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Watershed and Catchment Meshing Python Tool Utilizing the XmsMesh Meshing Software

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PURPOSE: This Coastal and Hydraulics Engineering Technical Note describes the approach, methodology, and utilities of a Python code to flexibly create finite element meshes for a single catchment, multiple catchments, or an entire watershed. This tool was developed with the intent of model development for rapid responses with an emphasis on Adaptive Hydraulics 5.0 Diffusive Wave (AdH-DW) applications, though any numerical code that uses an unstructured mesh could be applied.

This meshing tool, implemented in Python, filters watershed and catchment shapefiles into unique line segments. The code then utilizes the Engineered Resilient Systems (ERS) XmsMesh meshing software, written by Aquaveo, to create a watershed mesh that adheres to the spacing and geometry for each catchment within a watershed shapefile (Aquaveo 2019). The code provides this functionality as well as the flexibility within the model domain to vary the extent of the area meshed by allowing for the meshing of individual or multiple catchments within the watershed. Based on the nodal spacing along the catchment boundaries, which can be adjusted, the mesh geometry and spacing will be appropriate on the catchment or watershed scale.

MOTIVATION AND BACKGROUND: There are two major needs that facilitated the development of this tool. With the development the AdH-DW, which has been tested and shown to be accurate for flooding and multiple dam break scenarios (Savant et al. 2018), a need was identified for the capability to rapidly generate AdH meshes for overland flow modeling. In these domains, catchment shapefiles are readily available and are natural boundaries for AdH-DW models.

ERS funded Aquaveo to release its meshing software as open-source C++ libraries with Python Application Programming Interfaces to allow customized use of its XMS software capabilities. This software creates an unstructured, triangular finite-element grid. With the demand for more rapid response capability with the models used within the U.S. Army Corps of Engineers (USACE), the Army, and the Department of Defense, a code capable of leveraging the available capability to generate AdH-DW model meshes using catchment shapefiles and stream shapefiles of varying sizes and resolutions was deemed another important need.

METHODOLOGY: This tool produces a finite element mesh using a catchment shapefile and stream network shapefile. The major steps are the following:

1. **Catchment and stream network shapefiles (ESRI 1998) are read using utilities from the stream alignment tool (Stream Alignment 2019).**
2. **The polygons are arranged based on the corresponding stream Hydro identifications (ID).** This is done to maintain consistent numbering between the watersheds and streams, which will allow for easier calculations and remove the need to reorder the catchments for later operations. The Hydro ID numbering is imported from the stream network shapefile,

which also includes the connectivity. Figure 1 shows an example of numbered polygons from Hydro IDs.

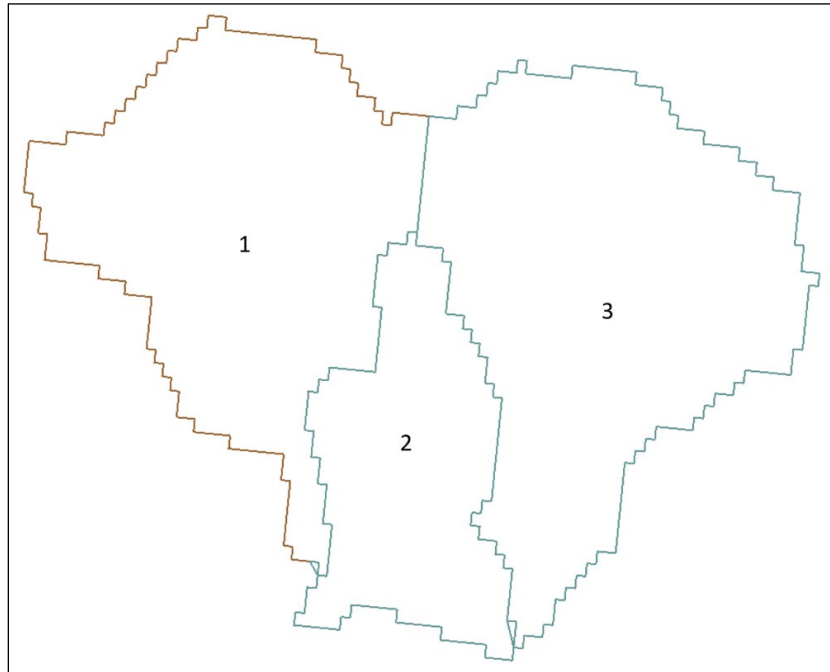


Figure 1. Catchments arranged by Hydro ID.

- 3. Identify unique and shared segments and relate these to the corresponding catchment polygons.** Segments are flagged as either unique, which would be a boundary, or shared between two polygons. Figure 2 identifies how the segments are categorized using Polygon 1 as an example.

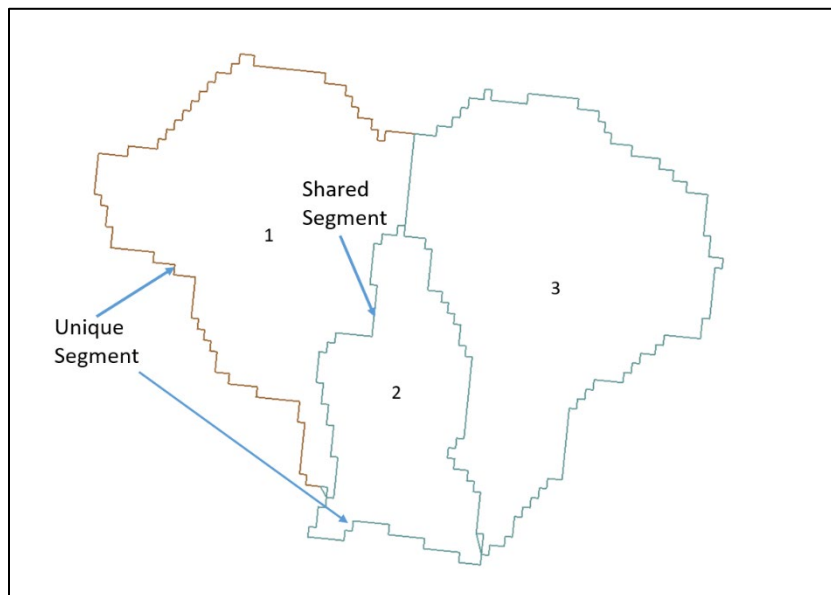


Figure 2. Unique and shared segments.

Recombine catchment polygons using the sorted segments. Polygons are then arranged in order from the sorted segments with the nodal point arrays arranged in clockwise order. At this point, the node spacing along the polygons could be resampled to add or remove resolution when the mesh is generated. This would remove erroneous elements from along the boundaries and smooth out the boundary segments. Figures 3 and 4 illustrate the arrangement of the nodes along the boundary for Polygon 1 and show a unique and a shared segment.

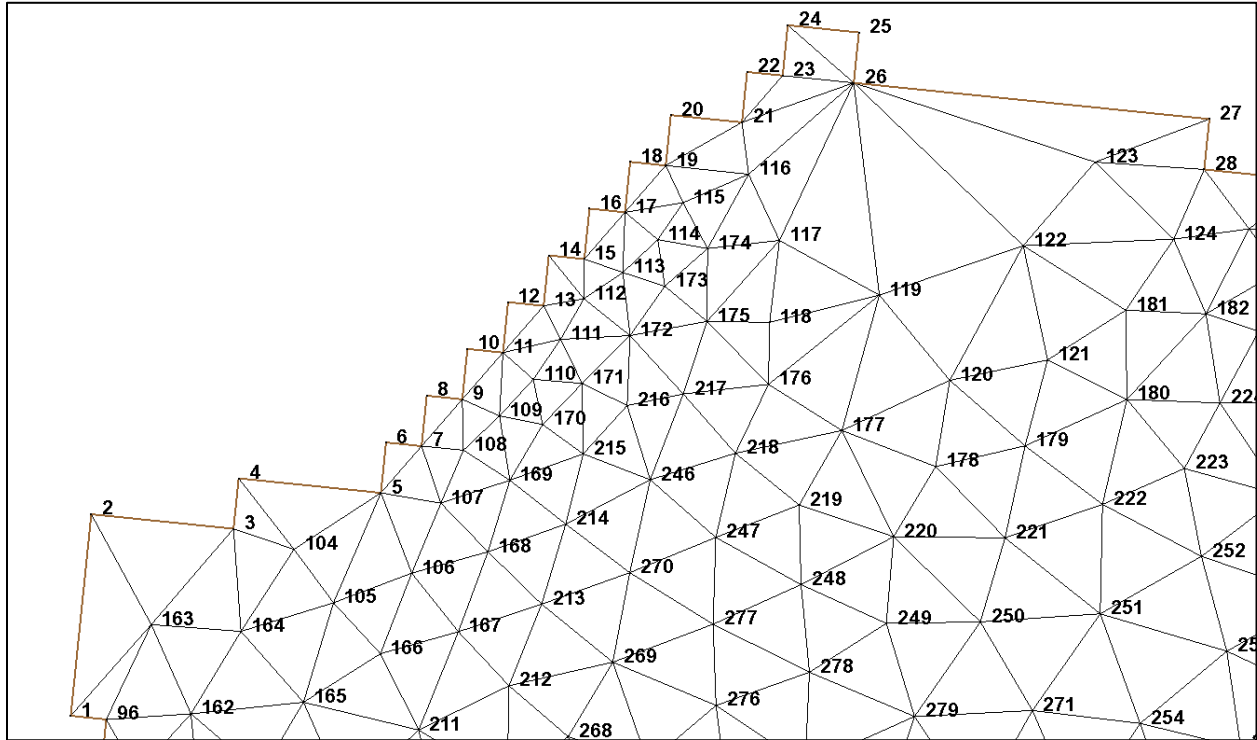


Figure 3. Ordered nodal points for Polygon 1 along the top of the unique segment.

Pass the recombined catchment polygons to the XmsMesh meshing software, generating a mesh for each selected catchment, group of catchments, or the watershed as a whole. The sorted and organized polygons are then passed to XmsMesh to create a model mesh. A single polygon can be meshed, or a group of polygons can be meshed together. Figure 5 displays an example mesh using the three polygons shown previously.

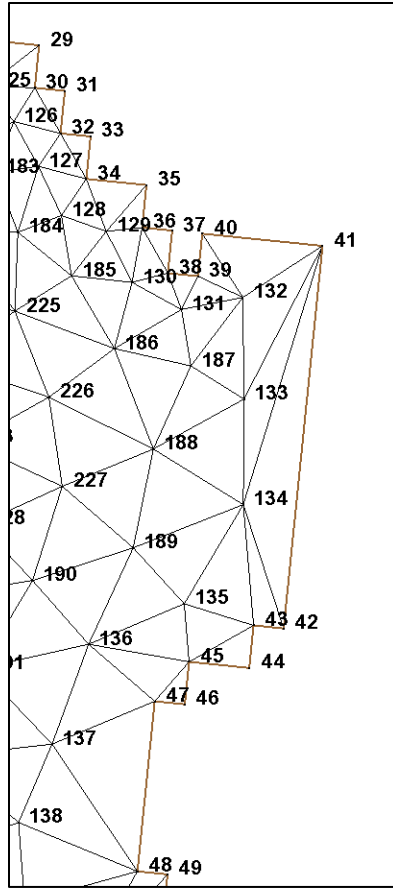


Figure 4. Ordered nodal points for Polygon 1 including the side of the shared segment.

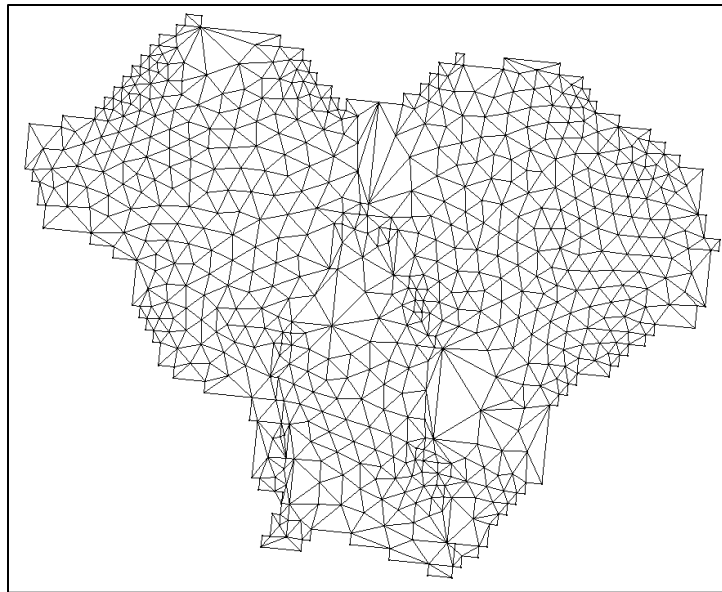


Figure 5. Example mesh for group of three polygons shown above.

4. **Write the mesh to a formatted AdH input file using the utilities provided from the ROAMS (Rapid Operational Access and Maneuver Support) UTIL package.** The ROAMS UTIL package is then used to generate an AdH model object. This package is used to write the formatted AdH mesh file that can be viewed and edited using the Aquaveo hydrodynamic modeling software, SMS, and is also ready to be used for AdH simulations (ROAMSUTIL 2019).

EXAMPLE RESULTS: A larger set of polygons, from the shapefiles used as the test case for this tech note, were selected to show how the mesher would operate with a larger number of input watersheds. These shapefiles were downloaded from HydroSHEDS¹ (Lehner 2008). The first eight watershed polygons were chosen to mesh and are shown in the figures below. These polygons are not all connected, illustrating how the software can mesh an example with discontinuities between the polygons. Figure 6 shows the boundaries for these eight polygons. Polygons 7 and 8 are not connected to the previous 6. Figure 7 displays the same polygons after being meshed. The mesh spacing and element areas are controlled by the resolution of the shapefiles used to generate the meshes.

The mesh shown in Figure 7 contains 7660 elements and 4142 nodes. The nodal spacing is dictated by the original shapefile and varies from approximately 200 meters to 1000 meters for this example.

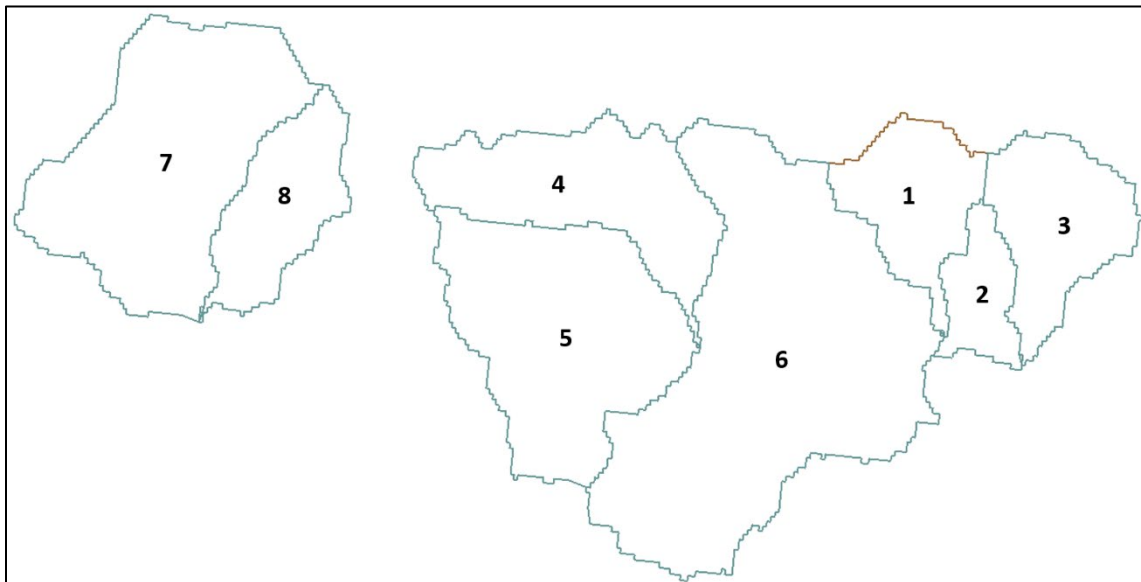


Figure 6. The first eight polygons from the shapefile.

¹ **H**ydrological data and maps based on **S**huttle **E**levation **D**erivatives at multiple **S**cales

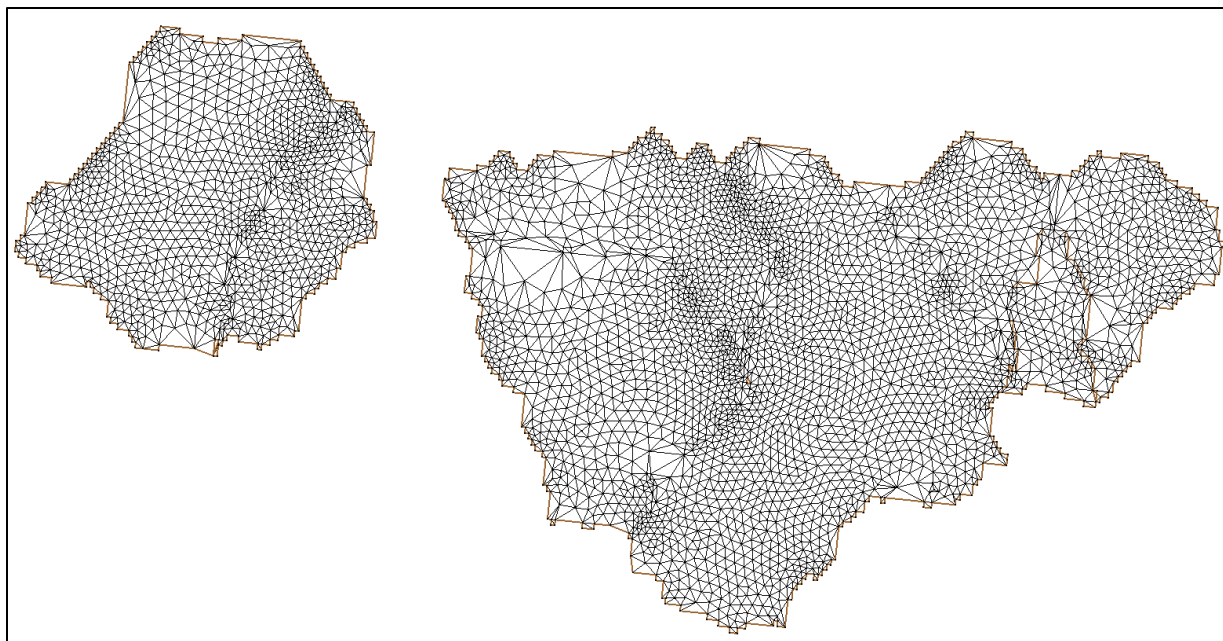


Figure 7. The first eight polygons from the shapefile meshed.

SUMMARY OF FINDINGS: This python tool will create AdH model meshes starting only with catchment and stream shapefiles. These file types are accessible and widely circulated for regions throughout the globe. The code has been tested with many variable polygon arrangements and performs well under all scenarios. This tool adds important capabilities to the existing suite of codes and provides the ability to rapidly generate AdH model meshes from readily available file types. This utility will add the important capability of rapidly creating AdH-DW model meshes for overland flow applications.

FUTURE APPLICATIONS: This tool provides the capability to use catchment shapefiles as an input for a model mesh and to have the ability to only mesh chosen catchments for rapid response overland flow modeling. It will complement many existing projects or models. It will add another capability to the tools already available within the ROAMS platform and the ERS program's Environmental Simulation. ROAMS is a software suite of analysis, automation, and visualization tools designed to support and enhance existing USACE models (Loney et al. 2017). Environmental Simulation advocates a Python-based flexible, modular approach to automating workflows with web-based visualization and dashboards.

This tool will also leverage the Stream Alignment Tool, which produces corrected stream and catchment shapefiles (Stream Alignment 2019). It will be able to use the corrected catchment shapefiles as inputs and to create model meshes for these domains that will now have more accurate stream and catchment shapefiles.

Mesh refinement and improvement options will also be added in the future. The option to guide the ERS XmsMesh mesher along the streamline will be incorporated in order for the mesh geometry to better resolve and follow the bathymetry of the streams. ROAMS includes utilities that can add resolution and clean meshes using edge flips and by imposing gradients. These utilities will be employed to improve the meshes. Another option would be to utilize AutoMesh, which is another

existing USACE utility capable of carrying out mesh creation and refinement, to add resolution and improve the mesh generated with this tool (Loney et al. 2018). Internal routines to smooth boundaries and remove erroneous elements along the boundaries will also be incorporated into the tool.

This tool will provide flexibility for creating rapid response AdH-DW model meshes generated from the watershed shapefiles that are readily available for many areas throughout the world, especially areas where rapid response modeling efforts could be required.

ADDITIONAL INFORMATION: For additional information, contact Jared McKnight, Research General Engineer, Coastal and Hydraulics Laboratory, U.S. Army Engineer Research and Development Center, 3909 Halls Ferry Road, Vicksburg, MS 39180 at 601-634-2844; email: Charles.J.McKnight@erdc.dren.mil. This effort was funded through the ERS program's Environmental Simulation work package through the Information Technology Laboratory.

McKnight, C. J., D. Loney, and K. Winters. 2019. *Watershed and Catchment Meshing Python Tool Utilizing the XMS Meshing Software*. ERDC/CHL CHETN-VIII-13. Vicksburg, MS: U.S. Army Research and Development Center. <http://dx.doi.org/10.21079/11681/34323>

REFERENCES

Aquaveo GitHub Repository. 2019. <https://github.com/Aquaveo>

Environmental Systems Research Institute, Inc. (ESRI). 1998. *ESRI Shapefile Technical Description*. <https://www.esri.com/library/whitepapers/pdfs/shapefile.pdf>

Lehner, B., K. Verdin, and A. Jarvis. 2008. "New Global Hydrography Derived from Spaceborne Elevation Data." *Eos, Transactions, AGU* 89(10): 93-94.

Loney, D., K. Pevey, J. McAlpin, B. Nelsen, and B. Hargis. 2017. *Rapid Operational Access and Maneuver Support (ROAMS) Platform for Improved Military Logistics Lines of Communication and Operational Vessel Routing*. ERDC/CHL CHETN-IX-45. Vicksburg, MS: U.S. Army Engineer Research and Development Center. <http://dx.doi.org/10.21079/11681/22642>

Loney, D. A., E. M. Yeates, and B. H. Hargis. 2018. *Automatic Mesh Generation and Filtering: The AutoMesh Tool*. ERDC/CHL CHETN-VI-47. Vicksburg, MS: U.S. Army Engineer Research and Development Center. <http://dx.doi.org/10.21079/11681/26530>

ROAMSUTIL GitHub Repository. 2019. <https://github.com/erdc/roamsUTIL>

Savant, G., C. J. Trahan, and T. O. McAlpin. 2018. *Formulation, Implementation and Testing of the Diffusive Wave (DW) Module of Adaptive Hydraulics (AdH)*. ERDC/CHL CHETN-IV-112. Vicksburg, MS: U.S. Army Engineer Research and Development Center. <http://dx.doi.org/10.21079/11681/29351>

Stream Alignment GitHub Repository. 2019. https://github.com/erdc/stream_alignment

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