Interim tsunami evacuation planning zone boundary mapping for the Wellington and Horizons regions defined by a GIS-calculated attenuation rule

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ABSTRACT

Wellington and Horizons regions have engaged GNS Science to provide indicative evacuation zones. The selected method for defining evacuation zone boundaries is an attenuated elevation-distance relationship calculated in ArcGIS Workstation as an AML script (detailed in Section 4). The primary input datasets are a digital elevation model, river lines, river polygons and coastline.

There are limitations to this method and local checking of the accuracy of outputted zones is needed. Over time it is recommended that zones are revised as the science is improved. A more robust simulation model could in future be used to calculate the above. Further in the future it may be possible to draw an envelope around all inundations from multiple/many well-tested computer models – this is the ideal method.

The probabilistic wave height with a 500 year return period, from regional and distant sources (>1hr travel time away), is used to define the orange evacuation zone. This is the zone which we may reasonably expect to provide official warning for now or in the foreseeable future. The probabilistic wave height with a 2500 year return period (i.e. maximum credible event) from all sources is used to define the yellow evacuation zone. This zone must encompass all credible tsunami, including those for which there will only be enough time for natural or informal warning. Zones are capped at 35 m above mean sea level along the coast because inundations above this elevation are extremely rare from subduction zone sources, and to take this remote possibility into account would cause over-evacuation in the vast majority of situations. The 84th percentile wave height is used from the probabilistic model to allow a margin of safety. The off-shore near-shore modelled height was doubled to define the evacuation zone, because run-up can be up to double the arriving wave height through momentum. The orange zone height is rounded to the nearest draft GeoNet ‘threat level’ boundary, to aid pre-planning for calling official evacuations.

The GIS model allows for attenuation by reducing the maximum potential run-up by 1.0 m every 200 m as the tsunami travels inland, 1m every 400m up significant rivers and 1.0 m every 50 m away from rivers. It has been tested against limited available data from real tsunami and against other models.

KEYWORDS

Tsunami, evacuation, GIS, zone, model

1.0 INTRODUCTION

In accordance with national guidelines for tsunami evacuation mapping, Wellington and Horizons regions have engaged GNS Science to provide indicative evacuation zones for their regions. Zones have been delivered as GIS datafiles on compact disc.

The objectives of this report are to:

1. define the method by which zones have been delineated;
2. explain the basis for elevations used to define those zones; and
3. document known limitations to the method and a recommended course for improvement over time.

1.1 Background

Prior to 2004, several Civil Defence Emergency Management Groups (CDEMG) had listed tsunami as a high priority hazard. Following the 26th December, 2004 Indian Ocean tsunami New Zealand political and public awareness of tsunami risk rose. A national tsunami hazard and risk review (Berryman, 2005) and a risk and preparedness review (Webb, 2005) were instigated by a request from the Minister of Civil Defence and commissioned by the Ministry of Civil Defence and Emergency Management (MCDEM). The MCDEM have produced a formal signage standard (MCDEM, 2008a) and an evacuation mapping guideline (MCDEM, 2008b)

The methods developed here build upon a system initially commissioned by Northland Regional Council for the purposes of the 2006 Pacific Wave exercise. Northland plans to update their maps as necessary to match the methods used for Wellington and Horizons regions.

2.0 METHODS

This report should be read in conjunction with the national signage recommendations and technical standard (Signage Subcommittee, 2007; MCDEM, 2008a) and evacuation mapping guideline (Evacuation Subcommittee, 2008; MCDEM, 2008b). These two reports summarise the background information on tsunami, warnings and the framework of maps and signage that these zone definitions inform.

The selected method for defining evacuation zone boundaries is an attenuation height-distance relationship calculated in ArcGIS Workstation as an Arc Macro Language (AML) script (detailed in Section 4).

2.1 Input data

The primary input datasets are:

- a Digital Elevation Model (DEM); and
- natural features: river lines, river polygons, coastline.

The DEM for the majority of coastline was derived at 10 m horizontal grid spacing from the LINZ 1:50 000 topographic data using the Topogrid tool in ArcGRID. The input features for elevation modelling were 20 m elevation contours and spot height data points. The natural features are from the same LINZ 1: 50 000 Topo dataset.

Where available for Wellington Region, Light Detection and Ranging (LiDAR) point data was used on an as-delivered basis (*i.e.* no checking or further processing of the dataset by GNS Science). The zones derived from the LiDAR data are provided as an additional dataset and have not been merged with the contour-derived zones.

2.2 Requirements for local customisation and checking

There are significant problems that result from using the LINZ 1: 50,000 Topo data for elevation modelling:

- The input data have a vertical resolution of 20 m, which results in features smaller than 20 m (*e.g.* river banks, small hills) not being represented in the model.
- In some places the LINZ spot height point data used for elevation modelling contains spurious heights (e.g. elevation of a trig point may represent the elevation of a trig tower instead of the ground elevation). Where found, these points have been removed, but it is likely that some were not removed and have created artefacts in the DEM.
- There are also artefacts generated by the elevation modelling in ArcINFO as *Topogrid* tends to create artificial holes and hills on the flat areas near steep slopes where the horizontal spacing between contours is quite large.

These errors in the DEM are most significant on low-slope relatively flat land near the coast and these areas are generally most prone to tsunami inundation, therefore checking and correction of the zones using local knowledge is necessary.

LiDAR datasets may have limitations including the following:

- The overall elevation is out of register to the real elevation (e.g. sea-level), or drifts out of register across the dataset.
- The edges may contain erroneous effects that need to be trimmed out of the dataset.
- Spurious isolated point heights may be present that need to be cleaned out.

2.3 Methods for delineating zones

Emergency managers should be looking to improve the method by which their evacuation zones are delineated over time. This can be achieved by aiming to progress through the following stages as maps are revised and science improves:

2.3.1 Stage 1 Bathtub inundation

A zone that covers all ground up to a specific elevation. This does not adequately allow for the way tsunami inundation drops in elevation inland.

2.3.2 Stage 2 Approximation by a rule

Can be prepared in GIS, allowing for drop-off inland from the coast. The method used here constitutes a 'Stage 2' method by this definition and is detailed in Section 4. Future improvement could constitute a Stage 3 or 4 as follows.

2.3.3 Stage 3 A more robust simulation model to do the above

This could constitute a more complex simulation model than that used here. For example it would be an advantage to (a) allow for water moving laterally 'around corners' as it moves inland, and (b) allow for variations in roughness of the land surface. The input would still be zone heights derived from a probabilistic model of expected wave heights.

2.3.4 Stage 4 An envelope around all expected inundation scenarios

Ideally evacuation zones should be an envelope around all of the expected inundation patterns, of all of the tsunami that can be expected, from all credible sources. This would require well-tested accurate and precise models of inundation from all sources. The character of tsunami generated at those sources would also need to be well understood. This stage is feasible but is not likely to be achieved in New Zealand in the near future.

3.0 COASTAL DOMAINS AND ELEVATIONS USED IN THE MAPPING

The tsunami risk in these regions varies around the coast. For the purpose of mapping the evacuation zones, the coastline was divided into a set of domains based on this risk. The domains are given in Figure 1, the wave heights and the zone heights at the coast for the orange and yellow zones are given in Table 1. The wave height for each domain is calculated at a point location and is then assumed to represent the domain within which it sits.

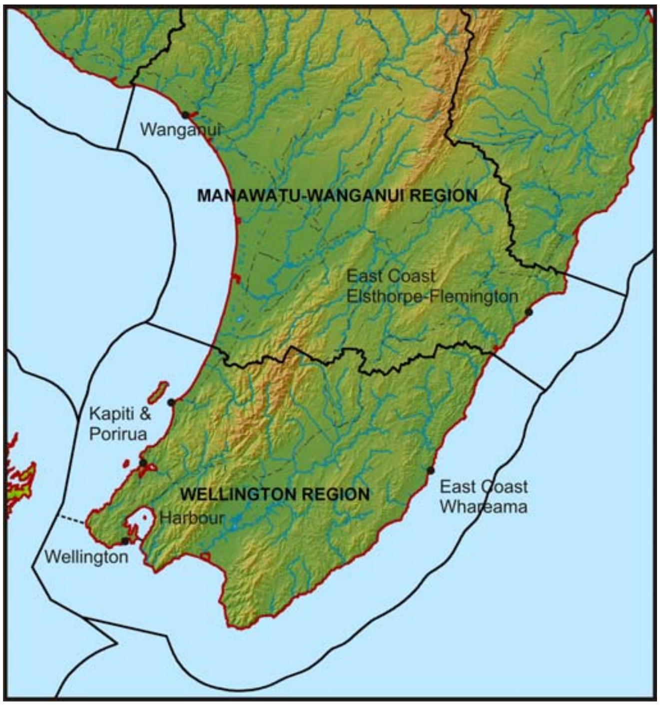

Figure 1 Domain boundaries – solid lines are regional council based boundaries, dashed lines are two additional boundaries within Wellington region.

Table 1 Domain elevations and their basis

	Wave height regional & distant sources 500 yr		Onshore height	***Orange zone height***	Wave height all sources 2500 yr		Onshore height	***Yellow zone height***
	median	*84%*	84% x 2		*median*	84%	84% x 2	
Horizons:								
Wanganui	2.6	3.6	7.2	***10***	5.2	7.8	15.6	***16***
East Coast*	2.2	3.1	6.2	***10***	14.2	24.2	35.0	***35***
Wellington:								
Porirua	1.2	1.7	3.4	***6***	5.4	8.7	17.4	***18***
Kapiti	1.4	1.9	3.8	***6***	5.2	8.3	16.6	***18***
Wellington	2.5	3.6	7.2	***10***	10.5	17.6	35.0	***35***
W. Harbour		(as above)		***10***	(70% of the above)		24.0	***24***
East Coast**	2.5	3.3	6.6	***10***	12.0	20.5	35.0	***35***

* Elsthorpe-Flemington

** Whareama

Zone height is that at the coast on-shore. It has been rounded up to the nearest whole metre for the yellow zone and up to the nearest GeoNet draft threat-level boundary (see below) for the orange zone (to facilitate planning for the calling of official evacuations). Waves in the near-shore off-shore, as are generated from wave models, can increase up to double in height through run up due to their momentum (in some rare cases an increase of more than double may be possible, but to take this into account would lead to over-evacuation in the vast majority of situations). Therefore, the on-shore height is twice the wave height from the model. The modelled height used is the 84th percentile, to allow some margin of safety due to the uncertainty in the model and source datasets.

3.1 Draft GeoNet threat levels

In cooperation with the CDEM sector GeoNet is considering implementing five distant-source threat levels that are nationally consistent. The threat levels allow the duty team to speak a predetermined language, realistically deal with uncertainty in data, and have a manageable workload; but still give different levels for predetermined sections of the coast. The sector can plan in advance the necessary actions to take on specific threat levels for their section(s) of coast.

These threat levels are for the sector and MCDEM only, as they are GeoNet related and are to be used by the sector for ordering official evacuations of coloured zones. GeoNet will aim to make sure that messages containing threat levels are clear, in case the public see them. They may include with the threat level a sentence such as "this threat level is to be used by local civil defence to consider which coloured zone needs to evacuate - follow evacuation instructions from local Civil Defence if and when they are given".

3.1.1 Threat levels tied to maximum water level at shore (draft)

20 cm – 1 m	Threat to beach and small boats, riverine or estuarine systems
1 m – 3 m	Some land threat
3 m – 5 m	Moderate land threat
5 m – 8 m	High land threat
8 m +	Severe land threat (local & regional sources)

3.2 Orange Zone

The probabilistic wave height with a 500 year return period, from regional and distant sources (>1hr travel time away), is used to define the orange evacuation zone. This is the zone which we may reasonably expect there to be official warning for now or in the foreseeable future.

3.3 Yellow Zone

The probabilistic wave height with a 2500 year return period (*i.e.* maximum credible event) from all sources is used to define the yellow evacuation zone. This zone must encompass all credible tsunami, including those for which there will only be enough time for natural or informal warning.

Zones are capped at 35 m because inundations above this elevation are extremely rare from subduction zone sources, and to take this remote possibility into account would cause over-evacuation in the vast majority of situations. This is from discussion of the data gathered so far internationally from the deposits and impacts of past tsunami.

4.0 GIS-CALCULATED ATTENUATION RELATIONSHIP

This section defines the purpose and method for using GIS to calculate an attenuation relationship into evacuation zones (Stage 2 as per Section 2.3). This is an interim method designed to provide zones that can be used now with the understanding that the method by which zones are defined is to be improved over time (Section 2.3). This principle is based on the following premises:

(1) It is better to make maps that can be used now and improve them, than to wait for science to improve.
(2) We need to allow for all of the many sources, many characteristics for those sources, and uncertainty in models of source, deep water propagation, shallow water propagation and inundation.
(3) Current elevation datasets available are variable in accuracy and precision.
(4) A conservative approach is needed – zones need allow for a margin of safety and their boundaries can be redefined over time, but should only shrink over time.

4.1 Attenuation from the coast over land

This relationship is 0.5% height attenuation by distance (*i.e.* water gets 1 m shallower every 200 m inland) based upon attenuation and testing outlined in Section 4.5 and Appendix 1.

4.2 From the coast up significant rivers and lakes

This relationship is 0.25% height attenuation by distance (*i.e.* water gets 1 m shallower every 400 m upriver) based upon attenuation at Banda Aceh (Umitsu et al, 2007). Rivers with a width near the coast of greater than 10 m across the water surface were modelled in this way. These rivers are defined in the LINZ 1:50 000 Topo database as polygons. River lines from the Topo database are used only to join detached river polygons. The list of modelled rivers follows:

<u>Wellington Region</u>:

West Coast
Witohu Stream
Otaki River
Waikanae River
Porirua Stream
Makara Stream

Wellington – Cape Palliser
Hutt River
Lake Kohangatera entrance
Wainuiomata River
Orongorongo River
Lake Onoke entrance and
Ruamahanga River

Wairarapa Coast
Mataikona River
Motuwaireka Stream
Patanui Stream
Pahaoa River
Oterei River
Awhea River

<u>Horizons Region</u>:

West Coast
Whanganui River
Whangaehu River
Turakina River
Rangitikei River
Manawatu River
Ohau River
Waikawa Stream

East Coast
Owahanga River
Akitio River
Wainui River

4.3 Over-bank across land from rivers, lagoons and estuaries

This relationship is 2% height attenuation by distance (i.e. zones get 1 m lower every 50 m across land away from a river).

4.4 GIS workflow

The input data for GIS modelling consisted of:

- A Digital Elevation Model (DEM) in ArcINFO grid format
- Significant river/lake grids generated from ArcINFO coverage.
- Sea polygon coverage created from the coastline and then converted to a grid to be used as a source of inundation.

The GIS procedure is conducted using three Arc Macro Language (AML) scripts (Appendix 1) with ArcGIS Workstation 9.1. The fourth AML script for river inundation is used in areas where LiDAR data is available.

1. AML for creating DEM (create_dem.aml)
   - Create a Digital Elevation Model (DEM) using 20 m contours and spot heights data
2. AML for calculating sea inundated areas (sea_inundation.aml)
   - Calculate attenuated relationship from the coast until it intersects topography and output the intersection as a polygon coverage for each zone type (orange or yellow)
   - Run AML script twice for two run-up heights
   - The AML calculates attenuation in two steps. Initially it creates an inundation area using the Euclidean distance function (the shortest distance from the coast). This function creates some inundated areas behind the high ground as they are low and close enough to the coast to satisfy the attenuation rule even though, in reality, the water would not be able to go over hills. In the next step the script uses that inundated area to define a source surface for the GRID *Pathdistance* function. This forces water to go around the hills that were not inundated in the first step instead of going over them.
   - The detached polygons produced by running the script are removed manually
3. AML for calculating inundation up and from rivers (river_inundation.aml)
   - Calculate inundation depth up the significant rivers and lakes using adequate attenuation relationship. The DEM could not be used to get elevation along rivers because of its spatial resolution limitations so the elevation was calculated using the distance along river to the intersection of the river, and the 20 m contour, and assuming a constant slope down-stream from that point.
   - Calculate over-bank inundation from rivers/lakes using the inundation depth at each point along river calculated from the previous step. The DEM was not used in this calculation, which assumes the surrounding ground has the same elevation as the river. The water is moved from the river step by step by calculating the water depth in each cell from all surrounding inundated cells and accepting the maximum value. The processing finishes when the water height drops to a zero value.
   - AML script was run twice for two run-up heights
   - The resulting zone polygon was manually clipped using 20 m / 40 m contour.

AML for calculating inundation up and from rivers (river_inundation_det.aml) using LiDAR DEM where available

- Calculate inundation depth up the significant rivers and lakes using adequate attenuation relationship. The water depth along the river was calculated as the difference between inundation height and elevation of the river extracted from the DEM. The inundation distance was defined by the intersection of the attenuated inundation and topography.
- Calculate over-bank inundation by attenuating water step by step from the river/lake. The processing finishes when the water elevation intersects the topography as read from the DEM.
- Run AML script twice for two run-up heights

After the sea and river inundation zones were produced they were manually merged together into a polygon coverage for each run-up height (orange and yellow zone). These two zones were also merged into one polygon coverage and converted to a shapefile.

4.5 Calibration and testing of the model

The GIS script and attenuation relationship has been calibrated against real data where possible. However, there is only limited data on the height and area inundated from historic tsunami and only a few real datasets provide enough information for adequate checking. Examples we have investigated (with varying degrees of utility) include:

(1) Banda Aceh following the December 26th 2004 tsunami in the Indian Ocean – Inundation up to 6 km inland (e.g. McAdoo et al., 2007) over relatively flat flood plains, with up to 35 m run-up (Tsuji et al., 2006) on steep coastal topography at the coast nearby. This was used to estimate the 1:200 overland attenuation rate. Subsequently aerial images were used to test that the evacuation zone defined by this rule was appropriate at intermediate distances (Appendix 1.1).

(2) Java following a tsunami in 2005 (Cousins et al., 2006) – Due to the generally flat topography of the areas surveyed it was difficult to determine how high the tsunami would have run-up had it encountered a steep slope close to the shore (this is a common problem with validation of this model). Nonetheless the 1:200 rule appears generally to be adequate even if inundation height is used instead of run-up height near shore[1] (Appendix 1.2).

(3) The general inundation pattern at the Solomon Islands (Fritz and Kalligeris, 2008).

(4) Published survey data for Sri Lanka (various data; Wijetunge, 2006; Fritz, 2005), (Appendix 1.3).

(5) Okushiri, Japan (12 July, 1993; 35 m max run-up). The 35 m run-up in the Monai valley of Okushiri Island is a possible exception to the assumption that the maximum run-up height can be up to twice the wave height at the coast. However it is noted that in the near vicinity of the Monai valley the run-up heights are still very large (20-25 m), so it is unclear to what extent the exceptional 35 m run-up in the valley is a consequence of on-land effects versus a particularly large wave at the coast (Appendix 1.4). This event exposes some limitations of the stage 2 approach (Section 2.3) as only a detailed numerical model would be likely to predict the effect of near-shore bathymetry near the Monai valley.

(6) 1700 inundation at Tsugaruishi (Atwater et al., 2005; 5 m near-shore offshore wave, and therefore ~10m assumed potential run-up, ~ 2 km inundation across gently sloping topography)

(7) 1960 inundation at Tanabe (Atwater et al., 2005; 3.7m elevation at shore onshore open coast, <400m inland from coast inside harbour)

(8) 1983 Japan Sea tsunami (Kajiura, 1986). The maximum run-up height in the Minehama area was 15.5m measured on an open-coast near-shore dune. Maximum run-in distance in this area ~1.25km (Appendix 1.5).

4.6 Summary of limitations and cautions

- The method outlined here can and should be improved upon over time (Section 2.3).
- The probabilistic wave heights used to define the zone sizes can and should be refined over time. This will require at least the following: improved source models, better near-shore bathymetry, more calibration data from real tsunami, and possibly improved tsunami inundation models.

[1] Inundation height (i.e. maximum water level not measured at the horizontal limit of inundation) is generally less than the maximum potential run-up height at the same distance from the coast.

- As new tsunami inundation data becomes available we may be able to further test and refine the attenuation rates used here (drop off per distance inland).
- We may also be able to revise over time, with more field data, the cross-sectional model of attenuation, which is currently linear, *i.e.* a set drop off per distance inland (e.g. Appendix 1.7)
- The evacuation zones are designed to encompass the range of inundation patterns for many individual possible tsunami. Any one tsunami will not inundate a zone fully.
- The GIS modelling can only be as good at the elevation data on which it is based.

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APPENDIX 1 CALIBRATION PLOTS

A1.1 Comparison to measured inundation at Banda Aceh

The GIS script was run on an elevation dataset for the Banda Aceh area of Indonesia using 35 m elevation at the coast. This zone (green line) for inundation from the west coast compared to the satellite image of damage from the tsunami is given in Figure 2. The damage wholly sits within the zone.

Figure A1 GIS-modelled evacuation zone for a wave from the left, overlain on the real Banda Aceh damage satellite images (Google Earth).

Note that the green zone is only modelled for inundation from the west coast, thus damage from inundation from the north coast is not included within a zone. This is because we have a good idea of the wave height and run-up elevation (input criteria for the GIS script) at only the west coast.

A1.2 Java survey results

The flat topography surveyed in Java (by Cousins et al, 2006) generally did not permit the estimation of maximum possible run-up heights on steep slopes near the coast. However, even if inundation heights near the coast are used in place of run-up heights it is generally found that the 1:200 attenuation rate is conservative (For example, figure 3).

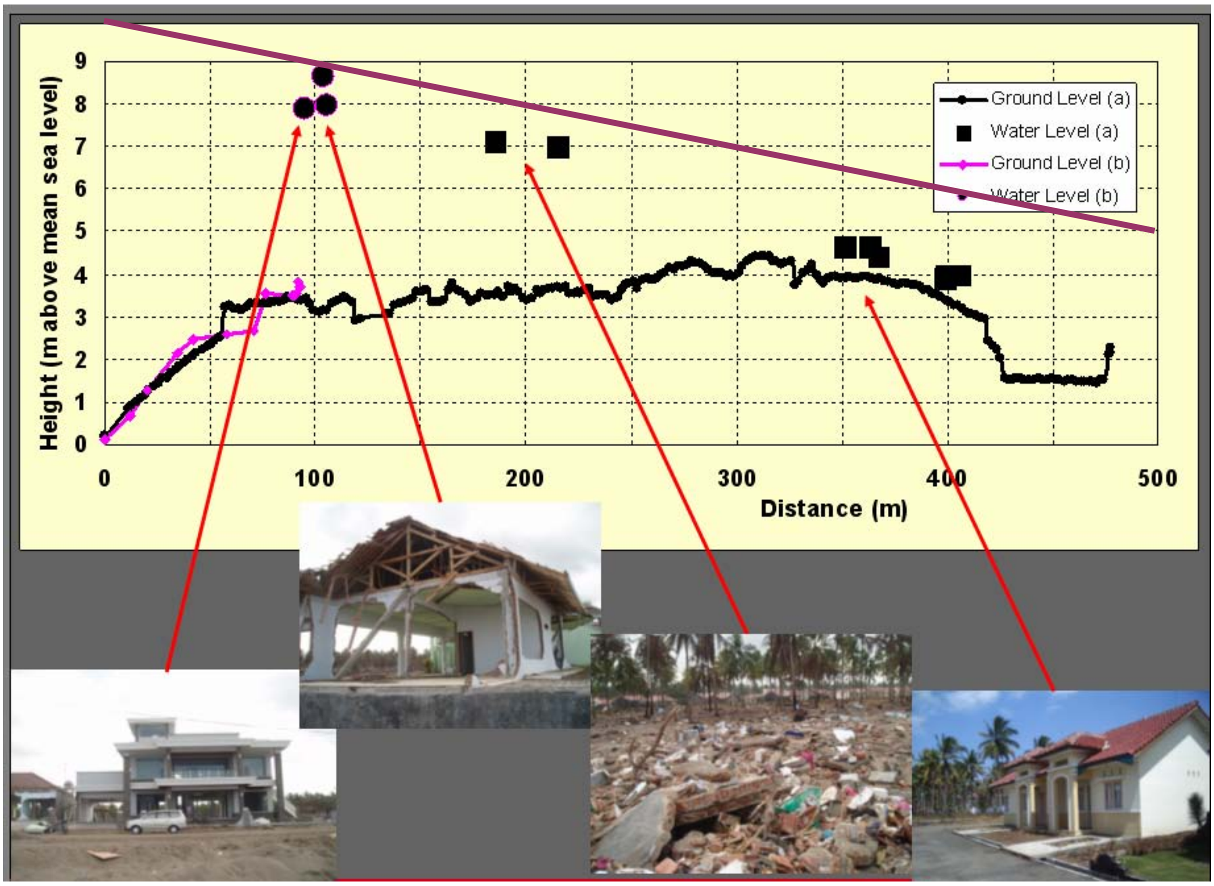

Figure A2 Inundation images from Java and water elevation. The purple line represents the 1:200 attenuation relation based on an assumed maximum possible run-up at the coast of 10 m (which may be an underestimate). The maximum run-in distance was ~480 m at an elevation of ~2 m. The attenuation rule appears to be conservative for this tsunami.

A1.3 Sri Lanka survey results

The published survey results of Wijetunge (e.g. figure 4) do not contain all of the information required for a comprehensive calibration. The elevation at the maximum inundation distance is not recorded, though where this distance is a local maximum it seems reasonable to assume that this occurs close to waterways that are likely to be at low elevation given the generally flat topography. It is also unclear whether the tsunami height records are of run-up or inundation height, though again given the flat topography it seems reasonable to assume that they are mostly inundation heights. This leads to the same issue as encountered in Java that we are unsure of the run-up height that would have been achieved had a steep slope been encountered.

Using the tsunami heights as (under-) estimates of the potential run-up the rule would imply that heights of 5-8 m would lead to inundation distances of 1-1.6 km which seems broadly consistent with the observations. Where the inundation distance is notably greater, e.g. ~3km around Kalkudah, it is noted that “In some areas, for instance, around Batticaloa and Kalkudah, the lagoons and other water bodies have certainly helped convey the tsunami surge large distances inland” so the 1:400 river attenuation rule is probably appropriate here.

Overall the data from Sri Lanka does not appear to directly contradict our rule, but is insufficient to act as a solid validation of it.

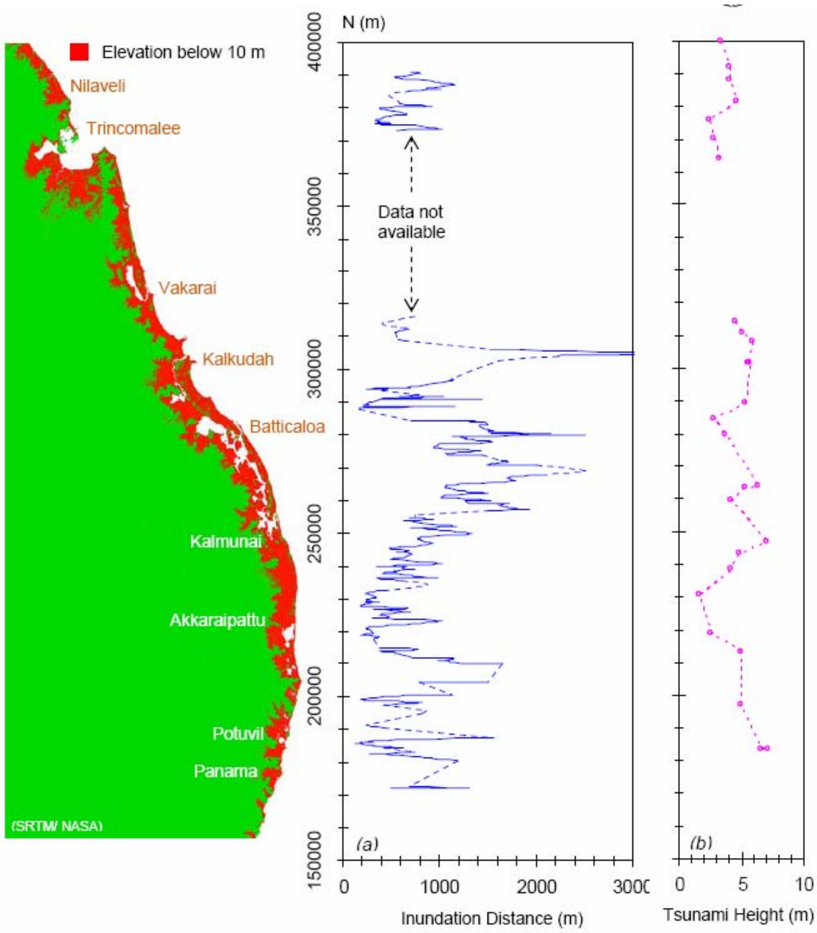

Figure A3 Inundation distance and Tsunami height measurements for the Sri Lanka east coast. From Wijetunge (2006).

A1.4 Okushiri survey results

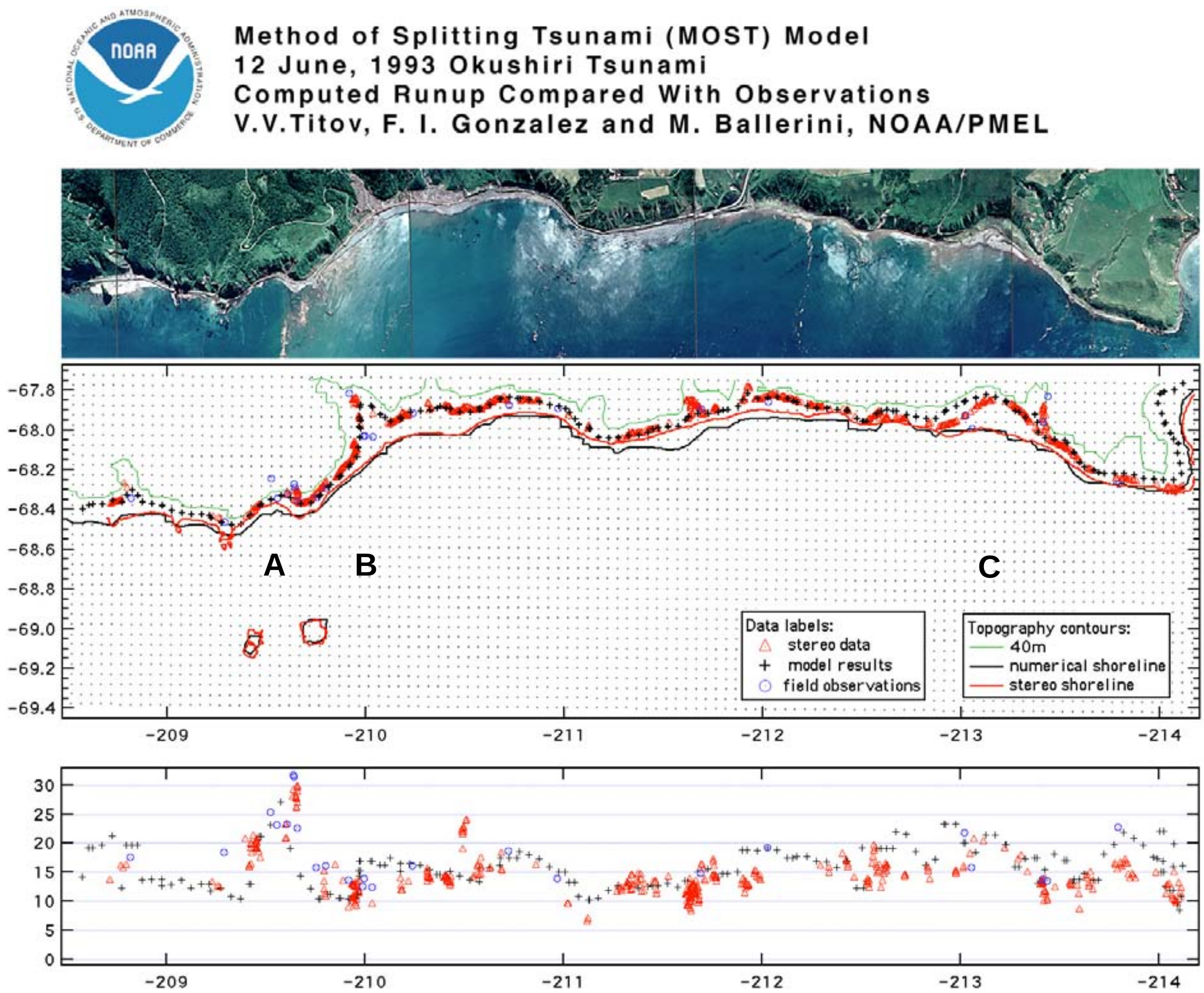

Figure A4 Inundation distance extent and maximum water level for the Okushiri southwest coast, from http://nctr.pmel.noaa.gov/Pdf/photo_graphs_title.pdf, colour bands and labels subsequently added (see text).

Analysis of field survey and aerial-photography data (Titov, 2005) for the 1993 Okushiri island tsunami shows inconclusive results when used to validate the model described here.

In region A consistently high run-up values (20-25 m) are seen which is believed to be due primarily to the focussing effect of the two offshore islands on the tsunami (only a detailed numerical model would be able to capture this effect). In one particular valley in this area a localised amplification effect has resulted in an exceptional 32m run-up.

In region B the maximum run-in distance is ~340 m at which point the maximum water level is ~14 m, approximately 2 m lower than at points either side of the valley entrance. This is broadly consistent with our model.

However in region C run-in distances of ~160 m do not appear to have caused a verifiable drop in maximum water levels relative to surrounding coasts. So this does not validate our model, though the anticipated effect is small. We note that the beach area is wide here and the width may be sensitive to the state of the tide.

A1.5 1983 Japan Sea survey results

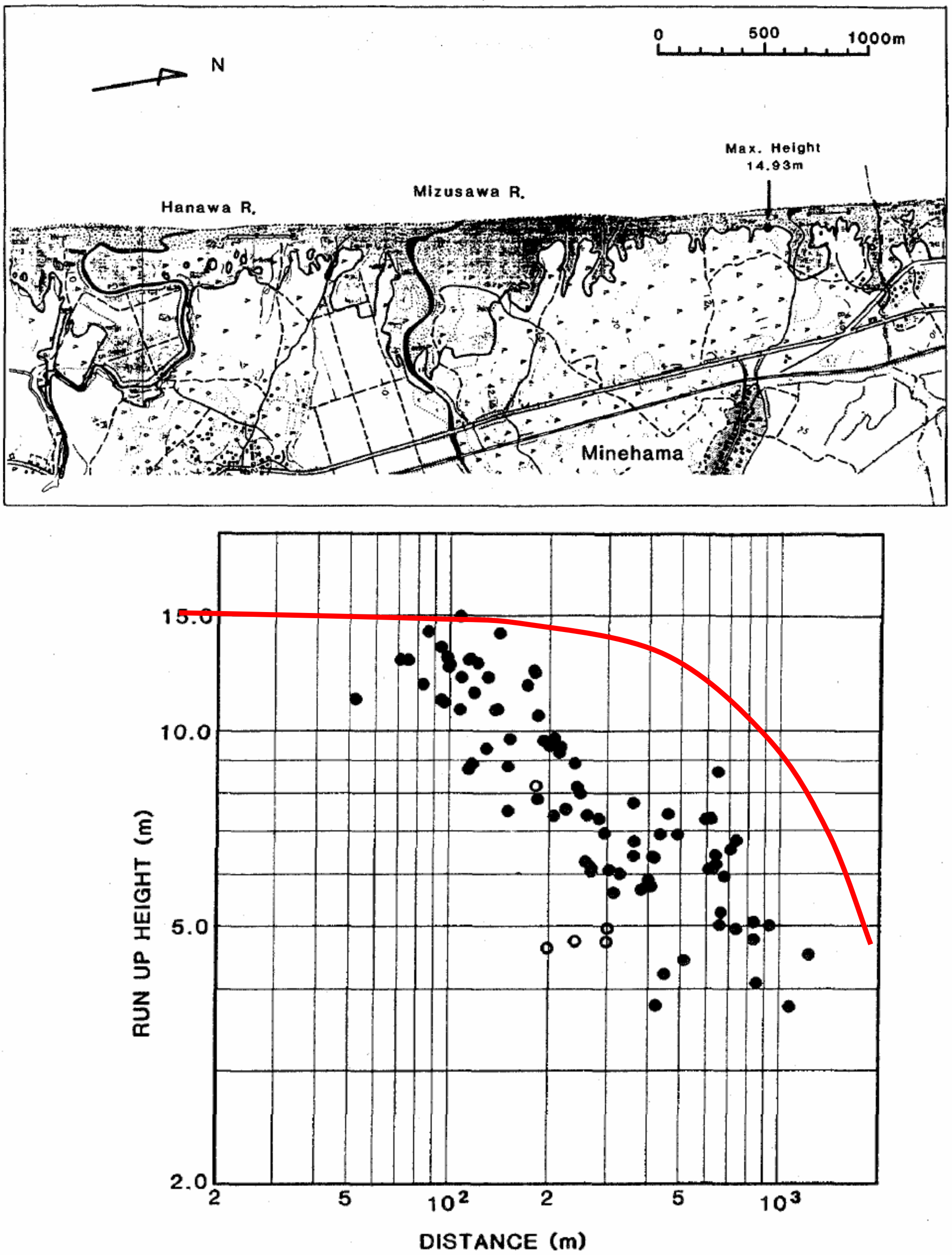

Figure A5 Run-up and inundation heights (m) as a function of the distance (m) from the shoreline on the Minehama coast (Kajiura, 1986). The superimposed red curve illustrates the envelope of points within the 1:200 attenuation curve, assuming a maximum possible run-up at the coast of 15.5m, the enveloped does not appear as a straight line because of the logarithmic scaling of the original plot.

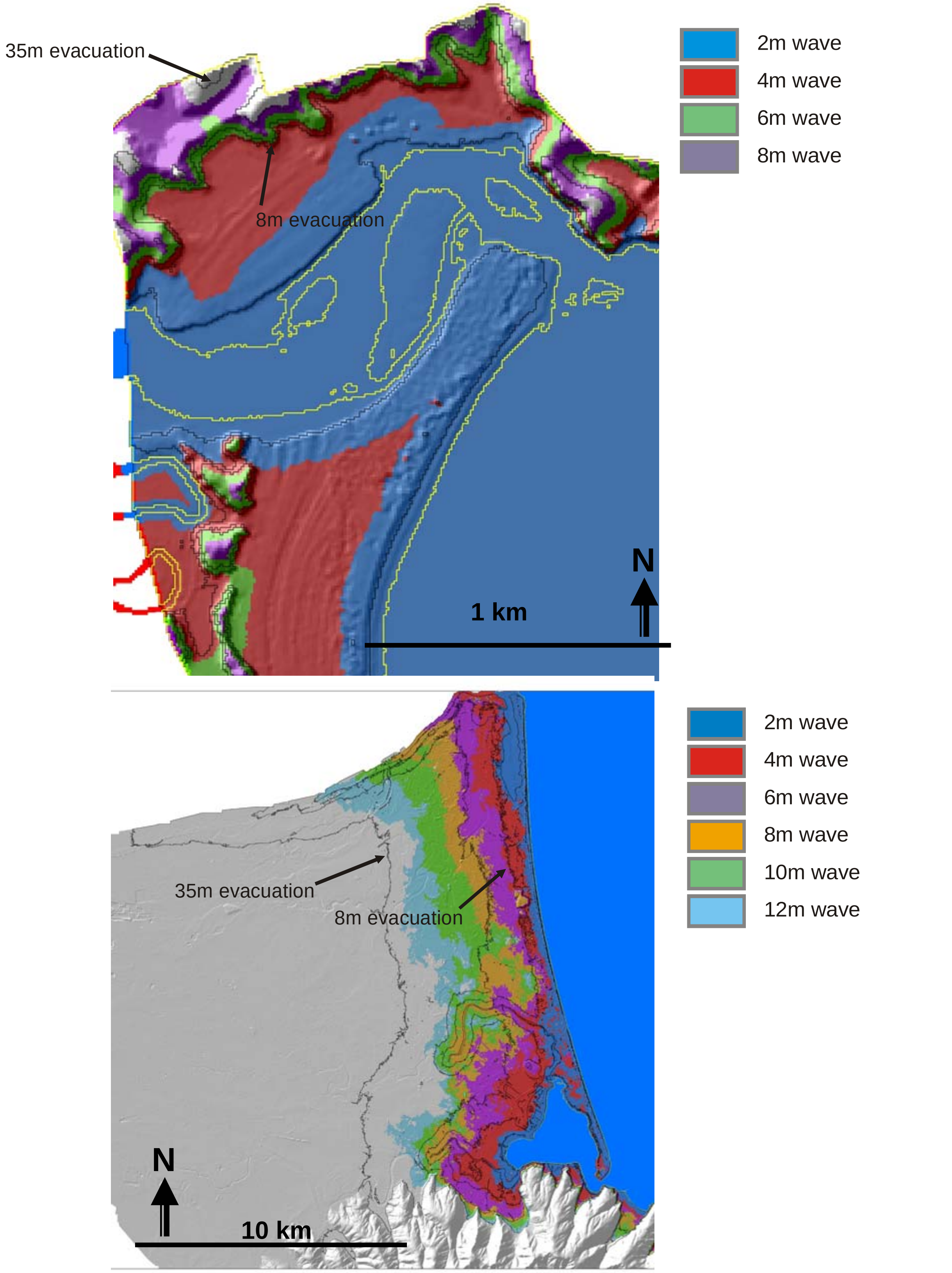

Figure A6 GIS-modelled evacuation zone lines (black, representative lines labelled) compared to Camfield inundation zones (coloured). Top figure is Whananaki, Northland, bottom is Pegasus Bay, Canterbury.

A1.6 Comparison to modelled inundation

We ran a more-complex inundation model where we have detailed elevation data at Whananaki in Northland and Christchurch in Canterbury. The modelled inundation by the GIS script used here and a US Army Corps of Engineers model (Camfield, 1980) for the same wave height at coast are shown in Figure 7. The results are relatively similar and in general the GIS rule zone is larger and thus the more conservative option. It is important to note that the Camfield model and other wave-propagation models are no better tested against real tsunami data than the script used here.

A1.7 Comparison of linear relationship to logarithmic options

One method being considered for places such as Hawai'i is referred to as the 'Fritz Criteria' (Meadows, draft) and suggests that there may be an exponential-decay relationship between decreasing inundation height and distance inland. The criteria are coarse-stepped and do not contain data points farther inland than 5 km. In a plot (Figure 8) of the relationship approximated as an exponential curve (equation 1) a 16 metre inundation at coast would go much further inland (light blue curve, Figure 8). The long-tail of the exponential curve would probably require some correction at large distances inland over flat terrain. While field data does not rule-out the exponential model, we have observed that it gives poor results (over-evacuation) when applied to areas where the topography data is based on interpolation of 0 and 20m contours. The linear relationship (green line, Figure 8, as used for modelling in this report) is therefore currently preferred.

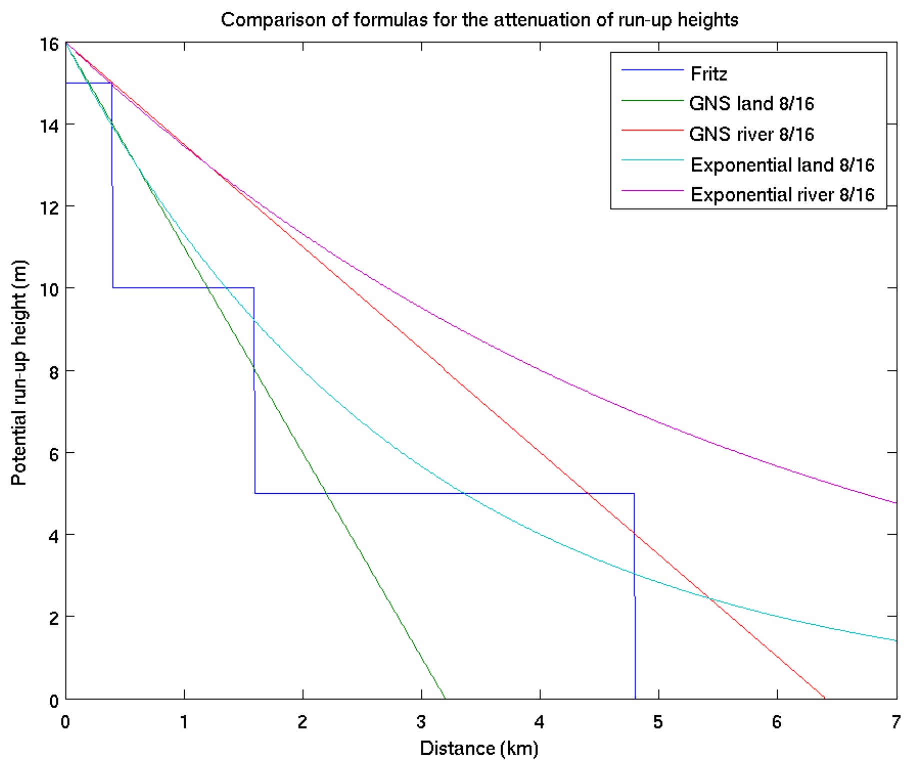

Figure A7 Comparison of Fritz Criteria, linear (used here) and exponential-decay attenuation relationships.

Equation 1: Maximum Potential Run-up height = 2 * H * exp(- ln(2) / alpha * X)

where: H is the height at the shore (m)
X is the distance from the shore (m)
alpha is the distance (in meters) in which the wave height drops by half

On land assume alpha = 2000 (chosen so that a 32m potential run-up drops to 4m potential run-up in 6km)

On rivers assume alpha = 4000 (chosen to decay half as fast as on land) ln(2) is the natural logarithm of 2

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