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Hydrologic Engineering Center

HEC-EFM
Ecosystem Functions Model

Quick Start Guide

Version 6.0
April 2025

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The Ecosystem Functions Model (HEC-EFM) is a planning tool that aids in analyzing ecosystem response to changes in flow regime. The Hydrologic Engineering Center (HEC) of the U.S. Army Corps of Engineers is developing HEC-EFM to enable project teams to visualize existing ecologic conditions, highlight promising restoration sites, and assess and rank alternatives according to the relative change in ecosystem aspects.

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US Army Corps of Engineers
Institute for Water Resources
Hydrologic Engineering Center
609 Second Street
Davis, CA 95616

(530) 756-1104
(530) 756-8250 FAX
www.hec.usace.army.mil

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Ecosystem Functions Model, HEC-EFM, Quick Start Guide

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CHAPTER 1

Introduction

The Ecosystem Functions Model (HEC-EFM) is a planning tool that aids in analyzing ecosystem response to changes in flow regime. The Hydrologic Engineering Center (HEC) of the U.S. Army Corps of Engineers is developing HEC-EFM to enable project teams to visualize existing ecologic conditions, highlight promising restoration sites, and assess and rank alternatives according to the relative change in ecosystem aspects.

Central to HEC-EFM analyses are "functional relationships". These relationships link characteristics of hydrologic and hydraulic time series (flow and stage) to elements of the ecosystem through combination of four basic criteria: 1) season, 2) duration, 3) rate of change, and 4) percent exceedance.

After relationships are developed, HEC-EFM performs statistical computations to analyze flow and stage time series for the specified criteria and produces a single flow value for each relationship. This process can then be repeated for alternative flow regimes to compare different project scenarios and indicate directions of changes to ecosystem health (Figure 1).

In addition to the statistical computations, HEC-EFM analyses typically involve hydraulic modeling (performed outside of HEC-EFM), which can translate statistical results to water surface profiles and spatial layers of water depth, velocity, and inundation areas. Geographic Information Systems (GIS) can then be used to display these generated layers as well as other relevant spatial data (i.e., soils, vegetation, and land-use maps).

Data requirements of HEC-EFM are related to the level of detail desired by the modeler. If only statistical results are desired, then required data consists of the flow regimes to be analyzed and the eco-hydro relationships. If the user intends to visualize statistical results spatially, data (and software) requirements increase significantly to include flow and stage time series, eco-hydro relationships, digital topography, a geo-referenced hydraulic model, and any other spatial data relevant to the ecosystem investigations.

This quick start guide provides an overview of the software (Chapter 2), a description of the numerical processes performed by the software (Chapter 3), examples that demonstrate its use (Chapter 4), information about application at different scales (Chapter 5), details about multivariate analyses (Chapter 6), and language support (Chapter 7). Text 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 HEC-EFM. 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.

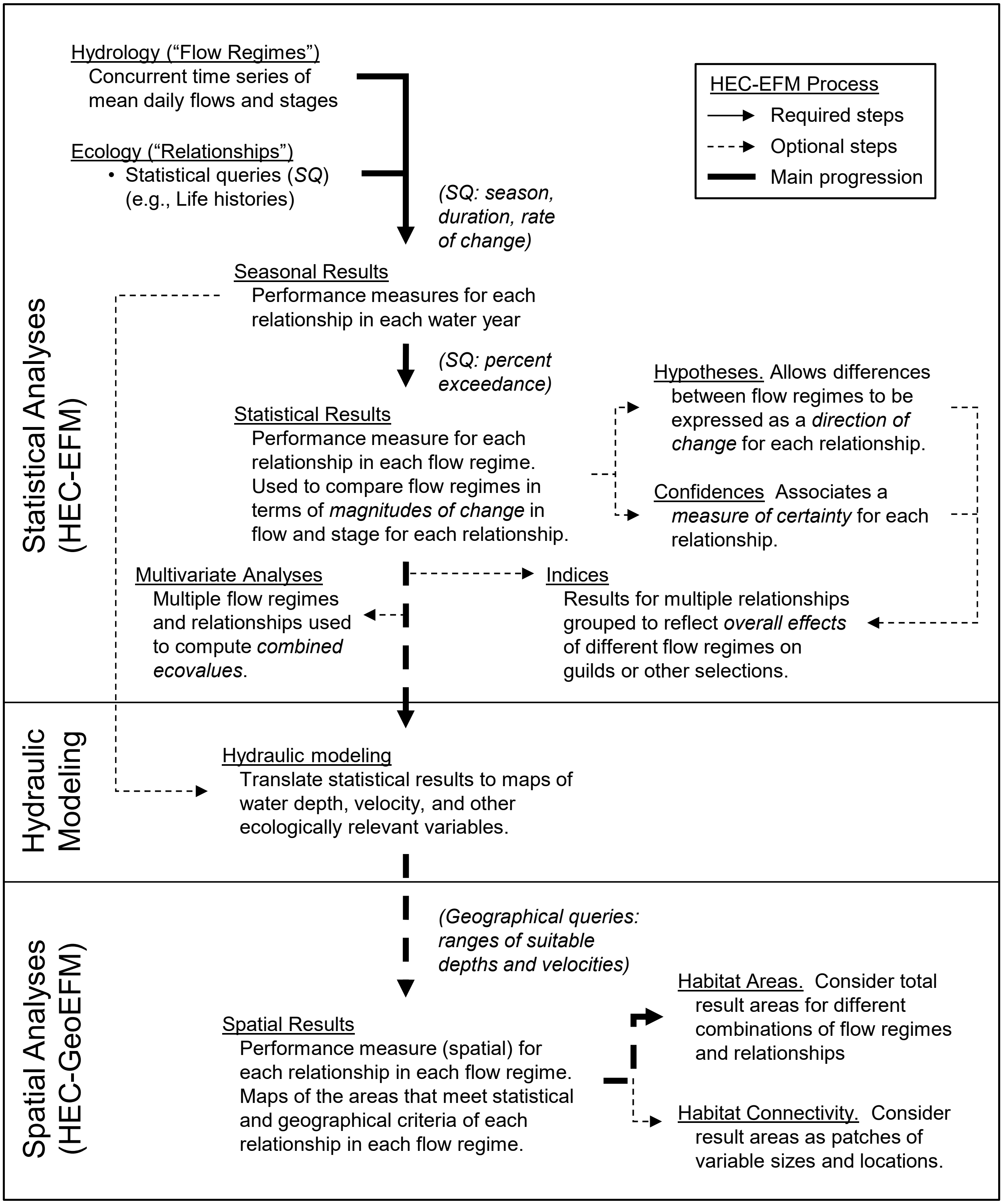


Figure 1. The process of applying HEC-EFM involves statistical analyses, river hydraulic modeling, and spatial analyses. Key inputs are hydrologic time series and ecological information such as the life history requirements of species of interest (e.g., seasons, durations, and frequencies).

CHAPTER 2

User Interface

The main interface of HEC-EFM consists of a title bar, a series of menus, four tabs (*Properties*, *Relationships*, *Tables*, and *Combo Relationships*), a message bar, and a *Recalculate* button (Figure 2). Most features are located on the tabs. The rest of this section provides more detail for those tabs.

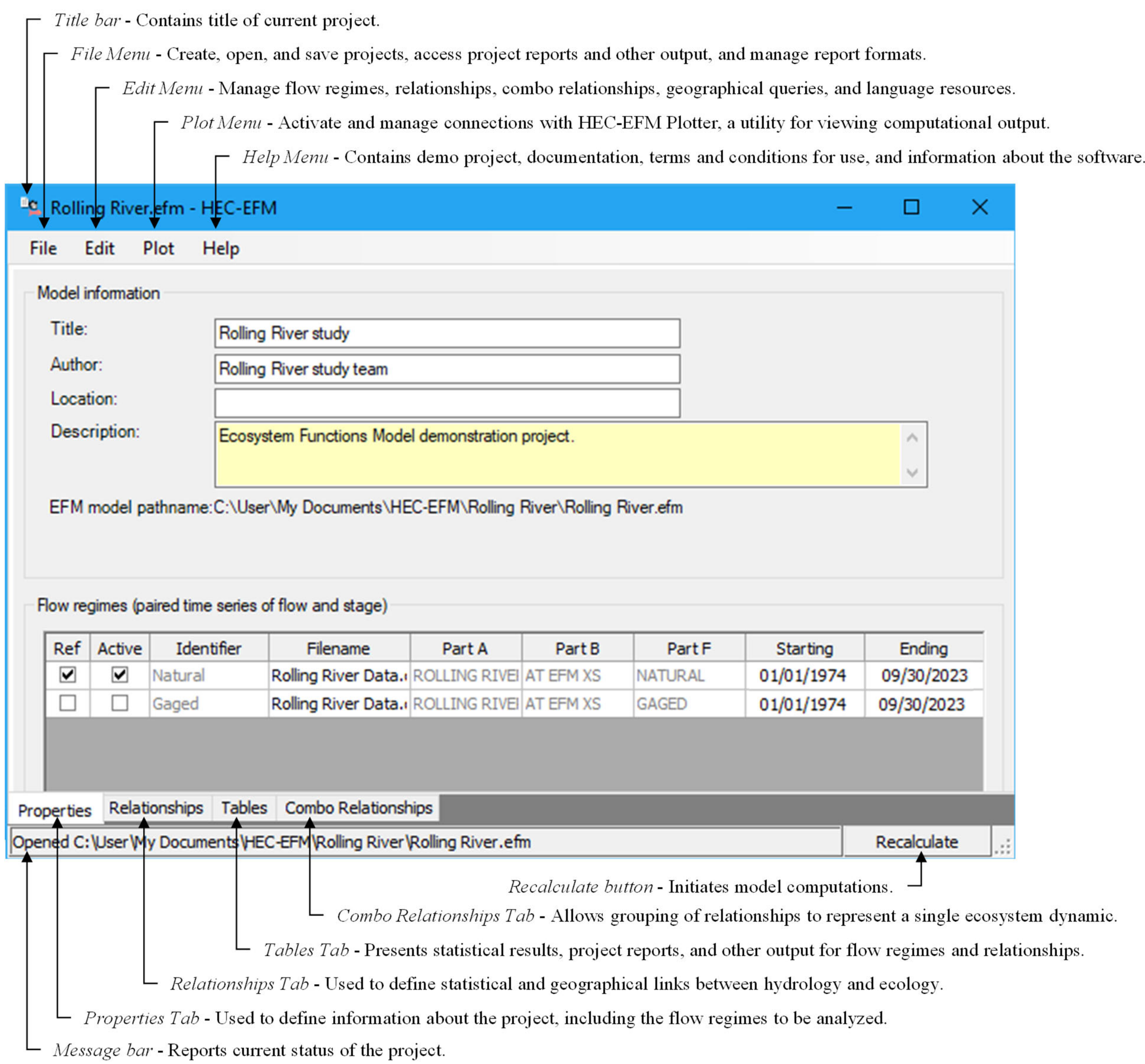


Figure 2. Key components of the main interface of HEC-EFM.

2.1 Properties

The *Properties Tab* contains information relevant to the model as a whole and is divided into two frames: *Model Information* and *Flow Regimes* (Figure 3).

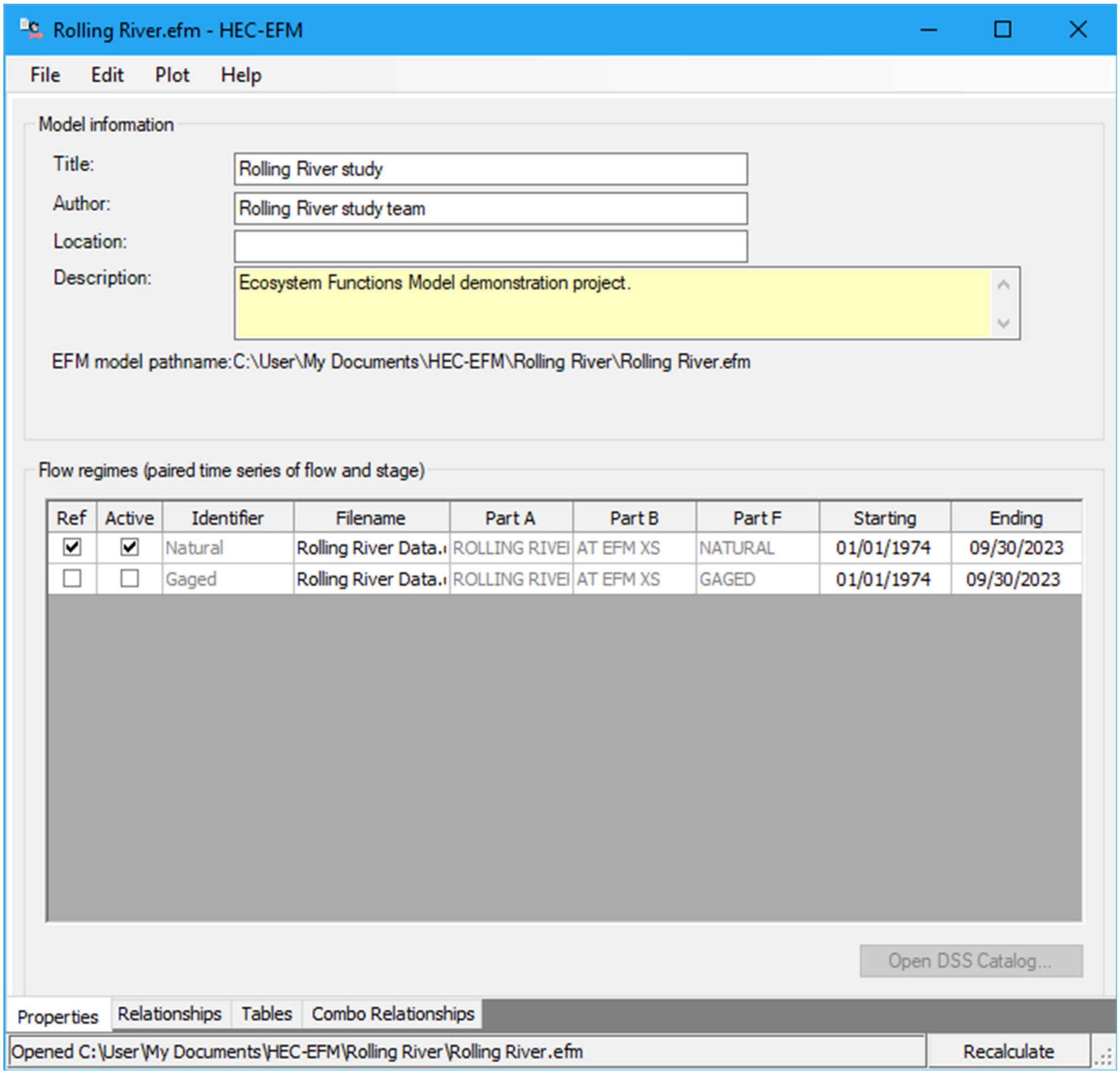


Figure 3. The *Properties Tab* of HEC-EFM is used to document information about the project and to define the flow regimes to be analyzed. Two flow regimes (Natural and Gaged) are shown.

Model Information – *Model information* documents metadata (*Title*, *Author*, *Location*, and *Description*) about the project.

Flow Regimes – An HEC-EFM "flow regime" is defined as two concurrent daily time series that reflect conditions at a single location in the study area. Typically, a flow regime is composed of time series of daily mean flow and daily mean stage data. HEC-EFM accepts input data from several text formats (i.e., comma, space, and tab delimited), from HEC Data Storage System

(HEC-DSS), which is the database used by HEC models for storage of time series and other data, and from the Hierarchical Data Format (HDF), which is a database used by a few HEC models for storing two dimensional outputs. The start and end dates for flow regimes are controlled by the user, which can be a handy feature when analyzing only part of the period of record.

2.2 Relationships

HEC-EFM "relationships" are statistical representations of links between hydrology and ecology. Relationships are typically developed by teams of scientists and engineers using a combination of expert knowledge and scientific literature. Relationships are defined on the *Relationships Tab*, which is broken up into four frames: *Statistical queries*, *Geographical queries*, *Other queries (nonstandard)*, and *Options* (Figure 4).

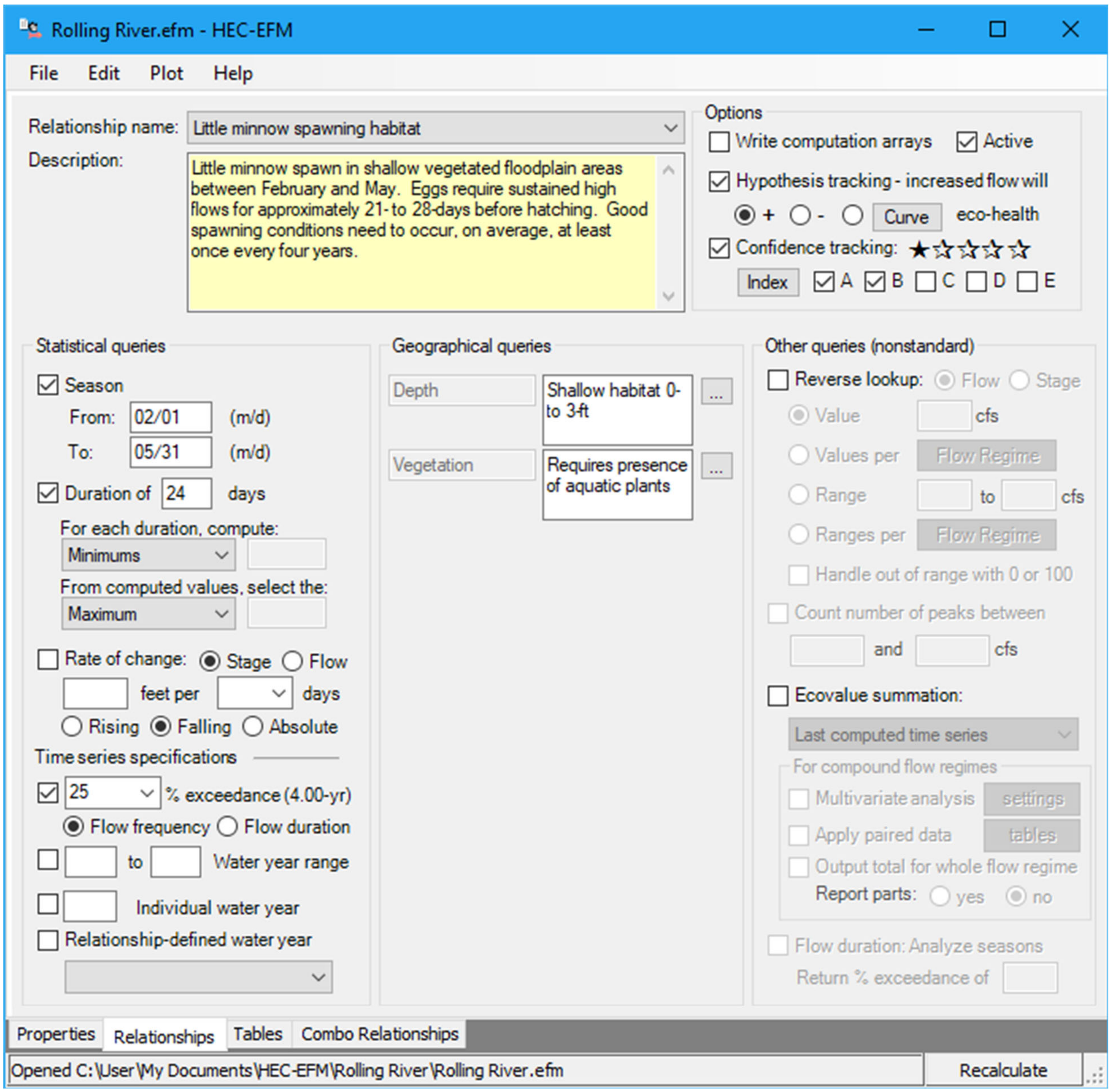


Figure 4. Using the *Relationships Tab* of HEC-EFM, modelers define individual relationships as combinations of statistical and geographical criteria.

Statistical Queries – Fields within *Statistical queries* allow users to input criteria (in terms of *Season*, *Duration*, *Rate of change*, and *Percent exceedance*) that define the statistical analysis to be performed for each relationship. All criteria do not need to be filled in for each relationship – only those that are important for the relationship. Time series specifications can be entered as *Flow frequency* (percent of years) or *Flow duration* (percent of time). *Statistical queries* also offer controls for managing the flow and stage data to be used for the statistical computations. Options are given for *Water year range*, *Individual water year*, or *Relationship-defined water year*, which allows a relationship to be based on the statistical results of a separate relationship.

Geographical Queries – *Geographical queries* allow users to specify criteria that define relationships from a spatial perspective. Geographical queries are created by the user through the *Manage Tags for Geographical Queries* interface (Figure 5), which is accessed by selecting the *"Edit – Manage Geo Queries…"* menu option. Users create tags and specify the tags that are important for each relationship. This action creates a text field in the HEC-EFM interface for recording how the tagged data sets need to be queried in GIS. A tag is a simple name that identifies sets of spatial data layers important to an HEC-EFM project.

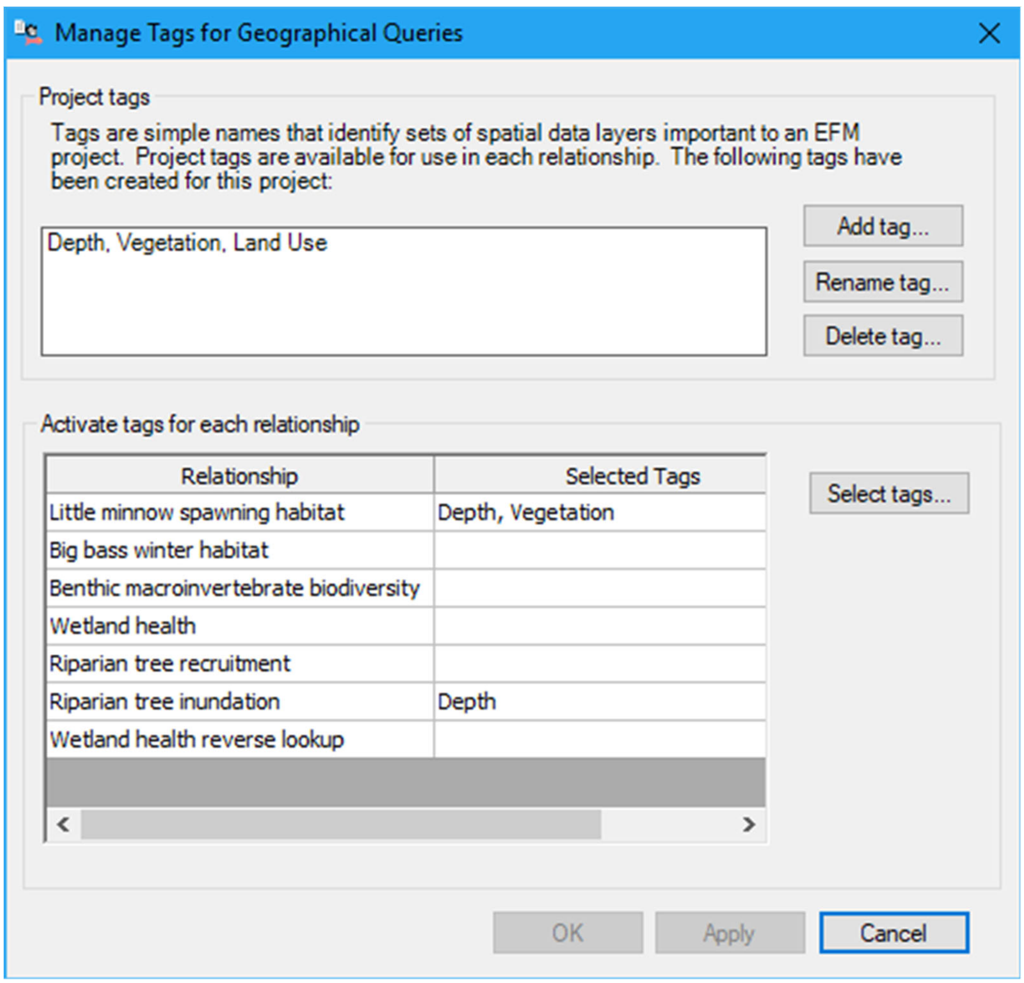


Figure 5. The *Manage Tags for Geographical Queries* interface in HEC-EFM is used for editing and creating tags, which are labels for sets of spatial data important to an HEC-EFM project.

Other Queries (nonstandard) – Statistical results for a standard HEC-EFM relationship is a pair of flow and stage data that meet the statistical criteria specified for that relationship. Currently, the only nonstandard queries available are *Reverse lookup* and *Ecovalue summation*. Reverse lookups do not compute a flow and stage, instead the user specifies a flow and HEC-EFM computes the percent of years or percent of time that flow is equaled or exceeded. Ecovalue summations tally the ecovalues (see sections 3.6.1 and 3.6.3) provided by different flow regimes. When the *Ecovalue summation* query is turned on for a relationship, summations are computed in addition to all steps normally performed to assess that relationship. Ecovalue summations can be done for standard or *Reverse lookup* relationships. The *Hypothesis tracking* option must be selected to use ecovalue summations.

Options – Three options are available for each relationship: *Write computation arrays*, *Hypothesis tracking*, and *Confidence tracking*. The *Write computation arrays* option prompts HEC-EFM to export the statistical computations performed for that relationship. *Hypothesis tracking* allows users to compare the direction of change of eco-health for different flow regimes. The question that hypothesis tracking asks is: "Increased flow *will do what to* eco-health?" for this relationship. Users have the option of saying that increased flow will help (+), hurt (-), or have a non-linear response (via the *Curve* button) to eco-health. *Confidence tracking* provides a way to track the relative certainty of HEC-EFM relationships. The default is one star. This starting point implies that there is the same amount of scientific understanding for each of the relationships. As confidence in a particular relationship grows, its number of stars can be increased at the discretion of the study team, perhaps when the relationship is verified with field data, backed with scientific literature, or approved by a group of scientists or agencies.

2.3 Tables

The *Tables Tab* presents statistical results for pairings of flow regimes and relationships. The *Tables Tab* is also where users can view project reports, arrays files, and output files (Figure 6). Tables can be printed or copied into other applications. After the *Recalculate* button is pressed, the HEC-EFM interface will automatically go to the *Tables Tab* to display the new statistical results.

2.4 Combo Relationships

Combo Relationships are used to detail how two or more individual relationships are grouped to represent a single ecosystem dynamic. For example, in Figure 7, Riparian tree establishment is defined as Riparian tree recruitment minus Riparian tree inundation.

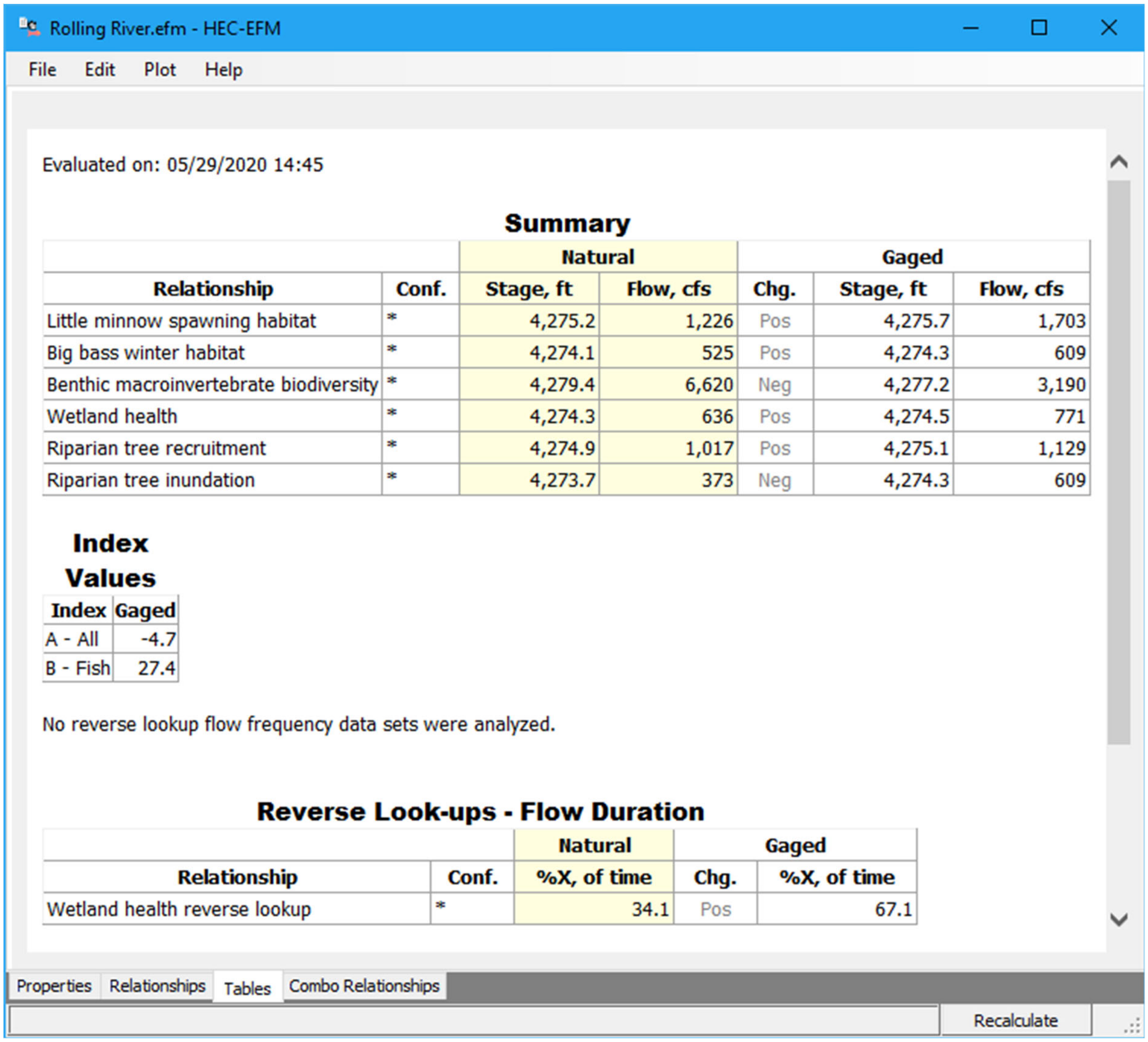


Figure 6. The *Tables Tab* of HEC-EFM is used to display statistical results for simulations (as in this figure), project reports, and computational output.

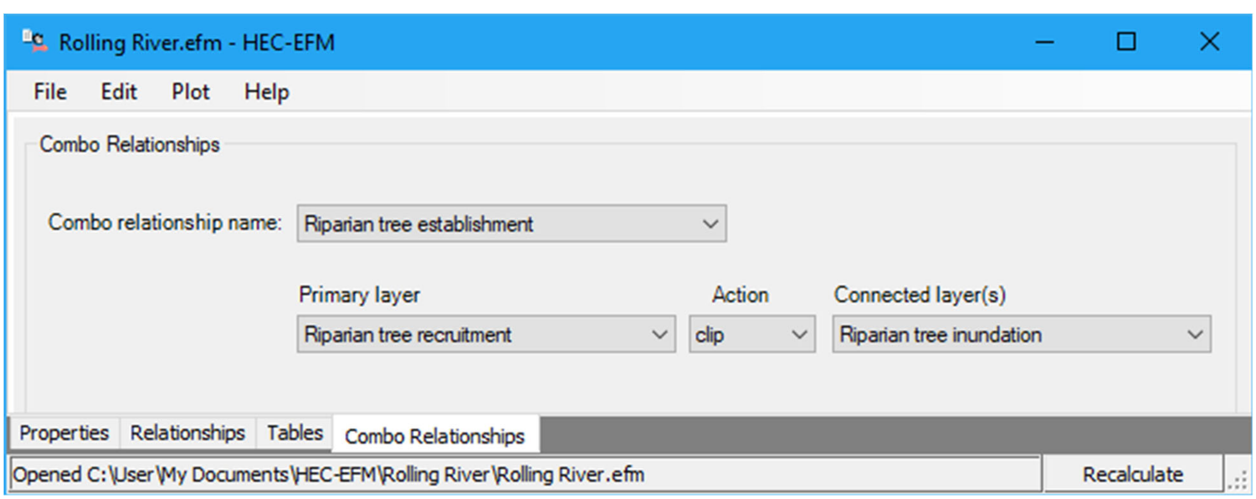


Figure 7. The *Combo Relationships Tab* of HEC-EFM allows for grouping of separate relationships to represent a single ecosystem dynamic.

CHAPTER 3

HEC-EFM Math

While the HEC-EFM process can involve hydraulic modeling and GIS, statistical analyses of links between hydrology and ecology are the foundation of HEC-EFM applications.

The math performed by HEC-EFM during these statistical analyses is actually very basic. The challenge is in understanding how the parameters that define relationships (*Season*, *Duration*, *Rate of change*, and *Percent exceedance*) are used by HEC-EFM to compute the flow and stage that meet those criteria.

3.1 Season

Season is the most intuitive of the parameters. Ecosystem dynamics (e.g., fish spawning or seed germination) typically occur in certain time periods of the year. Within HEC-EFM, season is defined by start and end dates. During computations, a seasonal extract is taken from each water year being investigated. All *Duration* and *Rate of change* queries are performed on these seasonal extracts.

3.2 Duration

Duration is a versatile, but complicated query. Three settings are available: 1) *number of days*, 2) a selection of statistics to be computed *for each duration* in the season, and 3) a selection of statistics to be computed using the time series of *computed values* produced in step two.

The *number of days* defines a duration interval (Figure 8). *Duration* calculations are performed from the beginning of season to the end of season. So for the start date, HEC-EFM considers all data values within the duration interval (per setting 1), computes a statistic (per setting 2), records that value for the start date, and then advances a day and repeats the process until the end of season is reached. This process produces a statistical time series of *Minimums*, *Medians*, *Maximums*, *User defined percentages*, or *Means* (per setting 2) that has one value for each day of the season.

The final step in the *Duration* query involves selecting a single seasonal value (per setting 3) from the statistical time series. Options are provided for *Minimum*, *Median*, *Maximum*, *User defined percentage*, and *Mean*. This process produces a time series of seasonal results that has one value per season.

Figure 8 provides an example of this process using an 8 day duration interval, minimums, and then maximum of the minimums.

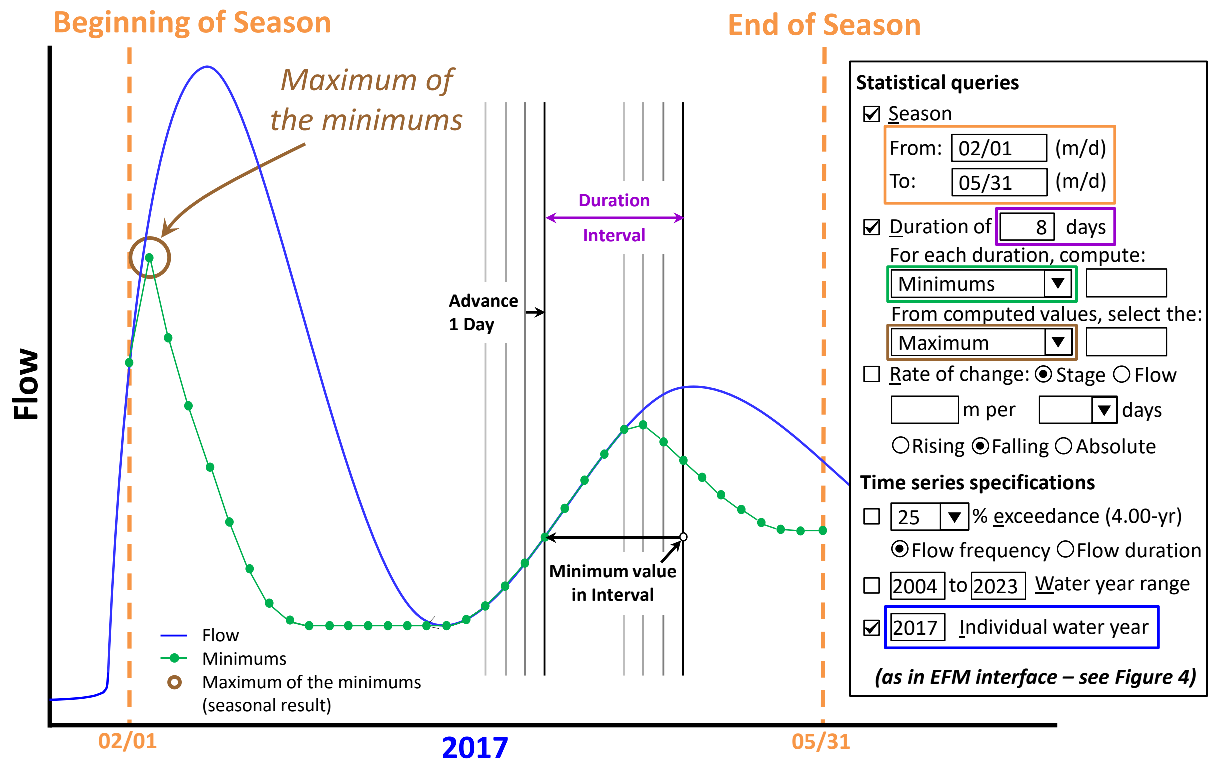


Figure 8. Sample use of the *Duration* query in HEC-EFM. Computations are shown for one water year. Statistical queries (to right of graph) are shown as in the EFM interface in Figure 4.

3.3 Rate of Change

The *Rate of change* query was originally added to HEC-EFM to look at ecological concerns connected to the recession limb of stage hydrographs. Its capabilities have since been expanded to include *Rising*, *Falling*, and *Absolute* rates of change for both *Stage* and *Flow*.

For all combinations of those settings (Figure 9), the *Rate of change* uses two parameters: 1) the *threshold value for change* and 2) the *number of days*. For each day beginning at the end of the season and working backwards in time, the actual rate of change is computed by subtracting the current flow or stage and the flow or stage that occurs at the end of the time interval defined by the *number of days* (i.e., if *number of days* is set to 4, the actual rate of change equals the current value minus the value 3 days into the future such that the total time interval being considered spans 4 days). The actual rate of change is then compared to the *threshold value*. If actual does not violate *threshold*, the rate of change is deemed acceptable, HEC-EFM moves backwards one day, and the test is repeated. This process continues until the *threshold* is violated or the beginning of season is reached.

If the *threshold* is violated, HEC-EFM selects the previous successful test (one day later than the failed test) as the seasonal result, which represents the date and conditions where rates of change became consistently acceptable for the rest of the season.

If the beginning of season is reached and passes the rate of change test, HEC-EFM selects that date and its corresponding conditions as the seasonal result.

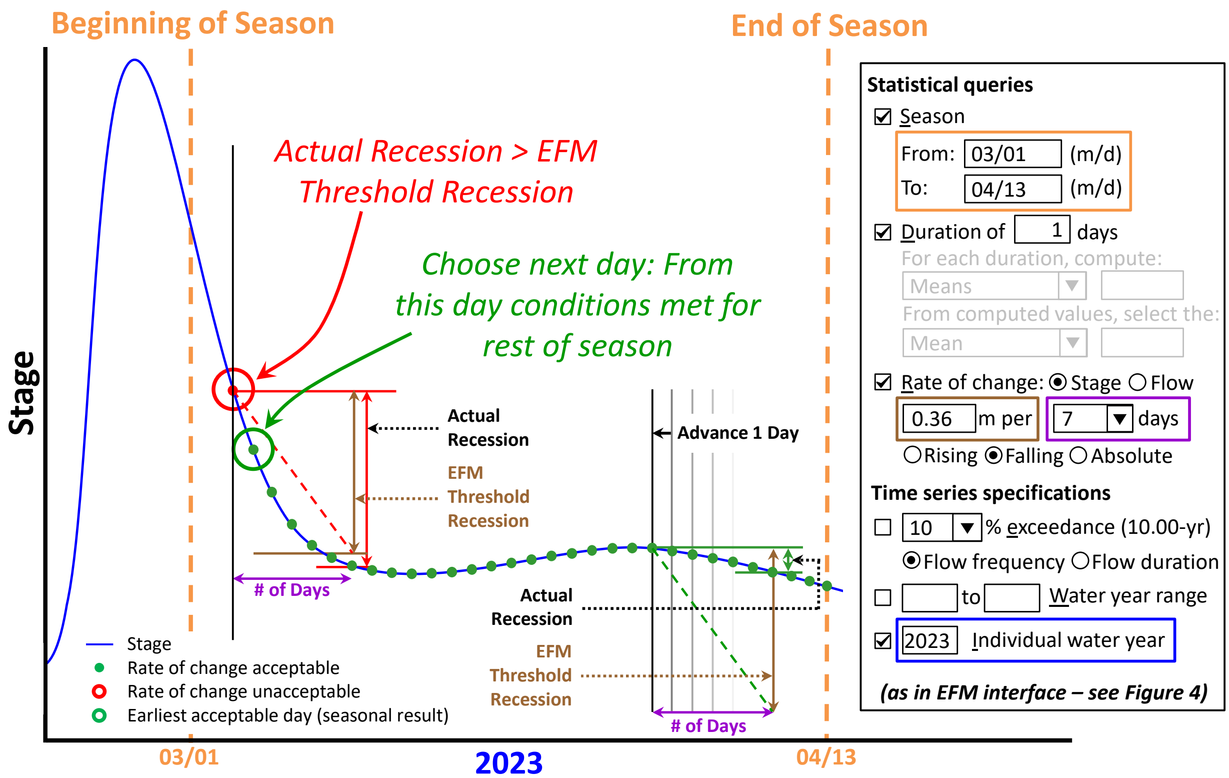


Figure 9. Sample use of the *Rate of change* query in HEC-EFM. Computations are shown for one water year. Statistical queries (to right of graph) are shown as in the EFM interface in Figure 4.

If the first test (at the end of season) fails, a zero value is recorded as the seasonal result, which indicates that no dates passed the rate of change test for that season.

It is also important to note that when *Rate of change* is selected in the HEC-EFM interface, the dropdown controls in the *Duration* query become gray and inoperable. This behavior is meant to communicate that the two queries are largely incompatible. In fact, the only *Duration* setting relevant to *Rate of change* is *number of days*. When duration is set to 1 day (as in Figure 9), the *Rate of change* query tests the mean daily values obtained from the flow regimes in the seasonal extract. When an integer of 2 or more is entered, HEC-EFM will compute a time series of mean values for that duration of flow or stage, depending on the setting in *Rate of change*, and then perform the rate of change tests for that computed series.

3.4 Time Series Specifications

Components in the *Time series specifications* section of HEC-EFM include *Percent exceedance* and three controls for managing the period of record assessed for each relationship (*Water year range*, *Individual water year*, and *Relationship-defined water year*).

The *Percent exceedance* query offers a choice of either *Flow frequency* or *Flow duration*. *Flow duration* should not be confused with the *Duration* query described earlier in this chapter. In fact, when *Flow duration* is selected in the HEC-EFM interface, the dropdown controls in the *Duration* query become gray and inoperable. As with *Rate of change*, the only *Duration* setting relevant to *Flow duration* is *Number of days*. When duration is set to 1 day, HEC-EFM generates a flow duration curve using mean daily values obtained from the flow regimes in the seasonal extract and then interpolates to obtain the flow that corresponds to the user-defined percentage. When an integer of 2 or more is entered, HEC-EFM computes a time series of mean flow values for that duration, uses those values to generate a flow duration curve, and then interpolates to obtain the flow that is equaled or exceeded for the **user-defined percentage of time**. The resulting value would be the statistical result.

When *Flow frequency* is selected (Figure 10), HEC-EFM ranks the seasonal results (computed via the *Season*, *Duration*, and *Rate of change* queries) and interpolates to obtain the flow (or stage, if *Rate of change* is being used to investigate stage dynamics) that is equaled or exceeded for the **user-defined percentage of years**. The resulting value would be the statistical result.

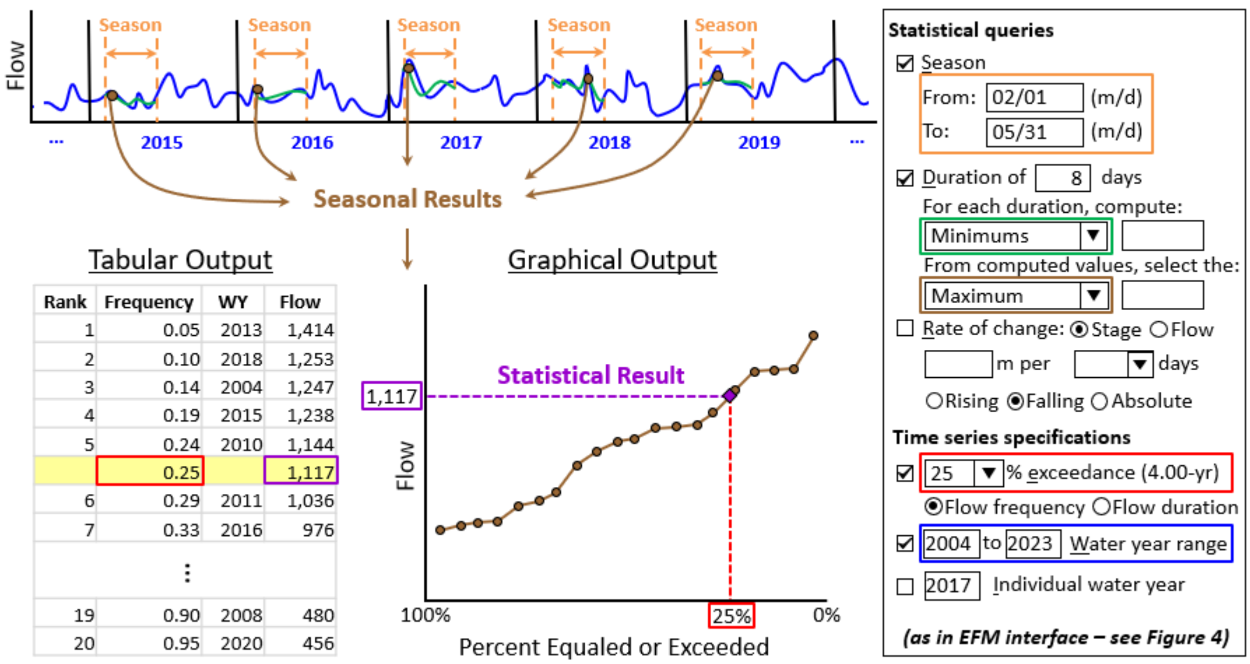


Figure 10. Sample use of the *Time series specifications* for a relationship with *Season* and *Duration* queries (as in Figure 8). The statistical result is the flow meeting the parameters in those queries that is equaled or exceeded in 25% of years (*Flow frequency*). Statistical queries (to right of graph) are shown as in the EFM interface in Figure 4.

This ranking and interpolation process is required only when seasonal results are computed for multiple years, whether for a whole flow regime as defined on the Properties tab (Figure 2) or via the *Water year range* control (Figure 10).

Both the *Individual water year* and the *Relationship-defined water year* controls limit analyses to a single water year. For the *Individual water year*, the user specifies which water year to assess. For *Relationship-defined water year*, the user selects a separate relationship that is of interest, and HEC-EFM determines which of its seasonal results (and corresponding historical water year) most closely equals its statistical result. That historical water year is then used when assessing the current relationship. In both cases, as there is only one seasonal result, it is also reported as the statistical result.

3.5 Reverse Lookups

Reverse lookup relationships follow the same numerical process described earlier in this chapter, except the last step in determining the statistical result is reversed. That is, instead of specifying a *Percent exceedance* and having the software compute the corresponding flow or stage (Figure 10), users specify the flow or stage of interest and the software computes the percentage of time or of years that flow or stage is equaled or exceeded (Figure 11). Application of *Season*, *Duration*, *Rate of change*, and *Flow frequency* or *Flow duration* settings are unchanged.

Users specify which flow regime data to analyze (flow or stage), the value or range of interest, and whether to report "out of range" results with a numeric result. Value and range can be applied to all flow regimes or set individually for each flow regime. The *per flow regime* options are useful when flow regimes are location-based. For example, especially over large areas, floodplains become inundated at different times and for different durations in accordance with local conditions. A relationship that investigates how frequently floodplain activation occurs could use the *Reverse lookup – Values per flow regime* setting to quantify floodplain dynamics for different location-based flow regimes per the local conditions that trigger inundation.

When values and ranges do not intersect with ranked seasonal results (Figure 10, bottom left and center), statistical results are "out of range" and reported as text messages. An option is offered that allows results to be reported as 0 when above range and 100 when below. For example, if a value of 600 was queried and all seasonal results were greater than 600, the statistical result would be "below range" or equaled or exceeded "100%" if the handle option was selected. Results are always computed for the percentage of time or years equaled or exceeded. For ranges, HEC-EFM computes this equaled or exceeded condition for the Min and Max values, subtracts Max from Min, and reports that difference as the percentage of time or years in range. "Out of range" conditions occur when either the Min value or Max value do not intersect.

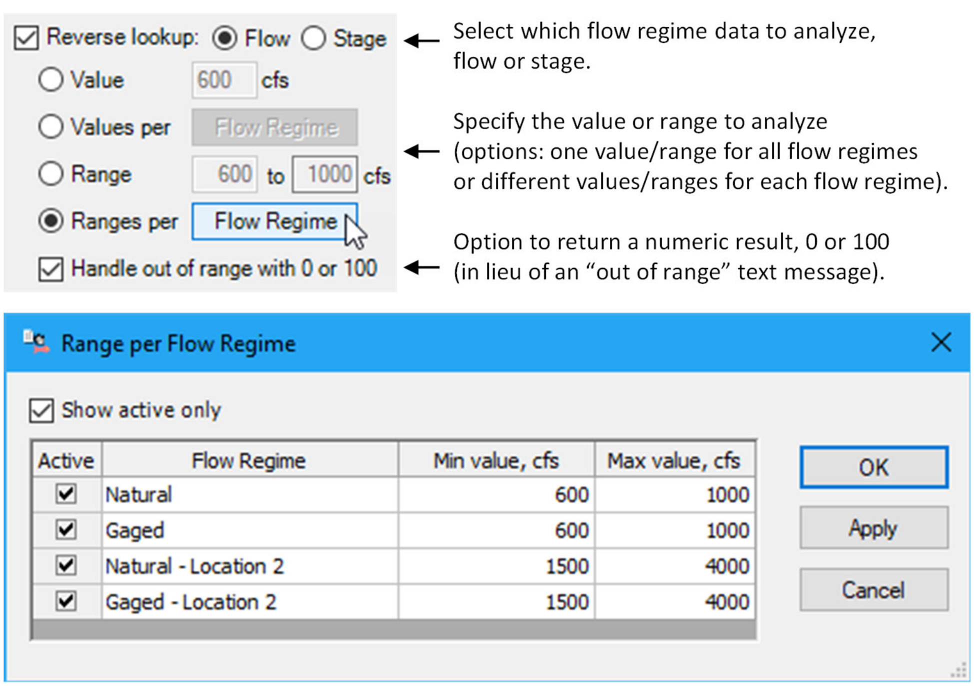


Figure 11. The *Reverse lookup* feature queries the percentage of years or time a value is equaled or exceeded or the percentage of time or years conditions are in range.

3.6 Other Math Features

In addition to seasonal and statistical results, HEC-EFM also computes relationship-based ecovalues and dates of occurrence for each season within the period of record, as well as indices that involve multiple relationships. Ecovalues are useful in assessing how successfully habitat is provided. Dates of occurrence are useful in assessing the seasonality of habitat availability. Indices are used to numerically combine several relationships to compute a single measure of how a flow regime more broadly affects an ecosystem or ecosystem component.

3.6.1 Ecovalues and Ecovalue Shift

Ecovalues are measures of how well flow regimes meet the needs of relationships. Users specify how seasonal and statistical results translate to ecovalues through the *hypothesis tracking* feature available as part of each relationship. Ecovalues can either be set equal to the flow result (i.e., when the "+" *hypothesis tracking* setting is active), the negation of the flow result (i.e., when the "-" setting is active), or interpolated based on the flow result and a table provided by the user (i.e., when the "*Curve*" setting is active). This interpolation option allows users to score the ecological success of different flow results. For example, a table could be applied that translates flow results for a relationship to ecovalues on a scale from 0 to 10.

Ecovalues are computed for each season within the period of record. Seasonal ecovalues are then used to compute a mean ecovalue for the whole flow regime (Figure 12). Mean ecovalues are used as a variable in the computations of *Indices*, as described later in this chapter.

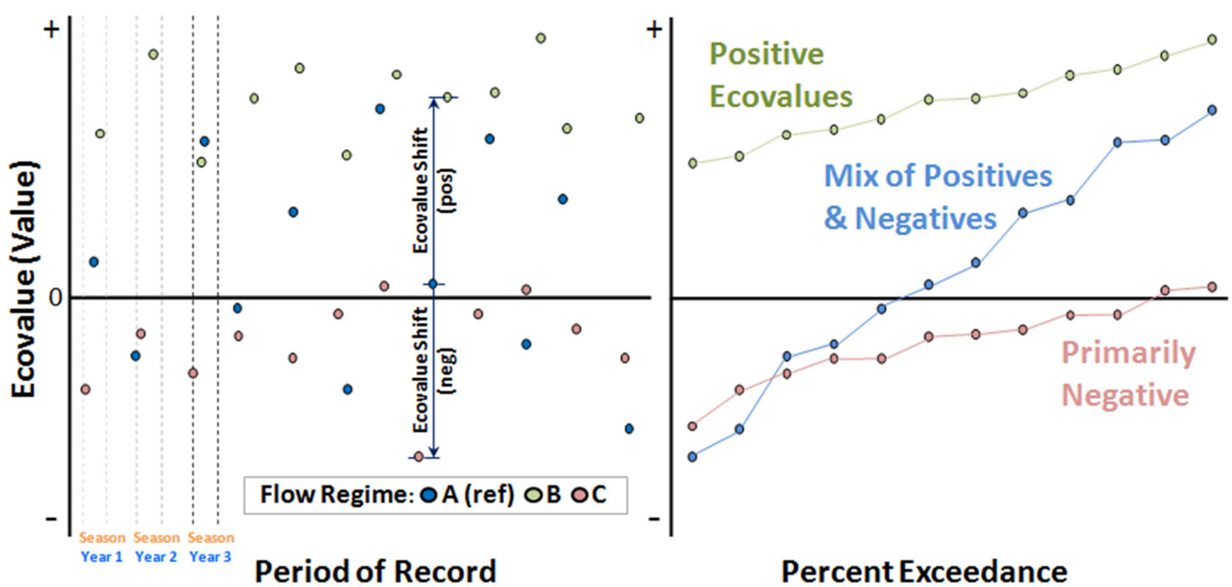


Figure 12. Seasonal ecovalues shown as a time series (left) and in accordance with percent exceedance (right). Ecovalues are measures of how successfully the criteria for a relationship are met by a flow regime. Typically, increasingly positive ecovalues correspond to increasingly beneficial habitat conditions.

For flow regimes that are active and not the reference, seasonal ecovalue "shifts" are computed as a percent change in ecovalue from the reference flow regime. Seasonal ecovalues and seasonal ecovalue shifts are output as time series (one value per season per year) and as ranked data (Figure 13). Both offer insights regarding how successfully habitat is provided and how that success differs between flow regimes.

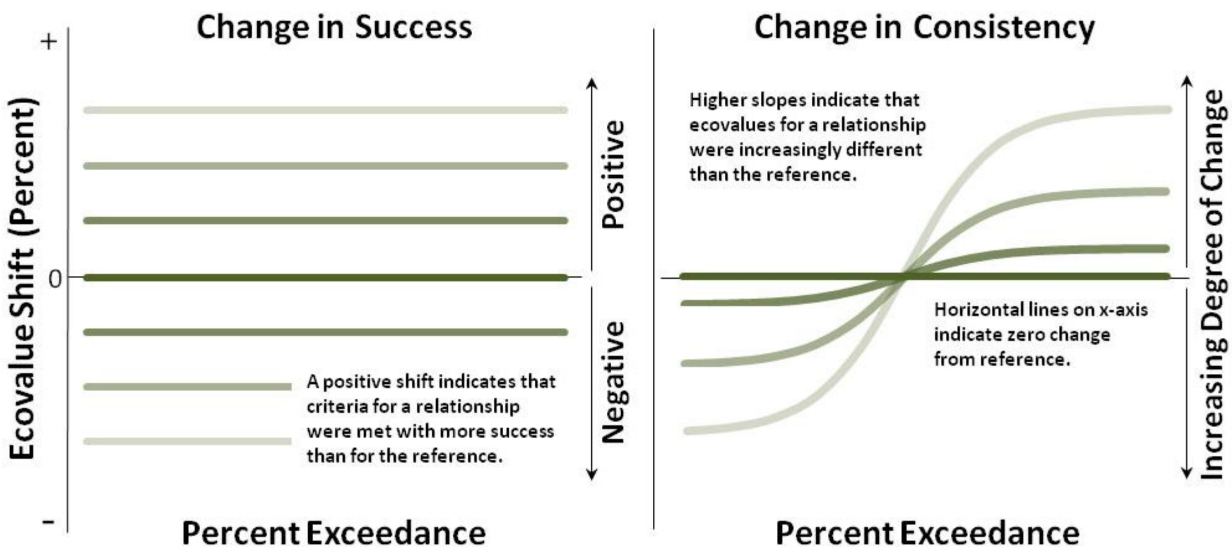


Figure 13. Ecovalue shifts provide insight regarding changes in success (left) and changes in the consistency of success (right) for a relationship. In HEC-EFM, "shifts" inherently compare an active flow regime with the reference flow regime. Ecovalue shifts are computed as the percent difference in ecovalue between active and reference flow regimes.

3.6.2 Dates and Date Shift

"Dates" are based on the day and month when the statistical parameters of a relationship are met for each water year in the period of record. Numerically, a seasonal date value is set equal to the number of days between 01 January and the day and month of its corresponding seasonal result (e.g., a seasonal date value of 31 would correspond to a seasonal result occurring on 31 January; Figure 14).

For flow regimes that are active and not the reference, seasonal date "shifts" are computed as the change in date value from the reference flow regime. Seasonal dates and seasonal date shifts are output as time series (one value per season per year) and as ranked data (Figure 15). Both offer insights regarding how habitat availability fluctuates within the *season* of interest and how that seasonality differs between flow regimes.

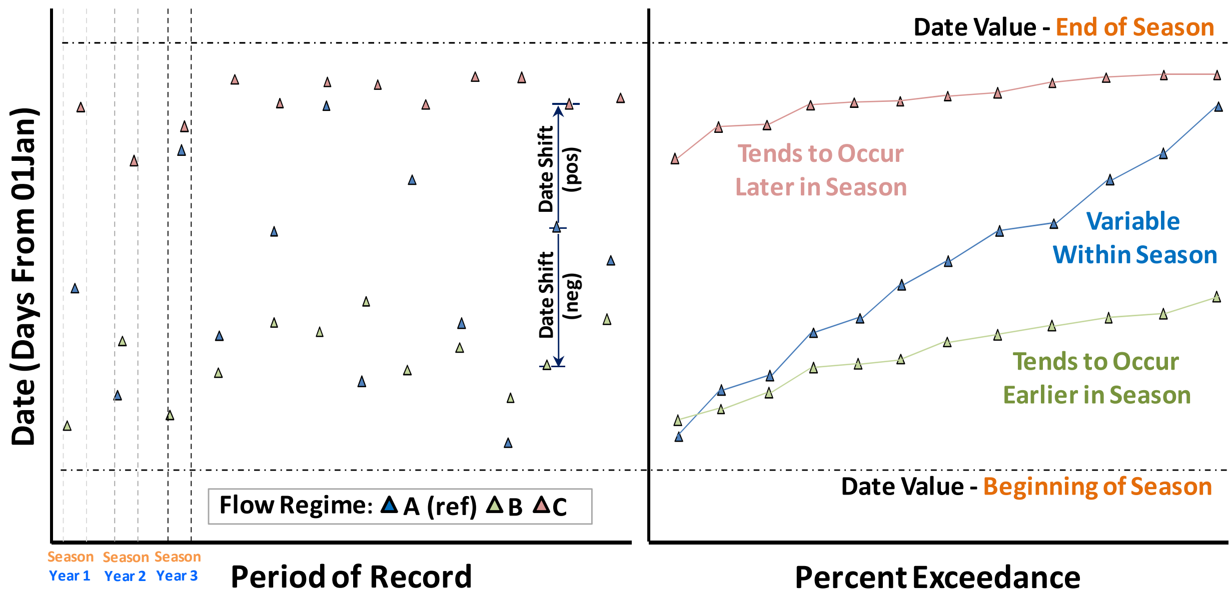


Figure 14. Seasonal date values shown as a time series (left) and in accordance with percent exceedance (right). Date values reflect when the criteria for a relationship were met within the season defined for the relationship.

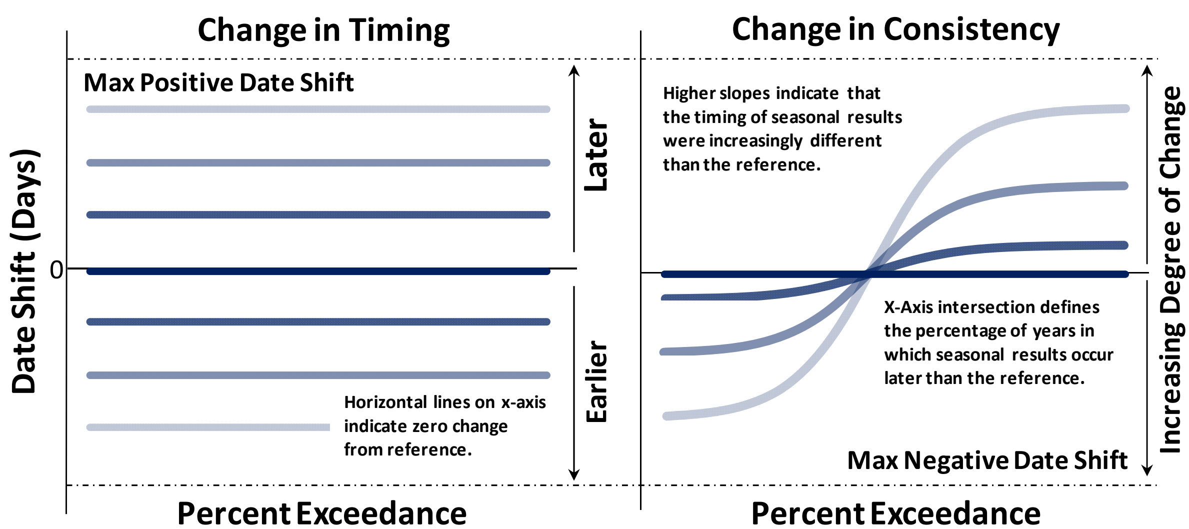


Figure 15. Date shifts provide insight regarding changes in the timing (left) and changes in the consistency of timing (right) of when criteria for a relationship were met. In HEC-EFM, “shifts” inherently compare an active flow regime with the reference flow regime. Date shifts are the time differences (numbers of days) between the seasonal date values of active and reference flow regimes.

3.6.3 Ecovalue Summations and Summations Shift

Ecovalue summations tally the accumulation of ecovalues provided by different flow regimes. Ecovalue summations differ from the ecovalues described in section 3.6.1 because, whereas ecovalues begin with the seasonal and statistical results of a relationship, summations begin with a daily time series of ecovalues. This ecovalues time series is obtained by multiplying the last computed time series for the relationship (one value for each day within season; in Figure 8, see the time series of minimums shown in green) with the paired data set of flow versus ecovalue (or percent exceedance versus ecovalue, for reverse lookups) from the *Hypothesis tracking* option. This time series is the first of seven series that are associated with summations and can be output to HEC-DSS per user settings.

Summations are tallied for the whole flow regime and independently for each season (Figure 16). The progression of output follows: 1) daily ecovalue series, 2) tally for flow regime, 3) tally status at the end of each season, 4) tally total for flow regime, 5) tally for each season, 6) tally total for each season, and 7) a ranked set of seasonal totals from #6. By considering and tallying the daily ecovalues provided, summations offer insight to services provided by whole seasons and flow regimes.

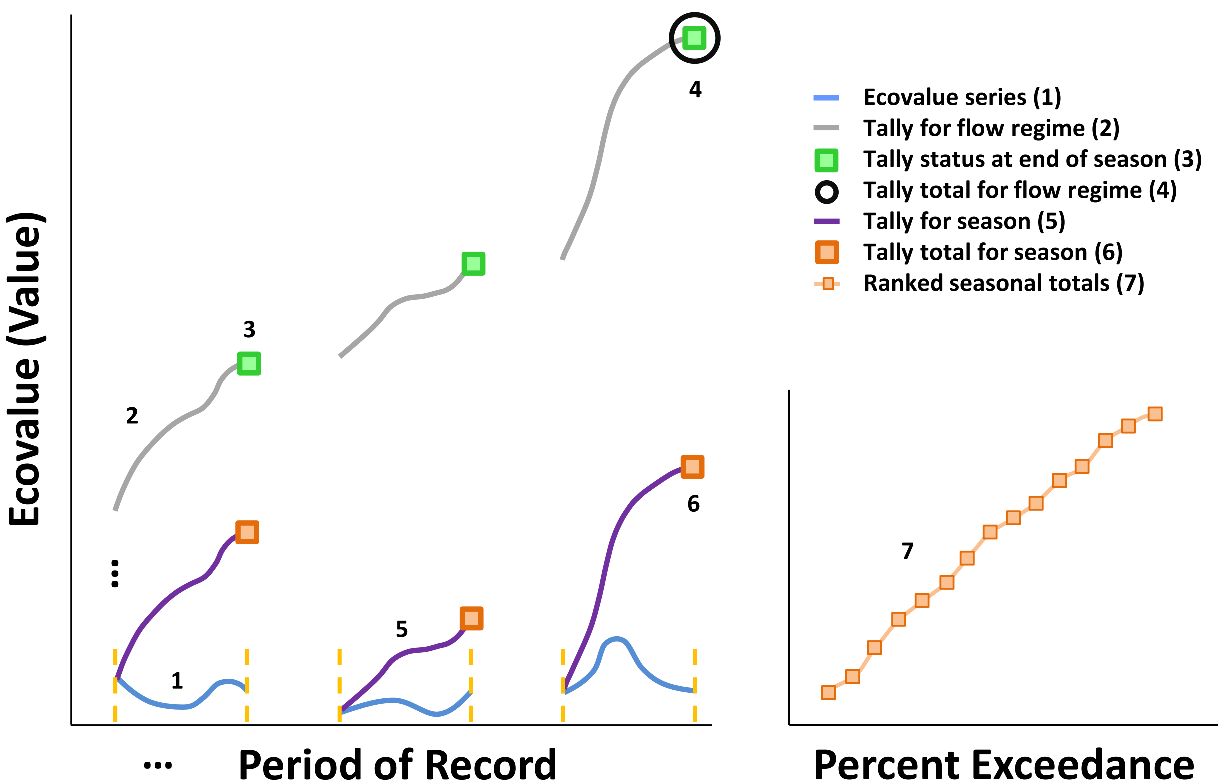


Figure 16. Ecovalue summations provide insight regarding ecovalue provided over whole seasons and flow regimes. In HEC-EFM, “shifts” inherently compare an active flow regimes with the reference flow regime. Summation shifts follow the sequence in figure, but are based on a time series of daily difference in ecovalue (active minus reference flow regime) instead of the daily ecovalue series (1).

For flow regimes that are active and not the reference, summation "shifts" are computed as the change in ecovalues provided from the reference flow regime. As for summations, summation shifts are tallied for the whole flow regime and independently for each season. At the end of each season, tally results are output as time series (one value per season per year). Seasonal tally results are also output as ranked data. Both offer insights regarding how successfully ecovalues are provided and how that success differs between flow regimes. Negative shifts are indicative of ecovalue deficits relative to the reference flow regime; positive shifts show surpluses.

In version 5.0 of HEC-EFM, summation results can be output only to HEC-DSS.

3.6.4 Indices

A common result when analyzing multiple relationships is that for a certain flow regime, some aspects of the ecosystem do well and others do poorly. *Indices* can help users look at the net effect of different flow regimes. The *confidence tracking* and *hypothesis tracking* options must be selected for a particular relationship to be included in an index. Indices are computed for flow regimes that are active and not the reference. Each index is computed using a combination of information about relationships and statistical results based on the following equation:

$$\textbf{\textit{Index}} = \sum_{i = 1\ldots n} (\text{Direction of Change}_i)*(\text{Confidence}_i)*(\text{\% Change in Eco-value}_i)$$

Where:

- $\boldsymbol{i}$ *= counter from 1 to n*
- $\boldsymbol{n}$ *= number of relationships in the index*
- ***Direction of Change***$_i$ *= 1, -1, or 0 for relationship*$_i$
  - *1 indicates that relationship*$_i$ *experienced a positive change from the reference flow regime*
  - *-1 indicates that relationship*$_i$ *experienced a negative change from the reference flow regime*
  - *0 indicates that relationship*$_i$ *experienced no change from the reference flow regime*
- ***Confidence***$_i$ *= an integer from 0 to 5 based on the confidence value for relationship*$_i$
- ***% Change in Eco-value***$_i$ = $\dfrac{(\text{Eco-value for relationship}_i - \text{Eco-value for relationship}_{reference})}{(\text{Eco-value for relationship}_{reference})}$

Note: % change in Eco-value is equal to % change in Flow (using statistical results for flow) when hypothesis tracking does not use the curve option.

3.7 Seasonal Flow Duration Analyses

The *Flow Duration: Analyze seasons* feature enables a hybrid flow duration - flow frequency analysis for relationships that also use *Time series specifications - Percent exceedance - Flow duration* and *Reverse lookup* options. Users are required to enter a *Percent exceedance* value (Figure 17).

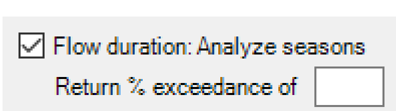


Figure 17. The Flow Duration: Analyze seasons feature is available via the Relationships tab. It requires the user to specify the % exceedance to compute and report.

The compute process begins by applying *Season* and *Duration* criteria - as done for basic flow duration reverse lookup relationships - though this is where the basic and hybrid approaches diverge. The basic approach would then rank all daily values from all seasons in the period of record and computes the percentage of time the reverse lookup value is equaled or exceeded. The hybrid approach considers each season independently. Daily values within each season are ranked and used to compute the percentage of time the reverse lookup value is equaled or exceeded. This is repeated for each season in the period of record to compute a set of seasonal results. Seasonal results are then ranked and the *% exceedance* value associated with the *Flow Duration: Analyze seasons* feature is used to compute a corresponding percentage of time for the whole period of record (Figure 18).

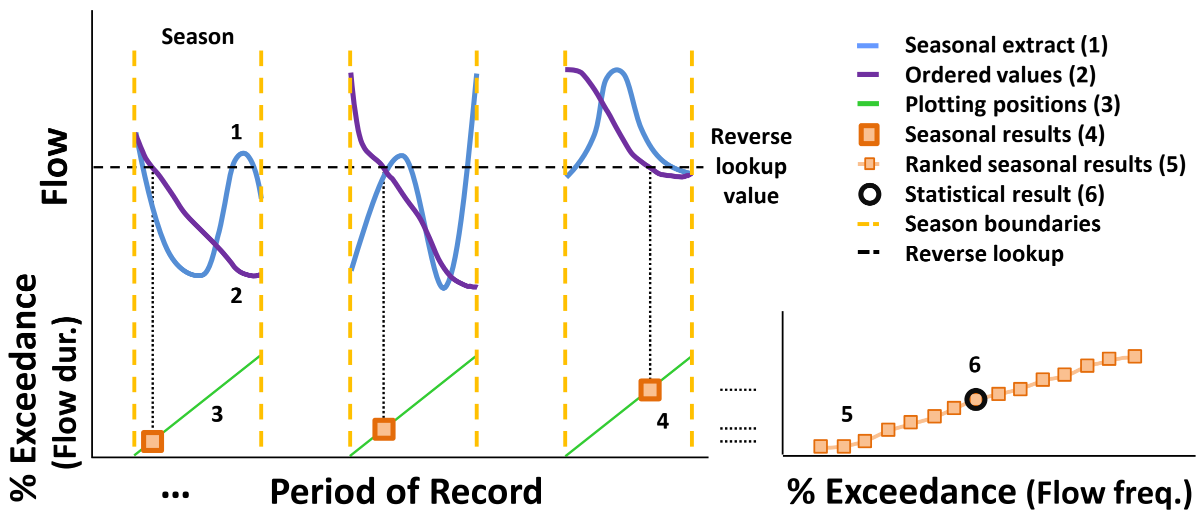


Figure 18. Seasonal flow duration analyses use flow duration and flow frequency concepts to gain insights about seasonal variability.

This nested approach supports consideration of season to season variability in flow duration statistics. Similar functionality is provided via the *Duration - User defined percentages* control, though the *User defined percentages* option can be applied only as part of *Time series specifications - Percent exceedance - Flow frequency relationships*. These hybrid approaches are among the most involved statistical analyses performed by HEC-EFM. Ordered flows and corresponding plotting position values are output to help clarify the compute sequence. The whole progression of output follows: 1) seasonal extract, 2) ordered values, 3) plotting positions, 4) seasonal results – per the *Flow duration* percent exceedance criterion, 5) a ranked set of seasonal results from #4, and 6) the statistical result - per the flow frequency *Percent exceedance* value specified by the user as part of the *Flow Duration: Analyze seasons* settings.

3.8 Handling Missing Data

As HEC-EFM considers ecosystem dynamics according to the percentage of years or percentage of time that a flow or ecological event occurs, no conceptual reason compels an analysis to be stopped due to missing data within a flow regime. Via the *"Edit"* menu, the software offers a check option entitled *"Handle Missing Data"*, which instructs HEC-EFM to work around any missing data, and a menu option called *"Missing Data Identifiers…"*, which opens an interface where users can specify the numeric values to be treated as missing data (Figure 19). Blanks and non-numbers are automatically identified as missing values.

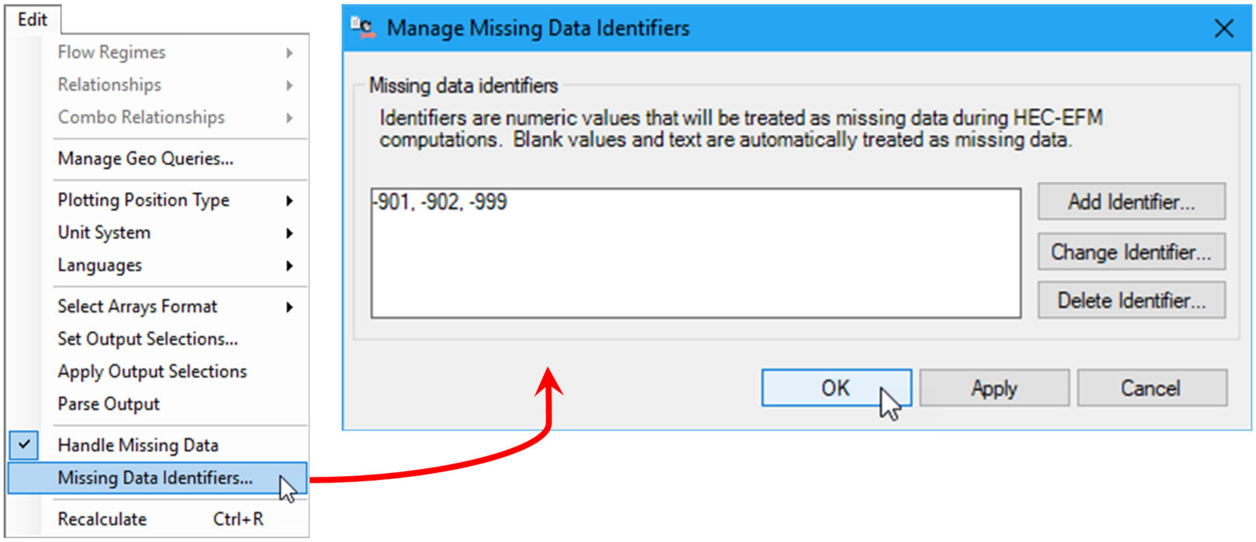


Figure 19. The *Missing Data Identifiers* interface is used to specify values to be treated as missing.

When the *"Handle Missing Data"* option is active and missing data are encountered, the software simply omits the water year with missing data from the relationship's calculations. The number of valid years (i.e., years that have all required data) associated with rankings, frequencies, and plotting positions are adjusted accordingly. As *season* is set for each relationship, each flow regime is screened for missing data for each relationship.

HEC-EFM also generates a report that lists water years omitted due to missing data. To view the report, use the *"File – Data Summary"* menu option (Figure 20).

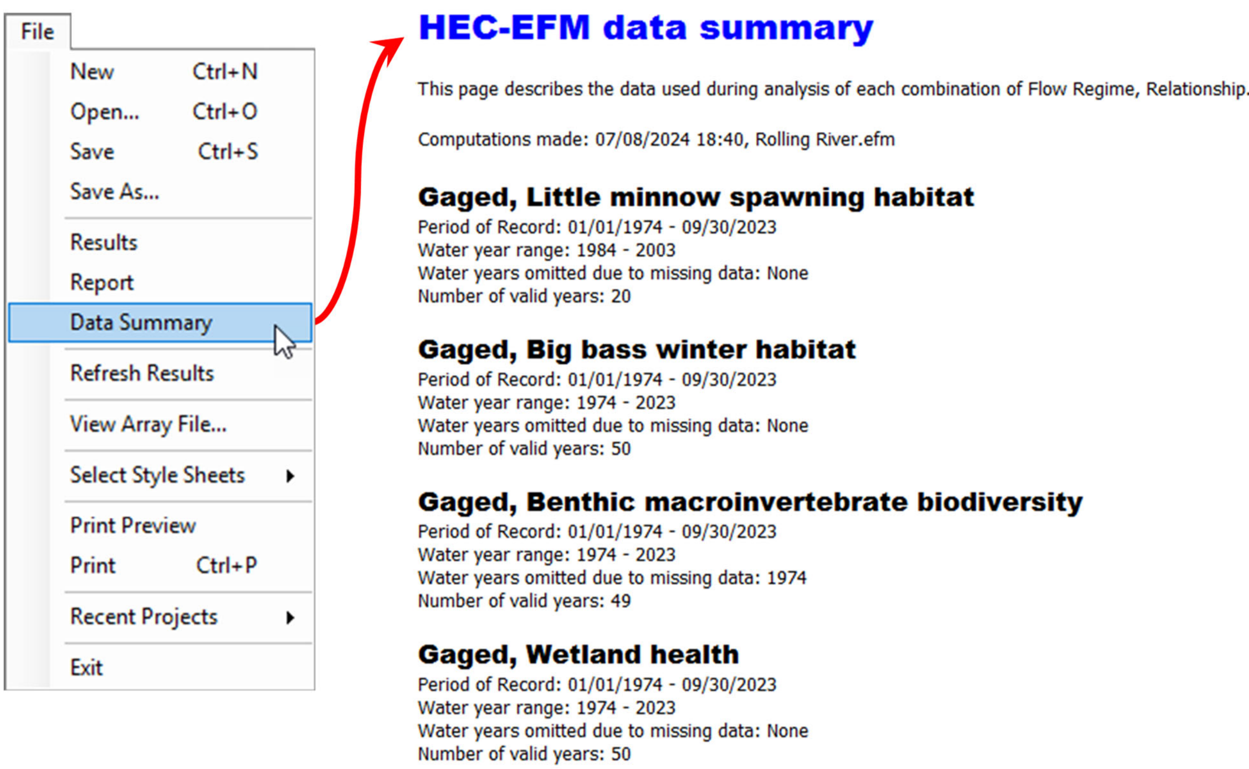


Figure 20. Excerpt from Data Summary report, which details periods of record, water year range, missing data, and number of valid years for each pairing of flow regime and relationship analyzed.

CHAPTER 4

Demonstration Project

This demonstration project will consider ecosystem relationships for a cross section of the fictional Rolling River. The progression of tasks is to 1) build eco-hydro relationships, 2) set up the model and compute statistical results, 3) simulate the statistical results with a hydraulic model, and 4) use GIS to investigate the ecosystem responses spatially.

Two flow regimes will be analyzed. The "Gaged" flow regime has flows and stages that reflect the current management plan for Rolling River, which is regulated by upstream dams. The "Natural" flow regime has flows and stages that reflect how the river would behave without reservoir regulation.

A completed demonstration project with flow regime data can be downloaded via the *"Help – Install Demonstration Project…"* menu option.

4.1 Building Relationships

Each scenario described below presents information about an aspect of the ecosystem that the Rolling River study team would like to investigate, the statistical and geographical queries used to define each as an HEC-EFM relationship, and the logic used to craft those criteria.

4.1.1 Little minnow spawning habitat

The little minnow is a threatened species of fish indigenous only to the Rolling River basin. Little minnow populations have declined (in magnitude and range) as dams and diversions limited access to upstream river stretches and as floodplain areas, critical to little minnow spawning, were transitioned to agricultural lands. Little minnow spawn in **shallow (no deeper than 3 ft)**, **vegetated** floodplain areas between **February and May**. Eggs require **sustained high flows** for approximately **21 to 28 days** before hatching. Little minnow reach sexual maturity in their first or second year and have a lifespan of approximately 6 years. Scientists suggest using the conditions within each spawning season that generate the **largest extent** of effective spawning habitat as an indicator of success for each year's spawn. Further, scientists suggest that good spawning conditions do not need to occur every year – it would be sufficient if there were good conditions in **25% of years**, so that, on average, each little minnow would have a chance to spawn in their lifespan.

HEC-EFM Relationship:

- *Season*: 2/1 to 5/31
- *Duration*: 24 days, *Minimums* (sustained highs) and then *Maximum* (largest extent)
- *Rate of change*: Not applied
- *Percent exceedance*: 25% (4 yr) - *Flow frequency*

- *Hypothesis tracking*: Increased flow will improve (+) floodplain spawning
- *Geographical queries*: Depth (0 to 3 ft) and vegetation (aquatic plants)

Comments. For the little minnow, successful spawning depends on having a sustained inundation long enough for the eggs to incubate. These types of scenarios, where any interruption will affect the ecosystem dynamic being modeled, typically use an initial statistical setting of *Minimums* or *Maximums* for the *Duration* query. *Minimums* return a flow that will be that high or higher for the length of the duration. *Maximums* return a flow that will be that low or lower. This relationship also thinks in terms of percentage of years. The *Percent exceedance - Flow frequency* option returns a flow and stage that are equaled or exceeded in the percent of years specified by the user. The *Percent exceedance - Flow duration* option returns a flow and stage that are equaled or exceeded in the percent of time specified by the user.

4.1.2 Big bass winter habitat

A study for big bass showed that fish mortality in a critical over-winter period, **January through May**, was caused by a chronic lack of habitat. Mortalities began to occur when generally poor conditions persisted for more than **two weeks**. Habitat shortages for these fish occur at low flows. Scientists said that these chronic conditions are best represented by **average low flows** and that, since these fish are in the river each winter, using a **typical year (median conditions)** would be a good indicator. The study showed that suitable habitat is proportional to increasing low flows (i.e., higher low flows create more habitat) until those low flows exceed **1,000 cfs**.

HEC-EFM Relationship:
- *Season*: 1/1 to 5/31
- *Duration*: 14 days, *Means* (average) and then *Minimum* (low)
- *Rate of change*: Not applied
- *Percent exceedance*: 50% (2 yr) - *Flow frequency*
- *Hypothesis tracking*: Curve with flow-value points of 0-0, 600-6, 1000-10, 10000-0
- *Geographical queries*: Not applied

Comments. The background for big bass used statements like "mortality…was caused by a chronic lack of habitat…generally poor conditions". These are clues that big bass are somewhat resilient and will be most affected by bad conditions that occur for long periods of time or sporadically, without enough time between episodes for the fish to recover. This scenario is unlike little minnow spawning where the eggs cannot have bad conditions – be dry – for any single day and survive. Relationships like this typically use an initial statistical setting of *Means* for the *Duration* query.

4.1.3 Benthic macroinvertebrate biodiversity

Reservoirs tend to reduce high flows and increase low flows, which creates a more stable flow regime. In these regulated systems, communities of benthic macro invertebrates often have reduced biodiversity because the few species that thrive in the more stable flow conditions out compete all of the others. **Flooding** initiates a return to more natural conditions which encourages the community to rebound to its original biodiversity. Scientists maintain that the **timing is not important**, but the high flows should occur **once every two years**, on average.

HEC-EFM Relationship:

- *Season*: 10/1 to 9/30
- *Duration*: 1 day, *Means* (average) and then *Maximum* (high)
- *Rate of change*: Not applied
- *Percent exceedance*: 50% (2 yr) - *Flow frequency*
- *Hypothesis tracking*: Increased flow will improve (+) benthic biodiversity
- *Geographical queries*: Not applied

Comments. HEC-EFM relationships do not need to be complicated. The background basically says that benthic biodiversity is a function of high flows. So to build this relationship, use statistical queries that focus on high flows of short duration at any time in the water year. Choosing a duration is related to the flashiness of the river system being studied. For the demonstration project, a value of 1 day was chosen, though any duration between 1 and 7 days would likely be a good indicator.

4.1.4 Wetland health

Water exchange between river and wetland areas has also been noted as a key component of wetland health. With frequent exchange, water quality in the wetlands remains good, but with isolation, dissolved oxygen levels drop, wetland areas become anoxic and aquatic species die. This scenario is only an issue in the warm summer months, **mid-May to mid-September**. A hydraulic engineer on your team has determined that flows of **600 cfs** and higher allow water exchange in your project area and a biologist, familiar with the region, suggests that active exchange for approximately **30% of the time** (in summer) will lead to healthy conditions.

HEC-EFM Relationship:

- *Season*: 5/15 to 9/15
- *Duration*: 1 day
- *Rate of change*: Not applied
- *Percent exceedance*: 30% (of time) - *Flow duration*
- *Hypothesis tracking*: Increased flow will improve (+) water exchange for Wetland health
- *Geographical queries*: Not applied

Comments. This relationship is the first demonstration relationship to use the *Percent exceedance - Flow duration* query. In this case, healthy conditions are created when active exchange between the river and wetlands occurs 30% of the time. As mentioned in the little minnow comments, using the *Percent exceedance - Flow duration* option will return a flow and stage that are equaled or exceeded in the percent of time specified by the user.

4.1.5 Riparian tree recruitment and inundation

Reservoir influence and transition of floodplain lands to agriculture has proved a destructive combination for riparian tree forests. Through scientific study, riparian tree establishment has been tied to high flows that occur and recede during germination periods. After germination, survival is a function of water level. If inundated, seedlings are prone to drowning and, conversely, if water levels recede too rapidly, roots desiccate and seedlings are lost.

Germination periods for the riparian tree have been shown to occur between **mid-June through July**. Scientists have found that, after germination, if water levels drop by more than **0.58 feet per week** then riparian tree seedlings will have a lower chance of survival. A high stage needs to occur at least once every **10 years** to keep sustainable riparian tree establishment.

HEC-EFM Relationship: Recruitment

- *Season*: 6/15 to 8/1
- *Duration*: 1 day
- *Rate of change*: 0.58 feet per 7 days - falling (stage)
- *Percent exceedance*: 10% (10 yr) - *Flow frequency*
- *Hypothesis tracking*: Increased flow will improve (+) Riparian tree recruitment
- *Geographical queries*: Not applied

Riparian tree seedlings are sensitive to prolonged periods of inundation. **Beginning of August through mid-September** represents the time period immediately following the establishment season, where riparian tree seeds would most likely drown if inundated for an extended length of time. **21 days** is the estimated length of time that a seedling could be continuously inundated before it dies. If the **sustained** inundation is less than 0.5 ft, seedlings are more likely to survive. Median conditions (**2 yr**) can be used as an estimate of typical inundation.

HEC-EFM Relationship: Inundation

- *Season*: 8/1 to 9/15
- *Duration*: 21 days, *Minimums* (sustained highs) and then *Maximum* (extent of effective seedling drowning)
- *Rate of change*: Not applied
- *Percent exceedance*: 50% (2 yr) - *Flow frequency*
- *Hypothesis tracking*: Increased flow will cause Riparian tree inundation to increase (–)
- *Geographical queries*: Depth (0 to 0.5 ft)

Comments. This scenario actually requires two individual relationships that are used to represent a single ecosystem dynamic. The real dynamic of interest is the establishment of new riparian tree seedlings. Establishment occurs when flow and stage conditions are suitable for new seedlings to begin growing (recruit) and when the new seedlings survive inundation that occurs later in the growing season.

The recruitment relationship uses the rate of change query. This query starts at the end of the season and works towards the start of the season one day at a time, checking for violations of the rate of change threshold. The flow and stage at the time of the last violation in the user-defined season is recorded as a “seasonal result”. These seasonal results (one pair of flow and stage for each water year) are then ranked into a frequency table. The statistical result for Riparian tree recruitment is interpolated as the 10% exceedance value.

The inundation relationship uses a *Minimums* - *Maximum Duration* query to compute the flow and stage that effectively drown or preempt any new recruitment.

These two relationships are used in combination to represent Riparian tree establishment, with the difference between recruitment and inundation results being the portion of recruitment that leads to establishment of new seedlings.

HEC-EFM Combo Relationship: Riparian tree establishment
Primary layer - Riparian tree recruitment
Connected layer - Riparian tree inundation

4.2 Setting up the Model

4.2.1 Creating a New Project and Defining Flow Regimes

1. Open HEC-EFM and use the *"File – New"* menu option to start a new project. Enter title, author, and project description into the *model information* section of the *Properties Tab*.

2. The dataset for this project is part of the completed demonstration project for HEC-EFM, which was copied to your computer when the HEC-EFM software was installed. Use the *"Help – Install Demonstration Project…"* menu option to extract the demonstration project to a directory on your computer or network (Figure 21).

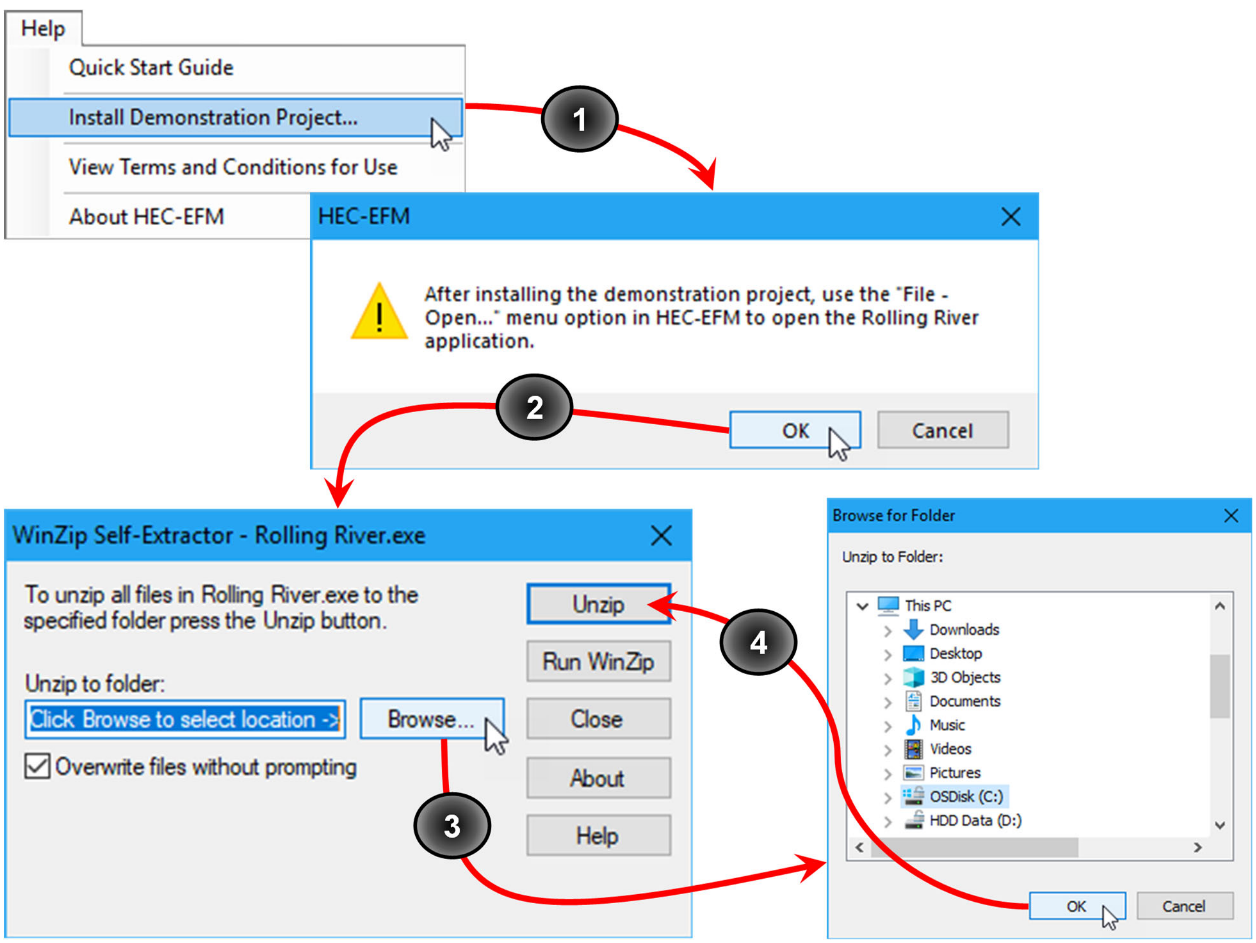


Figure 21. Setting up a working directory.

3. Data for the flow regimes are located in "Rolling River Data.dss", which is included in the demonstration project. The first flow regime acts as a placeholder and must be renamed. Use the *"Edit – Flow Regimes – Rename…"* menu option to open the *Rename Flow Regime* interface. In the *New name* text box, enter Natural and click *OK* (Figure 22).

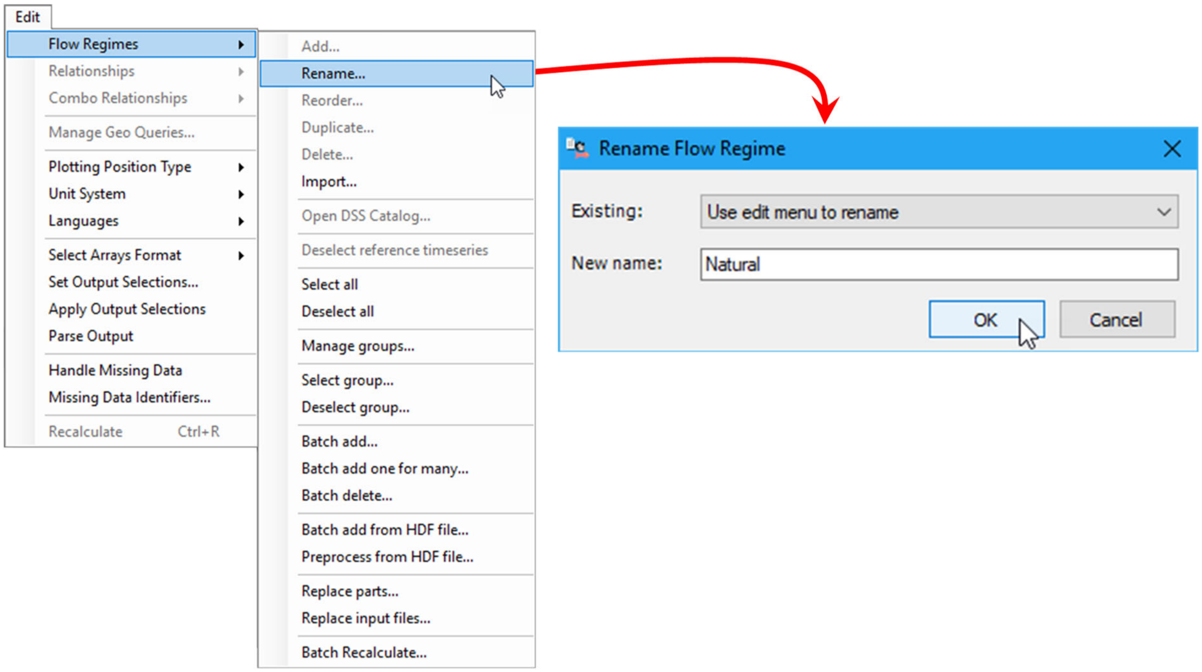


Figure 22. Naming a flow regime.

4. Add data to this flow regime by moving the cursor over the *Filename* cell and pressing the *browse* button (Figure 23). Browse to the Rolling River folder in the extraction location, select "Rolling River Data.dss", and click *OK*. *Note: The browse button only appears when you have the Filename cell selected.*

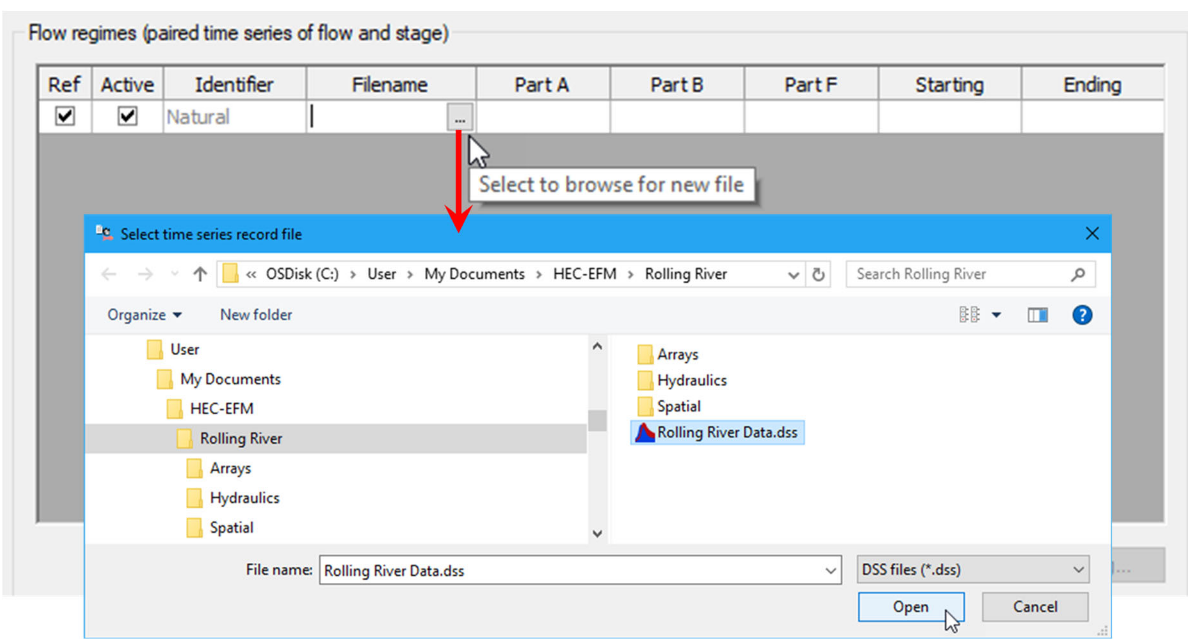


Figure 23. Adding the flow regime data file.

5. Click the *Open DSS Catalog* button to open the *HEC-DSS Catalog Browser* for that flow regime (Figure 24).

   Browse to /ROLLING RIVER/AT EFM XS/FLOW//1DAY/NATURAL/, highlight the *f-part* "NATURAL" and click *Select*. HEC-EFM has an auto-mapping feature that looks for stage time series whose *a-*, *b-*, and *f-parts* match the selected flow record. If HEC-EFM finds a match, a message box opens asking whether the matching time series should be used as the corresponding stage values for that flow regime. Click *Yes*. Once both the stage and flow time series have been selected, press *OK*.

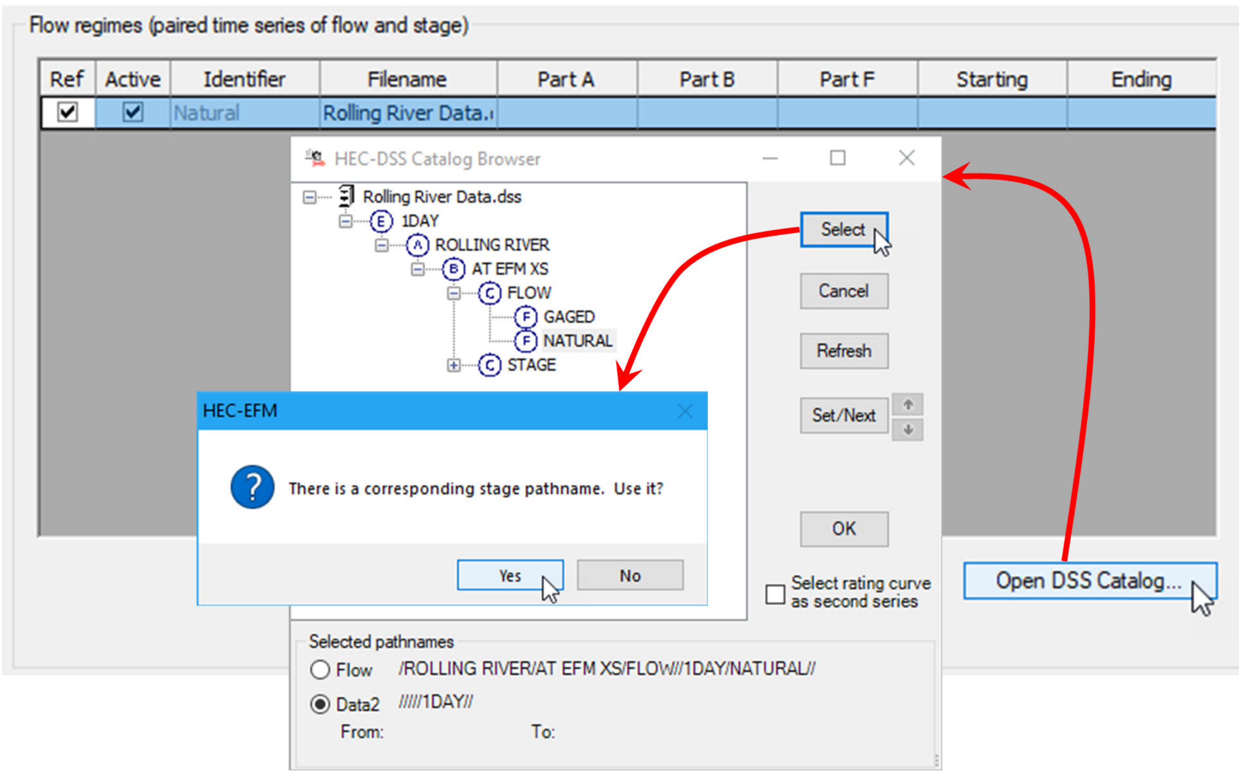


Figure 24. Selecting flow and stage time series.

6. Use the *"Edit – Flow Regimes – Add…"* menu option to open the *Add Flow Regime* interface. In the *Name* text box, enter Gaged and click *OK*. Repeat steps 4 and 5 to add data to the new flow regime. Remember to click the *Open DSS Catalog…* button while the cell highlighted in the table of flow regimes is in the row for Gaged and to select the *f-part* "GAGED" after opening the DSS catalog.

7. It is important to define the reference flow regime, which is the flow regime that serves as the basis for comparison when looking at direction of ecosystem change. In this example, use the Natural flow regime as the reference. To make a flow regime the reference, click on the box in the *Ref* column of that flow regime (Figure 25). In this case, a check mark is already in the box because Natural was the first flow regime created. Only active flow regimes are considered during calculations.

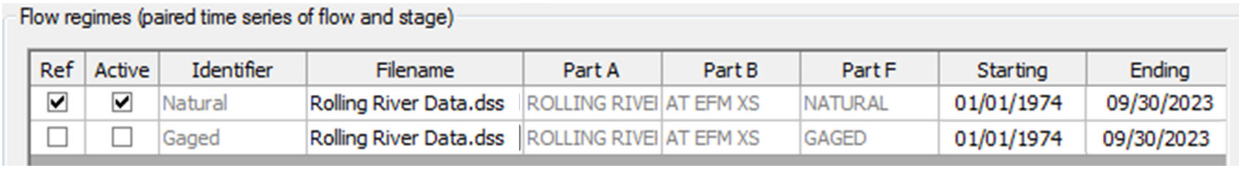


Figure 25. Reference and active flow regimes.

8. The *Properties Tab* should now look like Figure 26. Use the *"File – Save As"* menu option to save your project. *Note: The completed demonstration project is called Rolling River.efm. If saving in the extraction directory, please use a different name for your project.*

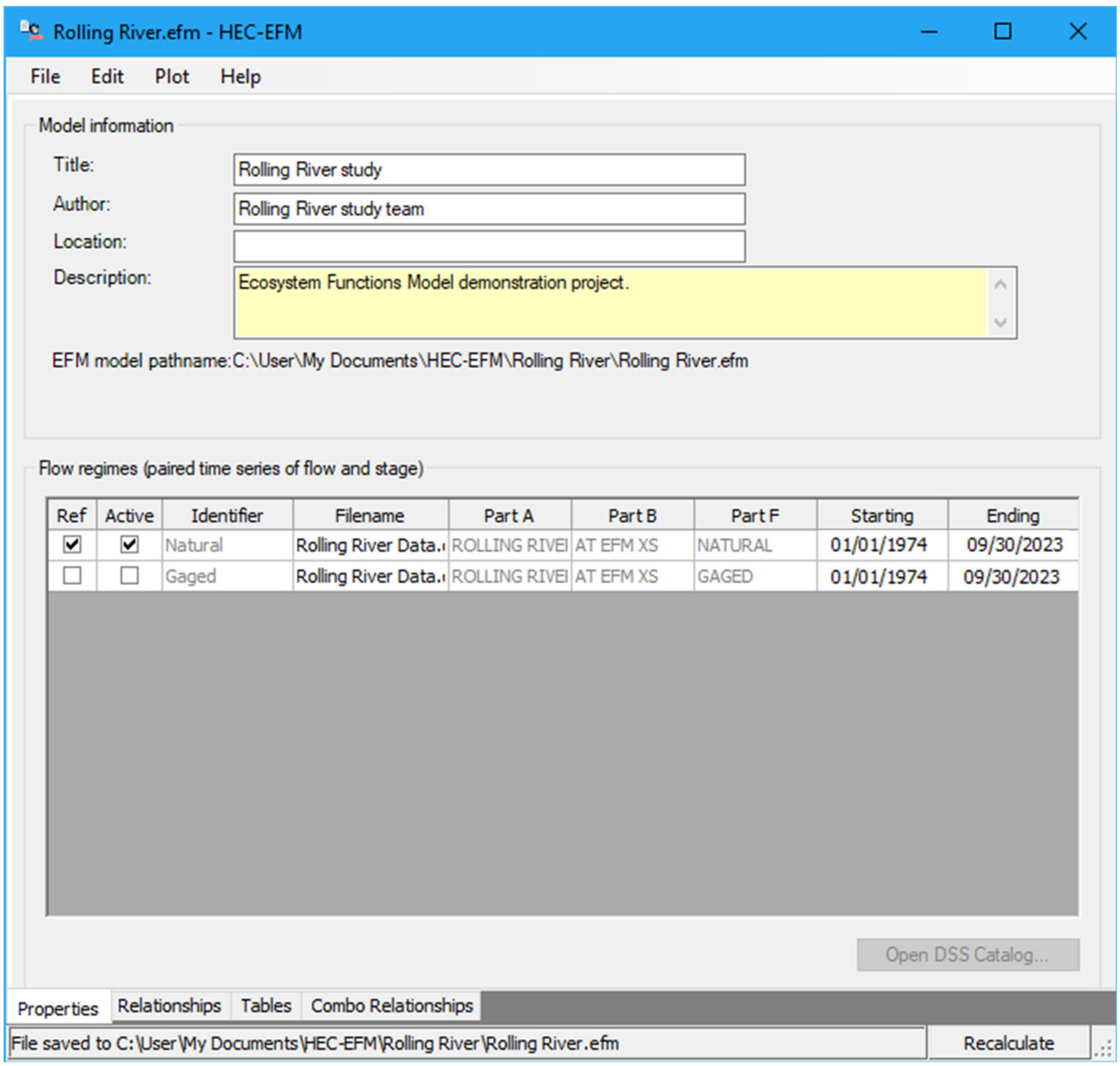


Figure 26. Completed *Properties Tab* for the demonstration project.

4.2.2 Defining Relationships

1. The next step is to enter the relationships. Go to the *Relationships Tab* and use the *"Edit – Relationships – Add…"* menu option to open the *Add Relationship* interface. In the *Name* text box, enter Little minnow spawning habitat and click *OK* (Figure 27).

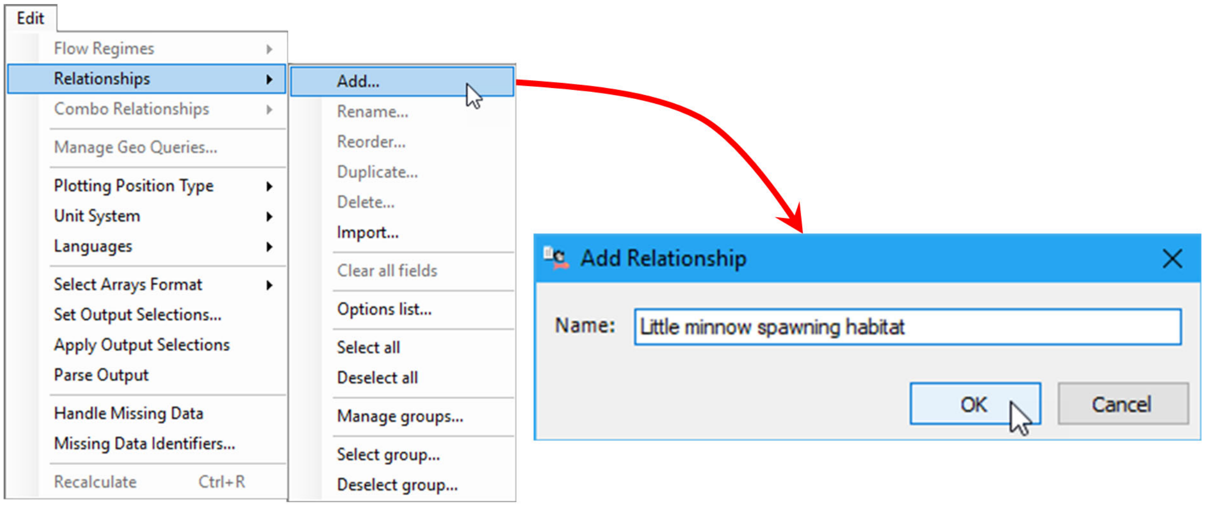


Figure 27. Adding a relationship.

2. Enter a description, statistical queries, and hypothesis for the Little minnow spawning habitat relationship (Figure 28).

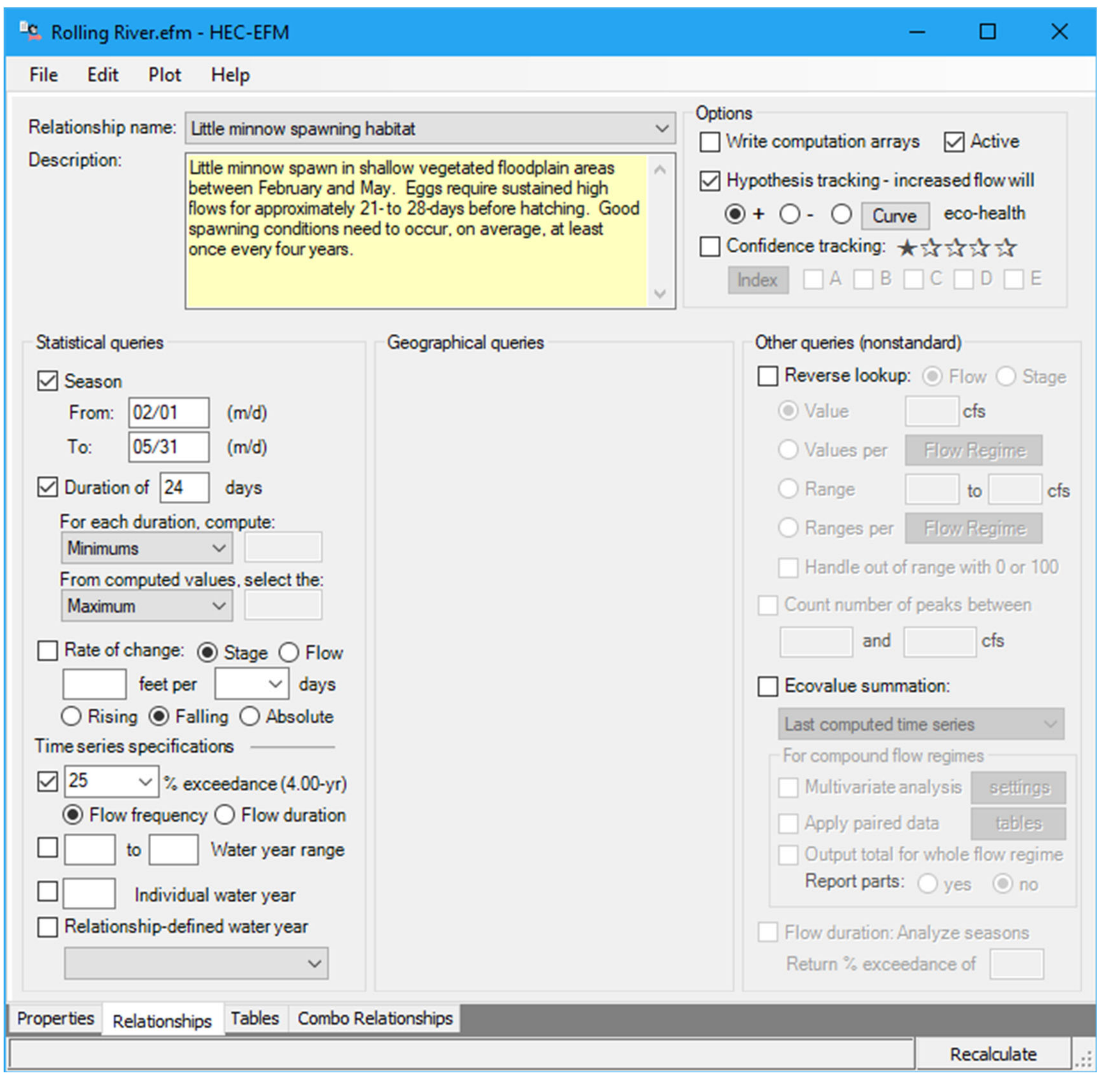


Figure 28. Statistical queries and hypothesis for the Little minnow relationship.

3. Click the *Recalculate* button (bottom right of the interface). Results are displayed on the *Tables Tab* (Figure 29).

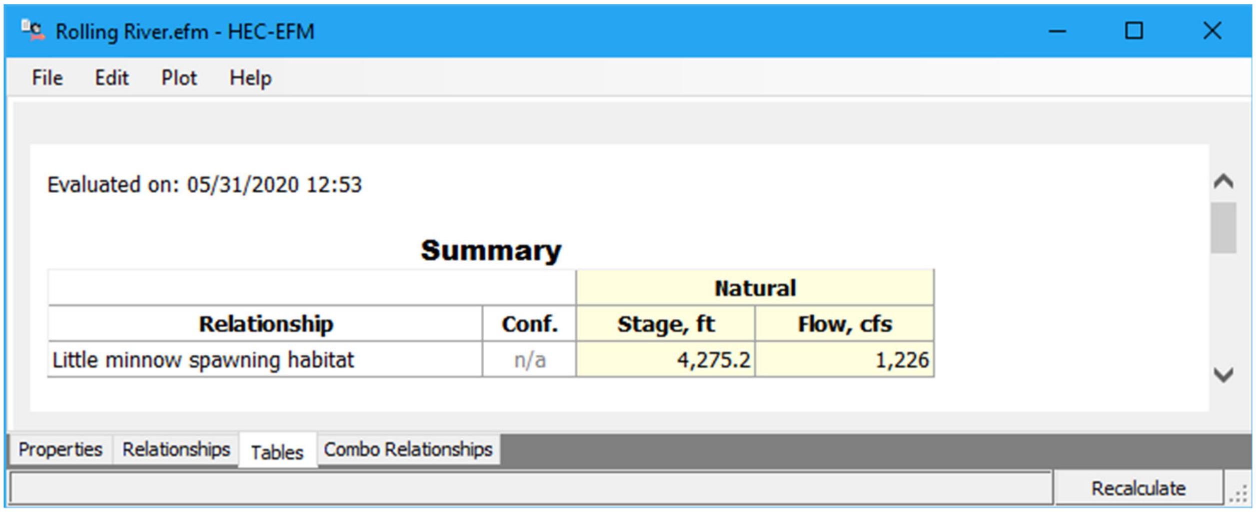


Figure 29. Statistical results for the Natural flow regime and the Little minnow relationship.

4. Next, click on the *Properties Tab*; activate the Gaged flow regime by checking its box in the *Active* column of the flow regime table. Click the *Recalculate* button. Results are now displayed for both the Natural and Gaged flow regimes (Figure 30).

   Note: It is important to recognize that the Little minnow relationship was not changed during this step. ***Flow regimes and relationships exist independently.*** *When the second flow regime (Gaged) was activated, HEC-EFM computed statistical results for each flow regime using the same statistical criteria, as defined for the Little minnow relationship. Results are different because each flow regime has its own distinct patterns of flow and stage.*

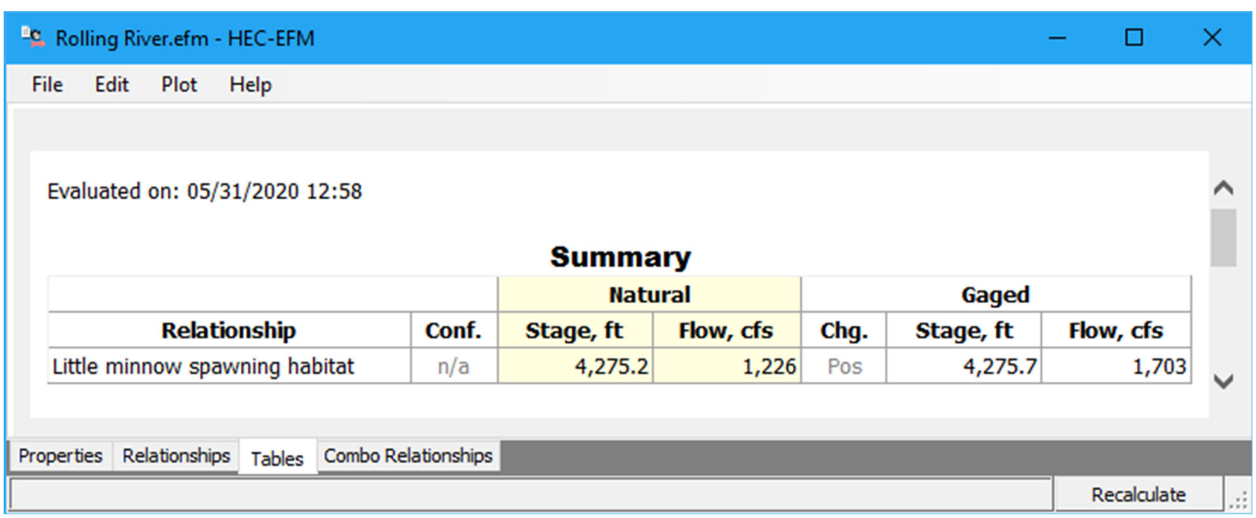


Figure 30. HEC-EFM statistical results of the Little minnow spawning habitat relationship using both the Natural and Gaged flow regimes.

5. The next step is to create geographical queries. Go to the *Relationships Tab* and use the *"Edit – Manage Geo Queries…"* menu option to open the *Manage Tags for Geographical Queries* interface (Figure 31). Click the *Add tag…* button to open the *Add Tag* interface. In the *Name* text box, enter "Depth" and click *OK*. Repeat this step to add tags named "Vegetation" and "Land Use". Now associate the tags with Little minnow spawning habitat by highlighting that relationship in the *Relationship* column and clicking the *Select tags…* button. The *Tag Selector* interface will open. Select Depth and Vegetation and click the *Add →* button. Click *OK* to save the selections to the *Manage Tags* interface and then click *OK* in the *Manage Tags* interface to save the tags and selections to the project. Text boxes for selected tags will appear on the *Relationships Tab*. Enter a description for each of the Little minnow tags. For Depth, enter "Shallow habitat 0 to 3 ft". For vegetation, enter "Requires presence of aquatic plants" (Figure 32).

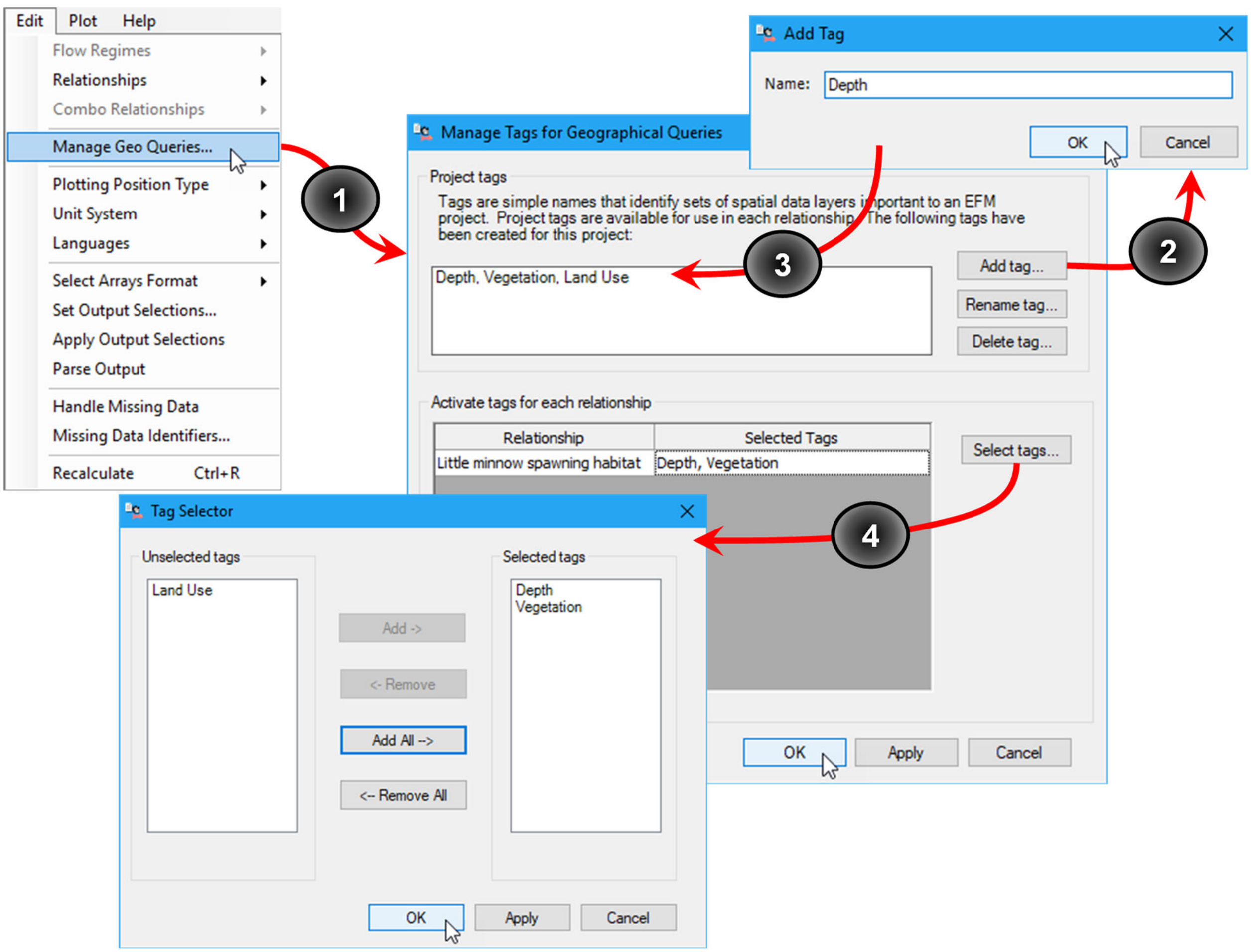


Figure 31. Adding geographical query tags.

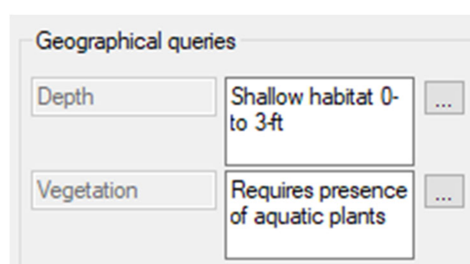
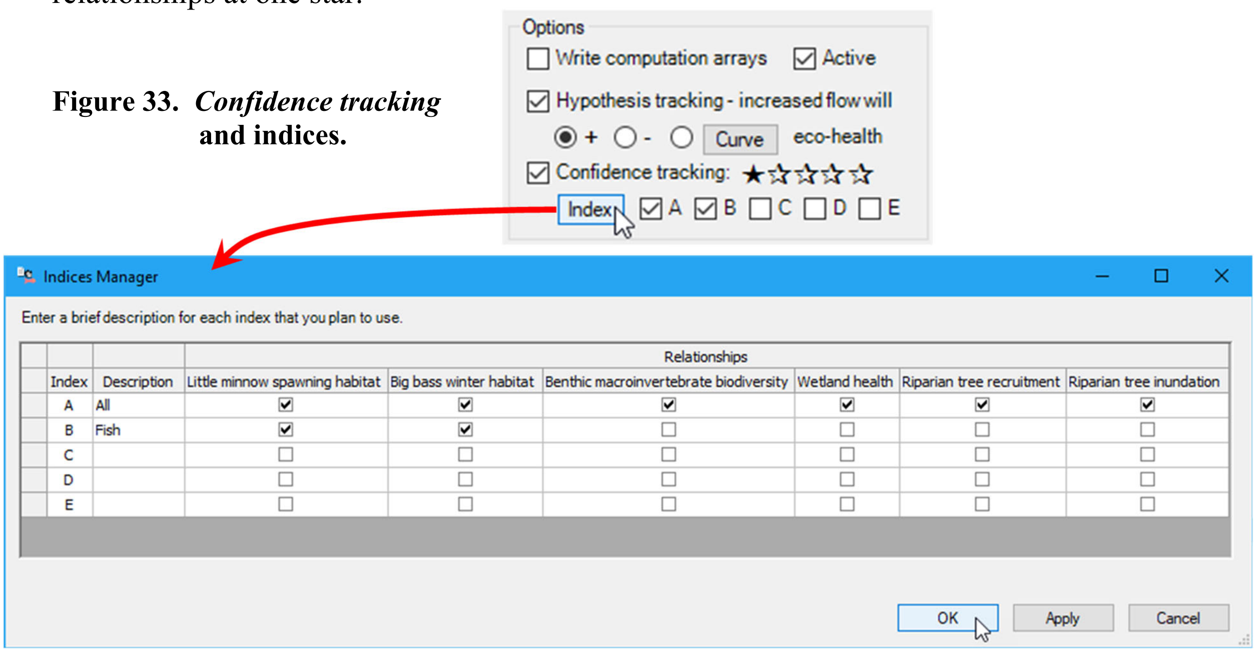


Figure 32. Geographical queries for the <u>Little minnow spawning habitat</u> relationship.

6. Repeat steps 1 through 5 for the other relationships (Big bass winter habitat, Benthic macroinvertebrate biodiversity, Wetland health, and Riparian tree recruitment and inundation).

7. Turn on *Confidence tracking* for the relationships (Figure 33). For now, leave all relationships at one star.

Figure 33. *Confidence tracking* and indices.



8. Next, create indices by clicking the *Index* button in the *Options* frame (Figure 33). The *Index Manager* interface will open. Enter "All" for index A and "Fish" for Index B. Associate each relationship with the appropriate indices by checking box A for each of the relationships and also checking box B for Little minnow and Big bass relationships.

9. Your project should now have 2 flow regimes, 6 relationships, and 2 indices. Use the *"File – Save"* menu option to save your project and then click *Recalculate* to compute results.

4.2.3 Results

Four of the six relationships show a positive change for the Gaged flow regime (Figure 34). Riparian tree inundation and Benthic biodiversity show a negative change. Benthic biodiversity had the most significant change in terms of difference in flow results.

Summary

		Natural			Gaged	
Relationship	**Conf.**	**Stage, ft**	**Flow, cfs**	**Chg.**	**Stage, ft**	**Flow, cfs**
Little minnow spawning habitat	*	4,275.2	1,226	Pos	4,275.7	1,703
Big bass winter habitat	*	4,274.1	525	Pos	4,274.3	609
Benthic macroinvertebrate biodiversity	*	4,279.4	6,620	Neg	4,277.2	3,190
Wetland health	*	4,274.3	636	Pos	4,274.5	771
Riparian tree recruitment	*	4,274.9	1,017	Pos	4,275.1	1,129
Riparian tree inundation	*	4,273.7	373	Neg	4,274.3	609

Figure 34. Summary of HEC-EFM results.

The index values show a negative response (Neg) for all relationships and a positive response (Pos) for the fish (Figure 35). A positive value suggests that the positive changes outweigh the negatives for the relationships in the index.

Index Values

Index	Gaged
A - All	-4.7
B - Fish	27.4

Figure 35. Index values for "All" relationships and only the relationships that are related to "Fish".

The Rolling River has been a popular study area for wetland research. This popularity has led to numerous peer reviewed studies and an abundance of field data. As these studies support the approach used to define Wetland health, change confidence for that relationship to five stars (Figure 36). Leave all others at 1 star.

☑ Confidence tracking: ★★★★★

Figure 36. Confidence tracking increase for the Wetland health relationship.

Click the *Recalculate* button. Note that the index value for all relationships goes from negative to positive (Figure 37). Indices are best used as screening tools. Lumping multiple, and pseudo-independent, relationships into one numeric index is an approach to be used with caution.

Index Values

Index	Gaged
A - All	9.5
B - Fish	27.4

Figure 37. Index values after a confidence tracking increase for the Wetland health relationship.

Let's also look at Wetland health with a *Reverse lookup* query. To do this, use the *"Edit – Relationships – Duplicate…"* menu option to open the *Duplicate Relationship* interface. In the *Name* text box, enter Wetland health reverse lookup and click *OK* (Figure 38).

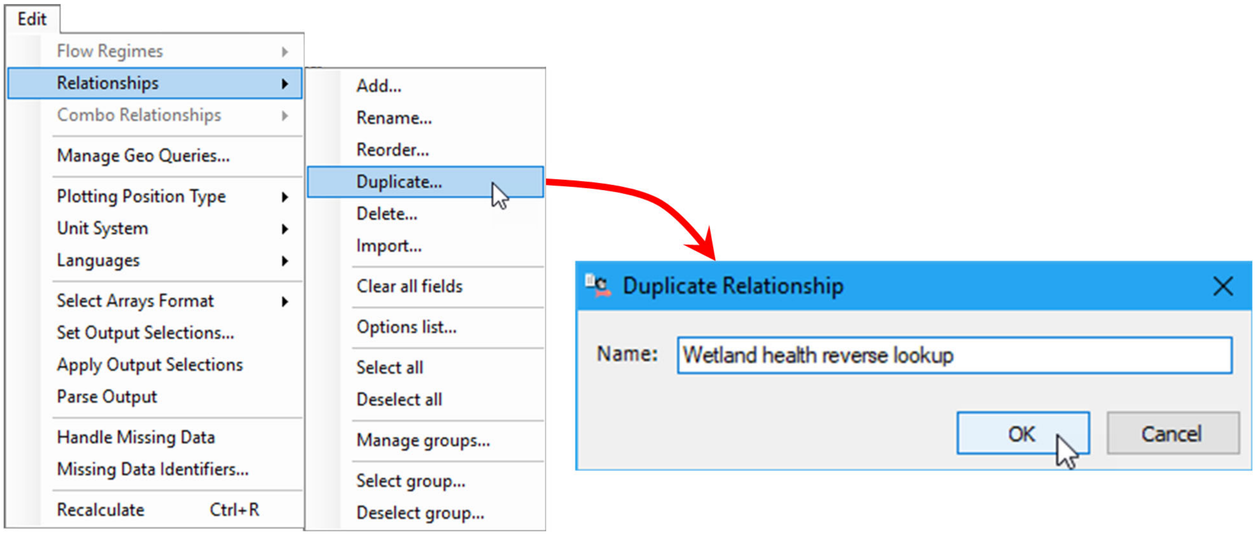


Figure 38. Duplicating a relationship.

Turn on the *Reverse lookup* query by checking its box in the *Other queries* frame. Enter 600 cfs in the text box (Figure 39). Notice that percent exceedance is now grayed out because reverse lookups do not compute a flow based on percent exceedance. Instead, the user specifies a flow and HEC-EFM computes the percent of years or percent of time that flow is equaled or exceeded. *Note: Non-standard queries (e.g., reverse lookups) cannot be included in the indices.*

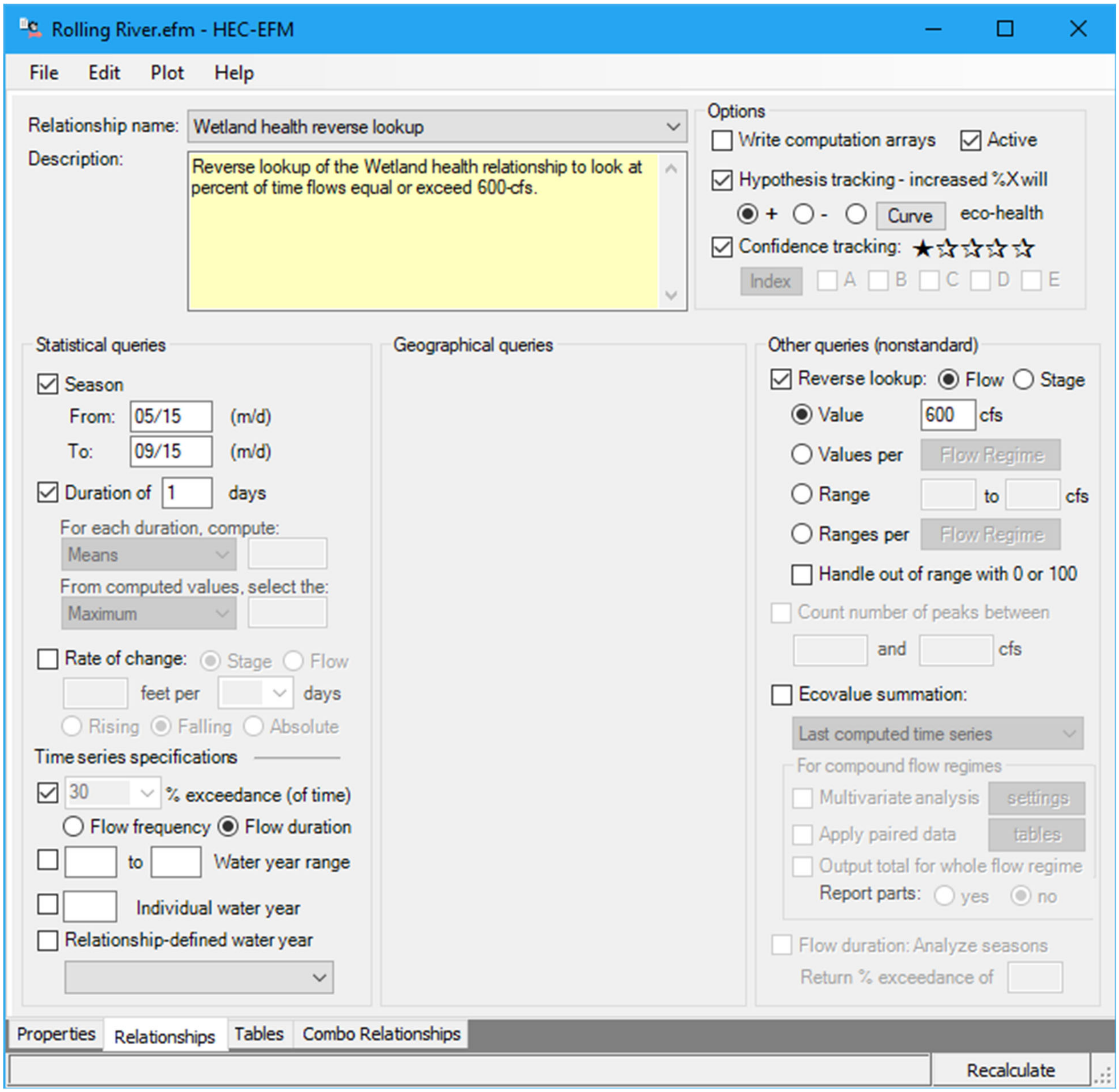


Figure 39. Reverse lookup for the Wetland health relationship in HEC-EFM.

Results for Wetland health reverse lookup show that both flow regimes were above the 30% criteria (Figure 40). Results for the Gaged flow regime (67.1%) nearly doubled the 34.1% of time Natural flows in Rolling River equaled or exceeded 600 cfs.

Reverse Look-ups - Flow Duration

		Natural	Gaged	
Relationship	**Conf.**	**%X, of time**	**Chg.**	**%X, of time**
Wetland health reverse lookup	*	34.1	Pos	67.1

Figure 40. Reverse lookup for Wetland health showing percent of time flows above 600 cfs.

4.2.4 HEC-EFM Output

In addition to the statistical results that are output to the *Tables Tab*, HEC-EFM also generates a project summary report and files of the computations it performs while generating the statistical results. To view the project summary report, use the *"File – Report"* menu option.

By default, computation files are not generated automatically by the software in order to minimize computation time. This output option is selected individually for each relationship. To test this feature, go to the *Relationships Tab*, select the Big bass winter habitat relationship, and check the box next to *Write computation arrays* in the *Options* frame (Figure 41).

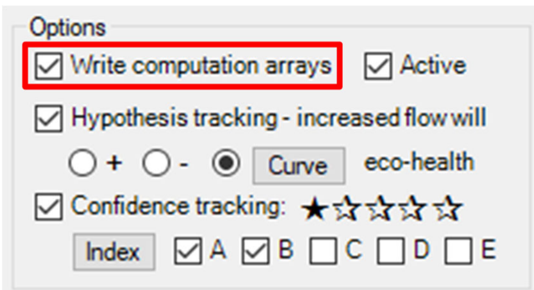


Figure 41. Checking the *Write computation arrays* box.

Output formats are selected via the "*Edit – Select Arrays Format*" menu option. Choices are provided for *XML*, *DSS*, or *Both*. Select *Both* and click the *Recalculate* button (Figure 42). A folder named "Arrays" will be created in the directory of the HEC-EFM project file to store the output.

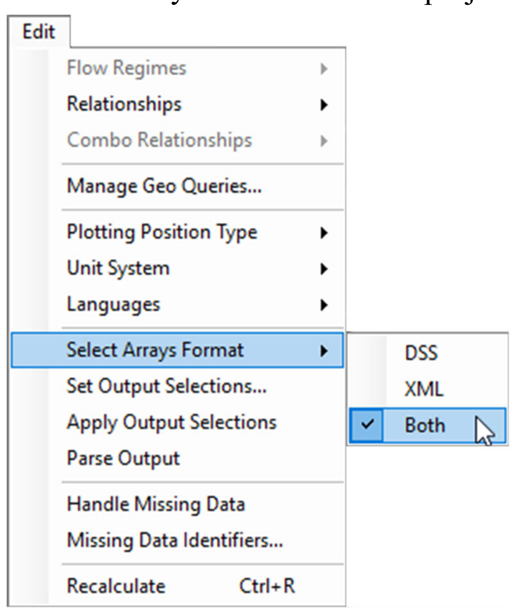


Figure 42. Output choices via the *Select Arrays Format* menu options.

The term XML stands for Extensible Markup Language. XML is a widely used format for archiving and viewing data. Separate XML files are generated for each combination of flow regime and relationship. Each of these files contains the computational steps, statistical results, and frequency curves produced by HEC-EFM. The XML arrays are organized such that the final results are located at the top of the file followed by each computational step in reverse order (Figure 43). Using the *"File – View Array File…"* menu option, select "Gaged_Big bass winter habitat.xml" and click *Open*.

Figure 43. Excerpt from the XML output file for Big bass winter habitat and the Gaged flow regime.

HEC-EFM computational arrays

This page shows intermediate computational arrays from the following analyses. Choose the *go* link to jump to a particular analysis.

1. Time series record: Gaged, relationship: Big bass winter habitat go

Gaged, Big bass winter habitat

Computations made: 07/09/2024 14:23, Rolling River.efm

Result: Flow = 608.5 , Stage = 4,274.3, Closest water year = 1989

Eco-value = 6.1

Water years omitted due to missing data: None

Frequency analysis

Plotting position: Weibull

Rank	Frequency	WY	Flow	Stage
1	.0196	1995	868.0	4,274.7
2	.0392	1993	867.9	4,274.7
3	.0588	2004	807.6	4,274.6
4	.0784	1998	776.6	4,274.5
5	.098	2000	763.6	4,274.5
6	.1176	1997	760.9	4,274.5
7	.1373	1996	745.4	4,274.5
8	.1569	2003	742.4	4,274.5
9	.1765	2018	735.9	4,274.5
10	.1961	1992	705.9	4,274.4
11	.2157	2010	693.3	4,274.4
12	.2353	1984	692.1	4,274.4
13	.2549	1985	683.9	4,274.4
14	.2745	1986	675.1	4,274.4
15	.2941	1978	668.4	4,274.4
16	.3137	2011	666.5	4,274.4
17	.3333	1974	657.3	4,274.4
18	.3529	1999	650.8	4,274.3
19	.3725	2013	650.1	4,274.3
20	.3922	1980	642.6	4,274.3
21	.4118	1994	638.6	4,274.3
22	.4314	1990	637.6	4,274.3
23	.451	1991	632.2	4,274.3
24	.4706	1988	624.3	4,274.3
25	.4902	1989	612.6	4,274.3
	.5		608.5	4,274.3
26	.5098	1987	604.5	4,274.3

This is the statistical result for the Big bass winter habitat relationship and Gaged flow regime. A statistical result is the pair of flow and stage that meet the statistical criteria used.

The highlighted value is the statistical result. The table also contains seasonal results for each historical water year in the period of record. This type of information provides more details about the relationships and flow regimes than the statistical results reported on the *Tables Tab* and can be very valuable to HEC-EFM applications.

These same data are stored in a file named "arrays.dss" and are archived according to flow regime and relationship names. The "arrays.dss" file can be accessed using HEC-EFM Plotter or HEC-DSSVue, which are available via the HEC website (http://www.hec.usace.army.mil). Figure 44 shows the catalog of data output to DSS for the Big bass winter habitat relationship, time series calculations done to compute seasonal results for the Natural flow regime, and frequency curves of seasonal results for Natural and Gaged flow regimes with the 50% exceedance values selected as the statistical results.

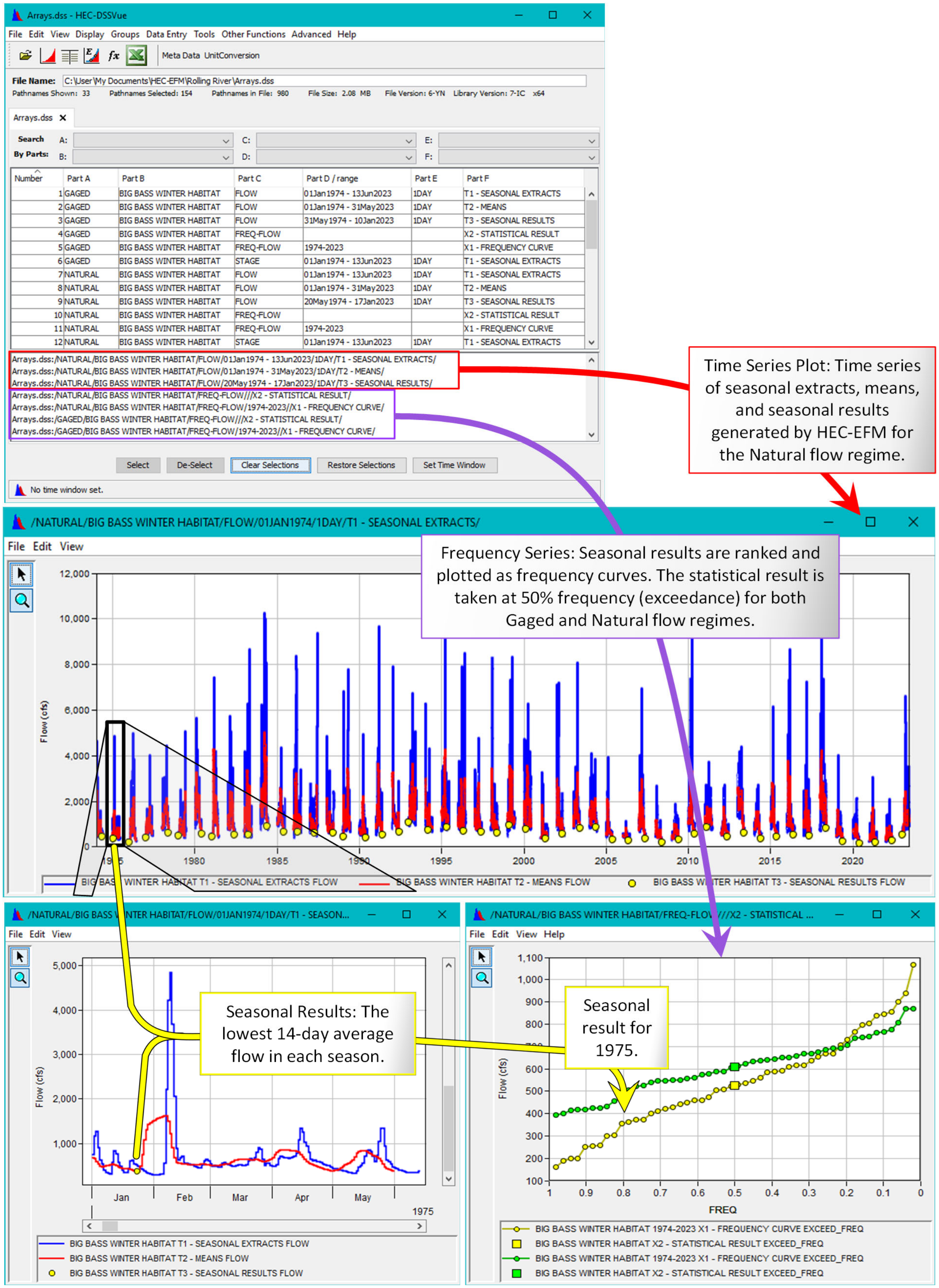


Figure 44. Catalog of HEC-EFM data output to DSS for the <u>Big bass winter habitat</u> relationship. Seasonal results for the <u>Natural</u> flow regime as well as a frequency curve of seasonal results for <u>Natural</u> and <u>Gaged</u> flow regimes are shown.

4.2.5 Using HEC-EFM Plotter

HEC-EFM Plotter is designed to help users view output and compare results for different flow regimes and relationships. Additionally, by displaying each computational step that HEC-EFM performs while analyzing time series, HEC-EFM Plotter offers an opportunity to understand the statistical process and settings being used to investigate each relationship.

EFM and EFM Plotter are separate software. To work together properly, EFM needs to know where Plotter is installed. In versions 1.0 and 1.1 of Plotter, the only standard way to install the software was via an install package that guided users through the install process. Users were encouraged to install Plotter to a consistent location such that subsequent installations would replace the existing version and leave only one version of the software available for use on a single computer. EFM used information written to the computer registry during install to locate and connect with Plotter.

Now, and especially with versions of Plotter that allow users to install the software by simply extracting it from an archive of files, it is more common to have multiple versions of Plotter available for use on a single computer. To support multiple versions and existing projects that users may want to continue applying with earlier software, connections between the two software have been made available for users to manage. Importantly, this change was made after release of EFM 4.0. EFM 4.0 users are encouraged to continue to install Plotter, whether 2.0 or earlier, to a consistent install location using the install package.

Connections between EFM and Plotter in EFM 5.0 and later are managed via the *"Plot – Manage Version-Specific Locations"* menu option. An interface will appear that allows the user to enter the EFM version number and open a file browser to identify the associated version of Plotter (Figure 45). If Plotter is launched from an unlisted version of EFM, the default location of Plotter will be used. If Plotter is not available at that location, a message will be returned to inform the user that EFM is unable to locate Plotter and ask the user to verify that Plotter is ready for use. The *"Plot – Specify HEC-EFM Plotter Location"* menu option is used to update the default location of Plotter.

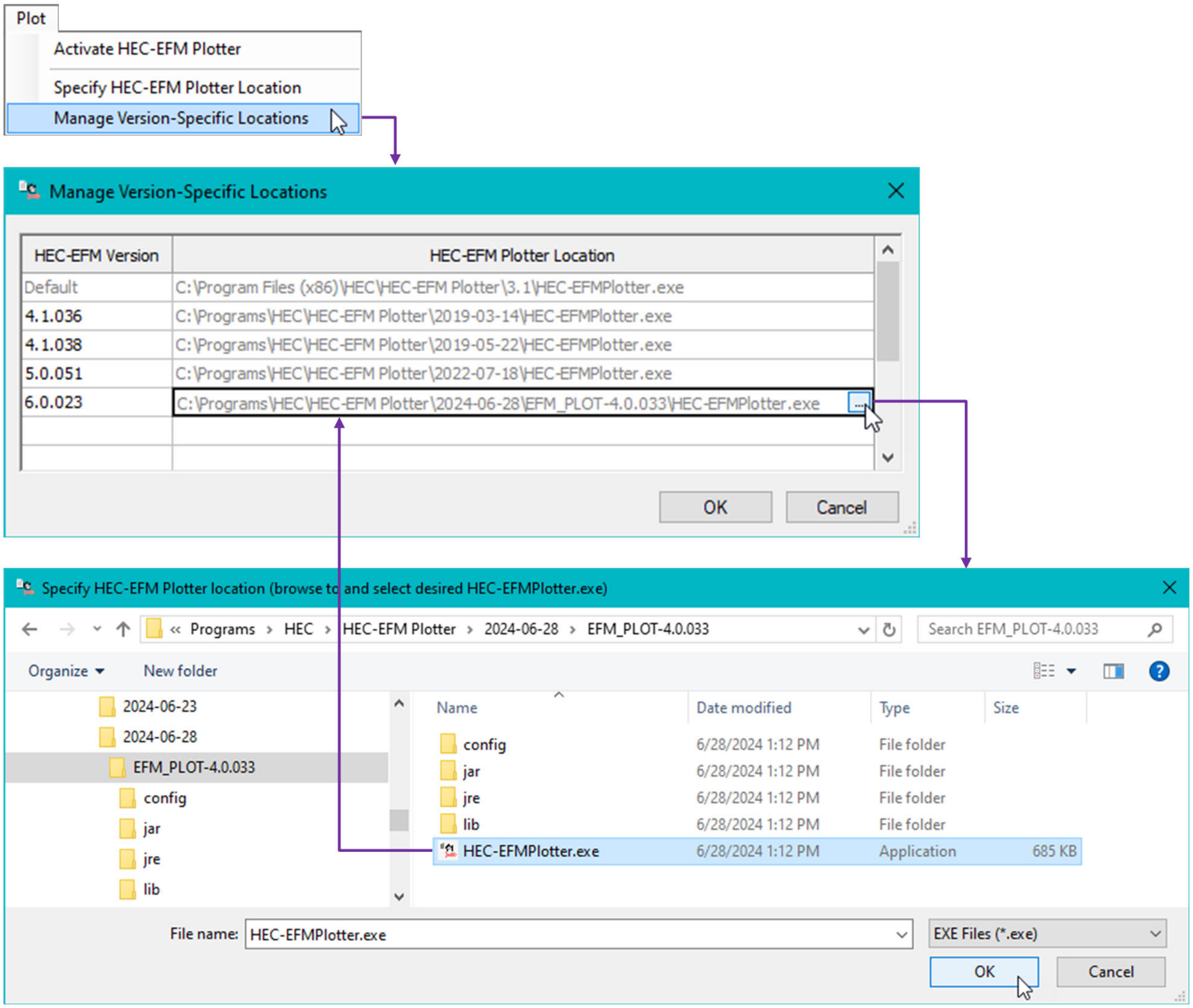


Figure 45. Connections between HEC-EFM and HEC-EFM Plotter can be managed to ensure proper software behaviors and to associate different versions of the two software.

Plotter is initiated via the "*Plot – Activate HEC-EFM Plotter*" menu option. DSS output is automatically imported to *Standard Plots* for each combination of flow regime and relationship. The *Relationship* dropdown list in the upper left hand corner of the main interface is used to select which relationship is displayed (Figure 46; Big bass winter habitat relationship). The *Flow Regime* dropdown list controls the flow regime being viewed (e.g., Natural or Gaged).

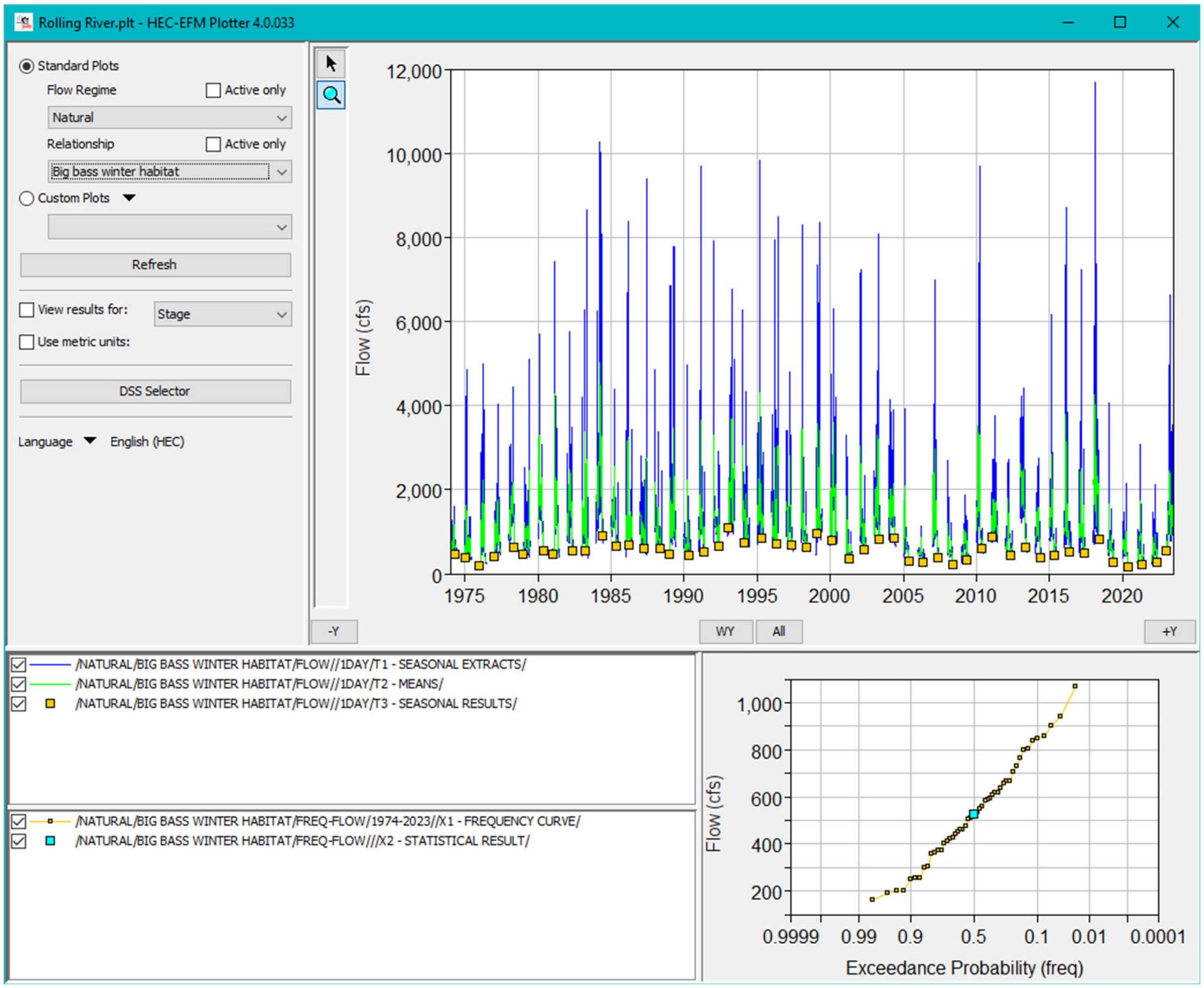


Figure 46. HEC-EFM Plotter showing results for the <u>Big bass winter habitat</u> relationship with the <u>Natural</u> flow regime.

Custom Plots are useful when comparing results for multiple relationships or flow regimes. Select the *Custom Plots* option and add a *Custom Plot* called "Bass Compare" by choosing *Add…*from the *Custom Plots* dropdown button (Figure 47).

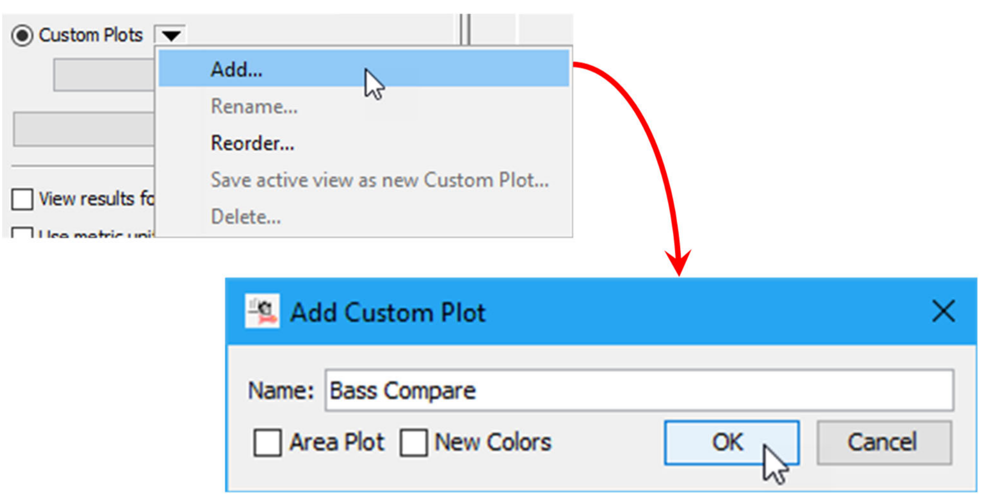


Figure 47. Adding a custom plot.

Click the *DSS Selector* button and browse to the arrays.dss file for your project. Select all records with a b-part of <u>Big bass winter habitat</u> and click the *Set Pathname* button (Figure 48) to import those data to the "Bass compare" plot (Figure 49).

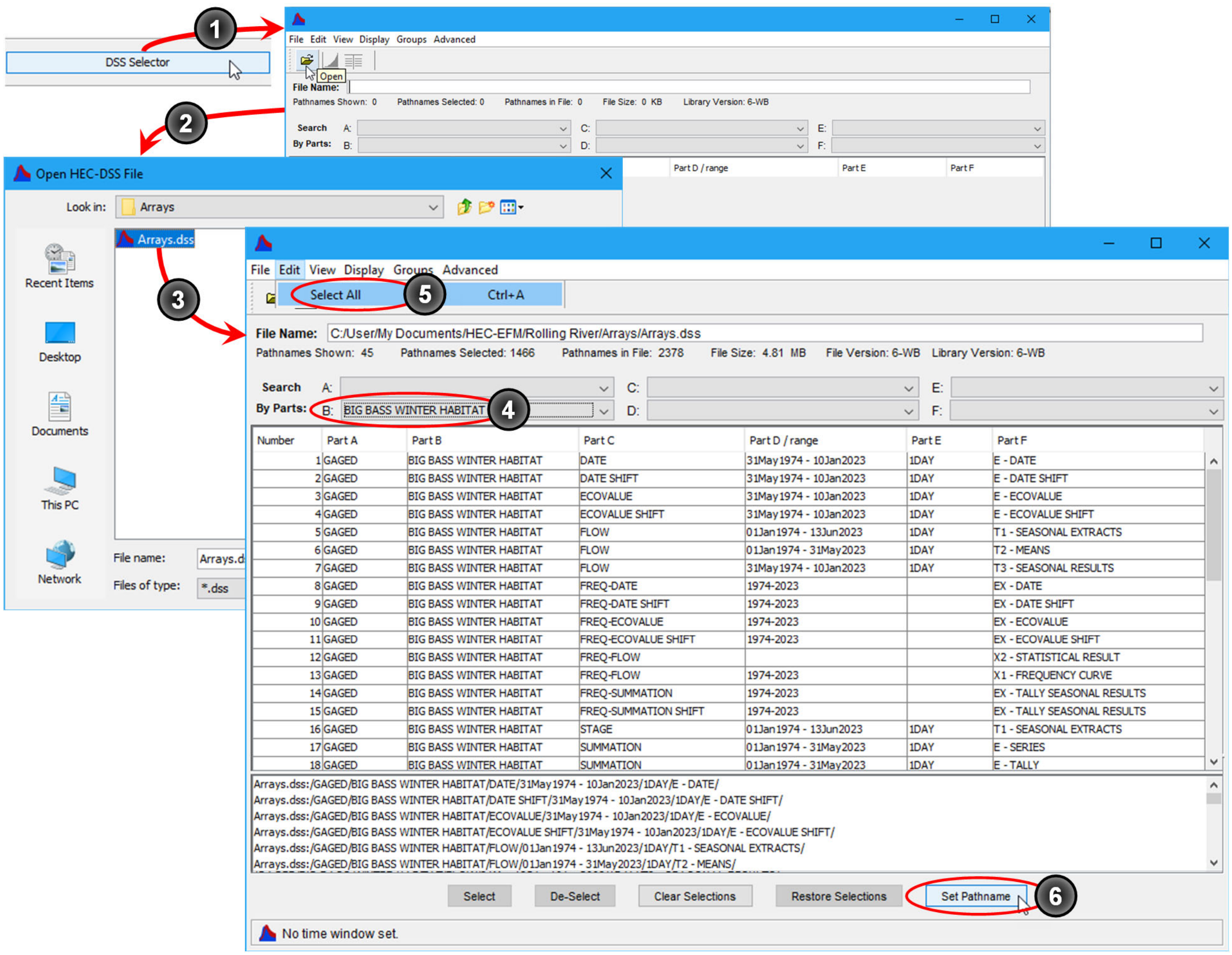


Figure 48. Process for selecting <u>Big bass winter habitat</u> results for comparison in a custom plot within HEC-EFM Plotter.

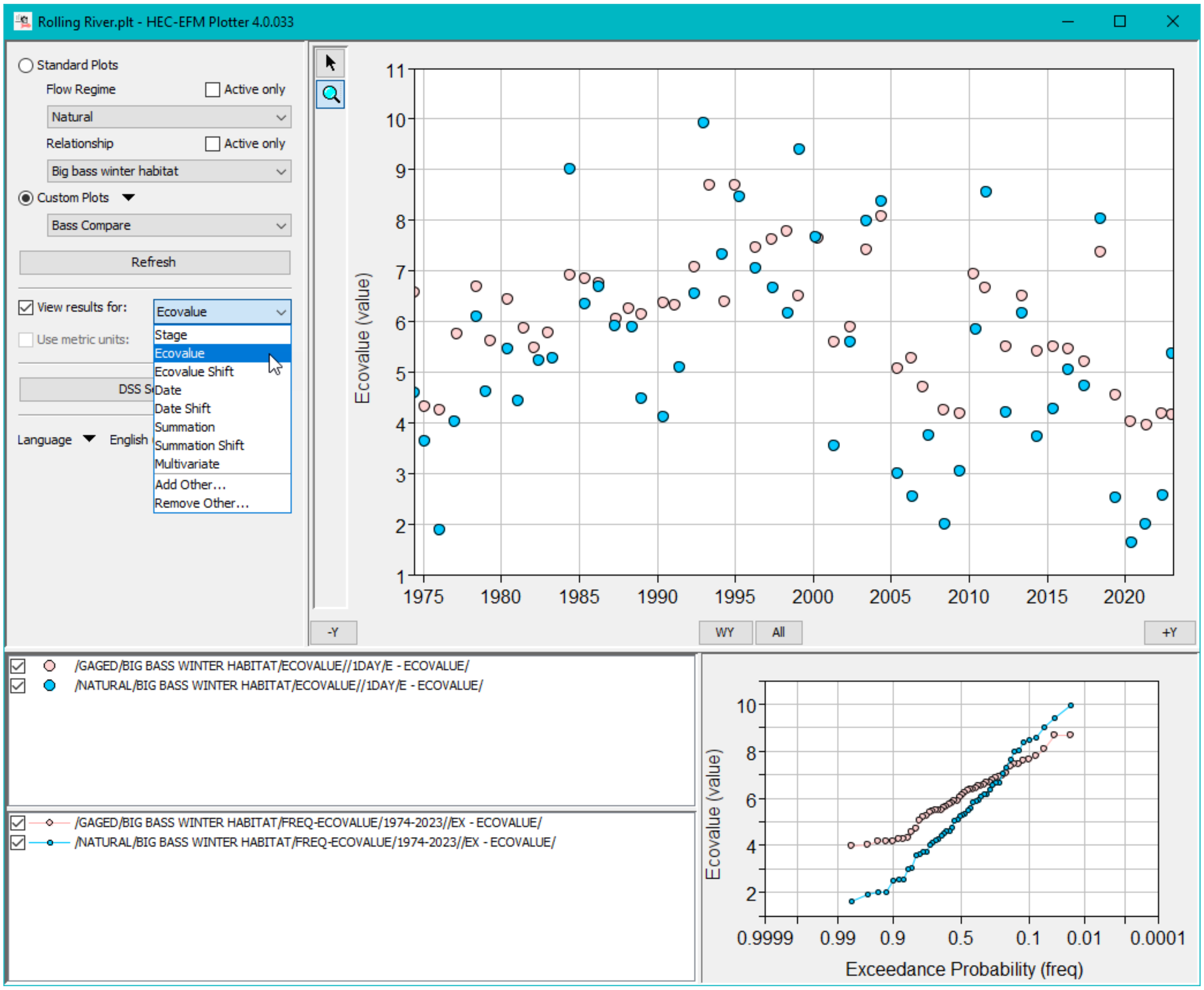


Figure 49. Custom plot in HEC-EFM Plotter comparing ecovalues of the Big bass winter habitat relationship for Gaged and Natural flow regimes.

HEC-EFM Plotter has many features for navigating (zoom, hover, snap to water year, advance/retreat a year) and viewing data sets (plot markers, show/hide/reorder data sets via the legend, axis settings, toggle plots with a Ctrl-T command).

HEC-EFM Plotter and HEC-EFM can be open at the same time. In fact, when a setting is changed in HEC-EFM and a *Recalculate* is performed, plots can be updated by clicking the *Refresh* button, which makes HEC-EFM Plotter an effective way for teams to explore and refine the statistical settings that define the relationships.

4.3 Hydraulic Analysis

Spatial analysis of HEC-EFM results can be done using water surface profiles and grids of depth and velocity produced by a geo-referenced hydraulic model. Past applications of HEC-EFM have used HEC-RAS, HEC-GeoRAS, and HEC-RAS Mapper, which can be found on HEC's website http://www.hec.usace.army.mil/. Documentation on use of these software is also available at the website.

4.3.1 HEC-RAS

The HEC-RAS software is used to simulate one-dimensional steady flow, one-dimensional and two-dimensional and combined one- and two-dimensional unsteady flow, sediment transport, and water temperature (Figure 50) in riverine systems. Water surface profiles can be rendered with HEC-RAS Mapper and exported to GIS for spatial analysis.

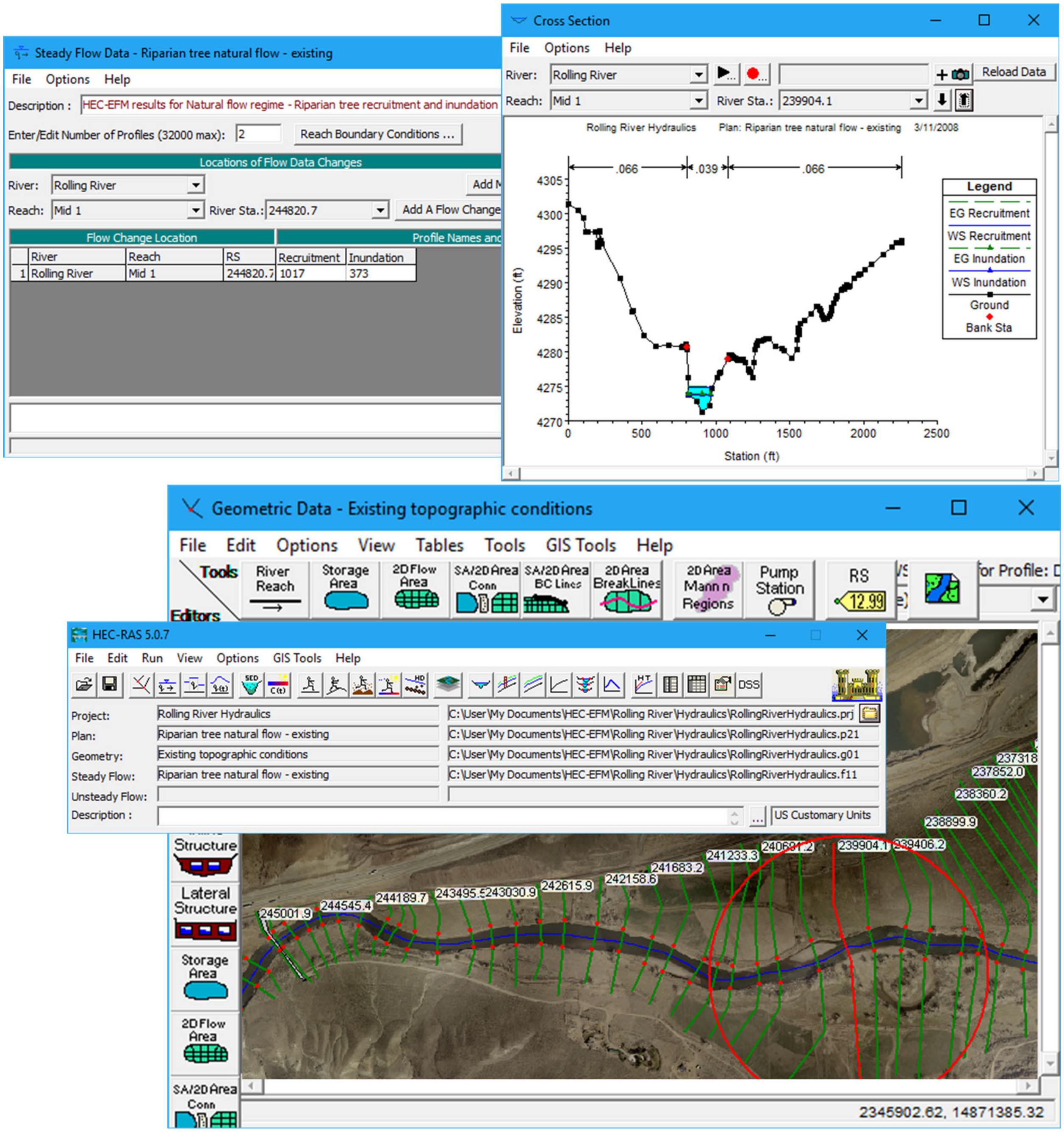


Figure 50. Example of HEC-RAS used to create water surface profiles for HEC-EFM statistical results (<u>Riparian tree recruitment</u> and <u>inundation</u> relationships using the <u>Natural</u> flow regime.)

4.3.2 HEC-GeoRAS and HEC-RAS Mapper

HEC-GeoRAS and HEC-RAS Mapper are software that assist with spatial operations related to the HEC-RAS river hydraulics model. HEC-GeoRAS is a set of procedures, tools, and utilities for pre and post-processing geospatial data in ArcGIS® (Figure 51). With these software, water surface profile data can be used with a digital terrain model to calculate depth grids, velocity grids, and floodplain boundary polygons.

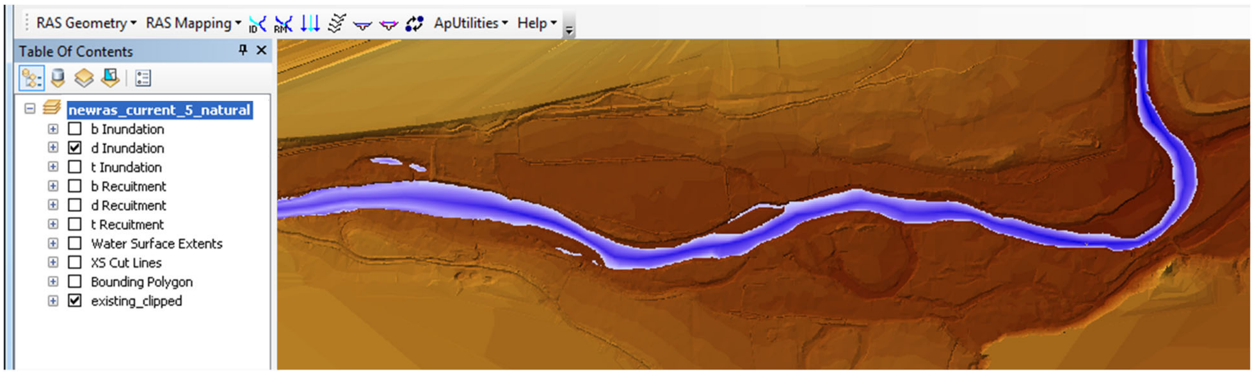


Figure 51. Example of a depth grid computed in HEC-GeoRAS using the water surface profile simulated by HEC-RAS for the statistical results of Riparian tree inundation from HEC-EFM.

4.4 HEC-EFM Analyses with GIS

Geographic information systems are technologies used to store, manage, edit, analyze, and display data that are spatially referenced to the earth. Using GIS in an application of HEC-EFM allows users to analyze data layers produced by HEC-RAS as well as any external data sets that have ecological significance. The following sequence of figures is an example of how GIS can be used to investigate ecosystem response spatially. Results are shown for Riparian tree establishment dynamics in the Natural flow regime. Depth grids were initially created for recruitment (Figure 52) and inundation (Figure 53). The inundation layer was then placed on top of the recruitment layer (Figure 54).

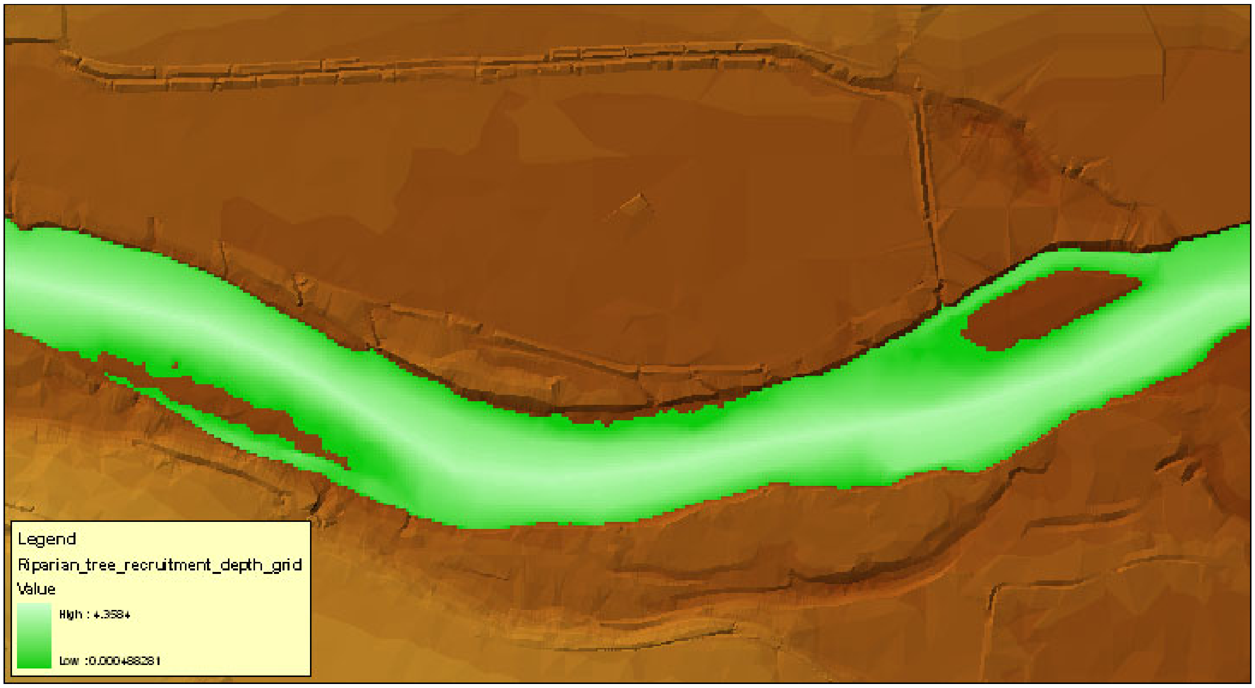


Figure 52. Depth grid created for <u>Riparian tree recruitment</u>. The green area shows where stage recession creates suitable conditions for seedlings to begin to grow.

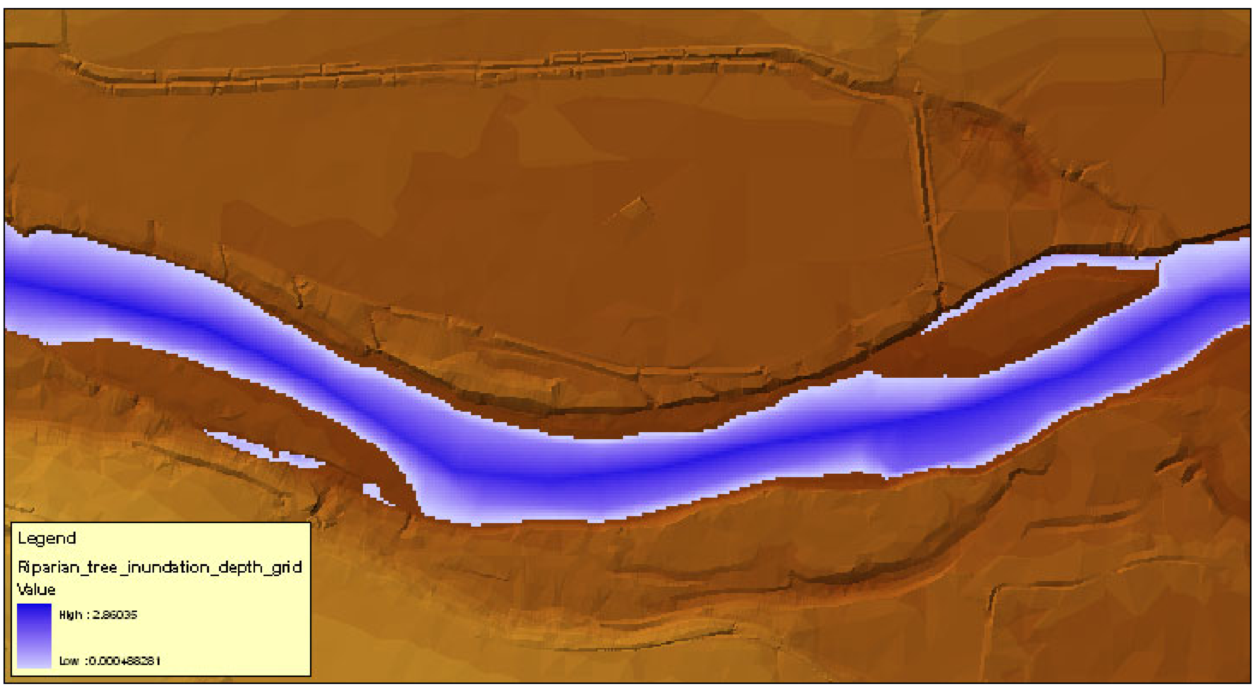


Figure 53. Depth grid created for <u>Riparian tree inundation</u>. This blue area shows where any new seedlings will be drowned by prolonged inundation.

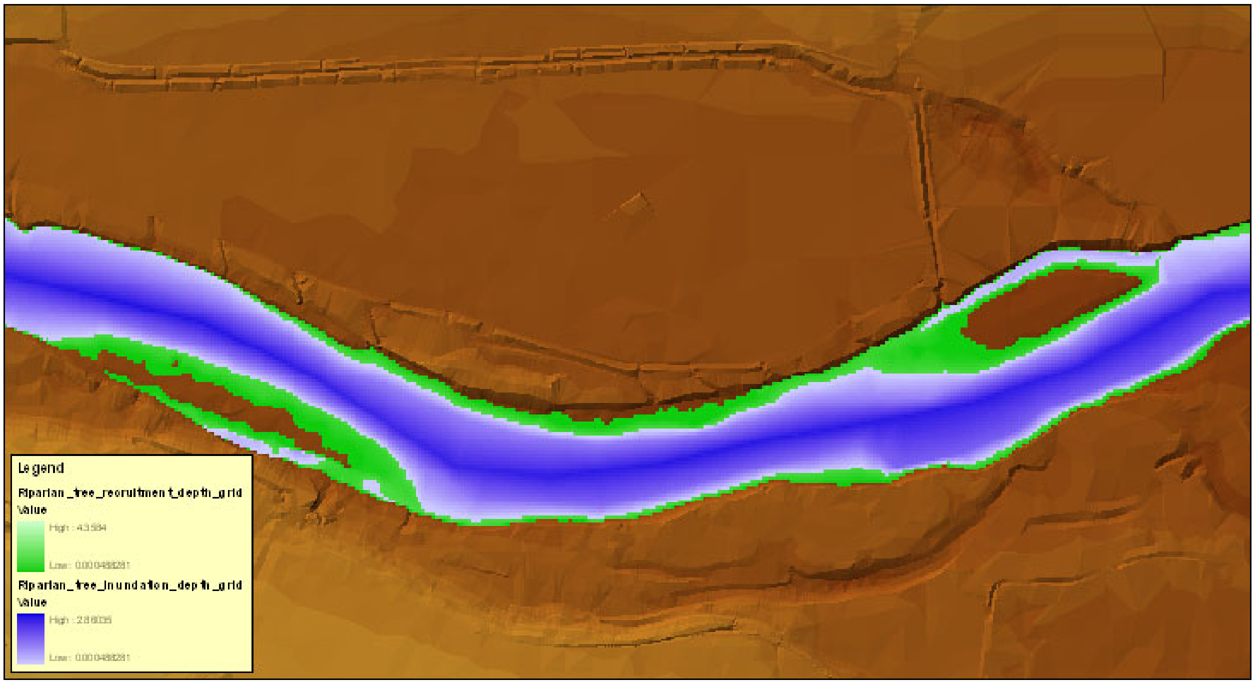


Figure 54. Overlay of Riparian tree recruitment and Riparian tree inundation depth grids.

In accordance with the combo relationship for Riparian tree establishment (Figure 7), the inundation depth grid was clipped from the recruitment depth grid. The resulting layer shows the area where HEC-EFM predicts Riparian tree establishment (Figure 55).

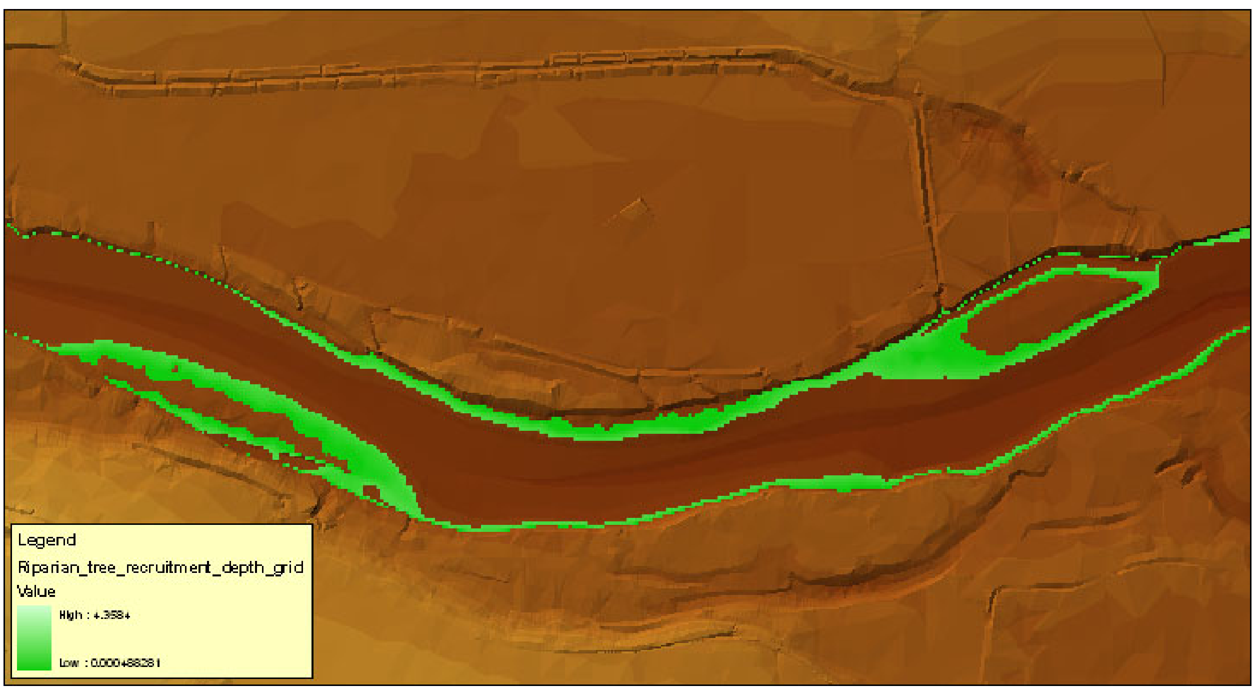


Figure 55. Depth grid created by clipping the inundation depth grid from the recruitment depth grid. The resulting area shows where HEC-EFM predicts Riparian tree establishment.

Information for the Riparian tree inundation relationship mentioned that seedlings were more likely to survive if sustained inundation did not exceed 0.5 ft. Delineating the area of inundation less than or equal to 0.5 ft shows the portion of Riparian tree inundation that may not lead to seedling mortality (Figure 56). This Riparian tree inundation fringe can then be layered with the clipped layer to create a new view of predicted and possible (due to the shallow depths) Riparian tree establishment (Figure 57).

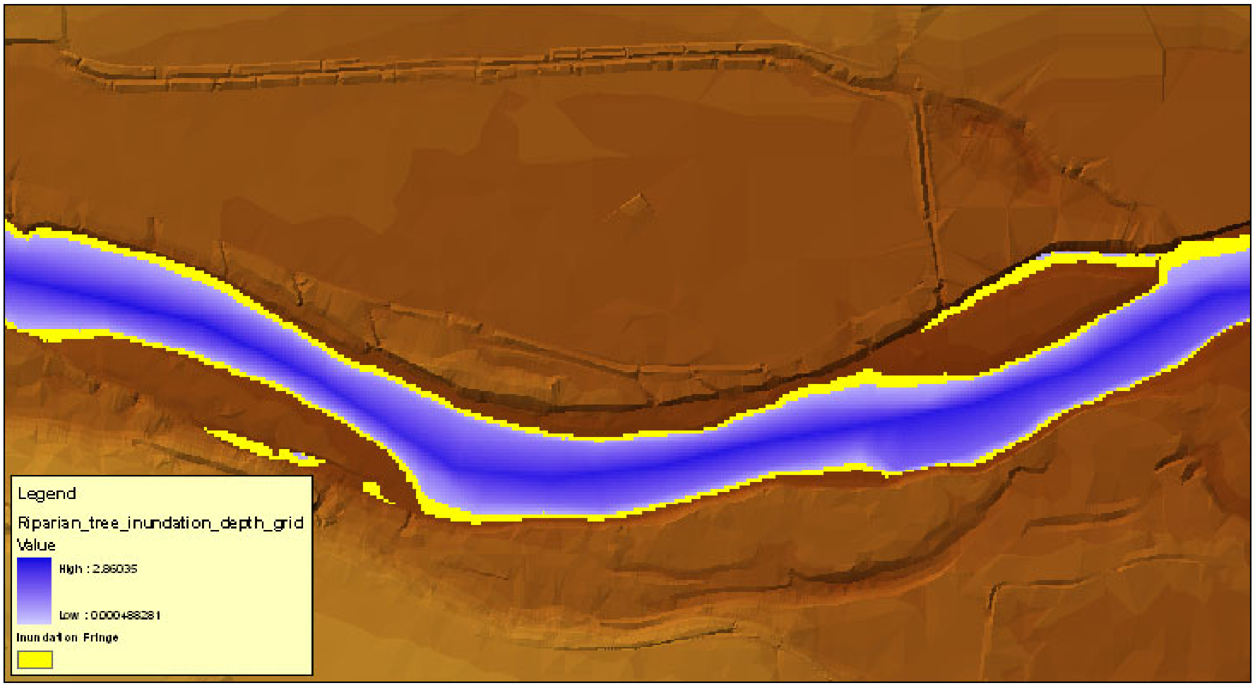


Figure 56. The yellow fringe shows areas of the Riparian tree inundation depth grid that are less than or equal to 0.5 ft, which may not be deep enough to drown new seedlings.

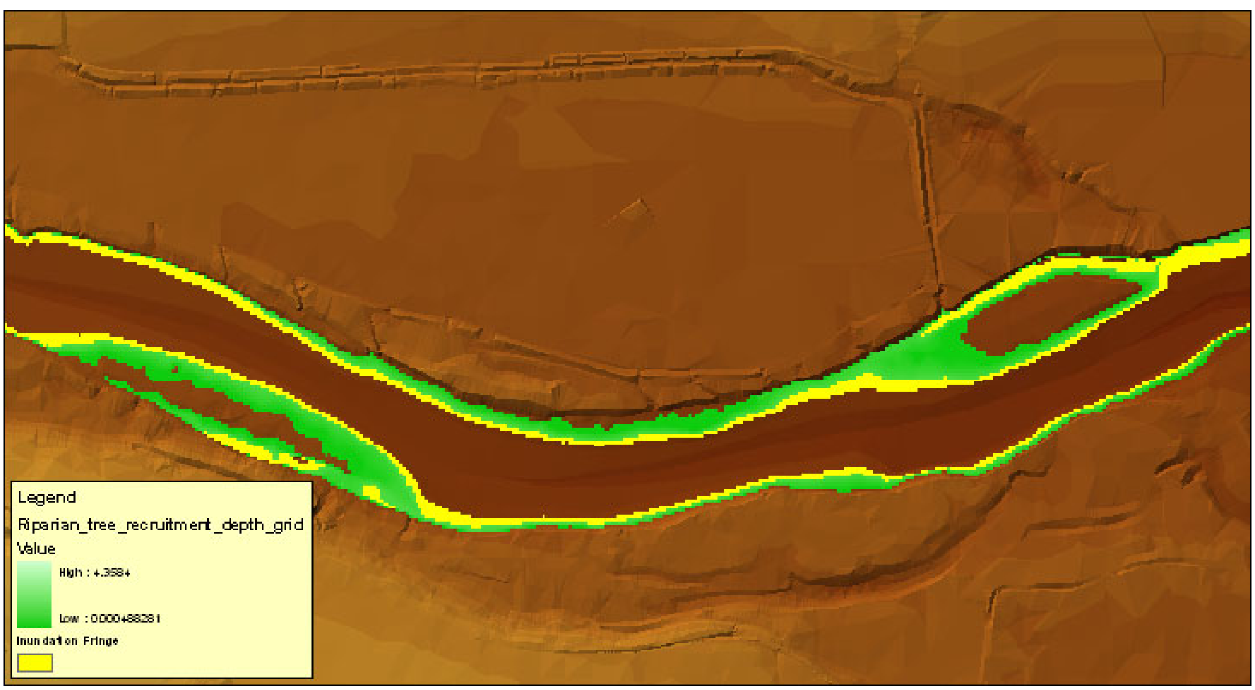


Figure 57. Potential recruitment sites for the Rolling River's Natural flow regime as computed using statistical and geographical queries in HEC-EFM, water surface profiles computed by HEC-RAS, and depth grids produced by HEC-GeoRAS.

So far the demonstration project has focused on comparing flow regimes with different hydrologic scenarios (Natural vs. Gaged). HEC-EFM can also be used to look at changes in topography, which will change the stage time series without changing the flow. Figure 58 shows a comparison of the current topography and a planned restoration project that increases stream meander. The same flows (Natural) are used for each of the channel topographies.

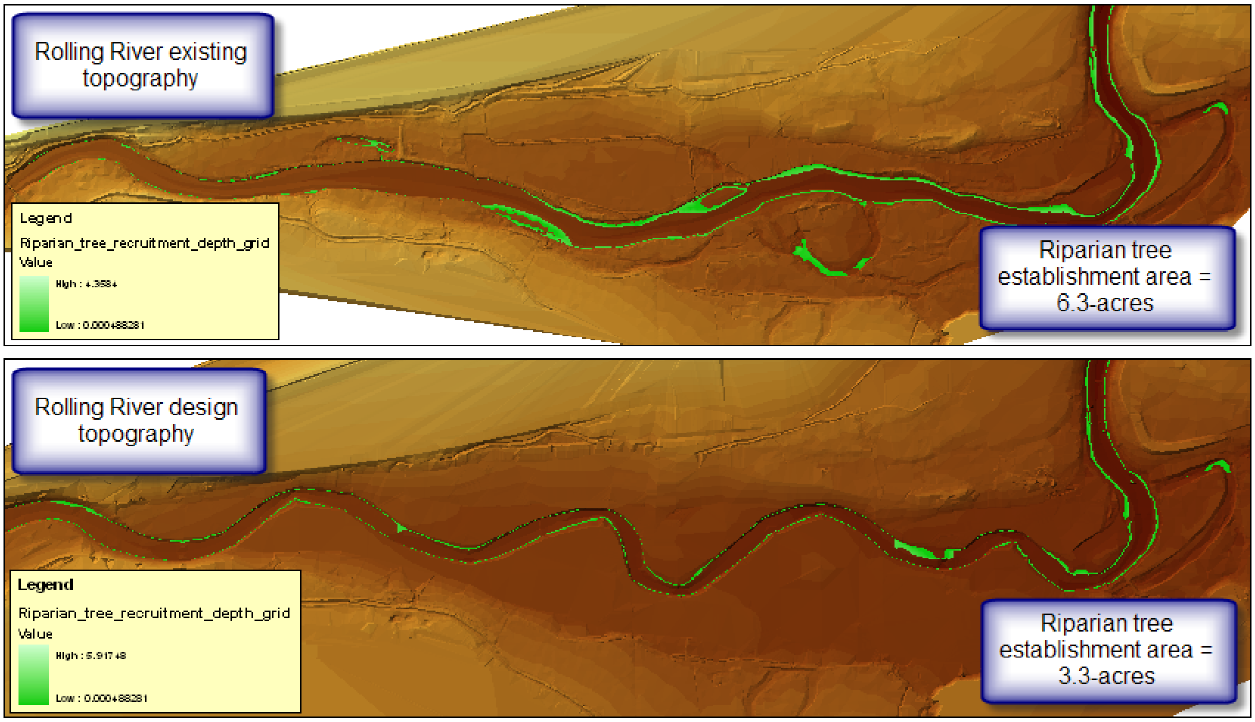


Figure 58. Comparison of Riparian tree establishment in existing and restored topographic conditions.

The following progression of tasks for the demonstration project has now been completed: 1) building relationships, 2) setting up an HEC-EFM project and computing statistical results, 3) simulating the statistical results with a hydraulic model, and 4) use of GIS to investigate ecosystem responses spatially.

Statistical results in HEC-EFM are computed as flows and stages, percent exceedances, index values, and directions of ecosystem change. Spatial results are shown as combinations of map layers with each combination presenting a snapshot of an ecosystem dynamic. Layers are typically translated to areas for spatial comparisons of different flow regimes and channel topographies. Working with GIS allows use of other ecologically relevant data. For example, a soils map for Rolling River could be used to intersect the Riparian tree establishment layer (Figure 55) with the extent of suitable soils for riparian trees.

4.4.1 HEC-GeoEFM

The process of applying HEC-EFM involves three basic phases: statistical analyses, hydraulic modeling, and use of GIS. Results from the statistical phase are input to external hydraulic models that generate layers of water depth, velocity, and inundation, which are then used in GIS to investigate spatial criteria and results for the flow regimes and relationships being analyzed. Application of the full process can generate many layers.

HEC-GeoEFM is a software tool developed to support spatial analyses commonly used during applications of HEC-EFM. HEC-GeoEFM provides three primary capabilities for planning ecosystem restoration projects or water management decisions: 1) management of spatial data sets, 2) computation and comparisons of habitat areas, and 3) assessment of the habitat connectivity. HEC-GeoEFM works with HEC-EFM and HEC-EFM Plotter to help users assess the ecological implications of water resource decisions. For more information, please see http://www.hec.usace.army.mil/software/hec-geoefm/.

CHAPTER 5

Applying HEC-EFM

Applications of HEC-EFM focus on aquatic habitat and land-water interactions inside the maximum inundated area associated with a river, wetland, or reservoir. Within this domain, the software is capable of testing a diverse and extensive array of management scenarios and ecological relationships. The software relies wholly on the user to define which aspects of the ecosystem are of interest (e.g., fish, vegetation, benthic macroinvertebrates), how those are to be investigated (e.g., at a single diagnostic location, for multiple locations, for many spatial areas), and which hydrologic, operational, or restoration scenarios are considered (e.g., climate change, reservoir releases, channel manipulation). This **flexibility in focus, scale, and scenario** is an important and defining aspect of HEC-EFM. It is also difficult to fully appreciate.

5.1 Leveraging Existing Applications

Applications of HEC-EFM are easy to initiate and can also borrow from existing applications. Incorporating pieces of existing models is done through menu options for import of both flow regimes and relationships. When *"Edit – Relationships (or Flow Regimes) – Import…"* is clicked, an interface will appear that allows users to browse to an existing (source) application, select the desired flow regimes or relationships, and perform the import (Figure 59). *"Import…"* is the only menu option that connects multiple model applications. All others (e.g., add, rename, reorder, duplicate, delete, select/deselect, manage and select/deselect groups) work within the open application. Please note that the *"Edit – Relationships"* menu is location-dependent and is only enabled when the user is working on the *Relationships Tab*. This restriction is also the case for the *"Edit – Flow Regimes and Combo Relationships"* menus (*Properties Tab and Combo Relationships Tab*, respectively).

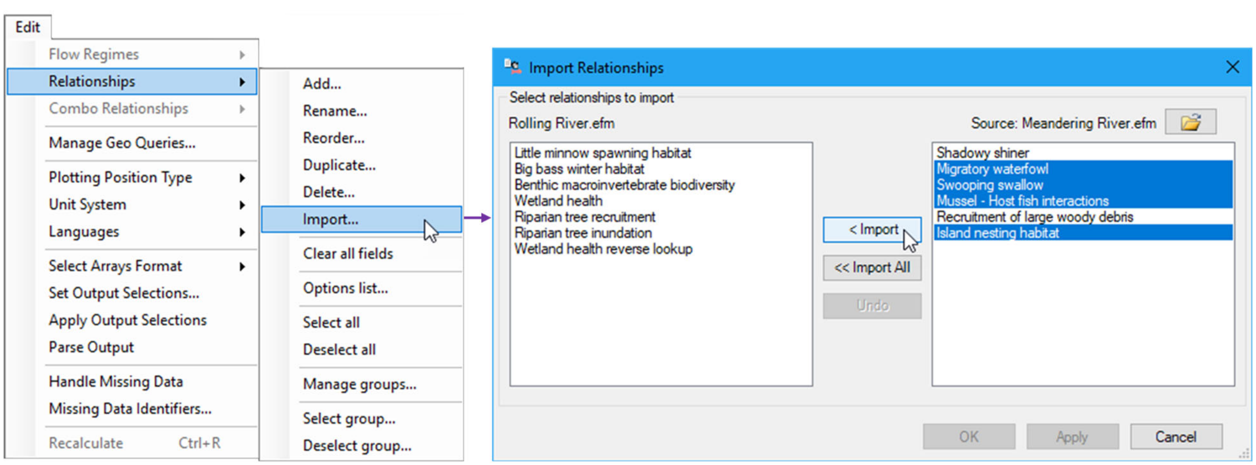


Figure 59. Using the *"Import…"* menu option to add relationships from source to current project. This can also be done for flow regimes.

5.2 Large-Scale Applications

The simplest HEC-EFM applications involve one flow regime and one relationship as would be the case when modeling the effects of one scenario on one aspect of the ecosystem. Applications become more complex as the numbers of flow regimes and relationships increase. HEC-EFM models that investigate many alternatives for only a few species are likely to have a higher number of flow regimes and a low number of relationships. Conversely, modeling done to better understand the status of whole ecosystems will tend to have a low number of flow regimes and a higher number of relationships. As spatial scales increase from a single restoration site to long reaches in dendritic river systems, HEC-EFM applications often have location-based flow regimes that serve as multiple diagnostic locations for a single management alternative. The number of relationships may grow as relationships are duplicated and modified to test model sensitivities. HEC-EFM has several features to help support this spectrum of applications.

5.2.1 Batch Creating Flow Regimes

To expedite addition of multiple flow regimes, HEC-EFM offers two features that automate creation of new flow regimes. Both are available through the *"Edit – Flow Regimes"* menu (Figure 60). *"Batch add…"* works only with data stored in HEC-DSS. Users specify input data file, types of data to associate with the flow regimes, and naming convention for flow regime identifiers. HEC-EFM will process all data in the input file per the selected data type. For example, the data file (Rolling River Data.dss) provided with the demonstration project has four records: Rolling River, flow and stage for both Natural and Gaged conditions. If that file was used in a batch add with a data type of Flow and Stage, two flow regimes would be added.

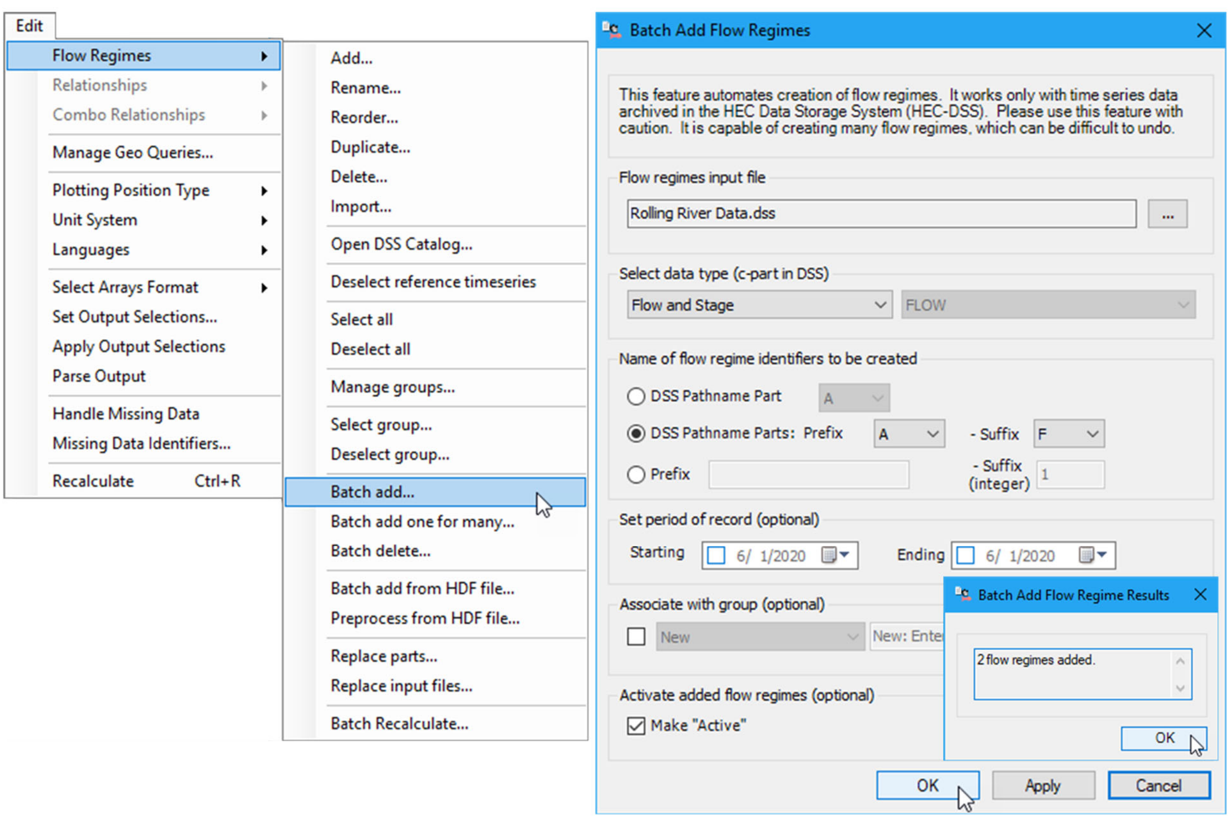


Figure 60. *"Batch add…"* and *"Batch add one for many…"* automate creation of flow regimes.

With *"Batch add one for many…"*, users specify the two data time series to use, the number of flow regimes to create, and a naming convention for the resulting flow regimes. Each of the flow regimes have the same time series data, which can be advantageous when investigating multiple sites around the same water body (e.g., separate habitat areas that respond differently to the same fluctuations in stage).

These features are particularly helpful when using data from large gage networks, watershed-scale hydrologic datasets, or output from substantial river hydraulics or reservoir system simulation models, but should always be used with caution. Each feature is capable of adding (or removing via *"Batch delete…"*) many flow regimes, which can be difficult to undo. New flow regimes can also be associated with groups as described in the next section.

5.2.2 Managing with Groups

HEC-EFM is capable of simulating thousands of flow regimes and relationships, but as numbers grow, it becomes increasingly difficult to use the main EFM interfaces to select and deselect the particular combinations of flow regimes and relationships desired for simulation. One way to manage applications with large numbers of flow regimes and relationships is to create "Groups". Groups are collections of flow regimes and relationships. Groups are defined separately for flow regimes and relationships (Figure 61) and then can be selected and deselected for simulation via menu options associated with the *"Edit – Flow Regimes – Groups"* and *"Edit – Relationships – Groups"* menu options (*Manage*, *Select*, and *Deselect* options). Relationship groups tend to be structured around ecological similarities. Flow regime groups tend to reflect a shared theme (separate groups for reservoir reoperations and channel modifications) or are organized per location-based flow regimes (tributary and mainstem diagnostic points, separately).

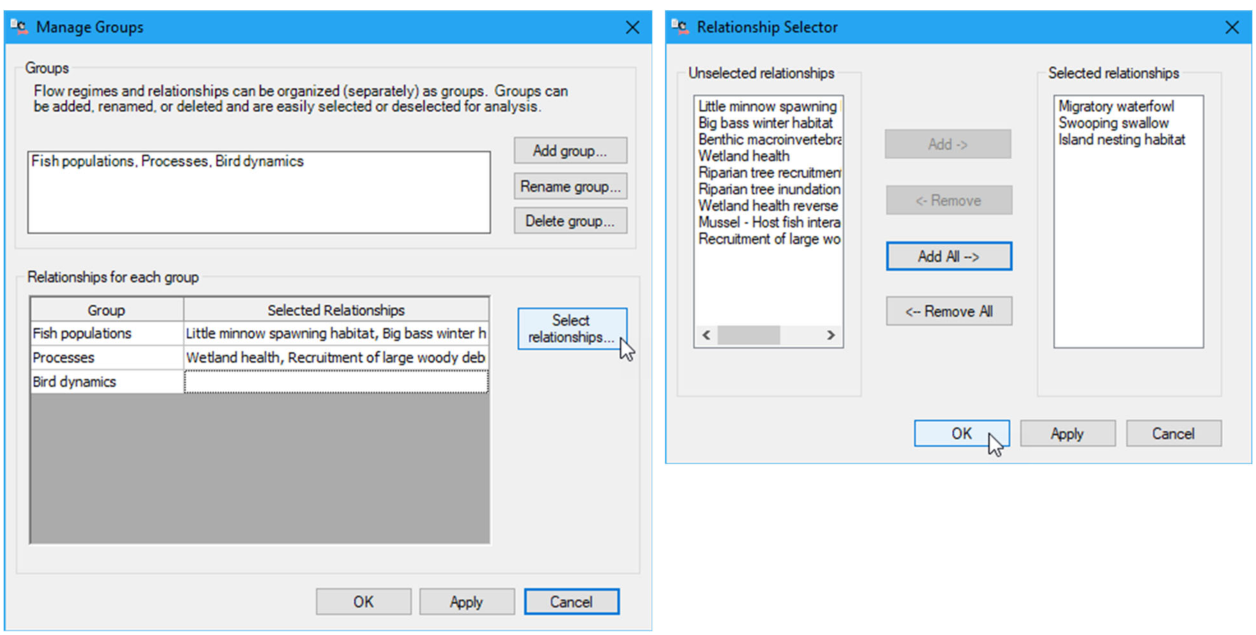


Figure 61. Creation of relationship groups (Fish populations, Processes, and Bird dynamics) and selection of relationships for the Bird dynamics group.

5.2.3 Managing Output

When the *Write Computation Arrays* relationship option is selected, HEC-EFM writes output for the computational steps performed while analyzing that relationship for each active flow regime. Many time series and paired data outputs records are generated. Management of these outputs becomes challenging as numbers of relationships and flow regimes increase, even when using HEC-EFM Plotter. To help, HEC-EFM enables users to select which types of output to write and to choose whether to apply those settings (Figure 62). Deselecting undesired outputs reduces the computer memory needed to store output files, reduces compute times, and makes use of HEC-EFM Plotter faster because there are fewer data records to track and display. The default is to write all output.

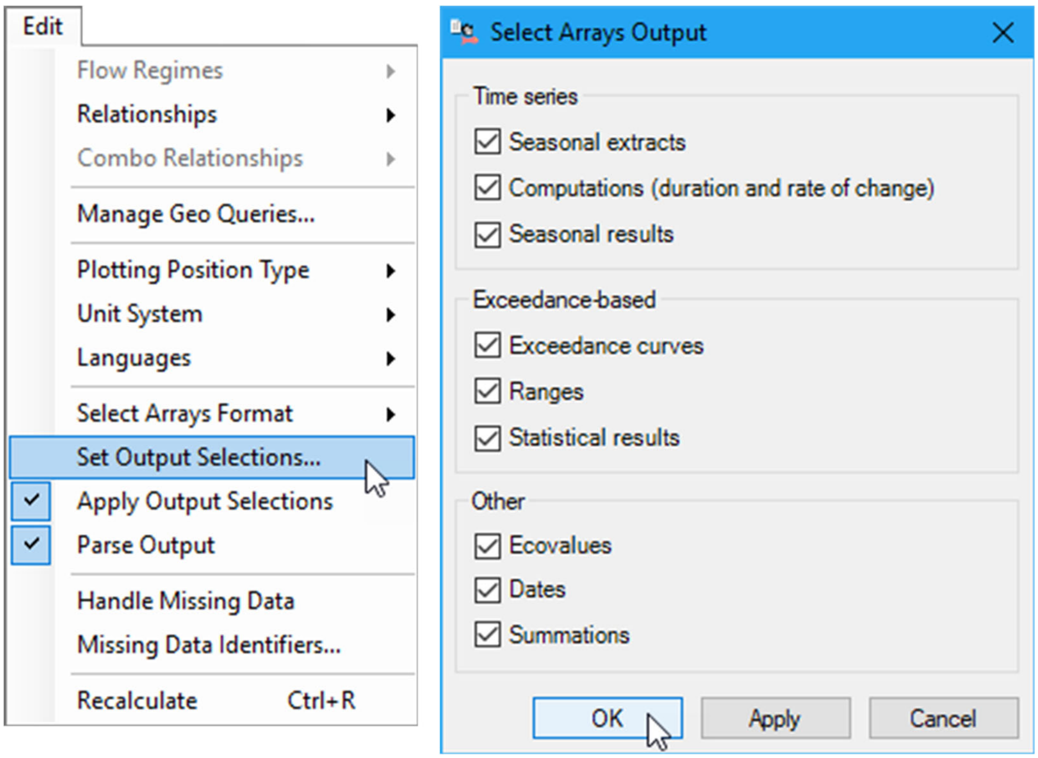
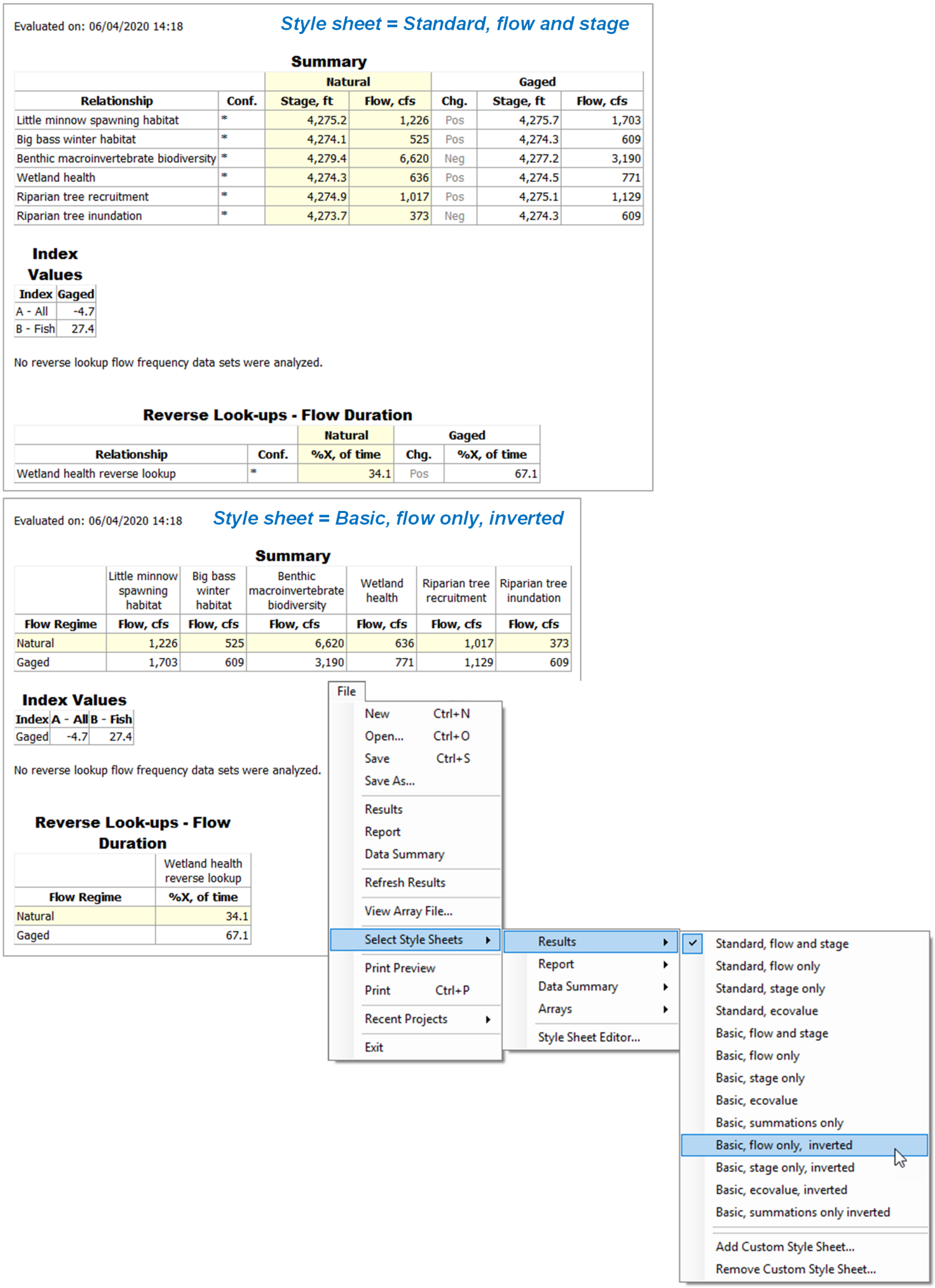


Figure 62. HEC-EFM enables users to select which outputs to write (*Set Output Selections…*) and to choose whether to apply those settings (*Apply Output Selections*).

5.3 Format Options for Model Tables

HEC-EFM also offers formatting options for tables generated by the software that report model results and parameters. Through the *"File – Select Style Sheets – Results"* menu, several pre-packaged options are available for the main results table (Figure 63). Different formats can be helpful when including tables in reports, copy-pasting statistical results to spreadsheets for additional calculations, or when suppressing unnecessary outputs. Choice of style sheet is a project setting, which means that the selected style sheet will be used until a different one is chosen by the user. New style sheet selections can be applied via the *"File – Refresh Results"* menu option - it is not necessary to *Recalculate*. Pre-packaged options are currently available only for the Results table.



Evaluated on: 06/04/2020 14:18 — Style sheet = Standard, flow and stage

Summary

		Natural			Gaged	
Relationship	**Conf.**	**Stage, ft**	**Flow, cfs**	**Chg.**	**Stage, ft**	**Flow, cfs**
Little minnow spawning habitat	*	4,275.2	1,226	Pos	4,275.7	1,703
Big bass winter habitat	*	4,274.1	525	Pos	4,274.3	609
Benthic macroinvertebrate biodiversity	*	4,279.4	6,620	Neg	4,277.2	3,190
Wetland health	*	4,274.3	636	Pos	4,274.5	771
Riparian tree recruitment	*	4,274.9	1,017	Pos	4,275.1	1,129
Riparian tree inundation	*	4,273.7	373	Neg	4,274.3	609

Index Values

Index	Gaged
A - All	-4.7
B - Fish	27.4

No reverse lookup flow frequency data sets were analyzed.

Reverse Look-ups - Flow Duration

		Natural		Gaged
Relationship	**Conf.**	**%X, of time**	**Chg.**	**%X, of time**
Wetland health reverse lookup	*	34.1	Pos	67.1

Evaluated on: 06/04/2020 14:18 — Style sheet = Basic, flow only, inverted

Summary

	Little minnow spawning habitat	Big bass winter habitat	Benthic macroinvertebrate biodiversity	Wetland health	Riparian tree recruitment	Riparian tree inundation
Flow Regime	**Flow, cfs**	**Flow, cfs**	**Flow, cfs**	**Flow, cfs**	**Flow, cfs**	**Flow, cfs**
Natural	1,226	525	6,620	636	1,017	373
Gaged	1,703	609	3,190	771	1,129	609

Index Values

Index	A - All	B - Fish
Gaged	-4.7	27.4

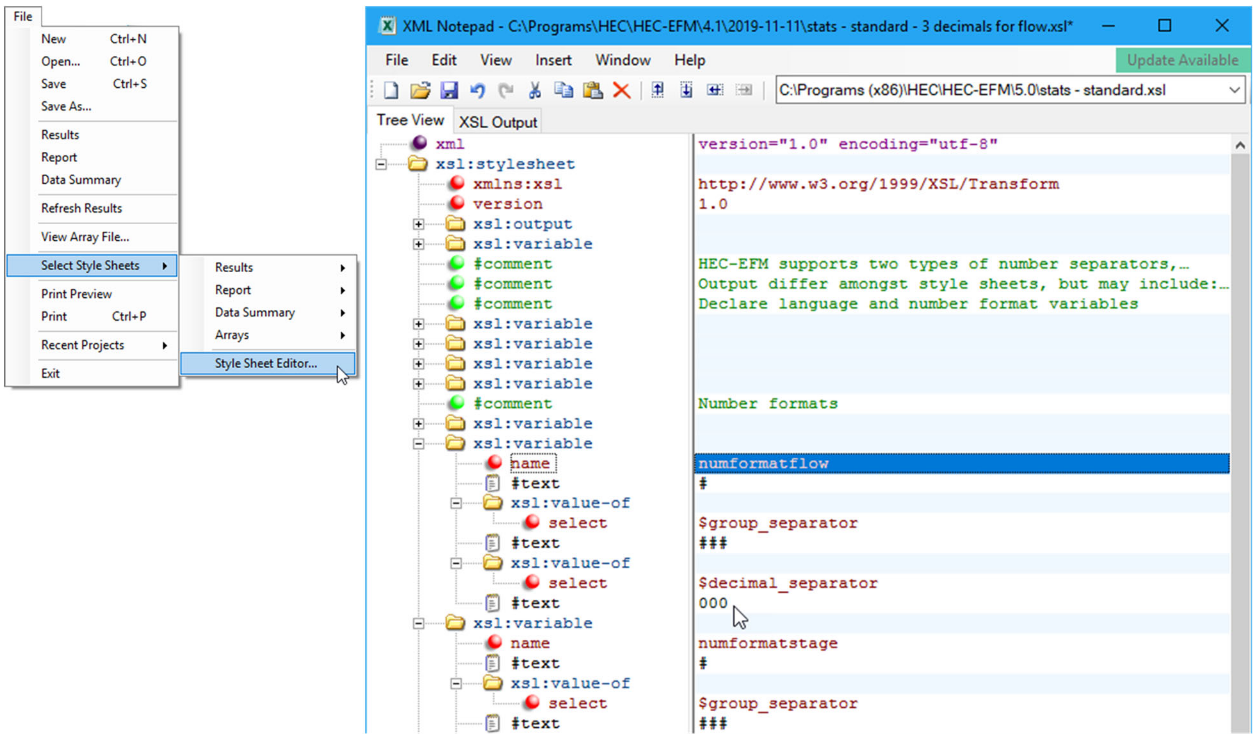
No reverse lookup flow frequency data sets were analyzed.

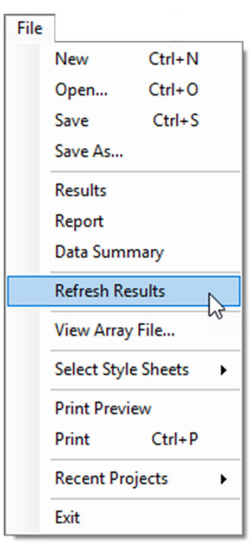
Reverse Look-ups - Flow Duration

	Wetland health reverse lookup
Flow Regime	**%X, of time**
Natural	34.1
Gaged	67.1

Figure 63. Choices of style sheets are made via the *"File – Select Style Sheets"* menu. The default Results table format is controlled by a style sheet called "Standard, flow and stage", as shown at the top of this figure. The "Basic, flow only, inverted" format is also shown.

Users are also able to add and remove custom style sheets for Results, Report, Data Summary, and Arrays tables. Modifying style sheets is best done through XML editors. Several editors are available online. An open source editor called XML Notepad is included with EFM and can be opened via the *"File – Select Style Sheets – Style Sheet Editor..."* menu option. Custom style sheets are used most often to modify numerical precision of output or appearance of tables. For the Results table, settings for numerical precision are located towards the beginning of the style sheets and can be modified by the user to adjust precision for each output variable, independently (Figure 64).





Summary

		Natural			Gaged	
Relationship	Conf.	Stage, ft	Flow, cfs	Chg.	Stage, ft	Flow, cfs
Little minnow spawning habitat	*	4,275.2	1,226	Pos	4,275.7	1,703
Big bass winter habitat	*	4,274.1	525	Pos	4,274.3	609
Benthic macroinvertebrate biodiversity	*	4,279.4	6,620	Neg	4,277.2	3,190
Wetland health	*	4,274.3	636	Pos	4,274.5	771
Riparian tree recruitment	*	4,274.9	1,017	Pos	4,275.1	1,129
Riparian tree inundation	*	4,273.7	373	Neg	4,274.3	609

Summary

		Natural			Gaged	
Relationship	Conf.	Stage, ft	Flow, cfs	Chg.	Stage, ft	Flow, cfs
Little minnow spawning habitat	*	4,275.2	1,225.721	Pos	4,275.7	1,702.500
Big bass winter habitat	*	4,274.1	524.874	Pos	4,274.3	608.536
Benthic macroinvertebrate biodiversity	*	4,279.4	6,620.048	Neg	4,277.2	3,190.000
Wetland health	*	4,274.3	635.921	Pos	4,274.5	771.000
Riparian tree recruitment	*	4,274.9	1,017.322	Pos	4,275.1	1,128.990
Riparian tree inundation	*	4,273.7	372.853	Neg	4,274.3	609.000

Figure 64. The EFM style sheet editor is used to customize the format of EFM generated tables. Image shows an increase in reported precision (from zero to three decimal places) for flow results.

5.4 Using 2-Dimensional Information

HEC-EFM can import time series data that are stored in the Hierarchical Data Format (HDF) for use as flow regimes. HDF is a frequently used database format (http://www.hdfgroup.org/) and is employed by at least two HEC software to store model simulation outputs (HEC-RAS for two-dimensional unsteady flow output and HEC-EFMSim for two-dimensional ecological simulation output). Through the *"Edit – Flow Regimes – Batch add from HDF…"* menu option, users specify input HDF files, dates and times of data being imported, data tables and key aspects of their structure and content, and a naming convention for the flow regime. Resulting flow regimes are compound in the sense that a single flow regime identifier contains multiple sets of concurrent time series (or time series and paired data). For example, the first flow regime in Figure 65, entitled "Wetland Restoration Zone", has data that would comprise 2,940 traditional HEC-EFM flow regimes and is one of the four listed that together have more than 32,000 parts. Each part is computed independently for all active relationships. Users should consider style sheet choice and output settings before applying HEC-EFM for large compound flow regimes.

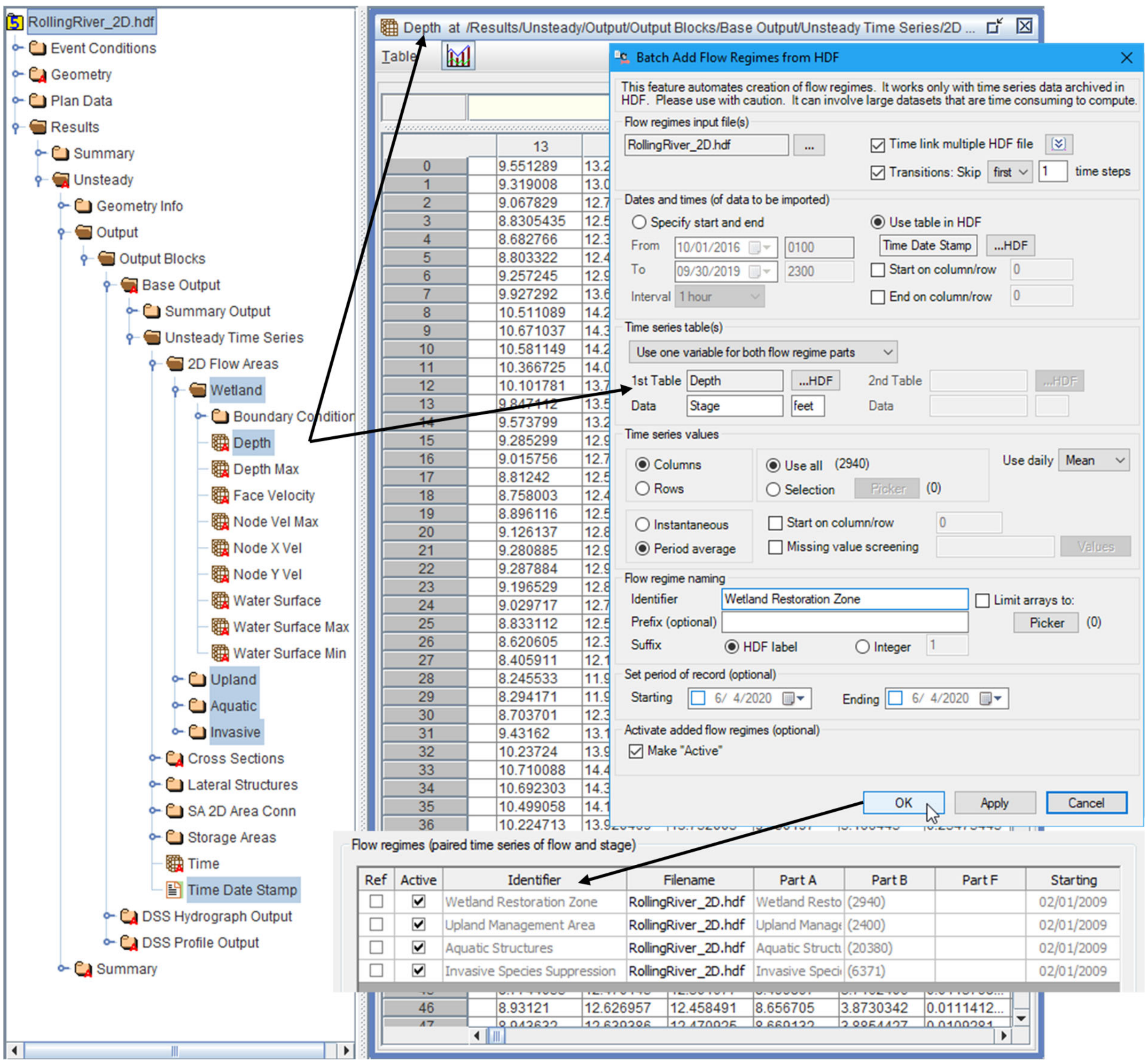


Figure 65. Importing HDF data for use in HEC-EFM. Structure and content of an HEC-RAS 2D output file is at back, *"Batch add from HDF…"* interface to right, and Flow regimes list at bottom.

The data and mathematical process HEC-EFM uses to analyze compound flow regimes is the same as for traditional flow regimes with one exception. Use of time series from HDF are supported for a wide range of time steps (19 increments ranging from 1 minute to 1 day) whereas only daily time series may be used in traditional flow regimes. During conversion from subdaily to daily, users may specify which daily time series is of interest: means, minimums, or maximums. HEC-EFM also provides a setting for the user to declare whether data from HDF are instantaneous or period average values, which affects the conversion to daily values. Apart from dealing with subdaily time steps, the process is unchanged. Data for each flow regime are queried per the season, duration, rate of change, and percent exceedance parameters for each relationship. Results are written and reported per output settings controlled by the user. Flow regime names are recorded as "Identifier-suffix" for compound flow regimes.

As with traditional flow regimes, subsequent recalculations simply repeat the whole process. Subdaily data are converted to daily, queried per relationship parameters, and then results are written and reported. To save time, HEC-EFM offers a menu option *"Preprocess from HDF file…"* that converts subdaily data to daily and saves the daily results in a new HDF table (Figure 66). An associated time/date table is also generated. The number of time series is unchanged; all time series are processed. The resulting HDF file can then be used via the *Batch Add Flow Regimes from HDF* interface as in Figure 65. Preprocessing has been shown to reduce overall compute times by approximately one third.

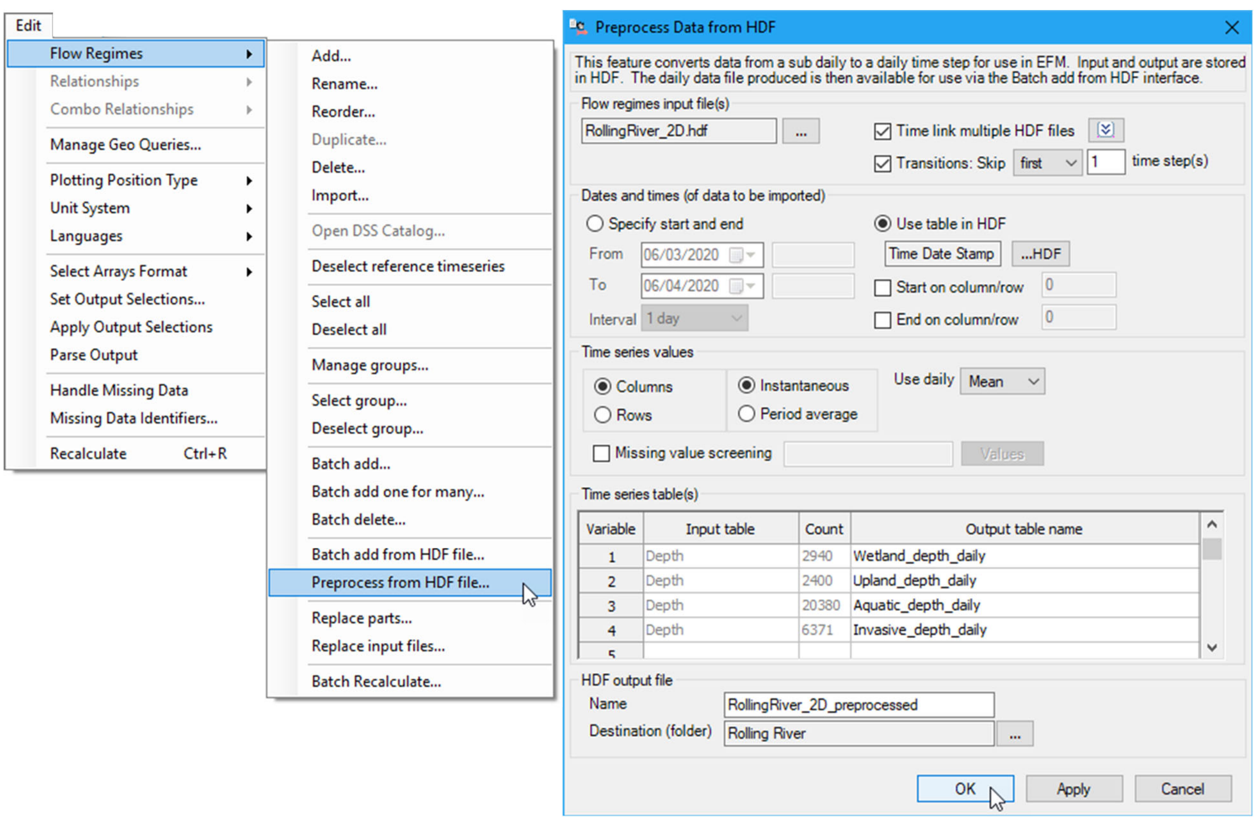


Figure 66. Avoid repetitive and time consuming conversions from subdaily to daily time steps via the *Preprocess Data from HDF* feature. With this, subdaily data are converted and written as daily values to a new HDF file that can then be used as input for flow regimes in HEC-EFM.

5.5 HEC-EFM for Design

HEC-EFM offers an option to cycle computations, replacing one piece of flow regime input in each iteration. This option is useful when designing hydrographs or designing topography – that is, considering many hydrograph options with a single topography (reservoir reoperations) or considering many topographic options for a single flow hydrograph (earthwork).

Cyclic application of HEC-EFM is initiated through the *"File – Flow Regimes – Batch Recalculate…"* menu option (Figure 67). Users specify which flow regime part to cycle through, input data files and records, and output location and naming conventions. A master switch for exporting results to DSS is provided here because this feature has the potential to generate much output. The switch is a checkbox option labeled *Compute arrays (export to DSS)*.

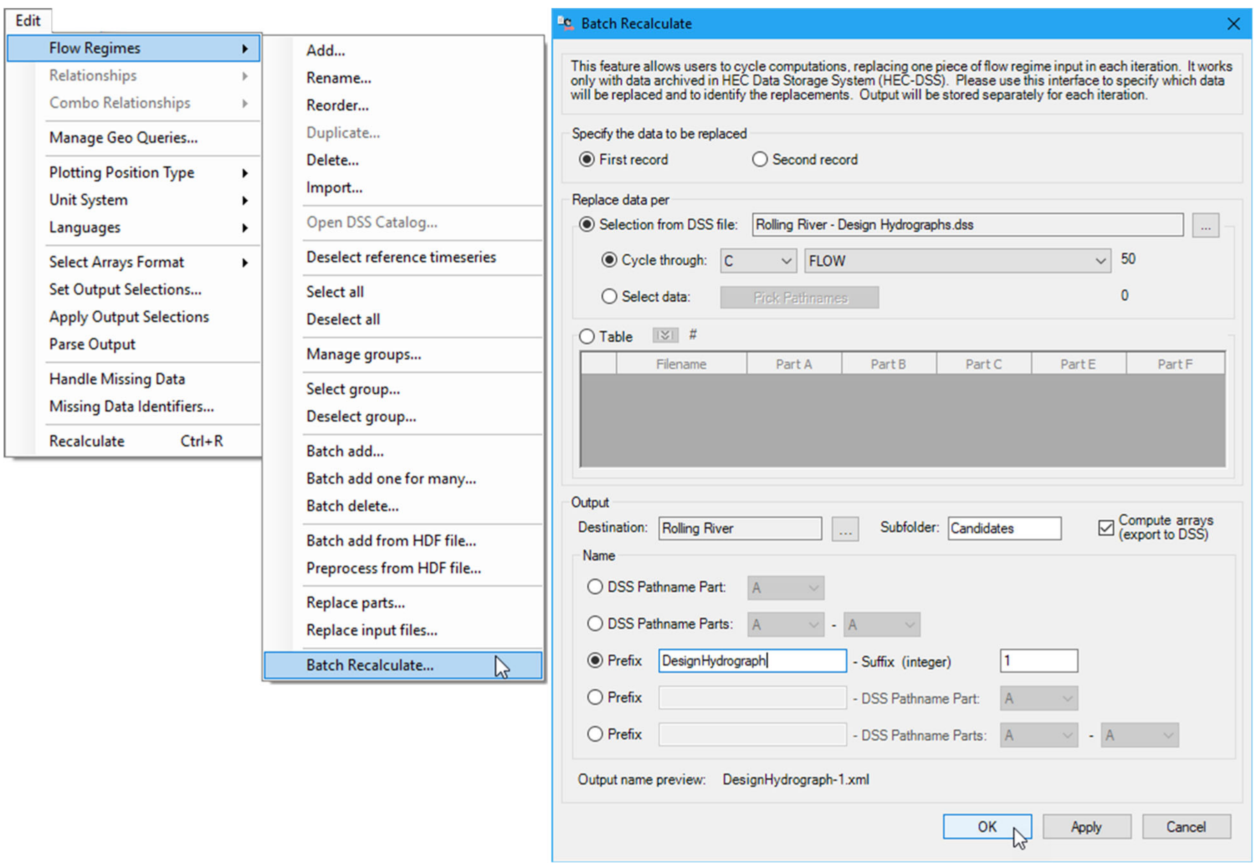


Figure 67. The "Batch Recalculate…" option in HEC-EFM allows users to cycle computations by replacing data associated with active flow regimes.

All other output controls (e.g., output settings and write computation arrays) remain in effect. Several options are provided for flow regime output names as combinations of pathname parts and user-defined prefixes and suffixes.

Again, it is important to note that only one data part of the flow regime is changed with each iteration. An early application of this feature involved testing several hydrographs to determine which generated the most ecological benefits. Flow regimes comprised of a flow time series and a local rating curve were added for locations along the river and made active. HEC-EFM was then used to test the set of hydrographs, each hydrograph being tested independently for all active flow regimes (locations). Output were written to tables and to HEC-DSS for subsequent analyses. Figure 67 shows a scenario in which 50 hydrographs (C = FLOW) will be tested.

CHAPTER 6

Multivariate Analyses

Habitat is often characterized by more than one variable. For example, per section 4.1.1, little minnow need shallow water for spawning (no deeper than 3 ft), which is an expression of habitat suitability based on a single variable, depth. If little minnow also needed water moving at more than 0.5 ft per second, ideally between 1 and 2 ft per second, and no more than 3 ft per second for spawning, then habitat suitability would be based on two variables, depth and velocity. Habitat suitabilities are typically expressed as a number from 0 (wholly unsuitable) to 1 (perfectly suitable).

In HEC-EFM, "multivariate analyses" numerically combine suitabilities for different variables into a single measure of suitability, which is useful for habitat mapping and when tallying habitat provided. In EFM, multivariate analyses are applied only for compound flow regimes (2-dimensional input).

Computations for multivariate analyses are done last during an EFM run because input to multivariate analyses are generated while computing results for individual flow regime-relationship pairings. Involving more than one flow regime-relationship pairing makes multivariate analyses quite different than other EFM analyses, which are almost always done independently for each flow regime-relationship pairing.

Using 2-dimensional data and multiple pairings can make multivariate analyses complex. This chapter details creation of multivariate analyses and related numerical options, validations to ensure viable analyses, and output.

6.1 Creating Multivariate Analyses

Multivariate analyses are set up via the HEC-EFM *Relationships Tab*. Technically, this means that a multivariate analysis is part of its host relationship, but since input data are obtained from multiple flow regime-relationship pairings, none of which need to be previously associated with the host, choice of host relationship is important only because it sets season and partially sets output name for the multivariate analysis.

Multivariate analyses are done as an option associated with ecovalue summations (Figure 68). Clicking the *settings* button opens an interface that allows users to select the numeric method and flow regime-relationship pairings for the multivariate analyses (Figure 69). Choice of flow regime is important because it sets period of record and partially sets output name for the multivariate analysis (output names are based on host flow regime and host relationship).

Clicking *Select pairings…* opens an interface that allows users to select the pairings relevant for the multivariate analysis (Figure 70). Pairings are offered for each combination of (compound) flow regime and relationship (i.e., flow regime || relationship). The host relationship is appended with "**" to acknowledge this association though use of pairings with the host relationship is not required. The host flow regime is listed in the first column. There can be only one multivariate analysis per host flow regime and host relationship.

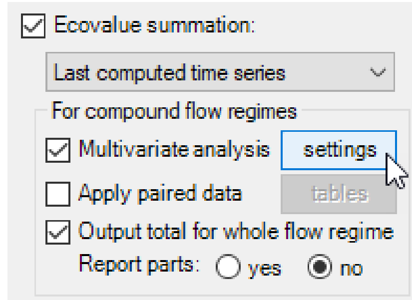


Figure 68. Multivariate analyses are created via the *Ecovalue summation* feature.

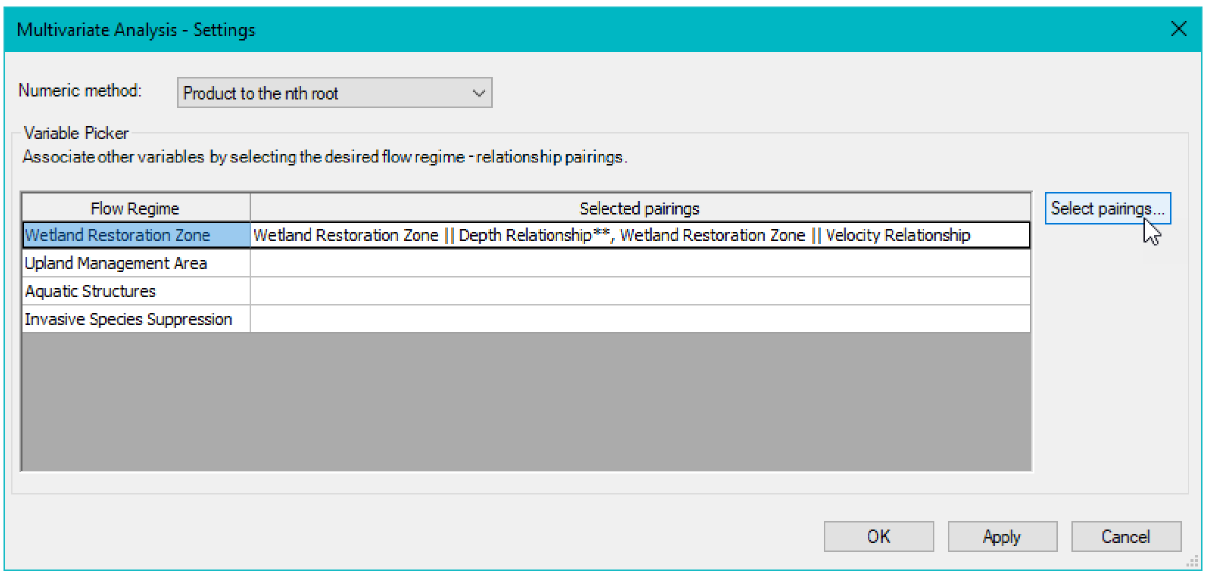


Figure 69. Multivariate analysis entitled "Wetland Restoration Area || Depth Relationship". Four multivariate analyses could be created for the host "Depth Relationship", one for each flow regime.

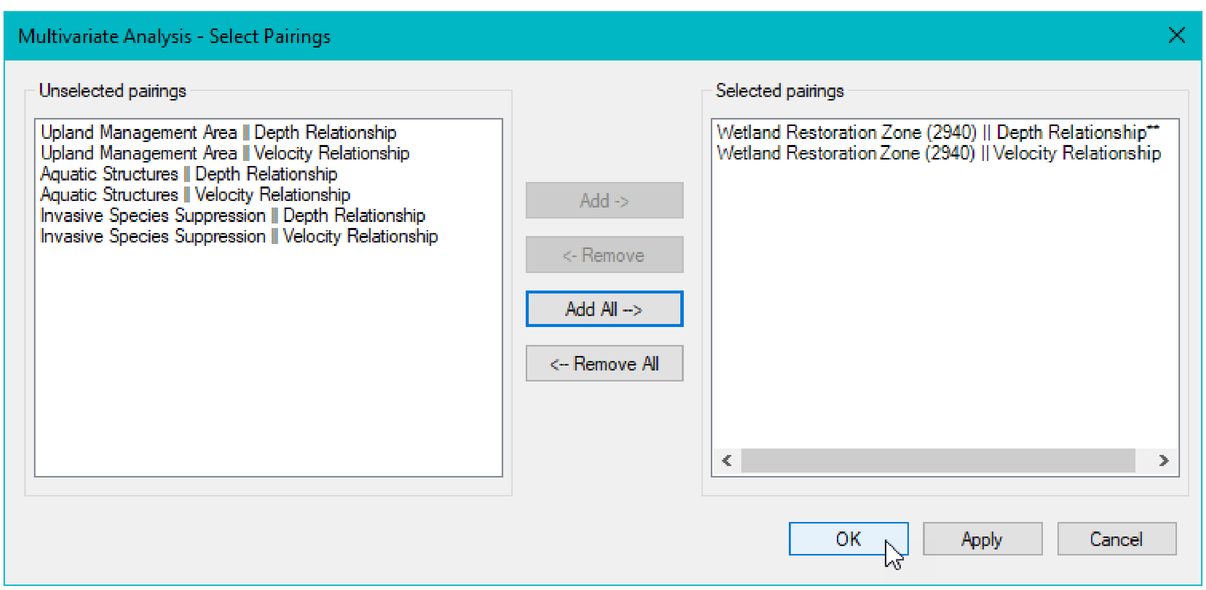


Figure 70. The *Select Pairings* interface allows users to pick which pairings to use in the multivariate analysis.

6.2 Numeric Methods

There are four options for numeric method: *Product to the nth root*, *product*, *mean*, and *minimum* (Figure 71). Please note that multivariate analyses in HEC-EFM and the associated numeric methods are intended to work with ecovalue time series based on suitabilities between 0 and 1.

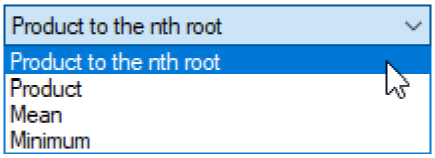


Figure 71. Numeric methods for multivariate analyses.

For each time step:

Product to the nth root combines ecovalues by multiplying the ecovalues of each selected pairing and then taking the nth root of that product.

Product combines ecovalues by multiplying the ecovalues of each selected pairing.

Mean combines ecovalues by summing the ecovalues of each selected pairing and then dividing that sum by the number of selected pairings.

Minimum combines ecovalues by selecting the minimum ecovalue of all selected pairings.

6.3 Validations

Several validations are done to help users create and manage viable multivariate analyses. There are a total of nine. All are applied at run time. The first seven are also applied as multivariate analyses are created. When an invalid combination is detected, HEC-EFM identifies the failed validation parenthetically at the end of the corresponding message.

1 - Current relationship has relationship-defined water year selected (all relationships invalid)
2 - Pairing relationship has relationship-defined water year selected (pairing relationship invalid)
3 - Flow regime inactive
4 - Relationship inactive
5 - Not an ecovalue summation relationship
6 - Mismatch in number of parts
7 - Season of pairing relationship not wholly nested in current relationship
8 - Temporal mismatch
9 - One or more ecovalue time series for selected pairings has values less than 0 or greater than 1

The first and second validations flag use of relationships that are incompatible with multivariate analyses. The third and fourth check whether requisite inputs will be available for multivariate analyses. The fifth checks whether relationships in selected pairings are ecovalue summation relationships. The sixth checks whether the flow regimes in selected pairings have the same number of parts. The seventh checks whether relationships in selected pairings have compatible seasons. The eighth checks whether the periods of record for selected pairings allow for computation of multivariate analyses. The ninth checks whether ecovalue time series for selected pairings have values less than 0 or greater than 1.

Failed validations for the first seven checks are reported via the *Multivariate Analyses - Select Pairings* interface and at run time. For example, Figure 72 shows a selected pairing that failed validation 6 - Mismatch in number of parts. The number of parts for the Aquatic Structures flow regime (20,380) is different than the number of parts for the Wetland Restoration Zone flow regime (2,940). Validation 6 checks that the number of parts for selected pairings are equal, which is a simple check intended to flag spatial discrepancies. Invalid selections can be saved, allowing users to continue working with their EFM projects, but will fail at run time.

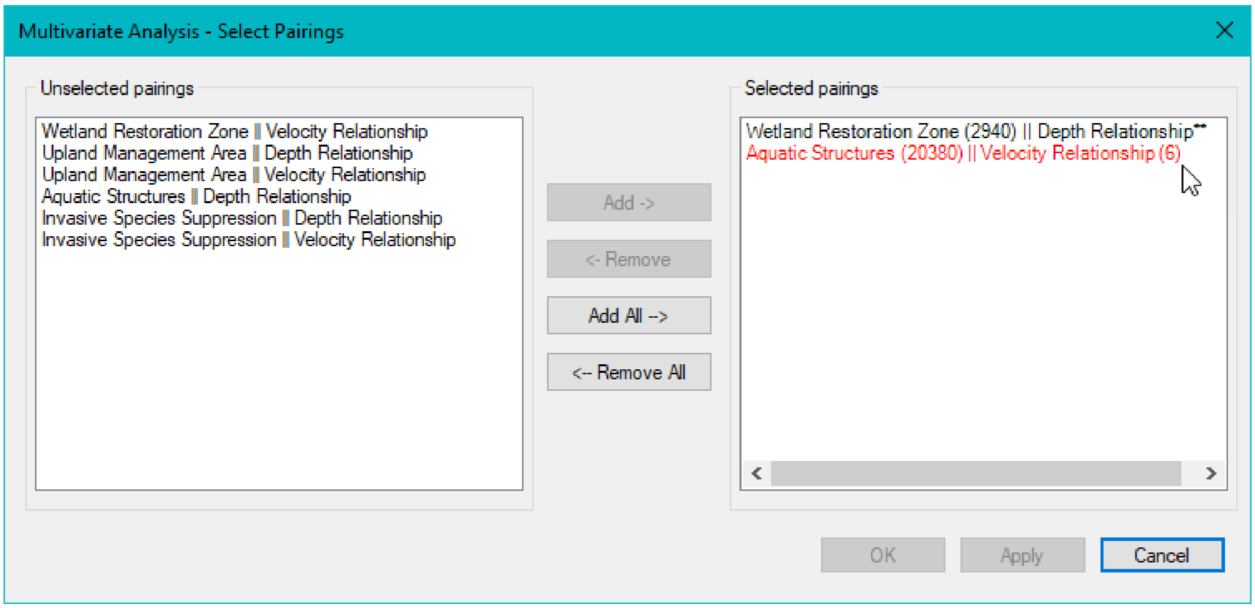


Figure 72. Failed validations are reported in the *Select Pairings* interface. Red text is used to highlight problems and includes the failed validation identifier (in this image, "6").

The eighth and ninth validations are only done at run time because the periods of record and ecovalues needed for validation are generated during the compute process. As multivariate analyses are done last, this approach does leave the possibility that a run will fail unexpectedly late in its compute cycle. Messages about run time validation fails (for all validations) are provided in EFM output tables and via pop-up windows that can be left open as a reference for users troubleshooting multivariate analyses (Figure 73).

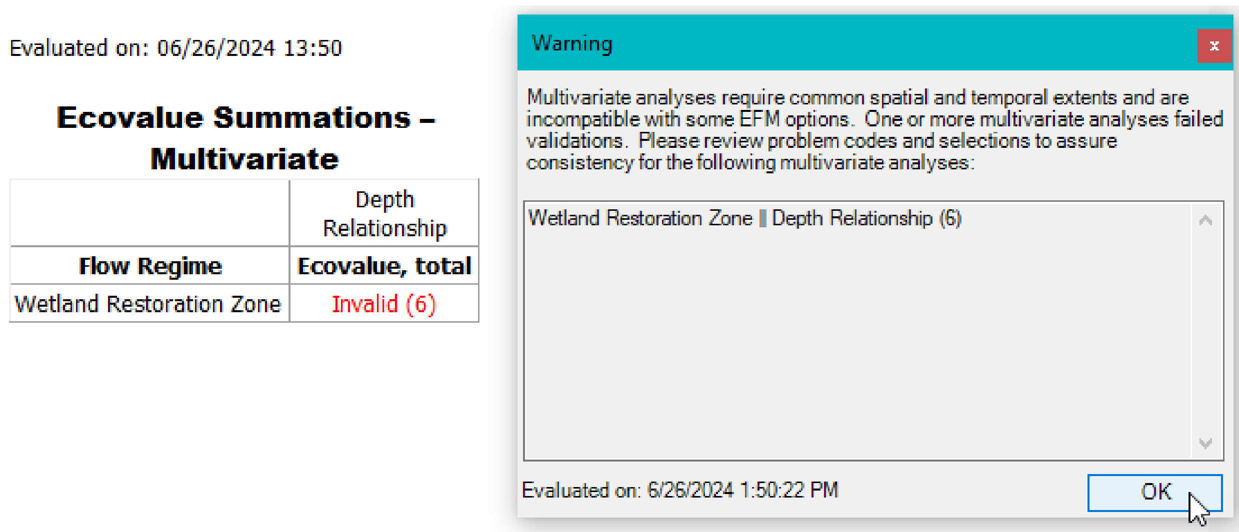


Figure 73. Validations failed at run time are reported in EFM output tables (left) and warning message windows (right).

6.4 Output

During compute, ecovalue time series for each selected pairing are combined based on the numeric method chosen by the user. Combined ecovalue time series are then tallied in the same progression (see section 3.6.3) as done for other ecovalue summations: 1) daily combined ecovalue series, 2) tally for flow regime, 3) tally status at the end of each season, 4) tally total for flow regime, 5) tally for each season, 6) tally total for each season, and 7) a ranked set of seasonal totals from #6.

There is an *Apply paired data* option (Figure 68, see section 6.1) that allows the combined ecovalue series to be multiplied by a paired data set prior to tallying. For multivariate analyses, paired data associated with the host flow regime are applied via this option. The most common application of paired data in multivariate analyses is to multiply the combined ecovalue time series (in terms of suitabilities) by area per flow regime part (paired data) to compute time series of suitable habitat (in terms of area).

Results of multivariate analyses are stored in HDF and DSS and reported in HEC-EFM results tables. All DSS outputs for multivariate analyses are labeled with a c-part that includes “multivariate”.

Two style sheets (see section 5.3) are provided for rendering output tables of multivariate results, “Basic, multivariate only” and “Basic, multivariate only inverted”, the latter of which has flow regimes in rows and relationships in columns and is recommended when rendering multivariate results for numerous flow regimes or flow regime parts.

Figure 74 provides an overview of the compute process and DSS outputs, which are then available for viewing in HEC-EFM Plotter.

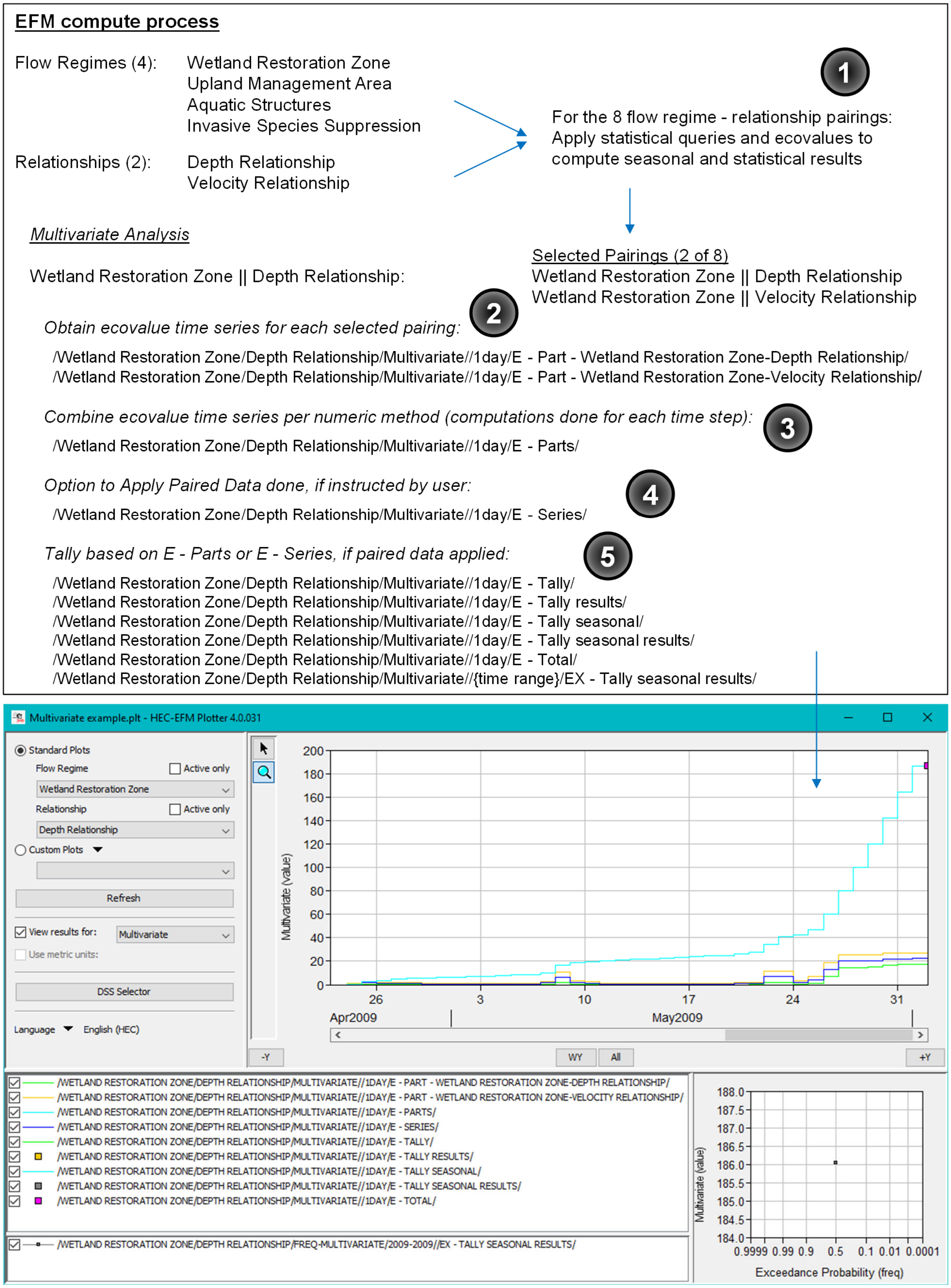


Figure 74. Compute process and DSS outputs related to multivariate analyses.

CHAPTER 7

Language Support

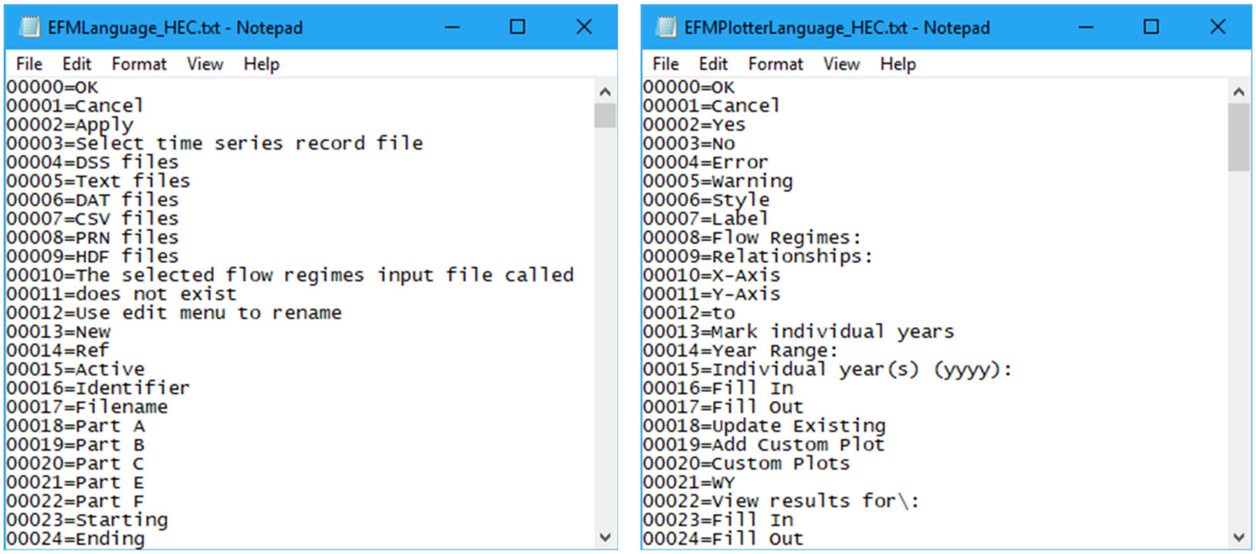
Since HEC-EFM was first publicly released, several suggestions have been offered regarding how particular features might be better labeled and documented to make them more intuitive. While this is a wonderfully simple and constructive idea, creating one ideal set of terms and descriptions is challenging because different teams have different preferences and lexicons. To empower study teams to make HEC-EFM as useful as possible, several features have been added that allow the software to be customized, including output format options, style sheet options, custom style sheets, set output selections, and style sheet editor. In HEC-EFM 5.0 and HEC-EFM Plotter 3.0, the software was further modified to allow users to specify interface labels. For individual users, this enables interface text to be changed to whatever is deemed most communicative. For international users, this enables translation of interface text.

7.1 Languages

In HEC-EFM, “languages” are comprised of: 1) name, 2) language file, 3) Quick Start Guide, 4) Demonstration Project, and 5) Language for system labels. Name is assigned by the user to identify the language. Language file is a text file that contains all interface labels. Quick Start Guide and Demonstration Project are file and pathname pointers to customized or translated versions of HEC-EFM user guidance and demonstration projects. Both are optional. If unspecified, HEC-EFM will continue to use the default files associated with those resources that are provided as part of the HEC-EFM install. Language for system labels offers users a choice of language and dialect, which is then used by HEC-EFM to determine format of numeric output in results tables. HEC-EFM 5.0 has a default language named “English (HEC)” that uses labels from a version-specific default language file entitled “EFMLanguage_HEC.txt”.

In HEC-EFM Plotter, languages are comprised of: 1) name and 2) language file. The other HEC-EFM language components are not relevant because Plotter guidance and demonstrations are included as part of the corresponding HEC-EFM materials and Plotter only uses number formats associated with the English (United States) language and dialect. HEC-EFM Plotter 3.0 has a default language named “English (HEC)” that uses labels from a version-specific default language file entitled “EFMPlotterLanguage_HEC.txt” (Figure 75).

Languages may be associated with the software or with particular applications. “Program languages” are languages associated with specific versions of the software. After one or more program languages are specified, new instances of the software will open with the most recently used program language and all program languages will be in the language list. “Project languages” are languages associated directly with an application. When the application is opened, its project language will be used, regardless of any subsequent changes to program languages. Project languages only appear in the language list of the associated project. Supporting both language types allows users to use the software with multiple languages on a single computer and have existing applications use different languages than used in new projects.



EFMLanguage_HEC.txt - Notepad

File Edit Format View Help

```
00000=OK
00001=Cancel
00002=Apply
00003=Select time series record file
00004=DSS files
00005=Text files
00006=DAT files
00007=CSV files
00008=PRN files
00009=HDF files
00010=The selected flow regimes input file called
00011=does not exist
00012=Use edit menu to rename
00013=New
00014=Ref
00015=Active
00016=Identifier
00017=Filename
00018=Part A
00019=Part B
00020=Part C
00021=Part E
00022=Part F
00023=Starting
00024=Ending
```

EFMPlotterLanguage_HEC.txt - Notepad

File Edit Format View Help

```
00000=OK
00001=Cancel
00002=Yes
00003=No
00004=Error
00005=Warning
00006=Style
00007=Label
00008=Flow Regimes:
00009=Relationships:
00010=X-Axis
00011=Y-Axis
00012=to
00013=Mark individual years
00014=Year Range:
00015=Individual year(s) (yyyy):
00016=Fill In
00017=Fill Out
00018=Update Existing
00019=Add Custom Plot
00020=Custom Plots
00021=WY
00022=View results for\:
00023=Fill In
00024=Fill Out
```

Figure 75. Language files for HEC-EFM (left) and HEC-EFM Plotter (right). Language files contain label integers and the corresponding label text.

7.2 Creating and Managing Languages

Languages can be added, updated, and removed. New languages will appear alphabetically in the languages list below the default language "English (HEC)". Language names must be unique.

Selecting the *"Add Language…"* menu option opens an interface where the parts and type of language are specified (Figure 76a, HEC-EFM; Figure 76b, HEC-EFM Plotter). Changing the language parts or type of an existing language is done through the *"Update Language…"* interface. Obsolete languages may be deleted via the *"Remove Language…"* interface. The *Associate with program* check box determines whether the language is a program (check box selected) or project (check box unselected) language.

Several validations are done to check whether languages are ready for use. Validations are performed when new instances of the software are initiated, when a language is added, when a language is updated, and when the language file associated with the active language is saved. When any of these events occur, a two-part validation is performed. First, the software checks whether files associated with the language are available. If the language file is not available, validation fails, a warning message is delivered, and the language is added as an invalid language (gray and unselectable). If the language file is available, the language advances to the second part of the validation (in HEC-EFM, advancement occurs even when files associated with the Quick Start Guide or Demonstration Project are not available - installed copies of those files are used in lieu of missing language specific files). The second part of validation compares the list of label integers in the language file to the corresponding list in the default language file. If all labels are present, validation is successful and the language is added to the language list (black and selectable). If one or more labels are missing, validation fails, a warning message is delivered, and the language is added as an invalid language.

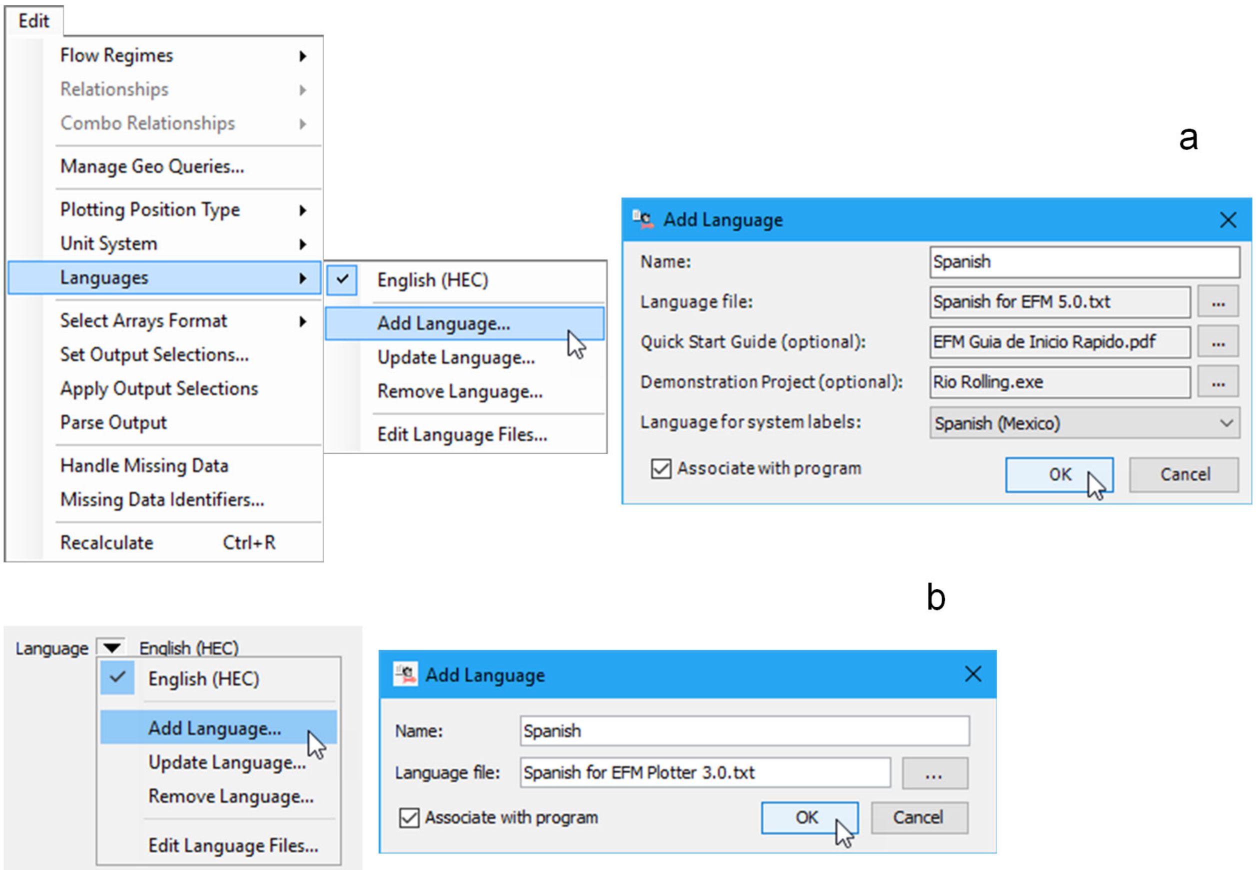


Figure 76. Adding a language involves specifying language parts, including name and language file. Image shows Spanish being added as a program language to HEC-EFM (a) and HEC-EFM Plotter (b).

Language file editors are accessible in HEC-EFM and HEC-EFM Plotter via the *"Edit Language Files…"* menu options. These editors allow users to open, create, and close language files. The *"Allow Editing"* menu option controls whether open language files can be edited (Figure 77a, HEC-EFM; Figure 77b, HEC-EFM Plotter). Editors initial open with only the default language shown. Additional language files can then be opened, viewed and edited via the *"Open Language File…"* and *"New Language File…"* right click menu options. Changes made to the language file of the active language are shown in software interfaces when that language file is saved via the editors.

Users are not required to use the editors in HEC-EFM and HEC-EFM Plotter. Language files are simple text files that are compatible with many different software. Customized labels or translations can be made in web translators, word processors, spreadsheets, and other software. New labels can be saved directly to language files or pasted into HEC-EFM and HEC-EFM Plotter editors and then saved.

The language list includes program and project languages, whether valid or invalid (Figure 78). Users may switch between valid languages whenever desired. Invalid languages must be fixed via the *"Update Language…"* menu option before use.

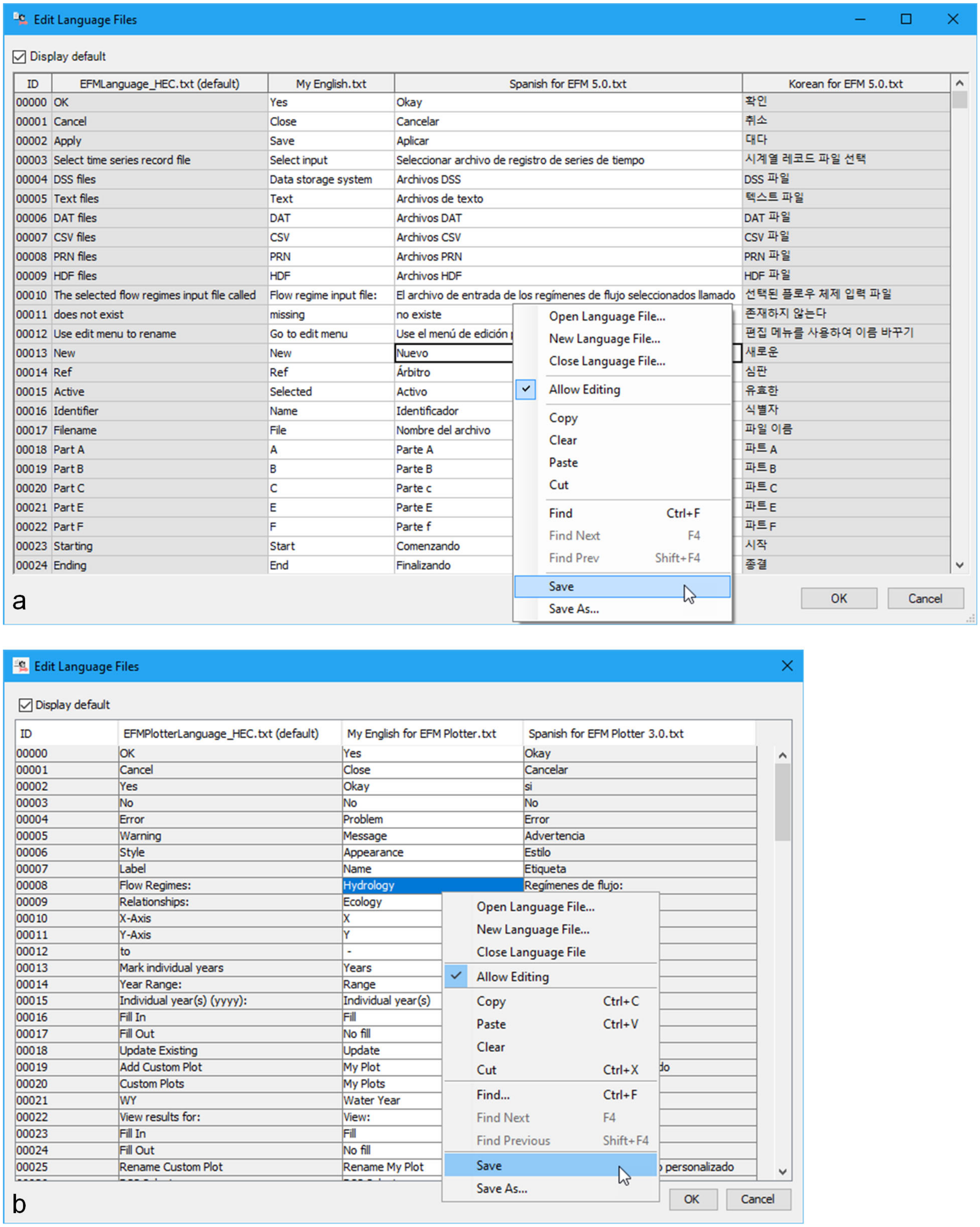


Figure 77. Language file editors in HEC-EFM (a) and HEC-EFM Plotter (b) are used to open, create new, close, edit, and save language files.

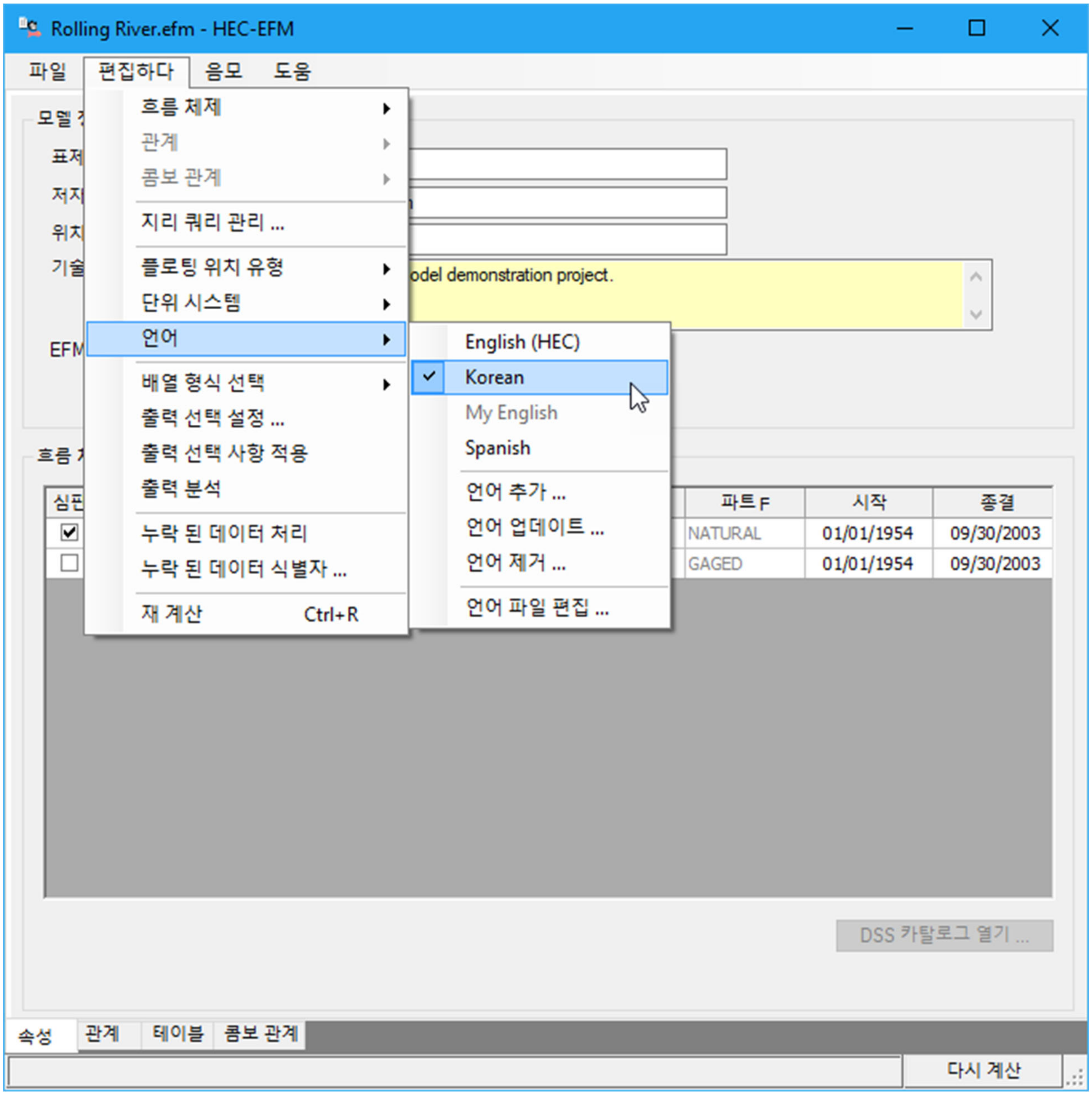


Figure 78. Language list and language selection in HEC-EFM. Image shows HEC-EFM demonstration project with Korean as the active language.

7.3 Compatibility with New Software Versions

HEC-EFM 5.0 and HEC-EFM Plotter 3.0 are the first versions of those software to allow customization and translation of user interfaces. As those software continue to advance, language files will change to accommodate revisions and new labels. In this sense, language files are version specific even though most labels will not change from version to version.

HEC-EFM and HEC-EFM Plotter store language information per version. This helps maintain compatibility with already built language resources because existing projects and software will open with the proper language resources.

To assist with forward compatibility, release notes for future versions will include a list of language integers that were added or altered. Also, language file editors add new language integers when an existing language file is opened and then saved as a new file (doing a file *Save* would work too, but doing a file *Save as…* would also maintain integrity of the original file, which is potentially a language resource for other existing projects). New interface labels are displayed with the corresponding integer values as placeholders pending inclusion of customized or translated labels.

Disconnects in languages can be caused by changing computers or relocating, renaming, or deleting files associated with languages. Repairing languages is straightforward as long as the language resources are still available.

Please note that HEC-EFM and HEC-EFM Plotter have been developed exclusively on computers that use English (United States) as the active windows language. International users have encountered problems with performance on computers that use other languages as the active windows language. It would be very difficult to thoroughly test the software for a wide selection of active windows languages.

International users are encouraged to apply HEC-EFM and HEC-EFM Plotter on computers with English (United States) as the active windows language. The language support features detailed in this chapter will allow software interface labels to be translated to the user's language of choice to assist with application.

7.4 Opportunities and Resources

HEC develops a wide range of software related to water resources, many of which work together and share databases in order to function. Language support, in terms of the coding needed to enable customization or translation of interfaces, is not consistent amongst HEC software. Also, internal testing of HEC software is done almost entirely with English (United States) as the language and dialect environment. Software like HEC-EFM and HEC-EFM Plotter, which offer language support, may require additional code enhancements to remedy problems that arise when applied in different language environments. This is the nature of software development. As a software expands, imperfections need to be resolved to achieve design performance.

With language support, knowledge of different languages is also a fundamental challenge. The developers of HEC-EFM and HEC-EFM Plotter invite partnerships to help translate these software, supporting documentation, and demonstration projects from English to other languages. These partnerships do not provide participating organizations with any exclusive advantages, whether competitive, financial, or other. No funds or source code will be exchanged. HEC will support these efforts by providing already publicly available text documents and assistance with questions pertaining to the translations. Partnering organizations perform translations and provide translated documents back to HEC for free distribution via the web, with no constraints.

This offer recognizes that user communities for these software are global and that a simple way to promote good water and ecosystem management practices in other parts of the world is to provide technologies in native languages, free of cost.

CHAPTER 8

Conclusions

This quick start guide is designed to demonstrate the process used to apply HEC-EFM and to highlight some features of the software. Everything covered in this document and all features active in the software have been tested extensively, but there is still the potential for undetected problems to surface. If a bug or suspect behavior is noted, please refer to HEC's website (www.hec.usace.army.mil/software/HEC-EFM/BugReporting/) for guidance on bug reporting.

To summarize, HEC-EFM is designed to help study teams determine ecosystem responses to changes in the flow regime of a river or connected wetland. HEC-EFM analyses involve: 1) statistical analyses of relationships between hydrology and ecology, 2) hydraulic modeling, and 3) use of GIS. Through this process, study teams define existing ecologic conditions, highlight promising restoration sites, and assess alternatives according to predicted ecosystem changes.

The spatial products of this process are commonly managed and analyzed with a tool called HEC-GeoEFM. Development of HEC-GeoEFM is a partnered effort between HEC and Environmental Systems Research Institute, Inc. (ESRI). Version 1.0 was released in June 2011. It contains a suite of features (habitat calculators, patch tools, etc.) that help modelers perform the spatial computations typically used in HEC-EFM applications.

HEC-EFM has many strengths, most notably it 1) is capable of testing change for many ecological relationships and management scenarios, 2) links ecology with established hydrologic, hydraulic, and GIS tools, and 3) can be applied quickly, inexpensively, and can incorporate expert knowledge. HEC-EFM is a generic software tool in the sense that it is applicable to a wide range of riverine and wetland ecosystems, water management concerns, and restoration projects.

HEC-EFM also has key limitations, including: 1) uses only daily data, 2) no explicit tracking of inter-year dynamics, and 3) outputs are often proxies or indicators for more tangible ecological attributes such as species population levels and ecosystem services.

New features are being added to HEC-EFM, HEC-EFM Plotter, and HEC-GeoEFM that advance their collective ability to analyze flow regimes and to map and assess habitats. Additionally, long-term development will enable HEC-EFM to simulate ecosystems in time and space and to animate results. This spatial and temporal linking promises to address the limitations noted above and is being implemented in parallel to the software's current capabilities.

This scalability, where applications of these software can be statistical analyses of flow regimes or also map habitat or simulate population dynamics, allows modeling to be customized per the needs of different projects and offers opportunities to engage study teams and stakeholders by producing results at each level of application.

HEC-EFM and HEC-GeoEFM are certified for national use by Headquarters of the U.S. Army Corps of Engineers as recommended by the Corps' Ecosystem Center of Expertise. Model certification is a corporate determination that a model is a technically, theoretically, and functionally sound and can be applied during the Corps planning process for purposes consistent with the model's design and limitations. HEC-EFM has many possible applications. The most common are ecosystem restoration planning, water management decision-making, benefit and impact analyses related to water levels, and natural resources management considerations.

CHAPTER 9

Terms and Conditions for Use

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