Impacts of Climate Change in Venice:

Using Simulations to Model Mitigation Strategies

An Interactive Qualifying Project Report Submitted to the Faculty of
WORCESTER POLYTECHNIC INSTITUTE in partial fulfillment of the
requirements for the Degree of Bachelor of Science

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Abstract

Venice has long been affected by extreme climate events. These events have been well-documented by organizations such as the Euro-Mediterranean Center on Climate Change and SerenDPT. Our team's mission was to explore the use of an interactive interface (Simtable) which could be used to replicate extreme events occurring in Venice and the Veneto region. The resulting deliverables of this project include a booklet detailing the uses, benefits, and applications of our interface, a repository for our simulations in the form of a website, this report to act as an addendum to our booklet, and a roll-up banner to be displayed next to the Simtable at he H3 Factory.

Authorship and Acknowledgements

Keira Coulard-Smith was responsible for the research and writing of sections 3.1, 3.4.1, Chapter 4, and the research for section 3.2. She also revised Chapter 1 and Chapter 2, and sections 3.2, and 3.3.

William Stottlemyer was responsible for the writing of the Executive Summary, Chapter 1, parts of Chapter 2, 3.5.1-3.5.2 and Appendix C. He also wrote parts of 3.1-3.4.1 and revised Chapters 2 and 3.

Everett Wonson was responsible for the writing of 3.2, 3.3, and 3.3.1, the Conclusion, and Appendices C, E, and F.

Kathryn Woodland was responsible for the research and writing of the Abstract, Chapter 2, and sections 3.4, 3.5, 3.6, and Appendices A, B, and D. She also revised Chapters 1 and 2, and sections 3.1, 3.2, 3.3.1, 3.4, 3.5, and 3.6.

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Executive Summary

When looking at the city of Venice, Italy, Venetians have been fighting floods essentially since the city was built. As climate change continues to become a worsening issue, the flooding situation directly correlates and follows the same decline. The increasing frequency and significant floods to hit Venice over the last century is the point of concern for this project. There are many mitigation measures that Venice has developed to deal with floods, but as the sea level continues to rise as a result of climate change, these mitigation measures may become ineffective.

In an effort to address this issue, this group worked with different flood simulation software to effectively showcase the results as higher floods hit Venice. Working with sponsors and the project center located in Venice, we contained all the necessary software packages and resource connections to create flooding maps and graphics. The four students placed on this project received all the support necessary through all the resources WPI had to offer as well, this included connections to other project centers, professors who specialized in softwares that were used in this project, as well as Information Technology Services that helped us with troubleshooting any of the software we used.

The urgency for focusing on flooding in Venice is always increasing, and if the world continues on its current path Venice may become inhabitable. By creating flood simulations and highlighting previous trends in flooding, this project will ideally be the basis for inspiring more efforts to help confront the climate change situation. This project effectively created many simulations that show floods of all different heights. Some of the simulations involved the floodgates and barrier islands of the Venetian lagoon in an effort to show failure of the current mitigation measures.

This project took place from Oct. 2021 to Dec. 2021, for a duration of 7 weeks abroad at the WPI project center in Venice, Italy. The team of four, third year students, worked with the knowledge they gained from previous classes and filled in the gaps by reaching out to many different resources including on the WPI campus, in Venice, and other WPI project centers. Overall, this project accomplished the main goals we set out to focus on and covered a lot of ground in the short amount of time we had to focus on such a detail oriented project.

The biggest results from this project came in the form of simulations of different parts of the city of Venice. After the manipulation of spatial data from different forms such as lidar, raster, and GeoTIFFs, more results from this project came in the form of maps created from softwares such as QGIS and ArcGIS. These maps were only a stepping stone for the final simulated results. Some of the major floods to occur in the last 100 years were simulated successfully in this project using the simtable the failure point of the MOSE gates was attempted as well.

Based on what was learned in this project, the rough estimate for when the MOSE gates and barrier islands would fail in Venice is between 100-200 years from now. Based on our findings the range where Venice starts to be heavily impacted by flooding is tide rises between 90-180 cm. At the end of this project the group developed some recommendations for the Simtable interface. Additionally, indications for what needs to change concerning greenhouse gas emissions in order to slow the progression of sea level rise and flooding.

Chapter 1: Introduction

Climate change is a term coined to encompass the effect of greenhouse gasses on planet Earth. There are many consequences and different trigger words that are closely related to the greenhouse gas effect and fall under the broad phrase of "climate change". Examples of the consequences of greenhouse gas emissions or climate change include rising sea level, global warming, and an increased number of natural disasters and extreme weather events. Greenhouse gasses produce an unstable equilibrium within the earth's boundaries and are contributing to unusual weather patterns and more environmentally damaging events.

The city of Venice has been particularly vulnerable to the impacts of climate change. It's low elevation combined with its placement on the Adriatic Sea allow relatively small changes in the water level to have significant impacts on the city. For example, an unusually high tide at the same time as strong winds could result in tides over one meter past the usual daily tides. The effects of climate change, which include rising sea levels and more frequent strong storms, are noticeably making a difference in the frequency and severity of these floods.

Certain areas of the city start to flood at tides 80 centimeters over the base sea level, and tides of only 110 centimeters would flood nearly fifteen percent of the city. Because of this, Venetians have acclimated to minor floods being a normal part of life in Venice. As floods have become more severe and more frequent, it was necessary to find a way to protect the city. In 1987, planning began for a set of retractable barriers at the inlets of the lagoon to be able to stop the water level within from rising significantly, therefore protecting the city from flooding. Funding and construction took many years due to the magnitude of the project. While MOSE was still being built in November of 2019, a particularly high tide reaching 187 cm flooded over 80 percent of the city and caused approximately one billion euros in damages (Carbognin, 2021). On October 3, 2020, the barrier system was first activated, and now can close off the three inlets to the lagoon and prevent high waters from reaching Venice.

In order to better prepare for the effects of climate change, this project will work closely with Ca'Foscari University and the Euro-Mediterranean Center on Climate Change (CMCC). In partnership with SerenDPT, these two entities are focused on researching climate change to better understand the future possibilities and implications. The goal of this project is to work alongside the Euro-Mediterranean Center on Climate Change to identify areas of risk. We plan to collect data and utilize a simulation table, or Simtable, to model climate events and to develop inundation maps and simulations of past and future extreme climate events for the use of researchers and scientists in the Veneto Region.

To meet our goal, we have identified the following objectives:

1. Analyze existing data on extreme climate events in Venice to determine completeness and suitability for simulations.
2. Integrate existing data with additional datasets and sources.
3. Demonstrate the potential interface to simulate climate events.

Our research will contribute to efforts to improve the city planning and preparedness for extreme climate events.

Chapter 2: Background

Climate change has become increasingly dangerous and detrimental to an innumerable amount of communities around the world. The growing need to address climate change is inspired by the negative outcomes that are expected from continued greenhouse gas emissions. Changing water levels have caused problems for Venice throughout its entire history, and adaptations have been made for both high and low tides. However, sea level has been on the rise since the 18th century, and so Venice has developed a number of methods for protecting the city from extreme high tide events, but the chance of these measures becoming ineffective grows as climate change intensifies. Hence, modeling risks is critical in order to predict the future for the city.

2.1 Climate Change and the Venetian Community

Communities around the world are struggling to adapt to climate change. As the climate crisis becomes more threatening, the urgency to alleviate the strain placed upon the world's population is great. Flooding, wildfires, droughts and heat waves are only a fraction of the extreme climate-driven events occurring globally. The impacts to Venice have been high tides and disastrous flooding (The ISMAR Team, 2021).

In order to effectively accomplish our objectives, our team identified the stakeholders of this project and their needs. While Venetians, tourists, policymakers, and wildlife are all critical stakeholders in the outcomes of this project, Venetian citizens have historically been most impacted. The rising canals have wiped out entire stock inventories of local shops (as shown in Figure 1), forced the closure of schools and caused regions of the city to become completely inaccessible (Carbognin, 2021). The rising water levels were the source of damages up to $1 billion to homes and historical sites (The ISMAR Team, 2021).

Figure 1: Inventory is destroyed as a store is flooded (An Apocalypse Happened, 2019).

In response to flooding events, tourists cancel trips and other activities. This can have an adverse effect on the Venetian economy. The hospitality and tourism industry lose bookings, contributing to a major loss of income (Carbognin, 2021). While Venice remains a popular vacation destination, the hospitality and tourism industry have seen spikes in canceled reservations leading to losses of $34 million as tourists hope to avoid these floods (The ISMAR Team, 2021). With MOSE now working, these high tides can be stopped, but this stops all traffic in and out of the lagoon for hours before and after the peak tide, which also contributes to economic losses.

Higher water levels in the Venetian lagoon would have devastating long-term impacts on areas further inland of the coast. Agricultural lands would be contaminated with saltwater, wetlands would flood, and habitats of birds, plants, and mammals would be destroyed (The ISMAR Team, 2021). In the lagoon and ocean regions, the rising sea temperatures will cause coral bleaching (high temperatures force the algae in coral out, which causes the coral to become white) and loss of breeding grounds for marine life (The ISMAR Team, 2021). As sea levels rise, Venice must continue to be at the forefront of efforts to mitigate the impacts of climate change otherwise the Venetian population, infrastructure, and its history are at risk of permanent erasure.

The Euro-Mediterranean Center on Climate Change (CMCC) is a research center partnered with the Ca ’Foscari University located outside the city on the mainland portion of

Venice called Mestre. An important resource they offer is one of the more powerful supercomputers in all of Europe. This computer has the ability to model and forecast the future of climate change and as well as assess the economic repercussions caused by climate change (“CMCC@Ca’Foscari,” n.d.). The CMCC works to evaluate risk factors that are associated with climate change as well as creating adaptation strategies. The CMCC additionally holds “Climathons”, which is a 24 hour challenge to all cities around the world to develop solutions to climate change. SerenDPT is partnering with these efforts to collect climate data in order to serve as a database for the development of technological solutions. The CMCC and SerenDPT partnership also extends to these “Climathons", where they are partnered in running these events in an effort to address climate change issues ("Climathon in Venice, Italy - 14 & 15 Novembre 2020,” n.d.).

Chapter 3: Simulating Tidal Events

A plethora of extreme climate events have impacted Venice for centuries. The most harmful includes the rising frequency of turbulent storms and strong winds. Flooding as a result of exceptionally high tides from these storms has caused many issues for the historic city. Mitigation measures such as flood barriers, sirens, and raised walkways have been used in previous years in efforts to minimize the damages.

3.1 Frequency of Storms and Strong Winds

The geographic placement of Venice, as seen in Figure 2, is an important factor contributing to the severity of floods in the city. The lagoon is positioned at the top of the Adriatic Sea, which allows winds to push storms across the water to make landfall at the lagoon. The sirocco winds shown in Figure 3 originate in Northern Africa and travel across the Mediterranean sea and prompt heavy rainstorms to form (Intense Air-Sea Exchanges and Heavy Orographic Precipitation Over Italy).

Figure 2: Venice's position on the Adriatic (Rising Sea Levels, 2019).

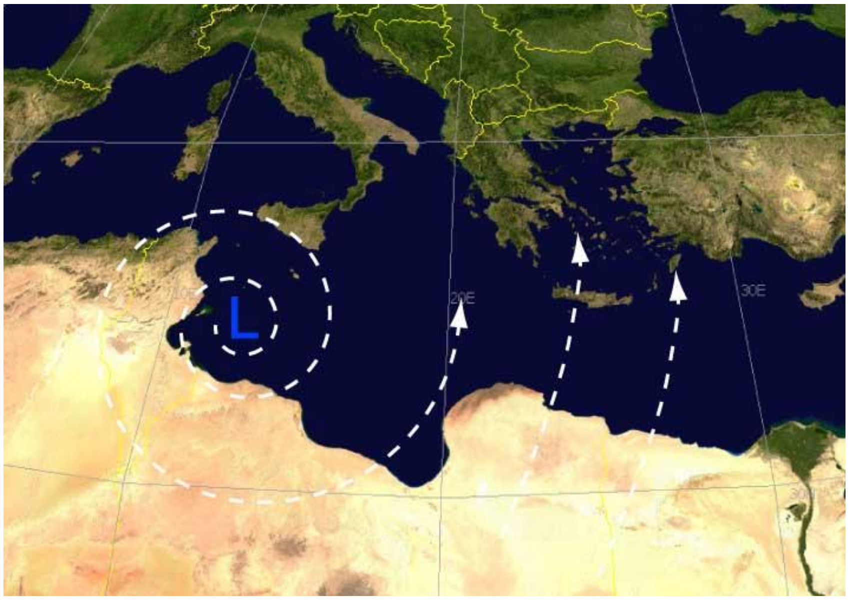


Figure 3: Sirocco winds (Rising Sea Levels, 2019).

These hot, humid winds can reach category one hurricane speeds (74 mph/119 km/h) and bring storms to Venice. The combination of heavy rainfall and winds blowing towards the coast cause a greater chance of flooding to occur in the city. (Rising Sea Levels and Sirocco Winds Worsen Flooding for Venice).

When evaluating some of the weather events that occur in the Veneto region, which includes the city of Venice, there are many examples of extreme storms. These storms have a large impact on the flooding situation in the Venetian lagoon as a result of immense wind speeds. The “Tempesta Vaia” or “storm Adrian” is an example of this and was one of the most devastating storms to impact Italy. The storm occurred from the 26-30 of October 2018 with wind speeds reaching 120 mph in the Veneto region. This event was a prime example of winds that occur near the coast of Venezia. This storm devastated the vegetation in the Veneto region causing large forests of trees to be entirely leveled. As a result of this storm the city of Venice was hit with the highest tide height in all of 2018 reaching 154 cm on the 29th of October.

Although it doesn't affect the flooding in Venice, these extreme events lead to more issues through the region such as wildfires. The forests in the Veneto region are subject to wildfires that destroy huge portions of the woodland (*Monitoraggio Degli Schianti Da Vento Della Tempesta Vaia - Regione Del Veneto*, n.d.). Wildfires spread more rapidly when high wind speeds occur causing more devastation due to these extreme weather events. The weather patterns around Venice play a huge role in the flooding issues that the city has to deal with, but causing higher tide rises is not the only impact of these occurrences.

3.2 Rapid Rise of Sea Level

The relative sea level (RSL) is considered to be “the position of sea surface relative to the base level” of the adjacent land (Harff, 2016). The Veneto region, more specifically Venice and its lagoon, are extremely vulnerable to increases in the relative sea level. This is due to the rising tide level and the sinking of the city as a result of a lack of effective land-support structures (Lionello et al., 2021). During the past 150 years, the average rate of sea level rise has been 2.5 millimeters per year.

Current estimates place global sea level rise at 3.6 millimeters per year, with levels having risen between 16 and 30 centimeters since 1902 (The Royal Sciences, 2020). Future models predict sea levels to rise between 30 and 60 centimeters by 2100 (Cocks, 21), assuming the global average temperature increases by 2℃. If the anticipated output of greenhouse gas emissions increases beyond the projections, the resulting global average temperature will exceed the current 2℃ estimate, causing a higher sea level increase between 60 and 110 centimeters (Cocks, 2021).

The ocean acts as a climate regulation system by regulating the concentration of carbon dioxide. Carbon dioxide is absorbed through photosynthesis by plant-like organisms known as phytoplankton. In addition, it reacts with seawater to create carbonic acid which releases hydrogen ions. These ions combine with carbonate found in seawater to form bicarbonate, a type of carbon that becomes trapped in the ocean (Riebeek, 2021).

As the output of greenhouse gasses increases, the ocean reaches its limit on the amount of carbon dioxide that it can absorb. The carbonate at the surface is depleted, and must be replenished from stores in deeper waters. Currents driven by wind bring carbonate to the surface of the ocean and push carbon saturated water to deeper levels. The ocean stratifies when the temperature increases and winds are unable to mix surface water with deeper water. The surface water becomes oversaturated with carbon dioxide and phytoplankton lose their habitat in the stagnant water. At this point, the amount of carbon dioxide the ocean can absorb is significantly reduced. An increase of carbon dioxide in the atmosphere contributes greatly to glacier melt, which adds to sea level rise (Riebeek, 2021).

As the level of the lagoon surges to higher levels, there becomes an increasing need to address the flooding situation. The increased frequency and magnitude of floods correlates directly to the variations of the sea level. The largest recorded flood to occur in Venice was in 1966, captured in Figure 4 below, where more than half of the island was flooded with water.

Figure 4: Highest tide height of 194 cm to impact Venice on November 4, 1966 (*Acqua Granda*, 2016).

3.3 A Submerged Venice

Floods have been recorded in the Venetian lagoon as early as 589. In the 18th century, documentation became more thorough and precise, thus showing the increasing frequency of these events. The rise in sea level caused by climate change is very apparent in Venice. The average elevation of Venice is 100 centimeters above sea level, but some sections are much lower and see floodwaters more frequently. When reporting tide levels, the 1897 mean sea level is used as the zero point to ensure consistent records, and a tide over +80 centimeters from the baseline is referred to as an “acqua alta,” which literally translates to high water. Saint Mark’s Square begins to flood at +90 centimeters, and the crypt of the basilica at +65 centimeters.

The figure below shows the number of tide levels at or above +110 centimeters recorded per year in the Venetian lagoon. It is important to note that the low number of 2 for 2020 can be attributed to the implementation of the MOSE system and without that, the number would have been closer to the 16 that were recorded at sea (Municipality of Venice, 2021). The frequency of acqua altas has been increasing severely in the past decades, with more severe events as well. An acqua alta over +140 centimeters is known as an exceptional high tide, and while this happened 9 times from 1900-1999, it has happened 16 times since 2000.

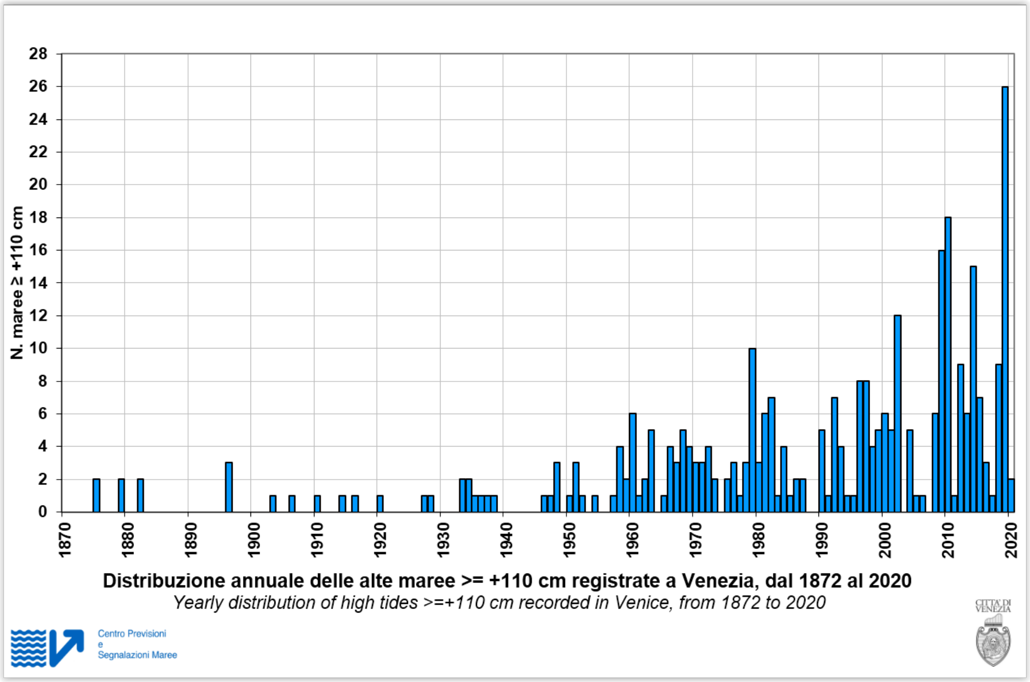


Figure 5: Frequency of floods above 110 cm between 1872 and 2020 in Venice (Città Di Venezia, 2020).

3.3.1 Mitigation Measures

The Tide Forecast and Report Center develops multiple daily predictions as well two days in advance forecasts for when high tides will occur in the Venetian Lagoon. These predictions are developed and uploaded to the website for the City of Venice in order to notify citizens when extreme flooding will occur. This tide center additionally has a large database of information and charts on previous floods (PF466620, 2017).

Venice uses warning sirens to indicate the occurrence of a high tide. The high-water warning sirens relay information regarding future tide height using a series of notes, with the number of notes played correlating to the following tide height:

Tide Height	Notes Played
+110 centimeters	1 Note
+120 centimeters	2 Notes
+130 centimeters	3 Notes
+140 centimeters	4 Notes

Table 1: The correlation between notes played and future tide height.

Each series of notes is played multiple times through speakers installed within bell towers interconnected via wifi networks to allow citizens to properly prepare for the incoming tide (see Figure 6 for speaker locations) (Municipality of Venice, 2016).

Figure 6: Distribution of warning sirens throughout Venice (Municipality of Venice, 2016).

Dry footbridge pathways have been utilized frequently in Venice during acqua altas. As seen in Figure 7, green lines indicate pathways which remain dry at tides of 120 centimeters, red lines indicate raised walkways, dashed lines indicate gondola crossings, and black dots indicate boat stops. The raised walkways, as indicated by red lines, are utilized between the months of September and April when acqua altas are most common (Municipality of Venice, 2016).

Figure 7: Raised walkways that remain dry at tides +120 cm (Municipality of Venice, 2016).

For the first time in October 2020, MOSE was used to prevent seawater from flooding the city (MOSE Flood Barrier Protects Venice - See How It Works, 2020). The flood gates began development in 2003 and were completed before the 2020 flood season. MOSE has been used multiple times since 2020 and has successfully prevented the city from being submerged. Generally, MOSE is not used for tides less than 110 centimeters, which is enough to cause minor flooding in approximately 14 percent of the city (MOSE, 2021). However, when used the barriers are effective when protecting Venice from tides up to 300 centimeters. Thus far, the highest recorded tide has been measured at 194 centimeters in 1966, which was the flood that inspired the creation of these flood gates (Venice’s Controversial Barriers Prevent Flooding for Second Time, 2020).

As shown in Figure 8, Venice’s flood defense system consists of three separate gate locations positioned at each of the inlets to the lagoon: Lido, Malamocco, and Chioggia. The Lido inlet is broken into two barriers, North and South, with each consisting of 21 and 20 individual gates respectively. The Malamocco barriers consist of 19 gates, where the majority of commercial ship traffic is seen. Chioggia, located at the southernmost region of the lagoon, contains 18 barriers (Ministero delle Infrastrutture e dei Trasporti, n.d.).

Figure 8: Location of the MOSE barriers (MOSE, 2021).

When inactive, the floodgates fill with seawater and are invisible under the surface of the water, they lay down on the seabed. In the event of a planned tide rise above 110 centimeters, compressed air flows into the sluices and pushes out water. As the water exits the sluices, the gates rotate around the axis of the hinges to rise above the water and block incoming tides from flooding the city. Each gate is 20 meters wide, and the length of each gate is proportional to the depth of the channel at which they are situated. The engaged floodgates cause traffic in the inlets of the lagoon to slow dramatically. Each ship must pass through a “lock” within the gates to travel between the lagoon and the Adriatic Sea (MOSE, 2021).

Not until recently was Venice able to prevent flood waters above 110 cm from flowing into the city. Before the floodgates were a viable form of mitigating flood waters, Venice’s citizens could only adapt to the situation with warning sirens and raised walkways; little could be done to prevent the waters from coming in. However, despite the success of the floodgates, more mitigation measures will be needed in the future as long as climate change and sea level rise remains at its current pace.

3.4 Simtable

Simtable is a modeling technology that integrates GIS mapping with human-computer interaction to create data visualization models. There are currently over 100 Simtables installed around the world, primarily in the United States. In Figure 9, Simtable blends computer operation with a sand table that can be molded to the specific topography of the area being modeled. The simulation features emergent climate scenarios incorporated with human interaction and “social phenomena" (Guerin, 2021).

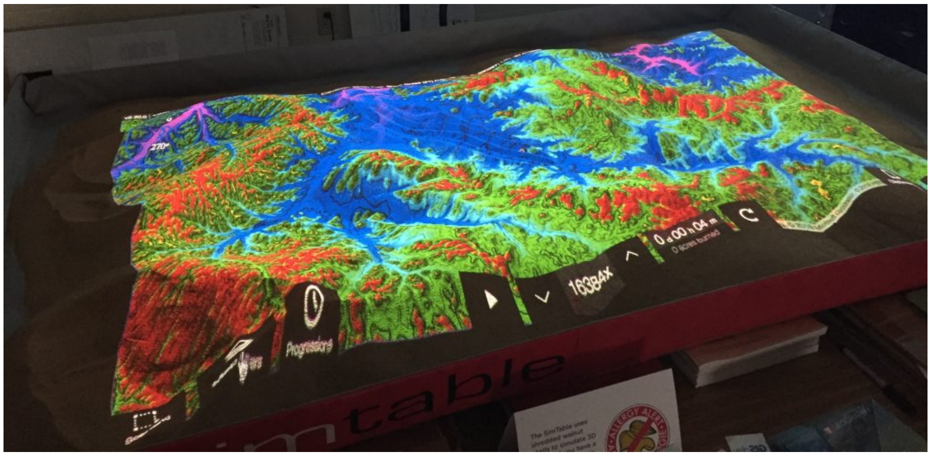


Figure 9: A Simtable in use to model events (Guerin, 2021).

The technology assists emergency teams in disaster preparation and awareness during hazardous events. The Simtable models are customized designs based on data obtained from “local communities…for floods, wildfires, evacuations and storms” (Guerin, 2021). The set-up of the Simtable can be seen below in Figure 10.

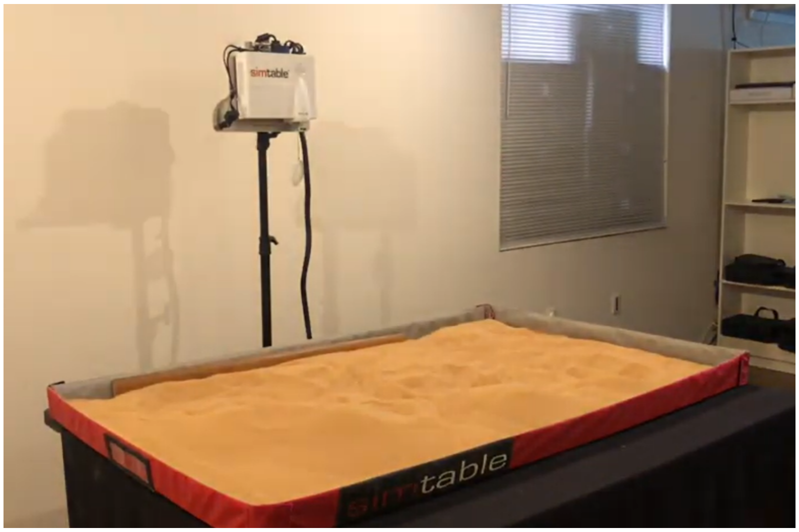


Figure 10: Set-up photo of the Simtable.

The physical set-up of the Simtable includes a projector stand, which supports a mac mini, projector, and camera. The table contains crushed walnut shells which represent the “sand”. Simtable uses information about the terrain, environmental data, and interactive inputs from the user to simulate extreme events. This information is read by AnyHazard, the software used by Simtable to simulate events, and a real-time, interactive visualization is created. AnyHazard uses three different “behaviors” to model events for fire, plumes, and water.

The first of which applies to fire. The model reads the fuel types and elevation values of a pixel (provided by the maps), and decides whether or not to burn that area. The speed at which a fire burns is entirely dependent on the direction of the wind, the slope of the area, and the land-cover data. For example, a fire in a flat, urban area with no wind will spread much more slowly than a fire in a wooded area pushed uphill by intense wind.

For a toxic gas release, the plume travels in the speed and direction set by the wind dial. The cloud of gas separates when it encounters a structure, and moves around the object in its way. The last of the models is used for the water module. AnyHazard analyzes the elevation value for each pixel, and decides whether or not to flood an area if the height of the water is greater than the elevation value of the pixel.

3.4.1 Modeling Venetian Mobility on Land and Sea

Utilizing Simtable for this project will aid in visualization of extreme climate events. By creating an interactive interface, we will be able to show experts and the public what might be expected in the case of an extreme weather event. Modeling these events helps to initiate preventative action to mitigate the increasing impacts of climate change. Currently, Simtable is used to train firefighters by showing historic or modeled situations, and teaches which actions would be most effective in dousing the fire. This same concept can be applied to the flooding scenarios to show which points of concern need to be addressed to lessen major damage.

Simtable has already been used in Venice to model complex environments. A project titled, "Venetian Mobility on Land and Sea," looked at types and volume of pedestrian traffic in Venice in order to develop a computer model of traffic to show possible evacuation routes. These models were used to aid city officials in municipal planning during floods. To accomplish this, the project collected significant data about two different types of traffic in Venice. Pedestrian volume and direction was recorded at 28 bridges and locations that were deemed significant, some include the Piazza San Marco, the Festa della Madonna della Salute, and the San Michele Cemetery on All Souls Day. Additionally, data was collected on boat traffic, street paths and most convenient boat stops based on location throughout the city. All of this was utilized to create a Simtable-based computer model to show possible evacuation routes in the event of an emergency (Aloisio, 2009).

3.5 Visualizing Scenarios

The different software that was used throughout this project was visually appealing and easy to understand because of this. The idea behind creating a tangible and visual result through simulations, was to engage people in our issue and increase motivation to work against the worsening climate crisis. Graphics showing our simulation data relays a more comprehensible, memorable, and captivating relay of information. Besides focusing on our audience of this project, visualizing flooding scenarios benefitted us by recreating historic floods and being able to visually see on a map what areas of the city were flooded. Without visual aids, this project would have been inefficient at conveying our results and understanding our results.

3.5.1 Analysis of Data

First, the team performed an analysis of data we received from our sponsors, the Euro-Mediterranean Center on Climate Change (CMCC). In partnership with the University of Venice Ca' Foscari, CMCC was our primary resource for past research, assistance, and analysis. The data was checked for completeness, validity, and usefulness for the purposes of our project. Analyzing the data provided to us gave us better insight into which weather events have caused the most disruption to the city and which have the potential to worsen into high risk events. The research shared with us included a table of relative concentration pathways predicted for the next 100 hundred years and spatial data contained in a Google Drive for the Veneto region in the form of geotiff files.

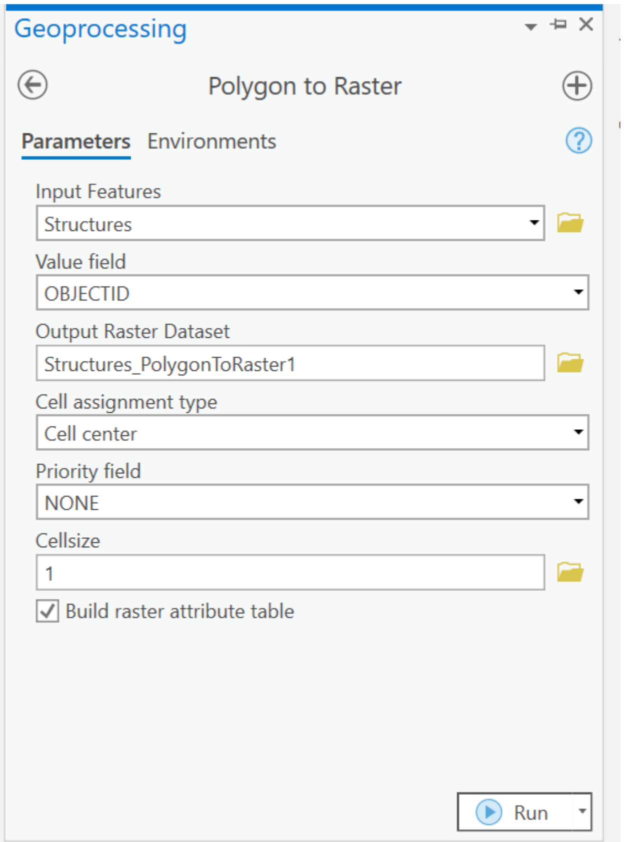
To organize the files within the shared drive, we made tables using Google Sheets. Each sheet represented a folder within the Drive, and within each contained a list of files. The purpose of this was to determine the extension of each file within the folders as well as to keep track of what was accessible to us with the softwares we had available. Conditional formatting was used to color code each of the files with the same extension. To the side of each list of files was a key that explained which extension type matched which color, as well as the software we needed to successfully open the file.

To analyze the spatial data, the team used ArcGIS and QGIS to open each file. Both softwares enabled our team to display data relative to positions on the Earth's surface. These softwares were ideal because they easily allowed the raster layers received from our sponsors to be added to a basemap for the purposes of exploring, visualizing, and analyzing data. This method allowed us to determine if data was in the correct resolution, had valid elevation values for each area it showed, and if the area was going to be useful enough to be imported into the Simtable later in the project. We found that LiDAR data for the mainland of the Veneto region and the outer islands (Lido and Pellestrina) would be the most useful to include in our project because they fulfilled the requirements described above.

3.5.2 Integration of Data

With the data fully analyzed, we were able to start filling in the gaps for what we needed to include, then compile new data with our existing files. Based on the results of our analysis, the team found that we were missing elevation data for the historic city. This data was extremely important to include in the package of data we would import into the Simtable because it contained elevation heights of the walkways and buildings. This data would show where a flood would go within the city if tides were high enough to flood the streets.

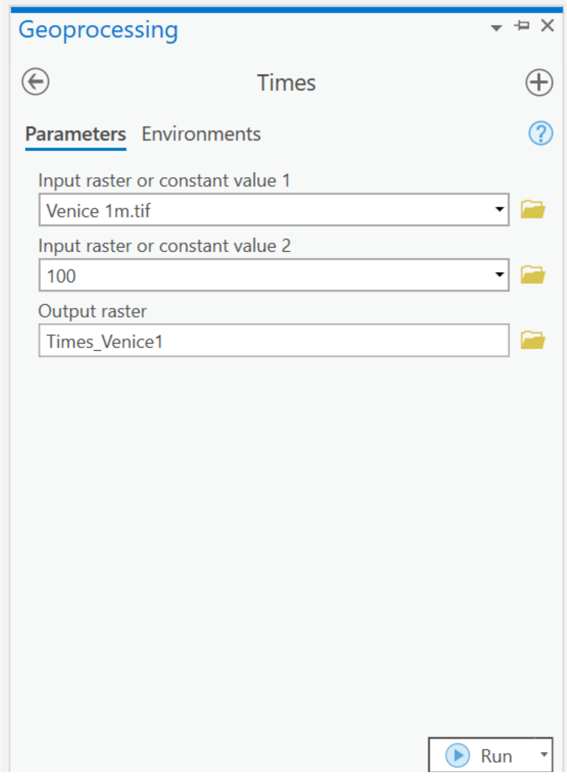
Using ArcGIS Pro, raster and feature layers of the structure and ground elevations were added to a basemap from the ESRI library. The layer containing building structures was turned into a raster file from a feature layer using the “Polygon to Raster” tool as seen in Figure 11.



Input Features: Structures
Value field: OBJECTID
Output Raster Dataset: Structures_PolygonToRaster1
Cell assignment type: Cell center
Priority field: NONE
Cellsize: 1
☑ Build raster attribute table

Figure 11: Polygon to Raster Tool with filled in fields.

The units were converted from meters to centimeters using the “Times" tool as seen below in Figure 12 to best apply the data to the Simtable. The input raster was multiplied by 100 to get the correct value. The ground elevation layer was added as a raster layer to the map, so our team only had to change the units of the resolution from meters to centimeters using the same conversion tool as before.



Input raster or constant value 1
Venice 1m.tif

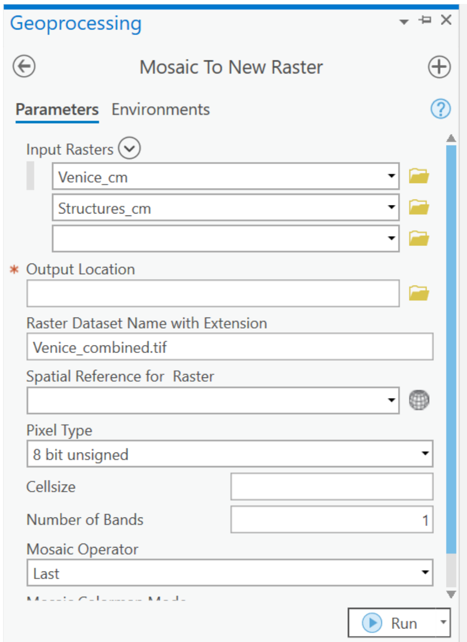
Input raster or constant value 2
100

Output raster
Times_Venice1

Figure 12: Times Tool with filled in fields.

Both rasters of the structures and the ground were combined using the “Mosaic to New Raster” tool to create a new raster that calculated the maximum heights of the elevations between the ground and buildings. Using this tool allowed our team to create a data file that would accurately show the correct elevations of each geographic point when it was displayed on the Simtable.

We integrated our new layers with the received files from our sponsors using similar methods as above. The lidar data of the Veneto coast and region were each converted from meters to centimeters using the “Raster Calculator” tool in QGIS. Then in ArcGIS Pro, each of those files were added to the same map as the combined raster of the structure and ground layers. Using the “Mosaic to New Raster” tool (seen below) the rasters of the coast and combined structures and ground were made into a single raster that included data of the whole region.



Input Rasters
Venice_cm
Structures_cm

Output Location

Raster Dataset Name with Extension
Venice_combined.tif

Spatial Reference for Raster

Pixel Type
8 bit unsigned

Cellsize

Number of Bands 1

Mosaic Operator
Last

Figure 13: Mosaic to New Raster Tool with filled in fields.

The final raster layer below (Figure 14) was sent to the Simtable team to be converted to red-blue-green tiles so the elevations from the raster would be recognized by the Simtable.

Figure 14: Combined raster of the barrier islands, structures, and ground elevations of the historic city.

The tools needed were Docker, Rasterio, and plugins from Mapbox RasterIO Plugin Registry. To begin, the raster was downloaded as a GeoTIFF file. To analyze the data within the raster, Rasterio was used to determine which projection the map was in, the block size of the

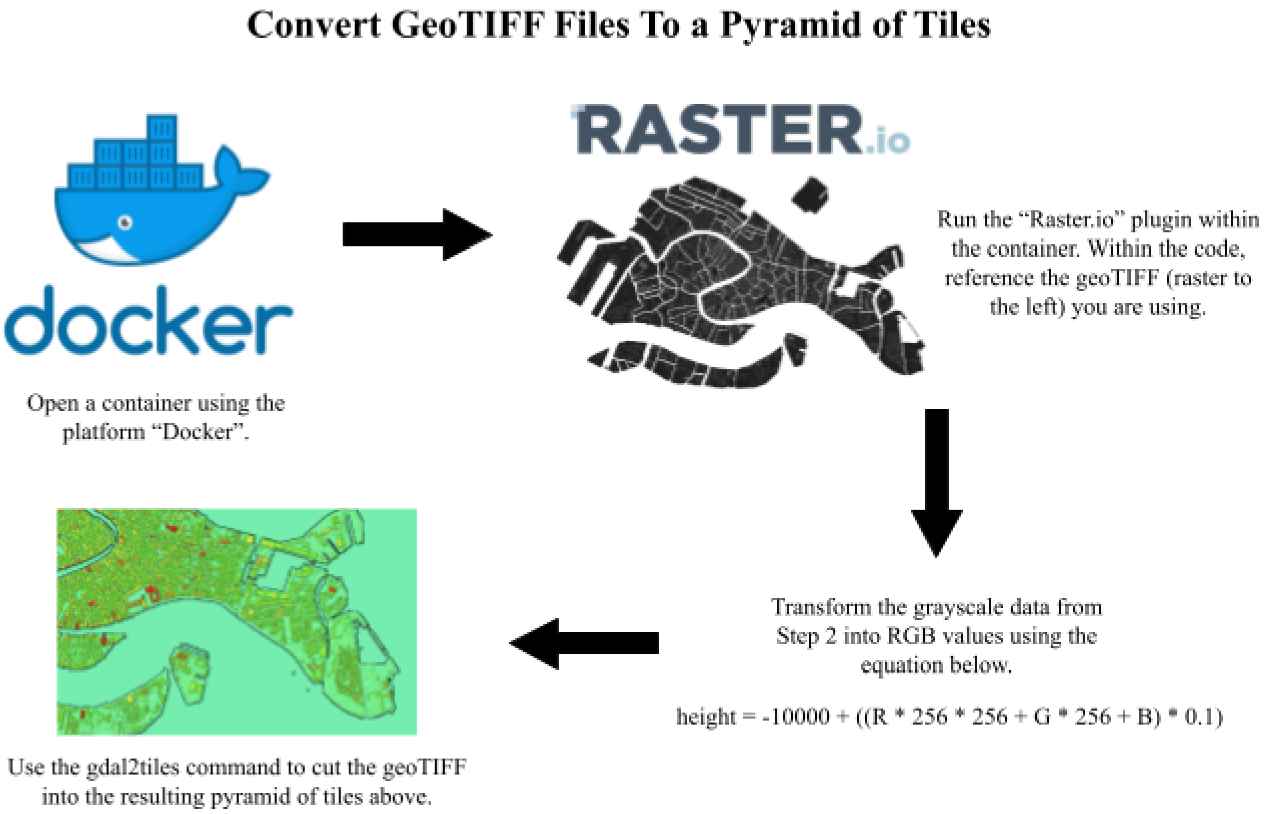
GeoTIFF, the data type (elevations are usually a Float32 type), and the value used to encode the semantic of *no data available* (Halwax, 2020).

From this information, the Simtable team reprojected the GeoTIFF so the tiles would use the WebMercator projection EPSG:3857. The command "gdalwarp" was used to reproject the file, and the value used for *no data available* was reset to "None". The purpose of this was to map the elevation values from a 32 bit signed float to 3 unsigned bytes. The previous value for this semantic was out of scope for the unsigned values (Halwax, 2020).

The resulting file had the coordinate reference system of EPSG:3857 and an increased resolution size. QGIS was used to visualize the grayscale area where the "No Data" values could be represented by the black around the areas of elevation. From this point, the formula used to calculate the elevation when transforming the data into RGB data was:

$$height = -1000 + ((R * 256 * 256 + G * 256 + B) * 0.1)$$

The base value of the equation was set to -1000 and the interval, or precision of the output, was set to 0.1. A folder was created for the tiles to be exported to once the "gdal2tiles" command was executed. This command "cut" the GeoTIFF into a pyramid of tiles. A pyramid is a downsampled version of a raster dataset and contains downsampled layers. To move the tileset into an MBTiles container, the tool "mbutil" was used to import a metadata.json file. From here, the Simtable team uploaded the container to the software so the correct elevations could be projected onto the sand (Halwax, 2020).



Convert GeoTIFF Files To a Pyramid of Tiles

Open a container using the platform "Docker".

Run the "Raster.io" plugin within the container. Within the code, reference the geoTIFF (raster to the left) you are using.

Transform the grayscale data from Step 2 into RGB values using the equation below.

height = -10000 + ((R * 256 * 256 + G * 256 + B) * 0.1)

Use the gdal2tiles command to cut the geoTIFF into the resulting pyramid of tiles above.

Figure 15: Graphic outlining steps to convert a geoTIFF to a pyramid of tiles.

3.5.3 Modeling Events

We began by using the Simtable Flood and Storms module to produce various climate scenarios. The module includes the following components: flooding from dam breaches, hurricane torrents, and other surge models. The technology allows for water to be initiated from a single source or in the form of a rainstorm with customizable water volume settings. For our project, we used the "Release" feature as the result the most accurate to a flood. For a flood, AnyHazard uses a process called a "breadth first traversal" which checks the elevation value of the pixel where the water release began. If the flood height is greater than the elevation of that area, it floods. If it is less, the area does not flood. The algorithm moves through the adjacent pixels after it determines the result of the initial pixel.

For each simulation, we designed several combinations of tide heights and wind direction to produce distinct events which can be modeled. The clipboard feature within the table allowed the user to specify the exact height, in whole feet, and location that water would be released at. The option to use centimeters for the height of release is not currently available. We began at tide heights of three feet, and simulated heights in increments of one or two feet depending on the area of the region we were in. For example, Piazza San Marco floods at four feet but stays dry at three feet, while other areas needed to be increased by two feet to see a difference. The areas which will be simulated include specific areas within the city of Venice, the surrounding lagoon, and the Lido. The specific areas we chose to simulate within the city include Giudecca and San Marco.

Additionally, our team chose to model fires in the Veneto region. For fire, AnyHazard uses a process called "rate of spread" which is determined by slope, wind, and fuel type. For example, a fire moving uphill in an area composed of timber will have a faster rate of spread than a fire in a flat urban area. The fire begins at one area and moves to a neighboring pixel once a certain amount of time, or rate of spread has elapsed.

The various simulations produced inundation maps and evacuation models. Videos and other imagery of the table in use will be captured and uploaded to our team website in order to recount the process and the results of using the technology.

3.6 Results and Analysis

The following images show the results of various flood heights in the San Marco sestiere. In Figure 16, we see that in the 90 centimeter tide some pathways flood but the square stays dry. This contradicts recent events, as the square has flooded following tides of 82 centimeters. The area to the bottom left of the Royal Gardens (red arrow) was flooded, as well as the walkways on the outer edge of the city. Other areas of the sestiere, such as Campo Manin in the upper left of the figure, is only partially flooded.

Figure 16: Results of a 90 centimeter tide in the San Marco sestiere.

In the 120 centimeter tide, Figure 17, the whole square is underwater. This is nearly the height of the 2019 flood, when certain parts of the basilica were underwater for over 24 hours. Both the northern and southern sections of the Royal Gardens are more flooded than in the 90 centimeter tide. Other sections of the sestiere also appear more flooded than they were in the 90 centimeter tide, such as Campo Manin near the upper left in both figures.

Figure 17: Results of a 120 centimeter tide in the San Marco sestiere.

180 centimeters of tide is on the upper end of the height of acqua altas usually seen by Venice. In the 180 centimeter tide, Figure 18, the whole square is underwater. This is nearly the height of the 2019 flood, when certain parts of the basilica were underwater for over 24 hours.

Campo Manin is entirely flooded, and the majority of the Royal Gardens are submerged. There are an increased number of walkways in this tide that are more flooded than the previous tides.

Figure 18: Results of a 180 centimeter tide in the San Marco sestiere.

The next simulation models are located at the island of Giudecca, part of the Dorsoduro sestiere and centered around where the project center is located. In Figure 19, the 90 centimeter tide floods pathways nearest to the edge of the island but leaves many streets clear. A large portion of the walkway on the northern edge of the island is flooded, but a small portion is still above water.

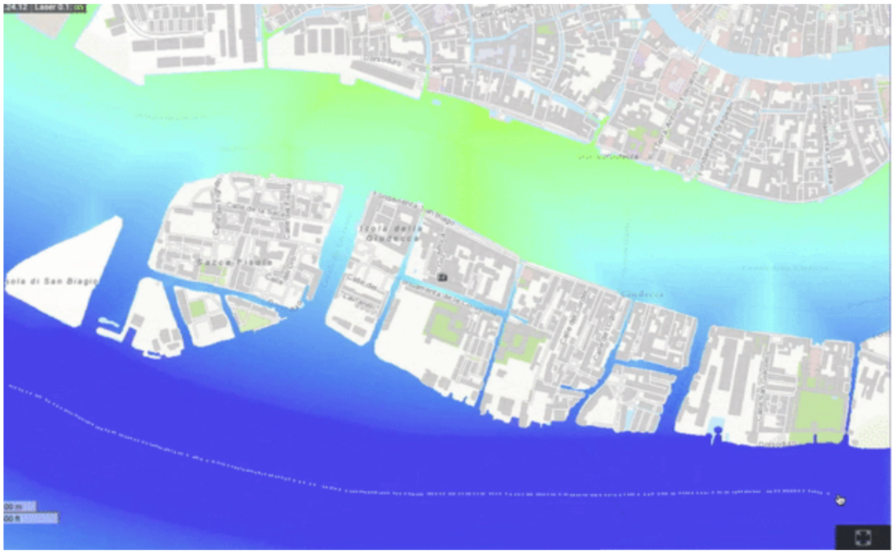


Figure 19: Results of a 90 centimeter tide at Giudecca.

In Figure 20, the 120 centimeter tide floods more streets and courtyards than in the 90 centimeter high tide. More walkways are flooded, and the tide reaches major courtyards and open areas leaving small areas that appear to be flooded. The center of the island remains unflooded, meaning at this point the acqua alta still only affects the outer portion of the island closest to the lagoon.

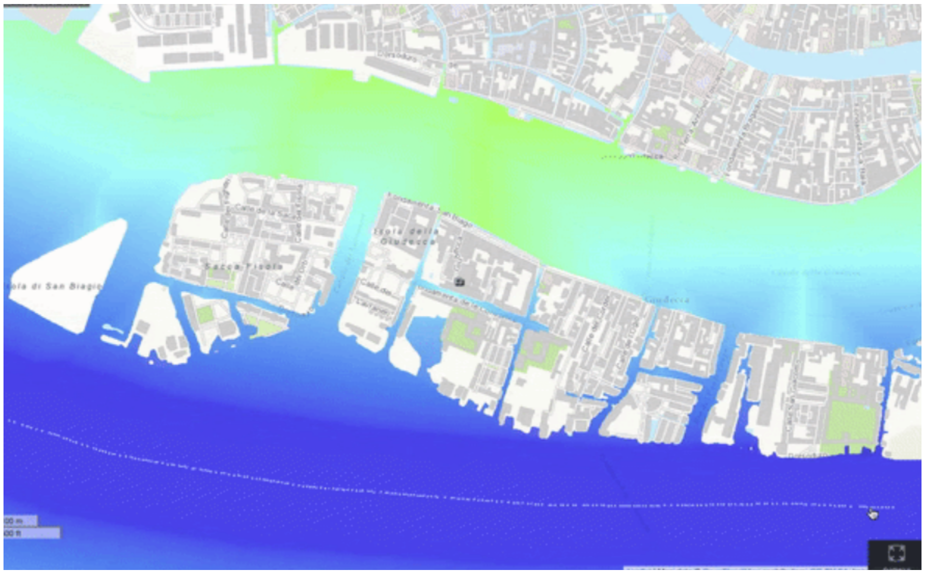


Figure 20: Results of a 120 centimeter tide at Giudecca.

In Figure 21, the 180 centimeter tide floods most streets and courtyards, putting a very large portion of the island underwater. Entire walkways are flooded, and the tide reaches major courtyards and open areas. The areas of the island that are not flooded at this height, are the areas that are enclosed by buildings. Therefore, the vast majority of areas that are not shielded by structures would be submerged at this tide height.

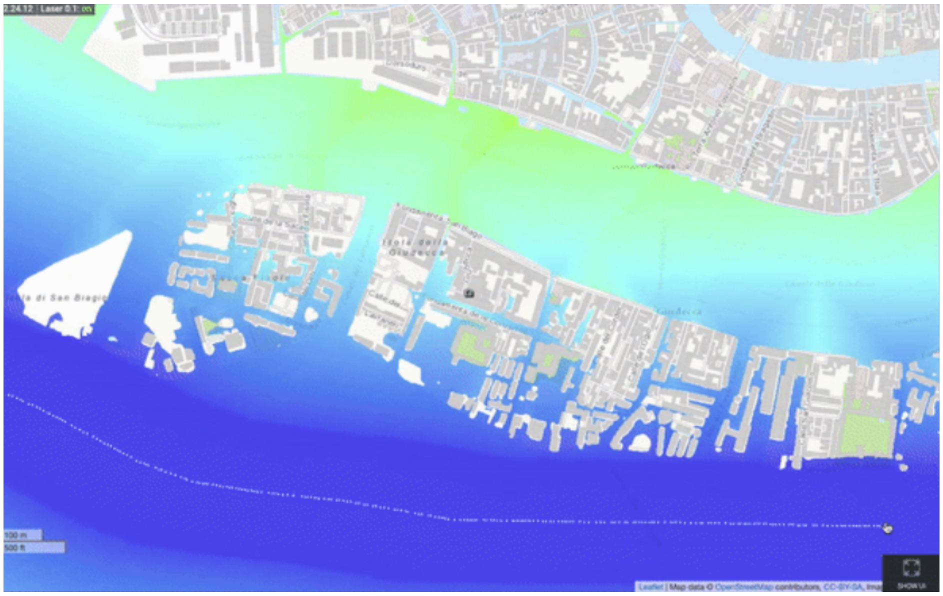


Figure 21: Results of a 180 centimeter tide at Giudecca.

The barrier islands to the lagoon, Lido and Pellestrina, have a slightly higher elevation than the main city which reduces the amount of minor flooding they experience. However, these islands are the main defense for the historic city, and have no means of protection other than a flood wall known as the murrazi. This flood wall was built on the ocean side of most of the Lido and all of Pellestrina.

Figure 22 is a flood model of a 125 centimeter tide on a section of the Lido. In this model, the dark blue areas show areas of elevations lower than 125 centimeters. On the eastern side nearest to the Adriatic Sea, the beaches are flooded up to a small point past the shoreline, but are not completely submerged. Within the island itself, there is minor flooding in some areas, but the majority of the area inland remains dry.

Figure 22: Results of a 125 centimeter tide at the Lido.

Figure 23 is a flood model of a 187 centimeter tide on the same section of the Lido as in Figure 22. In this model, the dark blue areas show areas of elevations lower than 187 centimeters. As seen in the figure, on the eastern side of the island nearest to the Adriatic Sea, the beaches are flooded up to the midpoint between the walkway and the shoreline. Inland of the seawall, there is a large area in the center that becomes flooded in this model.

Figure 23: Results of a 187 centimeter tide at the Lido.

It is important to note that Figures 22 and 23 are only flood models of a certain section of the Lido and are not simulations. The models show in dark blue the areas of the barrier island that are lower than a certain elevation (in these cases it was 125 and 187 centimeters). Therefore, there is no way to determine if the areas inland of the seawall would actually become flooded at these tide heights. In the previous simulations of San Marco and Giudecca using the Simtable, the buildings blocked the flow of water to courtyards and other areas. In this flood model using ArcGIS Pro, the flood water appears at all areas regardless of an open path to reach that location. Therefore, the ArcGIS flood models do not account for buildings or other structures that might obstruct the flow of the water.

Chapter 4: Future Recommendations

Currently, the water module in Simtable is optimized for showing estimates for large scale flooding, for example a dam break. To expand the capabilities, our team created a suggested interface for the theorized "tides" function. Though this could not be added in the timeframe of our project, its addition would allow for more accurate simulations for flooding in Venice and other coastal areas.

4.1 Interface Suggestions

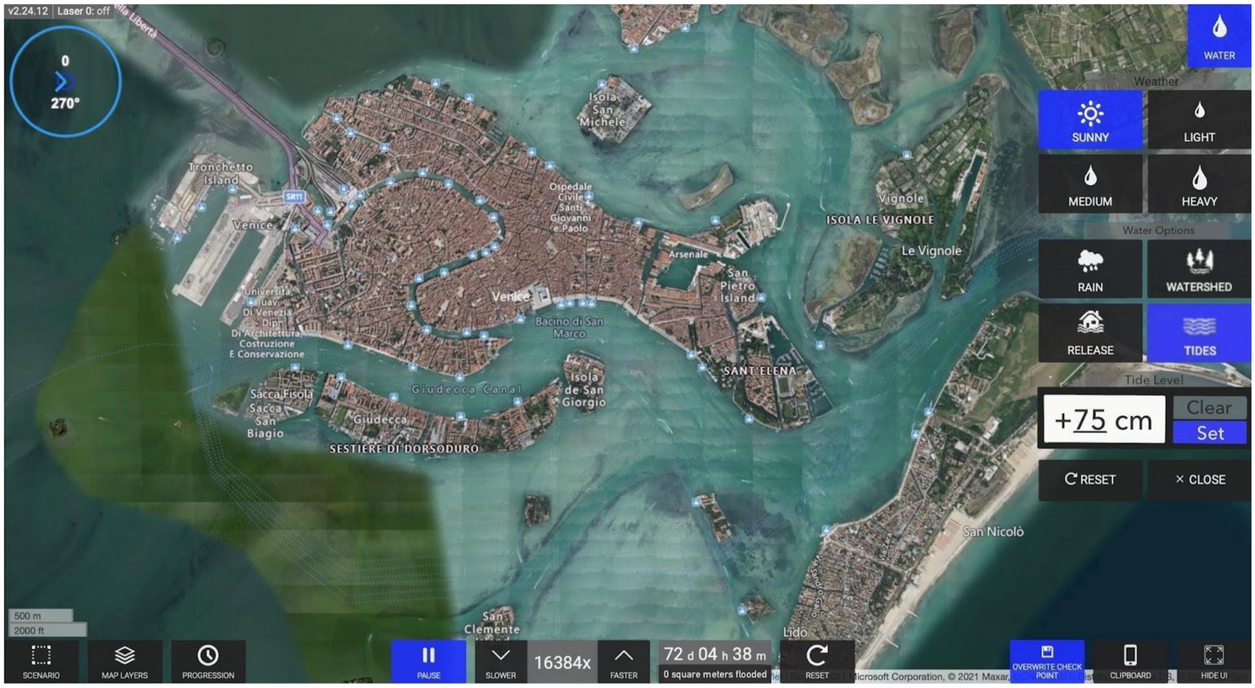


Figure 24: Suggestions for the Simtable water module interface.

There are three key differences of the tides interface compared to the current version. First, "tides" button is added to allow the option of changing the overall water level. Second, the interface for setting the water level, using the base sea level and either adding or subtracting the desired amount. This can be set using the keyboard to type in the level in centimeters. Lastly, "acres burned" is changed to "square meters flooded" when in the water option, to better represent the simulations.

Conclusion

Venice remains at the forefront of climate change because of its geography; its low elevation and placement within a lagoon on the Adriatic Sea make it susceptible to rising sea levels and tides. The current rate at which the world is producing greenhouse gas emissions would contribute to one meter worth of sea level rise between 100 and 200 years from now. When these numbers are combined with a rough change of two meters between high and low tides, Venice will see its lagoon barrier islands and MOSE tide defense gates overtopped by the Adriatic Sea.

November of 2019 brought some of the worst flooding Venice has seen in its over 1000 years of history. The second highest tide on record (187 centimeters) combined with a week of tides reaching 150 centimeters lead to nearly a billion euros in damages to the historic city. If Venice's tide defense gates and lagoon barrier islands are overtopped, flood levels will approach three meters in height, spelling disaster for not just Venice, but the whole Veneto coastal region.

The scope of the potential disastrous effects of sea level rise spells for Venice indicates the need for Simtable to help model flooding events to help educate both emergency responders and the public on how to safely respond. While simtable's flood modeling capabilities are still being developed, the flood simulations we produced after updating the elevation data for the historic city show, within roughly 10 centimeters of accuracy, where flooding will take place. In the San Marco region of Venice, we see a stark difference between a 90 centimeter tide and a 180 centimeter tide. Longer sections of walkways and larger plazas become flooded in a 180 centimeter tide when compared to the 90 centimeter tide. We see an even more drastic difference on the island of Giudecca. Most of the island remains untouched by a 90 centimeter tide, yet with a 180 centimeter tide, most of the island goes underwater. When looking at ArcGIS simulations for the Lido island of the Venice lagoon, we also see similar results.

Despite the ability to model flooding fairly accurately, the slight inaccuracies demonstrate the need for even more precise elevation data, as even only a few centimeters of water has the potential to cause large amounts of damage. Venice, along with other countries and coastal cities around the world, has shown the need for highly accurate flood modeling tools as sea levels continue to rise with climate change. Simtable, as long as it is continually developed, fills this need and will hopefully help save lives and educate society on how to deal with flooding safely and efficiently.

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Appendices

Appendix A: Definitions

Analysis is the mode in which new ideas and determinations are formed.

Arithmetic procedures entail basic mathematical calculations between attribute sections.

Buffers survey the proximity between features.

Categorical manipulations is the process of re-organizing data sets into new categories.

Docker is an open source platform for developing and running applications.

Geospatial Data Abstraction Library (GDAL) is a software library for reading and writing raster and vector geospatial data formats.

GeoTIFF enables geospatial metadata to be embedded into image files to be used for GIS applications.

Inundation correlates to flooding.

Least-cost path investigates the "method of least resistance" with regard to time, effort, cost between two geographic points.

Lidar is a remote sensing method that uses light in the form of a pulsed laser to measure various distances to the Earth.

Overlays explore the ways spatial phenomena are related.

Plugin is a software component that adds a feature to an existing program.

Queries recover data from systems based on the characteristics of the data.

Raster is a matrix of cells that contains various information, one of which being elevation.

Rasterio is a geospatial data abstraction library that uses python to read and write raster and vector data.

Semantic is the study of meaning.

Vector is a data model that represents geographic features as points, lines, and polygons.

Web-Mercator Projection is a variant of the Mercator projection and has become the standard for web-based mapping.

Appendix B: GeoTIFF Files

Rasters used for the red-green-blue tileset to be imported into the Simtable were in the format of GeoTIFFs. A GeoTIFF format enables geospatial metadata to be embedded into image files to be used for GIS applications.

Figure 25: Clipped section of a raster layer on top of an OSM Standard basemap showing elevations of the historic city and a section of the Lido.

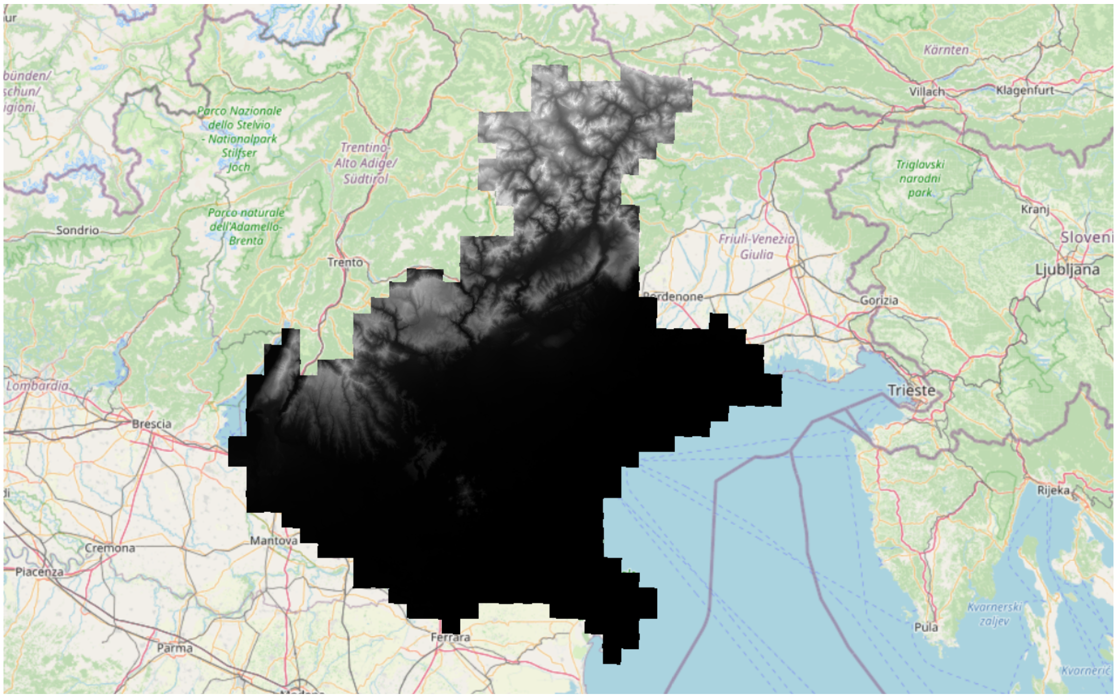


Figure 26: Raster layer of the upper Veneto region on top of an OSM Standard basemap. Black areas depict "no data" values and the grayscale indicates elevations for Dolomites.

Appendix C: High Tide Graph Data

The following graphs represent tide heights in Venice over the course of a 24 hour period in which the height, in centimeters, reached a maximum value for that given year. Our sponsors also requested data and timestamps of the tide progression for the tides between 2009 and 2019. While only the graphs for the highest tide each year are shown, we possess the data for every day of each year from 2009 to 2019. This data may also be found on the City of Venice's website.

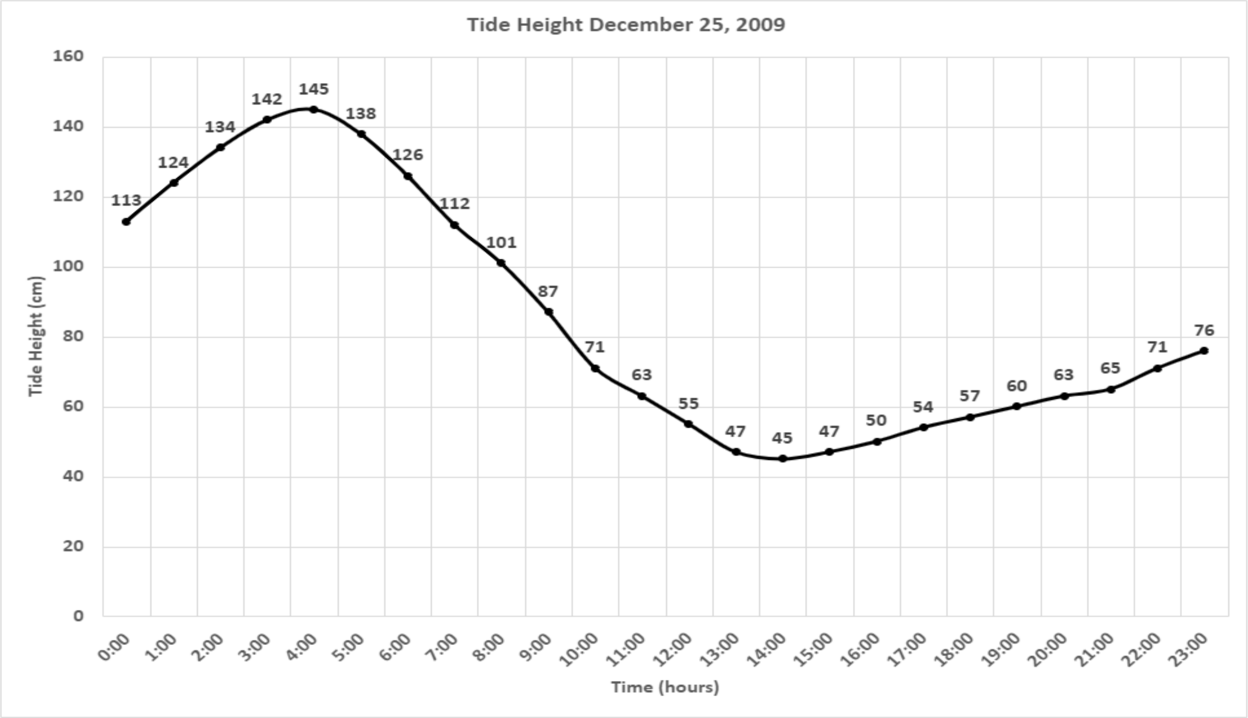


Figure 27: 24-Hour Tide Height Data for 25 December 2009.

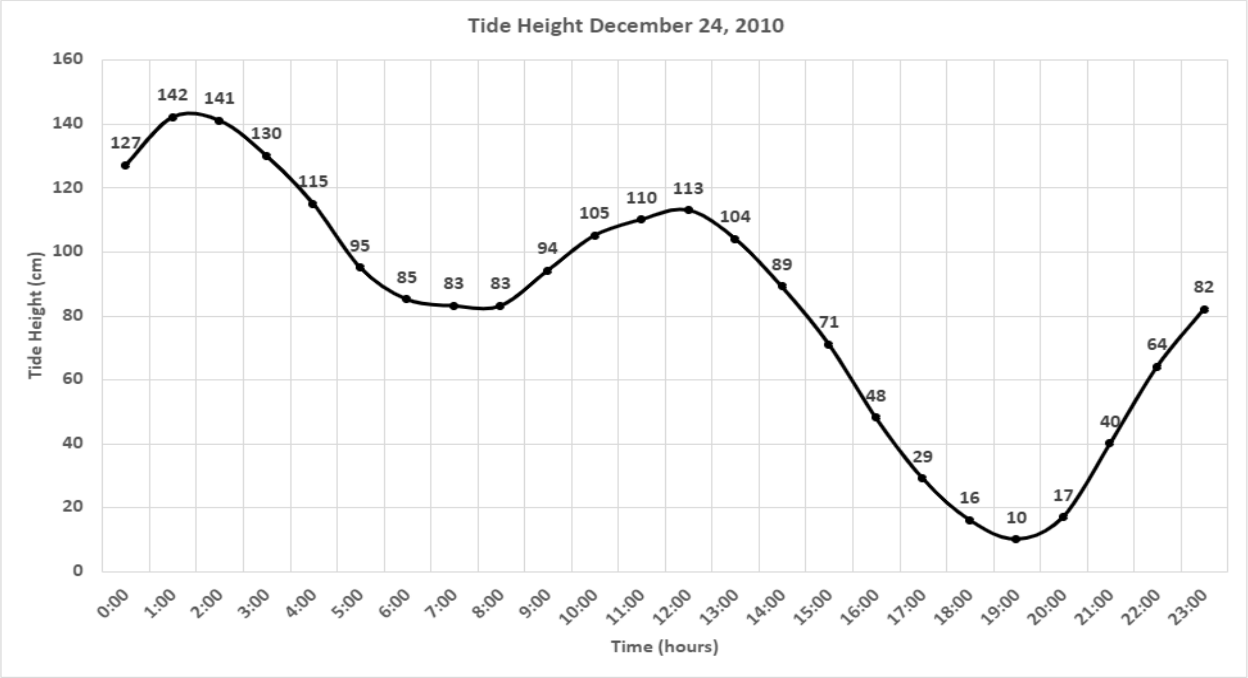


Figure 28: 24-Hour Tide Height Data for 24 December 2010.

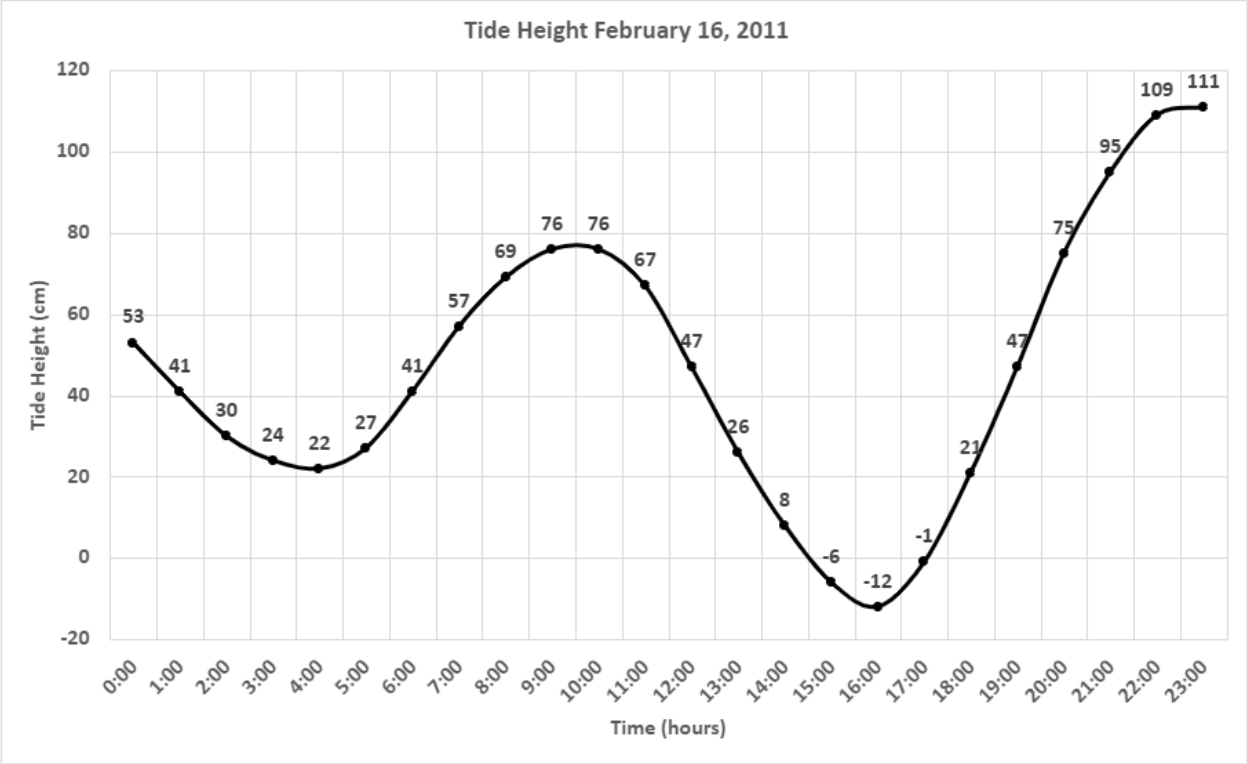


Figure 29: 24-Hour Tide Height Data for 16 February 2011.

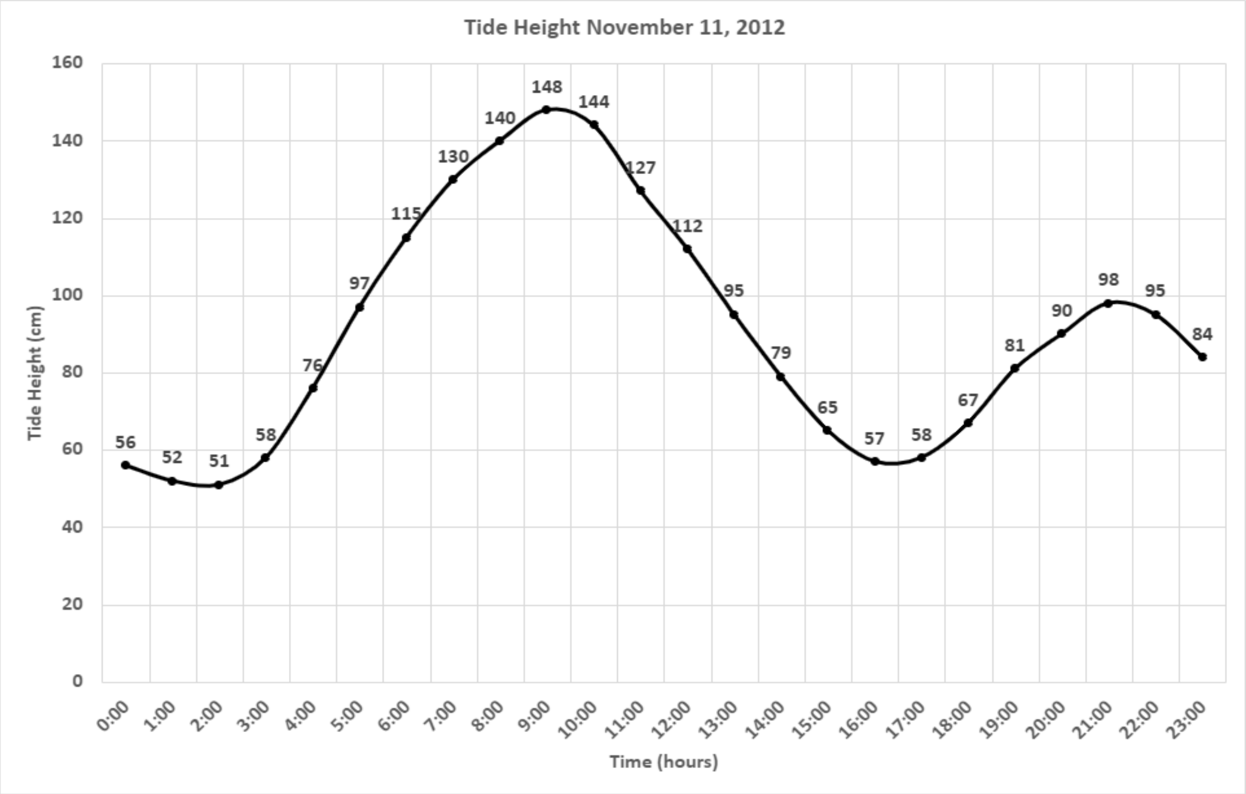


Figure 30: 24-Hour Tide Height Data for 11 November 2012.

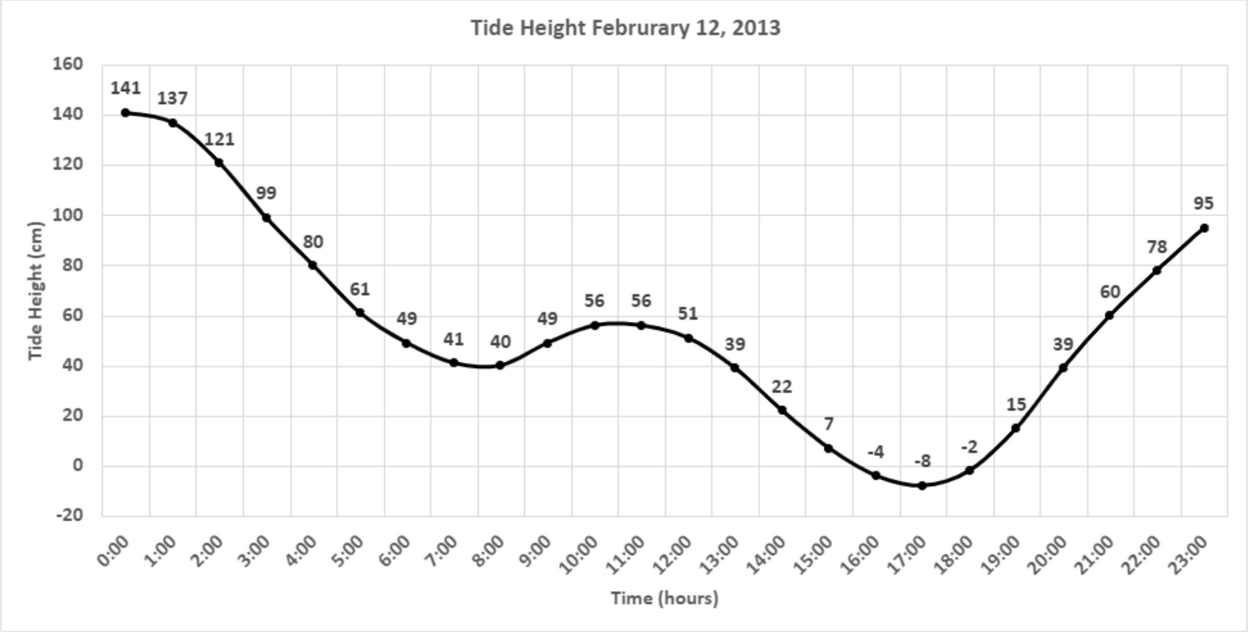


Figure 31: 24-Hour Tide Height Data for 12 February 2013.

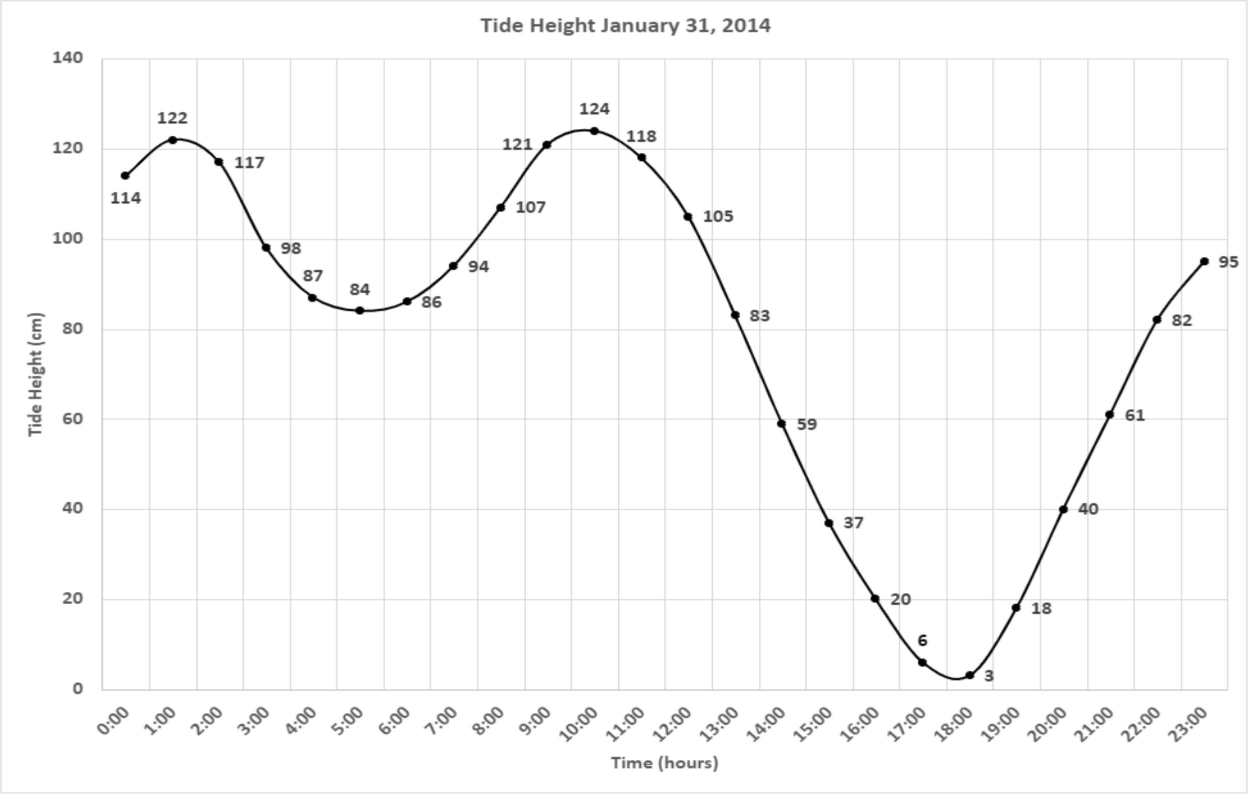


Figure 32: 24-Hour Tide Height Data for 31 January 2014.

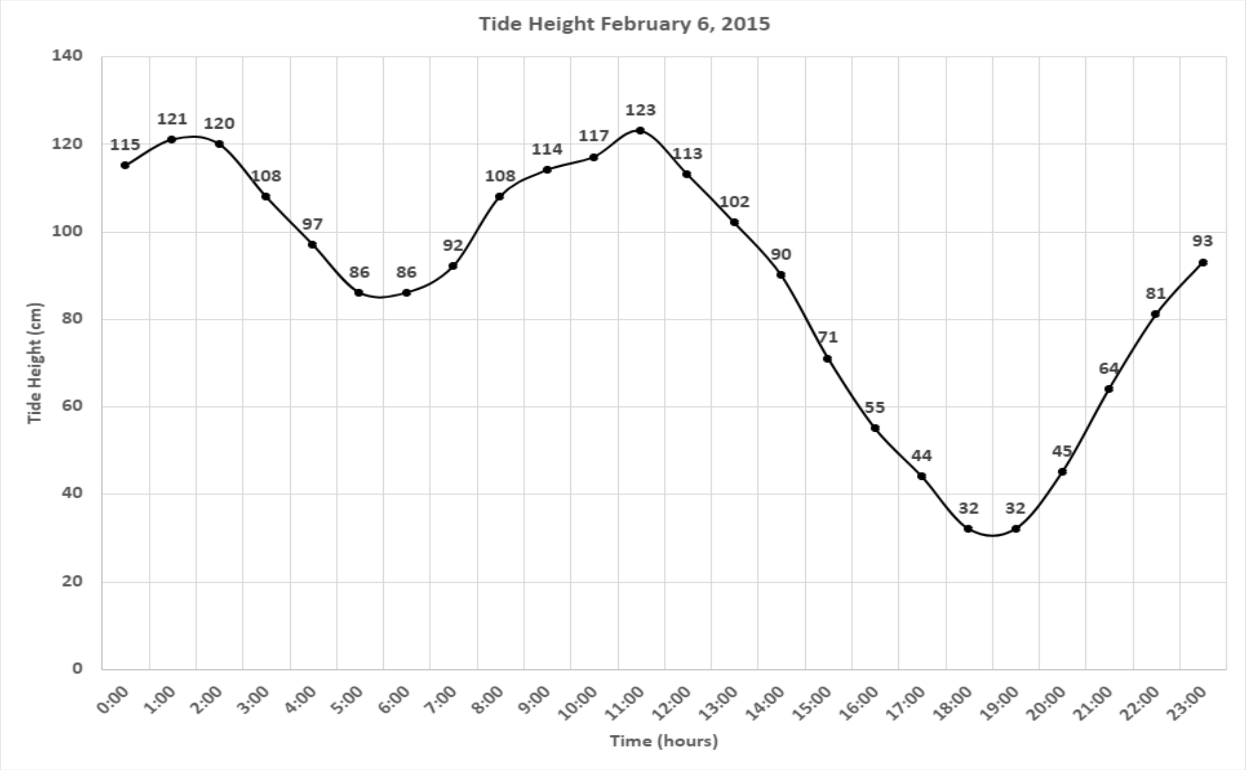


Figure 33: 24-Hour Tide Height Data for 6 February 2015.

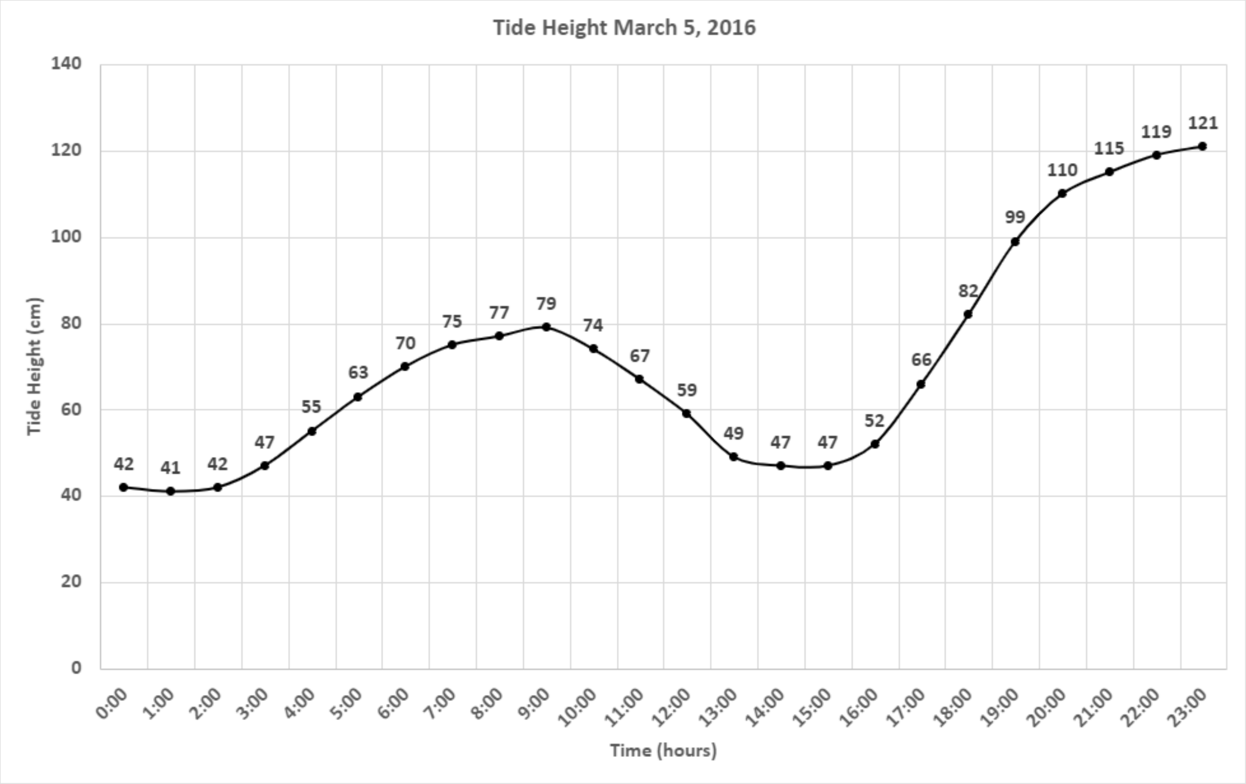


Figure 34: 24-Hour Tide Height Data for 5 March 2016.

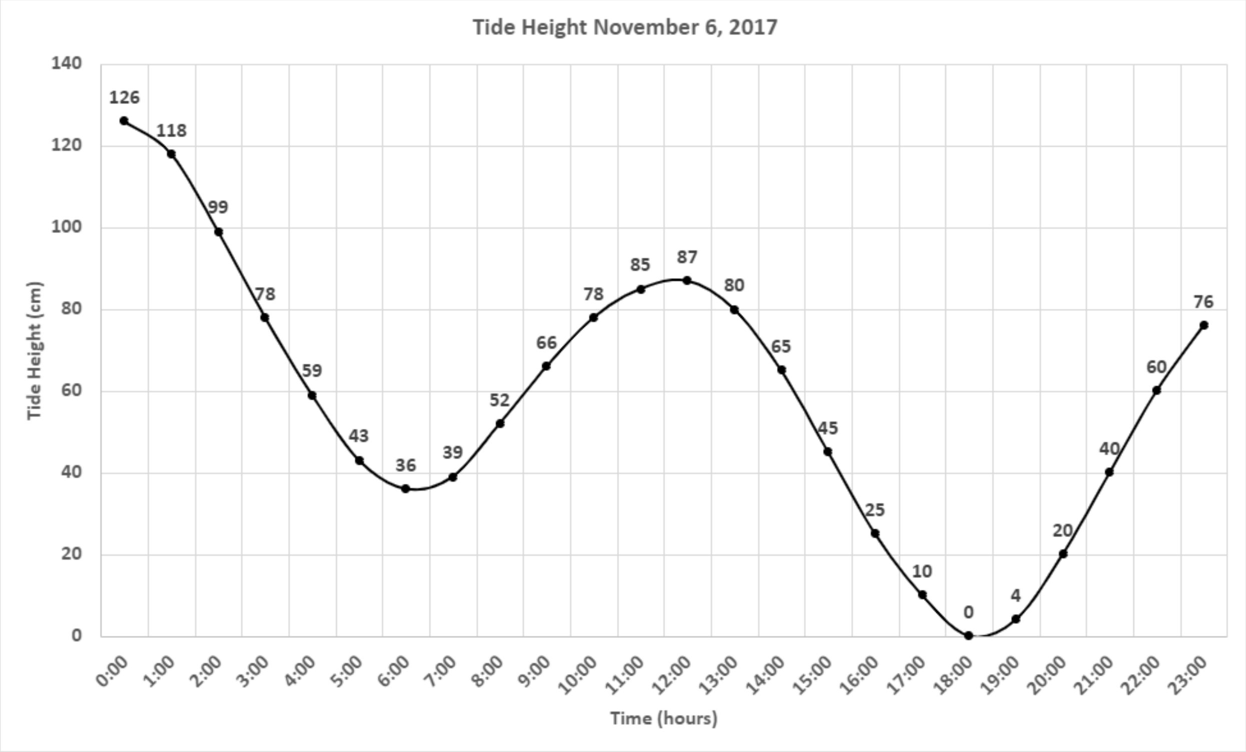


Figure 35: 24-Hour Tide Height Data for 6 November 2017.

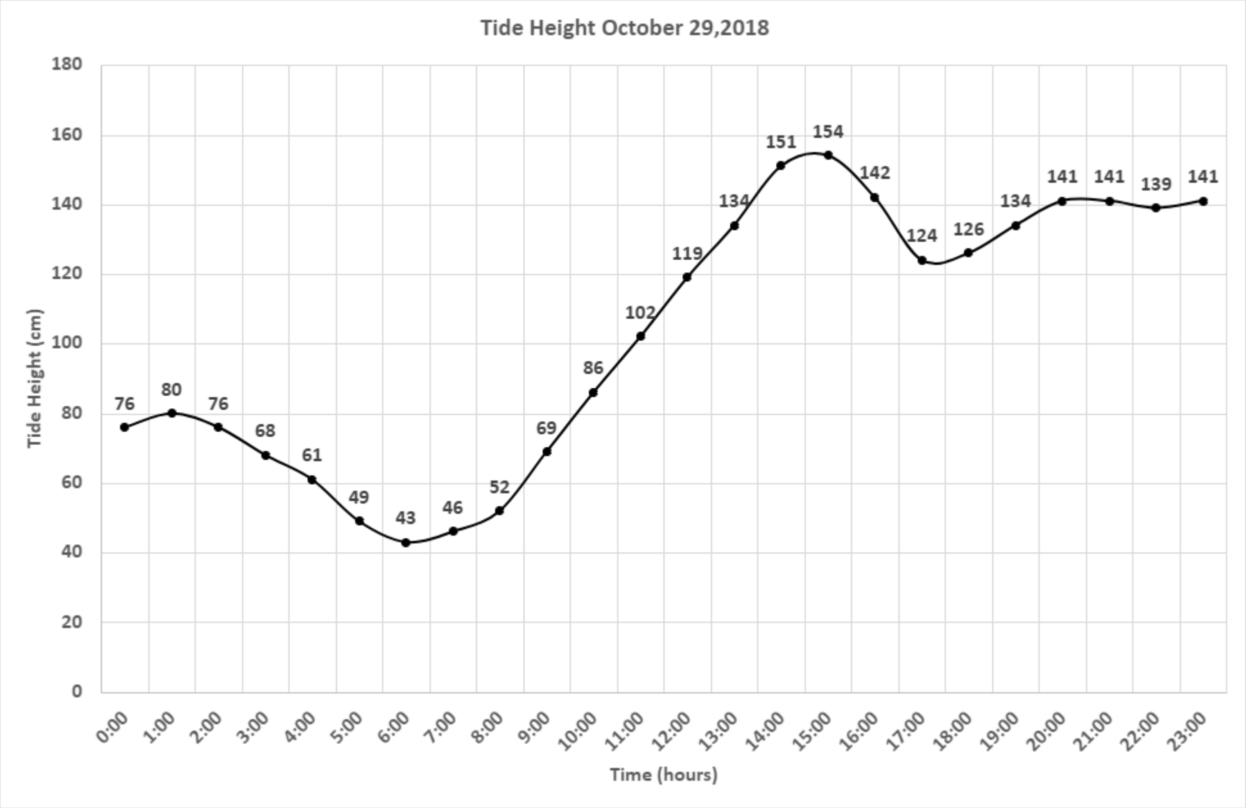


Figure 36: 24-Hour Tide Height Data for 29 October 2018.

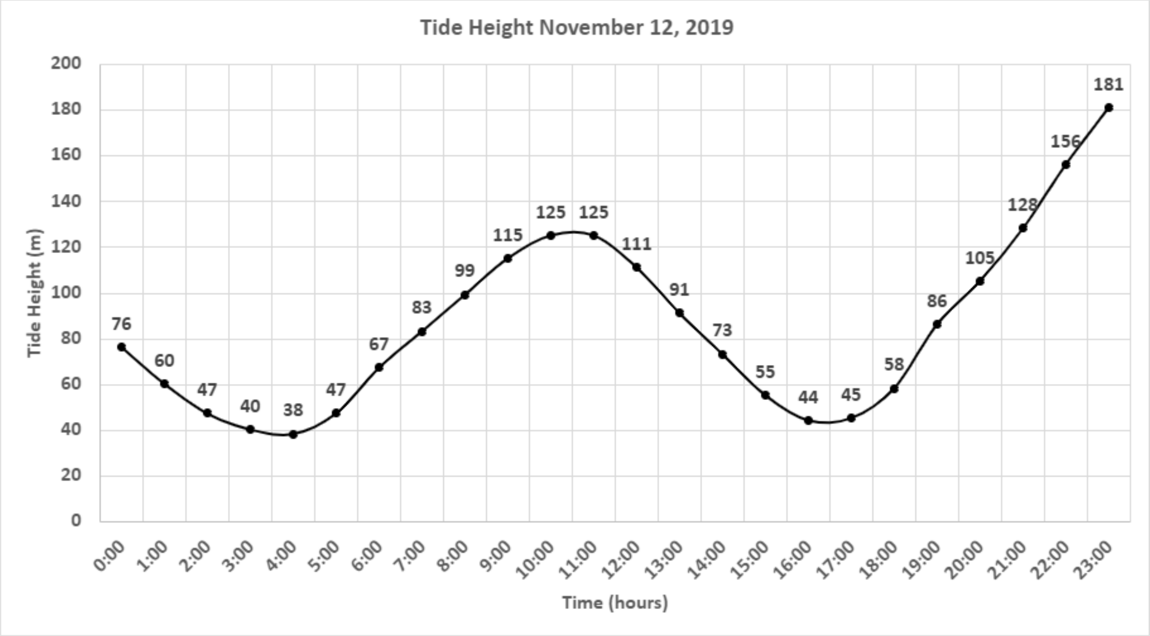


Figure 37: 24-Hour Tide Height Data for 12 November 2019.

Figure 38: 24-Hour Tide Height Data for 8 December 2020.

Appendix D: Geographic Information Systems

Geographic information systems (GIS) use computer technology and captured information to display data relative to positions on the Earth's surface (Evers, 2020). GIS software can read data as long as the information includes location (latitude, longitude, address, or zip code) (Evers, 2020). The technology can produce information about population sizes, landscape, and income as well as display spatial relationships (topography) and linear networks (roads, rivers, utility grids) (Evers, 2020). Geographic information systems are used frequently and extensively when researching cities. GIS-based research frequently assumes the form of a map, whether the mode of viewing is paper, web-based or found on a mobile app (Ward & Wilson, 2020). GIS has the capability to be the driving force behind the organization of groups and their representation.

Appendix D.1 ArcGIS Pro

ArcGIS Pro is a GIS software developed by ESRI. The software allows the user to create 2D and 3D maps for the purposes of exploring, visualizing, and analyzing data. The application includes a wide variety of tools within the Geoprocessing Pane. ArcGIS uses layers to build each map in 2D, and from this point features can be extruded to a 3D view. All data is imported from the ArcGIS Online library. Data includes map, tile, feature, and imagery layers.

Appendix D.1.1 Raster Calculator Tool

Applies a mathematical equation to an existing raster to create a new raster which estimates the extent of a flood within the map. The expression contains a set "flood value", which is compared to each pixel in the existing raster. Values of "1" or "0" are assigned to each pixel depending if the named value of the new raster is greater or less than each pixel. Values of "1" represent the flooded region and values of "0" represent regions that are not flooded.

Appendix D.1.2 Zonal Geometry Tool

Calculates the area for each zone of a raster. The flooded area is equal to one square meter (cell size) multiplied by the number of cells in the flood raster with a value of "1". After the tool is executed, the user can click on any area of the raster to see the total area of the flood zone.

Appendix D.1.3 Raster to Polygon Tool

Converts a raster layer to a polygon layer so that the layer can be extruded to a 3D view. When the polygon layer is created, the user can use the Attribute Table to add and calculate height values which can be extruded using the properties tab of the layer.

Appendix D.1.4 Polygon to Raster Tool

Converts polygon features to a raster dataset. The input field type determines the type of output raster. Users can specify a double, floating point, or string as the input.

Appendix D.1.5 Times Tool

Multiplies the values of two rasters on a cell-by-cell basis. To convert a raster from meters to centimeters, the user can set the “input raster or constant value 1” to be the raster layer that needs to be converted. The “input raster or constant value 2” can be set to 100, as that is the conversion factor between meters and centimeters.

Appendix D.1.6 Mosaic to New Raster Tool

Merges various raster datasets into a new raster dataset. User specifies the input rasters, the location where the new raster will be outputted, the new raster name with the file extension, the spatial reference, pixel type, cell size, number of bands, mosaic operator, and the mosaic colormap mode.

Appendix D.2 Conversion of Data to RGB Values

The simulation table uses red-green-blue values of data to display elevation surfaces on a map. To project these values, the data must be imported into the table through a Mapbox Python container. Mapbox allows users to create custom online maps, and the Python container is used to access certain commands and objects which can be iterated through. Tools needed for this conversion process are Docker, Rasterio, and plugins from the Mapbox RasterIO Plugin Registry. To be analyzed and converted, the file must be downloaded as a GeoTIFF file. Code for the process is found at: https://github.com/syncpoint/terrain-rgb

Appendix E: Simtable

Simtable uses interactive simulations to visualize hazards including wildfires, floods, and storms. The set-up includes a projector, laser pointer, keyboard, mac mini, and crushed walnut shells which act as the sand. The technology uses geographic information systems to produce a map which is projected onto a sand table. On the table, the user can mold the sand to the topography of the land area being projected. Then, a land cover map can be projected onto the table and fuel layers (trees, grass, water, timber) can be drawn with a laser pointer. After maps and fuel are added, the user can simulate wildfires, floods, gaseous plumes, and storms to see the effects on the area.
https://www.simtable.com/manual/

Appendix E.1 User Basics

Powering On
The Mac mini, located on the back of the projector, has a power button in the top left corner of the computer (Figure 39). After pressing the power button on the computer, a small light indicator on the right side of the computer will turn on (Figure 40). The projector may be turned on using either the power button on the remote, or the button located on the front of the projector (Figure 41).

Figure 39: Mac Mini Power on Button.

Figure 40: Mac Mini Power on Light.

Figure 41: Projector Power on Button.

Interface Overview

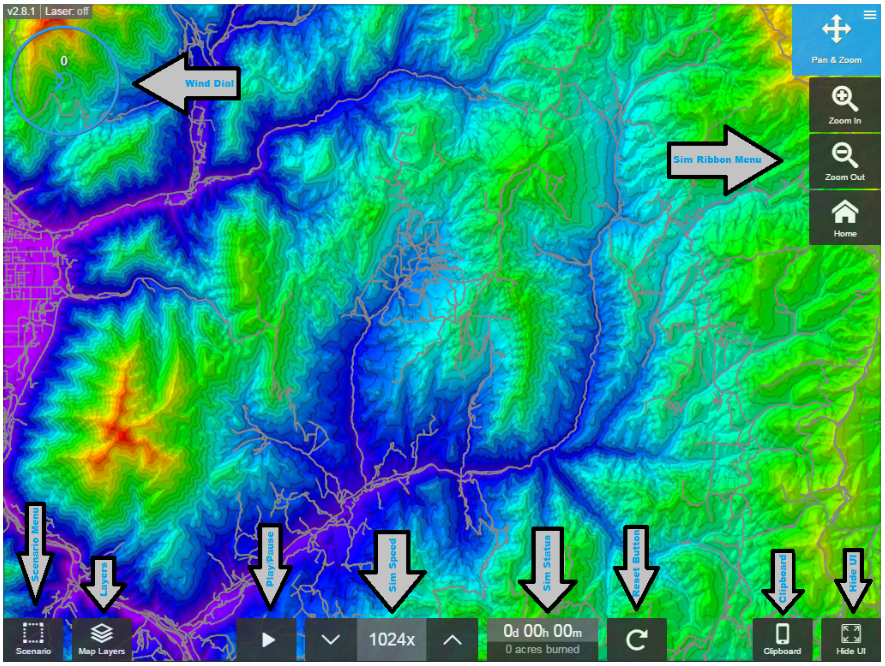


Figure 42: Main Interface (Guerin).

Wind Dial

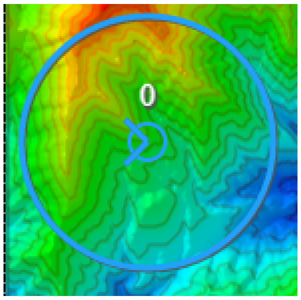


Figure 43: Wind Dial (Guerin).

The wind control (Figure 43) is located in the top left corner of the interface. The wind speed and direction can be altered by clicking and dragging the arrow. Increasing the arrow length will increase the wind speed. The maximum wind speed that can be displayed is 60 mph (Guerin).

Tools Menu

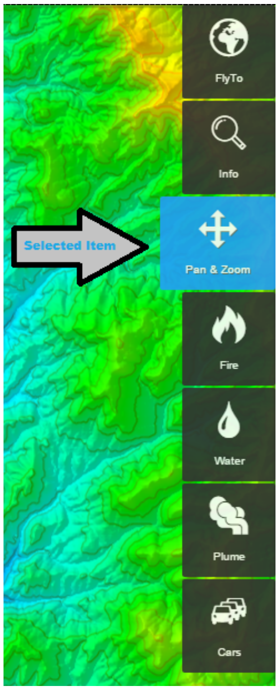


Figure 44: Tools Menu (Guerin).

If the tool menu is not displayed as in Figure 44, click the icon in the top right corner of the interface and the tool menu will expand. The various simulation functions can be accessed via this menu (Guerin).

Scenario Menu

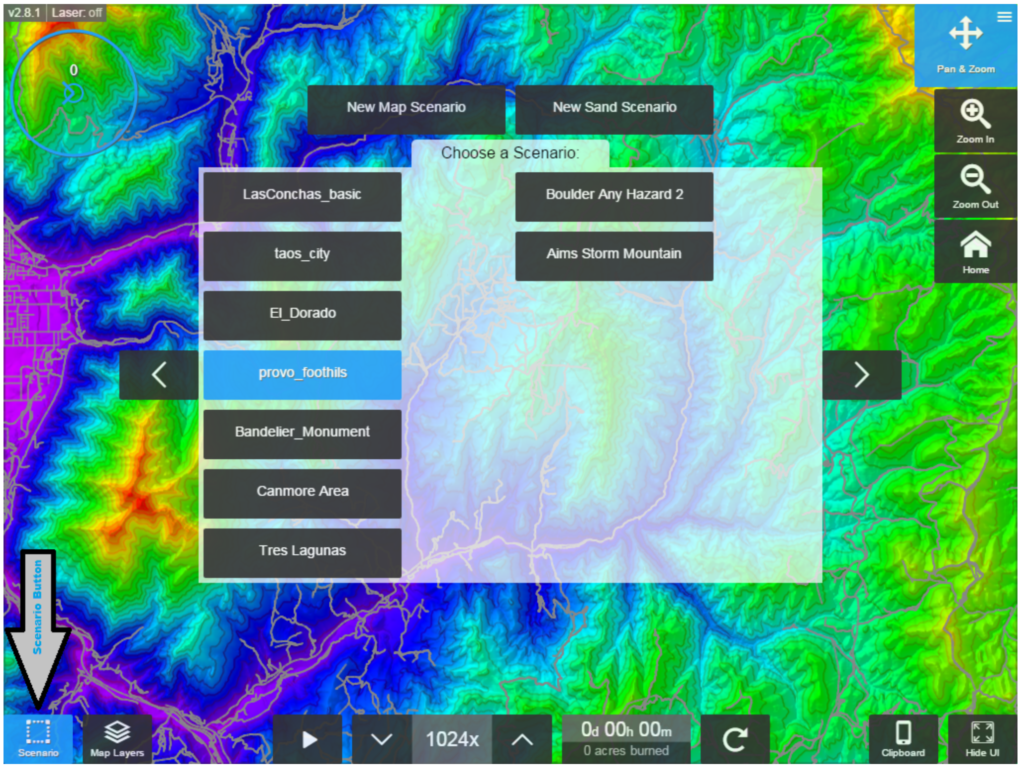


Figure 45: Scenario Menu Button (Guerin).

Clicking on the Scenario button in the lower left corner of the screen will bring up the menu displayed in Figure 45. To load a simulation scenario, click one of the names listed under "Choose a Scenario". To create a new scenario, click either "New Map Scenario" (Figure 46) or "New Sand Scenario" (Figure 48) (Guerin).

New Map Scenario

Figure 46: Map Scenario Button (Guerin).

To create a new map scenario, click the "New Map Scenario" button. This will bring up a map where you may enter the real world location of where you wish to create a new simulation (Guerin).

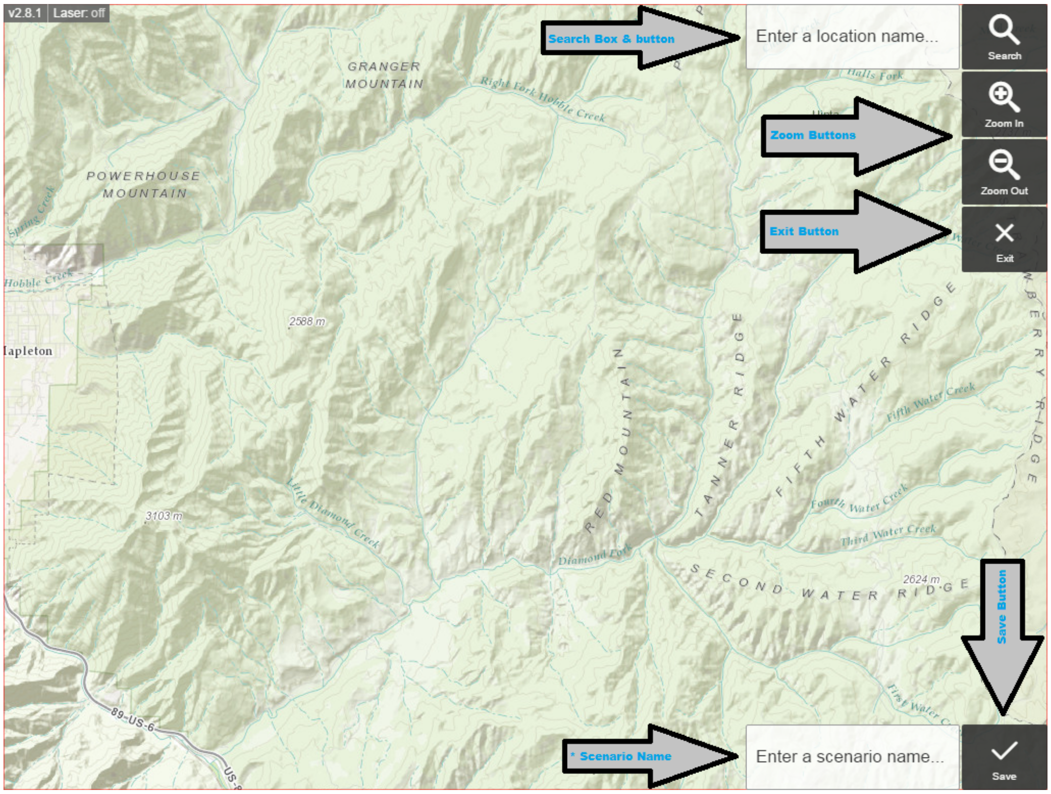


Figure 47: Map Scenario Creator (Guerin).

To search for a location, enter the name in the top right search bar on the screen (Figure 47). The view of the location can be adjusted using the pan and zoom functions. To save and load the scenario, a name must be entered in the bottom left bar and saved (Figure 47). Once the "Save" button is clicked, the created scenario will be loaded (Guerin).

New Sand Scenario

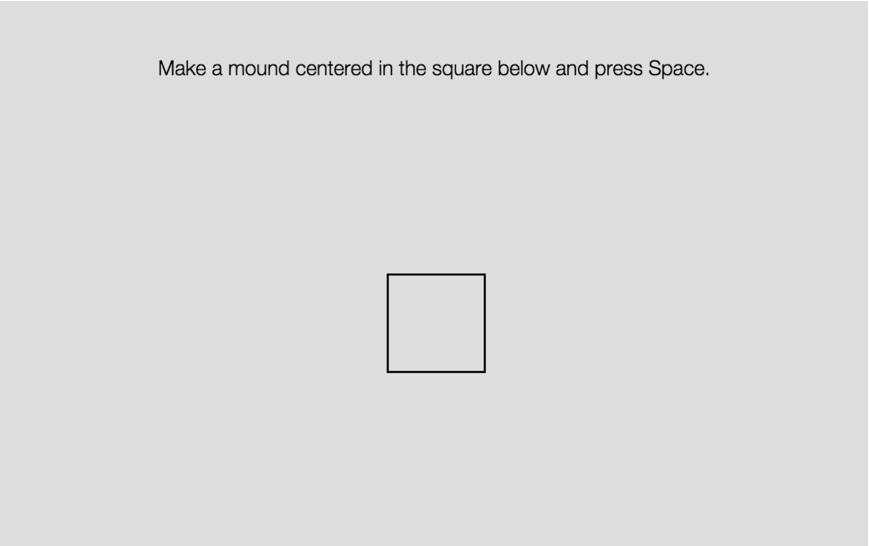
Figure 48: New Sand Scenario (Guerin).

A Sand Scenario uses a height scan of the sand to create a terrain map displaying elevation. To create a "New Sand Scenario", click the "New Sand Scenario" button (Figure 48) (Guerin).

Flatten the surface and press Space.

Figure 49: New Sand Scenario Calibration Screen 1 (Guerin).

First, the screen shown in Figure 49 will appear with the instruction to “Flatten the surface and press Space”. After flattening the sand surface and pressing the space bar on the keyboard, the camera will calibrate and the screen shown in Figure 50 will appear (Guerin).



Make a mound centered in the square below and press Space.

Figure 50: New Sand Scenario Calibration Screen 2 (Guerin).

Continue following the instructions provided on the screen and “Make a mound centered in the square below and press Space” (Guerin).

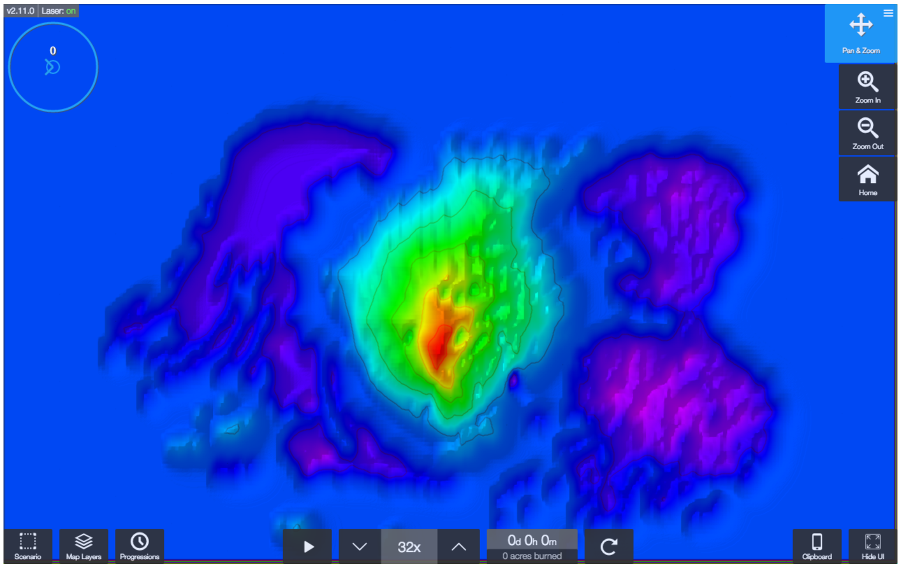


Figure 51: New Sand Scenario with Elevation Displayed (Guerin).

Upon pressing the spacebar, the camera will scan the sand again and then display an elevation map in accordance with the sand height (Figure 51). You may reshape the terrain and then press the “3” key and the camera will rescan the sand and display the new elevations as shown in Figure 52 (Guerin).

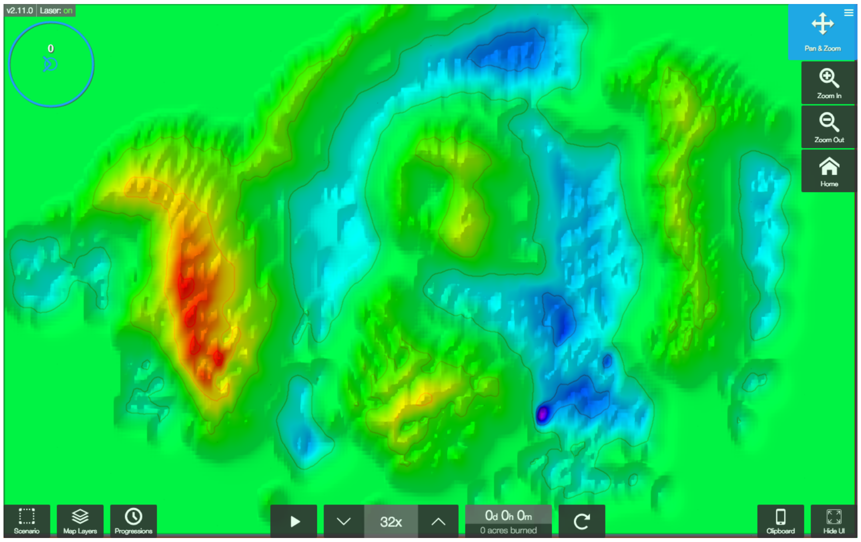


Figure 52: New Sand Scenario with Elevation Displayed After Recalibration (Guerin).

Map Layers

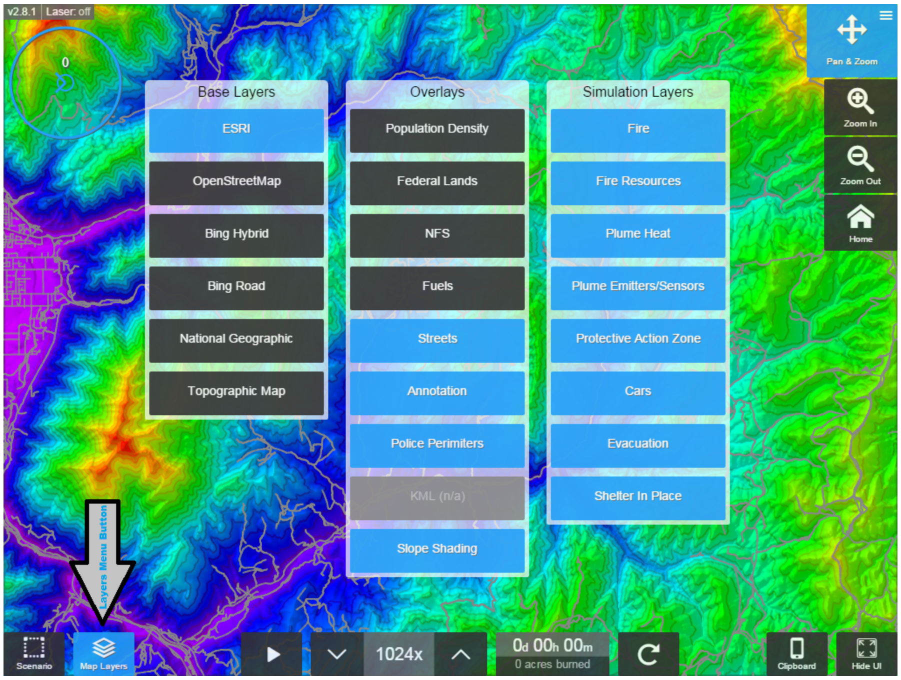


Figure 53: Map Layers Menu (Guerin).

Opening the “Map Layers” menu in Figure 53, will display 3 columns. The furthest column to the left contains the base layers maps. The middle column, labeled “Overlays” contains maps that can be turned on or off and will be displayed over the base map layer. The column furthest right, reading “Simulation Layers”, allows the user to turn on or off displays of the current simulations being run (Guerin).

Simulation Controls

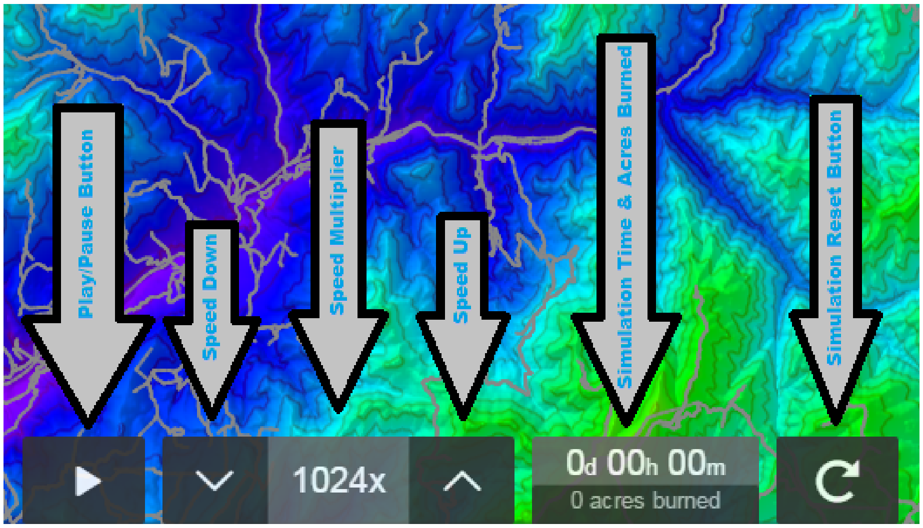


Figure 54: Simulation Controls and Display (Guerin).

The simulation controls are found at the bottom of the display as shown in Figure 54. Here the user may pause or play the simulation, control the speed at which a simulation runs, monitor the time elapsed, acres burned (if applicable), or reset the simulation (Guerin).

Clipboard QR Link

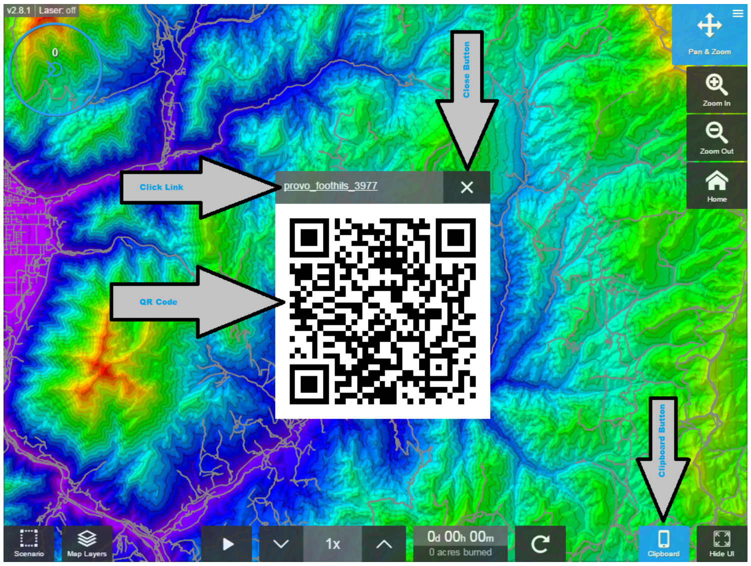


Figure 55: Clipboard Function Displayed (Guerin).

The clipboard button and feature shown in Figure 55 is located in the lower right of the display. The clipboard feature allows the user to share the map scenario currently being run to other devices. Anyone with a QR code scanner can open the simulation on their own device. Clicking the link above the QR code will open the clipboard in a new window if AnyHazard is being run on a laptop or desktop computer (Guerin).

Fire Sim Control

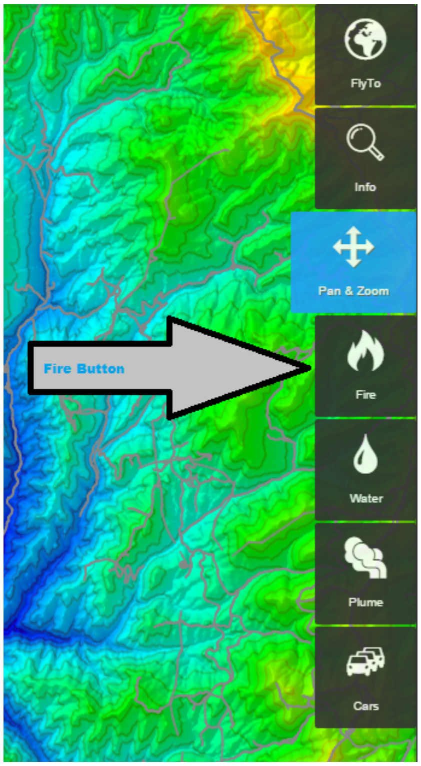


Figure 56: Fire Simulation Button (Guerin).

Shown in Figure 56, clicking the Fire button will allow the user to simulate a wildfire scenario (Guerin).

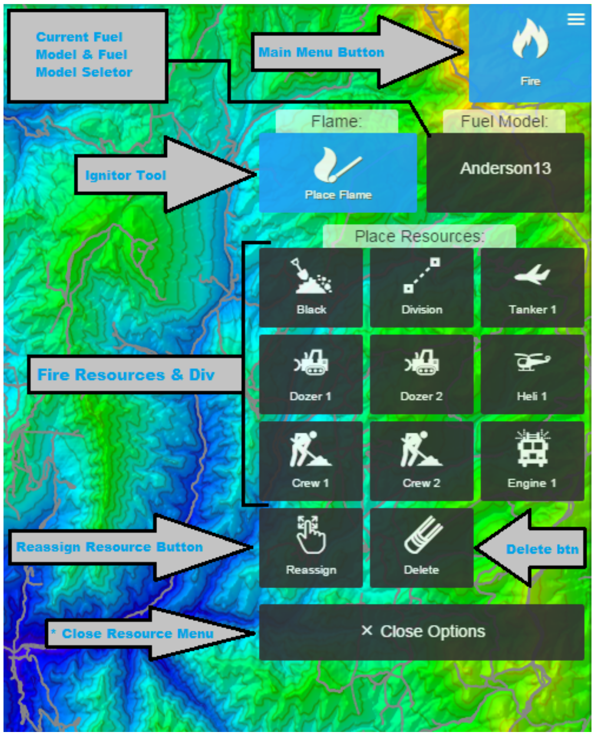


Figure 57: Fire Simulation Menu (Guerin).

The Fire simulation will allow the user to place flames and also select and place tools with which to fight the fire as shown in Figure 57 (Guerin).

Flood Sim Control

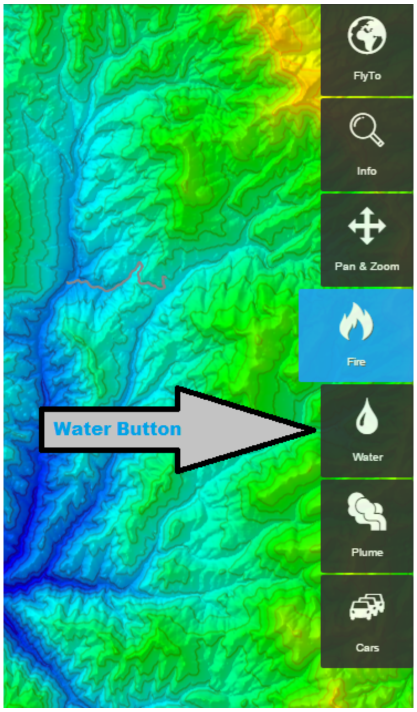


Figure 58: Water Simulation Button (Guerin).

The Water simulation button is located below the Fire simulation button as shown in Figure 58. Clicking on the Water simulation button will open the Water simulation menu displayed in Figure 59 (Guerin).

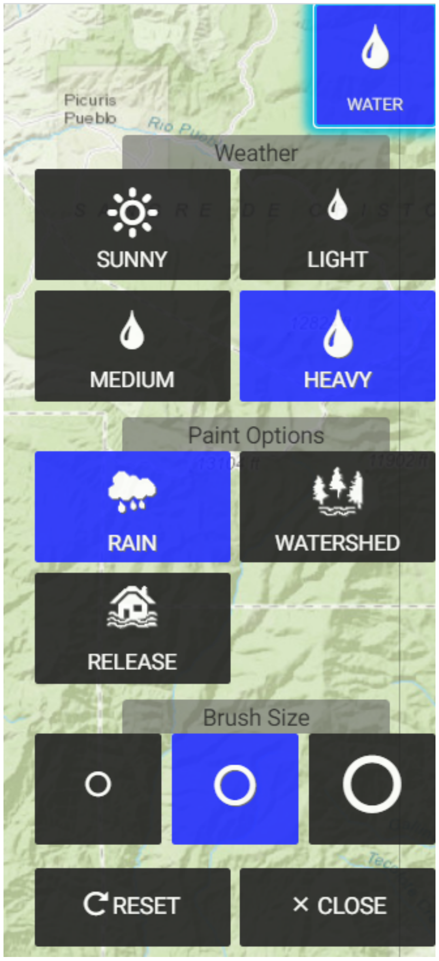


Figure 59: Water Simulation Menu (Guerin).

The Water simulation menu allows the user to simulate water releases, rain, and the watershed across all points on the map with options to set weather conditions and adjust the brush size (Guerin).

Hot Keys

Hot keys can be used to recalibrate the camera or the AnyHazard software itself.

The 'a' key will display the camera alignment screen. Press the spacebar to exit back to the display.

The 'b' key will display all of the camera blind spots on the display. There will normally be a scattering of blind spots across the entire display area. Should there be any large groupings of blindspots, the camera should be recalibrated.

The 'c' key will recalibrate the camera.

Press the **Windows key** or the **Command key** (⌘) and '**q**' at the same time to close AnyHazard.

Press the **Windows key** or **Command key** (⌘) and '**r**' at the same time to reload the AnyHazard software without closing the program (Guerin).

Clipboard User Basics

The clipboard interface can be accessed using the clipboard button on the main Simtable interface shown in Figure 55. Upon opening the clipboard, a screen, as seen in Figure 60, will appear. In the top left corner of Figure 60 is a map lock feature, zoom and pan functions, and a wind dial. The lower left corner of Figure 60 contains the map layers button. The lower right corner of the interface contains your simulation selection buttons (shown in Figures 75, 76, 79, 81, and 84). The upper right corner of Figure 60 contains a settings button and map drawing function.

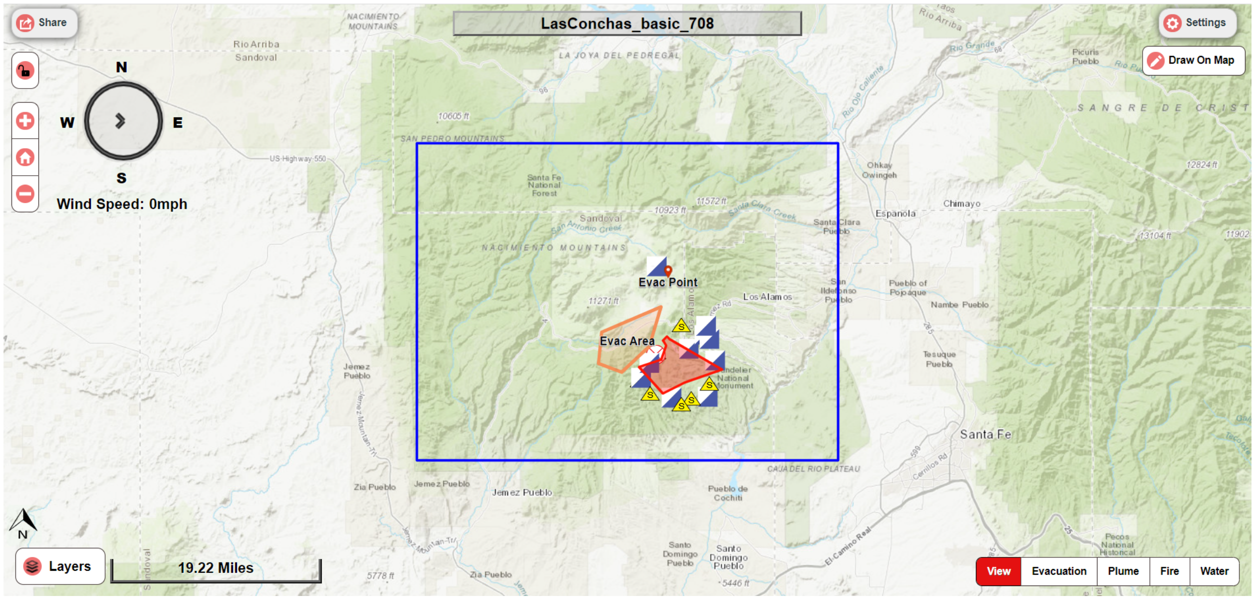


Figure 60: Main Clipboard Interface.

Clicking on the settings button in the upper right corner of Figure 60 will bring up the General Settings screen shown in Figure 62. While Figure 61 displays the settings menu that will appear at the bottom of the screen.

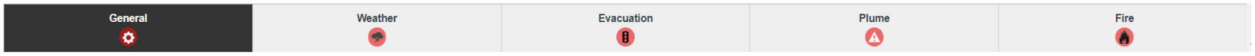
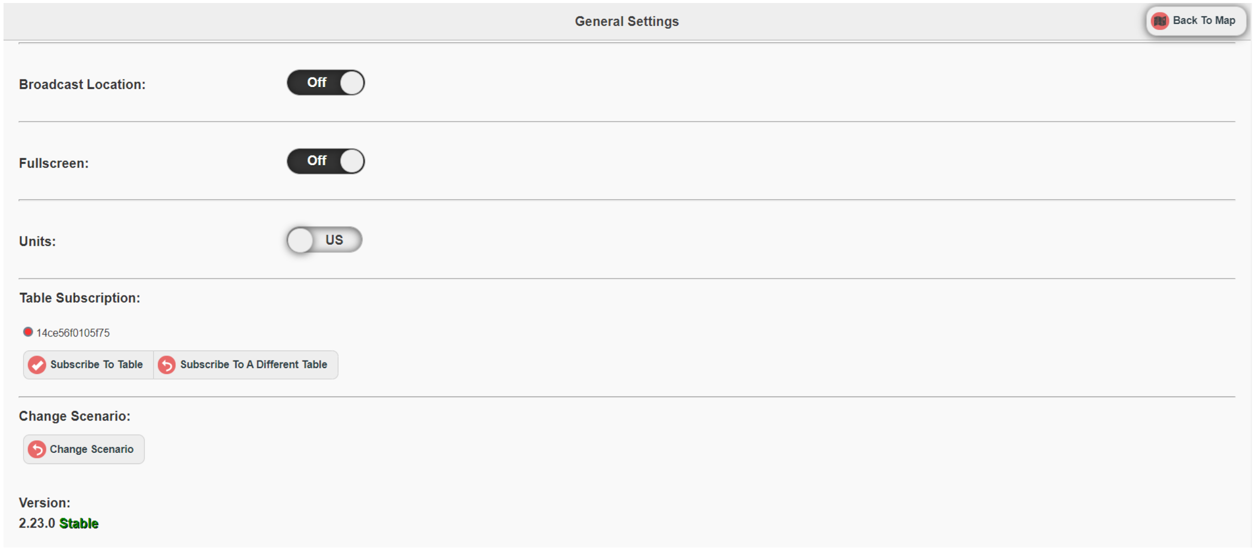


Figure 61: Clipboard Settings Menu Sections.

There are 5 different settings menus shown in Figure 61: General, Weather, Evacuation, Plume, and Fire.



Broadcast Location: Off

Fullscreen: Off

Units: US

Table Subscription:
14ce56f0105f75

Change Scenario:

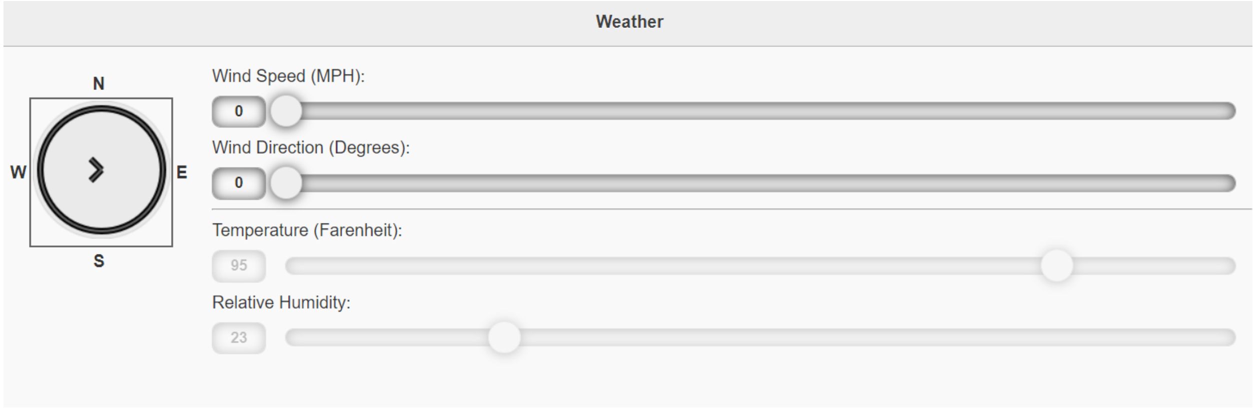
Version:
2.23.0 **Stable**

Figure 62: General Clipboard Settings.

The general settings menu, shown in Figure 62 allows the user to change things like the unit system used, full screen mode, or the map scenario being used.

Figure 63: Clipboard Weather Settings Button.

Figure 63 shows where the Weather settings button can be accessed.



Wind Speed (MPH): 0

Wind Direction (Degrees): 0

Temperature (Farenheit): 95

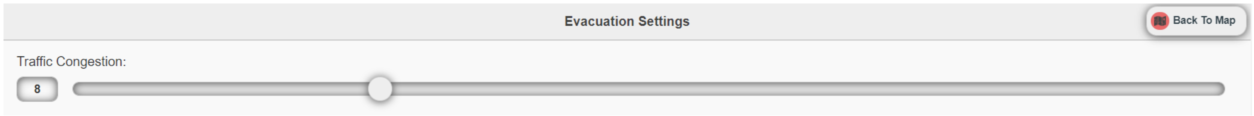
Relative Humidity: 23

Figure 64: Clipboard Weather Settings.

Upon opening the weather settings button shown in Figure 63, the screen in Figure 64 will appear. The user may change the wind speed and direction as well as the temperature and humidity.

Figure 65: Clipboard Evacuation Settings Button.

Figure 65 displays where the Evacuation settings button is located.



Traffic Congestion: 8

Figure 66: Clipboard Evacuation Settings.

The only setting the user may change using the Evacuation settings button is traffic congestion (Figure 66).

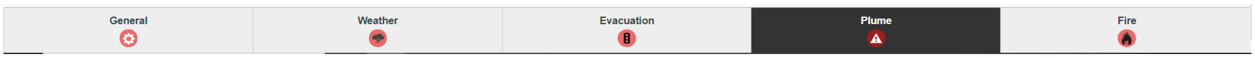
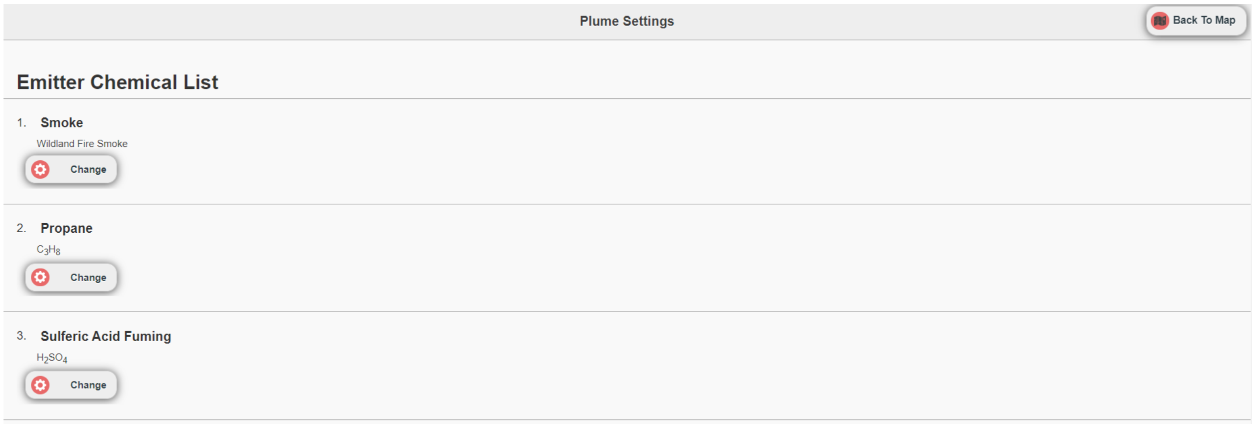


Figure 67: Clipboard Plume Settings Button.

Figure 67 shows where the Plume settings are located.



Emitter Chemical List

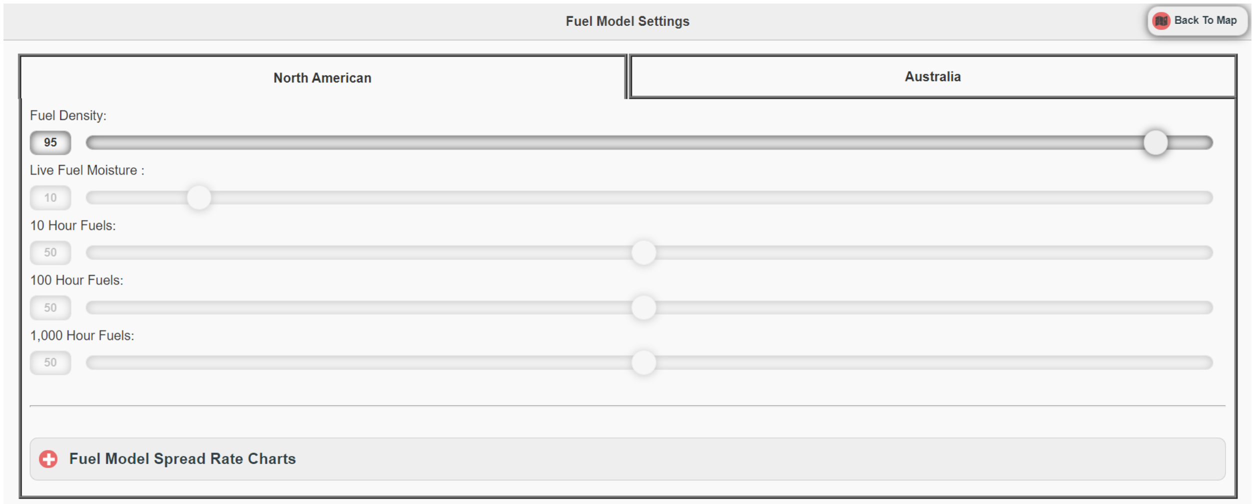
1. Smoke
   Wildland Fire Smoke
2. Propane
   C_3H_8
3. Sulferic Acid Fuming
   H_2SO_4

Figure 68: Clipboard Plume Settings.

The Plume settings, shown in Figure 68, allow the user to change what type of substance is being used for the simulation and set 3 main preferences.

Figure 69: Clipboard Fire Settings Button.

Figure 69 displays where the Fire settings button is located.


Fuel Model Settings

Back To Map

North American

Australia

Fuel Density: 95

Live Fuel Moisture : 10

10 Hour Fuels: 50

100 Hour Fuels: 50

1,000 Hour Fuels: 50

Fuel Model Spread Rate Charts

Figure 70: Clipboard North American Fire Settings.

Upon opening the Fire settings menu, you will see two tabs, one for North American fire settings and one for Australian Fire settings as shown in Figure 70. The American model contains sliders for fuel density, fuel moisture, and the amount of fuels that burn at different rates. Located at the bottom of the screen is the Fuel Model Spread Rate Charts button.

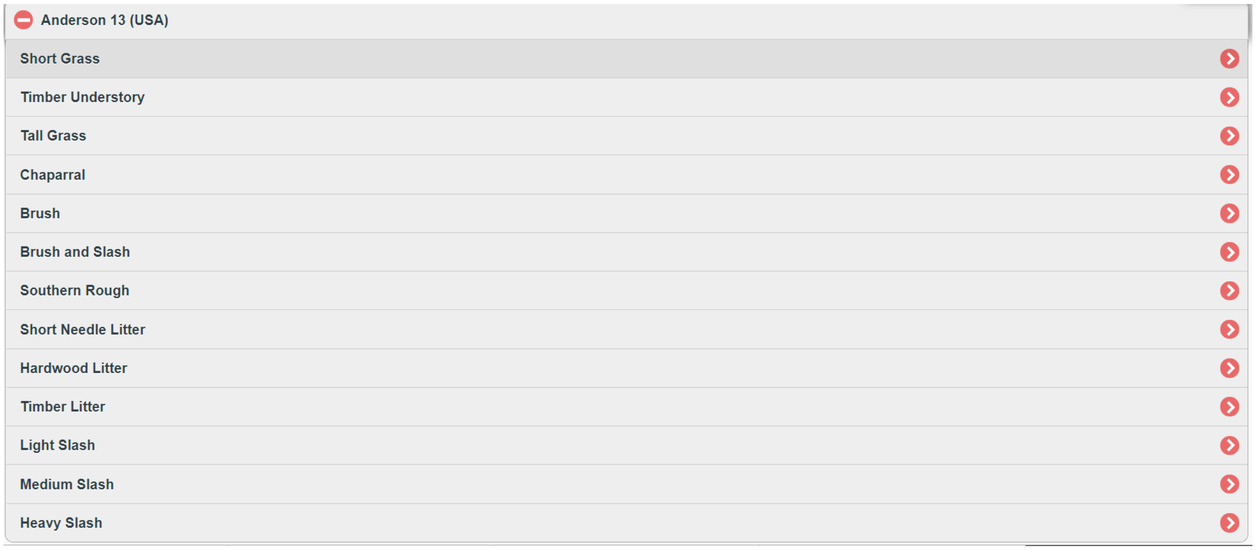

Fuel Model Spread Rate Charts

Anderson 13 (USA)

Prometheus (Canadian)

Figure 71: Fuel Model Spread Rate Options.

Shown in Figure 71 are the two subsections of the Fuel Model Spread Rate Charts tab.


Anderson 13 (USA)

- Short Grass
- Timber Understory
- Tall Grass
- Chaparral
- Brush
- Brush and Slash
- Southern Rough
- Short Needle Litter
- Hardwood Litter
- Timber Litter
- Light Slash
- Medium Slash
- Heavy Slash

Figure 72: Anderson 13 Fuel Model Options.

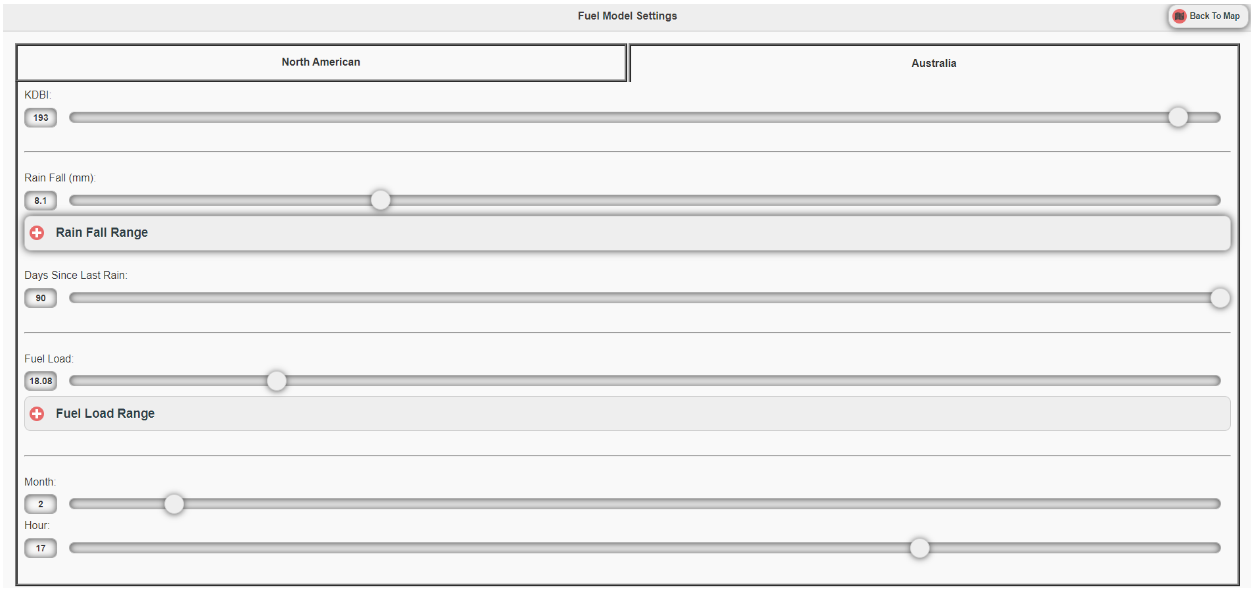
Figure 72 displays the different burn rate charts accessible for the Anderson 13 (USA) fuel models.

Prometheus (Canadian)

- C-1 Spruce-Lichen Woodland
- C-2 Boreal Spruce
- C-3 Mature Jack or Lodgepole Pine
- C-4 Immature Jack or Lodgepole Pine
- C-5 Red and White Pine
- C-6 Conifer Plantation
- C-7 Ponderosa Pine - Douglas-Fir
- D-1 Leafless Aspen
- D-2 Green Aspen (with BUI Thresholding)
- D-1/D-2 Aspen
- S-1 Jack or Lodgepole Pine Slash
- S-2 White Spruce - Balsam Slash
- S-3 Coastal Cedar - Hemlock - Douglas-Fir Slash

Figure 73: Prometheus Fuel Model Options.

Figure 73 displays the different burn rate charts accessible for the Prometheus (Canadian) fuel models.



KDBI: 193

Rain Fall (mm): 8.1

Days Since Last Rain: 90

Fuel Load: 18.08

Month: 2

Hour: 17

Figure 74: Clipboard Australian Fire Settings.

Figure 74 looks at the Australian Fuel Model Settings. Here, things like the KDBI (Keetch-Byram Drought Index), Rainfall, Days since last rain, the month and time, and fuel load can be altered.

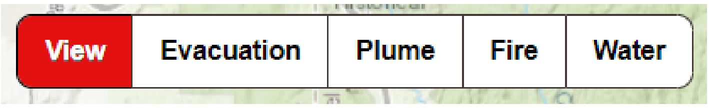


Figure 75: Clipboard Simulation Selection Menu.

Referring back to Figure 60, located in the lower right corner of the interface is the simulation selection bar, shown in greater detail here in Figure 75. There are 4 simulation modes to select from: Evacuation, Plume, Fire, and Water.

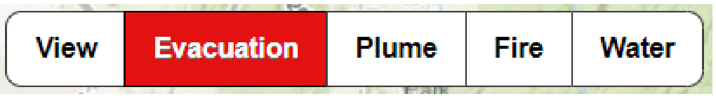


Figure 76: Clipboard Evacuation Simulation Button.

Figure 76 displays the Evacuation button on the simulation selection bar.

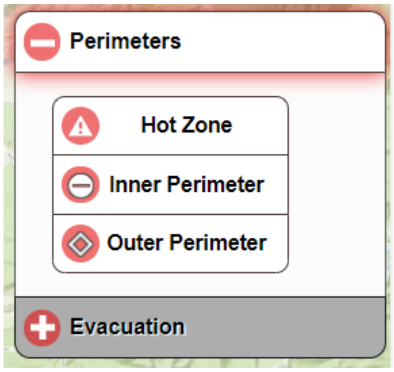


Figure 77: Evacuation Perimeters Option Menu.

Figure 77 shows the box of options that will appear in the top right corner of the interface. The user has the ability to draw hot zones, inner perimeters and outer perimeters through the perimeters tab.

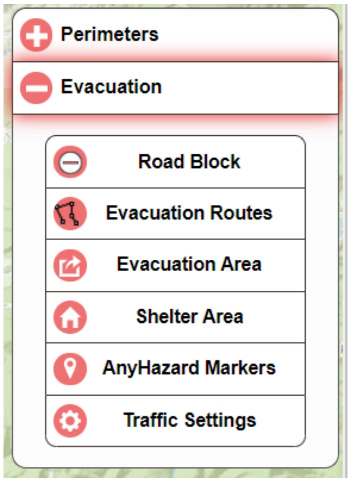


Figure 78: Clipboard Evacuation Option Menu.

Through the evacuation tab shown in Figure 78, the user can place roadblocks, evacuation routes or areas, shelter areas, markers or adjust traffic settings in the area.

Figure 79: Clipboard Plume Simulation Button.

Figure 79 shows the location of the Plume button on the simulation bar.

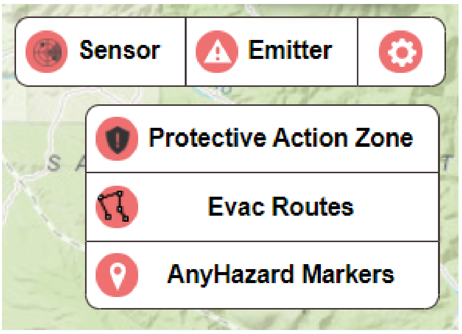


Figure 80: Clipboard Plume Option Menu.

In the top right corner of the interface, the buttons shown in Figure 80 will appear when the Plume mode is selected from the simulation bar. The user can place plume sensors or plume emitters and has the ability to place markers, evacuation routes, or a protective action zone.

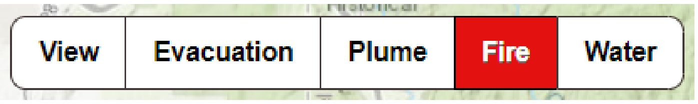


Figure 81: Clipboard Fire Simulation Button.

Figure 81 shows where the Fire button is located on the simulation bar.

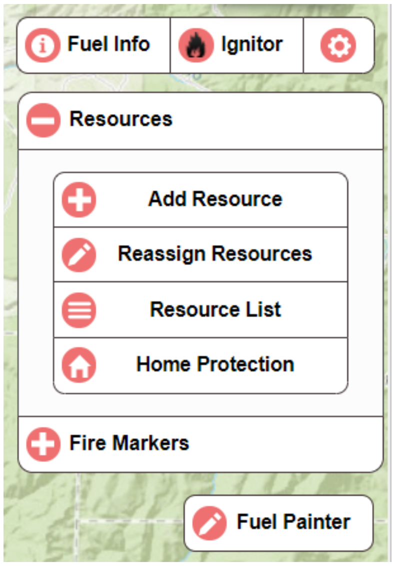


Figure 82: Clipboard Fire Resources Option Menu.

Upon clicking the fire simulation button, the buttons shown in Figure 82 will appear in the top right corner of the interface. The user can display the fuel info on the screen, paint/place additional fuels, and also place fires. The resources tab, allows the user to place fire fighting resources on the map, reassign those resources to different areas, pull up a resources available list, and also place home protection from fires on the map.

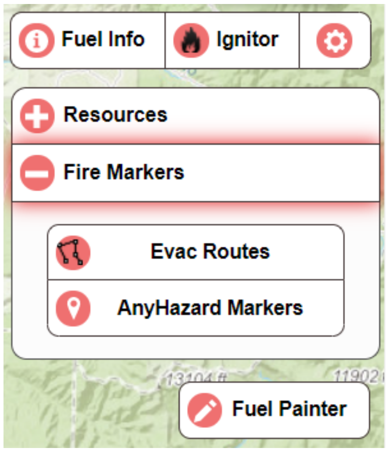


Figure 83: Clipboard Fire Markers Option Menu.

While using the fire simulation, the user may also place map markers and set evacuation routes by opening the fire markers tab shown in Figure 83.

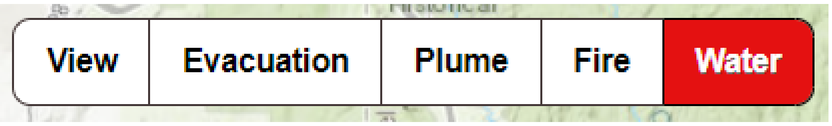


Figure 84: Clipboard Water Simulation Button.

Shown in Figure 84 is the location of the Water button on the simulation bar.

Figure 85: Clipboard Water Simulation Interface.

Upon clicking the Water button, the buttons shown in Figure 85 will appear in the top right of the interface. The user can place rain, flood an area, or display the watershed for a certain point on the map.

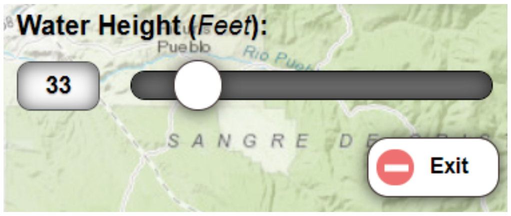


Figure 86: Clipboard Water Release Height Slider.

When clicking the release button shown in Figure 85, a water height slider will appear as shown in Figure 86. Depending on which units (US or Metric) the user has selected, the slider units will adjust accordingly. The user may adjust the height of the water they would like to flood any given area with.

Appendix E.2 Troubleshooting Large Camera Blind Spots

To check for camera blind spots, press “B” on the keyboard. A display of gray squares spotted throughout the map should appear. There should not be any large clumps of these spots. If any large clumps are present, press “C’ on the keyboard to recalibrate the camera. Recheck the blind spots. If blind spots are still present, restart both the mac mini and projector. Should restarting fail to solve the problem, check the cable connections between the camera, projector, and mac mini. Contact Stephen and support if the issue still persists.

Appendix E.3 Troubleshooting Camera Failing to Recognize Laser Pointer

If the laser pointer is not being recognized by the camera, look to the top left corner of the AnyHazard display for a box containing the version number and laser status (Figure 87).

Figure 87: Laser Status Bar (Guerin).

If the laser is listed as on and the laser still does not work, check the laser batteries first. Afterwards, restart the mac mini and projector. Should these steps fail to work, contact Stephen and support.

If the laser status is listed as off as shown in Figure 87, restart the mac mini and projector. If the issue still persists, contact Stephen and support.

Appendix E.4 Non-Full Screen Any Hazard

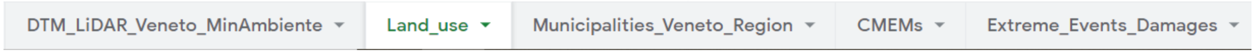
Begin by closing out of the program and then reloading AnyHazard from the dashboard. Should reloading the program not work, go to “View” along the top of the screen, and select “Fullscreen”. Otherwise, contact Stephen and support for further assistance.

Appendix E.5 Error Loading Roads

There is a current bug where a false error will appear upon the first time creating a scenario. First try navigating to a different scenario and then navigating back, and the “error loading roads” should no longer appear. However, it is also possible the scenario's area of interest is too big to bring in the roads. If the scenario covers a large region, a traffic simulation will not work as the roads don't fit into memory on a single machine.

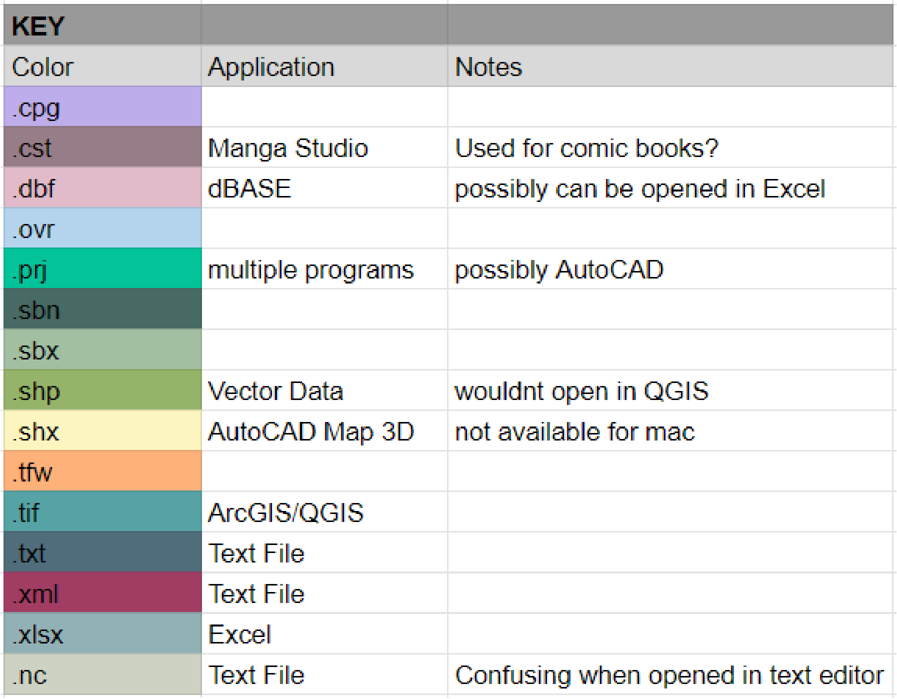
Appendix F: Data Organization Guide

Our sponsors gave us a shared data folder containing various files organized across a multitude of folders. We wanted a guide that allowed us to see where files were located and which applications a specific file could be opened in. We created an excel spreadsheet (Figure 88), which is linked at the end of this appendix, that color coded the file types and listed which application the file can be opened in and any additional notes (Figure 89). Seen in Figure 90, is the way in which we organized the folders and files within them.



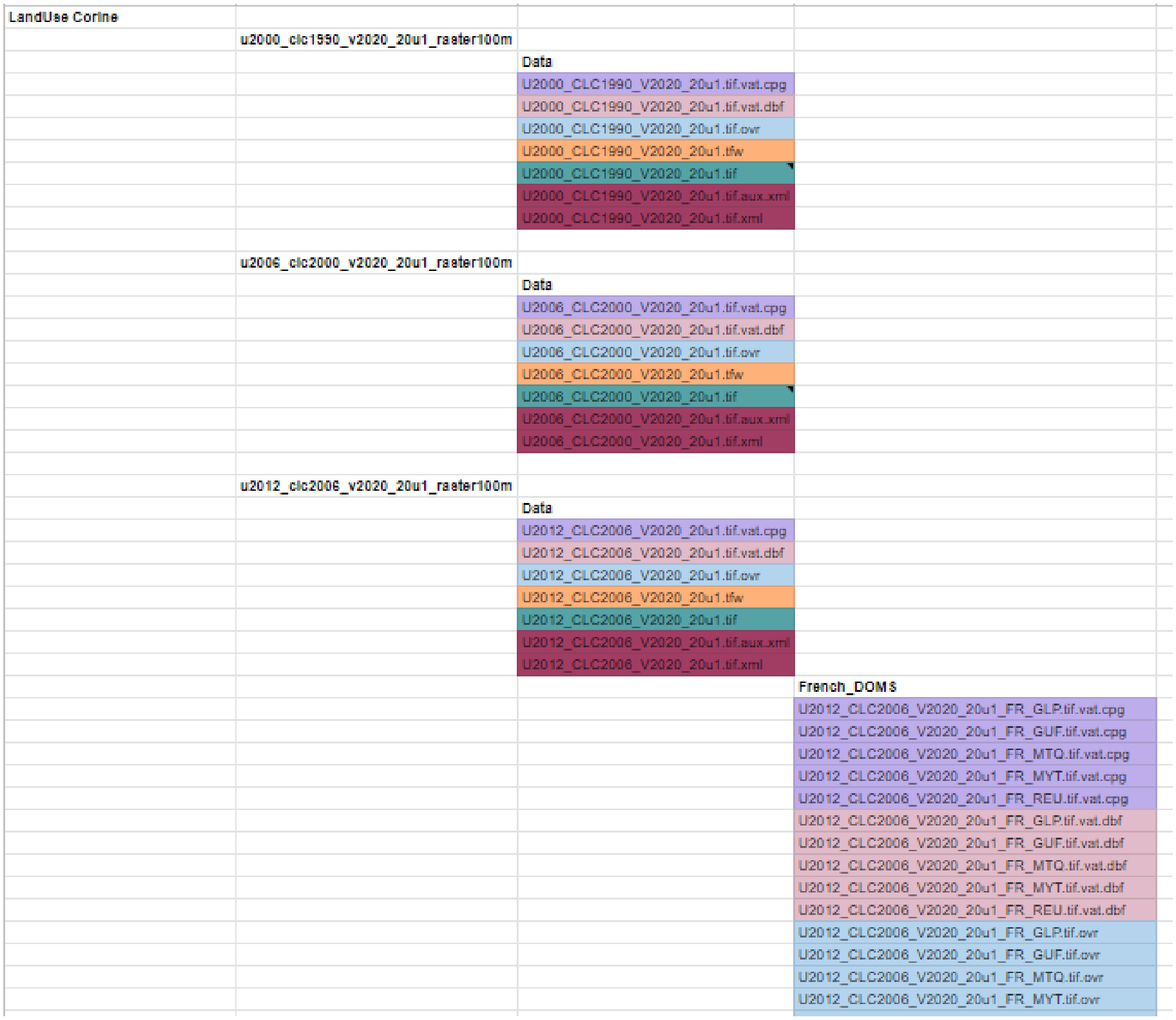
DTM_LiDAR_Veneto_MinAmbiente ▾ | Land_use ▾ | Municipalities_Veneto_Region ▾ | CMEMs ▾ | Extreme_Events_Damages ▾

Figure 88: Spreadsheet List of Folders.



KEY		
Color	Application	Notes
.cpg		
.cst	Manga Studio	Used for comic books?
.dbf	dBASE	possibly can be opened in Excel
.ovr		
.prj	multiple programs	possibly AutoCAD
.sbn		
.sbx		
.shp	Vector Data	wouldnt open in QGIS
.shx	AutoCAD Map 3D	not available for mac
.tfw		
.tif	ArcGIS/QGIS	
.txt	Text File	
.xml	Text File	
.xlsx	Excel	
.nc	Text File	Confusing when opened in text editor

Figure 89: File Key by Type and Application.



LandUse Corine			
	u2000_clc1990_v2020_20u1_raster100m		
		Data	
		U2000_CLC1990_V2020_20u1.tif.vat.cpg	
		U2000_CLC1990_V2020_20u1.tif.vat.dbf	
		U2000_CLC1990_V2020_20u1.tif.ovr	
		U2000_CLC1990_V2020_20u1.tfw	
		U2000_CLC1990_V2020_20u1.tif	
		U2000_CLC1990_V2020_20u1.tif.aux.xml	
		U2000_CLC1990_V2020_20u1.tif.xml	
	u2006_clc2000_v2020_20u1_raster100m		
		Data	
		U2006_CLC2000_V2020_20u1.tif.vat.cpg	
		U2006_CLC2000_V2020_20u1.tif.vat.dbf	
		U2006_CLC2000_V2020_20u1.tif.ovr	
		U2006_CLC2000_V2020_20u1.tfw	
		U2006_CLC2000_V2020_20u1.tif	
		U2006_CLC2000_V2020_20u1.tif.aux.xml	
		U2006_CLC2000_V2020_20u1.tif.xml	
	u2012_clc2006_v2020_20u1_raster100m		
		Data	
		U2012_CLC2006_V2020_20u1.tif.vat.cpg	
		U2012_CLC2006_V2020_20u1.tif.vat.dbf	
		U2012_CLC2006_V2020_20u1.tif.ovr	
		U2012_CLC2006_V2020_20u1.tfw	
		U2012_CLC2006_V2020_20u1.tif	
		U2012_CLC2006_V2020_20u1.tif.aux.xml	
		U2012_CLC2006_V2020_20u1.tif.xml	
			French_DOMS
			U2012_CLC2006_V2020_20u1_FR_GLP.tif.vat.cpg
			U2012_CLC2006_V2020_20u1_FR_GUF.tif.vat.cpg
			U2012_CLC2006_V2020_20u1_FR_MTQ.tif.vat.cpg
			U2012_CLC2006_V2020_20u1_FR_MYT.tif.vat.cpg
			U2012_CLC2006_V2020_20u1_FR_REU.tif.vat.cpg
			U2012_CLC2006_V2020_20u1_FR_GLP.tif.vat.dbf
			U2012_CLC2006_V2020_20u1_FR_GUF.tif.vat.dbf
			U2012_CLC2006_V2020_20u1_FR_MTQ.tif.vat.dbf
			U2012_CLC2006_V2020_20u1_FR_MYT.tif.vat.dbf
			U2012_CLC2006_V2020_20u1_FR_REU.tif.vat.dbf
			U2012_CLC2006_V2020_20u1_FR_GLP.tif.ovr
			U2012_CLC2006_V2020_20u1_FR_GUF.tif.ovr
			U2012_CLC2006_V2020_20u1_FR_MTQ.tif.ovr
			U2012_CLC2006_V2020_20u1_FR_MYT.tif.ovr

Figure 90: Folder and File Organization.

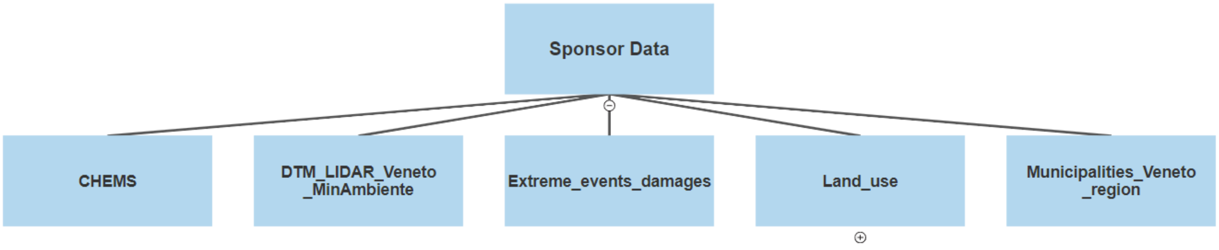


Figure 91: Sponsor Data Folder Organization.

Seen in Figure 91, the sponsor data is organized into five different folders: CHEMS, DTM_LIDAR_Veneto_MinAmbiente, Extreme_events_damages, Land_use, and

Municipalities_Veneto_region. Contained within the Land_use folder (Figure 92) were three more folders, each containing more files or another set of subfolders.

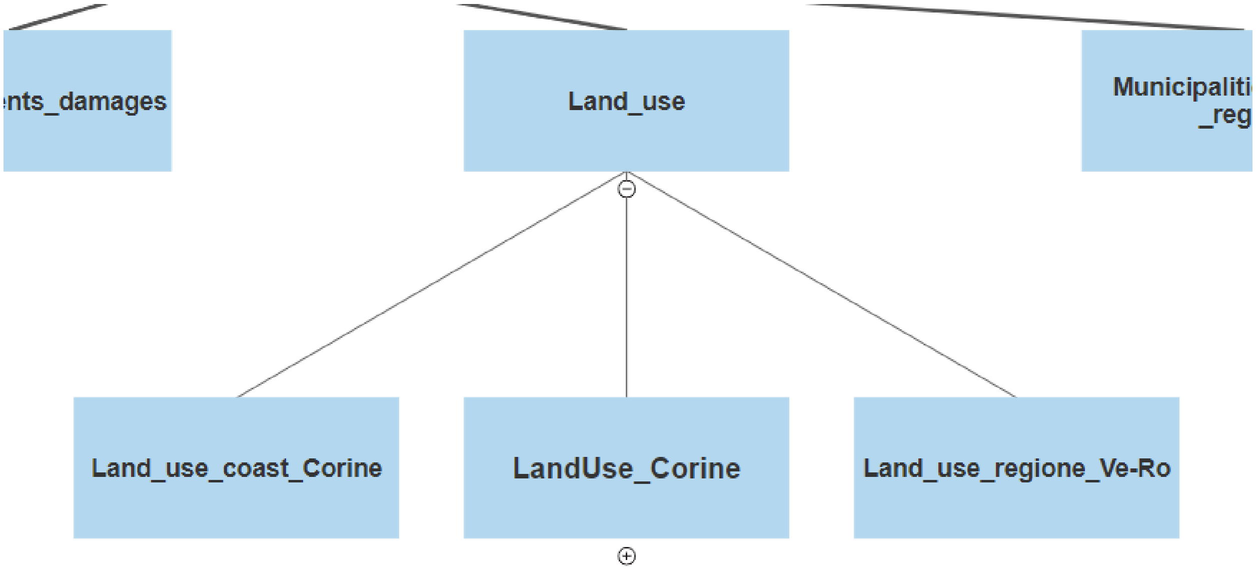


Figure 92: Land_use Folder Organization.

In the following figures (93-98), are diagrams showing the organization of the subfolders within the main folders given to us.

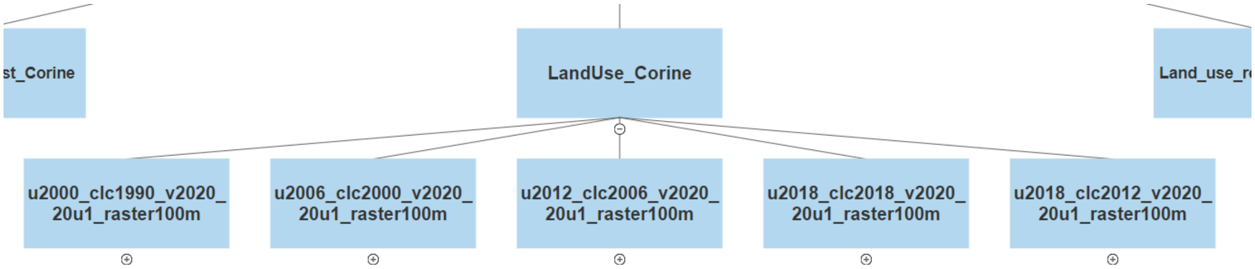


Figure 93: LandUse_Corine Folder Organization.

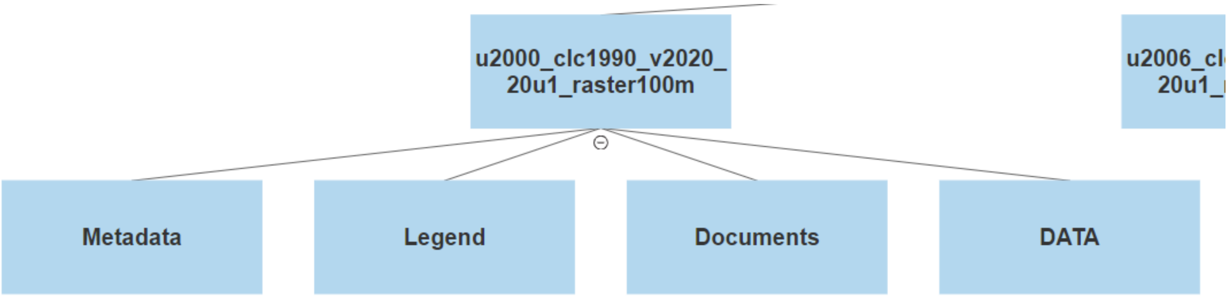


Figure 94: u2000_clc1990_v2020_20u1_raster100m Folder Organization.

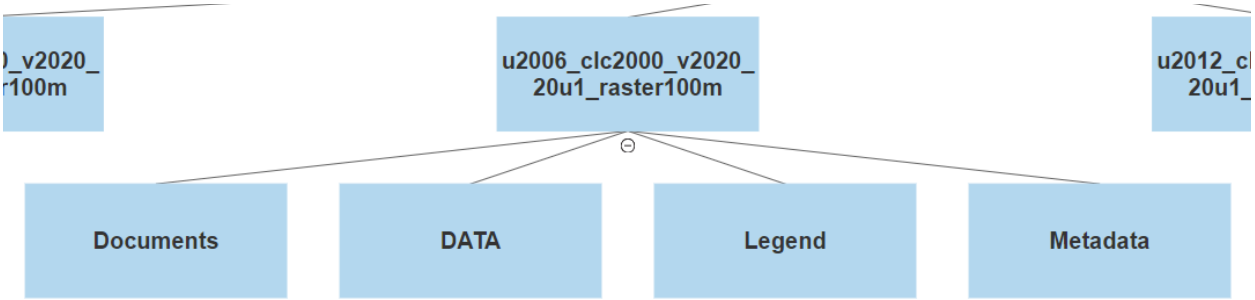


Figure 95: u2006_clc2000_v2020_20u1_raster100m Folder Organization.

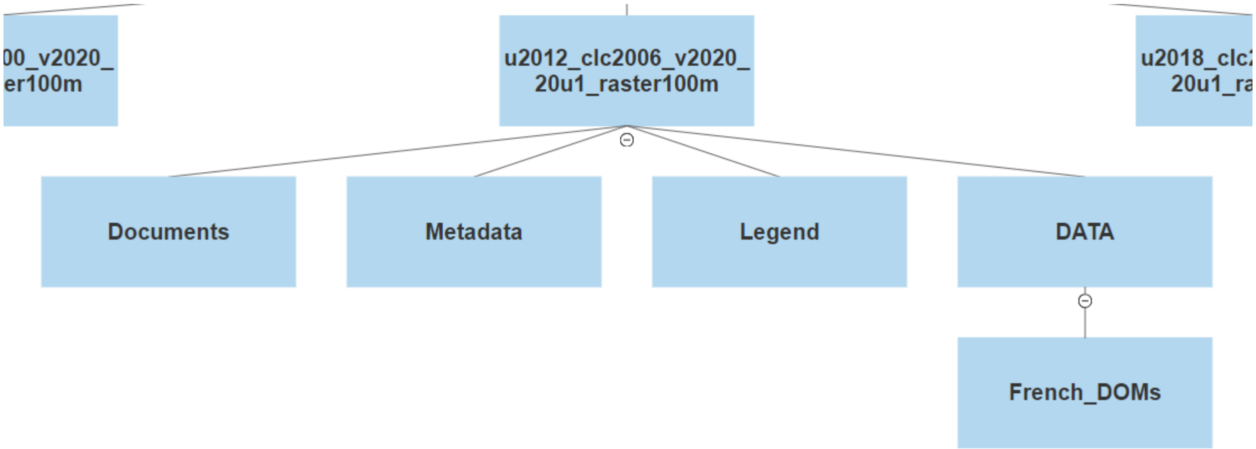


Figure 96: u2012_clc2006_v2020_20u1_raster100m Folder Organization.

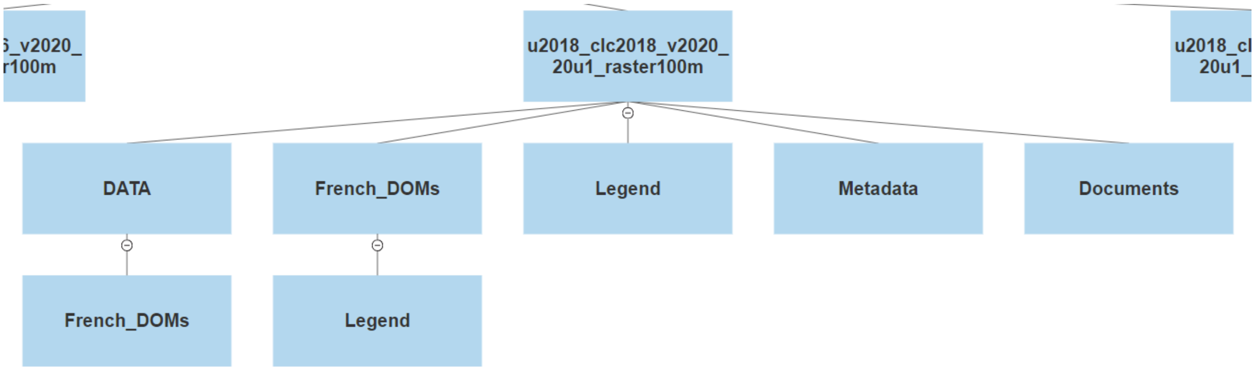


Figure 97: u2018_clc2018_v2020_20u1_raster100m Folder Organization.

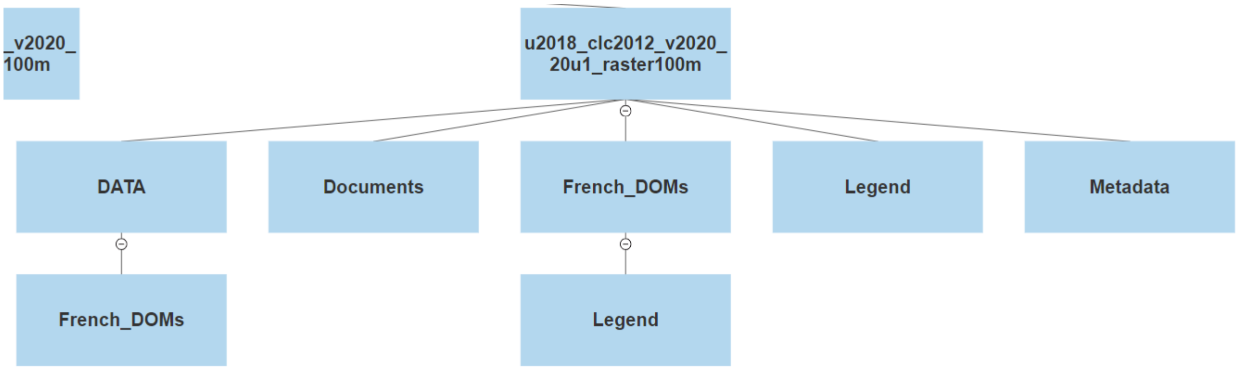


Figure 98: u2018_clc2012_v2020_20u1_raster100m Folder Organization.