User Guide

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Domain: https://efresh.erams.com/

E-FRESH DST

Environmental **F**lows for **R**iverine **E**co**S**ystem **H**abitats

Decision **S**upport **T**ool

One Water Solutions Institute

Colorado State University

Prepared in cooperation with the U.S. Geological Survey Fort Collins Science Center and U.S. Forest Service

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CONVERSION FACTORS

Table 1: U.S. Customary to SI Unit Conversion Factors

Multiply	By	To obtain
	Length	
feet (ft)	0.3048	meters (m)
miles (mi)	1.609	kilometers (km)
	Area	
square feet (ft^2)	0.09290	square meters (m^2)
	Volume	
cubic feet (ft^3)	0.02832	cubic meters (m^3)
	Flow rate	
feet per second (ft/s)	0.3048	meters per second (m/s)
cubic feet per second (ft^3/s)	0.02832	cubic meters per second (m^3/s)

Table 2: SI to U.S. Customary Unit Conversion Factors

Multiply	By	To obtain
	Length	
meters (m)	3.281	feet (ft)
kilometers (km)	0.6214	miles (mi)
	Area	
square meters (m^2)	10.76	square feet (ft^2)
	Volume	
cubic meters (m^3)	35.31	cubic feet (ft^3)
	Flow rate	
meters per second (m/s)	3.281	feet per second (ft/s)
cubic meters per second (m^3/s)	35.31	cubic feet per second (ft^3/s)

EXECUTIVE MESSAGE

The Environmental Flows for Riverine EcoSystem Habitats (E-FRESH) Decision Support Tool (DST) has been developed as a web-based platform to facilitate the assessment and comparison of the effects of different flow management scenarios on available habitat for various aquatic, riparian, and invertebrate species of interest using the Instream Flow Incremental Methodology (IFIM) (Stalnaker et al. 1995 and Bovee et al. 1998). The tool also enables users to conduct a variety of analyses ranging from large-scale data processing and export to detailed and complex flow scenario manipulation around water rights, dam management, and alternative climate futures.

E-FRESH is built on the Environmental Risk Assessment and Management System (eRAMS) web tool platform which has been developed by Colorado State University's One Water Solutions Institute (OWSI) over the last decade as an open-source technology that provides cloud-based, geospatially enabled software solutions as online services and a platform for collaboration, development, and deployment of online tools. OWSI has built numerous tools using the eRAMS platform that currently support major collaborative projects, including: USDA-NRCS water supply forecasting, Colorado Department of Public Health and Environment water quality DSS, and USACE Missouri River Restoration Program Information Management System (MRRP-IMS).

The development of the E-FRESH DST was informed by two previous environmental flow studies conducted by the U.S. Geological Survey (USGS)Fort Collins Science Center, the upper Delaware River Decision Support System (Bovee et al. 2007 and Talbert et al. 2014) and the Cherry Creek Habitat Time Series Analysis Model (Waddle and Bovee 2010). The output produced by the E-FRESH DST has been cross-checked with the original output from Waddle and Bovee (2010) to verify that IFIM is being properly applied and producing similar values.

E-FRESH DST (v1.0) aims to recreate the base functionality of these previous standalone project/site specific environmental flow study tools in a more adaptable and user-friendly manner using a web-based platform where users can access, share, and upload data for any project location for which a user may want to conduct an environmental flow study.

The E-FRESH DST was developed at Colorado State University (CSU) under the supervision of Dr. Ryan Morrison, Principal Investigator (PI) at CSU and Tyler Wible, Assistant Director of Software Innovation at the One Water Solutions Institute (OWSI) at CSU and through collaboration with federal partners, including Dr. Christopher Holmquist-Johnson, Hydrologist, U.S. Geological Survey Fort Collins Science Center and Dr. David Merritt, National Instream Flow Coordinator, U.S. Forest Service.

Who Should Use This Guide

This guide is a tutorial to get users started using the Environmental Flows for Riverine EcoSystem Habitats (E-FRESH) Decision Support Tool (DST). The guide provides instructions for commonly performed tasks and uses of the tool. This tool is intended for use by water resource managers, academic groups, regulatory officials, and consultants as well as state, local, and federal agencies planning for the future of water resources.

Need Help?

If users need additional assistance after reviewing the guide, we are here to help! This guide is designed to provide instruction on commonly performed operations and answers to frequently asked questions. If users find any aspect of the tool challenging or find any information that is missing from this guide, please engage an eRAMS expert to guide users through any hurdles. Contact us at eramsinfo@gmail.com

Acknowledgments

We would like to thank Rachel Spurrier for lending her time and expertise in her editorial review of this document. We would also like to thank Jonathan Friedman, Research Hydrologist at the USGS Fort Collins Science Center, and Dr. Mazdak Arabi, Borland Endowed Professor of Water Resources at Colorado State University's Department of Civil and Environmental Engineering, for their time, expertise, and contributions as peer reviewers.

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Software Availability

Domain

https://efresh.erams.com/

Documentation URL

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INTRODUCTION

Managing the natural flow needs in regulated rivers is complex due to the myriad of interacting physical and hydrological factors that affect these ecosystems. The need for better integration of science and decision-making in environmental management is widely documented (Tonkin et al. 2020, Alafifi and Rosenberg 2020, Steinschneider et al. 2014, Arthington 2012). Considering anticipated climate change and other changes in demographics, land use, and water management practices, decision-makers are confronted with the need to make major decisions in the face of high system complexity and uncertainty. Having access to tools that synthesize scientific data and provide the ability to integrate useful and relevant scientific information in a web-based user-friendly format is critical to enable informed decision-making.

Accessing the effects of environmental flows on available habitat for multiple types of species of interest requires the integration of hydrologic (stream flow magnitude and frequency), hydraulic, and species habitat suitability data. The Environmental Flows for Riverine EcoSystem Habitats (E-FRESH) Decision Support Tool (DST) was designed to aid in this integration of useful and relevant scientific information across multiple disciplines. As such, each section of E-FRESH DST is designed around the data inputs, review, adjustments/modifications, and assessment associated with the various disciplines (i.e. water resource management, fish biology, riparian ecology, etc.) necessary to understand the wholistic nature of species habitat availability under varying hydrologic conditions.

PURPOSE

The E-FRESH DST facilitates the assessment and comparison of the effects of different flow management scenarios on available habitat for various aquatic, riparian, and invertebrate species of interest. This tool also enables users to conduct a variety of analyses ranging from large-scale data processing and export to detailed and complex flow scenario manipulation around water rights and alternative climate futures. The E-FRESH DST enables environmental flow assessments to support aquatic habitat under multiple flow regimes utilizing the Instream Flow Incremental Methodology (IFIM) (Stalnaker et al. 1995 and Bovee et al. 1998). However, the E-FRESH DST provides additional capacities for multidimensional assessments of riparian and invertebrate species in addition to aquatic species for a system-wide estimate of impacts in flow regime changes.

The E-FRESH DST is deployed as a web-based tool (Figure 1) using the Catena Analytics cloud computing platform developed by the project team at Colorado State University (CSU). The tool is organized in seven modules (Home Page, Project Management, Hydrology Input, Hydraulic Input, Habitat Suitability, Review Results, and User Manual) which are described in detail in the user and technical guide below.

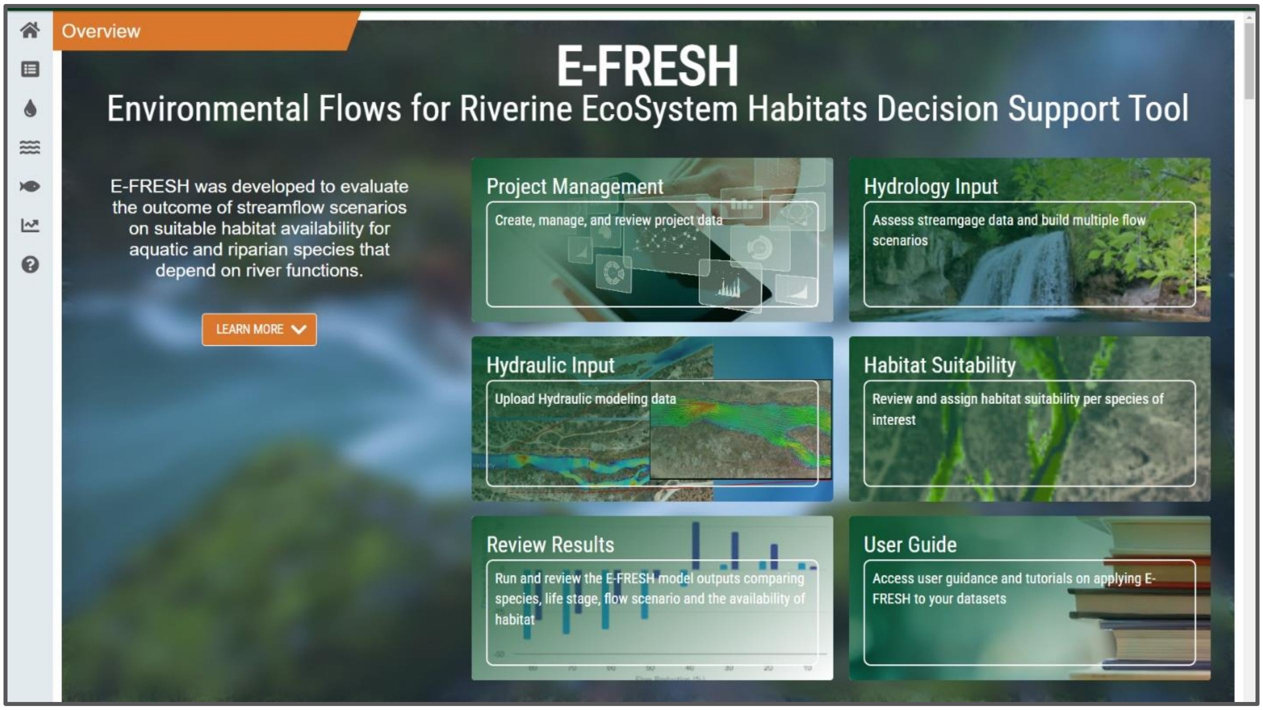

Figure 1: Environmental Flows for Riverine EcoSystem Habitats (E-FRESH) Decision Support Tool Landing Page

USER AND TECHNICAL GUIDE

OVERVIEW

Hydrologic modification can have profound affects on riparian and aquatic species in a river system through the change of habitat characteristics. Habitat suitability curves (HSCs) characterizing species responses to changes in physical properties, like depth and velocity of flow as well as frequency of inundation, can be combined with detailed hydraulic modeling data to establish locations and extents of preferred habitat for each species and life stage of interest. The E-FRESH DST does just that to determine the extent of available habitat as a function of discharge, as well as combining streamgage monitoring data, to assess overall frequency of occurrence of preferred habitat by species and life stage.

The E-FRESH DST integrates numerous types of spatially explicit data and synthesizes modeled discharge for alternative flow management scenarios, flow-specific one-dimensional (**1D**) or two-dimensional (**2D**) hydrodynamic modeled estimates of local hydraulic conditions (depth, velocity, shear stress, etc.) at a fine pixel-scale (<1 m^2), and HSCs for a variety of aquatic and riparian taxa. E-FRESH computationally integrates these data and outputs the amount of potentially available habitat for each species under each flow scenario as well as the flow effects on riparian vegetation habitat suitability.

Layered onto the tool is a scenario manager that allows definition and comparison of alternative flow management scenarios to evaluate the effects of instream and riparian habitat availability for the selected species of interest under the contrasting management scenarios. These side-by-side alternative outcomes of habitat availability can be used to inform managers on future environmental flow regulation for multiple aquatic and riparian species benefits and objectives (including disadvantaging undesirable species).

Quick Start

The E-FRESH DST navigation menu (left panel icons in Figure 1) includes 7 sections as listed below to help users navigate the tool. The User and Technical Guide outlines how to get started using the tool.

1. Home Page
    a. Overview of E-FRESH DST
2. Project Management
    a. Available datasets and project metadata
3. Hydrology Input
    a. Data import for stream discharge data review and scenarios
4. Hydraulic Input
    a. Data import from hydraulic model output
5. Habitat Suitability Input
    a. Data review for guild and species level habitat suitability
6. Review Results
    a. Results viewer and summaries
7. User Guide

a. User guidance and tutorials

Each section of the E-FRESH DST includes several navigation elements in the left panel. These include a “Next Section” button to help advance through the various data input and upload steps as well as a “Display Units” selector (Figure 2). Note that the units of the uploaded Hydrology and Hydraulic data are handled separately. However, in the Habitat Suitability Input, changing this entry will change the display of the data and allow data entry in those units. That is, habitat suitability metrics (depth, velocity, etc.) can be entered in either unit type.

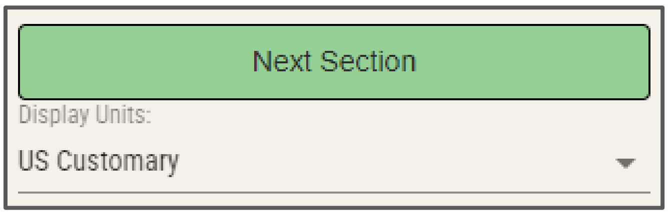

Figure 2: Environmental Flows for Riverine EcoSystem Habitats (E-FRESH) Units and Next Section

System Requirements

A modern web browser is required to connect and run the E-FRESH DST. Minimum supported browser versions include Google Chrome v.69, Mozilla Firefox v.62, Safari v.11.1, and Microsoft Edge v.17.

Logging In

Existing Users

When arriving at https://efresh.erams.com/, users will see a blank screen with a “Login” button in the top right corner (Figure 3). Click “Login” to be redirected to the login screen shown in Figure 4. If users have previously created an account, use those credentials to log in.

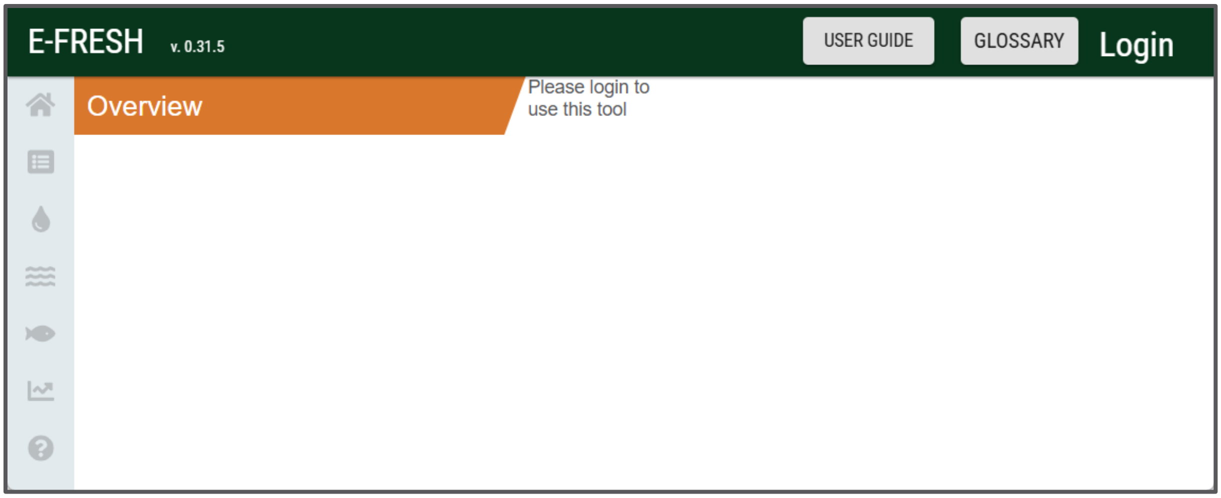

Figure 3: Environmental Flows for Riverine EcoSystem Habitats (E-FRESH) Landing Page (Not Logged In)

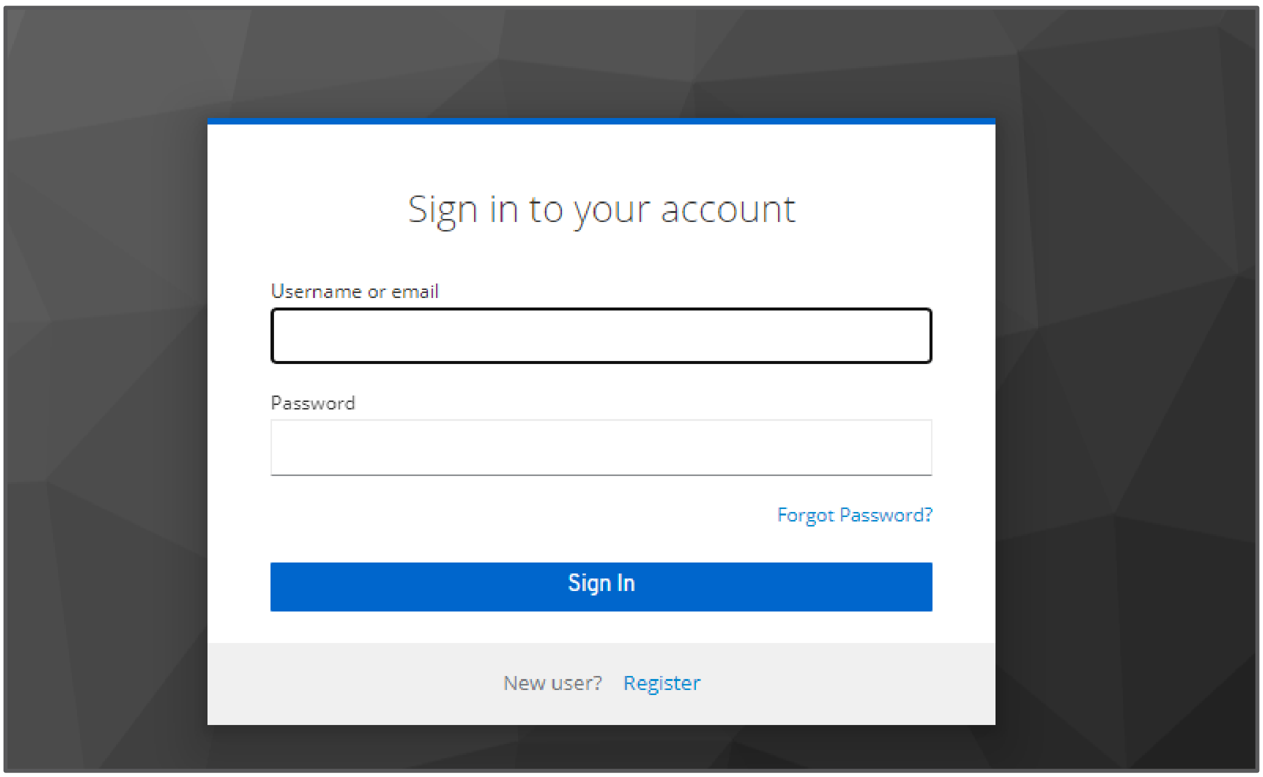

Figure 4: Environmental Flows for Riverine EcoSystem Habitats (E-FRESH) Login

New Users

If users have not created an account, click "Register" underneath the main login area next to "New User?" (Figure 4). Users will be directed to an account creation page (Figure 5) where users can fill out the form and click "Register." New users will need to verify their email address before accessing the tool for the first time.

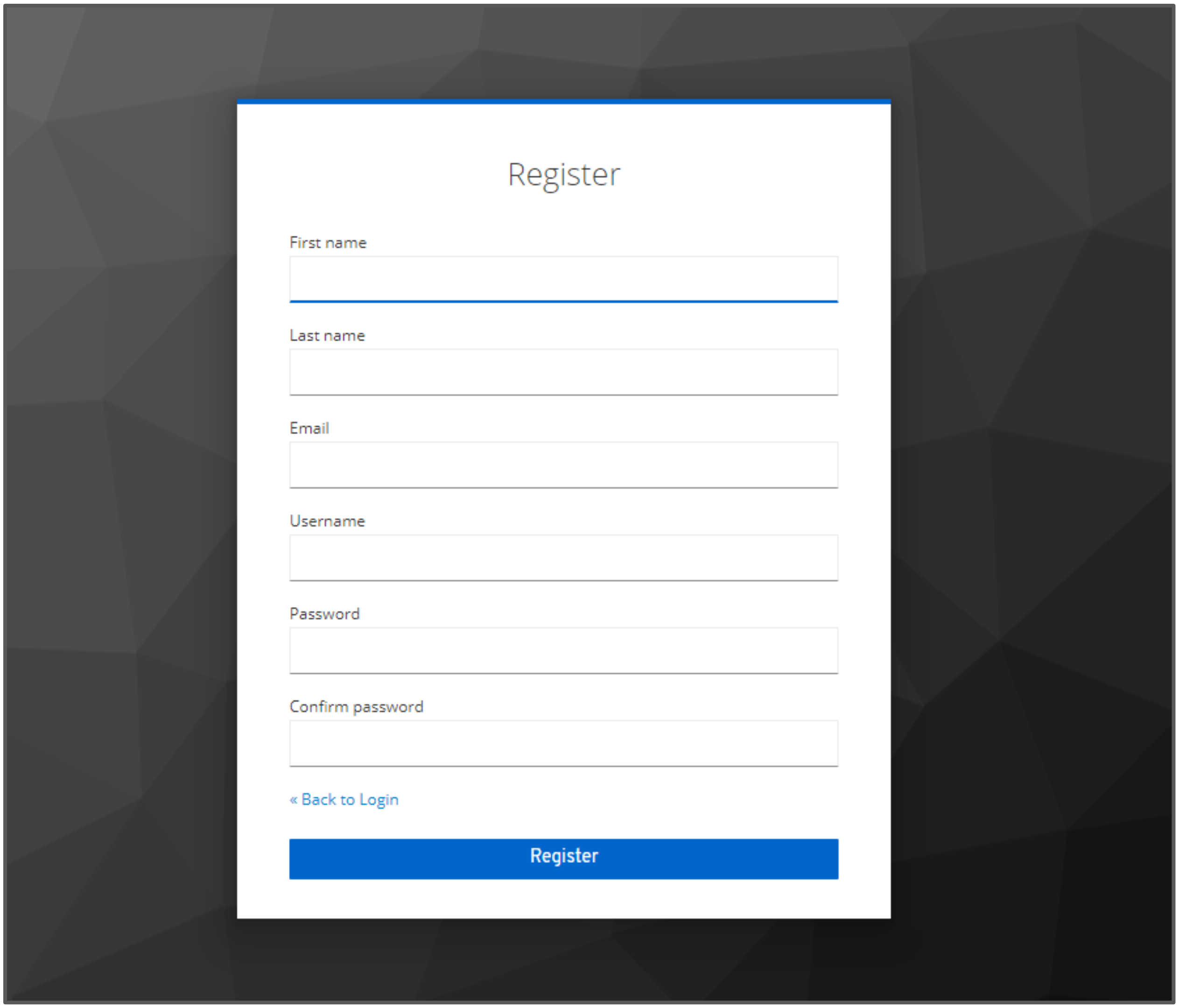

Figure 5: Environmental Flows for Riverine EcoSystem Habitats (E-FRESH) Account Registration

Home Page

Overview

The home page (Figure 6) gives an overview of the E-FRESH DST, direct links to its different sections, and an overview of its use cases.

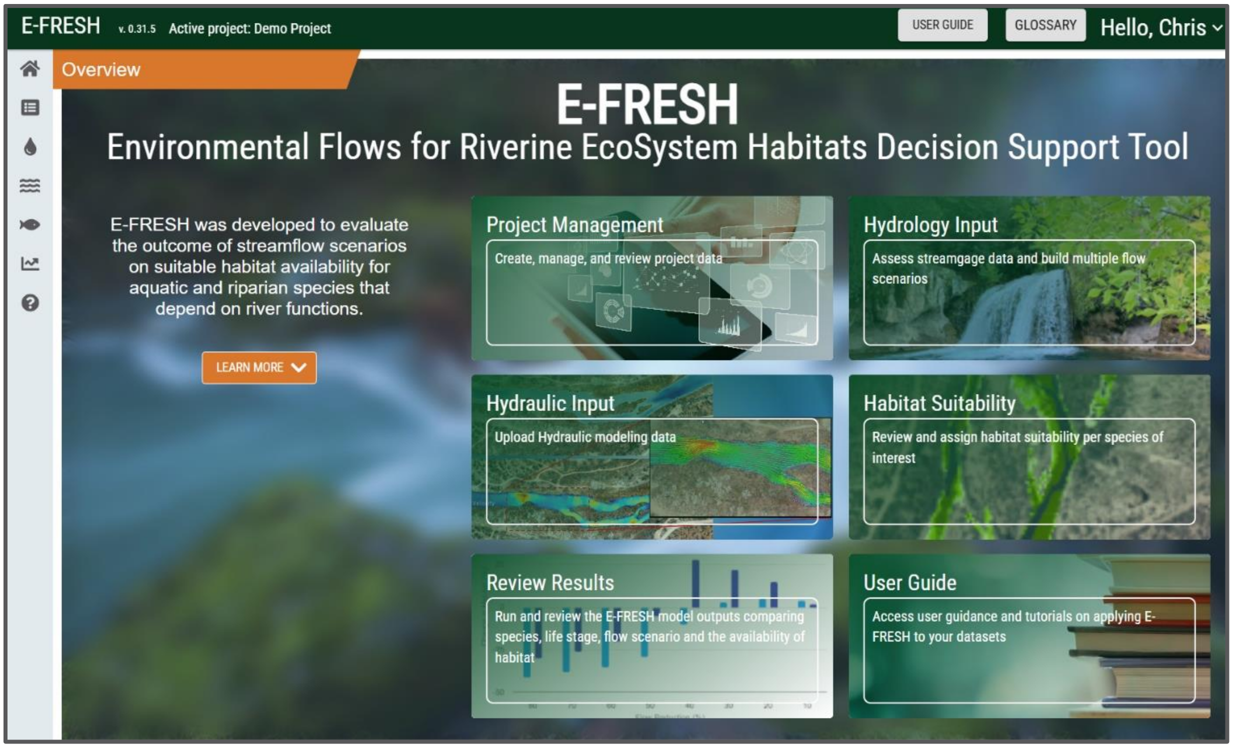

Figure 6: Environmental Flows for Riverine EcoSystem Habitats (E-FRESH) Home Page

The E-FRESH DST banner at the top of the page will show users which project they are actively working in (Figure 7), and the tiles on the center of the home page (Figure 6) are direct links that will take users to the described section (Project Management, Hydrology Input, Hydraulic Input, Habitat Suitability, Review Results, and User Guide).

Figure 7: Environmental Flows for Riverine EcoSystem Habitats (E-FRESH) Active Project Banner Label

Scrolling down the home page will provide background information and the purpose of the different analyses and features available in E-FRESH DST.

Users need to either select an existing project from the Project Management section or create a new project before users can use or upload data to the various sections of the E-FRESH DST.

Project Management

The E-FRESH DST is designed for each user to have their own project space that contains their datasets, analyses, and results that are only accessible to the project creator and any other users to whom they grant access. The framework is also flexible to allow public access to completed projects and datasets that other users can review and/or copy as a new project to conduct additional analysis or modifications. This flexibility allows research project teams to continue or expand on previously completed projects by assessing additional hydrology scenarios, hydraulic inputs, or aquatic/riparian species habitat criteria. Users can coordinate with the OWSI development team to manage permissions for their projects (private or shared) and, if desired, to contribute a completed project (peer-reviewed and published in the literature) for review and approval by OWSI to be included in the E-FRESH DST public database.

Available Datasets

The Project Management section (Figure 8) shows all the projects and available data in E-FRESH associated with a user's login. If a user has not yet created a project, the project list will include only projects in E-FRESH that have been approved for public use, such as a completed research project assessing a particular river and species that has been published in a peer-reviewed publication or equivalent manner and approved by OWSI. In addition to these projects, users will see the projects they have created from scratch or copied from an available project. Permissions associated with a specific project and other user access can be set through collaboration with OWSI.

The project that a user is actively working on will appear **bolded** as shown in the red rectangle in Figure 8 and the button to the right of the project information will say "Active". Users can choose any of the datasets by clicking the "Select" button (red arrow in Figure 8).

Each column on the Project Management page (Figure 8) provides summary information related to each project and what portions of the tool (hydrology input, hydraulic input, habitat suitability) have available data provided/uploaded, how many species are available, and how many have been processed with results ready for review.

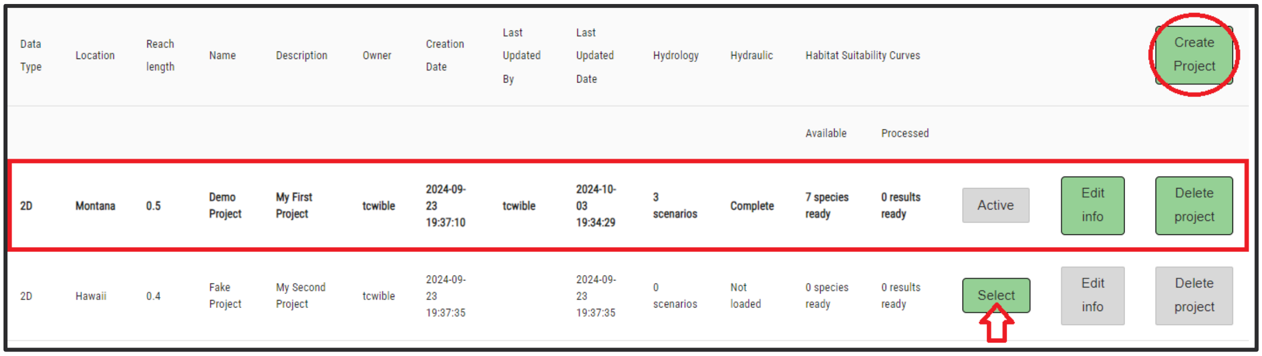

Figure 8: Environmental Flows for Riverine EcoSystem Habitats (E-FRESH) Project Overview, Selection and Creation

To create a new project with a user's own data or make a copy of an existing project, click "Create project" in the upper right-hand corner (circle in Figure 8). A dialog box (Figure 9) will pop up and ask users to enter the name, location, description, reach length, and project source. Users can use an existing dataset available within the tool, but if users would like to input their own data, choose "Root" as the project source.

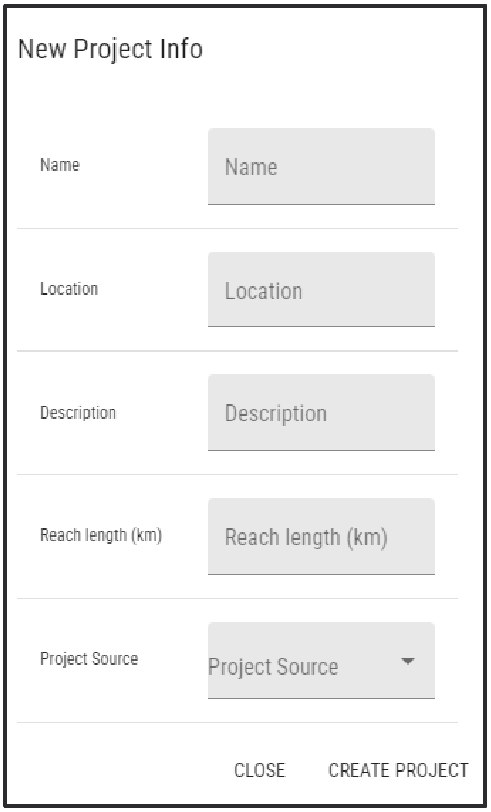

Figure 9: Environmental Flows for Riverine EcoSystem Habitats (E-FRESH) New Project Metadata

If users choose a pre-existing dataset as the project source, the original data from the "master" version will be copied for local edits and available in the subsequent Hydrology Input, Hydraulic Input, Habitat Suitability Input, and Review Results sections. Once all the project information has been entered, click "Create Project," and the new project will load as the active project in the upper left banner. Users can now proceed to the "Hydrology Input" section by clicking either the Hydrology Input tile or the water droplet in the left navigation pane (Figure 6).

Hydrology Input

This section of the tool (Figure 10) is dedicated to the selection and assessment of streamflow data for consideration of multiple hydrology scenarios in the results section. For example, a user can select a nearby gage record and review a baseline "what were conditions like" or modify that baseline into a what-if scenario, such as "if they put in a dam and divert x cfs, what does that do to the river?" In this section, users can review, adjust, and save hydrology scenarios. Additionally, users can also download the exceedance (and non-exceedance) probabilities of a particular flow.

Figure 10: Environmental Flows for Riverine EcoSystem Habitats (E-FRESH) Hydrology Input

E-FRESH supports two hydrologic data input sources at this time, and more are anticipated to be added. Currently the U.S. Geological Survey (USGS) National Water Information System (NWIS) streamflow monitoring sites are integrated, and the tool also supports user-supplied streamflow data through a .csv file upload. Users must specify the location (latitude/longitude) of their monitoring location (for visualization reasons only).

From USGS NWIS (https://waterdata.usgs.gov/nwis), both daily average discharge and 15-minute "instantaneous discharge" (if it exists for a monitoring station) are auto-imported for a selected station. E-FRESH pre-processes 15-minute data for both the daily maximum (important for shear-stress and gravel bed system mobilization) and daily minimum (important for dry-out in flashy river systems) prior to display in the interface.

Stream Monitoring Station Selection

This section (Figure 11) shows a map that users can use to zoom into a specific area. Use the drop-down menu to choose how to select an area. Single clicking will move the map until users select a "Filter by Area" option.

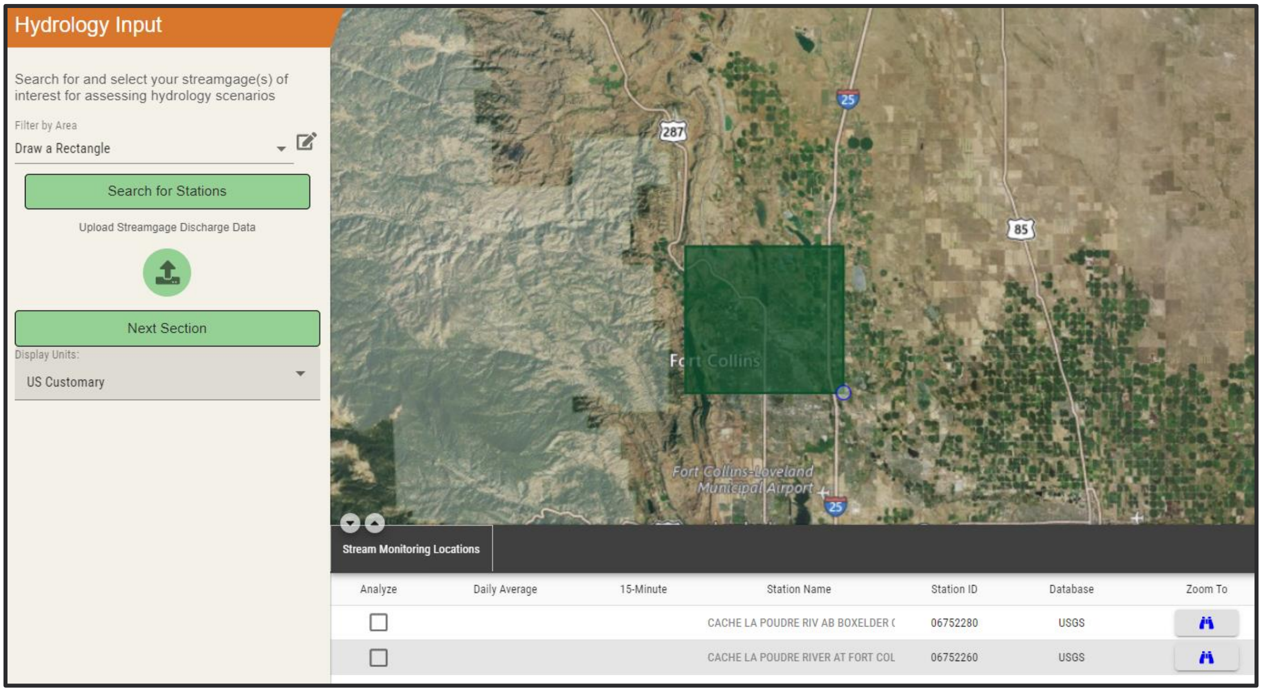

Figure 11: Environmental Flows for Riverine EcoSystem Habitats (E-FRESH) Stream Monitoring Stations

There are multiple methods for finding USGS stream monitoring locations utilizing different map interactions. Follow the instructions below per type of area filter, and when map interaction is complete, click "Search for Stations" button. This will actively check USGS NWIS if there are any stations within the area users specified, if so, they will appear in a list under the map (grey table in Figure 11).

Draw a Rectangle

The options for manual selection of the geographic region of interest include the area within a rectangle. This example is shown in Figure 11.

1. Select boundary type
2. Click to start drawing rectangle on desired map location
3. Click to end drawing rectangle

Draw a Line

The options for manual selection of the geographic region of interest include the area within a buffer of a line.

1. Select boundary type
    - Enter desired buffer radius
2. Place point(s) on desired map location

Draw a Point

The options for manual selection of the geographic region of interest include the area within a desired radius of a point (point buffer).

1. Select boundary type
    - Enter desired buffer radius (point or line)
2. Place point(s) on desired map location

Draw a Polygon

The options for manual selection of the geographic region of interest include the area within a free-hand polygon.

1. Select boundary type
2. Place point(s) (single click) on desired map location
3. End drawing and add final point by double click

Draw a circle

The options for manual selection of the geographic region of interest include the area within a desired radius of a hand drawn circle.

1. Select boundary type
2. Place point(s) on desired map location

Known Boundaries

Users can select a region from known boundaries such as states, counties, cities, or hydrological unit codes (HUCs).

1. Select "Known Boundary"
2. Select predefined boundary from drop-down list (states, counties, cities, HUC-8, HUC-10 or HUC-12 watersheds)

User-Supplied Layer

Users can upload a layer (shapefile).

1. Select "User-Supplied Layer"
2. Select a shapefile for upload from your device
    - All files associated with a shapefile can be zipped into a ZIP archive (*.zip) then uploaded, or multiple files can be uploaded at the same time outside of a ZIP archive

- Depending on the size of your file(s), it may take a few minutes to process

User Supplied Streamgage Discharge Data

Alternatively, if users have data for a specific station or their own stream flow data that they are interested in analyzing, use the green arrow (Figure 11) to upload a .csv file into the E-FRESH tool in the following format (date, discharge). Each .csv file needs to be named using the following format: "siteID_QscenarioID_units.csv" for example "Demo1_baseline_cms.csv" or "Demo1_scenario2_cfs.csv". These examples would be interpreted as user upload discharge data for site "Demo1" for a baseline condition of flows in cubic meters per second (cms) and a "scenario2" condition at the same site with flows in cubic feet per second (cfs). The system may take a few moments to process the information.

Tabs within Hydrology Input

After selecting an area of interest or uploading a stream discharge time series and selecting at least one station, two new tabs will become active (Hydrology and Scenario Editor). They are useful for reviewing available stream discharge data (Figure 12).

Stream Monitoring Locations

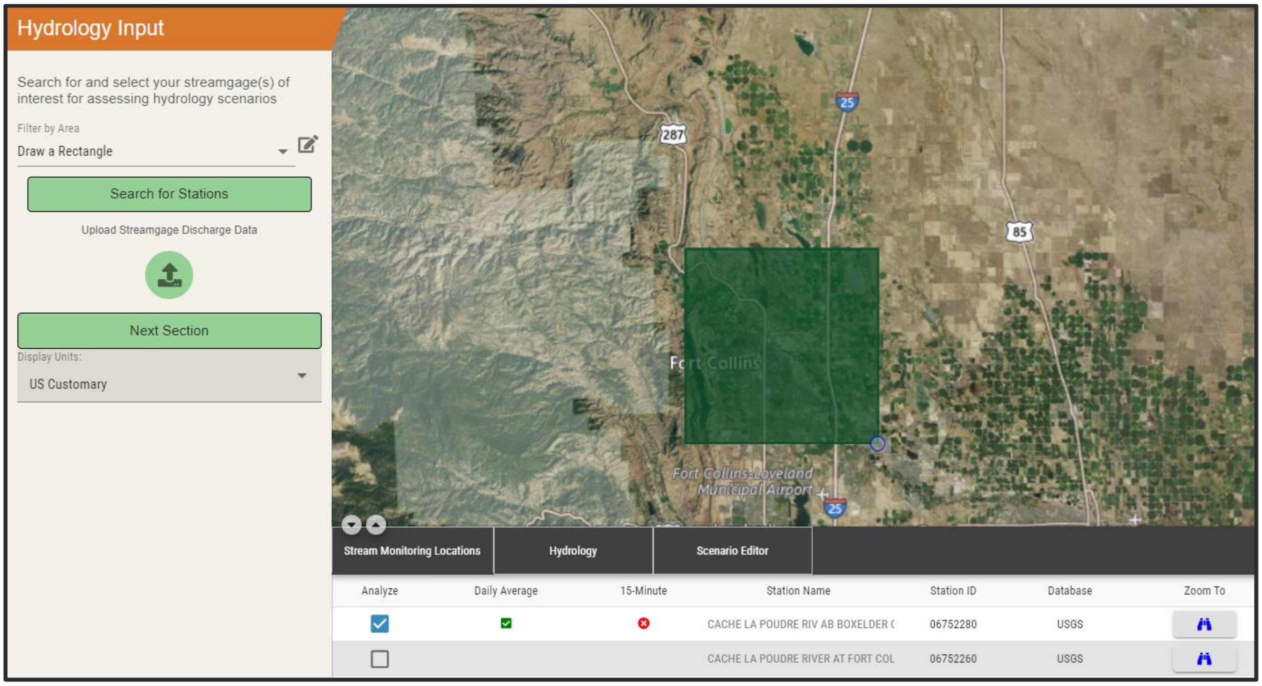

Figure 12: Environmental Flows for Riverine EcoSystem Habitats (E-FRESH) Review Streamgage Discharge Data

Hydrology

The Hydrology tab is intended for reviewing the discharge data associated with the selected station(s). Initially this page takes a moment to load, potentially several minutes depending on the size of analysis period. For the selected station(s), visualizations summarizing discharge data include a basic time series chart and a cumulative distribution frequency (CDF) graph (Figure 13), as well as an envelope plot and a heatmap (raster hydrograph) (Figure 14).

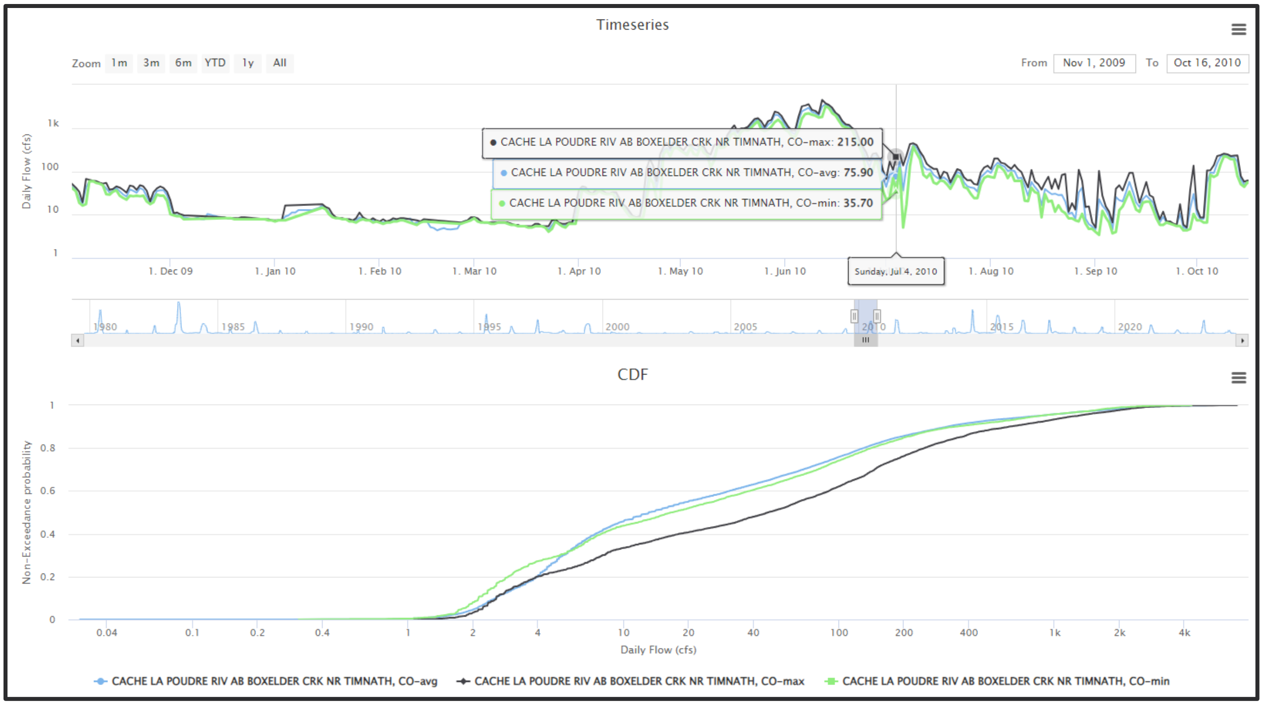

Figure 13: Environmental Flows for Riverine EcoSystem Habitats (E-FRESH) Hydrology Discharge Data Review – Time series and cumulative distribution frequency (CDF) graphs

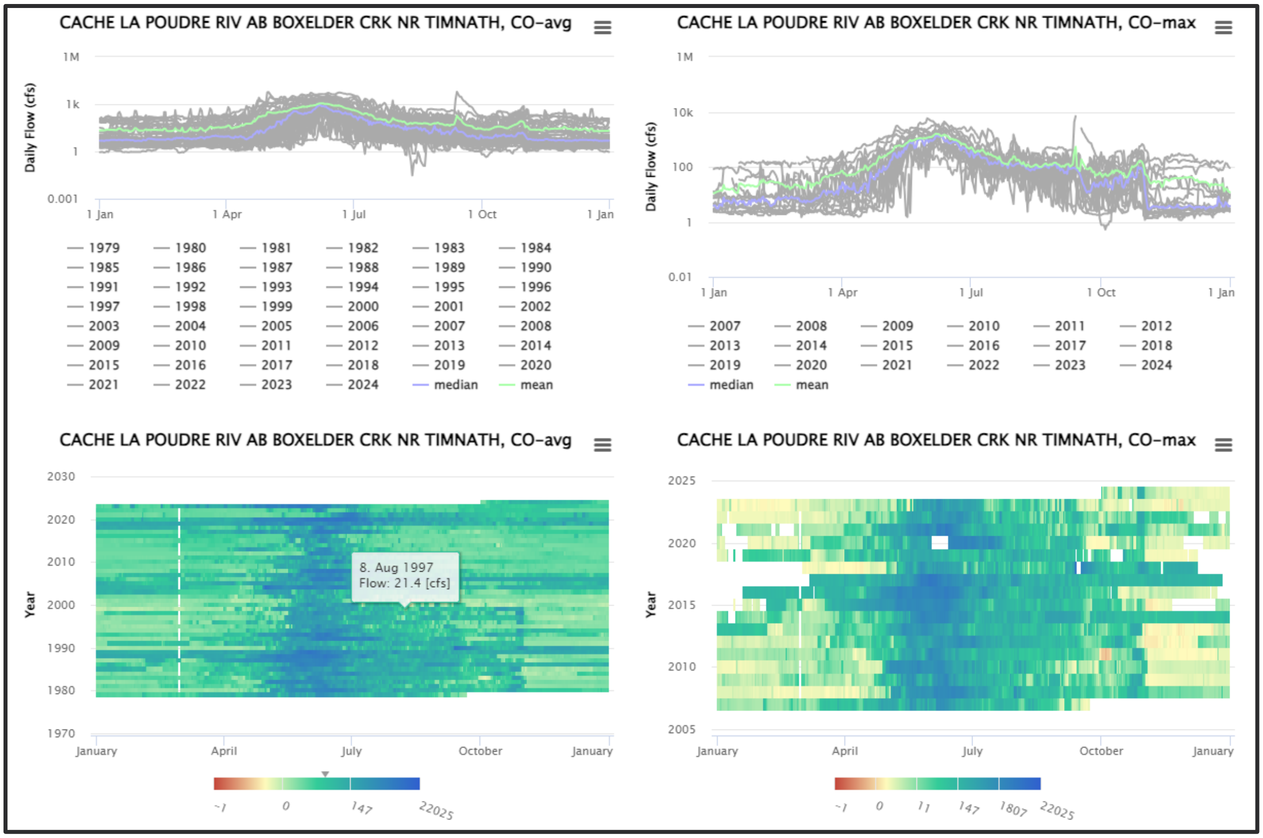

Figure 14: Environmental Flows for Riverine EcoSystem Habitats (E-FRESH) Hydrology Discharge Data Review – Time series Annual Comparison and Heatmap

Scenario Editor

After selecting a monitoring station and its associated data source, users can customize one or more hydrologic scenarios to assess. A "scenario" is an altered flow regime of interest for analysis; for example, peak flows above 1000 cfs are removed. There are numerous options shown in Figure 15 and detailed below, which allow side-by-side assessment of existing flows (daily average, daily maximum, daily minimum data [Figure 15]) as well as more complex scenarios like historic conditions versus potential future hydrologic conditions (e.g., water diversions or dam regulated streamflow). Users can also use the Scenario Editor to review different types of scenarios associated with that station. Make sure to name and save the scenarios for future use.

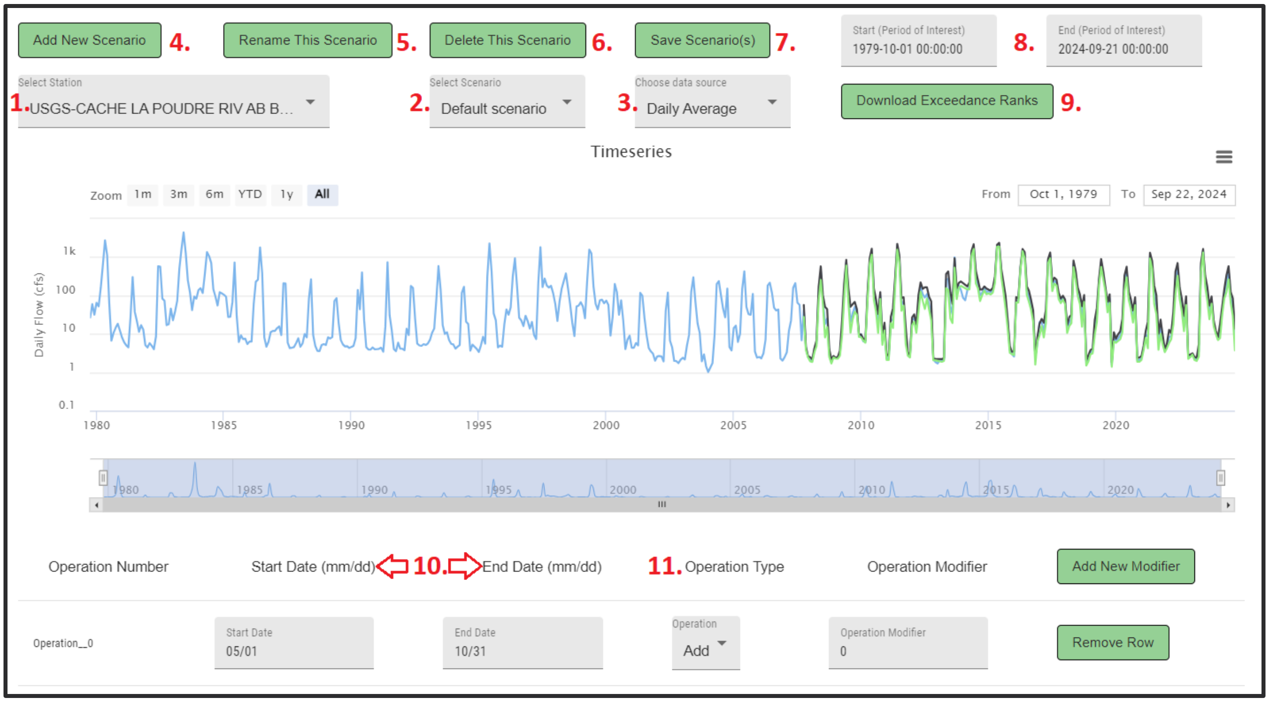

Figure 15: Environmental Flows for Riverine EcoSystem Habitats (E-FRESH) Hydrology Scenario Editor

Select Station

This option (#1 in Figure 15) allows users to pick which of the selected stations from the Stream Monitoring Locations tab to build or review a scenario for.

Select Scenario

This option (#2 in Figure 15) allows users to pick which of the scenarios to edit or review. Note that the very first time a station is selected, a “Default Scenario” will be generated for that station. The Default Scenario is the current existing flow regime (the supplied stream discharge data) with no modifications (period of interest, hydrologic modifiers, etc.).

Choose Data Source

This option (#3 in Figure 15) allows users to pick which data source to use from a stream monitoring location. Specifically, USGS monitoring locations may have both daily average discharge and 15-minute data available for assessment. In this case, the user can choose between using the daily average discharge value, the daily maximum or minimum (calculated from the 15-minute data), or a combination of the two (uses maximum/minimum from 15-minute data if available, otherwise uses daily average data). The latter allows for a longer assessment period since many daily average discharge records extend back multiple decades, if not a century, while 15-minute discharge data only exist for the last ~20 years of monitoring at ongoing stream monitoring locations.

Add New Scenario

This part of the tool creates new hydrologic scenarios for evaluating the effects of hydrologic flow regimes on habitat. This button (#4 in Figure 15) will allow users to create and name a new hydrologic scenario for evaluation.

Rename This Scenario

After creation of any number of scenarios, a user can load one with the Select Scenario option. At that point, they can use this button (#5 in Figure 15) to rename the scenario. This is useful in identifying the different scenarios the user may want to compare in final presentation of results in the Review Results section.

Delete This Scenario

After creating any number of scenarios, a user can delete the one currently selected with this button (#6 in Figure 15).

Save Station Scenarios

At any point, a user can save their current selection (data type, modifiers, etc.). Note that if the "Save Scenario" button (#7 in Figure 15) is not selected prior to leaving the tab or section of E-FRESH, any unsaved edits will be lost.

Period of Interest

The top left of the page (#8 in Figure 15) provides a selector for the period of interest. Users may enter a start and/or end date (yyyy-mm-dd format) to restrict E-FRESH's calculations to only the period selected rather than the entire period of record. In the case of leveraging 15-minute data, this input will eventually, but does not currently, allow clipping of the discharge record to a particular date-time stamp.

Download Exceedance Ranks

An important part of understanding streamflow statistics, and of particular interest to riparian vegetation analyses, are exceedance probabilities (the likelihood a given flow will be equaled or exceeded). E-FRESH calculates exceedance and non-exceedance probabilities for the initial gage record, as well as each user-defined/modified hydrology scenario available. These probabilities can be used in E-FRESH with riparian logistic regression equations (for probability of occurrence of a particular species), and they may also be downloaded (#9 in Figure 15) for use outside of E-FRESH. These calculations are made using a Weibull Plotting Position tied-rank-maximum methodology (Weibull 1939 and Helsel et al 2020).

Scenario Modifier Operations

There are multiple types of modifications a user can make to a hydrologic scenario (#10 and #11 in Figure 15). These options give flexibility to include diversions, augmentations, or dam management scenarios.

- "Add": Use the "Add" option to augment or divert (add negative numbers) water in a stream.
    - For example, this modifier can be used to analyze environmental flows, where additional water is kept in-river as water rights are reapportioned, as well as diversions, where ditches remove water from a river. This modifier can be applied to an entire flow record (January 1 to December 31) or a limited period of time or season.
- "Multiply": Use the "Multiply" option to analyze proportional changes in flow; numbers greater than 1 increase flow, while numbers less than 1 decrease flow.
    - For example, this modifier can be used to assess the potential streamflow changes from climate change (a 7% reduction in streamflow would be entered as 0.93 while a 2% increase in stream flow would be entered as 1.02) across the whole period of analysis or a particular period (spring gets more water, summer gets less water, or other examples).
- "Enforce Maximum" and "Enforce Minimum": These modifiers operate similarly; the user specifies a maximum or minimum flow within a river. These operations are intended to assess the effects of future water diversions and/or dam management.
    - For example, a new or revised dam operation may limit future low flows to no-less than 12 cfs. To assess this management action in E-FRESH, an "Enforce Minimum" modifier of 12 would be entered. Similarly, if new management of a river system reduces flooding risks and limits flooding to no more than 10,000cfs, an "Enforce Maximum" option of 10,000 would be entered.

HYDRAULIC INPUT

The E-FRESH DST utilizes numerous types of spatially explicit data for integration of hydraulic modeling. Specifically, E-FRESH is designed to integrate and assess both 1D and 2D hydraulic modeling results to output the amount of potentially available habitat area for each species under each flow scenario as well as the flow effects on the probability of occurrence of riparian vegetation. As such, the Hydraulic Input section of E-FRESH (Figure 16), begins with the selection of the type of assessment (1D or 2D hydraulic model) followed by the upload and review of those results.

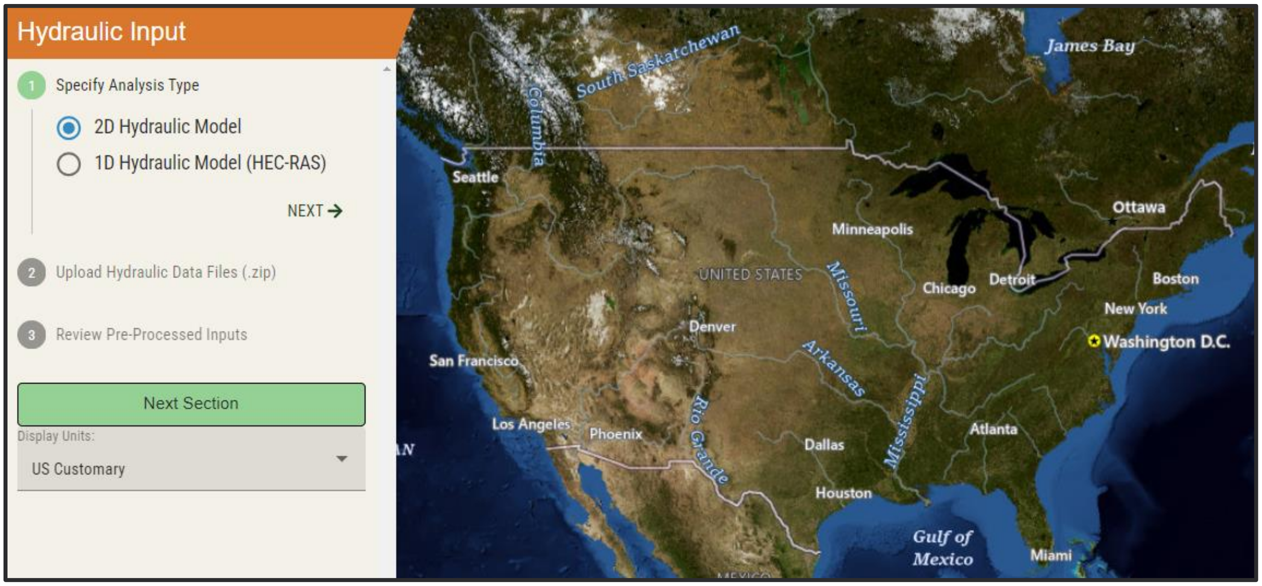

Figure 16: Environmental Flows for Riverine EcoSystem Habitats (E-FRESH) Hydraulic Input Section

Specify Analysis Type

E-FRESH was designed for generic compatibility with both 2D and 1D hydraulic model outputs. Use this section to specify what kind of hydraulic model users are working with. Generalized support for 2D hydraulic model results is provided in the 2D Hydraulic Data Upload section by importing and pre-processing these data. Some examples of 2D hydraulic models include Flow and Sediment Transport with Morphological Evolution of Channels (FaSTMECH), Nays2D, and Hydraulic Engineering Center - River Analysis System (HEC-RAS) 2D model outputs. Additionally, E-FRESH was expanded beyond this to support assessment of 1D HEC-RAS models (version 6.1 through 6.4), one of the most common 1D step backwater hydraulic models utilized by river managers in the United States and worldwide.

Upload Hydraulic Data Files (ZIP)

If users are working with their own data, upload the corresponding data files. If users are working from a project for which hydraulic data have already been uploaded, this section will load the status and summary of those data. In the case of 2D analyses, the input of hydraulic data will take a while to process, potentially several hours depending on the data size and file type in order to convert .csv content into spatially explicit raster map files (.tifs). During this loading process, the left panel of the Hydraulic Input section will have a status message (Figure 17).

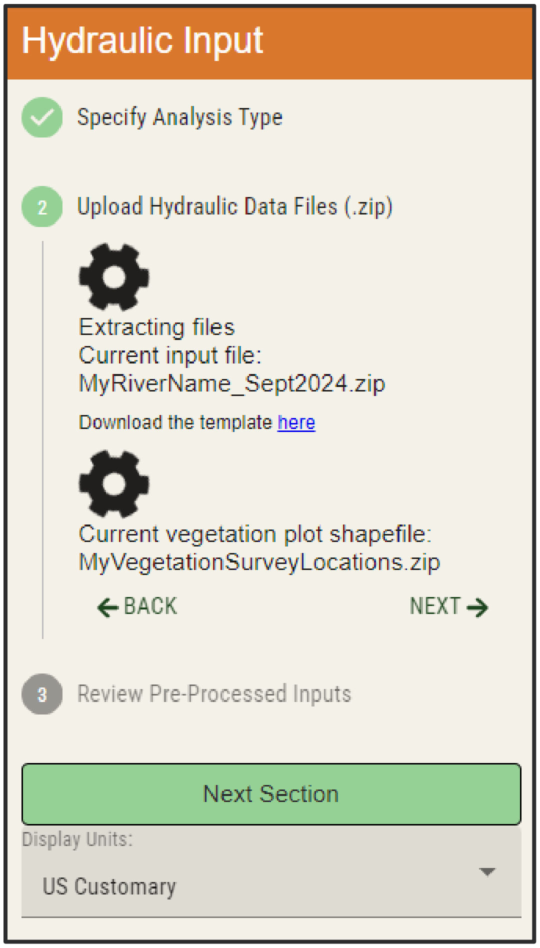

Figure 17: Environmental Flows for Riverine EcoSystem Habitats (E-FRESH) Screen During Upload of Hydraulic Data Files

2D Hydraulic Data Upload

The E-FRESH DST is designed for generic compatibility with most 2D hydraulic models. To support this, it handles the upload of both .csv file data of hydraulic properties (depth, velocity, shear stress) at spatial locations (*x*,*y*) exported from a 2D model (grids or triangular irregular networks [TINs]) as well as the direct upload of rasters (.tif) of hydraulic properties. Use of the .csv file format simplifies upload of large spatial datasets related to 2D hydraulic modeling. These outputs need to be arranged as described in the next section, and an example template file is also available for download from the Hydraulic Input page.

Additionally, regardless of file format of uploaded hydraulic data, a digital inundation map (DIM: map of inundating discharges per map location representing the discharge at which a particular cell is wetted) is also calculated and available for download in Download Digital Inundation Map (DIM). Upon selection and upload of hydraulic modeling results, users will specify their unit types. E-FRESH supports either upload of U.S. Customary units (cubic feet per second [cfs] and corresponding depth in feet and velocity in feet per second) or SI units (cubic meters per second [cms] and corresponding depth in meters and velocity in meters per second).

2D Upload: CSV Data

In the event a user wants to upload .csv files of point-based 2D hydraulic model results, E-FRESH anticipates a zipfile containing multiple .csv files and the base-DEM (digital elevation model) that was used to construct the hydraulic model (used for map extent while generating each input raster). Each .csv file needs to be named using the following format: "siteID_Qvalue_units.csv" for example "Demo1t_00001.0_cms.csv". This example will be interpreted as hydraulic model data for site "Demo1" (should correspond to the project location entered in the Project Management) and hydraulic data (depth/velocity) for the modeled discharge of 1.0 cubic meter per second (cms).

At a minimum these .csv file uploads need to contain the following column headers (case insensitive) in any order, additional columns may be present but will be ignored at this time and simply contribute to large files and slow upload speeds.

- X: the x-coordinate of the grid cell center (easting or longitude coordinate)
- Y: the y-coordinate of the grid cell center (northing or latitude coordinate)
- Depth: The hydraulic model's depth output for this grid cell and discharge in the units specified by the file name (if "cms" then depth is expected in meters; if "cfs" then depth is expected in feet)
- Velocity: The hydraulic model's velocity output for this grid cell and discharge in the units specified by the file name (if "cms" then velocity is expected in meters per second; if "cfs" then velocity is expected in feet per second)

After uploading the zipfile, E-FRESH will enter its Pre-Processing step and begin to rasterize the .csv data for each habitat metric. These rasters are generated using the same projection system and cell size as the DEM included with this upload.

2D Upload: Raster Data

In the event a user wants to upload .tif files (rasters of hydraulic grid data), E-FRESH anticipates a zipfile containing multiple .tif files and the base-DEM that was used to construct the hydraulic model (used for map extent while generating the DIM). Each .tif file needs to be named using the following format: "siteID_Qvalue_units-HydraulicProperty.tif." For example, the file name "Demo1_00001.0_cms-depth.tif" will be interpreted as hydraulic model data for depth at site "Demo1" (should correspond to the project location entered in the Project Management) at the modeled discharge of 1.0 cms. A second .tif file, "Demo1_00001.0_cms-velocity.tif," is anticipated to complete the upload of relevant hydraulic data (depth and velocity) for this discharge.

After uploading the zipfile, E-FRESH will enter its Pre-Processing step and begin to generate the DIM for later review.

1D Hydraulic Data Upload

Additionally, E-FRESH has been designed to integrate with the 1D hydraulic model: HEC-RAS 6.1 through 6.4. HEC-RAS has a number of different export types handling both cross-section averaged hydraulic properties (hydraulic depth, average velocity) and subsection depth and velocity, so E-FRESH has been designed to integrate either output. As a result, the format for the outputs from HEC-RAS vary based on which HEC-RAS model "type" is being used.

Simple

The so-called "simple" version of 1D Hydraulic Data Upload refers to support for the common type of HEC-RAS models that do not contain "subsections" and thus represent cross-section averaged hydraulic properties (hydraulic depth, not actual depth). The files required for inclusion and upload to E-FRESH in a zipfile are the following:

1. The HEC-RAS geometry file ".g0#" used in the model
2. A shapefile of the cross-section locations
3. A text file containing the hydraulic properties result data (hydraulic depth, velocity, discharge, area, etc.).

#1 and #2 are combined to determine spatial locations (*x*,*y*) of each station-elevation pair in the HEC-RAS cross-section geometry file. This step is necessary because frequently there are differences in the total number and location of vertices of the shapefile's "polyline" compared to the actual number of points in a cross section. This is further combined with #3 to have a spatial representation of cross-section hydraulic properties like depth (as measured from water surface elevation to cross-section elevation) from which to compute inundating discharge and frequency of inundation. The following instructions illustrate how to export the results text file from HEC-RAS:

From the HEC-RAS interface, similar to the one shown in Figure 18, select the results table viewer, identified by the red rectangle.

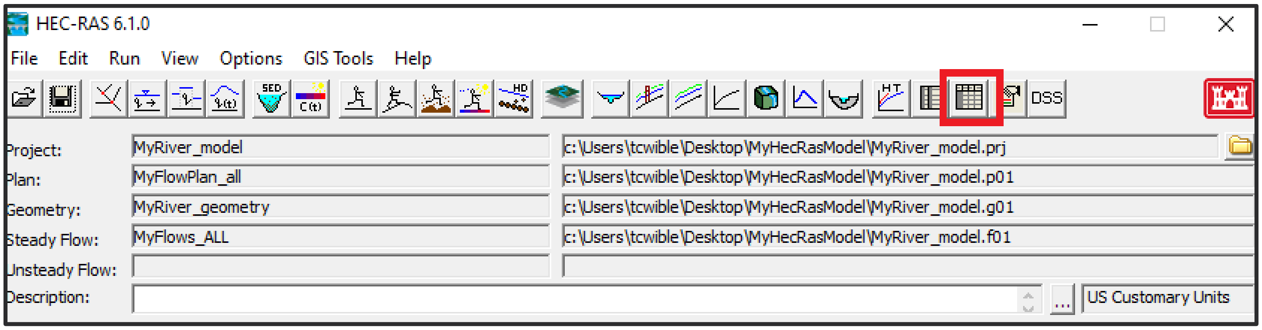

Figure 18: Hydraulic Engineering Center - River Analysis System (HEC-RAS) Review Simple Results for Export

Then adjust the results viewer to include all the flow profiles modeled, red rectangle (Figure 19) as well as all of the cross-section locations.

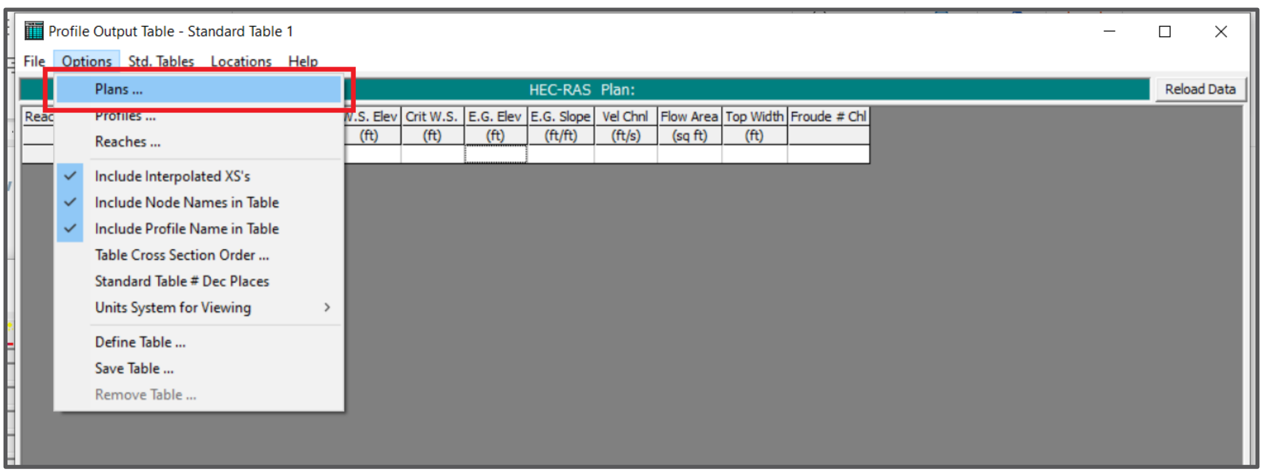

Figure 19: Hydraulic Engineering Center - River Analysis System (HEC-RAS) Select Flow Plans for Simple Export

Finally, export this content to a text file (Figure 20) for inclusion in upload to E-FRESH.

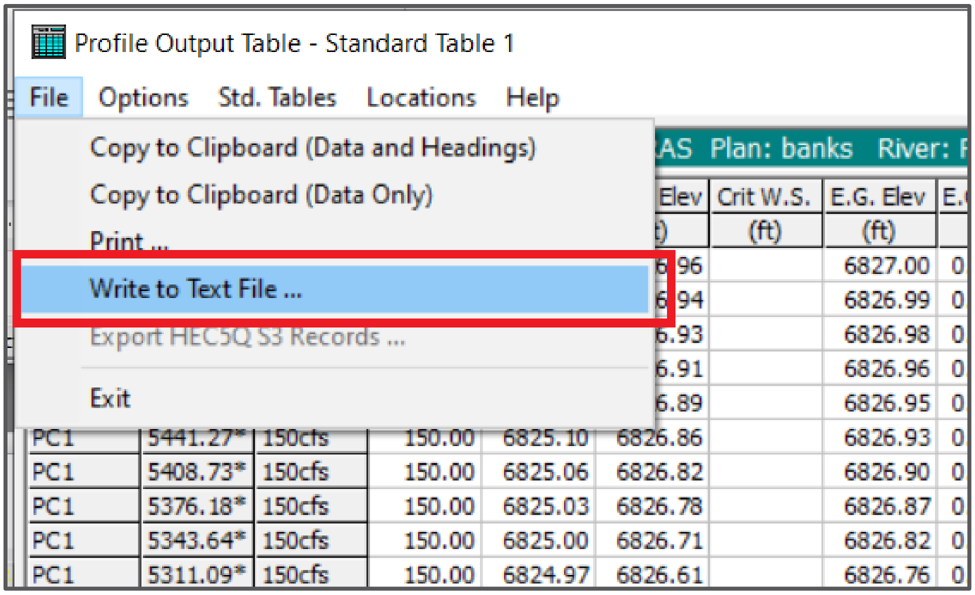

Figure 20: Hydraulic Engineering Center - River Analysis System (HEC-RAS) Simple Export

Advanced

The "advanced" version of 1D Hydraulic Data Upload refers to the upload of HEC-RAS models with cross sections that are sliced into subsections which adds a higher resolution to the model output (each slice has a calculated depth, velocity, shear stress, etc.). This higher resolution is an improvement over the cross-section-averaged habitat metrics (hydraulic depth, cross-section averaged velocity, and total cross-section area). The precise calculation of hydraulic parameters within a cross section through this "advanced" 1D model allows E-FRESH to better analyze changes in habitat for aquatic and riparian species. An "advanced" 1D HEC-RAS model requires the following files to be uploaded to E-FRESH:

1. The HEC-RAS geometry file ".g0#" used in the model
2. A shapefile of the cross-section locations
3. A .pdf file containing the hydraulic properties result data (hydraulic depth, velocity, discharge, area, etc.) for each subsection at each flow.

To generate the .pdf file of the hydraulic outputs from HEC-RAS users first need to click "View detailed output at XS, culverts, bridges, weirs, etc." (red rectangle in Figure 21).

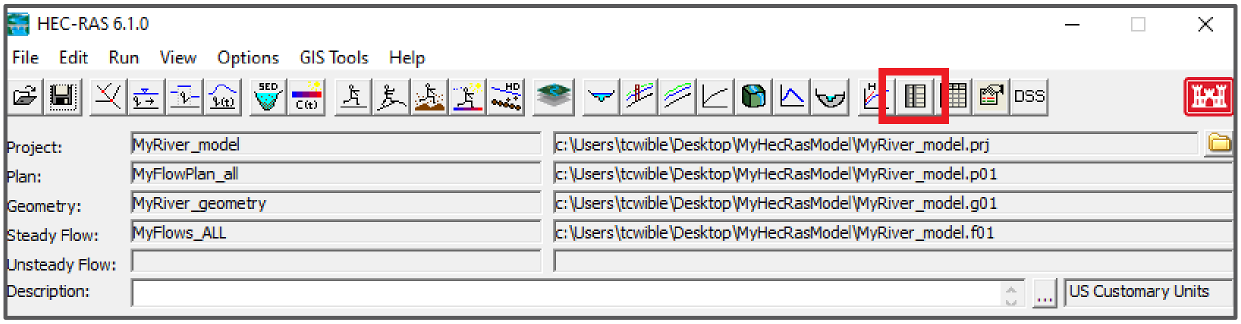

Figure 21: Hydraulic Engineering Center - River Analysis System (HEC-RAS) Review Advanced Results for Export

Then switch “type” from “Cross Sections” to “Flow Distribution in Cross Sections” (red rectangle in Figure 22). Also, select the “Plan” users desire to output (red oval in Figure 22), which should be a series of flows covering the same range of conditions measured in the streamgage record reviewed in the Hydrology.

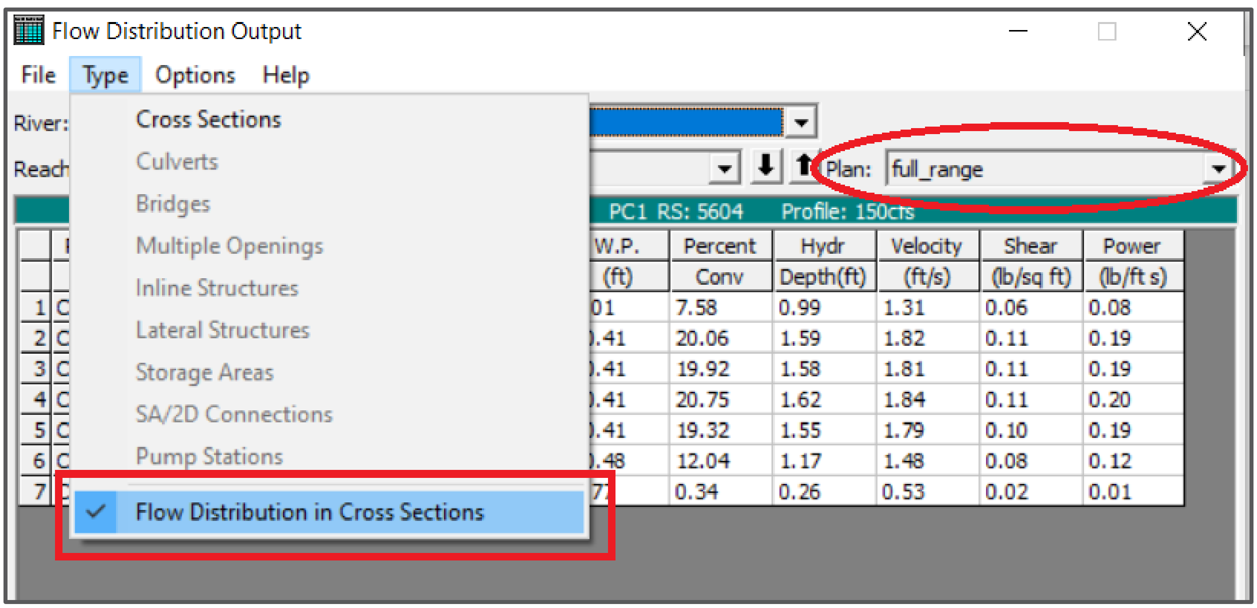

Figure 22: Hydraulic Engineering Center - River Analysis System (HEC-RAS) Select Type of Advanced Export

Users can now begin to export this content from HEC-RAS to .pdf, shown in Figure 23, using the “Print multiple” to file option.

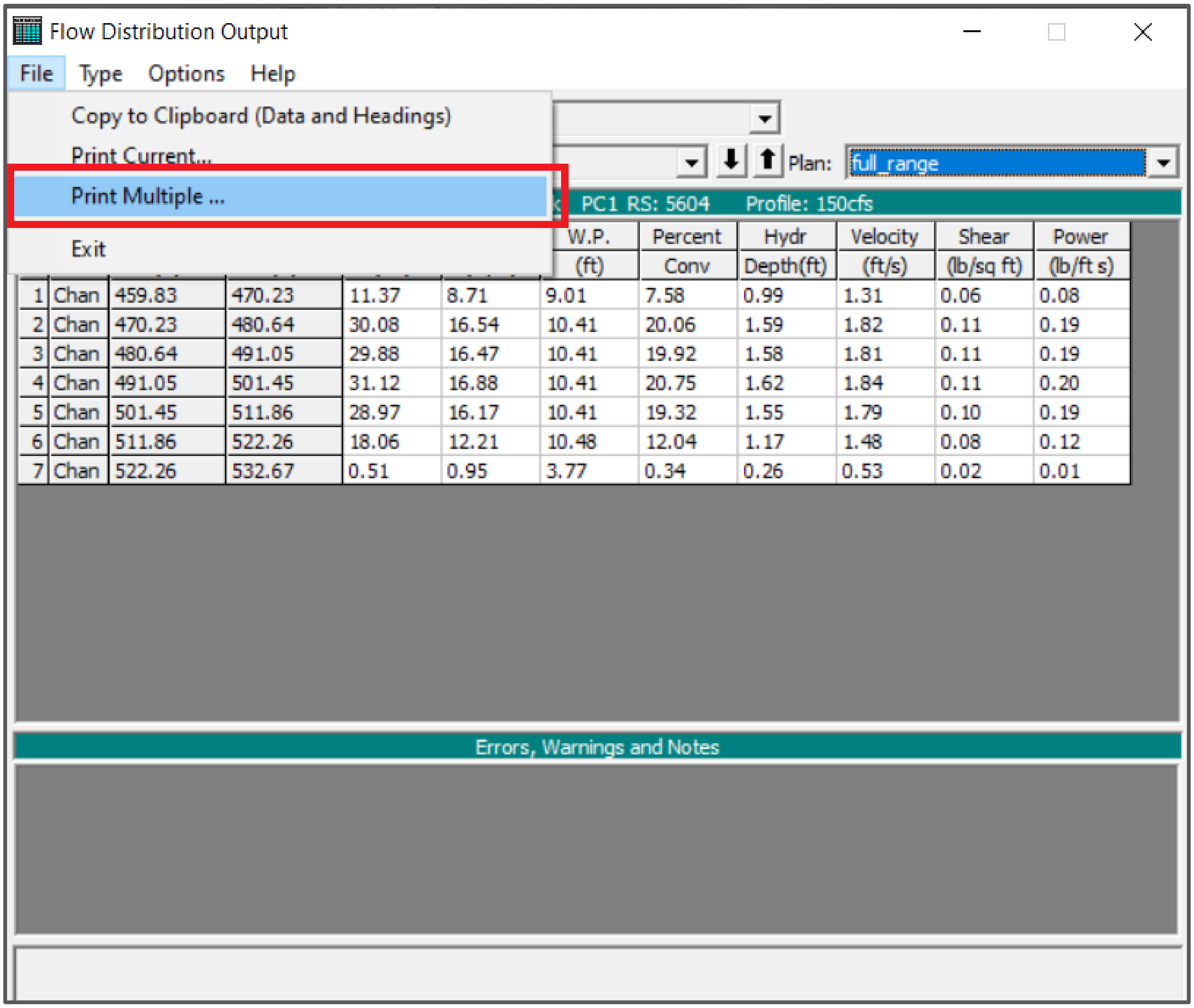

Figure 23: Hydraulic Engineering Center - River Analysis System (HEC-RAS) Advanced Export "Print Multiple" results to file

This option will open a selection for which profiles (individual discharges) within the selected plan (set of discharges) users want to export. As shown in Figure 24, you should select all of the profiles available for export.

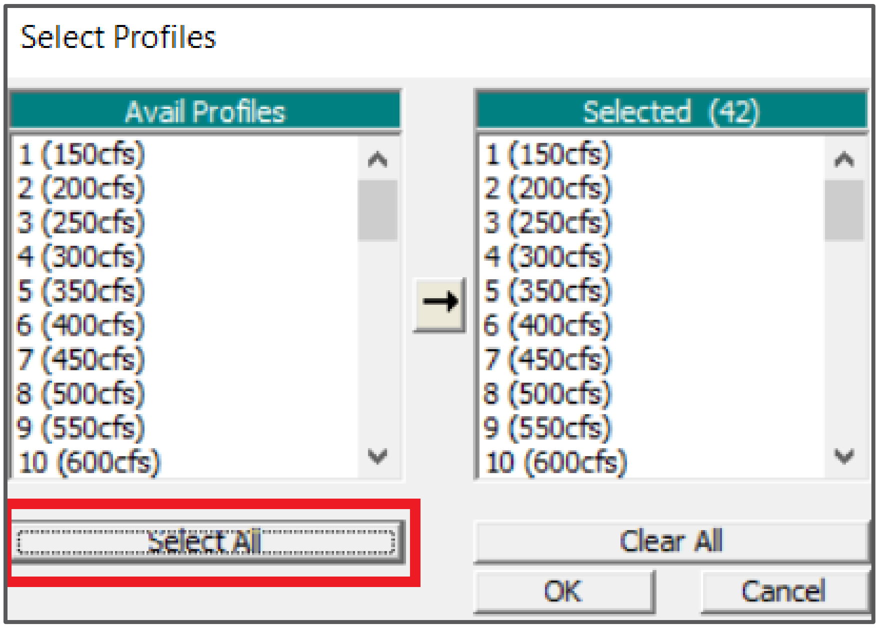

Figure 24: Hydraulic Engineering Center - River Analysis System (HEC-RAS) Select Individual Discharge Profiles for Advanced Export

Similarly, users will need to select all the cross sections for export. It is recommended to include both the surveyed cross sections and the interpolated cross sections to give a better coverage of the river system for habitat assessment. Click "Select All" to choose all sections, as shown in Figure 25.

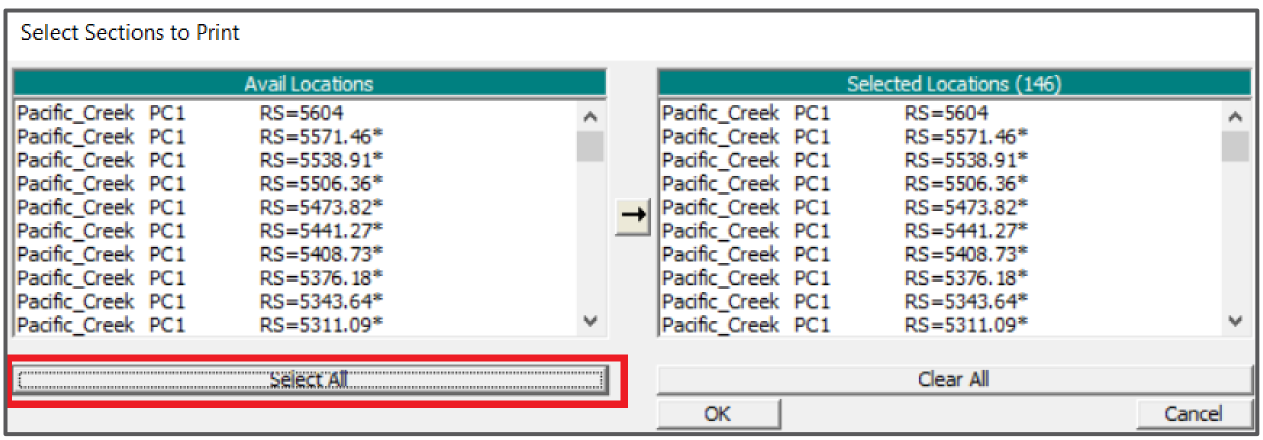

Figure 25: Hydraulic Engineering Center - River Analysis System (HEC-RAS) Select Individual Cross-Sections for Advanced Export

Finally, users can print the export content to .pdf (not to an actual paper printer) for upload and use in E-FRESH. Make sure to use the "Microsoft Print to PDF" option as shown in Figure 26 so that the file is in the right format to be integrated.

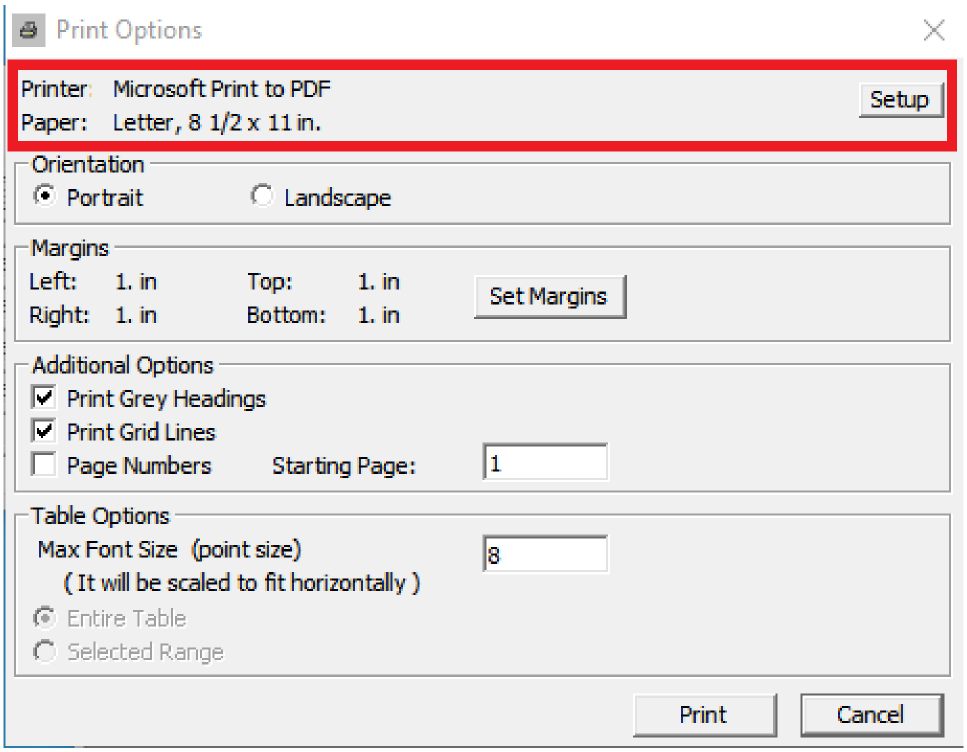

Figure 26: Hydraulic Engineering Center - River Analysis System (HEC-RAS) Advanced Export to PDF

Once users click “Print,” please wait while HEC-RAS loads because it may take several minutes depending on the number of cross sections and interpolated cross sections as well as subsections and number of flow profiles. Once the resulting .pdf file (which can be hundreds of pages long) is ready, include it in the upload for E-FRESH.

Vegetation Plot Data Upload

Vegetation Plot locations can be added to either the 2D or 1D HEC-RAS E-FRESH models. This upload option expects the selection of a zipfile containing one or more point-shapefiles (.cpg, .dbf, .prj, .shp, .shx files zipped together) for plot locations within the hydraulic model’s extent.

These are used as additional locations where input and output data from E-FRESH are summarized. In the Exceedances tab, the inundating discharge and associated exceedance/non-exceedance (frequency) for each plot location (in each shapefile) is summarized in the file from the Download Exceedance Data option. Further, in 1D HEC-RAS models, in the Cross-Section Results of the Results section of E-FRESH, the habitat suitability for each selected species will be displayed for each cross-section and each grouping of these vegetation plots.

Pre-Processing

After uploading the hydraulic data, regardless of 1D or 2D format, it will be pre-processed for use in E-FRESH. For 1D projects, this pre-processing includes reading the multiple input files and formats (.txt, .shp, .pdf, .g01) and aggregating its information into a simpler format for the model to use. In the case of 2D hydraulic data, if rasters are uploaded, they will be pre-processed for their relevant usage. However, if .csv file data is uploaded for 2D hydraulic data, this pre-processing step will generate raster files to use for modeling and display of results. This may take a while (minutes to multiple hours), and this section of the tool will include a status message that is continuously updated to indicate which file is currently being processed.

After uploading and pre-processing hydraulic data, a user may return to this section to upload one or more additional vegetation plot surveys (a point shapefile) of locations where they need hydrologic information (inundating discharge and corresponding exceedance/non-exceedance frequency of that value for a particular hydrologic scenario). This information is typically useful in the generation of riparian vegetation probability of occurrence equations. See Appendix A for more details on this example use case.

Review Pre-Processed Inputs

Once the data are processed, several outputs are available as shown in Figure 27, including a downloadable map or raster file of inundation extents.

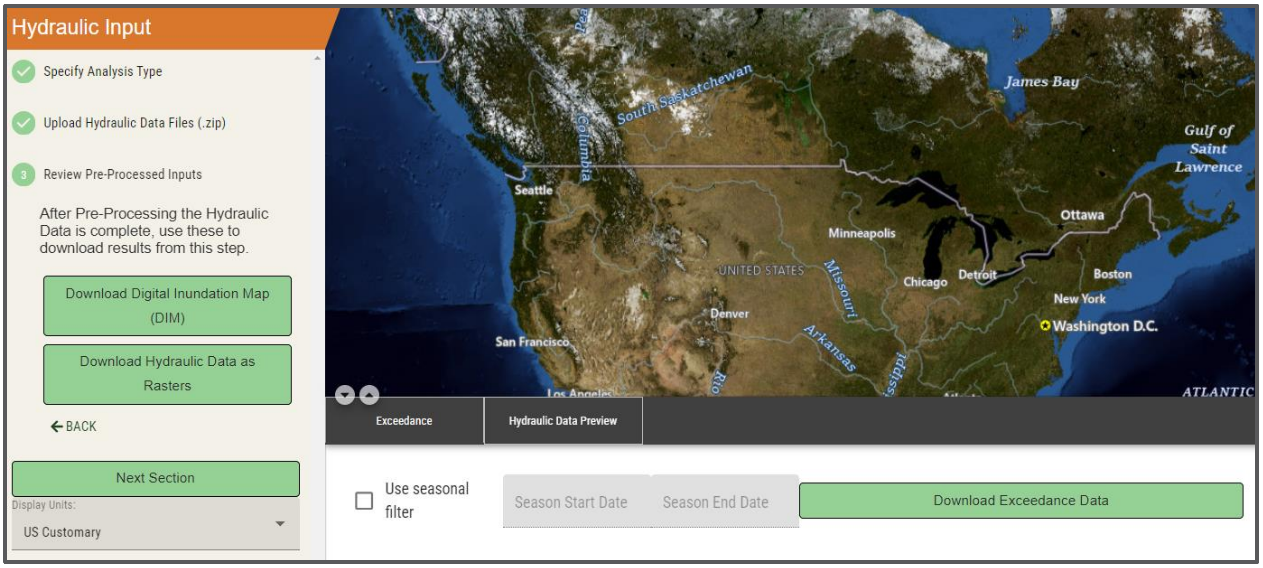

Figure 27: Environmental Flows for Riverine EcoSystem Habitats (E-FRESH) Hydraulic Review and Exceedance Tab

Download Digital Inundation Map (DIM)

This is available for 2D hydraulic model projects only.

The pre-processing of 2D rasters or .csv hydraulic data includes the generation of a DIM giving the discharge for each pixel in the raster that is inundated by the river. Please note some locations will never be inundated at the modeled discharges (i.e., they will always stay dry for the flows modeled in the hydraulic model). The resulting raster, a .tif file, is available for download at this point.

Download Hydraulic Data as Rasters

This is available for 2D hydraulic model projects only.

If .csv data are uploaded to E-FRESH, then it will generate .tif files for each hydraulic property (depth, velocity, etc.) and modeled flow (matching the input .csv files). These results can be downloaded once available based on the status bar described in the Pre-Processing section. Please note, this may be 100 gigabytes of data, so be sure to click this download button only when on an internet connection with sufficient bandwidth (i.e. 100 to 500Mbps connection).

Download Reformatted Hydraulic Data

This option is available for 1D HEC-RAS hydraulic model projects only.

Similar to the 2D model specific Download Output TIFFs section, this section downloads the reformatted HEC-RAS data (.txt, .g01, .pdf, .shp) pre-processed and reformatted for ease of use in E-FRESH in a new format (.json).

Tabs Within Hydraulic Input

Exceedances

This tab (Figure 27) leverages the stream monitoring location discharge data and associated scenarios generated in the Hydrology Input to generate exceedance data for each of the hydrologic scenarios. There is an option here to include a season in the assessment. This option is useful for generating metrics like spring flows that are pertinent to many riparian vegetation species and guilds.

For 2D hydraulic data, the exceedance data are presented in exceedance raster maps (.tif files). For 1D hydraulic data, the exceedance data are presented in a .csv file with an entry for each cross-section point and its associated inundation, exceedance, and non-exceedance per hydrology scenario.

Download Exceedance Data

This button downloads a zipfile containing exceedance data, per hydrologic scenario, for the specified analysis period and optionally the season.

Hydraulic Data Preview

For 2D hydraulic data, users can also use the data to run an animation of flow in the E-FRESH map on this tab of the Hydraulic Input section using the "Load Animation Map" button (Figure 28). The first time the animation loads, it may take a couple passes through the animation for it to load completely, based on users' internet bandwidth. Controls for the animation include "Play/Pause," "Slow down," and "Speed up" buttons. If users wish to clear the preview from the map, click the "Unload Animation Map" button. A single flow can be selected using the "Flow Value" drop-down.

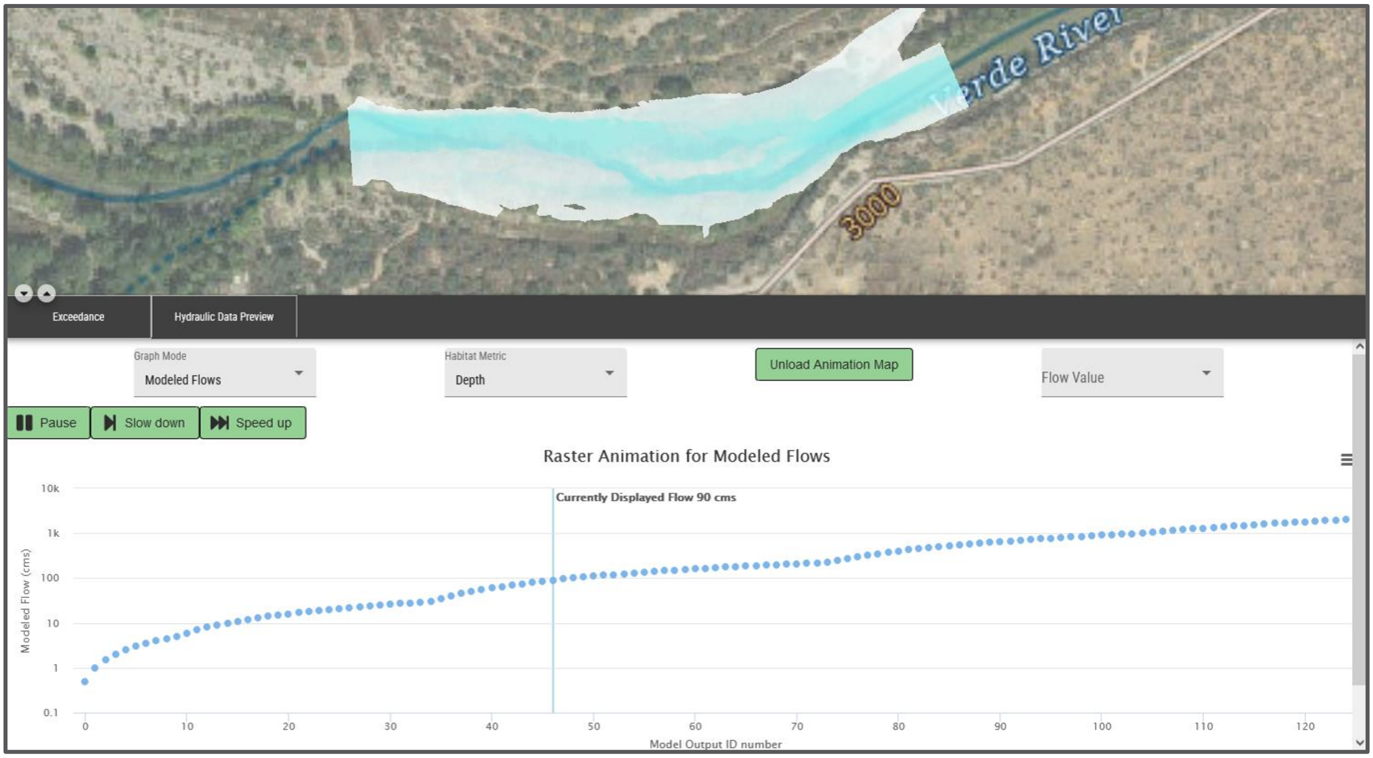

Figure 28: Environmental Flows for Riverine EcoSystem Habitats (E-FRESH) Hydraulic Data Preview

This animated preview of the hydraulic data is available for all of the hydraulic data (sorted smallest to largest) as well as for a selected period of a hydrograph to provide a sense of the river filling and draining based on the combined hydrologic scenarios and hydraulic data. These visualizations can be used to help convey river flooding and floodplain connectivity in review of large events in the watershed, changes to flow regimes, as well as channel connectivity at low flow conditions.

This animation method is planned, but not yet available for 1D cross sections.

Habitat Suitability Input

The habitat suitability input section (Figure 29) of the tool is where the user provides information about the relationship between the abundance or suitability of a species and the various environmental factors within a habitat (depth, velocity, substrate, flow exceedance). Habitat suitability curves (HSCs) are used to assess and predict the quality of habitats for specific organisms under varying flow conditions. These curves help researchers and resource managers understand how environmental variables influence the distribution and abundance of suitable habitat for a given species and category (life stage or other grouping).

Species specific habitat conditions can be pre-loaded from E-FRESH's existing database of location-specific habitat suitability curves, or users can add new species and their associated habitat needs. This section (Figure 29) is broken out to handle three primary types of species habitat (Aquatic, Riparian, and Macrohabitat) as well as their individual habitat suitability parameters.

Habitat suitability input is broken out into two primary sections (Figure 29):

1. Select and Review the habitat suitability for each species (red rectangle in Figure 29)
2. Select and Process the HSCs to the hydraulic data (blue rectangle in Figure 29) and calculate the corresponding area of suitable habitat as a function of flow (habitat time series) in the hydraulic data based on the hydraulic properties of suitable habitat (depth, velocity, exceedance, and non-exceedance)

Habitat time series and weighted usable area (WUA), first introduced in the Instream Flow Incremental Methodology (IFIM) by Bovee et al. (1998), are used to determine the amount of suitable habitat that is available for a species over a range of discharge values. WUA is calculated by assessing how different flow levels create usable habitat for target species (like fish) using habitat suitability indices that range from 0 (not suitable) to 1 (suitable). When habitat suitability criteria are delivered in binary format (0 or 1), meaning habitat quality is not considered (Bovee 1986), habitat area may simply be the sum of suitable area in the reach.

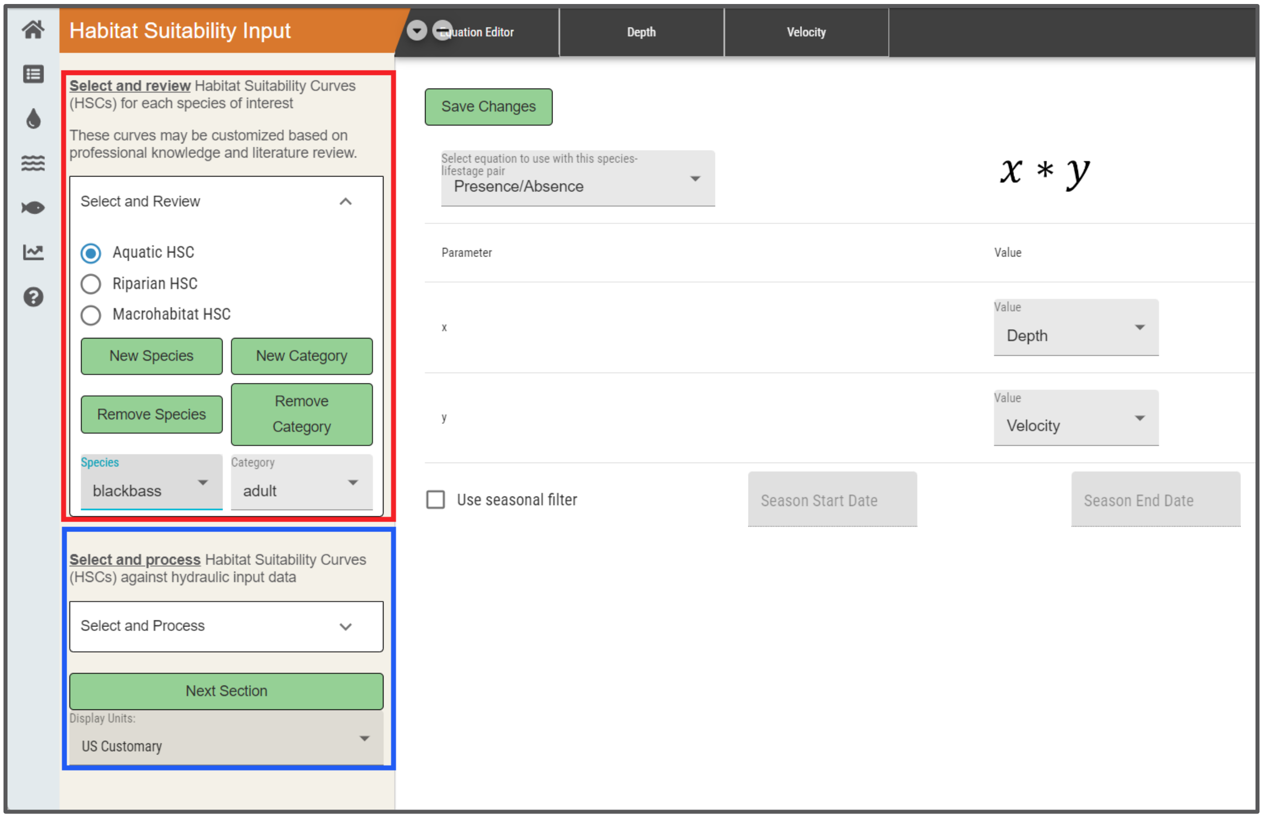

Figure 29: Environmental Flows for Riverine EcoSystem Habitats (E-FRESH) Habitat Suitability Curve (HSC) Select and Review versus Select and Process

Select and Review

This portion of the E-FRESH tool (red rectangle Figure 29) looks at the suitability for either species groups or individual species based on your data input. Users can select from the tabs in the grey menu bar to review or edit the depth and velocity HSC information.

Users can review or edit suitability for aquatic, riparian, or macrohabitats. Users do not need to choose a species from all three, but users can choose all three if they wish. The left panel in this section (Figure 29) includes selection of which species to review. Each selection is detailed below.

Aquatic Species

This section is formatted to support assessing the necessary habitat for aquatic species in a riverine system (Figure 30). This section relates mostly to the depth, velocity, and shear stress present in a river system for some duration of time (a life span, a month, during spawning, etc.). Examples of these species include fish and anurans (frogs/toads) that typically require some level of fast- or slow-moving water with a particular depth for feeding, spawning, hatching, avoiding predators, and more.

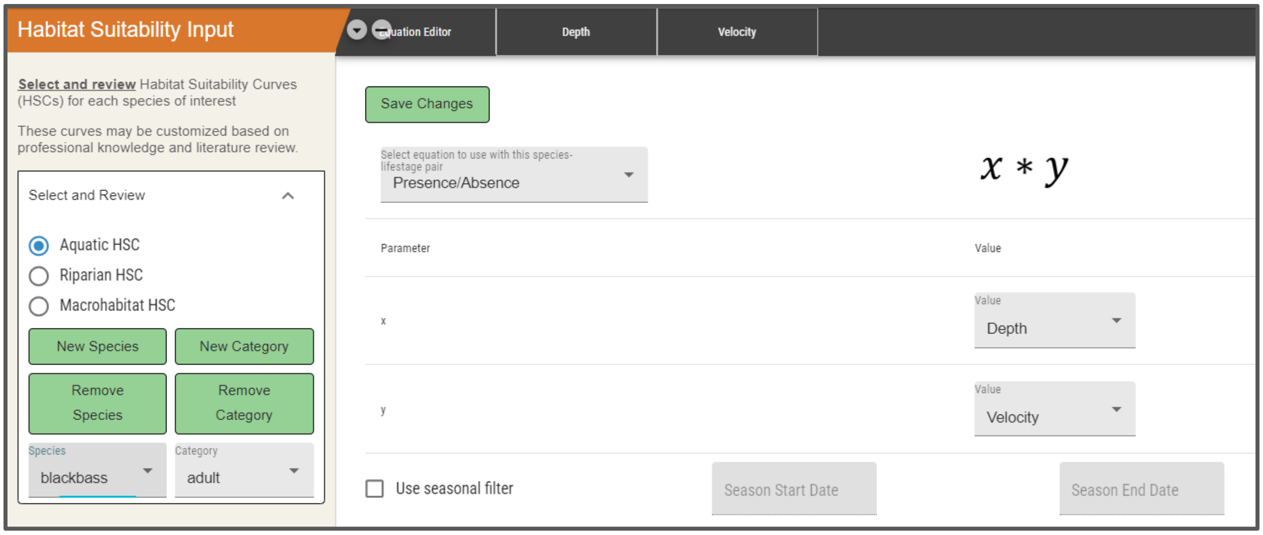

Figure 30: Environmental Flows for Riverine EcoSystem Habitats (E-FRESH) Select and Review Aquatic Habitat Suitability Curve (HSC)

Species

This selection includes the individual species or species group to be assessed.

Category

This selection reflects the particular life stage or other category for assessment reflecting the changing needs of aquatic species like fish as they move from the life stages of incubation, adult fish, and spawning.

Riparian Species

This section (Figure 31) is set up to assess either guilds (*sensu* Merritt *et al.* 2010) of similar species of riparian vegetation or individual species needs (e.g., plains cottonwood trees versus narrow-leaf cottonwood trees). Because riparian plants occupy surfaces that are not inundated most of the time, presence of these species is more likely to be correlated to frequency of inundation than to depth or velocity.

Examples of riparian vegetation include guilds like xeric shrubs that typically require a characteristic frequency of inundation to sustain vegetation. An example of the steps for identifying and integrating riparian vegetation habitat suitability is included in Appendix A.

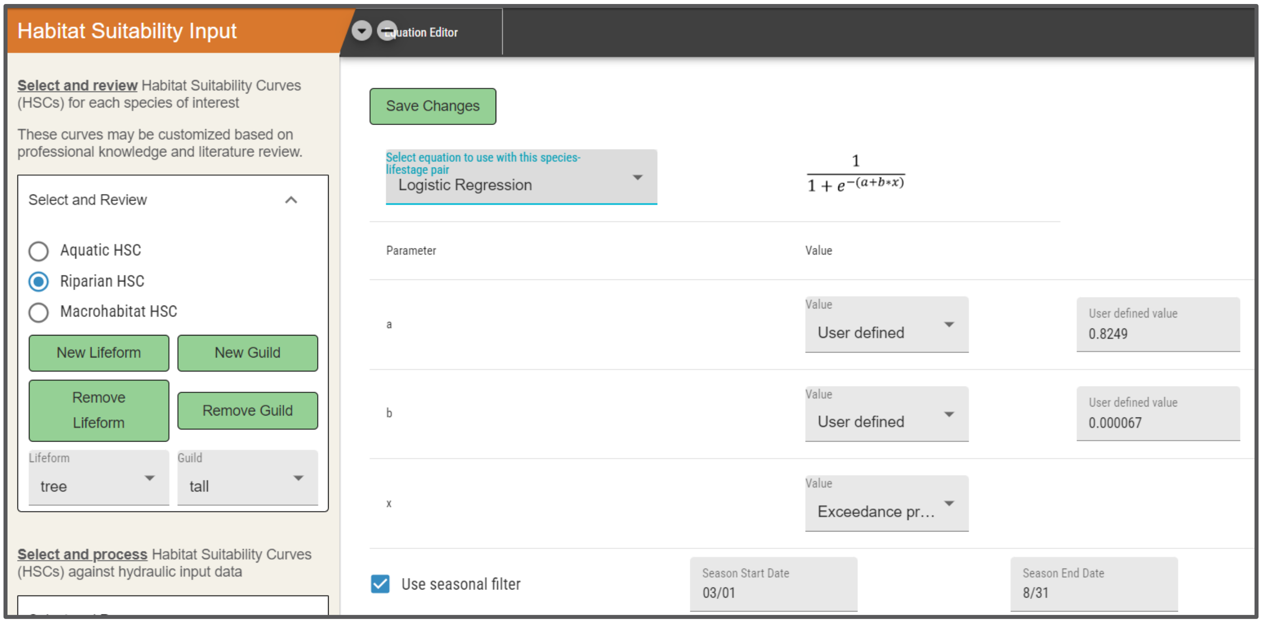

Figure 31: Environmental Flows for Riverine EcoSystem Habitats (E-FRESH) Select and Review Riparian Habitat Suitability Curve (HSC)

Lifeform

This includes the general category or vegetation type (tall trees, short trees, shrubs, etc.).

Guild

This includes groups of plant species or "guilds" for development of guild-specific HSC probability of occurrence.

Macrohabitat

Included in E-FRESH is a hydrologic method for determining extent and persistence of macrohabitat characteristics (depth, velocity, and substrate) typically associated with geomorphic features in the stream like pools, riffles, and runs, and these are assessed in the same way as Aquatic Species. Delineation of these physical features better quantifies these geomorphic forms to then evaluate how many of them are inundated or not during particular flow stages in a hydraulic model. In the interest of assessing these characteristics and how they potentially vary based on flow conditions, E-FRESH includes this section for generalized habitat suitability for multiple species types (Figure 32). It should be noted that these macrohabitat definitions (e.g., deep enough/slow enough to be considered a pool) are hydraulically defined as opposed to a geomorphic definition that a pool does exist in a riverbed regardless of river stage/depth/velocity.

Differences in geomorphology and hydraulics between riffle, run, and pool macrohabitats impose a major environmental filter that affects species distribution and abundance for fish and macroinvertebrates. Riffle macrohabitats are typically characterized by fast-flowing water (shallow-fast) and larger substrate sizes, while pool macrohabitats are characterized by reduced water velocity (deep-slow) and smaller substrates, with run macrohabitats occupying intermediate flow (deep-fast) and substrate characteristics.

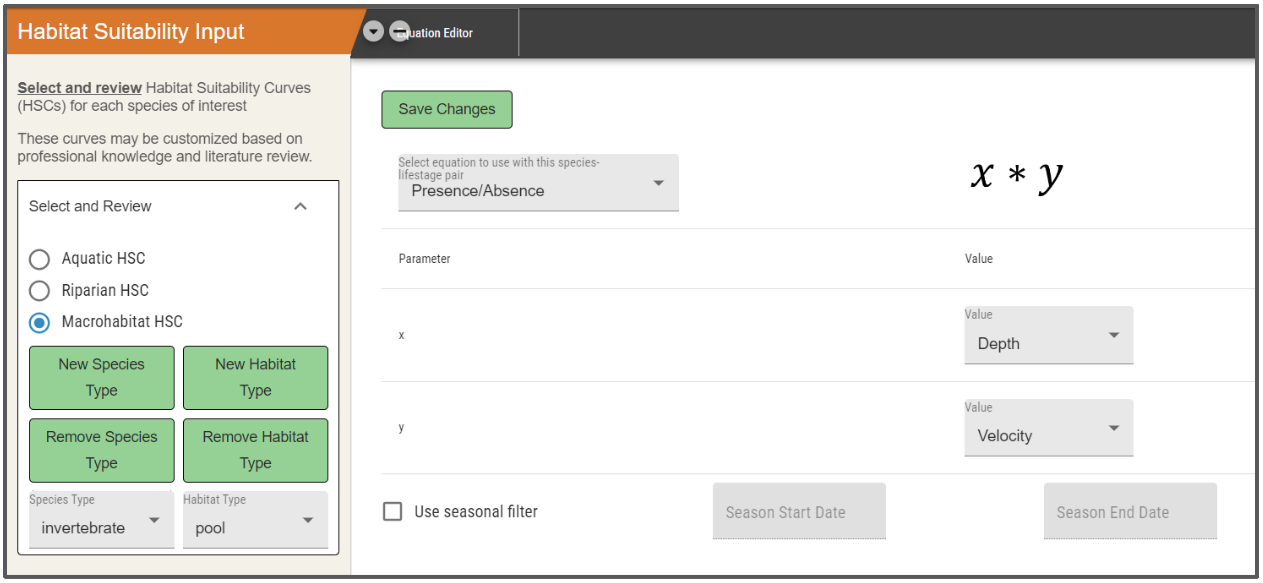

Figure 32: Environmental Flows for Riverine EcoSystem Habitats (E-FRESH) Select and Review Macrohabitat Habitat Suitability Curve (HSC)

Species Type

The first selector allows for the selection, or creation, of macrohabitat suitability for a general category of species (fish, invertebrates, etc.).

Habitat Type

This refers to the specific macrohabitat type or classification (pool, deep-slow, riffle, shallow-fast, etc.) that is being selected or defined for the species type selected in the previous step.

Tabs within the Habitat Suitability Input

The tabs in this section correspond to the Select and Review (red rectangle in Figure 29) and are intended to be used to review and confirm the habitat suitability ranges by hydraulic property or the combining suitability equation.

Equation Editor

This tab is dedicated to the unifying habitat suitability equation (HSE) for determining the overall habitat of a species or species group. In the case of most riparian vegetation, the unifying HSE will calculate probability of occurrence (e.g. logistic regression or polynomial logistic regression). In the case of many aquatic species, the HSE could be as simple as a presence/absence equation: that the desirable depth and velocity of water must occur at the same place and time to be suitable. As a result, this equation tab is present for Aquatic Species, Riparian Species, and Macrohabitat. However, for Riparian Species, the equation editor is the only tab available as individual hydraulic suitability (depth, velocity, etc.) is not typically useful for assessment of habitat for riparian plants. Activating the "Use seasonal filter" checkbox will clip the analysis and results summary to the period of interest.

Equation Selection

This selection picks the form of the equation that unifies the hydraulic parameter suitability (i.e., appropriate depth and velocity for a fish) with the other parameters. Currently there are three options implemented:

1. "Presence/Absence" represents the association between species occurrence and one or more hydraulic factors. For example, a fish species may tend to occur only at locations with both the appropriate depth (i.e., it's not too shallow) and velocity (i.e., the fish is not swept away).
2. "Logistic Regression" is useful for fitting probability of occurrence data to hydraulic and hydrologic information for riparian species. A full example of developing hydrology scenarios that drive changes in flow exceedances which thus impact or relate to the habitat necessary to maintain certain types of riparian vegetation is included in Appendix A. At their core, these options simply reflect the inclusion of fitted models of probability of occurrence to the hydraulic and hydrologic data (depth, velocity, exceedance, and non-exceedance).
3. "Polynomial Logistic Regression" is a similar model design and purpose as the above described "Logistic Regression" that incorporates the square or higher-order multiples of the hydraulic variable. For example, including the square term is necessary for species that occur at intermediate levels of a hydraulic gradient, but not at either extreme.

Users can collaborate with the OWSI development team as the need arises to work on including additional equation templates or functionality in the HSE Selection.

Seasonal Filter

This checkbox allows the optional inclusion of a season to the suitable habitat. For aquatic species, this may be associated with habitat specific to spawning necessary only for a portion of the year. Specifically, the filter includes the specification of a start date in mm-dd format (March 8th would be 03-08) and end date of a season. For example, riparian vegetation establishment may be limited to suitable surfaces exposed during the season of seed dispersal. Activating this option will clip results summarized in Review Results to only the data within the specified season for that species/lifeform.

Depth

This tab (Figure 33) is only available for Aquatic Species and Macrohabitat groups and includes a chart to define ranges of suitable (*y*=1) and non-suitable (*y*=0) habitat. Selecting a different species or life stage will update this tab to reflect the range for that species.

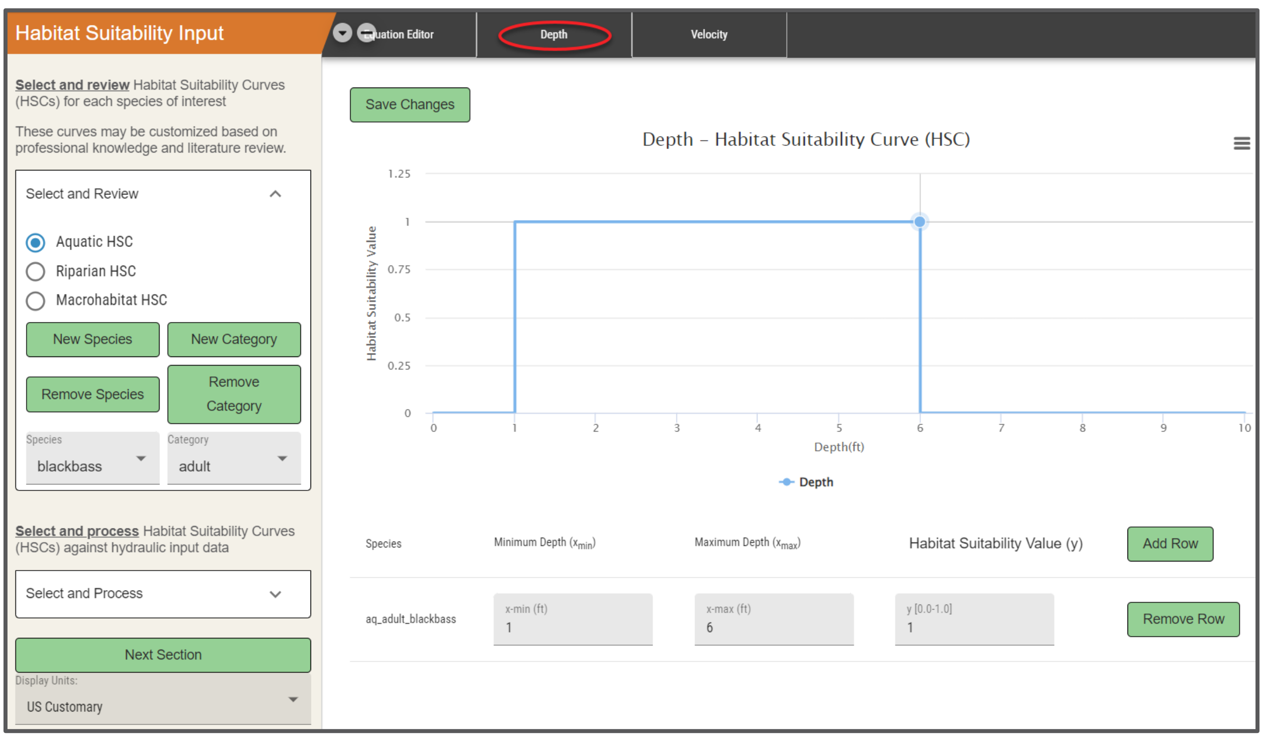

Figure 33: Environmental Flows for Riverine EcoSystem Habitats (E-FRESH) Select and Review Habitat Suitability Curve Editing for Depth

Depth Habitat Suitability Curve (HSC)

The first component of this tab is a graph depicting the user-editable HSC for the selected hydraulic property (tab) and species/category (e.g., adult smallmouth bass). If needed, this graph can be exported as an image (.png, .jpg, .svg) or a .csv file.

HSC Ranges

The second component of this tab is a table summarizing the editable ranges of the habitat suitability. Specifically, a minimum and maximum value (range) for the selected hydraulic parameter (depth) are the first two entries. The second component of this tab is a table summarizing editable ranges of the habitat suitability:

1. Minimum value: this represents the lowest value of depth, velocity, etc. that a species would find suitable. Below this, species would not prefer this habitat (e.g. the water is too shallow for that size of fish)
2. Maximum value: this represents the highest value of depth, velocity, etc. that a species would find suitable. Above this, species would not prefer this habitat (e.g. the water is moving too fast for the fish to stay in this location)
3. Habitat suitability value: this value must be between 0 (unsuitable habitat) and 1 (suitable habitat). Careful interpretation of the results is necessary for use of non-integer habitat suitability values.

Add Row

This button will add another row of ranges to the HSC for the selected species.

Remove Row

This button will delete this particular row of HSC ranges to the HSC for the selected species (without recovery or undo).

Save Changes

This button will save all current edits for the HSC for the selected species/category.. Edits to HSC ranges must be saved or changes will not be applied.

Velocity

Similar to Depth, this tab is for defining the suitable ranges of velocity per aquatic species and life stage (Figure 34).

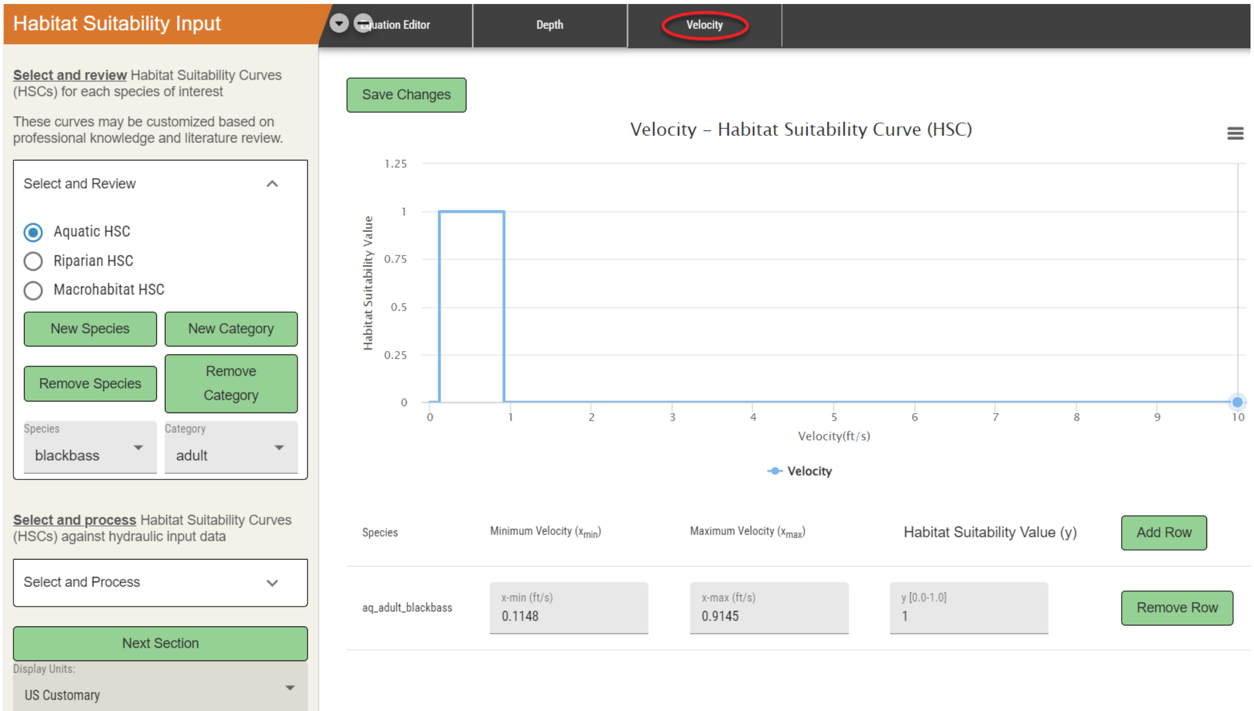

Figure 34: Environmental Flows for Riverine EcoSystem Habitats (E-FRESH) Select and Review Habitat Suitability Curve Editing for Velocity

Select and Process

This section is dedicated to applying the HSE for the desired species. A user can select which types (Aquatic, Riparian, Macrohabitat) and individual species/guilds to calculate available suitable habitats (Figure 35). This step combines the user-defined HSCs with the unifying equation and the hydraulic data to determine available suitable habitat for each modeled discharge. This section must be completed AFTER all edits to a species' Equation Selection and HSC Ranges are made for changes to be reflected in the Review Results section.

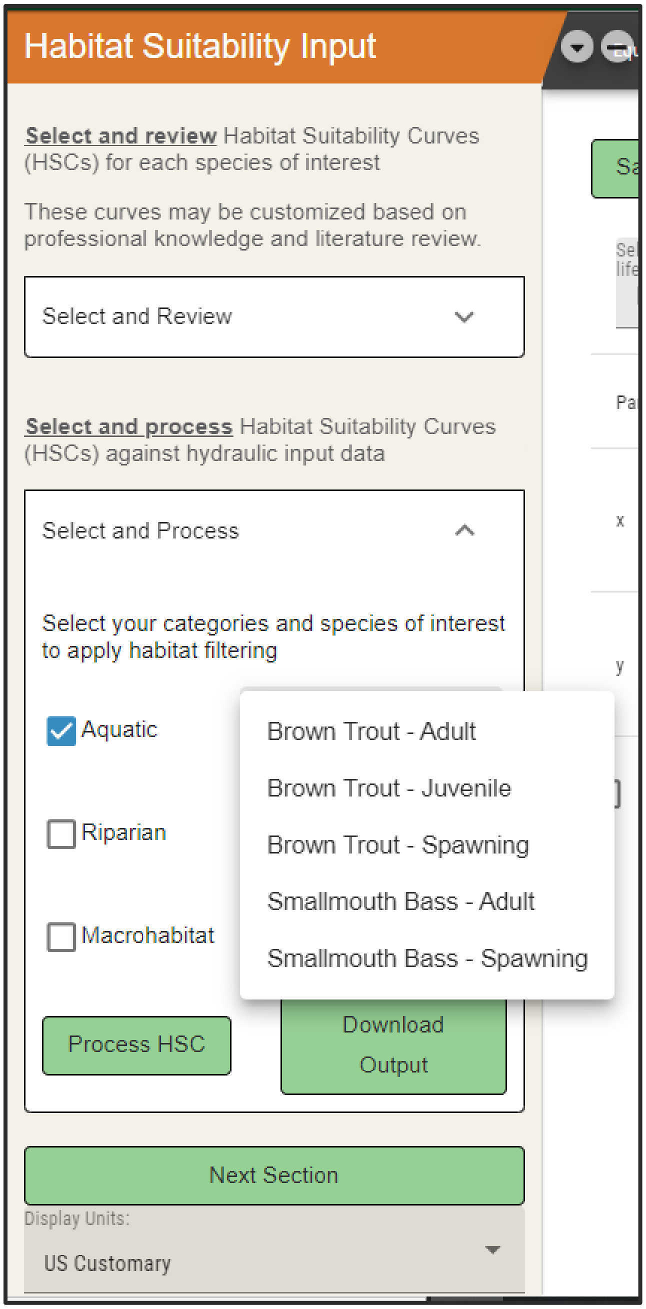

Figure 35: Environmental Flows for Riverine EcoSystem Habitats (E-FRESH) Habitat Suitability – Select and Process

Process HSC

This terminology varies for whether a 2D or 1D HEC-RAS Hydraulic Model is used. In the case of a 2D hydraulic model, the "Process HSC" button applies the HSCs to the relevant hydraulic property raster and combines them using the Habitat Suitability Equation (HSE). This processing is computationally expensive because a unique raster must be prepared for each flow modeled in the 2D model. In addition, HSCs and equations are applied to each pixel of each hydraulic raster file. A loading bar will reflect results as they are available and data will be cached between browser sessions so users can start applying these HSCs, shut their browser and return later to their complete dataset.

In the case of a 1D hydraulic model, the same HSCs are used to calculate suitable habitat availability for each cross section at each of the modeled flows per species. The 1D HCS processing is performed using text files processed from the HEC-RAS output files uploaded to E-FRESH, so it is a much faster process but still may require a few minutes depending on how many cross-sections, profiles, and species are analyzed.

Download Output

Similar to the Download Output TIFFs section, this step will download a zipfile containing all of the habitat estimates for each modeled flow. In the case of 2D hydraulic data, this zipfile will contain many raster files (.tif files) and may be 100s of gigabytes of data, so be sure only to click this download button when using an internet connection with sufficient bandwidth.

Review Results

This portion of the tool (Figure 36) uses data from the Hydrology Input, Hydraulic Input, and Habitat Suitability Input sections. Users **must** complete all three sections to be able to review results. After review and assessment of the hydrologic, hydraulic, and species habitat suitability data, E-FRESH combines and summarizes this dataset for the scenarios of interest selected by the user.

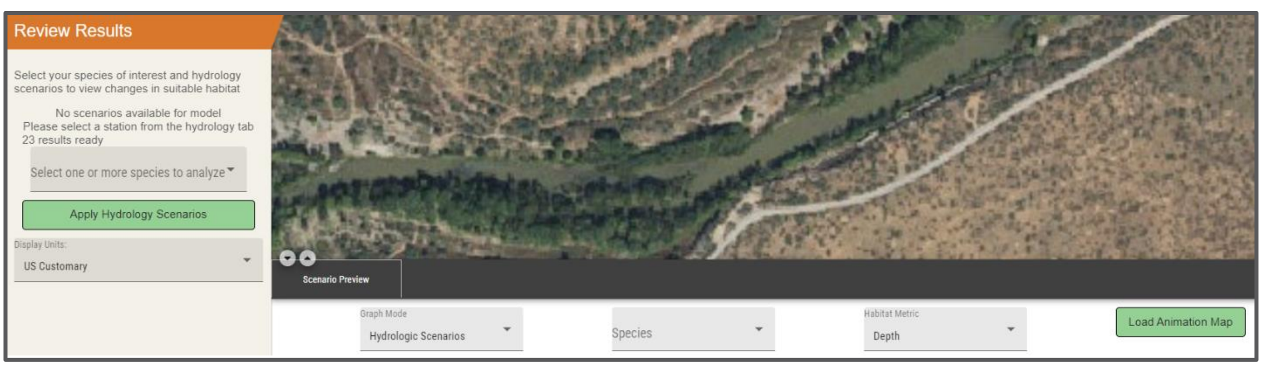

Figure 36: Environmental Flows for Riverine EcoSystem Habitats (E-FRESH) Review Results Section

Generally, individual daily discharges in a hydrologic scenario are used to select and interpolate hydraulic conditions from the hydraulic model, which are then compared against the habitat suitability curve for the selected species (presence/absence of suitable depth and velocity for an aquatic species or the logistic regression probability of occurrence for a riparian species).

Numerous edge cases exist in this methodology, including the fundamental data limit of hydrology scenarios having discharges not included in the calibrated hydraulic model. For example, a stream monitoring record of discharge or E-FRESH hydrology scenario may include a 10.3 cfs discharge, whereas a hydraulic model may have been designed and calibrated to include hydraulic outputs for a 10 cfs discharge and a 12 cfs discharge. In this case, the total area of a particular suitable habitat at the 10 cfs discharge and the 12 cfs discharge are interpolated linearly to determine an estimated suitable habitat area at 10.3 cfs.

Hydrology Scenarios and Species of Interest

Use the drop-down menus (Figure 37) to select which species and hydrology users would like to analyze. Users can choose one or more species and one or more hydrology scenarios. Additionally, just above the species selection is a count of how many species' combinations have gone through the Select and Process section and data computations.

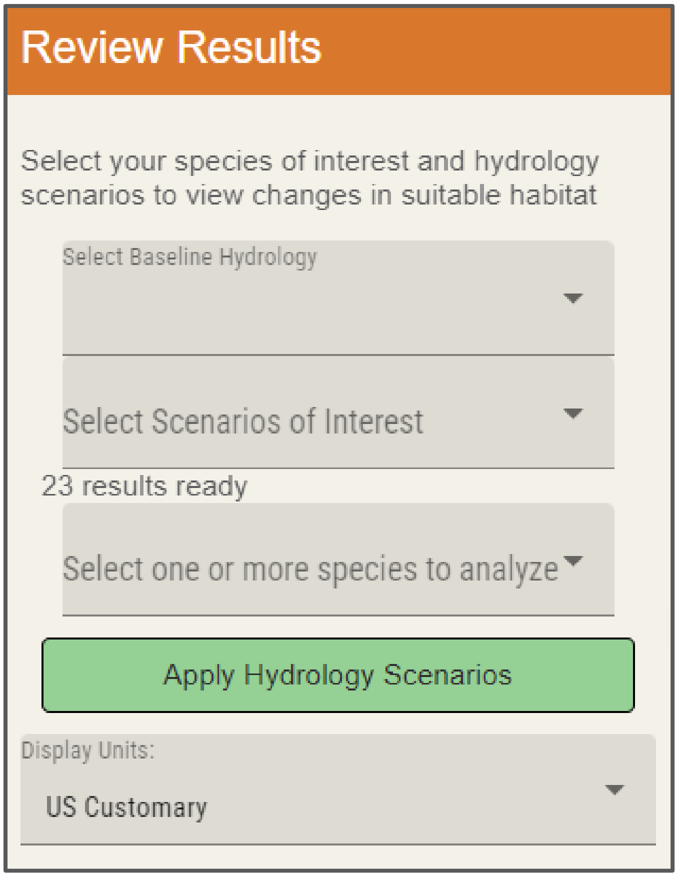

Figure 37: Environmental Flows for Riverine EcoSystem Habitats (E-FRESH) Review Results – Hydrology Scenario and Species Selection

Clicking "Apply Hydrology Scenarios" will load and combine the hydrologic, hydraulic, and HSC data for summary.

Tabs within Results Review

The tabs in the grey menu bar on top can be used to review charts and animations of your scenarios or hydrology results.

Results by Species / Results by Scenario

The Results by Species (Figure 38 and Figure 39) and Results by Scenario (Figure 40) tabs summarize either the species-level effects for a selected hydrologic scenario or the scenario-level effects across multiple species. The tabs are formatted similarly and contain monthly (Figure 38 and Figure 40), annual, and total (Figure 39) summary charts for the impact to the species/scenario combination.

These summaries provide the ability for a user to review how a particular hydrologic scenario (e.g., climate change driving a 10% decrease in spring snow melt) affects habitat for all species of interest (Figure 40). Alternatively, a user can review how numerous hydrologic scenarios impact a particular species of interest (Figure 38) such as an endangered species and projecting 5%, 10%, or 30% decreases in stream flow.

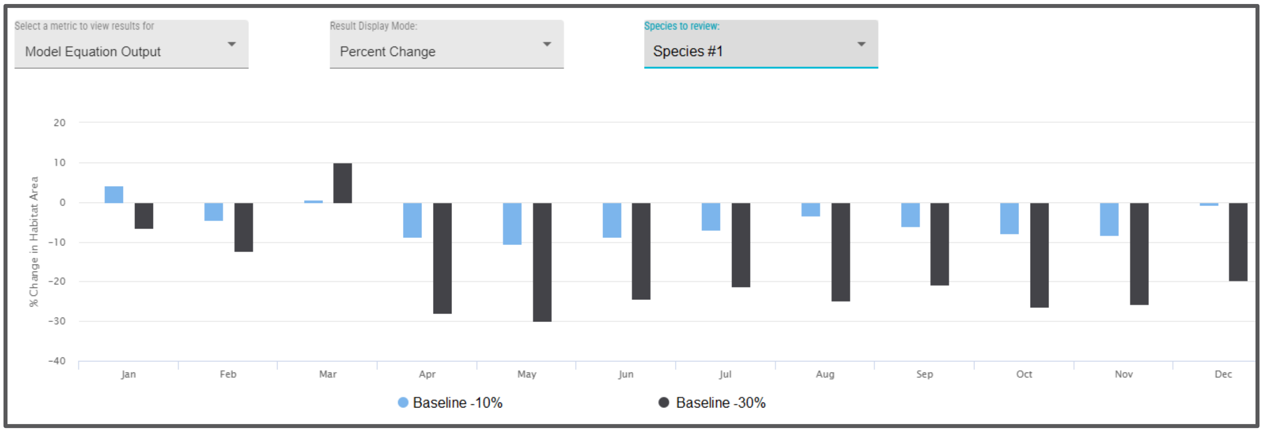

Figure 38: Environmental Flows for Riverine EcoSystem Habitats (E-FRESH) Results by Species Monthly Summary

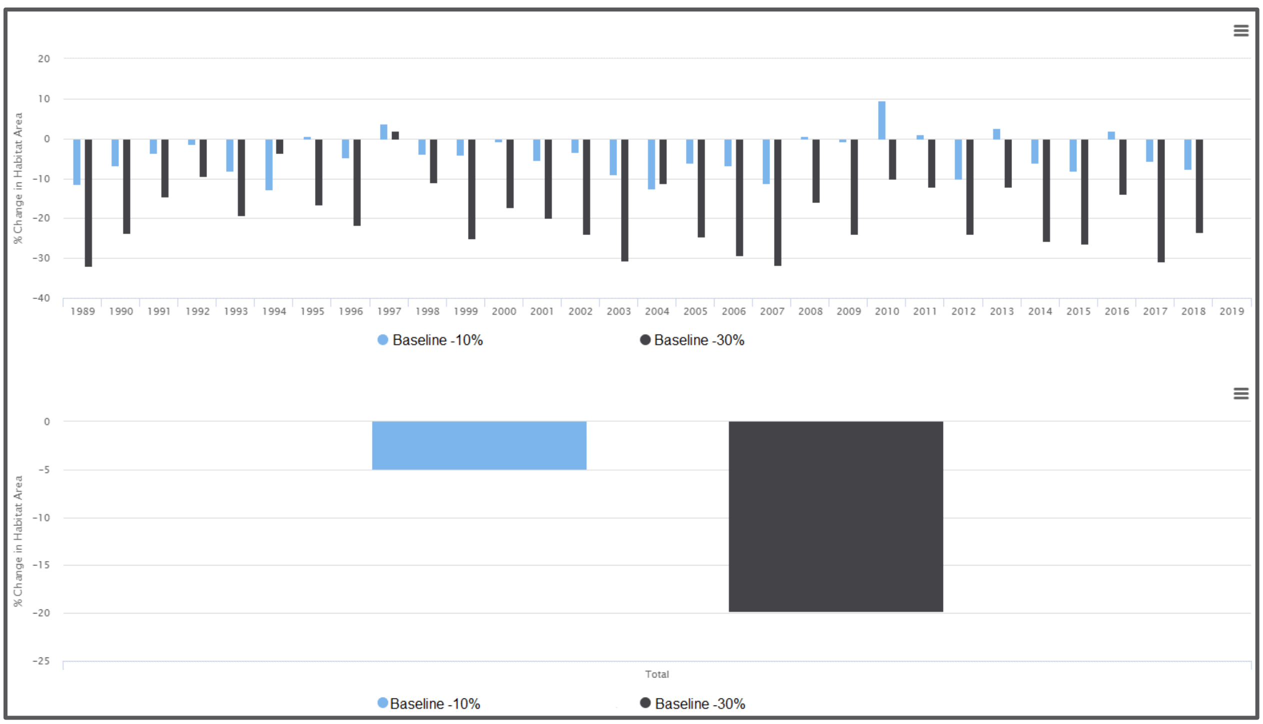

Figure 39: Environmental Flows for Riverine EcoSystem Habitats (E-FRESH) Results by Species Annual and Total Summary

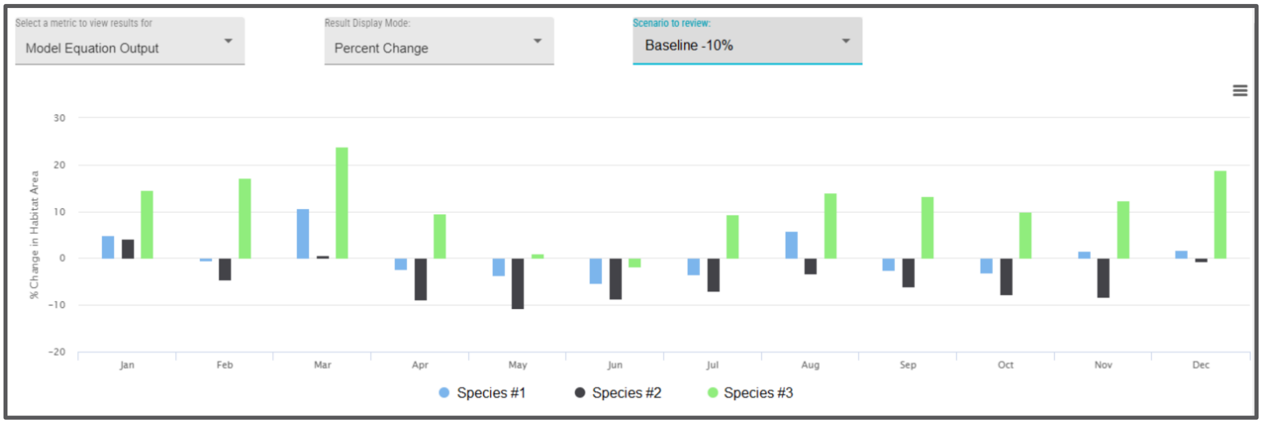

Figure 40: Environmental Flows for Riverine EcoSystem Habitats (E-FRESH) Results by Scenario

Scenario Preview

This section is similar to the Hydraulic Data Preview in the Hydraulic Input section of E-FRESH. It presents both raw hydraulic data (depth, velocity, etc.) across the number of modeled flows and visualizes this on the map sequentially low to high "filling" then "draining" the river. Additionally, users can select a period of interest of a hydrograph of a particular flooding event and visualize that in this section.

In addition to visualizing the hydraulic data, this section also allows the selection and visualization of the resulting habitat data: specifically, the flow-dependent area that fits the habitat suitability curve for the selected species of interest. It also includes visualizing the final suitable habitat (Figure 41) based on the Equation Editor section of the Habitat Suitability Input section of E-FRESH.

Figure 41: Environmental Flows for Riverine EcoSystem Habitats (E-FRESH) 2D Results Scenario Preview

Cross-Section Results

This is available for 1D HEC-RAS hydraulic model projects only.

This tab contains cross-section level visualization and summary of both exceedance probabilities and habitat suitability. This section summarizes those results and allows for download outside of E-FRESH. Specifically, users can select a cross section of interest and review the inundating discharge and corresponding exceedance/non-exceedance as well as the suitable habitat (Figure 42), as calculated based on the Equation Editor section of the Habitat Suitability Input. This allows the visualization of hot spots of good habitat (and cold spots for poor habitat) in the 1D hydraulic model for species of interest (aquatic, riparian vegetation, or macrohabitat).

Similarly, if vegetation transect locations were uploaded in the hydraulic data Pre-Processing section, those transects can be visualized and summarized, and the resulting habitat suitability can be downloaded from this point of the tool as well.

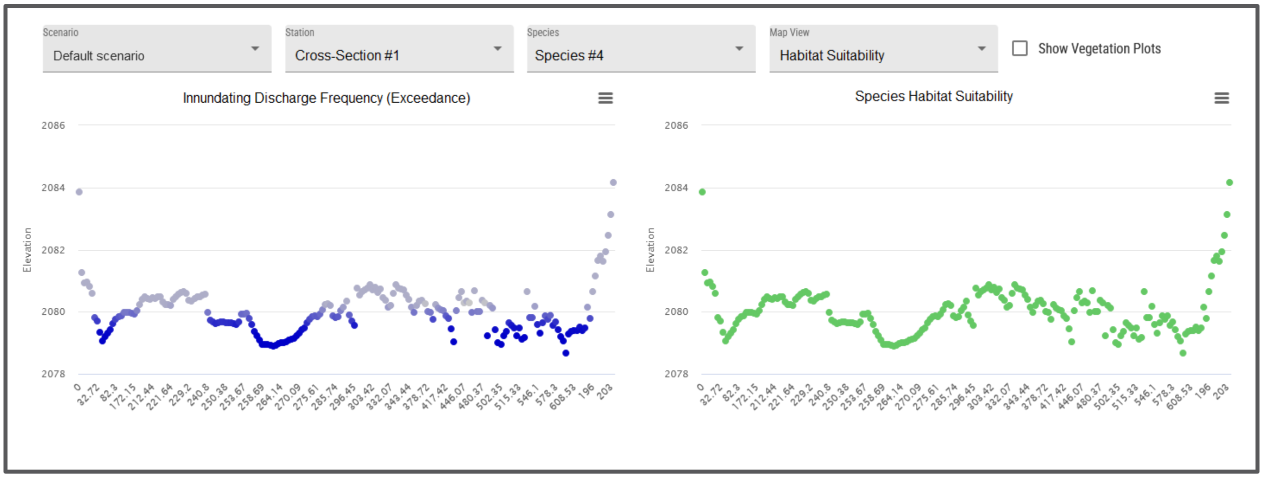

Figure 42: Environmental Flows for Riverine EcoSystem Habitats (E-FRESH) 1D Cross-section Results Preview

User Guide Section

The user guide section of E-FRESH provides access to user guidance and tutorials on applying E-FRESH.

SUMMARY

Development of the E-FRESH DST through the eRAMS platform harnesses open-source technologies providing project data management, geospatial data analysis, management of time series data, data processing, visualization, and presentation, including collaboration features for sharing natural resource and environmental inventories and assessments. The E-FRESH DST not only supports the priority data and modeling needs of USGS Fort Collins Science Center and U.S. Forest Service researchers, but it also provides a tool for water resource managers, planners, decision makers, and stakeholders to assess how different flow management scenarios affect both instream and riparian habitat availability for species of interest within the riverine ecosystem they are responsible for managing.

Strengths and Limitations

The service-oriented architecture of eRAMS used in the development of the E-FRESH DST provides several advantages that address challenges associated with previous stand-alone site specific DSS applications/tools. First, the system is platform independent, allowing users to access the E-FRESH DST from their preferred desktop and mobile devices using common browsers (e.g. Google Chrome, Microsoft Edge, Mozilla Firefox, and Apple Safari) and does not rely on a standalone application or desktop software package. Second, eRAMS facilitates seamless integration of heterogeneous data and models from diverse sources in their native formats (i.e. USGS NWIS stream flow data), catalyzing and accelerating synthesis of information. Finally, access to the core E-FRESH DST project data and models is managed and deployed through services and includes grouping capacities for sharing resources among project members with full and read-only access. This approach facilitates the integration of information with user-specific tailored project data, visualization and reporting tools that can be customized to the needs of specific stakeholders, without duplication of efforts or the need for copying/transferring large amounts of project data for each user to access.

This being the initial release of the E-FRESH DST (v1.0), one major limitation of the tool is that there are no publicly available E-FRESH projects or data sets currently available under the Project Management section. OWSI is working with its federal partners through multiple existing project agreements to include previous instream flow studies that have been conducted as well as existing projects associated with the development and application of the E-FRESH DST once they have been completed, published, and approved for public use. It is also anticipated that as new users apply the E-FRESH DST to their individual projects, they will choose to submit their completed and published projects for inclusion in the E-FRESH DST public database which would increase over time.

Another limitation to the E-FRESH DST includes the scale of assessed data. Because E-FRESH is a cloud-based system synthesizing datasets for analysis, larger datasets must first be uploaded on a sufficient internet connect (speed/stability) and review summaries are limited to the scale of data that a web browser may display so large number of alternative analyses or large numbers of species comparisons (i.e. dozens or hundreds) may not be feasible given computer memory limitations allocated to web browsers.

Additional limitations with the initial release of E-FRESH DST relates to the 2D and 1D hydraulic model (HEC-RAS) upload process under the hydraulic input section. The hydraulic input variables currently used in the 2D and 1D upload process include depth, velocity, and shear stress. As users determine the need for inclusion of additional hydraulic variables, they will need to work with the OWSI team to provide additional input functionality. Additionally, the currently E-FRESH DST has been tested and is compatible with HEC-RAS version 6.1, as newer versions of HEC-

RAS are released, they will have to be verified by the OWSI team for compatibility with the E-FRESH DST.

Future Work

Development and implementation of additional E-FRESH DST features and capabilities are ongoing through multiple existing project agreements. As users identify new features or capabilities that they would like to have included in the E-FRESH DST they should reach out to the OWSI team at eramsinfo@gmail.com to discuss future development needs and opportunities.

Additional features and capabilities that are currently planned under existing agreements include the following:

- Inclusion of additional flow statistics summary comparison, specifically the Nature Conservancy's Indicators of Hydrologic Alteration (IHA) metrics. These allow for more comprehensive comparison of historic and proposed hydrology scenarios.
- Inclusion of additional modifiers (e.g. conditional logic operators) for creating hydrologic scenario modifications under the Scenario Editor tab in the Hydrology Input section. This aims to better align E-FRESH hydrology scenario development with current flow management methods being implemented by resource managers.
- Generalized support for additional suitability data layers is ongoing and intended to expand the use case of assessing species needs for soil types (sandy vs. clay soils for vegetation establishment), depth to groundwater (vegetation establishment and health), substrates (aquatic spawning needs for clean gravels vs sands/boulders), distance to vegetative cover (aquatic species heat refuge), and distance to woody debris (aquatic species refuge from predators).
- Additional HSE capabilities utilizing an equation editor tool allowing users to enter custom equations associated with various species of interest and habitat suitability metrics (e.g. depth, velocity, shear stress, substrate, temperature, etc.). This will also include the option to identify persistent habitat needs associated with various species and life stages (e.g. co-location of spawning/incubation habitat must occur to be considered suitable habitat for that species).

- Inclusion of a digitizing tool in the macrohabitat suitability input section to allow users to define geomorphic features (i.e. pools, riffles, etc.) on a base map and the ability to assess the effects of hydrologic scenarios at one or more user defined geomorphic features to quantify their extent, associated hydraulic properties and corresponding habitat suitability for a given species and flow.
- Addition of a simple particle size calculator feature to support sediment transport type assessments (e.g. critical shear stress and incipient motion).
- Adding the functionality for single cross-section analyses for cases in which generating a 1D or 2D hydraulic model in not feasible. This includes handling discharge/roughness calculations, creation and leveraging of rating curve data for stage discharge relationships, sediment transport equations for calculation of metrics like 'maintenance flows' necessary to mobilize cobbled bedrock systems and/or flush finer particle sizes. This generalized cross-section analysis support will be included as a third hydraulic data option alongside the existing 1D HEC-RAS and generic 2D hydraulic model support.

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APPENDIX A – MODELING TIPS

There are a number of nuances to properly assessing a particular river for aquatic and riparian species habitat. This section provides guidance to properly developing hydrologic scenarios, hydraulic models, and species habitat suitability curves (HSCs).

Hydraulic Model Development

One important step in integrating hydrologic scenarios with hydraulic modeling data is to ensure that the range of flows in the hydrologic scenarios are 1) covered by the range of flows modeled in the hydraulic model and 2) have sufficient granularity between flows to limit issues with extrapolation and interpolation.

Additionally, it is important to have adequate spatial representation of the hydraulic model for the area to be assessed. This includes fine enough raster cell sizes for 2D models. In the case of 1D Hydraulic Engineering Center – River Analysis System (HEC-RAS) modeling, it can also involve using "interpolated cross sections" which is a method in HEC-RAS to add additional cross sections beyond the surveyed ones and increase spatial resolution of the hydraulic model to both the benefit of the hydraulic modeling engine and the spatial representation of hydraulic inundation and habitat (depth/velocity).

Probability of Occurrence Riparian Vegetation Modeling (Exceedances and Habitat Suitability)

The example provided below combines the capabilities of the Environmental Flows for Riverine EcoSystem Habitats Decision Support Tool (E-FRESH DST) with vegetation species field data, to develop probability of occurrence regression estimates which are then used to assess the impact hydrologic changes on vegetation extent under flow scenarios of interest.

A user would begin this process by going to the Hydrology Input section for their active project and select or upload the stream monitoring data associated with their location. Then they would use the Scenario Editor to develop a number of hydrologic scenarios of interest that likely had the most influence over the current distribution of vegetation like the recent past (last 1–2 years) or recent history (last 5–10 years), as relevant to plants like annual non-woody plants versus shrubs and trees, respectively. The user would then develop several potential hydrologic scenarios representing multiple potential future scenarios based on river management, climate projection scenarios, and more.

Once the hydrologic scenarios have been developed, the user would proceed to the Hydraulic Input section of the tool and upload the hydraulic model they intend to leverage with E-FRESH. After uploading and processing this model, regardless of whether it is a 1D HEC-RAS simple, 1D HEC-RAS advanced, or 2D hydraulic model, the user could then upload one or more shapefiles of vegetation plot survey locations. These locations are typically transects across a stream or river that have been sampled for the presence/absence (among other characteristics) of multiple riparian species and/or guilds. For each plot, the user could then download from E-FRESH the inundating discharge (derived from the hydraulic model and the spatial location of each vegetation plot) and associated inundation frequency (exceedance/non-exceedance derived from the combination of the uploaded hydraulic model and user-created hydrologic scenarios).

At this point, to finish this workflow, the user would use this information outside of E-FRESH to fit a regression model, typically something like generalized linear model like logistic regression or polynomial logistic regression. This combined information (vegetation extent and frequency of inundation) can be used to develop and calibrate regression equations for the probability of occurrence. Once a sufficiently calibrated equation is developed by a riparian ecologist, the user can return to E-FRESH to enter that equation in the Habitat Suitability Input section.

Once all the above is completed, the user can proceed to the Review Results section and select which riparian vegetation species they would like to review as well as which pertinent hydrologic scenarios to review. This section of E-FRESH will then show the results by scenario, by species, and compare them.

Upload Layers

Users can upload files (Figure 43) and add their own information under the “Layers” tab located on the right dashboard:

1. Upload geospatial user layers
2. Import data from public sources such as U.S. Geo Data, U.S. Hydro Data, and U.S. Environmental Protection Agency water data

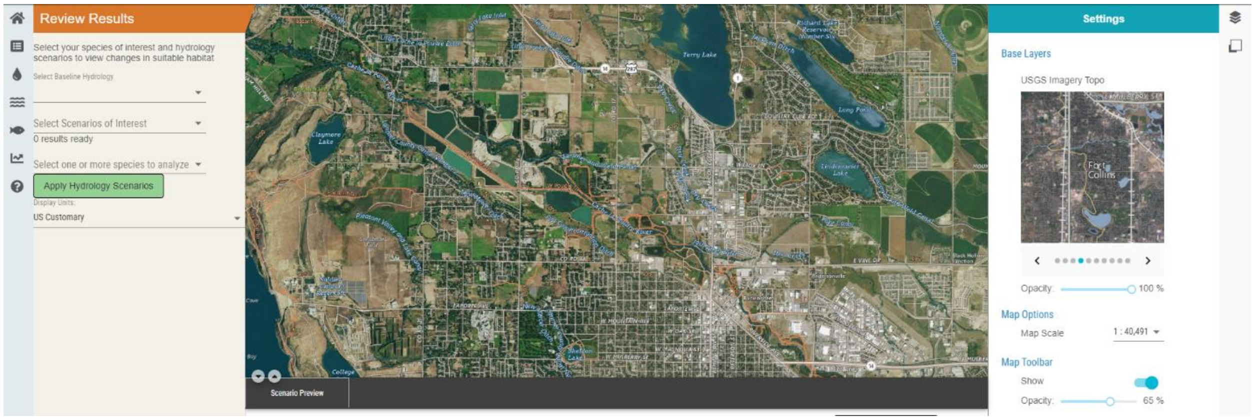

Figure 43: Environmental Flows for Riverine EcoSystem Habitats (E-FRESH) Map Layers Panel

Map Features

The dashboard also allows users to navigate basic mapping features from the toolbar located on top of the map canvas (search location, zoom in/out/to specific place, enter location, layer attributes).

APPENDIX B – GLOSSARY OF TERMS

1D Hydraulics: hydraulic analysis that focuses on the flow of water in a single dimension. In this approach, the variation of hydraulic properties (water velocity, depth, and shear stress) is considered only along one axis, typically the flow direction.

2D Hydraulics: hydraulic modeling approach that considers variations in flow properties in two dimensions: both along the flow direction (longitudinal) and across the channel or river (lateral). 2D hydraulics consider spatial variations in water depth, velocity, and other flow properties across a channel or river's cross-section. This is particularly important in situations where the flow is non-uniform or there are significant changes in channel geometry.

Aquatic: wetted areas within stream channels and influenced by streamflow and fluvial processes associated with river flow and sediment regimes, surface and groundwater interactions, and region-specific disturbance regimes, species pools, and climates and geologies.

Base Layer: This is the background map on which stream monitoring locations, hydraulic data, and result data are drawn. This can be something as simple as satellite imagery or road maps or combinations of both.

Baseline Hydrology: refers to the initial or pre-project conditions of the hydrological characteristics within a specific area before any significant changes or disturbances occur due to human activities or natural events. Understanding baseline hydrology is crucial for various purposes, including environmental impact assessments, water resource management, and ecological studies. It serves as a reference point against which changes or effects can be measured.

.csv: a file format for comma separated values. This format is used for hydrology and other input/output data supported by E-FRESH

Cumulative Distribution Function (CDF): gives the probability that the random variable X is less than or equal to x (non-exceedance).

Daily Average Flow: the average volume of water flow in a river, stream, or any water channel over the course of a single day.

Daily Maximum Flow: the highest volume of water flow in a river, stream, or water channel that occurs during a 24-hour period.

Daily Minimum Flow: the lowest volume of water flow in a river, stream, or water channel that occurs during a 24-hour period.

Depth: the vertical distance from the water surface to the channel bed or riverbed in a flowing water system.

Digital Inundation Map (DIM): shows the flows required to inundate a given location on the landscape and is generated based on physical field measurements or hydraulic modeling, which simulates how water would flow and spread across the channel and floodplain during different flow quantities.

Discharge: the volume of water that flows through a specific cross-sectional area of a river, stream, or canal over a given period of time. Discharge is commonly denoted by the symbol "Q" and is measured in cubic meters per second (cms) or cubic feet per second (cfs).

Ecosystem: a dynamic and interconnected system of living organisms (biotic components) and their non-living environment (abiotic components), interacting as a functional unit.

Environmental Flow: Environmental flows describe the quantity, timing, and quality of freshwater flows and levels necessary to sustain aquatic ecosystems which, in turn, support human cultures, economies, sustainable livelihoods, and well-being (Brisbane Declaration on Environmental Flows) .

Exceedance: The probability that the discharge is greater than a particular value, i.e. exceeded. The complement of exceedance is non-exceedance and is calculated as:

$$exceedance = 1 - non\ exceedance$$

E-FRESH DST: Environmental Flows for Riverine EcoSystem Habitats Decision Support Tool

FaSTMECH: Flow and Sediment Transport with Morphological Evolution of Channels (FaSTMECH) is a quasi-steady two-dimensional river flow and morphodynamics solver available in the iRIC software package (https://i-ric.org/en/solvers/fastmech/).

Fluvial: of, relating to, or produced by flowing water.

Functional Group/Guild: groups of species that share common traits, set(s) of traits, or common requirements, tolerances, or response to stressors and/or resources.

Habitat Suitability Curves (HSC): graphical representations that illustrate the relationship between the abundance or suitability of a species and various environmental factors within a habitat. These curves are used to assess and predict the quality of habitats for specific organisms. HSCs help researchers and resource managers understand how environmental variables influence the distribution and abundance of species.

Habitat Suitability Equation (HSE): the combination of HSCs for various environmental factors for a combined effect. These equations can be as simple as a presence-absence (fish needs the appropriate depth and velocity at the same time to live in) or as complicated as a logistic regression or polynomial logistic regression typically relating flow exceedance (or non-exceedance) representing how frequently an area is inundated by river discharges limiting (xeric species) or supporting (wetland species) riparian vegetation establishment.

HEC-RAS: U.S. Army Corps of Engineers Hydraulic Engineering Center - River Analysis System (HEC-RAS) developed by the Hydrologic Engineering Center. This software allows users to perform one-dimensional steady flow, one and two-dimensional unsteady flow calculations, sediment transport/mobile bed computations, and water temperature/water quality modeling (https://www.hec.usace.army.mil/software/hec-ras/)

Hydraulic: transmission of energy or the effects of flow of water in motion.

Hydrologic Modification: alterations made to the natural flow patterns and water-related processes within a watershed or river basin.

Hydrologic Unit Code (HUC): refers to the Hydrologic Unit Code system used to classify and identify watersheds at various levels of detail. The US Geological Survey (USGS) maintains a comprehensive database of HUCs through the National Hydrography Dataset webpage.

- HUC-8: This is an eight-digit code that delineates larger watersheds and is useful for regional water resource management and analysis.

- HUC-10: This ten-digit code provides a finer scale of watershed delineation and corresponds to a sub-watershed within a HUC-8 area. It allows for more detailed management and planning at a smaller scale.
- HUC-12: This twelve-digit code represents even smaller watersheds and are useful for localized studies and project implementation, such as habitat restoration or water quality monitoring.

Hydrology: the flow of water in stream channels and the changes in the quantity of water flowing through time (intervals raging from any interval from instantaneous, to daily, to seasonal and interannual).

Instream Flow: The quantity, timing, and variability of water flow within a river or stream maintaining the ecological integrity of the aquatic ecosystem. Instream flows are essential for sustaining fish habitats, preserving biodiversity, and supporting overall ecosystem health. Instream flows help maintain the physical characteristics of river and stream habitats, including the depth and velocity of water, substrate composition, and the availability of pools and riffles. These factors influence the survival and reproduction of aquatic organisms.

Instream Flow Assessment: Balancing the needs of ecosystems with human water use is a complex task, and instream flow assessments often involve collaboration between hydrologists, ecologists, water resource managers, and stakeholders. Various tools and models are used to determine appropriate instream flow regimes that support both ecological objectives and human water needs. Sustainable water management involves recognizing the importance of instream flows and implementing strategies to protect and enhance the health of riverine ecosystems.

Instream Flow Incremental Methodology (IFIM): a systematic approach used in river and stream management to assess and quantify the environmental flow requirements necessary for maintaining aquatic and riparian ecosystems. IFIM is designed to determine how changes in river flow, often influenced by water withdrawals, dams, or other alterations, affect the ecological health of the water body.

The Instream Flow Incremental Methodology (IFIM) was originally developed in the late 1970s by the U. S. Fish and Wildlife Services and since has been widely used in the field of river and stream ecology to balance water resource development with the conservation of aquatic ecosystems. The methodology is applied globally to address challenges related to water allocation, dam operations, and sustainable river management. Implementing IFIM helps to strike a balance between human water needs and the preservation of ecological processes critical for biodiversity and ecosystem health.

Layer: a geospatial element drawn on the map handled like most Geographic Information Systems allowing custom symbology and ordering (top to bottom) of various layers to form a cohesive map image of many different pieces of information.

Life Stage: phase in the development of an organism characterized by specific physical, physiological, and behavioral traits.

Lifeform Type (riparian: tree, shrub, others): This category is used to separate riparian plant species into meaningful groupings based on physiognomy, physical size, presence or absence of woody stems and extent of branching, longevity (annual, biennial, perennial) and other factors.

Macrohabitat: recurring fluvial settings in a stream channel that are mediated as habitat by flowing water.

Modifier (Hydrology Scenarios and HSCs): This term is used collectively to define the adjustments to either a hydrology scenario or an HSC. These generally involve specifying a period of time or parameter value range within which an adjustment (multiplication/division, maximum, minimum, addition/subtraction) is applied.

Nays2D: Nays2D is a plane 2D solver for calculating flow, sediment transport, bed evolution and bank erosion in rivers and is available in the iRIC software package (https://i-ric.org/en/about/).

Non-exceedance: The probability that the discharge is less than a particular value: i.e., not exceeded. The complement of non-exceedance is exceedance and is calculated as:

$$exceedance = 1 - non\ exceedance$$

Pool Macrohabitat: A pool macrohabitat refers to a specific type of aquatic habitat found in rivers or streams. In fluvial ecosystems, pools are distinct areas characterized by deeper water, often with reduced flow velocities compared to surrounding riffles or runs. Pools play a crucial role in river ecosystems, providing unique conditions that support various aquatic organisms during different stages of their life cycles.

Raster: refers to a grid-based data structure used to represent and store spatial information in a two-dimensional array of cells or pixels. Each cell in the grid contains a value, and collectively, these values form a matrix representing a spatial dataset.

Riffle Macrohabitat: A riffle macrohabitat refers to a specific type of aquatic habitat found in rivers or streams. Riffles are areas characterized by shallow, fast-flowing water that tumbles over a substrate of coarse materials such as gravel, cobbles, and rocks. Riffles are vital components of river ecosystems, contributing to the overall health and diversity of aquatic life.

Riparian: areas along/adjacent to stream channels and influenced by streamflow and fluvial processes associated with river flow and sediment regimes, surface and groundwater interactions, and region-specific disturbance regimes, species pools, and climates and geologies.

Riverine: aquatic and riparian ecosystems occurring along streams and rivers and influenced by streamflow volumes, stream processes, and human influences.

Run Macrohabitat: A run macrohabitat refers to a specific type of aquatic habitat found in rivers or streams. Runs are characterized by relatively uniform and moderate flow velocities, creating smoother water surfaces and typically have intermediate depths, deeper than riffles but shallower than pools.

Scenario: A custom combination of hydrology data (changes in flow) defining different potential patterns or conditions of water flow within a river or stream system. These scenarios are often used to assess the potential impact of various factors, such as land use changes, climate variability, water management practices, or the construction of dams. Analyzing alternative flow scenarios is crucial for understanding the resilience of aquatic ecosystems, managing water resources, and making informed decisions about water-related projects.

Shear Stress: quantifies the force exerted by flowing water on the bed (bottom) of a river, channel, or any open channel. It represents the force per unit area acting parallel to the bed, and it is a key factor in understanding the erosional and sediment transport processes in rivers and streams.

Species: a group of living organisms consisting of similar individuals capable of exchanging genes or interbreeding. The species is the principal natural taxonomic unit, ranking below a Genus.

Species Type (Aquatic: Specific/General): This category is used to separate definitions of aquatic species (e.g., brown trout) versus general groups of aquatic species (e.g., species that prefer shallow-fast water).

Streamflow: the volume of water flowing through a cross section oriented perpendicular to the direction of flow over time. Common measurements are in units of cubic meters per second or cubic feet per second (1 cms = 35.3147 cfs).

Streamgage: a measuring station along a stream usually comprised of a water level recorder (pressure transducer) that is submerged and measuring head (height of water over a datum). These measurements of hydraulic head are converted to streamflow (discharge) using a rating curve constructed from physical measurements of flow related to measured stage.

Substrate: bed material of a stream comprised of any physical unit from bedrock to various sizes of mineral (boulders, cobbles, pebbles, sand, silt, and clay) and or organic particles (wood, diatoms, biofilms, etc.).

Suitable habitat: habitat featuring ecological characteristics that may provide for the breeding, feeding, resting, or sheltering of any endangered and/or threatened wildlife species.

Taxon or Taxa: a group of one or more populations of an organism or organisms observed to form a unit (species, family, or class).

.tif: a raster file format used by GIS software like E-FRESH and ArcGIS for rendering gridded data like depth of water in a flowing river from a 2D Hydraulic model.

Time series: series of data points or observations measured or recorded over a sequence of time intervals (i.e., hourly, daily, or monthly).

Velocity: the rate of motion of water particles within a flowing stream. It is usually expressed in units such as meters per second (m/s) or feet per second (ft/s).