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Automatic, Unstructured Mesh Generation for 2D Shelf Based Tidal Models

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AUTOMATIC, UNSTRUCTURED MESH GENERATION FOR 2D, SHELF-BASED TIDAL MODELS

by

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GRADUATE COMMITTEE APPROVAL

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ABSTRACT

AUTOMATIC, UNSTRUCTURED MESH GENERATION FOR 2D,

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Master of Science

Numeric models use a collection of triangular facets called elements connected over a domain in what is referred to as a mesh or unstructured grid as the computational basis for calculations. The density of elements in a mesh affects the numeric stability of a model when performing computations. Furthermore, these meshes can be difficult and time consuming to create. This thesis describes an automated process of creating meshes which utilizes local truncation analysis to generate a spatially varied size function. An advancing frontal mesh generation algorithm uses this function to optimize node placement and density. Further analysis to better understand appropriate applications of this technique is also presente

The toolbox was able to create efficient meshes with relatively little user input. The final mesh spacing honored the guidelines from the truncation error analysis and resulted in appropriate mesh density. It was also shown that the process could be applied to several shelf based meshes.

ACKNOWLEDGMENTS

I would like to acknowledge my wife and family for their support and patience. Without there support, I would have never been able to work as hard or be as focused. I would also like to thank my friends and associates who listen to me explain things even though they do not have the same interest in the subject as I do.

I would also like to thank Dr. Zundel for all of his help and patience. As a Teacher and Advisor he has been exceptional. Thanks to my committee for the help in putting together this thesis as well as the SMS developers who work so hard to write the code that made all this possible. I would also like to thank those in the Civil Engineering office who have helped with this thesis.

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1 Introduction

1.1 Background

Engineers use numeric models to calculate water levels and current patterns in various bodies of water. Many of these models use a mesh or unstructured grid consisting of triangular facets, which make up a surface that represents the bathymetry of the area being modeled and serves as the computational basis for the model. Each triangle in a mesh represents a finite portion of area in the domain of a numerical model and is referred to as a finite element. The Advance Circulation Model (ADCIRC) (Luettich 2006), on which this research centers, uses only triangular elements; however, elements can be quadrilateral in other models. Elevation values, associated with the corner or nodes of elements, define the shape of the bathymetric surface.

A good discretization is essential for successful approximation of the physics of the tidal flow and circulation in a domain. (Bilgili 2005) In general, this means that areas of the mesh where the geometry or solution change rapidly require a higher density of nodes than areas where the solution or geometry changes less. With such a mesh, solutions may be obtained without over-resolving. Preliminary evaluations of depth or changes in depth give an idea of where a modeler may need increased resolution based on geometric variations. Experienced modelers can recognize other characteristics which indicate where more or less resolution is required. However, this process can become more artistic than systematic.

A typical mesh consists of thousands of nodes. If every node were placed by hand, mesh creation would be a monumentally expensive and time-consuming process. Therefore, tools have been created to automate the process of mesh generation. These tools include the Surface-water Modeling System (SMS) software package as well as other commercial and public domain mesh generators. One such generator is BatTri, which is a Matlab public-domain, two-dimension (2-D) mesh generation package. (Bilgili 2005) A list of other mesh generation software can be found in Schneiders 2006.

Mesh generators make use of many algorithms including adaptive tessellation (Formaggia 1999) (Shepard 1999), patches (Gonzales (2000), advancing front (Rees 1997), paving (Blacker 1990, Schneiders 1999), and normal offsetting (Sullivan 1997). Size-based mesh generation, which is the type utilized by the process proposed in this thesis, uses a spatially varying size function to guide the mesh generator in creating a mesh. (Howlett 2005)

This thesis examines the use of Local Truncation Error Analysis (LTEA) (Hagen 1998) to guide an automatic mesh generation technique to create efficient meshes for use in running the ADCIRC Model. In order to facilitate the process of generating meshes, the mesh generation toolbox was put into SMS. Chapter 3 includes a detailed description of the toolbox interface and implementation of the toolbox.

1.2 Local Truncation Error Analysis (LTEA)

The LTEA section of the toolbox requires an ADCIRC solution to approximate truncation error. A more detailed explanation of how LTEA operates is covered in Chapter 2. The result of LTEA in the form of a relative size function makes the mesh generation toolbox unique. By using the guidelines generated by LTEA, the resulting mesh will have nodes spaced appropriately across the domain with no manual editing.

1.3 ADCIRC

"ADCIRC is a system of computer programs for solving time dependent, free surface circulation and transport problems in two and three dimensions. These programs utilize the finite element method in space allowing the use of highly flexible, unstructured grids. Typical ADCIRC applications have included: modeling tides and wind driven circulation, analysis of hurricane storm surge and flooding, dredging feasibility and material disposal studies, larval transport studies, and near shore marine operations." (Luettich 2006)

1.4 Surface-water Modeling System (SMS)

SMS (EMRL 2006) is a pre and post-processor for surface water modeling developed by the Environmental Modeling Research Laboratory (EMRL). The EMRL is part of the Civil and Environmental Engineering Department at Brigham Young University (BYU).

In the case of the ADCIRC model, a user can create a mesh, assign boundary conditions and model parameters, and then save the files needed for input to ADCIRC through the SMS interface. After running ADCIRC, the solution can be imported into SMS and analyzed using contours, plots and several other analysis options. In the case of this study, SMS will be used for its mesh generation and post processing capabilities.

The frontal offset algorithm used in the mesh generation toolbox utilizes a spatially varying size guideline or size function. This function is defined by a value at each point in a scattered data set. Values are then interpolated from these locations to any location in the domain. This implementation supports three different interpolation options consisting of piecewise linear, inverse distance weighted, or natural neighbor. When a size function exists, the algorithm redistributes spacing along the domain boundary to match the spacing recommended by the size function. Equilateral triangles are then created on the inside of each segment of the domain boundary, and a new boundary is created by connecting the apexes of these triangles and cleaning up the resulting polygon. The process is then repeated iteratively on the new boundaries until the domain is completely filled. This process is described in (Howlett 2005).

1.5 Research Objectives

The process of mesh generation can be difficult and time consuming. Without the help of guidelines and automation, the process becomes impractical for most applications. With that thought in mind, this study has two main objectives:

1. Create a streamlined toolbox based on LTEA which requires minimal inputs to create a mesh with appropriate density.

2. Evaluate meshes generated by the toolbox to determine how well the process honors the LTEA guidelines and how well the meshes perform in terms of running in ADCIRC.
3. Evaluate different types of domains to obtain a better understanding of applications that are well suited for mesh generation using LTEA guidelines.

The following sections explain these objectives and how they will be accomplished.

1.6 Procedure

"Previously, Hagen and Parrish, applied a localized truncation error analysis (LTEA) to the expansive Western North Atlantic Tidal (WNAT) domain." This domain proved to be efficient, meaning a "low number of computational nodes with largest possible time step." (Zundel 2006) The WNAT domain is large and the open ocean boundary is far from the continental shelf of North America. A picture of the mesh used in the WANT study can be seen in Figure 1.6-1. As a follow up of the WNAT study, the process of applying LTEA guidelines to smaller domains that have their open water boundaries located on or near the continental shelf will be analyzed.

For each of these domains, meshes with varying number of nodes were created using the mesh generation toolbox. The meshes were then analyzed to determine how well the mesh generation process conserves or honors the LTEA guidelines. After it is decided that a mesh sufficiently honors LTEA guidelines, the mesh is tested for stability by running ADCIRC and by comparing output with existing data when possible.

Typically ADCIRC should be run for a full range of tides, from neap to spring. This requires a minimum of a two week simulation. If the mesh goes unstable before this time, the mesh is considered unusable.

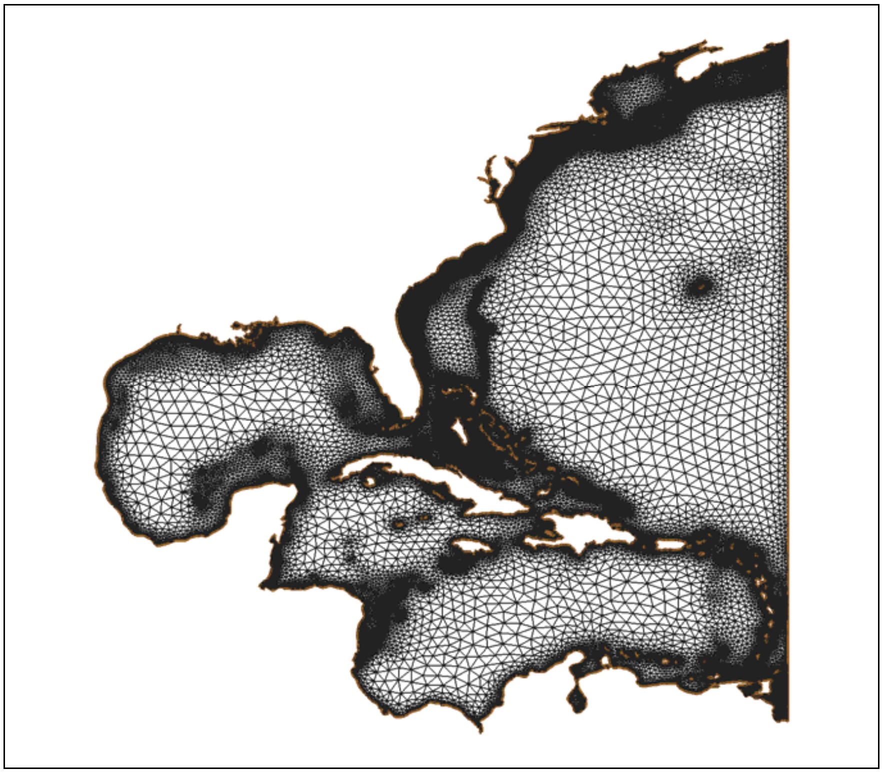

Figure 1.6-1 Western North Atlantic Domain and Mesh from Previous Study

To determine how well shelf based meshes created using LTEA guidelines performed, several domains with different features were gathered. These domains were grouped according to similarities in features and size.

1. Large
    a. Escambia Bay/Gulf of Mexico
2. Tidal flats

    a. Tagus Estuary, Portugal
    b. Grays Harbor, Washington
3. Inland water ways
    a. Loxahatchee River, Florida
    b. Lake George, Florida
4. Medium size, coastal islands
    a. Matagorda Bay, Texas
5. Small with narrow inlet
    a. Shinnecock Bay, New York
    b. Cape Fear, North Carolina
6. Island
    a. American Samoa

The Escambia Bay/Gulf of Mexico domain is the largest domain tested for this research. For this reason alone, it is the most like the WANT domain. The Shinnecock Bay domain is located on Long Island and has a small inlet to the bay. The Grays Harbor domain is located in Washington State and has both a small inlet and tidal flats. The Tagus Estuary domain is located in Portugal and has substantial tidal flats. The Loxahatchee River and the Lake George domains are in Florida and have long inland waterways with little variation in bathymetry. The American Samoa domain is an island with several small bays and inlets.

2 Description of LTEA

LTEA was initially presented by Dr. Scott Hagen as part of his doctoral research at Notre Dame. Development has continued on the methodology at the University of Central Florida. The LTEA algorithm performs analysis on an existing ADCIRC mesh and its solution to help quantify the error associated with the mesh. Normally, this ADCIRC solution is taken from a "linear ADCIRC" run. The term "linear ADCIRC" will be described later. This type of run is used to make the process faster and to simplify the LTEA algorithm applied to the unstructured mesh. A second phase of the LTEA process uses the error values at each node to create a relative size function covering the domain called DelX.

2.1 Linear ADCIRC

The term linear ADCIRC is used because several of the non linear terms on the ADCIRC solution schemes are turned off. The LTEA toolbox uses the following settings for the linear ADCIRC run:

- Finite Amplitude Terms are off
- Advective Terms are off
- Time Derivative Terms are off
- Coriolis Method is set to a constant value of 0

- Lateral Viscosity is set to 0
- Bottom Stress/Friction is set to Constant Linear
- Harmonic analysis is performed for the last 1.5 days of the simulation
- A single M2 tidal forcing constituent is extracted from the LeProvost database along the ocean boundaries. The Nodal Factor and Equilibrium Argument are set to 0.
- Minimum Water Depth is set to 1.25 times the maximum extracted tidal forcing amplitude

Using ADCIRC in this way gives the benefits of stability on a less precise mesh and provides for a more timely computation. For a linear simulation, a time step as large as 15 seconds can be used. For some of the test cases included in this study, the linear run was completed in as short as five minutes. When high resolution was required to represent inland features, the linear run time increased to several hours. (Note: all run times listed were performed on a single processor Pentium machine.)

2.2 Output from ADCIRC

The results from the linear run provide a harmonic solution (phase and amplitude of both water level and velocity) in the form of an ADCIRC fort.53 and fort.54 file. These values approximate the solutions at each node in the initial mesh and approximate how the solutions vary from one area of the domain to another. This harmonic solution data provides the needed input for an LTEA analysis.

2.3 Local Truncation Error Analysis

With the harmonic solution to the linear form of the primitive momentum equation, the truncation error can be estimated. An assumption that the final finite element grid will have equilateral triangles is used so the truncation error estimate can be simplified and it also permits the calculation of a single scalar value for grid spacing at each node. (Hagen 1998)

The harmonic solution contains the amplitude and phase of water surface elevation and velocities. The amplitude of water surface elevation represents the maximum elevations reached at that node for the duration of the tidal cycle. The amplitudes for the velocities are in the form of vectors and represent the maximum magnitude of the two velocity vector components during the tidal cycle. The phase represents where in that tidal cycle each point is at a reference time.

The solutions are analyzed by comparing the values of each node to the values at neighboring nodes. If there were an infinite number of points in the mesh, there would be a continuous solution to the domain but because meshes have a finite number of nodes, truncation error exists in the solution. For example, if a circle were to be drawn with only four points, the result would be a square. The difference in a perfect circle to one drawn with four points is the truncation error. To explain this better, a short description of how LTEA examines each part of the harmonic solution follows.

For simplicity in explaining LTEA, an example showing how differences in water surface elevation (WSE) amplitude and phase is discussed below. Figure 2.3-1 shows the WSE of two adjacent points: A and B. In this figure, the points are considered to be in phase with one another. The difference in amplitude at any point in time is very apparent. The elevations of point B are half that of point A.

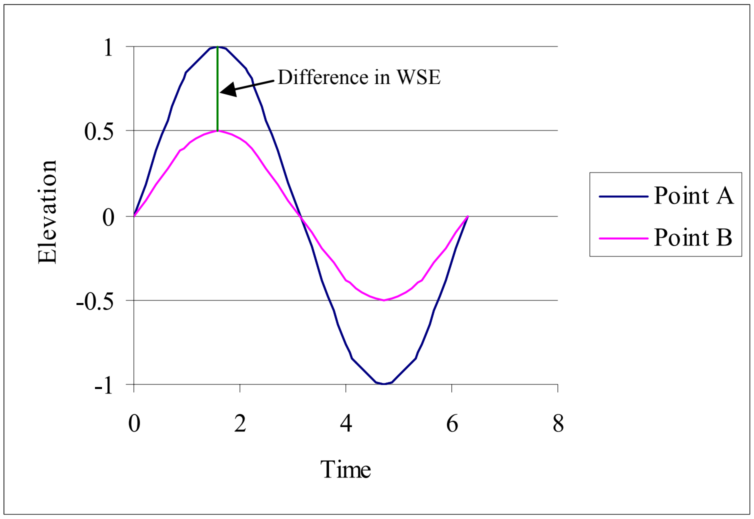

Figure 2.3-1 Sample WSE Amplitude of a Tidal Harmonic

The difference between these two points also comes into play. If two points are in close proximity, but have a large difference in amplitude, the truncation error will be larger than if the two points were further apart. LTEA uses the rate of change of the solution to calculate error.

In the study of waves and tidal signals, not only can the amplitude vary spatially but also the phase of the WSE solution. Figure 2.3-2 illustrates how the phase of the solution affects the actual difference in the WSE. If the two points are in phase, the maximum difference in WSE would be the difference in the maximum amplitudes. When their phases vary, the maximum difference increases as shown.

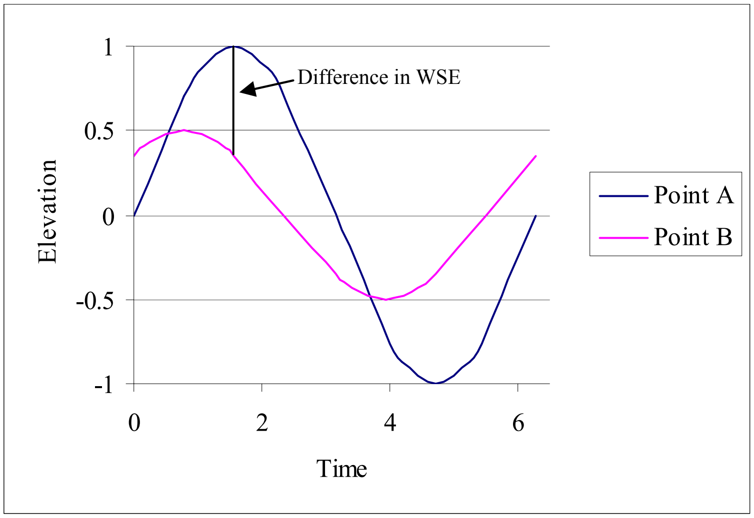

Figure 2.3-2 Sample WSE Phase of a Tidal Harmonic

Analyzing the amplitude and phase of the velocity can be a little more complicated. Instead of using a time series curve to represent the velocities, an ellipse called a tidal ellipse is used. A tidal ellipse is a plot of tidal current vectors through a tidal cycle. The tails can be thought of as spokes emanating from the point of interest. Over a tidal cycle, the current vectors trace out a full tidal ellipse. The dot in Figure 2.3-3 indicates the direction of the current at a specific reference point in the tidal cycle such as when high tide occurs. The arrow outside of the ellipse is the direction of the rotation of the tidal currents. (Thompson 2005) Figure 2.3-4 shows an example of comparing two tidal ellipses.

The maximum amplitude is split into x and y components, referred as Vx and Vy. When Point A is compared with Point B, at the reference time the magnitudes are identical but the y component of Point B is in the opposite direction. This is because the phase of the velocity is different. Again, the gradient of the solution, computed from the difference in the values and the proximity of these points determines how much truncation error results.

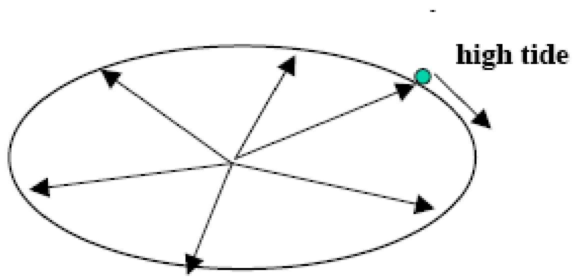

Figure 2.3-3 Sample Tidal Ellipse

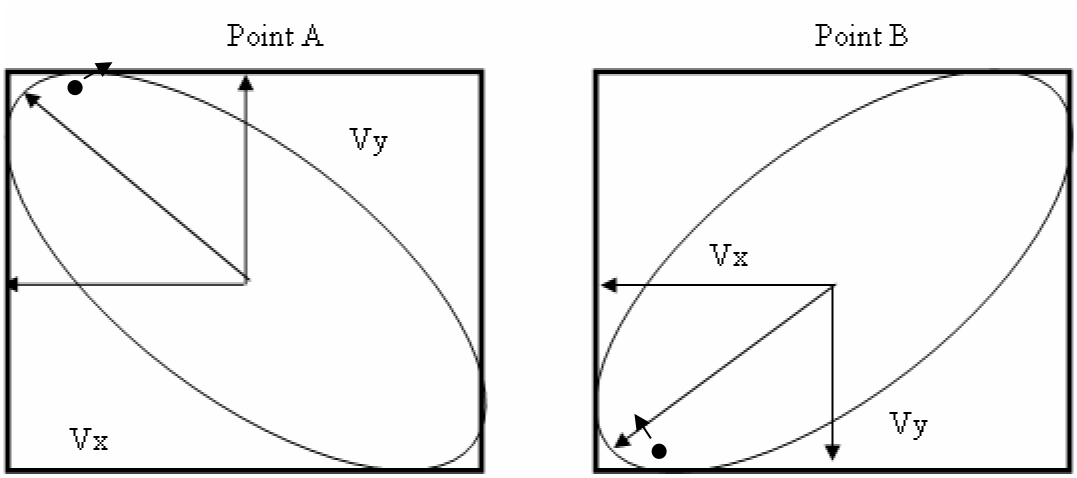

Figure 2.3-4 Sample Comparison of Two Tidal Ellipse

To compute the truncation error, a molecule is constructed around each node. This molecule is made up of a uniform 9 X 9 grid, making a total of 81 cells. The size of the cells in the molecule which varies for each node is determined by the spacing adjacent to each node of the mesh used for the ADCIRC run. Areas of the mesh with dense spacing will have smaller molecules than areas of the mesh with larger spacing. The algorithm interpolates the solution values from the mesh to the centroid of each cell in the molecule. These values are used to quantify the gradients of the solution at the node. A molecule, centered inside the domain has a value for each cell and is called a “full” molecule. If the molecule extends outside of the mesh domain, the molecule is said to be a partial molecule. Figure 2.3-5 contains an example of a partial molecule.

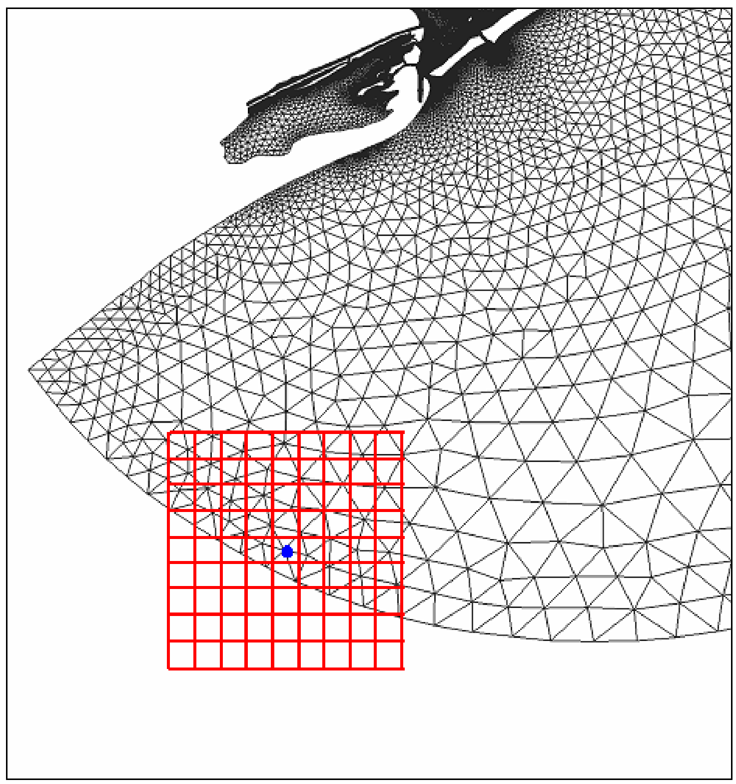

Figure 2.3-5 Example of a Partial Molecule on the Matagorda Mesh

The uniform grid is the molecule and the bold dot in the middle represents the node of interest. All of the cells outside of the mesh domain do not have values for the harmonic solution so the cell is partial. The consequences of using full or partial molecules for analysis will be discussed further in Chapter 4.

The calculation of truncation error is based on Taylor's theorem which allows all dependent variables to be evaluated at a common point, essentially the calculus equivalent of the arithmetic operation for finding a common denominator. (Kolar 1996)

2.4 Creation of the Relative Size Function - DelX

In order to use the results from LTEA in the toolbox, the values need to be converted into a size function. In areas where the truncation error values are large, the mesh resolution needs to be higher. When the values are small, there can be less mesh resolution. The smallest value of one is assigned to the node with the highest LTEA value and all other values are calculated based on the maximum LTEA value. There is not a linear correlation between LTEA values and DelX values. The exact spacing associated with the DelX function is arbitrary, but areas with a value of two should have twice the spacing as areas with a value of one and so on. Following LTEA guidelines ensures a solution with constant error throughout the mesh.

3 Mesh Generation Toolbox

To automate the process of using LTEA to generate meshes, a toolbox was implemented into SMS called the mesh generation toolbox. The toolbox consists of a series of steps designed to make the LTEA mesh generation process as simple for the user as possible without turning the process into a black box.

3.1 Initial Input

The toolbox requires two inputs consisting of the bathymetry of the area being modeled, and a definition of the model domain. As will be illustrated later, the provides options to stop and start at various points, allowing mesh generation to be performed in a single command, or allowing user intervention and control at various times in the process.

The most significant component of any numerical hydraulic model is an accurate representation of the geometric shape over which the water flows. In the case of shelf based tidal models, this geometric shape consists of bathymetric data points as shown in Figure 3.1-1. These may be obtained from survey or several online data acquisition sites.

The other required input for the mesh generation process defines the shape of the model domain. The toolbox accepts this definition in the form of GIS style arcs and polygons.

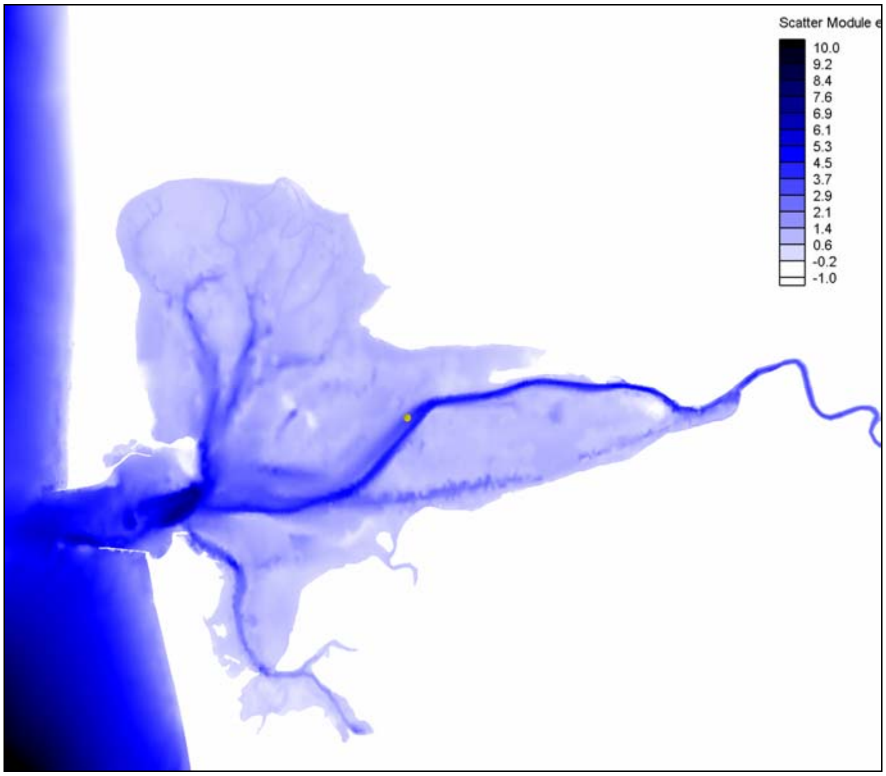

Figure 3.1-1 Sample of a Bathymetric Data Set

Typically this consists of a coastline arc, arcs defining any islands in the domain, and an ocean boundary arc as seen in Figure 3.1-2. The toolbox refers to these arcs as a conceptual model of the domain. The coastline arcs may be digitized from a map or aerial photo, extracted from a coastline database, or imported from a local survey, GIS CAD file. The definition of the ocean boundary is at the user's discression, but must be inside the extents of the bathymetric data.

It should be noted, that an existing finite element mesh defines both bathymetry and model domain. Therefore, an existing mesh can be used as the input for the meshing toolbox.

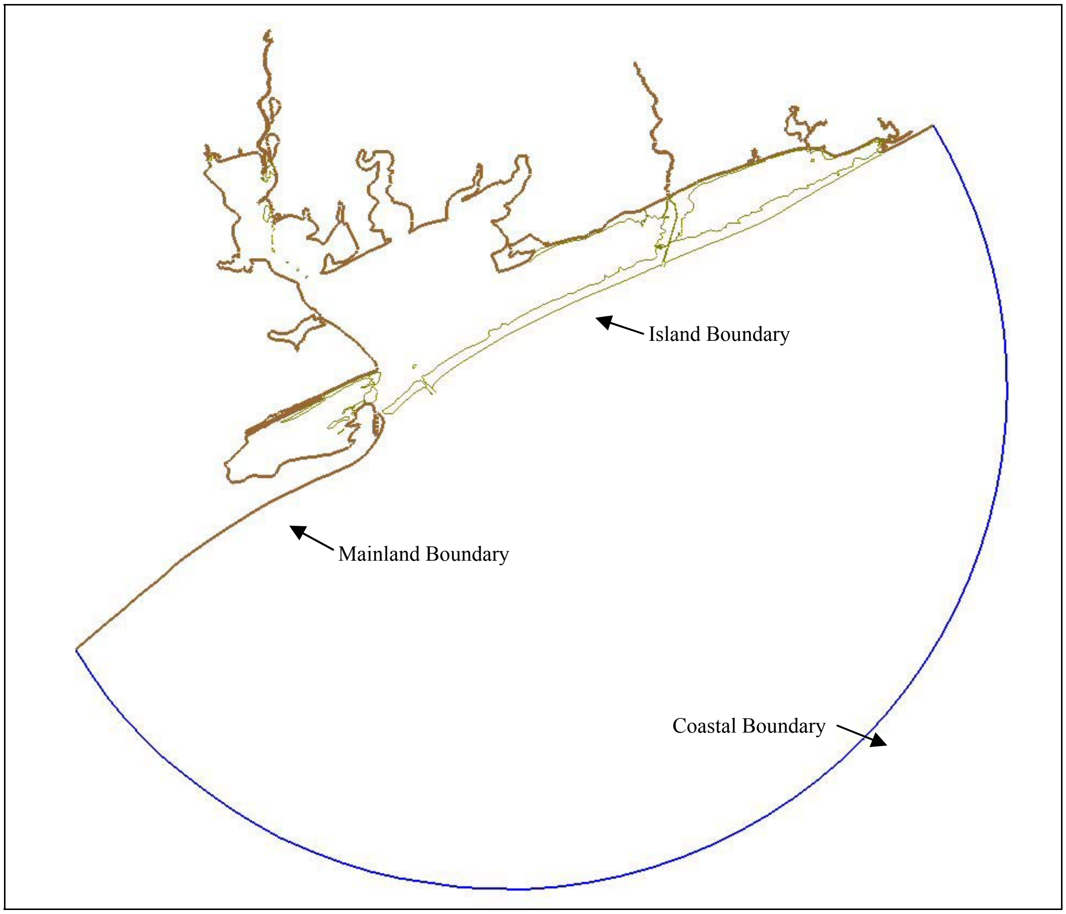

Figure 3.1-2 Domain Boundary in the Form of a Conceptual Model

3.2 Initial Mesh

The mesh generation process launches the ADCIRC model to make a linear run to approximate the solution in the domain. This run, as with any simulations requires a mesh. However, the linear run mesh does not need the high level of detail to maintain numerical stability. Therefore, the mesh generation toolbox generates an initial mesh with the goal of allowing a stable and fast linear analysis to occur. In its most automatic form, the toolbox redistributes the spacing of data along the domain boundaries. Along the coastline arcs, the algorithm places a vertex every 100 meters to represent the variations in the land boundary. Along the ocean boundary, the algorithm starts with 100 meter spacing near the shore, and transitions in a smooth fashion to a maximum of 10,000 meter spacing in very deep water as seen in Figure 3.2-1. If higher resolution is required, the conceptual model may be manually adjusted and an option se to keep the spacing for the initial grid. The toolbox fills the interior of the initial grid using the boundary spacing as a resolution guide and a frontal offsetting algorithm. Figure 3.2-2 shows an example of an initial mesh generated by the toolbox. It illustrates variations in the resolution based on the domain boundary spacing. Options also exist as seen in Figure 3.2-3 to allow the user to provide an existing grid to be used as the initial grid, and to save a generated initial grid for evaluation or later use.

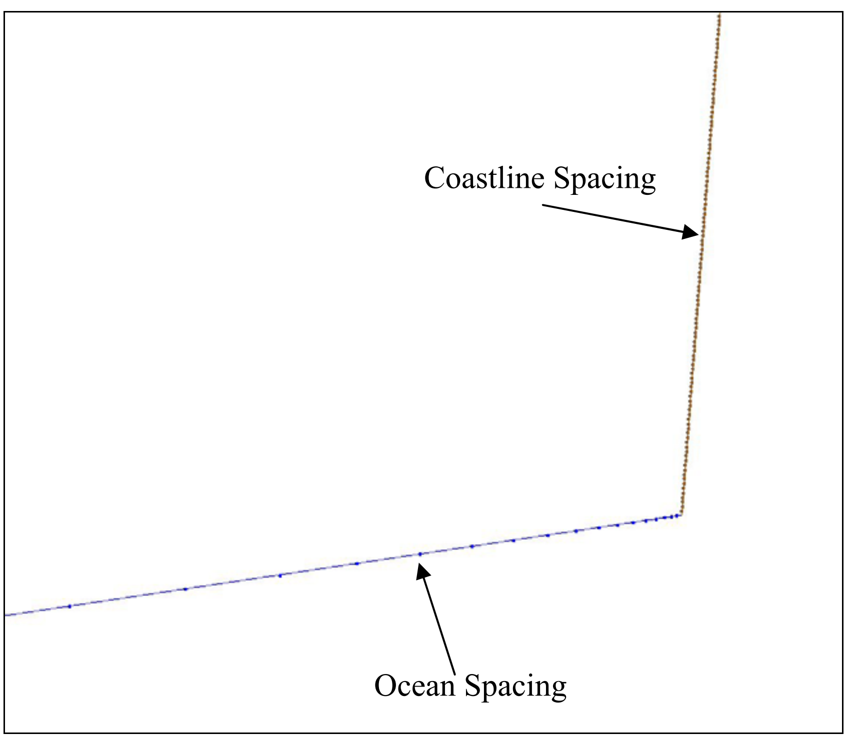

Figure 3.2-1 Automatic Vertex Spacing on Initial Mesh

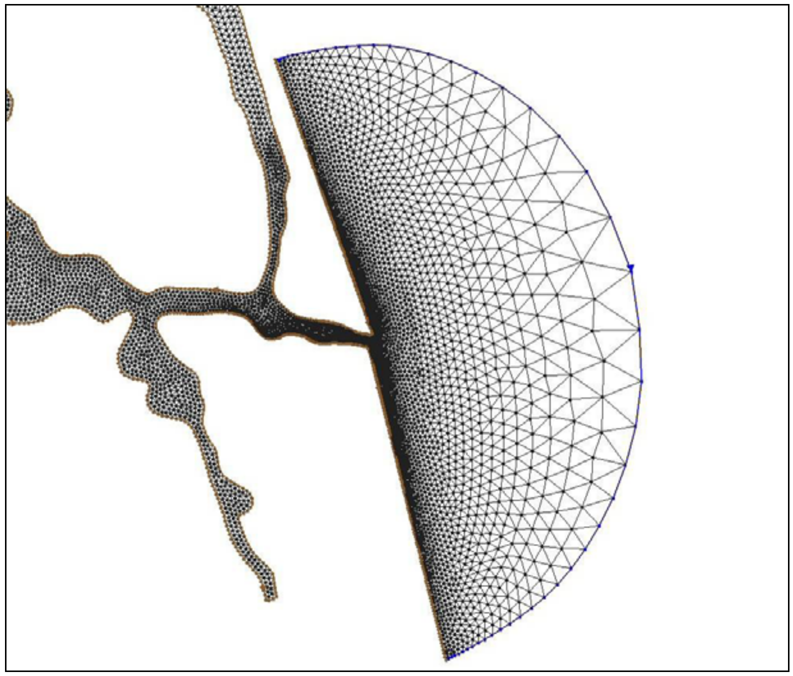

Figure 3.2-2 Sample Initial Mesh

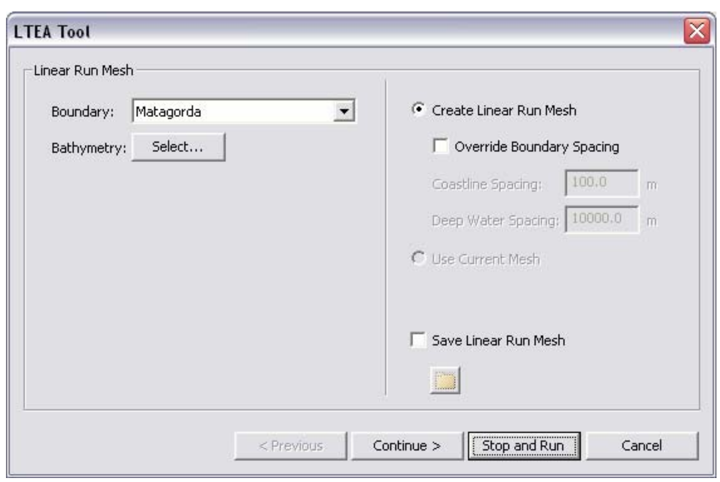

Figure 3.2-3 Initial Mesh Page of the Toolbox

The nodes in the initial mesh become the basis of the size guidelines for the final mesh. A higher resolution initial grid may increase the quality of the linear solution, but comes at a cost of increased run time .Since the linear solution is, an approximation, any mesh that provides a stable run is sufficient for the process. This fact motivated the simple guidelines for linear mesh creation.

3.3 Linear ADCIRC

Although the toolbox sets several ADCIRC parameters, it still allows the user to manage a number of parameters. The left side of Figure 3.3-1 illustrates these options. For this work, defaults for these inputs were sufficient for this research.

If a linear ADCIRC run has already been achieved, the toolbox supports the option to read and use the solutions. To do this, the user selects the Provided Harmonic Solutions' options (Figure 3.3-1) and specifies the data sets. The last option of providing the DelX function can be selected if relative size guideline function exists. This would be the case if the LTE analysis had been completed for an earlier mesh and now a higher or lower resolution mesh is required. This way, many meshes of various resolutions can be created quickly and easily.

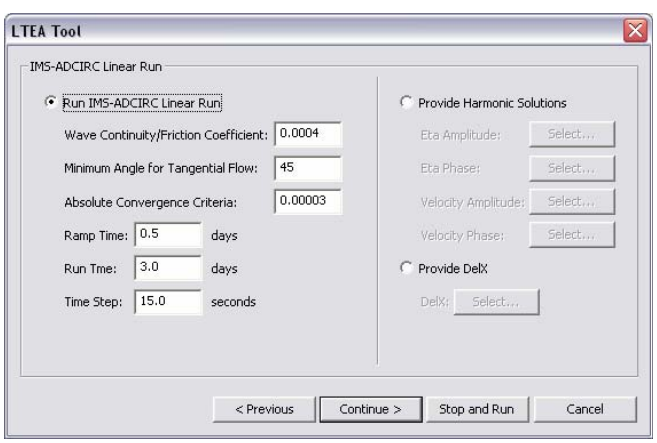

Figure 3.3-1 Linear ADCIRC Run Page of the Toolbox

3.4 LTEA

The inputs from the ADCIC solutions are used to do the LTEA analysis. There is an option to use a partial molecule in the analysis process. Traditionally, LTEA requires a full molecule around each node to compute a truncation error value. Molecules for nodes close to the edge of the domain have empty entries. This results in no output from the LTEA process for areas close to the domain edges. In other words, the process does not generate size guidelines along the domain boundary. By allowing LTEA to use partial molecules, a size guideline can be achieved for every node. It should be noted that with limited points to analyze, these values achieved with partial molecules are not as accurate as those with full molecules.

In the future the user may be able to specify what size of molecule would be used in the LTEA process. Currently SMS only supports the 9X9 molecule. This is the most robust molecule that gives the best results.

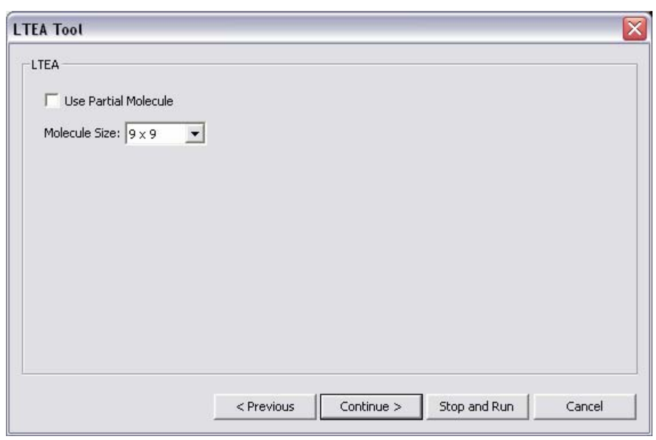

Figure 3.4-1 LTEA Options Page for the Toolbox

If a solution for an LTEA run in the form of a DelX function has been achieved, there is an option to use this as input and the LTEA process does not have to be run twice for the same mesh. In fact any size function could be used here. A picture of the dialog can be seen in Figure 3.4-1

3.5 Final Mesh Generation

The final step of the mesh generation process involves the application of the relative size guideline function (DelX) in an iterative fashion to create a mesh which matches a target number of nodes within a user specified range. The appropriate value of the target number depends on the application of the final mesh. As resolution increases, accuracy also increases. However computation times also increase. As the target value changes, the relative resolutions stay the same. This means an area that has high local error, will still have the highest resolution. However, extremely small target sizes result in meshes that cannot honor the variations of resolution requested by the computed size function. For example, if a coastline and coast arcs have 5,000 vertices and the user tries to create a mesh with 3,000 nodes, the resulting mesh probably not honor the guidelines accurately.

The toolbox computes an approximate scale value for the size guideline function based on the area of the domain and the average size guideline. The size function is scaled, and a mesh is generated. Rarely does toolbox create a mesh with the required number of nodes on the first try so the initial scale is then adjusted based on the number of nodes in the first mesh. Another mesh is then generated and the process is repeated until a mesh with an appropriate number of nodes is created. Figure 3.5-1 shows four meshes of a domain for the Pacific Northwest coast with various scales. Note that the relative resolutions from area to area remain constant.

The user also has the option to provide a size transition limit. (Figure 3.5-2) As this value approaches 1.0, the variation in element sizes decreases. The default value of 0.5 is a practical minimum. This means that no element will be more that twice the area of its neighbors. Some modelers prefer to use a more stringent value of 0.7 or even as high as 0.8. It should be noted that this reduces the ability of the finite element mesh to respond to requests for changes in resolution. In these cases, the higher resolution request takes precedence.

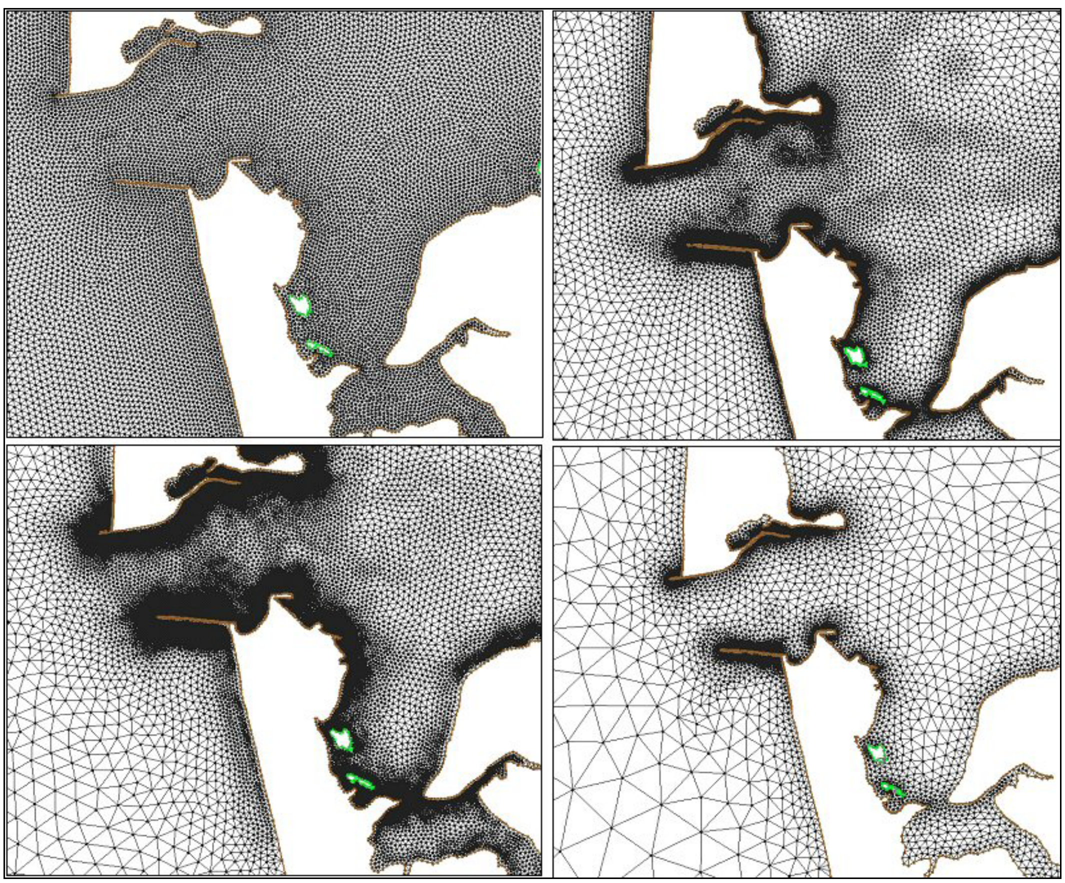

Figure 3.5-1 Various Resolution Meshes of Pacific Coast Domain

The user also has the option to force the final mesh to honor the original distribution specified in the conceptual model by leaving the option to "Redistribute Boundaries" unchecked. This allows a modeler to retain effort spent in delineating the desired boundary definition and spacing. It should be noted that if the provided boundary spacing is irregular, this poor spacing on the boundary will then be integrated into the final mesh. Usually the change in boundary definition created by redistributing the boundary is small. Therefore, in most cases it is more efficient to allow redistribution to fully utilize the LTEA solution and subsequent spacing.

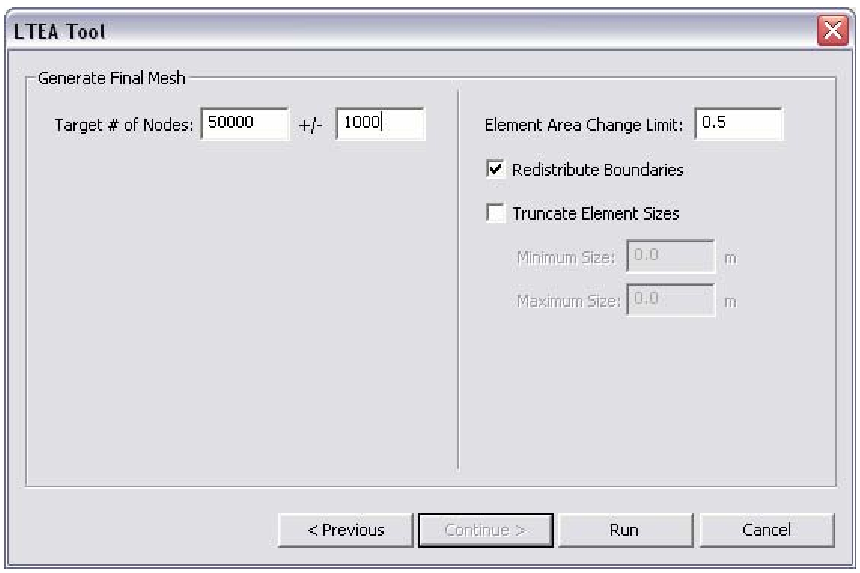

Figure 3.5-2 Final Mesh Page of the Dialog

4 Test Results and Analysis

The mesh generation toolbox was used to create several meshes for each of the before mentioned domains. These meshes were created using various different options in the toolbox and the resulting meshes were analyzed to see how the different options affect the final mesh. The results will help give guidelines for the use of the LTEA toolbox. The meshes were also compared to the LTEA guidelines to see how well the final mesh spacing honored them. These meshes were then tested in ADCIRC to check for the stability and quality of the solutions.

4.1 Process of Comparing LTEA Guidelines with Final Mesh Spacing

The process used to compare LTEA guidelines with final mesh spacing is done through SMS. To do this, a modeler must create two new data sets on the mesh. The first represents the actual spacing of the mesh, and the second represents the recommendation generated by the LTEA process.

As a byproduct of the meshing process, the toolbox creates two extra scatter sets. One scatter set is called “Size” and the other “LTEA.” This can be seen in Figure 4.1-1. The Size scatter set has two datasets associated with it: “Size” and “smoothed – (0.500000).” Under the scatter set labeled “LTEA” there are at least two datasets, “DelX” and “LteaResults.” The other datasets are called “DelX – Scaled (…).” The number in parenthesis is the scale factor used to create a mesh in the iterative process.

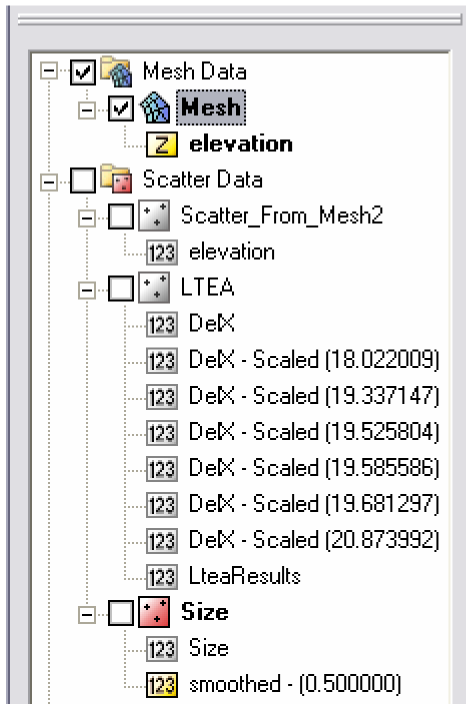

Figure 4.1-1 Sample Project Explorer Window from SMS after Running the Toolbox

The steps to create the data sets on the mesh representing spacing and LTEA include:

1. Under the scatter set “Size” the “Size” dataset has a minimum and a maximum value which can be found by right clicking on the dataset and selecting “Info.” The minimum value of the dataset is the final scale used to create the final size function. This value should be noted for later use.
2. The final mesh spacing needs to be in the form of a dataset. This is done by selecting the “Create Data Sets” tool in the “Data” menu option of

SMS. The “Coastal” toggle box can be unchecked and only the “Grid Spacing option under “Geometry” needs to be left checked. This can be seen in Figure 4.1-2. This will create a dataset associated with the mesh labeled with the specified name.

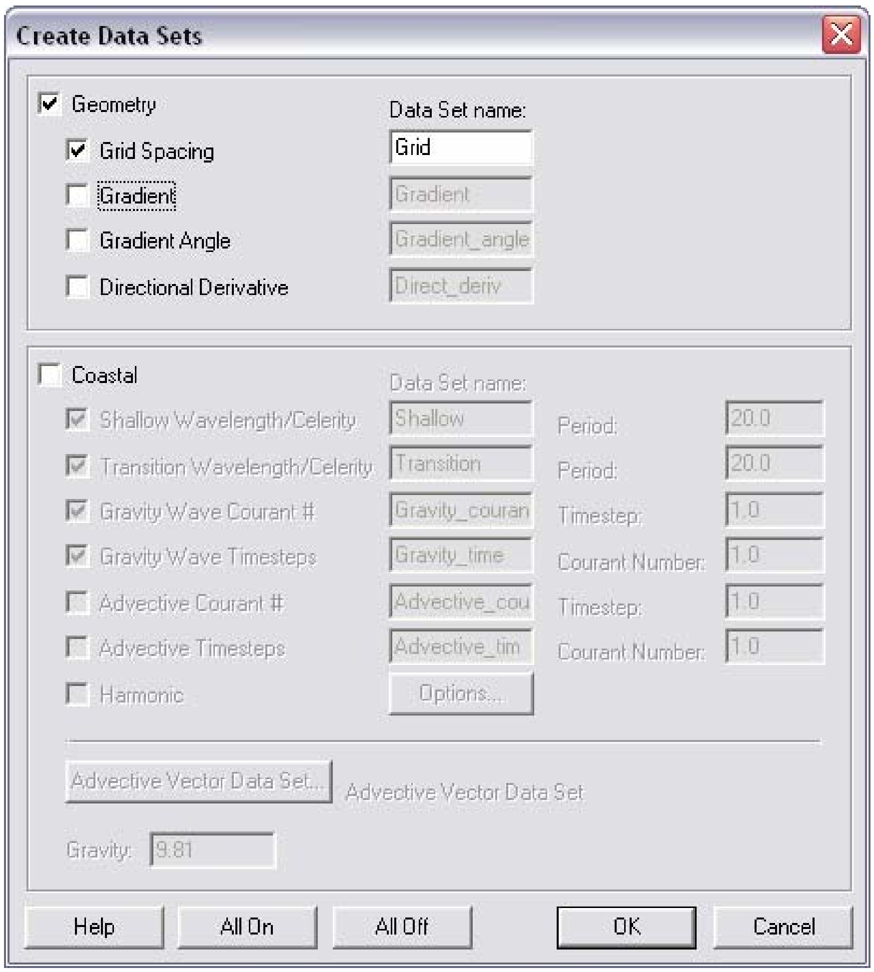

Figure 4.1-2 Create Data Sets Dialog in SMS used for Comparing LTEA Guidelines with Final Mesh Spacing

3. The DelX dataset under the “LTEA” scatter set can be interpolated to the mesh. This is done by selecting the “LTEA scatter set and selecting the

"Interpolate to Mesh" option under the "Scatter" menu option in SMS. The option for interpolating for this analysis was set to linear interpolation with an extrapolation value of 1.0 . The extrapolation value of 1.0 is used because the smallest DelX value is 1.0. Care should be taken to make sure that the "DelX" dataset is selected for interpolation. The "Interpolate to Mesh" dialog can be seen in Figure 4.1-3.

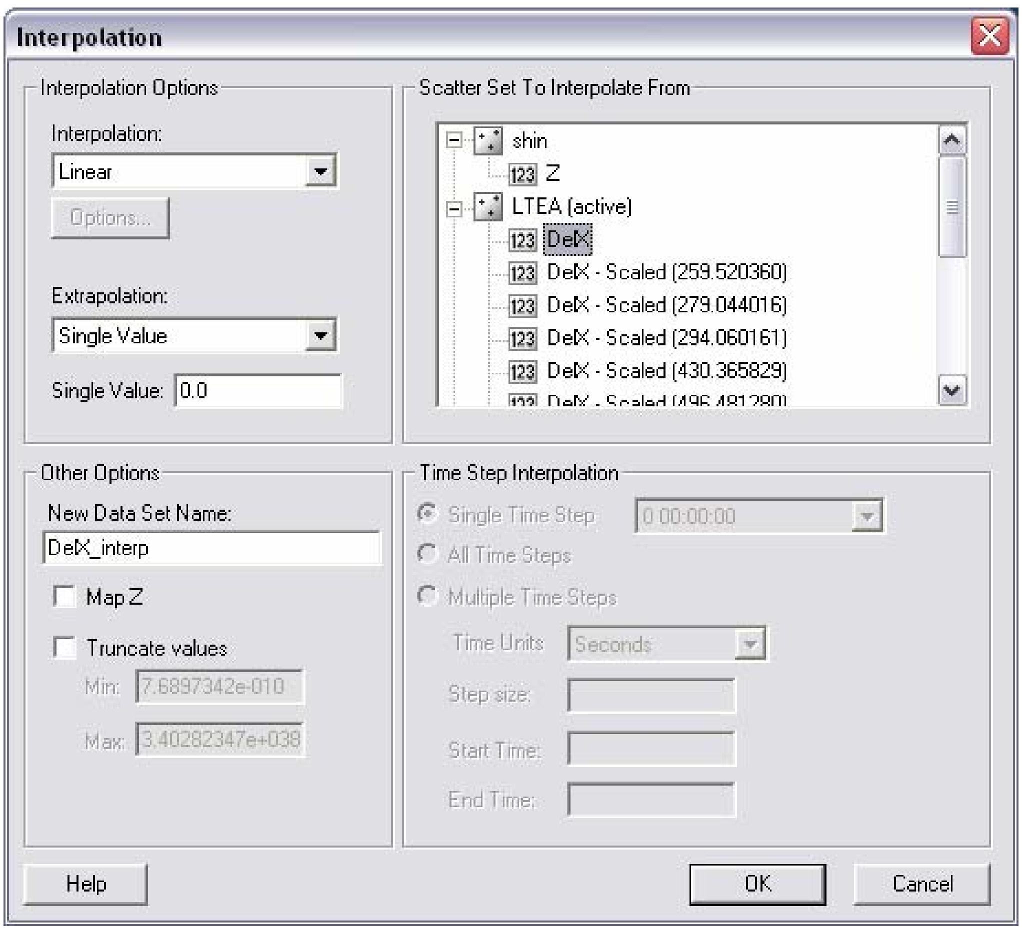

Figure 4.1-3 Interpolate to Mesh Dialog in SMS

4. Using the data calculator in SMS, the final mesh spacing needs to be divided by the final scale from step one and then a ratio of the difference of the computed scale to interpolated DelX can be calculated. This equation, shown in Figure 4.1-4 can be expressed as:

$$PercentError = \frac{abs\left(\frac{GridSpacing}{Scale} - DelX\right)}{DelX} * 100 \quad \textbf{(4-1)}$$

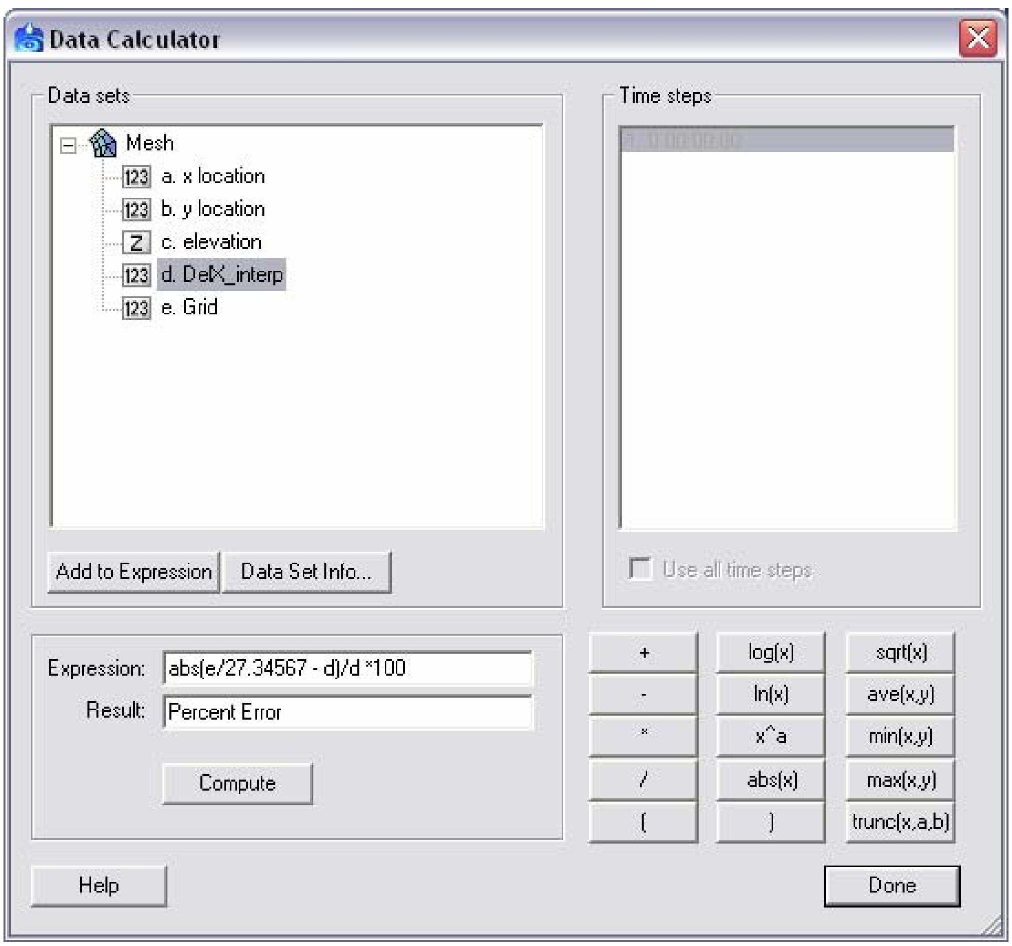

Figure 4.1-4 Data Calculator Dialog in SMS used to Calculate Percent Error between LTEA Guidelines and Final Mesh Spacing

This procedure produces a dataset with the mesh with the specified name. To be consistent, the display options min and max should be manually set from zero for the min and 100 for the max. All of the comparisons for this thesis are done with this scale. It should also be noted that this data calculation uses the absolute value of the difference. This means that over resolved areas will show as an error. While over resolution will result in less efficiency while performing the numerical calculations, they actually decrease the localized error and are caused in this case by smoothing the transition from small elements to large which results in increased stability. The figures shown in the discussion below utilize this function and therefore indicate error in some areas that could be ignored. To limit the errors displayed to areas of under resolution, change the equation in step 4 above to

$$PercentError = \frac{Max\left(0.0, \frac{GridSpacing}{Scale} - DelX\right)}{DelX} * 100 \qquad \textbf{(4-2)}$$

4.2 Creating Meshes with Various Options

As stated in Chapter 3, there are several options available when using the mesh generation toolbox. In order to better understand how these different options affect the final mesh, tests were done on several meshes. A sample of those tests is included in this paper. The most important objective in using the LTEA guidelines is to make sure that they are being honored. The following section explains how LTEA can be preserved or "washed out" by other factors. The factors that control how well LTEA is preserved are

1. Using Partial Molecules
2. Redistributing Boundaries
3. Number of Nodes
4. Element Area Change

4.2.1 Using Partial Molecules

The option to use or not use partial molecules makes a big difference in the final mesh. Because there are only values for points with full molecules, the areas close to the domain are controlled by the coastline or ocean spacing rather than LTEA. For example, Figure 4.2-1 shows in the shaded area the portion of the domain for which full molecules existed. In traditional applications of LTEA, no DelX values exist outside of this shaded area.

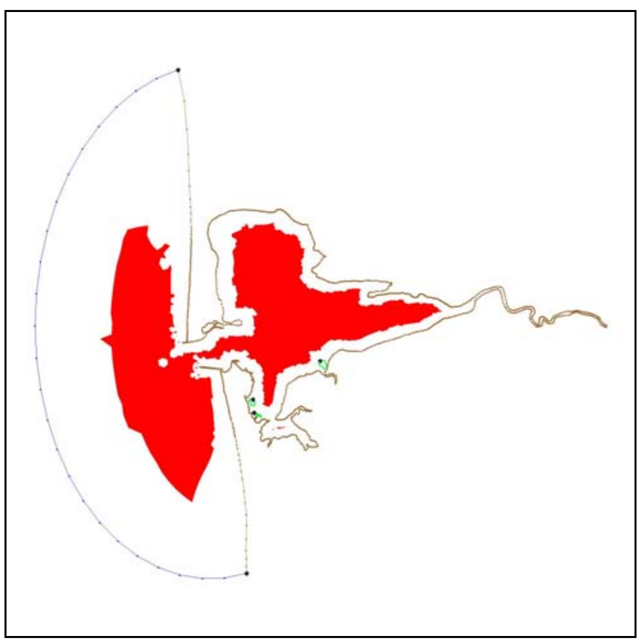

Figure 4.2-1 Sample of Full Molecule DelX Data Set

Note that even crucial areas, such as around the inlet, have few points represented in the DelX function. This is significant because areas of importance are often close to the boundary. Without using the partial molecule, there is no guidance given for these areas. High resolution initial meshes increase the area with full molecules but this also drastically increases the initial run time. There will still be areas near the boundary that will not have a full molecule. For this reason, the meshes used for analysis have all been created using partial molecules. In the future, there is a proposed algebraic LTEA which does not require a uniform grid to compute a truncation error.

4.2.2 Redistributing the Boundary

The option to redistribute boundaries has already been discussed but its affect on the final mesh can be very important. When the option to not redistribute is chosen, the spacing provided by the definition of the domain has precedence over the values of LTEA near the boundary. This may not have drastic affects if the spacing of the domain is good but in most cases, the original spacing is the product of arbitrary distributions and differ from the LTEA guidelines. Figure 4.2-2 contains a mesh with 100 meter spacing along the coastline and 140 meter spacing for the island. The spacing on the final mesh is not that different from the original coastline spacing, which results in a relatively good looking mesh. This is because there are only 20,000 nodes in the mesh, which is not enough to honor LTEA recommendations. Therefore, the coastline spacing takes precedence.

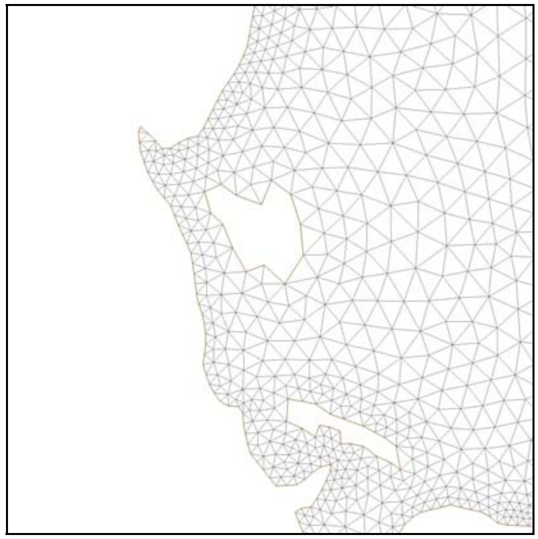

Figure 4.2-2 Gray's Harbor Mesh with 20,000 Nodes and No Redistribution

If the same domain is used for a 60,000 node mesh, the result is much different. With the increased number of nodes, more nodes can be placed between the boundaries and more of the LTEA guidelines can be honored. This result can be seen in Figure 4.2-3

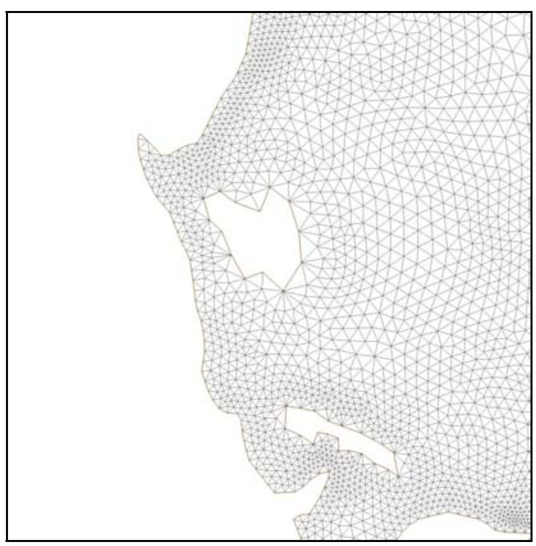

Figure 4.2-3 Gray's Harbor Mesh with 60,000 Nodes and No Redistribution

The spacing along the coast is closer to the LTEA guidelines but the island spacing is not. Since the spacing along the coast is not controlled by LTEA guidelines, the result is a transition zone between the border of the island and the region where the mesh can honor the LTEA guidelines. For this reason, the following meshes will be created by redistributing the boundaries to honor LTEA guidelines.

4.2.3 Target Number of Nodes

The target number of nodes option can either make or break a mesh. It may be tempting to make a mesh with as few nodes as possible to decrease run time but this can compromise a mesh and in terms of using the toolbox, can wash out the LTEA guidelines. To illustrate this, a comparison of the Escambia Bay Domain using 20, 60, and 100 thousand nodes are shown in the following series of figures. Each mesh is shown with its respective number of nodes followed by a figure showing the percent error of final spacing vs. DelX or LTEA recommendations. Basically, lighter areas are areas where LTEA is preserved and darker areas indicate where LTEA is not preserved.

The general trend is simple, the more nodes in the mesh, the better the final mesh follows LTEA guidelines. This is illustrated by comparing the 20,000 node mesh to the 60,000 node mesh. The 60,000 node mesh has fewer areas that differ greatly from LTEA guidelines and the areas are smaller as compared to the 20,000 node mesh. On the other hand, the 100,000 node mesh does not have the same increase in the ability to honor the LTEA guidelines. Although 40,000 nodes were added, most of those nodes were added near the shore where the LTEA values are the smallest. The areas with large differences in the open ocean remained relatively the same.

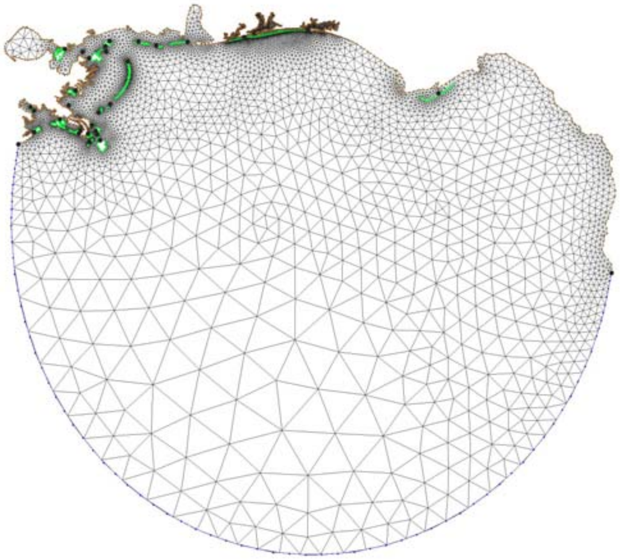

Figure 4.2-4 Escambia Bay 20,000 Node Mesh

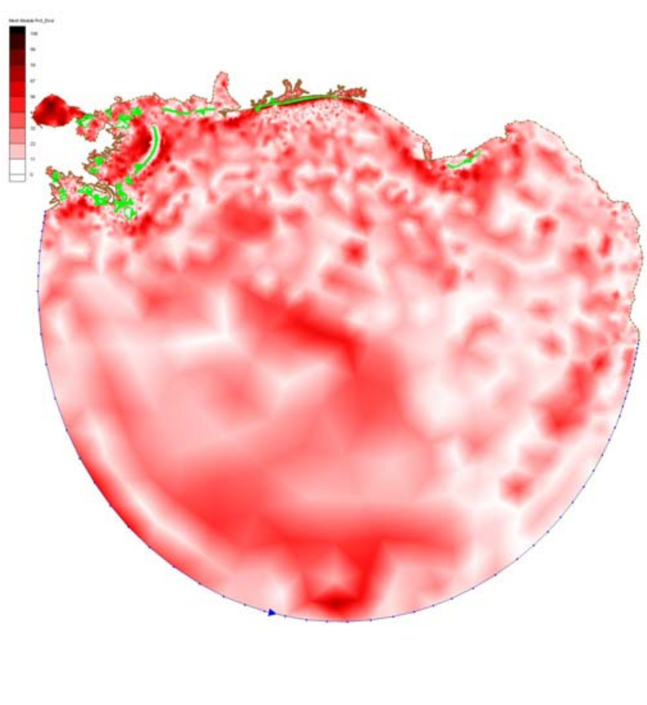

Figure 4.2-5 Escambia Bay Comparison of LTEA vs. Actual Spacing for 20,000 Node Mesh

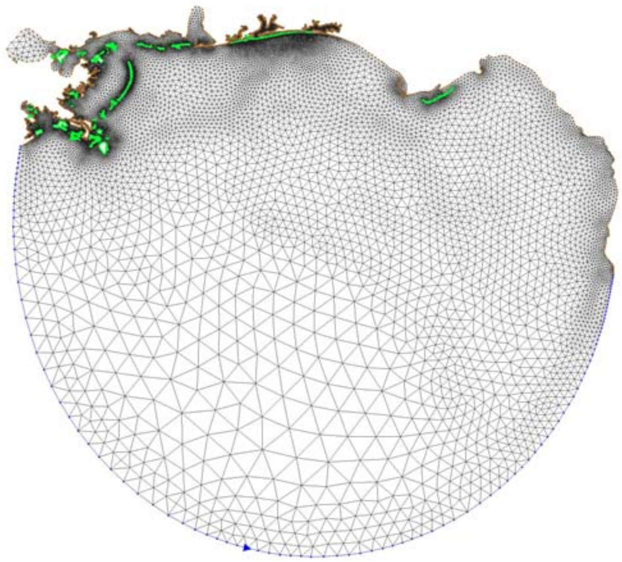

Figure 4.2-6 Escambia Bay 60,000 Node Mesh

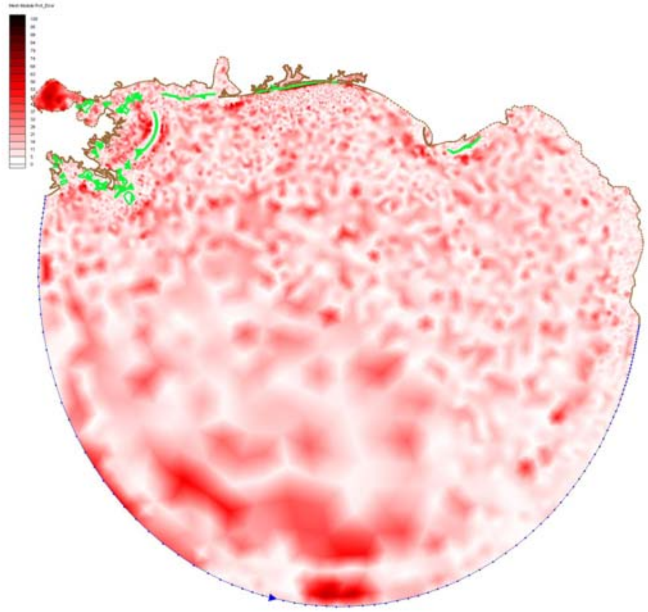

Figure 4.2-7 Escambia Bay Comparison of LTEA vs. Actual Spacing for 60,000 Node Mesh

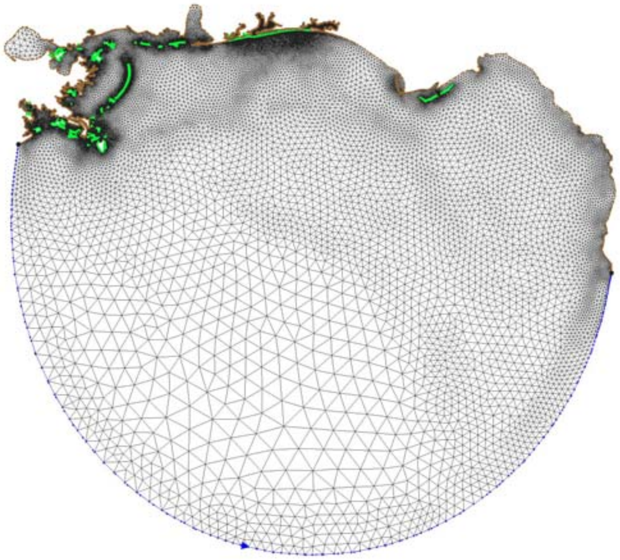

Figure 4.2-8 Escambia Bay 100,000 Node Mesh

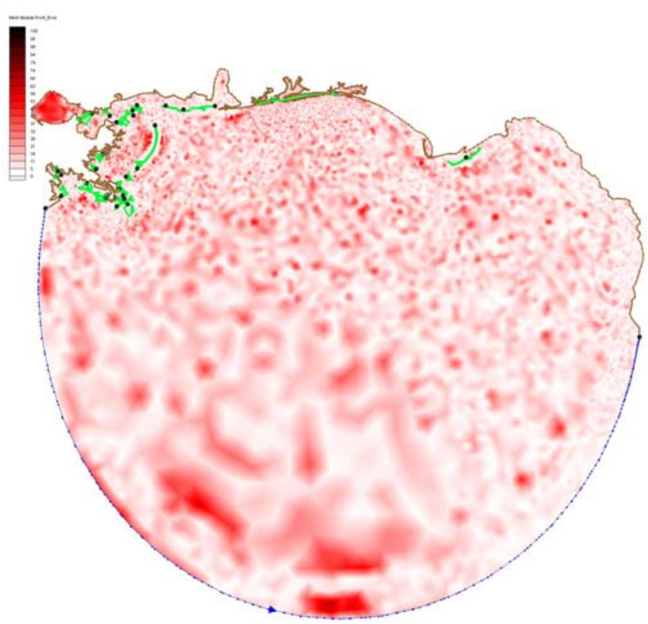

Figure 4.2-9 Escambia Bay Comparison of LTEA vs. Actual Spacing for 100,000 Node Mesh

For the reasons given above, it would be difficult to give a "best" target number of nodes for any mesh. The user should do a similar test with their respective domain and decide how much his or her final mesh can differ from the LTEA guidelines.

4.2.4 Element Area Change

One identifier of a good mesh is comparing how quickly the element areas within a mesh change. For example, an element with an area of 1000 m^2 transitions to elements with areas of 10 m^2, this is an element area change of 0.01 or 100 depending on the ratio that is used. Most modelers would agree that an area change limit of 0.5 is an indication of a good mesh. With this limitation, LTEA guidelines sometimes cannot be honored. The Escambia Bay domain is an example of this problem. In Figure 4.2-10, the values of LTEA rapidly change around the barrier island from about 10 next to the island to about 40 with only 10 kilometers between the values. If converted to areas, this would mean that on the boundary elements would have areas of about 56 m^2 to areas of about 900 m^2.

It should be noted that if the ratio for element area change were to be relaxed the final mesh spacing could match LTEA guidelines more appropriately. This is not recommended however. Large transitions from small elements to large elements and visa versa can cause instabilities in the model. Again, if error results in smaller elements than recommended by LTEA guidelines some efficiency is lost but the model will be more stable than if the error results in larger than recommended elements. The alternate equation used to distinguish larger then recommended spacing should be used if there is concern about a specific area. From this study, it was found that few areas if any have larger spacing then recommended by LTEA guidelines.

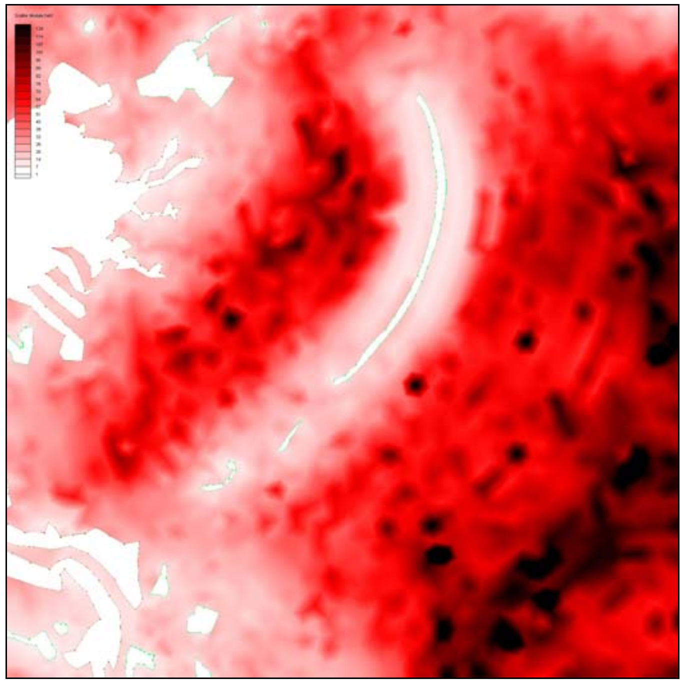

Figure 4.2-10 Escambia Bay LTEA Results

This rapid transition results in error when comparing actual LTEA guidelines and actual mesh spacing. The smoothing procedure that takes place for the final size function also tends to introduce slight differences when comparing the final mesh spacing to DelX. These differences usually result in the mesh spacing being smaller rather than larger so the change is not as detrimental as it would be if the spacing were larger. Figure 4.2-11 shows the difference in spacing for a 20,000 node mesh. Figure 4.2-12 and Figure 4.2-13 show differences for 60,000 and 100,000 node meshes. The darker areas are areas with bigger differences in the actual mesh spacing and the LTEA guidelines. These differences could be detrimental to the final mesh in terms of stability if they result in larger spacing than recommended by LTEA guidelines. White areas are areas with very little differences in spacing guidelines.

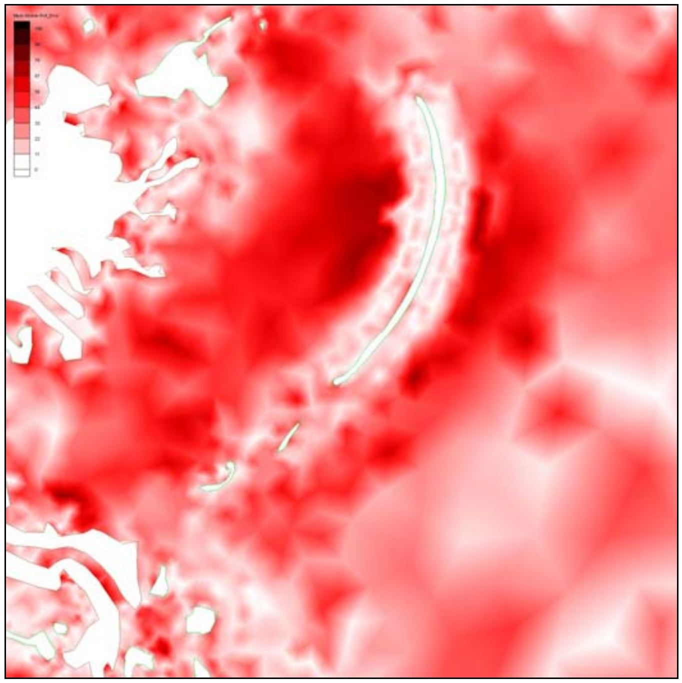

Figure 4.2-11 Percent Error for a 20,000 Node Mesh

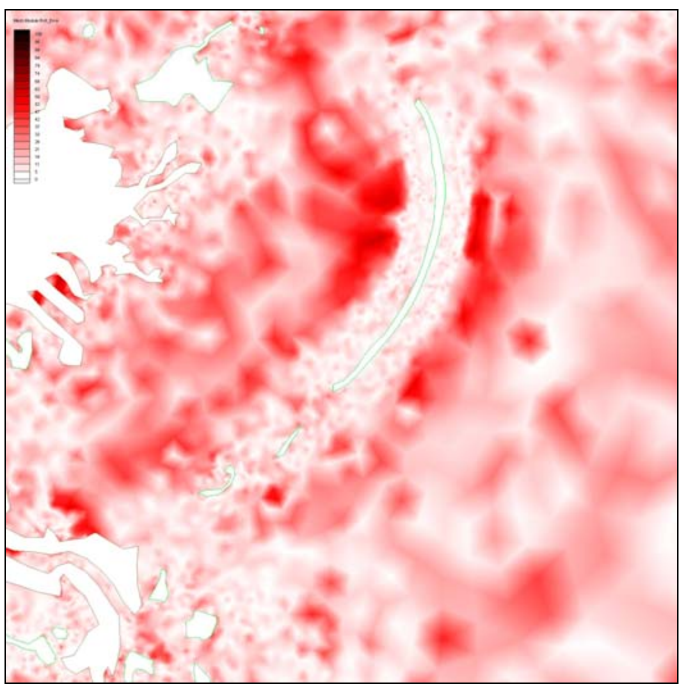

Figure 4.2-12 Percent Error for a 60,000 Node Mesh

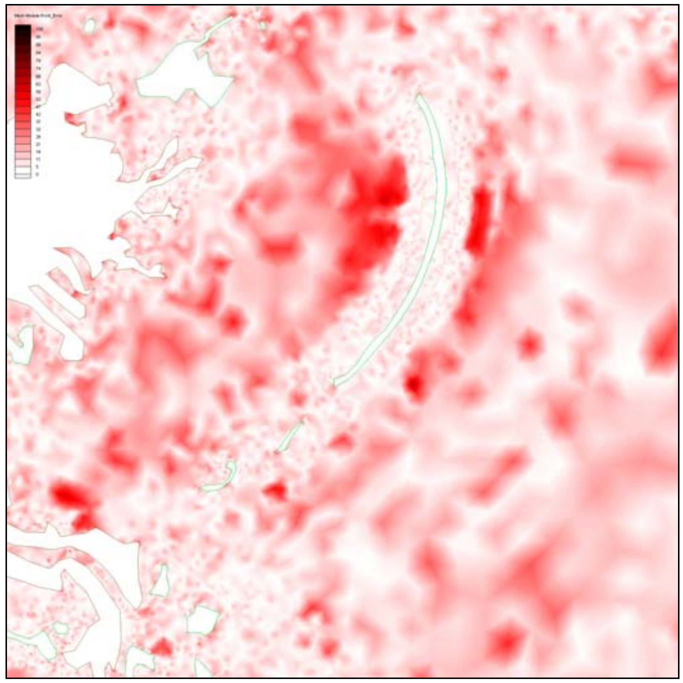

Figure 4.2-13 Percent Error for a 100,000 Node Mesh

The rapid transition of LTEA values and the limitation of a 0.50 element area change results in large differences even with the 100,000 node mesh. The error results because the mesh spacing is smaller than the LTEA guidelines due to the limitations of element areas change. This smaller spacing is not as detrimental to the final mesh as it would be if the spacing were greater than LTEA guidelines. This does show that some differences in the final spacing and LTEA guidelines are acceptable.

4.2.5 Optimal Target Number of Nodes

For the scope of this study, an optimal number of nodes for each domain cannot be determined because of the varying requirements and options in creating a mesh. Each mesh has its own special features and each person may have different requirements. As a recommendation, when using the mesh generation toolbox, the final mesh should be influenced by the LTEA values but the extent of the influence is up to the user.

4.3 Mesh Performance

After the mesh is created, if the ADCIRC run goes unstable the mesh is not considered useful. Some steps can be taken to try and make a mesh stable. For example, decreasing the time step or changing the wetting and drying parameters but the most important input to the model for stability is the mesh. Because of this, if each permutation of a domain consistently become unstable LTEA may not be suitable for creating a mesh for that domain. For each domain, meshes were created and tested for stability. In some cases, historical data exists to test solutions and other times, a previous mesh exists to compare run length or time step size.

4.3.1 Tagus Estuary

The Tagus Estuary domain gave consistent problems. This domain has substantial tidal flats that are located in the estuary. These flats are always "wet" in the linear ADCIRC run because there is no wetting or drying. Therefore the solution does not capture the activity of wetting and drying. When this final mesh is then run in ADCIRC, the model becomes unstable: the instability occurs in the tidal flats where a random isolated low spot stays wet, while the surrounding elements stay dry. This can be seen in Figure 4.3-1. The darker areas are wet areas. In the enlarged area, isolated wet elements surrounded by dry elements can be seen. The natural channel thalweg is not preserved by the DelX function and the mesh generation technique.

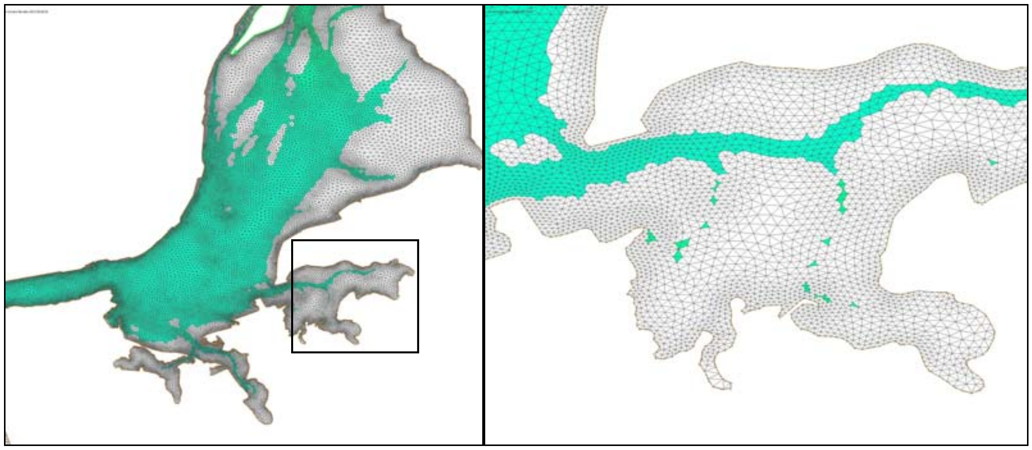

Figure 4.3-1 Tagus Estuary with Wet Cells Shaded.

4.3.2 Grays Harbor

The Grays Harbor domain did not have an original mesh to compare, so a suitable mesh that sufficiently honors LTEA guidelines had to be created. Meshes with 10,000, 20,000, and 40,000 nodes were created and a comparison of how well the final spacing matched LTEA is shown next to them in Figure 4.3-2.

The final mesh for Grays Harbor contained just less than 20,000 nodes. This mesh was chosen because it matched LTEA significantly and there did not seem to be an excessive number of nodes. The meshed used for analysis can be seen in Figure 4.3-3.

The Grays Harbor domain did contain one tidal station, although the location of the tidal station was some distance from the edge of the mesh as seen in Figure 4.3-4. Tidal elevations were extracted from the solution at the location with the red dot. Although these areas are separated by 473 meters, a comparison was made to see how well the mesh performed in a general sense. This comparison is shown in Figure 4.3-5.

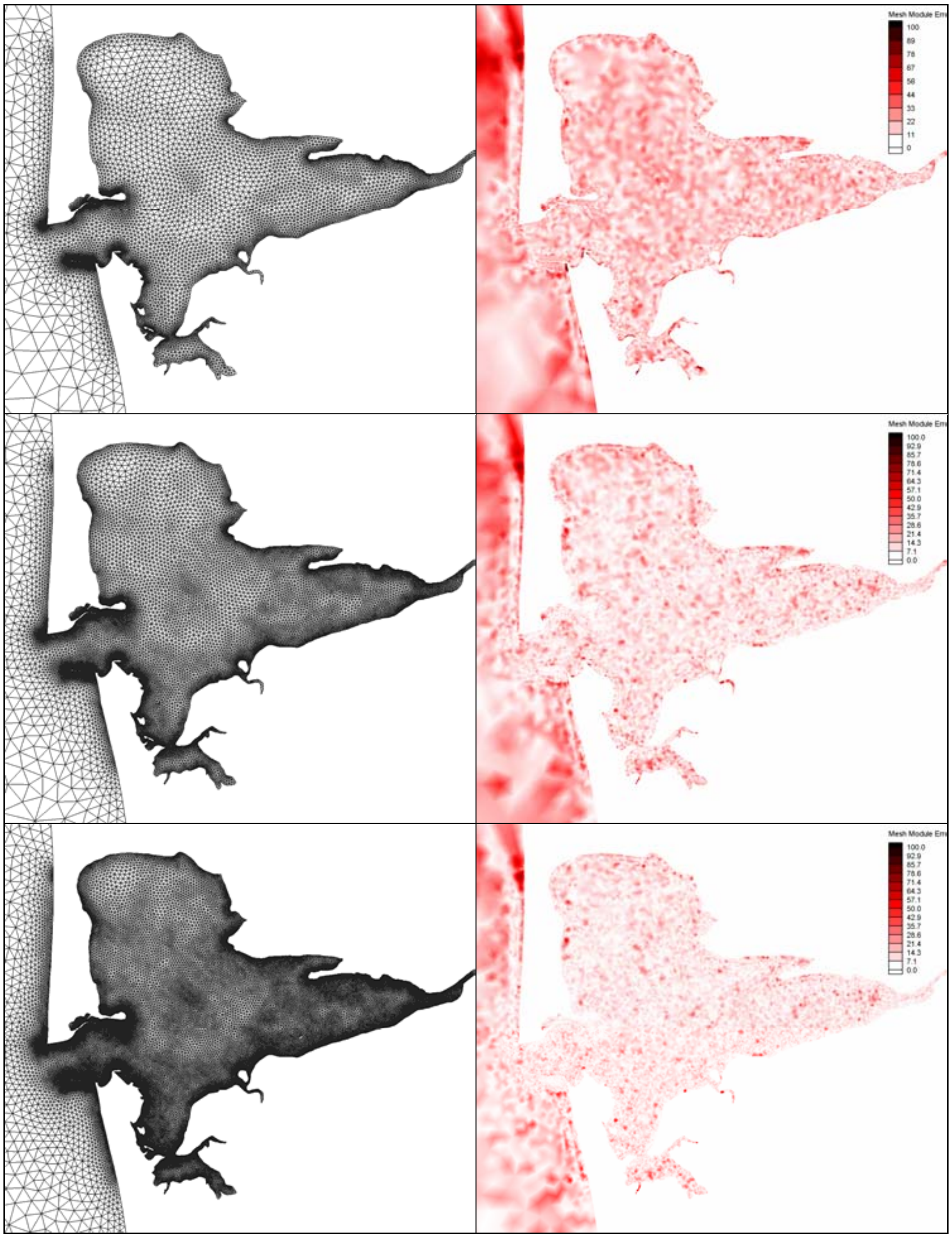

Figure 4.3-2 From Top to Bottom: 10,000, 20,000, and 40,000 Node Meshes with Percent Error from LTEA Guidelines

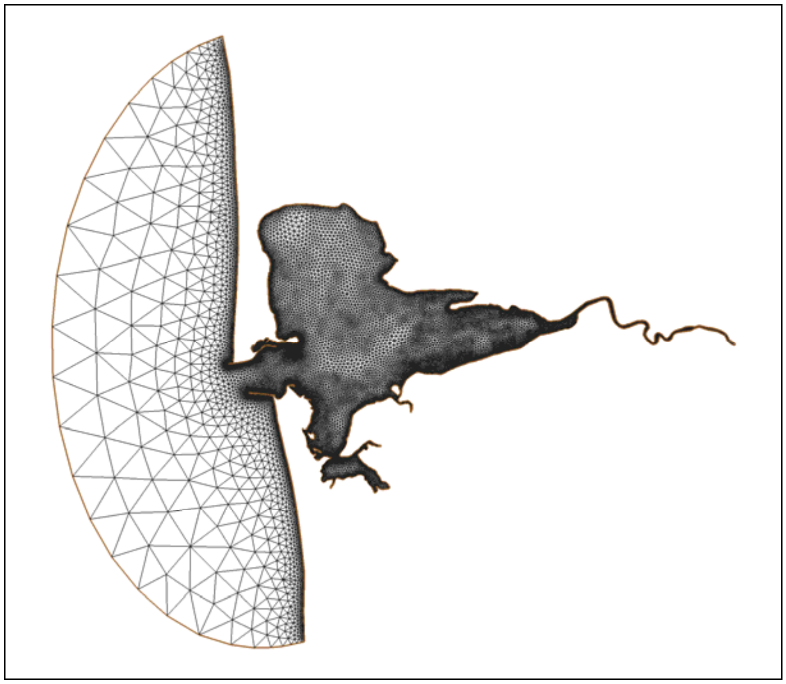

Figure 4.3-3 Mesh Used for Analysis of Grays Harbor

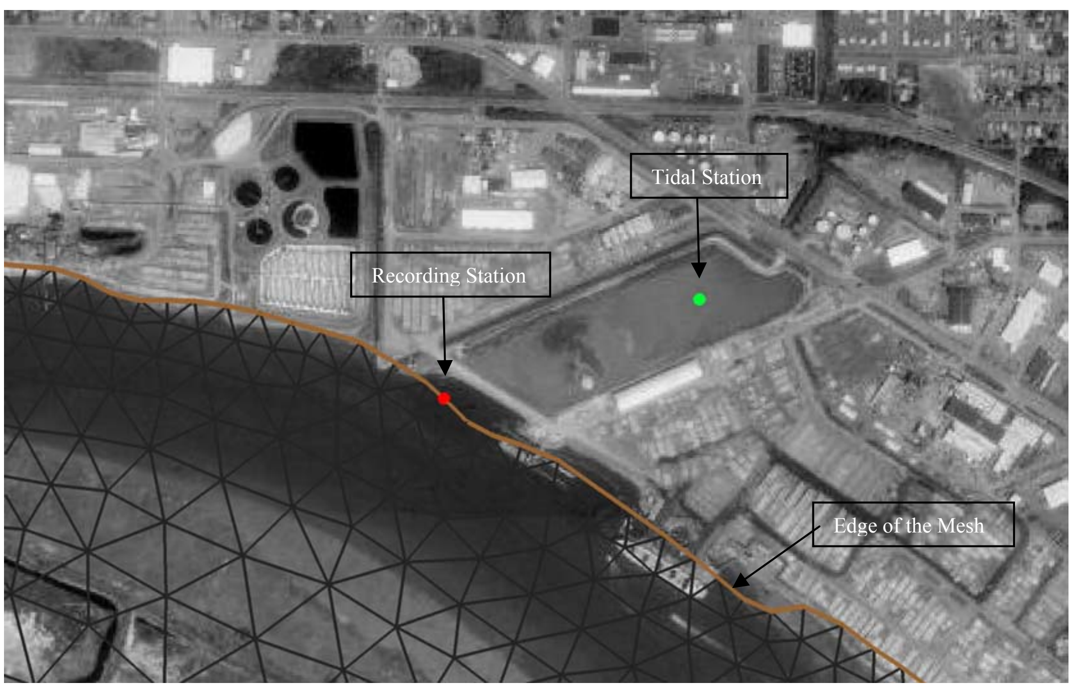

Figure 4.3-4 Location of Tidal Station for Grays Harbor Domain

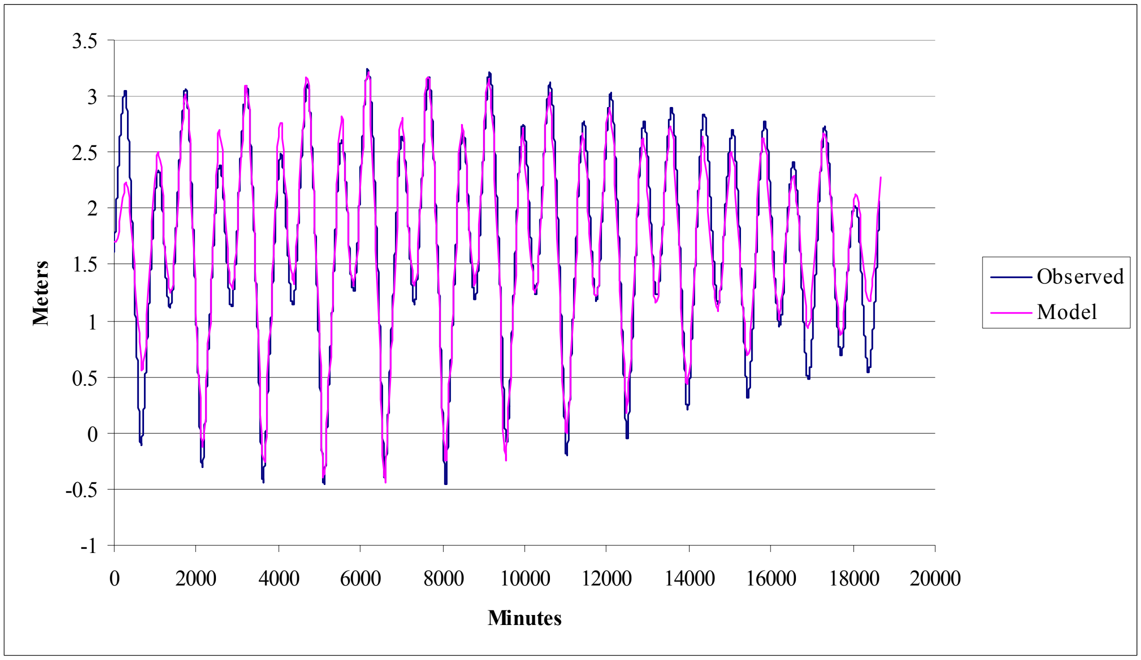

Figure 4.3-5 Comparison of Model vs. Observed Data for Grays Harbor Domain

Even though the location of the tidal gauge is far away, the comparison shows that the model is able to capture the phase very well and the amplitude is also comparable.

4.3.3 Escambia Bay

The Escambia Bay domain is the largest of the domains in this study. Because an original mesh did not exist, several meshes of varying number of nodes were created and checked to see how well they honored LTEA. Meshes of 20,000, 40,000, 60,000, 80,000, and 100,000 nodes were generated along with their comparison to LTEA guidelines. A portion of the meshes with their comparisons are shown in Figure 4.3-6. The final mesh that was used for the ADCIRC run consisted of 60,000 nodes. This mesh was chosen after analyzing how well the mesh preserved LTEA recommendations. The final mesh used for analysis had 60.000 nodes.

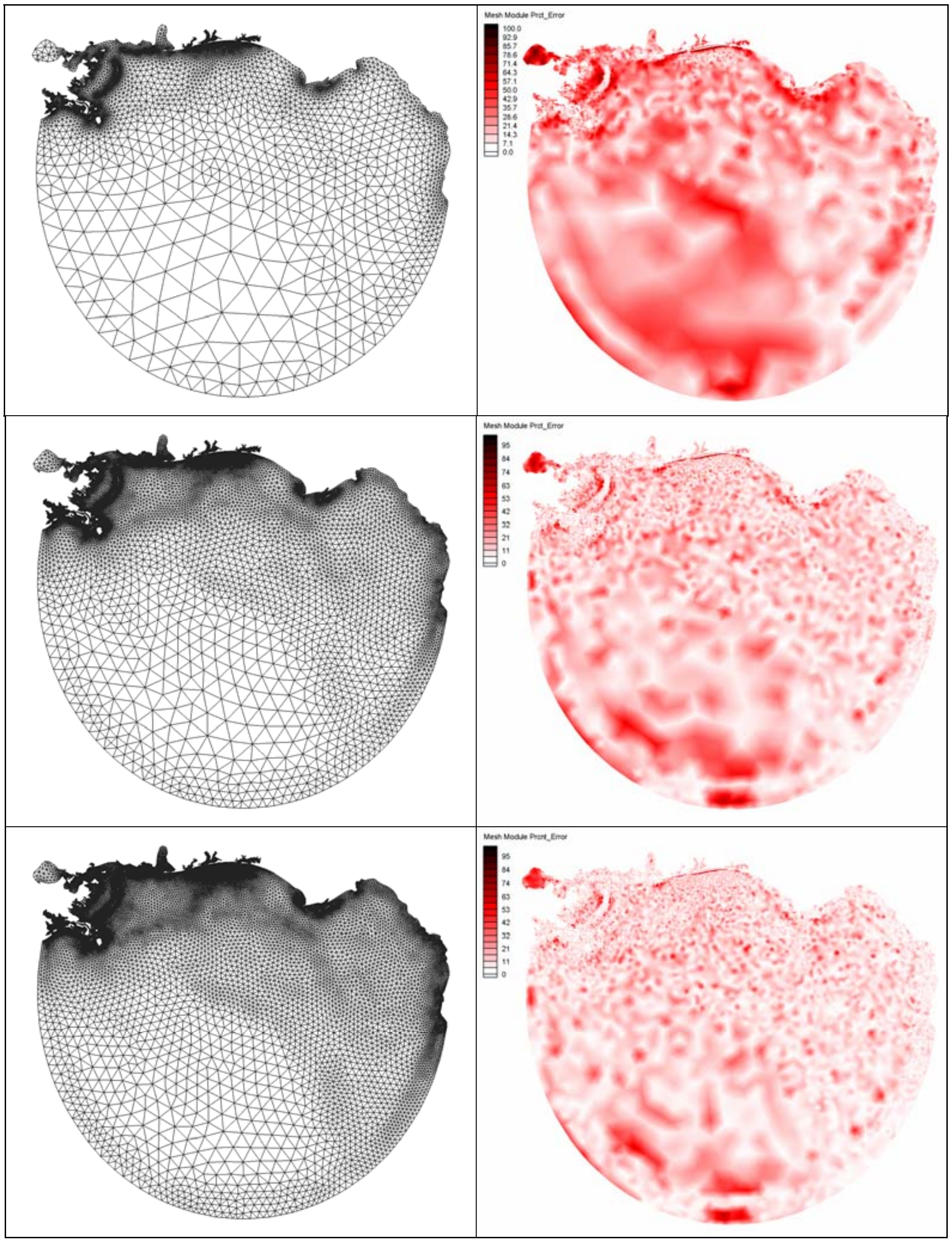

Figure 4.3-6 From Top to Bottom: 20,000 60,000, and 100,000 Node Meshes of Escambia Bay and Comparison to LTEA Guidelines

The ADCRIC run remained stable for the entire 14 day run with a time step of one second. In order to better analyze the performance of the mesh, several tidal stations were available to compare model results with real time values. The tidal stations are located in Cedar Key, and Panama City Florida. The results can be seen in Figure 4.3-7 and Figure 4.3-8 respectively.

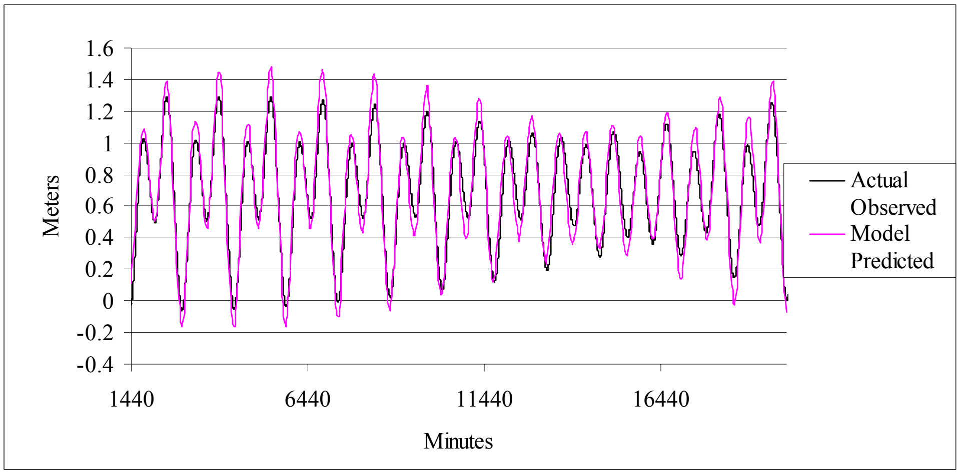

Figure 4.3-7 Actual Tidal Data vs. Model Data for Cedar Key Tidal Station

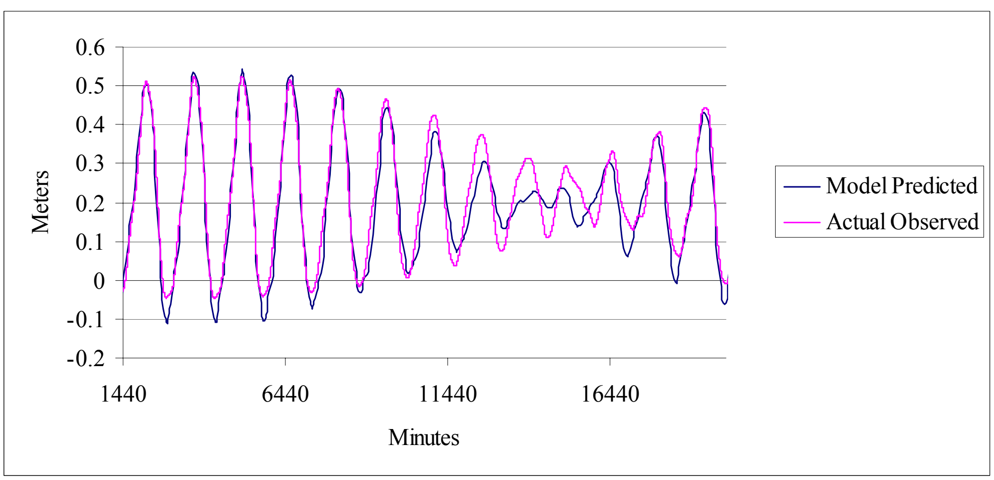

Figure 4.3-8 Actual Tidal Data vs. Model Data for Panama City Tidal Station

The model results are better for the Cedar Key location than for the Panama City location. When the tides are large and regular, the model is able to predict phase and amplitude relatively well. For the Panama City site, the model seems to break down for the smaller tides. The difference in these two tidal stations shows that the model is capturing differences in the ways tides are propagated.

4.3.4 Lake George

The Lake George domain was not able to run in even the Linear ADCIRC mode. This problem occurred because of the nature of the data. The scatter set used for bathymetry was not acceptable in creating a simple mesh. This simple mesh becomes unstable in running linear ADCIRC. This result shows the need for good data no matter the process. The domain is shown in Figure 4.3-9.

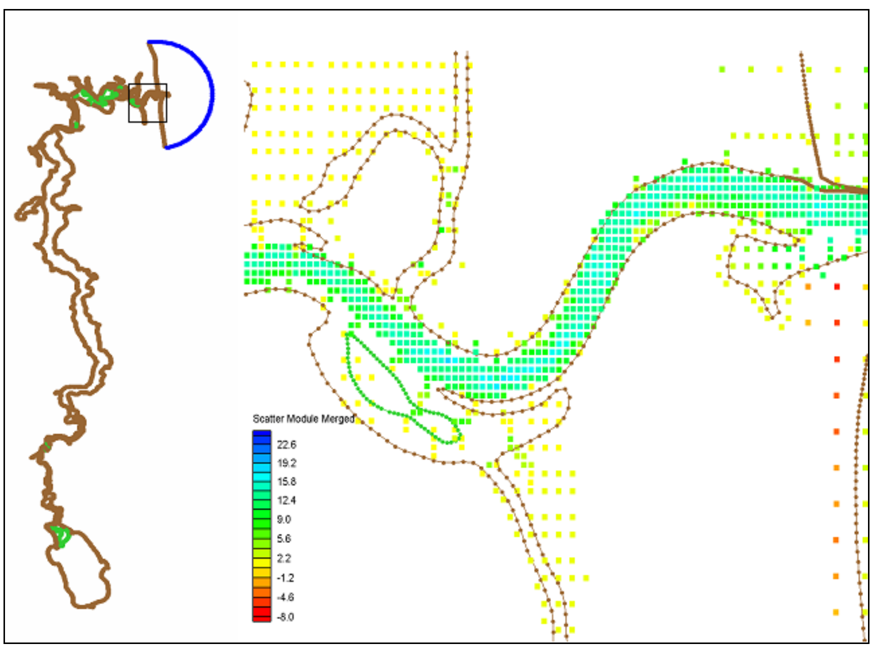

Figure 4.3-9 Feature and Bathymetry Data for the Lake George Doman

The bathymetry points are very coarse along the main channel but outside of that the points are sparse and no longer on a grid. When this scatter set is triangulated, there are isolated low spots and irregularities in the bathymetry. This as well as other factors may have contributed to the instability of this domain even in the linear ADCIRC run.

4.3.5 Loxahatchee Bay

The Loxahatchee Bay domain is an inland waterway with little variation in bathymetry. The mesh used in the domain can be seen in Figure 4.3-10.

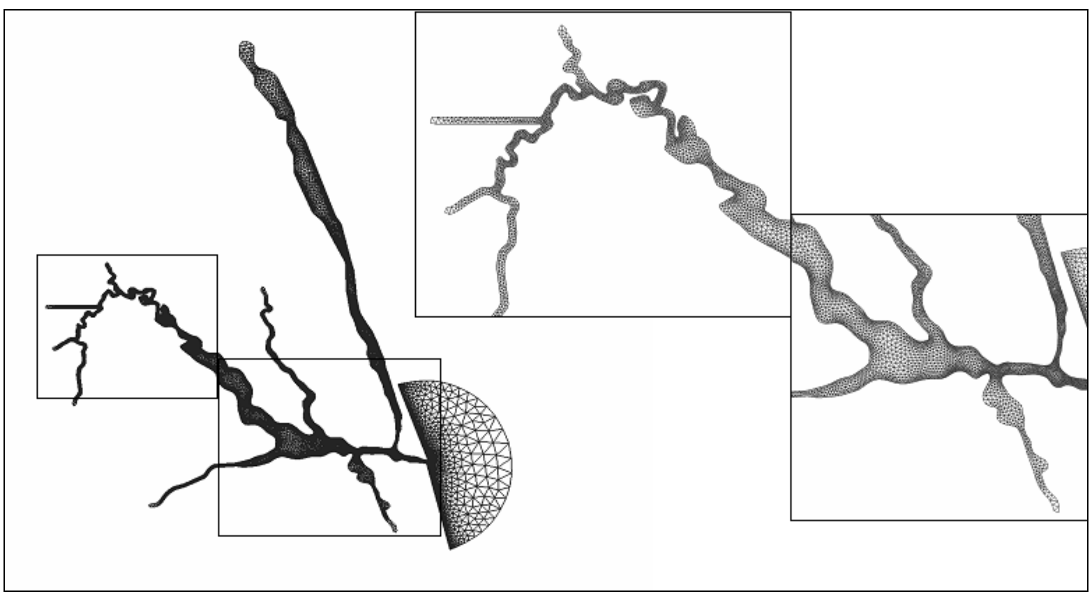

Figure 4.3-10 Mesh Used for Analysis of Loxahatchee Bay

This mesh remained stable for a 14 day run with a 2 second time step. The mesh consisted of 10,000 nodes and ran in approximately 8 hours. There is no data with which to compare the results but a portion of the results are shown in Figure 4.3-2

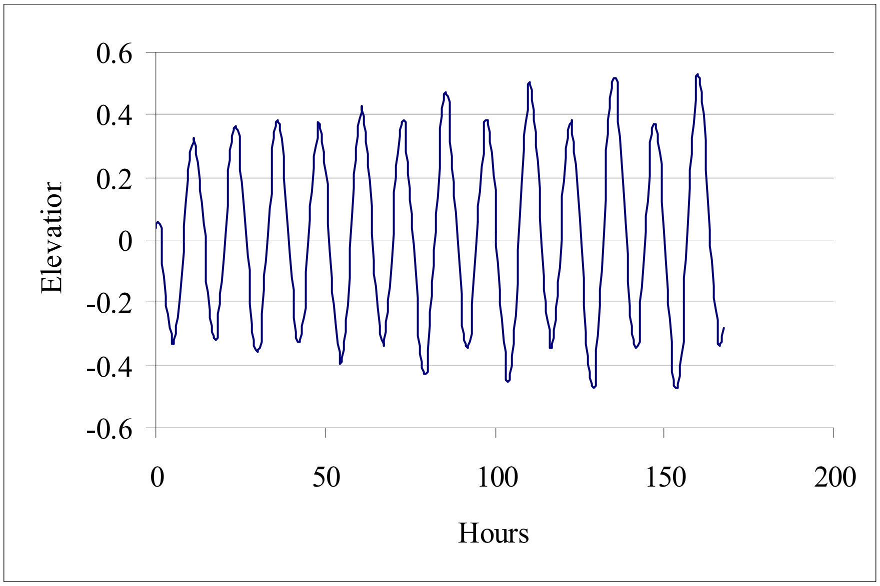

Figure 4.3-11 Results from the Loxahatchee Domain

4.3.6 Matagorda Bay

The Matagorda Bay domain data was taken directly from an already existing mesh. The existing mesh was created using automatic techniques mixed with intense hands-on manipulation. The mesh took several weeks to complete. This domain is by far the most intricate in terms of coastal features such as islands, multiple inlets, and dredged sea floor. One mesh with a similar number of nodes to the original mesh was created rather than several meshes. This mesh consisting of approximately 60,000 nodes was compared to the original mesh and checked for stability as well as model solution comparison. The importance of this comparison lies in the great detail in coastal islands and channels that are hard to capture using LTEA guidelines. The existing and LTEA meshes are shown in Figure 4.3-12.

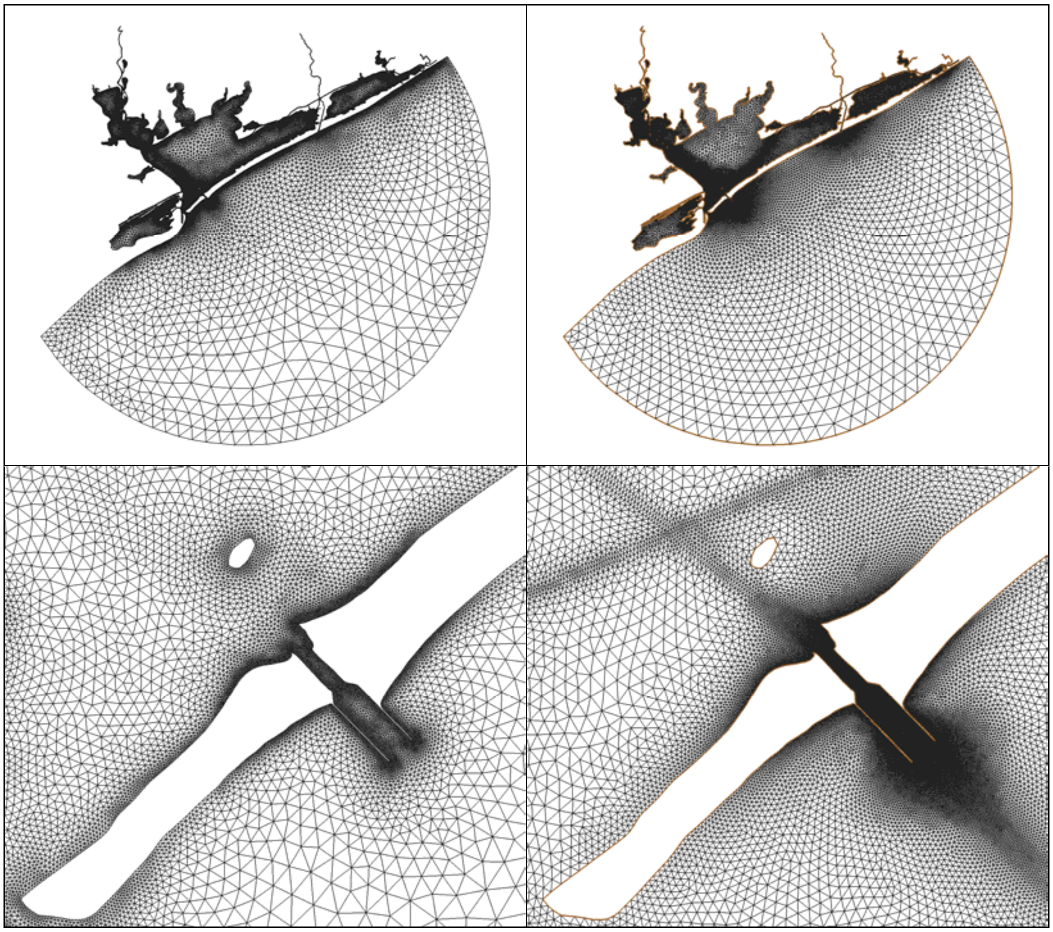

Figure 4.3-12 Meshes Used for Matagorda Bay Analysis, LTEA Mesh on the Left, Existing Mesh on the Right.

The existing mesh has more resolution in the channel and along the dredged areas of the mesh. The mesh generated with LTEA guidelines has fewer nodes in these areas. With time steps of two seconds and higher, the LTEA mesh became unstable in the channel. However, the mesh was stable for a 14 day run with a time step of one second. The existing mesh also was stable with a time step of one second and run time was slightly faster for the existing mesh.

The real data to be compared is incomplete and inconsistent. For this reason, the predicted tidal data found on the NOAA web site is used for comparison. This is not historical data but it does give us an idea of what the solution should look like. This comparison can be seen in Figure 4.3-13

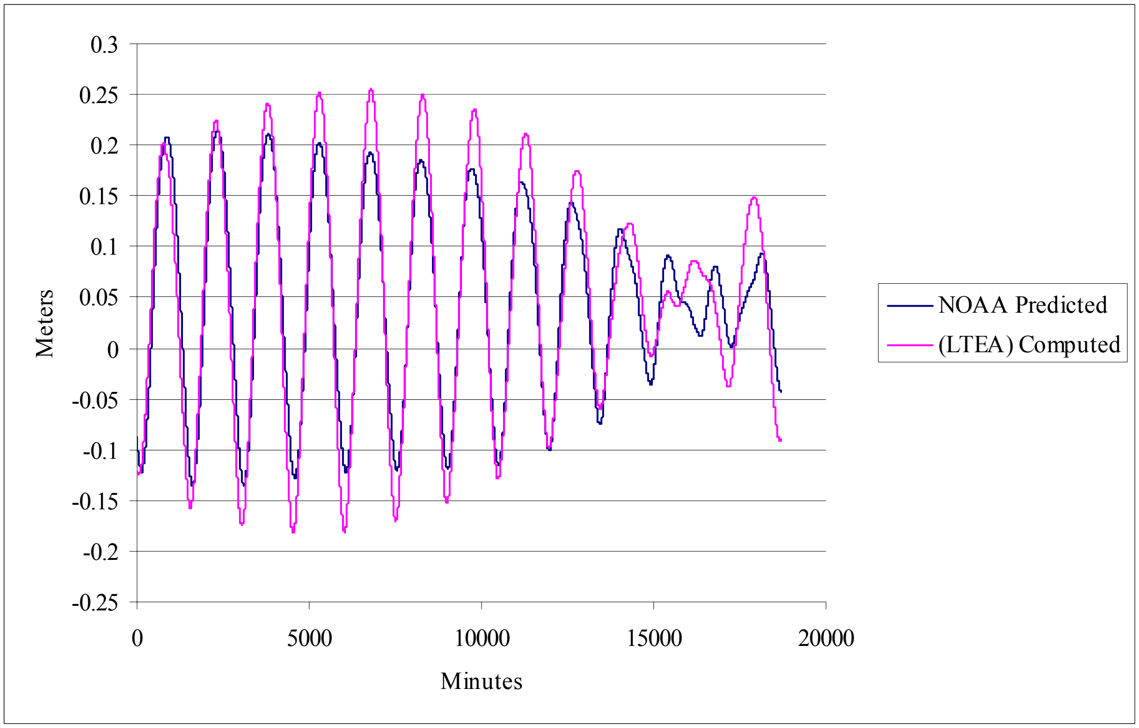

Figure 4.3-13 Comparison of NOAA Predictions to LTEA Tide Elevations at Port O'Conner, Texas.

The LTEA mesh solution did not match the predictions well during the low tides; the peaks and troughs are off by as much as half a meter. The general trend seems to be followed in terms of phase but the overall comparison is not favorable. This does not say that the LTEA mesh solutions are unacceptable, only that it was found lacking in terms of matching NOAA predictions.

The comparison of the original mesh to the LTEA influenced mesh is seen in Figure 4.3-14

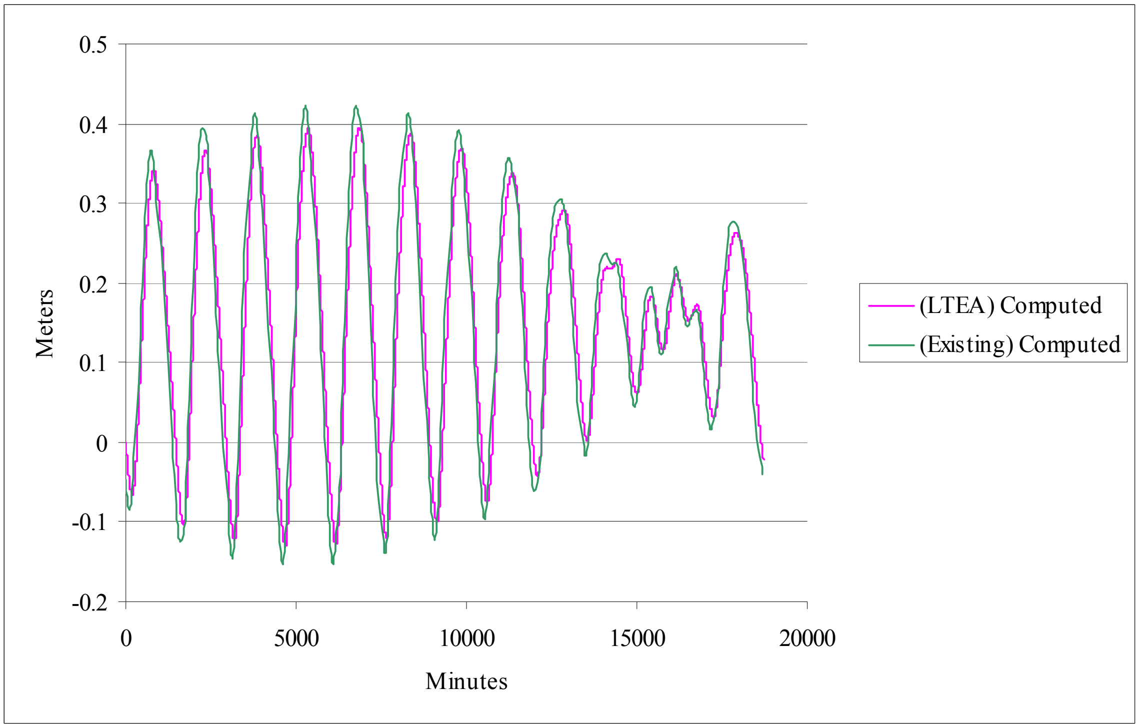

Figure 4.3-14 Comparison of Original Mesh Predictions to LTEA Tide Elevations at Port Lavaca, Texas.

This shows that the phase predictions are almost identical and probably result from the boundary conditions imposed on the models. The amplitudes are actually higher for the original mesh, which is not as acceptable as the LTEA guidelines mesh.

Overall, the LTEA mesh performed as well in terms of output but runs slightly slower than the original mesh (approximately 4 hours slower for the full 14 day run). One difficulty in comparing these meshes is that they were created using different data. This is to say the bathymetry used to create the LTEA mesh was taken from the existing mesh rather than directly from the original bathymetry. It is unclear how this may affect the final results but it would be more ideal to have the same data used to create the original mesh. Although the LTEA mesh is not "better" in terms of run time, the mesh creation process created the Matagorda mesh in hours rather than weeks and with very little user input.

4.3.7 Shinnecock

The Shinnecock domain presented a unique problem. An existing mesh was created using bathymetry, Celerity, and distance from the channel to determine node density. These values for each node were used to create a size function, which was used to create a mesh of about 5,500 nodes. This mesh stays stable with a 4 second time step and takes about 4 hours to run a full 14 days. A mesh with about 5,500 nodes created using LTEA also stayed stable with a 4 second time step but only took about two hours to run. LTEA was also used to create a mesh of only 2,000 nodes. This mesh only took 1.5 hours to run with a two second time step. The toolbox is unique in that a mesh of any reasonable target number of nodes (i.e. not too few nodes) can be created.

There were no NOAA tidal stations available to compare model data to real data. The 10,000 node LTEA mesh used for comparison is shown in Figure 4.3-15.

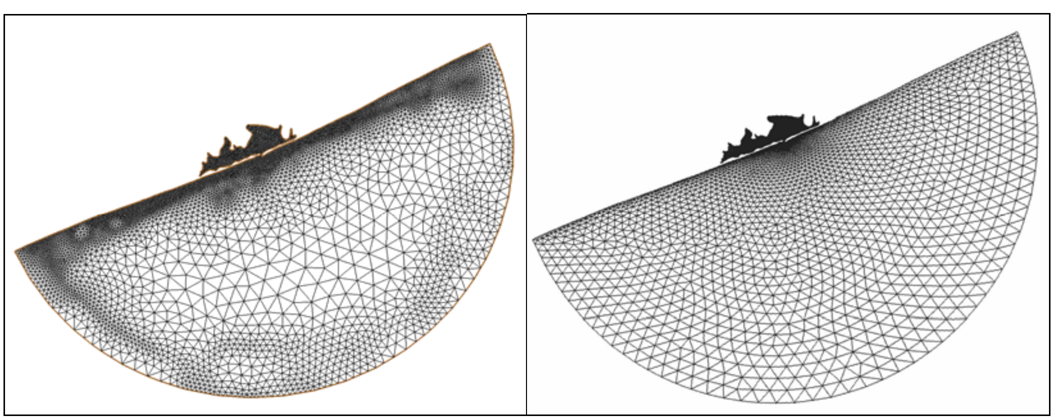

Figure 4.3-15 Mesh Used for Analysis of the Shinecock Domain

The mesh created using LTEA guidelines does not have a uniform node placement like the existing mesh. There are fewer nodes in the center of the mesh and more on the edges.

4.3.8 Cape Fear

The mesh used for analysis of the Cape Fear domain contained around 20,000 nodes and can be seen in Figure 4.3-16. There are three tidal stations located within the mesh domain that can be used for analysis.

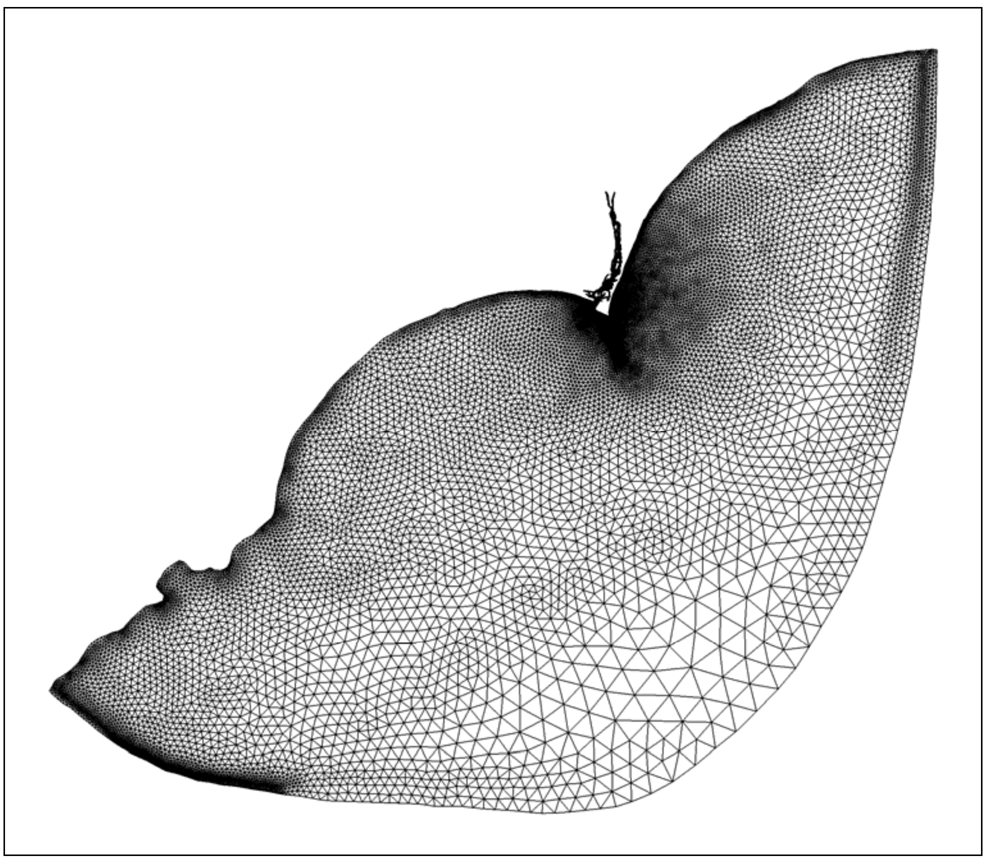

Figure 4.3-16 Mesh Used for Analysis of the Cape Fear Domain

The Cape Fear domain remained stable for a full 14 day run and the first tidal station is located at Sunset Beach, North Carolina. The model results show that the amplitude is off at times by as much as 0.2-0.3 meters. The phase is consistent with the observed data. The results can be seen in Figure 4.3-17.

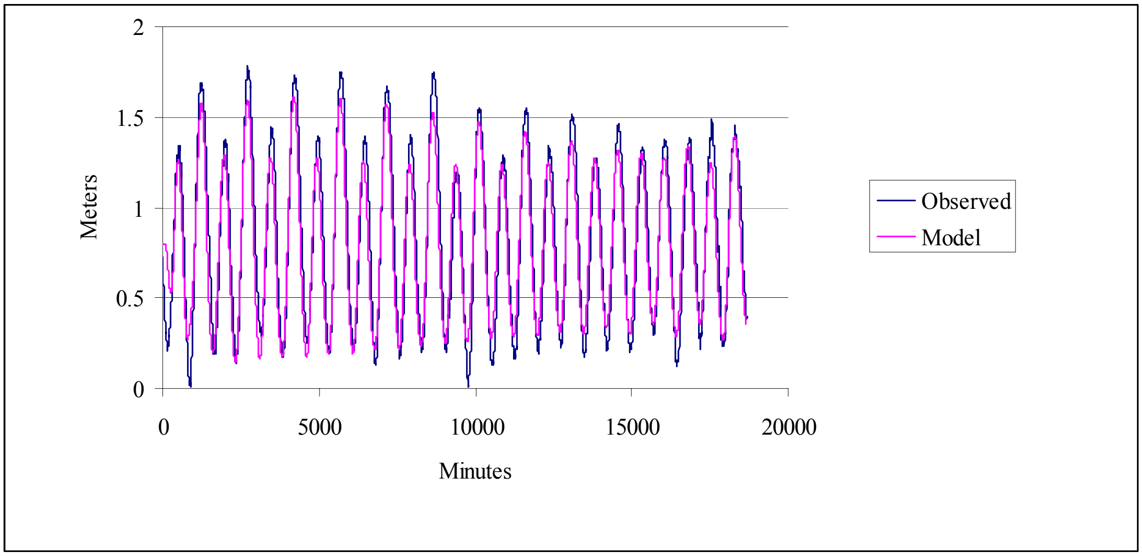

Figure 4.3-17 Actual Tidal Data vs. Model Data for Sunset Beach Tidal Station

The next two tidal stations are located at Wilmington and Wrightsville Beach, North Carolina and can be seen in Figure 4.3-18 and Figure 4.3-19, respectively. The results are similar to Sunset Beach in terms of how well the model matches the amplitude and phase. This is significant because locations of these sites vary from the coast to deep inside the inlet. The original purpose of this data was to test new dredged channels near the inlet to discover if there would be any problems with them. The result of this mesh shows that a mesh created using LTEA may be used for such a purpose.

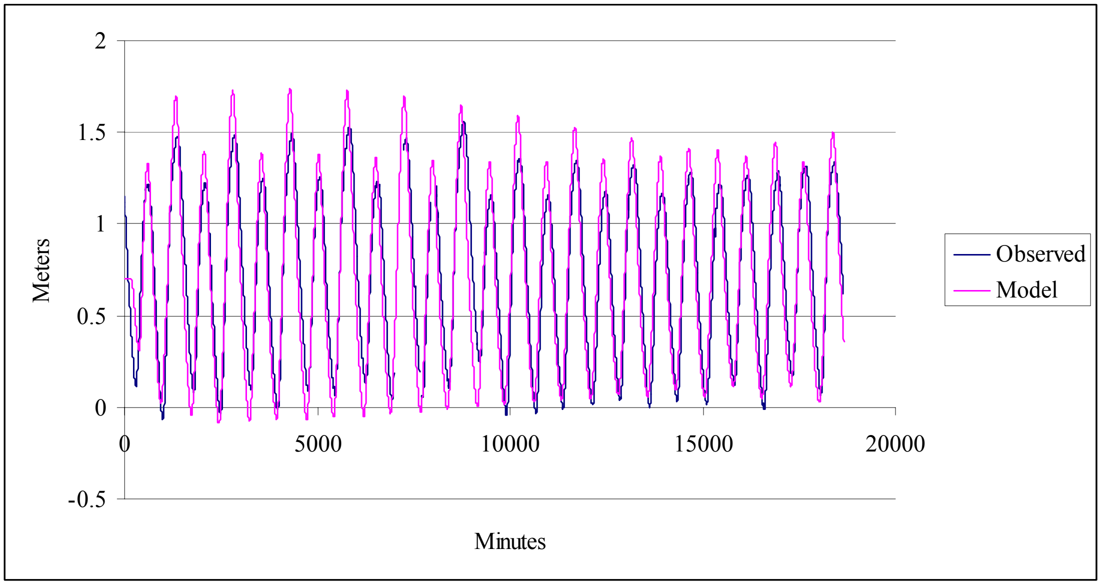

Figure 4.3-18 Actual Tidal Data vs. Model Data for Wilmington Tidal Station

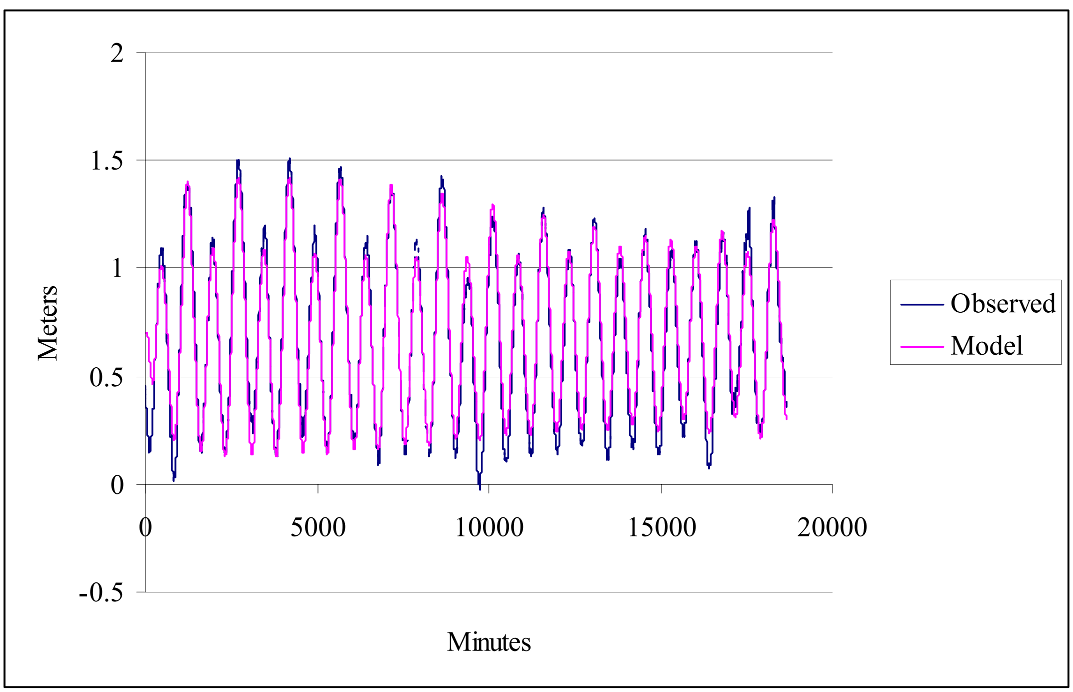

Figure 4.3-19 Actual Tidal Data vs. Model Data for Wrightsville Beach Tidal Station

4.3.9 American Samoa

The original mesh of American Samoa was created by an inexperienced modeler with automatic mesh generation techniques. The American Samoa domain mesh contains close to 24,000 nodes which is similar to the number of nodes in the existing mesh used for comparison. The mesh generated from LTEA guidelines can be seen in Figure 4.3-20.

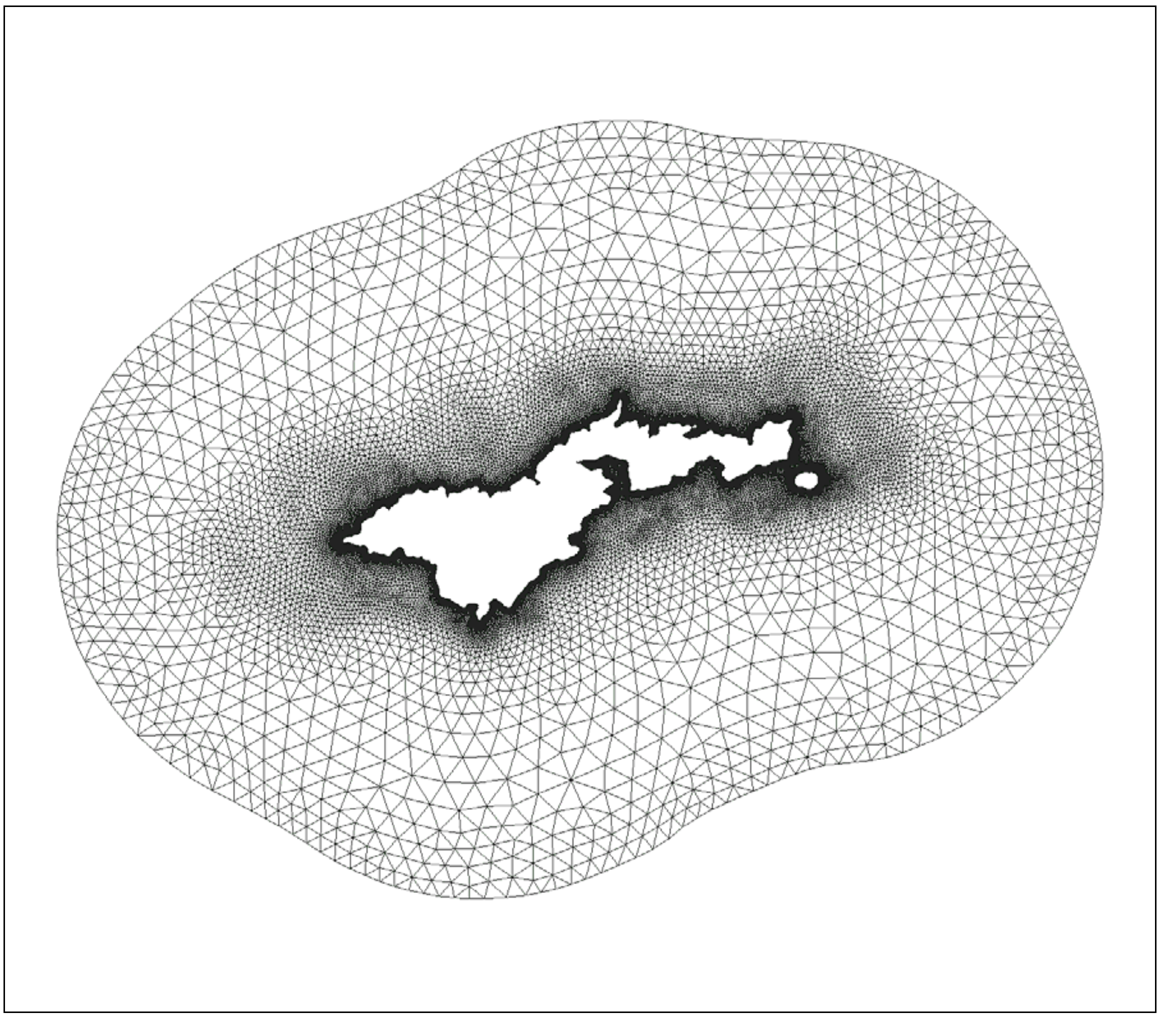

Figure 4.3-20 Mesh Used for Analysis of American Samoa

When compared to the original mesh, the LTEA mesh ran with a two second time step, while the original mesh quickly became unstable with a two second time step. This alone is very significant since using a time step of two seconds rather than one second cuts the run time in half.

There is one tidal station that lies within the mesh domain, the Pago Pago tidal station. The LTEA mesh seemed to match the real data well in terms of amplitude and phase. There are a few points where the amplitude is slightly higher but the overall results are very favorable. The results can be seen in. Figure 4.3-21.

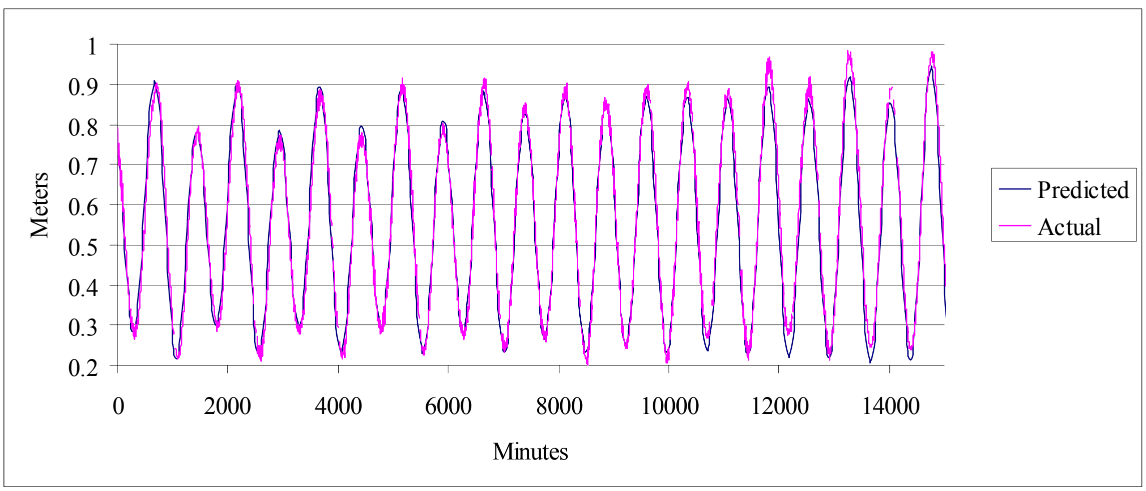

Figure 4.3-21 Actual Tidal Data vs. Model Data for Pago Pago Tidal Station

4.4 Future Work

After testing the various options and types of meshes, there have been many ideas for future considerations. The first consideration is how to deal with the problem of tidal flats. Grays Harbor domain seemed to respond better than the Tagus mesh but the tidal flats in it are not as deep, and the channels are not as prominent. To respond to the problem of honoring the thalweg of the channels, one solution could be to use arcs that fallow the thalweg. These arcs would then be redistributed following LTEA guidelines and the channels would be preserved. The depressions would need to be “filled” as well to ensure that the channels have a continuous path to the wet part of the mesh. There are applications, such as TOPAZ, which calculate flow directions and fill low lying areas and could be used to create arcs along the thalweg of channels. This process could be automated and added to the toolbox. This type of application could possibly help with meshes such as Matagorda Bay which has distinct dredged channels for shipping.

Currently, the toolbox uses a Linear ADCRIC run with just the M2 tidal constituent as input for the boundary condition. This assumes that the M2 constituent is the most important constituent in terms of causing change in the solutions. This may not be the case however. The most optimal solution is the one that results in the smallest spacing over the largest area. In future considerations, the toolbox has the options of allowing the user to specify which constituents to use for the ADCIRC run and subsequent solution to use for the LTEA analysis.

The LTEA process also has more development to undergo such as using adjacent nodes to calculate truncation error instead of the 9 X 9 molecule. This process is planned for future development into the SMS mesh generation toolbox. There are also other forms of analysis such as being able to pick any variable, like bed stress, and take recommendations according to how rapidly that variable is changing. The toolbox should also be designed to work with multiple models and not just ADCIRC.

Finally, a more in depth study comparing real life data to the results produced using meshes created with the toolbox needs to be performed. This kind of a study would require a quality run with specific boundary conditions and not just generalized data. The Le Provost database may not be the most accurate way to extract tidal forcing values for smaller domains like estuaries and bays.

5 Conclusions

This thesis proposed the creation of a streamline toolbox based on LTEA which requires minimal inputs to create a mesh with appropriate density. This toolbox was created, implemented into SMS and extensively tested with good success. The toolbox requires little input and manual user interaction, yet allows flexibility in the sense that the process can be stopped or restarted at any step of the process. The actual time required of a user to create a mesh is only a few minutes for the initial set up and then depending on the size of the initial mesh, the process can take anywhere from ten minutes to several hours. However, this processing time does not require any user input.

The meshes generated by the toolbox should honor the LTEA guidelines to ensure that the nodes are placed appropriately. The toolbox does not ensure this automatically but a process to determine how well the final mesh conserves LTEA guidelines is outlined in Chapter 4. It was determined that LTEA guidelines are honored when a sufficient number of nodes is specified for the final mesh. Except for the Tagus mesh, meshes created with the toolbox did remain stable for a full tidal cycle with time steps larger than those required for manually created meshes.

The WNAT domain was proven to be an acceptable domain for using LTEA to generate a mesh with appropriate density. This domain is large and has well defined circulation zones. The Escambia Bay domain is similar in terms of definition and detail along the coastline. This domain also was deemed suitable for LTEA. Smaller domains like Shinnecock Bay, and Cape Fear, North Carolina and American Samoa also performed well.

Domains with Tidal flats did not perform as well. The Grays Harbor domain did remain stable although it had tidal flats but The Tagus domain had instability problems. It was found that the tidal flats and channels were not preserved in the meshing process. These areas also experience a lot of wetting and drying of elements which is not captured by LTEA since the ADCIRC run used for analysis leaves the entire domain wet for the duration of the run. The Matagorda Bay domain also had channels that were dredged for shipping. When larger time steps were used, the model would become unstable in areas in the channels.

Riverine domains like Loxahatchee and Lake George performed well when good data is used in the analysis. These areas also have distinct channels that can be cut off with false dams when incomplete bathymetry sets are used. The Lake George domain was did not have acceptable data to run an initial ADCRIC run. The Loxahatchee domain ran with no problems because the data was more complete.

Overall the toolbox allows an inexperienced modeler using good data to quickly create an ADCIRC mesh. Use of the toolbox reduces time requirements for mesh generation by orders of magnitude, even for experienced modelers. All but two of the domains allowed for a stable mesh to be created with little user interaction. The toolbox can be used to help in the study of current patterns and tides in various bodies of water.

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