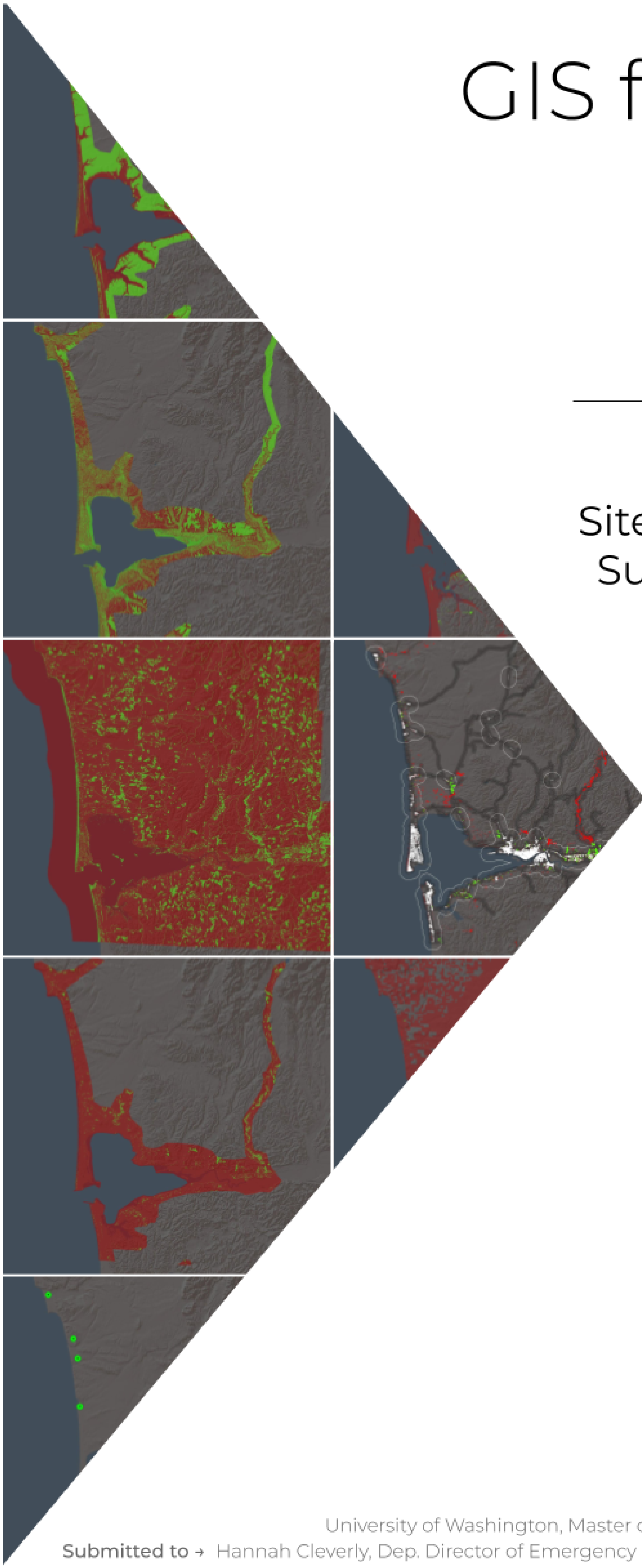


GIS for **Tsunami Evacuation Planning**

Site Selection Analysis for Suitable Assembly Areas

GIS Decision Support for the Office of Emergency Management in Grays Harbor County, WA

Nathaniel Santa Cruz
Marco Brettmann
Alina Luce

August 23, 2019

University of Washington, Master of GIS (MGIS), GEOG 569 GIS Workshop
Submitted to → Hannah Cleverly, Dep. Director of Emergency Management for Grays Harbor County

Table of Contents

Executive Summary

Seated on the western coast of Washington State, Grays Harbor County remains one of the most vulnerable regions to tsunami devastation. In order to mitigate the risks associated with this type of event, emergency managers for Grays Harbor County needed to know the following information:

1. What is the total number of people that live within the inundation zone?
2. Of those, how many are disabled, children ages 0-4, or non-english speaking?
3. Where do suitable assembly areas exist and what is their capacity?
4. Where and how many remain isolated?

To help answer these questions, graduate students from the University of Washington, Master of GIS (MGIS) program, volunteered to work with the leaders of Grays Harbor County by leveraging the power of GIS and publicly available spatial data.

Method

In discussion, it was agreed that an ideal assembly area included the following characteristics:

1. Located outside of the inundation zone
2. No Trees
3. Flat
4. Not Environmentally Protected
5. Accessible by Road
6. Close to population centers
7. Public Land
8. Large Area

Using this criteria, the graduate students created a model that identified all the locations throughout Grays Harbor County that meet these conditions and then conducted a population study with the results.

Results

The model identified 17 locations that were well distributed across the county. They were comprised of 2 high schools, 1 park, 2 cemeteries, and 7 areas of undeveloped land; a total of 49.11 acres.

The population study revealed that 60% of Grays Harbor County (43,548 people) live within the inundation zone; of this, only 35% (15,329 people) live within 1-mile of the 17 locations; and of that, only 16% (7,046 people) could actually fit within the space available. Additionally, of those living in the inundation zone, 22% (9,865) are households with 1 or more disabilities (17%), are younger than 4-years old (5%), or only speak Spanish (0.01%).

Summary

The northern coastal communities (Taholah, Moclips, Pacific Beach, Copalis Beach) each have suitable public land with room to spare, but their distribution has isolated small groups of people in between.

Ocean Shores (5,927 people) remains the most vulnerable community as the entire city will be inundated in the event of a tsunami, and there are no suitable public assembly areas nearby. There does exist one privately owned area that is suitable which may be acquired, but vertical evacuation structures (VES) are still the only viable option for the majority of residents in this city.

It is possible for the entire population of Westport (2,051) to safely evacuate to Ocosta High School. Both the campus and the facility, which is a VES, are suitable locations capable of holding 3,500 people together.

The inner cities of Hoquiam, Aberdeen, and Cosmopolis have several suitable public lands, but together, there is not enough public space to hold the evacuating population. For these three cities, there are over 8,000 people who will still need some other form of safety provision such as a VES or other suitable private lands.

In the city of Montesano, the number of people that live in the inundation zone is *unknown* due to data constraints. However, there exists an abundance of land, both public and private, that would be suitable for an assembly area. However, one of the largest locations is Wynoochee Cemetery (10.53 acres). It rests upon the county to decide if such areas are suitable for evacuation areas or not.

Conclusion

Given the criteria used for the site selection of suitable assembly areas, there is not enough public land for the population to use during a tsunami evacuation. The land that is both suitable and available for Grays Harbor County to use for this purpose can only satisfy 16% of the people who will be evacuating the inundation zone, *not including tourists*. This leaves over 36,500 local residents who will be in need of some other form safety provision, such as a vertical evacuation structure (VES), privately owned land that meets the remaining criteria, or cleared shrublands.

1 Introduction

1.1 Background

In 1995, a series of studies produced by Brian Atwater[1] greatly increased the national concerns about the potential devastation that a tsunami from a Cascadia Subduction Zone (CSZ) earthquake could inflict upon coastal communities throughout western Washington, Oregon, and Northern California. With subsequent studies[2] later revealing the frequency of these catastrophic events, the most recent having taken place 300 years ago (1700 AD), news outlets began to raise the alarm, causing residents of these coastal communities to become very concerned about their safety. The resulting distress was recognized by the U.S Congress, who later directed the National Oceanic and Atmospheric Administration (NOAA) to develop a mitigation plan to ensure the safety of the people residing along the western coast of the United States. Thereafter, representatives from NOAA, the Federal Emergency Management Agency (FEMA), the U.S. Geological Survey (USGS), along with input from five coastal states, proposed a plan to Congress, which led to the creation of the National Tsunami Hazard Mitigation Program (NTHMP) in October of 1996. This program provided the basis for future research supporting emergency planning and evacuation of coastal communities at risk from tsunamis.

With funding provided by FEMA through the NTHMP, a team of geologists, from the Washington Department of Natural Resources (DNR), mapped the first tsunami inundation zone for a 9.0 CSZ earthquake, which was modeled after the 1700 A.D. event (1A w/ asperity). These initial findings were first published in October of 2000[3], and were then revised with more accurate data and advanced technology in March of 2018[4] after an even larger 2,500-year event, a model now known as the *L1 scenario*. During such an event, wave heights are estimated to be between 20 to 60 feet for the outer communities of Ocean Shores and Westport, giving residents only 15 - 20 minutes to evacuate following the initial shock of the earthquake. In communities within Grays Harbor, such as Hoquiam, Aberdeen, and Cosmopolis, wave heights will are expected to lower to 10 feet, giving residents closer to 30 - 60 minutes to evacuate the inundation zone. For all these coastal communities, both inner and outer, the developed areas would be completely inundated by tsunami flooding. Considering these inundation depths, survival is highly unlikely without retreat to high ground or a vertical evacuation structure (VES) such as Ocosta High School in Westport, WA, which is presently the only VES in Grays Harbor County.

While these estimates represent a worst-case scenario, a lesser and more likely event would be a distant source tsunami, which last occurred in 1964 following the Great Alaskan Earthquake. For an event such as this, residents may have up to 4 hours to evacuate the inundation zone following the initial shock of an earthquake.

For both scenarios, emergency planners use the inundation zone modeled after the L1 scenario, while *time* remains the primary factor that distinguishes the two events from one another. However, additional factors to consider during a CSZ that would not be an issue during a distant source event are that (1) the primary roads would likely be destroyed following the earthquake, and (2) due to an expected 5 ft drop in elevation, immediate flooding would also occur for low lying areas before the tsunami rushes upon the shoreline.

Foreseeing that residents would likely not be able to drive to high ground following a CSZ

[1] Summary of Coastal Geologic Evidence for Past Great Earthquakes at the Cascadia Subduction Zone. Earthquake Spectra. 1995. Atwater, Nelson, Clague, Carver, Yamaguchi, Bobrowsky, Bourgeois, Darienzo, Grant, Hemphill-Haley, Kelsey, Jacoby, Nishenko, Palmer, Peterson, Reinhart

[2] Statistical Analyses of Great Earthquake Recurrence along the Cascadia Subduction Zone. Kulkarni, Ram, Wong, Ivan, Zachariasen, Judy, Goldfinger, Chris, Lawrence, Martin. 2013.

[3] Tsunami hazard map of the southern Washington coast--Modeled tsunami inundation from a Cascadia subduction zone earthquake. Walsh, Caruthers, Heinitz, Myers, Baptista, Erdakos, Kamphaus. 2000, Geologic Map 49.

[4] Washington Geological Survey, 2017, Tsunami inundation--GIS data. 2017: Washington Geological Survey Digital Data Series

event due to the probable destruction of roads, the Washington State DNR recently published *Walking Maps*[5] to show how long it would take to traverse from any part of the inundation zone at a standard pace. The results show the most vulnerable locations at 120+ minutes away from high ground. However, only a few walking maps for communities in Grays Harbor County have been published, although more are expected to be released by the end of 2019.

1.2 Problem Statement

What remains unknown is the *scope* of mitigating risk for either a distance source tsunami, or CSZ tsunami. This includes:

1. Knowing the total number of people that live within the inundation zone
2. Of those, how many are especially vulnerable (disabled, children ages 0-4, or non-english speaking)
3. Knowing where suitable assembly areas exist
4. Knowing the capacity of those assembly areas
5. Knowing both where and how many remain isolated and are in need of some other form of safety provision, such as a vertical evacuation structure (VES).

Knowledge gaps such as these need to be addressed in order for the emergency managers of Grays Harbor County to develop an adequate evacuation plan and to secure federal funding to support further development. Without this information, mitigating tsunami risk may not be possible.

1.3 Project Objectives

The purpose of this project is to address these knowledge gaps by leveraging GIS and publicly available spatial data. In particular, this study will focus on achieving the following objectives:

1. Measure population living in the tsunami inundation zone, to include a breakdown of vulnerable populations (disabled, children ages 0-4, and non english-speaking)
2. Locate where *suitable* assembly areas exist (defined by criteria agreed upon with stakeholders)
3. Measure capacity of suitable assembly areas against populations within 1-mile
4. Identity & measure isolated populations (those without assembly areas) to determine additional need for VES.

After reviewing the results of this study, it was determined best not proceed with the following objectives until further stakeholder decisions and policy development were completed:

1. Propose new evacuation routes from population centers to suitable assembly areas
2. Propose new evacuation zones for emergency management
3. Overlay suitable assembly areas with the DNR Walking Maps to determine walking times to these locations.

1.4 Overview

The remainder of this report will be a review of the system and data requirements needed to conduct this study, the step-by-step process and workflow used to conduct analysis, a presentation of the results, important considerations, and lastly, how this study might benefit Grays Harbor County. Closing remarks will be provided in the conclusion, followed by a list of references.

[5] Tsunami! Evacuation Map for Ocean City, Copalis Beach, Pacific Beach, and Moclips. 2014. WA DNR.

2 System Requirements

In order to repeat the results of this study, the following system requirements are needed.

2.1 Hardware

The computer used to perform this analysis was an HP Z8 with a Windows 10 operating system (version 1709), Intel Xeon Gold 5120 CPU (2.20GHz) and 32 GB of RAM. However, any computer capable of hosting ESRI ArcGIS will be able to perform this analysis, though processing speeds may vary.

2.2 Software

Analysis was conducted using ESRI ArcGIS 10.4, utilizing tools from the Spatial Analyst and 3D Analyst extension. An advanced license must be registered through ESRI in order to proceed.

Additionally, student access to ArcPro allowed the project team to access ESRIs' GeoEnrichment service, which allows users to quickly apply demographics and metrics to their maps with data from a variety of sources. Access to this service is given by administrators and runs on user credits, and so must be managed accordingly. This service greatly expedited the acquisition population totals and demographics and allowed data to be pulled per a user defined area instead of predefined census blocks.

2.3 Data Sources

The following data layers are required to perform the site selection analysis with the *Assembly Areas Model* and were acquired through four different sources (1) Grays Harbor County[6], (2) WA State DNR[7], (3) the Multi-Resolution Land Characteristics Consortium (MRLC)[8], and (4) the ESRI GeoEnrichment service.

From Grays Harbor County, the following data layers were downloaded:

- **County Boundary** (Polygon)
- **Population Centers** (Polygon)
- **Parcels** (Polygon)
- **Wetlands** (Polygon)
- **Roads** (Polyline)

From the MRLC, the 2016 National Land Cover dataset (NLCD) was downloaded as a raster (30 m resolution), which includes the following attributes required for this analysis:

- **Open, Barren, Grasslands, Pastures** (Grid Codes: 21, 31, 71, 81)
- **Wetlands** (Grid Codes: 90, 95)
- **Developed Area**s (Grid Codes: 22, 23, 24)

From the WA State DNR, a sub-meter resolution digital terrain model (DTM), collected by FEMA in 2009, was acquired directly from the DNR LiDAR Portal.

- **LiDAR** - 2009 FEMA

Additionally, the inundation zones (polygons) generated from both DRN studies were acquired directly through a point of contact, Daniel Eugard, a geologist at the DNR:

- **Inundation Zone** (L1 Scenario) - 2018
- **Inundation Zone** (1A w/ Asperity) - 2000

Lastly, population data for areas of interest were acquired through the ESRI GeoEnrichment service, which adds the 2019 American Community Survey (ACS, an annual US Census Bureau survey) estimates to population demographics. Assessing vulnerable populations within the study area included households with one or more disabled persons, children ages 0-4, and non-English speaking (Spanish) populations. These particular demographics have been

[6] Grays Harbor County GIS Mapping Portal. Updated 2017.
[7] WA DNR GIS Open Data Portal. Updated 2019.
[8] Multi-Resolution Land Characteristics Consortium. Updated 2019.

identified as vulnerable due to either an increased inability to physically evacuate themselves or additional time needed to evacuate, as well as the potential understanding barriers that a non-English speaker might encounter in an area with only English emergency signage. The State of Washington also passed regulations that emergency messaging would require a Limited English Proficiency (LEP) check of populations.[9] If a population demographic is 5% or 1000 person- whichever is less- emergency messages must be administered in that particular language. This Geo Enriched data should provide insight on minorities that may fall under this heading.

2.4 Data Limitations

Most notably, the greatest limitation of this study was the extent of LiDAR, which only covers the immediate coastline and inner parts of the county. However, since our analysis is only focused on areas near population centers, the coverage of LiDAR is complete where needed, with the exception of areas east of Cosmopolis, WA- such as the city of Montesano.

Additionally, with NCLD being at a 30-meter resolution and being over 3-years old, the results of this study will be limited land cover that spans 30m x 30m blocks, which may not accurately represent areas as they exist today. This may or may not include temporary clearings in forest areas, failing to account for new developments since the data was collected, or recent changes to land use that may be smaller than 30-meters, which would not be captured.

Understanding this, the results of the study may be different once newer or higher resolution data is acquired and processed through the *Assembly Areas Model*. Considering the frequent changes to land, it is recommended that this study be conducted at least every 3-5 years to stay up to date.

[9] LEP Communication Planning Framework. 2018. Emergency Management Division, WA Military Department.

3 Data Preparation

Once the required data was downloaded, it was processed for analysis. We will briefly discuss how this data was prepared and then will proceed with how analysis was conducted.

3.1 Vector Data

When preparing data, the best practice is to first created a file geodatabase with feature datasets classified for appropriate data storage. For this project, the coordinate system was set to NAD 1983 HARN WA State Plane, South (FIPS 4602, Feet). The following feature datasets were used for classification of vector data:

1. *Admin*
2. *Hydrology*
3. *Transportation*
4. *Tsunami*

Like most sources, when downloading vector data from Grays Harbor County, it was packaged in a zip file, which after unzipping, was formatted as a shapefile. From here, each shapefile needed to be imported as a feature class into one of the four feature datasets listed above. This is to ensure proper data storage and organization. Through the import process, vector data was reprojected into the coordinate system of the hosting feature dataset.

This being considered, all administrative boundaries, such as population centers, urban areas, and county jurisdictions, were imported into *Admin;* water features such as wetlands, water bodies, rivers, and lakes, were imported into *Hydrology;* roads, streets, and highways were imported into *Transportation*; and all features related to tsunami planning, such as the inundation zones and current assembly areas, were imported into *Tsunami.*

Additionally, due to limitations on the extent of the inundation zone for the L1 scenario, which is cut off just north of Ocean Shores and east of Cosmopolis, the older inundation zone (1A w/ Asperity) was used to cover the data gaps. This resulted in a *combined inundation zone* where all areas north of Ocean Shores would be measured against 1A (w/ Asperity) scenario, while all other areas would be measured against the L1 scenario.

3.2 Raster Data

The 2016 NLCD was downloaded as an .img file (15.68 GB), which covered the entire contentinal United States. This raster was first clipped to the extent of Grays Harbor County, reducing the file size from 15 GB to less than 20 KB, and then reprojected in to NAD 1983 HARN WA State Plane, South (FIPS 4602, Feet). The output of this process was imported directly into the geodatabase as a raster dataset.

The 2009 FEMA LiDAR was downloaded as 30 individual tiles (5.66 GB) that were stitched together into a mosaic dataset, and then clipped to the extent of Grays Harbor County by using the processing extent within the environment settings. This reduced the file size to 4.74 GB and was then imported directly into the geodatabase as a single raster dataset.

3.2 Model Builder

Following data preparation, a *Toolbox* was created within the geodatabase with a new model titled *Assembly Areas Model* (*see Fig 1, pg. 14*), which was later developed into the automated workflow that will be discussed in section 4.2.

---

4 Spatial Analysis

With all required data in order, we then proceeded to geoprocessing. In this section, we will review the suitability criteria used for the selection of assembly areas, the workflow used to generate results, and the process of enriching these results with 2019 ACS population data.

4.1 Suitability Criteria

In order to determine what to look for in a suitable assembly area, we gathered feedback from stakeholders, which included members of the State and Grays Harbor County level Emergency Management Teams, local Police and Fire Departments, as well as representatives from the National Parks Service (NPS), Washington State Parks, and prominent businesses in the area, such as the Weyerhaeuser Company. Once there appeared to be a consensus upon what was considered to be an ideal location, we translated these characteristics into measurable criteria that could be quantified and represented in terms of spatial data properties. Below are the eight criteria that were used for this analysis. The bolded subtitles represents the stakeholder value and the italicized metric is the translated spatial criteria.

4.1.1 Criterion 1 - Outside of the Inundation Zone

Elevation > 20 meters above sea level

The first criterion excludes all areas below 20 meters because a tsunami wave will not breach this height. However, this does not account for the potential drop in elevation in an L1 Scenario. With this, all areas within inundation zone will also be excluded.

4.1.2 Criterion 2 - No Trees

Land cover is open space, barren, grassland, or pasture

The second criterion excludes all areas with tree cover. Areas without trees are desirable because the costs of clearing trees in order to make space is expensive. So locations that are *ready* in the present state are considered ideal. To select these areas, we used the following grid codes from the NCLD:

Open Developed Space (21) - areas with a mixture of some constructed materials, but mostly vegetation in the form of lawn grasses. Impervious surfaces account for less than 20% of total cover. These areas most commonly include large-lot single-family housing units, parks, golf courses, and vegetation planted in developed settings for recreation, erosion control, or aesthetic purposes.

Barren (31) - areas of bedrock, desert pavement, scarps, talus, slides, volcanic material, glacial debris, sand dunes, strip mines, gravel pits and other accumulations of earthen material. Generally, vegetation accounts for less than 15% of total cover.

Grassland (71) - areas dominated by gramanoid or herbaceous vegetation, generally greater than 80% of total vegetation. These areas are not subject to intensive management such as tilling, but can be utilized for grazing.

Pasture (81) - areas of grasses, legumes, or grass-legume mixtures planted for livestock grazing or the production of seed or hay crops, typically on a perennial cycle. Pasture/hay vegetation accounts for greater than 20% of total vegetation.

4.1.3 Criterion 3 - Flat

Slope gradient is <= 5%

The third criterion is all areas must be less than or equal to a 5% slope gradient, which is equivalent to a 2.86° incline. This was for many considerations, such as accessibility for the elderly or disabled populations, navigability, and the cost of leveling ground. Per the U.S. Military[10], areas with a slope greater than 7% are not recommended for helicopter landing zones; the National Wildfire Coordinating Group recommends a slope under 6%[11]; and per the United Nations[12] (UN), areas with slope greater than 6% are not considered suitable refugee camp sites. Therefore, a maximum of 5% slope is a good conservative option.

4.1.4 Criterion 4 - Not Environmentally Protected

Not a wetland

The fourth criterion is that areas must not be a wetland. Although there may be more areas that are designated as environmentally protected, wetlands were adopted as a primary feature for this requirement not only because it is scalable through the NLCD, but acquisition of protected lands can be made difficult when looking at the diversity of protection levels across the conservation spectrum. Further, wetlands are simply poor for trafficability and are heavily protected across the United States.

When first conducting this analysis, the wetlands used were derived directly as a shapefile from the Grays Harbor County website. However, wetlands were later derived from the NLCD

[10] Helicopterborne Operations Manual, US Marine Corps. 2016.
[11] NWCG Standards for Helicopter Operations. 2019.
[12] UNHCR Emergency Handbook, 2015.

because after comparing the two versions, the NLCD had a greater extent represented than the vector data provided by the county; likely due to the 30-meter resolution. For this reason, it was decided to use to NCLD instead of the data provided by Grays Harbor County because (1) the NLCD was the more conservative option, and (2) it was more scalable, being one less data input required for the *Assembly Areas Model (see Fig. 1, pg 14)*. To select these areas, we used the following grid codes from the NLCD:

Wood Wetlands (90) - areas where forest or shrubland vegetation accounts for greater than 20% of vegetative cover and the soil or substrate is periodically saturated with or covered with water.

Emergent Herbaceous Wetlands (95) - Areas where perennial herbaceous vegetation accounts for greater than 80% of vegetative cover and the soil or substrate is periodically saturated with or covered with water.

4.1.5 Criterion 5 - Accessible by Road

Area is within 500 meters of a paved road

The fifth criterion was that areas need to be within 500 meters of a paved road. In order to prevent the selection of areas that are isolated, accessibility by road was an important consideration. In particular, we limited our analysis to *paved* roads, which intentionally excluded the labyrinth of forest roads throughout Grays Harbor County- not only because they are so abundant, but because they are greatly limited in capacity to move large volumes of traffic, and are highly variable in maintenance and condition. The input for this feature was a direct copy of the shapefile acquired from the Grays Harbor County website.

4.1.6 Criterion 6 - Close to Population Centers

Area is within 1-mile of a developed area

The sixth the criterion was that areas must be within 1-mile of a developed area. This was also the most important and most constricting condition. Although determining what constitutes as being ‘close’ can be highly variable depending on the situation, the Grays Harbor Emergency Management Team felt that a 1-mile proximity was the maximum acceptable distance for evacuees, especially for an L1 scenario, which may only permit 15-20 minutes. This measure is also aligned with the walking speeds outlined in the Washington DNR’s Walking Maps.

Initially, city limits, as they were provided from Grays Harbor County, were used to draw this 1-mile buffer, but this excluded several populated areas between the larger cities, and so proved to be problematic. We then adopted the developed areas from the NLCD as a more accurate measure for where people were living, and this proved to be not only more accurate, but much more scalable given that it was one less data input that would be required. To select these areas, we used the following grid codes from the NLCD:

Developed, Low Intensity (22) - areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 20% to 49% percent of total cover. These areas most commonly include single-family housing units.

Developed, Medium Intensity (23) - areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 50% to 79% of the total cover. These areas most commonly include single-family housing units.

Developed, High Intensity (24) - highly developed areas where people reside or work in high numbers. Examples include apartment complexes, row houses and commercial/industrial. Impervious surfaces account for 80% to 100% of the total cover.

4.1.7 Criterion 7 - Public Land

Parcel is federal, state, county, city, or tribal owned

The seventh criterion was that the area needed to be public land. In order for the emergency managers to designate a given space as an evacuation assembly area, the area cannot be privately owned, which would require additional bargaining with the owner, and possibly a lease arrangement, which can be both expensive and tedious to manage. For this reason, ideal locations were decided to be those that the government already owned. For the purpose of this study, tribal lands in trust were also included as being suitable.

To separate privately owned lands from publicly owned lands, we leveraged the parcel data provided by Grays Harbor County[13], which included revenue exempt codes for each parcel. The exempt codes used was 010; all other parcels were considered privately owned:

Revenue Exempt Code (010) - *All public property*, which includes:

- State
- Cities
- Public Schools
- Fire Districts
- Ports
- PUD
- Indian Trusts
- Public Libraries

Disclaimer: Grays Harbor County Assessor's office recently stopped using these exempt codes. They will remain in the attribute table of the GIS data provided by Grays Harbor County, but the field will no longer be updated/populated. Instead, the Assessor's Office is only maintaining a record of either YES or NO for being an exempt property, which may prove to make querying for public land more difficult in the future. Contact the County GIS department for assistance if necessary.

4.1.8 Criterion 8 - Large Area

Area is > 1 acre

The eighth, and last criterion is that the area needed to be larger than one acre, or rather, large enough to hold the population that would be evacuating to it. Considering this, we set the lower limit to 1 acre, not only to improve geoprocessing speeds and to remove the erroneous slivers generated by the selection process, but 1 acre was also deemed the minimum area requirement for several communities throughout Grays Harbor County. Additionally, this size requirement also helps reduce the effects of having lower resolution NCLD data, which is limited to 30 meters.

4.2 Site Selection Analysis

In order to account for all of the suitability criteria mentioned above, the next section will review the step-by-step process used to conduct the site selection analysis. Steps have been aggregated into generalized tasks, as there are 24 separate geoprocesses within the *Assembly Areas Model* (*see Fig. 1, pg 14*), which has successfully automated the entire process outlined for repeatability and scalability purposes. Each step will list the tools used in the sequential order performed by the model.

[13] Provided upon request by the GHC GIS Mapping Office

Fig. 1 - Assembly Areas Model

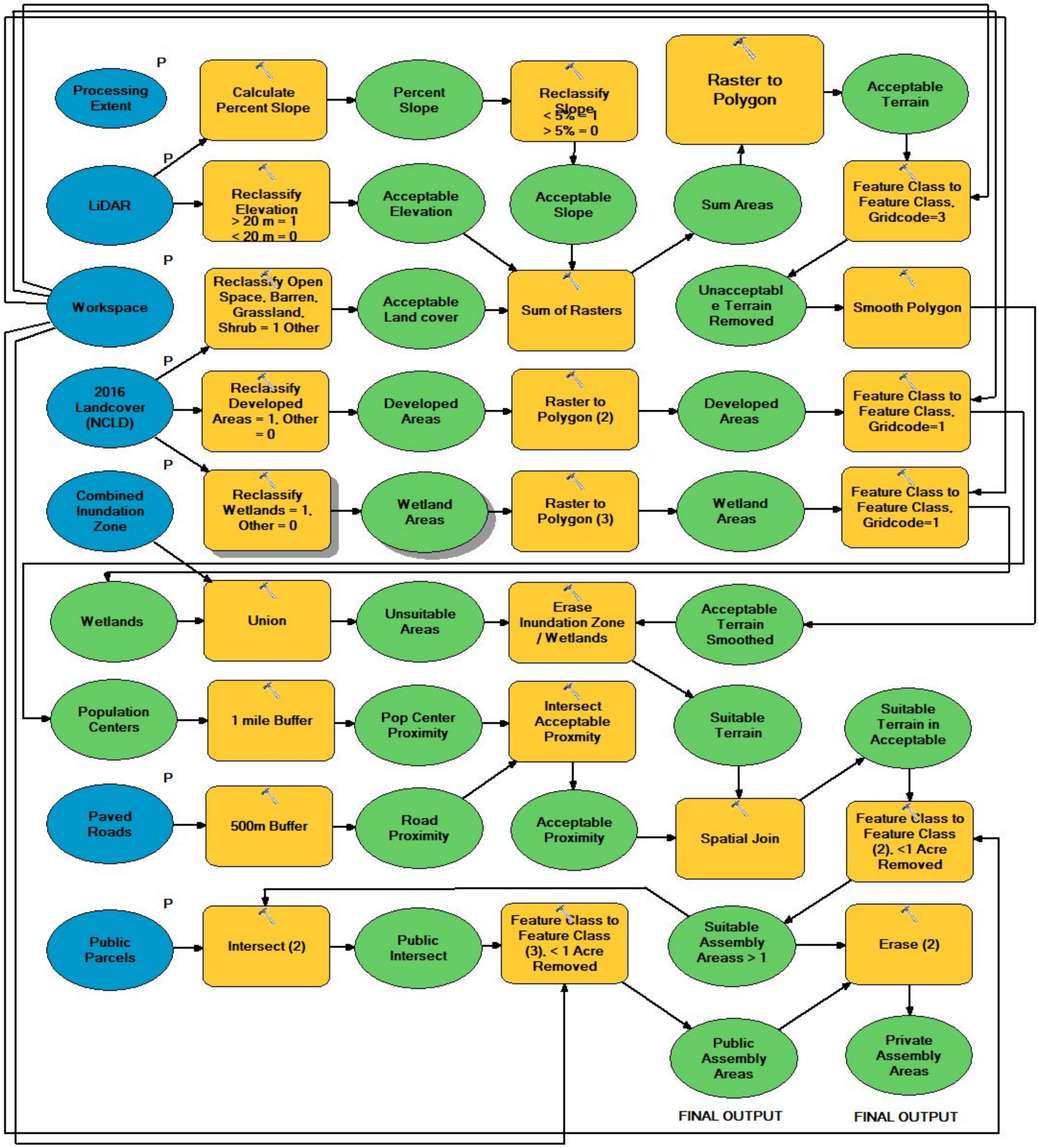
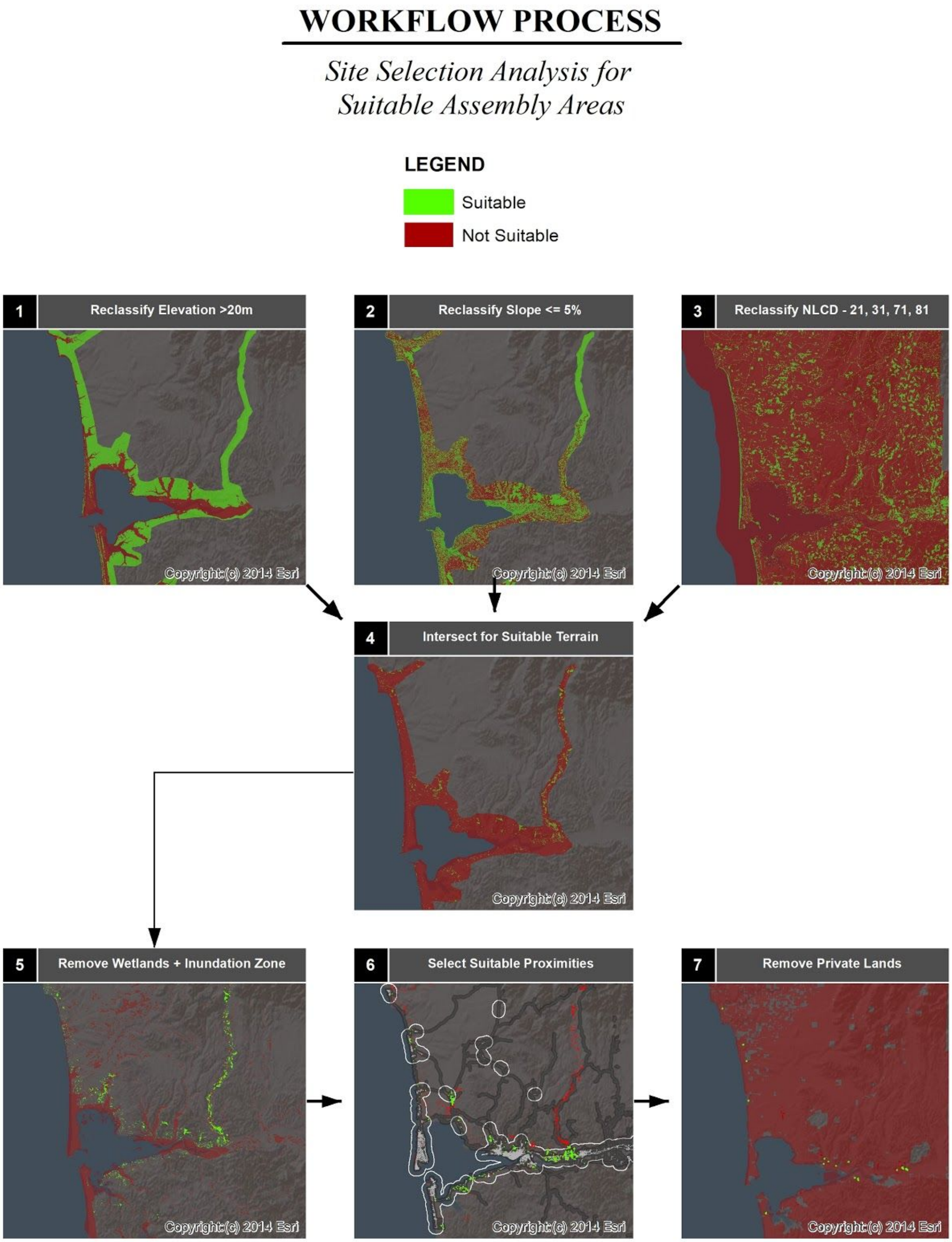


Fig. 2 - Step-by-Step Workflow



For data management purposes, when using this model, it is recommended that the workspace be set to a new file geodatabase where the output of each iteration can be stored separately, not over written, with intermediary data that can be reviewed independently in the event of unexpected errors or changed variables.

4.2.1 - Step 1: Reclassify Elevation >20m

To begin, we first identified all areas that were greater than 20 meters above sea level *(see Step 1, Fig 2, pg 15)*. These areas were considered *acceptable*, while all others were considered *unacceptable*. To do this, we use the *Reclassify* (3D Analyst) tool process the LiDAR data into two values:

1 = Acceptable (> 20m)
0 = Unacceptable (< 20m)

Because LiDAR is measured in meters, all values greater than 20 were reclassified as [1] and all values less than 20 were reclassified as [0].

4.2.2 - Step 2: Reclassify Slope <=5%

Next, we identified all areas that were either equal to, or less than 5% slope. *(see Step 2, Fig 2, pg 15)*First, we calculated slope using the *Slope* (3D Analyst) tool, set to percent, then like elevation, we used the *Reclassify* (3D Analyst) tool to process values 0-5 as [1], and all other values as [0].

1 = Acceptable (0 - 5)
0 = Unacceptable (> 5)

Note: LiDAR must be in a projected coordinate system to work properly as the unit of measurement needs to be *meters*, otherwise the *Z-value* in the tool will throw an error.

4.2.3 - Step 3: Reclassify NLCD

Next, we identified all areas that met the suitable criteria for land cover, which were determined to be open developed space (21), barren (31), grasslands (71), and pastures (81) *(see Step 3, Fig 2, pg 15)*. Like the steps before, we used the *Reclassify* (3D Analyst) tool to process values 21, 31, 71, and 81 as [1] and all other values as [0].

1 = Acceptable (21, 31, 71, 81)
0 = Unacceptable (All Other Values)

4.2.4 - Step 4: Intersect for Suitable Terrain

With suitable elevation, slope, and land cover now determined, we then added these rasters together, a process known as Map Algebra, using the *Raster Calculator* (Spatial Analyst) tool, where the values of each overlapping cell were added together *(see Step 4, Fig 2, pg 15)*. Cells with the value of [3] represented locations that meet all three criteria for elevation, slope, and land cover; all other values meet either zero, or only one or two of those conditions. Values equal to [3] are then considered to be suitable terrain for assembly areas.

3 = Acceptable (Elevation, Slope, Land Cover)
0 - 2 = Unacceptable (All Other Values)

In order to proceed with further geoprocessing, we then converted this suitable terrain from a raster dataset into a vector feature class so that it may be compatible with the remaining data. To do this, we used the *Raster to Polygon* (Conversion) tool with *simplify* checked; this was to reduce the number of vertices within the generated feature class, which greatly helped with geoprocessing speeds.

Once the polygon was generated, we then removed all other features with a Grid Codes [0-2] by using the following definition query within the *Feature Class to Feature Class* (Conversion) tool.

Definition Query:
gridcode = 3

The output was a new feature class that only contained suitable terrain (elevation, slope, NLCD). To clean this data, we then used the *Smooth Polygon* (Cartography) tool with a 10m tolerance to help the features appear less rigid since they were generated from the grids of a raster dataset. It should be noted that by smoothing polygons, there was some loss in data due to the change of shape, but the areas that may have been excluded through this process are considered to be an acceptable loss due to it being just a fraction below 1 acre in size. There were not many.

4.2.5 - Step 5: Remove Wetlands / Inundation Zone

With the suitable terrain processed, we then paused to prepare the wetlands for use by separate them from the NCLD and then converting the values to vector format *(see Step 5, Fig 2, pg 15)*. To do this, we used the *Reclassify* (3D Analyst) tool to process the NCLD in to acceptable and unacceptable areas just as before; where values 90, 95 were reclassified to [1], and all other values were reclassified to [0].

1 = Acceptable (90, 95)
0 = Unacceptable (All Other Values)

The resulting raster was then converted to a polygon using the *Raster to Polygon* (Conversion) tool, and then queried using the *Feature Class to Feature Class* (Conversion) tool to remove all areas that were not wetlands.

Definition Query:
gridcode = 1

Additionally, we also merged the inundation zone with this new wetlands feature class using the *Union* (Analysis) tool to create a single zone that represented all areas that were *not* suitable. Once created, we then used the *Erase* (Analysis) tool to remove the wetlands and inundation zone from the suitable terrain feature class.

The result was all locations that meet the elevation, slope, and land cover criteria, which were also not a wetland, or located within the inundation zone.

4.2.6 - Step 6: Select Suitable Proximities

Of these remaining areas, we then refined our selection by identifying those areas that were within 1-mile of a developed area and within 500 meters of a paved road *(see Step 6, Fig 2, pg 15)*.

To do this, we first used the *Reclassify* (3D Analyst) tool process the NCLD into highlighting the only developed areas, in which case values 22, 23, and 24 were reclassified to [1] and all other values were reclassified to [0].

1 = Acceptable (22, 23, 24)
0 = Unacceptable (All Other Values)

Just as before, this output raster was then converted to a polygon using the *Raster to Polygon* (Conversion) tool, and queried to removed all areas that were not developed using the *Feature Class to Feature Class* (Conversion) tool. Additionally, during this process, we also removed all the areas that are less than 1 acre (45,000 square feet, slight more than an acre) as this limited the consideration to areas that were equivalent to a small town.

Definition Query:
gridcode = 1 AND Shape_Area > 45000

Once a new feature class had been created with developed areas identified, we then drew a 1-mile buffer around each feature using the *Buffer* (Analysis) tool, with polygons dissolved, to create a single output feature. We then paused to create a 500 meter buffer around the paved roads using the same *Buffer* (Analysis) tool, with polygons dissolved.

With buffers created for both developed areas and roads, we then used the *Intersect* (Analysis) tool on both buffers to highlight all areas that are both within a 1-mile developed area and 500 meters of a paved road. With this intersect, we selected the remaining suitable locations; where if any of these areas touch the intersected buffer, it will meet the proximity criteria.

Within ArcMap this process is called *Select by Location*, however, within ModelBuilder, this process cannot be performed so simply. Instead, we created a workaround by using the *Spatial Join* (Analysis) tool to add the attribute table of the intersected buffer to the remaining suitable terrain features, and queried for all areas that contained acceptable proximity marks for both developed areas and roads by using the *Feature Class to Feature Class* (Conversion) tool. Features with a grid code value of [1] listed under the added fields Pop_Buff_1m and Road_Buff_500m were selected; and any areas less than 1 acre were also removed.

Definition Query:
FID_Pop_Buff_1m =1 AND
FID_Road_Buff_500m =1 AND Shape_Area >
45000

The result of this query was a new feature class with areas that met all the suitability criteria- with the exception of public land ownership.

4.2.7 - Step 7: Remove Private Lands

The last step for identifying suitable assembly areas was discerning which of the remaining areas were located on public land *(see Step 7, Fig 2, pg 15)*. To do this, we used the *Intersect* (Analysis) tool between the previous feature class and the county parcel data to add land ownership information to remain suitable locations. Using the *Feature Class to Feature Class* (Conversion) tool, we queried out public lands by using the exempt code 010, which is associated with all public lands; and all other values are marked as private[14].

010, 011 = Public Land
All Other Values = Private Land

The final output provided us with all locations within Grays Harbor County that are:

1. Higher than 20 meters elevation
2. Less than, or equal to 5% slope
3. Land cover that is developed open space, barren, grassland or pasture
4. Not a wetland AND not in the inundation zone
5. Located within 500 meters of a paved road
6. Located within 1 mile of developed area
7. Public land
8. Larger than 1 acre

4.3 GeoEnrichment of Population Data

Once the final assembly areas were identified, the next step was to review the population totals within proximity of these locations, to include:

1. How many people live within the inundation zone?

2. Of those who live within the inundation zone, how many are considered highly vulnerable (disabled, Ages 0-4, non-English speaking)?

3. Of those who live within the inundation zone, how many people live within 1-mile

[14] Provided upon request by the GHC GIS Mapping Office.

of an these assembly areas? And how many do not?

4. Of those who live within 1-mile of an assembly area, how many can fit in the space available?

To answer these questions, we leveraged the GeoEnrichment service provided by ESRI, which takes any polygon and adds a user's choice of fields within the attribute table. This process *enriches* the data with information about that location, to include population. For our purposes, we selected the following fields from the 2019 American Community Survey:

- 2019 Total Population
- Households with 1+ Disabled
- Ages 0-4
- Ages 5-7 Non English Speaking (Spanish)
- Ages 18-64 Non English Speaking (Spanish)
- Ages 65+ Non English Speaking (Spanish)

However, before enriching the data, we first prepared the polygons to represent exactly which areas to pull data for. In order to answer the four questions listed above, we created three new feature classes to just for this purpose. We will review them briefly in the next sections.

4.3.1 Tsunami Inundation Zone

How many people live within the inundation zone (combined)?

To answer the first question, we used inundation zone as the feature class to enrich since we needed to know how many in total lived in this area. This layer was enriched with the fields listed above and a new output feature class was created with the populations per feature listed in the attribute table. To collect the total for how many people lived within the inundation zone, we summarized the entries by right-clicking the 2019 Total Population field and selecting *Statistics.* A sum of all values was provided.

4.3.2 Vulnerable Demographics

Of those who live within the inundation zone, how many are considered highly vulnerable (disabled, Ages 0-4, non-English speaking)?

To answer the second question, we summarized each of the other fields using the same method; by right-clicking *Statistics* and collecting a sum of all values..

4.3.3 1-Mile from Public Assembly Area

Of those who live within the inundation zone, how many people live within 1-mile of a public assembly area? And how many do not?

To answer the third question, a second feature class was made by creating a 1-mile *Buffer* (Analysis) around each of the assembly areas identified. We then created an *Intersect* (Analysis) between this 1-mile buffer and the inundation zone to outline only those areas that are within both features. This intersected buffer was then enriched just like the previous feature classes, and the output contained population data for each of the fields selected. Totals were then collected by summarizing the fields with *Statistics.*

To determine how many, of those who live within the inundation zone, currently live beyond 1-mile from a public assembly area, we subtracted the totals of this feature class from the totals of the entire inundation zone.

4.3.4 Capacity of Public Assembly Areas

Of those who live within 1-mile of a public assembly area, how many can fit in the space available?

To answer the fourth question, we needed to compare the population totals of those within 1-mile of public assembly area to the size of the assembly area they would be evacuating to.

To do this, we needed to determine how to measure people per acre. So first, we confirmed with stakeholders that we were to assume a distance source event, which means:

- 4 hours to evacuate
- Residents could drive to these locations
- Roads would be intact

With these assumptions, we took the average number of people per vehicle from the 2017 National Household Travel Survey[15] (1.67), multiplied it by the square footage of a standard 18’ x 9’ parking space, per the Washington Department of Transportation’s Roadside Manual 25-30[16], (162 sq ft), and divided 43,560 by it to convert to acres. Using this method, we determined a maximum number of people per acre to 449.

$$X = P / 449$$

X = Minimum acres required
P = Population
449 = Persons per acre

If this was depicted visually, you would see one square acre, gridlocked with vehicles, with 1-2 people per car. In reality, there may be many more people per vehicle in a distant source event, and it is very unlikely that each vehicle would organize itself into perfect rows and columns, especially without driving space between. A more robust plan would account for aisles and a certain percentage of each assembly area to serve as a staging area for supplies and coordination space. However, understanding this, the metric serves as a baseline that provides a generalized idea about how many people each area could hold, and serves as a common denominator by which to compare the size of assembly areas to each other in terms other than acres, which can be useful in emergency management discussions.

5 Results

We will now proceed to the results of the study and report upon public assembly areas that were identified through this process, the population totals and demographics of these areas, and examine the capacity of these locations to accommodate the evacuees immediately surrounding each location.

5.1 Suitable Assembly Areas

From the eight suitability criteria used for conducting the site selection analysis, 17 sites across Grays Harbor County met all necessary conditions. They include 3 schools, 1 park, 2 cemeteries, and 7 areas of undeveloped land. Together, they make up a total 49.11 acres, which is enough space for 22,000 people, assuming 449 people per acre *(see Fig. 4, pg 21)*.

Fig. 3 - Acres by Land Use

Qty	Land Use	Acres	%
3	School	8.81	17.9%
1	Park	2.00	4.1%
2	Cemetery	11.85	24.1%
7	Undeveloped Land	26.45	53.9%
17	**N/A**	**49.11**	**100%**

[15] Summary of Travel Trends 2017 National Household Travel Survey. Federal Highway Administration. US DOT. 2017.
[16] WA DOT Roadside Manual (M25-30). 2003.

Fig. 4

Assembly Area Land Use Type

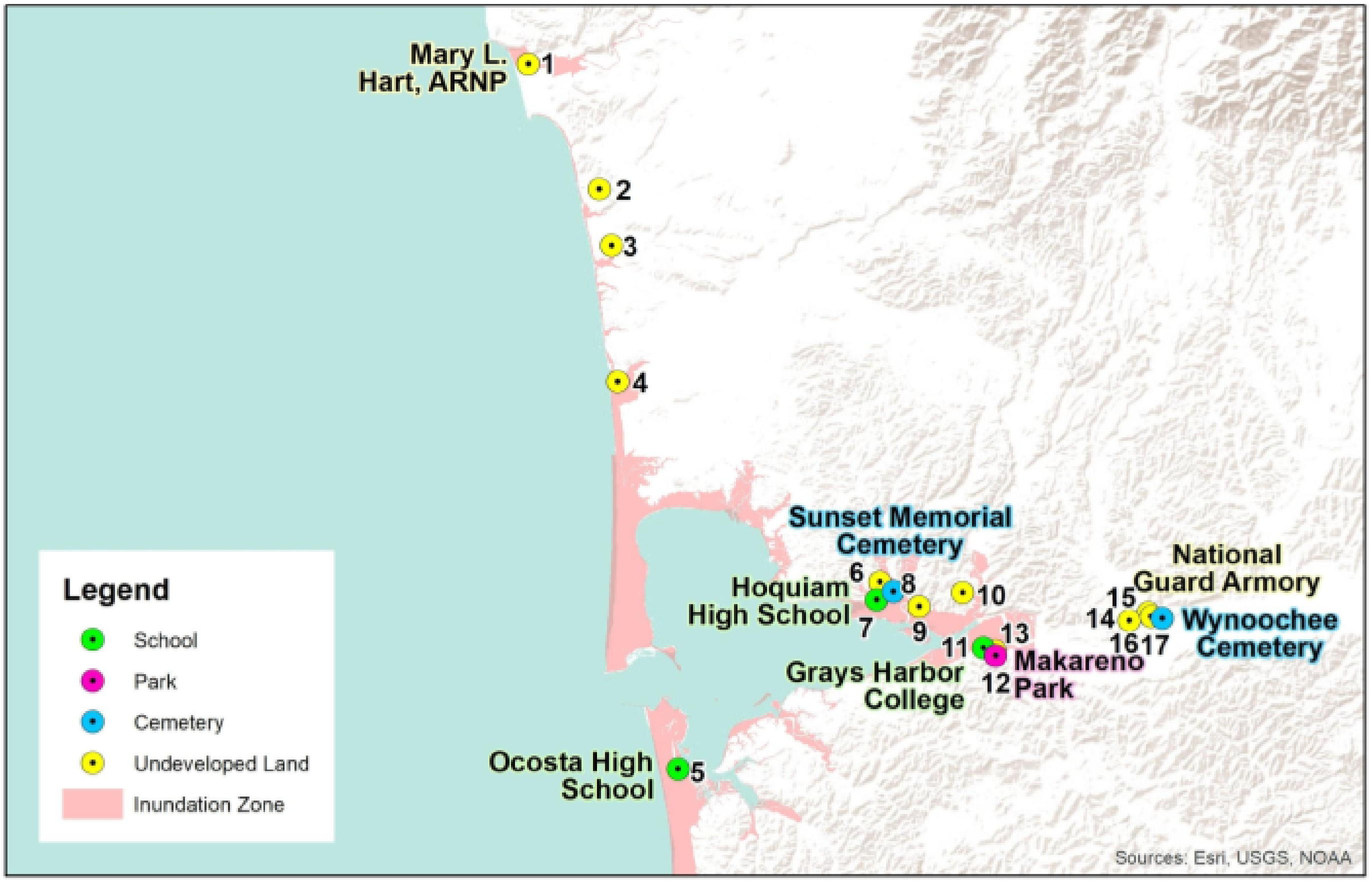


Fig. 5

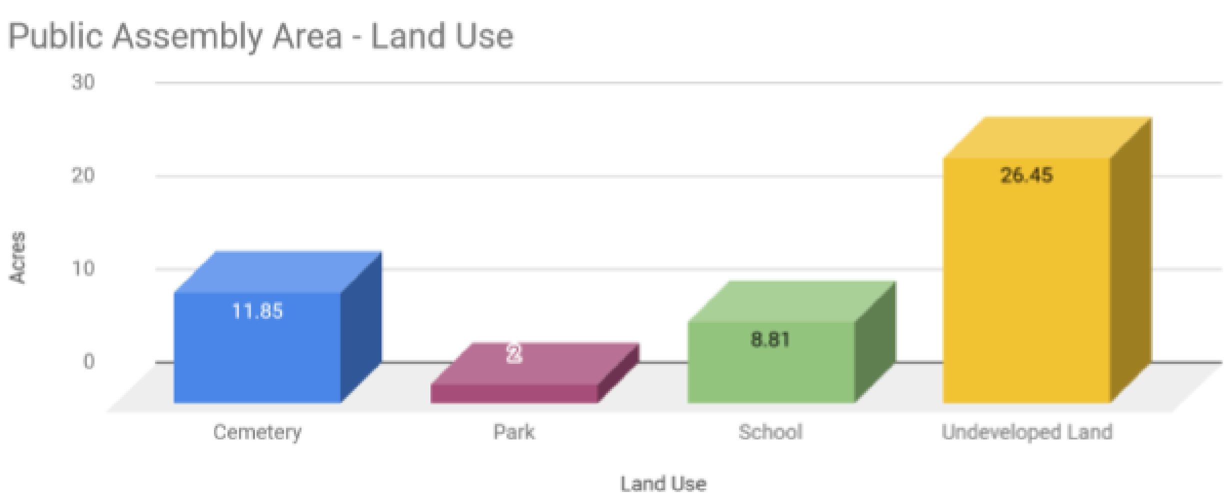


Fig. 6 - Acres by City

Qty	City	Acres	%
1	Taholah, WA	2.74	5.6%
1	Moclips, WA	1.32	2.7%
1	Pacific Beach, WA	2.00	4.1%
1	Copalis Beach	2.46	4.1%
1	Westport, WA	5.69	11.6%
4	Hoquiam, WA	5.60	11.4%
3	Aberdeen, WA	4.42	9.0%
1	Cosmopolis, WA	2.02	4.1%
4	Montesano, WA	22.85	46.5%
17	**N/A**	**49.11**	**100%**

5.2 Population Totals

Per the 2019 ACS survey, there are 43,548 people living within the inundation zone, which comprise of over 60% of the entire population of Grays Harbor County *(see Fig 7-8, pg 23)*. Of those who live within the inundation zone, only 35% (15,329) live within a mile of a public assembly area; and of those who live within a mile of a public assembly area, only 16% (7,186) can actually fit within these locations, assuming 449 people per acre *(see Fig 9-10, pg. 24)*. In other words, only 16% of the total population that lives in inundation zone can leverage one of the proposed 17 public assembly areas in the event a major tsunami. Consequently, this also means that 36,502 people (84%) are in need of some other form of safety provision; either a vertical evacuation structure (VES) or suitable private lands.

5.3 Vulnerable Demographics

If we take into account the vulnerable populations that live within the inundation zone, there are 7,570 households with one or more disabled residents *(see Fig 8, pg. 23)*. Of these, only 69% (5,230) live within a mile of a public assembly are. There are 2,231 children between the ages 0-4 living in the inundation zone, of which only 54% (1,222) live within a mile of a public assembly area; and there are 65 non-English speaking persons (Spanish), of which, 94% live within a mile of a public assembly area.

In total, of the population living within the inundation zone, 22% will likely be in need of special assistance due to a disability (17%), youth (5%), or language barrier (0.01%). Of this vulnerable population, only 66% (6,512) live within 1 mile of a public assembly area.

5.5 Public Assembly Areas

Now that we have seen the overview of results, we will continue by reviewing each of the 17 public assembly areas in more detail, from north to south, then west to east, taking note of their characteristics, size, capacity, and land ownership.

Additionally for each inset, the locations of suitable private lands and suitable shrublands will be included (see Legend), both of which represent potential opportunities for expansion that may exist if additional space is needed. **Note**: The imagery depicted within each of the following insets is from 2013 and may not accurately reflect present conditions.

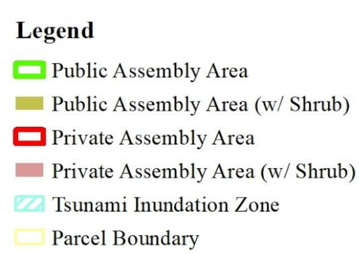


Fig. 7

2019 Population Totals

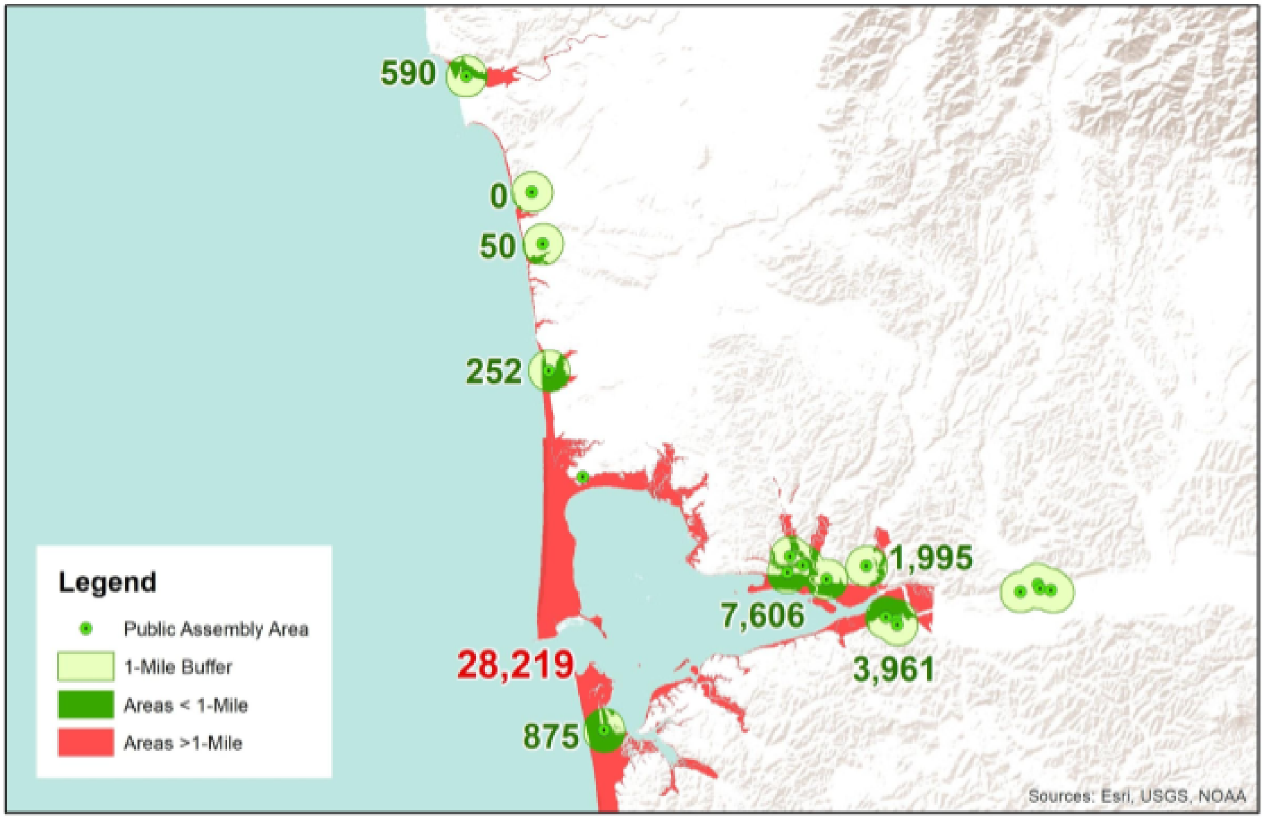


Fig. 8

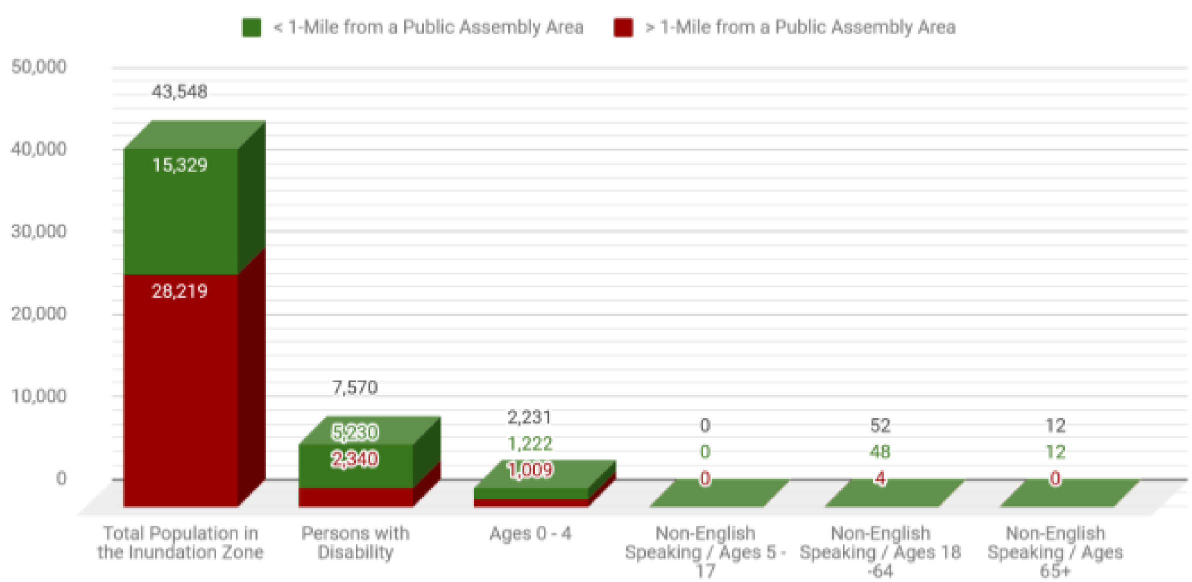


Fig. 9

Assembly Area Capacity *- 449 people per acre*

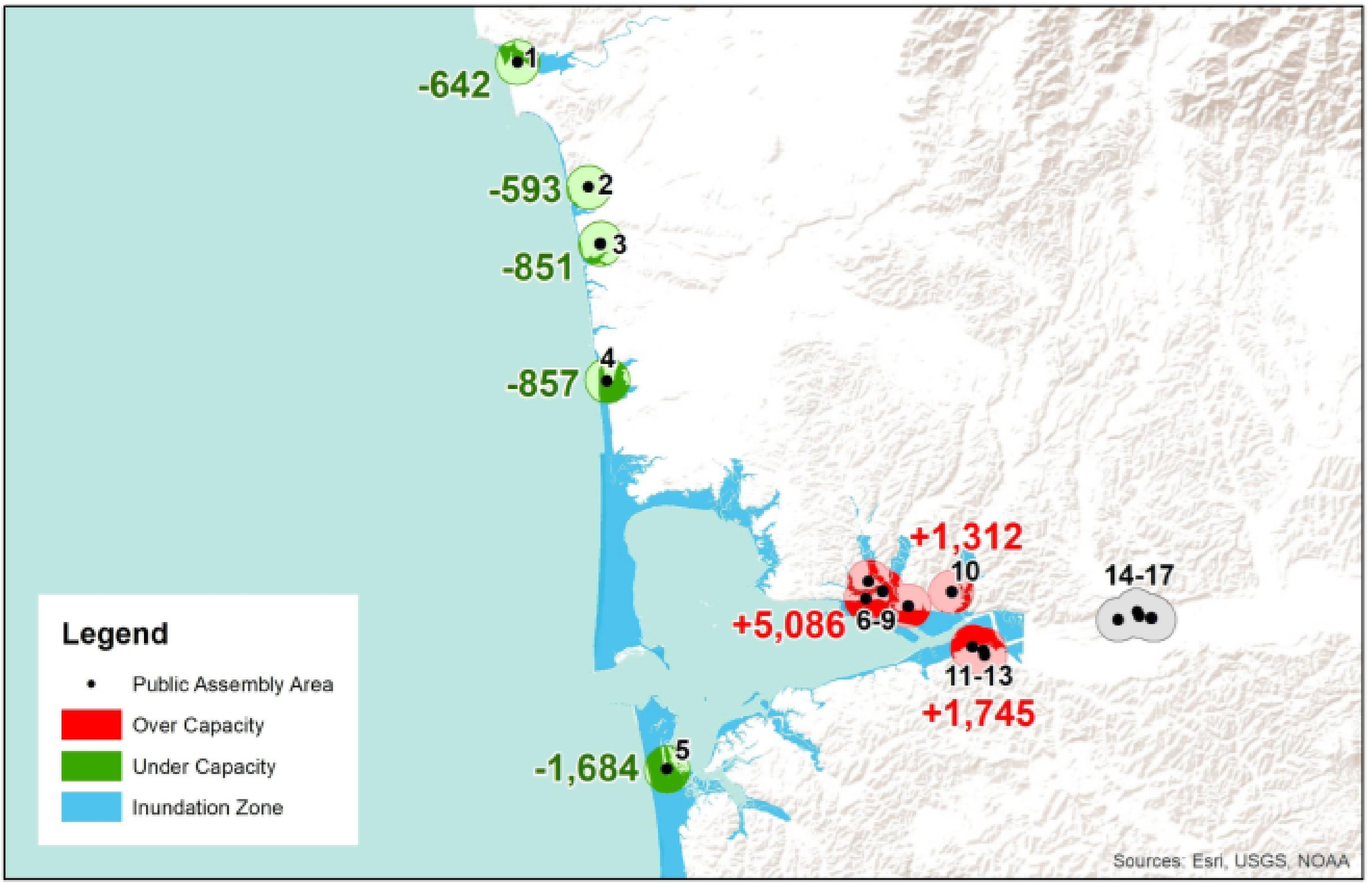
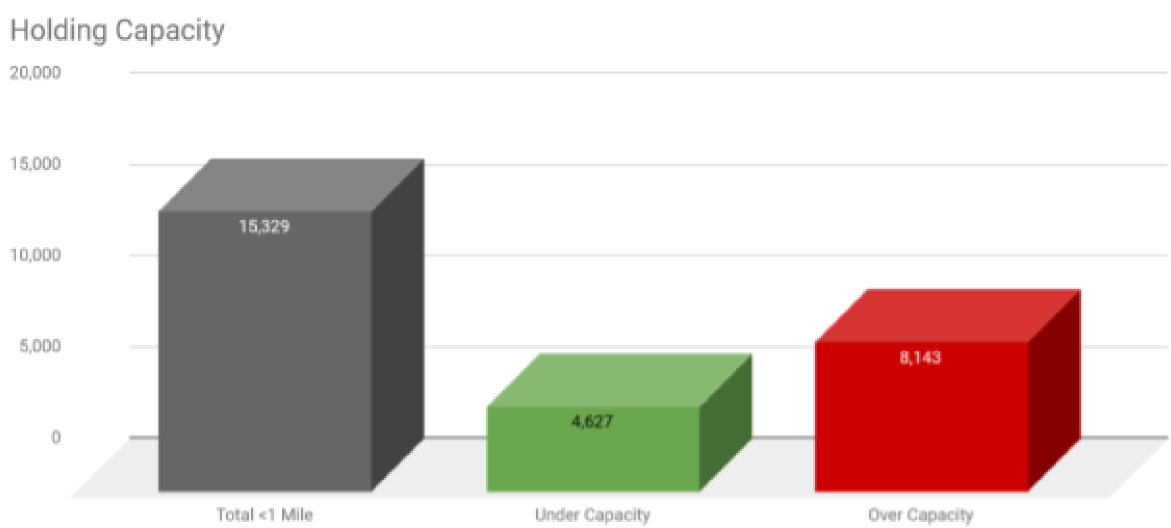


Fig. 10



5.5.1 *Assembly Area 1 - Mary L Hart ARNP*

The first public assembly area is 2.74 acres and is located near the Mary L. Hart Advanced Registered Nurse Practitioner (ARNP) facility in Taholah, WA. The land is tribally owned, and appears to have been cleared of trees within the last few years- for what purpose is unknown.

There are 590 people who live within 1 mile of this location who would need to evacuate in the event of a tsunami. The capacity of this area is 1,231, which leaves enough space for 642 more people *(see Fig. 9, pg 24)*.

5.5.2 *Assembly Area 2 - Undeveloped Land*

The second public assembly area is 1.32 acres of undeveloped land in Moclips, WA, held in Trust with the Quinault Nation. Zero people live within 1 mile of this location and the capacity is 593 *(see Fig. 9, pg 24)*.

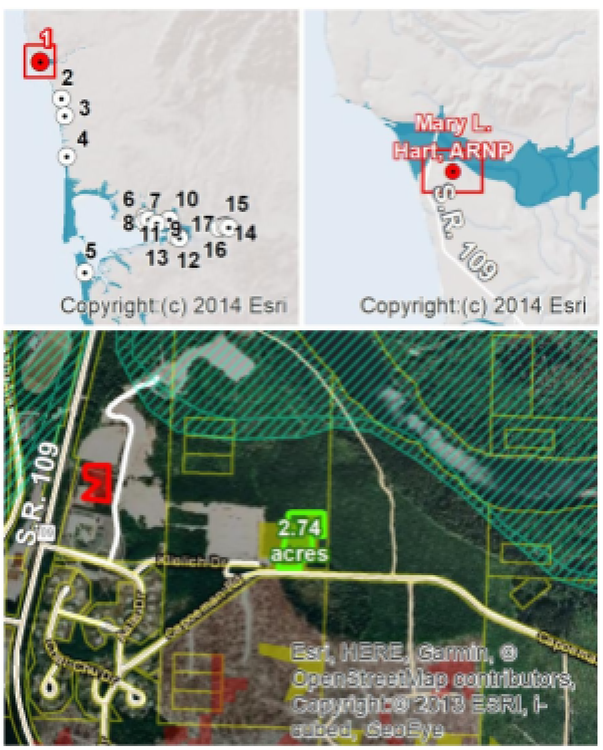


Fig. 11 - Assembly Area 1 - Mary L. Hart ARNP
Taholah, WA / 47.339253, -123.278744

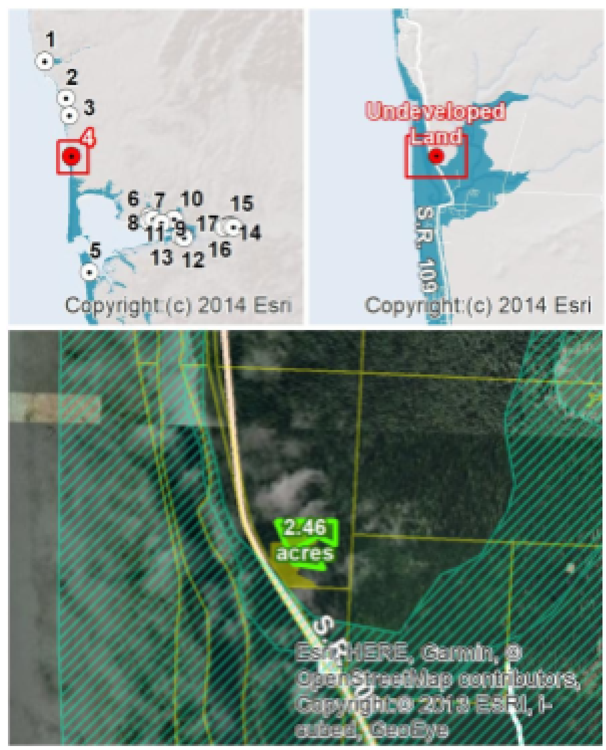


Fig. 12 - Assembly Area 2 - Undeveloped Land
Moclips, WA / 47.256322, -124.20213

5.5.3 Assembly Area 3 - Undeveloped Land

The third public assembly area is exactly 2 acres of undeveloped land located in Pacific Beach, WA. The land is owned by the State of Washington and is a small part of much larger forestland parcel. There is a possibility that this area is a recent forest clearing that may grow back over the next few years, depending on timber development.

There are 50 people who live within 1 mile of this location who would need to evacuate in the event of a tsunami. The capacity of this area is 901, which leaves enough space for 851 more people *(see Fig. 9, pg 24)*.

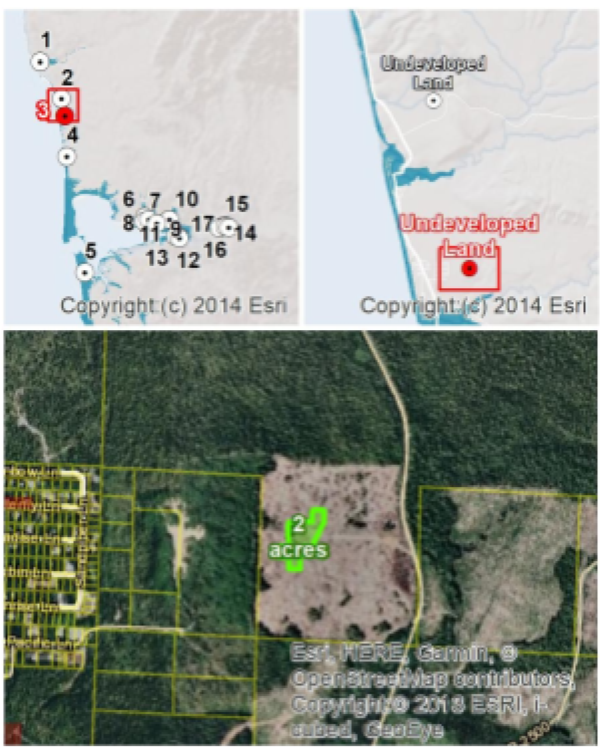


Fig. 13 - Assembly Area 3 - Undeveloped Land
Pacific Beach, WA / 47.21839, -124.187766

5.5.4 Assembly Area 4 - Undeveloped Land

The fourth public assembly area is 2.46 acres of undeveloped land located in Copalis Beach, WA. The land is owned by the State of Washington.

There are 252 people who live within 1 mile of this location who would need to evacuate in the event of a tsunami. The capacity of this area is 1,109, which leaves enough space for 857 more people *(see Fig. 9, pg 24)*.

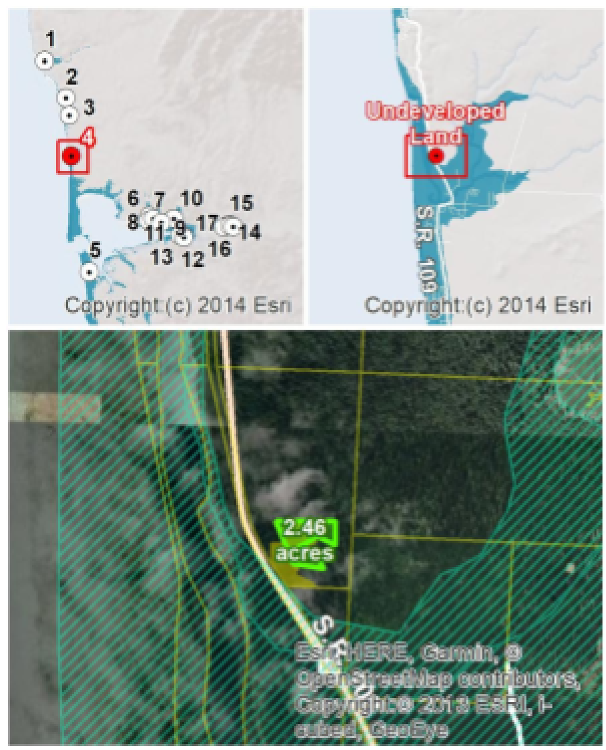


Fig. 14 - Assembly Area 4 - Undeveloped Land
Copalis Beach, WA / 47.125574, -124.175288

5.5.5 Assembly Area 5 - Ocosta H.S.

The fifth public assembly area is the athletic field at Ocosta High School in Westport, WA, which is 5.69 acres with surrounding grassland. The campus is owned by the Ocosta School District #172 and the building itself is also a VES capable of holding 1,000[17] people comfortably.

There are 875 people who live within 1 mile of this location who would need to evacuate in the event of a tsunami; 2,051[18] live in the city of Westport, WA, and the capacity of this area is 2,559. Together, this enough room to hold the entire population of Westport and an additional 1,508 tourists *(see Fig. 9, pg 24)*.

5.5.6 Assembly Area 6 - Undeveloped Land

The sixth public assembly area is 1.15 acres of undeveloped land located in Hoquiam, WA owned by the City. It is located 350 meters from a current assembly area (see landfill). It is unknown if the proposed area is a part of the same landfill.

Due to the close proximity of assembly areas 6 - 9, the total population of those who live within 1 mile of this location is taken together, which is 7,606. The capacity of this area is 518, which leaves a remainder of 7,088 people in the Hoquiam Area unaccommodated *(see Fig. 9, pg 24)*.

Fig. 15 - Assembly Area 5 - Ocosta High School
Westport, WA / 46.996304, -123.906278

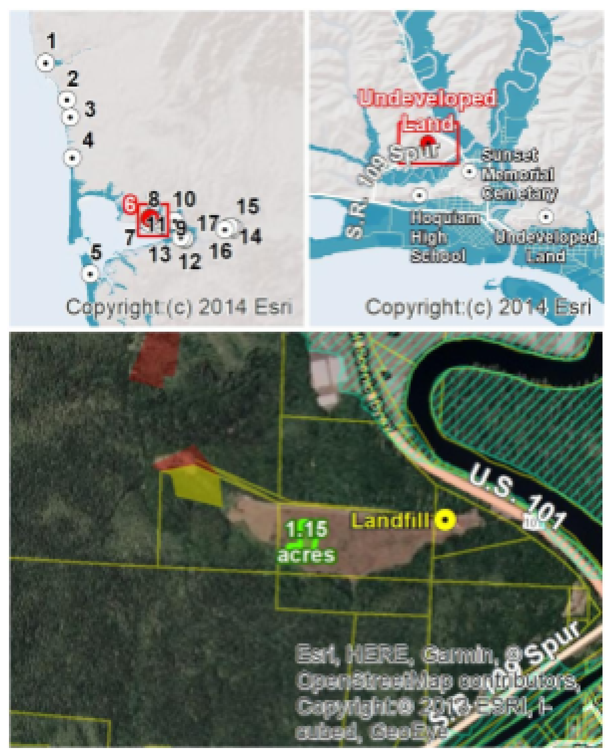


Fig. 16 - Assembly Area 6 - Undeveloped Land
Hoquiam, WA / 46.984393, -123.908651

---

17 The First Tsunami Vertical Evacuation Structure in the United States: Ocosta Elementary School, Washington. Walsh, Schelling, Ash, LeVeque, Adams, Gonzales. University of Washington, Department of Earth and Space Sciences. Published Nov 2018.

18 Data USA's Profile of Westport, WA. Updated 2019.

5.5.7 *Assembly Area 7 - Hoquiam H.S.*

The seventh public assembly area is the baseball field at Hoquiam High School in Hoquiam, WA, which is 1.58 acres with surrounding areas. The land is owned by Hoquiam School District #28, and is already designated as a current assembly area. However, only the open space north of W. Chenault Ave appears to be safe from potential tsunami inundation. The parking lots and the athletic field with a track could be inundated.

There are 7,606 people who live within 1 mile of assembly areas 6-9 who would need to evacuate in the event of a tsunami. The capacity of the baseball field and surrounding areas is 710. When combined with the capacity of assembly area 6, this leaves a remainder of 6,378 people in the Hoquiam Area to address *(see Fig. 9, pg 24)*.

5.5.8 *Assembly Area 8 - Sunset Memorial Cemetery*

The eighth public assembly area is 1.34 acres in Sunset Memorial Cemetery, located in Hoquiam, WA. The land is owned by the by the City and has already been designated as a current assembly area. However, given the cultural significance of the land, it rests upon the County to decide if it remains suitable as a place to evacuate residents in the event of a tsunami.

There are 7,606 people who live within 1 mile of assembly areas 6-9 who would need to evacuate in the event of a tsunami. The capacity of this area is 603. When taken with the combined capacity of assembly areas 6-7, this leaves a remainder of 5,775 people in the Hoquiam Area to address *(see Fig. 9, pg 24)*.

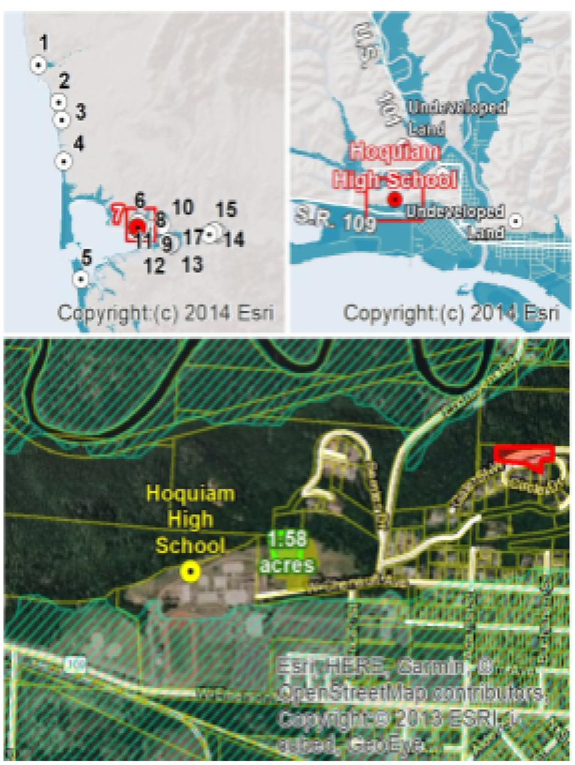


Fig. 17 - Assembly Area 7 - Hoquiam High School
Hoquiam, WA / 46.990261, -123.892202

Fig. 18 - Assembly Area 8 - Sunset Memorial Cemetery
Hoquiam, WA / 46.991535, -123.823483

5.5.9 Assembly Area 9 - Undeveloped Land

The ninth public assembly area is 1.53 acres of undeveloped land located in Hoquiam, WA along Beacon Hill Dr. Although this land is owned by the city, the surrounding land- which is private- is also suitable. However, this area is also known as a high risk area for potential landslides, so it rests upon the county to decide if this location is suitable or not. This location is a good candidate for a FEMA hardening grant to improve viability.

There are 7,606 people who live within 1 mile of assembly areas 6-9 who would need to evacuate in the event of a tsunami. The capacity of this area is 689.

When taken with the combined capacity of assembly areas 6-8, this leaves a total of 5,086 people in the Hoquiam Area that are in need of either a VES, suitable private lands, or shrublands to be cleared *(see Fig. 9, pg 24)*.

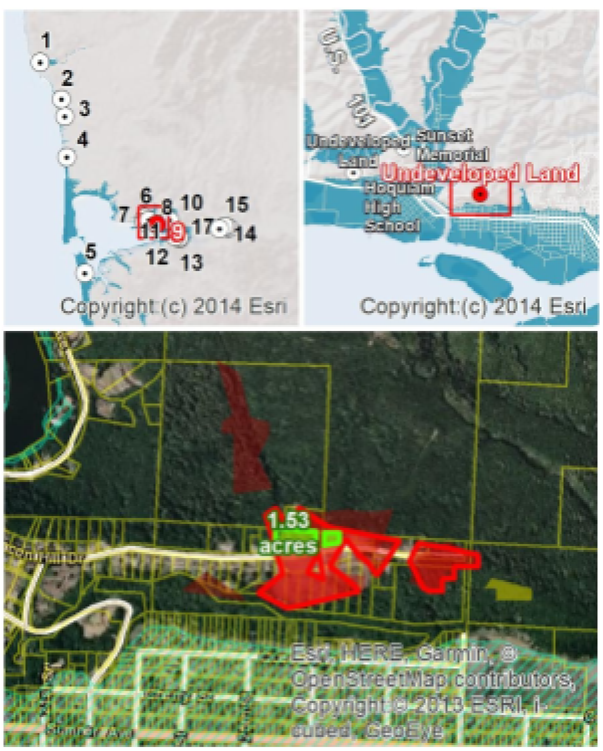


Fig. 19 - Assembly Area 9 - Undeveloped Land
Hoquiam, WA / 46.982615, -123.637974

5.5.10 Assembly Area 10 - Undeveloped Land

The tenth public assembly area is 1.52 acres of undeveloped land located next to a reservoir on 9th Ave in Aberdeen, WA. The land is owned by the city and is located near a residential area.

There are 1,995 people who live within 1 mile of this location who would need to evacuate in the event of a tsunami. The capacity of this area is 683, which leaves a remainder of 1,312 people who are in need of either a VES, suitable private lands, or shrublands to be cleared *(see Fig. 9, pg 24)*.

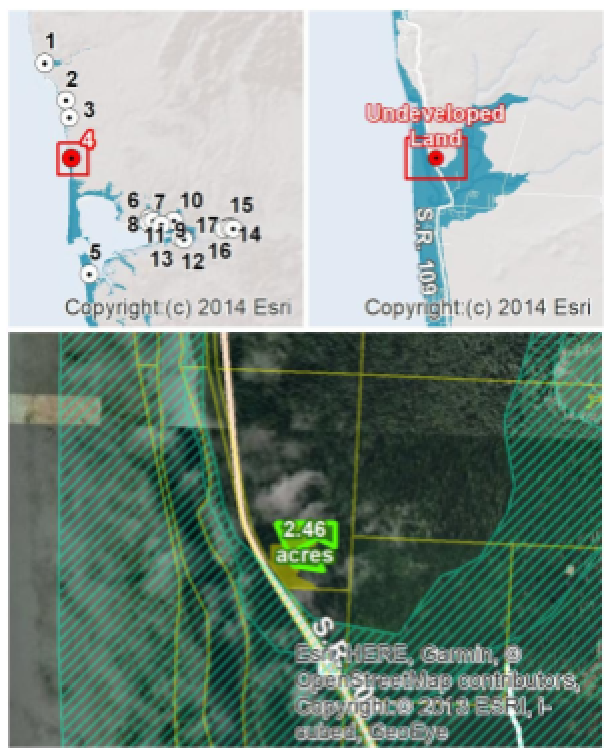


Fig. 20 - Assembly Area 10 - Undeveloped Land
Aberdeen, WA / 46.980713, -123.865961

5.5.11 Assembly Area 11 - Grays Harbor College

The eleventh public assembly area is 1.57 acres of land on Grays Harbor College in Aberdeen, WA. The land is owned by the Grays Harbor College State Board and also exists as a current assembly area. What is worth considering is that this location does not include paved areas, which was not included as part of the original criteria used for this analysis. There are 3,961 people who live within 1 mile of assembly areas 11-13, but this does not account for the number of students who may be attending class who would need to evacuate in the event of a tsunami, nor for some prohibitive topography which might reduce that number during a later route analysis. The capacity of this area is 705, which leaves a remainder of 3,256 people to address in the Aberdeen / Cosmopolis area *(see Fig. 9, pg 24)*.

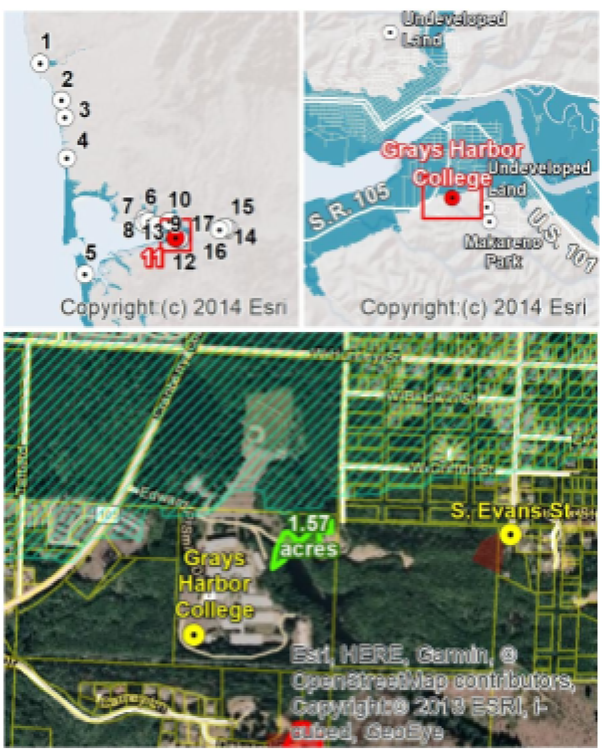


Fig. 21 - Assembly Area 11 - Undeveloped Land
Aberdeen, WA / 46.976827, -123.656603

5.5.12 Assembly Area 12 - Undeveloped Land

The twelth public assembly area is 1.33 acres of undeveloped land in Aberdeen, WA, located behind a residential area along Bell Dr. The land is owned by the Aberdeen School District #5.

There are 3,961 people who live within 1 mile of assembly areas 11-13, and the capacity of this area is 601. When combined with the capacity of assembly area 11, this leaves a remainder of 2,655 people in the Aberdeen / Cosmopolis area who are in need of either a VES, suitable private lands, or shrublands to be cleared *(see Fig. 9, pg 24)*.

Fig. 22 - Assembly Area 12 - Undeveloped Land
Aberdeen, WA / 46.979912, -123.635286

5.5.13 Assembly Area 13 - Makareno Park

The thirteenth public assembly area is 2.02 acres of open space in Makareno Park. Located in Cosmopolis, WA, the land is owned by the City and is currently identified as an assembly area.

There are 3,961 people who live within 1 mile of assembly areas 11-13, and the capacity of this assembly area is 910. When taken with the combined capacity of assembly area 11-12, this leaves a remainder of 1,745 people in the Aberdeen / Cosmopolis area who are in need of either a VES, suitable private lands, or shrublands to be cleared *(see Fig. 9, pg 24)*.

5.5.14 Assembly Area 14 - National Guard Armory

The fourteenth public assembly area is 1.13 acres of land just south of the National Guard Armory in Montesano, WA. The land is owned by the Washington State Military, and is also surrounded by suitable private lands.

Unfortunately, because the inundation zone does not extend into Montesano due to the lack of LiDAR, the number people who live within the inundation zone of a tsunami is unknown for this region. Once LiDAR is collected for this area, perhaps further analysis can be conducted by processing the data through the *Assembly Areas Model.* What is known is the capacity of this area, which is 510 *(see Fig. 9, pg 24)*.

Fig. 23 - Assembly Area 13 - Makareno Park
Cosmopolis, WA / 46.978957, -123.623674

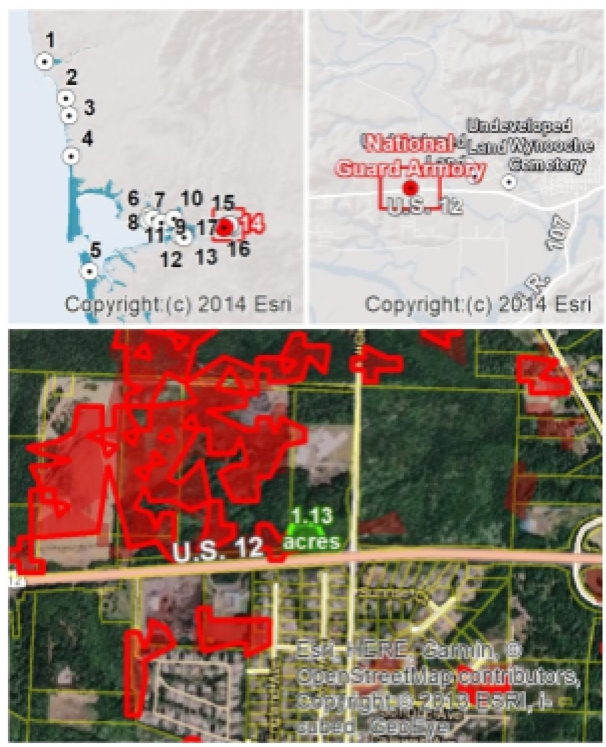


Fig. 24 - Assembly Area 14 - National Guard Armory
Montesano, WA / 46.952588, -123.789116

5.5.15 Assembly Area 15 - Undeveloped Land

The fifteenth public assembly area is 8.85 acres of land that appears to be adjacent to a large reservoir. The land is owned by the Washington State Department of Transportation and is also surrounded by suitable private lands. The capacity of this area is 3,981.

Unfortunately, because the inundation zone does not extend into Montesano due to the lack of LiDAR, the number people who live within the inundation zone of a tsunami is unknown for this region. Once LiDAR is collected for this area, perhaps further analysis can be conducted by processing the data through the *Assembly Areas Model (see Fig. 9, pg 24)*.

5.5.16 Assembly Area 16 - Undeveloped Land

The sixteenth public assembly area is 2.35 acres of land just over 200 meters south of the previous location. The land is also owned by the Washington State Department of Transportation and is also surrounded by suitable private lands. The capacity of this area is 1,055; no data for the total population who live within the inundation zone *(see Fig. 9, pg 24)*.

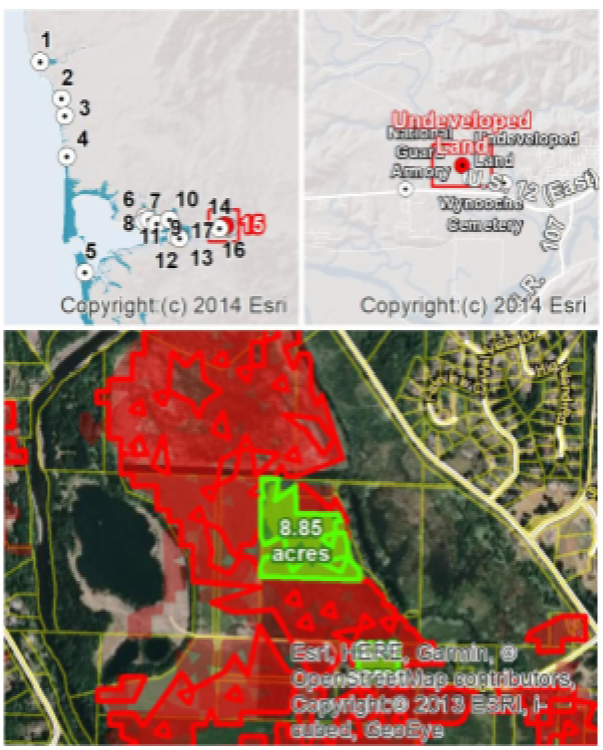


Fig. 25 - Assembly Area 15 - Undeveloped Land
Montesano, WA / 46.954503, -123.800707

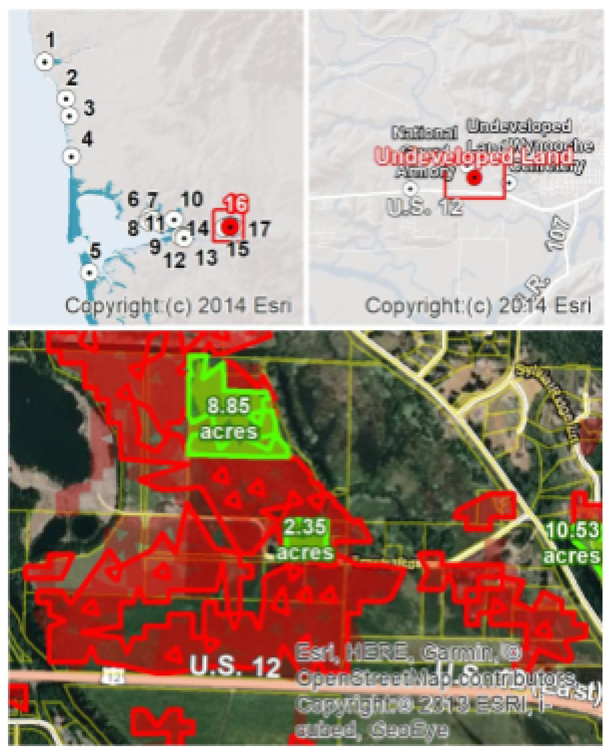


Fig. 26 - Assembly Area 16 - Undeveloped Land
Montesano, WA / 46.949371, -123.787997

5.5.17 Assembly Area 17 - Wynoochee Cemetery

The last and largest public assembly is the Wynoochee Cemetery, which consists of 10.53 acres of land in Montesano, WA. The land is owned by the City and has a capacity of 4,737 people; no data for the total population who live within the inundation zone *(see Fig. 9, pg 24).*

Like Sunset Memorial Cemetery (Assembly Area 8), it rests upon the County to decide if cemeteries are suitable locations for an evacuation site.

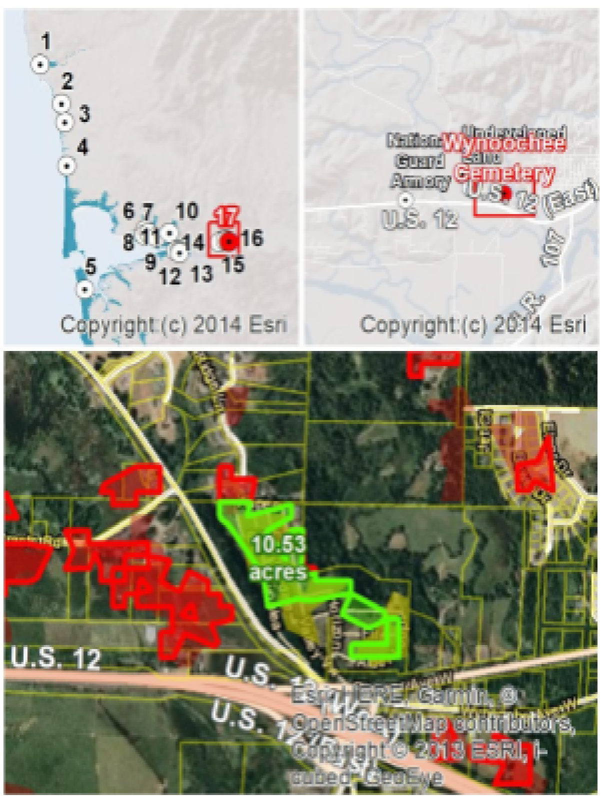


Fig. 27 - Assembly Area 17 - Wynoochee Cemetery
Montesano, WA / 46.863203, -124.099042

5.6 Private Assembly Areas

5.6.1 Assembly Area A - Undeveloped Land

Due to concern about the lack of available space for Ocean Shores, which is entirely within the inundation zone *(see Fig. 9, pg 24)*, a special request was made by stakeholders of Grays Harbor County to identify *any* suitable lands near the city. By eliminating 2 criteria (outside the inundation zone, publicly held), a privately owned area along Highway 109 was found, located within 3 miles of the northern part of the developed area of Ocean Shores. Owned by the Timberlands Holding Company Inc., the parcel contains 3 suitable locations totalling 7.96 acres. This is room for 3,547 people; the city of Ocean Shores contains 5,927. Assuming that all residents are able to evacuate in time, 2,353 people are still left bereft. However, if the surrounding shrublands are considered, the combined space could accommodate the full population. The land value of this entire parcel, containing all 3 areas, is estimated to be $14,257, which is quite affordable in terms of land acquisition and could make this feasible.

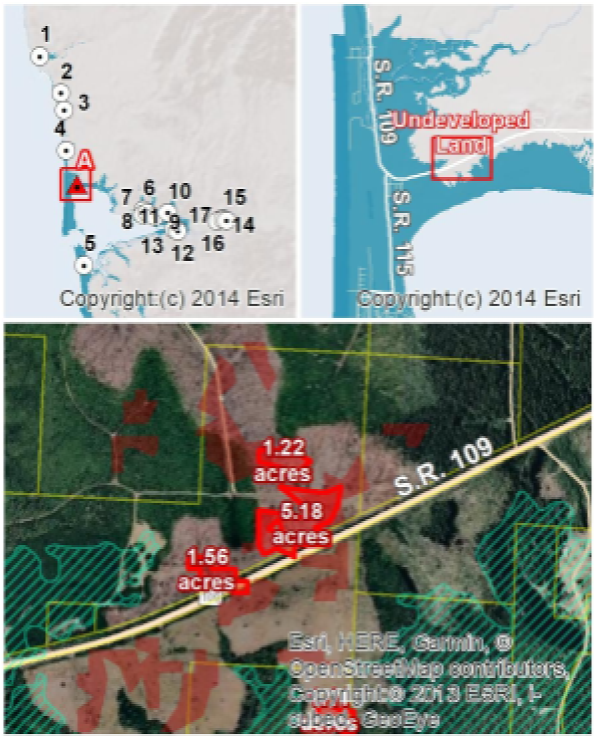


Fig. 28 - Assembly Area A - Undeveloped Land
Ocean Shores, WA / 47.048769, -124.133364

6 Considerations

Given the results of this analysis, it is important to remember that these are all contingent upon the eight suitability criteria outlined at the beginning of this report. Any changes or modifications to those criteria will also change the output of the *Assembly Areas Model (see Fig. 1, pg 14)*, and subsequently, the population totals therein. For this reason, the following paragraphs will highlight a few important variables worth considering while reviewing the initial results of this study.

6.1 Tourist Population

The population totals used in this analysis only includes the residential population; this does not account for the thousands of tourists who visit the area during vacations and festivals. Grays Harbor County is a popular area for shellfish collection, charter fishing, beach recreation, and a busy entryway to the popular Washington coastline.

From 2015 - 2016, tourism as an industry grew 9.4% in Grays Harbor County, a number well over the State's growth rate as a whole. Nearly $1 million dollars in tourism dollars were collected in 2015, rising to just over $1 million in 2016[19]. During peak season, there could be as many as 20-30,000 people staying at hotels and rentals in the county while they enjoy the beaches, coast living, and other festivities[20].

While these visitors bring in dollars and attention to the area, they also create wear and tear on the roads, resources, and public utilities of the County, and complicate the planning and preparation for tsunami risk mitigation. If a tsunami were to occur during one of these heightened periods of tourism, there would be a significant lack of space to accommodate the extra people within the currently identified public assembly areas.

When looking to establish a scope for this study, attempts were made to quantify the tourism numbers present in the area during peak seasons, but after consulting with stakeholders, it was decided to focus only on the residential populations to establish a baseline. This being considered, a more thorough estimate of tourist populations and the amount the County is willing to be prepared for is highly encouraged to aid the mitigation tsunami risks, requiring a discussion and decision from the County in terms of what margin to plan for and how best to address this concern

6.2 Distant Source vs CSZ Tsunami

The 1-mile buffer used to calculate population totals around each of the public assembly areas is a spatial measure that assumes all persons located within that proximity will be able to reach the

[19] Grays Harbor County Tourism Levels Thriving. Daily World. 2016.

[20] Numbers provided by Grays Harbor County Tourism Office

assembly area before a tsunami impacts the area *(see Fig 7, pg 23)*. However, the size of this buffer may be highly variable between a distant source tsunami, which may permit up to 4 hours of evacuation time, implying a potentially larger buffer than 1 mile, and a CSZ tsunami, which may actually constrict the buffer to smaller than 1 mile. Any changes to this proximity buffer will greatly influence the population totals.

Further, for areas that are located within Grays Harbor, such as Hoquiam, Aberdeen, and Cosmopolis, there is even more evacuation time alloted than for those who live on the outer coastline, such as Ocean Shores and Westport. Similarly, this may influence how many people may be able to reach these assembly areas before a tsunami impacts the area.

6.3 Landslide Vulnerability

A very important consideration that was not included in this study are areas that are vulnerable to landslides. Historically, landslides have been a serious risk throughout Washington State and some areas would be especially prone to this following a CSZ earthquake.

Although landslide vulnerability was not included as one of the suitability criteria, adding this criteria to the *Assembly Areas Model (see Fig 1, pg. 14)* would be a simple addition and new results could readily be generated. Adding this to one of the necessary conditions may have a significant influence on suitable locations and subsequent population totals.

6.4 Land Use Changes

The results generated from this study were based upon land uses from 2016. Considering how quickly areas can develop and change, the areas which have met the suitability criteria may be different now or in the very near future.

Two occurrences for land use change worth noting are (1) the effects of urban sprawl and newly developed areas, and (2) annual forest clearings, which may regrow in the next few years. For this reason, it is recommended that this analysis be reconducted every 3-5 years to maintain a current baseline.

6.5 Shrublands

In order to meet the criteria of *No Trees*, the analysis was limited to open developed spaces, barren, grasslands, and pastures. However, what was not included were shrublands (NLCD Grid Code: 52), which are *area areas dominated by shrubs; less than 5 meters tall with shrub canopy typically greater than 20% of total vegetation. This class includes true shrubs, young trees in an early successional stage or trees stunted from environmental conditions.*

The reasons shrublands were not included as a part of suitable land cover was because it would require a clearing, which can be expensive. However, given that there is much need for additional space, including shrublands as suitable land cover could be a viable option.

To demonstrate, we proceeded to re-run the *Assembly Areas Model* with this one change, and the results showed that if shrublands were included, a total of 157 acres of public lands would be suitable; this is an additional 107 acres to the 49 acres reviewed in this study.

Although population totals and capacity analysis has not been performed on these new areas, the gain in acreage alone could potentially increase the number of people within 1-mile of a public assembly area by 48,000, which is more than the population who live in the inundation zone.

6.6 Paved Areas

Another consideration that was not included within this study was existing paved areas, which include parking lots, streets, and highways. These areas are not parsed within the NLCD, so geoprocessing this additional feature would require a serious modification to the current *Assembly Areas Model (see Fig 1, pg 14)*. Provided that it meets all other criteria, there is an unknown amount of paved acres that may also be suitable for assembly areas not outlined in this study.

6.7 Suitable Private Lands

Beyond the suitable public lands, there exists many more acres of privately owned land which meet all other criteria for suitability. Results from the original analysis indicate there are 1,380 acres of private land which may be used as an assembly area if the owners are willing to permit the arrangement. Assuming 449 people per acre, that is enough space for over 619,620 people, which is more than enough space for the populations at risk, and likely with a distribution that covers several gaps across the inundation zone.

Taken further, if shrublands were to be considered suitable for assembly areas, the amount of suitable private land increases to 4,137 acres, which is three times as much area. This equates to nearly 2 million people in terms of capacity.

Although the cost of gaining permission from private owners, and clearing these areas if necessary, can be significant, suitable land *does* exist throughout Grays Harbor County if funding is made available to acquire or develop them.

7 Review of Project Benefits

Now that we have reviewed the data, process, results, and other considerations, it is worthwhile to discuss the benefits of this project for key stakeholders.

Grays Harbor County, as the primary stakeholder for this project, now has key information for evacuation planning efforts moving forward. Using this information, the county tsunami working group will take the following steps:

1. Finalize site selection process based on public parcels available for both near and distant source events
2. Determine key locations for VES
3. Determine private partnerships required for near term planning while finalizing VES as long term solutions
4. Conduct exercises to validate planning decisions

Additional stakeholders at the state level include both the WA Geological Survey (WA Department of Natural Resources) and WA Hazards and Outreach Program (WA Emergency Management Division). The WA Geological Survey could also benefit from the use of this model utilized within GIS. Further, it can be applied to DNR controlled lands throughout the inundation zone of the coastline to include the Puget Sound. The results of this study will also assist state efforts within existing coastal and inner coastal tsunami working groups. For the WA Hazards and Outreach Program, additional counties throughout the state now have a template to plan for assembly areas that can be incorporated into county GIS sections to assist Emergency Managers.

7.1 Scope of Population at Risk

One of the primary factors needed by the Grays Harbor Emergency Management Team was knowing how many people they needed to plan for in the event of a tsunami. Although tourist populations still need to be estimated, this study provided the number of local residents to plan for, namely- those living within the inundation zone.

With a baseline estimate in place, the emergency managers for Grays Harbor County can now effectively scope what needs to be done to accommodate at least 43,548 people, per the 2019 ACS Survey *(see Fig 7-8, pg. 23)*.

7.2 Defined Suitability Criteria

With feedback from stakeholders, a major contribution of this study was laying the groundwork for what constitutes a suitable assembly area, as least for a distance source tsunami where residents may stage for a few hours during the tsunami inundation.

No doubt the criteria used in this analysis will continue to be refined to account for additional considerations, such as the ones mentioned earlier in this report.

7.3 Identified Suitable Assembly Areas

Although assembly areas had already been designated at the time of this study, this analysis actually validated six of them as being suitable:

1. **Ocosta High School** (*See 5.5.5)*
2. **Hoquiam Landfill** (*See 5.5.6)*
3. **Hoquiam High School** (*See 5.5.7)*
4. **Sunset Memorial Cemetery** (*See 5.5.8)*
5. **Grays Harbor College** (*See 5.5.11)*
6. **Makareno Park** (*See 5.5.13)*

In addition, eleven more areas were identified that met suitability criteria.

Knowing what suitable locations exist alleviates uncertainties about the capacity of the public lands available. It also provides security in knowing that these locations are indeed suitable and capable of supporting at least 16% of the people who need it.

Although there remains over 35,000 residents without suitable public land to use as an assembly area, future studies which may include roads and parking lots, shrublands, and perhaps even private lands as suitable characteristics, could help reduce this displaced number.

7.4 Identified Need for Vertical Evacuation Structures (VES)

Beyond identifying suitable lands that residents may evacuate to, this study also identified locations that have need for vertical evacuation structures. In particular, Ocean Shores claims the greatest need, as this is the only option most of those residents have; but Hoquiam, Aberdeen and Cosmopolis have a need due to the lack of available public space *(see Fig. 9, pg. 24)*.

Additionally, the population and capacity study conducted in tandem with the site selection analysis provides a real number that can be used to scope how many VES might be needed in each location.

To illustrate, if we assume that those who live within 1 mile of a public assembly area all reach it and no other suitable lands are leveraged, then between Hoquiam, Aberdeen, and Cosmopolis, there are least 8,000 residents who would be in need of a VES, not including tourists *(see Fig. 9, pg. 24)*. An existing proposal for a new VES in Ocean Shores[21] is estimated to hold about 1,225 people, which if taken as an average, means that at least 6 VES are needed within those three cities, while at least 4 more are needed in Ocean Shores (5,927 people). This is assuming a set size for VES, which can vary significantly depending on need.

7.5 Support to Gain Federal Funding

With the intelligence provided within this report, community members throughout Grays Harbor County can leverage these results to gain funding for VES, further developing one of the 17 sites identified, clearing more land where feasible, or even acquiring suitable private lands, such as Assembly Area A located outside Ocean Shores.

[21] Numbers provided upon request from the Tsunami Program Coordinator of the Washington Emergency Management Division

With this data, stakeholders can make a stronger case for their communities, which increases the likelihood of having their proposals for new VES approved for federal funding.

7.6 Repeatable & Scalable Process

An important effort made by the authors of those who conducted this study was ensuring that the process was not only repeatable, but scalable for use in other coastal communities throughout Washington, Oregon, and Northern California who also face the same risks as those living in Grays Harbor County.

With data that is widely available and a model that automates the analytical process, working in tandem with the capacity to adjust variables where needed, our hope is that this study provides a means for others to identify suitable assembly areas in communities that may be at risk of experiencing a tsunami in the near future.

---

8 Conclusions

8.1 Summary

All things being considered, what is clear from this study is that there is not enough public land for the population to use as an assembly area during a tsunami evacuation. The land that is both suitable and available for the Grays Harbor County to use for this purpose can only satisfy 16% of the people who will be evacuating the inundation zone, not including tourists. This leaves over 36,500 local residents who will be in need of either a vertical evacuation structure (VES), permission to use suitable private lands, or areas that will require clearing in order to be made useable (shrublands).

8.1.1 Northern Coastline

The northern coastline of Grays Harbor County, which includes small towns such as Taholah, Moclips, Pacific Beach, and Copalis Beach, have a good distribution of suitable public lands very near each of the developed areas. Because these locations are more rural, there is more space than people. However, there does exist a few gaps between assembly areas 1-4 where the most isolated resident lives 2-3 miles away from one of these four locations *(see Fig. 9, pg. 24)*. In the event of a distant source tsunami, there may be enough time to cover this ground during evacuation, but this may not be the case for CSZ tsunami.

8.1.2 Ocean Shores

The largest risk exists within Ocean Shores, which will be completely inundated in the event of a tsunami. The city also lacks any suitable public lands that may be used for evacuation, with the closest being over 5 miles away in Copalis Beach *(see Fig. 9, pg. 24)*. This analysis confirms that the only viable option for the majority of residents living in Ocean Shores would be vertical evacuation structures, of which none presently exist. However, the city recently applied for federal funds to build additional VES structures, which total a proposed capacity of 1,225 people and would cost the County around $8,757,705 [22].

For those who live in the northern regions of Ocean Shores, there is one area of suitable private lands owned by the Timberlands Holding Co. which is valued at $14,257 and has a capacity of over 3,500 people *(see Fig. 28, pg. 34)*. It is not known how many residents of Ocean Shores may be able to reach this location in the event of a tsunami. However, if land acquisition is possible for the county, this land may still be worth securing for the sake of providing a suitable assembly area for Ocean Shores.

---

[22] Numbers provided upon request from the Tsunami Program Coordinator of the Washington Emergency Management Division

8.1.3 Westport

The city of Westport is fortunate to have a sliver of suitable ground where their local high school presides. Both the campus and the school building, which is the county's only VES presently, provide enough evacuation space to hold the entire population of the city (2,051) and an additional 1,500 tourists *(see Fig 15. Pg 27)*.

If the residents of Westport practice their evacuation protocol, it seems very possible that the majority of this population could safely evacuate to Ocosta High School in the event of a tsunami.

8.1.4 Hoquiam, Aberdeen, and Cosmopolis

The inner cities of Hoquiam, Aberdeen, and Cosmopolis have a number of suitable locations that could be used as an assembly area during a tsunami evacuation, but there is not enough space for everyone to fit into these locations *(see Fig. 9, pg. 24)*. There remains an excess of over 8,000 residents between all three cities that are in need of a safe place to evacuate too. However, there does exist several acres of suitable private lands that are located immediately around these suitable public lands; as well as shrublands that may become suitable if cleared. Vertical evacuation structures are also encouraged within these cities to help reduce the amount of residents without a safe evacuation space.

One area in particular worth noting is around Beacon Hill Dr in Hoquiam *(see Fig. 19, pg. 29)*. Although this area is a known risk for landslides, it may be possible to reinforce this highground (perhaps utilizing a FEMA hardening grant) and negotiate with private landowners about enlarging the potential use of this space as an evacuation assembly area.

8.1.5 Montesano

Due to the lack of data, we do not know how many people may be at risk of a tsunami at this location. However, there exists a number of suitable locations that residents may evacuate to if a tsunami were to occur, including both public and private lands *(see Fig. 25-26, pg 32)*.

The largest public space suitable for tsunami evacuation is Wynoochee Cemetery, which accounts for over 10 acres of suitable land *(see Fig 27, pg 33)*. However, as a culturally sensitive location, the county may need to decide if utilizing this space for mass evacuation would be acceptable, or if bargaining for the several acres of private lands surrounding the area might be a more preferable option.

9 Recommendations

For continued research on this topic, below are a few recommendations on future iterations.

9.1 Data

Considering that the results of this study are highly contingent upon the data inputs to the *Assembly Area Model*, it is encouraged to repeat this study once newer or more accurate data becomes available.

The LiDAR used in this iteration was limited to the immediate coastal areas, being cut off east of Cosmopolis. However, new LiDAR that covers the remainder of Grays Harbor County was recently collected by the WA DNR and will be publicly available in the near future. This new data may yield additional public assembly areas for locations like Montesano, or further upstream where the impact of tsunami inundation has yet to be determined.

Similarly, the land cover used in this iteration was dated to 2016, which is 3-years old.

Much can change in three years and for this reason, it is recommended that this study be conducted every 3-5 years to maintain a current baseline. The NCLD is published every five years and the next version will be ready in 2021.

9.2 Suitability Criteria

The suitability criteria used in this study was the first draft of its kind. However, throughout the process of execution, and with additional feedback from stakeholders, there are several opportunities to refine this criteria for a distance source tsunami versus a CSZ tsunami; to include landslides as a factor, or include paved areas such as roads and parking lots. The possible combinations of variants is virtually limitless, but now that the initial groundwork has been laid out through this study, continued refinement and adjustments are encouraged to produce more meaningful results.

---

10 References

1. *Summary of Coastal Geologic Evidence for Past Great Earthquakes at the Cascadia Subduction Zone*. Earthquake Spectra. Atwater, Nelson, Clague, Carver, Yamaguchi, Bobrowsky, Bourgeois, Darienzo, Grant, Hemphill‐Haley, Kelsey, Jacoby, Nishenko, Palmer, Peterson, Reinhart. 1995.

2. *Statistical Analyses of Great Earthquake Recurrence along the Cascadia Subduction Zone*. Kulkarni, Ram, Wong, Ivan, Zachariasen, Judy, Goldfinger, Chris, Lawrence, Martin. 2013.

3. *Tsunami hazard map of the southern Washington coast--Modeled tsunami inundation from a Cascadia subduction zone earthquake*. Walsh, Caruthers, Heinitz, Myers, Baptista, Erdakos, Kamphaus. 2000.

4. Tsunami inundation--GIS data. 2017: Washington Geological Survey Digital Data Series. Washington Geological Survey. 2017.

5. *Tsunami! Evacuation Map for Ocean City, Copalis Beach, Pacific Beach, and Moclips*. WA DNR. 2014.

6. Grays Harbor County GIS Mapping Portal. Updated 2017.

7. WA DNR GIS Open Data Portal. Updated 2019.

8. Multi-Resolution Land Characteristics Consortium Data Portal. Updated 2019

9. *LEP Communication Planning Framework*. Emergency Management Division, WA Military Department. 2018.

10. *Helicopterborne Operations Manual*, US Marine Corps. 2016.

11. *NWCG Standards for Helicopter Operations*. 2019.

12. *UNHCR Emergency Handbook*. 2015.

13. Provided upon request by the GHC GIS Mapping Office. 2019.

14. Provided upon request by the GHC GIS Mapping Office. 2019.

15. *Summary of Travel Trends 2017 National Household Travel Survey*. Federal Highway Administration. US DOT. 2017.

16. *WA DOT Roadside Manual* (M25-30). 2003.

17. *The First Tsunami Vertical Evacuation Structure in the United States: Ocosta Elementary School, Washington*. Walsh, Schelling, Ash, LeVeque, Adams, Gonzales. University of Washington, Department of Earth and Space Sciences. Published Nov 2018.

18. *Data USA's Profile of Westport, WA*. Updated 2019.

19. *Grays Harbor County Tourism Levels Thriving*. Daily World. 2016.

20. Numbers provided by Grays Harbor County Tourism Office

21. Numbers provided upon request from the Tsunami Program Coordinator of the Washington Emergency Management Division

22. Numbers provided upon request from the Tsunami Program Coordinator of the Washington Emergency Management Division

11 Appendices

A Points of Contact

Name	Title	Role
Nathaniel Santa Cruz	*Sr. GIS Analyst, JBLM Public Works*	MGIS Graduate Student
Marco Brettmann	*Maj. National Guard*	MGIS Graduate Student
Alina Luce	*Independent Contractor*	MGIS Graduate Student
Hannah Cleverly	*Dep. Director of Emergency Management for Grays Harbor County*	Stakeholder
Daniel Eugard	*Geologist, WA Dep. of Natural Resources WA Geology Survey*	Stakeholder / Data Provider
Maximilian Dixon	*Hazards and Outreach Program Supervisor, WA EMD*	Stakeholder
Elyssa Tappero	*Tsunami Program Coordinator, WA EMD*	Stakeholder