



70 Dean Knauss Drive  
Narragansett, RI USA 02882  
phone: +1 401 789-6224  
fax: +1 401 789-1932

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## Technical Report

TITLE:

# Visualization of Inundation of Critical Coastal Facilities due to Flood Events and Sea-Level Rise

AUTHOR(S):

Kelly Knee, ASA  
Greg Rowe, ESS Group, Inc.

CLIENT:

Massachusetts Office of Coastal  
Zone Management

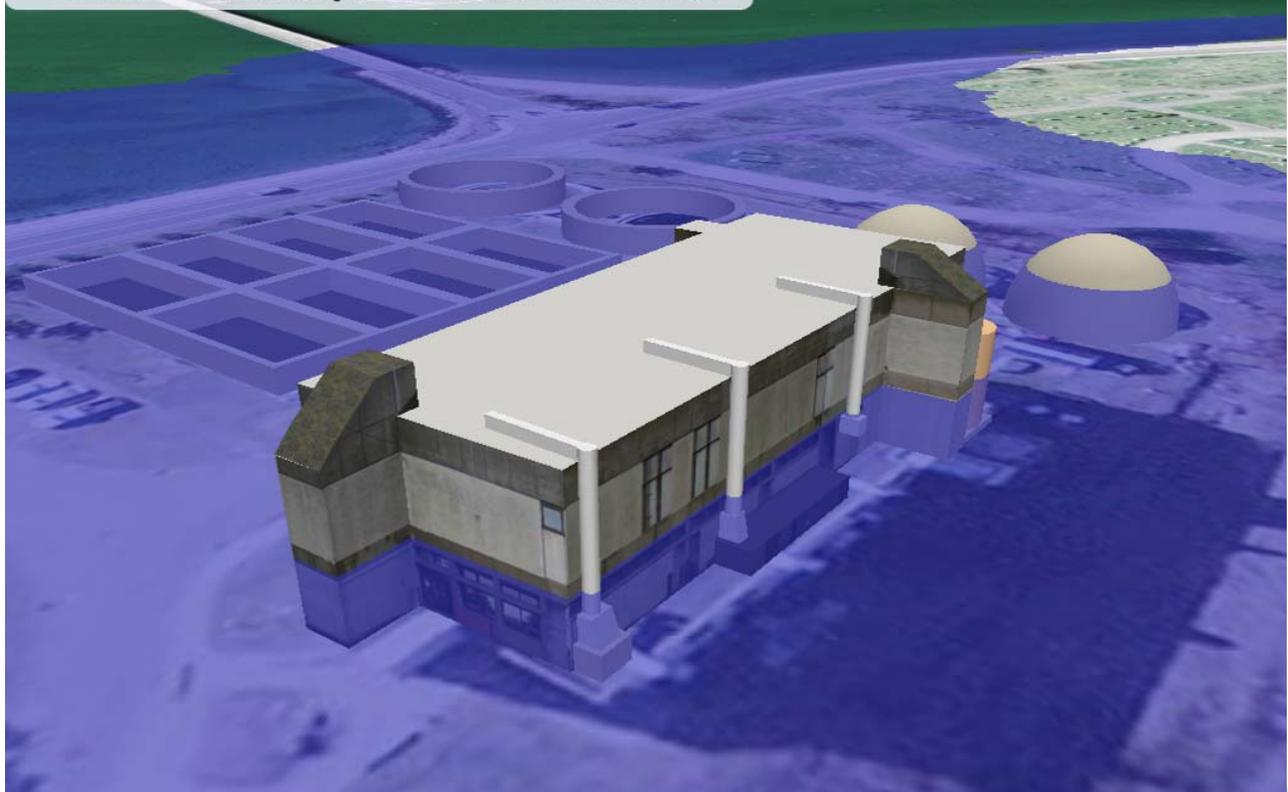
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Waste Water Treatment Plant during the base flood with 9.8 feet of sea level rise



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## 1. Introduction

The Executive Office of Environmental Affairs through Massachusetts Coastal Zone Management (MACZM) contracted Applied Science Associates (ASA) to generate three-dimensional (3D) simulations of sea level rise and flood event inundation in an effort to enhance hazard mitigation planning, emergency response, and public awareness through improved flood visualization products. This pilot study focuses on seven critical facilities in Hull, MA. Hull has been selected as a StormSmart Coasts pilot community and needs to develop support for a freeboard standard in the coastal A zone. Coastal A zones are found adjacent to V zones, and are expected to experience wave action between 1.5 and 3 feet.

The 3D models will serve as educational materials for local officials whose support is needed for this initiative. Longer-term goals involve implementation of the 3D modeling process by other coastal communities and planning agencies and the use of the models in a climate change adaptation initiative. With this in mind, the project was designed to facilitate its implementation in other geographic areas; this technical report outlines the details of generating similar 3D models in other coastal communities around the state of Massachusetts and presents the challenges and results of the pilot study in Hull, MA.

Applied Science Associates (ASA), working together with subcontractors ESS Group and WSP SELLS, used LIDAR and survey data to create 3D models of five flooding scenarios at seven critical facilities around Hull. The facilities and flooding scenarios were determined by the entire project team which consisted of representatives of MACZM, the town of Hull, ASA, and ESS. These facilities identified include:

1. Hull High School
2. Hull Waste Water Pollution Control Facility
3. Allerton Post Office
4. Hull Memorial School
5. Anne M. Scully Senior Center
6. Draper Ave. Stormwater Pump Station
7. Hull Municipal Light Plant

The first step in this process, described in Section 2, is to perform a field survey of each site. These surveys serve multiple purposes: (1) provide ground elevations for confirming LIDAR data accuracy, (2) provide building corner points for construction of building footprints, and (3) provide building heights for constructing three-dimensional building models. ASA used the survey data to confirm the LIDAR accuracy (described in



Section 3) and construct two-dimensional building footprints (described in Section 4). ESS Group combined building footprints and building height surveys to construct the three-dimensional building models (described in Section 4). Using the LIDAR data and the flooding scenarios defined by MACZM, ASA generated the 3D flood layers to overlay on the building models. The flooding scenarios defined by the project team include:

- 1) Base Flood Elevation (BFE), expected elevation of flood waters and wave effects during the 100-year flood
- 2) BFE + 0.3 m
- 3) BFE + 0.5 m
- 4) BFE + 1.0 m
- 5) BFE + 3.0 m

The building models and flood layers were all converted to KML and linked together for visualization in [Google Earth](#). Ultimately the 3D buildings were also submitted for inclusion in the native [Google Earth](#) 3D buildings layer. This process is outlined in Sections 5 and 6.

Software products used in this project include:

- [ArcGIS Desktop](#) application such as [ArcView](#)<sup>®</sup>
- Microsoft Office Excel
- [Google™ SketchUp](#)
- [Google™ Earth](#)
- Text editor such as WordPad
- [Adobe® Photoshop®](#)
- Web browser such as Internet Explorer<sup>®</sup>

The following sections describe the process of evaluating LIDAR data, building 3D models, creating flood overlays, and migrating all data to [Google Earth](#) in detail.

## **2. Field Survey of Critical Facilities**

ASA contracted with WSP SELLS to provide the surveys of each critical facility. The surveys are critical to this process because they allow construction of building footprints, provide building heights, and allow confirmation of the LIDAR data accuracy.



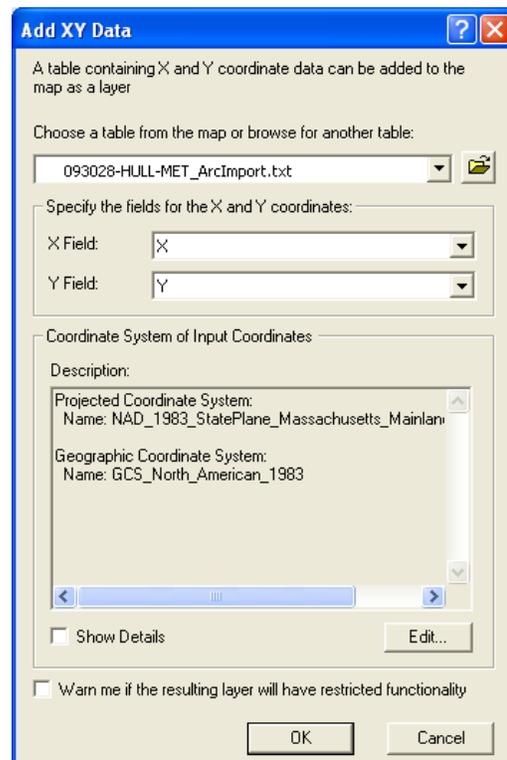
## Analysis Steps

Buildings should be surveyed by a professional surveyor. When requesting field surveys ensure:

1. At least one baseline survey is established at each building site at a location from which the peak building height is visible.
2. After establishing a baseline at each site, ground elevations are shot at multiple locations along the base of the building, including corner points.
3. At least several ground elevations are shot at locations that are clear of foliage that may have affected the LIDAR survey values.
4. The horizontal and vertical accuracy are at least as good as the LIDAR accuracy.
5. The height survey includes the peak building height as well as any other roof elevations visible from the baseline.

The building survey data was provided to ASA in the format of a comma separated values (CSV) file. This file can be read easily by [Microsoft Excel](#), and with the correct header can be ingested directly into [ArcView](#). The file was processed using the following steps to allow ingestion to ArcMap:

1. Open the survey data with [Microsoft Excel](#).
2. Save a copy of the file in .csv format for import to [ArcView](#).
3. Delete any excess header information.
4. Ensure that the necessary field headers exist and are properly labeled as follows:
  - a. ID: A unique identifier for each survey point.



- b. X: the easting coordinate of the survey point (in known coordinate system such as Mass State Plane).
  - c. Y: the northing coordinate of the survey point (in known coordinate system such as Mass State Plane).
  - d. Z: the elevation of the survey point (with known vertical datum such as NAVD88).
  - e. Location: name of the facility at which the point was taken.
  - f. Description: type of point (e.g. "Building Corner Ground Elevation" or "Building Height").
5. Save the file and close Excel.
  6. Open Windows Explorer and rename the file with a .txt extension. Saving a file as .txt directly from Excel makes the file tab-delimited, which cannot be read by ArcView.
  7. Open ArcView and select *Add XY Data* from the *Tools* menu.
  8. Use the *Browse* button to navigate to the survey points text file.
  9. Set the X and Y fields using the drop-down menus.
  10. Set the spatial reference using the *Edit* button and navigating to the appropriate coordinate system.
  11. Click the OK button to import the points to ArcView.
  12. A temporary feature class will automatically be loaded into the ArcView project. Right click on the feature class and choose *Data >> Export Data* to make a permanent copy of the file. When prompted, load the permanent copy into the ArcView project. The file is now ready to be used for further analysis.

Section 3 outlines how to use the survey points to confirm the LIDAR data accuracy. Section 4 details the process of generating two-dimensional building footprints from the survey points.



## Pilot Study Results

WSP SELLS provided multiple survey points, in text file format. The original file was delivered with a long header describing the metadata, a header describing each field, and individual headers separating the points from each facility. The survey points in the file represented both ground elevations and building heights at each of the seven critical facilities for a total of 101 survey points. Of these points, 73 provided ground elevations useful for the statistical comparison of surveyed and LIDAR points, 45 provided building corner locations and ground elevations useful for delineating building footprints and 23 provided building heights useful for constructing three-dimensional building models from the two dimensional footprints. Once imported into ArcView, following the steps in Section 3, it became clear that one of the Draper Avenue Pump Station building corner points was mis-located. This point was thrown out, leaving 44 points providing building corner points and 72 points providing ground elevations.

The file contained fields for X, Y, and Z position as well as facility name and point description. Table 2.1 summarizes the descriptions and the use of each category in the pilot study.

**Table 2.1 Summary of Building Survey Points**

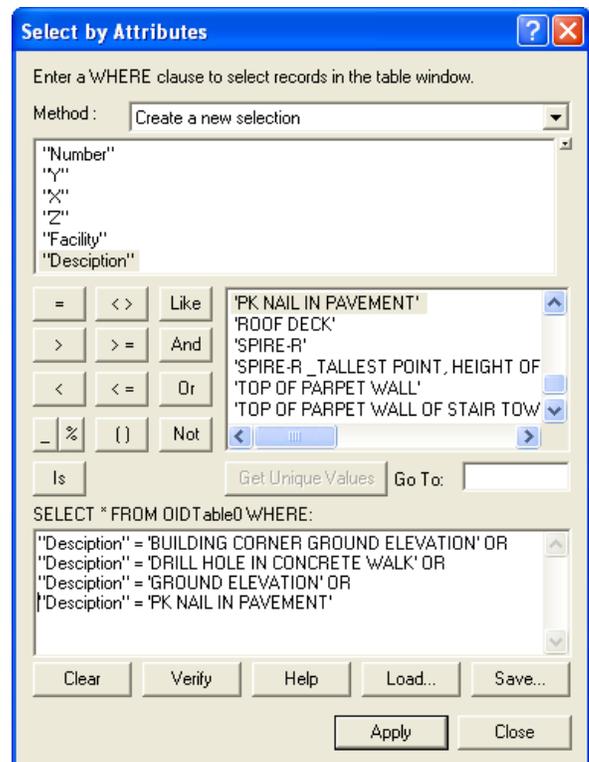
Pilot Study Use	Point Description
Ground Elevation	Building Corner Ground Elevation Building Corner Ground ElevationG Drill Hole in Hole in Concrete Walk Ground Elevation PK Nail in Pavement
Building Height	Building Height Building Height_Tallest Point Flat Roof Flat Roof_Tallest Point Peak of Sloped Roof Peak of Sloped Roof-R Peak of Sloped Roof_Tallest Point Spire-R Spire-R_Tallest Point Top of Parapet Wall Top of Parapet Wall_Tallest Point

### 3. LIDAR Statistical Analysis

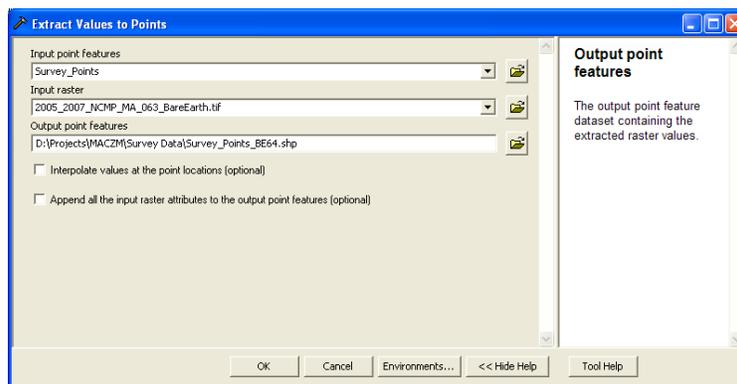
To use the survey points for confirming LIDAR data accuracy, they must be filtered so that they contain only ground elevation data. Once filtered, each point should be associated with the LIDAR elevation at the same location. To confirm the LIDAR dataset's accuracy a statistical analysis should be performed on the differences between the surveyed and the LIDAR elevations. To prepare the data and perform the statistical analysis:

#### Analysis Steps

1. Open ArcView and load the feature class containing the surveyed points (generated by following the steps in Section 2).
2. Open the attribute table by right-clicking the layer name in ArcView's Table of Contents and choosing *Open Attribute Table*.
3. Determine which points represent ground elevations by using the *Description* field. If necessary contact the surveyor to confirm which points represent ground elevations.
4. From the attribute table's *Options* drop-down menu, choose the *Select by Attributes* tool.
5. In the *Select by Attributes* dialog, create a query to select all features representing the ground elevation points using the *Description* field.
6. With the ground elevation points selected, close the attribute table, right-click on the feature class and choose *Data >> Export Data* to save a copy of the selected features as a new feature class. When prompted load the new feature class into the ArcView project and remove the original survey points file by right-clicking on the layer name and selecting *Remove*.



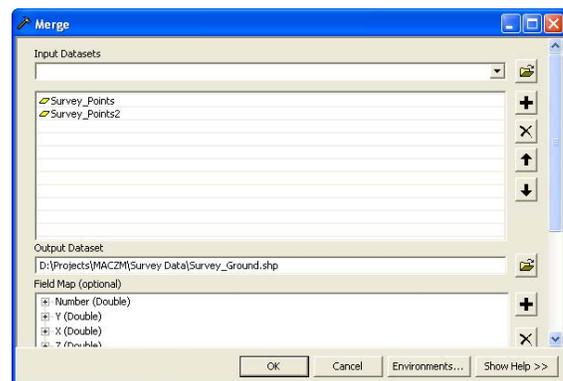
7. Load the bare earth LIDAR grid(s) into the ArcView project.
8. Load *ArcToolbox* by clicking the toolbox button, , and open the *Extract Values to Points* tool from the *Spatial Analyst Tools > Extract* toolbox.
  - a. Set *Input Point Features* equal to the ground elevation points feature class.
  - b. Set the *Input Raster* equal to the bare earth LIDAR elevation grid.
  - c. Set the output path and file name.
  - d. Click the OK button.



- e. A new point feature class will be created. This feature class will contain a new field with the LIDAR data elevations. Each point will be assigned the elevation from the LIDAR cell directly below it.
9. Repeat steps 8a to 8e for each LIDAR dataset that overlaps the survey points. This will create a separate point shapefile for each LIDAR dataset.

10. If multiple datasets with LIDAR elevations were created in step 9, use the *Merge* tool from *ArcToolbox* (in the *Data Management Tools > General* toolbox) to combine them into a single feature class.

- a. In the *Merge* dialog, use the *Input Datasets* drop down menu to add



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all survey point layers to the *Input Datasets* list.

- b. Set the output name and location of the merged file and click OK.
11. Open the attribute table of the ground elevation feature class. It should contain one field for the surveyed elevation and one field for the associated LIDAR elevation.
  12. Click the *Options* button and choose the *Export* option.
  13. In the *Export* dialog, use the browse button to save the attribute table as a DBF file.
  14. Open the DBF file with Excel and save it as an Excel file.
  15. Create a new column and set it equal to the difference between the survey and LIDAR elevations.
  16. Calculate basic statistics from the elevation differences, including mean, minimum, maximum, and standard deviation.
  17. Check whether the elevation differences follow a normal distribution by using standard statistical methods (e.g. the Chi-Squared Test).
    - a. If the elevation differences are normally distributed, calculate the Root Mean Square Error (RMSE). The vertical accuracy of the LIDAR data at a 95% confidence interval is equal to  $RMSE * 1.96$  (FGDC, 1998).
    - b. If the elevation differences are not normally distributed, the vertical accuracy at the 95% confidence interval is equal to the 95<sup>th</sup> percentile error for all survey points (North Carolina Cooperating Technical State Flood Mapping Program, 2008).
  18. Compare the computed vertical accuracy with the stated vertical accuracy of the LIDAR dataset.



## ***Pilot Study Results***

For the Hull pilot study, the field survey provided 72 ground elevation points. Each of these points was assigned an LIDAR elevation in addition to the Z value provided by the survey team. The differences between the survey and LIDAR elevations were calculated and used to determine basic statistics and vertical accuracy. Using the Kolmogorov-Smirnov Test and the Chi-Square Test, it was found that the differences in elevations between the LIDAR and surveyed points are not normally distributed. The elevation differences were then matched against a variety of distributions until the best fit, a lognormal distribution, was found. That the elevation differences are lognormally distributed was confirmed using the Kolmogorov-Smirnov and Chi-Square tests with a 5% significance level.

Since the data are not normally distributed, the vertical accuracy was determined using the percentile error method outlined in step 15b. The vertical accuracy at a 95% confidence interval is 17 cm, which is better than the stated vertical accuracy of 30 cm. A statistical summary of the differences between the surveyed and LIDAR elevations is provided in Table 3.1.

**Table 3.1: Summary Statistics of Elevation Differences**

<b>Descriptive Statistics (m)</b>	
Maximum	0.36
Minimum	0.004
Mean	0.07
Std. Deviation	0.07
RMSE	0.10
95% Percentile	0.17
68% Percentile	0.07



## 4. Constructing Building Models

During the early phases of the pilot project seven critical facilities were identified to provide context to the inundation visualizations. Using the survey results and photos of the facilities, 3D building models were constructed. The purpose of this analysis is to show the depth of flooding for each combination of BFE and sea level rise at each structure. Generating three dimensional models of each facility is a crucial step to visualizing inundation because the models provide the viewer with a baseline against which to judge the flood depths. Realistic 3D model building involves three major components (1) generating two-dimensional (2D) building footprints from plans, surveys, or measurements (2) constructing walls and rooflines and (3) adding textures from actual photographs of the structures. These steps are outlined below.

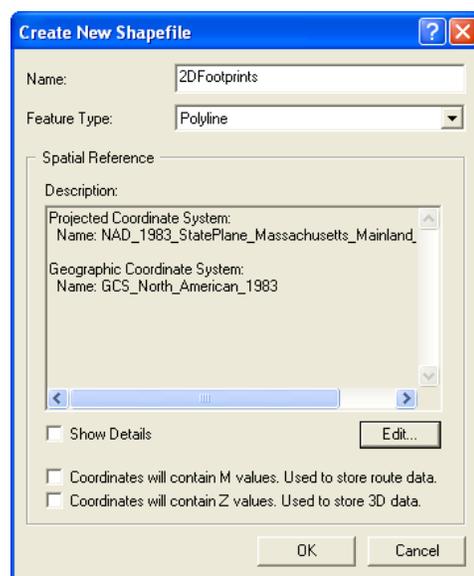
### Analysis Steps

The first step to building 3D models is to create the 2D building footprints. This step is only necessary if building plans are not available. For the pilot project plans were not immediately available and 2D footprints were created.

#### Creation of 2D Building Footprints

A combination of the building corner survey points, high resolution orthophotos, downloaded from [MassGIS](#), and first-return LIDAR data was used to create the building footprints. Building footprint data has already been extracted from LIDAR data for 33 towns in the metro-Boston area. If building footprints already exist, then the steps described here for creating them can be skipped. Once created, the building footprints can be used to define building dimensions in [SketchUp](#) providing the base upon which the photorealistic 3D models of the facilities are built.

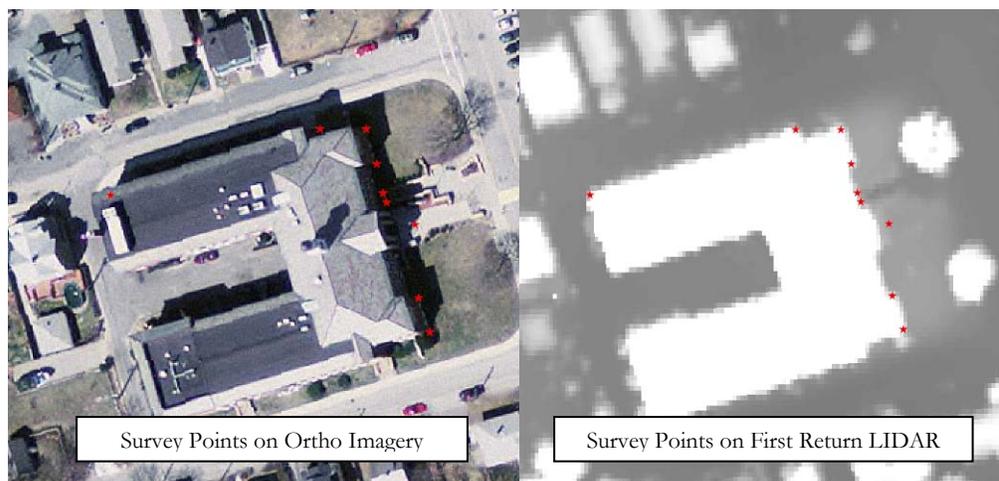
1. Create a shapefile to store the 2D building footprints:
  - a. Open [ArcCatalog](#) and browse to the project working folder.
  - b. Right-click in the *Contents* window and choose *New > Shapefile*.
  - c. Give the shapefile a meaningful name.



- d. Set the *Feature Type* to *Polyline* – the footprints will be constructed of polylines and then converted to polygons.
  - e. Set the desired Spatial Reference using the *Edit* button (the pilot study used to NAD 1983, Massachusetts State Plane).
  - f. Click *OK* to create the shapefile.
2. Open ArcView and load the empty 2D footprints shapefile
  3. Load the feature class containing the surveyed points (generated by following the steps in Section 2).
    - a. Open the attribute table by right clicking the layer name in ArcView's *Table of Contents* and choosing *Open Attribute Table*.
    - b. Determine which points represent building corners by using the *Description* field. For the pilot study in Hull, building corner points included all variations of “Building Corner Ground Elevation”
    - c. From the attribute table’s *Options* drop-down menu, choose the *Select by Attributes* tool.
    - d. In the *Select by Attributes* dialog, create a query to select all features representing the building corner points using the *Description* field.
    - e. Close the attribute table, right-click on the feature class and choose *Data >> Export Data* to save a copy of the selected features as a new feature class. When prompted load the new feature class into the ArcView project and remove the original survey points file by right-clicking on the layer name and selecting *Remove*.
  4. If available, load the first return LIDAR grid(s) to the project. These grids provide the elevation of the highest reflective object that each LIDAR pulse encounters and are useful in delineating building footprints.
  5. Load high resolution ortho imagery:
    - a. Open an internet browser and go to the [MassGIS](#) data index website.



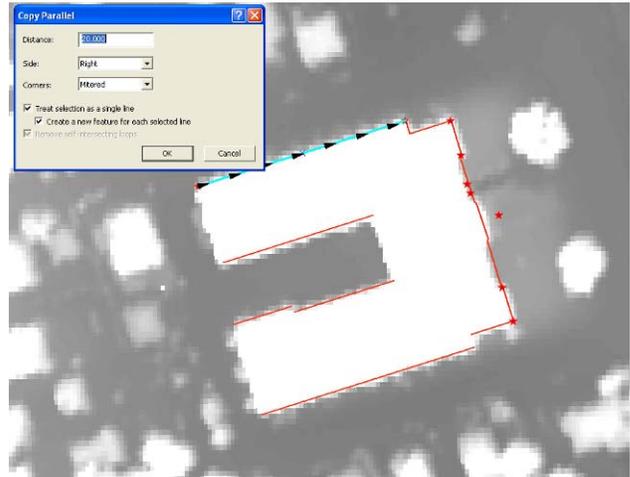
- b. From the list of Ortho Imagery, determine the highest resolution imagery available in the area of interest.
    - i. For all coastlines north of Cape Cod use the USGS Color Ortho Imagery (2008) dataset.
    - ii. For the Cape Cod, Buzzards Bay, and Narragansett Bay shorelines, use the 1: 5000 Color Ortho Imagery (2005) dataset.
  - c. Download the relevant tiles (each dataset will provide a link to an index map which can be used to identify the necessary tiles) ensuring that all three files (.sid, .sdw, .sid.aux.xml) with the same name as the tile index are downloaded.
  - d. Load the ortho imagery files into the ArcView project
6. Create the 2D building footprints
- a. Overlay the survey points on top of the first return LIDAR and/or the ortho imagery to help trace in the building outlines. Depending on the survey extent, only two sides of the building may be represented with survey points. These sides will be drawn first; the remaining sides will be drawn with the assistance of the LIDAR data and ortho imagery. Note that the survey points may not appear to line-up with the imagery as the building roof may obscure the base, as shown below:



- b. Start editing the empty 2D footprint shapefile by selecting *Start Editing* from the *Edit* menu. If prompted, make sure to choose the correct source folder for the edits.

c. Choose *Snapping* from the *Edit* menu and check-on *Vertex*, *Edge*, and *End* snapping for the survey points layer and the 2D Footprint lines layer.

d. Using the Editor's *Sketch Tool*, , connect the survey points along the base of the building, making sure to snap the endpoints to the survey points. Use the LIDAR and orthophotos to digitize any features missed by the survey such as the jogs in the Hull Memorial School façade, visible aerially in the images above.



e. Once the surveyed sides of the building have been drawn. Use the *Copy Parallel* tool, available from the *Editor* menu, to create the remaining building walls. Use the editor's *Edit* tool, , to drag-and-drop the lines into place and snap the endpoints together.

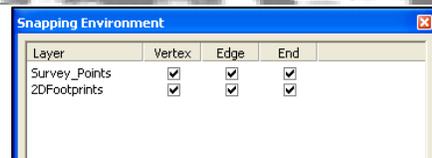
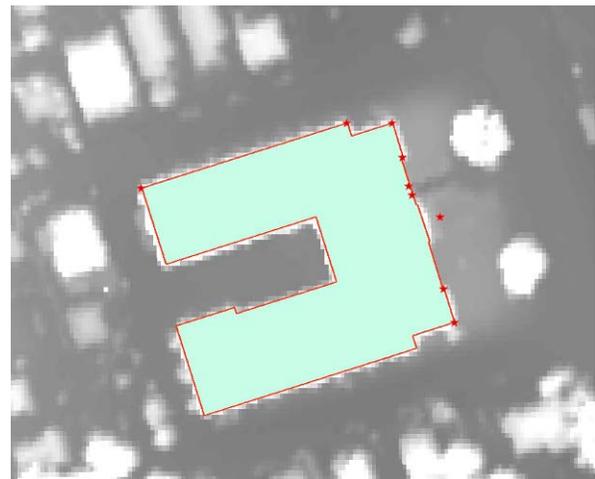
f. After creating all the walls, choose *Editor > Save Edits* and then *Editor > Stop Editing* to finalize the shapefile.

7. Convert the footprint polylines to polygons using ETGeoWizards, which can be downloaded from: <http://www.ian-ko.com/>.

a. Follow the ETGeoWizards installation instructions and then open the tool in ArcView.

b. From the ETGeoWizards *Convert* tab, choose the *Polylines to Polygon* tool and click *GO*.

c. Follow the instructions in the Wizard to create a polygon shapefile of the building footprint polylines.



- d. If you cannot download [ETGeoWizards](#), use [ArcCatalog](#) to create a new polygon shapefile (as in Step 1) and using the Editing tools to create a polygon by tracing the footprint polylines.

### Extraction of 3D Building Models

The 3D models for the Hull pilot study were produced using a combination of software packages and different techniques. In general, 2D building foundations were created using measurements from existing site plans and field data collected by survey crews. [SketchUp](#) was then used to extrude these 2D foundations and create a basic 3D model of each building. Once the base model was completed, field photos of each building were used to texture the exterior of the 3D buildings giving the models a realistic representation. The final models were then georeferenced using the [Google Earth](#) controls in [SketchUp](#). Finally, the models were uploaded to [Google™ 3D Warehouse](#) for public distribution and approval into [Google Earth's](#) 3D Buildings layer.

Use the steps below to create 3D building models using [SketchUp](#) and [Google Earth](#). Remember, each building is different and can pose unique challenges, for more information about building 3D models see [Google's Modeling Guide](#).

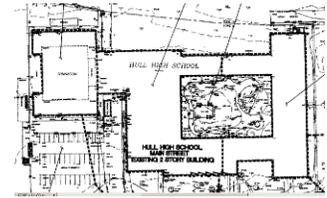
1. Obtain Photos and Building Heights:
  - a. Perform a site visit to each building and take photographs of all the faces of each building.
  - b. Ideal photos are taken perpendicular to the face of the building.
  - c. Obtain heights of any features not surveyed during the survey process. ESS used a TruPulse™ 360 Laser Rangefinder to supplement the building heights taken by the survey crew.
2. Create a building base in [SketchUp](#): Depending on the complexity of the building, site plans/blueprints may not be needed to create the 2D foundation of the model. Simple length measurements on a rectangular building are easy to obtain (e.g. from the 2D footprints created above) and can provide the base data needed for the foundation. However, with more complex buildings, blueprints provide more detailed information which facilitates the process of building a foundation. ESS used both techniques for the development of the models.



- a. Open SketchUp ([download](#) and install if necessary)
- b. Load the *Views* toolbar (*View > Toolbars > Views*).
- c. Switch the view to *Plan* view by pressing the Top button, , on the *Views* toolbar.
- d. Load the building blue-prints, if available, and scale according to the dimensions of the site plan

- i. Load the blueprint image (*File > Import*)

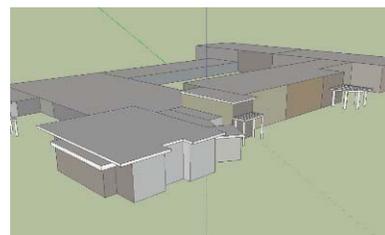
- ii. Click and place the image roughly where the XYZ planes meet on the screen and drag the image to the approximate size of the building dimensions.



- iii. Scaling at this stage is a very rough estimate so use the Tape Measure Tool, , to verify the blueprint dimensions are correct and use the Scale Tool, , to adjust the image as necessary by dragging the outer nodes.

- e. Once the blueprints are scaled, draw the base of the building using the Line tool, . Trace the building footprint by drawing a line and entering the line length in the dimension length window. Double-click to complete each polygon. Buildings with varied heights should have individual shapes for each different height.
- f. If no blueprints are available, either use Google Earth to obtain dimensions by zooming into the building of the model at an eye altitude of roughly 200ft and using the Ruler Tool to derive the dimensions of the building footprint or use the 2D shapefile footprints created in the section above to determine the building dimensions. Once the building dimensions have been determined draw the foundation lines as described in Step e.

3. Building the 3D Model: once the 2D footprint is created in SketchUp and all necessary building heights have been collected, the footprint can

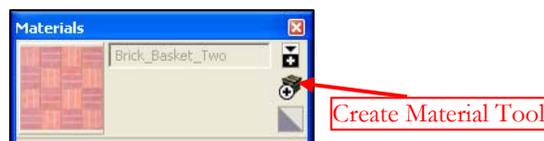


- be extruded to the correct height using the *Push/Pull* tool.
- a. Switch to an oblique view of the building by clicking the *Iso* icon, , found on the *Views* toolbar.
  - b. Select the *Push/Pull* tool, , click on the object to be extruded, type in the height (in meters), and press Enter. The object will now be extruded to the specified height.
    - i. The *Tape Measure Tool*, , can be used to verify heights and distances between features by clicking on the endpoints of the building.
  - c. Since no data were available on roof angles, the rooflines were rendered from field photographs and height measurements.
    - i. Depending on the roof type, roofs can be created two ways:
      1. For flat roofs: by extruding an overlapping, slightly larger polygon to the proper dimensions for the roof;
      2. For peaked roofs: by dividing the roof top using the *Line* tool, , and using the *Move Tool*, , to raise or lower the line to the proper peak height.
4. Editing the Field Photos: the photographs taken during the field survey contain elements such as vegetation and vehicles that obscure the exterior faces of the buildings. These features must be removed from the photos to create realistic depictions of the facilities
- a. Open each field photograph in an image editing software program. The pilot project team used Adobe Photoshop.
  - b. Select and erase any element that obscures the building façade
  - c. To fill in the empty spaces, select and copy similar components from other areas of the photo and paste them into the empty areas

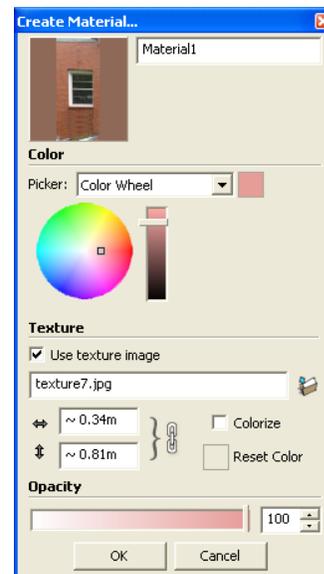


- d. Adjust tones as necessary to achieve a uniform appearance.
  - e. Resize the image to 512 pixels along the shorter axis; this will help to control the file size of the final 3D model.
5. Using the Field Photos for Texture: the modified photos can now be used to add texture to the walls of the 3D models in SketchUp.

- a. Open the *Paint Bucket* tool, , by clicking on the icon.
- b. In the *Paint Bucket* dialog, choose the *Create Material* tool



- c. In the *Create Material* dialog, in the *Texture* section, select *Use Texture Image*, and navigate to the image to be imported. Repeat this process for each photo to be imported.



- d. Apply the imported textures to building faces
  - i. In the *Materials* window, highlight the texture to be used.
  - ii. Click on a face on the model to place the texture on the face.
    1. This image can be stretched using the *Position Texture Tool*, . Access the tool by right-clicking on the image and selecting *Texture > Position*.

2. To position the image to match the model, drag the tool's pinpoints to the corners of the corresponding building face.
  3. Once the image is positioned correctly on the face, right click on the image and select *Done*.
  4. Finally, right click on the image and select *Make Texture Unique*. This step crops the photo to the building edges, if necessary and helps to reduce the final file size.
- e. To reduce the file size of the model, select *Purge Unused* images from the *Materials* window by clicking on the *Details*, , button.
6. Placing the Model: when the model is completed it needs to be placed in a geographically correct position in order to be viewed in Google Earth. The link between SketchUp and Google Earth facilitates this process. ESS used survey data as well as the Google Earth base orthophotos to place the models correctly in Google Earth.
- a. Open Google Earth and zoom to the location of the building.
  - b. Open the SketchUp building model and load the Google toolbar (*View menu > Toolbars > Google*).
  - c. Use the *Get Current View* tool, , to import a snapshot of the current view in Google Earth.
  - d. Use the *Select* tool, , to select the entire model.
  - e. Use the *Move*, , and *Rotate*, , tools to adjust the model to fit over the Google Earth image of the building.
  - f. Once located correctly, use the *Place Model* tool, , on the *Google Toolbar* to export the model to Google Earth. View the model in Google Earth to ensure accuracy.



7. Publishing the Models to Google Earth: while placing the model in Google Earth, as described in Step 6, creates a KML version of the model that can be opened in Google Earth by the user, it does not publish the model to 3D Warehouse or add the model to the native Google Earth 3D buildings layer. Due to a bug in the Google Earth software, in order for the transparent flood overlays created in the next step to display correctly, the 3D building models must be accepted by Google for public distribution in the native 3D buildings layer.
  - a. Once the 3D model is completed in SketchUp, go to *File > 3D Warehouse > Share Model*. The user will be prompted to login to a Google account. If necessary, create a Google account [here](#).
  - b. The user will be prompted for information about the model including model title, address, description, etc. Once completed click on the *Upload* button.
  - c. The Google review process can take up to 30 days. Periodically check your account to see if the model has been accepted or check the 3D Building layer in Google Earth to see if your model appears. If the model is not accepted, Google will give you a brief description of the edits necessary for acceptance.

## ***Pilot Study Results***

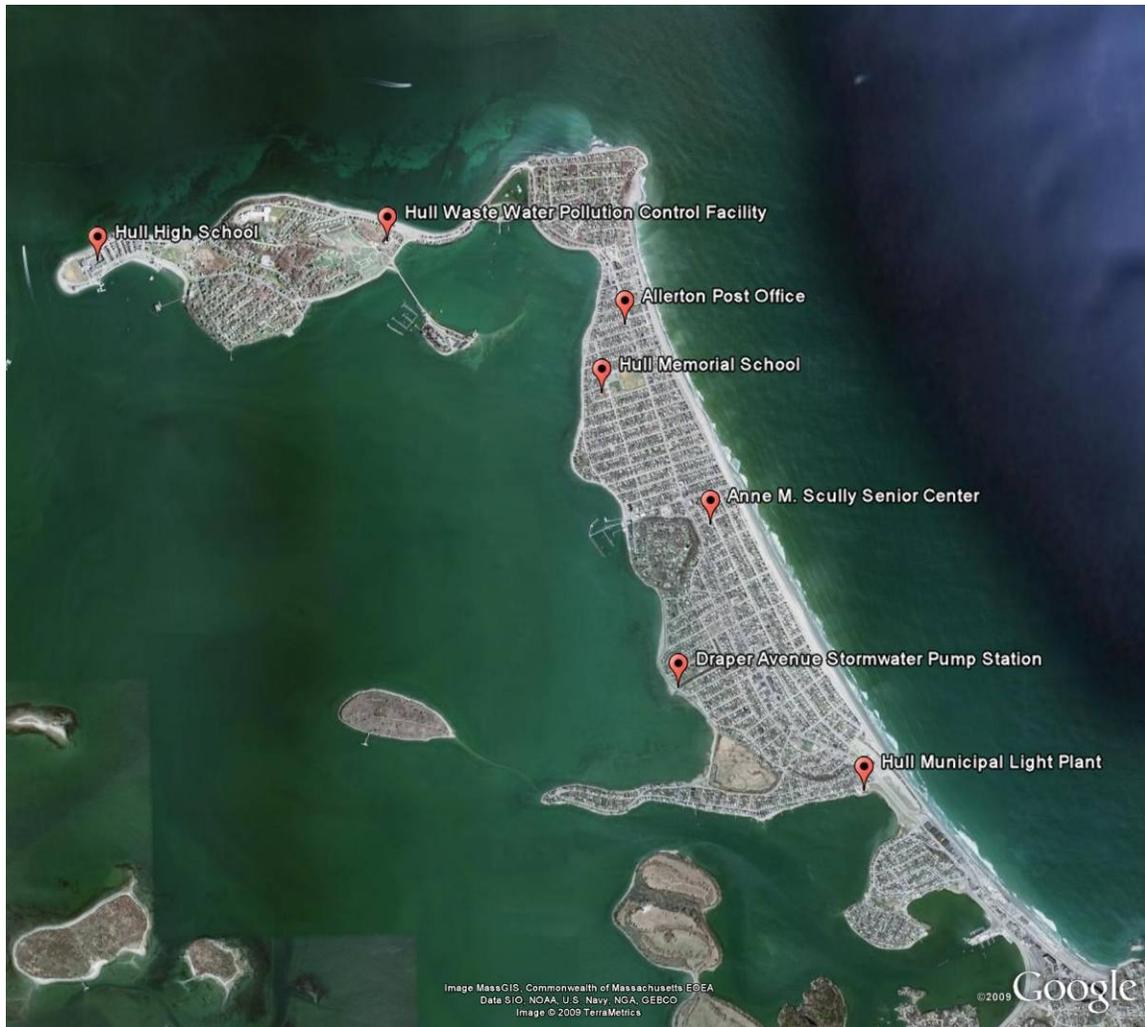
Seven critical facilities around Hull were chosen for the pilot study. These facilities were chosen during the initial planning meeting of the project team which included representatives from MACZM, the town of Hull, ASA, and ESS. The locations chosen are all public buildings and are well dispersed throughout the town (Figure 4.1). The facilities, addresses, and corner elevations are summarized in Table 4.1.



**Table 4.1. Hull critical facilities and addresses.**

<b>Facility</b>	<b>Address</b>	<b>Elevation NW (m NAVD 88)</b>	<b>Elevation NE (m NAVD 88)</b>	<b>Elevation SE (m NAVD 88)</b>	<b>Elevation SW (m NAVD 88)</b>
Hull High School	180 Main Street	3.55	2.99	2.82	3.20
Hull Memorial School	81 Central Avenue	2.58	3.73	3.85	2.39
Waste Water Treatment Facility	1111 Nantasket Avenue	3.10	3.04	3.37	3.26
Anne M. Scully Senior Center	197 Samoset Avenue	2.89	2.89	2.89	3.16
Allerton Post Office	797 Nantasket Avenue	2.78	3.25	3.22	2.95
Draper Ave Pump Station	200 Newport Avenue	1.67	1.74	2.03	1.96
Municipal Light Plant	15 Edgewater Road	5.24	4.67	3.16	3.44





**Figure 4.1. Critical facilities used for flood visualizations.**

Initially 2D footprints of each building were constructed using the survey points, orthophotos, and first return LIDAR datasets. Screen shots of these footprints are shown in figure 4.2 through 4.8.



Figure 4.2. Two-dimensional model of Allerton Post Office.



Figure 4.3. Two-dimensional model of the Waste Water Pollution Control Facility.



Figure 4.4. Two-dimensional model of Hull High School.



Figure 4.5. Two-dimensional model of Hull Municipal Light Plant.



Figure 4.6. Two-dimensional model of the Anne M. Scully Senior Center.



Figure 4.7. Two-dimensional model of the Hull Memorial School.





**Figure 4.8. Two-dimensional model of the Draper Avenue Stormwater Pumping Station.**

All seven 3D models have been completed in SketchUp and to date all but the Draper Avenue Pump Station have been accepted into the native Google Earth 3D Buildings layer. The 3D Warehouse Links to the models used for this project are listed below:

1. [Allerton Post Office](#)
2. [Hull Waste Water Pollution Control Facility](#)
3. [Hull High School](#)
4. [Hull Municipal Light Plant](#)
5. [Anne M. Scully Senior Center](#)
6. [Hull Memorial School](#)
7. [Draper Avenue Stormwater Pumping Station](#)

Several of the models required tweaking before they were accepted by Google Earth. The project team experienced issues with model file size, terrain conflicts, z-fighting, and number of structures as summarized in Table 4.2. General acceptance criteria for Google Earth models is available [here](#).

**Table 4.2. Summary of Google's feedback for the 3D models.**

Facility	Issue	Solution
Hull High School Hull Memorial School	File Size	Reduced file size of texture images following techniques outlined in the steps above.
Hull Memorial School	Z-Fighting	Followed <a href="#">Google recommendations</a> .
Municipal Light Plant Draper Avenue Pump Station	Elevation Conflicts	Enabled <i>Terrain Mode</i> in SketchUp and adjusted models as necessary
Municipal Light Plant	Model contained more than one discreet structure	Removed rear garage structures from model.

Figures 4.9 through 4.15 show the 3D version of each facility. These buildings can be located in [Google Earth](#) using the addresses provided in Table 4.1.



**Figure 4.9. Three dimensional view of Allerton Post Office.**



**Figure 4.10. Three dimensional view of Hull Waste Water Pollution Control Facility.**



**Figure 4.11. Three dimensional view of Hull High School.**



**Figure 4.12. Three dimensional view of Hull Municipal Light Plant.**



Figure 4.13. Three dimensional view of Anne M. Scully Senior Center.



Figure 4.14. Three dimensional view of Hull Memorial School.

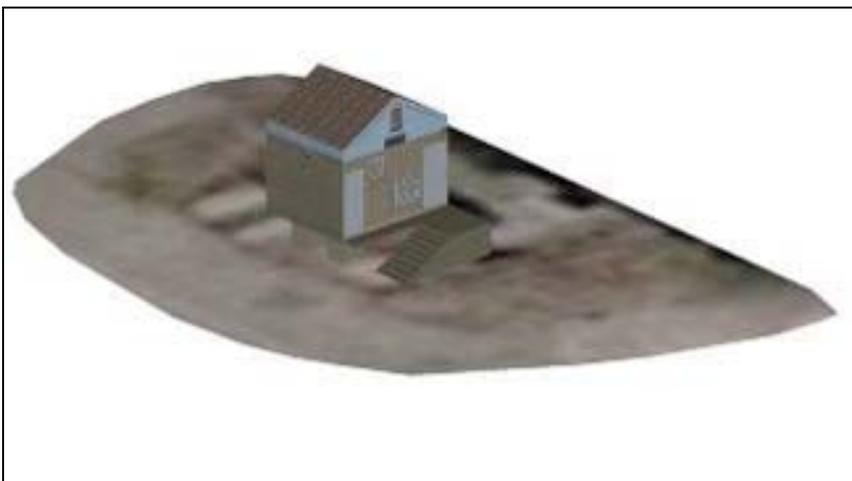


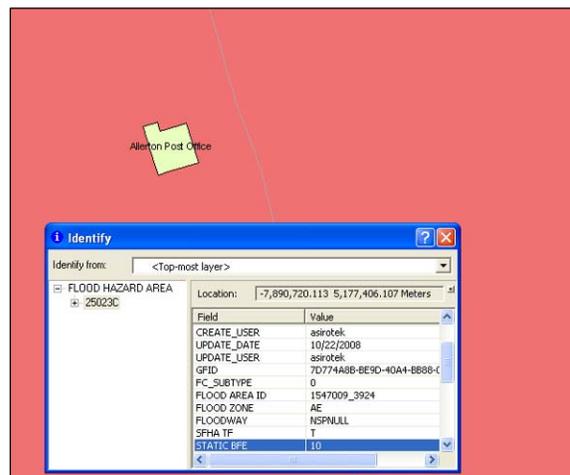
Figure 4.15. Three dimensional view of the Draper Avenue Stormwater Pump Station.

## 5. Creating Flood Layers

### Analysis Steps

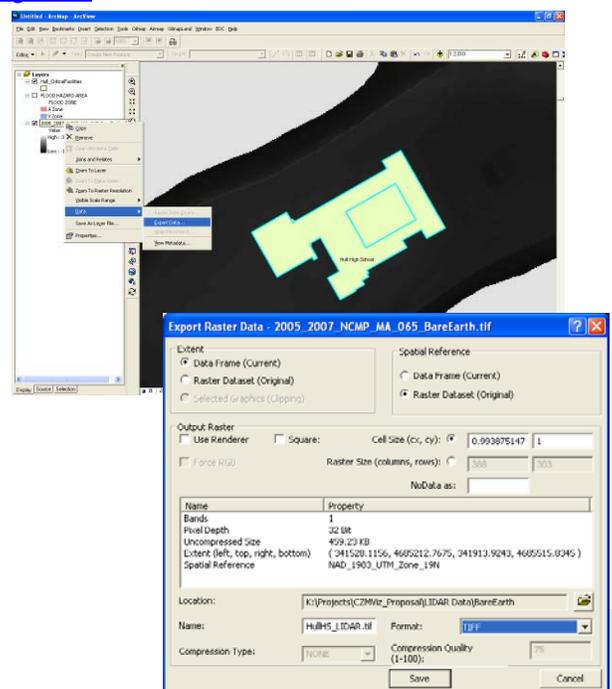
The creation of flood layers requires two input data sources (1) the flood elevation to be simulated and (2) a high resolution elevation dataset. The process of creating the layers involves determining the land area at elevations less than the flood elevation. Isolated low-lying areas, i.e. those not connected to a flooding source, need to be removed from the dataset. The process of creating these layers can largely be accomplished with ArcView. The entire process is described in the steps below.

1. Determine Flood Elevations: for the Hull pilot study, flood elevations were defined by using the recently determined (November 2008) Base Flood Elevations (BFE) from the Federal Emergency Management Agency (FEMA) Preliminary Digital Flood Insurance Rate Map (DFIRM) for Plymouth County plus some amount of sea level rise. Under the FEMA's Map Modernization and RiskMAP Programs, most floodplains are being updated and converted to DFIRM format. Priority is given to coastal flood zones, so be sure to check for the most recent maps before proceeding with this process. BFEs will generally be referenced to NAVD88, however ensure that this is the case before proceeding.
  - a. DFIRMS are available in the format of ESRI personal geodatabases (GDB). These database files contain a suite of spatial and non-spatial information including a base map, features such as floodplain boundaries, BFEs, floodways, cross sections and bench marks, a digital copy of the Flood Insurance Study (FIS), all metadata, and backup engineering data (FEMA, 2003).
  - b. To determine BFE elevations at a particular location, open ArcView and load the 2D building footprints and the *DFIRM S\_FLD\_HAZ\_A* feature class (found in the *DFIRM* geodatabase > *DFIRM\_MapLayers* feature dataset).
  - c. Using ArcView's zoom tools, , zoom into your area of interest.
  - d. Activate the *Identify* tool, , and click on the map near the facility to query the BFE.



- e. The BFE value will be in the the *Static\_BFE* field.
  - f. Record the BFE at each facility by following the steps above.
  - g. Sea level rise elevations will require researching the most recent climate change literature. Any number of sea level rise estimates can be added to the BFE allowing visualization of the variation between predictions.
2. Load and Subset Elevation Data: the elevation data used for a flooding study should be at a resolution appropriate to the scale of the study. In the case of the Hull pilot study, determining flooding at individual facilities required the use of LIDAR data (generally available at a 1-meter resolution) to ensure the necessary resolution and accuracy. Larger study areas could potentially use the 10-meter or 30-meter resolution National Elevation Dataset (NED) data available from the USGS. All elevation datasets should be in raster format to facilitate processing in ArcView and in the case of LIDAR data should be processed to represent bare earth.
- a. Check the vertical datum of the elevation dataset by opening the spatial metadata in ArcCatalog or checking with the data provider.
    - i. If the vertical datums of the BFEs and the elevation data are not consistent convert them to a single vertical datum using the datum conversions at the [nearest tide station](#) or using one of NGS's [vertical datum conversion programs](#).

- b. Load the raster elevation dataset(s) into the ArcView project
- c. Use ArcView's navigation tools to zoom into your area of interest.
- d. Right-click on the elevation dataset layer in ArcView's Table of Contents and choose *Data > Export Data*.
- e. In the ensuing *Export Raster Data* dialog, set the *Extent* to *Data*

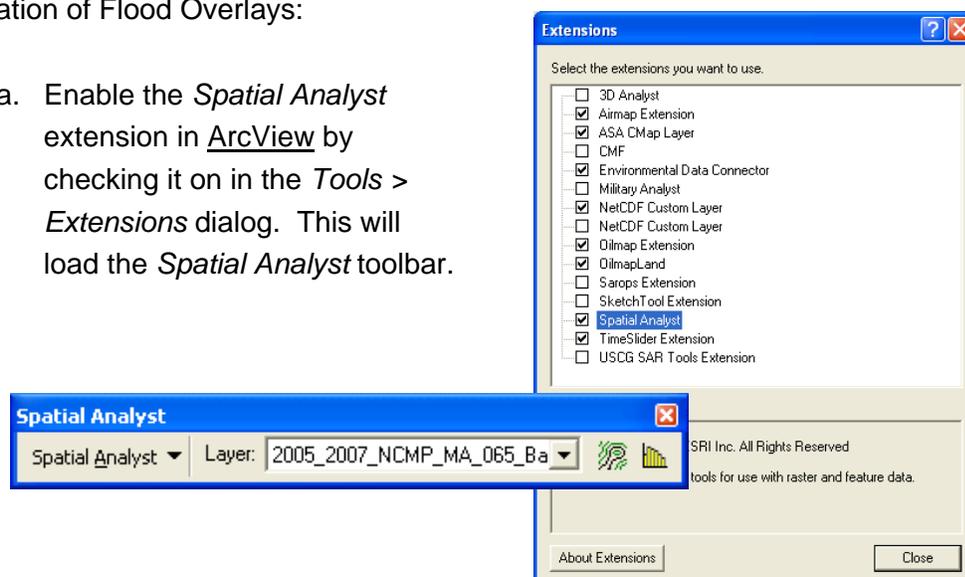


*Frame (Current)*, choose a *Location*, *Name* and *Format* for the extracted dataset and click *Save*.

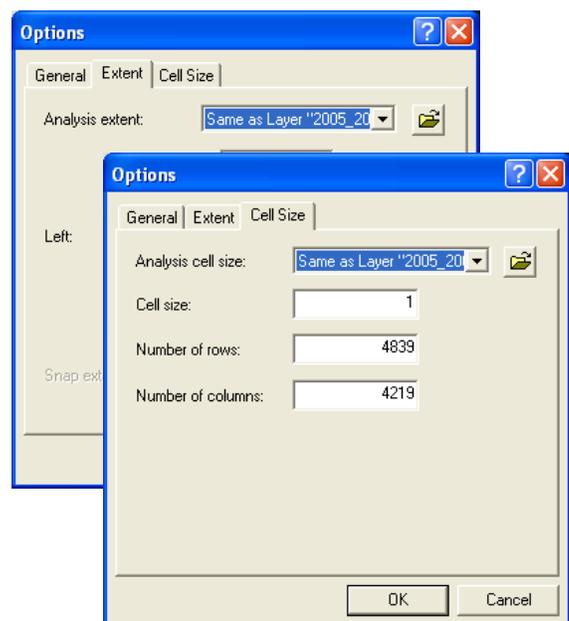
- f. The extracted dataset will be loaded into ArcView. Turn off or remove the original dataset before proceeding.

### 3. Creation of Flood Overlays:

- a. Enable the *Spatial Analyst* extension in ArcView by checking it on in the *Tools > Extensions* dialog. This will load the *Spatial Analyst* toolbar.

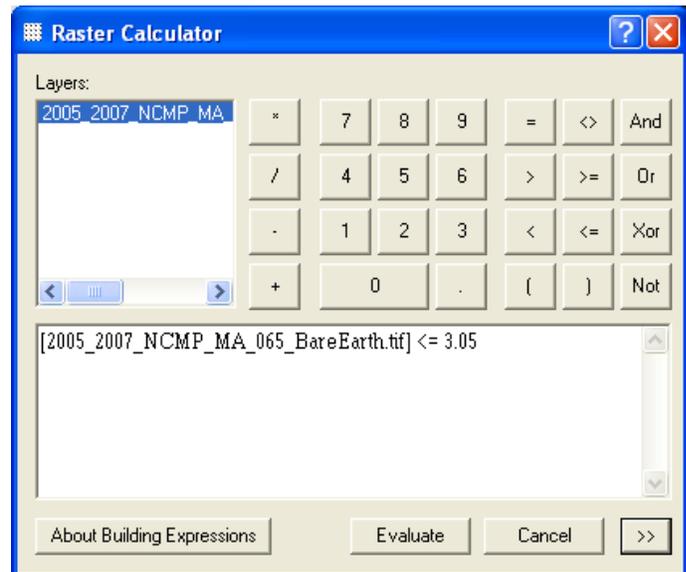


- b. From the *Spatial Analyst* drop-down menu on the *Spatial Analyst* toolbar, select *Options*.
- c. In the *Extent* tab set the *Analysis extent* equal to the extent of the extracted elevation dataset.
- d. In the *Cell Size* tab set the *Analysis cell size* equal to the cell size of the extracted elevation dataset.



- e. From the *Spatial Analyst* drop-down menu on the *Spatial Analyst* toolbar, select the *Raster Calculator* tool. The extracted elevation dataset will be listed in the *Layers* list.

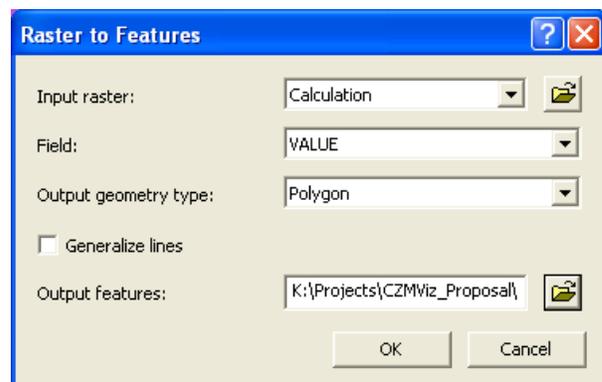
- i. Double-click the elevation dataset to add it to the equation window.
- ii. Click the '<=' button to add an operator to the equation.
- iii. Type in the flood elevation value (in the same units as the elevation dataset) to add it to the equation



- iv. Click *Evaluate*
- v. A new true/false raster representing those areas less than the flood elevation with '1' and those areas greater than the flood elevation with '0' will be loaded into *ArcView*. The dataset is a temporary file and will be called 'Calculation'.

4. Conversion of Flood Overlays: in order to remove those areas representing dry land and any areas of disconnected flooding the raster flood overlay must be converted to a feature class.

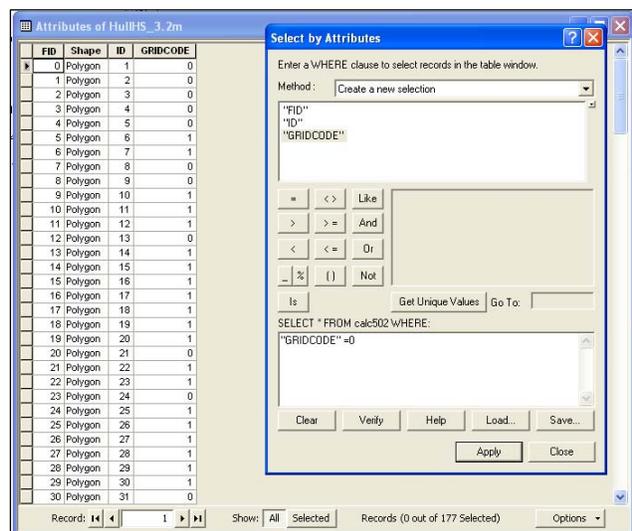
- a. From the *Spatial Analyst* menu select the *Convert > Raster to Features* tool.
- b. Set the *Input raster* to the Raster Calculator result.
- c. Set the *Field* equal to 'Value'



- d. Set the *Output geometry type* to *Polygon*
  - e. Check off the option to *Generalize lines*
  - f. Define a location and name for the *Output features* and click OK.
  - g. A feature class version of the raster flood overlay will automatically be loaded into ArcView.
5. Editing of Flood Overlays: two types of polygons must be deleted from the flood overlay, those that represent land and those that represent areas of disconnected flooding.

a. If not already loaded, click the *Editor Toolbar* button, , to load the *Editor* toolbar.

b. From the *Editor* drop-down menu on the *Editor* toolbar, choose *Start Editing*. If prompted, select the folder containing the feature class flood overlay.



- c. Right-click on the feature class name in ArcView's Table of Contents and choose *Open Attribute Table*.
- d. From the attribute table's *Options* drop-down menu choose the *Select by Attributes* function
- e. In the *Select by Attributes* dialog create a query to select features where *GRIDCODE = 0* and click apply.
- f. This query will select all polygons that have elevation values greater than the flood elevation. When the query is finished press the *Delete* key to delete these polygons from the feature class.

- g. From the *Editor* menu, choose the *Save Edits* option to update the feature class permanently.
- h. Now that all dry land features have been deleted it should be easy to identify those features that represent areas of disconnected flooding. These areas will be completely surrounded by dry land. Because they are surrounded by areas of higher elevation flooding will be physically unable to reach them. To delete these areas, close the attribute table and examine the feature class by zooming and panning. Select those features completely surrounded by dry land with ArcView's *Select* tool, , and then press the *Delete* key to remove them from the layer.
- i. When all disconnected polygons have been removed choose *Stop Editing* from the *Editor* toolbar to save the edits and complete the editing process. The finalized shapefile will be converted to a KML file in Section 6.

## ***Pilot Study Results***

Base Flood Elevations for the Hull pilot study were determined from the FEMA DFIRM for Plymouth County (November 2008). Table 5.1 contains a summary of the BFE at each facility used in the study. Two facilities, Hull High School and the Municipal Light Plant do not fall within the 100-year flood zone. When the Municipal Light Plant facility was overlaid with the DFIRMS it was apparent that a portion of the facility did overlap with the 100-year flood zone and a BFE was assigned using the overlapping DFIRM polygon. The high school did not overlap with any 100-year zone, though it is surrounded by several 100-year zones. Using the LIDAR elevation data at the site, various flood elevations were simulated until the results matched the extents of the FEMA 100-year floodplains at the site. The flood elevation that mostly closely matched was 10.5 ft (3.2 m) NAVD88.

**Table 5.1: Base Flood Elevations at Hull Critical Facilities**

Facility	Base Flood Elevation (NAVD88)
Hull High School	10.5 ft (3.2 m)
Hull Memorial School	10.0 ft (3.05 m)
WWTP	13.0 ft (3.96 m)
Scully Senior Center	10.0 ft (3.05 m)
Allerton Post Office	10.0 ft (3.05 m)
Draper Ave Pump Station	12.0 ft (3.66 m)
Municipal Light Plant	10.0 ft (3.05 m)

Sea level rise elevations were defined during an initial planning meeting of the Hull pilot project team. At that time four sea level rise elevations were agreed upon, 1 ft (0.3 m), 1.6 ft (0.5 m), 3.3 ft (1 m), and 9.8 ft (3 m). These rates were determined so that a variety of sea level rise acceleration rates could be represented with the study results.

LIDAR elevation data for the Hull pilot study was provided by the Massachusetts Office of Coastal Zone Management. This data was collected between 2005-2007 for the US Army Corps of Engineers (USACE) and the National Coastal Mapping Program (NCMP). Elevation data was collected in a 0.5 mile swath along the coastline at 1 m spacing and processed to create seamless 1 m grids representing bare earth with a horizontal accuracy of 3 m and a vertical accuracy of 30 cm. Because Hull is so narrow complete coverage of the town was available.

For each facility, the corresponding LIDAR layer was clipped to the area around the facility and the flood overlays were calculated using this subset of data. Because the pilot project visualizes a variety of sea level rise projections with a BFE specific to each location, the project team did not want to show projected flood impacts in locations other than directly around the critical facilities, which are all publically owned.

Using the methods described above, each LIDAR dataset was used to calculate five flood overlay layers for each critical facility (one for BFE plus each of four sea level rise scenarios). These flood overlay layers were then converted to KML files for visualization in [Google Earth](#).



## 6. Visualizing Results in Google Earth

### ***Analysis Steps***

To bring flood polygon feature classes into Google Earth for visualization with the 3D building models they must be converted to KML files. KML files can consist either of features (vector-based KML files) or of georeferenced images (ground overlay KML files). There are pros and cons to both file types, but for this application the feature classes will be converted to vector-based KML files because they provide the best format for accurately depicting flood elevations. Vertical accuracy is critical because the flood overlays will be shown in relation to 3D buildings.

Once the individual KML flood layers are created, they will be combined into a single KML file for each facility and these will be combined into a single network link KML file utilizing the KML *Regions* functionality. A network link KML file is simply a master file that contains links to many additional layers. Layers can include images, models, and other KML files. The networking functionality is useful for splitting one large KML file into many smaller and more manageable files.

The KML *Regions* option loads and draws data only when it falls within the user's view. This option allows the flood layers around each facility to be drawn only when the viewer gets close to the facility, which is important since flood elevations were based on the BFE at each individual facility and may not be valid in surrounding areas. The FEMA flood zones have been added so that the 100-year floodplain for Hull becomes visible as the user zooms or pans away from each critical facility. Also included in the networked KML file are predefined viewpoints for each building and labels for each building and flood elevation, allowing the user to easily navigate through the results.

Once the data processing is completed ArcView, and a text editor such as WordPad are all that is necessary to place the layer into the display software, Google Earth. In the first step ArcView will be used to create vector-based KML files from the flood overlay shapefiles. Next the flood overlay layers will be loaded into Google Earth and organized according to facility. Finally a text editor will be used to combine all of the individual KML files into a single network link KML file, utilizing the *Regions* functionality, for final display in Google Earth.



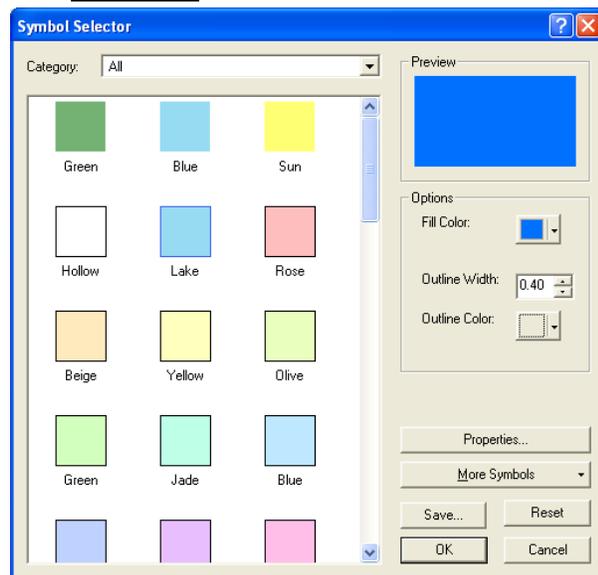
### Create the feature-based KML files:

1. Download and install the [Export to KML tool](#) from ESRI's ArcScripts site. Follow the instructions for installing and loading the tool into [ArcView](#).
2. Open [ArcView](#) and load the flood layers to be converted to KML.
3. Symbolize each flood layer as you want it to appear in [Google Earth](#).

a. Right-click on the layer name in [ArcView's Table of Contents](#) and select the *Properties* option.

b. In the *Layer Properties* dialog, select the *Symbology* tab and click on the layer's symbol to access its properties.

c. In the *Symbol Selector* dialog, set the *Fill Color* to blue and set the *Outline Color* to 'no color'. Click OK.



d. Back in the *Layer Properties* dialog, click the *Display* tab and set the *Transparency* to 60%. Click OK.

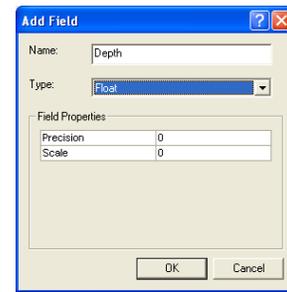
4. Determine the Water Depth – the KML file will float above the ground surface at the specified height, which should be set equal to the local water depth. To determine the water depth at each facility, compare the land elevation with the flood elevation.

a. Load the elevation grid(s) and 2D footprints into [ArcView](#).

b. Use the *Identify* tool, , to determine the land elevation at the foundation of each building.

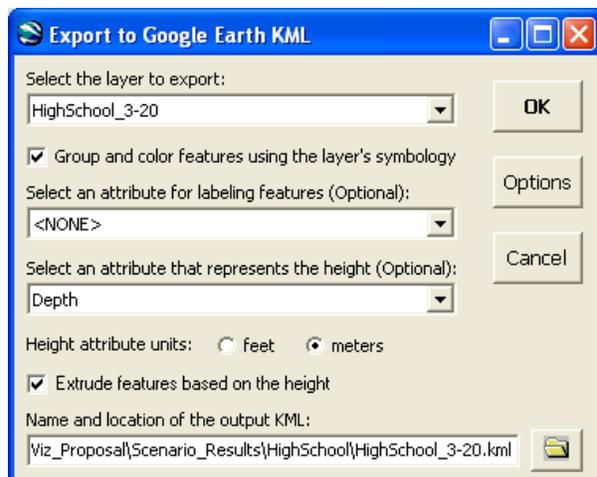
c. Subtract the land elevation from the flood elevation to determine water depth at the building foundation.

- d. Right-click on the flood layer in ArcView's Table of Contents and select the *Open Attribute Table* option.
- e. From the attribute table options drop-down menu, select the *Add Field* option.
- f. Using the *Add Field* dialog create a new field called *Depth* and set the Type to *Float*. Click OK to create the new field.
- g. To populate the *Depth* field, right-click on the field name in the attribute table and select *Field Calculator*.
- h. In the *Field Calculator* dialog type the water depth in the '*Depth =*' equation box and click *OK* and close the attribute table. Each flood feature will now be populated with the water depth at the building foundation.



5. Click the *Export to KML* button, , to open the export dialog

- a. Select the flood layer from the *Select the layer to export* drop down box.
- b. Check-on *Group and color features using the layer's symbology*.
- c. Leave the *Select an attribute for labeling features* option set to *<NONE>*.



- d. Set the *Select an attribute that represents the height* equal to the depth field just created.
- e. Set the *Height attributes units* to meters
- f. Check-off *Extrude features base on the height*

- g. Use the browse dialog to set the name and location of the output KML file.
6. Repeat Steps 1 to 5 to create KML files for each flood elevation at each facility for input to the final networked KML file.
  7. If you would like to add a floating title bar to each flood overlay layer, open each flood overlay KML file in a text editor and add the following KML tags just above the <Folder> tag containing the flood geometry. Change the <href> value to the name of the image file to be used as the floating title.

```

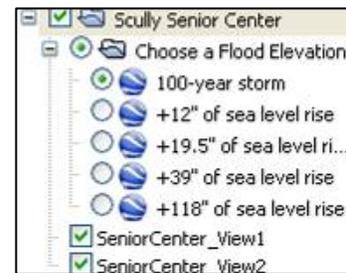
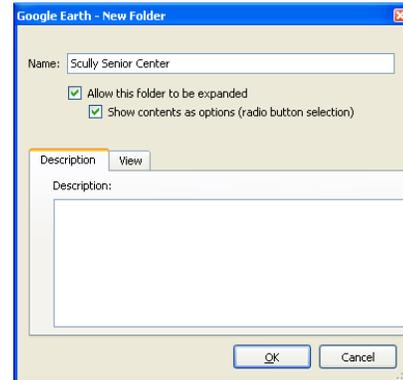
<ScreenOverlay>
  <name>Flood Index</name>
  <Icon>
    <href>ScullySC_0.png</href>
  </Icon>
  <overlayXY x="0.01" y="0.1" xunits="fraction" yunits="fraction"/>
  <screenXY x="0.01" y="0.95" xunits="fraction" yunits="fraction"/>
  <rotationXY x="0.5" y="0.5" xunits="fraction" yunits="fraction"/>
  <size x="0" y="0" xunits="pixels" yunits="pixels"/>
</ScreenOverlay>

```

8. Open each flood KML file in [Google Earth](#) and ensure that it displays correctly. If the flood polygons cover large areas they intersect with the curvature of the earth, causing them to disappear in the center. This issue can be solved by splitting large polygons into smaller features (using [ArcView's](#) editing tools), which creates more vertices and helps [Google Earth](#) to display the polygons correctly.
9. With the flood overlay KML open in [Google Earth](#) right-click on the layer to open the *Properties* dialog and check-off the option to *Allow this folder to be expanded*. This will help to keep the KML file organized by hiding access to the flood polygons and floating title.

Organize the flood overlays by facility:

1. Load all the KML flood overlay files for a single facility into Google Earth.
2. Right-click on the *Temporary Places* folder and choose the *Add > Folder* option.
  - a. Name the folder after the facility.
  - b. Check-on the options for *Allow this folder to be expanded* and check-off *Show contents as options (radio button selection)*.
3. Create a subfolder in the facility folder called “Choose a Flood Elevation” and check-on the options for *Allow this folder to be expanded* and *Show contents as options (radio button selection)*.
  - a. Drag-and-drop each of the flood layers into the “Choose a Flood Elevation” folder and place them in the desired order.
4. If specific viewpoints for the facility have been created, load those into Google Earth and drag them into the facility folder. The final structure will look something like the Scully Senior Center example to the right.
5. Right-click on the new facility folder and choose *Save Place As*. Save the folder as a KML file and note the location for use in the networked KML file.



Create a single networked KML files using the *Regions* functionality:

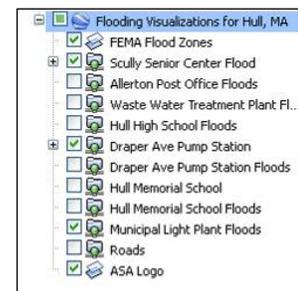
1. Open the network linked KML template provided (Network\_Template.kml) in a text editor and save it as a new KML document. The template contains all the KML tags necessary to define a single network link file.

```
<name>Flooding Visualizations for Hull, MA</name>
<open>1</open>

<NetworkLink>
  <name>Flood Overlay 1</name>
  <visibility>0</visibility>
  <Region>
    <LatLonAltBox>
      <north>xx.xxx</north>
      <south>xx.xxx</south>
      <east>xx.xxx</east>
      <west>-xx.xxx</west>
    </LatLonAltBox>
    <Lod>
      <minLodPixels>512</minLodPixels>
      <maxLodPixels>-1</maxLodPixels>
      <minFadeExtent>512</minFadeExtent>
      <maxFadeExtent>0</maxFadeExtent>
    </Lod>
  </Region>
  <Link>
    <href>FloodOverlay1.kml</href>
  </Link>
</NetworkLink>
```

2. Edit the title

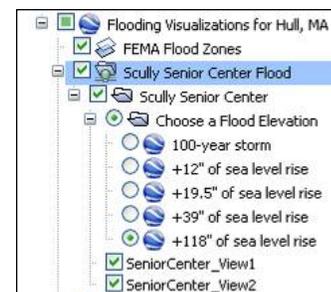
- a. Locate the <name> tag directly under the <Document> tag and update the text. This will be title of your KML file, as shown in the highlighted text.



- b. Keep the <open> tag set to 1, ensuring that the flood overlay folder will be expanded when it is loaded into Google Earth.

3. Edit the text between the <NetworkLink> tags

- a. Set the name of the layer using the <name> tag this will be the name of the folder containing the network links for a single facility, shown the highlighted text.
- b. Set the <visibility> tag to 0. This will ensure that the layer is not drawn on initial load into Google Earth, which is important since the layer's visibility is location specific.



- c. The <Region> tag and its children set the geographic extents of the layer's visibility:
  - i. The <LatLonBox> tag and its children allow definition of a 3D bounding box which will control visibility. Set the <north>, <south>, <east>, and <west> tags with coordinates that define the horizontal extents of the bounding box.
  - ii. The <Lod> tag and its children define the level of detail of the linked file, which controls how the layer fades in and out based on zoom level. Use the following values (for more information about setting these values click [here](#)):
    - <minLodPixels>512</minLodPixels>
    - <maxLodPixels>-1</maxLodPixels>
    - <minFadeExtent>512</minFadeExtent>
    - <maxFadeExtent>0</maxFadeExtent>
  - d. The <href> tag defines the actual file to be linked. Edit this tag to reflect the appropriate file name. If the linked file will reside in the same folder as the network link KML file only the file name is necessary, otherwise the full file path must be specified.
4. To link additional KML files, copy the <NetworkLink> tag and all of its children and paste it below the first <NetworkLink> tag (ensuring that it is above the </Document> tag). Follow steps 3a through 3d to define a new link file.

## ***Pilot Study Results***

While ASA has years of experience visualizing flood impacts with [Google Earth](#), the Hull pilot project was the first project where actual flood depths were visualized using 3D building models. Bringing this third dimension into the visualization posed some new challenges, namely, configuring the custom 3D models so that they interact correctly with the transparent flood overlays and ensuring that the flood depths calculated from the LIDAR data in [ArcView](#) were depicted properly in [Google Earth](#), which has a much less accurate terrain model.

When the final flood overlays and 3D building models were initially loaded into [Google Earth](#) to build the network link KML file it became apparent that the transparent flood layers caused the 3D building models to disappear completely under the water surface.



Because the flood overlay was 60% transparent it should have allowed the underwater portion of the building to show through. Contact with a Google representative confirmed that there is a bug in the [Google Earth](#) software that causes 3D models to disappear behind vector based KML files.

To solve this issue a variety of workaround solutions were attempted, including:

- Transforming the flood overlays (in vector KML format) to ground overlay KML files.
- Building 3D versions of the building layer from shapefiles to replace the missing underwater portions models.
- Recreating all the flood overlays in [SketchUp](#) as 3D models instead of vector KMLs.
- Submitting the 3D models to the [Google Earth](#) 3D buildings layer, which does not experience the same bug with transparent overlays.

Ground overlay representations of the flooding worked allowed the 3D models to show through the transparent water. However, this method posed a problem because the altitude definition for ground overlays is much less accurate than for vector-based KML files. In this case the flood elevations were being rounded to the nearest meter for elevations less than one meter and to the nearest half-meter for elevations greater than one meter. Because of the lack of precision this solution was deemed unacceptable as all of the vertical accuracy gained by using the LIDAR data would have been lost in the conversion to ground overlay based KML file.

Converting the flood overlays into 3D models using [SketchUp](#) also allowed the 3D building models to show through the transparent flood layer and in this case, vertical accuracy was not a problem as [SketchUp](#) allows exact definition of heights. The issue with this solution is horizontal accuracy. Because [SketchUp](#) has no real geographic reference, some horizontal accuracy is lost when placing the models in [Google Earth](#).

Building non-textured versions of the 3D building models was a very viable solution for working around the Google Earth bug and this method was presented to MACZM during the final project meeting. As the flood elevations increase with sea level rise, a grey version of the 3D building appears under the water to replace the missing textured version of the building. These non-textured buildings were created from the 2D footprints originally constructed in [ArcView](#). To create 3D buildings, the 2D footprints were extruded to each of the flood elevations and saved as a separate vector KML file. These KML files were then grouped with the associated flood overlay KML file, so that



as each flood overlay was displayed, the associated 3D grey building was automatically displayed in place of the missing 3D model.

The final, and ideal, solution was to submit all of the 3D building models to Google Earth for inclusion in Google's native 3D building model layer. This solution allowed the team to use the original vector-based flood KML files and preserve all the texture of the buildings underneath the transparent flood layer. Permission to publish the models to Google Earth was granted by the Town Manager of Hull on June 23<sup>rd</sup>, and the project team began submitting models to Google immediately. The turnaround time for model approval is approximately 30 days and by the end of July three models had been accepted and feedback for editing the remaining four (outlined in Table 4.2) had been provided by Google. ESS updated the models and resubmitted. To date, six of the seven models have been accepted; the Draper Avenue Stormwater Pump Station is still outstanding.

Because the terrain data in Google Earth is highly smoothed, visualizing the results at the correct elevation also posed a challenge. In the flood overlay KML files, each flood polygon is represented by X,Y, Z values at each vertex. The X and Y values provide the geographic coordinates of the vertex so that Google Earth knows where to draw the polygon and the Z value provides the altitude of the polygon. How the Z value is interpreted by Google Earth depends on the 'altitude mode' specified in the KML file. There are three standard altitude modes available: *clampToGround*, *relativeToGround*, and *absolute*. The *clampToGround* option ignores any Z values in the KML file. The *relativeToGround* option uses the Z value to draw the feature relative to the ground elevation. The *absolute* option uses the Z value to draw the feature at an elevation relative to sea level.

Two approaches were taken to defining the altitudes and altitude modes for the flood overlay KML files. For those facilities on relatively flat ground the Z values were set to the depth of water at the facility (determined using the LIDAR data in ArcView) and the altitude mode was set to *relativeToGround*, but for display purposes the terrain layer in Google Earth was turned off so that the ground did not interact with the flood overlays. For those facilities set on slopes (the Municipal Light Plant and Draper Avenue Pump Station), the Z values were set to the total flood elevation (BFE + sea level rise), converted to mean sea level, and displayed in Google Earth with an altitude mode of *absolute*. In these cases, because of the steep changes in terrain, the Google Earth terrain model tends to be less smoothed and thus more accurate. Once loaded into Google Earth the flood overlay Z values were then adjusted until they reached the correct depths on the building models. This manual process was necessary because



the reference for the Google Earth terrain is unknown and it was therefore impossible to calculate the difference between the Google Earth and LIDAR elevations.

The final images for each flood elevation at every facility are provided in Appendix A to this report. A Google Earth KML file containing all the flood layers has also been provided.



## **7. References**

Federal Emergency Management Agency (FEMA), 2003. Guidelines and Specifications for Flood Hazard Mapping Partners Appendix L: Guidance for Preparing Draft Digital Data and DFIRM Database.

Federal Emergency Management Agency (FEMA), 2008. Flood Insurance Study Plymouth County, Massachusetts. Flood Insurance Study Number 25023CV000A.

Federal Geographic Data Committee (FGDC), 1998, Part 3, National Standard for Spatial Data Accuracy, Geospatial Positioning Accuracy Standards, FGDC-STD-007.3-1998: Washington, D.C., Federal Geographic Data Committee, 28 p.

North Carolina Cooperating Technical State Flood Mapping Program, 2008. LIDAR Accuracy Assessment Report – Cherokee County, 2008.



## Appendix A: Critical Facility Figures

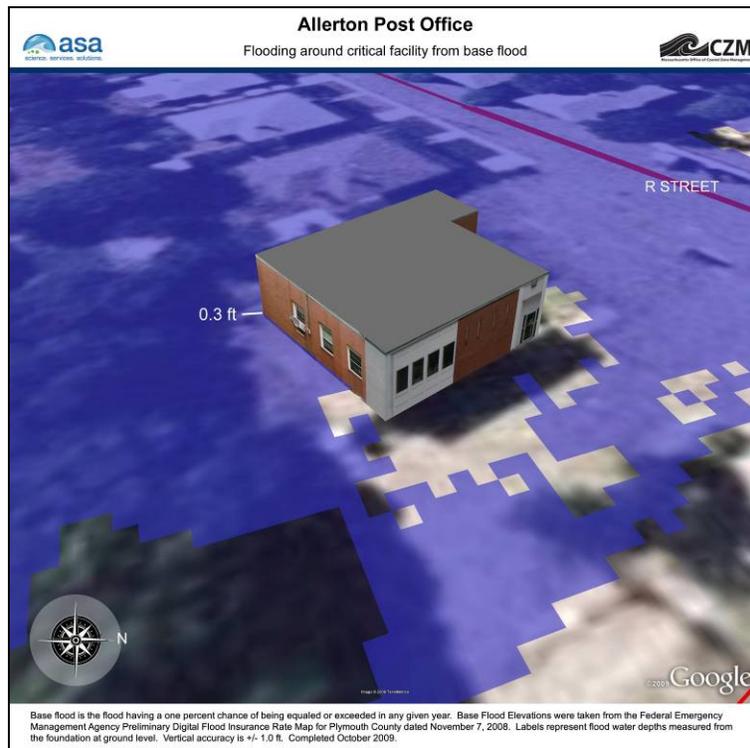


Figure A-1. Allerton Post Office, View 1, Base Flood Elevation.

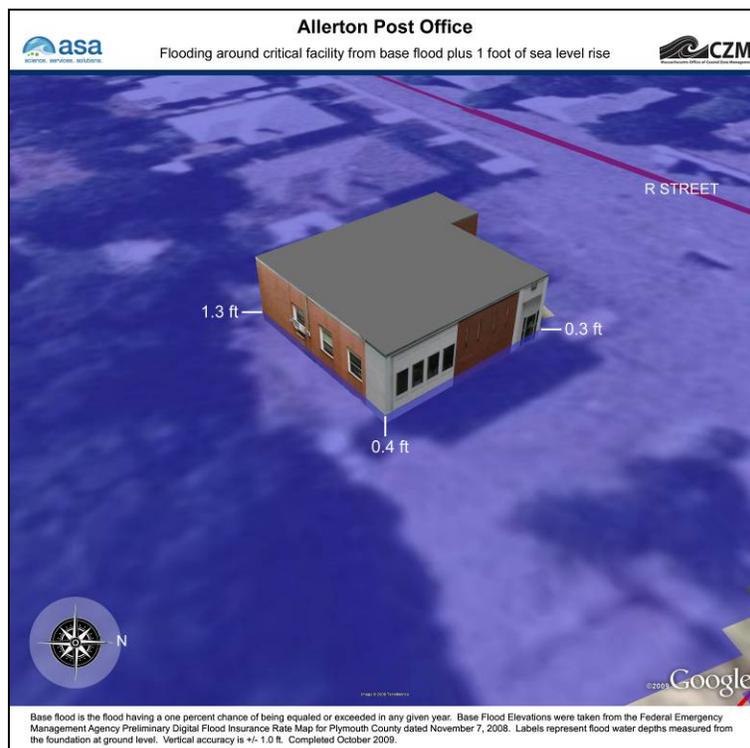
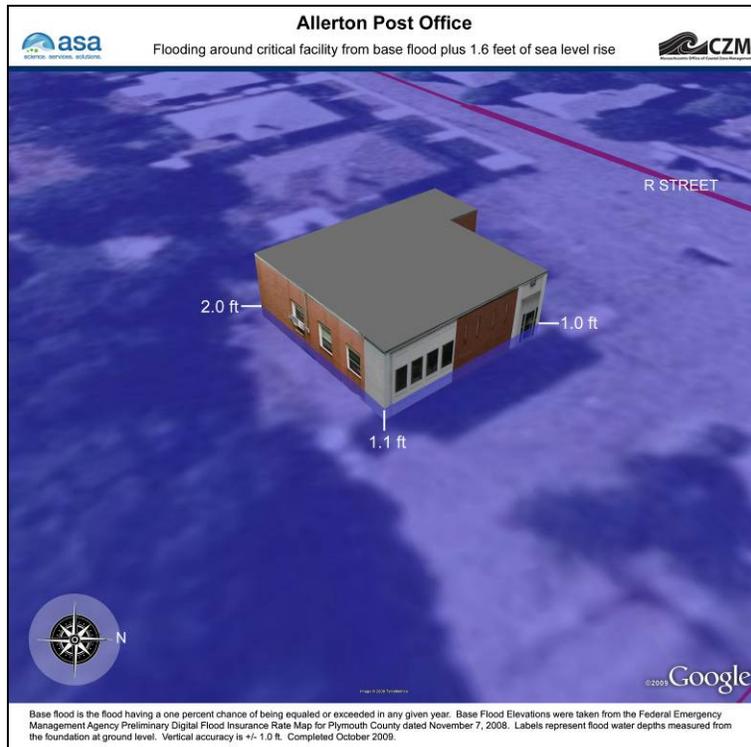
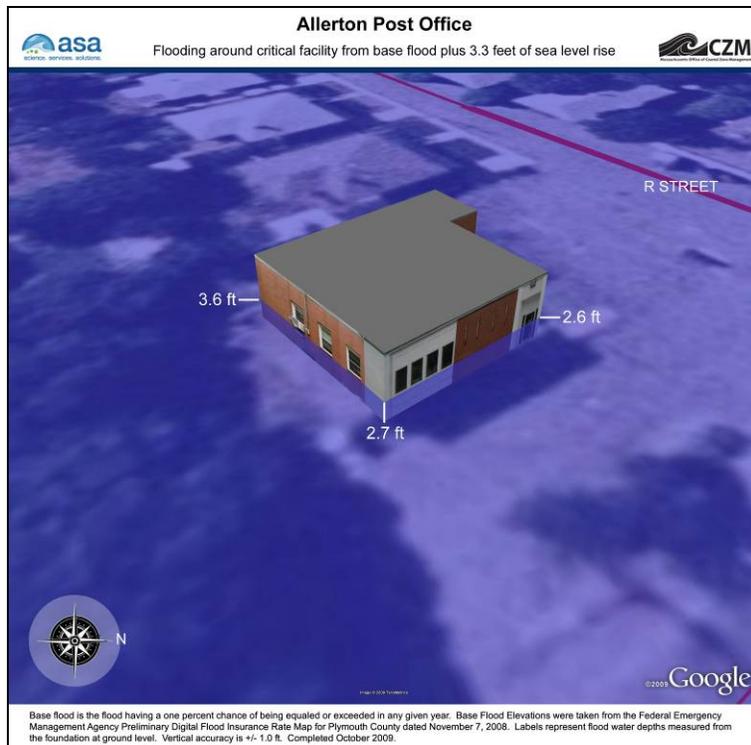


Figure A-2. Allerton Post Office, View 1, Base Flood Elevation plus 1 foot of sea level rise.

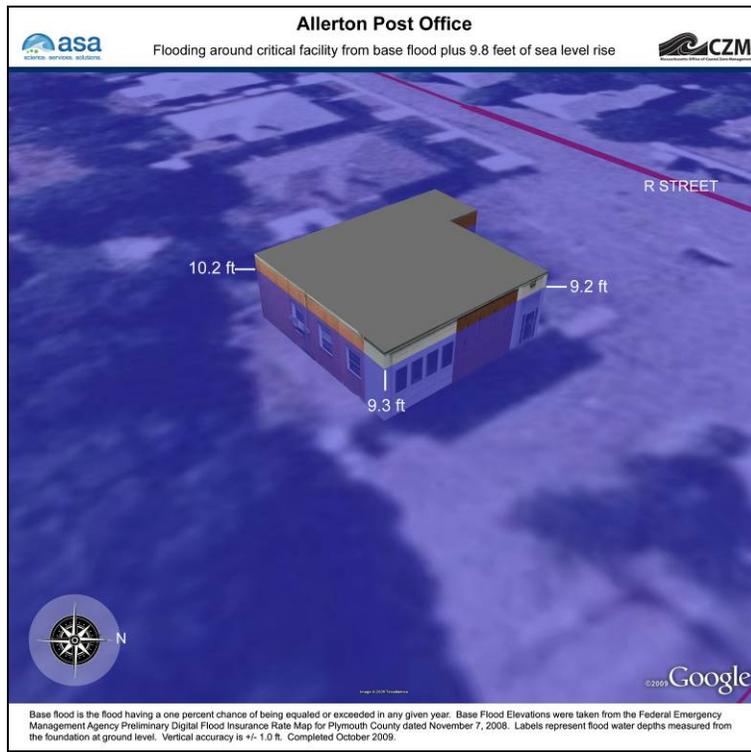


**Figure A-3. Allerton Post Office, View 1, Base Flood Elevation plus 1.6 feet of sea level rise.**

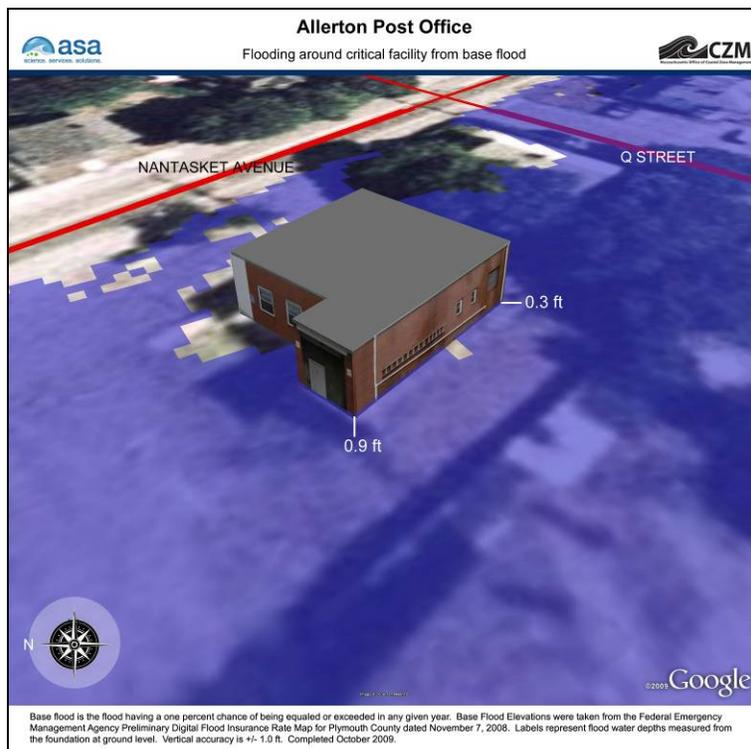


**Figure A-4. Allerton Post Office, View 1, Base Flood Elevation plus 3.3 feet of sea level rise.**





**Figure A-5. Allerton Post Office, View 1, Base Flood Elevation plus 9.8 feet of sea level rise.**



**Figure A-6. Allerton Post Office, View 2, Base Flood Elevation.**



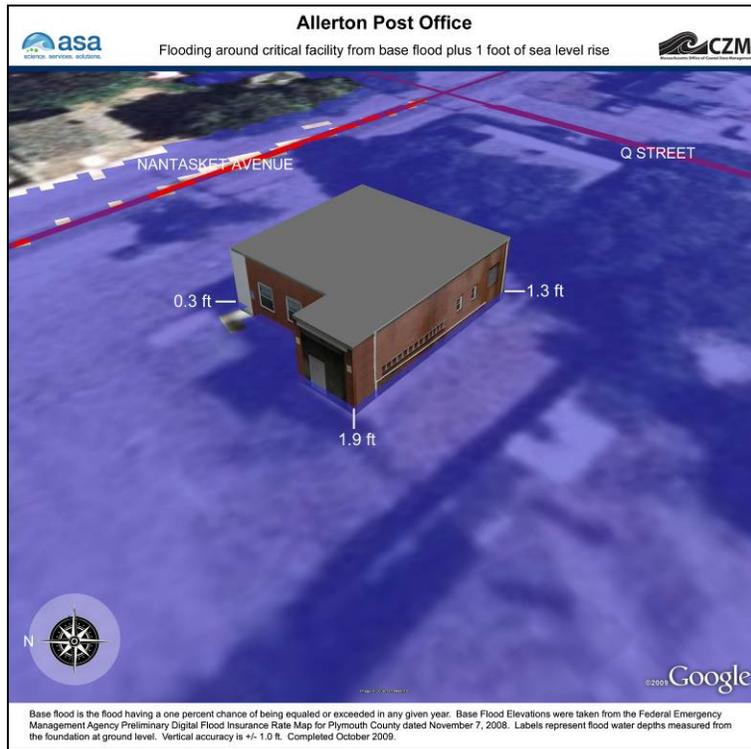


Figure A-7. Allerton Post Office, View 2, Base Flood Elevation plus 1 foot of sea level rise.

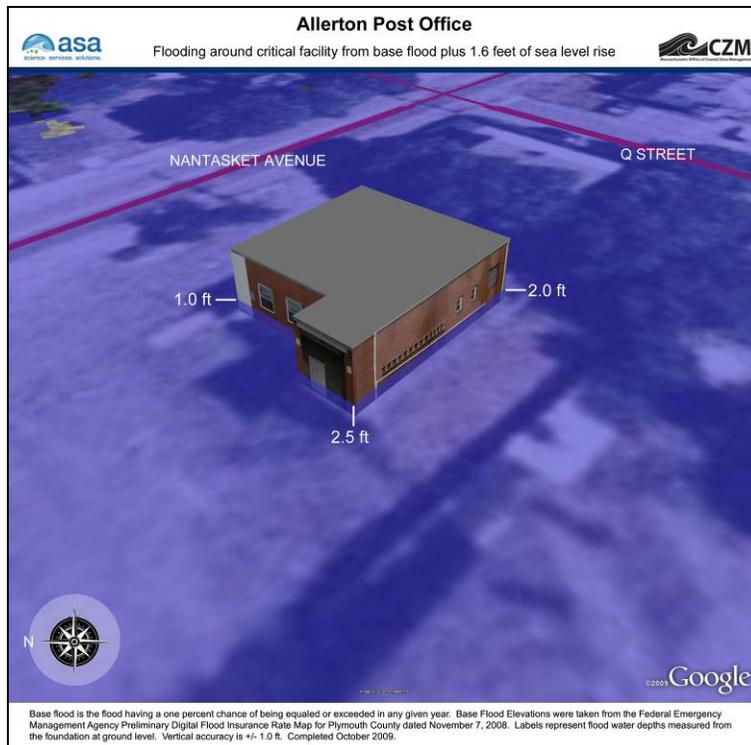
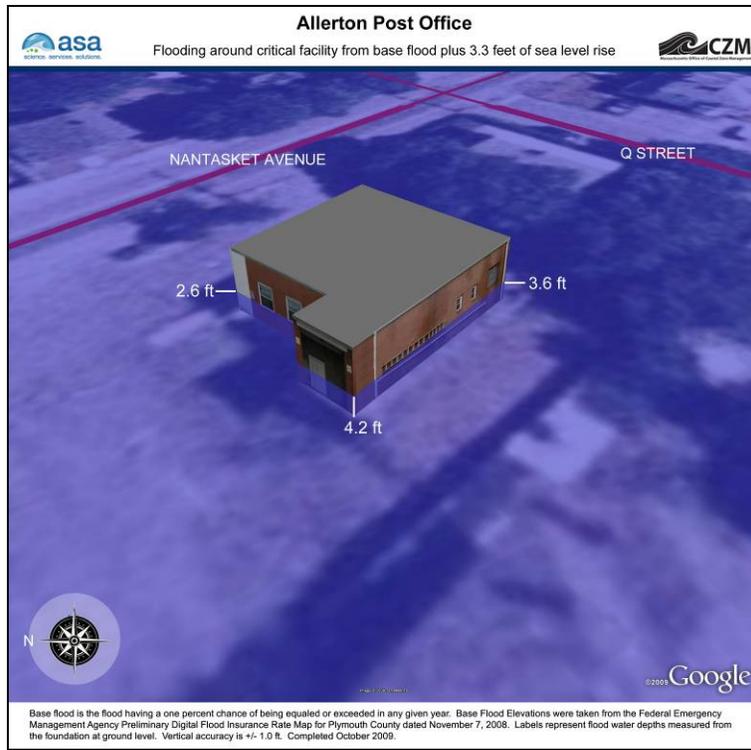
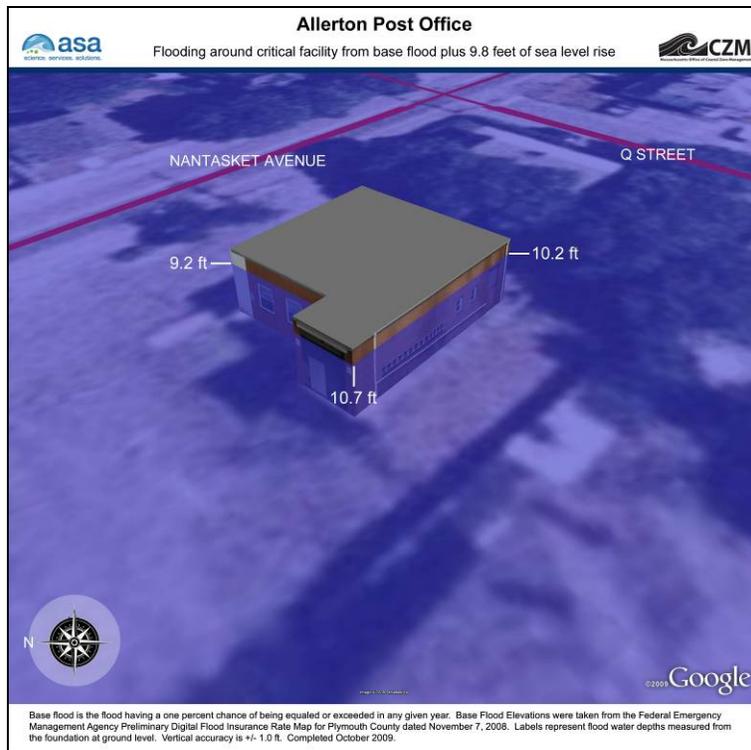


Figure A-8. Allerton Post Office, View 2, Base Flood Elevation plus 1.6 feet of sea level rise.



**Figure A-9. Allerton Post Office, View 2, Base Flood Elevation plus 3.3 feet of sea level rise.**



**Figure A-10. Allerton Post Office, View 2, Base Flood Elevation plus 9.8 feet of sea level rise.**



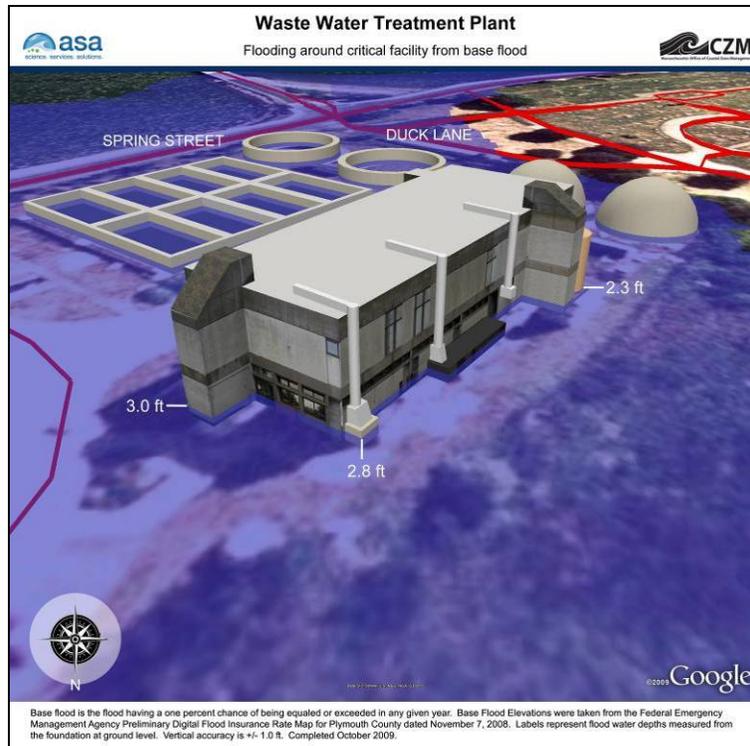


Figure A-11. Waste Water Pollution Control Facility, View 1, Base Flood Elevation.

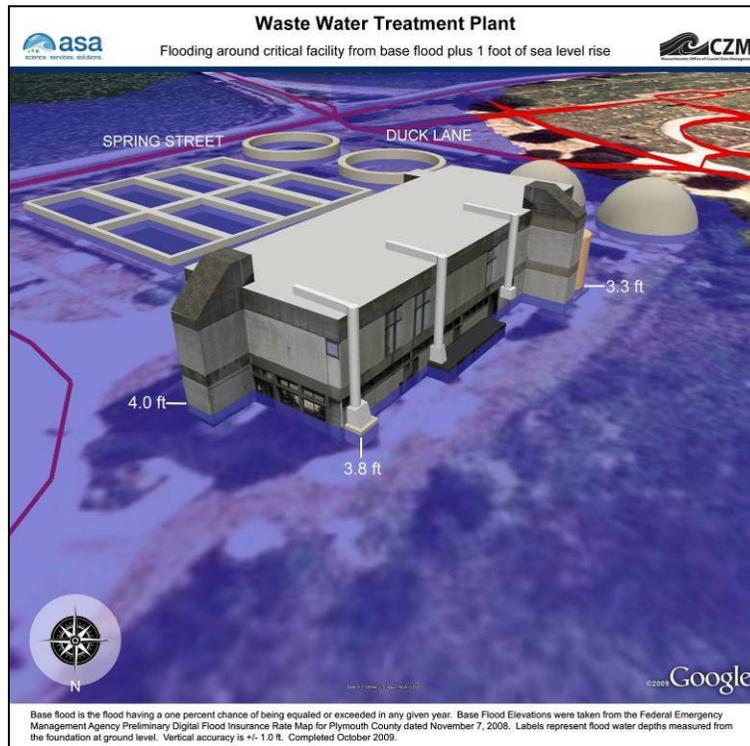
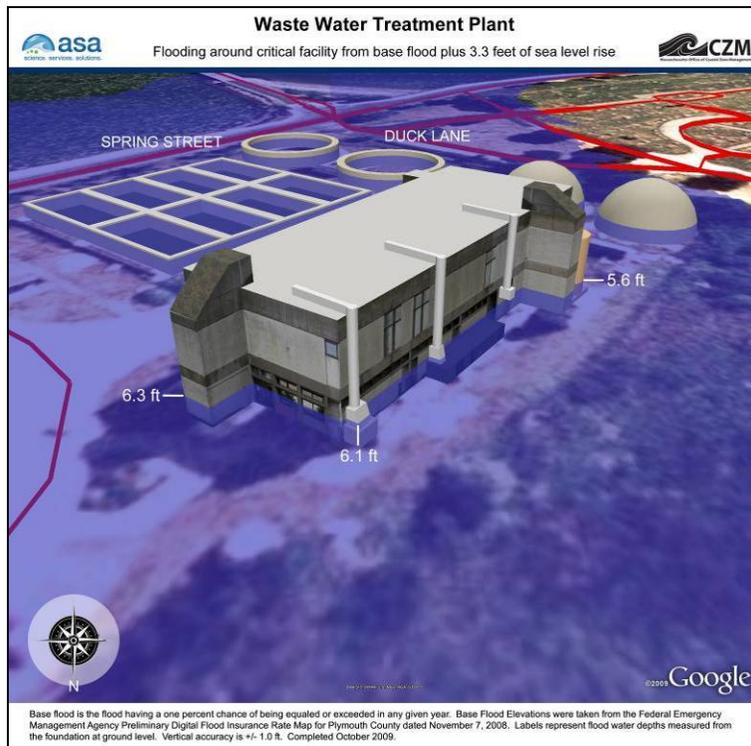


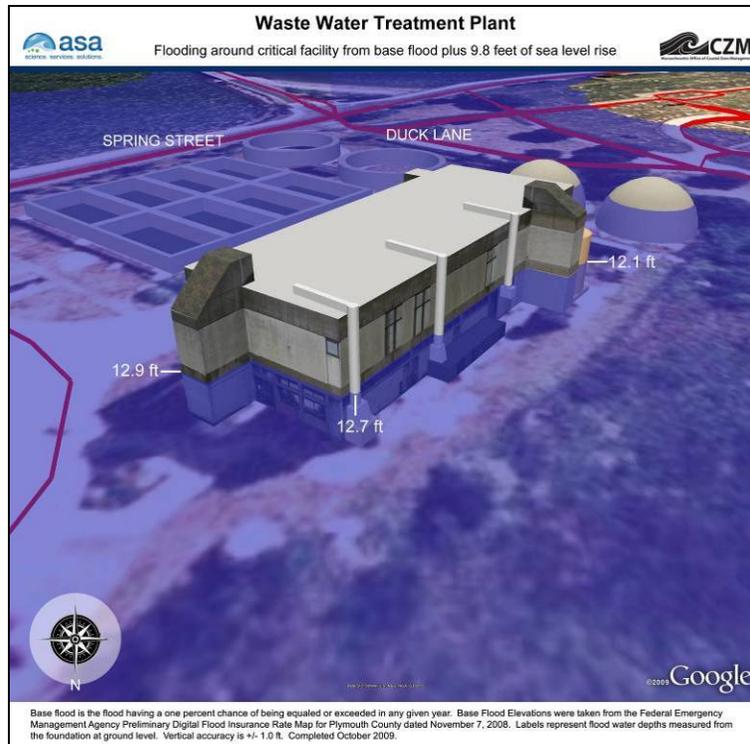
Figure A-12. Waste Water Pollution Control Facility, View 1, Base Flood Elevation plus 1 foot of sea level rise.



**Figure A-13. Waste Water Pollution Control Facility, View 1, Base Flood Elevation plus 1.6 feet of sea level rise.**



**Figure A-14. Waste Water Pollution Control Facility, View 1, Base Flood Elevation plus 3.3 feet of sea level rise.**



**Figure A-15. Waste Water Pollution Control Facility, View 1, Base Flood Elevation plus 9.8 feet of sea level rise.**



**Figure A-16. Waste Water Pollution Control Facility, View 2, Base Flood Elevation.**





**Figure A-17. Waste Water Pollution Control Facility, View 2, Base Flood Elevation plus 1 foot of sea level rise.**



**Figure A-18. Waste Water Pollution Control Facility, View 2, Base Flood Elevation plus 1.6 feet of sea level rise.**



**Figure A-19. Waste Water Pollution Control Facility, View 2, Base Flood Elevation plus 3.3 feet of sea level rise.**



**Figure A-20. Waste Water Pollution Control Facility, View 2, Base Flood Elevation plus 9.8 feet of sea level rise.**



Figure A-21. Hull High School, View 1, Base Flood Elevation.

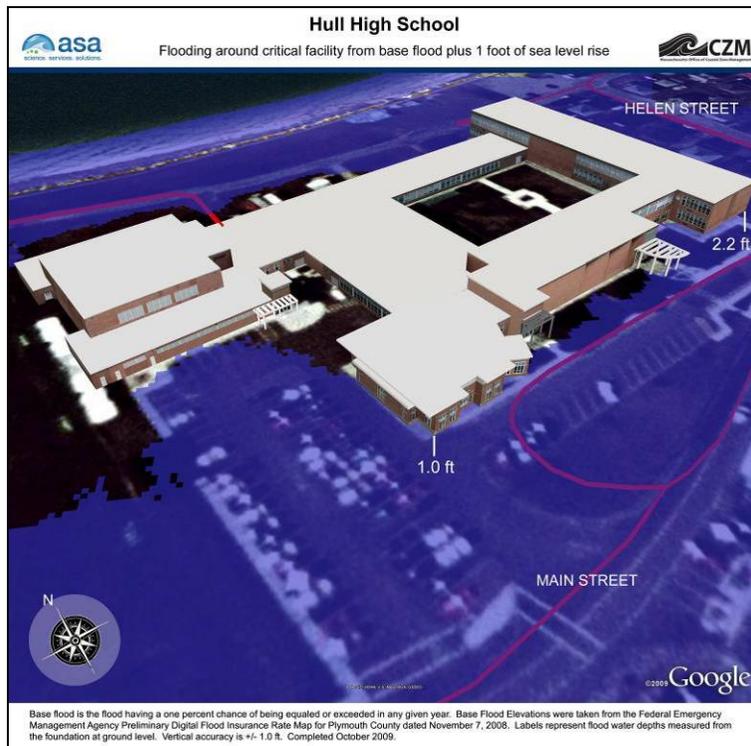


Figure A-22. Hull High School, View 1, Base Flood Elevation plus 1 foot of sea level rise.



Figure A-23. Hull High School, View 1, Base Flood Elevation plus 1.6 feet of sea level rise.



Figure A-24. Hull High School, View 1, Base Flood Elevation plus 3.3 feet of sea level rise.





Figure A-25. Hull High School, View 1, Base Flood Elevation plus 9.8 feet of sea level rise.



Figure A-26. Hull High School, View 2, Base Flood Elevation.

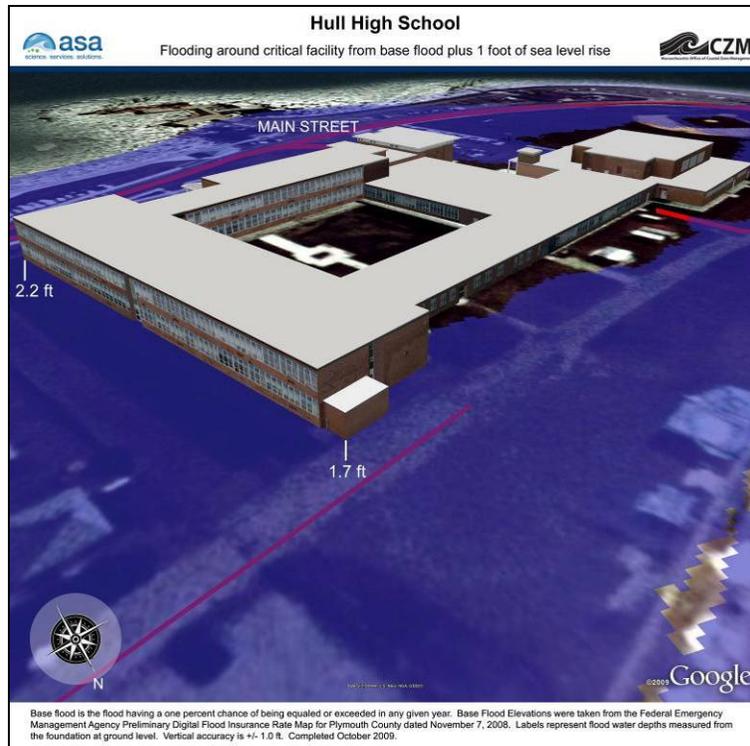


Figure A-27. Hull High School, View 2, Base Flood Elevation plus 1 foot of sea level rise.

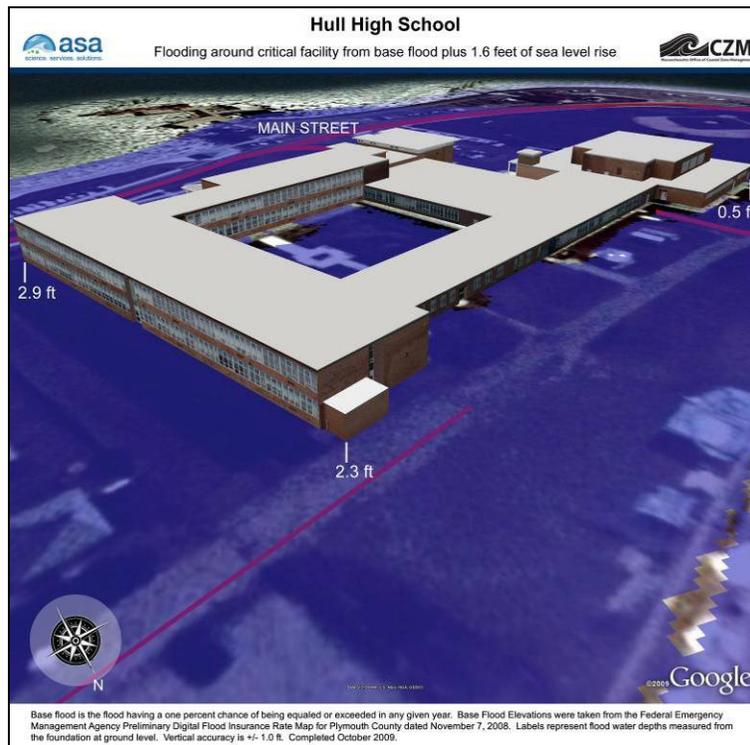


Figure A-28. Hull High School, View 2, Base Flood Elevation plus 1.6 feet of sea level rise.



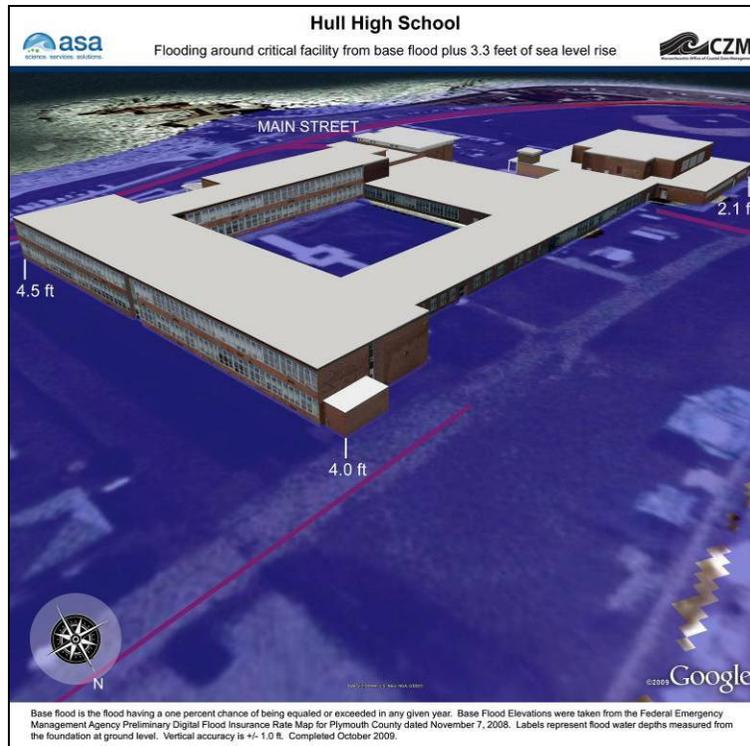


Figure A-29. Hull High School, View 2, Base Flood Elevation plus 3.3 feet of sea level rise.

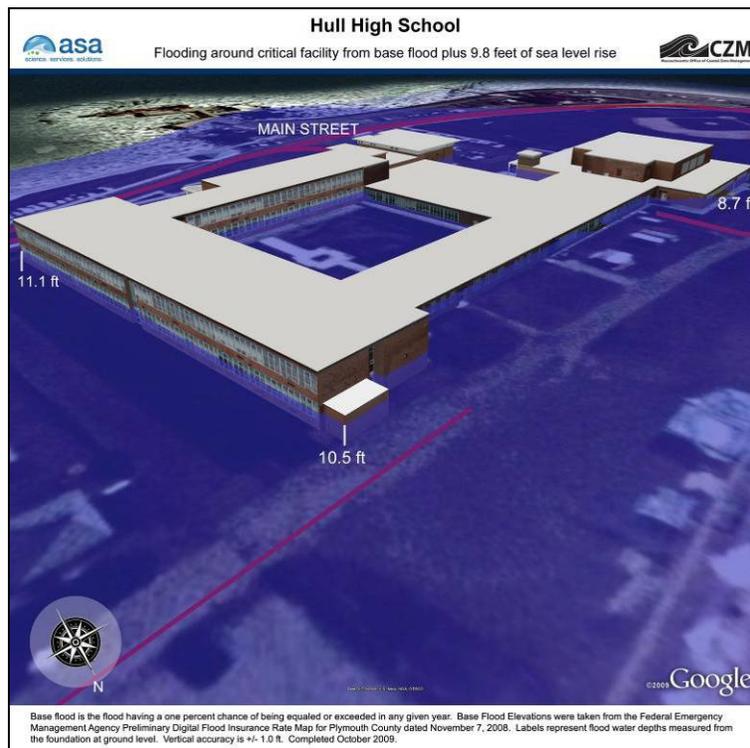


Figure A-30. Hull High School, View 2, Base Flood Elevation plus 9.8 feet of sea level rise.



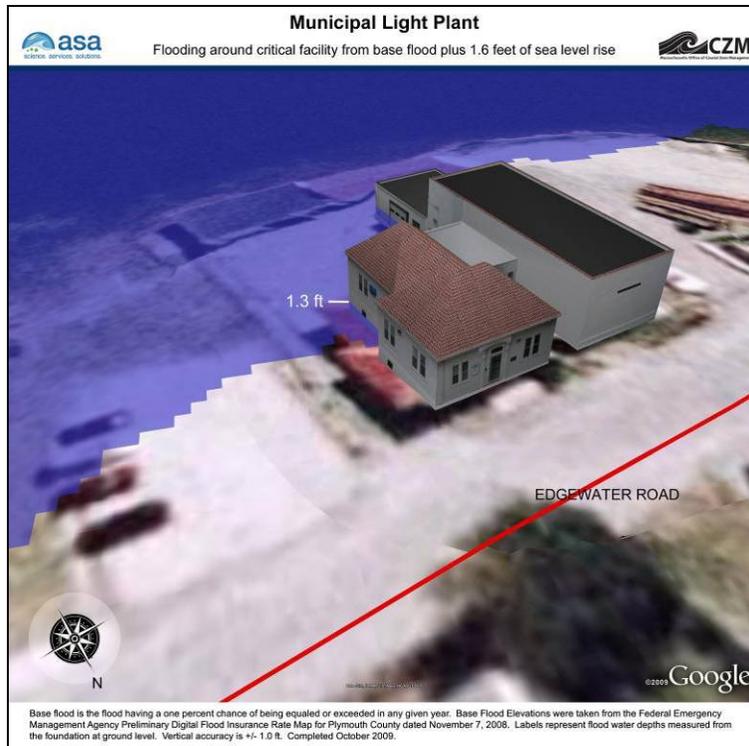


**Figure A-31. Municipal Light Plant, View 1, Base Flood Elevation.**



**Figure A-32. Municipal Light Plant, View 1, Base Flood Elevation plus 1 foot of sea level rise.**





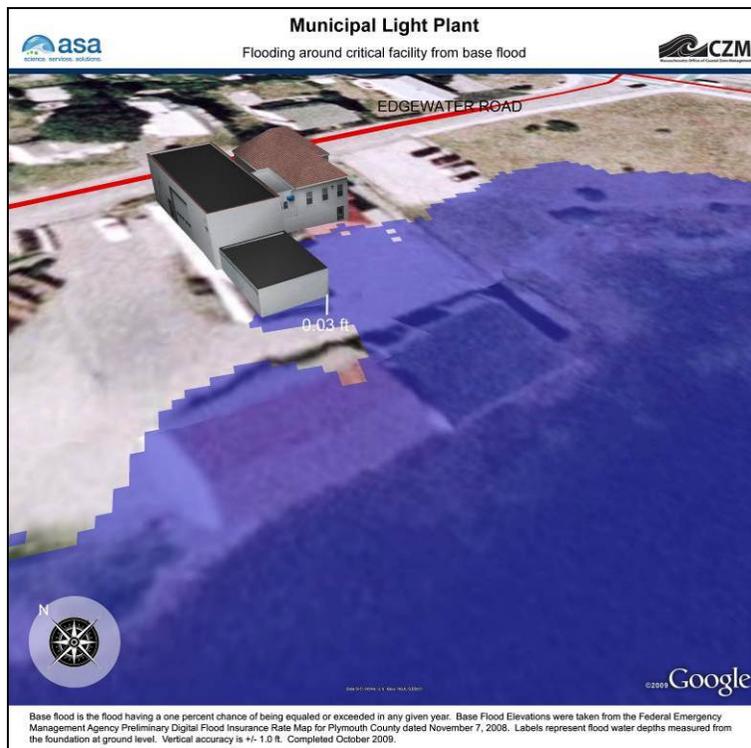
**Figure A-33. Municipal Light Plant, View 1, Base Flood Elevation plus 1.6 feet of sea level rise.**



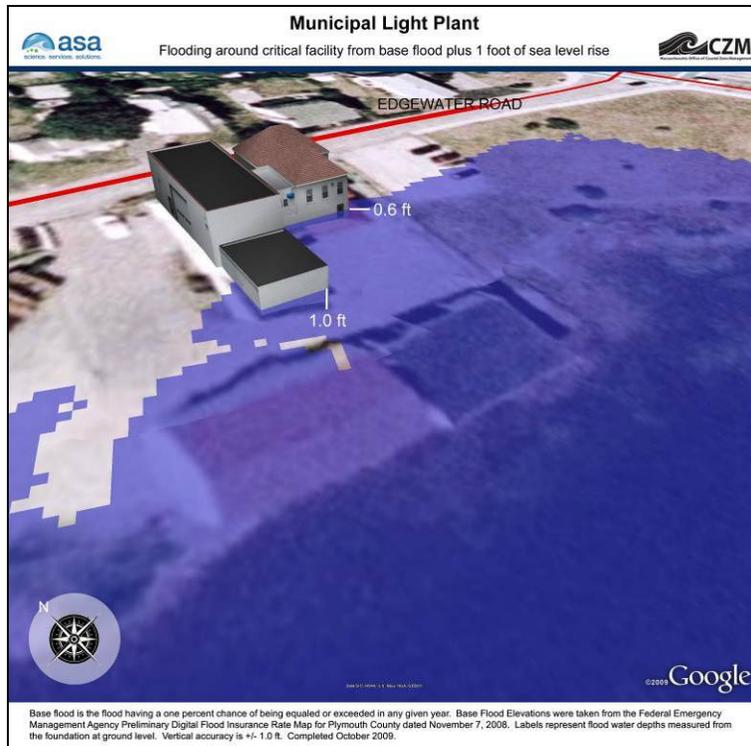
**Figure A-34. Municipal Light Plant, View 1, Base Flood Elevation plus 3.3 feet of sea level rise.**



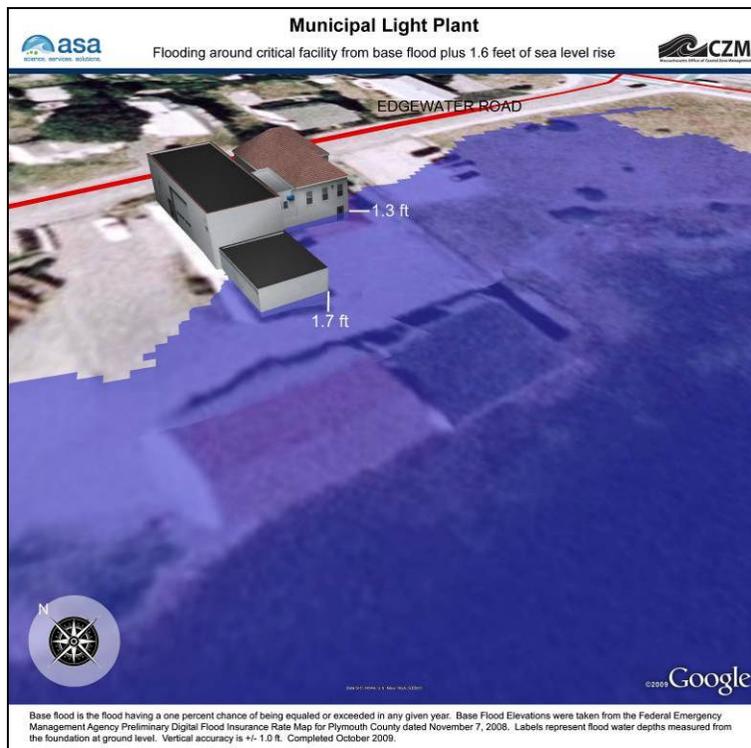
**Figure A-35. Municipal Light Plant, View 1, Base Flood Elevation plus 9.8 feet of sea level rise.**



**Figure A-36. Municipal Light Plant, View 2, Base Flood Elevation.**



**Figure A-37. Municipal Light Plant, View 2, Base Flood Elevation plus 1 foot of sea level rise.**



**Figure A-38. Municipal Light Plant, View 2, Base Flood Elevation plus 1.6 feet of sea level rise.**

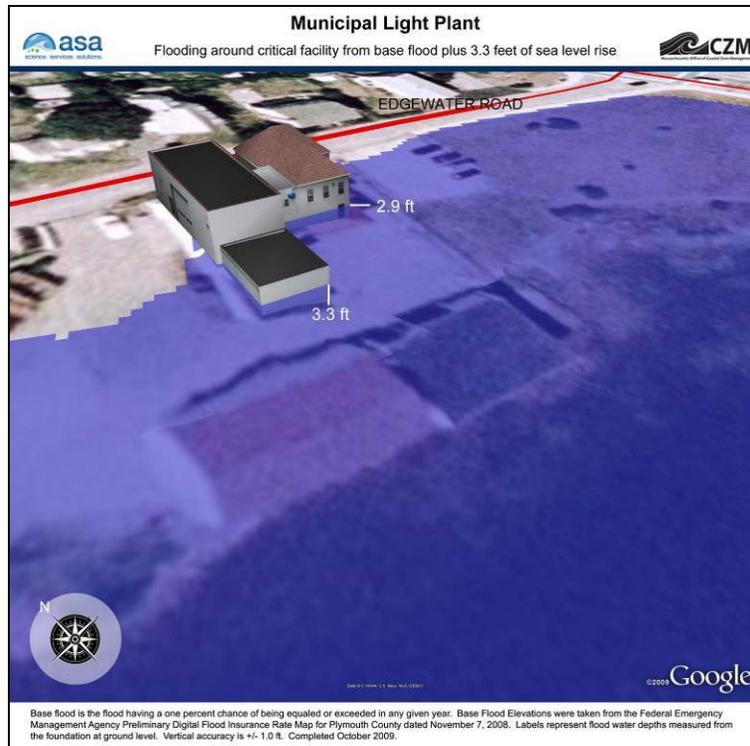


Figure A-39. Municipal Light Plant, View 2, Base Flood Elevation plus 3.3 feet of sea level rise.



Figure A-40. Municipal Light Plant, View 2, Base Flood Elevation plus 9.8 feet of sea level rise.

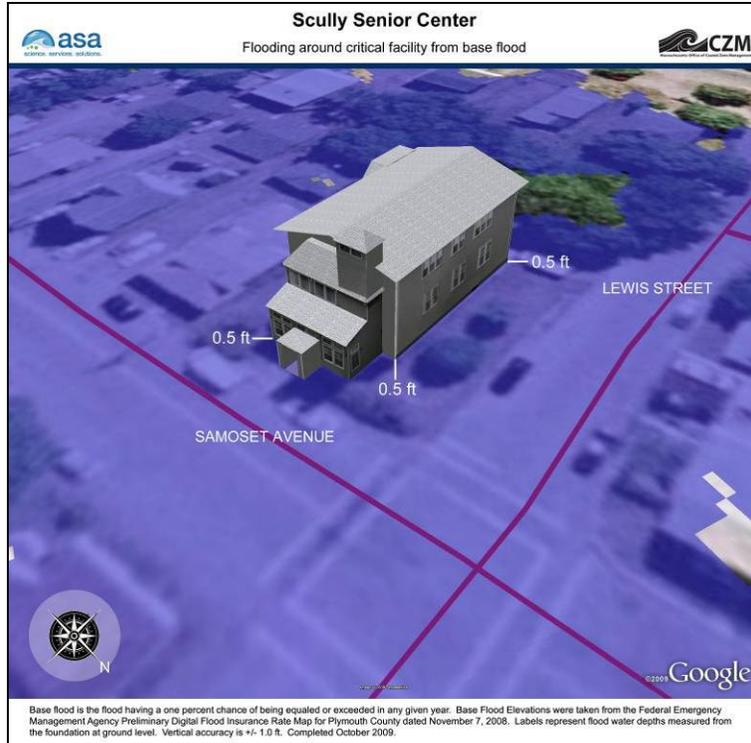


Figure A-41. Anne M. Scully Senior Center, View 1, Base Flood Elevation.

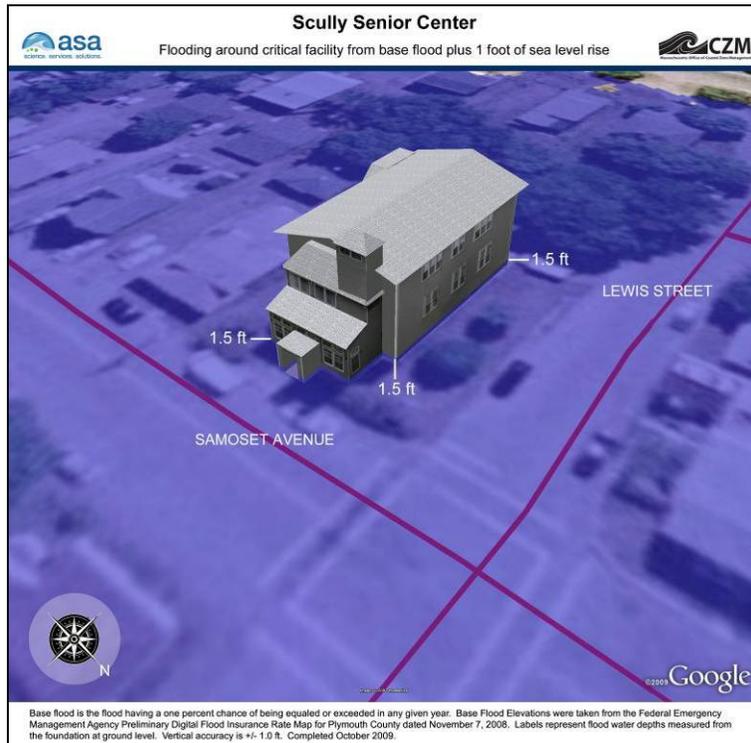
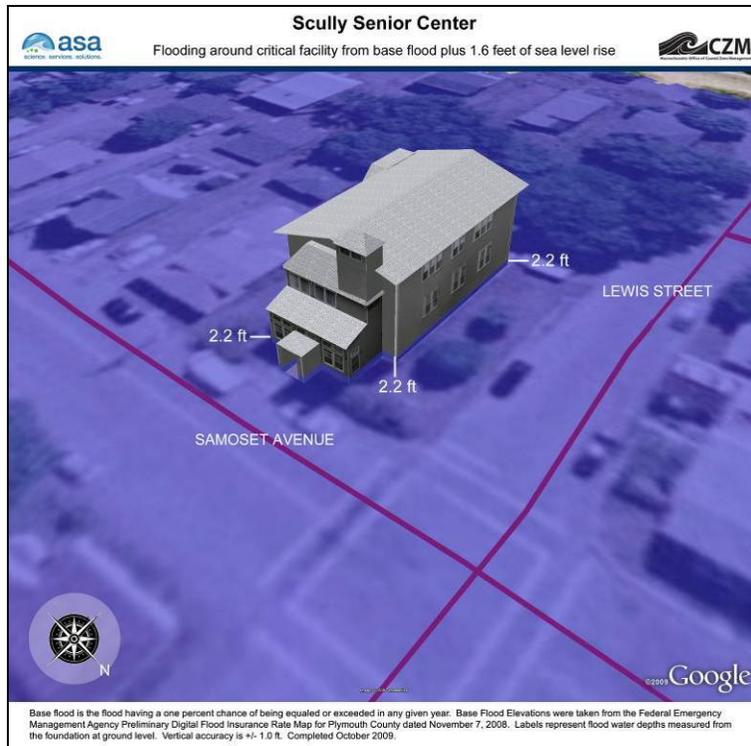
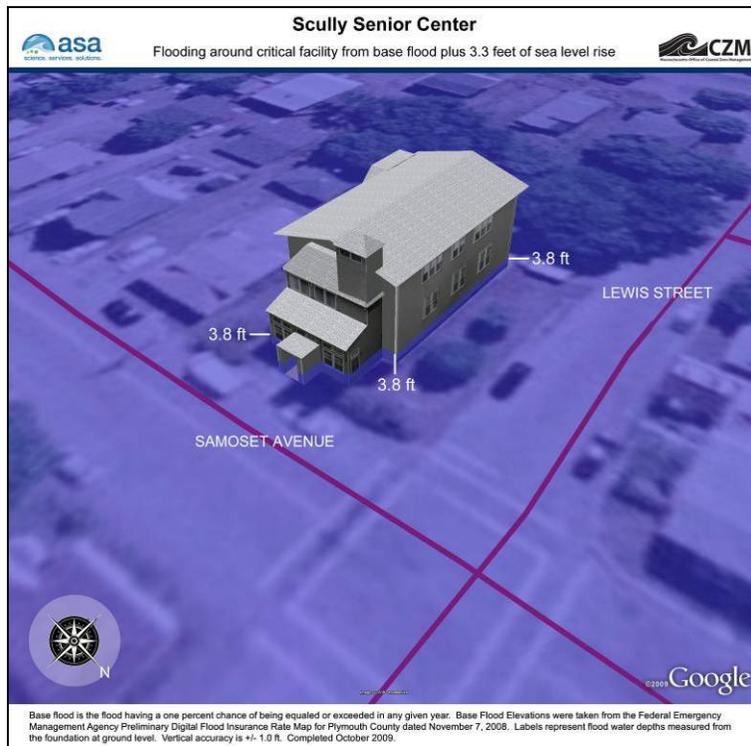


Figure A-42. Anne M. Scully Senior Center, View 1, Base Flood Elevation plus 1 foot of sea level rise.

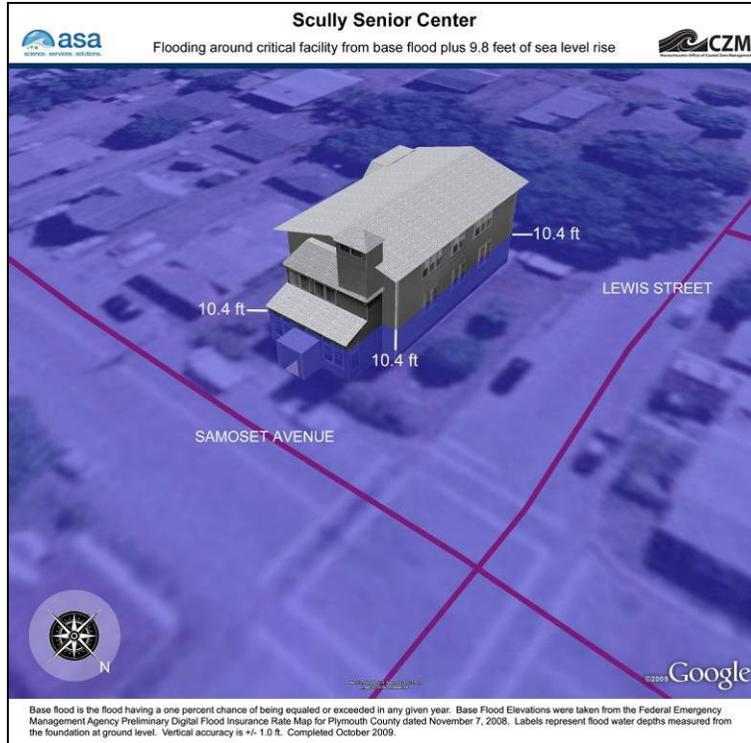


**Figure A-43. Anne M. Scully Senior Center, View 1, Base Flood Elevation plus 1.6 feet of sea level rise.**



**Figure A-44. Anne M. Scully Senior Center, View 1, Base Flood Elevation plus 3.3 feet of sea level rise.**

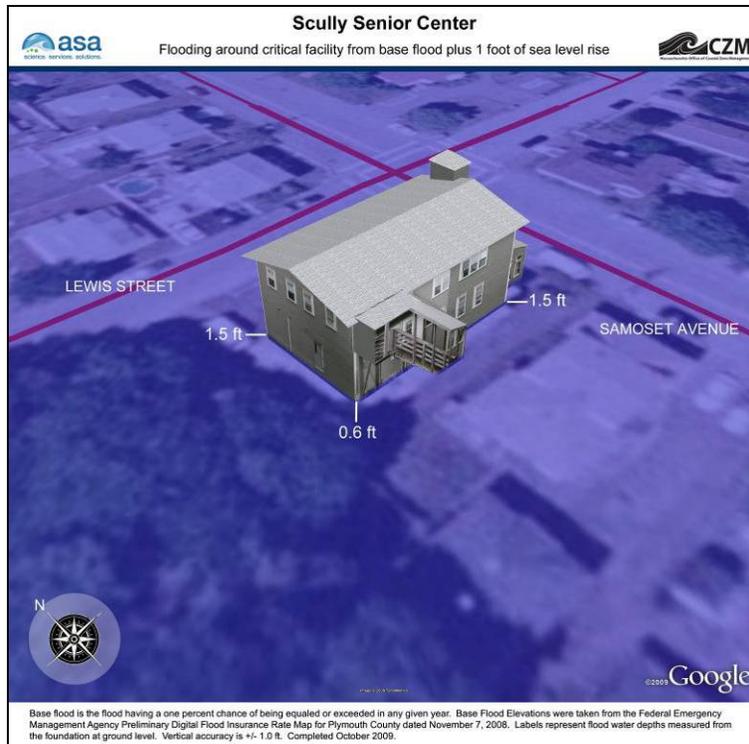




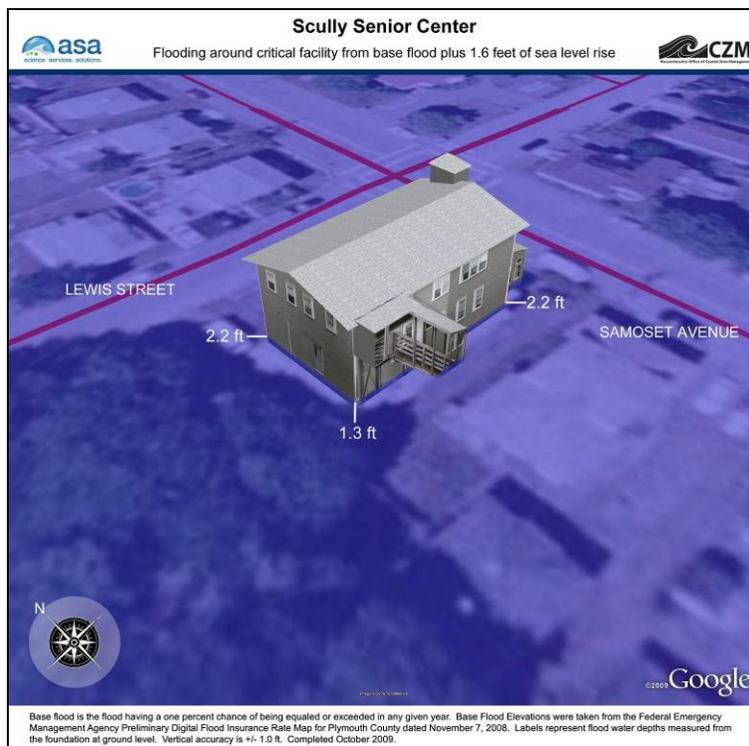
**Figure A-45. Anne M. Scully Senior Center, View 1, Base Flood Elevation plus 9.8 feet of sea level rise.**



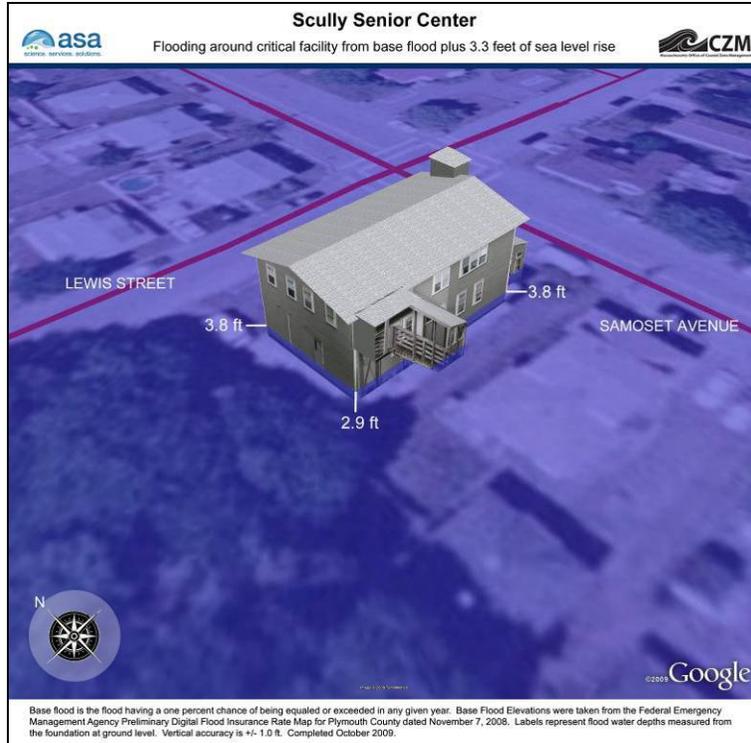
**Figure A-46. Anne M. Scully Senior Center, View 2, Base Flood Elevation.**



**Figure A-47. Anne M. Scully Senior Center, View 2, Base Flood Elevation plus 1 foot of sea level rise.**



**Figure A-48. Anne M. Scully Senior Center, View 2, Base Flood Elevation plus 1.6 feet of sea level rise.**



**Figure A-49. Anne M. Scully Senior Center, View 2, Base Flood Elevation plus 3.3 feet of sea level rise.**



**Figure A-50. Anne M. Scully Senior Center, View 2, Base Flood Elevation plus 9.8 feet of sea level rise.**



**Figure A-51. Hull Memorial School, View 1, Base Flood Elevation.**



**Figure A-52. Hull Memorial School, View 1, Base Flood Elevation plus 1 foot of sea level rise.**



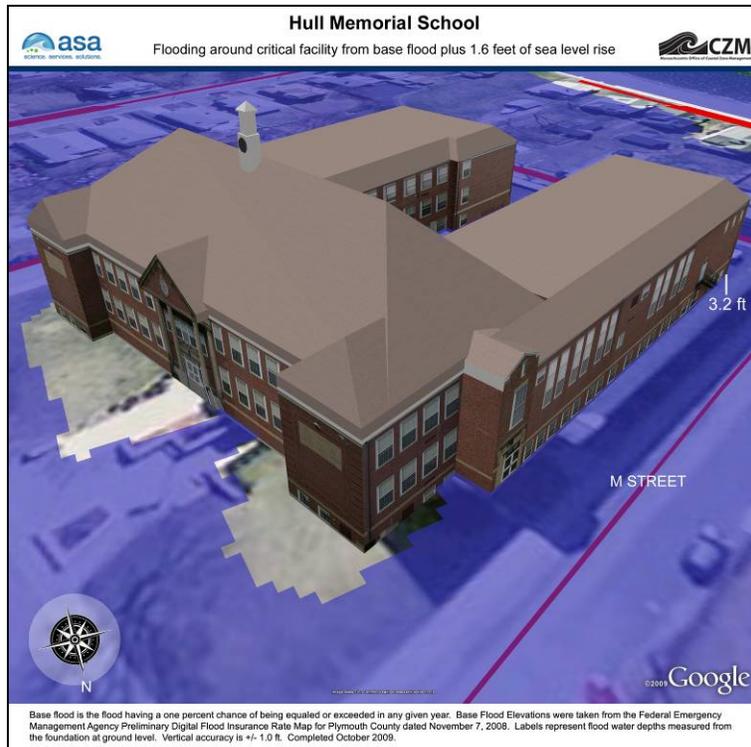


Figure A-53. Hull Memorial School, View 1, Base Flood Elevation plus 1.6 feet of sea level rise.

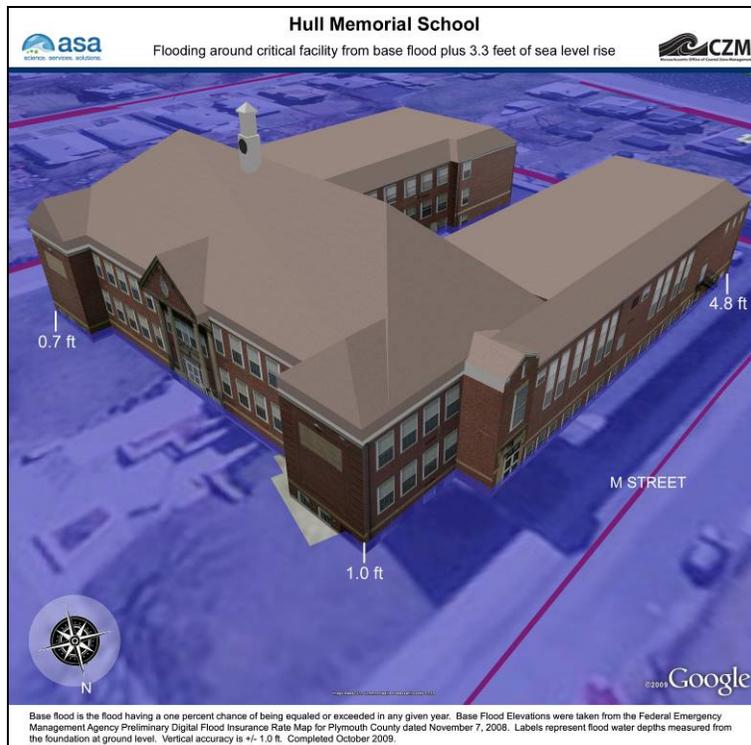


Figure A-54. Hull Memorial School, View 1, Base Flood Elevation plus 3.3 feet of sea level rise.

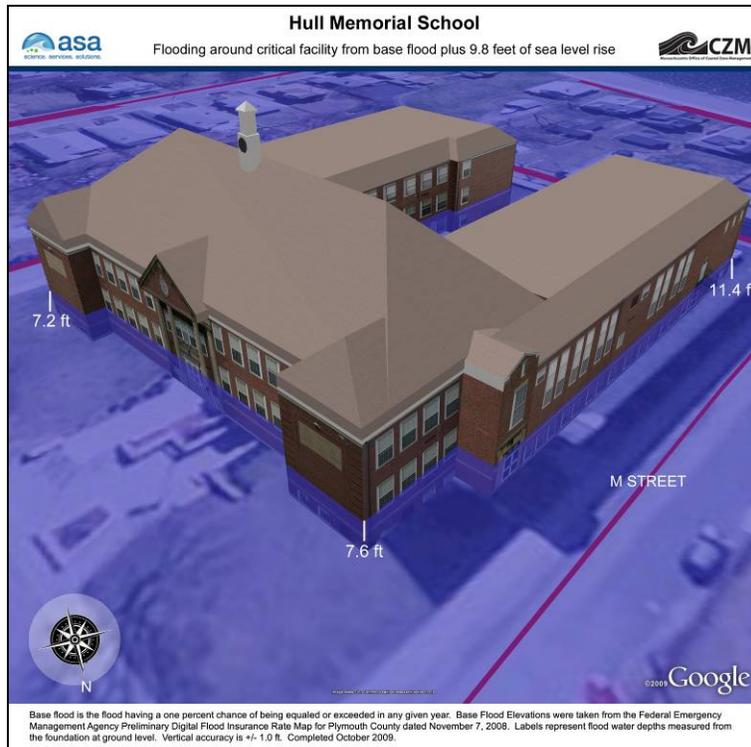


Figure A-55. Hull Memorial School, View 1, Base Flood Elevation plus 9.8 feet of sea level rise.

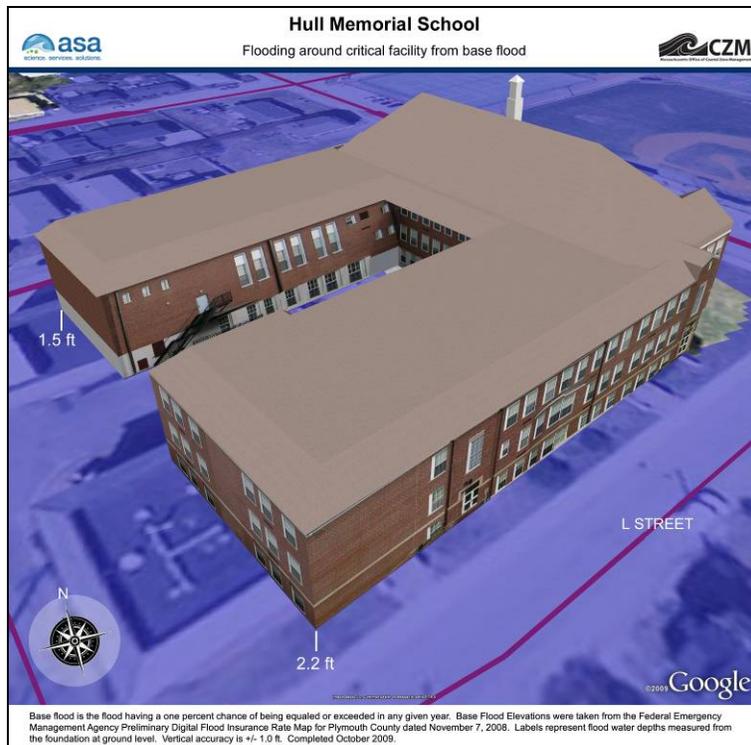
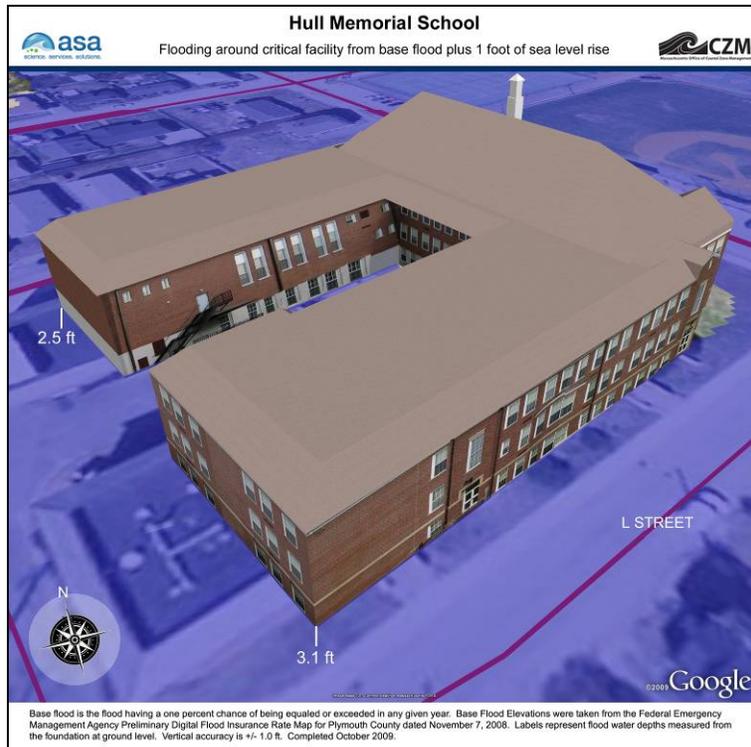


Figure A-56. Hull Memorial School, View 2, Base Flood Elevation.



**Figure A-57. Hull Memorial School, View 2, Base Flood Elevation plus 1 foot of sea level rise.**



**Figure A-58. Hull Memorial School, View 2, Base Flood Elevation plus 1.6 feet of sea level rise.**

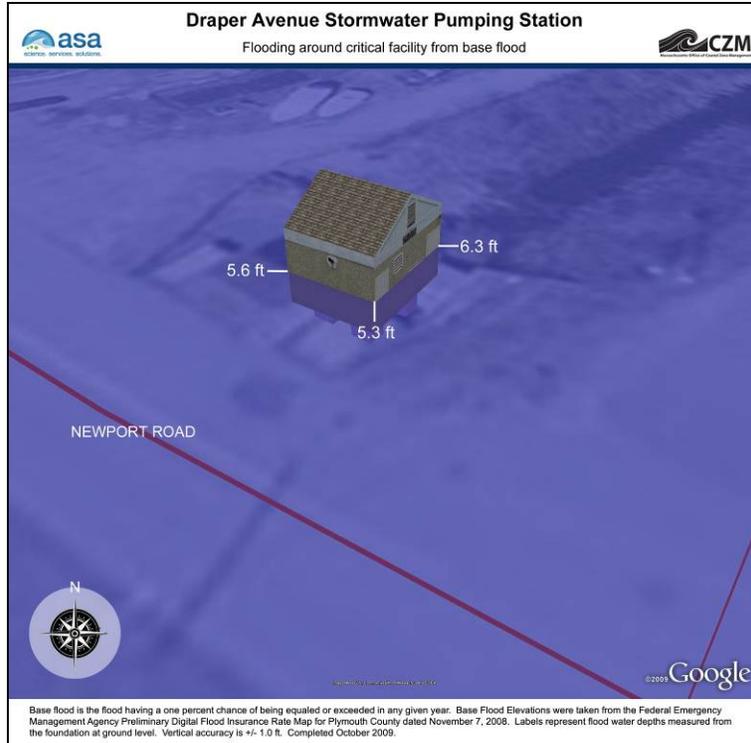




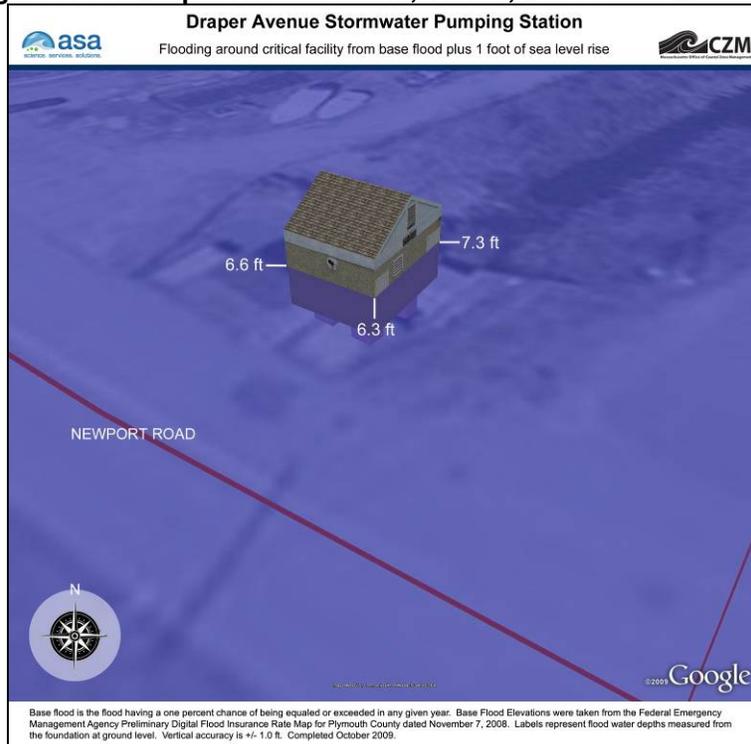
Figure A-59. Hull Memorial School, View 2, Base Flood Elevation plus 3.3 feet of sea level rise.



Figure A-60. Hull Memorial School, View 2, Base Flood Elevation plus 9.8 feet of sea level rise.

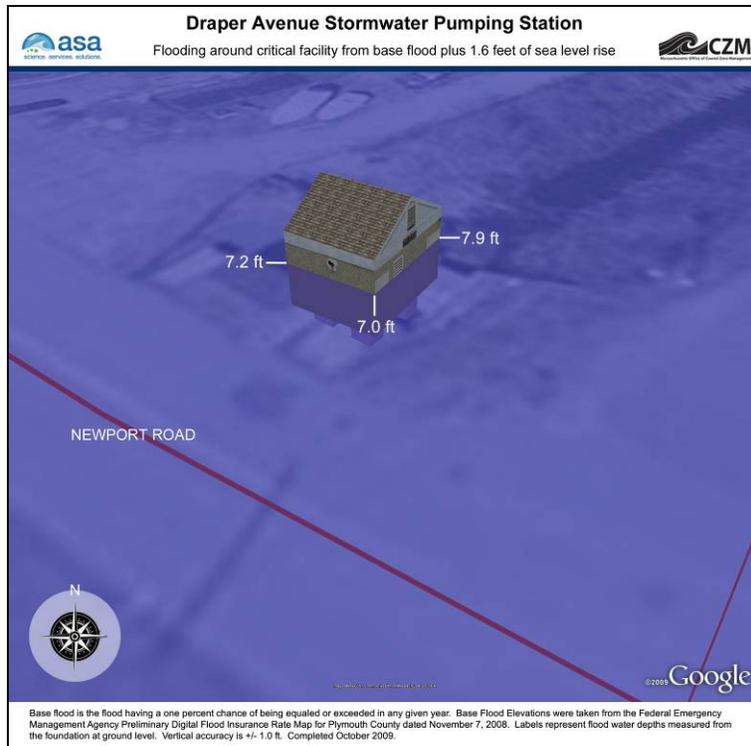


**Figure A-61. Draper Avenue Storm, View 1, Base Flood Elevation.**

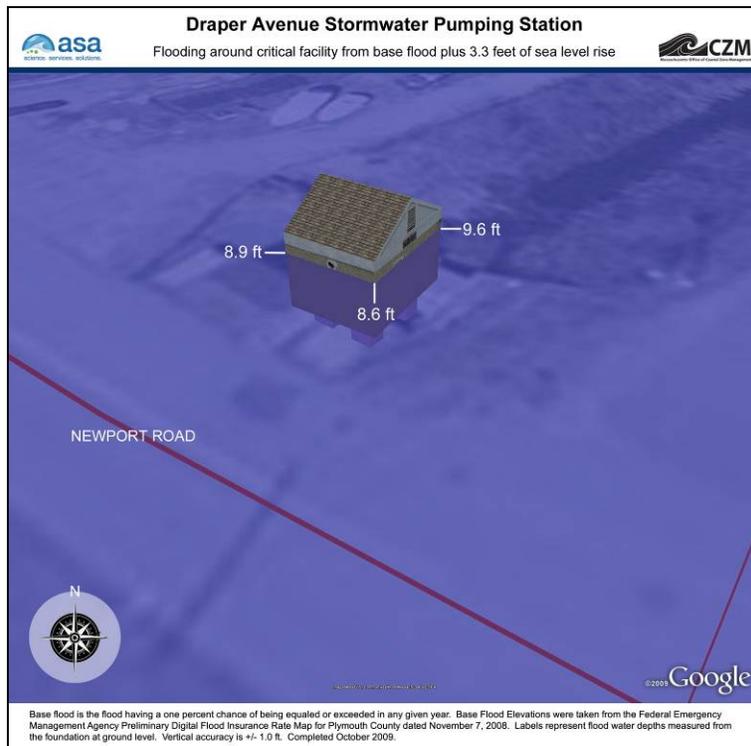


**Figure A-62. Hull Memorial School, View 1, Base Flood Elevation plus 1 foot of sea level rise.**



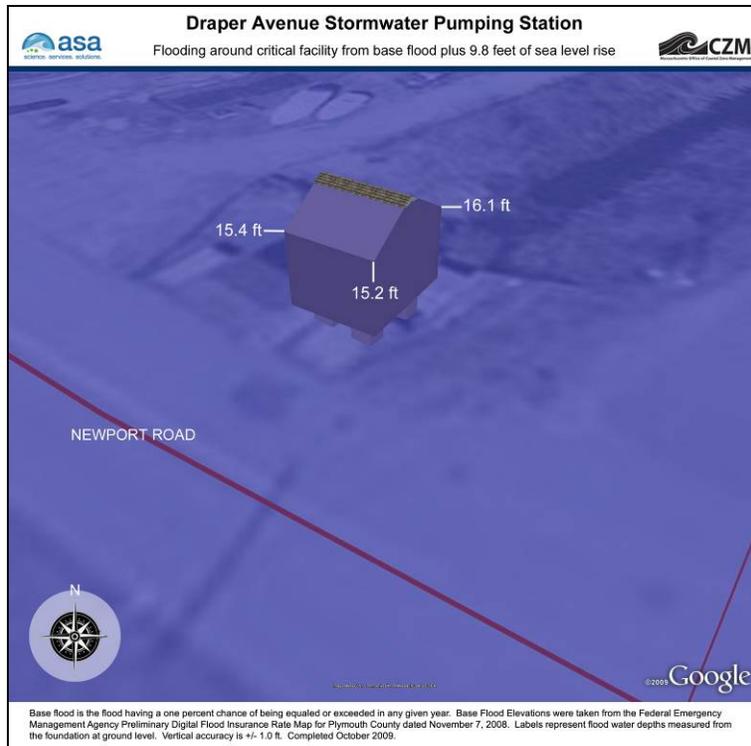


**Figure A-63. Hull Memorial School, View 1, Base Flood Elevation plus 1.6 feet of sea level rise**

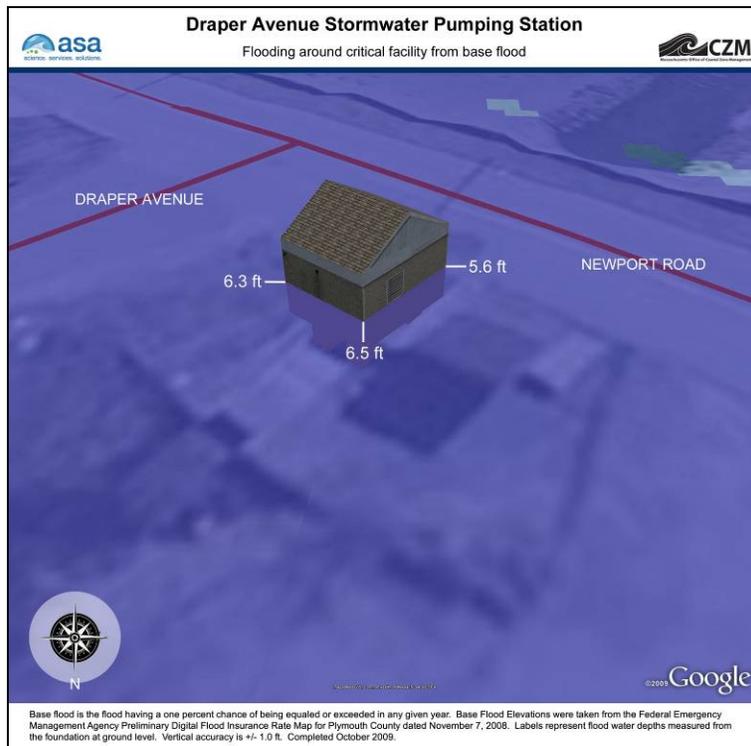


**Figure A-64. Hull Memorial School, View 1, Base Flood Elevation plus 3.3 feet of sea level rise**



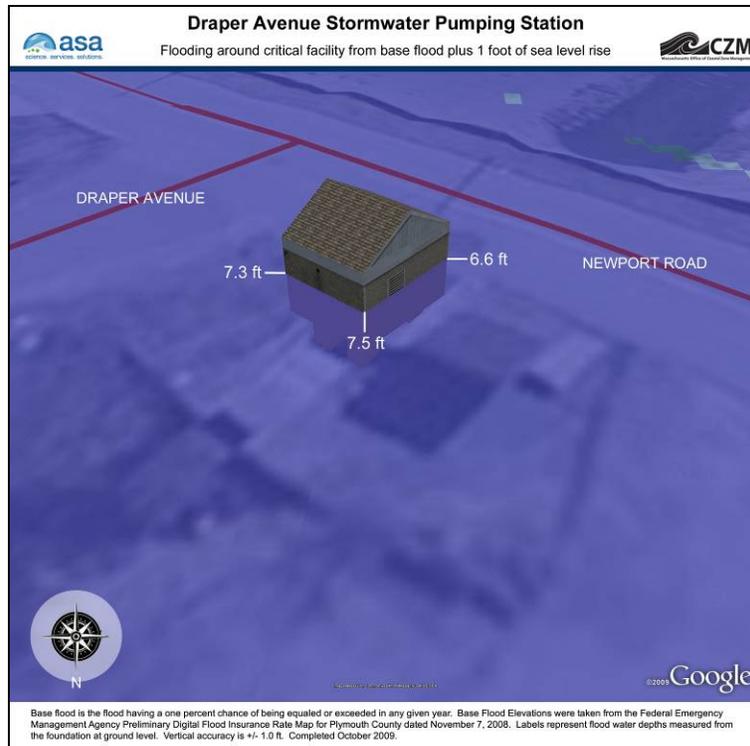


**Figure A-65. Hull Memorial School, View 1, Base Flood Elevation plus 9.8 feet of sea level rise**

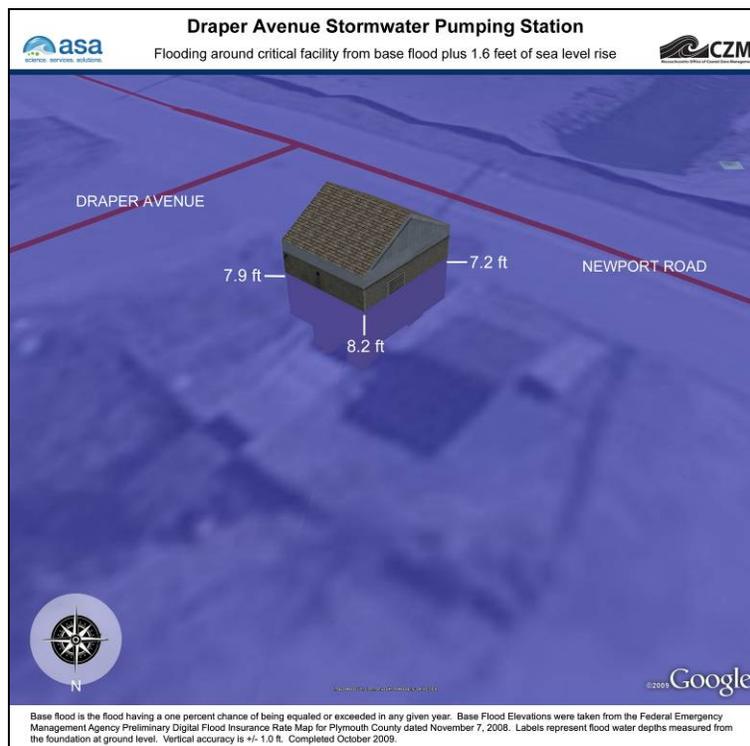


**Figure A-66. Draper Avenue Storm, View 2, Base Flood Elevation.**





**Figure A-67. Hull Memorial School, View 2, Base Flood Elevation plus 1 foot of sea level rise**



**Figure A-68. Hull Memorial School, View 2, Base Flood Elevation plus 1.6 feet of sea level rise**

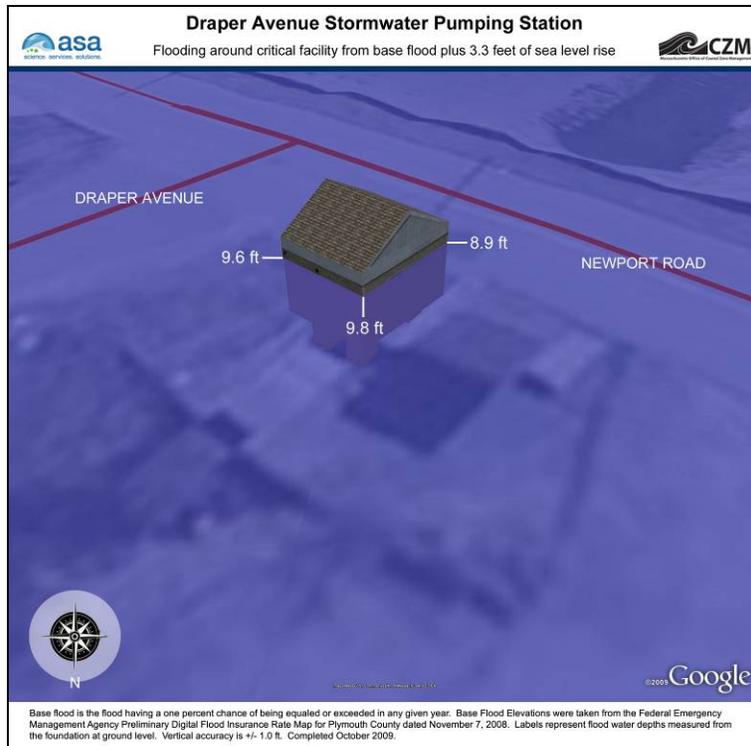


Figure A-69. Hull Memorial School, View 2, Base Flood Elevation plus 3.3 feet of sea level rise

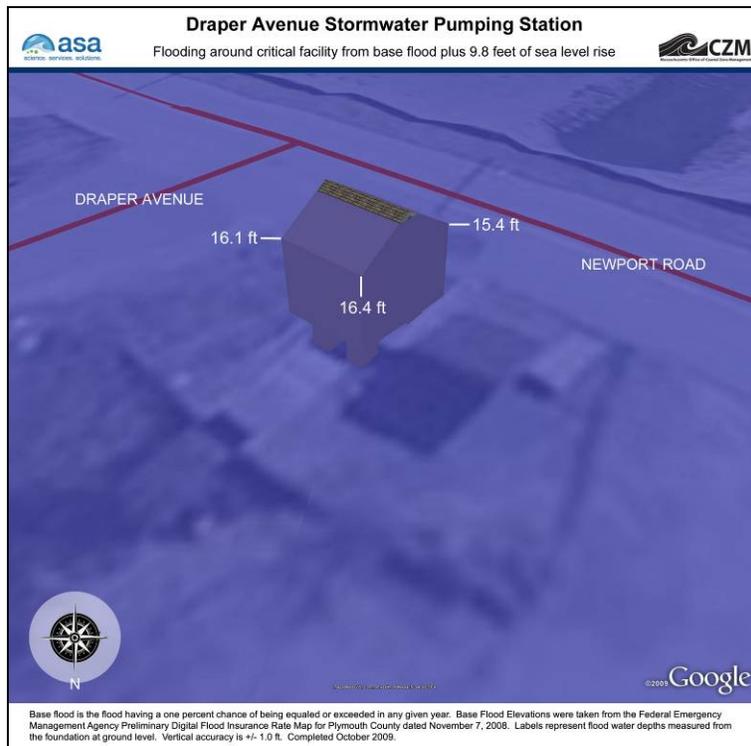


Figure A-70. Hull Memorial School, View 2, Base Flood Elevation plus 9.8 feet of sea level rise