BECQ 2017 SLR Map Layer Updates: Methodology for Coastal Flood Geoprocessing

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This paper summarizes the local and regional sea level data used to develop coastal flooding scenarios for the island of Saipan, CNMI, and outlines the basic geospatial processing steps used to derive spatial data for six of those scenarios. This document is an update to the original “Saipan SLR Mapping Methodology”, which was appended to the Saipan Climate Vulnerability Assessment (2014).

Since the publication of the Saipan Climate Vulnerability Assessment in 2014, the primary means of assessing Saipan’s exposure to changes in sea level has been through a simple coastal flooding mapping approach. Inundation and flood mapping required data processing and analysis using Geographic Information Systems (GIS). Geospatial data layers for sea level change (SLC) and rise (SLR) scenarios, in the form of raster and vector data types, have been developed using ESRI ArcGIS 10.x software. Geoprocessing methods were originally developed by NOAA Coastal Services Center (see document “Detailed Methodology for Mapping Sea Level Rise Inundation” NOAA CSC, 2011). The NOAA methods were modified and applied to sea level data specific to the Mariana Islands.

It should be noted that several elements of the mapping approach introduce significant limitations and caveats to exposure analysis. While these limitations present obstacles to visualizing accurate representations of future conditions, they also offer opportunities for enhanced modeling as inundation scenarios on Saipan continue to be studied. Enhanced efforts could integrate more detailed hydrologic features, updated elevation and shoreline positions, or adopt numerical models that incorporate wave run-up and other coastal processes.

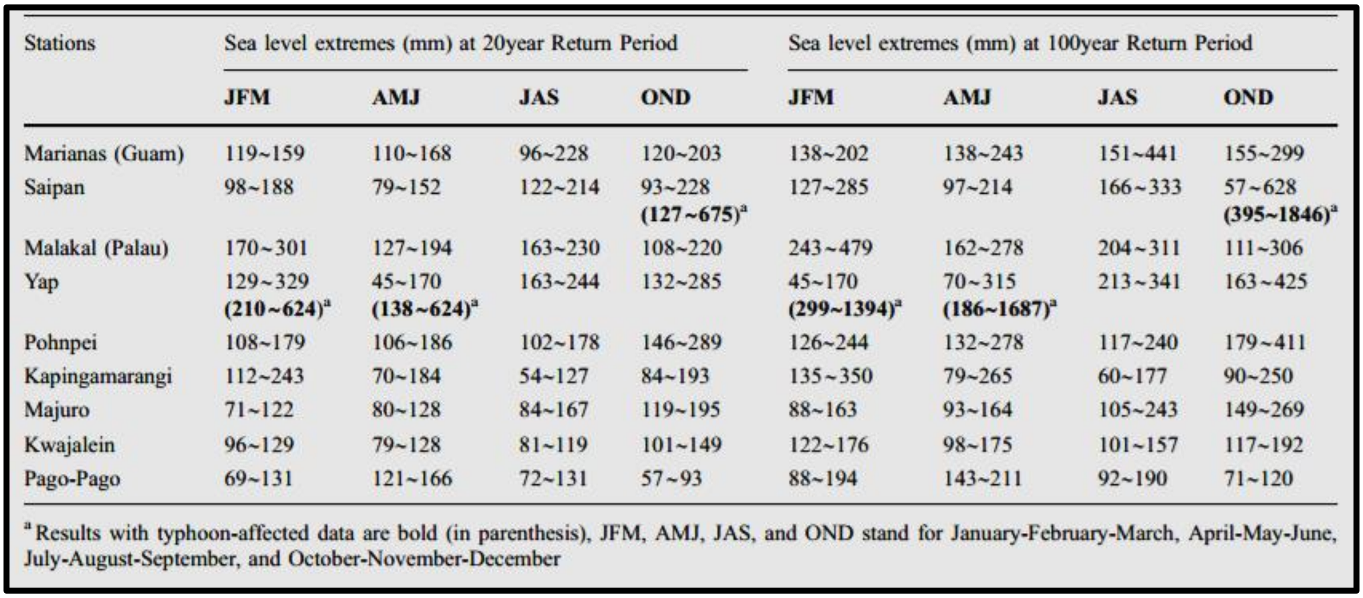
For the 2017 SLR Mapping update, a modified bathtub model has been utilized, which allows for mapping of changes in still-water levels over a high-resolution, conditioned digital elevation model. The bathtub approach does not consider future changes in shoreline due to coastal processes such as erosion and accretion, nor does it account for wave run-up or the influence of certain hydraulic features such as stormwater/sewer infrastructure. A detailed comparison of the bathtub approach to a dynamic, numerical wave run-up model is provided in USGS Open Report 2013-1069 (Storlazzi, et al. 2013).

Sea Level Scenarios and Data Sources

The 2017 updates to the Saipan SLR & Coastal Flooding maps resulted in 6 new spatial data layers reflecting increased future sea levels due to both climate change-driven processes (referred to as SLR), as well as seasonal extremes estimated for a 100-year return period (referred to as SLC). Both drivers of sea level rise/change were analyzed using local and regional data, primarily from Saipan & Guam tide gauges. These scenarios are detailed on the following pages.

SLC Scenarios Due to Seasonal Sea Level Extremes (Chowdury et al, 2010)

SLC scenarios based on seasonal sea level extremes were derived from Chowdhury et al.'s (2010) statistical modeling of 20 and 100-year return periods & monthly maximum data from 1978-2003 on Saipan. This study leveraged a more robust and locally relevant set of input data than the USACE Typhoon Surface Water Analysis for Saipan Lagoon (Chou, L. 1989), which was used as a data source in BECQ's previous flood mapping efforts. For BECQ's purposes of mapping sea level changes and extremes for Saipan, the 1989 USACE modeling can be considered superseded by Chowdhury et. al's analysis (see table below).



Stations	Sea level extremes (mm) at 20year Return Period				Sea level extremes (mm) at 100year Return Period			
	JFM	**AMJ**	**JAS**	**OND**	**JFM**	**AMJ**	**JAS**	**OND**
Marianas (Guam)	119~159	110~168	96~228	120~203	138~202	138~243	151~441	155~299
Saipan	98~188	79~152	122~214	93~228 **(127~675)**[a]	127~285	97~214	166~333	57~628 **(395~1846)**[a]
Malakal (Palau)	170~301	127~194	163~230	108~220	243~479	162~278	204~311	111~306
Yap	129~329 **(210~624)**[a]	45~170 **(138~624)**[a]	163~244	132~285	45~170 **(299~1394)**[a]	70~315 **(186~1687)**[a]	213~341	163~425
Pohnpei	108~179	106~186	102~178	146~289	126~244	132~278	117~240	179~411
Kapingamarangi	112~243	70~184	54~127	84~193	135~350	79~265	60~177	90~250
Majuro	71~122	80~128	84~167	119~195	88~163	93~164	105~243	149~269
Kwajalein	96~129	79~128	81~119	101~149	122~176	98~175	101~157	117~192
Pago-Pago	69~131	121~166	72~131	57~93	88~194	143~211	92~190	71~120

[a] Results with typhoon-affected data are bold (in parenthesis), JFM, AMJ, JAS, and OND stand for January-February-March, April-May-June, July-August-September, and October-November-December

Table from Chowdhury, et. al, 2010

Sea level extremes for the months of October, November, and December (OND) at the 100-year return period were used in BECQ's 2017 mapping updates. This resulted in a base sea level of +0.628 meters above datum.

BECQ's "extreme scenario" utilized the same return period with OND values during years in which typhoons skewed the sea level values on Saipan (bold in table above). While this data is technically "skewed", it is also representative of what Saipan could expect during a year in which a typhoon passes in close proximity to the island or makes landfall. The OND sea levels during an "extreme" or "typhoon year" could reach +1.846 meters.

Additional information regarding these seasonal extreme values can be found in the paper:

Chowdhury, Md. R., Chu, P., Zhao, X., Schroeder, T.A., and Marra, J.J. (2010). Sea level extremes in the U.S.-Affiliated Pacific Islands—a coastal hazard scenario to aid in decision analyses. *Journal of Coastal Conservation. 14:1, pp 53-62.*

SLR Scenarios Due to Climate Change

Sea level rise projections for Saipan were based on revisions to two primary resources: 2017 updates to NOAA sea level trend analyses (Sweet, W.V. et. al. (2017).Global and Regional Sea Level Rise Scenarios for the United States. *NOAA Technical Report NOS CO-OPS 083*.) and the 2017 update to the U.S. Army Corps' *Sea Level Curve Calculator* (http://corpsclimate.us/ccaceslcurves.cfm).

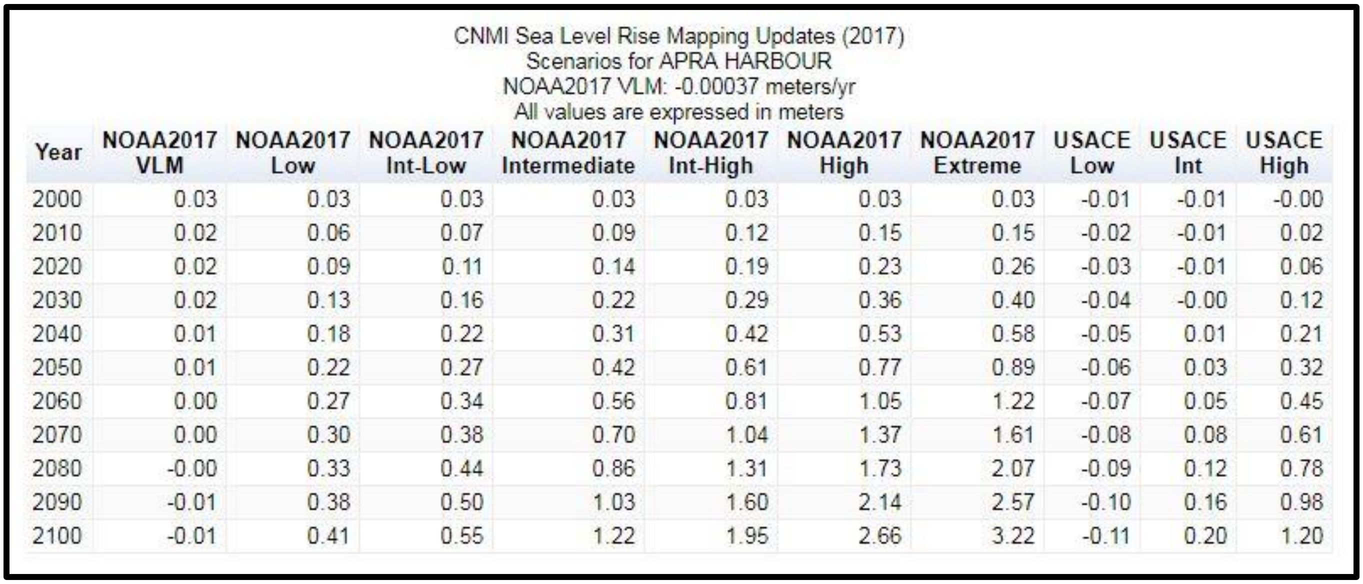
Future sea levels were calculated using the "NOAA High" curve as the projection basis for the USACE Curve Calculator. The NOAA High Curve assumes a "business-as-usual" greenhouse gas emissions scenario through the end of the century (Representative Concentration Pathway 8.5 from the International Panel on Climate Change 5th Assessment Report, 2014) in which carbon emissions are not substantially curbed, and initial contributions of Antarctic ice melt are factored in. Details concerning these computations and associated probabilities are available in Sweet et al., 2017.

The USACE Curve Calculator further refines these calculations by factoring in local vertical land movement at tide gauges with complete records for the current tidal epoch. The Apra Harbor tide gauge on Guam contains the most thorough sea level records for the Marianas, and was therefore used as a proxy for Saipan in these calculations.

A table and graph illustrating the lower and upper bounds of Marianas sea level projections are included on the following page. NOAA guidance suggests selection of scenarios for coastal planning and decision making based on the relative risk of the systems that are being planned for (e.g. development on Saipan's western coastal plain), the risk aversion of decision makers and stakeholders (e.g. developers' relative comfort level with certain probabilities of a hazard), and the flexibility or adaptive capacity of the system within a given time frame.

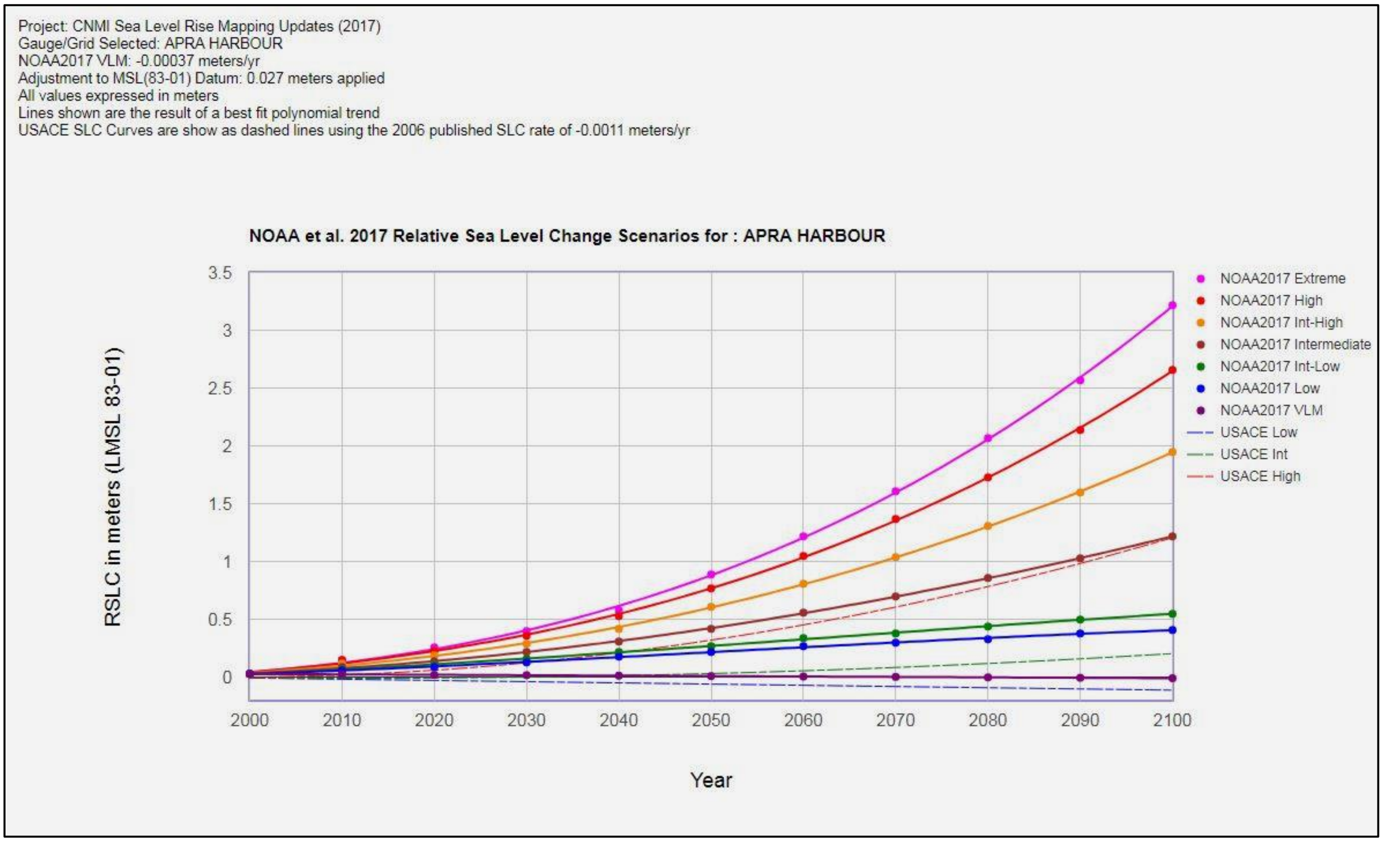
For Saipan, the NOAA High Curve was selected based on the relatively large-scale investments and rapid development currently (2016-2017) observed, and the relatively low flexibility or adaptive capacity once these developments and investments are put into motion, which include large changes to land use and the built environment along coastal flood plains, as well as substantial investments in island-wide infrastructure and public works.

In addition, lifespans for buildings, utilities, and water resources range from 30 years to 75 years, with projects often being bounded by 55 year land leases. The largest structures to have ever been built in the CNMI may aspire to life spans surpassing the 75 year horizon, while materials used in public works projects may require upgrades or replacement in as little as 25 years. Considering this planning envelope, mapping scenarios were built off of 30, 50, and 75 year projections.



CNMI Sea Level Rise Mapping Updates (2017)
Scenarios for APRA HARBOUR
NOAA2017 VLM: -0.00037 meters/yr
All values are expressed in meters

Year	NOAA2017 VLM	NOAA2017 Low	NOAA2017 Int-Low	NOAA2017 Intermediate	NOAA2017 Int-High	NOAA2017 High	NOAA2017 Extreme	USACE Low	USACE Int	USACE High
2000	0.03	0.03	0.03	0.03	0.03	0.03	0.03	-0.01	-0.01	-0.00
2010	0.02	0.06	0.07	0.09	0.12	0.15	0.15	-0.02	-0.01	0.02
2020	0.02	0.09	0.11	0.14	0.19	0.23	0.26	-0.03	-0.01	0.06
2030	0.02	0.13	0.16	0.22	0.29	0.36	0.40	-0.04	-0.00	0.12
2040	0.01	0.18	0.22	0.31	0.42	0.53	0.58	-0.05	0.01	0.21
2050	0.01	0.22	0.27	0.42	0.61	0.77	0.89	-0.06	0.03	0.32
2060	0.00	0.27	0.34	0.56	0.81	1.05	1.22	-0.07	0.05	0.45
2070	0.00	0.30	0.38	0.70	1.04	1.37	1.61	-0.08	0.08	0.61
2080	-0.00	0.33	0.44	0.86	1.31	1.73	2.07	-0.09	0.12	0.78
2090	-0.01	0.38	0.50	1.03	1.60	2.14	2.57	-0.10	0.16	0.98
2100	-0.01	0.41	0.55	1.22	1.95	2.66	3.22	-0.11	0.20	1.20



Project: CNMI Sea Level Rise Mapping Updates (2017)
Gauge/Grid Selected: APRA HARBOUR
NOAA2017 VLM: -0.00037 meters/yr
Adjustment to MSL(83-01) Datum: 0.027 meters applied
All values expressed in meters
Lines shown are the result of a best fit polynomial trend
USACE SLC Curves are show as dashed lines using the 2006 published SLC rate of -0.0011 meters/yr

Detailed documentation concerning these calculations can be found in USACE Circular 1165-2-2012 (http://corpsclimate.us/docs/EC_1165-2-212%20-Final_10_Nov_2011.pdf) and on the USACE Sea Level Change website: http://corpsclimate.us/ccacesl.cfm .

Combining the October-November seasonal sea level extreme estimates for 100-year recurrence at Saipan Harbor with the USACE Sea Level Curve Calculator/NOAA 2017 Projections, the following scenarios were computed and mapped:

2017 Saipan Coastal Flood Mapping Updates: Scenario Descriptions

Scenario	Data Code	Seasonal Extreme (meters)	Seasonal Extreme Description*	Sea Level Rise (m.)	Sea Level Rise Description**	Cumulative Sea Level Change (m.)
OND Seasonal Extreme (Typhoon Year)	OND_TY	1.85	Historically derived (1978-2003) maximum sea level for 100-year recurrence at Saipan Harbor, during the months of October - December including data from years with typhoon passage.	0	Climate change-related sea level rise not factored into this scenario.	1.85
50 years SLR	SLR50	0	No seasonal extreme estimates factored into this scenario.	1.31	Sea level rise projection for 2067 based on NOAA 2017 "High" curve and U.S. Army Corps sea level curve calculator for Apra Harbor tide gauge (local vertical land movement)	1.31
30 years SLR + OND Seasonal Extreme	SLR30_OND	0.63	Historically derived (1978-2003) maximum sea level estimate for 100-year recurrence at Saipan Harbor for months Oct.-Dec., with Typhoon-affected data removed.	0.74	Sea level rise projection for 2047 based on NOAA 2017 "High" curve and U.S. Army Corps sea level curve calculator for Apra Harbor tide gauge (local vertical land movement)	1.37
50 years SLR + OND Seasonal Extreme	SLR50_OND	0.63	Historically derived (1978-2003) maximum sea level estimate for 100-year recurrence at Saipan Harbor for months Oct.-Dec., with Typhoon-affected data removed.	1.31	Sea level rise projection for 2067 based on NOAA 2017 "High" curve and U.S. Army Corps sea level curve calculator for Apra Harbor tide gauge (local vertical land movement)	1.94
75 years SLR + OND Seasonal Extreme	SLR75_OND	0.63	Historically derived (1978-2003) maximum sea level estimate for 100-year recurrence at Saipan Harbor for months Oct.-Dec., with Typhoon-affected data removed.	2.14	Sea level rise projection for 2093 based on NOAA 2017 "High" curve and U.S. Army Corps sea level curve calculator for Apra Harbor tide gauge (local vertical land movement)	2.77
50 years SLR + OND Seasonal Typhoon Year	SLR50_ONDTY	1.85	Historically derived (1978-2003) maximum sea level for 100 year recurrence interval at Saipan Harbor, during the months of October - December including data from years with typhoon passage.	1.31	Sea level rise projection for 2067 based on NOAA 2017 "High" curve and U.S. Army Corps sea level curve calculator for Apra Harbor tide gauge (local vertical land movement)	3.16

* See **Chowdhury, Md. R., Chu, P., Zhao, X., Schroeder, T.A., and Marra, J.J. (2010). Sea level extremes in the U.S.-Affiliated Pacific Islands—a coastal hazard scenario to aid in decision analyses.** ***Journal of Coastal Conservation. 14*** **:1, pp 53-62.**

** See **http://corpsclimate.us/ccaceslcurves.cfm (Revised 2017)** and ***U.S. Army Corps of Engineers. (2011). Sea Level Change Considerations for Civil Works Programs. U.S. Army Corps Circular 1065-2-212. http://corpsclimate.us/docs/EC_1165-2-212%20-Final_10_Nov_2011.pdf***

Mapping Methods

Inputs:

- Digital Elevation Model (DEM)
    - The DEM for Saipan is based on 2007 USACE high-resolution lidar data. Hydrographic breaklines in the DEM were derived from lidar intensity images, and the DEM is hydro-flattened so that water elevations are set to 0 meters.
    - Source lidar has a horizontal accuracy of 1 meter, and vertical accuracy root mean square error of 20 cm. DEM resolution is 2.69 meters. The source data meets FEMA standards for flood hazard mapping.
    - DEM was conditioned and distributed by NOAA CSC. Metadata for the DEM, including process steps and software used is available upon request to CNMI Coastal Resources Management Office.

- Tidal surface in NAVD88 values
    - NOAA methodology suggests the use of VDATUM software to develop a tidal surface that captures spatial variation in water levels. The VDATUM tool and associated data packages did not include coverage of the CNMI at the time that SLC layers were developed, and therefore was not used. The alternative recommended method for creating a tidal surface involves interpolation of sea level values at different tide gauges within the area of interest. Saipan has only one tide gauge, therefore a single value tidal surface was generated.

- Sea level change values
    - Values (in meters) for each of the SLC scenarios are described on the previous page of this document.

Workflow in ESRI ArcGIS Desktop

(as detailed by NOAA CSC SLR Inundation Mapping Whitepaper)

Note: While the following workflow was completed for the six coastal flooding scenarios, only the *connected depth grid* (step 7) and an associated polygon for each scenario was exported and published in a file geodatabase to the BECQ Server. The polygons for each scenario were also merged into a single feature, and published to the BECQ online data portal, providing the primary means of public access to visualize and download the data as a single file.

1. Add SLC value to the tidal surface grid

Spatial Analyst > Math > Plus
- Input raster or constant value 1 = tidal surface
- Input raster or constant value 2 = SLC value for OND_TY
- Output raster = **surface_OND_TY**

2. Subtract DEM values from water surface to derive initial inundation depth grid

Spatial Analyst > Single Ouput Map Algebra
- Map Algebra expression: con(DEM <= surface_OND_TY, surface_OND_TY – DEM)
- Output raster = **depth_ OND_TY**

3. In preparation for evaluating connectivity, create single value DEM to show inundation extent

Spatial Analyst > Single Output Map Algebra
- Map Algebra expression: con(DEM <= surface_OND_TY, 1)

- Output raster = **single_ OND_TY**

4. Evaluate connectivity of extent raster

Spatial Analyst > Generalization > Region Group
- Input raster = single_OND_TY
- Number of neighbors to use = 8
- Zone grouping method = Within
- Output raster = **clumped_OND_TY**

5. Extract connected inundation surface to be used as a mask for the original depth grid

Spatial Analyst > Extraction > Extract by Attributes
- Input raster = clumped_OND_TY
- Where clause: “Count” = maximum value
- Output raster = **connect_OND_TY**

6. Derive low-lying areas greater than an acre

Spatial Analyst > Extraction > Extract by Attributes
- Input raster = clumped_OND_TY
- Where clause: “Count” > 40
- Output raster = **lowlying_OND_TY**

For Saipan

- The value of 40 is based on the use of 10 meter grid cells (1 acre = 4046.85m2, 4046.85 m2 / 100 m2 = 40.46).

- The DEM has ~3 meter cells, therefore ‘Count’ value was 450 (1 acre = 4046.85m2, 4046.85 m2 / 9 m2 = 449.65)

7. Create depth grid for connected areas

Spatial Analyst > Extraction > Extract by Mask
- Input raster = depth_OND_TY
- Input raster or feature mask data = connect_OND_TY
- Output raster = **con_depth_OND_TY**

Additional steps for Saipan

To derive polygons with “con_depth_OND_TY” values (for additional analysis using feature-based queries, etc…)

Convert from floating point raster to polygon without losing significant figures (to the third decimal)

Spatial Analyst -> Map Algebra
- Int([con_depth_OND_TY]*1000) *or* Int([Susupe_OND_TY]*1000)
- New Raster has whole integer values that are 1000 times larger than original depths
- Output Raster = **integer_OND_TY**

Conversion Tools -> From Raster -> Raster to Polygon
- Input raster: integer_OND_TY
- Field = ‘value’
- New Polygon = **OND_TY_Poly**

- In OND_TY_Poly: Create new depth field to match original floating raster values
- In attribute table for OND_TY_Poly, Create new field “depth”, field type ‘double’
- Field Calculator: “depth” = ‘grid_code’/1000

To create single polygons for quick display of inundation extend, excluding flood depth values

Cartography Tools -> Generalization -> Aggregate Polygons OR ‘Dissolve’ based on new field with single value
- Input: OND_TY_Poly
- Distance: 0.5 meters (other search distances will work, but must be less than original raster cell resolution to avoid aggregation across areas that are not inundated) OR Dissolve based on attribute field with single value
- Output: **OND_TY_Aggregate OR Dissolve**

References

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