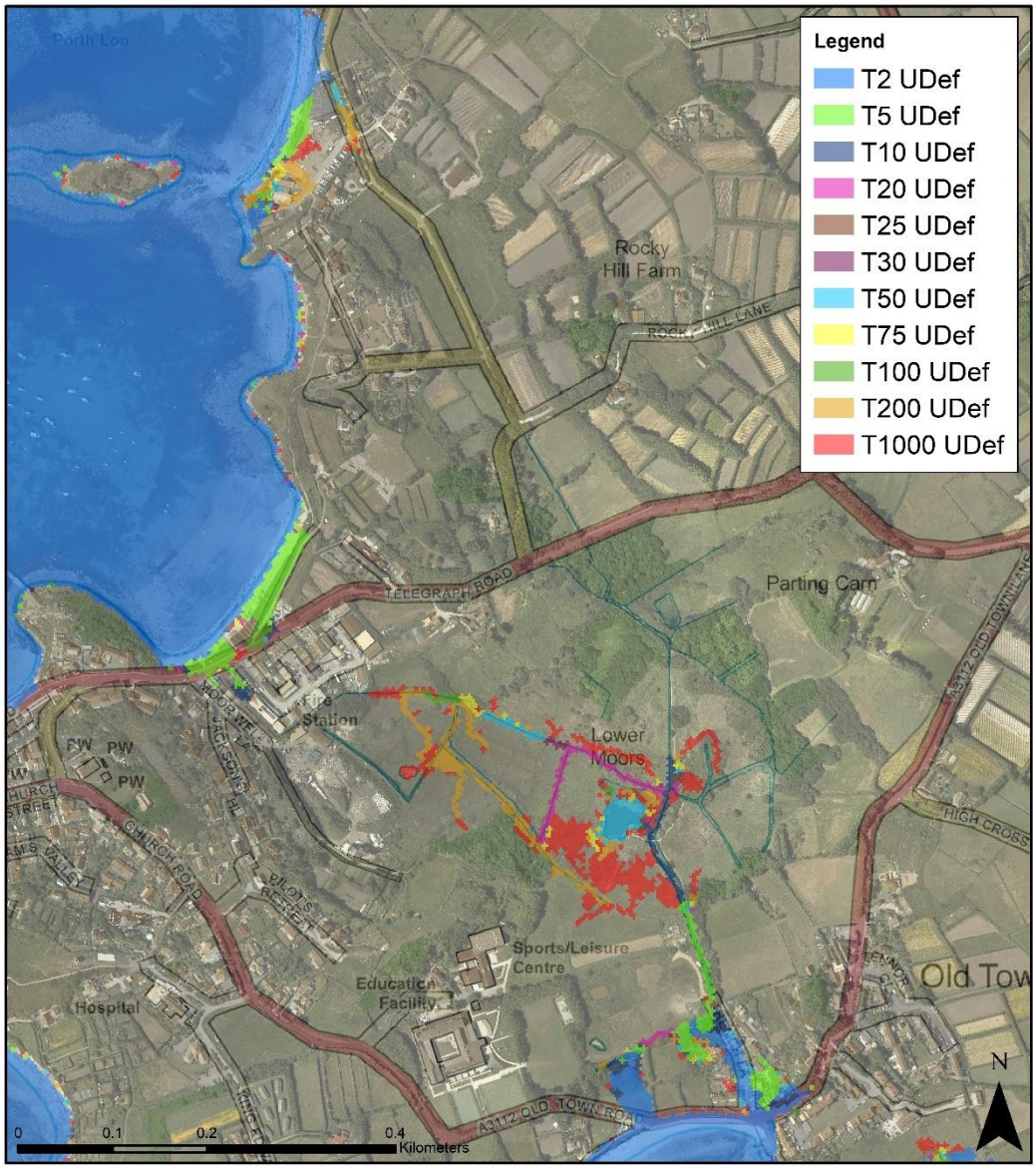
Aerial image courtesy of Channel Coastal Observatory

Figure 5-64: Model flood extents St Mary's Hugh Town Undefended 2117 NPPF



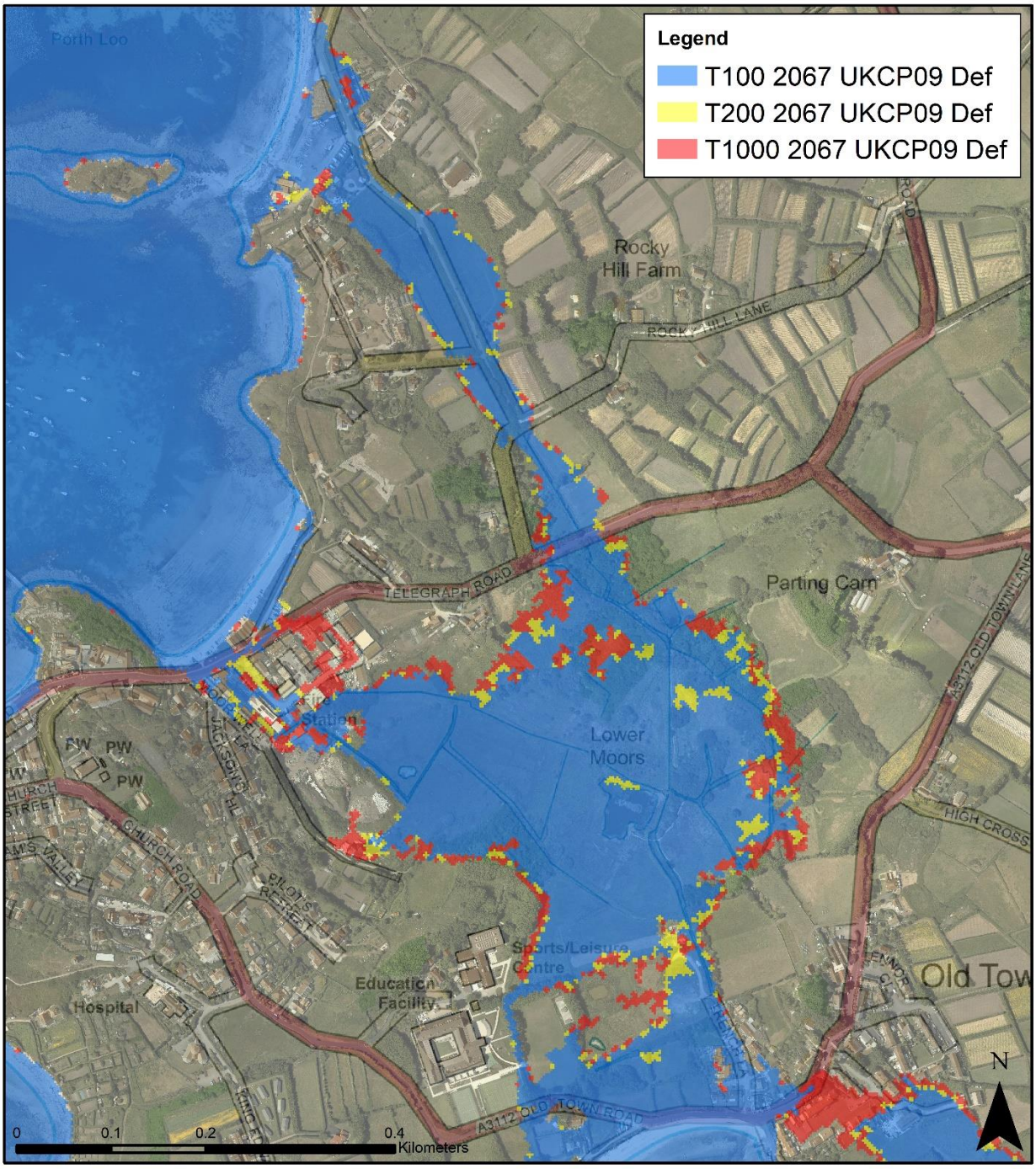
Aerial image courtesy of Channel Coastal Observatory

Figure 5-65: Model flood extents St Mary's Porthloo Defended present day



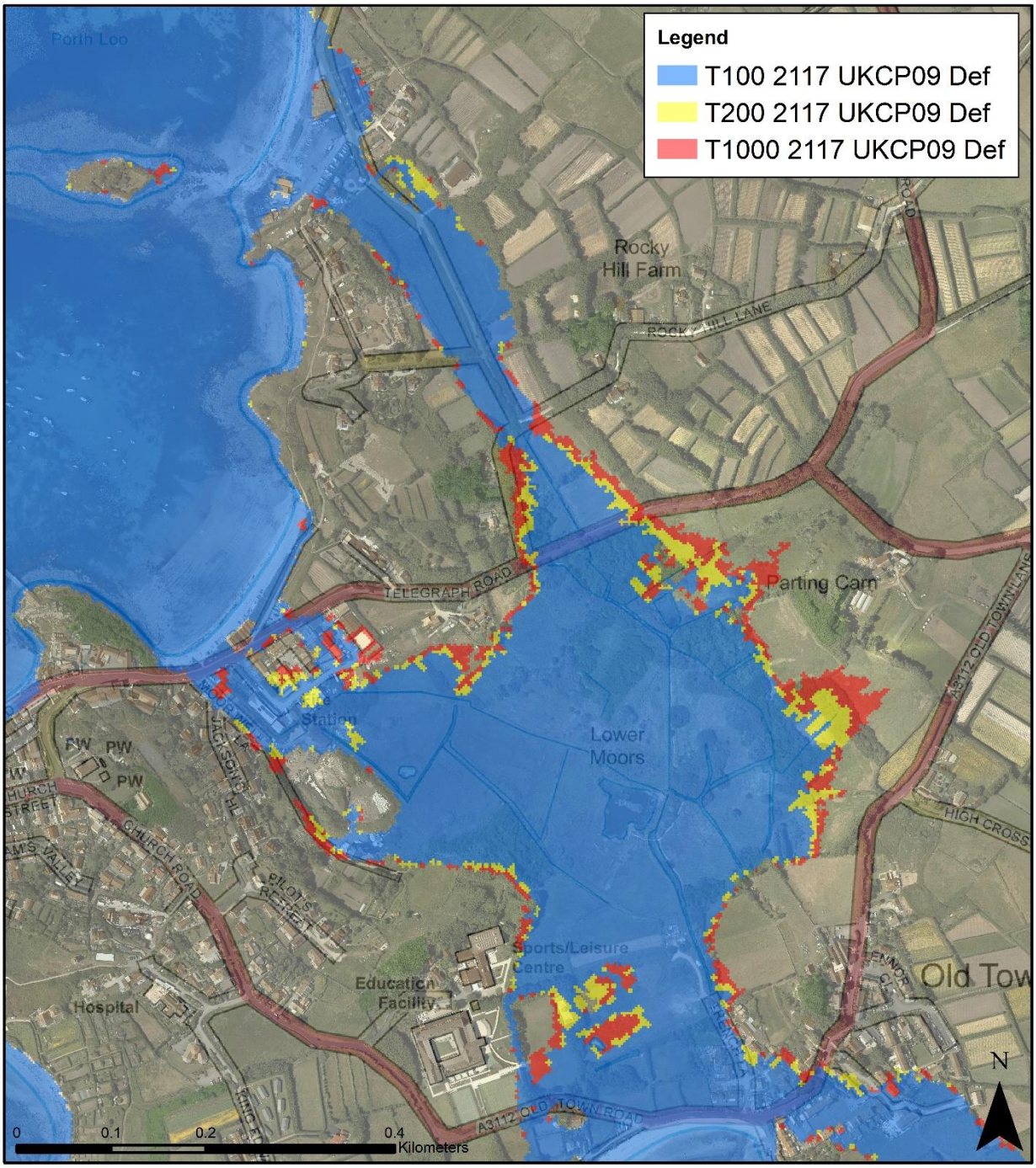
Aerial image courtesy of Channel Coastal Observatory

Figure 5-66: Model flood extents St Mary's Porthloo Undefended present day



Aerial image courtesy of Channel Coastal Observatory

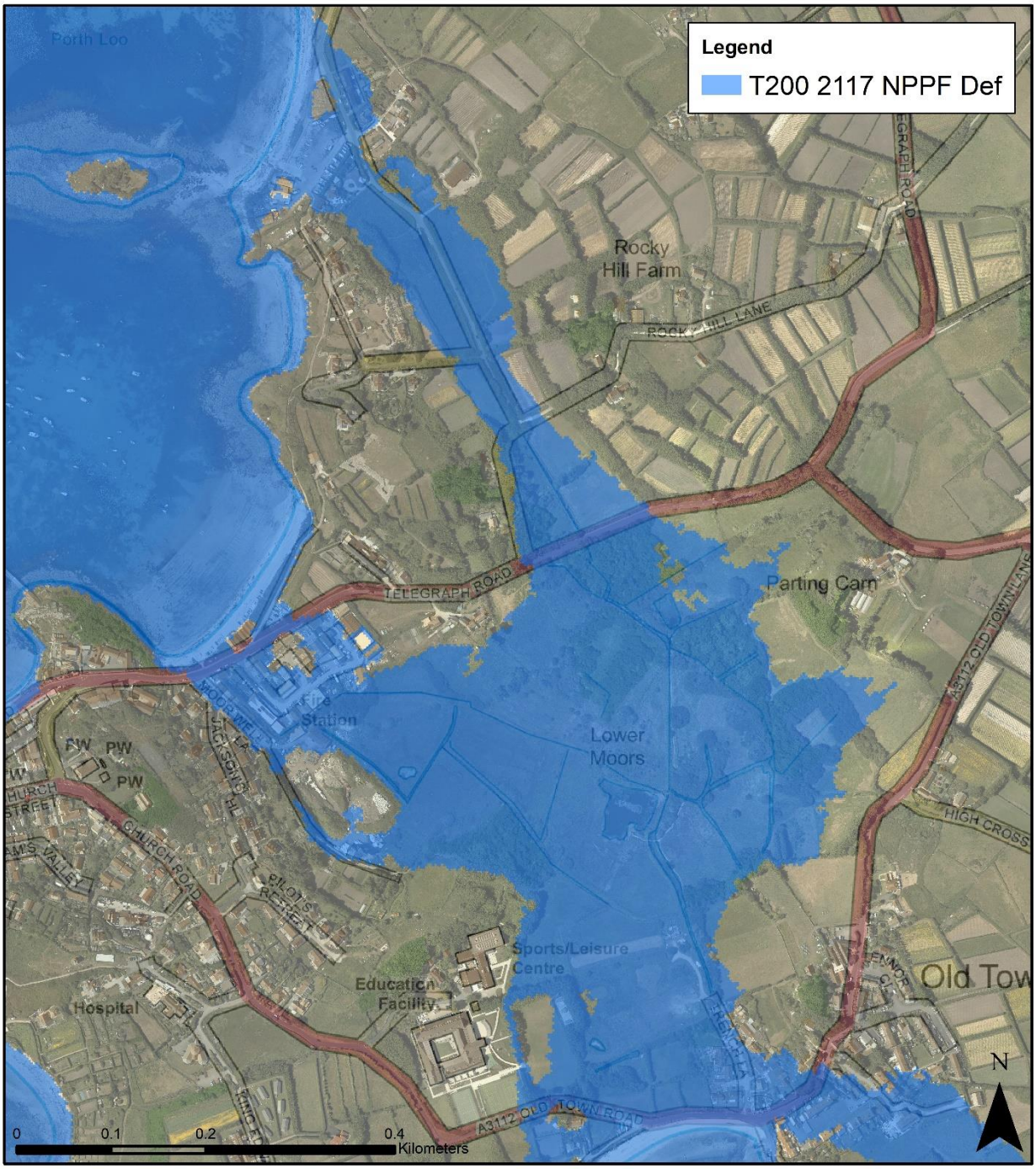
Figure 5-67: Model flood extents St Mary's Porthloo Defended 2067 UKCP09



Aerial image courtesy of Channel Coastal Observatory

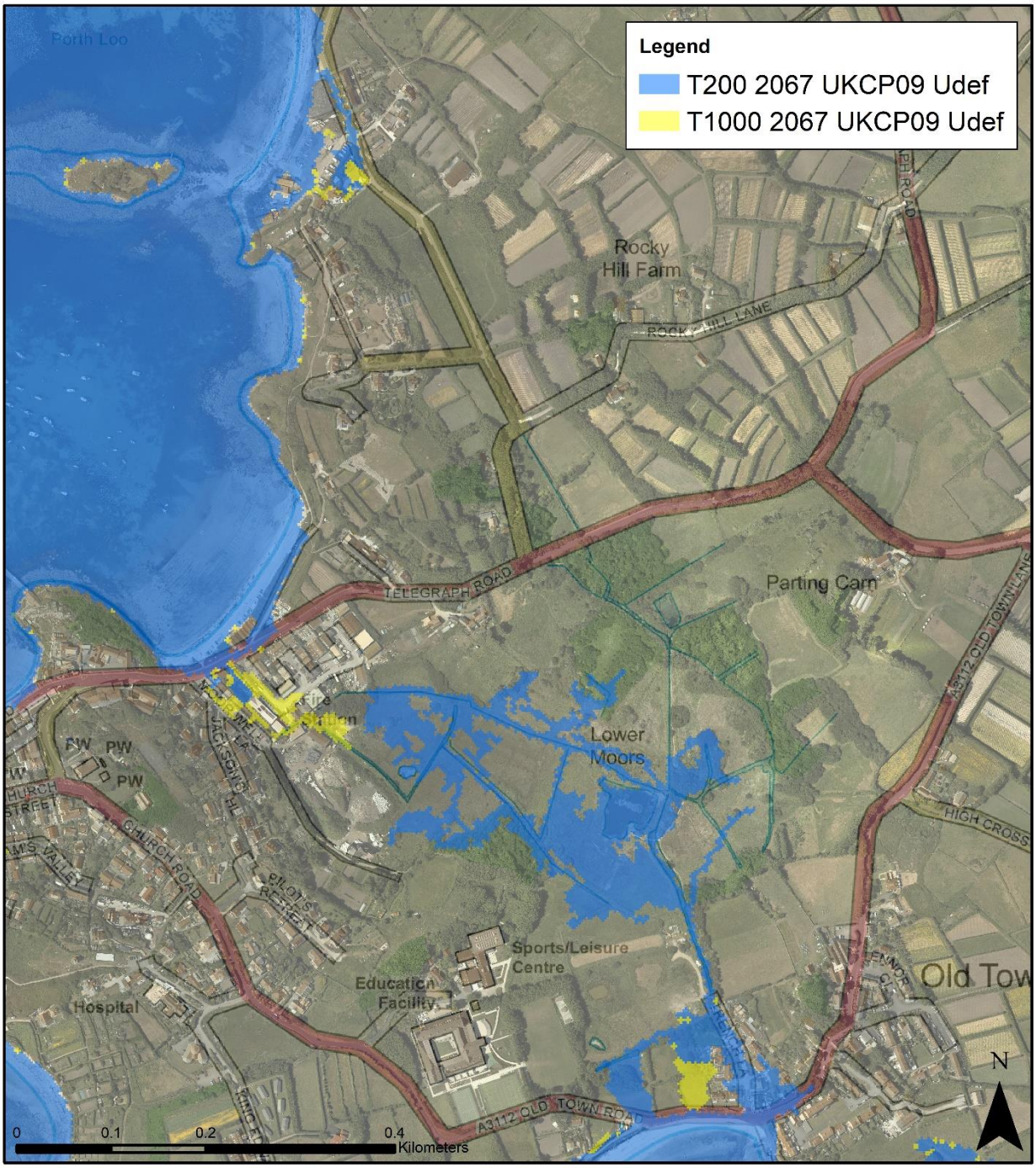
Figure 5-68: Model flood extents St Mary's Porthloo Defended 2117 UKCP09

Aerial image courtesy of Channel Coastal Observatory



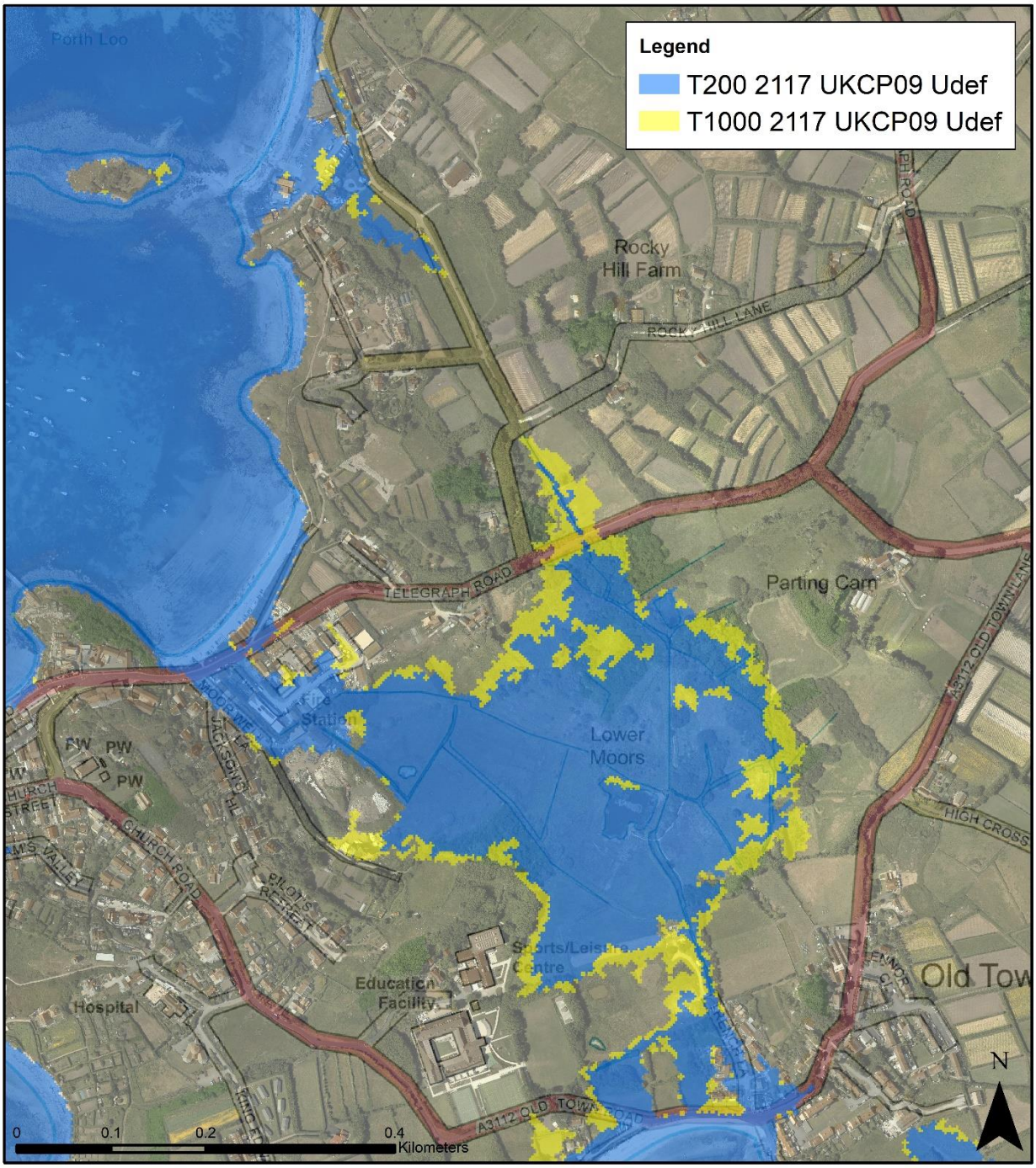
Aerial image courtesy of Channel Coastal Observatory

Figure 5-69: Model flood extents St Mary's Porthloo Defended 2117 NPPF



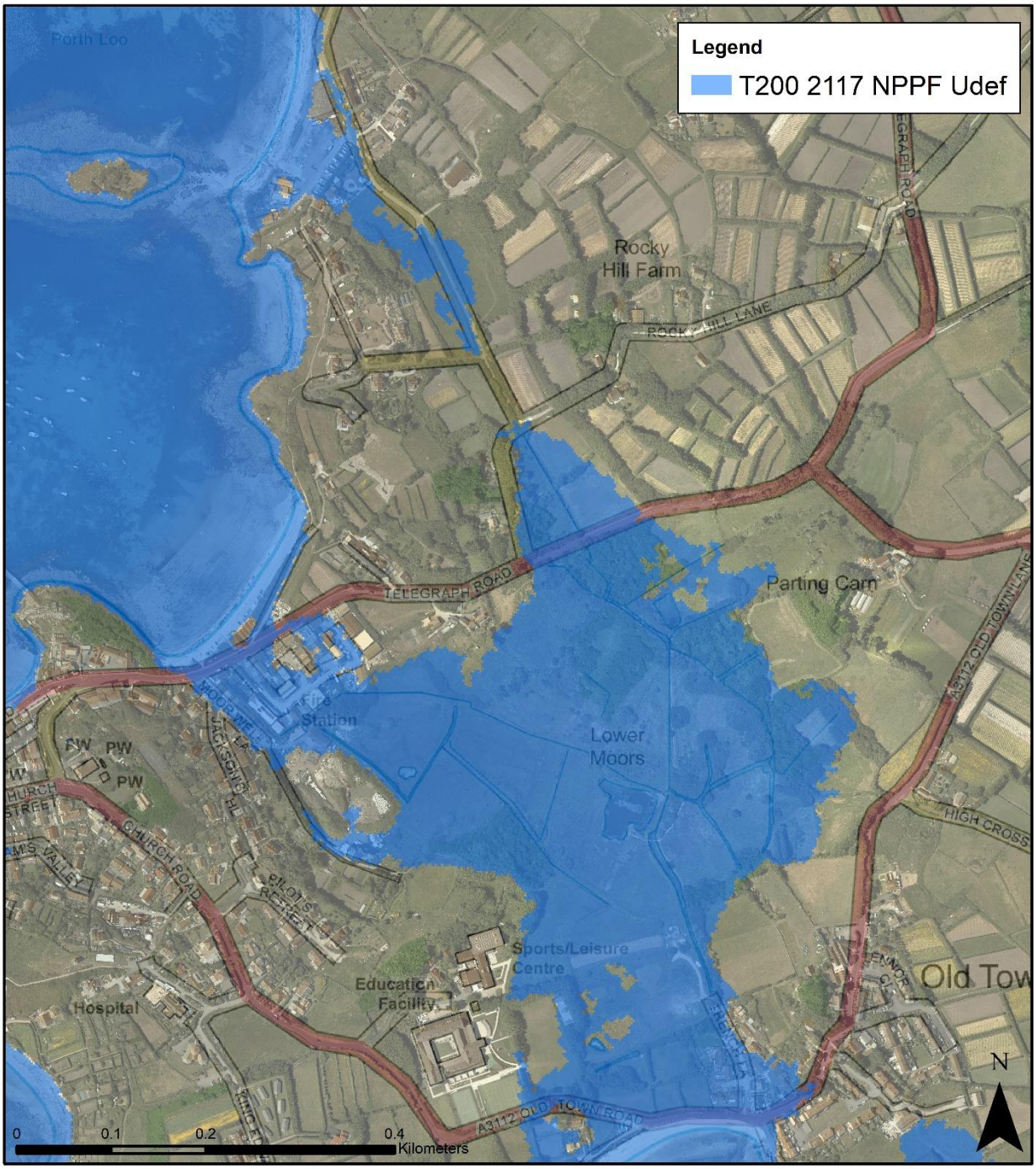
Aerial image courtesy of Channel Coastal Observatory

Figure 5-70: Model flood extents St Mary's Porthloo Undefended 2067 UKCP09



Aerial image courtesy of Channel Coastal Observatory

Figure 5-71: Model flood extents St Mary's Porthloo Undefended 2117 UKCP09



Aerial image courtesy of Channel Coastal Observatory

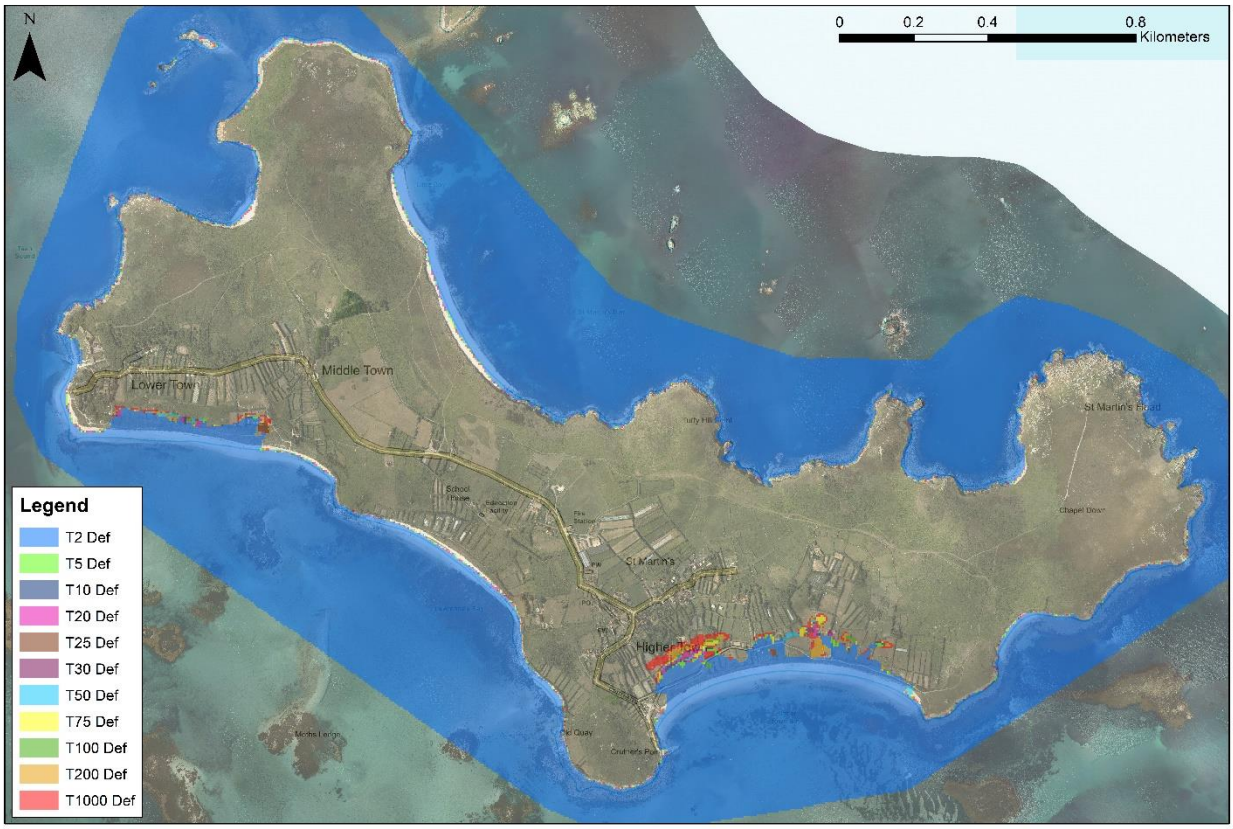
Figure 5-72: Model flood extents St Mary's Porthloo Undefended 2117 NPPF

5.2.5 St Martin's

Defended present-day results for St Martin's are shown in Figure 5-73. Two main areas on St Martin's flood, these being Higher and Lower Town. At Lower Town, the only property to flood is the toilet block on the campsite which floods at the 0.5% AEP event and above with no other properties flooded in Lower Town. At Higher Town, the main areas to flood include the cricket pitch and a few farm buildings that are situated along the shoreline. Overall no residential properties flood on St Martins in the defended scenario.

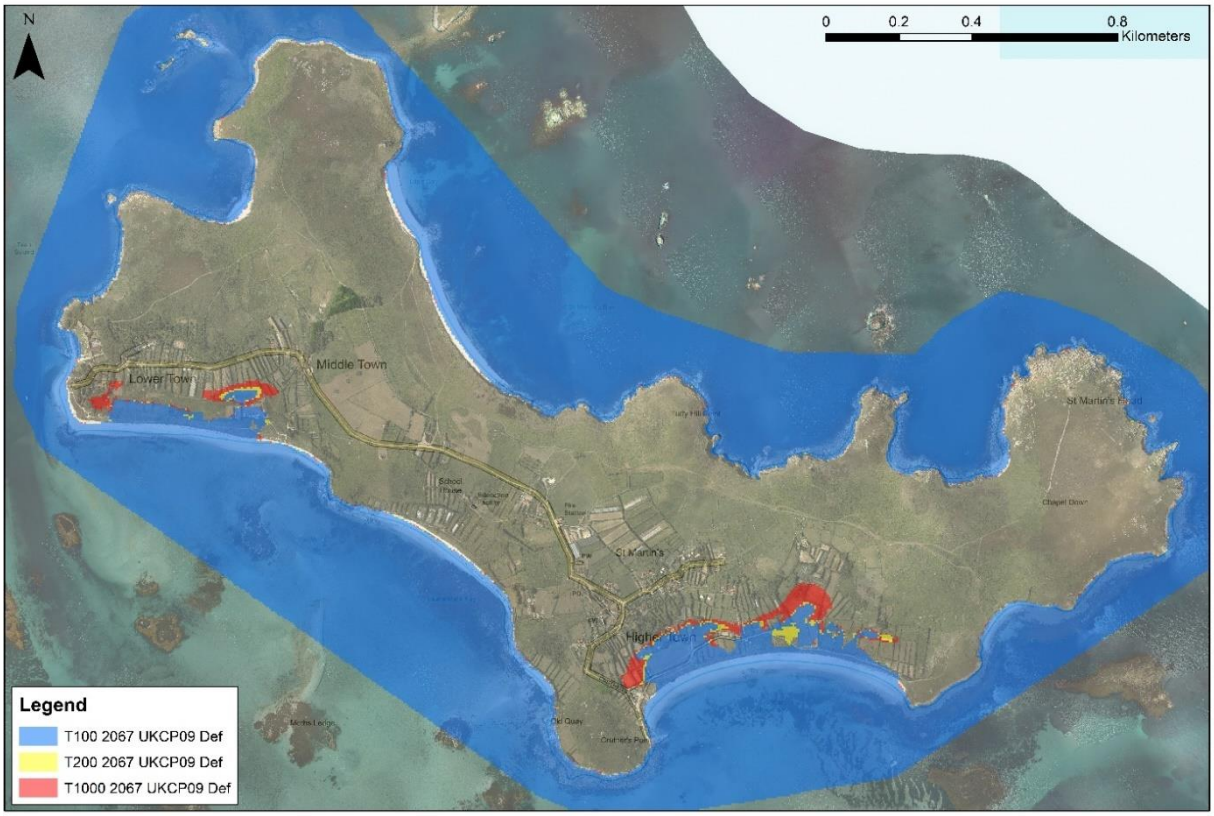
Defended results for 2067 and 2117 using UKCP09 projections for St Martin's are shown in Figure 5-74 and Figure 5-75. Defended climate change runs show more inundation when compared to present-day defended scenarios. Again, the campsite and the cricket pitch on the island flood with a few additional commercial properties at Higher Town flooded but no additional residential properties flood during the climate change runs.

NPPF results for the defended scenario in 2117 are shown in Figure 5-76. Results for the 0.5% AEP event again show flooding of the same areas on the island as previously stated, however there is the exception of Lower Town where two small residential properties are flooded near the campsite. At Higher Town, the flood water is mostly constrained by the topography with flood water here not inundating any further properties when compared to UKCP09 model runs.



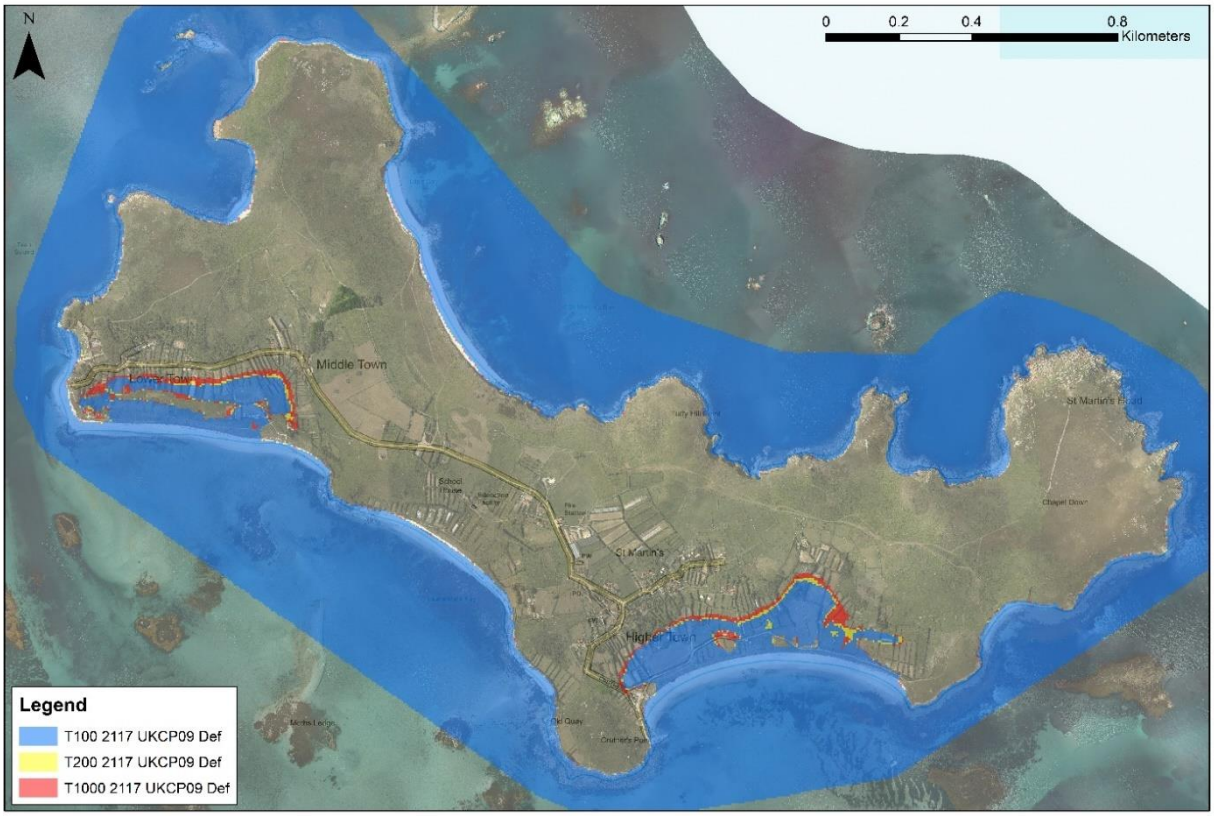
Aerial image courtesy of Channel Coastal Observatory

Figure 5-73: Model flood extents St Martin's Defended present day



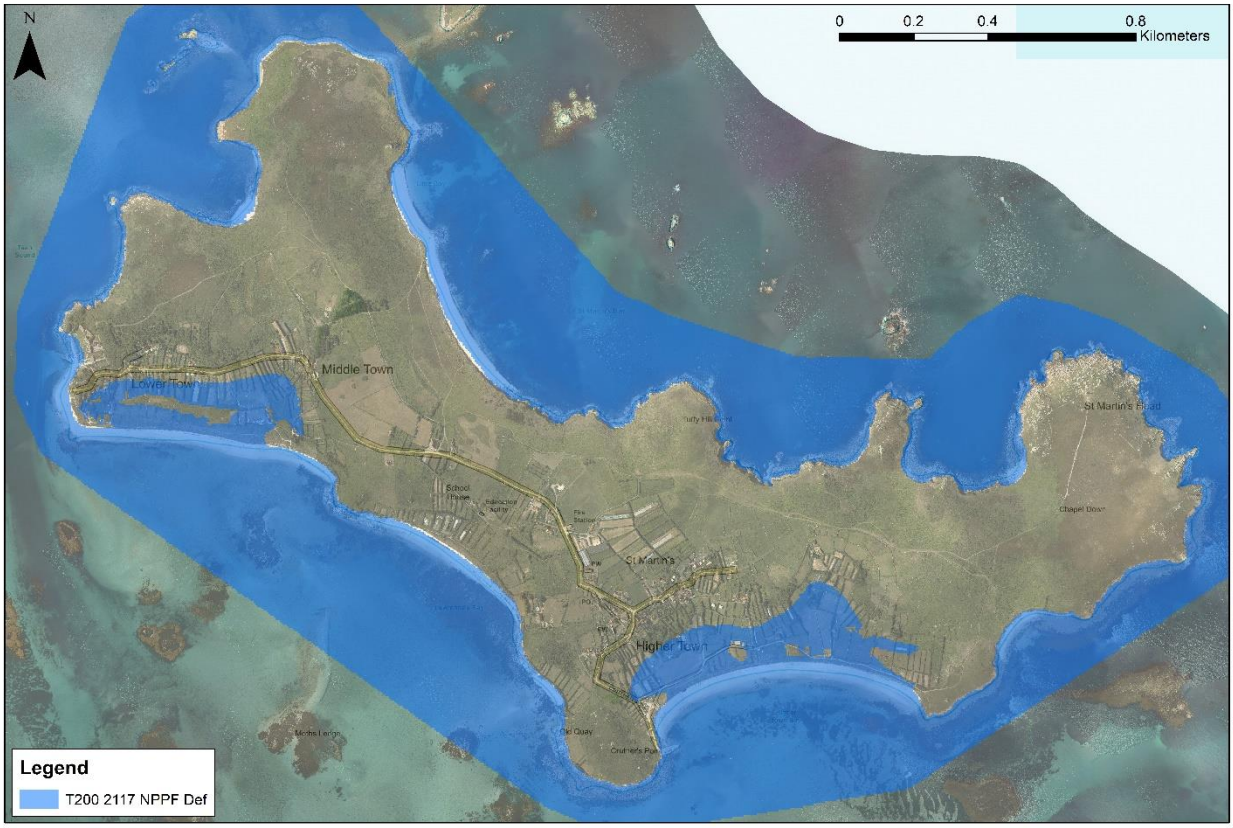
Aerial image courtesy of Channel Coastal Observatory

Figure 5-74: Model flood extents St Martin's Defended 2067 UKCP09



Aerial image courtesy of Channel Coastal Observatory

Figure 5-75: Model flood extents St Martin's Defended 2117 UKCP09



Aerial image courtesy of Channel Coastal Observatory

Figure 5-76: Model flood extents St Martin's Defended 2117 NPPF

6 Flood resilience Procedures

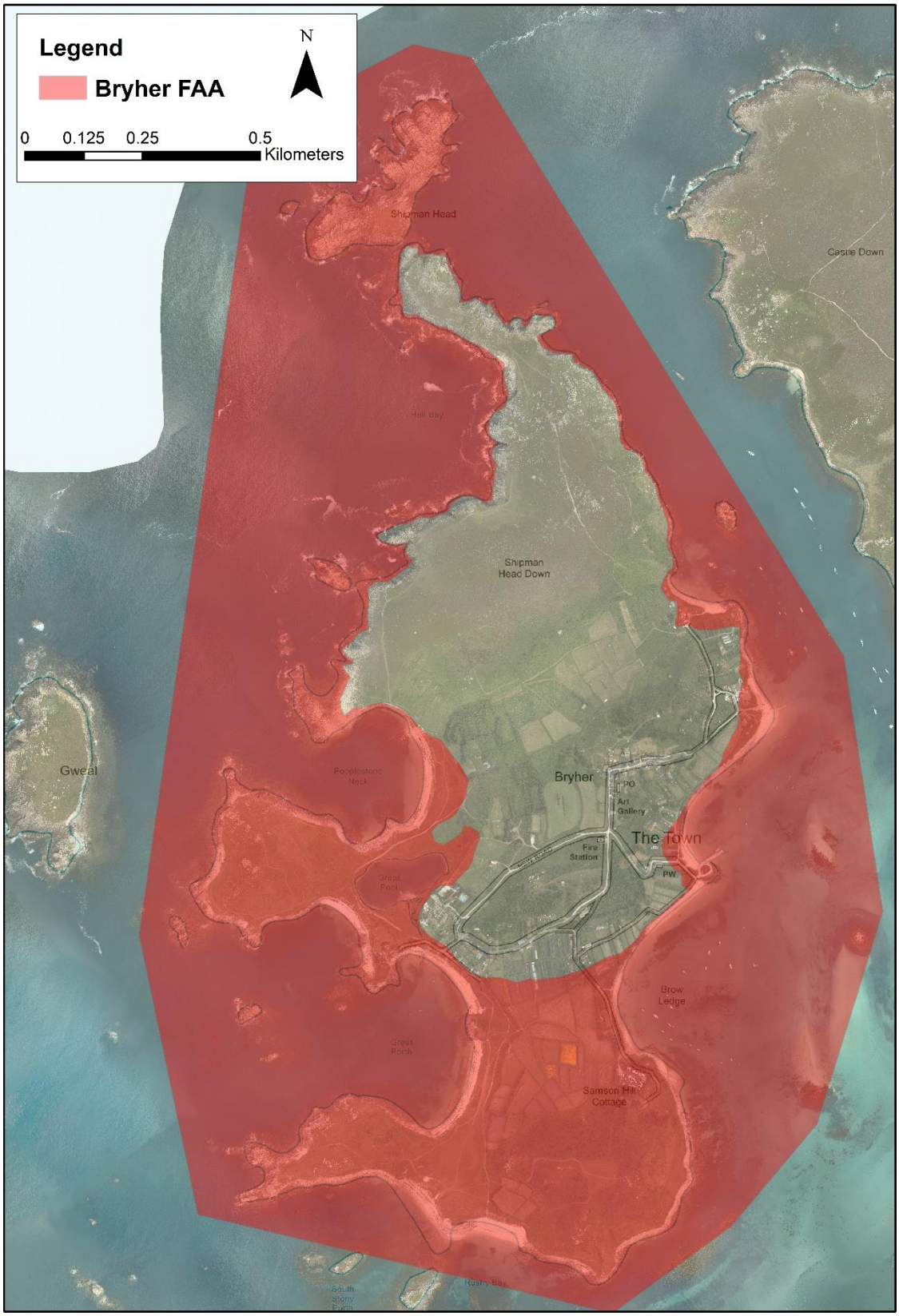
6.1 Flood Warning areas

This chapter describes the creation of Flood Warning procedures for the Isles of Scilly. Using the model outputs from the five TUFLOW models for the islands Flood Alert Areas (FAA), Flood Warning Areas (FWA) and thresholds have been proposed.

6.2 Flood Alert and Warning Area creation

There is currently no flood warning system in place on the Isles of Scilly. Hence, a new system of Flood Alert Areas (FAA) and Flood Warning Areas (FWA) was created. FAA were based on the Flood Zone 2 extents with each island having its own FAA. Additionally, the FAA were broken down into smaller FWA that cover selected communities on the islands. These areas only consider the coastal flood risk posed to these communities. The proposed FAA and FWA are detailed below in Figure 6-1-Figure 6-10.

6.2.1 Bryher



Aerial image courtesy of Channel Coastal Observatory

Figure 6-1: Bryher proposed FAA

Aerial image courtesy of Channel Coastal Observatory

Figure 6-2: Bryher proposed FWA's

6.2.2 St Agnes

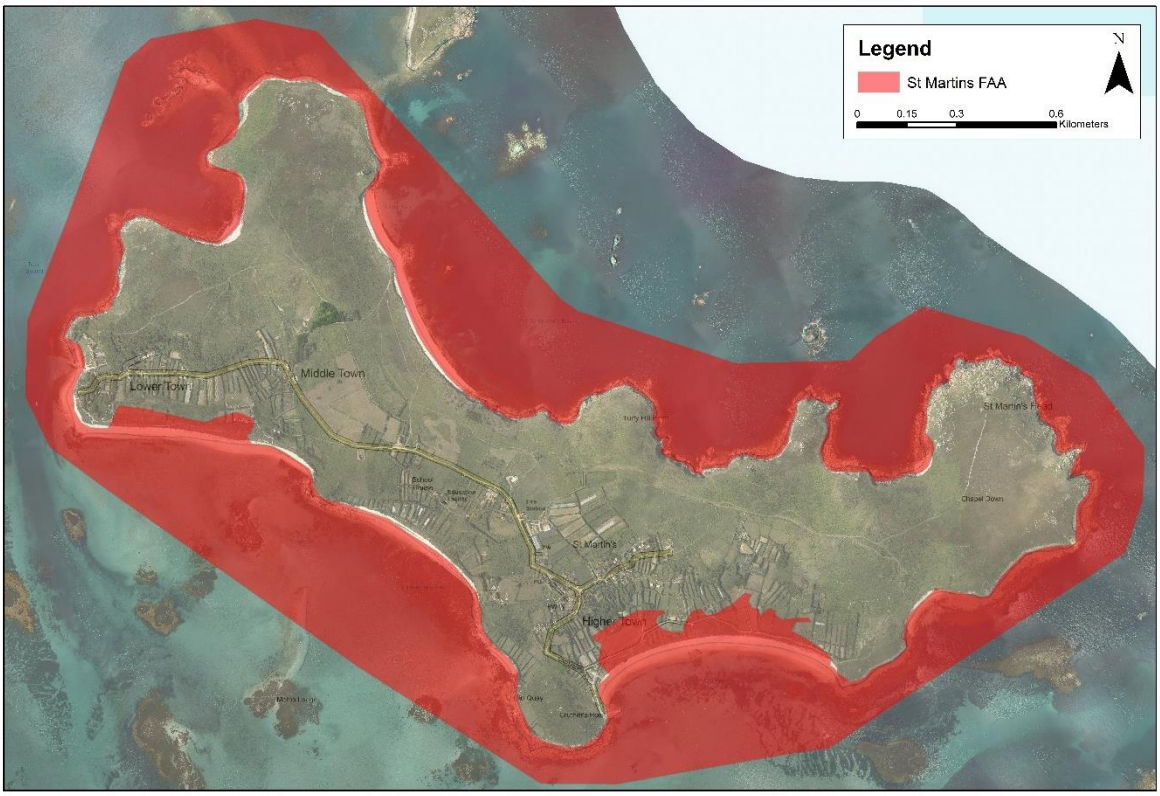
Aerial image courtesy of Channel Coastal Observatory

Figure 6-3: St Agnes proposed FAA

Aerial image courtesy of Channel Coastal Observatory

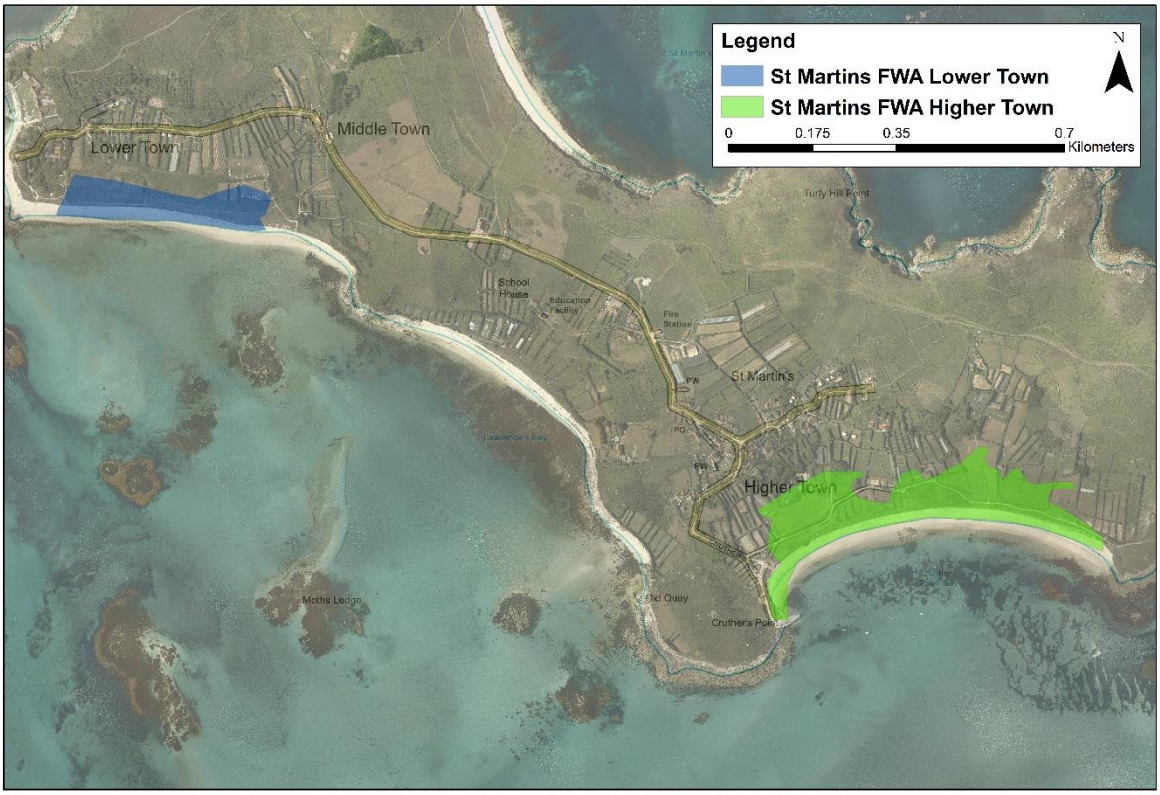
Figure 6-4: St Agnes proposed FWA

6.2.3 St Martins



Aerial image courtesy of Channel Coastal Observatory

Figure 6-5: St Martins proposed FAA



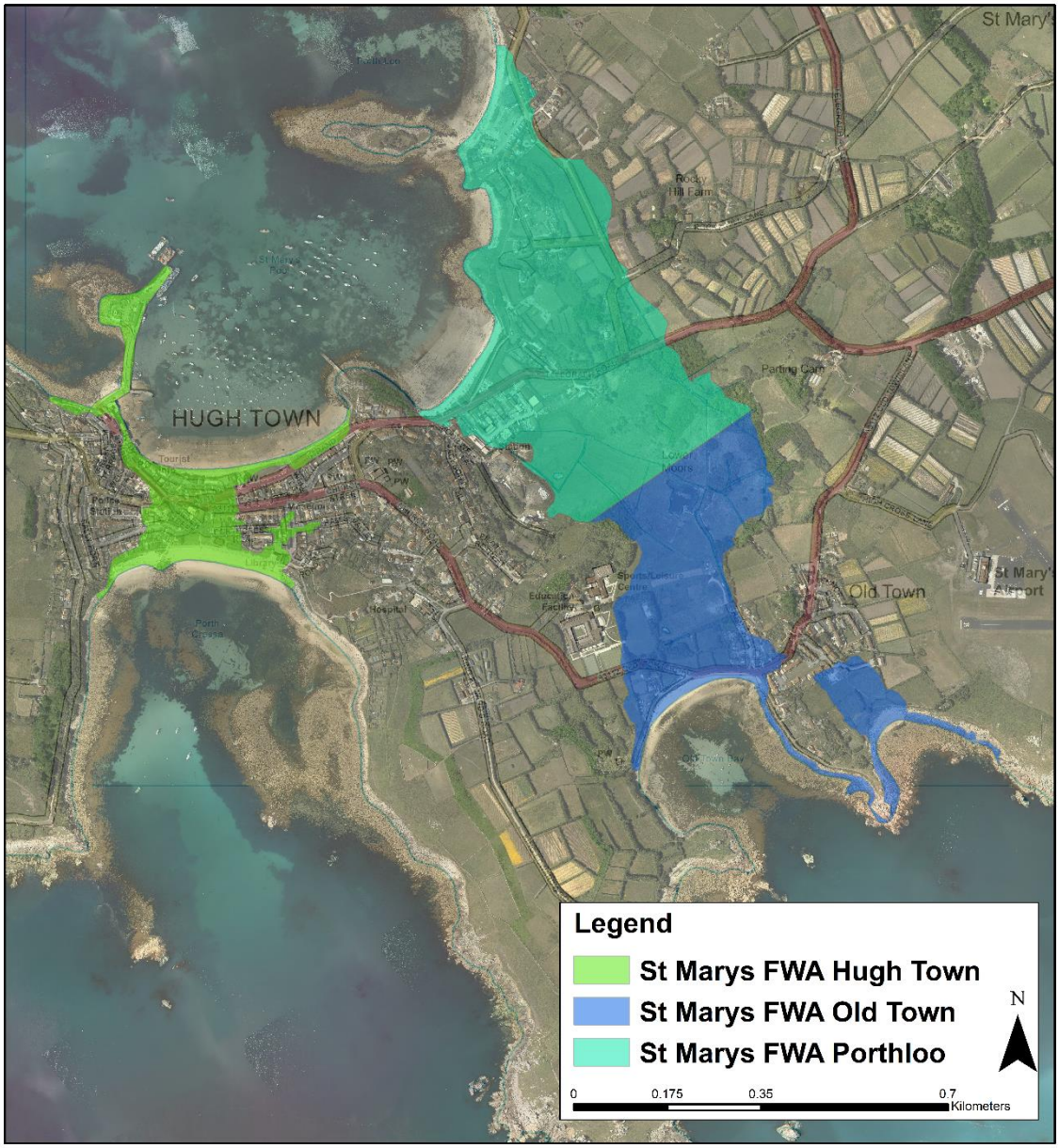
Aerial image courtesy of Channel Coastal Observatory

Figure 6-6: St Martins proposed FWA's

6.2.4 St Marys

Aerial image courtesy of Channel Coastal Observatory

Figure 6-7: St Marys proposed FAA



Aerial image courtesy of Channel Coastal Observatory

Figure 6-8: St Marys proposed FWA's

6.2.5 Tresco

Aerial image courtesy of Channel Coastal Observatory

Figure 6-9: Tesco proposed FAA

Aerial image courtesy of Channel Coastal Observatory

Figure 6-10: Tesco proposed FWA's

6.3 FW creation

The proposed flood warning procedures for the FWAs on the Isles of Scilly use wave overtopping rates and water levels, taking account of the defence crest levels and the modelled flood risk.

6.3.1 Data

The same method was applied to derive the flood warning procedures for each of the proposed FWAs. The data used to derive the flood warning procedures were:

- The first property to flood (FPTF) in each FWA,
- The 10,000-year offshore dataset of wave and wind conditions,
- The 10,000-year nearshore dataset of wave overtopping rates for the defence protecting the FPTF,
- The 10,000-year dataset of wave overtopping rates associated with each event in the 10,000-year offshore dataset. This dataset was derived during the wave overtopping calculations process for each defence, ranked based on AEP event.

6.3.2 Flood Alert and Flood Warning criteria

The flood alert (FA) thresholds for the FWA's on the Isles of Scilly were derived using the overtopping thresholds stipulated in the EurOtop Manual I. The EurOtop threshold chosen to derive the FA threshold depended on the susceptibility of the defence to overtopping, details for each FWA are outlined in the following sections.

Table 6-1: EurOtop Manual Limits for pedestrians and vehicles

Hazard Type	Reason	Wave overtopping rate (l/s/m)
Driving at moderate to high speed	Impulsive overtopping giving falling or high velocity jets	0.01
Unaware pedestrian	Unusual conditions where pedestrian has no clear view of incoming waves. Pedestrian may be easily upset of frightened, may be on a narrow walkway.	0.031
Aware pedestrian	Clear view of the sea not easily upset of frightened. Able to tolerate getting wet, wider walkway.	0.10
Trained staff	Well shod and protected, expecting to get wet. Overtopping flows at lower levels only, no falling jet, low danger of fall from walkway.	1.00-10.00
Driving at low speed	Overtopping by pulsating flows at low flow depths, no falling jets, vehicle not immersed.	10.00

The flood warning (FW) threshold was derived using the overtopping rate that caused the FPTF in each of the proposed FWAs.

6.3.3 Method

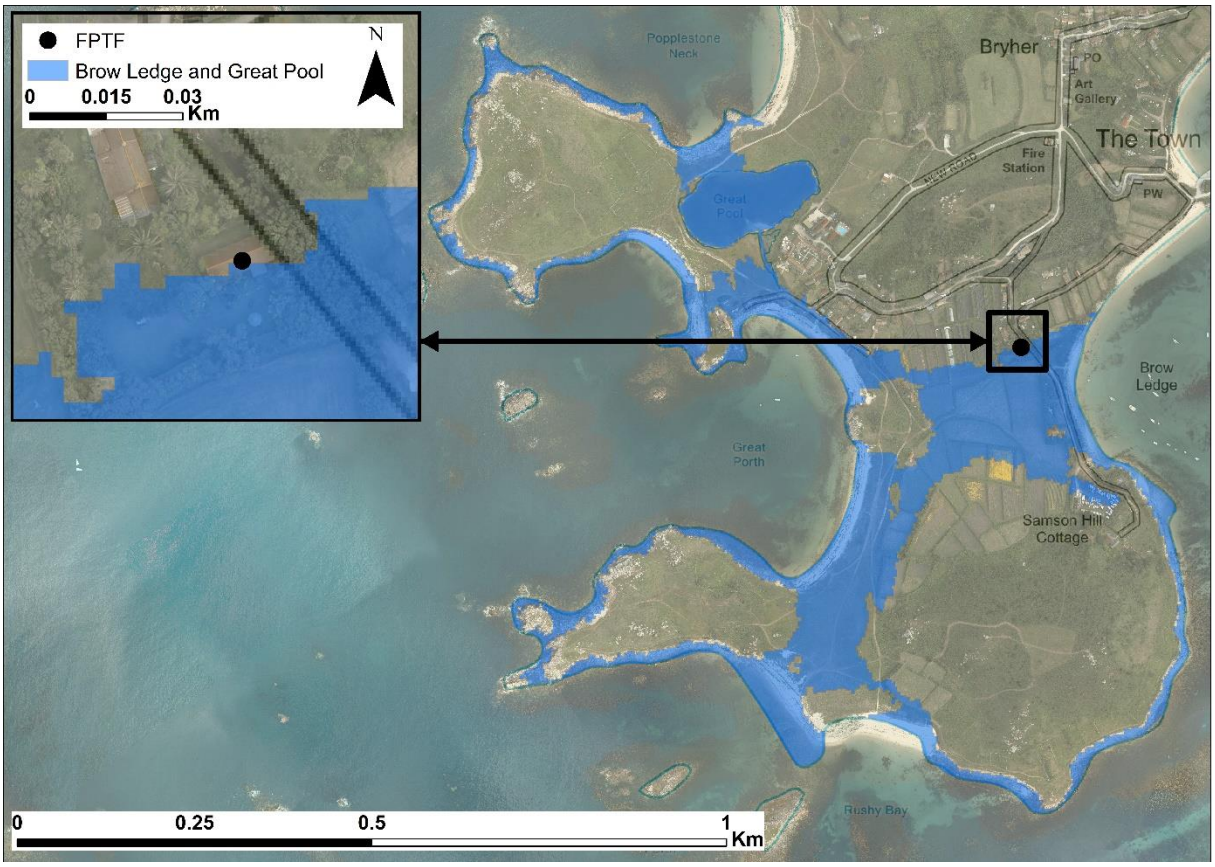
The first step was to identify the defence protecting the FPTF in each FWA. The 10,000-year dataset of wave overtopping rates specific to this defence was then extracted. This dataset was derived during the wave overtopping calculations using the 10,000-year offshore dataset.

The second step was to derive the water level thresholds for the FA and FW. Unless stated otherwise these are as follows:

- **The FA threshold for wave overtopping** was set depending on the susceptibility of the defence to overtopping.
- **The FW threshold for wave overtopping** was set as the wave overtopping rate AEP event that caused the FPTF.

6.3.4 Brow Ledge and Great pool

The Brow Ledge and Great Pool FWA covers the southern edge of Bryher, including the properties on Samson Hill and the properties that front Great Porth. The FPTF in this FWA is a residential property at Brow Ledge, Figure 6-11.



Aerial image courtesy of Channel Coastal Observatory

Figure 6-11: FPTF in the proposed Brow Ledge and Great Pool FWA

Table 6-2 shows the proposed thresholds for a FA and FW in the Brow Ledge and Great Pool FWA. The tide level gauge used to trigger the flood warning system is the St Mary's gauge.

The thresholds were chosen using the following criteria, based on Bryher profile 9:

- Wave overtopping of 0.000031m^3/s – Flood Alerts to be issued when the wave overtopping rate is greater than or equal to the "Aware pedestrian" EurOtop threshold.
- 3.25mODK – The average water level that results in overtopping that floods the FPTF.
- Wave overtopping of 0.002819m^3/s – the minimum wave overtopping rate for the AEP event that caused the FPTF.
- 3.69mODK – The maximum water level associated with the peak overtopping that causes the FPTF.

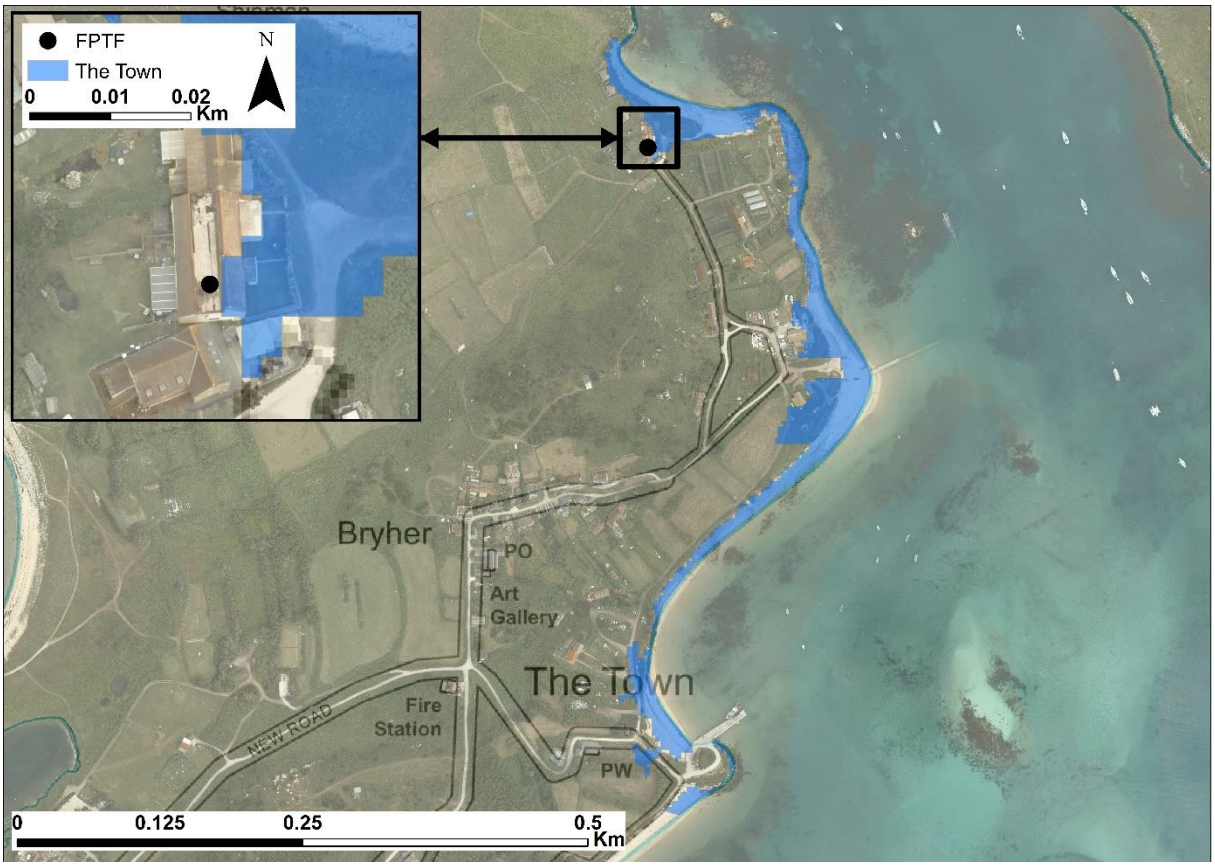
Table 6-2: Proposed Flood Warning Procedures for Brow Ledge and Great Pool FWA

TIDE LEVEL mODK	Wave overtopping threshold (m3/s/m)	MFDO ACTIONS	Average threshold exceedances per year
	0.000031	Issue Flood Alert	6.89
3.25		Issue Flood Alert	3.63

TIDE LEVEL mODK	Wave overtopping threshold (m3/s/m)	MFDO ACTIONS	Average threshold exceedances per year
	0.002819	Issue Flood Warning	0.05
3.69		Issue Flood Warning	0.00

6.3.5 The Town

The Town FWA covers the eastern edge of Bryher from Bryher Church to Fraggle Rock Bar, including the properties in The Town. The FPTF in this FWA is a residential property, Figure 6-12.



Aerial image courtesy of Channel Coastal Observatory

Figure 6-12: FPTF in the proposed The Town FWA

Table 6-3 shows the proposed thresholds for a FA and FW in The Town FWA. The tide level gauge used to trigger the flood warning system is the St Mary's gauge.

The thresholds were chosen using the following criteria, based on Bryher profile 5:

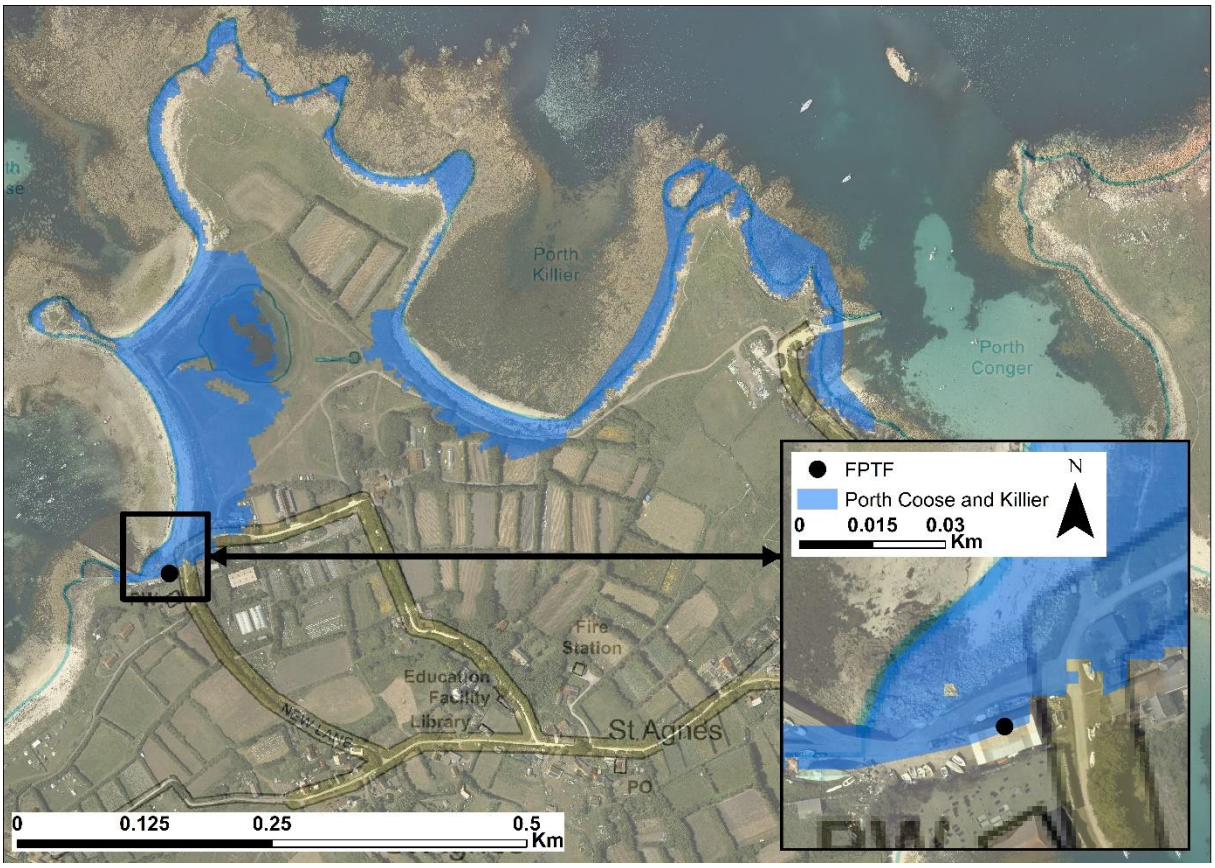
- Wave overtopping of 0.01m^3/s – Flood Alerts to be issued when the wave overtopping rate is greater than or equal to the "Aware pedestrian" EurOtop threshold.
- 3.25mODK – The average water level that results in overtopping that floods the FPTF.
- Wave overtopping of 0.01245m^3/s – the minimum wave overtopping rate for the AEP event that caused the FPTF.
- 3.59mODK – The maximum water level associated with the peak overtopping that causes the FPTF.

Table 6-3: Proposed Flood Warning Procedures for The Town FWA

TIDE LEVEL mODK	Wave overtopping threshold (m3/s/m)	MFDO ACTIONS	Average threshold exceedances per year
	0.01	Issue Flood Alert	0.38
3.25		Issue Flood Alert	3.63
	0.01245	Issue Flood Warning	1.05
3.59		Issue Flood Warning	0.14

6.3.6 Porth Coose and Killier

The Porth Coose and Killier FWA extends between the two jetties on St Agnes, including the properties around Porth Coose. The FPTF in this FWA is property bordering the western jeet on St Agnes, Figure 6-13.



Aerial image courtesy of Channel Coastal Observatory

Figure 6-13: FPTF in the proposed Porth Coose and Killier FWA

Table 6-4 shows the proposed thresholds for a FA and FW in the Porth Coose and Killier FWA. The tide level gauge used to trigger the flood warning system is the St Mary's gauge.

The thresholds were chosen using the following criteria, based on St Agnes profile 49:

- Wave overtopping of 0.0001m^3/s – Flood Alerts to be issued when the wave overtopping rate is greater than or equal to the "Aware pedestrian" EurOtop threshold.
- 3.14mODK – The average water level that results in overtopping that floods the FPTF.

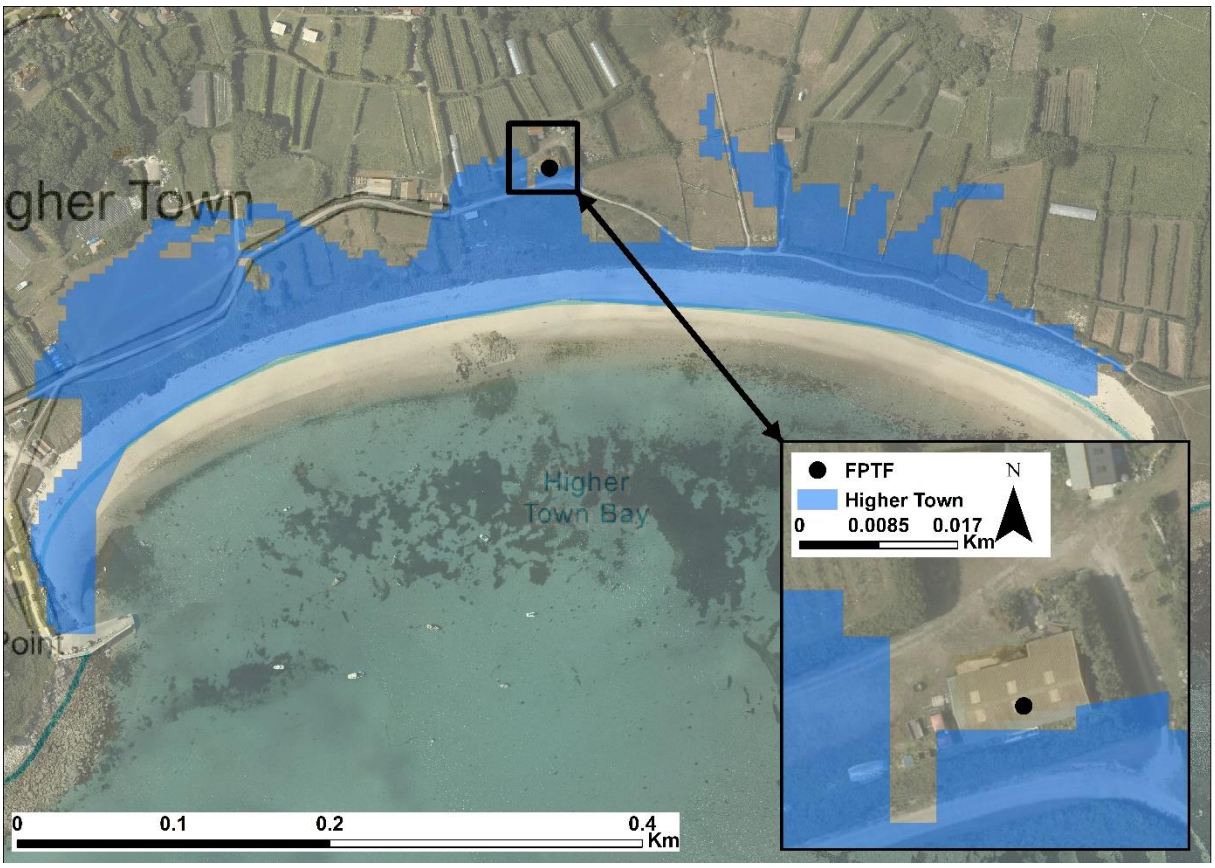
- Wave overtopping of 0.0006448m^3/s – the minimum wave overtopping rate for the AEP event that caused the FPTF.
- 3.51mODK – The maximum water level associated with the peak overtopping that causes the FPTF.

Table 6-4: Proposed Flood Warning Procedures for Porth Coose and Killier FWA

TIDE LEVEL mODK	Wave overtopping threshold (m3/s/m)	MFDO ACTIONS	Average threshold exceedances per year
	0.0001	Issue Flood Alert	12.4
3.14		Issue Flood Alert	7.65
	0.0006448	Issue Flood Warning	0.14
3.51		Issue Flood Warning	1.29

6.3.7 Higher Town

The Higher Town FWA covers the properties that sit around Higher Town Bay. The FPTF in this FWA is a commercial property, Figure 6-14.



Aerial image courtesy of Channel Coastal Observatory

Figure 6-14: FPTF in the proposed Higher Town FWA

Table 6-5 shows the proposed thresholds for a FA and FW in the Higher Town FWA. The tide level gauge used to trigger the flood warning system is the St Mary's gauge.

The thresholds were chosen using the following criteria, based on St Martins profile 29:

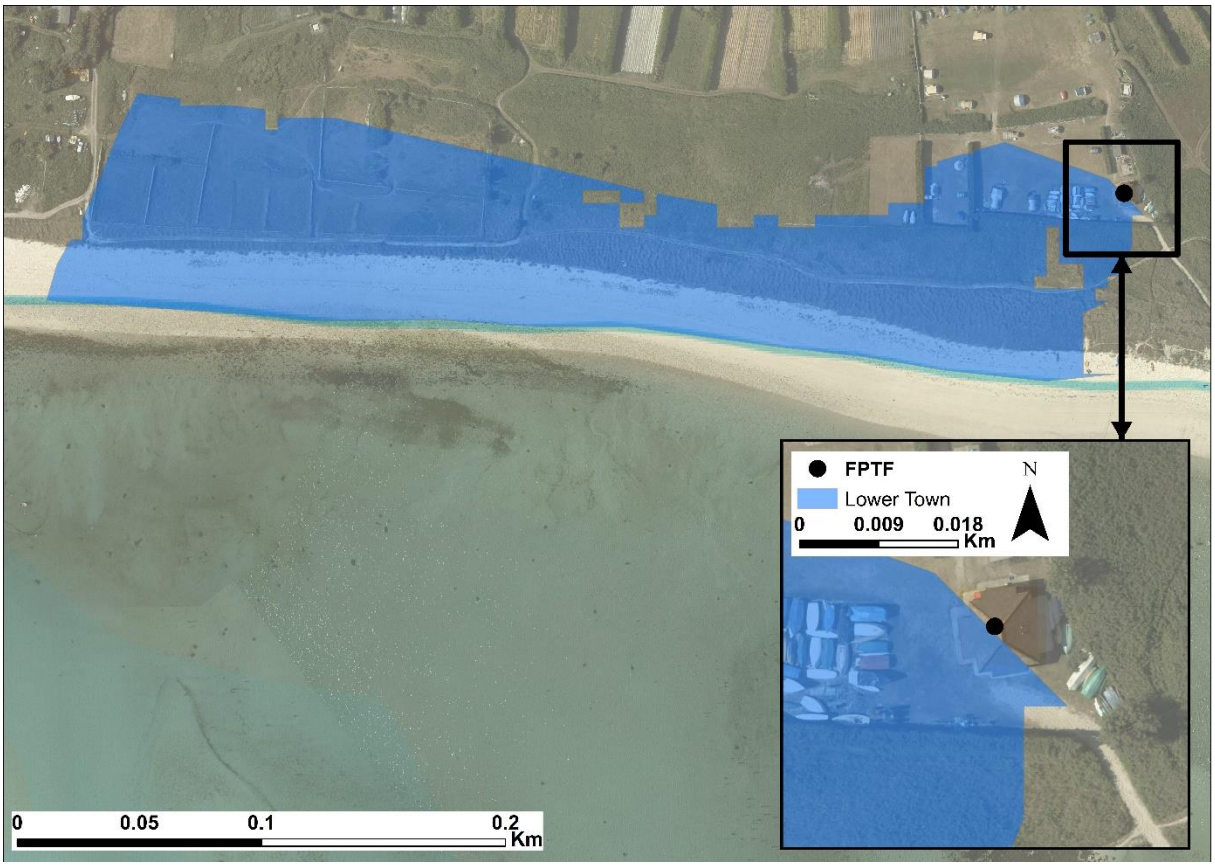
- Wave overtopping of 0.000031m^3/s – Flood Alerts to be issued when the wave overtopping rate is greater than or equal to the "Aware pedestrian" EurOtop threshold.
- 3.32mODK – The average water level that results in overtopping that floods the FPTF.
- Wave overtopping of 0.0000749m^3/s – the minimum wave overtopping rate for the AEP event that caused the FPTF.
- 3.71mODK – The maximum water level associated with the peak overtopping that causes the FPTF.

Table 6-5: Proposed Flood Warning Procedures for Higher Town FWA

TIDE LEVEL mODK	Wave overtopping threshold (m3/s/m)	MFDO ACTIONS	Average threshold exceedances per year
	0.000031	Issue Flood Alert	0.24
3.32		Issue Flood Alert	2.00
	0.0000749	Issue Flood Warning	0.19
3.71		Issue Flood Warning	0.00

6.3.8 Lower Town

The Lower Town FWA extends along the beach at Lower Town, including the campsite. The FPTF in this FWA is a commercial property on the campsite, Figure 6-15.



Aerial image courtesy of Channel Coastal Observatory

Figure 6-15: FPTF in the proposed Lower Town FWA

Table 6-6 shows the proposed thresholds for a FA and FW in the Lower Town FWA. The tide level gauge used to trigger the flood warning system is the St Mary's gauge.

The thresholds were chosen using the following criteria, based on St Martins profile 27:

- Wave overtopping of 0.000031m^3/s – Flood Alerts to be issued when the wave overtopping rate is greater than or equal to the "Aware pedestrian" EurOtop threshold.
- 3.36mODK – The average water level that results in overtopping that floods the FPTF.
- Wave overtopping of 0.001745m^3/s – the minimum wave overtopping rate for the AEP event that caused the FPTF.
- 3.95mODK – The maximum water level associated with the peak overtopping that causes the FPTF.

Table 6-6: Proposed Flood Warning Procedures for Lower Town FWA

TIDE LEVEL mODK	Wave overtopping threshold (m3/s/m)	MFDO ACTIONS	Average threshold exceedances per year
	0.000031	Issue Flood Alert	0.91
3.36		Issue Flood Alert	1.39
	0.001745	Issue Flood Warning	0.00
3.95		Issue Flood Warning	0.00

6.3.9 Hugh Town (south and north)

The Hugh Town FWA extends from the lifeboat station at the north of Hugh Town to Porth Cressa, including the properties that front both the northern and southern edge of the town. As the FWA can flood from either the northern or southern bay a flood warning threshold has been provided for both the north and south of Hugh Town. The two FPTF in this FWA are both commercial properties, Figure 6-16.

Aerial image courtesy of Channel Coastal Observatory

Figure 6-16: FPTF in the proposed Hugh Town FWA

Table 6-7 and Table 6-8 shows the proposed thresholds for a FA and FW in the Hugh Town FWA. The tide level gauge used to trigger the flood warning system is the St Mary's gauge.

The thresholds were chosen using the following criteria, based on St Marys profile 38:

- Wave overtopping of 0.001m^3/s – Flood Alerts to be issued when the wave overtopping rate is greater than or equal to the "Aware pedestrian" EurOtop threshold.
- 3.23mODK – The average water level that results in overtopping that floods the FPTF.
- Wave overtopping of 0.001304m^3/s – the minimum wave overtopping rate for the AEP event that caused the FPTF.
- 3.64mODK – The maximum water level associated with the peak overtopping that causes the FPTF.

Table 6-7: Proposed Flood Warning Procedures for Hugh Town FWA (south)

TIDE LEVEL mODK	Wave overtopping threshold (m3/s/m)	MFDO ACTIONS	Average threshold exceedances per year
	0.001	Issue Flood Alert	0.29
3.23		Issue Flood Alert	3.87
	0.001304	Issue Flood Warning	0.91
3.64		Issue Flood Warning	0.00

The thresholds were chosen using the following criteria, based on St Marys profile 41:

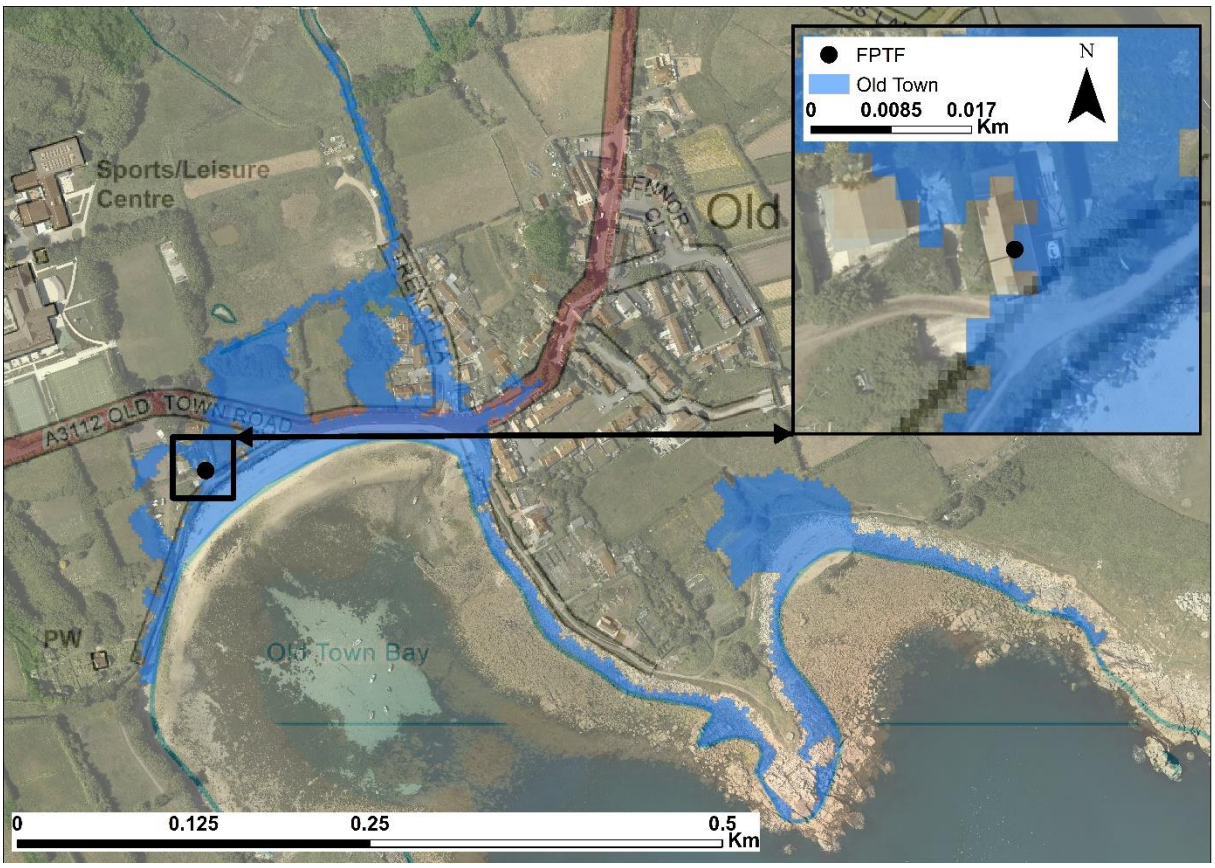
- Wave overtopping of 0.01m^3/s – Flood Alerts to be issued when the wave overtopping rate is greater than or equal to the "Aware pedestrian" EurOtop threshold.
- 3.15mODK – The average water level that results in overtopping that floods the FPTF.
- Wave overtopping of 0.01829m^3/s – the minimum wave overtopping rate for the AEP event that caused the FPTF.
- 3.51mODK – The maximum water level associated with the peak overtopping that causes the FPTF.

Table 6-8: Proposed Flood Warning Procedures for Hugh Town FWA (north)

TIDE LEVEL mODK	Wave overtopping threshold (m3/s/m)	MFDO ACTIONS	Average threshold exceedances per year
	0.01	Issue Flood Alert	3.11
3.15		Issue Flood Alert	7.27
	0.01829	Issue Flood Warning	0.81
3.51		Issue Flood Warning	0.14

6.3.10 Old Town

The Old Town FWA covers the area around Old Town Bay and the properties at Old. The FPTF in this FWA is a residential property on Old Town Road, Figure 6-17.



Aerial image courtesy of Channel Coastal Observatory

Figure 6-17: FPTF in the proposed Old Town FWA

Table 6-9 shows the proposed thresholds for a FA and FW in the Old Town FWA. The tide level gauge used to trigger the flood warning system is the St Mary's gauge.

The thresholds were chosen using the following criteria, based on St Marys profile 36:

- Wave overtopping of 0.001m^3/s – Flood Alerts to be issued when the wave overtopping rate is greater than or equal to the "Aware pedestrian" EurOtop threshold.
- 3.06mODK – The average water level that results in overtopping that floods the FPTF.
- Wave overtopping of 0.01829m^3/s – the minimum wave overtopping rate for the AEP event that caused the FPTF.
- 3.51mODK – The maximum water level associated with the peak overtopping that causes the FPTF.

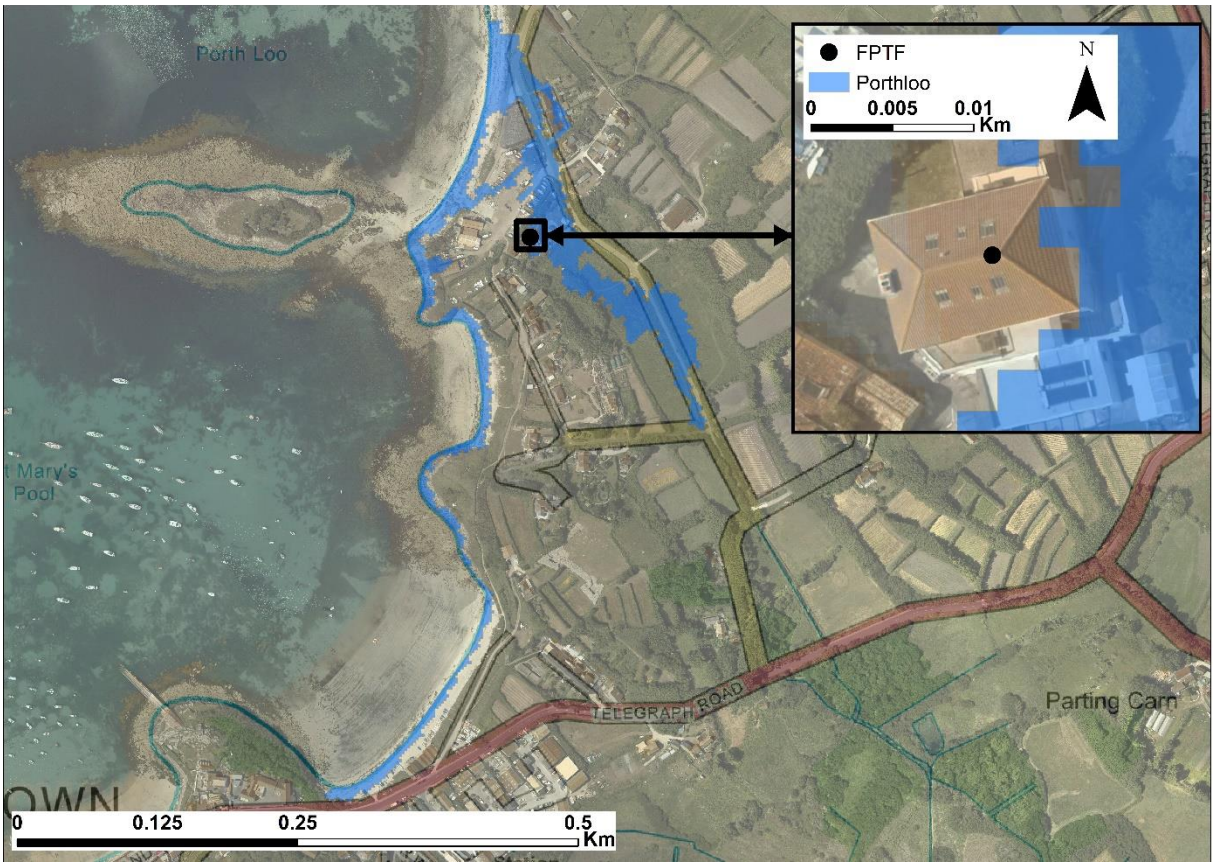
Table 6-9: Proposed Flood Warning Procedures for Old Town FWA

TIDE LEVEL mODK	Wave overtopping threshold (m3/s/m)	MFDO ACTIONS	Average threshold exceedances per year
	0.001	Issue Flood Alert	3.11
3.06		Issue Flood Alert	7.27

TIDE LEVEL mODK	Wave overtopping threshold (m3/s/m)	MFDO ACTIONS	Average threshold exceedances per year
	0.01829	Issue Flood Warning	0.81
3.51		Issue Flood Warning	0.14

6.3.11 Porthloo

The Porthloo FWA extends from the lifeboat station in Hugh Town to Porthloo Lane, including the properties around St Marys Pool. The FPTF in this FWA is a residential property at Porthloo, Figure 6-18.



Aerial image courtesy of Channel Coastal Observatory

Figure 6-18: FPTF in the proposed Porthloo FWA

Table 6-10 shows the proposed thresholds for a FA and FW in the Porthloo FWA. The tide level gauge used to trigger the flood warning system is the St Mary's gauge.

The thresholds were chosen using the following criteria, based on St Marys profile 47:

- Wave overtopping of 0.001m^3/s – Flood Alerts to be issued when the wave overtopping rate is greater than or equal to the "Aware pedestrian" EurOtop threshold.
- 3.12mODK – The average water level that results in overtopping that floods the FPTF.
- Wave overtopping of 0.003537m^3/s – the minimum wave overtopping rate for the AEP event that caused the FPTF.
- 3.51mODK – The maximum water level associated with the peak overtopping that causes the FPTF.

Table 6-10: Proposed Flood Warning Procedures for Porthloo FWA

TIDE LEVEL mODK	Wave overtopping threshold (m3/s/m)	MFDO ACTIONS	Average threshold exceedances per year
	0.001	Issue Flood Alert	5.79
3.12		Issue Flood Alert	8.94
	0.003537	Issue Flood Warning	1.00
3.51		Issue Flood Warning	0.14

6.3.12 New Grimsby

The New Grimsby FWA covers the properties on the western side of Tresco. The FPTF in this FWA is a commercial property on New Grimsby Quay, Figure 6-19.

Aerial image courtesy of Channel Coastal Observatory

Figure 6-19: FPTF in the proposed New Grimsby FWA

Table 6-11 shows the proposed thresholds for a FA and FW in the New Grimsby FWA. The tide level gauge used to trigger the flood warning system is the St Mary's gauge.

The thresholds were chosen using the following criteria, based on Tresco profile 15:

- Wave overtopping of 0.001m^3/s – Flood Alerts to be issued when the wave overtopping rate is greater than or equal to the "Aware pedestrian" EurOtop threshold.
- 3.09mODK – The average water level that results in overtopping that floods the FPTF.

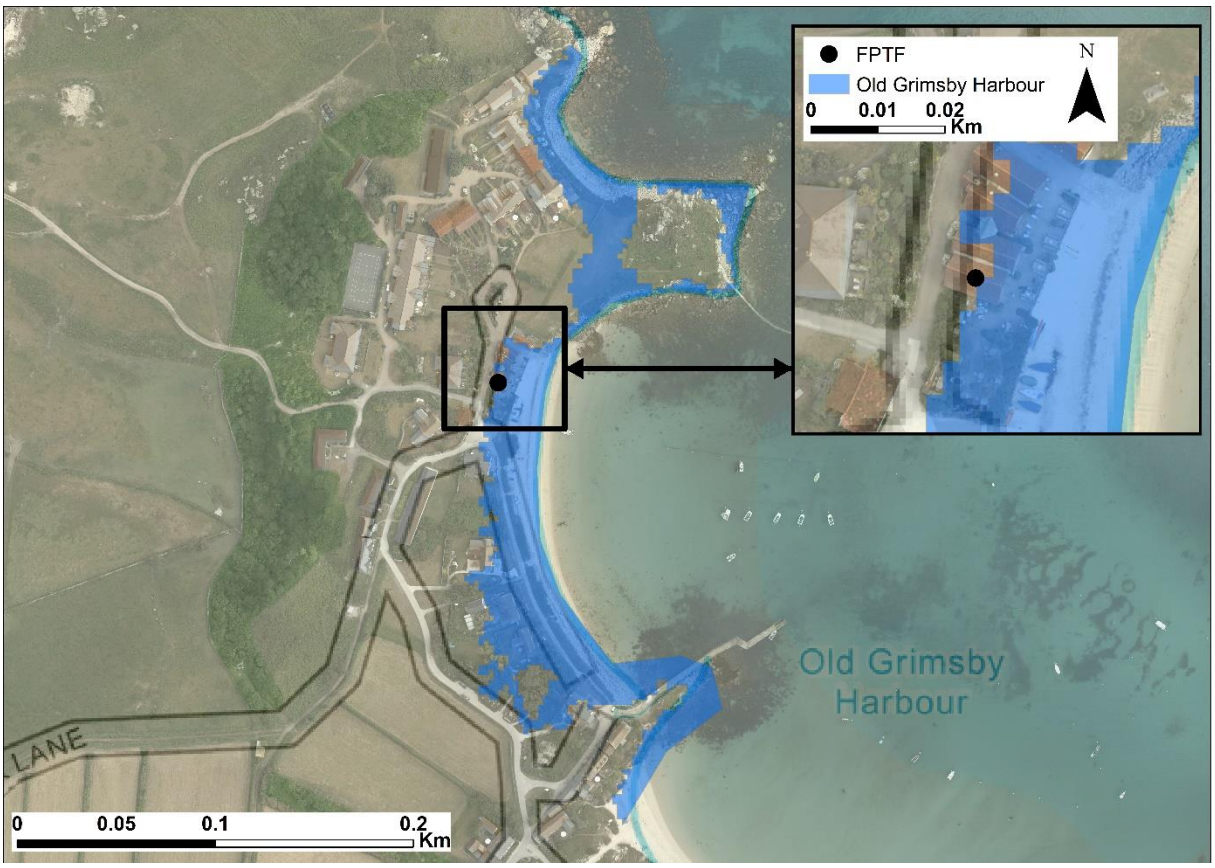
- Wave overtopping of 0.002933m^3/s – the minimum wave overtopping rate for the AEP event that caused the FPTF.
- 3.51mODK – The maximum water level associated with the peak overtopping that causes the FPTF.

Table 6-11: Proposed Flood Warning Procedures for New Grimsby FWA

TIDE LEVEL mODK	Wave overtopping threshold (m3/s/m)	MFDO ACTIONS	Average threshold exceedances per year
	0.001	Issue Flood Alert	3.63
3.09		Issue Flood Alert	10.81
	0.002933	Issue Flood Warning	0.91
3.51		Issue Flood Warning	0.14

6.3.13 Old Grimsby Harbour

The Old Grimsby Harbour FWA covers the properties around Old Grimsby. The FPTF in this FWA is a commercial property in Old Grimsby, Figure 6-20.



Aerial image courtesy of Channel Coastal Observatory

Figure 6-20: FPTF in the proposed Old Grimsby Harbour FWA

Table 6-12 shows the proposed thresholds for a FA and FW in the Old Grimsby Harbour FWA. The tide level gauge used to trigger the flood warning system is the St Mary's gauge.

The thresholds were chosen using the following criteria, based on Tresco profile 17:

- Wave overtopping of 0.000031m^3/s – Flood Alerts to be issued when the wave overtopping rate is greater than or equal to the "Aware pedestrian" EurOtop threshold.
- 3.32mODK – The average water level that results in overtopping that floods the FPTF.
- Wave overtopping of 0.0000387m^3/s – the minimum wave overtopping rate for the AEP event that caused the FPTF.
- 3.51mODK – The maximum water level associated with the peak overtopping that causes the FPTF.

Table 6-12: Proposed Flood Warning Procedures for Old Grimsby Harbour FWA

TIDE LEVEL mODK	Wave overtopping threshold (m3/s/m)	MFDO ACTIONS	Average threshold exceedances per year
	0.000031	Issue Flood Alert	2.34
3.32		Issue Flood Alert	2.00
	0.0000387	Issue Flood Warning	1.67
3.51		Issue Flood Warning	0.14

6.4 Property risk

Property counts for the five islands are detailed below.

Table 6-13: Property counts for Bryher defended scenarios

AEP	Residential	Commercial	Critical infrastructure	Total
50%	0	3	1	4
20%	0	3	1	4
10%	0	3	1	4
5%	0	4	1	5
4%	0	4	1	5
3.33%	0	4	1	5
2%	0	6	1	7
1.33%	0	7	1	8
1%	0	7	1	8
0.5%	0	7	1	8

AEP	Residential	Commercial	Critical infrastructure	Total
0.1%	1	8	1	10
1% UKCP09 2067	2	9	1	12
0.5% UKCP09 2067	2	10	1	13
1% UKCP09 2067	3	12	2	17
0.5% UKCP09 2117	5	12	2	19
1% UKCP09 2117	5	12	2	19
0.1% UKCP09 2117	5	12	2	19
0.5% NPPF 2117	5	13	3	21

Table 6-14: Property counts for Bryher undefended scenarios

AEP	Residential	Commercial	Critical infrastructure	Total
50%	0	4	1	5
20%	0	4	1	5
10%	0	4	1	5
5%	1	7	1	9
4%	1	7	1	9
3.33%	1	8	1	10
2%	1	8	1	10
1.33%	1	8	1	10
1%	1	8	1	10
0.5%	1	8	1	10
0.1%	2	10	1	13
0.5% UKCP09 2067	3	11	1	15

AEP	Residential	Commercial	Critical infrastructure	Total
0.5% UKCP09 2117	5	12	2	19
0.5% NPPF 2117	5	13	3	21

Table 6-15: Property counts for St Agnes defended scenarios

AEP	Residential	Commercial	Critical infrastructure	Total
50%	0	5	2	7
20%	0	5	2	7
10%	0	5	2	7
5%	0	5	2	7
4%	0	5	2	7
3.33%	0	5	2	7
2%	0	5	2	7
1.33%	0	5	2	7
1%	0	5	2	7
0.5%	0	5	2	7
0.1%	1	5	2	8
1% UKCP09 2067	1	6	2	9
0.5% UKCP09 2067	1	6	2	9
1% UKCP09 2067	1	7	3	11
0.5% UKCP09 2117	3	7	3	13
1% UKCP09 2117	3	8	3	14
0.1% UKCP09 2117	3	8	3	14
0.5% NPPF 2117	3	8	3	14

Table 6-16: Property counts for St Agnes undefended scenarios

AEP	Residential	Commercial	Critical infrastructure	Total
50%	0	1	0	1
20%	0	1	0	1
10%	0	1	0	1
5%	0	1	0	1
4%	0	1	0	1
3.33%	0	1	0	1
2%	0	2	0	2
1.33%	0	2	0	2
1%	0	2	0	2
0.5%	0	2	0	2
0.1%	0	3	0	3
0.5% UKCP09 2067	0	3	0	3
0.5% UKCP09 2117	0	6	3	9
0.5% NPPF 2117	0	6	3	9

Table 6-17: Property counts for St Martins defended scenarios

AEP	Residential	Commercial	Critical infrastructure	Total
50%	0	2	0	2
20%	0	2	0	2
10%	0	2	0	2
5%	0	2	0	2
4%	0	2	0	2
3.33%	0	2	0	2

2%	0	2	0	2
1.33%	0	2	0	2
1%	0	2	0	2
0.5%	0	2	0	2
0.1%	0	3	0	3
1% UKCP09 2067	0	3	0	3
0.5% UKCP09 2067	0	3	0	3
1% UKCP09 2067	0	9	0	9
0.5% UKCP09 2117	0	12	1	13
1% UKCP09 2117	0	12	1	13
0.1% UKCP09 2117	1	14	1	16
0.5% NPPF 2117	2	13	1	16

Table 6-18: Property counts for St Marys defended scenarios

AEP	Residential	Commercial	Critical infrastructure	Total
50%	42	32	1	75
20%	52	36	1	89
10%	54	37	1	92
5%	65	41	1	107
4%	72	43	1	116
3.33%	71	43	1	115
2%	73	44	1	118
1.33%	81	50	1	132
1%	81	51	1	133

AEP	Residential	Commercial	Critical infrastructure	Total
0.5%	85	58	1	144
0.1%	99	63	1	163
1% UKCP09 2067	104	65	1	170
0.5% UKCP09 2067	110	73	3	186
1% UKCP09 2067	110	88	4	202
0.5% UKCP09 2117	155	109	6	270
1% UKCP09 2117	167	117	6	290
0.1% UKCP09 2117	183	138	6	327
0.5% NPPF 2117	188	144	6	338

Table 6-19: Property counts for St Marys undefended scenarios

AEP	Residential	Commercial	Critical infrastructure	Total
50%	32	29	1	62
20%	38	30	1	69
10%	47	33	1	81
5%	48	34	1	83
4%	49	34	1	84
3.33%	49	34	1	84
2%	52	35	1	88
1.33%	60	40	1	101
1%	60	40	1	101
0.5%	68	45	1	114
0.1%	83	54	1	138

AEP	Residential	Commercial	Critical infrastructure	Total
0.5% UKCP09 2067	102	61	2	165
0.5% UKCP09 2117	149	116	6	271
0.5% NPPF 2117	173	135	7	315

Table 6-20: Property counts for Tresco defended scenarios

AEP	Residential	Commercial	Critical infrastructure	Total
50%	2	1	0	3
20%	2	2	0	4
10%	2	2	0	4
5%	3	6	0	9
4%	3	7	0	10
3.33%	3	7	0	10
2%	3	7	0	10
1.33%	3	7	0	10
1%	3	9	0	12
0.5%	3	10	0	13
0.1%	5	12	0	17
1% UKCP09 2067	7	12	0	19
0.5% UKCP09 2067	7	12	0	19
1% UKCP09 2067	10	16	0	26
0.5% UKCP09 2117	12	17	0	29
1% UKCP09 2117	12	17	0	29
0.1% UKCP09 2117	12	19	0	31

AEP	Residential	Commercial	Critical infrastructure	Total
0.5% NPPF 2117	12	20	1	33

Table 6-21: Property counts for Tresco undefended scenarios

AEP	Residential	Commercial	Critical infrastructure	Total
50%	0	1	0	1
20%	0	1	0	1
10%	0	1	0	1
5%	1	1	0	2
4%	1	1	0	2
3.33%	1	1	0	2
2%	1	2	0	3
1.33%	1	2	0	3
1%	2	2	0	4
0.5%	2	2	0	4
0.1%	2	3	0	5
0.5% UKCP09 2067	5	9	0	14
0.5% UKCP09 2117	11	17	0	28
0.5% NPPF 2117	12	22	1	35

6.5 Flood intelligence files

Flood intelligence files have been provided for the five islands in a pdf format. These are included within the appendices.

7 Conclusions

JBA Consulting were commissioned by the Environment Agency to assess coastal flood risk posed to the Isles of Scilly. The study area covers the five inhabited islands in the archipelago.

The latest coastal flood modelling techniques were employed to assess the flood risk. Multivariate joint probability statistics were used to provide the offshore model boundaries. The multivariate data used at the model boundaries represent 10,000-years of synthetic storm events, extrapolated from the WW3 hindcast model data. A detailed 2D wave transformation model was developed to cover the study area. All of the multivariate events were transformed from the boundaries into the nearshore through detailed wave transformation models to provide nearshore wave data. Wave overtopping modelling was undertaken using the nearshore wave data at over 50 identified discrete defences. Wave overtopping discharges were calculated for every event in the 10,000-year event set to enable the calculation of each event probability for all of the modelled events at each defence. Finally, the wave overtopping discharges for a range of design events, were combined with still water tidal timeseries to provide boundary conditions for the flood inundation models.

Five new 2D hydrodynamic model were developed to map the flood risk posed to the five main inhabited islands. The models were used to assess the flood risk for a range of design events and different model scenarios, these were:

- Present-day flood risk was modelled for the 50, 20, 10, 5, 4, 3.33, 2, 1.33, 1, 0.5 and 0.1% Annual Exceedance Probability (AEP) flood events.
- Climate change flood risk was modelled for the 1, 0.5 and 0.1% events based on the medium emission 95th percentile UKCP09 scenario projected to the year 2067 and 2117.
- Climate change flood risk was modelled for the 0.5% events based on the NPPF sea-level rise values projected to the year 2117.

The model outputs were used to:

- Map coastal flood risk and produce a variety of outputs including gridded outputs for flood depths, levels, velocities and hazard.
- The model results were processed to produce flood extents.
- To derive new Flood Map components for Flood Zone 3, Flood Zone 2 and identify the Areas Benefitting from Defences (ABDs).
- Create Flood Warning Areas and criteria/procedures for flood incident management

7.1 Study findings and conclusions

7.1.1 Baseline defended scenario

In the defended scenarios the main risk on posed to the islands is from wave overtopping. The only major urban area at risk is Hugh Town on St Mary's.

In the present defended scenario, the island with the most number of properties at risk is St Mary's with 163 properties at risk in the 0.1% AEP event. In total there are 201 properties at risk during the 0.1% AEP event across all of the five islands.

7.1.2 Baseline undefended scenario

The undefended models were used to simulate the still water flood risk with additional wave overtopping inflows. Much of the flooding in the defended scenarios came from water overtopping defences and being trapped behind the defences inundating properties. This means that for the coastal communities which are built on high ground, above the reach of the extreme sea-levels, there is no flood risk when undefended wave overtopping is included as much of the water can flow back to sea. It should be noted that the wave overtopping inflows do not represent the momentum of the water that is associated with wave overtopping, therefore, the flood extents from wave overtopping may be underestimated. Across the Isles of Scilly when defences were removed overtopped water could flow back to sea, this results in much less inundation for some of the undefended runs.

In the present-day undefended scenario, the model with the most number of properties at risk is still St Mary's, with 138 properties at risk in the 0.1% AEP event. In total there are 159 properties at risk during the 0.1% AEP event across all of the islands.

7.1.3 Impacts of climate change

Model scenarios were completed with increases to the still water levels, wind speeds and wave heights to represent the impacts of climate change. The increased still water levels and wave overtopping discharges increased the flood risk for the defended scenario. The total number of properties at risk for the 0.1% AEP event increased from 201 in the present day to 265 in 2067 and 407 in 2117 using UKCP09 figures.

7.2 Recommendations

The approaches taken in this study incorporate the most advanced methods currently available for coastal modelling on the scale of the study area. However, the results of a numerical model are only as accurate as the input data that are used. Whilst all due care and diligence was taken to use appropriate data management and methods, the results should be viewed with a margin of caution given the inherent uncertainty in coastal modelling and in particular in the estimation of wave overtopping.

A number of assumptions were made and there are elements of subjectivity throughout all stages of the modelling process. While the joint probability approaches use the most advanced statistical methods based on the Heffernan and Tawn (2004) multivariate model, there is still the reliance on an extrapolation of 30-years of available data out to 10,000-years of synthetic data. In this context, even the most advanced methods are still limited by the amount and quality of the underlying data. As more data becomes available, the confidence in the extrapolation of the extreme values will increase. It is recommended that the statistics are periodically revisited to improve confidence in the boundary data as more modelled and recorded sea-level and wave data becomes available.

The behaviour of waves in the nearshore and surf zone is highly complex and the subject of detailed research. Due to this, assumptions have been made to represent wave overtopping at the model boundary for the appropriate design conditions. Firstly, for the purposes of a flood inundation model, it is unnecessary to incorporate details of individual wave processes but rather a mean discharge to represent the predicted conditions at each individual defence. It was assumed that the wave conditions, remain constant throughout the progression of the tidal time series. This approach is appropriate for modelling design events as it simulates the conditions at the boundary of the model where extreme tides, surge levels and waves occur at the same time, as would be expected during the progression of a large weather system. Changes in overtopping rates are therefore a result of the changing water level conditions rather than any changes in the incident wave conditions. Environment Agency Flood and Coastal Risk Management Modelling Guidance recommends modelling wave action over a 12-24-hour period, as the waves will then diminish as the storm moves and the wind changes direction. For the wave modelling, it was assumed that the storm continues with constant wind speeds and direction for the entire progression of the tidal curve, concurrent with the wave action.

All wave overtopping calculations assume a static beach profile. It is known that beach profiles do change throughout the year and throughout individual events. It is not currently possible to accurately model these changes throughout the event for any of the present day and future design events. The overtopping is therefore representative of a single snapshot in time.

The seabed, particularly in the nearshore, is also subject to constant change and the bathymetry used on the wave modelling is a snapshot in time of a particular seabed state. It is not currently possible to model the changing bathymetry within the wave model, it is therefore assumed that the modelling is representative of normal seabed conditions.

The phases-averaging model used for the wave transformation is suitable for modelling the offshore to nearshore transformation over wide areas and represent the dominant transformation processes of refraction, shoaling, non-linear interactions and energy decay due to depth limiting and seabed friction. These models do not accurately represent other processes such as diffraction and reflection which are important for the harbour areas or complex areas with submerged or partly submerged rocks such as the outer edges of the islands. To more accurately represent these processes a phase-resolving model would be more reliable; due to computation demands it is not currently possible to run these types of model over a wide area.

Infiltration losses into the ground within the flood inundation model have not been considered and no account has been taken of the joint flood risk from tidal, fluvial, surface water and groundwater events, only coastal flooding from tides and waves were modelled.

Appendices

Offices at
Coleshill
Doncaster
Dublin
Edinburgh
Exeter
Glasgow
Haywards Heath
Isle of Man
Limerick
Newcastle upon Tyne
Newport
Peterborough
Saltaire
Skipton
Tadcaster
Thirsk
Wallingford
Warrington

Registered Office
South Barn
Broughton Hall
SKIPTON
North Yorkshire
BD23 3AE
United Kingdom

t:+44(0)1756 799919
e:info@jbaconsulting.com

Jeremy Benn Associates Ltd
Registered in England 3246693

Visit our website
www.jbaconsulting.com