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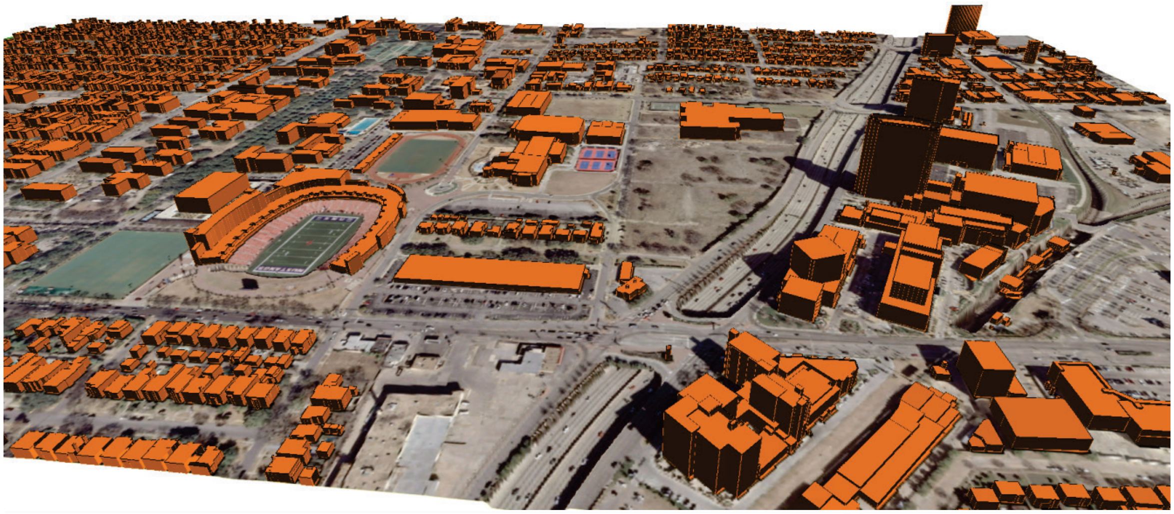
Remote Assessment of Critical Infrastructure

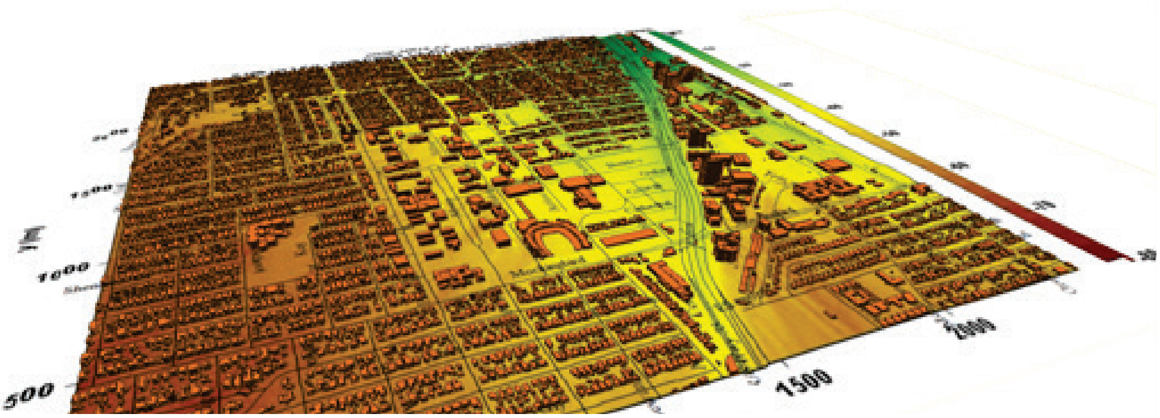
Persistent Monitoring of Urban Infrasound Phenomenology

Report 1: Modeling an Urban Environment for Acoustical Analyses using the 3-D Finite-Difference Time-Domain Program PSTOP3D

Michael E. Pace, Sarah L. McComas, and Mihan H. McKenna

August 2015





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Report 1: Modeling an Urban Environment for Acoustical Analyses using the 3-D Finite-Difference Time-Domain Program PSTOP3D

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Abstract

A 25 square kilometer urban area located in University Park, Texas was modeled using geographic information systems (GIS) software. A smaller 6.25 square kilometer area around the Southern Methodist University was extracted from the larger area and analyzed using an acoustic finite-difference time-domain (FDTD) code. The procedures to model the area using GIS software, extract required data, produce the data files necessary to perform the acoustic analyses, and view the results are described in this report. This report is focused on the details of using the particular software packages used in this study, but the concepts are general in nature and can be applied to other applications if needed.

Contents

Abstract ii

Figures and Tables vi

Preface xi

Unit Conversion Factors xii

1 Overview of Modeling an Urban Area 1

- 1.1 Introduction 1
- 1.2 Purpose of report 2
- 1.3 Description of urban area modeled 2
- 1.4 Discussion of programs used and steps to produce urban data sets and perform analyses 4

2 GIS Data Sets Used to Model the Urban Area 8

- 2.1 Sources for GIS data 8
- 2.2 Topography data 9
- 2.3 Aerial orthophotography 9
- 2.4 Building data 10
- 2.5 Paved areas data 12
- 2.6 Trees and water features data 13
- 2.7 Projected coordinate systems 13

3 Process GIS Data 15

- 3.1 Overview 15
- 3.2 Define topography 15
  - *3.2.1 Read topography into Global Mapper* 15
  - *3.2.2 Create clip region for topography* 16
  - *3.2.3 Create GeoTIFF for MATLAB* 18
- 3.3 Model buildings 21
  - *3.3.1 Read buildings into Global Mapper* 24
  - *3.3.2 Clip buildings to desired area* 25
  - *3.3.3 Delete and add custom buildings* 27
  - *3.3.4 Trim data set based on attributes* 30
  - *3.3.5 Select features by location* 32
  - *3.3.6 Create aggregated building sets* 33
  - *3.3.7 Compute weighted averages of heights of aggregated buildings* 37
  - *3.3.8 Save building data to shapefiles in Global Mapper* 46
  - *3.3.9 Save building data to shapefiles in ArcMap* 47
  - *3.3.10 View buildings in 3-D* 48
  - *3.3.11 Create files for Urban Modeler* 50
- 3.4 Model paved areas 53

- *3.4.1 Read paved areas into Global Mapper 53*
- *3.4.2 Clip paved areas to desired area 53*
- *3.4.3 Break larger paved areas into smaller areas 54*
- *3.4.4 Detect islands in data 54*
- *3.4.5 Create files for Urban Modeler 55*
- 3.5 Model bridges 58
  - *3.5.1 Select bridges from paved areas 58*
  - *3.5.2 Flatten terrain under bridges 59*
  - *3.5.3 Save terrain with flattened areas to GeoTIFF 65*
  - *3.5.4 Create files for Urban Modeler 65*
- 3.6 Model other area features 66

4 Run Urban Modeler to Produce CSV Files 67

- 4.1 Produce CSV files for buildings 68
- 4.2 Produce CSV files for areal features 69

5 Use of Microsoft Excel to Describe Data 72

- 5.1 Open CSV files in Excel 72
- 5.2 General description of use of Excel spreadsheets 72
- 5.3 Main spreadsheet to describe problem setup 73
- 5.4 Spreadsheet to describe grid 75
- 5.5 Spreadsheet to describe medium properties and layers 75
- 5.6 Spreadsheet to describe topography 77
- 5.7 Spreadsheet to describe buildings 79
- 5.8 Spreadsheet to describe paved areas 82
- 5.9 Spreadsheet to describe bridges 85

6 Run MATLAB to Produce PSTOP3D Data Files 87

- 6.1 General 87
- 6.2 Generate grid 90
- 6.3 Generate topography function 92
- 6.4 Define propagation medium 94
- 6.5 Define auxiliary structures 95
- 6.6 Generate source 99

7 Compile and Run PSTOP3D 106

- 7.1 PSTOP3D discussion 106
  - *7.1.1 General background 106*
  - *7.1.2 Implicit/Explicit formulation 107*
  - *7.1.3 Sound propagation in porous medium 107*
- 7.2 Time Step for Convergence of Analysis 110
- 7.3 Determination of time step and SNAP file interval 111
- 7.4 Selection of grid spacing and number of processors for PSTOP 113
- 7.5 Grid spacing, time step, and snap interval for urban area 114
- 7.6 Edit the pstop3d.h file for PSTOP3D 115
- 7.7 Compile PSTOP3D 117
- 7.8 Edit the COMMAND.FIL file for PSTOP3D 119

7.9 Edit the COMMAND.AUX file for PSTOP3D........121
7.10 How to execute PSTOP3D........122

8 Post-process PSTOP3D Results........125

8.1 General........125
8.2 How to execute SNAPPS........125
8.3 Produce animations of pressures........128
8.4 Output time series information........132
8.5 Plot peak pressures........140
8.6 Produce integrated energy plots........143
8.7 Compare to reference........146
8.8 Using Global Mapper to enhance visual display of results........150

9 Conclusions and Implications........153

References........154

Appendix A........156

Report Documentation Page

Figures and Tables

Figures

Figure 1.1. 25 km^2 area in University Park, Texas with smaller (green) analysis area. 3

Figure 1.2. 2.5 km^{2}area around Southern Methodist University.. 3

Figure 1.3. 3-D view of area around Southern Methodist University. 4

Figure 1.4. Steps in modeling and running an acoustic analysis of an urban area. 5

Figure 2.1. Topography of 6.25 km^{2}area. 10

Figure 3.1. Selection of geographic coordinate system. 16

Figure 3.2. Topography and clip areas for analysis area. 17

Figure 3.3. Adding an area to provide a clip boundary. 17

Figure 3.4. Name the clip feature. 18

Figure 3.5. View the overlay control center. 19

Figure 3.6. Changing projection system to geographic. 19

Figure 3.7. Select feature info tool. 19

Figure 3.8. Exporting the DEM data as a GeoTIFF. 20

Figure 3.9. GeoTIFF options in Global Mapper. 20

Figure 3.10. Select the export bounds to trim data to a specified extent. 21

Figure 3.11. Buildings greater than (orange) and less than or equal to (blue) 51 ft in height. 22

Figure 3.12. Building greater than (blue) and within (pink) 200 m of U.S. Highway 75.................... 23

Figure 3.13. Aggregated buildings greater than (purple) and within (green) 200 m of U.S. Highway 75.. 23

Figure 3.14. Buildings for large area (red) and area of interest (green). 24

Figure 3.15. Changing display projection to UTM. 26

Figure 3.16. Dialog to select features for shapefile. 26

Figure 3.17. Dialog to select export bounds for shapefile. 27

Figure 3.18. Additional edits to the building data set. 28

Figure 3.19. Image of Bush Library on Google Earth. 29

Figure 3.20. Create new area feature. 29

Figure 3.21. Creating new area feature by tracing photo. 29

Figure 3.22. Name the added feature. 30

Figure 3.23. Add an attribute to feature. 30

Figure 3.24. Select by attributes to create a new layer. 31

Figure 3.25. Create a new layer from the selection. 32

Figure 3.26. Select buildings (cyan color) within 200 m of U.S. Highway 75. 33

Figure 3.27. Switch selection of buildings (cyan color) to produce buildings away from U.S. Highway 75.. 34

Figure 3.28. Aggregate Polygons function inside ArcToolbox. 35

Figure 3.29. Parameters for aggregating buildings. 35
Figure 3.30. Individual (green) and aggregated (purple) buildings located away from U.S. Highway 75. 36
Figure 3.31. Aggregated buildings located away from U.S. Highway 75. 36
Figure 3.32. Spatial Join function in ArcToolbox. 39
Figure 3.33. Use a spatial join to make a data set containing building height information grouped by aggregated polygon. 40
Figure 3.34. Result of spatial join showing heights and areas of buildings grouped by aggregated polygon. 40
Figure 3.35. Add field dialog. 41
Figure 3.36. Selection of the field calculator. 41
Figure 3.37. Field calculator to compute area times height for each building. 42
Figure 3.38. Result of calculations using field calculator. 42
Figure 3.39. Summarize data for a field to create a new table. 43
Figure 3.40. Join individual building data with the aggregated building data. 43
Figure 3.41. Result of join. 44
Figure 3.42. Add a field for the weighted average of the heights. 44
Figure 3.43. Use the field calculator to compute a weighted average. 45
Figure 3.44. Table showing the weighted average for the heights of the buildings contained in aggregated polygons. 45
Figure 3.45. Shapefile export options for Global Mapper. 46
Figure 3.46. Selecting export data option to save data. 47
Figure 3.47. Export data dialog for shapefiles in ArcMap. 48
Figure 3.48. Vector options dialog to set elevation data for buildings. 49
Figure 3.49. Select 3D view. 49
Figure 3.50. Change display properties of 3D view. 50
Figure 3.51. 3D view properties. 50
Figure 3.52. Export file options. 51
Figure 3.53. ASCII export options for buildings. 52
Figure 3.54. Paved areas of analysis region. 53
Figure 3.55. Island areas contained in the paved area data highlighted in red. 55
Figure 3.56. ASCII export options for paved areas. 56
Figure 3.57. Gridding option for paved areas. 57
Figure 3.58. Export bounds options for paved areas. 57
Figure 3.59. Select features by attribute. 58
Figure 3.60. Selecting bridges based on attribute value. 59
Figure 3.61. Copy objects to new layer. 59
Figure 3.62. Raised terrain under bridge. 61
Figure 3.63. Create area feature encompassing area to flatten. 61
Figure 3.64. Dialog for newly created area feature. 62
Figure 3.65. Dialog for selected area. 62

Figure 3.66. Selection of vertices to edit. 63
Figure 3.67. Editing elevation of all vertices. 63
Figure 3.68. Elevation grid options. 63
Figure 3.69. Flattened terrain under bridge. 64
Figure 3.70. 3-D view of flattened area. 64
Figure 3.71. ASCII export options for bridges. 66
Figure 4.1. Reading building information into the Urban Modeler program. 68
Figure 4.2. Defining method used to denote height of building in input file. 69
Figure 4.3. Complete building data set. 69
Figure 4.4. Paved area data set in Urban Modeler. 71
Figure 4.5. Bridge information displayed in Urban Modeler. 71
Figure 5.1. Main spreadsheet containing problem setup. 74
Figure 5.2. Definition of finite difference grid. 75
Figure 5.3. Definition of medium properties and layers. 76
Figure 5.4. Definition of topography. 78
Figure 5.5. Definition of buildings. 80
Figure 5.6. Definition of paved areas. 83
Figure 5.7. Definition of islands in paved areas. 85
Figure 5.8. Definition of bridge objects. 86
Figure 6.1. Main MATLAB screen. 88
Figure 6.2. Set path for MATLAB. 88
Figure 6.3. Running rvgModel.m. 89
Figure 6.4. Main menu for MATLAB preprocessing routines. 89
Figure 6.5. Variable grid parameters denoting a constant grid in the x-direction. 90
Figure 6.6. Variable grid parameters denoting a constant grid in the y-direction. 91
Figure 6.7. Variable grid parameters denoting a constant grid in the z-direction. 91
Figure 6.8. Informational dialog displaying grid limits. 92
Figure 6.9. Display of topography as defined in spreadsheet. 92
Figure 6.10. Informational dialog giving information about topography. 93
Figure 6.11. Defining the position of the grid on the topography. 93
Figure 6.12. Display of location of grid on topography. 93
Figure 6.13. Informational dialog about grid location. 94
Figure 6.14. Input for slice plots. 94
Figure 6.15. Slice showing the layers in the medium. 95
Figure 6.16. Elevation data for partial building data. 96
Figure 6.17. Partial building data shown in 3-D. 96
Figure 6.18. Slice plot selection for auxiliary structures. 97
Figure 6.19. x-z plane slice plot showing buildings. 97
Figure 6.20. 3-D plot of processed aggregated buildings close to U.S. Highway 75. 97
Figure 6.21. 3-D plot of processed buildings greater than 51 ft in height. 98

Figure 6.22. 3-D view of processed individual buildings. 98
Figure 6.23. Magnified 3-D view of processed buildings. 98
Figure 6.24. Processed partial paved areas without islands. 99
Figure 6.25. Processed partial islands of paved areas. 99
Figure 6.26. Definition of a Ricker pulse. 105
Figure 8.1. Main menu for SNAPPS. 127
Figure 8.2. Choose data to visualize. 127
Figure 8.3. Specify if SNAPPS should change or create directories. 127
Figure 8.4. Choose section cut to extract data. 128
Figure 8.5. Select type of results to view. 128
Figure 8.6. Input of region. 129
Figure 8.7. Selection of frames for animation. 130
Figure 8.8. Specify color limits for the animation. 130
Figure 8.9. Selection of number of contours. 131
Figure 8.10. Contour of topography. 131
Figure 8.11. Example of frame from animation of pressures. 131
Figure 8.12. Options after creation of animation. 132
Figure 8.13. Locations for output of time history information. 133
Figure 8.14. Select region to compute time series information. 134
Figure 8.15. Select grid size for time series information. 134
Figure 8.16. Select the extents of the time history. 135
Figure 8.17. Select filter for results. 135
Figure 8.18. Time history output at grid points. 136
Figure 8.19. Prompt to save time history signals. 136
Figure 8.20. Specify output at points. 137
Figure 8.21. Input of points at which to output time histories. 137
Figure 8.22. Select how to plot signals. 138
Figure 8.23. Time history of pressure at single point. 138
Figure 8.24. Time histories of pressure at multiple points. 138
Figure 8.25. Time series tools in MATLAB. 139
Figure 8.26. Time and spectral plots in MATLAB. 140
Figure 8.27. Specify time extents for peak values. 141
Figure 8.28. Peak pressures in x-y plane for 5 Hz source in upper right corner for 410 frames. 141
Figure 8.29. Peak pressures in y-z plane for source located on interior for 410 frames. 142
Figure 8.30. Options for peak values. 142
Figure 8.31. Peak pressures for frame 200 (5 sec) for source in upper left corner. 143
Figure 8.32. Peak pressures for frame 1 through 200 (5 sec) for source in upper left corner. 143
Figure 8.33. Integration period for energy. 144
Figure 8.34. Integrated energy for the x-y plane for a source in the upper right corner. 145

Figure 8.35. Integrated energy for frame 200 (5 ec) for source in upper left corner. 145

Figure 8.36. Integrated energy for frame 1 through 200 (5 sec) for source in upper left corner. 146

Figure 8.37. Compare a set of values to a reference set. 147

Figure 8.38. Options for reference plot. 147

Figure 8.39. Peak pressures in x-y plane for 10 Hz source in upper right corner for 410 frames. 148

Figure 8.40. Results of reference calculation using 5 and 10 Hz sources. 148

Figure 8.41. Peak pressures for 5 Hz source located in upper right corner for individual buildings. 149

Figure 8.42. Peak pressures for 5 Hz source located in upper right corner for aggregated buildings. 149

Figure 8.43. Comparison plot for difference between individual buildings and aggregated buildings. 150

Figure 8.44. Selecting point 1 to rectify an image to GIS data. 151

Figure 8.45. Selecting point 4 to rectify an image to GIS data. 152

Figure 8.46. Final rectified figure with buildings and roads added. 152

Tables

Table 5.1. Porous material properties (Wilson and Liu 2004). 77

Table 7.1. Typical values of static-flow resistivity, porosity, and tortuosity for common porous ground surfaces (Wilson and Liu 2004). 108

Preface

This study was conducted for the Office of the Assistant Secretary of the Army for Acquisition, Logistics, and Technology (AASALT) under "Infrasound Distribution and Monitoring in Man-Made Environments." The technical monitor was Military Engineering.

The work was performed by the Computational Analysis Branch (IE-C) of the Computational Science and Engineering Division, U.S. Army Engineer Research and Development Center, Information Technology Laboratory (ERDC-ITL). At the time of publication, Elias Arrendondo was Chief, CEERD-IE-C; Robert Wallace was Chief, CEERD-IE; and Dr. David Horner, CEERD-GV-T was the Technical Director for Military Engineering. The Deputy Director of ERDC-ITL was Patti Duett and the Director was Dr. Reed Mosher.

The modeling effort discussed in this report was led by Michael E. Pace, ERDC-ITL. The report was written by Michael E. Pace, Computational Analysis Branch (IE-C) of the Computer-Aided Engineering Division, ERDC, Information and Technology (ERDC-ITL) and Sarah L. McComas and Dr. Mihan H. McKenna of the Structural Engineering Branch (GS-S) of the Geosciences and Structures Division, ERDC, Geotechnical and Structures Laboratory (ERDC-GSL).

At the time of publication, LTC John T. Tucker was the Acting Commander of ERDC, and Dr. Jeffery P. Holland was the Director.

Unit Conversion Factors

Multiply	By	To Obtain
acres	4,046.873	square meters
atmosphere (standard)	101.325	Kilopascals
bars	100	Kilopascals
feet	0.3048	meters
inches	0.0254	meters
miles (US statute)	1,609.347	meters
miles per hour	0.44704	meters per second
square feet	0.09290304	square meters
square inches	6.4516 E-04	square meters
square miles	2.589998 E+06	square meters
square yards	0.8361274	square meters
Yards	0.9144	meters

1 Overview of Modeling an Urban Area

1.1 Introduction

Infrasound signals are acoustic signals below 20Hz and can be monitored at distances of tens to thousands of kilometers (Hedlin et al. 2012). These signals are generated by natural sources (surf, earthquakes, volcanoes, etc.), explosions (nuclear and non-nuclear), infrastructure sources (bridges, dams, large buildings, etc.), and human sources (trains, highway traffic, etc.) (Campus and Christie 2010; McKenna et al. 2009; Guzas and Tricys 2010). Recent observations show that human activity and infrastructure emit surprisingly ubiquitous and high levels of infrasound. Because the wavelengths of infrasound are on the scale of tens to hundreds of meters, infrasonic energy can propagate tens of kilometers through areas of human activity without loss-of-signal character because the wavelengths are transparent to the audible acoustic obstructions, such as buildings. Consequently, infrasound deployments would result in new human environment-monitoring capabilities.

The production mechanisms and extent to which different sources can be differentiated and monitored is still poorly understood. If infrasound is to be used for monitoring the “health” of a human environment and for identifying anomalous activities, the following key scientific issues must be examined: 1) What are the typical infrastructural sources of infrasound and their levels? 2) How *saturated* is the environment of interest with infrasonic signals (i.e., do many signals propagate over long distances to reach a given sensor, or can individual sources be well differentiated)? 3) Does infrasound provide new information to characterize rapidly evolving physical, cultural, economic, and military actions of interest?

Numerical modeling method is used to explore signal generation and propagation in the complex urban environment, while controlling a single infrasound source in the environment. Parameterization studies for understanding the effect of the urban terrain on infrasound signal propagation and the effects of the short propagation distances related to local metrological effects can be completed while controlling the sources and other variables in the environment. As the parameterization studies are completed, base cases are validated with real-world data.

1.2 Purpose of report

This report describes the modeling of the structures and landscape in the urban area with sufficient resolution and accuracy to allow the subsequent analysis with an acoustic finite-difference time-domain (FDTD) code. The purpose of the report is to lead the reader through the steps involved in gathering the required geographical data, modeling the 3-dimensional (3-D) urban area of interest in geographical information systems (GIS) software, production of needed data files, analysis requirements, and viewing of results. This report details techniques and methods to evaluate the principles of urban infrasound propagation. This report is focused on the details of using various software packages to perform the modeling, but some of the concepts are general in nature and can be applied to other applications if needed. The software packages used are discussed in Section 1.4.

1.3 Description of urban area modeled

A 25 km^2 urban area was modeled in support of infrasound studies related to acoustic propagation through urban environments. The area was in University Park, Texas, around the Southern Methodist University, as shown by the red outlined area in Figure 1.1. The area measured 5 km on each side. A smaller 6.25 km^2 area was used for analysis purposes, as shown by the green outlined area in Figure 1.2. This area was 2.5 km on each side. The location of the lower-left corner of the areas shown in Figures 1.1 and 1.2 are given in the Universal Transverse Mercator (UTM) coordinate system.

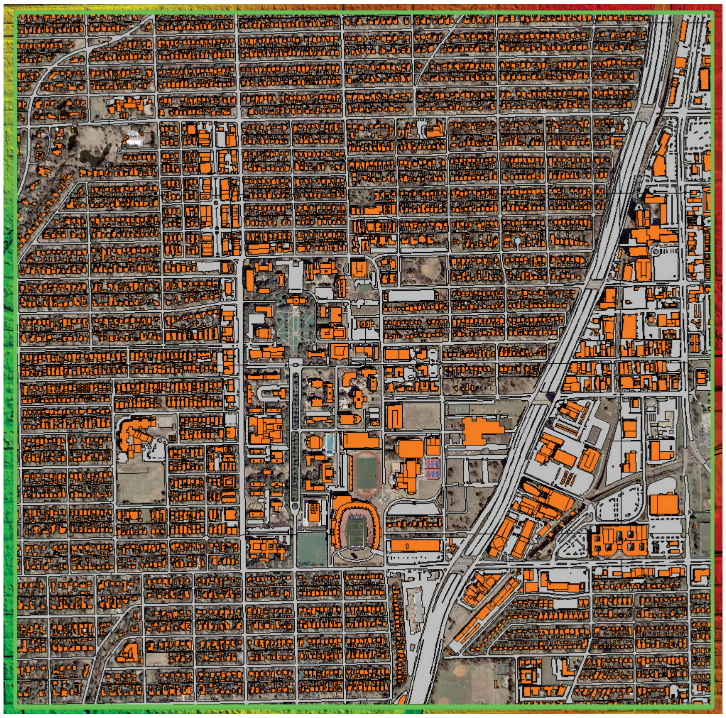
The work required the synthesis of GIS data from various sources to produce a 3-D model of the urban area. The main GIS data used pertained to defining the topography, the paved areas (e.g. road, highways, and parking lots), and the buildings. The orange areas shown in Figures 1.1 and 1.2 are buildings. The gray areas shown in Figures 1.1 and 1.2 are the paved areas. The GIS data is more fully described in Chapter 2.

Analyses were performed on the area shown in Figures 1.2 and 1.3 using an acoustic FDTD code running on the ERDC Major Shared Resource Center supercomputers.

Figure 1.1. 25 km^2 area in University Park, Texas with smaller (green) analysis area.

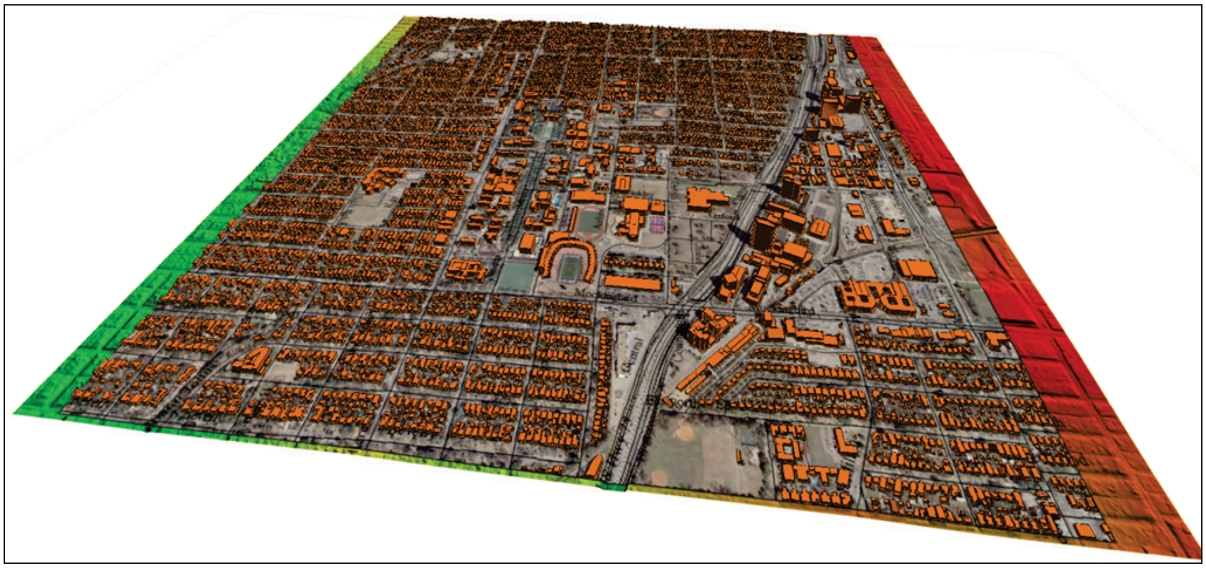
(704837.812, 3633790.296)

Figure 1.2. 2.5 km^{2}area around Southern Methodist University.



(706301.196, 3634845.629)

Figure 1.3. 3-D view of area around Southern Methodist University.



1.4 Discussion of programs used and steps to produce urban data sets and perform analyses

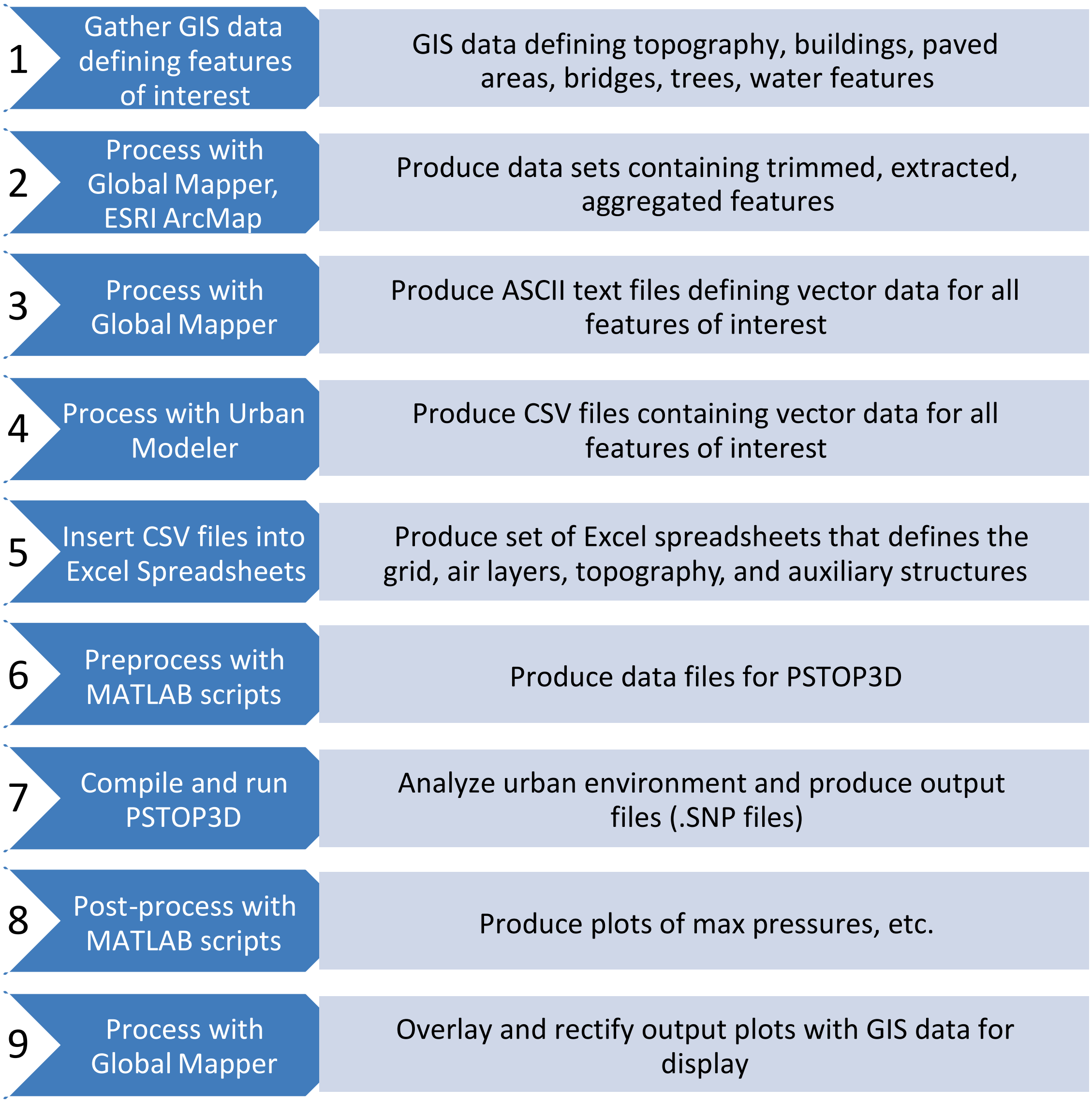
Several commercial and custom programs were used to produce the urban data files and to conduct acoustic analyses of the 6.25 km^{2}area shown in Figure 1.2. A short discussion of each program follows to explain how the programs were used to process the GIS urban data sets. The GIS data sets will be explained more fully in Chapter 2. The process steps are shown in Figure 1.4 below.

Two GIS programs were used to manipulate the data sets used to model the urban area. Global Mapper (version 14.0) from Blue Marble Geographics (2013) and ArcMap (version 10.0) from the ArcGIS product from Environmental Systems Research Institute (ESRI 2013).

Global Mapper was used to:

- Convert all data to a common projected coordinate system.
- Trim large data sets to the extents of the desired analysis area.
- Modify the elevation of the topography under bridges.
- Extract certain features from larger data sets based on location, size, or height.
- View 2-D buildings in 3-D given a height attribute.
- Output ASCII vector files defining the needed data sets for additional processing by other software.

Figure 1.4. Steps in modeling and running an acoustic analysis of an urban area.



The output of ASCII files by Global Mapper made for an easy path to read the data and perform other custom operations.

ArcMap was used to:

- Perform custom queries of data to segment the data by desired ranges of attributes.
- Perform queries based on containment of one feature in another.
- Make needed data sets by performing relational database joins on the information contained in the geodatabase.

- Aggregate buildings into larger polygons that represented buildings with a common range of a desired attribute (i.e., height). This also effectively segmented the buildings based on function, such as residential and commercial.
- Compute weighted averages of heights of buildings contained with larger polygons
- Make data sets based on the proximity of a feature set (e.g., buildings) to other geographic features (e.g., roads).
- Output features in the ESRI shapefile format for reading into Global Mapper.

ArcMap was used to aggregate the buildings in the urban environment into larger areas based on the proximity of buildings to one another and in computing weighted averages of heights of buildings within desired polygons. This is further explained in Chapter 3.

A piece of custom software termed the Urban Modeler was used to read the sets of data in the ASCII format output by Global Mapper. Urban Modeler was then used to:

- Convert the units of vertical measurement of attributes to a common unit of meters.
- Determine if islands exist in the data and write the island information out separately from the feature information.
- Break large sets of data (e.g., thousands of buildings) into many smaller sets of data to improve processing later in MATLAB.
- Produce data files for buildings and area features (i.e., paved features consisting of streets, highways, parking lots, driveways, and medians).
- Write GIS information out to ASCII comma separated variable (CSV) files for use with Microsoft Excel.

Islands represent open spaces in a larger area. That is, a building may exist with an interior courtyard, which can be modeled using an island. Paved areas, such as highways, may have interior open spaces that represent the medians. The network of streets may be represented as large solid areas with islands representing the city blocks. The GIS programs will display the features and the islands will cause the large solid areas to appear to have open spaces in them. The islands must be accounted for in the modeling process. This is discussed further in Chapter 4.

The CSV files produced by the Urban Modeler program define the structures (buildings and paved areas) that sit on the topography. These files were read into Microsoft Excel (version 2007) and then inserted into other Excel spreadsheets that contained the definition of the problem domain. This information consisted of the definition of the analysis grid size, default material property for the ground, air layers and properties, topography, and the structures that reside on the topography. The use of the Excel spreadsheets is explained more in Chapter 5.

The MATLAB (version 2012b) program from MathWorks (2013) was used to run custom scripts that processed the information contained in the Excel spreadsheets and produced output used to compile and run the 3-D acoustic FDTD program called PSTOP3D. The use of the MATLAB scripts is explained in Chapter 6.

PSTOP3D (version AS217), which roughly stands for parallel stair-casing topography in 3-D, was used to perform an acoustical analysis of the 3-D data representing the urban environment. PSTOP3D is a FDTD code produced by the ERDC Cold Regions Research Laboratory (Ketcham 2006; Ketcham et al. 2005, 2007, 2008; Parker et al. 2007). The procedures to compile and run PSTOP3D are explained in Chapter 7.

MATLAB was also used to post-process the results to produce various plots and animations. The post-processing is discussed in Chapter 8.

2 GIS Data Sets Used to Model the Urban Area

2.1 Sources for GIS data

The information contained in this chapter corresponds with Step 1 in Figure 1.4. There are many commercial and government sources of GIS data. Some of the government sources that were investigated in this study were the:

- Army Geospatial Center (AGC)
- National Geospatial Intelligence Agency (NGA)
- United States Geological Service (USGS)
- United States Departments of Agriculture (USDA)
- United States Census Bureau

These agencies have information consisting of:

- Digital elevation data at varying resolutions
- Photographic data consisting of satellite and aerial imagery
- Land cover and land use data
- Road and highway data

The two state agencies that were used to collect data were the North Central Texas Council of Governments (NCTCOG) and the Texas Natural Resources Information System (TNRIS).

The data sets of interest defined the:

- Topography
- Individual building footprints with a height attribute
- Areal extents of paved areas such as highways, roads, streets, parking lots, and medians
- Areal extents of water features
- Areal extents of trees or forests with height information

2.2 Topography data

Sources given in Section 2.1 for topographical data were investigated and several sets of digital elevation data were collected. The data set determined to best represent the topography of the given area was obtained from TNRIS (2013).

The topography was modeled by using light detection and ranging (LIDAR) data purchased from TNRIS which is part of the Texas Water Development Board. The LIDAR data was flown during 2009 and consisted of data points spaced at 1 meter.

LIDAR systems are typically mounted on an aircraft and use a laser to densely sample the surface of the earth and produce highly accurate terrain models.

The data set was provided in several formats including LIDAR laser (LAS) files and files in the United States Geological Service (USGS) digital elevation model (DEM) format. The LAS files contain information on the classification of the LIDAR points, the return value, and the intensity value. Points are classified as objects such as trees, water, and buildings. The last return value represents the bare earth model.

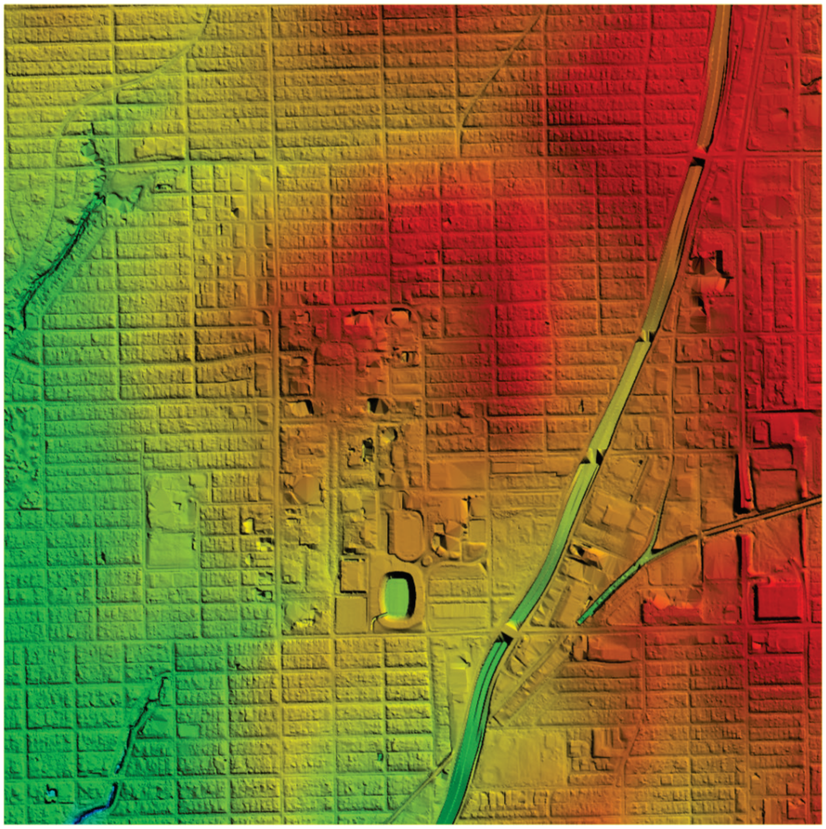
The DEM files contained the bare earth model that could also be extracted from the LAS files. This study used the DEM files to input the topography into Global Mapper. The topography defined by the LIDAR data is shown in Figure 2.1.

2.3 Aerial orthophotography

2009 6 in. aerial orthophotography was obtained from NCTCOG in the GeoTIFF image format. The imagery was mainly used to provide a nice overlay for the topography when producing displays of the 3-D modeled area.

Additional orthophotography was obtained from the USDA National Agriculture Imagery Program (NAIP 2013) obtained in 2012. This imagery was used to add a custom building to the building data set.

Figure 2.1. Topography of 6.25 km²area.



2.4 Building data

Data were sought that would provide a definition of the building footprints with an associated height attribute. This would be enough information to construct an extruded building with the appropriate footprint and a representative height to adequately represent the building in an analysis.

Several sources of data were examined as described in Section 2.1. The AGC had information from NGA from a project called the 133 Cities Project. This project collected LIDAR data on urban areas and processed the data to produce a bare earth model, footprints of buildings with a height attribute, and definition of trees and forested areas. These data would have been perfect except that data for only a portion of the desired area were available.

Planimetric data sets from the NCTCOG were available for the entire area. Planimetric data consist of 2-D representations of objects as seen from aerial photography. The features include roads, building footprints, sidewalks, trails, rivers, lakes, etc. These features are often digitized from orthorectified aerial photography producing images that have been adjusted for topographic relief, lens distortion, and camera tilt. The images may be used to accurately measure distances. Unfortunately, the building footprints contained in the planimetric data did not have height attributes.

Eventually, a contract was undertaken with CyberCity 3D (2012), a commercial company located in El Segundo, CA, to construct the buildings. The company specializes in the production of accurate 3-D models of cities including 3-D buildings, streets, trees, and urban objects that can be used for various visualization of planning functions.

CyberCity 3D used 6 in. stereoscopic aerial photography to construct 3-D models of the buildings. These models were quite detailed and included the shape of the roof (e.g. flat, hip, gable, gambrel) and additional shapes, such as dormers. CyberCity 3D processed the data using their in-house custom software.

A set of 2-D buildings were also produced that included the footprints of the buildings and a height attribute. The height of the building was defined as the lower edge of the building up to the mid-height of the roof. For a flat roof, the measurement is from the lowest bottom edge of the building to the top of the roof. For a roof that is not flat, such as a hip or gable roof, the measurement is from the lowest bottom edge of the building up to the mid-height of the roof. The height measurement was provided in feet.

The data set was provided as ESRI shapefiles and AutoCAD DXF files. The shapefiles were used for the 2-D footprints while the AutoCAD DXF files were used to represent the 3-D features.

The 2-D definitions of the buildings were used in this study to determine the effect of buildings on infrasound propagation. The footprints of the buildings are shown in Figures 1.1 and 1.2 as orange areas. The larger area shown in Figure 1.1 consisted of 54,225 footprints. The smaller area shown in Figure 1.2 consisted of 12,568 footprints. This is not the total number of buildings because a single building may have multiple footprints defining different levels or pieces of geometry such as dormers. The actual number of buildings used in the analysis for the area shown in Figure 1.2 is 11,059.

2.5 Paved areas data

Data were needed to define paved areas such as roads, streets, highways, parking lots, and medians. Data defining the roads, streets, and highways were found from the U.S. Census Bureau as TIGER/Line (Topologically Integrated Geographic Encoding and Referencing) files. These files were ESRI shapefiles and defined the roads, streets, and highways in sufficient detail topologically. Attributes were provided that gave the feature name and the type of the feature such as residential road. The problem with the data was that the roads did not have a width specified. Therefore, a width would have to be assumed based upon the feature type specified.

Planimetric data from the NCTCOG were available for the entire area for 2007. Planimetric data consist of 2-D representations of objects as seen from aerial photography. The features include items such as roads, building footprints, sidewalks, trails, rivers, lakes, bridges, etc., which were traced using digital orthorectified aerial photography, thereby resulting in the accurate areal definition of the objects.

All visible paved parking lots large enough to accommodate five automobiles were digitized. No gravel or dirt parking lots were digitized. The accuracy of all digitized features matches the accuracy of the aerial photography used. Aerial photography from NCTCOG meets National Map Accuracy Standards at a map scale of 1 in. = 200 ft (1:2400).

The planimetric data set was useful because it defined the areal extents of the roads, streets, highways, and bridges. The data set also provided information for parking lots, medians, and sidewalks. Since the areal extents were defined, a width did not have to be assumed for the roads, streets, or highways. The sidewalk information was not used in the analyses, but was modeled by using buffer zones of a specified size that corresponded to an average sidewalk width. This process is explained in Chapter 3. The planimetric files were provided as ESRI shapefiles.

For the area defined in Figure 1.1, there were 2,155 paved-area objects. The trimmed objects for the smaller area shown in Figure 1.2 consisted of 648 objects. The objects could cover very large areal extents and this caused some problems with the data processing. To alleviate the problems, larger objects were split into smaller objects for processing which resulted in a total of 947 objects being processed. This is explained in Chapter 3.

2.6 Trees and water features data

Other objects of interest in the urban environment are trees (individual), forests (conglomeration of individual trees), and water features such as lakes, streams, and rivers.

For the analyses performed, trees and water features were not included. The data sources discussed in Section 2.1 did contain some information concerning these features. For trees and forests, the data sets from AGC were defined using LIDAR data and included a height attribute. The area under consideration did not have complete coverage. The LIDAR data from TNRIS did include point feature definitions of trees that could be used to model the tree coverage. This was not done in this study.

The water features were not adequately defined in any of the data sets obtained. Water features were not included in the initial analyses, but were modeled by simply tracing water features shown on 2009 6 in. orthophotography obtained from NCTCOG. This allowed the width of the features to be accurately modeled.

2.7 Projected coordinate systems

All GIS data sets are defined using a geographic or projected coordinate system. An example of a geographic coordinate system is the typical latitude-longitude that defines a point on the earth using degrees of latitude and longitude. A projected coordinate system maps the points on a sphere to a flat map. There are many projected coordinate systems and you must know what system is used to define your data. The projected coordinate system information may be supplied with the GIS information as metadata files, as projection files, or from information provided by the GIS data provider. For the data described in the report, the projected coordinate systems were supplied with the data received from the various data sources.

Even if the projected coordinate system of your data is known, attributes supplied with the data may be in different units. For example, the data set defining the areal footprints of buildings in this study was in meters, but the attribute defining the heights of the buildings was in feet.

For this study, the data sets that were obtained were not all in the same projected coordinate system. Therefore, all data sets were re-projected to the UTM coordinate system which Global Mapper does on the fly. That is, the first data set read into Global Mapper sets the default coordinate system. All other data sets read in afterwards are re-projected to this default coordinate system.

The UTM coordinate system uses a 2-D Cartesian coordinate system to give locations on the surface of the earth. The horizontal and vertical locations are given in meters. The UTM system divides the earth into sixty zones that are each composed of six degrees of longitude. This system must also reference a vertical datum. The one used in this study was the World Geodetic System (WGS) 1984 datum. All data in this study fell within UTM zone 14.

Projecting data to the UTM coordinate system provides a 2-D Cartesian coordinate system, in which accurate linear measurements can be performed.

3 Process GIS Data

3.1 Overview

The information in this chapter pertains to Steps 2 and 3 in Figure 1.4 of the process map. The processing of the GIS data was performed by the program Global Mapper from Blue Marble Corporation and ArcMap from ESRI. These programs were used to convert the data sets into one common geographic coordinate system, trim the data sets to the needed areal extents, extract certain features from the data, and aggregate the building data into larger more general areas. The specific steps to accomplish these tasks are discussed within this chapter.

Although most of the tasks could be performed with either program, some tasks were easier to perform with Global Mapper and others with ArcMap. The discussion in this chapter will show the steps required to perform a task using either Global Mapper or ArcMap, but not both. There are some tasks, such as the aggregation of buildings, which could only be performed in one program.

Global Mapper was mainly used to perform the manipulations and display of the data (both 2-D and 3-D), while ArcMap was used to perform a few specific tasks.

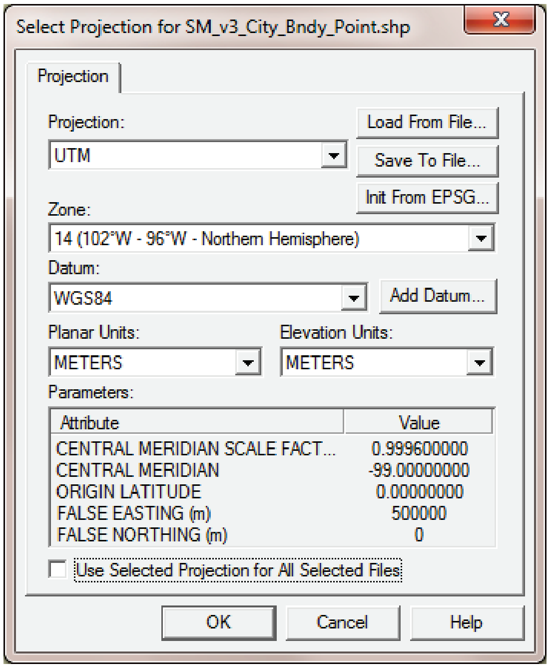
3.2 Define topography

3.2.1 Read topography into Global Mapper

Global Mapper was used to read the topography information obtained from TNRIS in the USGS DEM format. The topography for the 6.25 km^2 area is shown in Figure 2.1.

Data are read into Global Mapper by opening the specific file using the **File** menu option or dragging the file from Windows Explorer. If the file contains a definition of the projected coordinate system used, Global Mapper will automatically read and display the data. If a projected coordinate system is not found, a dialog box will display asking the user to verify the appropriate projected coordinate system as shown in Figure 3.1. The user would select the appropriate projected coordinate system that the data use and select the **OK** button.

Figure 3.1. Selection of geographic coordinate system.



Projection: UTM

Zone: 14 (102°W - 96°W - Northern Hemisphere)

Datum: WGS84

Planar Units: METERS

Elevation Units: METERS

Parameters:

Attribute	Value
CENTRAL MERIDIAN SCALE FACT...	0.999600000
CENTRAL MERIDIAN	-99.00000000
ORIGIN LATITUDE	0.00000000
FALSE EASTING (m)	500000
FALSE NORTHING (m)	0

☐ Use Selected Projection for All Selected Files

3.2.2 Create clip region for topography

Topography was obtained for an area slightly larger than the 25 km^2 area shown in Figures 1.1 and 3.2. The red outlined area in Figure 3.2 is the clip area for the topography for the smaller area of interest. The green outlined area is the area of interest used for the analysis. A larger topography is used for the analysis area to give the MATLAB code information to interpolate elevations at the edges of the analysis area. The topography for the analysis area was clipped from the larger area using Global Mapper as follows:

1. Create a box that surrounds the area of interest. In Global Mapper, a box is created by selecting the **Digitizer Tool** button and then selecting the **Add Rectangular/Square Area** button as shown in Figure 3.3.
2. Left-click a starting point and drag out the square or rectangular region desired. If the **SHIFT** key is held down, a square is created when dragging the mouse.
3. When the box is created, a dialog pops up to name the feature as shown in Figure 3.4. Type a name and click **OK**. This feature will be used when saving the topography data as described in Section 3.2.3. Another feature can be created to clip data to the analysis region.

Figure 3.2. Topography and clip areas for analysis area.

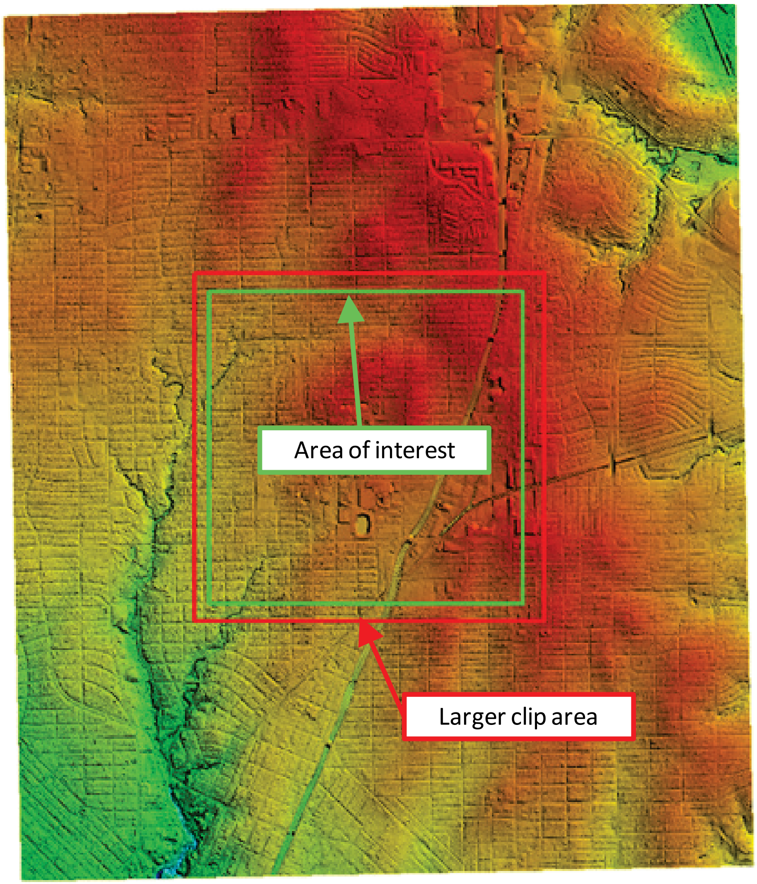


Figure 3.3. Adding an area to provide a clip boundary.

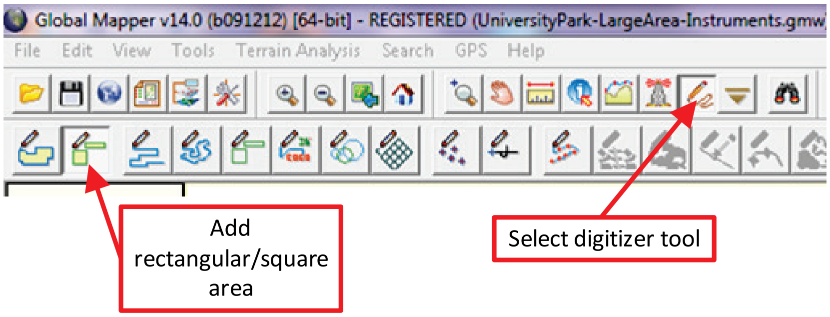
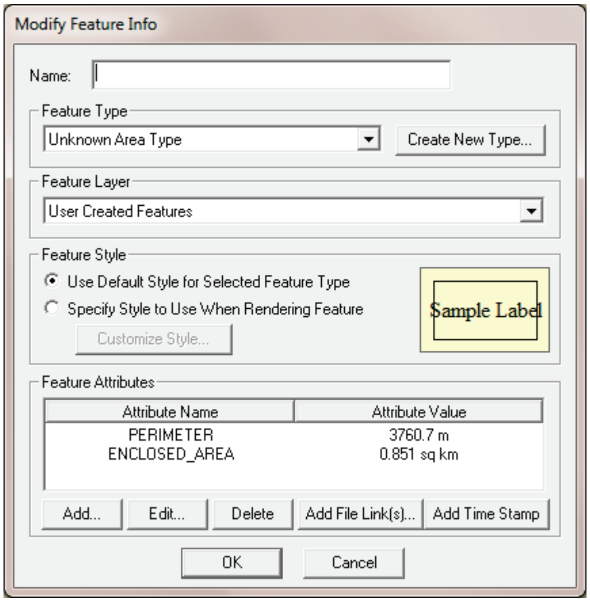


Figure 3.4. Name the clip feature.



Name:

Feature Type: Unknown Area Type

Feature Layer: User Created Features

Feature Style
● Use Default Style for Selected Feature Type
○ Specify Style to Use When Rendering Feature

Feature Attributes

Attribute Name	Attribute Value
PERIMETER	3760.7 m
ENCLOSED_AREA	0.851 sq km

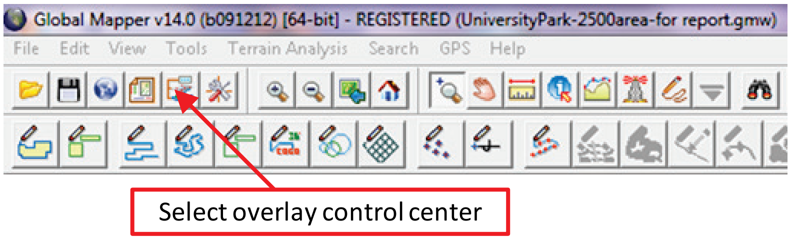
3.2.3 Create GeoTIFF for MATLAB

The MATLAB processing routines require that the digital elevation model data be saved as a 32-bit GeoTIFF file with the geographic coordinate system set as latitude-longitude. This GeoTIFF file can be created in Global Mapper as follows:

1. Turn on the **Overlay Control Center** by left-clicking the icon shown in Figure 3.5. Select objects to display by left-clicking the object to display a check mark. Select all the topography and any edits to the topography, such as, flattened areas under bridges as described in Section 3.5.2. Turn on a clip outline if desired as discussed in 3.2.2. Turn off all other objects. Flattening the terrain under bridges is described in Section 3.5.2.
2. From the **Tools** menu option, select the **Configure** option and change the display projection to **Geographic (latitude/longitude)** as shown in Figure 3.6 and click **OK**. The GeoTIFF file needs to be in geographic coordinates versus UTM coordinates for use in the MATLAB routines. The MATLAB routines automatically apply a display projection to convert geographic coordinates to UTM.
3. Select the **Feature Info Tool** as shown in Figure 3.7 and click on the clip feature to select it.
4. Select **File** > **Export** > **Export Elevation Grid Format** as shown in Figure 3.8.
5. Select the option **Elevation (32-bit floating point samples)** as shown in Figure 3.9.

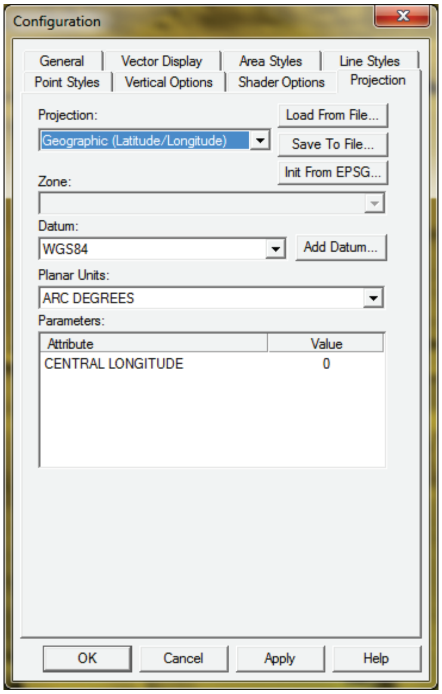
6. Click on the **Export Bounds** tab shown in Figure 3.10 and click on the **Crop to Selected Area Feature(s)** option. Click **OK** and name the export file.

Figure 3.5. View the overlay control center.



Select overlay control center

Figure 3.6. Changing projection system to geographic.



Projection: Geographic (Latitude/Longitude)

Zone:

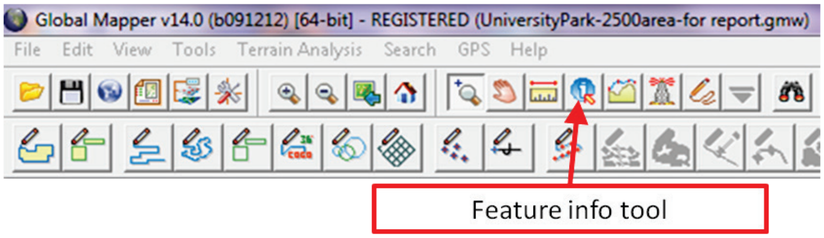
Datum: WGS84

Planar Units: ARC DEGREES

Parameters:

Attribute	Value
CENTRAL LONGITUDE	0

Figure 3.7. Select feature info tool.



Feature info tool

Figure 3.8. Exporting the DEM data as a GeoTIFF.

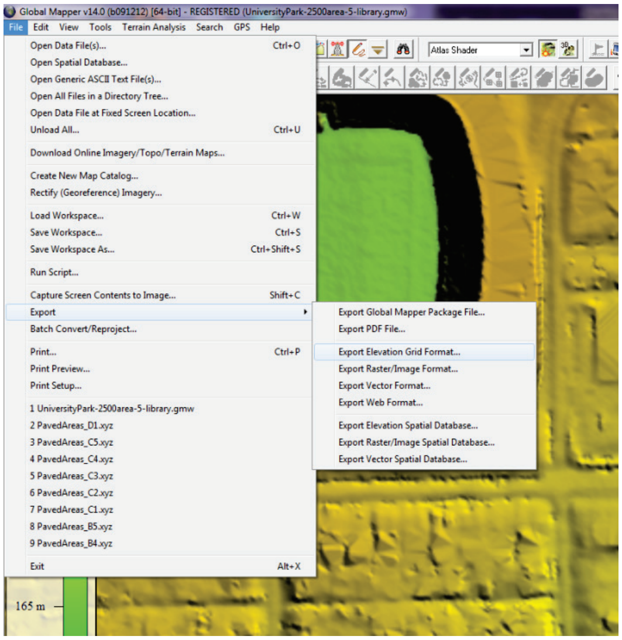
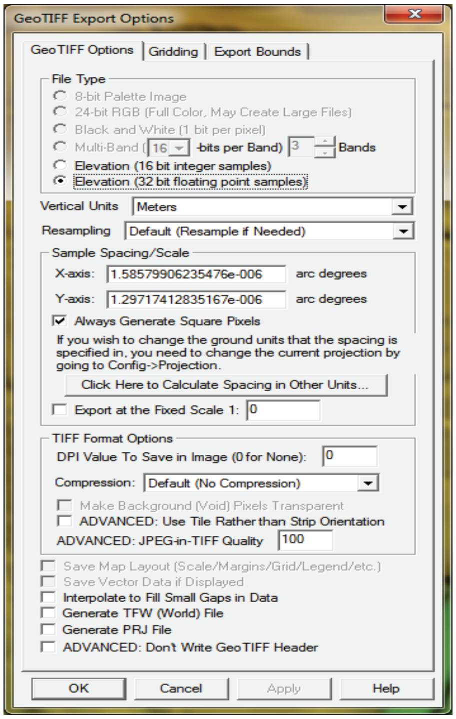


Figure 3.9. GeoTIFF options in Global Mapper.



File Type

○ 8-bit Palette Image
○ 24-bit RGB (Full Color, May Create Large Files)
○ Black and White (1 bit per pixel)
○ Multi-Band (16 -bits per Band) 3 Bands
○ Elevation (16 bit integer samples)
● Elevation (32 bit floating point samples)

Vertical Units: Meters

Resampling: Default (Resample if Needed)

Sample Spacing/Scale

X-axis: 1.58579906235476e-006 arc degrees

Y-axis: 1.29717412835167e-006 arc degrees

☑ Always Generate Square Pixels

If you wish to change the ground units that the spacing is specified in, you need to change the current projection by going to Config->Projection.

Click Here to Calculate Spacing in Other Units...

☐ Export at the Fixed Scale 1: 0

TIFF Format Options

DPI Value To Save in Image (0 for None): 0

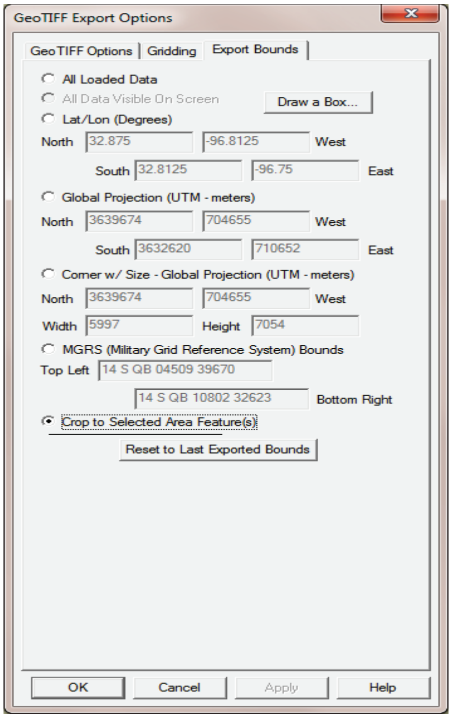
Compression: Default (No Compression)

☐ Make Background (Void) Pixels Transparent
☐ ADVANCED: Use Tile Rather than Strip Orientation

ADVANCED: JPEG-in-TIFF Quality 100

☐ Save Map Layout (Scale/Margins/Grid/Legend/etc.)
☐ Save Vector Data if Displayed
☐ Interpolate to Fill Small Gaps in Data
☐ Generate TFW (World) File
☐ Generate PRJ File
☐ ADVANCED: Don't Write GeoTIFF Header

Figure 3.10. Select the export bounds to trim data to a specified extent.



○ All Loaded Data
○ All Data Visible On Screen
○ Lat/Lon (Degrees)
North 32.875 -96.8125 West
South 32.8125 -96.75 East
○ Global Projection (UTM - meters)
North 3639674 704655 West
South 3632620 710652 East
○ Comer w/ Size - Global Projection (UTM - meters)
North 3639674 704655 West
Width 5997 Height 7054
○ MGRS (Military Grid Reference System) Bounds
Top Left 14 S QB 04509 39670
14 S QB 10802 32623 Bottom Right
● Crop to Selected Area Feature(s)

3.3 Model buildings

The building data set provided by CyberCity 3D was processed to produce several building data sets used for analysis. The building data set was processed to:

1. Construct a building data set that eliminated buildings that were under 1 m^2 in area and 2 m in height. This eliminated small inconsequential buildings or pieces of buildings and aided in the computation of the finite difference grid.
2. Further divide the buildings into two data sets that consisted of buildings less than or equal to 51 ft and greater than 51 ft in height.
3. For the building data set that was less than 51 ft in height, the data set was further divided into buildings that were within 200 meters of U.S. Highway 75 and buildings that were further than 200 meters from U.S. Highway 75.
4. Both building data sets that were less than or equal to 51 ft in height were then aggregated based on an aggregation distance of 25 m. This process combined buildings that were within the aggregation distance into larger buildings.

5. The height of the aggregated building data sets was computed as a weighted average of the individual buildings contained in the larger aggregated polygons.

The above processing results in five data sets were used to perform the acoustic analyses. The data sets consisted of:

1. Buildings that were greater than 51 ft in height (orange buildings in Figure 3.11)
2. Buildings that were 200 m away from U.S. Highway 75 and less than or equal to 51 ft in height (blue buildings in Figure 3.12).
3. Buildings that were within 200 m of U.S. Highway 75 and less than or equal to 51 ft in height (pink buildings in Figure 3.12).
4. Aggregated buildings that were 200 m away from U.S. Highway 75 and less than or equal to 51 ft in height (purple buildings in Figure 3.13).
5. Aggregated buildings that were within 200 m of U.S. Highway 75 and less than or equal to 51 ft in height (green buildings in Figure 3.13).

Figure 3.11. Buildings greater than (orange) and less than or equal to (blue) 51 ft in height.

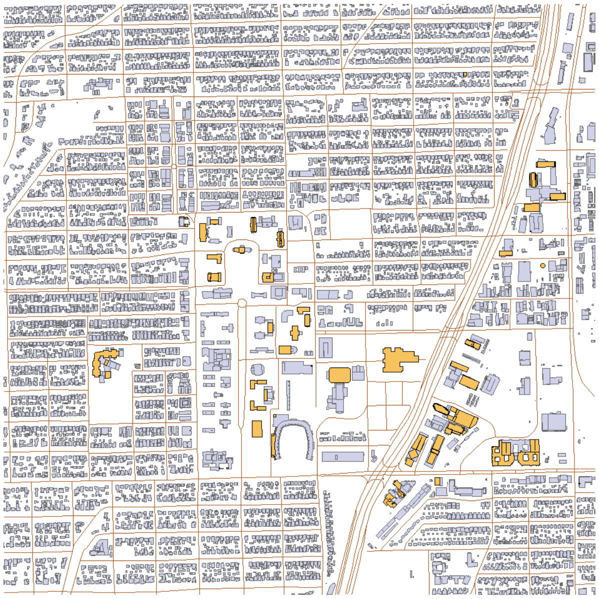


Figure 3.12. Building greater than (blue) and within (pink) 200 m of U.S. Highway 75.

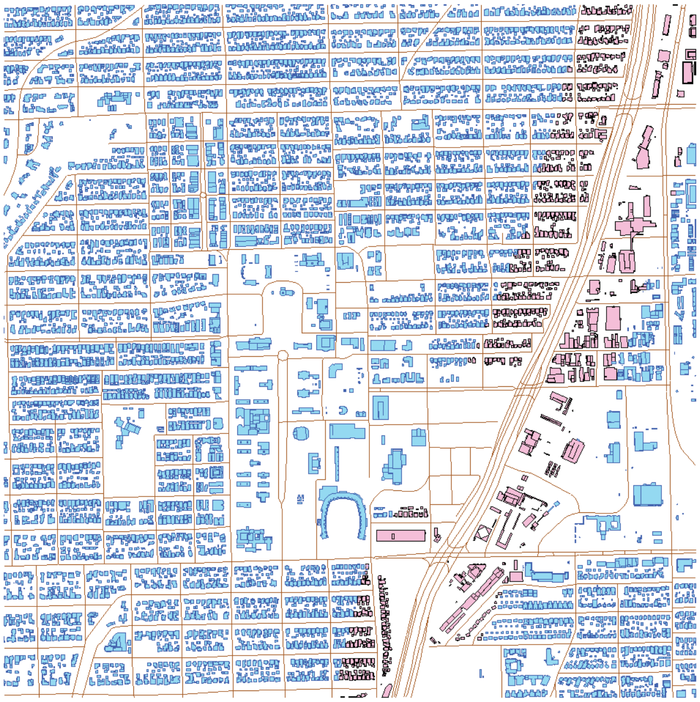
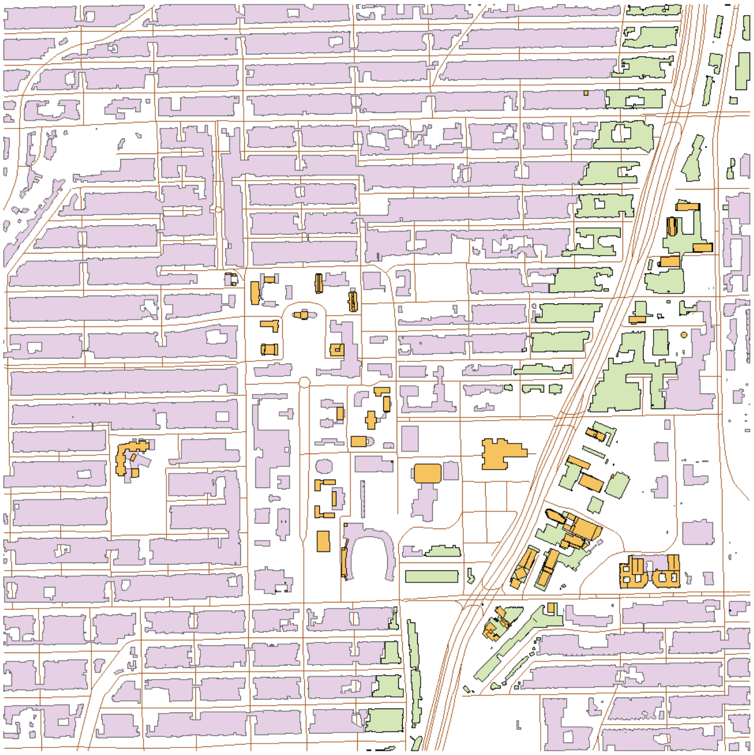


Figure 3.13. Aggregated buildings greater than (purple) and within (green) 200 m of U.S. Highway 75.

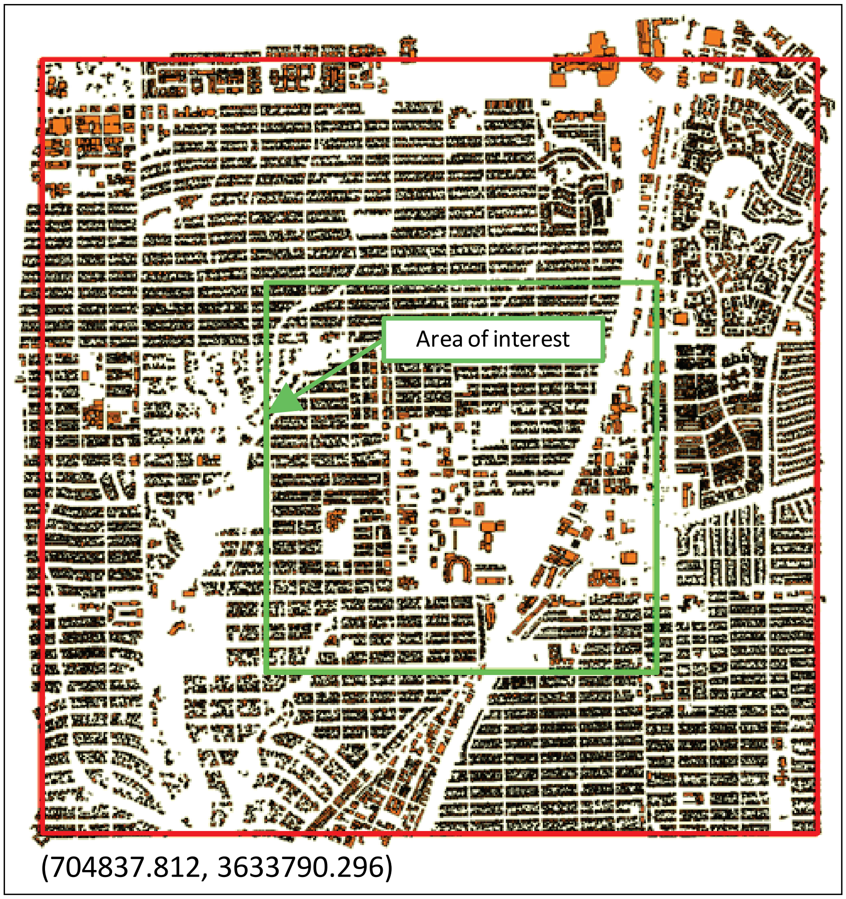


The following sections will provide the processing information necessary to produce these data sets.

3.3.1 Read buildings into Global Mapper

Global Mapper was used to read 2-D building data produced by CyberCity 3D in the ESRI shapefile format. The buildings for the 25 km² area are shown in Figure 3.14 in the red outlined area and are colored orange. The buildings from this larger area may be trimmed to the smaller 6.25 km² area that is outlined in green as detailed in the following section.

Figure 3.14. Buildings for large area (red) and area of interest (green).



Data are read into Global Mapper by opening the specific file using the **File** menu option or dragging the file from Windows Explorer. If the file contains a definition of the projected coordinate system used, Global Mapper will automatically read and display the data. If a projected coordinate system is not found, a dialog box will display asking the user to verify the appropriate projected coordinate system as shown in Figure 3.1.

The user would select the appropriate projected coordinate system that the data set uses and select the **OK** button.

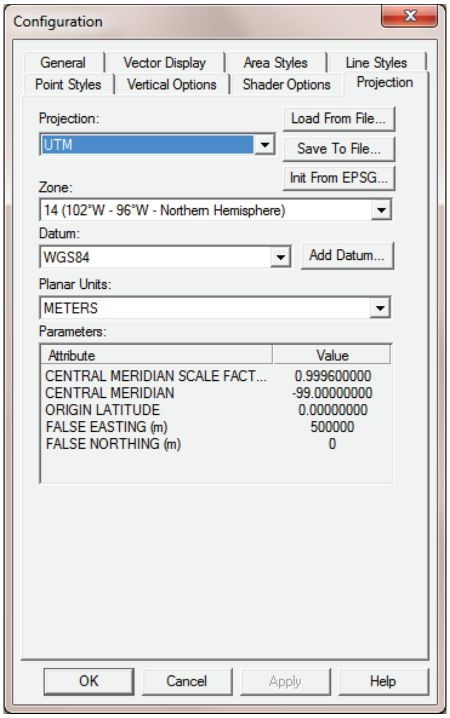
3.3.2 Clip buildings to desired area

The building data must be clipped (or trimmed) to the area used for the analysis. This clipping operation will clip features located on the edges of a specified clip area in order to have edges that correspond with the clip feature. All features inside the clip area will not be affected and all features totally outside of the clip area will be discarded. This produces a set of buildings that exactly fits inside the clip area.

The construction of a clip area is explained in Section 3.2.2. After the clip area is constructed, the steps to clip and save the data in Global Mapper are as follows:

1. Turn on the **Overlay Control Center** by left-clicking the icon shown in Figure 3.5. Select objects to display by left-clicking the object to display a check mark. Turn all layers off except for the building data that is to be clipped. Turn on the clip area as discussed in 3.2.2.
2. If the display projection is not already UTM, it must be changed to UTM. The MATLAB routines can read data in the UTM coordinate system and this makes inputting the buildings easier than using a local coordinate system. From the **Tools** menu option, select the **Configure** option and change the display projection to **UTM** as shown in Figure 3.15 and click **OK**.
3. Select the **Feature Info Tool** as shown in Figure 3.7 and click on the clip feature to select it.
4. Select **File** > **Export** > **Export Vector Format**. From the pop-up box, select Shapefile.
5. A dialog box will appear as shown in Figure 3.16. Click **Export Areas**. A dialog box will pop up in which to type in a file name to save the shapefile. Make sure the **Generate Projection** box is checked.
6. Click on the **Export Bounds** tab shown in Figure 3.17 and click on the **Crop to Selected Area Feature(s)** option. Click **OK**.

Figure 3.15. Changing display projection to UTM.



Projection: UTM

Zone: 14 (102°W - 96°W - Northern Hemisphere)

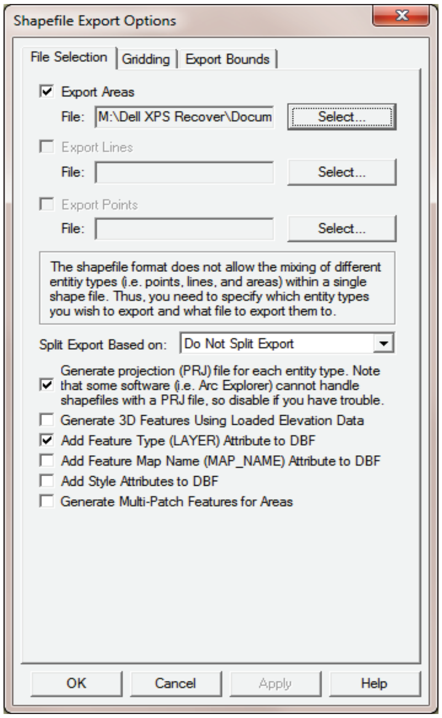
Datum: WGS84

Planar Units: METERS

Parameters:

Attribute	Value
CENTRAL MERIDIAN SCALE FACT...	0.999600000
CENTRAL MERIDIAN	-99.00000000
ORIGIN LATITUDE	0.00000000
FALSE EASTING (m)	500000
FALSE NORTHING (m)	0

Figure 3.16. Dialog to select features for shapefile.



☑ Export Areas

File: M:\Dell XPS Recover\Docum

☐ Export Lines

File:

☐ Export Points

File:

The shapefile format does not allow the mixing of different entitiy types (i.e. points, lines, and areas) within a single shape file. Thus, you need to specify which entity types you wish to export and what file to export them to.

Split Export Based on: Do Not Split Export

☑ Generate projection (PRJ) file for each entity type. Note that some software (i.e. Arc Explorer) cannot handle shapefiles with a PRJ file, so disable if you have trouble.

☐ Generate 3D Features Using Loaded Elevation Data

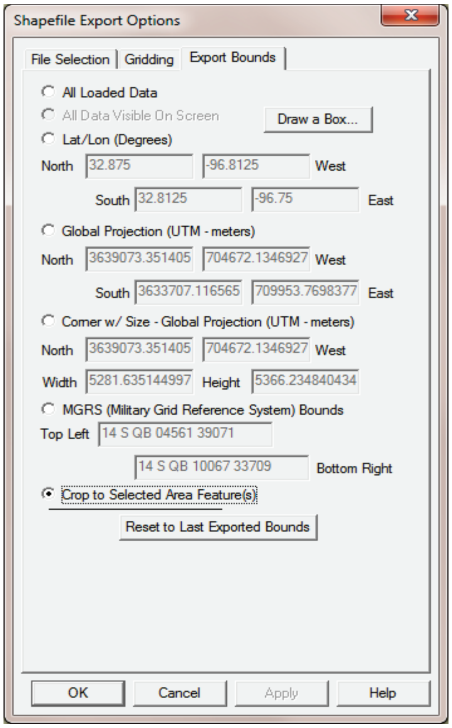
☑ Add Feature Type (LAYER) Attribute to DBF

☐ Add Feature Map Name (MAP_NAME) Attribute to DBF

☐ Add Style Attributes to DBF

☐ Generate Multi-Patch Features for Areas

Figure 3.17. Dialog to select export bounds for shapefile.



○ All Loaded Data

○ All Data Visible On Screen

○ Lat/Lon (Degrees)

North 32.875 -96.8125 West

South 32.8125 -96.75 East

○ Global Projection (UTM - meters)

North 3639073.351405 704672.1346927 West

South 3633707.116565 709953.7698377 East

○ Corner w/ Size - Global Projection (UTM - meters)

North 3639073.351405 704672.1346927 West

Width 5281.635144997 Height 5366.234840434

○ MGRS (Military Grid Reference System) Bounds

Top Left 14 S QB 04561 39071

14 S QB 10067 33709 Bottom Right

● Crop to Selected Area Feature(s)

Reset to Last Exported Bounds

3.3.3 Delete and add custom buildings

Some of the building details have changed since the data set produced for the buildings was constructed from 2009 imagery. Some buildings that were next to U.S. Highway 75 were deleted, and the George W. Bush Presidential Library was added, as shown in Figure 3.18.

To delete features in Global Mapper:

1. Select the building using the **Feature Info** tool (Figure 3.7).
2. Click the **Delete** button.

Figure 3.18. Additional edits to the building data set.

The George W. Bush Presidential Library was added to the building data set using imagery from the USDA NAIP from 2012, as well as images from Google (Figure 3.19) for reference. To add the custom building, perform the following steps in Global Mapper:

1. Turn the imagery layer on using the **Overlay Control Center** as shown in Figure 3.5.
2. Select the **Digitizer Tool** and click the **Create New Area Feature** as shown in Figure 3.20.
3. Click on points to trace the outline of the building as shown in Figure 3.21. Right-click on the last point to end the feature creation.
4. The **Modify Feature Info** dialog box will display as shown in Figure 3.22. Click on **Add**.
5. The **Edit Attribute/Value** dialog will display as shown in Figure 3.23. Enter the attribute **Height** and the value **59**. The value of 59 ft was considered an average height for the entire building from information about heights contained on the internet and inferred from Google Earth. Click on **OK**.

Figure 3.19. Image of Bush Library on Google Earth.

Figure 3.20. Create new area feature.

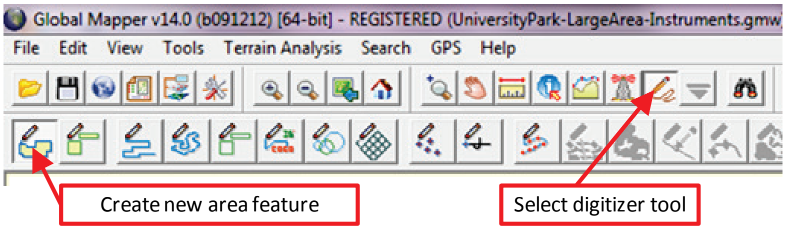


Figure 3.21. Creating new area feature by tracing photo.

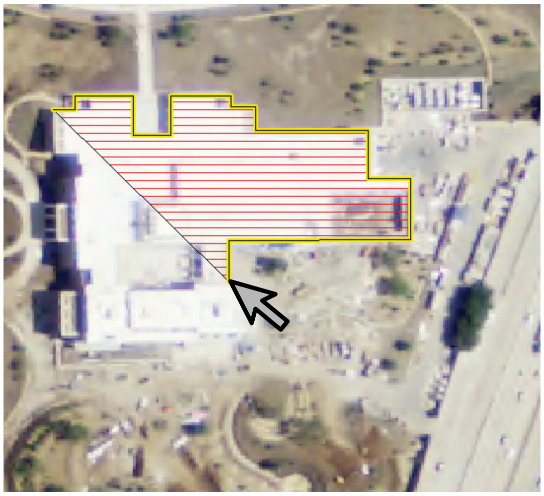
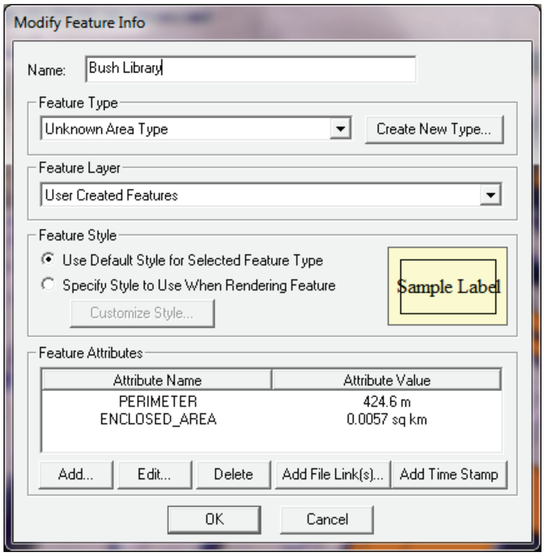


Figure 3.22. Name the added feature.



Name: Bush Library

Feature Type: Unknown Area Type

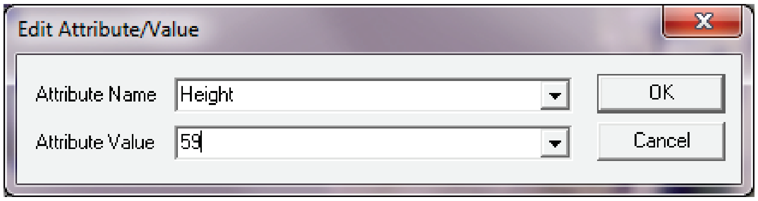
Feature Layer: User Created Features

Feature Style:
● Use Default Style for Selected Feature Type
○ Specify Style to Use When Rendering Feature

Feature Attributes:

Attribute Name	Attribute Value
PERIMETER	424.6 m
ENCLOSED_AREA	0.0057 sq km

Figure 3.23. Add an attribute to feature.



Attribute Name: Height

Attribute Value: 59

3.3.4 Trim data set based on attributes

It was necessary to trim the larger building data set into smaller data sets that satisfied certain criteria. This was done to create data sets that only contained buildings of a certain size (1 m^2) and height (2 m). This was done to remove smaller features such as dormers and ensure that buildings were greater than a specified height. Since the grid spacing of the finite difference grid was approximately 1 m, the buildings needed to be at least 2 m in height to ensure that at least 2 nodes were used to define a building.

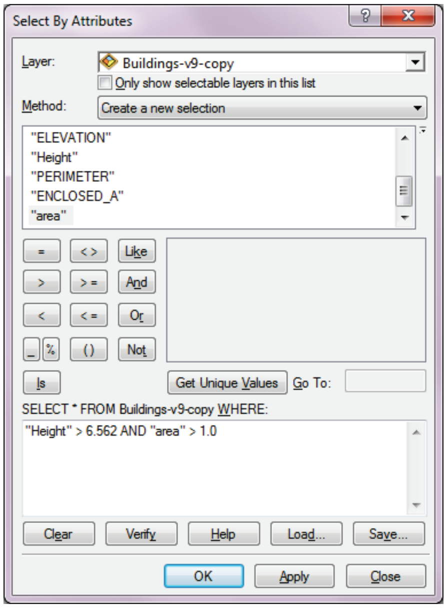
In ArcMap, a new smaller data set satisfying certain user-specified conditions can be created from a larger data set using the following steps:

1. Select **Selection > Select by Attributes** from the main menu. The dialog box shown in Figure 3.24 will appear.
2. Select the **Layer** that is to be used to perform the selection.
3. Select the **Create a new selection** option for the **Method**.

4. Create the selection query by typing the requirements into the text box as shown in Figure 3.24. In this case, all buildings are selected that are greater than $1m^2$ in area and greater than 2 meters (6.562 ft) in height. The height attribute is defined in feet.
5. Press **OK** .
6. Right-click on the layer used for the query as shown in Figure 3.25.
7. Select **Selection** > **Create Layer from Selected Features**.
8. The created layer will appear in the layer's list and can be renamed if desired.

Once a new layer is created, it may also be used to further refine the data. Therefore, the layer created from the above procedure may be further refined to segment the buildings into sets that are less than or equal to 51 ft in height and greater than 51 ft in height. This height was selected as the height that best segmented the buildings into residential and commercial buildings.

Figure 3.24. Select by attributes to create a new layer.



Layer: Buildings-v9-copy

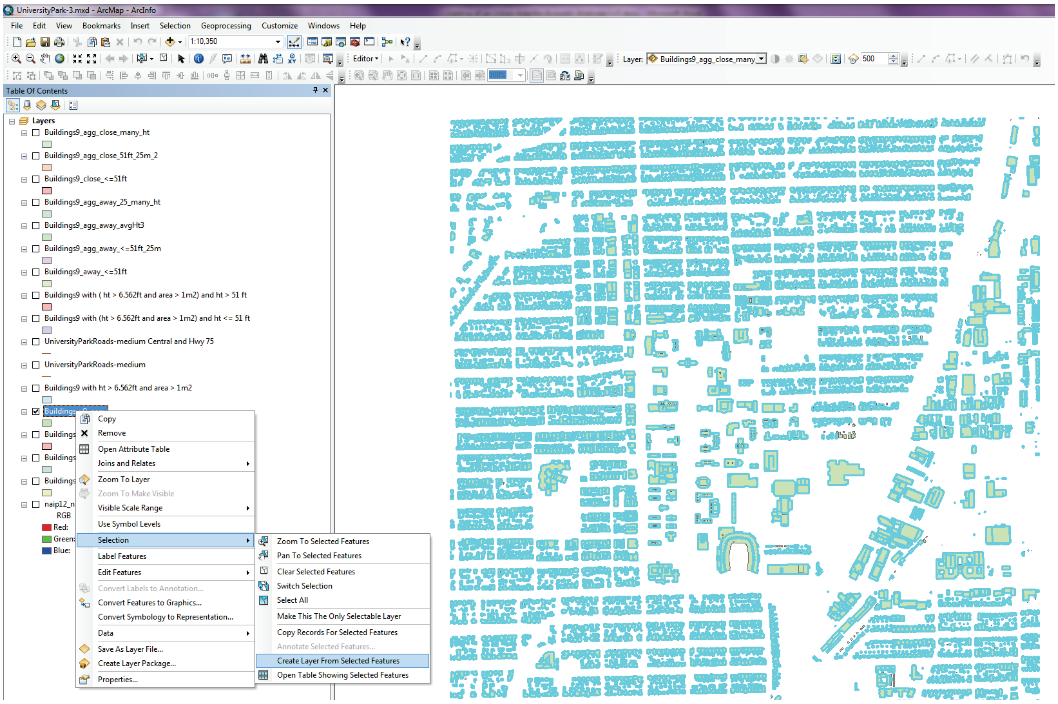
☐ Only show selectable layers in this list

Method: Create a new selection

SELECT * FROM Buildings-v9-copy WHERE:

"Height" > 6.562 AND "area" > 1.0

Figure 3.25. Create a new layer from the selection.

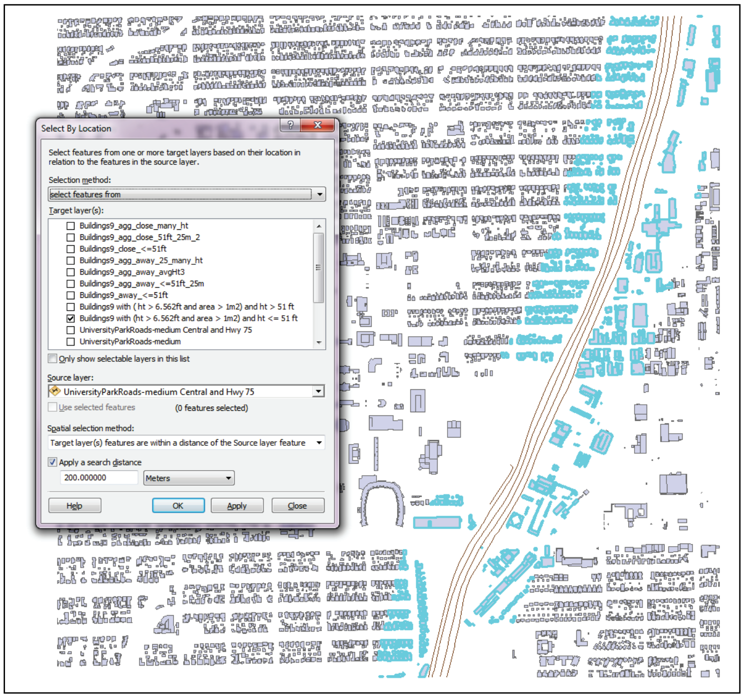


3.3.5 Select features by location

Using ArcMap, data sets were created for buildings that were close to or away from U.S. Highway 75. To create the data set that contains buildings within 200 m of U.S. Highway 75, perform the following steps:

1. Select **Selection** > **Select by Location** from the main menu. The dialog box shown in Figure 3.26 will appear.
2. Select **Select Feature From**.
3. Select the **Target Layer** that is to be used to perform the selection. This is the layer from which the objects are selected.
4. Select the **Source Layer** that is to be used to perform the selection. This is the layer that objects are close to.
5. Select **Target Layer(s) Features are Within a Distance of the Source Layer Feature**.
6. Enter **200** m. Press **OK** or **Apply**.
7. As shown in Figure 3.25, right-click on the layer used for the query and select **Selection** > **Create Layer from Selected Features**.
8. The created layer will appear in the layer's list and can be renamed if desired.

Figure 3.26. Select buildings (cyan color) within 200 m of U.S. Highway 75.



Select By Location

Select features from one or more target layers based on their location in relation to the features in the source layer.

Selection method: select features from

Target layer(s):

☐ Buildings9_agg_close_many_ht
☐ Buildings9_agg_close_51ft_25m_2
☐ Buildings9_close_<=51ft
☐ Buildings9_agg_away_25_many_ht
☐ Buildings9_agg_away_avgHt3
☐ Buildings9_agg_away_<=51ft_25m
☐ Buildings9_away_<=51ft
☐ Buildings9 with (ht > 6.562ft and area > 1m2) and ht > 51 ft
☑ Buildings9 with (ht > 6.562ft and area > 1m2) and ht <= 51 ft
☐ UniversityParkRoads-medium Central and Hwy 75
☐ UniversityParkRoads-medium

☐ Only show selectable layers in this list

Source layer: UniversityParkRoads-medium Central and Hwy 75

☐ Use selected features (0 features selected)

Spatial selection method: Target layer(s) features are within a distance of the Source layer feature

☑ Apply a search distance

200.000000 Meters

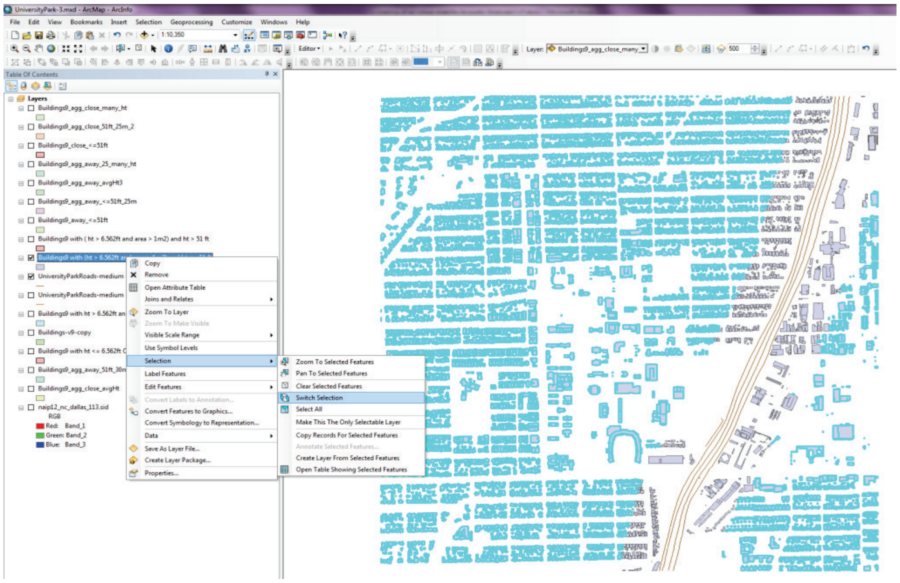
To create the data set that contains buildings greater than 200 m from U.S. Highway 75, perform the following steps:

1. As shown in Figure 3.27, right-click on the layer used for the query and select **Selection** > **Switch Selection**.
2. As shown in Figure 3.25, right-click on the layer used for the query and select **Selection** > **Create Layer from Selected Features**.
3. The created layer will appear in the layer's list and can be renamed if desired.

3.3.6 Create aggregated building sets

The effect of the size of the buildings was investigated by combing buildings within a certain distance (aggregation distance) into a larger building polygon. The aggregation function in ArcMap combined smaller buildings into larger ones while also keeping the orthogonal nature of the building footprints intact. The tools in ArcMap made these computations easier than Global Mapper. The aggregation functions could be performed in Global Mapper by creating buffers, but the ArcMap functions were much quicker and gave better results.

Figure 3.27. Switch selection of buildings (cyan color) to produce buildings away from U.S. Highway 75.



To run the aggregation function in ArcMap, do the following:

1. Select the **Geoprocessing** > **ArcToolbox** option from the main menu.
2. Within the ArcToolbox, select **Cartography Tools** > **Generalization** > **Aggregate Polygons** as shown in Figure 3.28.
3. From the dialog shown in Figure 3.29, select the **Input Features** to use from the drop-down menu.
4. Type in an **Output Feature Class** name.
5. Type in an **Aggregation Distance** of **25** m.
6. Enter a **Minimum Area** of **0**. This will cause the algorithm to use all buildings.
7. Enter a **Minimum Hole Size** of **2500**. This will cause the algorithm to discard all holes below this minimum size. Holes can occur in the larger aggregated polygons based on building proximity.
8. Check the box to **Preserve Orthogonal Shape**. This will cause the algorithm to keep the outside shape of the building footprints when combining.
9. Press **OK**. The buildings will be aggregated as shown in Figures 3.30 and 3.31.

Figure 3.30 shows the individual buildings overlaid upon the aggregated polygons, while Figure 3.31 shows just the aggregated polygons. This building data set was for the buildings located more than 200 m from U.S. Highway 75. The same aggregation procedure can be used with the building data set containing buildings within 200 m of U.S. Highway 75.

Figure 3.28. Aggregate Polygons function inside ArcToolbox.

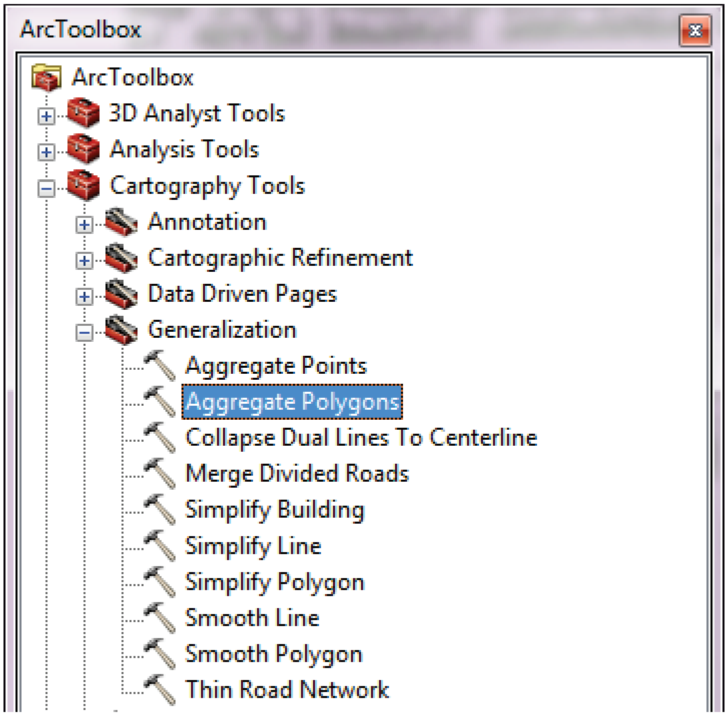
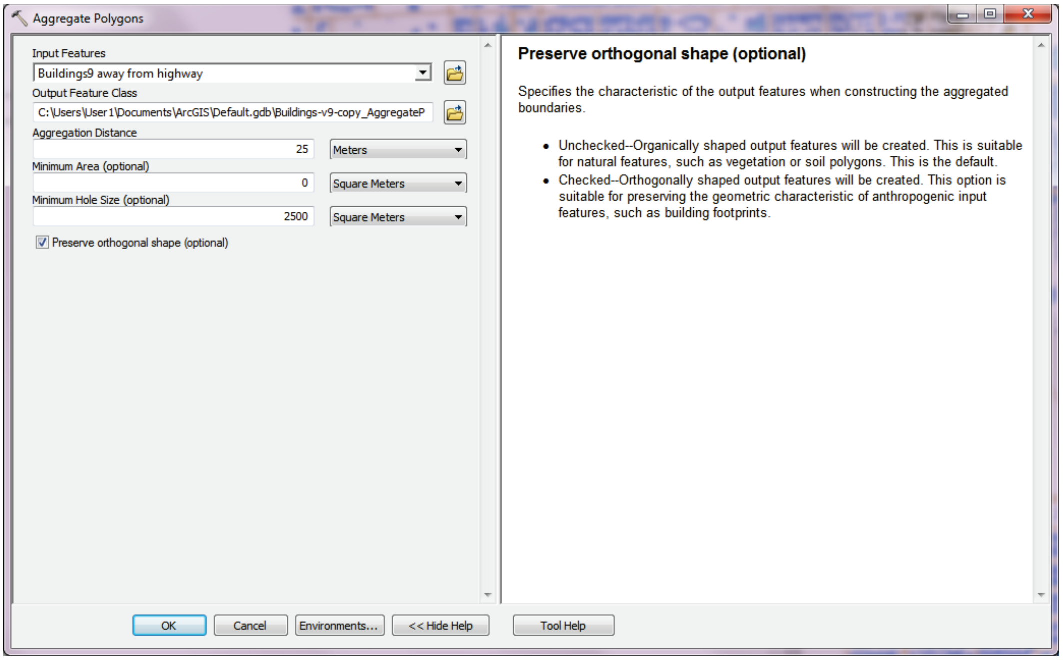


Figure 3.29. Parameters for aggregating buildings.



Input Features: Buildings9 away from highway

Output Feature Class: C:\Users\User1\Documents\ArcGIS\Default.gdb\Buildings-v9-copy_AggregateP

Aggregation Distance: 25 Meters

Minimum Area (optional): 0 Square Meters

Minimum Hole Size (optional): 2500 Square Meters

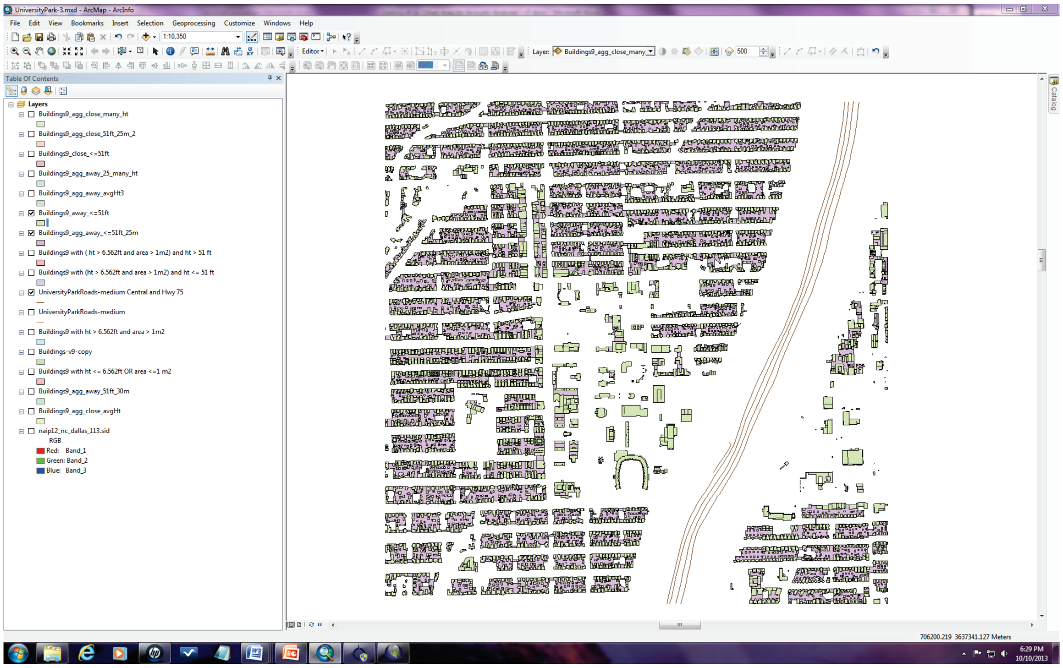
☑ Preserve orthogonal shape (optional)

Preserve orthogonal shape (optional)

Specifies the characteristic of the output features when constructing the aggregated boundaries.

- Unchecked--Organically shaped output features will be created. This is suitable for natural features, such as vegetation or soil polygons. This is the default.
- Checked--Orthogonally shaped output features will be created. This option is suitable for preserving the geometric characteristic of anthropogenic input features, such as building footprints.

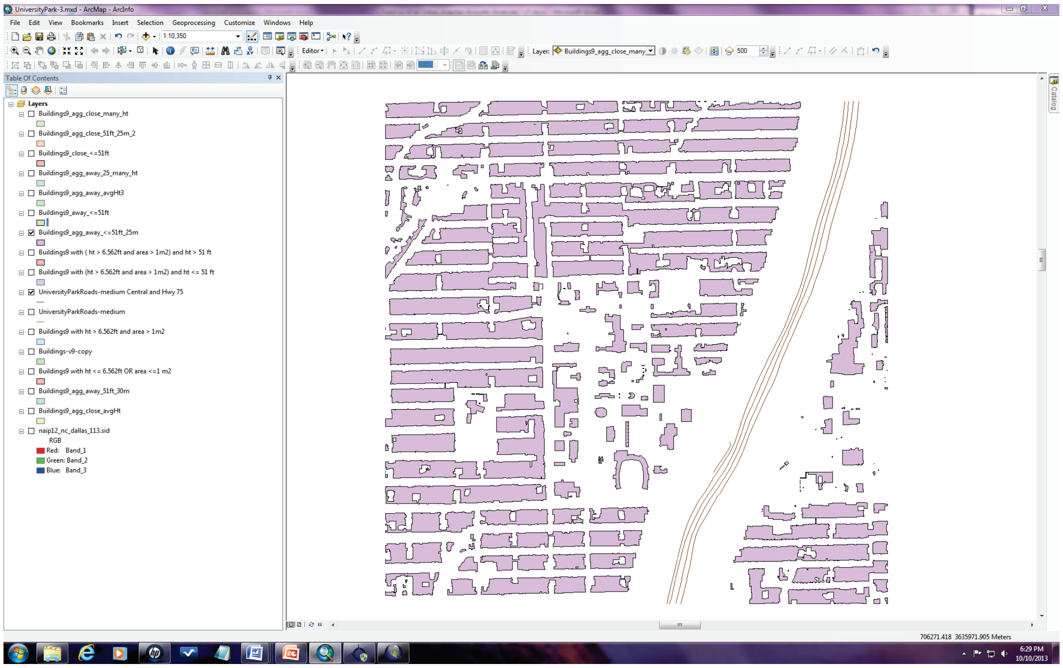
Figure 3.30. Individual (green) and aggregated (purple) buildings located away from U.S. Highway 75.



Layers
- ☐ Buildings9_agg_close_many_ht
- ☐ Buildings9_agg_close_51ft_25m_2
- ☐ Buildings9_close_<=51ft
- ☐ Buildings9_agg_away_25_many_ht
- ☐ Buildings9_agg_away_avgHt3
- ☑ Buildings9_away_<=51ft
- ☑ Buildings9_agg_away_<=51ft_25m
- ☐ Buildings9 with (ht > 6.562ft and area > 1m2) and ht > 51 ft
- ☐ Buildings9 with (ht > 6.562ft and area > 1m2) and ht <= 51 ft
- ☑ UniversityParkRoads-medium Central and Hwy 75
- ☐ UniversityParkRoads-medium
- ☐ Buildings9 with ht > 6.562ft and area > 1m2
- ☐ Buildings-v9-copy
- ☐ Buildings9 with ht <= 6.562ft OR area <=1 m2
- ☐ Buildings9_agg_away_51ft_30m
- ☐ Buildings9_agg_close_avgHt
- ☐ naip12_nc_dallas_113.sid
  - RGB
  - 🟥 Red: Band_1
  - 🟩 Green: Band_2
  - 🟦 Blue: Band_3

706200.219 3637341.127 Meters

Figure 3.31. Aggregated buildings located away from U.S. Highway 75.



Layers
- ☐ Buildings9_agg_close_many_ht
- ☐ Buildings9_agg_close_51ft_25m_2
- ☐ Buildings9_close_<=51ft
- ☐ Buildings9_agg_away_25_many_ht
- ☐ Buildings9_agg_away_avgHt3
- ☐ Buildings9_away_<=51ft
- ☑ Buildings9_agg_away_<=51ft_25m
- ☐ Buildings9 with (ht > 6.562ft and area > 1m2) and ht > 51 ft
- ☐ Buildings9 with (ht > 6.562ft and area > 1m2) and ht <= 51 ft
- ☑ UniversityParkRoads-medium Central and Hwy 75
- ☐ UniversityParkRoads-medium
- ☐ Buildings9 with ht > 6.562ft and area > 1m2
- ☐ Buildings-v9-copy
- ☐ Buildings9 with ht <= 6.562ft OR area <=1 m2
- ☐ Buildings9_agg_away_51ft_30m
- ☐ Buildings9_agg_close_avgHt
- ☐ naip12_nc_dallas_113.sid
  - RGB
  - 🟥 Red: Band_1
  - 🟩 Green: Band_2
  - 🟦 Blue: Band_3

706271.418 3635971.905 Meters

3.3.7 Compute weighted averages of heights of aggregated buildings

Once aggregated building data sets were constructed, an appropriate height attribute still needed to be assigned to the aggregated polygons. A weighted average of the height was computed for each aggregated polygon using Equation 3.1:

$$HtWtAvg = \frac{\Sigma(A \times Ht)}{\Sigma A} \tag{3.1}$$

where

HtWtAvg= weighted average of heights for buildings within aggregated polygon
A = area of individual building within aggregated polygon
Ht = height of individual building within aggregated polygon

To compute the weighted average of the height of each aggregated polygon:

1. Select the **Geoprocessing > ArcToolbox** option from the main menu.
2. Within the ArcToolbox, select **Analysis Tools > Overlay > Spatial Join** as shown in Figure 3.32.
    a. From the dialog shown in Figure 3.33, select the **Target Features** to use from the drop-down menu.
    b. Select the **Join Features** from the drop-down menu.
    c. Enter the **Output Feature Class** to save the query to.
    d. Select JOIN_ONE_TO_MANY for the Join Operation.
    e. Select CONTAINS for the Match Option.
    f. Press **OK**.
3. Right-click the new layer created and select **Open Attribute Table**. The table is shown in Figure 3.34. The data set now contains each individual building with its corresponding area and height grouped by the TARGET_FID which defines the aggregated polygon for the individual buildings.
4. Click the left icon (**Table Options**) on the menu of the **Attribute Table** and select **Add Field**. This will be used to compute the area times the height of each building. The dialog in Figure 3.35 will display.
    a. Enter **AxHt** for the name of the field.

  b. Select **Float** for the **Type** of field.
  c. Set the field properties as shown in Figure 3.35.
  d. Press **OK**. The field is added to the table attributes and is initially assigned a <Null> value.

5. Right-click the newly created field and select **Field Calculator** as shown in Figure 3.36. The Field Calculator will display as shown in Figure 3.37.

    a. Select **VB Script**.
    b. Click **area** in the Fields box.
    c. Click the **multiplication button**.
    d. Click **Height** in the Fields box.
    e. Click **OK**. This will compute the formula entered and fill in the values for the field AxHt as shown in Figure 3.38.

6. A summary table must be computed to sum the areas and the areas times the heights for every building in an aggregated polygon. In the **Attribute Table**, right-click the **TARGET_FID** field and select **Summarize**. The **Summarize** dialog will display as shown in Figure 3.39.

    a. Select **TARGET_FID** from the **Select a field to summarize**.
    b. Check the **Sum** box for both the area and the height as shown in Figure 3.39.
    c. Under **Specify output table**, enter a name for the summary.
    d. Click **OK**.

7. The summary table computed must be joined with the table containing the aggregated buildings. Right-click the layer containing the aggregated buildings in the Table of Contents.
8. Select **Joins and Relates > Joins**. The Join Data dialog shown in Figure 3.40 will display.

    a. Select **Join attributes from a table**.
    b. Select **OBJECTID** for the field the join will be based on.
    c. Choose the summary table previously computed in Step 6 as the join layer.
    d. Select **OBJECTID** as the field to base the join on.
    e. Select **Keep all records**.
    f. Press **OK**. The attribute table shown in Figure 3.41 will be created. In this table, the sum of the areas and the sum of the areas times the heights has been created for each aggregated polygon. For each TARGET_FID in the table

there is a FREQUENCY attribute that tells how many buildings are in the aggregated polygon.

9. In the attribute table for the aggregated polygons, a field must be added to compute the weighted average of the heights.
    a. Add a field to the table as described in Step 4 and name it **WtAvgHt** as shown in Figure 3.42.
    b. Fill in the rest of the values shown in Figure 3.42 and click **OK**.
10. Use the field calculator on the new field as described in Step 5. Fill in the values shown in Figure 3.43.
11. The results of the field calculator showing the weighted averages of the heights for the individual buildings contained in an aggregated polygon are shown in Figure 3.44.
12. Save the building data to a shapefile as described in Section 3.3.9.

Figure 3.32. Spatial Join function in ArcToolbox.

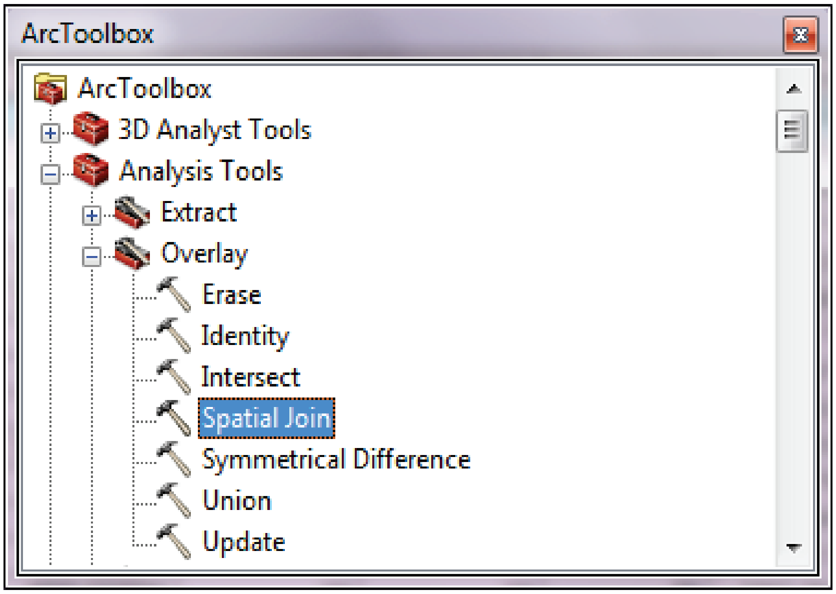
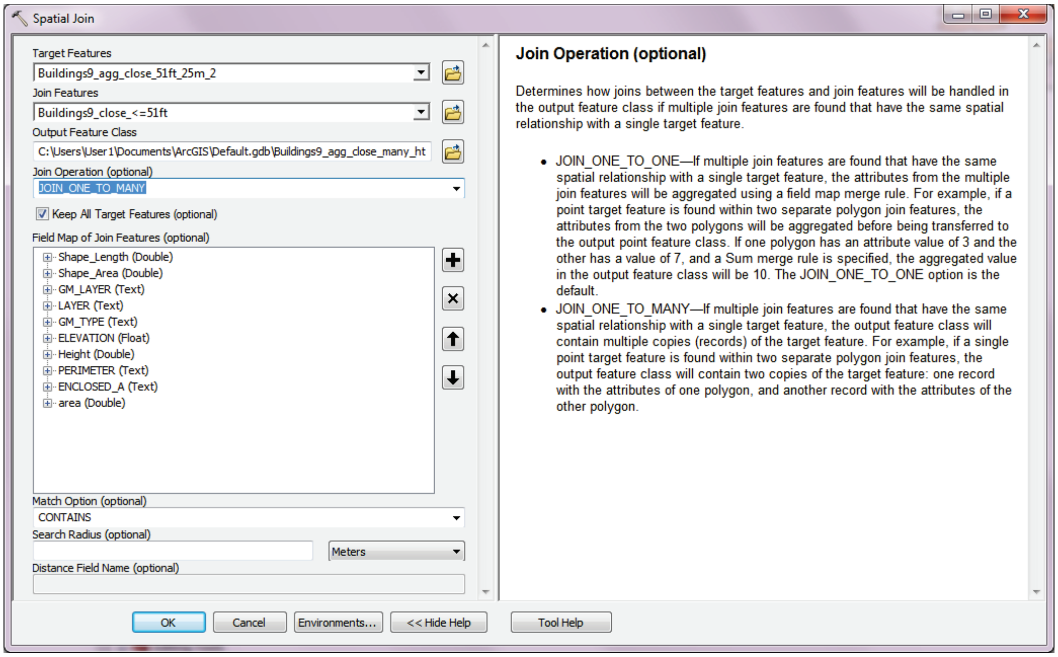


Figure 3.33. Use a spatial join to make a data set containing building height information grouped by aggregated polygon.



Spatial Join

Target Features: Buildings9_agg_close_51ft_25m_2

Join Features: Buildings9_close_<=51ft

Output Feature Class: C:\Users\User1\Documents\ArcGIS\Default.gdb\Buildings9_agg_close_many_ht

Join Operation (optional): JOIN_ONE_TO_MANY

☑ Keep All Target Features (optional)

Field Map of Join Features (optional)

- Shape_Length (Double)
- Shape_Area (Double)
- GM_LAYER (Text)
- LAYER (Text)
- GM_TYPE (Text)
- ELEVATION (Float)
- Height (Double)
- PERIMETER (Text)
- ENCLOSED_A (Text)
- area (Double)

Match Option (optional): CONTAINS

Search Radius (optional): Meters

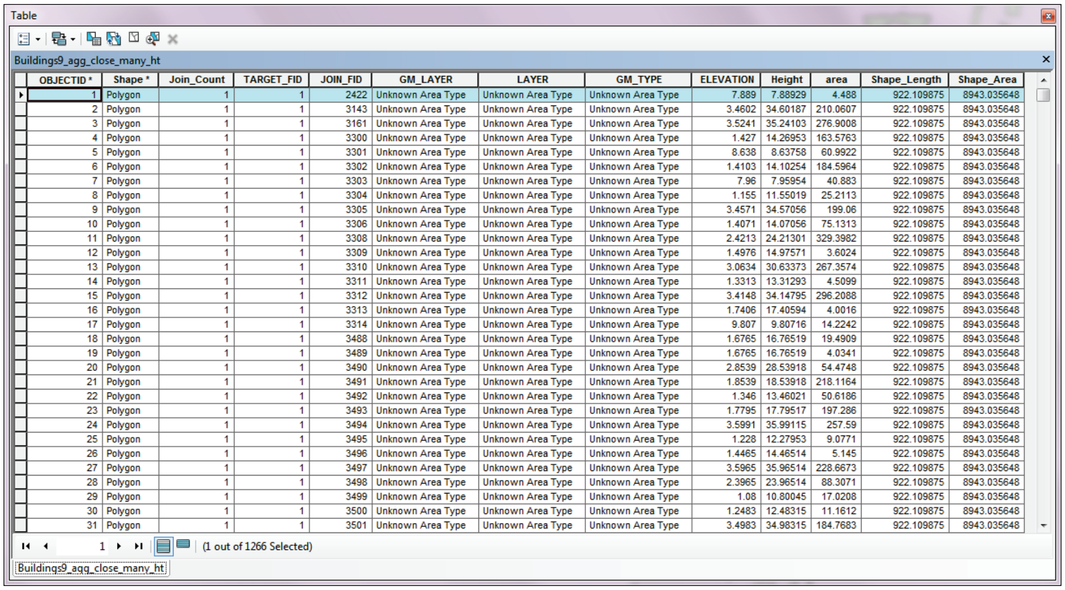
Distance Field Name (optional)

Join Operation (optional)

Determines how joins between the target features and join features will be handled in the output feature class if multiple join features are found that have the same spatial relationship with a single target feature.

- JOIN_ONE_TO_ONE—If multiple join features are found that have the same spatial relationship with a single target feature, the attributes from the multiple join features will be aggregated using a field map merge rule. For example, if a point target feature is found within two separate polygon join features, the attributes from the two polygons will be aggregated before being transferred to the output point feature class. If one polygon has an attribute value of 3 and the other has a value of 7, and a Sum merge rule is specified, the aggregated value in the output feature class will be 10. The JOIN_ONE_TO_ONE option is the default.
- JOIN_ONE_TO_MANY—If multiple join features are found that have the same spatial relationship with a single target feature, the output feature class will contain multiple copies (records) of the target feature. For example, if a single point target feature is found within two separate polygon join features, the output feature class will contain two copies of the target feature: one record with the attributes of one polygon, and another record with the attributes of the other polygon.

Figure 3.34. Result of spatial join showing heights and areas of buildings grouped by aggregated polygon.

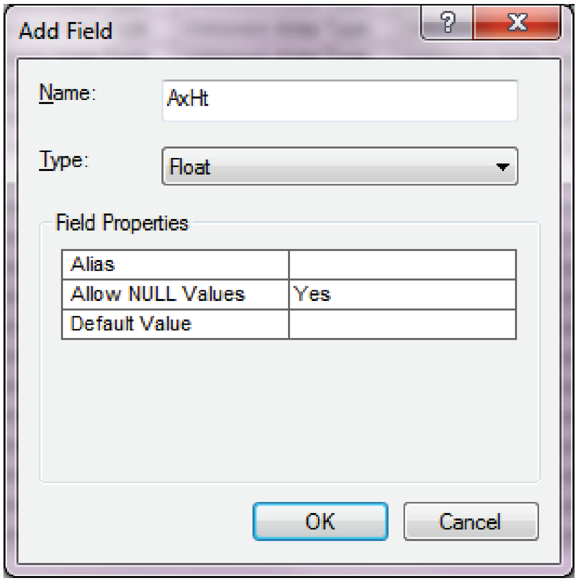


Table

Buildings9_agg_close_many_ht

OBJECTID *	Shape *	Join_Count	TARGET_FID	JOIN_FID	GM_LAYER	LAYER	GM_TYPE	ELEVATION	Height	area	Shape_Length	Shape_Area
1	Polygon	1	1	2422	Unknown Area Type	Unknown Area Type	Unknown Area Type	7.889	7.88929	4.488	922.109875	8943.035648
2	Polygon	1	1	3143	Unknown Area Type	Unknown Area Type	Unknown Area Type	3.4602	34.60187	210.0607	922.109875	8943.035648
3	Polygon	1	1	3161	Unknown Area Type	Unknown Area Type	Unknown Area Type	3.5241	35.24103	276.9008	922.109875	8943.035648
4	Polygon	1	1	3300	Unknown Area Type	Unknown Area Type	Unknown Area Type	1.427	14.26953	163.5763	922.109875	8943.035648
5	Polygon	1	1	3301	Unknown Area Type	Unknown Area Type	Unknown Area Type	8.638	8.63758	60.9922	922.109875	8943.035648
6	Polygon	1	1	3302	Unknown Area Type	Unknown Area Type	Unknown Area Type	1.4103	14.10254	184.5964	922.109875	8943.035648
7	Polygon	1	1	3303	Unknown Area Type	Unknown Area Type	Unknown Area Type	7.96	7.95954	40.883	922.109875	8943.035648
8	Polygon	1	1	3304	Unknown Area Type	Unknown Area Type	Unknown Area Type	1.155	11.55019	25.2113	922.109875	8943.035648
9	Polygon	1	1	3305	Unknown Area Type	Unknown Area Type	Unknown Area Type	3.4571	34.57056	199.06	922.109875	8943.035648
10	Polygon	1	1	3306	Unknown Area Type	Unknown Area Type	Unknown Area Type	1.4071	14.07056	75.1313	922.109875	8943.035648
11	Polygon	1	1	3308	Unknown Area Type	Unknown Area Type	Unknown Area Type	2.4213	24.21301	329.3982	922.109875	8943.035648
12	Polygon	1	1	3309	Unknown Area Type	Unknown Area Type	Unknown Area Type	1.4976	14.97571	3.6024	922.109875	8943.035648
13	Polygon	1	1	3310	Unknown Area Type	Unknown Area Type	Unknown Area Type	3.0634	30.63373	267.3574	922.109875	8943.035648
14	Polygon	1	1	3311	Unknown Area Type	Unknown Area Type	Unknown Area Type	1.3313	13.31293	4.5099	922.109875	8943.035648
15	Polygon	1	1	3312	Unknown Area Type	Unknown Area Type	Unknown Area Type	3.4148	34.14795	296.2088	922.109875	8943.035648
16	Polygon	1	1	3313	Unknown Area Type	Unknown Area Type	Unknown Area Type	1.7406	17.40594	4.0016	922.109875	8943.035648
17	Polygon	1	1	3314	Unknown Area Type	Unknown Area Type	Unknown Area Type	9.807	9.80716	14.2242	922.109875	8943.035648
18	Polygon	1	1	3488	Unknown Area Type	Unknown Area Type	Unknown Area Type	1.6765	16.76519	19.4909	922.109875	8943.035648
19	Polygon	1	1	3489	Unknown Area Type	Unknown Area Type	Unknown Area Type	1.6765	16.76519	4.0341	922.109875	8943.035648
20	Polygon	1	1	3490	Unknown Area Type	Unknown Area Type	Unknown Area Type	2.8539	28.53918	54.4748	922.109875	8943.035648
21	Polygon	1	1	3491	Unknown Area Type	Unknown Area Type	Unknown Area Type	1.8539	18.53918	218.1164	922.109875	8943.035648
22	Polygon	1	1	3492	Unknown Area Type	Unknown Area Type	Unknown Area Type	1.346	13.46021	50.6186	922.109875	8943.035648
23	Polygon	1	1	3493	Unknown Area Type	Unknown Area Type	Unknown Area Type	1.7795	17.79517	197.286	922.109875	8943.035648
24	Polygon	1	1	3494	Unknown Area Type	Unknown Area Type	Unknown Area Type	3.5991	35.99115	257.59	922.109875	8943.035648
25	Polygon	1	1	3495	Unknown Area Type	Unknown Area Type	Unknown Area Type	1.228	12.27953	9.0771	922.109875	8943.035648
26	Polygon	1	1	3496	Unknown Area Type	Unknown Area Type	Unknown Area Type	1.4465	14.46514	5.145	922.109875	8943.035648
27	Polygon	1	1	3497	Unknown Area Type	Unknown Area Type	Unknown Area Type	3.5965	35.96514	228.6673	922.109875	8943.035648
28	Polygon	1	1	3498	Unknown Area Type	Unknown Area Type	Unknown Area Type	2.3965	23.96514	88.3071	922.109875	8943.035648
29	Polygon	1	1	3499	Unknown Area Type	Unknown Area Type	Unknown Area Type	1.08	10.80045	17.0208	922.109875	8943.035648
30	Polygon	1	1	3500	Unknown Area Type	Unknown Area Type	Unknown Area Type	1.2483	12.48315	11.1612	922.109875	8943.035648
31	Polygon	1	1	3501	Unknown Area Type	Unknown Area Type	Unknown Area Type	3.4983	34.98315	184.7683	922.109875	8943.035648

Figure 3.35. Add field dialog.



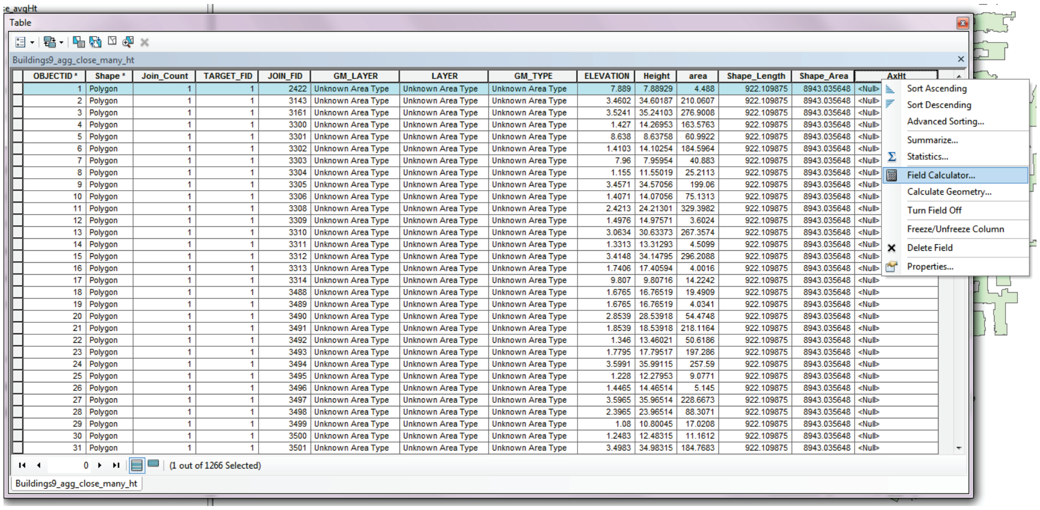
Name: AxHt

Type: Float

Field Properties

Alias	
Allow NULL Values	Yes
Default Value	

Figure 3.36. Selection of the field calculator.



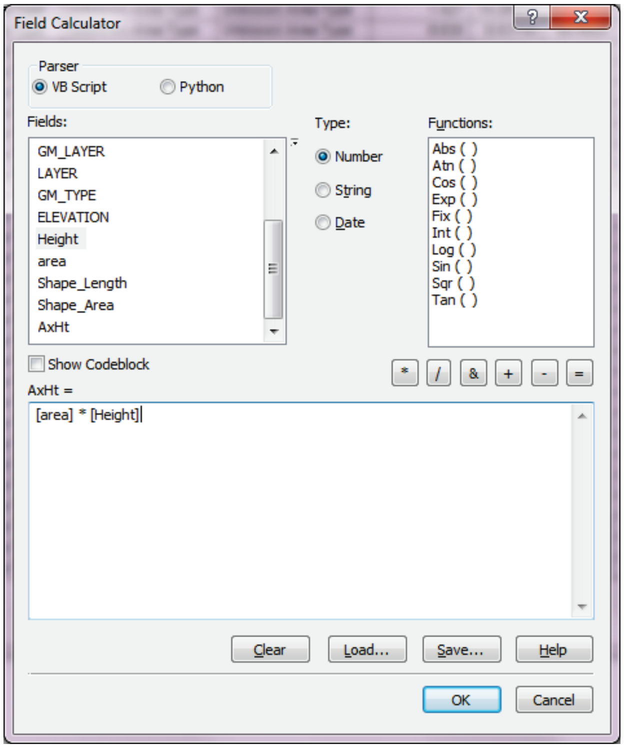
Buildings9_agg_close_many_ht

OBJECTID *	Shape *	Join_Count	TARGET_FID	JOIN_FID	GM_LAYER	LAYER	GM_TYPE	ELEVATION	Height	area	Shape_Length	Shape_Area	AxHt
1	Polygon	1	1	2422	Unknown Area Type	Unknown Area Type	Unknown Area Type	7.889	7.88929	4.488	922.109875	8943.035648	<Null>
2	Polygon	1	1	3143	Unknown Area Type	Unknown Area Type	Unknown Area Type	3.4602	34.60187	210.0607	922.109875	8943.035648	<Null>
3	Polygon	1	1	3161	Unknown Area Type	Unknown Area Type	Unknown Area Type	3.5241	35.24103	276.9008	922.109875	8943.035648	<Null>
4	Polygon	1	1	3300	Unknown Area Type	Unknown Area Type	Unknown Area Type	1.427	14.26953	163.5763	922.109875	8943.035648	<Null>
5	Polygon	1	1	3301	Unknown Area Type	Unknown Area Type	Unknown Area Type	8.638	8.63758	60.9922	922.109875	8943.035648	<Null>
6	Polygon	1	1	3302	Unknown Area Type	Unknown Area Type	Unknown Area Type	1.4103	14.10254	184.5964	922.109875	8943.035648	<Null>
7	Polygon	1	1	3303	Unknown Area Type	Unknown Area Type	Unknown Area Type	7.96	7.95954	40.883	922.109875	8943.035648	<Null>
8	Polygon	1	1	3304	Unknown Area Type	Unknown Area Type	Unknown Area Type	1.155	11.55019	25.2113	922.109875	8943.035648	<Null>
9	Polygon	1	1	3305	Unknown Area Type	Unknown Area Type	Unknown Area Type	3.4571	34.57056	199.06	922.109875	8943.035648	<Null>
10	Polygon	1	1	3306	Unknown Area Type	Unknown Area Type	Unknown Area Type	1.4071	14.07056	75.1313	922.109875	8943.035648	<Null>
11	Polygon	1	1	3308	Unknown Area Type	Unknown Area Type	Unknown Area Type	2.4213	24.21301	329.3982	922.109875	8943.035648	<Null>
12	Polygon	1	1	3309	Unknown Area Type	Unknown Area Type	Unknown Area Type	1.4976	14.97571	3.6024	922.109875	8943.035648	<Null>
13	Polygon	1	1	3310	Unknown Area Type	Unknown Area Type	Unknown Area Type	3.0634	30.63373	267.3574	922.109875	8943.035648	<Null>
14	Polygon	1	1	3311	Unknown Area Type	Unknown Area Type	Unknown Area Type	1.3313	13.31293	4.5099	922.109875	8943.035648	<Null>
15	Polygon	1	1	3312	Unknown Area Type	Unknown Area Type	Unknown Area Type	3.4148	34.14795	296.2088	922.109875	8943.035648	<Null>
16	Polygon	1	1	3313	Unknown Area Type	Unknown Area Type	Unknown Area Type	1.7406	17.40594	4.0016	922.109875	8943.035648	<Null>
17	Polygon	1	1	3314	Unknown Area Type	Unknown Area Type	Unknown Area Type	9.807	9.80716	14.2242	922.109875	8943.035648	<Null>
18	Polygon	1	1	3488	Unknown Area Type	Unknown Area Type	Unknown Area Type	1.6765	16.76519	19.4909	922.109875	8943.035648	<Null>
19	Polygon	1	1	3489	Unknown Area Type	Unknown Area Type	Unknown Area Type	1.6765	16.76519	4.0341	922.109875	8943.035648	<Null>
20	Polygon	1	1	3490	Unknown Area Type	Unknown Area Type	Unknown Area Type	2.8539	28.53918	54.4748	922.109875	8943.035648	<Null>
21	Polygon	1	1	3491	Unknown Area Type	Unknown Area Type	Unknown Area Type	1.8539	18.53918	218.1164	922.109875	8943.035648	<Null>
22	Polygon	1	1	3492	Unknown Area Type	Unknown Area Type	Unknown Area Type	1.346	13.46021	50.6186	922.109875	8943.035648	<Null>
23	Polygon	1	1	3493	Unknown Area Type	Unknown Area Type	Unknown Area Type	1.7795	17.79517	197.286	922.109875	8943.035648	<Null>
24	Polygon	1	1	3494	Unknown Area Type	Unknown Area Type	Unknown Area Type	3.5991	35.99115	257.59	922.109875	8943.035648	<Null>
25	Polygon	1	1	3495	Unknown Area Type	Unknown Area Type	Unknown Area Type	1.228	12.27953	9.0771	922.109875	8943.035648	<Null>
26	Polygon	1	1	3496	Unknown Area Type	Unknown Area Type	Unknown Area Type	1.4465	14.46514	5.145	922.109875	8943.035648	<Null>
27	Polygon	1	1	3497	Unknown Area Type	Unknown Area Type	Unknown Area Type	3.5965	35.96514	228.6673	922.109875	8943.035648	<Null>
28	Polygon	1	1	3498	Unknown Area Type	Unknown Area Type	Unknown Area Type	2.3965	23.96514	88.3071	922.109875	8943.035648	<Null>
29	Polygon	1	1	3499	Unknown Area Type	Unknown Area Type	Unknown Area Type	1.08	10.80045	17.0208	922.109875	8943.035648	<Null>
30	Polygon	1	1	3500	Unknown Area Type	Unknown Area Type	Unknown Area Type	1.2483	12.48315	11.1612	922.109875	8943.035648	<Null>
31	Polygon	1	1	3501	Unknown Area Type	Unknown Area Type	Unknown Area Type	3.4983	34.98315	184.7683	922.109875	8943.035648	<Null>

0 (1 out of 1266 Selected)

Buildings9_agg_close_many_ht

Figure 3.37. Field calculator to compute area times height for each building.



Parser
● VB Script ○ Python

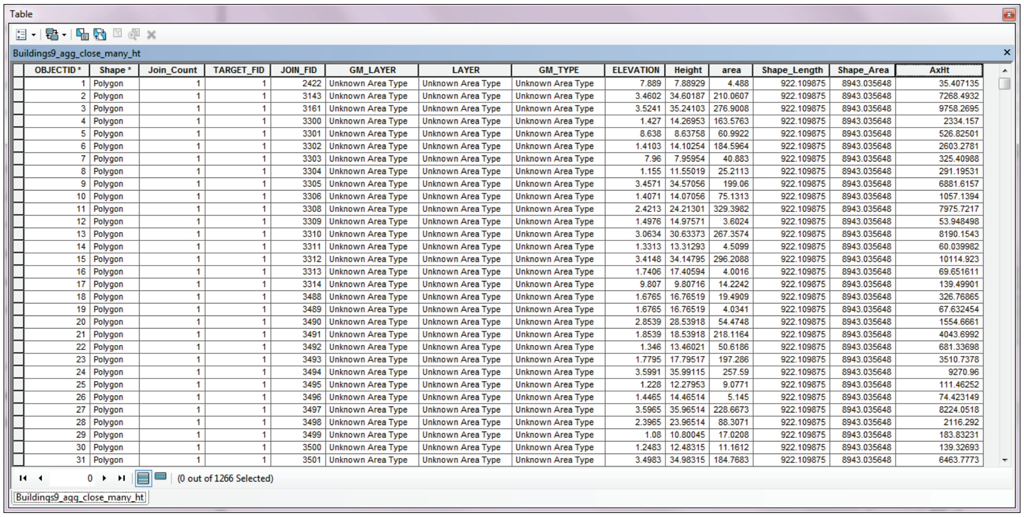
Type:
● Number
○ String
○ Date

☐ Show Codeblock

AxHt =

```
[area] * [Height]
```

Figure 3.38. Result of calculations using field calculator.

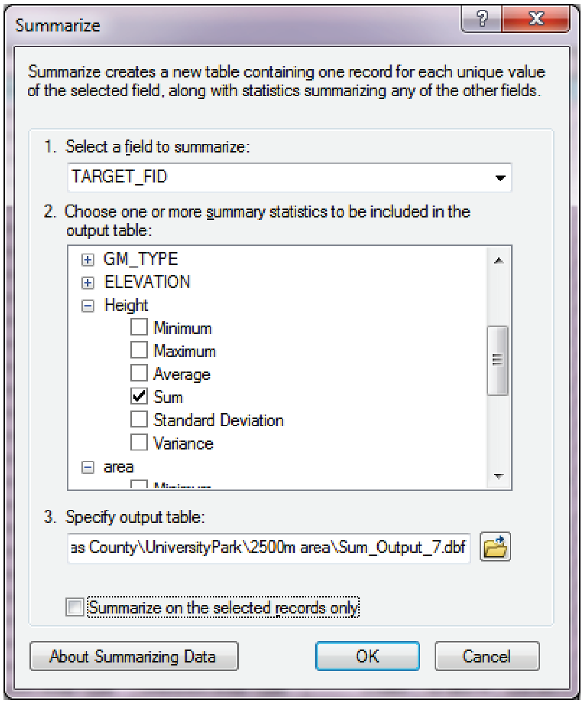


OBJECTID *	Shape *	Join_Count	TARGET_FID	JOIN_FID	GM_LAYER	LAYER	GM_TYPE	ELEVATION	Height	area	Shape_Length	Shape_Area	AxHt
1	Polygon	1	1	2422	Unknown Area Type	Unknown Area Type	Unknown Area Type	7.889	7.88929	4.488	922.109875	8943.035648	35.407135
2	Polygon	1	1	3143	Unknown Area Type	Unknown Area Type	Unknown Area Type	3.4602	34.60187	210.0607	922.109875	8943.035648	7268.4932
3	Polygon	1	1	3161	Unknown Area Type	Unknown Area Type	Unknown Area Type	3.5241	35.24103	276.9008	922.109875	8943.035648	9758.2695
4	Polygon	1	1	3300	Unknown Area Type	Unknown Area Type	Unknown Area Type	1.427	14.26953	163.5763	922.109875	8943.035648	2334.157
5	Polygon	1	1	3301	Unknown Area Type	Unknown Area Type	Unknown Area Type	8.638	8.63758	60.9922	922.109875	8943.035648	526.82501
6	Polygon	1	1	3302	Unknown Area Type	Unknown Area Type	Unknown Area Type	1.4103	14.10254	184.5964	922.109875	8943.035648	2603.2781
7	Polygon	1	1	3303	Unknown Area Type	Unknown Area Type	Unknown Area Type	7.96	7.95954	40.883	922.109875	8943.035648	325.40988
8	Polygon	1	1	3304	Unknown Area Type	Unknown Area Type	Unknown Area Type	1.155	11.55019	25.2113	922.109875	8943.035648	291.19531
9	Polygon	1	1	3305	Unknown Area Type	Unknown Area Type	Unknown Area Type	3.4571	34.57056	199.06	922.109875	8943.035648	6881.6157
10	Polygon	1	1	3306	Unknown Area Type	Unknown Area Type	Unknown Area Type	1.4071	14.07056	75.1313	922.109875	8943.035648	1057.1394
11	Polygon	1	1	3308	Unknown Area Type	Unknown Area Type	Unknown Area Type	2.4213	24.21301	329.3982	922.109875	8943.035648	7975.7217
12	Polygon	1	1	3309	Unknown Area Type	Unknown Area Type	Unknown Area Type	1.4976	14.97571	3.6024	922.109875	8943.035648	53.948498
13	Polygon	1	1	3310	Unknown Area Type	Unknown Area Type	Unknown Area Type	3.0634	30.63373	267.3574	922.109875	8943.035648	8190.1543
14	Polygon	1	1	3311	Unknown Area Type	Unknown Area Type	Unknown Area Type	1.3313	13.31293	4.5099	922.109875	8943.035648	60.039982
15	Polygon	1	1	3312	Unknown Area Type	Unknown Area Type	Unknown Area Type	3.4148	34.14795	296.2088	922.109875	8943.035648	10114.923
16	Polygon	1	1	3313	Unknown Area Type	Unknown Area Type	Unknown Area Type	1.7406	17.40594	4.0016	922.109875	8943.035648	69.651611
17	Polygon	1	1	3314	Unknown Area Type	Unknown Area Type	Unknown Area Type	9.807	9.80716	14.2242	922.109875	8943.035648	139.49901
18	Polygon	1	1	3488	Unknown Area Type	Unknown Area Type	Unknown Area Type	1.6765	16.76519	19.4909	922.109875	8943.035648	326.76865
19	Polygon	1	1	3489	Unknown Area Type	Unknown Area Type	Unknown Area Type	1.6765	16.76519	4.0341	922.109875	8943.035648	67.632454
20	Polygon	1	1	3490	Unknown Area Type	Unknown Area Type	Unknown Area Type	2.8539	28.53918	54.4748	922.109875	8943.035648	1554.6661
21	Polygon	1	1	3491	Unknown Area Type	Unknown Area Type	Unknown Area Type	1.8539	18.53918	218.1164	922.109875	8943.035648	4043.6992
22	Polygon	1	1	3492	Unknown Area Type	Unknown Area Type	Unknown Area Type	1.346	13.46021	50.6186	922.109875	8943.035648	681.33698
23	Polygon	1	1	3493	Unknown Area Type	Unknown Area Type	Unknown Area Type	1.7795	17.79517	197.286	922.109875	8943.035648	3510.7378
24	Polygon	1	1	3494	Unknown Area Type	Unknown Area Type	Unknown Area Type	3.5991	35.99115	257.59	922.109875	8943.035648	9270.96
25	Polygon	1	1	3495	Unknown Area Type	Unknown Area Type	Unknown Area Type	1.228	12.27953	9.0771	922.109875	8943.035648	111.46252
26	Polygon	1	1	3496	Unknown Area Type	Unknown Area Type	Unknown Area Type	1.4465	14.46514	5.145	922.109875	8943.035648	74.423149
27	Polygon	1	1	3497	Unknown Area Type	Unknown Area Type	Unknown Area Type	3.5965	35.96514	228.6673	922.109875	8943.035648	8224.0518
28	Polygon	1	1	3498	Unknown Area Type	Unknown Area Type	Unknown Area Type	2.3965	23.96514	88.3071	922.109875	8943.035648	2116.292
29	Polygon	1	1	3499	Unknown Area Type	Unknown Area Type	Unknown Area Type	1.08	10.80045	17.0208	922.109875	8943.035648	183.83231
30	Polygon	1	1	3500	Unknown Area Type	Unknown Area Type	Unknown Area Type	1.2483	12.48315	11.1612	922.109875	8943.035648	139.32693
31	Polygon	1	1	3501	Unknown Area Type	Unknown Area Type	Unknown Area Type	3.4983	34.98315	184.7683	922.109875	8943.035648	6463.7773

0 (0 out of 1266 Selected)

Buildings9_agg_close_many_ht

Figure 3.39. Summarize data for a field to create a new table.



Summarize

Summarize creates a new table containing one record for each unique value of the selected field, along with statistics summarizing any of the other fields.

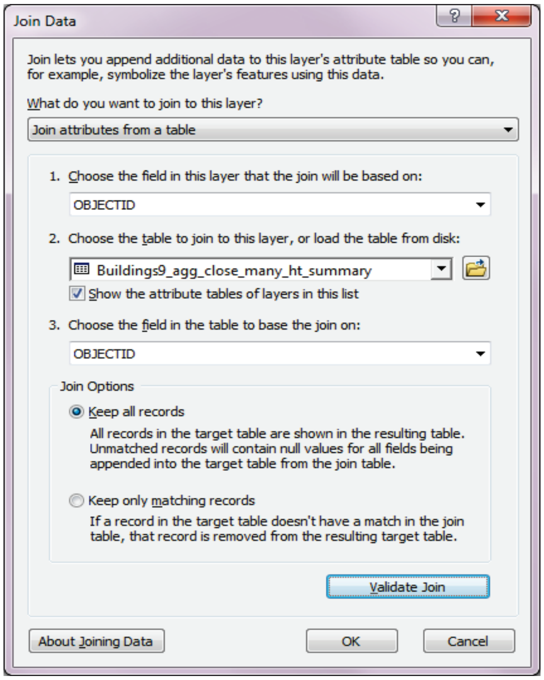
1. Select a field to summarize:
TARGET_FID

2. Choose one or more summary statistics to be included in the output table:
⊞ GM_TYPE
⊞ ELEVATION
⊟ Height
    ☐ Minimum
    ☐ Maximum
    ☐ Average
    ☑ Sum
    ☐ Standard Deviation
    ☐ Variance
⊟ area

3. Specify output table:
as County\UniversityPark\2500m area\Sum_Output_7.dbf

☐ Summarize on the selected records only

Figure 3.40. Join individual building data with the aggregated building data.



Join Data

Join lets you append additional data to this layer's attribute table so you can, for example, symbolize the layer's features using this data.

What do you want to join to this layer?
Join attributes from a table

1. Choose the field in this layer that the join will be based on:
OBJECTID

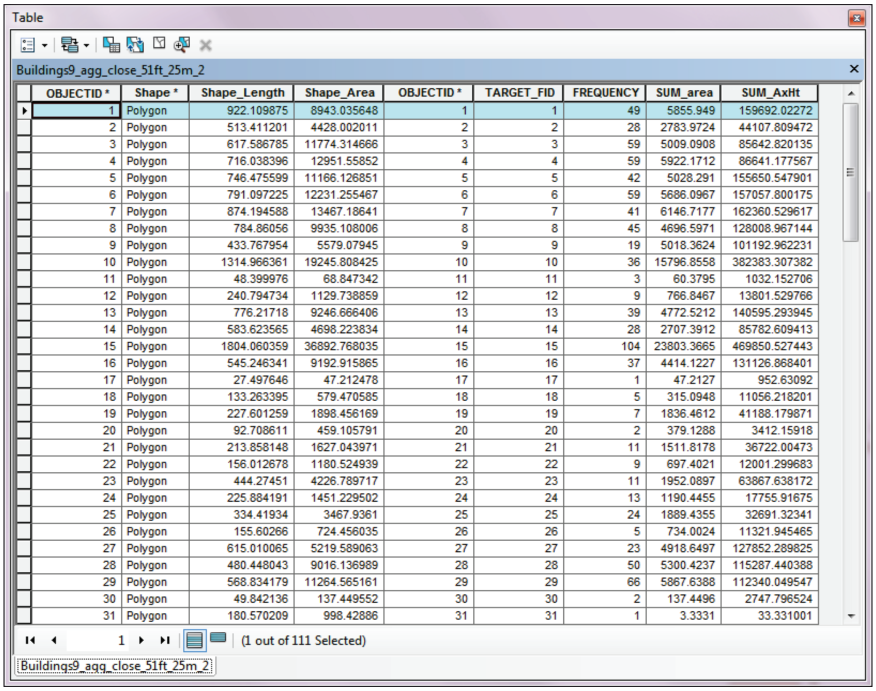
2. Choose the table to join to this layer, or load the table from disk:
Buildings9_agg_close_many_ht_summary
☑ Show the attribute tables of layers in this list

3. Choose the field in the table to base the join on:
OBJECTID

Join Options
● Keep all records
All records in the target table are shown in the resulting table. Unmatched records will contain null values for all fields being appended into the target table from the join table.

○ Keep only matching records
If a record in the target table doesn't have a match in the join table, that record is removed from the resulting target table.

Figure 3.41. Result of join.



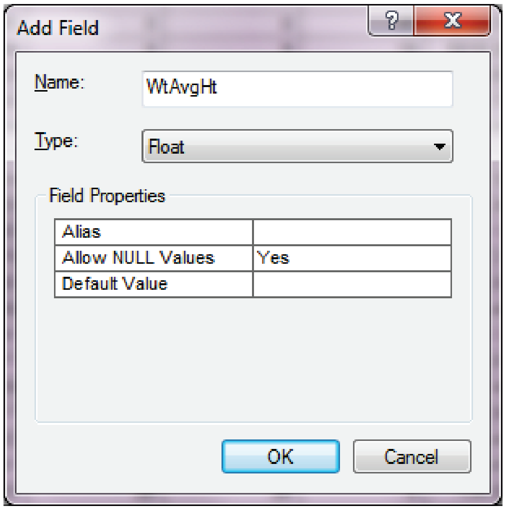
Buildings9_agg_close_51ft_25m_2

OBJECTID *	Shape *	Shape_Length	Shape_Area	OBJECTID *	TARGET_FID	FREQUENCY	SUM_area	SUM_AxHt
1	Polygon	922.109875	8943.035648	1	1	49	5855.949	159692.02272
2	Polygon	513.411201	4428.002011	2	2	28	2783.9724	44107.809472
3	Polygon	617.586785	11774.314666	3	3	59	5009.0908	85642.820135
4	Polygon	716.038396	12951.55852	4	4	59	5922.1712	86641.177567
5	Polygon	746.475599	11166.126851	5	5	42	5028.291	155650.547901
6	Polygon	791.097225	12231.255467	6	6	59	5686.0967	157057.800175
7	Polygon	874.194588	13467.18641	7	7	41	6146.7177	162360.529617
8	Polygon	784.86056	9935.108006	8	8	45	4696.5971	128008.967144
9	Polygon	433.767954	5579.07945	9	9	19	5018.3624	101192.962231
10	Polygon	1314.966361	19245.808425	10	10	36	15796.8558	382383.307382
11	Polygon	48.399976	68.847342	11	11	3	60.3795	1032.152706
12	Polygon	240.794734	1129.738859	12	12	9	766.8467	13801.529766
13	Polygon	776.21718	9246.666406	13	13	39	4772.5212	140595.293945
14	Polygon	583.623565	4698.223834	14	14	28	2707.3912	85782.609413
15	Polygon	1804.060359	36892.768035	15	15	104	23803.3665	469850.527443
16	Polygon	545.246341	9192.915865	16	16	37	4414.1227	131126.868401
17	Polygon	27.497646	47.212478	17	17	1	47.2127	952.63092
18	Polygon	133.263395	579.470585	18	18	5	315.0948	11056.218201
19	Polygon	227.601259	1898.456169	19	19	7	1836.4612	41188.179871
20	Polygon	92.708611	459.105791	20	20	2	379.1288	3412.15918
21	Polygon	213.858148	1627.043971	21	21	11	1511.8178	36722.00473
22	Polygon	156.012678	1180.524939	22	22	9	697.4021	12001.299683
23	Polygon	444.27451	4226.789717	23	23	11	1952.0897	63867.638172
24	Polygon	225.884191	1451.229502	24	24	13	1190.4455	17755.91675
25	Polygon	334.41934	3467.9361	25	25	24	1889.4355	32691.32341
26	Polygon	155.60266	724.456035	26	26	5	734.0024	11321.945465
27	Polygon	615.010065	5219.589063	27	27	23	4918.6497	127852.289825
28	Polygon	480.448043	9016.136989	28	28	50	5300.4237	115287.440388
29	Polygon	568.834179	11264.565161	29	29	66	5867.6388	112340.049547
30	Polygon	49.842136	137.449552	30	30	2	137.4496	2747.796524
31	Polygon	180.570209	998.42886	31	31	1	3.3331	33.331001

1 (1 out of 111 Selected)

Buildings9_agg_close_51ft_25m_2

Figure 3.42. Add a field for the weighted average of the heights.



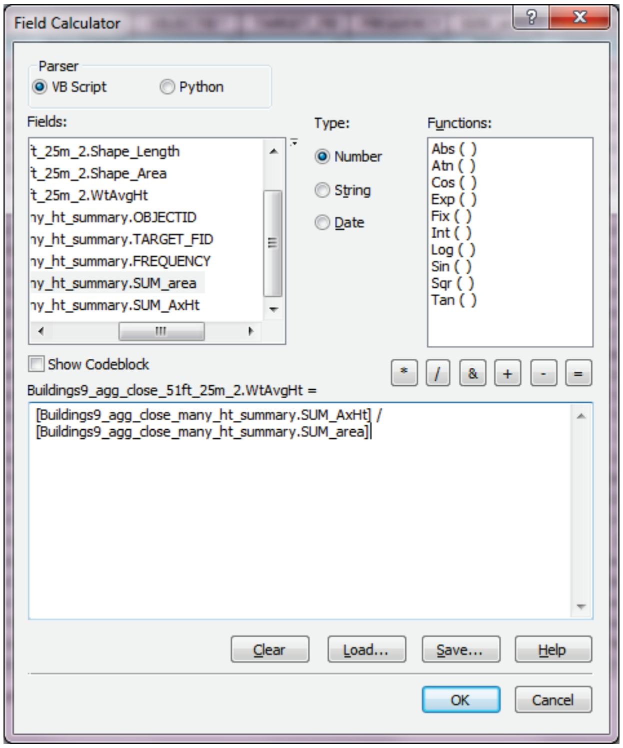
Name: WtAvgHt

Type: Float

Field Properties

Alias	
Allow NULL Values	Yes
Default Value	

Figure 3.43. Use the field calculator to compute a weighted average.



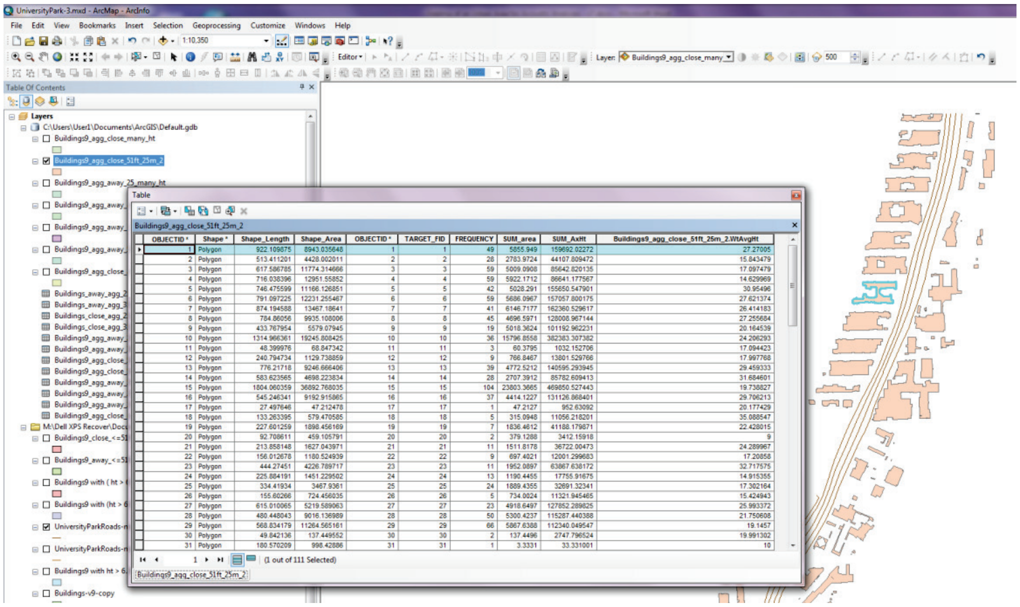
Fields:

t_25m_2.Shape_Length
t_25m_2.Shape_Area
t_25m_2.WtAvgHt
ny_ht_summary.OBJECTID
ny_ht_summary.TARGET_FID
ny_ht_summary.FREQUENCY
ny_ht_summary.SUM_area
ny_ht_summary.SUM_AxHt

Buildings9_agg_close_51ft_25m_2.WtAvgHt =

```
[Buildings9_agg_close_many_ht_summary.SUM_AxHt] /
[Buildings9_agg_close_many_ht_summary.SUM_area]
```

Figure 3.44. Table showing the weighted average for the heights of the buildings contained in aggregated polygons.



Buildings9_agg_close_51ft_25m_2

OBJECTID *	Shape *	Shape_Length	Shape_Area	OBJECTID *	TARGET_FID	FREQUENCY	SUM_area	SUM_AxHt	Buildings9_agg_close_51ft_25m_2.WtAvgHt
1	Polygon	922.109875	8943.035648	1	1	49	5855.949	159692.02272	27.27005
2	Polygon	513.411201	4428.002011	2	2	28	2783.9724	44107.809472	15.843479
3	Polygon	617.586785	11774.314666	3	3	59	5009.0908	85642.820135	17.097479
4	Polygon	716.038396	12951.55852	4	4	59	5922.1712	86641.177567	14.629969
5	Polygon	746.475599	11166.126851	5	5	42	5028.291	155650.547901	30.95496
6	Polygon	791.097225	12231.255467	6	6	59	5686.0967	157057.800175	27.621374
7	Polygon	874.194588	13467.18641	7	7	41	6146.7177	162360.529617	26.414183
8	Polygon	784.86056	9935.108006	8	8	45	4696.5971	128008.967144	27.255684
9	Polygon	433.767954	5579.07945	9	9	19	5018.3624	101192.962231	20.164539
10	Polygon	1314.966361	19245.808425	10	10	36	15796.8558	382383.307382	24.206293
11	Polygon	48.399976	68.847342	11	11	3	60.3795	1032.152706	17.094423
12	Polygon	240.794734	1129.738859	12	12	9	766.8467	13801.529766	17.997768
13	Polygon	776.21718	9246.666406	13	13	39	4772.5212	140595.293945	29.459333
14	Polygon	583.623565	4698.223834	14	14	28	2707.3912	85782.609413	31.684601
15	Polygon	1804.060359	36892.768035	15	15	104	23803.3665	469850.527443	19.738827
16	Polygon	545.246341	9192.915865	16	16	37	4414.1227	131126.868401	29.706213
17	Polygon	27.497646	47.212478	17	17	1	47.2127	952.63092	20.177429
18	Polygon	133.263395	579.470585	18	18	5	315.0948	11056.218201	35.088547
19	Polygon	227.601259	1898.456169	19	19	7	1836.4612	41188.179871	22.428015
20	Polygon	92.708611	459.105791	20	20	2	379.1288	3412.15918	9
21	Polygon	213.858148	1627.043971	21	21	11	1511.8178	36722.00473	24.289967
22	Polygon	156.012678	1180.524939	22	22	9	697.4021	12001.299683	17.20858
23	Polygon	444.27451	4226.789717	23	23	11	1952.0897	63867.638172	32.717575
24	Polygon	225.884191	1451.229502	24	24	13	1190.4455	17755.91675	14.915355
25	Polygon	334.41934	3467.9361	25	25	24	1889.4355	32691.32341	17.302164
26	Polygon	155.60266	724.456035	26	26	5	734.0024	11321.945465	15.424943
27	Polygon	615.010065	5219.589063	27	27	23	4918.6497	127852.289825	25.993372
28	Polygon	480.448043	9016.136989	28	28	50	5300.4237	115287.440388	21.750608
29	Polygon	568.834179	11264.565161	29	29	66	5867.6388	112340.049547	19.1457
30	Polygon	49.842136	137.449552	30	30	2	137.4496	2747.796524	19.991302
31	Polygon	180.570209	998.42886	31	31	1	3.3331	33.331001	10

(1 out of 111 Selected)

Buildings9_agg_close_51ft_25m_2

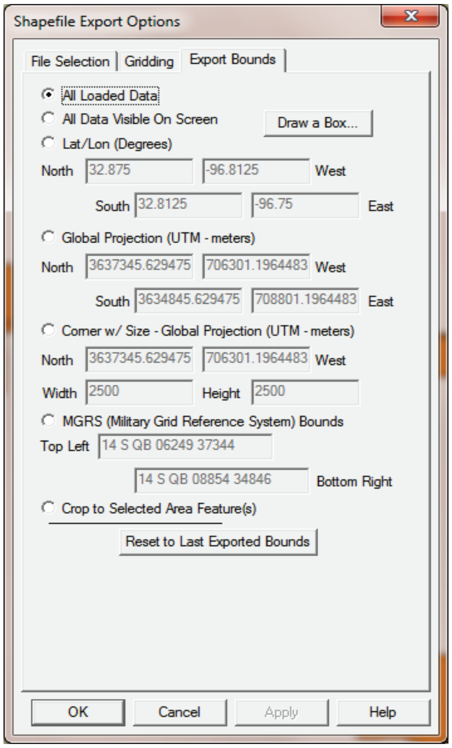
3.3.8 Save building data to shapefiles in Global Mapper

After clipping operations as described in Section 3.2.2 or addition or deletion of buildings as described in Section 3.3.3, the data set can be output to the ESRI shapefile format to provide one file that contains all editing operations for later use with ArcMap.

The output of the data is the same as described in Section 3.2.2. The **Export Bounds** tab as shown in Figure 3.45 may be used to select the bounds of the data to export. The bounds of the data to export may be specified by selecting:

1. **Crop to Selected Area Feature(s)** which will crop (clip) the data to the bounds of the feature.
2. **All Loaded Data** which will export all layers turned on in the Overlay Control Center.
3. **All Data Visible on Screen** which will export only the data that are visible on the screen.

Figure 3.45. Shapefile export options for Global Mapper.



● All Loaded Data
○ All Data Visible On Screen
○ Lat/Lon (Degrees)
North 32.875 -96.8125 West
South 32.8125 -96.75 East
○ Global Projection (UTM - meters)
North 3637345.629475 706301.1964483 West
South 3634845.629475 708801.1964483 East
○ Corner w/ Size - Global Projection (UTM - meters)
North 3637345.629475 706301.1964483 West
Width 2500 Height 2500
○ MGRS (Military Grid Reference System) Bounds
Top Left 14 S QB 06249 37344
14 S QB 08854 34846 Bottom Right
○ Crop to Selected Area Feature(s)

3.3.9 Save building data to shapefiles in ArcMap

ArcMap was used to perform editing operations on the building data set in order to produce several data sets based on height, area, and location as explained in Sections 3.3.4 - 3.3.6. To save the data sets for further processing in Global Mapper, the data can be saved to the shapefile format. To save data in ArcMap to the shapefile format:

1. Right-click the layer of interest as shown in Figure 3.46 and select **Export Data**.
2. The dialog in Figure 3.47 will appear. Select **All Features** and type a file name to save the data to. Click **OK**.

Figure 3.46. Selecting export data option to save data.

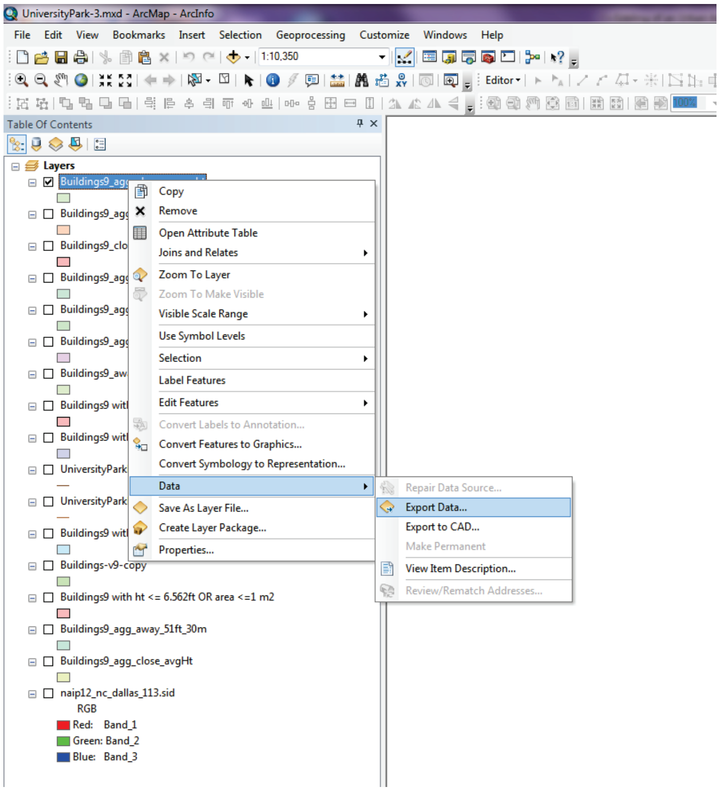
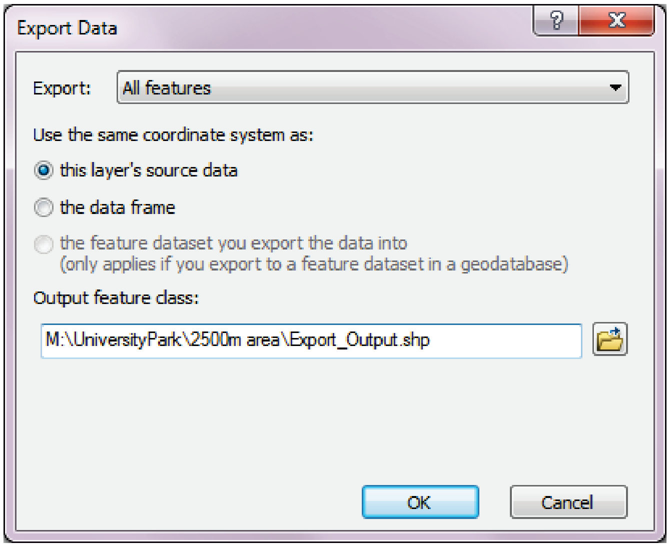


Figure 3.47. Export data dialog for shapefiles in ArcMap.



Export Data

Export: All features

Use the same coordinate system as:

● this layer's source data

○ the data frame

○ the feature dataset you export the data into
(only applies if you export to a feature dataset in a geodatabase)

Output feature class:

M:\UniversityPark\2500m area\Export_Output.shp

3.3.10 View buildings in 3-D

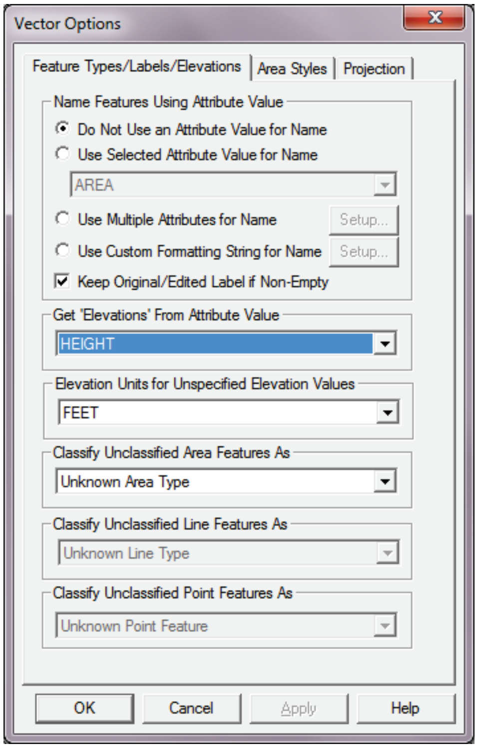
In Global Mapper, the building data may be viewed in 3-D. It is very useful to see the height of buildings in relation to the terrain.

The building data from CyberCity 3D provided the height attribute of the buildings in feet. In Global Mapper, the attribute used to select the elevation of the buildings and the units must be specified. To set the options:

1. In the **Overlay Control Center**, click on a layer containing the building data. Turn on other layers of interest to display in the 3-D view such as highways or orthophotography. Turn on the topography layer to display the buildings on the actual terrain; otherwise, the buildings will be displayed on a flat surface.
2. Click the **Options** button. The **Vector Options** dialog will display as shown in Figure 3.48.
    a. Set the **Get Elevation from Attribute Value** to **HEIGHT**.
    b. Set the **Elevation Units for Unspecified Elevation Values** to **FEET**.
3. Select the **3D View** icon on the main menu to display the 3-D view as shown in Figure 3.49. The 3D view will display as shown in Figure 3.50.
4. Select the **Change display properties** from the main menu of the 3-D view as shown in Figure 3.50. The dialog to change display properties will appear as shown in Figure 3.51.

a. Under **3D Vector Display Options**, check all boxes.
b. Since the height of the buildings is specified as a height and not an elevation, the box **Treat 3D Vector Elevations as Relative to the Terrain Surface** must be checked.
c. Checking the **Extrude 3D Areas to Surface** causes the walls of the buildings to be extruded to the surface of the terrain.

Figure 3.48. Vector options dialog to set elevation data for buildings.



Name Features Using Attribute Value
- ● Do Not Use an Attribute Value for Name
- ○ Use Selected Attribute Value for Name: AREA
- ○ Use Multiple Attributes for Name
- ○ Use Custom Formatting String for Name
- ☑ Keep Original/Edited Label if Non-Empty

Get 'Elevations' From Attribute Value: HEIGHT

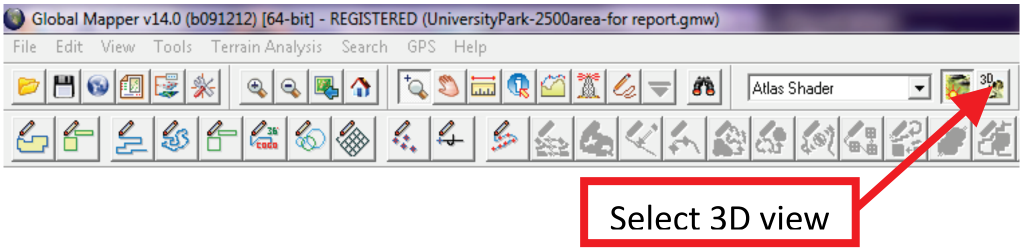
Elevation Units for Unspecified Elevation Values: FEET

Classify Unclassified Area Features As: Unknown Area Type

Classify Unclassified Line Features As: Unknown Line Type

Classify Unclassified Point Features As: Unknown Point Feature

Figure 3.49. Select 3D view.



Select 3D view

Figure 3.50. Change display properties of 3D view.

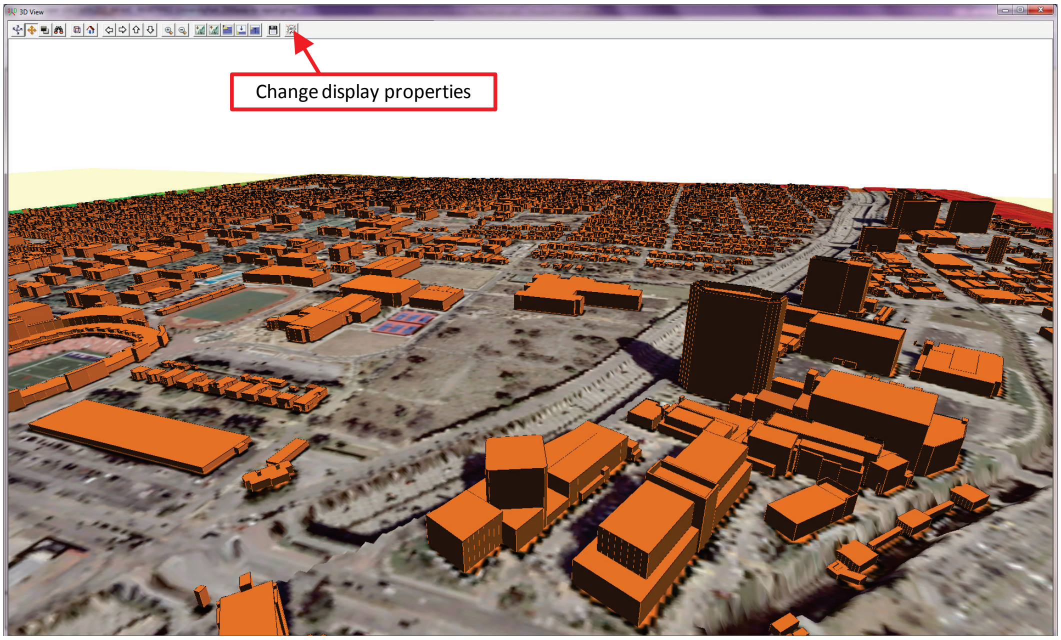
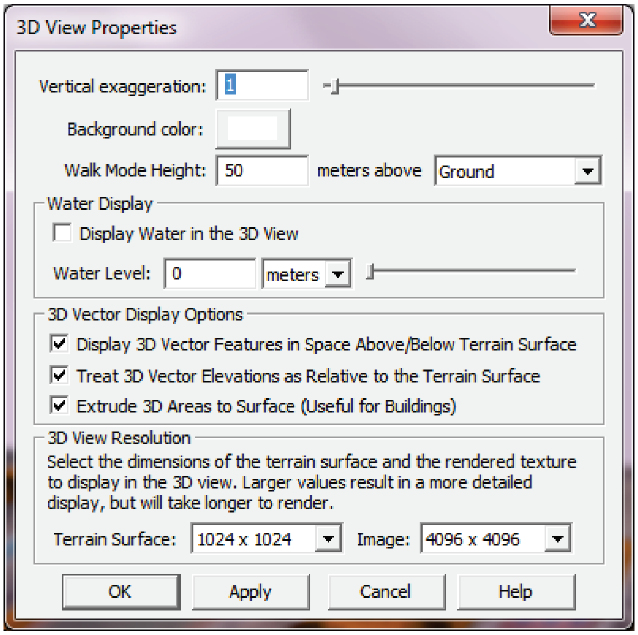


Figure 3.51. 3D view properties.



3D View Properties

Vertical exaggeration: 1

Background color:

Walk Mode Height: 50 meters above Ground

Water Display

☐ Display Water in the 3D View

Water Level: 0 meters

3D Vector Display Options

☑ Display 3D Vector Features in Space Above/Below Terrain Surface

☑ Treat 3D Vector Elevations as Relative to the Terrain Surface

☑ Extrude 3D Areas to Surface (Useful for Buildings)

3D View Resolution

Select the dimensions of the terrain surface and the rendered texture to display in the 3D view. Larger values result in a more detailed display, but will take longer to render.

Terrain Surface: 1024 x 1024 Image: 4096 x 4096

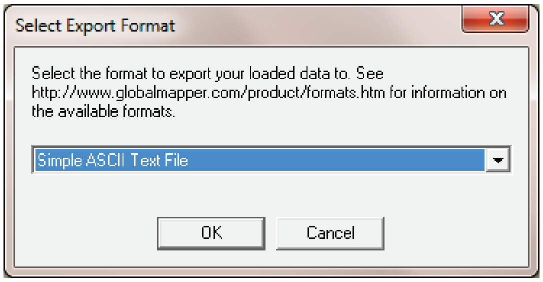
3.3.11 Create files for Urban Modeler

A piece of custom software, termed the Urban Modeler, was used to provide further processing of data obtained from Global Mapper. The vector information concerning buildings can be output from Global Mapper in several vector file formats. The output of the data in the shapefile format is described in Section 3.3.8. The ASCII vector file format was chosen for ease of use with the Urban Modeler software.

To output data in the ASCII vector file format from Global Mapper:

1. The data should be exported in the UTM coordinate system for use with Urban Modeler. If the coordinate projection needs to be changed, follow the instructions in Section 3.2.3 and select the UTM coordinate projection.
2. Select the **Overlay Control Center** button from the main toolbar.
3. Turn on the building data layer(s) by checking the appropriate layers.
4. From the main menu, select **File > Export > Export Vector Format**.
5. From the dialog shown in Figure 3.52, select **Simple ASCII Text File**.
6. The **ASCII Export Options** dialog will appear as shown in Figure 3.53.
    a. Under **Coordinate Separator**, click **Comma**.
    b. Under **Feature Separator**, click **Custom** and then enter **\nBuilding**. This causes a new line and the word **Building** to be written before each data record. Urban Modeler uses sets of key words to recognize types of data.
    c. Check **Export Elevation for Each Vertex**.
    d. Check **Include Feature Attributes Before Coordinate Data**.
7. The default options on the other tabs may be left as the default.
8. Click **OK** and input a file name.

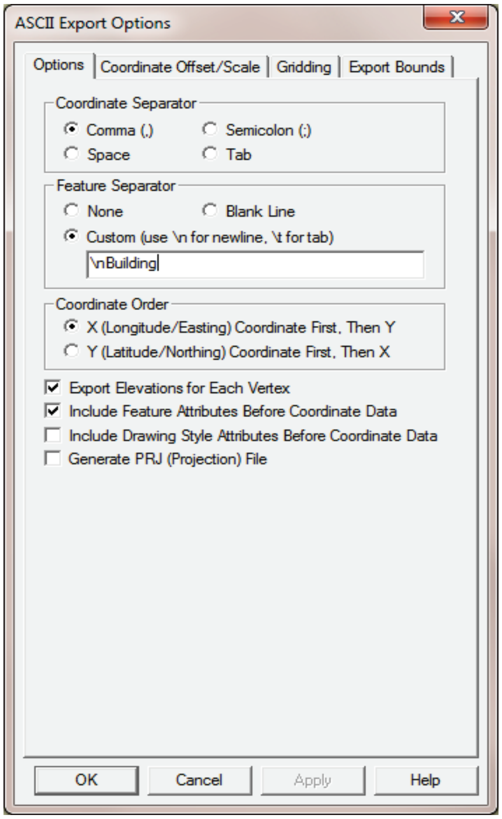
Figure 3.52. Export file options.



Select the format to export your loaded data to. See http://www.globalmapper.com/product/formats.htm for information on the available formats.

Simple ASCII Text File

Figure 3.53. ASCII export options for buildings.


ASCII Export Options

Options | Coordinate Offset/Scale | Gridding | Export Bounds

Coordinate Separator
● Comma (,) ○ Semicolon (;)
○ Space ○ Tab

Feature Separator
○ None ○ Blank Line
● Custom (use \n for newline, \t for tab)
\nBuilding

Coordinate Order
● X (Longitude/Easting) Coordinate First, Then Y
○ Y (Latitude/Northing) Coordinate First, Then X

☑ Export Elevations for Each Vertex
☑ Include Feature Attributes Before Coordinate Data
☐ Include Drawing Style Attributes Before Coordinate Data
☐ Generate PRJ (Projection) File

The building data will be output in one file. Urban Modeler will read the data and perform additional processing as discussed in Chapter 4.

The units of the UTM coordinate system are meters, whereas, the units of the height attribute for the buildings defined by CyberCity 3D are in feet. Global Mapper does not alter attribute units; therefore, the height attribute will remain in feet even though the building footprint data are defined in meters.

In Figure 3.53, the option to export the elevation for each vertex may be selected. This will cause the height attribute to be written as the z-coordinate and it will be converted to meters automatically.

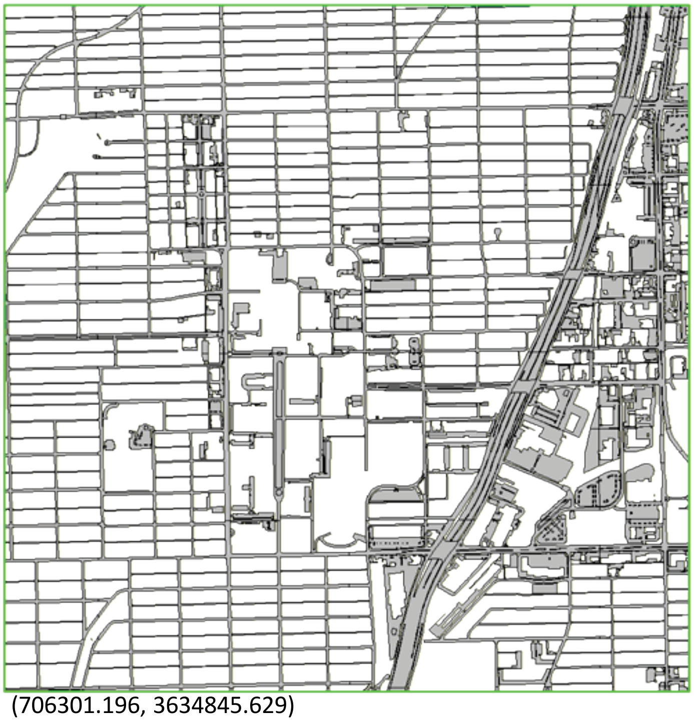
Global Mapper also allows the z-coordinate to be set from the topography. This option is not used for buildings, but is for bridges as discussed in Section 3.5. If the z-coordinate of the vertices of an object is set using the topographic elevation, the units of the coordinates will be converted to meters.

3.4 Model paved areas

3.4.1 Read paved areas into Global Mapper

Global Mapper was used to read 2-D planimetric data from NCTCOG defining the paved areas of the urban area shown in Figure 3.54 in the ESRI shapefile format. The coordinates of the lower-left corner are shown in UTM coordinates in Figure 3.54.

Figure 3.54. Paved areas of analysis region.



Data are read into Global Mapper by opening the specific file using the **File** menu option or dragging the file from Windows Explorer. If the file contains a definition of the projected coordinate system used, Global Mapper will just automatically read and display the data. If a projected coordinate system is not found, a dialog box will display asking the user to verify the appropriate projected coordinate system as shown in Figure 3.1. The user would select the appropriate projected coordinate system that the data set uses and select the **OK** button.

3.4.2 Clip paved areas to desired area

The initial planimetric data set obtained from NCTCOG was much larger than the analysis region. Therefore, the data set was clipped at the boundaries of the analysis region as shown by the green outline in Figure 3.54. The clipping procedure is the same as described for buildings in Section 3.3.2. The result of the clipping operation was an ESRI shapefile that contained only the paved areas within the green outline shown in Figure 3.54.

3.4.3 Break larger paved areas into smaller areas

When processing area features such as the paved areas, it was found that the MATLAB preprocessing algorithms performed better if the data were split into smaller areas. This seemed to help with the speed of processing plus alleviated any memory problems arising from trying to process large areas.

Breaking larger area features into smaller area features is accomplished in Global Mapper when saving the vector data to a vector output file (i.e., a shapefile or ASCII vector file) as described in Section 3.4.5.

3.4.4 Detect islands in data

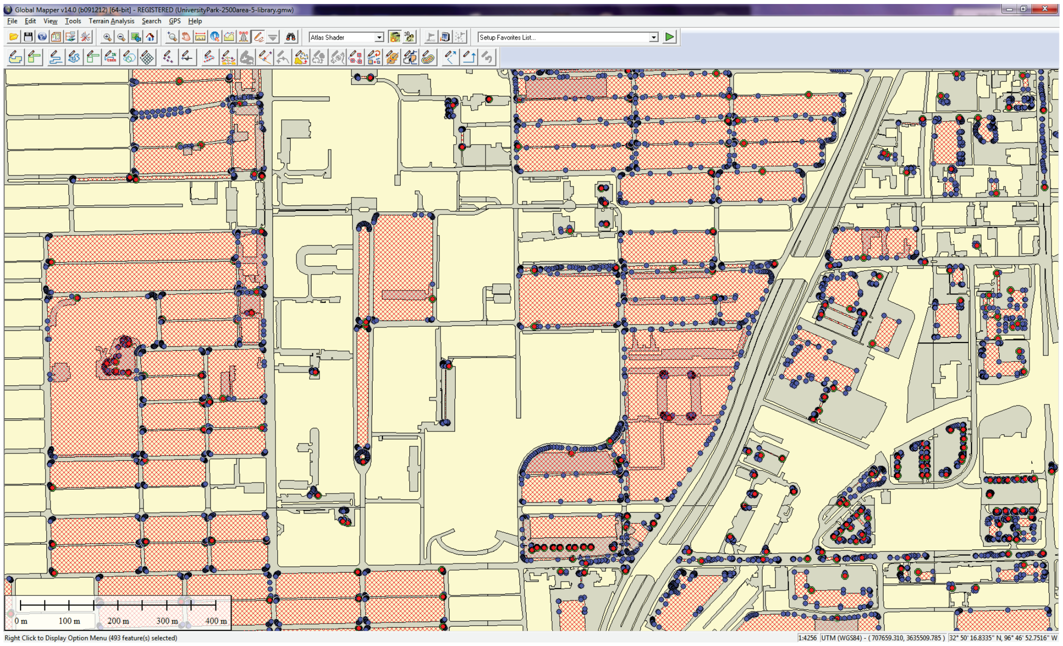
Islands represent open spaces in a larger area. That is, a building may exist with an interior courtyard, which can be modeled using an island. Paved areas, such as highways, may have interior open spaces that represent the medians. The network of streets may be represented as large solid areas with islands representing the city blocks. When data containing islands are displayed in GIS programs, the islands will cause the large solid areas to appear to have open spaces in them.

For the MATLAB preprocessing routines to properly handle the islands, the islands must be detected and written out separately. This is accomplished with the Urban Modeler program. No special processing is needed within Global Mapper to account for the islands. To detect the presence of islands in Global Mapper:

1. Select the **Overlay Control Center** button from the main toolbar.
2. Click the layer containing the paved-area data to view it on the screen.
3. Right-click the layer containing the paved-area data in the **Overlay Control Center**.
4. From the pop-up menu, choose **Select All Features in Selected Layer(s) with Digitizer Tool**. The points defining the data will highlight.

5. Right-click on the highlighted data on screen.
6. Select **Advanced Selection Options** > **Select Island Areas in Selected Area Feature**.
7. The display will highlight all islands in red as shown in Figure 3.55.

Figure 3.55. Island areas contained in the paved area data highlighted in red.



3.4.5 Create files for Urban Modeler

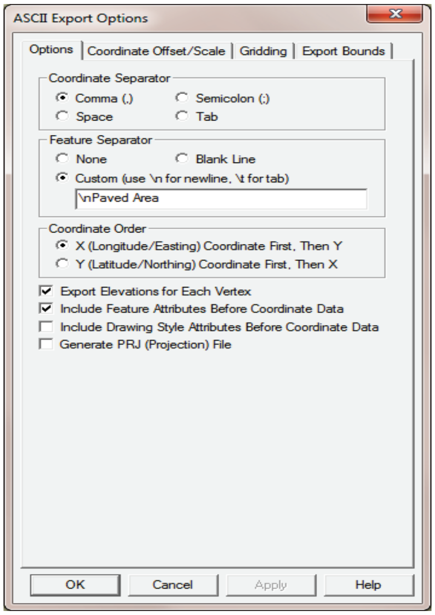
A piece of custom software, termed the Urban Modeler, was used to provide further processing of data obtained from Global Mapper. The vector information concerning paved areas can be output from Global Mapper in several vector file formats. The output of the data in the shapefile format is described in Section 3.3.8. The ASCII vector file format was chosen for ease of use with the Urban Modeler software.

To output data in the ASCII vector file format from Global Mapper:

1. The data should be exported in the UTM coordinate system for use with Urban Modeler and the MATLAB preprocessing routines. If the coordinate projection needs to be changed, follow the instructions in Section 3.2.3 and select the UTM coordinate projection.
2. Select the **Overlay Control Center** button from the main toolbar.
3. Turn on the paved area data layer(s) by checking the appropriate layers. Also turn on the clipping area.

4. Select the **Feature Info Tool** as shown in Figure 3.7 and click on the clip area to select it.
5. From the main menu, select **File** > **Export** > **Export Vector Format**.
6. From the dialog shown in Figure 3.52, select **Simple ASCII Text File**.
7. The **ASCII Export Options** dialog will appear as shown in Figure 3.56.
    a. Under **Coordinate Separator**, click **Comma**.
    b. Under **Feature Separator**, click **Custom** and then enter **\nPaved Area**. This causes a newline and the words **Paved Area** to be written before each data record. Urban Modeler uses sets of key words to recognize types of data.
    c. Check **Export Elevation for Each Vertex**.
    d. Check **Include Feature Attributes Before Coordinate Data**.
8. Click on the **Gridding** tab shown in Figure 3.56. The tab shown in Figure 3.57 will display.
9. Click **Specified Number of Rows and Columns**. Input the number of rows and columns desired. As shown in Figure 3.57, enter **5** rows and **5** columns. The data will be segmented into a grid with the data split along the grid boundaries. For a 5 by 5 grid, 25 files will be written.
10. The grid naming convention can be left as shown in Figure 3.57.
11. Click on the **Export Bounds** tab shown in Figure 3.58 and click on the **Crop to Selected Area Feature(s)** option.
12. Click **OK** and input a file name.

Figure 3.56. ASCII export options for paved areas.



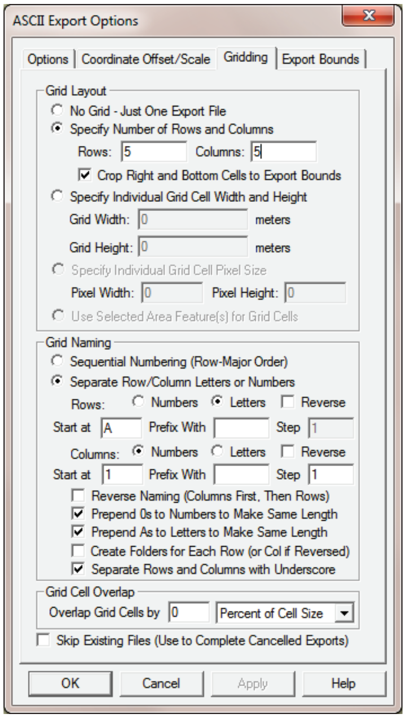
Coordinate Separator
● Comma (,) ○ Semicolon (;)
○ Space ○ Tab

Feature Separator
○ None ○ Blank Line
● Custom (use \n for newline, \t for tab)
\nPaved Area

Coordinate Order
● X (Longitude/Easting) Coordinate First, Then Y
○ Y (Latitude/Northing) Coordinate First, Then X

☑ Export Elevations for Each Vertex
☑ Include Feature Attributes Before Coordinate Data
☐ Include Drawing Style Attributes Before Coordinate Data
☐ Generate PRJ (Projection) File

Figure 3.57. Gridding option for paved areas.



Grid Layout

○ No Grid - Just One Export File
● Specify Number of Rows and Columns
Rows: 5 Columns: 5
☑ Crop Right and Bottom Cells to Export Bounds
○ Specify Individual Grid Cell Width and Height
Grid Width: 0 meters
Grid Height: 0 meters
○ Specify Individual Grid Cell Pixel Size
Pixel Width: 0 Pixel Height: 0
○ Use Selected Area Feature(s) for Grid Cells

Grid Naming

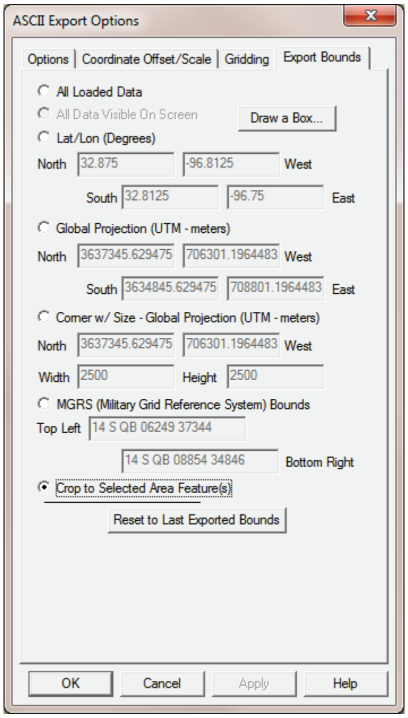
○ Sequential Numbering (Row-Major Order)
● Separate Row/Column Letters or Numbers
Rows: ○ Numbers ● Letters ☐ Reverse
Start at A Prefix With Step 1
Columns: ● Numbers ○ Letters ☐ Reverse
Start at 1 Prefix With Step 1
☐ Reverse Naming (Columns First, Then Rows)
☑ Prepend 0s to Numbers to Make Same Length
☑ Prepend As to Letters to Make Same Length
☐ Create Folders for Each Row (or Col if Reversed)
☑ Separate Rows and Columns with Underscore

Grid Cell Overlap

Overlap Grid Cells by 0 Percent of Cell Size

☐ Skip Existing Files (Use to Complete Cancelled Exports)

Figure 3.58. Export bounds options for paved areas.



○ All Loaded Data
○ All Data Visible On Screen
○ Lat/Lon (Degrees)
North 32.875 -96.8125 West
South 32.8125 -96.75 East
○ Global Projection (UTM - meters)
North 3637345.629475 706301.1964483 West
South 3634845.629475 708801.1964483 East
○ Corner w/ Size - Global Projection (UTM - meters)
North 3637345.629475 706301.1964483 West
Width 2500 Height 2500
○ MGRS (Military Grid Reference System) Bounds
Top Left 14 S QB 06249 37344
14 S QB 08854 34846 Bottom Right
● Crop to Selected Area Feature(s)

3.5 Model bridges

3.5.1 Select bridges from paved areas

Bridges were contained within the planimetric data obtained from NCTCOG. They were denoted with an attribute called FEATURE, which contained the values of BRIDGE or PEDESTRIAN BRIDGE. To extract the bridge information using Global Mapper:

1. Select the **Overlay Control Center** button from the main toolbar.
2. Turn on the paved area data layer(s) by checking the appropriate layers.
3. Click the **Select by Attribute/Name/Description** button on the main toolbar, as shown in Figure 3.59.
4. Sort the features by clicking on the **FEATURE** tab as shown in Figure 3.60. This will group all the bridges together.
5. Select all bridges by clicking on the first **BRIDGE** object. Scroll down to the last **BRIDGE** object and while holding down the **SHIFT** key, click the **BRIDGE** object. You may also scroll down to the **PEDESTRIAN BRIDGE** objects and individually select a bridge by holding down the **CTRL** key and clicking on each object.
6. Right-click the selected **BRIDGE** objects and select **Copy the Selected Objects to the Clipboard**.
7. Click on **Edit > Paste Features From Clipboard**. The dialog shown in Figure 3.61 will display.
8. Select **Paste to New Layer**. This will create a layer containing just the bridges.
9. Right-click the new bridge layer in the **Overlay Control Center** and select **Select All Features in Selection Layer(s) with Digitizer Tool**.
10. Right-click on a selected bridge and select **Attribute Functions > Apply Elevations from Terrain Layers to Selected Feature(s)**. This adds a z-coordinate to the vertices of the bridge object based on the elevation of the underlying terrain. These elevations will be used in Urban Modeler to compute the placement of the bridge.

Figure 3.59. Select features by attribute.

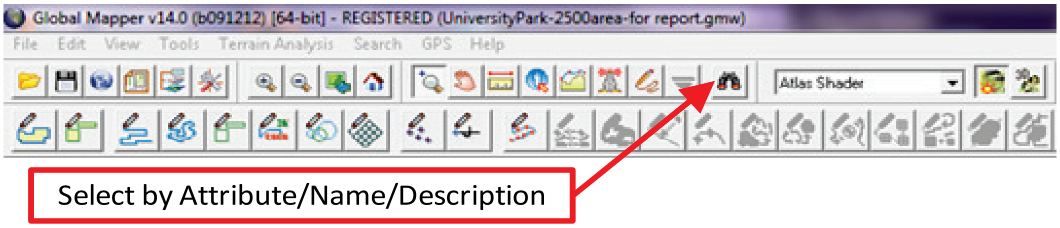
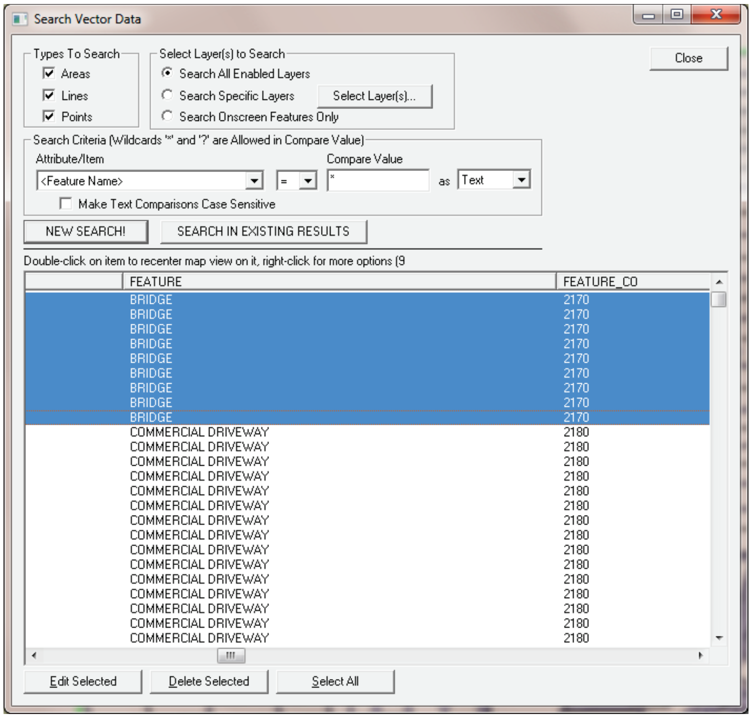


Figure 3.60. Selecting bridges based on attribute value.



Search Vector Data

Types To Search
☑ Areas
☑ Lines
☑ Points

Select Layer(s) to Search
● Search All Enabled Layers
○ Search Specific Layers
○ Search Onscreen Features Only

Search Criteria (Wildcards '*' and '?' are Allowed in Compare Value)
Attribute/Item: <Feature Name>
=
Compare Value: *
as Text
☐ Make Text Comparisons Case Sensitive

Double-click on item to recenter map view on it, right-click for more options (9

	FEATURE	FEATURE_CO
	BRIDGE	2170
	BRIDGE	2170
	BRIDGE	2170
	BRIDGE	2170
	BRIDGE	2170
	BRIDGE	2170
	BRIDGE	2170
	BRIDGE	2170
	BRIDGE	2170
	COMMERCIAL DRIVEWAY	2180
	COMMERCIAL DRIVEWAY	2180
	COMMERCIAL DRIVEWAY	2180
	COMMERCIAL DRIVEWAY	2180
	COMMERCIAL DRIVEWAY	2180
	COMMERCIAL DRIVEWAY	2180
	COMMERCIAL DRIVEWAY	2180
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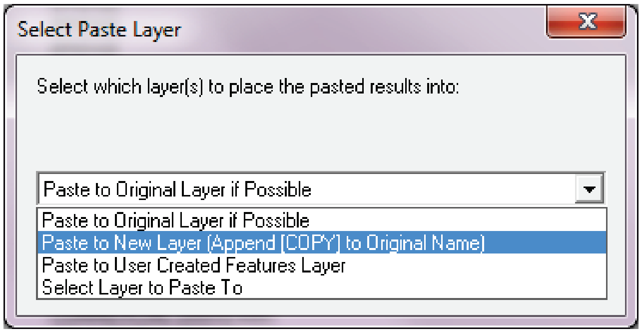
	COMMERCIAL DRIVEWAY	2180
	COMMERCIAL DRIVEWAY	2180
	COMMERCIAL DRIVEWAY	2180
	COMMERCIAL DRIVEWAY	2180
	COMMERCIAL DRIVEWAY	2180

Figure 3.61. Copy objects to new layer.



Select Paste Layer

Select which layer(s) to place the pasted results into:

Paste to Original Layer if Possible

Paste to Original Layer if Possible
Paste to New Layer (Append [COPY] to Original Name)
Paste to User Created Features Layer
Select Layer to Paste To

3.5.2 Flatten terrain under bridges

The LIDAR data from TNRIS resulted in raised areas of terrain under the bridges, which should be flattened (or lowered) to the elevation of the roadway as shown in Figure 3.62. To flatten the terrain under a bridge:

1. Turn the imagery layer on using the **Overlay Control Center** as shown in Figure 3.5.
2. Select the **Digitizer Tool** and click the **Create New Area Feature** as shown in Figure 3.20.

3. For each bridge, click on points to trace the outline of the area under the bridge to be flattened as shown in Figure 3.63. Right-click on the last point to end the feature creation.
4. The **Modify Feature Info** dialog box will display as shown in Figure 3.64. Click **OK**.
5. Continue to create areas defining the regions to flatten beneath each bridge feature.
6. When all areas are defined, click and drag the mouse to create a selection box around the new areas.
7. Right-click on one of the selected areas and select **Attribute Functions > Apply Elevations from Terrain Layers to Selected Feature(s)**. This adds a z-coordinate to the vertices of the areas used to flatten the terrain.
8. Double-click on an individual area to select it. The dialog shown in Figure 3.65 will appear.
9. Click on the **Vertices** button. The dialog in Figure 3.66 will appear.
10. Click on the first vertex. Move down to the last vertex and press the **SHIFT** key and click on the vertex. This will select all vertices.
11. Click the **Edit Elevation** button. The dialog in Figure 3.67 will appear.
12. Enter an elevation and click **OK**. All elevation values will change to the new value.
13. Select all area features as described in Step 6.
14. Right-click an area feature and select **Advanced Feature Creation Options > TERRAIN - Create/Flatten Terrain from Selected Area Feature(s)**.
15. The **Elevation Grid Creation Options** dialog will display as shown in Figure 3.68.
16. Check the **Flatten 3D Area Features**. Click **OK**.
17. Figures 3.69 and 3.70 show the result of flattening the terrain under the bridge.

Figure 3.62. Raised terrain under bridge.

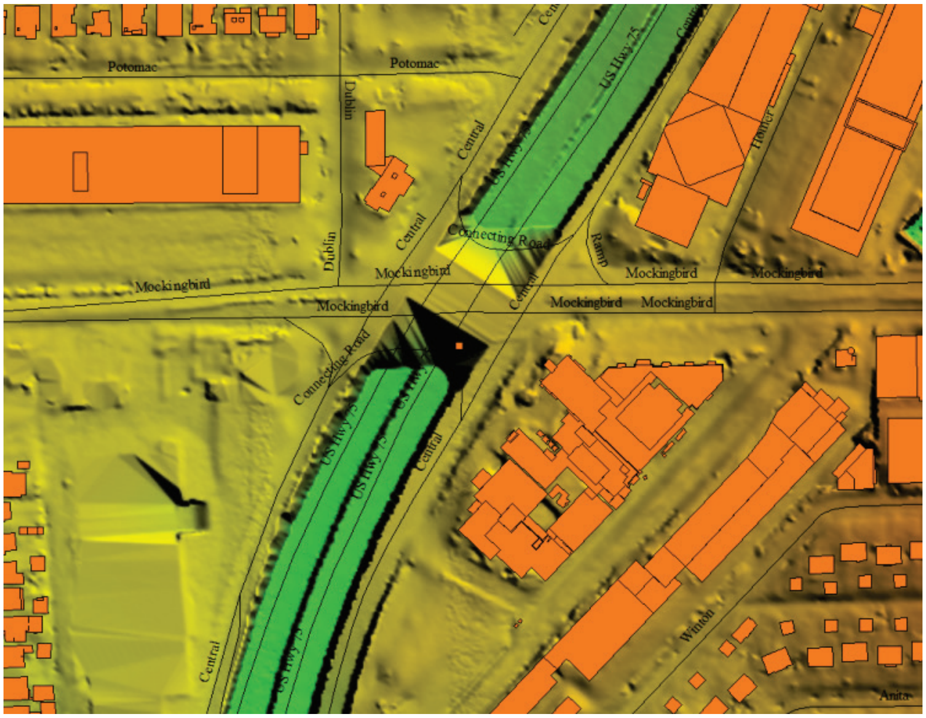


Figure 3.63. Create area feature encompassing area to flatten.

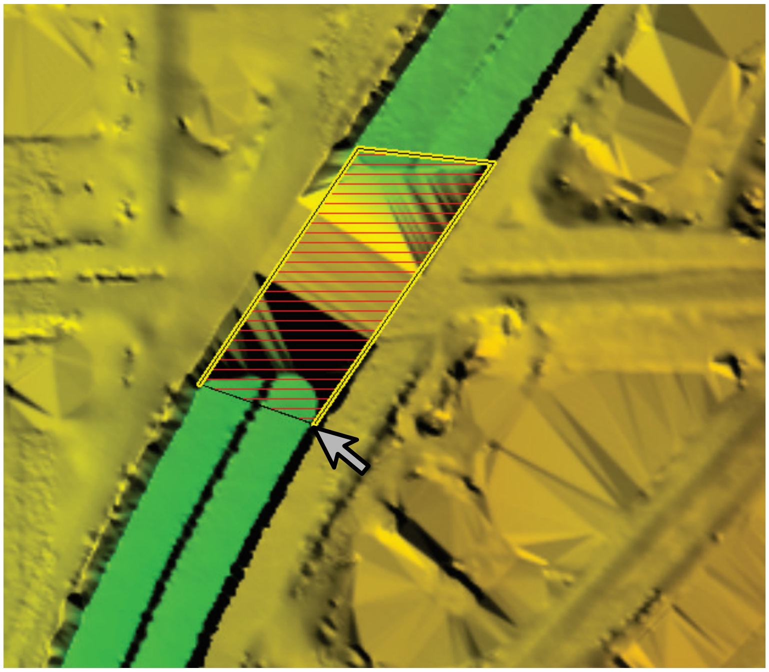
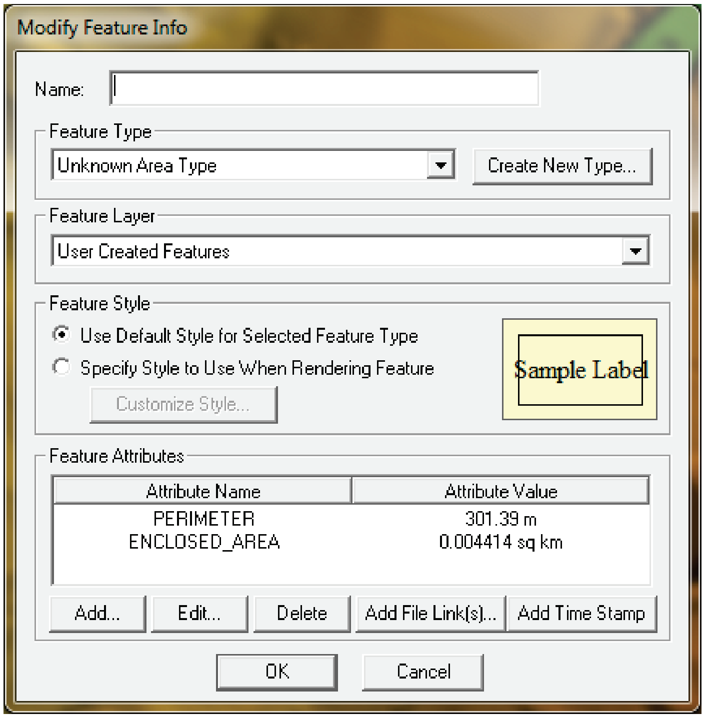


Figure 3.64. Dialog for newly created area feature.



Modify Feature Info

Name:

Feature Type: Unknown Area Type

Feature Layer: User Created Features

Feature Style

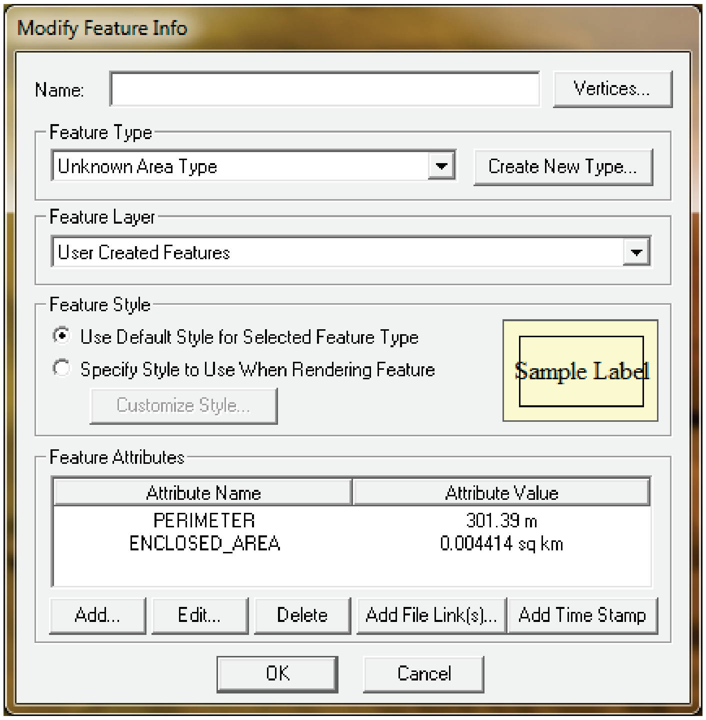
● Use Default Style for Selected Feature Type

○ Specify Style to Use When Rendering Feature

Feature Attributes

Attribute Name	Attribute Value
PERIMETER	301.39 m
ENCLOSED_AREA	0.004414 sq km

Figure 3.65. Dialog for selected area.



Modify Feature Info

Name:

Feature Type: Unknown Area Type

Feature Layer: User Created Features

Feature Style

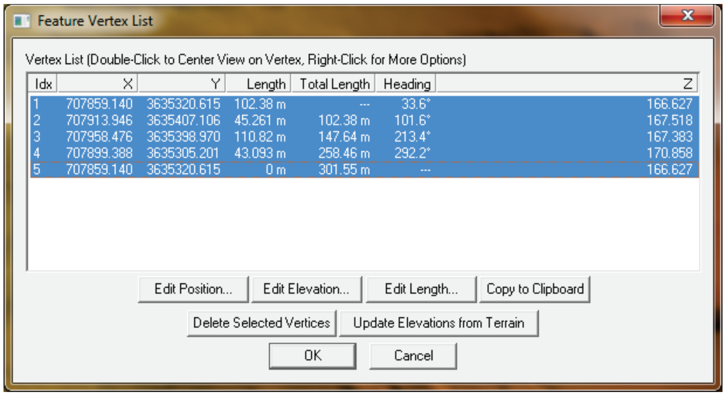
● Use Default Style for Selected Feature Type

○ Specify Style to Use When Rendering Feature

Feature Attributes

Attribute Name	Attribute Value
PERIMETER	301.39 m
ENCLOSED_AREA	0.004414 sq km

Figure 3.66. Selection of vertices to edit.



Feature Vertex List

Vertex List (Double-Click to Center View on Vertex, Right-Click for More Options)

Idx	X	Y	Length	Total Length	Heading	Z
1	707859.140	3635320.615	102.38 m	---	33.6°	166.627
2	707913.946	3635407.106	45.261 m	102.38 m	101.6°	167.518
3	707958.476	3635398.970	110.82 m	147.64 m	213.4°	167.383
4	707899.388	3635305.201	43.093 m	258.46 m	292.2°	170.858
5	707859.140	3635320.615	0 m	301.55 m	---	166.627

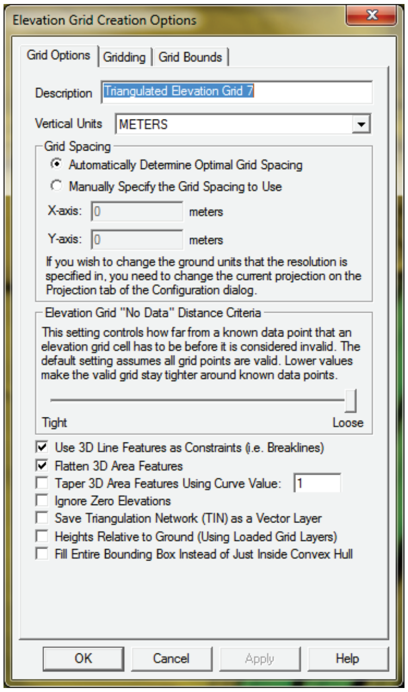
Figure 3.67. Editing elevation of all vertices.

Enter New Elevation

Enter the new elevation value to use for the selected vertices.

165

Figure 3.68. Elevation grid options.



Elevation Grid Creation Options

Description: Triangulated Elevation Grid 7

Vertical Units: METERS

Grid Spacing

● Automatically Determine Optimal Grid Spacing

○ Manually Specify the Grid Spacing to Use

X-axis: 0 meters

Y-axis: 0 meters

If you wish to change the ground units that the resolution is specified in, you need to change the current projection on the Projection tab of the Configuration dialog.

Elevation Grid "No Data" Distance Criteria

This setting controls how far from a known data point that an elevation grid cell has to be before it is considered invalid. The default setting assumes all grid points are valid. Lower values make the valid grid stay tighter around known data points.

☑ Use 3D Line Features as Constraints (i.e. Breaklines)

☑ Flatten 3D Area Features

☐ Taper 3D Area Features Using Curve Value: 1

☐ Ignore Zero Elevations

☐ Save Triangulation Network (TIN) as a Vector Layer

☐ Heights Relative to Ground (Using Loaded Grid Layers)

☐ Fill Entire Bounding Box Instead of Just Inside Convex Hull

Figure 3.69. Flattened terrain under bridge.

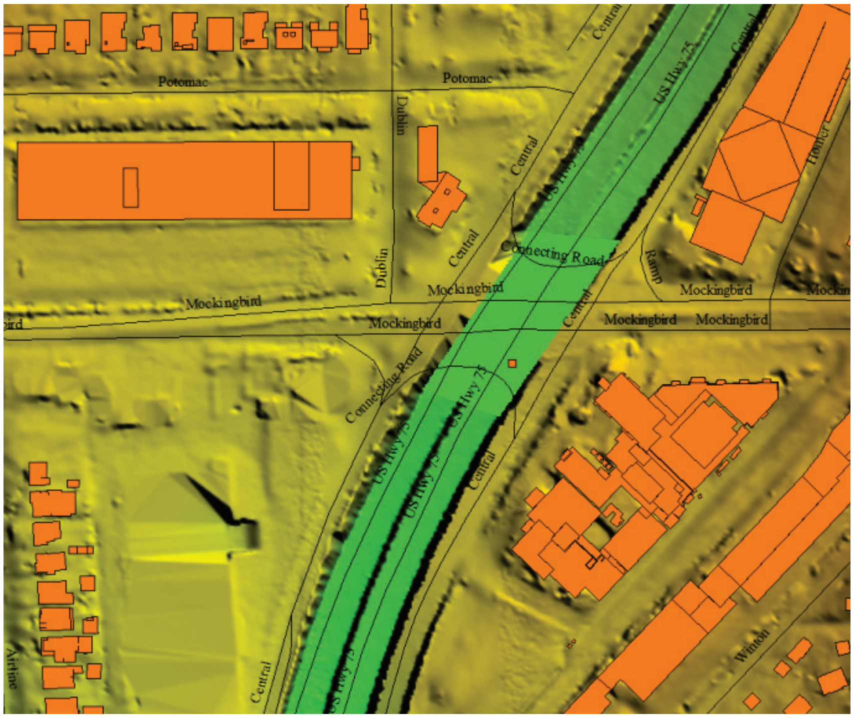
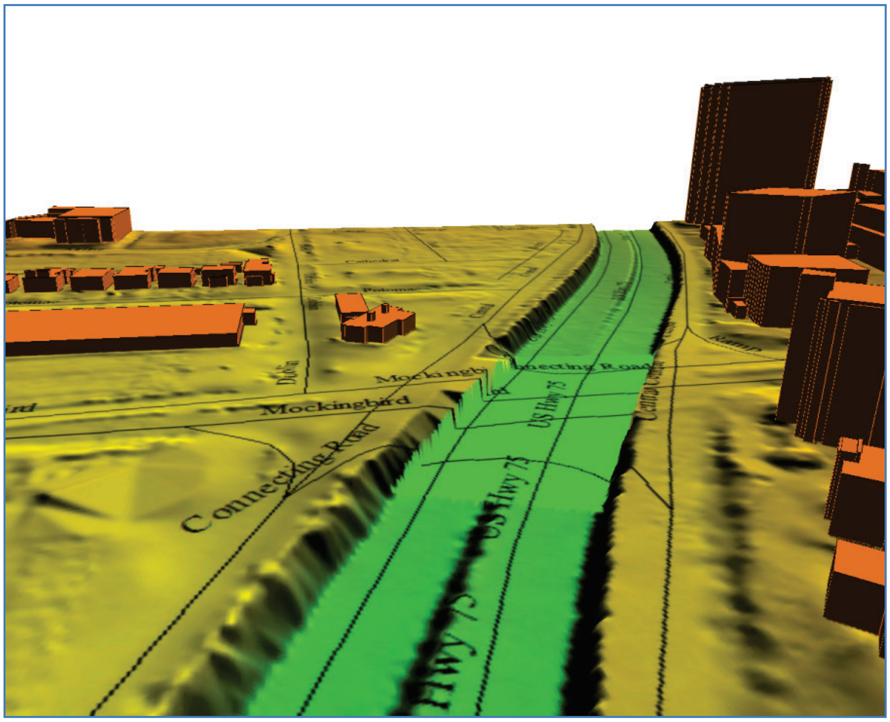


Figure 3.70. 3-D view of flattened area.



3.5.3 Save terrain with flattened areas to GeoTIFF

The terrain with the flattened portions may be selected and output as a 32-bit GeoTIFF file as described in Section 3.2.3.

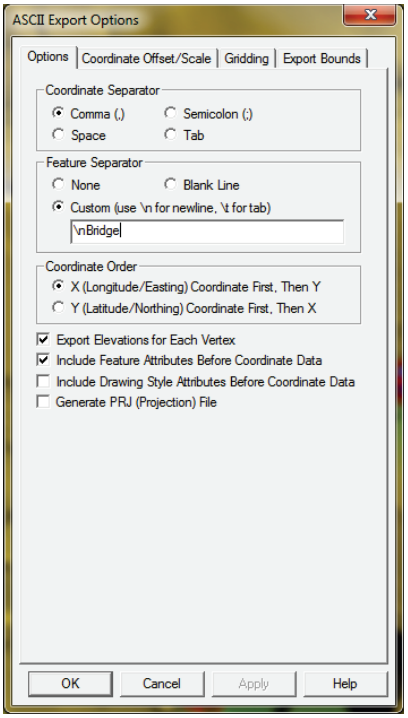
3.5.4 Create files for Urban Modeler

A piece of custom software, termed the Urban Modeler, was used to provide further processing of data obtained from Global Mapper. The vector information concerning bridge features can be output from Global Mapper in several vector file formats. The output of the data in the shapefile format is described in Section 3.3.8. The ASCII vector file format was chosen for ease of use with the Urban Modeler software.

To output data in the ASCII vector file format from Global Mapper:

1. The data should be exported in the UTM coordinate system for use with Urban Modeler and the MATLAB preprocessing routines. If the coordinate projection needs to be changed, follow the instructions in Section 3.2.3 and select the UTM coordinate projection.
2. Select the **Overlay Control Center** button from the main toolbar.
3. Turn on the bridge data layer(s) by checking the appropriate layers. Also turn on the clipping area.
4. Select the **Feature Info Tool** as shown in Figure 3.7 and click on the clip area to select it.
5. From the main menu, select **File** > **Export** > **Export Vector Format**.
6. From the dialog shown in Figure 3.52, select **Simple ASCII Text File**.
7. The **ASCII Export Options** dialog will appear as shown in Figure 3.71.
    a. Under **Coordinate Separator**, click **Comma**.
    b. Under **Feature Separator**, click **Custom** and then enter **\nBridge**. This causes a newline and the words **Bridge** to be written before each data record. Urban Modeler uses sets of key words to recognize types of data.
    c. Check **Export Elevation for Each Vertex**.
    d. Check **Include Feature Attributes Before Coordinate Data**.
    e. Check **Export Elevation for Each Vertex**.
    f. Check **Include Feature Attributes Before Coordinate Data**.
8. The default options on the other tabs may be left as the default.
9. Click **OK** and input a file name.

Figure 3.71. ASCII export options for bridges.



Coordinate Separator

● Comma (,) ○ Semicolon (;)
○ Space ○ Tab

Feature Separator

○ None ○ Blank Line
● Custom (use \n for newline, \t for tab)
\nBridge

Coordinate Order

● X (Longitude/Easting) Coordinate First, Then Y
○ Y (Latitude/Northing) Coordinate First, Then X

☑ Export Elevations for Each Vertex
☑ Include Feature Attributes Before Coordinate Data
☐ Include Drawing Style Attributes Before Coordinate Data
☐ Generate PRJ (Projection) File

3.6 Model other area features

The processing discussed in this chapter was specific to buildings, paved areas, and bridges. The information given may be used to process other types of area features, such as, water features or forested areas. These features were not specifically modeled in the study described in this report.

4 Run Urban Modeler to Produce CSV Files

A piece of custom software called the Urban Modeler was used to read in the sets of ASCII vector data that were output by Global Mapper as described in Chapter 3. The processing of this data corresponds to Step 4 in the process map of Figure 1.4. Urban Modeler was used to:

- Convert the units of vertical measurement of attributes to a common unit of meters.
- Check if islands exist in the data and write the island information out separately from the feature information.
- Break large sets of data (e.g., thousands of buildings) into many smaller sets of data to improve processing later in MATLAB.
- Process bridge information to compute the top and bottom elevation of the bridge features.
- Eliminate objects that have a small area (less than 1 m^2) or height (less than 2 m). ArcMap was used to provide this same functionality.
- Eliminate islands with a small (less than 1 m^2) or zero area.
- Produce data files for buildings and area features (i.e., paved features and bridges).
- Write GIS information out to ASCII comma separated variable (CSV) files for use with Microsoft Excel.

Islands represent open spaces in a larger area. That is, a building may exist with an interior courtyard, which can be modeled using an island. Paved areas, such as highways, may have interior open spaces that represent the medians. The network of streets may be represented as large solid areas with islands representing the city blocks. The islands must be written out separately to properly account for the material properties of the objects.

The CSV files produced by the Urban Modeler program define the structures (buildings and paved areas) that sit on the topography. These files are used in Microsoft Excel to define the object geometry and material properties for use with the MATLAB processing routines. The use of the Excel spreadsheets is described in Chapter 5.

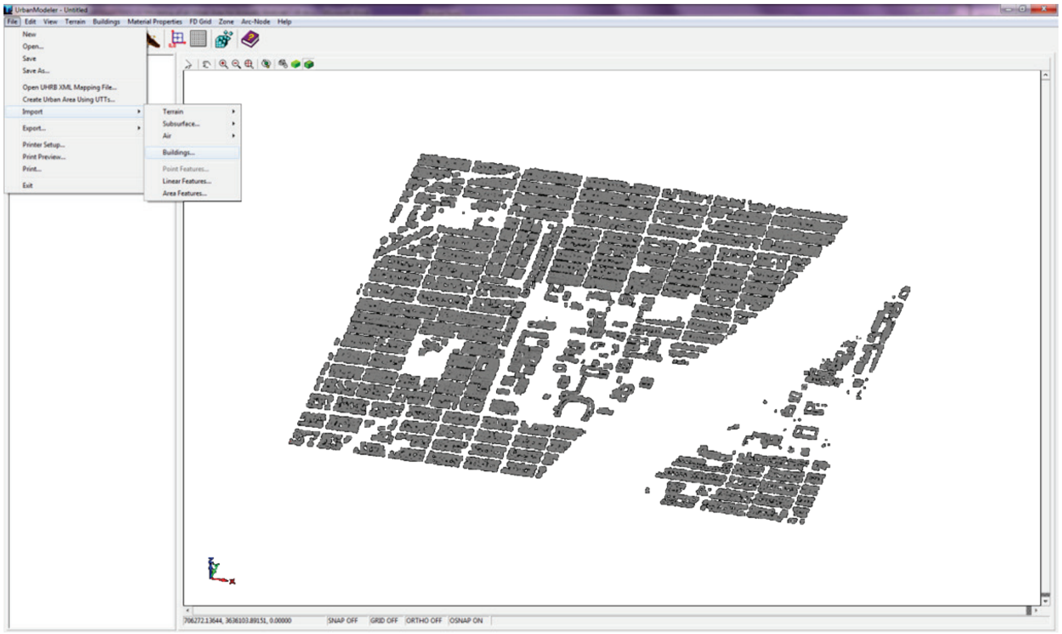
4.1 Produce CSV files for buildings

The building information produced by Global Mapper is input into the Urban Modeler program and processed as follows:

1. Select **File > Import > Buildings** to select an ASCII data file from Global Mapper containing building information as shown in Figure 4.1.
2. The dialog in Figure 4.2 will display. Click **OK**.
3. Repeat Steps 1 and 2 to continue to read in building files until all building data has been entered. The complete building data set is shown in Figure 4.3.
4. Select **FD Grid > Save Building Footprints to CSV**. This saves the footprint of the building features in a format necessary for the MATLAB preprocessing routines.
5. Input a file name.

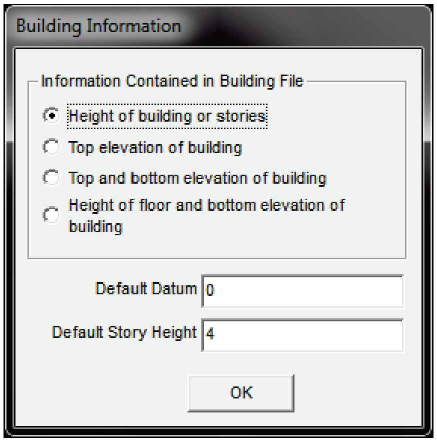
The buildings are saved to a CSV file for later use in Microsoft Excel. Multiple files are written depending upon the number of building objects. Files are written containing 3000 buildings per file. The file name contains the name of the CSV file entered plus an additional numeric designator identifying the number of the output file (e.g., buildings_away4.csv).

Figure 4.1. Reading building information into the Urban Modeler program.



706272.13644, 3636103.89151, 0.00000

Figure 4.2. Defining method used to denote height of building in input file.



Building Information

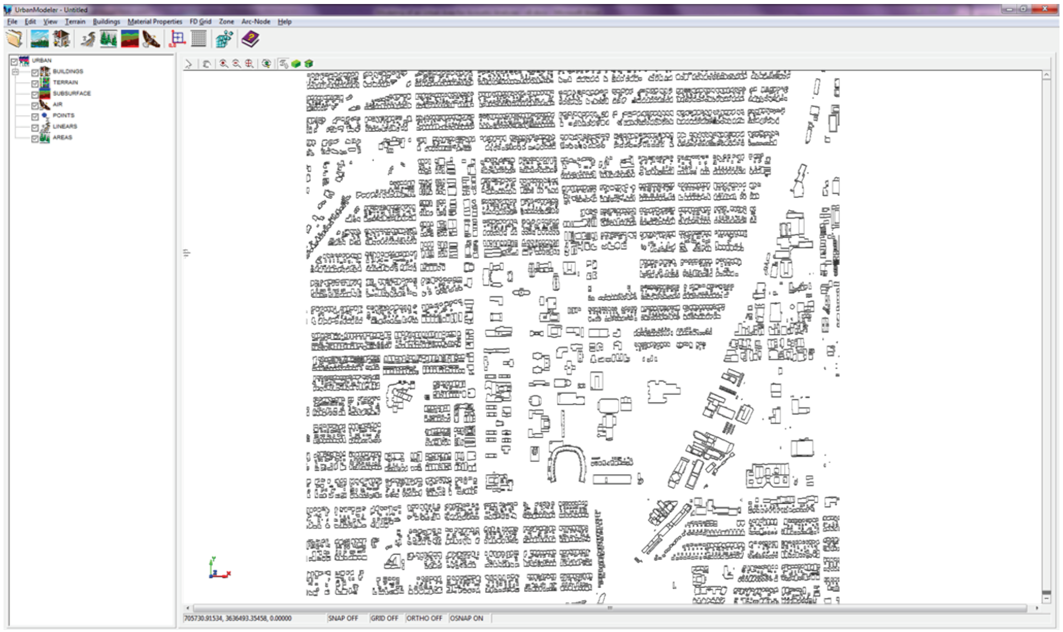
Information Contained in Building File

● Height of building or stories
○ Top elevation of building
○ Top and bottom elevation of building
○ Height of floor and bottom elevation of building

Default Datum: 0

Default Story Height: 4

Figure 4.3. Complete building data set.



4.2 Produce CSV files for areal features

The area feature information for both paved area and bridge features output by Global Mapper are processed by Urban Modeler to produce files necessary for the MATLAB preprocessing routines. The procedure to produce the files is as follows:

1. Select **File > Import > Area Features** to select an ASCII data file from Global Mapper containing the paved area or bridge information. Urban Modeler will ask if multiple files are to be read in based on a base name. This can be used to read in multiple files with a common base name. For

example, the paved area information consisted of 25 data sets with names ending in the letters A through E and numbers 1 through 5. Therefore, there were five files with the letter A, five files with the letter B, and so on. An example file name would be **PavedAreas_A4.txt**. To read in all files containing the letter A, the user would enter **PavedAreas_A.txt** when prompted for a file name.

2. Repeat Step 1 to continue to read in paved area or bridge files until all data have been entered. The user can read in a single input file and process the data or read in multiple input files and process many sets of data at once.
3. The complete paved area data set is shown in Figure 4.4. The yellow shaded areas are the islands. The bridge data are shown in Figure 4.5. The paved area and bridge data sets should be processed separately so that the resulting data can be written to separate files. This is needed because the file structure is not exactly the same for both sets of data.
4. Select **FD Grid > Save Area Sets to CSV**. This saves the footprint of the area features in a format necessary for the MATLAB preprocessing routines. The program will detect if islands are present and write out two files. One file will contain the area feature definitions while the other file with **-islands** appended to the file name will contain the island definitions. Urban Modeler will ask if one output file or multiple output files are to be written. If multiple output files are selected, area features will be written to separate output files with names based on the input file names read. For example, if five input files had been read in with the name **PavedAreas-A.txt** as discussed in Step 1, the output files would be named **PavedAreas_A.csv** and **PavedAreas_A-islands.csv**.
5. Input a file name to save the processed data sets.

All area features representing roads, streets, highways, parking lots, and medians are assigned a height of -2 m when processed. The negative height causes the area feature to be placed below the topography. This is explained in greater detail in Chapter 5.

Bridges features are defined by a perimeter. The points defining the perimeter of the bridge have z-coordinates taken from the topography and assigned by Global Mapper as discussed in Section 3.5.1. Urban Modeler uses these z-coordinates to compute a minimum elevation for the bridge. The thickness of the bridge is set to 2 m.

Figure 4.4. Paved area data set in Urban Modeler.

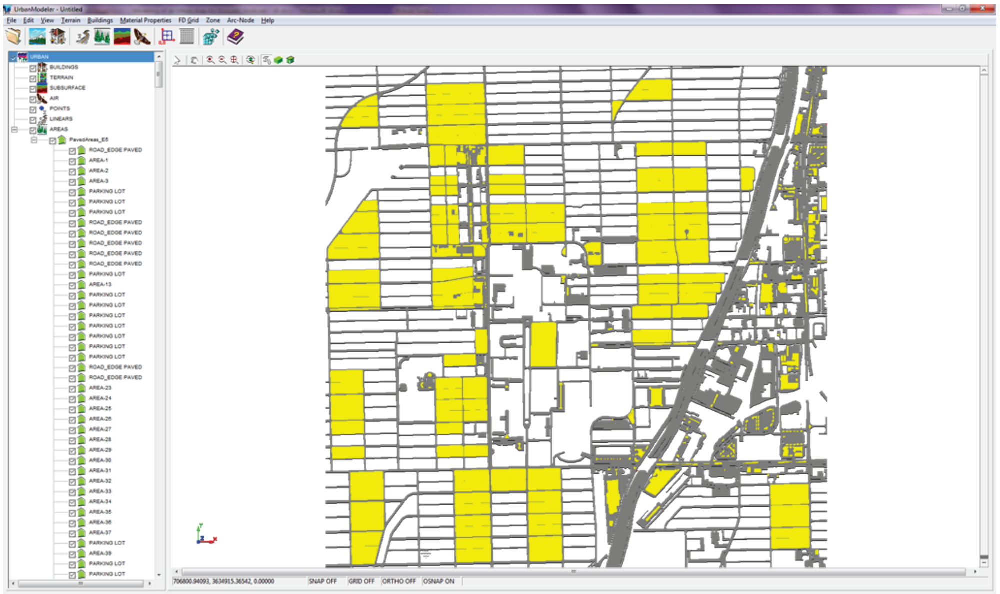
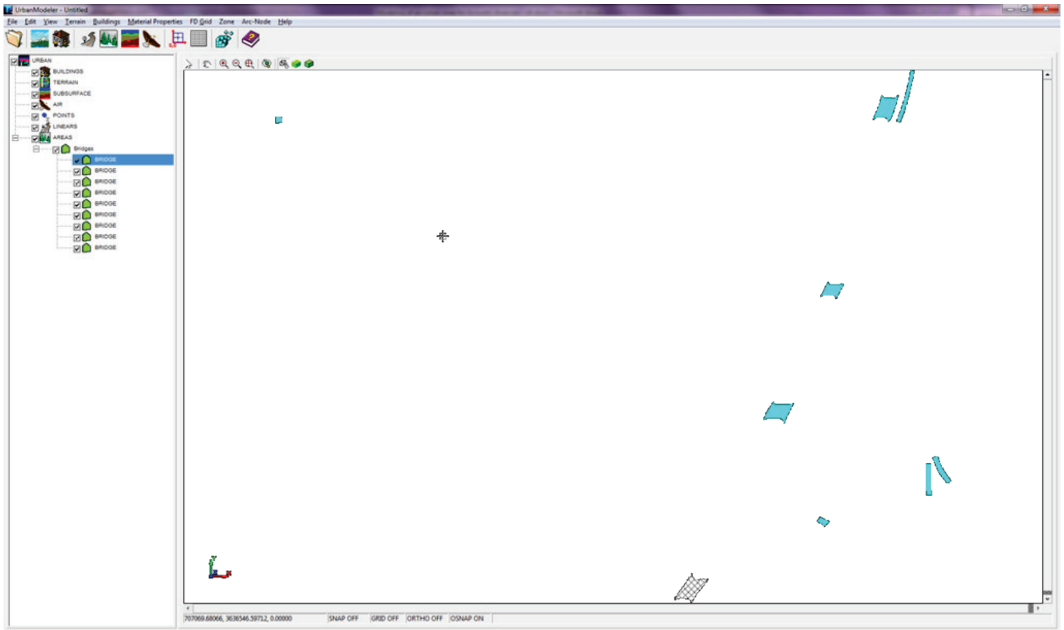


Figure 4.5. Bridge information displayed in Urban Modeler.



5 Use of Microsoft Excel to Describe Data

As described in Chapter 4, CSV files produced by the Urban Modeler program are used to aid in the definition of the urban area. The CSV files are inserted into various Excel spreadsheets to aid in defining auxiliary structures such as buildings, bridges, and paved areas. The Excel spreadsheets are also used to define the grid, air layers, material properties, and topography. The spreadsheets are used by the MATLAB preprocessing routines to construct the data files necessary to run the PSTOP3D program. This chapter explains the setup of the spreadsheets and corresponds to Step 5 of the process flowchart in Figure 1.4.

5.1 Open CSV files in Excel

Information contained within CSV files can easily be put into an Excel spreadsheet by opening the CSV file directly into Excel and copying the information into the appropriate spreadsheet. This can be done as follows:

1. Open the master Excel workbook containing the spreadsheet templates.
2. Double-click on the **CSV** file. The file will open in Excel.
3. Click on the first line of data.
4. Press **CTRL-SHIFT-END** to select all data.
5. Press **CTRL-C** to copy data.
6. Go to the specific spreadsheet required for the data (e.g., a building template) and press **CTRL-V** to paste the data into the sheet.
7. Repeat the above procedure for each CSV file.

5.2 General description of use of Excel spreadsheets

Excel spreadsheets are used to setup the definition of the data for the acoustic analysis. The spreadsheets are contained in an Excel workbook. There are several types of spreadsheets that control the setup of the acoustic analysis. For the acoustic analyses, the Excel workbook consists of spreadsheets to define the:

1. Problem setup.
2. Size of the grid used in the analysis.
3. Topography.

4. Air layers and type of material properties (e.g., poroacoustic) used in the analysis.
5. Auxiliary structures (e.g., buildings, paved areas, and bridges).

Some of the spreadsheets (e.g., the spreadsheet defining buildings) will consist of a top or header section that will not change and a lower section that will consist of the information contained in the CSV files generated by the Urban Modeler program.

The spreadsheets consist of various data items designated by command words with an associated value of the data item. The command words for the data items should be left as shown in the spreadsheets.

Each of these spreadsheets will be discussed in the following sections explaining the data items and options available for an acoustic analysis. The data items and options that are explained are the ones used in this study for acoustic analyses. More options exist than will be covered in this discussion; these options, for example, are for seismic analysis. Some options may be left blank as shown in the following sections.

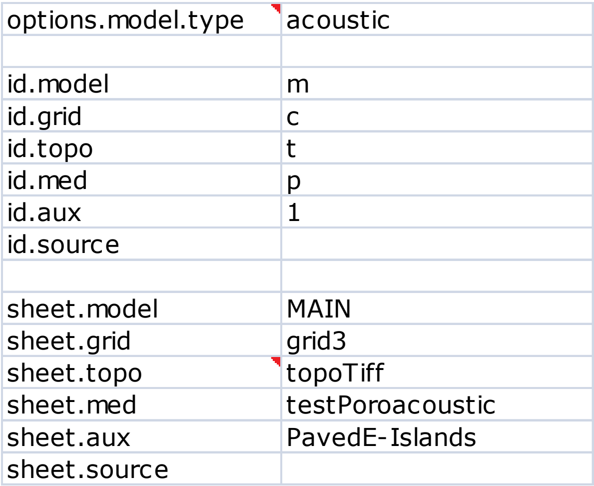
5.3 Main spreadsheet to describe problem setup

The spreadsheet shown in Figure 5.1 contains information that controls the naming of data files and the names of the spreadsheets used to define the problem.

The data items in the spreadsheet are defined as follows:

1. **options.model.type** should be set to acoustic to compute particle velocities and pressure fields.
2. **id.model** is a designator for the model being run.
3. **id.grid** is the name of the grid.
4. **id.topo** is the name of the topography.
5. **id.med** is the name of the medium.
6. **id.aux** is the name of the auxiliary structures.
7. **sheet.model** is the name of the sheet containing these definitions.
8. **sheet.grid** is the name of the sheet containing the definition of the finite difference grid.
9. **sheet.topo** is the sheet containing the definition of the topography.
10. **sheet.med** is the sheet defining the acoustic medium.
11. **sheet.aux** is the sheet defining the auxiliary structures such as buildings, paved areas, and bridges.

Figure 5.1. Main spreadsheet containing problem setup.



options.model.type	acoustic
id.model	m
id.grid	c
id.topo	t
id.med	p
id.aux	1
id.source	
sheet.model	MAIN
sheet.grid	grid3
sheet.topo	topoTiff
sheet.med	testPoroacoustic
sheet.aux	PavedE-Islands
sheet.source	

The **id** fields will be strung together to provide a unique name for the analysis and data files. This will be called the **MODELID**. The **MODELID** is a concatenation of the **id.model, id.grd**, **id.topo**, and **id.med** data items. For the spreadsheet shown in Figure 5.1, the **MODELID** is **mctp**. More than one character can be entered for an **id** field, but this would make the name longer.

More than one sheet name can be entered on the line for **sheet.aux**. For example, if there are eight sheets describing the buildings, eight sheet names can be entered on this line in the adjacent eight cells. There is an option in the auxiliary sheets that instructs MATLAB to modify the topography to include the tops of the auxiliary structures. For this to work correctly, all auxiliary structures must be loaded in memory at one time. Therefore, all of the sheets describing the structures must be entered on the **sheet.aux** line. This allows the extraction of results at a desired distance above the topography and the top of the auxiliary structures (e.g., the tops of the roofs of buildings). Otherwise, all results will be extracted for a specific elevation or a specific height above the topography. If the flag is used to modify the topography, but each auxiliary file is run separately by rerunning the MATLAB processing routines, the results will only be output at the top of the auxiliary structures for the last sheet processed.

The **sheet.topo** can be left blank to use zero topography, which is appropriate for propagation without a topographic surface. An example would be acoustic propagation well away from a topographic surface.

All sheet names used are case sensitive. That is, if a sheet is named **Building8** and **building8** is used on this sheet, an error will occur.

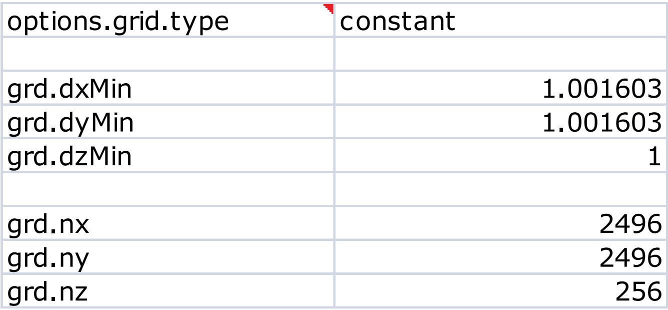
5.4 Spreadsheet to describe grid

The spreadsheet shown in Figure 5.2 contains information that controls the spacing and size of the finite difference grid. The options are:

1. **options.grid.type** can either be **constant** or **variable**. **Constant** specifies that the spacing between the grid points does not change and is a constant. **Variable** specifies that the spacing can vary by stretching transformations. Additional information is required to define a variable grid than is shown in Figure 5.2.
2. **grd.dxMin** is the spacing in the x direction.
3. **grd.dyMin** is the spacing in the y direction.
4. **grd.dzMin** is the spacing in the z direction.
5. **grd.nx** is the number of grid points in the x direction.
6. **grd.ny** is the number of grid points in the y direction.
7. **grd.nz** is the number of grid points in the z direction.

A variable grid could be used to provide for fewer grid points in areas were the wavelengths in the materials are larger based on the wave speed and target frequency (Ketcham et al. 2005). Since buildings covered the entire area under consideration is this analysis, a constant spacing was used. A larger spacing in the z direction could have been used above the tops of the buildings, but for simplicity a constant was used. The data items concerning a variable grid are not shown in Figure 5.2.

Figure 5.2. Definition of finite difference grid.



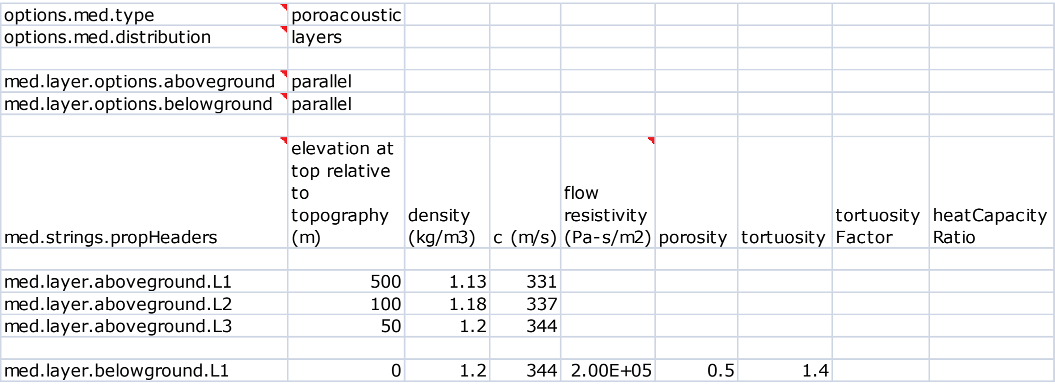
options.grid.type	constant
grd.dxMin	1.001603
grd.dyMin	1.001603
grd.dzMin	1
grd.nx	2496
grd.ny	2496
grd.nz	256

5.5 Spreadsheet to describe medium properties and layers

The spreadsheet shown in Figure 5.3 contains information that describes the medium material properties and air layering. The options are:

1. **options.med.type** sets the type of material being used for the medium. The options are **elastic**, **viscoelastic**, or **poroacoustic**. For the acoustic analyses, **poroacoustic** was used.
2. **options.med.distribution** specifies how the material properties are described. The options are **layers** or **point**.
3. **med.layer.options.aboveground** specifies how the above-ground layers are defined. The options are **parallel** and **horizontal**.
4. **med.layer.options.belowground** specifies how the below-ground layers are defined. The options are **parallel** and **horizontal**.
5. **med.strings.propHeaders** are the material property headers. They should remain as given.
6. **med.layer.aboveground.L1** specifies the material properties of the layer 1 above the ground surface. The layers are specified from the top down.
7. **med.layer.aboveground.L2** specifies the definition of layer 2 above the ground surface.
8. **med.layer.aboveground.L3** specifies the definition of layer 3 above the ground surface.
9. **med.layer.belowground.L1** specifies the definition of layer 1 below the ground surface.

Figure 5.3. Definition of medium properties and layers.



options.med.type	poroacoustic							
options.med.distribution	layers							
med.layer.options.aboveground	parallel							
med.layer.options.belowground	parallel							
med.strings.propHeaders	elevation at top relative to topography (m)	density (kg/m3)	c (m/s)	flow resistivity (Pa-s/m2)	porosity	tortuosity	tortuosity Factor	heatCapacity Ratio
med.layer.aboveground.L1	500	1.13	331					
med.layer.aboveground.L2	100	1.18	337					
med.layer.aboveground.L3	50	1.2	344					
med.layer.belowground.L1	0	1.2	344	2.00E+05	0.5	1.4		

The **layers** option defines the material distribution by horizontal, sloped (seismic), or parallel-to-topography layering. The **point** option defines the material distribution using a point-cloud distribution of materials, i.e., each node in the 3D volume is assigned an integer value representing a material.

The medium layers are defined using either the option **parallel** or **horizontal**. **Parallel** will define the layers parallel to the topography at the given height while **horizontal** will define the layers to be horizontal at the given height.

The sheet shown in Figure 5.3 has three above-ground air layers and one below-ground layer. More layers may be entered by adding additional lines in the sheet with a designation of **.aboveground.L#** or **.belowground.L#** where # is the layer number. All layers are defined using a height in meters above the topography.

The material properties entered for the above and below ground layers in this sheet are the default materials for the finite difference mesh. The material properties may be changed for regions of the grid based on the material properties of objects defined in other spreadsheets.

The poroacoustic material properties are explained in Wilson and Liu (2004) and given in Table 5.1. The material properties approximate a porous-ground reflecting/absorbing surface. From Figure 5.3, the material properties for a poroacoustic material for an acoustical analysis consist of the density, wave speed, and optional flow resistivity, porosity, and tortuosity parameters. The air layers have material properties consisting of the density and wave speed. The tortuosity factor and heat-capacity ratio properties were not used, and are therefore blank. The tortuosity factor defaults to 4/3 while the heat-capacity ratio defaults to 1.4. The density and wave-speed values entered should be for the fluid portion of the porous material (i.e., the fluid that fills the pores of the porous material).

Table 5.1. Porous material properties (Wilson and Liu 2004).

Material	Flow Resistivity Pa-s/m^2	Porosity	Tortuosity
Asphalt	3.00E+07	0.1	3.2
Grass	2.00E+05	0.5	1.4
Forest	1.00E+05	0.6	1.3
Sand	5.00E+04	0.35	1.6
Snow	1.00E+03	0.6	1.7

5.6 Spreadsheet to describe topography

The spreadsheet shown in Figure 5.4 contains information that describes the topography. The options are:

1. **options.topo.type** specifies how the topography is defined. The options are **geotiff** and **slope**.
2. **DEM.Filename** is the name of the GeoTIFF file.
3. **DEM.numZNodesAdjacent** is the number of nodes below the lowest ground elevation for the acoustic analysis.
4. **DEM.initial.gridRotation** specifies a rotation for the placement of the GeoTIFF file. The rotation is in degrees counterclockwise from the positive x-axis. This value can be changed in MATLAB.
5. **DEM.initial.xEAlign** specifies the x alignment of the GeoTIFF file. This value is the initial x and Easting values that the grid origin is aligned to. The grid origin starts at x=0. This value can be changed in MATLAB.
6. **DEM.initial.yNAlign** specifies the y alignment of the GeoTIFF file. This value is the initial y and Northing values that the grid origin is aligned to. The grid origin starts at y=0. This value can be changed in MATLAB.

Figure 5.4. Definition of topography.

options.topo.type	geotiff		
DEM.Filename	ElevLIDAR2010-latlon-bridges-2500.tif		
DEM.numZNodesAdjacent	20		
DEM.initial.gridRotation			
DEM.initial.xEAlign			
DEM.initial.yNAlign			

The topography can be defined by the option **slope**, which would create horizontal or sloped flat models. The **geotiff** option specifies the topography defined by a GeoTIFF file. Global Mapper can output a GeoTIFF as described in Chapter 3.

The **DEM.numZNodesAdjacent** option specifies the number of nodes below the lowest ground elevation for the acoustic analysis. This number of nodes should also accommodate the absorbing boundary condition. The thickness of the perfectly matched layer (PML) is hardcoded to 10 nodes in MATLAB. Therefore, the value of 20 entered in the sheet includes 10 nodes below the lowest elevation and 10 nodes for the perfectly matched layer. The PML is the same on all sides of the mesh.

The values for the placement of the GeoTIFF were left blank and entered when running the MATLAB preprocessing routines.

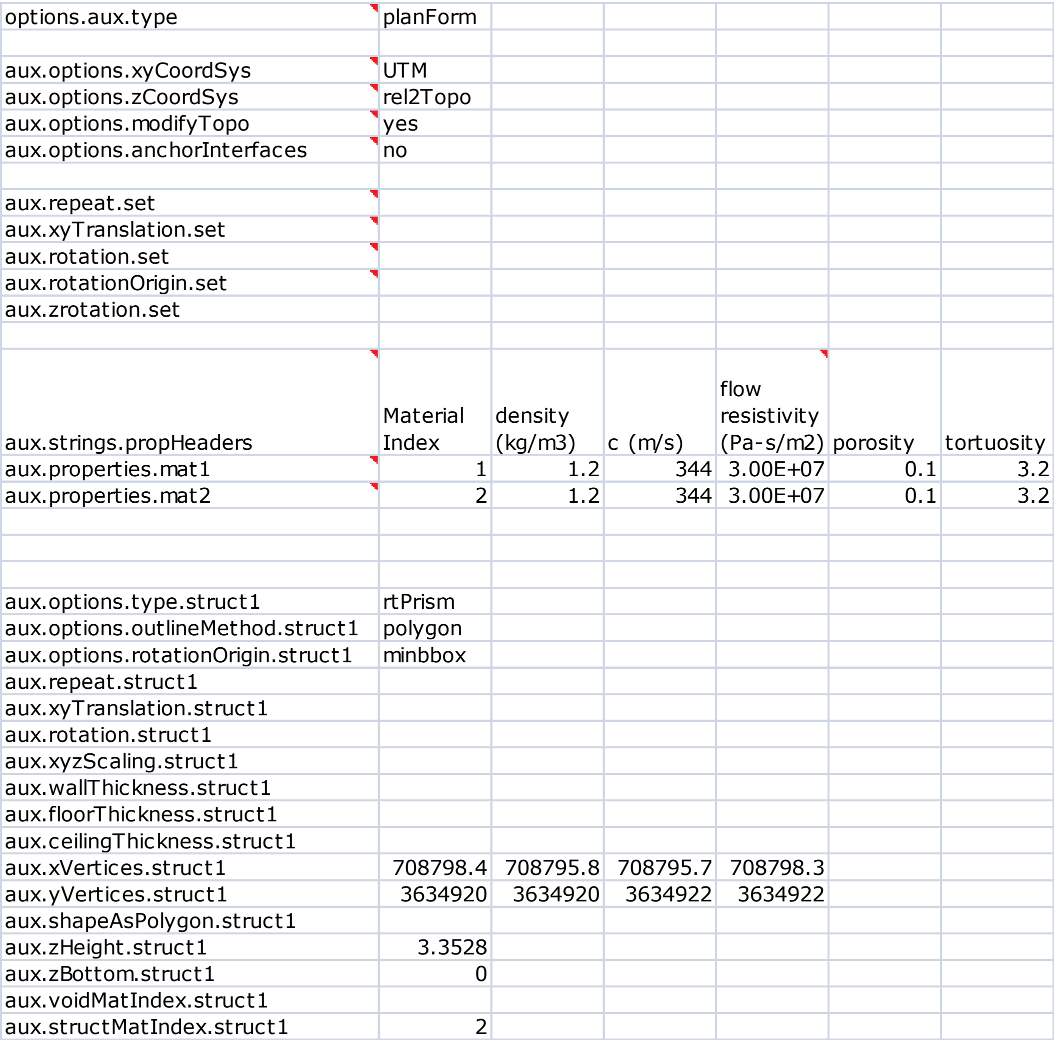
5.7 Spreadsheet to describe buildings

The spreadsheet shown in Figure 5.5 contains information that describes the buildings. Multiple spreadsheets may be used to describe parts of the total building data set. The options are:

1. **options.aux.type** specifies how auxiliary structures are described. The options are **vtk3DFV**, **planForm**, and **landCoverGeoTiff**. For buildings, **planForm** was used.
2. **aux.options.xyCoordSys** defines the coordinate system for the buildings. This option is either **model** or **UTM**. For buildings, **UTM** was used.
3. **aux.options.zCoordSys** defines how the z elevation is defined. The options are **rel2ModelZero**, **rel2SeaLevel**, and **rel2Topo**. For buildings, **rel2Topo** was used.
4. **aux.options.modifyTopo** indicates whether the original topography should be modified to include the tops of the buildings. **Yes** or **no** are the options. For buildings, **yes** was used.
5. **aux.options.anchorInterfaces** indicates whether the footprint of a structure is aligned to the FD grid. Options **yes** or **no** can be chosen. For buildings, **no** was used.
6. **aux.strings.propHeaders** are the strings defining the material properties and should be left as shown.
7. **aux.properties.mat1** specifies the material properties of material 1. The material entered represents asphalt (Table 5.1).
8. **aux.properties.mat2** specifies the material properties of material 2. The material entered represents asphalt (Table 5.1).
9. **aux.options.type.struct1** specifies how the structures are created. The options are **rtPrism** and **surfFeat**. For buildings, **rtPrism** was used.
10. **aux.options.outlineMethod.struct1** specifies the outline method for the structure. The options are **polygon**, **rectAsPolygon**, **circleAsPolygon**, or **ellipseAsPolygon**. For buildings, **polygon** was used.
11. **aux.options.rotationOrigin.struct1** defines the rotation point for the structure. The options are **minBBox** and **centroid**. For buildings, **minBBox** was used.
12. **aux.xVertices.struct1** are the x vertices of the polygon defining the structure. The vertices are listed horizontally in cells adjacent to the data option.

13. **aux.yVertices.struct1** are the x vertices of the polygon defining the structure. The vertices are listed horizontally in cells adjacent to the data option.
14. **aux.zHeight.struct1** is the height of the structure in meters.
15. **aux.zBottom.struct1** is the bottom elevation of the structure in meters.
16. **aux.structMatIndex.struct1** is the number of the material property applied to this structure.

Figure 5.5. Definition of buildings.



options.aux.type	planForm					
aux.options.xyCoordSys	UTM					
aux.options.zCoordSys	rel2Topo					
aux.options.modifyTopo	yes					
aux.options.anchorInterfaces	no					
aux.repeat.set						
aux.xyTranslation.set						
aux.rotation.set						
aux.rotationOrigin.set						
aux.zrotation.set						
aux.strings.propHeaders	Material Index	density (kg/m3)	c (m/s)	flow resistivity (Pa-s/m2)	porosity	tortuosity
aux.properties.mat1	1	1.2	344	3.00E+07	0.1	3.2
aux.properties.mat2	2	1.2	344	3.00E+07	0.1	3.2
aux.options.type.struct1	rtPrism					
aux.options.outlineMethod.struct1	polygon					
aux.options.rotationOrigin.struct1	minbbox					
aux.repeat.struct1						
aux.xyTranslation.struct1						
aux.rotation.struct1						
aux.xyzScaling.struct1						
aux.wallThickness.struct1						
aux.floorThickness.struct1						
aux.ceilingThickness.struct1						
aux.xVertices.struct1	708798.4	708795.8	708795.7	708798.3		
aux.yVertices.struct1	3634920	3634920	3634922	3634922		
aux.shapeAsPolygon.struct1						
aux.zHeight.struct1	3.3528					
aux.zBottom.struct1	0					
aux.voidMatIndex.struct1						
aux.structMatIndex.struct1	2					

The PSTOP3D program and the MATLAB processing routines refer to any structures that sit on or under the topography as auxiliary structures. The option **vtk3DFV** allows 3-D structures to be defined using the Visualization Toolkit (VTK) format from Kitware (Kitware 2014). This is a file format for describing the face and vertex data of the 3-D structure. The **planForm** option allows the definition of a structure by extruding an outline in the x-y plane. Objects can either have a thickness and z-extents relative to the surface topography or extrude in the z-direction as right prisms. The **landCoverGeoTiff** option allows for surface features to be defined based on a USGS land cover geoTIFF file. The **planForm** option is used in this study to model the buildings and surface features.

The **model** option specifies coordinates relative to the model origin (x=0, y=0), where the **UTM** option specifies coordinates in the UTM coordinate system. For the acoustic analyses, the UTM coordinate system was easier to use since the GIS output was in UTM coordinates.

The **rel2ModelZero** option specifies the z values relative to z=0 (the model origin). The **rel2SeaLevel** option specifies the z values relative to sea level, which is useful with UTM coordinates and known topographic elevations. The **rel2Topo** option specifies the z values relative to the lowest topography value within the object footprint.

For the acoustic analyses, the **rel2Topo** option worked best. Since a height value was specified for each building, this height was relative to the topography. Placing the building at the z elevation of the lowest elevation within the building footprint ensures that the bottom of the building is not above the terrain anywhere within the footprint. This option best models the actual building placement.

The .**modifyTopo** data item can be used to modify the original topography to include the tops of the buildings. PSTOP3D will use this modified topography when saving slice data relative to the topography, which is useful if the results at the tops of the buildings are desired. To modify the topography correctly, all buildings must be listed on the main setup sheet as discussed in Section 5.3. Two files are created when this spreadsheet is processed by MATLAB. The first file ends with **_geo.dat.0.origtopo** and is the original topography that has not been modified, the second file ends with **_geo.dat.0.2Doutotpo** and is the modified topography.

The .**anchorInterfaces** data item can be used to anchor a polygon's x-y vertices at material interface grid locations; otherwise, the vertices are free-floating. This can be used to make the buildings exactly line up with the FD grid nodes. For the acoustic analyses, the vertices were left free-floating.

The .**type.struct1** data item for the auxiliary structures can be **rtPrism** (right prism) or **surfFeat** (surface feature). The **rtPrism** option indicates that the structure should be defined by extruding a polygon that defines the footprint of the object. The polygon will have a horizontal (flat) bottom and top. The **surFeat** option indicates that the object has a designated thickness and follows the topography. The buildings for the acoustic analyses used the **rtPrism** option.

The **.struct1** ending on the data items means that the data item is for structure number 1. Many structures can be defined on one sheet and the data items would simply repeat themselves but with an ending of **.struct#,** where # is the number of the structure being defined.

The **.outlineMethod** specifies how the coordinates of the object are defined. The **polygon** option allows the polygon vertices to be entered directly. The other options allow shapes to be used to define the structure coordinates. Since the building footprint vertices are known, the **polygon** option was the easiest to use.

The **.rotationOrigin** data item can be **minBBox** to use the origin of the bounding box for the structure or **centroid** to use the centroid of the polygon. For the acoustical analyses, the placement of the buildings was from the actual building layout; therefore, buildings did not need to be rotated. A value is required, so **minBBox** was used.

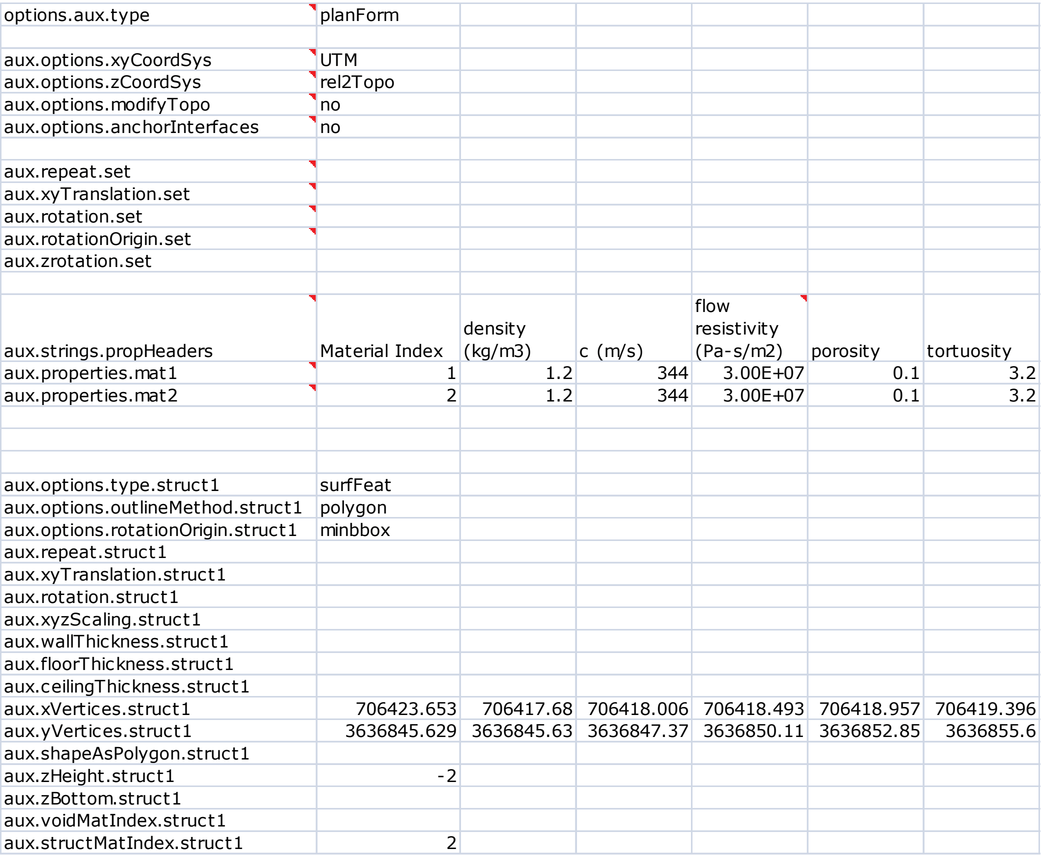
The .**zheight** is the height of the object above the object's bottom for right prisms or the height of the surface above the topography for the surface feature. The **.zheight** will be positive (+) for buildings. The **.zbottom** data item is used for buildings (right prisms) and is blank for surface features.

5.8 Spreadsheet to describe paved areas

The Urban Modeler program will output two files for area features: one file will contain information for the area features, while the other file will contain information for the islands. The spreadsheet shown in Figure 5.6 contains information that describes the paved areas representing roads, streets, highways, parking lots, and medians. The data items and options are similar to the ones discussed for buildings in Section 5.7. The differences in data items are:

1. **aux.options.zCoordSys** is given a value but is not used for paved areas which are modeled as surface features.
2. **aux.options.modifyTopo** is set to **no**.
3. **aux.options.type.struct1** is set to **surfFeat**.
4. **aux.zHeight.struct1** is set to **-2** m.
5. **aux.zBottom.struct1** is left blank.

Figure 5.6. Definition of paved areas.



options.aux.type	planForm					
aux.options.xyCoordSys	UTM					
aux.options.zCoordSys	rel2Topo					
aux.options.modifyTopo	no					
aux.options.anchorInterfaces	no					
aux.repeat.set						
aux.xyTranslation.set						
aux.rotation.set						
aux.rotationOrigin.set						
aux.zrotation.set						
aux.strings.propHeaders	Material Index	density (kg/m3)	c (m/s)	flow resistivity (Pa-s/m2)	porosity	tortuosity
aux.properties.mat1	1	1.2	344	3.00E+07	0.1	3.2
aux.properties.mat2	2	1.2	344	3.00E+07	0.1	3.2
aux.options.type.struct1	surfFeat					
aux.options.outlineMethod.struct1	polygon					
aux.options.rotationOrigin.struct1	minbbox					
aux.repeat.struct1						
aux.xyTranslation.struct1						
aux.rotation.struct1						
aux.xyzScaling.struct1						
aux.wallThickness.struct1						
aux.floorThickness.struct1						
aux.ceilingThickness.struct1						
aux.xVertices.struct1	706423.653	706417.68	706418.006	706418.493	706418.957	706419.396
aux.yVertices.struct1	3636845.629	3636845.63	3636847.37	3636850.11	3636852.85	3636855.6
aux.shapeAsPolygon.struct1						
aux.zHeight.struct1	-2					
aux.zBottom.struct1						
aux.voidMatIndex.struct1						
aux.structMatIndex.struct1	2					

The **.modifyTopo** data item is set to **no**. This item is usually used for buildings.

The **.type.struct1** data item for the auxiliary structures is set to **surfFeat** (surface feature). The **surFeat** option indicates that the object has a designated thickness and follows the topography. Since the paved areas essentially follow the topography, this option adequately models the paved features.

The **.zheight** is the height of the surface above the topography for a surface feature. The **.zheight** will be positive (+) for surface features above the topography and negative (-) for surface features below the topography. The **.zbottom** data item is not used for surface features and is left blank.

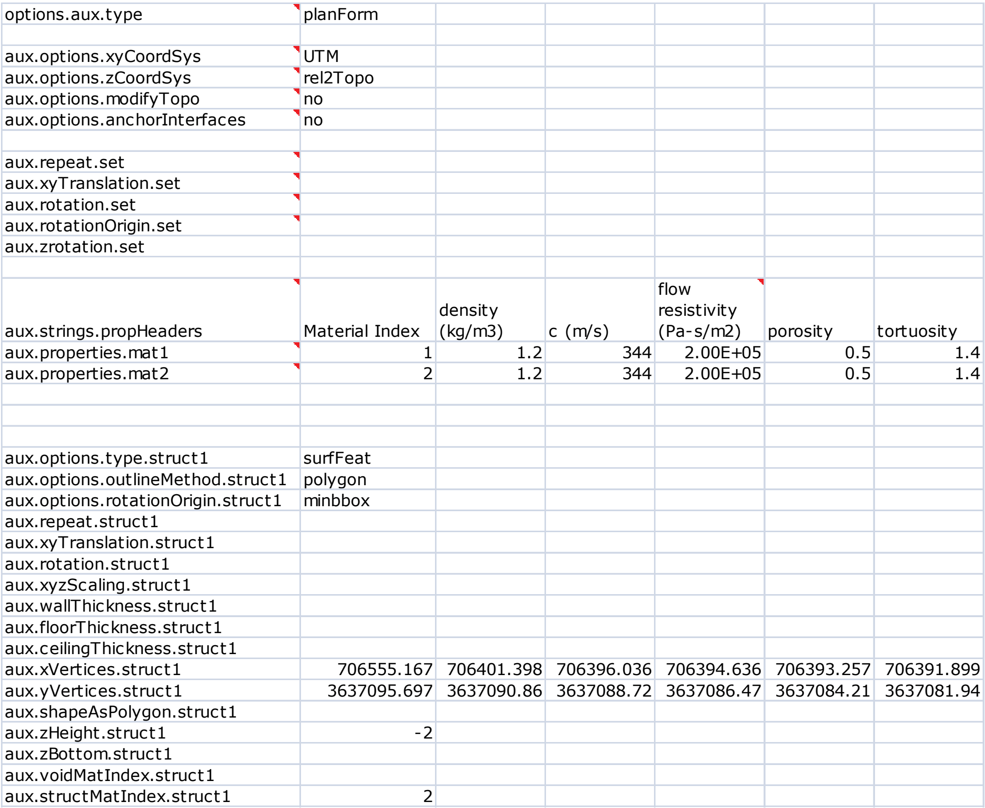
The GIS information defining the paved areas contains what are known as islands. The islands are essentially holes specified in larger complex polygons. That is, a large rectangular polygon could be defined that represents a road network. Islands would model the places where the streets are not present, essentially cutting out regions that would define a city block. Example islands are shown in Figure 4.4. The process to save paved area information including the islands is discussed in Section 3.4.5.

The definition of the islands is the same as the paved areas except a different material property is used to model the islands. Since the islands are essentially a hole into the underlying topography, the islands are assigned a material property of grass as given in Table 5.1 and shown in Figure 5.7. Therefore, the data items in Figure 5.7 that are different for an island versus a paved area are:

1. **aux.properties.mat1** specifies the material properties of material 1. The material entered represents grass (Table 5.1).
2. **aux.properties.mat2** specifies the material properties of material 2. The material entered represents grass (Table 5.1).

The islands can be detected using Global Mapper as discussed in Section 3.4.4 and with Urban Modeler as discussed in Section 4.2. There may be differences between the two sets of islands seen in Global Mapper versus Urban Modeler. The differences arise because of the processing of the data when saving the paved-area information from Global Mapper. If the paved areas are output using a grid as discussed in Section 3.4.5, the features are split along the grid lines. Any islands that are split by a grid line will disappear. This is because the grid line separates the feature surrounding the island into two separate features that do not require the use of an island.

Figure 5.7. Definition of islands in paved areas.



options.aux.type	planForm					
aux.options.xyCoordSys	UTM					
aux.options.zCoordSys	rel2Topo					
aux.options.modifyTopo	no					
aux.options.anchorInterfaces	no					
aux.repeat.set						
aux.xyTranslation.set						
aux.rotation.set						
aux.rotationOrigin.set						
aux.zrotation.set						
aux.strings.propHeaders	Material Index	density (kg/m3)	c (m/s)	flow resistivity (Pa-s/m2)	porosity	tortuosity
aux.properties.mat1	1	1.2	344	2.00E+05	0.5	1.4
aux.properties.mat2	2	1.2	344	2.00E+05	0.5	1.4
aux.options.type.struct1	surfFeat					
aux.options.outlineMethod.struct1	polygon					
aux.options.rotationOrigin.struct1	minbbox					
aux.repeat.struct1						
aux.xyTranslation.struct1						
aux.rotation.struct1						
aux.xyzScaling.struct1						
aux.wallThickness.struct1						
aux.floorThickness.struct1						
aux.ceilingThickness.struct1						
aux.xVertices.struct1	706555.167	706401.398	706396.036	706394.636	706393.257	706391.899
aux.yVertices.struct1	3637095.697	3637090.86	3637088.72	3637086.47	3637084.21	3637081.94
aux.shapeAsPolygon.struct1						
aux.zHeight.struct1	-2					
aux.zBottom.struct1						
aux.voidMatIndex.struct1						
aux.structMatIndex.struct1	2					

5.9 Spreadsheet to describe bridges

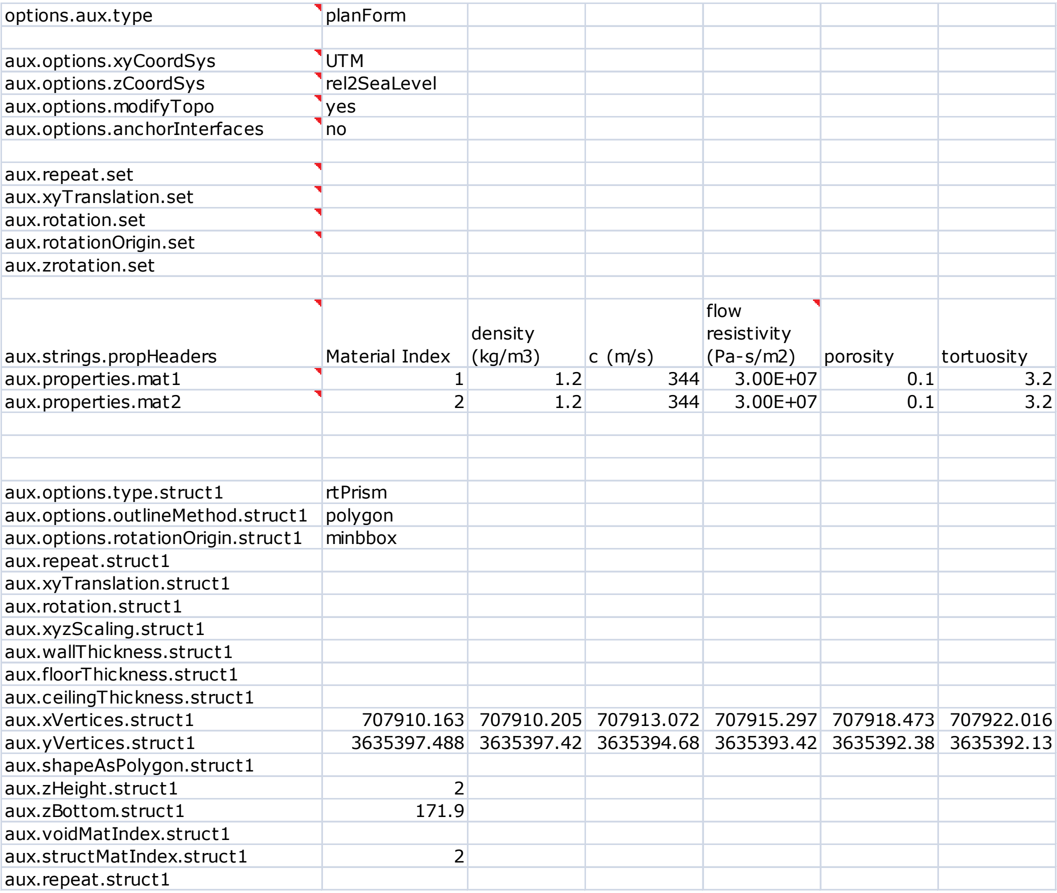
The spreadsheet shown in Figure 5.8 contains information that describes the bridge objects. The data items and options are similar to the ones discussed for buildings in Section 5.7. The differences in data items are:

1. **aux.options.zCoordSys** is set to r**el2SeaLevel**.
2. **aux.zHeight.struct1** is the height of the structure in meters.
3. **aux.zBottom.struct1** is the bottom elevation of the structure in meters.

The **rel2SeaLevel** option specifies the z values relative to sea level, which is useful with UTM coordinates and known topographic elevations. For bridges, the Urban Modeler program computes a minimum elevation of the bridge based on the z-coordinates assigned to the bridge vertices by Global Mapper as discussed in Section 3.5.1. This minimum elevation is the **.zbottom** data item. Since this elevation is in UTM coordinates, the **rel2SeaLevel** option works best.

Bridges use the **rtPrism** (right prism) option as described Section 5.7. The .**zheight** is the height of the object above the object's bottom for right prisms. For bridges, **.zheight** is assigned a value of 2 m.

Figure 5.8. Definition of bridge objects.



options.aux.type	planForm					
aux.options.xyCoordSys	UTM					
aux.options.zCoordSys	rel2SeaLevel					
aux.options.modifyTopo	yes					
aux.options.anchorInterfaces	no					
aux.repeat.set						
aux.xyTranslation.set						
aux.rotation.set						
aux.rotationOrigin.set						
aux.zrotation.set						
aux.strings.propHeaders	Material Index	density (kg/m3)	c (m/s)	flow resistivity (Pa-s/m2)	porosity	tortuosity
aux.properties.mat1	1	1.2	344	3.00E+07	0.1	3.2
aux.properties.mat2	2	1.2	344	3.00E+07	0.1	3.2
aux.options.type.struct1	rtPrism					
aux.options.outlineMethod.struct1	polygon					
aux.options.rotationOrigin.struct1	minbbox					
aux.repeat.struct1						
aux.xyTranslation.struct1						
aux.rotation.struct1						
aux.xyzScaling.struct1						
aux.wallThickness.struct1						
aux.floorThickness.struct1						
aux.ceilingThickness.struct1						
aux.xVertices.struct1	707910.163	707910.205	707913.072	707915.297	707918.473	707922.016
aux.yVertices.struct1	3635397.488	3635397.42	3635394.68	3635393.42	3635392.38	3635392.13
aux.shapeAsPolygon.struct1						
aux.zHeight.struct1	2					
aux.zBottom.struct1	171.9					
aux.voidMatIndex.struct1						
aux.structMatIndex.struct1	2					
aux.repeat.struct1						

6 Run MATLAB to Produce PSTOP3D Data Files

6.1 General

Once the Excel spreadsheets are composed, the MATLAB preprocessing routines can be run. This corresponds to Step 6 on the process diagram in Figure 1.4. To run the MATLAB routines:

1. Execute MATLAB in Windows.
2. On the main MATLAB screen shown in Figure 6.1, navigate to the directory where the scripts are installed. The main script to execute is called rvgModel.m.
3. The path may need to be changed to include the directory and sub-directories where the scripts are installed. On the **Home** tab, click the **Set Path** button.
4. As shown in Figure 6.2, click **Add with Subfolders** and select the appropriate directory. Click **Save**.
5. Double-click on the **rvgModel.m** script shown in Figure 6.1.
6. The editor with rvgModel.m will appear as shown in Figure 6.3. Click on the **Run** button on the main toolbar.
7. The main menu for the processing routines will appear as shown in Figure 6.4.
8. On the menu, select the button **Select spreadsheet with input data**.
9. Navigate to where the spreadsheet is saved and click on the file.

The menu in Figure 6.4 references the Excel 1995 format. If the spreadsheet is in the Excel 1995 format, the spreadsheet can only contain 16,384 rows (lines). The amount of data that needs to be stored in the spreadsheets exceeded these limits. Since the processing was performed on a Windows 7 machine, the Excel 2007 format was a better format to use. The Excel 2007 format allows 1 million lines per spreadsheet.

The processing of the spreadsheets is performed in the order of the buttons on the menu in Figure 6.4. Therefore, click the buttons and perform the processing from the top of the menu downward.

Figure 6.1. Main MATLAB screen.

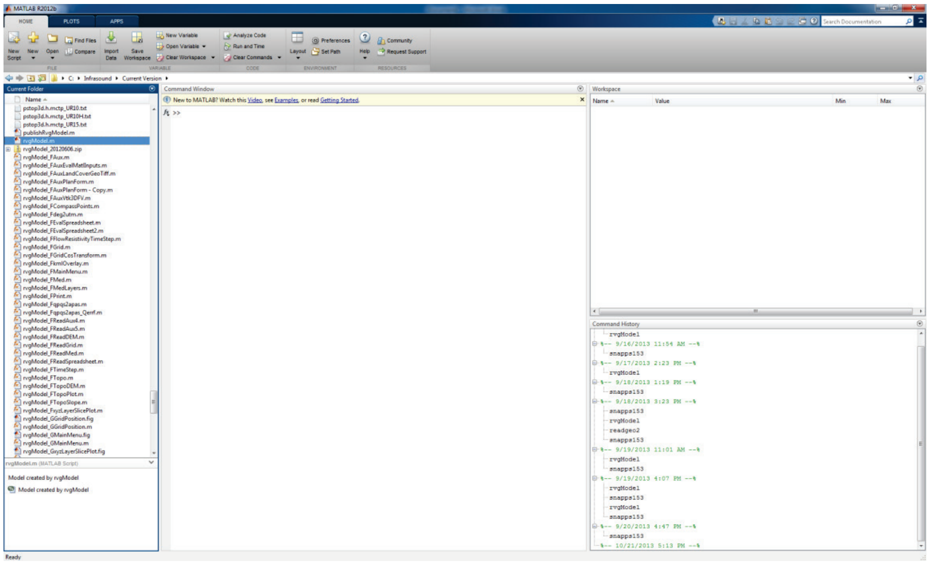
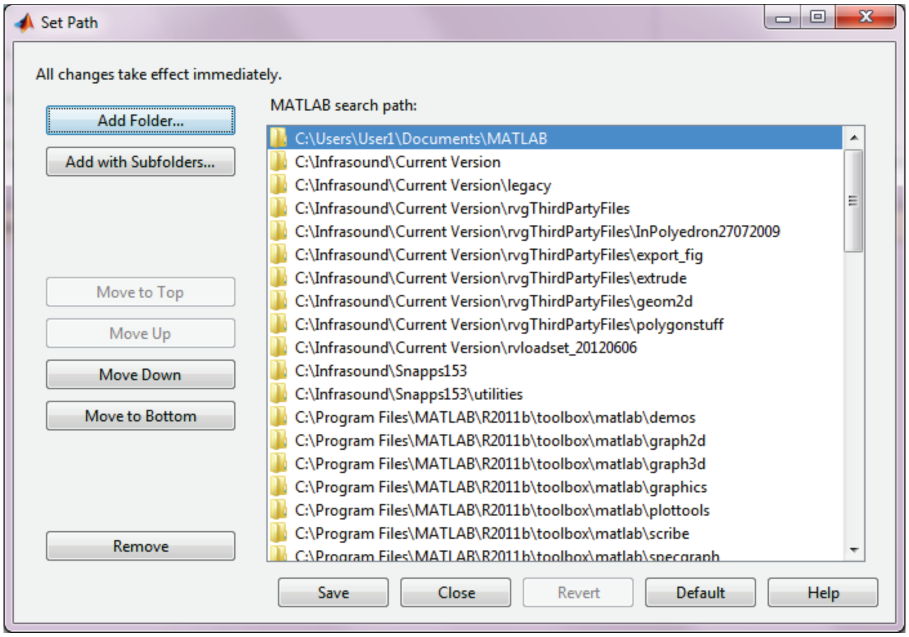


Figure 6.2. Set path for MATLAB.

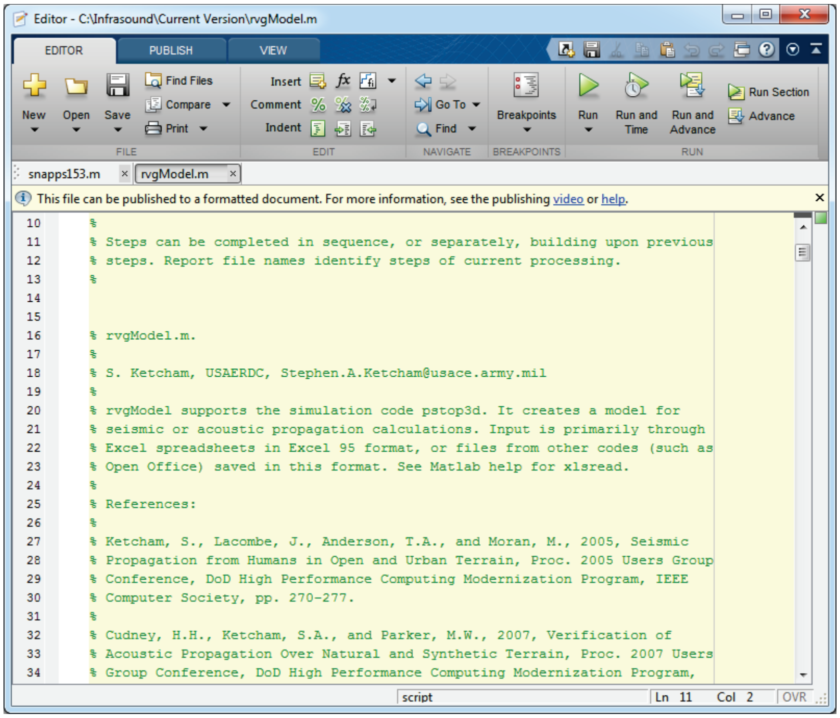


All changes take effect immediately.

MATLAB search path:

C:\Users\User1\Documents\MATLAB
C:\Infrasound\Current Version
C:\Infrasound\Current Version\legacy
C:\Infrasound\Current Version\rvgThirdPartyFiles
C:\Infrasound\Current Version\rvgThirdPartyFiles\InPolyedron27072009
C:\Infrasound\Current Version\rvgThirdPartyFiles\export_fig
C:\Infrasound\Current Version\rvgThirdPartyFiles\extrude
C:\Infrasound\Current Version\rvgThirdPartyFiles\geom2d
C:\Infrasound\Current Version\rvgThirdPartyFiles\polygonstuff
C:\Infrasound\Current Version\rvloadset_20120606
C:\Infrasound\Snapps153
C:\Infrasound\Snapps153\utilities
C:\Program Files\MATLAB\R2011b\toolbox\matlab\demos
C:\Program Files\MATLAB\R2011b\toolbox\matlab\graph2d
C:\Program Files\MATLAB\R2011b\toolbox\matlab\graph3d
C:\Program Files\MATLAB\R2011b\toolbox\matlab\graphics
C:\Program Files\MATLAB\R2011b\toolbox\matlab\plottools
C:\Program Files\MATLAB\R2011b\toolbox\matlab\scribe
C:\Program Files\MATLAB\R2011b\toolbox\matlab\specgraph

Figure 6.3. Running rvgModel.m.



This file can be published to a formatted document. For more information, see the publishing video or help.

```
%
% Steps can be completed in sequence, or separately, building upon previous
% steps. Report file names identify steps of current processing.
%


% rvgModel.m.
%
% S. Ketcham, USAERDC, Stephen.A.Ketcham@usace.army.mil
%
% rvgModel supports the simulation code pstop3d. It creates a model for
% seismic or acoustic propagation calculations. Input is primarily through
% Excel spreadsheets in Excel 95 format, or files from other codes (such as
% Open Office) saved in this format. See Matlab help for xlsread.
%
% References:
%
% Ketcham, S., Lacombe, J., Anderson, T.A., and Moran, M., 2005, Seismic
% Propagation from Humans in Open and Urban Terrain, Proc. 2005 Users Group
% Conference, DoD High Performance Computing Modernization Program, IEEE
% Computer Society, pp. 270-277.
%
% Cudney, H.H., Ketcham, S.A., and Parker, M.W., 2007, Verification of
% Acoustic Propagation Over Natural and Synthetic Terrain, Proc. 2007 Users
% Group Conference, DoD High Performance Computing Modernization Program,
```

Figure 6.4. Main menu for MATLAB preprocessing routines.

This code supports the parallel FDTD code pstop3d. It creates a model for seismic or acoustic propagation calculations.

Input is primarily through Excel spreadsheets in Excel 95 format, or files from other codes (such as Open Office) saved as such.

S. Ketcham, USAERDC, Stephen.A.Ketcham@usace.army.mil

6.2 Generate grid

To generate the grid, click the **Generate grid** button shown in Figure 6.4. The plots shown in Figures 6.5 through 6.7 will display. These plots display the variable grid parameters for the grid, which is the relationship between the stretching transformations and the physical grid. The relationship is seen to be linear from the figures and the derivative is a constant value of 1, denoting a one-to-one relationship between the transformed grid and the physical grid. These parameters describe constant grid spacing.

After the grid is processed, the informational dialog shown in Figure 6.8 is displayed that reports the limits of the grid.

Figure 6.5. Variable grid parameters denoting a constant grid in the x-direction.

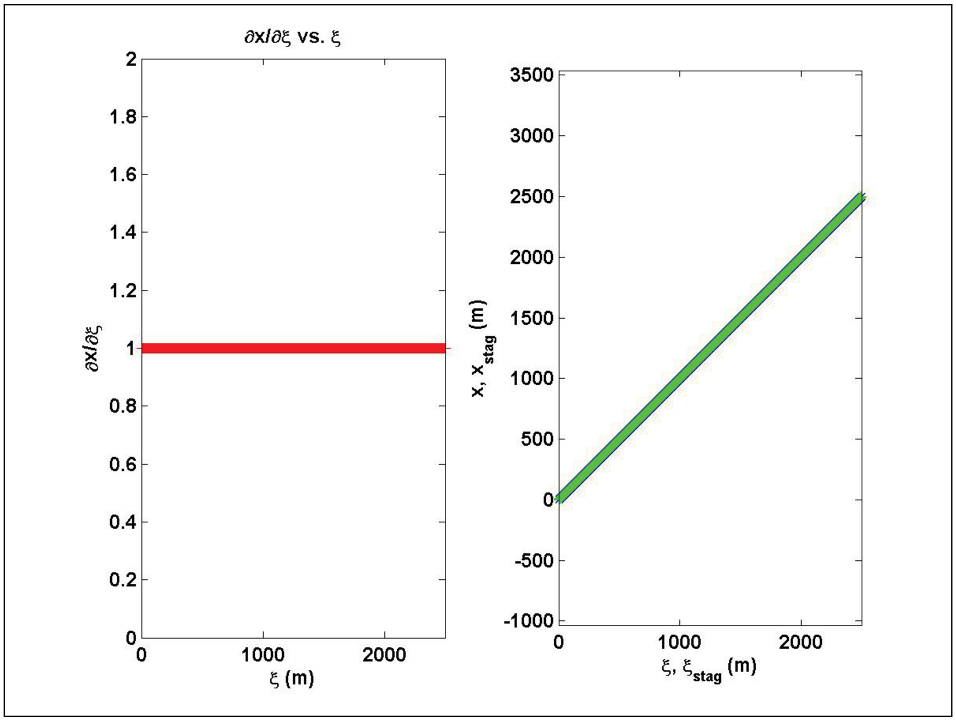


Figure 6.6. Variable grid parameters denoting a constant grid in the y-direction.

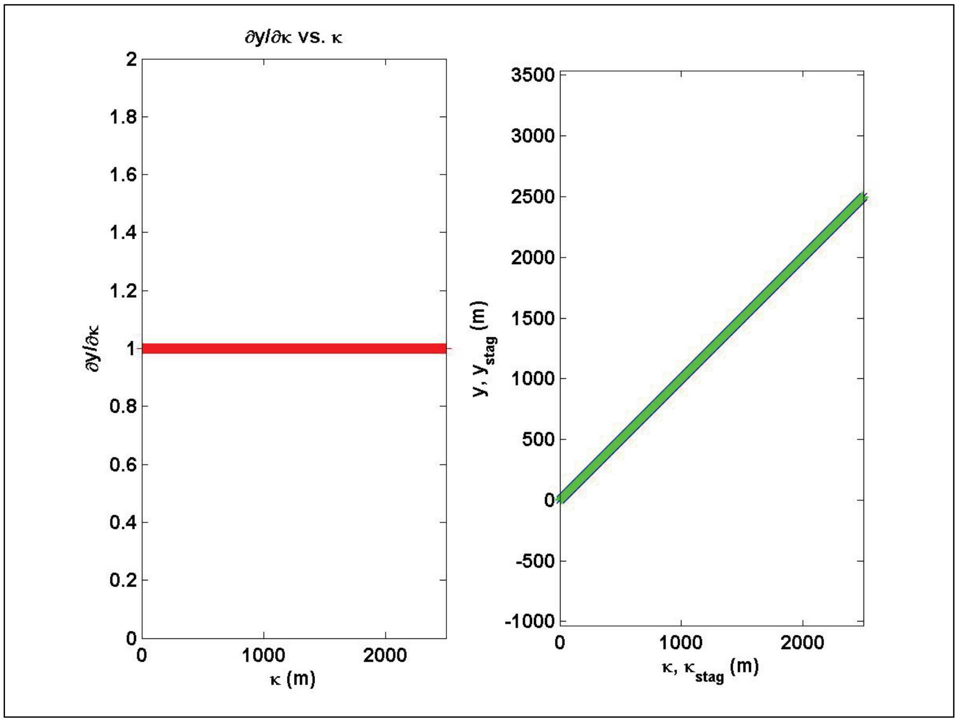


Figure 6.7. Variable grid parameters denoting a constant grid in the z-direction.

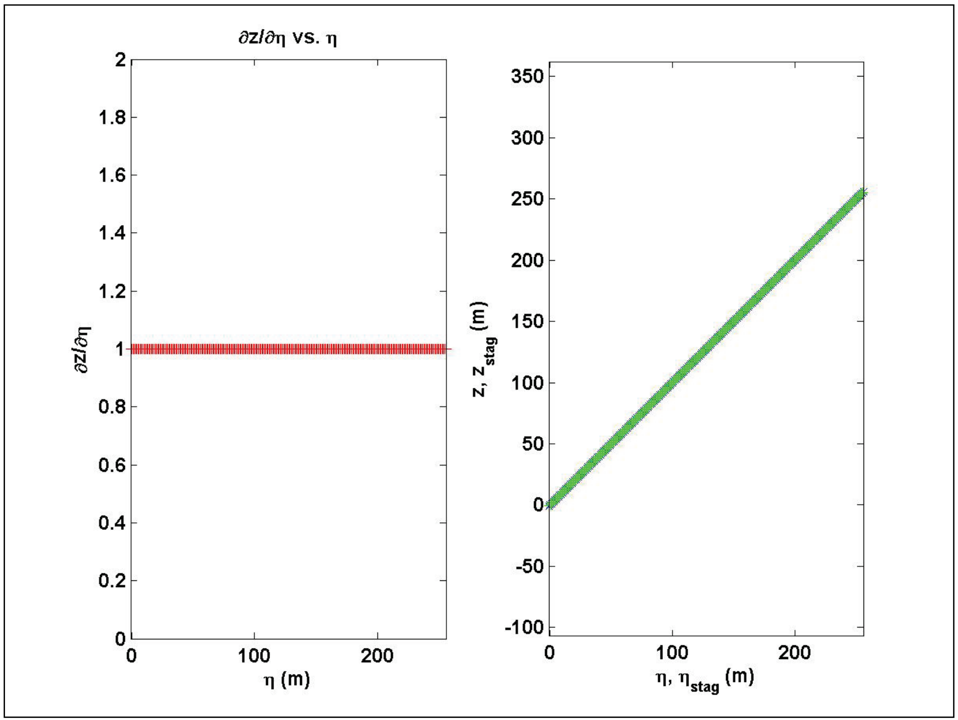
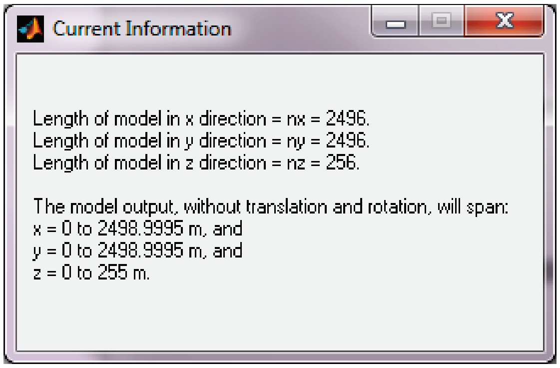


Figure 6.8. Informational dialog displaying grid limits.



Length of model in x direction = nx = 2496.
Length of model in y direction = ny = 2496.
Length of model in z direction = nz = 256.

The model output, without translation and rotation, will span:
x = 0 to 2498.9995 m, and
y = 0 to 2498.9995 m, and
z = 0 to 255 m.

6.3 Generate topography function

To generate the topography:

1. Click the **Generate topography function** button shown in Figure 6.4. The plots shown in Figure 6.9 along with the informational dialog shown in Figure 6.10 will display.
2. Figure 6.11 will display and the x (Easting) and y (Northing) location of the grid can be input as shown.
3. Click on the **Draw grid on DEM** button and Figure 6.12 will display showing the location of the grid on the topography. The dialog in Figure 6.13 will display with information about the location of the grid.

Figure 6.9. Display of topography as defined in spreadsheet.

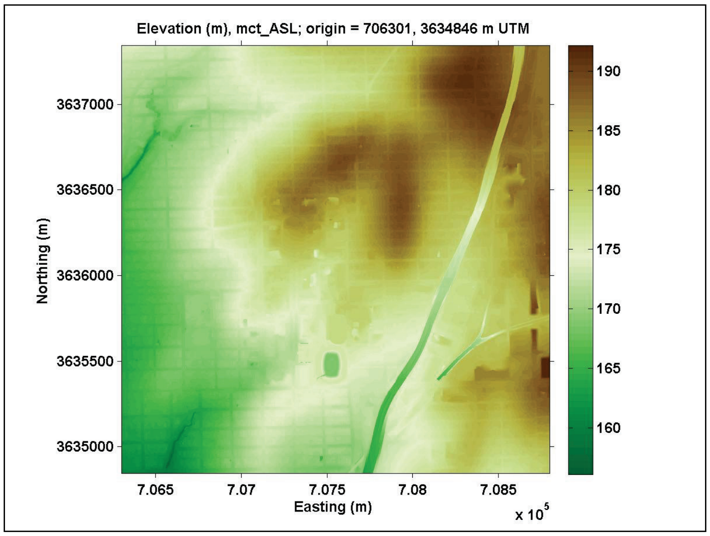
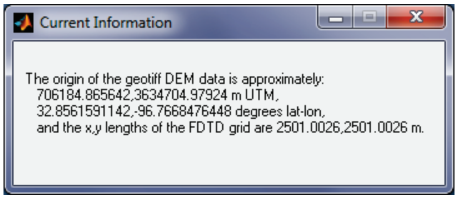
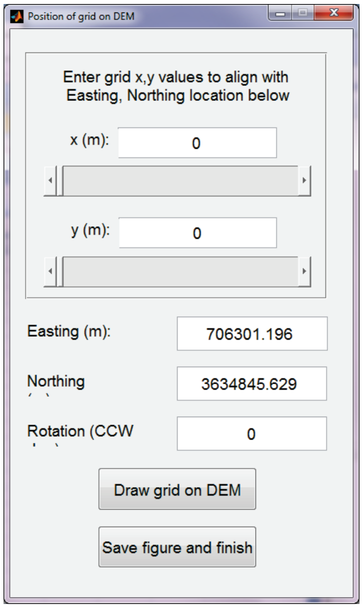


Figure 6.10. Informational dialog giving information about topography.



The origin of the geotiff DEM data is approximately:
706184.865642,3634704.97924 m UTM,
32.8561591142,-96.7668476448 degrees lat-lon,
and the x,y lengths of the FDTD grid are 2501.0026,2501.0026 m.

Figure 6.11. Defining the position of the grid on the topography.



Enter grid x,y values to align with Easting, Northing location below

x (m): 0

y (m): 0

Easting (m): 706301.196

Northing 3634845.629

Rotation (CCW 0

Figure 6.12. Display of location of grid on topography.

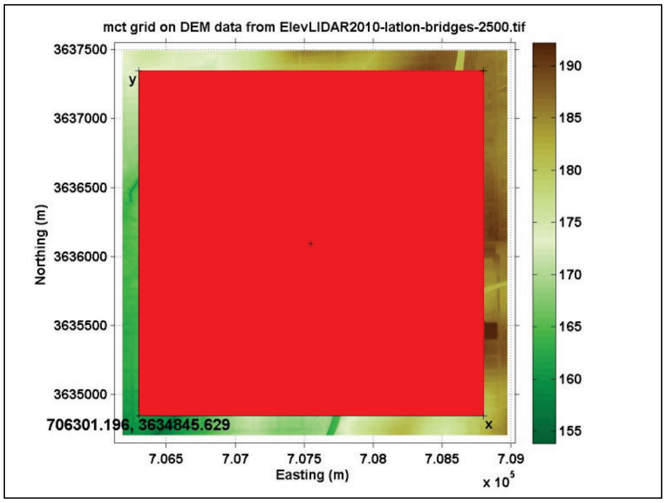
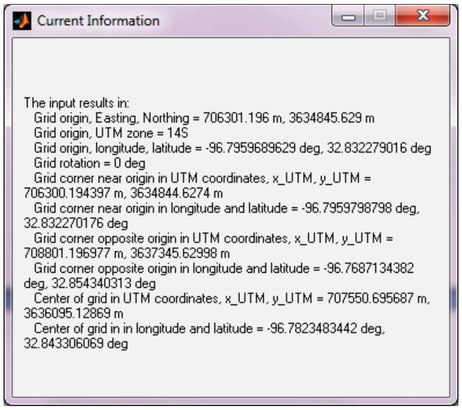


Figure 6.13. Informational dialog about grid location.



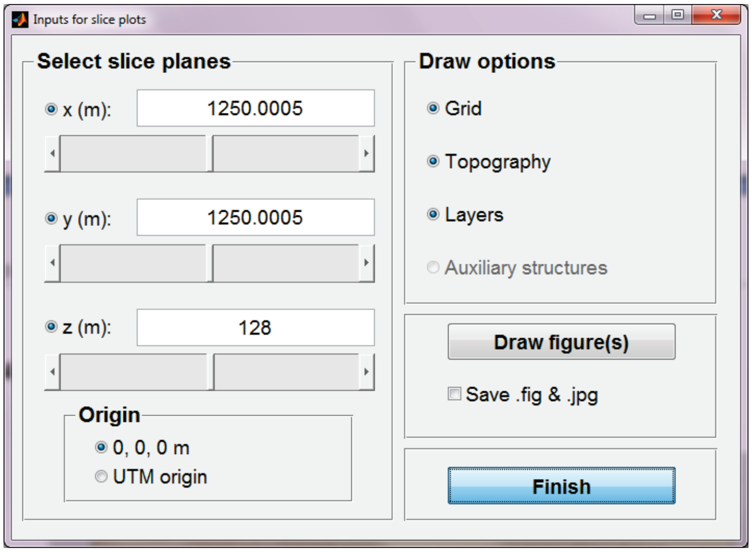
```
The input results in:
   Grid origin, Easting, Northing = 706301.196 m, 3634845.629 m
   Grid origin, UTM zone = 14S
   Grid origin, longitude, latitude = -96.7959689629 deg, 32.832279016 deg
   Grid rotation = 0 deg
   Grid corner near origin in UTM coordinates, x_UTM, y_UTM =
706300.194397 m, 3634844.6274 m
   Grid corner near origin in longitude and latitude = -96.7959798798 deg,
32.832270176 deg
   Grid corner opposite origin in UTM coordinates, x_UTM, y_UTM =
708801.196977 m, 3637345.62998 m
   Grid corner opposite origin in longitude and latitude = -96.7687134382
deg, 32.854340313 deg
   Center of grid in UTM coordinates, x_UTM, y_UTM = 707550.695687 m,
3636095.12869 m
   Center of grid in in longitude and latitude = -96.7823483442 deg,
32.843306069 deg
```

6.4 Define propagation medium

To define the propagation medium:

1. Click on the **Define propagation medium** button in Figure 6.4.
2. The dialog to generate slice plots will display as shown in Figure 6.14. Choose a slice location by moving the sliders and click **Draw figure(s)**.
3. The slice plot will display as shown in Figure 6.15. The plot may be zoomed in and panned to display the data as desired. This plot shows four layers, which corresponds to the data shown in Figure 5.3. The green line in Figure 6.15 denotes the top of the topography.
4. Click **Finish**.

Figure 6.14. Input for slice plots.



● x (m): 1250.0005

● y (m): 1250.0005

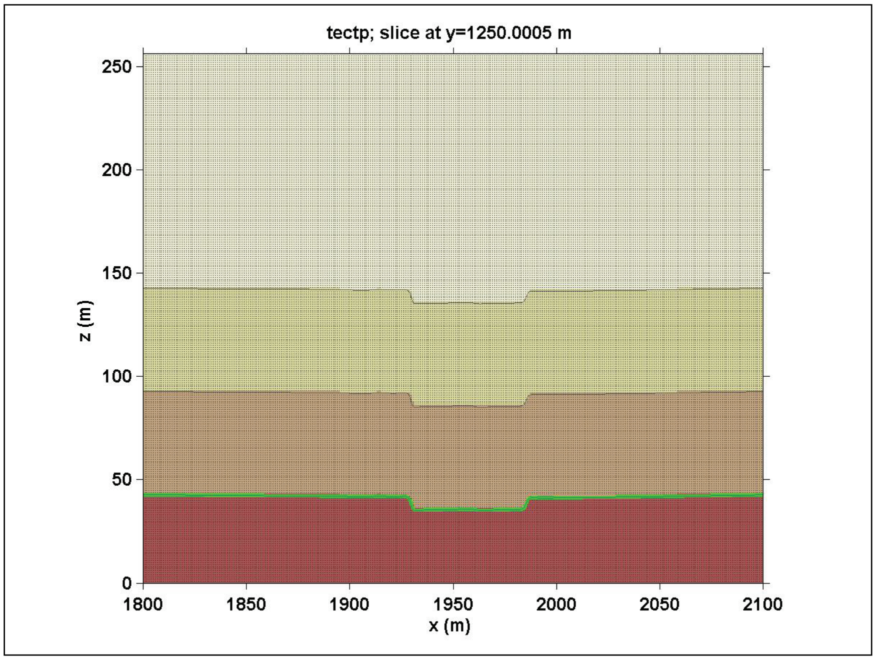
● z (m): 128

● 0, 0, 0 m
○ UTM origin

● Grid
● Topography
● Layers
○ Auxiliary structures

☐ Save .fig & .jpg

Figure 6.15. Slice showing the layers in the medium.



6.5 Define auxiliary structures

To define the auxiliary structures:

1. Click on the **Define auxiliary structure** button in Figure 6.4.
2. The spreadsheets listed on the **sheet.aux** line of the main spreadsheet discussed in Section 5.3 will be processed. A single sheet or multiple sheets may be processed. If a single sheet is processed, the name of the spreadsheet on the **sheet.aux** line can be changed, the spreadsheet saved, and the MATLAB rvgModel.m script run again. All previously processed data will be read in and the additional auxiliary sheet will be processed. This can be done as many times as required to process the auxiliary structures sheet by sheet.
3. Figures 6.16 and 6.17 show the result of processing partial building data.
4. After a sheet containing auxiliary structures is processed, the slice plot selection dialog as shown in Figure 6.18 is displayed.
5. Move the sliders to select a slice location. Click **Draw figure(s)**.
6. Slice plots are displayed for the selected locations. The x-z plane slice plot is shown in Figure 6.19. The green line in the figure represents the topography. The red squares represent nodes defining an auxiliary structure. As seen from Figure 6.19, the topography has been modified to include the tops of the buildings.
7. Figures 6.20 through 6.23 show various sets of processed buildings.

8. Figure 6.24 shows the processed paved areas for a strip that represents one-fifth of the paved areas. This set does not include islands and is defined with a material property of asphalt as discussed in Section 5.8.
9. Figure 6.25 shows the processed paved areas for the islands that exist for the areas defined in Figure 6.24. These areas are defined with a material property of grass.
10. Click **Finish** to exit the dialog shown in Figure 6.18.

Figure 6.16. Elevation data for partial building data.

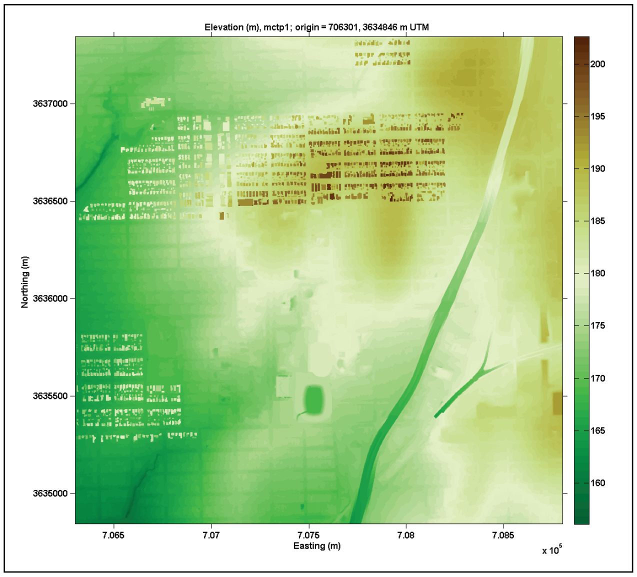


Figure 6.17. Partial building data shown in 3-D.

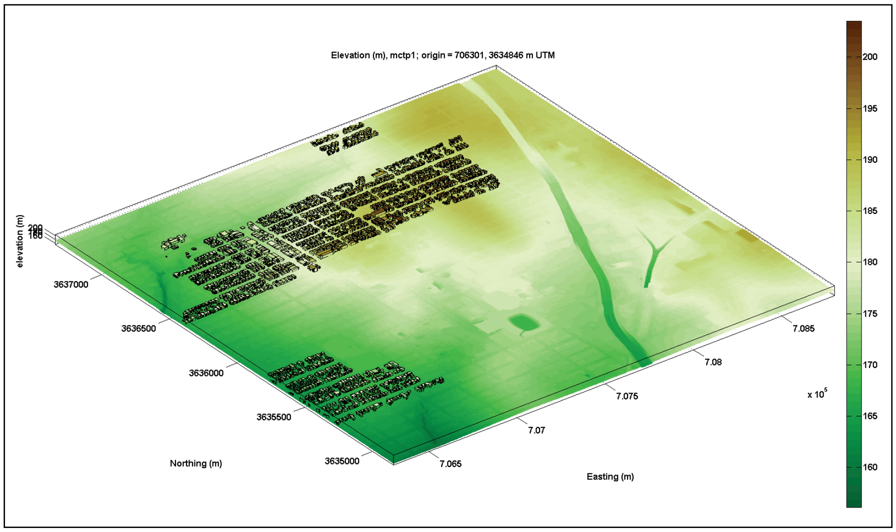
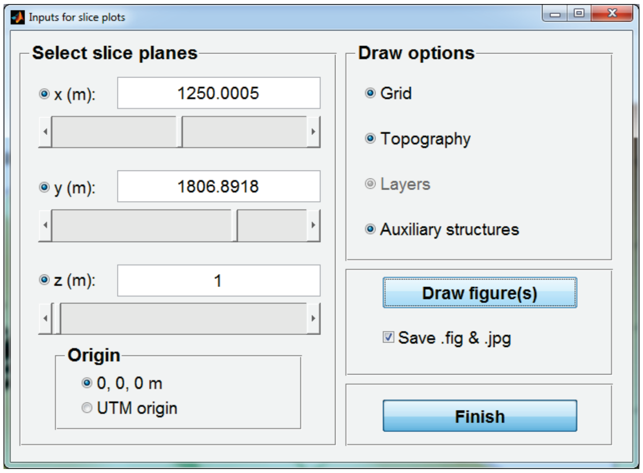


Figure 6.18. Slice plot selection for auxiliary structures.



Select slice planes

● x (m): 1250.0005

● y (m): 1806.8918

● z (m): 1

Origin

● 0, 0, 0 m

○ UTM origin

Draw options

● Grid

● Topography

○ Layers

● Auxiliary structures

☑ Save .fig & .jpg

Figure 6.19. x-z plane slice plot showing buildings.

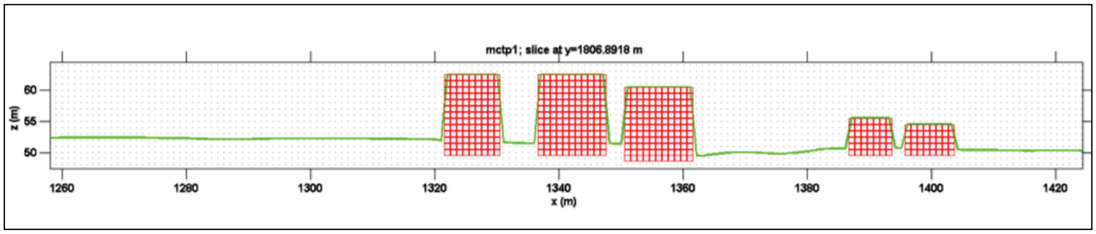


Figure 6.20. 3-D plot of processed aggregated buildings close to U.S. Highway 75.

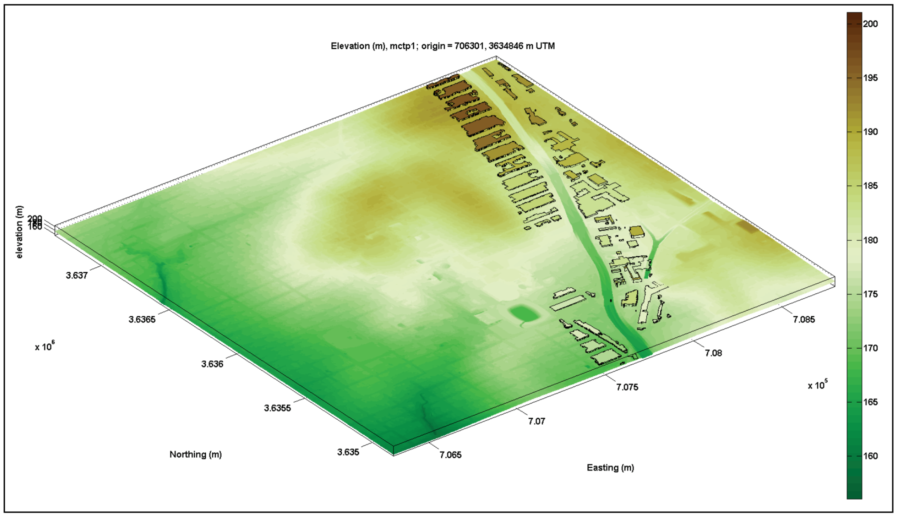


Figure 6.21. 3-D plot of processed buildings greater than 51 ft in height.

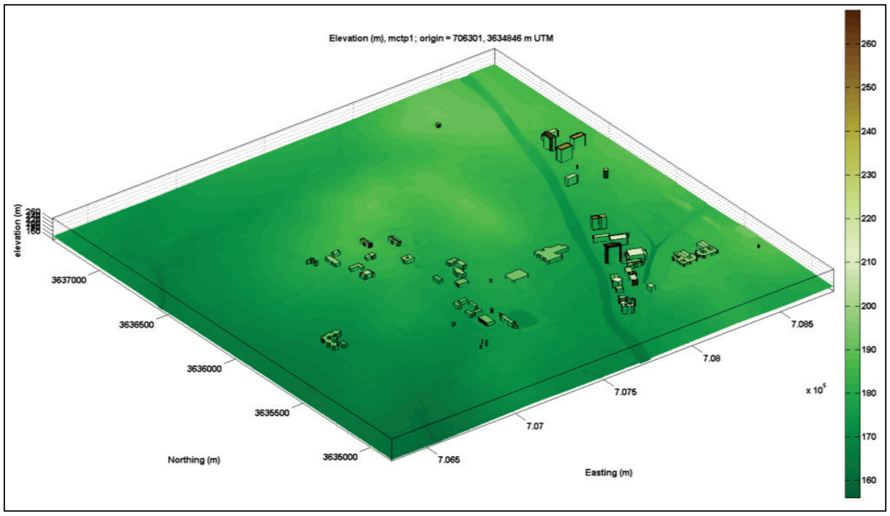


Figure 6.22. 3-D view of processed individual buildings.

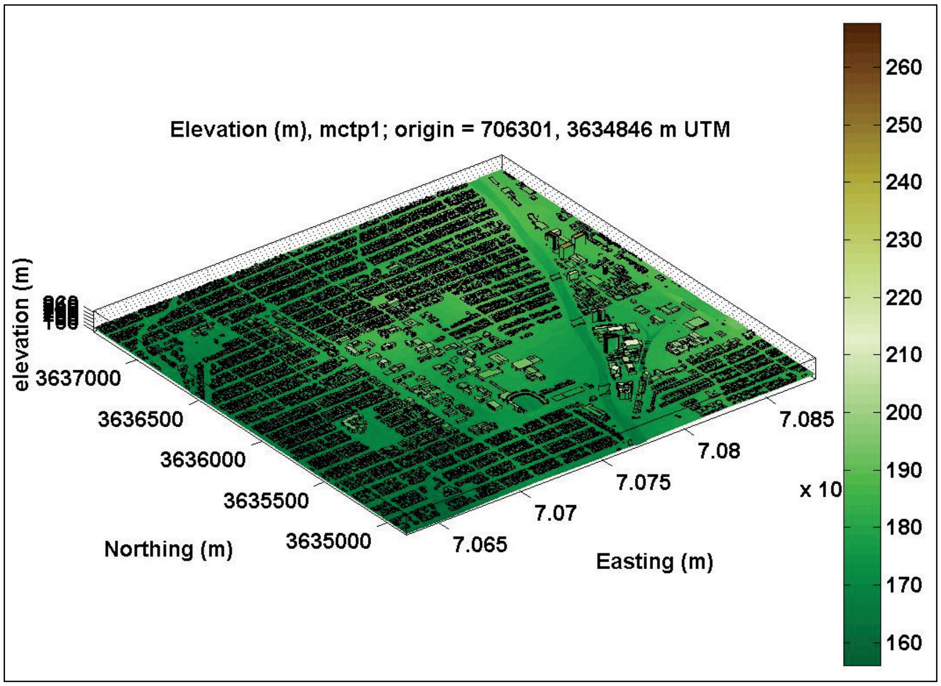


Figure 6.23. Magnified 3-D view of processed buildings.

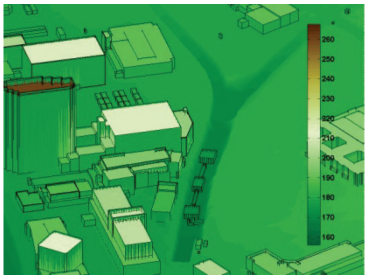


Figure 6.24. Processed partial paved areas without islands.

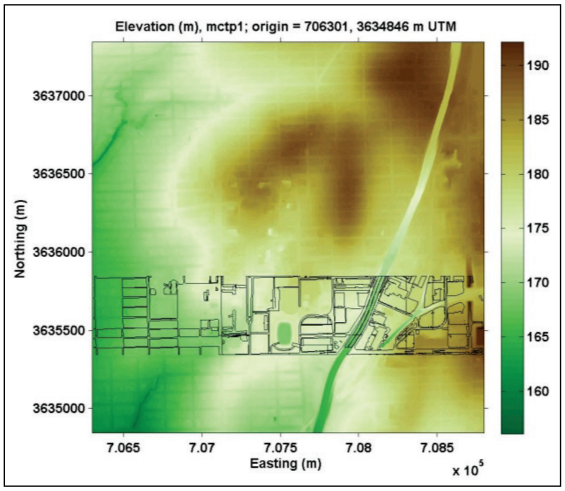
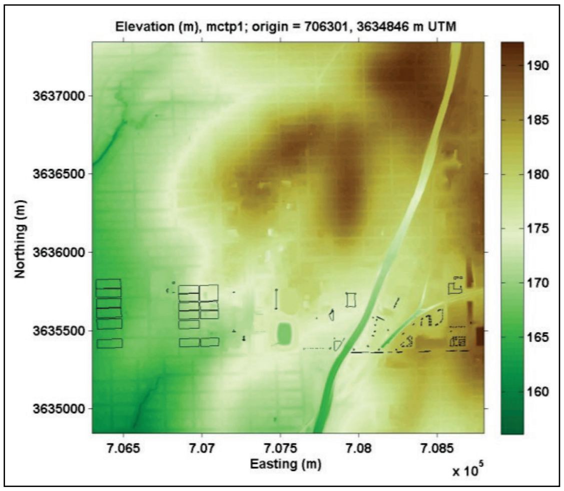


Figure 6.25. Processed partial islands of paved areas.



6.6 Generate source

The MATLAB script rvloadset_10.m is run to define a source and its type, location, and magnitude. The script is run similar to the rvgModel.m script described in Section 6.1. It also creates several files: a header file needed to compile PSTOP3D, a file defining the run parameters for PSTOP3D, and two files that define the source. These files are discussed in more detail in Chapter 7.

The question-and-answer sequence is shown in the following text in `Courier` font. The user may press the **Enter** key to accept the default text located between the left and right chevrons (< and >). Green text denotes an input response. Red text is additional explanation.

```
C:\rvloadset_20120606\rvloadset_10
16-Nov-2012; computer type: PCWIN64
**************************************************************************
POC: S. Ketcham, USAERDC, Stephen.A.Ketcham@erdc.usace.army.mil.

rvloadset_V.m generates a set of inputs to be applied to a geo_model in PSTOP3D.
 For each input the user sets:
 (1) Input location
 (2) Input amplitude
 (3) Input time series (the signal as a function of time
 For seismic simulations, each input is a set of force vectors converted
 to body forces using the cell volume in the 3D-d grid.
 For acoustic simulations, each input is an acoustic volumetric source
 at the input location.

 rvloadset_V.m uses the "geo model" file generated by rvgeo_V.m.

rvloadset_V.m generates PSTOP3D input files COMMAND.FIL and pstop3d.h. Open these
 files in a text editor & read instructions for preparing them for final use.

The PSTOP3D m-files should be in your matlabpath., and Matlab's "current
directory"
 is where rvgeo_V.m "geo model" will be read, and where rvloadset_V.m output will
be written.

Clear all figures (y/n)? < n > : y

 INPUT "GEO" MODEL FILES
**************************************************************************

Input ID of previously generated "geo" model
 (i.e., the characters before "_geo.dat") < > : mctp
```

This name is generated based on the information given in the spreadsheet in Figure 5.1 and discussed in Section 5.3. This ID is the MODELID and is a concatenation of the id.model, id.grid, id.topo, and id.med data items.

```
>>>>>>>>>> rvgeo_readgeo.m: Binary data from "geo" model files.

Beginning reading "geo" model data from mctp_geo.dat files.
 Finished reading grid and model parameters from mctp_geo.dat.4.
 Finished reading DEM origin parameters from mctp_geo.dat.5.
 Finished reading x,y,z grid vectors from mctp_geo.dat.3.
 Finished reading topography elevation function from mctp_geo.dat.0.
 Finished reading topography elevation function from mctp_geo.dat.0.origtopo,
 which is used by PSTOP3D to save 3D output relative to topography without
 auxiliary structures.
 Finished reading indexed material properties from mctp_geo.dat.1.
 Finished reading layer elevation functions from mctp_geo.dat.01 (z0 for layer 1).
 Finished reading layer elevation functions from mctp_geo.dat.02 (z0 for layer 2).
 Finished reading layer elevation functions from mctp_geo.dat.03 (z0 for layer 3).
 Finished reading layer elevation functions from mctp_geo.dat.04 (z0 for layer 4).
 Finished reading layer elevation functions from mctp_geo.dat.05 (z0 for layer 5).
Completed data read from "geo" files mctp_geo.dat.

Size of 2D topography matrices "z0_topo" returned by rvgeo_readgeo.m is:
 NX_MODEL_SIZE+2*LO x NY_MODEL_SIZE+2*LO = 2498 x 2498.

Size of all-layers topography matrix "z0_layers" returned by rvgeo_readgeo.m is:
 num_layers + 1 x NX_MODEL_SIZE+2*LO x NY_MODEL_SIZE+2*LO = 5 x 2498 x     2498.
 For example: z0_layers includes the upper grid boundary max(z) in
 z0_layers(1,:,:); surfaces of increasingly lower layers follow in
 z0_layers(2,:,:), z0_layers(3,:,:), etc; z0_layers(num_layers+1,:,:)
 includes the lower grid boundary min(z).

3D material indices matrix "matl_indices" not returned; obsolete.
```

```
Length of x array returned by rvgeo_readgeo.m is NX_MODEL_SIZE+2*LO.
Length of y array returned by rvgeo_readgeo.m is NY_MODEL_SIZE+2*LO.
Length of z array returned by rvgeo_readgeo.m is NZ_MODEL_SIZE+2*LO.
Length of x_stag array returned by rvgeo_readgeo.m is NX_MODEL_SIZE+2*LO-1.
Length of y_stag array returned by rvgeo_readgeo.m is NY_MODEL_SIZE+2*LO-1.
Length of z_stag array returned by rvgeo_readgeo.m is NZ_MODEL_SIZE+2*LO-1.
Number of materials returned by rvgeo_readgeo.m is 4.

<<<<<<<<<< rvgeo_readgeo.m complete.

 ASSIGN ANALYSIS ID AND PARALLEL-TO-TOPOGRAPHY OUTPUT LAYER
**************************************************************************

Enter a short descriptive analysis ID to append to mctp
 (suggestion: use <= 4 characters to distinctly describe source) < > : UR15
```

This descriptor for the analysis is the LOADID. This ID and the previously entered "geo" ID will be used when naming the load files created.

```
Enter number of nodes above topo surface of output layer that will be
 draped over topo surface (can be changed later by editing COMMAND.FIL);
 for example, use -1 to get seismic surface response, or 10 to get
 acoustic response at approximately one shortest wavelength above ground
 <10> : 1
```

Using 1 node will extract results 1 node above the topography. If the modifyTopo option was used as described in Section 5.7, then the results will be extracted 1 node above the topography and 1 node above the tops of the buildings.

```
The lowest DT from the Courant condition, found in mctp_geo.txt
 or auxiliary-file text outputs for mctp, is the estimated
 governing criterion for time-step stability. Enter the DT to be used
 for the pstop analysis (suggestion, use 0.995 x the lowest DT)
 < > : 0.0005
```

This value must be selected to satisfy accurate representation of the wavelength of interest and also to provide stability of the solution. This is discussed in Chapter 7.

```
LOAD NUMBER 1: INPUT BASIC SOURCE TYPE
**************************************************************************

Select from the following basic source types, which will be given a time series
history

1. "BODY FORCE," force vector components with selected configuration
 and distribution around source location point.
2. "CONSTRAINED PARTICLE VELOCITY," particle vector vector components
 with selected configuration and distribution.
3. "Q SOURCE," volume source, i.e., expressed as a dilatation rate,
 at a source location point.
Note: additional functions can be added to the program.

Input number of basic source type, to be refined with later inputs: <3> :

 LOAD NUMBER 1: INPUT Q-SOURCE DATA
**************************************************************************

 LOAD NUMBER 1: INPUT SOURCE LOCATION
**************************************************************************

>>>>>>>>>> rvloadset_location.m: Specification of source-center location.

fnam_command_aux_loc_prompt assigned as global variable in rvloadset_location.m

Input loads graphically? (y/n) < n > : n

Default source location is at mid-domain (m):
Input source location [x,y] (m) < 1250.0005 1250.0005> : 2470 2470
```

This is the location of the source. Since the analysis region is 2500 meters square, the source is located 30 meters in from the upper right corner of the region.

```
Source 1 x-location = 2469.9529 m at x-dir node # 2468
Source 1 y-location = 2469.9529 m at y-dir node # 2468
At this location the land elevation = 49.7091 m at z-dir node # 52
At this location the output layer = 51 m at z-dir node # 53
Input desired source height (default = output layer) (m) <51> :
Source 1 z-location = 51 m at z-dir node # 53
Do you want to keep this source location? (y/n) [y]
The center of the source is x=2469.9529, y=2469.9529, z=51 m.

<<<<<<<<<< rvloadset_location.m complete.

>>>>>>>>>> rvloadset_Qsourcedata.m: Q-source magnitude specification and output to
file.

The source term in the PDE describing acoustic propagation is the applied change
in
volume per unit time per unit volume, given the symbol "Q" and has units m^3/s/m^3
= 1/s.
Since we usually think in terms of sound pressure (Pa), we present three choices
to go
from pressure to dilatation-rate time series acting on a single 3D grid element:

The final source history will be Q*g(t), where g(t), selected later, is a unitless
time series.

1. "NOMINAL PRESSURE" calculates Q(t) = (nominal pressure)/(bulk modulus*dt)*g(t)
 where the nominal pressure is a realistic value for linear computations.
2. "MEASURED PRESSURE," calculates Q(t) = (4*pi/density)*int[(P*g(t)@1m*dt],
 where the input pressure P(t) is assumed to be measured at 1 m from the source
 in free space, and numerical integration is done to calculate Q(t)
3. "ANALYTICAL PRESSURE," calculates Q(t) = (4*pi/density)*int[(P*g(t)@1m*dt],
where
 the input pressure P(t) is an analytical function, and Q(t) includes
 the analytical integration of this function (e.g., FHarm_Pulse, FInt_Harm, etc.)
Note: additional source functions and source types can be added to this program.

Input number of selected Q source type: <1> :
```

The source will be defined using a nominal pressure.

```
Enter nominal pressure amplitude (Pa) to scale time series <1000> :
For the 4 acoustic materials of the "geo" model, the bulk moduli are:
1: c = 331 m/s; density = 1.13 kg/m3; bulk modulus = 123803.9295 Pa.
2: c = 337 m/s; density = 1.18 kg/m3; bulk modulus = 134011.414 Pa.
3: c = 344 m/s; density = 1.2 kg/m3; bulk modulus = 142003.2056 Pa.
4: c = 179.8444 m/s; density = 6.272 kg/m3; bulk modulus = 202861.6969 Pa.

Enter the material bulk modulus at the source point (consider auxiliary material
 properties if source is within an auxiliary material; they are not listed above)
<123803.9295> : 142003.2056

For this nominal pressure and bulk modulus, dilatation-rate amplitude Q = 14.0842
(1/s).

Writing acoustic source amplitude & location to PSTOP3D file mctp_UR15_ls.dat ...
```

This is one of the files needed for the source definition.

```
<<<<<<<<<< rvloadset_Qsourcedata.m complete.

 LOAD NUMBER 1: INPUT SOURCE HISTORY
**************************************************************************

>>>>>>>> rvloadset_history.m: Information & specification of source time-series.

history_mfilename_prompt filter_flag_prompt delay_flag_prompt delay_prompt
nomalize_gt_flag_prompt
```

```
 assigned as global variable in rvloadset_history.m

Acoustic wave speeds and 1-km travel times:
c (m/s) =
 [331.0000 337.0000 344.0000]
Duration (s) for acoustic wave to travel 1000 m =
 [3.0211 2.9674 2.9070]

Estimated accurate analysis bandwidth using 10 nodes per minimum acoustic
 wavelength as the criterion to mitigate grid dispersion errors:

 For acoustic wavelength = 10*max([Dxi,Dkappa,Deta]) = 10.016 m,
 the maximum allowable frequency of the slowest-speed material is
 33.047 Hz (this is a reasonable governing bandwidth).

 The maximum allowable frequencies of the next-slowest-speed materials are
 33.6461 34.3449 Hz

Time-series generating functions (rvloadset_window_*.m) in PSTOP3D m-files
directory
 C:\Infrasound\Current Version\rvloadset_20120606:
rvloadset_window_FC4pulse.m
rvloadset_window_FGauspuls.m
rvloadset_window_FHarm_Pulse.m
rvloadset_window_FHarmonic.m
rvloadset_window_FInteg_Harm.m
rvloadset_window_FPulse.m
rvloadset_window_FRicker.m
rvloadset_window_FexGauspuls.m

Input root filename of time-series "window" function that defines source history
 (this window acts on previously input source to give full definition of source
 magnitude vs time--the function must be written with correct i/o format)
 < > : rvloadset_window_FRicker
```

This will define a Ricker pulse. Other options are a Gaussian pulse and a harmonic pulse.

```
>>>>>>>>>> rvloadset_window_FRicker.m: Ricker-pulse source window function.

f_ctr_prompt and tp_prompt assigned as global variables in
rvloadset_window_FRicker.m

Enter center frequency (Hz) for Ricker pulse [50]: 15
```

This is the frequency of the source that is desired.

```
Enter greater time (s) to move Ricker pulse peak to later time
 (default starts Ricker pulse at 0 s) [0.0745]:

<<<<<<<<<< rvloadset_window_FRicker.m complete.

>>>>>>>>>> rvloadset_gtplot.m: Source time-series plot with Fourier and energy
spectra.

<<<<<<<<<< rvloadset_gtplot.m complete.

From Figure 1,
 at f = 15 25 28 33 41 48 Hz, the source energy
 is down 0 6 10 20 40 60 dB, respectively.
```

The plots of the Ricker pulse are displayed in Figure 6.26. Figure 6.26a is the unitless time variation of the Ricker pulse, Figure 6.26b is the normalized Fourier amplitude of the pulse, and Figure 6.26c is the energy of the pulse in dB relative to the peak energy. The numbers above represent the circles on the graphs in Figure 6.26. These numbers should be used to compare the source bandwidth and the analysis bandwidth (that can be accurately represented) with the bandwidth associated with the 10 node per wavelength criterion. The decibels for the source energy should be -40 dB or below for the maximum frequency that can be represented or a low-pass filter will need to be applied to the source.

```
Do you want to keep this signal? (y/n) [y] y

IMPORTANT: Confirm source- signal- spectral amplitude is not significant
 above accurate-analysis-bandwidth frequency. Judge based on estimated
 accurate-analysis bandwidth above.

Low-pass filtering the time- series signal g(t) lowers high-frequency amplitude.
 Do you want to lowpass filter g(t)? (y/n) < y > : n

Adding a delay to the time- series signal g(t) starts the signal at a later time.
 Do you want to add a delay? (y/n) < n > :
Normalizing the time- series signal g(t) make the maximum absolute value = 1,
 in which case the source amplitude will be the previously entered value.
 Do you want to normalize? (y/n) < n > :
>>>>>>>>>> rvloadset_gtplot.m: Source time-series plot with Fourier and energy
spectra.

<<<<<<<<<< rvloadset_gtplot.m complete.

++++++++++ rv_print.m
mctp_UR15_load1_gt.fig written to disk.
mctp_UR15_load1_gt.jpg written to disk.
++++++++++ rv_print.m complete.

Writing g(t) to PSTOP3D file mctp_UR15_gt.dat
```

This is the second file needed for the definition of the source. The g(t) function is a normalized unit-less variation of the source with time.

```
<<<<<<<<<< rvloadset_history.m complete.


LOAD NUMBER 1: OUTPUT TO COMMAND.FIL.mctp_UR15.txt (load #1 only)
 and PARAMETER FILE pstop3d.h.mctp_UR15.txt
**************************************************************************

>>>>>>>>>> rvloadset_commandfile.m: Output of "COMMAND" file and parameter file.

Writing COMMAND.FIL.mctp_UR15.txt ...
```

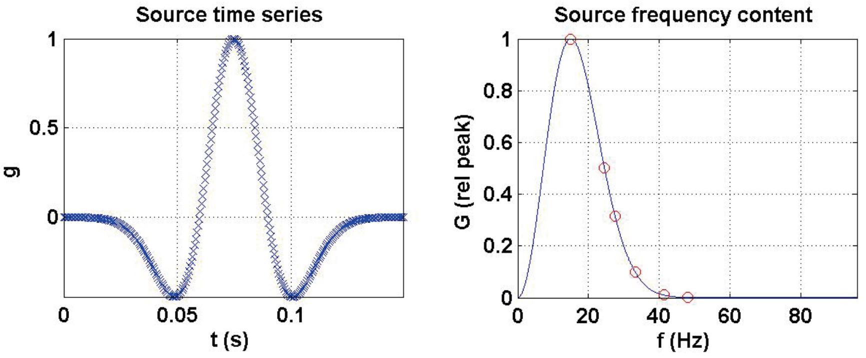
This file contains information to run PSTOP3D. The name is based on the previous input for the "geo" model name and the 4 character analysis description.

```
Writing pstop3d.h.mctp_UR15.txt ...
```

This file contains the header information needed to compile PSTOP3D. The name is based on the previous input for the "geo" model name and the four-character analysis description.

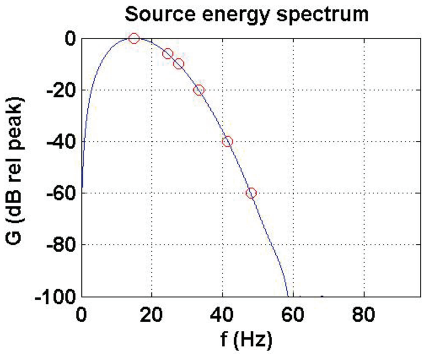
```
<<<<<<<<<< rvloadset_commandfile.m complete.

Add another load to the load set? (y/n) < n > : n

FINAL OUTPUT TO pstop3d.h.mctp_UR15.txt
**************************************************************************

<<<<<<<<<< rvloadset_10.m complete.
```

Figure 6.26. Definition of a Ricker pulse.



a) Time variation of pulse

b) Fourier amplitude of pulse



c) Pulse energy in dB relative to peak energy

7 Compile and Run PSTOP3D

7.1 PSTOP3D discussion

This chapter discusses specifics about the PSTOP3D program including files necessary to compile and run the program. This corresponds to Step 7 of the process diagram shown in Figure 1.4.

7.1.1 General background

The theoretical background for the PSTOP3D code can be found in Wilson and Liu (2004) and Ketcham et al. (2005). Some of the capabilities of PSTOP3D are (Ketcham 2006):

1. PSTOP3D allows the acoustic propagation in static medium, i.e., the acoustic propagation is not coupled with wind.
2. PSTOP3D uses a rectangular variable staggered grid. The spacing of the grid can be a constant value or may vary based on stretching transformations. The spacing of the physical grid is variable while the spacing of the computational grid is a constant. The staggered grid results in more efficient computations.
3. PSTOP3D is a parallel processing code that uses the message passing interface (MPI) software library for parallelization by spatial-domain decomposition and message passing at the edges of the domain.
4. The finite difference time-domain implementation uses second-order finite differences, which spatially allow highly discontinuous material interfaces and temporally allows time steps just below the Courant time step.
5. The second-order acoustic implementation has the ability to model ground surface and structures in the model by directly modeling their contact with air. The code uses a porous-material model discussed in Wilson and Liu (2004) that allows the ground and building materials to both reflect and absorb acoustic energy as real geologic and construction materials do.
6. The porous models help the efficiency of the acoustic calculations because they produce materials that do not control the time step, i.e., they do not make the time step for convergence smaller and therefore the analysis more computationally demanding. Because acoustic propagation in the porous materials is not required to be modeled accurately, the number of nodes per wavelength based on the generally shorter wavelengths in the

porous materials can be avoided. The porous materials use a flow resistance that introduces a non-linearity in the porous-material response.

7. PSTOP3D allows for the input of a "geo" model that defines the topography of the problem. Also, auxiliary data files contain information about objects placed on the topography such as buildings or roads.
8. Propagation through air in the low frequencies in the acoustic models does not require a material-attenuation model.
9. The errors associated with the second-order solutions for acoustic propagation are small compared to the relative uncertainty of the ground or air properties.
10. Output from the acoustic analyses is pressures on 2-D slices or 3-D volumes. The output can be decimated in time and space.

The PSTOP3D code uses data files to define the:

1. Grid
2. Topography
3. Propagation medium and material properties
4. Buildings, roads, pavements, trees, water, etc. (auxiliary files)
5. Source inputs

7.1.2 Implicit/Explicit formulation

Explicit and implicit methods are used in numerical analysis to obtain numerical solutions of time-dependent ordinary and partial differential equations. PSTOP3D uses an explicit second-order-accurate, forward-finite-difference algorithm.

Explicit methods use the state of the system at the current time to calculate the state of the system at a later time. Implicit methods find a solution by solving an equation involving both the current and future state of the system. Implicit methods require more computations and can be harder to implement, but they can use larger time steps than an explicit method. Explicit methods have the disadvantage of requiring smaller time steps for convergence of the solution. The determination of the time step to use for PSTOP3D analysis is critical and is discussed in Sections 7.2 and 7.3.

7.1.3 Sound propagation in porous medium

From Wilson and Liu (2004), most common outdoor ground surfaces cannot be modeled satisfactorily as ideal, rigid surfaces. This is because sound energy propagates into the pores of the ground, where it is dissipated by viscosity and thermal conduction. Ground surfaces with relatively large open pores, such as snow, absorb much of the sound-energy incident upon them. Surfaces with small pores, such as cement and asphalt, reflect most of the energy. The acoustical behavior of soils is intermediate between these extremes. Typical values of the material properties for porous materials are given in Table 7.1. The material properties for a porous material needed for PSTOP3D consist of the density, wave speed, flow resistivity, porosity, and tortuosity.

Table 7.1. Typical values of static-flow resistivity, porosity, and tortuosity for common porous ground surfaces (Wilson and Liu 2004).

Material	Flow Resistivity, σ Pa-s/m^2	Porosity, Ω	Tortuosity, q
Asphalt	3.00E+07	0.1	3.2
Grass	2.00E+05	0.5	1.4
Forest	1.00E+05	0.6	1.3
Sand	5.00E+04	0.35	1.6
Snow	1.00E+03	0.6	1.7

The governing equations for the acoustical analysis are shown in Equations 7.1 and 7.2 (Cudney et al. 2007, 2008).

$$\frac{\partial p}{\partial t} = -K_e \nabla \cdot \mathbf{v} + K_e Q \tag{7.1}$$

$$\frac{\partial v}{\partial t} = \frac{1}{\rho_e}(\nabla p + \sigma \mathbf{v}) \tag{7.2}$$

where

p = acoustic pressure
$\mathbf{v}$ = vector of particle velocity components
t = time (seconds)
K_e = effective bulk modulus of material
ρ_e = effective density of medium (kg/m^3)
σ = static flow resistivity (Pa/m^2/s)
= 0 for air (nonporous), not equal to zero for porous material
Q = dilation-rate source, radially oscillating sphere (m^3/sec/m^3)

The effective bulk modulus and effective density are given in Equations 7.3 and 7.4, respectively (Wilson and Liu 2004; Cudney et al. 2007; Cudney et al. 2008; Attenborough 1983).

$$K_e = \frac{\rho c^2}{\gamma \Omega} \tag{7.3}$$

$$\rho_e = \frac{4}{3}\frac{\rho q^2}{\Omega} \tag{7.4}$$

where

Ω = void fraction or material porosity (volume of pores/unit volume, m^3/m^3)
q = tortuosity, reflects the geometry of the pores (unit-less)
γ = ratio of specific heats of fluid portion of porous material, equals 1.4
ρ = density of fluid portion of porous material (kg/m^3)
c = wave speed in the fluid portion of the porous material (m/sec)

The effective wave speed of the porous medium is given in Equation 7.5.

$$c_e = \sqrt{\frac{K_e}{\rho_e}} \tag{7.5}$$

For grass, inserting the values given in Table 7.1 into Equations 7.3 through 7.5 with a wave speed of 330 m/sec yields:

$$K_e = \frac{\rho c^2}{\gamma \Omega} = \frac{1.2(330)^2}{1.4(0.5)} = 90124.1\, Pa/m^2$$

$$\rho_e = \frac{4}{3}\frac{\rho q^2}{\Omega} = \frac{4}{3}\frac{1.2(1.4)^2}{0.5} = 6.272\, kg/m^3$$

$$c_e = \sqrt{\frac{K_e}{\rho_e}} = \sqrt{\frac{90124.1}{6.272}} = 119.87\, m/sec$$

For asphalt, inserting the values given in Table 7.1 into Equations 7.3 through 7.5 with a wave speed of 330 m/sec yields:

$$K_e = \frac{\rho c^2}{\gamma \Omega} = \frac{1.2(330)^2}{1.4(0.1)} = 933428.6\, Pa/m^2$$

$$\rho_e = \frac{4}{3}\frac{\rho q^2}{\Omega} = \frac{4}{3}\frac{1.2(3.2)^2}{0.1} = 163.84\, kg/m^3$$

$$c_e = \sqrt{\frac{K_e}{\rho_e}} = \sqrt{\frac{933428.6}{6.2163.8472}} = 75.48\, m/sec$$

As seen from these calculations, the effect of the porous material is to reduce the effective wave speed. The wave speed for a porous material is less than the wave speed in air. Also, the wavelengths in the porous materials will be shorter than the wavelengths in air.

7.2 Time Step for Convergence of Analysis

The stability of explicit time-marching numerical procedures to solve partial differential equations (usually hyperbolic partial differential equations) is subject to the Courant time condition. The numerical procedure should use a time step less than or equal to the Courant time condition to insure the solution converges to a correct result. The Courant time condition is based on the smallest grid increment and the largest velocity used in the analysis. Equation 7.6 defines the Courant time step (Yee 1966; Zheng et al. 1999).

$$\Delta t \le \frac{1}{c_{max}\sqrt{\frac{1}{\Delta x^2} + \frac{1}{\Delta y^2} + \frac{1}{\Delta z^2}}} \tag{7.6}$$

where

c_{max} = the maximum wave speed within the model
Δx = the minimum grid spacing in the x direction
Δy = the minimum grid spacing in the y direction
Δz = the minimum grid spacing in the z direction

Since wave speeds are smaller in porous materials, as shown in Section 7.1.3, they do not increase the time step required for stability as computed from Equation 7.6. However, the use of porous materials causes instability to occur as discussed in Cudney et al. (2007, 2008). For the solution to be stable, the following condition must be met:

$$1-\frac{\Delta t\sigma}{\rho_e}\geq 0 \tag{7.7}$$

This can be met by requiring the time step to be less than or equal to $\frac{\rho_e}{\sigma}$. But for a material such as asphalt with a large flow resistivity, the time step would become unreasonably small increasing the computational cost by orders of magnitude for the analysis of wave propagation over long distances. For asphalt, the time step would need to be below:

$$\Delta t\leq\frac{\rho_e}{\sigma}\leq\frac{163.84}{3x10^7}\leq 5x10^{-6}\,sec$$

For a 10 sec analysis, asphalt would require 2 million time steps. The solution presented by Cudney el al. (2007, 2008) was to artificially cap the static flow resistivity to satisfy

$$\frac{\Delta t}{\rho_e}\sigma\leq 1 \tag{7.8}$$

This was found to give good results for asphalt, which is the most reflective of the materials listed in Table 7.1. The time step used in Equation 7.8 would be smaller than the Courant time step but larger than time step computed using the actual flow resistivity.

The procedure to cap the static-flow resistivity is automatically included in the PSTOP3D program.

7.3 Determination of time step and SNAP file interval

The time step used in PSTOP3D is dependent upon two considerations:

1. The spatial increment steps must be small enough in comparison with the wavelength of interest in order to make the numerical-dispersion error negligible. This is satisfied if there are 10 nodes per wavelength.
2. The time step must be small enough to satisfy the Courant stability condition in Equation 7.6, which depends on the spacing of the grid.

Assuming 10 nodes per wavelength and a given grid spacing, the shortest wavelength that can be reproduced is:

$$\lambda_{min} = 10(\Delta s_{min}) \tag{7.9}$$

where Δs_{min} is the smallest grid spacing in any direction.

The maximum frequency that can reliably be represented in the analysis is dependent upon the minimum wave speed, c_{min}, and the maximum spatial increment, Δs_{max}, as shown in Equation 7.10.

$$f_{max} = \frac{c_{min}}{\lambda_{max}} = \frac{c_{min}}{10\left(\Delta s_{max}\right)} \tag{7.10}$$

The minimum wave speed and maximum grid spacing of the entire grid are used to compute the maximum frequency for the analysis. That is, the values produce a minimum value for the maximum frequency that can be reliably reproduced. Smaller grid spacings or larger wave speeds will allow larger maximum frequencies to be used. The maximum frequency defined in Equation 7.10 should be greater than or equal to the maximum frequency of interest (f_I). Once a grid spacing is determined that supports the maximum frequency of interest, the time step for stability can be computed using Equation 7.6.

A time increment used to decimate the output information is contained in the COMMAND.FIL file discussed in Section 7.8. This time increment is specified as a multiple of the time step input for stability (e.g., output information at every 50 time steps). The snap time interval defines a sampling frequency called the Nyquist rate defined as:

$$f_R = \frac{1}{\Delta t \times INTERVAL\_SNAP} \tag{7.11}$$

The frequency that can reliably be reproduced from this sampling rate is called the Nyquist frequency and is defined as:

$$f_N = \frac{f_R}{2} \tag{7.12}$$

The Nyquist frequency for the snap interval should be greater than or equal to the maximum frequency of interest as shown in Equation 7.13.

$$f_N \geq f_I \tag{7.13}$$

Substituting Equation 7.11 into 7.12 and inserting the result into Equation 7.13 yields Equation 7.14, which defines the snap interval required to represent the maximum frequency of interest.

$$\mathit{Snap\,Interval} \leq \frac{1}{2 \times \Delta t \times f_I} \tag{7.14}$$

7.4 Selection of grid spacing and number of processors for PSTOP

An High Performance Computing (HPC) machine contains a certain number of processors per node. Nodes can be requested through the batch system as described in Section 7.10. If the number of processors requested is not a multiple of the number of processors per node, there will be idle processors on a node. For example, if five processors are requested on a machine that contains four processors per node, then two nodes will be allocated for a total of eight processors. Three of the processors will not be used. Therefore, to maximize efficiency on the HPC machine, full nodes should be utilized.

PSTOP3D requires the number of grid points in the x, y, and z directions to be evenly divisible by the number of processors (also referred to as cores or CPUs) in the same direction. For example, for a grid with 2496 nodes in the x direction and 16 processors in the x direction, the ratio of grid points to processors would be 156.

Therefore, the number of grid points used in the x, y, and z directions should be divisible by the number of processors in the same direction and the total number of processors should be divisible by the number of processors per node on the machine.

For example,

1. Assume that the grid is 2336 x 2328 x 508 nodes in x, y, z directions.
2. Assume 32 processors per node.
3. Use 16 x 12 x 4 processors in the x, y, z directions.

4. x direction, 2336 / 16 = 146 FD nodes/processor
5. y direction, 2328/12 = 194 FD nodes/processor
6. z direction, 508/4 = 127 FD nodes/processor
7. Total number of processors = 16 x 12 x 4 = 786 processors
8. (Total number of processors)/(processors per node) = 786/32 = 24
9. Request a total of 768 processors (24 nodes).
10. In the pstop3d.h file discussed in Section 7.6, the number of processors in the x, y, and z directions would be 16 x 12 x 4.

PSTOP3D also has a restriction that must be observed concerning the number of processors in the z direction. PSTOP3D requires that the PML region must be contained within a single processor. Also, for non-flat topography, the parallel-to-topography output must be contained within a single processor. PSTOP3D will alert the user if these conditions are not met and halt execution. If this occurs, the number of processors used in the z direction would have to be reduced.

7.5 Grid spacing, time step, and snap interval for urban area

The modeling of the urban area described in this report focused on the propagation effects of infrasound signals observed in the urban environment. Infrasound is sound that is 20 Hz and below. For the analyses performed, the maximum frequency of interest was chosen to be 15 Hz.

The grid size, time step, and snap interval were determined by the following procedure:

1. The modeling of buildings was an important aspect of the analysis, so a spacing of approximately 1 m was selected as a maximum spacing to use to adequately reflect the geometry of the buildings.
2. f_{max} was computed from Equation 7.10 using a minimum wave speed of 330 m/sec and a grid spacing of 1 m. This frequency (32.9 Hz) was greater than the maximum frequency of interest (15 Hz).
3. The time step required for stability (i.e., the Courant time step) was computed using Equation 7.6. The maximum wave speed and minimum grid spacing in the x, y, and z directions were used to compute the time step of 0.00175 sec.
4. Due to the use of porous materials in the model, the time step was required to be less than 5×10^{-6} sec as discussed in Section 7.2. The use of this time step was deemed to be unfeasible. Therefore, a larger time step was selected and the stability of the algorithms was assured by letting

PSTOP3D cap the flow resistivities as discussed in Section 7.2. A time step of 0.0005 sec was selected as a reasonable time step and is less than the Courant time condition. This resulted in 20,500 time steps being run to allow the waves to propagate across the complete urban area.

5. The snap interval was computed using Equation 7.14 using the time step of 0.0005 sec and the maximum frequency of interest of 15 Hz. This resulted in a maximum snap interval of 66.7. Therefore, a snap interval of 50 was used in the analyses.
6. Based on the grid, a frequency of 32.9 Hz could be represented. Based on the analysis time step, a frequency of 2000 Hz could be represented. Based on the snap interval, a frequency of 20 Hz could be represented. Therefore, the maximum frequency for the analysis that could be represented was 20 Hz.

7.6 Edit the pstop3d.h file for PSTOP3D

To compile PSTOP3D, a header file is required for the FORTRAN program. This header file contains information about the dimensions of arrays specific to the problem being analyzed. This header file is created by the MATLAB script rvloadset_10.m as discussed in Section 6.6. This header file must be edited for the number of processors used in the analysis as discussed in Section 7.4.

The header file has a name like **PSTOP3D.h.RUNID.txt** where **RUNID** has the form **MODELID_LOADID**. **MODELID** is based on the model information contained in the spreadsheet discussed in Section 5.3 and **LOADID** is taken from the analysis identifier entered when running the script rvloadsdet_10.m as discussed in Section 6.6. The **MODELID** is a concatenation of the **id.model, id.grd**, **id.topo**, and **id.med** data items. The file name shown in Section 6.6 was **pstop3d.h.mctp_UR15.txt** where the **MODELID** is **mctp** and the **LOADID** is **UR15**. The header file is shown below in `Courier` font. Green text denotes text that must be edited and red text is additional explanation.

```
C === START OF FILE: pstop3d.h, written by Matlab m-file rvloadset_V.m;
C === edit where indicated to correct undesired default values.

C S.A. KETCHAM
C USA ERDC CRREL, 72 LYME RD, HANOVER NH 03755
C EMAIL:STEPHEN.A.KETCHAM@USACE.ARMY.MIL
C VOICE: 603-646-4601

C PURPOSE:
C INCLUDE FILE, DEFINES PARAMETERS FOR PSTOP3D_*.F
C PARALLEL MPI FD-TD VISCOELASTIC OR ACOUSTIC PROPAGATION MODEL
```

```
C ****GENERAL DEFINITIONS****
C nEW_mesh = NUMBER OF PROCESSORS IN X (EAST-WEST) DIRECTION
C nNS_mesh = NUMBER OF PROCESSORS IN Y (NORTH-SOUTH) DIRECTION
C nUD_mesh = NUMBER OF PROCESSORS IN Z (UP-DOWN) DIRECTION
C NNX = NUMBER OF SINGLE-PROCESSOR-DOMAIN GRID POINTS IN X (EAST-WEST) DIRECTION
C NNY = NUMBER OF SINGLE-PROCESSOR-DOMAIN GRID POINTS IN Y (NORTH-SOUTH) DIRECTION
C NNZ = NUMBER OF SINGLE-PROCESSOR-DOMAIN GRID POINTS IN Z (UP-DOWN) DIRECTION
C LO = LENGTH OF THE OVERLAP BETWEEN PROCESSOR DOMAINS FOR SPATIAL DIFFERENCES
C NX_MODEL_SIZE+2*LO = NUMBER OF FULL-MODEL GRID POINTS IN X (EAST-WEST) DIRECTION
C NY_MODEL_SIZE+2*LO = NUMBER OF FULL-MODEL GRID POINTS IN Y (NORTH-SOUTH)
DIRECTION
C NZ_MODEL_SIZE+2*LO = NUMBER OF FULL-MODEL GRID POINTS IN Z (UP-DOWN) DIRECTION
C NREL = NUMBER OF VISCOELASTIC RELAXATION MECHANISMS
C NNP = WIDTHS OF PML ABSORBING ANULUS ALL MODEL SIDES (<=NNX,NNY,NNZ);
C NRANK = RANK OF STRESS (OR PRESSURE) TENSOR TO DIMENSION PML MATRIX SIZE;

C =================================================================

C ***** IMPORTANT !!!! *****
C NX_MODEL_SIZE / NNX MUST EQUAL A WHOLE NUMBER BEFORE ROUNDING!
C NY_MODEL_SIZE / NNY MUST EQUAL A WHOLE NUMBER BEFORE ROUNDING!
C NZ_MODEL_SIZE / NNZ MUST EQUAL A WHOLE NUMBER BEFORE ROUNDING!

C E.G., THIS WORKS:
C NX_MODEL_SIZE=120
C nEW_MESH=3
C NX_MODEL_SIZE/nEW_MESH=40=NNX
C THIS DOES NOT WORK:
C NX_MODEL_SIZE=121
C nEW_MESH=3
C NX_MODEL_SIZE/nEW_MESH=40=NNX

C =================================================================

C EDIT THE PARAMETER STATEMENTS BELOW TO DESIRED ANALYSIS SPECIFICATIONS

C SPECIFY PROCESSOR MESH (DEFAULT IS 4-CORE DOMAIN):
 PARAMETER (nEW_mesh=16) ! SIZE IN X-DIRECTION, i.e., EAST-WEST DIMENSION
 PARAMETER (nNS_mesh=16) ! SIZE IN Y-DIRECTION, i.e., NORTH-SOUTH DIMENSION
 PARAMETER (nUD_mesh=2) ! SIZE IN Z-DIRECTION, i.e., UP-DOWN DIMENSION
```

The values of the size of the processors in the x, y, and z directions should be determined as discussed in Section 7.4. This file was composed for a 32 processor/node machine.

```
C SPECIFY WIDTH OF PML ANULUS SURROUNDING MODEL ALL SIDES:
 PARAMETER (NNP=10)
```

This value of NNP should remain 10. A value of 10 for the PML region is hardcoded in the MATLAB routines. This is discussed in Section 5.6. The PML region must be contained within a single processor level.

```
C SPECIFY NUMBER OF VISCOELASTIC MECHANISMS (CHANGE DEFAULT IN ONE CIRCUMSTANCE
C ONLY: TO PERFORM ELASTIC ANALYSIS WITH VISCOELASTIC MODEL, SET NREL=0):
 PARAMETER (NREL=0)

C =================================================================

C DO NOT EDIT THE PARAMETER STATEMENTS BELOW

C ENTIRE MODEL'S GRID SIZE:
 PARAMETER (NX_MODEL_SIZE=2496) This is the number of x nodes in the mesh.
 PARAMETER (NY_MODEL_SIZE=2496) This is the number of y nodes in the mesh.
 PARAMETER (NZ_MODEL_SIZE=256) This is the number of z nodes in the mesh.
```

If the topography is not flat, the parallel-to-topography output must be contained within a single z-processor level.

```
C I_SEISMIC_FLAG=1: SEISMIC ANALYSIS; I_SEISMIC_FLAG=0: ACOUSTIC ANALYSIS
 PARAMETER (I_SEISMIC_FLAG=0)
```

```
C DOMAIN GRID SIZE FOR EACH PROCESSOR IS CALCULATED--DO NOT CHANGE:
 PARAMETER (NNX=NX_MODEL_SIZE/nEW_mesh)
 PARAMETER (NNY=NY_MODEL_SIZE/nNS_mesh)
 PARAMETER (NNZ=NZ_MODEL_SIZE/nUD_mesh)

C OVERLAPS:
 PARAMETER (LO=1)
 PARAMETER (LOA=1)
 PARAMETER (LOE=0)
 PARAMETER (LOV=0)

C VARIABLE-DIMENSION PARAMETERS:
 PARAMETER (NNXA=NNX,NNYA=NNY,NNZA=NNZ)
 PARAMETER (NNXE=1,NNYE=1,NNZE=1)
 PARAMETER (NNXV=1,NNYV=1,NNZV=1)
 PARAMETER (NREL_DIMPARAM=1)
 PARAMETER (NNPA=NNP,NNPE=1,NNPV=1)

C RANK OF STRESS TENSOR (=2 FOR STRESS, =0 FOR PRESSURE):
 PARAMETER (NRANK=0)

C MATERIAL INDEX DEFINITION TYPE CAN BE, E.G., BY NODES, LAYERS, ETC.,
C AS DEFINITION CAPABILITIES EVOLVE--DO NOT CHANGE:
 PARAMETER (MATL_DEF_TYPE=1)
C NUMBER OF LAYERS TO DEFINE MATERIAL INDICES--DO NOT CHANGE:
 PARAMETER (MATL_DEF_PARAMETER_1=4)

C =================================================================

C EDIT THE PARAMETER STATEMENTS BELOW: SET TO 1 TO SAVE MEMORY WHEN NOT
CALCULATING STRAIN

C VARIABLE-DIMENSION PARAMETERS FOR STRAIN QUANTITY CALCULATION
 PARAMETER (NNXEE=1,NNYEE=1,NNZEE=1)

C =================================================================

C DO NOT EDIT PARAMETER STATEMENTS BELOW

C LOAD NUMBER 1: A1. NOMINAL PRESSURE, rvloadset_window_FRicker
C NUMBER OF APPLIED SOURCES (I.E., BODY FORCES, VELOCITY CONSTRAINTS, OR Q
SOURCES)=1
C NUMBER OF g(t) TIME STEPS=299
C SOURCE POSITION (xs,ys,height)=(30.0481,2469.95,1.40349); height IS HEIGHT ABOVE
TOPOGRAPHIC SURFACE
C SOURCE POSITION (xs,ys,zs)=(30.0481,2469.95,38); zs IS Z-COORDINATE POSITION AND
ELEVATION ABOVE DATUM = z = 0 m

C VECTOR INPUT FLAG (FLAG=1 FOR VECTOR INPUT, 0 FOR SCALAR INPUT)
 PARAMETER (I_VECTOR_INP_FLAG=0)
C NUMBER OF LOADS IN LOAD SET
 PARAMETER (NUM_LOADS=1)
C TOTAL NUMBER OF SOURCES IN ALL LOADS OF LOAD SET
 PARAMETER (NUM_FORCES=1)
C TOTAL NUMBER OF G(t) STEPS IN ALL LOADS OF LOAD SET
 PARAMETER (NUM_GSTEPS=299)
```

The NUM_GSTEPS is for the specific source. If the source changes, this number will change. The files defining the source are written by the rvloadset.m script described in Section 6.6. The COMMAND.FIL file described in Section 7.8 lists the files for use in PSTOP3D.

7.7 Compile PSTOP3D

To compile PSTOP3D, the **pstop.h.RUNID.txt** file should be copied to the directory where the PSTOP Fortran files are located on the HPC machine. The **RUNID** part of the file name is explained in Section 7.6. The following script can be run to compile PSTOP3D:

```
#!/bin/ksh
# pstop3d compile for Garnet script

# 754=rwxr-xr-- Group can read and execute
# Use "chmod 754 pstop3d_compile.sh" if not executable

# Current directory must have this script, pstop3d.h.$1.txt, and all pstop3d .f
files
# Current directory will be the output directory

# $1 is the analysis and pstop3d executable ID (long form, i.e., not necessarily
the .SNP file prefix)

# To submit for analysis mctp_UR15 (example below), with input for $1
# pstop3d_compile.sh mctp_UR15

# Initiate log entries
date 2>&1 | tee -a pstop3d_compile_$1.log
echo "using file pstop3d.h.$1.txt"

# Copy include .txt file for current analysis
cp pstop3d.h.$1.txt pstop3d.h 2>&1 | tee -a pstop3d_compile_$1.log

# Compile code
echo "compiling..."
ftn -fast -byteswapio -c pstop3d_main.f 2>&1 | tee -a pstop3d_compile_$1.log
ftn -fast -byteswapio -c pstop3d_mpi.f 2>&1 | tee -a pstop3d_compile_$1.log
ftn -fast -byteswapio -c pstop3d_abc.f 2>&1 | tee -a pstop3d_compile_$1.log
ftn -fast -byteswapio -c pstop3d_strs.f 2>&1 | tee -a pstop3d_compile_$1.log
ftn -fast -byteswapio -c pstop3d_pak.f 2>&1 | tee -a pstop3d_compile_$1.log
ftn -fast -byteswapio -c pstop3d_vel.f 2>&1 | tee -a pstop3d_compile_$1.log

echo "linking..."
ftn -fast -byteswapio -o pstop3d_$1 *.o 2>&1 | tee -a pstop3d_compile_$1.log
```

The script may be executed by typing:

./compile.ksh RUNID

where **RUNID** is the designator for the analysis defined by the rvloadset_10.m script (e.g., mctp_UR15).

This script does the following:

1. Copies **pstop3d.h.RUNID.txt** to **pstop.h**.
2. Compiles the FORTRAN modules and links them creating the executable.
3. The executable file **pstop3d_RUNID** is made, e.g., **pstop3d_mctp_UR15**.
4. This executable is "good" for the grid size and load set defined. Therefore, if all load sets are the same and just vary in their location, then this file is the same. The executable will be the same and can be used for multiple loadings.

7.8 Edit the COMMAND.FIL file for PSTOP3D

One of the files created by the rvloadset_10.m script is a file named **COMMAND.FIL.RUNID.txt** where the **RUNID** is the run identifier described in Section 7.6. This file controls the run parameters for PSTOP3D and needs to be edited for the specific problem being analyzed. The file is written for a specific load set as defined by the rvloadset_10.m script. The file is shown below in `Courier` font. Green text denotes text that must be edited while red text is additional explanation.

```
===============================================================================
Parameter inputfile COMMAND.FIL for pstop3d written by Matlab m-file
rvloadset_V.m.
===============================================================================
mctp_UR15              ; SNAP_FILE. EDIT TO DISTINGUISH OUTPUT FILES IF NEEDED.
<15 CHARACTERS.

This will be the name of the SNAP files created during the analysis. The SNAP
files are files that contain snapshots of the output at selected time increments.

mctp_geo.dat           ; GEO_FILE. DO NOT EDIT.
1.0016,1.0016,1        ; Dxi,Dkappa,Deta (m). DO NOT EDIT: FOR INFO-FILE OUTPUT
ONLY.
0.0005                 ; DT (s). DO NOT EDIT.

This is the time step for the analysis which must satisfy the Courant condition
discussed in Section 7.2.

20500                  ; NT. EDIT TO SET/CHANGE DURATION OF ANALYSIS.

This is the number of time steps in the analysis.

0                      ; Blank spot for future pml parameter.
50                     ; INTERVAL_SNAP. EDIT TO ENSURE DESIRED NYQUIST FREQUENCY
OF OUTPUT.

The value of the SNAP interval should be selected to insure the desired Nyquist
frequency as described in Section 7.3. This is a multiple of DT. Therefore, the
time increment of the output for this case is DT*INTERVAL_SNAP.

1626,545,31            ; IX_SNAP_PLN,IY_SNAP_PLN,IZ_SNAP_PLN. EDIT TO SELECT 2D-
OUTPUT PLANES (0=NO SAVE).

The IX_SNAP_PLN, IY_SNAP_PLN, IZ_SNAP_PLN values are the nodes through the point
of application of the source. This can be changed to select another location.

1,1,1                  ; NDX_SNAP_2D,NDY_SNAP_2D,NDZ_SNAP_2D: EDIT TO SPATIALLY
DECIMATE 2D-OUTPUT PLANES.
1                      ; I_TOPO_OUTPUT_FLAG. SET=0 FOR Z=Z(IZ_SNAP_PLN) SLICE;
SET=1 FOR PARALLEL-TO-TOPO "SLICE."
1                      ; NODES_ABOVE_TOPO. EDIT TO SELECT PARALLEL-TO-TOPO 2D
OUTPUT. (IGNORED WHEN I_TOPO_OUTPUT_FLAG = 0).

The TOPO_OUTPUT_FLAG is set for parallel to topography; therefore, this line
selects the results at 1 node above the topography. If the aux.options.modifyTopo
flag as discussed in Section 5.7 for buildings is set, the results are output 1
node above the tops of the buildings.

11,2486                ; IX_BEG_SNAP_2D,IX_END_SNAP_2D. EDIT TO CHOOSE INDICES FOR
BOUNDING 2D OUTPUT.
11,2486                ; IY_BEG_SNAP_2D,IY_END_SNAP_2D. EDIT TO CHOOSE INDICES FOR
BOUNDING 2D OUTPUT.
11,246                 ; IZ_BEG_SNAP_2D,IZ_END_SNAP_2D. EDIT TO CHOOSE INDICES FOR
BOUNDING 2D OUTPUT.
```

The node numbers for the 2D output should be adjusted to accommodate the 10 node PML. So for 2496 nodes, begin at 11 and stop at 2486. For 256 nodes, begin at 11 and end at 246.

```
1,2496              ; IX_BEG_SNAP_3D,IX_END_SNAP_3D. EDIT TO CHOOSE INDICES FOR
BOUNDING 3D OUTPUT.
1,2496              ; IY_BEG_SNAP_3D,IY_END_SNAP_3D. EDIT TO CHOOSE INDICES FOR
BOUNDING 3D OUTPUT.
1,256               ; IZ_BEG_SNAP_3D,IZ_END_SNAP_3D. EDIT TO CHOOSE INDICES FOR
BOUNDING 3D OUTPUT.
0,0,0               ; NDX_SNAP_3D,NDY_SNAP_3D,NDZ_SNAP_3D: EDIT TO SPATIALLY
DECIMATE 3D OUTPUT (any 0=NO SAVE).
0,0,0,1             ; Indicators for saving quantities U,V,W,P. (1=SAVE, 0=NO
SAVE).
mctp_UR15_ls.dat    ; SOURCESET_FILE. DO NOT EDIT EXCEPT IN SPECIAL
CIRCUMSTANCES. <28 CHARACTERS.
mctp_UR15_gt.dat    ; GT_FILE. DO NOT EDIT EXCEPT IN SPECIAL CIRCUMSTANCES. <28
CHARACTERS.
```

The above file names are for the source defined when the rvloadset_10.m script is run. This can be changed, but this also affects lines in the pstop3d.h header file as discussed in Section 7.6.

```
================================================================================
GLOSSARY FOR INPUT TERMS ABOVE
================================================================================

SNAP_FILE: ROOT OF OUTPUT FILE NAME.
GEO_FILE: TOPOGRAPHY AND VELOCITY MODEL INPUT FILE NAME.
Dxi,Dkappa,Deta (m): MIN X,Y,Z SPACING OF THIS ANALYSIS' RECTANGULAR F-D GRID.
DT (s): TIME STEP. MUST MEET STABILITY CONDITION. MUST MATCH DT IN GT_FILE.
NT: TOTAL NUMBER OF TIME STEPS (IF ANALYSIS COMPLETES).
Future pml coefficient if needed.
INTERVAL_SNAP: TIME DECIMATION ORDER FOR SNAPSHOT OUTPUTS.
IX_SNAP_PLN,IY_SNAP_PLN,IZ_SNAP_PLN: PLANE INDICES FOR 2D SLICE OUTPUT
 (0=NO SAVE). OUTPUT WILL BE AT X(IX_SNAP_PLN), Y(IY_SNAP_PLN), AND
 Z(IZ_SNAP_PLN), WHERE THE COORDINATES HERE USE PSTOP3D INDICES
 THAT START AT 1-LO, WHICH ARE NOT TO BE CONFUSED WITH rvgeo_V.m
 INDICES THAT START AT 1. THE CONVERSION BETWEEN THESE TWO INDEXING
 SYSTEMS IS index_pstop=index_rvgeo-LO. ALSO Z=CONSTANT OUTPUT WILL BE
 OVERRIDDEN BY PARALLEL-TO-TOPO-SURFACE OUTPUT IF I_TOPO_OUTPUT_FLAG=1.
NDX_SNAP_2D,NDY_SNAP_2D,NDZ_SNAP_2D: SPATIAL DEC ORDERS FOR 2D SNAPSHOTS.
I_TOPO_OUTPUT_FLAG: = 0 TO OUTPUT Z=Z(IZ_SNAP_PLN) SLICE; = 1 TO OUTPUT
 PARALLEL-TO-TOPO-SURFACE "SLICE".
NODES_ABOVE_TOPO: = NUMBER OF Z-DIRECTION NODES BETWEEN THE TOPO LAYER AND THE
 X-Y OUTPUT "SLICE" (IGNORED WHEN I_TOPO_OUTPUT_FLAG = 0). USE POSITIVE
 NUMBER TO DESIGNATE OUTPUT FROM ABOVE TOPO SURFACE, AND A NEGATIVE NUMBER
 TO DESIGNATE OUTPUT FROM ABOVE TOPO SURFACE.
IX_BEG_SNAP_2D,IX_END_SNAP_2D: INDICES FOR BOUNDING 2D X-DIRECTION OUTPUT
 BY X(IX_BEG_SNAP_2D) AND X(IX_END_SNAP_2D), WHERE THE COORDINATES HERE USE
 PSTOP3D INDICES THAT START AT 1-LO. THE CONVERSION BETWEEN THE PSTOP AND
 rvgeo_V.m INDEXING SYSTEMS IS index_pstop=index_rvgeo-LO.
IY_BEG_SNAP_2D,IY_END_SNAP_2D: INDICES FOR BOUNDING 2D Y-DIRECTION OUTPUT.
IZ_BEG_SNAP_2D,IY_END_SNAP_2D: INDICES FOR BOUNDING 2D Z-DIRECTION OUTPUT.
IX_BEG_SNAP_3D,IX_END_SNAP_3D: INDICES FOR BOUNDING 3D X-DIRECTION OUTPUT.
IY_BEG_SNAP_3D,IY_END_SNAP_3D: INDICES FOR BOUNDING 3D Y-DIRECTION OUTPUT.
IZ_BEG_SNAP_3D,IY_END_SNAP_3D: INDICES FOR BOUNDING 3D Z-DIRECTION OUTPUT.
NDX_SNAP_3D,NDY_SNAP_3D,NDZ_SNAP_3D: SPATIAL DECIMATION ORDERS FOR 3D X,Y,Z
 OUTPUTS RESPECTIVELY.
IU_SNAP,IV_SNAP,IW_SNAP,IP_SNAP: U,V,W,P OUTPUT INDICATORS (1=SAVE, 0=NO SAVE).
LOADSET_FILE: FILE WITH SETS OF BODY FORCES, VELOCITY CONSTRAINTS, OR Q SOURCES
AND LOCATIONS FOR EACH LOAD.
GT_FILE: FILE WITH TIME SERIES GIVING FINAL AMPLITUDE VARIATION FOR EACH LOAD.

================================================================================
```

7.9 Edit the COMMAND.AUX file for PSTOP3D

PSTOP3D uses files termed auxiliary files. These files define auxiliary structures that are placed on or under the topography such as buildings, bridges, and paved areas. The modeling of auxiliary structures is discussed in Sections 3.3, 3.4, and 3.5. The definitions of auxiliary structures in the Excel spreadsheets are discussed in Sections 5.7 and 5.8. The processing of auxiliary structures using MATLAB is discussed in Section 6.5.

When the auxiliary structures are processed by MATLAB, a file named **COMMAND.AUX.ID_AUX.legacy.txt** is created. This file is created in a subdirectory named **legacy**. The **ID_AUX** part of the file name is a concatenation of the **MODELID** described in Section 5.3, the text **_aux_**, and the **id.aux** data item. The **ID** is a concatenation of the **id.model, id.grd**, **id.topo**, and **id.med** data items (e.g., mctp_aux_1).

This file lists the names of the auxiliary files created as defined in the Excel spreadsheets. If one auxiliary spreadsheet is processed, the file will contain one file name, if five auxiliary spreadsheets are processed in the same execution of the MATLAB rvgModel.m script as described in Section 5.3, then five file names will be written to the **COMMAND.AUX.ID_AUX.legacy.txt** file.

If auxiliary spreadsheets are processed one at a time, the **COMMAND.AUX.ID_AUX.legacy.txt** file will only contain the file name generated by the last auxiliary spreadsheet processed. Therefore, the file will need to be edited to include the names of all auxiliary files generated and to be used in the analysis. Only the desired auxiliary files for a particular analysis should be included in this file. For example, a set of auxiliary files could be used to define buildings as individual buildings and another set could be used to define buildings aggregated into larger areas representing the buildings. This would require two different **COMMAND.AUX.ID_AUX.legacy.txt** files to describe these sets of buildings for analysis.

The auxiliary files created have names like **mctp_aux_1building2.dat**. The first part of the name is the **ID_AUX** identifier discussed previously. The last part of the file name is based on the name of the spreadsheet defining the auxiliary structures as discussed in Section 5.3.

The **COMMAND.AUX.ID_AUX.legacy.txt** is shown below in `Courier` font. Green text denotes text that must be edited.

```
COMMAND.AUX provides auxiliary model data for PSTOP3D: # files, file names,
max DT. Later data overwrites earlier data--order aux files accordingly.
===========================================================================
19                            ; Number of matl & indices auxiliary-file pairs
mctp_aux_1PavedA.dat          ; Prefix for matl & indices auxiliary files
mctp_aux_1PavedB.dat
mctp_aux_1PavedC.dat
mctp_aux_1PavedD.dat
mctp_aux_1PavedE.dat
mctp_aux_1PavedA-Islands.dat
mctp_aux_1PavedB-Islands.dat
mctp_aux_1PavedC-Islands.dat
mctp_aux_1PavedD-Islands.dat
mctp_aux_1PavedE-Islands.dat
mctp_aux_1building1.dat
mctp_aux_1building2.dat
mctp_aux_1building3.dat
mctp_aux_1building4.dat
mctp_aux_1building5.dat
mctp_aux_1building6.dat
mctp_aux_1building7.dat
mctp_aux_1building8.dat
mctp_aux_1Bridge.dat

===========================================================================
0.00764907                    ; = max time step (s) for these files
```

Modify the above file to list all auxiliary files in the correct order. Later files overwrite previous file definitions. Therefore, the paved areas are listed first. These areas define larger areas than needed because they do not account for islands as discussed in Section 5.8. The islands are defined next to set portions of the larger paved areas defined as asphalt back to grass. Auxiliary files defining buildings are listed next. Finally, the auxiliary file defining bridges is listed.

The time step shown in the file corresponds to the Courant condition computed for the auxiliary materials. This value is for the material that the file was written. That is, if an auxiliary structure is processed one spreadsheet at a time, this is for the last spreadsheet processed. If several spreadsheets are processed, this is the smallest time computed for all of the materials specified in the spreadsheets.

7.10 How to execute PSTOP3D

After the PSTOP3D program has been compiled as discussed in Section 7.7, the data files that PSTOP3D requires must be uploaded to the HPC machine. The files needed are:

5. The load set files produced by the rvloadset_10.m script discussed in Section 6.6. These files are listed in the **COMMAND.FIL** file discussed in Section 7.8. These files are named **RUNID_ls.dat** and **RUNID_gt.dat** where the **RUNID** is defined in Section 7.6.
6. The **COMMAND.FIL.RUNID.txt** file (e.g., **COMMAND.FIL.mctp_UR15.txt**)
7. The **COMMAND.AUX.ID_AUX.legacy.txt** file (e.g., **COMMAND.AUX.mctp_aux_1.legacy.txt**)
8. All files beginning with **RUNID** and **ID_AUX** in the **legacy** directory. RUNID is described in Section 7.6 and ID_AUX in Section 7.9. For example, if **RUNID** is **mctp** and **ID_AUX** is **mctp_aux_1** then all files starting with **mctp_geo.dat** and **mctp_aux_1** should be copied. This is all files containing information about the topography and auxiliary structures.

The files should be copied to an analysis directory on the HPC machine. The PSTOP3D executable should be copied to the same directory.

Once all required files are copied to a directory, a batch script can be submitted to execute the PSTOP3D analysis. A shell script can be written to interactively generate the required batch script as shown in Appendix A. A typical batch script to execute PSTOP3D is given in the following text. Green text is text the user must tailor to their particular problem. Red text is additional explanation.

```
!/bin/ksh
# pstop3d qsub script
#
#PBS -N mctp_C5
```

This is the name of the job. Used for description in the job queue.

```
#PBS -l select=16:ncpus=32:mpiprocs=32
```

This is the number of nodes needed on Garnet. Each node contains 32 processors.

```
#PBS -l walltime=05:30:00
```

This is the execution time in hours:minutes:seconds.

```
#PBS -q standard_sm
```

This is the name of the standard queue for small problems.

```
#PBS -A ERDCACCOUNT
```

This is the account number needed that provides time resources for running the job.

```
#PBS -m be
#PBS -M joe.somebody@usace.army.mil
```

This is your email. An email will be sent when the job starts running.

```
cd /u/userid/data/mctp_C5
```

Change to the directory where the PSTOP3D files are located.

```
mkdir /work/userid/mctp_C5
```

Make a work directory.

```
cp /u/userid/data/mctp_C5/* /work/userid/mctp_C5
```

Copy all files from the user directory to the work directory.

```
cd /work/userid/mctp_C5
```

Change to the work directory. It is important to change the directory before the remaining lines are executed.

```
cp COMMAND.FIL.mctp_C5.txt COMMAND.FIL
```

Copy the COMMAND.FIL for the particular problem to the general name COMMAND.FIL.

```
cp COMMAND.AUX.mctp_aux_1.legacy.txt COMMAND.AUX
```

Copy the COMMAND.AUX file for the particular problem to the general name COMMAND.AUX.

```
cp mctp_geo.dat.0.origtopo mctp_geo.dat.0.2Douttopo
```

Copy the topography file used to define the topography for 2D slice output. The .origtopo file is the original unmodified topography. The .2Douttopo file is the modified topography that includes the tops of the buildings. This line is optional depending on whether the output is desired at a distance above the topography or above the topography and tops of the buildings.

```
aprun -n 512 ./pstop3d_mctp_C5
```

This line submits the batch file. 512 is the total number of processors (number of nodes x 32). pstop3d_mctp_C5 is the name of the executable.

```
exit
```

To submit the batch script to the job queue, type:

```
qsub batch_script_name
```

where “batch_script_name” is the name of the batch script.

8 Post-process PSTOP3D Results

8.1 General

The information contained in this chapter corresponds to Step 8 on the process diagram shown in Figure 1.4. Post-processing of the results from PSTOP3D can be performed using a MATLAB utility called SNAPPS. SNAPPS requires the use of several files. Three of the files are produced by PSTOP3D and will need to be downloaded from the HPC machine to the local machine where MATLAB is installed. The files needed are:

1. RUNID_PX.SNP
2. RUNID_PY.SNP
3. RUNID_PZ.SNP
4. RUID.INFO

The **RUNID** part of the file names listed above is explained in Section 7.6. The other files required pertain to the topography and the load definition. These will be requested by SNAPPS.

The **.SNP** files or SNAP files are the output files produced by PSTOP3D that have been temporally decimated. That is, the files were produced using the **INTERVAL_SNAP** discussed in Section 7.8. The **_PX** file contains the results for a section cut along the x axis, the **_PY** file contains the results for a section cut along the y axis, and the **_PZ** file contains the results for a section cut along the z axis. The location of the section is determined by the **IX_SNAP_PLN**, **IY_SNAP_PLN**, and **IZ_SNAP_PLN** data items explained in Section 7.8.

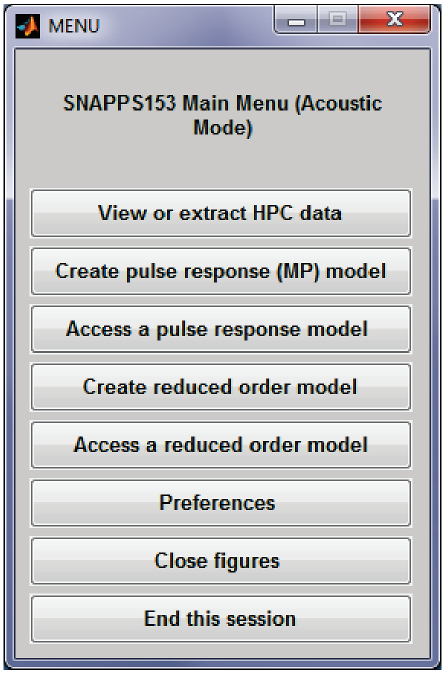
8.2 How to execute SNAPPS

Once the output files have been downloaded from the HPC machine, SNAPPS can be executed. To execute SNAPPS:

1. Execute MATLAB in Windows.
2. On the main MATLAB screen shown in Figure 6.1, navigate to the directory where the scripts are installed. The main script to execute is called snapps153.m. The numbers in the file name indicate the version number.

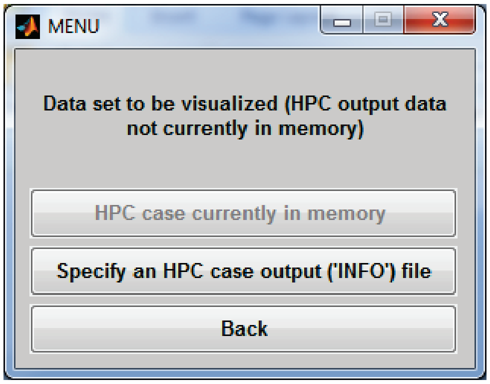
3. The path may need to be changed to include the directory and subdirectories where the scripts are installed. On the **Home** tab, click the **Set Path** button.
4. As shown in Figure 6.2, click **Add with Subfolders** and select the appropriate directory. Click **Save**.
5. Double-click on the **snapps153.m** script.
6. The editor with **snapps153.m** will appear. Click on the **Run** button on the main toolbar.
7. The main menu for the processing routines will appear as shown in Figure 8.1.
8. On the menu, select the button **View or extract HPC data**.
9. The dialog in Figure 8.2 will appear. Click on **Specify an HPC case ("INFO") file**. Navigate to where the **INFO** file is saved and click on the file name.
10. The dialog in Figure 8.3 will appear. Click **Yes** to allow SNAPPS to change the directory to where the data file is located.
11. A file dialog will appear for the input of the **MODEL_geo.dat.4** file for these data. The **MODEL** parameter is explained in Section 7.6. Navigate to the location of this file and select it. This file is located in a directory called **legacy**.
12. A file dialog will appear for the input of the **RUN_ls.dat** file that was generated by the rvloadset_10.m script as explained in Section 6.6.
13. The dialog in Figure 8.4 will appear to select the section cut for processing results. This corresponds to the sections defined in the COMMAND.FIL file described in Section 7.8.
14. The dialog in Figure 8.5 will appear to select the type of results to view. This menu applies to each section cut selected in Step 13.

Figure 8.1. Main menu for SNAPPS.



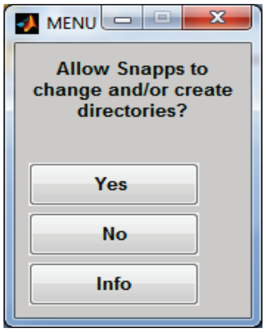
SNAPPS153 Main Menu (Acoustic Mode)

Figure 8.2. Choose data to visualize.



Data set to be visualized (HPC output data not currently in memory)

Figure 8.3. Specify if SNAPPS should change or create directories.



Allow Snapps to change and/or create directories?

Figure 8.4. Choose section cut to extract data.

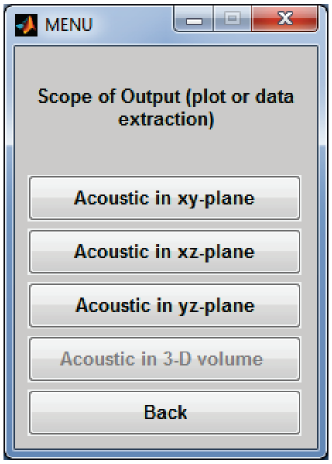
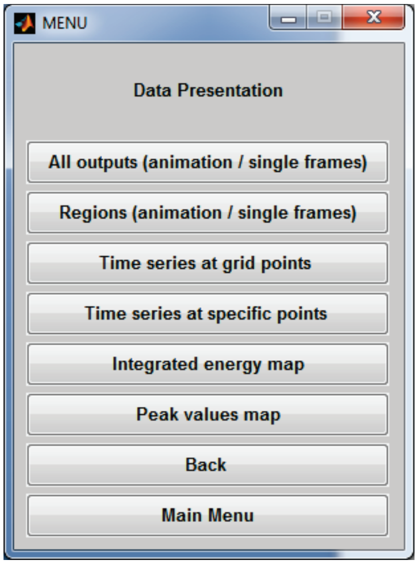


Figure 8.5. Select type of results to view.



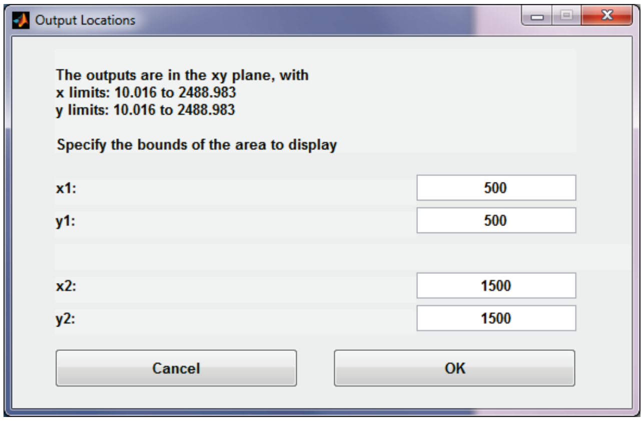
8.3 Produce animations of pressures

To produce an animation of the pressures over time:

1. Select either the **All outputs (animation/single frames)** or **Regions (animation/single frames)** option from the menu shown in Figure 8.5. The difference in the options is the **All outputs** will output for the entire analysis region and the **Regions** will allow the user to window in on a specific area.
2. If **Regions** are selected, the dialog in Figure 8.6 will request the region to display. Input the lower left and upper right coordinates of the box defining the region to plot.

3. The time extents will be requested as shown in Figure 8.7. The time extents of the animation can be specified in frames, seconds, or milliseconds. For each option, a starting and ending point are specified. For the data shown in Figure 8.7, **First frame** is **1** and **Last frame** is **410**. Since there are 410 output frames, the animation will encompass the entire analysis time period.
4. The color limits are selected as shown in Figure 8.8. The symmetrical color limit will cause the color to be centered around 0 Pa, and the upper and lower limits to be 1 and -1, respectively.
5. The dialog shown in Figure 8.9 will display requesting the number of contours to use for the topography. If the topography has been modified as discussed in Section 5.7, then the contour lines will include the tops of the buildings as shown in Figure 8.10. Click **OK** to re-plot with the specified contours. Click **Done** to continue.
6. The animation will be constructed and displayed. An example of one frame of an animation is shown in Figure 8.11.
7. After the animation is completed, the dialog in Figure 8.12 is displayed. Options are available to regenerate the animation, save the animation, modify the colors or contour levels, or generate a Google Earth placemark.

Figure 8.6. Input of region.



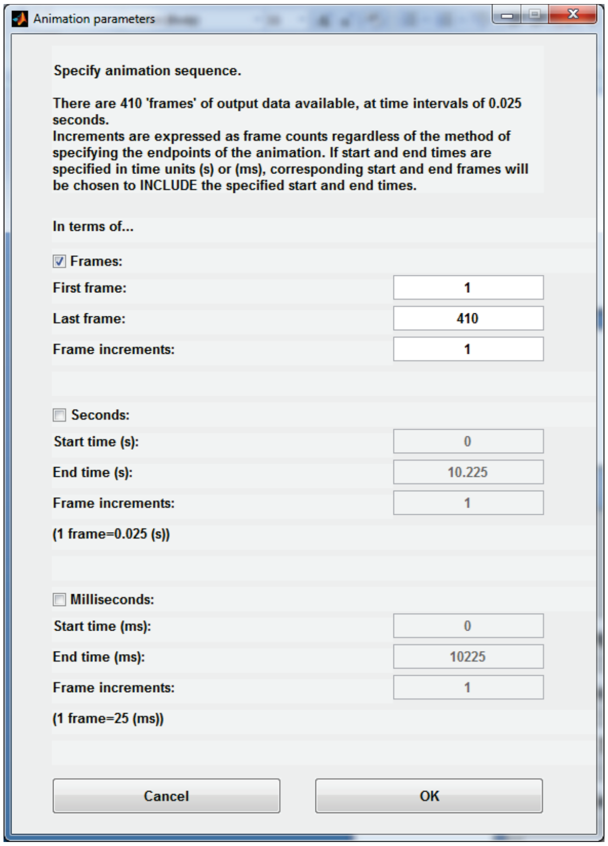
The outputs are in the xy plane, with
x limits: 10.016 to 2488.983
y limits: 10.016 to 2488.983

Specify the bounds of the area to display

x1: 500
y1: 500

x2: 1500
y2: 1500

Figure 8.7. Selection of frames for animation.



Specify animation sequence.

There are 410 'frames' of output data available, at time intervals of 0.025 seconds.
Increments are expressed as frame counts regardless of the method of specifying the endpoints of the animation. If start and end times are specified in time units (s) or (ms), corresponding start and end frames will be chosen to INCLUDE the specified start and end times.

In terms of...

☑ Frames:

First frame: 1

Last frame: 410

Frame increments: 1

☐ Seconds:

Start time (s): 0

End time (s): 10.225

Frame increments: 1

(1 frame=0.025 (s))

☐ Milliseconds:

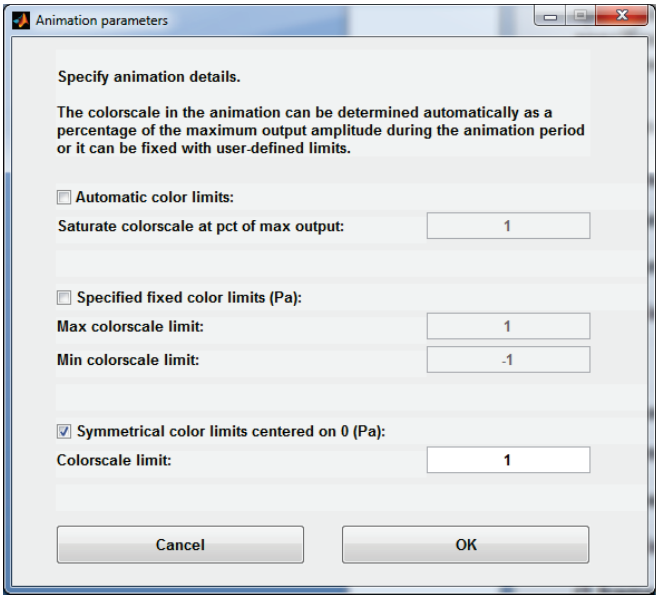
Start time (ms): 0

End time (ms): 10225

Frame increments: 1

(1 frame=25 (ms))

Figure 8.8. Specify color limits for the animation.



Specify animation details.

The colorscale in the animation can be determined automatically as a percentage of the maximum output amplitude during the animation period or it can be fixed with user-defined limits.

☐ Automatic color limits:

Saturate colorscale at pct of max output: 1

☐ Specified fixed color limits (Pa):

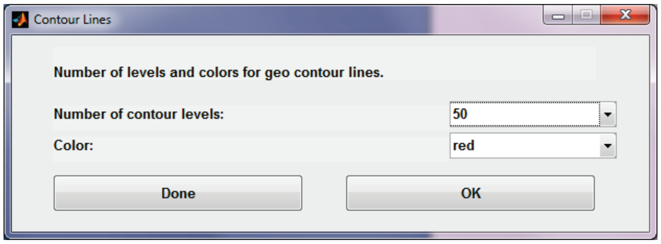
Max colorscale limit: 1

Min colorscale limit: -1

☑ Symmetrical color limits centered on 0 (Pa):

Colorscale limit: 1

Figure 8.9. Selection of number of contours.



Number of levels and colors for geo contour lines.

Number of contour levels: 50

Color: red

Figure 8.10. Contour of topography.

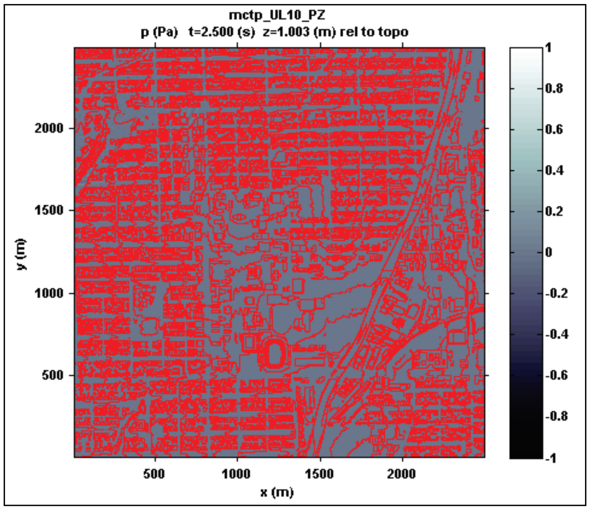


Figure 8.11. Example of frame from animation of pressures.

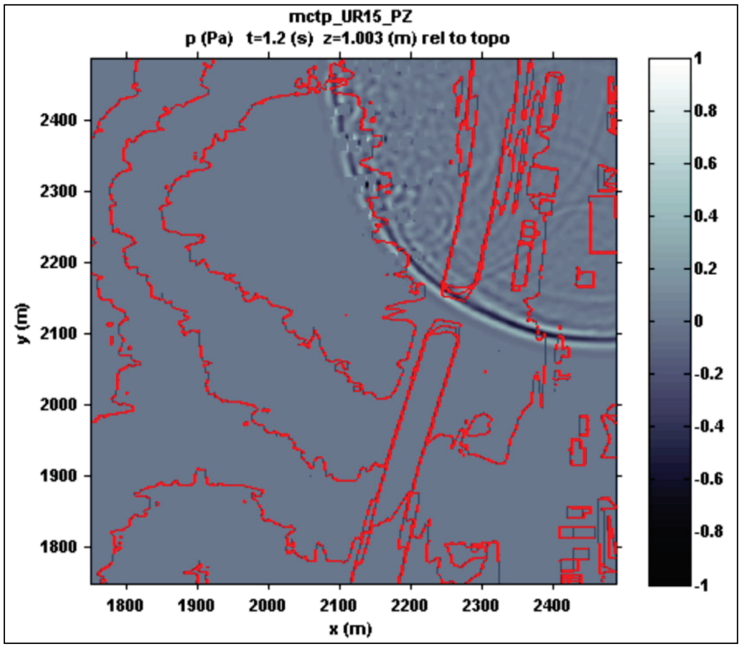
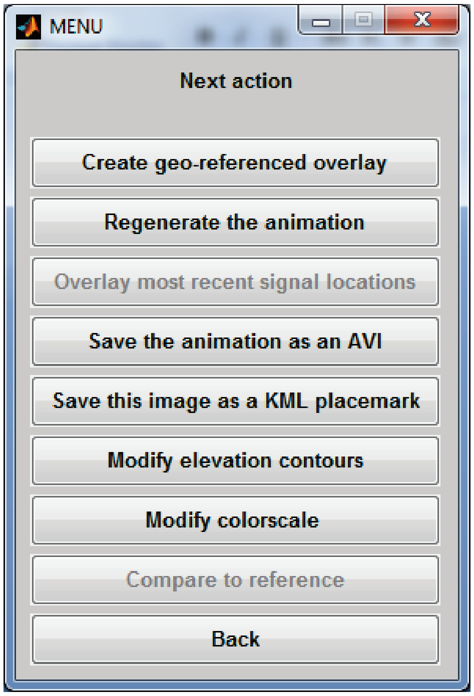


Figure 8.12. Options after creation of animation.



8.4 Output time series information

There were several locations where instrumentation had been installed on the SMU Campus. At these locations, the time histories of the pressure variations were extracted. The locations for this study are shown in Figure 8.13. To plot the time histories at specific locations:

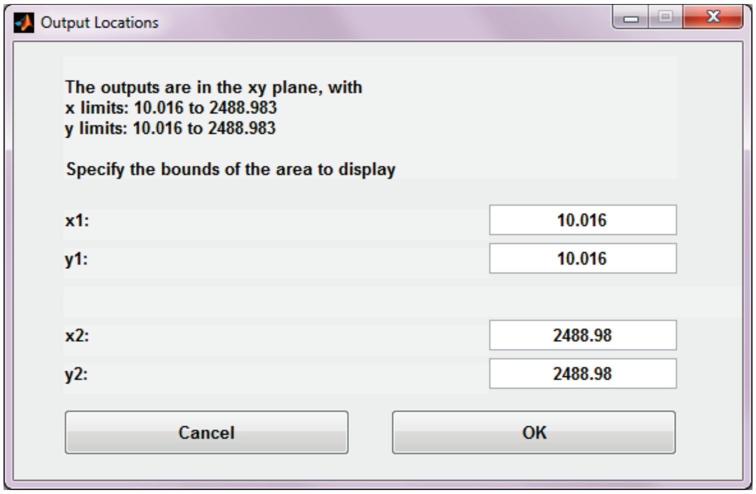
1. Convert all UTM coordinates into local coordinates. To perform this conversion, the lower left-hand UTM coordinates will be subtracted from each of the desired locations. This will result in a local coordinate system with x=0, and y=0 in the lower left-hand corner.
2. From the menu shown in Figure 8.5, select either **Time series at grid points** or **Time series at specific points**.
3. If the **Time series at grid points** is selected, the dialog in Figure 8.14 is displayed. Input the lower left (**x1, y1**) and upper right **(x2, y2**) corner of the region to extract results. Click **OK**.
4. The dialog in Figure 8.15 will display. Input values for the **Number of x points in the grid** and **Number of y points in the grid**. This will form a grid for the extraction of values.
5. Select **Centered in equal area regions** for the **Locate the output points** option. This will select the location that is at the center of the grid

defined. This option may also be set to extract results at the nodes of the grid defined.

6. The time extents will be requested as shown in Figure 8.16. The time extents of the time history can be specified in frames, seconds, or milliseconds. For each option, a starting and ending point are specified. For the data shown in Figure 8.16, **First frame** is **1** and **Last frame** is **410**. Since there are 410 output frames, the time history will encompass the entire analysis time period.
7. The filter dialog as shown in Figure 8.17 will display. For the version of SNAPPS used, the filter functionality was not fully developed. Therefore, check the **No filter** option and click **OK**.
8. The time histories of the pressures are output at the selected grid locations as shown in Figure 8.18.
9. An option will be displayed to save these histories with a KML if desired.
10. The time histories can be saved as a MATLAB time series object as shown in Figure 8.19, which can be later analyzed with the Time Series Tools in MATLAB.

Figure 8.13. Locations for output of time history information.

Figure 8.14. Select region to compute time series information.



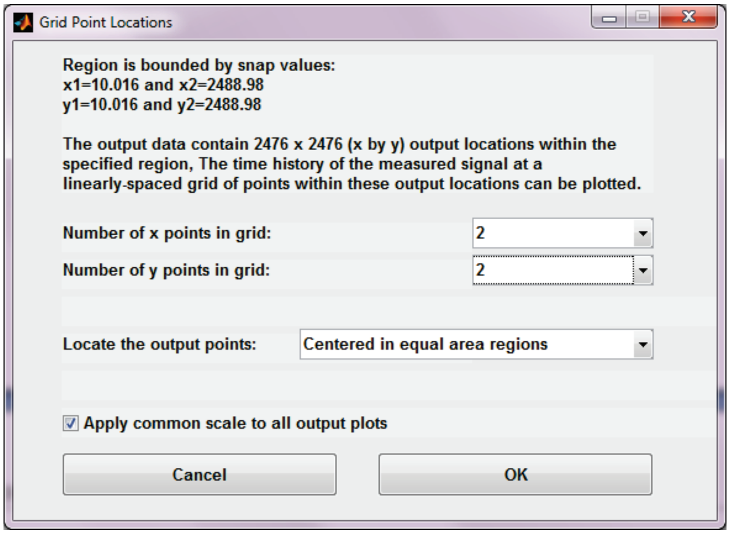
The outputs are in the xy plane, with
x limits: 10.016 to 2488.983
y limits: 10.016 to 2488.983

Specify the bounds of the area to display

x1: 10.016
y1: 10.016

x2: 2488.98
y2: 2488.98

Figure 8.15. Select grid size for time series information.



Region is bounded by snap values:
x1=10.016 and x2=2488.98
y1=10.016 and y2=2488.98

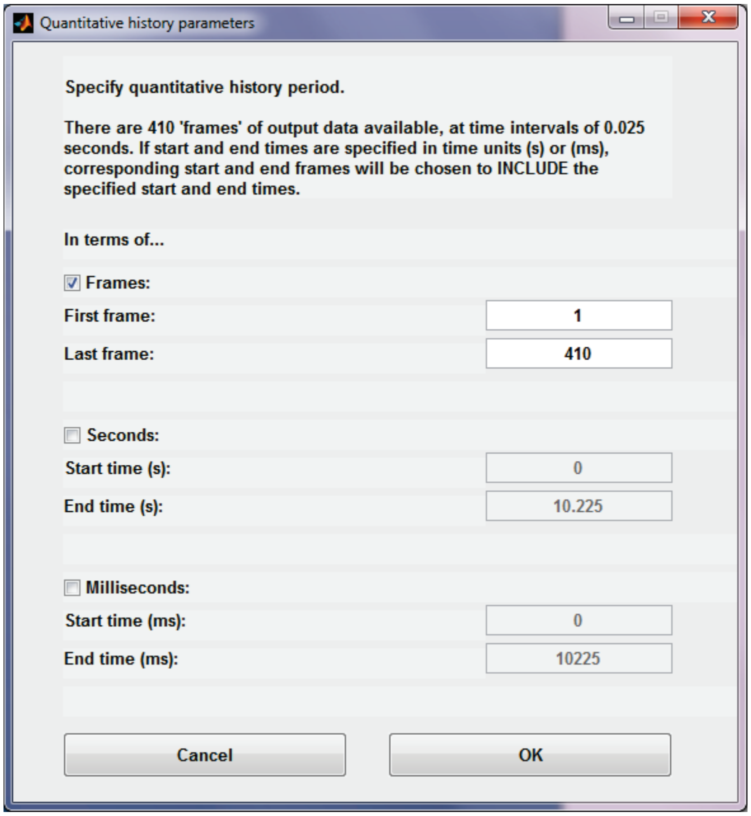
The output data contain 2476 x 2476 (x by y) output locations within the specified region, The time history of the measured signal at a linearly-spaced grid of points within these output locations can be plotted.

Number of x points in grid: 2
Number of y points in grid: 2

Locate the output points: Centered in equal area regions

☑ Apply common scale to all output plots

Figure 8.16. Select the extents of the time history.



Specify quantitative history period.

There are 410 'frames' of output data available, at time intervals of 0.025 seconds. If start and end times are specified in time units (s) or (ms), corresponding start and end frames will be chosen to INCLUDE the specified start and end times.

In terms of...

☑ Frames:

First frame: 1

Last frame: 410

☐ Seconds:

Start time (s): 0

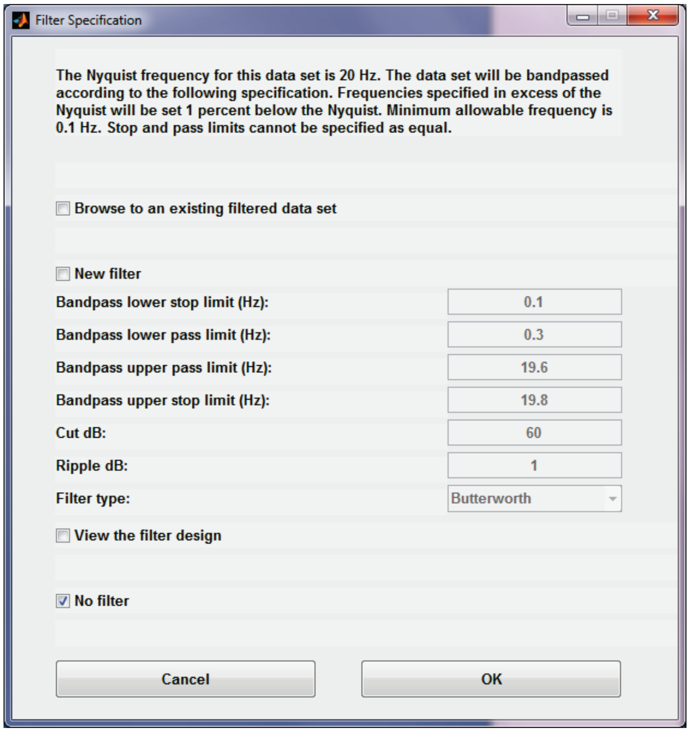
End time (s): 10.225

☐ Milliseconds:

Start time (ms): 0

End time (ms): 10225

Figure 8.17. Select filter for results.



The Nyquist frequency for this data set is 20 Hz. The data set will be bandpassed according to the following specification. Frequencies specified in excess of the Nyquist will be set 1 percent below the Nyquist. Minimum allowable frequency is 0.1 Hz. Stop and pass limits cannot be specified as equal.

☐ Browse to an existing filtered data set

☐ New filter

Bandpass lower stop limit (Hz): 0.1

Bandpass lower pass limit (Hz): 0.3

Bandpass upper pass limit (Hz): 19.6

Bandpass upper stop limit (Hz): 19.8

Cut dB: 60

Ripple dB: 1

Filter type: Butterworth

☐ View the filter design

☑ No filter

Figure 8.18. Time history output at grid points.

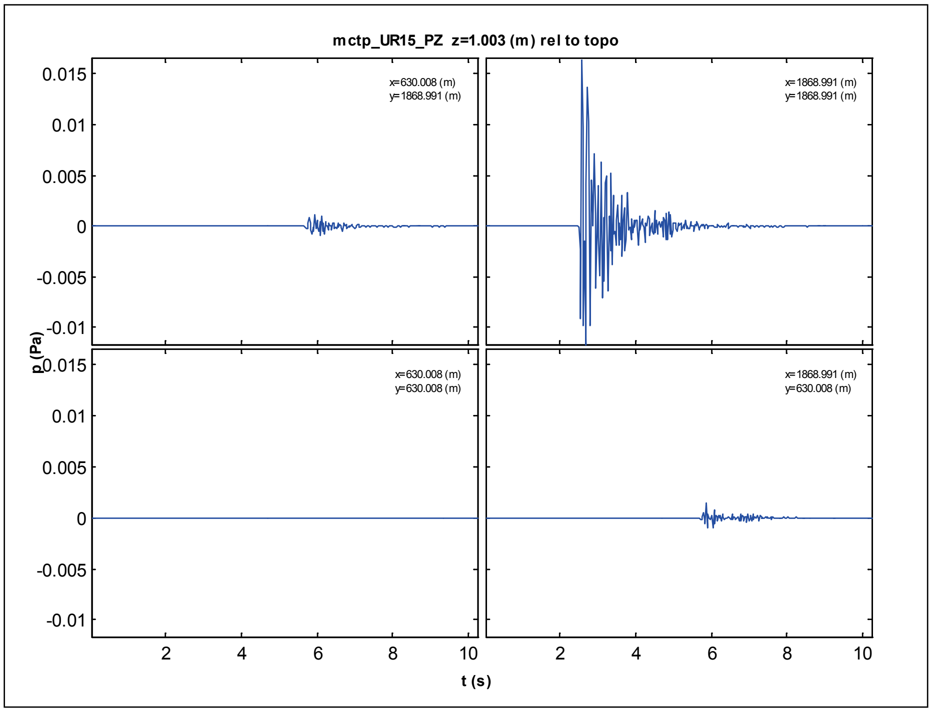
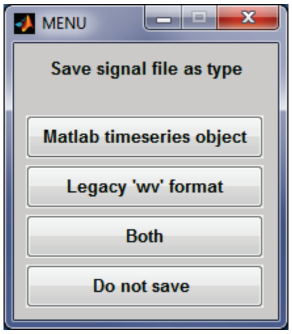


Figure 8.19. Prompt to save time history signals.



Save signal file as type

To enter the locations at specific points:

1. From the menu shown in Figure 8.5, select **Time series at specific points**.
2. The dialog in Figure 8.20 will display. Select the **Point-by-point** option.
3. The dialog in Figure 8.21 will display. Input the **x** and **y** location of a point and click the **Add this location** button.
4. Continue to add points and click the **Add this location** button each time.
5. For the last point, click **Add this location** and then click **Done**.
6. Select the time extents as shown in Figure 8.16 and the filter option as shown in Figure 8.17.

7. The dialog in Figure 8.22 will display. Select **Plot the signal using format for individual time history**. Each input location will be plotted as shown in Figure 8.23.
8. If the option **Plot the signal using format for multi-signal on common axis** is selected, the time histories will be plotted as shown in Figure 8.24.
9. Click **Save this signal to a file** in Figure 8.22 to save the time history to a file. The options shown in Figure 8.19 will display.

Figure 8.20. Specify output at points.

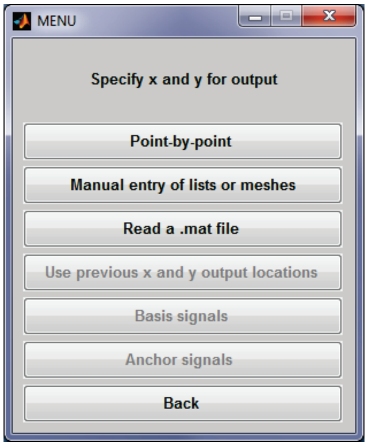
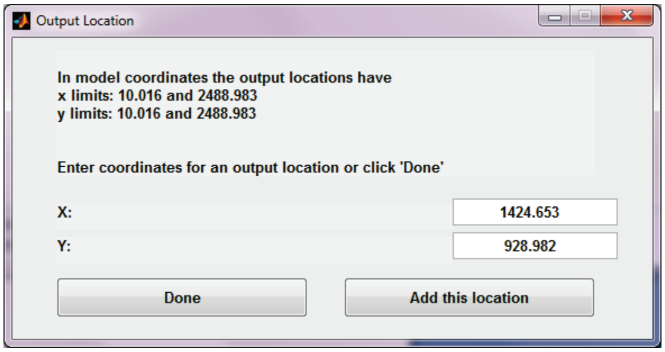


Figure 8.21. Input of points at which to output time histories.

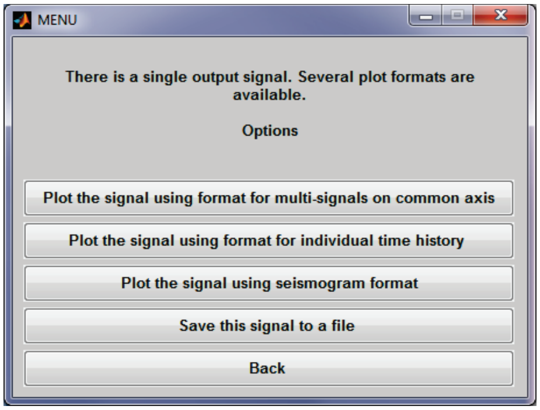


In model coordinates the output locations have
x limits: 10.016 and 2488.983
y limits: 10.016 and 2488.983

Enter coordinates for an output location or click 'Done'

X: 1424.653
Y: 928.982

Figure 8.22. Select how to plot signals.



There is a single output signal. Several plot formats are available.

Figure 8.23. Time history of pressure at single point.

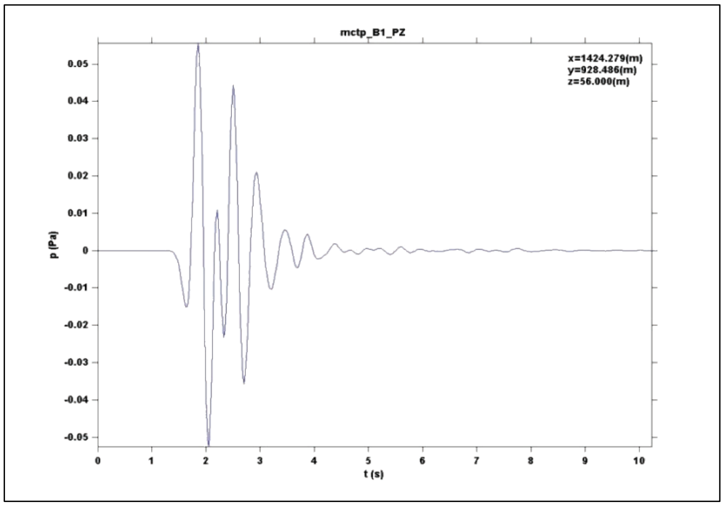
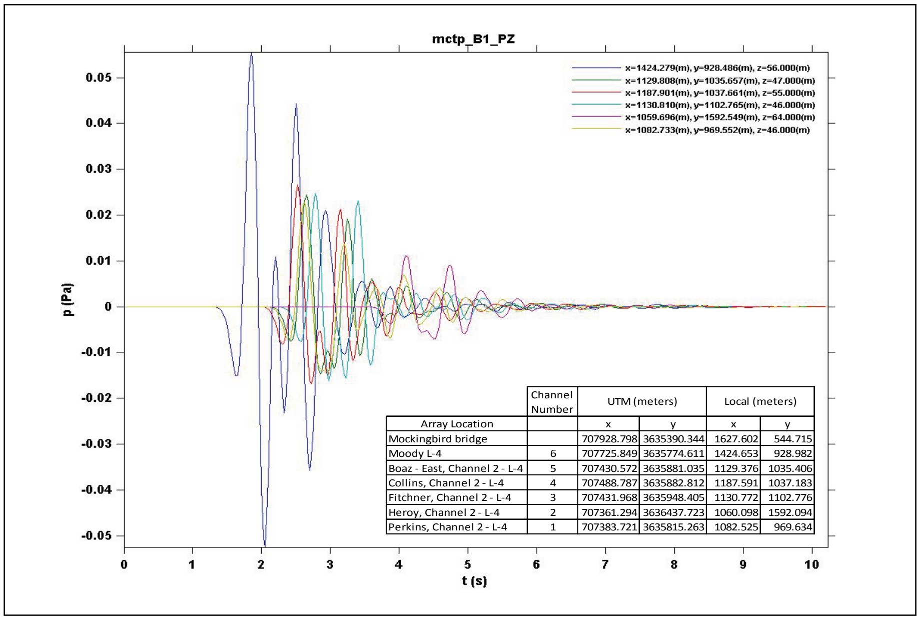


Figure 8.24. Time histories of pressure at multiple points.

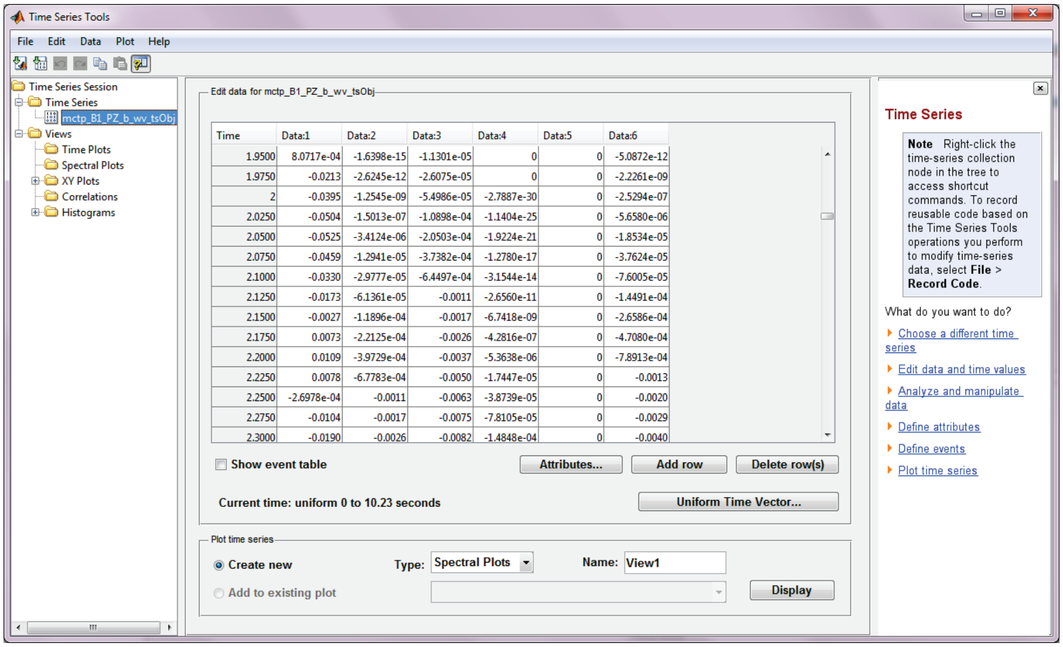


	Channel Number	UTM (meters)		Local (meters)	
Array Location		x	y	x	y
Mockingbird bridge		707928.798	3635390.344	1627.602	544.715
Moody L-4	6	707725.849	3635774.611	1424.653	928.982
Boaz - East, Channel 2 - L-4	5	707430.572	3635881.035	1129.376	1035.406
Collins, Channel 2 - L-4	4	707488.787	3635882.812	1187.591	1037.183
Fitchner, Channel 2 - L-4	3	707431.968	3635948.405	1130.772	1102.776
Heroy, Channel 2 - L-4	2	707361.294	3636437.723	1060.098	1592.094
Perkins, Channel 2 - L-4	1	707383.721	3635815.263	1082.525	969.634

If the time histories are saved to a MATLAB time series object file, then the MATLAB time series tools can be used to display and perform data manipulations. To read and display a time series object file:

1. Execute MATLAB.
2. Navigate to the directory where the file is saved using the **Current Folder** window in MATLAB. The file will have a **.mat** extension.
3. Right-click on the file and select **Load**.
4. The time series object will appear in the **Workspace** window of MATLAB.
5. Right-click the time series object and select **Open in Time Series Tools**.
6. Select the type of plot, e.g., **Spectral Plots** or **Time Plots**, as shown in Figure 8.25. Click **Display**.
7. Both the spectral and time plots are shown in Figure 8.26. The spectral plots indicate that for the time histories plotted, the dominant frequencies are 1.8 and 3 Hz.

Figure 8.25. Time series tools in MATLAB.



Edit data for mctp_B1_PZ_b_wv_tsObj

Time	Data:1	Data:2	Data:3	Data:4	Data:5	Data:6
1.9500	8.0717e-04	-1.6398e-15	-1.1301e-05	0	0	-5.0872e-12
1.9750	-0.0213	-2.6245e-12	-2.6075e-05	0	0	-2.2261e-09
2	-0.0395	-1.2545e-09	-5.4986e-05	-2.7887e-30	0	-2.5294e-07
2.0250	-0.0504	-1.5013e-07	-1.0898e-04	-1.1404e-25	0	-5.6580e-06
2.0500	-0.0525	-3.4124e-06	-2.0503e-04	-1.9224e-21	0	-1.8534e-05
2.0750	-0.0459	-1.2941e-05	-3.7382e-04	-1.2780e-17	0	-3.7624e-05
2.1000	-0.0330	-2.9777e-05	-6.4497e-04	-3.1544e-14	0	-7.6005e-05
2.1250	-0.0173	-6.1361e-05	-0.0011	-2.6560e-11	0	-1.4491e-04
2.1500	-0.0027	-1.1896e-04	-0.0017	-6.7418e-09	0	-2.6586e-04
2.1750	0.0073	-2.2125e-04	-0.0026	-4.2816e-07	0	-4.7080e-04
2.2000	0.0109	-3.9729e-04	-0.0037	-5.3638e-06	0	-7.8913e-04
2.2250	0.0078	-6.7783e-04	-0.0050	-1.7447e-05	0	-0.0013
2.2500	-2.6978e-04	-0.0011	-0.0063	-3.8739e-05	0	-0.0020
2.2750	-0.0104	-0.0017	-0.0075	-7.8105e-05	0	-0.0029
2.3000	-0.0190	-0.0026	-0.0082	-1.4848e-04	0	-0.0040

☐ Show event table

Current time: uniform 0 to 10.23 seconds

Plot time series

● Create new

○ Add to existing plot

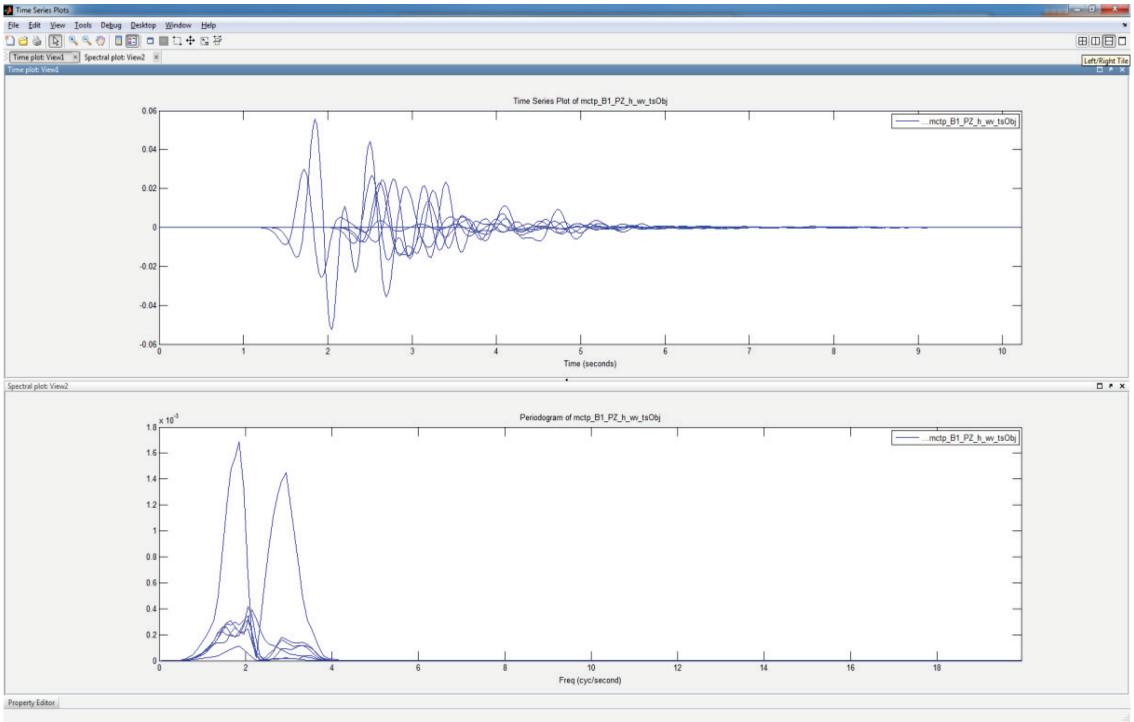
Type: Spectral Plots

Name: View1

Time Series

Note Right-click the time-series collection node in the tree to access shortcut commands. To record reusable code based on the Time Series Tools operations you perform to modify time-series data, select **File** > **Record Code**.

Figure 8.26. Time and spectral plots in MATLAB.



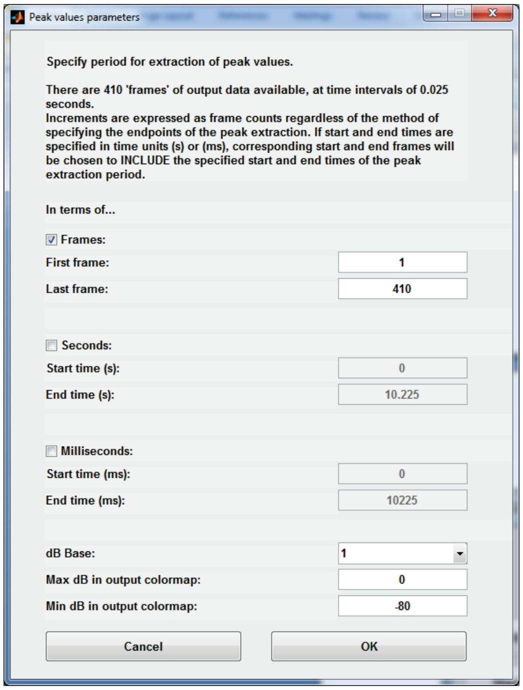
8.5 Plot peak pressures

The peak pressures can be plotted for the entire analysis region as follows:

1. Select Peak values map from the menu shown in Figure 8.5.
2. The time extents will be requested as shown in Figure 8.27. The time extents of the peak values can be specified in frames, seconds, or milliseconds. For each option, a starting and ending point are specified. For the data shown in Figure 8.27, **First frame** is **1** and **Last frame** is **410**. Since there are 410 output frames, the peak values will encompass the entire analysis time period.
3. The peak values for the x-y plane are plotted as shown in Figure 8.28. Roads and buildings have been added to the plot with Global Mapper. Refer to Section 8.8 for instructions on how to add GIS data to a results plot. An example of peak pressures for the y-z plane is shown in Figure 8.29.
4. The dialog shown in Figure 8.9 will display requesting the number of contours to use for the topography. If the topography has been modified as discussed in Section 5.7, then the contour lines will include the tops of the buildings. The **Number of contour levels** and the **Color** are input. Click **OK** to re-plot with the specified contours. Click **Done** to continue.

5. After the peak values are plotted, the dialog in Figure 8.30 is displayed. Options are available to save the image as a KML placemark, modify the contours and colors, or compare to a reference set of pressures. The **Compare to reference** option is explained in Section 8.7.

Figure 8.27. Specify time extents for peak values.



Peak values parameters

Specify period for extraction of peak values.

There are 410 'frames' of output data available, at time intervals of 0.025 seconds.
Increments are expressed as frame counts regardless of the method of specifying the endpoints of the peak extraction. If start and end times are specified in time units (s) or (ms), corresponding start and end frames will be chosen to INCLUDE the specified start and end times of the peak extraction period.

In terms of...

☑ Frames:

First frame: 1

Last frame: 410

☐ Seconds:

Start time (s): 0

End time (s): 10.225

☐ Milliseconds:

Start time (ms): 0

End time (ms): 10225

dB Base: 1

Max dB in output colormap: 0

Min dB in output colormap: -80

Figure 8.28. Peak pressures in x-y plane for 5 Hz source in upper right corner for 410 frames.

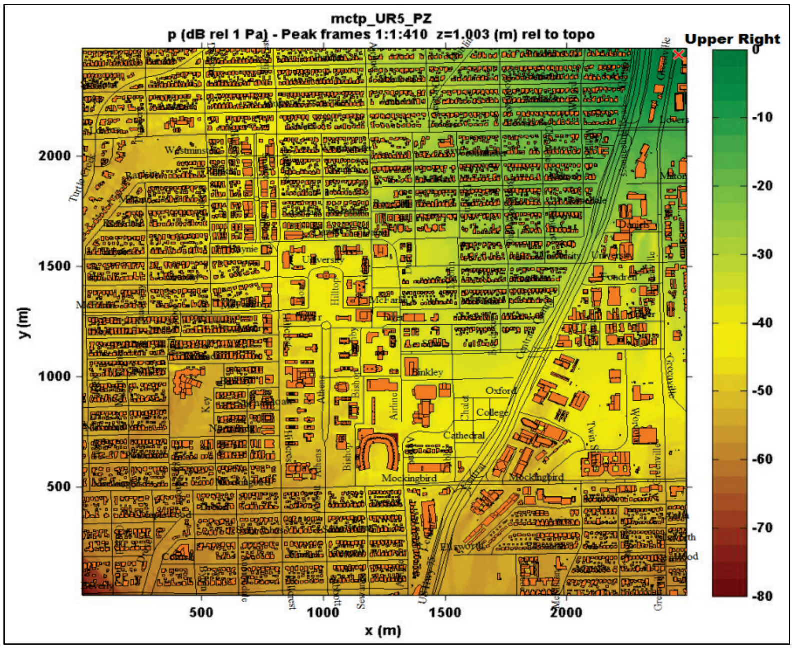


Figure 8.29. Peak pressures in y-z plane for source located on interior for 410 frames.

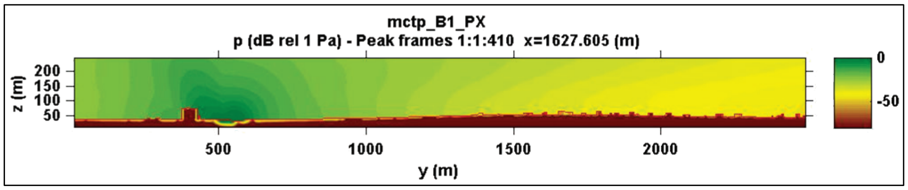
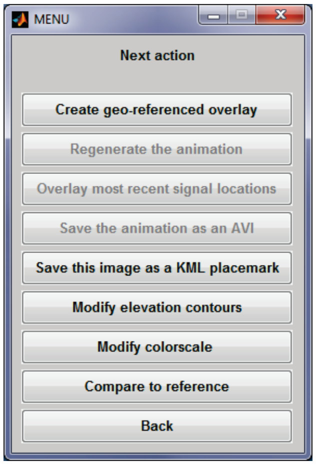


Figure 8.30. Options for peak values.



The peak pressure plot gives the peak pressure at every nodal point location in the analysis region over the time period specified. If the first frame value in Figure 8.27 is input as 200 and the last frame value is 200, the peak pressures over the entire region are computed at each nodal point for frame 200 (or 5 sec) as shown in Figure 8.31. If the first frame value in Figure 8.27 is input as 1 and the last frame value is 200, the peak pressures over the entire region are computed at each nodal point for frames 1 through 200 (or 0 sec through 5 sec) as shown in Figure 8.32.

Figure 8.31. Peak pressures for frame 200 (5 sec) for source in upper left corner.

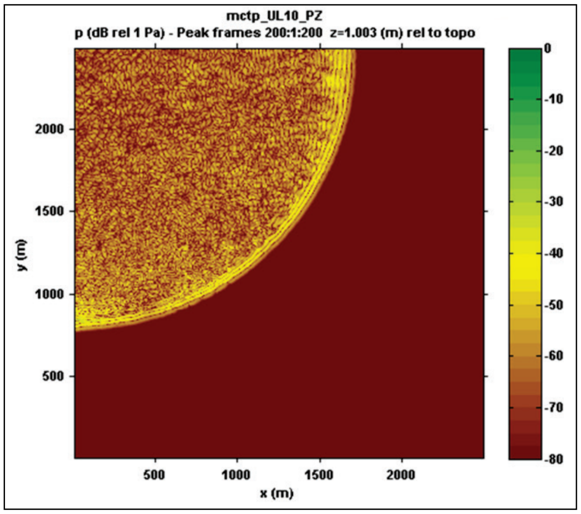
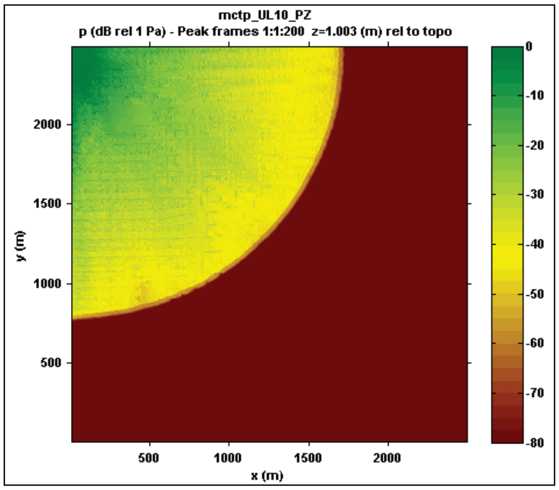


Figure 8.32. Peak pressures for frame 1 through 200 (5 sec) for source in upper left corner.



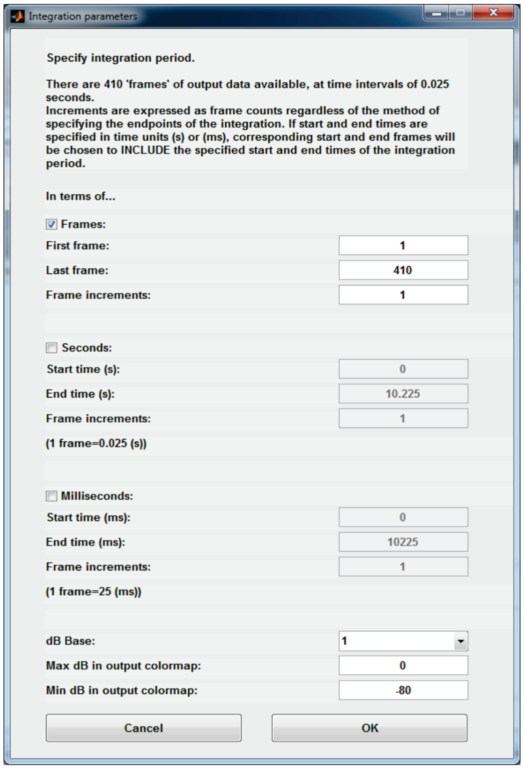
8.6 Produce integrated energy plots

The integrated energy can be plotted for the entire analysis region as follows:

1. Select **Integrated energy map** from the menu shown in Figure 8.5.
2. The time extents will be requested as shown in Figure 8.33. The time extents of the integrated energy can be specified in frames, seconds, or milliseconds. For each option, a starting and ending point are specified. For the data shown in Figure 8.33, **First frame** is **1** and **Last frame** is **410**. Since there are 410 output frames, the integrated energy will encompass the entire analysis time period.

3. The integrated energy for the x-y plane is plotted in Figure 8.34. The red lines in the figure are contours of the topography. The solid red areas are buildings.
4. The dialog shown in Figure 8.9 will display requesting the number of contours to use for the topography. If the topography has been modified as discussed in Section 5.7, then the contour lines will include the tops of the buildings. The **Number of contour levels** and the **Color** are input. Click **OK** to re-plot with the specified contours. Click **Done** to continue.
5. After the integrated energy values are plotted, the dialog in Figure 8.30 is displayed. Options are available to save the image as a KML placemark, modify the contours and colors, or compare to a reference set of pressures. The **Compare to reference** option is explained in Section 8.7.
6. The integrated energy plot gives the integrated energy at every nodal point location in the analysis region over the time period specified. If the first frame value in Figure 8.27 is input as 200 and the last frame value is 200, the integrated energy over the entire region is computed at each nodal point for frame 200 (or 5 sec) as shown in Figure 8.35. If the first frame value in Figure 8.27 is input as 1 and the last frame value is 200, the integrated energy over the entire region is computed at each nodal point for frames 1 through 200 (or 0 sec through 5 sec) as shown in Figure 8.36.

Figure 8.33. Integration period for energy.



Specify integration period.

There are 410 'frames' of output data available, at time intervals of 0.025 seconds.
Increments are expressed as frame counts regardless of the method of specifying the endpoints of the integration. If start and end times are specified in time units (s) or (ms), corresponding start and end frames will be chosen to INCLUDE the specified start and end times of the integration period.

In terms of...

☑ Frames:
First frame: 1
Last frame: 410
Frame increments: 1

☐ Seconds:
Start time (s): 0
End time (s): 10.225
Frame increments: 1
(1 frame=0.025 (s))

☐ Milliseconds:
Start time (ms): 0
End time (ms): 10225
Frame increments: 1
(1 frame=25 (ms))

dB Base: 1
Max dB in output colormap: 0
Min dB in output colormap: -80

Figure 8.34. Integrated energy for the x-y plane for a source in the upper right corner.

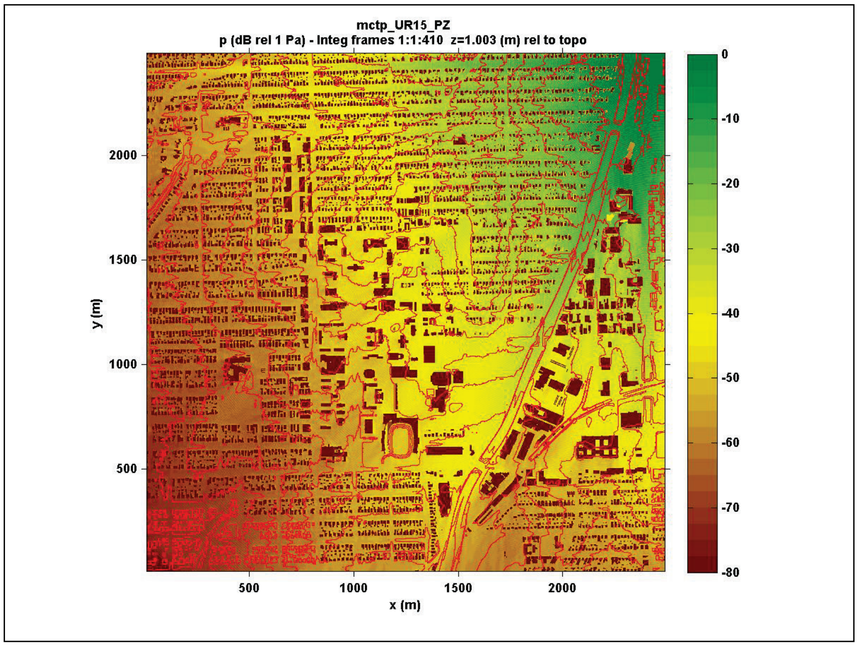


Figure 8.35. Integrated energy for frame 200 (5 ec) for source in upper left corner.

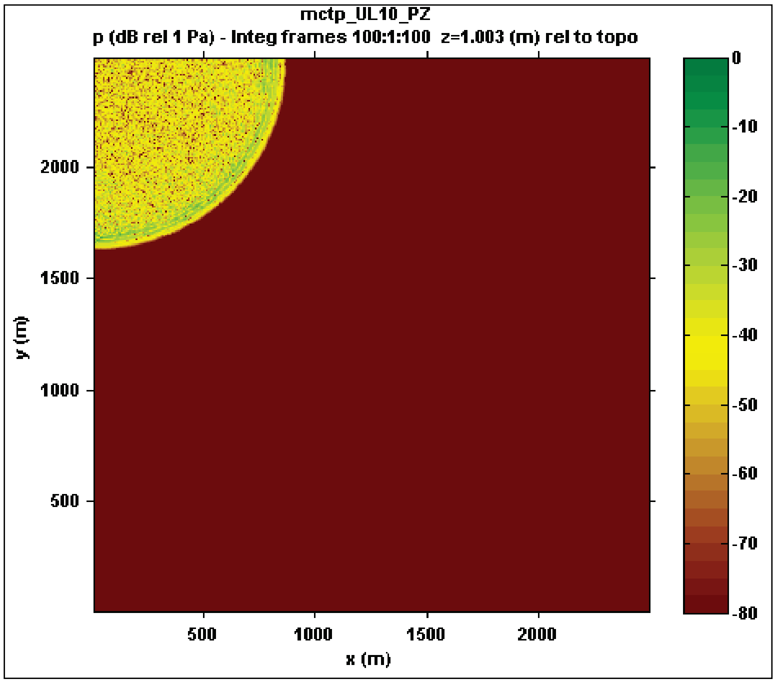
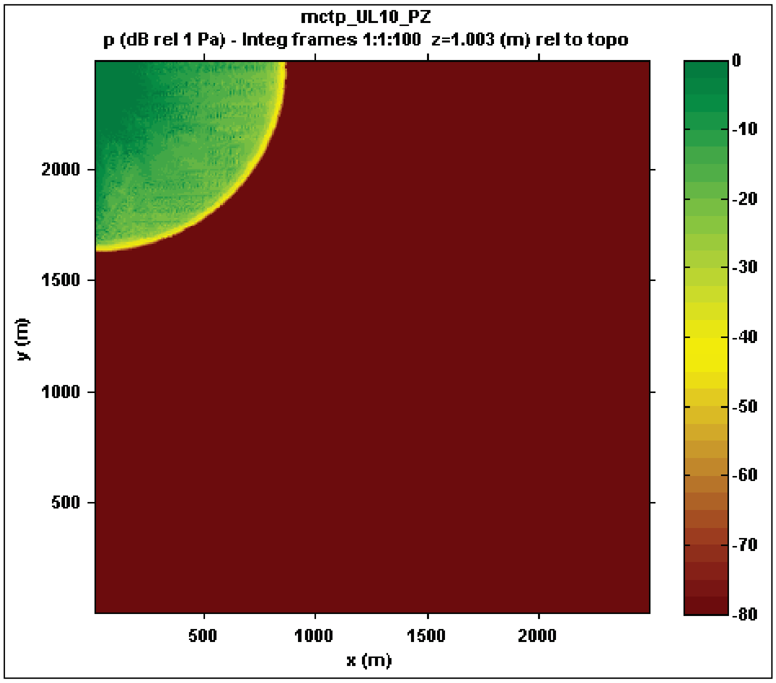


Figure 8.36. Integrated energy for frame 1 through 200 (5 sec) for source in upper left corner.



8.7 Compare to reference

The **Compare to reference** option available for peak pressures and integrated energy allows the comparison of a set of values to a reference set. The comparison is made by subtracting the reference set from the current values plotted. This allows the difference between the two sets of values to be highlighted. To specify a reference set:

1. After a set of values have been plotted, the menu shown in Figure 8.37 is displayed. The menu lists several options for selecting the reference set.
2. As the plots are made in MATLAB, they are also saved to disk with a **.fig** extension. If the **Browse to .fig file** option is selected, a previous plot may be selected as the reference source.
3. Browse to the stored figure and select the file. The dialog shown in Figure 8.38 is displayed. Select the number of colors and the min and max values. Click **OK**. The comparison plot will be generated.

Figure 8.39 shows the peak pressures for a 10 Hz source in the upper right corner of the urban area. If Figure 8.28, which shows the peak pressures for a 5 Hz source, is used as the reference, the results are shown in Figure 8.40. The results indicate that the sunken highway is acting as a waveguide. The purple color indicates an increase from the reference values.

Another example of comparing to a set of reference values is shown in Figure 8.41 through 8.43. In Figure 8.41, the peak pressures for a 5 Hz source in the upper right corner of the analysis region are shown. Figure 8.42 shows the peak pressures for the same source, but with the buildings aggregated into larger areas. The difference plot shown in Figure 8.43 shows that in the region of the sunken highway, the aggregation did not make a significant difference.

Figure 8.37. Compare a set of values to a reference set.

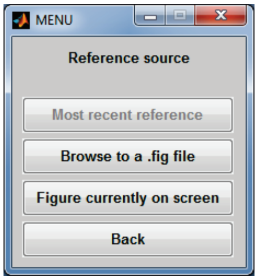
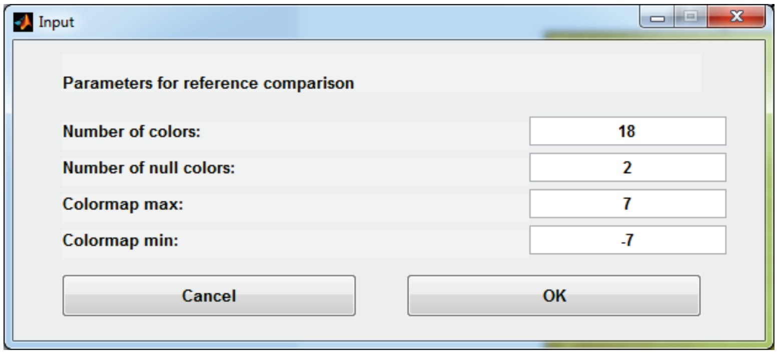


Figure 8.38. Options for reference plot.



Parameters for reference comparison

Number of colors: 18

Number of null colors: 2

Colormap max: 7

Colormap min: -7

Figure 8.39. Peak pressures in x-y plane for 10 Hz source in upper right corner for 410 frames.

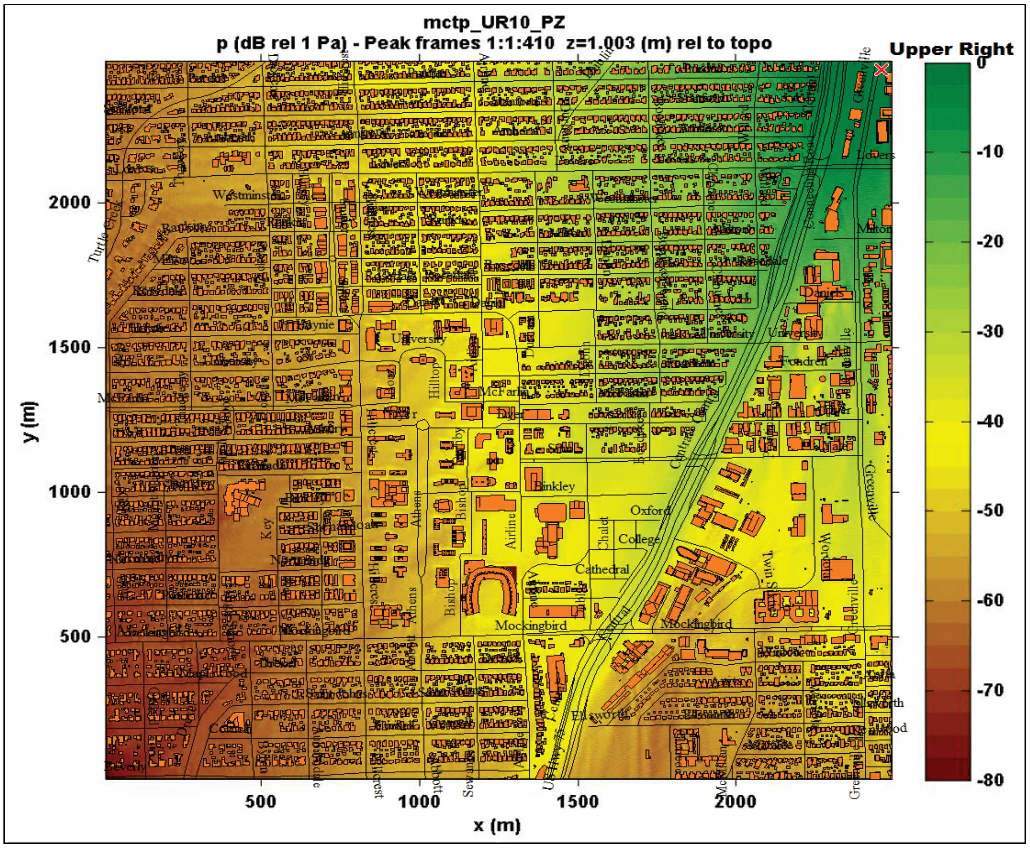


Figure 8.40. Results of reference calculation using 5 and 10 Hz sources.

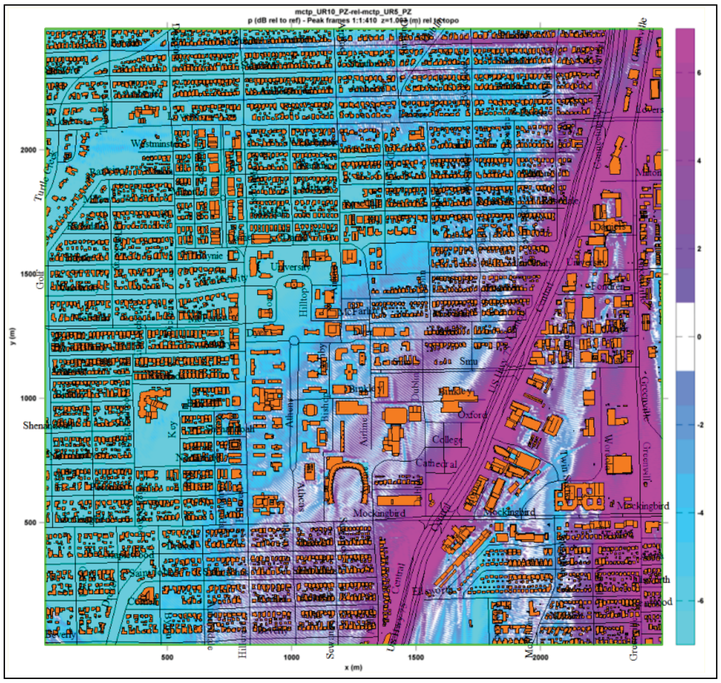


Figure 8.41. Peak pressures for 5 Hz source located in upper right corner for individual buildings.

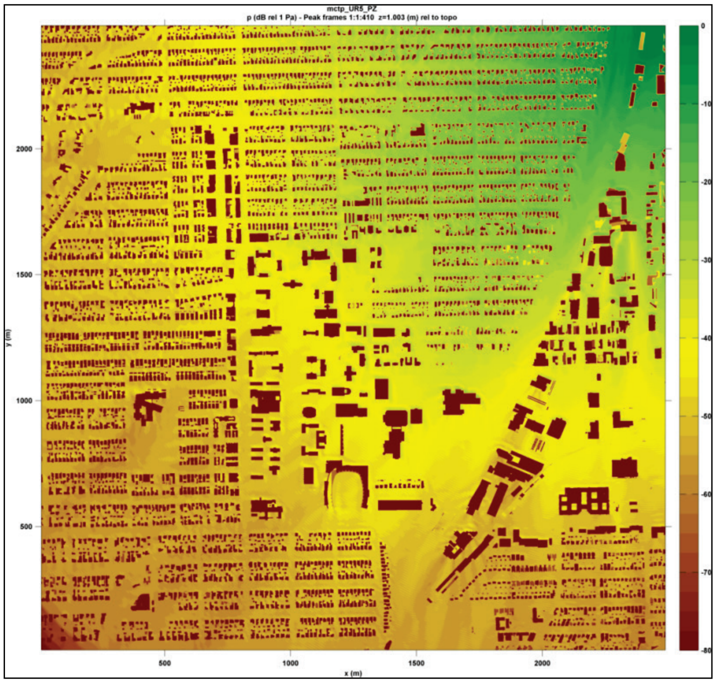


Figure 8.42. Peak pressures for 5 Hz source located in upper right corner for aggregated buildings.

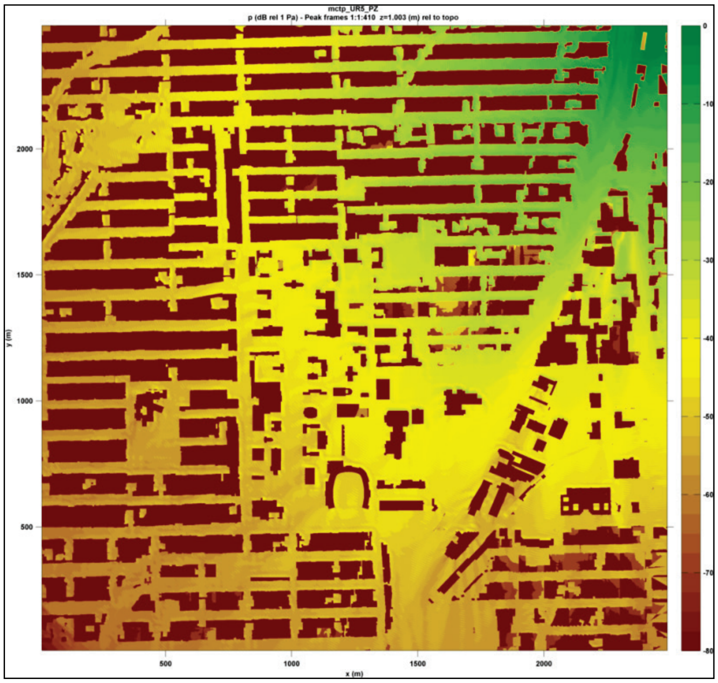
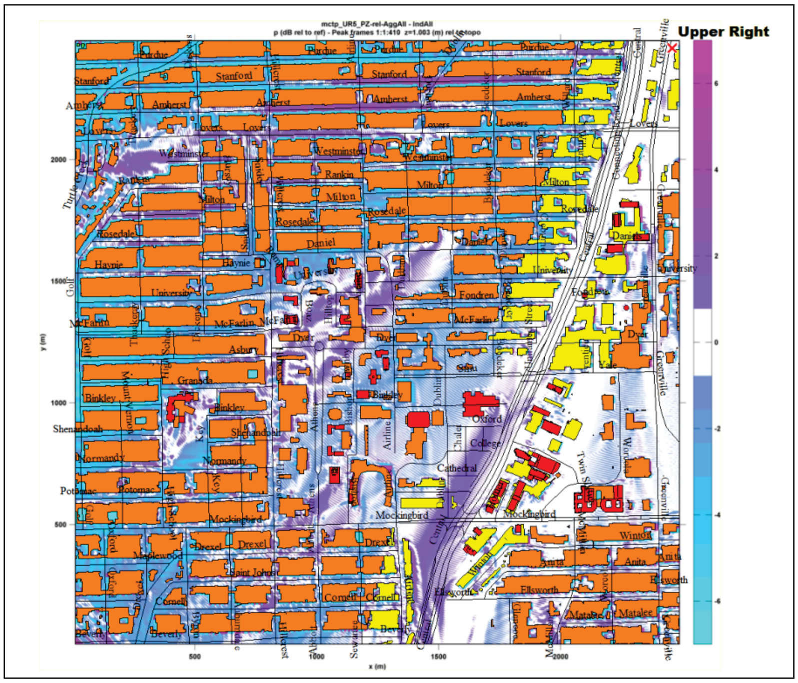


Figure 8.43. Comparison plot for difference between individual buildings and aggregated buildings.



8.8 Using Global Mapper to enhance visual display of results

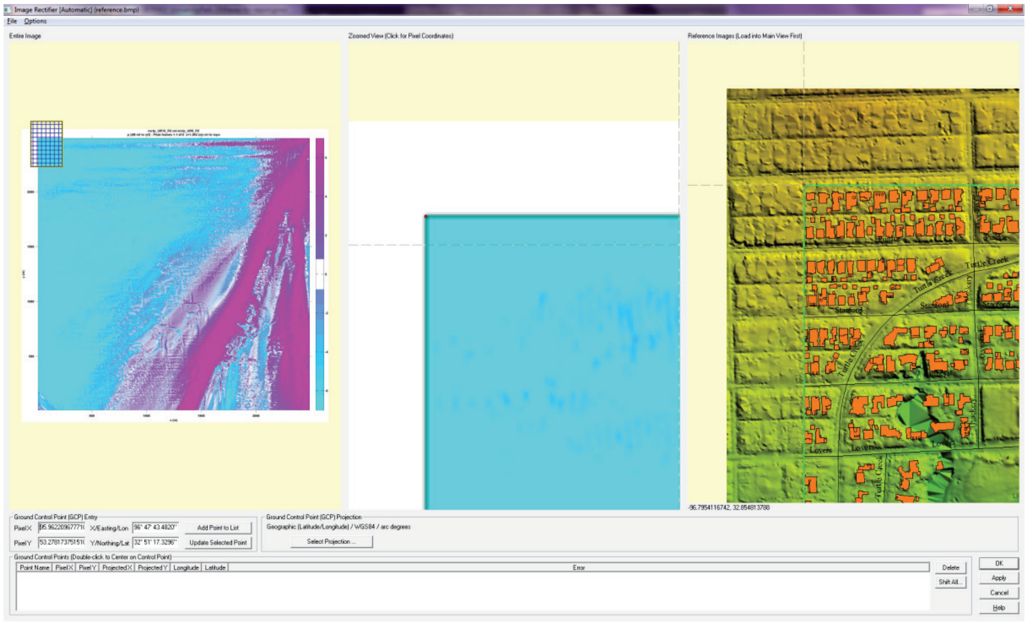
Graphics of the results that are generated by the SNAPPS utility in MATLAB can be enhanced for presentation by combining the results with GIS features. This can be performed using the Global Mapper program. For example, the difference plot shown in Figure 8.40 was enhanced by adding roads and buildings to the plot. To enhance a picture:

1. Execute Global Mapper and have the GIS information for the area displayed.
2. Navigate to the directory where the plot is saved that is to be enhanced. The plot can be in several bitmap formats including BMP, JPG, and TIFF.
3. Click on the file name in Windows Explorer and drag the file to the Global Mapper window.
4. Global Mapper will ask if the user would like to rectify the image. Select **Yes**.
5. Global Mapper loads the image and displays it as shown in Figure 8.44. In the leftmost window, click and drag a box to zoom to an area to select the first point to rectify.
6. In the middle window, the zoomed-in area is displayed. Click the mouse to select the upper-left point of the region.

7. Zoom to the same area in the right-most window. Click to select the same location of the upper left corner on the GIS data. Click the **Add Point to List** button.
8. Continue to zoom and select the corners of the box defining the analysis region. Only four points will be required to rectify the image.
9. After the final and fourth point is selected as shown in Figure 8.45, click the **OK** button.
10. The image will be rectified to the GIS area and displayed. Now any GIS information can be overlaid upon the image.
11. The completed figure with roads and buildings added is shown in Figure 8.46.

Using Global Mapper, the rectified image can have any of the GIS data overlaid upon the image to enhance presentation. The image can be saved from Global Mapper in a variety of image formats for insertion in Microsoft Word or PowerPoint. The image can also be copied from desktop by using the CTRL-ALT key sequence and pasting directly into Word or PowerPoint where it can be cropped to the desired size.

Figure 8.44. Selecting point 1 to rectify an image to GIS data.



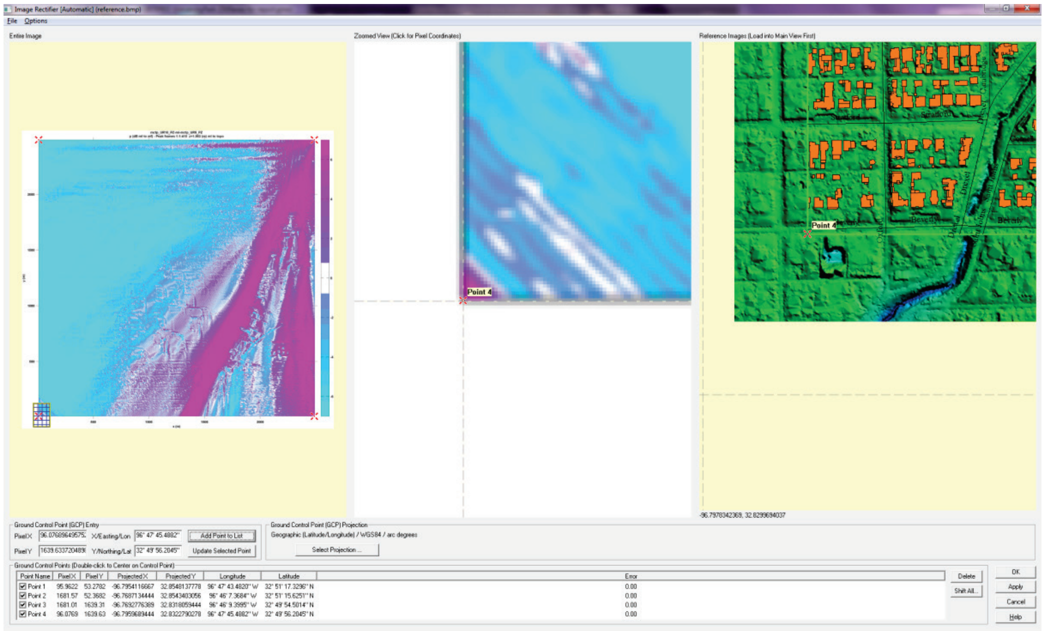
-96.7954116742, 32.8548137888

Pixel X: 95.96220967771(
X/Easting/Lon: 96° 47' 43.4820"

Pixel Y: 53.27817375151(
Y/Northing/Lat: 32° 51' 17.3296"

Geographic (Latitude/Longitude) / WGS84 / arc degrees

Figure 8.45. Selecting point 4 to rectify an image to GIS data.



Ground Control Point (GCP) Entry

Pixel X: 96.07689649575
X/Easting/Lon: 96° 47' 45.4882"
Pixel Y: 1639.633720489
Y/Northing/Lat: 32° 49' 56.2045"

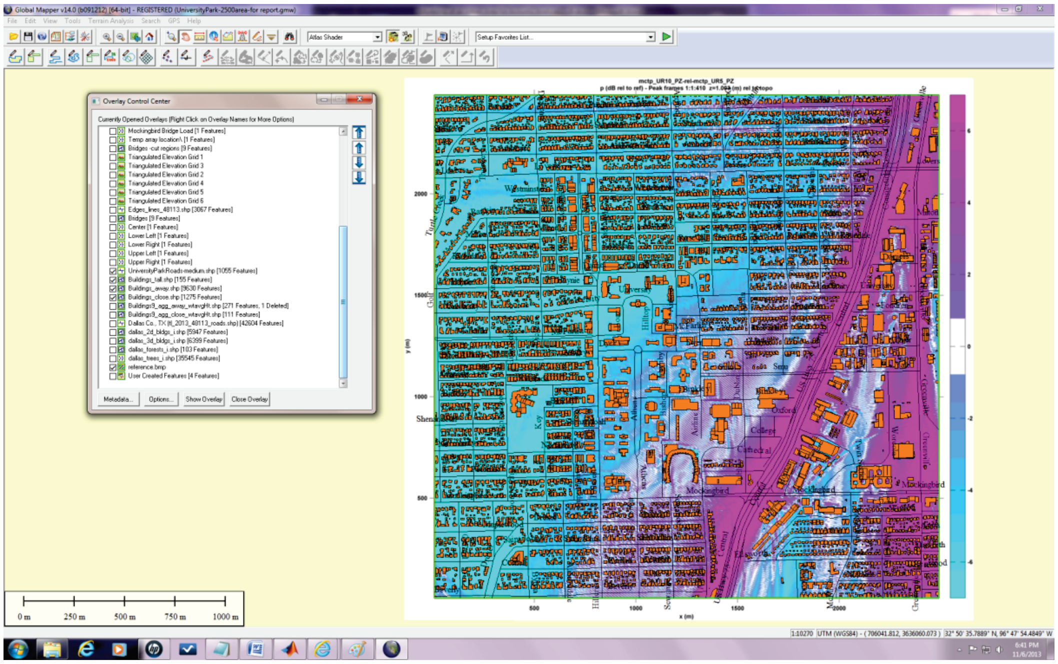
Ground Control Point (GCP) Projection

Geographic (Latitude/Longitude) / WGS84 / arc degrees

Ground Control Points (Double-click to Center on Control Point)

Point Name	Pixel X	Pixel Y	Projected X	Projected Y	Longitude	Latitude	Error
☑ Point 1	95.9622	53.2782	-96.7954116667	32.8548137778	96° 47' 43.4820" W	32° 51' 17.3296" N	0.00
☑ Point 2	1681.57	52.3682	-96.7687134444	32.8543403056	96° 46' 7.3684" W	32° 51' 15.6251" N	0.00
☑ Point 3	1681.01	1639.31	-96.7692776389	32.8318059444	96° 46' 9.3995" W	32° 49' 54.5014" N	0.00
☑ Point 4	96.0769	1639.63	-96.7959689444	32.8322790278	96° 47' 45.4882" W	32° 49' 56.2045" N	0.00

Figure 8.46. Final rectified figure with buildings and roads added.



Currently Opened Overlays (Right Click on Overlay Names for More Options)

☐ Mockingbird Bridge Load [1 Features]
☐ Temp array location\ [1 Features]
☐ Bridges -cut regions [9 Features]
☐ Triangulated Elevation Grid 1
☐ Triangulated Elevation Grid 3
☐ Triangulated Elevation Grid 2
☐ Triangulated Elevation Grid 4
☐ Triangulated Elevation Grid 5
☐ Triangulated Elevation Grid 6
☐ Edges_lines_48113.shp [3067 Features]
☐ Bridges [9 Features]
☐ Center [1 Features]
☐ Lower Left [1 Features]
☐ Lower Right [1 Features]
☐ Upper Left [1 Features]
☐ Upper Right [1 Features]
☑ UniversityParkRoads-medium.shp [1055 Features]
☑ Buildings_tall.shp [155 Features]
☑ Buildings_away.shp [9630 Features]
☑ Buildings_close.shp [1275 Features]
☐ Buildings9_agg_away_wtavgHt.shp [271 Features, 1 Deleted]
☐ Buildings9_agg_close_wtavgHt.shp [111 Features]
☐ Dallas Co., TX (tl_2013_48113_roads.shp) [42604 Features]
☐ dallas_2d_bldgs_i.shp [5947 Features]
☐ dallas_3d_bldgs_i.shp [6399 Features]
☐ dallas_forests_i.shp [103 Features]
☐ dallas_trees_i.shp [35545 Features]
☑ reference.bmp
☐ User Created Features [4 Features]

9 Conclusions and Implications

The PSTOP3D finite difference time domain program can be used to perform an acoustical analysis of a 3-D urban environment in the infrasound passband. The modeling for the environment can be accomplished using the commercial GIS programs Global Mapper and ArcMAP. Items such as roads, streets, highways, parking lots, and buildings can be modeled to effectively represent the urban environment.

The results from the 3-D urban models allow users to understand propagation path effects in an urban setting. The output of the model is a peak energy map of the area, which could be used in pre-deployment planning for infrasound array installation selection to determine the propagation effects expected at a given location. Results of a real-world modeled environment compared to infrasound and seismic data collected will be discussed in a future report in this report series.

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Appendix A

This appendix contains a Unix script that generates a batch script for running a PSTOP3D analysis. This script simplifies the running of PSTOP3D by taking input from the user and generating a script for the specific problem being analyzed. The script is as follows:

```
#!/bin/ksh
# Write runpstop.sh

# 754=rwxr-xr-- Group can read and execute
# Use "chmod 754 pstop3d_writeQsubScript_ksh.sh" if not executable

# To use, current directory must have this script and all pstop3d input files
# Current directory will be the output directory

#------------------------------------------------------------------------------

# Print number of arguments
echo "Number of arguments is $#"

# Test for correct number of arguments
if (test "$#" = "1") then
 echo >> /dev/null
elif (test "$#" = "4") then
 echo >> /dev/null
elif (test "$#" = "6") then
 echo >> /dev/null
elif (test "$#" = "7") then
 echo >> /dev/null
else
 echo
 echo "The correct usage is:"
 echo " ./makerun.sh datafile [nodes walltime queue] [topo auxfile] [account]"
 echo " datafile = data file name without extension."
 echo " Identifier for the set of data files, e.g., COMMAND.FIL.identifier.txt"
 echo " nodes = number of nodes to use (default is 4)."
 echo " walltime = time limit of run in HH:MM:SS (default is 00:30:00)."
 echo " queque = debug or standard (default is standard)."
 echo " topo = topographic surface to use for slice output."
 echo " orig = for original topography."
 echo " mod = for modified topography (default)"
 echo " auxfile = auxillary file to use from COMMAND.AUX.identifier.legacy.txt"
 echo " account = account to run job under (default is ERDCNUM)."
 echo
 exit
fi

# Set defaults
dfile=$1
nodes=4
timelimit="00:30:00"
qname="standard_sm"
topo="mod"
account="ERDCNUM"
auxfile=$dfile

#assign values from parameters entered

# Test arguments for queue name.
if (test "$#" = "4") then
 if (test "$4" = "debug") then
 echo >> /dev/null
```

```
 elif (test "$4" = "standard_sm") then
 echo >> /dev/null
 else
 echo
 echo "Invalid queue name entered. Valid names are debug or standard_sm."
 exit
 fi
fi

if (test "$#" = "4") then
 nodes=$2
 timelimit=$3
 qname=$4
fi

if (test "$#" = "6") then
 nodes=$2
 timelimit=$3
 qname=$4
 topo=$5
 auxfile=$6
fi

if (test "$#" = "7") then
 nodes=$2
 timelimit=$3
 qname=$4
 topo=$5
 auxfile=$6
 account=$7
fi

# Define directories
# Customize for your individual directory.
thisdir=`pwd`
jobid=${dfile}_$$
workdir=$WORKDIR/$thisdir

# Create run file
runFile="run_pstop3d_${dfile}_by_qsub_$nodes.txt"
echo "#!/bin/ksh" > $runFile
echo "# pstop3d qsub script" >> $runFile
echo "#" >> $runFile

# Command line OK. Start job.
# Add PBS lines using required arguments
echo "#PBS -N $dfile" >> $runFile
echo "#PBS -l select=$nodes:ncpus=32:mpiprocs=32" >> $runFile
echo "#PBS -l walltime=$timelimit" >> $runFile
echo "#PBS -q $qname" >> $runFile
echo "#PBS -A $account" >> $runFile

# Change dir to current directory where job executed from. This should be the
directory
# that contains the data files. Need to do this so script will work from qsub.
echo "cd $thisdir" >> $runFile
echo "mkdir $workdir" >> $runFile

# Copy needed files
echo "cp $thisdir/* $workdir" >> $runFile
echo "cd $workdir" >> $runFile

# Add lines to copy topography to use the .2Douttopo file
if (test "$topo" = "orig") then
 echo "cp ${dfile}_geo.dat.0.origtopo ${dfile}_geo.dat.0.2Douttopo" >> $runFile
fi

# Add lines to copy files to required names
#echo 'echo "..... Copying files to work directory - $workdir"' >> $runFile
echo "cp COMMAND.FIL.$dfile.txt COMMAND.FIL" >> $runFile
echo "cp COMMAND.AUX.$auxfile.legacy.txt COMMAND.AUX" >> $runFile
```

```
# Add lines to execute code and exit
#echo 'echo "..... Submitting batch job"' >> $runFile
echo "aprun -n (($nodes*32)) ./pstop3d_$dfile" >> $runFile
echo "exit" >> $runFile

# Ask to run
echo "Do you want to run now? \c"
read answer
if (test "$answer" = "y") then
 #submit job
 qsub $runFile
else
 exit
fi
```

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14. ABSTRACT

A 25 square kilometer urban area located in University Park, Texas was modeled using geographic information systems (GIS) software. A smaller 6.25 square kilometer area around the Southern Methodist University was extracted from the larger area and analyzed using an acoustic finite-difference time-domain (FDTD) code. The procedures to model the area using GIS software, extract required data, produce the data files necessary to perform the acoustic analyses, and view the results are described in this report. This report is focused on the details of using the particular software packages used in this study, but the concepts are general in nature and can be applied to other applications if needed.

15. SUBJECT TERMS

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	Urban area	

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