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HEC-GeoEFM

A Spatial Accessory for HEC-EFM (Ecosystem Functions Model)

User's Manual

Version 3.0
March 2025

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14. ABSTRACT

The Ecosystem Functions Model (HEC-EFM) is a planning tool that aids in analyzing ecosystem response to changes in flow regime. EFM analyses involve: 1) statistical analyses of relationships between hydrology and ecology, 2) hydraulic modeling, and 3) use of Geographic Information Systems (GIS) to display results and other relevant spatial data. Through this process, study teams visualize and define existing ecologic conditions, highlight promising restoration sites, and assess and rank water management alternatives according to predicted changes in different aspects of the ecosystem.

HEC-GeoEFM is a software tool developed to support spatial analyses commonly used during applications of the EFM. GeoEFM is programmed as toolbox for ArcGIS Pro and offers the following capabilities for users planning ecosystem restoration or water management scenarios: 1) management of spatial data sets, 2) computation and comparisons of habitat areas, and 3) assessment of the habitat functionality.

15. SUBJECT TERMS
HEC-GeoEFM, HEC-EFM, Ecosystem Functions Model, ecosystem modeling, ecosystem restoration, time series analysis, hydraulic modeling, Geographic Information Systems, river and wetland flow regimes, ecological relationships

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HEC-GeoEFM, User's Manual

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Foreword

HEC-GeoEFM works with HEC-EFM and HEC-EFM Plotter to help users assess the ecological implications of water resource decisions. GeoEFM focuses on spatial questions such as: How much habitat is generated by a particular water management strategy or configuration of river channels and wetlands? Which species would be helped or hurt by implementation of new management practices? Where is the habitat? Are different habitat areas connected? Where does it make sense to protect or restore habitat?

GeoEFM was developed by the Hydrologic Engineering Center (HEC) of the U.S. Army Corps of Engineers (USACE) and the Environmental Systems Research Institute, Inc. (ESRI) in recognition of both the power of GIS and the importance of ecological considerations in water systems.

Dr. John Hickey, HEC, Water Resource Systems Division, designed the software and managed its development. Drs. Zichuan Ye and Dean Djokic, Ms. Christine Dartiguenave, and Mr. Ezra Bosworth-Ahmet, ESRI, contributed to design and performed the programming. Christine and Dean also helped manage the project and led ESRI participation. Ezra also assisted with software review and testing. Mr. Josh Willis was Chief of the Water Resource Systems Division and Ms. Lea Adams was Director of HEC at the time of completion and public release of GeoEFM 3.0.

HEC is a division of the Institute for Water Resources, U.S. Army Corps of Engineers.

CHAPTER 1

Introduction

GeoEFM is a software tool developed to support spatial analyses commonly used during applications of the Ecosystem Functions Model (HEC-EFM). GeoEFM is programmed as a toolbox for ArcGIS Pro 3.0, 3.1, 3.2, and 3.3. Previous versions of GeoEFM are programmed as extensions for ArcMap. Use of GeoEFM 1.0 requires a user license for ArcMap 9.3, 9.3.1, 10.0 or 10.1 (ArcView level license). Use of GeoEFM 2.0 requires a user license for ArcMap 10.1, 10.8.1, or 10.8.2 (advanced level license). Spatial Analyst and 3D Analyst extensions for ArcMap must also be installed and activated for any combination of GeoEFM and ArcMap. Use of GeoEFM 3.0 requires an advanced level license for ArcGIS Pro (Pro).

GeoEFM provides three primary capabilities for users planning ecosystem restoration or water management scenarios: 1) management of spatial data sets, 2) computation and comparisons of habitat areas, and 3) assessment of the habitat functionality via a selection of routines that consider habitat area, connectivity, and distribution.

Additionally, GeoEFM packages spatial functions that are commonly used in EFM applications:

- Entry, import, archival, editing, and viewing of habitat suitability indices
- Application of habitat suitability indices
- Splicing of habitat maps for systems of wetlands, streams, and rivers

This user's manual provides an overview of GeoEFM and illustrates how the software is applied. Many figures in this document show a GeoEFM project being built and used to assess ecosystem conditions for the Rolling River, which is the fictional river also used in the demonstration project and user guidance for EFM.

Use of GeoEFM follows use of EFM. Therefore, it is important for GeoEFM users to understand EFM and the process that software supports to analyze water and environmental resources. This is true whether GeoEFM is being used to compute habitat areas, assess habitat suitability, splice maps to make habitat mosaics, or investigate the spatial distribution and functionality of habitat in long reaches of river or wetland areas.

A brief description of EFM is provided in Chapter 2 of this manual. Please refer to the EFM Quick Start Guide (USACE 2024) and other user guidance for more background about EFM (https://www.hec.usace.army.mil/software/hec-efm/documentation.aspx). The hydrologic and ecologic scenarios described herein are detailed in the Quick Start Guide. The reference for the Quick Start Guide follows:

U.S. Army Corps of Engineers (USACE). 2024. HEC-EFM: Ecosystem Functions Model - Quick Start Guide. CPD-80a. Hydrologic Engineering Center, Davis, CA.

GeoEFM is part of a group of technologies called the EFM Suite. Collectively, the EFM Suite assists users with tasks common in ecological modeling, including time series analyses, habitat mapping, and simulation of population dynamics, thereby supporting a range of possible applications. The EFM Suite consists of EFM, EFM Plotter, GeoEFM, and EFMSim, as shown in Figure 1 and described in Table 1.

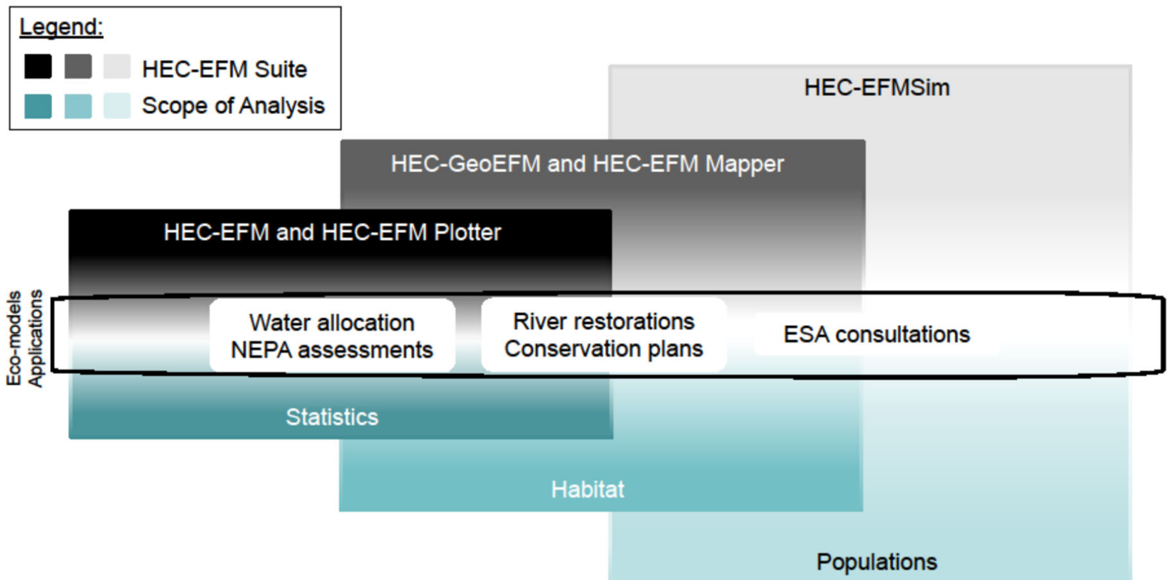


Figure 1. The EFM Suite and the tasks and applications it supports.

Table 1. Software of the EFM Suite.

Software	**Description**
HEC-EFM	Used to perform time series analyses to help determine ecosystem responses to changes in the flow regime of a river or connected wetland - https://www.hec.usace.army.mil/software/hec-efm/
HEC-EFM Plotter	Displays and assists with interpretation of EFM output. Commonly used in conjunction with EFM - https://www.hec.usace.army.mil/software/hec-efm-plotter/
HEC-GeoEFM	ArcMap extension to support habitat mapping and other spatial analyses commonly performed during applications of EFM - https://www.hec.usace.army.mil/software/hec-geoefm/
HEC-EFMSim	Performs spatial and temporal simulations of ecosystems. Outputs include animations of ecosystems. Population dynamics model - https://www.hec.usace.army.mil/software/hec-efmsim/

Text in this manual has been formatted to help readers keep track of the different types of information presented. *Italics* are used to identify *software features* that are available through the user interfaces of GeoEFM. Underlines are used to identify model input data, which includes the names of flow regimes and relationships used in the demonstration project. **Bold** is used to highlight **key information** for individual sections of text.

CHAPTER 2

EFM and GeoEFM

The process of applying EFM involves three basic phases: statistical analyses, river hydraulics modeling, and spatial analyses (Figure 2). Most user interfaces in EFM support the statistical phase where users identify the ecosystem restoration or water management scenarios ("flow regimes") and the aspects of the ecosystem ("relationships") to be investigated. Results from the statistical phase are then input to hydraulics models that generate layers of water depth, velocity, and inundation, which are then used in Geographic Information Systems (GIS) to investigate spatial criteria and results for the flow regimes and relationships.

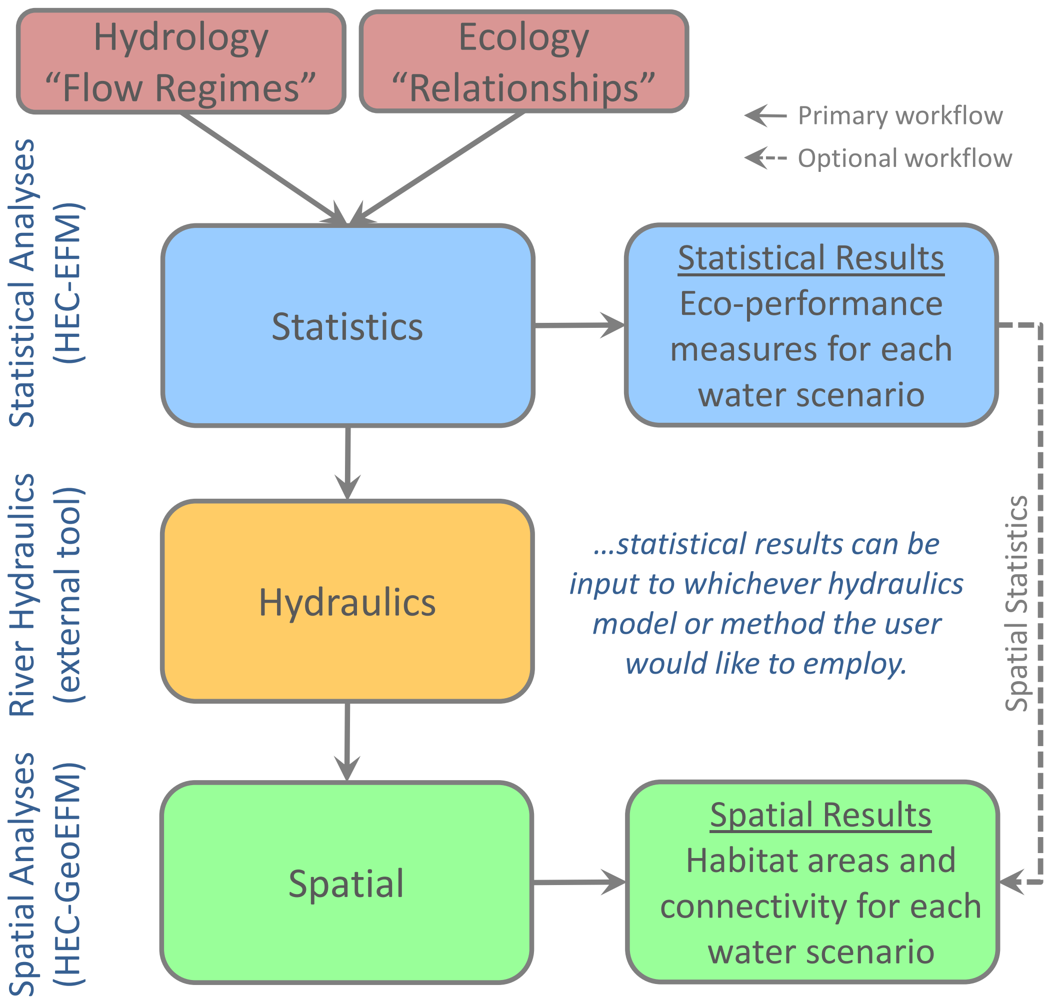


Figure 2. Statistics, hydraulics, and spatial phases of the EFM process. GeoEFM is used in the spatial analyses phase to investigate habitat areas and habitat connectivity produced by different restoration or water management scenarios.

"Flow regime" and "relationship" are terms that appear frequently in this manual. An EFM "flow regime" is defined as two concurrent daily time series that reflect conditions for a study area. Typically, the two series are mean flows and mean stages of a water body. Multiple flow regimes can be activated for consideration in a single analysis, but only one may be identified as the reference, which is the flow regime that all other active flow regimes will be compared to when considering model outputs.

"Relationships" are links between characteristics of flow regimes and elements of the ecosystem. Individual relationships are defined by the user via combinations of statistical criteria (seasonality, flow duration, rate of change, and flow frequencies) and geographical criteria (suitable ranges of water depth and velocity). Statistical criteria are considered in the first phase of the EFM process. Geographical criteria are considered in the last.

As GeoEFM is used in the last phase (spatial analyses), much of the structure for data and modeling will already have been determined before beginning work with GeoEFM. It is important to remember that due to this sequence **information such as names of flow regimes and relationships are always passed from EFM to GeoEFM**.

For more information about EFM use and terminology, please refer to the user guidance for that software or visit HEC's webpage (www.hec.usace.army.mil).

CHAPTER 3

GeoEFM: Installation and Construct

GeoEFM 3.0 is a toolbox for ArcGIS Pro. GeoEFM 3.0 is used with an **advanced level license** for Pro. Spatial Analyst and 3D Analyst extensions must be installed and activated.

There are two ways to install GeoEFM 3.0. The first is via a windows install package (HEC-GeoEFM_3.0.034_Setup.msi). Using the installer requires administrative privileges and installs GeoEFM as a system toolbox for Pro (Figure 3). The second is by extracting GeoEFM from a compressed file (GeoEFM_3.0.034.zip) and then inserting the extracted GeoEFM toolbox (HEC-GeoEFM.atbx) into the desired Pro project. The toolbox can be added via the *Insert - Toolbox - Add Toolbox* feature in Pro.

After installation, the GeoEFM toolbox can be accessed via the list of system toolboxes (when GeoEFM installed via the install package) or via the list of project toolboxes (when GeoEFM installed from the compressed file and then added to the Pro project). Figure 3 shows both.

Typically, GeoEFM applications begin with layers generated during the hydraulic modeling phase of the EFM process as well as other relevant data such as maps of land use, soils, and vegetation. The GeoEFM toolbox (Figure 4) has four toolsets (*Manage Project*, *Patches*, *Reporting*, and *Splicing*) with 10 tools that involve python scripts containing the code that determines the functionality of the tools. Each tool is detailed in this user guidance. A basic overview of GeoEFM 3.0 is that it can be used to share information from an EFM project to a GeoEFM project (via *Manage Project*), assess habitat functionality (via *Patches*), compute and compare habitat areas (via *Reporting - Tabulate Areas*), apply habitat suitability indices (via *Reporting - HSI Calculator*), and create habitat mosaics (via *Splicing*).

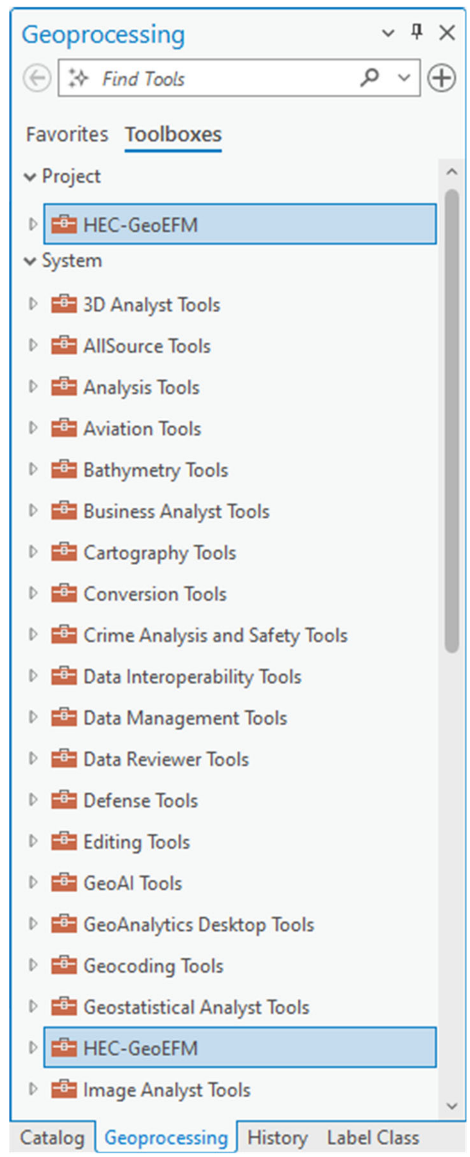


Figure 3. GeoEFM toolbox installed as a Project toolbox (top) and as a System toolbox (bottom).

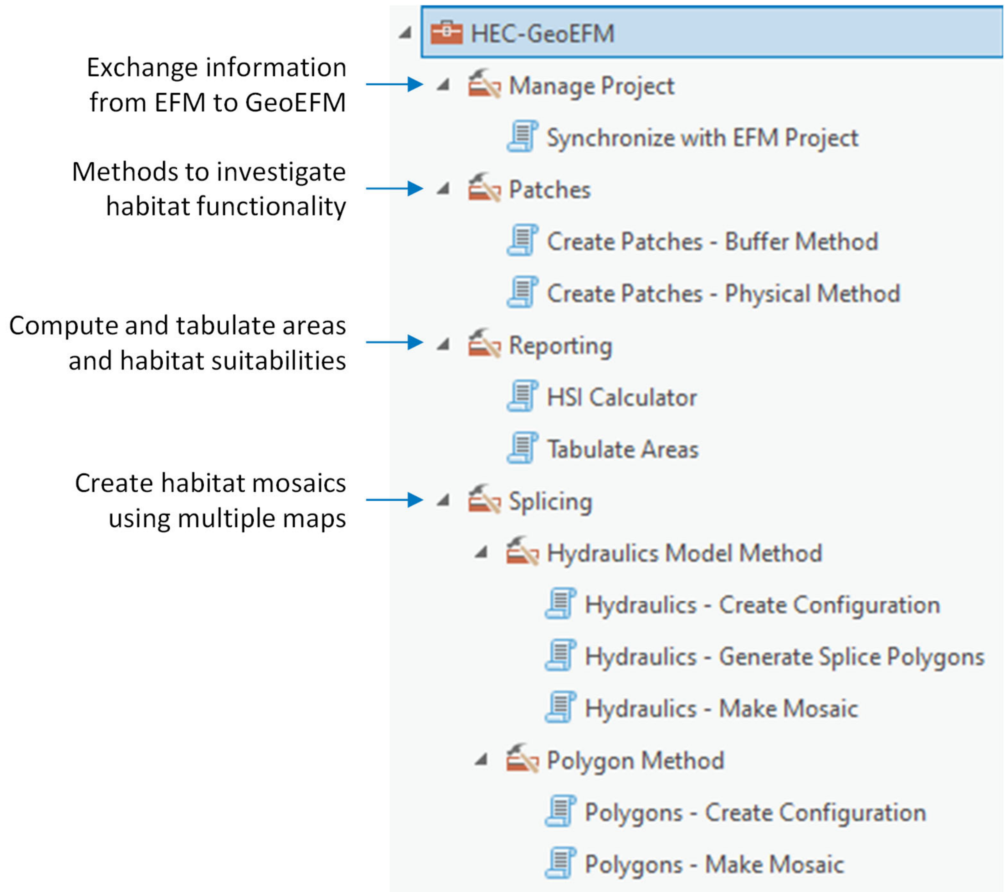


Figure 4. Key components of the GeoEFM toolbox.

Project toolboxes can also be identified as "favorites" or as toolboxes to be "added to new projects". To do this, go to the Catalog tab in Pro (Figure 3), click on the "Project" header, right click on "folders", select the "Add Folder Connection" menu option, browse to the folder that contains the GeoEFM toolbox (usually /xtoolboxes/), and click OK. The toolbox folder should appear as a subfolder. Right click on that folder and select the "Add To Favorites" or "Add to New Projects" menu option. Favorites will appear under the Favorites header for quick access. Toolbox folders identified as "Add to New Projects" will be automatically added to new instances of Pro.

3.1 Getting Started

To start a GeoEFM project in Pro, open Pro and select the *New Project - Map* option (Figure 5). For organizational purposes, it is recommended (not required) that new GeoEFM projects be created with the checkbox option for *Create a folder for this local project* turned on (Figure 6).

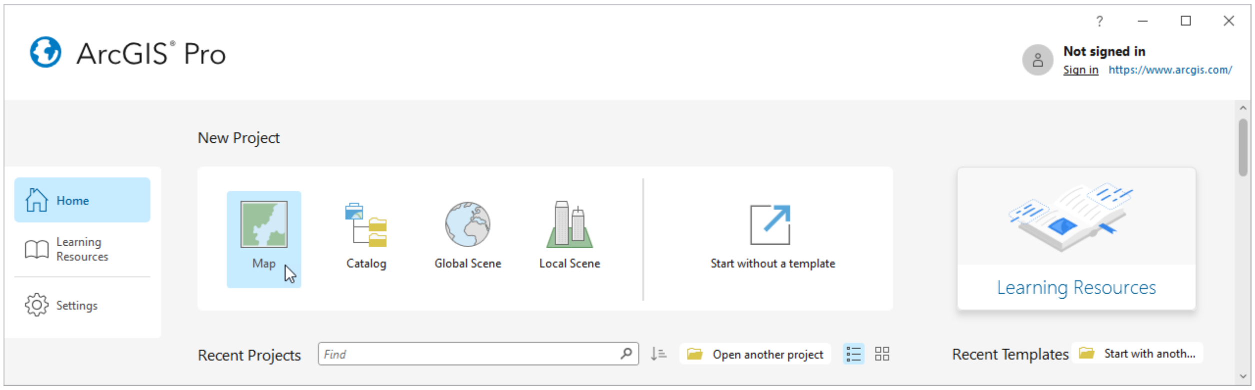


Figure 5. Click *New Project - Map* to initiate create a new project.

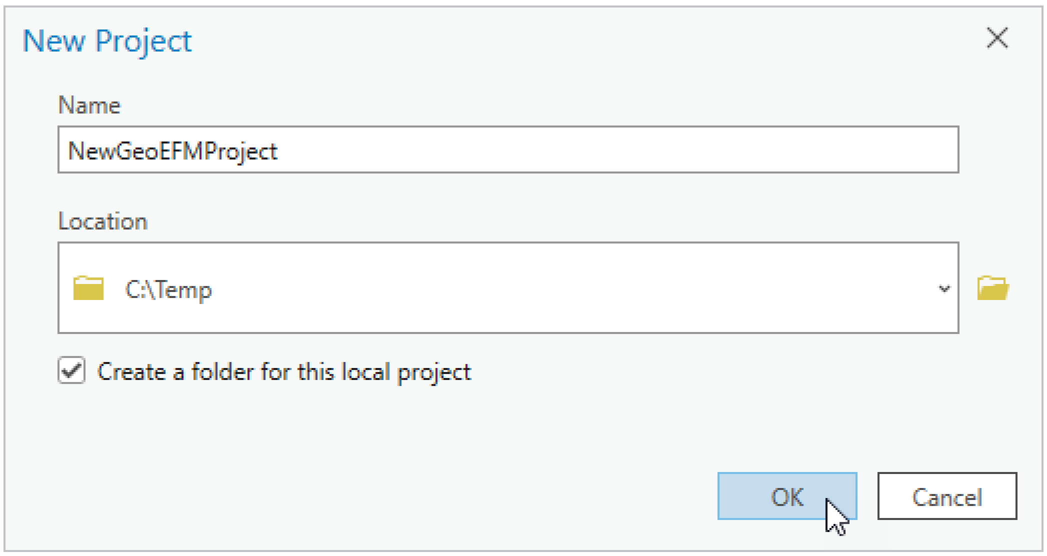


Figure 6. Enter a name and location for the new project and click *OK*.

When a new project is created (e.g., NewGeoEFMProject.aprx), a project geodatabase (NewGeoEFMProject.gdb) is also created at the same location. Both the project file and the associated geodatabase are important to GeoEFM. The project file stores information such as map contents and the geodatabase stores information such as tables and feature classes, all of which are needed for use of GeoEFM tools. Please note that doing a *Project - Save Project As* action in Pro only saves the project file, which means that new project files created via "save as" retain association with their original geodatabase. This can be confusing and problematic for GeoEFM applications and is not recommended.

After a new project is created, use the *Map - Add Data* feature to add layers to the map (Figure 7). When layers are added and GeoEFM is installed, you're ready to begin using GeoEFM.

The next chapters detail the four GeoEFM toolsets - Manage Project, Reporting, Patches, and Splicing.

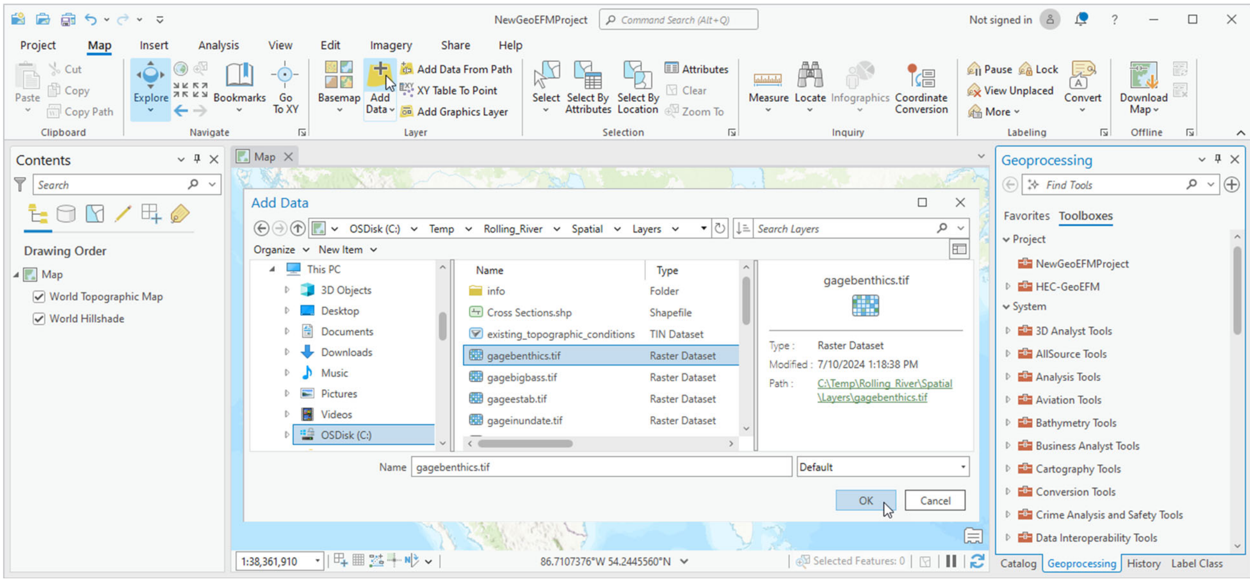


Figure 7. Add relevant layers to the new project.

CHAPTER 4

GeoEFM: Manage Project

In Pro, a project is a body of related work that may include maps, scenes, layouts, and connections to resources such as system folders and databases. Project files have the extension ".aprx". By default, a project is stored in its own folder along with an associated file geodatabase and toolbox (https://pro.arcgis.com/en/pro-app/latest/get-started/get-started.htm).

A GeoEFM project is a Pro project that has accessed and can be synchronized with an EFM project to obtain information such as Flow Regime names and Relationship names. Information is passed from EFM to GeoEFM. Connections between the two software are done through the *GeoEFM – Manage Project* toolset. The *Manage Project* toolset has one tool called *Synchronize with EFM Project*, which can be started via a double-left-click or via the right-click *Open* menu option (Figure 8).

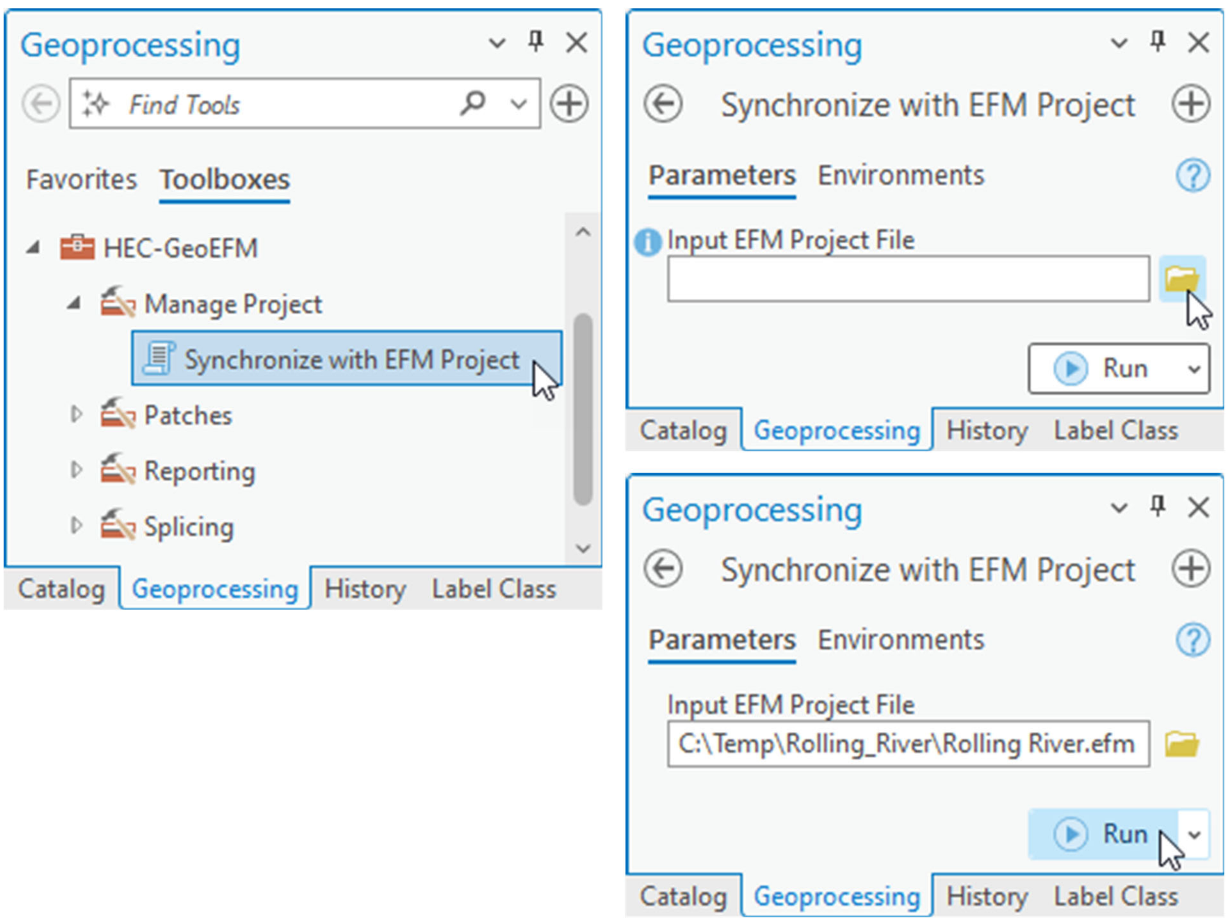


Figure 8. The *Manage Project* tool allows users to synchronize EFM and GeoEFM projects.

When the tool is started, an interface opens prompting the user to identify the desired EFM file. Clicking *Run* synchronizes the GeoEFM project with its associated EFM project (Figure 9).

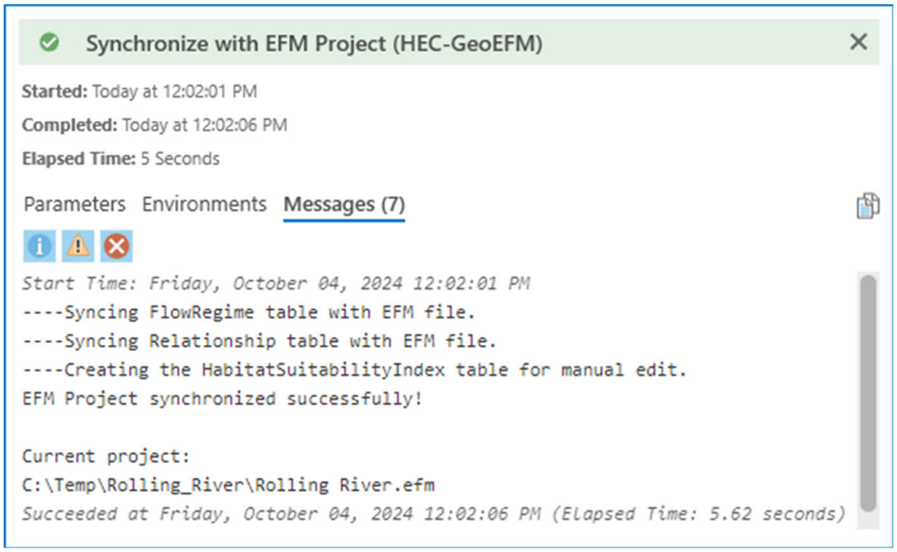


Figure 9. Synchronizing an EFM project.

Three tables are created or updated. The *FlowRegime* table contains names and integer identifiers for Flow Regimes. The *Relationship* table contains names and integer identifiers for Relationships. The *HabitatSuitabilityIndex* table is used to store habitat suitability indices (HSIs) for application in the *Reporting - HSI Calculator* tool (Figure 10). These tables are stored in the project geodatabase and can be added to the map via a right-click add to map menu option. Subsequent *Synchronize with EFM Project* runs update flow regime and relationship information and do not update the indices table to assure integrity of manually added indices.

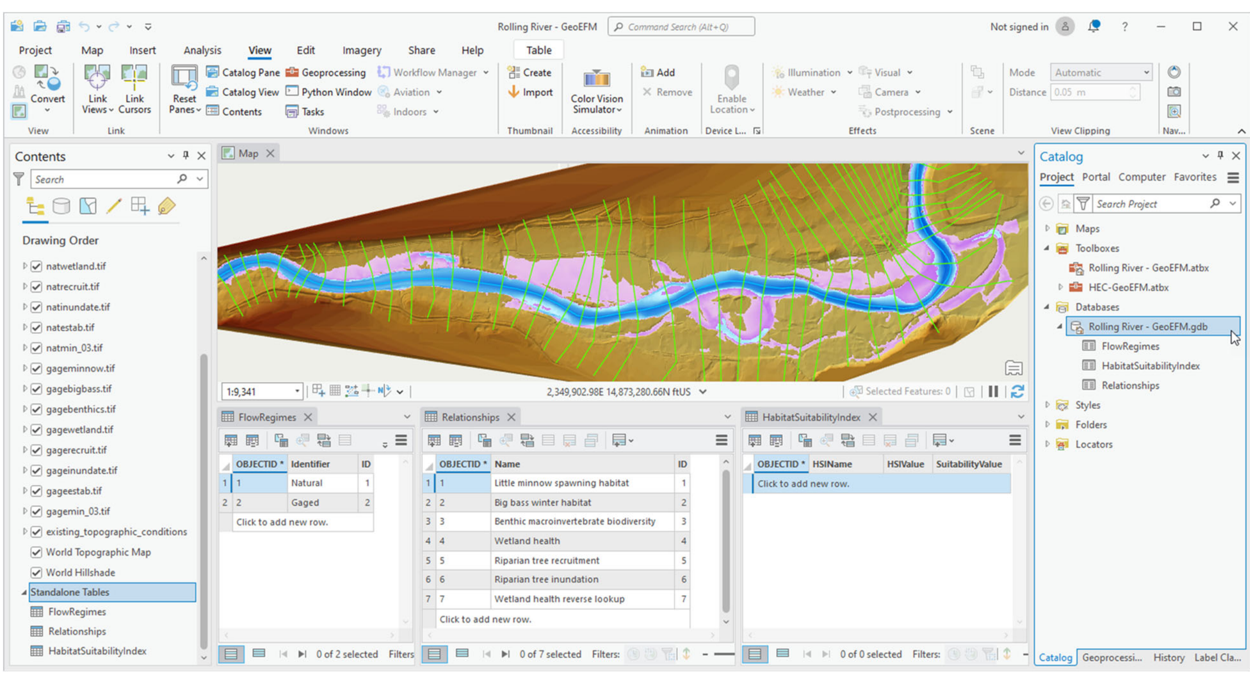


Figure 10. GeoEFM project tables.

In EFM, integer identifiers are assigned to flow regimes and relationships when those are first created. The integer does not change as the flow regime or relationship is renamed and is never reused over the life of the EFM project. With each subsequent *Synchronize with EFM Project* run, GeoEFM retrieves the latest saved version of those data from its associated EFM project. Any changes, including adding, renaming, or deleting flow regimes and relationships, must be performed and saved in EFM and then updated in GeoEFM by running the *Synchronize with EFM Project* tool.

The *Synchronize with EFM Project* tool also allows users to redirect a GeoEFM application to a different EFM project. This should be done with caution. Switching projects is intended to allow update of connections between GeoEFM and EFM where the EFM project has been either moved (to a new computer location) or renamed (to reflect a change in content or status). However, GeoEFM performs the "switch" according only to the integer identifiers of flow regimes and relationships and could lead to confusion such as legacy layers that are in the project but no longer relevant to any of the new flow regimes and relationships.

4.1 Habitat Suitability Indices

A Habitat Suitability Index (HSI) is a paired data set of habitat quality (*SuitabilityValue*) that ranges from 0 (wholly unsuitable) to 1 (perfectly suitable) and a corresponding habitat variable (*HSIValue*) such as water depth or velocity. Indices are available for many species and life stages and are commonly used in ecological analyses.

Indices are added to the *HabitatSuitabilityIndex* table by entering or copy-pasting information into the table (Figure 11). To begin, click the initial row in the table, which is labeled "Click to add new row". Enter HSI information or copy-paste.

Multiple indices can be stored in the *HabitatSuitabilityIndex* table – just be sure to use a unique name (*HSIName*) for each index and take care when entering names. GeoEFM uses the names to identify indices. If the same name is used for two indices, GeoEFM will simply merge their data into a single index, which can lead to odd results. Also, name errors will split a single index into multiple HSIs. For example, an index with 6 rows of information, 4 that use "trout" for the *HSIName* and 2 that errantly use "trot", will be treated as two indices regardless of how those data are ordered in *HabitatSuitabilityIndex* table.

Habitat quality values of a HSI are dimensionless and range from 0 to 1, as described above. However, HSIs relate quality to habitat variables such as depth or velocity, which do have dimensions and units. HSI names can be used to reference that information (e.g., "Little Minnow Spawning – Depth"), which may help avoid errors when applying HSIs.

When done, save edits via the *Table - Save* feature in Pro. This table "edit and save" functionality is entirely in Pro and does not require the use of any GeoEFM tools. Indices in the *HabitatSuitabilityIndex* table will be available for application via the *Reporting - HSI Calculator* tool.

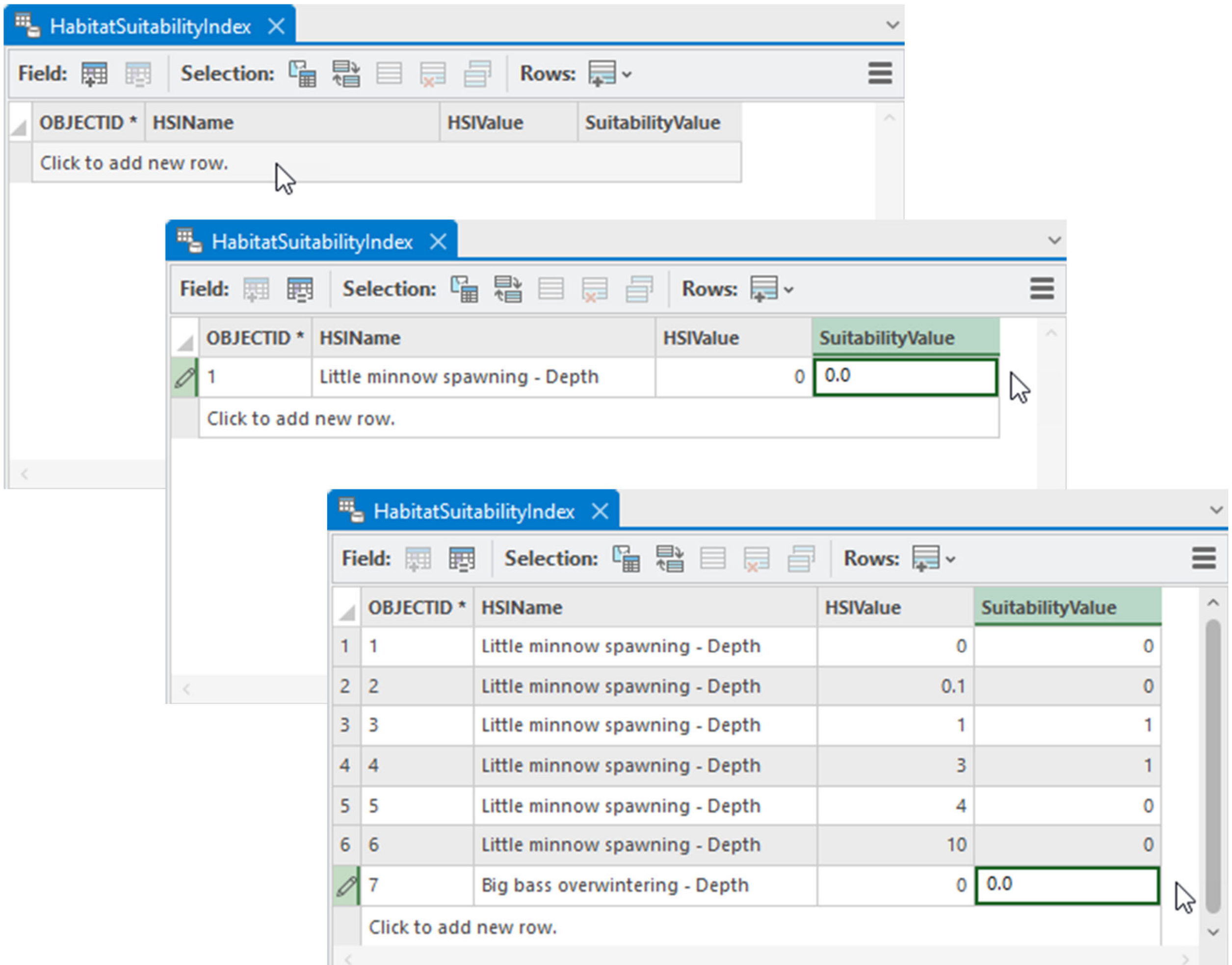


Figure 11. Entering habitat suitability information into the *HabitatSuitabilityIndex* table. The <u>Little Minnow Spawning – Depth</u> HSI shows that depths become more suitable for little minnow between 0.1 and 1 feet, are ideal between 1 and 3 feet, and become less suitable from 3 to 4 feet, and have no suitability for depths greater than or equal to 4 feet. Note this logic is slightly different than information provided elsewhere in EFM user guidance that says little minnows require shallow depths between 0 and 3 feet for spawning (USACE 2024).

CHAPTER 5

GeoEFM: Reporting

The *Reporting* toolset has two tools. The first is called *HSI Calculator*. The second is called *Tabulate Areas*. Tools can be started via a double-left-click or via the right-click *Open* menu option.

5.1 HSI Calculator

Applying a HSI to create a layer of suitable habitat is done via the *Reporting - HSI Calculator* tool. Initiating the *HSI Calculator* tool opens an interface that prompts the user to pick an *Input Raster*, an *Input HSI*, and to name an *Output Raster*. Additionally, there is an option to either exclude (checked) or include (unchecked) zero suitability areas from the output raster (Figure 12).

Clicking the *Run* button translates input raster values to suitabililities according to the selected HSI paired data set and then stores suitability results as output raster values (Figure 13). For example, a value of 2.1 feet from an input raster of water depths (natminnow.tif) would be translated to a suitability of 1.0 based on the "Little minnow spawning - Depth" HSI and then that and other values would be saved to the output raster. A depth value of 5.1 feet would be translated to a suitability of 0.0 and included in the output raster as 0.0 if the Exclude Zero Suitability Areas option was unchecked and as NoData if the option was checked.

Please note that quality control for application of the *HSI Calculator* is left wholly to the user. GeoEFM does not verify data, check units, monitor suitability ranges, or enforce ranges. Recommended practices are to 1) make sure that the input raster and the *HSIValue* use the same variable and units, 2) use suitabilities (*SuitabilityValue*) that range from 0 to 1, and 3) define HSIs with *HSIValue* ranges that fully encompass the range of input raster values.

In GeoEFM, HSI are applied only to raster layers. Output layers generated are also rasters. The values of these suitability rasters are a measure of quality and can be used by other GeoEFM tools to investigate the areas and connectivities of suitable habitat. Output rasters are automatically added to map contents of the GeoEFM project and assigned a red-green color ramp (Figure 14).

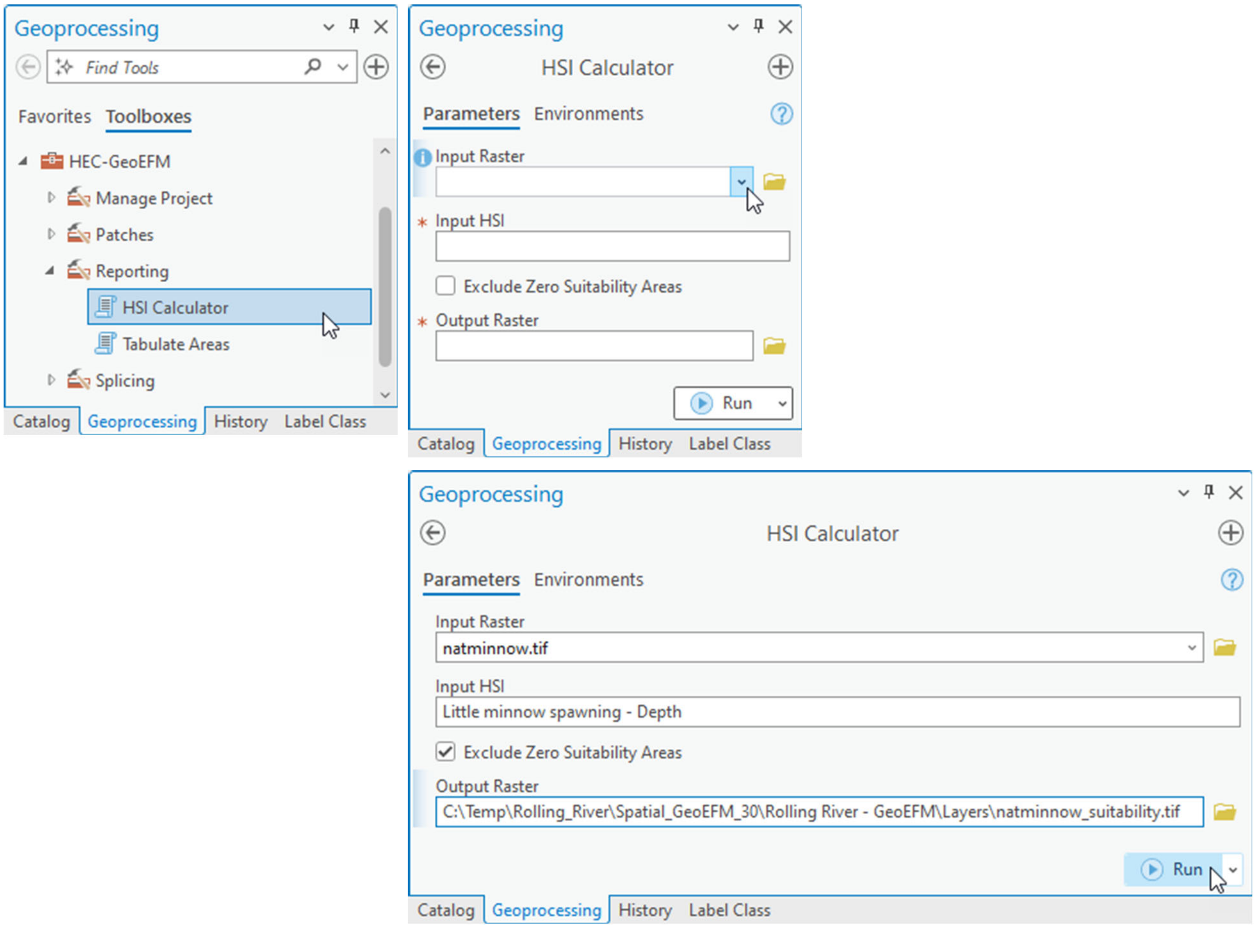


Figure 12. *Reporting - HSI Calculator* allows users to apply an HSI to compute a suitability raster.

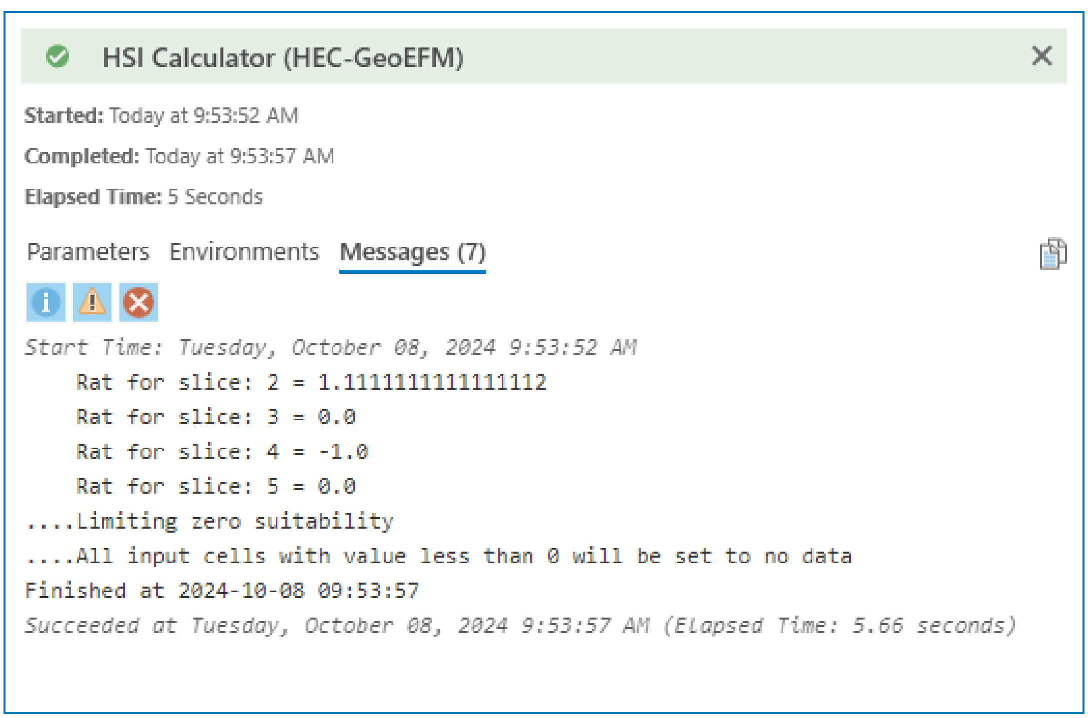


Figure 13. Applying the *HSI Calculator* to compute a suitability raster.

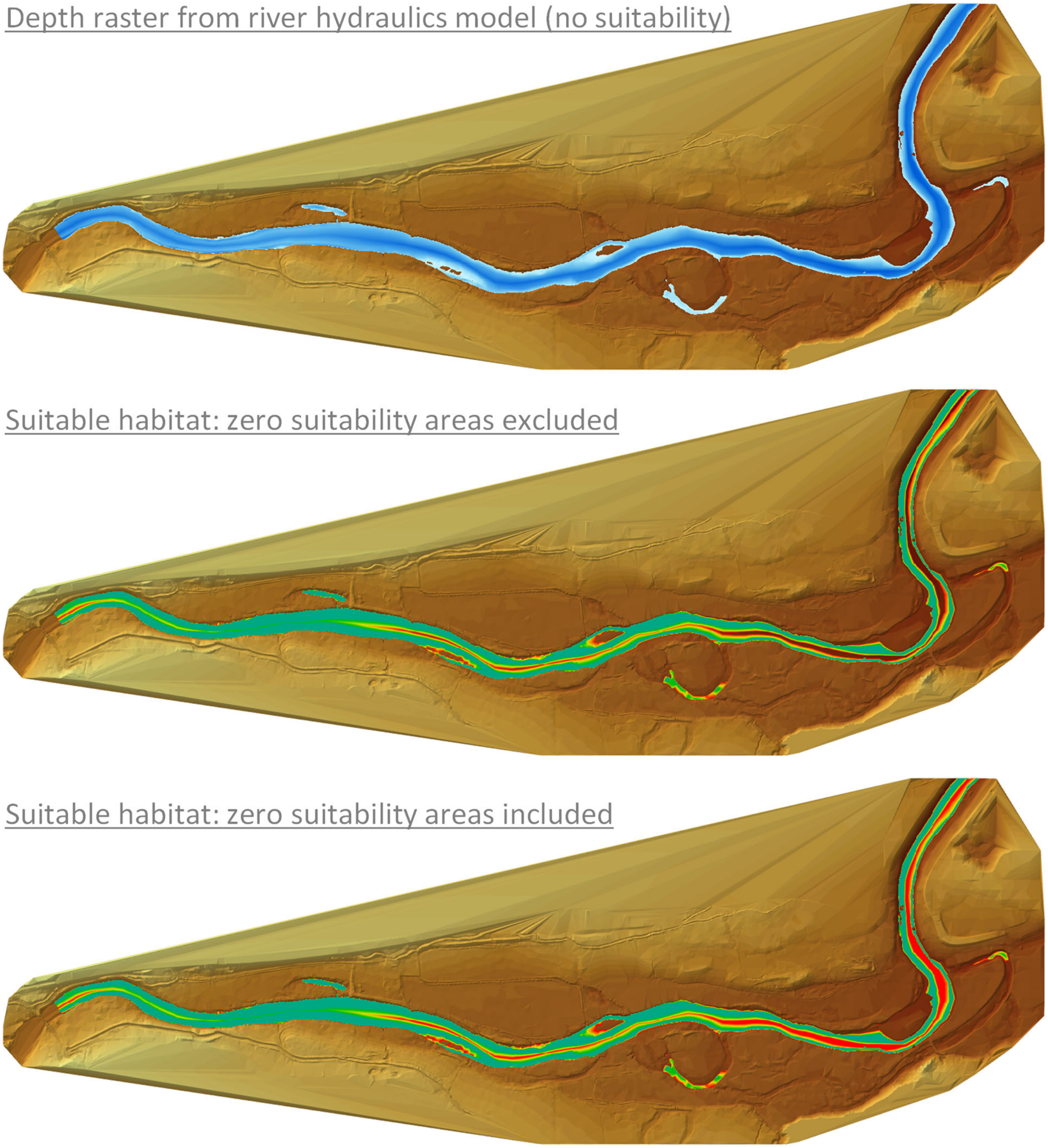


Figure 14. Spatial layers for <u>Little minnow spawning habitat</u> overlaid on land surface topography. Top image shows a depth raster (blue) generated by a river hydraulics model. Middle and bottom images show suitability rasters generated by applying a HSI to the depth raster with zero suitability areas excluded and included, respectively.

5.2 Tabulate Areas

The *Tabulate Areas* tool allows users to compute, report, and archive total and suitable habitat areas. Options are provided for *Use Suitabilities*, selecting the desired flow regimes and relationships, mode of comparison for multiple flow regimes, output units, and the file and path name of the report to be generated by GeoEFM (Figure 15).

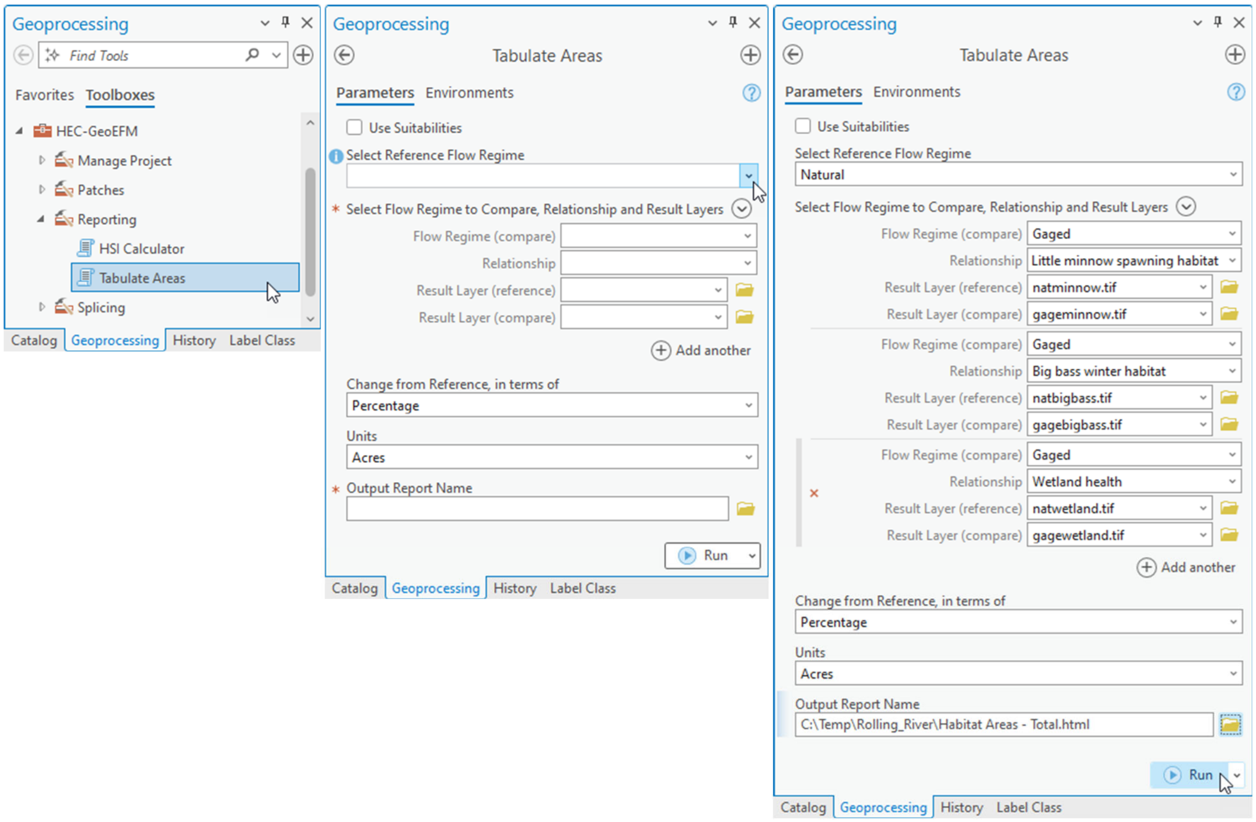


Figure 15. *Reporting - Tabulate Areas* allows users to compute, tabulate, and compare habitat areas.

As in EFM, only one flow regime may be selected as the reference. Habitat areas generated by flow regimes selected in the “Flow Regime (compare)” fields will be compared to habitat areas generated by this reference in accordance with the *Change from Reference* setting. When the *Run* button is clicked, **GeoEFM assesses area for the identified layer of each flow regime - relationship pairing as specified in the tool interface** (Figure 16).

A “ReportName.html” file is generated that can be opened in web browsers and other software (Figure 17). Results can also be copy-pasted from that table to other software applications for word processing and use in spreadsheets.

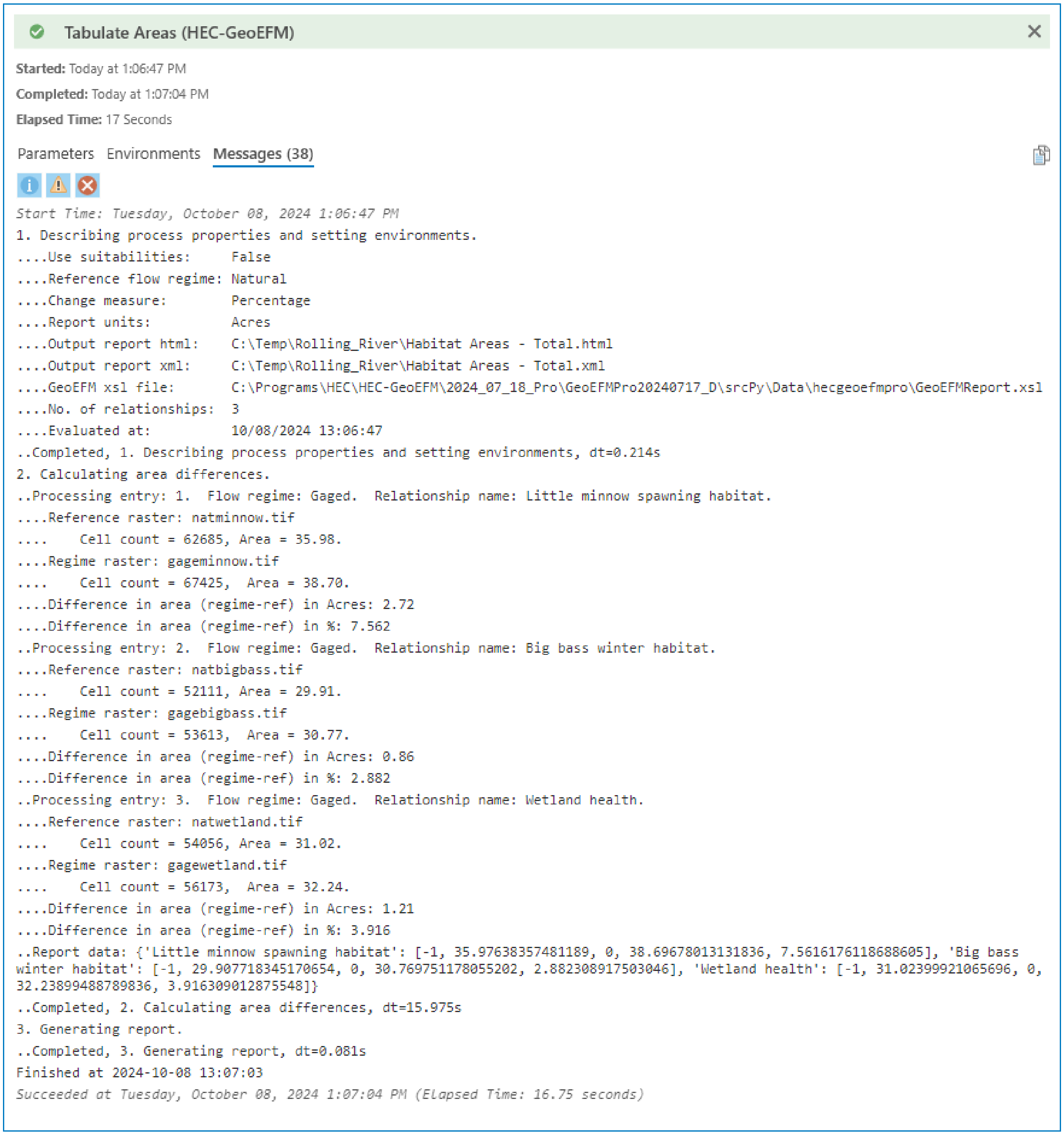


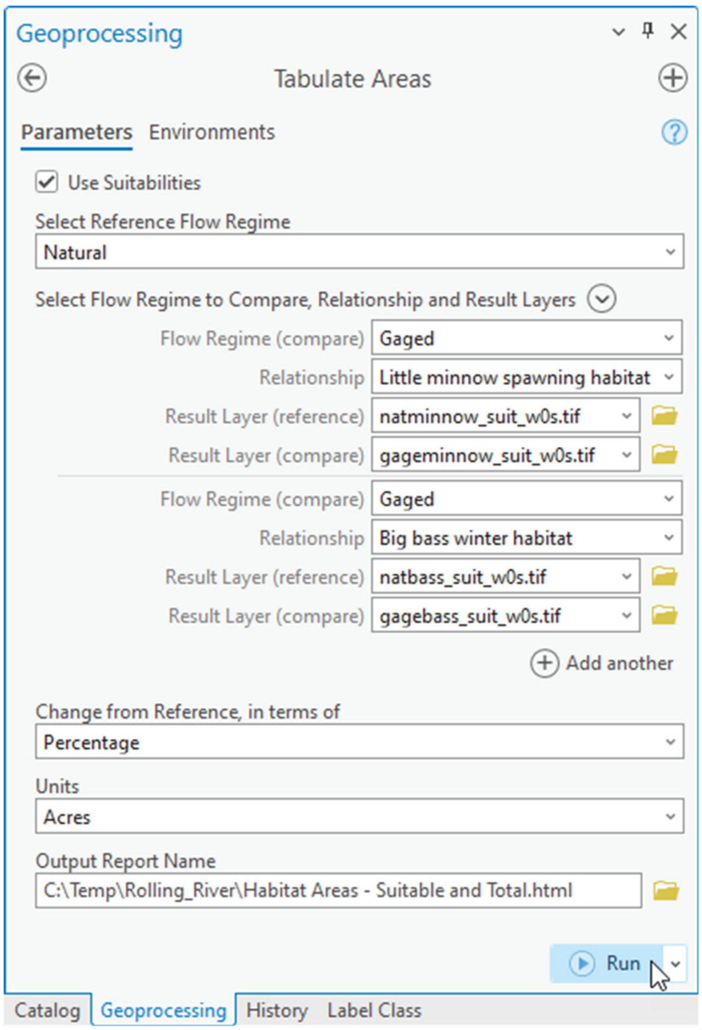
Figure 16. Applying *Tabulate Areas* to compute habitat areas for flow regimes and relationships.

Summary

	Natural	Gaged	
Relationship	**Area, Acres**	**Area, Acres**	**Change, Percentage**
Little minnow spawning habitat	35.976	38.697	7.562
Big bass winter habitat	29.908	30.770	2.882
Wetland health	31.024	32.239	3.916

Figure 17. Table of habitat areas for flow regimes and relationships.

The *Use Suitabilities* option allows for reporting of suitable areas in addition to the total areas (Figure 18) tabulated for results layers when the option is turned off. Tallying suitable area is done by summing the product of raster cell areas and corresponding raster cell values, with value intended to be a measure of suitability ranging from 0 (wholly unsuitable) to 1 (perfectly suitable). Total areas are computed by summing raster cell areas, which means that if a cell is part of the result layer, it is habitat and tallied as such (as if it were wholly suitable). Please note that GeoEFM does not process suitable habitat areas when selected layers have values outside of the normal range of suitabilities (0 to 1).



Summary

	Natural		Gaged		
Relationship	**Suitable Area, Acres**	**Total Area, Acres**	**Suitable Area, Acres**	**Total Area, Acres**	**Change, Percentage**
Little minnow spawning habitat	25.114	35.976	20.732	38.697	-17.448
Big bass winter habitat	20.759	29.908	22.532	30.770	8.543

Figure 18. Options and settings for the Tabulate Spatial Results interface in GeoEFM.

CHAPTER 6

GeoEFM: Patches

Fragmentation in habitat maps produced by the EFM process is generated by land surface topography that affect the connectedness of aquatic habitats through human or natural features, splicing of multiple layers into a habitat mosaic, and application of habitat suitability criteria that split otherwise connected areas into smaller pieces surrounded by areas with zero suitability.

In GIS, raster datasets are grids of continuous cells organized in rows and columns. Areas with raster values can be separated by areas of no data. Connected raster cells that provide habitat are herein called "chunks" (Figure 19).

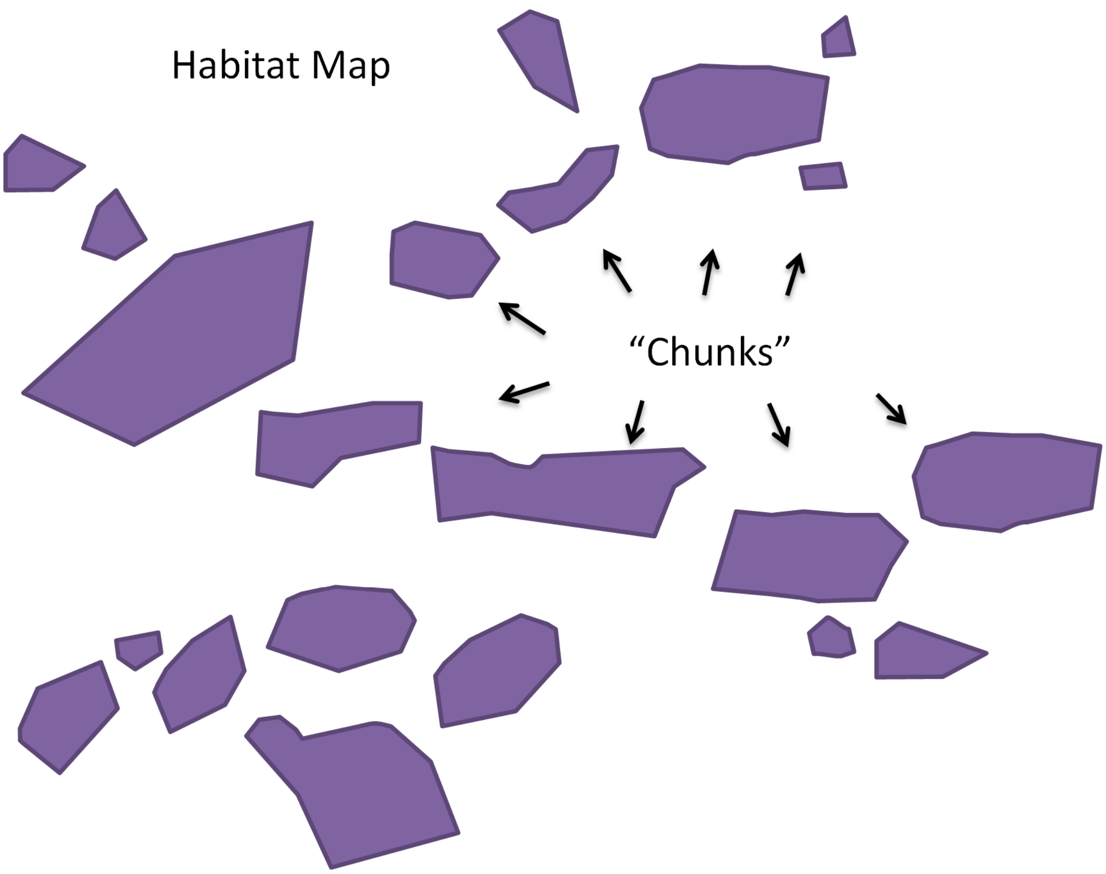


Figure 19. Illustration of a habitat map. Separate pieces of habitat are referred to as "chunks".

The GeoEFM *Patches* toolset includes two connectivity methods. The physical connectivity method has options for identifying chunks based on connected edge or connected point. The buffer method includes cells in chunks based on connected points.

Chunks separated by less than or equal to twice the buffer radius (in the buffer method) are grouped into "neighborhoods" (Figure 20). If a chunk is separated by more than the threshold distance in all directions, it is placed in its own neighborhood. Neighborhoods are not used for the physical connectivity method because that method assumes chunks that are physically disconnected do not interact ecologically.

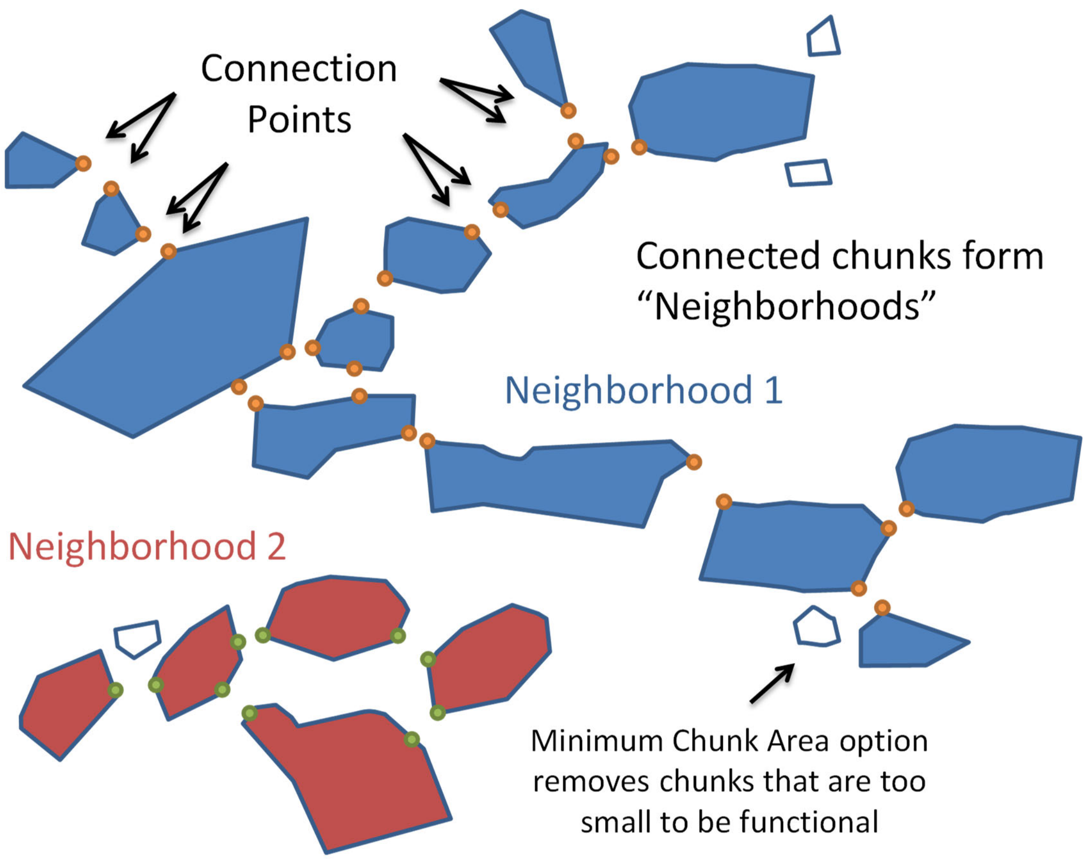


Figure 20. Chunks with areas greater than or equal to the minimum chunk area (user specified and optional) and that are spaced tightly enough to act together ecologically are grouped into "neighborhoods".

Each neighborhood is assessed separately to split habitat into "patches", each of which would be a unit of ecological importance such as the amount of habitat needed to support an individual, or habitat for a pack of individuals, or habitat for a nesting site. Being in a neighborhood does not indicate whether there is enough habitat to create a patch, it simply means that the collection of chunks are spaced tightly enough to act together to potentially support one or more patches.

Currently, connectivity can be assessed only for raster datasets.

The *Patches* toolset has two tools. The first is called *Create Patches - Buffer Method*. The second is called *Create Patches - Physical Method*. Tools can be started via a double-left-click or via the right-click *Open* menu option.

6.1 Create Patches - Buffer Method

The *Buffer* method is parameterized with at least a *Radius* and a *Minimum Patch Area*. A raster layer of habitat is analyzed to determine areas that meet the corresponding density criteria (where available habitat within circles of the buffer radius equals or exceeds the minimum patch area). Options are provided that allow users to maximize the number of identified areas and to allow flexibility in the buffer radius (Figure 21).

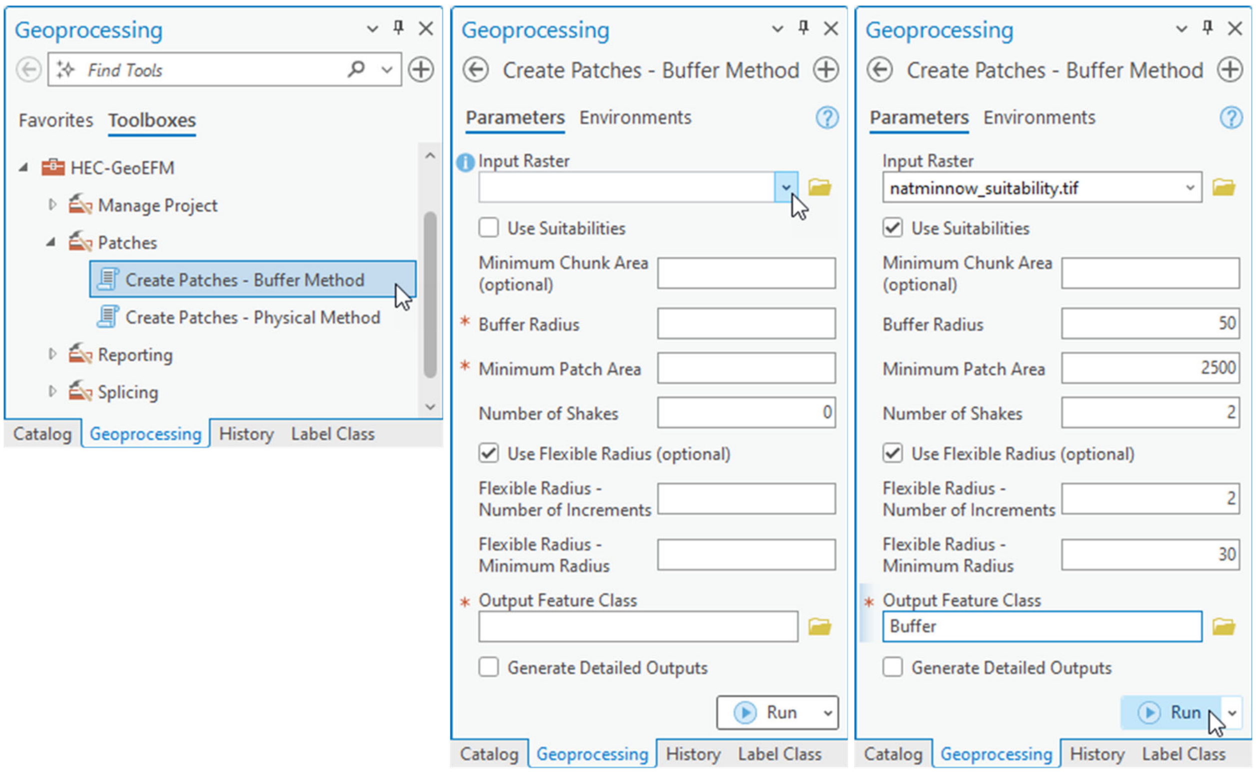


Figure 21. *Patches - Create Patches - Buffer Method* is a habitat functionality tool.

Clicking the *Run* button starts the buffer algorithm. Details about the algorithm are provided below. Buffer can have long compute times, especially when runs are made for large areas with high numbers of shakes and radii. Using suitabilities also increases run times. Step-by-step progress is reported in the View Details log (Figure 22).

Buffer begins by grouping chunks into neighborhoods if chunks are separated from each other by less than or equal to twice the buffer radius. Separation between chunks is measured as the smallest distance from edge to edge. A chunk isolated by more than twice the buffer radius in all directions is placed in its own neighborhood. Once neighborhoods have been identified, each neighborhood is assessed to determine areas of sufficient habitat density, which are then assigned patch identifiers and removed from the habitat layer being analyzed.

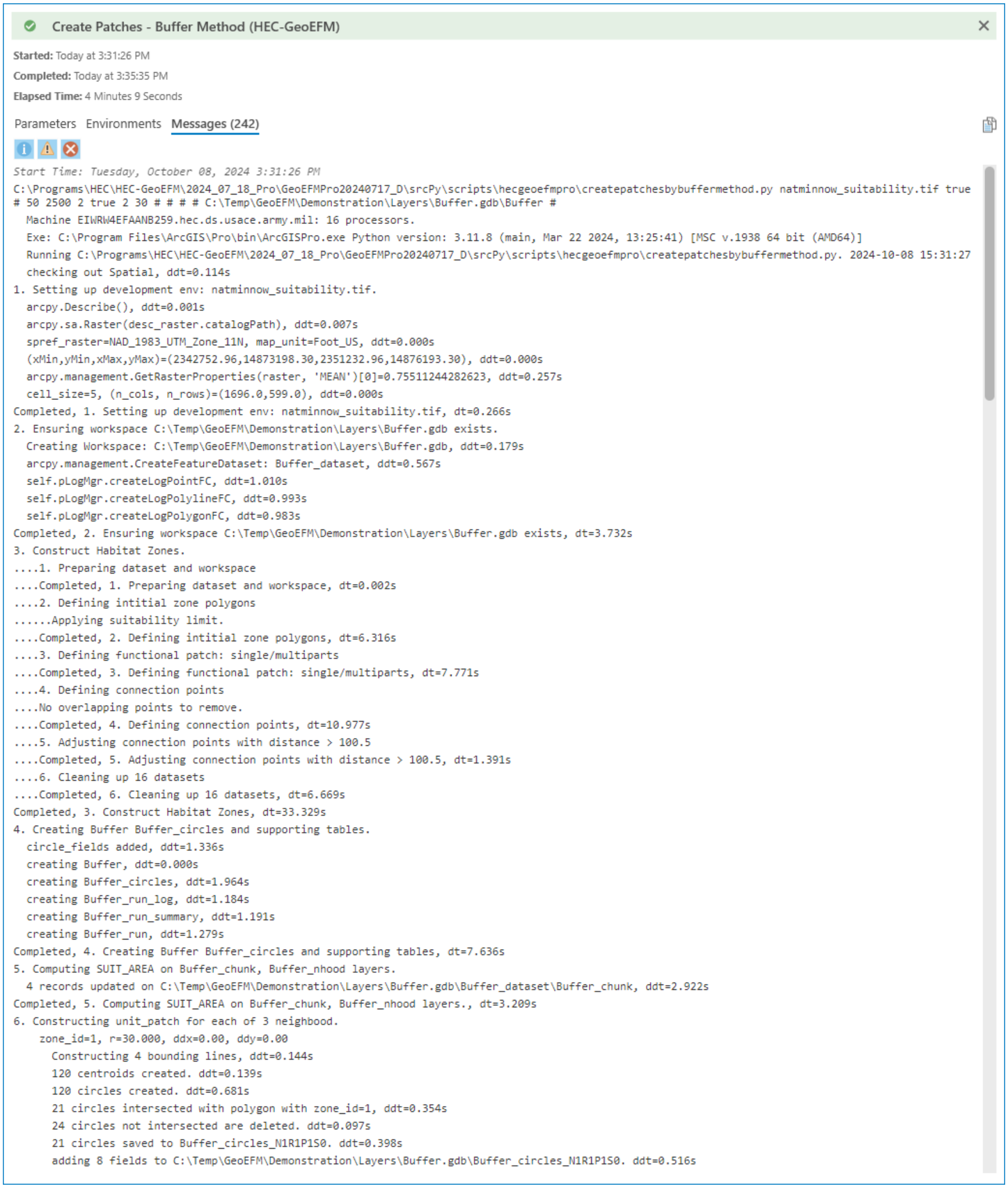


Figure 22. Applying *Patches - Create Patches - Buffer Method* involves several steps.

Patch processing involves the use of stencils. For each neighborhood, a bounding box is drawn around its member chunks. This bounding box is expanded on each side by 4 times the buffer radius and then filled with touching but non-overlapping circles of the buffer radius (Figure 23a). This stencil of circles is laid over a raster layer of habitat and circles that capture equal to or greater than the minimum patch area are cut from the habitat raster as patches (Figure 23b).

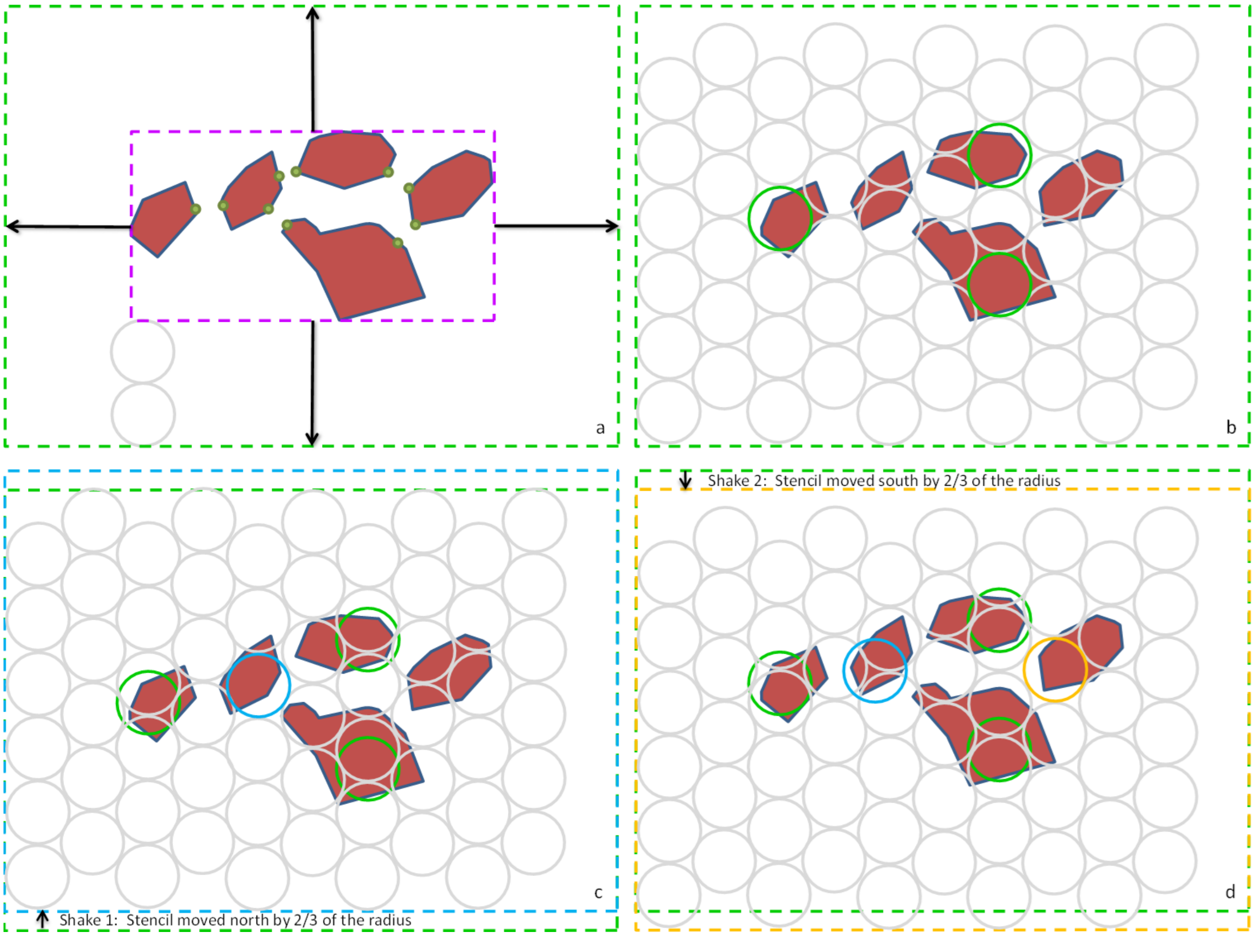


Figure 23. Patch processing with the *Buffer* method. First, the bounding box of neighborhood is expanded by four times the user-defined buffer radius to create the initial stencil outline (a), which is then filled with buffer radius circles (b). Shakes, or slight repositions of the stencil, are considered (c and d) prior to cutting of patches.

The *Buffer* algorithm allows for iterations of stencil placement during processing. This is done by shifting the stencil by two-thirds of the buffer radius in a user-defined number of directions called *Shakes*. The first shake is always to the north of the initial position of the expanded bounding box. Additional shakes are evenly spaced from north in a circular direction. For example, a shake setting of 2 would check areas for the initial expanded bounding box (shake 0; Figure 23b), a shift to the north (shake 1; Figure 23c), and a shift to the south (shake 2; Figure 23d); a shake setting of 4 would use the initial position plus north, east, south, and west. Each shake is considered separately. The shake that yields the most patches is cut, with the corresponding patch areas removed from the layer. When two or more shakes would yield the same number of patches, the lowest number shake is cut. This sequence is repeated for uncut shakes and remaining habitat. Additional cuts are done only where a patch can be made without intersecting an already cut patch circle.

There is an additional option that allows consideration of a *Flexible Radius* (Figure 24). This option has two parameters: minimum radius and number of increments. When selected, patch processing begins with a stencil of circles of the minimum radius, shaking and cutting as described above until no more patches of that radius can be cut, then advances to the next larger radius and repeats the shaking and cutting, and so on. The last and largest radius used is the buffer radius. The user-defined number of increments includes the minimum and buffer radii. For example, a run with minimum radius of 5 map units, buffer radius of 15 map units, and increment number of 3 would have 3 cycles of shaking and cutting (radii of 5, 10, and 15).

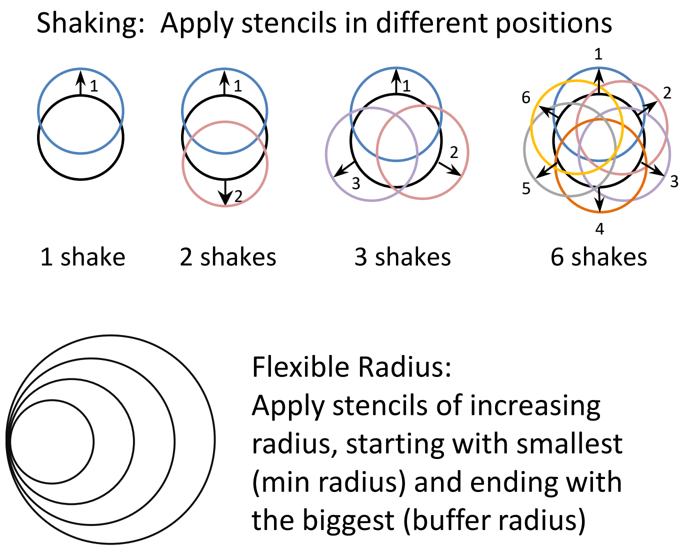


Figure 24. *Buffer* method options include shaking and flexible radius. Shaking considers different stencil positions before cutting patches. Flexible radius uses stencils of different radii. The original position of the expanded bounding box is applied as shake 0.

Standard output for *Buffer* includes displayed layers of patch circles and actual patches. Attribute information includes patch areas, neighborhood, pass, validity, and suitable area, if the use suitabilities option was selected. Information about the simulation, connected points, neighborhood characteristics, and chunk characteristics are stored in a geodatabase specific to each run. When the generate detailed output option is selected, displayed output also include the connection point, neighborhood, and chunk layers. A pass name comprised of counters for neighborhood, radius, pass, and shake is provided for each patch to inform when it was cut during processing. The pass component is used to record the order in which shakes were cut.

When the *Use Suitabilities* option is selected, chunks are split into patches based on value-weighted areas. The complication for buffer is again related to potential scale issues associated with processing large rasters. To account for suitability and maintain process integrity, input rasters are converted internally to point coverages. Stencil circles that captured points whose values (suitabilities) multiplied by the raster cell area summed to at least the minimum patch area criterion were identified as potential patches during shaking and cutting. This use of circular shapes in a matrix of points can lead to results that seem spatially inconsistent with inconsistencies becoming more apparent as circle radii decrease in size relative to raster cells.

Figure 25 shows Buffer patch results for little minnow spawning habitat processed with suitabilities. Patches cut with the larger radius (50 map units) tend to occur in the poorest or sparsest habitat because the larger radius was needed to cut enough habitat to meet the minimum (suitable) patch area parameter.

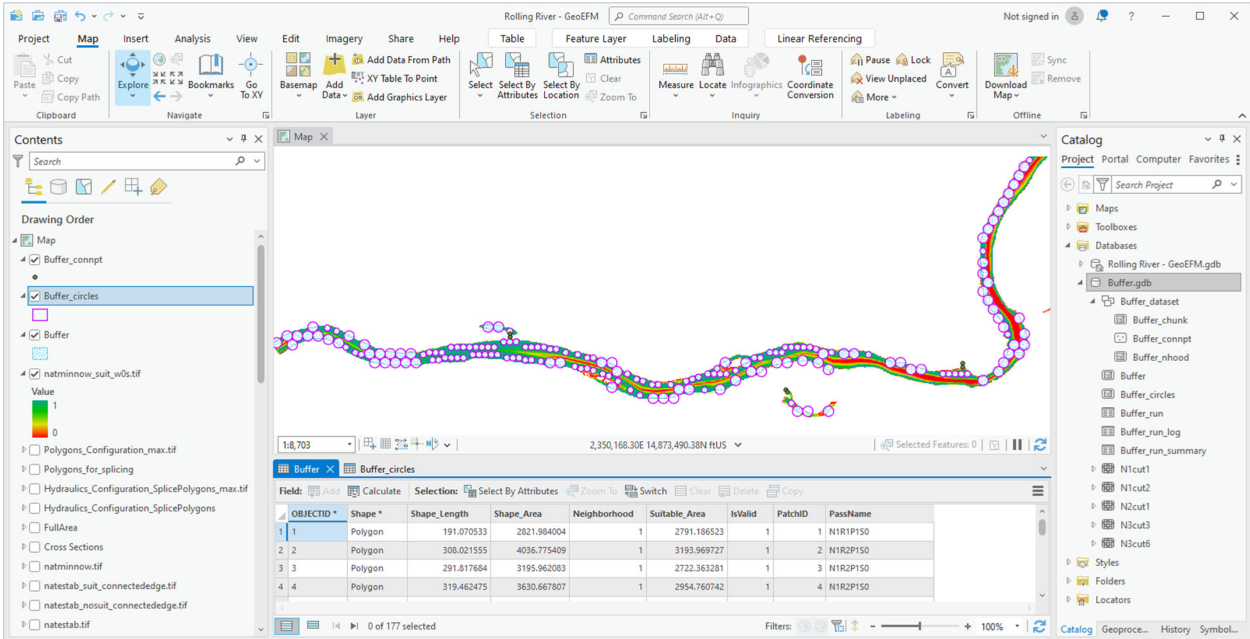


Figure 25. Patch results for a habitat connectivity analyses using the *Buffer* method.

6.2 Create Patches - Physical Method

The *Physical* method is parameterized with at least an *Input Raster* and a *Connection Type*. A raster layer of habitat is analyzed to determine areas that meet the specified type (Figure 26). A default output name of "InputRasterName_SuitabilitySetting_ConnectionType.tif" is provided but can be modified by the user.

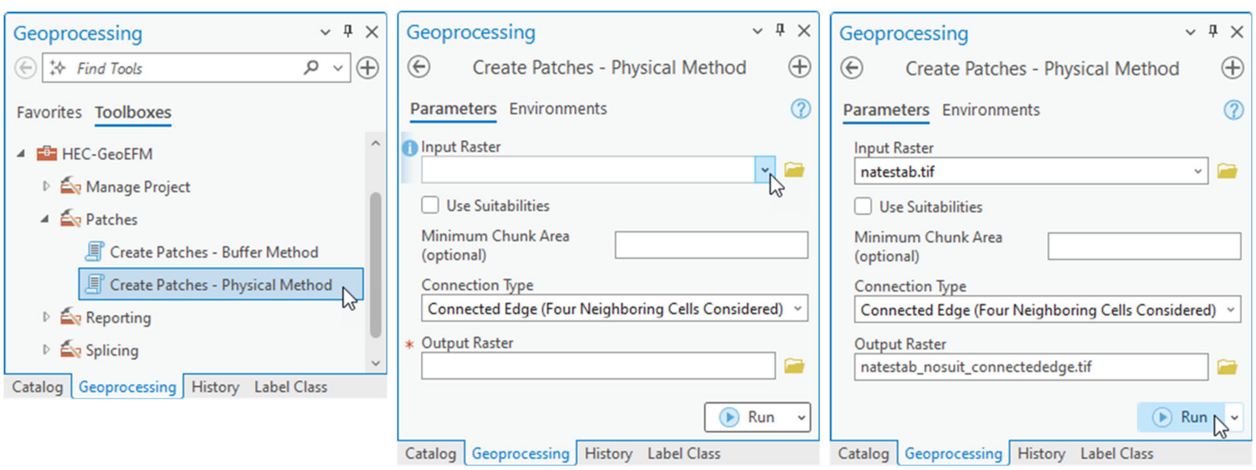


Figure 26. *Patches - Create Patches - Physical Method* is a habitat functionality tool.

Clicking the *Run* button starts the physical method algorithm (Figure 27). The algorithm follows 1) apply *Minimum Chunk Area* (if option is selected) to the *Input Raster*, 2) apply *Connection Type*, and 3) save the *Output Raster*. Output attributes include patch identifier, count of raster cells per patch, patch area, and patch suitable area.

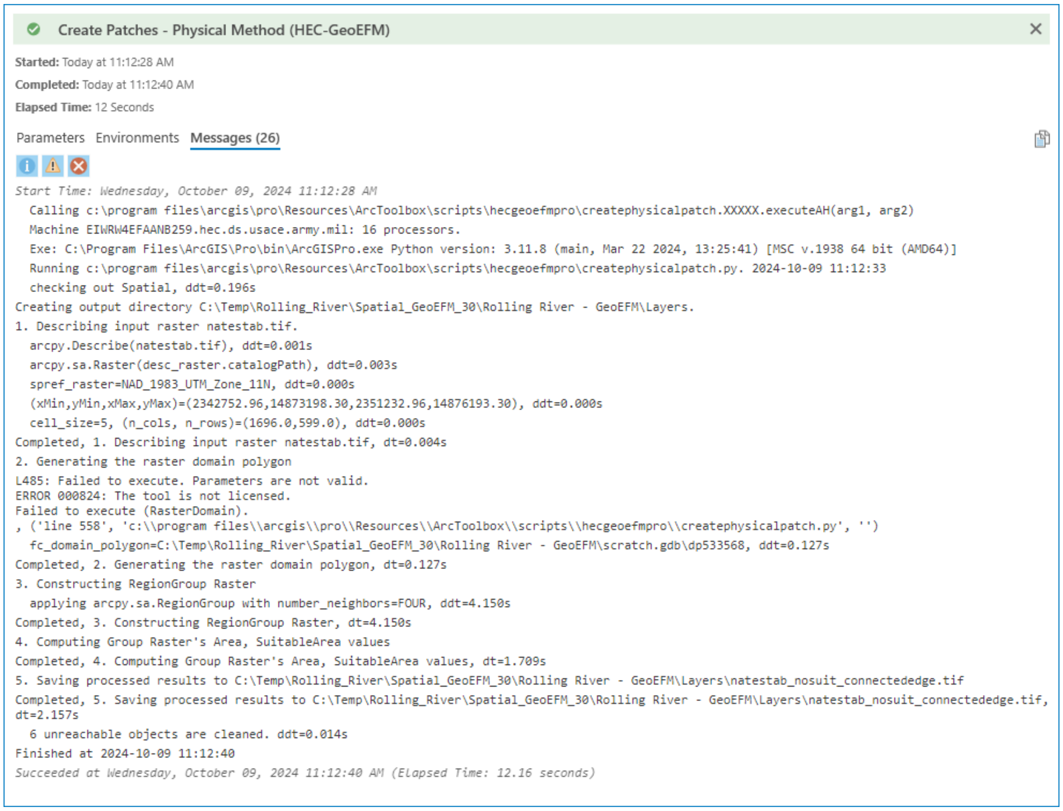


Figure 27. Applying *Patches - Create Patches - Physical Method* involves several steps.

Figure 28 shows a patch raster using the *Physical* patch method for Riparian tree establishment that was generated using the *Connected Edge* setting for defining patches. The small thumbnail image in the map portion of the figure shows five patches (wholly or partially circled) that would have been identified as a single patch if the *Connected Point* setting was used.

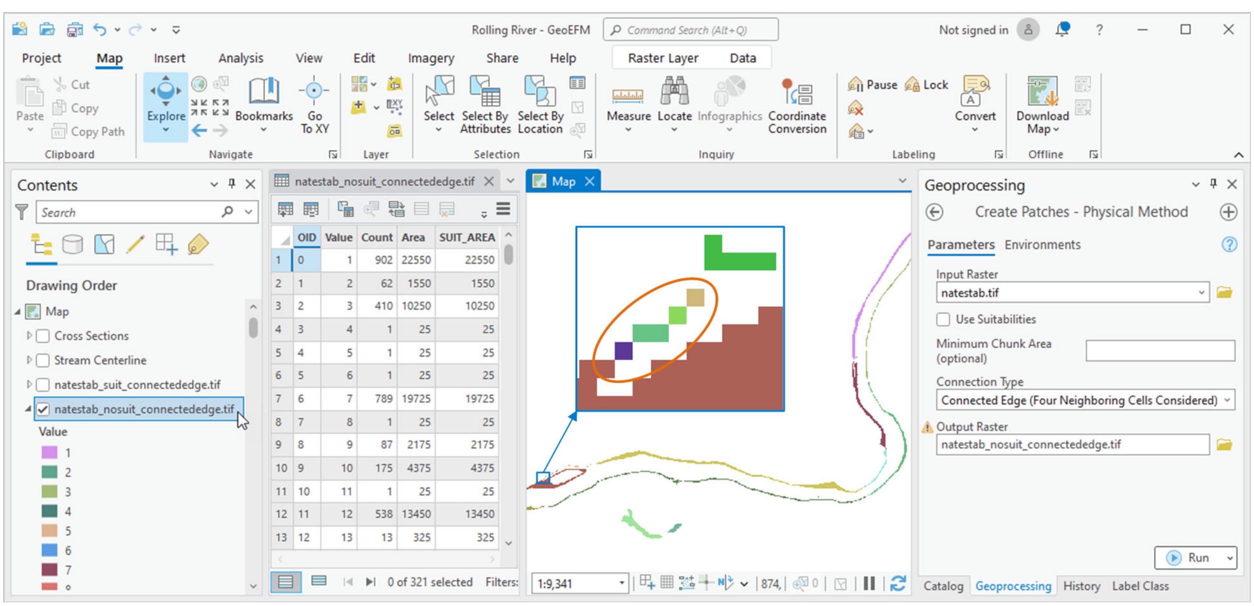


Figure 28. Output of the *Patches - Create Patches - Physical Method* with the *Connected Edge* method.

CHAPTER 7

GeoEFM: Splicing

In GeoEFM, the *Splicing* toolset assists with creation of habitat mosaics that are comprised of pieces from multiple layers. For example, *Splicing* could be used to create a mosaic that includes habitat in a tributary stream and its receiving river. In EFM, the stream and river would be assessed separately for the same habitat relationship because each has a different flow regime. Statistical results would be simulated with a hydraulics model to generate maps for the stream reach and for the river reach. *Splicing* tools in GeoEFM would assist with merging the two layers spatially to create a single map for that habitat type. The basic process for *Splicing* is to make a *Splicing Configuration* and then apply it to a set of layers. Though not shown in the images below, splicing can be done for overlapping and discontiguous areas.

GeoEFM executes splices per the following user specifications: *Configuration*, *Snap Raster*, and *Overlap Method*. Configurations for the *Hydraulics Model Method* and *Polygons Method* are detailed later in this guidance. The snap raster deals with offsets and cell size differences amongst the splice layers. Four options are provided for handling areas of overlap: proceed with maximum value, proceed with minimum value, first to splice, and last to splice (Figure 29).

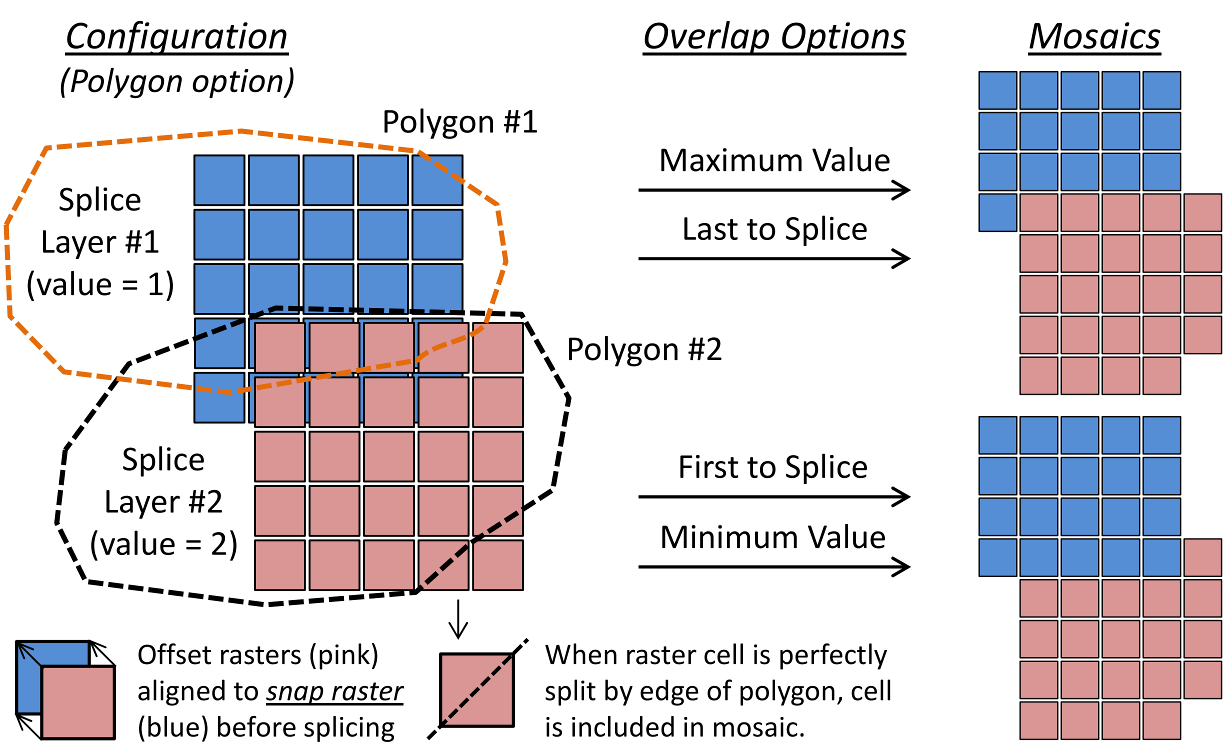


Figure 29. A splice is based on a configuration, a snap raster, and an overlap option. The resulting mosaic reflects all of these user-selections.

The *Splicing* toolset has two methods and five tools (Figure 30). The first method is the *Splicing - Hydraulics Model Method* and has three tools. The second method is the *Splicing - Polygon Method* and has two tools. Tools can be started via a double-left-click or via the right-click *Open* menu option.

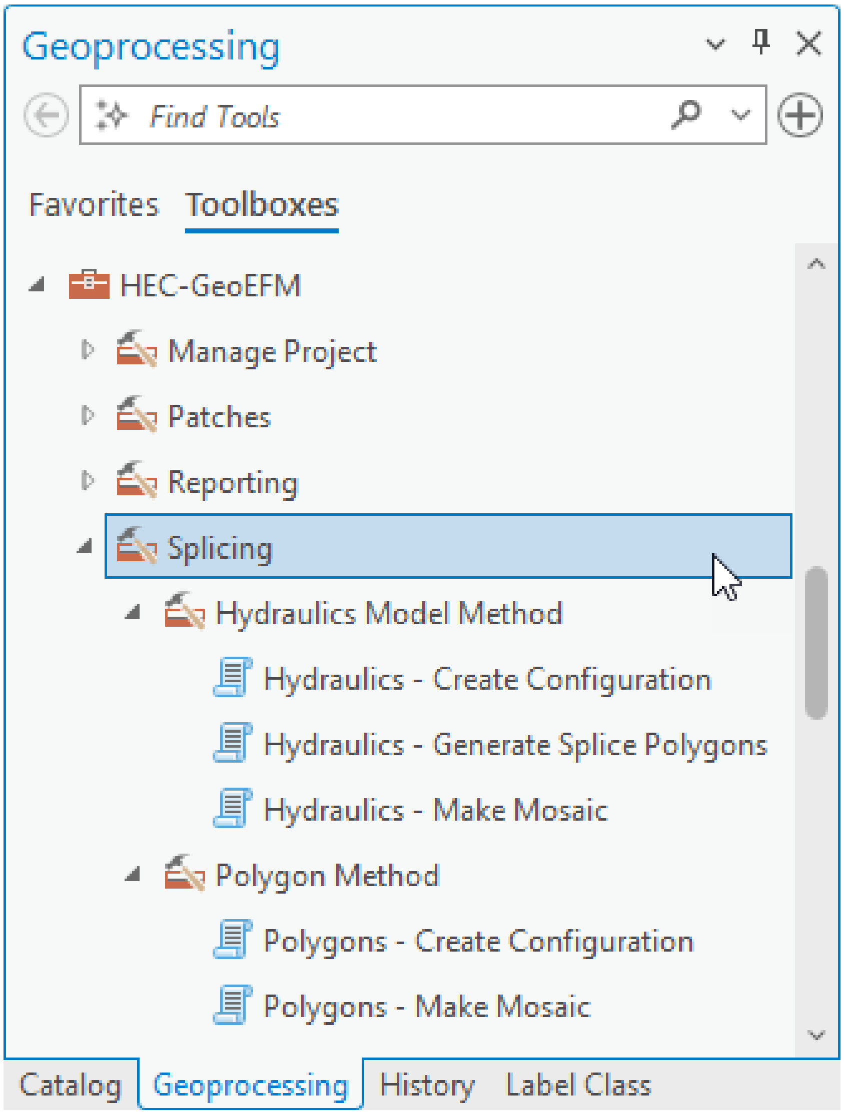


Figure 30. The *Splicing* toolset has two methods and five tools.

7.1 Hydraulics Model Method

The *Splicing - Hydraulic Model Method* has three tools that must be run in sequence to successfully make a habitat mosaic. The tools are *Hydraulics - Create Configuration*, *Hydraulics - Generate Splice Polygons*, and *Hydraulics - Make Mosaic*. The third tool can be run as many times as desired with new combinations of user-specified settings after the first two tools are completed.

7.1.1 Hydraulics - Create Configuration

Hydraulics - Create Configuration is a simple tool that generates a table to store the parameters associated with a hydraulics-based splice. When the tool is started, the user is prompted to enter a name for the table (Figure 31).

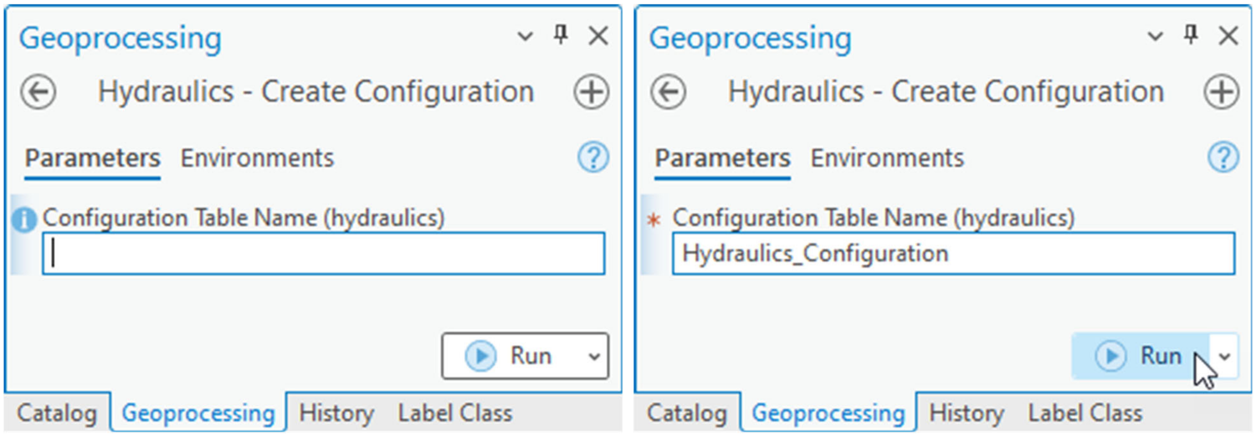


Figure 31. *Hydraulics - Create Configuration* is used to generate a table for splicing parameters.

Clicking *Run* generates the corresponding table in the project geodatabase (Figure 32).

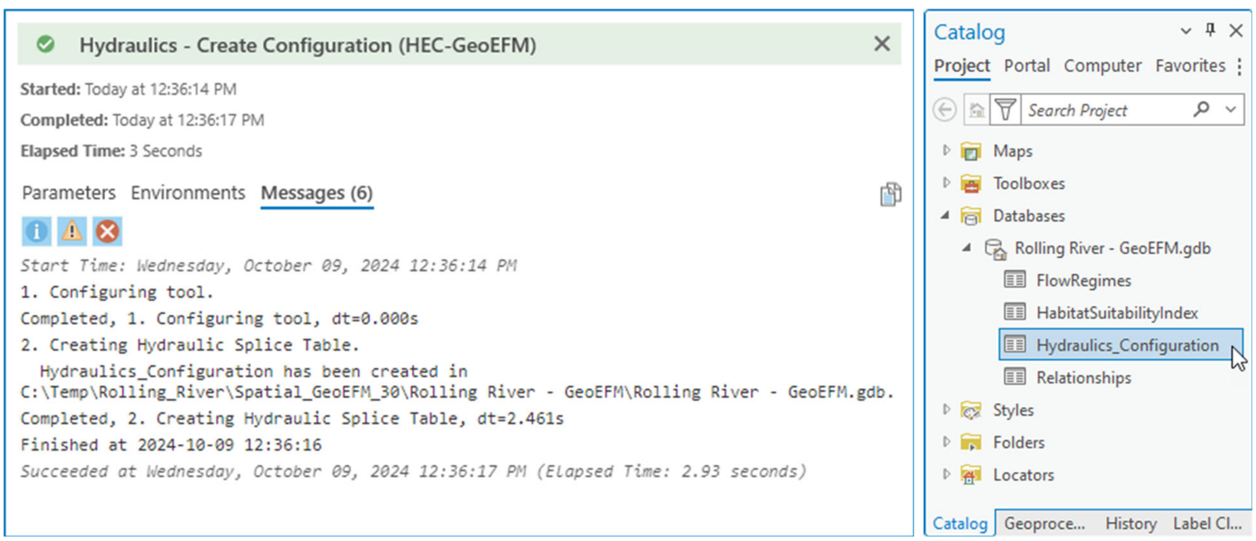
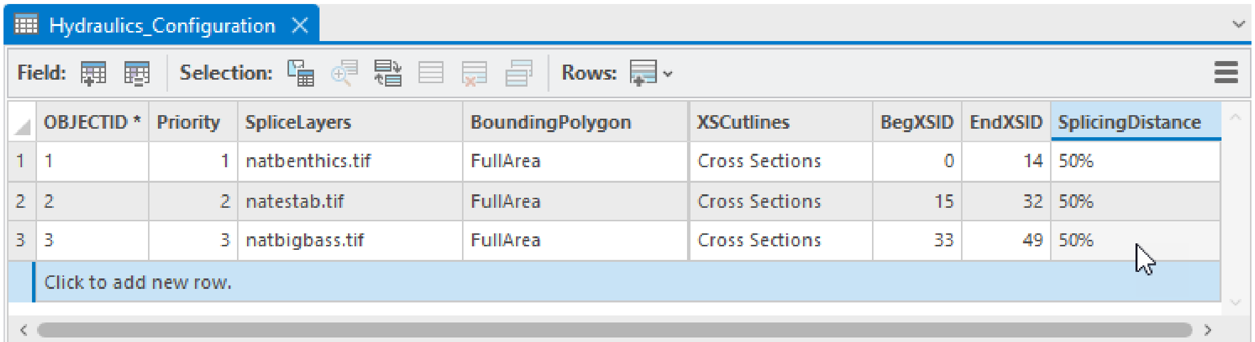


Figure 32. Applying *Hydraulics - Create Configuration* generates a table for splicing parameters.

After the table is generated, it can be populated by the user with the splicing parameters (Figure 33). Users specify *Priority*, the *Splice Layers* to be merged, the extent of the mosaic (*BoundingPolygon*), the cross section layer (*XSCutlines*), the beginning and ending cross sections for each area of the splice (*BegXSID* and *EndXSID*), and the location between cross sections at which each splice is to be done (*SplicingDistance*). The bounding polygon can be defined using a feature class from the project geodatabase or a shape file in the project map contents.



	OBJECTID *	Priority	SpliceLayers	BoundingPolygon	XSCutlines	BegXSID	EndXSID	SplicingDistance
1	1	1	natbenthics.tif	FullArea	Cross Sections	0	14	50%
2	2	2	natestab.tif	FullArea	Cross Sections	15	32	50%
3	3	3	natbigbass.tif	FullArea	Cross Sections	33	49	50%
	Click to add new row.							

Figure 33. A *Configuration Table* is a set of splicing parameters used to create habitat mosaics.

When done, save edits via the *Table - Save* feature in Pro. This table "edit and save" functionality is entirely in Pro and does not require the use of any GeoEFM tools. The saved table will be available for use in the *Hydraulics - Generate Splice Polygons* tool.

7.1.2 Hydraulics - Generate Splice Polygons

Hydraulics - Generate Splice Polygons is a tool that creates a polygon feature class for hydraulic splicing based on the splicing parameters defined in the *Configuration Table*. When started, the tool opens an interface prompting the user to pick the *Configuration Table* to use and to name the *Output Polygon Feature Class* (Figure 34).

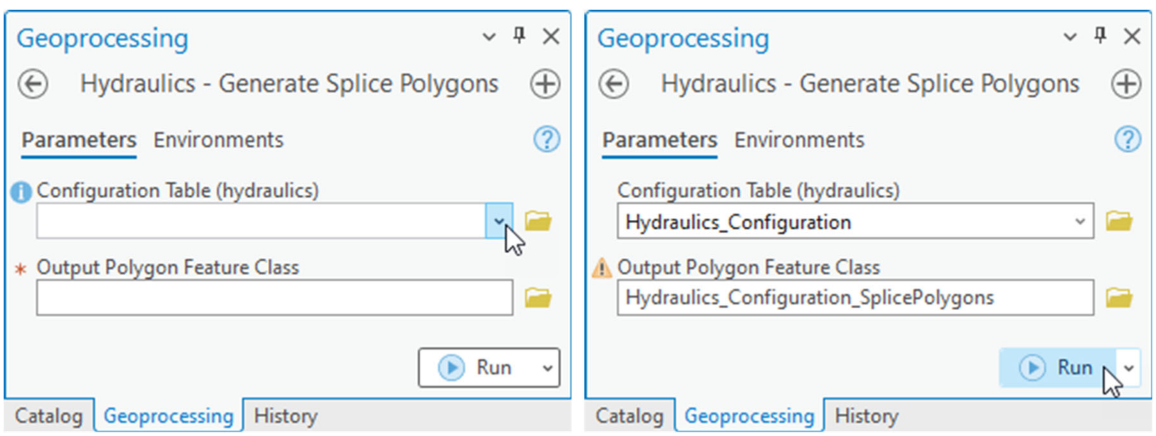


Figure 34. *Hydraulics - Generate Splice Polygons* is used to generate a table for splicing parameters.

Clicking *Run* generates the corresponding feature class in the project geodatabase (Figure 35).

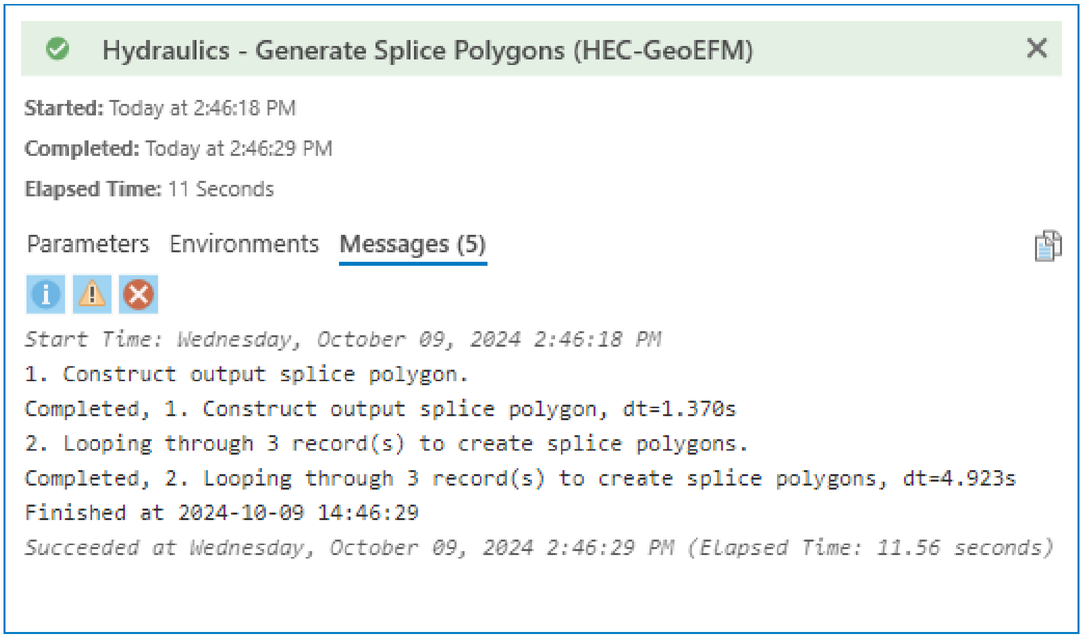


Figure 35. Applying *Hydraulics - Generate Splice Polygons* generates a feature class for splicing.

The resulting feature class is a required input for the *Hydraulics – Make Mosaics* tool and is also a helpful visual that can be added to the map (from the project geodatabase) to confirm that splice locations are configured as intended (Figure 36).

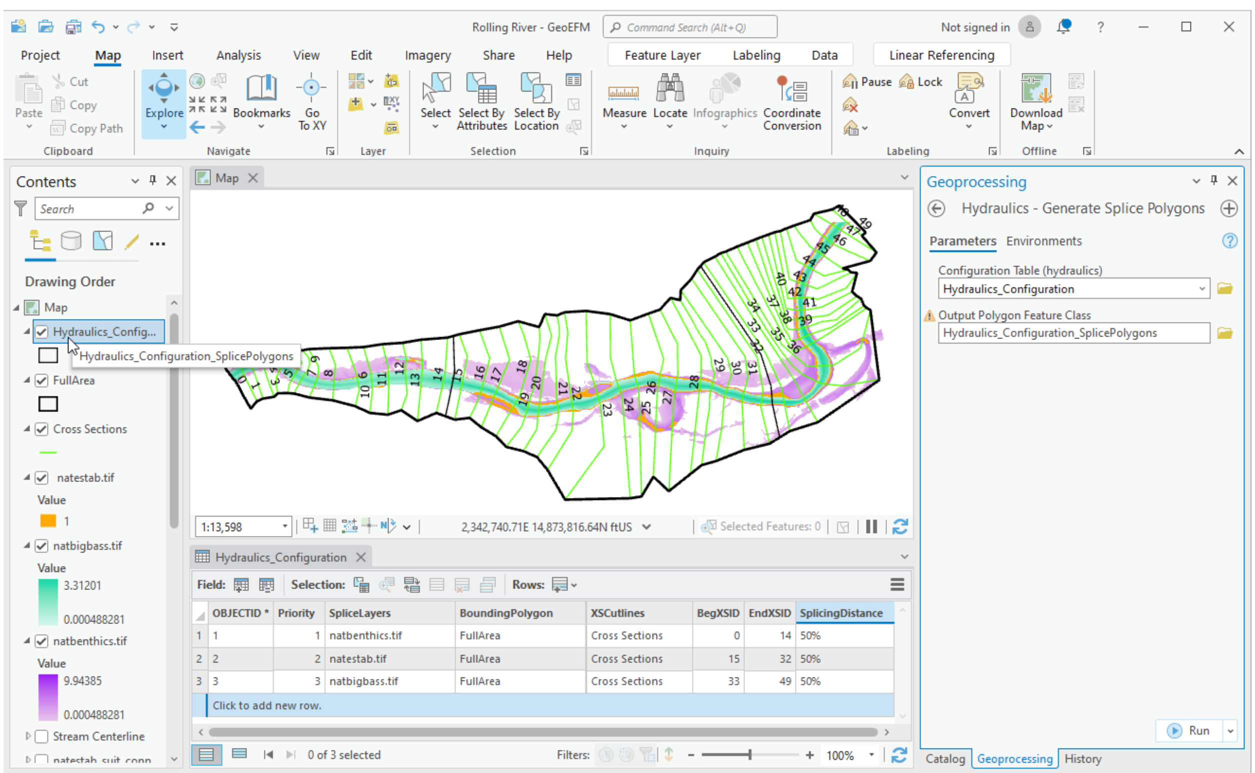


Figure 36. A *Configuration Table* is a set of splicing parameters used to create habitat mosaics.

Functionally, the Hydraulic Model Method behaves much like the Polygon Method. The only difference is that polygon configurations use already drawn polygons and polygons are generated for hydraulic model configurations based on the specified bounding polygon, cross section ranges, and splicing distance. For example, in Figure 33, the first row of the splicing configuration table has a bounding polygon, a cross section range from 0 to 14 (cross section 0 is the leftmost cross section and shares an edge with the bounding polygon), and a splicing distance of 50%. To generate the corresponding polygon, the cross section range is extended by the splicing distance. In other words, cross section 14 is extended to the right 50% of the distance between cross sections 14 and 15 (cross section 0 would be extended to the left but is constrained by the bounding polygon). Those polylines (cross section 0 and cross section "14.5") are joined with the edges of the bounding polygon to form a polygon for the natbenthics splice layer. Similarly, the second row in the splicing configuration table would result in a polygon from cross sections 14.5 to 32.5 joined with the bounding polygon for the natestab splice layer. The third row would result in a polygon from cross sections 32.5 to 49 (cross section 49 is the rightmost cross section and cannot be extended past the edge of the bounding polygon) joined with the bounding polygon for the natbigbass splice layer. Splicing would stitch the splice layers associated with each generated polygon to form a single mosaic.

7.1.3 Hydraulics - Make Mosaic

Hydraulics - Make Mosaic generates a habitat mosaic. When started, the tool opens an interface prompting the user to pick the *Splice Polygon* feature class, *Snap Raster*, and *Overlap Method* to apply during splicing. A default output name of "SplicePolygon_OverlapMethod.tif" is provided for the mosaic but can be modified by the user (Figure 37).

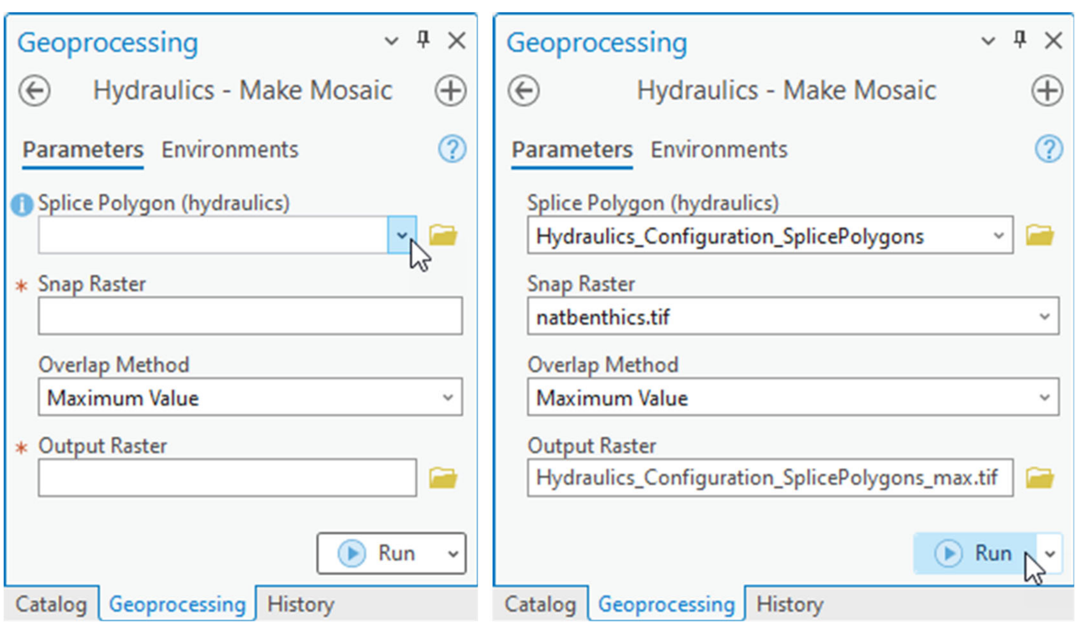


Figure 37. *Hydraulics - Make Mosaic* is used to generate habitat mosaics.

Clicking *Run* (Figure 38) generates the habitat mosaic and adds it to the map (Figure 39).

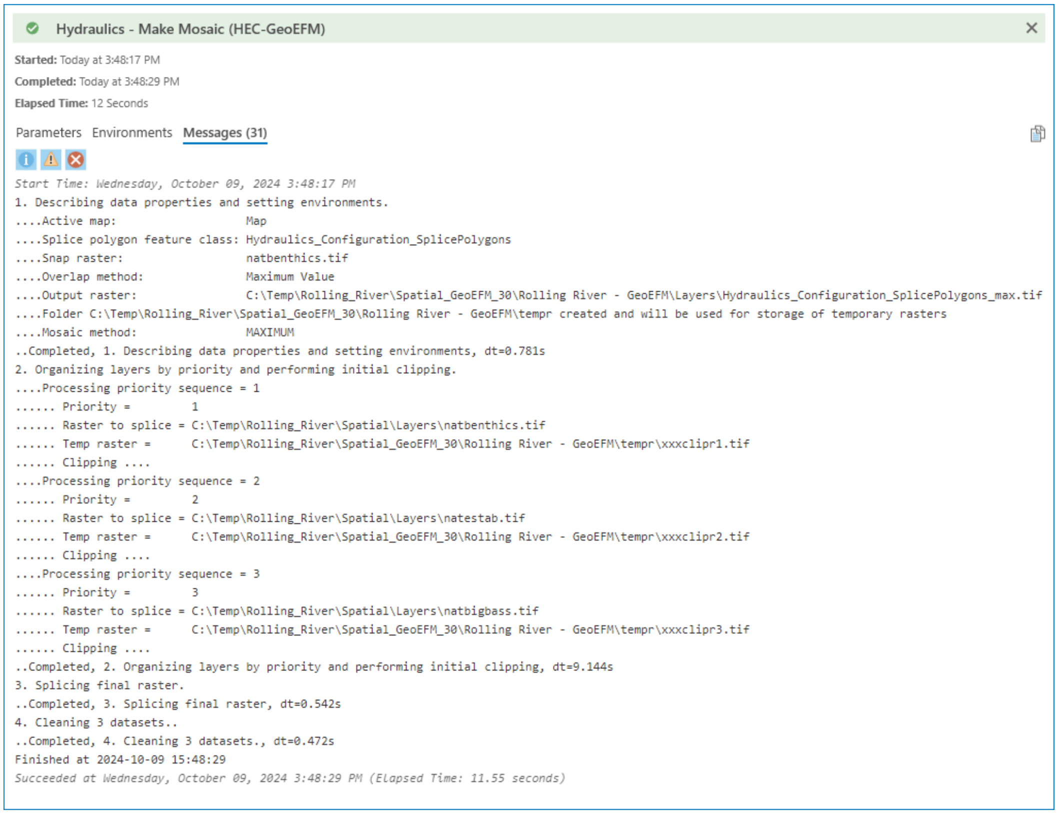


Figure 38. Applying *Hydraulics – Make Mosaic* generates a habitat mosaic.

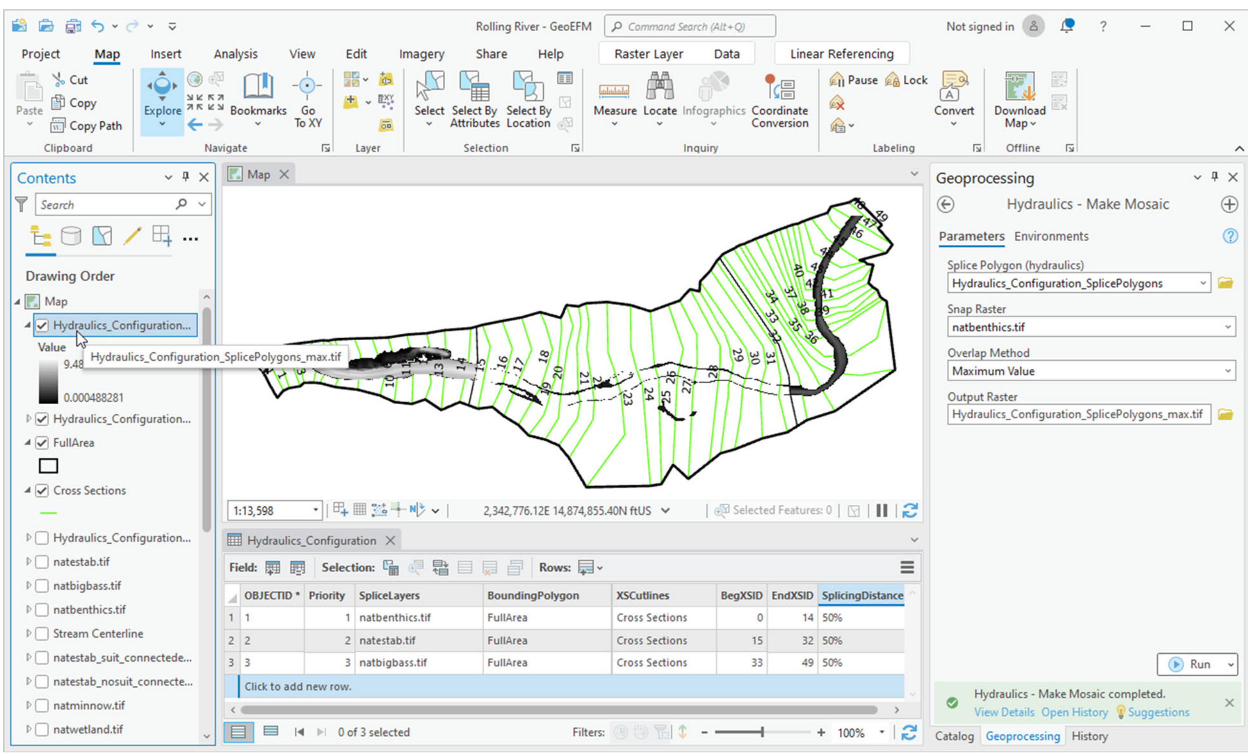


Figure 39. Habitat mosaics are comprised of pieces from multiple raster layers.

7.2 Polygon Method

Conceptually, mosaics made with the *Polygon* option are much like quilts. Polygons are used to define the areas of the quilt and the layers associated with those areas serve as the fabrics that are stitched together to form the mosaic. Polygons are selected for use according to their layer (*mask layer*), *attribute*, and *value*. *Splice layers* are associated with the individual polygons. Figure 27 shows a polygon configuration and corresponding preview with 3 polygons. Splicing would stitch the splice layers associated with each polygon together to form a single mosaic.

The *Splicing - Polygon Method* has two tools that must be run in sequence to successfully make a habitat mosaic. The tools are *Polygons - Create Configuration* and *Polygons - Make Mosaic*. The second tool can be run as many times as desired with new combinations of user-specified settings after the first tool is completed.

7.2.1 Polygons - Create Configuration

Hydraulics - Create Configuration is a simple tool that generates a table to store the parameters associated with a polygon-based splice. When the tool is started, the user is prompted to enter a name for the table (Figure 40).

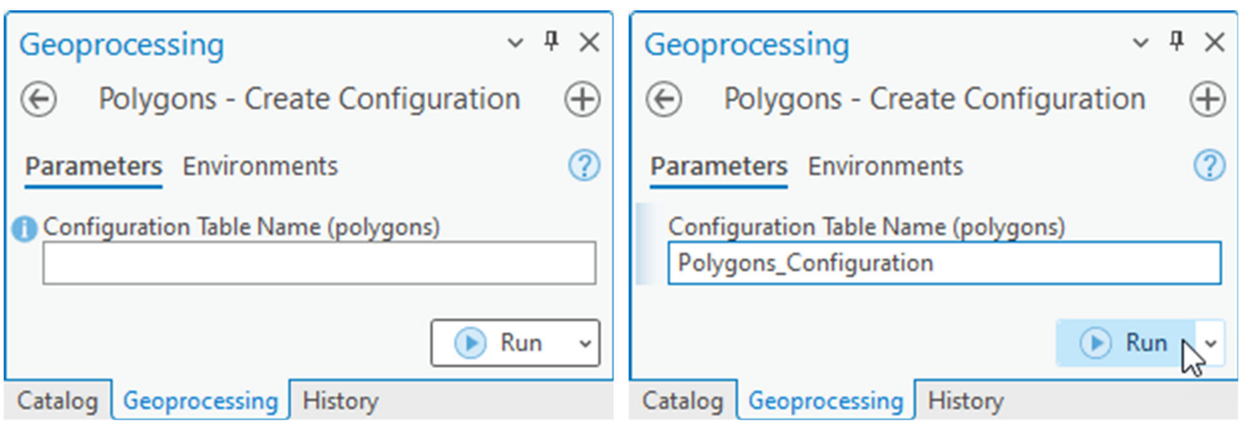


Figure 40. *Polygons - Create Configuration* is used to generate a table for splicing parameters.

Clicking *Run* generates the corresponding table in the project geodatabase (Figure 41).

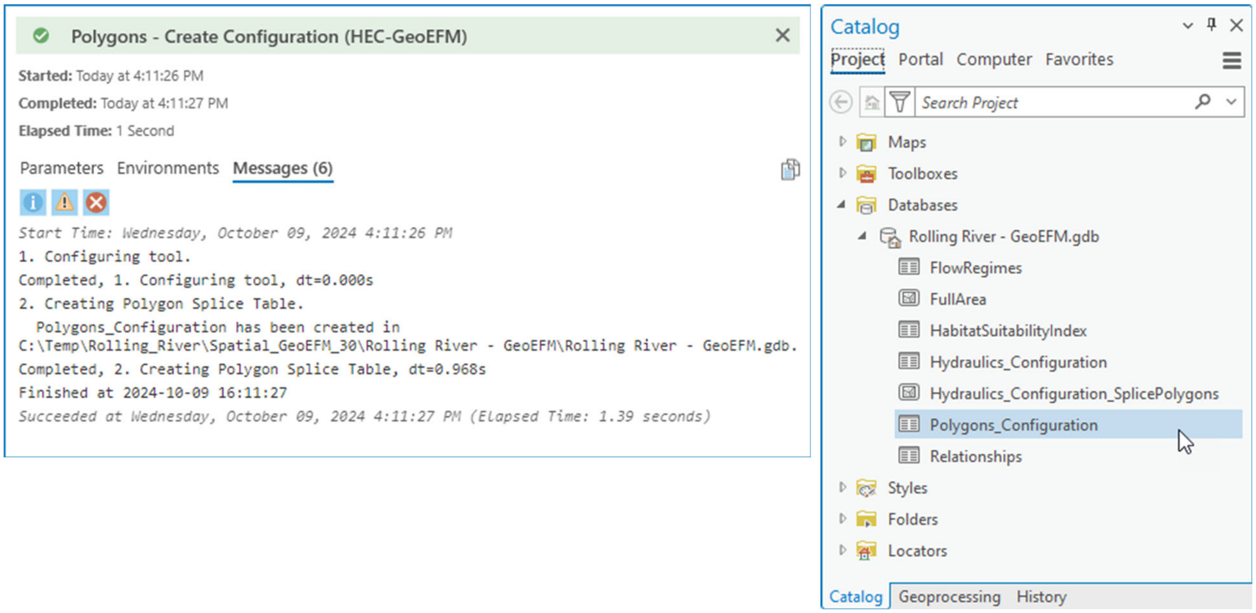
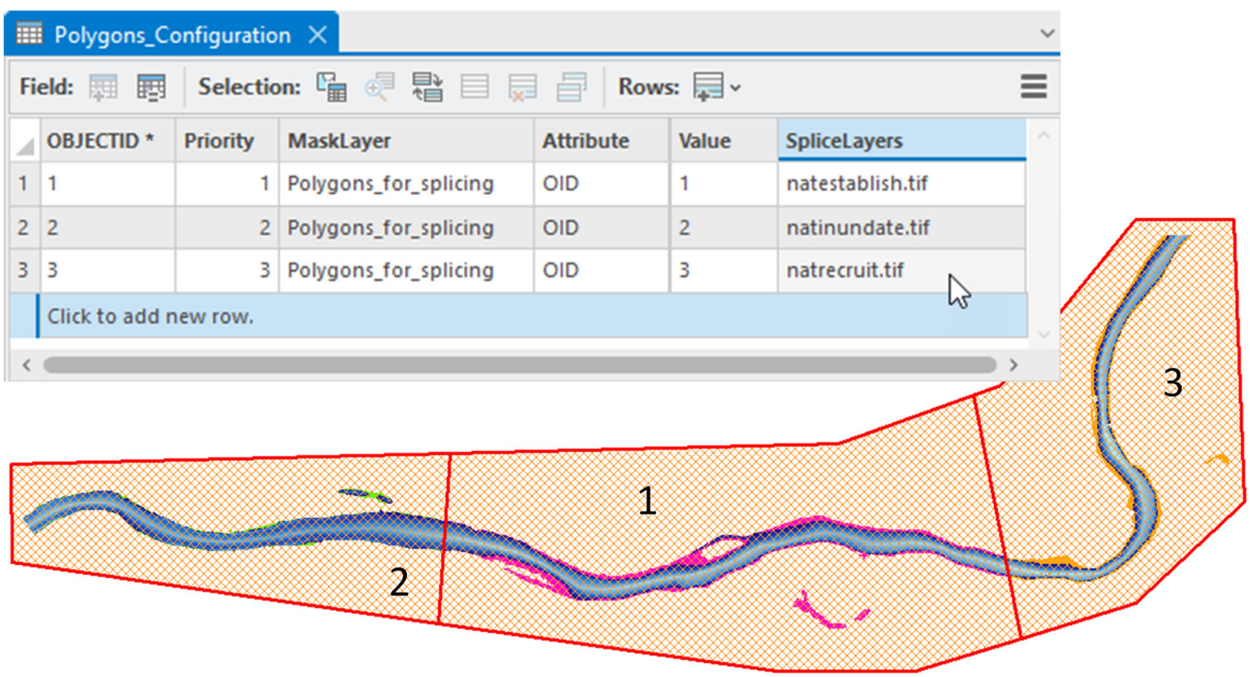


Figure 41. Applying *Polygons - Create Configuration* generates a table for splicing parameters.

After the table is generated, it can be populated by the user with the splicing parameters (Figure 42). Users specify *Priority*, the polygon areas associated with the mosaic (layer, Attribute, and Value), and the layers to be spliced (*SpliceLayers*). OBJECTID is filled by the software automatically. Polygon areas can be defined using feature classes from the project geodatabase or from shape files in the project map contents.



	OBJECTID *	Priority	MaskLayer	Attribute	Value	SpliceLayers
1	1	1	Polygons_for_splicing	OID	1	natestablish.tif
2	2	2	Polygons_for_splicing	OID	2	natinundate.tif
3	3	3	Polygons_for_splicing	OID	3	natrecruit.tif

Figure 42. A *Configuration Table* is a set of splicing parameters used to create habitat mosaics.

When done, save edits via the *Table - Save* feature in Pro. This table "edit and save" functionality is entirely in Pro and does not require the use of any GeoEFM tools. The saved table will be available for use in the *Polygons - Make Mosaic* tool.

7.2.2 Polygons - Make Mosaic

Polygons - Make Mosaic generates a habitat mosaic. When started, the tool opens an interface prompting the user to pick the *Configuration Table*, *Snap Raster*, and *Overlap Method* to apply during splicing. A default output name of "ConfigurationTable_OverlapMethod.tif" is provided for the mosaic but can be modified by the user (Figure 43).

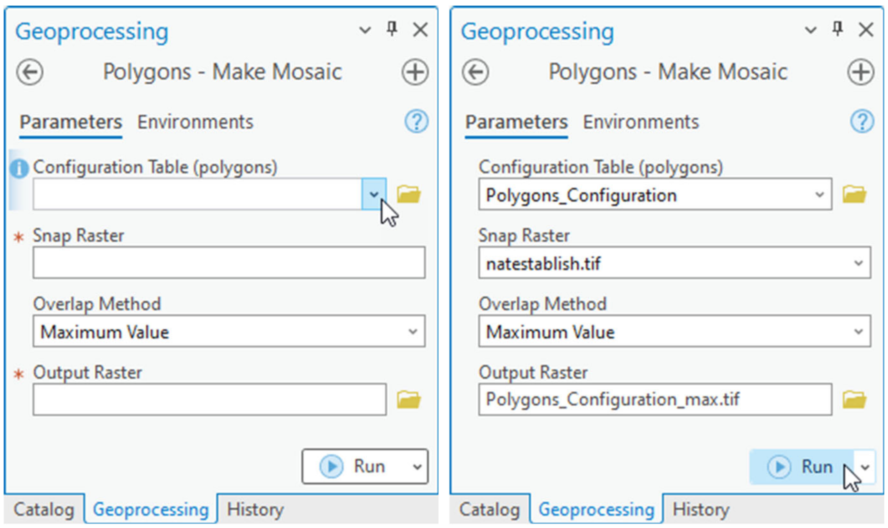


Figure 43. *Polygons - Make Mosaic* is used to generate habitat mosaics.

Clicking *Run* (Figure 44) generates the habitat mosaic and adds it to the map (Figure 45).

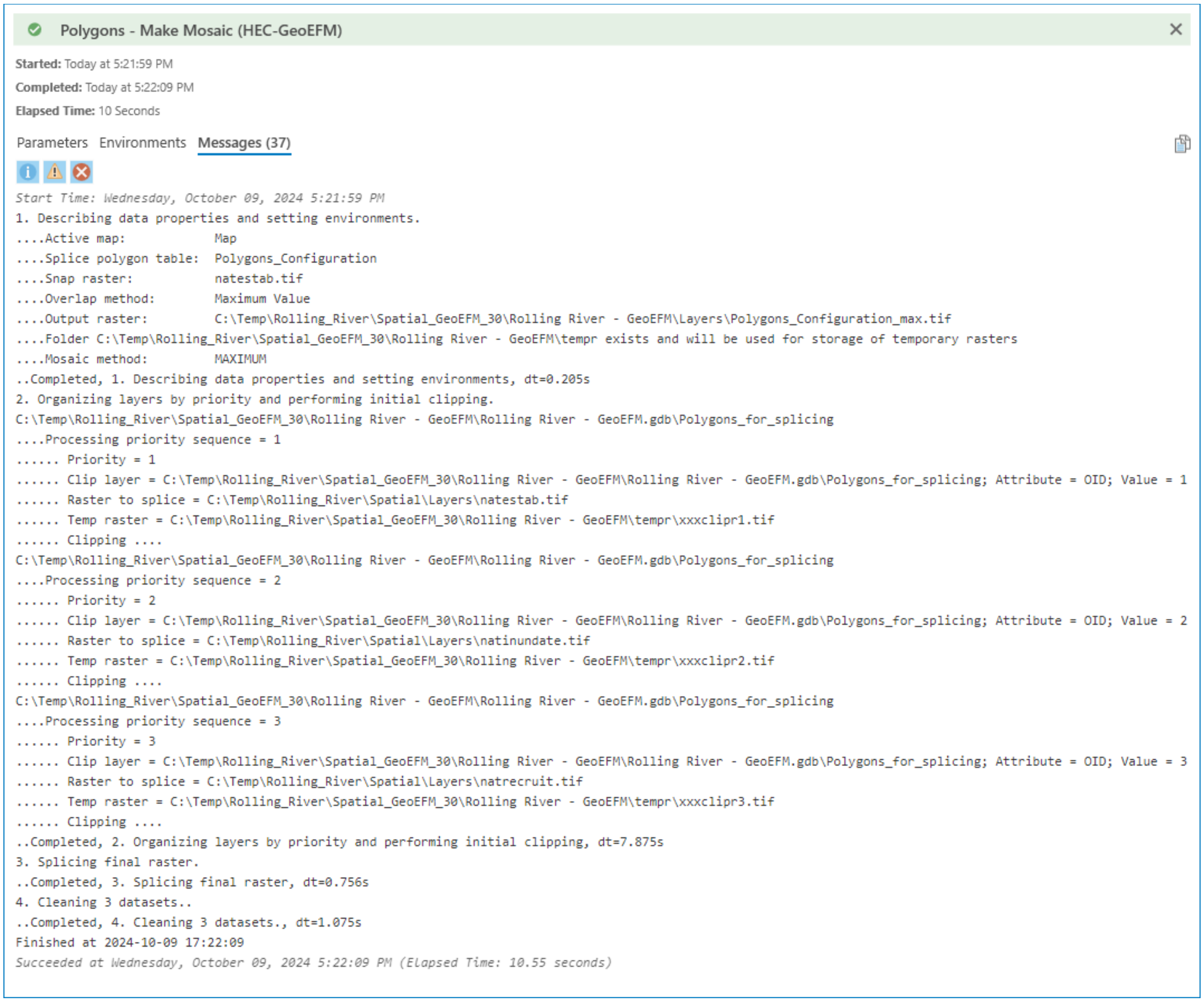


Figure 44. Applying *Polygons - Make Mosaic* generates a habitat mosaic.

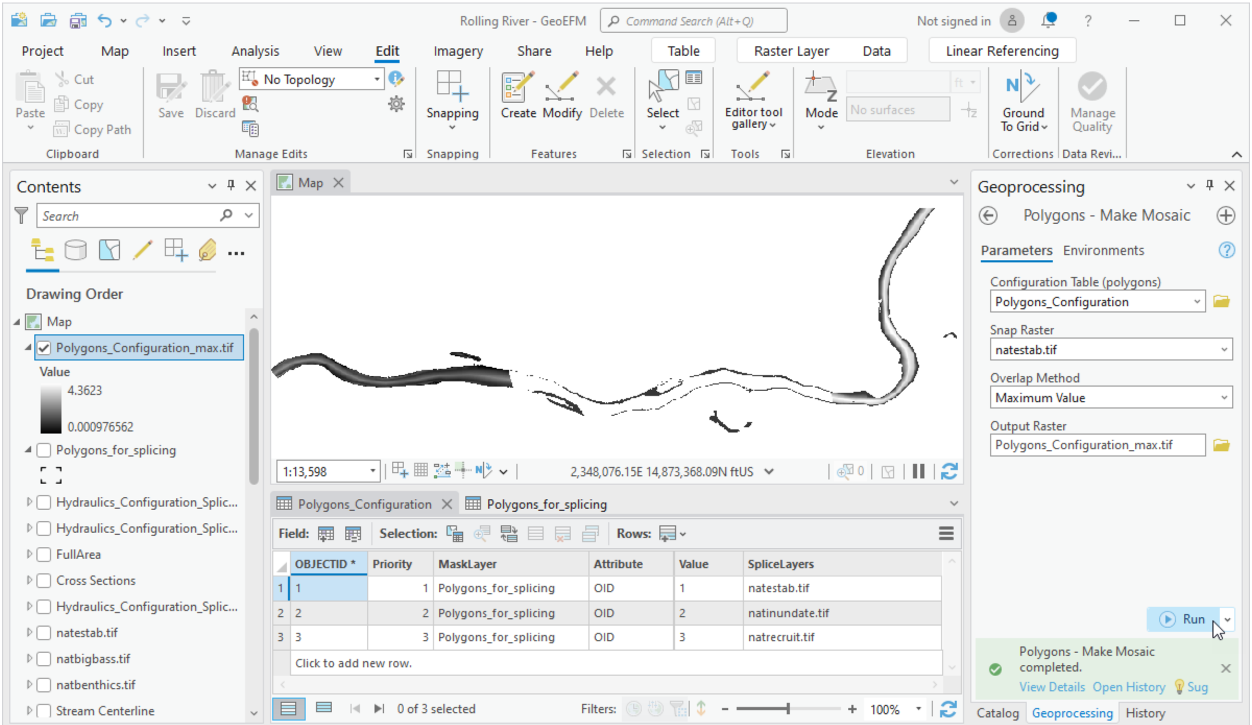


Figure 45. Habitat mosaics are comprised of pieces from multiple raster layers.

CHAPTER 8

Conclusions

GeoEFM is used in the spatial analyses phase of the EFM process to help manage and assess spatial data layers and to quantify the amount, quality, connectivity, and functionality of ecological habitats generated by different water management or ecosystem restoration scenarios.

GeoEFM was developed by HEC and the Environmental Systems Research Institute, Inc. (ESRI) in recognition of both the power of GIS and the importance of ecological considerations in water systems.

A demonstration project for GeoEFM 3.0 is provided as part of the installation materials for EFM 6.0^{+} and includes an EFM project, a river hydraulics model, a GeoEFM project, and many of the layers shown herein. EFM and GeoEFM are available for download via https://www.hec.usace.army.mil/.

To access the GeoEFM demonstration project, install EFM and use the EFM *Help - Install Demonstration Project…* menu option to install a copy of the demonstration project. After the demonstration project is installed, the GeoEFM project can be opened with ArcGIS Pro and the GeoEFM *Manage Project - Synchronize with EFM Project* tool to synchronize the EFM and GeoEFM projects. The relative path and file name of the GeoEFM project is \Rolling_River\Spatial_GeoEFM_30\Rolling River - GeoEFM\Rolling River - GeoEFM.aprx.

Please note that the demonstration project folder for EFM 6.0 / GeoEFM 3.0 is titled "Rolling_River". This is the first version of GeoEFM (i.e., 3.0) to have demonstration project materials included as part of the EFM demonstration project. Earlier versions of GeoEFM had separate demonstration projects. In GeoEFM 1.0, the demonstration project folder was titled "Rolling River - GeoEFM" and in GeoEFM 2.0 it was titled "RR_GeoEFM".

The project management, habitat area and habitat suitability features of GeoEFM 3.0 support many habitat considerations commonly done in ecological restoration and management efforts and the habitat functionality and splicing features allow for more detailed analyses such as habitat bottlenecks, nesting sites, and habitat provision in diverse aquatic systems. Future development plans include habitat density measures for assessing habitat connectivity, calculators for considering spatial habitat preferences of biota and cumulative variables, incorporation of spatial hypothesis and confidence tracking, and incorporation of ecological indices based on habitat areas.

HEC-GeoEFM has been certified for use in USACE Planning Studies by USACE Headquarters as recommended by the National Ecosystem Planning Center of Expertise as being sound in contemporary theory, computationally correct, usable for Civil Works planning, and compliant with USACE policy.

Anyone with other ideas for enhancing GeoEFM is encouraged to submit suggestions to the EFM team via email at hec.efm@usace.army.mil.

CHAPTER 9

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