US Army Corps
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Hydrologic Engineering Center

HEC-GeoEFM

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

User's Manual

Version 2.0
May 2024

CPD-80b

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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 an extension for ArcMap 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. Amit Sinha, formerly ESRI, and Zichuan Ye, ESRI, contributed to design and performed the programming. Ms. Christine Dartiguenave and Dr. Dean Djokic, ESRI, helped manage the project and leads ESRI participation. Mr. Ezra Bosworth-Ahmet, ESRI, assisted with software review and testing. Ms. Kelsey Walak, Sacramento District USACE, assisted with update of user guidance and demonstration project. Ms. Lea Adams was Chief of the Water Resource Systems Division and Mr. Chris Dunn was Director of HEC at the time of completion and public release of GeoEFM 2.0.

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 an extension 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.

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 several spatial functions that are commonly used in EFM applications:

- Entry, import, archival, editing, and viewing of habitat suitability indices.
- Use and display of spatial statistics
- Splicing of habitat maps for systems of wetlands, streams, and rivers
- Calculator functions for raster queries
- Application of habitat suitability indices

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 view statistical results from EFM spatially or working with habitat maps produced by the linked use of EFM and river hydraulics models.

A brief description of EFM is provided in Chapter 2 of this manual. Please refer to the EFM Quick Start Guide (USACE 2020) for more background about EFM as well as the hydrologic and ecologic scenarios described herein. The reference for that document follows:

U.S. Army Corps of Engineers (USACE). 2020. HEC-EFM: Ecosystem Functions Model - Quick Start Guide. CPD-80a. Hydrologic Engineering Center, Davis, CA.

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 1). 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.

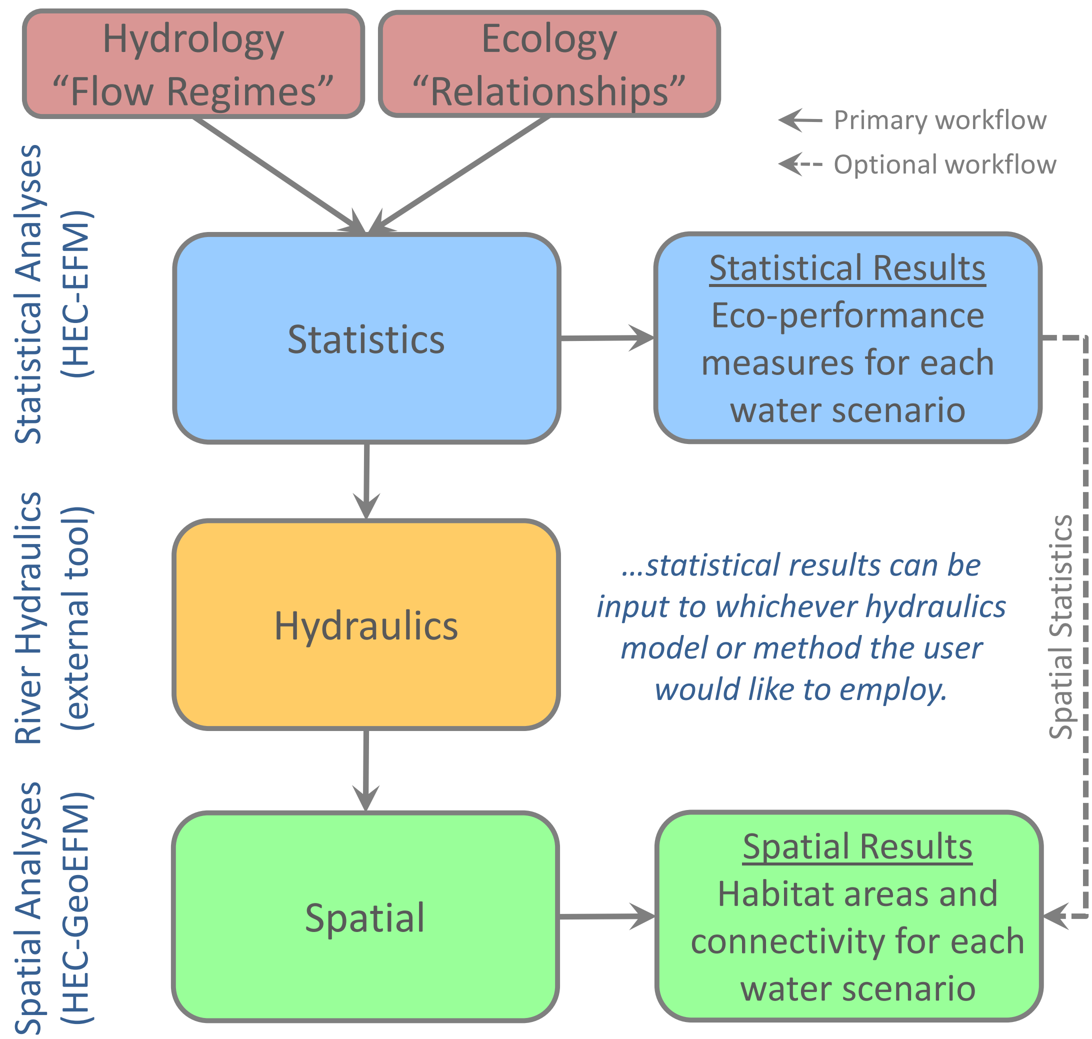


Figure 1. Statistics, hydraulics, and spatial phases of the EFM process. GeoEFM is used in the spatial analyses phase to investigate habitat areas and habitat connectivity produced by different restoration or water management scenarios.

"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 is a toolbar in ArcMap 10.1, 10.8.1, and 10.8.2 for Windows. GeoEFM 2.0 is used with an ArcMap **advanced level license**. Spatial Analyst and 3D Analyst extensions must be installed and activated. There is also a software component, the Water Utilities Application Framework, which provides functions that are required for use of GeoEFM. The Water Utilities Application Framework is installed, verified, or updated as needed by the GeoEFM installer.

After installation, the GeoEFM toolbar can be activated via right clicking on the toolbar area of the ArcMap interface and selecting the "HEC-GeoEFM" option (Figure 2).

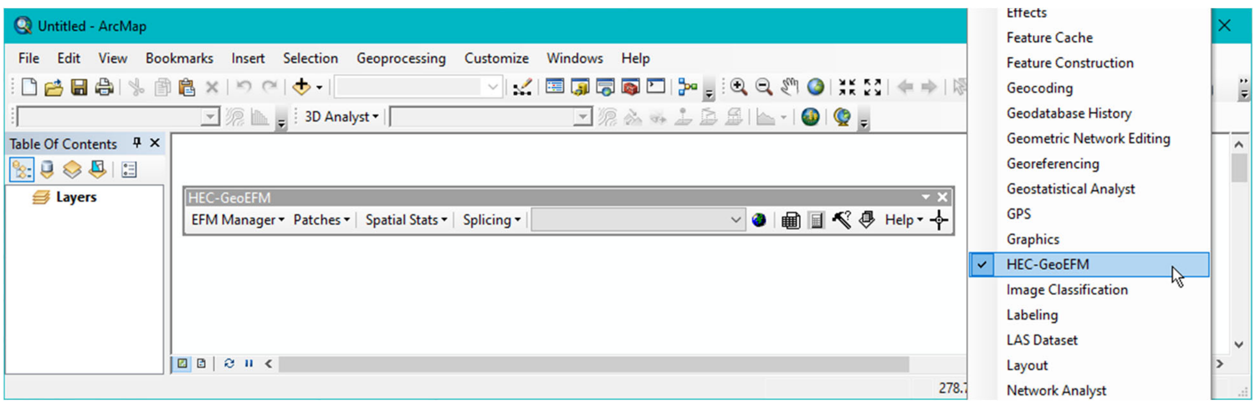


Figure 2. Activating the GeoEFM toolbar.

Typically, GeoEFM applications begin with <u>layers generated during the hydraulic modeling phase</u> of the EFM process as well as <u>other relevant data such as maps of land use, soils, and vegetation</u>. The GeoEFM toolbar (Figure 3) can then be used to organize these layers per the flow regime-relationship structure already established in the EFM project (via the *EFM Manager* menu), navigate this structure (via *View Manager*), compute and compare habitat areas (via *Tabulate Tool*), assess habitat suitability (via *Habitat Suitability Indices* in the *EFM Manager* menu), assess habitat functionality (via *Patches*), view and investigate distributions of metrics (via *Spatial Stats*), query habitat rasters (via *Calculator* and *Batch Calculator*), and create habitat mosaics (via *Splicing*).

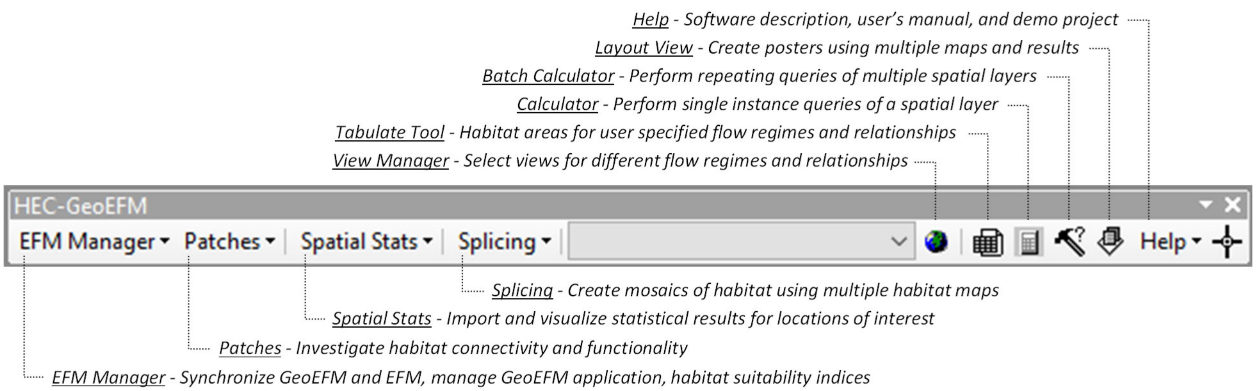


Figure 3. Key components of the GeoEFM toolbar.

CHAPTER 4

GeoEFM: Project Management

A GeoEFM project is simply an ArcMap document and geodatabase (i.e., "ProjectName.mxd" and "ProjectName.mdb" files, respectively) associated with an EFM project, such that ArcMap can access, interpret, and store information from EFM for use in GIS.

Data and project structure are passed from EFM to GeoEFM. This is done through the *EFM Manager – Synchronize Project* menu option. The first time *Synchronize Project* is selected for a new GeoEFM project, the user will be prompted to identify the EFM project to be associated with the GeoEFM project (Figure 4).

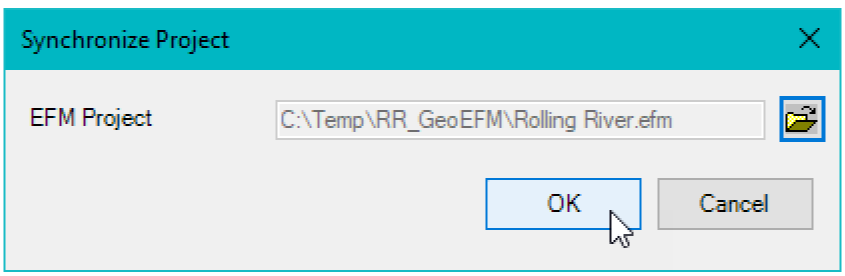


Figure 4. Initial synchronization of an EFM project.

When the *OK* button is clicked, the file and path names of that EFM project are saved as part of the GeoEFM project and **the following information is passed from EFM to GeoEFM: flow regime names and integer identifiers, relationship names and integer identifiers, tag names, and combo relationship names and integer identifiers.** 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 Project* command, GeoEFM retrieves the latest saved version of those data from its parent 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 through a *Synchronize Project* command. When GeoEFM successfully retrieves data from its parent EFM project a message will be provided for acknowledgement by the user (Figure 5).

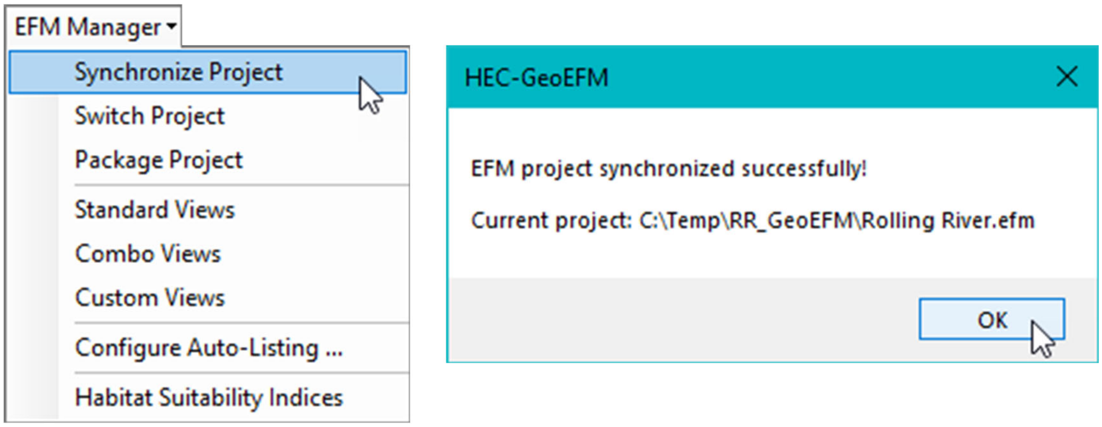


Figure 5. Synchronizing an EFM project.

The *EFM Manager – Switch Project* menu option allows users to redirect a GeoEFM application to a new parent EFM project (Figure 6). This command should be used with caution. *Switch Project* 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 a "switch" according only to the integer identifiers of flow regimes and relationships. Any Views and associated settings that are not an exact identifier match between old and new EFM projects will be removed. The file and path name of the current EFM parent project is provided as the default in the *Switch Project* interface.

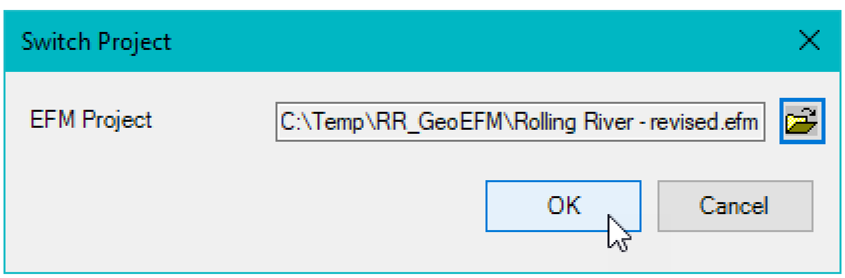


Figure 6. Switching an EFM project.

The *EFM Manager – Package Project* menu option is designed to allow users to quickly organize and compress the spatial data associated with an application of GeoEFM. There are several packaging options (Figure 7), including "full project", which packages all associated data, and "Select flow regimes and relationships…", which allows users to choose particular pairing(s) of flow regimes and relationships for packaging. Be aware that the *Package Project* feature has not been tested thoroughly in the current version of GeoEFM.

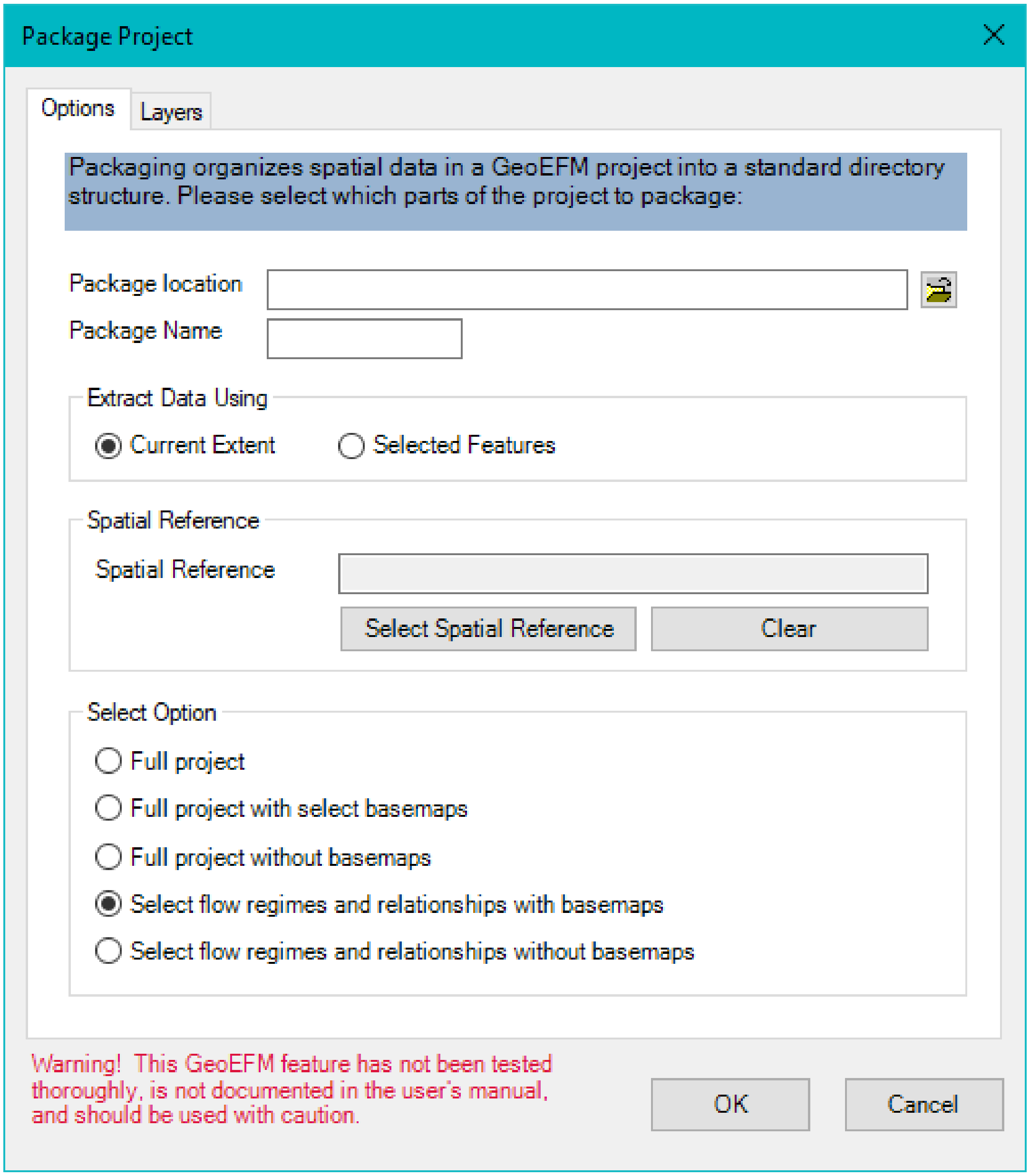


Figure 7. Package project supports selective packaging of layers in GeoEFM projects.

The *EFM Manager – Configure Auto-Listing* menu option allows users to select whether GeoEFM generated layers are automatically associated with their corresponding views when those layers are created (Figure 8). This is a handy time-saving option, especially when working with habitat suitability indices, habitat splicing, and habitat functionality. Each of those GeoEFM features is capable of producing many output layers. Please note that the default auto-listing settings for new projects are set to off.

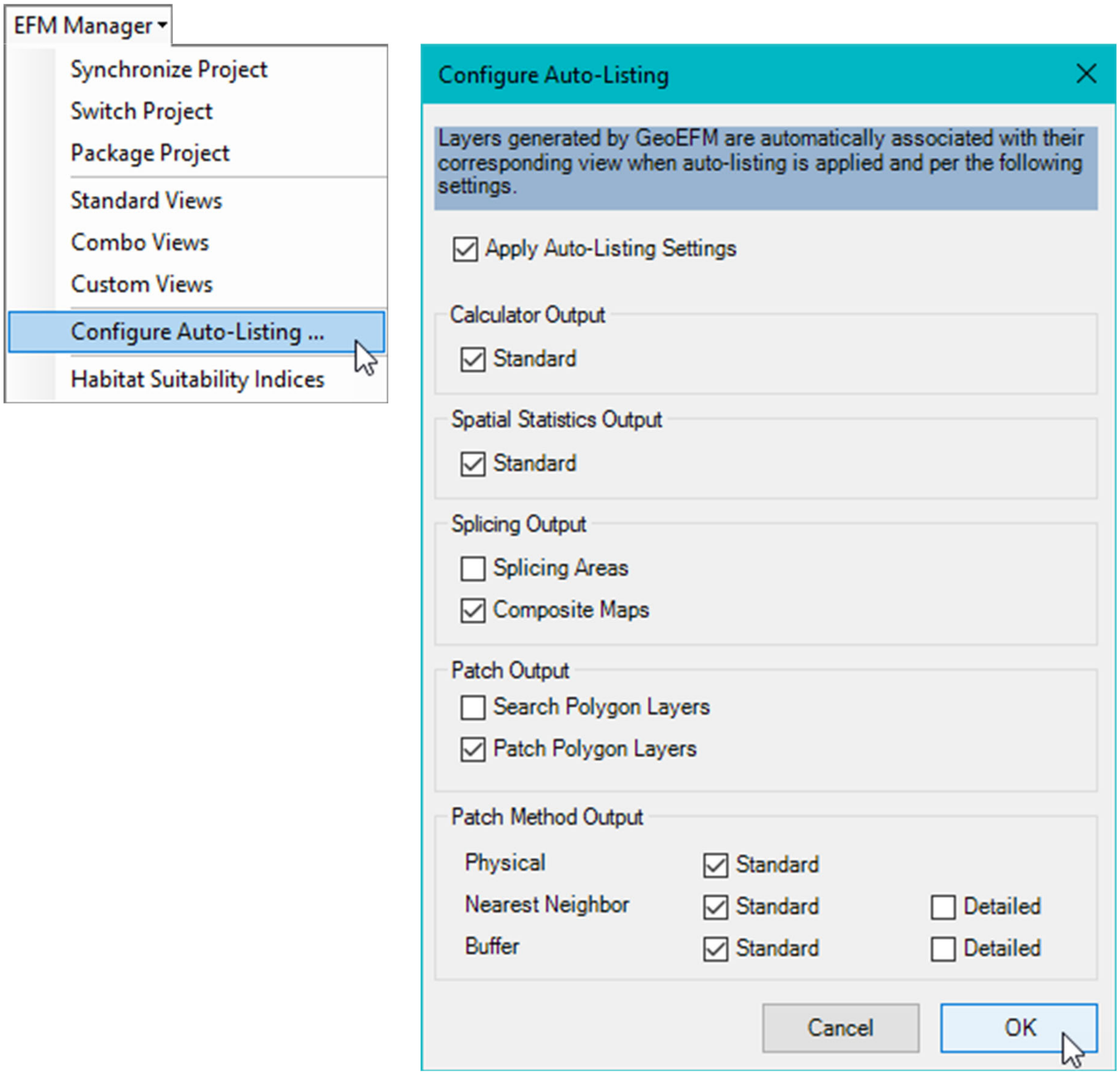


Figure 8. Auto-Listing supports management of layers generated by GeoEFM projects.

Flow regime and relationship names imported from EFM create a structure for GeoEFM applications. Essentially **each pairing of flow regime and relationship acts as a placeholder for a "data frame"**. In ArcMap, a data frame is the fundamental map element of a GIS project – it defines geographic extent, coordinate system, and display properties for the map layers that belong to that data frame. GeoEFM can be used to create data frames, add layers to them, and analyze ecosystem responses generated by different water management scenarios or restoration designs.

CHAPTER 5

GeoEFM: Application

In addition to the data and structure obtained from the EFM project, GeoEFM applications typically 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. These spatial data may be added to the GeoEFM project through the standard *Add Data* mechanisms available in ArcMap or ArcCatalog. Figure 9 shows a GeoEFM project that has been synchronized with an EFM application and has data added to the default "Layers" data frame (statistical results from EFM, which were subsequently used in hydraulic modeling to generate the corresponding layers, are also shown). Many of the layers shown in Figure 9 are included with the GeoEFM demonstration project, which is intended as a helpful starting point for new users (for more information, see section 5.9).

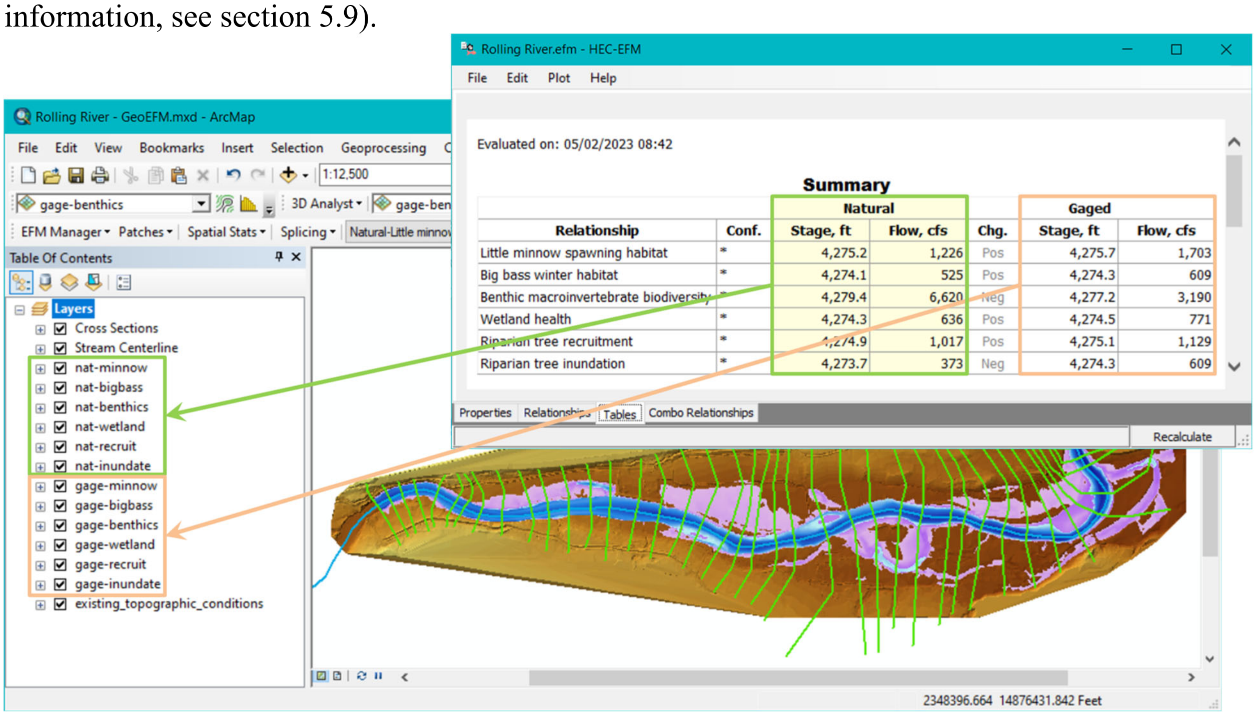


Figure 9. New GeoEFM project with connections to EFM statistical results.

5.1 Managing Spatial Layers (Managers)

The next step in a GeoEFM project is to organize the spatial layers per the structure obtained from the EFM project. Adhering to that structure is advantageous because it will ultimately facilitate the use of GIS functions for groups of spatial layers (e.g., apply a fish spawning criteria to depth grids for multiple water management scenarios) and enable comparisons of habitat areas for user selected flow regimes and relationships.

In GeoEFM, sets of "views" are built per the structure obtained from the EFM project. Each "view" is a data frame. There are three types of views: *Standard, Combo, and Custom*. *Standard Views* and *Combo Views* correspond directly to different parts of the EFM structure. In fact, placeholders for all possible *Standard* and *Combo Views* are made when the EFM and GeoEFM projects are synchronized.

5.1.1 Standard Views

Standard Views are used as workspace for pairings of flow regimes and relationships. When the *EFM Manager – Standard Views* menu option is selected, the *Manage Standard Views* interface activates and allows users to assign layers from the Source View to the Destination Standard View. Layers are assigned to the data frame associated with the Destination Standard View (Figure 10). If that data frame does not exist when layers are assigned, it will be created automatically by GeoEFM.

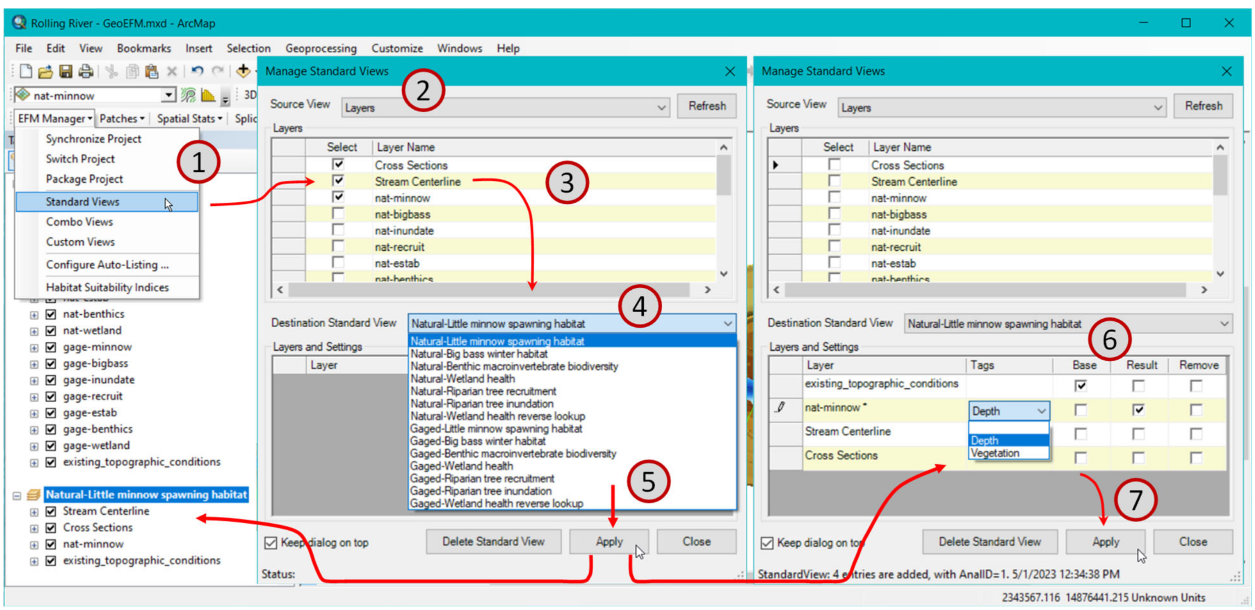


Figure 10. Creating and managing Standard Views in GeoEFM. Click sequence shows 1) open *Manage Standard Views*, 2) select *Source View*, 3) select desired layers, 4) select *Destination Standard View*, 5) click *Apply* to add selected layers, 6) specify whether added layers have *Tags*, are base maps, or are the result layer, and 7) click *Apply* to save those settings.

The Source View list includes all data frame names in the GeoEFM project. The Destination Standard View list includes all pairings of flow regime and relationships. The Source and Destination View selections are controlled by the user through dropdown text boxes. When layers are selected in the Source for addition to the Destination, the user must click the *Apply* button to actually add those layers. Clicking the *Close* button will deactivate the interface without assigning selected layers or saving any unapplied settings. Clicking the *Delete Standard View* button removes the data frame and all associated layers and settings for the *Destination Standard View* selected at the time of the delete command. *Delete Standard View* does not remove that selection from the list of Standard Views because the flow regime - relationship pairings are determined by the parent EFM application and must be managed at that level.

After the data frame for a Standard View is created, the user can specify *Tags*, *Base*, and *Result* settings for individual data layers. There is also a setting option for *Remove*, which, if selected when the Apply button is clicked, will remove that layer and its settings from the layer list and associated data frame.

In the current version of GeoEFM, *Tags* simply indicate that a relationship has a geographical requirement that could be used to further define which spatial areas meet all of the criteria needed for suitable habitat. For example, the <u>Little minnow spawning habitat relationship</u> has *Tags* called "Depth" and "Vegetation" (Figure 10). The ecological meaning of these tags is that, in addition to the statistical criteria considered by EFM, suitable spawning habitat for Little minnows is also characterized by a particular range of water depth (0 to 3 feet) and the presence of aquatic vegetation (USACE 2020). GeoEFM allows users to perform geographic queries based on layers associated with individual tags via the *Batch Calculator*. That is, based on the relationship, tag, and criteria specified by the user, GeoEFM will map areas that meet those criteria for multiple flow regimes per a single user command.

The *Base* setting allows users to designate layers as base maps. Bulky layers, in terms of memory requirements, are often stored in shared databases in order to limit memory use on individual computers. The *EFM Manager – Package Project* feature offers users the choice of whether or not to include layers designated as base maps when packaging GeoEFM applications.

The *Result* setting identifies the layer whose area meets all criteria for the relationship and flow regime being considered. There can be only one "results layer" per *Standard View*. The Tabulate feature discussed later herein queries results layers when computing and reporting total habitat areas for different flow regime - relationship pairings.

5.1.2 Combo Views

In EFM, combo relationships are used to detail how two or more relationships are grouped to represent a single ecosystem dynamic. In GeoEFM, combo relationships are treated much the same as regular relationships with one exception. As a tag indicates a geographical criteria for a relationship, the *Tags* setting is not relevant for combo relationships (geographical criteria are applied for each individual relationship) and has been replaced by the *Combo* setting (Figure 11).

The *Combo* setting allows users to identify layers as "Primary" or "Connected". Only one layer per *Combo View* can be designated as primary; multiple layers can be designated as connected. Primary and connected layers are typically results layers for the regular relationships being grouped to represent the combo relationship. The primary layer serves as the starting point. Connected layers are then used to alter the primary layer via GIS functions such as clip or intersect to create a results layer for the combo relationship.

For example, the <u>Riparian tree establishment</u> combo relationship uses layers from both the <u>Riparian tree recruitment</u> and the <u>Riparian tree inundation</u> relationships. The recruitment layer is designated as primary and the inundation layer as connected, with the logic that to generate a layer of <u>Riparian tree establishment</u> areas start with areas suitable for seedlings to begin to grow (recruitment) and then remove areas where potential seedlings would be drowned (inundation). All other buttons and settings in the *Manage Combo Views* interface behave as described above for their counterparts in the Standard Views manager.

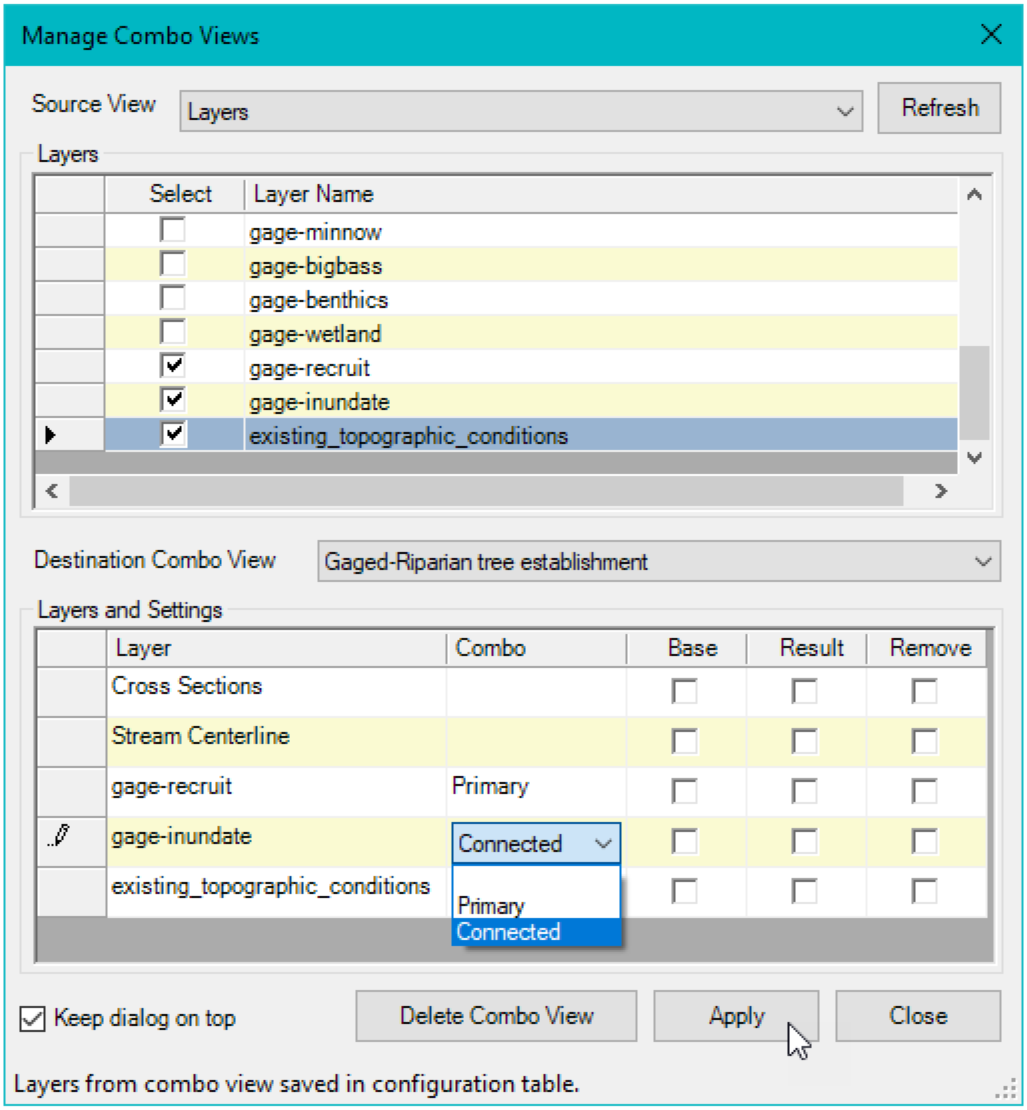


Figure 11. Creating and managing Combo Views in GeoEFM.

5.1.3 Custom Views

Users can create *Custom Views* to perform comparisons of different water management scenarios, analyze data, or simply as workspace to do whatever GIS efforts are needed for the project. The only difference between a *Custom View* and a generic data frame in ArcMap is that Custom Views, while not part of the EFM structure, are part of the GeoEFM project and can therefore be managed through the *EFM Manager – Package Project* menu option and the *View Finder* feature, which is described later in this manual.

To create a Custom View, enter a name in the text box to the far right of the Custom View dropdown list and click the *Add View* button (Figure 12). The name, which must be unique in the project, will be added to the list of *Custom Views*. Any layers selected in the *Source View* will also be associated with the new *Custom View* at that time. Subsequent additions can be done by selecting those layers and clicking the *Apply* button.

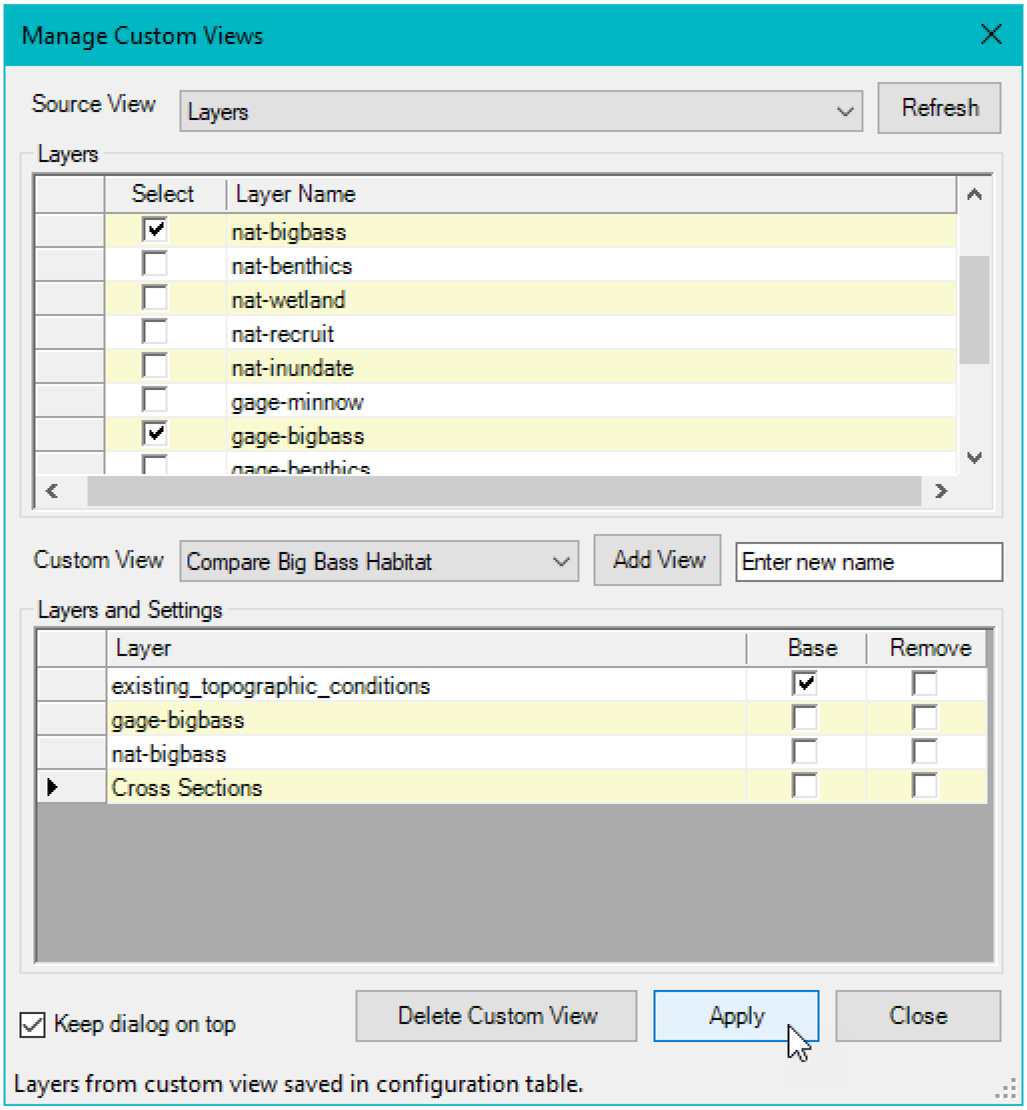


Figure 12. Creating and managing Custom Views in GeoEFM.

5.2 Navigating GeoEFM Projects (View Finder)

The *View Manager* is a simple feature that allows users to switch between views associated with a GeoEFM project. This includes all Standard, Combo, and Custom Views. Functionally, this feature performs the same action as right clicking on a data frame and selecting the Activate menu option in ArcMap.

To use *View Manager*, select the desired view from the dropdown list on the GeoEFM toolbar and click the *View Manager* button, which has a globe icon and is located to the right of the dropdown list. Figure 13 shows the first step in the process of switching from the Gaged-Little minnow spawning habitat *Standard View* to Natural-Riparian tree establishment *Combo View*.

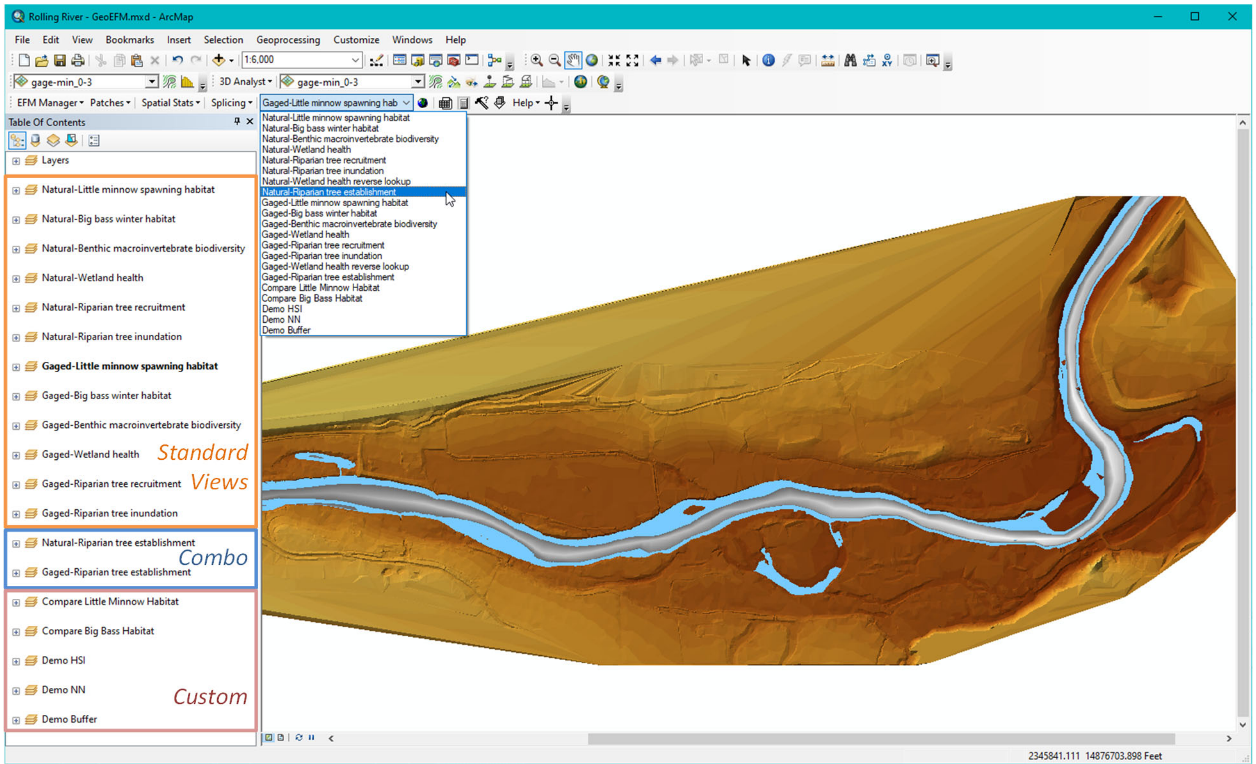


Figure 13. Using the View Finder in GeoEFM to toggle between different project views.

5.3 Habitat Suitability Indices

A Habitat Suitability Index (HSI) is a paired data set of habitat quality that ranges from 0 (wholly unsuitable) to 1 (perfectly suitable) and a corresponding habitat variable such as water depth or velocity. Indices are available for many species and life stages and are commonly used in ecological analyses. The *EFM Manager – Habitat Suitability Indices* menu option allows users to add (by entering or pasting values), copy, rename, and delete HSIs. Additionally, HSIs can be imported from existing GeoEFM projects, a feature which can be used to create an archive of HSI datasets.

To add a HSI manually, click the *Add HSI* button after entering a name in the associated text box (Figure 14). Names must be unique to the GeoEFM project. If a duplicate HSI name is entered, GeoEFM will notify the user and return to the *Habitat Suitability Index Manager* interface. Data values may be entered and edited in the variable - suitability table. Desired changes can be saved to the GeoEFM project by clicking the *Apply* or *OK* buttons.

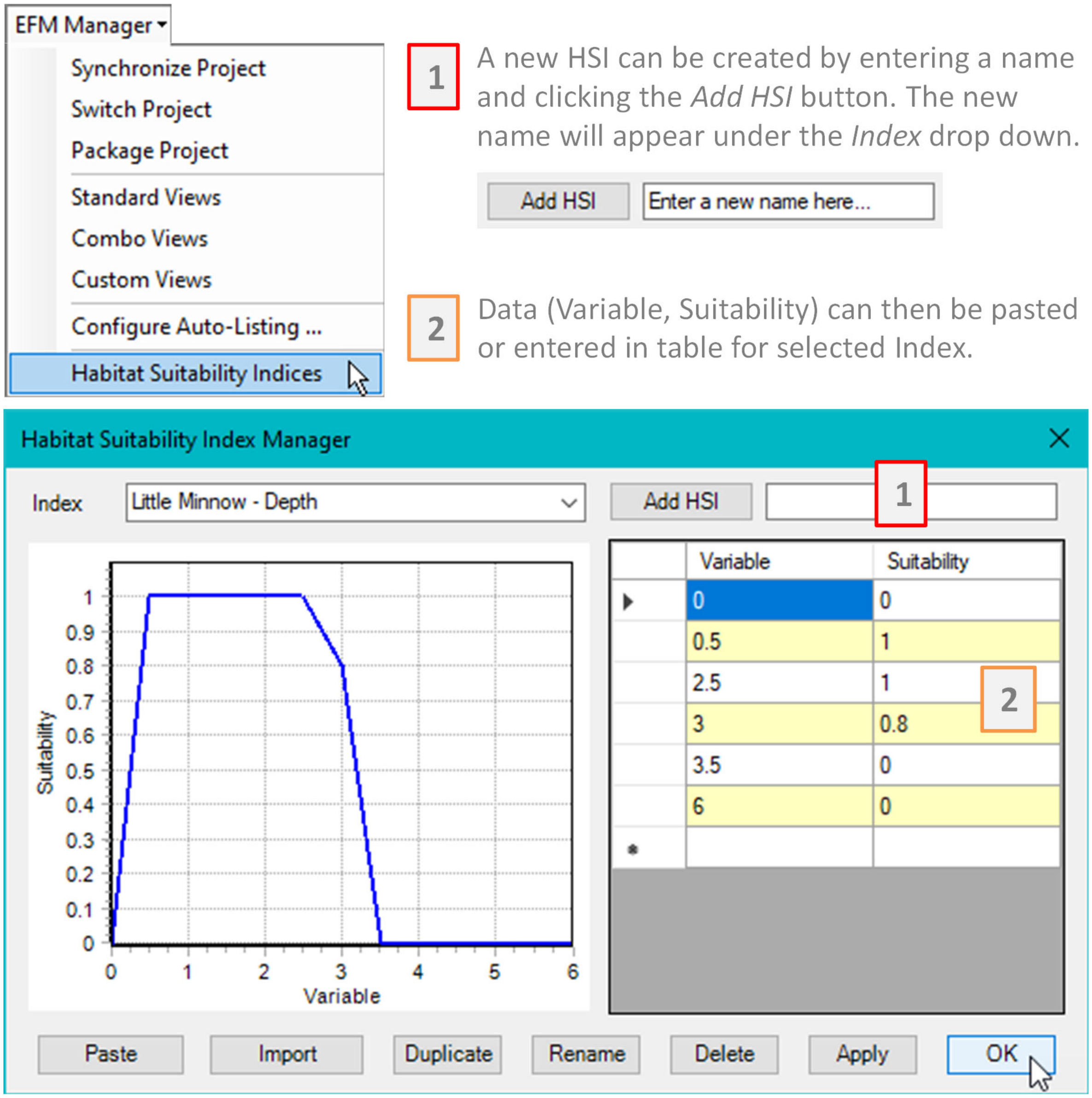


Figure 14. Creating and managing Habitat Suitability Indices (HSIs) in GeoEFM. The <u>Little Minnow – Depth</u> HSI shows that depths become more suitable for little minnow between 0 and 0.5 feet, are ideal between 0.5 and 2.5 feet, and become less suitable from 2.5 to 3.5 feet, and have no suitability for depths greater than or equal to 3.5 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 2020).

HSIs can be imported from other GeoEFM projects by clicking the *Import* button, browsing to the GeoEFM project that has the desired HSI and then clicking the *Open* button, selecting one or more HSIs and then clicking the *OK* button (Figure 15). GeoEFM will report successful imports. Any HSI whose name already exists in the destination GeoEFM project will not be imported.

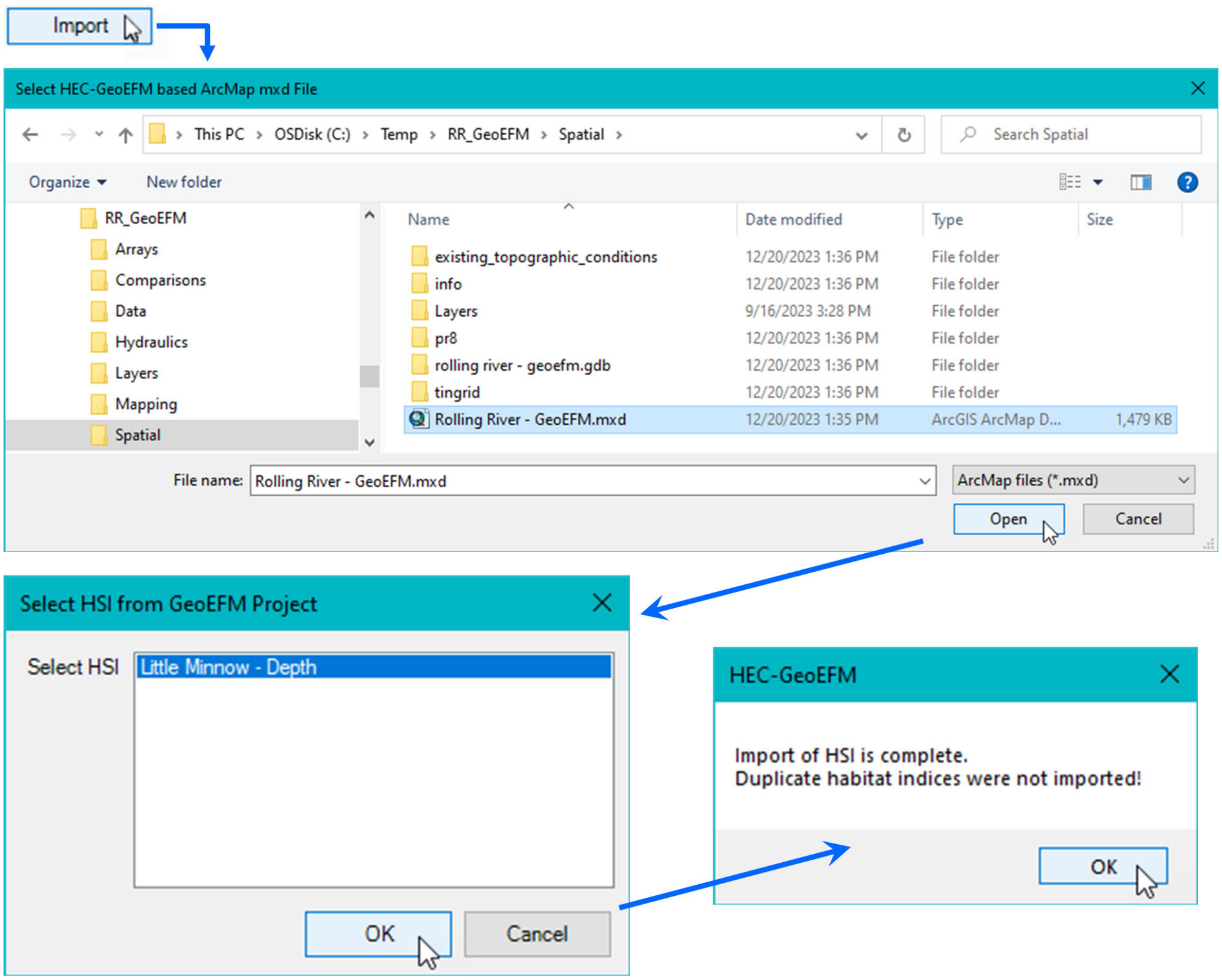


Figure 15. Importing Habitat Suitability Indices (HSIs) from another GeoEFM project.

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 – Depth – Feet", which may help avoid errors when applying HSIs.

Applying a HSI to create a layer of suitable habitat is done through the GeoEFM *Calculator*. Clicking the *Calculator* button opens an interface that offers several spatial queries commonly used in GeoEFM applications (Figure 16). To apply a HSI, enter the name and location of the output raster (output names are limited to a maximum of 13 characters for raster operations), select the input raster from a list of rasters associated with the active view, select the HSI to apply from a list of all indices associated with the GeoEFM project, use the checkbox option to either exclude (checked) or include (unchecked) zero suitability areas from the output raster, and then click *OK*. The range of input raster values must be wholly within the range of HSI variable values. Otherwise, GeoEFM will simply ask the user to specify a different input raster or HSI and return to the *Calculator* interface. In Figure 16, the input raster values range from 0 to 4.7 and the HSI variable values range from 0 to 6.

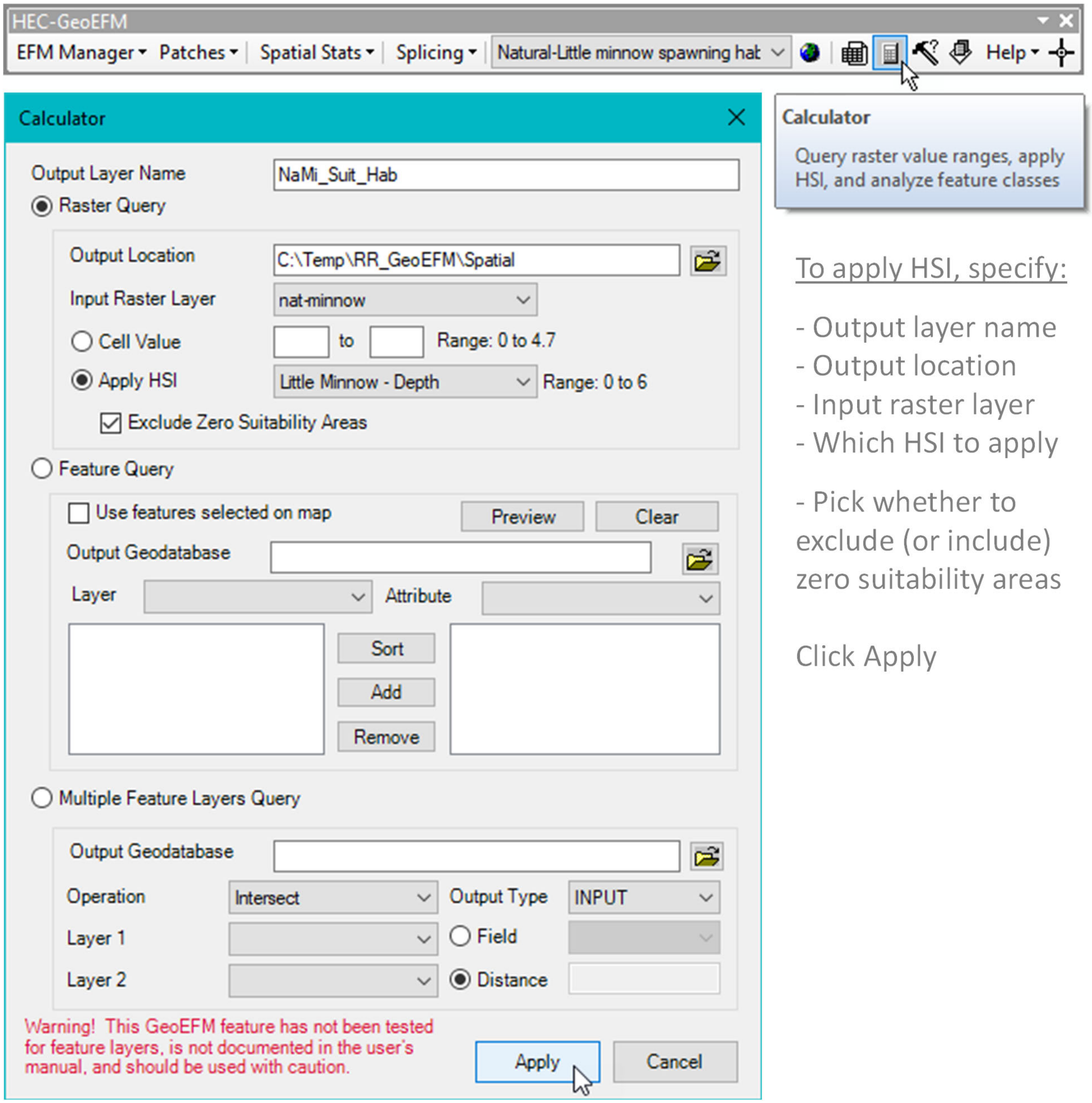


Figure 16. Using the GeoEFM *Calculator* to apply Habitat Suitability Indices.

In GeoEFM, HSI are applied only to raster layers. Output layers generated are also rasters (Figure 17) and can be automatically associated with the active view via the *Auto-Listing* feature described in Chapter 3. 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. If the suitability raster produced is also the results layer for a *Standard* or *Combo View*, the associated view managers can be used to identify it accordingly. Other components of the *Calculator* feature are detailed later in this chapter.

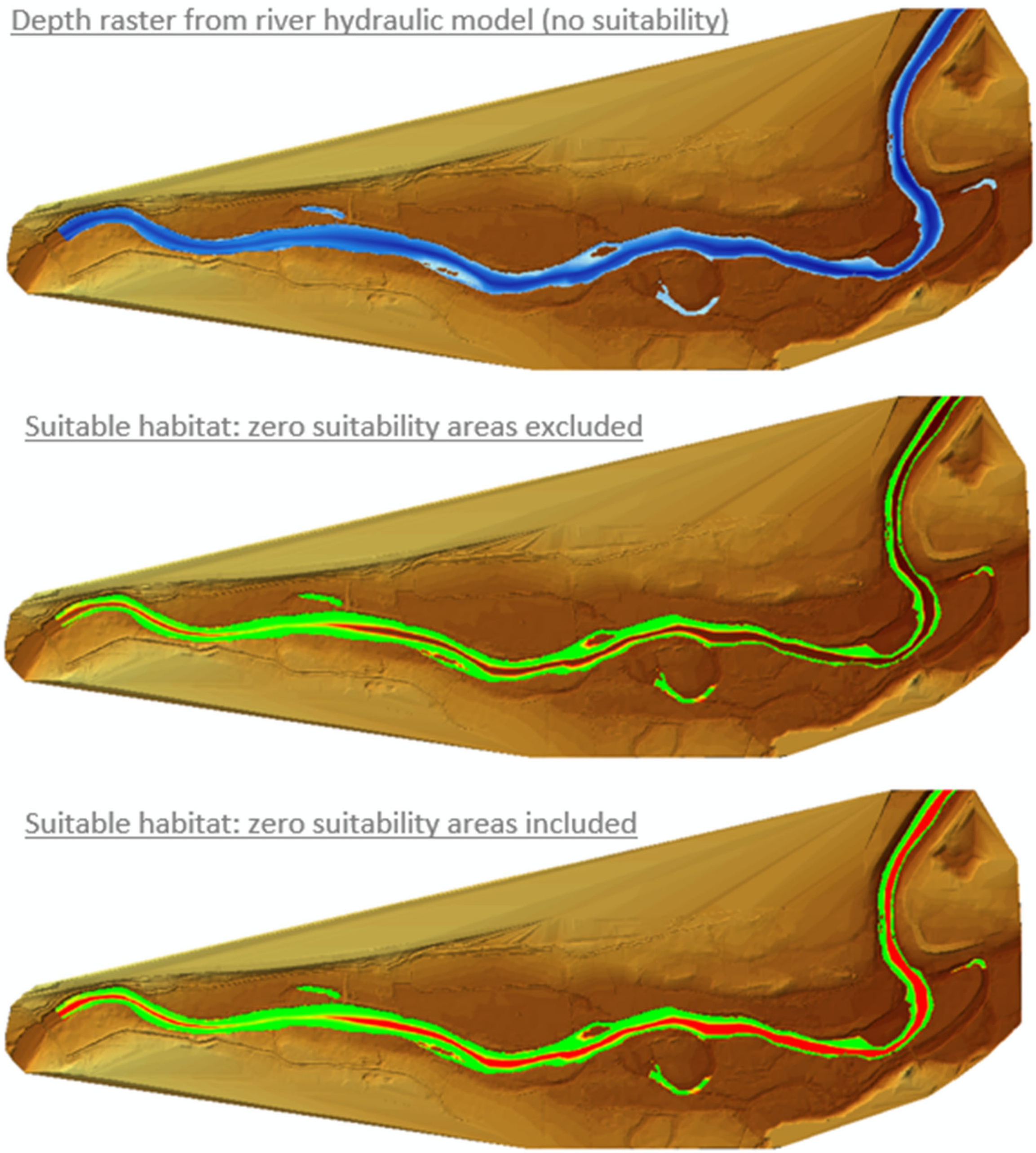


Figure 17. Spatial layers for Little minnow spawning habitat. Top image shows a depth raster (blue) generated by a river hydraulics model. Middle and bottom images show suitability rasters generated by applying a HSI to the depth raster with zero suitability areas excluded and included, respectively.

5.4 Working with Spatial Layers (Calculators)

GeoEFM has two calculators, one that performs single instance queries of spatial layers (*Calculator*) and one that performs repeating queries of spatial layers (*Batch Calculator*). In addition to the HSI features described earlier in this chapter, the *Calculator* can also be used to query raster value ranges (Figure 18). The *Calculator* also has several components related to feature classes, though those have not been rigorously tested and should be used with caution.

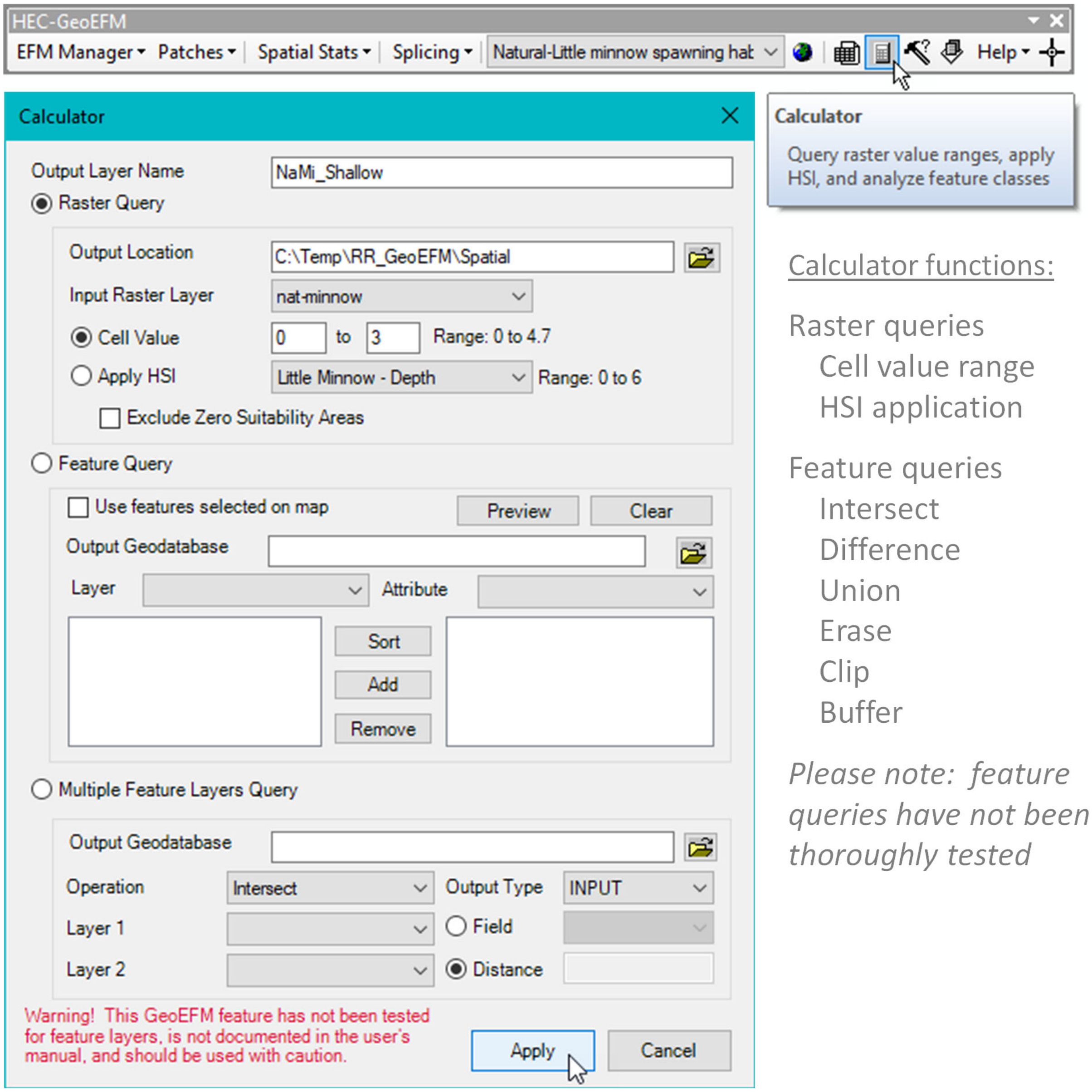


Figure 18. GeoEFM *Calculator* interface being used to apply a raster cell value range.

Cell Value is a simple query that applies a user-defined range to an input raster resulting in an output raster that contains only the cells and corresponding values that are within the range (Figure 19). Ecologically, this is typically used to filter areas that are not relevant to the EFM relationship being considered. In this sense, *Cell Value* is similar to the *Apply HSI* option, though *Cell Value* does not allow for partial suitability, areas are either in range or dropped from the output layer. Output names are limited to a maximum of 13 characters for raster operations, as required by ArcMap.

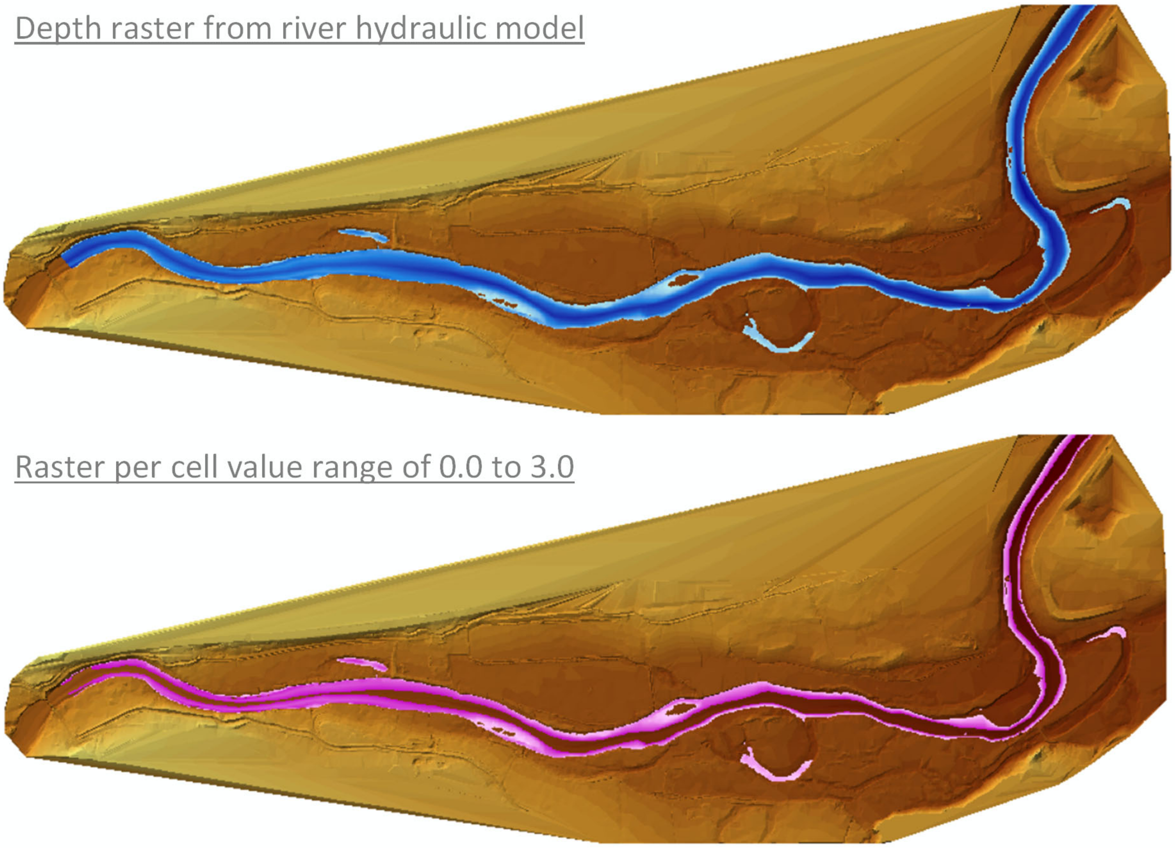


Figure 19. Spatial layers for Little minnow spawning. Top image shows a depth raster (blue) from a river hydraulics model. Bottom image show raster of depths from 0.0 to 3.0.

The *Batch Calculator* performs a user-defined spatial operation for multiple raster layers. This feature is most commonly used when processing layers for one EFM relationship and many flow regimes. In this case, the same spatial operations, whether *Cell Value* or *Apply HSI*, needs to be done for each of the implicated relationship-flow regime *Standard Views*. To use the *Batch Calculator*, layers to be processed must share a common tag as created in EFM and set via the *Manage Standard View* interface.

The *Batch Calculator* allows users to declare the relationship and tag (and, thereby, the corresponding layer set) to be processed, to specify an output prefix and location, and to define the spatial operation (Figure 20). Clicking the *Process* button executes the operations. Output rasters are shown in their *Standard Views* and associated in accordance with *Auto-List* settings. Output name length can be challenging for layers generated by the *Batch Calculator*. The default name is "prefix_InputRasterName". Prefix is allowed a maximum of 2 characters and then "InputRasterName" is truncated as necessary to stay within the 13-character ArcMap limit.

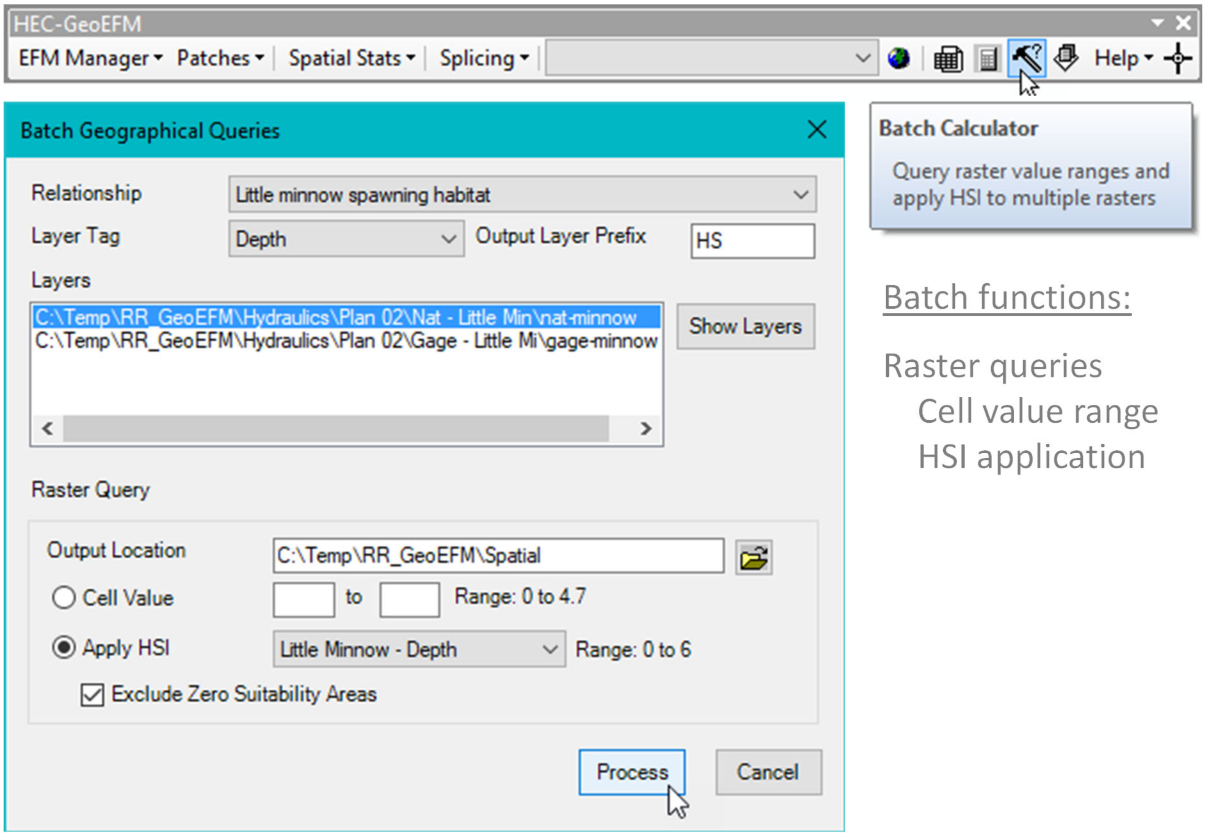


Figure 20. GeoEFM *Batch Calculator* interface being used to apply a HSI to two raster layers.

5.5 Mapping Statistical Results (Spatial Statistics Tool)

Statistical results from EFM can be imported to GeoEFM for visualization. This is a different workflow than using a river hydraulics model to generate spatial layers based on EFM results (Figure 1). Instead, statistical results (or derivations based on those results) are associated with locations and then plotted. **Information for plotting is stored in three basic data tables**: Locations, Relationships, and Datasets (Figure 21).

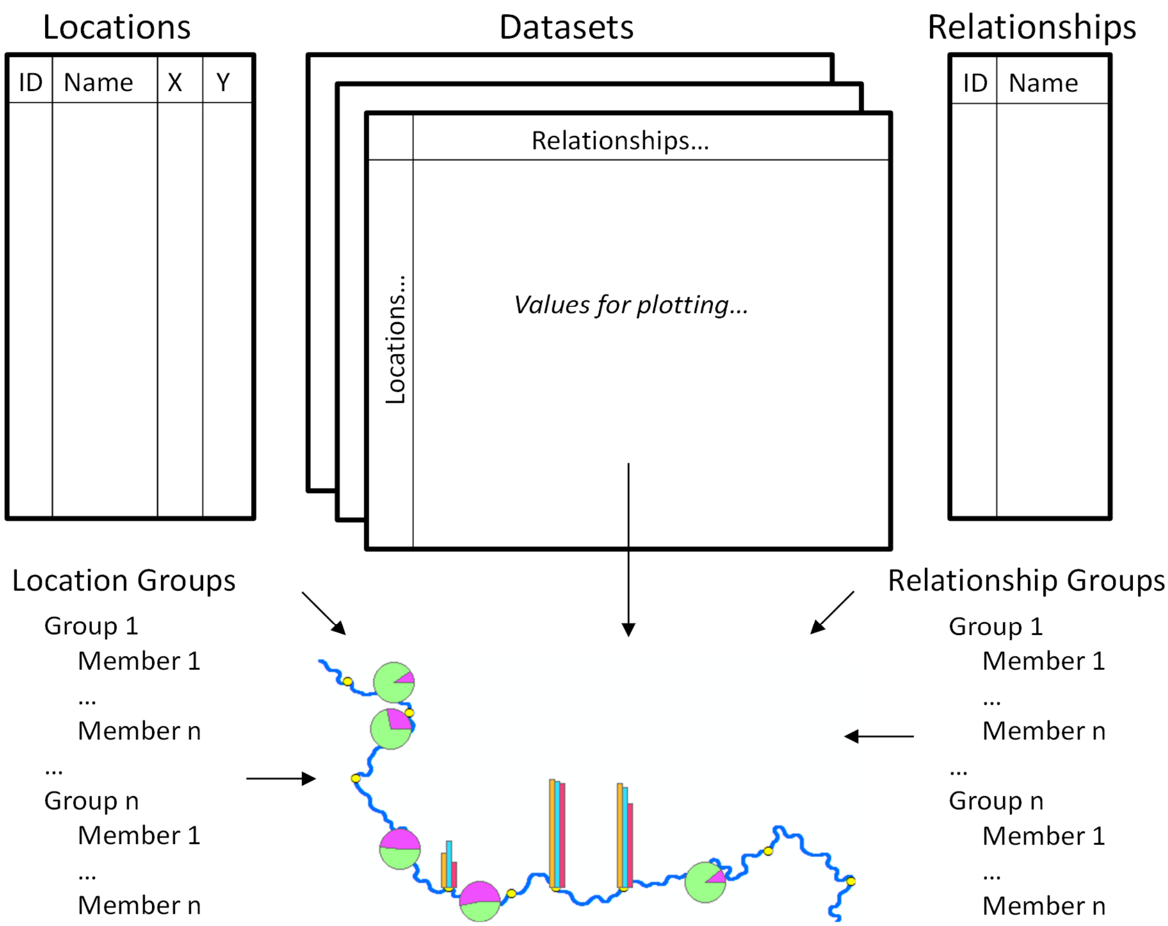


Figure 21. Overview and data tables related to GeoEFM mapping of spatial statistics.

5.5.1 Locations

Locations are spatial points where values are displayed. Locations are comprised of names and associated coordinates. This information can be defined by selecting appropriate fields in existing GIS data sources, by pasting from a spreadsheet, or by entering names and clicking on corresponding location in GIS (Figure 22). The Locations table in GeoEFM should have all locations where the user may choose to display data values. Locations can be added or edited through the *Locations and Relationships* interface. Locations names must be unique. Locations can be removed via the *Manage Locations* interface by highlighting a location row and clicking the delete button.

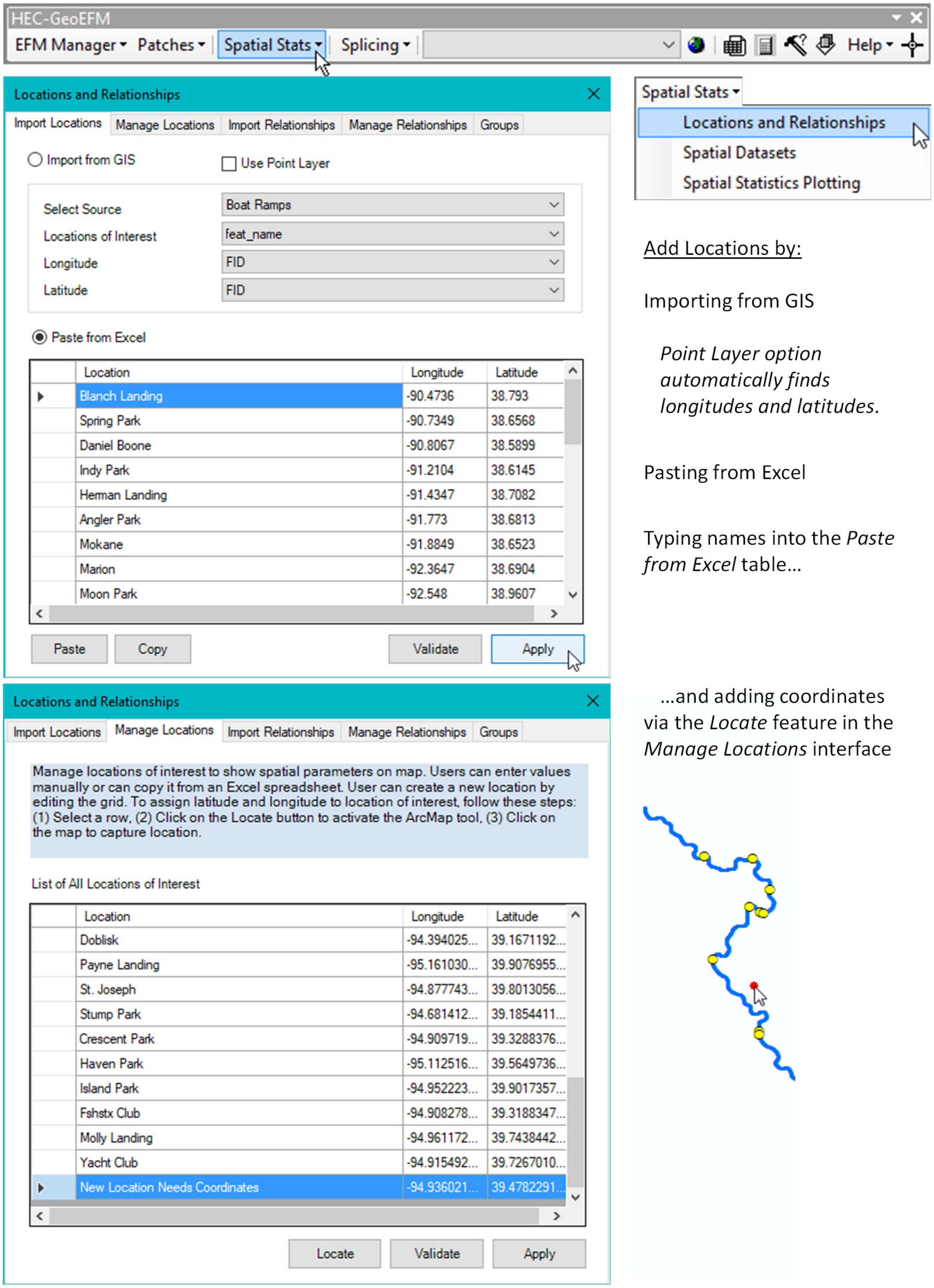


Figure 22. **<u>Locations</u> are added and edited via the *Locations and Relationships* interface.**

5.5.2 Relationships

For spatial statistics, relationships describe the type of values available for display and are comprised only of a name. Names are typically adopted from EFM projects though GeoEFM users are not constrained to only EFM relationship names while working with spatial statistics. Instead, GeoEFM allows users to specify whichever Relationships they may want to display data values for. Relationships can be added and edited through the *Locations and Relationships* interface (Figure 23). Relationship names must be unique.

Please note that spaces will be removed from relationship names after those names are entered or imported as part of a dataset (see section 5.5.3). This can create disconnects between relationship names and associated data values, which makes those data unplottable during visualization (see section 5.5.4). For spatial statistics, it is best to **avoid spaces in relationship names**. Spaces in location names are acceptable.

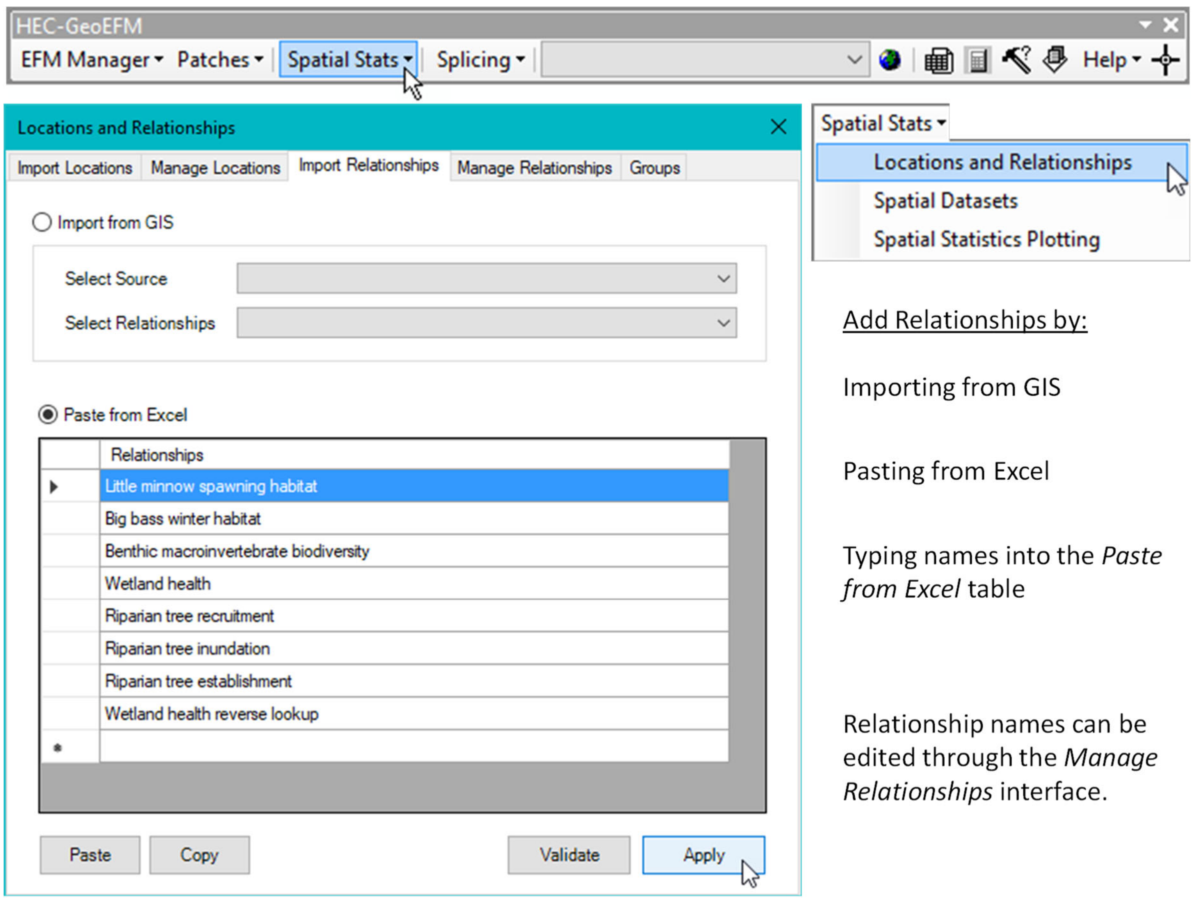


Figure 23. Relationships are added and edited via the *Locations and Relationships* interface.

Groups are collections of flow regimes and relationships that can later be used to create quick plots of spatial statistics. Groups are created, renamed, copied, and deleted through the *Groups* tab in the *Locations and Relationships* interface (Figure 24). Group membership is managed through a picker that displays lists of potential and current members and allows members to be added or removed from the group.

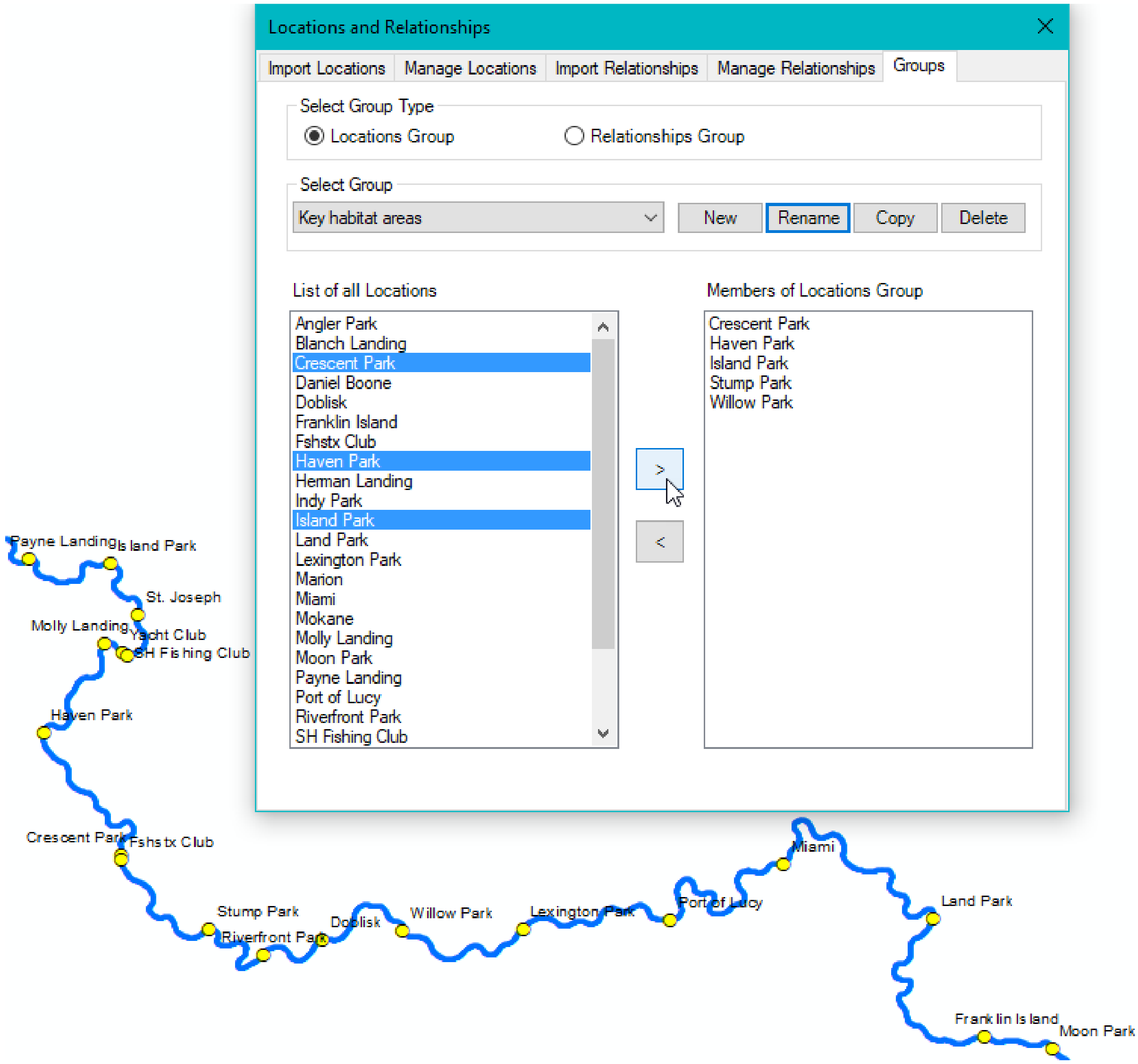


Figure 24. Locations and Relationships may be added to Groups to expedite plotting.

5.5.3 Datasets

Datasets are tables of values imported by the user and then available for display. Format is important. Location names are in the first column and relationship names are in the first row. There can be many datasets. Each dataset does not need to include all locations or relationships though all desired locations and relationships in a dataset must be in the Locations and Relationships tables to be available for display. Dataset values do not need to be entered for each pairing of location and relationship; blank values will simply plot as blanks if requested. Dataset names must be unique to project.

Datasets may be imported from GIS by selecting the appropriate data source from a list of available feature classes and shapefiles (list is per data frame) and then identifying attributes for Locations and Relationships. Location names are imported as the values associated with the Location attribute. Relationship names are imported as the names associated with the

Relationship attributes. Dataset values are imported as the values associated with each of the selected Relationships.

Datasets may also be created via a *Paste from Excel* option. Users simply copy-paste a table of information with location names in the first column, relationship names in the first row, and data values in the body of the table (Figure 25). Once created, datasets can be selected and edited using the *Manage Datasets* tab.

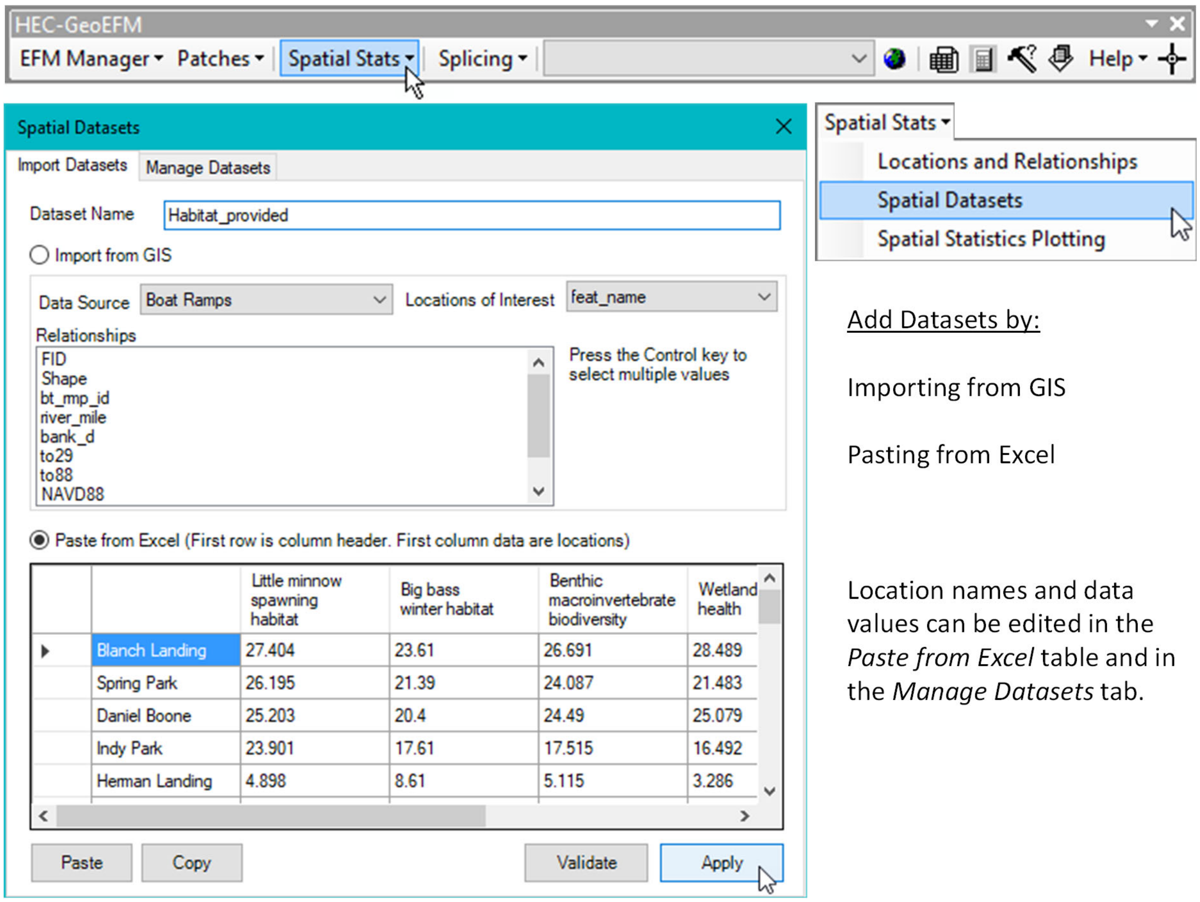


Figure 25. Datasets are added and edited in the *Spatial Datasets* interface.

5.5.4 Visualization

After the Locations, Relationships, and Dataset tables are populated, data values may be viewed spatially. To create a plot, select the relevant Dataset, enter a custom name for the output layer (optional), adjust chart type and symbology as desired, select relevant locations and relationships (or groups), and click the Plot button (Figure 26). Output layers are shown in the active *Standard View* and associated in accordance with *Auto-List* settings.

Three chart types are available: bar, pie, and stacked. Colors can be adjusted by switching the start and end of ramp colors. Double-clicking the filled *Color Ramp* boxes will open a *Color Selector* that allows selection of a new start or end color. The *Color Schemes* list offer palette options for ramping between the start and end colors. A preview of colors can be refreshed by clicking the *Show Color Ramp* label.

When the Plot button is clicked, an output layer will be displayed as part of the active data frame. Output layer names do not need to be unique, though duplicate names will replace the existing output layer, which allows easy updating of output layers.

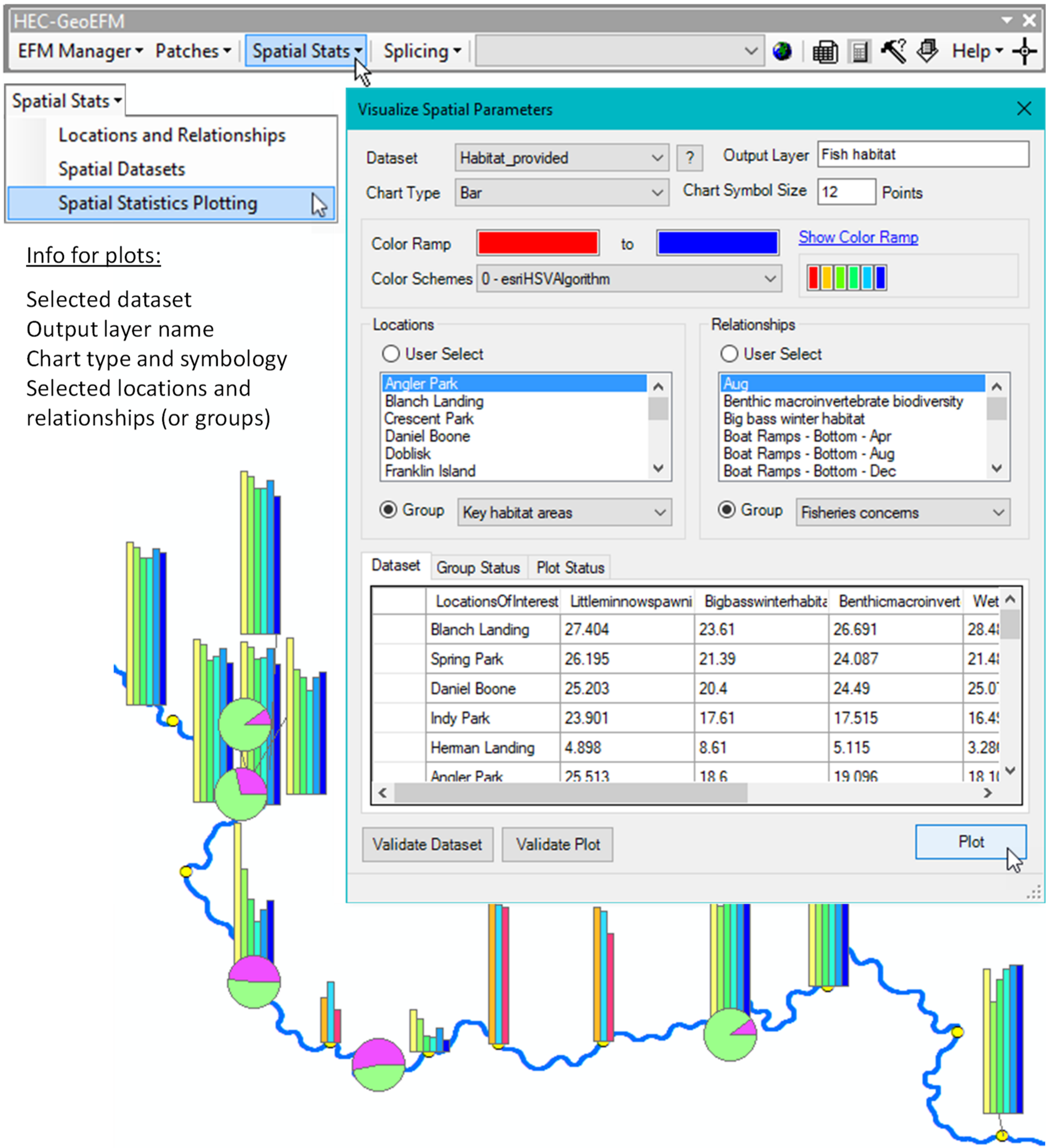


Figure 26. Plots are created and updated via the *Visualize Spatial Parameters* interface.

Please note that Datasets should be edited via the *Spatial Datasets - Manage Datasets* interface. Datasets are viewable in the *Visualize Spatial Parameters* interface for informational purposes only. Any manual changes to dataset values through the visualize interface will not be reflected in plots.

5.6 Combining Layers into Habitat Mosaics (Splicing Tool)

In GeoEFM, *Splicing* tools assist 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.

5.6.1 Splicing Configurations

Splicing Configurations are comprised of the information needed to assemble a mosaic. There are three types of configurations: *Polygon*, *Raster*, and *Hydraulic Model*. Choice of type is controlled by the user via the Select Splicing Option feature. Each type requires different information to guide assembly.

5.6.1.1 Polygon Option

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.

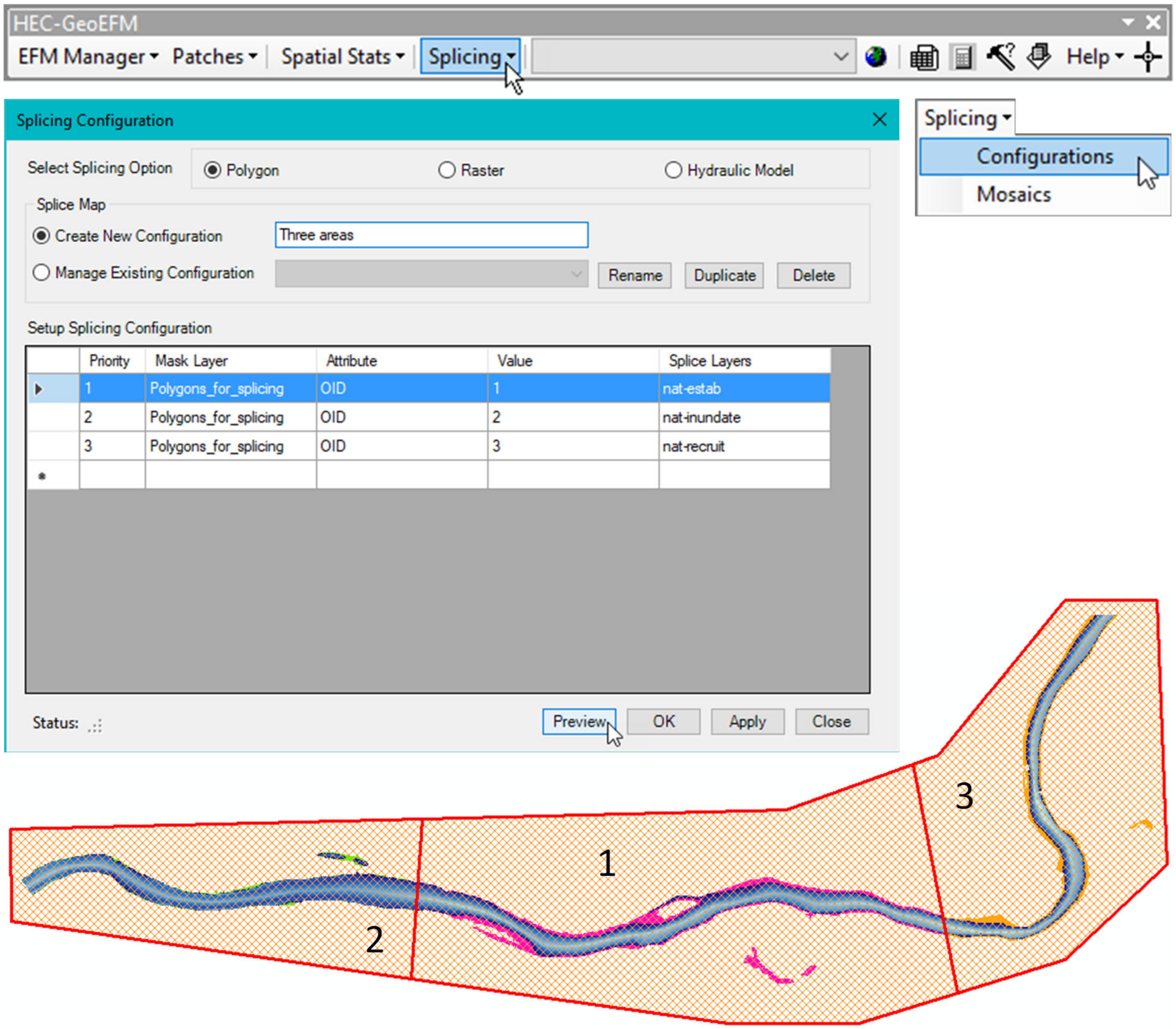


Figure 27. ***Polygon*** **splicing configurations associate spatial areas (polygons) with the layers that will represent those areas in the mosaic.**

5.6.1.2 Raster Option

The *Raster* option uses rasters as both the domain (*Mask Layer*) and the areas within that domain to be included in the splice (*Splice Layers*). Figure 28 shows a raster configuration and corresponding preview. Splicing would stitch the two *Splice Layers* within the domain of the specified *Mask Layer* to form a single mosaic.

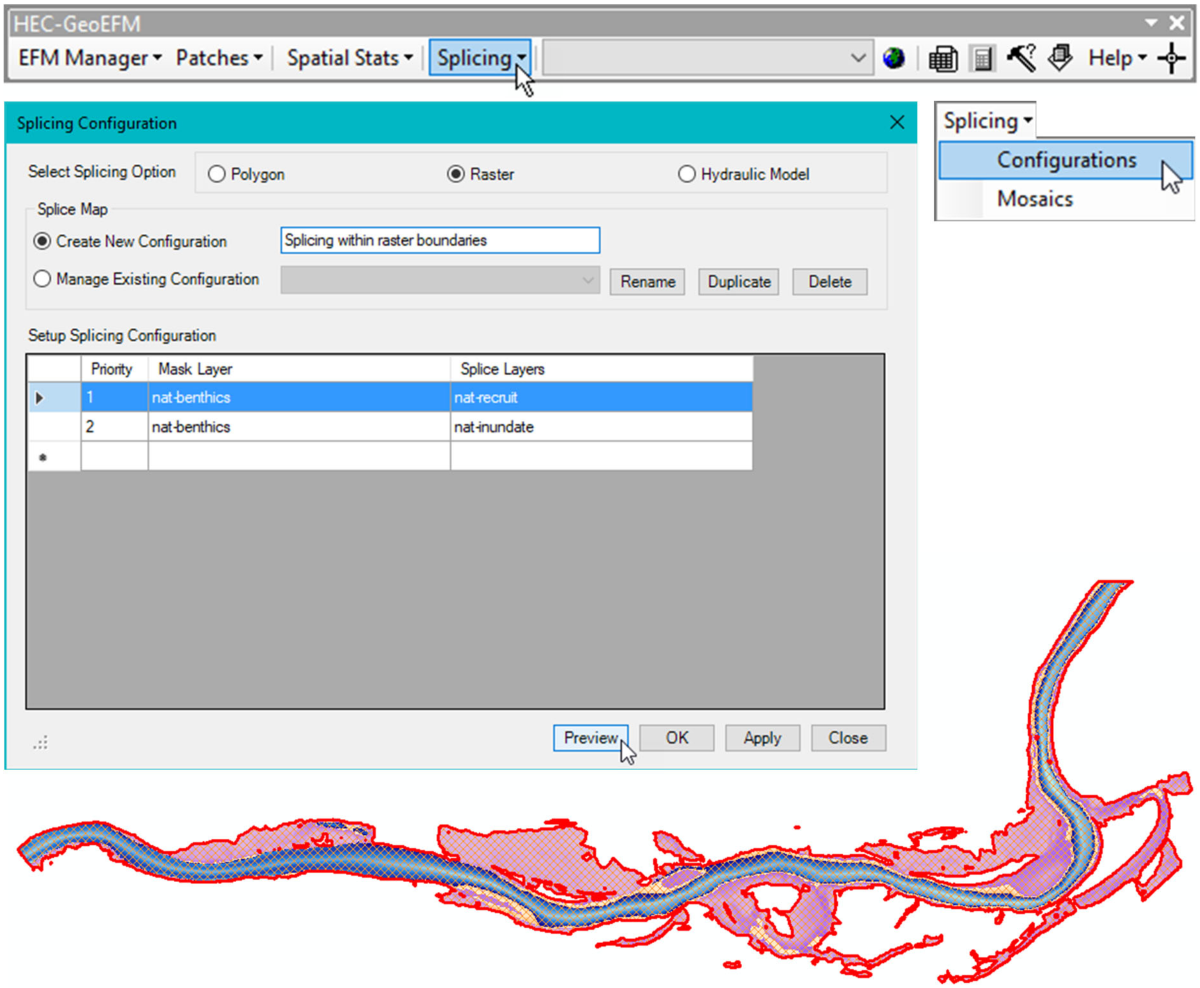


Figure 28. ***Raster*** **splicing configurations merge layers into a mosaic whose domain is limited to the extent of a user-specified raster layer.**

5.6.1.3 Hydraulic Model Option

The *Hydraulic Model* option allows mosaics to be assembled based on the layout of 1-dimensional river hydraulics models. Users specify the extent of the mosaic (*Bounding Polygon*), the cross section layers (*XS Cutlines*), the beginning and ending cross sections for each area of the splice (*Beg XSID* and *End XSID*), the *Splice Layers* to be merged, and the location between cross sections at which each splice is to be done (*Splice Distance*).

Figure 29 shows a hydraulic model configuration and corresponding preview. Functionally, hydraulic model configurations behave much like polygon configurations. 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 29, 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 nat-benthics 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 nat-estab 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 nat-bigbass splice layer. Splicing would stitch the splice layers associated with each generated polygon to form a single mosaic.

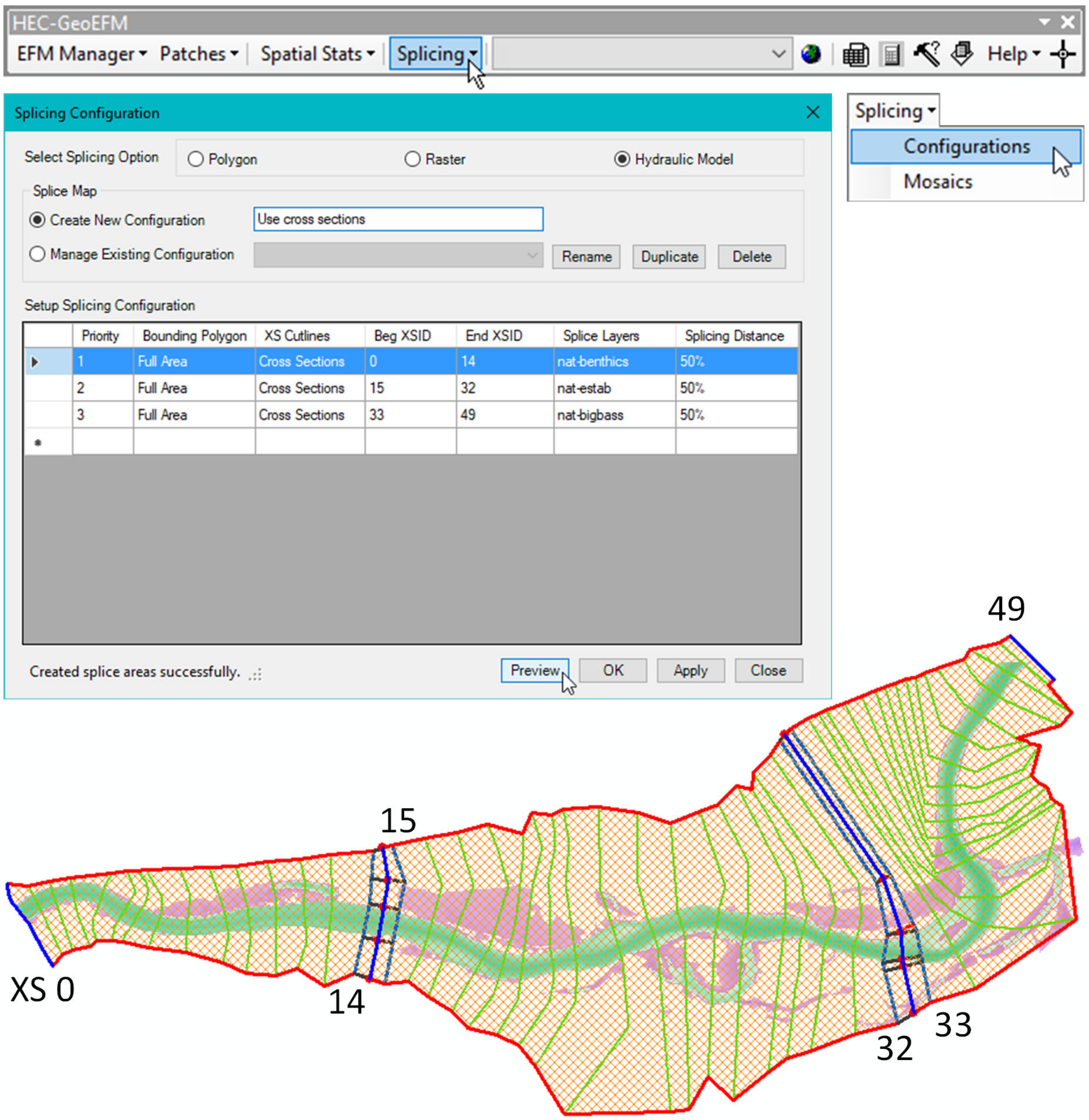


Figure 29. ***Hydraulic Model*** **splicing configurations locate splices based on cross section locations in a river hydraulics model. Cross section 0 is the most upstream cross section and is shown in blue at the far left of the preview. Cross section 49 is shown in blue at the far right.**

5.6.2 Splicing

The splicing interface executes splices per the following user specifications: *Configuration*, *Snap Raster*, and method for *Handling Areas of Overlap* (Figure 30). Configurations are detailed in the previous section. The snap raster is used to deal 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.

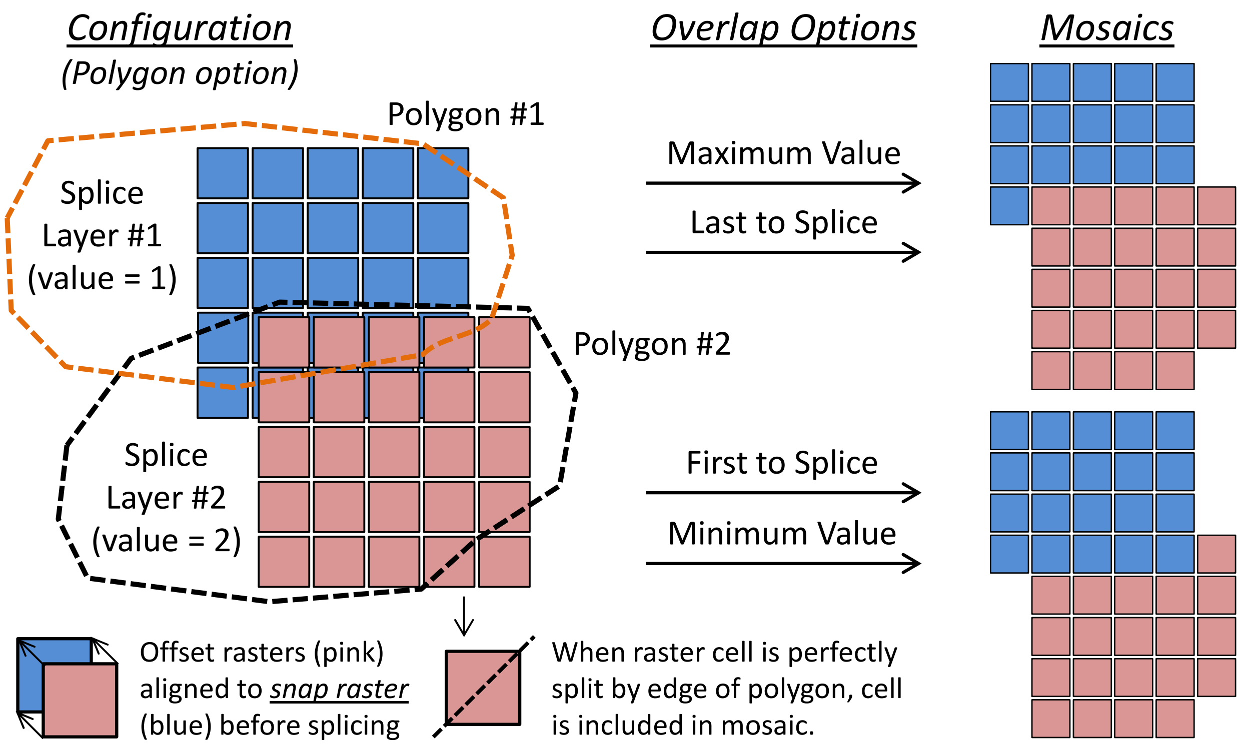


Figure 30. A splice is based on a configuration, a snap raster, and an overlap option. The resulting mosaic reflects all of these user-selections.

The interface that allows users to set and apply splicing specifications to create a mosaic is accessed via the *Splicing – Mosaics* menu option (Figure 31). Available configurations are listed per splicing option. The mosaic generated is a raster and therefore the output name must conform to current raster naming conventions (maximum of 13 characters and no spaces). Splices are performed by clicking the *OK* or *Apply* buttons. The resulting mosaic is generated and displayed in the current view.

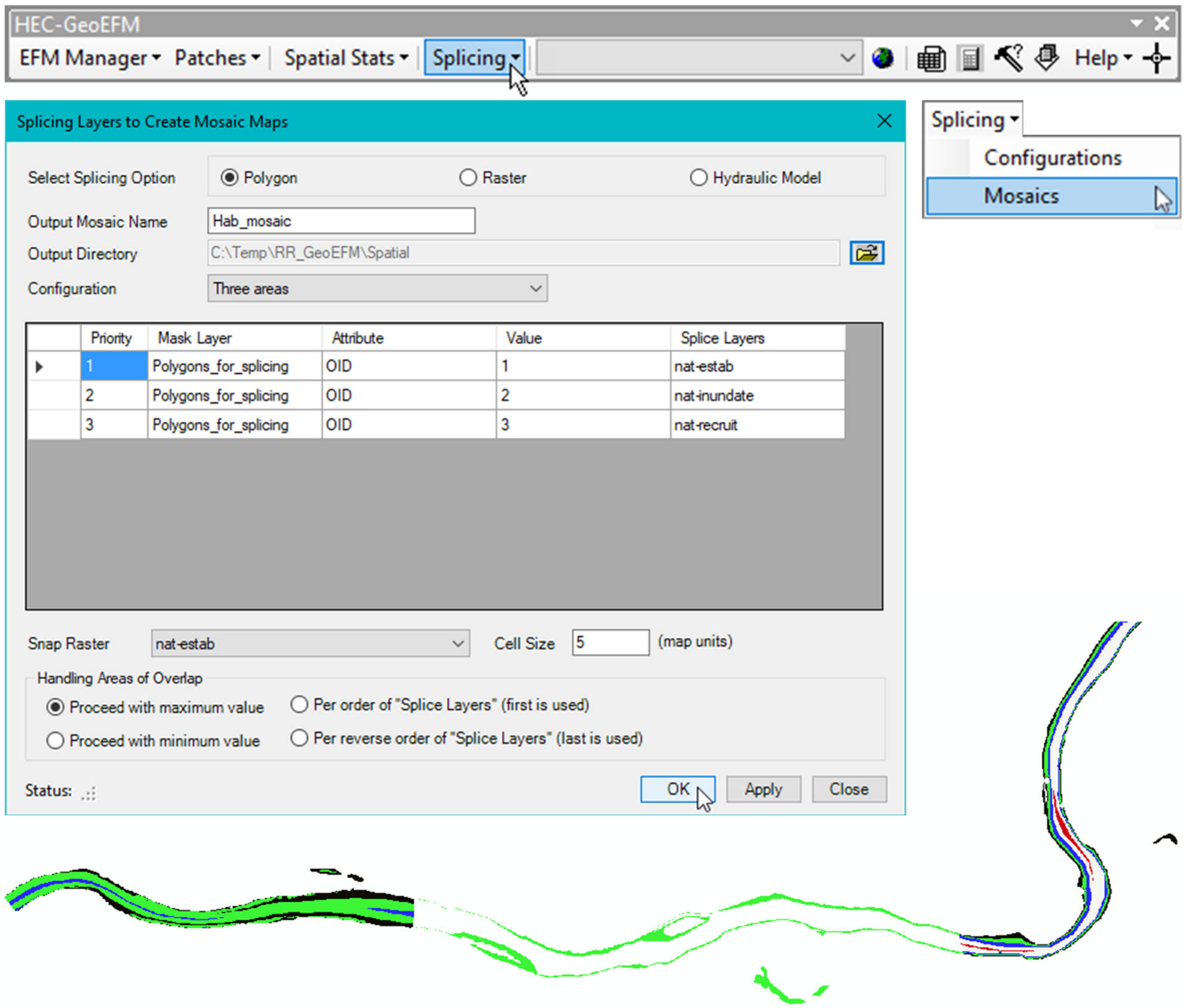


Figure 31. The splicing interface allows users to select and apply combinations of *Configuration*, *Snap Raster*, and overlap option to create raster mosaics.

5.7 Computing Habitat Areas (Tabulate Tool)

The *Tabulate* tool allows users to compute, report, and archive total and suitable habitat areas. Options are provided for selecting the desired flow regimes and relationships, output units, mode of comparison for multiple flow regimes, use suitabilities, and the file and path names for the report to be generated by GeoEFM (Figure 32).

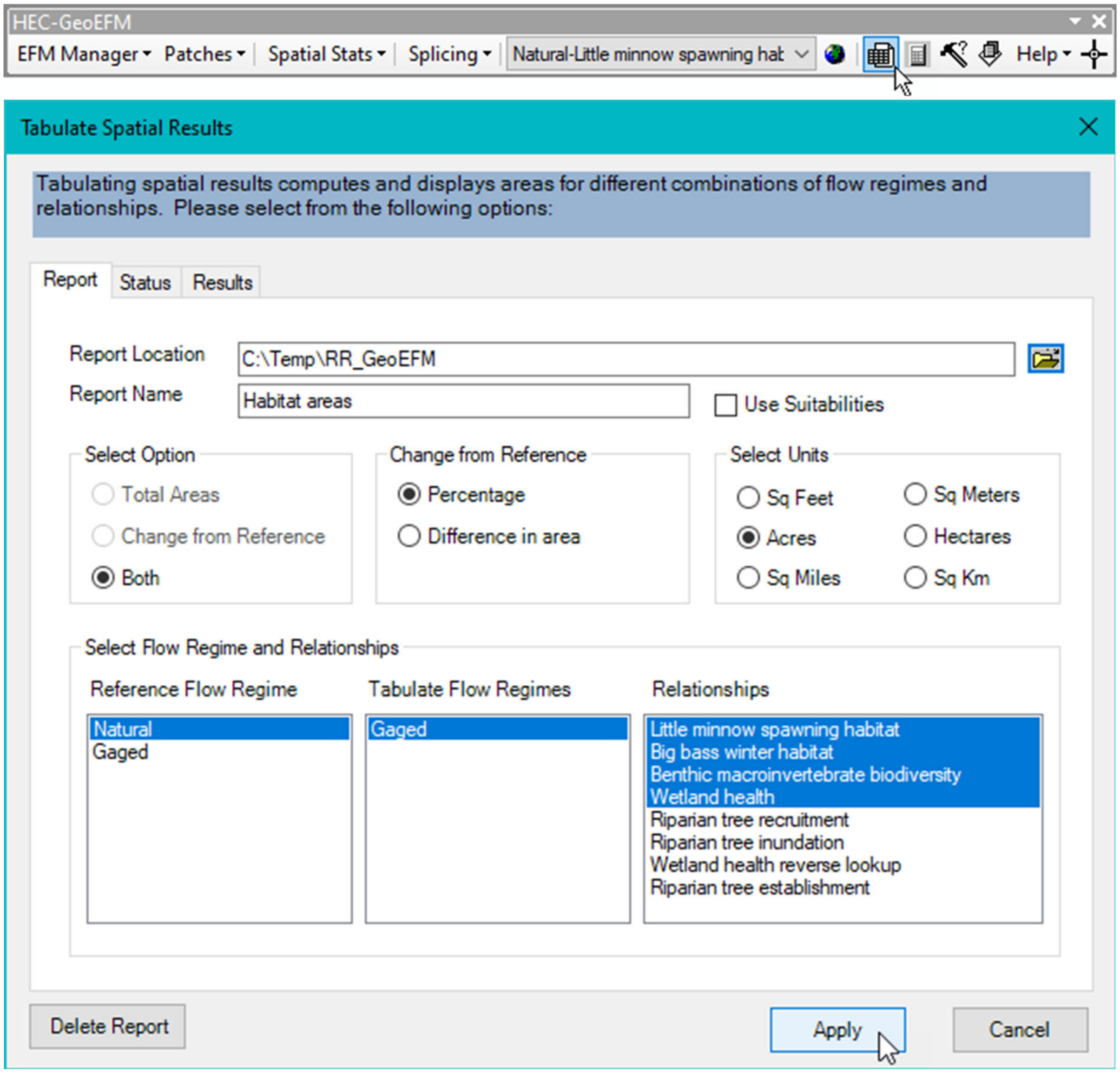


Figure 32. Options and settings for the Tabulate Spatial Results interface in GeoEFM.

As in EFM, only one flow regime may be selected as the reference. Habitat areas generated by any other flow regimes highlighted for analysis will be compared to habitat areas generated by this reference in accordance with the *Change from Reference* setting in the *Tabulate* interface. When the *Ok* button is clicked, **GeoEFM assesses area for the result layer of each flow regime - relationship pairing selected for tabulation**. A "ReportName.xml" file is generated that can be opened in web browsers and other software (Figure 33).

The *Status Tab* details progress as output is generated and provides warning messages if any problems are encountered. Please note that **GeoEFM will not compute and report habitat areas unless all required results layers are identified and have defined spatial references.** Use the *ArcToolbox – Data Management Tools – Projections and Transformations – Define Projection* feature to assign the appropriate projections.

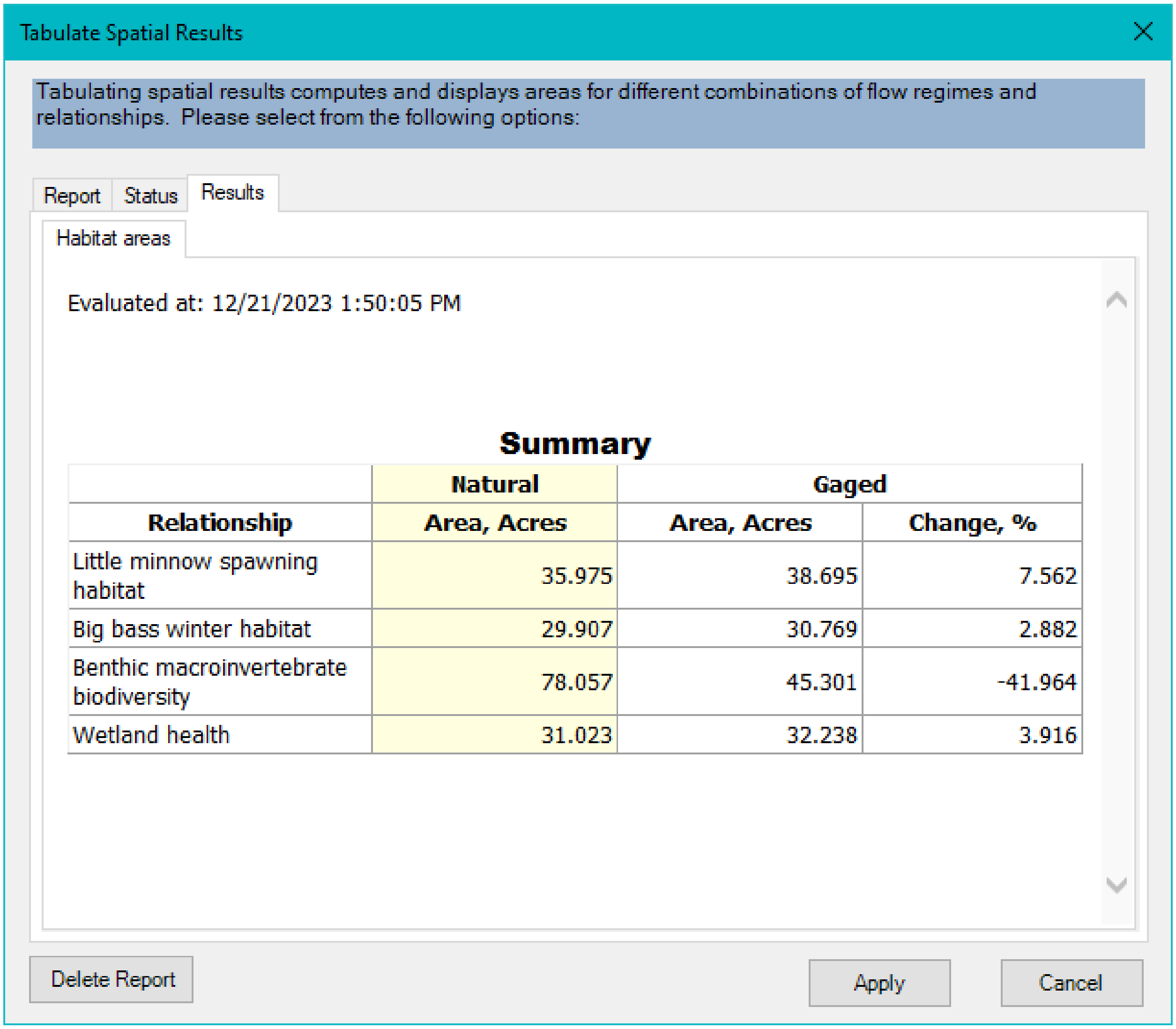
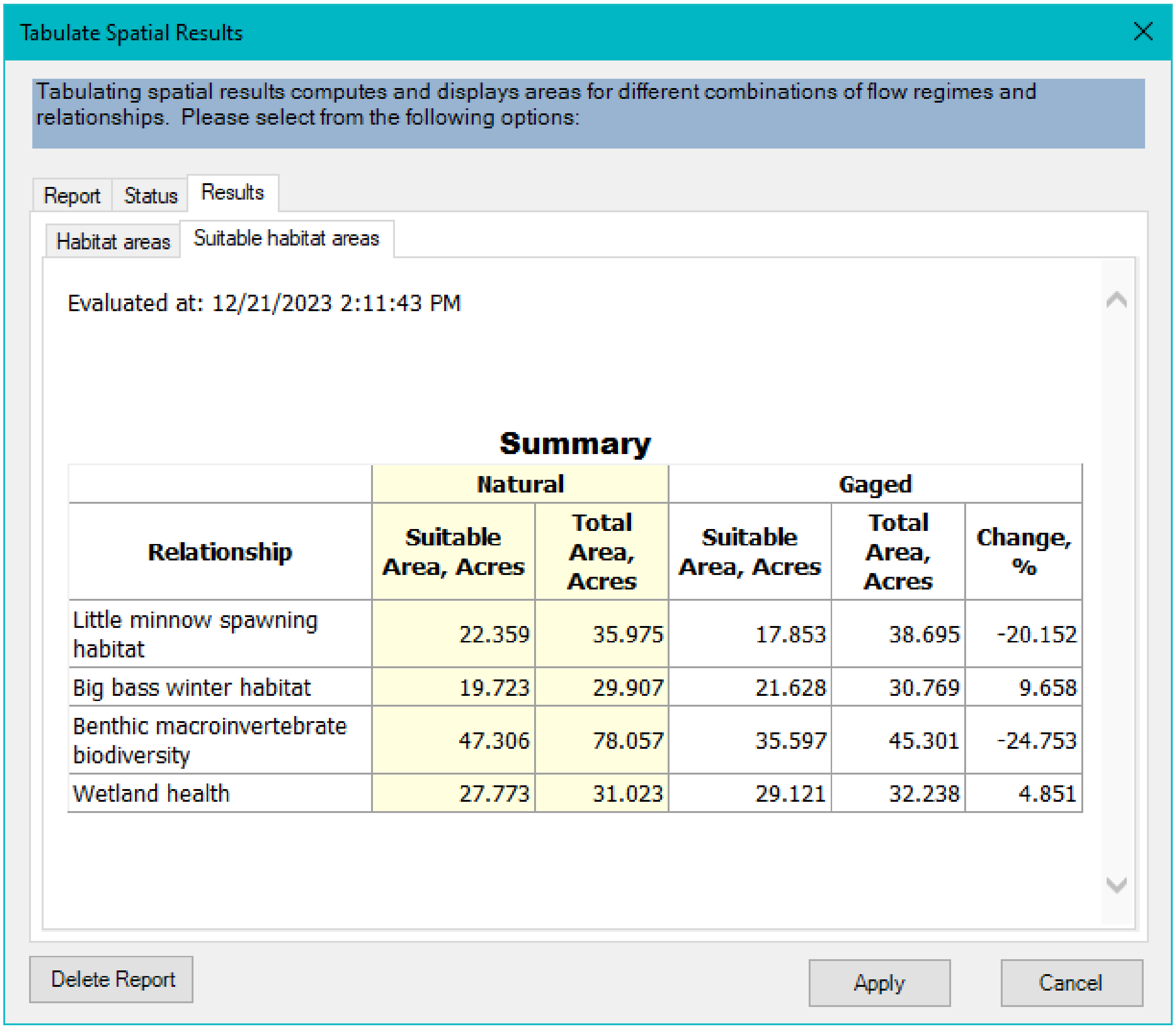


Figure 33. Total habitat areas for select pairings of flow regimes and relationships.

The *Use Suitabilities* option (Figure 32) allows for reporting of suitable areas in addition to the total areas (Figure 34) 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 provides a warning message when results layers have values outside of the normal range of suitabilities (0 to 1), but then allows users to proceed, which can lead to potentially odd results. Changes from reference, whether as a percent difference in habitat or a change in area, are tallied based on suitable area results when the use suitabilities option is on (Figure 34).



	Natural		Gaged		
Relationship	**Suitable Area, Acres**	**Total Area, Acres**	**Suitable Area, Acres**	**Total Area, Acres**	**Change, %**
Little minnow spawning habitat	22.359	35.975	17.853	38.695	-20.152
Big bass winter habitat	19.723	29.907	21.628	30.769	9.658
Benthic macroinvertebrate biodiversity	47.306	78.057	35.597	45.301	-24.753
Wetland health	27.773	31.023	29.121	32.238	4.851

Figure 34. Suitable and total habitat areas for select pairings of flow regimes and relationships.

5.8 Analyzing Habitat Connectivity (Patch Analysis Tool)

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 35).

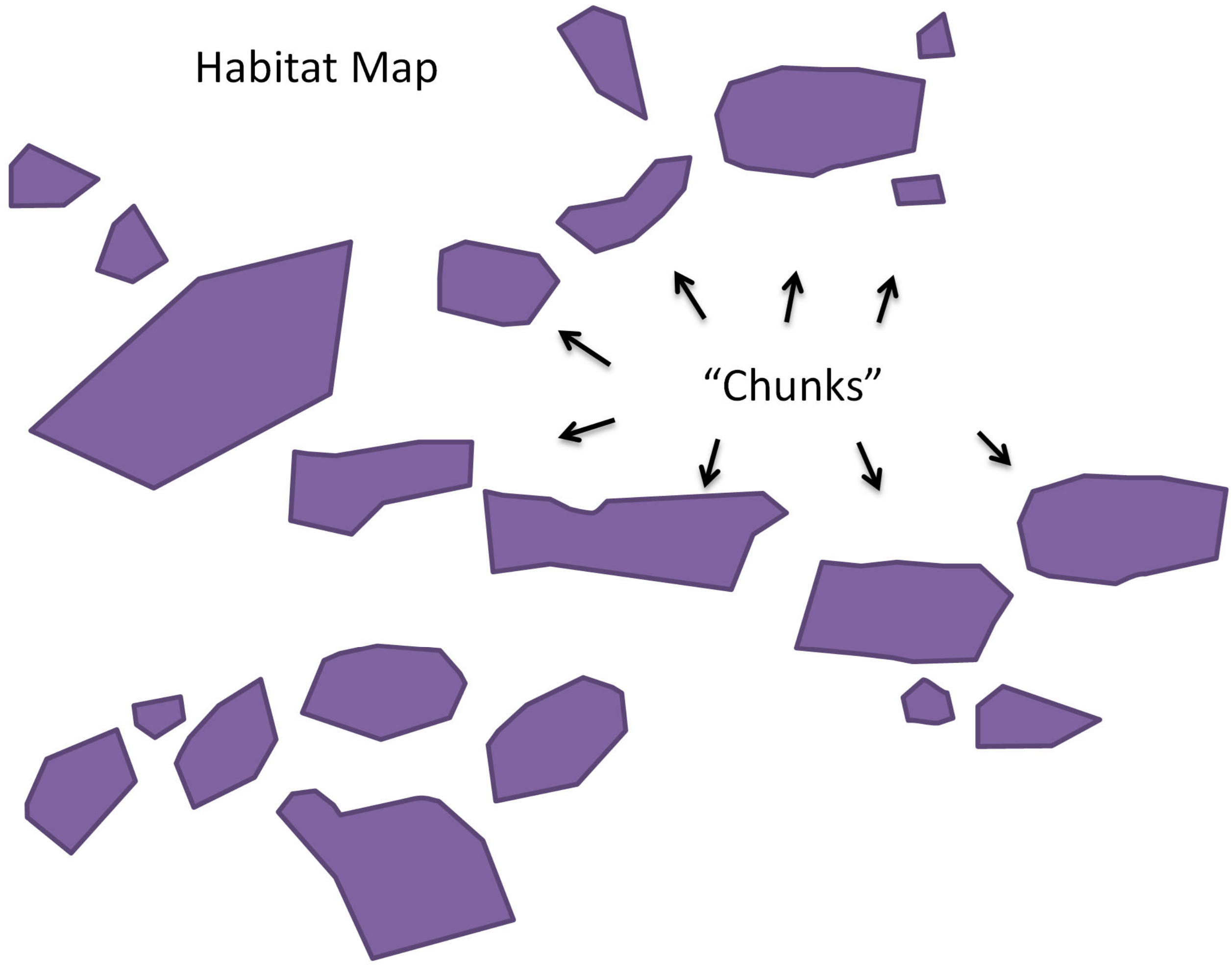


Figure 35. Illustration of a habitat map. Separate pieces of habitat are referred to as "chunks".

The GeoEFM *Patches* tool includes three connectivity methods. The physical connectivity method has options for identifying chunks based on connected edge or connected point. The nearest neighbor and buffer methods include cells in chunks based on connected points.

Chunks separated by less than or equal to the user-defined proximity thresholds in the nearest neighbor and buffer methods are grouped into "neighborhoods" (Figure 36). 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.

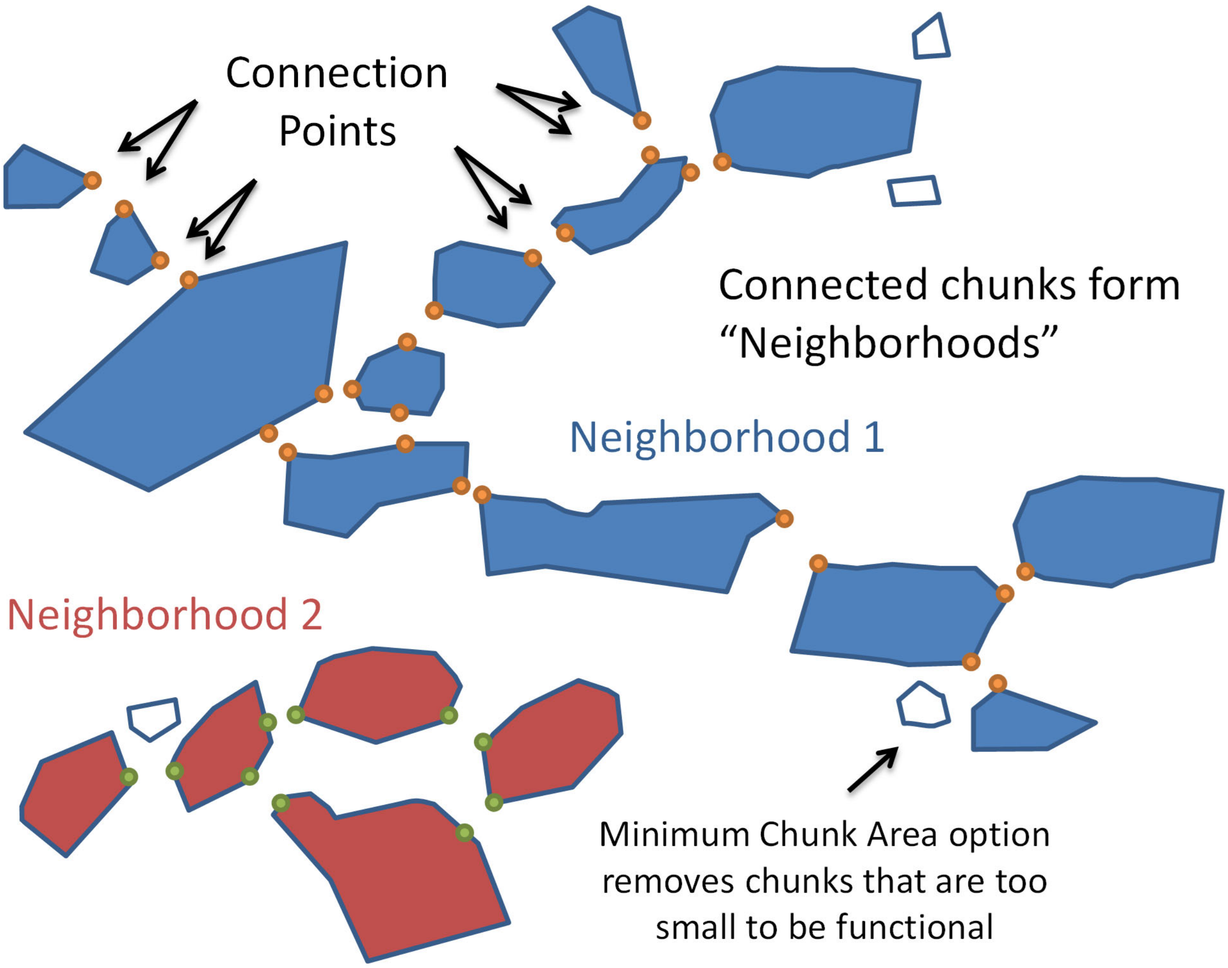


Figure 36. Chunks with areas greater than or equal to the minimum chunk area (user specified and optional) and that are spaced tightly enough to act together ecologically are grouped into "neighborhoods".

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.

Patch results can be summarized and plotted for areas of interest known as Search Polygons.

Search polygon layers can be created, adopted from other views, or populated with polygons from existing layers. Figure 37 shows the process for creating a new search polygon layer entitled Demo_Search_Polygons through the *Patches – Create Search Polygon Layer* menu option and then drawing search polygons through the *Trace* and *Split* tools in the *Manage Search Polygons* interface. There is no known limit to the number of search polygons that GeoEFM can consider. Also, search polygons do not need to intersect with or encompass the habitat being considered.

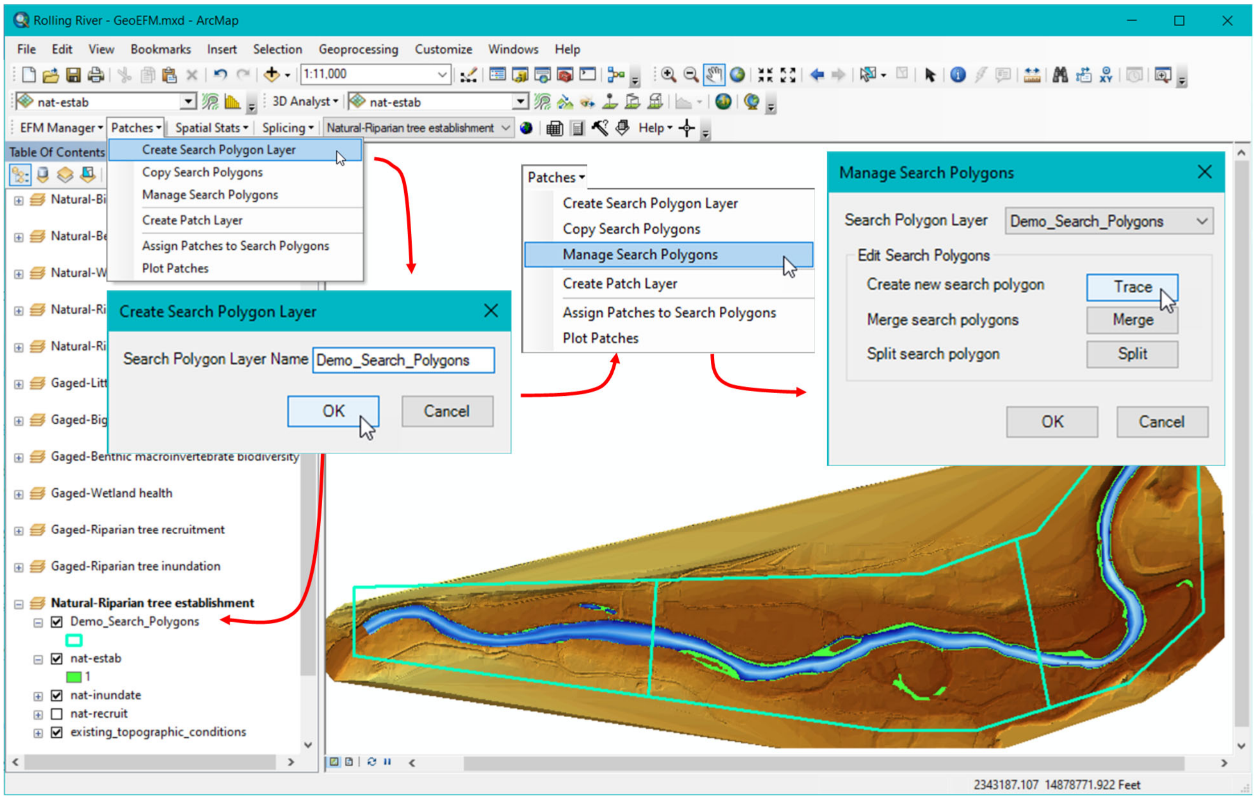


Figure 37. Creating and managing a search polygon layer for use in habitat connectivity analyses.

Once search polygons are established, the next step is to create a "patch raster", which is simply a raster data set whose data has been split into separate habitat areas known herein as "patches". For the *Physical* method a patch is defined by areas that share either a *Connected Edge* or a *Connected Point*.

Currently, connectivity can be assessed only for raster datasets.

5.8.1 Patch Method: Physical

Figure 38 shows a patch raster using the *Physical* patch method for Riparian tree establishment that was generated using the *Connected Point* setting for defining patches. The small thumbnail image in the lower left corner of the figure shows a single patch (circled) that would have been split into two patches if the *Connected Edge* setting were used.

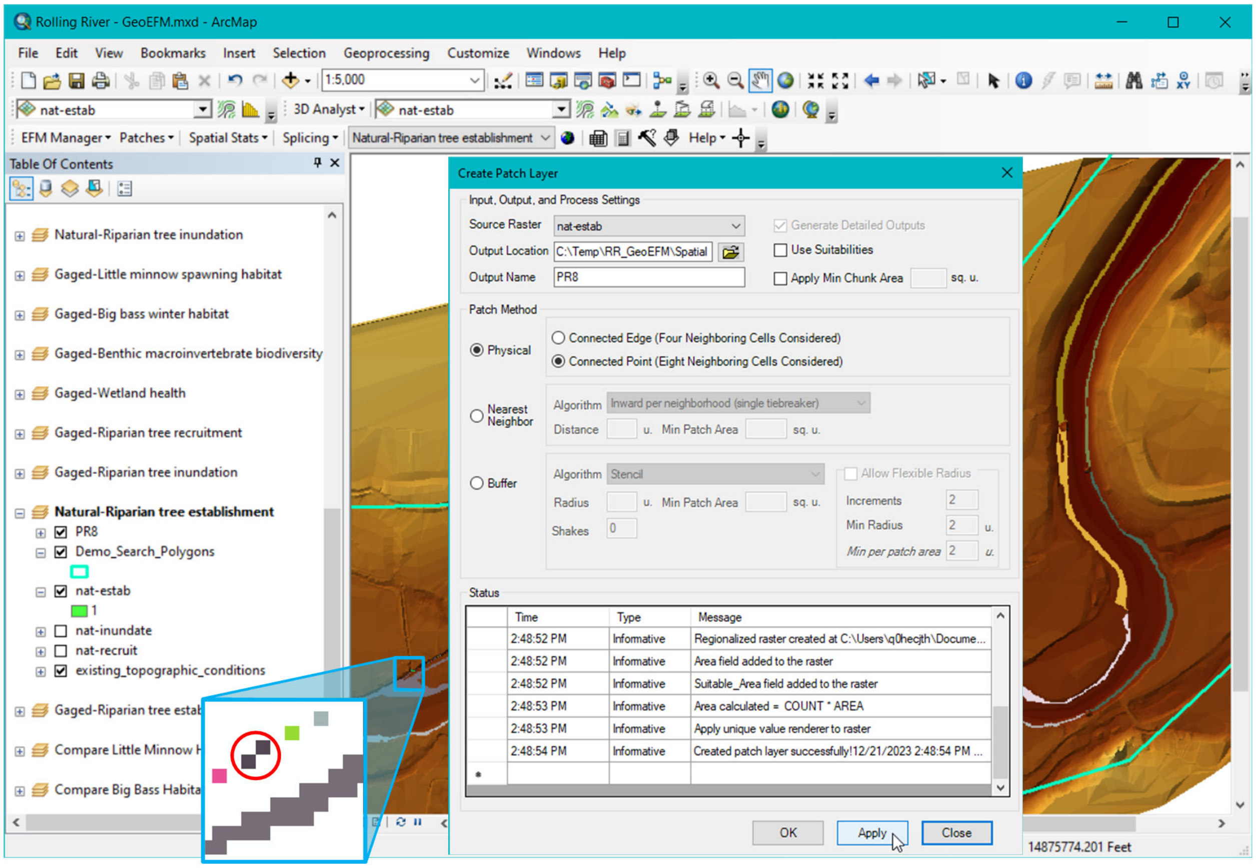


Figure 38. Creating a patch raster layer for use in habitat connectivity analyses using *Physical* Patch Method.

Patches are then assigned to search polygons through the *Patches – Assign Patches to Search Polygons* menu option. Users are given the option of assigning patches by splitting patches at the search polygon boundaries or according to the search polygon that contains the most patch area. Figure 39 shows results of a patch analysis where the Riparian tree establishment patch raster was assigned to polygons in the Demo_Search_Polygons layer using the split at *Split at search polygon boundary and assign patch* method. Results were then displayed via the *Patches – Plot Patches* menu option and could be accessed through the attribute table of the generated "PR8_Split" layer.

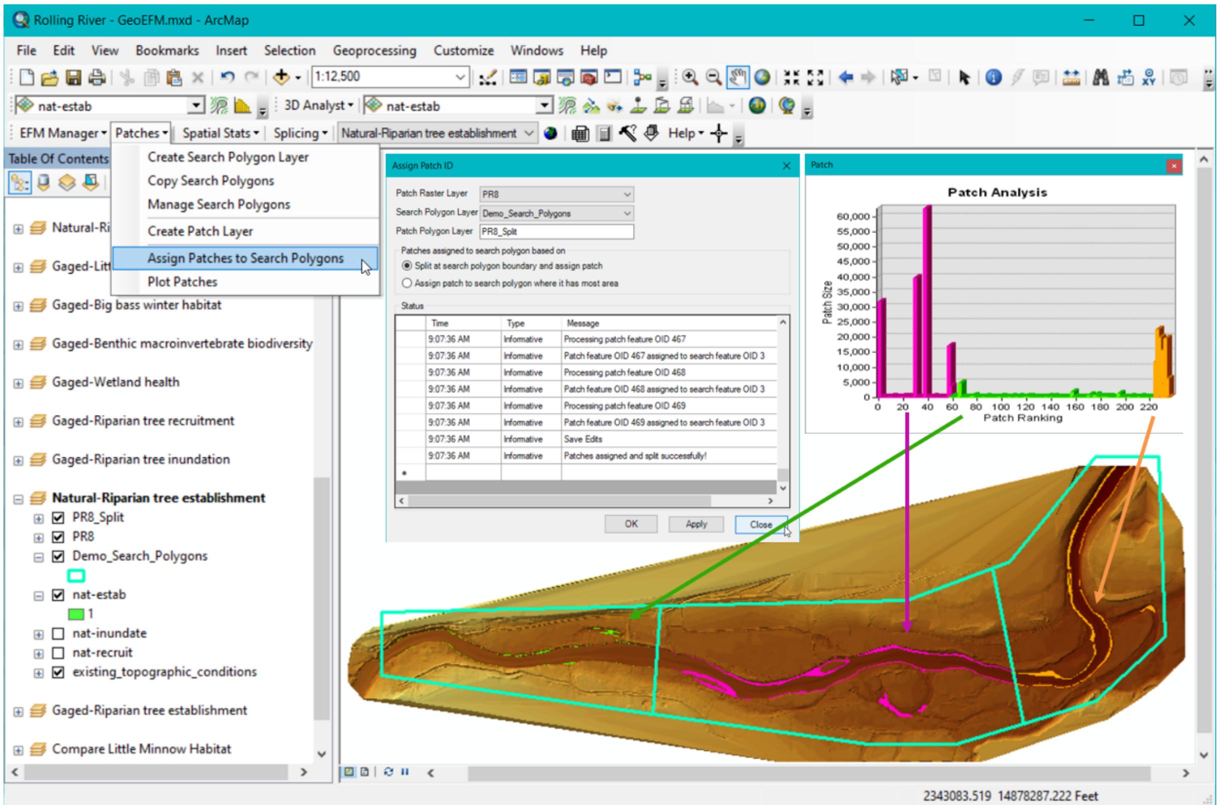


Figure 39. Assigning patches to search polygons in GeoEFM. Results of patch analysis plotted.

5.8.2 Patch Method: Nearest Neighbor

The *Nearest Neighbor* method is parameterized with a *Distance* and a *Minimum Patch Area*. Chunks are grouped into a neighborhood if separated from each other by less than or equal to the user-defined distance value. Separation between chunks is measured as the smallest distance from edge to edge. Individual chunks can have many connections to other chunks. A chunk isolated by more than the distance value in all directions is placed in its own neighborhood. Once neighborhoods have been identified, habitat areas for each neighborhood are divided into patches per the user-defined minimum patch area value.

Patch processing is quite involved (Figure 40). The process begins with a rule that governs throughout: Process single connected chunks whenever available. Connections between chunks are established when identifying neighborhoods. Chunks with only one connection act with other chunks through that connection. When a chunk is processed, it is split into patches per the user-defined *Minimum Patch Area*. For a single connected chunk, this is done by radiating from the chunk point most remote from the connection until the captured area satisfies the minimum patch area criterion. The captured area is then assigned a patch identifier plus associated attributes and removed. This process repeats, radiating from the new most remote point, cutting the next patch, and so on. When the remaining area of the chunk is too small to make a patch, the additional area needed is captured by radiating from the connection point on the connected chunk to complete the patch. The single connected chunk is then fully processed and its connection point pair is resolved, thereby reducing the complexity of the neighborhood and perhaps creating other single connected chunks that can be processed.

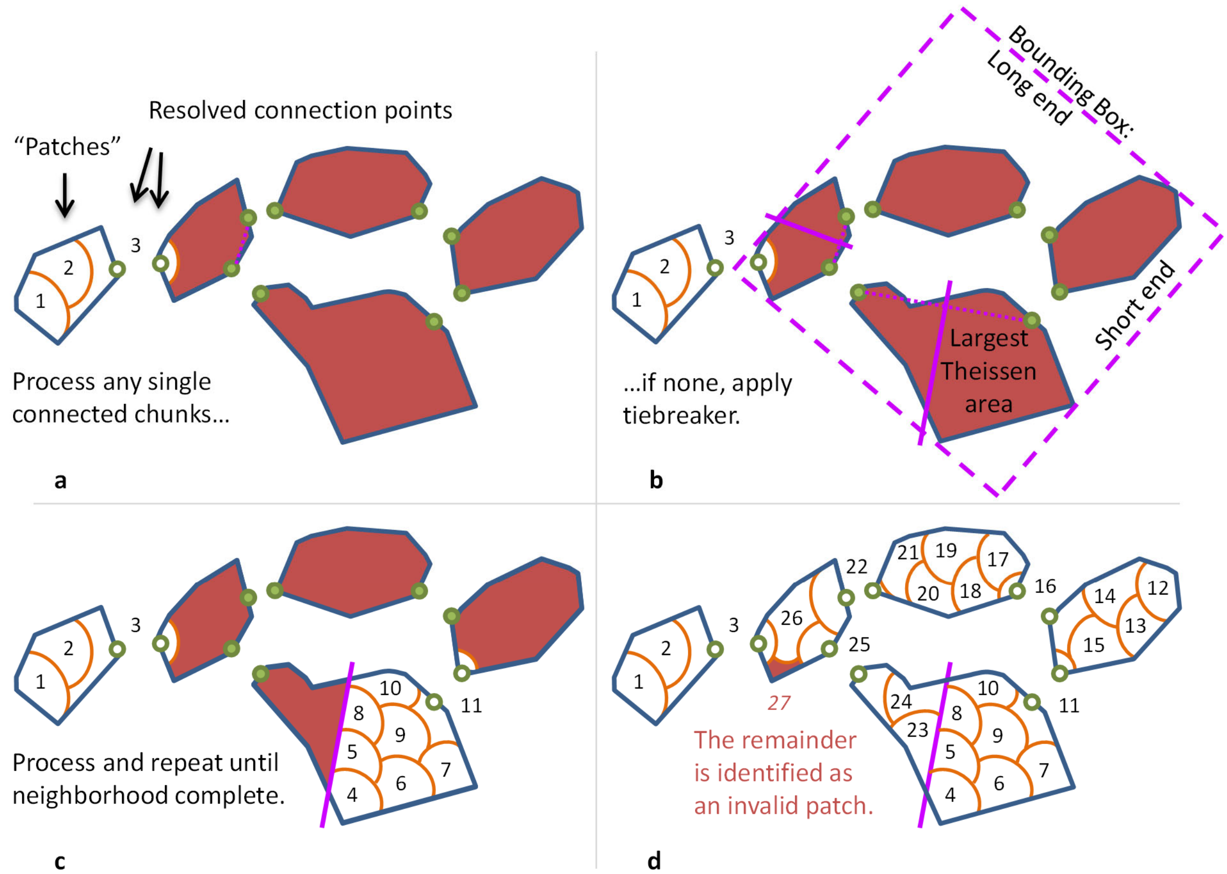


Figure 40. Patch processing with the *Nearest Neighbor* method. First, any single connected chunks are processed (a). If none, a tiebreaker is applied that identifies (b) the largest Theissen area of patches connected to the short end of a bounding box and then processes that area as if it were a single connected chunk (c). This sequence of processing single connected chunks and applying tiebreakers is repeated until remaining area is not enough to make a patch (d).

Tiebreakers are applied when all chunks have multiple connections. In this case, the algorithm frames the remaining chunks with a bounding box. Chunks that touch the short ends of the bounding box are split into Theissen areas based on the locations of their connected points. The largest Theissen area is processed as through it were a single connected patch. This action is repeated as many times as necessary.

Standard output for *Nearest Neighbor* includes a displayed results layer of patches with attribute information about area, 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 connection point, neighborhood, and chunk layers. Theissen areas and bounding boxes are stored in the geodatabase. Pass refers to a counter that advances with each application of a tiebreaker, which is useful when reviewing process results.

When the *Use Suitabilities* option is selected, chunks are split into patches based on value-weighted areas. This presents two main complications for the nearest neighbor method. First, the areas gained when radiating from the starting point of a patch are now variable in value.

Second, the algorithm now needs to consider each raster cell (raster values are used as suitabilities), which could lead to scale issues when the tool is instructed to process large rasters comprised, potentially, of millions of cells. To account for suitability and maintain process integrity, input rasters were converted internally to point coverages. Radii expanding from the starting point of the patch were tested until a radius captured enough value-weighted (raster value multiplied by cell area) points to satisfy the minimum patch area criterion. A bisection method was used to iterate between the radius that first met the criterion and the radius that last failed to meet the criterion in search of a solution that would yield a patch area at least but close to the minimum patch area. The default number of iterations performed is set to 6, but could be changed by the user to any integer from 2 to 10.

Figure 41 shows *Nearest Neighbor* patch results for Little minnow spawning habitat processed with suitabilities. Larger patches occur in the poorest habitat because more total area is required to meet the minimum (suitable) patch area parameter.

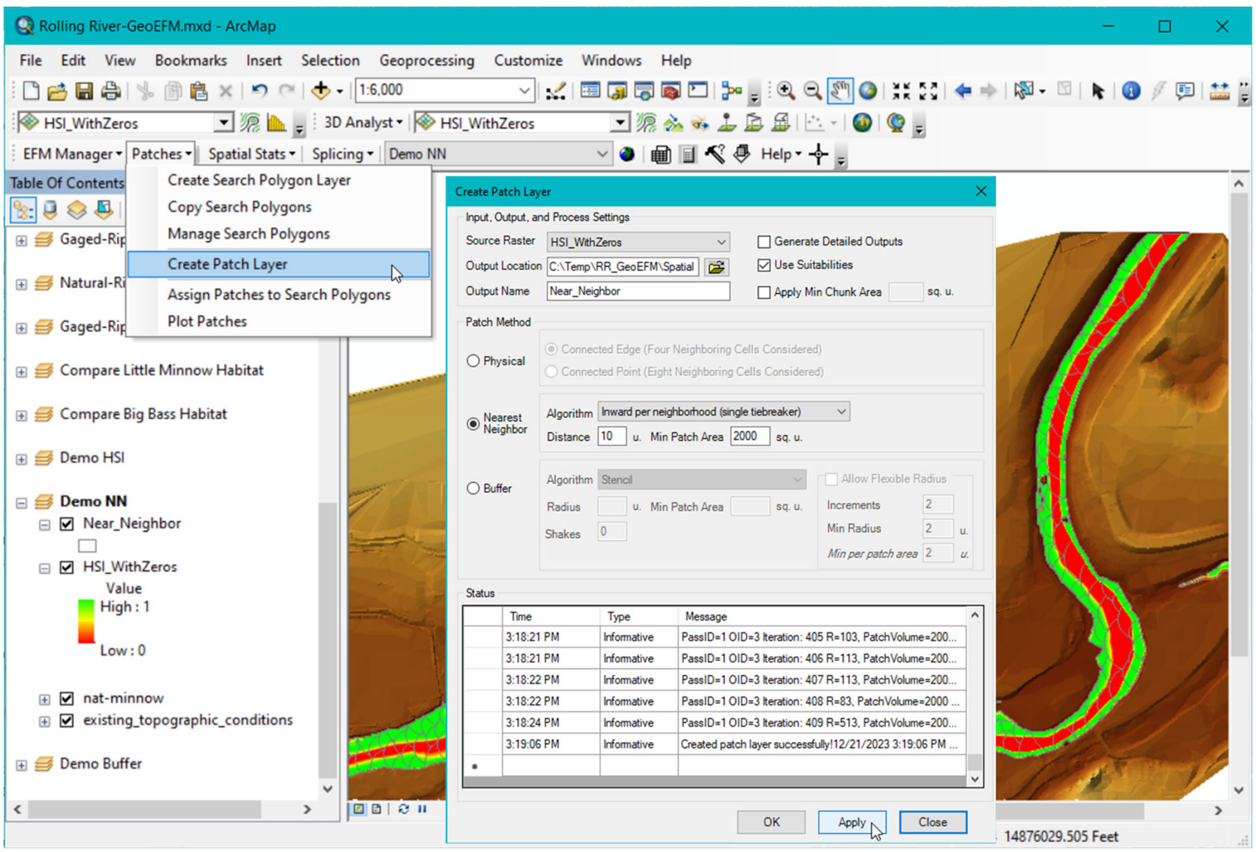


Figure 41. Creating a patch layer using *Nearest Neighbor* method.

5.8.3 Patch Method: Buffer

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.

As in the *Nearest Neighbor* method, *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.

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 42a). 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 42b).

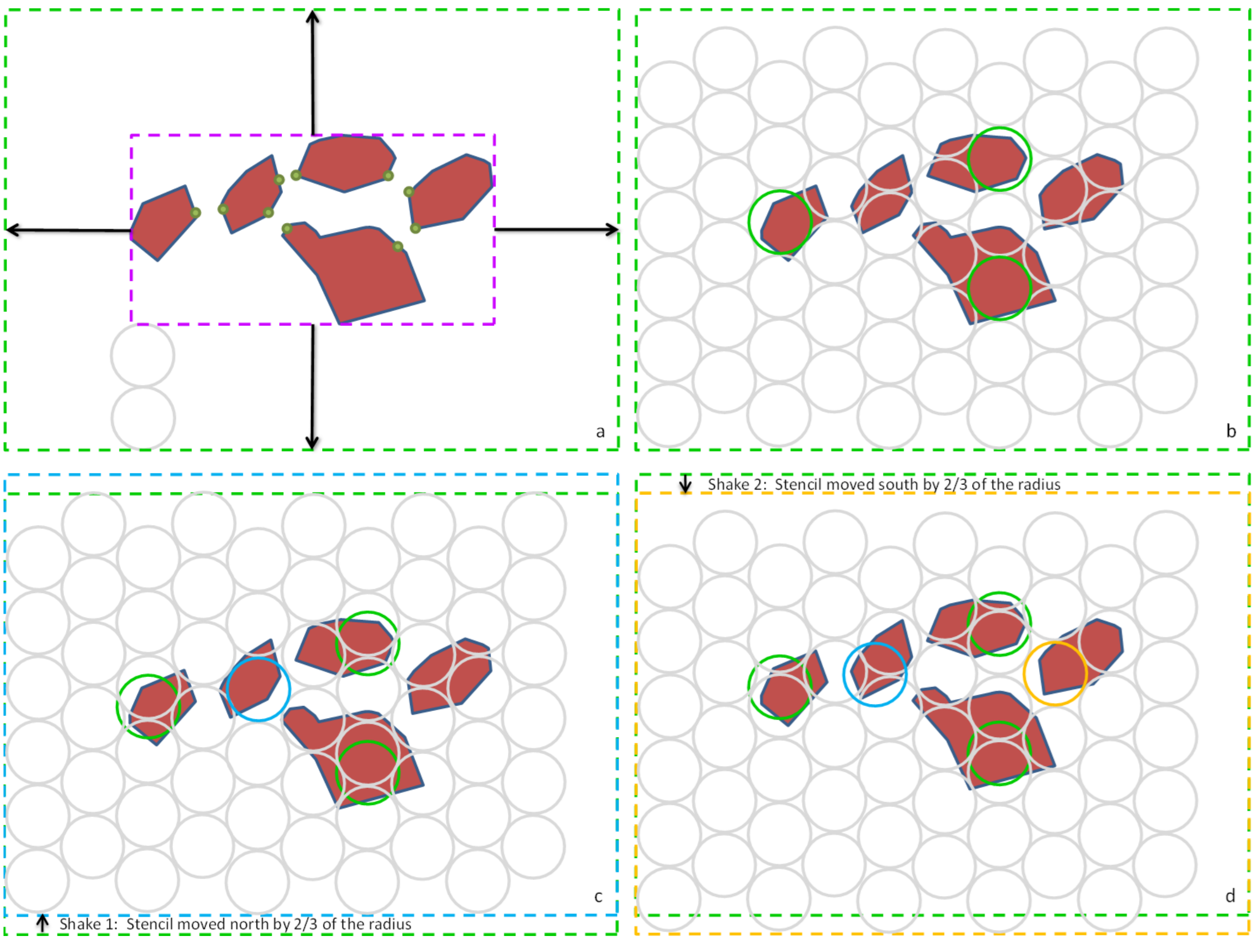


Figure 42. Patch processing with the *Buffer* method. First, the bounding box of neighborhood is expanded by four times the user-defined buffer radius to create the initial stencil outline (a), which is then filled with buffer radius circles (b). Shakes, or slight repositions of the stencil, are considered (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 42b), a shift to the north (shake 1; Figure 42c), and a shift to the south (shake 2; Figure 42d); 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 43). 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).

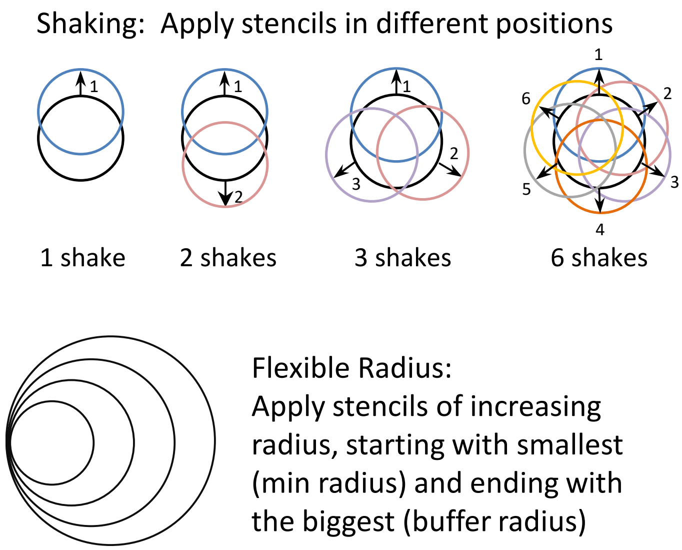


Figure 43. *Buffer* method options include shaking and flexible radius. Shaking considers different stencil positions before cutting patches. Flexible radius uses stencils of different radii. The original position of the expanded bounding box is applied as shake 0.

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. Additional output including the sequence of rasters used for each cut and circles tested (and their center points) are stored in the geodatabase.

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 document 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 were 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 cell size.

Figure 44 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.

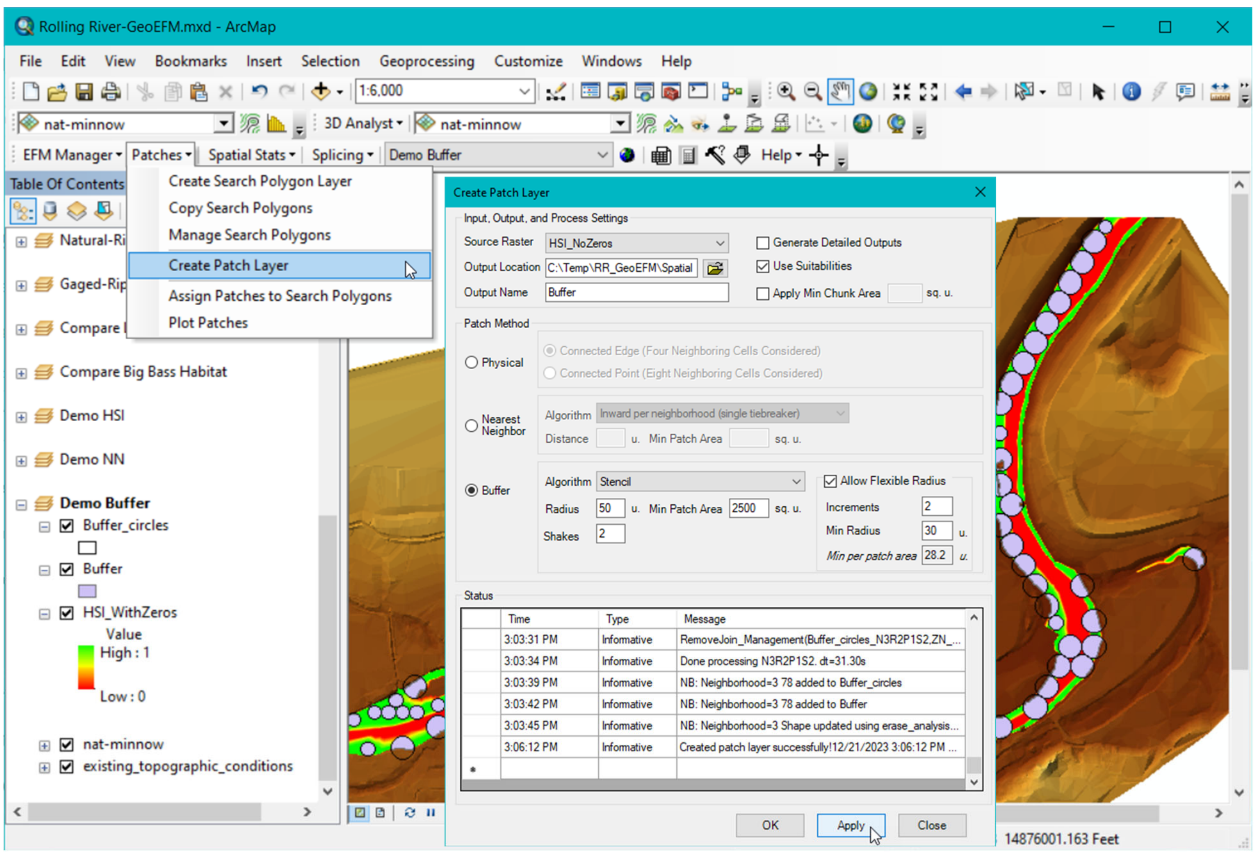


Figure 44. Creating a patch raster for habitat connectivity analyses using *Buffer* patch method.

5.9 User Support (Help Menu)

The Help menu (Figure 45) provides access to the Rolling River demonstration project, GeoEFM user's manual, an information page that includes software version number, and a web link to the GeoEFM homepage.

The demonstration project includes an EFM project, a river hydraulics model, and a GeoEFM project that includes many of the layers and data frames shown herein. **Accessing the demonstration project requires two steps.** First, the *Install Demo Project* menu option allows users to specify where project files will be placed on their computer. Then, the *Configure Demo Project* menu option must be used to update the locations of spatial data layers associated with the project.

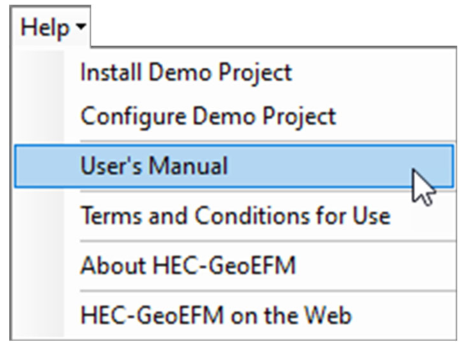


Figure 45. Help menu options for GeoEFM user support.

The ArcMap document of the GeoEFM project is entitled "Rolling River - GeoEFM.mxd" and is located in a folder named "Spatial". When first opened, user's will need to do a *Switch Project* command to reconnect the GeoEFM project with its associated EFM project, "Rolling River.efm", which is located in the "RR_GeoEFM" folder.

Please note that the demonstration project folder for GeoEFM 2.0 is titled "RR_GeoEFM". In GeoEFM 1.0, it was titled "Rolling River - GeoEFM". When using the *Configure Demo Project* menu option, please select the "RR_GeoEFM" folder and click OK to update the demonstration project.

CHAPTER 6

Conclusions

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.

The project management, habitat area, habitat suitability, and spatial statistics features of GeoEFM Version 2.0 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 raster splicing to map ecosystem functions over broad landscapes, 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.

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 7

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