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Incorporating new locations into a hydrodynamic model using ArcGIS Pro

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I. ABSTRACT

ALGE3D is a 3-D hydrodynamic model developed at the Savannah River National Laboratory to predict pollutant dispersion. The model has several predefined locations incorporated, however adding new locations into ALGE3D is manually intensive and time-consuming. In the event of an emergency, ALGE3D can only be used if an event occurs at one of the predefined locations incorporated into the GUI. This project focuses on streamlining the integration of new locations into ALGE3D by utilizing tools in ArcGIS Pro. The Stream Order tool was used to delineate streams and assign them an order, using the Strahler method, versus manually defining these streams in Microsoft Excel. This work advances development to turn ALGE3D into a product for emergency response use by allowing the user to incorporate a new location into ALGE3D quickly, should an event occur at a location that is not already predefined.

II. INTRODUCTION AND BACKGROUND

A. Introduction

ALGE3D is a three-dimensional, finite-differenced aqueous transport model developed at the Savannah River National Laboratory in the 1990s[1]. The model was originally created to look at thermal cooling for lakes at the Savannah River Site and was further developed to examine fate and transport of pollutants[1]. ALGE3D solves the conservation equations for mass, momentum, and energy, and considers tidally driven flow, water depth, radioactive decay, and salinity for dissolved, particulate, and sediment tracers[1-3]. The model is currently comprised of a GUI, an executable, and post processer. The GUI allows the user to define the location of interest and has a series of predefined locations across the continental United States. The executable for ALGE3D computes the transport equations and the post processor is responsible for plotting the results. If a new location should be added to the model, A user guide is followed to incorporate that location using existing National Oceanic and Atmospheric Administration (NOAA) bathymetry data.

Although ALGE3D can compute the transport equations for numerous locations that are already predefined, the process to add new locations is complex and time consuming. One process that consumes the most time is distinguishing river inflow for a body of water, which is then defined as a secondary mass source to compute the transport equations in ALGE3D. Establishing the network of streams has previously been accomplished using Microsoft Excel by manually labelling each point in a dataset. Each location has a large dataset with high-resolution, with some file sizes reaching over thirty gigabytes. This increases the chances for human error because it is manually intensive.

To streamline the process of incorporating new locations into ALGE3D, we proposed a method to reduce the manually intensiveness of inputting inflow points by utilizing the Hydrology toolset. This toolset contains a Stream Order tool that assigns each tributary and stream with an order which are defined by a number that identifies which of the streams receives the most input from other smaller streams. This tool also labels the streams with the most input from other streams with the highest order. The highest order streams can be used to estimate the mass source river inflow in the ALGE3D code. Work completed for this project contributes to the goal of making ALGE3D a product that can be used for emergency response at the national level.

B. Background

The previous procedure established for adding new locations required the user to convert and merge between 1 and over 100 one-ninth arc/s (~3-meter resolution) DEM tiles from NOAA Bathymetric Data Viewer (FIG. 1.), and process bathymetry data using a series of codes (written in csh & python). After these codes are computed, an output of elevation (idenInit) and bathymetric data (bathInit) files are created and added to the ALGE3D GUI. These files were also manually edited in Microsoft Excel to set river inflow, mass outflow, and tidal boundary locations. This method of setting inflow, outflow, and boundary points would take an extended period of time for one location. Since this method is so manually intensive there is an increased risk of human error, which in turn could lead to inaccurate results of pollutant fate and transport produced by ALGE3D.

Geographic Information Systems (GIS), or ArcGIS Pro, has a range of uses from creating maps, to analyzing, managing, and sharing data[4]. For this project, data can easily be spatially analyzed through a series of tools instead of manually editing the data. This is a better option for working with ALGE3D because it is more compatible with bathymetry data and reduces the number of codes required to add a new location. With ArcGIS Pro, the files needed for ALGE3D can be exported in the format we need, instead of having to convert them from a code. We propose that using ArcGIS Pro will reduce the manual labor needed and risk of human error while adding new locations into ALGE3D.

Other research has also implemented the Stream Order tool into their work. One example of how stream order is being used, is in studying how floodplains are affected by artificial levees[5]. The stream order tool was used to determine if the artificial levees were more likely to enhance inundation or disconnect a floodplain[5]. Another way that stream order has been implemented is through studying watersheds and flood-prone areas.[6] Stream order was used as a variable to test the effectiveness of the Geographically Weighted Regression method [6].

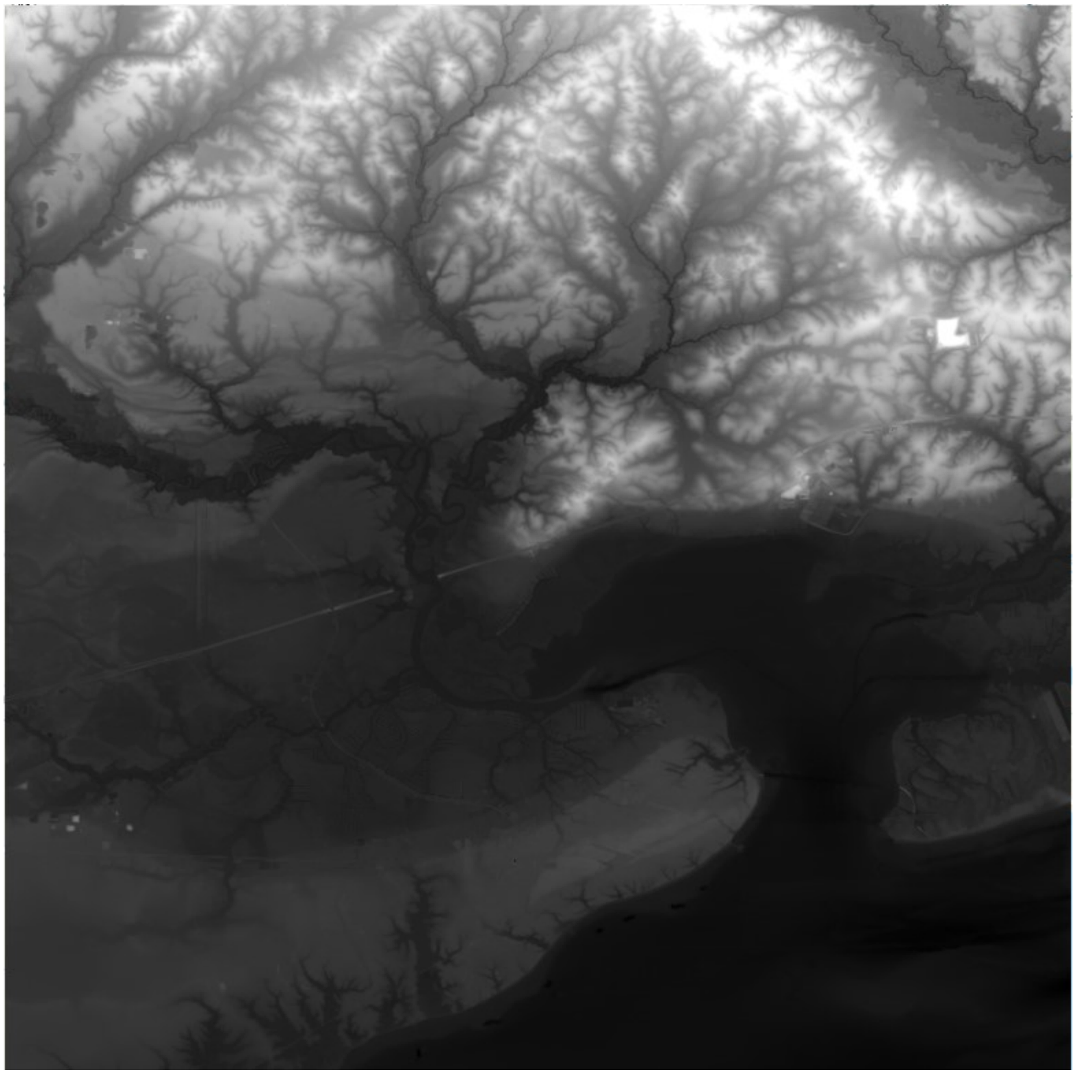

FIG. 1. Example of a singular 1/9 arc/s (~3m) resolution DEM tile extracted from NOAA Bathymetric Data Viewer[7] from Mississippi coastline.

III. METHODS

Similar to the original guide of adding a new location into ALGE3D, NCEI DEM bathymetry files were downloaded from NOAA Bathymetric Viewer[7]. For this project, we examined a single DEM tile from the Mississippi coastline. Once the location files were downloaded, the files are then uploaded into ArcGIS Pro as a new project file. Each of the individual DEM tiles (FIG.1), were combined into one raster dataset using the “Mosaic to New

Raster" tool. From this step, a series of tools within the Hydrology and Map Algebra toolbox were utilized to spatially analyze the bathymetry files:

- Fill
- Flow Direction
- Flow Accumulation
- Feature Class
- Snap Pour Points
- Watershed
- Raster Calculator
- Stream Order

The Fill tool is used to fill in small imperfections within the surface DEM. Flow Direction is used to create a raster of cells flowing in the direction of the downslope in elevation. After this, Flow Accumulation creates a raster based on Flow Direction and the accumulation that flows into each cell. The Feature Class tool is used to create outflow points and the Snap Pour Points tool ensures the outflow point feature is on the cell of the highest flow near the outflow point. After this, the Watershed tool is used to identify the watersheds based on the outflow points. To create a stream network, the Raster Calculator tool is used to write a conditional statement to identify what is a stream. The flow accumulation is considered to determine how many pixels are needed to define what is a stream and what is not. Lastly, the Stream Order tool uses the stream network to order each of the streams.

One of the most notable tools used is the Stream Order tool[8], which was used to characterize and assign each stream an order. Ordering the streams simply assigns different tributaries with a number based on the input they receive from other streams. The stream order can be defined in two separate ways, one is the Strahler method[9, 10] and the other is the Shreve method[8]. Strahler's method was proposed in 1952 in an article where he investigated percentage hypsometric curve and how it relates to the cross-sectional area of a drainage basin[9]. The work done in 1952 led to his work completed in 1957 that produced the Strahler stream ordering method[10]. Strahler's method increases the order when streams of the same order intersect, where the Shreve method accounts for all links in a network and increases when a link of a higher order meets another stream (FIG. 2.). To put it simply, Strahler's method is less complex, but is dependent on adding or removing links, where Shreve method is more detailed and is not as effective in achieving the goals needed in the case of this project. The Strahler method determines which rivers receive the most input through the increasing orders. As shown in FIG.2. the 3rd order stream receives input from each of the tributaries preceding it. Using the Strahler method to define and order the streams in a new location, each stream is assigned a number that can then be implemented into the code for ALGE3D. Once the stream order files were completed, the DEM and the stream order files were written into the python code for the GUI. The GUI resulting ASCII files were then added into the executable that runs ALGE3D. After running the executable for ALGE3D, the results can be written into a post-processor that plots the results.

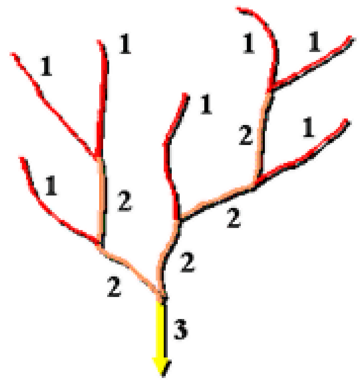

FIG. 2. Strahler stream ordering method.

I. RESULTS

The Stream Order tool is effective with assigning inflow points of rivers by delineating an order to each stream to determine which receives the most inflow. Flow direction, flow accumulation and the network of streams are considered when calculating stream order. The outputs for stream order yield a series of numbers ordered in increasing order. Number, or order 1 represents 1000 pixels joining based on the elevation, which creates the smallest tributary. As the numbers increase, the streams of the same order meet and then increase by one order (FIG. 2.). Therefore, the stream with the highest number is determined to receive the most inflow as seen in FIG. 3. These highest order streams receive the most inflow from lower order streams because they tend to have a lower elevation. Stream ordering always begins with a number 1, or 1st order, but the number of orders is location dependent. The 8th order streams in red (FIG. 3) represent the largest inflow and are usually the largest rivers in the respective area. In the instance of a radioactive, chemical, or hazardous spill, the highest order streams will be moving the most water. This is important to consider when using ALGE3D as an emergency response tool, because anything from lower order streams is washed into the highest order streams. When the largest inflow points are defined, this can better equip the parties responsible for the clean up to respond accordingly since the source can be traced.

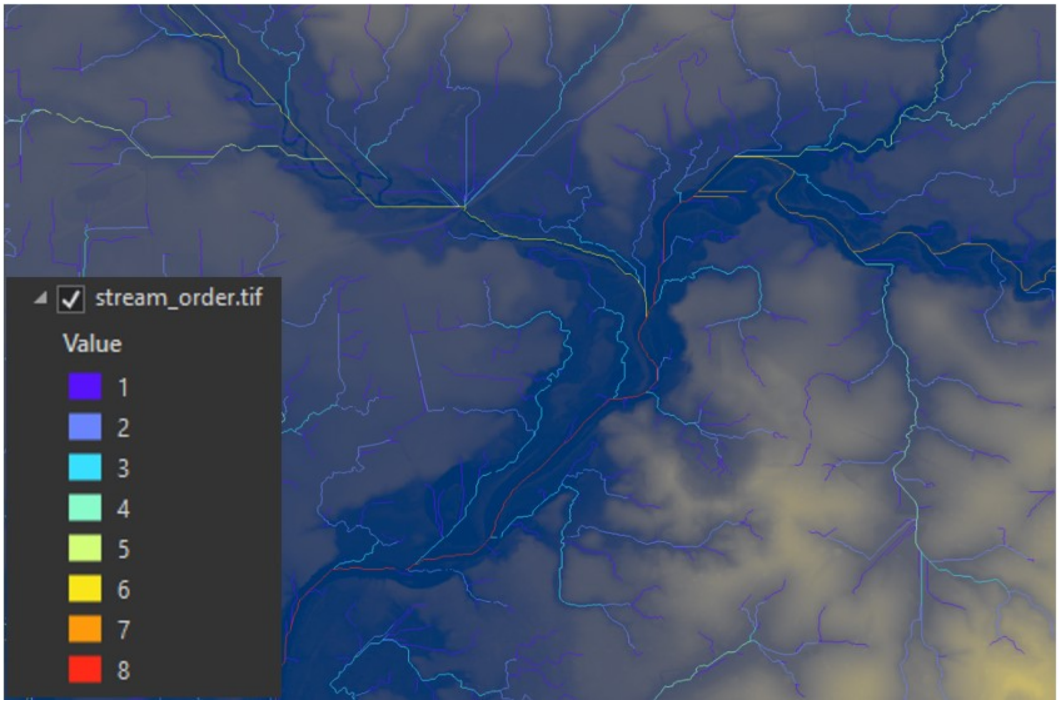

FIG. 3. Stream Order tool in ArcGIS Pro (Strahler Method) example from Mississippi coastline. In the legend titled "stream_order.tif," the Value is set equal to the stream order assigned using the stream order tool. The values are arranged in increasing order with the darker indigo representing 1st order streams, and the red representing 8th order streams.

After the stream ordering is complete, the file can then be exported and added into the ALGE3D GUI. Exporting the file from ArcGIS Pro is completed by transferring the stream order file as a TIFF file. This TIFF file is then converted into a NetCDF file which can be incorporated into the GUI. The NetCDF can successfully be implemented into the model as a new location. This GUI then creates ASCII files (FIG. 4) that are used to compute the transport equations in ALGE3D. The results from the stream order tool output the same quality of results as the previous method (FIG. 5).

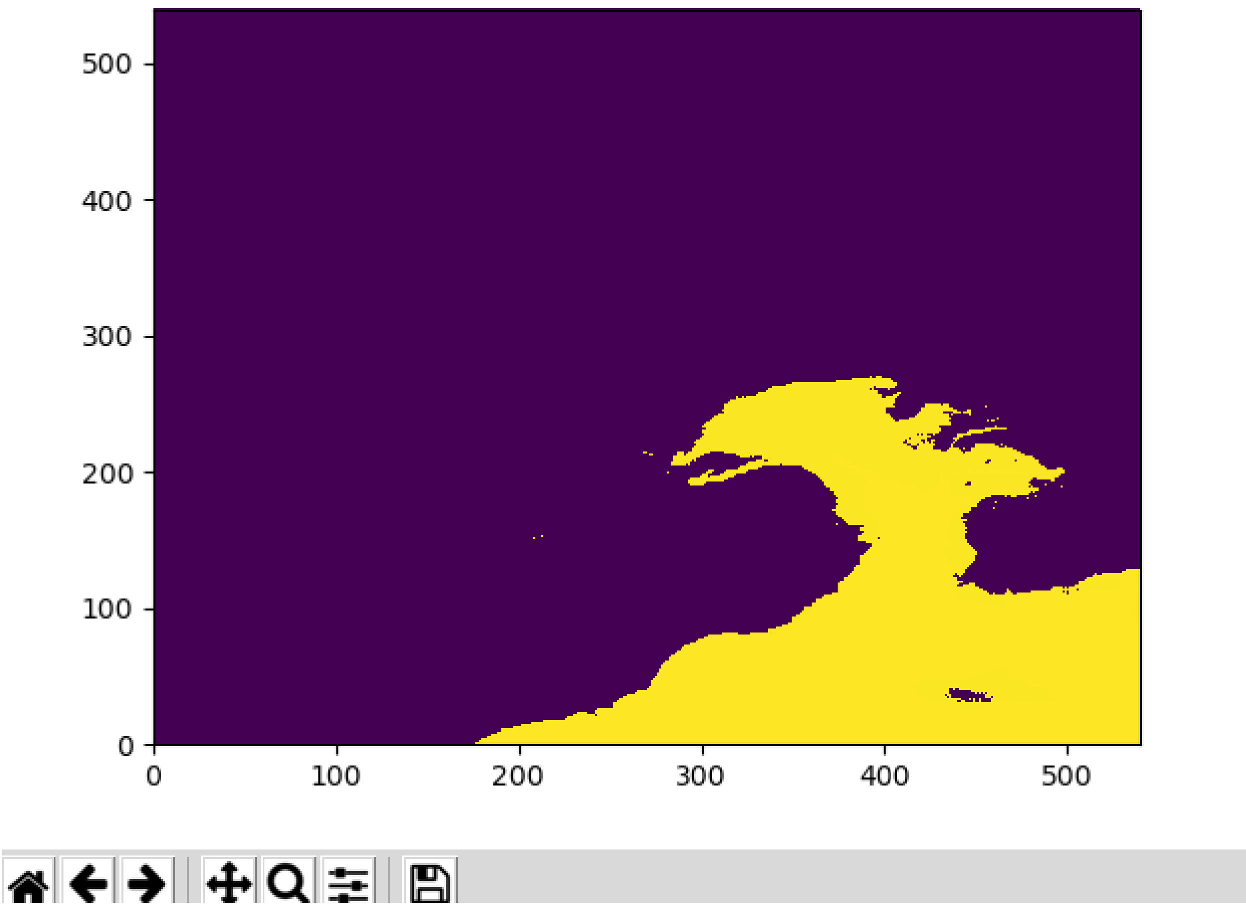

FIG. 4. Resulting DEM and stream order implemented into the GUI, plotted on a 540 x 540 grid.

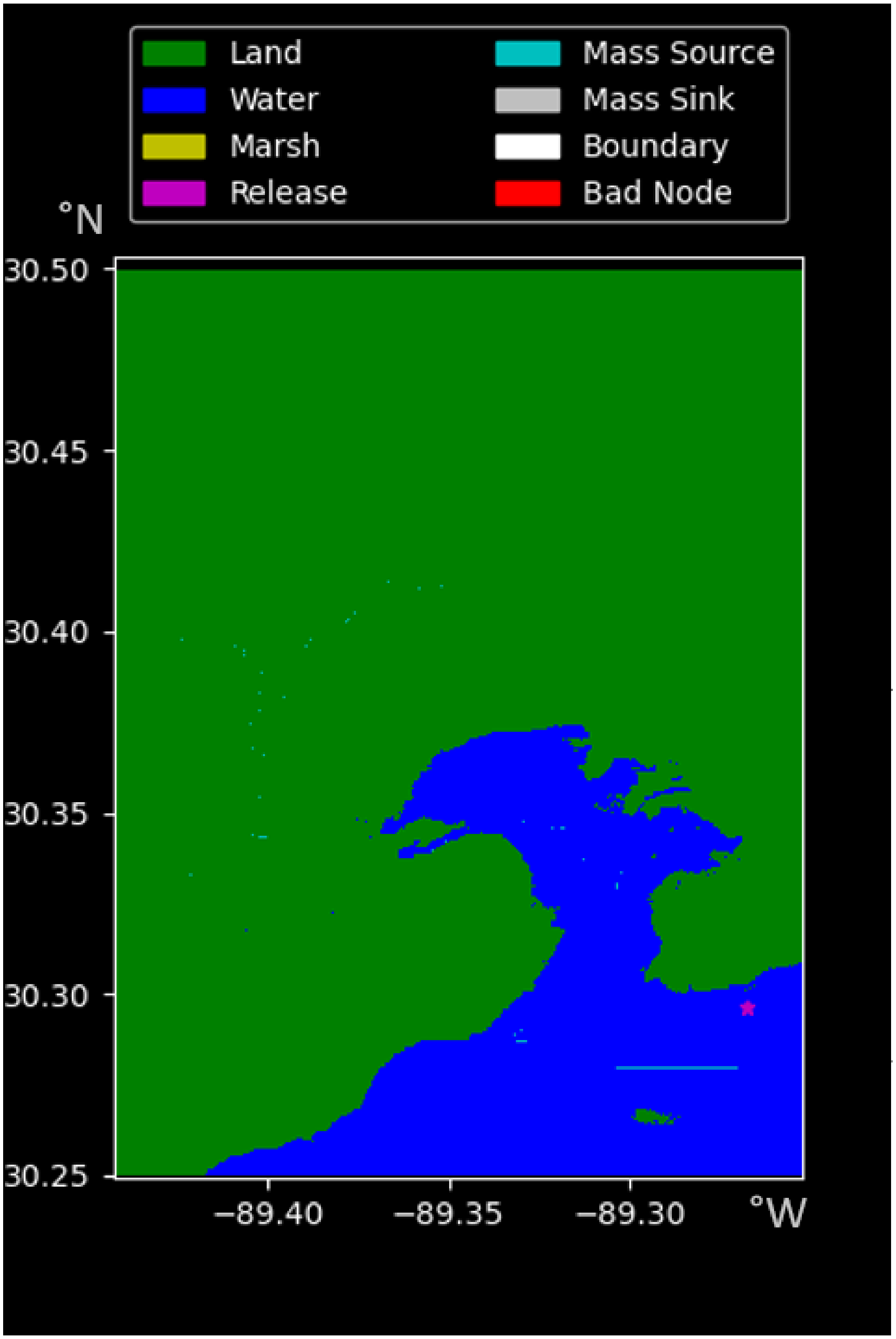

FIG. 5. Resulting ASCII file from ALGE3D GUI after incorporation of stream order. Stream Order is represented as a "Mass Source" and is plotted in its respective lat/lon axis.

II. APPLICATIONS AND FUTURE WORK

With newly incorporated methods, ALGE3D can continue to be further developed and eventually become an emergency response product for national use. By monitoring spills more accurately and modeling it, the public and environment can be better protected. Although this new method has many benefits, there are also some limitations to be considered. For larger areas, with larger datasets, runtime for ArcGIS Pro analysis is largely dependent on the speed of the computer. The runtime for some tools can last over twenty-four hours. In addition to adding the river inflow information into ALGE3D, identifying outflow points and tidal boundaries also need to be defined in a more efficient way. In the future, projects could focus on finding a method to successfully add outflow points and ArcGIS Pro-compatible tidal data into ALGE3D.

Future funding through NA-22 is supporting the development of ALGE3D. Some of these developments include backtracking an unknown source location, adding the sediment breakup and flocculation processes, and creating shorter user inputs into the GUI. As ALGE3D is continually advanced, the model will increase in accuracy. New parameters within ALGE3D can be added to create a marketable and useful product for a rapid response to a spill and its magnitude.

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