Fall 2024 Workflow Documentation

Modeling Structural Interventions with XBeach Documentation

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ONE

OVERVIEW

1.1 Introduction

XBeach is a software that is commonly used ot simulate nearshore conditions during severe weather events. It can be used to project storm surge, erosion, flooding, and more. It is also widely flexible, in that it allows for the user to assign a variety of ground materials and plantings anywhere in the simulation area.

This flexibility makes it very attractive for designers- particularly landscape architects and environmental engineers- to plan nature-based coastal reinforcements. The effectiveness of mangrove barriers, for example, can be accurately projected due to XBeach's high level of detail in calculating wave dispersion.

Vegetation can quickly be placed in a model by filtering the grid cells in the bathymetric matrix by things like elevation and distance to the shoreline, but solid structures function differently. This is because vegetation is calculated as an object water can pass through with a certain degree of friction and dispersion, and a solid structure doesn't allow for that. Thus, any solid structures need to be represented as a part of the bathymetric matrix to be treated as impermeable.

The problem with this is that it takes significantly longer for a designer to modify the bathymetry than it does to create a vegetation map. Many lack the skills to do this, which would mean they would need to send the details off to another person and cause delay. This is what led me to develop a designer-friendly workflow which speeds up that process and allows for more simulations and more iterations, and therefore a better design overall. And, while XBeach specializes in natural solutions, that does not mean designers should be limited to those when trying to improve coastal resilience. After all, those are just one tool in their arsenal.

The process starts with a digital model of your intervention. The software you create it in doesn't matter as long as the file is exported as a .dxf. Once this is done, you will bring the file into ArcGIS Pro and overlay it with DEM data of your site, merging the two together.

From this point, you'll be able to bring the new bathymetry into Matlab. Using commands there you can make some tweaks and smooth a few things out, then write a new file that's ready to use with your regular XBeach setup scripts.

Here’s a list of the things you’ll need:

- Bathymetry Data
- CAD Model
- ArcGIS Pro
- XBeach
- Matlab
- create_sim script
- import_bath script
- visualize_result script

There will be a light description of how to obtain and use bathymetric data, a CAD model, and the matlab scripts that I’ve created in this document. The primary focus will be on the workflow itself, though.

These instructions assume a basic knowledge of the modeling process, as well as an understanding of the basic variables of an XBeach simulation. For clarification on any points, please refer to the XBeach Documentation located in the shared folder. Use ctrl + f to find a description of the variable you need. Grid sizes will be different, so your values likely won’t work with the ones I’ve set as placeholders.

If you aren’t able to figure out what your values should be or don’t understand what they mean, you can feed the both this documentation and the official XBeach documentation to an LLM like ChatGPT and it should be able to provide an explanation and approximate a better value. You would also need to inform it of your grid size, boundary conditions, etc. to get an accurate result.

Chapter

TWO

GETTING THE DATA

2.1 Bathymetry

DEM (Digital Elevation Model) data is the foundation for XBeach simulations. It consists of a grid whose cells each have an elevation tied to them. Typically downloaded in the form of a raster, you'll need this for XBeach to determine how the waves will behave.

The US Geological Survey is a good place to get DEM data. To get started, go to https://apps.nationalmap.gov/downloader/

To get your DEM data, check the "Elevation Products" box and type your target area in the box on the top-right. After that, click "Search Products".

Choose the product that contains your target area, then click the download link. If there isn't one that fits your site completely, you'll have to merge them together.

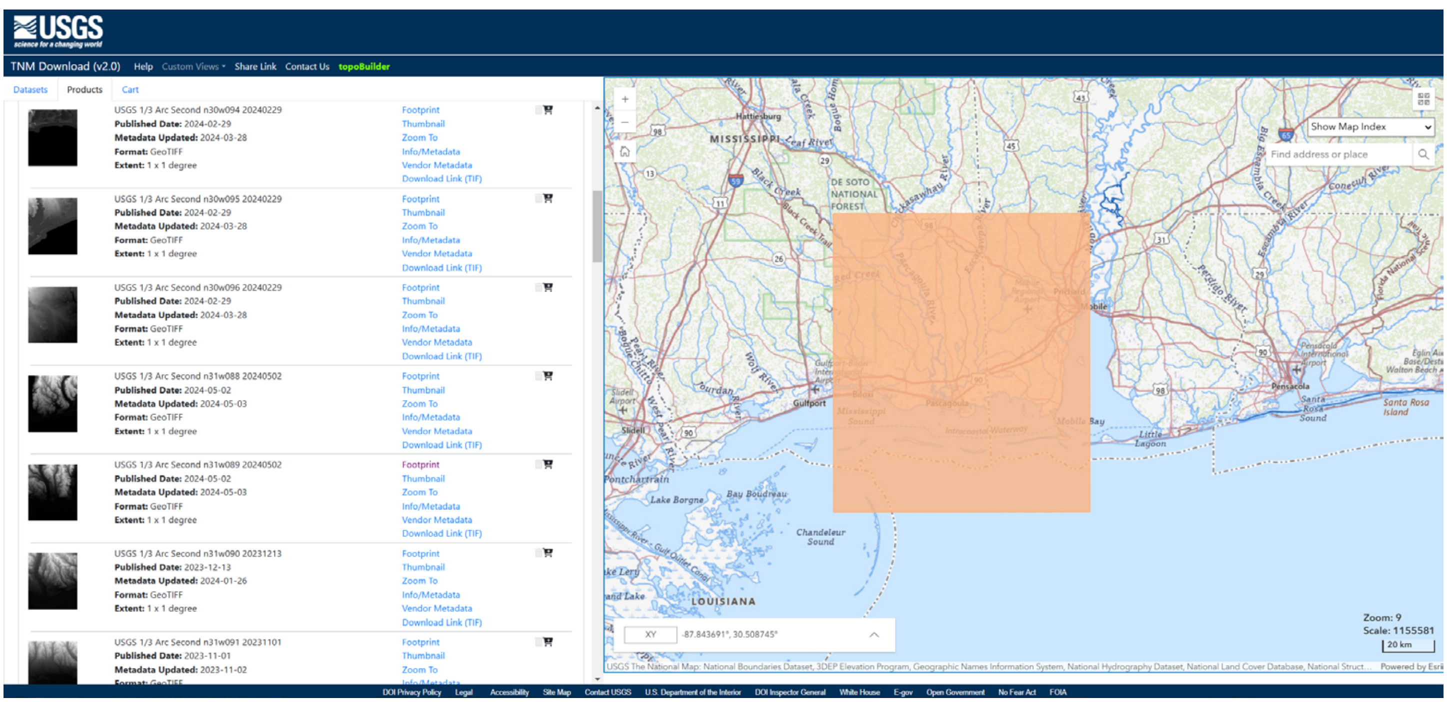

Figure 2.1.1
Selecting bathymetric data from the USGS website. Clicking on the "footprint" button will show where a given file is. Using "show all footprints" at the top of the search menu is useful to see the extents of all available data.

2.2 CAD Model

The difficulty of this step varies greatly depending on the specific design you're trying to create. Here are a few tips to remember:

- The software will only record the highest elevation at each point when you're running the simulation. So if you're using a model that has any roofs or overhangs above the functional aspects of the intervention, you should remove them first.
- You need to set your object's elevation before importing it into ArcGIS. The elevation can be negative, and it should be relative to sea level. Use whatever unit corresponds with the DEM data you have for consistency.

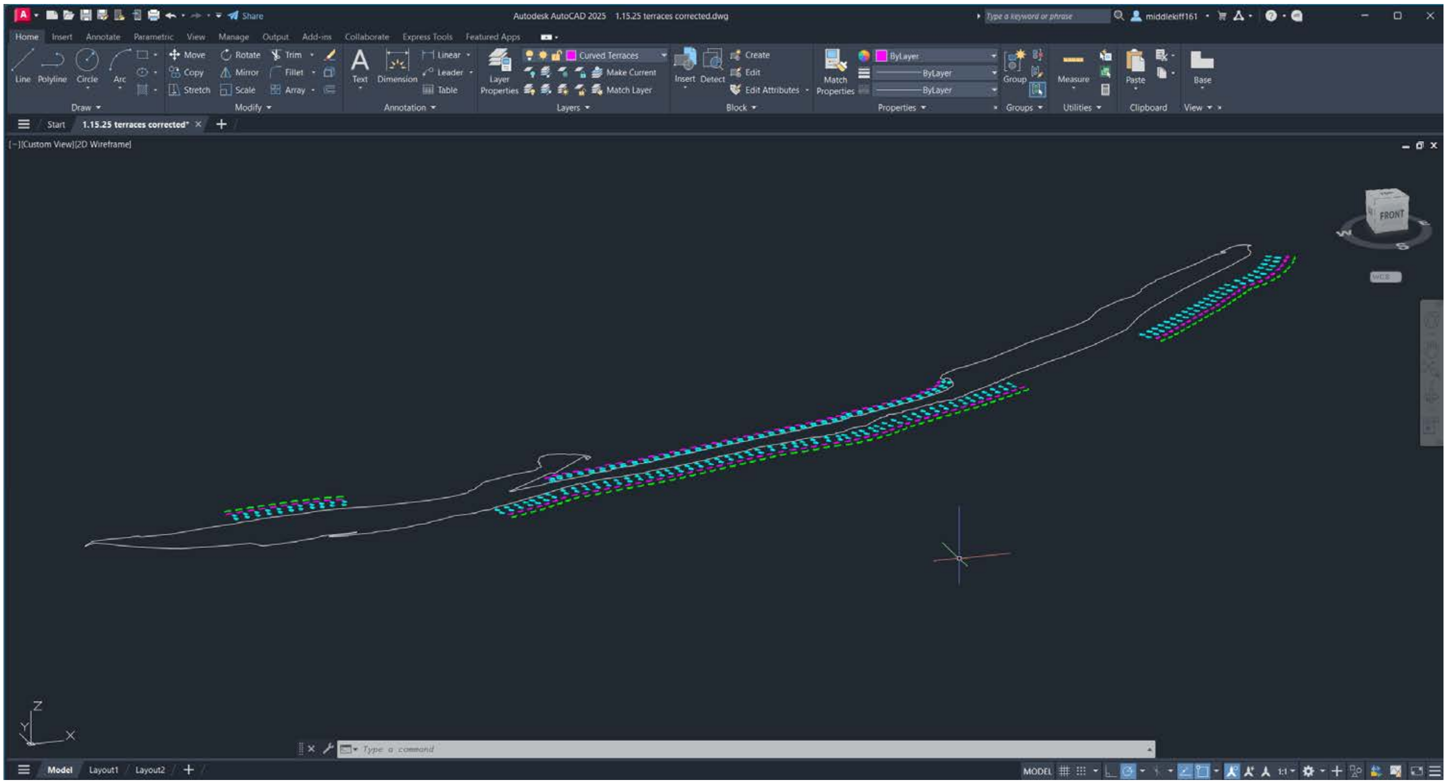

Figure 2.2.1
A 3D model laid out in AutoCAD 2025. Note that the offshore structures are positioned around a 1:1 scale footprint of the site for easier georeferencing later

2.3 Wave Data

In order to run the simulations properly, XBeach will need data on the boundary conditions of the simulation area. These will determine the behavior of the waves further inward. Generally, this data will be obtained from other people doing larger-scale models. Sometimes this data can also be found online. An ADCIRC model can give you this information as an output.

The data is formatted as a plain text list of variables and values. It includes things like significant wave height and peak wave period. For the full list of accepted variables, check the XBeach documentation. The text document needs to be in the same folder as the XBeach application when you run it.

2.3 Material Information

When running an XBeach model you'll have the option to simulate morphology. This will make the simulation mimic erosion, which will be dependent upon the characteristics of materials that you will have to assign. The specifications of each material are formatted the same as the wave data in a plain text document. You'll need to know things like grain size across different percentiles of the material. Again, this can be found online.

The second part of this involves assigning materials to different locations in the grid. You can just define one material for the entire grid, but it's rare for an area worth testing morphology on to only have one material. By creating a material layer file and defining it in the parameters document, it's possible to use multiple material files in one simulation.

The way that I prefer to do this involves using Matlab to select areas of the grid that have different properties and assigning them to a different index. One example of this would be to select everything between certain elevation values in the bathymetry, such as everything above 0. This could be used to represent sand or a topsoil layer, below that could be something like clay, and so forth.

This will make the effects of erosion much more accurate, because the unstable surface layer will change much more than the rocky ocean floor, for example. You can also make some of the surfaces impermeable if you prefer not to simulate them at all and focus on a specific area. This helps to cut down on simulation time as well.

2.4 Vegetation Characteristics

Vegetation works similarly to the two previous types of data. A plain text document is needed for each type of vegetation that you want to use. To mimic organic structures, XBeach divides them into three components: a crown, a trunk, and a root system. Each is comprised of a series of cylinders, and you need to define the size, spacing, and friction coefficients of all of them. Once you have a file for each plant, you need to define where they are.

I use a script to make a vegmap file. It creates a matrix with different values for each type of plant. It has to be the exact size of the simulation grid or XBeach will give you an error. A quick way to create this is to select all values of the grid between the minimum and maximum elevations that the plants can grow and intersect that with a bounding box. This gives you the maximum possible area your plants could spread across and essentially lets you crop the area down to a more suitable fit. It would also be possible to force it to only select cells that are a certain distance away from the water, or have a certain slope, etc.

Once this process is repeated for each plant and each has its own matrix, you can create a new blank one and add the matrices to it one at a time. Note that the plants cannot stack in the simulation. Each grid cell can only contain data for one plant species.

Chapter

THREE

COMBINING THE INFORMATION

3.1 ArcGIS

This step of the process is both the most important and the most time-consuming. It only involves a few commands, but each one takes a while to execute.

You should have already brought your DEM data into ArcGIS Pro by dragging and dropping it in. Do the same thing with the .dxf file containing your model. Many modeling applications such as AutoCAD don’t contain a coordinate system. This means that your imported model won’t appear where you want it to. To find out where it’s located, right click on the layer in the Contents pane and press “Zoom to Layer”.

Next, you’ll need to convert the dxf to a raster. This is necessary so that you can merge the two sets of data into one later. Go to the toolbox, and search for the “Feature to Raster” command. There are a couple of input options you can use. “Polyline” tends to work the best for me, but you can experiment.

Now that you have your intervention properly loaded in, you’ll need to move it to the correct location. Go to “Imagery > Georeference > Add Control Points” to do this. Make sure to save in the “Georeference” tab when you’re done, then click “Close Georeference”. Don’t search for the “Add Control Points” command in the search bar- it won’t work the same way.

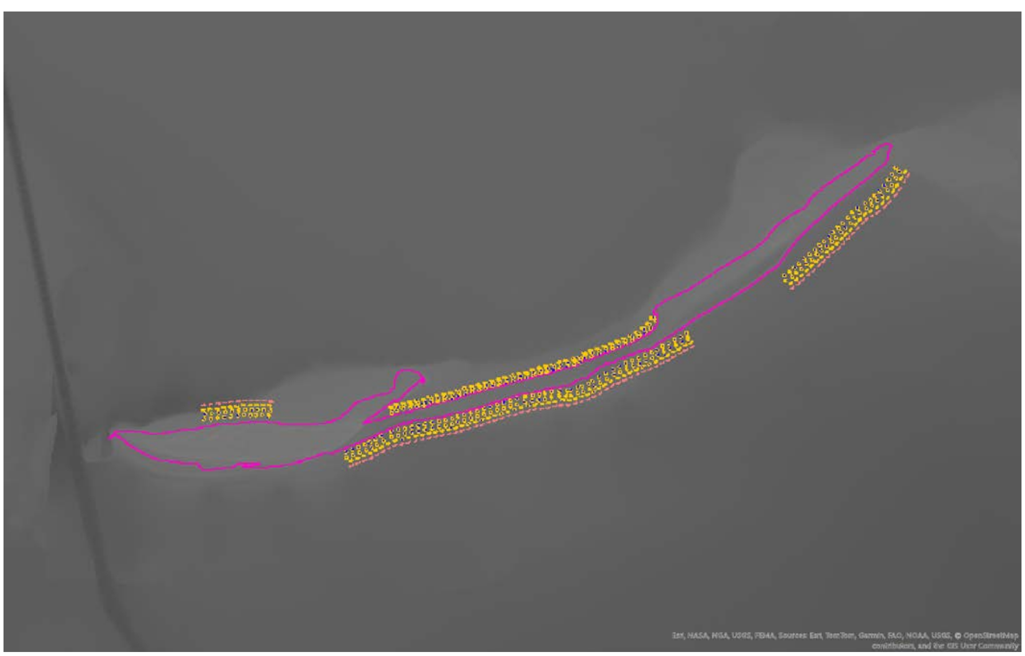

Figure 3.1.1
An example model plan overlaid with bathymetry. I prefer to use bright colors to help with visibility while I work. The colors of these lines are dependent on their type (spline, polyline, etc.), but you can also change it to be based on elevation. It will switch to that automatically in the next step.

You'll need to use the "Mosaic to New Raster" command to combine the two of them. There are a couple of important things to consider:

- The pixel type should either be "16-bit signed" or "32-bit signed". This is because some of your elevation values will be negative, and 8-bit data isn't detailed enough. 16-bit is sufficient if your elevation values are whole numbers, but you can also use 32-bit.
- You only need 1 band unless your data needs to record multiple elevation values per cell. This means that you could technically have things like roofs and pavilions over your elevations and not mess up the data, but I'm not sure how Matlab would handle that in the setup- I haven't tested it.
- Everything else can be left at the default settings. Output location doesn't matter if you can find your file and bring it onto the map.

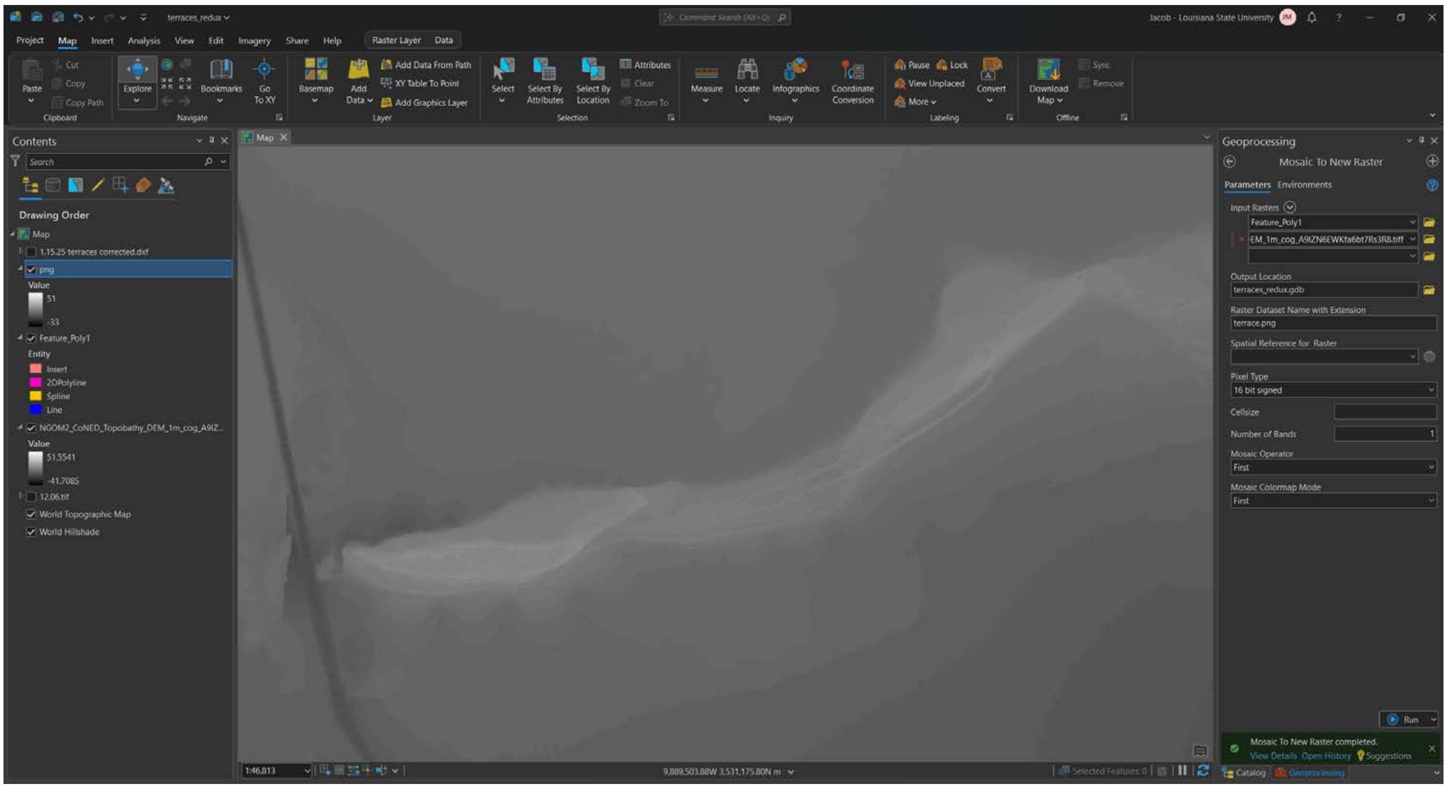

Figure 3.1.2
The combined raster with both the previous bathymetry and the CAD model

After you've merged them, use the Raster to Point command and make sure to save. When using the Raster to Point command, be conscious of the number of points. If you use too many, the file it creates will be so large that Matlab won't be able to process it. I'd recommend not going beyond a 500 by 500 grid if possible.

Right now, the points you created only have elevation values assigned to them, not x- and y-values. We can fix this by running the "Add XY Coordinates" command. Now that our two sets of data are merged and in the proper format, all that's left to do is export it.

Using the Export Table command on the new layer, create a .csv output file. If that isn't an option, you can create a Microsoft Excel file and convert it to a .csv in that application.

3.2 Matlab Import

Now that you have your .csv files, you can use the import_csv.m script and adjust it to work with your intervention. It includes a lot of checks and commands designed to provide the user with feedback on specific parts, but all you really need are a few commands.

First, you need to use the readmatrix command. Right now, the data is separated into one column with elevation values, one column of x values, and one column of y values. Using the readmatrix command, you can target one of those columns at a time and assign it to a variable in Matlab.

After you have the values identified, you'll need to use the linspace command twice to adjust the grid to the proper size. Once this is done, you can create a meshgrid from the x- and the y-values.
The griddata command will allow you to assign the elevation values to the proper grid cells. For any extra smoothing you can use the imgaussfilt command. After that, the only thing left is to use the writematrix command to produce a .txt file and it's ready to use in a simulation.

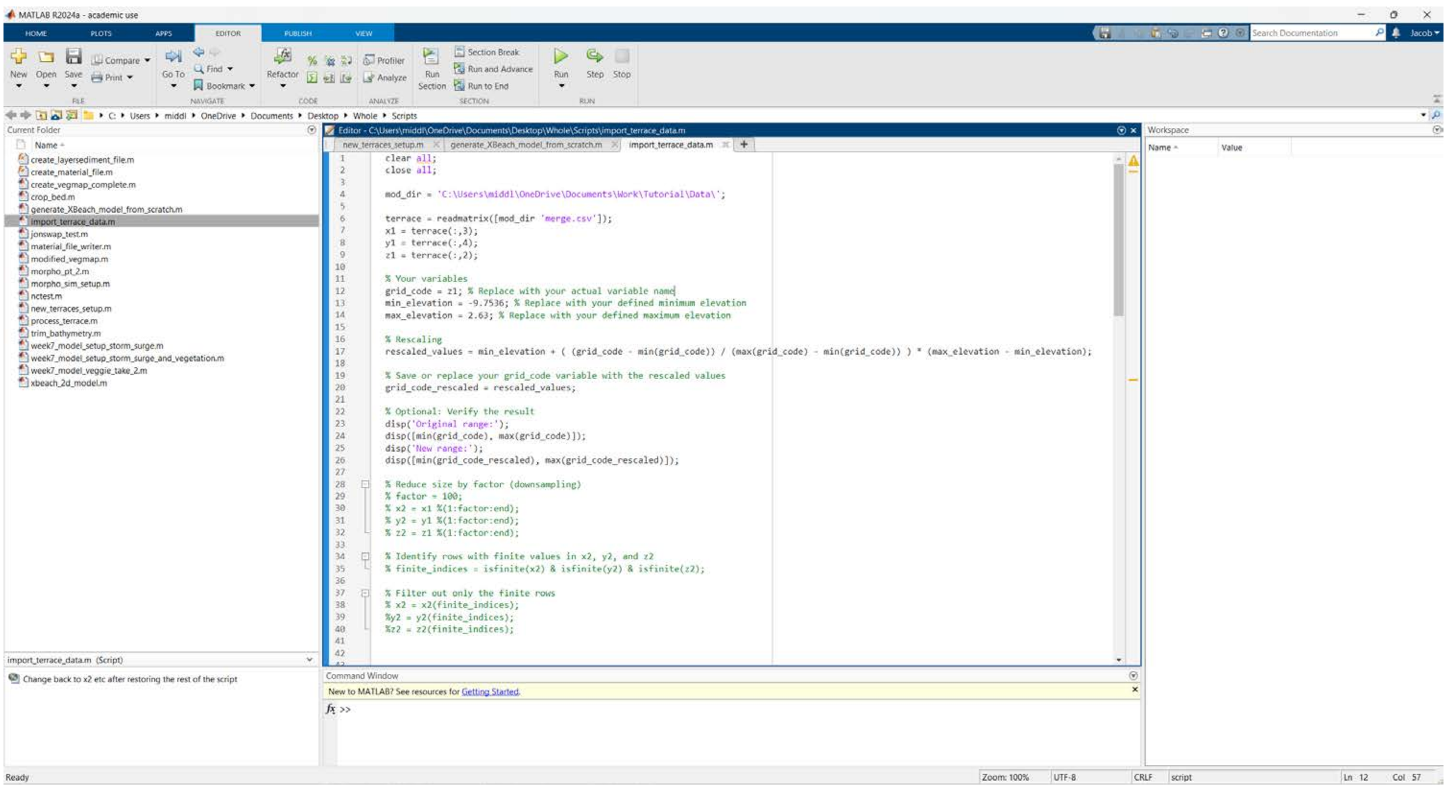

Figure 3.2.1
An example of the import script with the important variables filled in

Chapter

FOUR

RUNNING THE SIMULATION

4.1 The Import Script

In order for the simulation to run properly, the grid needs to be tied to a document with parameters so XBeach knows how to calculate the water's movement. To do this, we use a series of matlab scripts that help with organization and speed up processing.

Since the bathymetry was setup and formatted in ArcGIS, all of the data is organized in a table, with x, y, and elevation values all being in separate columns. The basic premise of the import script involves loading in the table and assigning each column to a variable with the proper name. Then each column can be used to create vectors and a grid, which Matlab has an easier time understanding. After this is done, the script will write the bathymetric grid to a new text file with the proper formatting.

This is a good point to include a lot of optional checks to ensure that your data doesn't have problems before you try to run a simulation with it. Checking for NaN and undefined values is a good start. The import script is also a good place to downsample if your grid is too large. It's possible that the table that came from ArcGIS can be loaded into Matlab and then crash when you try to process it. This is because text files are smaller than the matrices we use for model setup. By selecting every 10th or 100th value in the grid, it's easy to create a much smaller file to simulate with.

4.2 The Setup Script

The next script is the one that does the actual writing of the parameters file. It also resizes the bathymetric grid and alters its resolution in different areas, allowing for more detailed results without comprimising on time. This script requires the use of the Open Earth Toolkit, which can be obtained through an SVN checkout from Deltares.