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Hydrologic Engineering Center

HEC-EFM
Ecosystem Functions Model

Quick Start Guide

Version 4.0
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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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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), and information about application at different scales (Chapter 5). 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.

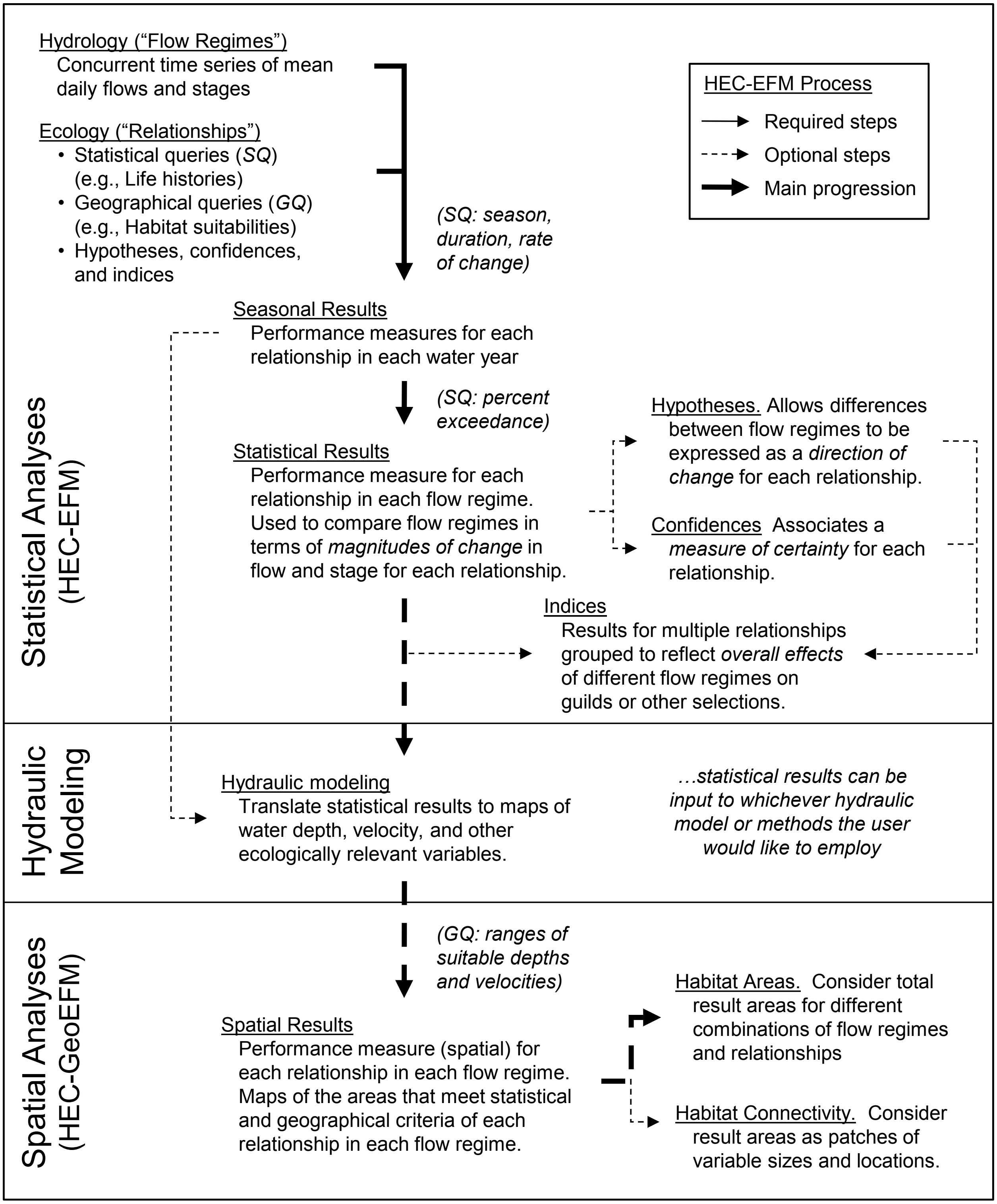


Figure 1. The process of applying HEC-EFM involves statistical analyses, river hydraulic modeling, and spatial analyses. Key inputs are hydrologic time series and ecological information such as the life history requirements of species of interest (e.g., seasons, durations, and frequencies).

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.

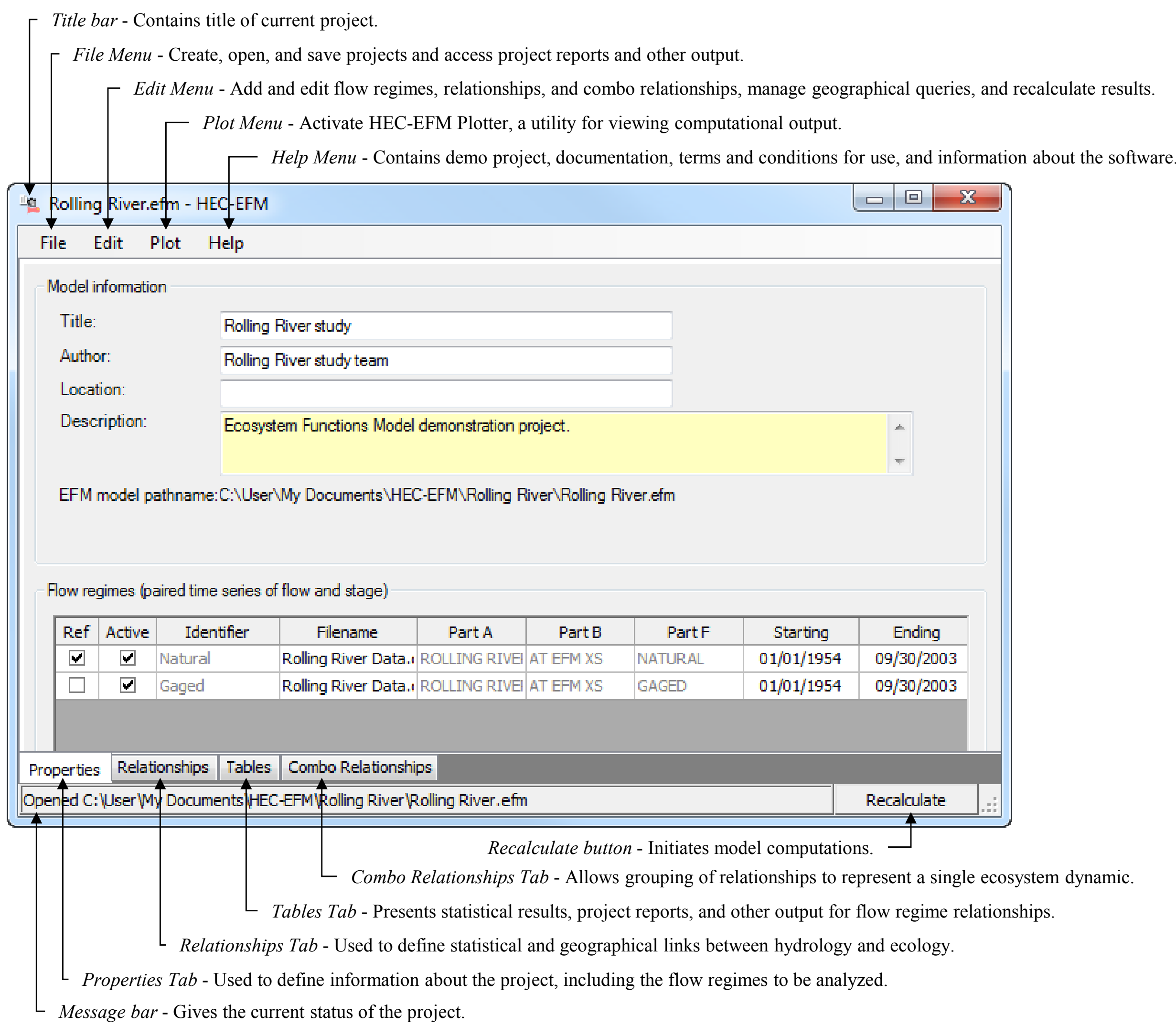


Figure 2. Key components of the main interface of HEC-EFM.

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).

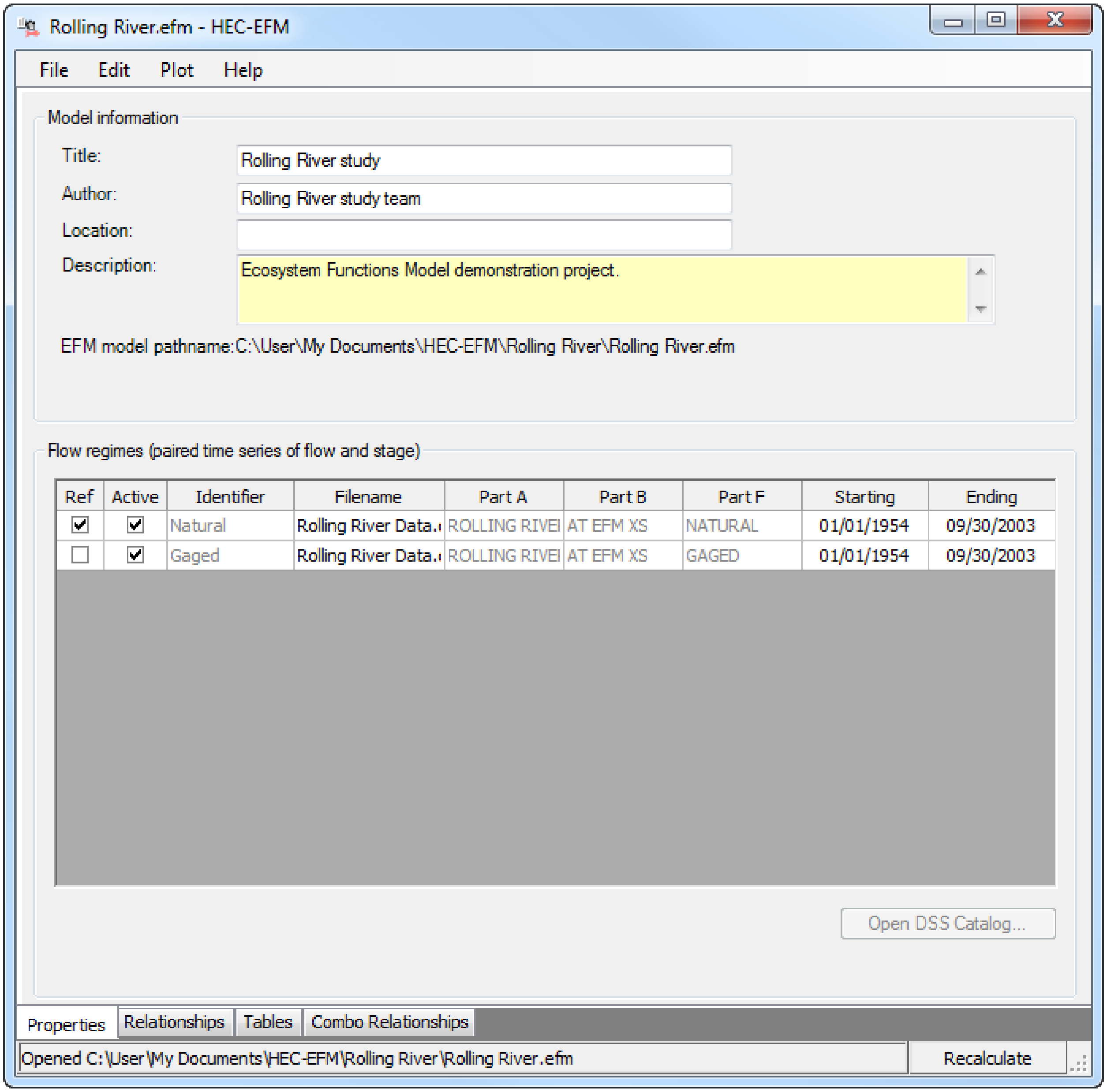


Figure 3. The *Properties Tab* of HEC-EFM is used to document information about the project and to define the flow regimes to be analyzed. Two flow regimes (Natural and Gaged) are shown.

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).

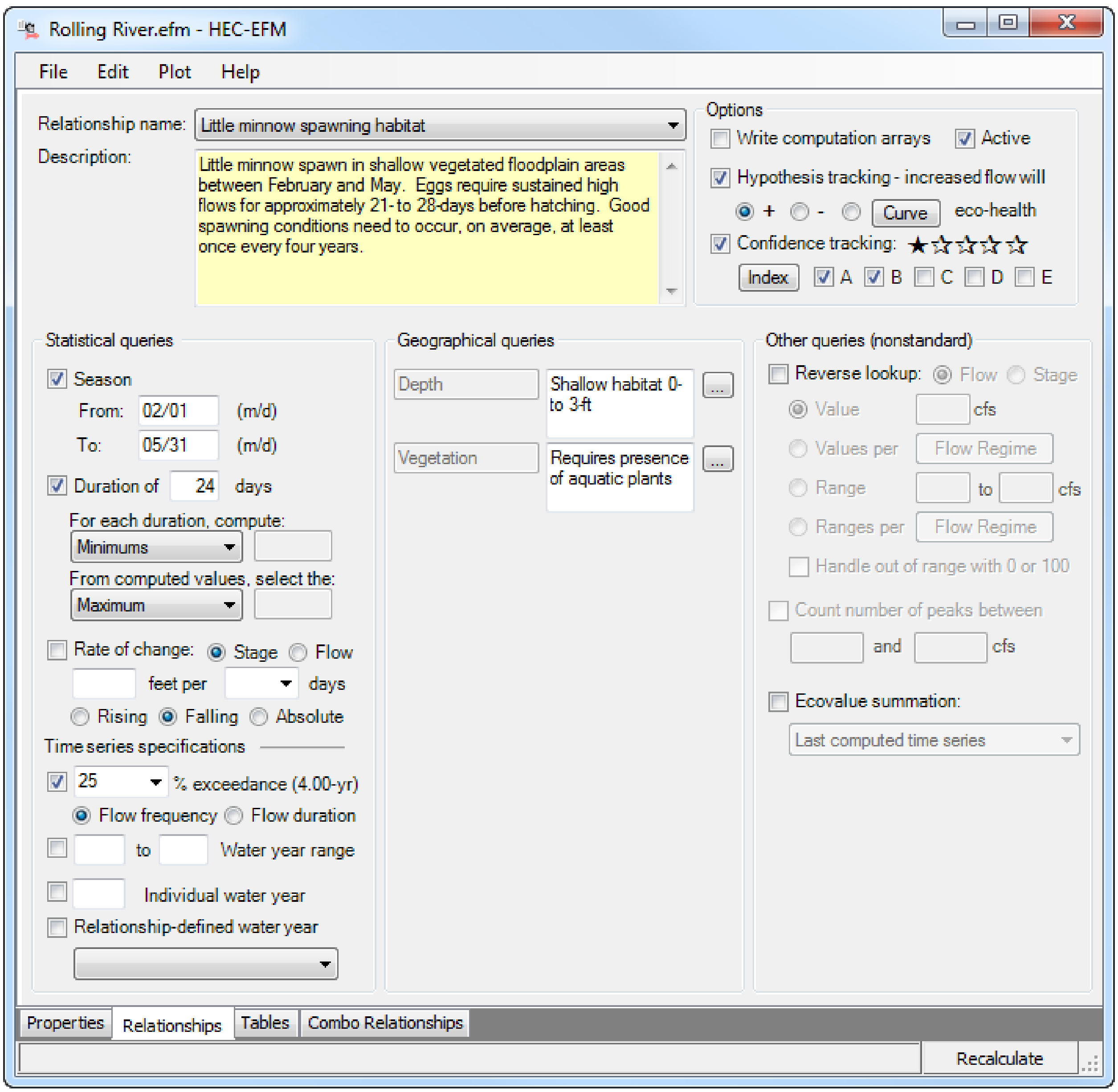


Figure 4. Using the *Relationships Tab* of HEC-EFM, modelers define individual relationships as combinations of statistical and geographical criteria.

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.

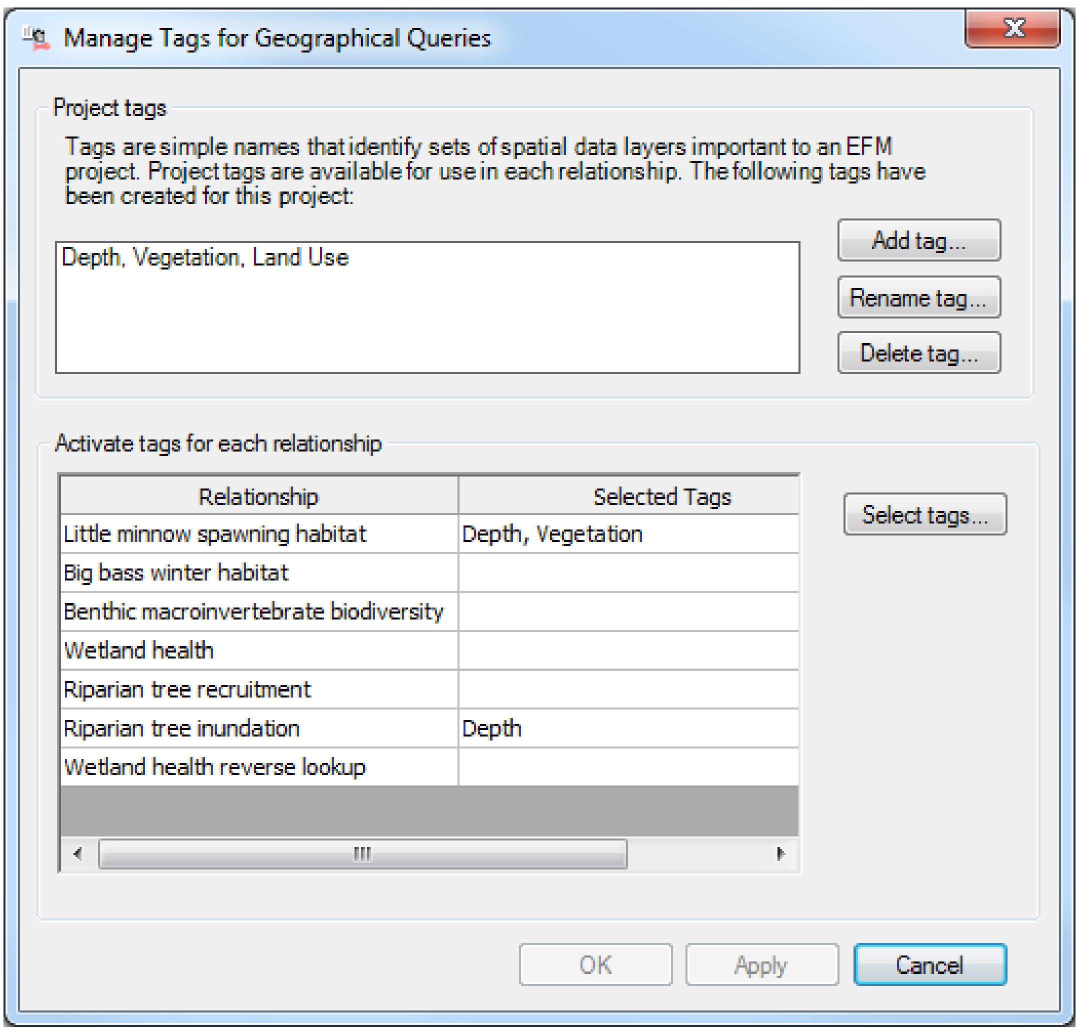


Figure 5. The *Manage Tags for Geographical Queries* interface in HEC-EFM is used for editing and creating tags, which are labels for sets of spatial data important to an HEC-EFM project.

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 section 3.6.1) 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.

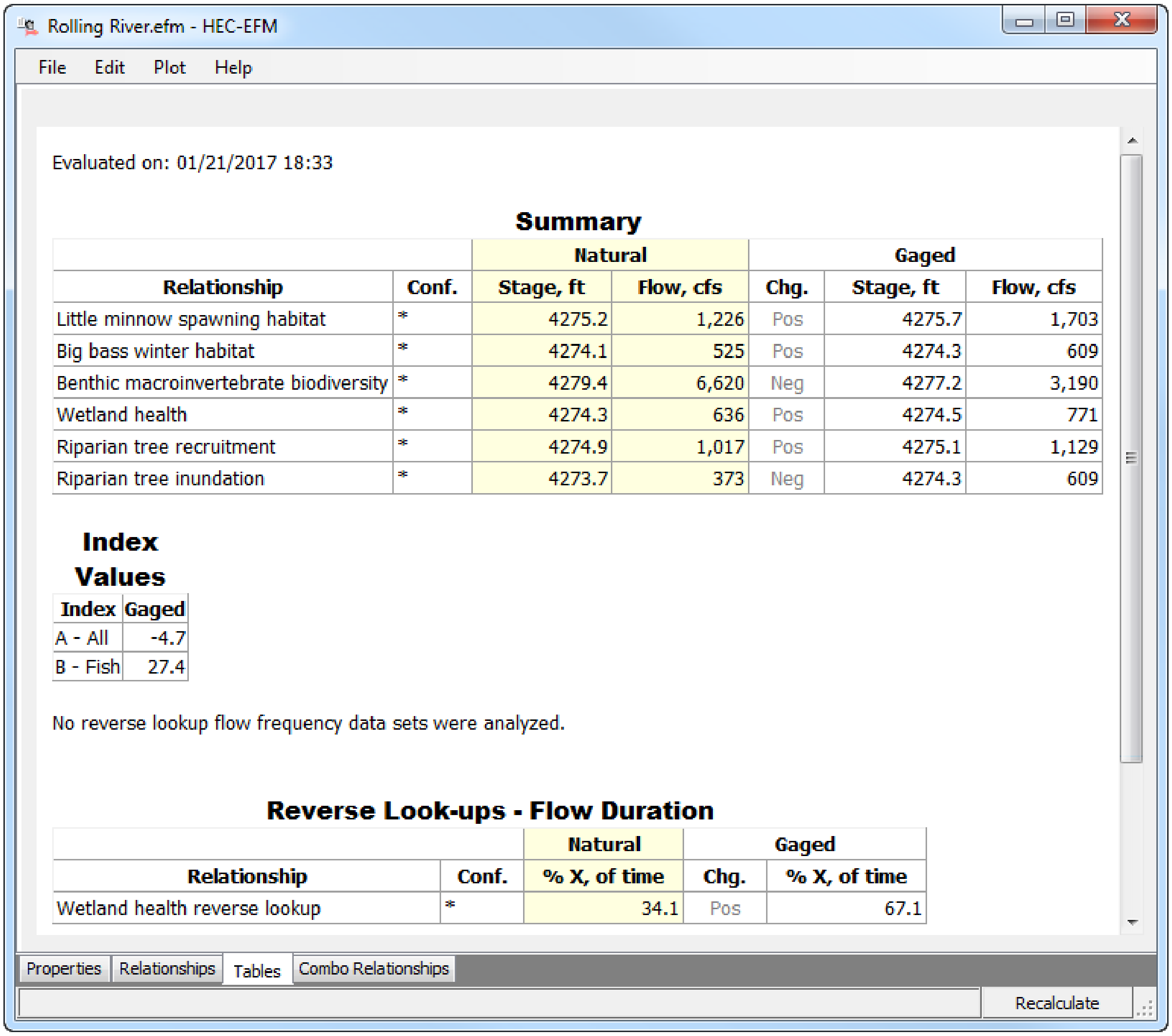


Figure 6. The *Tables Tab* of HEC-EFM is used to display statistical results for simulations (as in this figure), project reports, and computational output.

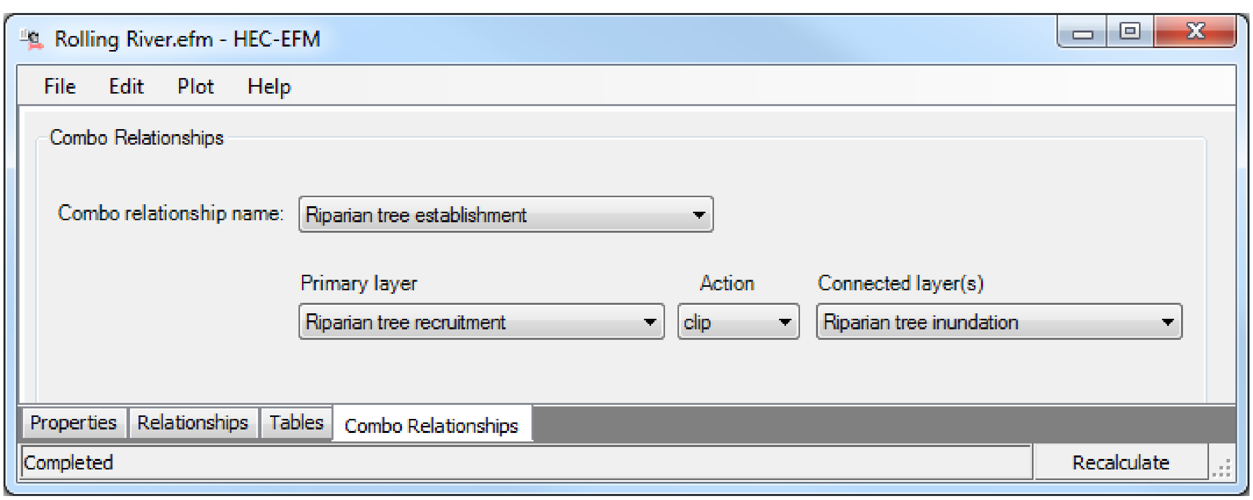


Figure 7. The *Combo Relationships Tab* of HEC-EFM allows for grouping of separate relationships to represent a single ecosystem dynamic.

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.

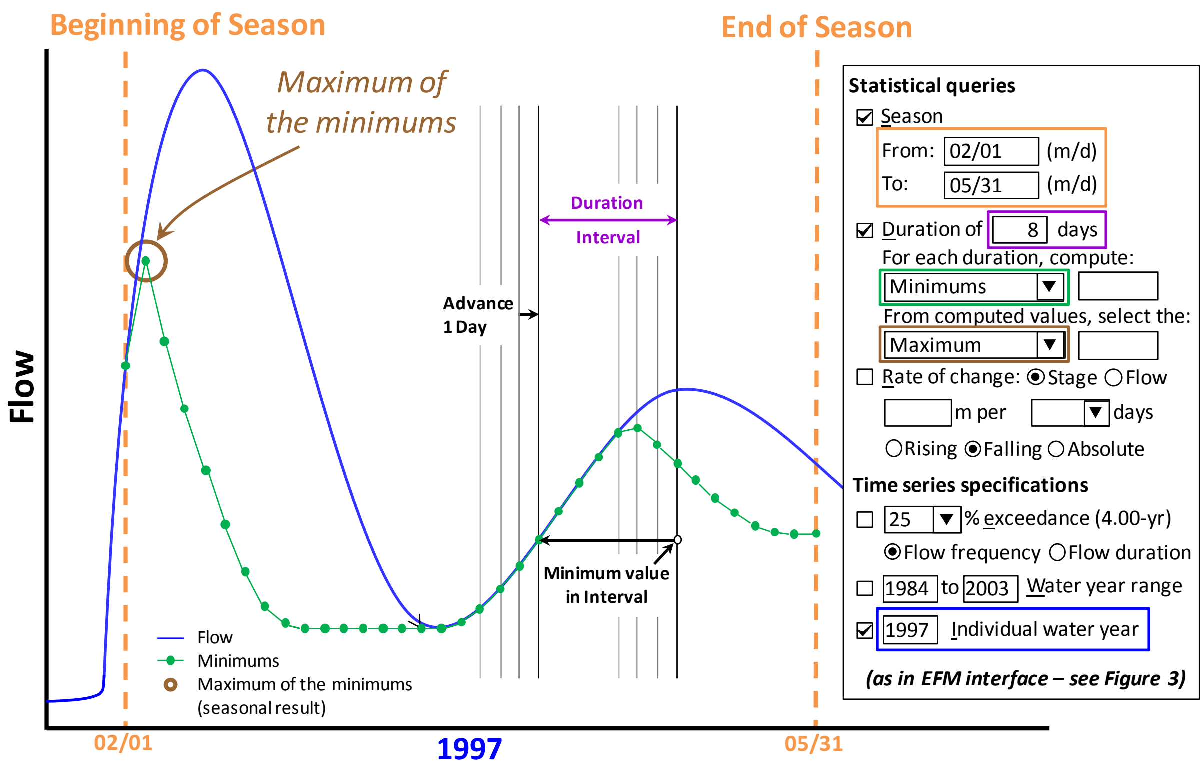


Figure 8. Sample use of the *Duration* query in HEC-EFM. Computations are shown for one water year. Statistical queries (to right of graph) are shown as in the EFM interface in Figure 4.

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.

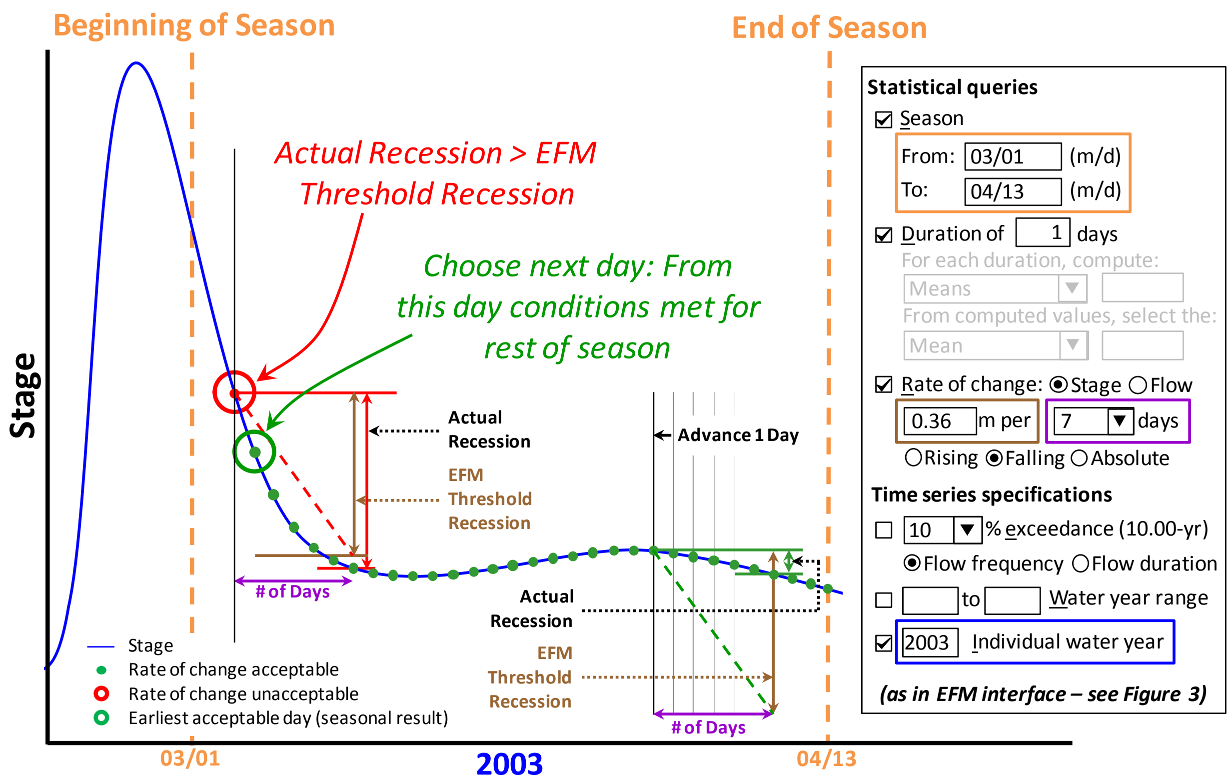


Figure 9. Sample use of the *Rate of change* query in HEC-EFM. Computations are shown for one water year. Statistical queries (to right of graph) are shown as in the EFM interface in Figure 4.

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.

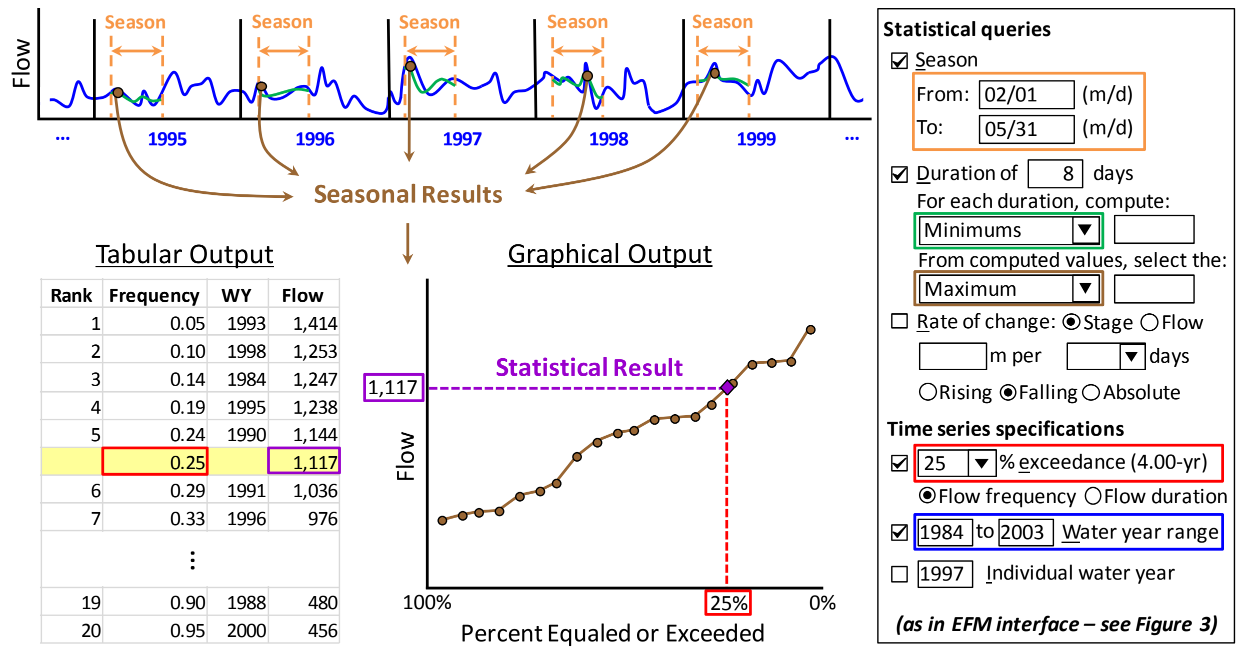
It is also important to note that when *Rate of change* is selected in the HEC-EFM interface, the dropdown controls in the *Duration* query become gray and inoperable. This behavior is meant to communicate that the two queries are largely incompatible. In fact, the only *Duration* setting relevant to *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.



Rank	Frequency	WY	Flow
1	0.05	1993	1,414
2	0.10	1998	1,253
3	0.14	1984	1,247
4	0.19	1995	1,238
5	0.24	1990	1,144
	0.25		1,117
6	0.29	1991	1,036
7	0.33	1996	976
	⋮		
19	0.90	1988	480
20	0.95	2000	456

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.

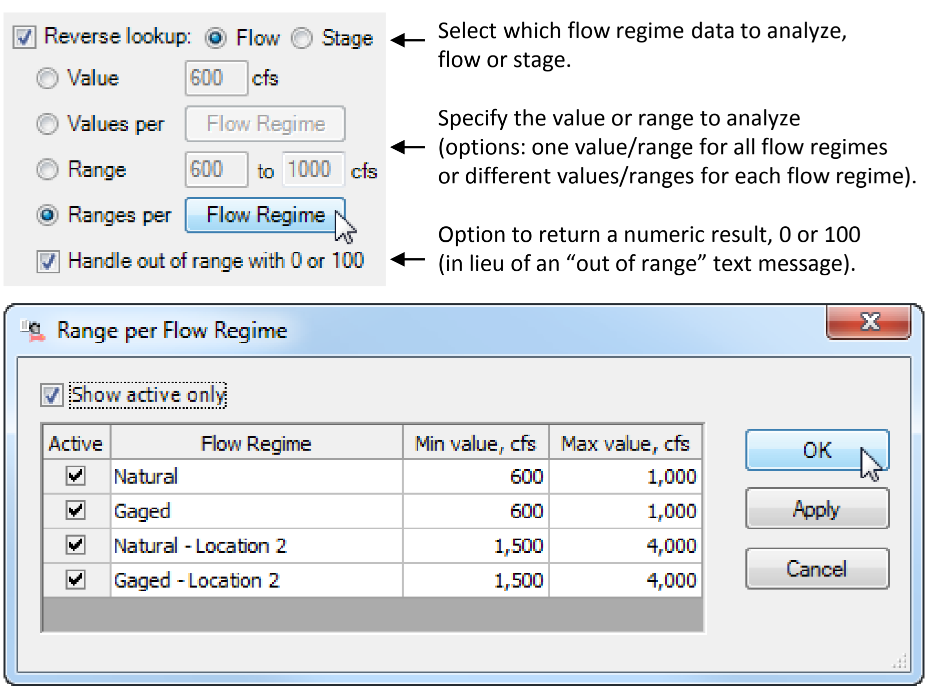


Figure 11. The *Reverse lookup* feature queries the percentage of years or time a value is equaled or exceeded or the percentage of time or years conditions are in range.

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.

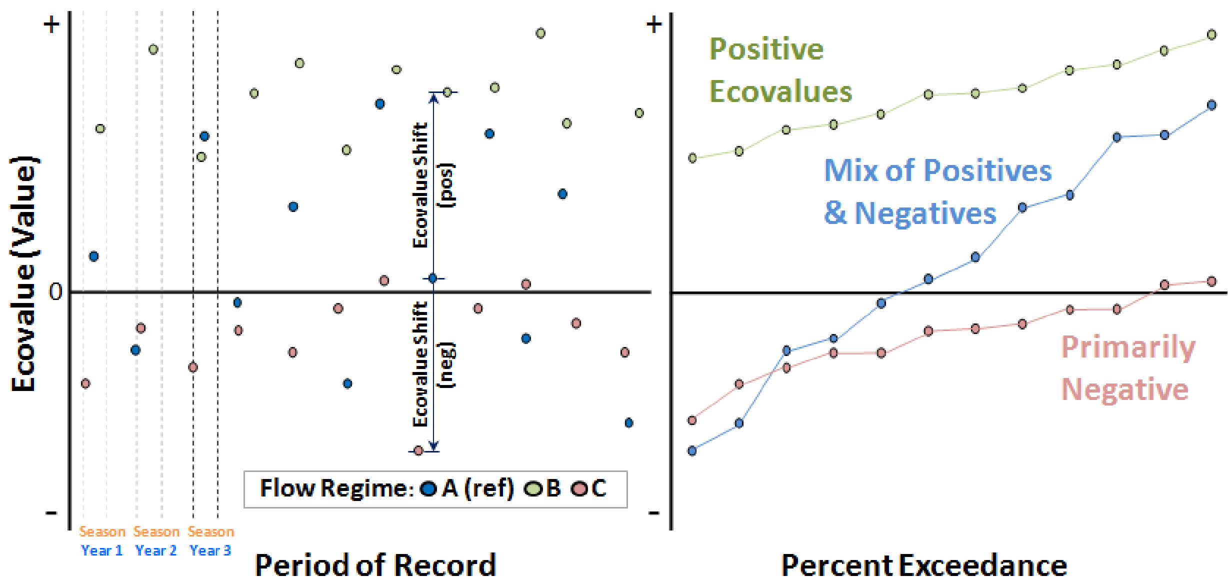


Figure 12. Seasonal ecovalues shown as a time series (left) and in accordance with percent exceedance (right). Ecovalues are measures of how successfully the criteria for a relationship are met by a flow regime. Typically, increasingly positive ecovalues correspond to increasingly beneficial habitat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

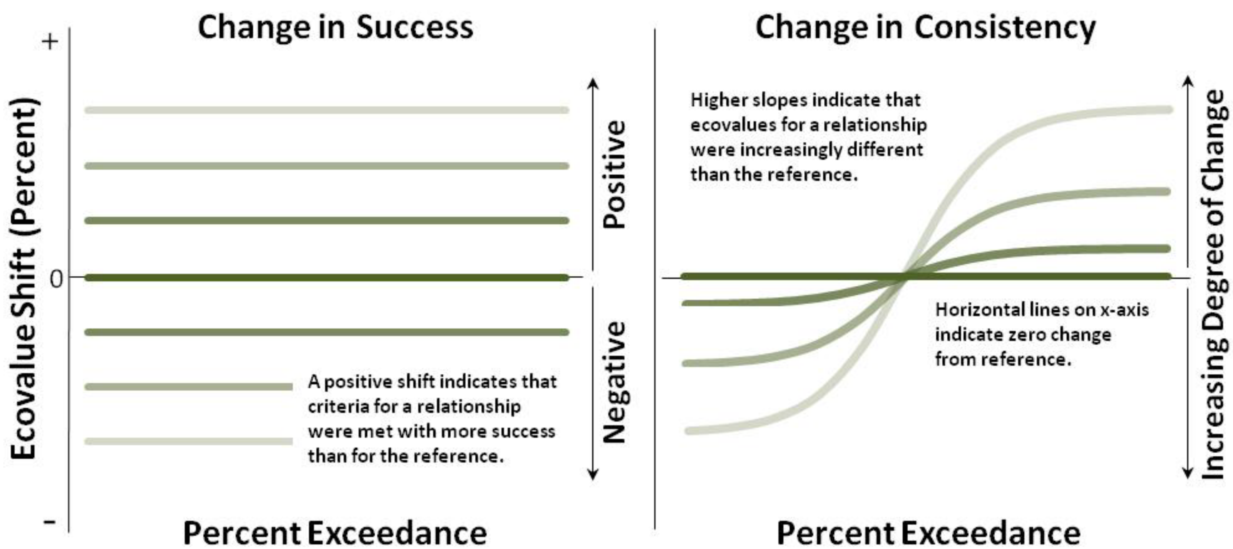


Figure 13. Ecovalue shifts provide insight regarding changes in success (left) and changes in the consistency of success (right) for a relationship. In HEC-EFM, "shifts" inherently compare an active flow regime with the reference flow regime. Ecovalue shifts are computed as the percent difference in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

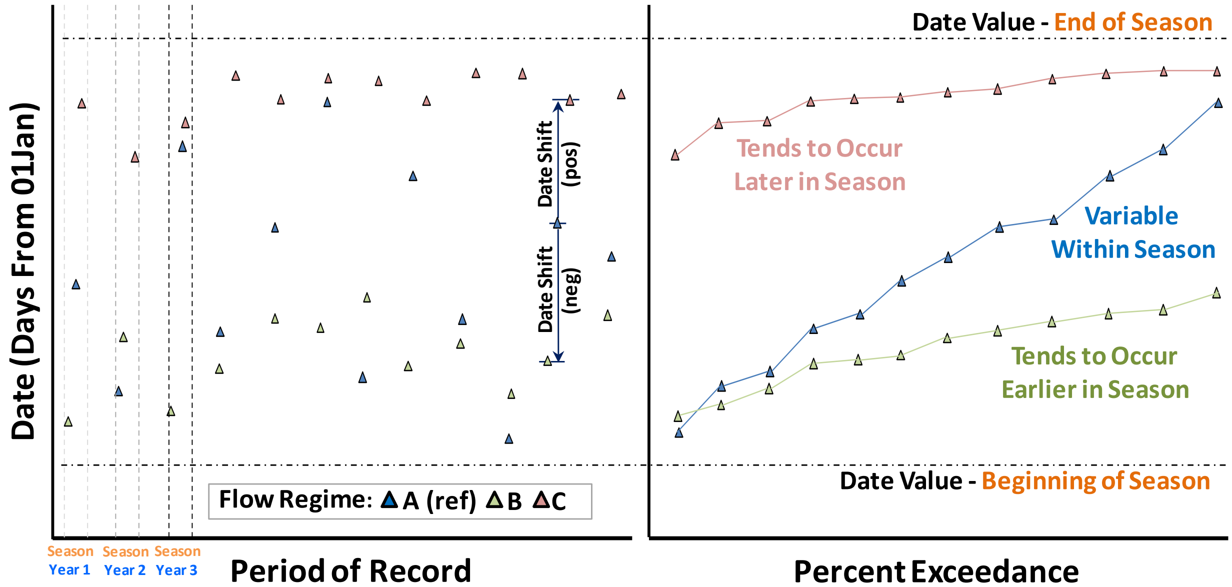


Figure 14. Seasonal date values shown as a time series (left) and in accordance with percent exceedance (right). Date values reflect when the criteria for a relationship were met within the season defined for the relationship.

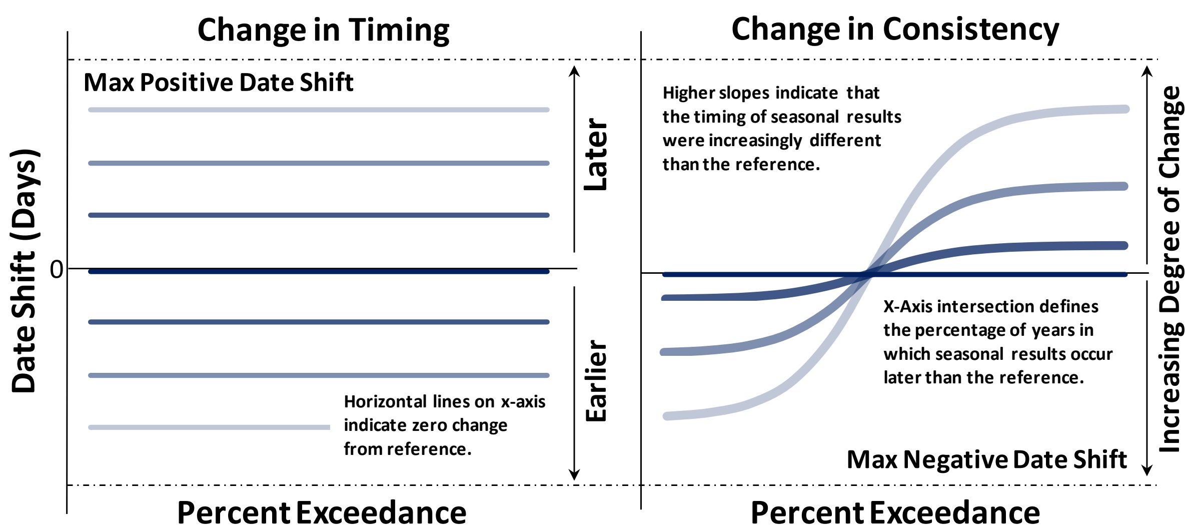


Figure 15. Date shifts provide insight regarding changes in the timing (left) and changes in the consistency of timing (right) of when criteria for a relationship were met. In HEC-EFM, "shifts" inherently compare an active flow regime with the reference flow regime. Date shifts are the time differences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

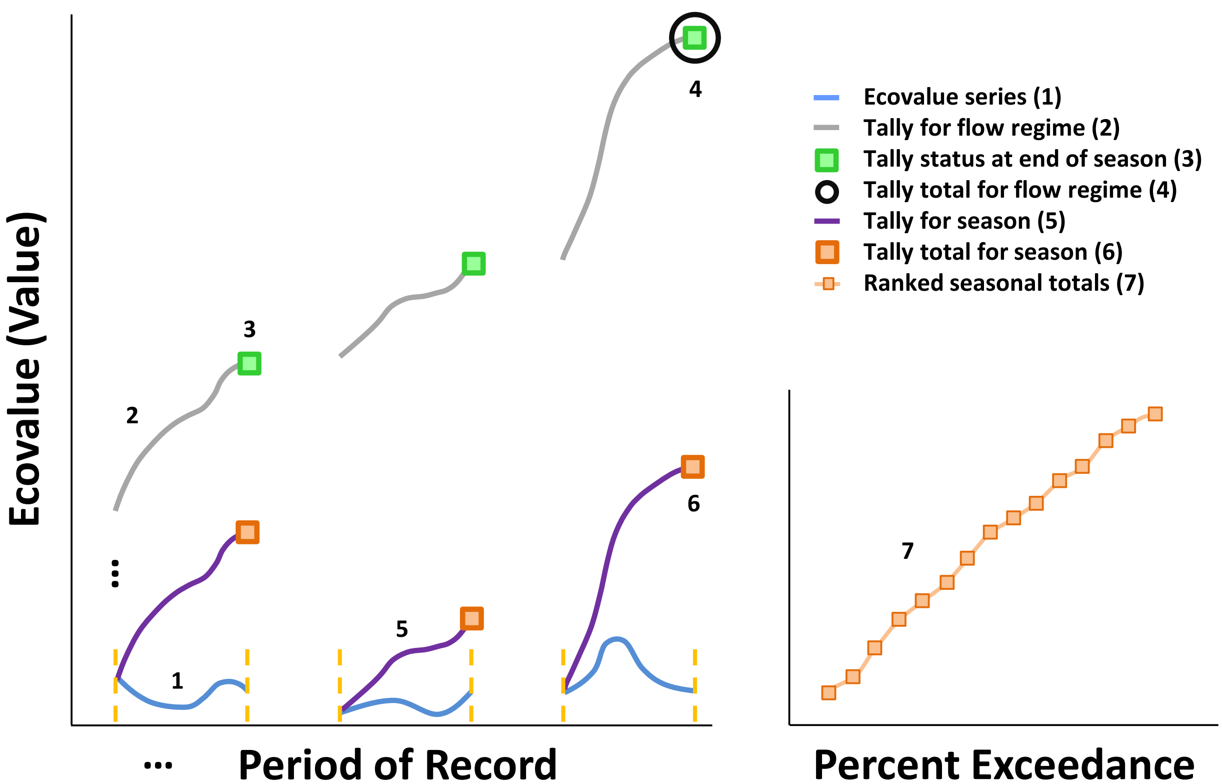


Figure 16. Ecovalue summations provide insight regarding ecovalue provided over whole seasons and flow regimes. In HEC-EFM, "shifts" inherently compare an active flow regimes with the reference flow regime. Summation shifts follow the sequence in figure, but are based on a time series of daily difference 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 4.0 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*$_i$

$$\textbf{\% Change in Eco-value}_i = \frac{(\text{Eco-value for relationship}_i - \text{Eco-value for relationship}_{reference})}{(\text{Eco-value for relationship}_{reference})}$$

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 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 17). Blanks and non-numbers are automatically identified as missing values.

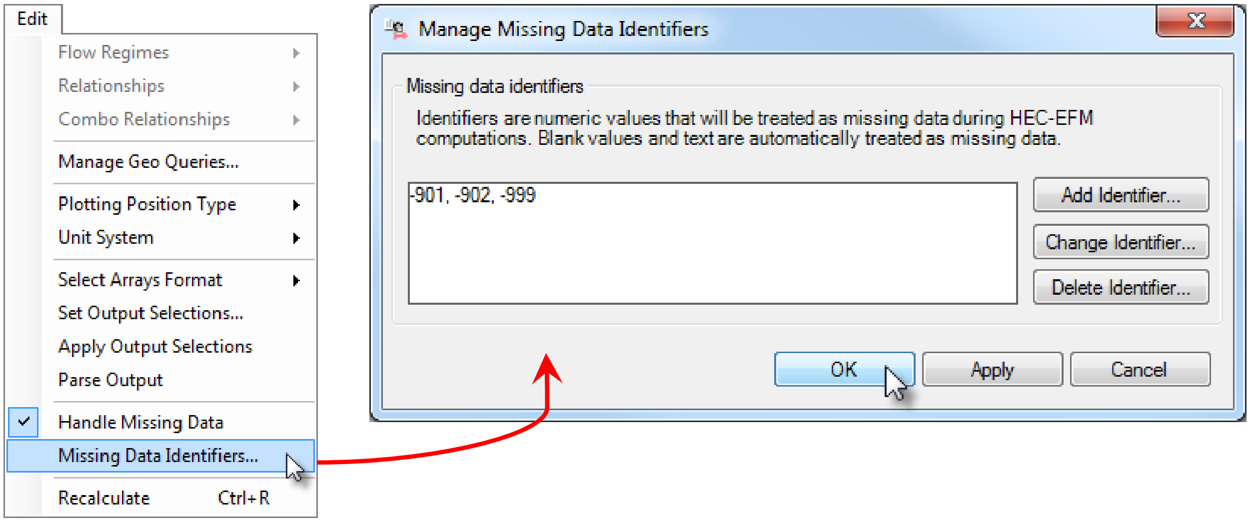


Figure 17. Use of the *Missing Data Identifiers* interface to specify the numeric values to be treated as missing data.

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 18).

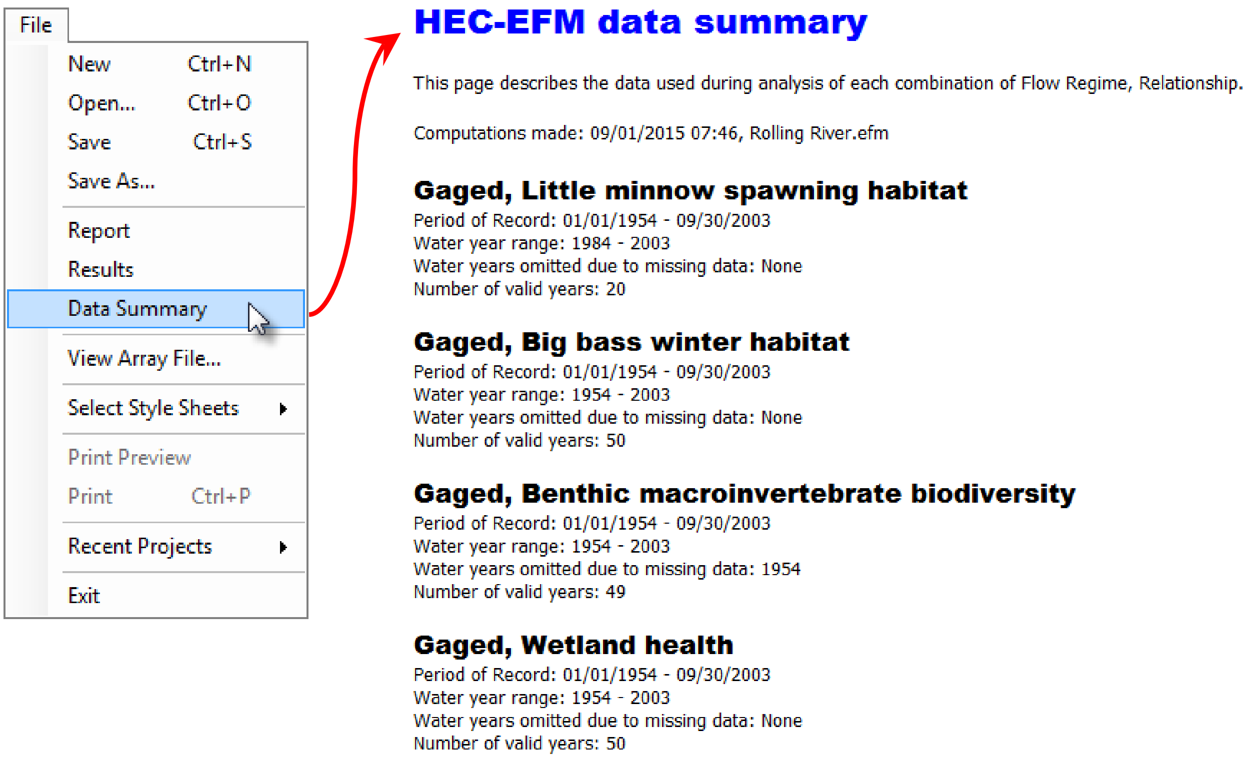


Figure 18. Excerpt from the Data Summary report, which details periods of record, water year range, missing data, and number of valid years for each combination of flow regime and relationship analyzed.

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 of 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*: 02/01 to 05/31
- *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*: 06/15 to 08/01
- *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*: 08/01 to 09/15
- *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 19).

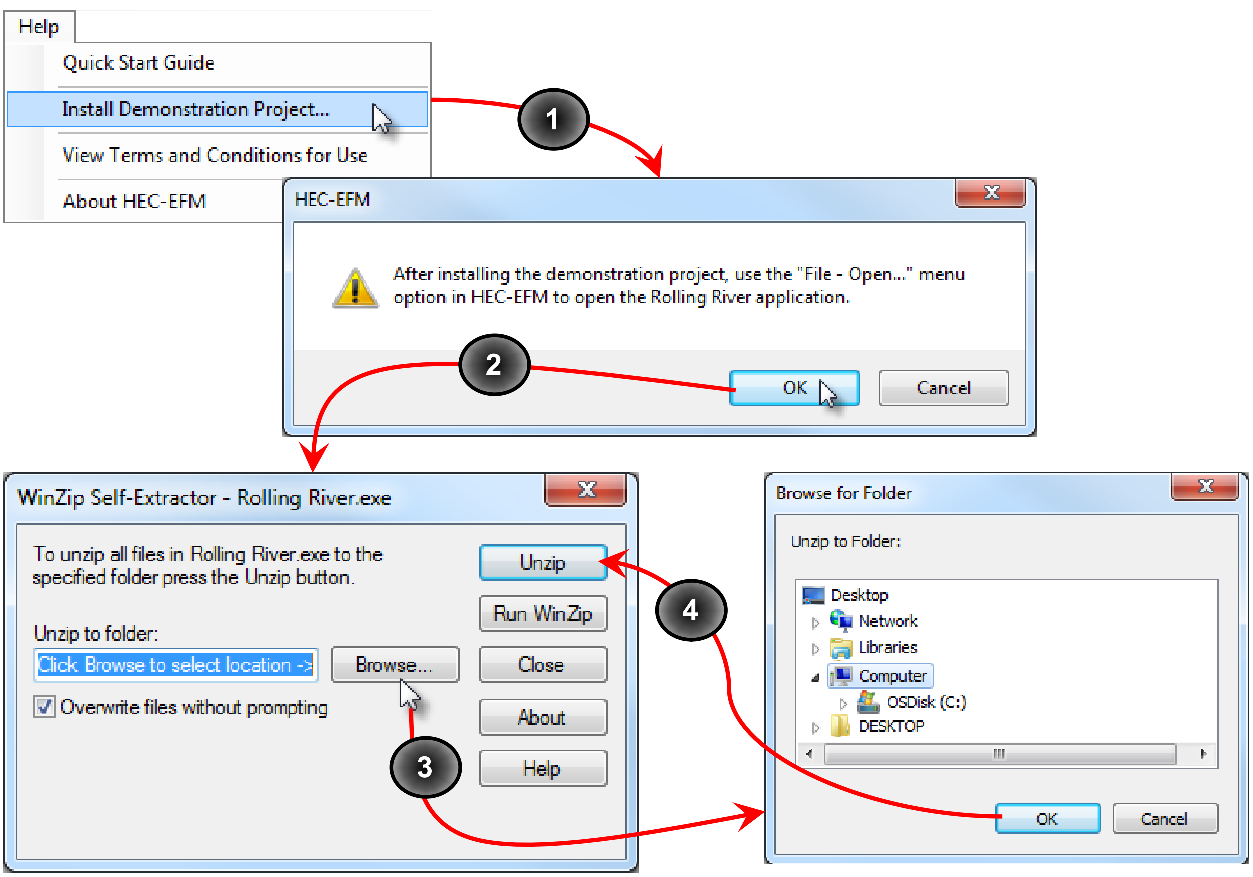


Figure 19. Setting up a working directory.

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 20).

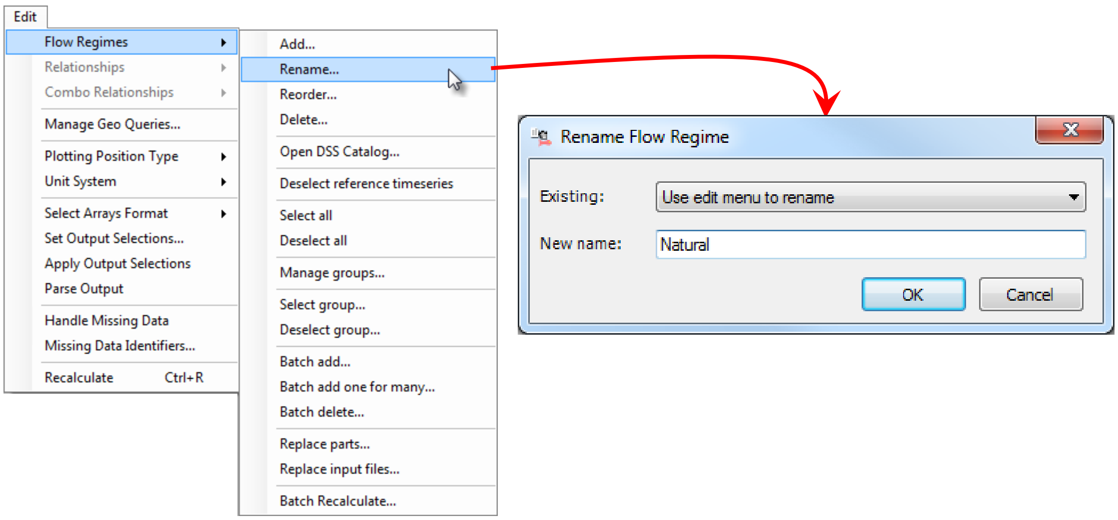


Figure 20. Naming a flow regime.

4. Add data to this flow regime by moving the cursor over the *Filename* cell and pressing the *browse* button (Figure 21). 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.*

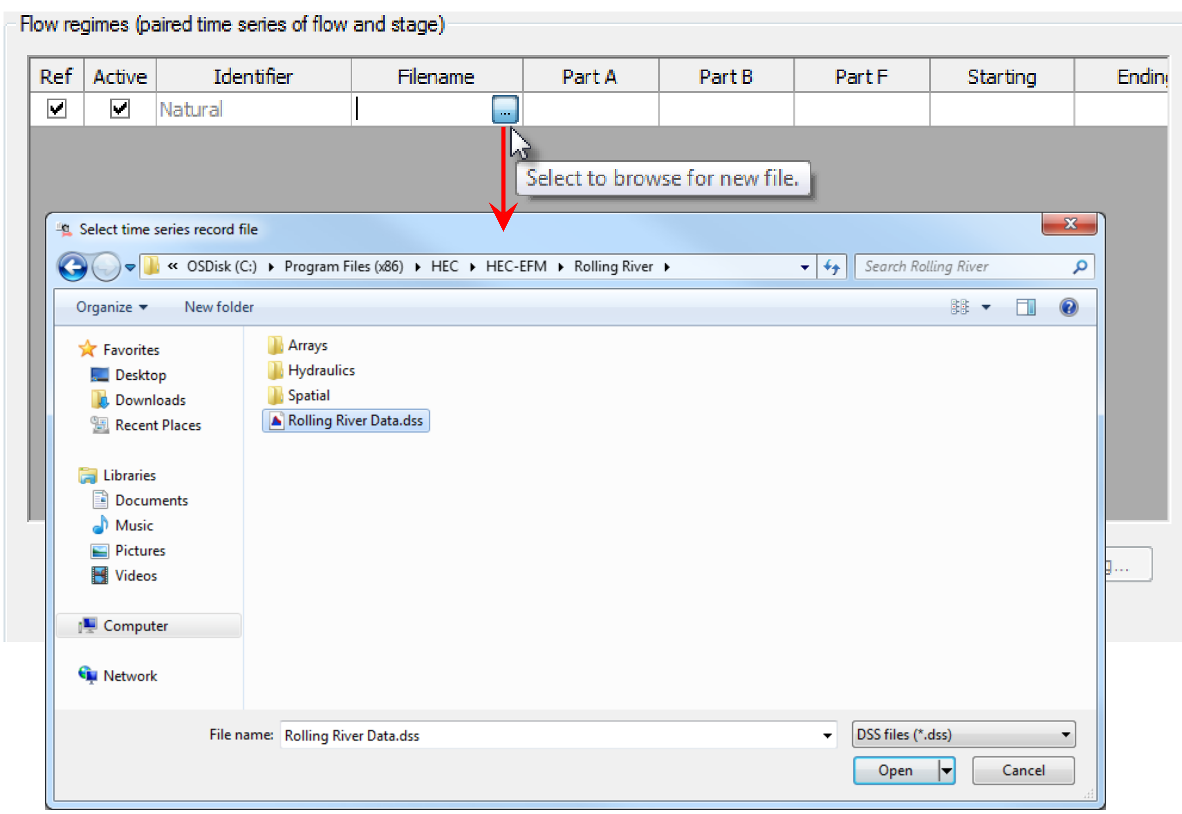


Figure 21. Adding the flow regime data file.

5. Click the *Open DSS Catalog* button to open the *HEC-DSS Catalog Browser* for that flow regime (Figure 22).

   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*.

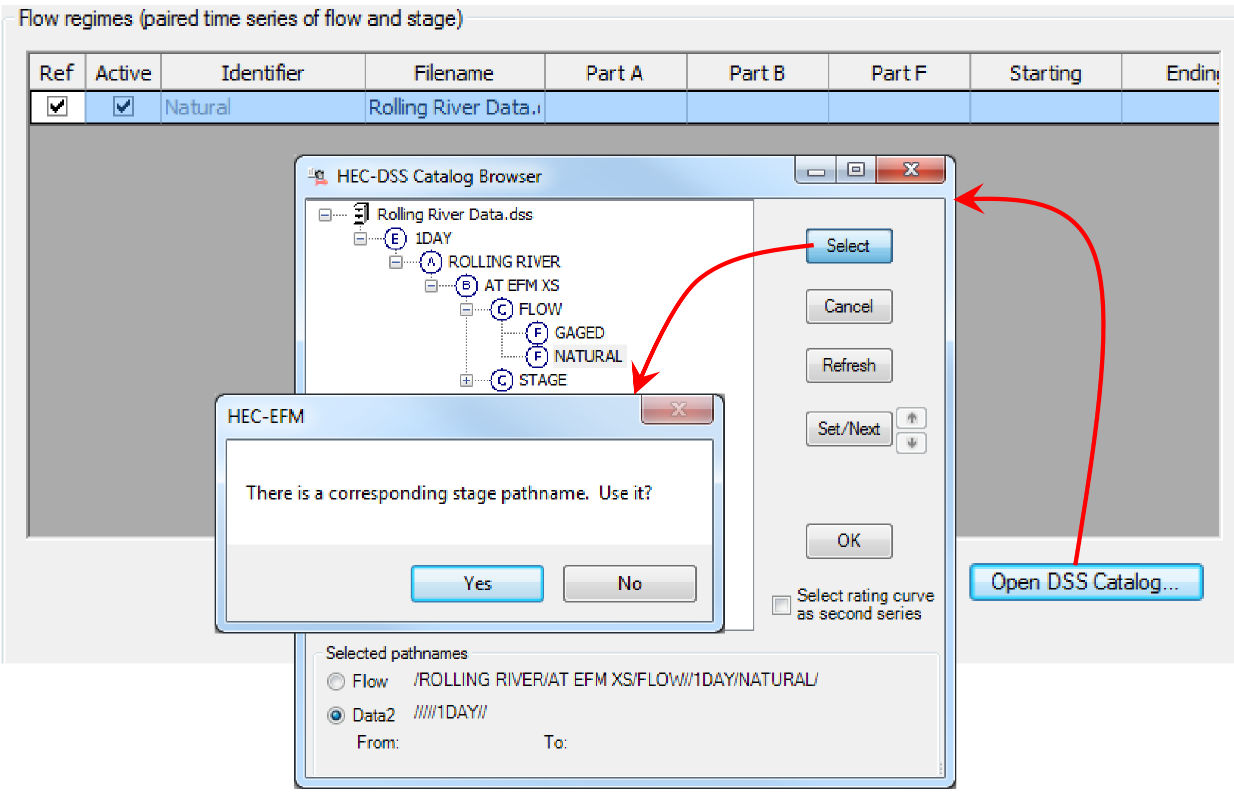


Figure 22. Selecting flow and stage time series.

6. Use the *"Edit – Flow Regimes – Add…"* menu option to open the *Add Flow Regime* interface. In the *Name* text box, enter <u>Gaged</u> and click *OK* (Figure 19). 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 <u>Gaged</u> 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 <u>Natural</u> 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 23). In this case, a check mark is already in the box because <u>Natural</u> was the first flow regime entered. Only active flow regimes are considered during calculations.

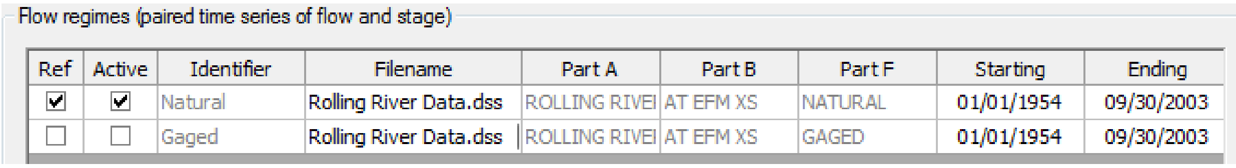


Figure 23. Reference and active flow regimes.

8. The *Properties Tab* should now look like Figure 24. 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.*

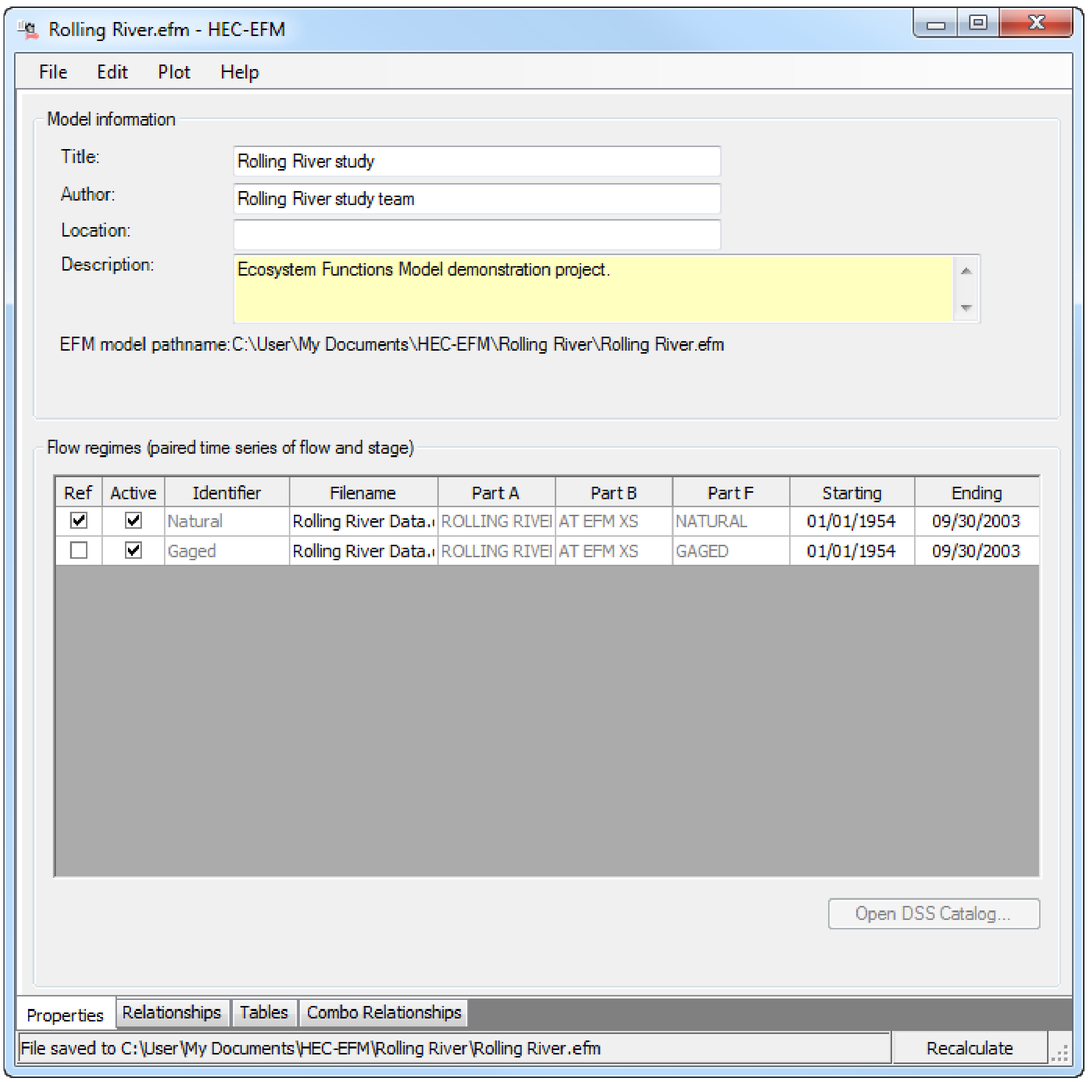


Figure 24. Completed *Properties Tab* for the demonstration project.

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 <u>Little minnow spawning habitat</u> and click *OK* (Figure 25).

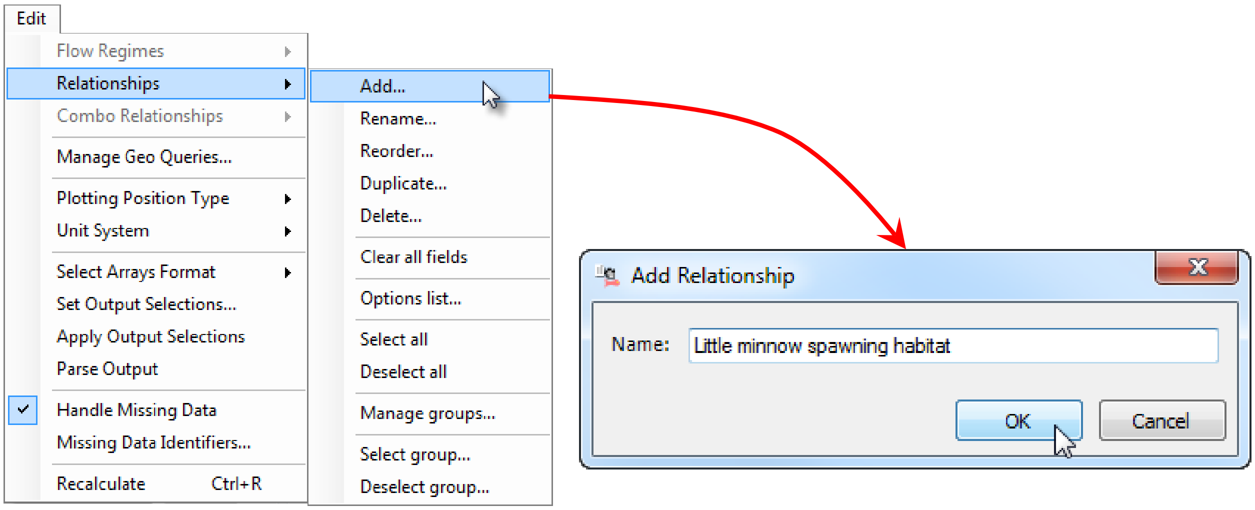


Figure 25. Adding a relationship.

2. Enter a description, statistical queries, and hypothesis for the <u>Little minnow spawning habitat</u> relationship (Figure 26).

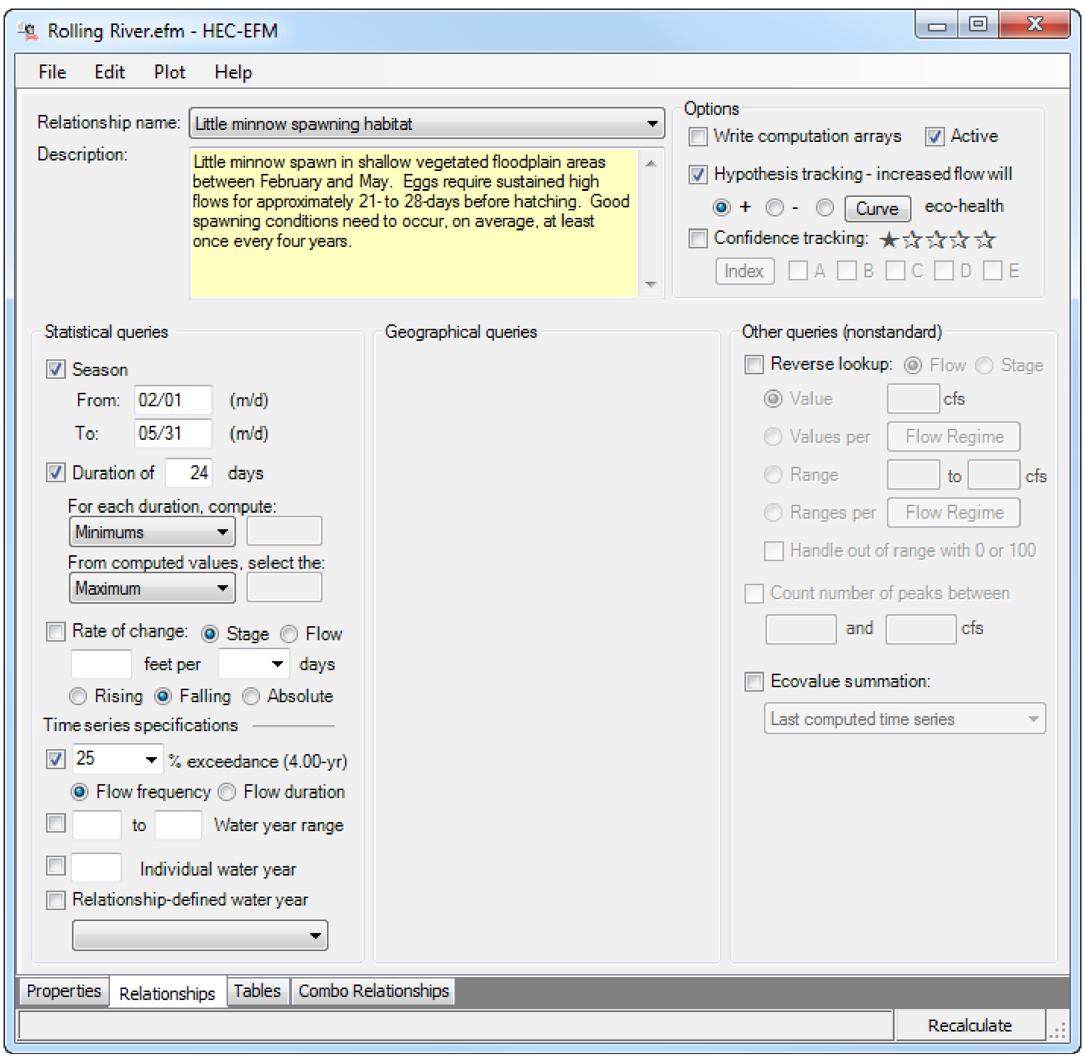


Figure 26. Statistical queries and hypothesis for the <u>Little minnow</u> relationship.

3. Click the *Recalculate* button (bottom right of the interface). Results are displayed on the *Tables Tab* (Figure 27).

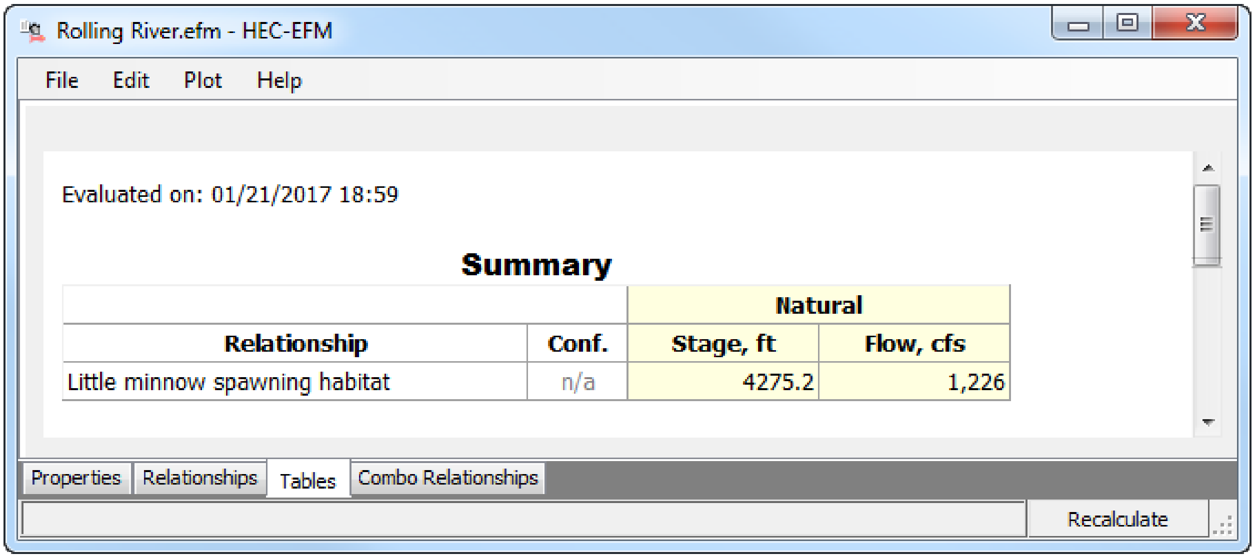


Figure 27. Statistical results for the <u>Natural</u> flow regime and the <u>Little minnow</u> relationship.

4. Next, click on the *Properties Tab*; activate the <u>Gaged</u> 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 <u>Natural</u> and <u>Gaged</u> flow regimes (Figure 28). *Note: It is important to recognize that the <u>Little minnow</u> relationship was not changed during this step.* ***Flow regimes and relationships exist independently.*** *When the second flow regime (<u>Gaged</u>) was activated, HEC-EFM computed statistical results for each flow regime using the same statistical criteria, as defined for the <u>Little minnow</u> relationship. Results are different because each flow regime has its own distinct patterns of flow and stage.*

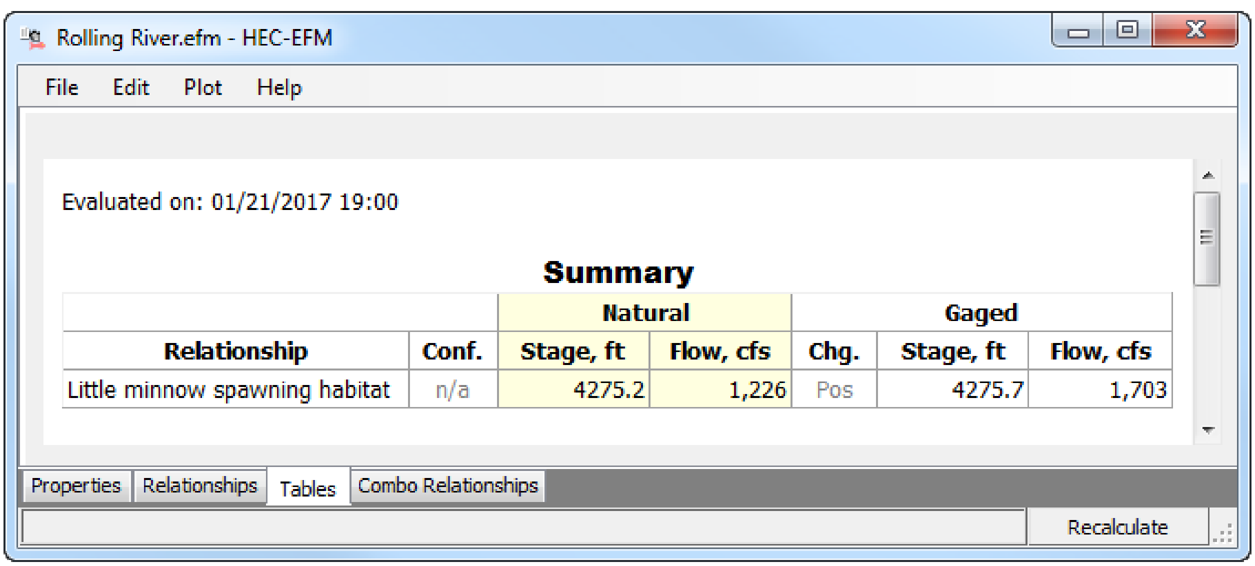


Figure 28. HEC-EFM statistical results of the <u>Little minnow spawning habitat</u> relationship using both the <u>Natural</u> and <u>Gaged</u> flow regimes.

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 29). 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 another tag named "Vegetation". 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 30).

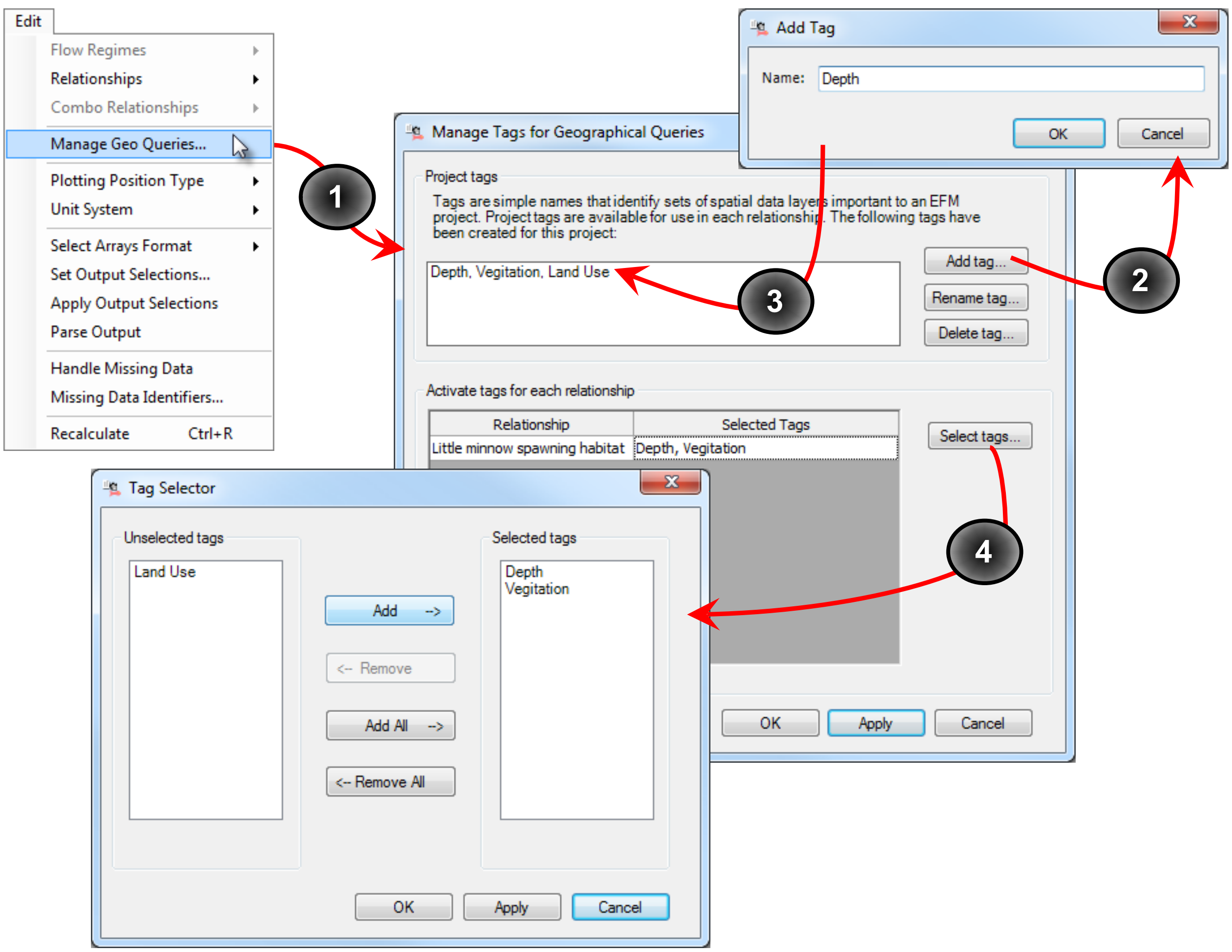


Figure 29. Adding geographical query tags.

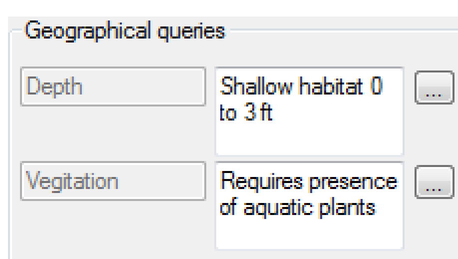
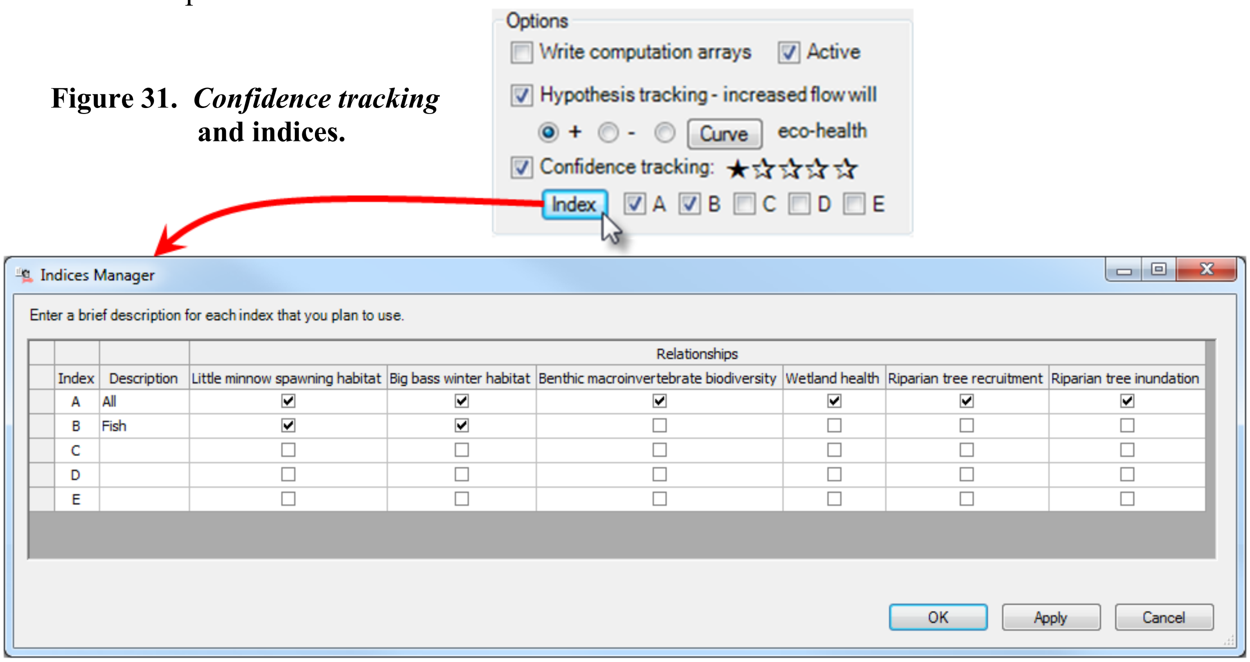


Figure 30. Geographical queries for the Little minnow spawning habitat relationship.

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 31). For now, leave all relationships at one star.

Figure 31. ***Confidence tracking* and indices.**



8. Next, create indices by clicking the *Index* button in the *Options* frame (Figure 30). 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 32). 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	*	4275.2	1,226	Pos	4275.7	1,703
Big bass winter habitat	*	4274.1	525	Pos	4274.3	609
Benthic macroinvertebrate biodiversity	*	4279.4	6,620	Neg	4277.2	3,190
Wetland health	*	4274.3	636	Pos	4274.5	771
Riparian tree recruitment	*	4274.9	1,017	Pos	4275.1	1,129
Riparian tree inundation	*	4273.7	373	Neg	4274.3	609

Figure 32. 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 33). 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 33. 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 34). Leave all others at 1 star.

Figure 34. 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 35). 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 35. 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 36).

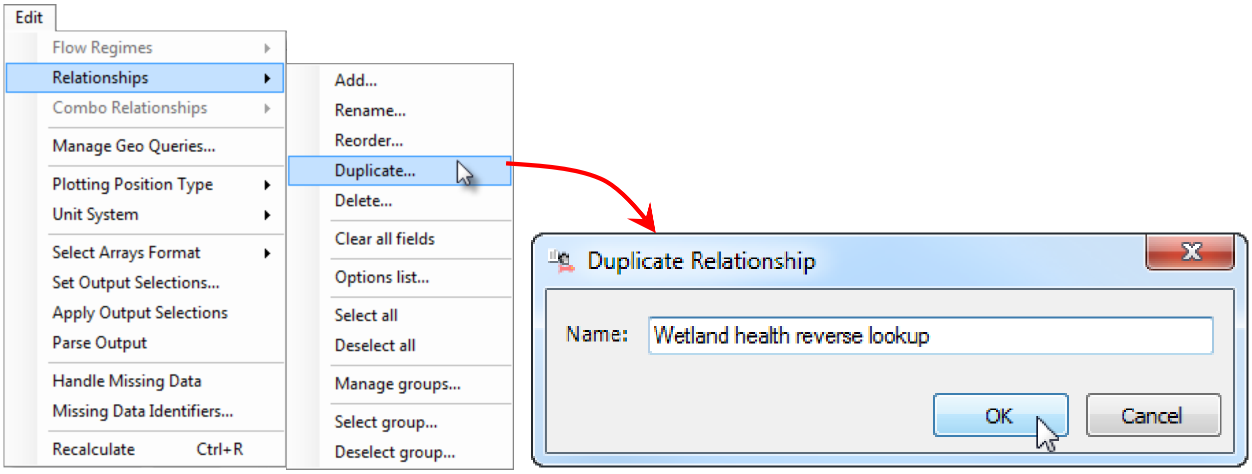


Figure 36. Duplicating a relationship.

Turn on the *Reverse lookup* query by checking its box in the *Other queries* frame. Enter 600 cfs in the text box (Figure 37). 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.*

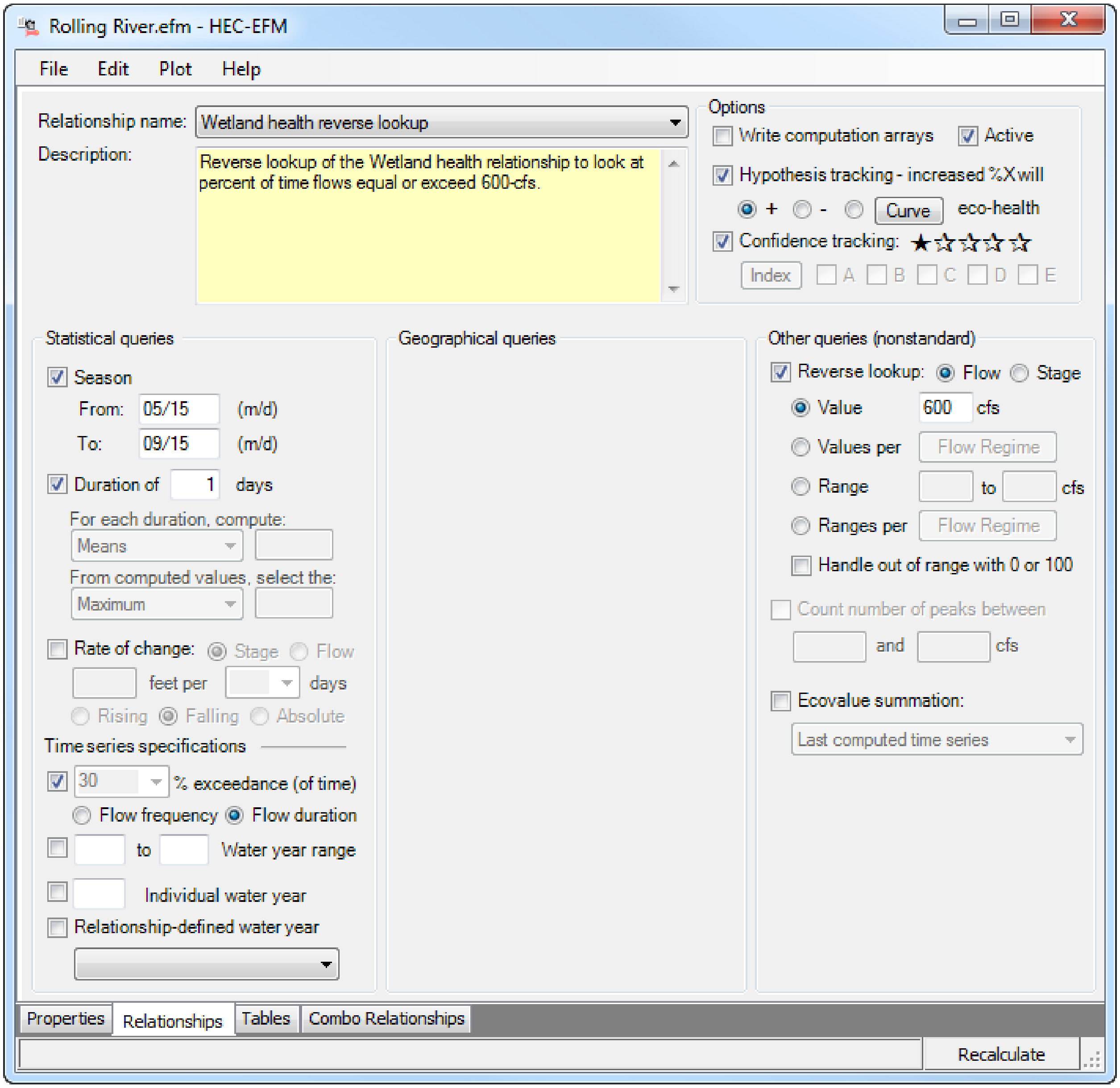


Figure 37. Reverse lookup for the Wetland health relationship in HEC-EFM.

Results for Wetland health reverse lookup show that both flow regimes were above the 30% criteria (Figure 38). 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 38. 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 39).

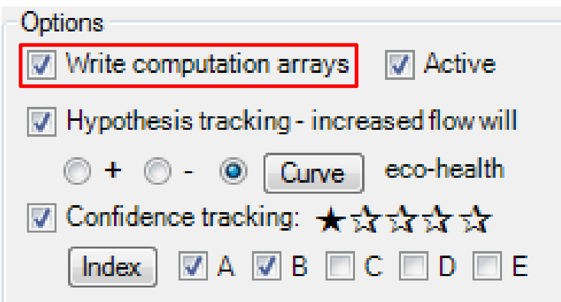


Figure 39. Checking the *Write computation arrays* box.

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 40). A folder named "Arrays" will be created in the directory of the HEC-EFM project file to store the output.

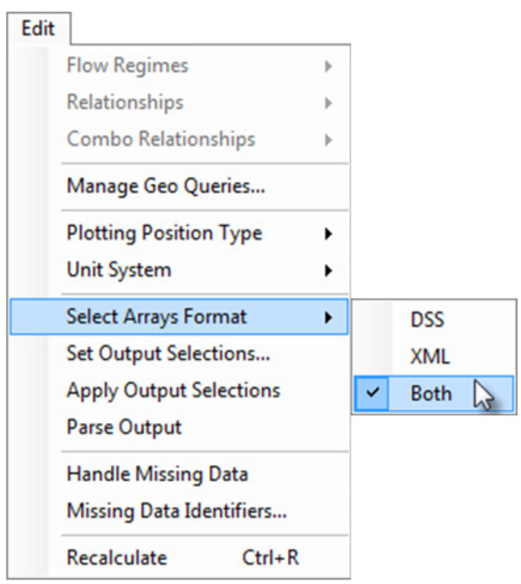


Figure 40. Output choices via the *Select Arrays Format* menu options.

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 41). Using the *"File – View Array File..."* menu option, select "Gaged_Big bass winter habitat.xml" and click *Open*.

Figure 41. 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: 9/2/2015 12:08:39 PM, Rolling River.efm

Result: Flow = 608.5 , Stage = 4,274.3, Closest water year = 1969

Eco-value = 6.1

Water years omitted due to missing data: None

Frequency analysis

Plotting position: Weibull

Rank	Frequency	WY	Flow	Stage
1	.0196	1975	868.0	4,274.652
2	.0392	1973	867.9	4,274.688
3	.0588	1984	807.6	4,274.592
4	.0784	1978	776.6	4,274.542
5	.0980	1980	763.6	4,274.522
6	.1177	1977	760.9	4,274.518
7	.1373	1976	745.4	4,274.493
8	.1569	1983	742.4	4,274.488
9	.1765	1998	735.9	4,274.478
10	.1961	1972	705.9	4,274.430
11	.2157	1990	693.3	4,274.406
12	.2353	1964	692.1	4,274.407
13	.2549	1965	683.9	4,274.394
14	.2745	1966	675.1	4,274.380
15	.2941	1958	668.4	4,274.370
16	.3137	1991	666.5	4,274.365
17	.3333	1954	657.3	4,274.352
18	.3529	1979	650.8	4,274.341
19	.3726	1993	650.1	4,274.333
20	.3922	1960	642.6	4,274.328
21	.4118	1974	638.6	4,274.322
22	.4314	1970	637.6	4,274.320
23	.4510	1971	632.2	4,274.312
24	.4706	1968	624.3	4,274.29[illegible]
25	.4902	1969	612.6	4,274.280
	.5000		608.5	4,274.273
26	.5098	1967	604.5	4,274.267

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 42 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 42. Catalog of HEC-EFM data output to DSS for the Big bass winter habitat relationship. Seasonal results for the Natural flow regime as well as a frequency curve of seasonal results for Natural and Gaged 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.

Initiate HEC-EFM Plotter by selecting the "*Plot – Activate HEC-EFM Plotter*" menu option. DSS output is automatically imported to *Standard Plots* for each combination of flow regime and relationship. Use the *Relationship* dropdown list in the upper left hand corner of the main interface to select the <u>Big bass winter habitat</u> relationship (Figure 43). Choose which flow regime (e.g. <u>Natural</u> or <u>Gaged</u>) to view using the *Flow Regime* dropdown list.

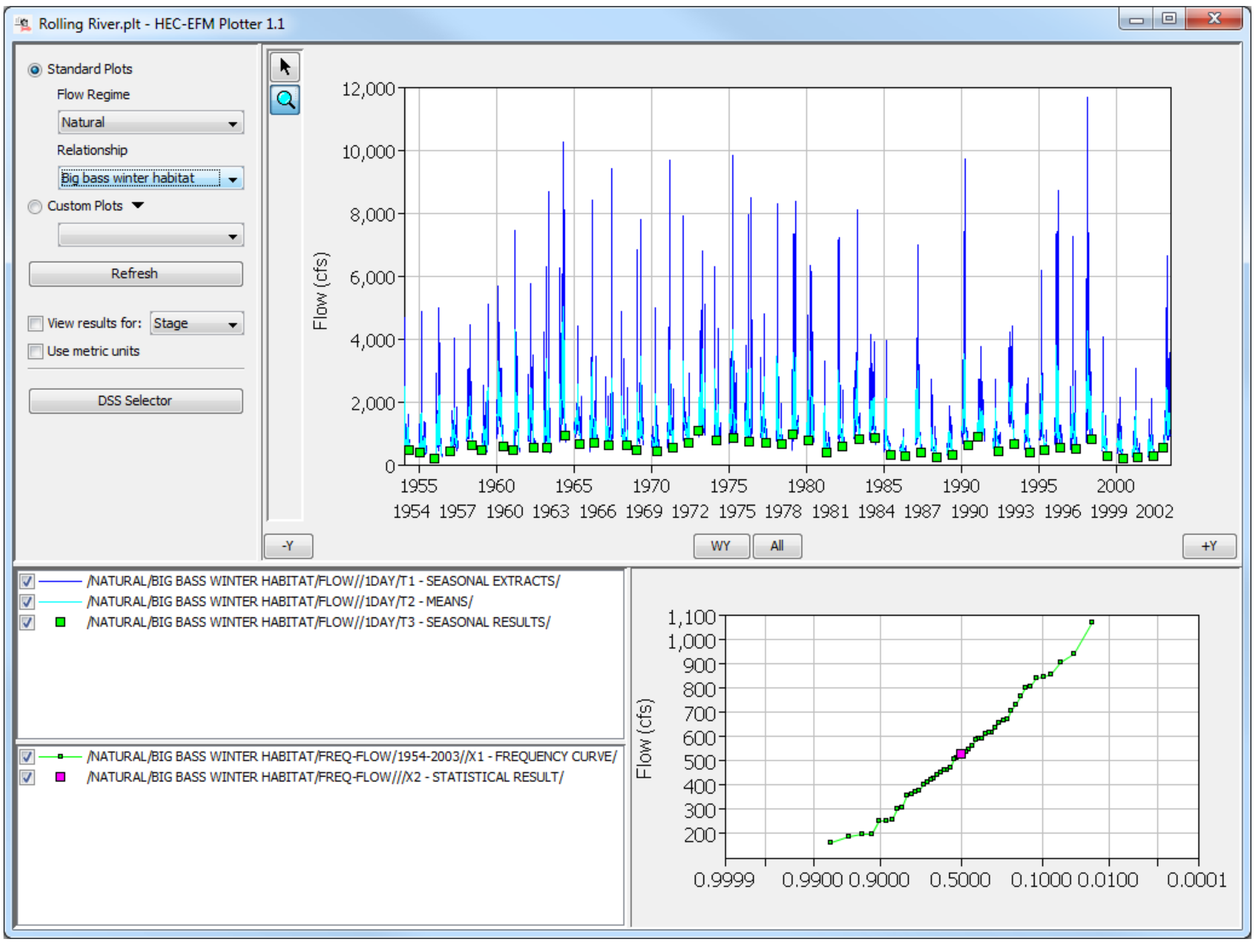


Figure 43. HEC-EFM Plotter showing results for the <u>Big bass winter habitat</u> relationship with the <u>Natural</u> flow regime.

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 44).

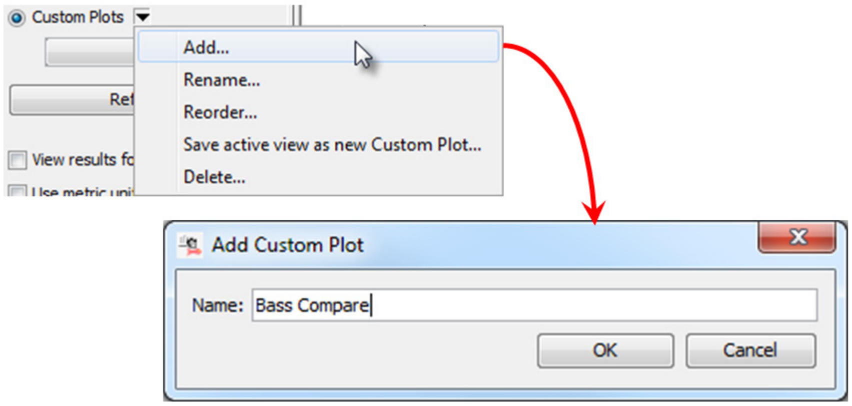


Figure 44. Adding a custom plot.

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 45) to import those data to the "Bass compare" plot (Figure 46).

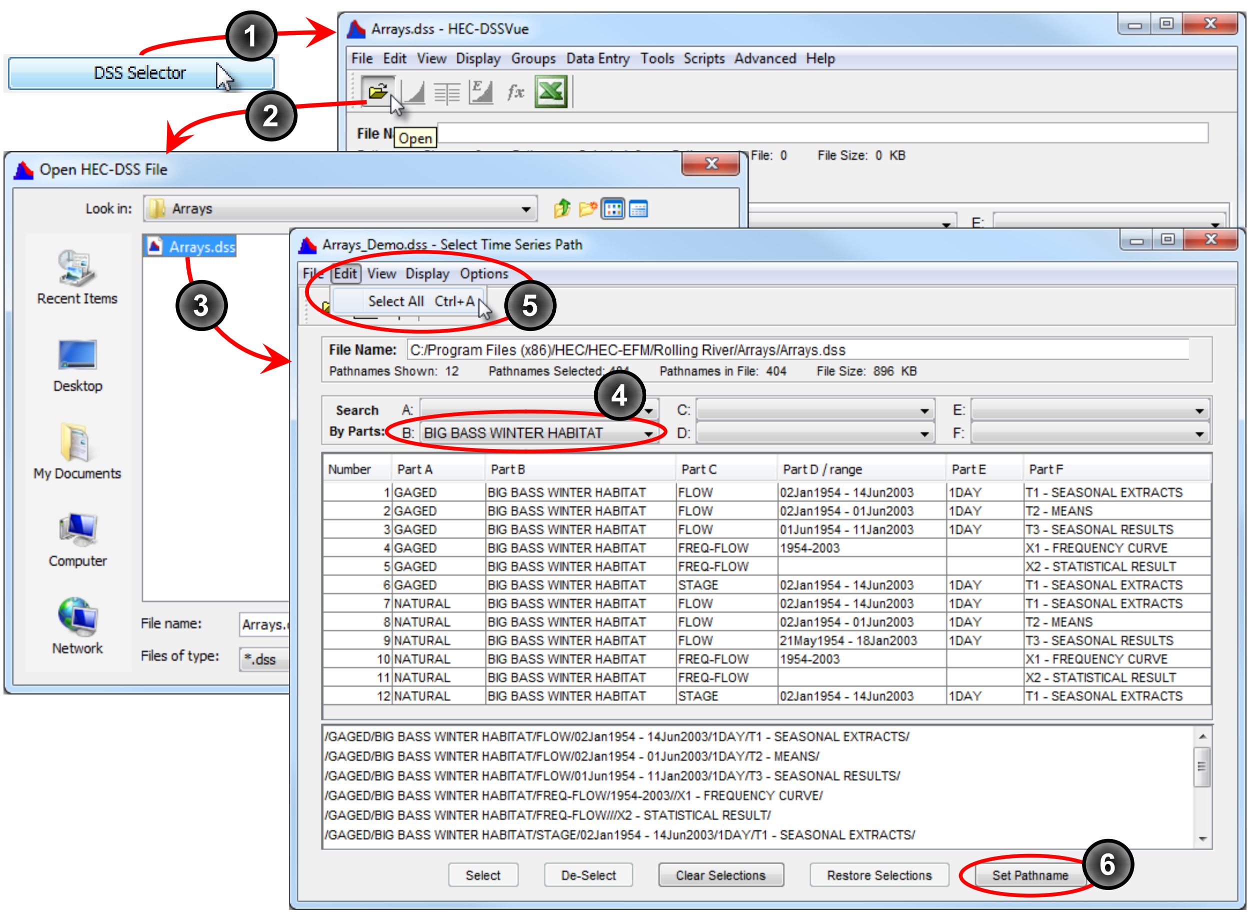


Figure 45. Process for selecting <u>Big bass winter habitat</u> results for comparison in a custom plot within HEC-EFM Plotter.

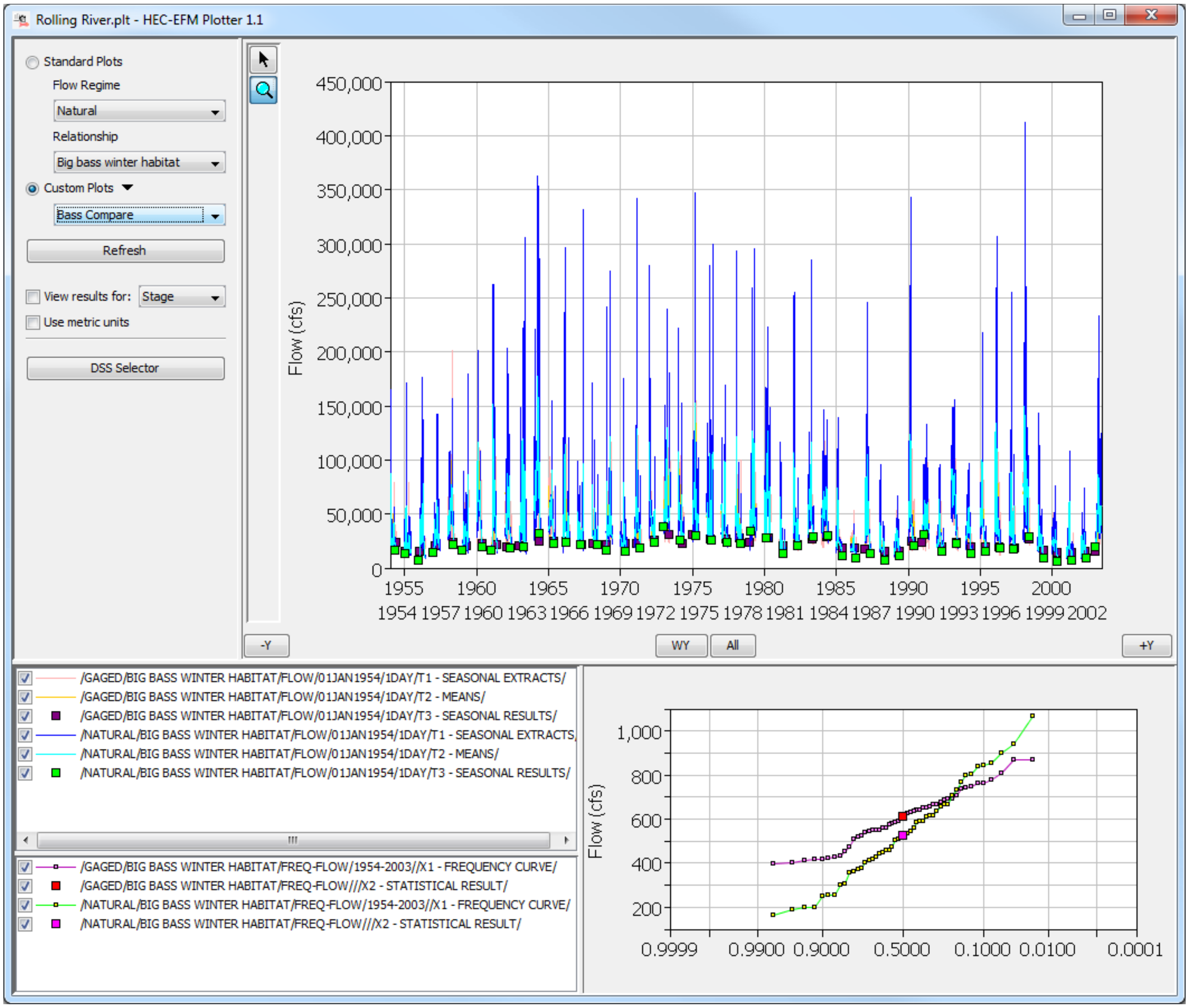


Figure 46. Custom plot in HEC-EFM Plotter comparing the Big bass winter habitat relationship for Gaged and Natural flow regimes.

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 47) in riverine systems. Water surface profiles can be rendered with HEC-RAS Mapper and exported to GIS for spatial analysis.

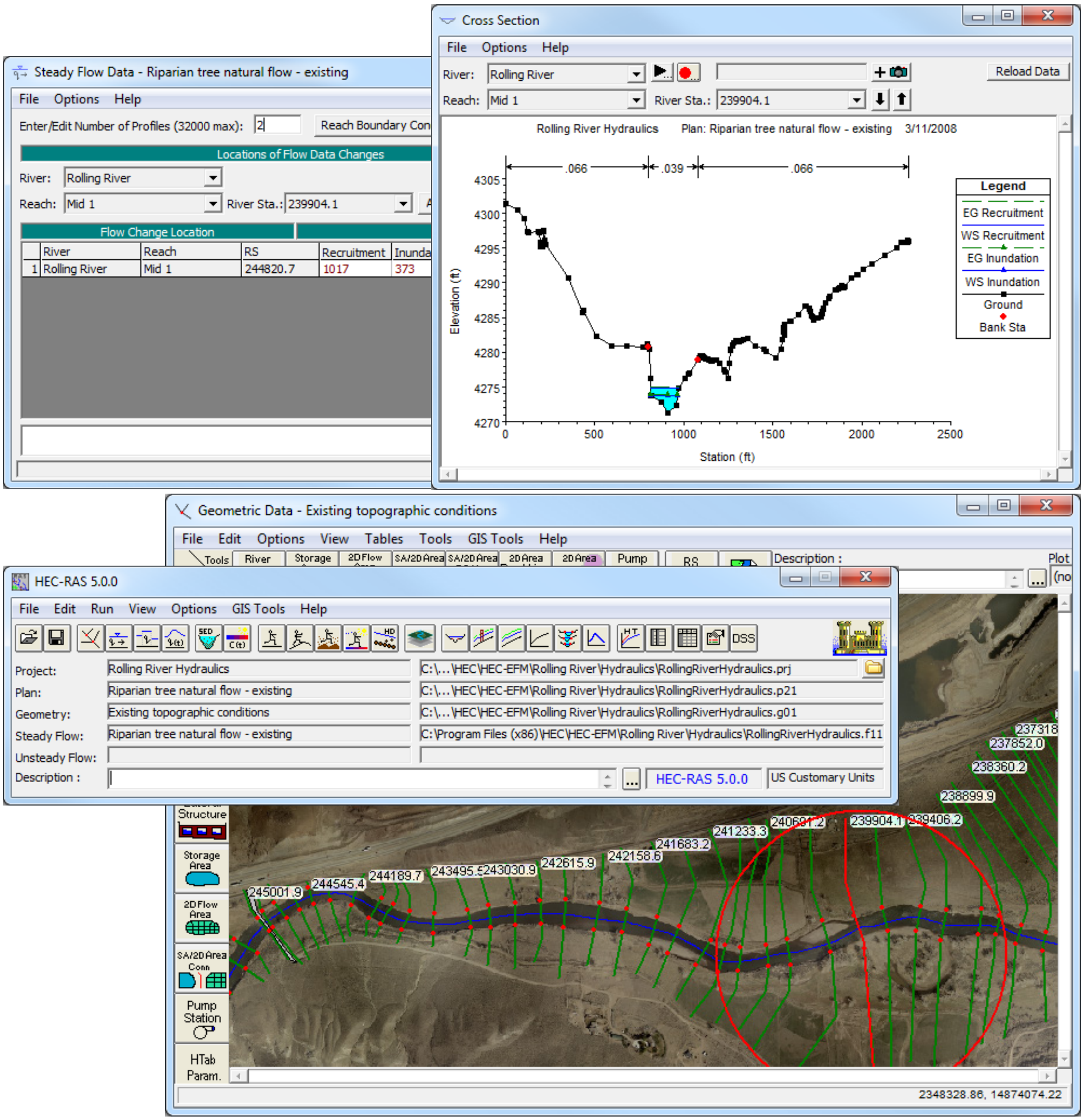


Figure 47. Example of HEC-RAS used to create water surface profiles for HEC-EFM statistical results (<u>Riparian tree recruitment</u> and <u>inundation</u> relationships using the <u>Natural</u> flow regime.)

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 48). 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.

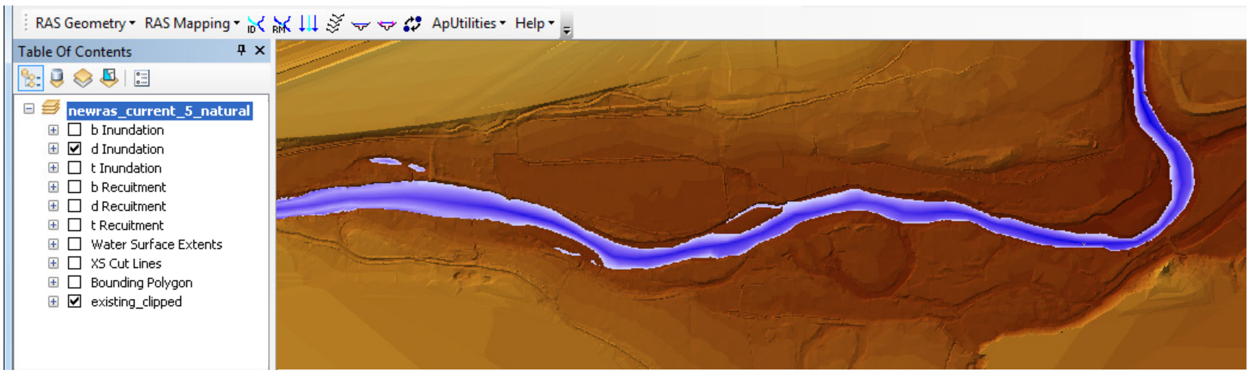


Figure 48. Example of a depth grid computed in HEC-GeoRAS using the water surface profile simulated by HEC-RAS for the statistical results of <u>Riparian tree inundation</u> from HEC-EFM.

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 <u>Riparian tree establishment</u> dynamics in the <u>Natural</u> flow regime. Depth grids were initially created for recruitment (Figure 49) and inundation (Figure 50). The inundation layer was then placed on top of the recruitment layer (Figure 51).

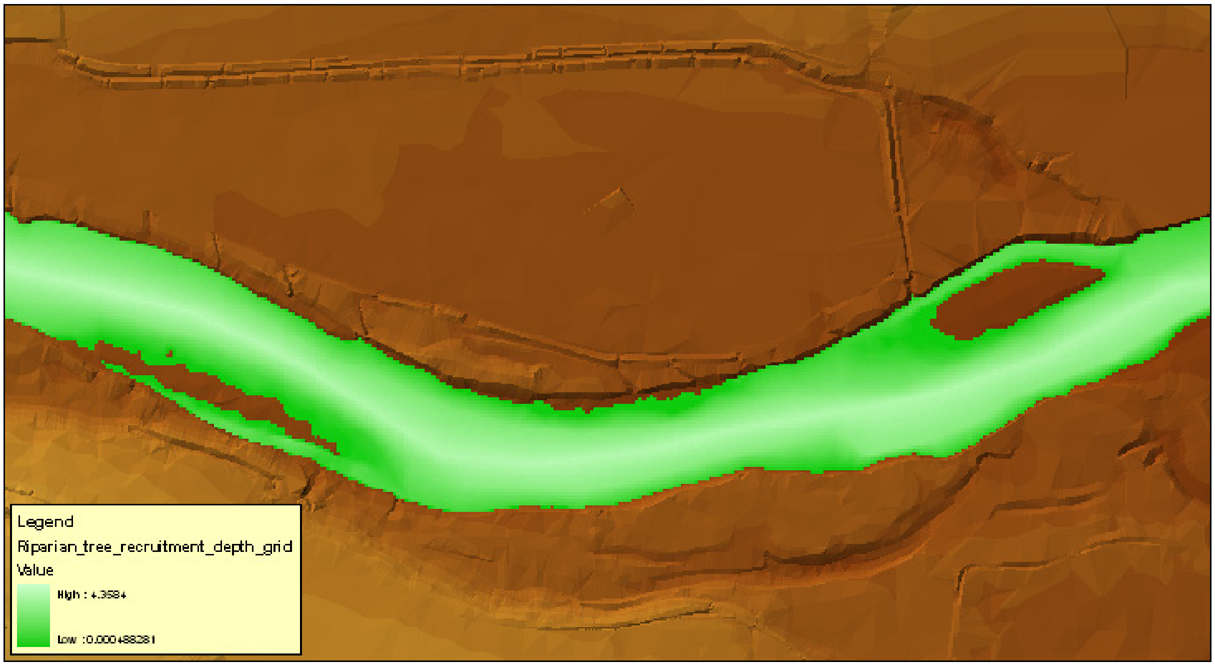


Figure 49. Depth grid created for <u>Riparian tree recruitment</u>. The green area shows where stage recession creates suitable conditions for seedlings to begin to grow.

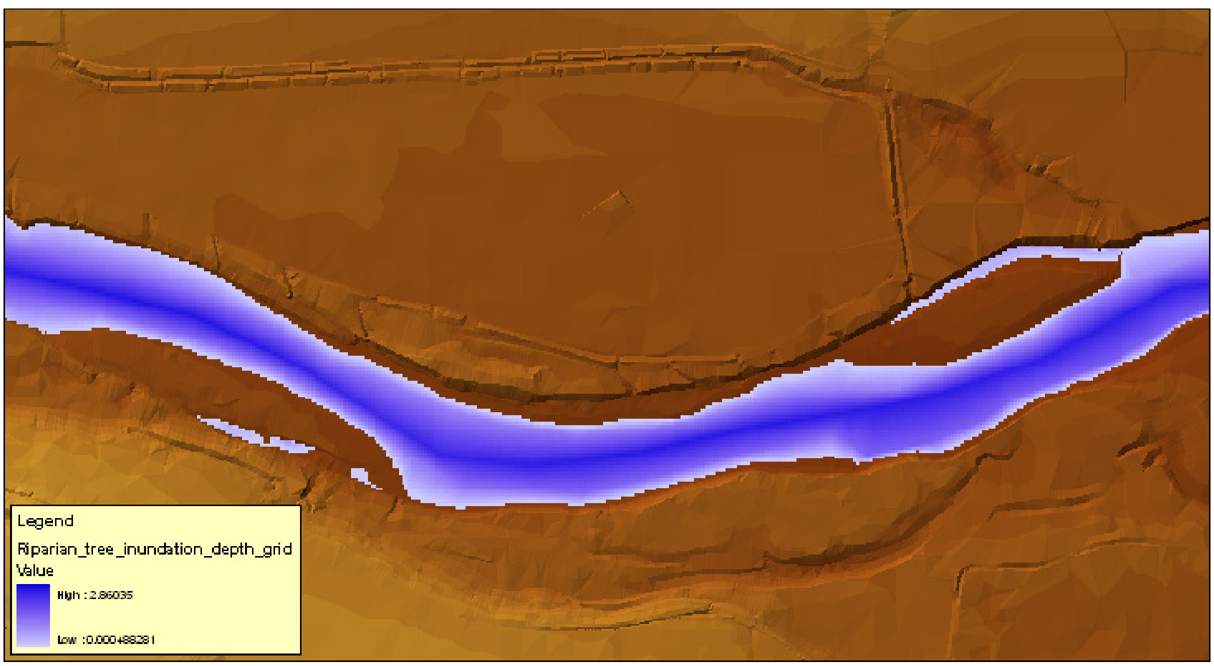


Figure 50. Depth grid created for <u>Riparian tree inundation</u>. This blue area shows where any new seedlings will be drowned by prolonged inundation.

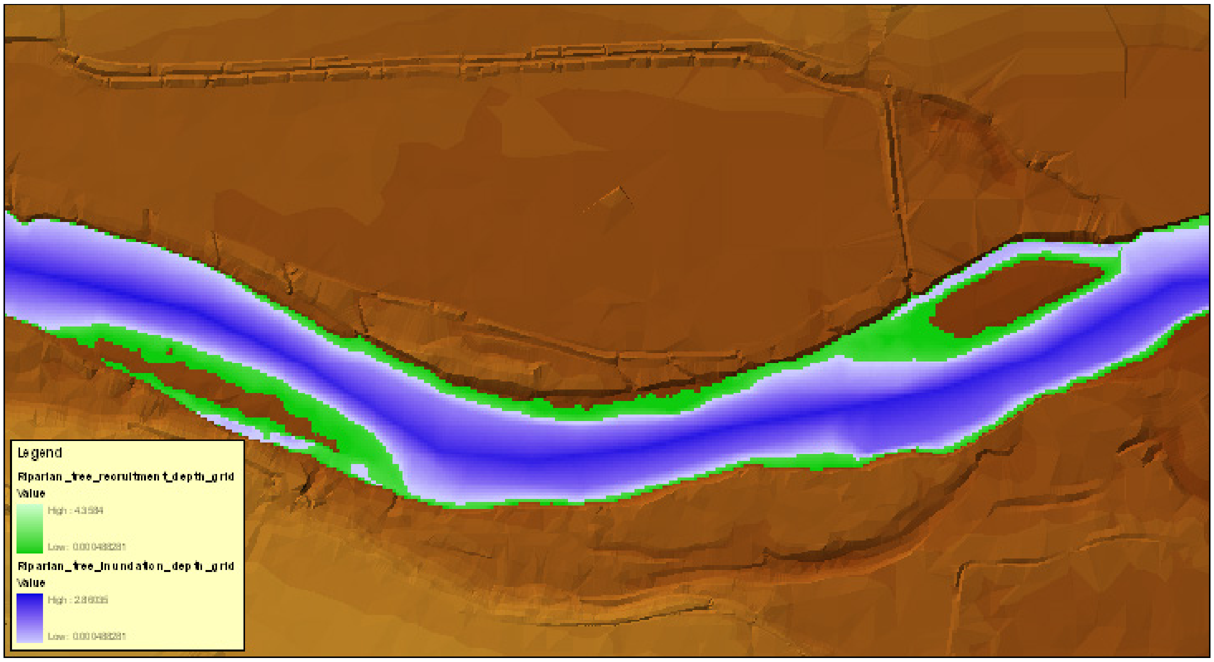


Figure 50. Overlay of <u>Riparian tree recruitment</u> and <u>Riparian tree inundation</u> depth grids.

In accordance with the combo relationship for <u>Riparian tree establishment</u> (Figure 7), the inundation depth grid was clipped from the recruitment depth grid. The resulting layer shows the area where HEC-EFM predicts <u>Riparian tree establishment</u> (Figure 52).

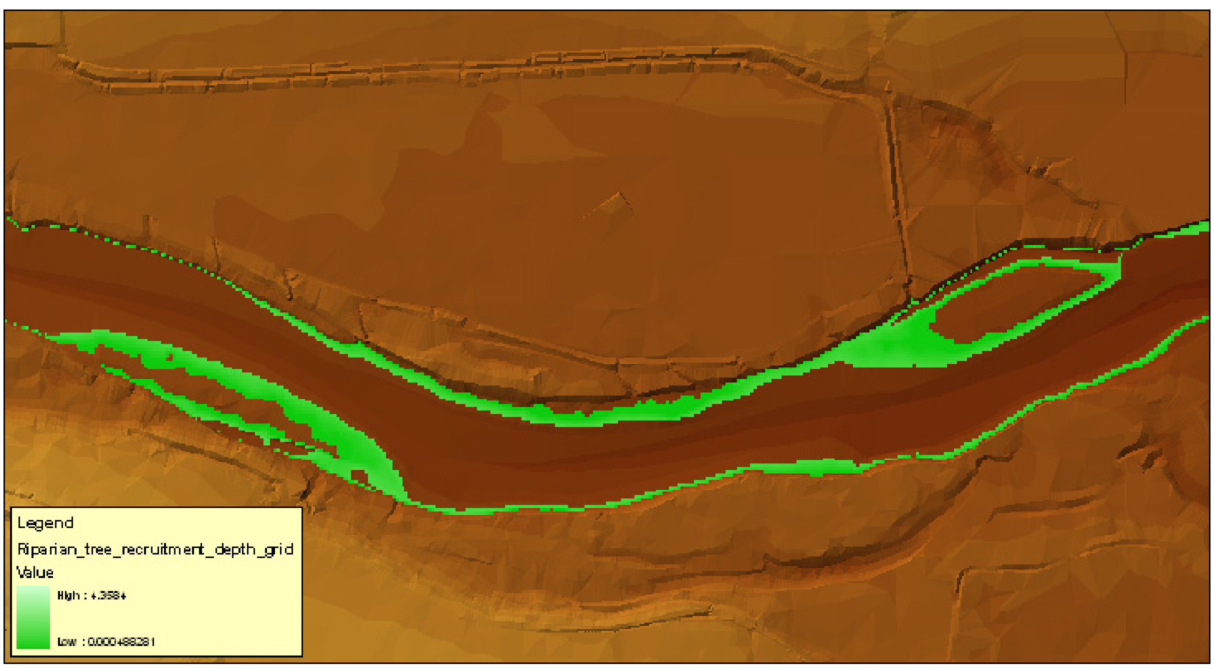


Figure 51. Depth grid created by clipping the inundation depth grid from the recruitment depth grid. The resulting area shows where HEC-EFM predicts <u>Riparian tree establishment</u>.

Information for the <u>Riparian tree inundation</u> 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 <u>Riparian tree inundation</u> that may not lead to seedling mortality (Figure 53). This <u>Riparian tree inundation</u> 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 54).

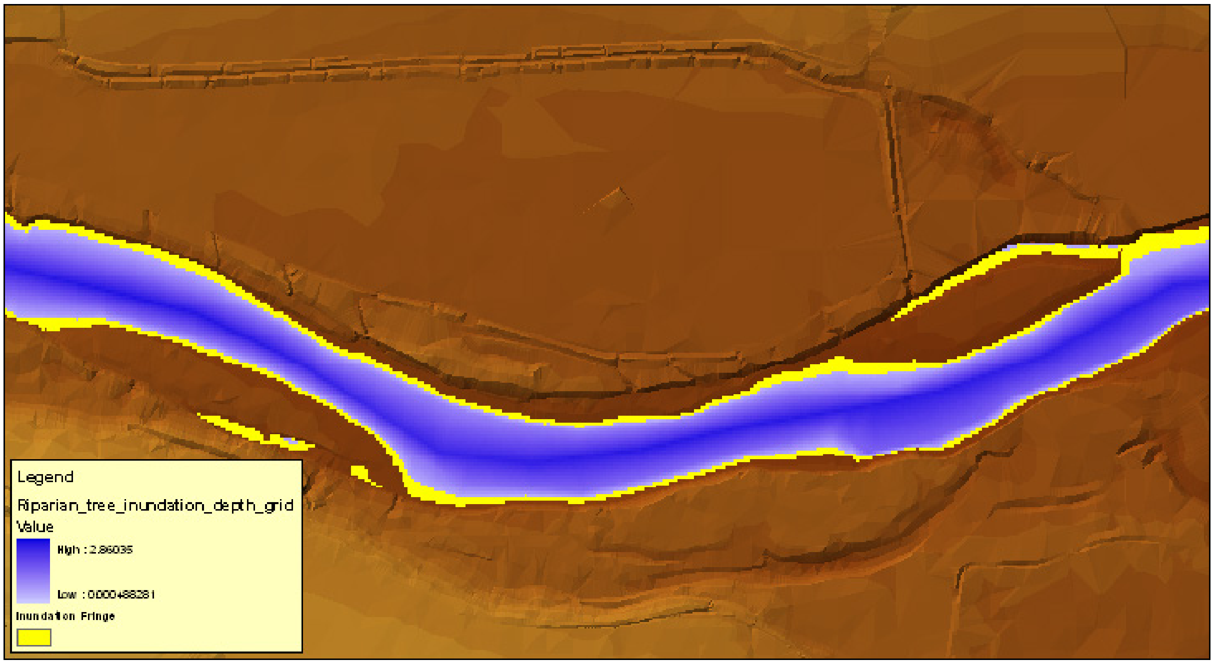


Figure 52. The yellow fringe shows areas of the Riparian tree inundation depth grid that are less than or equal to 0.5 ft, which may not be deep enough to drown new seedlings.

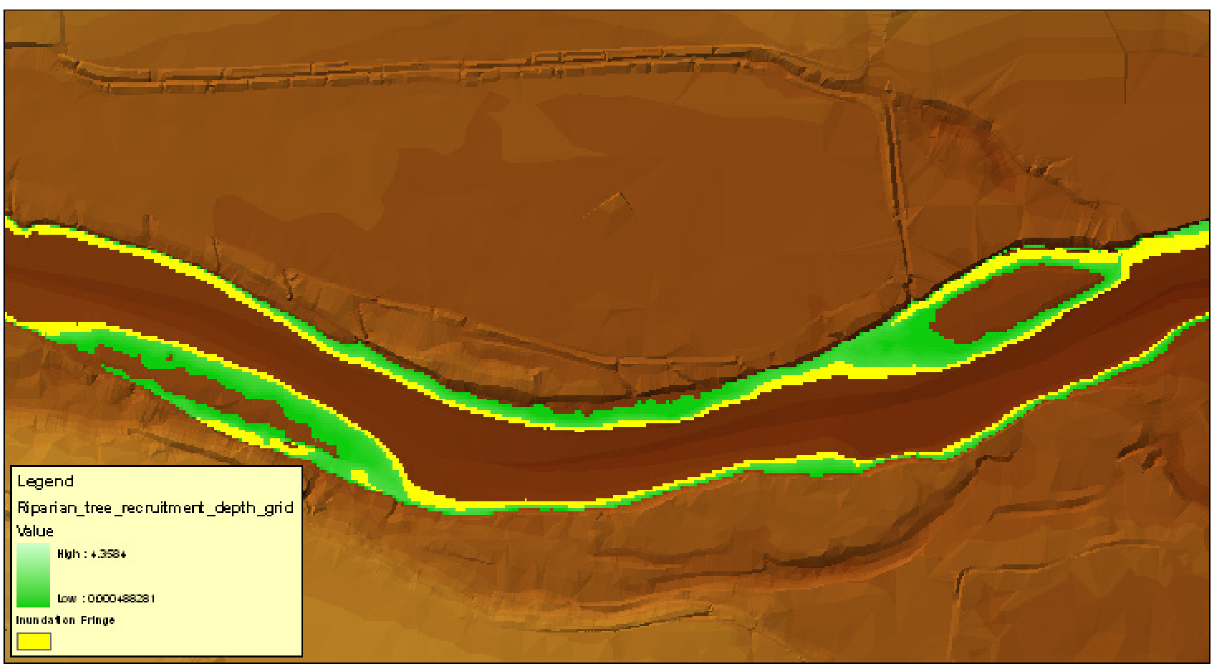


Figure 53. Potential recruitment sites for the Rolling River's Natural flow regime as computed using statistical and geographical queries in HEC-EFM, water surface profiles computed by HEC-RAS, and depth grids produced by HEC-GeoRAS.

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 55 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.

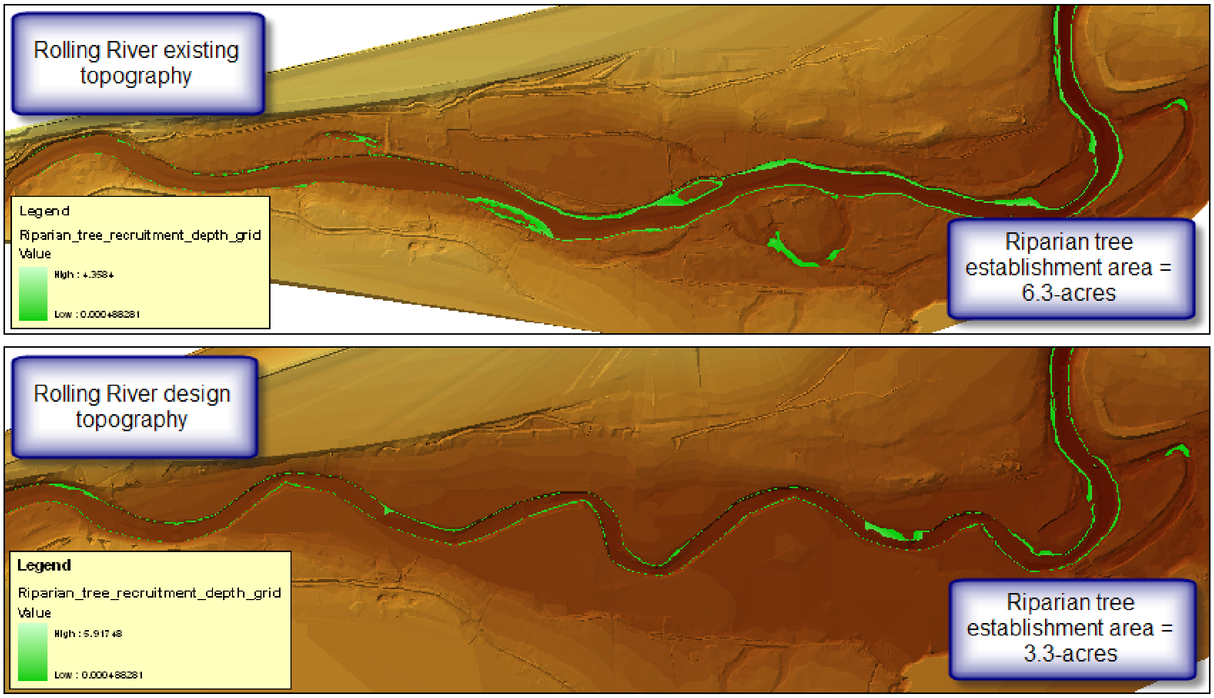


Figure 54. Comparison of Riparian tree establishment in existing and restored topographic conditions.

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 52) with the extent of suitable soils for riparian trees.

4.4.1 HEC-GeoEFM

The process of applying 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 56). *"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).

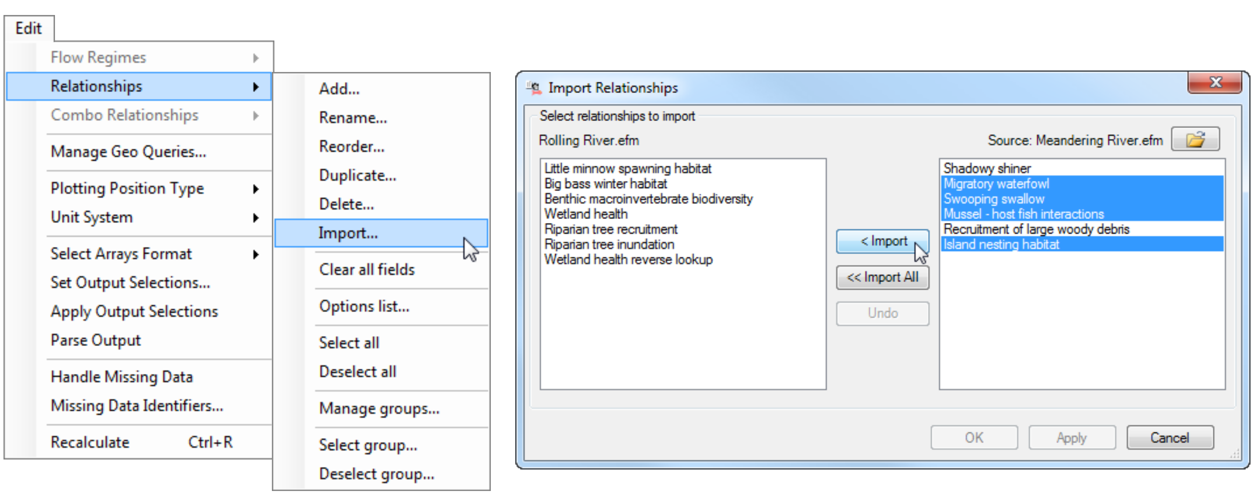


Figure 55. Using the *"Import…"* menu option to add relationships from source to current project. This can also be done for flow regimes.

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 57). *"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 (<u>Rolling River Data.dss</u>) 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.

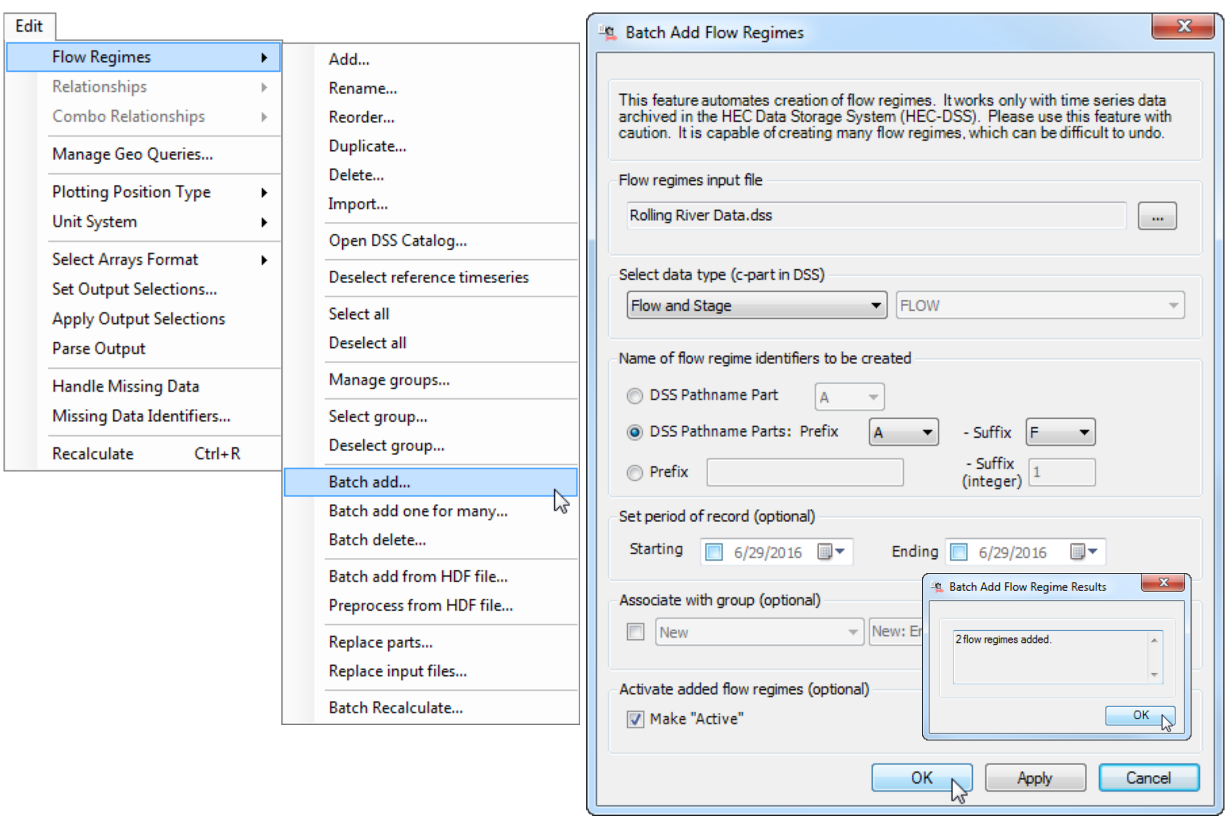


Figure 56. *"Batch add…"* and *"Batch add one for many…"* automate creation of flow regimes.

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 58) 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).

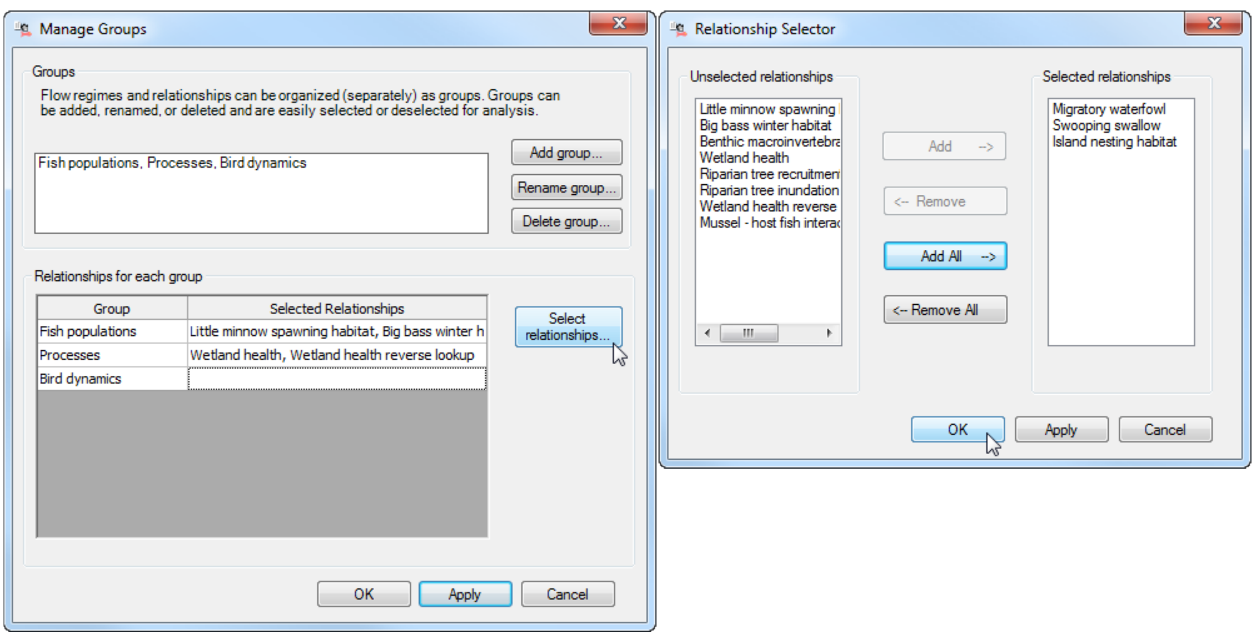


Figure 57. Creation of relationship groups (Fish populations, Processes, and Bird dynamics) and selection of relationships for the Bird dynamics group.

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 59). 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.

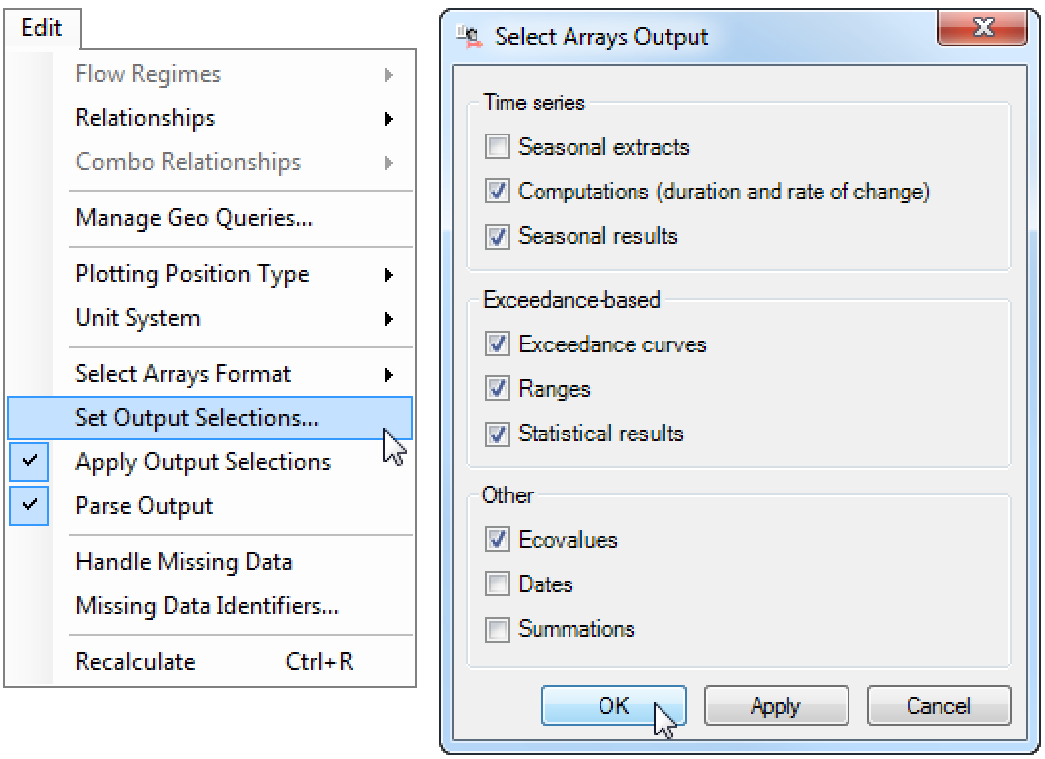
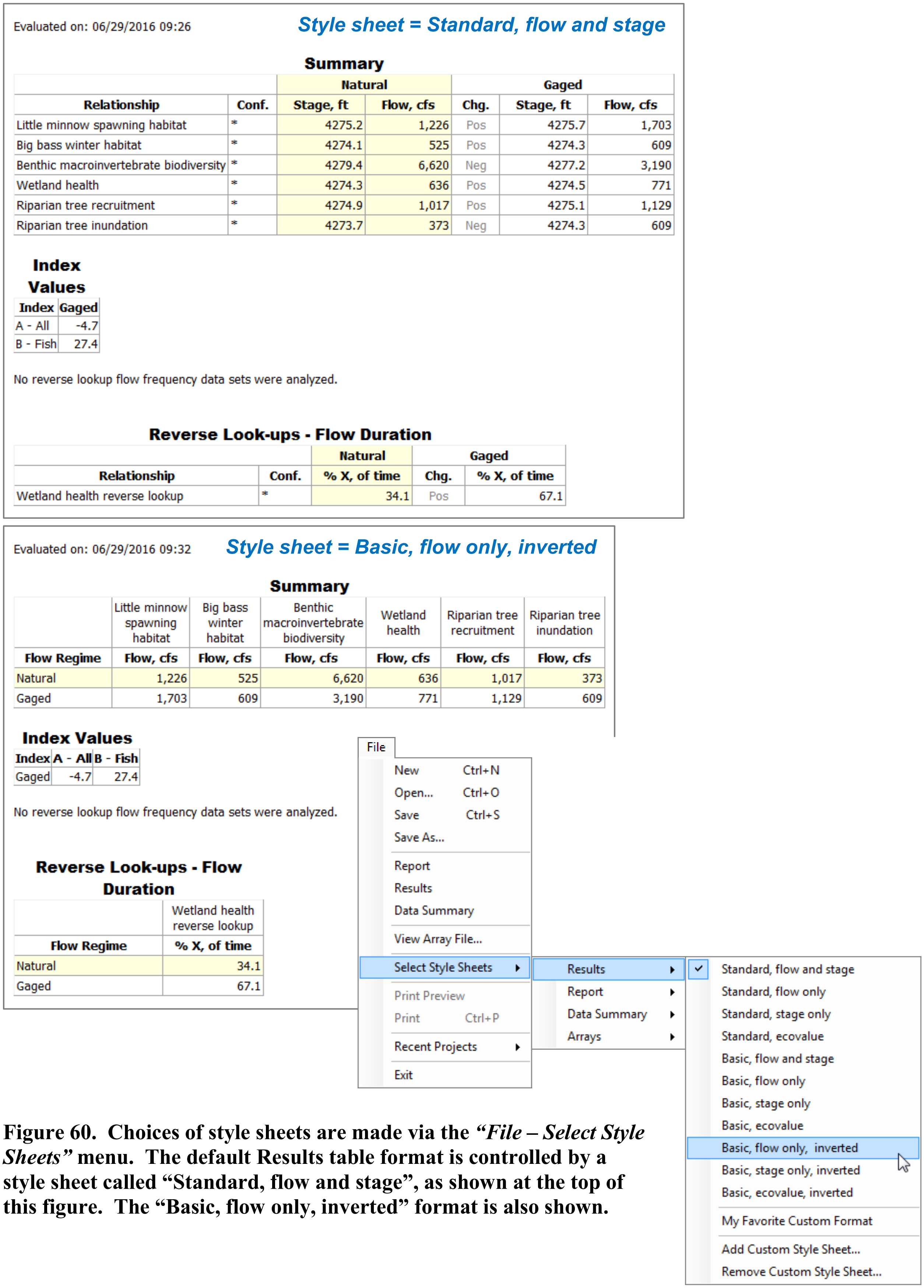


Figure 58. HEC-EFM enables users to select which outputs to write (*Set Output Selections…*) and to choose whether to apply those settings (*Apply Output Selections*).

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 60). 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. Users are also able to add and remove custom style sheets for Results, Report, Data Summary, and Arrays tables. 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. Modifications of style sheets is best done through XML editors, which are available online. Pre-packaged options are currently available only for the Results table.



Evaluated on: 06/29/2016 09:26 **Style sheet = Standard, flow and stage**

Summary

		Natural			Gaged	
Relationship	**Conf.**	**Stage, ft**	**Flow, cfs**	**Chg.**	**Stage, ft**	**Flow, cfs**
Little minnow spawning habitat	*	4275.2	1,226	Pos	4275.7	1,703
Big bass winter habitat	*	4274.1	525	Pos	4274.3	609
Benthic macroinvertebrate biodiversity	*	4279.4	6,620	Neg	4277.2	3,190
Wetland health	*	4274.3	636	Pos	4274.5	771
Riparian tree recruitment	*	4274.9	1,017	Pos	4275.1	1,129
Riparian tree inundation	*	4273.7	373	Neg	4274.3	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: 06/29/2016 09:32 **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 60. 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.

5.3 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 61, 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.

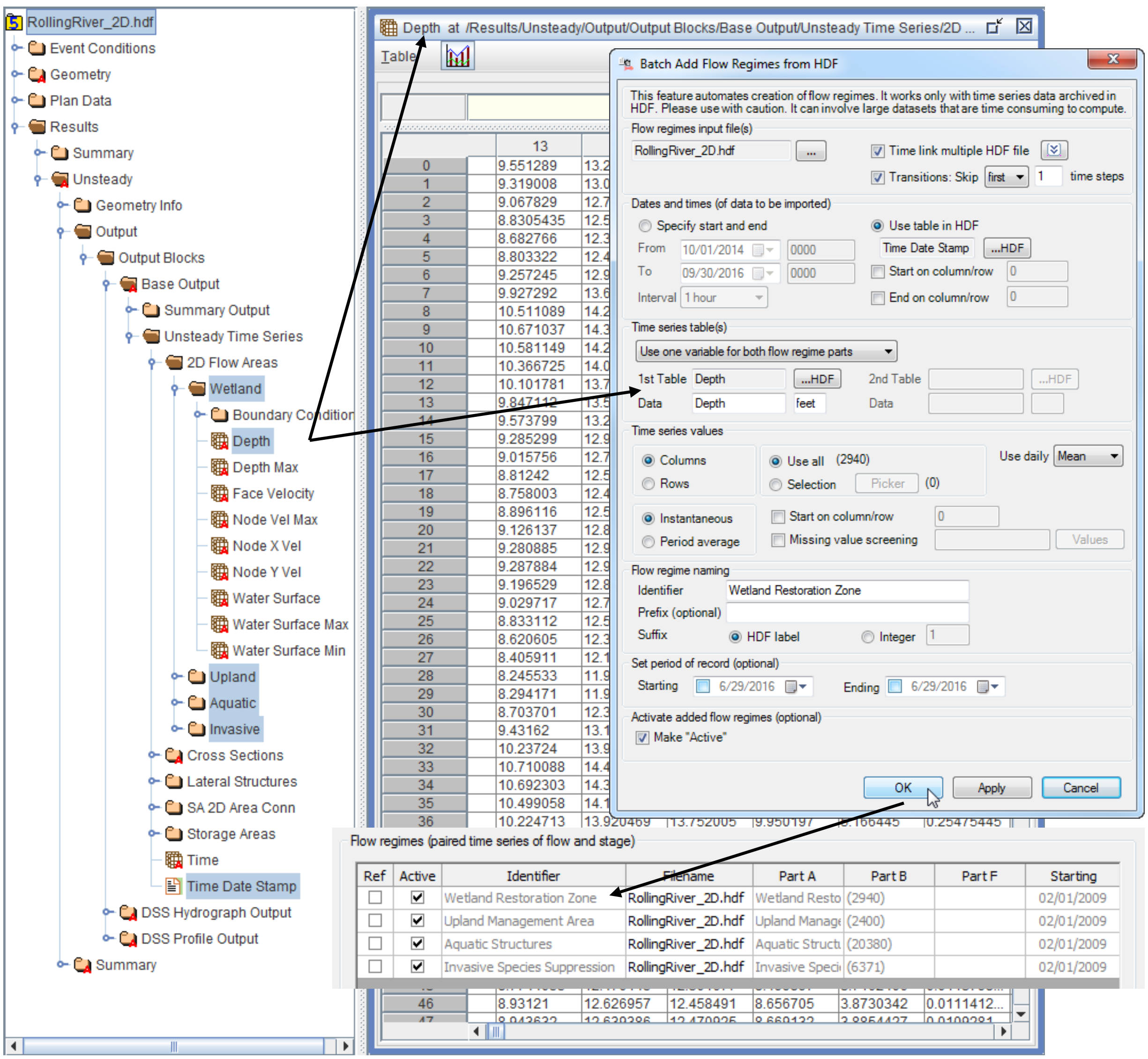


Figure 59. Importing HDF data for use in HEC-EFM. Structure and content of an HEC-RAS 2D output file is at back, *"Batch add from HDF…"* interface to right, and Flow regimes list at bottom.

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 62). 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 61. Preprocessing has been shown to reduce overall compute times by approximately one third.

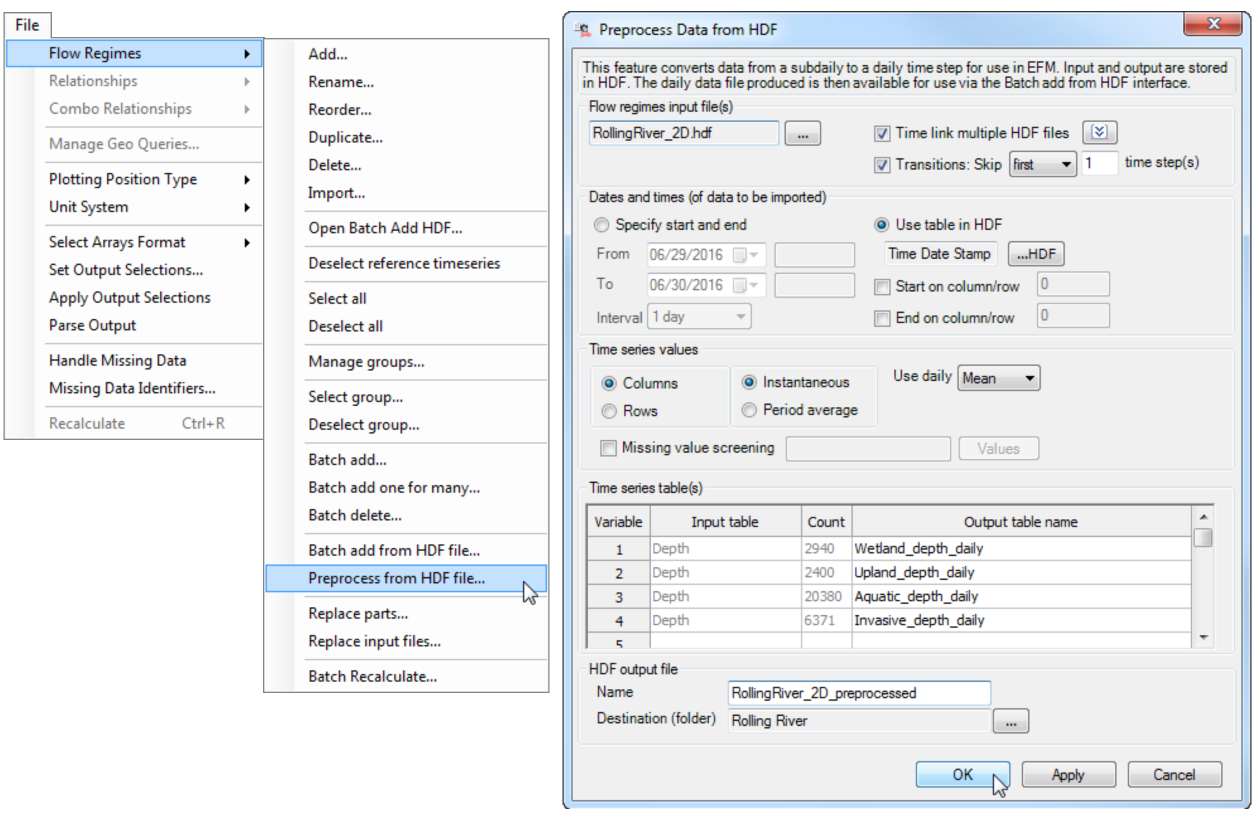


Figure 60. Avoid repetitive and time consuming conversions from subdaily to daily time steps via the *Preprocess Data from HDF* feature. With this, subdaily data are converted and written as daily values to a new HDF file that can then be used as input for flow regimes in HEC-EFM.

5.4 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). This cyclic application of HEC-EFM is initiated through the *"File – Flow Regimes – Batch Recalculate…"* menu option (Figure 63). 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. 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.

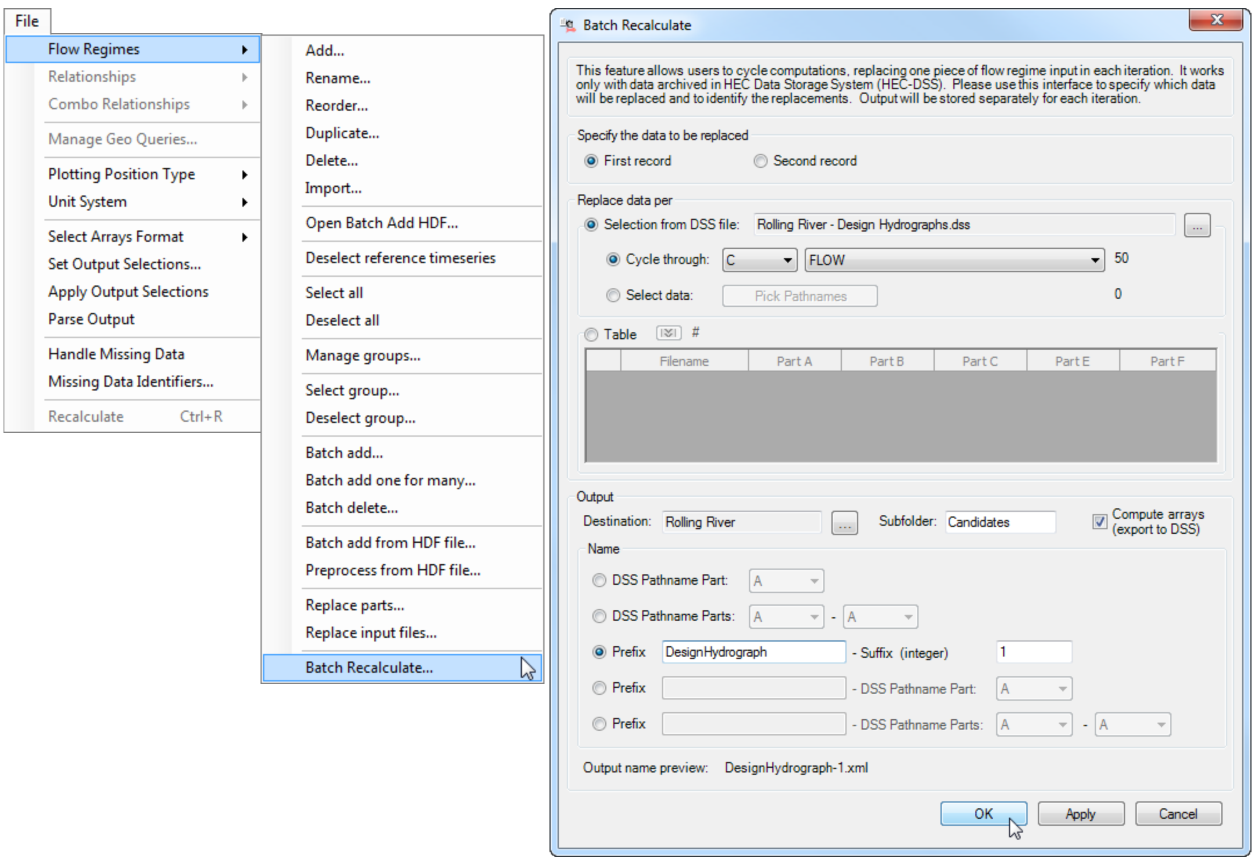


Figure 61. The "Batch Recalculate…" option in HEC-EFM allows users to cycle computations by replacing data associated with active flow regimes.

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 63 shows a scenario in which 50 hydrographs (C = FLOW) will be tested.

CHAPTER 6

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 versions 2.0 and 3.0 and HEC-GeoEFM 1.0 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 endangered species considerations.

CHAPTER 7

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