Wetbud Manual

Print Version of Online Help

Saturday, July 1, 2023

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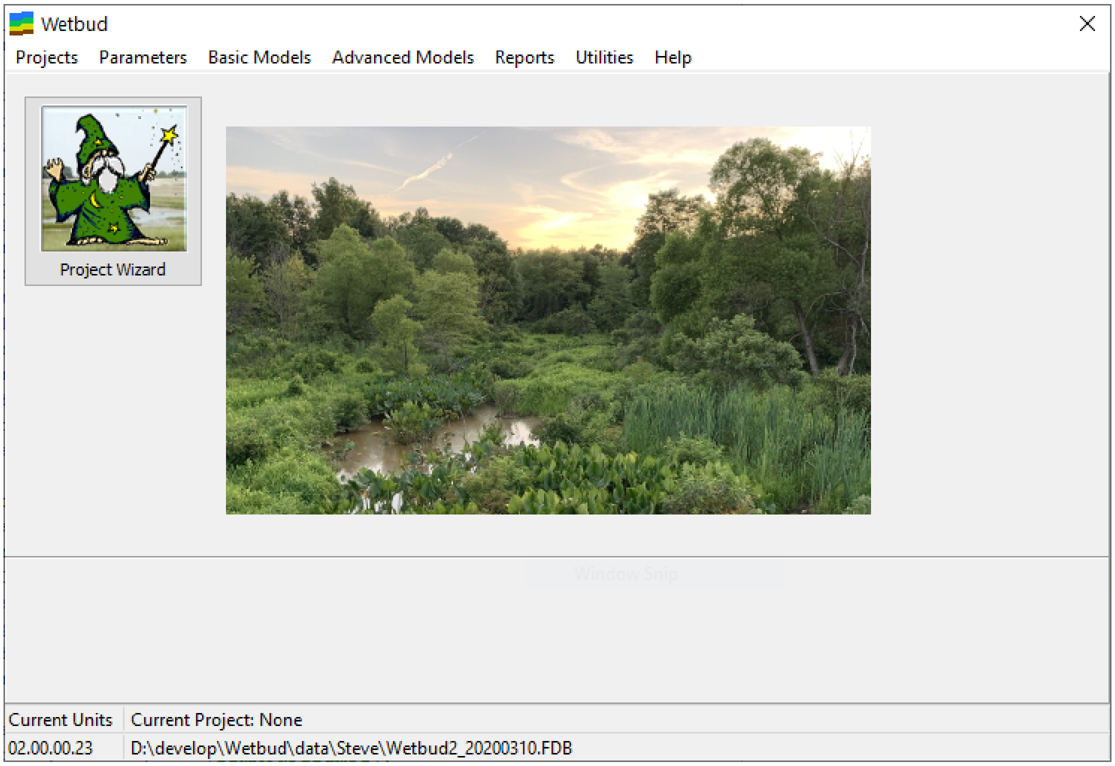
Wetbud Main Menu

1 Wetbud Main Menu

The screenshot below shows the main program screen that the user will see when the Wetbud program is started. In the status line at the bottom of the home screen, the version number, the currently selected Project, and the Wetbud database location are identified.

At the left of the home screen is the Project Wizard icon, which, when selected, allows users to quickly set up Projects and associated Scenarios using default parameters, including a preloaded database for 138 weather stations covering the states of CT, DE, FL, GA, IN, KY, MA, MD, MN, MS, NC, NH, NJ, NY, OH, PA, RI, SC, TN, VA, VT, WV, to calculate water budgets using the Basic Model.

Preloaded data include precipitation, other weather information elements such as temperature, solar data, and evapotranspiration values calculated using the respective equations by Penman-Monteith and Thornthwaite.



At the top of the home screen there are navigation drop-down menus titled *Projects, Parameters, Basic Models, Advanced Models, Reports, Utilities*, and *Help*. These drop-down menus will be used to navigate through Wetbud.

The photo on the main menu is from the Julie J. Metz Wetlands Bank courtesy of WSSI.

Help File compiled on Saturday, July 1, 2023

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End User License Agreement

2 End User License Agreement

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Governing Law

This Agreement shall be governed by the laws of the Commonwealth of Virginia without reference to its conflict of laws provisions. You consent to exclusive jurisdiction and venue of the state and federal courts sitting in Virginia.

Ownership of Wetbud

Wetbud was developed as a collaborative effort by Zach Agioutantis, W. Lee Daniels, Theresa Thompson, and G. Richard Whittecar, with support from the Resource Protection Group, Inc., a 501(c)(3) organization founded to foster research on wetlands and stream restoration—which collectively comprise the "Owners" for the purposes of this Agreement.

Direct any inquiries concerning this Agreement to:

Michael S. Rolband
Resource Protection Group, Inc.
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Miscellaneous

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This Agreement does not grant You the right to distribute Wetbud. Parties may obtain a licensed copy of Wetbud by contacting the Owners or by downloading it from https://resourceprotectiongroup.org/wetbud/.

Although this license to use Wetbud is provided to You without charge, Owners reserve the right to charge maintenance fees, subscription fees, or other fees for future updates, expansions, services, or related products.

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About Wetbud

3 About Wetbud

Wetbud is a tool for estimating wetland water budgets using available weather data and site-specific topographic, soil, and geohydrologic data. Wetbud is primarily intended as a planning tool for use in the design of created wetlands, but it can also be applied to native wetlands where the required input parameters can be specified.

Wetbud was first developed in two versions, a Basic 2-D formulation with simplified groundwater functions and the Advanced 3-D version with full groundwater modeling capabilities. A fully documented example of the application of both models to an actual field project site in northern Virginia can be found in Stone (2017). The initial version was later enhanced to Wetbud Plus which featured a preloaded database with 14 selected VA weather stations. These stations were selected at the request of the Resources Protection Group (RPG), the sponsor of the Wetbud package.

The current version, Wetbud 2.0, features a preloaded database comprised of 138 weather stations covering the states of CT, DE, FL, GA, IN, KY, MA, MD, MN, MS, NC, NH, NJ, NY, OH, PA, RI, SC, TN, VA, VT, WV.

A polygonal influence area has been defined for each of the preloaded weather stations. Preloaded weather data include precipitation, weather information, and calculated evapotranspiration (ET) values using either the Penman-Monteith method or the Thornthwaite equation, depending on data availability. The Wetbud Project Wizard allows users to quickly set up Projects and associated Scenarios using default parameters and to calculate water budgets using the Basic Model.

Please refer to https://resourceprotectiongroup.org/wetbud/ to get the latest version of Wetbud, to get access to the Wetbud Technical Support forum, and to view presentations from Wetbud workshops.

Important Note: Users should ensure that Wetbud is appropriate for their application, that it closely mimics the proposed project's design situation, and it cannot, and should not, be pushed beyond its intended scope with an expectation that the results can be relied upon.

The following individuals have contributed to the development of the Wetbud software and the Wetbud manual:

- Stephen F. Stone, Old Dominion University, Wetlands Studies and Solutions Inc.
- Kerby M. Dobbs, Old Dominion University
- Benjamin Hiza, Old Dominion University
- Bryce Shoup, Old Dominion University, Wetlands Studies and Solutions Inc.
- John McLeod, Old Dominion University
- Candice Piercy, Virginia Tech
- Eric Neuhaus, Virginia Tech
- Matt Gloe, Virginia Tech
- Suraye Solis, Virginia Tech

- Ethan Sneesby, Virginia Tech
- Kathryn C. Haering, Virginia Tech
- Theresa Wynn-Thompson, Virginia Tech
- G. Richard Whittecar, Old Dominion University
- Mike Rolband, Resource Protection Group Inc., Wetlands Studies and Solutions Inc.
- Zach Agioutantis, University of Kentucky
- W. Lee Daniels, Virginia Tech

Wetbud Programmer
Zach Agioutantis, University of Kentucky

Wetbud Project Leader
W. Lee Daniels, Virginia Tech

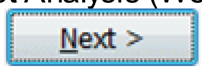
4

Installing Wetbud

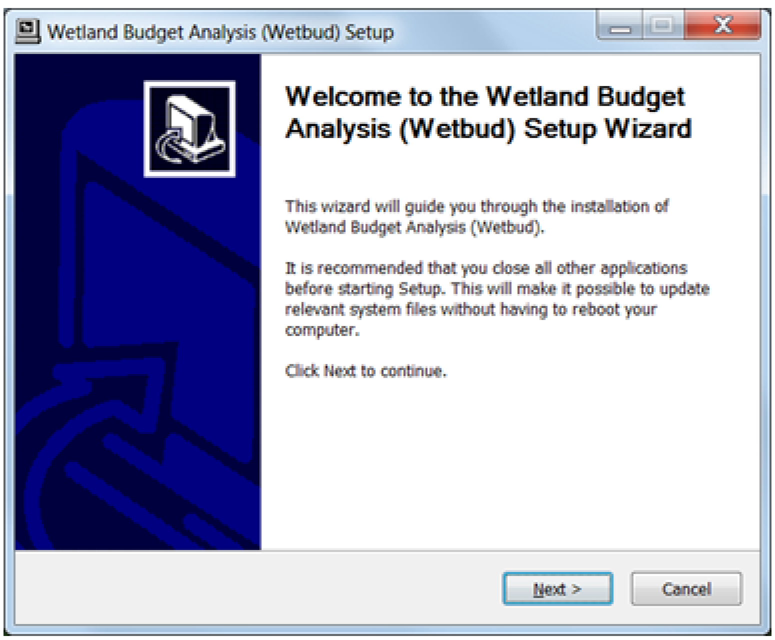
4 Installing Wetbud

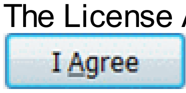
Wetbud is distributed as a single self-extracting executable. It is a database-driven application that is designed to work either in a stand-alone mode or in a distributed environment such as an office.

The following installation instructions apply to an installation where Wetbud is installed from a file downloaded through an internet URL, and the database and the executable files will reside on the same computer. Note that users installing the standalone version may be prompted by the antivirus software on their computer to confirm that this is a trusted software package.

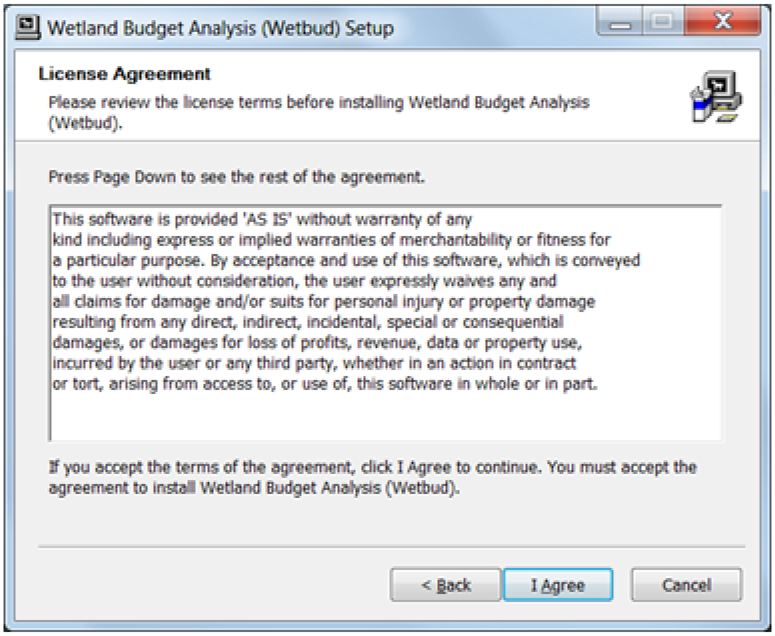
1. Click on the link provided and select Download, then select Save File. The Wetbud installer file will be downloaded to your computer. Run the downloaded file. The Welcome to the Wetland Budget Analysis (Wetbud) Setup Wizard screen will appear (see figure below). Click on the 

button.



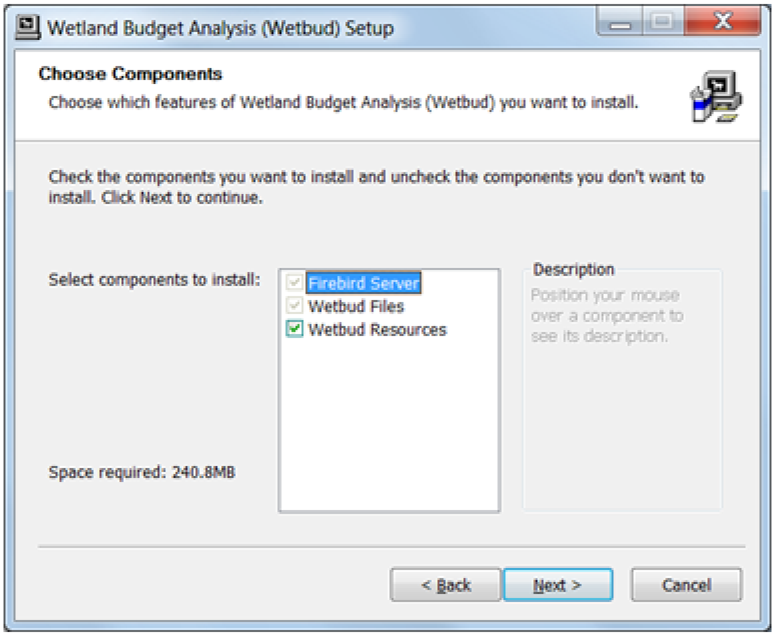
2. The License Agreement screen will appear (see figure below). Click on the 

button.



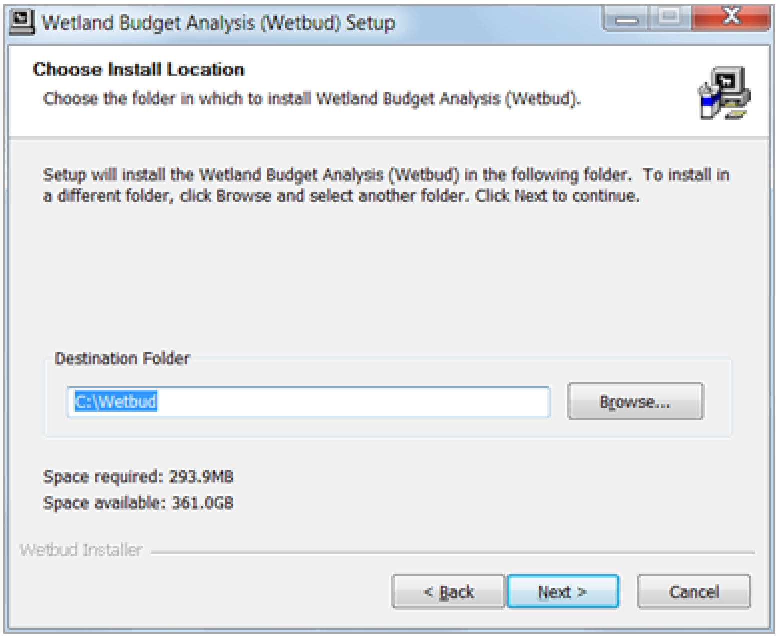
3. The Choose Components screen will appear (see figure below). Firebird Server and Wetbud Files are mandatory. Wetbud Resources (user’s manuals and associated help and demonstration files) is optional, but it is highly recommended that you keep it checked so that you can access those files. Click on the 

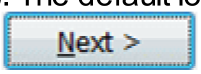
button.

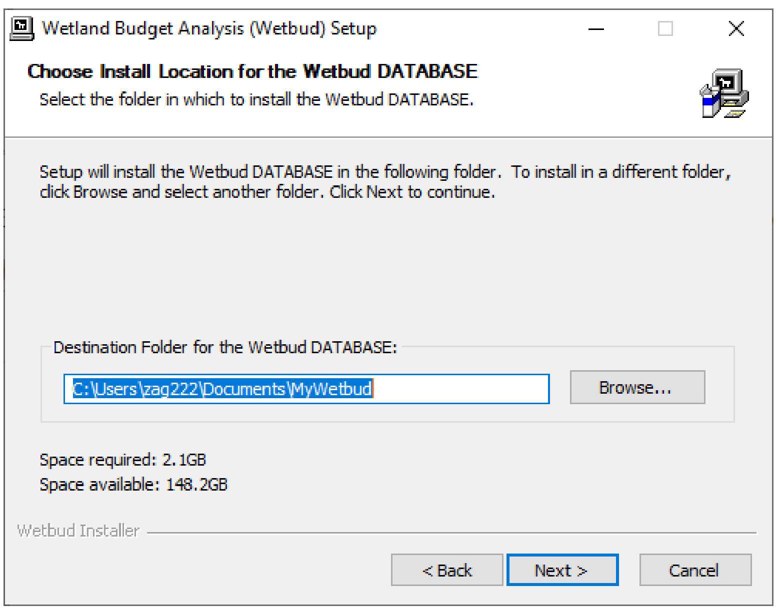


4. If you are installing Wetbud on a computer for the first time, the following two Choose Install Location screens will appear (see figure below). Wetbud will install into C:\Wetbud as the default location. Click on the 

button.



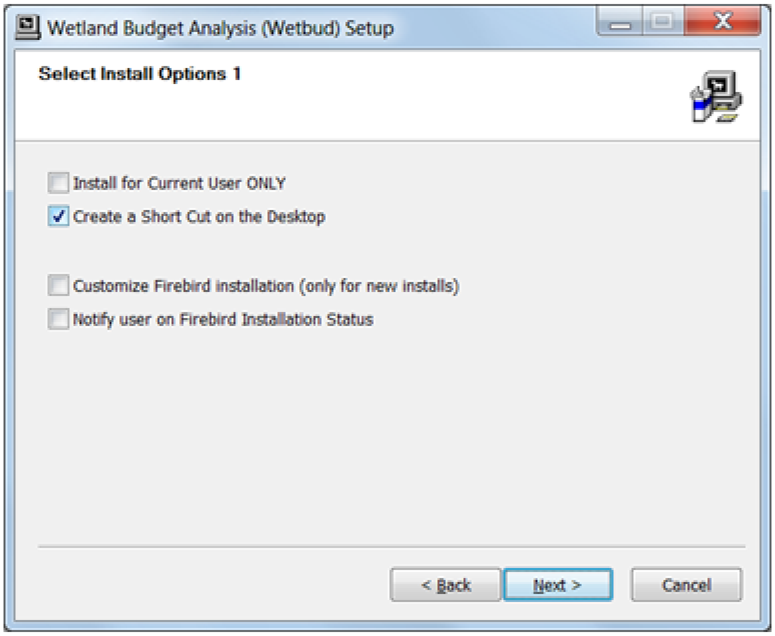
5. The Choose Install Location for Wetbud DATABASE screen will appear (see figure below). The default location for the Wetbud Database is the “MyWetbud” folder. Click on the  button.

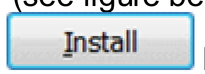


6. For all installations, the Select Install Options 1 screen will appear (see figure below). Note that Wetbud stores all associated data in a Firebird database (Firebird is open source software available in the public domain), so the Firebird database software will be installed along with Wetbud. Choose your preferred options for installation. *Customize Firebird installation* will allow you to choose your preferred folder for the Firebird software, while *Notify User on Firebird Installation Status* will inform you of the progress of the Firebird software installation. It is recommended that the user

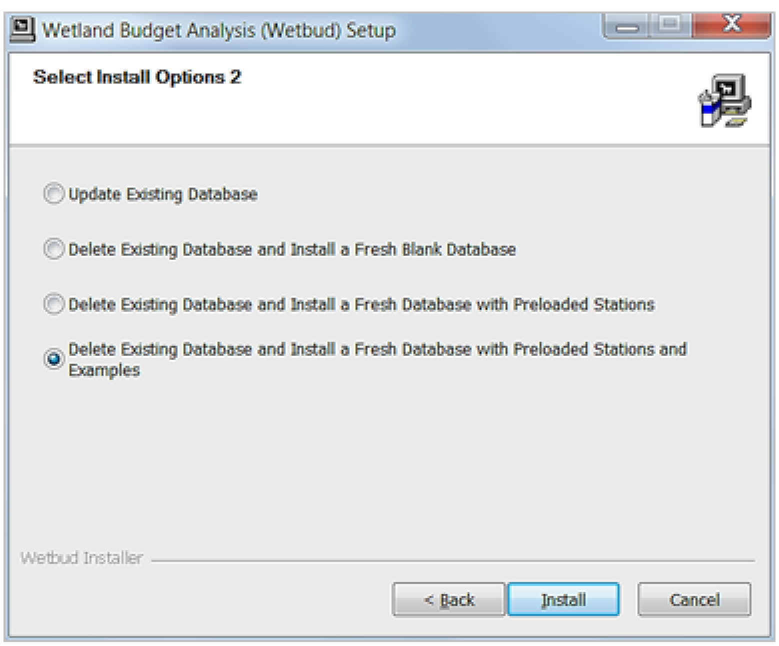
select the default options, as shown in the figure below. Then click on the 

button.



7. If there is an existing installation of Wetbud on your computer, the *Select Install Options 2* screen will appear (see figure below). Select from one of the following options and then click on the 

button.



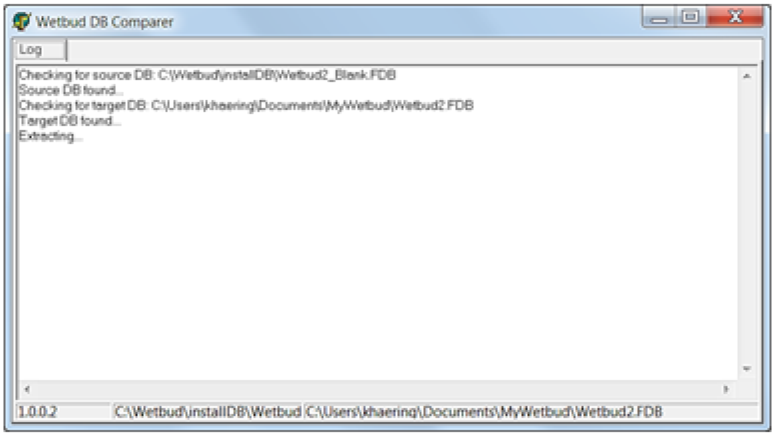
a. The default choice is to *Delete Existing Database and Install a Fresh Database with Preloaded Stations and Examples*. This option will delete your existing database and install a new database with preloaded weather stations so that you may easily construct water budgets for sites in CT, DE, FL, GA, IN, KY, MA, MD, MN, MS, NC, NH, NJ, NY, OH, PA, RI, SC, TN, VA, VT, WV using the *Project Wizard*. This new database will also include examples of completed Wetbud Basic and Advanced Models and Scenarios.

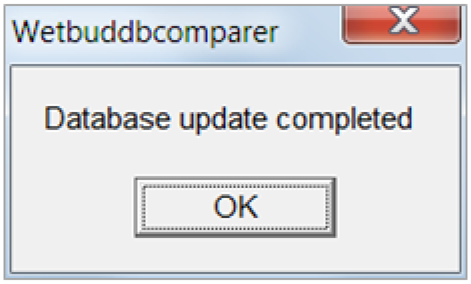
Note for new installations: If you do not have an existing installation of Wetbud on your computer, Wetbud will default to this option and you will not see the *Select Install Options 2* window.

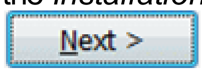
b. If you have an existing installation of Wetbud but you don't really care to keep the original database and you don't want any examples to show up in your projects, choose *Delete Existing Database and Install a Fresh Database with Preloaded Stations*.
c. If you have an existing installation of Wetbud on your computer, and you would like to delete your current database and install a fresh blank database that does not include preloaded weather stations or examples, choose *Delete Existing Database and Install a Fresh Blank Database*.
d. If you have already installed Wetbud on your computer, and have projects and scenarios you would like to save, choose *Update Existing Database*. The figure below will appear as Wetbud compares and updates databases. Click on the 

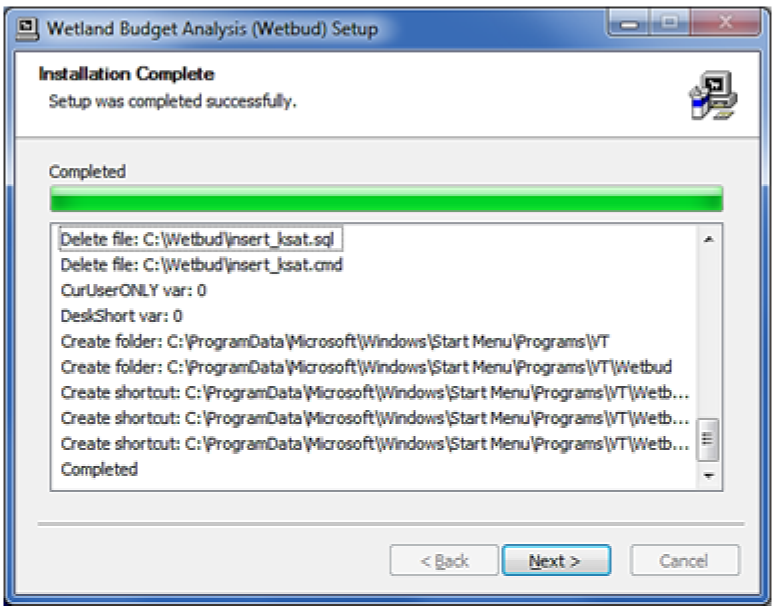
button.

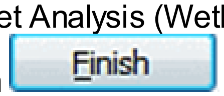
Note for users upgrading to version 2.0: If you would like to keep your existing projects and also load the newly available weather stations, you need to contact the development team and to help you install the additional weather stations and data.

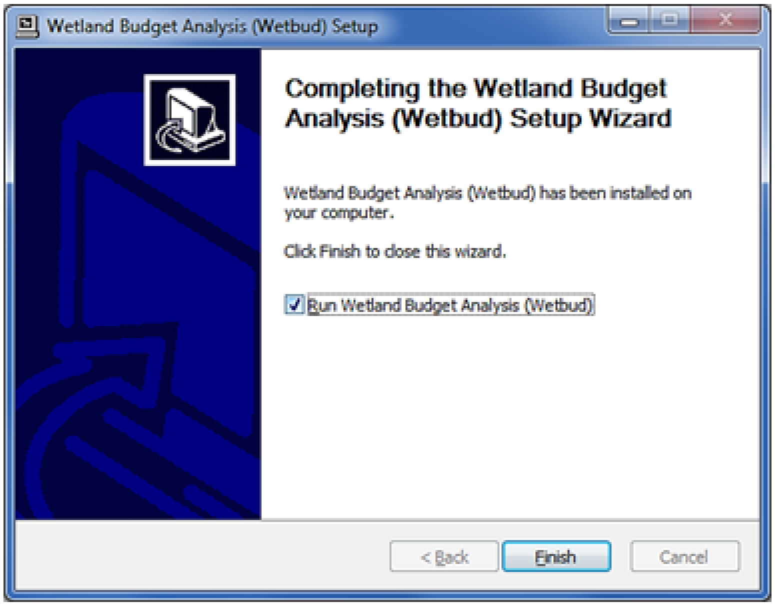




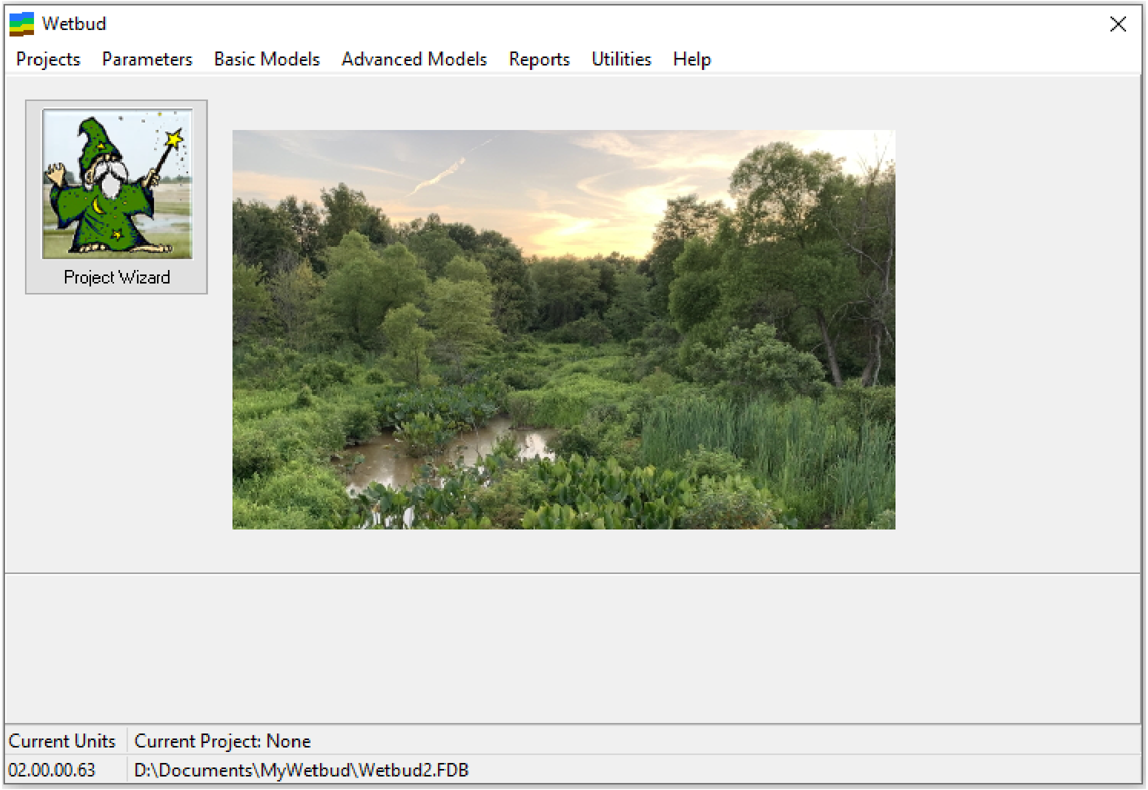
8. Wetbud will then begin installing (1) the Wetbud software and (2) the Firebird database software (if new installation) on your computer. Note that if Wetbud is re-installed on a system, the installation script will automatically create a backup copy of the existing database and place it in a dated folder within C:\Wetbud. Therefore, an existing database cannot be accidentally overwritten during reinstallation.
9. When installation is concluded, the *Installation Complete* window will then appear (see figure below). Click on the  button.



10. The Completing the Wetland Budget Analysis (Wetbud) Setup Wizard screen will appear (see figure below). Click on 



11. If Run Wetland Budget Analysis (Wetbud) is checked, the Wetbud home screen (see figure below) will appear.



12. Wetbud can be un-installed through the Windows Control Panel or by executing the "uninstall.exe" program in the C:\Wetbud directory.

5

Introduction to Basic and Advanced Models

5 Introduction to Basic and Advanced Models

The following sections present a short overview of the Project / Scenario structure in Wetbud.

5.1 Overview

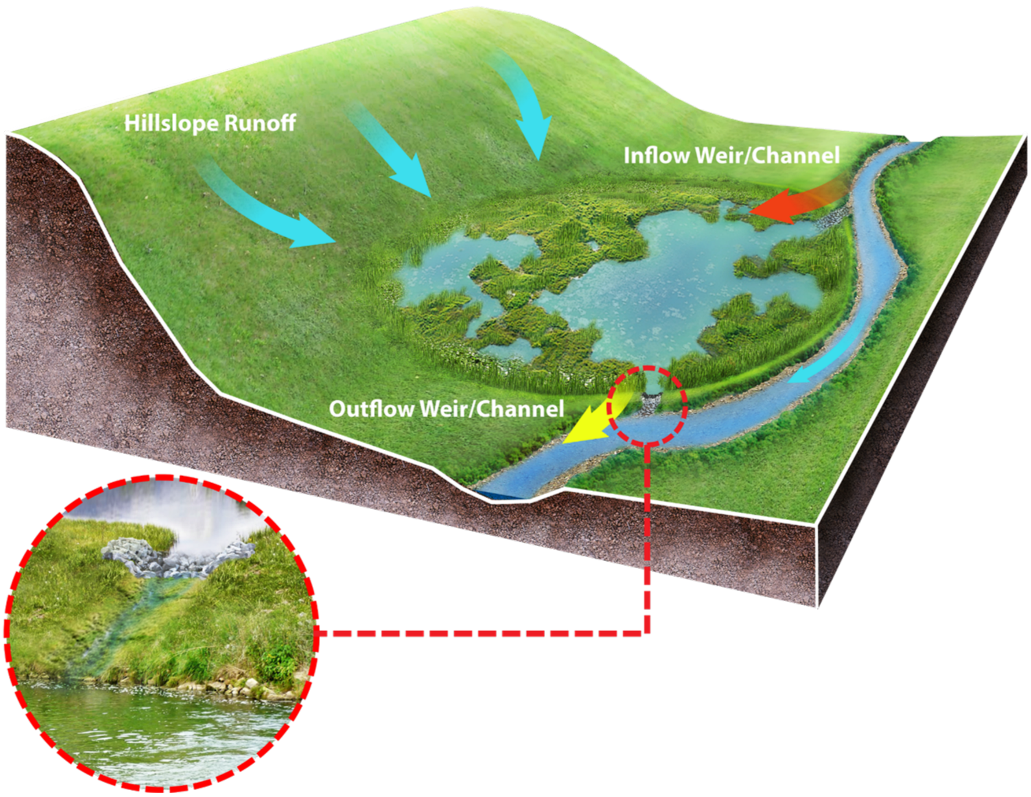
Wetbud is designed to be a user-friendly water budget modeling tool. However, building a water budget model is a complex process that requires patience and attention to detail. The following five-step procedure provides a generalized overview of the recommended order of operations that will lead to a successful Basic Model or Advanced Model created with Wetbud. Instructions and detailed explanations for each step can be found in the sections of this manual that pertain to them.

Note: Some items in the general tasks listed in the sequential operations may not appear in this manual in the exact order as described in the five steps below. These steps simply provide the user guidance and a basic understanding of the logical flow that is recommended to efficiently generate wetland water budgets using Wetbud. Thus, following the exact order of operations as listed below is recommended, but not required.

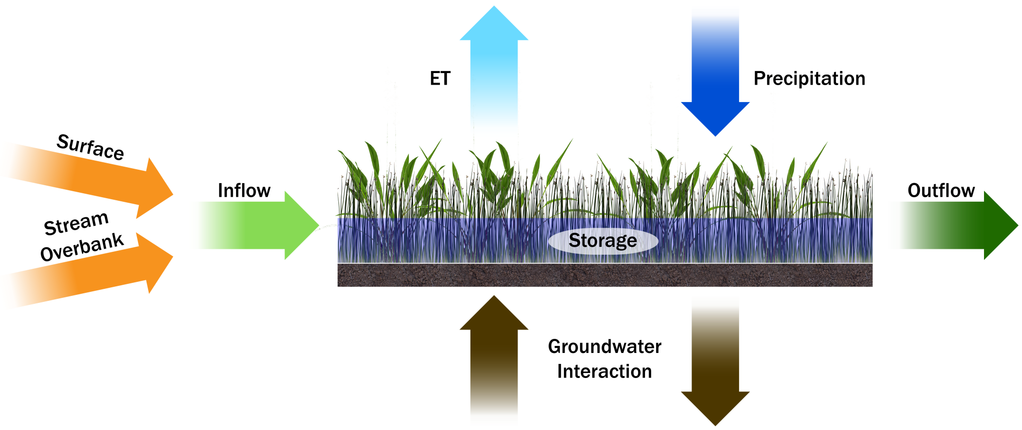
1. Locate the nearest weather station and build a weather station data set. Prior to defining a Project, the user must locate the nearest usable weather station to their Project site and create a weather station record from the station in the NOAA (GSOD) weather stations database. Next, the user must build a complete weather station data set to be used in Basic Model and Advanced Model water budget calculations. The weather station data set will consist of precipitation, weather (temperature, wind speed, etc.), and solar data, often combined from multiple weather stations. Building a complete data set is the first and most important step for water budget modeling because sources and losses of water will be estimated based on changes in weather. User compiled weather data should be reviewed to ensure that Wetbud generates the most accurate water budget possible for a given site. Instructions for building weather station records and data sets can be found in Parameters.
2. Parameterize the site for Basic and/or Advanced Scenario setup. Prior to Scenario set up in Wetbud, it is helpful to obtain data for the physical parameters (e.g., wetland size, stratigraphic data, etc.) of the site to be modeled and for the variables that are expected to affect water levels (e.g., groundwater inputs or losses, stream overbank additions, weir elevations, etc.) in the wetland. Lists of specific parameters required for the Project Wizard, Basic and Advanced Scenario setup are located in Basic Models and Advanced Models.
3. Define/create a Project (see Projects), assign the reference weather station, and locate the nearest WETS station, which will be used to determine dry, normal, and wet years to be included in water budget analyses. Instructions for defining/creating a Project and assigning a reference weather station are located in Projects. Instructions and details pertaining to WETS stations are located in Station Data-WETS (NRCS).

4. Select a Project (see Selecting a Project) for further use in building model scenarios.
5. Create and set up Scenario(s) within the selected Project. For instructions pertaining to Basic Scenario setup, see Basic Scenarios. For instructions pertaining to Advanced Scenario setup, Advanced Scenarios.
6. Generate Model output and view Scenario results. For instructions pertaining to Basic Model output and results, see Basic Analysis and Output. For instructions pertaining to Advanced Model output and results, see Advanced Output.

The figure below presents a summary graphic of how the Wetbud Basic Model manages various surface water input including local direct runoff and stream overbank additions. Figure designed by Dillon Conner.

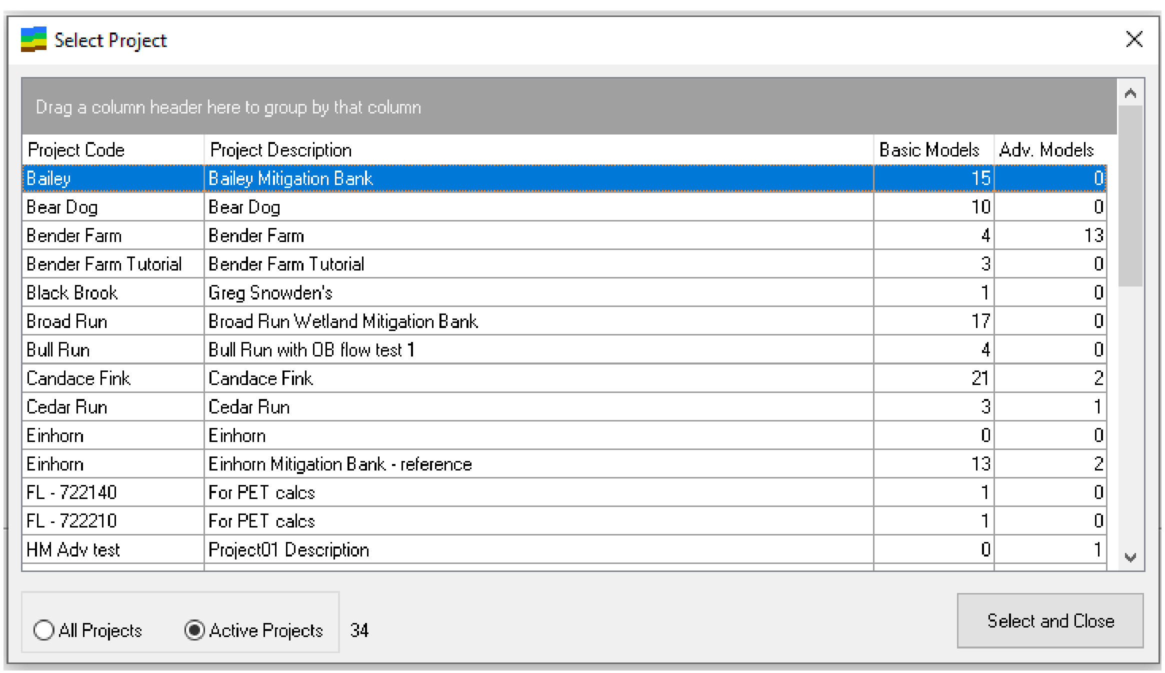


The figure below presents a summary graphic of how the Wetbud Basic Model manages various surface water and groundwater input. Figure designed by Dillon Conner.



5.2 Selecting a Project

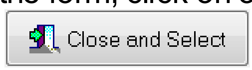
To begin creating or editing a Basic or Advanced Scenario within a Project, the user must first select the Project for which they would like to create a Scenario. In the Projects drop-down menu, click *Select Current Project*. In the *Select Project* window, choose the Project from the Projects list and click Select and Close.



Project Code	Project Description	Basic Models	Adv. Models
Bailey	Bailey Mitigation Bank	15	0
Bear Dog	Bear Dog	10	0
Bender Farm	Bender Farm	4	13
Bender Farm Tutorial	Bender Farm Tutorial	3	0
Black Brook	Greg Snowden's	1	0
Broad Run	Broad Run Wetland Mitigation Bank	17	0
Bull Run	Bull Run with OB flow test 1	4	0
Candace Fink	Candace Fink	21	2
Cedar Run	Cedar Run	3	1
Einhorn	Einhorn	0	0
Einhorn	Einhorn Mitigation Bank - reference	13	2
FL - 722140	For PET calcs	1	0
FL - 722210	For PET calcs	1	0
HM Adv test	Project01 Description	0	1

Note 1: A project should be defined (created) (see Projects), before it can be selected.
Note 2: If a Project is not selected prior to selecting an option in the *Basic Models* or *Advanced Models* menu, the user will automatically be directed to the *Select Project* window.

Once a Project has been defined and selected within Wetbud, users will be able to develop Basic and Advanced Scenarios within that Project.

Note 3: When working on multiple Projects the user may need to frequently compare parameters stored in the *Define Projects* form. To select a Project from the *Define Projects* form, when closing the form, click on one of the Projects listed in the *Project Code* grid and then click the 

button. This button allows the user to leave the *Define Projects* form and immediately begin editing *Parameters* or *Scenarios* within the selected Project without needing to open the *Select Project* form.

6

Project Wizard

6 Project Wizard

The Project Wizard allows users to quickly set up Projects and Scenarios (see next section) using **default** parameters and to calculate water budgets using the basic model.

The Wizard utilizes the preloaded database that includes data from 108 selected weather stations covering several states (CT, DE, FL, GA, IN, KY, MA, MD, MN, MS, NC, NH, NJ, NY, OH, PA, RI, SC, TN, VA, VT, WV). A polygonal influence area has been defined for each of the preloaded weather stations. Preloaded weather data include precipitation, weather information, and calculated evapotranspiration (ET) values using either the Penman-Monteith method or the Thornthwaite equation, depending on data availability.

Note: This section includes a very brief description of the parameters associated with projects and scenarios. The user is advised to read the full section on Projects, Parameters and Basic Scenarios

Projects and Scenarios
The following notes explain the steps users should follow to operate the Wetbud Setup Wizard to create a new Project and then a Basic Scenario within that Project. Once a Project is created, the user can create one or many Basic or Advanced Scenarios for the Project using the options under the Basic Models and Advanced Models drop down menus found on the Wetbud home screen.

Note: When creating a Project, users will be prompted to select a unit system for their Project (English or Metric). The selected unit system will be used for all of the variables and parameters within all of the Scenarios for the newly created Project. Once a unit system is selected, the Project Units may not be changed.

Data Required to Create a Project and a Scenario
Before constructing a Basic Model with the Wetbud Project Wizard, the user should have collected the following information and data:

1. Project name (up to 20 characters).
2. Latitude and longitude of a central point within the study area, in decimal degrees (e.g., 37.349, -77.584). These values are used to select the appropriate reference weather station.
3. Average wetland bottom elevation (ft or m). Note that this value should be obtained from a topographic map or actual survey data.
4. Wetland watershed area (acres or m^2). (Boundaries for these areas can be drawn using Google Earth Pro based on USGS topographic maps available in Google Earth format. These measured areas can be determined by using Google Earth Pro and an on-line area conversion site.)
5. Constructed wetland area (acres or m^2).
6. Existing wetland area (acres or m^2).

7. Wetland watershed NRCS Curve Number (CN). This ranges from 40-100, with a suggested default of 70. The CN needed is the area-weighted value based on Hydrologic Soil Group (HSG) classes and land use for the watershed. The proportion of the watershed with each HSG class can be obtained most easily from NRCS Web Soil Survey; Google Earth images may be useful in assessing land use. CN values for each HSG and land use can be obtained from on-line tables. To get the single, area weighted, CN for the watershed, the CN values for each HSG must be multiplied by the proportion of the basin with that HSG classification; then those weighted values must be totaled.

Project Wizard Assumptions

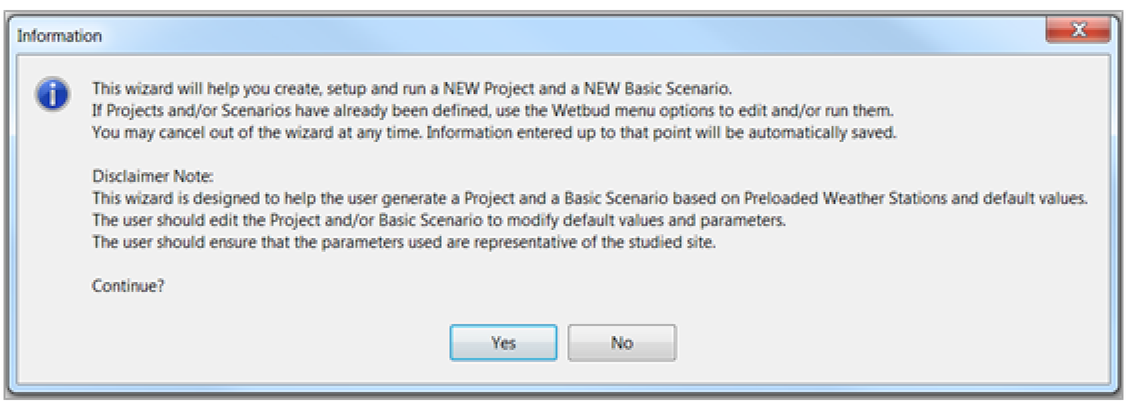
When creating a Basic Scenario, the Project Wizard assumes water inputs from precipitation, runoff from adjacent slopes, and an assumed initial fill depth of 2.00 inches (5.08 cm). Water is assumed to be lost through evapotranspiration, groundwater seepage (at 1 inch/month, 2.54 cm/month), and surface outflow when water depths overtop the designated weir elevation. The default water management assumes a weir height of 3.00 inches (7.62 cm) above the flat wetland soil surface, a soil storage factor of 0.25, and a surface storage factor of 1.

Once the Project and first Basic Scenario are established within the Wizard and the first calculations are made, the user may add more inputs (e.g., stream bank overflow, groundwater contributions, etc.) and may adjust any of the default values if/as necessary to better match anticipated field conditions.

Operating the Project Wizard

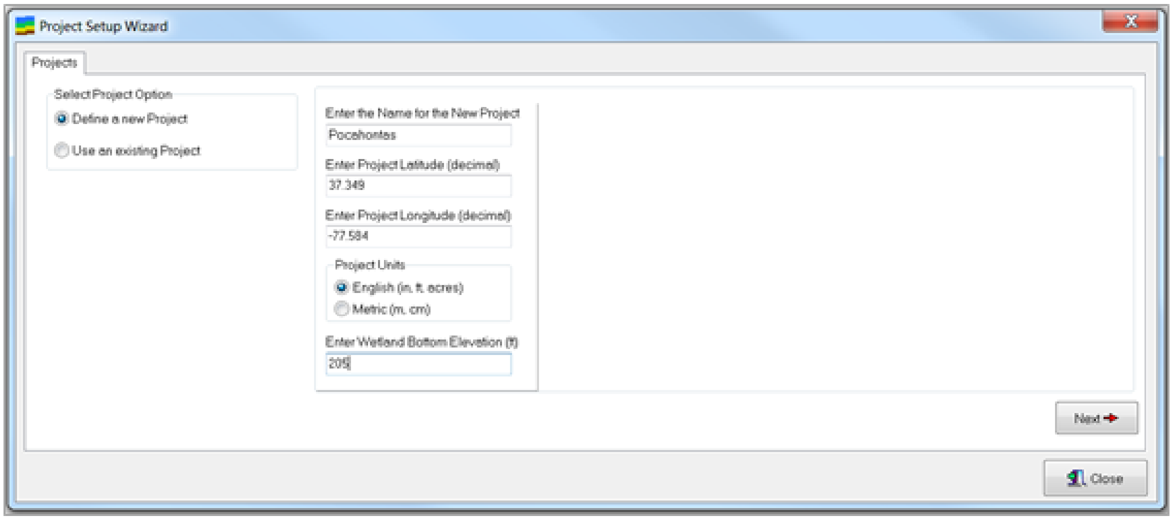
The Project Wizard Icon is on the left of the main Wetbud window. In the status line at the bottom of the home screen, the version number, the currently selected Project, and the Wetbud database location are identified.

From the Wetbud Home Screen, select the Wizard icon to run the Project Wizard. The disclaimer message will appear (see figure below). Click 'Yes' to proceed.

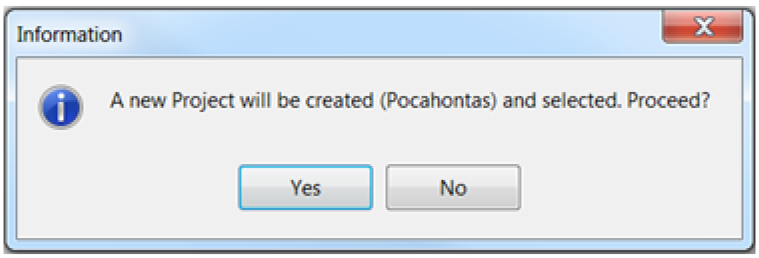


To define a new Project, select *Define A New Project*, and enter the Project name, latitude and longitude in decimal degrees (e.g., 37.349, -77.584), and elevation (ft or m) (see figure below), then click 

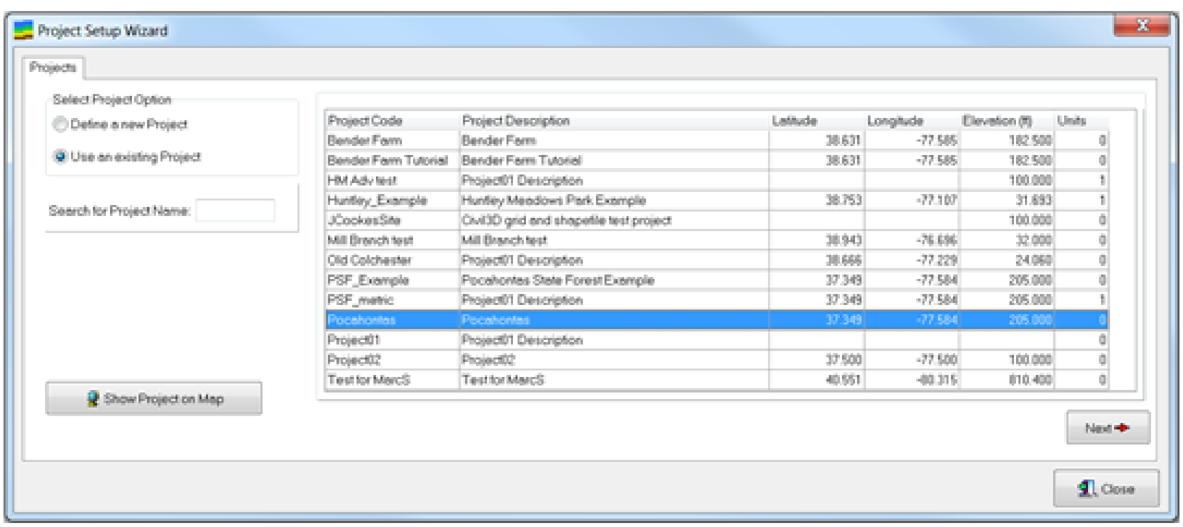
.



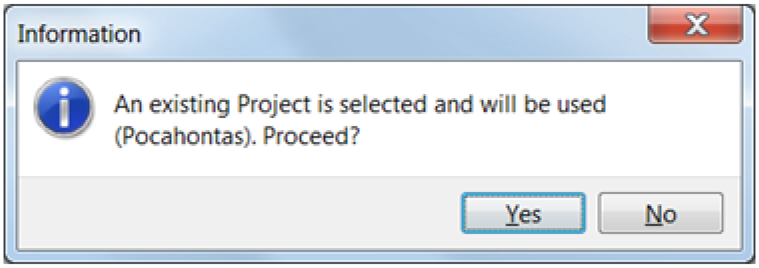
The message in the figure below will appear. Click 'Yes' to proceed.



To use an existing Project, select *Use an existing Project*, highlight the Project that you want to use, and click  as shown in the figure below.



The message in the figure below will appear. Click 'Yes' to proceed.



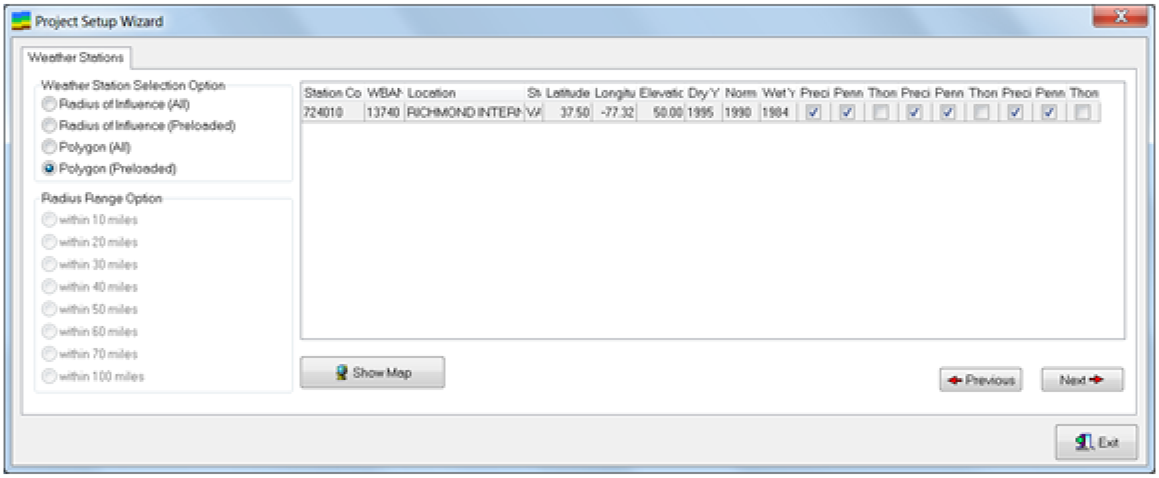
After creating a new Project or selecting an existing Project, the weather station selection screen will appear. Weather stations are filtered based on the entered latitude and longitude of the Project and the following four options (see figure below) will appear:

1. Radius of Influence (All) will display all weather stations that are within the selected range of miles from the Project (wetland) location as determined by its latitude and longitude.
2. Radius of Influence (Preloaded) will display only the preloaded weather stations within the selected range of miles from the Project (wetland) location.
3. Polygon (All) will display all the weather stations whose polygonal area of influence includes the Project (wetland) location as determined by its latitude and longitude. **Note:** If the project location is not included in any of the defined polygons, then no weather stations will be displayed under that option and the user cannot continue using this option.
4. Polygon (Preloaded), which is the default, will select all the preloaded weather stations in the polygonal area of influence that includes the Project location.

Note: As stated earlier, the weather station selection options marked Preloaded include a total of 138 stations covering the states of CT, DE, FL, GA, IN, KY, MA, MD, MN, MS, NC, NH, NJ, NY, OH, PA, RI, SC, TN, VA, VT, WV. If there are no preloaded stations covering the area of interest to the user, then no weather stations will be displayed under that option and the user cannot continue. Users may create their own weather stations which can be used in the Project Wizard by following the instructions in the Parameters Section. Weather stations used in the Wizard will need to contain complete data sets (weather, precipitation, and solar) for the years that will be modeled.

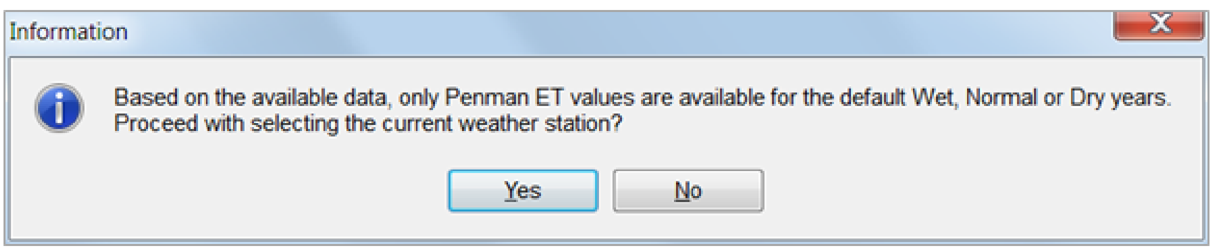
To use the default [Polygon (Preloaded)] station, click on it and click 

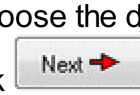
(see figure below). When the Polygon (Preloaded) option is selected, Wetbud will either display one station if the Project location falls within a predefined polygon, or no stations at all.



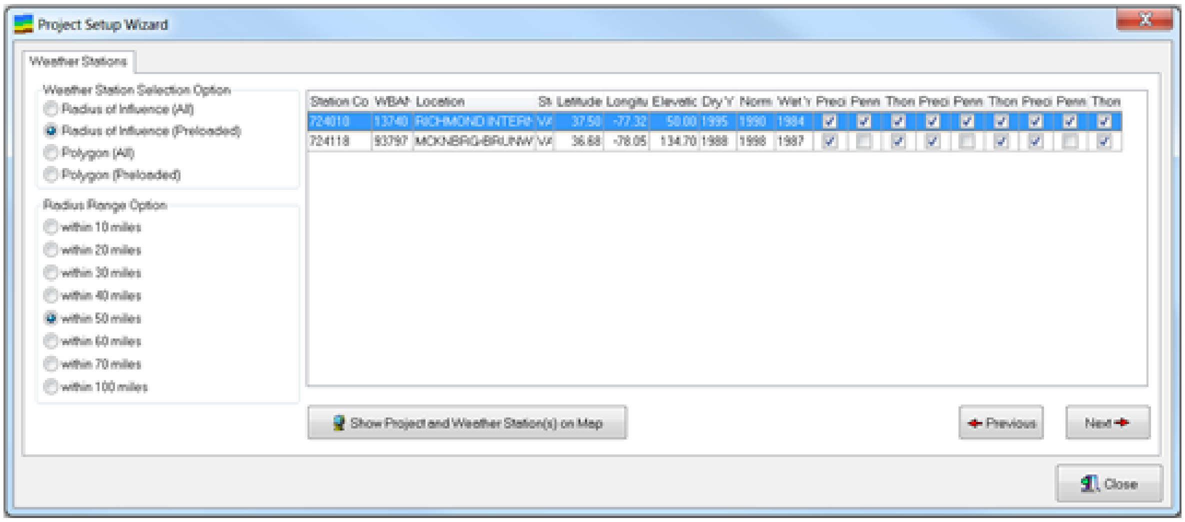
Wetbud will then tell the user what type of ET values are available for the default Dry, Normal and Wet years at that station, as shown in the figure below. When Penman-Monteith ET values are not available for a preloaded station due to missing solar data, then only Thornthwaite ET values will be provided. This information is available in the Wetbud database with the 138 preloaded stations. Click 'Yes' to proceed.

Note: If a non-preloaded weather station is used, then the user should make sure that ET values are available for that station. See Potential Evapotranspiration (PET) Data for more information on PET data.



To use the Radius of Influence (Preloaded) option, click on it, choose the desired mileage range, highlight your preferred weather station and click 

(see figure below). More than one weather station may fulfill the radius of influence criterion, so the user should select a specific station.

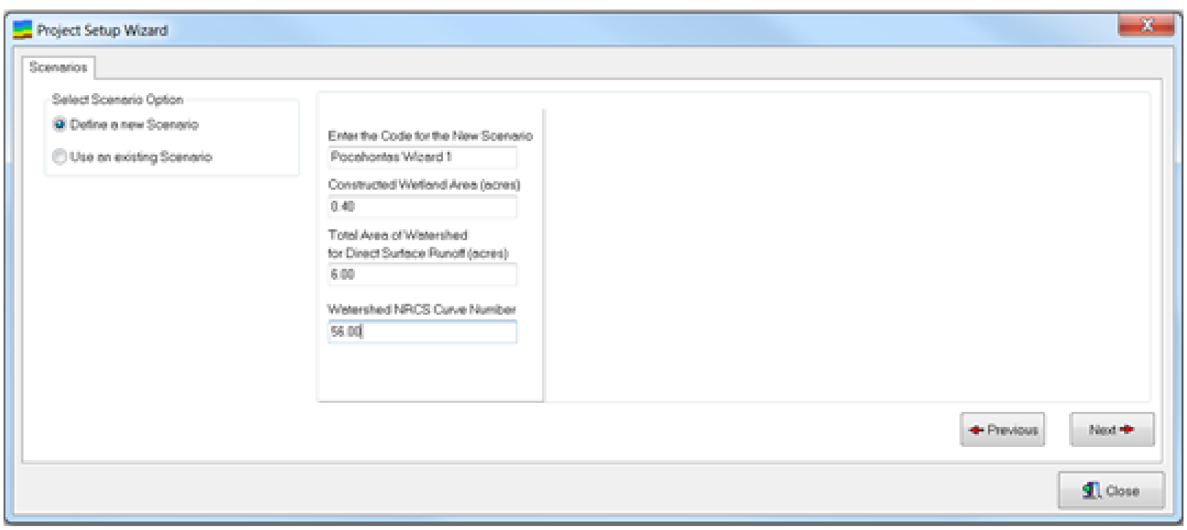


In the following example, the Polygon (Preloaded) weather station will be used.

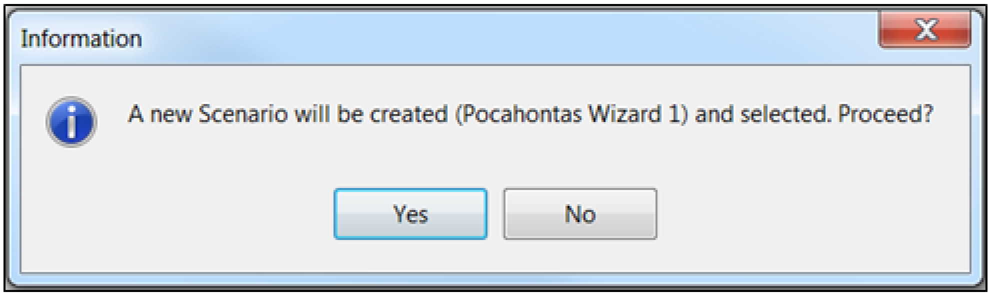
After weather station selection, the screen in the figure below will appear. To define a new Scenario, choose “Define a new Scenario”, and enter:

- the Scenario Code (a short descriptor used to identify the Scenario)
- the area of the constructed wetland (in acres)
- the total area of the watershed for direct surface runoff (in acres)
- the watershed NRCS curve number

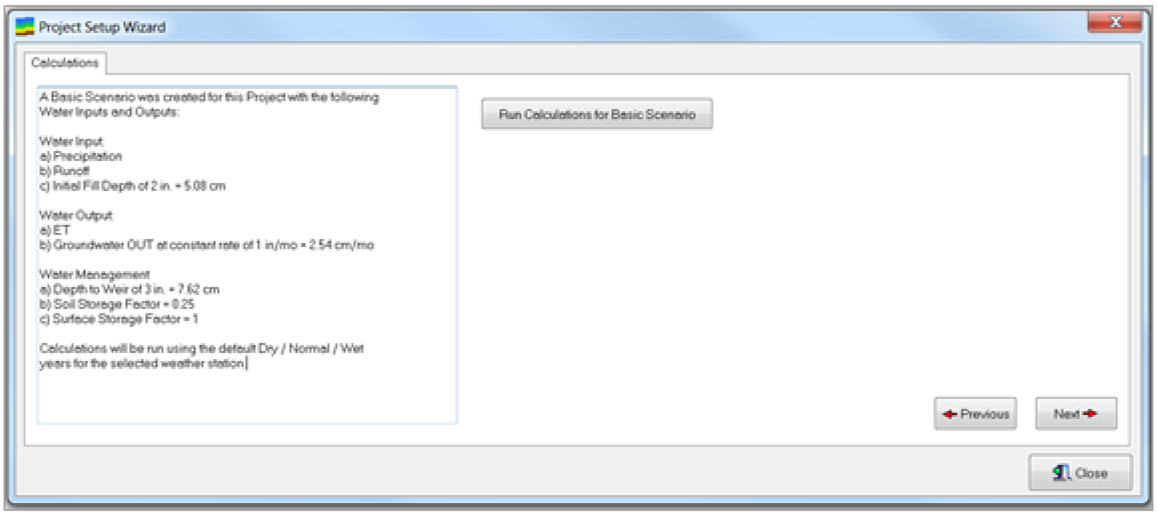
Then click 'Next'.



The message in the figure below will appear.



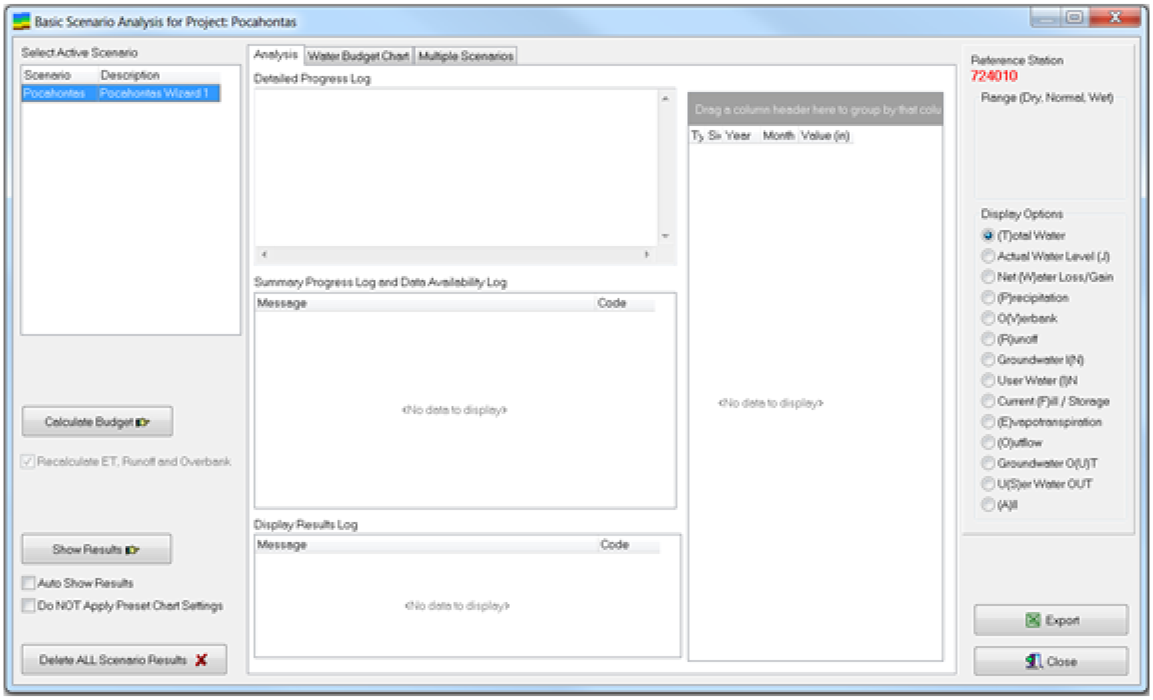
Click 'Yes' to proceed to the screen shown in the figure below, which summarizes the water inputs, outputs, and water management.



Click 

and the Basic Scenario Analysis screen (see figure below) will appear.

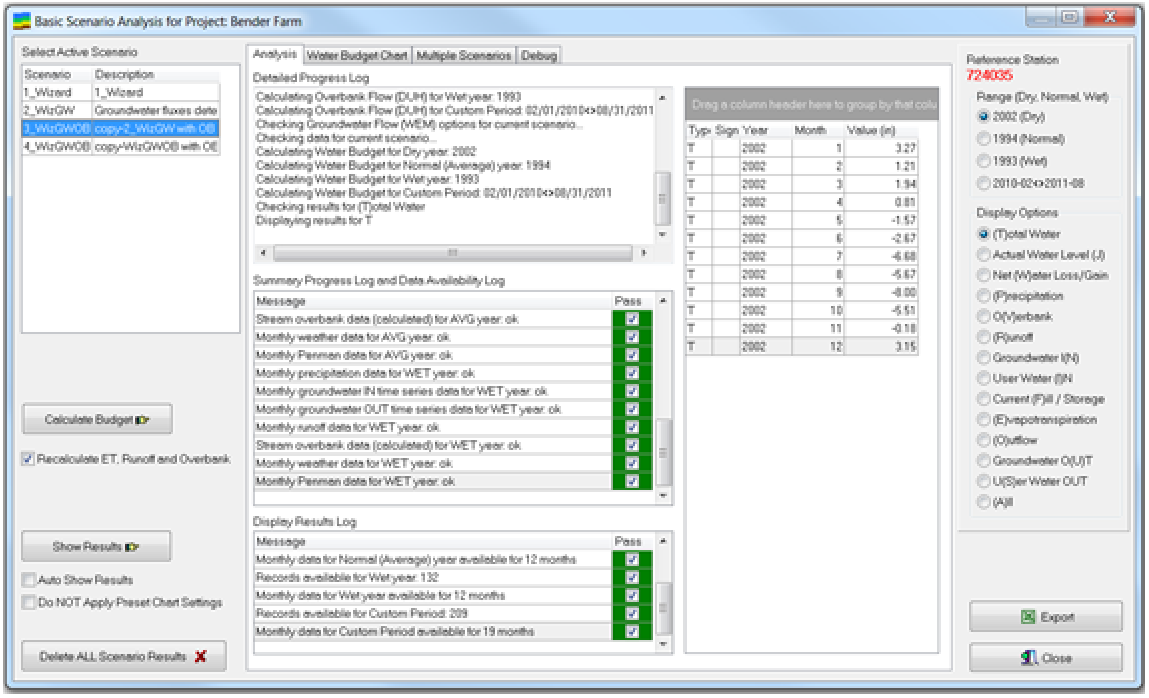
Note: If multiple scenarios are available for the selected project, only the currently selected scenario will be visible in the form shown in this figure.



Basic Scenario Water Budget Analysis

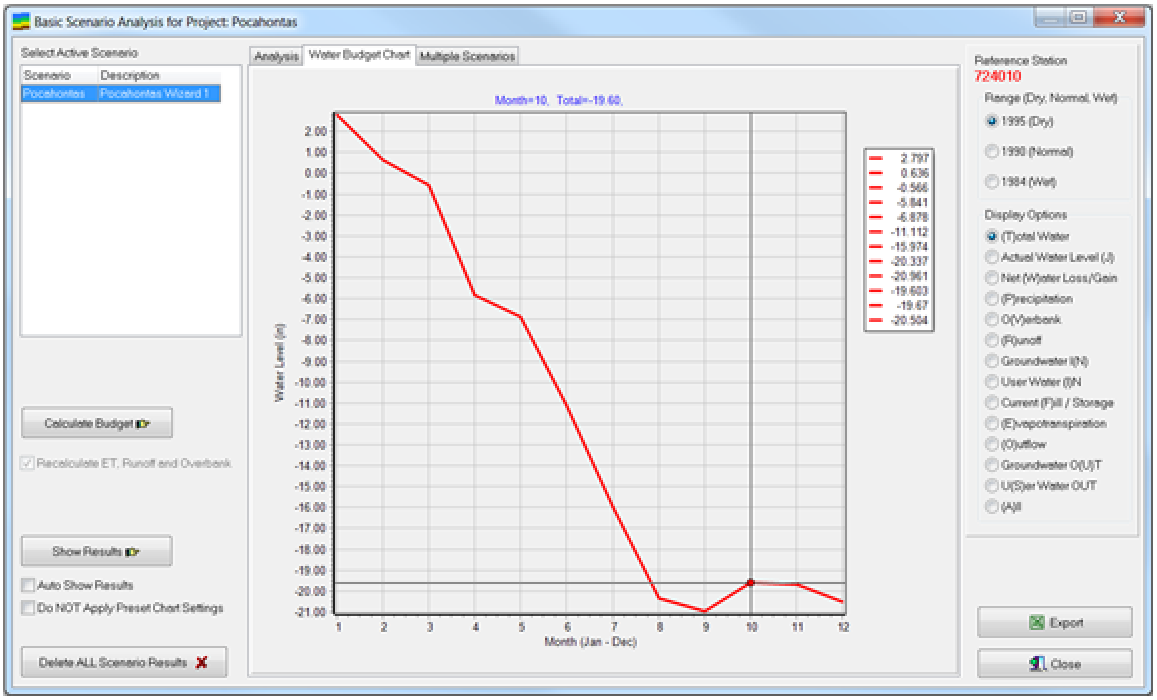
1. To complete a Basic Scenario water budget analysis, click 

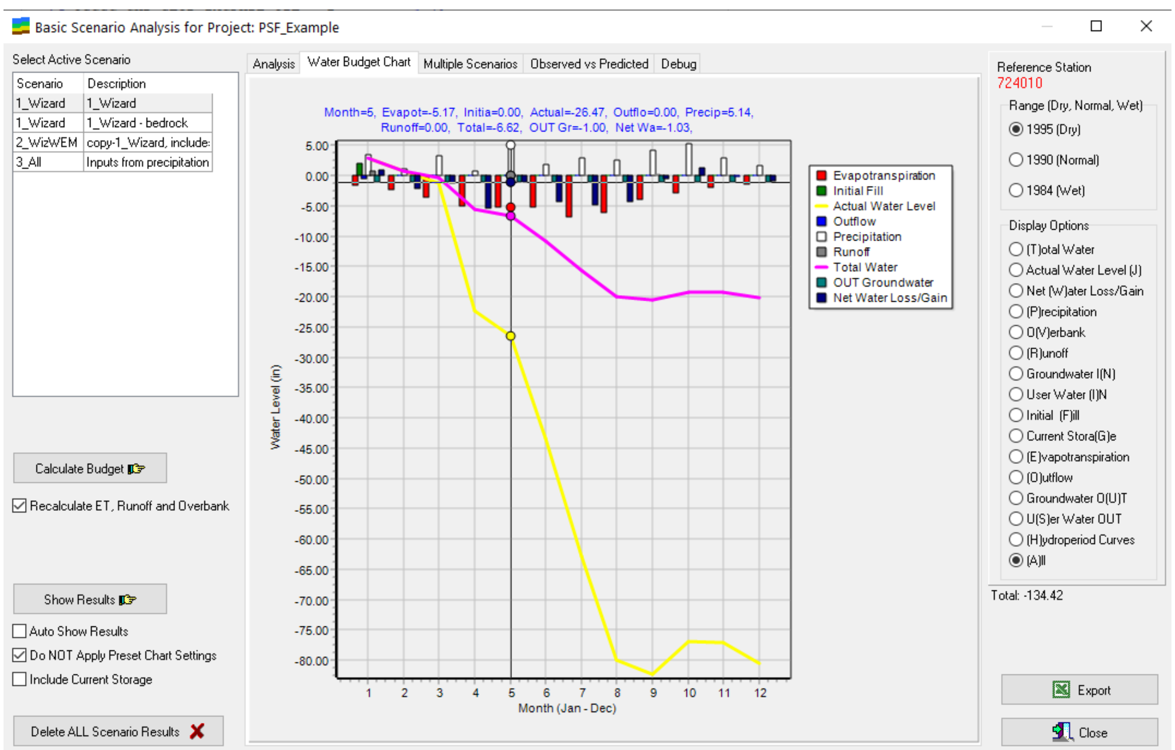
(see figure above). If adjustments are made to any parameters that may affect ET and/or runoff calculation (e.g., PET option, Curve Number, etc.), the user must check the box next to Recalculate ET, Runoff, and Overbank before recalculating the water budget for a water budget previously calculated within that Scenario.
2. The Analysis tab will then display a detailed progress log, a summary progress log and data availability log, a display results log, and a table of monthly results for the year. Wetbud will then display the options selected in the Range and Display Options boxes on the right side of the window, respectively (see figure below).



3. The *Detailed Progress Log* displays messages regarding the progress of model calculations and it should be reviewed when troubleshooting a scenario run.
4. The *Summary Progress Log* and *Data Availability Log* displays whether the different data components are present after calculations are completed. The color of the code box at the end of a run indicates whether the run was successful; green = all data was present (passed check); red = missing data (failed check).
5. The *Display Results Log* displays the number of records available for each water component and each year included in the water budget calculations. The codes in the *Display Results Log* work the same as they do in the *Summary Progress Log* and *Data Availability Logs*.
6. The grid to the right of the *Detailed Progress Log* panel displays monthly results for the year and variable selected in the *Range* and *Display Options* boxes on the right side of the Basic Scenario Analysis window. The user can view tabulated results for each variable in the water budget analysis by adjusting the selection in the *Display Options* box.
7. The *Water Budget Chart* tab (see the two figures below) shows a graphical display of the Basic Model results (for the Dry year). The user can choose to display each variable individually or combine all water budget components on the same graph by changing the selection in the *Display Options* box. The first two variables in the *Display Options* box, *(T)otal Water* (see figures below) and *Actual Water Level (J)* are displayed as a line graph. (T)otal values are the total monthly mass balance water levels. *Actual Water Level (J)* values are water levels relative to the ground surface (adjusted for soil storage when the water level drops below the ground surface and/or surface storage); these values represent the monthly water surface or water table elevation within the wetland. All other variables are displayed as a bar graph (see figures below). Each year in the standard analysis range can be displayed by changing the selection in the *Range (Dry, Normal, Wet)* box.

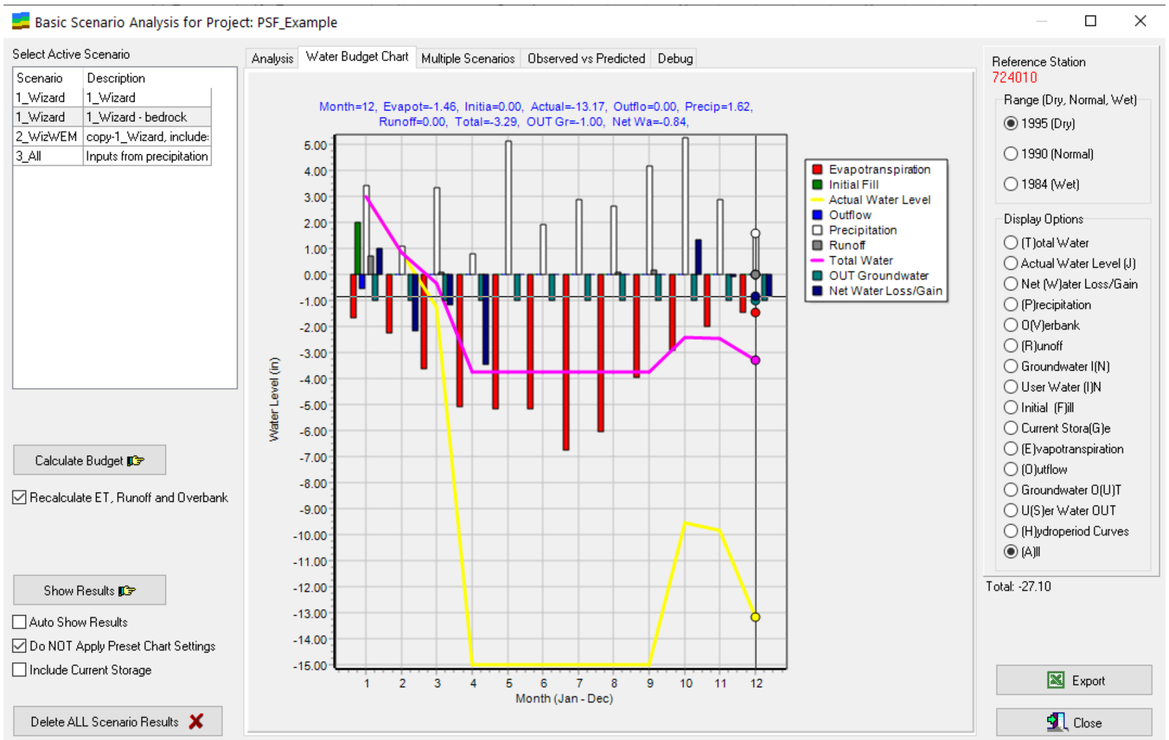
8. Results are stored in the database, so they can be promptly displayed without having to re-calculate the water budget (see also Basic Analysis and Output).



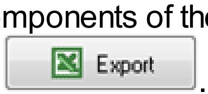


Note: The results shown in the figure above do not account for the presence of an impermeable layer below the wetland bottom. In Wetbud, an 'impermeable layer' provides a limit for predicted water levels to drop to and rebound from during dry conditions. This depth is typically more than rooting depth and is related to the soil structure below the wetland bottom. This is an important consideration to prevent the model from arbitrarily drawing the water level down below the presumed level of active rooting and associated water withdrawal. Conceptually, this is similar to the use of the "ET extinction depth" used in the Advanced Model (see Advanced Scenarios - Layers).

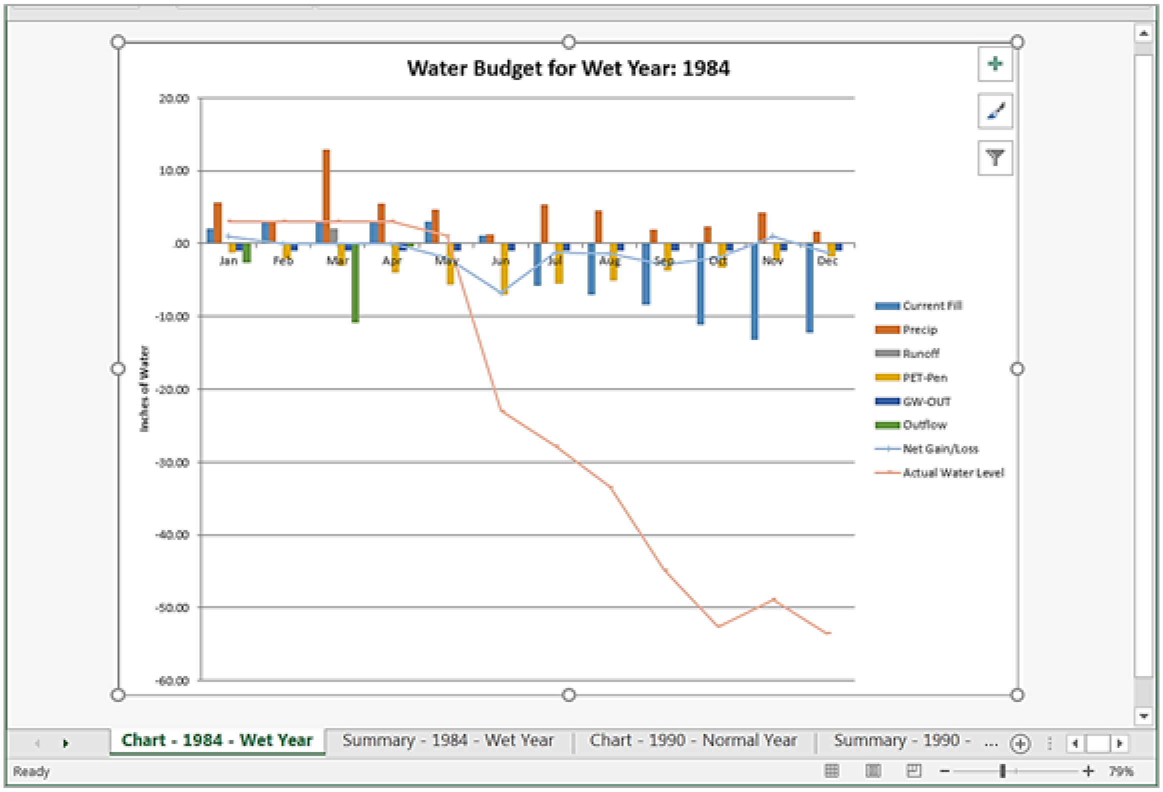
To implement an impermeable layer the user needs to adjust the Basic Scenario data under Site Parameters and specify the depth of the impermeable layer. If a depth of 15 inches is specified, then the water budget is adjusted as shown below.



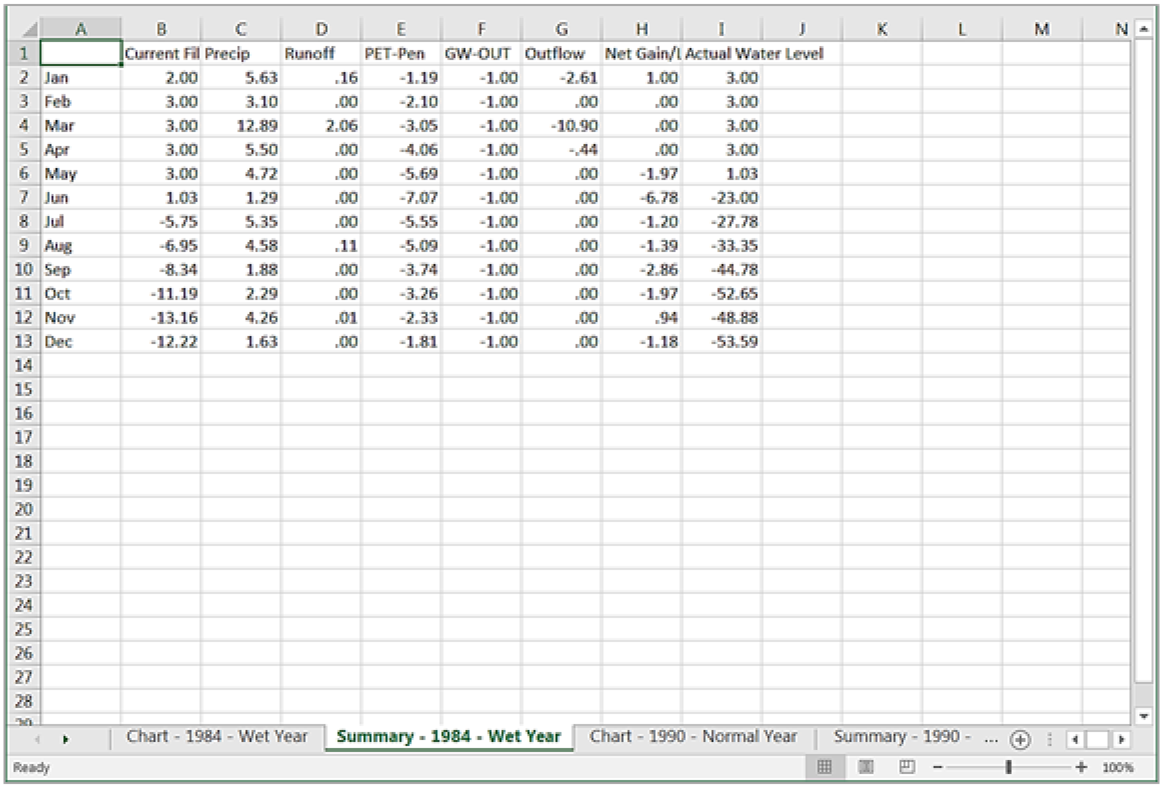
Exporting Basic Scenario Water Budget Results

The user can export all Basic Analysis water components of the current water budget analysis in an Excel file. To export results, click . Wetbud will produce a single Excel file with charts and a data summary for the Dry, Normal and Wet years, on separate worksheet pages. (The user may generate a Word file with all these results through the Wetbud Report options.)

For example, the Excel worksheet in the figure below shows the water budget for the wet year that could be saved as its own worksheet, or automatically inserted into the Word document summarizing the scenario output.



The Excel worksheet in the figure below shows the data summary for the same wet year.



	Current Fil	Precip	Runoff	PET-Pen	GW-OUT	Outflow	Net Gain/l	Actual Water Level
Jan	2.00	5.63	.16	-1.19	-1.00	-2.61	1.00	3.00
Feb	3.00	3.10	.00	-2.10	-1.00	.00	.00	3.00
Mar	3.00	12.89	2.06	-3.05	-1.00	-10.90	.00	3.00
Apr	3.00	5.50	.00	-4.06	-1.00	-.44	.00	3.00
May	3.00	4.72	.00	-5.69	-1.00	.00	-1.97	1.03
Jun	1.03	1.29	.00	-7.07	-1.00	.00	-6.78	-23.00
Jul	-5.75	5.35	.00	-5.55	-1.00	.00	-1.20	-27.78
Aug	-6.95	4.58	.11	-5.09	-1.00	.00	-1.39	-33.35
Sep	-8.34	1.88	.00	-3.74	-1.00	.00	-2.86	-44.78
Oct	-11.19	2.29	.00	-3.26	-1.00	.00	-1.97	-52.65
Nov	-13.16	4.26	.01	-2.33	-1.00	.00	.94	-48.88
Dec	-12.22	1.63	.00	-1.81	-1.00	.00	-1.18	-53.59

As stated earlier, once the Project and first Basic Scenario are established within the Wizard and the first calculations are made, the user may add more inputs (e.g., stream overbank flow) and may adjust any of the default values if/as necessary to better match anticipated field conditions. Further details are available in Basic Models and Parameters.

7

Projects

7 Projects

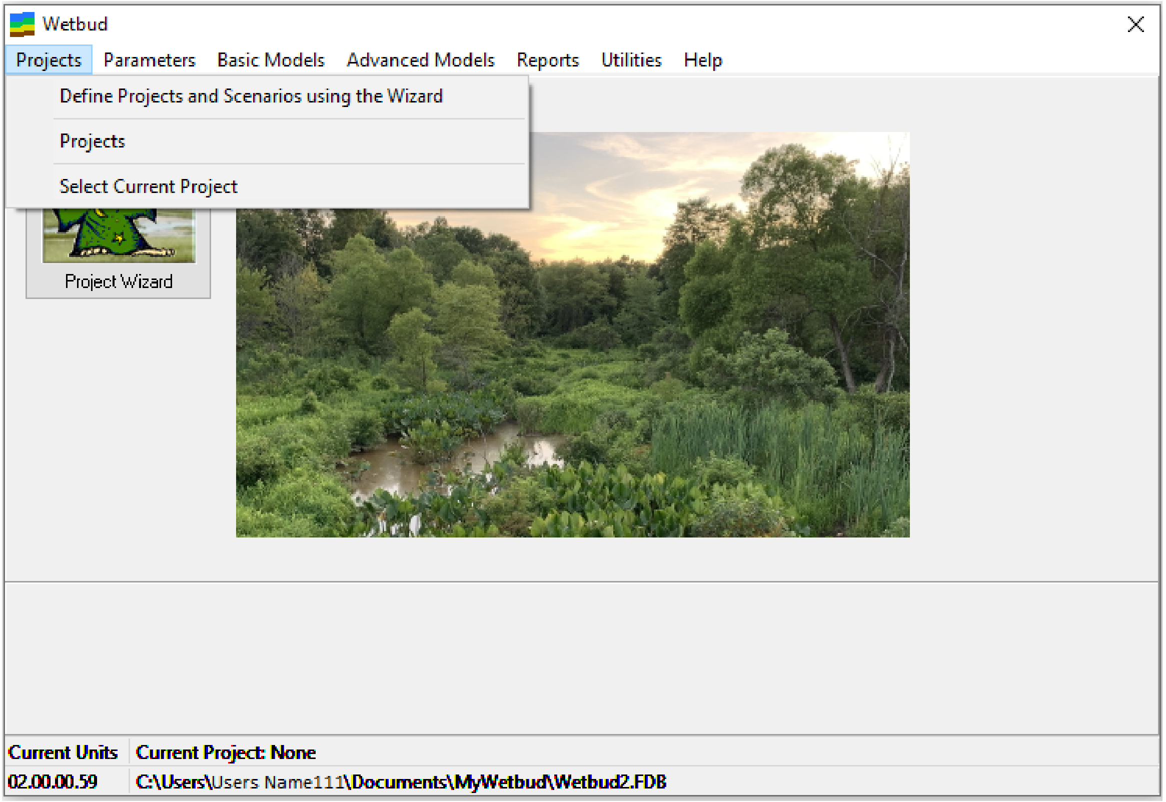
In Wetbud, the Project designates site-specific characteristics that are determined by the location of the site and will be held constant during different design iterations (e.g., name, latitude and longitude, elevation, reference weather station, wetland watershed characteristics, etc.). Different design iterations, for both Basic and Advanced models, are referred to as Scenarios in Wetbud. Once a Project is created, the user can create one or many Basic Scenarios and/or Advanced Scenarios for the Project.

Basic Models in Wetbud (including those created with the Project Wizard) are analytical models that sum inputs and outputs to calculate water budgets for specific sites on a monthly basis. Individual implementations of Basic Models within a given Project are referred to as Basic Scenarios.

Advanced Models in Wetbud are numerical models processed using the USGS MODFLOW software for groundwater flow models. Individual implementations of Advanced Models within a given Project are referred to as Advanced Scenarios.

Creating multiple Scenarios is useful for those who wish to model individual portions of large sites that would otherwise be very difficult to model, for users modeling separate sites that are proximal to the same weather station, or for users testing multiple design options for the same site.

The Projects tab lets you create a new project or select a current project. Click the Projects menu item as seen below to create a new project. The first option is equivalent to the Project Wizard button on the main menu, while the second option allows the user to edit the Project parameters. The third option allows selecting a project as the current project or changing the selection of the current project.

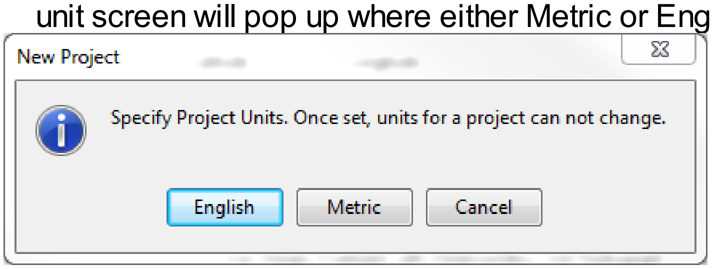


7.1 General

This tab is used to define the most basic information about a Project.

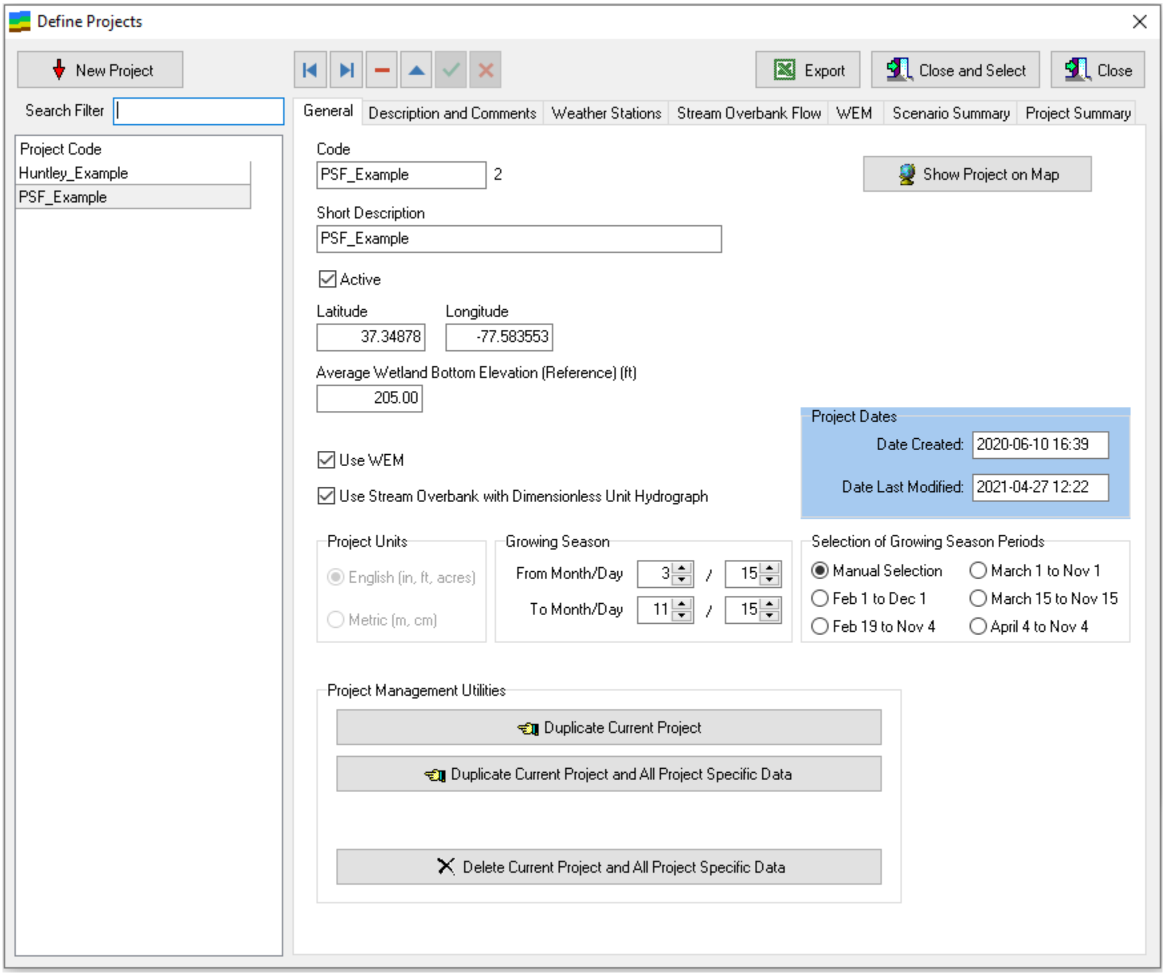
1. To create a new Project, select the General tab and then click 

. A unit screen will pop up where either Metric or English units can be chosen.



2. Once selected, units cannot be changed. The box under Code is initialized with the text 'Project##'. Delete this text and replace it with a new code for your Project. Next, click Save .
3. A code has now been generated for your Project in the Project Code list on the left side of the window. Proceed by adding a short description, project coordinates (decimal degrees, 0.000), and an average wetland bottom elevation (ft or m, 0.00) which serves as the initial reference elevation (see discussion below). This value will automatically populate the average wetland bottom elevation at scenario level; the user can change the latter to adjust the final design.

4. Click Save .
5. Verify that your site coordinates have been entered properly by clicking Show Project on Map. After verifying your Project coordinates, close the map window.



6. Adjust the growing season months for the project. By default, the growing season starts on March 15 and ends on November 15. See discussion below.
7. There are four Project Management functions available to the user:
   a. Duplicate Current Project.
   b. Duplicate Current Project and all Project Specific Data (such as groundwater time series, channel profiles, etc).
   c. Duplicate Current Project and all Project Specific Data and Swap Units (from English to Metric or from Metric to English).
   d. Delete Current Project and all Project Specific Data (note that this action can not be undone).

Growing Season

To assess your water budget results, one element that you must examine is the projected hydroperiod to determine if wetland hydrology will be met. To do that you need to (a) establish the beginning and ending date of the growing season, and (b) determine the period of time that the projected water is either ponding or present (as a phreatic water table elevation) within 12 inches of the soil surface.

The 1987 Manual Regional Supplements (USACE, 2012) describe several ways to determine the growing season that range from (a) biological indicators, (b) soil temperature (when soil temperature measured at the 12 in. (30 cm) depth is 41° F (5° C) or higher), (c) air temperature (then growing season dates may be approximated by the median dates (i.e., 5 years in 10, or 50% probability) of 28° F (−2.2° C) air temperatures in spring and fall, based on long-term records gathered at National Weather Service meteorological stations). Some Corps Districts also post growing season dates for specific years. These dates can vary by several weeks (e.g. in Northern Virginia soil temperatures suggest the growing season starts around Feb 19 (with a trend to an earlier date) vs. April 4 from air temperature; in SE Virginia soil temperatures indicated a growing season start 90 to 128 days earlier than published air temperature based growing season dates (Burdt et al., 2005) – and thus you should consult with the appropriate regulators to reach consensus on the growing season for your site – and enter those dates into Wetbud.

In addition to the ability for user-selected growing season start and stop dates, Wetbud has five default growing season periods to select from:

- February 1 – December 1
- February 19 - November 4
- March 1 – November 1
- March 15 – November 15
- April 4 – November 4

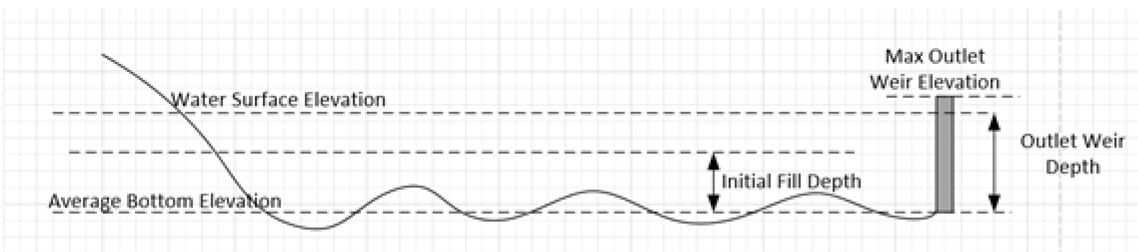
The period of time that the projected water is either ponding or present within 12 inches of the soil surface (as a phreatic water table elevation) to meet the wetland hydrology criterion is also a topic that should be addressed with the appropriate regulators to reach consensus on the appropriate duration as a % of the growing season for your site. Several durations can be selected:

1. 14 or more consecutive days of flooding or ponding, or a water table 12 in (30 cm) or less below the soil surface during the growing season at a min. frequency of 5 years in 10 (USACE, 2012 - pages 78-79; USACE, 2018).
2. Either 5% or 12.5% of the growing season in most years (50% probability or recurrence), depending up on regulator interpretation of Table 5 (USACE,1987).
3. 12.5% in multiple approved Permits and mitigation plans.

Average Bottom Elevation

Average Bottom Elevation is the weighted average of the subject wetlands system's soil surface elevation. It can be calculated by several methods commonly used by site civil engineers based on the proposed design's grading plan. The Initial Fill Depth is expressed as a height above this Average Bottom Elevation. This depth is often set so that it starts the water at the Outlet Weir Depth, or at the elevation of an adjustable weir proposed for the month of January. The reason is that Wetbud starts its hydroperiod analysis on January 1, and in our experience most wetlands in the Mid-Atlantic area “fill up” with water in the fall/early winter as evapotranspiration is at its lowest rate. The Maximum Outlet Weir Elevation is the highest elevation that an adjustable weir system can achieve. In a fixed outlet weir system it is the same as the Average Bottom Elevation plus the Outlet Weir Depth. Adjustable weirs are typically used in waste water treatment wetlands and wetlands systems being managed to maximize habitat and/or food production in birding parks and wildlife preserves managed for waterfowl.

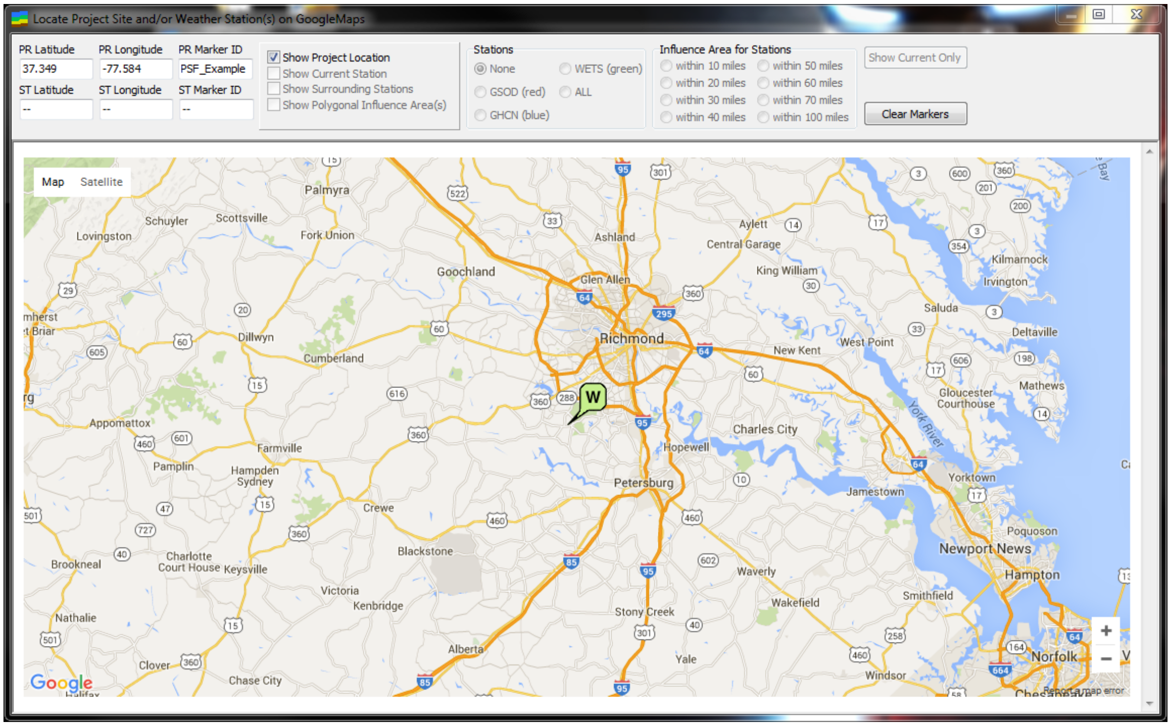
The Water Surface Elevation is assumed, in the level pool routing used in the Basic Model, to reach a maximum height equal to the outlet weir. It can be drawn down to lower elevations from exfiltration through the soil below the wetlands and from evapotranspiration. Wetbud provides that elevation on a monthly basis, and uses the data from the inputted stage storage curve to adjust the Water Surface Elevation based on water volume lost/gained in each period to reflect the topography from the proposed wetlands area grading plan below the Maximum Outlet Weir Elevation. For additional details, see Supplementary Material.



7.1.1 Show Map

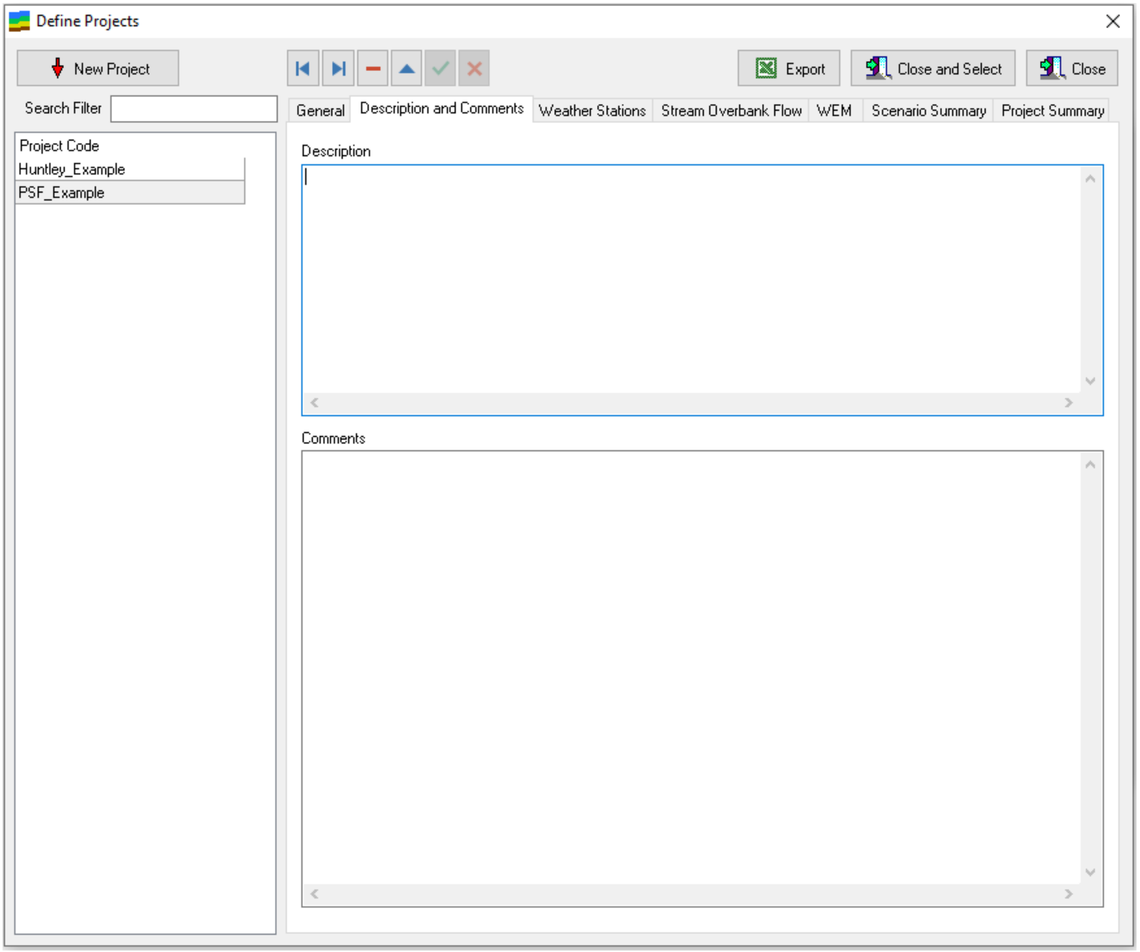
Click 

to display the selected site on a Google Maps interface based on the latitude and longitude entered by the user.



7.2 Description and Comments

This tab is used to enter additional details the user wishes to include about a given Project. Select the Description tab and proceed by entering a detailed Project description and any additional comments or notes that pertain to the Project. Click ✓ to save.



7.3 Weather Stations

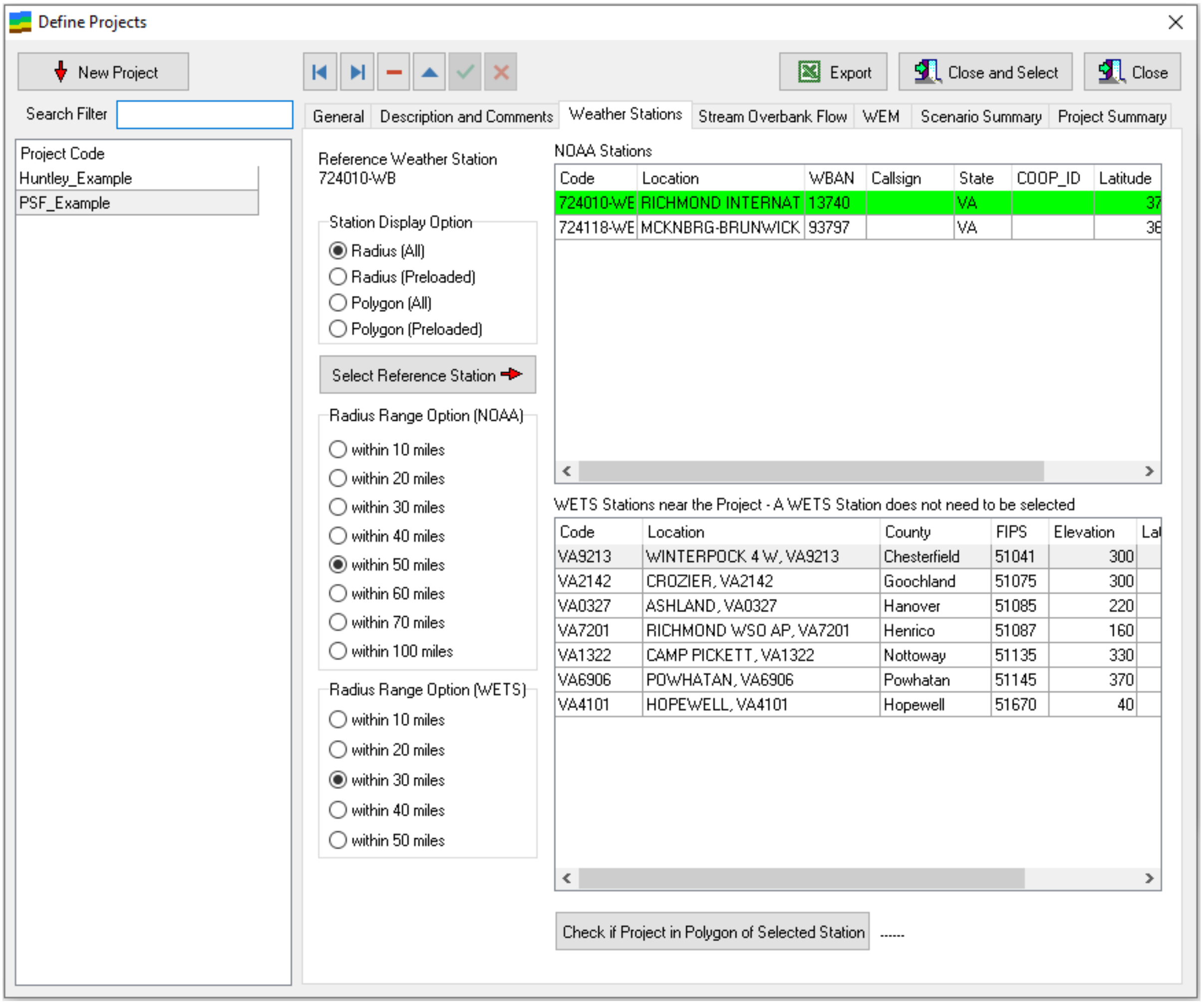
This tab is used to assign a reference weather station and locate the nearest WETS stations to associated Project site(s).

This tab is used to view a list of weather stations created in the NOAA (GSOD) station database and WETS stations within a pre-selected radius (up to 100 miles) of the Project site. To adjust the radius of stations being displayed, simply adjust the selection in the Radius Range Option box. The station display can also be updated through the use of the Station Display Option box. To select a Reference Weather Station for a Project, click the station in the NOAA Stations list and then click 

. The row containing the selected Reference Weather Station will now be highlighted green. Precipitation data from the Reference Weather Station selected in this tab will become the data used to determine dry, normal and wet years when selecting the Automatically Calculated option in the Standard Analysis Years box displayed in the General tab of the Basic Scenario setup (see Basic Models for additional details).

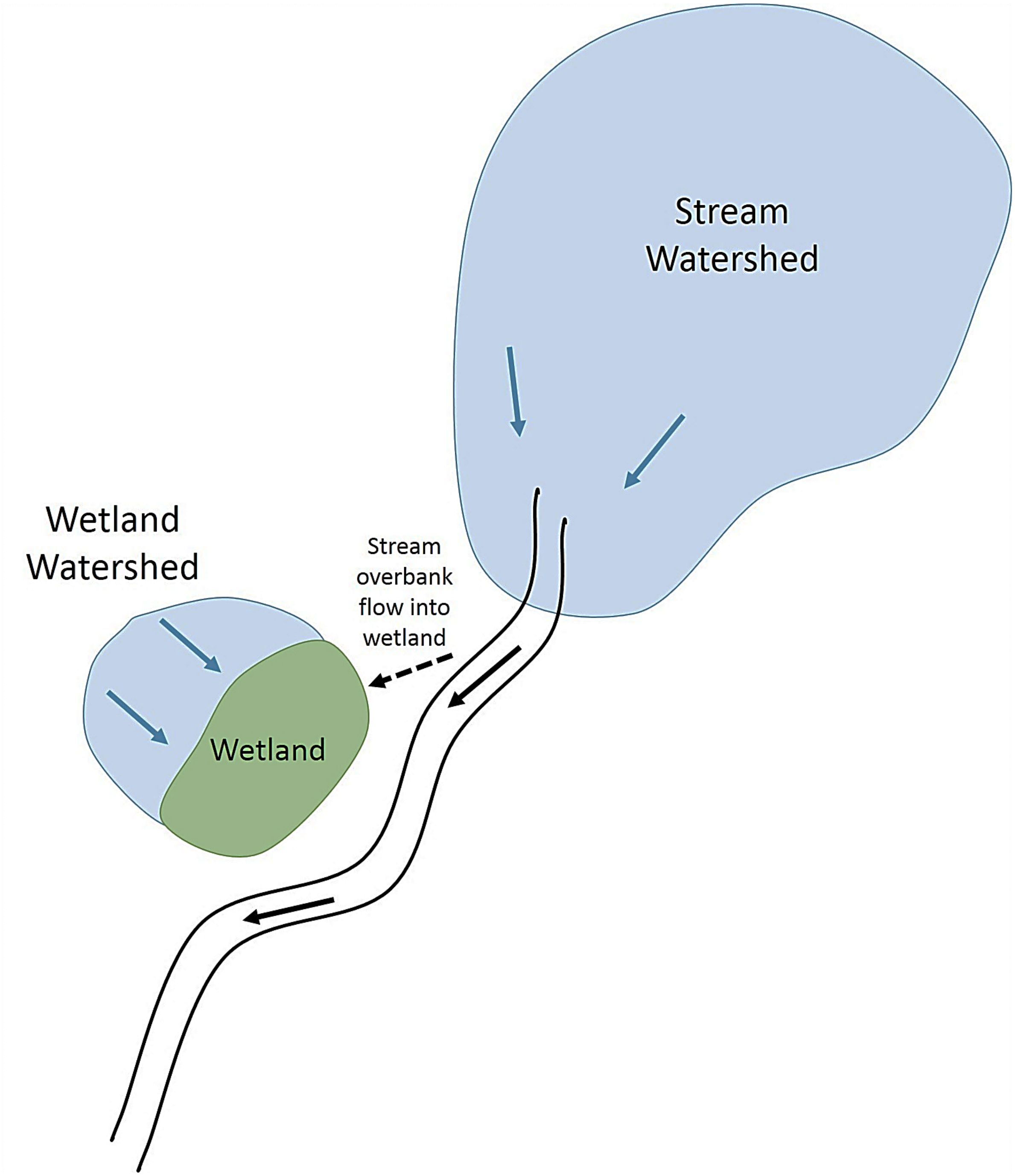
Note: Weather stations created in the NOAA (GHCN) weather station database will not be listed in the NOAA Stations box in the Weather Stations tab. See Station Data -

GSOD (NOAA) and Station Data - GHCN (NOAA) for more information regarding the creation and use of weather station records in Scenario setup.



7.4 Stream Overbank

As shown in the figure below, Wetbud considers two different watersheds. The “wetland watershed” is the land area that drains directly into the wetland. Surface runoff (precipitation excess) from the wetland watershed is calculated using the NRCS curve number method for each 24-hr period (NRCS, 2004). Wetbud assumes this runoff enters the wetland as sheet flow or shallow concentrated flow in an ephemeral channel. This runoff is added directly to the wetland and no flow routing is conducted. Larger intermittent or perennial streams adjacent to the wetland that contribute water to the wetland only during high flow events can also be modeled in Wetbud. Wetbud calculates the runoff volume (i.e., precipitation excess) for the “stream watershed” using the NRCS curve number method, determines the time of concentration following the NRCS velocity method (NRCS, 2010), and creates a stream hydrograph using the NRCS dimensionless unit hydrograph (NRCS, 2007). This procedure is similar to the one used in the NRCS TR-55 model (USDA-NRCS, 1986).



Note: Each watershed is modeled as a single catchment: the watersheds cannot be divided into subwatersheds. For large and/or complex watersheds, it is recommended that the user run TR-55, TR-20, or HEC-HMS and HEC-RAS externally to Wetbud and upload a stream water surface elevation file.

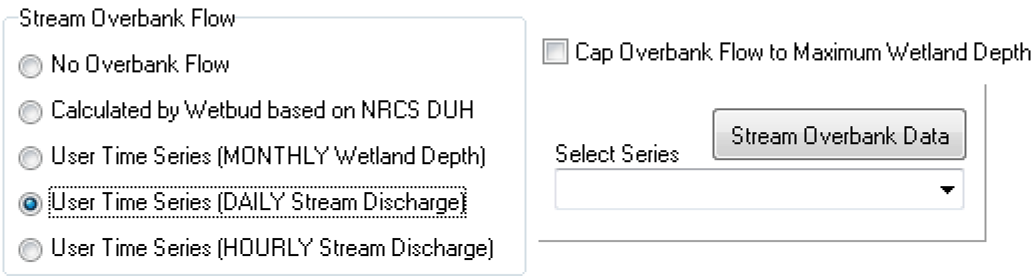
Given user-supplied stream geometry, Wetbud converts the calculated stream discharge hydrograph into a stream stage hydrograph using Manning's equation. Inflow into the wetland from the stream is determined assuming an inflow structure has been constructed to allow water inflow into the wetland from the stream at stream discharges that do not inundate the wetland or floodplain. A Cipoletti weir, trapezoidal channel, or broad-crested weir can be modeled. Inflow rates are calculated based on the difference between the stream water surface elevation and the invert elevation of the inflow structure using a weir equation or Manning's equation. The incremental inflow rates are then converted to inches of water over the wetland and summed for each 24-hour rainfall depth in each month.

Users who wish to include stream overbank flow inputs in a Basic Scenario water budget analysis can manually create a monthly stream data data set using their own data or choose to have Wetbud calculate stream overbank flow. For Wetbud to calculate stream overbank inputs in a Basic Scenario analysis, the user must characterize the watershed for the stream adjacent to the site, the stream channel geometry, and the inflow structure between the stream and the wetland.

The user will input parameters needed to model the stream watershed in the stream unit hydrograph tab (Stream UH Flow) described in the following section of the manual. The wetland watershed is parameterized in the Wetland Watershed tab of Basic Scenario setup. The parameters needed for the “Stream overbank into the wetland” portion of this diagram will be established in the Stream Overbank Flow sub-tab under the Water Inputs and Outputs tab of Basic Scenario setup.

7.4.1 Stream Overbank Flow Setup

A number of stream overbank flow calculations are available at the scenario level as shown below.



If the user is to select the second option (calculation using the NRCS Dimensionless Unit Hydrograph) then the Time of Concentration for the stream watershed needs to be calculated. The "Time of Concentration" calculation is a project level calculation.

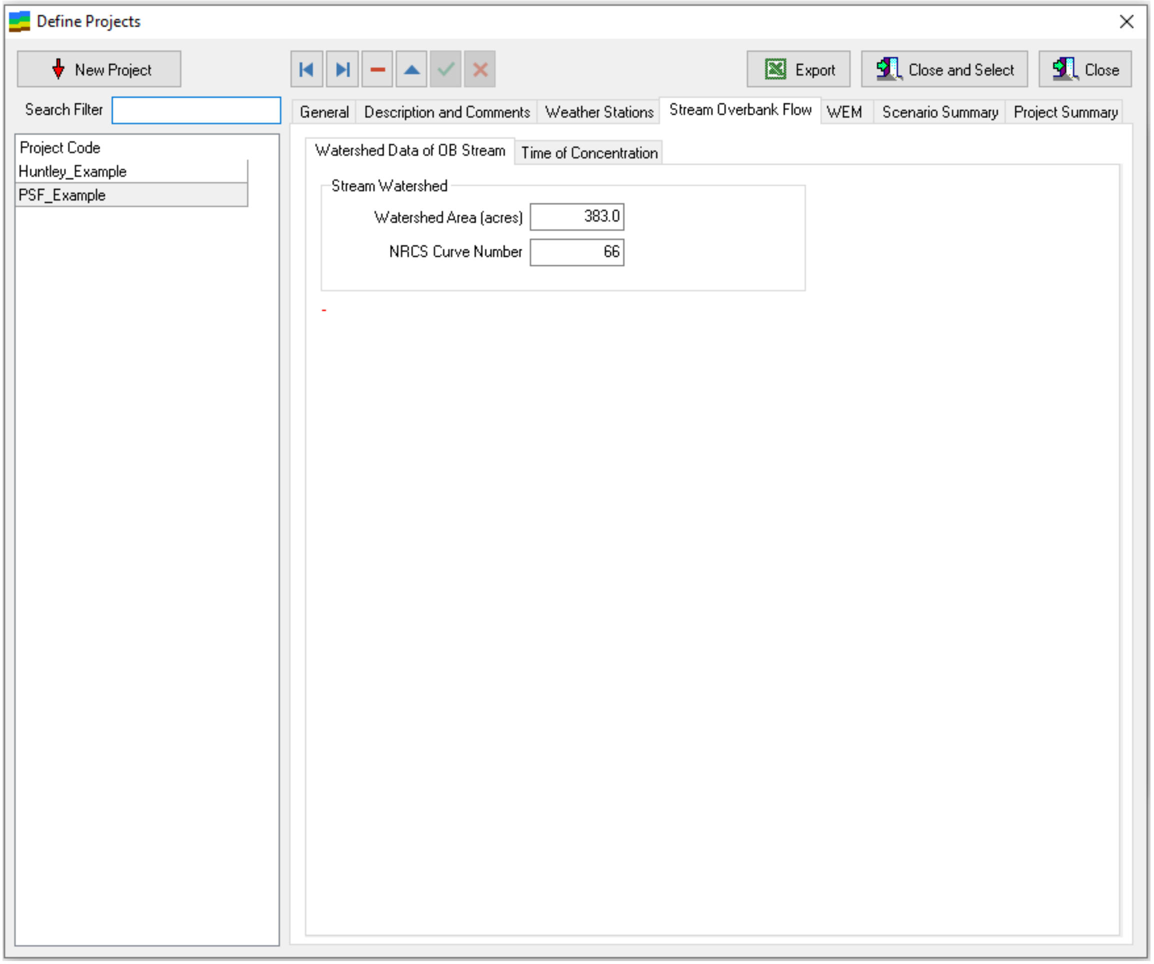
For this calculation the "Use Stream Overbank with Dimensionless Unit Hydrograph" option should be checked (selected) under the General Tab. Then information about Stream Overbank Flow can be entered at project level. The Stream Overbank Flow tab has two sub-tabs: Watershed Data of Overbank Stream and Time of Concentration.

Watershed Data of Overbank Stream

The Watershed Data of Overbank Stream section pertains to the entire watershed contributing to the stream adjacent to the Project site (i.e., the “stream watershed”). The required input data are:

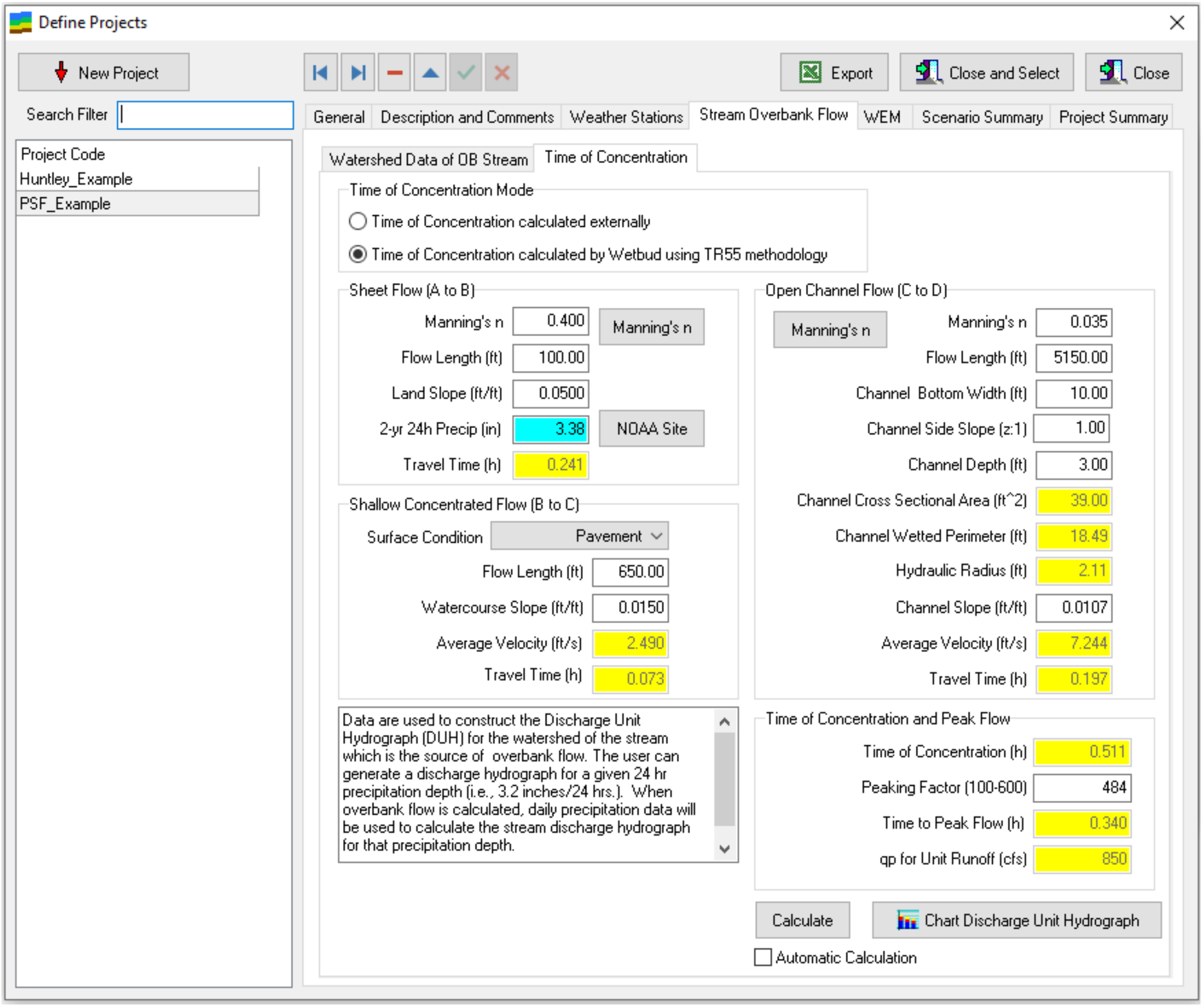
1. The Watershed Area (acres or m^2), and
2. The NRCS Curve Number.

The input related to the Stream Watershed is shown below



Time of Concentration

The user can select to manually enter the time of concentration or have Wetbud calculate it based on the form below. To manually enter the time of concentration select Time of Concentration calculated externally and a box will appear. Once the time of concentration has been entered, the user is prepared to have Wetbud calculate overbank flow using the DUH option.

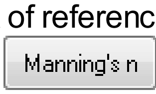


The Time of Concentration tab has four sections: Sheet Flow (A to B), Shallow Concentrated Flow (B to C), Open Channel Flow (C to D) and the calculation window. The white boxes in this window are boxes that must be filled out by the user. Yellow boxes contain values automatically calculated by Wetbud based on the values entered in the white boxes of the corresponding section. See the next section, Sheet Flow (A to B) for information about the cyan box.

Instructions on setting up each section are provided below. For additional information, see Urban Hydrology for Small Watersheds TR-55 (USDA-NRCS, 1986) at https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1044171.pdf.

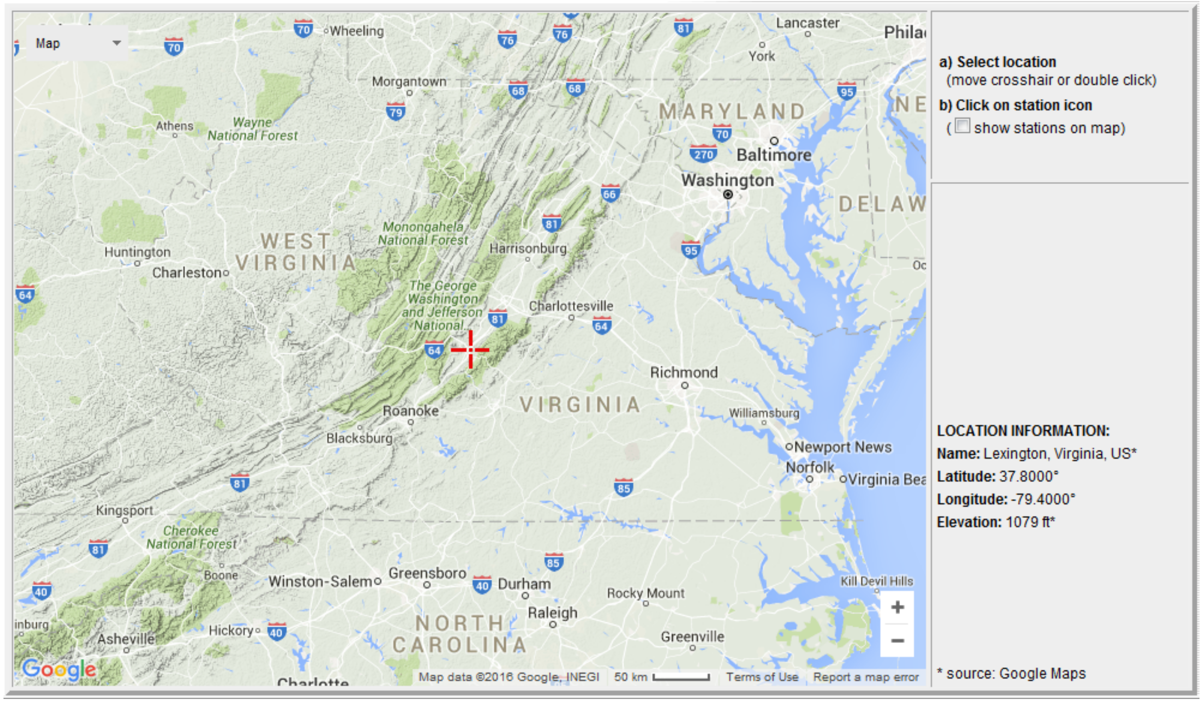
Sheet Flow (A to B)

Sheet flow is shallow flow (<0.1 ft.) that occurs as overland flow on hillslopes (USDA-NRCS, 1986). The Manning's roughness coefficient (n) for this section should be chosen based on the dominant type of surface/land cover in the overall watershed.

1. To view a list of reference coefficients for sheet flow in the Manning's Coefficients window click 

.

2. Choose Sheet Flow under Coefficient Type.
3. In the Manning’s Coefficients window, select an n value that best suits your land cover and click Select and Insert Into Project, which will enter the n value in the box next to Manning’s n in the Sheet Flow section.
4. Enter the flow length (ft or m; normally less than 300 ft) and the watershed slope (ft/ft or m/m) in their adjacent boxes.
5. Click NOAA Site to determine the 2-yr 24-hour Precipitation (in or cm) value for the Project site. You will be directed to the NOAA National Weather Service Hydrometeorological Design Studies Center Precipitation Frequency Data Server (PFDS). The map that appears will automatically be directed to the correct State based on your Project’s coordinates.
6. Select the location of your Project site by double-clicking on the location in the map, which will position the red crosshairs in the selected location.



7. After you have selected your site on the map and verified the red crosshairs are in the correct location, scroll down the page to view the Point Precipitation Frequency (PF) Estimates table. Record the value in the box that corresponds to the 2-year recurrence interval (column heading '2') and the 24-hour duration (row heading '24-hr'). This box is highlighted yellow in the table below.
8. Return to the Stream UH Flow tab in Wetbud and enter this value in the 2-yr 24h Precip (in) box that is highlighted cyan.
9. Next, click Calculate (bottom of window). The value calculated for Travel Time (h) will appear in the yellow box. Save and proceed to Shallow Concentrated Flow (B to C).

PDS-based precipitation frequency estimates with 90% confidence intervals (in inches)[1]										
Duration	Average recurrence interval (years)									
	1	2	5	10	25	50	100	200	500	1000
5-min	0.334 (0.304–0.369)	0.398 (0.362–0.439)	0.472 (0.428–0.520)	0.532 (0.482–0.585)	0.601 (0.541–0.660)	0.652 (0.584–0.717)	0.702 (0.624–0.772)	0.747 (0.659–0.825)	0.800 (0.697–0.888)	0.843 (0.728–0.941)
10-min	0.534 (0.485–0.589)	0.637 (0.579–0.703)	0.756 (0.686–0.833)	0.851 (0.771–0.936)	0.958 (0.863–1.05)	1.04 (0.931–1.14)	1.12 (0.992–1.23)	1.18 (1.05–1.31)	1.27 (1.10–1.41)	1.33 (1.15–1.48)
15-min	0.667 (0.607–0.736)	0.801 (0.728–0.883)	0.957 (0.868–1.05)	1.08 (0.975–1.18)	1.21 (1.09–1.33)	1.32 (1.18–1.45)	1.41 (1.25–1.55)	1.49 (1.32–1.65)	1.59 (1.39–1.77)	1.67 (1.44–1.86)
30-min	0.915 (0.832–1.01)	1.11 (1.01–1.22)	1.36 (1.23–1.50)	1.56 (1.41–1.72)	1.80 (1.62–1.98)	1.98 (1.78–2.18)	2.16 (1.92–2.38)	2.32 (2.05–2.57)	2.54 (2.21–2.81)	2.70 (2.33–3.01)
60-min	1.14 (1.04–1.26)	1.39 (1.26–1.53)	1.74 (1.58–1.92)	2.03 (1.84–2.23)	2.39 (2.16–2.63)	2.68 (2.41–2.95)	2.97 (2.65–3.27)	3.26 (2.88–3.60)	3.64 (3.17–4.04)	3.94 (3.40–4.40)
2-hr	1.35 (1.23–1.50)	1.65 (1.49–1.83)	2.08 (1.89–2.31)	2.45 (2.21–2.71)	2.92 (2.62–3.22)	3.31 (2.95–3.65)	3.71 (3.28–4.09)	4.11 (3.60–4.54)	4.65 (4.03–5.17)	5.10 (4.36–5.69)
3-hr	1.47 (1.33–1.63)	1.78 (1.61–1.98)	2.25 (2.03–2.50)	2.64 (2.38–2.93)	3.15 (2.82–3.49)	3.57 (3.18–3.96)	4.00 (3.54–4.44)	4.44 (3.89–4.94)	5.04 (4.35–5.62)	5.53 (4.71–6.20)
6-hr	1.85 (1.67–2.07)	2.23 (2.02–2.50)	2.80 (2.52–3.13)	3.30 (2.96–3.68)	3.96 (3.53–4.42)	4.54 (4.01–5.05)	5.13 (4.49–5.72)	5.77 (4.98–6.43)	6.66 (5.65–7.45)	7.42 (6.20–8.33)
12-hr	2.29 (2.07–2.59)	2.77 (2.50–3.12)	3.47 (3.12–3.91)	4.11 (3.68–4.63)	5.01 (4.44–5.62)	5.79 (5.07–6.49)	6.64 (5.74–7.44)	7.56 (6.44–8.48)	8.90 (7.41–10.0)	10.1 (8.23–11.4)
24-hr	2.83 (2.61–3.10)	3.43 (3.16–3.76)	4.38 (4.03–4.79)	5.17 (4.73–5.64)	6.32 (5.76–6.90)	7.31 (6.62–7.96)	8.38 (7.53–9.12)	9.56 (8.50–10.4)	11.3 (9.90–12.3)	12.8 (11.1–13.9)
2-day	3.34 (3.08–3.63)	4.04 (3.73–4.40)	5.13 (4.72–5.58)	6.01 (5.52–6.54)	7.29 (6.65–7.92)	8.36 (7.58–9.07)	9.50 (8.56–10.3)	10.7 (9.60–11.7)	12.5 (11.1–13.7)	14.0 (12.3–15.3)
3-day	3.55 (3.27–3.87)	4.29 (3.95–4.68)	5.44 (5.00–5.93)	6.37 (5.84–6.94)	7.71 (7.02–8.39)	8.83 (8.00–9.60)	10.0 (9.02–10.9)	11.3 (10.1–12.3)	13.2 (11.6–14.4)	14.7 (12.8–16.1)
4-day	3.76 (3.45–4.11)	4.55 (4.18–4.97)	5.75 (5.28–6.28)	6.73 (6.16–7.35)	8.13 (7.40–8.87)	9.30 (8.41–10.1)	10.6 (9.47–11.5)	11.9 (10.6–13.0)	13.8 (12.2–15.1)	15.4 (13.4–16.9)
7-day	4.34 (4.01–4.71)	5.23 (4.83–5.67)	6.52 (6.01–7.07)	7.57 (6.96–8.19)	9.05 (8.28–9.79)	10.3 (9.35–11.1)	11.6 (10.5–12.5)	12.9 (11.6–14.0)	14.9 (13.2–16.1)	16.5 (14.5–17.9)
10-day	4.95 (4.60–5.34)	5.94 (5.51–6.40)	7.31 (6.78–7.87)	8.40 (7.77–9.04)	9.90 (9.12–10.7)	11.1 (10.2–12.0)	12.4 (11.3–13.3)	13.7 (12.4–14.7)	15.5 (13.9–16.7)	17.0 (15.1–18.4)
20-day	6.55 (6.13–7.04)	7.81 (7.30–8.38)	9.40 (8.78–10.1)	10.7 (9.93–11.4)	12.3 (11.5–13.2)	13.7 (12.7–14.7)	15.0 (13.8–16.1)	16.4 (15.0–17.6)	18.2 (16.6–19.6)	19.6 (17.7–21.2)
30-day	8.05 (7.58–8.55)	9.53 (8.98–10.1)	11.2 (10.6–11.9)	12.5 (11.8–13.3)	14.2 (13.4–15.1)	15.5 (14.5–16.5)	16.8 (15.6–17.8)	18.0 (16.7–19.2)	19.6 (18.1–20.9)	20.8 (19.1–22.2)
45-day	10.1 (9.57–10.7)	11.9 (11.3–12.6)	13.9 (13.1–14.7)	15.3 (14.5–16.2)	17.2 (16.2–18.2)	18.6 (17.5–19.6)	19.9 (18.7–21.0)	21.2 (19.8–22.4)	22.8 (21.2–24.2)	24.0 (22.3–25.5)
60-day	11.9 (11.3–12.5)	14.0 (13.3–14.7)	16.1 (15.3–16.9)	17.6 (16.8–18.5)	19.6 (18.6–20.6)	21.0 (19.9–22.1)	22.3 (21.1–23.5)	23.6 (22.2–24.9)	25.2 (23.6–26.6)	26.3 (24.6–27.9)

[1] Precipitation frequency (PF) estimates in this table are based on frequency analysis of partial duration series (PDS).

Numbers in parenthesis are PF estimates at lower and upper bounds of the 90% confidence interval. The probability that precipitation frequency estimates (for a given duration and average recurrence interval) will be greater than the upper bound (or less than the lower bound) is 5%. Estimates at upper bounds are not checked against probable maximum precipitation (PMP) estimates and may be higher than currently valid PMP values.

Please refer to NOAA Atlas 14 document for more information.

Shallow Concentrated Flow (B to C)

After some distance, typically less than 300 ft (~100 m), sheet flow becomes shallow concentrated flow (USDA-NRCS, 1986). The velocity of this flow is calculated based on the surface condition (paved or unpaved), flow length (ft or m), and watercourse slope (ft/ft or m/m). To complete this section:

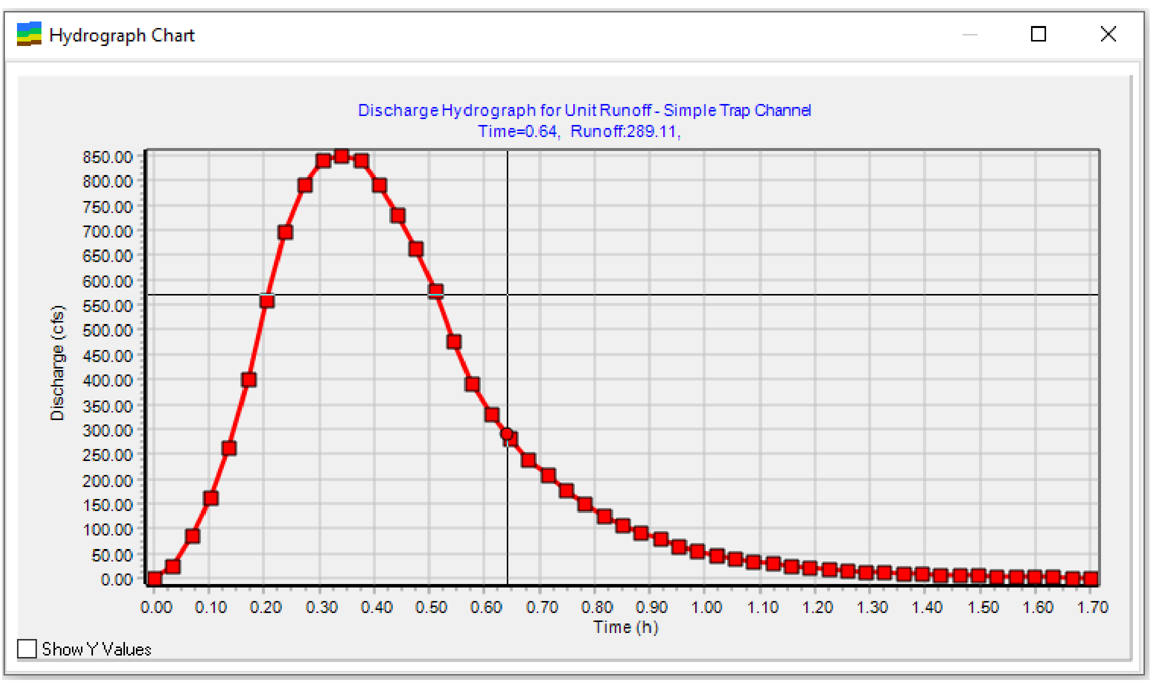
1. Select an option from the Surface Condition drop-down menu.
2. Enter the flow length (ft or m), and watercourse slope (ft/ft or m/m).
3. Calculate Average Velocity (ft/s or m/s) and Travel Time (h) by clicking Calculate (bottom of window). The values calculated for Average Velocity (ft/s or m/s) and Travel Time (h) will appear in their respective boxes.
4. Save and proceed to Open Channel Flow (C to D).

Open Channel Flow (C to D)

Open channels carry concentrated flow and have a distinct, measurable cross section and a free water surface that is open to the atmosphere (flows are not pressurized, such as in a full pipe). The open channel flow calculations for the time of concentration assume the channel shape can be estimated as a trapezoid.

1. To view a list of reference coefficients for open channel flow in the Manning's Coefficients window click Manning's n.
2. Choose Channel Flow under Coefficient Type.
3. In the Manning's Coefficients window, select an n value that best suits your channel and click Select and Insert Into Project, which will enter the n value in the box next to Manning's n in the Open Channel Flow section.
4. Next, enter the flow length (ft or m), channel bottom width (ft or m), channel side slope ratio (x:1), channel depth (ft or m), and channel slope (ft/ft or m/m) in their adjacent boxes. Channel depth should be entered as the channel depth for bank full flow.
5. Next, click Calculate at the bottom of the window to calculate values for the Channel Cross-sectional Area (m^2 or ft^2), the Channel Wetted Perimeter (ft or m), the Hydraulic Radius (ft or m), the Average Velocity (ft/s or m/s) and the Travel Time (h). Wetbud then calculates the Time of Concentration (h), the Time to Peak Flow (h), and qp for Actual Runoff (cfs or cms). The calculated values will appear in their respective boxes highlighted in yellow.

Display a chart of the discharge unit hydrograph by clicking Chart Discharge Unit Hydrograph. An example hydrograph is shown below.



After all calculations in the Time of Concentration tab are completed, the project may need to be saved as the values in multiple fields may have changed. To utilize these calculations the user will need to select the Calculated by Wetbud based on NRCS DUH option for Stream Overbank Flow in the Water Inputs section of Basic Scenario setup.

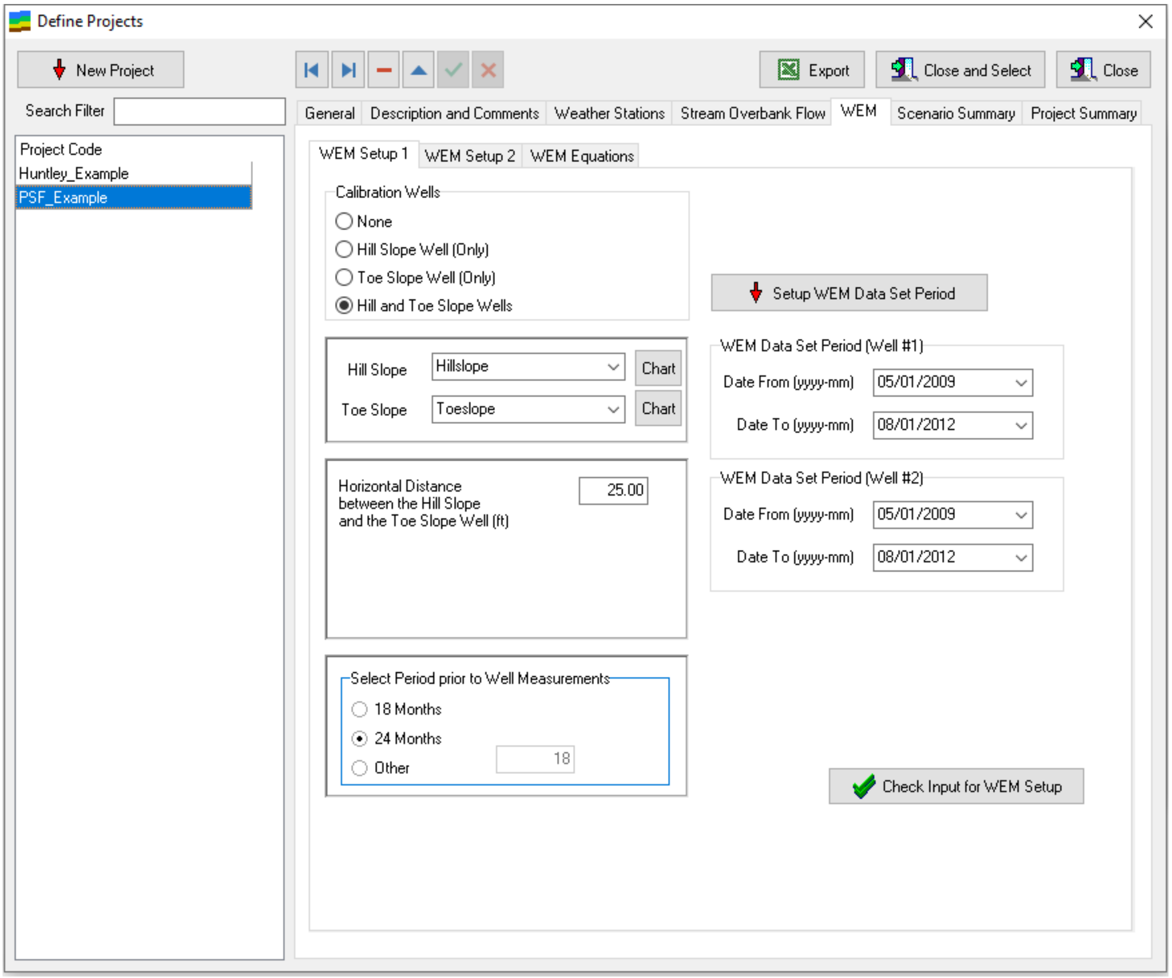
Users who choose this option must then complete the Stream Overbank Flow sub-tab to enable Wetbud to calculate stream overbank flow at the Scenario level.

Notes

- The default value for the Peaking Factor is 484. Only users experienced in modeling surface flow should consider changing the Peaking Factor from the default value.
- The Wetbud estimation of overbank flow is reasonable for small, simple, watersheds. The suggested maximum area is 20 square miles (12,800 acres, 5,180 hectares). Wetbud will allow users to estimate discharge rates for watersheds larger than 20 mi^2. For larger, more complex watersheds or watersheds with storage elements, such as lakes and reservoirs, users should model stream hydrographs in TR-55, TR-20, HEC-HMS, or a similar hydrology model and then import the stream flow time series into Wetbud. Information on creating and importing time series into Wetbud is provided in Creating a Water Inputs/Outputs data set.

7.5 WEM

Use of the WEM tab is only necessary for users who wish to use the Effective Monthly Recharge (WEM) model to calculate groundwater input for years in which there are no measured hydraulic head data available to manually calculate groundwater input for the Basic Model or to parameterize MODFLOW for the Advanced Model. The two sub-tabs, WEM Setup and WEM Equations, are used to set up the WEM model and to view the equations Wetbud will use to predict head elevation in wells during years that lack observed hydraulic head data.



7.5.1 WEM Overview

Users that would like to include estimates of historical groundwater fluxes into their site will need to perform WEM calculations in order to include WEM in their water budgets.

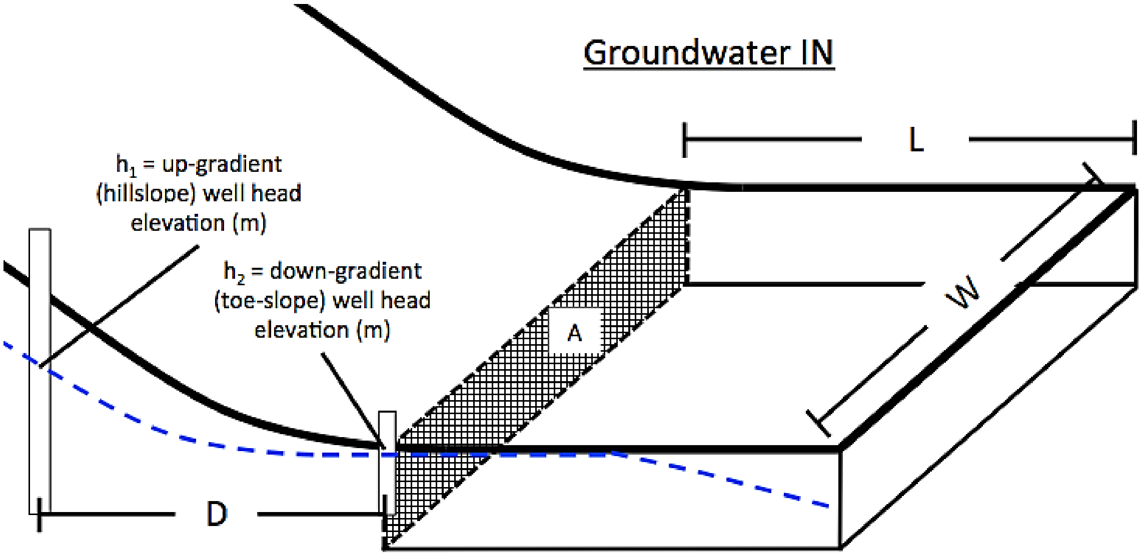
WEM (Effective Monthly Recharge Model or Wem) analyses use historical weather data (e.g., precipitation and evapotranspiration) to calculate monthly recharge values, which are then used to predict head elevations in wells for years for which there are no measured head data. The predicted head elevations are used in the Darcy's Law calculation of groundwater discharge (see Groundwater IN and Groundwater OUT), which is the first step in the calculations used by Wetbud to calculate groundwater input.

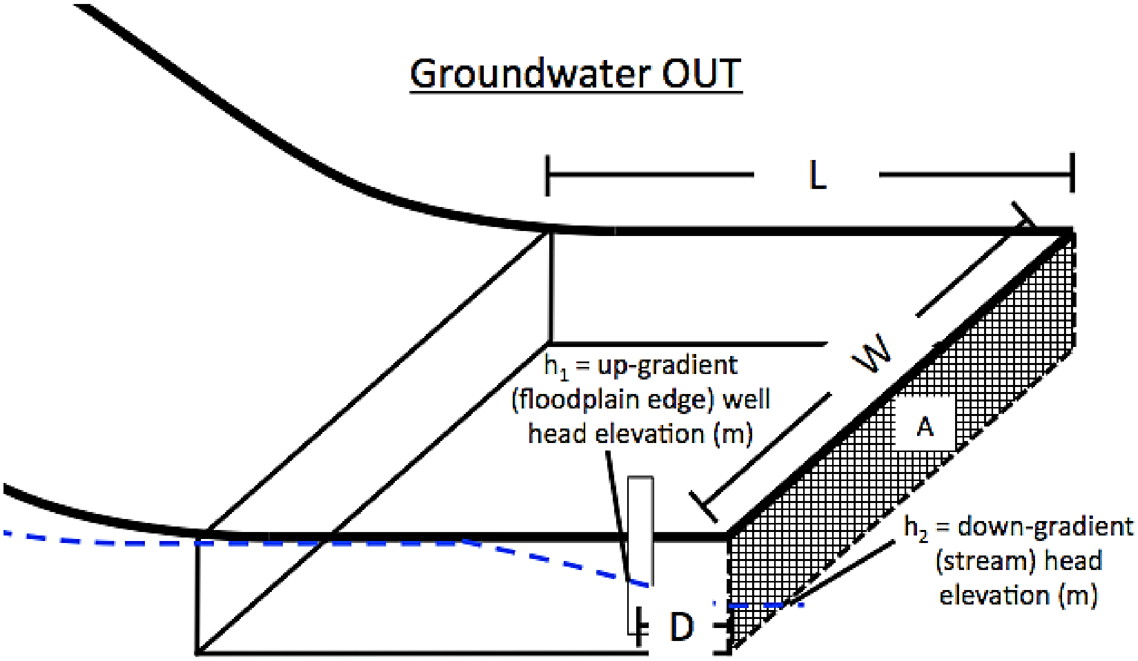
For more information see:
- WEM Setup
- WEM Calculations

7.5.2 WEM Setup

WEM (Effective Monthly Recharge Model) uses historical precipitation and evapotranspiration data to calculate effective monthly recharge values, which are used to predict head elevations in wells for years that lack head elevation data. For a brief explanation of the equations used in WEM calibration and how it is used to predict monthly head elevations for years that lack hydraulic head data, see Whittecar et al., 2017 or WEM Calculations.

Wetbud uses the predicted head elevations for up-gradient (hillslope, h1) and down-gradient (toe-slope, h2) wells, saturated hydraulic conductivity (Ksat), distance (D), cross-sectional area (A), and wetland surface area (L × W) values assigned by the user to calculate groundwater input as described in the Groundwater IN and Groundwater OUT section. The calculated groundwater input values can then be included in Basic Scenario water budget calculations, which may improve water budget predictions during periods that lack hydraulic head data needed to quantify groundwater input.





Prior to WEM setup, the user must create individual monthly head elevation data sets to calibrate the WEM for the up-gradient (hillslope, h1) and down-gradient (toe-slope, h2) wells (see Wells, for instructions on how to create a well data set). In many situations, the user will not have observed head elevation data for both of these wells. In these situations, the user must have at least six months of observed monthly head elevation data for one of the two (hillslope or toe-slope) wells needed for groundwater input calculations in addition to an estimate of average water table elevation in the location (up-gradient or down-gradient) that lacks observed well data. Wetbud will then use the average water table elevation the user has entered for this location (the one that lacks data) for every month an automatic groundwater input calculation is performed.

In order to run the WEM, users must have also previously assigned the following parameters needed for the groundwater input calculations (as described above) in the Wetland Watershed tab during Basic Scenario setup:

1. Hydraulic conductivity (Ksat) of hillslope soils or sediments (in/d or cm/d).
2. Width of constructed wetland at adjacent hillslope bottom (ft or m).
3. Thickness of permeable material in constructed wetland at slope bottom (ft or m).
4. Constructed wetland area (acres or m^2).

To set up the WEM:

1. Select Projects from the drop-down menu under Projects in the Wetbud home screen. Navigate to the WEM tab in the Define Projects window.
2. In the WEM Setup 1 sub-tab, select the calibration wells for which Well data sets have been created.
    a. If well data sets have been created for hillslope and toe-slope wells, then select the Hill and Toe Slope Wells option. Next, select the corresponding well data sets from the Well #1 Data (for hillslope well) and Well #2 Data (for toe-slope well)

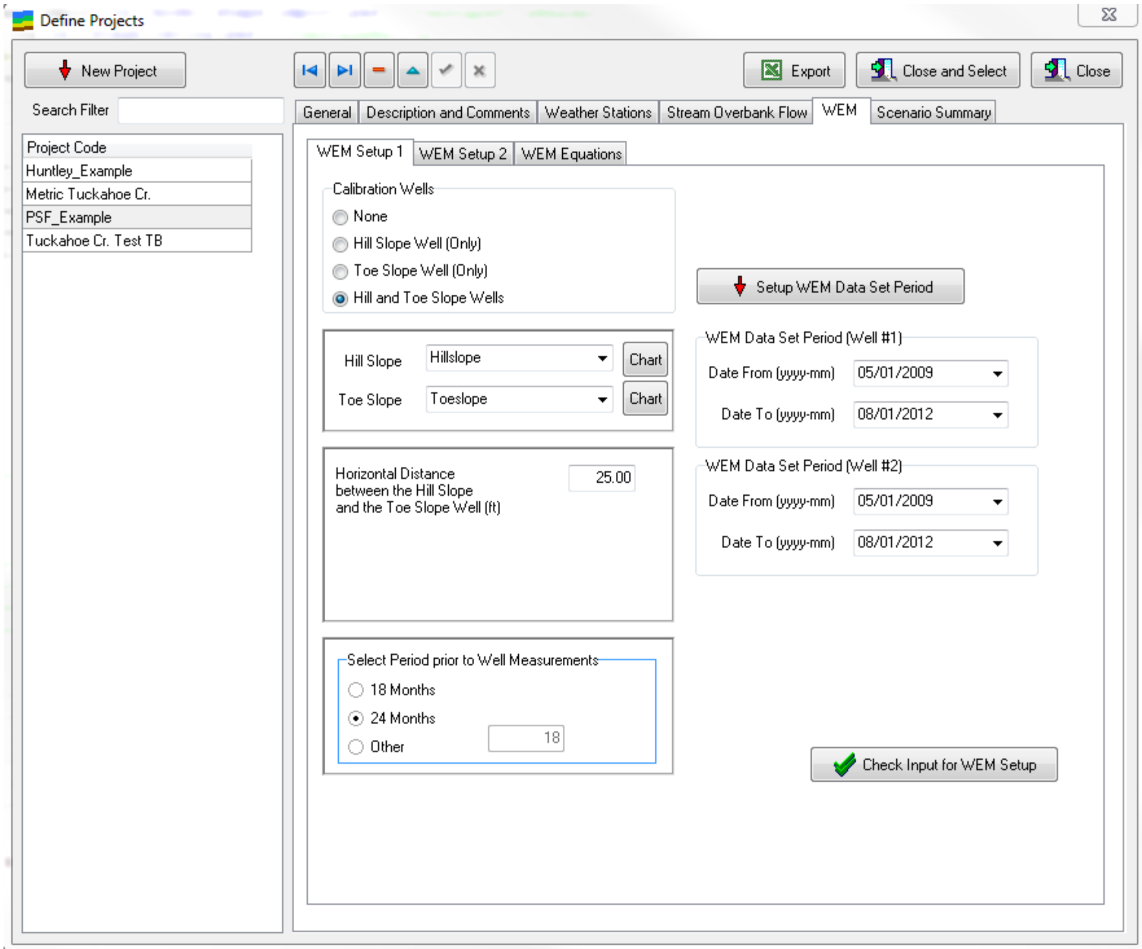
   drop-down lists and enter the Horizontal Distance between the Hill Slope and Toe Slope Well (ft or m) in the box below.

   b. If a well data set has only been created for one of the wells, select the option that applies [Hill Slope Well (Only) or Toe Slope Well (Only)] and assign the corresponding well data set by selecting it from the drop-down list (Well #1 or a hillslope well or Well #2 for a toe-slope well). Next, enter the Horizontal Distance between the Hill Slope and Toe Slope Well (ft or m) and the Ground Surface Elevation or Elevation of Average Water Table (ft or m) for the well that lacks observed head elevation data in their corresponding boxes.

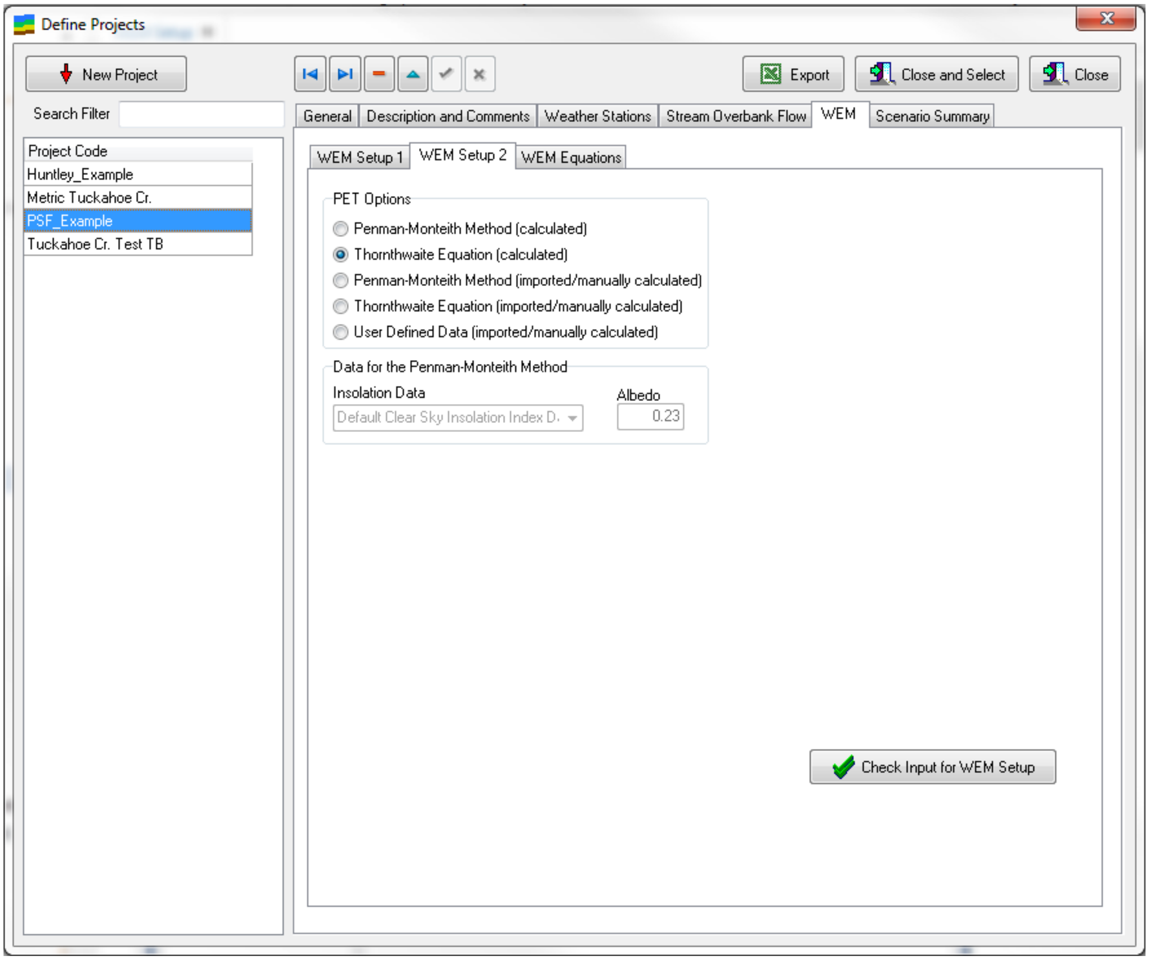
Note: The value assigned as the ground surface elevation or elevation of average water table (ft or m) for the well not being included in the WEM calibration will be used by Wetbud for every month of all years included in groundwater input calculations. If only one set of well data is available, it is best for it to be from the hillside because water tables at toe-slope seeps are often close to the surface and do not vary as much as hillside water levels. Use of the WEM procedure based on hillside well data can give reasonable results in Wetbud. However, use of only a toe-slope well for WEM calculations with an estimated static water level for the hillside well can significantly decrease the accuracy of groundwater input estimates. For example, if a user lacks observed data necessary for a WEM calibration in a hillslope well and enters a value of 30.0 m (100 ft) for the elevation of average water table (ft or m), then that value will be h1 in the Darcy's Law equation for every month of every year included in the Basic Scenario Analysis. It should be noted that choosing this option will greatly decrease the accuracy and reliability of groundwater input values calculated by Wetbud. Thus, results of Basic Scenario water budget analyses should be interpreted with caution when choosing this option.

3. In the Select Period Prior to Well Measurements section, select the number of months prior to the first month in the well data set(s) to be included in the WEM analysis for determining the WEM equation. This section has three options: 18 Months (recommended) 24 Months, and Other, where the user can enter the number of months prior to the first well reading to be included.
4. Next, click Setup WEM Data Set Period, which will automatically generate dates in the WEM data set Period section for each well. The WEM data set Period is the period of time that WEM uses to determine the combination of the number of prior months, and the decay factor, that results in the highest R-Squared value for the WEM equation. Save and proceed to the WEM Setup 2 tab.

Note: A minimum of 12 months of precipitation and evapotranspiration data prior to the first month included in the Well data set is necessary to successfully calibrate the WEM. In addition, once the calibration periods are established, they cannot be adjusted manually.



5. In the PET Options section of the WEM Setup 2 tab, select a PET option.

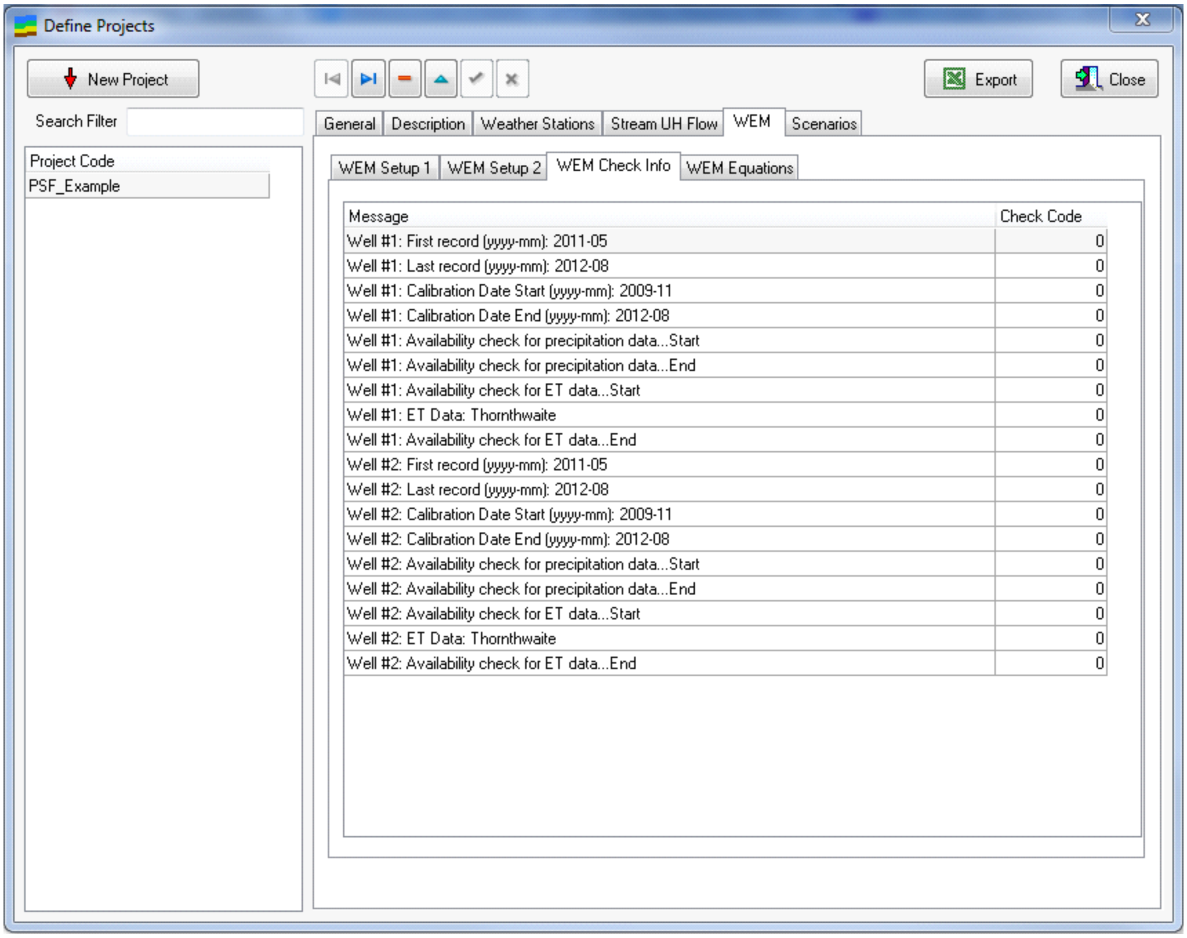


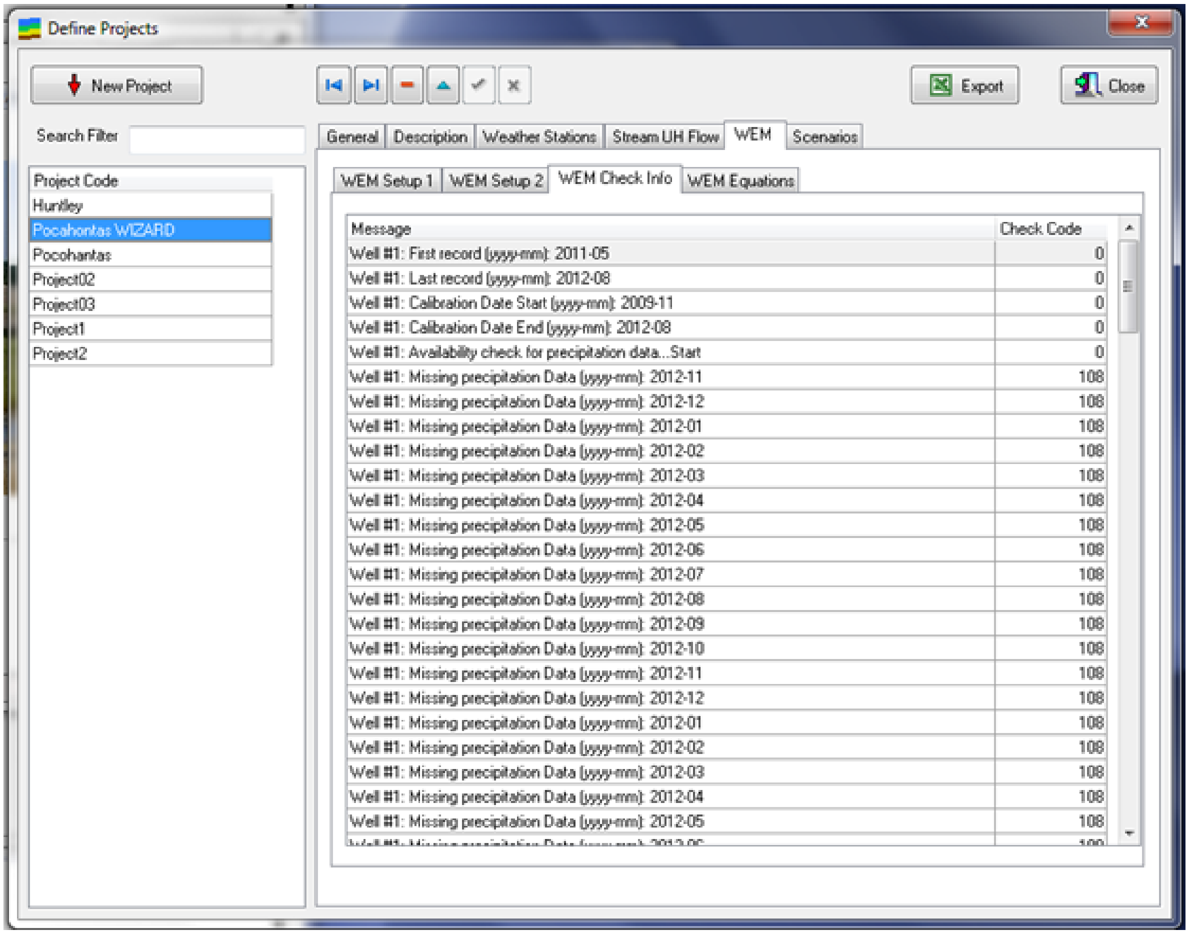
a. If the Penman-Monteith Method (calculated) option is selected, the user must assign an insolation data set and enter a value for Albedo in the box (default = 0.23). See Parameters for Penman-Monteith ET for instructions on creating an insolation data set and choosing a value for albedo.
b. If the Thornthwaite Equation (calculated) option is selected the user must have previously created a daylight length data set that corresponds to the latitude of the site. See Parameters for Thornthwaite ET for instructions on creating a daylight length data set.

6. After entering all WEM setup information, click 

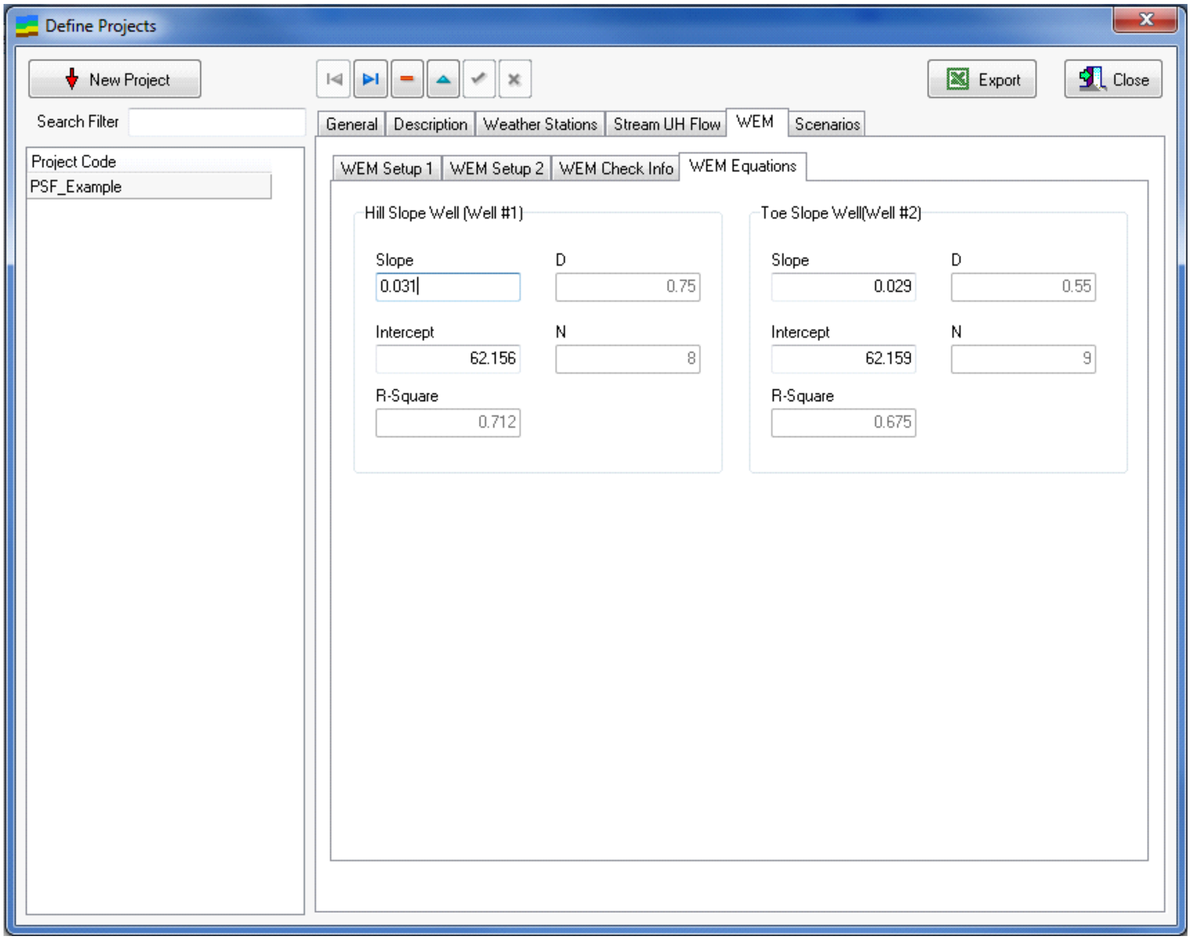
and select Yes from the prompt to confirm you would like Wetbud to run through the check procedure, which will determine if all of the necessary data are available to run WEM calculations. When the WEM check procedure is complete, a WEM Check Info tab will appear with a table of data required for each calibration well. Values of ‘0’ in the column on the right indicate the data are satisfactory. Values greater than ‘0’ indicate there is a problem with the data that correspond to the message displayed in the Message column. Once the check procedure is complete the user may proceed to WEM Calculations.
7. The WEM Equations tab displays the variables from the best WEM calibration run (selected by the user) for each well used in WEM calculations. The values for Slope,

Intercept, and R-Squared pertain to the linear regression of Effective Monthly Recharge (Wem) and Observed Head Elevation using the given N (number of months prior)-and-D (decay factor) combination for all months included in the WEM calibration period. See WEM Calculations for details and explanation of variables and the calibration equation selection process.





The figure above presents a case where the user tried to setup WEM calculations but well data are missing. The figure below shows the WEM equations calculated for each of the wells. The same information is also saved under each Well data set. See Wells - WEM Equations.



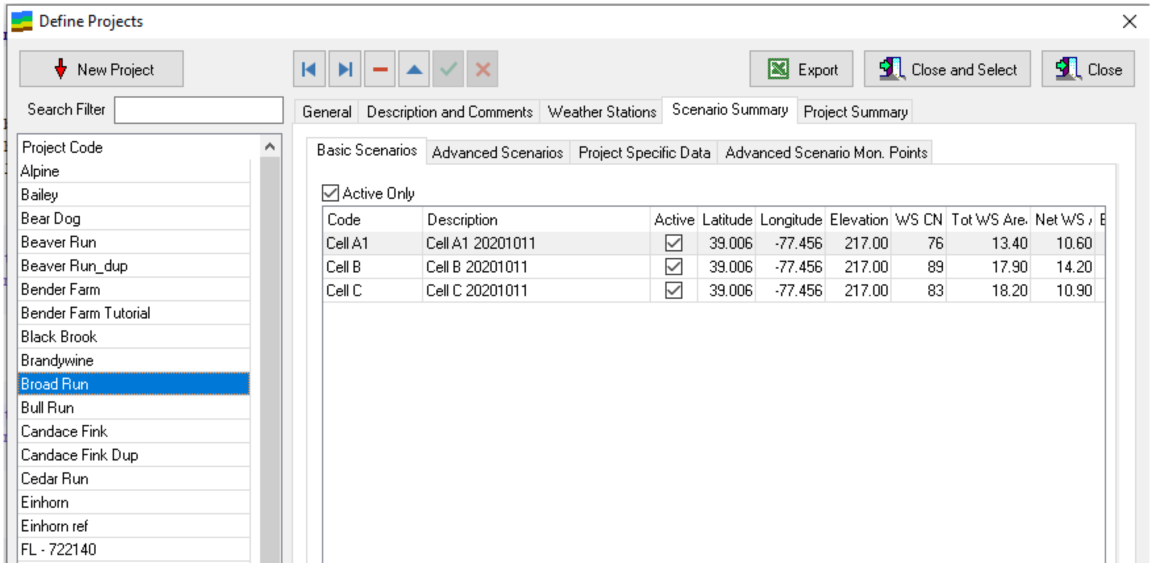
7.6 Scenarios

This tab is used to view all Scenarios associated with a given Project.

This tab has three sub-tabs: Basic Scenarios, Advanced Scenarios, and Project Specific Data. These tabs display a list of all Basic and Advanced Scenarios, and Project Specific Data created within the selected Project.

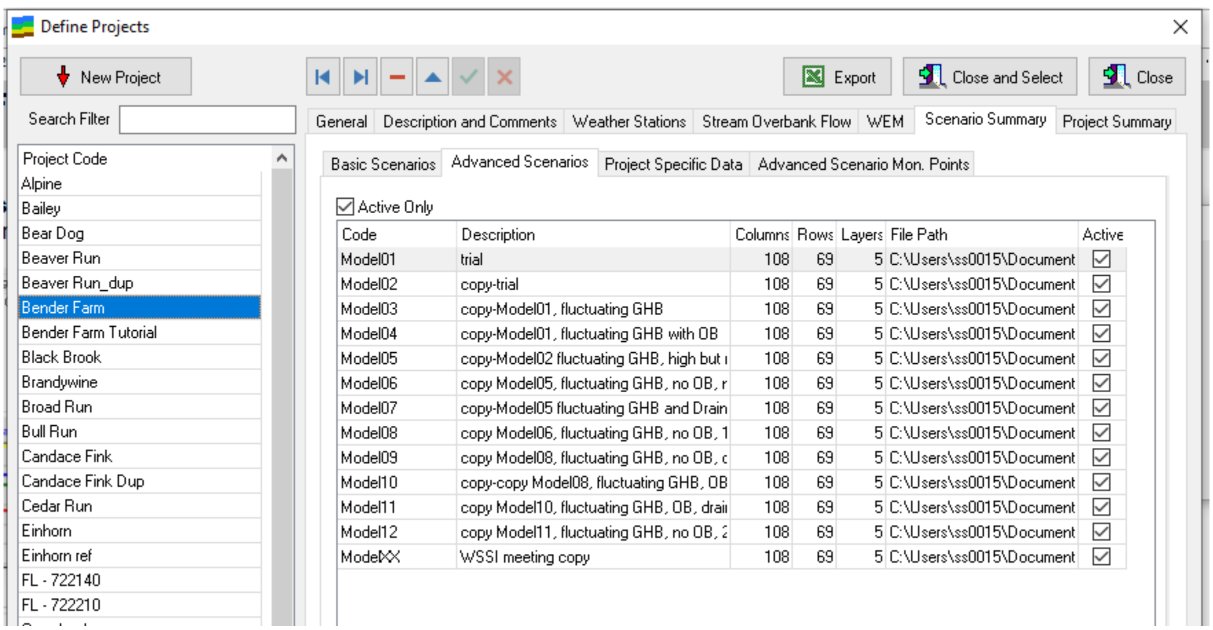
7.6.1 Basic

This grid allows for all Basic scenarios within a Project to be viewed within a one screen overview.



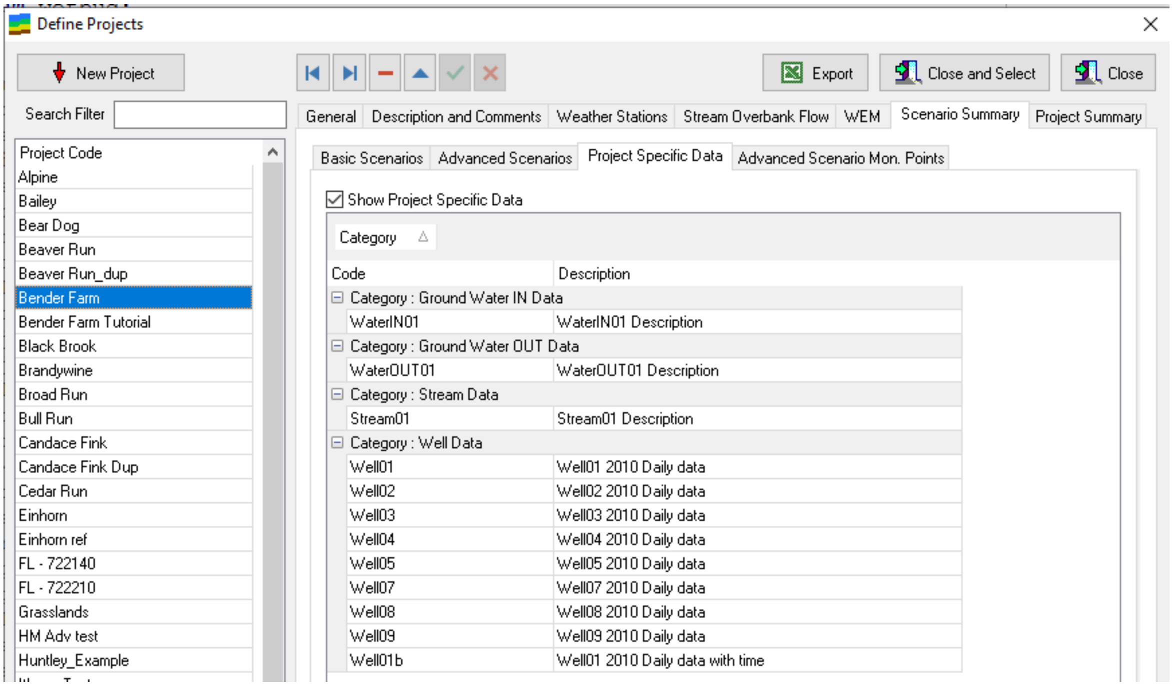
7.6.2 Advanced

This grid allows for all Advanced scenarios within a Project to be viewed within a one screen overview. Advanced models are described in detail in later sections.



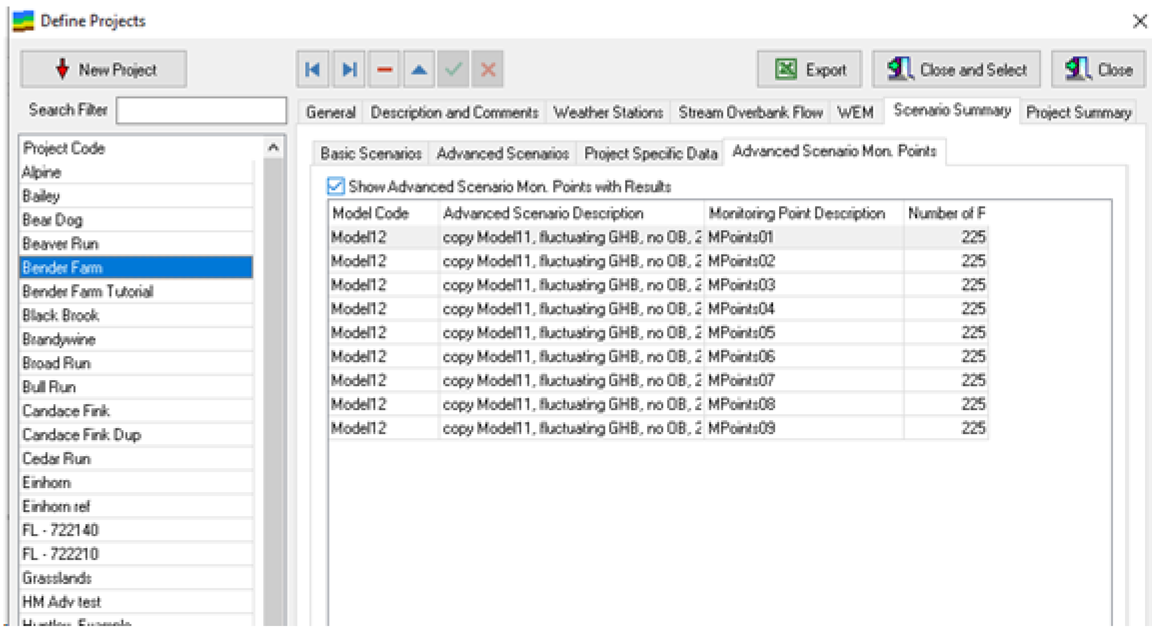
7.6.3 Project Specific Data

This grid allows for all Project Specific Data to be viewed within a one screen overview.



7.6.4 Advanced Scenarios Monitoring Points

This grid allows the user to view all monitoring points defined for a given advanced scenario.

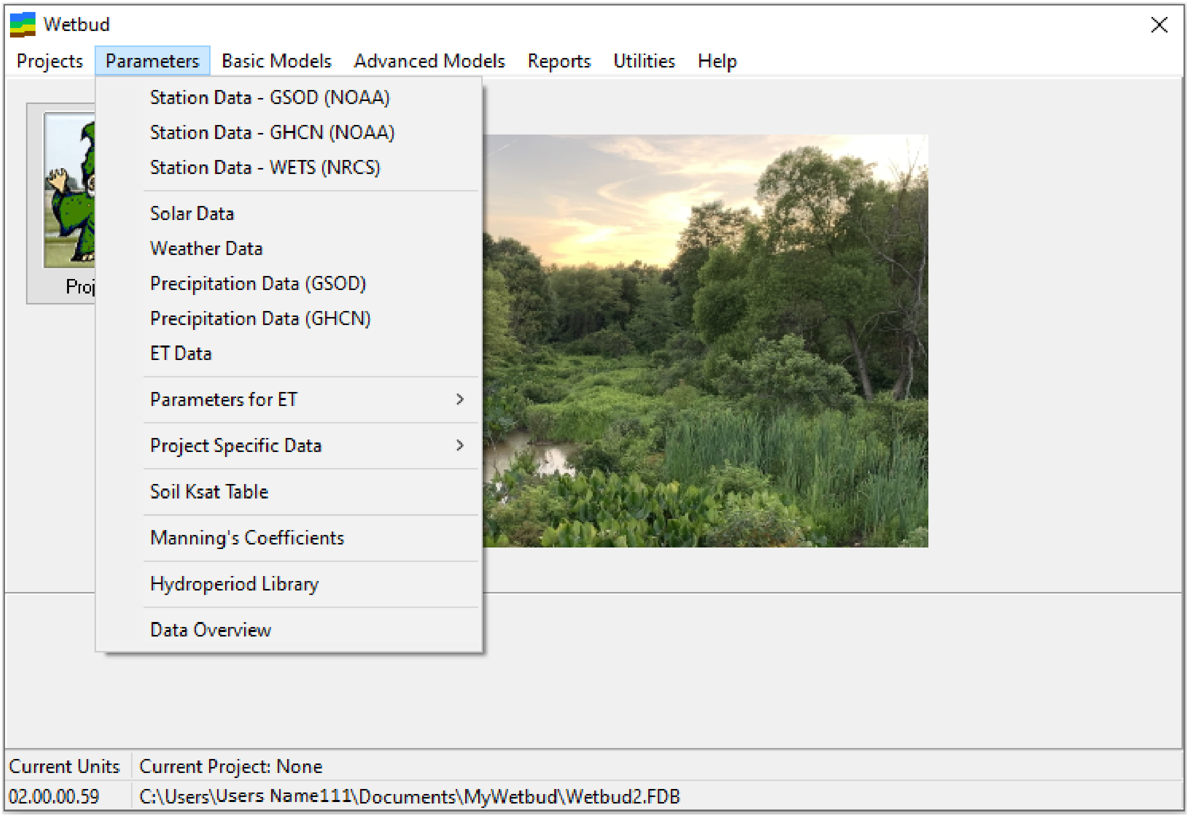


8

Parameters

8 Parameters

The Parameters menu in the Wetbud home screen is used to manage weather station data and other major parameters for the water budget calculations. The following pages provide a detailed explanation of each parameter and how to properly specify and include them in water budget analyses. In some instances, advice is given on how to select and/or manipulate parameters such as potential evapotranspiration (PET) to generate the most accurate wetland water budget for your Project site.



Before creating a new Project in Wetbud, the user must set up or define a weather station for the project. The weather station can be a NOAA station or any other station, including stations that the user installed at the site. Once a weather station has been defined the user can then assign it to a Project as a reference weather station in the *Define Project* window, in the *Weather Stations* tab. Weather stations are used to store data used in water budget calculations, such as solar and/or weather data needed for PET calculations, along with totals for calculated PET, precipitation, and runoff.

Wetbud currently supports two types of National Oceanic and Atmospheric Administration (NOAA) weather stations:

- NOAA Global Summary of the Day (GSOD)
- NOAA Global Historical Climatology Network (GHCN)

Additional details pertaining to these types of NOAA weather stations can be found at http://www.ncdc.noaa.gov/data-access/quick-links#ghcn.

In Wetbud, the NOAA (GSOD) weather station database serves as the main database from which Wetbud will extract data to generate water budgets. Wetbud easily downloads precipitation, weather, and solar data for GSOD stations from the NOAA (GSOD) database. The NOAA (GHCN) database only serves as an additional source from which Wetbud can download precipitation data. Wetbud does not provide functionality to download weather data or solar data for GHCN stations. If the user wishes to include precipitation data from a GHCN station in a water budget analysis they must download the data for the GHCN station in the GHCN station database and copy the data into the GSOD database. See Creating a custom weather station record in the GSOD data set and Creating a custom weather station in the GHCN data set for instructions to create a record for a GHCN station in the GSOD database. Once a record for the GHCN station has been created in the GSOD station database, the user can then copy the GHCN precipitation data into the GSOD database. For more information about importing GHCN precipitation data see Precipitation Data.

Note: GSOD stations provide readily available summaries of hourly data, that can easily be retrieved by Wetbud, for the majority of the parameters necessary to calculate water budgets. While NOAA GSOD data is of sufficient quality to generate water budgets, NOAA GHCN data is considered (by NOAA) to be of better quality. One notable difference is that GSOD uses UTC times, while GHCN stations typically use local standard time. Note that this difference in data collection times can result in differences of values reported by GSOD and GHCN stations.

As with precipitation data, users who wish to incorporate additional weather data from a GHCN station must externally obtain the data and manually import the weather data for the GHCN station into the GSOD record created for that station.

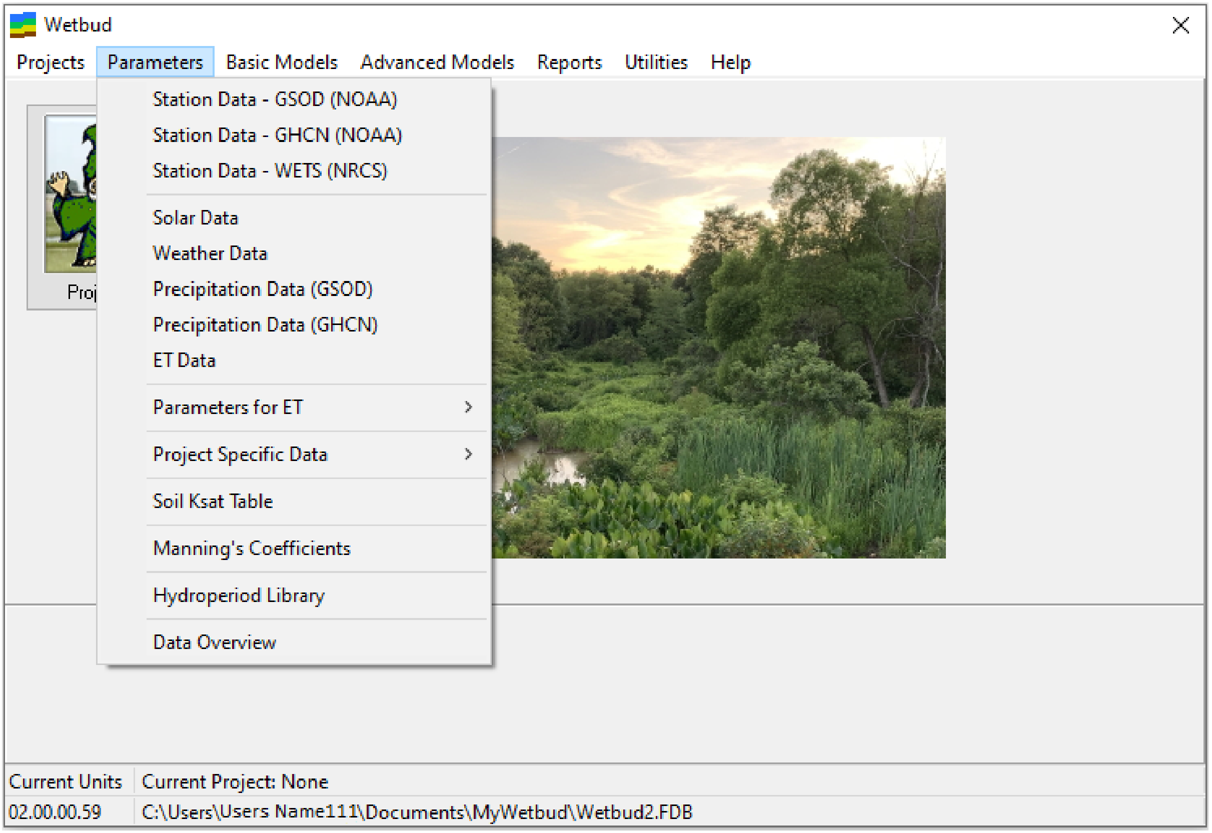
Note: Only stations with records created in the NOAA (GSOD) database can be selected as a Reference Weather Station when setting up a Project in the Weather Stations tab of the Define Projects window.

8.1 Station Data - GSOD

Wetbud comes prepackaged with 138 complete GSOD weather stations covering much of the eastern United States. A list of stations is provided here. Maps of station locations and precipitation distribution are provided in the Available Data in the GSOD Database section. Wetbud also provides functionality for users to develop custom weather stations derived from their own weather data as explained in the Create Custom Weather Station Record section, or to download data from NOAA stations around the world, addressed in this section.

To create a NOAA station record:
1. Select Station Data – GSOD (NOAA) from the Parameters drop-down menu in the Wetbud home screen.
2. Import the Station Header information and select a station based on the header information. See Import Station Header Information for more details.

3. Alternatively create a custom weather station. This option is useful when using a local weather station which is not part of the NOAA grid. See Create a Custom Weather Station for more details.



8.1.1 Create Custom Weather Station Record - GSOD

To create a custom station record:

1. First select Station Data – GSOD (NOAA) from the Parameters drop-down menu in the Wetbud home screen.
2. Next, in the General tab of the weather station data window click 

. The box under Station Code - Site Code is initialized with the text ‘GSODXX’ with XX representing two digits. Delete this text and replace it with a new code (up to 11 digits) for your station. Leave the WBAN ID number, COOP-ID, and Call Sign boxes blank. Enter the latitude, longitude, state, and station location. Click Save . You will now see a code and location that have been generated for your station in the list on the left side of the window.
3. Verify your Station coordinates have been entered properly by clicking 

, which displays your station on a Google Maps interface. In this window you can display NOAA or WETS stations (or both) within a radius of 10-50 miles of your Project latitude and longitude. This map will display all WETS stations, however, only those NOAA stations for which records have been created in the weather station set will be visible. After verifying your station coordinates, close the map window.

4. All precipitation, solar, and weather data to be associated with this station must now be manually imported or copied from an existing station record before using this as a reference station in a Basic Scenario water budget analysis. See Solar Data, Weather Data and Precipitation Data for information about importing these data.

8.1.2 Available Data in the GSOD Database

WSSI has prepared more than 138 preloaded stations to aid in the development of wetland water budgets. Preloaded weather stations have been created for Delaware, Florida, Georgia, Indiana, Maryland, New Jersey, New York, North Carolina, Ohio, Pennsylvania, South Carolina, Tennessee (Partial), Vermont (Partial), Virginia, and West Virginia. Influence Areas determined by the Thiessen Method were constrained using the geologic physiographic provinces to account for variations in topography and were grouped as follows:

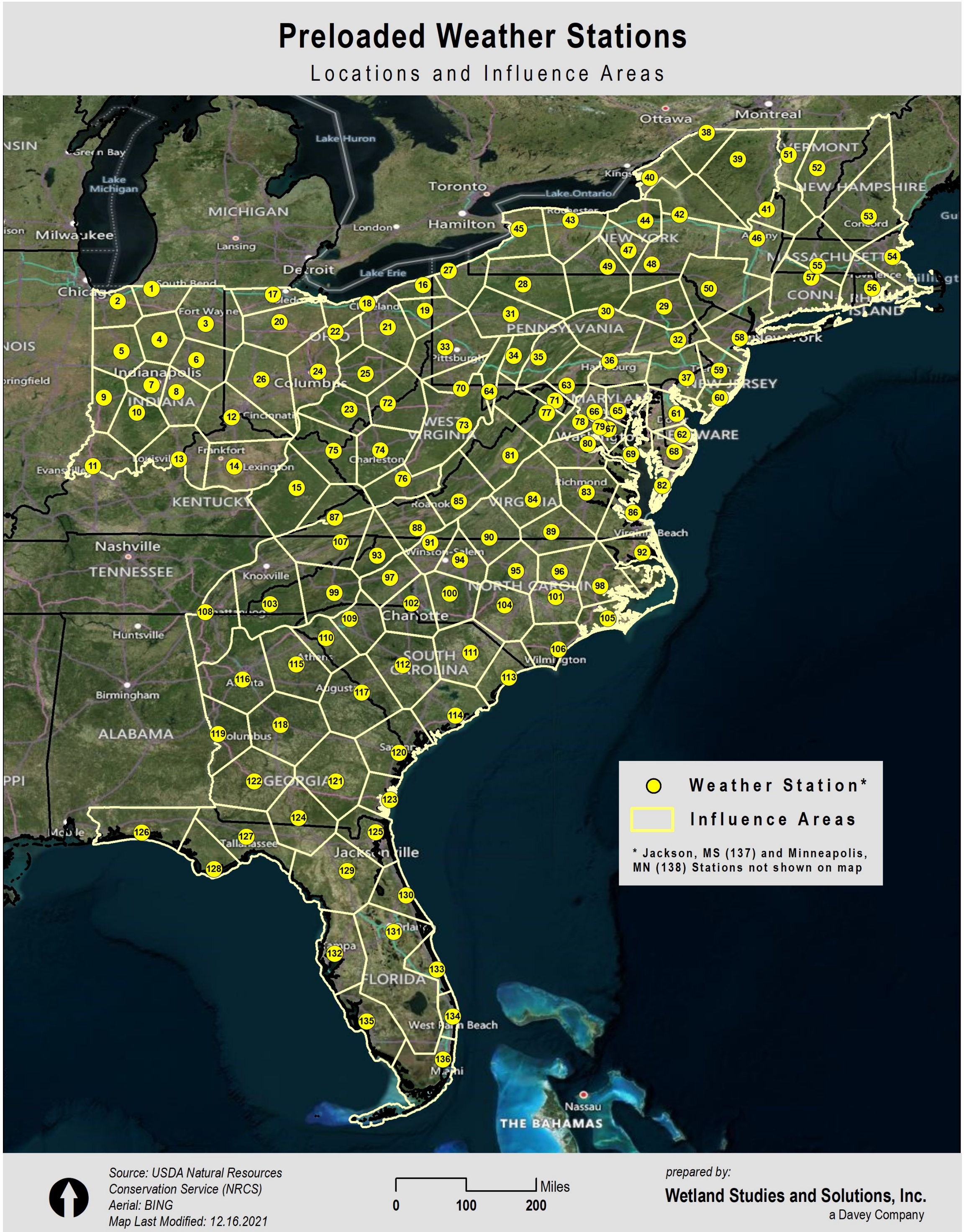
1. Everything west of the western boundary of the Appalachian Plateau, extending north to Lake Erie.
2. From the western boundary of the Appalachian Plateau to the eastern side of the Appalachian Plateau north to the New York-Vermont state line.
3. From the eastern boundary of the Appalachian Plateau to the western side of the Piedmont. The boundary is extended to the north where the Piedmont intersects the New England-Coastal Plain boundary.
4. From the western boundary of the Piedmont to the coast.

After developing Thiessen polygons within the four regions described above, PRISM precipitation data was overlaid to ensure adequate coverage within 30-year average precipitation patterns. Thiessen polygons were adjusted to account for areas with distinct precipitation patterns and/or no useable weather stations.

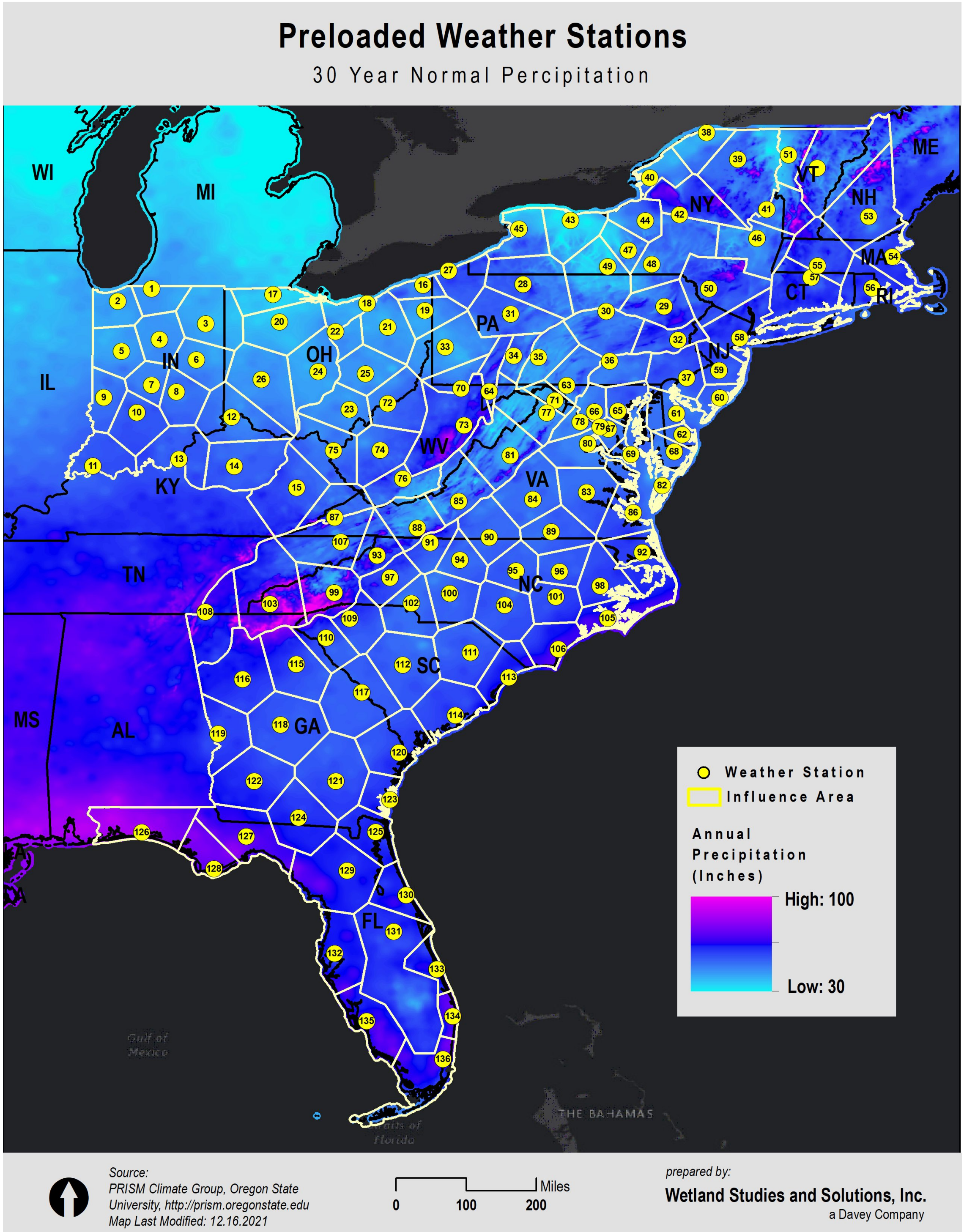
In areas strongly affected by orographic precipitation, such as the eastern side of the Blue Ridge Mountains, data from a more local gage is preferred. See Create Custom Weather Station Record - GSOD for guidance on creating a custom weather station.

While topography and precipitation patterns were considered in the creation of the Influence Areas depicted below, they are suggested Influence Areas. Professional judgment should be used when selecting a weather station for a Project or Scenario.

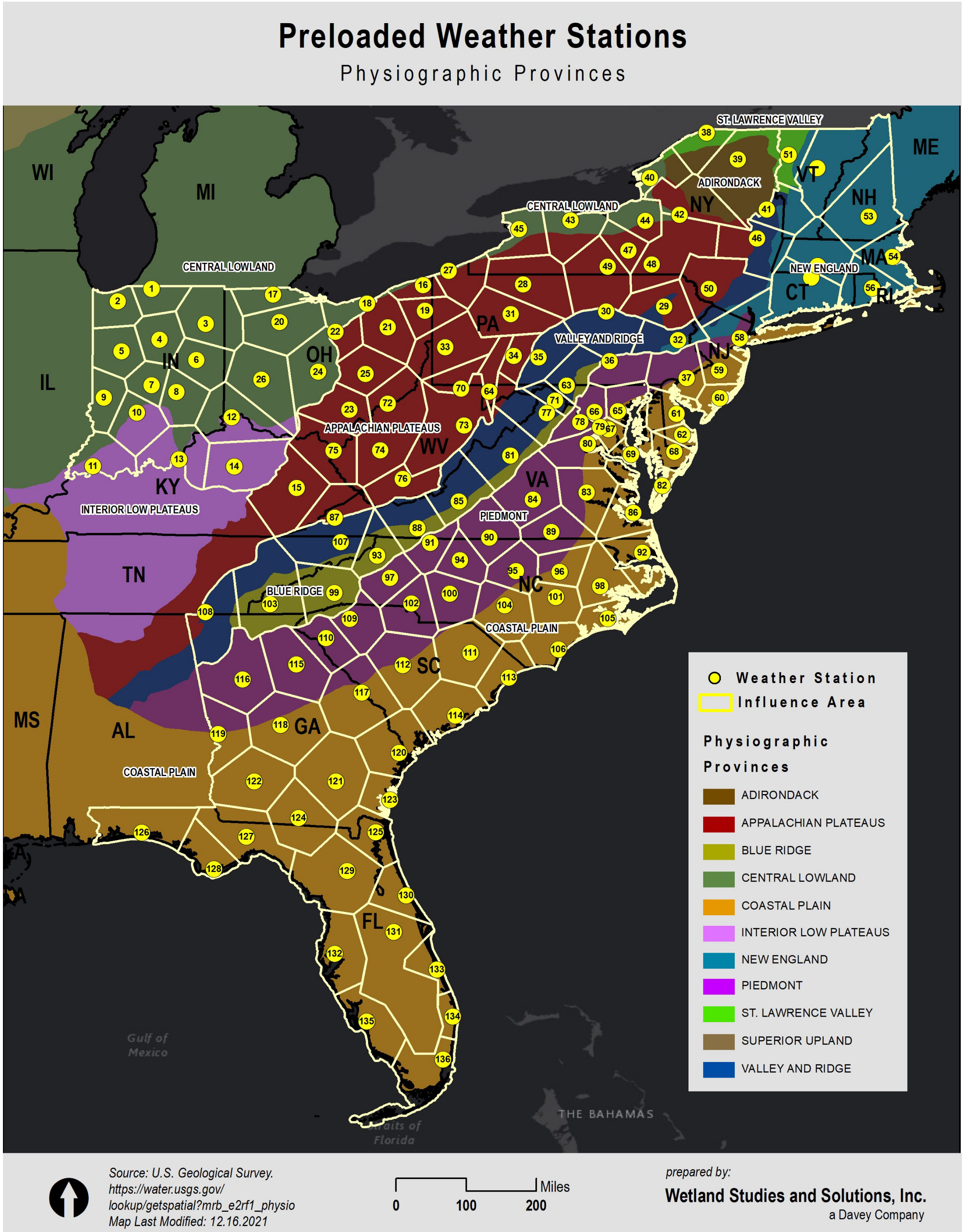
The figure below shows the preloaded weather stations. The yellow lines correspond to the influence area of each weather station.



The figure below shows the annual precipitation (30 year normal conditions) for the preloaded stations. The yellow lines correspond to the influence area of each weather station.



The figure below shows the physiographic provinces for the preloaded weather stations.



The numbers inside each polygon on the maps above correspond to a weather station. These stations are listed below sorted by state:

Indiana

1. South Bend Regional Airport
2. Porter Municipal County Airport

3. Fort Wayne International Airport
4. Grissom ARB Airport
5. Purdue University Airport
6. Delaware Co. Johnson
7. Indianapolis International Airport
8. Shelbyville Municipal Airport
9. Terre Haute Hulman Regional Airport
10. Monroe County Airport
11. Evansville Regional Airport

Kentucky

12. Cincinnati/Northern Kentucky International Airport
13. Louisville International Standiford Airport
14. Blue Grass Airport
15. Julian Carroll Airport

Ohio

16. Ashtabula Co. Airport
17. Toledo Express Airport
18. Cleveland-Hopkins International Airport
19. Youngstown-Warren Regional Airport
20. Findlay Airport
21. Akron Canton Regional Airport
22. Mansfield Lahm Regional Airport
23. Ohio State University Snyder Field
24. Port Columbus International Airport
25. Zanesville Municipal Airport
26. Wright-Patterson AFB Airport

Pennsylvania

27. Erie International Airport
28. Bradford Regional Airport
29. Wilkes-Barre International Airport
30. Williamsport Regional Airport
31. Du Bois-Jefferson Co. Airport
32. Lehigh Valley International Airport
33. Pittsburgh International Airport
34. J Murtha JWTN CMBRA Co. Airport
35. Altoona Blair County Airport
36. Harrisburg Capital City Airport
37. Philadelphia International Airport

New York

38. Massena Airport
39. Adirondack Regional Airport
40. Watertown International Airport
41. Floyd Bennet Memorial
42. Griffiss Airpark
43. Greater Rochester International Airport
44. Syracuse Hancock International Airport
45. Buffalo Niagara International Airport

46. Albany International Airport
47. Ithaca Tompkins Regional Airport
48. Greater Binghamton and E A Link Field
49. Elmira/Corning Regional Airport
50. Sullivan County International Airport

Vermont

51. Burlington International Airport
52. Edward F Knapp State Airport

New Hampshire

53. Concord Municipal Airport

Massachusetts

54. General E Logan International Airport
55. Westover AFB

Rhode Island

56. Theodore F Green State Airport

Connecticut

57. Bradley International Airport

New Jersey

58. Newark Liberty International Airport
59. McGuire AFB
60. Atlantic City International Airport

Delaware

61. Dover AFB
62. Sussex County Airport

Maryland

63. Hagerstown Regional Airport
64. Garrett County Airport
65. Baltimore-Washington International Airport
66. Gaithersburg Montgomery County
67. Andrews AFB
68. Salisbury Ocean City
69. Naval Air Station

West Virginia

70. MGTN RGNL-W L B Hart Airport
71. ETRN WV RGNL/Shepherd Airport
72. Mid-Ohio Valley Regional Airport
73. Elkins-Rand Co J Rand Field
74. Yeager Airport
75. Tri-state M.J. Ferguson Field
76. Raleigh County Memorial Airport

Virginia

77. Winchester Regional Airport
78. Washington Dulles International Airport
79. Ronald Reagan Washington National Airport
80. Quantico MCAF
81. Shenandoah Valley Regional Airport
82. Accomack County Airport

83. Richmond International Airport
84. Farmville Regional Airport
85. Roanoke Regional Airport
86. Langley AFB
87. Lonesome Pine Airport
88. Twin County Airport
89. Mecklenburg-Brunswick Regional Airport
90. Danville Regional Airport

North Carolina

91. Mount Airy/Surry Co.
92. Elizabeth City CGAS
93. Boone
94. Piedmont Triad International Airport
95. Raleigh-Durham International Airport
96. Rocky Mount Wilson
97. Hickory Regional Airport
98. Warren Field Airport
99. Asheville Regional Airport
100. Stanley County Airport
101. Seymour-Johnson AFB
102. Charlotte-Douglas International Airport
103. Andrews Murphy Airport
104. Pope AFB
105. Cherry Point MCAS
106. Wilmington

Tennessee

107. Bristol Tri City Airport
108. Lovell Field Airport

South Carolina

109. Greenville-Spartanburg International Airport
110. Anderson Regional Airport
111. Florence Regional Airport
112. Columbia Metropolitan Airport
113. Myrtle Beach International Airport
114. Charleston AFB

Georgia

115. Athens/Ben Epps Airport
116. Hartsfield-Jackson Atlanta International Airport
117. Augusta Regional at Bush Field
118. Middle Georgia Regional Airport
119. Columbus Metro Airport
120. Savanna/Hilton Head International Airport
121. Alma/Bacon Co.
122. SW Georgia Regional Airport
123. Malcolm McKinnon Airport
124. Valdosta Regional Airport

Florida

125. Jacksonville International Airport
126. Eglin AFB
127. Tallahassee Regional Airport
128. Apalachicola Municipal Airport
129. Gainesville Regional Airport
130. Daytona Beach International Airport
131. Orlando International Airport
132. Tampa International Airport
133. Vero Beach Municipal Airport
134. West Palm Beach International Airport
135. Page Field Airport
136. Miami International Airport

Mississippi

137. Jackson International Airport (* no polygon available)

Minnesota

138. Minneapolis-St. Paul International Airport (* no polygon available)

8.1.3 General

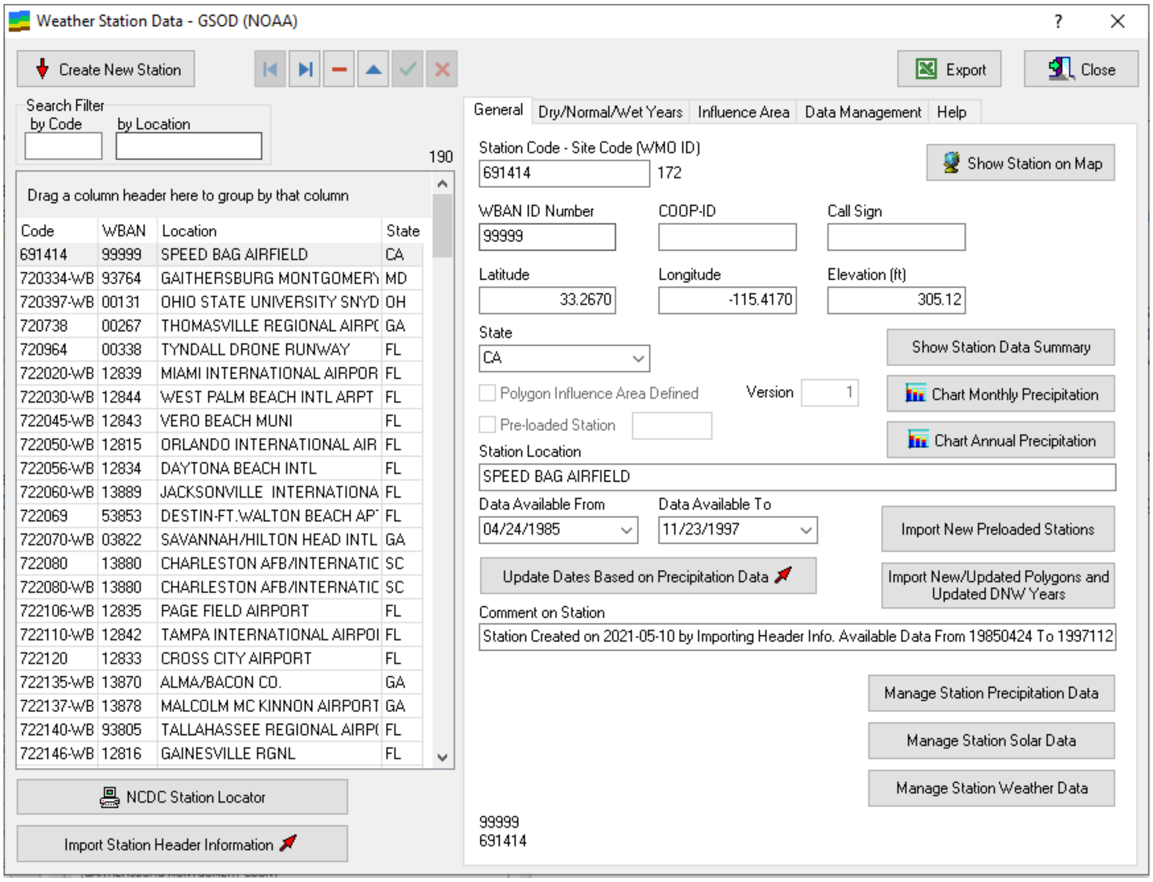
The header information for NOAA stations is listed in the General tab. The header information for GSOD weather stations includes the WBAN ID number (5-digits), COOP-ID number, Call Sign, Latitude, Longitude, Elevation, State, and Station Location.

World Meteorological Organization (WMO) ID Number
A five-digit station identifier assigned by the World Meteorological Organization (WMO), used for international weather data exchange and station documentation. The authoritative documentation of the WMO Station Identifier is the publication: Volume A, Observing Stations, WMO - No. 9, World Meteorological Organization, Geneva Switzerland (issued periodically).

WBAN ID Number
A five-digit station identifier used at NCDC for digital data storage and general station identification purposes. WBAN is an acronym, invented in the 1950's, which stands for Weather-Bureau-Army-Navy. WBAN station numbers were first used as identifiers for stations reporting meteorological observations on the then-standard WBAN series of forms (e.g., WBAN 10A, 10B, and 10C). WBAN numbers were the first major attempt at a coordinated station numbering scheme among several weather reporting authorities. Original participants in the WBAN number plans were the United States Weather Bureau, Air Force, Navy, and Army; the Canadian Department of Transportation; and certain German and Korean stations in close cooperation with the US Weather Services.

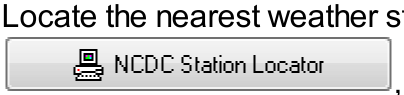
Cooperative Stations
These stations are identified by a 6-digit number and are part of the National Weather Service's Cooperative Station Network. The first two digits designate a USA state or territory code. The last four digits are assigned to stations within a state in general

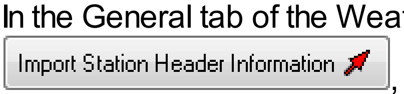
accordance with the alphabetic order of the station name. A station in this network, as designated by a single Cooperative Station Identifier, can be one site or a series of sites whose locations fall within 2 miles horizontal or 100 feet vertical difference. There are exceptions to this rule, with "climatic compatibility," as determined by the NWS field manager, being the overriding factor.



8.1.3.1 Import Station Header Information

To import station header information for a NOAA station directly from the web and into the station database, use the following procedure. Users who already know the location and station ID of the station for which they will create a record can skip to step 2:

1. Locate the nearest weather station to your Project site by clicking 

, which will direct you to the NOAA National Climatic Data Center Climate Data Online webpage. Go to the Mapping Tool and select Global Summary of the Day. Next, use the map tools to locate and identify the weather station nearest to your Project site. After identifying the nearest NOAA weather station, record the station code and location name (5-digit WMO ID for GSOD or 11-digit code for GHCN) and close the Interactive Map Application.
2. In the General tab of the Weather Station Data window, click 

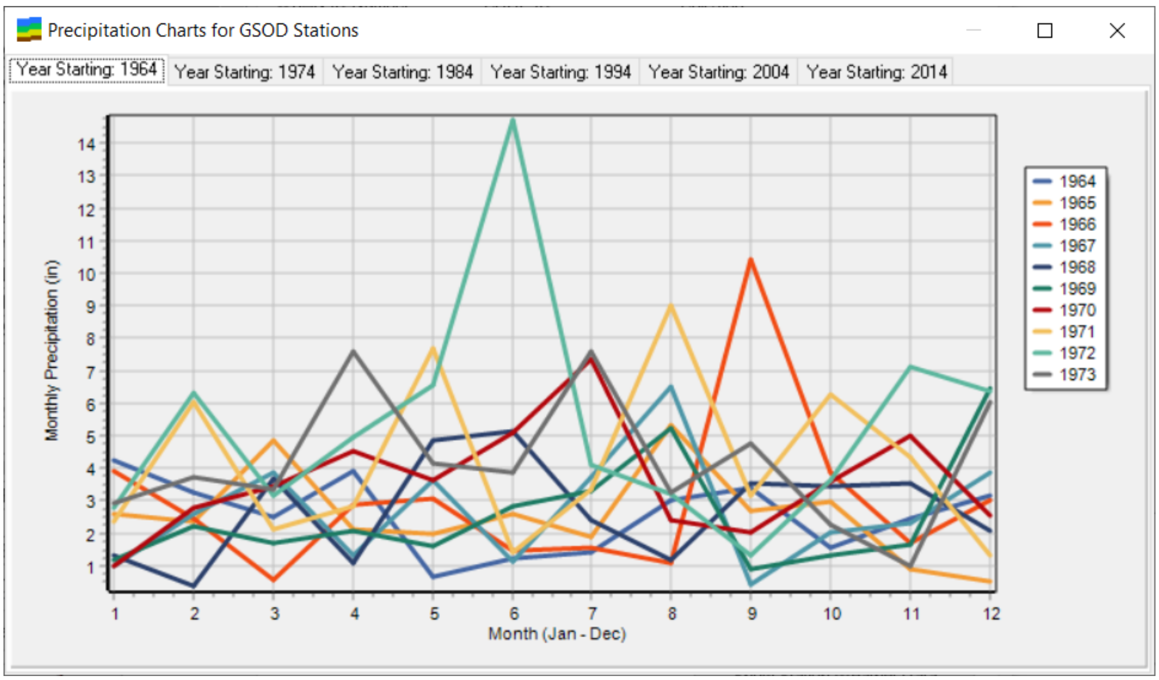
, which will display a separate window of the database of all weather station header information. See List of GSOD Stations on how to import Station Header Data.

3. Once a record for the weather station exists in the weather station database, the user can proceed to automatically download or manually import available data for that station.

Click Show Station Data Summary to view the summary information for the selected station in the Data Management tab.

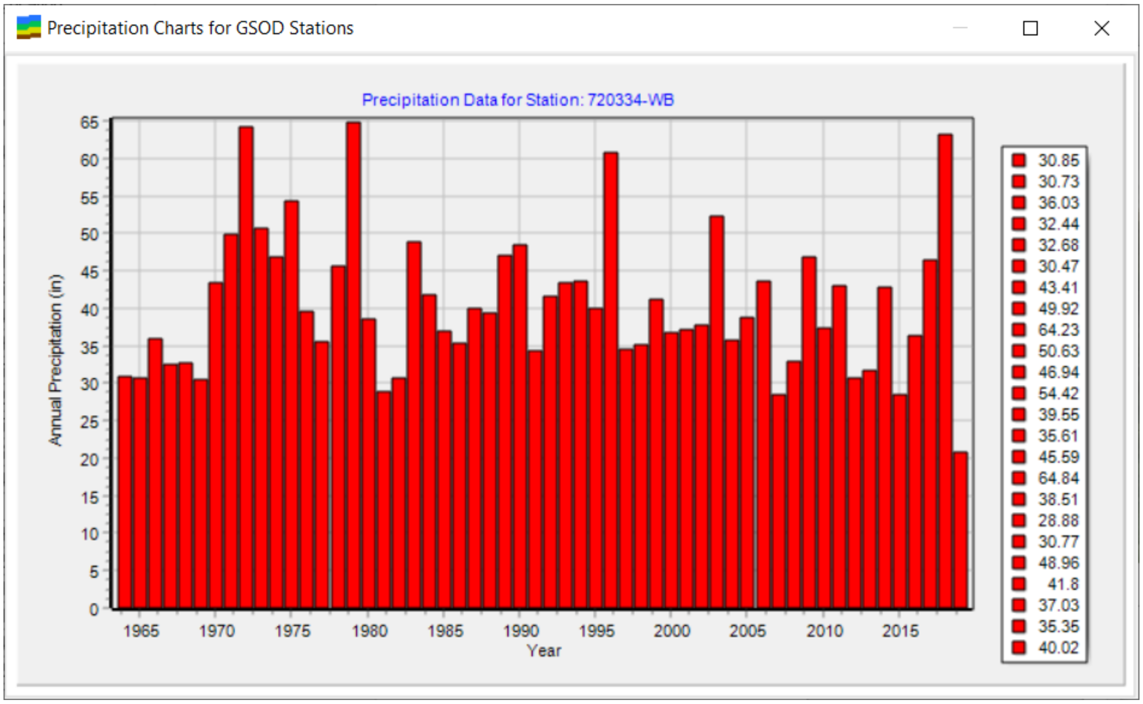
8.1.3.2 Chart Monthly Precipitation

To view a chart of imported monthly precipitation data for this station, click Chart Monthly Precipitation. A typical chart is shown below where data are charted monthly by decade.



8.1.3.3 Chart Annual Precipitation

To view a chart of imported annual precipitation data for this station, click Chart Annual Precipitation. A typical chart is shown below where data are charted by year.



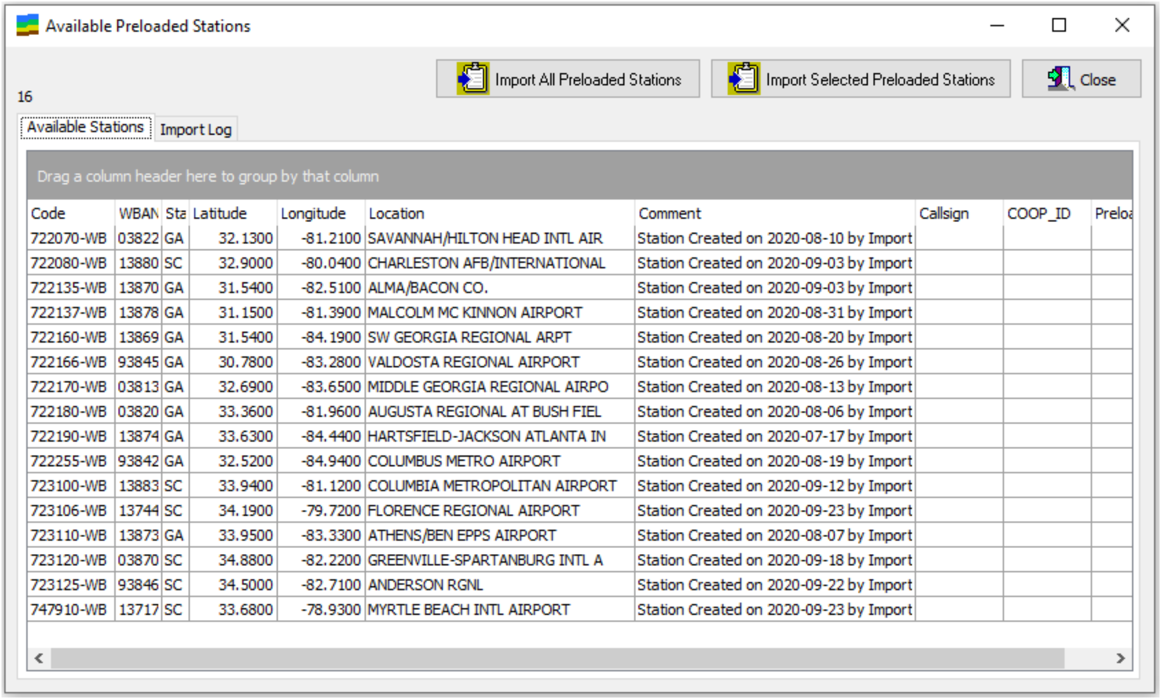
8.1.3.4 Update with New Preloaded Stations and Data

This screen shows the new preloaded stations and data available to be imported to the Wetbud station database.

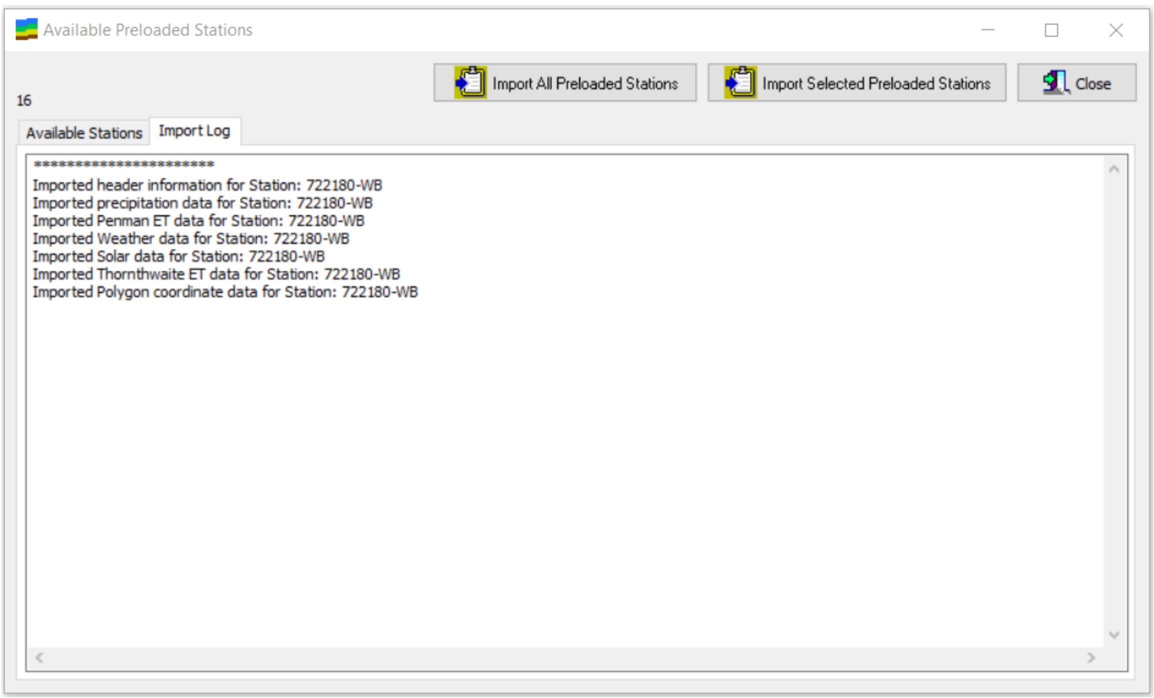
To import all preloaded stations, click 

. To import individual stations, select stations from the list provided and click 

. The import log shows the status of the data import for each station.

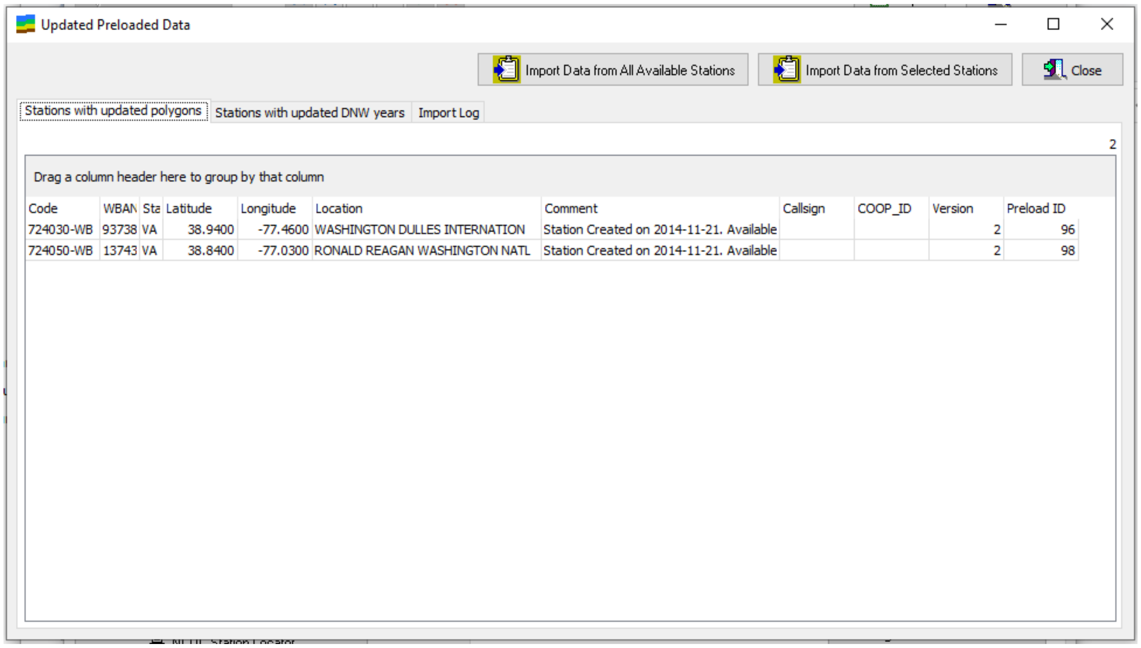


Code	WBAN	Sta	Latitude	Longitude	Location	Comment	Callsign	COOP_ID	Preloa
722070-WB	03822	GA	32.1300	-81.2100	SAVANNAH/HILTON HEAD INTL AIR	Station Created on 2020-08-10 by Import			
722080-WB	13880	SC	32.9000	-80.0400	CHARLESTON AFB/INTERNATIONAL	Station Created on 2020-09-03 by Import			
722135-WB	13870	GA	31.5400	-82.5100	ALMA/BACON CO.	Station Created on 2020-09-03 by Import			
722137-WB	13878	GA	31.1500	-81.3900	MALCOLM MC KINNON AIRPORT	Station Created on 2020-08-31 by Import			
722160-WB	13869	GA	31.5400	-84.1900	SW GEORGIA REGIONAL ARPT	Station Created on 2020-08-20 by Import			
722166-WB	93845	GA	30.7800	-83.2800	VALDOSTA REGIONAL AIRPORT	Station Created on 2020-08-26 by Import			
722170-WB	03813	GA	32.6900	-83.6500	MIDDLE GEORGIA REGIONAL AIRPO	Station Created on 2020-08-13 by Import			
722180-WB	03820	GA	33.3600	-81.9600	AUGUSTA REGIONAL AT BUSH FIEL	Station Created on 2020-08-06 by Import			
722190-WB	13874	GA	33.6300	-84.4400	HARTSFIELD-JACKSON ATLANTA IN	Station Created on 2020-07-17 by Import			
722255-WB	93842	GA	32.5200	-84.9400	COLUMBUS METRO AIRPORT	Station Created on 2020-08-19 by Import			
723100-WB	13883	SC	33.9400	-81.1200	COLUMBIA METROPOLITAN AIRPORT	Station Created on 2020-09-12 by Import			
723106-WB	13744	SC	34.1900	-79.7200	FLORENCE REGIONAL AIRPORT	Station Created on 2020-09-23 by Import			
723110-WB	13873	GA	33.9500	-83.3300	ATHENS/BEN EPPS AIRPORT	Station Created on 2020-08-07 by Import			
723120-WB	03870	SC	34.8800	-82.2200	GREENVILLE-SPARTANBURG INTL A	Station Created on 2020-09-18 by Import			
723125-WB	93846	SC	34.5000	-82.7100	ANDERSON RGNL	Station Created on 2020-09-22 by Import			
747910-WB	13717	SC	33.6800	-78.9300	MYRTLE BEACH INTL AIRPORT	Station Created on 2020-09-23 by Import			



The screen below shows the stations that have updated polygon definitions. The second tab on the same form shows the stations with updated DNW years that can be imported to the Wetbud station database.

To import all preloaded stations, click . To import individual stations, select stations from the list provided and click . The import log shows the status of the data import for each station.



8.1.3.5 Show Station Precipitation

See [Parameters: Precipitation Data for GSOD]

8.1.3.6 Show Station Solar Data

See [Parameters: Solar Data]

8.1.3.7 Show Station Weather Data

See [Parameters: Weather Data]

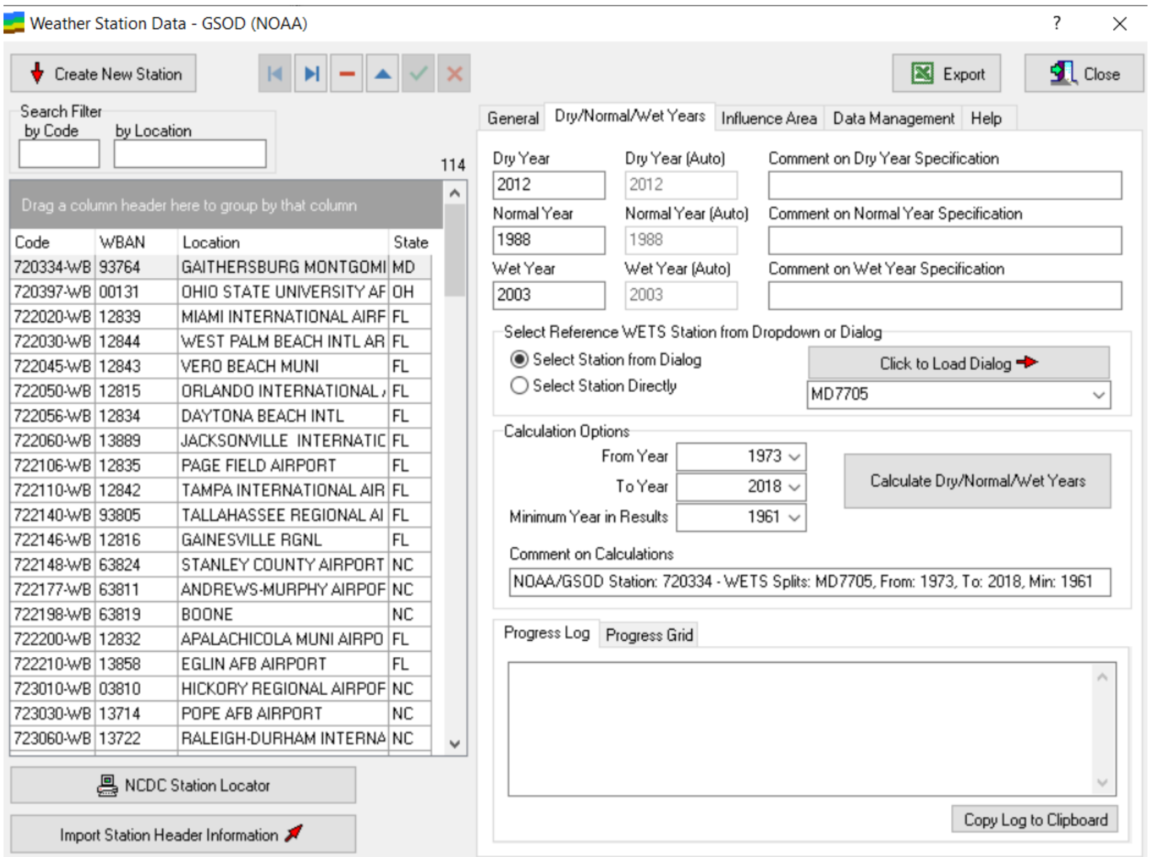
8.1.4 Dry/Normal/Wet Years

The Dry/Normal/Wet Years tab is used to calculate Dry (D), Normal (N) and Wet (W) years for the selected station. The DNW years calculated in this tab will be used as the Standard Analysis Years when choosing the Automatically Calculated option in the General tab of Basic Scenario setup. To calculate DNW years for this station, first select a reference WETS station using one of the two options provided.

Note: DNW years must first be determined for the reference WETS station before calculating DNW years for the GSOD station. See WETS Dry/Normal/Wet Years.

The detailed steps for calculating the DNW years are:

1. Select a station from Dialog by clicking Click to Load Dialog, which will display a list of WETS stations within a radius of 10-40 miles, based on your selection. See Nearby WETS Stations.
2. Assign the reference WETS station. Select the appropriate WETS station in the list and then click Select WETS Station for Reference
3. Close the window and continue to the next step.

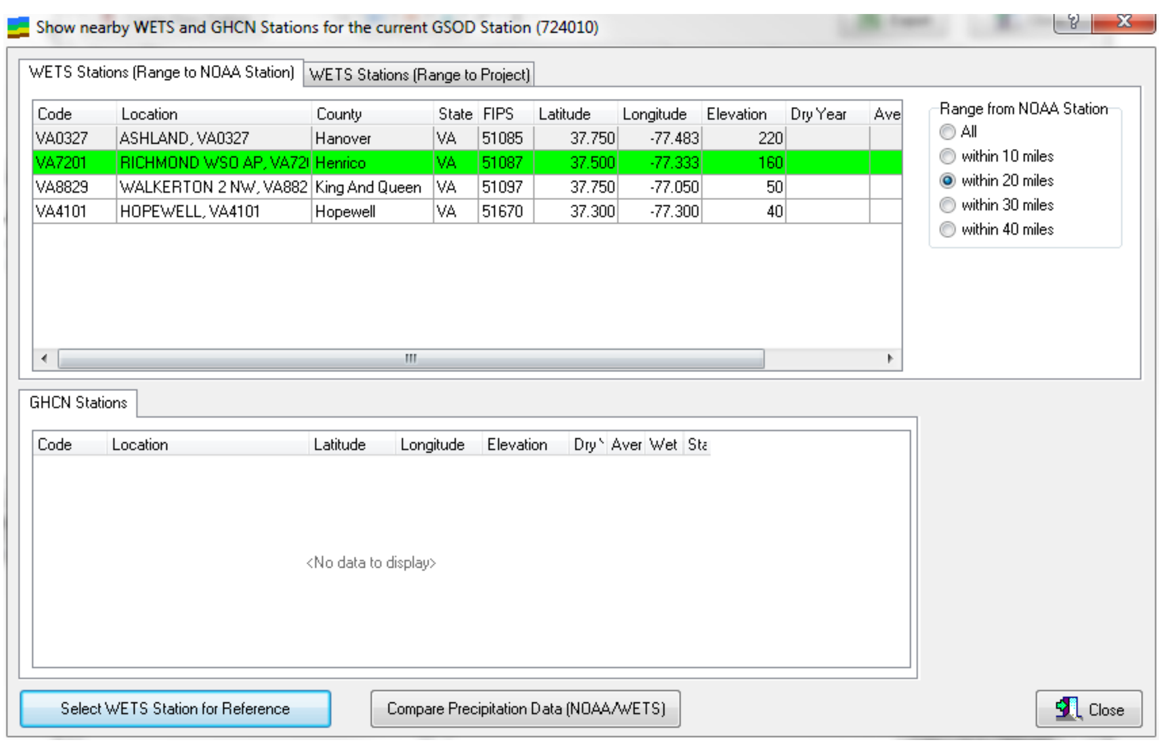


4. Select the range of years you wish to include in the From Year, To Year, and Minimum Year (under Calculation Options) in the Results drop-down lists.
5. Click Calculate Dry/Normal/Wet Years.
6. The DNW years calculated from the selected range of years will appear in their respective boxes.
7. To export an Excel file of the DNW calculations as performed by Wetbud (shown in the Progress Log), click Export, then name and save the file.
8. Click Save to save the DNW years calculated for this station.
9. To view a chart of monthly or annual precipitation data for this station, click Chart Monthly Precipitation or Chart Annual Precipitation in the General tab.

Note: Wetbud calculates DNW years based on the procedure developed by McLeod (2013). This procedure was designed to determine if years classified as dry, normal or wet based on total annual precipitation also have a dry, normal, or wet spring, respectively. For example, a year that is classified as wet based on total annual precipitation that does not meet the wet spring criteria is rejected as a 'wet' year and another year must be selected as 'wet'. For more details, see Dry, Normal, Wet Year Calculations.

8.1.4.1 Nearby WETS Stations

This form will display a list of WETS stations within a specified radius from the GSOD or GHCN station selected.



8.1.4.2 Dry, Normal, Wet Year Calculations

The procedure used by Wetbud to select a specific year as representing Dry conditions for wetlands, one for Normal conditions, and one for Wet conditions, for a given county in any State, is:

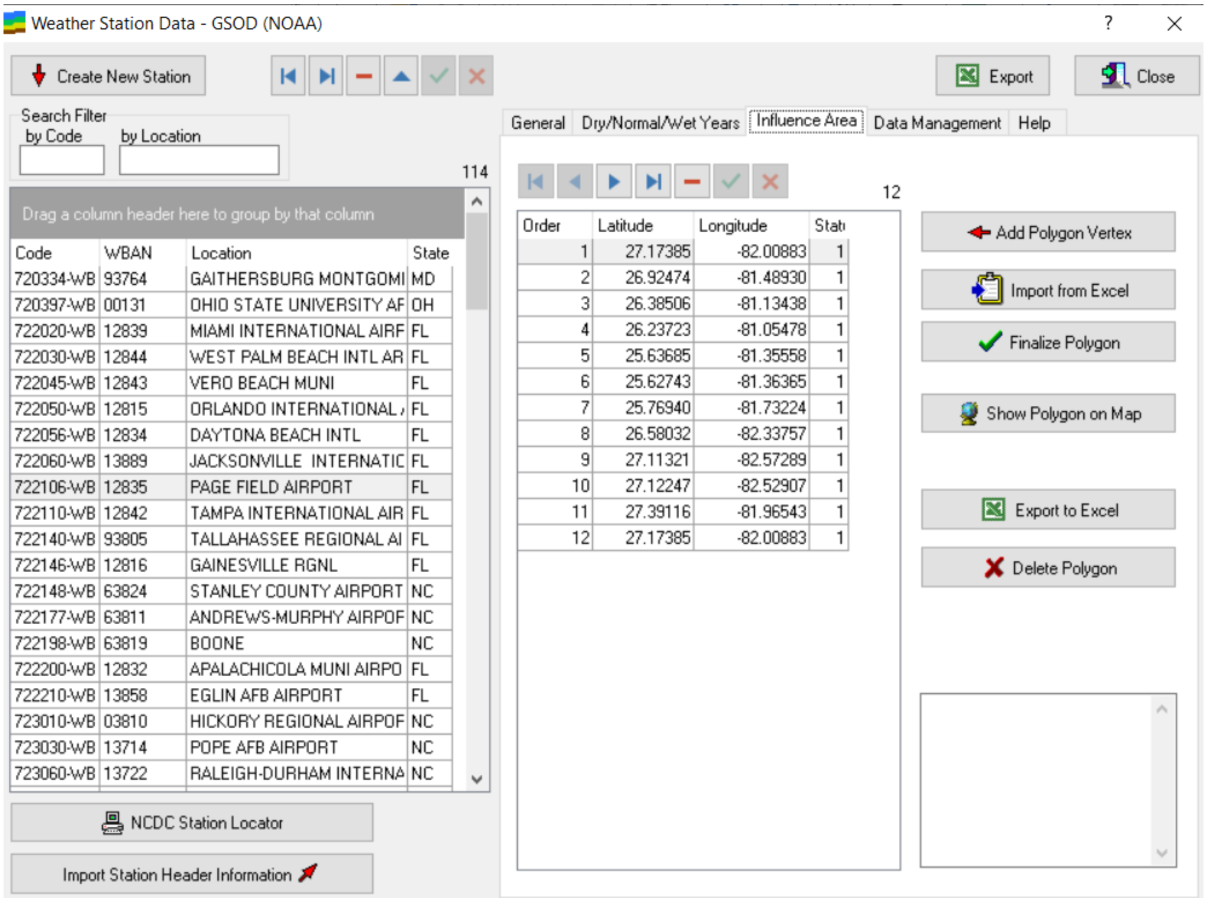
1) Rank all of the annual total precipitation data given with that WETS table; usually is at least 30 years and may be more.
2) Use the values on the WETS Table to split that list into the DRY, NORM, and WET years.
3) Select the year with the median precipitation value in each of those splits.
4) Look at the monthly precipitation data for the key months of March, April, May and June, and use the standard NRCS procedure to determine if each of those months are DRY, NORM or WET. The procedure uses the values of the three preceding months to make the determination. For the four key months, assign a score of 3, 2, or 1 to each month, as does the NRCS for DRY, NORM and WET, and total the scores for the four key months. Those values will range between 4 (for 4 DRY months) to 12 (for 4 WET months).
5) These four spring months would be DRY if they had a score of 4-6, they would be NORM if they had a score of 7-9, and they would be WET with a score of 10-12.
6) Therefore a typical WET year would be one with a median WET annual precipitation AND a WET spring; a NORM year will have a median precipitation in the NORM range AND a NORM spring, and a DRY year will have a precipitation value that is median in the DRY range and a DRY spring.
7) In the event that the Spring for the median DNW year does not correspond to the Annual DNW determination, the next year in the split is evaluated. If the median-plus-one-year Spring DNW corresponds to the Annual DNW determination, the year is accepted. Otherwise, Wetbud will continue checking subsequent years within the split.

WETS Data can be downloaded from the Natural Resources Conservation Service (NRCS) site.

8.1.5 Influence Areas

The Influence Area tab is used to develop or edit an irregularly shaped area of influence for the weather station. Adding an area of influence defines an area within which weather data unique to that station is appropriate for any given Project latitude and longitude that falls within the area of influence.

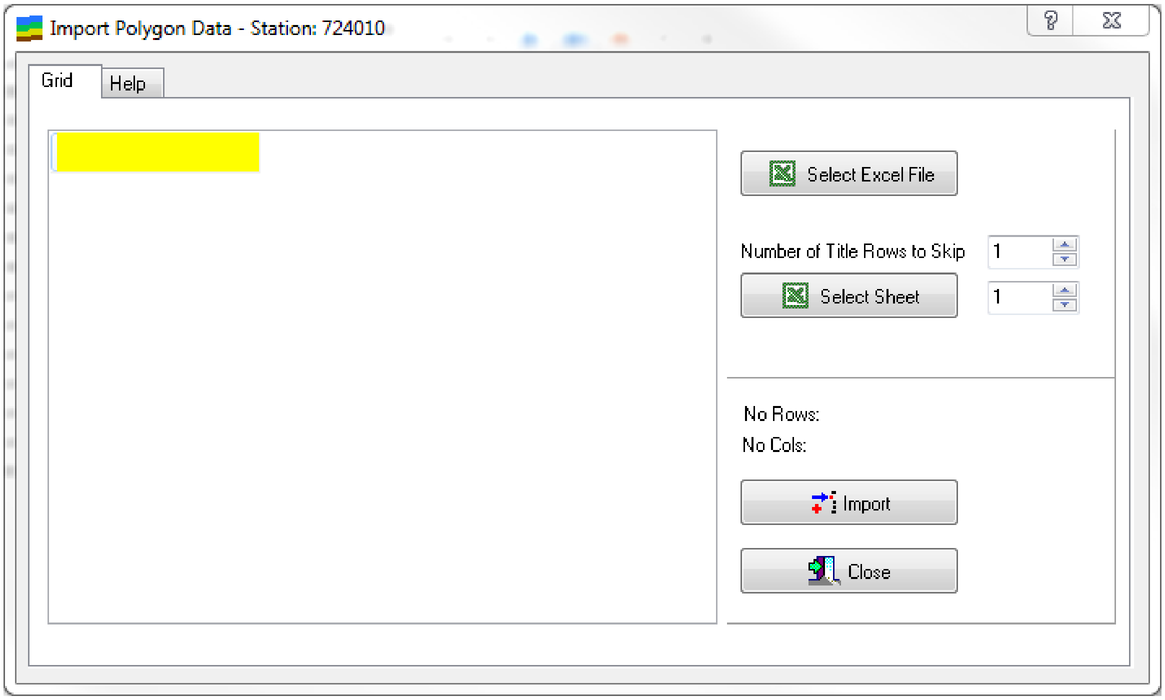
Note: Influence areas have been added to expedite the development of wetland water budgets. As regional weather patterns vary greatly throughout the country, professional judgment should be used in determining the appropriate weather station for any given Project.



8.1.5.1 Import from Excel

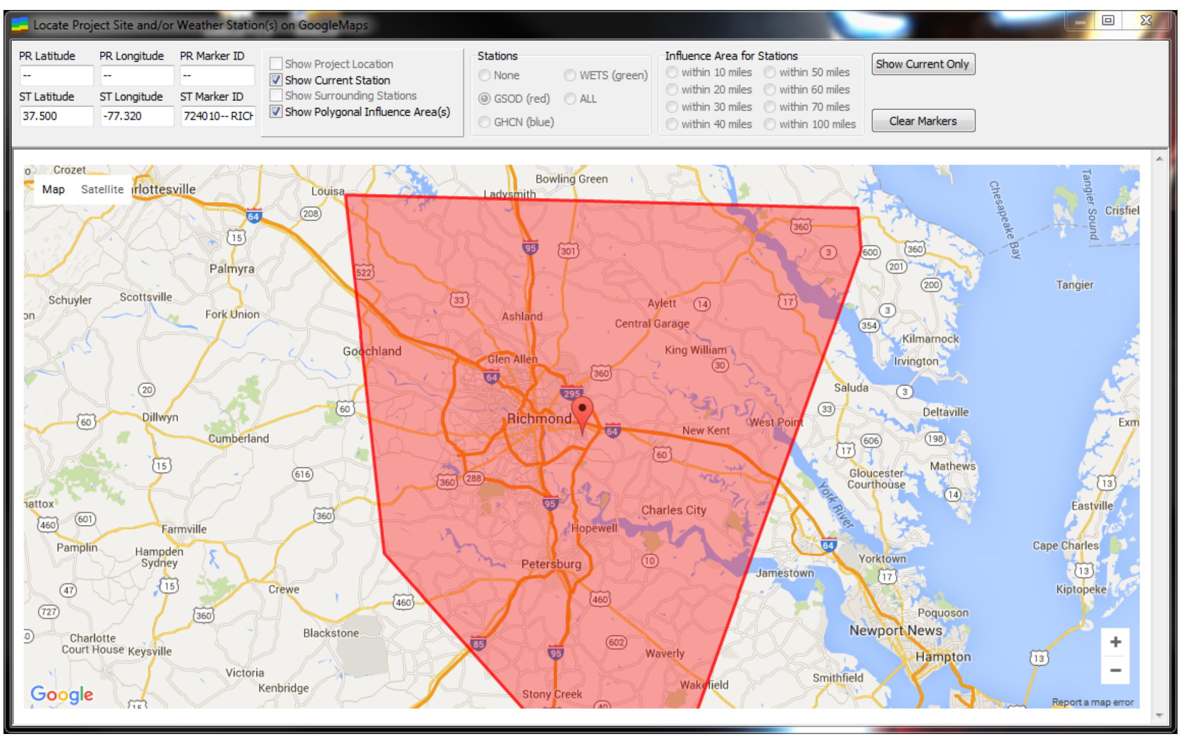
Click 

to import polygon data into Wetbud. You may select the Excel file with the specific sheet you would like to import.



8.1.5.2 Show Polygon on Map

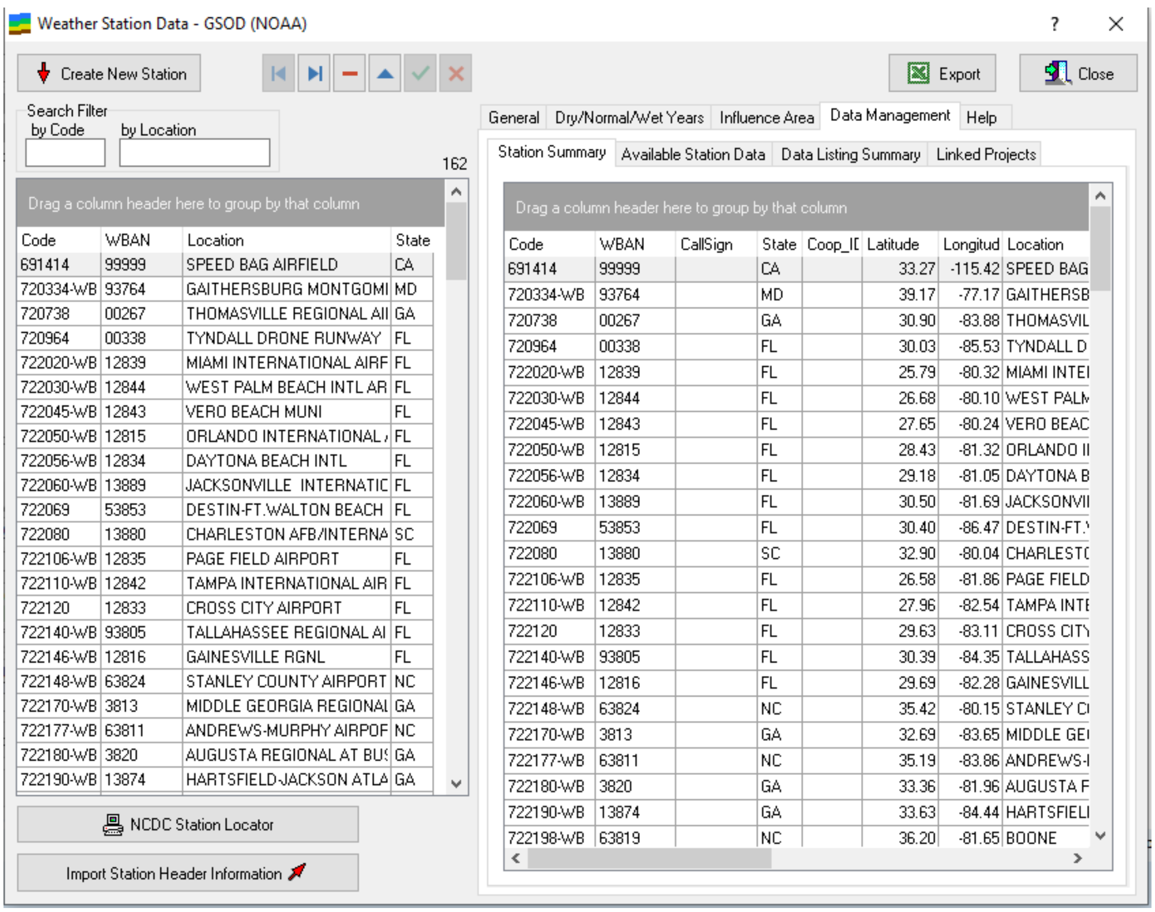
Click show polygon on map Google Maps to pop up with a polygon that bears the same vertices as specified.

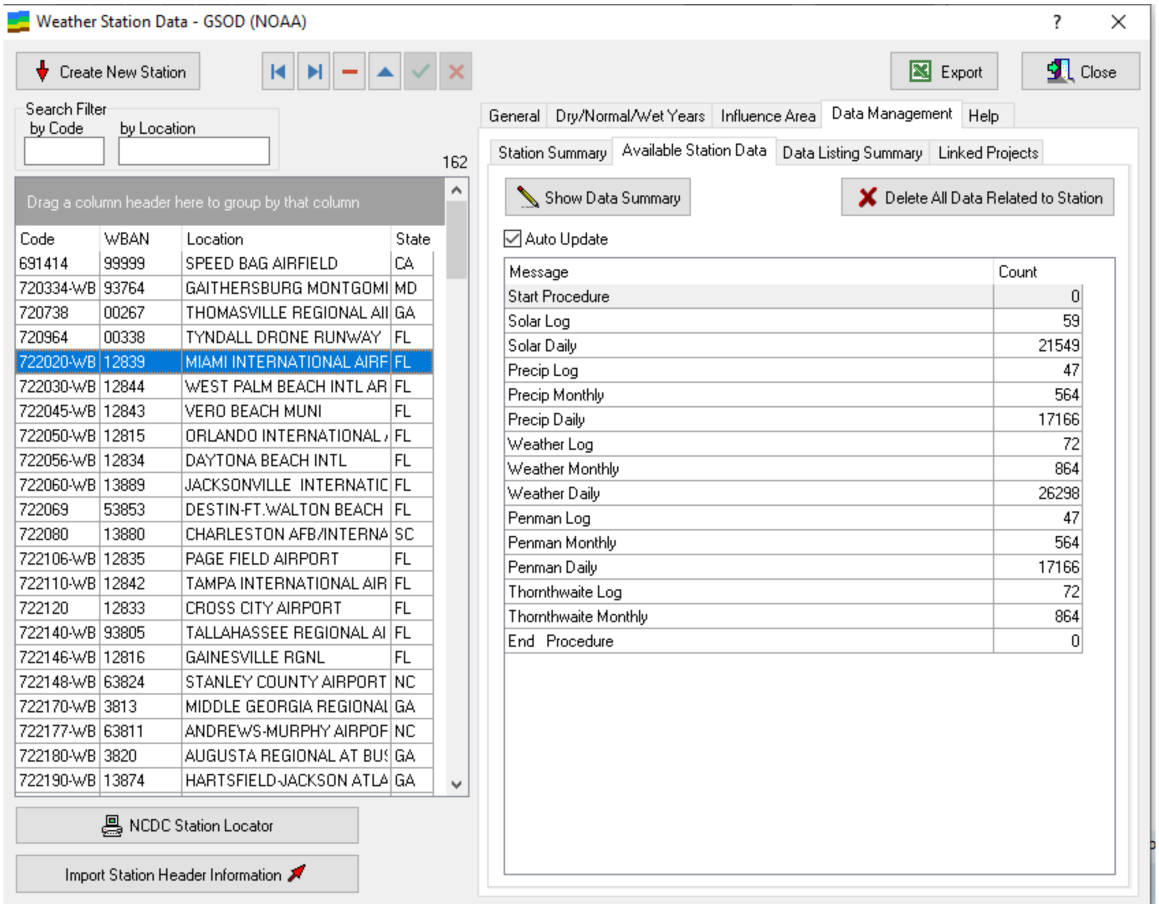


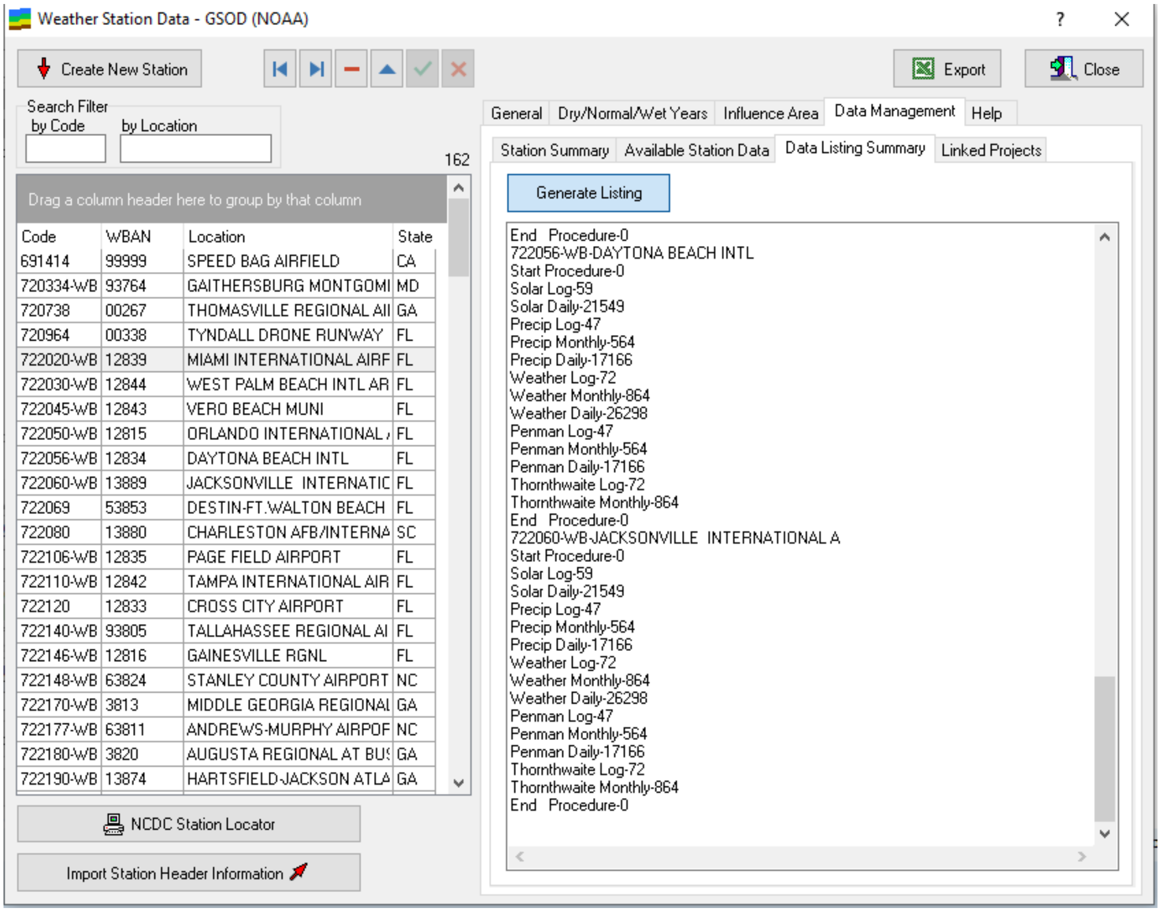
8.1.6 Data Management

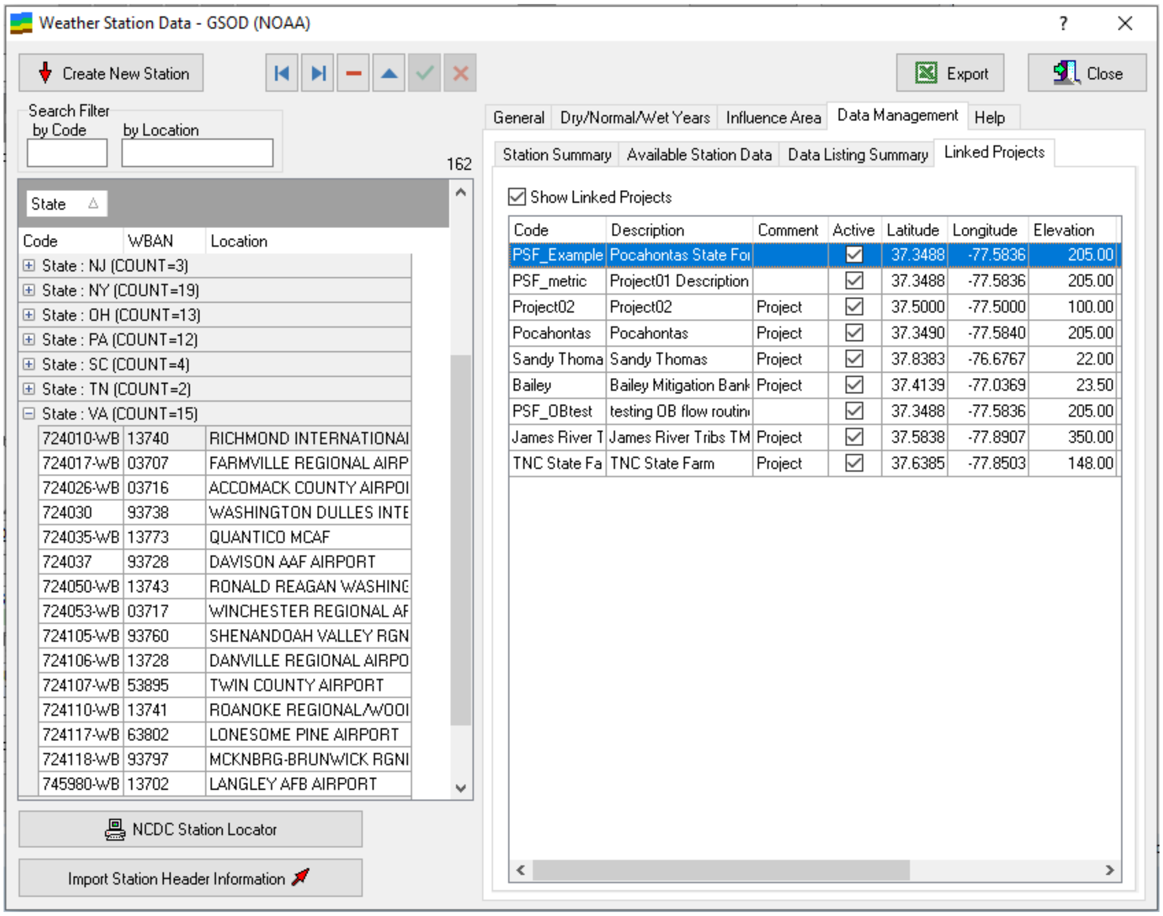
The Data Management tab is used to manage and show total usage of all data associated with a station. By selecting a station in the Stations tab and clicking Show Data Summary in the Available Data tab, the user can view and delete the usage records. Completely deleting a weather station record cannot be accomplished unless all usage records have been deleted first. Once usage data for the selected station has been deleted, the user can delete it from the list by selecting the station from the list, clicking , and then selecting OK from the prompt to confirm the deletion of the selected weather station record.

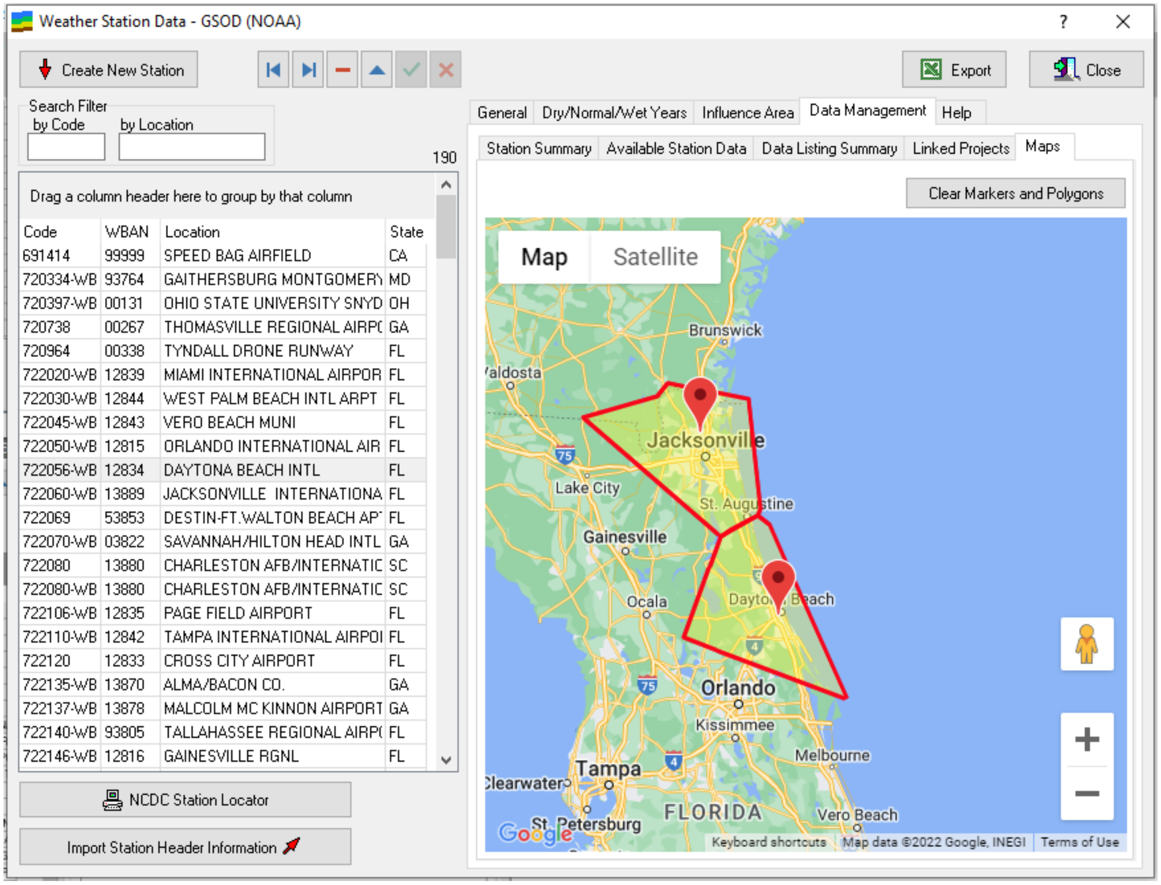
Data listings for all stations can be generated by selecting Generate Listing in the Data Listing for All Stations tab.




Weather Station Data - GSOD (NOAA)
Create New Station
Export
Close
Search Filter
by Code
by Location
162
General
Dry/Normal/Wet Years
Influence Area
Data Management
Help
Station Summary
Available Station Data
Data Listing Summary
Linked Projects
Show Data Summary
Delete All Data Related to Station
Auto Update
Drag a column header here to group by that column
Code WBAN Location State
691414 99999 SPEED BAG AIRFIELD CA
720334-WB 93764 GAITHERSBURG MONTGOMI MD
720738 00267 THOMASVILLE REGIONAL AII GA
720964 00338 TYNDALL DRONE RUNWAY FL
722020-WB 12839 MIAMI INTERNATIONAL AIRF FL
722030-WB 12844 WEST PALM BEACH INTL AR FL
722045-WB 12843 VERO BEACH MUNI FL
722050-WB 12815 ORLANDO INTERNATIONAL / FL
722056-WB 12834 DAYTONA BEACH INTL FL
722060-WB 13889 JACKSONVILLE INTERNATIC FL
722069 53853 DESTIN-FT.WALTON BEACH FL
722080 13880 CHARLESTON AFB/INTERNA SC
722106-WB 12835 PAGE FIELD AIRPORT FL
722110-WB 12842 TAMPA INTERNATIONAL AIR FL
722120 12833 CROSS CITY AIRPORT FL
722140-WB 93805 TALLAHASSEE REGIONAL AI FL
722146-WB 12816 GAINESVILLE RGNL FL
722148-WB 63824 STANLEY COUNTY AIRPORT NC
722170-WB 3813 MIDDLE GEORGIA REGIONAI GA
722177-WB 63811 ANDREWS-MURPHY AIRPOF NC
722180-WB 3820 AUGUSTA REGIONAL AT BU! GA
722190-WB 13874 HARTSFIELD-JACKSON ATLA GA
Message Count
Start Procedure 0
Solar Log 59
Solar Daily 21549
Precip Log 47
Precip Monthly 564
Precip Daily 17166
Weather Log 72
Weather Monthly 864
Weather Daily 26298
Penman Log 47
Penman Monthly 564
Penman Daily 17166
Thornthwaite Log 72
Thornthwaite Monthly 864
End Procedure 0
NCDC Station Locator
Import Station Header Information


Weather Station Data - GSOD (NOAA)
Create New Station
Export
Close
Search Filter
by Code
by Location
162
Drag a column header here to group by that column
Code WBAN Location State
691414 99999 SPEED BAG AIRFIELD CA
720334-WB 93764 GAITHERSBURG MONTGOMI MD
720738 00267 THOMASVILLE REGIONAL AII GA
720964 00338 TYNDALL DRONE RUNWAY FL
722020-WB 12839 MIAMI INTERNATIONAL AIRF FL
722030-WB 12844 WEST PALM BEACH INTL AR FL
722045-WB 12843 VERO BEACH MUNI FL
722050-WB 12815 ORLANDO INTERNATIONAL / FL
722056-WB 12834 DAYTONA BEACH INTL FL
722060-WB 13889 JACKSONVILLE INTERNATIC FL
722069 53853 DESTIN-FT.WALTON BEACH FL
722080 13880 CHARLESTON AFB/INTERNA SC
722106-WB 12835 PAGE FIELD AIRPORT FL
722110-WB 12842 TAMPA INTERNATIONAL AIR FL
722120 12833 CROSS CITY AIRPORT FL
722140-WB 93805 TALLAHASSEE REGIONAL AI FL
722146-WB 12816 GAINESVILLE RGNL FL
722148-WB 63824 STANLEY COUNTY AIRPORT NC
722170-WB 3813 MIDDLE GEORGIA REGIONAL GA
722177-WB 63811 ANDREWS-MURPHY AIRPOF NC
722180-WB 3820 AUGUSTA REGIONAL AT BU! GA
722190-WB 13874 HARTSFIELD-JACKSON ATLA GA
NCDC Station Locator
Import Station Header Information
General
Dry/Normal/Wet Years
Influence Area
Data Management
Help
Station Summary
Available Station Data
Data Listing Summary
Linked Projects
Generate Listing
End Procedure-0
722056-WB-DAYTONA BEACH INTL
Start Procedure-0
Solar Log-59
Solar Daily-21549
Precip Log-47
Precip Monthly-564
Precip Daily-17166
Weather Log-72
Weather Monthly-864
Weather Daily-26298
Penman Log-47
Penman Monthly-564
Penman Daily-17166
Thornthwaite Log-72
Thornthwaite Monthly-864
End Procedure-0
722060-WB-JACKSONVILLE INTERNATIONAL A
Start Procedure-0
Solar Log-59
Solar Daily-21549
Precip Log-47
Precip Monthly-564
Precip Daily-17166
Weather Log-72
Weather Monthly-864
Weather Daily-26298
Penman Log-47
Penman Monthly-564
Penman Daily-17166
Thornthwaite Log-72
Thornthwaite Monthly-864
End Procedure-0


Weather Station Data - GSOD (NOAA)
Create New Station
Export
Close
Search Filter
by Code
by Location
162
General
Dry/Normal/Wet Years
Influence Area
Data Management
Help
Station Summary
Available Station Data
Data Listing Summary
Linked Projects
Show Linked Projects
State
Code WBAN Location
State : NJ (COUNT=3)
State : NY (COUNT=19)
State : OH (COUNT=13)
State : PA (COUNT=12)
State : SC (COUNT=4)
State : TN (COUNT=2)
State : VA (COUNT=15)
724010-WB 13740 RICHMOND INTERNATIONAL
724017-WB 03707 FARMVILLE REGIONAL AIRP
724026-WB 03716 ACCOMACK COUNTY AIRPO
724030 93738 WASHINGTON DULLES INTE
724035-WB 13773 QUANTICO MCAF
724037 93728 DAVISON AAF AIRPORT
724050-WB 13743 RONALD REAGAN WASHING
724053-WB 03717 WINCHESTER REGIONAL AF
724105-WB 93760 SHENANDOAH VALLEY RGN
724106-WB 13728 DANVILLE REGIONAL AIRPO
724107-WB 53895 TWIN COUNTY AIRPORT
724110-WB 13741 ROANOKE REGIONAL/WOO
724117-WB 63802 LONESOME PINE AIRPORT
724118-WB 93797 MCKNBRG-BRUNWICK RGN
745980-WB 13702 LANGLEY AFB AIRPORT
Code Description Comment Active Latitude Longitude Elevation
PSF_Example Pocahontas State For 37.3488 -77.5836 205.00
PSF_metric Project01 Description 37.3488 -77.5836 205.00
Project02 Project02 Project 37.5000 -77.5000 100.00
Pocahontas Pocahontas Project 37.3490 -77.5840 205.00
Sandy Thoma Sandy Thomas Project 37.8383 -76.6767 22.00
Bailey Bailey Mitigation Bank Project 37.4139 -77.0369 23.50
PSF_OBtest testing OB flow routin 37.3488 -77.5836 205.00
James River T James River Tribs TM Project 37.5838 -77.8907 350.00
TNC State Fa TNC State Farm Project 37.6385 -77.8503 148.00
NCDC Station Locator
Import Station Header Information

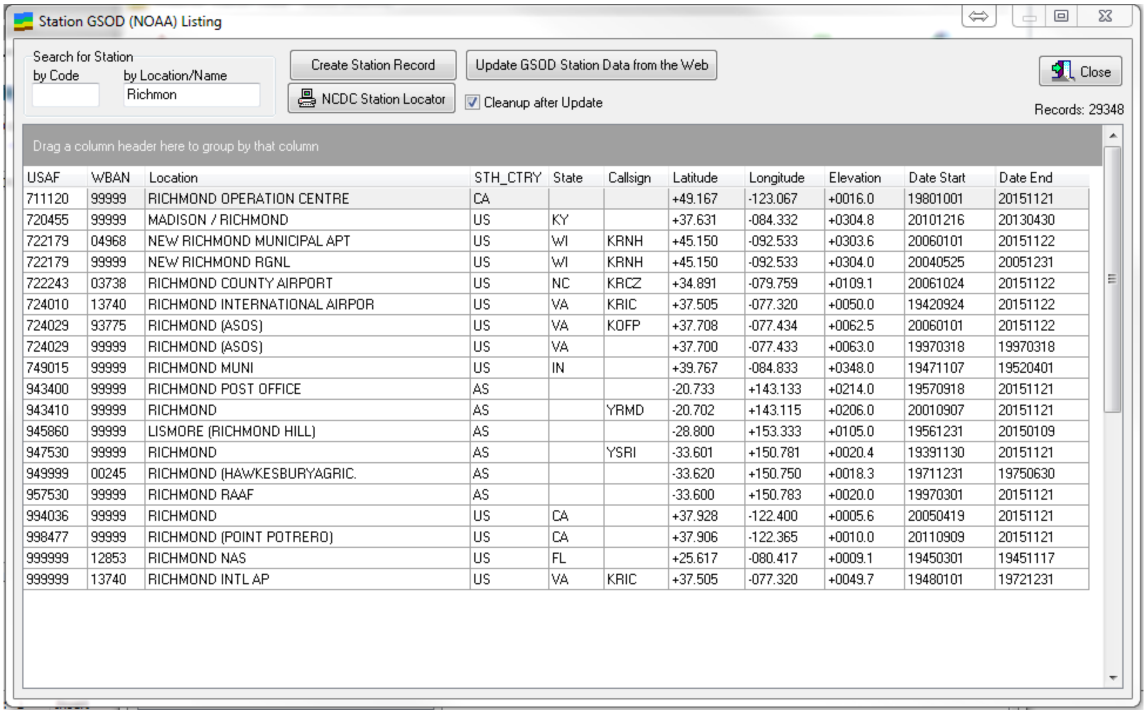


8.1.7 List of GSOD Stations

This form should display station header information. If station header information is not displayed, click Update GSOD Station Data from the Web to populate the database with available station header information. Stations can be grouped by state, latitude, longitude, etc. by dragging column labels into the gray area above the table.

The list of stations is searchable by Code and by Location/Name. When typing up a name or code the program will immediately start filtering the records that match the criteria.

Select the desired station from the list and click Create Station Record to create a record for the station in the weather station database. Select Yes to insert the currently selected station into the Stations Table and click OK when prompted to confirm you would like to create a record for the selected station, then close the Station Listing window.



USAF	WBAN	Location	STH_CTRY	State	Callsign	Latitude	Longitude	Elevation	Date Start	Date End
711120	99999	RICHMOND OPERATION CENTRE	CA			+49.167	-123.067	+0016.0	19801001	20151121
720455	99999	MADISON / RICHMOND	US	KY		+37.631	-084.332	+0304.8	20101216	20130430
722179	04968	NEW RICHMOND MUNICIPAL APT	US	WI	KRNH	+45.150	-092.533	+0303.6	20060101	20151122
722179	99999	NEW RICHMOND RGNL	US	WI	KRNH	+45.150	-092.533	+0304.0	20040525	20051231
722243	03738	RICHMOND COUNTY AIRPORT	US	NC	KRCZ	+34.891	-079.759	+0109.1	20061024	20151122
724010	13740	RICHMOND INTERNATIONAL AIRPOR	US	VA	KRIC	+37.505	-077.320	+0050.0	19420924	20151122
724029	93775	RICHMOND (ASOS)	US	VA	KOFP	+37.708	-077.434	+0062.5	20060101	20151122
724029	99999	RICHMOND (ASOS)	US	VA		+37.700	-077.433	+0063.0	19970318	19970318
749015	99999	RICHMOND MUNI	US	IN		+39.767	-084.833	+0348.0	19471107	19520401
943400	99999	RICHMOND POST OFFICE	AS			-20.733	+143.133	+0214.0	19570918	20151121
943410	99999	RICHMOND	AS		YRMD	-20.702	+143.115	+0206.0	20010907	20151121
945860	99999	LISMORE (RICHMOND HILL)	AS			-28.800	+153.333	+0105.0	19561231	20150109
947530	99999	RICHMOND	AS		YSRI	-33.601	+150.781	+0020.4	19391130	20151121
949999	00245	RICHMOND (HAWKESBURYAGRIC.	AS			-33.620	+150.750	+0018.3	19711231	19750630
957530	99999	RICHMOND RAAF	AS			-33.600	+150.783	+0020.0	19970301	20151121
994036	99999	RICHMOND	US	CA		+37.928	-122.400	+0005.6	20050419	20151121
998477	99999	RICHMOND (POINT POTRERO)	US	CA		+37.906	-122.365	+0010.0	20110909	20151121
999999	12853	RICHMOND NAS	US	FL		+25.617	-080.417	+0009.1	19450301	19451117
999999	13740	RICHMOND INTL AP	US	VA	KRIC	+37.505	-077.320	+0049.7	19480101	19721231

A list of all 138 stations available in the database is shown below. The table is sorted alphabeticall by state and then mostly by code.

ID	Code	WBAN	State	Latitude	Longitude	Location
1	724088-WB	13707	DE	39.1300	-75.4700	DOVER AFB AIRPORT
2	724093-WB	13764	DE	38.6900	-75.3600	SUSSEX COUNTY AIRPORT
3	722020-WB	12839	FL	25.7900	-80.3200	MIAMI INTERNATIONAL AIRPORT
4	722045-WB	12843	FL	27.6500	-80.2400	VERO BEACH MUNI
5	722050-WB	12815	FL	28.4300	-81.3200	ORLANDO INTERNATIONAL AIRPORT
6	722056-WB	12834	FL	29.1800	-81.0500	DAYTONA BEACH INTL
7	722060-WB	13889	FL	30.5000	-81.6900	JACKSONVILLE INTERNATIONAL A
8	722106-WB	12835	FL	26.5800	-81.8600	PAGE FIELD AIRPORT
9	722110-WB	12842	FL	27.9600	-82.5400	TAMPA INTERNATIONAL AIRPORT
10	722140-WB	93805	FL	30.3900	-84.3500	TALLAHASSEE REGIONAL AIRPORT
11	722146-WB	12816	FL	29.6900	-82.2800	GAINESVILLE RGNL
12	722200-WB	12832	FL	29.7300	-85.0300	APALACHICOLA MUNI AIRPORT
13	722210-WB	13858	FL	30.4800	-86.5200	EGLIN AFB AIRPORT
14	722030-WB	12844	FL	26.6800	-80.1000	WEST PALM BEACH INTL ARPT
15	724320-WB	93817	IN	38.0400	-87.5200	EVANSVILLE REGIONAL AIRPORT
16	724356-WB	53866	IN	39.5800	-85.8000	SHELBYVILLE MINUCIPAL ARPT
17	724370-WB	93823	IN	39.4500	-87.3000	TERRE HAUTE HULMAN REGIONAL A
18	724375-WB	03893	IN	39.1300	-86.6200	MONROE COUNTY AIRPORT
19	724380-WB	93819	IN	39.7300	-86.2800	INDIANAPOLIS INTERNATIONAL AI
20	724386-WB	14835	IN	40.4100	-86.9400	PURDUE UNIVERSITY AIRPORT
21	725327-WB	04846	IN	41.4500	-87.0100	PORTER COUNTY MUNICIPAL AIRPO
22	725330-WB	14827	IN	40.9700	-85.2100	FORT WAYNE INTERNATIONAL AIRP

23	725335-WB	99999	IN	40.6500	-86.1500	GRISSOM ARB
24	725336-WB	99999	IN	40.2300	-85.3800	DELAWARE CO JOHNSON
25	725350-WB	14848	IN	41.7100	-86.3200	SOUTH BEND REGIONAL AIRPORT
26	724190-WB	03889	KY	37.5900	-83.3100	JULIAN CARROLL AIRPORT
27	724210-WB	93814	KY	39.0400	-84.6700	CINCINNATI/NORTHERN KENTUCKY
28	724220-WB	93820	KY	38.0400	-84.6100	BLUE GRASS AIRPORT
29	724230-WB	93821	KY	38.1800	-85.7400	LOUISVILLE INTL-STANDIFORD F
30	720334-WB	93764	MD	39.1700	-77.1700	GAITHERSBURG MONTGOMERY COUNT
31	724040-WB	13721	MD	38.3000	-76.4200	NAVAL AIR STATION
32	724045-WB	93720	MD	38.3400	-75.5100	SALISBURY OCEAN CIT
33	724060-WB	93721	MD	39.1700	-76.6800	BALTIMORE-WASHINGTON INTL AIR
34	724066-WB	99999	MD	39.7000	-77.7200	HAGERSTOWN RGNL RIC
35	745940-WB	13705	MD	38.8200	-76.8700	ANDREWS AIR FORCE BASE AIRPOR
36	999999-WB	03755	MD	39.5800	-79.3400	GARRETT COUNTY AIRPORT
37	722148-WB	63824	NC	35.4200	-80.1500	STANLEY COUNTY AIRPORT
38	722177-WB	63811	NC	35.1900	-83.8600	ANDREWS-MURPHY AIRPORT
39	722198-WB	63819	NC	36.2000	-81.6500	BOONE
40	723010-WB	03810	NC	35.7400	-81.3800	HICKORY REGIONAL AIRPORT
41	723030-WB	13714	NC	35.1700	-79.0100	POPE AFB AIRPORT
42	723060-WB	13722	NC	35.8900	-78.7800	RALEIGH-DURHAM INTERNATIONAL
43	723066-WB	13713	NC	35.3400	-77.9600	SEYMOUR-JOHNSON AFB AIRPORT
44	723068-WB	99999	NC	35.8500	-77.8800	ROCKY MOUNT WILSON
45	723090-WB	13754	NC	34.9000	-76.8800	CHERRY POINT MCAS
46	723140-WB	13881	NC	35.2200	-80.9600	CHARLOTTE/DOUGLAS INTERNATION
47	723150-WB	03812	NC	35.4300	-82.5400	ASHEVILLE REGIONAL AIRPORT
48	723170-WB	13723	NC	36.1000	-79.9400	PIEDMONT TRIAD INTERNATIONAL
49	723177-WB	63807	NC	36.4600	-80.5500	MOUNT AIRY/SURRY CO ARPT
50	746925-WB	03741	NC	35.5700	-77.0500	WARREN FIELD AIRPORT
51	746943-WB	13786	NC	36.2600	-76.1800	ELIZABETH CITY CGAS
52	999999-WB	13748	NC	34.2700	-77.9000	WILMINGTON
53	724070-WB	93730	NJ	39.4500	-74.5700	ATLANTIC CITY INTERNATIONAL A
54	724096-WB	14706	NJ	40.0200	-74.6000	MCGUIRE AFB AIRPORT
55	725020-WB	14734	NJ	40.6800	-74.1700	NEWARK LIBERTY INTERNATIONAL
56	725145-WB	54746	NY	41.7000	-74.7900	SULLIVAN COUNTY INTL ARPT
57	725150-WB	04725	NY	42.2100	-75.9800	GREATER BINGHAMTON/E A LINK F
58	725155-WB	99999	NY	42.4900	-76.4700	ITHACA TOMPKINS RGNL
59	725156-WB	14748	NY	42.1600	-76.8900	ELMIRA/CORNING RGNL ARPT
60	725180-WB	14735	NY	42.7400	-73.8100	ALBANY INTERNATIONAL AIRPORT
61	725185-WB	14750	NY	43.3500	-73.6200	FLOYD BENNETT MEM
62	725190-WB	14771	NY	43.1100	-76.1000	SYRACUSE HANCOCK INTERNATIONA
63	725196-WB	14717	NY	43.2300	-75.4100	GRIFFISS AIRPARK
64	725280-WB	14733	NY	42.9400	-78.7400	BUFFALO NIAGARA INTERNATIONAL
65	725290-WB	14768	NY	43.1200	-77.6800	GREATER ROCHESTER INTERNATION
66	726221-WB	94725	NY	44.9400	-74.8500	MASSENA AP
67	726227-WB	94790	NY	43.9900	-76.0200	WATERTOWN INTL AIRPORT

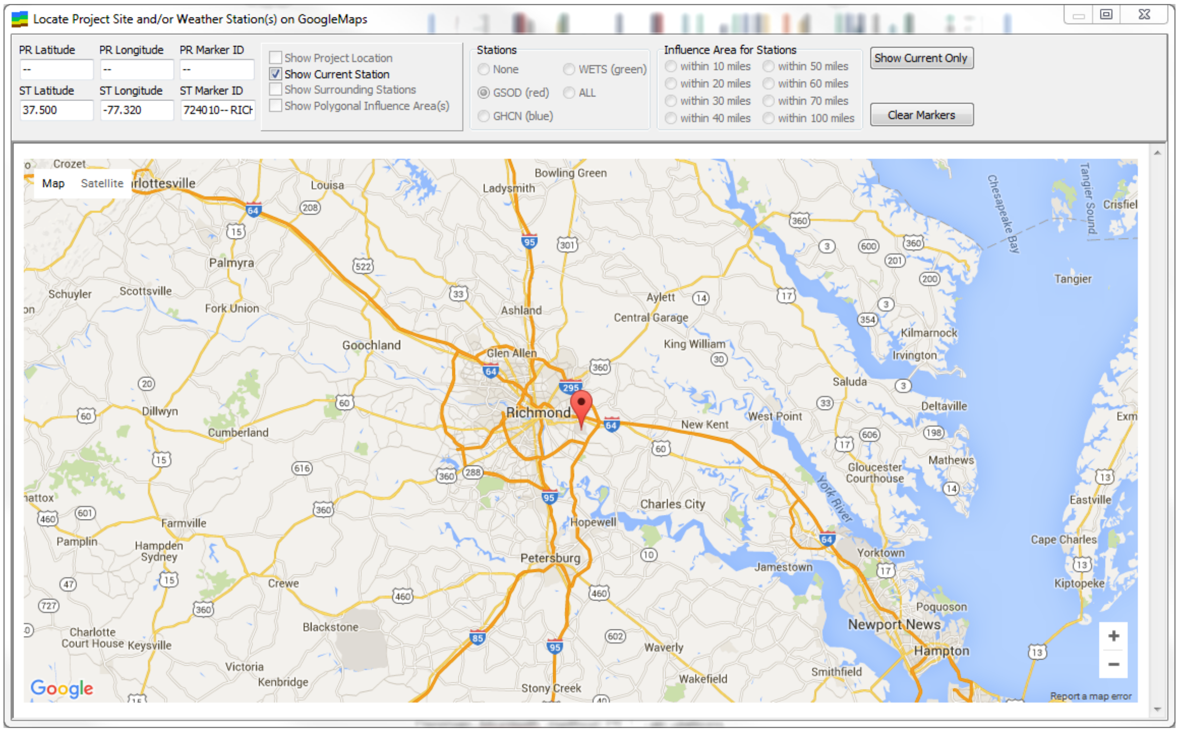
68	726228-WB	94740	NY	44.3800	-74.2100	ADIRONDACK REGIONAL ARPT
69	724280-WB	14821	OH	39.9900	-82.8800	PORT COLUMBUS INTERNATIONAL A
70	724286-WB	93824	OH	39.9400	-81.8900	ZANESVILLE MUNICIPAL ARPT
71	720397-WB	00131	OH	40.0800	-83.0800	OHIO STATE UNIVERSITY SNYDER
72	725240-WB	14820	OH	41.4000	-81.8500	CLEVELAND-HOPKINS INTERNATION
73	725246-WB	14891	OH	40.8200	-82.5200	MANSFIELD LAHM RGNL
74	725250-WB	14852	OH	41.2500	-80.6700	YOUNGSTOWN-WARREN REGIONAL AI
75	725256-WB	99999	OH	41.7800	-80.7000	ASHTABULA CO
76	725360-WB	94830	OH	41.5900	-83.8000	TOLEDO EXPRESS AIRPORT
77	725366-WB	14825	OH	41.0100	-83.6700	FINDLAY AIRPORT
78	745700-WB	13840	OH	39.8300	-84.0500	WRIGHT-PATTERSON AFB AIRPORT
79	999999-WB	14895	OH	40.9200	-81.4300	AKRON AKRON-CANTON AIRPORT
80	724080-WB	13739	PA	39.8700	-75.2300	PHILADELPHIA INTERNATIONAL AI
81	725110-WB	14751	PA	40.2200	-76.8500	HARRISBURG CAPITAL CITY ARPT
82	725125-WB	04787	PA	41.1800	-78.9000	DU BOIS-JEFFERSON CO ARPT
83	725126-WB	14736	PA	40.3000	-78.3200	ALTOONA-BLAIR COUNTY ARPT
84	725127-WB	04726	PA	40.3200	-78.8300	J MURTHA JTWN-CMBRA CO APT
85	725130-WB	14777	PA	41.3300	-75.7300	WILKES-BARRE/SCRANTON INTL AI
86	725140-WB	14778	PA	41.2400	-76.9200	WILLIAMSPORT REGIONAL AIRPORT
87	725170-WB	14737	PA	40.6500	-75.4500	LEHIGH VALLEY INTERNATIONAL A
88	725200-WB	94823	PA	40.4900	-80.2100	PITTSBURGH INTERNATIONAL AIRP
89	725260-WB	14860	PA	42.0800	-80.1800	ERIE INTL/T. RIDGE FIELD AIRP
90	725266-WB	04751	PA	41.8000	-78.6300	BRADFORD REGIONAL AIRPORT
91	723181-WB	13877	TN	36.4700	-82.4000	BRISTOL TRI CITY AIRPORT
92	723240-WB	13882	TN	35.0300	-85.2000	LOVELL FIELD AIRPORT
93	724010-WB	13740	VA	37.5000	-77.3200	RICHMOND INTERNATIONAL AIRPOR
94	724017-WB	03707	VA	37.3500	-78.4300	FARMVILLE REGIONAL AIRPORT
95	724026-WB	03716	VA	37.6400	-75.7600	ACCOMACK COUNTY AIRPORT
96	724030-WB	93738	VA	38.9400	-77.4600	WASHINGTON DULLES INTERNATION
97	724035-WB	13773	VA	38.5000	-77.3000	QUANTICO MCAF
98	724050-WB	13743	VA	38.8400	-77.0300	RONALD REAGAN WASHINGTON NATL
99	724053-WB	03717	VA	39.1400	-78.1400	WINCHESTER REGIONAL ARPT
100	724105-WB	93760	VA	38.2600	-78.8900	SHENANDOAH VALLEY RGNL ART
101	724106-WB	13728	VA	36.5700	-79.3300	DANVILLE REGIONAL AIRPORT
102	724107-WB	53895	VA	36.7600	-80.8200	TWIN COUNTY AIRPORT
103	724110-WB	13741	VA	37.3100	-79.9700	ROANOKE REGIONAL/WOODRUM FIEL
104	724117-WB	63802	VA	36.9800	-82.5300	LONESOME PINE AIRPORT
105	724118-WB	93797	VA	36.6800	-78.0500	MCKNBRG-BRUNWICK RGNL ARPT
106	745980-WB	13702	VA	37.0800	-76.3600	LANGLEY AFB AIRPORT
107	726170-WB	14742	VT	44.4700	-73.1500	BURLINGTON INTERNATIONAL AIRP
108	724120-WB	03872	WV	37.7800	-81.1200	RALEIGH COUNTY MEMORIAL AIRPO
109	724140-WB	13866	WV	38.3800	-81.5900	YEAGER AIRPORT
110	724170-WB	13729	WV	38.8800	-79.8500	ELKINS-RAND CO-J.RAND FIELD A
111	724176-WB	13736	WV	39.6400	-79.9200	MGTN RGNL-W L B HART FD AP
112	724177-WB	13734	WV	39.4000	-77.9800	ETRN WV RGNL/SHPHERD FD AP

113	724250-WB	03860	WV	38.3700	-82.5600	TRI-STATE/M.J.FERGUSON FIELD
114	724273-WB	03804	WV	39.2000	-81.2700	MID-OHIO VALLEY REGIONAL AIRP
115	722070-WB	03822	GA	32.1300	-81.2100	SAVANNAH/HILTON HEAD INTL AIR
116	722080-WB	13880	SC	32.9000	-80.0400	CHARLESTON AFB/INTERNATIONAL
117	722135-WB	13870	GA	31.5400	-82.5100	ALMA/BACON CO.
118	722137-WB	13878	GA	31.1500	-81.3900	MALCOLM MC KINNON AIRPORT
119	722160-WB	13869	GA	31.5400	-84.1900	SW GEORGIA REGIONAL ARPT
120	722166-WB	93845	GA	30.7800	-83.2800	VALDOSTA REGIONAL AIRPORT
121	722170-WB	03813	GA	32.6900	-83.6500	MIDDLE GEORGIA REGIONAL AIRPO
122	722180-WB	03820	GA	33.3600	-81.9600	AUGUSTA REGIONAL AT BUSH FIEL
123	722190-WB	13874	GA	33.6300	-84.4400	HARTSFIELD-JACKSON ATLANTA IN
124	722255-WB	93842	GA	32.5200	-84.9400	COLUMBUS METRO AIRPORT
125	723100-WB	13883	SC	33.9400	-81.1200	COLUMBIA METROPOLITAN AIRPORT
126	723106-WB	13744	SC	34.1900	-79.7200	FLORENCE REGIONAL AIRPORT
127	723110-WB	13873	GA	33.9500	-83.3300	ATHENS/BEN EPPS AIRPORT
128	723120-WB	03870	SC	34.8800	-82.2200	GREENVILLE-SPARTANBURG INTL A
129	723125-WB	93846	SC	34.5000	-82.7100	ANDERSON RGNL
130	747910-WB	13717	SC	33.6800	-78.9300	MYRTLE BEACH INTL AIRPORT
131	744910-WB	14703	MA	42.2000	-72.5330	WESTOVER AFB/METROPOLITAN AIR
132	725080-WB	14740	CT	41.9380	-72.6820	BRADLEY INTERNATIONAL AIRPORT
133	725070-WB	14765	RI	41.7230	-71.4330	THEODORE F GREEN STATE AIRPOR
134	722350-WB	03940	MS	32.3210	-90.0780	JACKSON INTERNATIONAL AIRPORT
135	725090-WB	14739	MA	42.3610	-71.0100	GEN E L LOGAN INTERNATIONAL A
136	726580-WB	14922	MN	44.8830	-93.2290	MINNEAPOLIS-ST PAUL INTERNATI
137	726050-WB	14745	NH	43.2050	-71.5030	CONCORD MUNICIPAL AIRPORT
138	726145-WB	94705	VT	44.2040	-72.5620	EDWARD F KNAPP STATE ARPT

8.1.7.1 GSOD Map

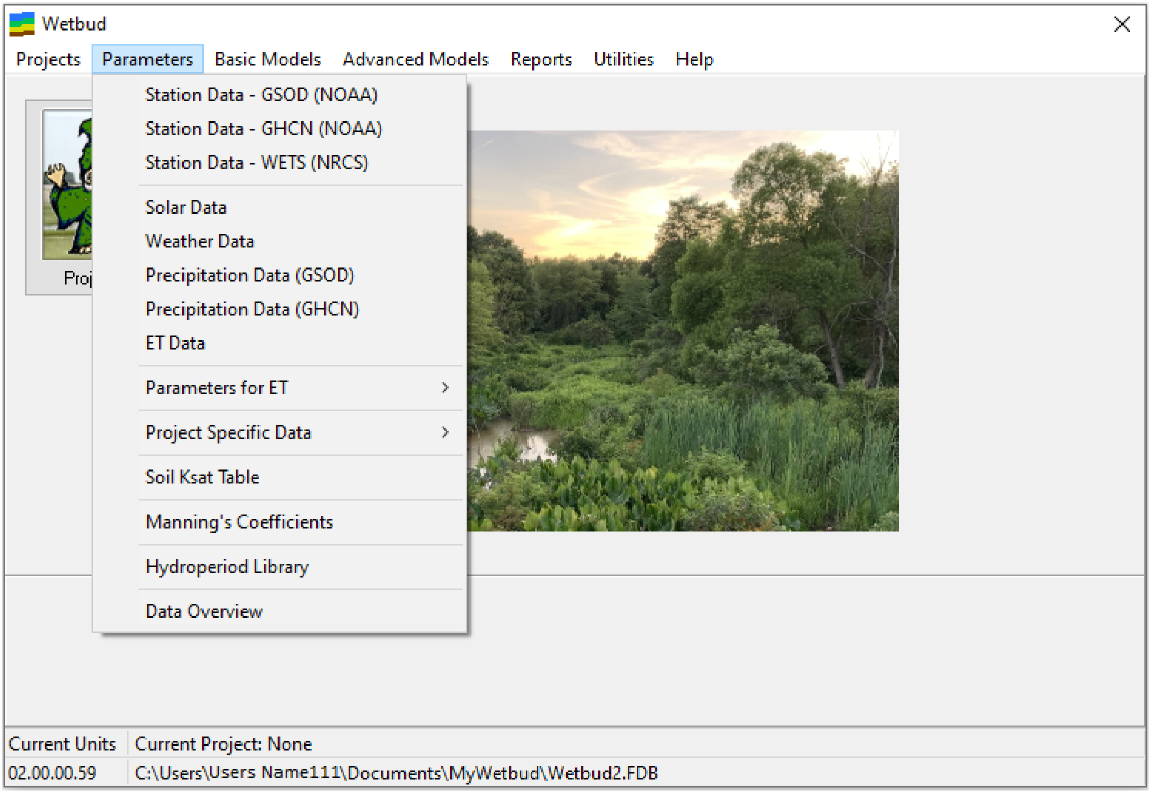
You can use 

to view the location of the GSOD weather Station. GSOD stations are marked with red pins.



8.2 Station Data - GHCN

As stated previously, GHCN precipitation data can be used to supplement GSOD data sets. This section describes how to develop GHCN station data sets for use in Wetbud.



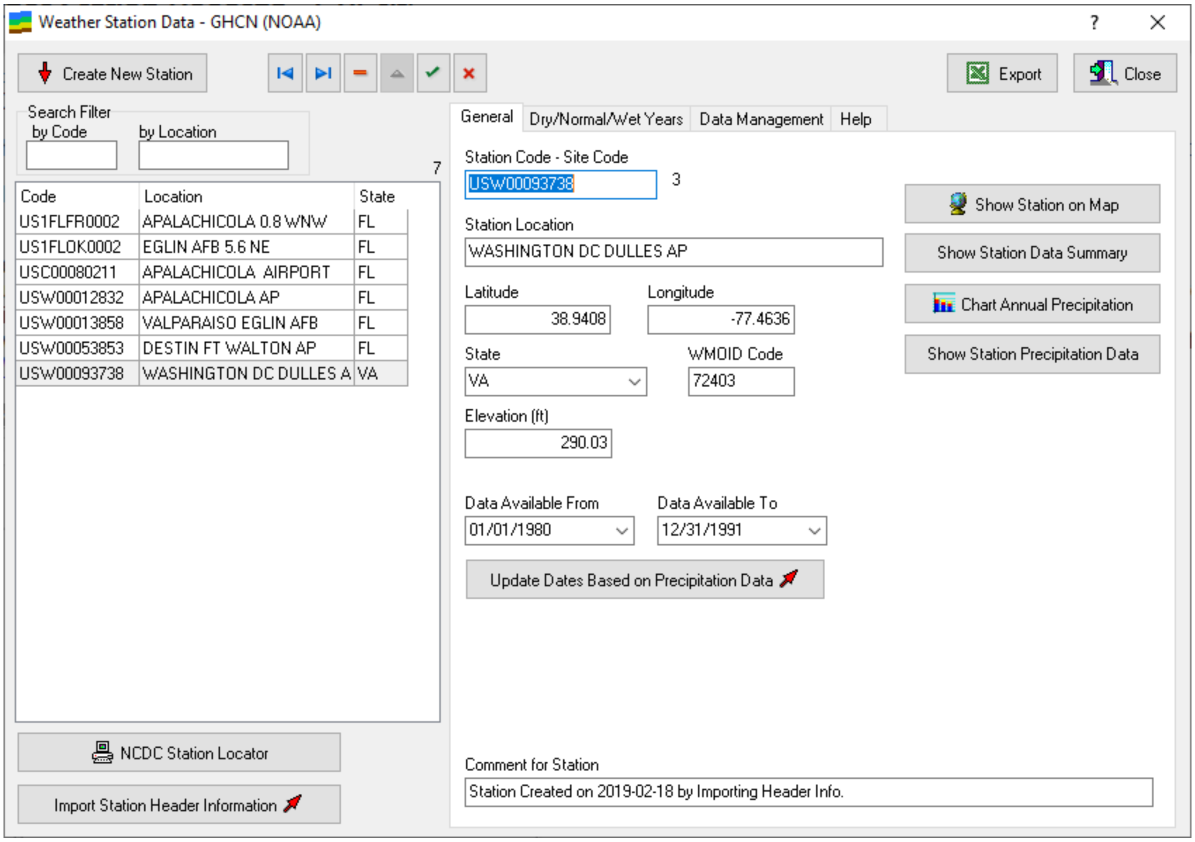
8.2.1 Create Custom Weather Station Record - GHCN

To create a custom station record:

1. First select Station Data – GHCN (NOAA) from the Parameters drop-down menu in the Wetbud home screen.
2. Next, in the General tab of the weather station data window click 

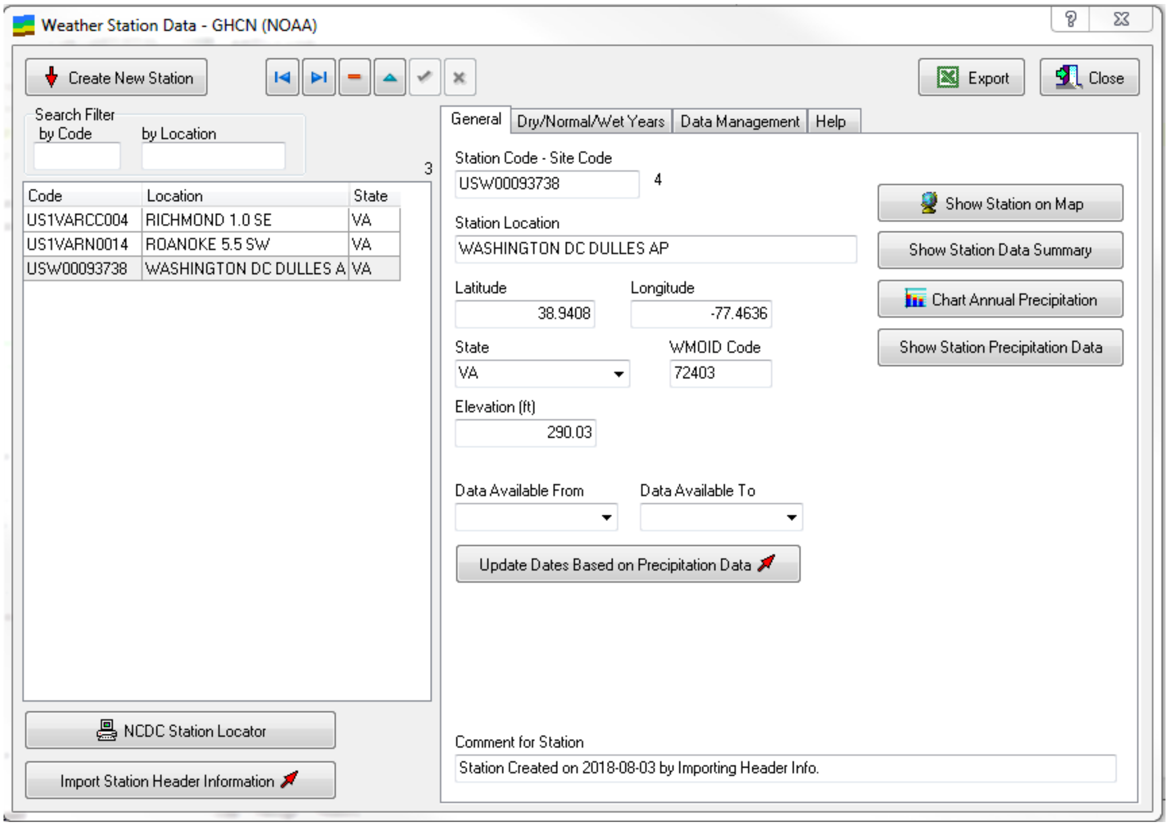
. The box under Station Code - Site Code is initialized with the text 'GHCNXX' with XX representing two digits. Delete this text and replace it with a new code (up to 11 digits) for your station. Enter the latitude, longitude, state, and location. Click Save . You will now see a code and location that have been generated for your station in the list on the left side of the window.
3. Verify your Station coordinates have been entered properly by clicking 

, which displays your station on a Google Maps interface. In this window you can display NOAA or WETS stations (or both) within a radius of 10-50 miles of your Project latitude and longitude. This map will display all WETS stations, however, only those NOAA stations for which records have been created in the weather station set will be visible. After verifying your Station coordinates, close the map window.
4. All precipitation data to be associated with this station must now be manually imported or copied from an existing station record before using this as a reference station in a Basic Scenario water budget analysis. See Precipitation Data for information about importing these data.



8.2.2 General

The header information for GHCN NOAA stations is listed in the General tab. The header information for GHCN weather stations includes the Station Code, Station Location, Latitude, Longitude, State, WMOID Code, and Elevation.



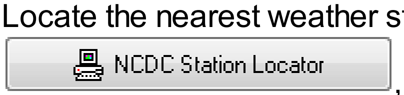
For more details see:

- Import Station Header Information on how to import Station Headers from the Web
- Create a Custom Weather Station on how to manually create a custom weather station

8.2.2.1 Import Station Header Information

The header information includes the 11-digit station code, location, latitude, longitude, and state.

To import station header information for a NOAA station directly from the web and into the station database, use the following procedure. Users who already know the location and station ID of the station for which they will create a record can skip to step 3:

1. Locate the nearest weather station to your Project site by clicking 

, which will direct you to the NOAA Daily Observation Data Map. Select GHCN Daily from the Layers list. Next, use the map tools to locate and identify the weather station nearest to your Project site. After identifying the nearest NOAA weather station, record the station code and location name (5-digit WMO ID for GSOD or 11-digit code for GHCN) and close the Interactive Map Application.

2. In the General tab of the Weather Station Data window, click **Import Station Header Information**, which will display a separate window of the database of all weather station header information. If station header information is not displayed, click **Update GHCN Station Data from the Web** to populate the database with available station header information. Stations can be grouped by state, latitude, longitude, etc. by dragging column labels into the gray area above the table.
3. Select the desired station from the list and click **Create Station Record** to create a record for the station in the weather station database. Select Yes to insert the currently selected station into the Stations Table and click OK when prompted to confirm you would like to create a record for the selected station, then close the Station Listing window. Once a record for the weather station exists in the weather station database, the user can proceed to automatically download or manually import available data for that station.

8.2.2.2 Chart Annual Precipitation

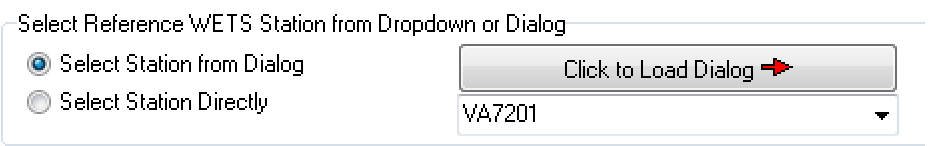
To view a chart of annual precipitation data for this station, click **Chart Annual Precip**.

8.2.2.3 Show Station Precipitation data

See Parameters: Precipitation Data for GHCN

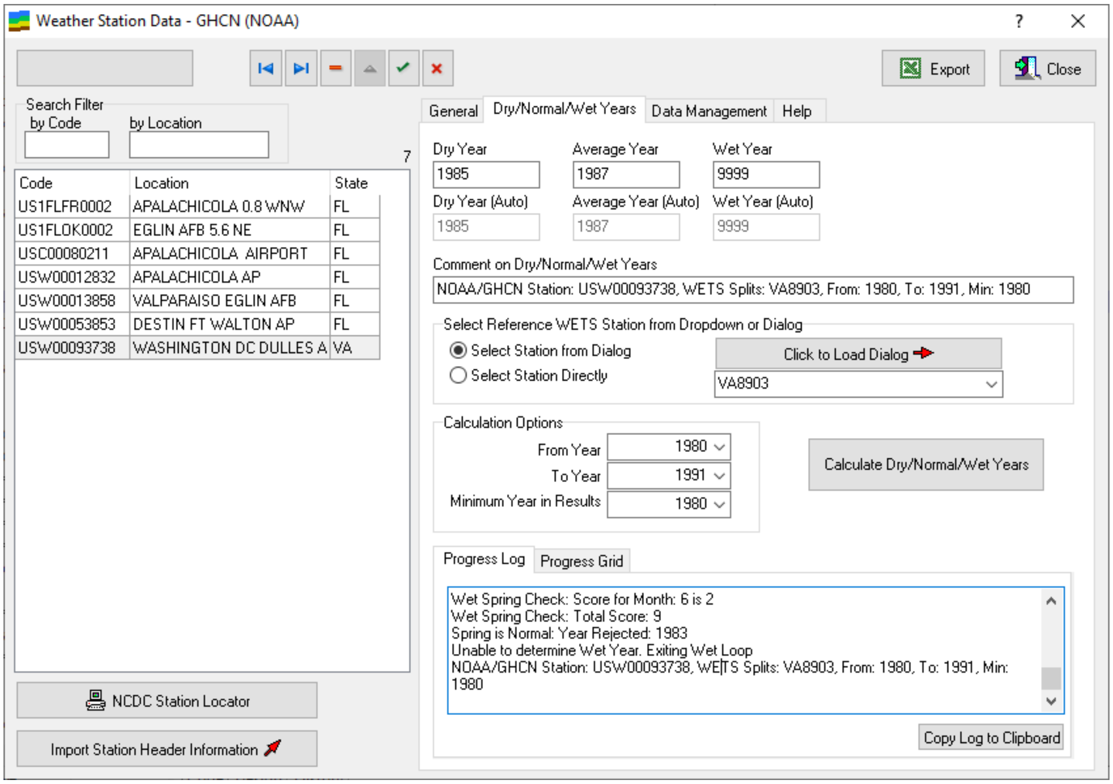
8.2.3 Dry/Normal/Wet Years

The Dry/Normal/Wet Years tab is used to calculate Dry (D), Normal (N) and Wet (W) years for the selected station. The DNW years calculated in this tab can be used to compare the DNW years calculated for the corresponding GSOD station(s). To calculate DNW years for the selected station, first select a reference WETS station using one of the two options provided:



The detailed steps for calculating the DNW years are:

1. Select a station from Dialog by clicking **Click to Load Dialog**, which will display a list of WETS stations within a radius of 10-40 miles, based on your selection. See Nearby WETS Stations.
2. Assign the reference WETS station. Select the WETS station in the list and then click **Select WETS Station for Reference**
3. Close the window and continue to the next step.



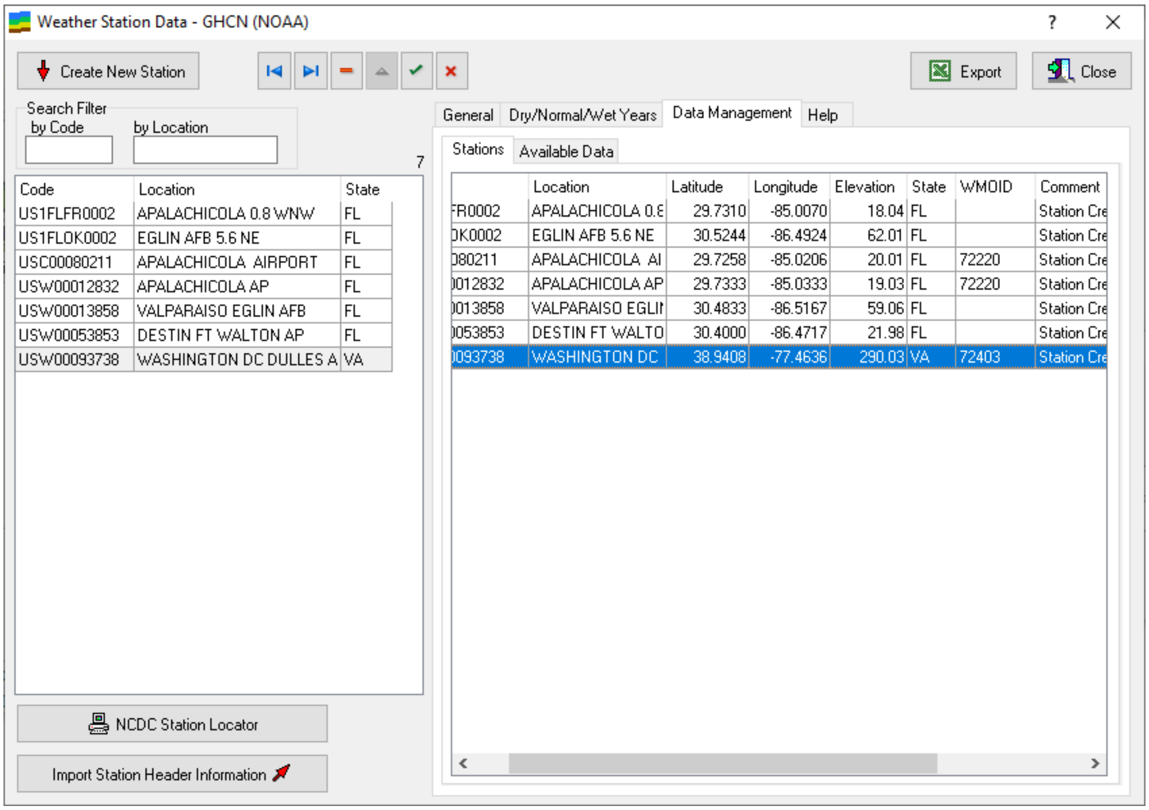
4. Select the range of years you wish to include in the From Year, To Year, and Minimum Year (under Calculation Options) in the Results drop-down lists.
5. Click Calculate Dry/Normal/Wet Years.
6. The DNW years calculated from the selected range of years will appear in their respective boxes.
7. To export an Excel file of the DNW calculations as performed by Wetbud (shown in the Progress Log), click Export, then name and save the file.
8. Click Save to save the DNW years calculated for this station.
9. To view a chart of annual precipitation data for this station, click Chart Annual Precipitation in the General tab.

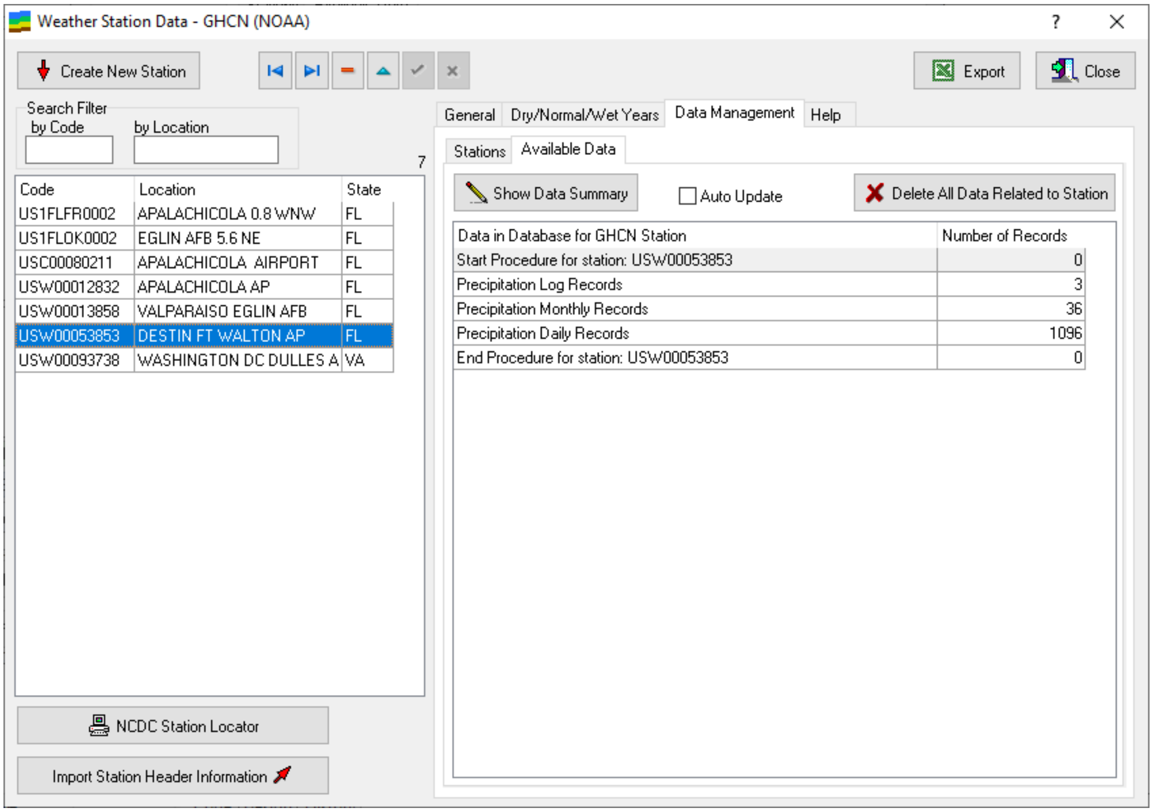
Note 1: Wetbud calculates DNW years based on the procedure developed by McLeod (2013). This procedure was designed to determine if years classified as dry, normal or wet based on total annual precipitation also have a dry, normal, or wet spring, respectively. For example, a year that is classified as wet based on total annual precipitation that does not meet the wet spring criteria is rejected as a ‘wet’ year and another year must be selected as ‘wet’. For more details, see Dry/Normal/Wet Year Calculations.

Note 2: As shown in the above figure, Wetbud will provide feedback on the progress of the WETS analysis. In this example there was not enough data to determine DNW years.

8.2.4 Data Management

The Data Management tab is used to display a summary of the station data (Stations) and a summary of the available data for the currently selected weather station as shown in the figures below.

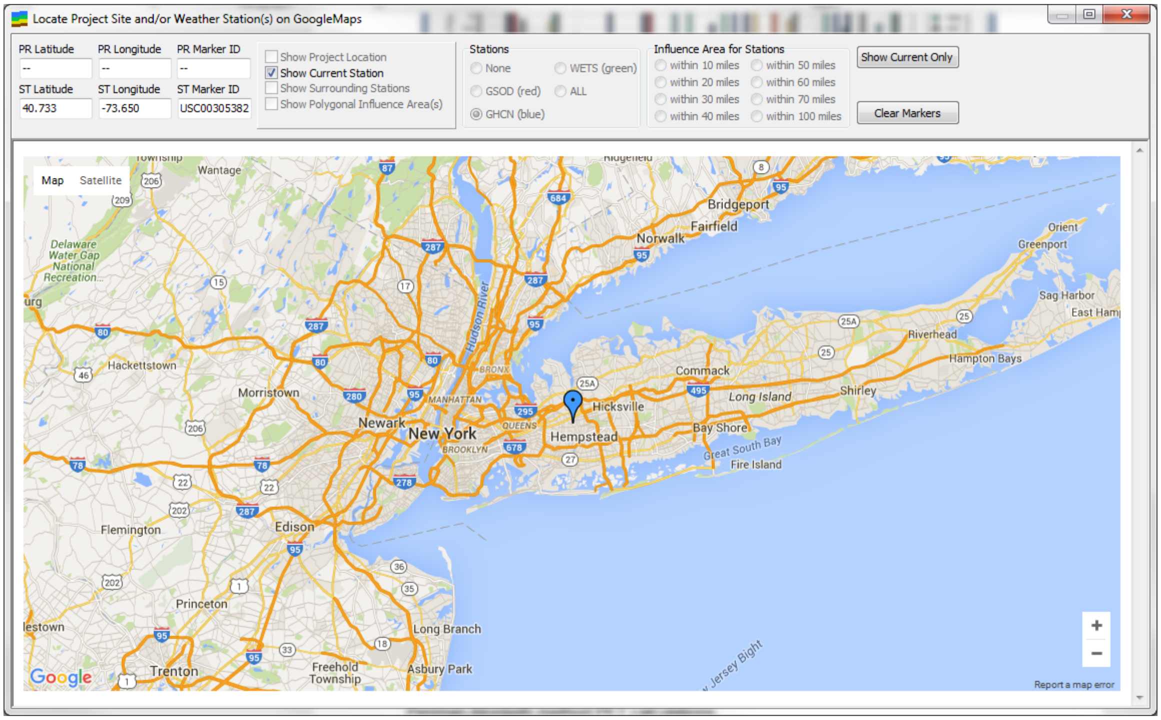




8.2.5 GHCN Map

You can use 

to view the location of the GHCN Station. GHCN stations are marked with blue pins.

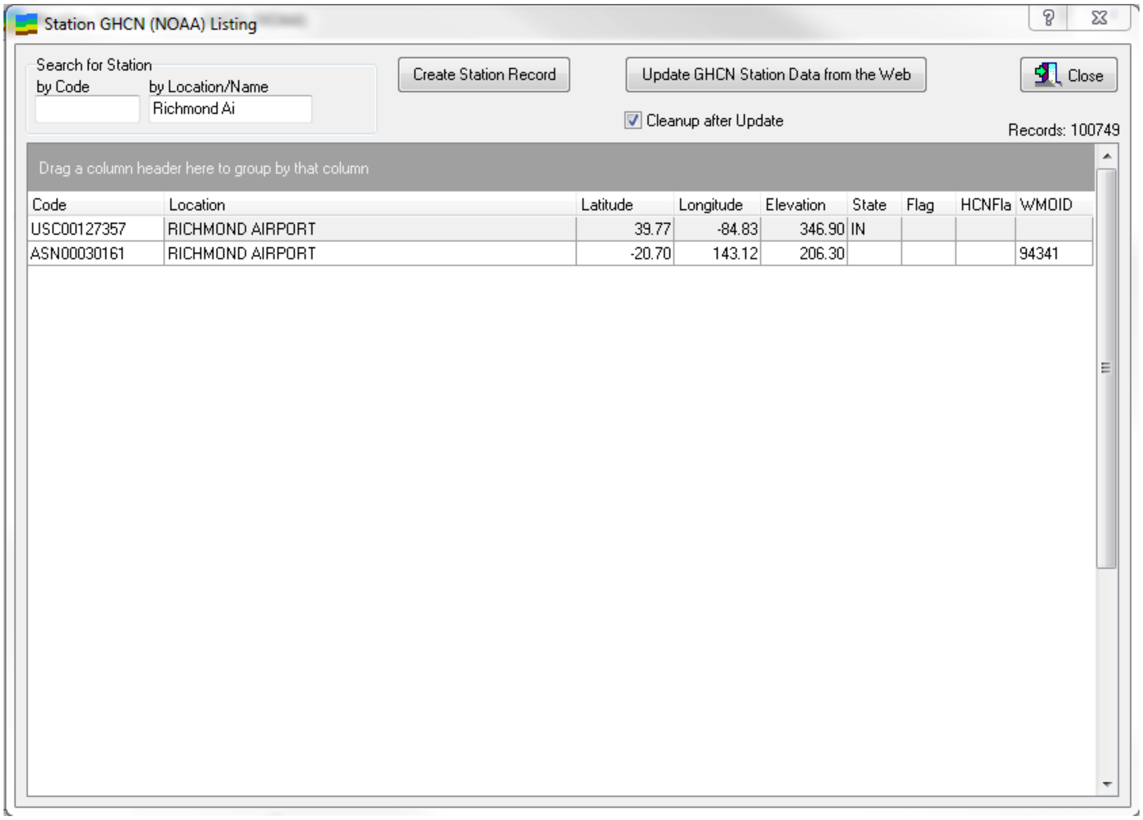


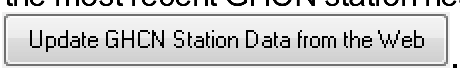
8.2.6 List of GHCN Stations

This form should display station header information. If station header information is not displayed, click Update GHCN Station Data from the Web to populate the database with available station header information. Stations can be grouped by state, latitude, longitude, etc. by dragging column labels into the gray area above the table. Station Elevation values are given in feet.

The list of stations is searchable by Code and by Location/Name. When typing up a name or code the program will immediately start filtering the records that match the criteria.

Select the desired station from the list and click Create Station Record to create a record for the station in the weather station database. Select Yes to insert the currently selected station into the Stations Table and click OK when prompted to confirm you would like to create a record for the selected station, then close the Station Listing window.



In addition, the most recent GHCN station header data can be downloaded from the Web using 

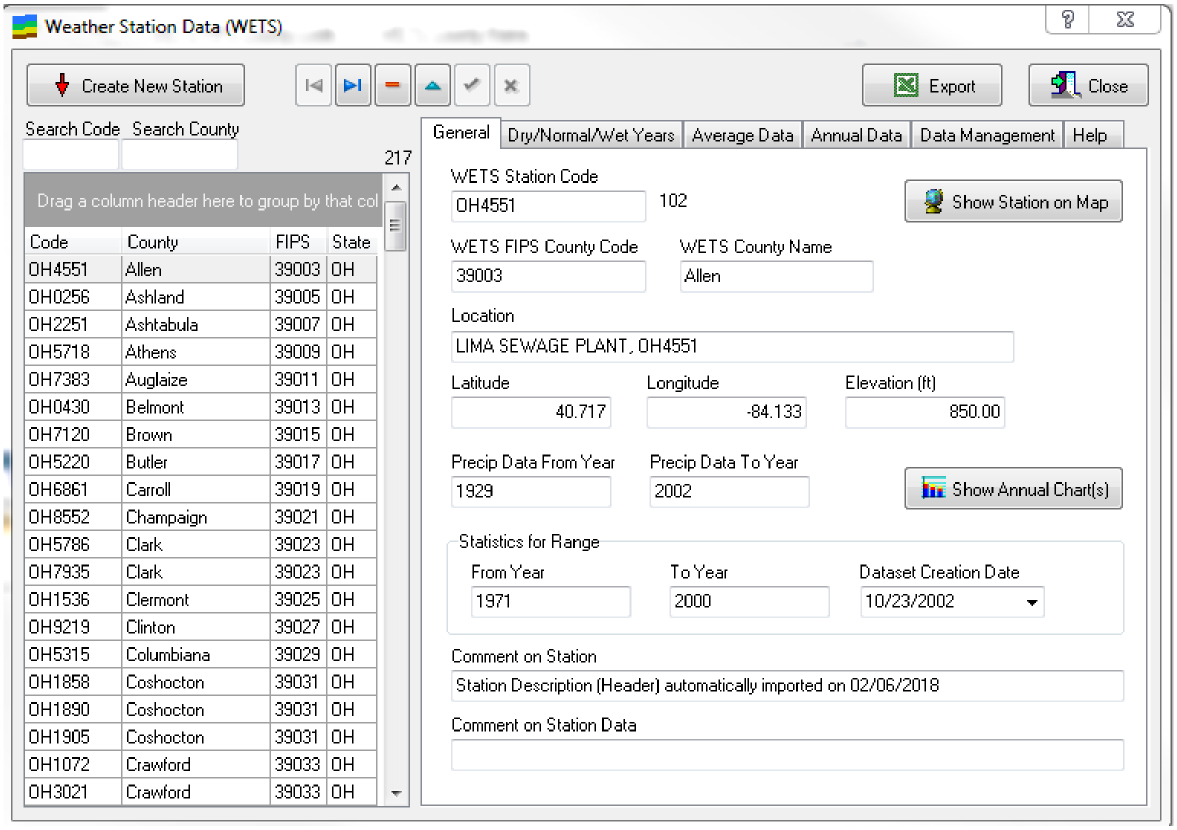
. This data is used to populate the list of stations in this form.

8.3 Station Data - WETS

WETS stations and their associated WETS tables were created by the Natural Resources Conservation Service (NRCS) to define the normal range for monthly precipitation and growing season necessary to characterize the climate in a given area over a representative time period.

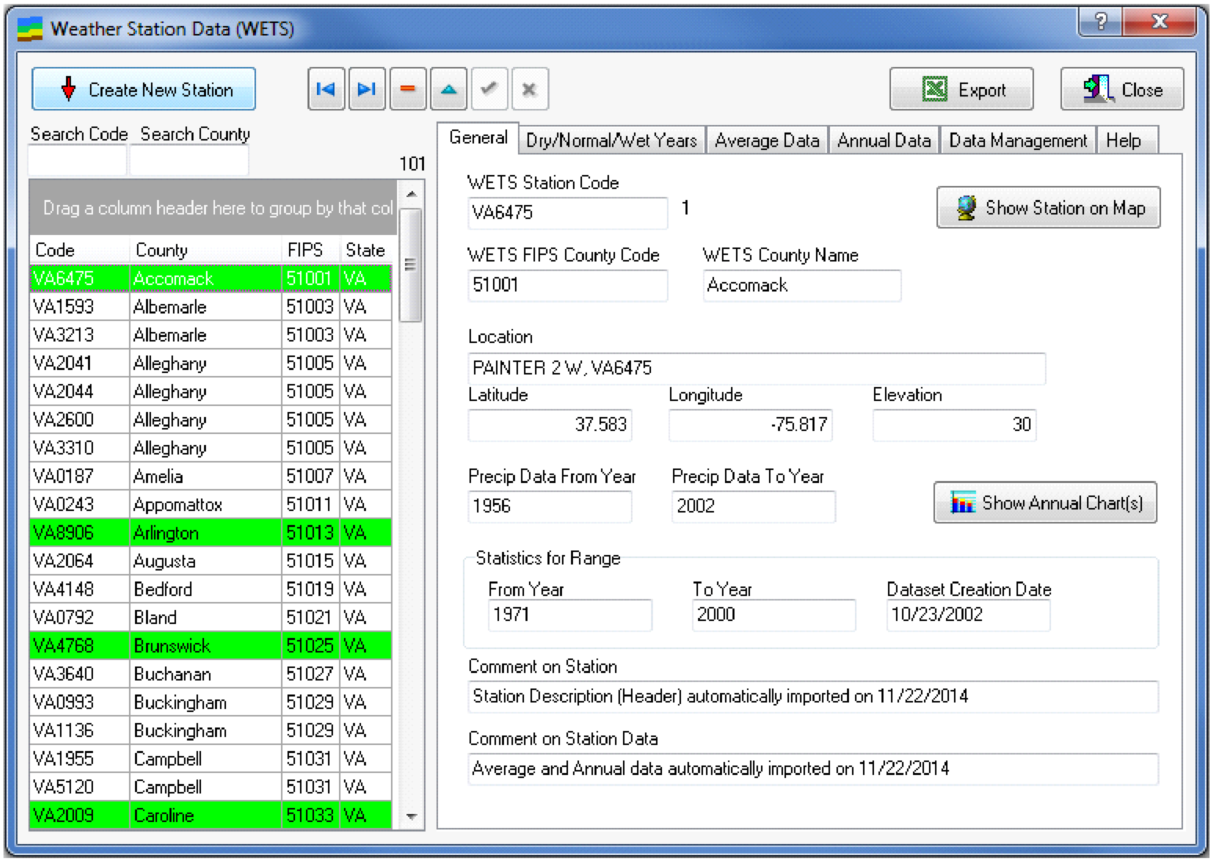
WETS stations in each state are organized by county and each county may contain one or more WETS stations. The data from these stations are used in Wetbud to help define typical Dry (D), Normal (N) and Wet (W) years for a given area.

The inclusion of DNW years in water budget calculations is a prudent measure when modeling the expected range of conditions that affect water levels in a natural wetland or a created wetland mitigation site.



8.3.1 General

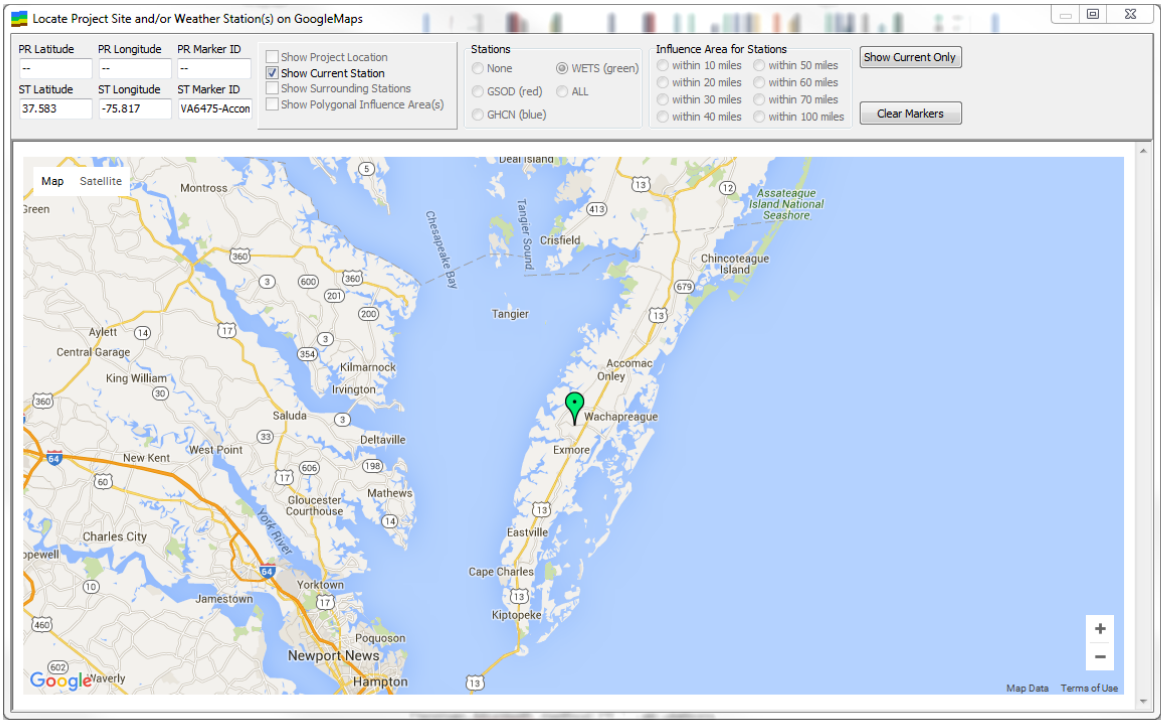
The header information for WETS NRCS stations is listed in the General tab. The header information for WETS weather stations includes the Station Code, the FIPS County code, the County Name, the Location, the Latitude, Longitude and Elevation as well as the range of data available and how the data was imported.



8.3.1.1 WETS Map

You can use 

to view the location of the WETS station. WETS stations are marked with green pins.

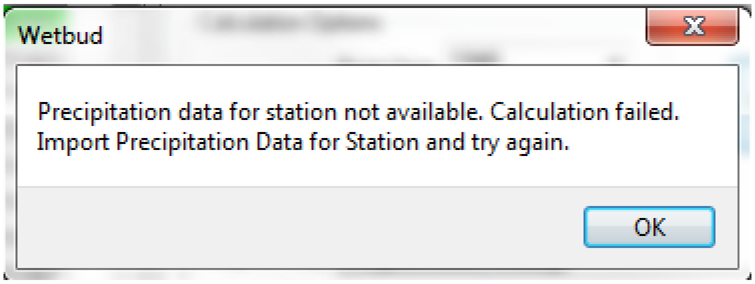


8.3.2 Dry/Normal/Wet Years

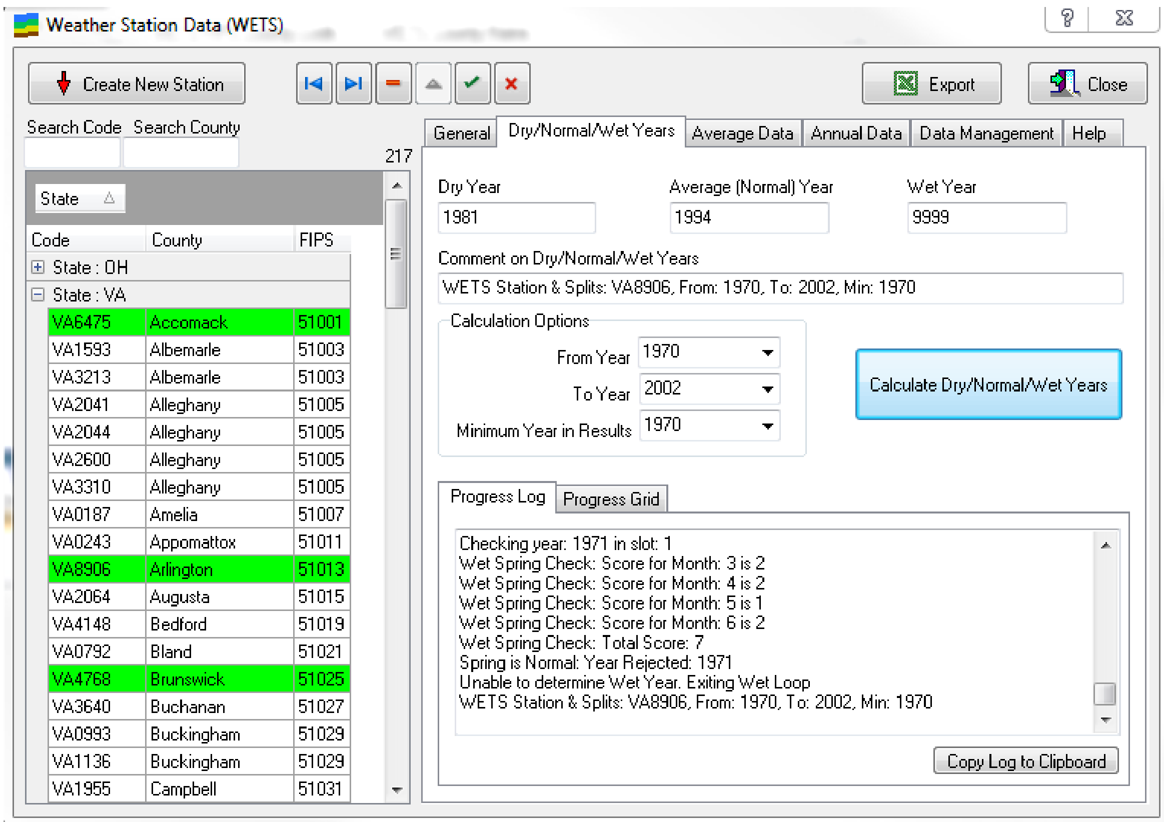
The Dry/Normal/Wet Years tab is used to calculate and display Dry (D), Normal (N) and Wet (W) years for the selected station. DNW years for a station cannot be calculated until WETS data have been imported for that station. Stations for which WETS data have been imported are highlighted green in the station list. The DNW years calculated in this tab are not used in the Analysis, but can be used to verify DNW years calculated using GSOD station information.

To calculate DNW years for a WETS station:

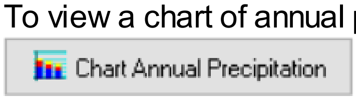
1. First select the range of years to be included in the calculations in the From Year, To Year, and Minimum Year drop-down lists in the Calculation Options section. Typical values are 1970, 2000 and 1970 respectively.
2. Next, click Calculate Dry/Normal/Wet Years. The calculated DNW years will appear in their respective boxes. DNW year calculations as performed by Wetbud will be displayed in the Progress Log tab. If data are not available for a selected station, the following message will be displayed and calculations will not be completed.



3. The DNW years calculated from the selected range of years will appear in their respective boxes.



4. To export an Excel file of the DNW calculations as performed by Wetbud (shown in the Progress Log), click 

, then name and save the file.
5. Click Save  to save the DNW years calculated for this station.
6. To view a chart of annual precipitation data for this station, click 

in the General tab.

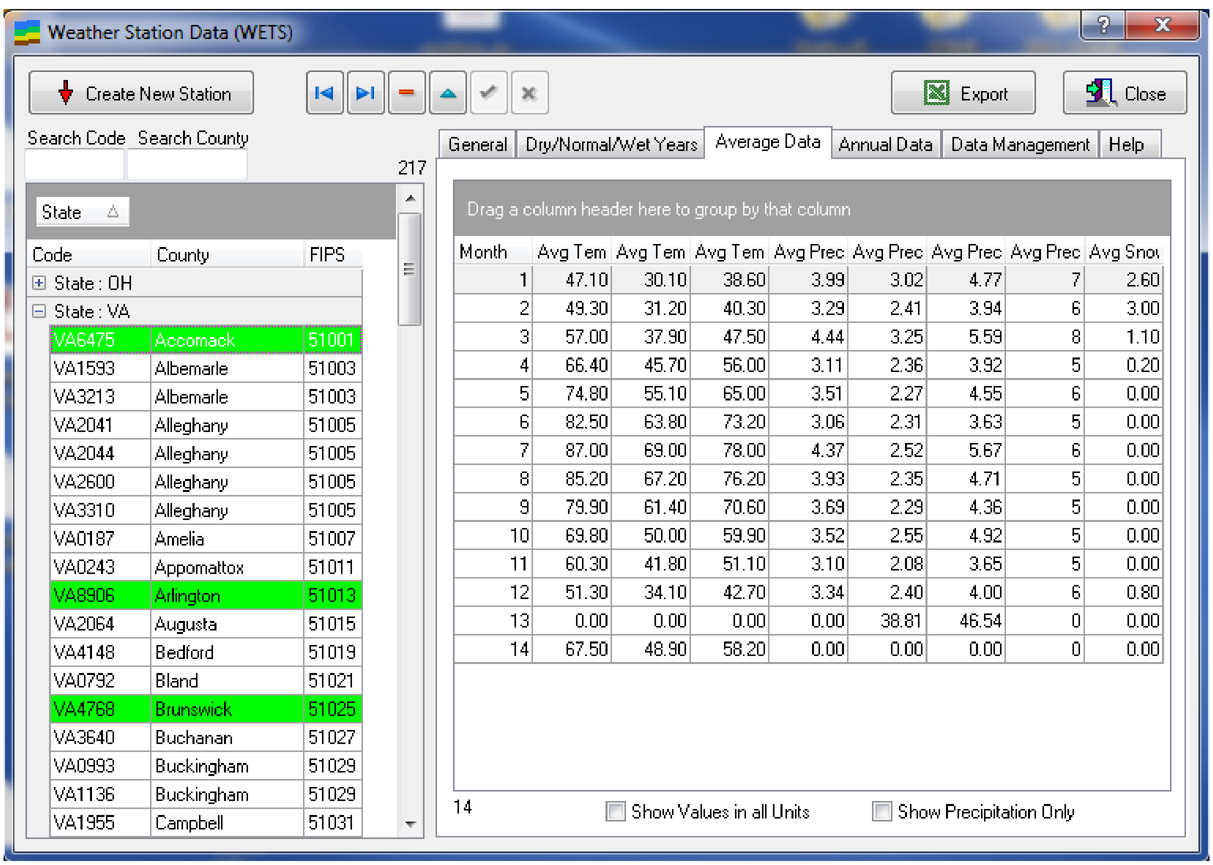
Note: Wetbud calculates DNW years based on the procedure developed by McLeod (2013). This procedure was designed to determine if years classified as dry, normal or wet based on total annual precipitation also have a dry, normal, or wet spring, respectively. For example, a year that is classified as wet based on total annual precipitation that does not meet the wet spring criteria is rejected as a ‘wet’ year and another year must be selected as ‘wet’. For more details, see Dry, Normal, Wet Year Calculations.

8.3.3 Average Data

The Average Data tab displays average meteorological data for a selected WETS station in a table. Temperatures are shown in Fahrenheit and Celsius and precipitation is shown in inches and centimeters. Data can be grouped by any column heading by dragging the heading into the gray area above the table. The user can choose to only display English units and/or precipitation by clicking the box at the bottom of the tab.

The data correspond to the Average Maximum Temperature, the Average Minimum Temperature, the Average Temperature, the Average Precipitation 30% Low, the average Precipitation 30% High, the Average Precipitation and Average Snow.

Note: Data are provided for 12 months (months 1-12). Row 13 in the Average Data tab applies to average annual totals for precipitation data only and does not apply to temperature data. Row 14 displays overall annual average, average maximum, and average minimum temperature and does not apply to precipitation data.

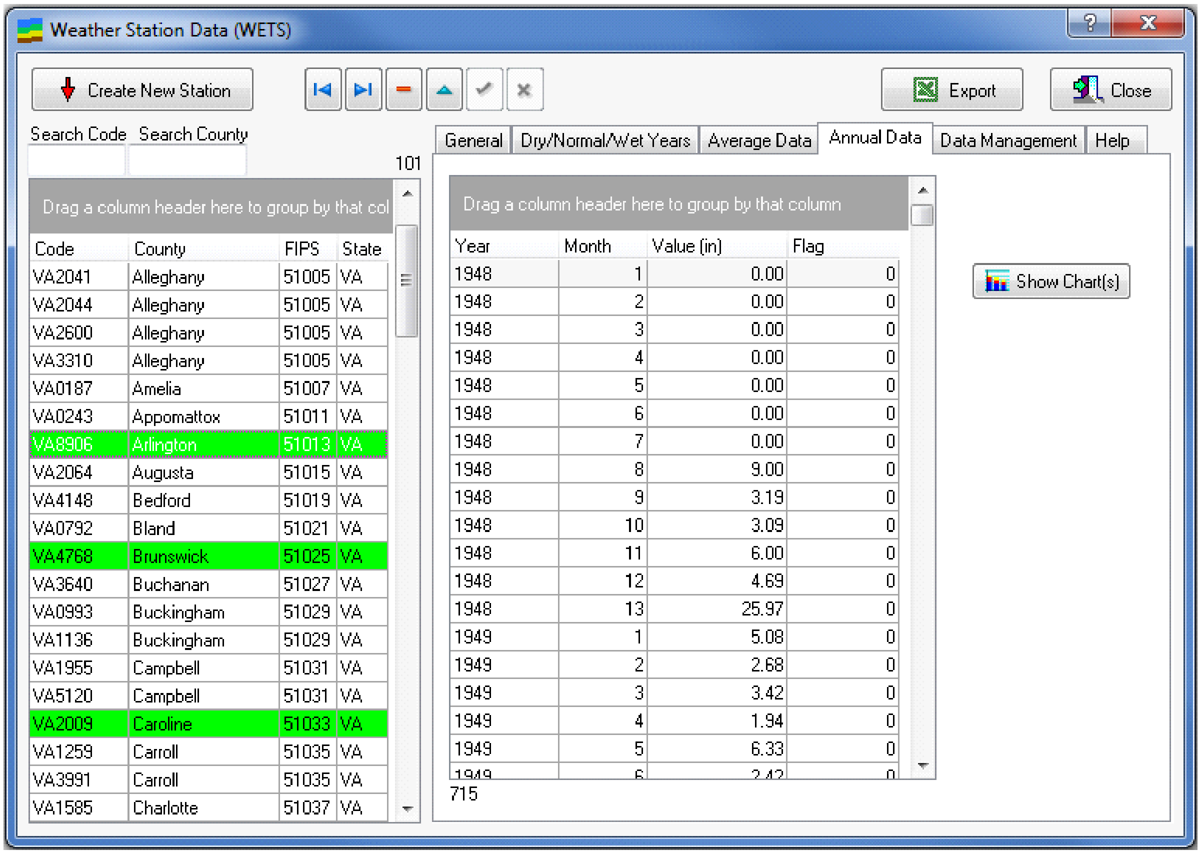


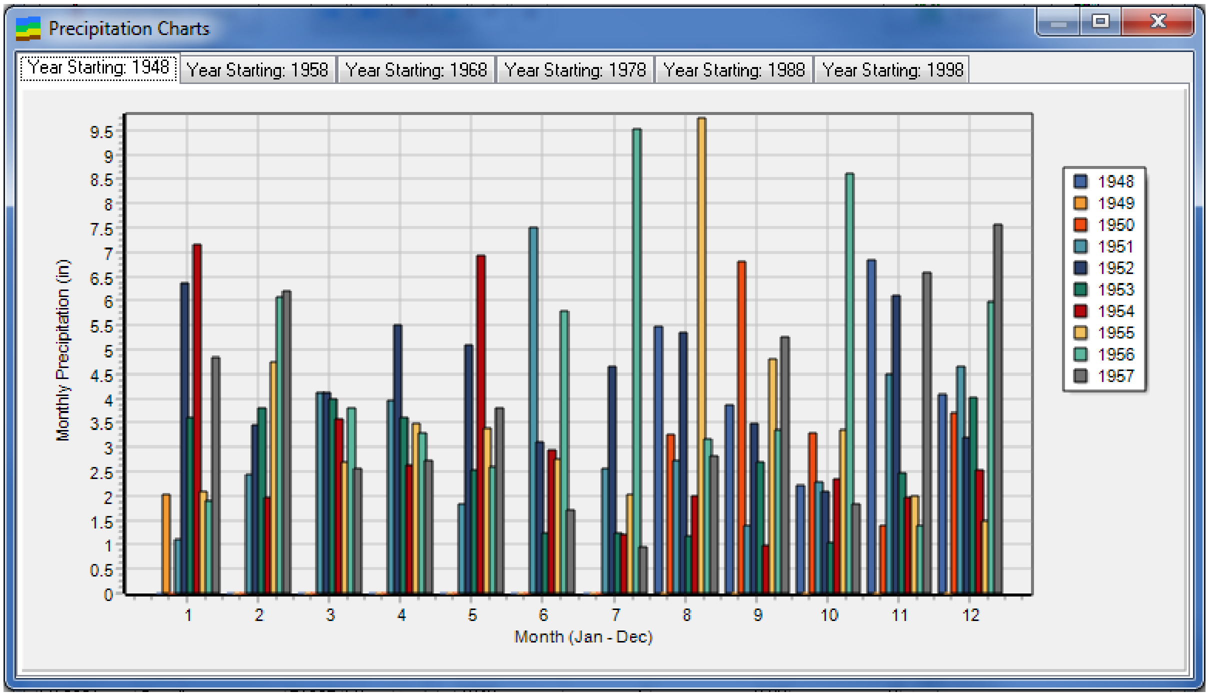
8.3.4 Annual Data

The Annual Data tab displays monthly and annual precipitation totals for a selected station for the range of years available. Total precipitation values are displayed in inches for each month (labeled as 1-12) and year in the range. Data can be grouped by month, total precipitation, etc. by dragging the corresponding column heading into the gray area above the table.

A graph of monthly precipitation data can be viewed for 10-year intervals by clicking 

.

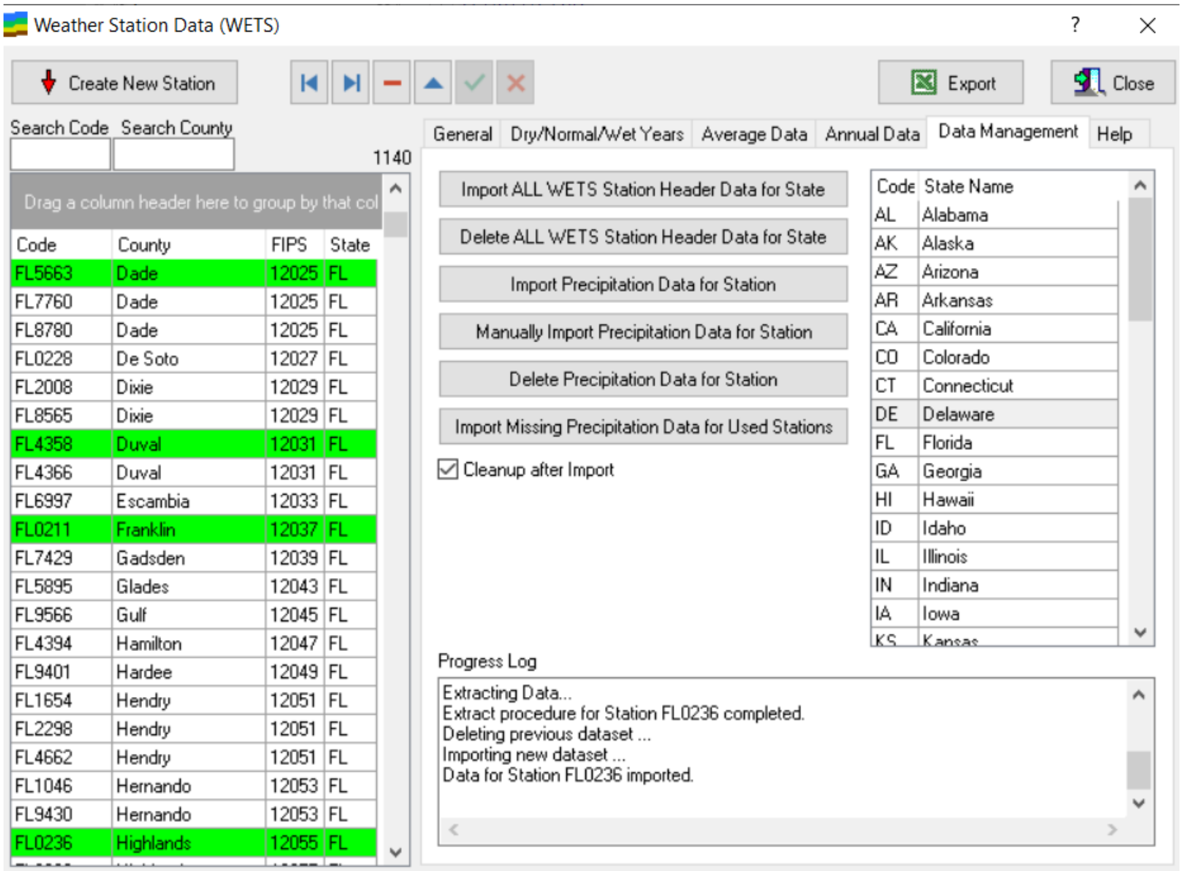




8.3.5 Data Management

The Data Management tab is used to display, import, and manage data for all available WETS stations in the United States. To import WETS table data:

1. First, in the Data Management tab, select the state from the list on the right and then click Import ALL WETS Station Data for State. WETS station header data for the selected state will appear in the list on the left.



2. The imported WETS station header information is listed in the General tab of the Weather Station Data (WETS) window and includes the WETS station code, WETS FIPS county code, WETS county name, location, latitude, longitude, elevation, and range of available data. The range of years used in the statistical analysis of the data (performed by NRCS to establish normal ranges for total monthly precipitation) is shown in the Statistics for Range section. In the General tab, the location of a station can be plotted in Google Maps by clicking [Show Station on Map]. Selecting a group in the Stations section in the Google map window will display NOAA or WETS stations (or both) within a radius of 10-50 miles of the selected station.
3. WETS station header data for a state can be deleted by selecting the state from the list on the right and clicking [Delete ALL WETS Station Header Data for State] in the Data Management tab.
4. To import precipitation data for a specific WETS station, first select the station from the station header list on the left and then click [Import Precipitation Data for Station] in the Data Management tab. The WETS station for which precipitation data has been imported will now be highlighted green in the stations list on the left side of the window. Once the precipitation data for a station have been imported, the user can calculate DNW years and view the data for that station in the tabs labeled Dry/Normal/Wet Years, Average Data, and Annual Data.

5. Previously imported precipitation data for a WETS station can be deleted by selecting the station from the list on the left and clicking [Delete Precipitation Data for Station] in the Data Management tab.
6. WETS tables for every county in the US are being updated to include precipitation data up to year 2012. In addition to updated precipitation data for existing WETS stations, many counties have included one or more additional WETS stations in their database. Currently, Wetbud is programmed to import WETS tables that do not include the latest updates. However, the user can manually import the updated WETS station data available through the NRCS website.
7. To import a WETS table manually, click [Manually Import Precipitation Data for Station] and follow the directions in the Manual Import of WETS Data into Wetbud window. This step is necessary for those who wish to include the most recent decade in calculations to determine dry, normal, and wet years.

According to https://www.wcc.nrcs.usda.gov/climate/navigate_wets.html there are three methods to access the updated WETS tables:

Method 1:
1. In your web browser, go to https://efotg.sc.egov.usda.gov/
2. Select the state of interest (e.g., Virginia).
3. Select Section II in the list on the left side of the page.
4. Click the Climatic Data folder, which is located in the list of folders under Section II.
5. Click Agricultural Applied Climate Information System link (http://agacis.rcc-acis.org/)

6. States vary in the naming of this folder, and some states may have it located yet another folder level beneath. It is not available in some states.
7. A selection page will open in the center of the page, showing available documents and resources for the climate stations.
8. Select the Document Title to open the document or resource.

Methods 2 and 3 require you to know the 5-digit FIPS (Federal Information Processing Standards) code for the desired state (first 2 digits) and county (last 3 digits). A listing of these codes can be found under wikipedia through https://en.wikipedia.org/wiki/List_of_United_States_FIPS_codes_by_county.

Method 2: Go to http://agacis.rcc-acis.org. Select the State and County from the dropdown list. Then enter the 5-digit FIPS code in the popup box and click Go.

Method 3: In your web browser address bar, insert the 5-digit FIPS code into the following url: http://agacis.rcc-acis.org/?fips=FIPSCODE.

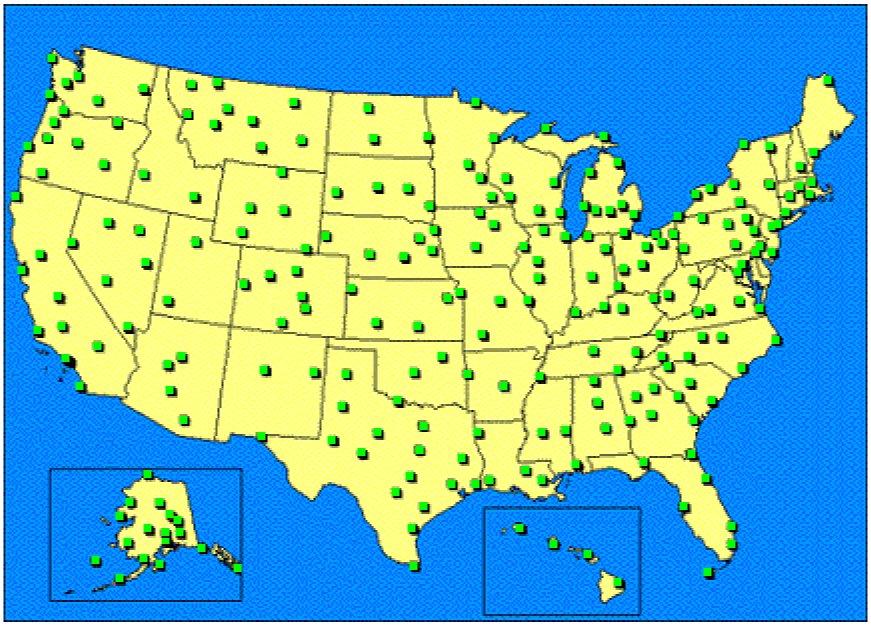
At this point in Methods 2 and 3, a selection page will open as in Step 5 of Method 1 above. Proceed with the desired selections.

8.4 Solar Data

Wetbud uses solar radiation data in the calculation of potential evapotranspiration (PET) using the Penman-Monteith method. Two solar radiation parameters, hourly extraterrestrial radiation on a horizontal surface (ETR) (Wh/m^2) and measured global horizontal radiation (METASTATGLO) (Wh/m^2), must be downloaded automatically and/or manually imported by the user for a selected weather station to be included in Penman-Monteith method PET calculations.

Solar data from 1961-1990 and 1991-2005 can be collected from NSRDB archives website and can be accessed here: https://nsrdb.nrel.gov/data-sets/archives.html

Sites from 1961-1990 are quite limited but can be located using the 1961-1990 NSRDB map (see Figure which shows a map of the available stations from 1961-1990 https://openei.org/w/images/3/34/NSRDB-1961-1990-locations.gif) as well as the NSRDB 1961-1990 manual of stations (see Table below). Access to the manual can be found downloading the 1961-1990 data set found at the above link.



State	City	WBAN	State	City	WBAN
AL	Montgomery	13895	ID	Boise	24131
AK	Fairbanks	26411	IN	Indianapolis	93819
AZ	Phoenix	23183	KS	Dodge City	13985
AZ	Tucson[1]	23160			
			LA	Lake Charles	03937
CA	Daggett[1]	23161			
CA	Fresno	93193	ME	Caribou	14607
CA	Los Angeles	23174			
CA	San Diego[1]	23188	MA	Boston	14739
CA	Santa Maria	23273			
			MO	Columbia	03945
CO	Alamosa[1]	23061			
CO	Boulder/Denver	94018	MT	Great Falls	24143
CO	Grand Junction	23066			
			NE	Omaha	94918
FL	Daytona Beach[2]	12834			
FL	Miami	12839	NV	Ely	23154
FL	Tallahassee/ Apalachicola	93805	NV	Las Vegas	23169
			NM	Albuquerque	23050
GA	Atlanta[3]	13874			
GA	Savannah[4]	03822	NY	Albany[5]	14735
			NY	New York City	94728
HI	Honolulu	22521			

Once the station has been decided upon, use the manual to find the WBAN number for the station. Using the 1961-1990 file downloaded from the NSRDB archive site, use 7-Zip to extract the site's solar data. The files once extracted come in yearly text files. Using a text collector such as TXTcollector found here:
https://bluefive.pairsite.com/txtcollector.htm

From this data file the 5th and 7th column are of importance. The 5th column is Extraterrestrial Horizontal Radiation, what Wetbud refers to as ETR. The 7th column is Global Horizontal Radiation, what Wetbud refers to as MetStatGLO.

For the 1991-2005 again download the data from the NSRDB archive site. For this data set the WBAN numbers changed from the 1961-1990 numbers. Using the 1991-2005 manual, find the station needed as well as the WBAN number. Using 7-Zip again, find the station and extract the data. The set of data comes in yearly excel files. The important solar information from these files is labeled, but what is needed is the 5th column (E) labeled ETR and the 13th column (M) labeled METSTAT Glo. For both data sets it is necessary to sum up the hourly data into days.

Additionally, Appendix B in the 1991-2005 manual has the information to determine if the 1991-2005 has a corresponding 1961-1990 station.

Using the NSRDB viewer found here: https://maps.nrel.gov/nsrdb-viewer data can be downloaded from 1998-2020. To start, zoom into the chosen location, switch the upper left tab to download data and click the NSRDB Data Download (Point). Using the Physical Solar Model (PSM3) , select the years of data needed, clear all attributes and select GHI (Global Horizontal Irradiance) also called Global Horizontal Radiation. In the download options Clear all and select Leap Day. This data will come to the user as an excel file. For these data sets the user will need to calculate ETR which can be done with the provided spreadsheet in the similar manner as collecting the solar data from RAWS.

Definitions

Extraterrestrial Horizontal Radiation: Amount of solar radiation in Wh/m^2 receive on a horizontal surface at the top of the atmosphere during the 60 minutes preceding the hour indicated (1961-1990 manual).

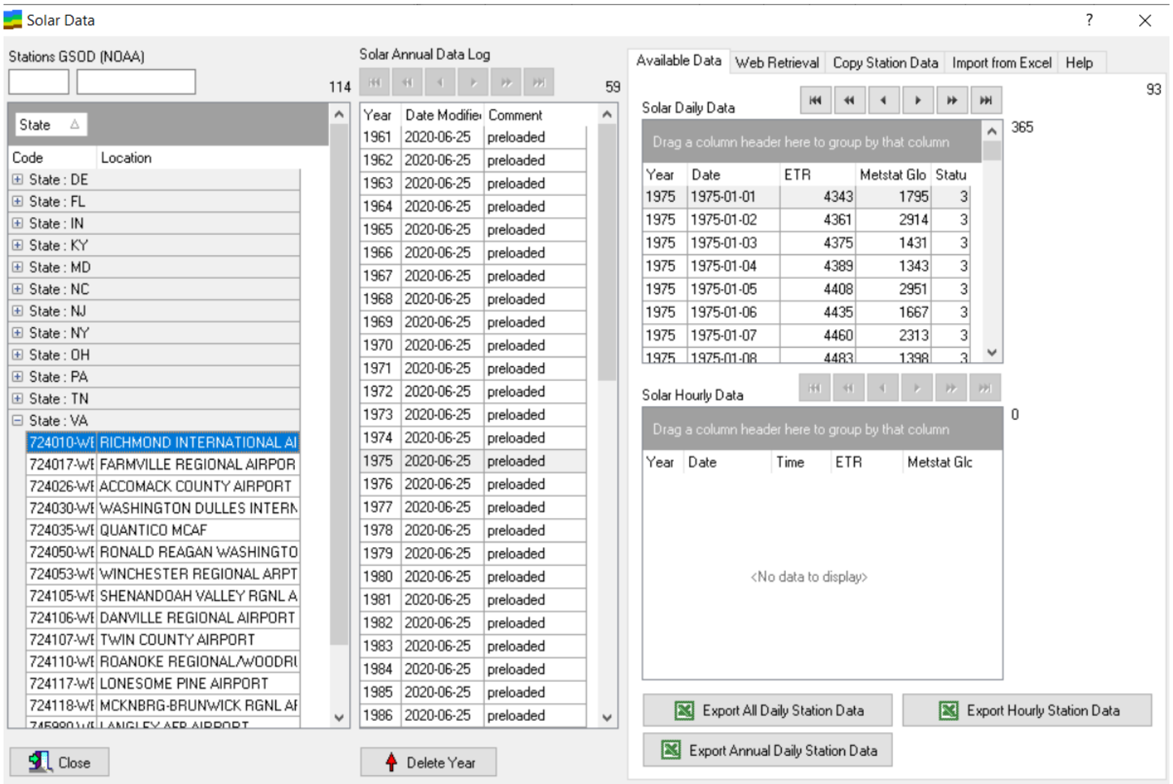
Global Horizontal Radiation (GHI): Total amount of direct and diffuse solar radiation in Wh/m^2 received on a horizontal surface during the 60 minutes preceding the hour indicated (1961-1990 manual).

ETR or (Hourly extraterrestrial radiation on a horizontal surface): Amount of solar radiation received on a horizontal surface at the top of the atmosphere during the 60-minute period ending at the timestamp (1991-2005 manual).

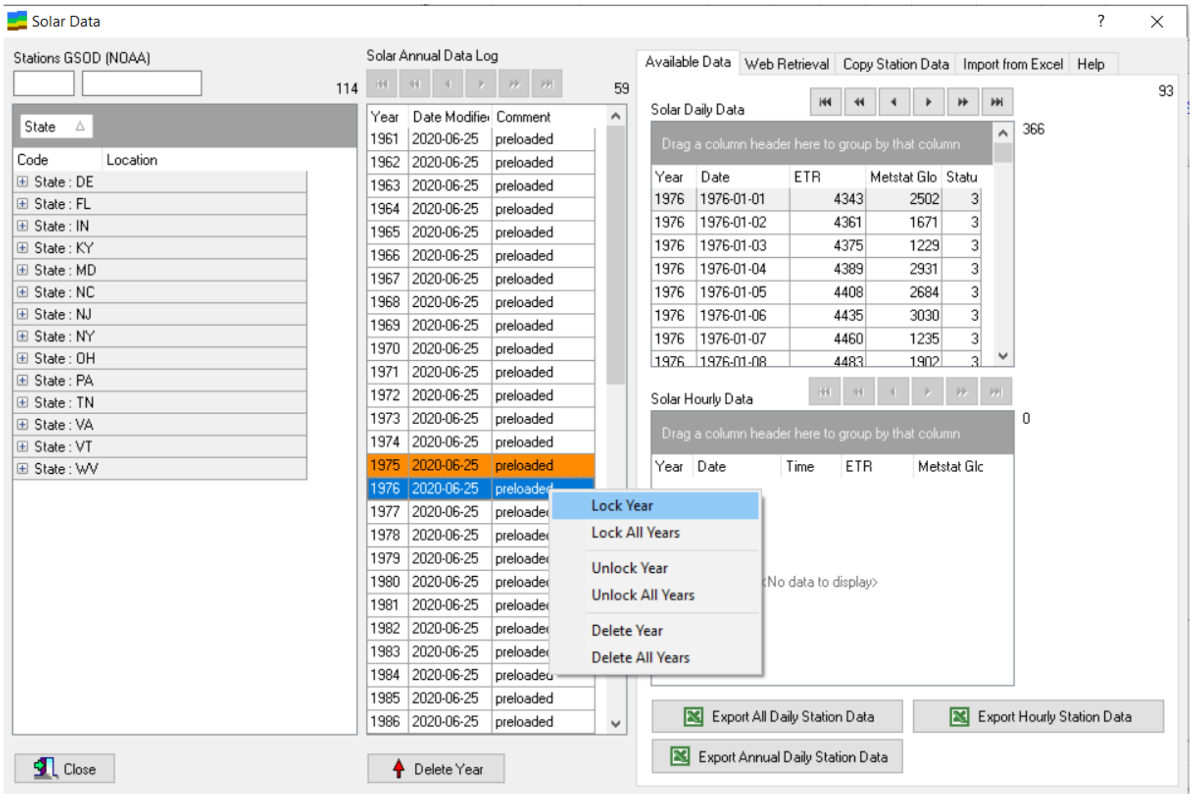
METSTAT- modeled global horizontal: Total amount of direct and diffuse solar radiation (METSTAT-modeled) received on a horizontal surface during the 60-minute period ending at the timestamp (1991-2005 manual).

8.4.1 Solar Stations - Available Data

This screen allows for all available data to be listed and checked.

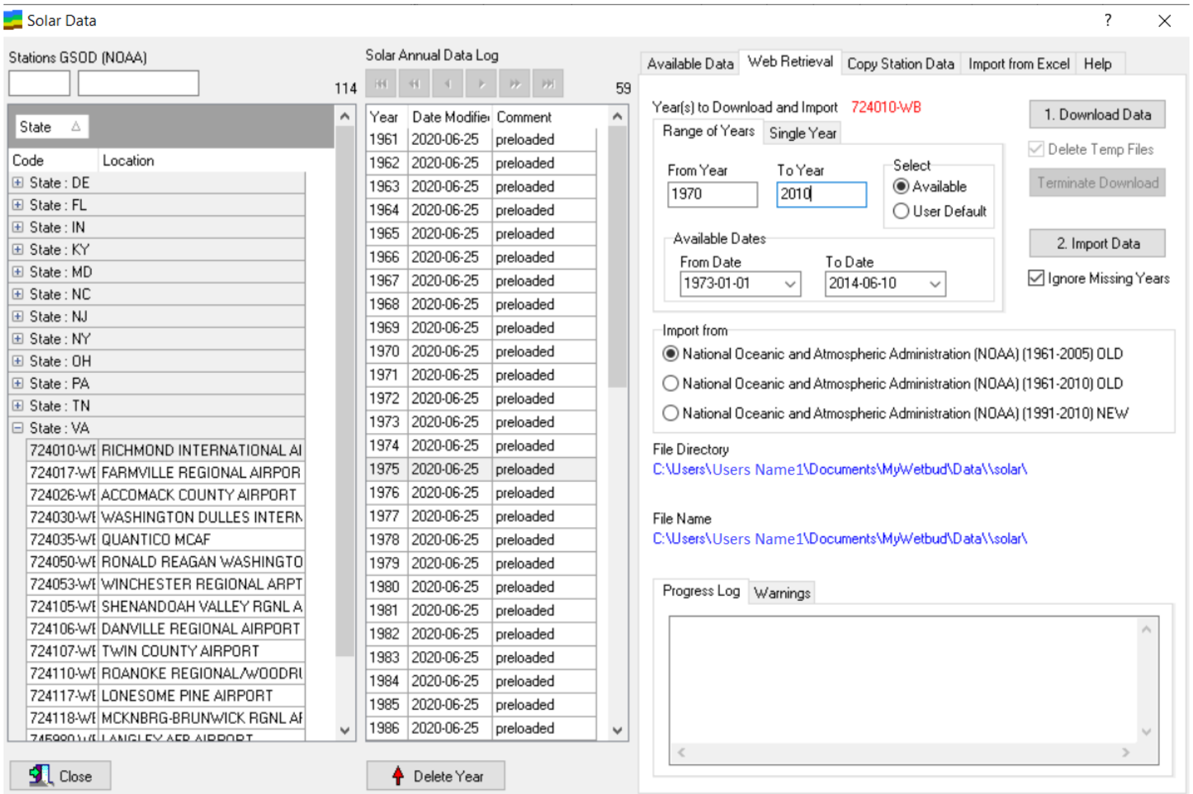


Once data are finalized, the user can right click a selection in the Solar Annual Data Log to lock a single year or all years for the selected station. Locked years are shown in orange.



8.4.2 Solar Stations - Web Retrieval

1. First, select Solar Data from the Parameters menu in the Wetbud home screen.
2. Next, click the Web Retrieval tab and select a station from the list on the left side of the window. Enter the range of years or year to be downloaded in the Range of Years or Single Year tab.
3. In the Import From section, select the source from which the data will be downloaded. See the notes below for guidance on your selection.
4. Click 1. Download Data. Download progress is shown in the Progress Log at the bottom of the window. After the download is complete click 2. Import Data to import the data. Select OK from the prompt that follows.



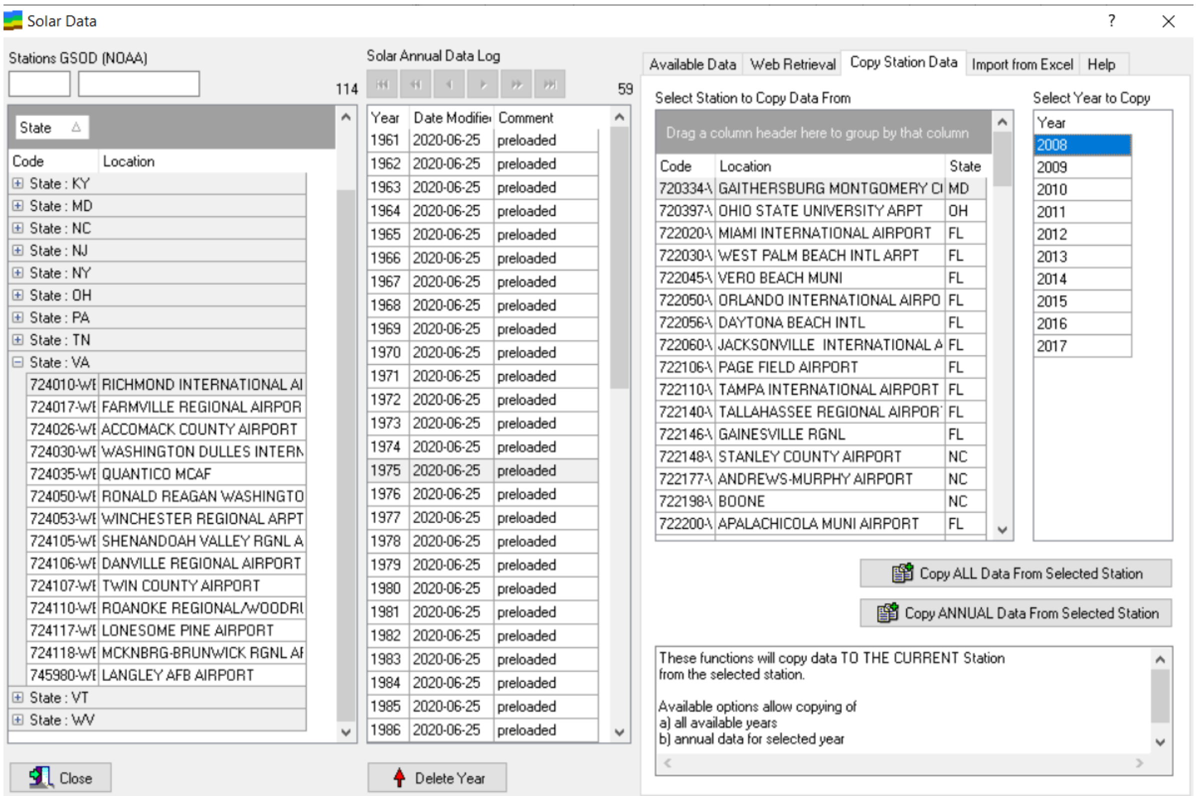
5. The National Solar Radiation Database (NSRD) maintained by NOAA includes data for two periods: 1961-1990 and 1991-2010. Some NOAA stations may not have data available for the entire period from 1961-2010. For many states, post-1990 solar data are available for more localities due to the addition of weather stations. Also, the record of solar data for a given locality may be recorded by separate stations during separate time periods. In some cases, the data for these stations exists in separate databases from which Wetbud can download data. It is for these reasons that the user is presented with three options in the Web Retrieval tab of the Solar Data window. If your original selection in the Import From section of the Solar Data window does not retrieve data that is listed as available for the selected station, select the next option and repeat steps 3-5 above.

Note: For solar data and detailed explanations of all variables in the National Solar Radiation Database files see http://rredc.nrel.gov/solar/old_data/nsrdb/. The National Oceanic and Atmospheric Administration (NOAA) site at http://ftp.ncdc.noaa.gov/pub/data/nsrdb-solar/solar-only/ also includes solar data.

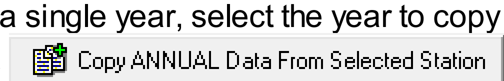
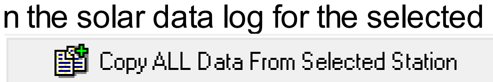
8.4.3 Solar Stations - Copy Station Data

Due to the fact that solar data is only available for NOAA GSOD stations, solar data for non-NOAA GSOD stations must be copied from solar data downloaded and imported for the nearest NOAA GSOD station. Once solar data for a given station are imported the user can view the data in the Available Data tab. The data is organized per year

(Solar Data Log), per day (Solar Daily Data) and then per hour in a single year (Solar Hourly Log).



To copy solar data from one station to another:

1. Select the Copy Station Data tab in the Solar Data window.
2. Select the station to which data will be copied from the station list on the left side of the Solar Data window.
3. Select the station from which data will be copied in the Select Station to Copy Data From list.
4. To copy data for a single year, select the year to copy from the Select Year to Copy list and then click  . Click Yes at the prompt to overwrite existing data to confirm your selection. The annual data that have been copied will now appear in the solar data log for the selected station. To copy all solar data from a station click  . Click Yes at the prompt to overwrite existing data to confirm your selection. The data that have been copied will now appear in the solar data log for the selected station.

8.4.4 Solar Stations - Import from Excel

1. Select the Import from Excel tab in the Solar Data window.
2. Select the station to which you wish to import data from the station list on the left side of the window.

3. Click Import Daily Solar Data and follow the instructions in the dialog.
4. The user can check data for missing dates by clicking Check for Missing or Zero Values.

8.4.5 Solar Stations - Export Data

To export all daily solar data for a station:
1. In the Available Data tab, select the station from the station list on the left side of the Solar Data window.
2. Click Export All Daily Station Data.
3. Name and save the file in the desired format.

To export a single year of daily solar data:
1. In the Available Data tab, select the station from the station list on the left side of the Solar Data window.
2. Select the year from the Solar Data Log and click Export Annual Daily Station Data.
3. Name and save the file in the desired format.

To export hourly solar data for a single day:
1. In the Available Data tab, select the station from the station list on the left side of the Solar Data window.
2. Select the year from the Solar Data Log. Next, select the day from the Solar Daily Data list. Click Export Hourly Station Data.
3. Name and save the file in the desired format.

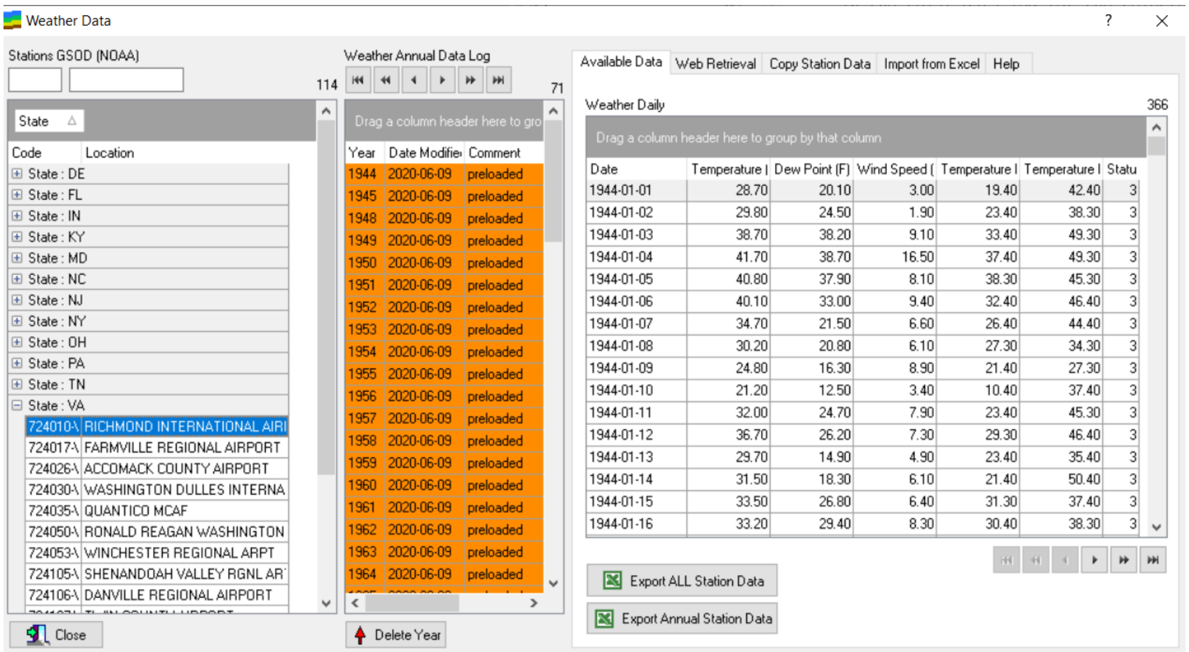
8.5 Weather Data

Weather data of several types are needed when choosing the Penman-Monteith Method (calculated by Wetbud) or Thornthwaite Equation (calculated by Wetbud) PET option in a Basic Scenario. Weather data are provided by the National Climate Data Center (NCDC). The daily elements included in the data set (as available from each station) are mean temperature (0.1 Fahrenheit); mean dew point (0.1 Fahrenheit); mean sea level pressure (0.1 mb); mean station pressure (0.1 mb); mean visibility (0.1 miles); mean wind speed (0.1 knots); maximum sustained wind speed (0.1 knots); maximum wind gust (0.1 knots); maximum temperature (0.1 Fahrenheit); minimum temperature (0.1 Fahrenheit); precipitation amount (0.01 inches); snow depth (0.1 inches); and an indicator for the occurrence of fog, rain or drizzle, snow or ice pellets, hail, thunder, or tornado/funnel cloud.

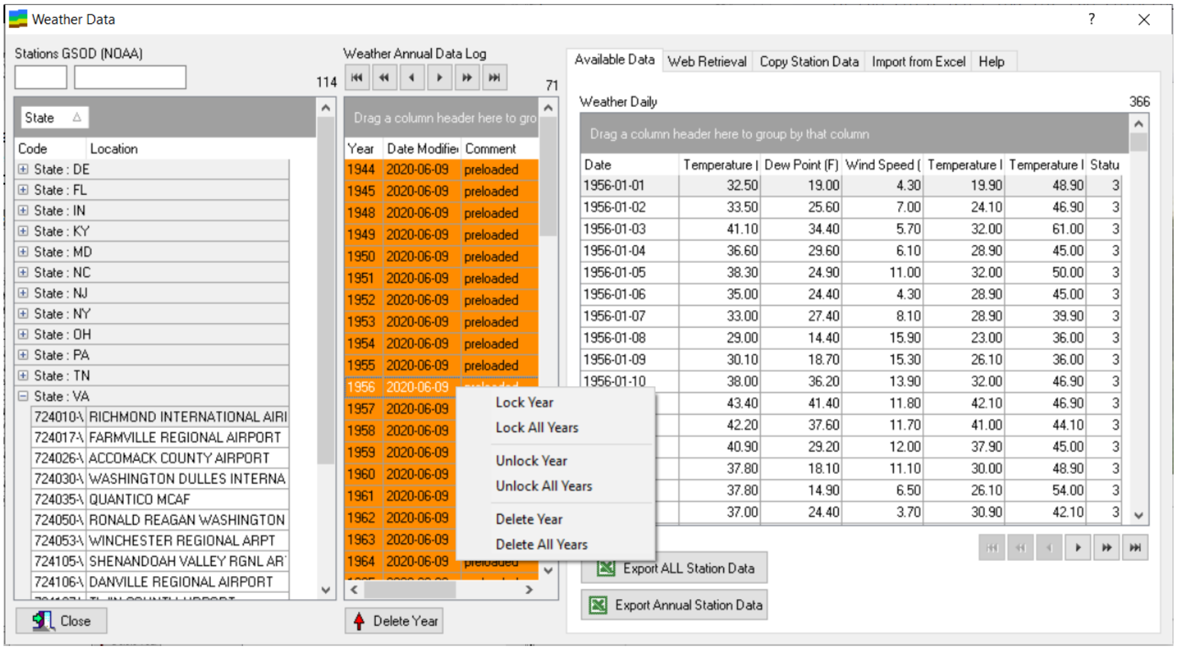
Weather data may be automatically downloaded by Wetbud (for NOAA GSOD stations only) but can also be manually imported by the user. Wetbud also allows the user to copy weather data from one station to another for all stations records created in the NOAA GSOD station list. This feature is particularly useful when two official stations exist in the same area, such as a new station and an old station, and they have different names. This way the user can populate the previous years of a new station to develop a larger data set.

8.5.1 Weather Stations - Available Data

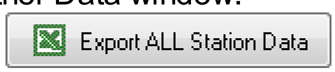
This screen allows for all available data to be checked and selected



Once data are finalized, the user can right click a selection in the Weather Annual Data Log to lock a single year or all years for the selected station. Locked years are shown in orange.



To export all daily weather data for a station:

1. In the Available Data tab, select the station from the station list on the left side of the Weather Data window.
2. Click 

3. Name and save the file in the desired format.

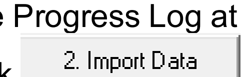
To export daily weather data for a single year:

1. In the Available Data tab, select the station from the station list on the left side of the Weather Data window.
2. Select the year from the Weather Data Log and click 

3. Name and save the file in the desired format.

8.5.2 Weather Stations - Web Retrieval

1. Select Weather Data from the Parameters menu in the Wetbud home screen.
2. Click the Web Retrieval tab and select a station from the list on the left side of the window.
3. Enter the range of years or year to be downloaded in the Range of Years or Single Year tab.
4. Click 

. Download progress is shown in the Progress Log at the bottom of the window. After the download is complete click 

to import the data. Select OK at the prompt that follows. A list of the years for which data has been imported in addition to the date of import is now shown in the Weather Data Log.
5. Select the Available Data tab to view a complete listing of daily data for all years that have been imported for the station. The column headings, from left to right, are as

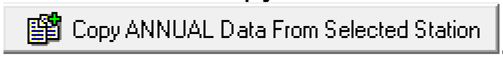
follows: date (yyyy-mm-dd), average temperature (°F), dewpoint (°F), average wind speed (mph), minimum temperature (°F), and maximum temperature (°F).

Note: The number displayed below the bottom left corner of the grid indicates the number of days included in the weather data set for the selected year. A number less than 365 (366 for leap years), indicates there are days that lack data. Should this occur, the user can export the data as an Excel file and supplement the missing data with data from a weather station nearby. The user can then manually re-import the corrected weather data set for that year. Alternatively, users can copy whole years or months from stations within their databases using the instructions in the Copying Weather Data from One Station Record to Another section.

8.5.3 Weather Stations - Copy Station Data

To copy weather data from one station to another:

1. Select the Copy Station Data tab in the Weather Data window.
2. Select the station to which you wish to copy data from the station list on the left side of the window.
3. Select the station from which you wish to copy data in the Select Station to Copy Data From list.
4. To copy all weather data from a station select the station from the Select Station to Copy Data From list and then click 

. Click Yes at the prompt to overwrite existing data to confirm your selection. All data that have been copied will now appear in the Weather Data Log for the selected station.
5. To copy data for a single year first select the year to copy from the Select Year to Copy list. Next, select the year from which to copy the data from the Select Year to Copy From list and then click 

. Click Yes at the prompt to overwrite existing data to confirm your selection. The annual data that have been copied will now appear in the Weather Data Log for the selected station.
6. To copy data for a specific month from a given year, first select the station from the Select Station to Copy From list. Next, select the year and month to copy from the Select Year to Copy From and Select Month to Copy From lists, respectively. Click 

. Click Yes at the prompt to overwrite existing data to confirm your selection. The data from the copied month will be added to the record of the corresponding year in the Weather Data Log.

Note: Weather data can only be copied from stations with records created in the NOAA GSOD station list. To add a station to this list, follow the instructions for creating a station in the Station Data – GSOD (NOAA) section.

8.5.4 Weather Stations - Import from Excel

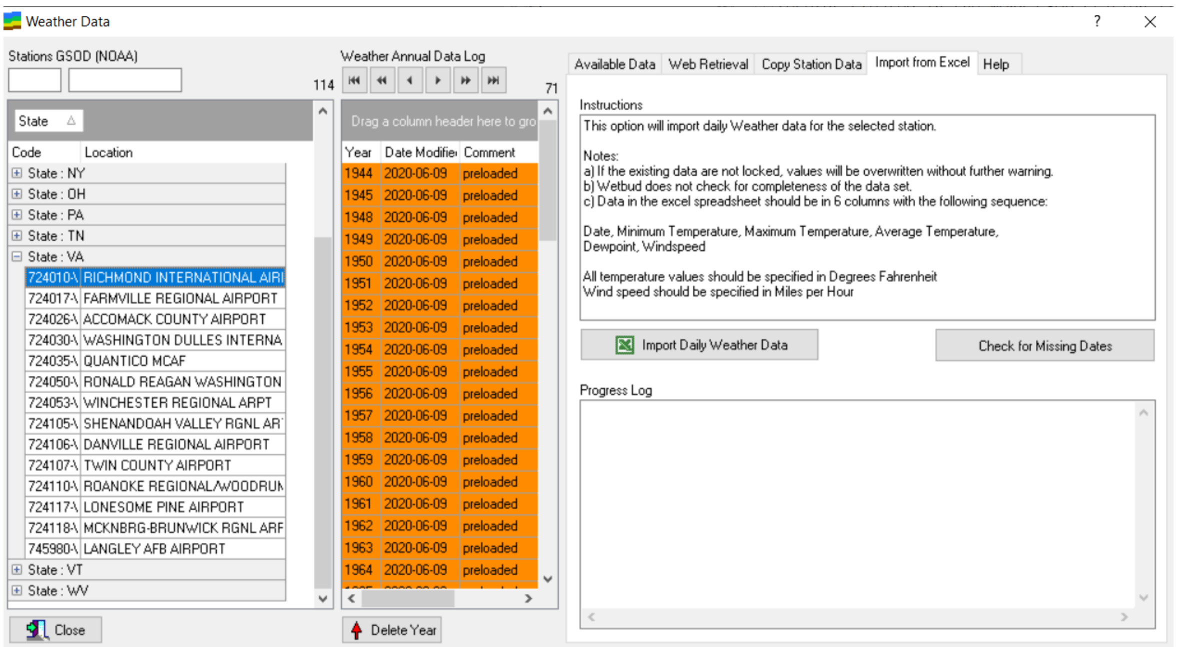
To manually import weather data:

1. Select the Import from Excel tab in the Weather Data window.

2. Select the station from which you wish to import data from the station list on the left side of the window.
3. Click 

and follow the instructions in the dialog.
4. Users can also check existing and imported weather data for continuity by clicking 

. If missing dates are found they must be populated in order for Wetbud to be able to calculate PET.

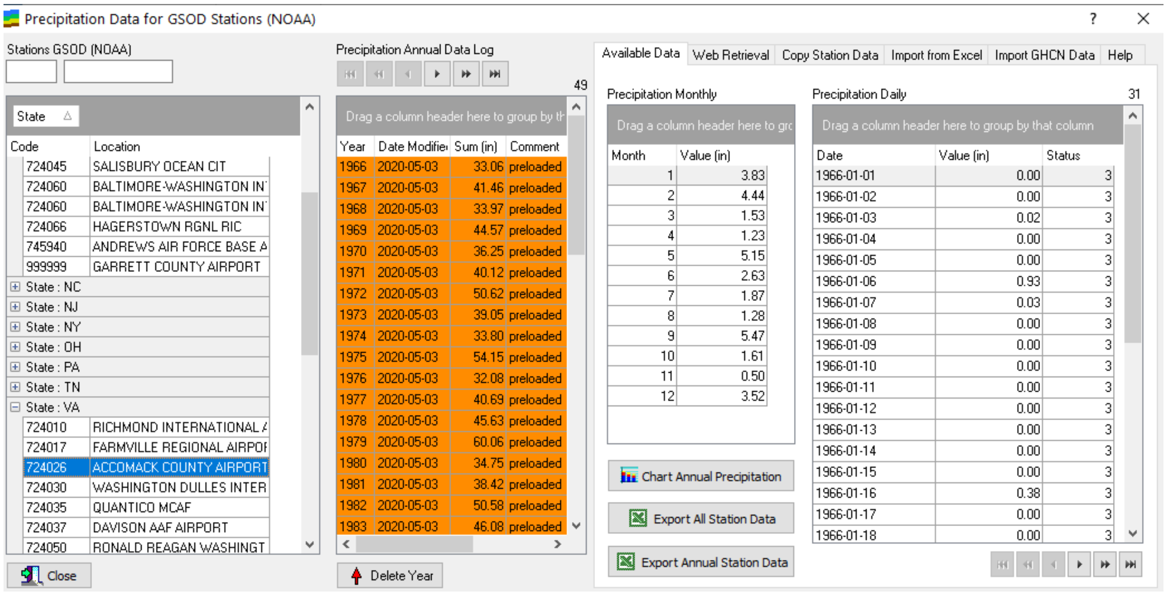


8.6 Precipitation Data for GSOD

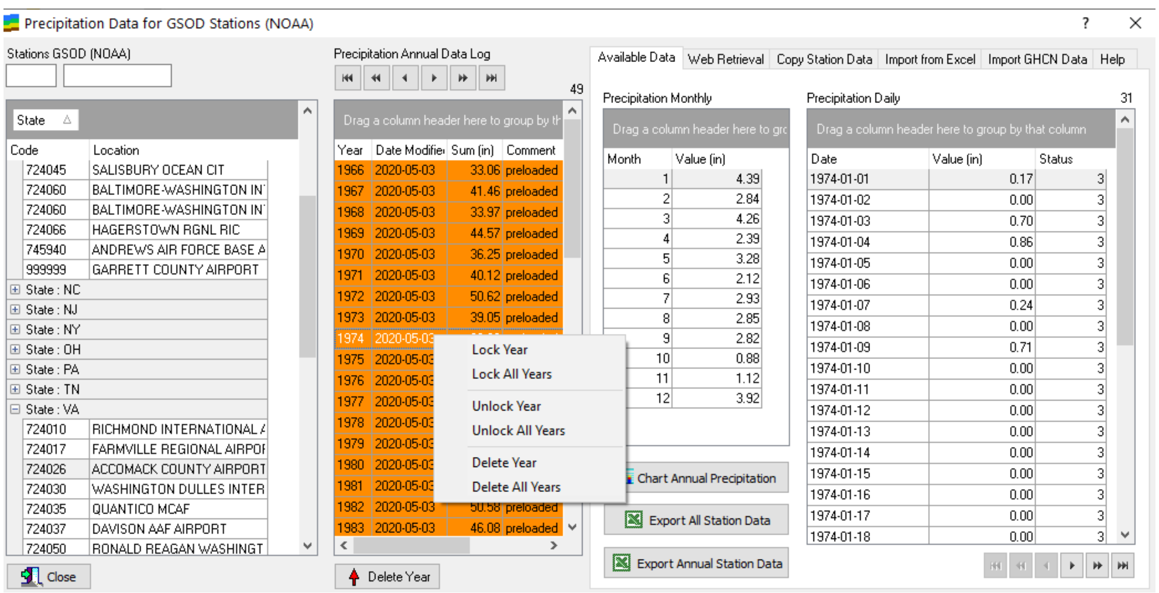
Under the Precipitation Data menu, the user can download the precipitation data available for each NOAA station in the Station list and/or manually import precipitation for any station in the Station list. Details regarding precipitation data downloaded for GSOD and GHCN stations can be found in the ‘Help’ tab in their respective Precipitation Data windows.

8.6.1 GSOD Stations - Available Data

This screen allows for all available data to be listed and checked.



Once data are finalized, the user can right click a selection in the Precipitation Annual Data Log to lock a single year or all years for the selected station. Locked years are shown in orange.



Under the Precipitation Data menu, the user can download the precipitation data available for each NOAA station in the Station list and/or manually import precipitation for any station in the Station list. Details regarding precipitation data downloaded for GSOD and GHCN stations can be found in the Help tab in their respective Precipitation Data windows.

To export all daily precipitation data for a station:

1. In the Available Data tab, select the station from the station list on the left side of the Precipitation Data window.

2. Next, click Export ALL Station Data.
3. Name and save the file in the desired format.

To export daily precipitation data for a single year:

1. In the Available Data tab, select the station from the station list on the left side of the Precipitation Data window.
2. Select the year from the Precipitation Annual Log and click Export Annual Station Data.
3. Name and save the file in the desired format.

To display a chart of annual precipitation for the selected station, click Chart Annual Precipitation.

8.6.2 GSOD Stations - Web Retrieval

1. Select Precipitation Data – NOAA (GSOD) from the Parameters menu in the Wetbud home screen.
2. Click the Web Retrieval tab and select a station from the list on the left side of the window.
3. Enter the range of years or year to be downloaded in the Range of Years or Single Year tabs.
4. Click 1. Download Data. Download progress is shown in the Progress Log at the bottom of the window. After the download is complete click 2. Import Data to import the data. Select OK from the prompt that follows. Years that have been imported will then be listed in the Precipitation Annual Log in addition to the date of import (date modified), annual totals in inches and centimeters, and the manner in which they were imported (e.g., automatically or manually), shown in the Comment section.
5. Select the Available Data tab to view tables of annual, monthly, and daily data for all years imported for the station. Totals are listed inches and centimeters in each table.

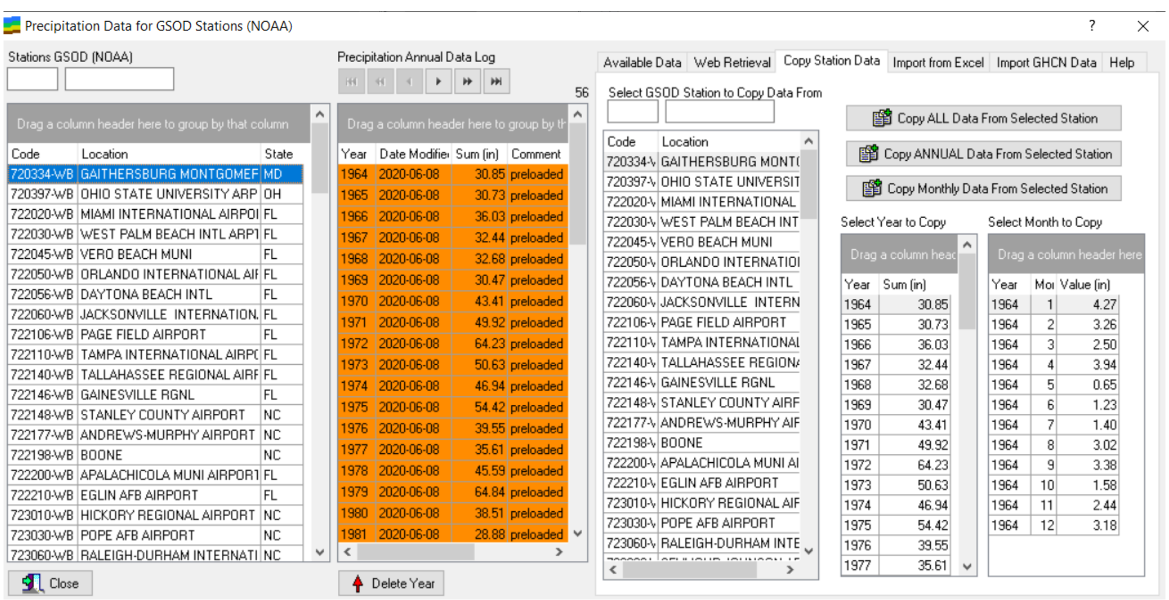
Note: The number displayed below the bottom left corner of the Precipitation Daily grid indicates the number of days included in the weather data set for the selected month. A number less than the total number of days in that month indicates that there are days that lack data. Should this occur, the user can export the data as an Excel file and supplement the missing data with data from a weather station nearby. The user can then manually re-import the corrected precipitation data set for that year. Alternatively, users can copy whole years or months from stations within their databases using the instructions in the Copy Station Data section.

8.6.3 GSOD Stations - Copy Station Data

To copy precipitation data:

1. Select the Copy Station Data tab in the Precipitation Data window.

2. Select the station to which you wish to copy data from the station list on the left side of the window.
3. Select the station from which you wish to copy data from in the Select Station to Copy Data From list.
4. To copy all precipitation data from a station, next click Copy ALL Data From Selected Station. Click Yes at the prompt to overwrite existing data to confirm your selection. All data that have been copied will now appear in the Precipitation Annual Log for the selected station.
5. To copy data for a single year first select the year to which to copy the data from the Select Year to Copy list, then click Copy ANNUAL Data From Selected Station. Click Yes at the prompt to overwrite existing data to confirm your selection. The annual data that have been copied will now appear in the Precipitation Annual Log for the selected station.
6. To copy data for a specific month from a given year, select the year and month to copy from the Select Year to Copy From and Select Month to Copy From lists respectively. Click Copy Monthly Data From Selected Station. Click Yes at the prompt to overwrite existing data to confirm your selection. The data from the copied month will be added to the record of the corresponding year in the Precipitation Annual Log.

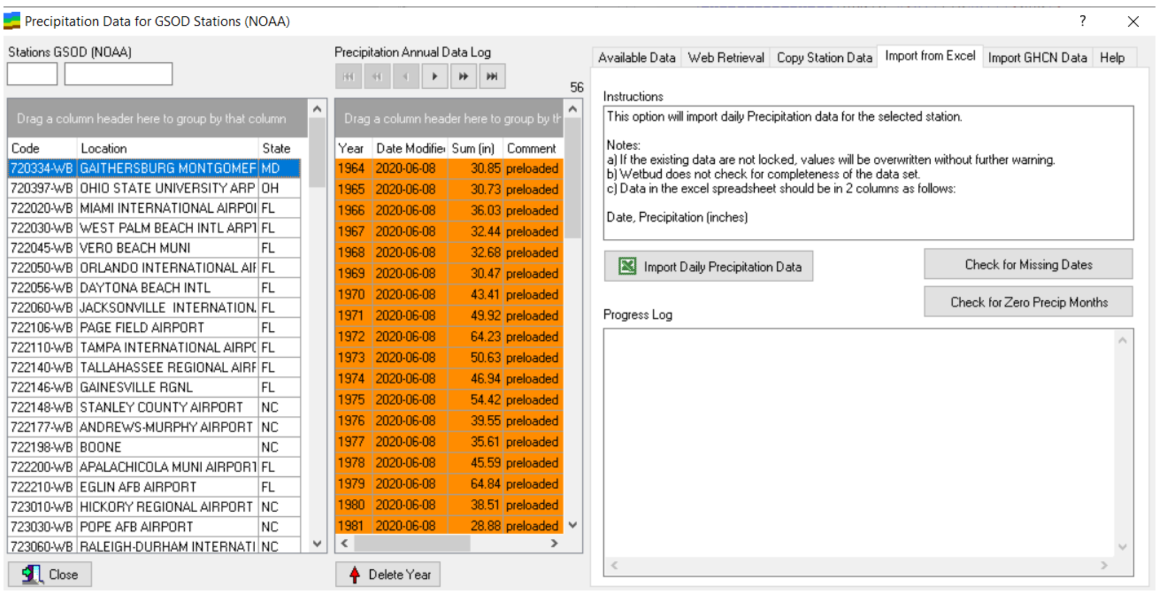


8.6.4 GSOD Stations - Import from Excel

To manually import precipitation data:

1. Select the Import from Excel tab in the Precipitation Data window and then select the station to which you wish to import data from the station list on the left side of the window.
2. Next, click Import Daily Precipitation Data and follow the instructions in the dialog.

3. The user can check data for missing dates and months with no precipitation by clicking on **Check for Missing Dates** and **Check for Zero Precip Months**, respectively. If missing dates are found they must be populated in order for Wetbud to be able to calculate the water budget.



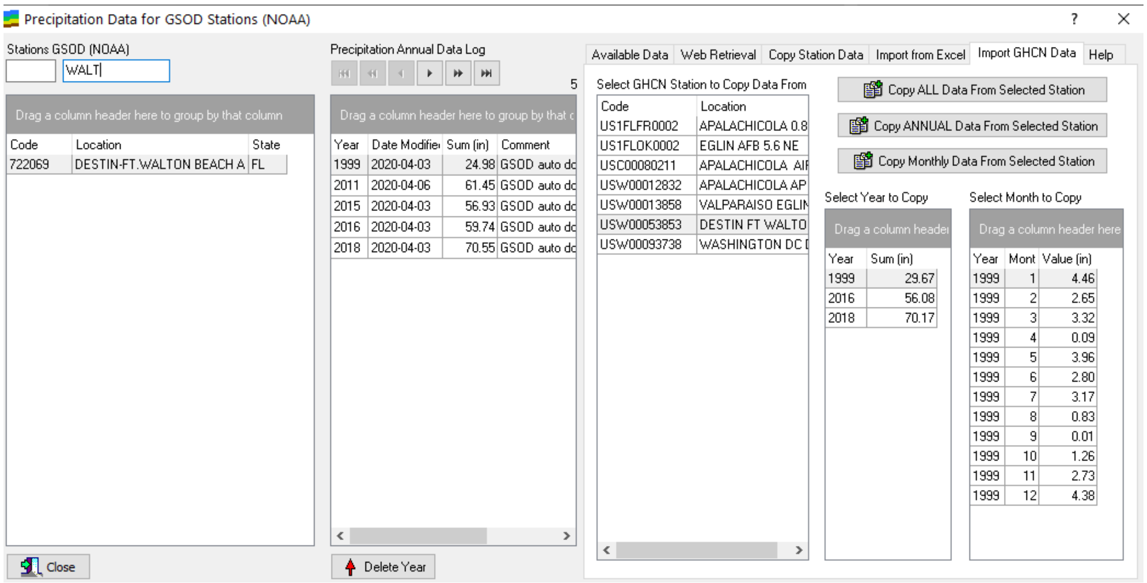
8.6.5 GSOD Stations - Import GHCN

Some users may want to use precipitation data from a GHCN station that is closer to their Project site than the nearest GSOD station from which weather and/or solar data have been downloaded (solar and weather data are not available for GHCN stations). In this situation the user can copy previously imported precipitation data from a GHCN station into the GSOD station precipitation data set.

1. Select the Import GHCN tab in the Precipitation Data window.
2. Select the GSOD station to which you wish to copy data from the station list on the left side of the window.
3. Select the station from which you wish to copy data in the Select GHCN Station to Copy Data From list.
4. To copy all available data for a station, click **Copy ALL Data From Selected Station**. Click Yes at the prompt to overwrite existing data to confirm your selection. The data that have been copied will now appear in the Precipitation Annual Log for the selected station.
5. To copy data for a single year first select the year to copy from the Select Year to Copy list then click **Copy ANNUAL Data From Selected Station**. Click Yes at the prompt to overwrite existing data to confirm your selection. The annual data that have been copied will now appear in the Precipitation Annual Log for the selected station.
6. To copy data for a specific month from a given year, select the year and month to copy from the Select Year to Copy From and Select Month to Copy From lists,

respectively. Click 

. Click Yes at the prompt to overwrite existing data to confirm your selection. The data from the copied month will be added to the record of the corresponding year in the Precipitation Annual Data Log.

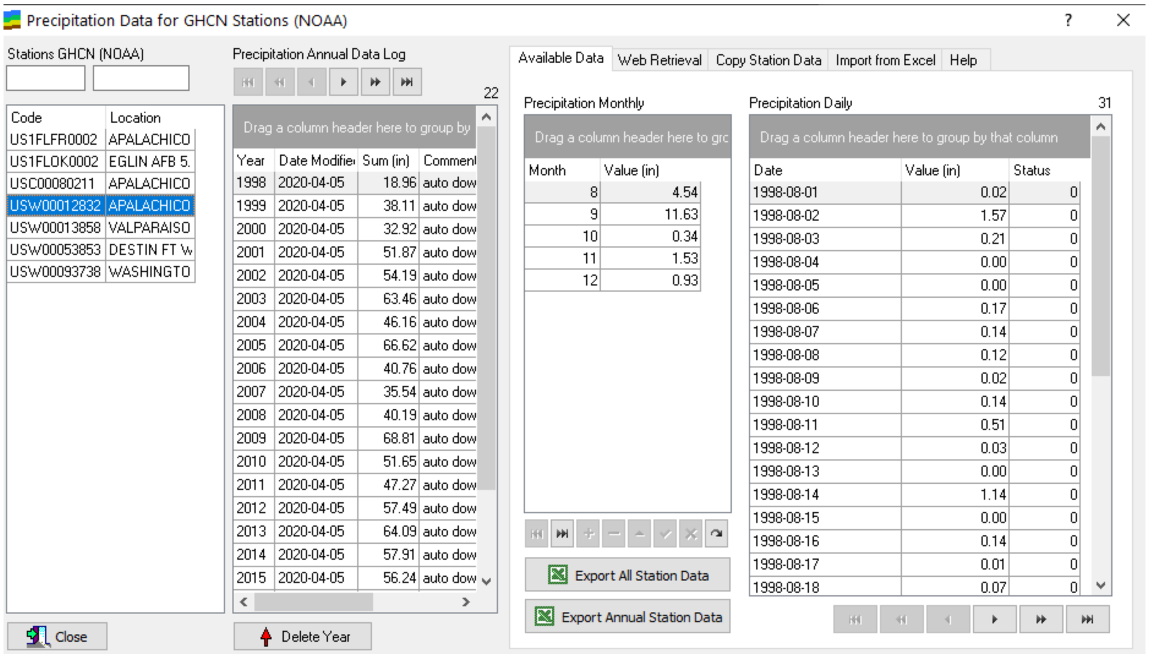


8.7 Precipitation Data for GHCN

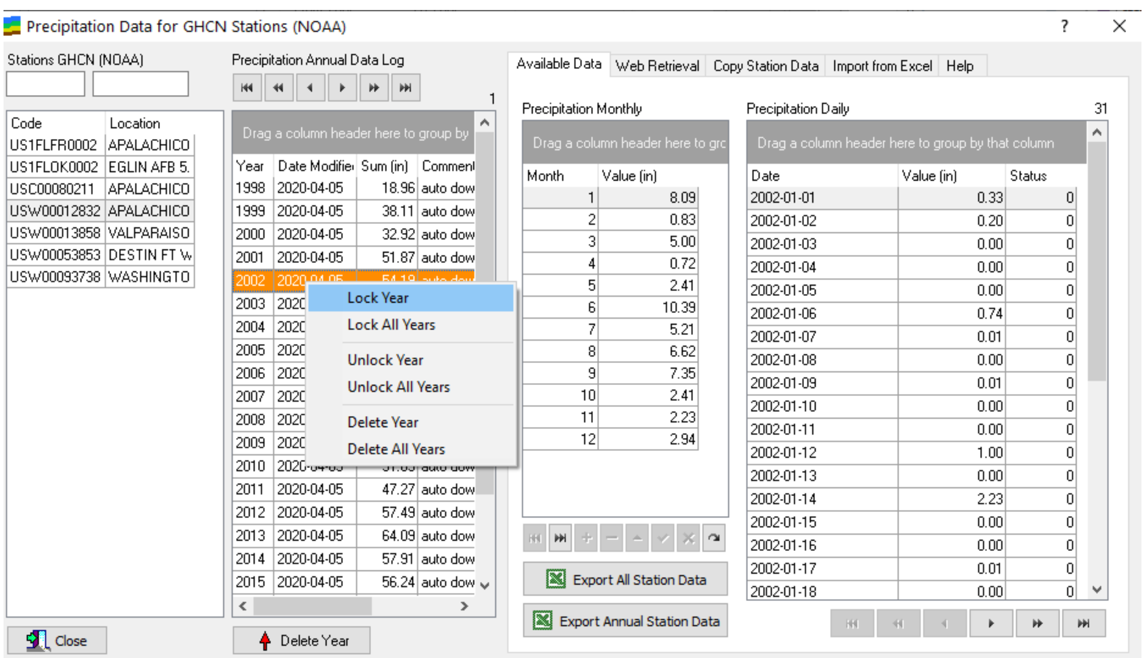
Under the Precipitation Data menu, the user can download the precipitation data available for each NOAA station in the Station list and/or manually import precipitation for any station in the Station list. Details regarding precipitation data downloaded for GSOD and GHCN stations can be found in the 'Help' tab in their respective Precipitation Data windows.

8.7.1 GHCN Stations - Available Data

This screen allows for all available data to be checked and selected



Once data are finalized, the user can right click a selection in the Precipitation Annual Data Log to lock a single year or all years for the selected station. Locked years are shown in orange.



Under the Precipitation Data menu, the user can download the precipitation data available for each NOAA station in the Station list and/or manually import precipitation for any station in the Station list. Details regarding precipitation data downloaded for GSOD and GHCN stations can be found in the 'Help' tab in their respective Precipitation Data windows.

To export all daily precipitation data for a station:

1. In the Available Data tab, select the station from the station list on the left side of the Precipitation Data window.
2. Next, click Export ALL Station Data.
3. Name and save the file in the desired format.

To export daily precipitation data for a single year:

1. In the Available Data tab, select the station from the station list on the left side of the Precipitation Data window.
2. Select the year from the Precipitation Annual Log and click Export Annual Station Data.
3. Name and save the file in the desired format.

8.7.2 GHCN Stations - Web Retrieval

1. Select Precipitation Data – NOAA (GHCN) from the Parameters menu in the Wetbud home screen.
2. Click the Web Retrieval tab and select a station from the list on the left side of the window.
3. Enter the range of years or year to be downloaded in the Range of Years or Single Year tabs.
4. Click 1. Download Data. Download progress is shown in the Progress Log at the bottom of the window. After the download is complete click 2. Import Data to import the data. Select OK from the prompt that follows. Years that have been imported will then be listed in the Precipitation Annual Log in addition to the date of import, annual totals in inches and centimeters, and the manner in which they were imported (e.g., automatically or manually).
5. Select the Available Data tab to view tables of annual, monthly, and daily data for all years imported for the station. Totals are listed inches and centimeters in each table.

Note: The number displayed below the bottom left corner of the Precipitation Daily grid indicates the number of days included in the weather data set for the selected month. A number less than the total number of days in that month indicates that there are days that lack data. Should this occur, the user can export the data as an Excel file and supplement the missing data with data from a weather station nearby. The user can then manually re-import the corrected precipitation data set for that year.

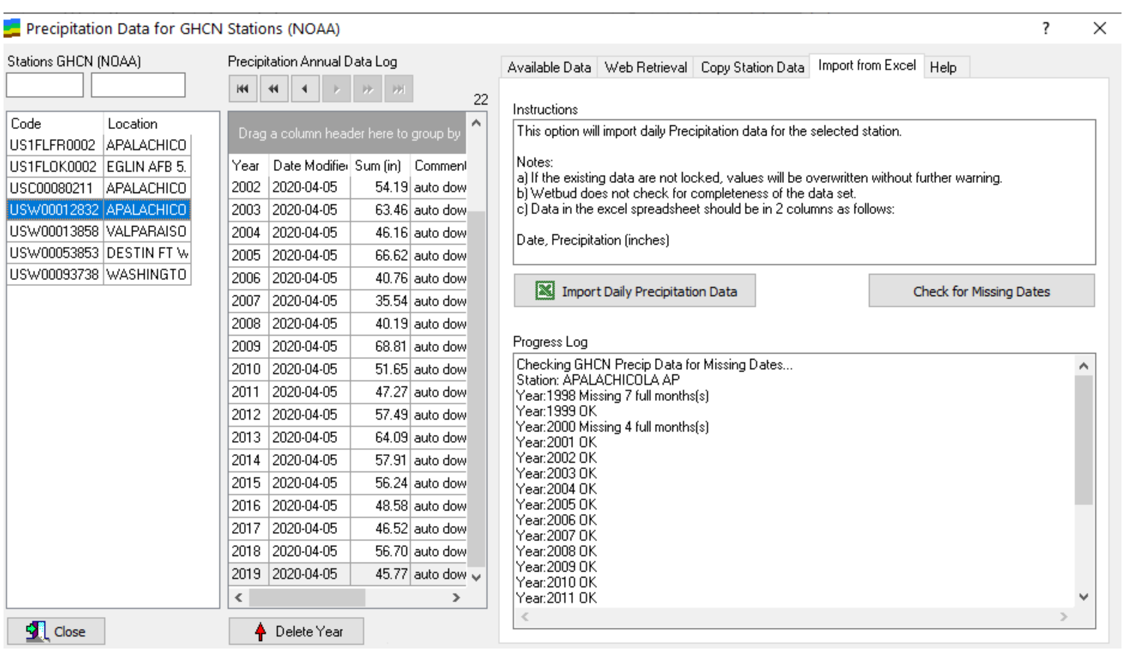
8.7.3 GHCN Stations - Copy Station Data

1. Select the Copy Station Data tab in the Precipitation Data window.
2. Select the station to which you wish to copy data from the station list on the left side of the window.
3. Select the station from which you wish to copy data from in the Select Station to Copy Data From list.

4. To copy all precipitation data from a station, click Copy ALL Data From Selected Station. Click Yes at the prompt to overwrite existing data to confirm your selection. All data that have been copied will now appear in the Precipitation Annual Log for the selected station.
5. To copy data for a single year first select the year to which to copy the data from the Select Year to Copy list, then click Copy ANNUAL Data From Selected Station. Click Yes at the prompt to overwrite existing data to confirm your selection. The annual data that have been copied will now appear in the Precipitation Annual Log for the selected station.
6. To copy data for a specific month from a given year, select the year and month to copy from the Select Year to Copy From and Select Month to Copy From lists, respectively. Click Copy Monthly Data From Selected Station. Click Yes at the prompt to overwrite existing data to confirm your selection. The data from the copied month will be added to the record of the corresponding year in the Precipitation Annual Data Log.

8.7.4 GHCN Stations - Import from Excel

1. Select the Import from Excel tab in the Precipitation Data window and then select the station to which you wish to import data from the station list on the left side of the window.
2. Next, click Import Daily Precipitation Data and follow the instructions in the dialog.
3. The user can check data for missing dates by clicking Check for Missing Dates.



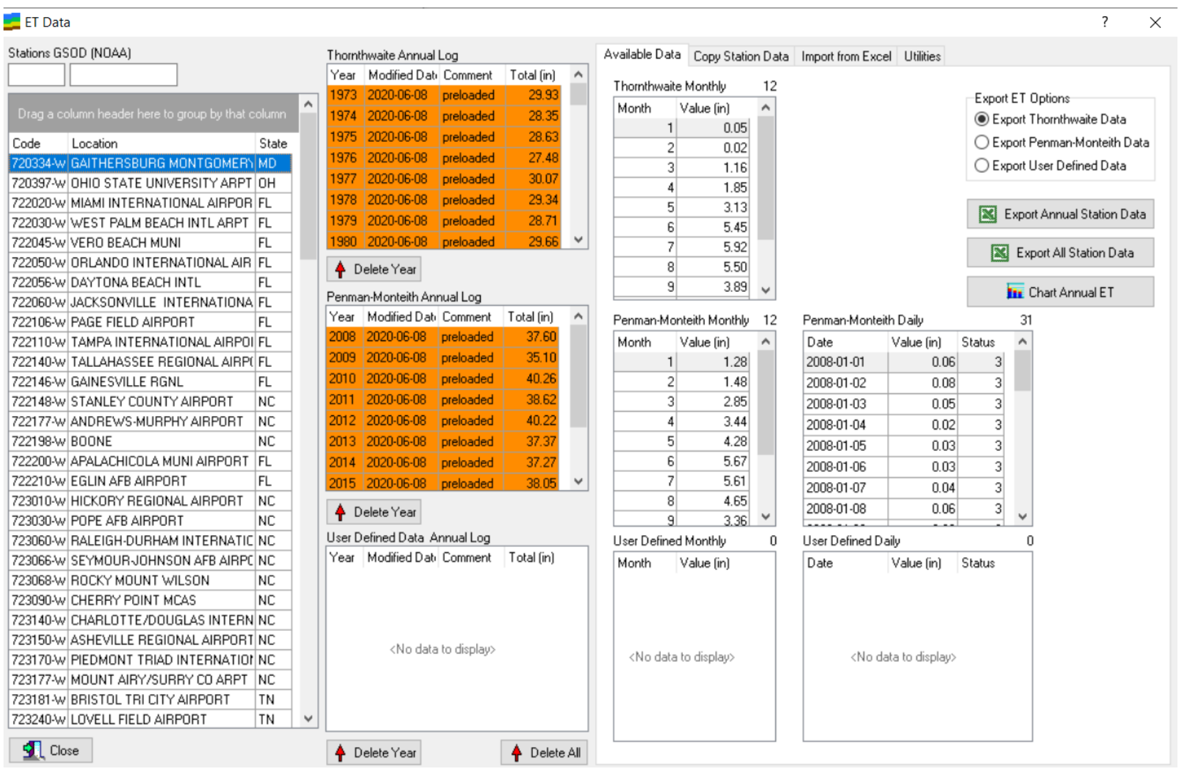
8.8 ET Data

The ET Data window is used to view annual, monthly, and/or daily totals of PET calculated by Wetbud or manually imported for a weather station. The PET data are organized in the Available Data tab annually and monthly for both the Thornthwaite and Penman-Monteith PET options as well as daily for Penman-Monteith PET.

In addition users can enter their own daily time series which can be either measured values or values calculated external to Wetbud.

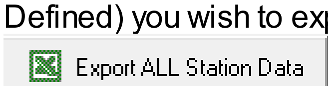
8.8.1 Available Data

This screen allows for all available data to be listed and checked.



PET data cannot be exported unless they have been calculated by Wetbud in Basic Scenario output or manually imported by the user.

To export all PET data for a station:

1. In the Available Data tab, select the station from which you wish to export data from the station list on the left side of the ET Data window.
2. Next, select the type of ET data (e.g., Thornthwaite, Penman-Monteith or User Defined) you wish to export from the Export ET Options box. Click 

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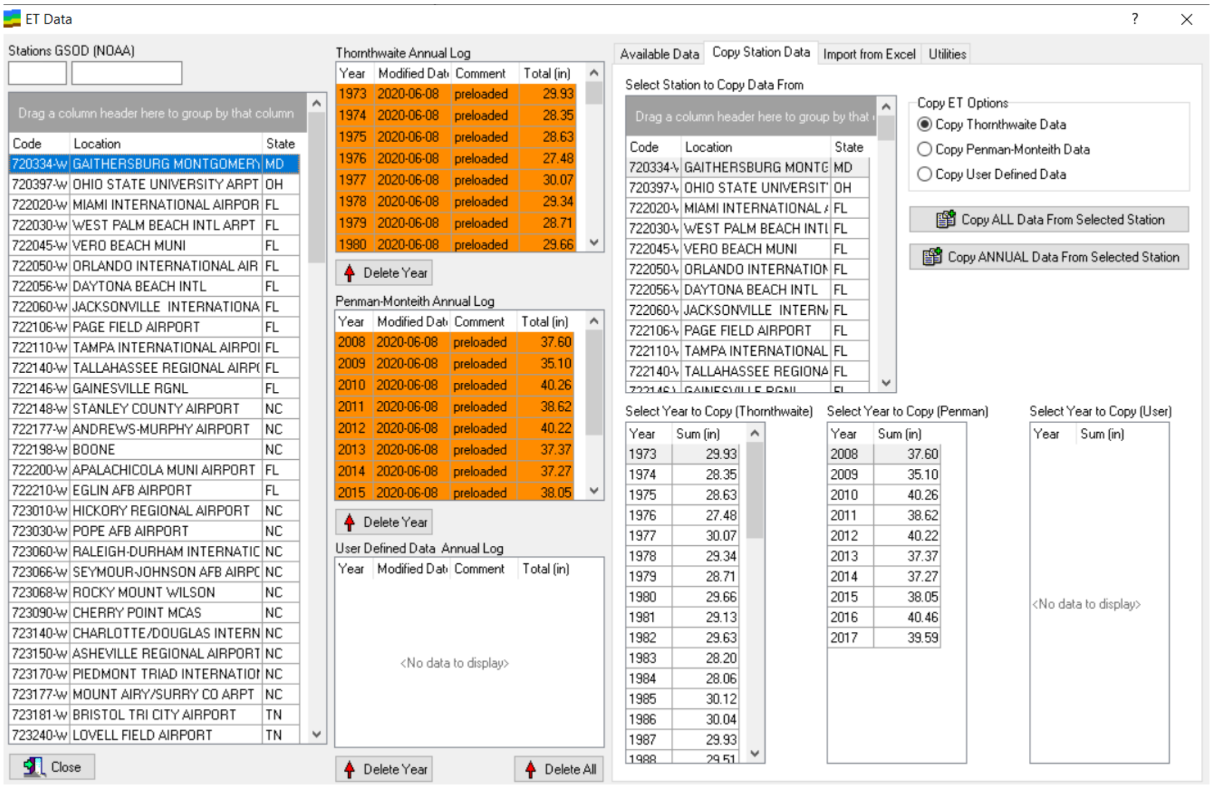
3. Name and save the file in the desired format.

To export PET data for a single year:
1. In the Available Data tab, select the station from which you wish to export data from the station list on the left side of the ET Data window.
2. Next, select the type of ET data (e.g., Thornthwaite, Penman-Monteith or User Defined) you wish to export from the Export ET Options box.
3. Select the year your wish to export from the Thornthwaite Annual Log, the Penman-Monteith Annual Log or the User Defined Data Annual Log. Click Export Annual Station Data.
4. Name and save the file in the desired format.

Note 1: Thornthwaite ET will be exported as monthly totals. Penman-Monteith ET will be exported as daily totals. User Defined ET will be exported as daily totals.
Note 2: Once data are finalized, the user can right click a selection in the corresponding Annual Log to lock a single year or all years for the selected station. Locked years are shown in orange.

8.8.2 Copy Station Data

To copy PET data from one station to another:
1. Select the Copy Station Data tab in the ET Data window.
2. Select the station to which you wish to copy data from the station list on the left side of the window.
3. Select the station from which you wish to copy data from the Select Station to Copy Data From list.
4. In the Copy ET Options box, select the type of ET data to be copied. To copy data for a single year, first select the year to copy from the Select Year to Copy list.
5. Next, select the year to copy from the Thornthwaite Annual Log, the Penman Annual Log or the User Defined Annual Log and then click Copy ANNUAL Data From Selected Station. Click Yes at the prompt to overwrite existing data to confirm your selection. The annual data that have been copied will now appear in the corresponding annual log for the selected station. To copy all data from a station, click Copy ALL Data From Selected Station. Click Yes at the prompt to overwrite existing data to confirm your selection. The data from the copied month will be added to the record of the corresponding year in the ET Annual Log.



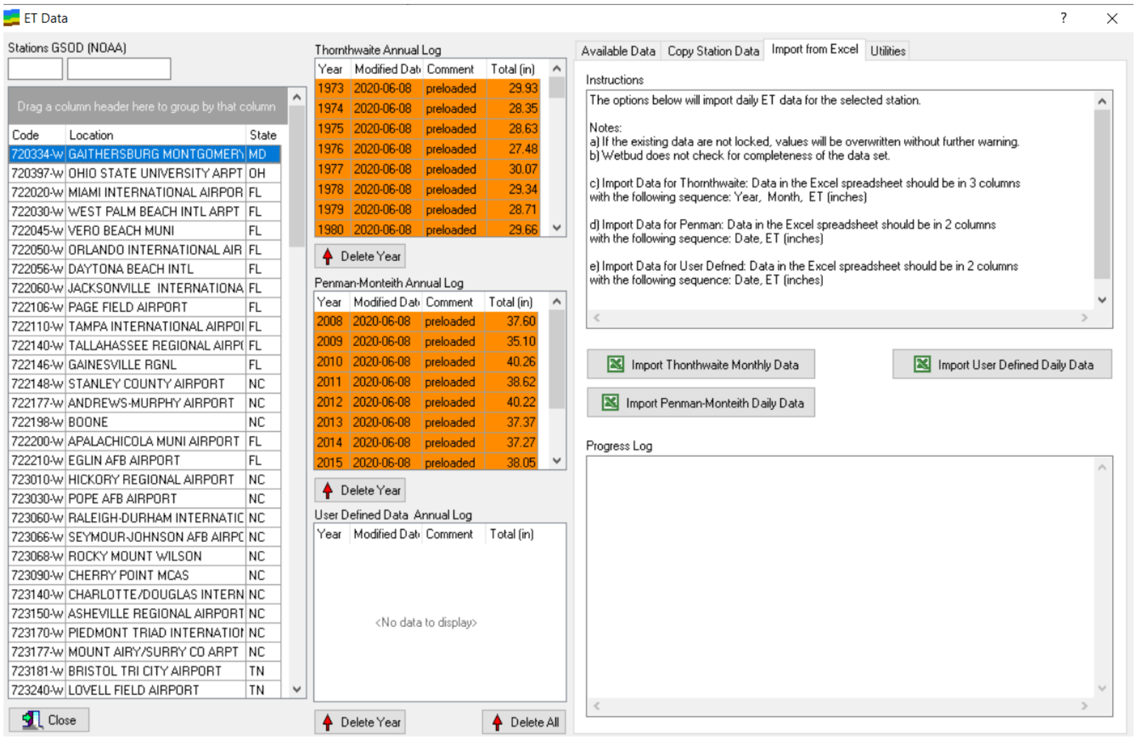
Note: The units in the figure above are metric. That depends on the default unit setting. See Settings for more information.

8.8.3 Import from Excel

To manually import PET data:

1. Select the Import from Excel tab in the ET Data window.
2. Select the station for which you wish to import data from the station list on the left side of the window.
3. Click Import Thonthwaite Monthly Data or Import Penman-Monteith Daily Data or Import User Defined Daily Data and follow the instructions in the dialog.

Note: The user may also choose this option if they have manually calculated daily or monthly PET values using a method other than Penman-Monteith or Thornthwaite. If the user chooses to do so it is recommended that the appropriate notes are made in the station and/or Scenario to which the data are applied.



8.8.3.1 Import Thornthwaite

To manually import Thornthwaite data:

1. Select the Import from Excel tab in the ET Data window.
2. Select the station for which you wish to import data from the station list on the left side of the window.
3. Click 

and follow the instructions in the dialog.

Note 1:

1. The imported Excel file should have three columns as follows: YEAR, MONTH, ET value (in).
2. Additional columns will be ignored.
3. Multiple title rows can be excluded.
4. Importing always starts from column 1.
5. The current weather Station is displayed on the title bar of the import window.
6. The name of the currently selected file for import is displayed below the grid.
7. The number of rows and columns of the Excel data sheet that will be used during the import procedure are automatically identified. If these values do not match the data that are available for import, a new Excel file should be created with the data to be imported.
8. If existing annual data are not locked, existing records for imported dates will be overwritten without warning.
9. Errors during data import are logged.
10. Monthly values will be automatically aggregated.

Note 2: The user may also choose this option if they have manually calculated daily or monthly PET values using a method other than Penman-Monteith or Thornthwaite. If the user chooses to do so it is recommended that the appropriate notes are made in the station and/or Scenario to which the data are applied.

8.8.3.2 Import Penman

To manually import Penman-Monteith data:

1. Select the Import from Excel tab in the ET Data window.
2. Select the station for which you wish to import data from the station list on the left side of the window.
3. Click 

and follow the instructions in the dialog.

Note:

1. The imported Excel file should have two columns as follows: Date, ET value (in).
2. Additional columns will be ignored.
3. Multiple title rows can be excluded.
4. Importing always starts from column 1.
5. The current Weather Station is displayed on the title bar of the import window.
6. The name of the currently selected file for import is displayed below the grid.
7. The number of rows and columns of the Excel data sheet that will be used during the import procedure are automatically identified. If these values do not match the data that are available for import, a new Excel file should be created with the data to be imported.
8. If existing annual data are not locked, existing records for imported dates will be overwritten without warning.
9. Errors during data import are logged.
10. Monthly values will be automatically aggregated.

8.8.3.3 Import User Defined Data

The use can also import data if they have manually calculated daily or monthly PET values using another method. Simply click 

to import your own data.

Note 1:

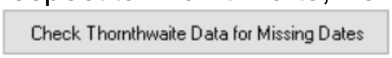
1. The imported Excel file should have two columns as follows: Date, ET value (in).
2. Additional columns will be ignored.
3. Multiple title rows can be excluded.
4. Importing always starts from column 1
5. The current weather Station is displayed on the title bar of the import window.
6. The name of the currently selected file for import is displayed below the grid.
7. The number of rows and columns of the Excel data sheet that will be used during the import procedure are automatically identified. If these values do not match the data

that are available for import, a new Excel file should be created with the data to be imported.

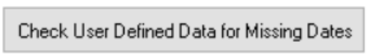
8. If existing annual data are not locked, existing records for imported dates will be overwritten without warning.
9. Errors during data import are logged.
10. Monthly values will be automatically aggregated.

Note 2: The user may choose this option if they have manually calculated daily or monthly PET values using a method other than Penman-Monteith or Thornthwaite. If the user chooses to do so it is recommended that the appropriate notes are made in the station and/or Scenario to which the data are applied.

8.8.4 Utilities

Missing dates can be searched for in the utilities tab. Dates can be checked for with respect to Thornthwaite, Penman-Monteith as well as User Defined Data by selecting 

, 

, and 

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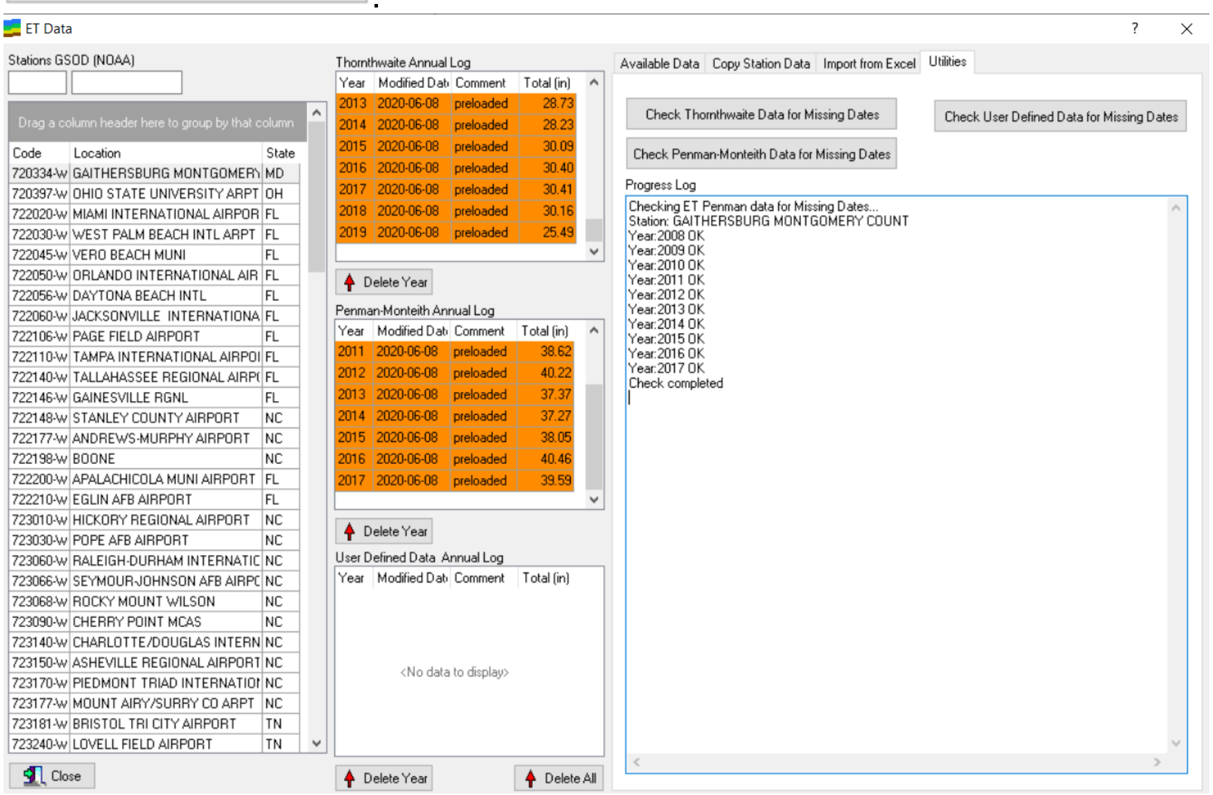


8.9 Parameters for ET (Penman-Montieth)

When the Penman-Monteith Method (calculated by Wetbud) PET option is chosen in the PET options of a Basic Scenario the user must assign a value for albedo and create and assign a Clear Sky Insolation data set for their Project site.

Details and explanation pertaining to the calculation of PET using the Penman-Monteith equations can be found in Jensen et al. (1990) and Allen et al. (1998).

8.9.1 Albedo

Albedo is defined as the fraction of short-wave radiation reflected by a surface. This value can be highly variable depending on land cover type. Wetbud uses a default (recommended) value of 0.23, which is the assumed albedo for a green grass reference crop. Albedo values for common land cover types are listed in the following table.

Albedo value ranges for land cover types are given below (adapted from http://www.climatedata.info/forcing/albedo/).

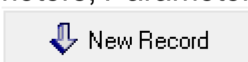
Surface	Range of Albedo
Fresh snow	0.80 to 0.90
Old/melting snow	0.40 to 0.80
Desert sand	0.40
Grassland	0.23
Deciduous trees	0.15 to 0.18
Coniferous forest	0.08 to 0.15
Tundra	0.20
Ocean	0.07 to 0.10

For additional information on albedo and its effect on PET using the Penman-Monteith method, you may refer to either Chaubey and Ward (2006), or http://www.climatedata.info/forcing/albedo/.

8.9.2 Clear Sky Insolation Index

According to NASA's Atmospheric Science Data Center (2012), the "Monthly Averaged Clear Sky Insolation Clearness Index (0 to 1.0) is defined as the monthly average amount of the total solar radiation incident on a horizontal surface at the surface of the earth when the cloud cover is less than 10% divided by the monthly average incoming top-of-atmosphere insolation for a given month, averaged for that month over the 22-year period (Jul 1983 - Jun 2005); (i.e., clearness index is the fraction of insolation at the top of the atmosphere which reaches the surface of the earth)."

To create a Clear Sky Insolation Index data set:

1. Navigate to Clear Sky Insolation Index Data in the drop-down menu under Parameters, Parameters for ET in the Wetbud home screen.
2. Click 

in the General tab in the Clear Sky Insolation Index Data window. Enter a code, description, latitude, and longitude of the Project site and click  to save.
3. In the Monthly Averages tab click 

. Wetbud automatically defaults to 1971 for the first year. Edit the year in the year box and save. Enter the monthly values (default = 0.7 for all months) for that year and save.
4. Repeat steps 1-3 for every year to be included in the Penman-Monteith calculations for PET. To delete a year, click Delete  and select OK from the prompt to confirm your selection
5. To obtain monthly Clear Sky Insolation Index values other than those listed as defaults in Wetbud, refer to https://power.larc.nasa.gov/data-access-viewer/ and follow the following steps. From the Data Access Viewer mapping application:
   a. Enter a lat/long or specify a location on the map.
   b. Select a representative time extent.
   c. Choose an output format.
   d. In the "Search Parameters" section expand "Solar fluxes and related."
   e. Then choose "All sky normalized insolation clearness index."
   f. Click "Submit."
   g. Record the average monthly index value from the representative time period you chose.
   h. More information about this dataset can be accessed through https://ceres.larc.nasa.gov/documents/DQ_summaries/CERES_SYN1deg_Ed4A_DQS.pdf.

8.10 Parameters for ET (Thornthwaite)

When the Thornthwaite Equation (calculated by Wetbud) is chosen in the PET Options section in a Basic Scenario, a daylight length data set must be created for the latitude of the Project site. Details and explanation pertaining to the calculation of PET using the Thornthwaite Equation can be found in Thornthwaite (1948).

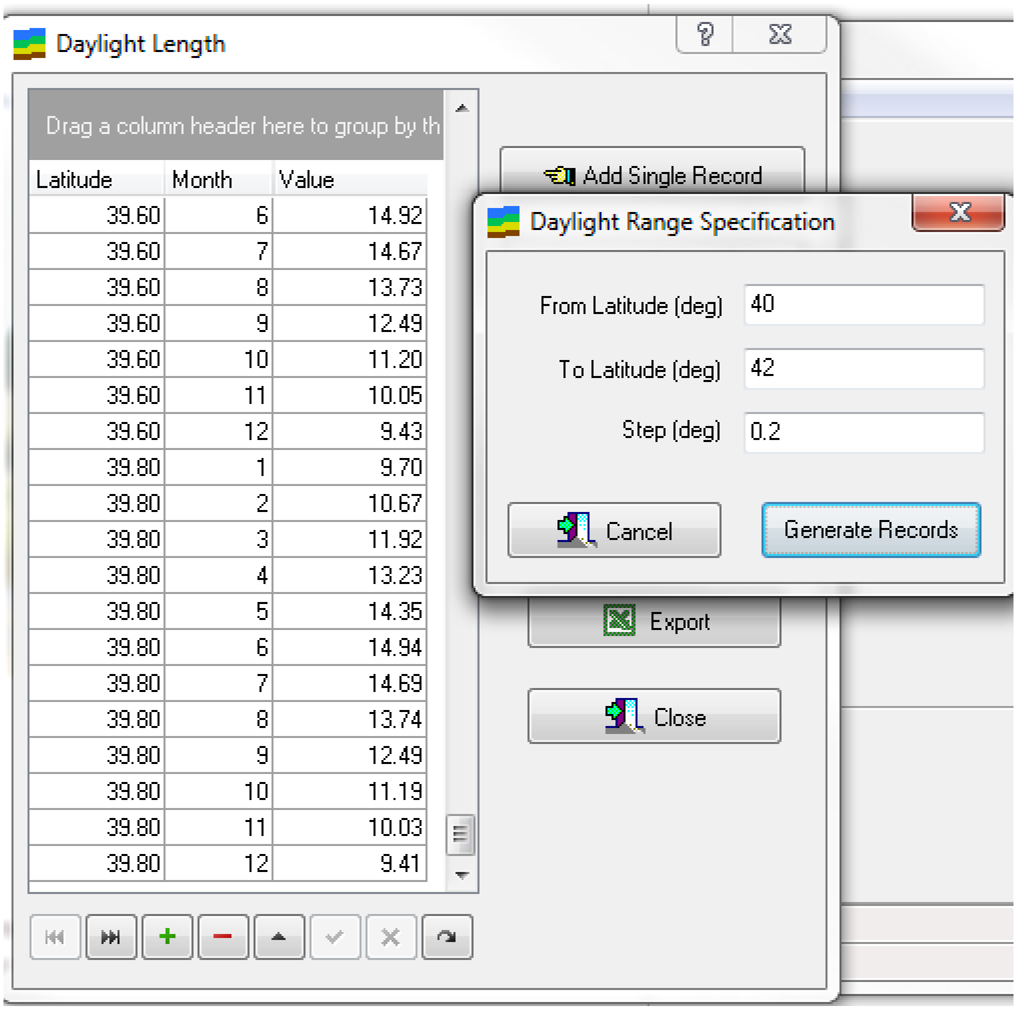
8.10.1 Daylight Length Data

Daylight length is defined as the maximum amount of daylight hours for a given month of the year at specific latitudes.

To create or add to the existing daylight length data set:

1. Navigate to Daylight Length Data (Thornthwaite) in the drop-down menu under Parameters, Parameters for ET in the Wetbud home screen.
2. Click Generate Record Range in the Daylight Length window. In the Daylight Range Specification window, enter the desired range of latitudes in the From Latitude and To Latitude boxes and assign a step interval (default = 0.5 degrees).
3. Next, click Generate Records. The daylight lengths corresponding to all months for all latitudes in the specified range are now listed in the Daylight Length window.
4. To add a single record for a specific month and latitude, click Add Single Record. A single record will appear at the bottom of the list with defaults of 99.00, 1, and 99.00 for latitude, month, and daylight length, respectively. Make the desired changes and save.

The figure below shows how to generate daylight values for latitudes between 40 and 42 with a step of 0.2.

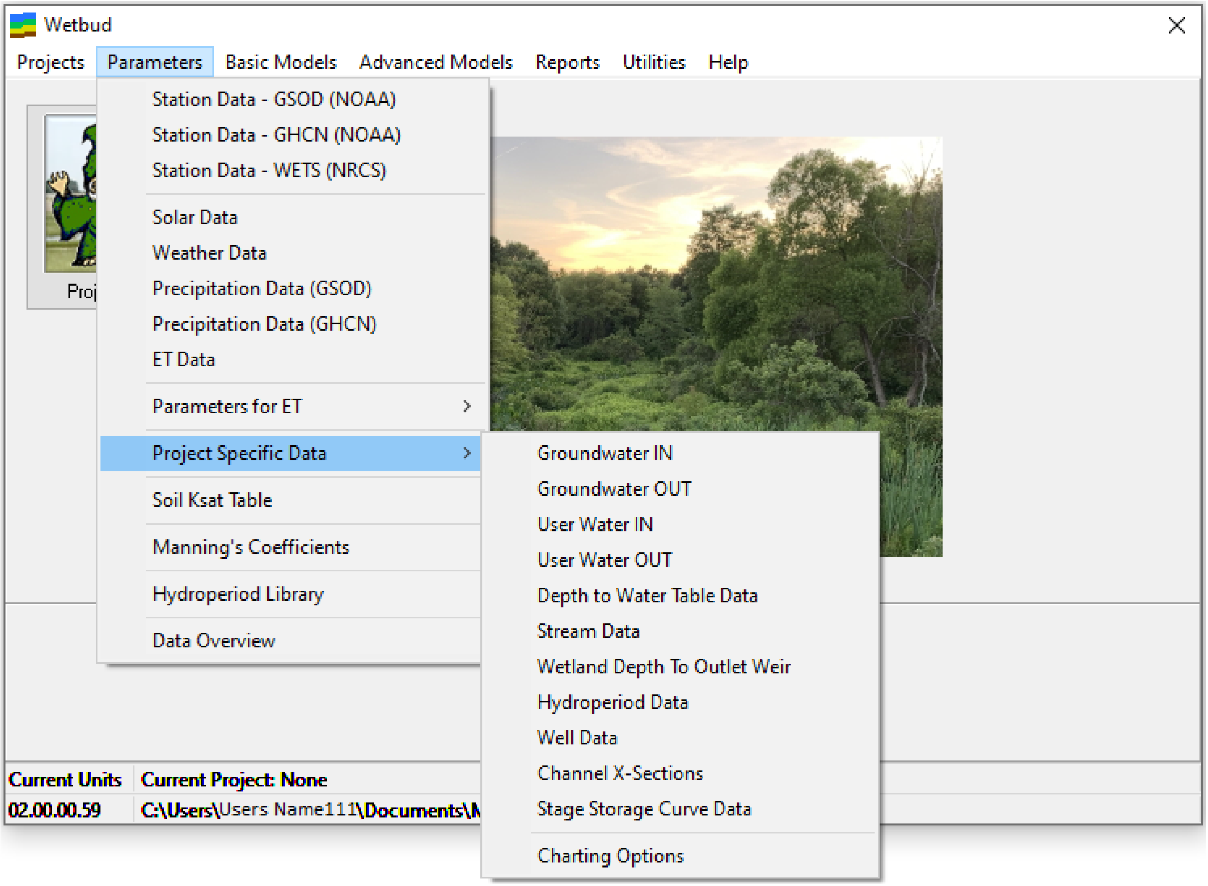


Note: There are several calculators available online that can be used to determine the maximum daylight hours for a given latitude. One resource that provides this information on a lat/lon basis is https://www.esrl.noaa.gov/gmd/grad/solcalc/.

8.11 Project Specific Data

The following section includes instructions for creating data sets for use in the Water Inputs/Outputs menu, as well as details and explanations of the following:

- Groundwater IN and Groundwater OUT
- User Water IN and User Water OUT
- Stream Data
- Wetland Depth to Weir
- Reference Hydroperiod Data
- Well Data
- Channel X-Sections
- Stage Storage Curve Data



Data sets for some of these parameters may need to be created prior to Basic or Advanced Model setup. Instructions pertaining to each are provided in this section. Lists of parameters needed for Basic and Advanced Model setup are located under Basic Models and under Advanced Models.

8.11.1 Creating a Water Inputs/Outputs Dataset

If one or more of the following options is selected in the Inputs and Outputs tab of Basic Scenario setup, the user must first create a monthly data set that contains the data to be included in the water budget analysis:

1. User Time Series for Groundwater In or Groundwater Out.
2. User Time Series Monthly Wetland Depth, or Daily Stream Discharge, or Hourly Stream Discharge for Stream Overbank Flow.
3. User Water In and/or User Water Out.
4. User Time Series for Wetland Depth to Outlet Weir.

Although each option in the Water Inputs/Outputs menu pertains to a different variable in the water budget calculations, the procedure to create a monthly data set for each option is essentially the same. Use the instructions below to create, import, and export a monthly data set for any of the options in the Project Specific Data section of the Parameters menu.

1. Select Groundwater IN/OUT, User Water IN/OUT, Stream Data, Wetland Depth to Weir, Hydroperiod Data, or Well Data from the drop-down menu under Parameters, Project Specific Data in the Wetbud home screen.
2. In the General tab, click . The box under Code is now filled with the default text. Delete this text and replace it with a code (10-character maximum) of your choice. Enter a description and any comments that pertain to the data, and the chart type (line or bar) you wish to use to display the monthly data. Click to save. You will now see the code you entered in the box on the left side of the window.

   Note 1: Users creating a Stream Data data set must assign the original data set resolution as Monthly Wetland Depth Values, Daily Stream Discharge Rate, or Hourly/Sub-daily Stream Discharge Rate. If Wetland Depth Values is selected as the data set Type, the user must enter average depth of surface water in the wetland for each month in the monthly values tab.
   Note 2: The default units assigned to each data set are the project units. However, the user may change the default units to either metric or English for importing or charting the data.
3. In the Monthly Depth Values tab, enter the first year in the analysis range in the Year box and click . To add a single month, click . To add all months for that year, check the Add All Months box and click . To delete a month, select that month from the list, click Delete , and select OK at the prompt to confirm. Once all months for the analysis range are entered in the list of monthly depth values, proceed by entering values (units shown in the Monthly Depth Values table) for each month in the list. Confirm you have correctly entered the monthly depth values by selecting the Data Chart tab or by clicking which displays a graph of monthly depth values entered in the data set.
4. The data set for the selected Water Inputs/Outputs parameter can now be chosen from the appropriate drop down list in Basic Scenario setup.

8.11.2 Importing a Water Inputs/Outputs Dataset

To import a Water Input/Output data set:

1. Select Groundwater IN/OUT, User Water IN/OUT, Stream Data, Wetland Depth to Weir, Hydroperiod Data, or Well Data from the drop-down menu under Parameters, Project Specific Data in the Wetbud home screen.
2. In the General tab, click . The box under Code is now filled with the default text. Delete this text and replace it with a code (10-character maximum) of your choice. Enter a description and any comments that pertain to the data, and the chart type (line or bar) you wish to use to display the monthly data. Click to save. You will now see the code you entered in the box on the left side of the window.

3. In the Monthly Depth Values tab, select the units of the data being imported (inches or cm), click 

and follow the instructions in the dialog. Note that some options allow for daily and/or sub-daily values.

8.11.3 Exporting a Water Inputs/Outputs Dataset

To export a Water Input/Output data set:

1. Select Groundwater IN/OUT, User Water IN/OUT, Stream Data, Wetland Depth to Weir, Hydroperiod Data, or Well Data from the drop-down menu under Parameters, Project Specific Data in the Wetbud home screen.
2. Select the data set you wish to export from the list on the left side of the window.
3. Click 

. Name and save the file in the desired format.

8.11.4 Groundwater IN/OUT

Users who wish to include groundwater input and/or groundwater output in a Basic Scenario water budget analysis for a site can calculate these values using observed hydraulic head data. Users who choose to calculate groundwater input and output using observed data at their site must create a monthly groundwater input data set in the Project Specific Data section of the Parameters menu. The rate (e.g., inches/month or cm/month) of groundwater input/output is calculated using the following procedure:

1. Calculate groundwater discharge (Q) using the following form of Darcy's Law:

$$Q = KA\frac{h_1 - h_2}{D}$$

where:

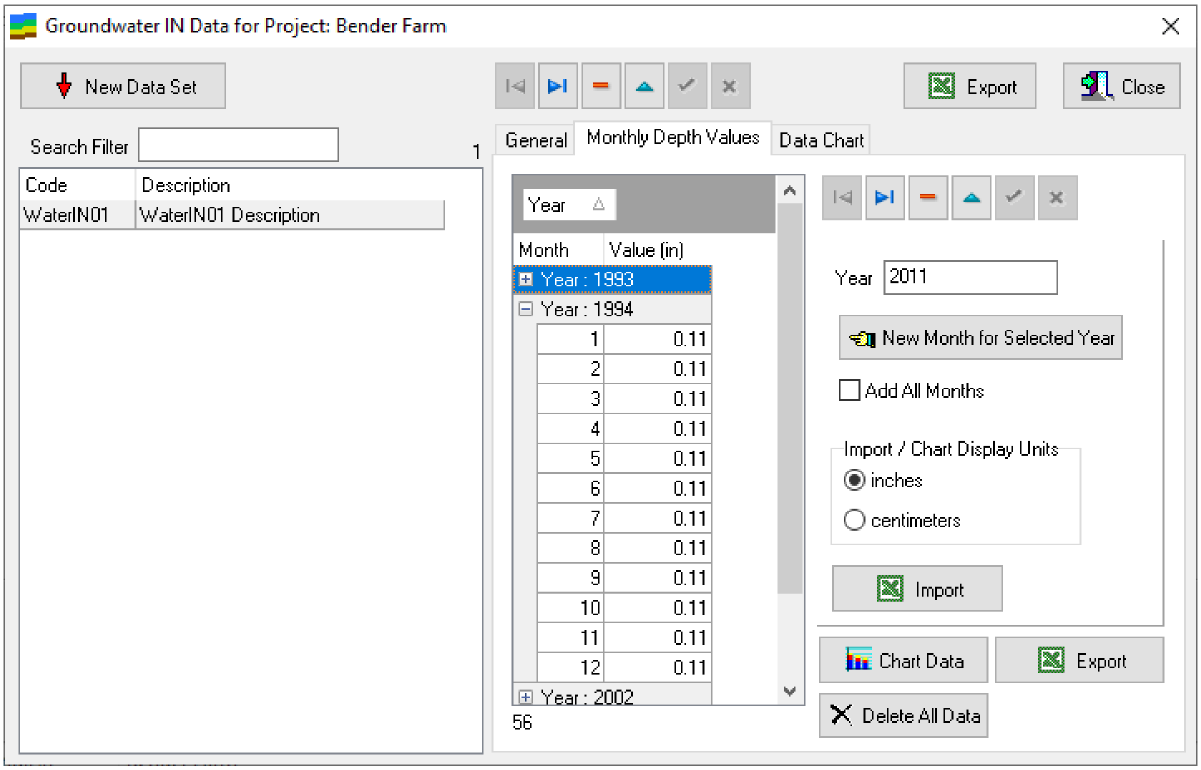
Q = groundwater discharge (cfs or m^3/sec)
K = hydraulic conductivity (ft/s or m/sec) of sediment in cross-section A
A = cross-sectional area (ft^2 or m^2); width of wetland x thickness of sediment
h1 = average head elevation (ft or m) in up-gradient well for chosen month
h2 = average head elevation (ft or m) in down-gradient well for chosen month
D = horizontal distance (ft or m) between h1 and h2

2. Divide groundwater discharge (Q) by the constructed wetland Surface Area (m^2) (SA = L x W). WEM Setup for representative positions of h1 and h2 for calculating groundwater input and groundwater output.

Note: For many wetlands, groundwater exits as downward seepage across much of the site and not just on the down-gradient end. Users that wish to calculate groundwater output as downward seepage should establish the hydraulic gradient in Darcy's Law using the vertical gradient between two adjacent piezometers, not monitoring wells, which are used to calculate groundwater exiting on the down-gradient end of the site. If piezometer data are not available to determine the downward gradient, users can estimate groundwater output as downward seepage by applying a value of 0.05 for the hydraulic gradient. A value of 0.05 is based on the average downward vertical gradients (typical range = 0.01-0.20) observed by the authors in piezometers nested in wetlands.

In many cases, users will not have sufficient head elevation data to calculate groundwater input or the ability to generate reliable estimates of groundwater input for years that lack observed head elevation data. Users who do not have sufficient head data for these calculations can perform a WEM analysis within Wetbud which estimates groundwater input. Using the WEM is a two-step process that consists of WEM setup and WEM calculations.

A groundwater IN/OUT time series may include multiple years that can be used in calculating water budgets for typical DNW years.



8.11.5 User Water IN/OUT

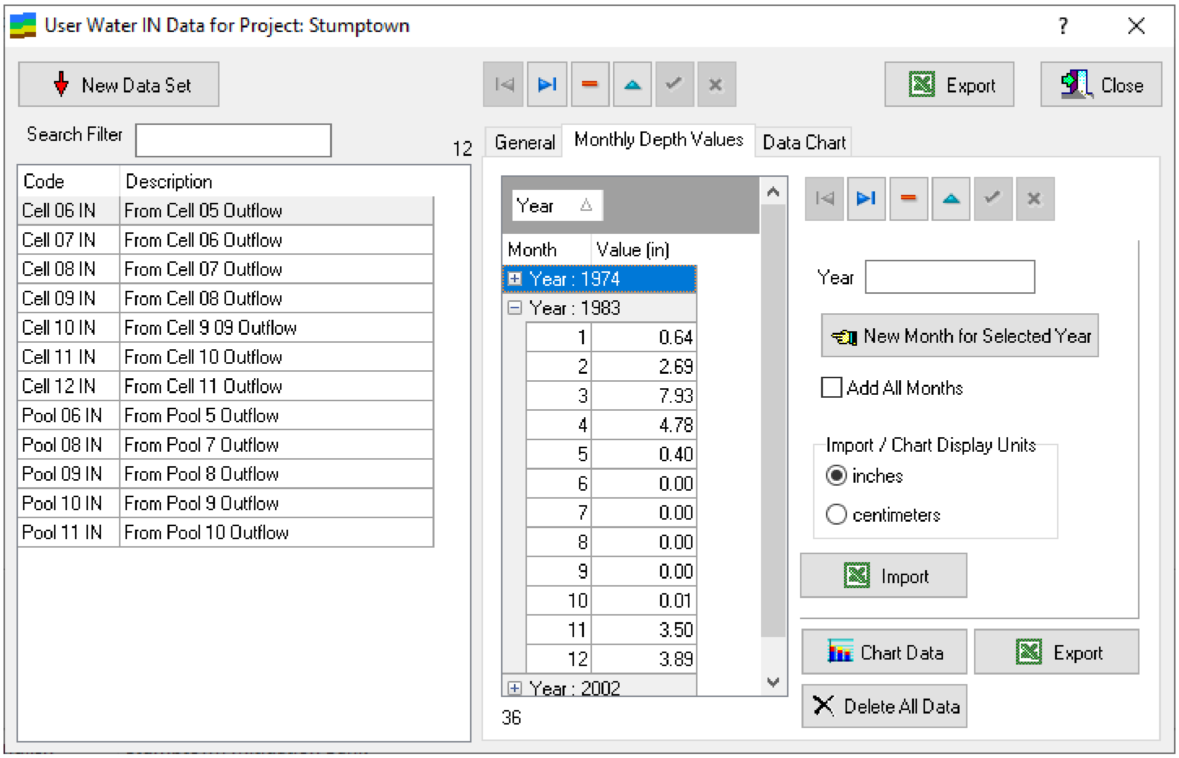
User Water IN and User Water OUT data sets allow the user to include additional water budget inputs or outputs for one or several months in a Basic Scenario without modifying any of the existing parameters.

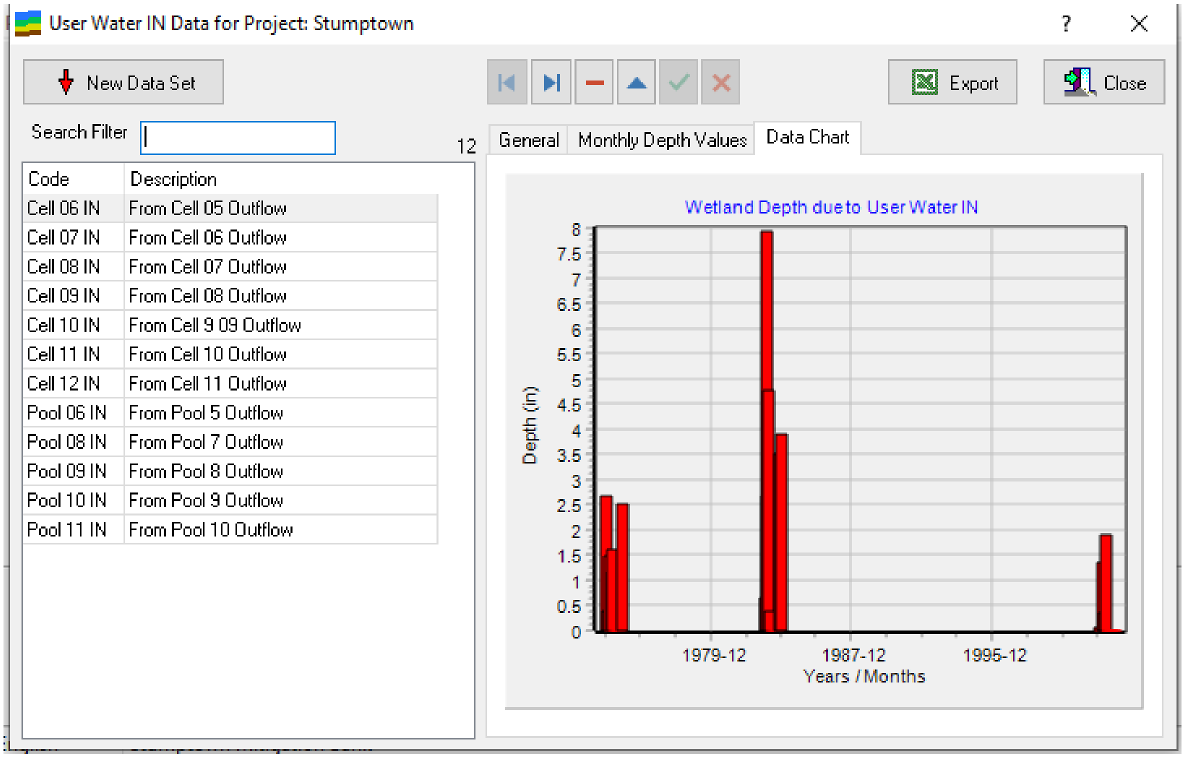
This option may be useful for sites where surface water is regulated by culverts where surface water fluxes can be readily constrained and quantified or in tiered wetland systems where the outflow from one cell becomes a source of water for the next wetland cell.

Users who choose to include a User Water IN or a User Water OUT data set in their Basic Scenario water budget analysis must create a monthly User Water In and/or User Water Out data set in the Project Specific Data section of the Parameters menu.

Once the data set is created it can be selected from the relevant drop-down menu when setting up a Basic Scenario.

The figures below show a number of User Water IN data sets. Each set includes three 12-month time series. User Water IN and OUT is specified as wetland depth.





8.11.6 Stream Data

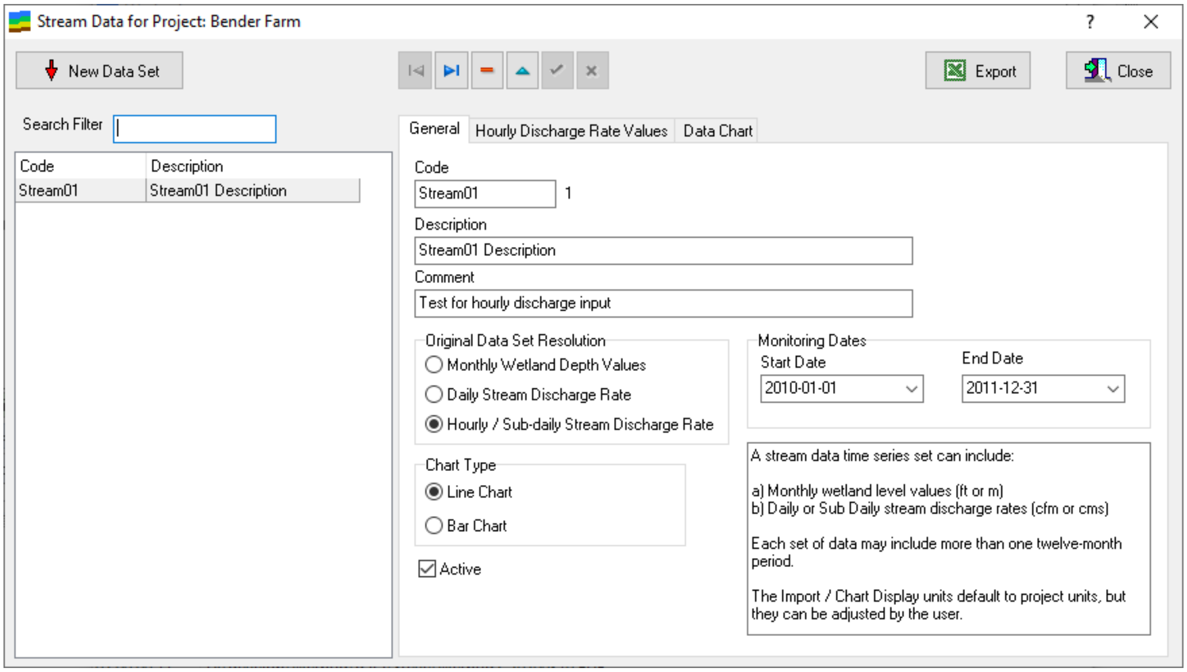
Stream data sets allow the user to:

- Add average depth values to a wetland attributed to overbank flow calculations performed outside of Wetbud.
- Utilize continuous stream discharge data from stream gages or other models that can be used to drive overbank flow calculations in a Basic Scenario.

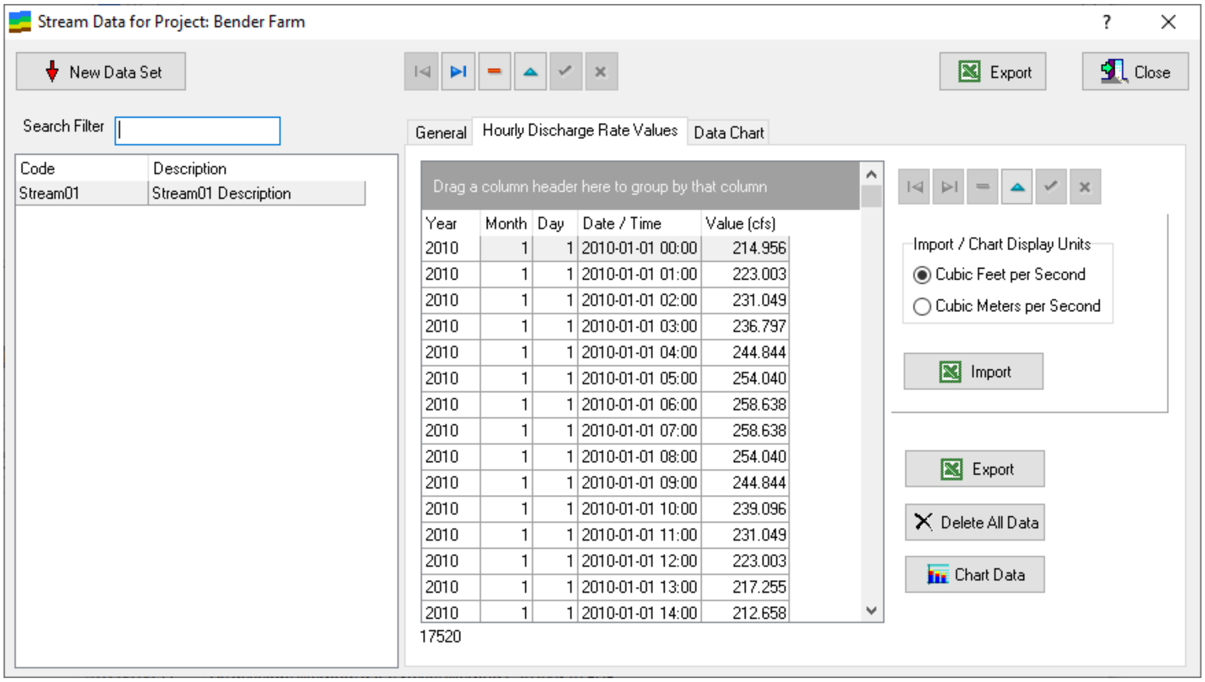
Once the data set is created it can be selected from its drop-down menu when setting up a Basic Scenario.

The figure below shows the stream management interface. Monthly, daily and sub-daily values (i.e., hourly) can be entered for a given data set.

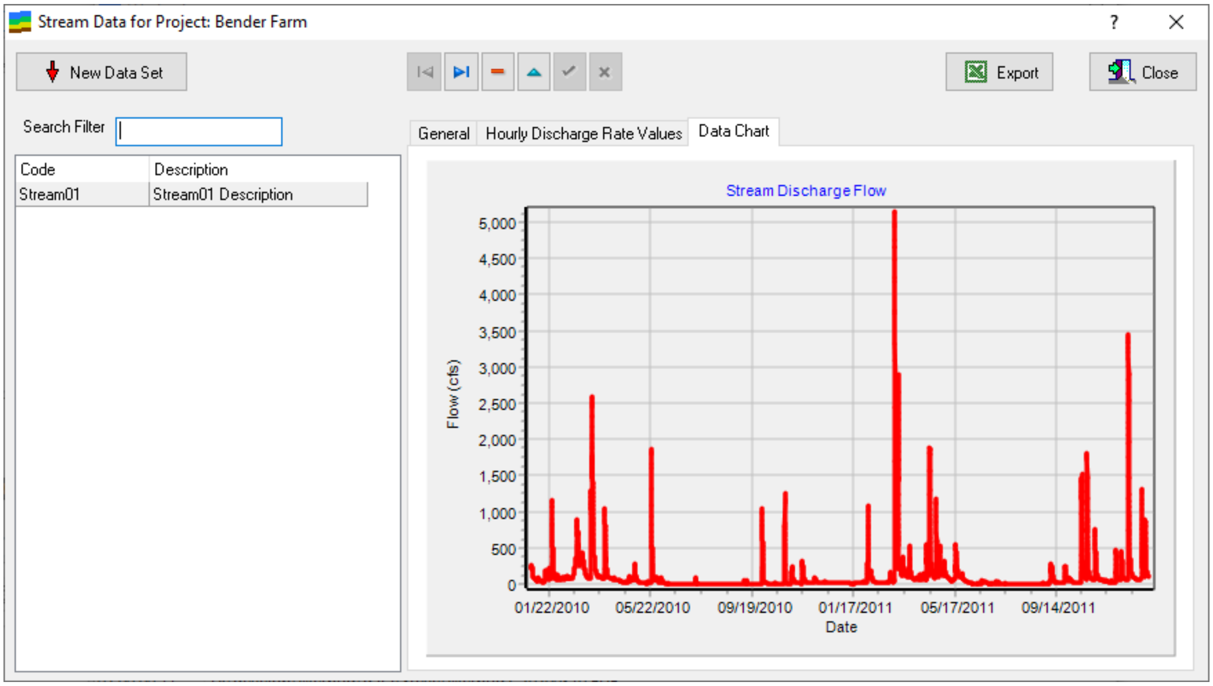
Note: Monthly depth values correspond to wetland depth values due to stream overbank flow, while the hourly and daily values correspond to stream flow values.



The figure below shows hourly stream water flow values.



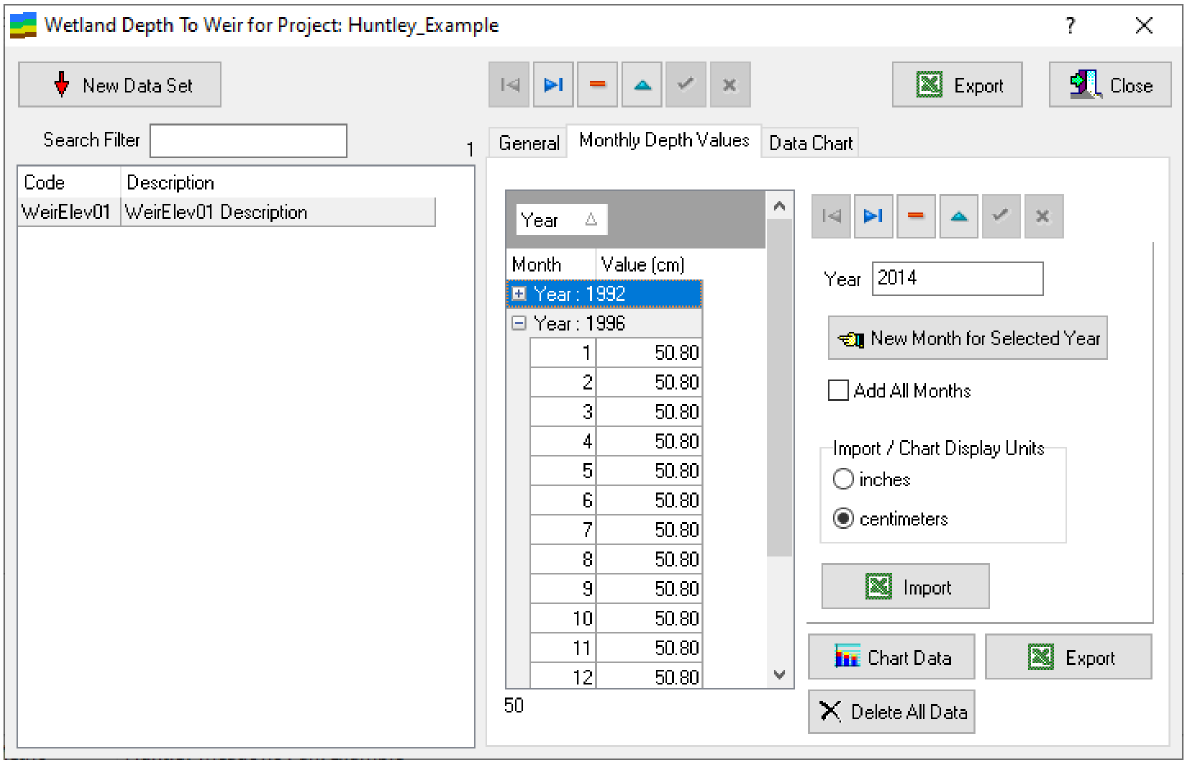
The figure below shows a chart of hourly stream water flow values.



8.11.7 Wetland Depth to Outlet Weir

Wetland Depth to Outlet Weir data sets allow the user to define a time series of wetland depth to outlet weir values for each month included in the analysis range. The User Time Series option should then be selected in the Site Parameters section of the Inputs and Outputs tab of a Basic Scenario. The assigned data set represents the maximum depth of water that can be reached before the model allows surface water to exit the wetland.

Users who choose to include a Wetland Depth to Outlet Weir data set in their Basic Scenario water budget analysis must create a monthly time series data set in the Project Specific Data section of the Parameters menu.



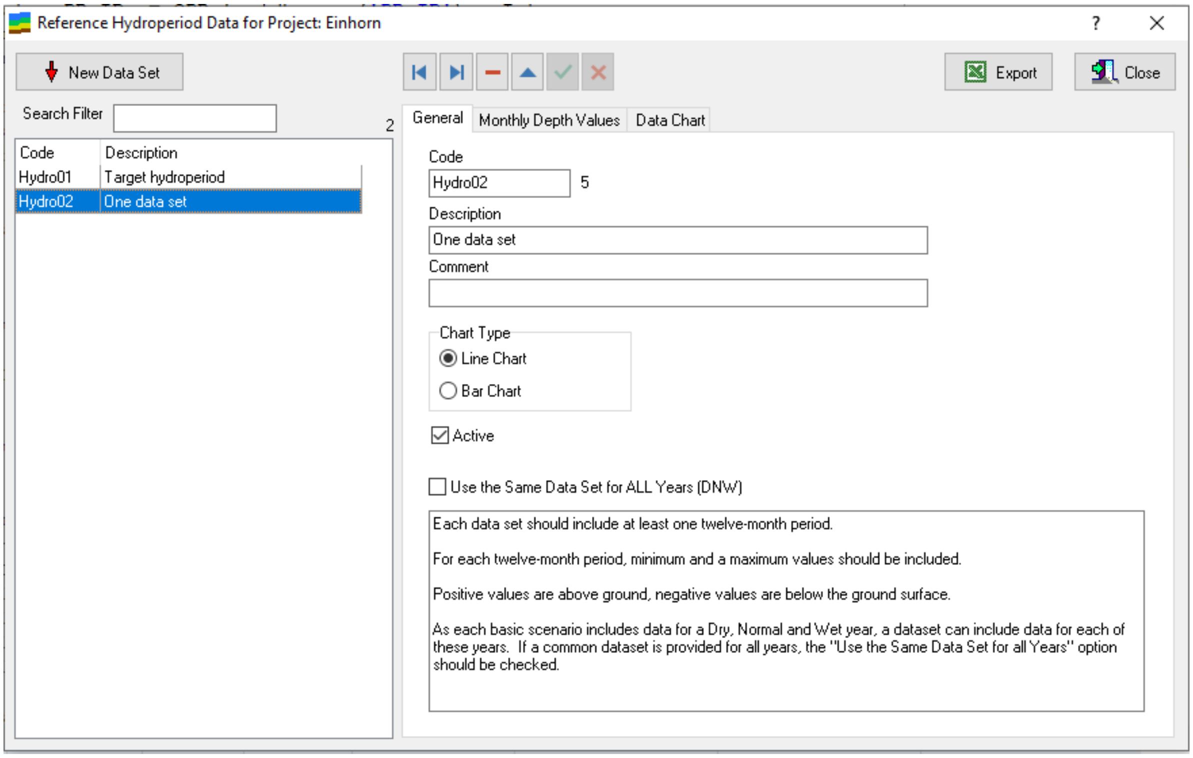
8.11.8 Reference Hydroperiod Data

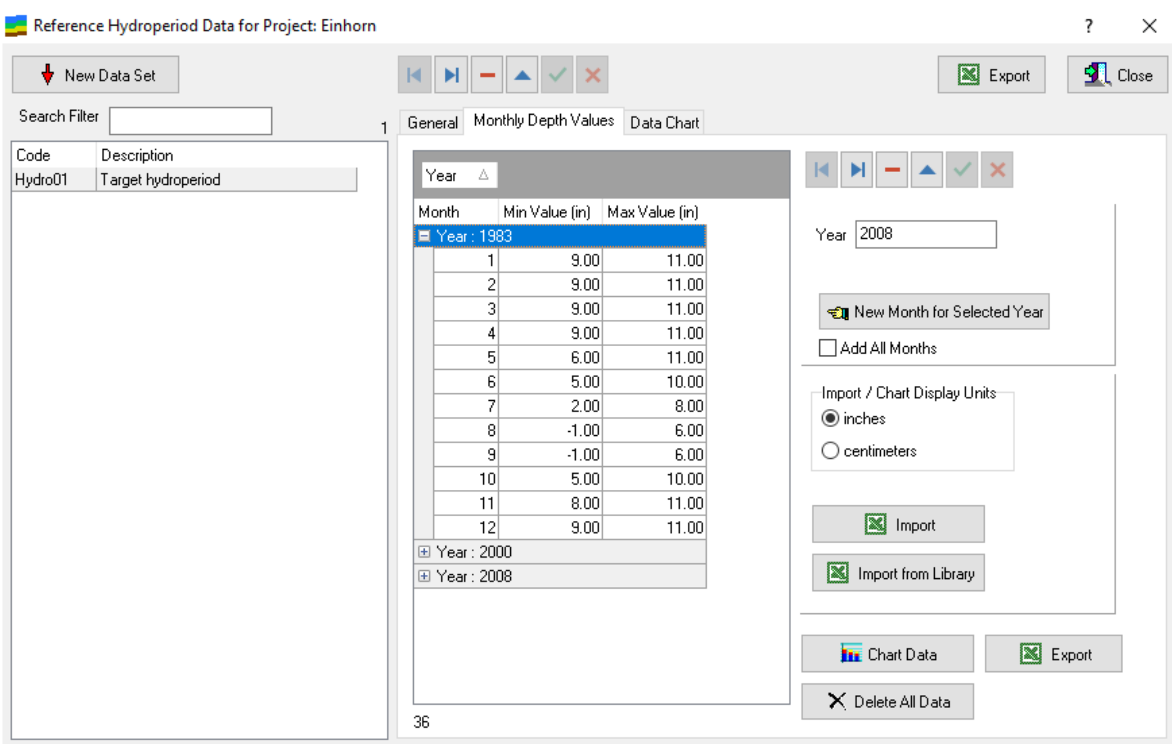
The user can define standard hydroperiod (or hydrograph) curves (minimum and maximum) for a given site. These curves can be plotted along with generated hydrographs for DNW years to compare predicted hydrographs to target (standard) hydrographs. The appropriate reference hydroperiod data set should be specified within a basic scenario.

The user can also specify only one reference hydroperiod data set by checking the Use the Same Data Set for ALL Years option.

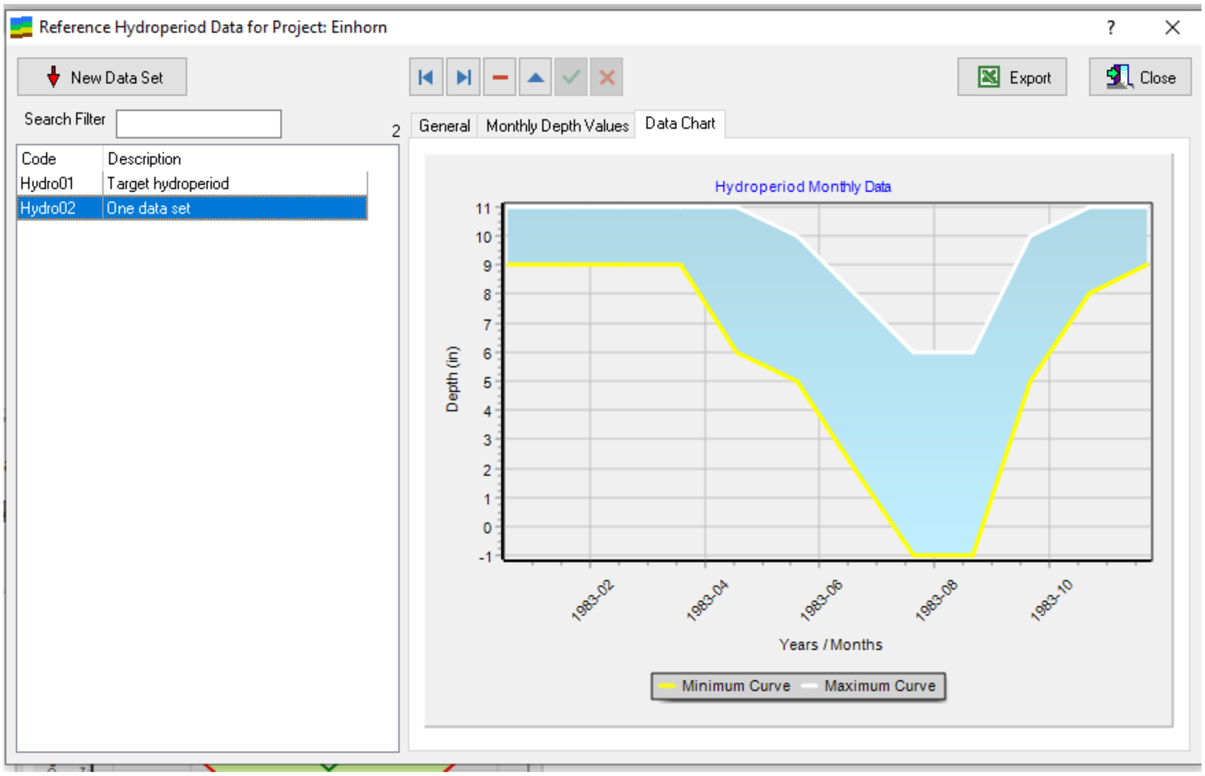
To import a reference hydroperiod data set from the Hydroperiod Library, click New Data Set and ✓ to save. Next, in the Monthly Depth Values tab, enter a year, check the box next to Add All Months, and click New Month for Selected Year. Click Import from Library and select "Yes" on the prompt that appears. Select the hydroperiod data to import and click Import and Close. For more information on hydroperiod data, see Reference Hydroperiods.

Note: Positive values are above ground, negative values are below the ground surface.





When both a minimum and a maximum curve are specified, the program will shade the area between them as shown in the figure below.



8.11.9 Well Data

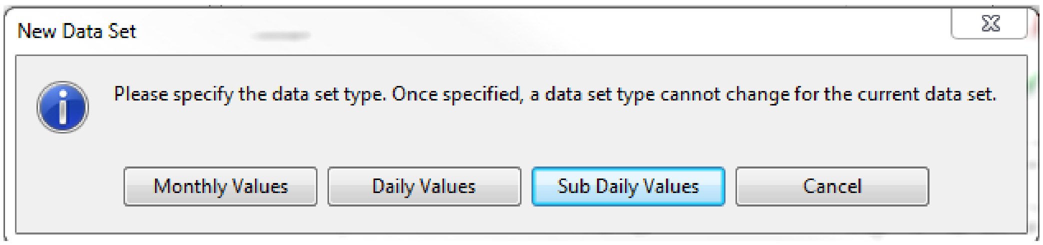
The Well Data option is only necessary for users who wish to calculate groundwater input in a Basic Scenario water budget analysis using the Effective Monthly Recharge Model (WEM). To perform an Effective Monthly Recharge Model analysis the user must create a data set of monthly head elevations for the up-gradient (hillslope) well and down-gradient (toe-slope) well to be included in the groundwater input calculations.

A minimum of six months which capture the range of water levels experienced in the well location (e.g., August - January), is necessary for a reliable WEM analysis. Ideally, the data set for a given well contains at least 12 months of water level data. Head levels for each month should be from readings taken on or near the 1st of the month. In addition, it is recommended that one should exclude/filter readings taken from wells at the beginning of each month that has experienced significant (> 0.5 inches) rainfall within 2-3 days of water level reading. However, this measure can be omitted if a limited number (< 12 months) of monthly water level readings exist.

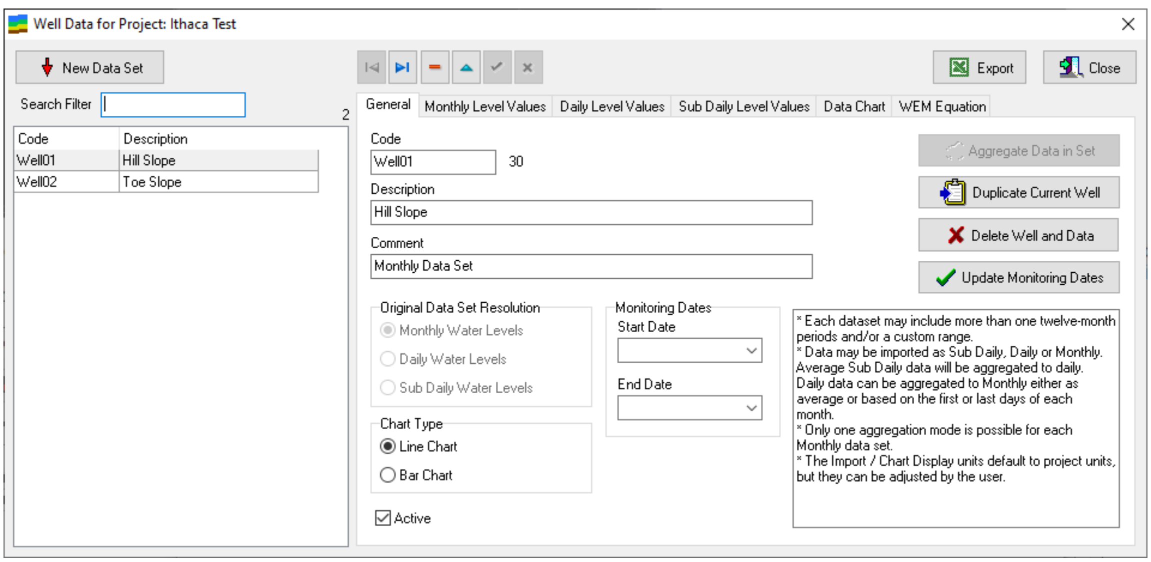
Note: The magnitude of rain events in the 2-3 days prior to water level reading having an effect on observed water levels will vary depending on local lithology, topography, and land cover. For information regarding the method used to determine which months should be excluded from WEM calibration, refer to Whittecar et al. (2017).

8.11.9.1 Creating a Well Dataset (Monthly Head Elevations)

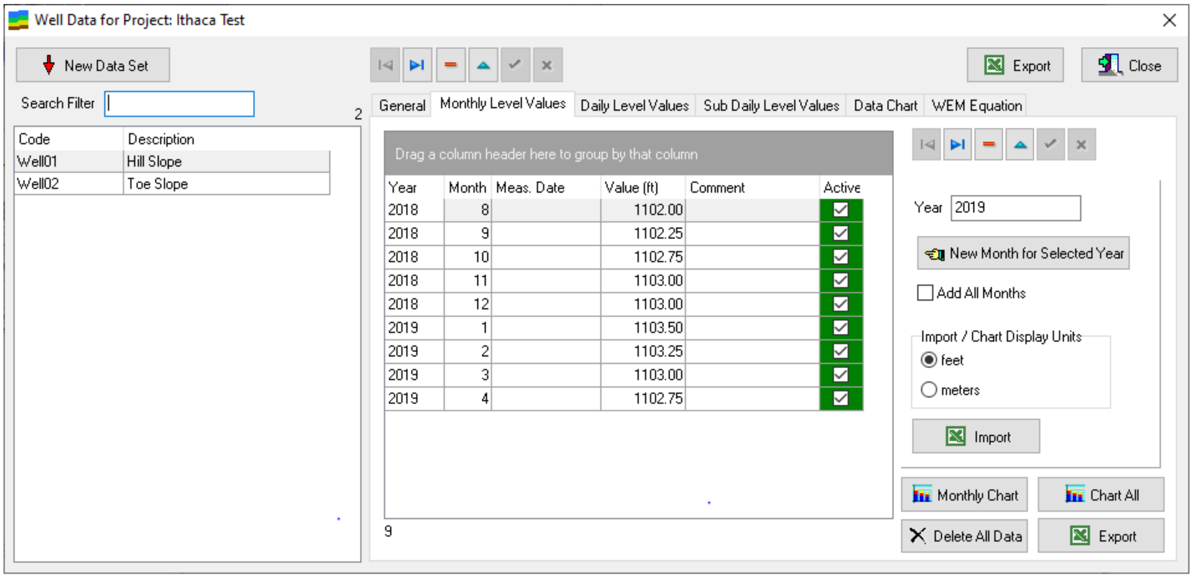
1. Select Wells from the drop-down menu under Parameters, Project Specific Data in the Wetbud home screen.
2. In General tab, click 
.
3. Select the type of data set, i.e., Monthly, Daily or Sub-daily (i.e., some interval less than 24 hours).



Note: Once a data set type is selected, it cannot be changed. A new data set needs to be created with a different data set type.



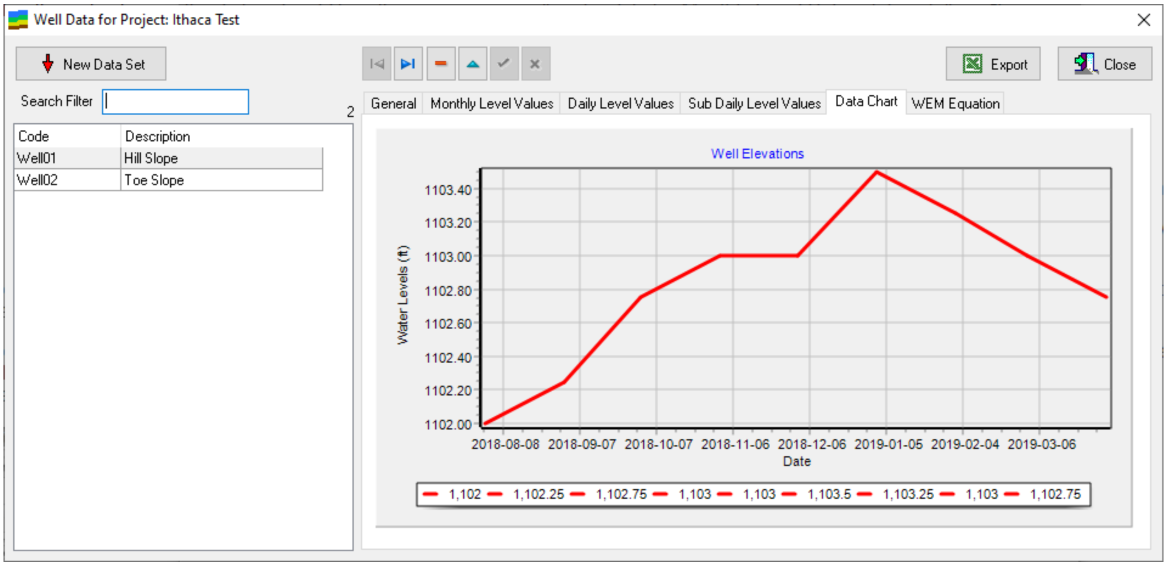
4. The box under Code is now filled with default text. Delete this text and replace it with a code (10-character maximum) of your choice. Enter a description and any comments that pertain to the data.
5. All tabs for Monthly, Daily and Sub-daily data are visible so that the user can view any aggregated data, however, only the input method pertaining to the particular data set is available. The image below shows the Monthly Level Values tab for a daily data set.



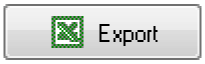
7. To import level values for a Monthly well data set, select the Monthly Level Values tab. Select the primary units (feet or meters) the values to be imported are recorded in. Then, click Import and follow the instructions in the dialog. In addition, the user can manually enter data for Monthly Level Values tab as follows:
   a. Enter the first year in the analysis range in the Year box and click ✔ to save.
   b. To add a single month, click New Month for Selected Year.
   c. To add all months for that year, check the Add All Months box and click New Month for Selected Year.
   d. To delete a month, select that month from the list and click Delete − and select OK in the prompt to confirm.
   e. Once all months for the analysis range are entered in the list of monthly level values, proceed by entering values (in primary units shown in the ‘Value’ field of the Monthly Level Values table) for each month in the list. Confirm you have correctly entered the monthly level values by selecting the Data Chart tab or by clicking Chart Data, which displays a graph of monthly level values entered in the data set.

8. To import level values for a daily well data set, select the Daily Level Values tab. Select the primary units (feet or meters) the values to be imported are recorded in. Then, click Import and follow the instructions in the dialog.
9. To import level values for sub-daily well data set, select the Sub-Daily Level Values tab. Select the primary units (feet or meters) the values to be imported are recorded in. Then, click Import and follow the instructions in the dialog.

10.Depending on the Chart Type option in the general tab, a line or bar chart will be used to display the data.



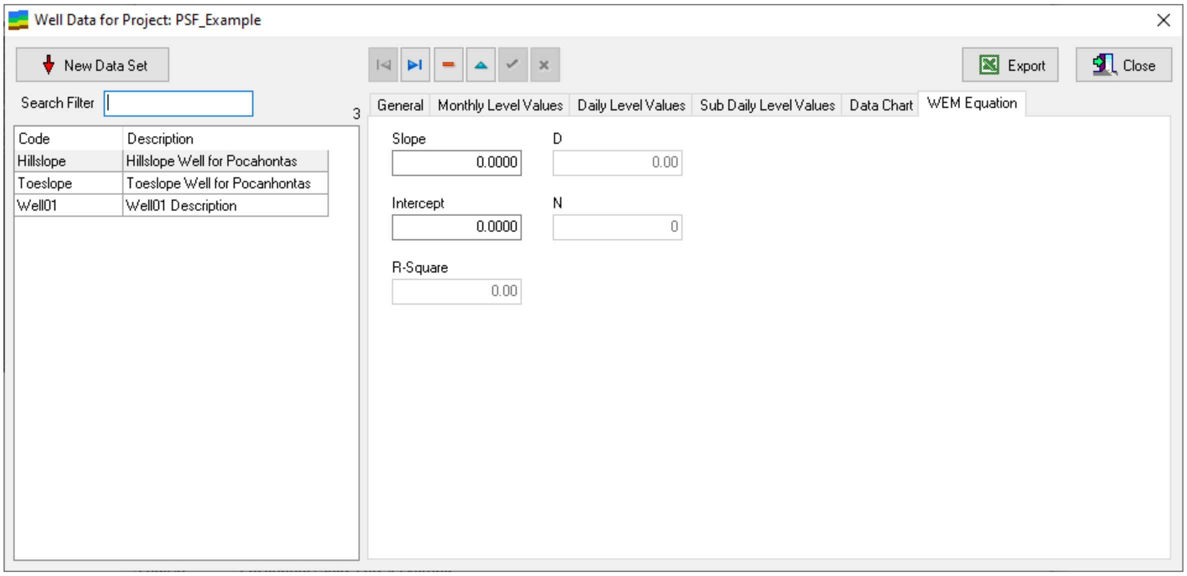
11.To export a data set, select the data set you wish to export from the list on the left side of the window.

12.Click 

under the appropriate tab (Monthly Level Values, Daily Level Values, etc).

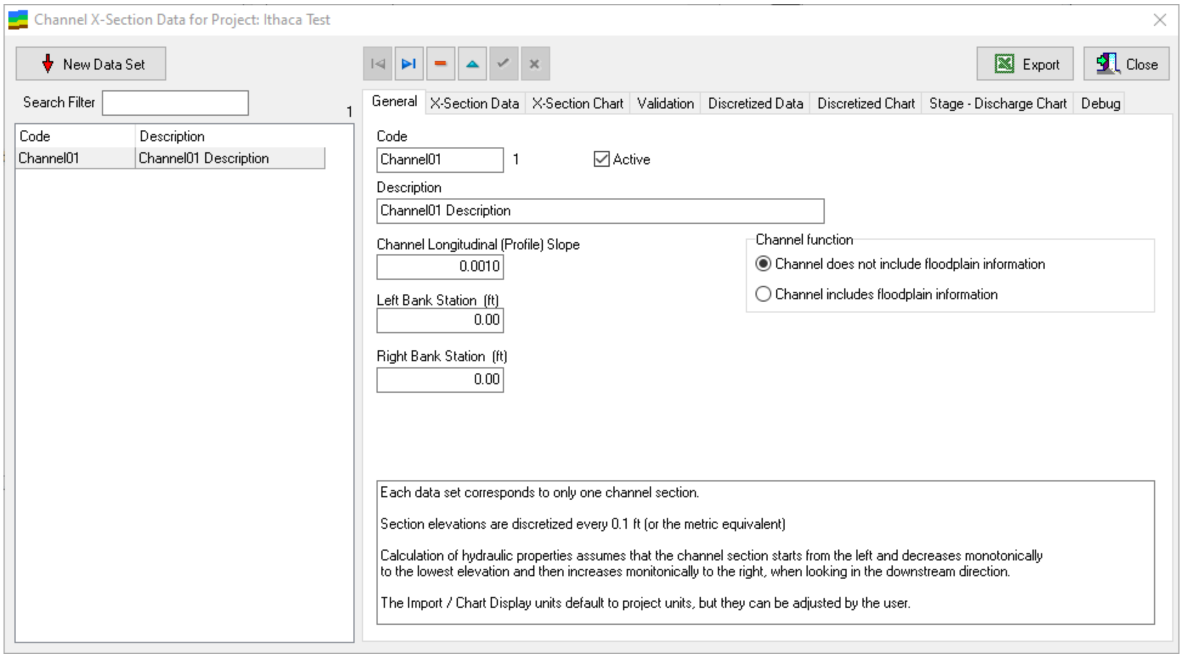
8.11.9.2 WEM Equations

The WEM equation (if any) developed for a specific well can be displayed under the tab WEM Equation. These values are calculated and populated by Wetbud each time WEM calculations are performed. See WEM Calculations for more details.



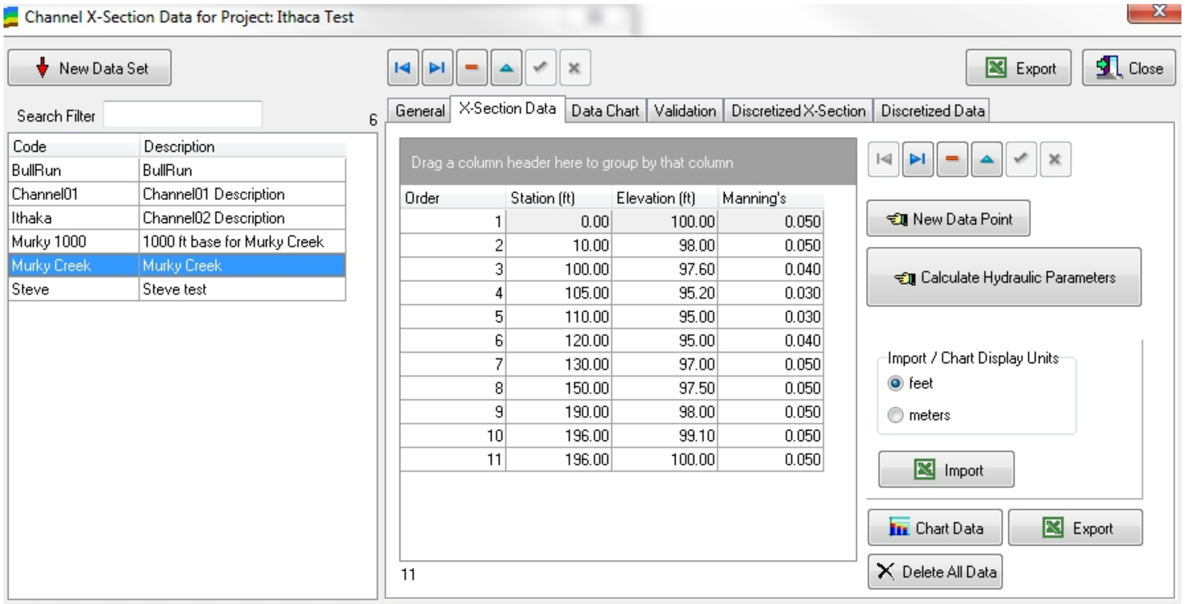
8.11.10 Channel X-Section Data

Channel data sets allow the user to define irregularly shaped channels and floodplains for the overbank flow calculation module.

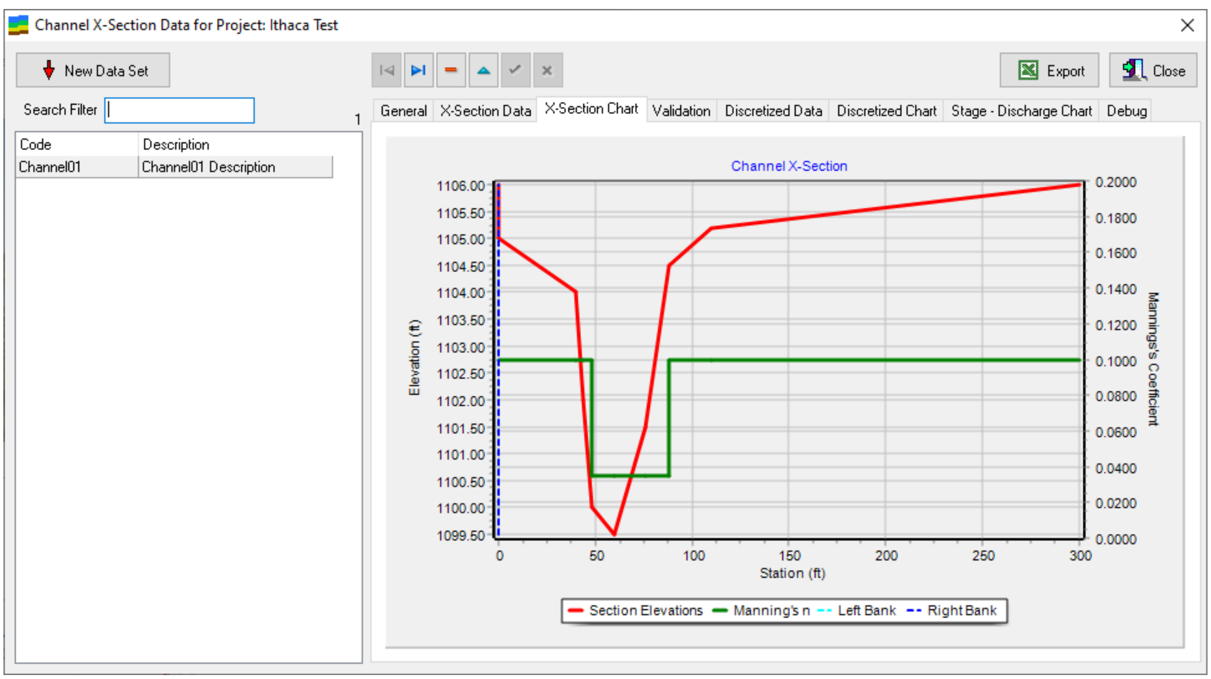


The user should define the stream using stations and elevations. Section data can be manually entered or imported from an Excel file. Once data input is completed, the hydraulic parameters should be calculated.

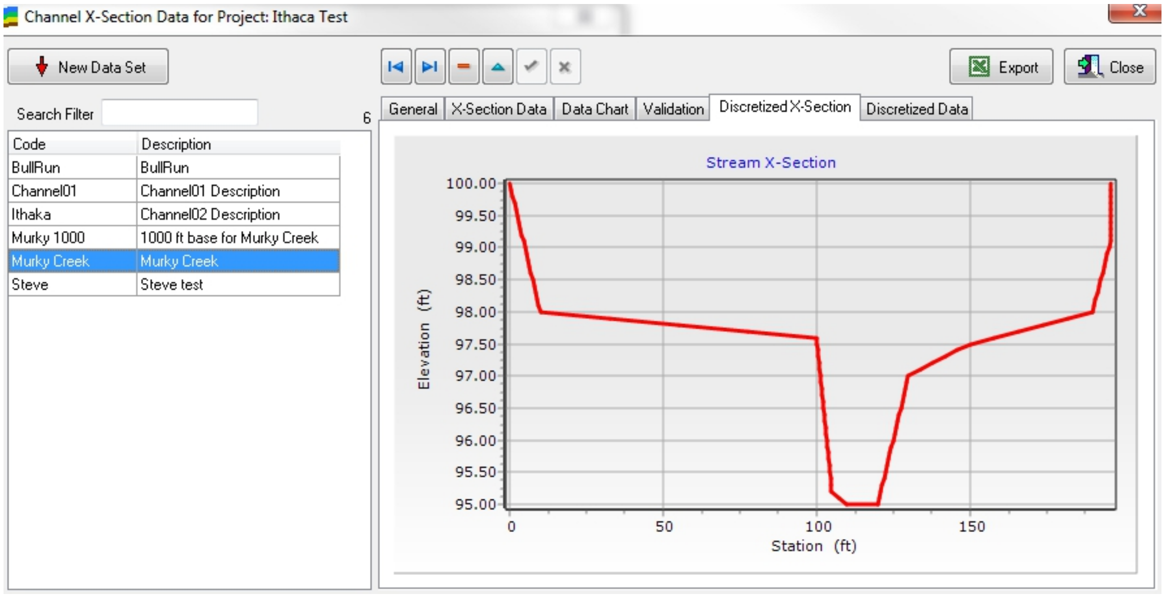
Note: Station distances and elevation values should start from the left (bank) and decrease monotonically to the lowest elevation and then increase monotonically to the right (bank).



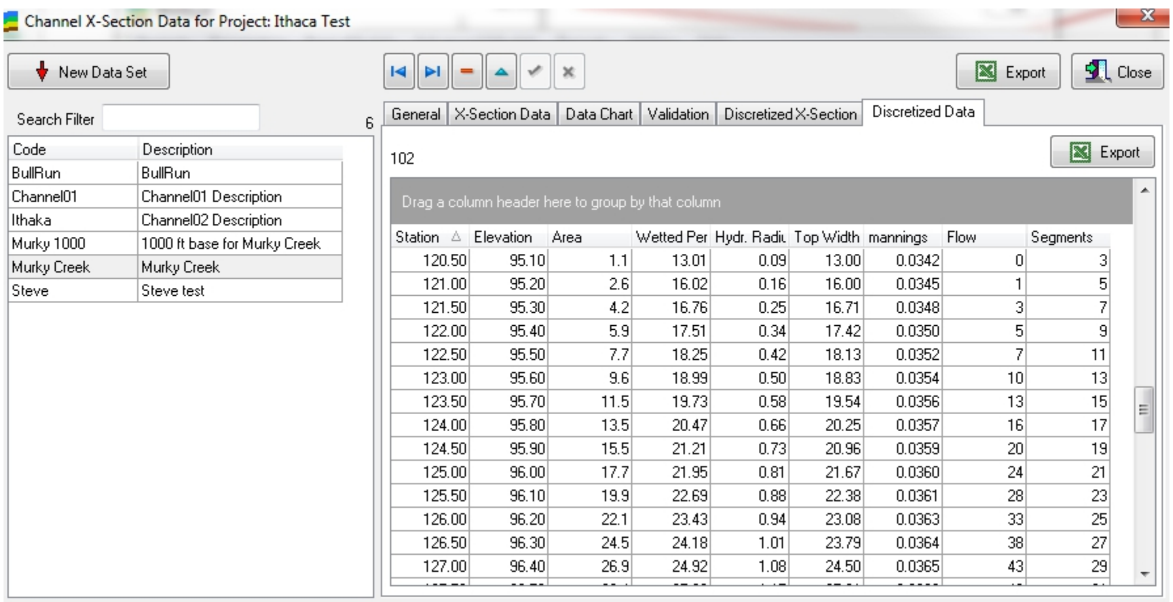
The figure below shows a channel section and how the Manning's roughness coefficient changes along the section. Channel section elevations are shown on the left axis, while Manning's roughness coefficients appear on the right axis.



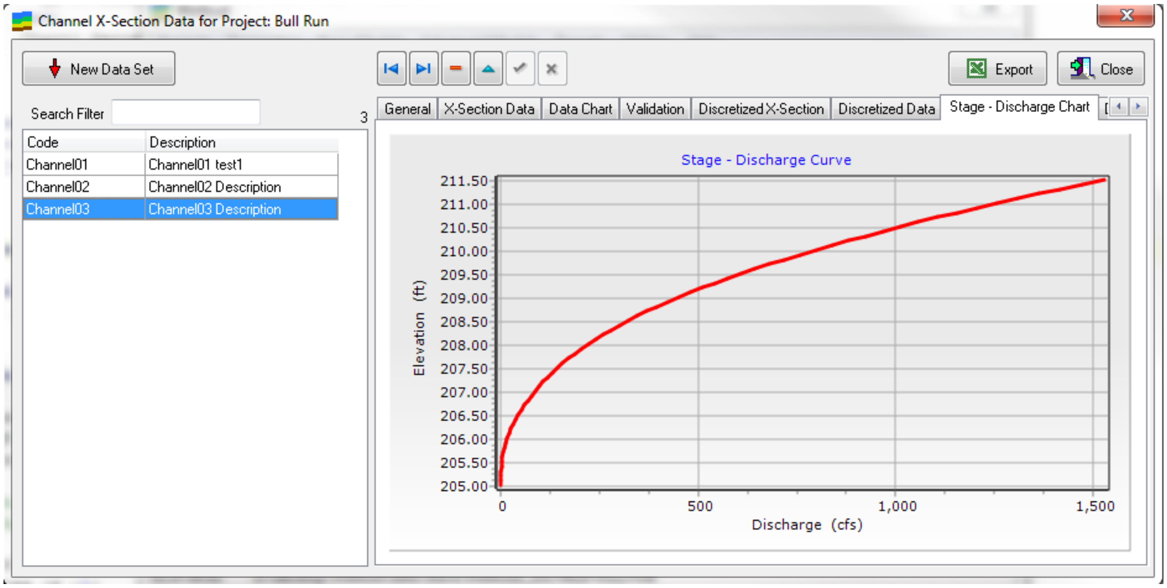
When calculating the hydraulic parameters of the channel, the defined section is then divided into left and right overbank areas, as indicated by the left and right bank stations, for cross sections that include the floodplain. Flow in the overbank areas is then computed separately from the main channel and the discharges are added. If the cross section does not include the floodplain, the right and left bank should be specified as the first and last stations along the section.



The table below shows the calculated parameters for each station location.



The figure below shows a stage - discharge curve that was generated for the channel geometry above.

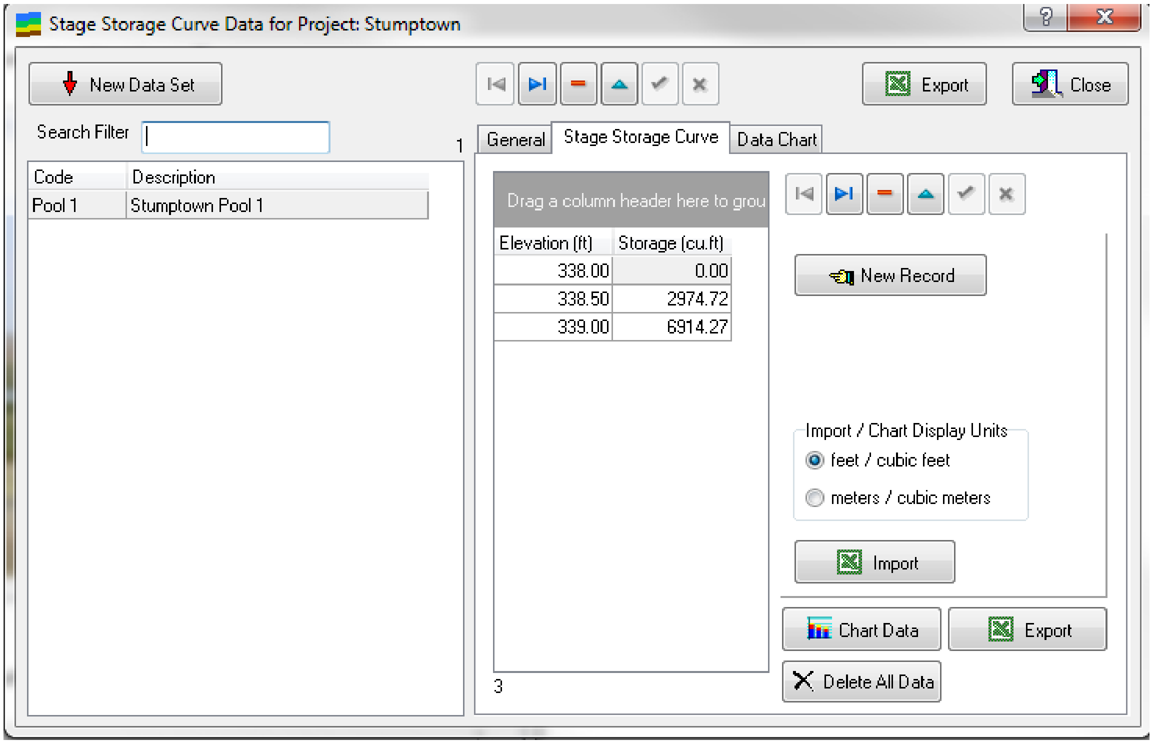


8.11.11 Stage Storage Rating Curve Data

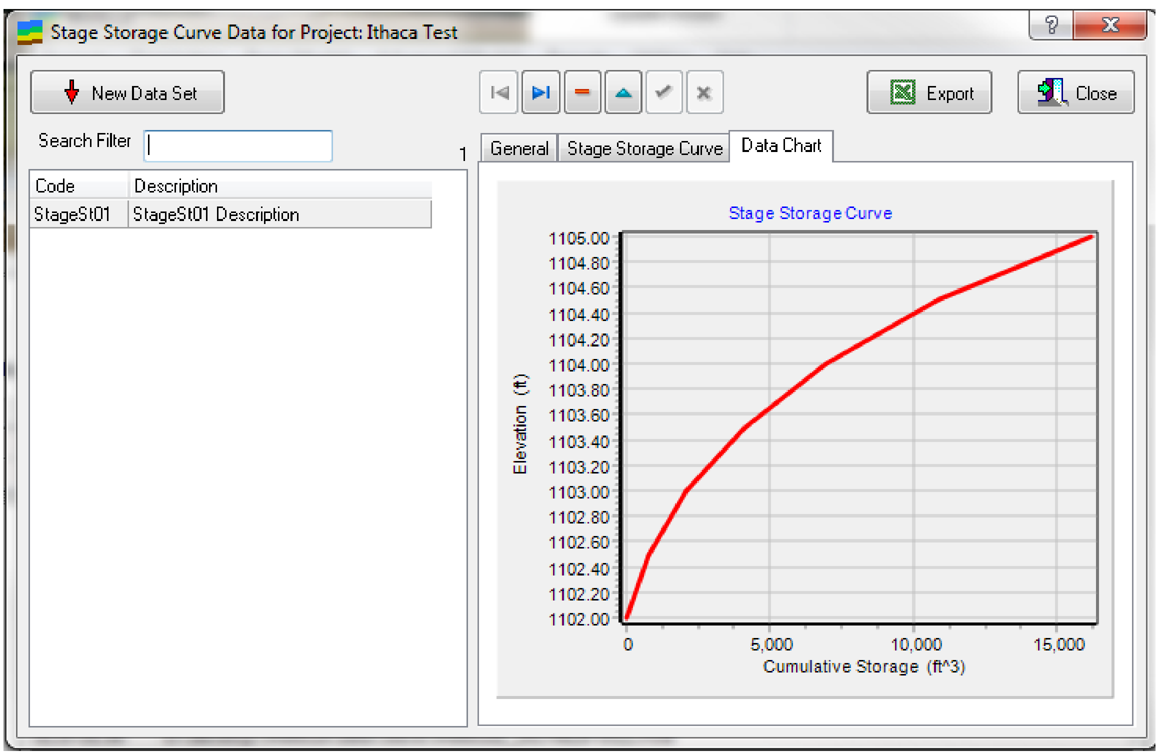
Stage-storage rating curve data sets allow the user to define a rating curve to convert storage volume to elevations, instead of assuming the wetland is shaped like a swimming pool with a flat bottom. By using a stage-storage rating curve, irregularly shaped wetlands can be more accurately modeled in Wetbud.

Once a data set is created it can be selected through the Basic scenario form.

The figure below shows how a stage storage rating curve is defined. Data can be imported from and exported to Excel.



The figure below shows a chart of a stage storage rating curve.



Note: The Stage Storage elevation should range from the actual wetland bottom to the maximum outlet weir elevation

8.11.12 Charting Options

The Chart Formatting window in Charting Options is used to create customized chart formatting to be applied to the outputs or results displayed for a given Scenario. Here the user can designate units, customize axes, specify titles, and create legends to be displayed on charts generated in Basic Scenario and Advanced Scenario outputs.

Note 1: To view results for an Advanced Scenario, the user must create a Charting Options data set and select it from the Chart Settings for Heads drop-down menu in the tab under Advanced Scenarios.

Note 2: Basic Scenarios do not require Charting Options data sets. However, Charting Options can be applied to Basic Scenarios.

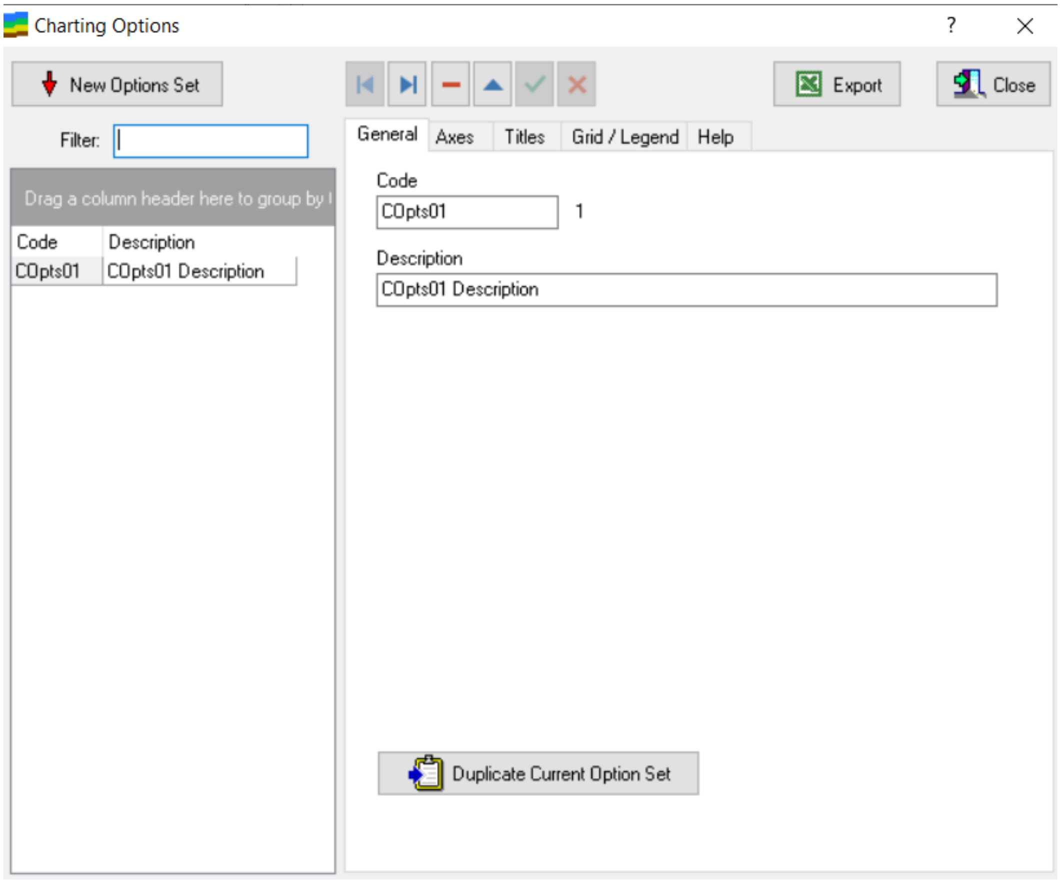
8.11.12.1 General

1. Begin by clicking 

in the Chart Formatting window. The box under Code is now filled with the text '--'. Delete this text and replace it with a code of your choice (note that the code is limited to 10 characters).
2. Next, click  to save. You will now see a code has been generated for your Scenario in the box on the left side of the window. Add a description (optional) and save.
3. Proceed by filling in the boxes in the Axes, Titles, and Grid/Legend tabs. Once the Chart Formatting data set has been created, it can be assigned to a Basic Scenario in the Management and Options tab or for an Advanced Scenario in the Setup tab.
4. To create a copy of the current options set, click 

.

Note: Axes and titles in Advanced Model output will be automatically selected by Wetbud based on output values when choosing the Auto option in the Axes and Titles tabs.

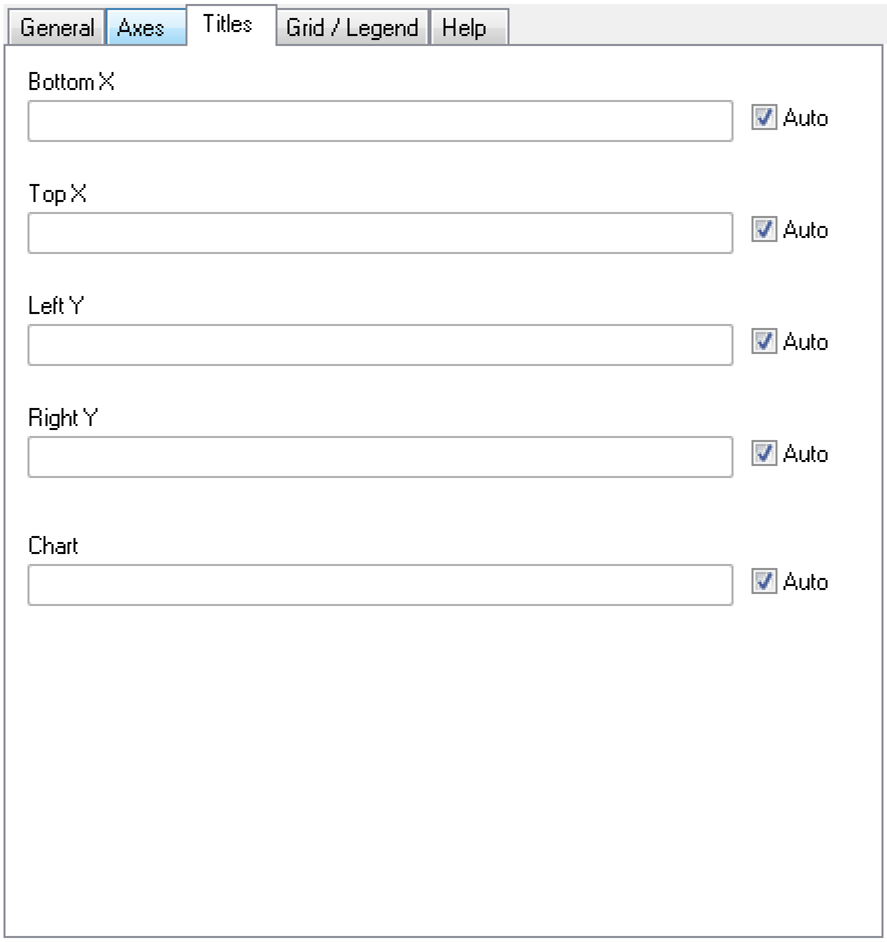


8.11.12.2 Axes

Axes can either be manually selected or auto-selected through Wetbud. The bottom, top, left, and right axes can be specified individually, with either a manual or auto input value.

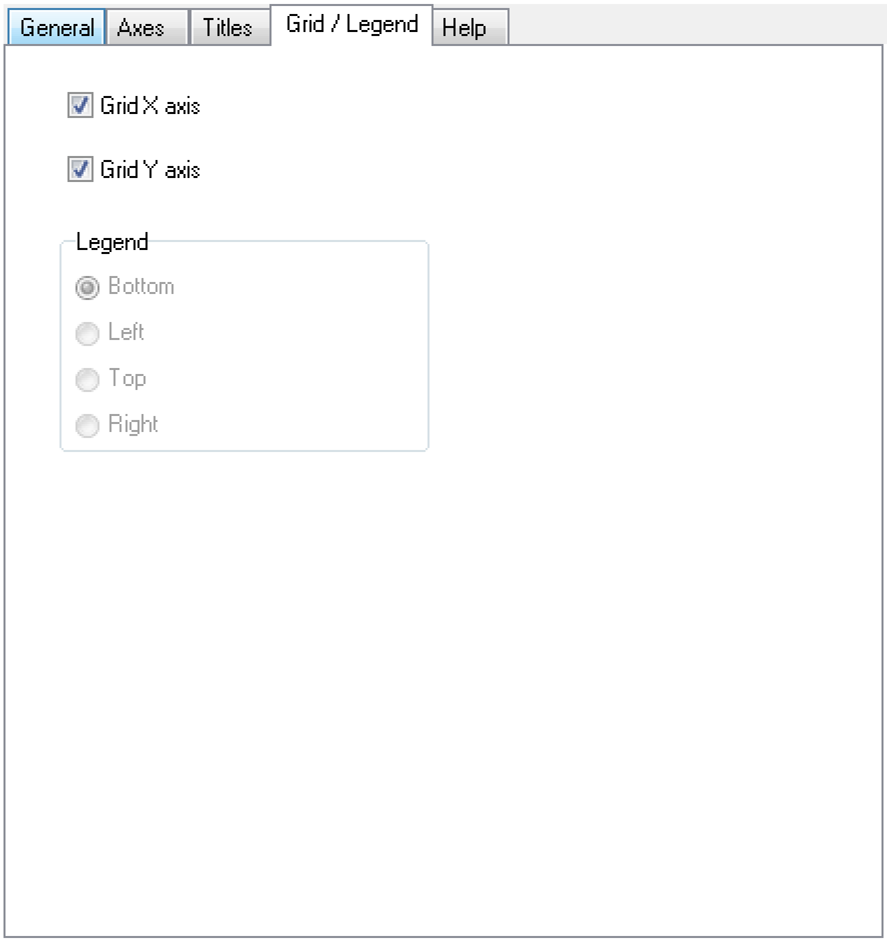
8.11.12.3 Titles

The user can specify the titles of the axes within this tab.



8.11.12.4 Grid/Legend

The user can specify which axes to have grids individually, and select where the legend is to be placed, if applicable.



8.12 Soil Ksat Table

In Wetbud, users will need to estimate saturated hydraulic conductivity (Ksat) values of soil layers or underlying strata in three situations:

1. When using the WEM to calculate groundwater input in a Basic Scenario,
2. When predicting a simple uniform “seepage loss” for an entire wetland floor in a Basic Model, and/or
3. When building layers in an Advanced Model. The Soil Ksat option in the Parameters menu contains saturated hydraulic conductivity (Ksat) values for all Virginia soil series currently contained in the NRCS Web Soil Survey NASIS database.

It is important for the user to understand that Ksat values are presumably constant for a given soil or subsoil layer and are not the same as the surface soil infiltration rate that can vary widely with time as the soil wets and dries. That being said, over extended periods of time under saturated/ponded conditions, the surface infiltration rate will approach the Ksat value of the least permeable underlying saturated horizon or layer. Older soil surveys and geotechnical literature also often use the term “permeability” along with cited values (e.g. min/in or cm/s) which may be similar to Ksat as long as estimated for saturated flow conditions.

To obtain the NRCS values for a given soil series in Virginia, enter the County/City name (e.g., Prince William) for your site location and then the name of the soil series (e.g., Albano) that is characteristic of your site. The Ksat values (in m/sec) by soil depth range (cm) are then listed in short tabular form. The user should then choose the value that best represents the Ksat for the soil horizon or stratum of interest. Certain subsoil horizons (e.g., tight shale saprolites) for some counties do not contain estimated or valid Ksat entries and will appear as null values. Since many of the soil series mapped and correlated in Virginia also occur throughout the mid-Atlantic and southeastern USA, Wetbud users may be able to find Ksat values for their onsite soil series by browsing the current Ksat table for a Virginia county in the same geologic x soil region (or NRCS Major Land Resource Area - MLRA).

It is important to note that these Ksat values are estimated (not actual field measurements by county) and assume an undisturbed soil condition with intact soil structure and normal (non-compacted) bulk density. Furthermore, as explained above, these values estimate internal saturated hydraulic conductance (or permeability) of the soil layer(s) at the cited depth (cm) and not infiltration per se. When estimating the Ksat for a cut, smeared and compacted subsoil layer in a created wetland, it is recommended that these values be decreased by at least one order of magnitude for loamy horizons and two orders of magnitude for clayey horizons. Users are strongly encouraged to use actual field measured values or lab estimates from intact cores for Ksat estimates when possible.

When that is not practicable, laboratory permeability tests at a density and moisture content that are expected to be found in your wetlands restoration or creation site can be useful (see Note 2 below).

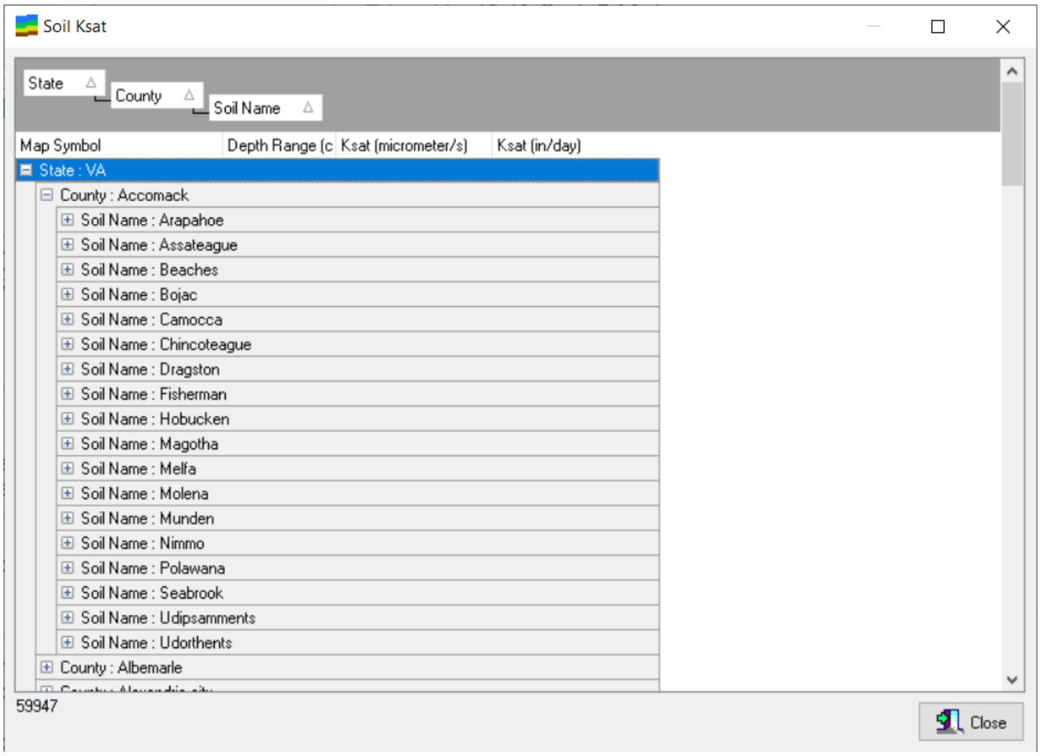
Practical guidance on use of a range of field infiltration and permeability methods is provided by Pierce et al. (2015) along with practical guidance on estimating Ksat based on texture, structure and other field conditions.

Additional information and details pertaining to soil units mapped in Virginia and the U.S. by the NRCS and their chemical and physical properties can be found at the Web Soil Survey site at http://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm. Users can use Web Soil Survey to determine the presumed dominant soil series for their site. However, it is important to note that the compiled scale (1:24,000) of modern soil surveys does not allow for detailed site-specific prediction of the soil type actually present. The user is encouraged to confirm actual on-site soil conditions. From the Web Soil Survey website, users can also navigate to the National Soil Information System (NASIS) data base that contains extensive data by soil series.

Note 1: Wetbud currently includes a Soil Ksat Table for the state of Virginia only.

Note 2: Some professionals have obtained results that appear (from monitoring over time) to represent field conditions for a cut, smeared and compacted clayey soil (over 25% clay content) with a Permeability test (in accordance with ASTM D-5084) conducted at 85% of Standard Proctor Density (SPD) (determined with a Standard

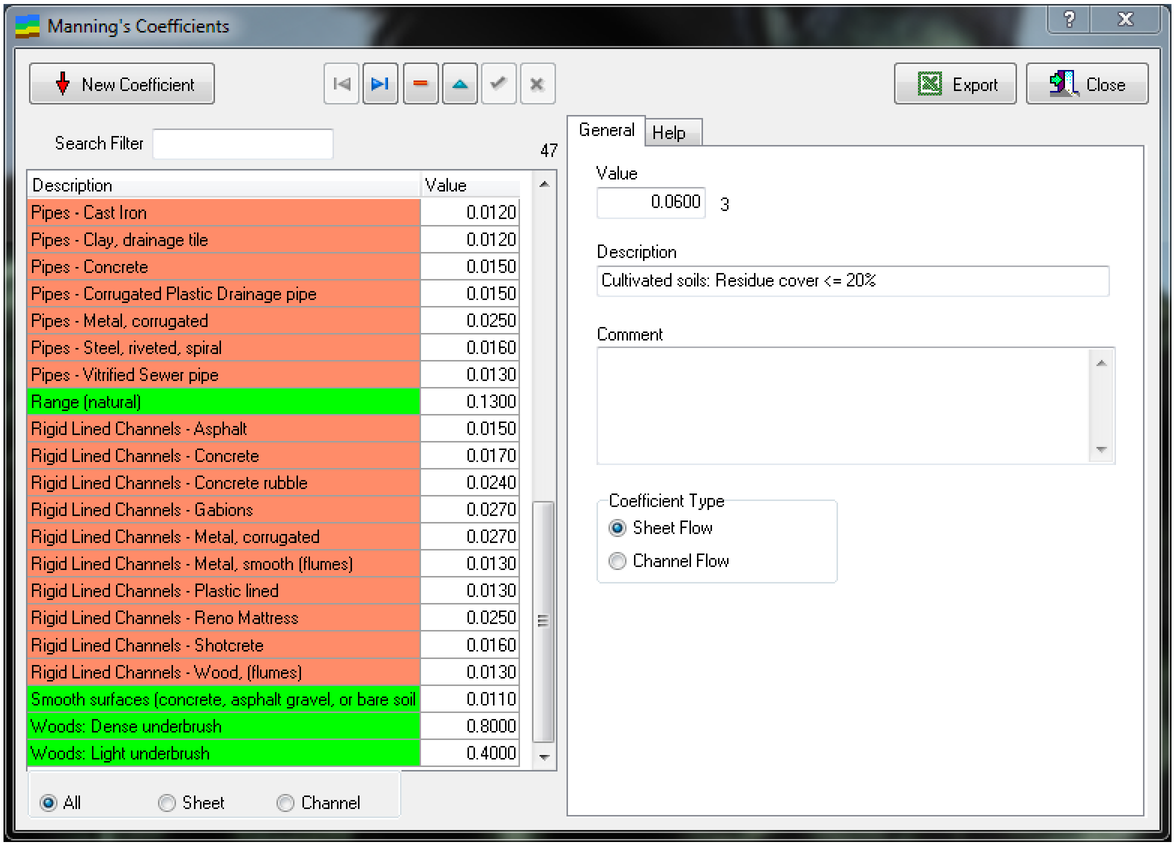
Proctor Test in accordance with ASTM D-698) with moisture content 3-7% above the optimum moisture content. The lower than typical density (85% vs. 95%) and high moisture content represent typical wetland construction conditions that occur when grading subsoil with tracked equipment in low lying areas.



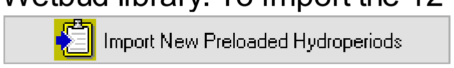
8.13 Manning's Coefficients

A list consisting of Manning's Coefficients (n-values) for various structures is available under the parameters tab. Sheet flow or channel flow can be chosen depending upon the scenario.

New coefficients can also be added manually by clicking 

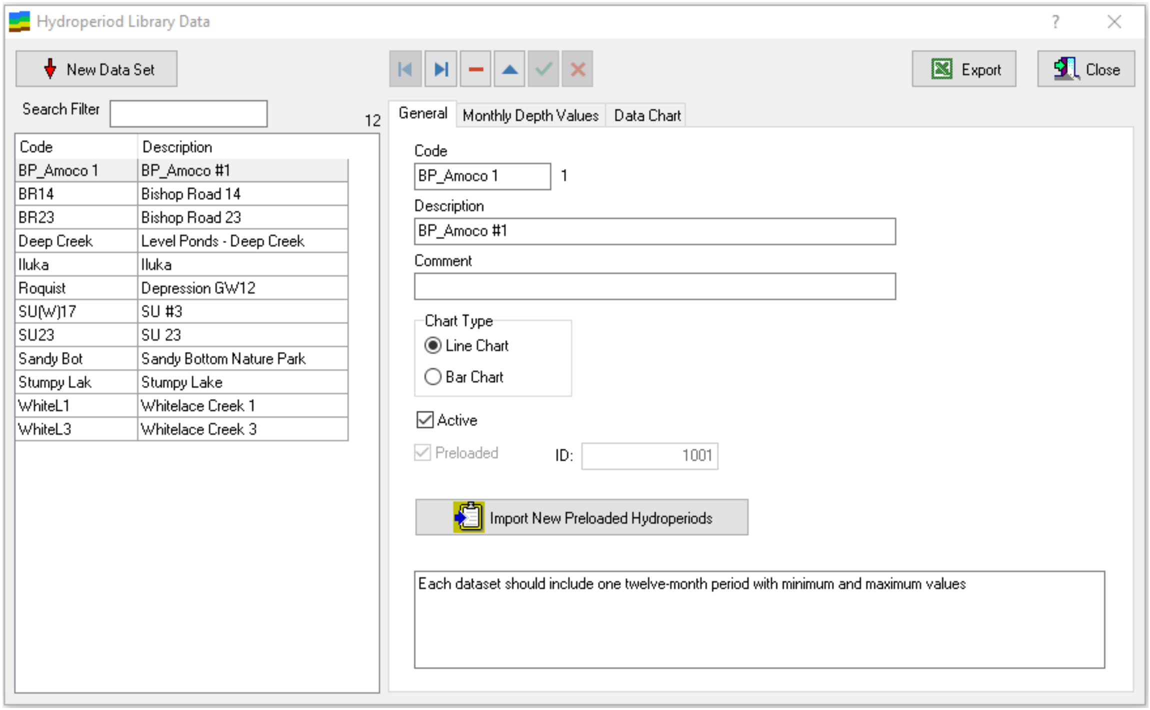


8.14 Hydroperiod Library

The Hydroperiod Library General tab displays the available hydroperiod data in the Wetbud library. To import the 12 preloaded curves into the database, click 

. To enter data for a new a new data set, click 

and fill in the required data. Once a data set is added, it will appear in the list on the left of the screen, shown in the figure below.



In the Monthly Depths Values tab, the minimum and maximum values for each month are listed, as shown in the figure below. For all data sets, the year is not specified and is defined when importing the data into the project definition in Hydroperiod Data. To add a new month for a data set, click 

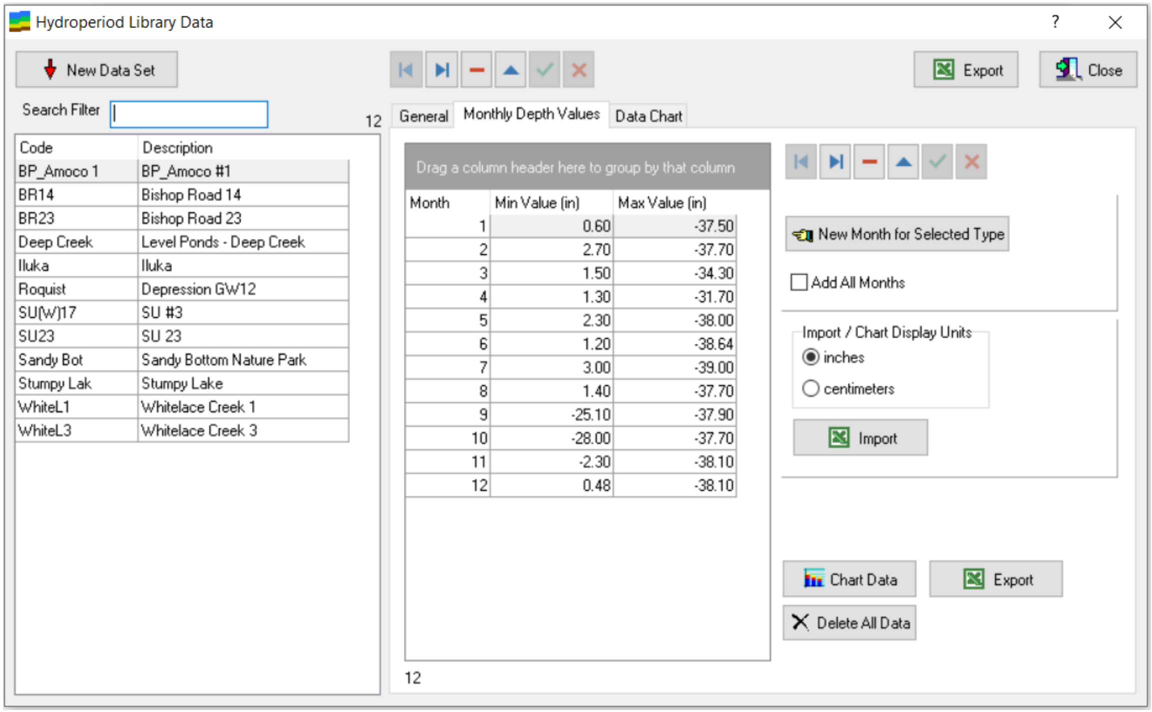
and enter the minimum and maximum values. To import data from Excel, click 

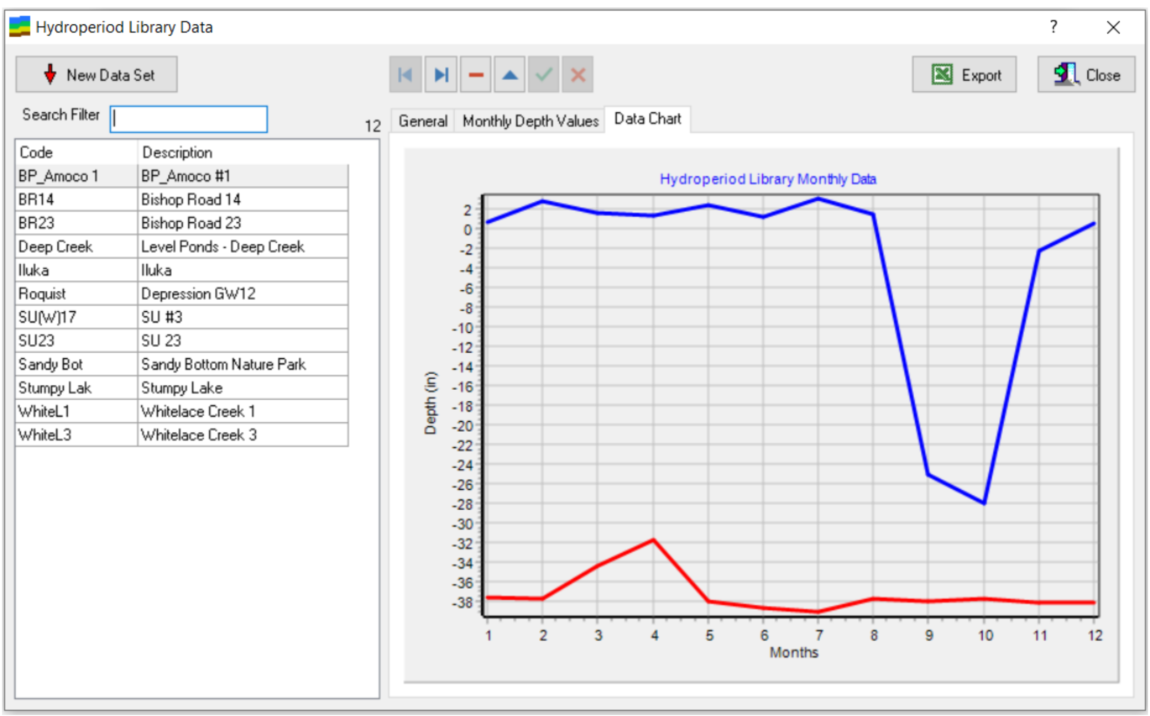
and to export the selected data, click 

.

To chart the monthly values click 

or the Data Chart tab. For more information on how the hydroperiod data is used, see Reference Hydroperiods.





A list of the 12 hydroperiod data sets provided by Wetbud are shown below:

Code	Description
PFO1B SE VA	BP_Amoco
PFO1A NE NC	Roquist

PFO1/4B SE VA	Sandy Bottom
PFO4Cd E NC	Bishop Road 14
PFO1/2F E NC	Bishop Road 23
PFO4Bd SE VA	Su Tract 23
PFO4/1B	Level Ponds
PFO1A E NC	Whitelace Creek 1
PFO1C E NC	Whitelace Creek 3
PFO4B E VA	Iluka
PFO1Bd SE VA	Stumpy Lake
PFO1Bd SE VA	Su Tract (W) 17

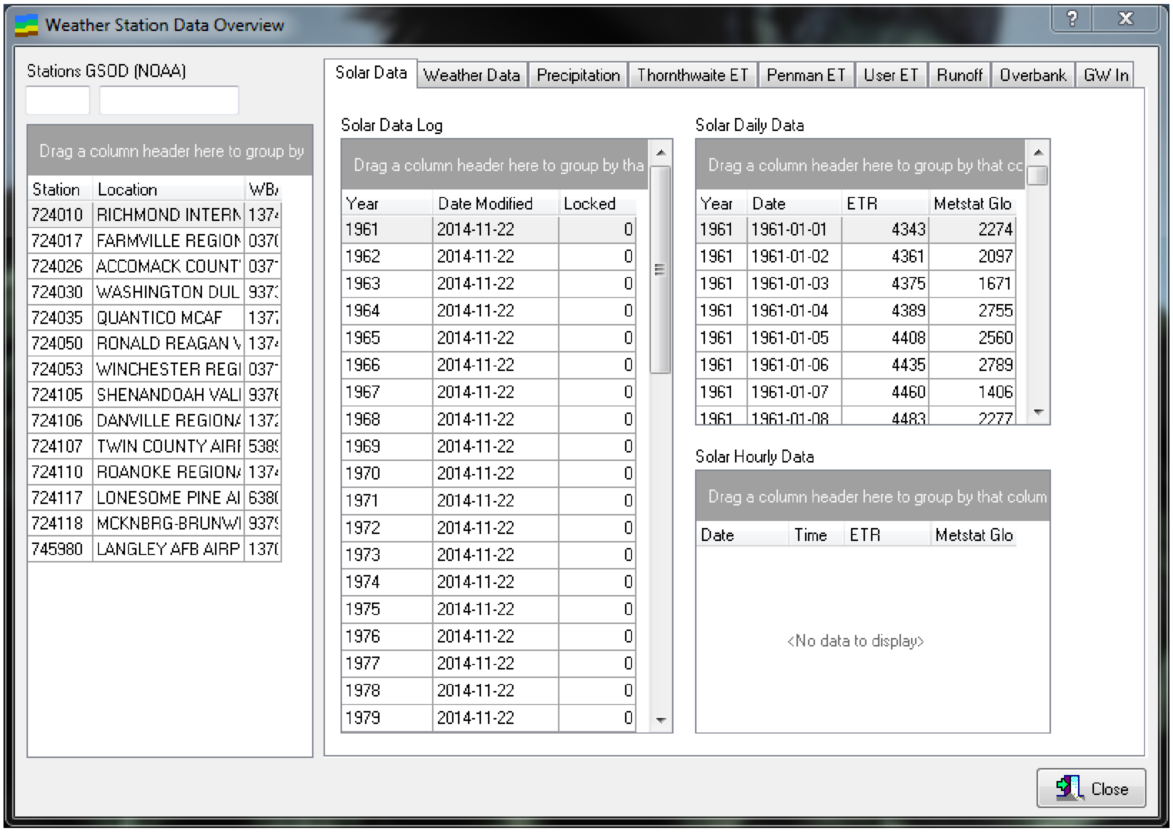
8.15 Data Overview

Selecting Data Overview in the drop-down menu under Parameters in the Wetbud home screen allows the user to review the database of all data associated with a given weather station record created in the NOAA GSOD station list (e.g., solar, weather, precipitation, Penman-Monteith ET, Thornthwaite ET, and calculated runoff).

Note: If multiple Scenarios have been assigned the same reference weather station, the values displayed for calculated runoff will pertain to the most recent Basic Scenario for which output has been generated.

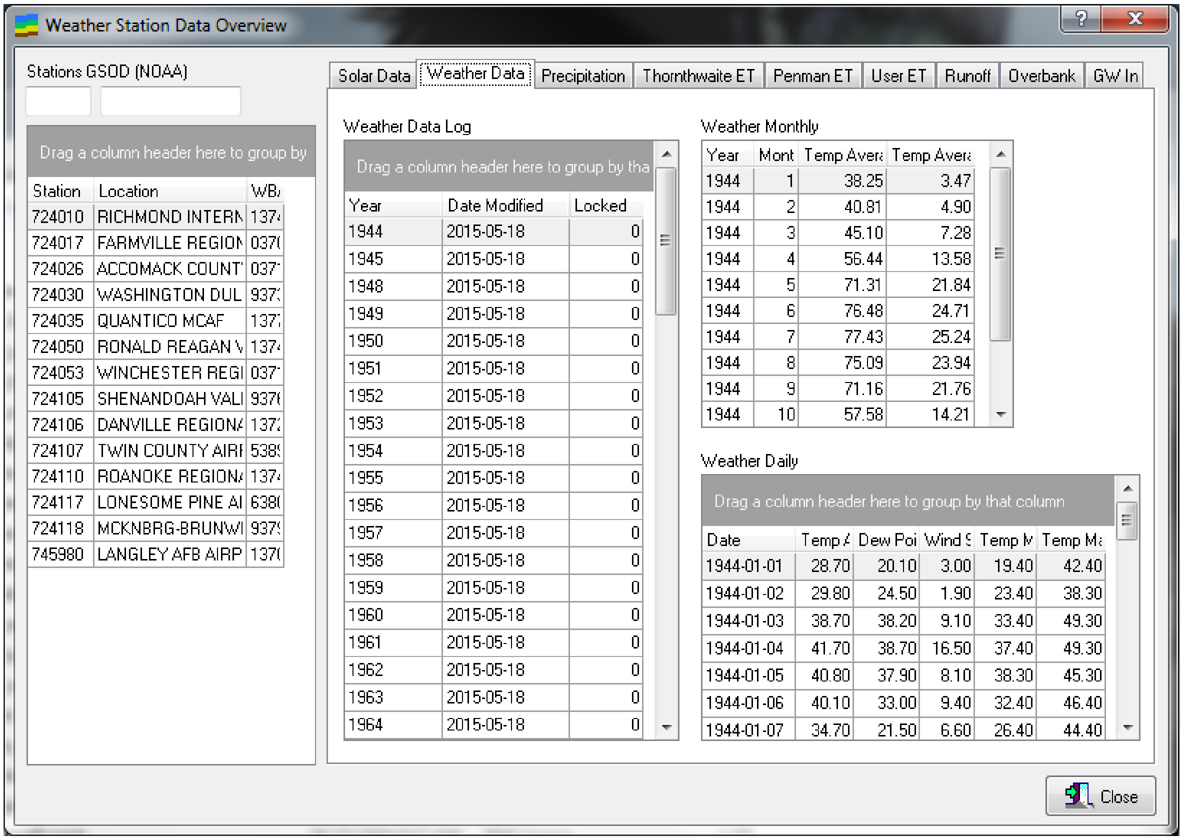
8.15.1 Solar Data

Solar data is arranged and can be viewed within this tab. No data can be edited from this screen.



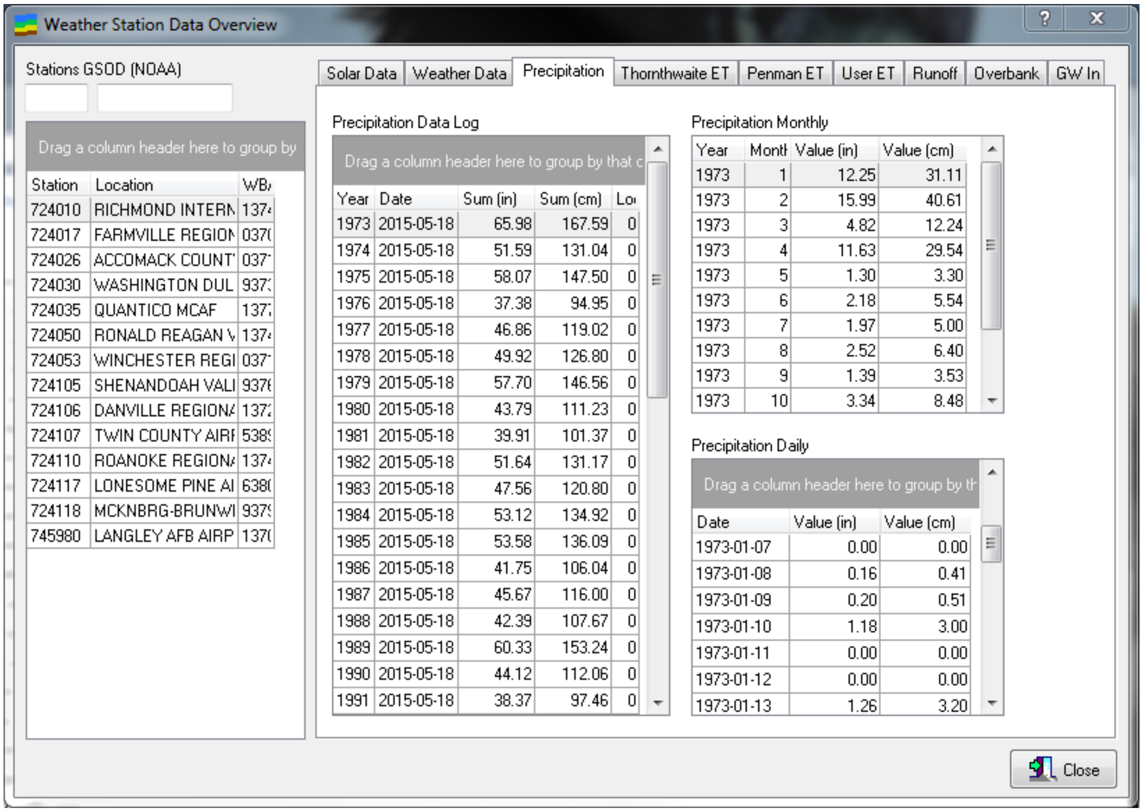
8.15.2 Weather Data

Weather data is arranged and can be viewed within this tab. No data can be edited from this screen.



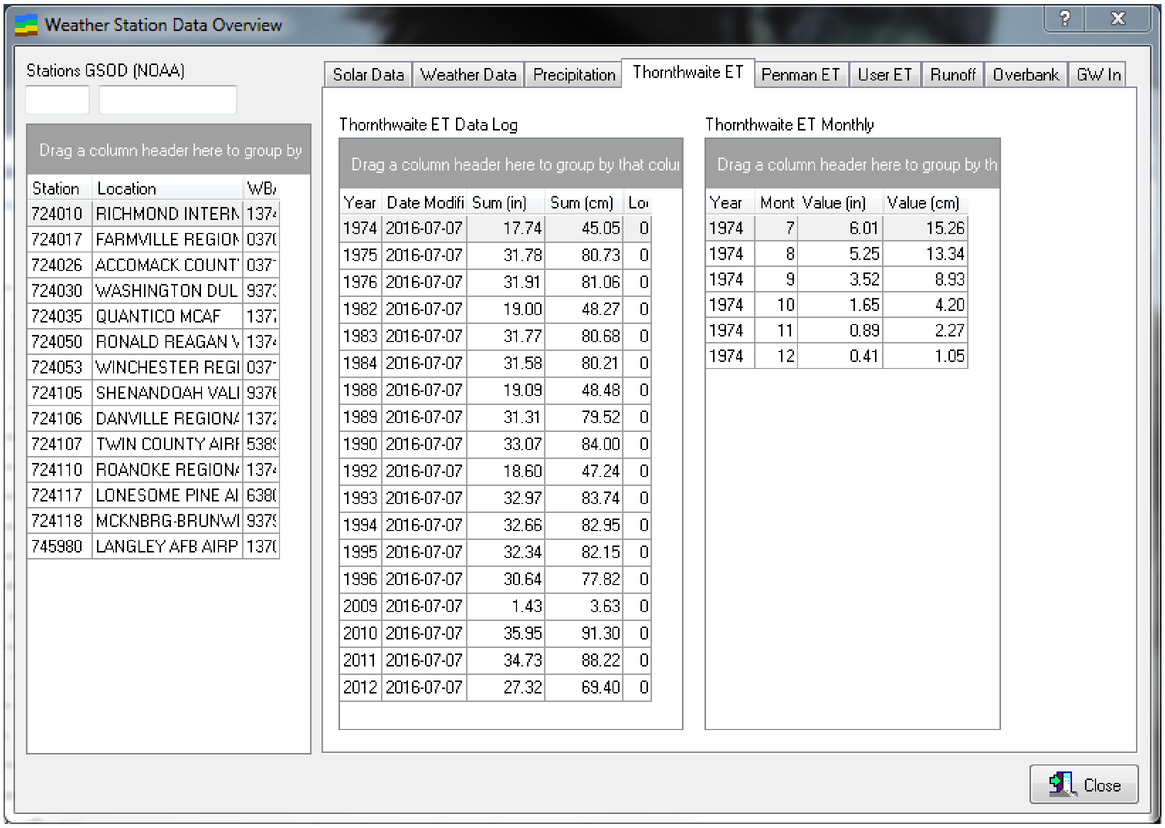
8.15.3 Precipitation Data

Precipitation data is arranged and can be viewed within this tab. No data can be edited from this screen.



8.15.4 Thornthwaite Data

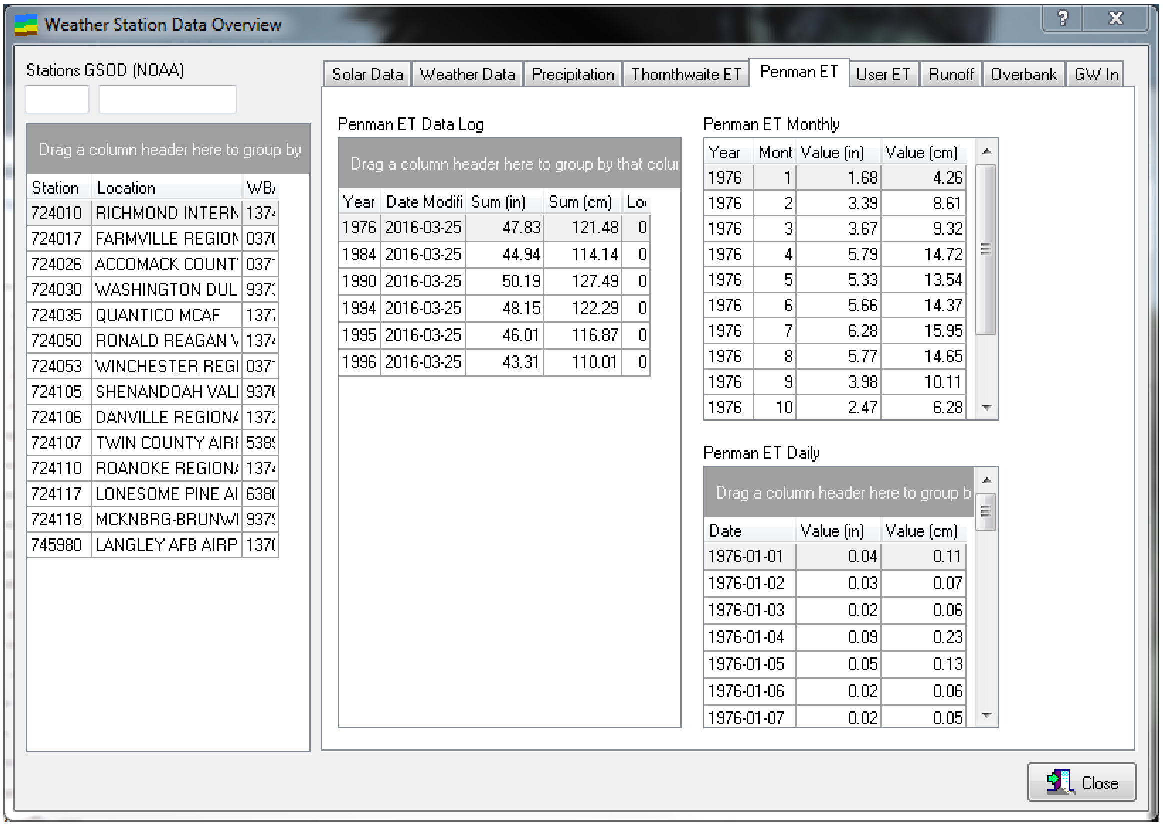
Thornthwaite ET data is arranged and can be viewed within this tab. No data can be edited from this screen.



Note: PET can be calculated by Wetbud. Unless a user has imported PET values from elsewhere, PET data will not be shown in this tab before being calculated using weather data associated with the station.

8.15.5 Penman Data

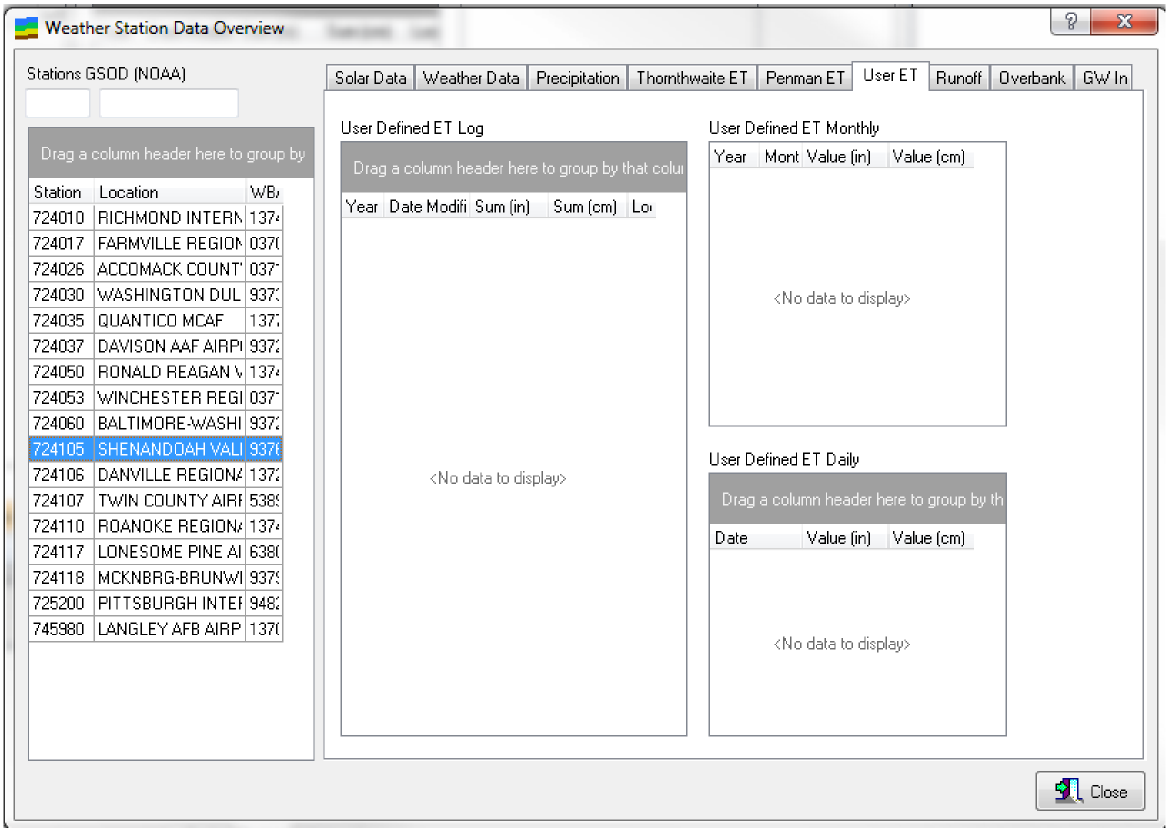
Penman-Monteith ET data is arranged and can be viewed within this tab. No data can be edited from this screen.



Note: PET can be calculated by Wetbud. Unless a user has imported PET values from elsewhere, PET data will not be shown in this tab before being calculated using weather data associated with the station.

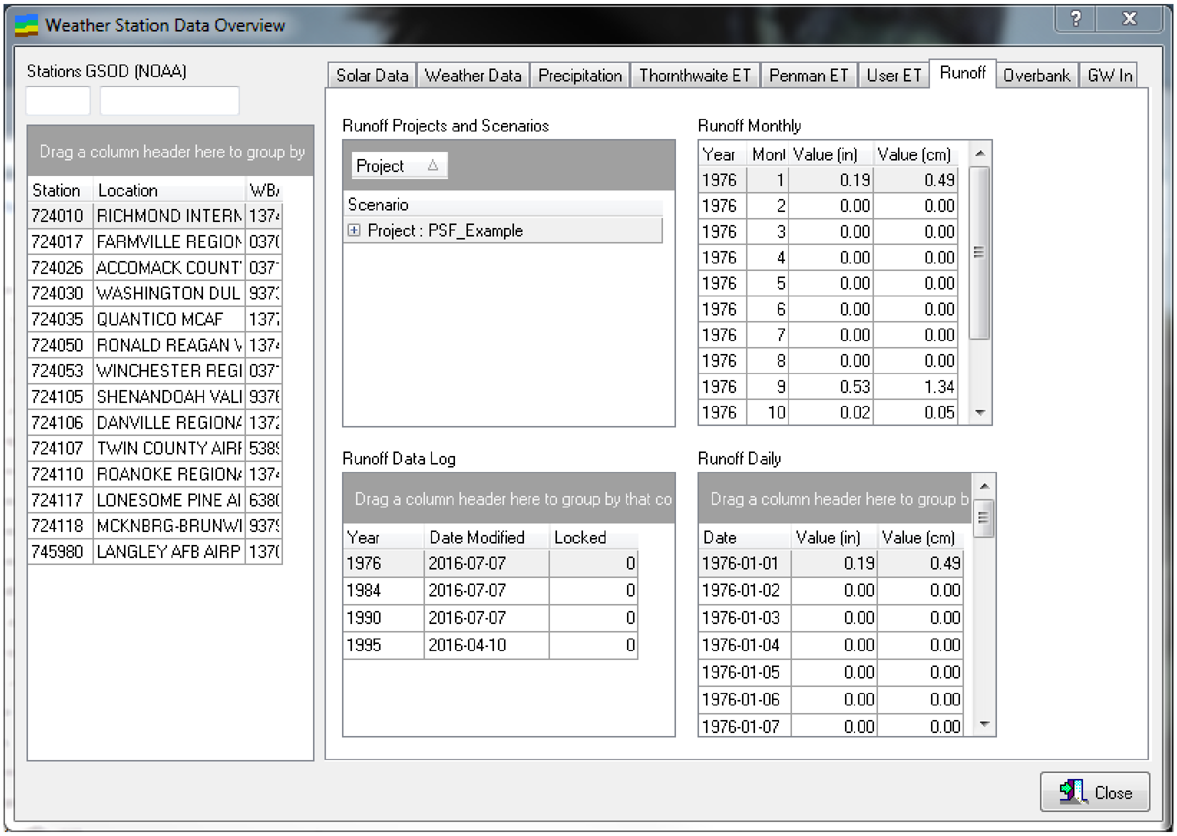
8.15.6 User ET Data

User defined ET data is arranged and can be viewed within this tab. No data can be edited from this screen.



8.15.7 Runoff Data

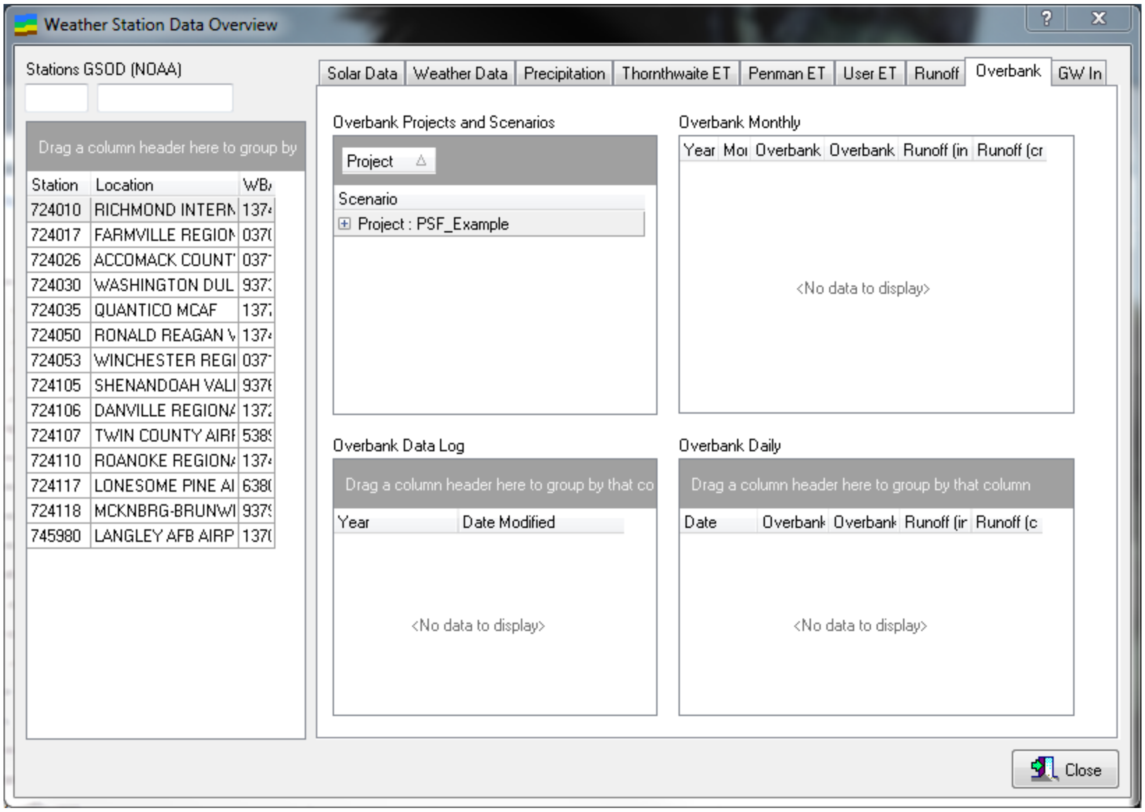
Runoff data is arranged and can be viewed within this tab. No data can be edited from this screen.



Note: Runoff is calculated by Wetbud. Runoff data will not be shown in this tab before being calculated using precipitation data associated with the station.

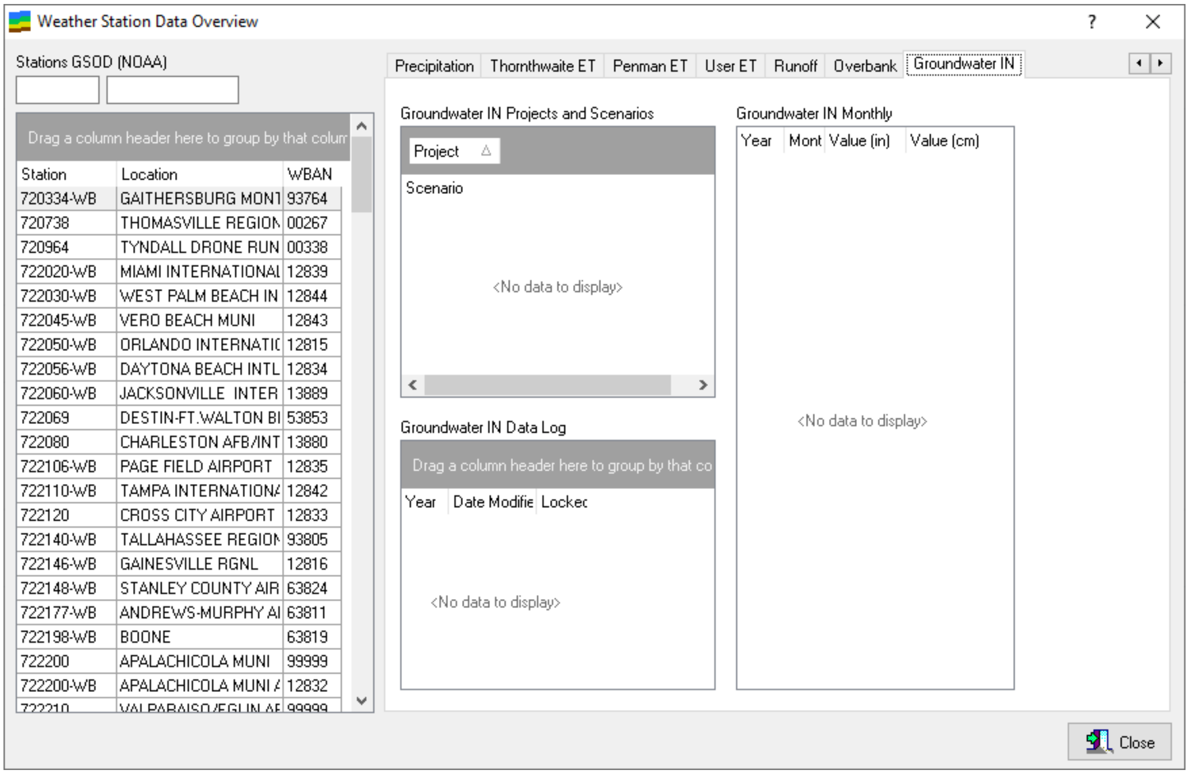
8.15.8 Overbank Data

Overbank data is arranged and can be viewed within this tab. No data can be edited from this screen.



8.15.9 Groundwater IN Data

Groundwater IN data is arranged and can be viewed within this tab. No data can be edited from this screen.


Weather Station Data Overview
Stations GSOD (NOAA)
Precipitation
Thornthwaite ET
Penman ET
User ET
Runoff
Overbank
Groundwater IN
Groundwater IN Projects and Scenarios
Project
Scenario
<No data to display>
Groundwater IN Monthly
Year
Mont
Value (in)
Value (cm)
<No data to display>
Groundwater IN Data Log
Drag a column header here to group by that co
Year
Date Modifie
Lockec
<No data to display>
Drag a column header here to group by that colum
Station
Location
WBAN
720334-WB GAITHERSBURG MONT 93764
720738 THOMASVILLE REGION 00267
720964 TYNDALL DRONE RUN 00338
722020-WB MIAMI INTERNATIONAL 12839
722030-WB WEST PALM BEACH IN 12844
722045-WB VERO BEACH MUNI 12843
722050-WB ORLANDO INTERNATIO 12815
722056-WB DAYTONA BEACH INTL 12834
722060-WB JACKSONVILLE INTER 13889
722069 DESTIN-FT.WALTON BI 53853
722080 CHARLESTON AFB/INT 13880
722106-WB PAGE FIELD AIRPORT 12835
722110-WB TAMPA INTERNATION 12842
722120 CROSS CITY AIRPORT 12833
722140-WB TALLAHASSEE REGION 93805
722146-WB GAINESVILLE RGNL 12816
722148-WB STANLEY COUNTY AIR 63824
722177-WB ANDREWS-MURPHY AI 63811
722198-WB BOONE 63819
722200 APALACHICOLA MUNI 99999
722200-WB APALACHICOLA MUNI 12832
Close

9

Basic Models

9 Basic Models

Basic Scenarios are models that use a simple mass balance and level pool routing routine to quantify the inputs and outputs of a wetland water budget on a monthly basis. In the Basic Model, the wetland is conceptualized as a “leaky swimming pool”, with a flat, level bottom and vertical side walls. When water is added to the wetland, it is assumed the wetland water surface instantaneously adjusts to a flat water surface. Water is not routed through the wetland; all surface water above the weir elevation is considered outflow and is removed from the wetland each month. Users must define the overall dimensions of the “swimming pool,” including an average wetland surface elevation (the bottom of the swimming pool), a wetland surface area, and a depth to weir (depth of water in the wetland, above which outflow occurs).

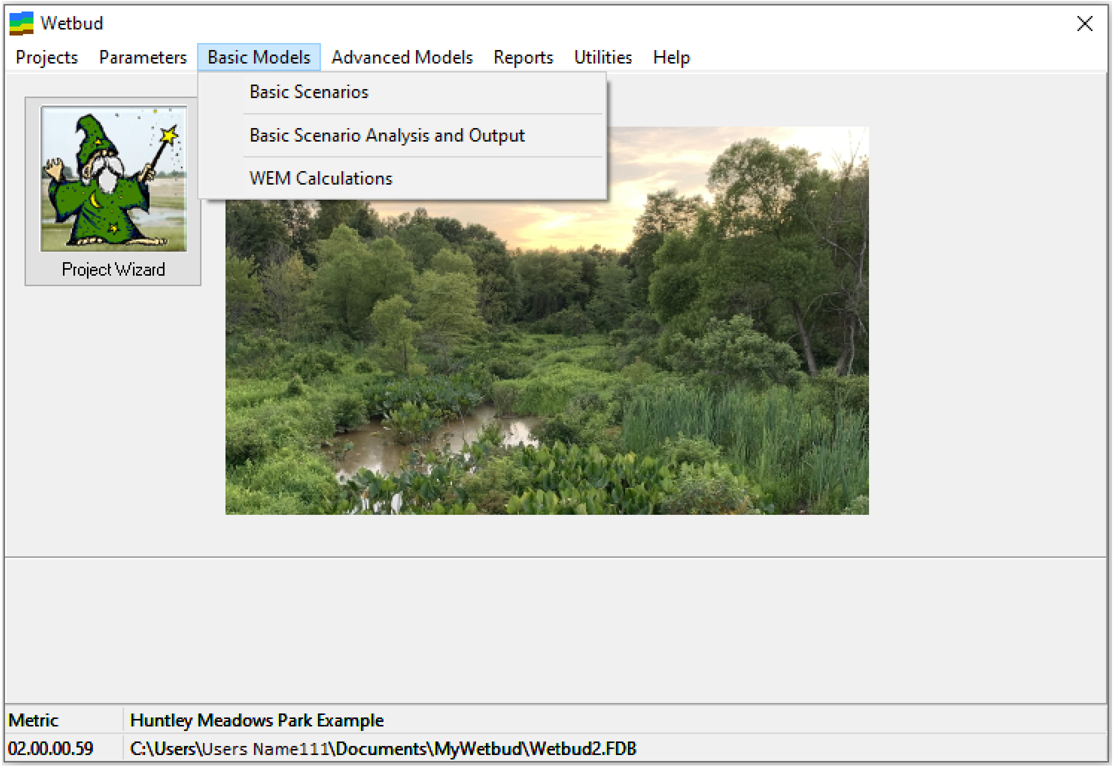
For wetlands with highly irregular topography, it is recommended that the user determine the wetland water volume below the outlet weir elevation using detailed topographic data (or maps) and then divide the actual wetland volume by the actual wetland surface area to determine an average depth to use in the Basic Model. The elevation of the wetland surface would then be set as the outlet elevation minus the average wetland depth and the depth to weir would be set as the average depth. Alternatively, users can enter stage-storage data into Wetbud to represent an irregular wetland bottom; the depth to weir is then set as the difference between the weir invert elevation and the lowest elevation in the wetland.

One or many Basic Scenarios can be generated for a Project. Setting up multiple Basic Scenarios for a Project allows the user to modify parameters (e.g., potential evapotranspiration estimation method, input and outputs, physical parameters, reference weather station, etc.) without having to duplicate basic site information under a new Project. Scenarios within a Project can also be copied for user convenience.

Note: This section of the user manual describes each of the options for modifying Basic Scenarios in the order the options are presented within the Basic Models drop down menu. Scenarios that refer to user generated data will need to reference data sets managed through the Project Specific Data section. Additional data need to be generated in advance for Scenarios that employ Wetbud’s advanced features, such as WEM or Overbank Flow. The user will need to develop all the corresponding data sets which can be referred to by the Basic Model.

The Basic Models menu has three options:
1. Basic Scenarios
2. Basic Scenario Analysis and Output
3. WEM Calculations

Note: If a Project is not selected prior to selecting an option in the Basic Models menu, the user will automatically be directed to the Select Project window.



9.1 Before Creating a Basic Scenario

Prior to creating a Basic Scenario, the user should have completed the following tasks and gathered the following data to parameterize their site and generate a water budget analysis using Wetbud:

1. Create a Weather Station record in the NOAA (GSOD) station database and import precipitation, weather, and solar data.
2. Determine years to be included in the water budget analysis. Dry, normal, and wet years can be calculated automatically using WETS station data or assigned manually by the user. See Station Data - GSOD and Station Data - GHCN and Station Data – WETS.
3. Determine the wetland area (acres or m^2), the wetland watershed area (acres or m^2), and the wetland watershed NRCS Curve Number (CN) (see the Wetland Watershed section for more information).
4. If you wish to include groundwater input, user water input/output, or stream overbank input, you must create monthly Groundwater IN/OUT, User Water IN/OUT, and/or Stream Overbank Flow data sets (see Project Specific Data).
   a. Users who wish to include groundwater input but do not have well data for the modeled periods should use WEM (Effective Monthly Recharge Model), the outputs from which will be used by Wetbud to calculate groundwater input data to include in the water budget analyses (see WEM Setup).
   b. Users who wish to include stream overbank input, but do not have stream discharge or stage data, must set up the Stream Overbank flow parameters.

Wetbud uses these parameters to automatically generate a stream stage time series to include in water budget analyses (see Stream Overbank Flow in the Projects section).

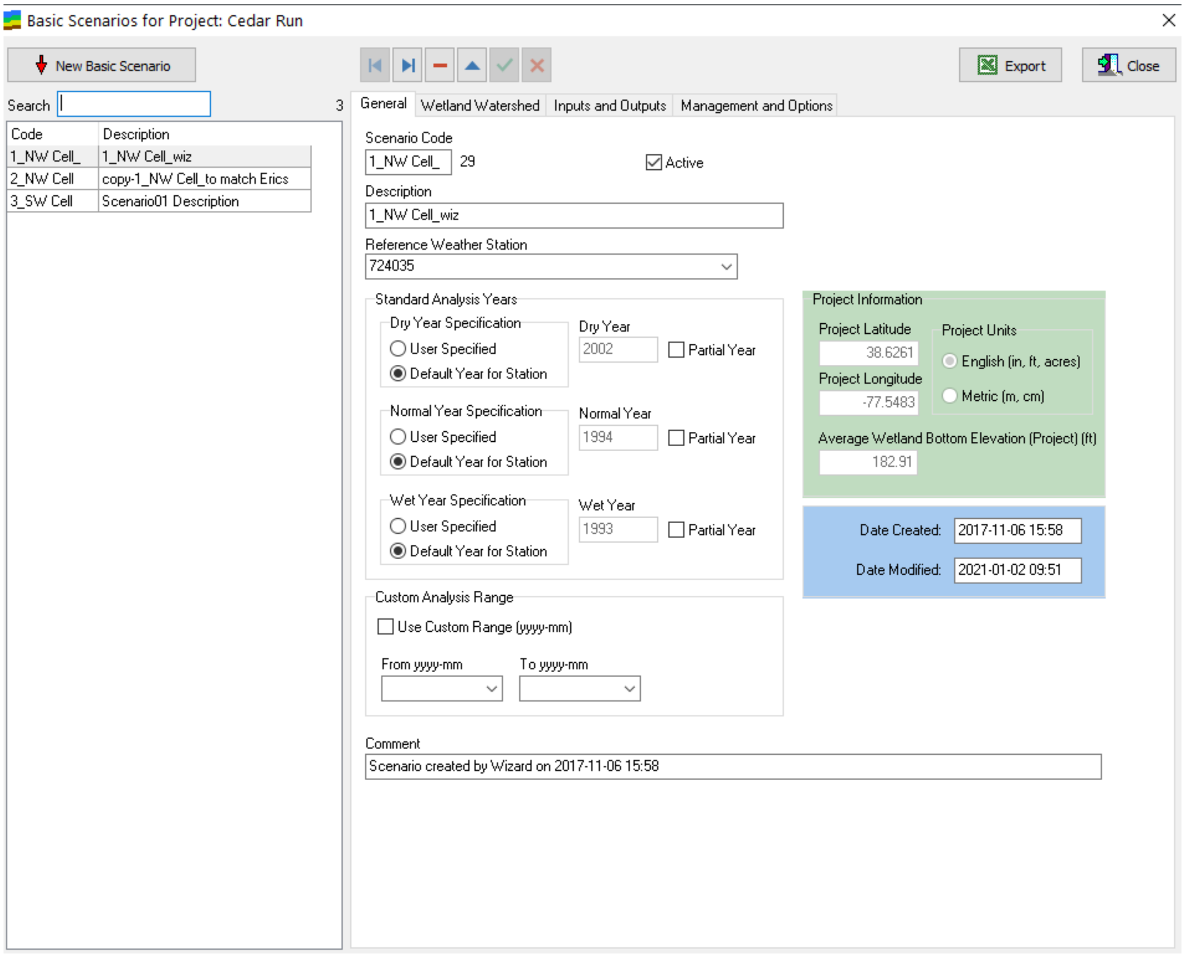
5. Estimate soil storage factor (e.g., specific yield/drainable porosity, effective porosity) of soil within the wetland.
6. Determine average depth below the weir (or other outlets) controlling surface water ponding within the wetland (if no weir is present, then estimate the average maximum depth of surface water ponding that occurs within the wetland).
7. Create the clear sky solar insolation data set or average daylight length data set to use in the calculations of Penman and Thornthwaite PET, respectively, or manually import PET data (see Potential Evapotranspiration Data).

Having each of these tasks and parameters ready prior to Basic Scenario setup will greatly increase the efficiency and accuracy of your Basic Scenario water budget model. However, many of these parameters (e.g., soil storage factor, wetland depth to weir) can be estimated during Scenario setup.

9.2 Basic Scenarios

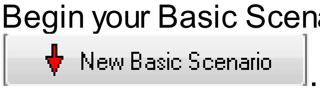
Start by selecting a Project in the Select Project window. Next, select Basic Scenarios from the Basic Models drop-down menu in the Wetbud home screen.

In the Basic Scenarios window (see figure below) there are four tabs: General, Wetland Watershed, Inputs and Outputs, and Management and Options.



The following sections explain how to setup and adjust all of the parameters relating to a Basic Scenario. Upon completing this section, users will be able to calculate water budgets through the Basic Scenario Analysis and Output menu and WEM Calculations menu.

9.2.1 General

1. Begin your Basic Scenario setup in the General tab. First, click 

. The box under Code is now filled with the text 'ScenarioXX'. Delete this text and replace it with a code (10 character limit) of your choice. Next, click  to save. You will now see a code has been generated for your Scenario in the box on the left side of the window.
2. Proceed by entering the Description and select the Reference Weather Station from the drop-down list. Your Project coordinates and reference elevation will automatically be filled in based on the coordinates and reference elevation previously defined in the Projects window.
3. Next, choose the years for analysis in the Standard Analysis Years or Specify Analysis Range section.

Note on selecting years for standard analysis and/or custom analysis range: The years chosen for the standard analysis can be user-specified or automatically calculated. To specify the year or years for analysis, click the User Specified option and enter the year in the adjacent box. Selecting the Automatically Calculated option will use the wet, normal, or dry year calculated by Wetbud in the GSOD weather stations Precipitation Info tab. In the event that a given year does not have a full calendar year of data (e.g., solar, weather, precipitation, etc.), or if the user wishes to only include a partial year in the analysis, the user must check the partial year box next to the specified year in the Standard Analysis Years section.
Note on selecting the partial year option: When this option is selected, Wetbud will not check for the presence of a full year's worth data in the data set. It is up to the user to ensure that all needed data are presented in the corresponding data sets.

4. To use a Custom Analysis Range, check the Use Custom Range checkbox and choose the starting and ending dates for the analysis in the From yyyy-mm and To yyyy-mm drop-down lists.
5. After entering your information in the General tab, save and proceed to the Wetland Watershed tab.

9.2.2 Wetland Watershed

1. In the Wetland Watershed tab users must specify four parameters:
   a. the Total Area of Watershed for Direct Surface Runoff (acres or m^2).
   b. the Constructed Wetland Area (acres or m^2).
   c. the Existing Wetland Area (acres or m^2).
   d. the Watershed NRCS Curve Number.

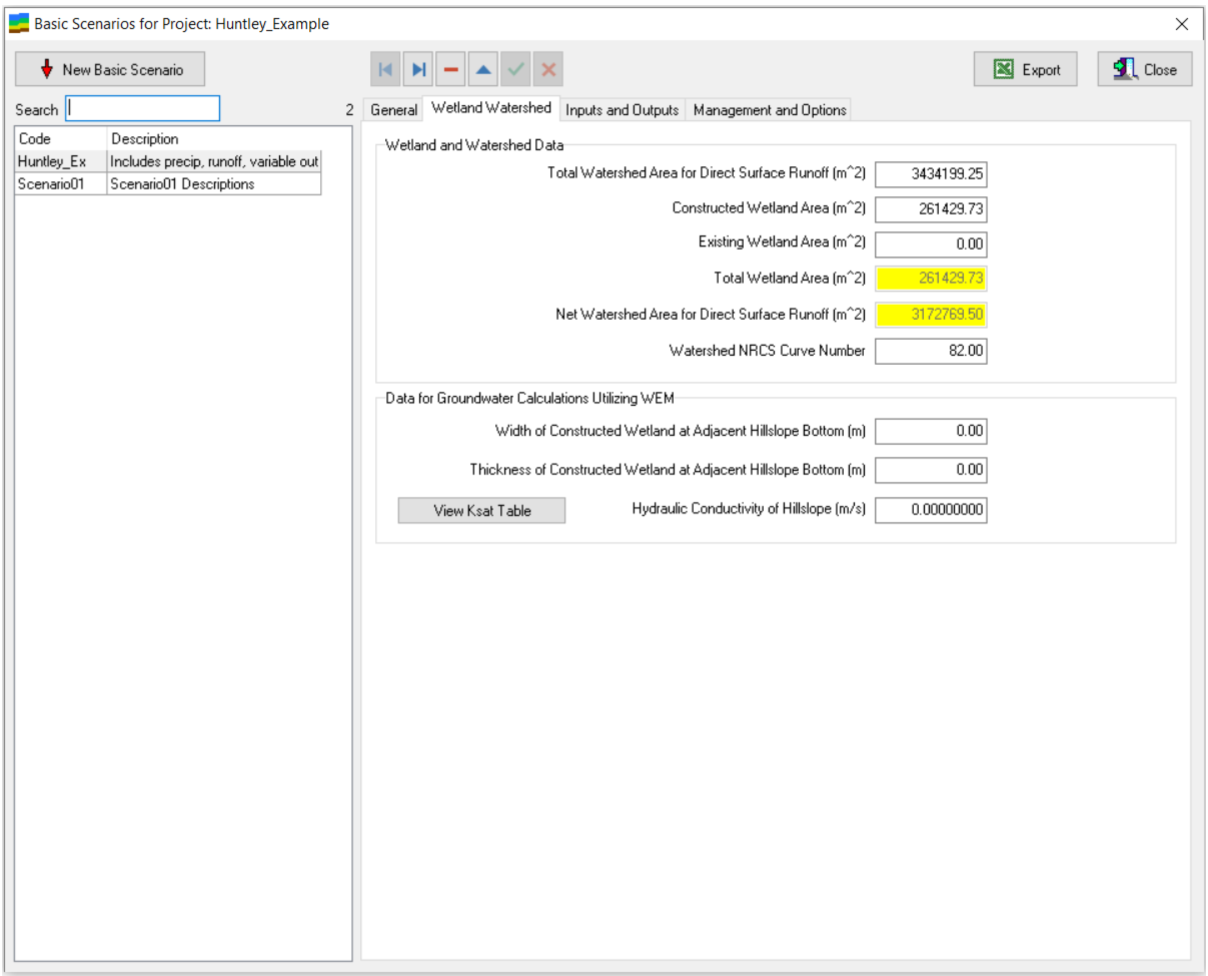
   More specifically,

   a. The Total Area of Watershed for Direct Surface Runoff is the entire area contributing runoff to the outlet in the created wetland. This corresponds to the "wetland watershed."
   b. The Constructed Wetland Area refers to the size of the constructed (or natural) wetland that applies to the current Scenario. For example, if your Project contains five Scenarios for five different wetland designs for a particular site, make sure the value entered for Constructed Wetland Area applies to the design in the current Scenario.
   c. The Existing Wetland Area refers to the size of the existing wetland that applies to the current Scenario within the Total Area of Watershed for Direct Surface Runoff.
   d. The Net Watershed Area for Direct Surface Runoff is calculated by subtracting the constructed wetland area and the existing wetland area from the total watershed area.
   e. The Watershed NRCS Curve Number must be determined externally by the user. The default value supplied by Wetbud is 70. The curve number entered in this field should correspond to the Net Watershed Area for Direct Surface Runoff.
2. Users who choose to use WEM to estimate groundwater input must also assign values for:
   a. the Width of Wetland at Adjacent Hillslope Bottom (ft or m),
   b. the Thickness of Constructed Wetland at Slope Bottom (ft or m), and
   c. the Hydraulic Conductivity of Hill Slope (ft/s or m/s).

More specifically,

a. The Width of Constructed Wetland at Adjacent Hillslope Bottom is defined as the width of the wetland along the toe-slope of the adjacent hillside or the width of the cross-section through which groundwater flows to the site.
b. The Thickness of Constructed Wetland at Slope Bottom is defined as the thickness of the cross-section through which groundwater flows to the site.
c. The Hydraulic Conductivity of Hill Slope is defined as the hydraulic conductivity of the material underlying the hillside from which groundwater is delivered to the site through cross-section 'A'. Estimates for this value are in the [Soil Ksat table in the Parameters menu](#).
d. See the images in [WEM Setup](#) for a visual depiction of how these dimensions are defined.

3. After entering the above values, save your Wetland Watershed data and proceed to the Inputs and Outputs tab.



9.2.3 Inputs and Outputs

Specific water inputs and outputs will vary from site to site and must be assigned based on the physical conditions expected to affect water levels in the wetland. The Inputs and

Outputs tab is used to designate which components of the water budget to include in the water budget calculations. This tab has four sub-tabs: Water Inputs, Water Outputs, Site Parameters, and Stream Overbank Flow. Details and information about the water budget inputs and outputs in each of these sub-tabs are explained below:

- Basic Models - Water Inputs
- Basic Models - Water Outputs
- Basic Models - Site Parameters
- Basic Models - Stream Overbank Flow

9.2.3.1 Water Inputs

The Water Inputs sub-tab is used to select water budget inputs to include in Basic Scenario water budget calculations.

1. Initial fill (inches) is defined as the water level within the wetland at the beginning of the simulation for a given year (e.g., water level in January for a one-year simulation). This value represents the depth of water relative to the average wetland bottom elevation (average wetland surface), where a positive value indicates the depth of ponded surface water and a negative value indicates the depth to water below the ground surface (default = 0.000 inches). Initial fills must be assigned for each year (e.g., Dry Year, Normal Year, Wet Year) and/or the Custom Period.
   Note: If initial fill levels are unknown for the beginning (e.g., January) of a given dry, normal, or wet year, then the user should use the average depth of ponding that can occur at the site. This recommendation is based on the assumption that many sites experience their highest water levels during mid-winter.
2. Precipitation data from the reference weather station assigned to the current Project will be included in water budget calculations. Uncheck the box next to Precipitation if you do not wish to include precipitation as a water budget input.
3. Direct Surface Runoff into Wetland is defined as the amount of water that will enter the wetland as surface runoff during storm events from the wetland watershed and is governed by the values (e.g., Curve Number and Total Area of Watershed for Direct Surface Runoff) assigned in the Wetland Watershed tab. Uncheck the box next to Direct Surface Runoff into Wetland if you do not wish to include direct surface runoff as a water budget input.
4. Groundwater IN is defined as the rate of groundwater entering the site (inches/month) from the adjacent uplands and/or from upward seepage. Groundwater IN has four options: No Groundwater IN, Constant Rate, Calculated by Wetbud using WEM, and User Time Series.
   a. If the site does not receive groundwater input from the surrounding uplands or upward seepage, or if the user chooses to not include groundwater input in the water budget calculations, then select No Groundwater IN. To add groundwater at a constant rate, select Constant Rate and enter the rate (inches/month) in the adjacent box.
   b. Users who lack observed groundwater input data for the time periods they wish to model can select Calculated by Wetbud through WEM, which allows Wetbud to automatically calculate monthly groundwater input based on hydraulic head

elevations generated using the WEM. Using the WEM is a two-step process that consists of WEM Setup and WEM Calculations. For WEM Setup instructions, refer to WEM Setup. For WEM calculations instructions, refer to WEM Calculations. WEM calculations must be performed prior to Basic Analysis and Output to Groundwater input calculated by Wetbud in water budget calculations. **Note:** A WEM analysis must be performed prior to selecting the Calculated by Wetbud through WEM option for Groundwater IN. If this analysis has not been, water budget calculations through the Basic Analysis and Output option will fail.

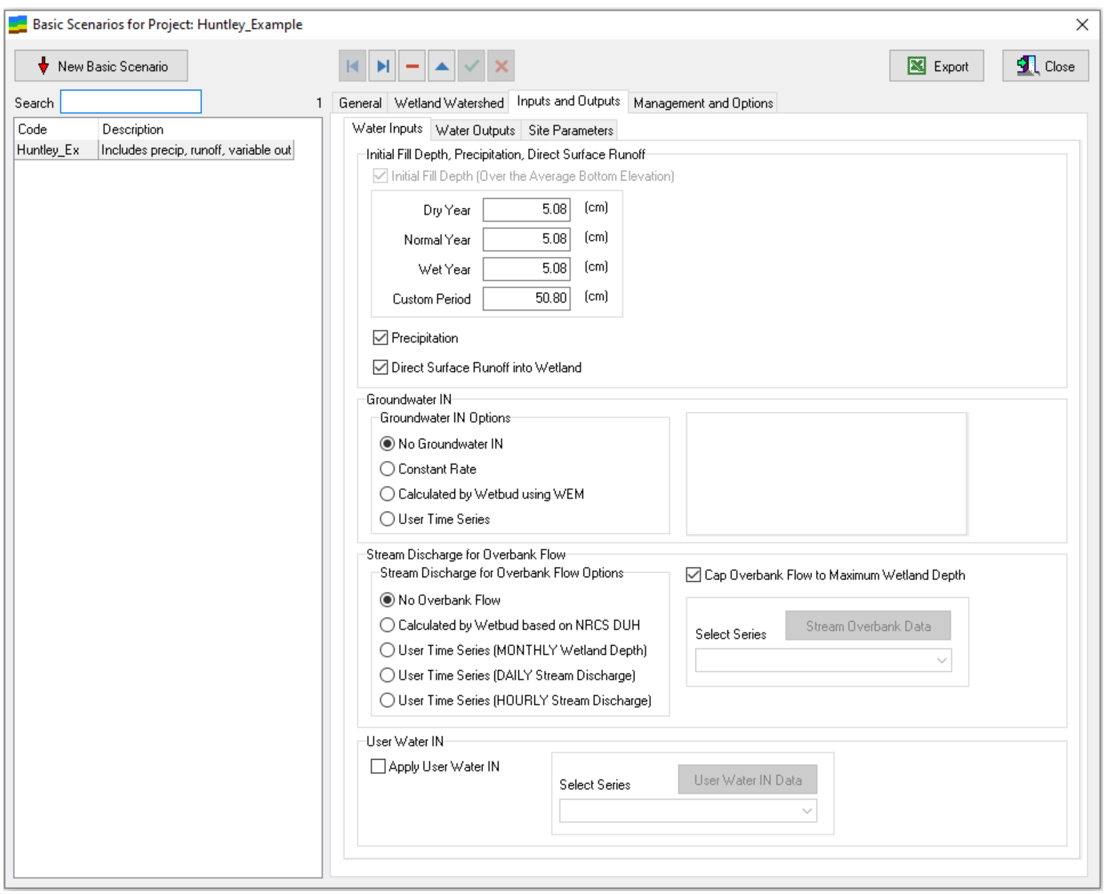
c. If rates of monthly groundwater input are known or have been estimated external to Wetbud, select User Time Series and the Groundwater IN file corresponding to the current Scenario in the Select Series drop-down list next to this option. **Note:** Users who select the User Time Series option must have previously created a Groundwater IN data set. For details about the method used to calculate groundwater input and instructions on how to create a Groundwater IN data set see Water Input/Outputs.

5. Stream Overbank Flow is water added to the wetland due to overbank flow from an adjacent stream during floods. Stream Overbank Flow has five options: No Overbank Flow, Calculated by Wetbud based on NRCS DUH, User Time Series (Monthly Wetland Depth), User Time Series (Daily Stream Discharge) and User Time Series (Hourly Stream Discharge).
   a. If the site does not receive overbank flow input or this component is not included in the water budget calculations, select the No Overbank Flow option.
   b. Users who wish to include stream overbank flow entered as an additional monthly water volume input, expressed as a depth over the entire wetland, then select User Time Series (Wetland Depth) and select the file corresponding to the current Scenario in the Select Series drop-down list, which will contain a list of previously created Stream Data data sets designated as Data Set Type – Wetland Depth Values. See Water Inputs/Outputs for instructions to create Stream Overbank data sets designated as Wetland Depth.
   c. Users who wish to include stream overbank flow input based on stream water discharge, then select User Time Series (Daily Stream Discharge) or select User Time Series (Hourly Stream Discharge) and select the file corresponding to the current Scenario in the Select Series drop-down list, which will contain a list of previously created, Stream Data data sets designated as Stream Discharge. See Water Inputs/Outputs for instructions to create Stream Data data sets designated as Stream Discharge.
   Note: If the User Time Series (Daily Stream Discharge) or the User Time Series (Hourly Stream Discharge) option is selected, the user must also complete the relevant sections of the Stream Overbank Flow sub-tab with respect to the Stream Channel Specification, the Type of Inflow Structure and related parameters. Wetbud will use the data assigned in these sections to determine the amount of overbank flow based on the stream water surface elevation data set. See also Stream Overbank Flow.
   d. Users who lack observed stream discharge or wetland inputs from overbank flows but who wish to include it as a water budget input can select Calculated by Wetbud, which will allow Wetbud to automatically calculate stream overbank input

based on the Stream UH Flow and Stream Overbank Flow parameters assigned to the current Project and Scenario, respectively.
Note 1: Prior to selecting this option, the user must first complete the Stream UH Flow tab in the Define Projects window for the current Project. Refer to Stream UH Setup under Stream Overbank.
Note 2: The Stream Overbank Flow sub-tab will only be visible if one of the Stream Overbank Flow options other than No Overbank Flow are selected.

e. The option Cap Overbank Flow to Maximum Wetland Depth limits the amount of water reported as water entering the wetland as overbank flow for each day to the difference between the invert elevation of the outflow weir and the average wetland bottom elevation (the maximum wetland depth). If this option is selected, the difference between the daily calculated overbank flow depth and the average wetland bottom elevation will be ignored and will not be included in the total monthly outflow from the wetland through the outflow weir. See Average Wetland Bottom Elevation for details on how average wetland bottom elevation is defined.

6. User Water IN values are any additional amount of water the user chooses to include as a water budget input for a given month(s). To include this as a water budget input check the box next to User Water IN and select the User Water IN file corresponding to the current Scenario.
Note: Users who select the User Water IN option must have previously created a User Water IN data set. For details about and instructions on how to create a User Water IN data set see Water Input/Outputs.



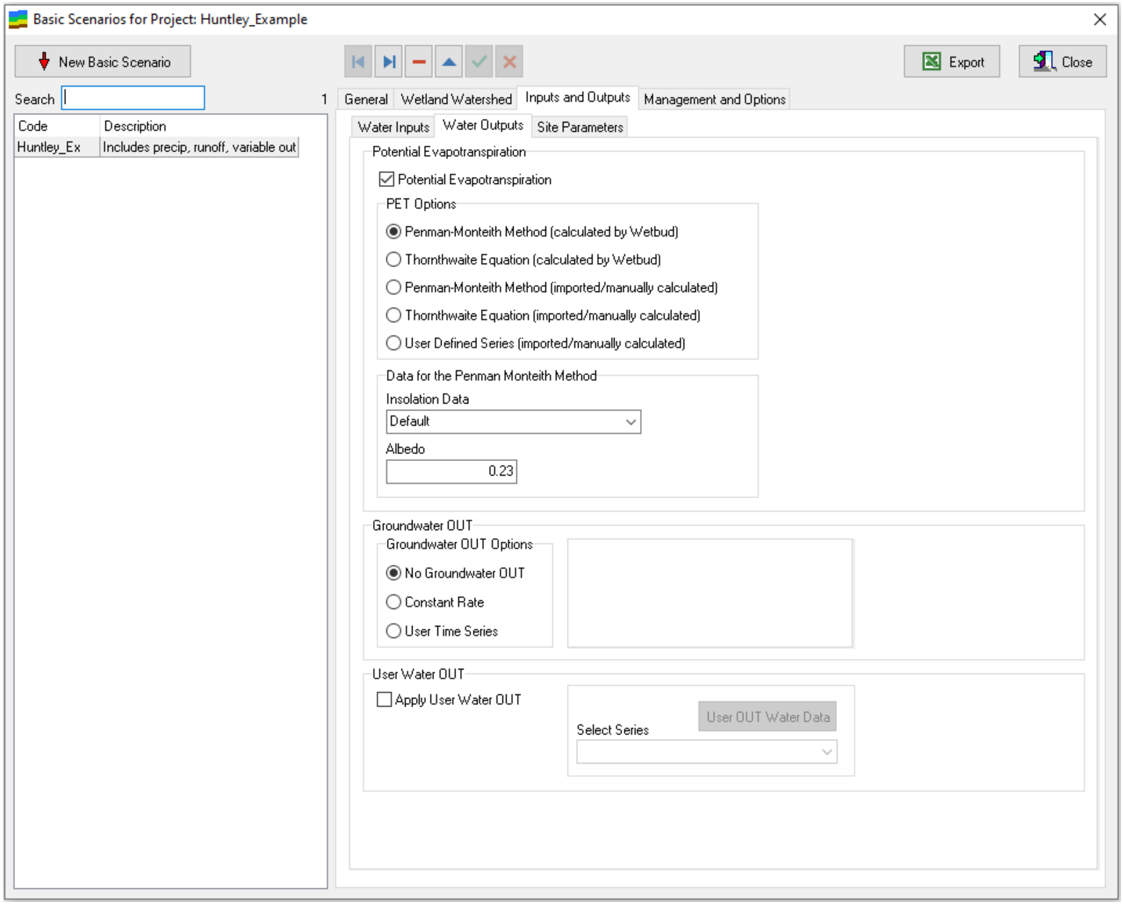
9.2.3.2 Water Outputs

The Water Outputs sub-tab is used to assign water budget outputs to include in Basic Scenario water budget calculations.

1. PET or potential evapotranspiration is defined as the combined loss of water due to direct evaporation and transpiration by plants. In the PET Options section, the user must select one of the five options used to quantify PET: Penman-Monteith Method calculated by Wetbud (recommended), Thornthwaite Equation calculated by Wetbud (default), Penman-Monteith (imported/manually adjusted), Thornthwaite Equation (imported/manually adjusted) or User Defined Series.
    a. While Penman-Monteith is the recommended PET estimator the default PET estimator for all Wetbud Basic Scenarios, including those created by the Project Wizard, is Thornthwaite. Thornthwaite computations only require temperature data. Penman-Monteith computes PET on a daily basis using several observed weather parameters. Penman-Monteith is the more accurate estimate of PET. Unfortunately, it can be difficult to meet all of the weather data needs for Penman-Monteith and the resulting PET estimate is often greater than what is estimated by Thornthwaite. As neither of these PET estimators take into consideration available water, the increased draw-down of the water budget resulting from Penman-Monteith can be misleading. Therefore, Penman-Monteith is recommended for all Advanced Models and for Basic Models that include Restrictive Layers (see Restrictive Layers under Site Parameters). Restrictive Layers provide a point that water levels can be drawn down to during dry periods and a point water levels can recover from when inputs exceed outputs. While Basic Models can utilize the depth to Restrictive Layer to limit draw down from all sources of loss (PET, GWout, etc.). Advanced Models allow users to specifically address the issue of water availability in PET calculations through user-defined ET Extinction Depths. The ET Extinction depth (see Layers under Advanced Scenarios) is defined as the depth at which evapotranspiration from the water table has ceased, or the depth to which plant roots extend below the land surface. When the depth of the water table in the model is beneath the extinction depth, ET ceases.
    b. The Penman-Monteith Method (calculated by Wetbud) option is *recommended* due to higher temporal resolution and greater accuracy than the Thornthwaite method (i.e., Penman determines daily estimates of PET as opposed to monthly estimates made by Thornthwaite). This method will utilize monthly totals of summed daily rates of PET calculated by Wetbud for the analysis range. However, this method can only be chosen if the user has previously imported all of the weather and solar data required for the Penman-Monteith equation for PET. The user must also select an insolation data set from the drop-down menu and choose an appropriate value for albedo based on land cover (default albedo = 0.23). See Parameters for Penman-Monteith ET in Potential Evapotranspiration for information on selecting albedo values for different land cover types and creating an insolation data set.

c. The Thornthwaite Equation (calculated by Wetbud) option will utilize monthly rates of PET calculated by Wetbud for the analysis range. If this method is chosen, the user must have previously imported all of the data required for the Thornthwaite equation for PET (e.g., weather and daylight length data). See Parameters for Thornthwaite ET for information pertaining to the Thornthwaite equation.
d. The Penman-Monteith (imported/manually adjusted) option will apply to daily rates of PET manually imported by the user for years included in the analysis range. If this method is chosen, the user must have previously imported daily values for PET calculated externally. See Manually Importing ET Data for information about how to manually import daily ET data.
e. The Thornthwaite Equation (imported/manually adjusted) option will apply monthly rates of PET manually imported by the user for years included in the analysis range. If this method is chosen, the user must have previously imported monthly values for PET calculated externally. See Manually Importing ET Data for information about how to manually import monthly ET data.
f. The User Defined Series option will apply monthly rates of PET manually imported by the user for years included in the analysis range. If this method is chosen, the user must have previously imported monthly values for PET measured or calculated externally. See Manually Importing ET Data for information about how to manually import monthly ET data.

2. Groundwater OUT is defined as the rate water exits the site due to downward seepage or groundwater discharge on the down-gradient end of the site. Groundwater OUT has three options: No Groundwater OUT, Constant Rate, and User Time Series.
   a. If the site does not lose groundwater due to downward seepage or due to groundwater discharge, or this is not included in the water budget calculations, then select No Groundwater OUT.
   b. To remove a constant rate of groundwater output for every month in the analysis range, select Constant Rate and enter the rate (inches/month) in the adjacent box.
   c. For situations where rates of monthly groundwater output are known or have been estimated external to Wetbud, select User Time Series and select the Groundwater OUT file corresponding to the current Scenario in the Select Series drop-down list adjacent to this option.
   Note: Users who select the User Time Series option must have previously created a Groundwater OUT data set. For details about the method used to calculate groundwater output and instructions on how to create a Groundwater OUT data set see Water Input/Outputs.
3. User Water OUT can be any additional amount of water the user chooses to include as a water budget output for a given month(s). To include this as a water budget output check the box next to User Water OUT and select the User Water OUT file corresponding to the current Scenario.
   Note: Users who select the User Water OUT option must have previously created a User Water OUT data set. For details about and instructions on how to create a User Water OUT data set see Water Input/Outputs.



9.2.3.3 Site Parameters

The Site Parameters sub-tab is used to assign four basic physical parameters that affect the water levels at a given site:

1. Soil Storage Factor,
2. Surface Storage Factor,
3. Average Wetland Bottom Elevation,
4. Restrictive Layer (if any),
5. Wetland Depth to Outlet Weir,
6. Site Reference Hydroperiod Data, and
7. Site Storage Rating Curve.

The Soil Storage Factor (0-1) is based on a measured or estimated specific yield (Sy) for the surface soil; similar to how specific yield is applied to aquifer flow models, but with higher values relative to rocks due to much higher porosity in soils. This value equates to the total volumetric water content that is readily available for ET and that will not be impeded by suction/matrix forces in the soil. In soil science terminology, this is equal to maximum retentive capacity (water at saturation) minus field capacity (water held at -0.1 to -0.3 bars (-10 to -30 kPa) suction).

For the upper soil zone of interest (top 30 cm) for legal jurisdiction, the value will likely vary between <0.10 in a very compact high clay soil to possibly 0.40 in loose, highly porous organic matter-rich loamy or sandy soil. The value could be higher than 0.40 in an organic soil.

The Surface Storage Factor (0-1) is essentially the total amount of ponded water not occupied by vegetation. For example, a value of 0.98 assumes that 2% of above ground space is occupied by vegetation. Dense emergent vegetation may occupy up to 5% of the above ground space.

The Average Wetland Bottom Elevation is used to convert the calculated volume of overbank flow into a depth of water over the wetland when overbank flow is calculated from stream discharge. This elevation should represent an average elevation of the wetland bottom, assuming the wetland volume is described by a regular geometric shape, such as a box or a cylinder.

Restrictive Layer: If an impermeable layer is present at some depth, then the user should select the Impermeable Layer Present option and then assign the depth to the impermeable layer (in or cm). Enabling this option restricts the predicted depth-to-water beneath the Average Wetland Bottom Elevation from being able to exceed the Depth to Impermeable Layer (in or cm) when water outputs exceed water inputs. If a water table is present at some depth, then the user should select the respective water table options. The user can also specify at Time Series for water table depths. When inputs exceed outputs and water levels in the wetland start to recover, the Depth to Impermeable Layer then becomes the base elevation that water levels will recover from. More information is available in Sneesby (2019) and Sneesby et al (2019).

The Basic version of Wetbud assumes that the modeled wetland is essentially flat and that maximum water levels are controlled by an outlet, berm, or similar structure, such as a weir. The Wetland Depth to Outlet Weir represents the average height of the outlet weir(s) above the wetland bottom surface, i.e., the maximum depth of water that can be reached before the model allows surface water to exit the wetland. For sites where outlet weirs are absent or ponding is rare, a value of 0.000 is recommended. The User Time Series option is useful for sites that have adjustable water control structures that may be raised or lowered for certain months of the year. When the User Time Series option is selected the user must assign a data set of wetland depth to outlet weir values for each month included in the analysis range. More specifically:

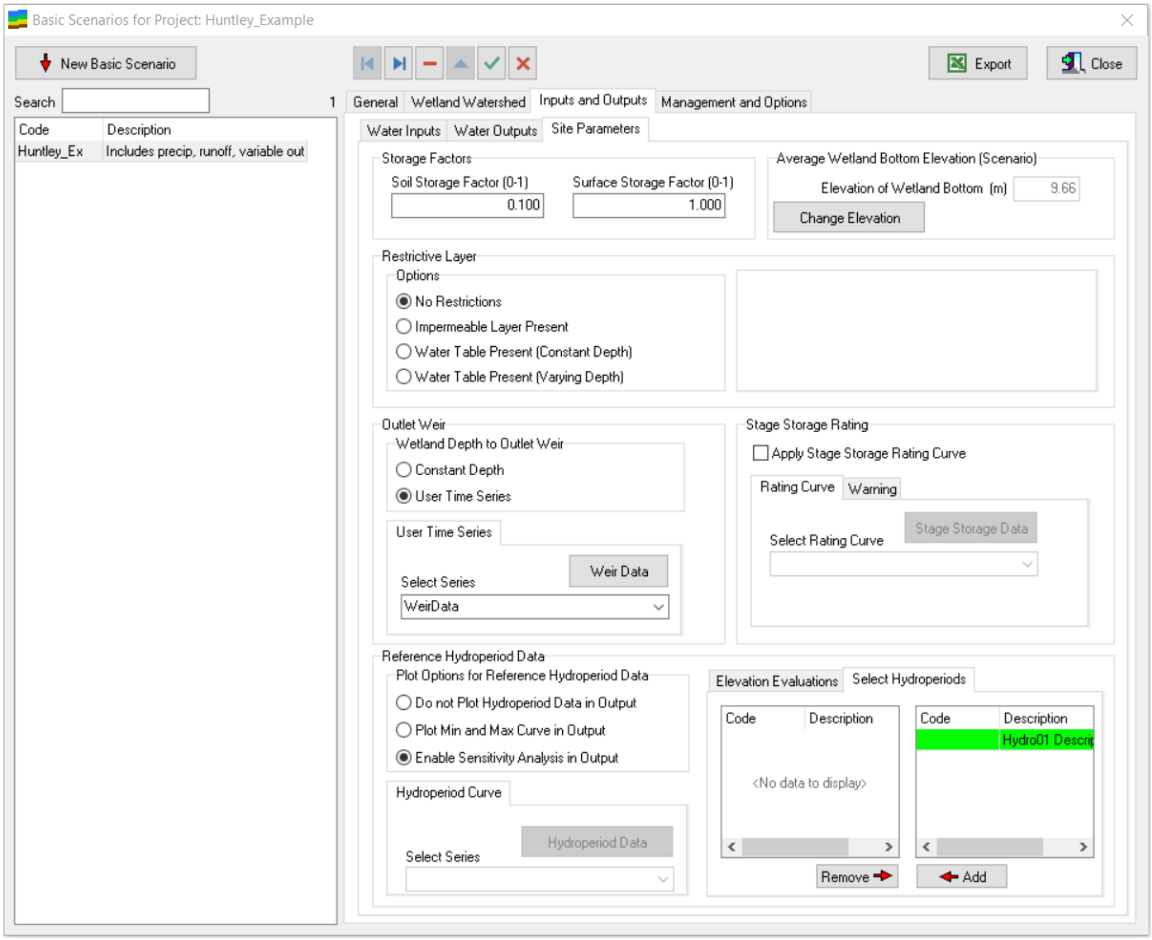
1. To assign a constant wetland depth, select Constant Depth and enter the value (inches or cm) in the Depth box.
2. To assign variable wetland depths, select User Time Series and select the Wetland Depth to Outlet Weir data set that corresponds to the current Scenario from the drop-down list.
3. To create a Wetland Depth to Outlet Weir data set click Weir Data and follow the instructions provided in the Creating a Water Input/Output Data Set.

The Wetbud Basic Model generates a graphical representation of the monthly hydroperiod as the relative depth of ponding or saturation above or below the soil surface. Users may also generate a “target hydroperiod” for comparison by inputting monthly values for the average and anticipated min/max water levels for an appropriate wetland system that is presumably similar in type to the created wetland being designed. Where available, it us suggested that actual field monitoring data over multiple years be used for this purpose. Alternatively, hypothetical or literature based data sets can be used for this purpose with appropriate caution. Examples of multi-year hydroperiods for a range of non-tidal wetland types in the Mid-Atlantic region can be found in Sneesby (2019).

A stage-storage curve can be specified for each scenario. The curve is defined through the project parameters menu option. The stage-storage curve is applied after all calculations are completed and, therefore, it does not affect how calculations are performed.

Note that the wetland water balance is calculated based on the depth of water over the wetland for each component of the water budget, assuming the wetland is approximated as a regular geometric shape with the wetland surface area as defined at the Project level and the average wetland bottom elevation defined in Site Parameters. The stage-storage relationship is only used to convert the depth of water in the wetland each month to a water surface elevation.

Finally, the user can specify reference hydroperiod data that can be plotted against the generated hydrograph. The reference hydroperiod data are project specific and can be defined through the Project Specific Parameters. The user can specify a single hydroperiod curve by using the option Plot Min and Max Curve in Output, or they can specify a series of curves that will be used in the sensitivity analysis for this scenario.



The Basic Scenario setup is complete, if none of the following options in the Water Inputs subtab were selected: Calculated through WEM option for Groundwater IN, Calculated by Wetbud for Stream Overbank Flow, or User Time Series (HOURLY Stream Discharge), or User Time Series (DAILY Stream Discharge), Save  and close  the Basic Scenarios window. The user is now ready to generate the wetland water budget in Basic Analysis and Output, which is located in the Basic Models menu in the Wetbud home screen. See Basic Analysis and Output for more information.

If the Calculated by Wetbud based on NRCS DUH option or the User Time Series (HOURLY Stream Discharge) option or the User Time Series (DAILY Stream Discharge) option for Stream Discharge for Overbank Flow, were selected, changes should be saved and additional information should be provided under the Stream Overbank Flow tab.

If the Calculated through WEM option under the Groundwater IN Options was selected, changes should be saved and the Basic Scenarios window should be closed. Next, go to WEM Calculations in the Basic Models menu of the Wetbud home screen to complete WEM calculations before running the analysis for the basic model.

Notes on how water level adjustments are calculated by Wetbud:
Water balance depths are converted to head levels (water surface or water table elevations), either above or below the ground surface, by accounting for soil storage (specific yield) or available surface storage (which may be reduced by dense vegetation) based on the following criteria:

First, the initial fill value (water depth or water level elevation relative to ground surface) is converted to a water balance value. The criteria used for conversion depends on the water level relative to ground surface and are as follows:

If Elev(t) < 0, then INtot = Elev(t) * Fsoil
If Elev(t) > 0, then INtot = Elev(t) * Fsrfc

where:
Elev(t) = initial water elevation relative to surface (in or cm) (ground surface = 0) for month t
INtot = initial mass balance water level value (in or cm)
Fsoil = soil storage factor (specific yield)
Fsrfc = surface storage factor (equals 1 for open water; set to 0.98 to account for vegetation in standing water)

The monthly water balance sum of all water budget inputs and outputs is then added to INtot. The total water balance is then converted to the new water level relative to ground surface (Elev (t+1)) by dividing the total monthly depth of water by the soil storage factor or the surface storage factor, which depends on the initial water surface elevation to water depth conversion.

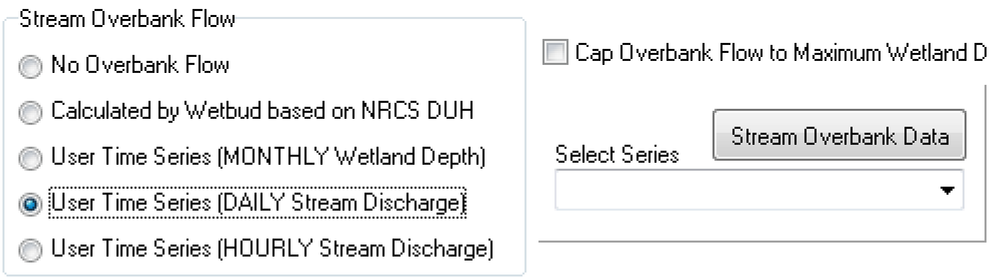
The following example applies to a change in water level when the water level is above the ground surface:

Fsrfc	=	0.98
Initial Elev(t)	=	7.47 cm
ΔW	=	-2.44 cm (sum of all inputs and outputs)
INtot	=	7.47 cm * 0.98 = 7.32 cm

Total water balance = 7.32 cm + (-2.44 cm) = 4.88 cm
Total water balance to Elev(t+1) = 4.88 / 0.98 = 4.98 cm

9.2.3.4 Stream Overbank Flow Parameters

A number of stream overbank flow calculations are available at the Scenario level as shown below.

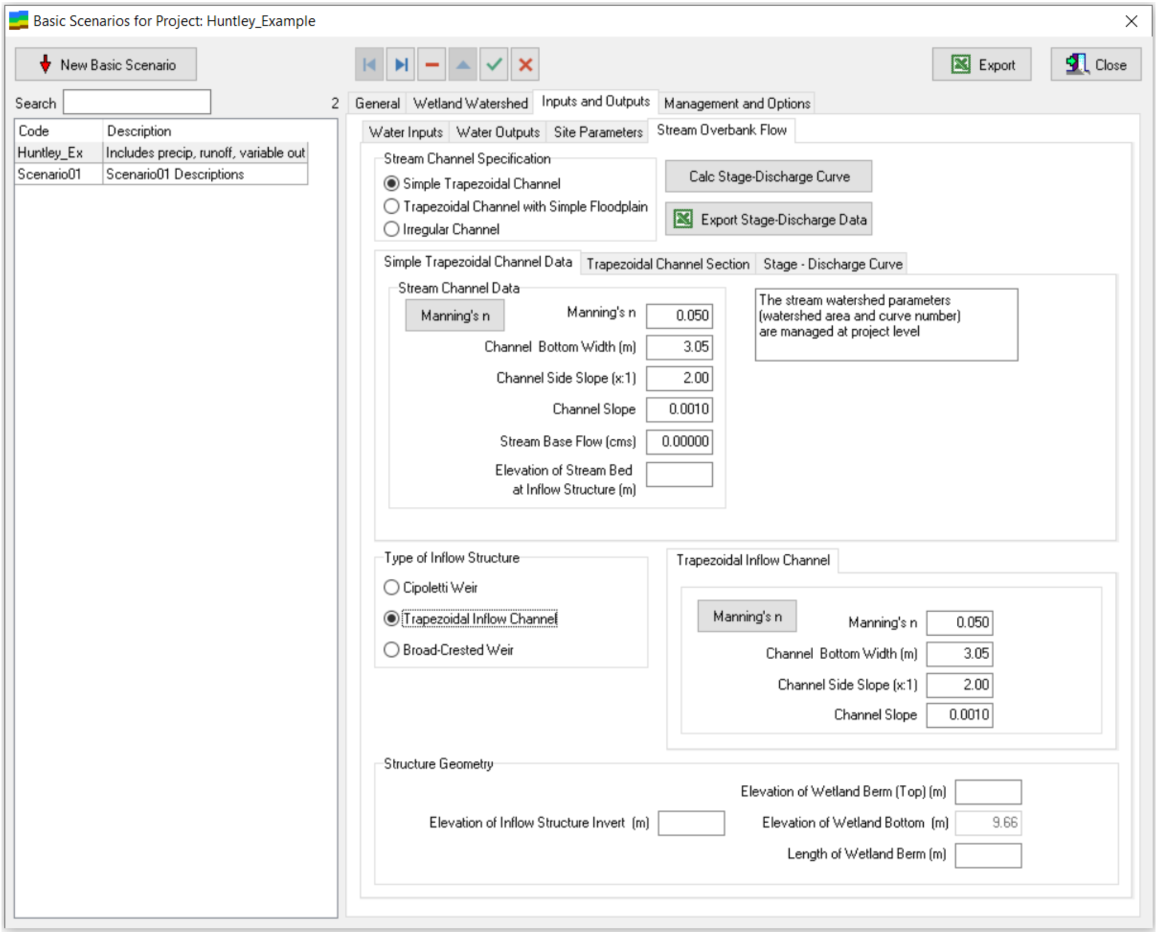


If the user selects the second option (calculation using the NRCS Dimensionless Unit Hydrograph) then the Time of Concentration for the stream watershed needs to be manually entered or calculated. For this option to work, users must fill in the information in the Stream Overbank Flow tab at the project level. See Stream Overbank Flow Setup for more details.

The User Time Series option (monthly wetland depth) allows the user to specify monthly time series of depths to be added to the wetland resulting from overbank flow quantities calculated outside of Wetbud. The time series should be defined under Project Specific Data. For more information see Stream Data.

If the user selects the Calculated by Wetbud based on NRCS DUH option or the User Time Series (HOURLY Stream Discharge) option or the User Time Series (DAILY Stream Discharge) option, then additional parameters need to be specified to calculate the overbank flow. These parameters include the shape of the channel as well as different elevations pertaining to the specific design, such as the inflow structure invert elevation, the elevation of the top of the wetland berm, etc.

The user can specify a Trapezoidal Channel with Simple Floodplain as shown below:



Note 1: Click Calc Stage-Discharge Curve to calculate the Stage - Discharge relationship for both the Simple Trapezoidal Channel and the Trapezoidal Channel with Simple Floodplain. The Stage - Discharge curve is then plotted under the Stage - Discharge Curve tab and can also be exported to an Excel file.

Note 2: The Chart Stream Hydrograph for Unit Runoff button is enabled when Advanced Options are enabled under Settings.

Stream Channel Specification

Users should select the type of stream channel to be modeled using one of the following options:

- Simple Trapezoidal Channel
- Trapezoidal Channel with Simple Floodplain
- Irregular Channel

For the Simple Trapezoidal Channel the user needs to specify the channel geometry only. Wetbud assumes there is no floodplain and the streambanks are infinitely high. For the Trapezoidal Channel with Simple Floodplain option, the user needs to specify the channel geometry for the main channel and the floodplains. If the wetland covers the entire floodplain, then the low floodplain elevation will equal the average wetland bottom elevation. If the floodplain is larger than the wetland, an average elevation for the floodplain should be specified as the low floodplain elevation.

For the Irregular Channel option, the user needs to select an irregular channel cross-section as shown below and indicate if the input cross section contains floodplain geometry or if there is no floodplain. If no floodplain is specified, Wetbud will create an infinitely high vertical wall from the last point at each end of the cross section. If a floodplain is specified, the wetland geometry can be represented using the irregular floodplain and the wetland will be considered in the stream stage-discharge relationship.

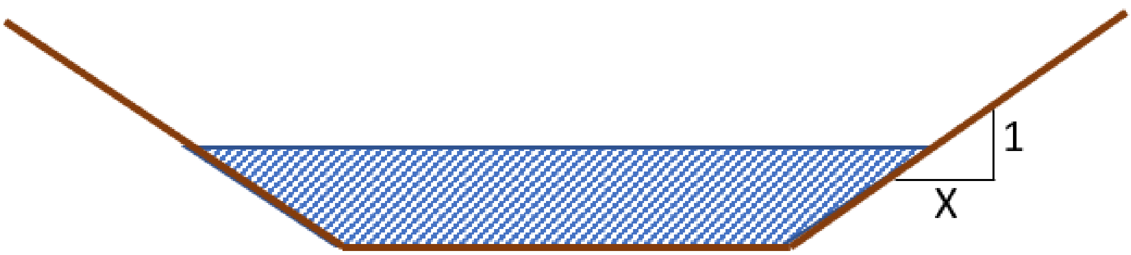
The user also needs to specify the stream base flow in all cases.

Trapezoidal Stream Channel Data
The Manning’s roughness coefficient (n) can be manually entered or selected from a list of reference coefficients in the Manning’s Coefficients window (click 

to access this window). After selecting an n value that best reflects your channel conditions click 

to copy the value into the appropriate field.

Next, enter the Channel Bottom Width (ft or m), Channel Side Slope Ratio (x:1, H:V), and Channel Slope (ft/ft or m/m) in their respective boxes. The Channel Slope is the longitudinal slope of the channel, while the Channel Side Slope Ratio is the slope of the streambanks, expressed as a ratio of x ft of horizontal distance per 1 ft of vertical distance. If the stream channel has a consistent base flow, enter the Stream Base Flow (cfs of cms).

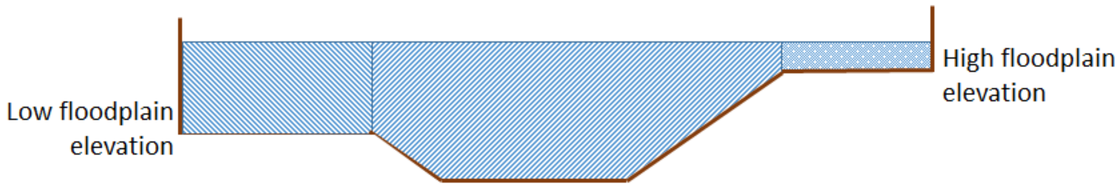


Floodplain Data
Because it is common for the floodplain on one side of a stream to be at a different elevation than the floodplain on the opposite side of the channel, both a low and high floodplain are included in the floodplain data. If the floodplain surface elevation on both sides of the channel are equal, set the low floodplain width to the sum of both floodplain widths and set the high floodplain width to zero. Similarly, if there is no floodplain on one side of the stream, the high floodplain width can be set equal to zero.

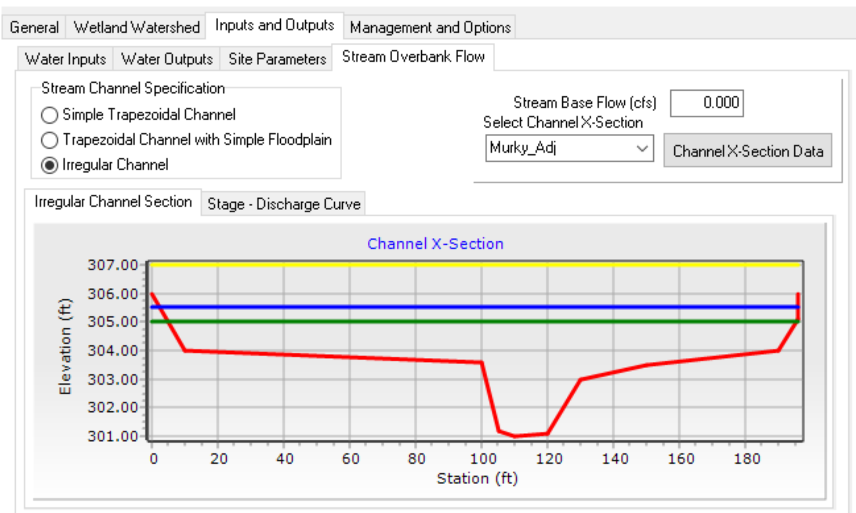
Enter the Manning’s n, Low Floodplain Width, and Low Floodplain Elevation for the lower floodplain. Enter the Manning’s n, High Floodplain Width, and High Floodplain Elevation for the higher floodplain. Manning’s n values can be manually entered or they can be selected from a reference list. The user must also provide the Floodplain

Longitudinal Slope. Flow in the main channel and both left and right floodplains are calculated separately for each stream stage and added together for the overall channel discharge at that stage.

Note: Wetbud assumes the floodplain width includes the wetland.



Irregular Channel Cross-sections
The user may also specify an irregular channel (defined through Channel X-section data) as shown below.



Note: The Stage - Discharge Curve for irregular channels can be calculated through the Channel X-section data form and plotted under the Stage - Discharge Curve tab on this window. The option to export the data to an Excel file is only available through the Channel X-section data form.

Type of Inflow Structure
In addition the user should specify the type of inflow structure that will be used to channel the water into the wetland. The above chart will also plot the bottom elevation of the wetland (green line), the bottom elevation of the inflow structure (blue line) as well as the top elevation of the berm (yellow line), to ensure that elevations are properly defined.

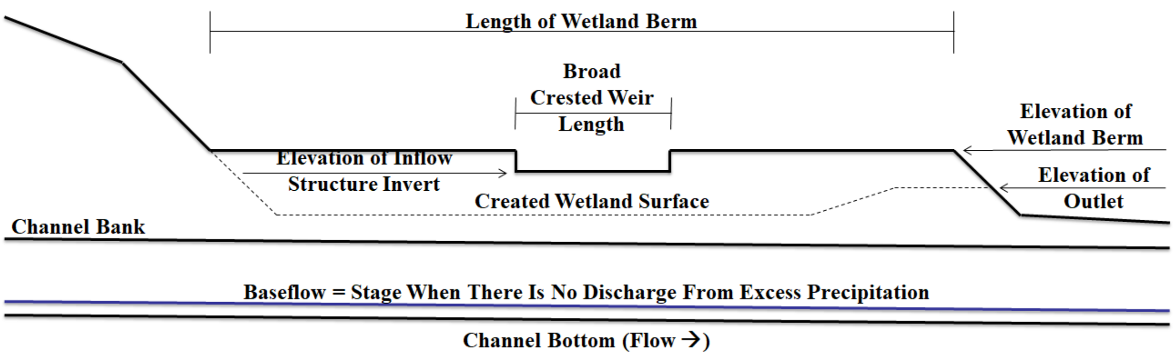
In the Type of Inflow Structure section, select Cipoletti Weir, Trapezoidal Inflow Channel, or Broad-Crested Weir. If Cipoletti Weir is selected, enter the Weir Length (ft or m) and Weir Crest Elevation (ft or m) in the boxes under Cipoletti Weir Inflow Structure. If Trapezoidal Channel is selected, enter the channel invert elevation at the upstream end, the cross sectional geometry, and the Manning's roughness coefficient (n) for the inflow channel. To view a list of reference coefficients in the Manning's Coefficients window click on Manning's n. After selecting an n value that best reflects your channel conditions click Select and Insert Into Project to copy the value into the appropriate field.

In case of a Trapezoidal Inflow Channel, enter the Channel Bottom Width (ft or m), the Channel Side Slope Ratio (x:1), and the Channel Slope (ft/ft or m/m) in their respective boxes. If Broad-crested Weir is selected, enter the Weir Length (ft or m).

Note: When the wetland is inundated, flow is calculated by adding the flow through the inflow structure and the flow over the berm. Flow over the berm is calculated assuming the berm behaves as a broad-crested weir. The effective length of the berm is calculated by subtracting the width of the inflow structure from the original length of the wetland berm. The total depth over the wetland due to flow through the inflow structure and over the berm is then compared to the peak flood depth over the floodplain. The lesser of these two depths is then reported as the overbank flow a given 24-hr storm event.

Structure Geometry and Stream Elevations

Enter the Elevation of Stream Bed at Inflow Structure (ft or m), Elevation of Inflow Invert (ft or m), and Elevation (Top) of Wetland Berm (ft or m) in their respective boxes. The figure below shows a conceptual cross-sectional view of the wetland berm and the channel.



Note1: In situations where an engineered inflow structure or berm is not present, the user should enter the elevation of the top of the stream bank for the invert elevation and a value 0.001 greater for the berm elevation.

Note2: If the no inflow structure is used Wetbud can still calculate the potential overbank flow by setting the Elevation of the Inflow Invert equal to the Elevation (top) of Wetland Berm. With these two values equal, Wetbud will calculate flow across the wetland berm using a Broad-Crested weir equation with the length of the weir equal to the Length of Wetland Berm.

9.2.4 Management and Options

The Management and Options tab is used to manage Scenario data and has several functions.

9.2.4.1 Scenario Management

The Scenario Management tab allows the user to duplicate Basic Scenarios and generate Advanced Scenarios based on Basic Scenario data.

The user can duplicate the current Scenario by clicking Duplicate Current Scenario. A copy of the selected Scenario will appear in the list of Scenarios. The user must then modify the Scenario code of the duplicate Scenario in the general tab.

Clicking Generate Advanced Model will generate an Advanced Model based on Basic Scenario parameters.

9.2.4.2 Scenario Data

The Scenario Data tab is used to view usage logs for each Basic Scenario in the current Project. By clicking Summarize Scenario Data the user can view a data log for the current Scenario. To delete the data and refresh the logs, click Delete Related Data Only and select OK to confirm that you want to delete the usage data related to the current Scenario. To delete a Scenario from the Scenarios list the user must first delete all data related to that Scenario by clicking Delete Scenario and Related Data.

9.2.4.3 Chart Settings

The Chart Settings tab is used to designate units and customize axes, titles, and legends on charts generated in Basic Scenario results. Instead of using default values chosen by Wetbud the user can select a previously created chart formatting data set that pertains to that Scenario from the drop-down menu(s) under Chart Settings. See **Charting Options** for details about creating chart settings data sets.

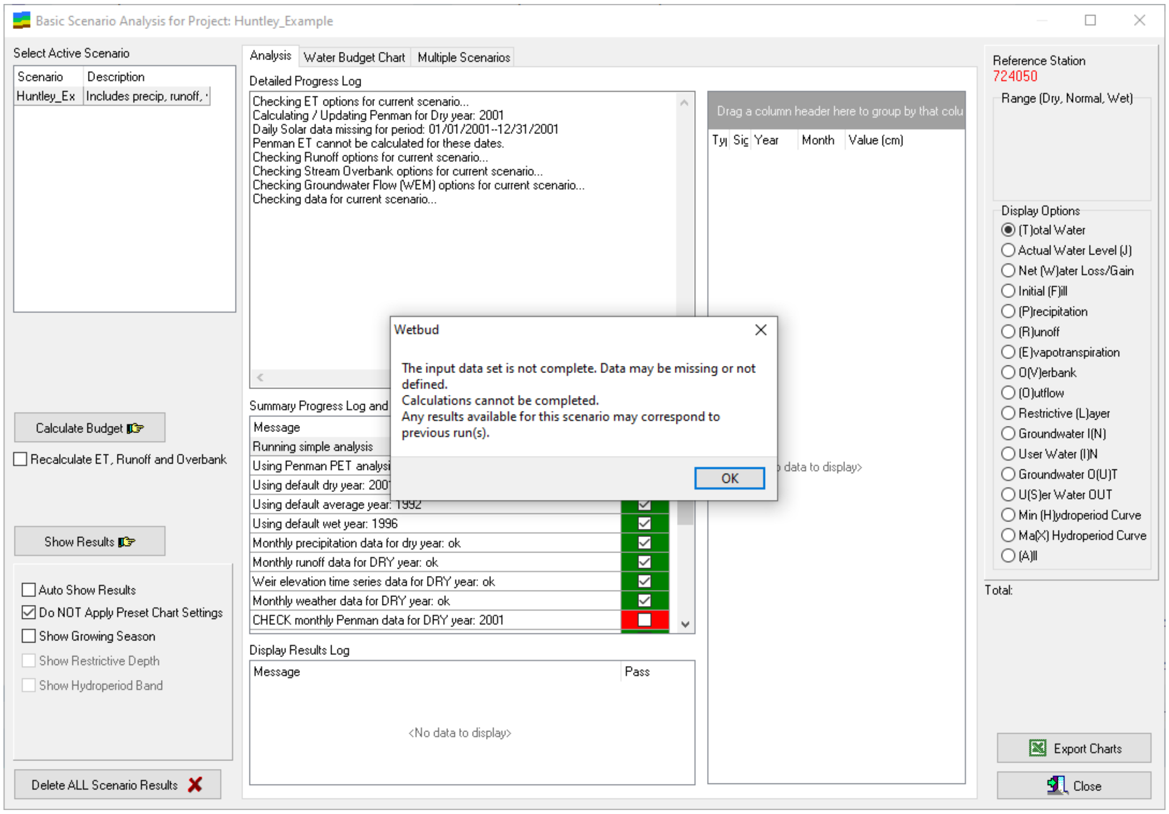
9.3 Basic Analysis and Output

After Basic Scenario setup is complete, the user can proceed to Basic Analysis and Output, located in the Basic Models menu of the Wetbud home screen, to generate monthly water budgets for years included in the Standard Analysis Range and Custom Analysis Range for a given Scenario.

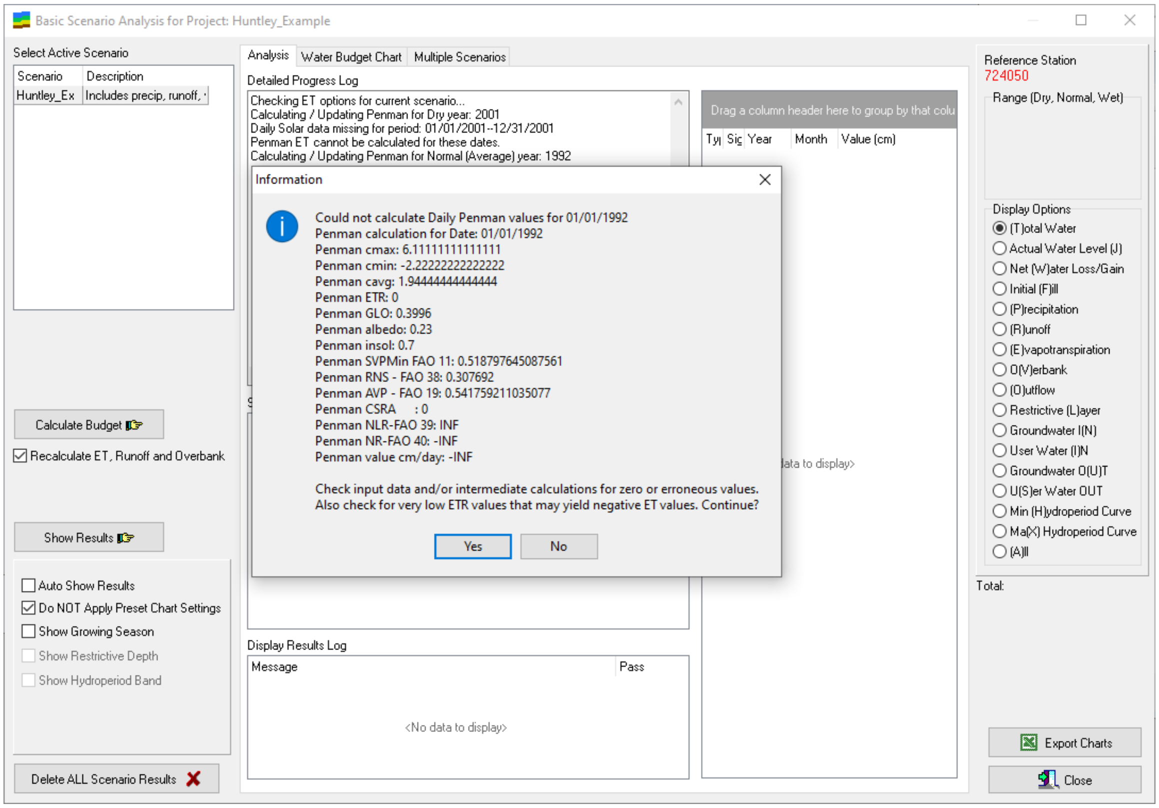
9.3.1 Analysis

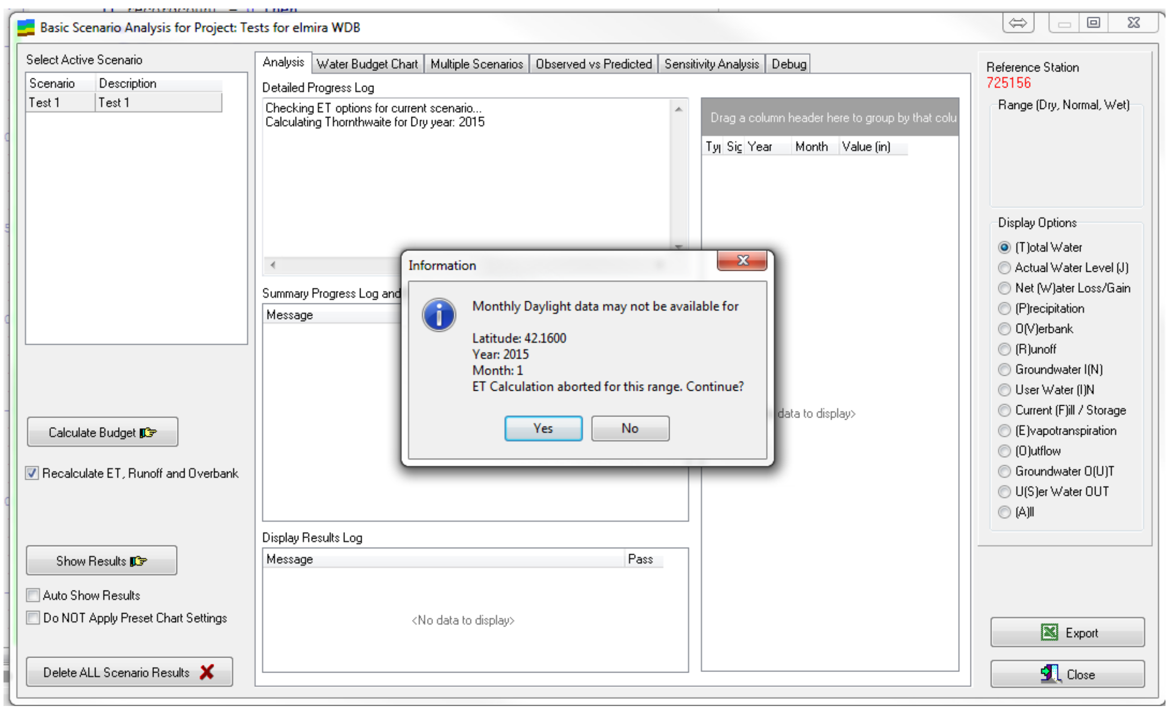
1. To complete a Basic Scenario water budget analysis, first select Basic Analysis and Output from the drop-down menu under Basic Models in the Wetbud home screen. Next, select the desired Scenario from the Select Scenario list in the Basic Analysis window and click 

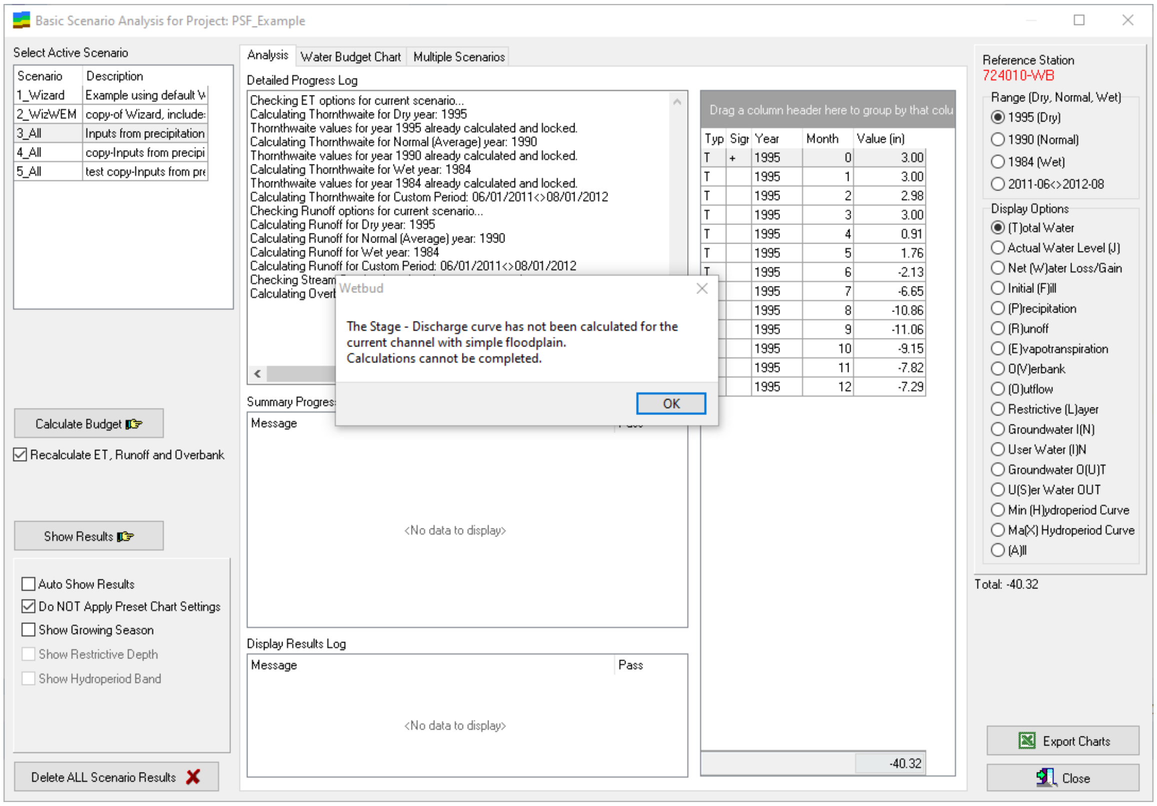
. If adjustments are made to any parameters that may affect ET and/or runoff calculation (e.g., PET option, Curve number, etc.), the user must check the box next to Recalculate ET, Runoff, and Overbank before recalculating the water budget for a water budget previously calculated within the Scenario.
Note: If you have chosen the Calculated through WEM option for Groundwater IN, WEM Calculations must be performed prior to calculating groundwater input for the Basic Analysis and Output water budget calculations. See WEM Calculations for more information.
2. The Analysis tab will then display a Detailed Progress log, a Summary Progress log, a Display Results log, and a table of monthly results for the year and display the options selected in the Range and Display Options boxes on the right side of the window, respectively.
3. The Detailed Progress Log displays messages regarding the progress of model calculations.
4. If there are errors in the water budget calculations due to a lack of necessary data (e.g., precipitation, solar, etc.) a message will be displayed in this window that will alert the user to check the data log for the missing data (e.g., Thornthwaite ET, Penman-Monteith ET, etc.). The number in the red box refers to the number of data sets that were not available or not complete during the run.



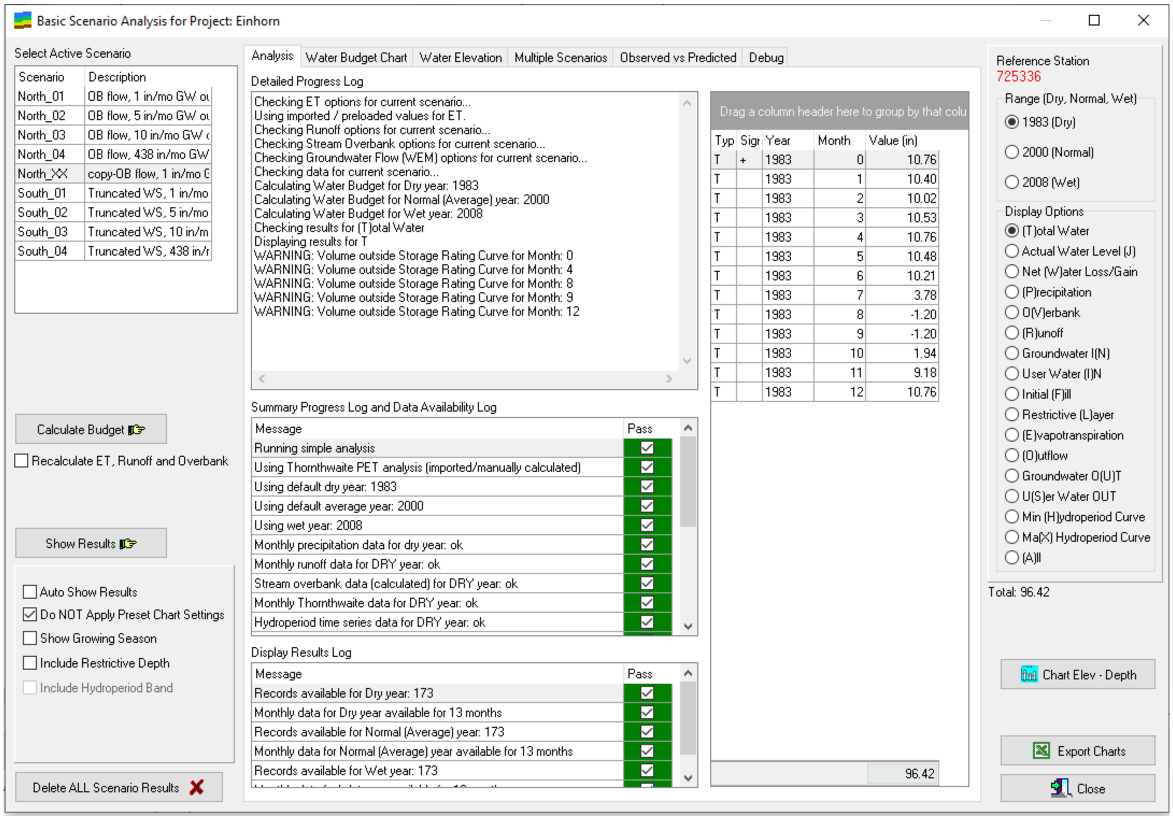
The figure below shows errors when calculating Penman ET due to poor solar data (ETR=0).


Basic Scenario Analysis for Project: Huntley_Example
Select Active Scenario
Analysis
Water Budget Chart
Multiple Scenarios
Detailed Progress Log
Checking ET options for current scenario...
Calculating / Updating Penman for Dry year: 2001
Daily Solar data missing for period: 01/01/2001--12/31/2001
Penman ET cannot be calculated for these dates.
Calculating / Updating Penman for Normal (Average) year: 1992
Information
Could not calculate Daily Penman values for 01/01/1992
Penman calculation for Date: 01/01/1992
Penman cmax: 6.11111111111111
Penman cmin: -2.22222222222222
Penman cavg: 1.94444444444444
Penman ETR: 0
Penman GLO: 0.3996
Penman albedo: 0.23
Penman insol: 0.7
Penman SVPMin FAO 11: 0.518797645087561
Penman RNS - FAO 38: 0.307692
Penman AVP - FAO 19: 0.541759211035077
Penman CSRA : 0
Penman NLR-FAO 39: INF
Penman NR-FAO 40: -INF
Penman value cm/day: -INF
Check input data and/or intermediate calculations for zero or erroneous values.
Also check for very low ETR values that may yield negative ET values. Continue?
Yes
No
Reference Station
724050
Range (Dry, Normal, Wet)
Display Options
(T)otal Water
Actual Water Level (J)
Net (W)ater Loss/Gain
Initial (F)ill
(P)recipitation
(R)unoff
(E)vapotranspiration
O(V)erbank
(O)utflow
Restrictive (L)ayer
Groundwater I(N)
User Water (I)N
Groundwater O(U)T
U(S)er Water OUT
Min (H)ydroperiod Curve
Ma(X) Hydroperiod Curve
(A)ll
Total:
Calculate Budget
Recalculate ET, Runoff and Overbank
Show Results
Auto Show Results
Do NOT Apply Preset Chart Settings
Show Growing Season
Show Restrictive Depth
Show Hydroperiod Band
Delete ALL Scenario Results
Display Results Log
Message
Pass
<No data to display>
Export Charts
Close

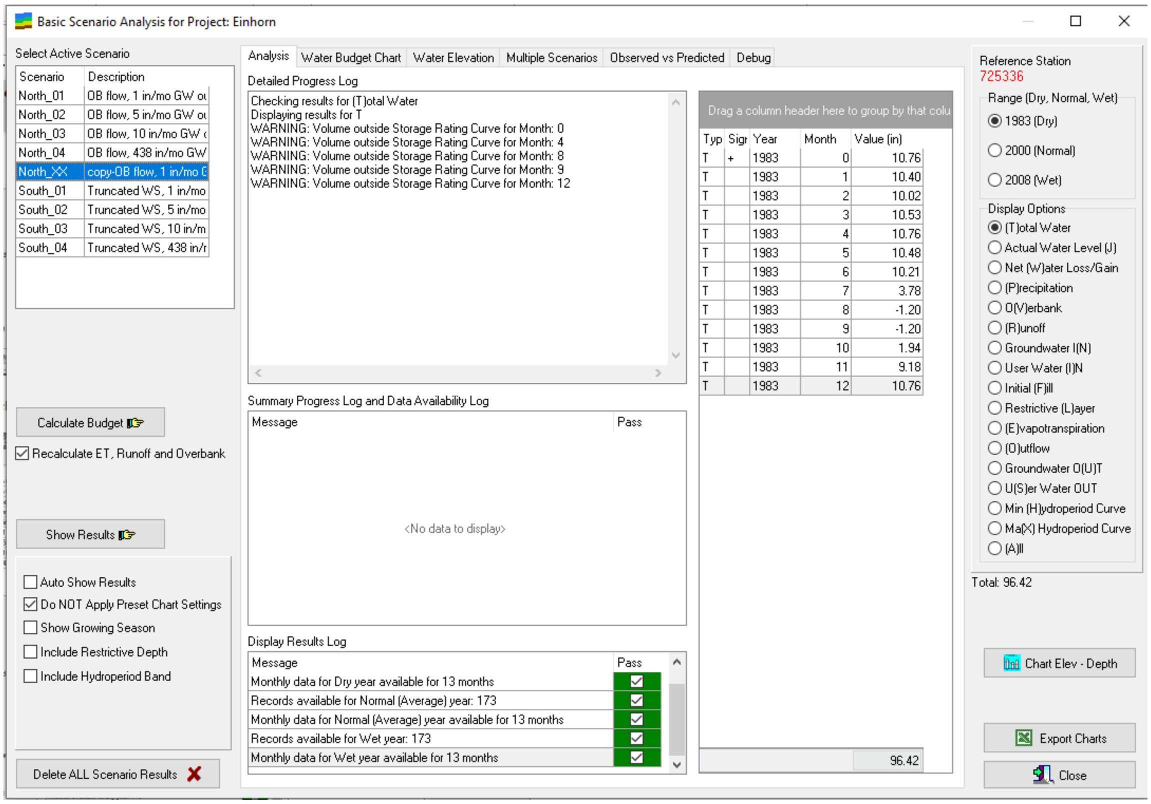

Basic Scenario Analysis for Project: Tests for elmira WDB
Select Active Scenario
Analysis
Water Budget Chart
Multiple Scenarios
Observed vs Predicted
Sensitivity Analysis
Debug
Detailed Progress Log
Checking ET options for current scenario...
Calculating Thornthwaite for Dry year: 2015
Information
Monthly Daylight data may not be available for
Latitude: 42.1600
Year: 2015
Month: 1
ET Calculation aborted for this range. Continue?
Yes
No
Reference Station
725156
Range (Dry, Normal, Wet)
Display Options
(T)otal Water
Actual Water Level (J)
Net (W)ater Loss/Gain
(P)recipitation
O(V)erbank
(R)unoff
Groundwater I(N)
User Water (I)N
Current (F)ill / Storage
(E)vapotranspiration
(O)utflow
Groundwater O(U)T
U(S)er Water OUT
(A)ll
Calculate Budget
Recalculate ET, Runoff and Overbank
Show Results
Auto Show Results
Do NOT Apply Preset Chart Settings
Delete ALL Scenario Results
Display Results Log
Message
Pass
<No data to display>
Export
Close



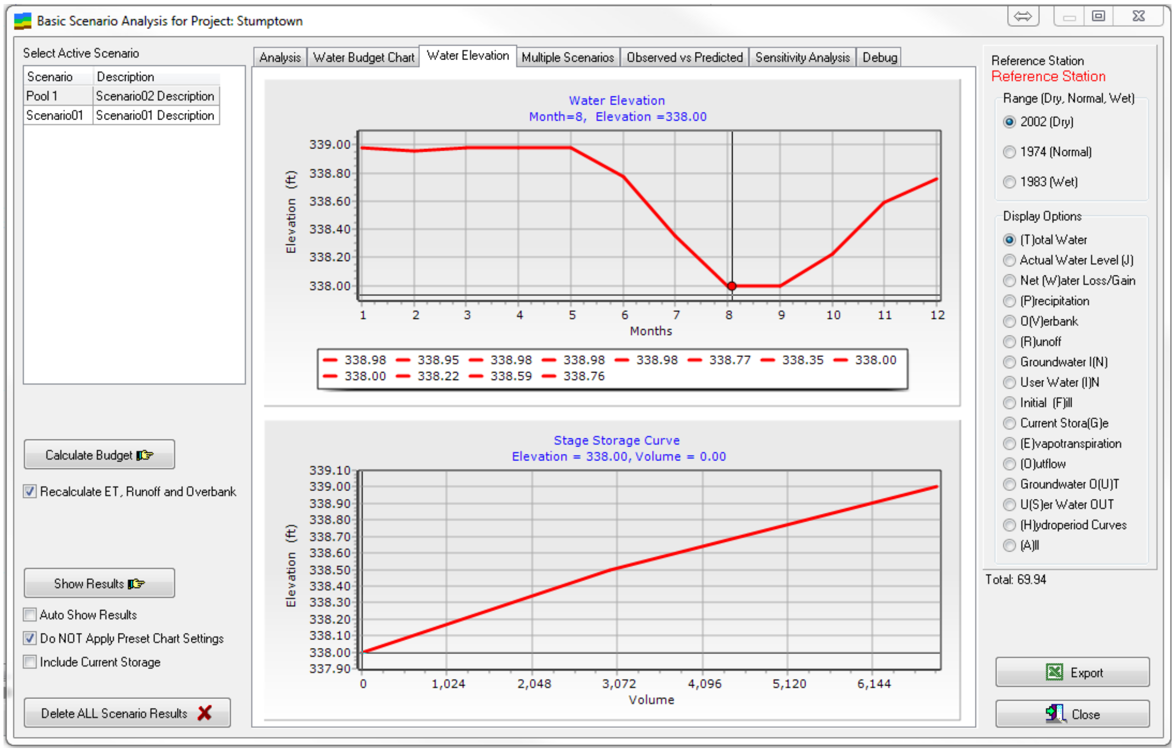
5. The Display Results Log displays the number of records available for each year included in the water budget calculations.



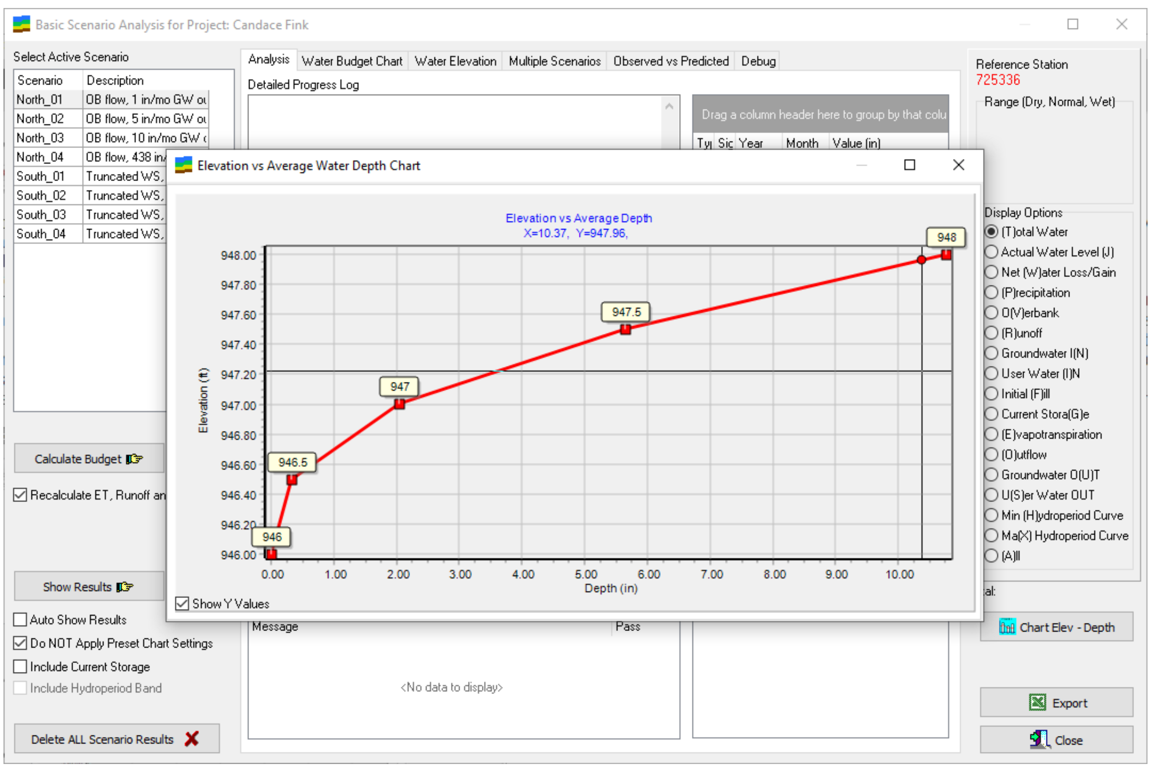
6. If the user only displays the results which have been generated previously, the Detailed Progress Log only logs the display actions and the Summary Progress Log is blank.



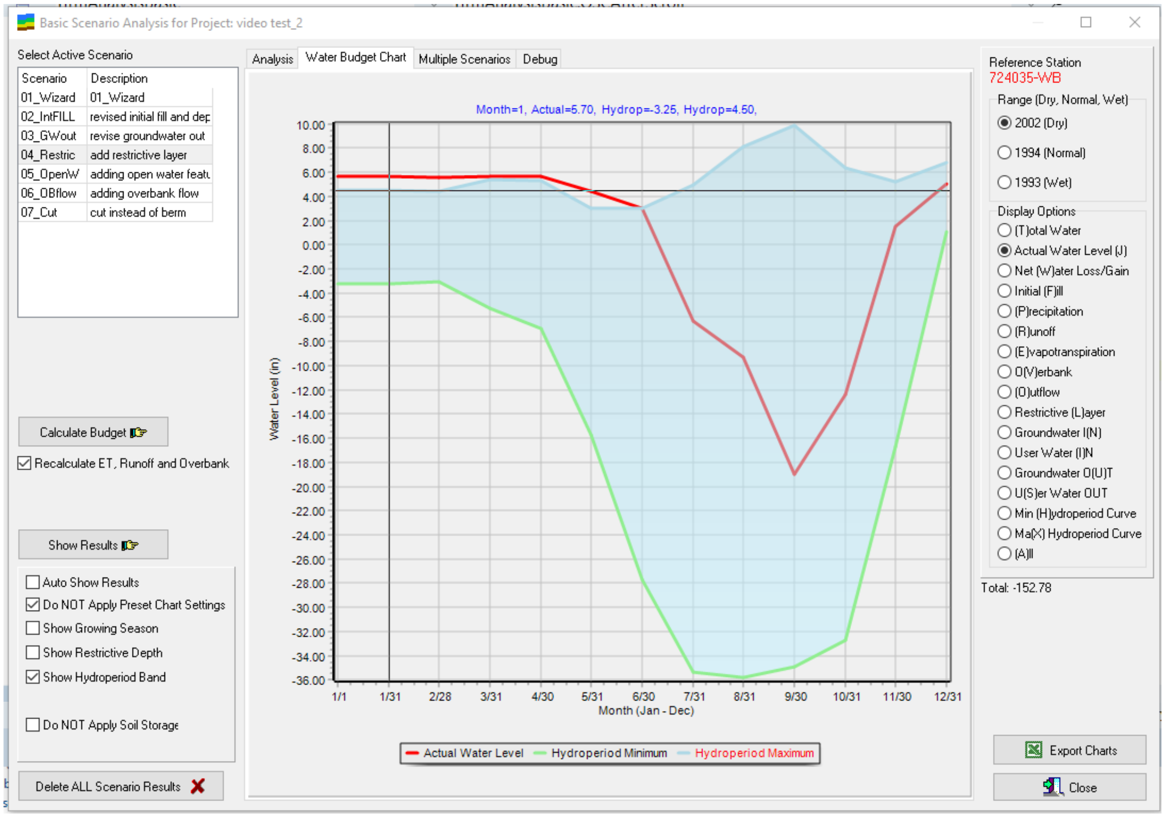
7. The grid to the right of log information displays monthly results for the year and variable selected in the Range and Display Options boxes on the right side of the Basic Analysis window. The user can view tabulated results for each variable in the water budget analysis by adjusting the selection in the Display Options box.
8. Water budgets are calculated as the sum of inputs and outputs for each month in the modeling period. Calculated depths reflect an approximation of the average depth in the wetland at the end of any given month. An initial fill value is provided on January 1st as a starting point for the model to add water to, or take water away from, depending on net loss/gain calculated on January 31st.
9. The Water Budget Chart tab shows a graphical display of the Basic Analysis results. The units of the y-axis of the upper and lower graphs are inches and centimeters, respectively. The user can choose to display each variable individually or combine all water budget components on the same graph by changing the selection in the Display Options box. The first two variables in the Display Options box, (T)otal and Total Ad(J)usted are displayed as a line graph. (T)otal values are the total monthly mass balance water levels. Total Ad(J)usted values are water levels relative to the ground surface (adjusted for soil storage when the water level drops below the ground surface and/or surface storage); these values represent the monthly water surface or water table elevation within the wetland. All other variables are displayed as a bar graph. Each year in the standard analysis range can be displayed by changing the selection in the Range (Dry, Normal, Wet) box.
10. If a stage storage rating curve has been specified in the input data, then a water elevation tab will be shown where the water elevation time series is plotted as well as the stage storage curve.



If the option to chart Elevation vs Average Water Depth is enabled under Settings, then the following graph can be generated based on the selected stage-volume rating curve.

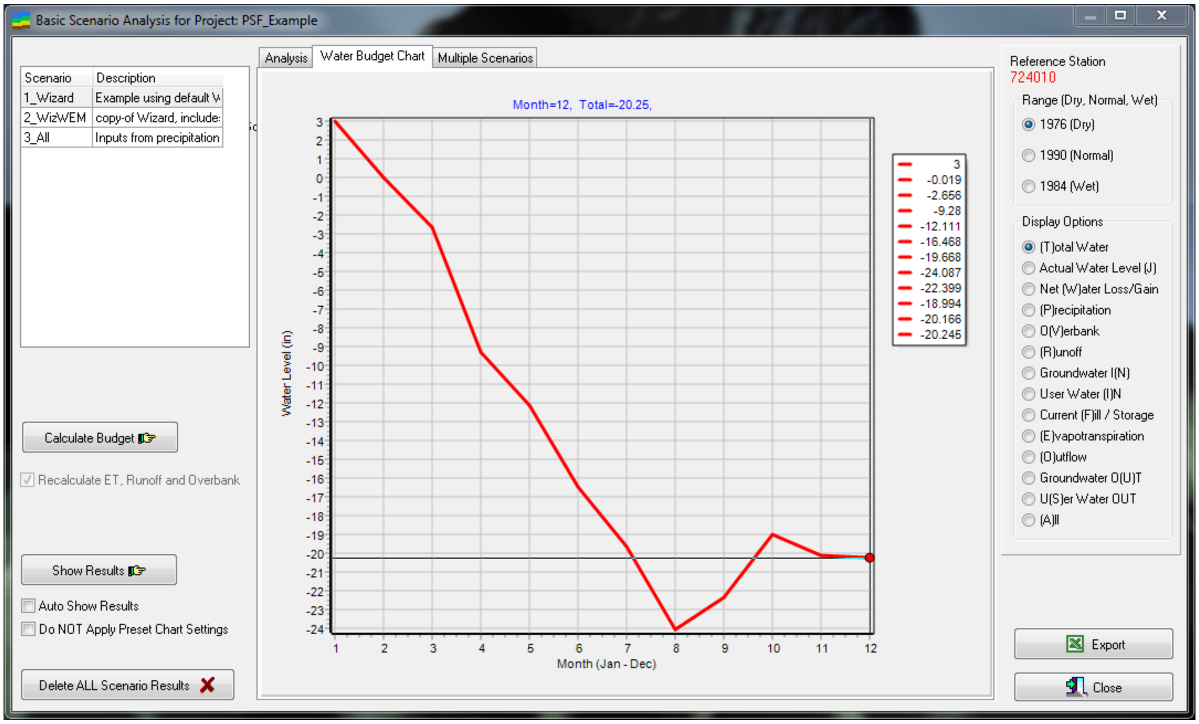


The option Show Hydroperiod Band is only enabled if a hydroperiod is defined and if Actual Water Level is selected as a Display Option. The figure below shows the band plotted together with actual water level.



9.3.2 Water Budget Chart

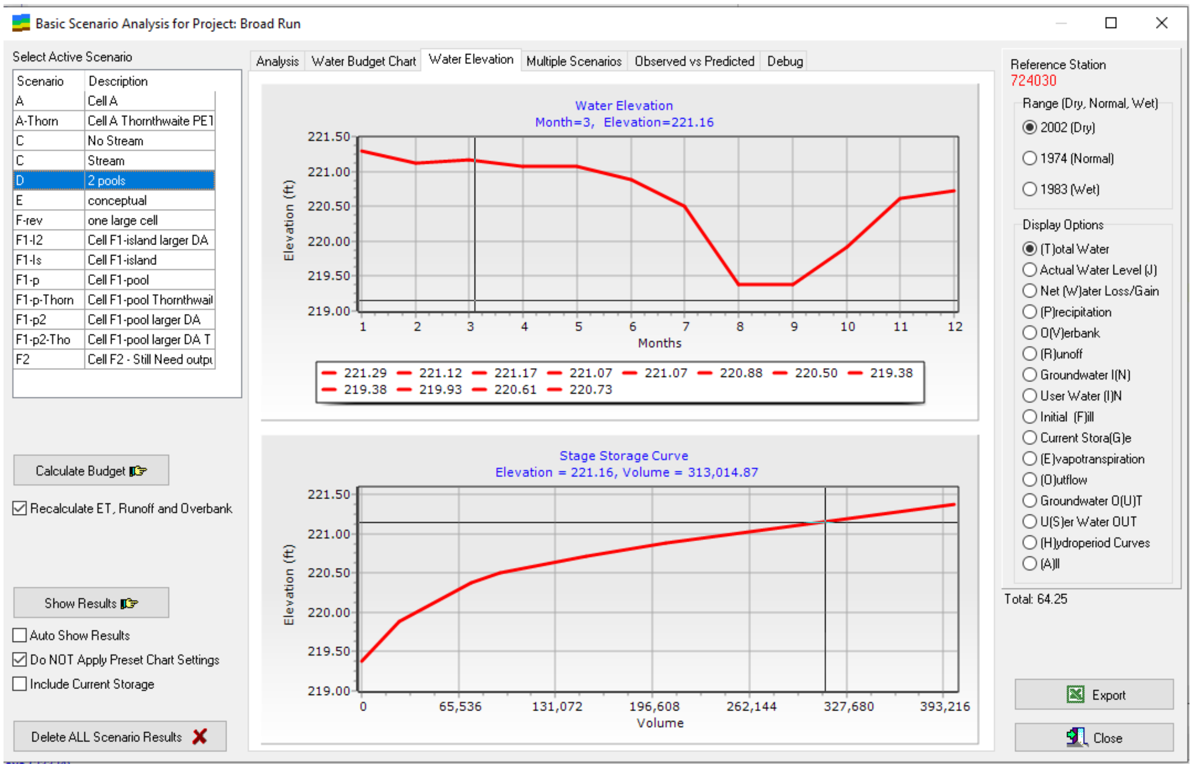
The Water Budget Chart tab shows a graphical display of the Basic Analysis results. The units of the y-axis of the upper and lower graphs are inches and centimeters, respectively. The user can choose to display each variable individually or combine all water budget components on the same graph by changing the selection in the Display Options box. The first two variables in the Display Options box, (T)otal and Total Ad(J) usted are displayed as a line graph. (T)otal values are the total monthly mass balance water levels. Total Ad(J)usted values are water levels relative to the ground surface (adjusted for soil storage when the water level drops below the ground surface and/or surface storage); these values represent the monthly water surface or water table elevation within the wetland. All other variables are displayed as a bar graph. Each year in the standard analysis range can be displayed by changing the selection in the Range (Dry, Normal, Wet) box.



9.3.3 Water Elevation

The Water Elevation tab will only be visible if the user has selected a stage-storage rating curve in the specific scenario.

When a stage-storage curve is used, then Wetbud will calculate the water balance based on depth of inflows and outflows. The volume corresponding to each monthly depth value is determined by multiplying the wetland depth times the input wetland area. It will then calculate the monthly wetland surface elevation based on the stage-storage curve. The Water Elevation tab displays two charts. The top chart corresponds to the actual wetland surface water elevation each month, while the bottom chart shows the actual stage storage curve used for the volume to elevation conversion. As the cursor moves on the top chart the cursor along the stage-storage rating curve moves accordingly.



Basic Analysis results can be exported as an Excel file for individual variables or as a file that includes all inputs and outputs displayed in the Basic Analysis window.

To export results for an individual variable, select the variable in the Display Options box and click 

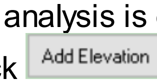
. Name and save the exported file in the prompt that appears on the desktop.

To export results for all variables in the Display Options box, select (A)ll in the Display Options box and click 

. Name and save the exported file in the prompt that appears on the desktop.

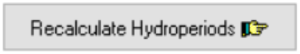
Note1: In the file exported to Excel variables are denoted by the letter in parenthesis in the Display Options box. For example, (T)otal will show as "T" in the data file export to exported Excel.
Note2: When total water is negative, the actual water level is subtracted from the lowest elevation in the stage storage curve to estimate the water elevation. No approximations of a sloping water table are made in the Basic Model.

9.3.4 Hydroperiods

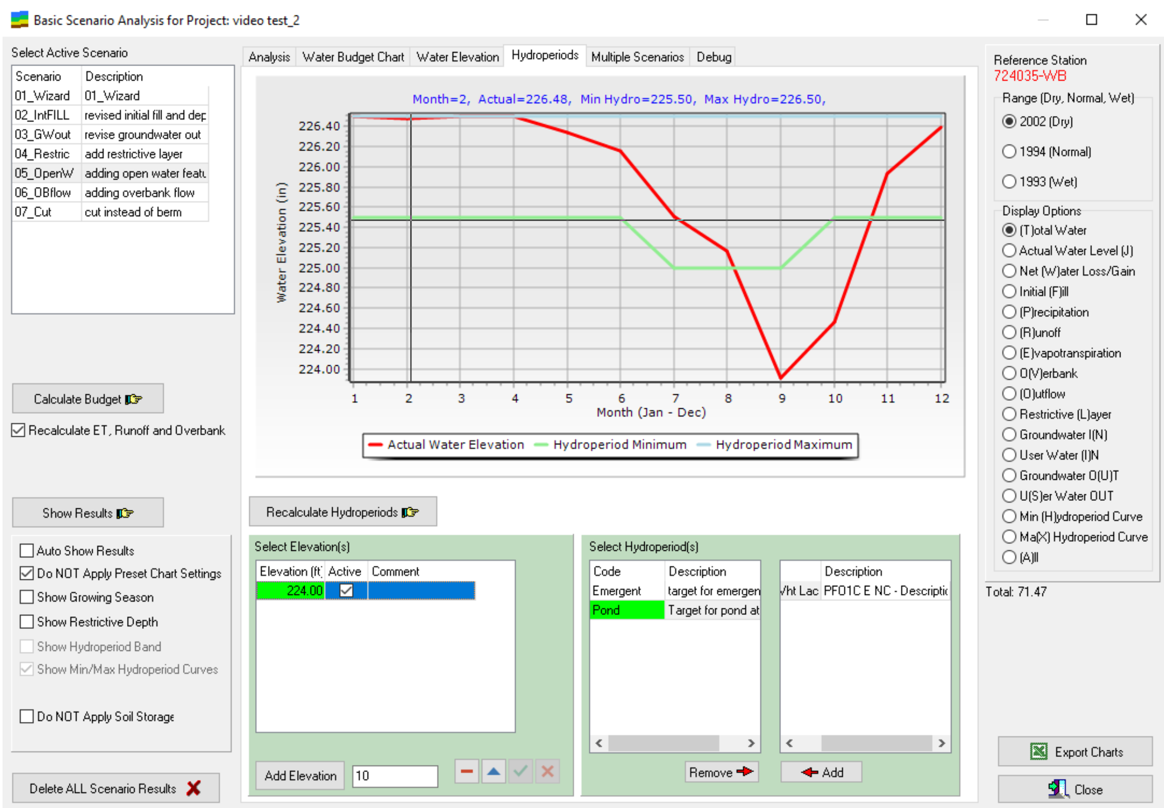
The hydroperiods tab appears only if the sensitivity analysis is enabled in output. Enter an elevation at the bottom left of the screen and click 

. Next, select a hydroperiod in the green box on the bottom right of the screen from the list on the right and click 

to add it to the list on the left. Click 

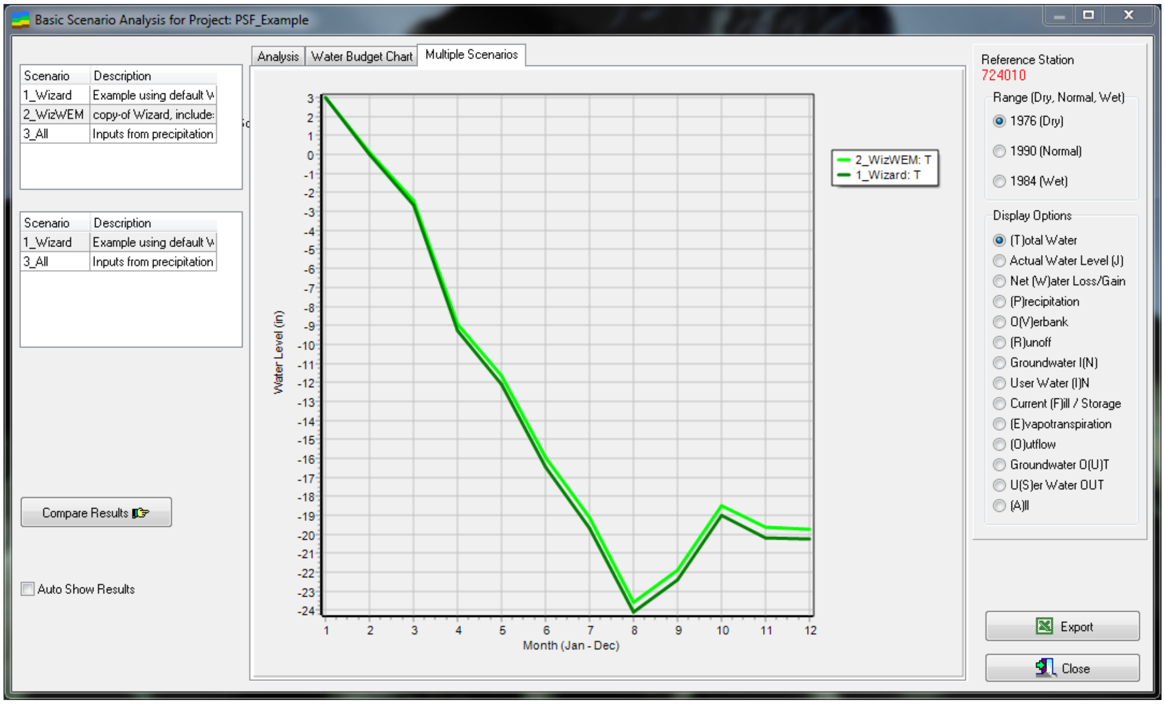
and return to the Hydroperiods tab. Finally, click 

to display the hydrograph for the given scenario.



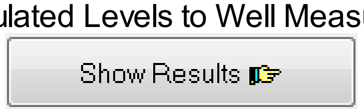
9.3.5 Multiple Scenarios

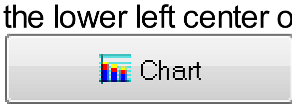
A comparison of separate scenarios is possible with this tab. Simply select which scenarios to compare and click compare results. Several display options are available. The results then can be exported to an Excel file format.



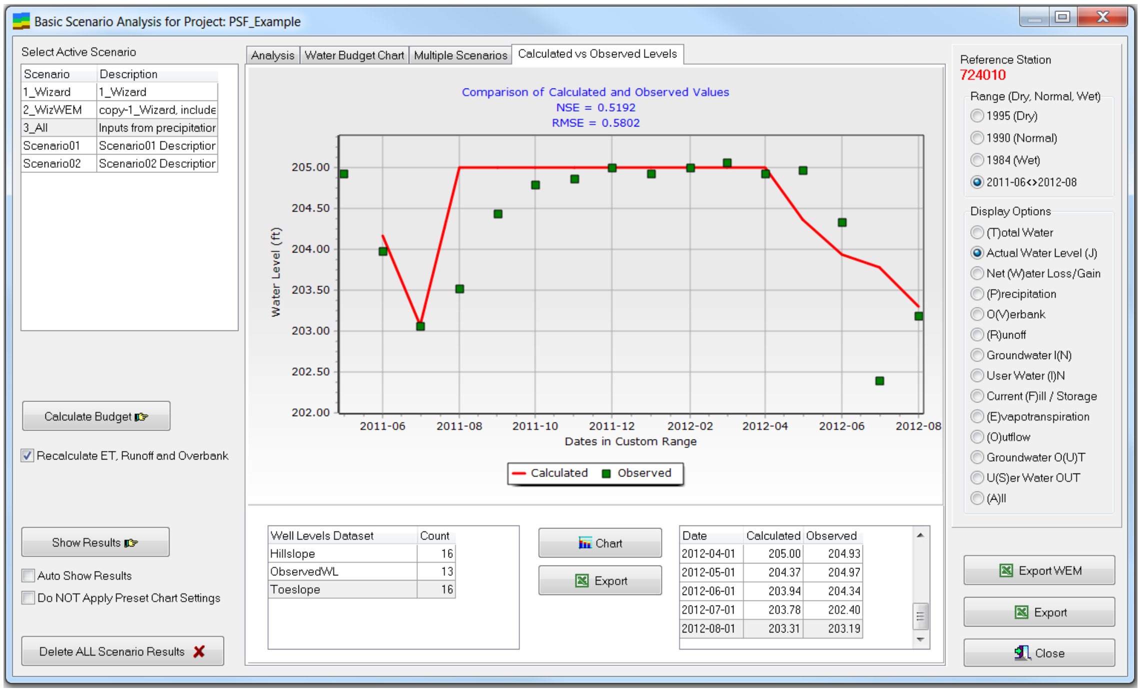
9.3.6 Observed vs Predicted Levels

Users that have collected water level data for their site prior to developing water budgets may wish to compare those observed levels to levels predicted by Wetbud for a corresponding time period. Wetbud has the ability to plot predicted and observed values together, as well as statistically evaluate model performance. Both the Basic and Advanced Models have this functionality. To use this feature, the user will need to take the following steps:

1. Create data sets within Wetbud of observed head values as well data sets. See Wells.
2. Create models that run for time periods that correspond to the Well data sets. In Basic Models, the model should include a Custom Time Period that overlaps the Well data set(s) (See Setting Up a Basic Scenario).
3. Under Settings, in the Basic Model tab check the box beside Enable Comparison of Calculated Levels to Well Measurements (Custom Range Only).
4. Click 

and then select the Observed vs Predicted Levels tab. Select the Custom time period from the Range (Dry, Normal, Wet) list in the upper right side of the window. Select Actual Water Level (J) from the Display Options on the right side of the window (this is the water level after it has been adjusted to account for soil storage space). Select the Well Levels data set from the list in the lower left center of the window.
5. Click 

to plot observed and predicted values



The model-calculated Actual Water Level (J) will be plotted as a red line. The Observed levels, from the selected well data set, will be plotted as green squares.

Above the plot there are two statistical values:
1. The Nash-Sutcliffe Efficiency parameter (NSE, negative infinity to 1, 0 = model is as good as average of observed, the closer to 1 the better the model is at predicting head values).
2. The Root Mean Square Error (RMSE) which is the average error of any value predicted by the model, reported in the units in which the model was run.

9.4 WEM Calculations

The following is a brief explanation of the equations used in WEM calibration and how it is used to predict monthly head elevations for an established well location for years that lack hydraulic head data. Please refer to Whittecar et al. (2017) and/or Dobbs (2013) for specific details and explanation of the Effective Monthly Recharge (Wem) Model and its applications.

The WEM requires a series of five steps to run and calibrate the model:
- Step one requires the user to create a Well Elevation data set that contains observed monthly head elevations at the beginning of each month for the chosen well. Whittecar et al. (2017) recommend that during the calibration process one should exclude readings taken from wells at the beginning of each month that have experienced significant recent rainfall (typically within 2-4 days prior to the reading). See Wells for more information.

- Step two includes gathering data for monthly totals for precipitation and potential evapotranspiration (PET) and determining appropriate values for interception for leaf-on and leaf-off months.
- Step three is the calculation of the WEM time series (performed automatically by Wetbud). First, monthly recharge (Wmo) is calculated for every month of the calibration period using the following equation:

Wmo=Pmo-ETmo

where:

Wmo = monthly recharge
Pmo = total monthly precipitation (cm)
ETmo = total monthly evapotranspiration (cm)

Next, using the Wmo values, calculate effective monthly recharge (Wem), which is a time-weighted sum of recharge from a certain number of months prior to each month for which Wem is calculated. The following equation is used to determine effective monthly recharge:

$$W_{em} = \sum_{a=1}^{n} W_{mo} \times D^{a-1}$$

where:

Wem = effective monthly recharge (cm)
n = number of prior months (1 through 18)
D = decay factor (between 0.99 and 0.55 at intervals of 0.05)

- Step four is the calibration process. For each time series using a given n-and-D, use linear regression to plot values of Wem vs. Observed monthly head and generate a correlation coefficient (R-Squared). Correlation coefficients of each regression are then recorded in an R-Squared matrix to determine which n-and-D combination generates the best correlation between Wem and observed head. Routines in Wetbud help the user make these calculations prior to running the water-budget analyses (see WEM Calculations).
- Step five estimates groundwater head elevations for each month of past years. The n-and-D values selected in step 4 are used to calculate the Wem value for every month of interest. This Wem value is converted to a predicted head value using the “best” regression equation (Wem vs observed head) developed in step 4. Thus, this process generates a synthetic hydrograph using recorded weather data for a historic period of interest when no well data were collected.

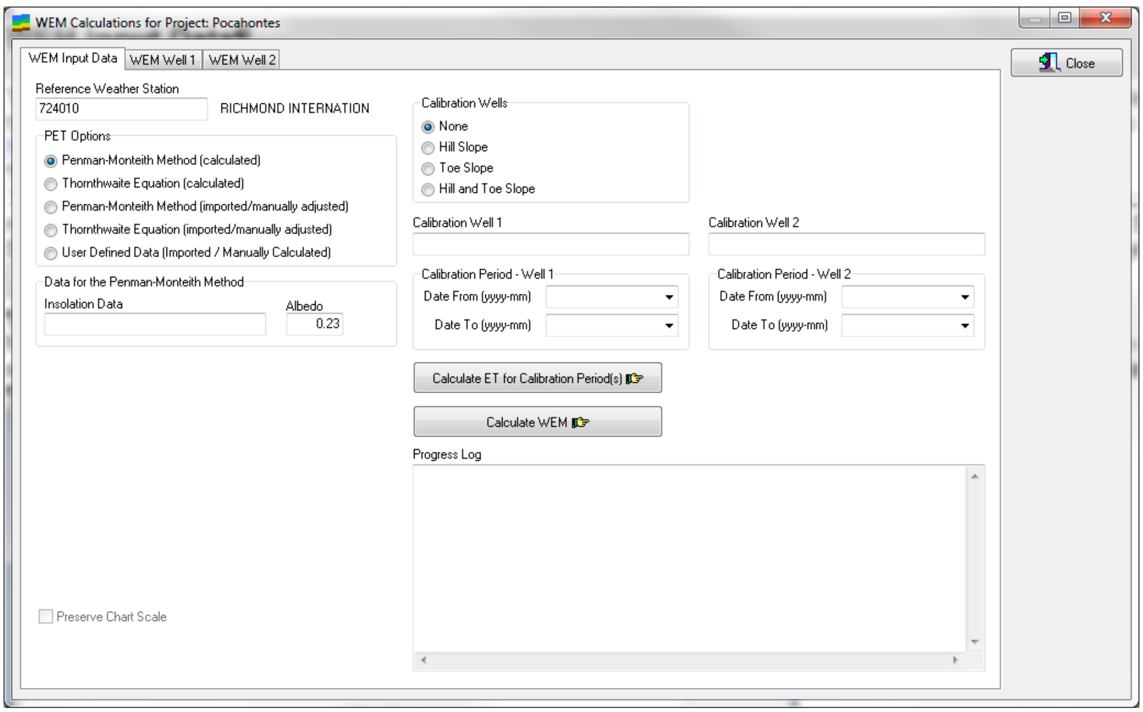
9.4.1 WEM Input Data

The following is a description of the procedure for performing WEM calculations in Wetbud. Note that prior to performing WEM calculations in Wetbud, the user must have created well data sets and completed WEM Setup for the current Project in the WEM tab of the Define Projects window. See WEM Setup, WEM Calculations and Wells).

To begin WEM calculations, select WEM Calculations from the Basic Models drop-down menu in the Wetbud home screen. Next, in the WEM Calculations window, review the data in the WEM Input Data to verify the inputs made in WEM Setup are correct. The Reference Weather Station ID listed in the Reference Weather Station box is the Reference Weather Station selected in the Weather Stations tab for the current Project.

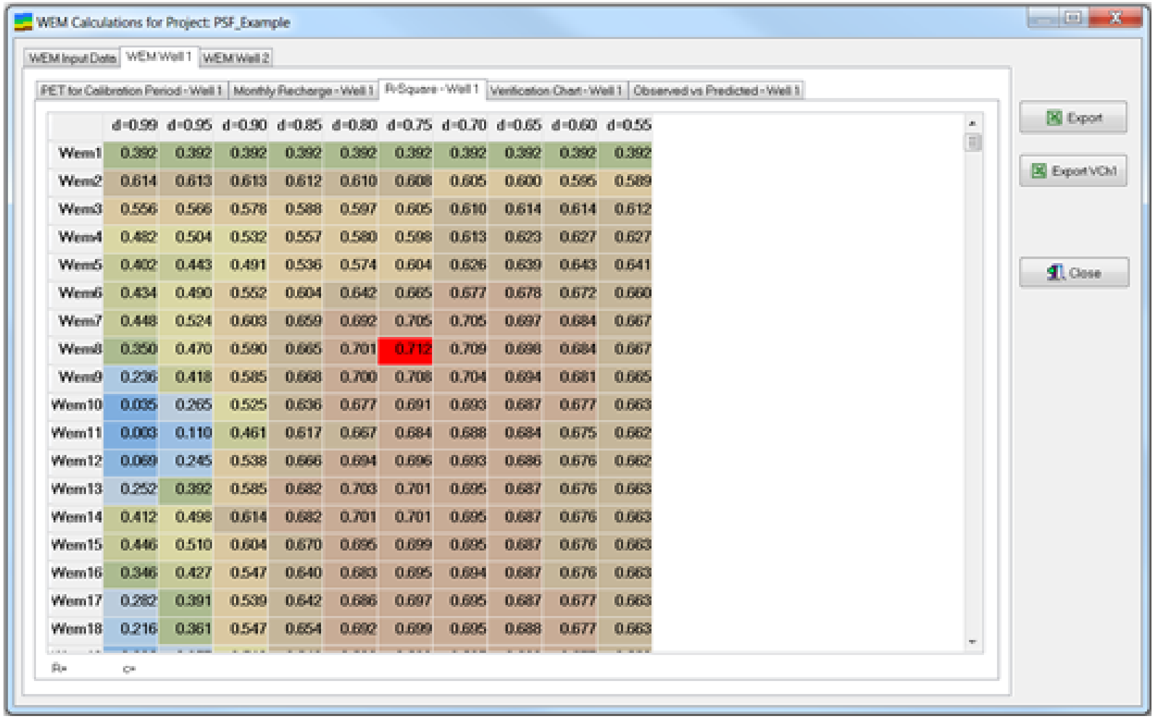
After verifying your data are correct, click Calculate ET for Calibration Period(s), which will calculate ET for the calibration period(s).

Note: Calculating ET for the calibration period is not necessary for users who have manually imported ET data for the duration of the calibration period and have selected one of the following options: Penman-Monteith Method (imported/manually adjusted), Thornthwaite Equation (imported/manually adjusted) or User Defined Data.



To calculate WEM:

Click Calculate WEM to run the Wem analysis. The R-Squared – Well 1 sub-tab of WEM Well 1 will be displayed immediately after clicking on Calculate WEM. The R-Squared – Well 1 tab displays a table of correlation coefficients for each linear regression (e.g., WEM vs. observed monthly head elevation) in the WEM calculations (see figure below).



	d=0.99	d=0.95	d=0.90	d=0.85	d=0.80	d=0.75	d=0.70	d=0.65	d=0.60	d=0.55
Wem1	0.392	0.392	0.392	0.392	0.392	0.392	0.392	0.392	0.392	0.392
Wem2	0.614	0.613	0.613	0.612	0.610	0.608	0.605	0.600	0.595	0.589
Wem3	0.556	0.566	0.578	0.588	0.597	0.605	0.610	0.614	0.614	0.612
Wem4	0.482	0.504	0.532	0.557	0.580	0.598	0.613	0.623	0.627	0.627
Wem5	0.402	0.443	0.491	0.536	0.574	0.604	0.626	0.639	0.643	0.641
Wem6	0.434	0.490	0.552	0.604	0.642	0.665	0.677	0.678	0.672	0.660
Wem7	0.448	0.524	0.603	0.659	0.692	0.705	0.705	0.697	0.684	0.667
Wem8	0.350	0.470	0.590	0.665	0.701	0.712	0.709	0.698	0.684	0.667
Wem9	0.236	0.418	0.585	0.668	0.700	0.708	0.704	0.694	0.681	0.665
Wem10	0.035	0.265	0.525	0.636	0.677	0.691	0.693	0.687	0.677	0.663
Wem11	0.003	0.110	0.461	0.617	0.667	0.684	0.688	0.684	0.675	0.662
Wem12	0.069	0.245	0.538	0.666	0.694	0.696	0.693	0.686	0.676	0.662
Wem13	0.252	0.392	0.585	0.682	0.703	0.701	0.695	0.687	0.676	0.663
Wem14	0.412	0.498	0.614	0.682	0.701	0.701	0.695	0.687	0.676	0.663
Wem15	0.446	0.510	0.604	0.670	0.695	0.699	0.695	0.687	0.676	0.663
Wem16	0.346	0.427	0.547	0.640	0.683	0.695	0.694	0.687	0.676	0.663
Wem17	0.282	0.391	0.539	0.642	0.686	0.697	0.695	0.687	0.677	0.663
Wem18	0.216	0.361	0.547	0.654	0.692	0.699	0.695	0.688	0.677	0.663

Warmer colors, such as red and orange, represent higher R-Squared values and cooler colors, such as blue and green, represent lower R-Squared values. The columns in the R-Squared table represent the decay factor (d) and rows represent the number of months prior (N) (e.g., Wem1) used for each regression. Each R-Squared value in the table is the correlation coefficient from a linear regression of Effective Monthly Recharge (Wem) vs. Observed Head Elevation using a given N-and-d combination. The regression equation that corresponds to the N-and-d combination that produces the highest correlation coefficient for each calibration well will then be used to generate predicted head elevations for years that lack hydraulic head data.

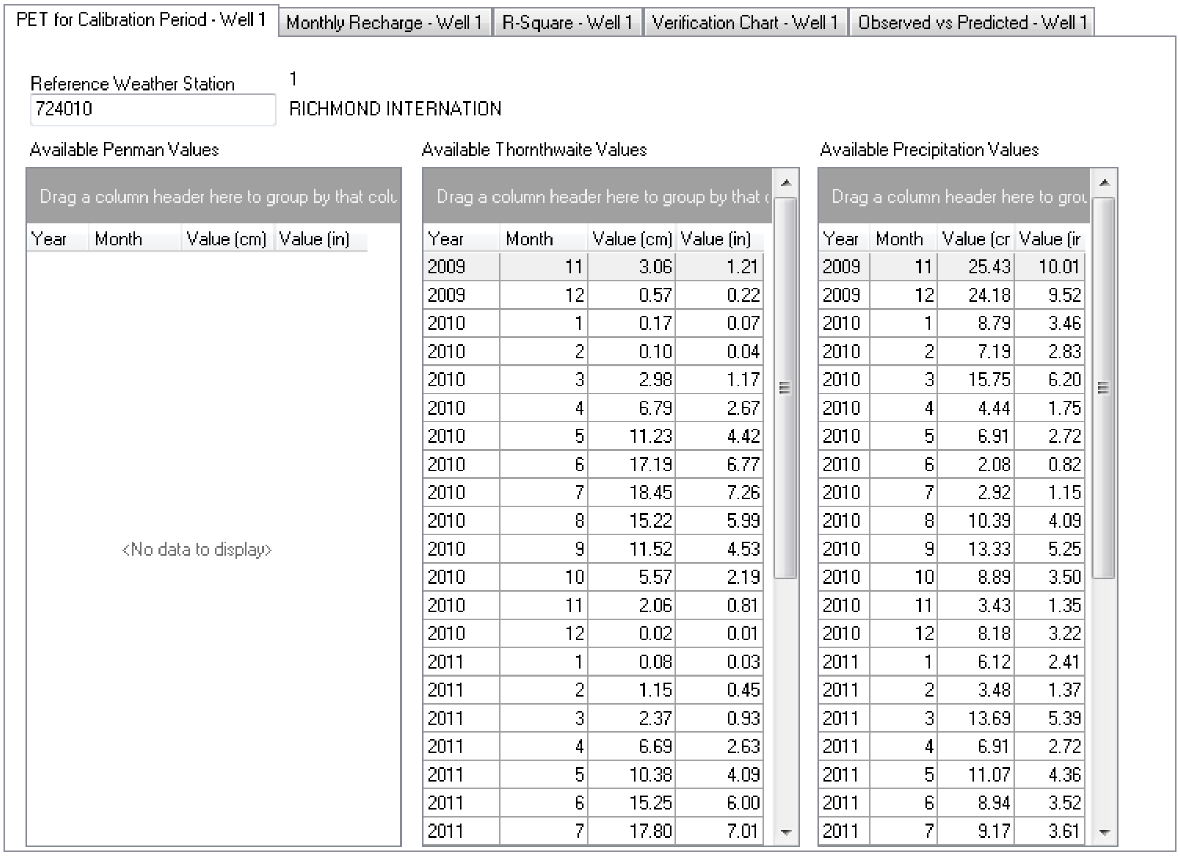
9.4.2 WEM Well 1

The following help items are available for WEM Well 1:

- PET for Calibration Period
- Monthly Recharge
- R-Squared
- Verification Chart

9.4.2.1 PET for Calibration Period - Well 1

The PET for Calibration Period tab for each well is used to view PET and precipitation values available for the months included in WEM calculations.

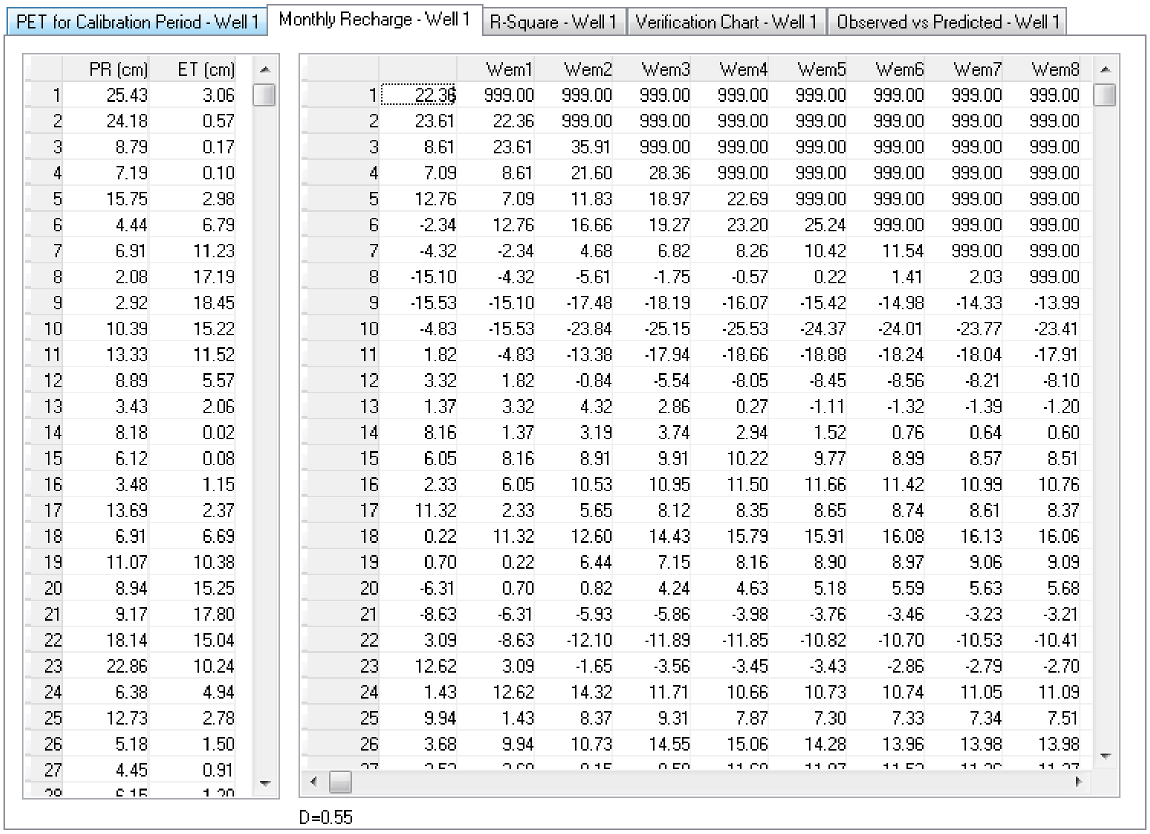


Year	Month	Value (cm)	Value (in)
2009	11	3.06	1.21
2009	12	0.57	0.22
2010	1	0.17	0.07
2010	2	0.10	0.04
2010	3	2.98	1.17
2010	4	6.79	2.67
2010	5	11.23	4.42
2010	6	17.19	6.77
2010	7	18.45	7.26
2010	8	15.22	5.99
2010	9	11.52	4.53
2010	10	5.57	2.19
2010	11	2.06	0.81
2010	12	0.02	0.01
2011	1	0.08	0.03
2011	2	1.15	0.45
2011	3	2.37	0.93
2011	4	6.69	2.63
2011	5	10.38	4.09
2011	6	15.25	6.00
2011	7	17.80	7.01

Year	Month	Value (cr	Value (ir
2009	11	25.43	10.01
2009	12	24.18	9.52
2010	1	8.79	3.46
2010	2	7.19	2.83
2010	3	15.75	6.20
2010	4	4.44	1.75
2010	5	6.91	2.72
2010	6	2.08	0.82
2010	7	2.92	1.15
2010	8	10.39	4.09
2010	9	13.33	5.25
2010	10	8.89	3.50
2010	11	3.43	1.35
2010	12	8.18	3.22
2011	1	6.12	2.41
2011	2	3.48	1.37
2011	3	13.69	5.39
2011	4	6.91	2.72
2011	5	11.07	4.36
2011	6	8.94	3.52
2011	7	9.17	3.61

9.4.2.2 Monthly Recharge - Well 1

The Monthly Recharge tab for each well displays two tables. Each row number corresponds to the number of the month used in the Wem calculations. The table on the left displays monthly totals used in Wem calculations for Precipitation (PR) and ET. The table on the right displays the monthly recharge matrix for all months included in the Wem for a given d value, which is shown in the lower left-hand corner of the table on the right. To change the d value, right-click on any cell in the column of the desired d value in the R-Squared - Well 1 tab and select Show Monthly Recharge Matrix.



	PR (cm)	ET (cm)
1	25.43	3.06
2	24.18	0.57
3	8.79	0.17
4	7.19	0.10
5	15.75	2.98
6	4.44	6.79
7	6.91	11.23
8	2.08	17.19
9	2.92	18.45
10	10.39	15.22
11	13.33	11.52
12	8.89	5.57
13	3.43	2.06
14	8.18	0.02
15	6.12	0.08
16	3.48	1.15
17	13.69	2.37
18	6.91	6.69
19	11.07	10.38
20	8.94	15.25
21	9.17	17.80
22	18.14	15.04
23	22.86	10.24
24	6.38	4.94
25	12.73	2.78
26	5.18	1.50
27	4.45	0.91

		Wem1	Wem2	Wem3	Wem4	Wem5	Wem6	Wem7	Wem8
1	22.36	999.00	999.00	999.00	999.00	999.00	999.00	999.00	999.00
2	23.61	22.36	999.00	999.00	999.00	999.00	999.00	999.00	999.00
3	8.61	23.61	35.91	999.00	999.00	999.00	999.00	999.00	999.00
4	7.09	8.61	21.60	28.36	999.00	999.00	999.00	999.00	999.00
5	12.76	7.09	11.83	18.97	22.69	999.00	999.00	999.00	999.00
6	-2.34	12.76	16.66	19.27	23.20	25.24	999.00	999.00	999.00
7	-4.32	-2.34	4.68	6.82	8.26	10.42	11.54	999.00	999.00
8	-15.10	-4.32	-5.61	-1.75	-0.57	0.22	1.41	2.03	999.00
9	-15.53	-15.10	-17.48	-18.19	-16.07	-15.42	-14.98	-14.33	-13.99
10	-4.83	-15.53	-23.84	-25.15	-25.53	-24.37	-24.01	-23.77	-23.41
11	1.82	-4.83	-13.38	-17.94	-18.66	-18.88	-18.24	-18.04	-17.91
12	3.32	1.82	-0.84	-5.54	-8.05	-8.45	-8.56	-8.21	-8.10
13	1.37	3.32	4.32	2.86	0.27	-1.11	-1.32	-1.39	-1.20
14	8.16	1.37	3.19	3.74	2.94	1.52	0.76	0.64	0.60
15	6.05	8.16	8.91	9.91	10.22	9.77	8.99	8.57	8.51
16	2.33	6.05	10.53	10.95	11.50	11.66	11.42	10.99	10.76
17	11.32	2.33	5.65	8.12	8.35	8.65	8.74	8.61	8.37
18	0.22	11.32	12.60	14.43	15.79	15.91	16.08	16.13	16.06
19	0.70	0.22	6.44	7.15	8.16	8.90	8.97	9.06	9.09
20	-6.31	0.70	0.82	4.24	4.63	5.18	5.59	5.63	5.68
21	-8.63	-6.31	-5.93	-5.86	-3.98	-3.76	-3.46	-3.23	-3.21
22	3.09	-8.63	-12.10	-11.89	-11.85	-10.82	-10.70	-10.53	-10.41
23	12.62	3.09	-1.65	-3.56	-3.45	-3.43	-2.86	-2.79	-2.70
24	1.43	12.62	14.32	11.71	10.66	10.73	10.74	11.05	11.09
25	9.94	1.43	8.37	9.31	7.87	7.30	7.33	7.34	7.51
26	3.68	9.94	10.73	14.55	15.06	14.28	13.96	13.98	13.98

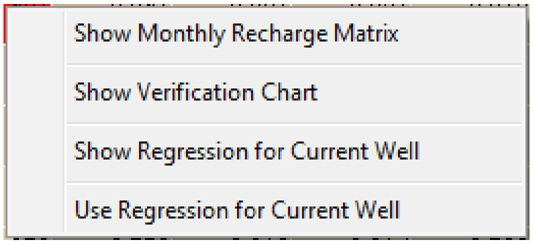
9.4.2.3 R-Squared - Well 1

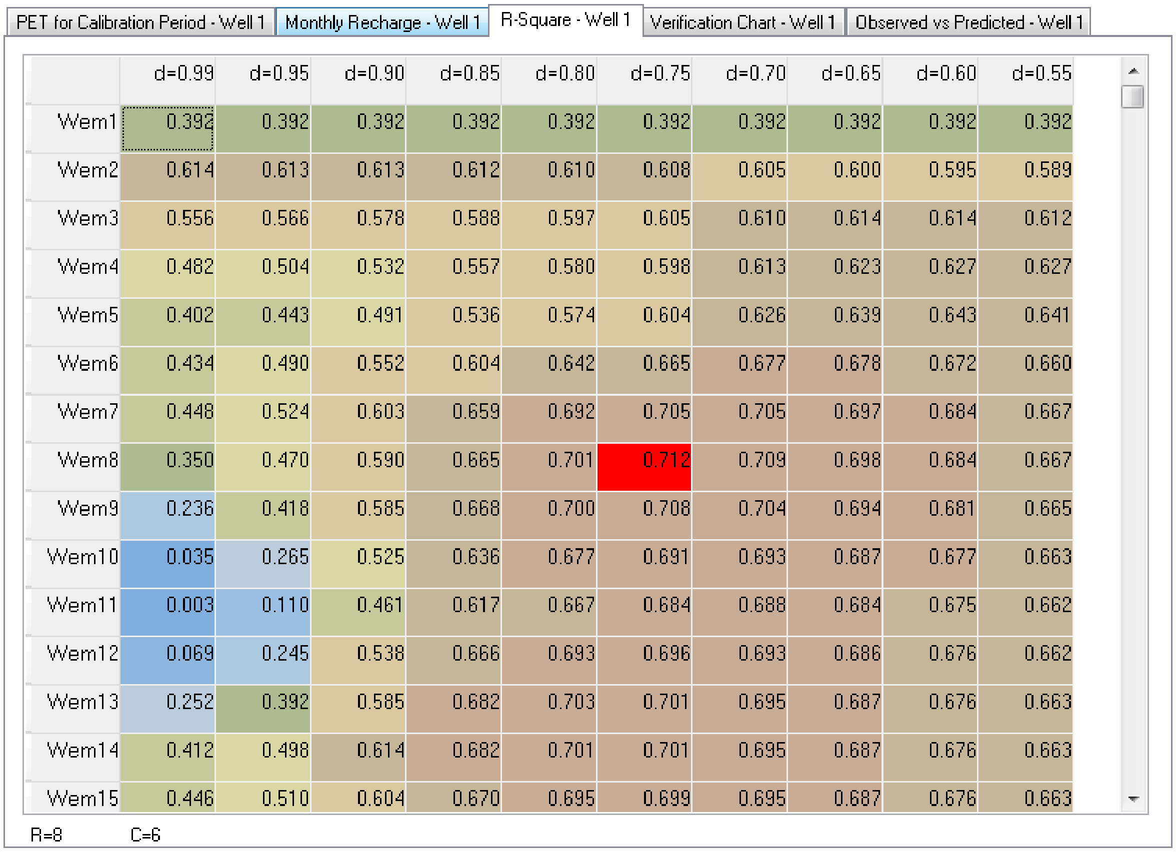
To select the regression equation for WEM Well 1, right-click on the cell with the highest correlation coefficient in the R-Squared table of the R-Squared - Well 1 tab and select Use Regression for Current Well from the list that appears. Click OK from the prompt to confirm your selection.

If a second well has been specified, repeat this procedure for WEM Well 2. The equation selected for WEM Well 1 will now be used by Wetbud to predict head elevations for the hillslope (up-gradient, h1) well in groundwater input calculations.

For the regression equation generated for Well 2, see R-Squared - Well 2.

Note: The values for Slope, Intercept, R-Squared, d, and N will now be registered in the WEM Equations sub-tab of the WEM tab for the current Project in the Define Projects window. The list in the figure will appear when right-clicking on any cell in the R-Squared table. Clicking Show Monthly Recharge Matrix, Show Verification Chart, or Show Regression for Current Well will direct the user to the tab of the corresponding selection.



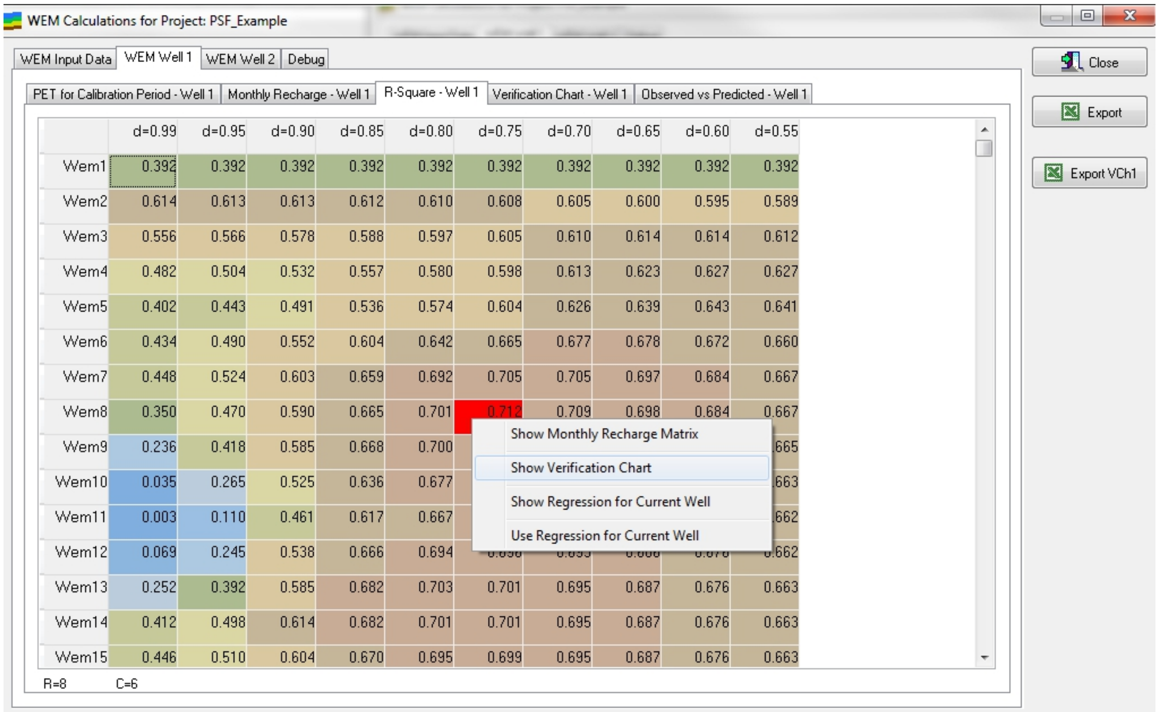


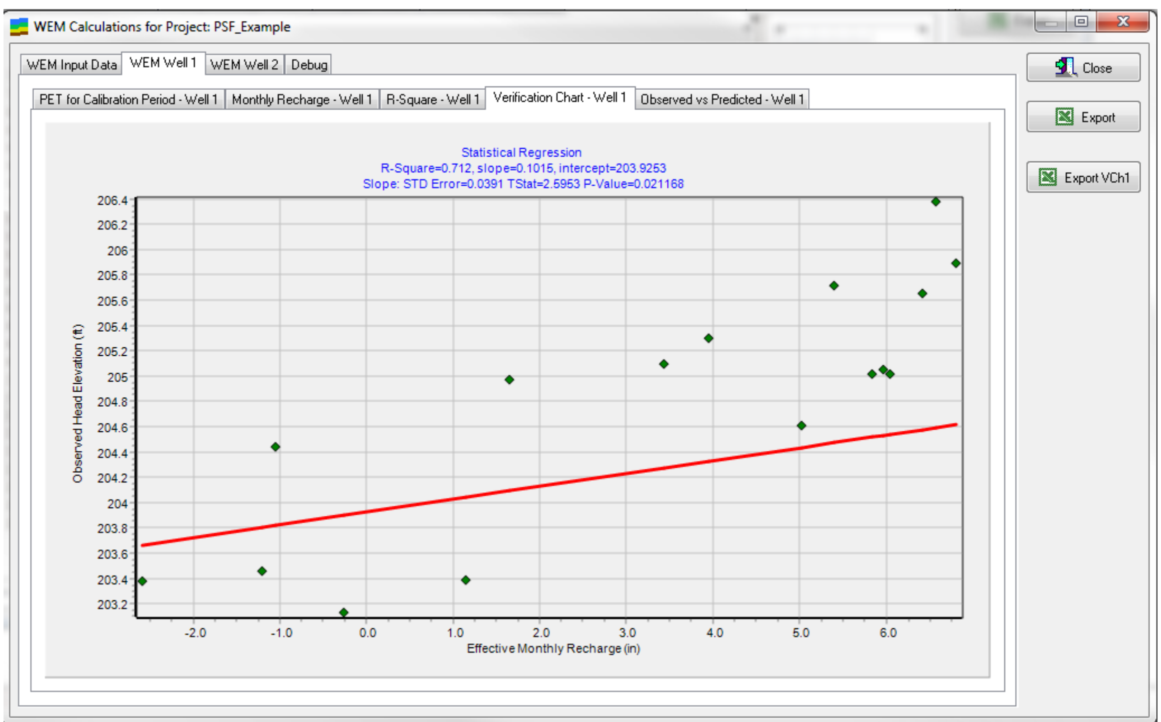
	d=0.99	d=0.95	d=0.90	d=0.85	d=0.80	d=0.75	d=0.70	d=0.65	d=0.60	d=0.55
Wem1	0.392	0.392	0.392	0.392	0.392	0.392	0.392	0.392	0.392	0.392
Wem2	0.614	0.613	0.613	0.612	0.610	0.608	0.605	0.600	0.595	0.589
Wem3	0.556	0.566	0.578	0.588	0.597	0.605	0.610	0.614	0.614	0.612
Wem4	0.482	0.504	0.532	0.557	0.580	0.598	0.613	0.623	0.627	0.627
Wem5	0.402	0.443	0.491	0.536	0.574	0.604	0.626	0.639	0.643	0.641
Wem6	0.434	0.490	0.552	0.604	0.642	0.665	0.677	0.678	0.672	0.660
Wem7	0.448	0.524	0.603	0.659	0.692	0.705	0.705	0.697	0.684	0.667
Wem8	0.350	0.470	0.590	0.665	0.701	0.712	0.709	0.698	0.684	0.667
Wem9	0.236	0.418	0.585	0.668	0.700	0.708	0.704	0.694	0.681	0.665
Wem10	0.035	0.265	0.525	0.636	0.677	0.691	0.693	0.687	0.677	0.663
Wem11	0.003	0.110	0.461	0.617	0.667	0.684	0.688	0.684	0.675	0.662
Wem12	0.069	0.245	0.538	0.666	0.693	0.696	0.693	0.686	0.676	0.662
Wem13	0.252	0.392	0.585	0.682	0.703	0.701	0.695	0.687	0.676	0.663
Wem14	0.412	0.498	0.614	0.682	0.701	0.701	0.695	0.687	0.676	0.663
Wem15	0.446	0.510	0.604	0.670	0.695	0.699	0.695	0.687	0.676	0.663

R=8 C=6

9.4.2.4 Verification Chart - Well 1

The Verification Chart tab for each well is used to view the linear regression associated with a given N-and-d combination selected in the R-Squared - Well 1 tab. To populate the graph in this window, the user must right-click on a cell in the R-squared - Well 1 tab and then select Show Verification Chart from the list that appears.

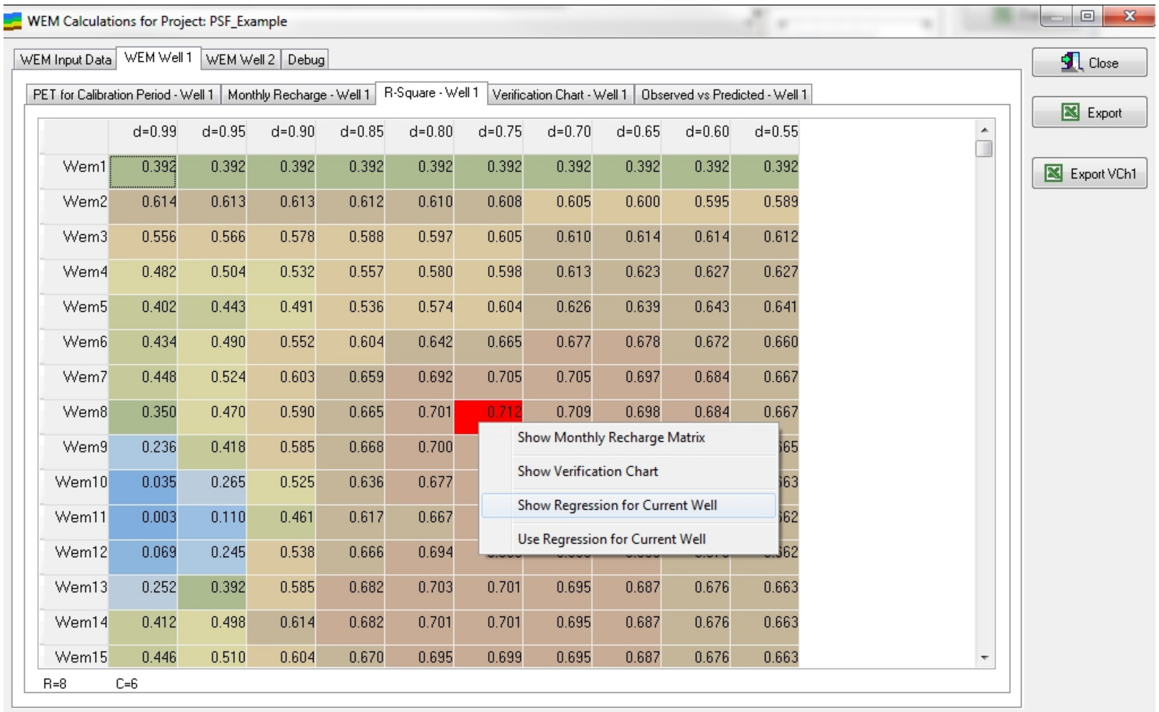


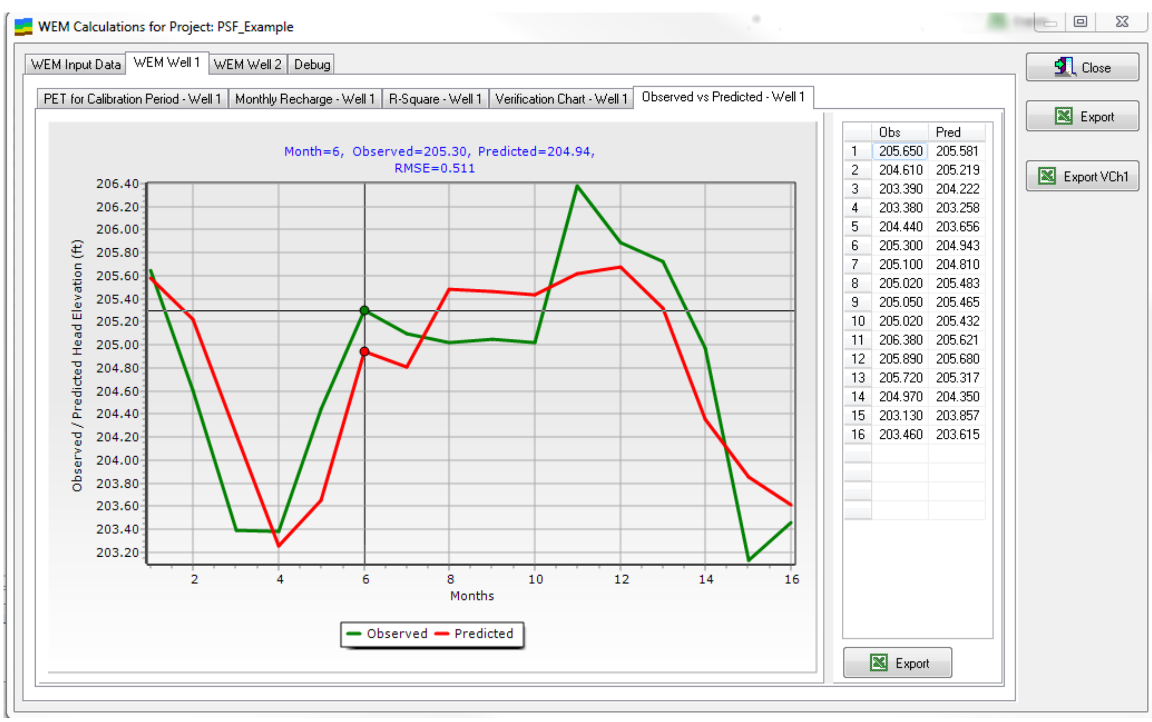


Note: Negative Effective Monthly Recharge values on the Verification Chart are acceptable, negative Effective Monthly Recharge values reflect months when the monthly Precipitation was less than Evapotranspiration for that same month.

9.4.2.5 Observed vs Predicted - Well 1

The Verification Chart tab for each well is used to view the correlation between the Observed and Predicted values for the well. To populate the graph in this window, the user must right-click on a cell in the R-squared - Well 1 tab and then select Show Regression for Current Well from the list that appears.





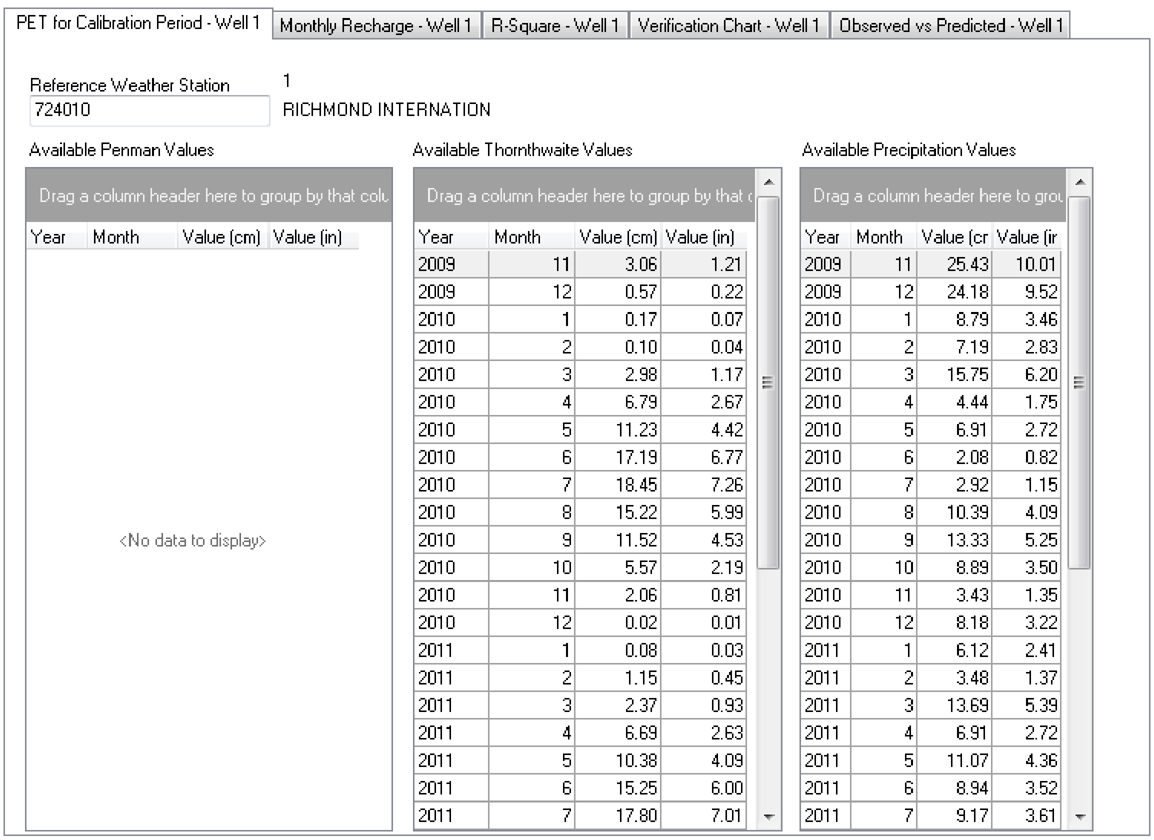
9.4.3 WEM Well 2

The following help items are available for WEM Well 2:

- PET for Calibration Period
- Monthly Recharge
- R-Squared
- Verification Chart

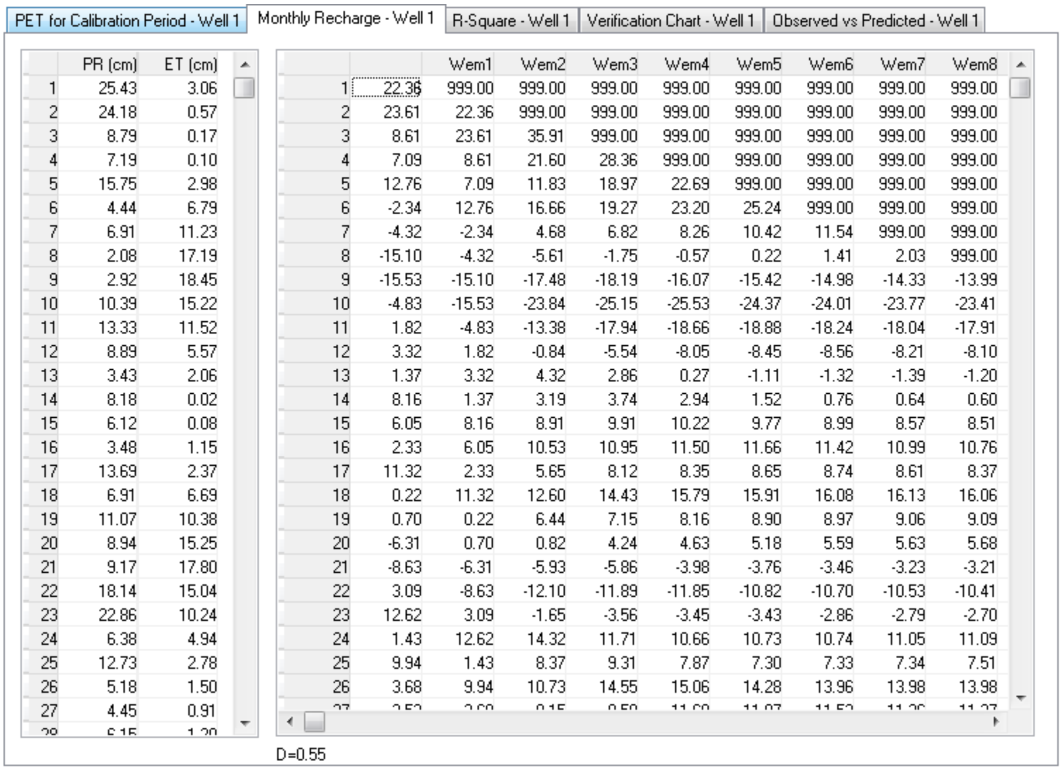
9.4.3.1 PET for Calibration Period - Well 2

The PET for Calibration Period tab for each well is used to view PET and precipitation values available for the months included in WEM calculations



9.4.3.2 Monthly Recharge - Well 2

The Monthly Recharge tab for each well displays two tables. Each row number corresponds to the number of the month used in the Wem calculations. The table on the left displays monthly totals used in Wem calculations for Precipitation (PR) and ET. The table on the right displays the monthly recharge matrix for all months included in the Wem for a given d value, which is shown in the lower left-hand corner of the table on the right. To change the d value, right-click on any cell in the column of the desired d value in the R-Squared - Well 2 tab and select Show Monthly Recharge Matrix.



PET for Calibration Period - Well 1 | Monthly Recharge - Well 1 | R-Square - Well 1 | Verification Chart - Well 1 | Observed vs Predicted - Well 1

	PR (cm)	ET (cm)
1	25.43	3.06
2	24.18	0.57
3	8.79	0.17
4	7.19	0.10
5	15.75	2.98
6	4.44	6.79
7	6.91	11.23
8	2.08	17.19
9	2.92	18.45
10	10.39	15.22
11	13.33	11.52
12	8.89	5.57
13	3.43	2.06
14	8.18	0.02
15	6.12	0.08
16	3.48	1.15
17	13.69	2.37
18	6.91	6.69
19	11.07	10.38
20	8.94	15.25
21	9.17	17.80
22	18.14	15.04
23	22.86	10.24
24	6.38	4.94
25	12.73	2.78
26	5.18	1.50
27	4.45	0.91

		Wem1	Wem2	Wem3	Wem4	Wem5	Wem6	Wem7	Wem8
1	22.36	999.00	999.00	999.00	999.00	999.00	999.00	999.00	999.00
2	23.61	22.36	999.00	999.00	999.00	999.00	999.00	999.00	999.00
3	8.61	23.61	35.91	999.00	999.00	999.00	999.00	999.00	999.00
4	7.09	8.61	21.60	28.36	999.00	999.00	999.00	999.00	999.00
5	12.76	7.09	11.83	18.97	22.69	999.00	999.00	999.00	999.00
6	-2.34	12.76	16.66	19.27	23.20	25.24	999.00	999.00	999.00
7	-4.32	-2.34	4.68	6.82	8.26	10.42	11.54	999.00	999.00
8	-15.10	-4.32	-5.61	-1.75	-0.57	0.22	1.41	2.03	999.00
9	-15.53	-15.10	-17.48	-18.19	-16.07	-15.42	-14.98	-14.33	-13.99
10	-4.83	-15.53	-23.84	-25.15	-25.53	-24.37	-24.01	-23.77	-23.41
11	1.82	-4.83	-13.38	-17.94	-18.66	-18.88	-18.24	-18.04	-17.91
12	3.32	1.82	-0.84	-5.54	-8.05	-8.45	-8.56	-8.21	-8.10
13	1.37	3.32	4.32	2.86	0.27	-1.11	-1.32	-1.39	-1.20
14	8.16	1.37	3.19	3.74	2.94	1.52	0.76	0.64	0.60
15	6.05	8.16	8.91	9.91	10.22	9.77	8.99	8.57	8.51
16	2.33	6.05	10.53	10.95	11.50	11.66	11.42	10.99	10.76
17	11.32	2.33	5.65	8.12	8.35	8.65	8.74	8.61	8.37
18	0.22	11.32	12.60	14.43	15.79	15.91	16.08	16.13	16.06
19	0.70	0.22	6.44	7.15	8.16	8.90	8.97	9.06	9.09
20	-6.31	0.70	0.82	4.24	4.63	5.18	5.59	5.63	5.68
21	-8.63	-6.31	-5.93	-5.86	-3.98	-3.76	-3.46	-3.23	-3.21
22	3.09	-8.63	-12.10	-11.89	-11.85	-10.82	-10.70	-10.53	-10.41
23	12.62	3.09	-1.65	-3.56	-3.45	-3.43	-2.86	-2.79	-2.70
24	1.43	12.62	14.32	11.71	10.66	10.73	10.74	11.05	11.09
25	9.94	1.43	8.37	9.31	7.87	7.30	7.33	7.34	7.51
26	3.68	9.94	10.73	14.55	15.06	14.28	13.96	13.98	13.98

D=0.55

9.4.3.3 R-Squared - Well 2

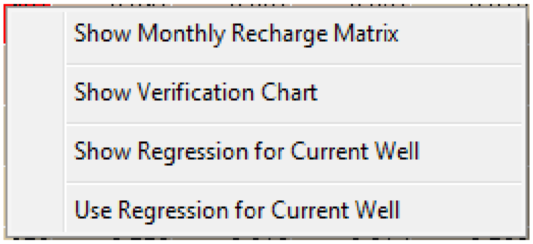
If two wells have been specified during WEM setup, then the user can generate regression equations for both wells. If only a toeslope well has been specified then the use can generate regression equations for Well 2 only.

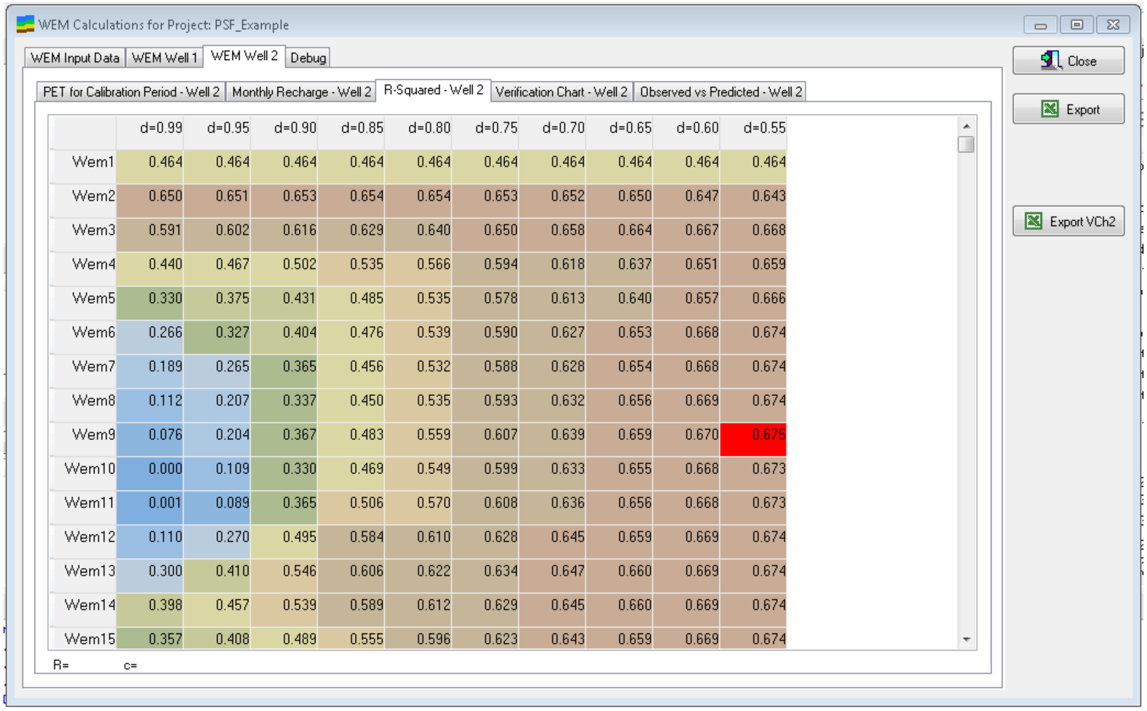
For regression equations pertaining to Well 1, see R-Squared - Well 1.

To select the regression equation for WEM Well 2, right-click on the cell with the highest correlation coefficient in the R-Squared table of the R-Squared - Well 2 tab and select Use Regression for Current Well from the list that appears. Click OK from the prompt to confirm your selection.

The equation selected for WEM Well 2 will now be used by Wetbud to predict head elevations for the toeslope (down-gradient, h2) well in groundwater input calculations. Once these equations have been selected, the user can choose the Calculated through WEM option for Groundwater IN for any Scenario in the current Project.

Note: The values for Slope, Intercept, R-Squared, d, and N will now be registered in the WEM Equations sub-tab of the WEM tab for the current Project in the Define Projects window. The list in the figure will appear when right-clicking on any cell in the R-squared table. Clicking Show Monthly Recharge Matrix, Show Verification Chart, or Show Regression for Current Well will direct the user to the tab of the corresponding selection.

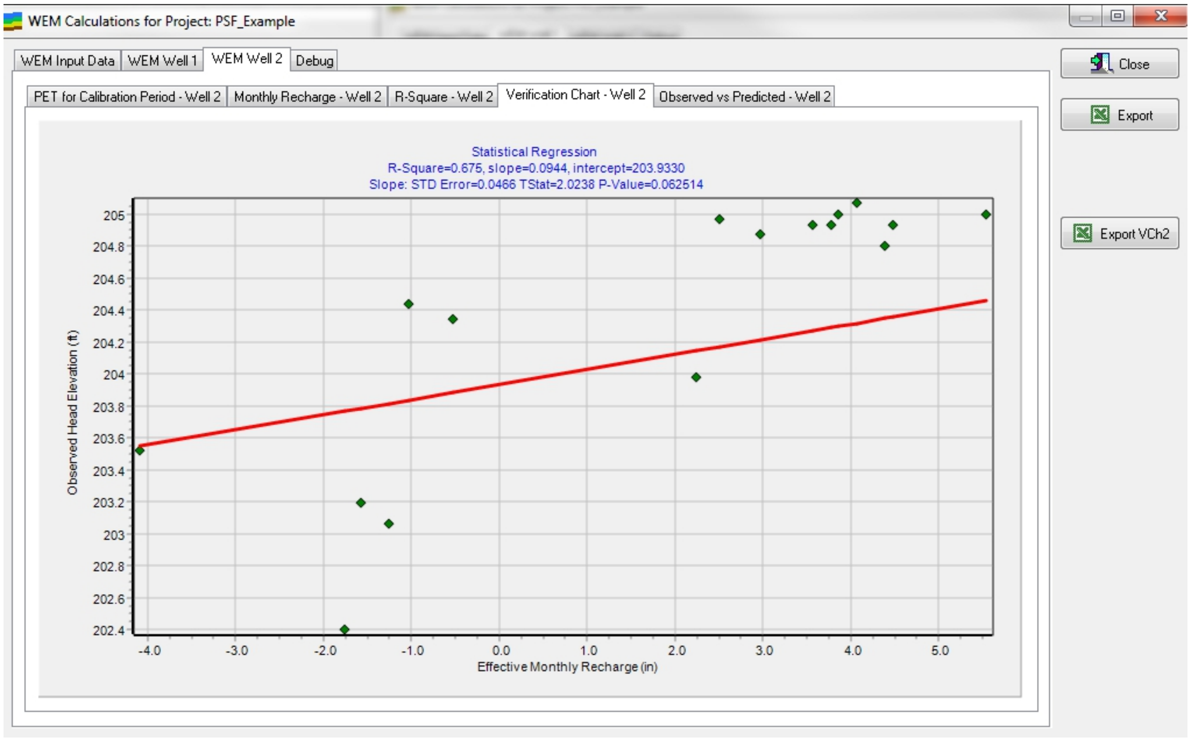




	d=0.99	d=0.95	d=0.90	d=0.85	d=0.80	d=0.75	d=0.70	d=0.65	d=0.60	d=0.55
Wem1	0.464	0.464	0.464	0.464	0.464	0.464	0.464	0.464	0.464	0.464
Wem2	0.650	0.651	0.653	0.654	0.654	0.653	0.652	0.650	0.647	0.643
Wem3	0.591	0.602	0.616	0.629	0.640	0.650	0.658	0.664	0.667	0.668
Wem4	0.440	0.467	0.502	0.535	0.566	0.594	0.618	0.637	0.651	0.659
Wem5	0.330	0.375	0.431	0.485	0.535	0.578	0.613	0.640	0.657	0.666
Wem6	0.266	0.327	0.404	0.476	0.539	0.590	0.627	0.653	0.668	0.674
Wem7	0.189	0.265	0.365	0.456	0.532	0.588	0.628	0.654	0.668	0.674
Wem8	0.112	0.207	0.337	0.450	0.535	0.593	0.632	0.656	0.669	0.674
Wem9	0.076	0.204	0.367	0.483	0.559	0.607	0.639	0.659	0.670	0.675
Wem10	0.000	0.109	0.330	0.469	0.549	0.599	0.633	0.655	0.668	0.673
Wem11	0.001	0.089	0.365	0.506	0.570	0.608	0.636	0.656	0.668	0.673
Wem12	0.110	0.270	0.495	0.584	0.610	0.628	0.645	0.659	0.669	0.674
Wem13	0.300	0.410	0.546	0.606	0.622	0.634	0.647	0.660	0.669	0.674
Wem14	0.398	0.457	0.539	0.589	0.612	0.629	0.645	0.660	0.669	0.674
Wem15	0.357	0.408	0.489	0.555	0.596	0.623	0.643	0.659	0.669	0.674

9.4.3.4 Verification Chart - Well 2

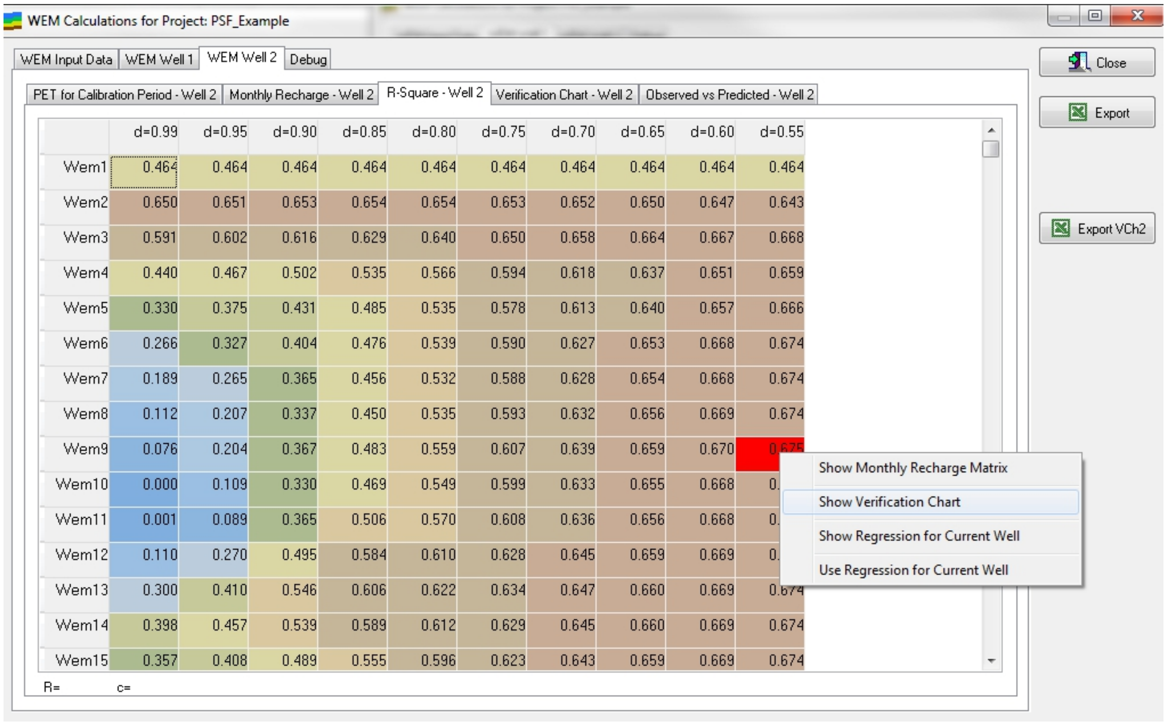
The Verification Chart tab for each well is used to view the linear regression associated with a given N-and-d combination selected in the R-Squared - Well 2 tab. To populate the graph in this window, the user must right-click on a cell in the R-Squared - Well 2 tab and then select Show Verification Chart from the list that appears.

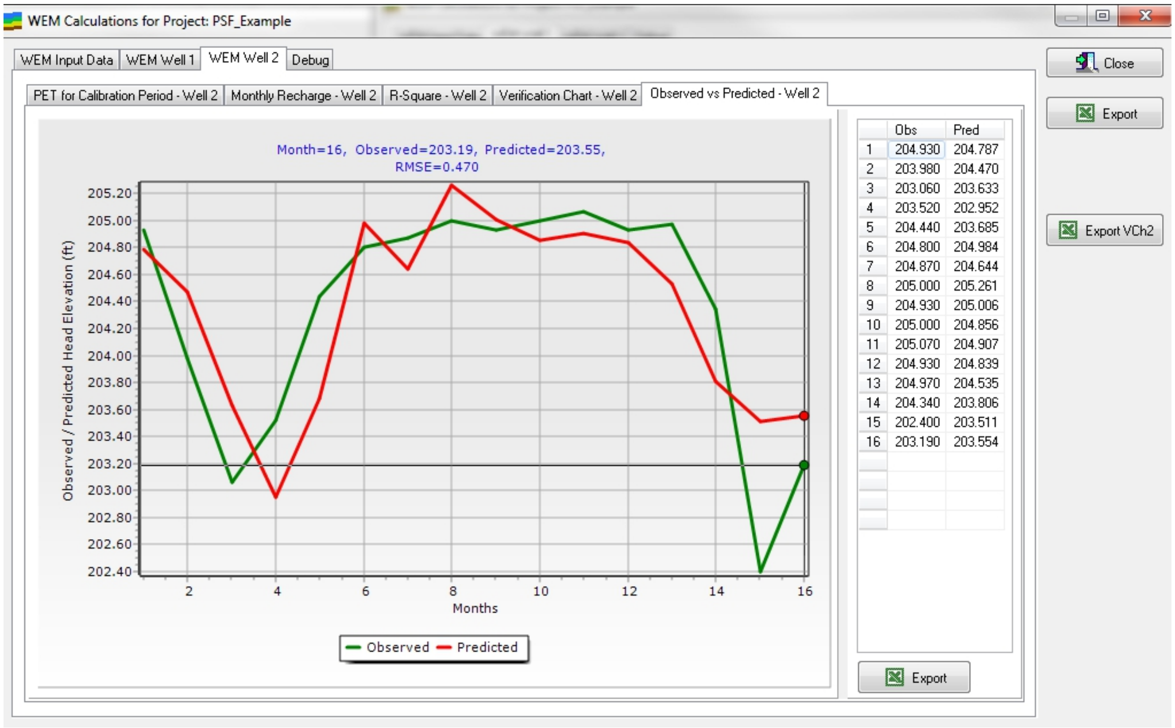


Note: Negative Effective Monthly Recharge values on the Verification Chart are acceptable, negative Effective Monthly Recharge values reflect months when the monthly Precipitation was less than Evapotranspiration for that same month.

9.4.3.5 Observed vs Predicted - Well 2

The Verification Chart tab for each well is used to view the correlation between the Observed and Predicted values for the well. To populate the graph in this window, the user must right-click on a cell in the R-Squared - Well 2 tab and then select Show Regression for Current Well from the list that appears.



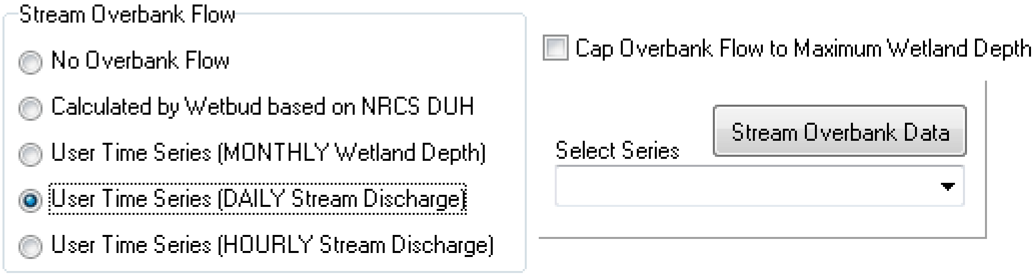


9.5 Overbank Calculations

In order to develop stream overbank flow calculations for the basic model, the user should follow the steps outlined below:

1. Select how Wetbud will estimate the discharge in the stream adjacent to the wetland. There are three options:
   a. Based on NRCS Dimensionless Unit Hydrograph.
   b. Based on user-input daily stream discharge values.
   c. Based on user-input hourly stream discharge values.

See also: Stream Overbank Flow Parameters



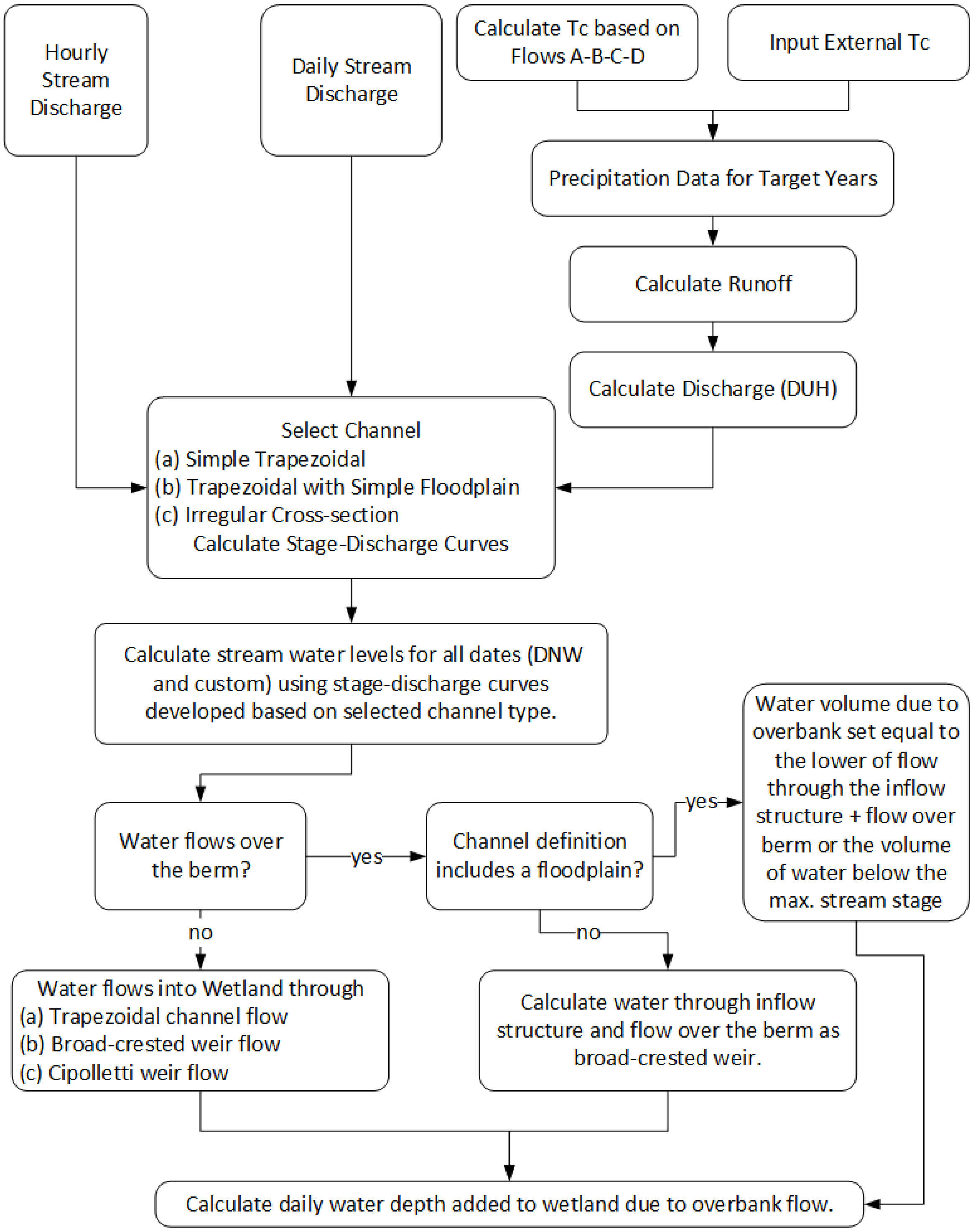
2. If the user would like to limit the amount of water entering the wetland for each storm event that overtops the wetland berm to the maximum allowed water depth in the wetland (based on weir height), the Cap Overbank Flow to Maximum Wetland Depth should be checked. Note that the Cap Overbank Flow to Maximum Wetland Depth option limits the depth of overbank flow for each day to a maximum depth, which is equal to the difference between the outlet weir elevation and the average wetland bottom elevation. See Average Wetland Bottom Elevation for details on how average wetland bottom elevation is defined.
3. From the Stream Overbank Flow menu, the user should input the channel geometry at a representative cross section. There are three options for channel geometry:
   a. Simple trapezoidal channel.
   b. Trapezoidal channel with simple floodplains.
   c. Irregular channel.

Note: The simple trapezoidal channel assumes there is no floodplain (i.e., the stream banks are infinitely high). Also note that the channel cross-section is assumed constant for the entire channel length.

See also: Stream Overbank Flow Parameters

4. Select the geometry of the inflow structure:
   a. Trapezoidal channel.
   b. Broad-crested weir.
   c. Cipoletti weir.

A general flow chart that shows how the above-mentioned input data time-series interact with each other is shown below.



Assumptions:

1. The entire channel is represented by a single cross-section.
2. Stream flow is uniform (constant slope, constant geometry).

Solution logic:

Wetbud will calculate how much water enters the wetland through the inflow structure and how much water enters the wetland over the berm. The depth of water resulting from overbank flows reported in the output may be capped by checking the Cap Overbank Flow to Maximum Wetland Depth checkbox as mentioned above.

1. For every time step, Wetbud will calculate the water elevation in the stream. It will then compare the water elevation with the inflow structure invert elevation and the top of the berm elevation. If the water level is above the inflow structure invert elevation but below the top of the berm, then water will flow into the wetland through the selected inflow structure.
2. If the water surface elevation is greater that the top elevation of the berm, then excess water fills the wetland. Calculations are performed as follows:
   a. If no floodplain is simulated (simple trapezoidal channel or irregular channel without floodplains), the stage-discharge relationship will be calculated assuming the channel has infinitely high streambanks. Wetbud will then calculate the amount of overbank flow into the wetland by modeling the berm as a broad-crested weir. The length of the berm excludes the top width of the inflow structure. In addition, water continues to flow into the wetland through the inflow structure. Water in the wetland can be limited to the maximum wetland storage by checking the Cap Overbank Flow to Maximum Wetland Depth check box in the Stream Overbank Flow Parameters.
   b. If floodplains are simulated (trapezoidal channel with simple floodplains or irregular channel with floodplains represented in the irregular channel geometry), the stage-discharge relationship will be calculated for both the channel and floodplains. The depth of water added to the wetland due to overbank flow (through the inflow channel and over the berm) will be compared to the depth of water over the wetland at the peak water surface elevation for that storm event. The lower of the two water depths will be used as the overbank flow input to the wetland for that 24-hr storm event. Furthermore, the total depth of overbank flow reported for each month can be capped by checking the “Cap Overbank Flow to max wetland depth” checkbox under Water Inputs. The maximum wetland depth is the difference between the outflow weir invert elevation and the average wetland bottom elevation. See Average Wetland Bottom Elevation for details on how average wetland bottom elevation is defined.

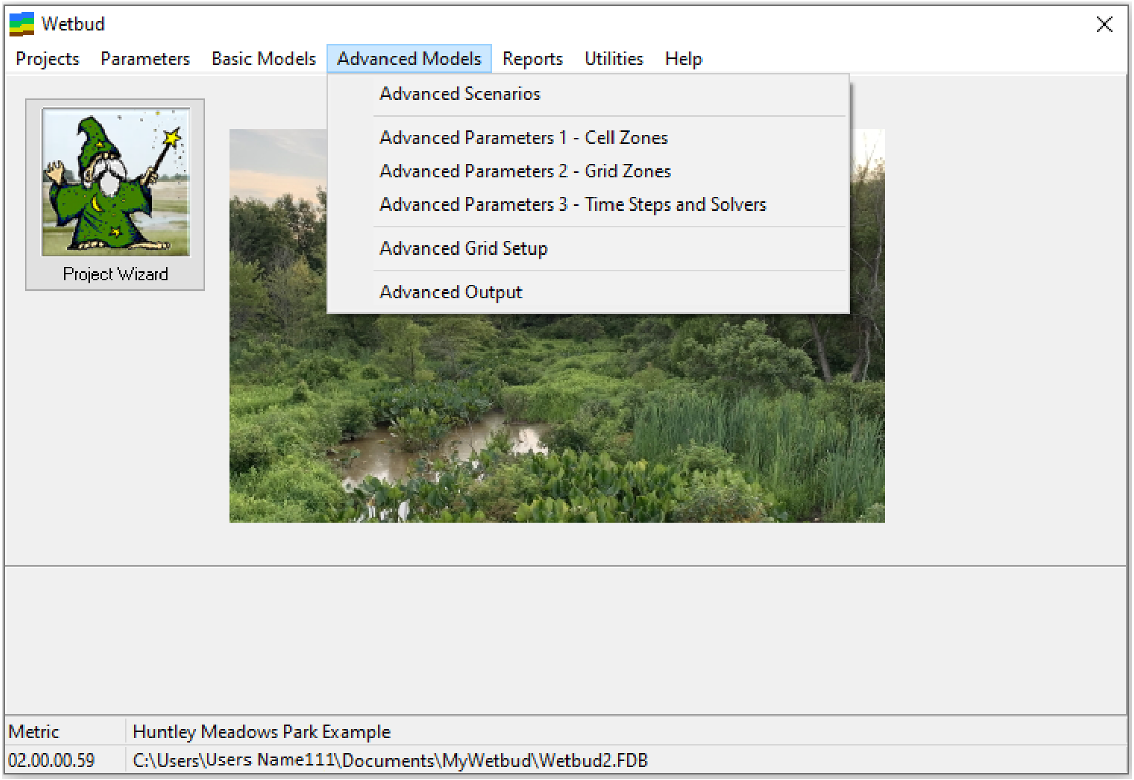
10

Advanced Models

10 Advanced Models

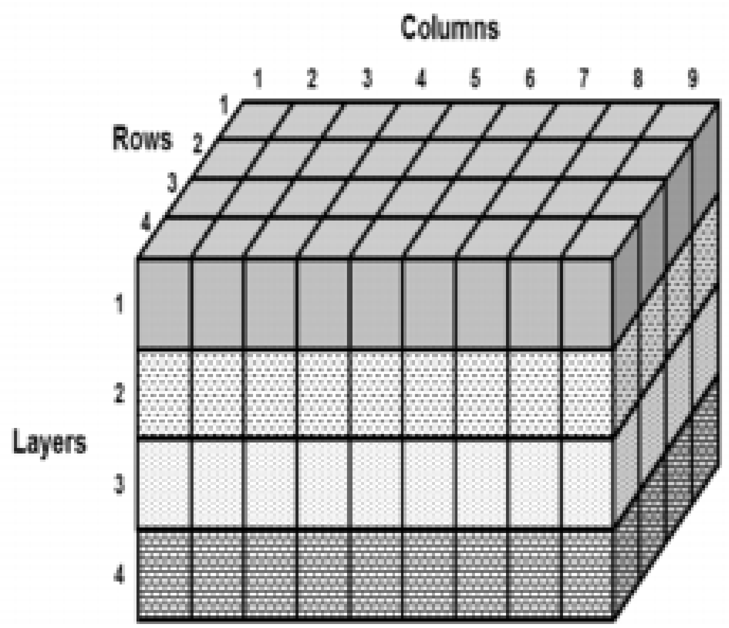
The Advanced Models menu has the following options:

- Advanced Scenarios
- Advanced Parameters 1 - Cell Zones
- Advanced Parameters 2 - Grid Zones
- Advanced Parameters 3 - Time Steps and Solvers
- Advanced Grid Setup
- Advanced Output



10.1 Advanced Scenarios

The Advanced Model of Wetbud is essentially a Graphical User Interface (GUI) for the USGS modular finite difference groundwater model, MODFLOW. Using MODFLOW, the wetland is described mathematically as one or multiple horizontal layers, similar to a cake. Each layer is subdivided using a uniform grid, resulting in a “wetland box” formed by similarly sized building blocks. Water storage and flow properties can vary for each block. Using Darcy’s Law and a basic water balance, water storage within each block and water flow between the blocks are calculated and summarized on a specified basis. Greater detail on the Advanced Model components and underlying assumptions and algorithms is available in Stone (2017).



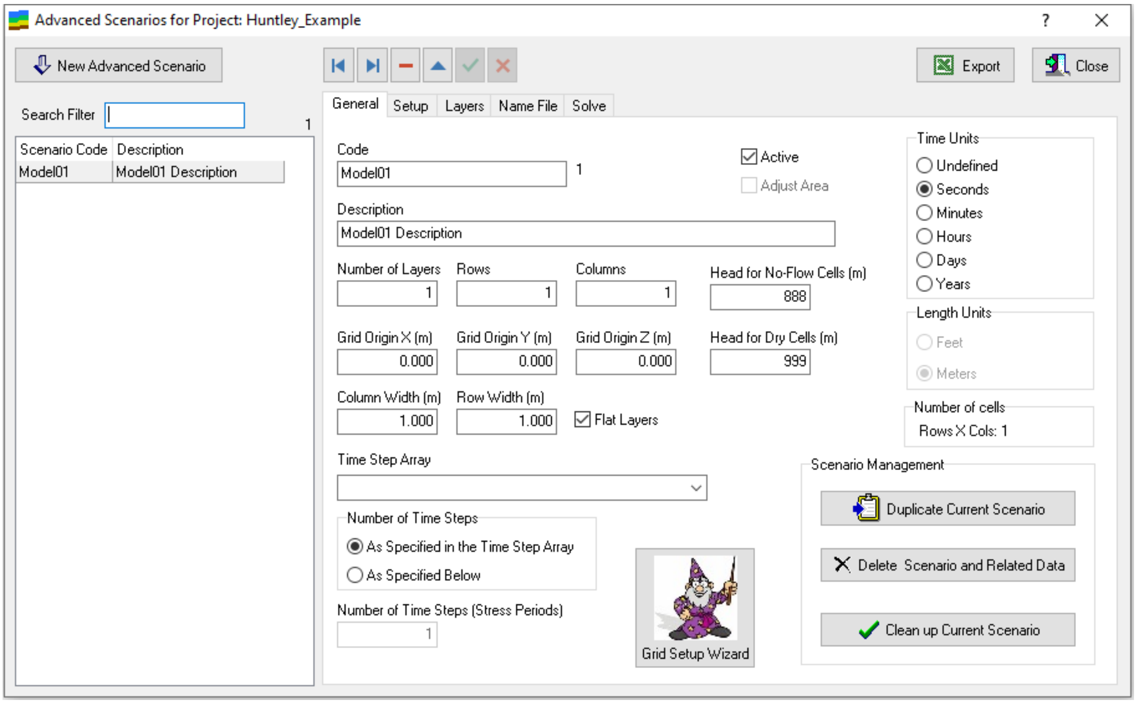
Both MODFLOW-2005 and MODFLOW-NWT are included in Wetbud. MODFLOW-NWT is a Newton formulation for MODFLOW-2005 and is used for solving problems that involve the drying and rewetting of cells (Niswonger et al., 2011). The Newton solver used in the MODFLOW-NWT model can compensate for the numerical instabilities caused by the large water level fluctuations typical of many wetland hydroperiods. The ability of MODFLOW-NWT to achieve model convergence with the drying and rewetting of cells in the model makes it a more robust software package for wetland water budget modeling than other MODFLOW versions. While Wetbud has a number of different options, the capabilities of MODFLOW-NWT have been optimized so that even users unfamiliar with the MODFLOW software can construct, edit, and run models. Model setup and analysis for the Advanced module requires more detailed information about the proposed wetland site than for the Basic module. However, the required meteorological information for the Advanced module is the same as for the Basic module and Wetbud allows the user to access and utilize stored Basic module meteorological data within the Advanced module. Advanced module results are provided as head values in each layer for each user-specified time step within every cell of the user-specified finite difference grid.

One or many Advanced Scenarios can be generated within a Project. Setting up multiple Advanced Scenarios for a Project allows the user to modify the Scenario without having to duplicate basic site information under a new Project. Scenarios within a Project can also be copied for user convenience.

To begin setting up an Advanced Scenario, click Select Current Project from the drop-down menu under Projects in the Wetbud home screen and select the Project within which your Advanced Scenario will be created. Next, select Advanced Scenarios from the Advanced Models drop-down menu in the Wetbud home screen. In the Advanced Scenarios window you will see five tabs:

- General
- Setup
- Layers
- Name File
- Solve

These tabs are used to establish the overall layout of the finite-difference grid, generate Advanced Model files, and execute the MODFLOW simulation.



10.1.1 Advanced Scenario Preparation and Setup Checklist

The success of an Advanced Scenario model simulation in Wetbud depends on the user's ability to design and set up a realistic model for their site. In most cases, the efficiency of model setup and design can be greatly enhanced with proper preparation. This section contains a list of recommended preparations to enhance user proficiency and to expedite Advanced Scenario setup in Wetbud, including a general step-by-step checklist to follow during Advanced Scenario setup. Users can refer to this checklist throughout the setup process to ensure a successful Advanced Model simulation. Some steps in the following list may not appear in this chapter in the exact order as described. These steps simply provide the user guidance and a general understanding of the logical flow used to efficiently set up and generate output for an Advanced Model using Wetbud. Thus, following the exact order of operations in the list below is recommended, but not required.

Advanced Scenario Preparation List

1. Develop a Complete Conceptual Model – Prior to developing an Advanced Model in Wetbud, the user should have created a detailed conceptual model of the site to be simulated using the Advanced Model grid. The conceptual model should include information such as wetland surface area and topography, surface water ponding depth, hydrologic boundaries, surface water inlet and outlet structures, soil/sediment/strata characteristics, number of layers, length of time to be simulated, etc. All of these wetland attributes must be parameterized by the user when creating an Advanced Model so it is prudent to have this information available prior to model development.
2. Create a Time Step Array and Solver Set – Every Advanced Scenario in Wetbud must be assigned a Time Step Array and a Solver Set. The Time Step Array contains the water input and output data that will be included in the simulation. In addition, these data will be assigned to Cell Zones and Grid Zones when designing the model grid. Thus, creating a Time Step Array prior to setting up an Advanced Scenario is highly recommended. A Solver Set is used to define the convergence criteria that govern the model solution for the simulation period.
3. Create Cell Zones (Boundary Conditions) and Grid Zones (Properties) – Cell Zones and Grid Zones are used to establish hydrologic boundaries and to parameterize the hydraulic properties of the actual wetland materials (e.g., sand, clay, topsoil) represented by cells in the model grid. Once these zones have been created, they can be assigned to cells in the model grid for any Advanced Scenario created within the selected Project. Thus, creating these zones early on will greatly increase the efficiency of initial and future Advanced Model setup and design.
4. Create Layer Elevation Files – Many users will have wetland designs with variable ground surface elevations and/or variable elevations of stratigraphic contacts for subsurface layers. Creating all elevation data files prior to setting up layers during Advanced Scenario setup will greatly accelerate the setup process. Wetbud allows users to import elevations from multiple file types including: XYZ Excel files, Excel Spreadsheets, XYZ ASCII files (from Civil 3D or similar), ARC/INFO ASCII grids, and Surfer ASCII grids.
   Note: This step is not necessary for users who wish to have all modeled layers be flat.
5. Create a Chart Formatting data set – A chart formatting data set is used to constrain and/or customize the axes of graphs displaying results in Advanced Model Output. During Advanced Scenario setup the user is required to assign a Chart Formatting (Settings) data set to the model. Thus, it is very helpful to have a Chart Formatting data set created prior to setup.

Setup Checklist

Once all of the preparations listed above are complete, the Advanced Scenario setup process becomes fairly simple. The following is a general step-by-step checklist the user can follow to setup and complete an Advanced Model simulation in Wetbud.

Note: Prior to designing an Advanced Scenario model grid, the user must create Cell Zones, Grid Zones, a Time Step Array and a Solver Set within the selected project.

To begin working on an Advanced Model, click Advanced Models on the Wetbud home screen and select Advanced Scenarios from the drop-down menu. If no Project is currently selected, you will be prompted to select a Project before going to the Advanced Scenarios window.

Steps 1-4 below are performed in the Advanced Scenarios window:

1. Create a new Advanced Scenario Code in the General tab of the Advanced Scenarios window. Proceed in this tab by adding a Scenario description, specify the size of the model grid, time units, length units, and select a Time Step Array. **Note:** If elevation files will be used to generate variable topography in the model, they can also be used in conjunction with the Grid Setup Wizard to automatically generate grid definitions.
2. In the Setup tab, select a flow package (NWT recommended), solver, Precipitation option, ET option, chart settings files, and assign the path for storing MODFLOW Input and Output files.
3. In the Layers tab, create all layers, import elevation data, and select layer parameters.
4. Make sure you have saved the information in each tab by clicking and close the Advanced Scenarios window.

Steps 5-7 are performed in the Advanced Grid Setup window. To access the Advanced Grid Setup window, click Advanced Models on the Wetbud home screen and select Advanced Grid Setup from the drop-down menu:

5. In the Cell Zones (Boundary Conditions) tab, assign Cell Zones (Boundary Conditions) to the appropriate cells within each layer of the model grid.
6. In the Grid Zones (Properties) tab, assign Grid Zones (Properties) to every cell in each layer of the model grid.
   Note: Grid Zones for hydraulic conductivity and specific yield/storage must be assigned to every cell in every layer of the model grid. Grid Zones for precipitation and ET must be assigned to layer 1. Time step array data for the precipitation and ET zones will then be applied to cells in the model grid as specified in the Precipitation Rate Options and ET Options in the Setup tab of the Advanced Scenarios window.
7. Close the Advanced Grid Setup window.

Steps 8-10 are performed in the Advanced Scenarios window:

8. In the Name File tab, generate name files for the current scenario (see Advanced Model Output for more information). Save and proceed to the Solve tab.
9. In the Solve tab, create MODFLOW input files, execute MODFLOW, and show MODFLOW results (see Advanced Model Output for more information).
10. After completing step 9, the user will automatically be directed to the Advanced Model Output window. However, the user still has the option to close the Advanced Scenarios window and access the Advanced Model Output window through the Advanced Models drop-down menu on the Wetbud home screen.

Step 11, the final step, is performed in the Advanced Model Output window:

11. In the Advanced Model Output window, import results and generate charts in the output display tabs. Use these tabs, and the additional tools provided in the Advanced Model Output window, to view and/or export results.

Important: The preparations and steps listed above should lead the user to a successful Advanced Model simulation for their site. However, the results of all successful simulations should be interpreted with caution.

It is crucial to note that, while a successful simulation means that the model is computationally sound, it does not signify the last step of using an Advanced Model to characterize a planned or existing wetland site. In many cases, the initial model output may not be an accurate representation of reality.

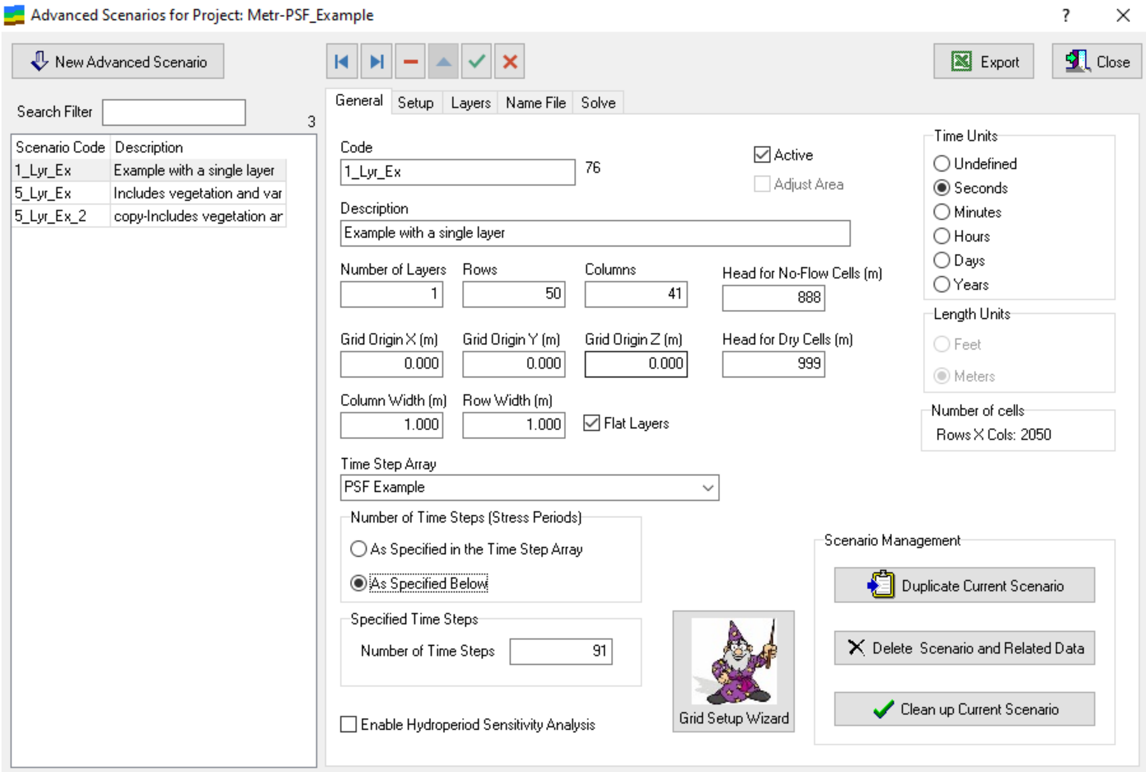
Thus, model calibration techniques coupled with professional judgment should be employed over multiple model runs before placing confidence in Advanced Model simulation output. The user may want to consult Stone (2017) for detailed description of the overall calibration and validation of an Advanced Model for an actual field location.

10.1.2 General Tab

Begin your Advanced Scenario setup in the General tab.

1. First, click 

. The box under Code is now filled with default text. Delete this text and replace it with a code (10-character limit) of your choice. Do not include spaces in this code. Next, click  to save. You will now see the code you entered for your Scenario in the box on the left side of the window.
2. Setting up the finite difference grid can be accomplished two ways, by manually assigning the Number of Layers necessary to accurately represent the site strata, the number of Rows and Columns for the finite difference grid, and the Column Width and Row Width for cells within the grid, or by using the Grid Setup Wizard. Be sure to check the Flat Layers checkbox if all model layers will be flat. For more information about having Wetbud generate a finite difference grid, see the Grid Setup Wizard portion of this section.

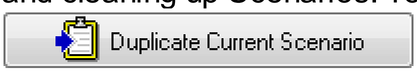


> **Note:** Column and row widths should be based on the unit of length selected in the Length Units section of this tab. If the Flat Layers box is checked in the General tab, the Flat Layers checkbox must be checked for every layer created in the Layers tab. If the Flat Layers box is unchecked in the General tab it must also be unchecked for every layer created in the Layers tab and the user must then import or manually assign top and bottom elevations for each layer created in the Layers tab.

The size of the grid is based on the size of the modeled site and the desired spatial detail of the model results. Grid Origin X, Grid Origin Y, and Grid Origin Z are used when elevations are imported from outside sources. These values should be set to correspond with the XYZ origin of the points to be imported (default origin coordinates of 0, 0, 0 are recommended).

1. In the Time Units and Length Units sections, choose a time unit and a length unit that will be used for every input and output within the Advanced Scenario model. Once model units have been designated, all values input into the model need to correspond to these units. English Projects will have units of feet; metric Projects will have units of meters. For example, if the user chooses units of meters for length and seconds for time, cell size (e.g., row and column width) will need to be in meters and time steps data will need to be in seconds. For this example, any rates input into the model would need to be in meters per second.
2. Select the Time Step Array to be used in the model calculations from the Time Step Array drop-down list.
   Note: A Time Step Array must be created within the selected Project prior to selecting it from the drop-down list.

3. Next, in the Number of Time Steps section, specify the number of time steps to be included in the Advanced Model calculations. If the As Specified in the Time Step Array option is selected, then model calculations will include data for all time steps in the selected Time Step Array. If the As Specified Below option is selected, the user must then specify the number of time steps in the selected Time Step Array they wish to include in model calculations in the Number of Time Steps box (default = 1). For example, if the Time Step Array selected from the drop-down list contains a total of 365 time steps, but the user only wants to include the first 15 time steps in the model calculations, the user should enter ‘15’ in the Number of Time Steps box.
   Note: The As specified below option is helpful because it allows the user to use the same Time Step Array for model simulations of varying lengths. This feature is useful for adjusting the initial conditions of the model and also for troubleshooting model simulations with many time steps.
4. The user can also enable an option for sensitivity analysis using selected hydroperiods and elevations. For more info see the Hydroperiod Tab below .
5. The last two parameters to be set up within the general tab are the Head for No-Flow Cells and the Head for Dry Cells. The values placed in these boxes correspond to the values that will be displayed in the Advanced Model Output windows for cells that are defined as no flow and for cells that have gone dry within the model (default values of 888 and 999 recommended).
6. Save and proceed to the Setup tab.

General Tab Utilities
The General tab has three functions under Scenario Management: copying, deleting, and cleaning up Scenarios. To copy the current Advanced Scenario, click


. A copy of the current Scenario will appear in the Scenarios list on the left side of the window. To delete a Scenario, click


. To clean up a model, click


. This function will delete unused information from the current model such as grids and cells in non-existent layers, rows, or columns. An additional utility provided in the General tab is the ability to mark scenarios as being ‘Active.’ By checking the checkbox marked Active, the user can indicate which scenarios will be visible in the Grid Setup and Advanced Model Output windows. Limiting the number of visible scenarios within these windows reduces the possibility of altering, or interpreting, a scenario unintentionally.

Grid Setup Wizard
As an alternative to manually defining a finite difference grid, users may choose to have Wetbud define a grid from a coordinate grid file containing values unique to cells within the grid they intend to create. To use the Grid Setup Wizard, click Advanced Models on the Wetbud home screen and select Advanced Scenarios from the drop down menu, once in the General tab, click on the button shown below:

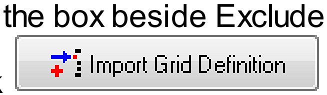
For more information see Advanced Model Grid Wizard.

10.1.2.1 Advanced Scenario Grid Wizard

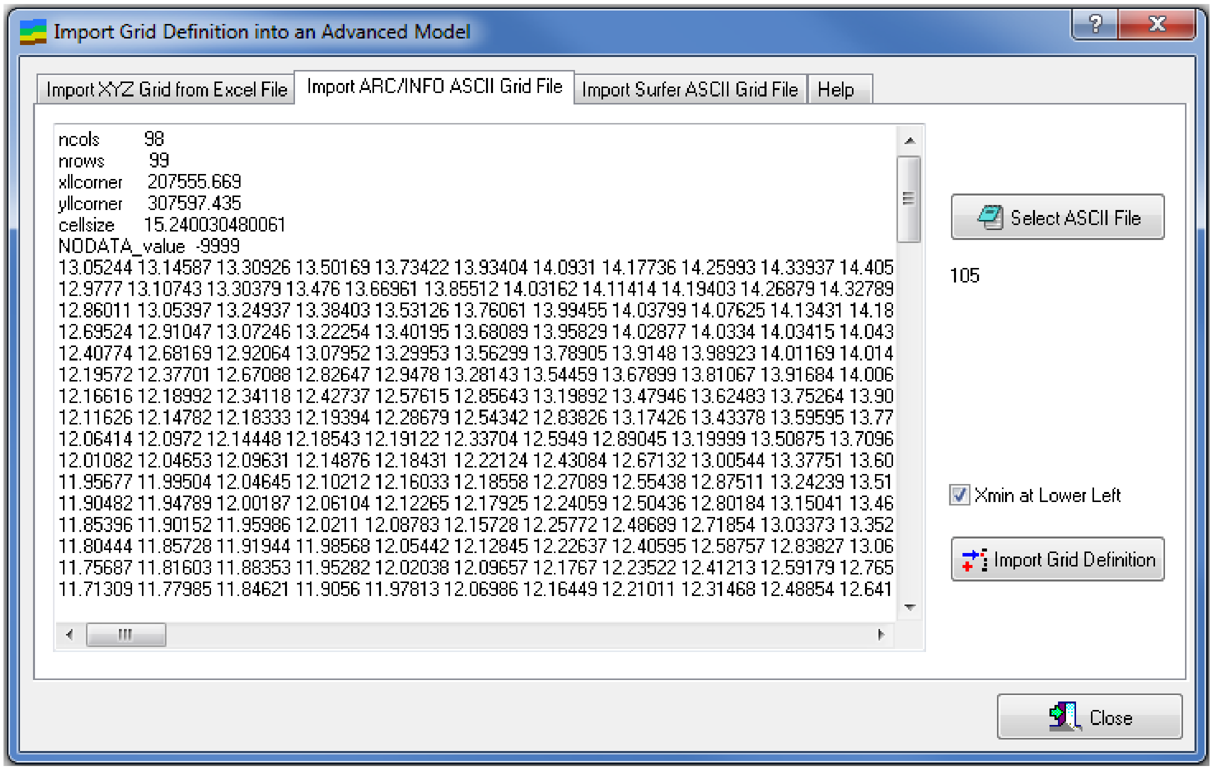
For an explanation of how MODFLOW interprets grid dimensions, see Preparing Grid Dimensions for MODFLOW below. To have Wetbud generate a finite difference grid, click the Grid Setup Wizard button within the General tab of the Advanced Scenarios window. A window will appear warning the user that executing this function will overwrite existing grid parameters, click Yes to continue. Wetbud is capable of generating grid definitions from three commonly used coordinate grid file types: XYZ Excel files, ARC/INFO ASCII text files, and Surfer ASCII text files; for information about the format needed in each of these file types in order for them to be compatible with Wetbud see the Help tab in the Import Grid Definition into an Advanced Model window.

Note: While the Grid Setup Wizard can import grid definitions from the same file that will later be used to import elevation data, the Grid Setup Wizard will not import the elevation data.

1. Select which type of file you wish to import grid definitions from by selecting the corresponding tab at the top of the Import Grid Definition into an Advanced Model window.
2. To import a grid definition from an XYZ Grid Excel File select the appropriate tab and click 

. Open the file you wish to import a grid definition from. Wetbud will populate the Import Grid Definition into an Advanced Model preview pane with the file you have selected. If the file has a header column that needs to be excluded from import, click the box beside Exclude Title Row. After verifying that your file is ready for import, click 

to have Wetbud generate a grid definition from the selected file.



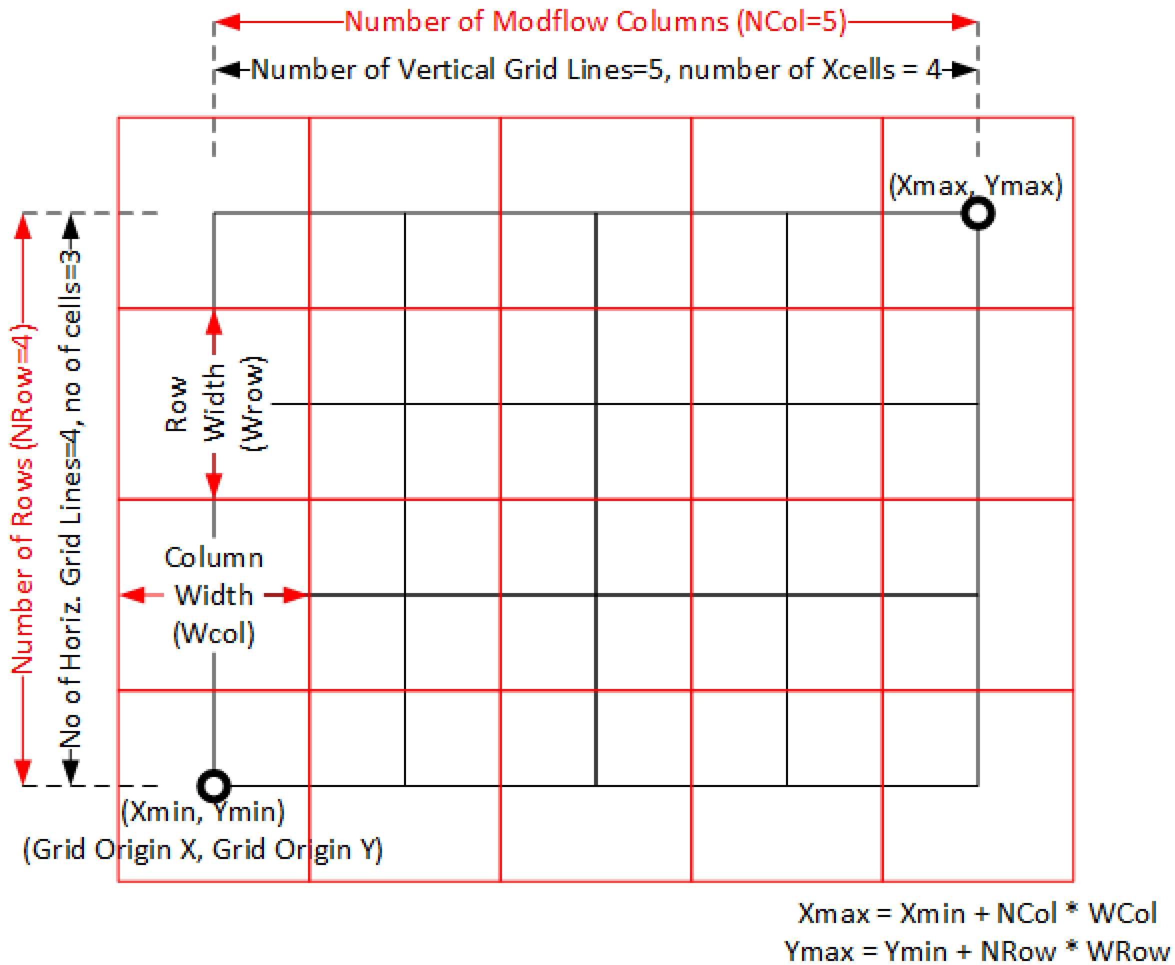
1. To import a grid definition from either an ARC/INFO ASCII Grid File or a Surfer ASCII Grid File, select the appropriate tab and click Select ASCII File. Open the file you wish to import a grid definition from. Wetbud will populate the Import Grid Definition into an Advanced Model preview pane with the file you have selected. Determine if the origin of the import grid is at the lower left corner of the preview plane, if it is click the box beside 'Xmin at Lower Left.' After verifying that your file is ready for import, click Import Grid Definition to have Wetbud generate a grid definition from the selected file.
2. After clicking Import Grid Definition, click Close to return to the Advanced Scenarios window. Notice that Wetbud has populated the Rows, Columns, Grid Origin X, Grid Origin Y, Grid Origin Z, Column Width and Row Width boxes in the Advanced Scenarios window.

Preparing Grid Dimensions for MODFLOW

When preparing to discretize an area that is to be modeled using MODFLOW it is important that one considers how MODFLOW interprets grids. MODFLOW assumes that the cell values correspond to the center of a block (block centered flow), therefore the MODFLOW grid will extend beyond the dimensions of the original grid.

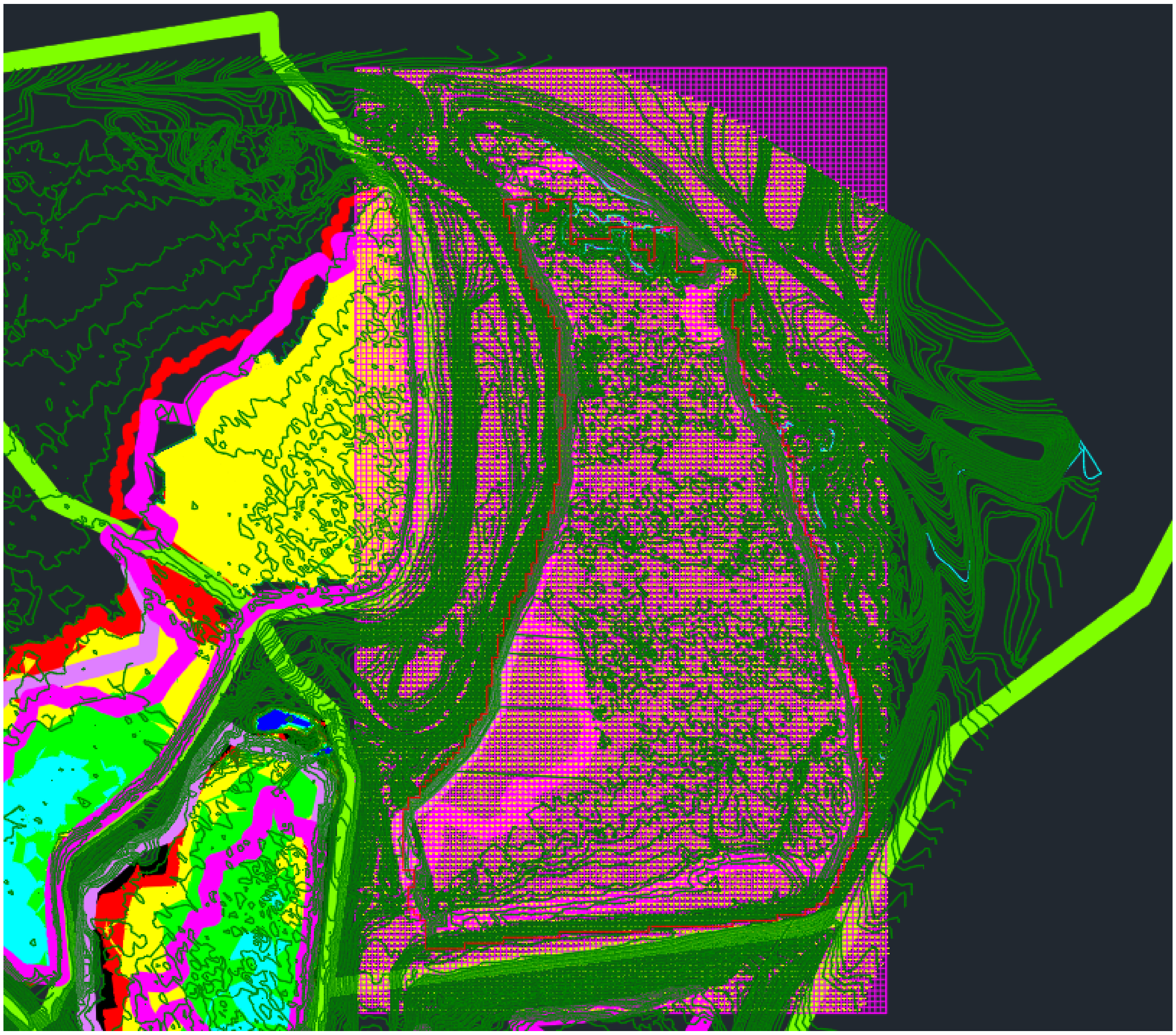
Take for example the grid shown in the figure below. The discretized study area contains five vertical grid lines (four cells) and four horizontal grid lines (3 cells), with original xmin, ymin to xmax, ymax reference points, all of which are shown in black.

Because cells interact with one another in MODFLOW based on conditions at the center of each cell, the MODFLOW grid can be interpreted as the red grid overlying the, black, discretized grid.

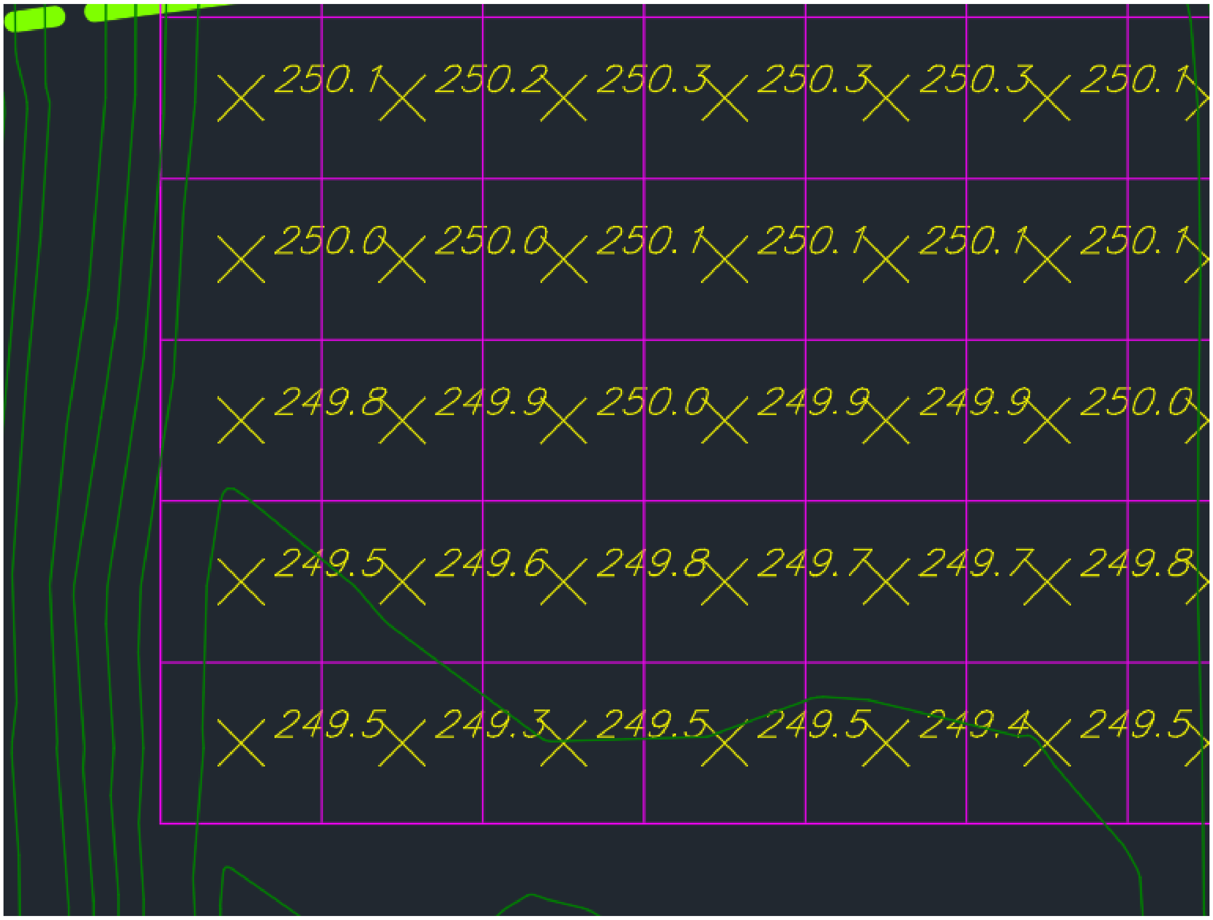


10.1.2.2 Advanced Scenario Grid Example

The figure below shows a screenshot of a CAD file of a wetland. The green lines correspond to elevation contours and the purple grid corresponds to the grid prepared for use in an Advanced Model.



The figure below shows the bottom left corner of the grid in CAD. The grid in Wetbud will assign property values at the center of each grid. Thus, the user should export the grid centers to Wetbud and not the nodes of the purple grid.

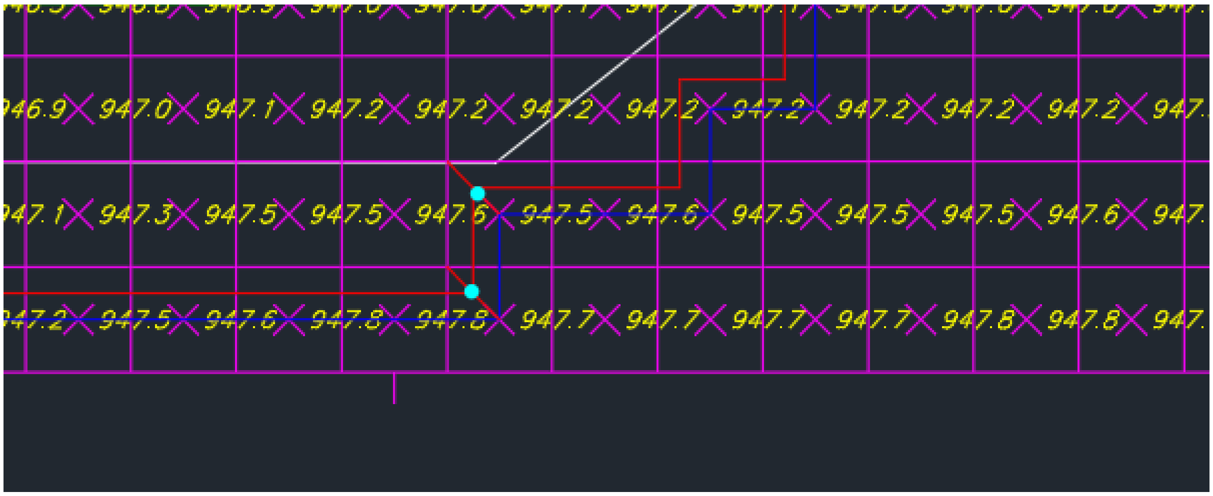


The user can also define boundary conditions in CAD, or ArcGIS, and export the closed polygons as shapefiles which can be used in Wetbud. The shapefile must have the same units as the Wetbud grid. Wetbud can assign a set of conditions to cells in the MODFLOW grid that are either inside or outside of the polygon. The example below shows how a grid could be setup in Civil3D so information can translate easily into Wetbud.

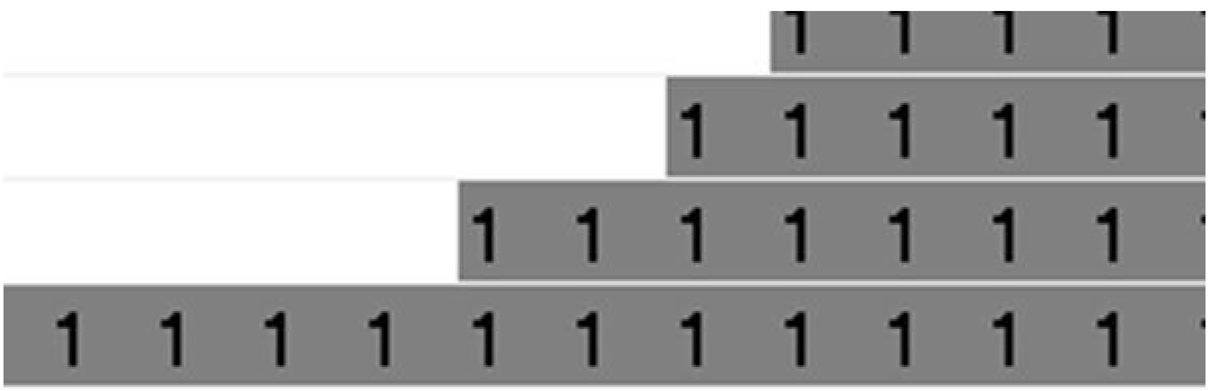
The purple X's (in the figure below) represent nodes of points with elevation values derived from the surface. In this example, the nodes are 10 ft apart and a grid has been drawn around the nodes with cells that are 10 ft x 10 ft. The white line represents the edge of the cells that are to be active during simulations. A No Flow boundary will be applied outside of the white, along the blue line. Note that the blue line has been drawn at right angles as MODFLOW calculates flow through adjoining faces of cells.

A red line has been drawn between the nodes of the cells, depicted by the blue line, (blue line for visual aide only, blue line connects the nodes of cells that will become No Flow cells in the model) and the nodes of the purple grid. The line is placed between the nodes of the grid and the nodes of the cells to avoid rounding errors that may occur by selecting discrete points. The red line can be exported as a shapefile (*.shp, with 2D data) and imported into Wetbud. The red line continues off-screen and is closed to the northwest. When importing into Wetbud the user will have two options:

- Apply to Cells Outside Boundary Line: The shapefile (red line) is used to create a polygon that would define cells outside the boundary. In the example below, cells with center points (nodes) outside of the red line (south and east in the image) would have the selected conditions applied to them. This application could be useful when discretizing the No Flow boundary along the perimeter of the model.
- Apply to Cells Inside Boundary Line: The shapefile (red line) is used to create a polygon that would define cells inside the boundary. In the example below, cells with center points (nodes) inside of the red line (north and west) would have the selected conditions applied to them. This application could be useful when discretizing soil units in the model.



The figure below shows the result in Wetbud when the shapefile representing the red line is used to apply conditions outside of the boundary line for the corresponding area in the model:



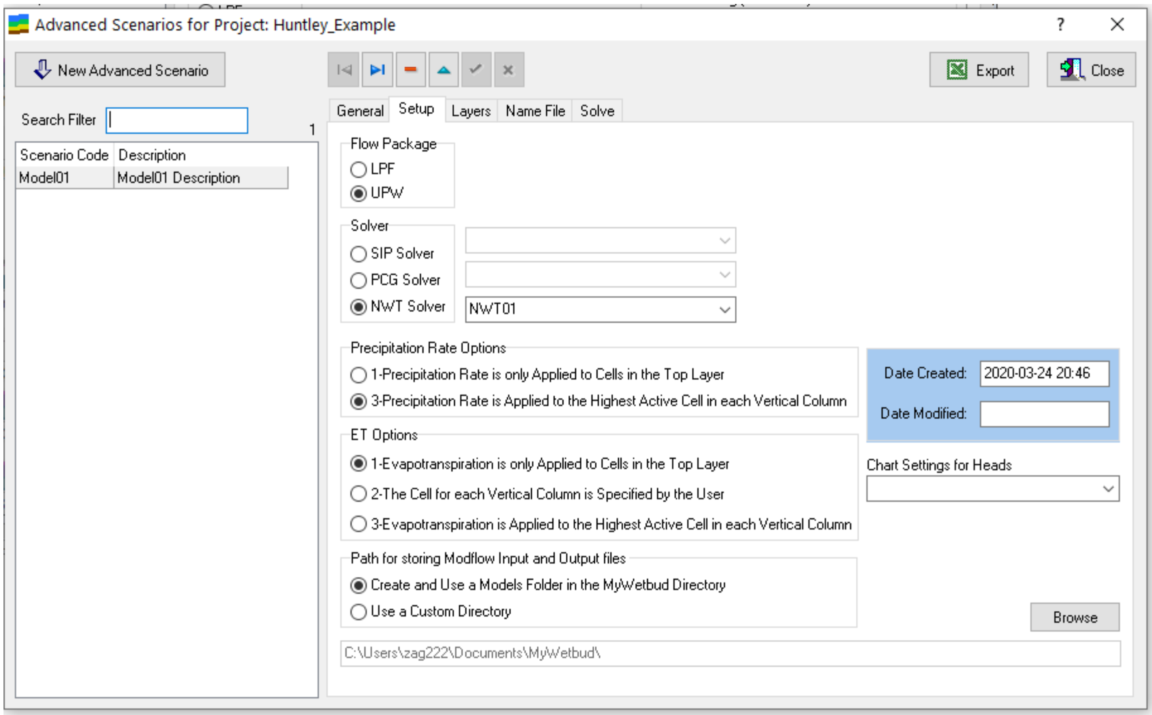
Selected Implementation steps

- The user can export the grid into an XYZ file and Wetbud can import an XYZ to define the grid for an Advanced Model (see Advanced Model Grid Wizard).

- The user can export a noflow boundary as a shapefile and then import it into Wetbud for delineating a noflow zone (see Advanced Grid Setup - Cell Zones for more information).

10.1.3 Setup Tab

The Setup tab is used to assign the model Flow Package, model Solver, Precipitation Options, ET Options, Chart Settings for Heads, and the Path for Storing MODFLOW Input and Output files.



Flow Package

When using the NWT solver (see below), it is recommended that the UPW (Upstream-Weighting) Flow Package is used, therefore Wetbud supports the UPW package. When the UPW flow package is used, Layer Type and Interblock Transmissivity (LPF) do not need to be specified by the user in the Layers tab. These options remain in the interface as Wetbud used to support the LPF (Layer Property Flow) Flow Package and the SIP and PCG Solvers

More detailed information on the different available MODFLOW flow packages can be found through the USGS software package website at https://water.usgs.gov/ogw/modflow/MODFLOW-2005-Guide/index.html?ground_water_flow_packages.htm

Solver

Wetbud currently supports one MODFLOW solver package: the NWT (Newton) package. The user can define multiple instances of the solver package with different parameters.

Notes:

- The user must create a solver data set that pertains to the selected solver prior to selecting a solver data set from the corresponding drop-down list. See the Solvers section in Advanced Parameter Setup 3 – Time Steps and Solvers for instructions on creating a Solver Set and detailed information about solver packages available in Wetbud. More detailed information on the different available MODFLOW solvers can be found through the USGS software package website https://water.usgs.gov/ogw/modflow/MODFLOW-2005-Guide/index.html?solvers.htm.
- Both the MODFLOW-NWT and the MODFLOW-2005 models also have online guides available through USGS.
- See also Deprecated Features for solvers that were previously supported by Wetbud.

Precipitation Options

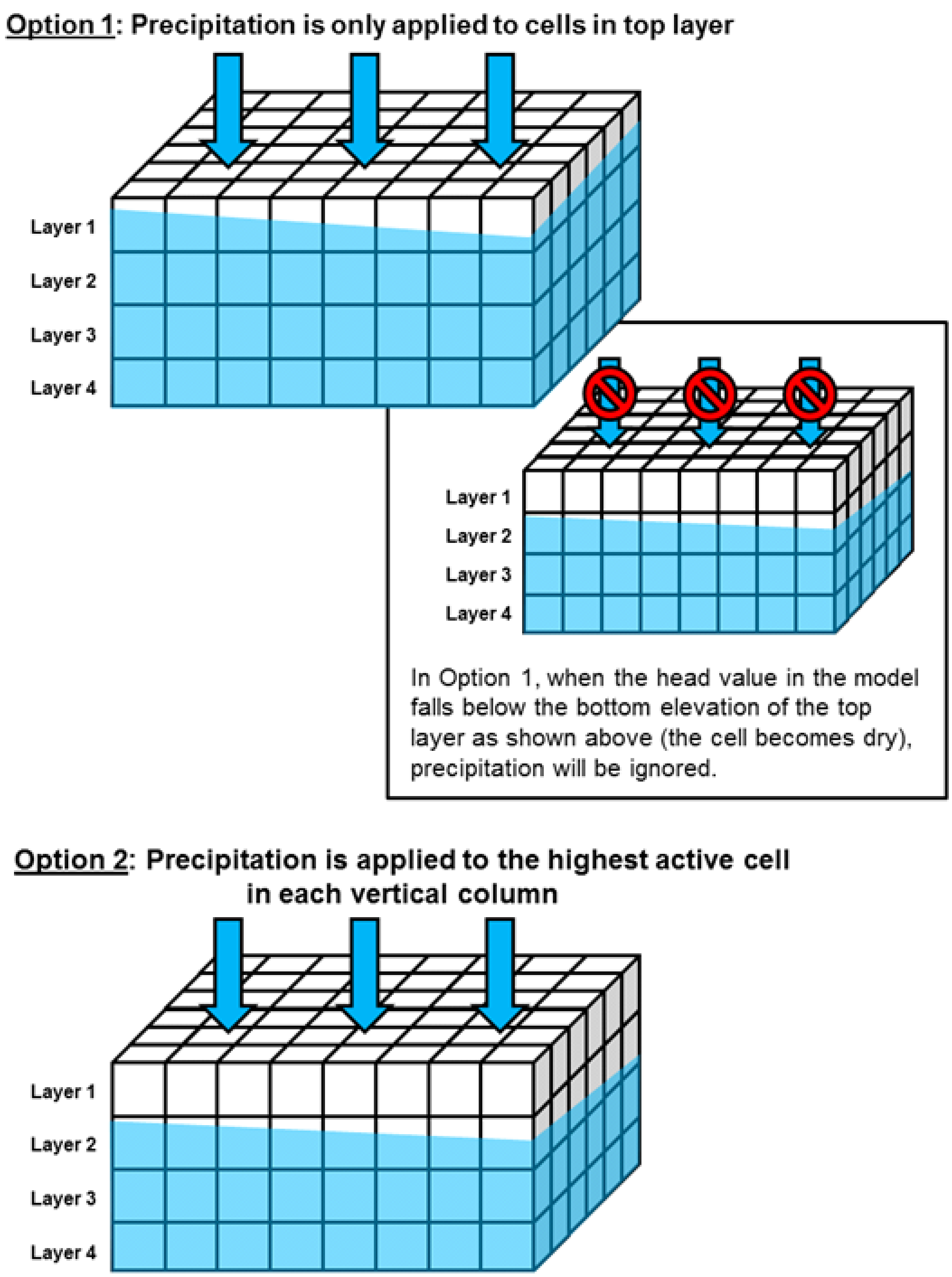
Precipitation is defined as water that enters the model from above during the simulation period. For the Advanced Model, the precipitation rate (length/time) is utilized as input. Precipitation rate can easily be calculated from daily or monthly precipitation values in a weather station data set.

In the Setup tab, precipitation options are used to specify the exact manner in which precipitation rate grid zone data are applied to cells in the model grid. The precipitation rate values for each time step are defined in the Time Step Array data column (Precip Rate 1 or Precip Rate 2) assigned to the precipitation rate grid zone in the Advanced Model grid (see Advanced Parameters 2 – Grid Zones). The Time Step Array must also be assigned to the current Scenario in the General tab of Advanced Scenario setup (see General Tab in Advanced Scenarios). For information about setting up a Time Step Array see Advanced Parameters 3 – Time Steps and Solvers.

Note: During Advanced Grid setup, users are only required to assign precipitation rate Grid Zones to layer 1. However, the precipitation option selected in the Setup tab (see figure above) will dictate the manner in which precipitation enters cells in all layers of the model grid.

The first option, Precipitation is only Applied to Cells in the Top Layer, allows precipitation to enter cells in the top layer only, as shown in Option 1 in the figure below. If this option is selected, the time step data column (e.g., Precip Rate 1 or Precip Rate 2) assigned to the precipitation rate grid zone is only permitted to enter into the top layer. When the head value in the model falls below the bottom elevation of the top layer (i.e., the cell becomes dry), the precipitation will be ignored.

The second (and recommended) option, Precipitation is Applied to the Highest Active Cell in each vertical Column, allows precipitation to enter the uppermost variable-head cell in each vertical column (Option 2 in the figure below). This option is useful for sites that have a sloping or non-uniform water table surface.



ET Options

In the Setup tab, evapotranspiration (ET) options are used to define how water is withdrawn from the model due to ET. The ET Option should be chosen based on the model design and the ET extinction depth of surface vegetation.

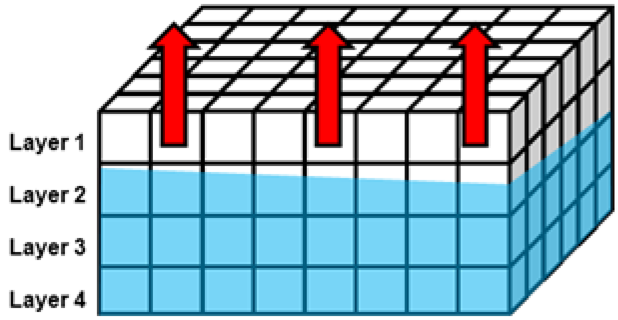
Note: During Advanced Grid setup, users are only required to assign ET Grid Zones to layer 1. However, the ET option selected in the Setup tab will dictate the manner in which ET is withdrawn from cells in all layers of the model grid.

In the first option, Evapotranspiration is only Applied to Cells in the Top Layer, the ET in the Time Step Array is always withdrawn from the uppermost layer of the model. Users should choose this option if the effects of ET are negligible at depths below the surface layer (layer 1) in the model.

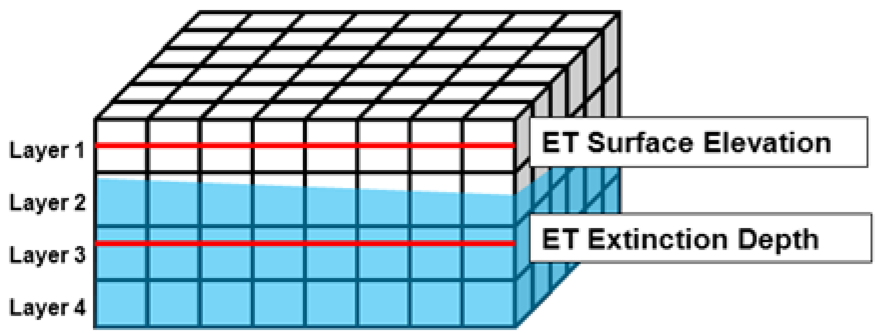
In the second option, The Cell for each Vertical Column is Specified by the User, the user defines the elevation in each active cell where maximum ET will begin by importing an ET surface elevation data set for layer 1 (see Assigning Layer Top Elevation, Bottom Elevation, and ET Surface Elevation in Setting Up an Advanced Scenario).

In the third option, Evapotranspiration is Applied to the Highest Active Cell in Each Vertical Column, the ET surface is defined as the highest variable head cell in each vertical column (Harbaugh, 2005). The highest variable head cell will vary based on the water table elevation throughout the modeled period.

Option 1: Evapotranspiration is only applied to cells in the top layer: ET will only be withdrawn from cells containing water in the first layer; if this option is selected, then no ET extinction depth need be assigned. In this option, if cells in the first layer are dry (as shown below), then no ET is withdrawn.



Option 2: The cell for each vertical column is specified by the user: The user defines the elevation in each active cell where maximum ET will begin by importing an ET surface elevation dataset for layer 1.



Option 3: Evapotranspiration is applied to the highest active cell in each vertical column. ET Surface Elevation is automatically set to highest active cell in each vertical column and will vary based on head elevations.

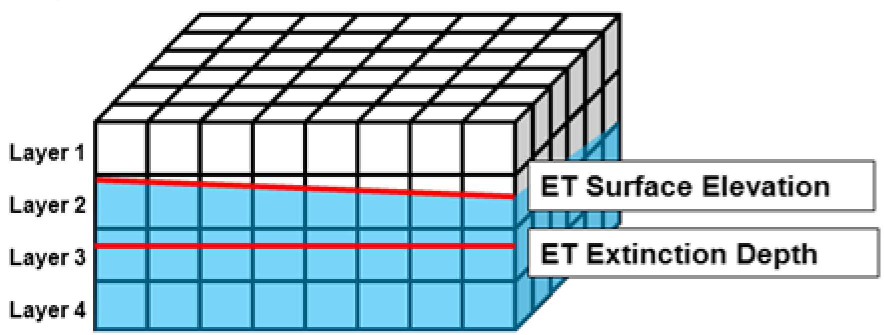


Chart Settings for Heads

The user must select the Chart Settings data set that applies to the current Scenario in the Setup tab. The settings in the selected file will be used by Wetbud when displaying graphs in Advanced Output. See Charting Options for instructions and information about creating a Chart Formatting data set.

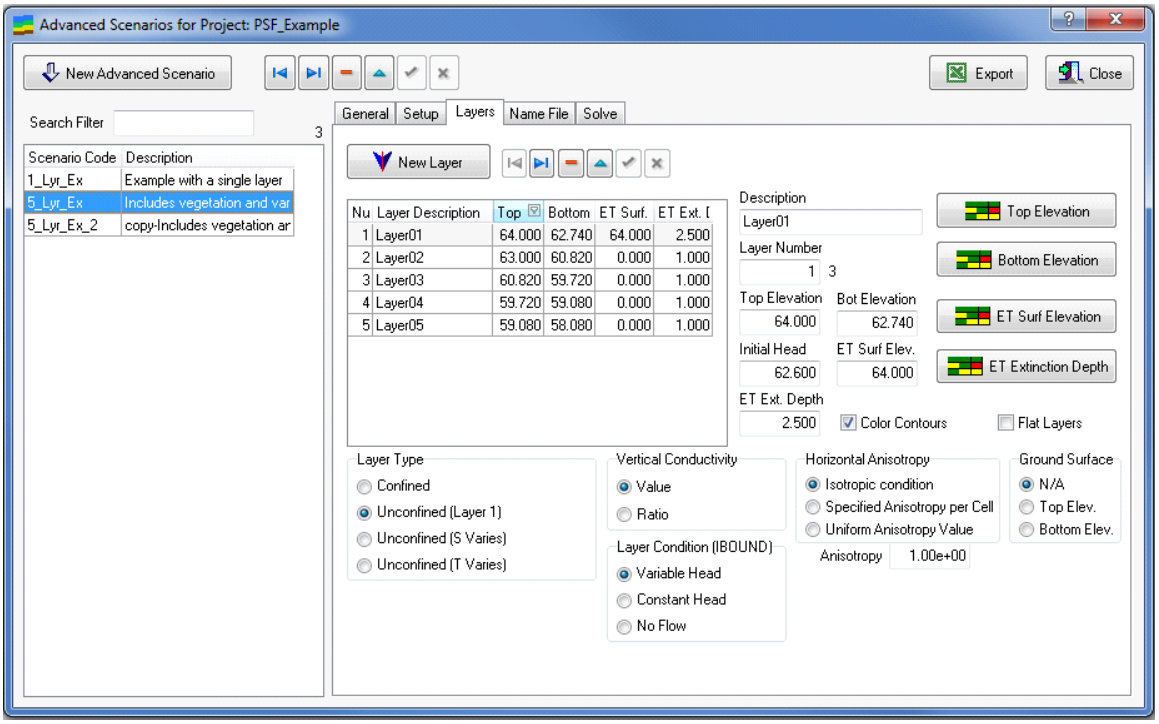
Path for Storing MODFLOW Input and Output Files

Under Path for storing MODFLOW Input and Output files in the Setup tab, the user must designate the location in which Wetbud will store the input and output files generated for the current Advanced Scenario. The default option for storing MODFLOW Input and Output files is to have Wetbud automatically create a folder for the files in the MyWetbud directory. However, users have the option to specify a custom directory as well by selecting Use a Custom Directory and then using the Browse button to choose the desired location for storing input and output files.

10.1.4 Layers Tab

The Layers tab is used to create and define layers in the Advanced Scenario model grid. The number of layers created in this tab must be equal to the number of layers specified in the General tab.

Note: There is no limit to the number of layers that can be included in the model grid. However, models containing more than five (5) layers may have convergence issues in model simulation if layer properties (e.g., hydraulic conductivity, specific storage, etc.) contain a wide range of values (differences of several orders of magnitude).



Note: Controls unique to the LPF flow package (Layer Wetting, Wetting Threshold, and Interblock Transmissivity) will only be visible in the Layers tab when LPF is selected under Flow package in the Setup tab of the Advanced Scenarios for Project window.

Creating Layers in an Advanced Scenario

To create a new layer, click 

. Next, enter a Description (e.g., soil type) and a Layer Number, where layer number 1 is the uppermost (surface) layer. Click the  button in the Layers tab to save the layer. Each new layer must then be assigned a Top Elevation, Bottom Elevation, ET Surf Elevation (ET surface elevation; for Layer 1 only), ET Extinction Depth (ET extinction depth; for Layer 1 only), and Initial Head.

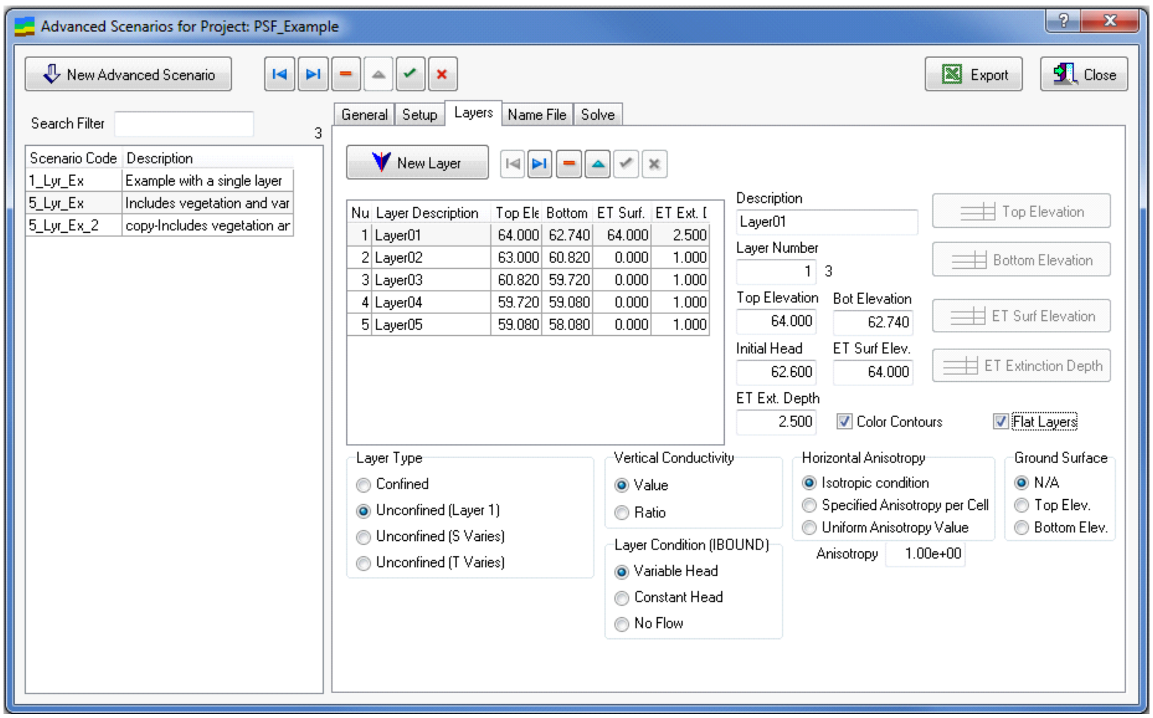
Note: Layer top and bottom surfaces, ET surface elevation, and ET extinction depth within the model grid can be flat, uniformly sloping, or contain variable elevations for each cell. These options are explained in the next section.

Next, choose the appropriate option for layer wetting, wetting threshold (LPF only), horizontal anisotropy, layer type, layer condition, and interblock transmissivity (LPF only) to characterize the layer in MODFLOW calculations. All of these options are described in their respective sections below.

Assigning Layer Top Elevation, Bottom Elevation, ET Surface Elevation, and ET Extinction Depth

In Wetbud, layer top and bottom surface elevation, ET surface elevation, and ET extinction depth within the model grid can be flat, uniformly sloping, or contain variable elevations for each cell. Layer grid elevations can also be manipulated using the additional layer grid tools. The procedure to implement these elevation options in layers of the model grid are as follows:

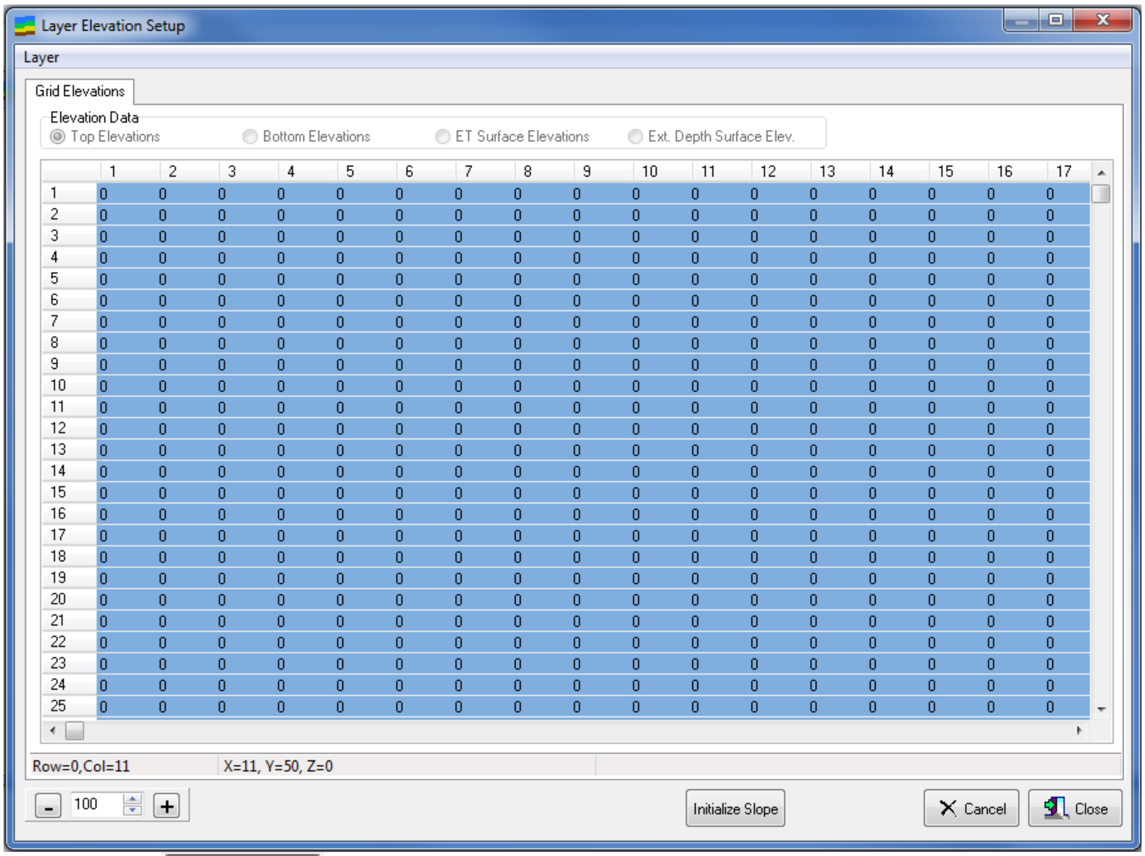
1. Flat Layers - If the user wants flat layers, the Flat Layers checkbox must be checked in the General tab and for each layer created in the Layers tab. Once the Flat Layers checkbox is checked, the buttons for Top Elevation, Bottom Elevation, ET Surf Elevation (surface elevation) and ET Extinction Depth will be inactive. When this option is selected, the values entered in the Top Elevation, Bottom Elevation, ET Surface Elevation, and ET Extinction Depth boxes will be applied to every cell in the model grid for the selected layer.



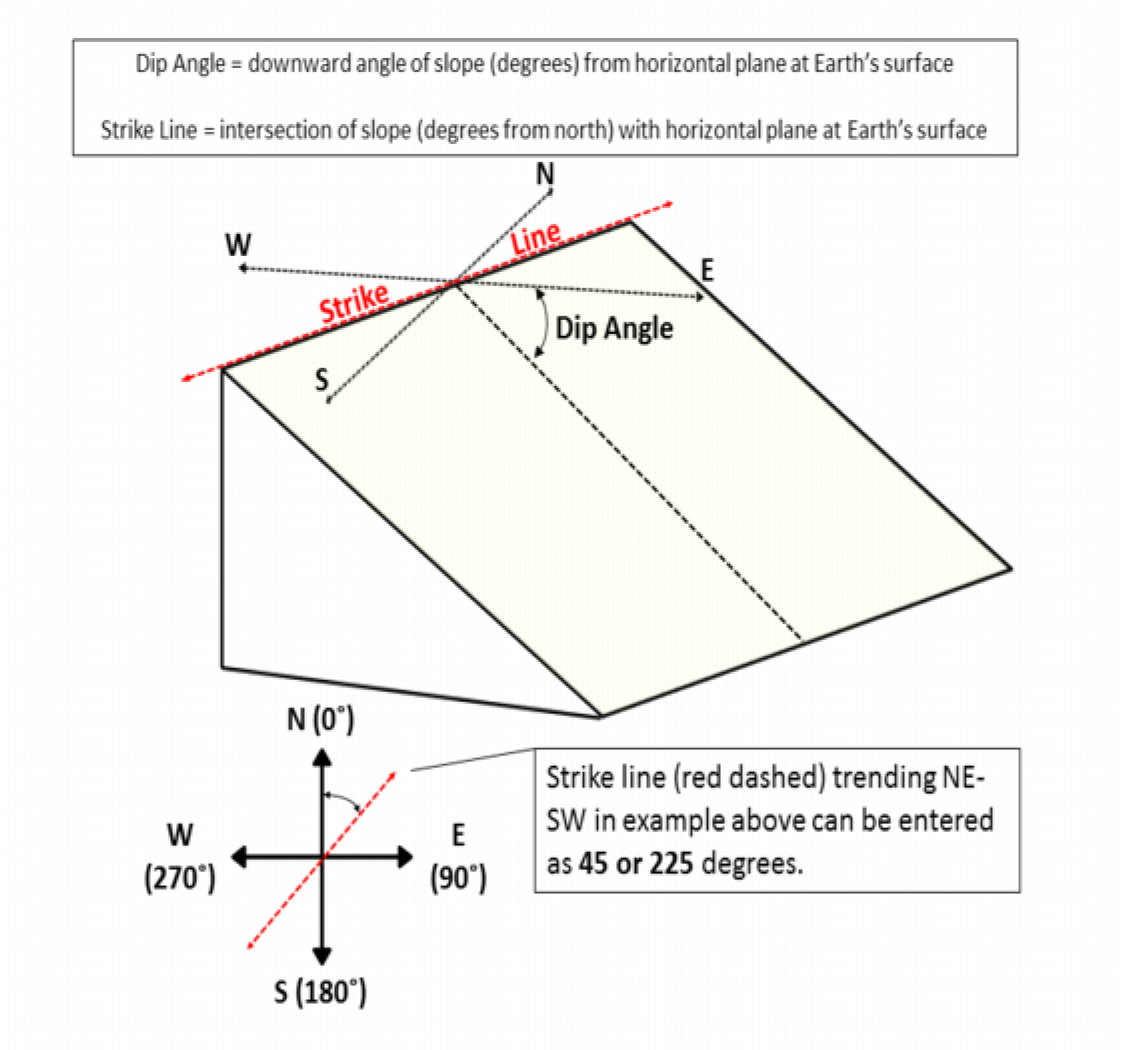
2. Sloping Layers - To generate a uniformly sloping surface for Top Elevation (layer 1 only), Bottom Elevation, ET Surf Elevation. (layer 1 only), or ET Extinction Depth (layer 1 only) for a selected layer:
   a. For the selected layer, enter the values for Top Elevation (uppermost top elevation in selected layer), Bot Elevation (lowermost bottom elevation in selected layer), ET Surf Elev. (uppermost ET surface elevation in selected layer; usually same as top elevation of layer 1), and ET Ext. Depth (depth from surface at which ET becomes zero or approximate depth of root extent) in their respective boxes.
   Note on top and bottom elevation: The bottom elevation of cells in the layer above will automatically be assigned as the top elevation of cells in the layer immediately below.
   Note on ET surface elevation and ET extinction depth: Although ET surface elevation and ET extinction depth can only be entered when layer 1 is selected,

the ET surface elevation and/or ET extinction depth do not have to fall within the top and bottom elevation range for layer 1.

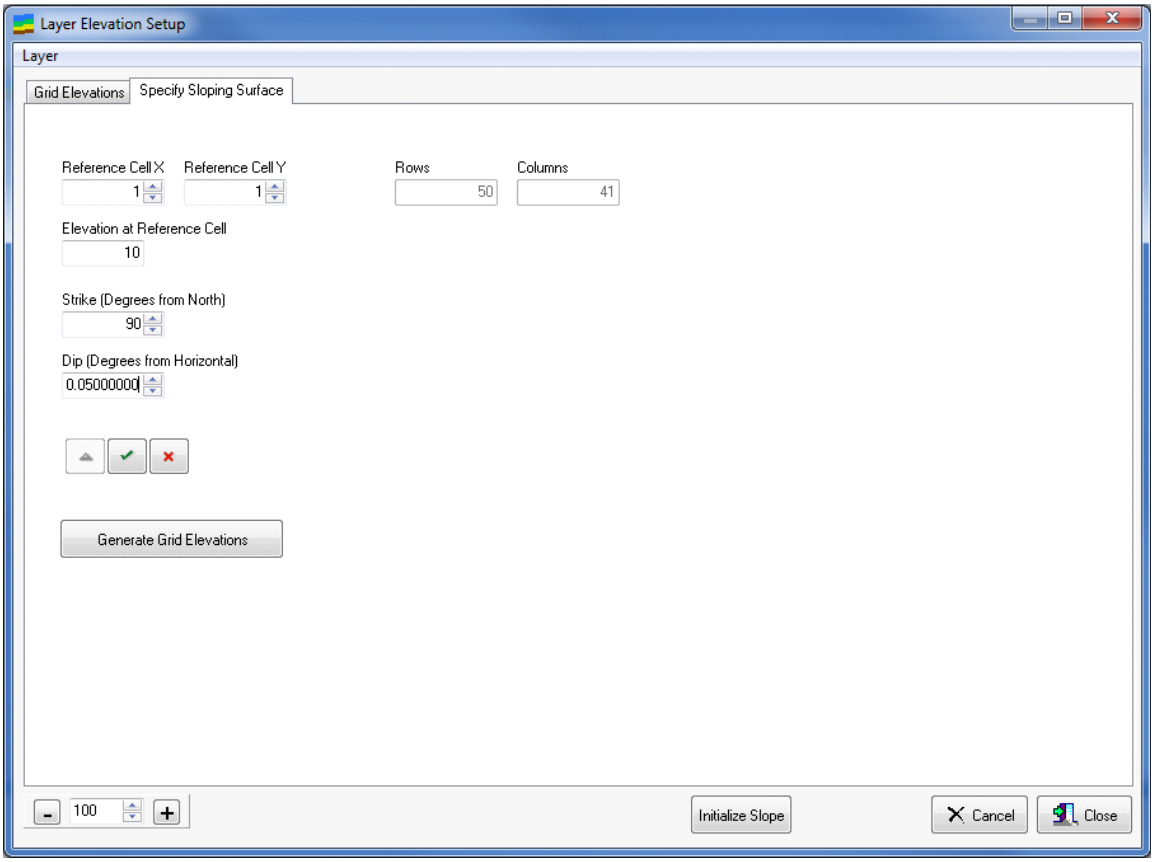
b. Next, click the button (Top Elevation, Bottom Elevation, ET Surf Elevation, ET Extinction Depth) that pertains to the parameter you wish to create a sloping surface. (Note that the Top Elevation, ET Surf Elev., and ET Extinction Depth buttons will only be active for layer 1.) The Layer Elevation Setup window will appear.



c. Click Initialize Slope to display the Specify Sloping Surface tab. Specify the grid location and elevation of the reference cell from which the sloping will begin in the Reference Cell X (column number), Reference Cell Y (row number), and Elevation at Reference Cell boxes, respectively. Next, assign the slope aspect in the Strike (Degrees from North) and Dip (Degrees from Horizontal) boxes. See the figure below for illustration and definitions for strike and dip.



d. Click to save and then click Generate Grid Elevations. The Grid Elevations tab will automatically appear with color contoured elevation data generated for the sloping surface.
e. Close the Layer Elevation Setup window.



3. Variable Elevation Layers - To assign variable Top Elevation (layer 1 only), Bottom Elevation, ET Surface Elevation (layer 1 only), or ET Extinction Depth (layer 1 only) for a given layer, users must import the elevation (or ET extinction depth) data into the model grid from an Excel spreadsheet, Excel XYZ file, ARC/INFO ASCII grid file, or a Surfer ASCII grid file using the import tool in the Layer Elevation Setup window. Wetbud automatically assigns the bottom elevations for the cells in the layer above as the top elevation of cells in the layer below. For example, the values assigned as bottom elevations for cells in layer 1 are automatically the values for top elevation for the layer 2 cells directly below each cell. This is a fixed default in Wetbud designed to avoid elevation conflicts for adjacent cells in the model. Elevations will need to be set up for all layers within a model that are not specified as flat.
   a. For the selected layer, enter the values for top elevation (uppermost top elevation in selected layer), bottom elevation (lowermost bottom elevation in selected layer), ET surface elevation (uppermost ET surface elevation in selected layer; usually same as top elevation of layer 1), and ET extinction depth (depth from surface at which ET becomes zero or approximate depth of root extent) in their respective boxes.
      Note about the top and bottom elevation: The bottom elevation of cells in the layer above will automatically be assigned as the top elevation of cells in the layer immediately below.
      Note about the ET surface elevation and ET extinction depth: Although ET surface elevation and ET extinction depth can only be entered when layer 1 is

selected, the ET surface elevation and/or ET extinction depth do not have to fall within the top and bottom elevation range for layer 1.

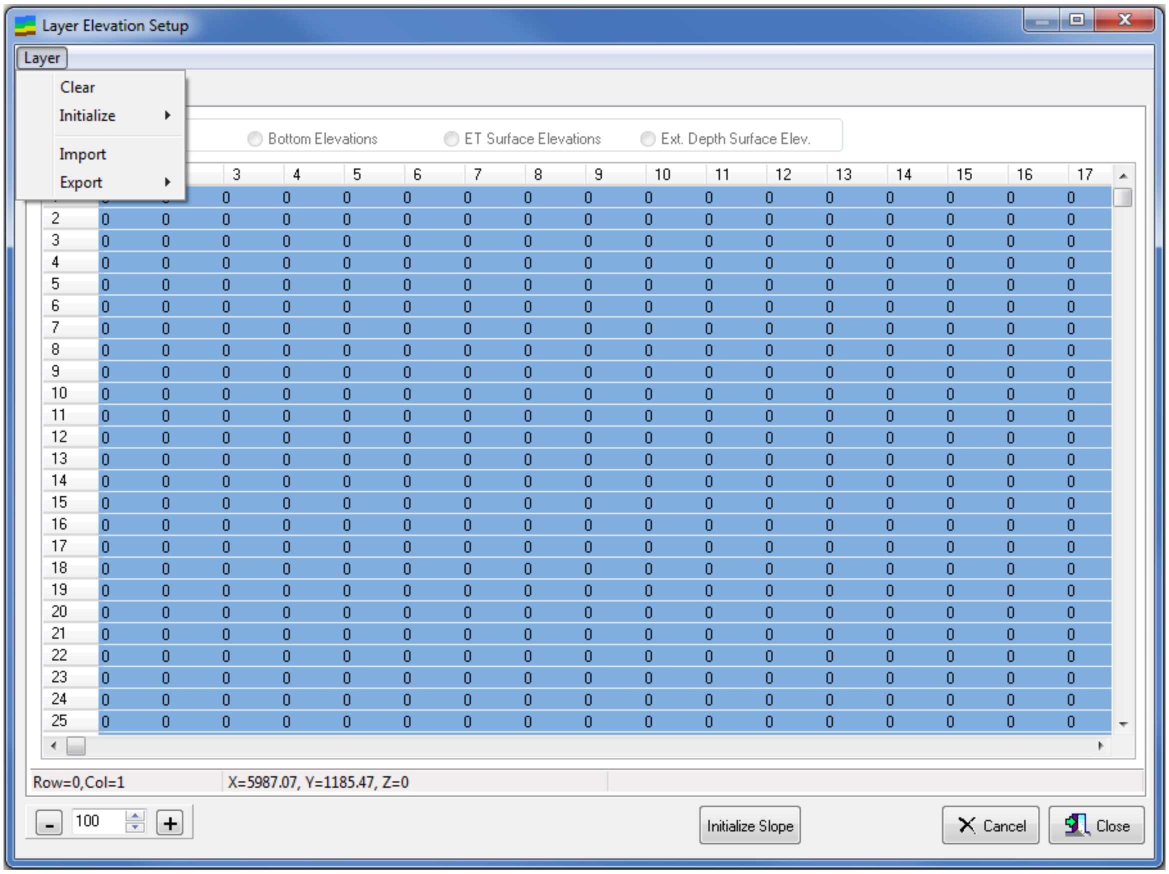
b. Next, click the button (Top Elevation, Bottom Elevation, ET Surf Elevation, ET Extinction Depth) that pertains to the parameter you wish to import elevation (or ET extinction depth) data.
Note: The top elevation, ET surface elevation, and ET extinction depth buttons will only be active for layer 1.

c. The Layer Elevation Setup window will appear. In this window, the options pertaining to the selected elevation data set button (e.g., top elevation, bottom elevation, ET surface elevation) will appear as the 'greyed-out' selection in the Elevation Data section. The grid that appears in this window will be the same dimensions (e.g., number of rows and columns) as specified in the General tab. Once the user populates the grid, the number within each cell in the grid corresponds to its elevation in that layer (at first, all cells in the grid will appear as having an elevation of '0'). If Top Elevation is selected, the number within each cell corresponds to the top elevation of each cell in the selected layer. If Bottom Elevation is selected, the number within each cell corresponds to the bottom elevation of each cell in the selected layer. If ET Surf Elevation is selected, the number within each cell corresponds to the highest elevation in each cell from which the model can withdraw water due to evapotranspiration (ET values are assigned in Time Step Array). If ET Extinction Depth is selected, the number within each cell corresponds to the depth from the ET surface that evapotranspiration will extend before reducing to zero. See Advanced Parameters 3 – Time Steps and Solvers).

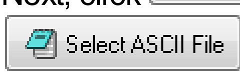
Notes about the ET Surface Elevation: The ET Surf Elevation button will only be active for layer 1. The ET surface elevation data set can only be applied by choosing option number 2 (The cell for each vertical column is specified by the user), in the ET Options section of the Setup tab. The ET surface elevation is a useful function for users whose surface layer is vegetation that extends above the ground surface. Users can then assign the ET surface elevation to the elevation of the actual ground surface.

1. To begin populating the model grid with variable elevation data, choose the Import option from the Layer drop-down menu of the Layer Elevation Setup window. The Import option allows the user to import variable elevation (or ET extinction depth) data for the selected layer from a spatial grid in an Excel Spreadsheet, an Excel XYZ grid, an ARC/INFO ASCII grid, or a Surfer ASCII grid into Wetbud. The origin of the XYZ coordinates should be set up in the General Tab.
   Note about layer elevation import: It is recommended that the top elevations of Layer 1 be imported first in order to avoid receiving error messages stating that the bottom elevation is greater than the top elevation of the layer. Wetbud automatically checks bottom elevations against top elevations to ensure MODFLOW will be able to run using the imported elevations.
2. To begin importing layer elevations from an Excel file:
   a. First select Import from the Layers menu, which will display the Import Layer Elevations window. The Import Layer Elevations window has four import options: Import Wetbud Grid from Excel, Import XYZ Grid from Excel, Import ACRC/INFO

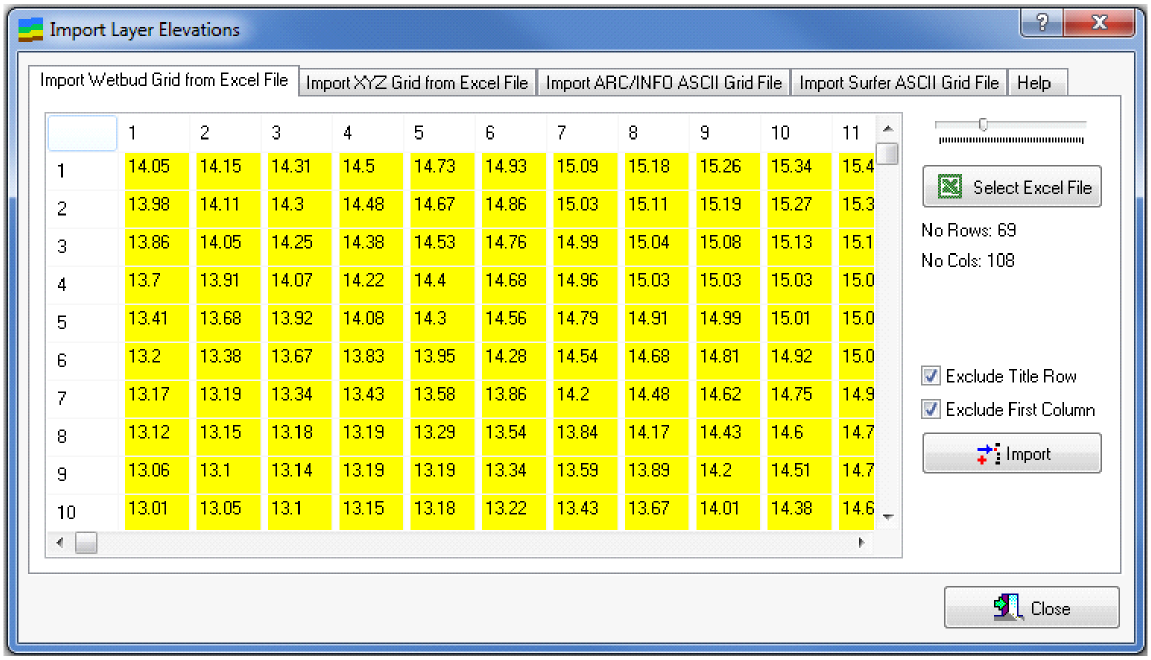
ASCII Grid File, and Import surfer ASCII Grid File. Select the tab that applies to the type of file from which elevation data will be imported.



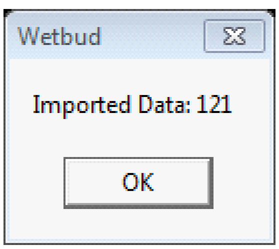
b. Next, click 

if importing from an Excel format, or click 

if using one of the ASCII formats, and select the file that contains the elevation data set. After selecting the file, the elevation values from the selected file will be displayed in the preview pane. The number of rows and columns, or lines for ASCII files, in the file will be displayed on the right side of the window. The Title Row and/or First Column in the file can be excluded from Excel files by checking their respective boxes in the Import Layers Elevations window.



4. Verify the elevation values and dimensions (e.g., number of rows and columns) being displayed in the grid are correct and click  to import the file. Click 'OK' from the prompt that appears. The number that follows 'Imported Data: ##' is the total number of cells for which elevation data has been imported. This number should be the total number of cells in the selected layer in model grid.



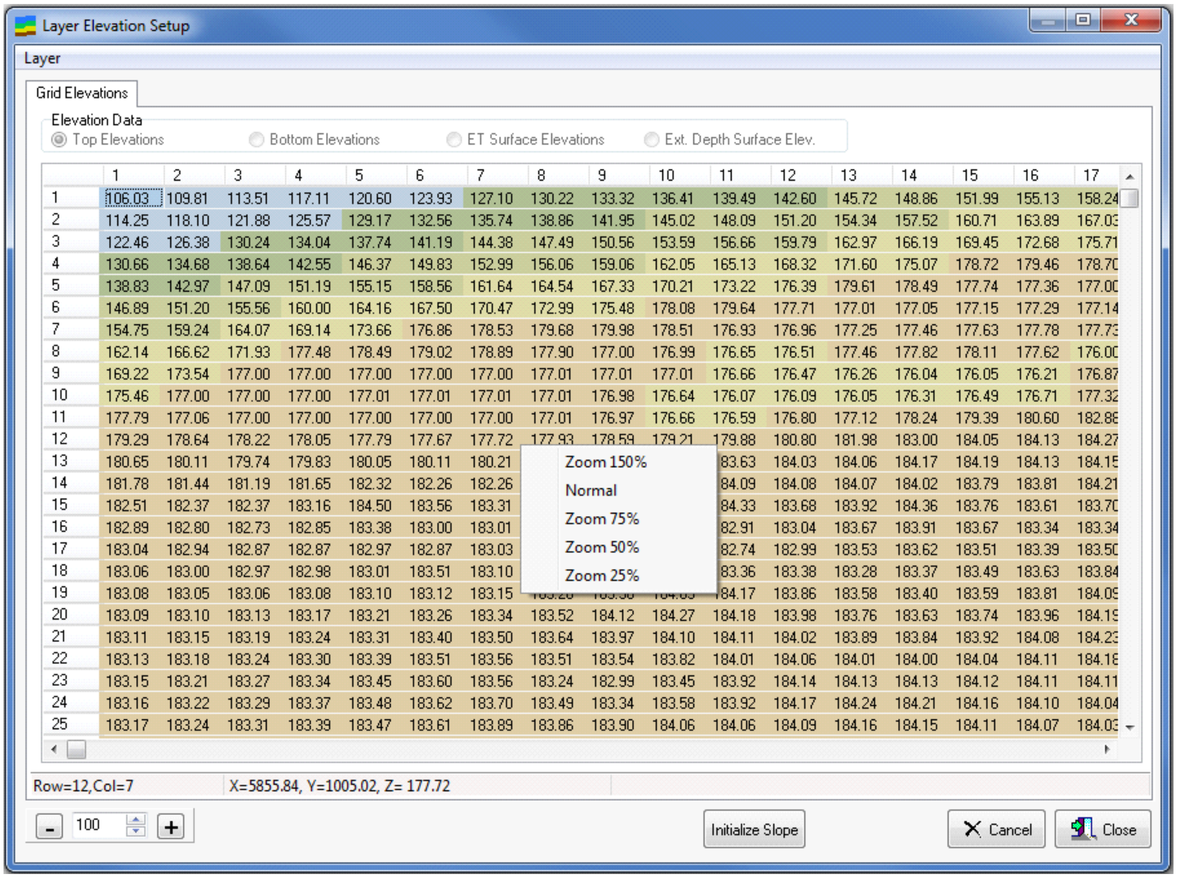
Imported Data Prompt for Elevation Data File Import

Exit the Import Layers Elevations window to view the imported elevation data grid. The imported elevation data will be displayed in the MODFLOW Layer Elevation Setup window as a color contoured grid after closing the Layer Elevation Setup window and opening it again. Color contours will not be displayed if Color Contours box is unchecked the in the Layers tab of the Advanced Scenarios window. There are multiple options for controlling the zoom of the MODFLOW Layer Elevation Setup window. The user can control the zoom with the  and  buttons, the  buttons, or by entering a specific value into the box beside the  buttons. Also, right clicking anywhere inside the Layer Elevation Setup window enables a menu which provides options to zoom to 150%, Normal, 100%, 75%, 50%, or 25%. Zoom functions are also shown in the figure below.

Additional Layer Elevation Setup Window Functions

The Layer Elevation Setup window also provides users with means of identifying cells so that they can be easily compared against material existing outside of Wetbud, or referenced when viewing other parameters, such as Cell Zones or Grid Zones within Wetbud. The cell Row and column (Col) within Wetbud, as well as the X and Y coordinates relative to the origin established in the General tab of the Advanced Scenarios window, are shown along with the cell Z value in the lower left corner of the Layer Elevation Setup window.

Note about Z-values: In the Layer Elevation Setup window, the Z value of the cell shown at the lower left corner of the window is the elevation of the cell. In the Grid Setup window, the Z value of the cell shown is the zone number that has been assigned to that cell for the selected zone parameter.



Additional Layer Elevation Setup Window Options

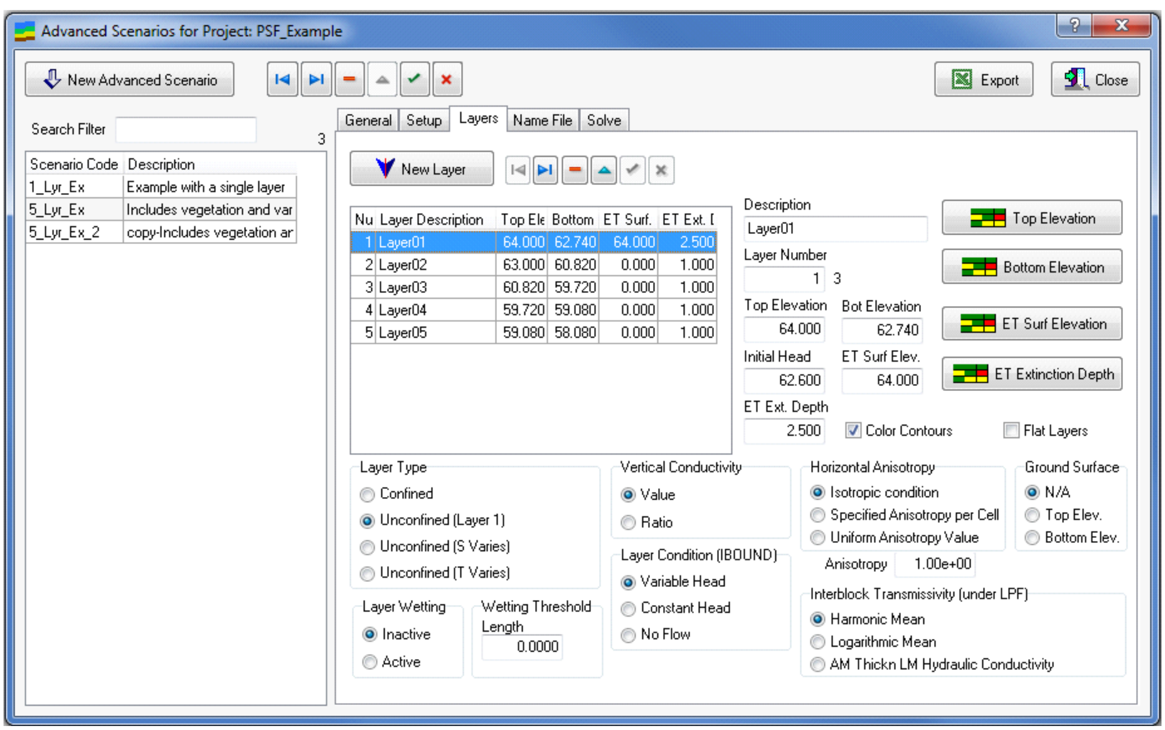
- To access Layer Elevation Setup window options, click Layer in the upper left corner of the Layer Elevation Setup window.
- The Clear option allows the user to clear all top elevation, bottom elevation, or ET surface elevation data for the selected layer.

- The Initialize option will assign the value designated for the selected parameter in the Layer tab in every cell for the selected layer. Once the selected layer elevations have been initialized, users can manually modify elevation data in any cell of the model grid by clicking on a cell and entering the elevation value.
- The Export option allows the user to export the layer grid elevations as an Excel file. Exported Excel files can then be imported using the Import tool as described above for variable elevation layers.

Initial Head

Initial Head in the Advanced Scenarios Layers tab is the head elevation where the model will begin the iterative solving process for head values within the wetland. If Variable Head is selected as the Layer Condition (IBOUND) (see following section [Layer Condition](#)), then the value in the Initial Head box should be the same as that entered for the first time step in the Head IN column of the Time Step Array selected in the General tab. If Constant Head is selected as the Layer Condition (IBOUND) (see following section [Layer Condition](#)), then the value assigned in the Initial Head box will be constant throughout the entire simulation.

Note: Initial Head values should be within a range that is reasonable for the wetland site. It is recommended that wetland water budget models begin in the winter months when the wetland sites will be inundated. The user can then reasonably assume the initial head value to be the maximum water surface elevation within the wetland. Since the finite difference model solves by iteration, the closer the Initial Head value is to the actual water surface elevation, the faster the model will run.



Wetting Threshold (Length)

Wetting Threshold (Length) in the Layers tab is a factor that is included in the calculation of the head that is initially established at a cell when it is converted from dry to wet. A Wetting Threshold (Length) value is only needed when either the PCG or SIP solver is used with the LPF flow package (See next section, Setup Tab for information about solvers and flow packages available in Wetbud), and the user must specify the Wetting Threshold (Length) for every layer where the selected layer type is Unconfined (Layer 1) or Unconfined (T Varies).

Note: The Wetting Threshold checkbox will be inactive in the Layers tab when the NWT solver is selected in the Setup tab.

The wetting threshold is determined as the absolute value of the MODFLOW term 'WETDRY', where WETDRY "is a combination of the wetting threshold and a flag to indicate which neighboring cells can cause a cell to become wet. If WETDRY < 0, then only the cell below a dry cell can cause the cell to become wet. If WETDRY > 0, then the cell below a dry cell and the four horizontally adjacent cells can cause a cell to become wet. If WETDRY equals 0, then the cell cannot be wetted." For more information, see 'WETDRY' in the USGS online guide to MODFLOW at https://water.usgs.gov/ogw/modflow/MODFLOW-2005-Guide/index.html?lpf.htm.

Layer Wetting

The Layer Wetting options (Inactive and Active) in the Layers tab determine which layers can rewet once they have become completely dry or which layers will always remain saturated. These options are used to prevent previously wet cells that become dry from staying dry for the remainder of the model simulation. Thus, the Active option should be selected for all layers within the expected range of water table fluctuation. The Active option will allow all cells in a layer to undergo wetting from above and below. The Inactive option will not allow cells to be rewetted from adjacent cells and should only be selected for layers that will remain completely saturated for the duration of the simulation. This option is normally restricted to the lowermost layer that is assumed to remain wet for the duration of the model run.

For example, in a 3-layer model the Layer Wetting should be set as 'Active' for layers 1 and 2 and set as 'Inactive' for layer 3, which is assumed to remain completely saturated for the entire simulation.

Layer Type

Each layer in the model must be assigned a Layer Type in the Advanced Scenarios Layers tab: either Confined, Unconfined (Layer 1), Unconfined (S Varies), or Unconfined (T Varies). A definition of each of these layers follows. For additional information about layer type, refer to https://water.usgs.gov/ogw/modflow/MODFLOW-2005-Guide/index.html?lpf.htm.

Note: Layer Type does not need to be defined when using the MODFLOW-NWT solver and the UPW flow package (see Flow Package in the Setup Tab section in this chapter).

1. Confined: This layer type is stratigraphically confined from layers above and below and has little to no hydrologic interaction with the layers confining it. Transmissivity and storage coefficient of the layer are constant for the entire simulation. Thus, the cell elevations in the discretization file are not used for computing transmissivity. Cell drying, cell wetting, storage term conversion, and vertical flow correction are not active. This layer type is normally used to simulate confined conditions and should not be chosen unless the user has experience with MODFLOW.
   Note: The discretization file contains data such as cell size, number of rows, columns, and layers, and time discretization.
2. Unconfined (Layer 1): All users should select this option for layer 1 in Advanced Scenario setup. This layer type indicates a water-table layer. Transmissivity of the layer varies and is calculated from the saturated thickness and hydraulic conductivity. The storage coefficient is constant. There is no check to determine if the head exceeds the top elevation. Cell drying is active. Cell wetting can be activated as described above in Layer Wetting. This layer type is valid only for the uppermost layer in the model.
3. Unconfined (S Varies): This indicates a limited convertible (a convertible layer is one where cells can convert from confined to unconfined conditions) layer. This layer type is used where heads may alternate between confined and unconfined conditions, so that storage term conversion and limitation of flow from above under dewatered conditions are both desirable. Thus, the storage coefficient may alternate between confined and unconfined values. An assumption is made, however, that the saturated thickness will remain a high fraction of the layer thickness throughout the period of simulation, and accordingly, transmissivity is not recalculated as the product of hydraulic conductivity and saturated thickness. Thus, the transmissivity of this layer type is constant. The vertical flow correction is active. The top elevation, which is required for the storage computations and vertical flow correction, is determined from elevation data in the discretization file. Cell drying and wetting are inactive. Vertical flow from above is limited if the layer desaturates.
4. Unconfined (T Varies): **This layer type is recommended for all subsurface layers consisting of unconsolidated (unlithified) sediments**. This is a fully convertible (a convertible layer is one where cells can convert from confined to unconfined conditions) layer. This layer type incorporates all of the Block-Centered Flow options associated with water-table conditions. At the beginning of each iteration, transmissivity is recalculated using hydraulic conductivity and layer top and bottom elevations, and both storage term conversion and vertical flow correction are implemented. Vertical flow from above is limited if the aquifer desaturates. Cell drying is active, and wetting can be activated as described above in Layer Wetting.

Vertical Conductivity

Vertical Conductivity for each cell in the selected layer must be assigned as one of two options: Value or Ratio, in the Advanced Scenarios Layers tab. The Value option (recommended) assigns the value of vertical hydraulic conductivity (KZ) associated with the hydraulic conductivity zones assigned to cells within the selected layer. The Ratio option assigns vertical conductivity as the ratio of vertical hydraulic conductivity (KZ) to horizontal conductivity (KX, KY) associated with the hydraulic conductivity zones assigned to cells within the selected layer. See Hydraulic Conductivity in Advanced Parameter Setup 2 - Grid Zones (Properties) for more information, or refer to Harbaugh et al. (2000) for specific details.

Note: If KX = KY = KZ for all hydraulic conductivity Grid Zones, then both options for vertical conductivity will produce the same results.

Layer Condition (IBOUND)

The Layer Condition (IBOUND) in the Advanced Scenarios Layers tab assigns a code to designate each cell in the selected layer as one of the following types: Variable Head, Constant Head, No Flow, or Not Active. The option chosen here should reflect the type of general head boundary that will be assigned to the selected layer in the model grid. In most cases, the Variable Head or Constant Head option should be selected. Users should only select No Flow or Not Active for situations where the entire selected layer is designed to act as a no flow zone or inactive layer. See General Heads in Advanced Parameter Setup 1 - Cell Zones (Boundary Conditions) for more information, and refer to Harbaugh (2005) for specific details.

Horizontal Anisotropy

Horizontal anisotropy is the ratio of hydraulic conductivity along a column to hydraulic conductivity along a row (Harbaugh et al., 2000). Horizontal anisotropy has a value of 1.000 for the isotropic condition. In the Advanced Scenarios Layers tab, the Horizontal Anisotropy condition must be defined for the hydraulic conductivities assigned to cells in a given layer. For Wetbud applications it is recommended that the user set Horizontal Anisotropy conditions for the selected layer to Isotropic condition. Other settings are possible, e.g., Specified Anisotropy per Cell or Uniform Anisostropy Value (refer to Harbaugh et al. (2000) for details and guidance on estimating this parameter).

Interblock Transmissivity (LPF)

This option in the Layers tab only applies to users who select the LPF flow package in the Setup tab of Advanced Scenario Setup (see Flow Package in the Setup Tab section in this chapter). The Interblock Transmissivity (LPF) option defines the method of calculating interblock transmissivity for each layer with three options: Harmonic Mean, Logarithmic Mean, and AM Thickn. LM Hydr. Cond. (arithmetic mean of saturated thickness and logarithmic-mean hydraulic conductivity), which are described below:

1. Harmonic Mean: This is most appropriate for confined and unconfined aquifers with abrupt boundaries in transmissivity at the cell boundaries or for confined aquifers with uniform hydraulic conductivity.

2. Logarithmic Mean: This is most appropriate for confined aquifers with gradually varying transmissivity.
3. AM Thickn. LM Hydr. Cond.: This is most appropriate for unconfined aquifers with gradually varying transmissivity.

Note: This option does not need to be defined when using the MODFLOW-NWT solver and the UPW flow package and will only be visible if the LPH flow package has been selected (see Flow Package in Setup Tab).

Ground Surface

The Ground Surface option allows the user to select whether the top of Layer 1 or the bottom of Layer 1 represents the actual ground surface in the model. The selected surface will be plotted, with water levels, in the Advanced Model Output form. Users that have opted to have the first layer of their model be a vegetative layer should select Bottom Elevation as the bottom of Layer 1, which would be equal to the actual ground surface, while the top of Layer 1 would be equal to the top of the vegetation. If this option is set to "N/A" for Layer 1, then surface elevation will not be plotted properly in the Advanced Model Output form.

10.1.5 Name File Tab

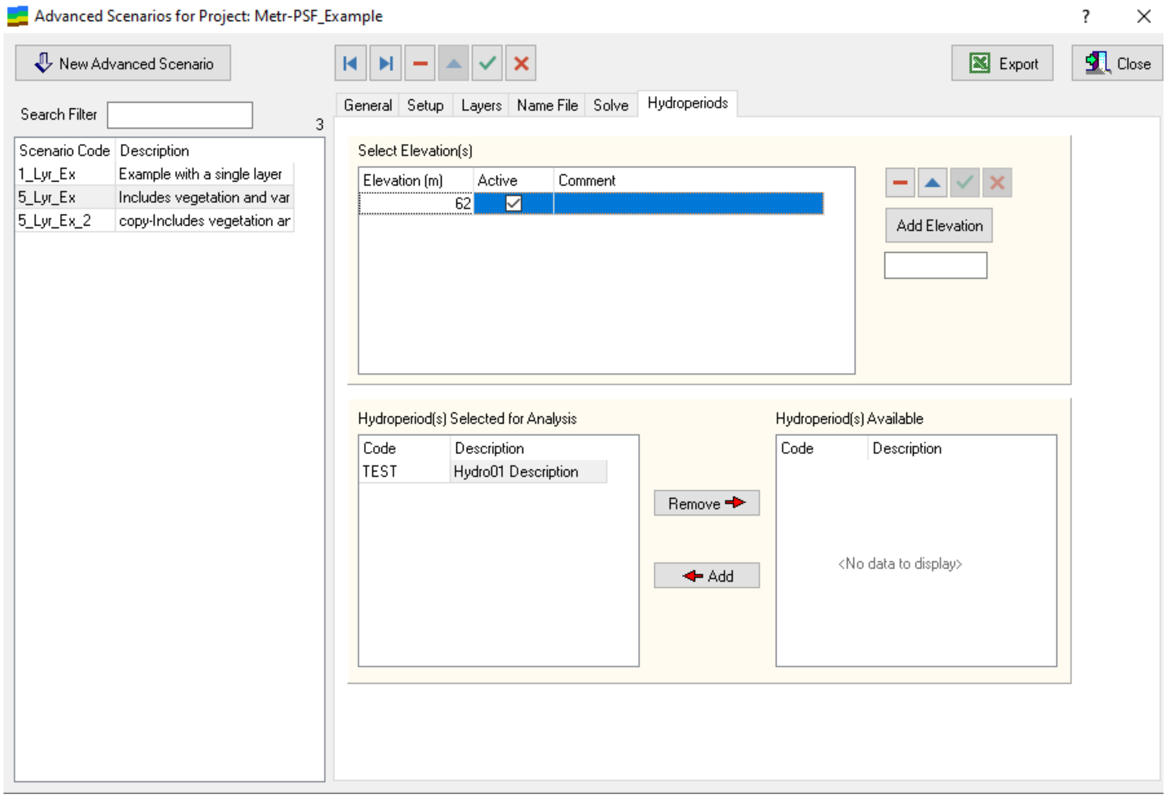
The functions of the Name File tab and Solve tab are only needed when generating Advanced Model output. See Advanced Model Output for more information.

10.1.6 Solve Tab

The functions of the Name File tab and Solve tab are only needed when generating Advanced Model output. See Advanced Model Output for more information.

10.1.7 Hydrioperiod Tab

This option allows the user to select a range of elevations and hydroperiod definitions to create a sensitivity analysis for hydroperiods when viewing the output. This option is utilized when viewing heads at monitoring points. For more information Head at Monitoring Points.



10.2 Advanced Parameters 1 - Cell Zones

To begin creating Cell Zones in a Project, select Advanced Parameters 1 – Cell Zones from the Advanced Models drop-down menu in the Wetbud home screen. Cell Zones, also known as boundary conditions in other modeling software, are used to parameterize and constrain the flux of water in the finite-difference model grid. In Wetbud, Cell Zones fall into six categories, as shown below:

1. Drains
2. General heads
3. Monitoring points
4. No flow areas
5. Wells
6. Drain returns

Cell Zones created within the selected Project can be assigned to cells in one or many layers in an Advanced Scenario model grid (see Advanced Grid Setup).

Note 1: Cell Zones are not interchangeable between Projects. Cell Zones created within a Project can only be assigned to an Advanced Scenario model grid within the selected Project. Thus, each Project must contain a unique set of Cell Zones and Grid Zones, which can then be assigned to Advanced Scenario model grids created within the selected Project.

Note 2: These Cell Zones represent interfaces for six different MODFLOW packages. Their implementation in Wetbud is described in the following sections. For more information about how these packages are defined in MODFLOW, please see: [link to MODFLOW manual].

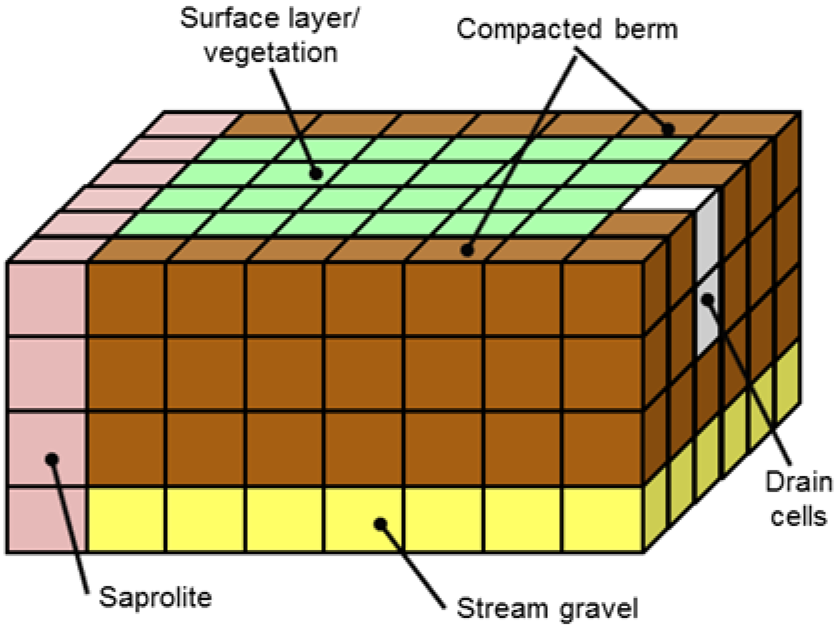
The type of Cell Zones created by the user will vary depending on the intended model design. Instructions for creating each type of Cell Zone and their function in an Advanced Scenario model grid are explained in their respective sections below.

To begin creating Cell Zones in a Project, select Advanced Parameters 1 – Cell Zones from the Advanced Models drop-down menu in the Wetbud home screen. The Advanced Parameters 1 – Cell Zones window has six tabs: Drains, General Heads, Monitoring Points, No Flow Areas, Wells, and Drain Returns, which are described below.

Note 3: Many Cell Zones and Grid Zones will utilize data from Time Step Arrays. It may be helpful to develop a Time Step Array prior to defining Cell and Grid Zones. See Advanced Parameters 3 – Time Steps and Solvers if necessary.

10.2.1 Drains

In Wetbud, drains simulate the removal of water from the wetland through an outlet structure. During the model simulation, the removal of water will occur at a rate proportional to the difference between the head in the wetland and the invert elevation (lowest point) of the outlet structure (Harbaugh, 2005). Once water is removed from the model through a drain it can only reenter the model through a drain return cell. One or multiple drains can be created and placed spatially in any active cell of any layer in the Advanced Scenario model grid to represent outlet structures (e.g., drains, culverts, ditches) in the wetland being modeled. The following figure illustrates how drains will be implemented when setting up the Advanced Model grid (see Advanced Grid Setup).

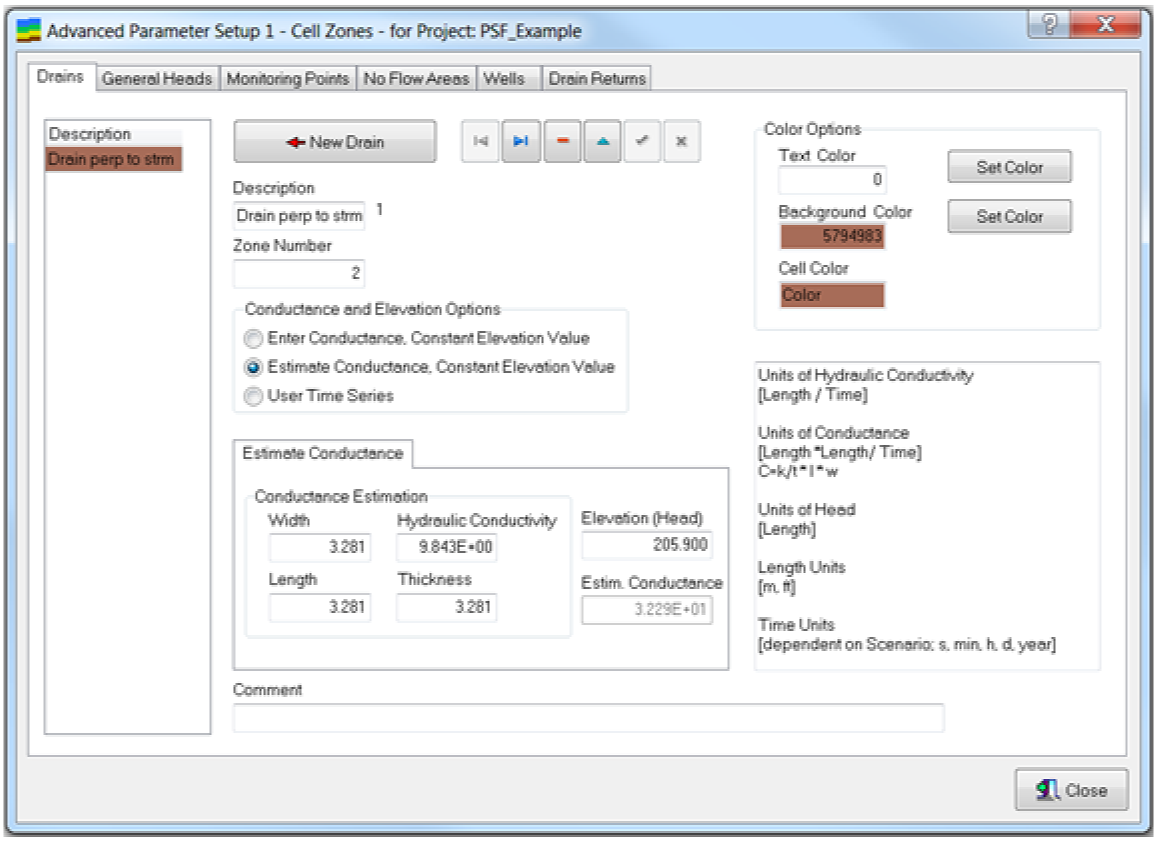


Use the following procedure to create a new drain in the Drains tab of the Cell Zones window:

1. Click the  button. In the Description box, delete the text ‘Drain01‘ and replace it with a short but unique description of the drain (e.g., culvert). Next, enter a zone number in the Zone Number box or leave it as the default, which is ‘1’ for first zone created, ‘2’ for the second zone created, and so on. This number is used to identify the Drain cell zone and will appear when this cell zone is assigned to a cell or cells in the model grid.
2. Enter the elevation (head) that corresponds to the drain invert elevation in the Elevation (Head) box. The elevation (head) entered in this box will be the maximum elevation water can reach in the surrounding cells before it can exit the model through the drain. If the head elevation falls below the drain elevation, then the drain will have no effect on the model.
   Note: The elevation of a drain cannot be higher than the top elevation of the cell to which the drain is assigned.
3. Enter the drain conductance (length^2/time) in the Conductance box. If drain conductance in unknown, enter drain parameters in the Width (W, column width), Hydraulic Conductivity (K), Length (L, row width), and Thickness (M, thickness of drain material in the direction of flow) boxes under Conductance Estimation and check the Estimate Conductance checkbox. After checking the Estimate Conductance checkbox, a value will appear in the Conductance box. These parameters are used to estimate drain conductance using the following equation:
   $$C = KLW / M$$
   Note: A value entered or estimated for conductance that is unreasonable for the designed outlet structure may not allow the model to converge, particularly if the cell size is small, the model time step is large, and/or the drain conductance is high. In

this situation, the user must adjust the conductance value to achieve model convergence. Refer to Harbaugh (2005) for details about Drains in MODFLOW.

4. In the Color Options section, click Set Color to select the Text Color and Background Color to represent this cell zone in the model grid.
5. Click ✓ to save. The description entered for the Drain will appear in the Description list on the left side of the tab window.

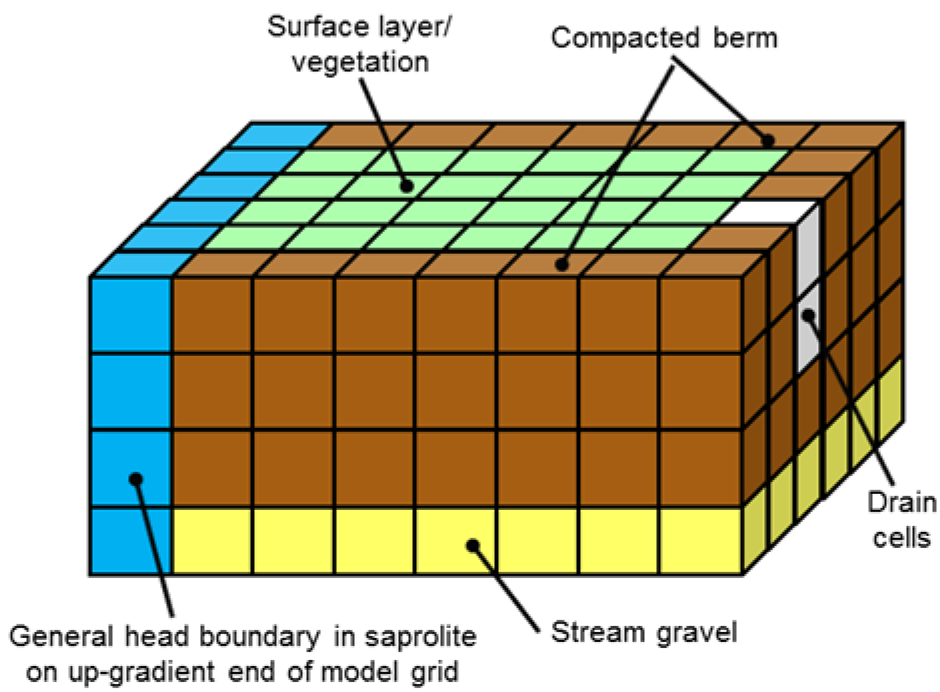


Note: Users also have the option to vary drain elevation and conductance through time. This option is useful when using a drain in the model to represent an adjustable outlet structure. If this option is selected, then the Drain Elevation and Drain Conductance columns must be populated in the Time Step Array assigned to the drain. See Time Step Arrays for further instructions on populating these columns.

Once a Drain cell zone has been created it can be assigned to cells in the Advanced Model Grid (see Advanced Grid Setup).

10.2.2 General Head Bounrdaries

General Head Boundaries (GHB) are spatially assigned in the model grid to simulate groundwater flow into or out of the site being modeled. The head elevations assigned to GHB cells (typically the up-gradient end of the site/grid) will determine how the model interacts with the entire flow system of the site being simulated. The following figure illustrates how a general head boundary can be implemented in the Advanced Model grid (see Advanced Grid Setup).



GHB head elevation values should be realistic and should be based on the elevations assigned to layers in the model grid. The GHB head elevation values for each time step are defined in the Time Step Array (see Advanced Parameters 3 – Time Steps and Solvers) assigned in the General tab of the Advanced Scenario setup (see Advanced Scenarios). For more information about the GHB zone calculation see the MODFLOW-2005 Modular Ground-Water model manual (Harbaugh, 2005).

Use the following procedure to create a new general head zone in the General Heads tab of the Cell Zones window.

1. Click the New General Head button. In the Description box, delete the text ‘GHB01‘ and replace it with a short but unique description of the general head (e.g., hillslope head). Next, enter a zone number in the Number box or leave it as the default, which is ‘1’ for first zone created, ‘2’ for the second zone created, and so on. This number is used to identify the General Head cell zone and will appear when this cell zone is assigned to a cell or cells in the model grid.
2. Enter the general head boundary conductance (length^2/time) in the Conductance box. If conductance in unknown, enter cell dimensions in the Width (W, column width), Hydraulic Conductivity (K), Length (L, row width), and Thickness (M, thickness of cell) boxes under Conductance Estimation and check the Estimate Conductance box. **Note:** The value entered for hydraulic conductivity (K, length/time) should pertain to the lithology of the cell(s) in which the general head boundary is assigned to in the model grid.

3. After checking the Estimate Conductance box, a value will appear in the Conductance box. These parameters are used to estimate conductance using the following equation:

$$C = \underline{KLW / M}$$

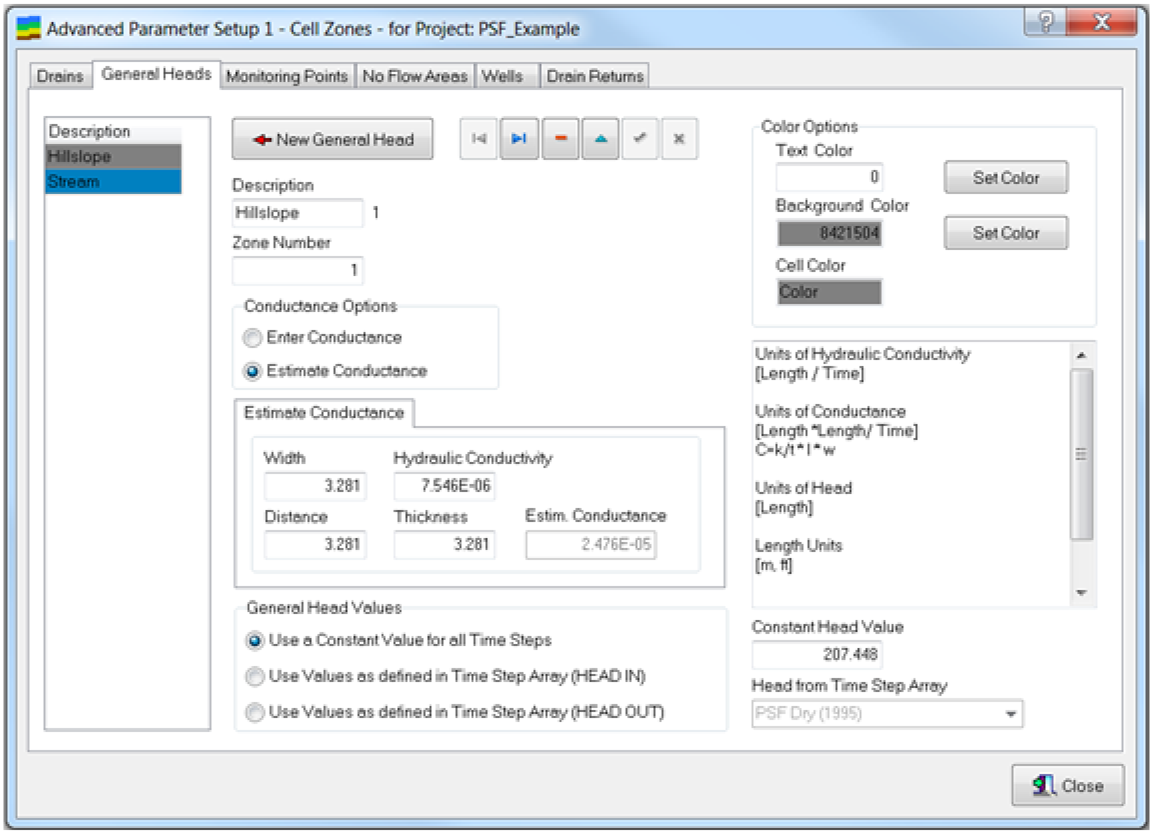
4. In the General Head Values section, select one of the following options to define the head elevations for the GHB.
   a. Use a Constant Value for all Time Steps – This option will assign a constant head elevation to GHB cells for all time steps in the model simulation. If this option is selected, the user must then enter a head elevation in the Constant Head Value box.
   b. Use Values as defined in Time Step Array (HEAD IN) – This option will use variable head elevation values assigned to each time step in the Head IN column of a Time Step Array. The head values in the Head IN column should correspond to head elevations on the up-gradient end of the site being modeled. If this option is chosen, the user must select a head value option from the Head from Time Step Array drop-down menu.
   Note: Check the Show Time Steps box to display the values in the selected Time Step Array. The selected Time Step Array should be the same as that selected in the General tab of Advanced Scenario setup (see Advanced Scenarios).
   a. Use Values as defined in Time Step Array (HEAD OUT) – This option will use variable head elevation values assigned to each time step in the Head OUT column of a Time Step Array. The head values in the Head OUT column should correspond to head elevations on the down-gradient end of the site. If this option is chosen, the user must select a head value option from the Head from Time Step Array drop-down menu. This option is available to users modeling sites that lack water outlet structures (e.g., drains, culverts, and/or an adjacent stream) and wish to represent the down-gradient end of their model grid as a general head boundary. Users may also want to choose this option to simulate an adjacent stream as a general head boundary in lieu of a drain.
   Note: Check the Show Time Steps box to display the values in the selected Time Step Array. The selected Time Step Array should be the same as that selected in the General tab of Advanced Scenario setup (see Advanced Scenarios).

5. In the Color Options section, click 

to select the Text Color and Background Color to represent this cell zone to cell assigned in the model grid.

6. Click  to save. The description entered for the general head boundary will appear in the Description list on the left side of the tab window.

Once a GHB cell zone has been created it can be assigned to cells in the Advanced Model Grid (see Advanced Grid Setup).



10.2.3 Monitoring Points

Monitoring points can be spatially assigned in the Advanced Model grid to allow straightforward comparison of model results to monitoring well data. Once monitoring points have been assigned in the grid editor, they can be selected in the results display interface and the Advanced Model results will be displayed for the assigned cell location. By assigning grid cells as monitoring points, users can pinpoint areas where measured well data may be available and make comparisons between modeled and measured data more easily.

Use the following procedure to create a new monitoring point in the Monitoring Points tab of the Cell Zones window:

1. Click the 

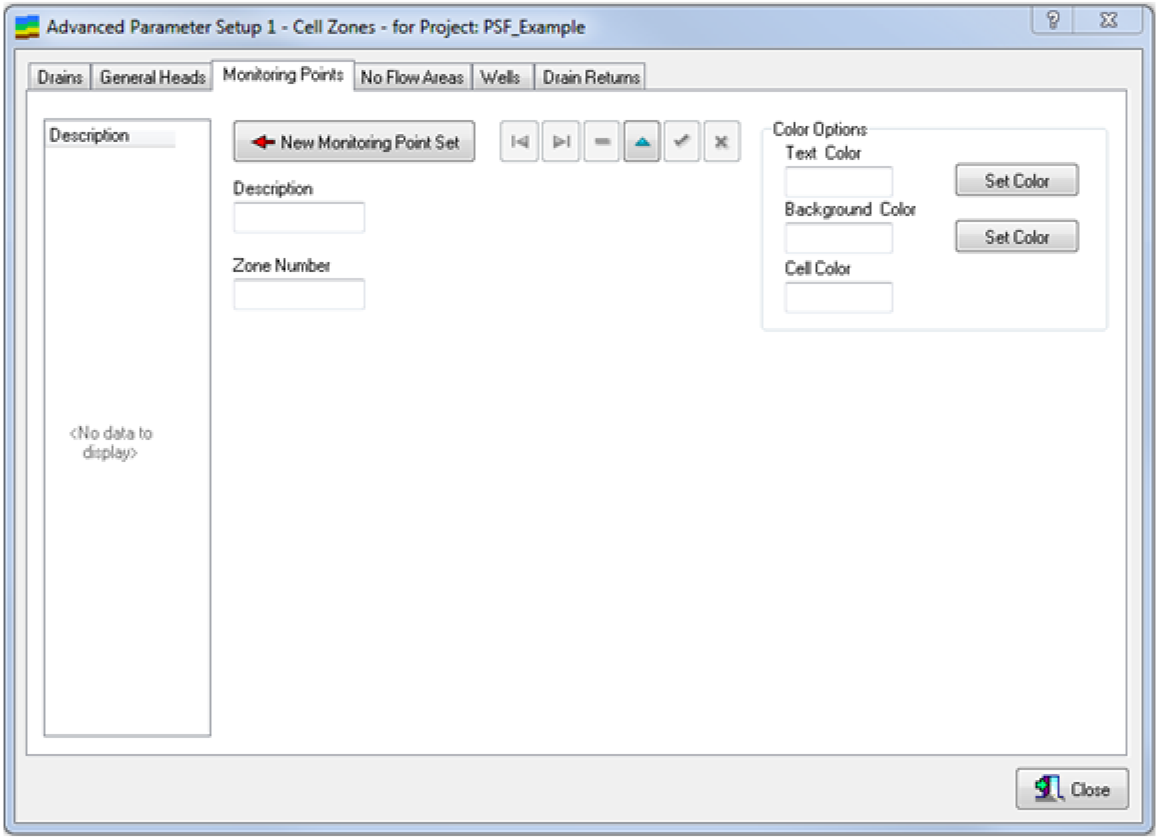
button. In the Description box, delete the text ‘MPoints01‘ and replace it with a short but unique description (e.g., toe-slope). Next, enter a zone number in the Zone Number box or leave it as the default, which is ‘1’ for first zone created, ‘2’ for the second zone created, and so on. This number is used to identify the monitoring point and will appear when this cell zone is assigned to a cell or cells in the model grid.

2. In the Color Options section, click 

to select the Text Color and Background Color to represent this cell zone for cells assigned in the model grid.

3. Click  to save. The description entered for the monitoring point will appear in the Description list on the left side of the tab window.

Once a monitoring point cell zone has been created it can be assigned to cells in the Advanced Model Grid (see [Advanced Grid Setup](#)).

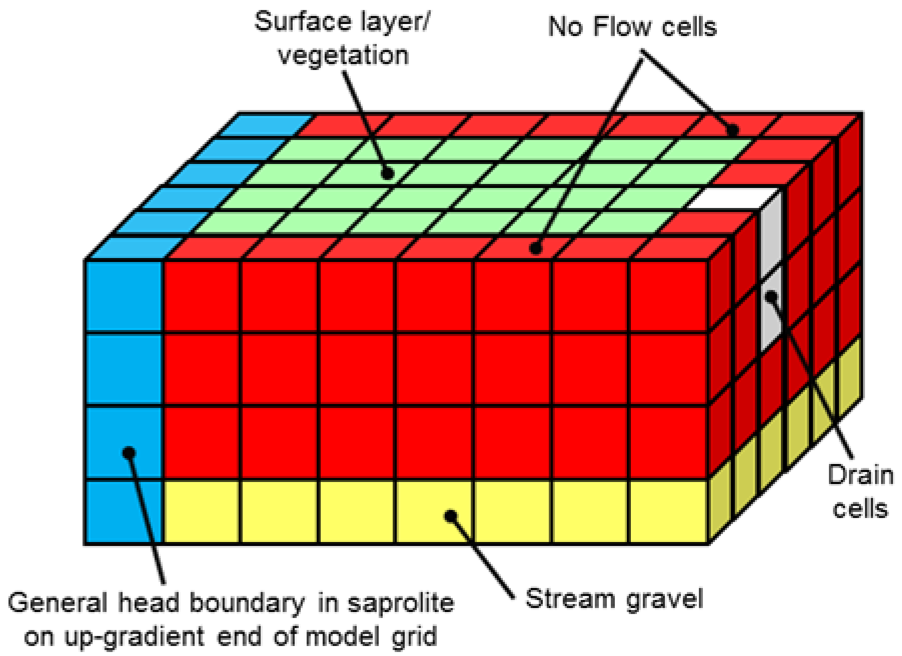


10.2.4 No Flow Areas

No flow cells are placed in the model grid to create an accurate shape of the modeled wetland site from the rectangular grid shape in the initial setup by removing cell activity outside the wetland boundary. In no flow cells, equations in the model are not formulated, and no influence on adjacent cells is calculated (Harbaugh, 2005). As a result, no modular package parameters or other grid zone parameters will have an effect on no flow cells. The following figure illustrates how no flow cells can be implemented in the Advanced Model grid (see [Advanced Grid Setup](#)).

Note 1: No flow cells may be used to constrain hydrologic boundaries or to represent impermeable materials (e.g., compacted clay berm, geotextile liners, etc.). In this design, the user has used no flow Cell Zones in lieu of a low hydraulic conductivity grid zone to represent a compacted berm.

Note 2: No flow area may be used to model wetland berms.

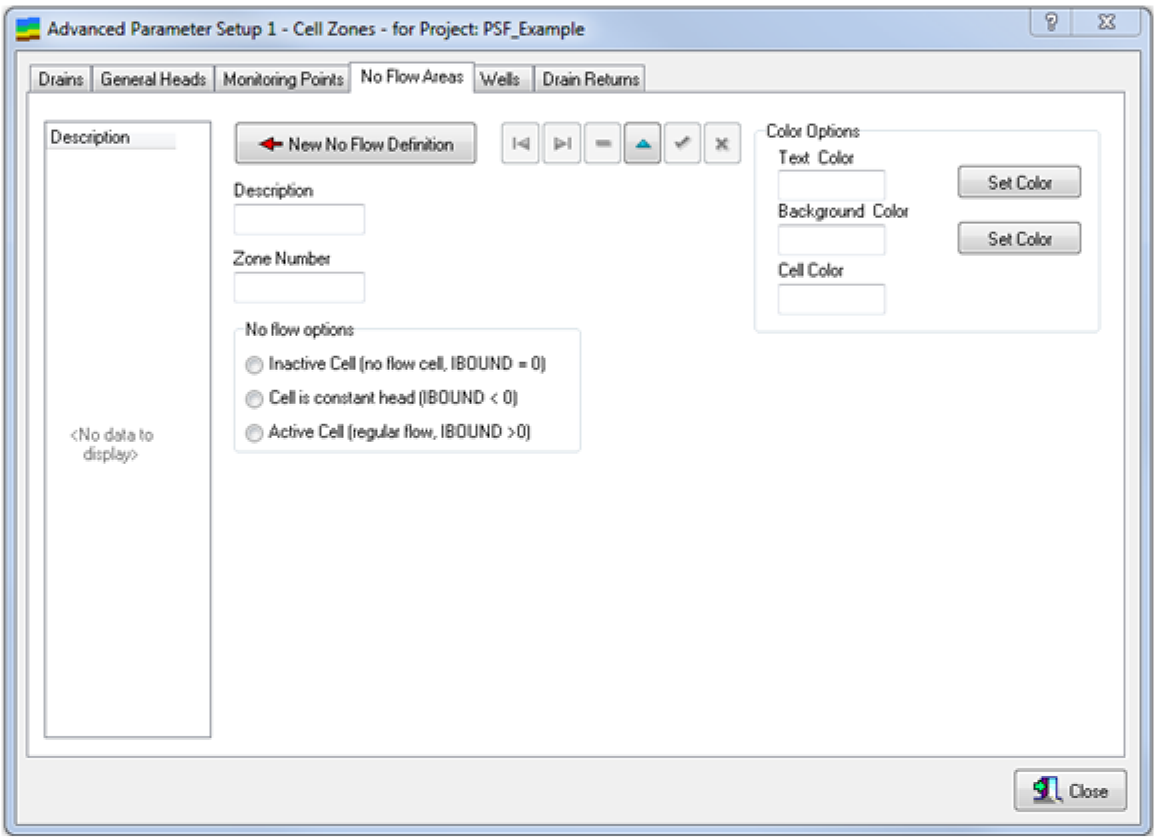


No flow cell patterns can also be copied from layer to layer in the Advanced Model grid (see Advanced Grid Setup) to decrease model setup time. Use the following procedure to create a new no flow area in the No Flow Areas tab of the Cell Zones window:

1. Click the  button. In the Description box, delete the text ‘NoFlow01‘ and replace it with a short but unique description (e.g., no-flow). Next, enter a zone number in the Zone Number box or leave it as the default, which is ‘1’ for first zone created, ‘2’ for the second zone created, and so on. This number is used to identify the no flow area and will appear when this cell zone is assigned to a cell or cells in the model grid.
2. In the No flow options section, select one of the following options:
   a. Inactive Cell (no flow cell, IBOUND = 0) (recommended): This option should be selected for all no flow areas that will be used to delineate the boundaries of the cells to be included in the model simulation. Water cannot flow through these cells and these cells will not be used in the model solution.
   b. Cell is constant head (IBOUND < 0) – this option will assign a constant head to no flow cells. The head value for this type of no flow cell is defined in the General tab of Advanced Scenario setup (see Advanced Scenarios). The head for no flow cells has no effect on the head in the active model area; it is simply a placeholder so the user can identify the no flow cells in the model results.
   c. Active Cell (regular flow, IBOUND > 0) – This option will allow no flow cells to become active in the model simulation and head elevations will vary based on the heads in the surrounding cells. During successive model runs, this option allows users to reactivate these cells instead of having to delete inactive no flow cells in between model runs. This is especially useful for large models with complex no flow boundaries and/or no flow zones within the model grid.

3. In the Color Options section, click Set Color to select the Text Color and Background Color to represent this cell zone for cells assigned in the model grid.
4. Click  to save. The description entered for the no flow area will appear in the Description list on the left side of the tab window.

Once a no flow cell zone has been created, it can be assigned to cells in the Advanced Model Grid (see Advanced Grid Setup).



10.2.5 Wells

In Wetbud, wells placed in the model grid are used to add water to the wetland system at a constant rate during a given time step. For example, a well can be used in the model to input additional water such as runoff from adjacent drainage areas. The input rate is independent of the cell area and the head in the cell (Harbaugh, 2005). The additional inputs of water from wells inserted in the model grid are entered for each time step in the Time Step Array defined in the General tab of Advanced Scenario setup (see Advanced Scenarios). If runoff rates are unknown, runoff rates can be calculated and imported into the Time Step Array using the Wetbud Basic Model with the SCS/NRCS rainfall excess estimation technique and the precipitation data stored within the model (see Time Steps and Solvers for more information).

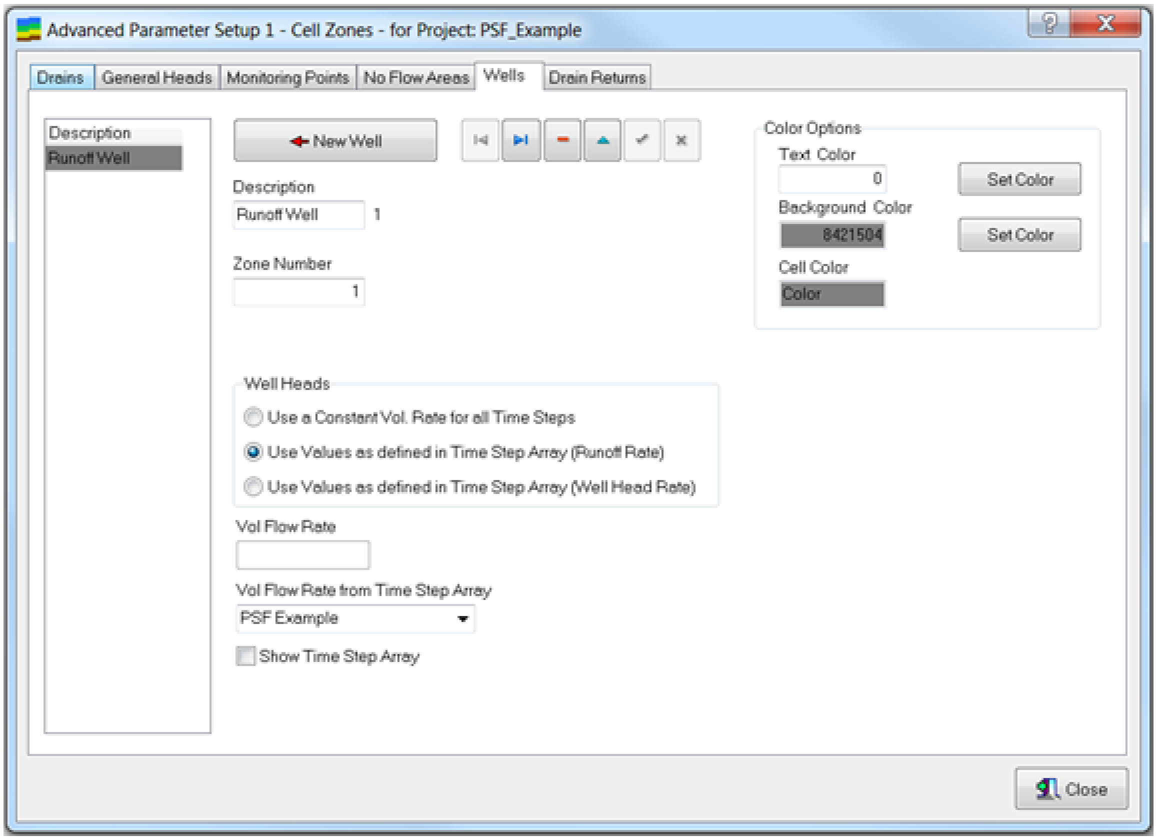
Use the following procedure to create a new well in the Wells tab of the Cell Zones window:

1. Click the 

button. In the Description box, delete the text ‘Well01‘ and replace it with a short but unique description (e.g., 'Well X'). Next, enter a zone number in the Zone Number box or leave it as the default, which is ‘1’ for first zone created, ‘2’ for the second zone created, and so on. This number is used to identify the well and will appear when this cell zone is assigned to a cell or cells in the model grid.
2. In the Well Heads options section, select one of the following options:
   a. Use a Constant Vol. Rate for all Time Steps – This option will assign a constant volume flow rate for all time steps in the model simulation. If this option is selected, the user must then enter a volume flow rate expressed in length3/time in the Vol Flow Rate box.
   b. Use Values as defined in Time Step Array (Runoff Rate) – This option will use variable volume flow rate values assigned to each time step in the Runoff Rate column of a Time Step Array. If this option is chosen, the user must select a Time Step Array from the Vol Flow Rate from Time Step Array drop-down menu.
   Note: Check the Show Time Steps box to display the values in the selected Time Step Array. The selected Time Step Array should be the same as that selected in the General tab of Advanced Scenario setup (see Advanced Scenarios).
   c. Use Values as defined in Time Step Array (Well Head Rate) – This option will use variable volume flow rate values assigned to each time step in the Well Head Rate column of a Time Step Array. If this option is chosen, the user must select a Time Step Array from the Vol Flow Rate from Time Step Array drop-down menu.
   Note: Check the Show Time Steps box to display the values in the selected Time Step Array. The selected Time Step Array should be the same as that selected in the General tab of Advanced Scenario setup (see Advanced Scenarios).
3. In the Color Options section, click 

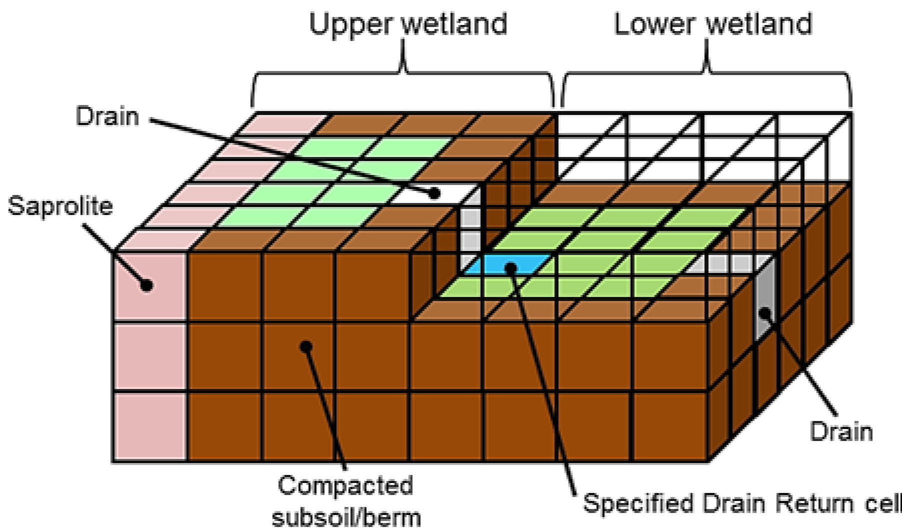
to select the Text Color and Background Color to represent this cell zone for cells assigned in the model grid.
4. Click  to save. The description entered for the well will appear in the Description list on the left side of the tab window.

Once a well cell zone has been created it can be assigned to cells in the Advanced Model Grid (see Advanced Grid Setup).



10.2.6 Drain Returns

Drain returns are used to return a percentage of water that has been removed from the wetland through a drain. By placing a drain return in the model grid, a specified flow proportion lost through an existing drain can be input back into the model at the drain return cell location. For example, drain returns are useful for users who wish to model stepped wetland systems with multiple cells where berms are placed between wetland cells and surface water is transferred between cells by a series of weirs or culverts. Once a drain return cell zone has been created, it must be assigned to the cell in the model grid containing the outflow drain (see Advanced Grid Setup). Drain return inflow will then reenter the model in a specified return cell.



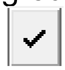
Use the following procedure to create a drain return in the Drain Returns tab of the Cell Zones window:

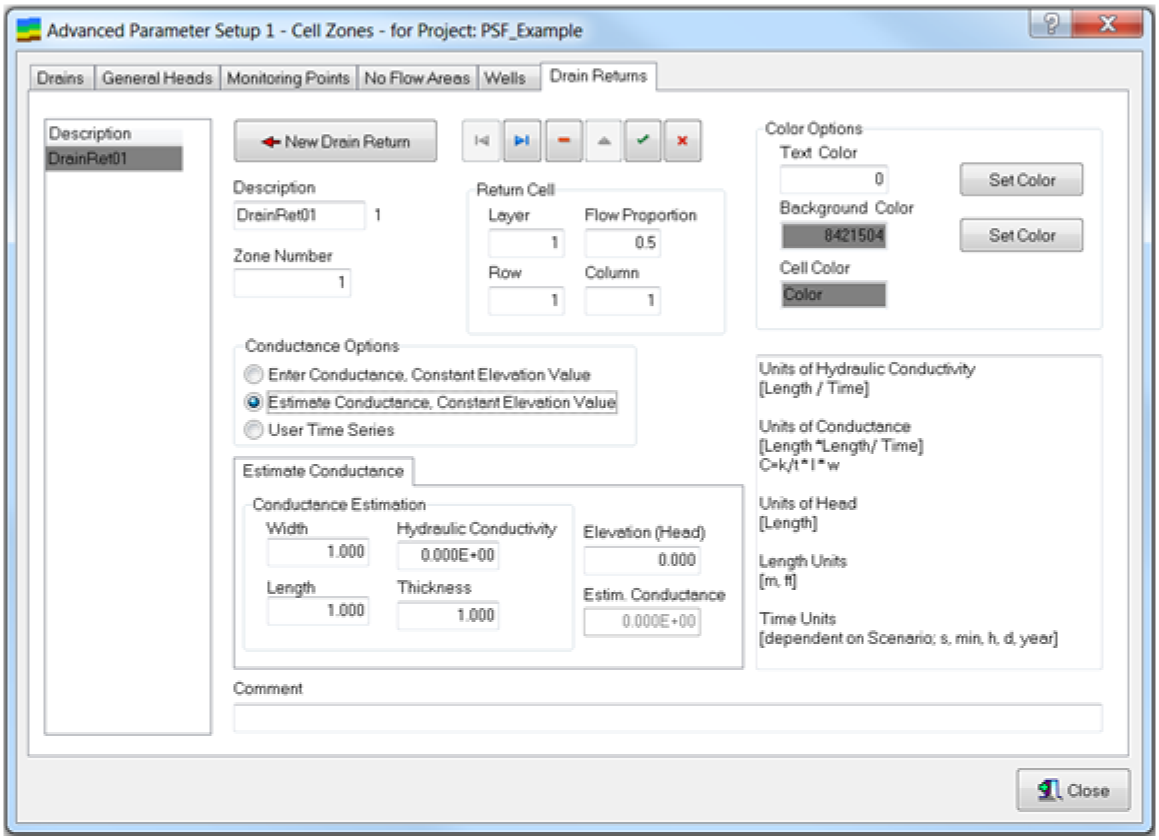
1. Click the 

button. In the Description box, delete the text ‘DrainRet01‘ and replace it with a short but unique description of the drain (e.g., “culvert return”, etc.). Next, enter a zone number in the Zone Number box or leave it as the default, which is ‘1’ for first zone created, ‘2’ for the second zone created, and so on. This number is used to identify the drain return cell zone and will appear when this cell zone is assigned to a cell or cells in the model grid.
2. Enter the elevation (head) that corresponds to the head elevation of the drain return in the Elevation (Head) box. The elevation (head) entered in this box will be the head elevation at which water will enter the drain return cell.
3. In the Return Cell section, specify the Layer, Row, Column, and Flow proportion (e.g., 0.50 = 50%) in their respective boxes. Water not returned to the wetland “disappears” from the model. The Layer, Row, and Column boxes should pertain to the grid location of the cell where the designated flow proportion is to return to the model. The value for Flow Proportion should correspond to a specific drain located in the model grid (see Advanced Grid Setup for additional details about assigning drain returns to cells in the model grid).
4. Enter the drain conductance (length^2/time) in the Conductance box. If drain conductance in unknown, enter drain parameters in the Width (W, column width), Hydraulic Conductivity (K), Length (L, row width), and Thickness (M, thickness of drain material) boxes under Conductance Estimation and check the Estimate Conductance box. After checking the Estimate Conductance box, a value will appear in the Conductance box. These parameters are used to estimate drain conductance using the following equation:

$$C = \underline{KLW / M}$$

Note: A value entered or estimated for conductance that is unreasonable for the designed inlet structure may not allow the model to converge, particularly if the cell size is small, the model time step is large, and/or the drain conductance is high. In this situation, the user must adjust the conductance value to achieve model convergence. Refer to Harbaugh (2005) for details about Drain Returns in MODFLOW.

5. In the Color Options section, click  to select the Text Color and Background Color to represent this cell zone for cells assigned in the model grid.
6. Click  to save. The description entered for the drain return will appear in the Description list on the left side of the tab window.



10.3 Advanced Parameters 2 - Grid Zones

To begin setting up Grid Zones, select Advanced Parameters 2 – Grid Zones from the Advanced Models drop-down menu in the Wetbud home screen. Grid Zones, also known as properties, are used to parameterize the hydraulic properties of cells in each layer of the model grid. In Wetbud, Grid Zones fall into four categories:

1. Hydraulic Conductivity
2. Specific Storage
3. Precip (precipitation) Rate
4. ET (evapotranspiration) rate

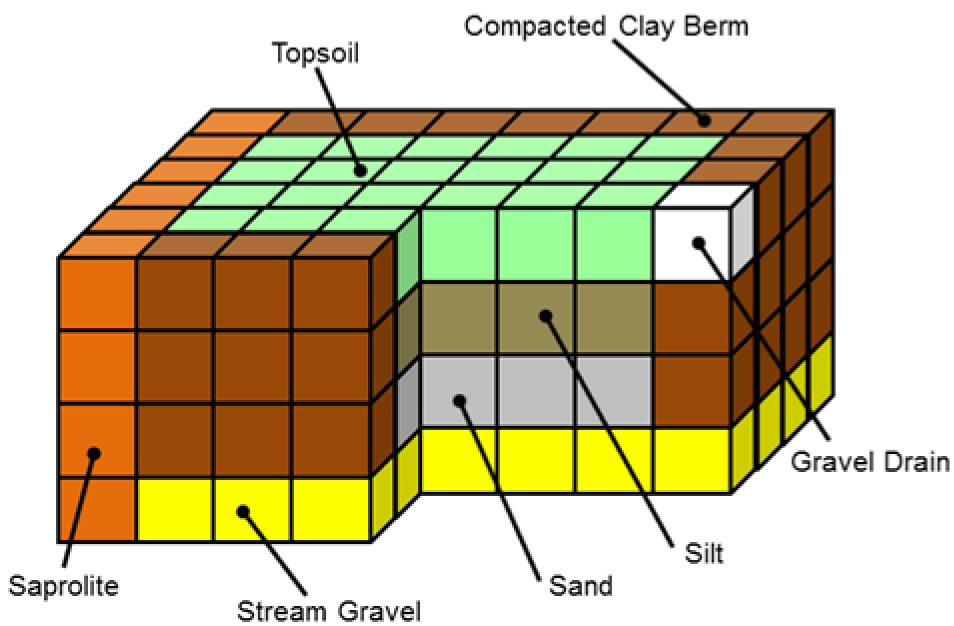
Once Grid Zones are created within the selected Project they can then be assigned to cells in one or many layers in an Advanced Scenario model grid (see Advanced Grid Setup).

Note: Grid Zones are not interchangeable between Projects. Grid Zones created within a Project can only be assigned to an Advanced Scenario model grid within the selected Project. Thus, each Project must contain a unique set of Cell Zones and Grid Zones, which can then be assigned to Advanced Scenario model grids created within the selected Project.

10.3.1 Hydraulic Conductivity

Hydraulic conductivity is defined as the rate at which water can flow through a fully saturated material for each unit of hydraulic gradient. Every cell in an Advanced Model grid must be assigned a value for hydraulic conductivity (length/time) in the X, Y, and Z directions. Thus, the user should create as many hydraulic conductivity Grid Zones as needed to represent all lithologies and/or structures for the site being simulated in the model grid. For example, a 4-layer model with four hydraulically distinct lithologies should contain four hydraulic conductivity zones.

The figure below is an example model grid for Hydraulic Conductivity Grid Zones for common materials. The user must create a Hydraulic Conductivity (K) and Specific Yield/Storage grid zone for each material in the site being simulated in the model grid.



To view the range of hydraulic conductivity (K_{sat}) values for common engineering materials, refer to the table below (US FHWA, 2006; Johnson, 1967). To obtain hydraulic conductivity values for a specific soil, refer to the Soil K_{sat} database (only available for Virginia) located under the Parameters menu in the Wetbud home screen.

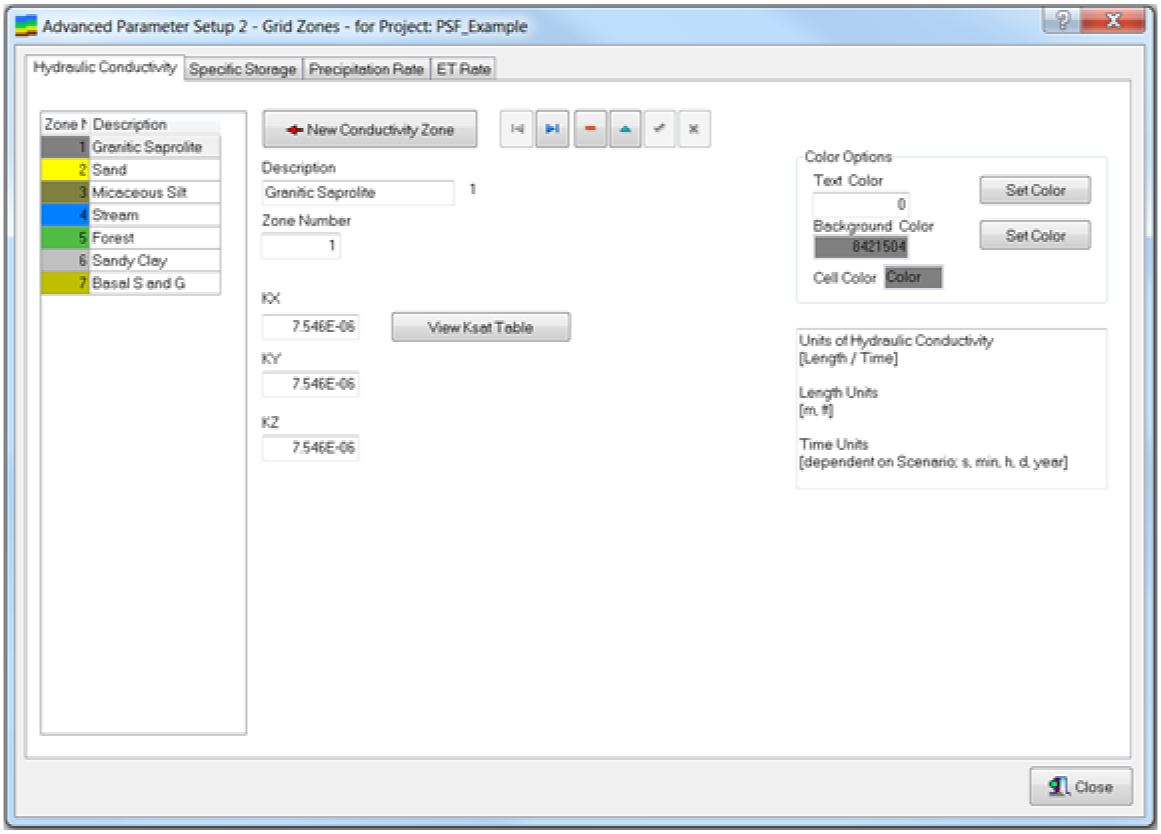
Sediment or Material Type	Hydraulic conductivity* (K_{sat})	Specific yield (Sy)**
	--- m/sec ---	--- % ---
Clean gravel	10^{-2} - 1	20 - 50
Clean coarse sand	10^{-4} - 10^{-2}	15 - 35
Fine sand	10^{-5} - 10^{-3}	10 - 30
Silty sand	10^{-5} - 10^{-4}	10 - 30
Clayey sand	10^{-6} - 10^{-4}	5 - 25
Silt	10^{-10} - 10^{-5}	3 - 20
Clay	10^{-12} - 10^{-8}	0 - 5
Uniformly graded coarse aggregate	0.4 - 10^{-3}	10 - 30
Well-graded coarse aggregate	10^{-5} - 10^{-3}	5 - 25
Concrete sand, variable dust content	10^{-8} - 10^{-4}	5 - 20
Compacted silt	10^{-10} - 10^{-8}	< 5
Compacted clay	< 10^{-9}	< 1

* Hydraulic conductivity values for grid zones must be entered in the same units as specified in the *General* tab during Advanced Scenario setup.
** Specific yield values for grid zones must be entered as a decimal between 0 and 1. For example, 10% should be entered as 0.10.

Use the following procedure to create a grid zone for hydraulic conductivity in the Hydraulic Conductivity tab of the Grid Zones window:

1. Click the New Conductivity Zone button. In the Description box, delete the text '--' and replace it with a short but unique description (e.g., top soil). Next, enter a zone number in the Zone Number box or leave it as the default, which is '1' for first zone created, '2' for the second zone created, and so on. This number is used to identify the hydraulic conductivity grid zone and will appear when this grid zone is assigned to a cell or cells in the model grid.
2. In the Color Options section, click Set Color to select the Text Color and Background Color to represent this grid zone for cells assigned in the model grid.
3. Click  to save. The description entered for the hydraulic conductivity grid zone will appear in the Description list on the left side of the tab window.

Once a hydraulic conductivity grid zone has been created it can be assigned to cells in the Advanced Model Grid (see [Advanced Grid Setup]).



10.3.2 Specific Storage

Specific yield (Sy) and specific storage (Ss) define the amount of groundwater that can be stored in and released from the cells in the model. Specific yield and specific storage are only used in transient model simulations. Specific yield is defined as the drainable porosity of aquifer material, or the fraction of the total aquifer volume that is yielded when water is drained by gravity. Specific storage is defined as the amount of water stored or released per unit volume of the aquifer per unit change in head. For unconfined layers, the specific yield values should be set equal to the specific storage. For surface water and vegetation layers, it is recommended that the specific storage value be set to a value close to 1.0 because even dense wetland vegetation occupies only a small fraction of the overall storage volume in the surface layer.

Typical values for emergent herbaceous wetlands are 0.95 for very dense vegetation (9000 stems/m^2) to 0.99 for areas with less dense emergent vegetation (1500 stems/m^2). Both values are unitless and should be between 0 and 1 depending on the site geologic conditions. To view the range of specific yield values for common materials, refer to the table in the Hydraulic Conductivity section. Users can create as many storage zones as needed to model a wetland site. As a general rule, users should create a specific storage grid zone for every hydraulic conductivity cell zone.

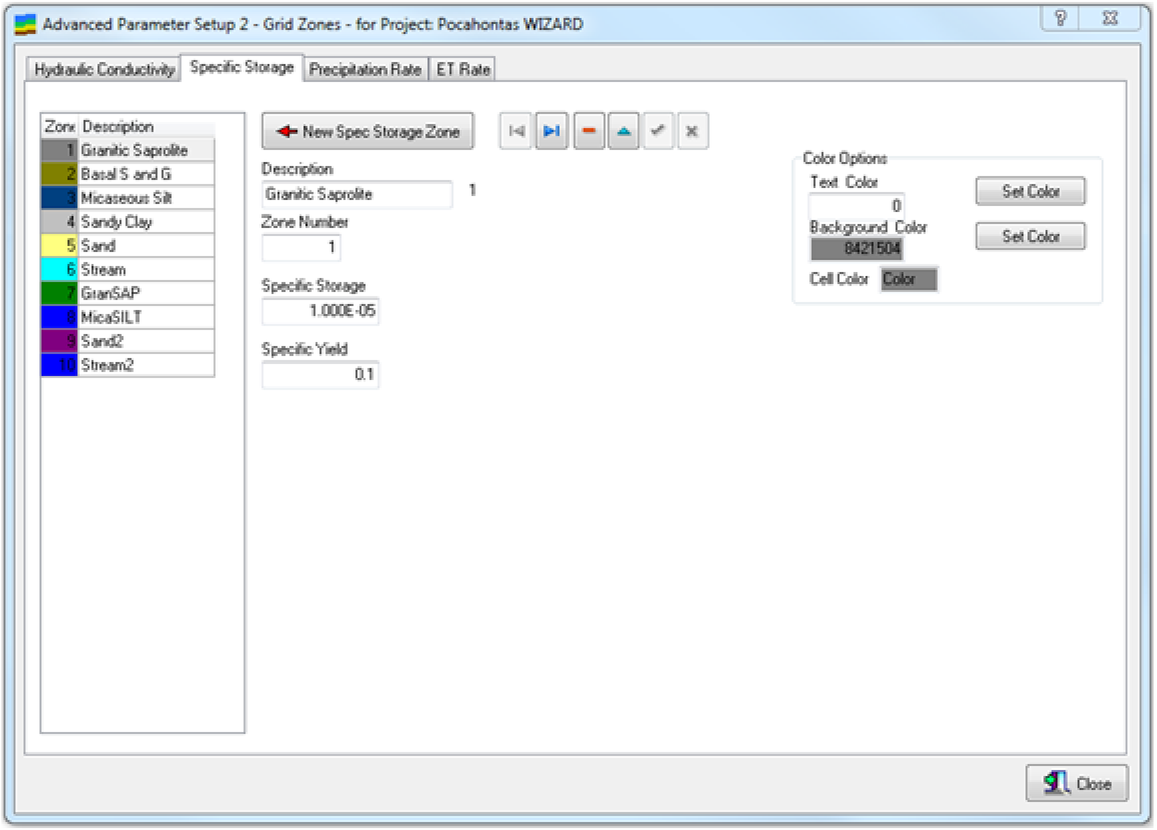
For example, the user creates the following three hydraulic conductivity Cell Zones: topsoil, a sandy subsoil, and saprolite. Since the storage properties differ for each of these substrates, the user must create a specific storage grid zone for each substrate. Once the user has created specific storage Grid Zones, every cell in an Advanced Model grid (see Advanced Grid Setup) must be assigned a value for specific storage and specific yield. When assigned zones in the model grid, the specific storage Grid Zones should correspond to the hydraulic conductivity zones assigned to those cells. Use the following procedure to create a grid zone for specific storage in the Specific Storage tab of the Grid Zones window (see figure below):

1. Click the 

button. In the Description box, delete the text '--' and replace it with a short but unique description (e.g., topsoil). Next, enter a zone number in the Zone Number box or leave it as the default, which is '1' for first zone created, '2' for the second zone created, and so on. This number is used to identify the specific storage grid zone and will appear when this grid zone is assigned to a cell or cells in the model grid.
2. Assign values for Specific Storage and Specific Yield in their respective boxes. For unconfined layers, the Specific Yield values should be set equal to the specific storage. Both values are unitless and should be between 0 and 1 depending on the site geologic conditions. For surface water and vegetation layers, it is recommended that the Specific Storage value be set to a value close to 1.0. See table in previous section for the range of specific yield values for common materials.
3. In the Color Options section, click 

to select the Text Color and Background Color to represent this grid zone for cells assigned in the model grid.
4. Click  to save. The description entered for the specific storage grid zone will appear in the Description list on the left side of the tab window.

Once a specific storage grid zone has been created, it can be assigned to cells in the Advanced Model Grid (see Advanced Grid Setup).

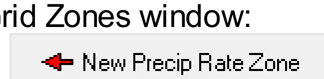


10.3.3 Precipitation Rate

Precipitation is defined as water that enters the model from above during the simulation period. For the Advanced Model, the precipitation rate (length/time) is utilized as input. Precipitation rate can easily be calculated from daily or monthly precipitation values in a weather station data set. When a precipitation rate grid zone is created, users can either choose a constant precipitation rate for all time steps or assign a Time Step Array containing a variable precipitation rate for each time step. Variable precipitation rate data must be entered in the Time Step Array in the Precip Rate 1 or Precip Rate 2 column. Once precipitation rate Grid Zones are created within a Project, they can be spatially assigned in layer 1 of the Advanced Model grid using the same process as other grid zone parameters discussed previously (see Advanced Grid Setup).

Important: Although precipitation rate Grid Zones must only be assigned to layer 1 during Advanced Model grid setup, the manner in which the model allows precipitation to enter all cells in the Advanced Model grid during the simulation period must be specified in the Precipitation Options in the Setup tab during Advanced Scenario setup.

Use the following procedure to create a precipitation rate grid zone in the Precip Rate tab of the Grid Zones window:

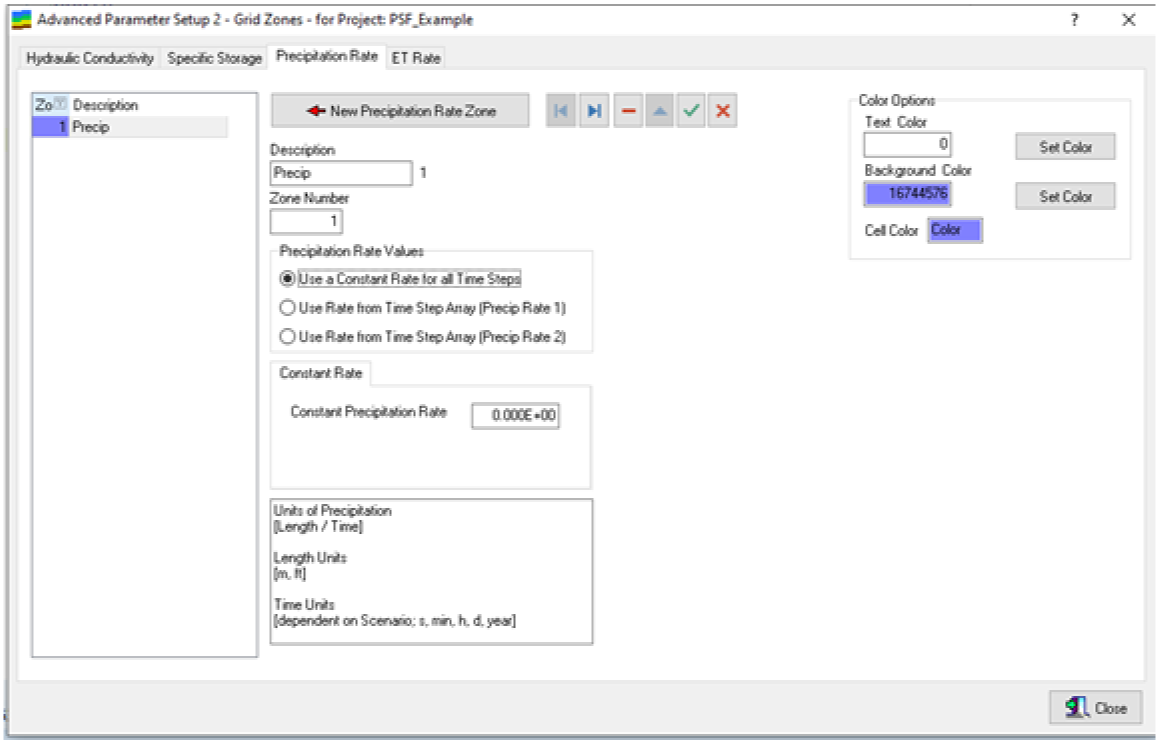
1. Click the 

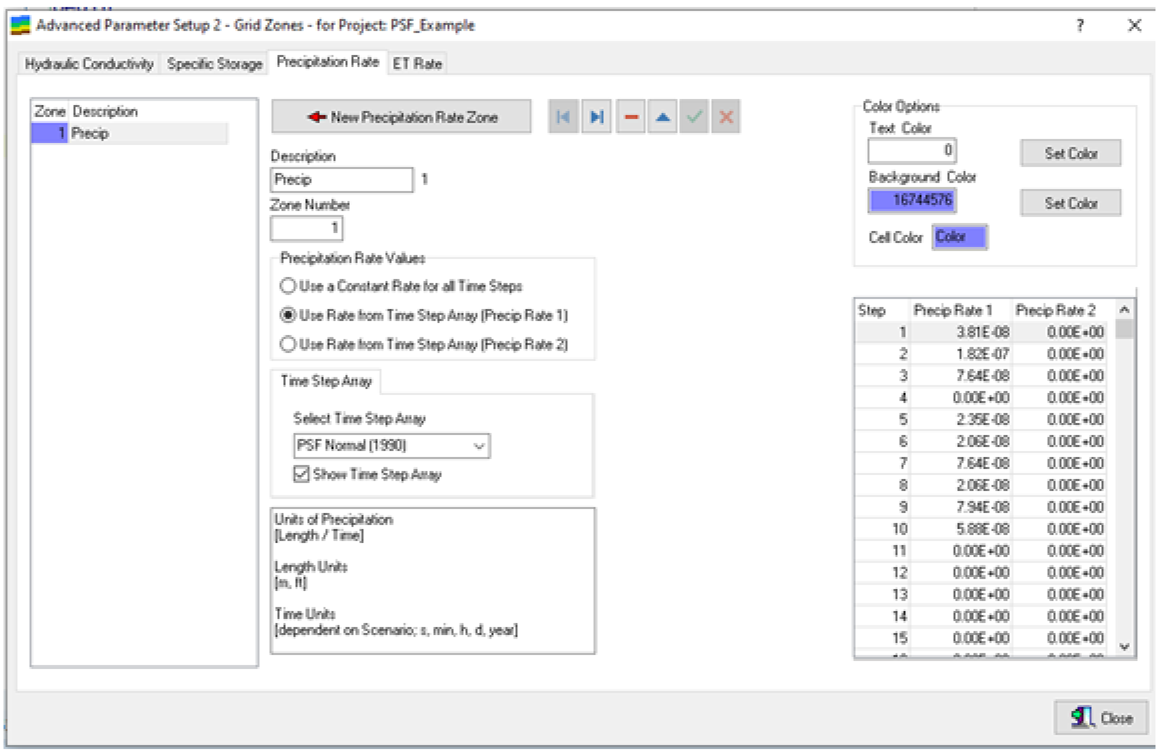
button. In the Description box, delete the text '--' and replace it with a short but unique description (e.g., precip 1). Next, enter a zone number in the Zone Number box or leave it as the default, which is '1' for first zone created, ‘2’ for the second zone created, and so on. This number is used to identify the precipitation rate grid zone and will appear when this grid zone is assigned to a cell or cells in the model grid.

2. In the Precipitation Rate Values section, select one of the following options:
   a. Use a Constant Vol. Rate for all Time Steps – This option will assign a constant precipitation rate for all time steps in the model simulation. If this option is selected, the user must then enter a precipitation rate (length/time) in the Constant Precip Rate box.
   b. Use Rate from Time Step Array (Precip Rate 1) – This option will apply the rates contained in the Precip Rate 1 column of the selected Time Step Array as precipitation in the model simulation. If this option is chosen, the user must select a Time Step Array from the Precip from Time Step Array drop-down menu.
   Note: Check the Show Time Step Array box to display the precipitation rate values in the selected Time Step Array as shown below. The selected Time Step Array should be the same as that selected in the General tab of Advanced Scenario setup.
   c. Use Rate from Time Step Array (Precip Rate 2) – This option will apply the rates contained in the Precip Rate 2 column of the selected Time Step Array as precipitation in the model simulation. If this option is chosen, the user must select a Time Step Array from the Precip from Time Step Array drop-down menu.
   Note: Check the Show Time Step Array box to display the values in the selected Time Step Array as shown below. The selected Time Step Array should be the same as that selected in the General tab of Advanced Scenario setup
3. In the Color Options section, click 

to select the Text Color and Background Color to represent this grid zone for cells assigned in the model grid.
4. Click  to save. The description entered for the precipitation rate grid zone will appear in the Description list on the left side of the tab window.

Once a precipitation rate grid zone has been created it can be assigned to layer 1 in the Advanced Model grid (see Advanced Grid Setup).



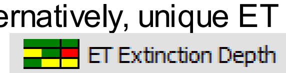


10.3.4 ET Rate

Evapotranspiration (ET) is defined as water removed from the system due to combined evaporation and plant transpiration. ET rates are assigned units of length per time and can be entered as a constant rate or as a variable (e.g., daily ET rate) rate for each time step in a selected Time Step Array (see Advanced Parameters 3 - Time Steps and Solvers). Values of ET can be calculated in the basic module of Wetbud using either the Penman-Monteith equation (recommended) or the Thornthwaite equation (see Potential Evapotranspiration Data). ET values from the basic module can be exported and converted into rates for the Advanced Model simulation.

In addition to ET rate, users must specify an ET surface elevation, an ET extinction depth, and an extinction depth layer.

ET surface elevation is defined as the elevation at which water withdrawal due to evapotranspiration is at its theoretical maximum. The ET surface elevation usually coincides with ground surface elevation or ponded surface water elevation.

The ET extinction depth is defined as the depth at which evapotranspiration from the water table has ceased, or the depth to which plant roots extend below the land surface. Extinction depths are based on the estimated root depth for a given vegetation type. When the depth of the water table in the model is beneath the extinction depth, ET ceases. When the water table is between the designated ET surface and the extinction depth, ET values vary linearly between the assigned ET rate at the ET surface and zero at the extinction depth (Harbaugh, 2005). In Wetbud, the extinction depth layer should be assigned to the model grid layer in which the extinction depth exists. Users can set a uniform ET extinction depth to apply to the whole model, which would be subtracted from the ET surface elevation. Alternatively, unique ET extinction depths may be set for every cell in the model by using the 

button in the Layers tab of the Advanced Scenarios window.

Once an ET rate grid zone is created, it can be assigned to the cells in the Advanced Model grid (see Advanced Grid Setup). Like precipitation rate Grid Zones, ET rate Grid Zones can only be added to Layer 1 of the Advanced Model grid.

Note: Prior to running an Advanced Model simulation, the user must also specify an ET Option in the Setup tab of Advanced Scenario setup.

Use the following procedure to create a grid zone for ET rate in the ET Rate tab of the Grid Zones window:

1. Click the 

button. In the Description box, delete the text '--' and replace it with a short but unique description (e.g., ET-2001, etc.) Next, enter a zone number in the Zone Number box or leave it as the default, which is '1' for first zone created, '2' for the second zone created, and so on. This number is used to identify the ET rate grid zone and will appear when this grid zone is assigned to a cell or cells in the model grid.
2. In the ET Rate Options section, select one of the following options:
   a. Use a Constant ET Rate - This option will assign a constant ET rate for all time steps in the model simulation. If this option is selected, the user must then enter the ET rate (length/time) and extinction depth layer in their respective boxes. In the

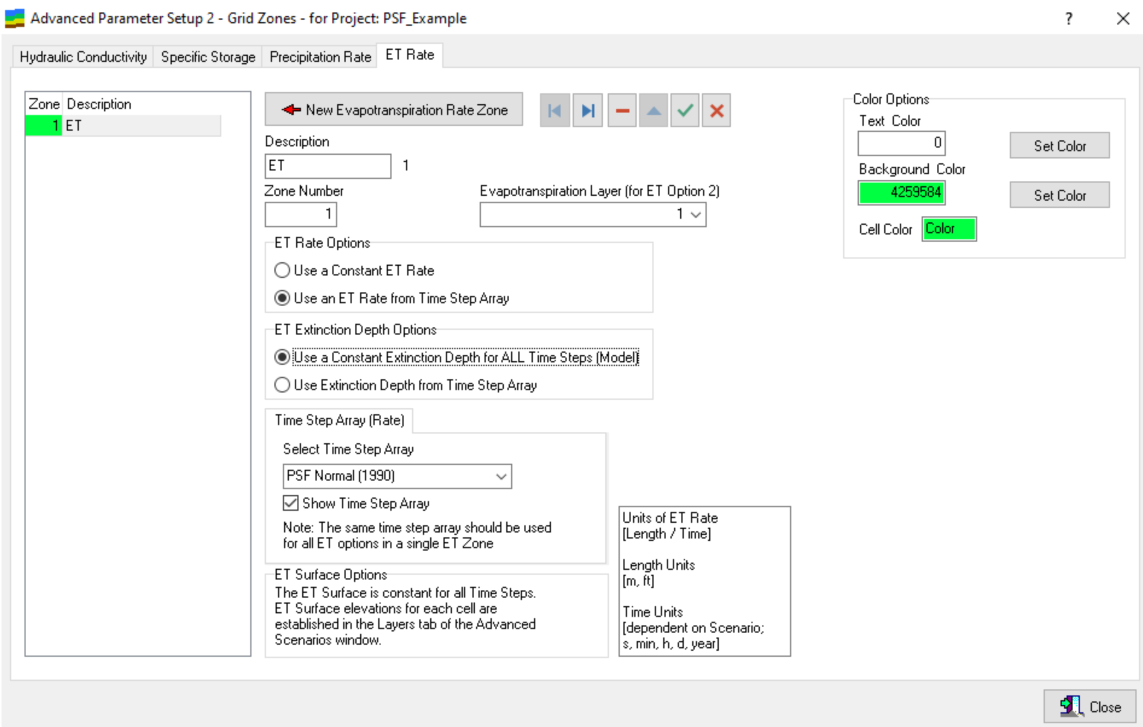
Extinction Depth Layer box, enter the layer number in which the ET extinction depth resides.
Note: If the ET extinction depth lies with multiple model layers (because of variable ET surface elevation), then the ET extinction depth layer should be entered as the layer in which the majority of ET extinction depth will reside.

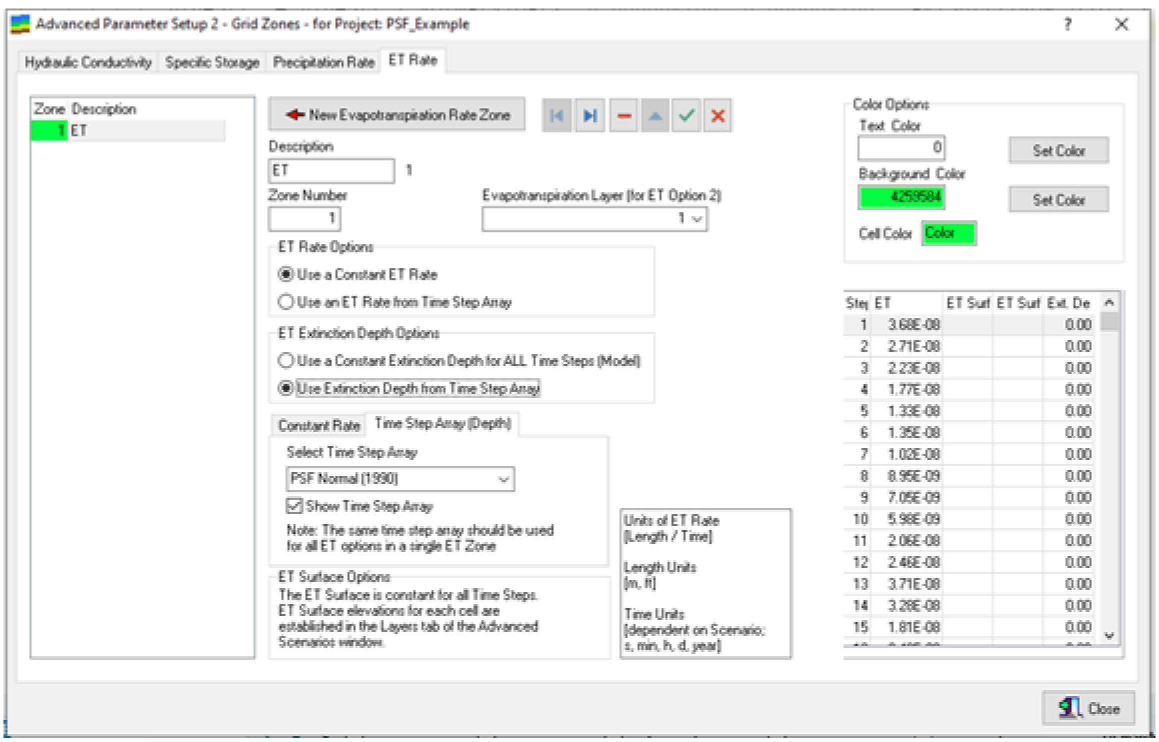
   b. Use ET Rate from Time Step Array - This option will use the ET rates assigned for each time step of a time step array. The time step array containing the ET rate data must then be selected from the ET from Time Step Array drop-down menu.
   Note: Check the Show Time Step Array box to display the ET Rate values in the selected Time Step Array as shown in column 2 of the table displayed in the figure below. The selected Time Step Array should be the same as that selected in the General tab of Advanced Scenario setup.

3. In the ET Surface Options section, select one of the following options:
   a. Use a Constant ET Surface for all time steps - This option will use the ET surface elevation entered in the ET Surface Elevation box in the Layers tab of Advanced Scenario Setup for all time steps in the model simulation.
   b. Use a Variable ET Surface Elevation from Time Step Array - This option will use the ET surface elevations assigned for each time step in the ET Surface Elevation of the time step array selected in Step 2. This option is useful for creating an ET surface that varies spatially and temporally during a model simulation.
   Note: When the Show Time Step Array box is checked, the ET surface elevation data for each time step is displayed in column 3 of the table shown in the figure below.
   a. Use a Variable ET Surface (Top Elev – ET Surface Diff) from Time Step Array – This option will determine the ET surface based on the top elevation of every cell in the model grid by subtracting the values entered for each time step in the ET Surface Elev Diff column of the time step array selected in Step 2. This option is useful for creating an ET surface that varies spatially and temporally during a model simulation.
   Note: When the Show Time Step Array box is checked, the ET surface elevation difference data for each time step is displayed in column 4 of the table shown in the figure below.
4. In the ET Extinction Depth Options section, select one of the following options:
   a. Use Constant Extinction Depth for all time steps - This option will use the ET extinction depth entered in the ET Extinction Depth box in the Layers tab of Advanced Scenario Setup for all time steps in the model simulation.
   b. Use Extinction Depth from Time Step Array - This option will use the ET extinction depths assigned for each time step in the ET Extinction Depth column of the time step array selected in Step 2.
   Note: When the Show Time Step Array box is checked, the ET extinction depth data for each time step is displayed in column 5 of the table shown in the figure below.
5. In the Color Options section, click 

to select the Text Color and Background Color to represent this grid zone for cells assigned in the model grid.
6. Click  to save. The description entered for the ET rate grid zone will appear in the Description list on the left side of the tab window.

Once an ET rate grid zone has been created it can be assigned to cells in the Advanced Model grid (see Advanced Grid Setup).





10.4 Advanced Parameters 3 - Time Steps and Solvers

In Wetbud, Time Step Arrays and Solvers are necessary to complete the MODFLOW simulation for an Advanced Scenario model. Time Step Array data control model inputs and outputs, and ultimately determine the length and number of time steps in the simulation period. Each Advanced Scenario created within a Project must be assigned a Time Step Array in the General tab of Advanced Scenario setup. Data in the Time Step Array assigned in the General tab must then be applied to Cell Zones (see Advanced Parameters 1 – Cell Zones) and Grid Zones (see Advanced Parameters 2 – Grid Zones), which are used to parameterize cells in each layer of the Advanced Model grid (see Advanced Grid Setup).

As stated earlier, solvers are mathematical techniques used in Advanced Models to calculate the solution for the system of finite-difference equations (Harbaugh, 2005). Solver Sets contain parameters that are used to constrain the MODFLOW simulation. Currently one solver package is available in Wetbud: the NWT (Newton) solver. To run an Advanced Scenario model simulation, the user must create a Solver Set and assign it in the Setup tab of Advanced Scenario setup (see the Setup Tab section in Advanced Scenarios).

To create a Time Step Array and/or Solver Set, select Advanced Parameters 3 – Time Steps and Solvers from the Advanced Models drop-down menu in the Wetbud home screen. The Advanced Parameters 3 – Time Steps and Solvers window has two tabs:

- Time Steps
- NWT Solver

10.4.1 Time Step Arrays

When designing a transient Advanced Scenario Model simulation in Wetbud, the user must first determine the number of time steps to be simulated. For example, to conduct a 1-year water budget using daily time steps, the number of time steps would be 365 (366 for leap years). Wetbud then breaks up each time step into sub-steps; the water balance equations are calculated at each sub-step. For each time step (e.g., each day) in the model simulation, the user must designate boundary conditions, water inputs, and water outputs in a Time Step Array.

For each Time Step Array, Wetbud can manage the following time-varying data that can be subsequently utilized in different parameter definition arrays:

1. Time Step Length
2. Transient Flow (yes/no)
3. Precip Rate 1
4. Precip Rate 2
5. ET Rate
6. ET Extinct. Depth (Extinction Depth)
7. Runoff Rate
8. Well Influx Rate

9. Head IN
10. Head OUT
11. Stream Elevations (Heads)
12. Drain Elevation
13. Drain Conductance

Each row in a Time Step Array contains data for a given time step. The number of rows in a Time Step Array should correspond to the number of time steps in the model simulation.

Time Step Array Data

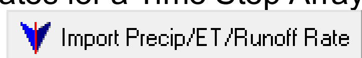
Once a new Time Step Array has been created, data for all time steps can be entered manually or imported one column at a time from an existing spreadsheet.

Note: In Wetbud, the terms 'time step' and 'sub-step' represent the MODFLOW terminology for 'stress period' and 'time step', respectively. Explanations of each data column and data importing procedures necessary for Time Step Array creation and setup are provided below:

1. Time Step Length (column 3) – This column is used to assign the length of time to be simulated in each model time step. For example, if each time step represents 1 day and model units are meters and seconds, then a value of 86400 should be entered in every row of the Time Step Length column.
   Note: The time step length should be entered in the same time unit that has been designated in the General Tab section in Advanced Scenario setup (see Advanced Scenarios).
2. Transient (column 4) – The Transient column is used to specify whether a time step will be steady-state (value = 0) or transient (value = 1). Usually, the first time step of an Advanced Model simulation is steady-state, followed by a transient simulation for all remaining time steps. Running a steady-state simulation for the first time step is useful for model convergence and helps ensure that initial conditions of the transient model simulation are established correctly for the intended model design.
3. Precip Rate 1 (column 5) – This column contains the precipitation rate values to be included as input for a given time step during the simulation period. To include precipitation data entered in the Precip Rate 1 column in an Advanced Model simulation, the data must be assigned to a precipitation rate grid zone created within the selected Project and assigned to layer 1 in the model grid (see Section Advanced Parameters 2 – Grid Zones for more information). When setting up a time step array, these values should be entered in the model units specified in the Units tab in Advanced Scenario setup (see Advanced Scenarios). For example, if units are specified as meters and seconds in a model with daily time steps of 86,400 seconds each, divide the precipitation value (meters) by time step length (seconds) to determine the precipitation rate for a given time step (e.g., 0.02 m of daily precipitation / 86,400 seconds = 2.3×10^{-7} meters/second = precipitation rate for time step). In Wetbud, users can automatically import precipitation data and convert to precipitation rates for a Time Step Array from an existing NOAA weather station

record using the 

tool. See Importing Precipitation/Runoff Rates from NOAA Station Data section below for more information.

4. Precip Rate 2 (column 6) – This column contains the precipitation rate values to be included as input for a given time step during the simulation period. To include precipitation data entered in the Precip Rate 2 column in an Advanced Model simulation, the data must be assigned to a precipitation rate grid zone created within the selected Project and assigned to layer 1 in the model grid (see section Advanced Parameters 2 – Grid Zones for more information). When setting up a time step array, these values should be entered in the model units specified in the Units tab in Advanced Scenario setup (see Advanced Scenarios). For example, if units are specified as meters and seconds in a model with daily time steps of 86400 seconds each, divide the precipitation value (meters) by time step length (seconds) to determine the precipitation rate for a given time step (e.g., 0.02 m of daily precipitation / 86,400 seconds = 2.3×10^{-7} meters/second = precipitation rate for time step). In Wetbud, users can automatically import precipitation data and convert to precipitation rates for a Time Step Array from an existing NOAA weather station record using the 

tool. See Importing Precipitation/Runoff Rates from NOAA Station Data section below for more information.
5. ET Rate (column 7) - This column contains the ET rate to be included as a water output for a given time step. These values should be entered in the model units specified in the Units tab in Advanced Scenario setup. Data entered in the ET Rate column must then be assigned to an ET rate grid zone created within the selected Project (see Advanced Parameters 2 – Grid Zones for more information). In Wetbud, users can automatically import previously calculated ET data and convert to ET rates for a Time Step Array from an existing NOAA weather station record using the 

tool. See Importing Precipitation/Runoff Rates from NOAA Station Data section below for more information.
6. ET Extinction Depth (column 8) – An ET Extinction Depth must be assigned for every time step in an Advanced Scenario model simulation when selecting the Use Extinction Depth from Time Step Array option when creating an ET Rate grid zone (see Advanced Parameters 2 – Grid Zones).
Note: Users who select the Use a Constant Extinction Depth for all Time Steps option in ET Rate grid zone setup (see Advanced Parameters 2 – Grid Zones for more information) are not required to assign an ET extinction depth in the Time Step Array designated in the General tab for the Advanced Scenario model (see the General Tab section in Advanced Scenarios). If the Use a Constant Extinction Depth for all Time Steps option in ET Rate grid zone setup is selected, then the ET extinction depth will be as specified in the Layers tab of Advanced Scenario Setup (see Advanced Scenarios).
7. Runoff Rate (column 9) - This column contains the runoff rate that can be included as an additional water input for a given time step. These values should be entered in the model units specified in the General Tab section in Advanced Scenarios. In Wetbud, users can automatically generate and import converted runoff rate data for their site from an existing NOAA weather station precipitation record using the

tool. See [Importing Precipitation/Runoff Rates from NOAA Station Data] section below for more information. To include runoff data entered in the Runoff Rate column in an Advanced Model simulation, the data must be assigned to a Well cell zone created within the selected Project and assigned to cells in the model grid (see Advanced Parameters 1 – Cell Zones for more information).

8. Well Influx Rate (column 10) – The well influx column can be used to introduce additional water inputs (e.g., surface water entering through a culvert) into an Advanced Scenario simulation. The well influx rate for each time step must be calculated externally by the user and entered as a rate in the model units specified in the General Tab in Advanced Scenarios. To include well influx data entered in the Well Influx Rate column in an Advanced Model simulation, the data must be assigned to a Well cell zone created within the selected Project and assigned to cells in the model grid (see section Advanced Parameters 1 – Cell Zones for more information).
9. Head IN (column 11) – The Head IN column contains head elevation values that are applied when selecting the Use Rates as defined in Time Step Array (HEAD IN) option when creating a general head cell zone (see Advanced Parameters 1 – Cell Zones for more information). The head elevation values entered in this column should represent the head elevations on the up-gradient end of the site being modeled. Head elevation values should be realistic and based on layer elevations assigned to the model grid (see the Layers Tab section in Advanced Scenarios).
   Note: Users who select the Use a Constant Value for all Time Steps option in General Head cell zone setup (see Advanced Parameters 1 – Cell Zones for more information) are not required to enter head elevation values in the Head IN column in the Time Step Array designated in the General tab for the Advanced Scenario model (see the General Tab section in Advanced Scenarios).
10. Head OUT (column 12) - The Head OUT column contains head elevation values that are applied when selecting the Use Rates as defined in Time Step Array (HEAD OUT) option when creating a general head cell zone (see Advanced Parameters 1 – Cell Zones for more information). The head elevation values entered in this column should represent the head elevations on the down-gradient end of the site being modeled. Head elevation values should be realistic and based on layer elevations assigned to the model grid (see the Layers Tab section in Advanced Scenarios). This option is available to users who wish to represent the down-gradient end of their model grid as a general head boundary in lieu of a drain.
   Note: Users who select the Use a Constant Value for all Time Step option in General Head cell zone setup (see Advanced Parameters 1 – Cell Zones for more information) are not required to enter head elevation values in the Head OUT column in the Time Step Array designated in the General tab for the Advanced Scenario model (see General Tab).
11. Stream Elevation (column 13) - The Stream Elevation column contains elevation values that are applied when selecting the Use Values as defined in Time Step Array (Stream Elevation) option when creating a general head cell zone (see Advanced Parameters 1 – Cell Zones for more information). The head elevation values entered in this column should represent the water elevation in the stream adjacent to the wetland. These values can be directly imported or generated or imported through the Import Stream Elevations for GHB tool in the Time Step Array window.

12. Drain Elevation (column 14) - The Drain Elevation column contains elevation value that are applied when selecting Use Conductance and Elevation from Time Step Array option when creating a drain return cell zone (see Advanced Parameters 1 – Cell Zones for more information). The elevation values entered in this column should represent the water elevation in the drain return in the wetland.
13. Drain Conductance (column 15) - The Drain Conductance column contains conductance values that are applied when selecting Use Conductance and Elevation from Time Step Array option when creating a drain return cell zone (see Advanced Parameters 1 – Cell Zones for more information). The conductance values entered in this column should represent the drain return conductance variation with time.

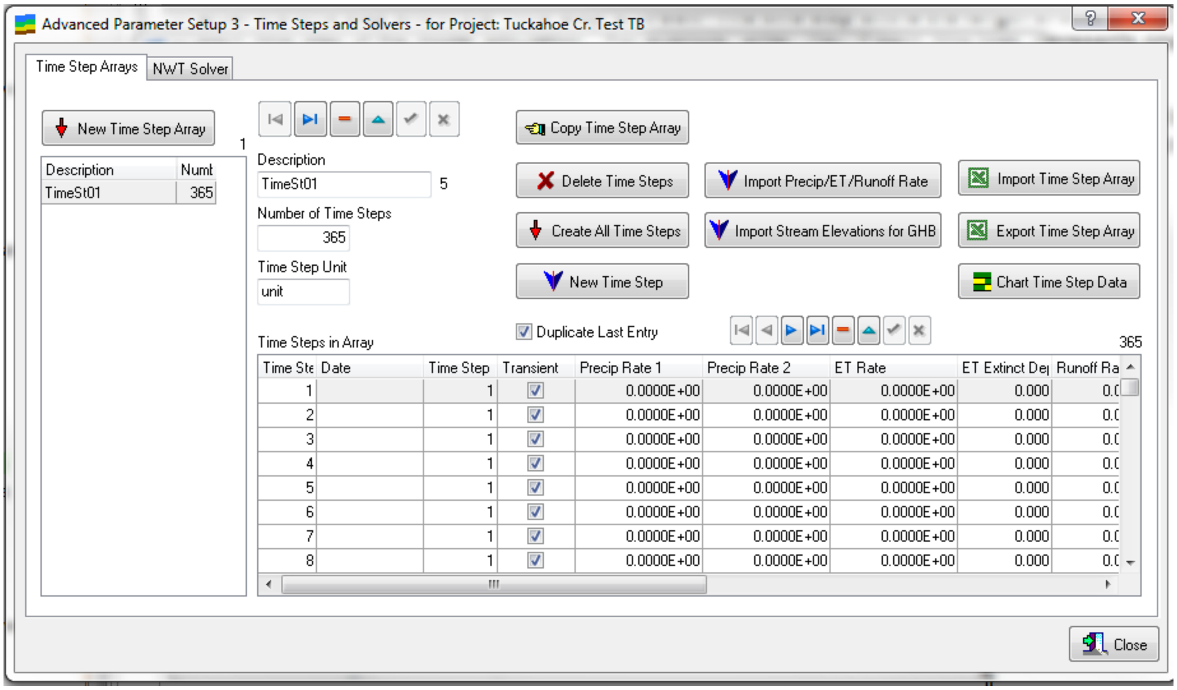
More information about each parameter contained in Time Step Arrays can be found in the MODFLOW-2005 manual (Harbaugh, 2005) or through the USGS software package website https://water.usgs.gov/ogw/modflow/MODFLOW-2005-Guide/index.html

Creating a Time Step Array

To create a Time Step Array for the selected Project:

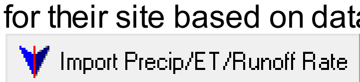
1. Select Advanced Parameters 3 – Time Steps and Solvers from the Advanced Models drop-down menu in the Wetbud home screen.
2. In the Time Steps tab of the Advanced Parameter Setup 3 – Time Steps and Solvers window below, click 

. In the Description box, enter a brief description to identify the Time Step Array.
3. Enter the number of time steps you wish to create in the Number of Time Steps box. For example, if you wish to simulate every day for an entire year, enter 365 in the time steps box.
4. Enter the time step unit in the Time Step Unit box. The time step unit is the length of time to be simulated in each time step of the model simulation. For example, enter ‘Day’ if each time step represents one day, and so forth.
5. Click  to save. The description and number of time steps will appear in the Time Step Array list on the left side of the tab window. At this point, the user can proceed to manually enter time step data or use the import tools.



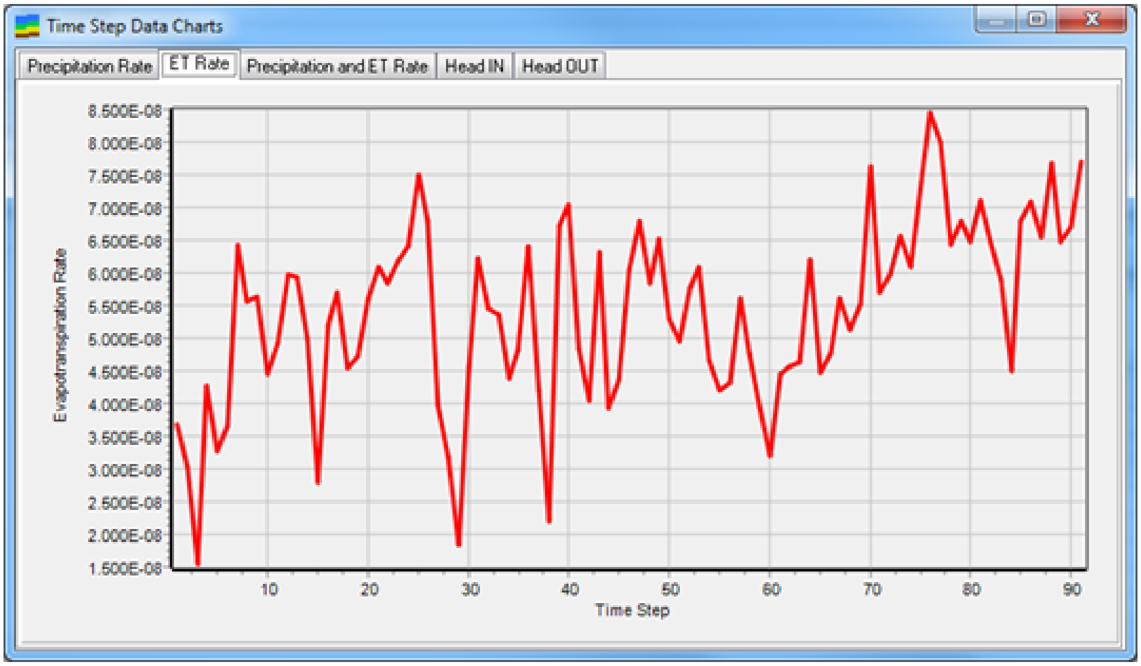
Manual Entry of Time Step Data

To create a new time step in a Time Step Array:

1. Click . This button will generate default entries for all columns of the new time step. The default values for Number of Sub-steps (column 3) and Time-step Multiplier (column 4) are recommended for all models and should not be changed by the user unless they have previous experience with MODFLOW transient models.
2. To designate a time step as ‘steady-state’, uncheck the box in the Transient column (this should only apply to the first time step in an otherwise transient model simulation).
3. Enter values for Time Step Length (column 2) and all additional water inputs and water outputs (columns 6-13) that you wish to include in the model simulation for the selected time step. If precipitation, ET, or runoff rate values are unknown, users can automatically generate and import converted precipitation, ET, and runoff rate data for their site based on data from an existing NOAA weather station record using the  tool. See Importing Precipitation/Runoff Rates from NOAA Station Data section below for more information.
   Note: Prior to importing ET data into a time step array, ET must be calculated in a basic scenario analysis.
4. Repeat this procedure until a record for all time steps has been created.
   Note: To duplicate ALL records for the previous time step, check the Duplicate Last Entry box before creating the next time step. Make sure to adjust the time step number in the Time Step column when duplicating time steps.

5. To view all time step data in a graphical format, click 

and select from the tabs in the Time Step Data Charts window.



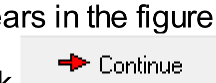
Importing Time Step Data

Prior to importing time step data, the user must first create an entry for each time step in the new Time Step Array by clicking 

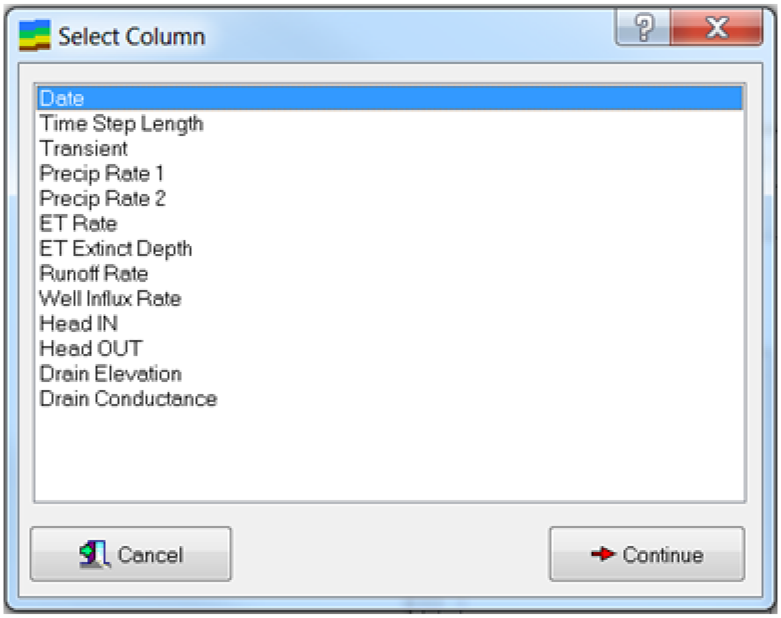
. Next, click ‘OK’ from the prompt to confirm the total number of time steps that will be created. Default entries for all time steps will now appear as shown in the figure below. As stated earlier, the default values for Number of Sub-steps (column 3) and Time-Step Multiplier (column 4) are recommended for all models and should not be changed by the user unless they have previous experience with MODFLOW transient models. To designate a time step as ‘steady-state’, uncheck the box in the Transient column (this should only apply to the first time step in an otherwise transient model simulation).

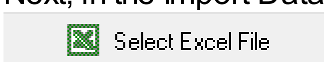
Once entries have been created for the number of time steps specified in the Number of Time Steps box, the user may import time step data one column at a time using the following procedure:

1. Click 

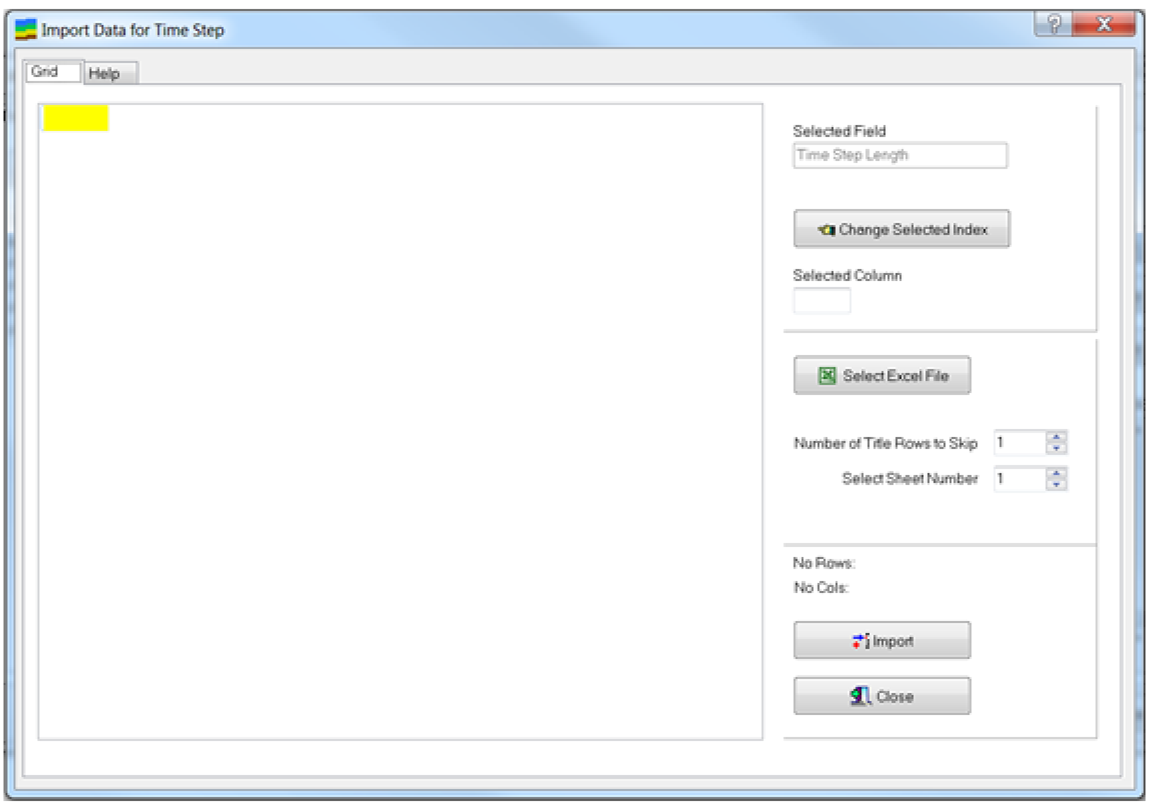
. In the Select Column window that appears in the figure below, select the column for which you wish to import data and click 

.



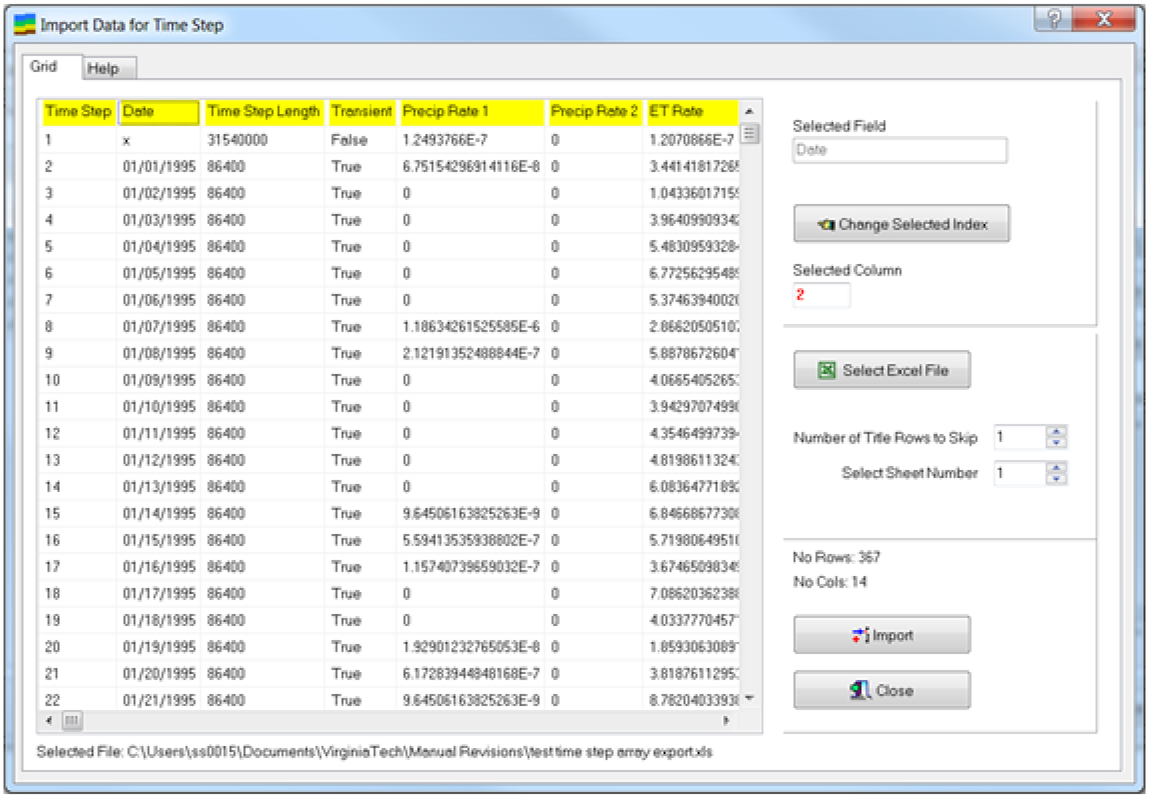
2. Next, in the Import Data for Time Step window as shown in the figure below, click 

and select the file from which the data will be imported.



3. A table of all data contained in the selected file will now appear in the Import Data for Time Step window as shown in the figure below. Click on the column heading that

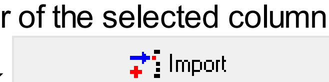
contains the data for the column selected in Step 1. The number of the selected column will appear as red text in the Selected Column box.



4. Now, click 

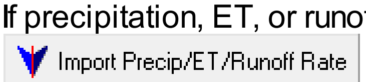
. Click 'OK' from the prompt to confirm the number of imported data points.
5. To import time step data for an additional column, click 

, select a new column in the Select Column window (see above figure), and click 

. In the Import Data for Time Step window, click on the column heading that contains the data for the column selected. The number of the selected column will appear as red text in the Selected Column box. Now, click 

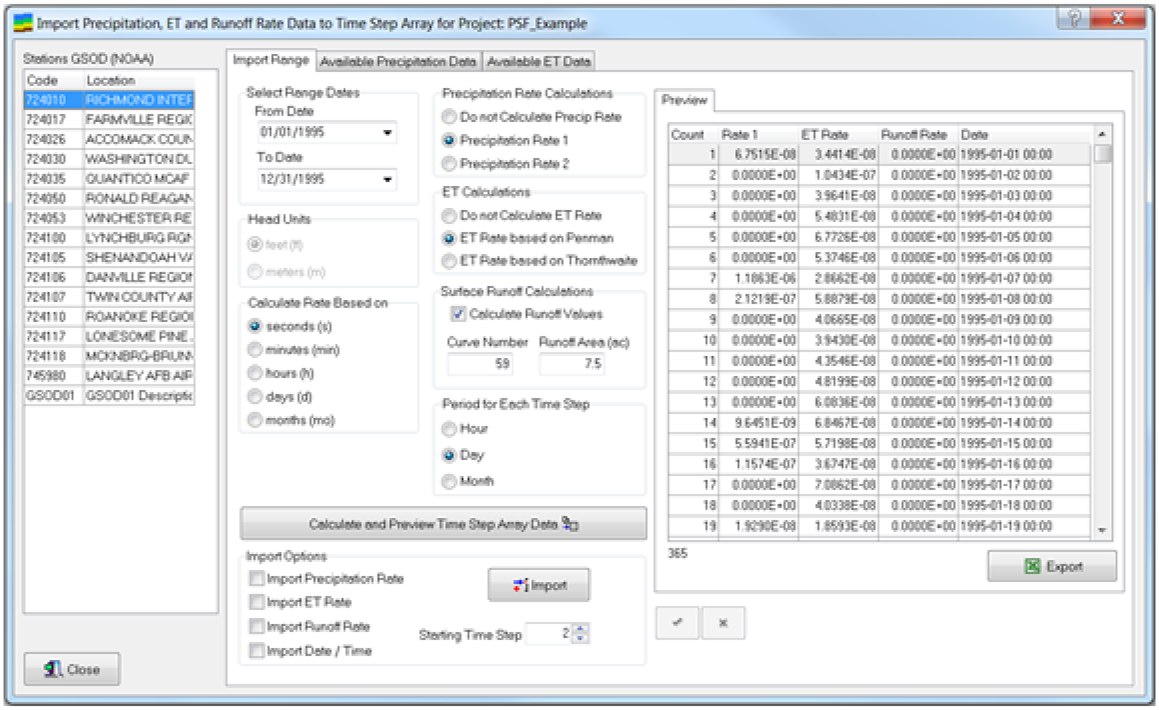
. Click 'OK' from the prompt to confirm the number of imported data points. Repeat this step until all data have been imported. The newly imported data can be viewed in the Time Step tab of the Advanced Parameter Setup 3 – Time Steps and Solvers window by closing the Import Data for Time Step window.
Note: Users can choose to omit Step 5 and continue importing data using steps 1-4 in the procedure outlined above.

Importing Precipitation/Runoff Rates from NOAA Station Data

If precipitation, ET, or runoff rates are unknown, users can use the 

tool to import converted precipitation and ET data and/or calculate and import runoff data based on precipitation data from an existing NOAA weather station record into a Time Step Array. Entries for all time steps must be created in the Time Steps tab before using the Import Precip/ET/Runoff Rate tool.

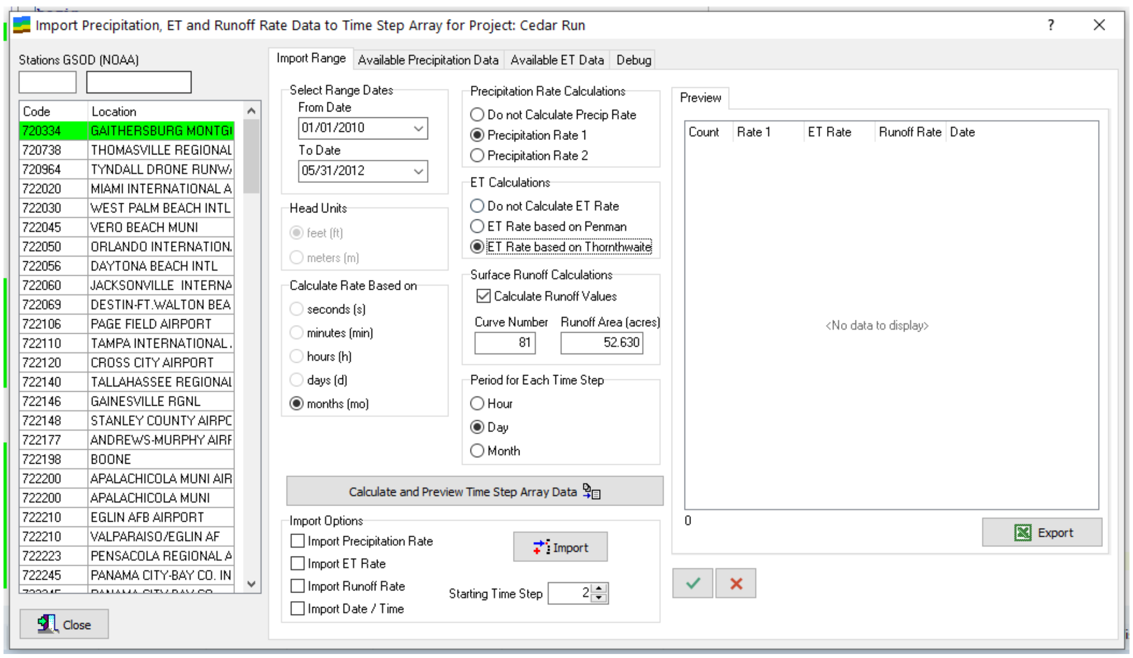
To begin, first click Import Precip/ET/Runoff Rate, which will display the Import Precipitation and Runoff Rate Data to Time Step Array window as shown in the figure below.



Then use the following procedure to import precipitation rate and/or runoff rate data from a NOAA station record:

1. Select the station from the Station (NOAA) list on the left side of the window.
2. Choose the range of dates from which to import data in the From Date and To Date boxes in the Select Range Dates section.
   Note: Use the Available Data tab to view records of available precipitation and ET data for the selected station.
3. Select the units of length and time into which the data will be converted in the Convert Head to and Calculate Rate Based on sections, respectively.
   Note: Units of length and time should be the same units as designated in the General Tab section of the Advanced Scenario setup (see Advanced Scenarios).
4. In the Precipitation Rate Calculations section, select one of the following options:
   a. Do not calculate Precip Rate – select this option if you do not wish to calculate precipitation rates for the selected range of dates.
   b. Precip Rate 1 – select Precip Rate 1 if you wish to import calculated precipitation rates for the selected range of dates into the Precip Rate 1 column of the time step array.
   c. Precip Rate 2 – select Precip Rate 2 if you wish to import calculated precipitation rates for the selected range of dates into the Precip Rate 2 column of the time step array.

5. In the ET Calculations section, select one of the following options:
    a. Do not calculate ET Rate – select this option if you do not wish to calculate ET rates from existing ET data for the selected range of dates.
    b. ET Rate based on Penman – select this option if you wish to import ET rates based on existing Penman ET data for the selected range of dates.
    Note: Penman ET for the selected range of dates must be calculated in a Basic Scenario analysis before ET rates can be converted and imported into a time step array. All available ET data for the selected station can be viewed in the Available ET Data tab.
    c. ET Rate based on Thornthwaite – select this option if you wish to import ET rates based on existing Thornthwaite ET data for the selected range of dates.
    Note 1: Thornthwaite ET for the selected range of dates must be calculated in a Basic Scenario analysis before ET rates can be converted and imported into a time step array. All available ET data for the selected station can be viewed in the Available ET Data tab.
    Note 2: When this option is select only monthly rates can be calculated as shown in the figure below.

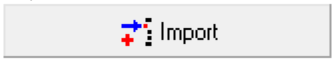


6. In the Surface Runoff Calculations section, check the Calculate Runoff Values box, enter the NRCS Curve Number for Runoff for the watershed and enter Runoff Area (ac), which specifies the total area of the watershed (in acres) that contributes direct surface runoff to the site. For watersheds with multiple land covers or soils, an area-weighted composite curve number should be entered. Users who do not wish to import surface runoff data should omit this step.
    Note: Curve Number for Runoff and Runoff Area (ac) must be determined externally by the user.
7. In the Period for Each Time Step section, select the time period (day or month) the precipitation, ET, and/or runoff rates will represent. Select Day if each time step represents one day. Select Month if each time step represents one month. Selecting

the Month option will calculate a rate based on total monthly precipitation, ET, and/or runoff for each full month included in the selected range dates.
Note: The Month option must be selected if ET rates are calculated based on Thornthwaite ET.

8. Next, click  to save the selected calculation options. Now, click 

to review the precipitation, ET, and/or runoff rates calculated from the selected station for the specified range of dates. A table containing these data will be displayed in the three columns on the right side of the window, as shown in the figure above. Note that precipitation and/or runoff rates displayed in the preview table may be exported as an Excel Spreadsheet by clicking 

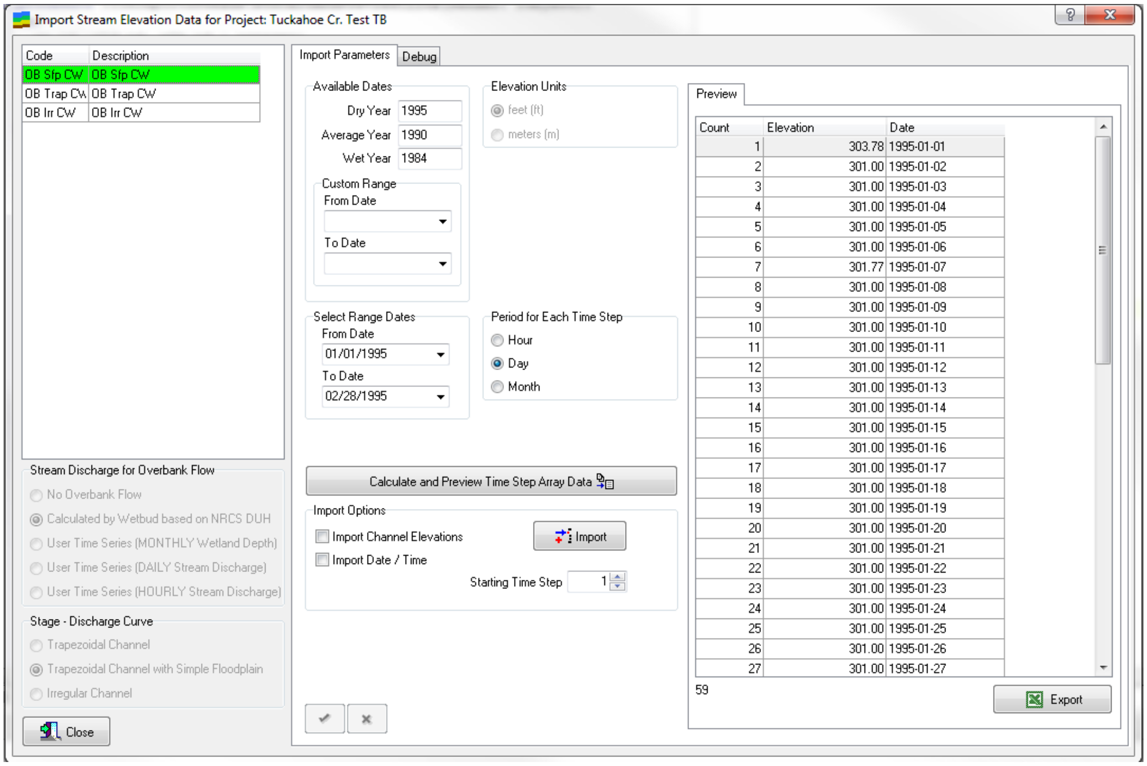
. The user must then name and save the file.
9. Next, in the Import Options section, check the Import boxes for the data you wish to import. To import these data for a specific portion of a Time Step Array, adjust the number in the Starting Period box (default = 1), which corresponds to the time step number of the first precipitation rate and/or runoff rate data point. For example, if your Time Step Array contains a total of 60 time steps but you only wish to import precipitation rate and/or runoff rate data for time steps 31-60, then enter 31 in the Starting Period box before clicking the Import button. Click 

to import the data into the time step array.
10. Close the Import Precipitation, ET, and Runoff Rate Data to Time Step Array window. The newly imported data can be viewed in their respective columns in the Time Step tab of the Advanced Parameter Setup 3 – Time Steps and Solvers window.
Note: Precipitation rates must be assigned to a Precip Rate grid zone and assigned to layer 1 of the Advanced Model grid to be included as a water input. ET rates must be assigned to an ET Rate grid zone and assigned to layer 1 of the Advanced Model grid to be included as water output (see Advanced Parameter Setup 2 – Grid Zones). Runoff rates imported into a Time Step Array must be assigned to a Well cell zone (see Wells section in Advanced Parameter Setup 1 – Cell Zones) and placed in the Wetbud Advanced Model grid (see Advanced Grid Setup) to be included as water input.

Importing Stream Elevation Data for Overbank Flow

If a GHB condition needs to be established represent flow from and into the stream adjacent to the wetland, then stream elevations should be generated for all the time steps in the simulation. The stream elevations that will populate the time step array are typically generated from the values created for Basic Scenario models for the same wetland. Click 

to invoke the import tool and the window shown below will appear.



The top left panel in the figure above shows the Basic Scenarios available for the currently selected project. If there are no scenarios visible in this panel, then stream elevations cannot be generated. Once a scenario is selected the bottom left panel shows the stream overbank settings for the basic scenario. The user cannot change these settings as they pertain to the basic model. The middle top panel shows the available years and dates for the selected scenario. The user can then select a date range which is covered by the available dates. The Period for Each Time Step depends on how the time step array is setup. If each record in the time step array corresponds to days, then Days should be selected in the Period for Each Time Step option.

The user should then click Calculate and Preview Time Step Array Data and the program will calculate the elevations at each time step and show them in the grid on the right panel. The final step is to import the data to the time step array (click Import) and close the window.

Additional Tools in the Time Step Array Tab

1. To view all time step data in a graphical format, click Chart Time Step Data and select from the tabs in the Time Step Data Charts window.
2. To export a Time Step Array as an Excel file, click Export, then name and save the file.

3. To copy a Time Step Array, click Copy Time Step Array and select 'OK' from the prompt. A copy of the Time Step Array will appear in the Time Step Array list with the text 'copy-' preceding the original description.
4. To delete all time steps in a Time Step Array, click Delete Time Steps and select 'OK' from the prompt to confirm. To completely delete a Time Step Array, select it from the Time Step Array list, click − and select 'Yes' from the prompt to confirm.

Solvers

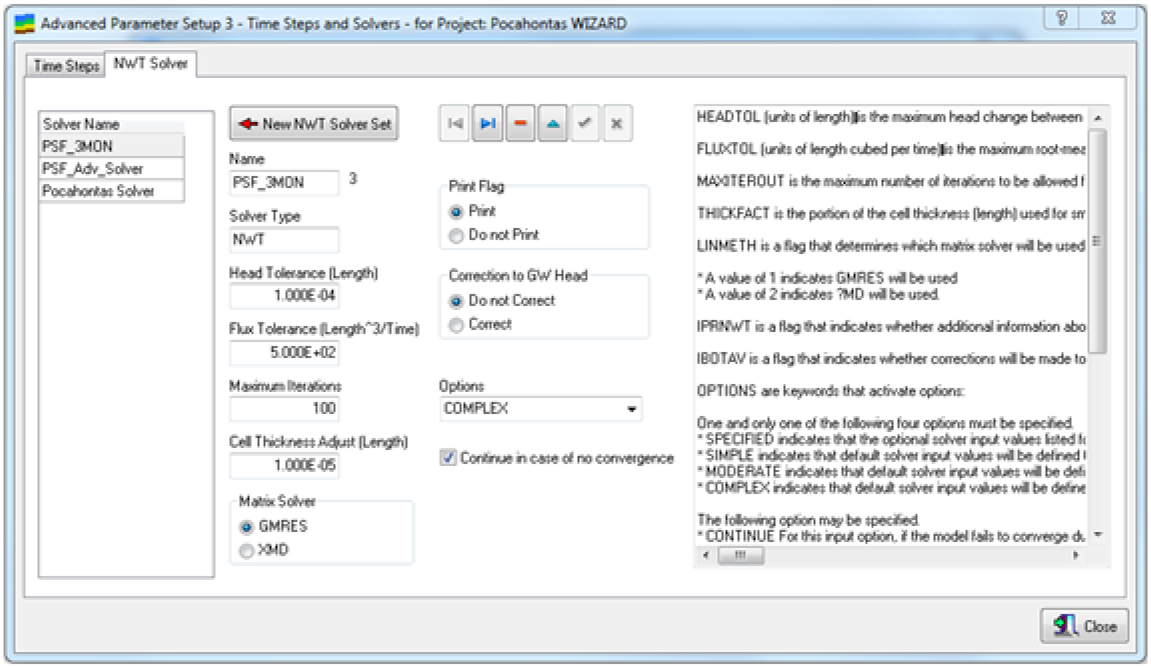
Currently, Wetbud is compatible with the NWT (Newton) solver package, because it is designed for simulations that involve the drying and rewetting of cells, which is common when simulating the full range of a wetland hydroperiod. Before running an Advanced Model simulation, the user must create a Solver Set for the solver and assign it in the Setup tab of Advanced Scenario setup.

Note: Users are also required to select a flow package in the Setup tab of Advanced Scenarios. As the NWT solver is currently only compatible with the UPW flow package, UPW flow package is selected by default. To create a Solver Set for the selected Project, first select Advanced Parameters 3 – Time Steps and Solvers from the Advanced Models drop-down menu in the Wetbud home screen. Next, in the Advanced Parameters 3 – Time Steps and Solvers window, select the NWT Solver tab to create a Solver Set.

10.4.2 NWT Solver

To create a new NWT Solver Set in the NWT Solver tab, first click New NWT Solver Set. The text 'NWTxx' will appear in the Name box and defaults values will populate the boxes for all additional solver parameters. The default values are recommended and should not be changed by the user unless they have previous experience with MODFLOW solver packages. Rename the Solver Set (optional) and click ✓ to save. The new Solver Set will appear in the list on the left side of the window. Once an NWT Solver Set is created, it can be selected in the Setup tab of Advanced Scenario setup (see Advanced Scenarios). For additional information about NWT solver parameters refer to https://water.usgs.gov/ogw/modflow-nwt/MODFLOW-NWT-Guide/index.html?nwt_newton_solver.htm.

Note: The NWT Solver selected in the Setup tab of Advanced Scenario setup is only compatible with the UPW flow package which must also be selected.



10.4.3 Deprecated Features

Note: The following columns have been removed from the Time Step Array form in recent versions of Wetbud:

1. Time Step (column 1) – Values entered in each row of this column pertain to the time step in the model simulation, where the first time step has a value of '1'.
2. Number of Sub-steps (column 3) – A specified number of sub-steps are computed for each time step in the model simulation. The Number of Sub-steps represents the number of iterations allotted within each time step for the model to converge on a solution. The number of sub-steps can range from 1-100. A greater number of sub-steps will increase the accuracy of the model solution but will increase the time needed to complete the simulation. For inexperienced users, a sub-step value of less than 10 for every time step is recommended (default sub-step value = 3).
3. Time Step Multiplier (column 4) – The Time Step Multiplier is the ratio of the length of each sub-step to the length of the preceding sub-step. The time step multiplier should be greater than 1. For inexperienced users, the default time step multiplier value of 1.2 is recommended for all time steps.
4. ET Surface Elevation (column 9) – This column contains ET surface elevation data for each time step. This data column is applied to the model grid when the Use Variable ET Surface from Time Step Array option is selected when creating an ET Rate grid zone (see ET Rate in Advanced Parameter Setup 2 – Grid Zones).
   Note: This data column is not required when the Use Constant ET Surface for all Time Steps option is selected when creating an ET Rate grid zone. If the Use Constant ET Surface for all Time Steps option is selected, then the ET surface elevation will be as specified in the Layers tab of Advanced Scenarios.
5. ET Surface Elevation Difference (column 10) – This column contains ET surface elevation difference data for each time step. This data column is used to establish the ET surface elevation for each time step when the Use Variable ET Surface (Top

Elev – ET Surface Diff) from Time Step Array option is selected when creating an ET Rate grid zone (see ET Rate in Section Advanced Parameter Setup 2 – Grid Zones). Thus, the ET surface elevation for each time step is calculated for each cell by subtracting the value in this column from the top elevation of each cell in layer 1 of the Advanced Model grid.
Note: This data column is not required when the Use Constant ET Surface for all Time Steps option is selected when creating an ET Rate grid zone. If the Use Constant ET Surface for all Time Steps option is selected, then the ET surface elevation will be as specified in the Layers tab of Advanced Scenario Setup (see Advanced Scenarios).

The following solvers have been removed from Wetbud:

SIP (Strongly Implicit Package)

To create a new SIP Solver Set in the SIP Solver tab, first click 

. The text '—' will appear in the Name box and defaults values will populate the boxes for all additional solver parameters. The default values are recommended and should not be changed by the user unless they have previous experience with MODFLOW solver packages. Rename the Solver Set (optional) and click  to save. The new Solver Set will appear in the list on the left side of the window. Once an SIP Solver Set is created, it can be selected in the Setup tab of Advanced Scenarios.
Note: If the SIP Solver is selected in the Setup tab of Advanced Scenario setup, the LPF Flow Package must also be selected. General information for the SIP Solver package parameters is displayed on the right side of the SIP Solver tab window. For additional information refer to https://water.usgs.gov/ogw/modflow/MODFLOW-2005-Guide/index.html?solvers.htm.

PCG (Preconditioned Conjugate-Gradient)

To create a new PCG Solver Set in the PCG Solver tab, first click 

. The text '—' will appear in the Name box and defaults values will populate the boxes for all additional solver parameters. The default values are recommended and should not be changed by the user unless they have previous experience with MODFLOW solver packages. Rename the Solver Set (optional) and click  to save. The new Solver Set will appear in the list on the left side of the window. Once a PCG Solver Set is created, it can be selected in the Setup tab of Advanced Scenario setup.
Note: If the PCG Solver is selected in the Setup tab of Advanced Scenario setup, the LPF flow package must also be selected. General information for the PCG solver package parameters is displayed on the right side of the PCG Solver tab window. For additional information refer to https://water.usgs.gov/ogw/modflow/MODFLOW-2005-Guide/index.html?solvers.htm.

10.5 Advanced Grid Setup

Once Advanced Scenario setup is complete, the user must populate the Advanced Model grid by performing the three-dimensional placement of Cell Zones and Grid Zones. The Advanced Grid Setup interface is simple; however, it is critical for users to fully understand the interface layout and the application of Cell Zones and Grid Zones in an Advanced Model. To gain an understanding of the Advanced Grid Setup interface layout and the tools within, see Advanced Grid Setup Overview in this section. Once comfortable with the interface layout, the user can begin assigning Cell Zones and Grid Zones, which is explained in Assigning Zones in an Advanced Model Grid in this section. For additional information and example illustrations pertaining to the application of all types of Cell Zones and Grid Zones, see Assigning Zones in an Advanced Model Grid in this section.

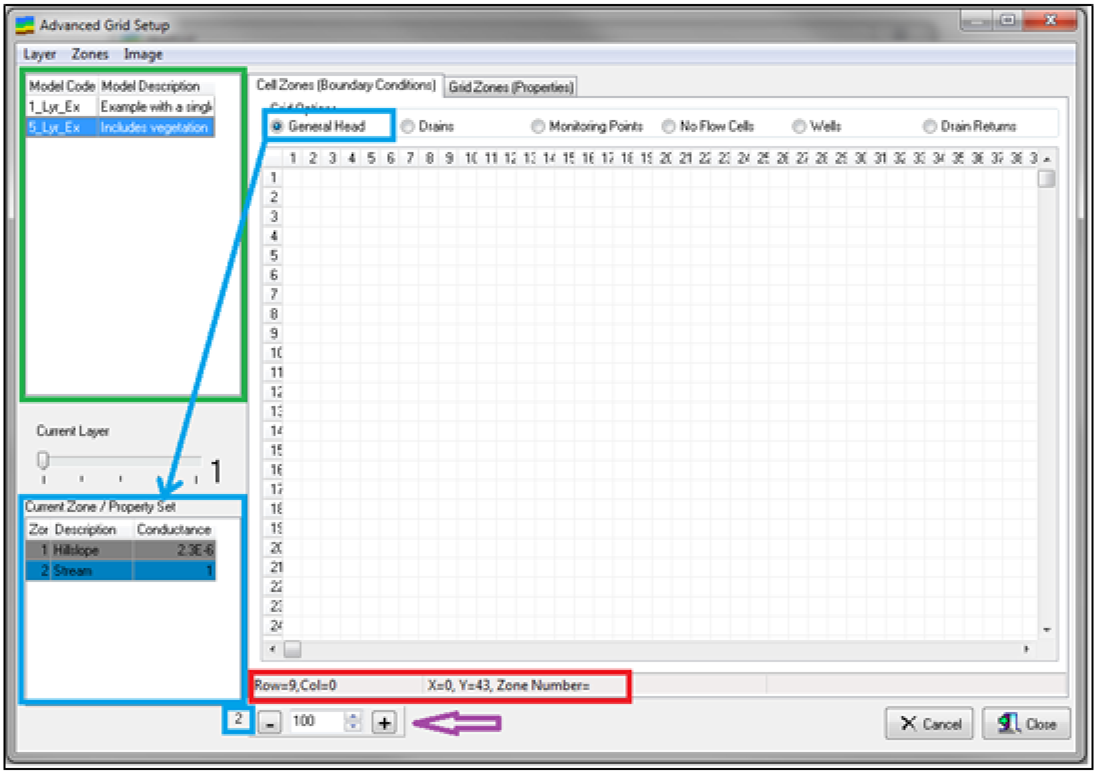
Note: Cell Zones and Grid Zones must be created within the selected Project prior to placement in the Advanced Model grid. See Advanced Parameter Setup 1 – Cell Zones and Advanced Parameter Setup 2 – Grid Zones for more information.

10.5.1 Cell Zones (Boundary Conditions)

To begin the Advanced Model grid setup, select Advanced Grid Setup from the Advanced Models drop-down menu in the Wetbud home screen. The Advanced Grid Setup window has five major features (see figure below):

1. Advanced Models Model Code and Model Description list (upper left).
2. Current Layer bar (middle left).
3. Current Zone/Property List (lower left).
4. Cell Zones (Boundary Conditions) tab.
5. Grid Zones (Properties) tab.

The figure below presents the Advanced Grid Setup window - Boundary Conditions tab. Scenarios list outlined in green (Layer, Zones, and Image menus located above). Current Zone/Property set list for current grid option selection and number of zones in list for current selection outlined in blue. Cell grid coordinates outlined in red, Row/Column refer to Wetbud grid while x/y refer to discretized grid, Zone Number would be reported as the Zone Number assigned to the cell with those coordinates. The purple arrow highlights the zoom controls.

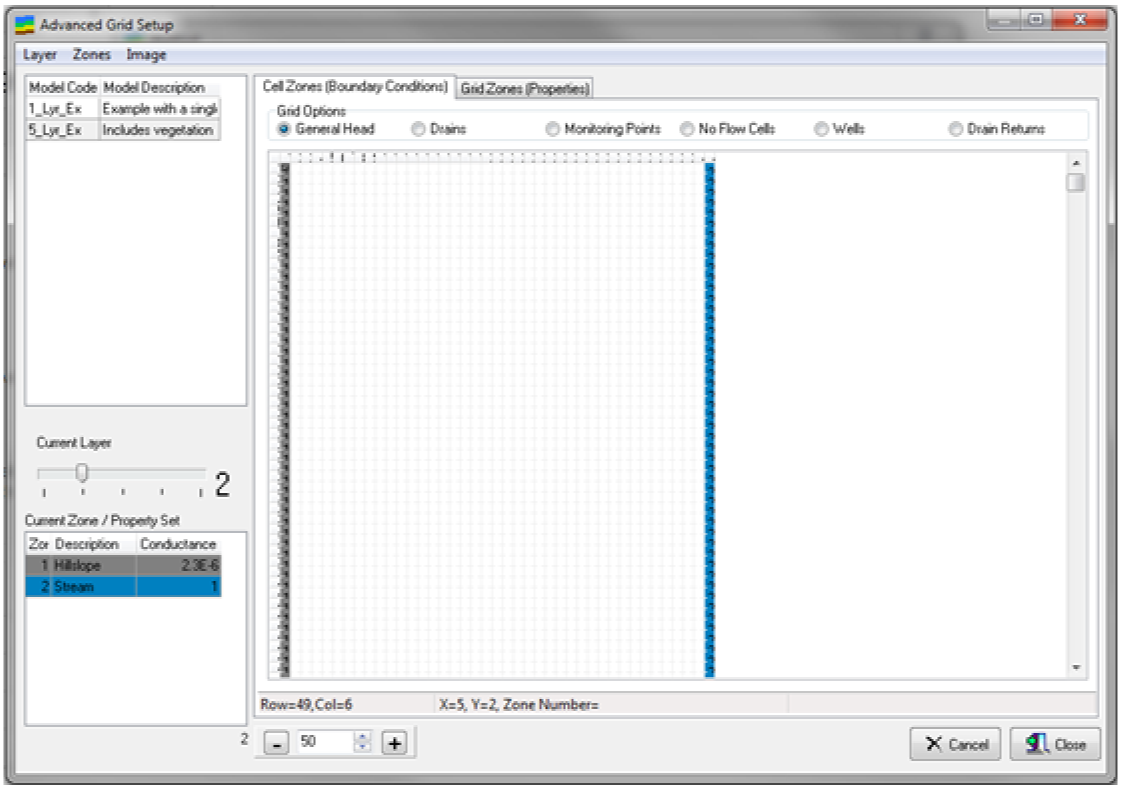


In addition to these five features, the Advanced Grid Setup window also has two menu options, Layer and Zones, with drop-down menus. The use of these features and options is described in the following sections:

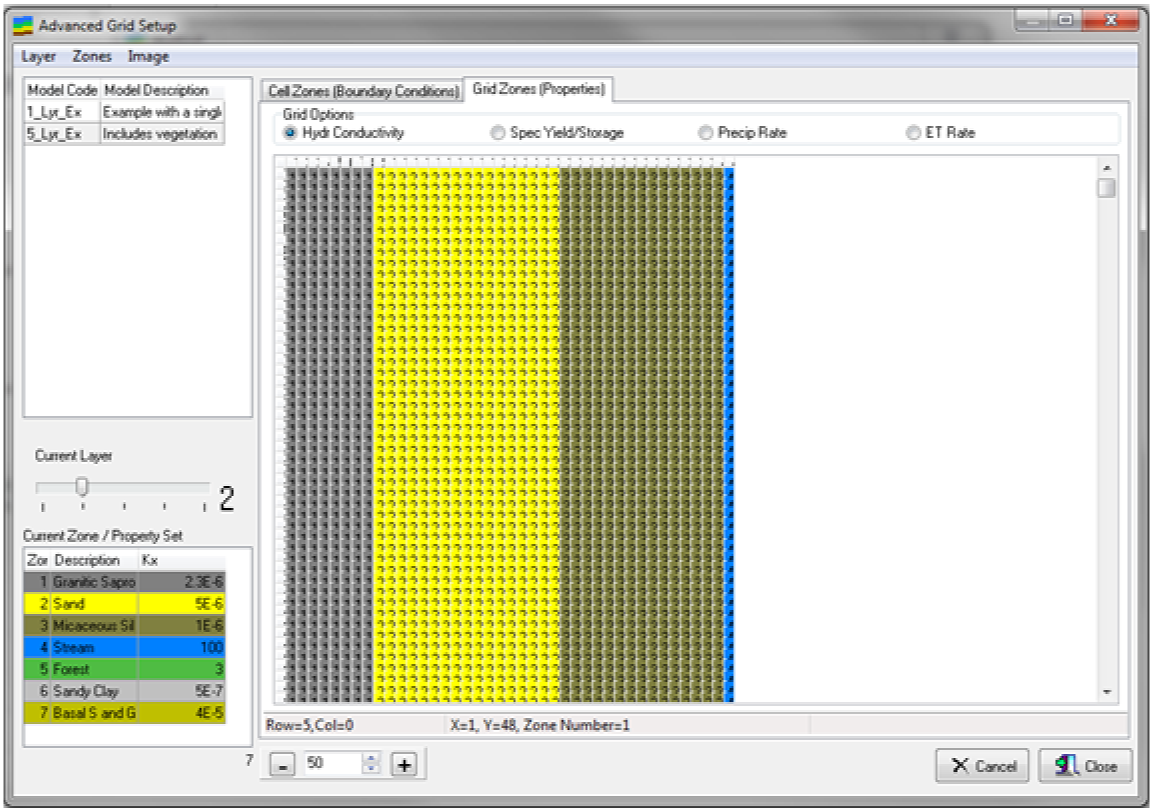
1. The Advanced Models list contains a list of all Advanced Scenarios Model Codes and Model Descriptions created within the selected Project. (Model codes and descriptions were assigned in the General tab of Advanced Scenario setup). Before proceeding to assign Cell Zones and Grid Zones, the user must select a Scenario from this list (green outline in figure).
2. The Current Layer bar is used to toggle between layers in the Advanced Model grid. The number of the current layer is displayed in the right side of the selection bar. To adjust the selected layer, click on the layer selection bar just above the hash marks (blue box in figure)
   Note: Cell Zones and Grid Zones will be assigned one layer at a time. Always make sure the appropriate layer is selected before assigning a zone in the grid.
3. The Current Zone/Property Set list displays a list of Cell Zones/Grid Zones for the Grid Option selected in the Cell Zones or Grid Zones tab. For example, if the Grid Option General Head is selected in the Cell Zones tab, then the Current Zone/Property Set list will display a list of general head Cell Zones created within the current Project. To view the list for a different cell zone, simply adjust the Grid Options selection in the Cell Zones or Grid Zones tab. Each zone in the list will be displayed with the zone number and description shown with the text color and background color chosen by the user when the zone was created (blue box in figure). To adjust the display zoom of the model grid for the current layer, use the slider bar

in the lower left corner of the Advanced Grid Setup window or right-click on any cell in the grid and choose from the options.

4. The Cell Zones (Boundary Conditions) tab is used to assign and view Cell Zones in the model grid. The grid displayed in the figure below is a map view of the current layer for the selected Grid Option. For example, if General Head is selected in Grid Options and the current layer is layer 1, the grid will only display cells that have been assigned as a general head boundary, and all other cells will be blank. Instructions and tips for assigning Cell Zones in the model grid are located in the next section, [Assigning Zones in an Advanced Model Grid](#).



5. The Grid Zones (Properties) tab is used to assign and view Grid Zones in the model grid. The grid displayed in the figure below is a plan view of the current layer for the selected Grid Option. For example, if Hydraulic Conductivity is selected in Grid Options and the current layer is layer 2, the grid will only display hydraulic conductivity zones for cells in layer 2. Every cell in every layer of an Advanced Model grid must be assigned a hydraulic conductivity and a specific storage value. Values for precipitation rate and ET rate assigned in Advanced Grid Setup will be applied to every cell in the model grid and will be governed by the Precipitation Options and ET Options designated by the user in the Setup tab of Advanced Scenario Setup (see [Setup Tab](#) section in [Advanced Scenarios](#)). Instructions and tips for assigning Cell Zones in the model grid can be found in the next section, Assigning Zones in an Advanced Model Grid.



The Advanced Grid Setup window also has two menu options, Layer and Zones. The Layer drop-down menu contains a set of tools that can be used to assign/edit zones within the model grid. These tools are explained in the next section, Assigning Zones in an Advanced Model Grid. The parameters of Cell Zones or Grid Zones can be adjusted quickly and without exiting the Advanced Grid Setup window by selecting Modify Parameters from the Zones drop-down menu at the top of the Advanced Grid Setup window.

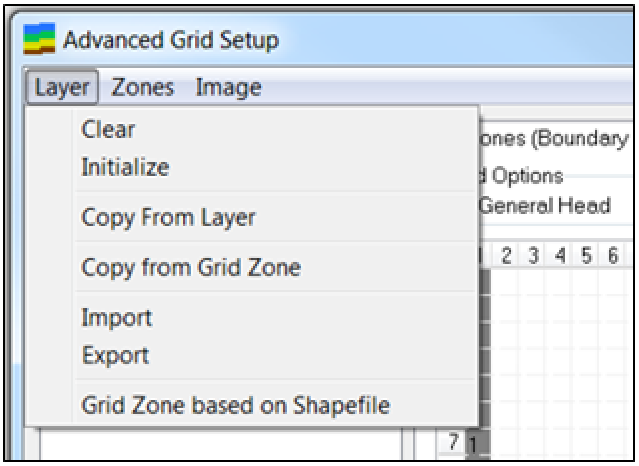
Assigning Zones in an Advanced Model Grid

In Wetbud, the procedure used to assign Cell Zones and Grid Zones in an Advanced Model grid is essentially the same. However, certain types of zones have specific requirements for assignment in the model grid and the success of an Advanced Model simulation depends on proper placement and application of these zones. The following section contains instructions for assigning zones in the model grid in addition to descriptions and requirements pertaining to the placement and application of each zone type in the Advanced Model grid.

Use the following procedure to assign any type of zone in the Advanced Model grid:

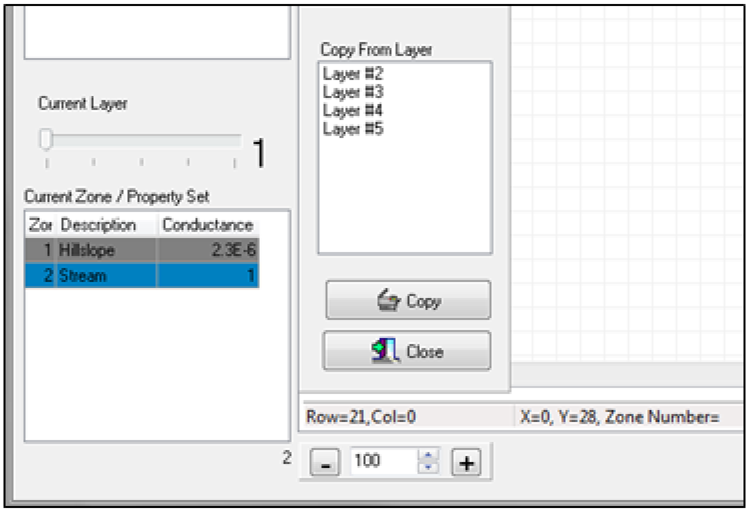
1. First, make sure the correct Scenario is selected in the Advanced Models list in the upper left corner of the Advanced Grid Setup Window.
2. Select the layer from the Current Layer bar.

3. Select a Grid Option in the current tab (Cell Zones tab or Grid Zones tab). The zones already defined (see Advanced parameters 1 - Cell Zones and Advanced parameters 2 - Grid Zones) for the selected Grid Option will be displayed in the Current Zone/Property Set list (at the bottom left corner of the form).
4. In the Current Zone/Property Set list, click on the zone that you wish to add to the model grid. For example, if there are three zones in the list and you wish to add zone 1 to the grid, click anywhere in the first row of the list.
5. At this point there are several options to assign the selected zone to cells in the model grid:
   a. To assign zones to individual cells, click on individual cells in the grid. Once a cell is clicked, the zone number will appear in the cell. The colors assigned to each zone appear by changing the Grid Option or layer selection and then returning to the previous Grid Option or layer where a zone has been assigned. To delete a zone in an individual cell, click the cell again. The zone number will disappear and the cell will appear as blank.
   b. To assign a zone to an entire column/row of cells, click the column/row heading. Once a column/row heading is clicked, the zone number will appear in all cells of the selected column/row. The colors assigned to each zone appear by changing the Grid Option or layer selection and then returning to the previous Grid Option or layer where zone has been assigned. To delete zone numbers in all cells for an entire column/row, hold the 'SHIFT' key and click the column/row heading again. The zone numbers will disappear and the cells will appear blank.
   c. To assign a zone to all cells in the current layer, select 'Initialize' from the Layer drop-down menu (see figure below). The zone number will appear in all cells of the current layer. The colors assigned to the zone appear by changing the Grid Option or layer selection and then returning to the previous Grid Option or layer where the zone has been assigned. To delete a zone in all cells of the current layer, select Clear from the Layer drop-down menu.



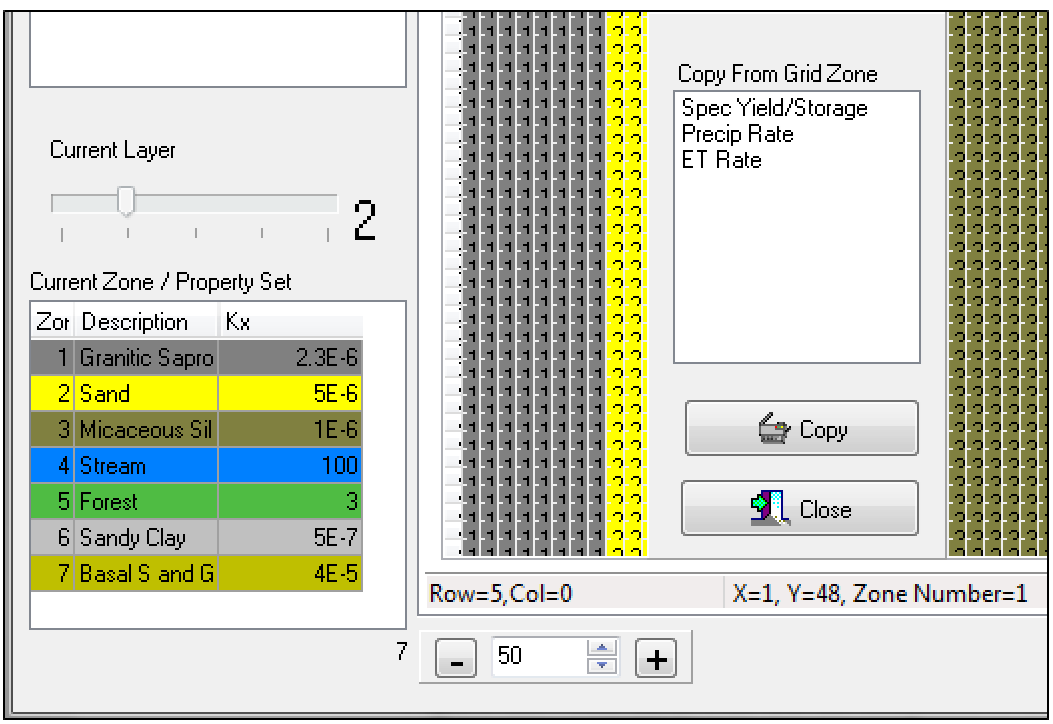
   d. To copy all zones for a specific Grid Option from another layer, select Copy From Layer from the Layer drop-down menu (see figure above). The Copy From Layer list will appear (see figure below). Select the layer from which you wish to copy and click 

. Click ‘Yes’ at the prompt to confirm. The zone numbers will now appear in the model grid for the current zone and layer.



e. To copy all zones for a specific Grid Option from Grid Zone, select Copy From Grid Zone from the Layer drop-down menu. The Copy From Grid Zone list will appear (see figure below). Select the zone from which you wish to copy and click 

. Click ‘Yes’ at the prompt to confirm. The zone numbers will now appear in the model grid for the current zone and layer.



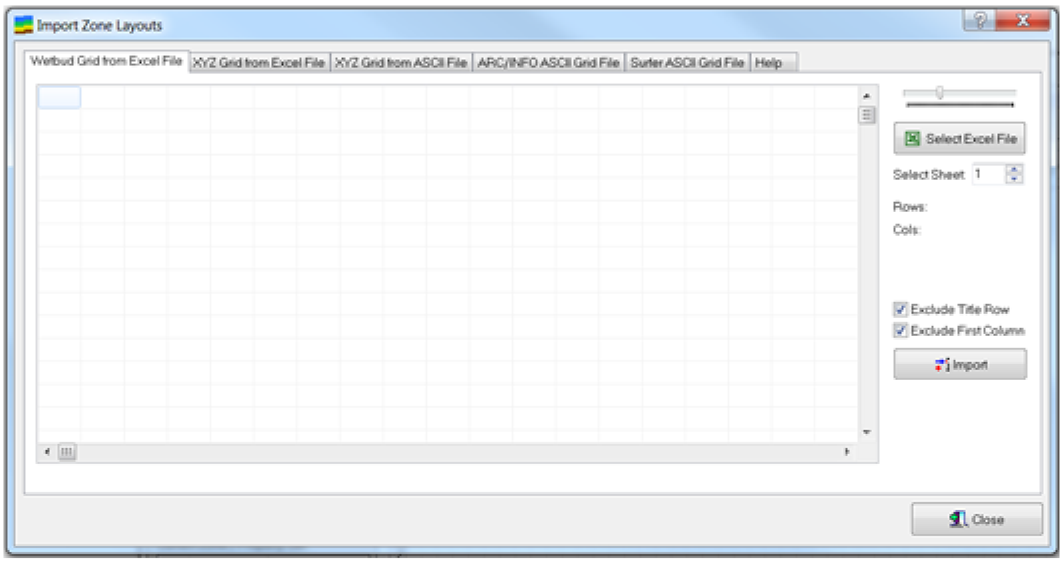
f. To import zones for a specific Grid Option for an entire layer from an Excel spreadsheet, select Import from the Layer drop-down menu. Next, in the Import

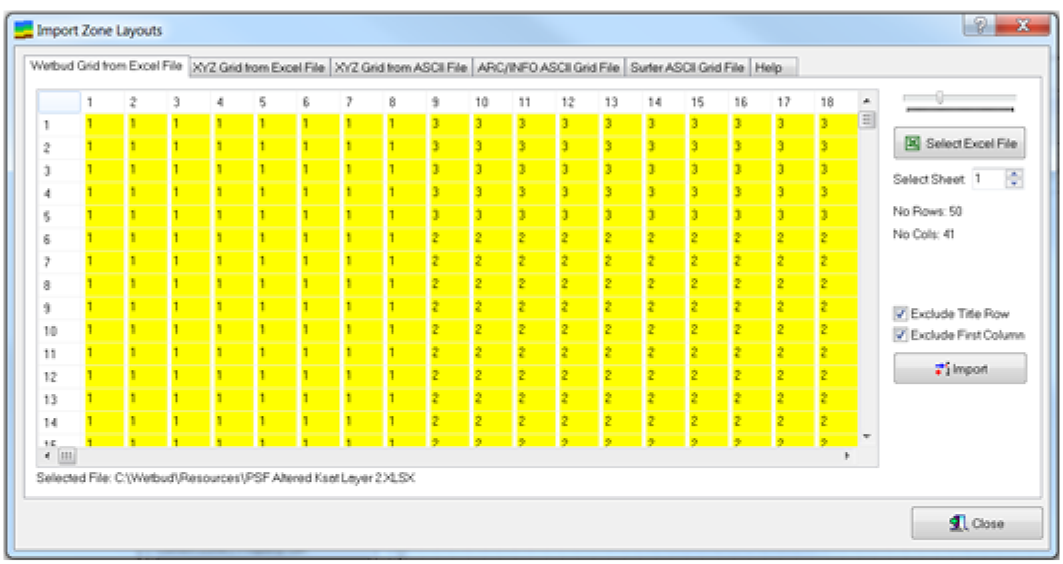
Zone Layouts window, click 

and choose the file to be imported (figure below). The data for the selected file will appear in the Import Zone Layouts window. The data that will be included in the import are highlighted yellow (figure below). Next, click 

and then click ‘OK’ from the prompt to confirm. Exit the Import Zone Layouts window to view the imported zone data, which will be displayed in the model grid. The colors assigned to the zones appear by changing the Grid Option or layer selection and then returning to the previous Grid Option or layer where the zones have been assigned.

Note on importing zones from Excel file: An Excel file containing zone numbers for a given layer should contain a zone number for every cell in the current layer. By default, the title row and first column are excluded. Un-check their respective boxes if the data in the title row or first column of the spreadsheet are to be included in import.





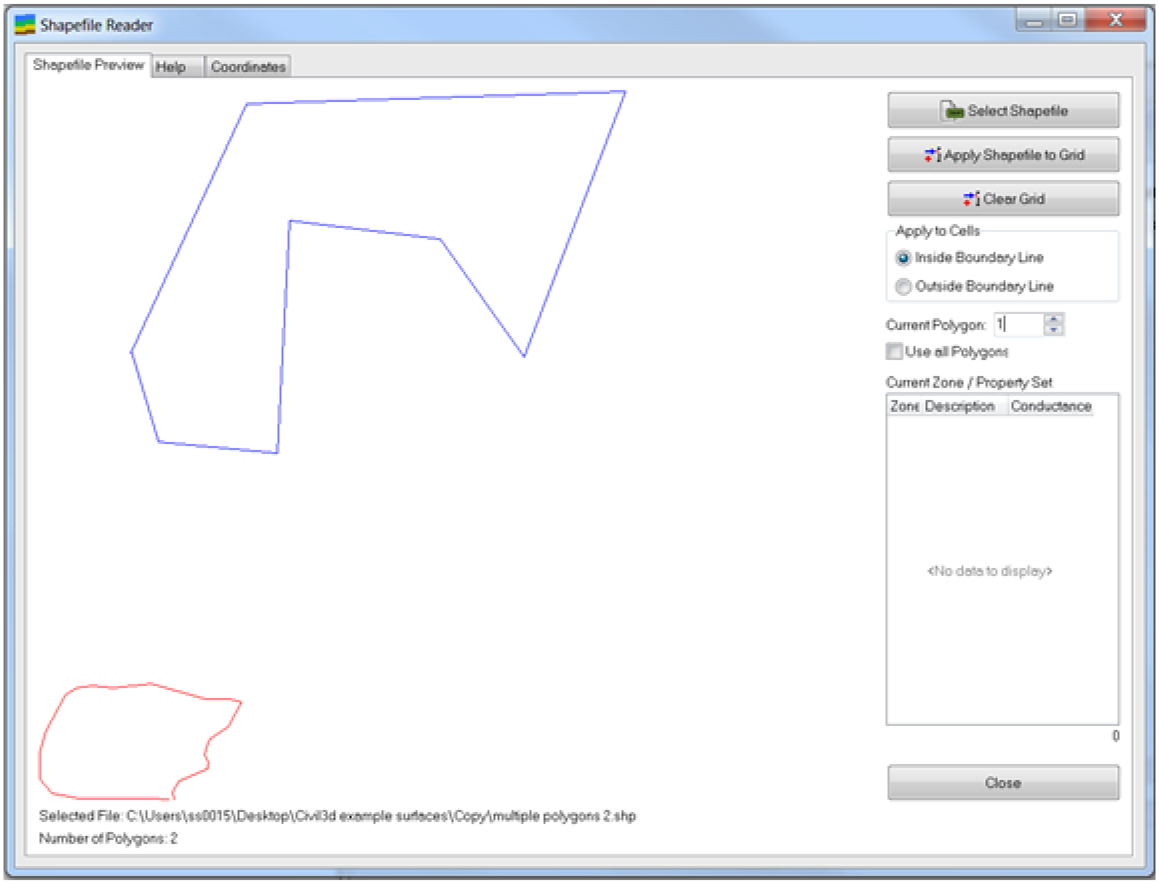
g. To export an Excel spreadsheet of zone numbers for a given Grid Option for an entire layer, select Export from the Layer drop-down menu. Name and save the file. The first row and first column of the exported file will contain the row number and column number, respectively.

h. Wetbud can also import zone assignments from Shapefiles. To use this feature, select Zone Based on Shapefile from the Layer drop-down menu. Click 

in the Shapefile Reader window and navigate to the Shapefile you wish to import. Shapefiles that are imported into Wetbud need to have the same units as the model the Shapefile will be used in. English models need Shapefiles with units of feet, Metric models need Shapefiles with units of meters.

Once a Shapefile is selected, the polygon(s) will be displayed in the Shapefile Preview pane (see figure below). Multiple polygons can be imported from a single Shapefile. Conditions can be applied inside or outside of the polygon Boundary Lines by selecting Inside Boundary Line or Outside Boundary Line from the Apply to Cells options. Wetbud allows the user to choose which polygon(s) within the Shapefile they wish import. Use the up/down toggles to choose the Current Polygon. The Current Polygon will be red while all others will be colored blue. Clicking 

will apply the selected Current Zone / Property Set, from the table on the lower right side of the window, inside (or outside, if selected), to the space defined by the polygon within the Wetbud model.



Note: The Coordinates tab provides a listing of the contents of the shapefile. The shapefile should include regular polylines and not polylineZ or polylineM structures.

Repeat steps 1-5 until every layer of the Advanced Model grid is fully populated for the intended model grid design. Although the procedure to assign zones is the same for all zone types, certain types of zones have specific requirements for assignment in the model grid and, as stated before, the success of an Advanced Model simulation depends on proper placement and application of these zones. The requirements for each type of zone and additional guidance regarding the placement of zones in the model grid are explained below.

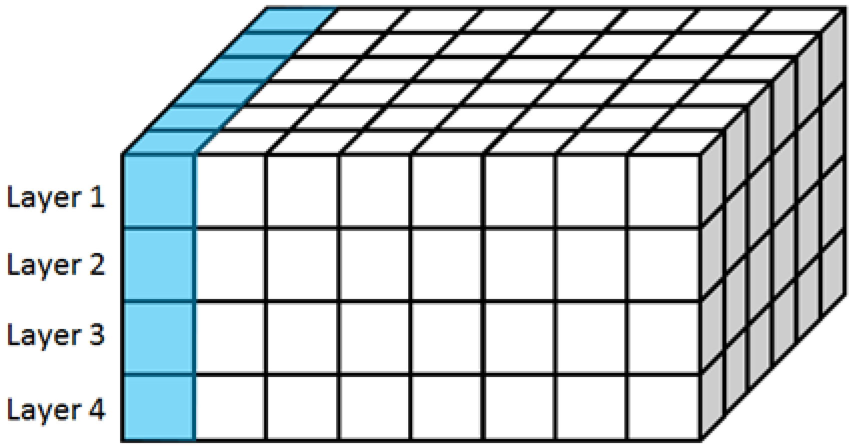
Cell Zones (Boundary Conditions) in an Advanced Model Grid

Cell Zones, also known as boundary conditions, are used to constrain the boundaries of the site being simulated and to define where water will enter and exit the model. Cell Zones include general head boundaries, drains, monitoring points, no flow cells, wells, and drain returns. The type and placement of Cell Zones will vary depending on the intended design and should be representative of the expected hydrology for the site being modeled. For clarity, the applications of each type of Cell Zone are explained in their respective sections below.

General Head

General head boundaries are used to represent areas of equal head elevation that form hydraulic boundaries of groundwater entering and/or exiting the site being modeled. In most cases, users should establish a general head boundary along the up-gradient edge(s) of their model grid, which is used to simulate groundwater entering the site being modeled.

Important: To accurately represent the actual groundwater system, general head boundaries should be assigned to the same cells in every layer of the Advanced Model grid except for layers with elevations lower than the upper end of the range of head values for the general head boundary. Once a general head boundary has been assigned to all layers, the map view of the general head boundary will be the same for every layer. The block diagram in the figure below illustrates this concept.



Some users may also wish to use a general head boundary (in lieu of a drain) to represent head elevations of a stream adjacent to their site.

Drains

Drains simulate the removal of water from the site through an outlet structure. Drains are usually assigned to one or several individual cells in the model grid but can also be used to represent an adjacent stream/culvert by assigning a series of drains to adjacent cells in the model grid.

Important: The placement of drains in the model grid should correspond to the head elevation assigned to the selected drain cell zone. The head elevation for the drain must not exceed the top elevation of the cell to which it is assigned. Failure to do so will result in model simulation failure.

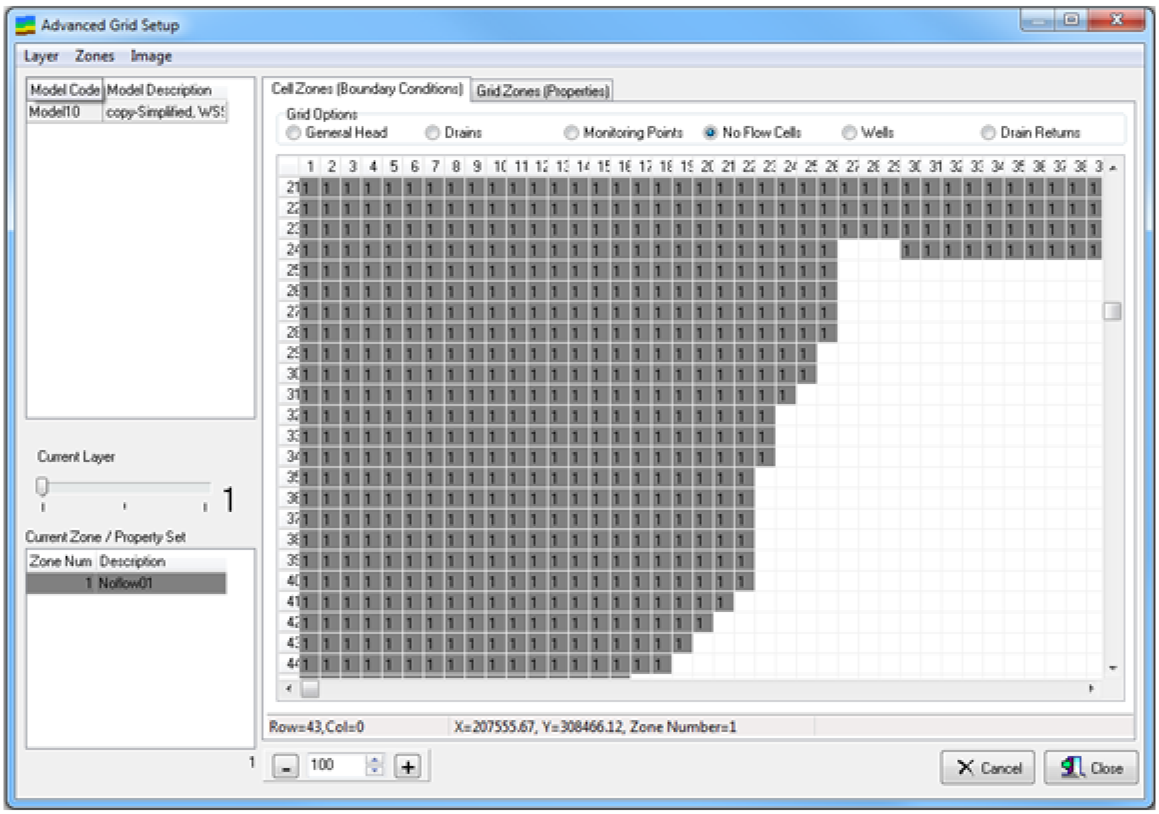
Monitoring Points

Although optional in an Advanced Model grid, monitoring points are a useful tool for model calibration. Monitoring points spatially assigned in the Advanced Model grid allow straightforward comparison of model results to monitoring well data. By assigning grid cells as monitoring points, users can pinpoint areas where measured well data may be available and make comparisons between modeled and measured data more easily.

Note: Currently, observed head elevation data cannot be displayed for a monitoring point in Wetbud. To compare observed and modeled data, users must export modeled head elevation data for the monitoring point as an Excel spreadsheet (see Advanced Model Output for more information).

No Flow Cells

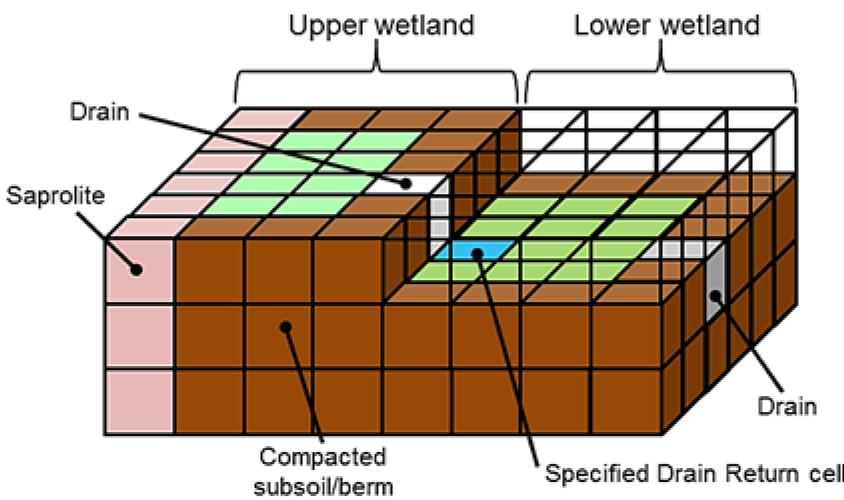
No flow cells are used to delineate hydrologic boundaries of the site being modeled. Assigning no flow boundaries to the model grid is optional, as the edges of the model grid are assumed to be no flow boundaries unless designated otherwise. However, the assignment of no flow cells is especially useful for delineating the boundaries of irregularly-shaped sites within the rectangular model grid (see figure below). No flow cells should be assigned to **all layers** of the model grid and the placement should correspond to the 3-dimensional shape of the site hydrologic boundaries.



Wells

Wells placed in the model grid are used to add additional water to the wetland system at a constant rate during a given time step. For example, a well can be useful in the model to input additional water such as runoff from adjacent drainage areas/culverts/etc. Wells are optional and are not required to run an Advanced Model simulation in Wetbud.

Drain Returns
As described earlier, Drain Returns are used to return a percentage of water that has been removed from the wetland through a Drain. By placing a Drain Return in the model grid, a specified flow proportion lost through an existing Drain can be input back into the model at the Drain Return cell location. For example, Drain Returns are useful for users who wish to model stepped wetland systems with multiple cells where berms are placed between wetland cells and surface water is transferred between cells by a series of weirs or culverts. The figure below shows an example of terraced design with upper and lower wetland separated by compacted/impermeable liner. Drain Return cell (blue) specified at up-gradient end of lower wetland will deliver a specified proportion of outflow from Drain cell (white) located at the down-gradient end of upper wetland. Note that the Drain Return must be assigned to the cell containing the actual outflow Drain in the model grid. Drain Return inflow will then occur in the specified return cell.



Drain returns are optional and are not required to run an Advanced Model simulation in Wetbud.

Important: A drain return must be assigned to the cell containing the Drain from which the specified proportion of outflow will return in the specified return cell.

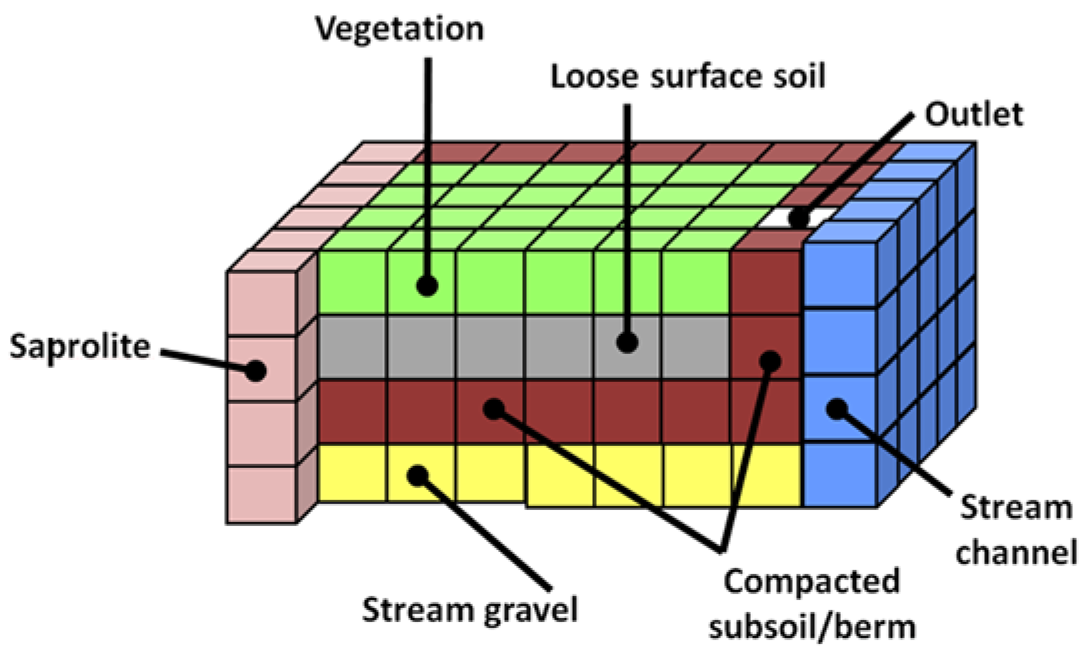
10.5.2 Grid Zones (Properties)

Grid Zones (Properties) in an Advanced Model Grid

Grid Zones, also known as properties, are used to assign hydraulic properties to cells in the model grid, define precipitation rate zones, and define evapotranspiration (ET) rate zones. Grid Zones include hydraulic conductivity, specific yield/storage, precipitation rate, and ET rate. Every cell in each layer of the model grid must be assigned a hydraulic conductivity zone and specific yield/storage zone. Precipitation rate and ET rate zones must only be assigned to every cell in layer 1. The placement of Grid Zones for hydraulic conductivity and specific storage should be based on site stratigraphy and locations of any additional engineered substrates/materials. Each type of grid zone is briefly explained in the sections below.

Hydraulic Conductivity and Specific Yield/Storage Grid Zones

The number of hydraulic conductivity and specific yield/storage zones assigned in layers of the model grid should correspond to the number of distinct lithologies/substrates/materials that are/will be present at the actual site being modeled. Every cell in each layer of the model grid must be assigned a hydraulic conductivity zone and specific yield/storage zone. For example, the conceptual block diagram below represents a 4-layer model designed with seven different materials. Each of these seven different materials must be assigned a grid zone for hydraulic conductivity and specific storage.



Precipitation Rate and ET Rate Grid Zones

Wetbud only allows precipitation rate and ET rate Grid Zones to be placed in layer 1 of the grid, unlike other grid zone parameters. The manner in which the data for these Grid Zones are applied to cells in subsurface layers during the model simulation is specified in the Precipitation Options and ET Options of the Setup tab during Advanced Scenario setup (see Advanced Scenarios). The precipitation rate and ET rate data for these zones are contained within the Time Step Array assigned to each grid zone during grid zone setup (see Advanced Parameter Setup 2 – Grid Zones).

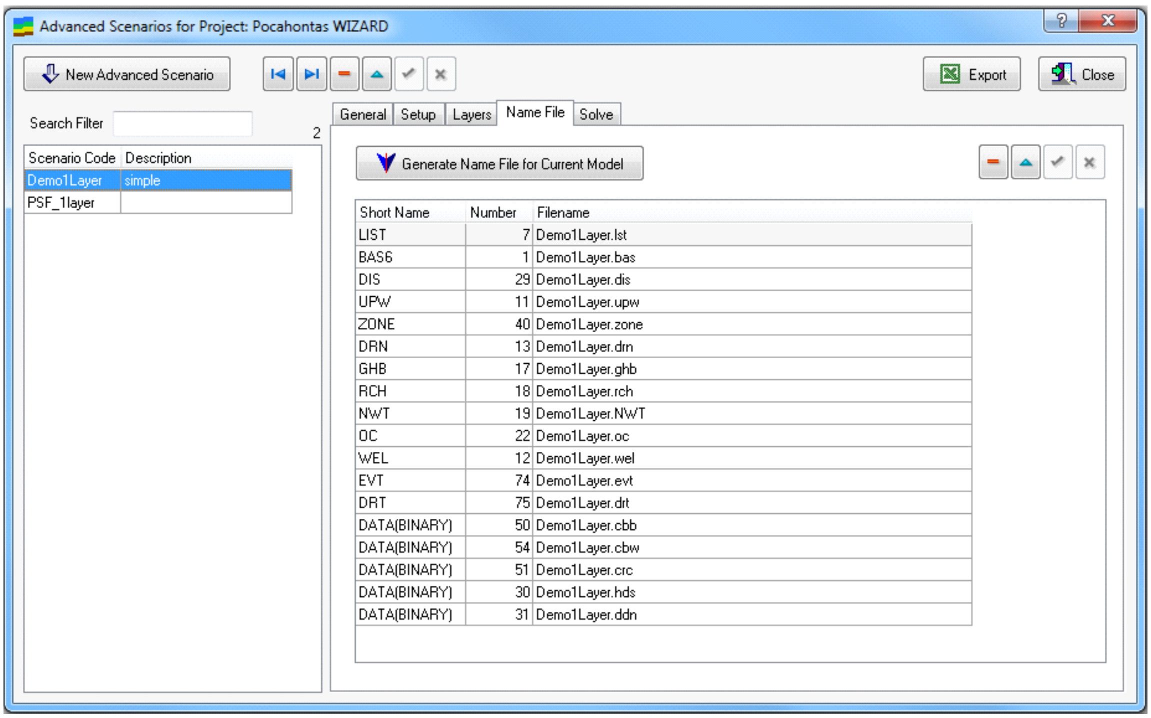
Once the model grid has been properly populated with Cell Zones and Grid Zones the user can proceed to generate Advanced Model output and view results.

10.6 Advanced Output

Once Advanced Scenario setup has been completed (see Advanced Scenarios) and the model grid has been populated with Cell Zones and Grid Zones (see Advanced Grid Setup), the user is ready to run the model simulation and view results after a few final steps, which are as follows:

Step 1: Name File Generation
Begin by navigating to the Name File tab in Advanced Scenarios window. The Name File tab is used to generate file names for each data file (e.g., drains, head boundaries, wells, etc.) that will be included in model computation. Once in the Name File tab, the user must generate the name files for the current Advanced Scenario model by clicking 

. Once file names have been generated, the screen should look similar to the screen pictured below. Now, proceed to Step 2 to run the MODFLOW simulation.

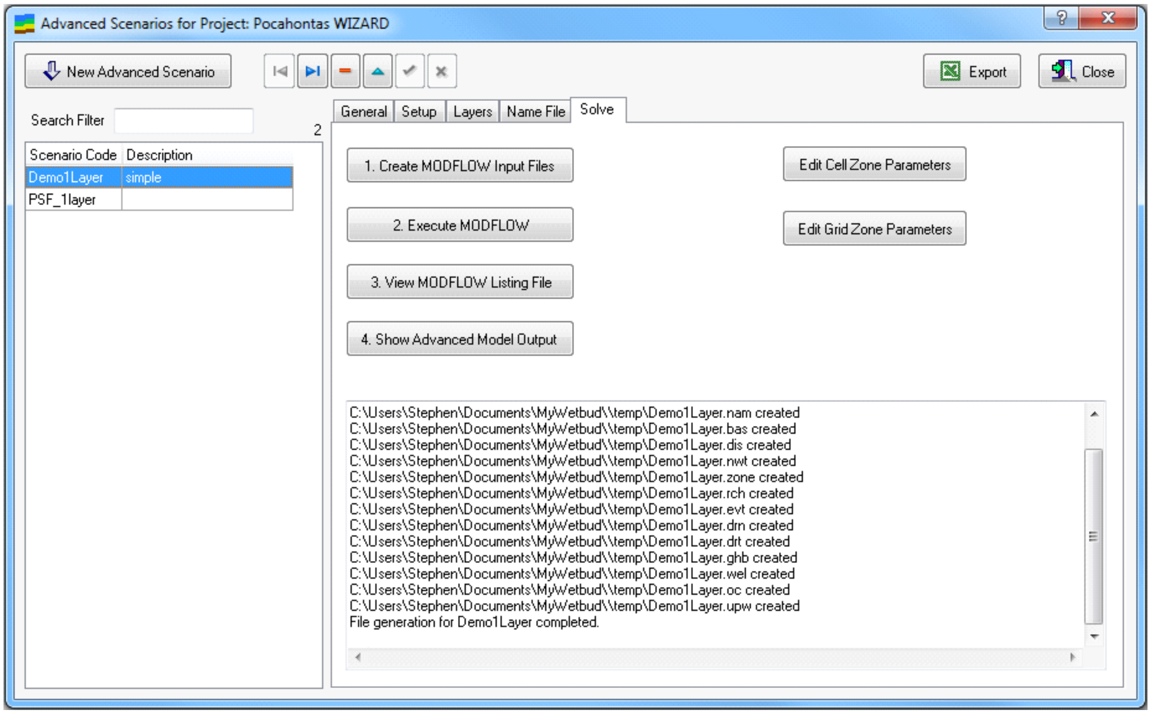


Step 2: Solve Model
Once name files have been generated in the Name File tab, select the Solve tab in the Advanced Scenarios window (see figure below). Here the user will execute the MODFLOW simulation, which generates model output for an Advanced Scenario. The procedure used to generate Advanced Scenario model output in the Solve tab is as follows:

a. Click 

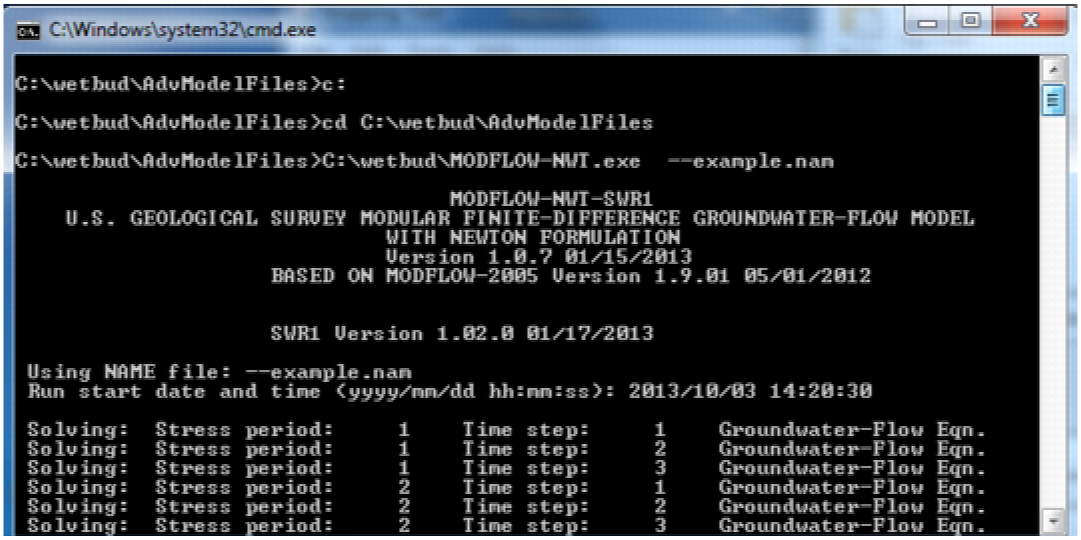
to generate MODFLOW input files for the MODFLOW execution. The MODFLOW input files will be displayed at the bottom of the window (as shown in the figure below). If all MODFLOW input files are

successfully created, a message will appear at the bottom the list that reads ‘File generation for [YOUR PROJECT NAME] completed’. Proceed to Step b.
Note: If there is an error when creating the input files, a prompt with the corresponding error message will appear in a separate window. Make the necessary corrections to the Advanced Scenario model and retry.



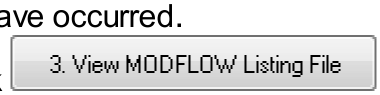
b. Click 

to execute MODFLOW calculations. The MODFLOW calculations will appear in a separate window. If the MODFLOW simulation is successful, the text ‘Normal termination of simulation’ will appear at the end of the bottom of the MODFLOW simulation text. Press any key, skip Step c (Troubleshooting) and proceed to Step d. Any MODFLOW simulation that does not conclude with the text ‘Normal termination of simulation’ has failed to execute. In this situation, the user should proceed to Step c (Troubleshooting) below before proceeding to Step d.

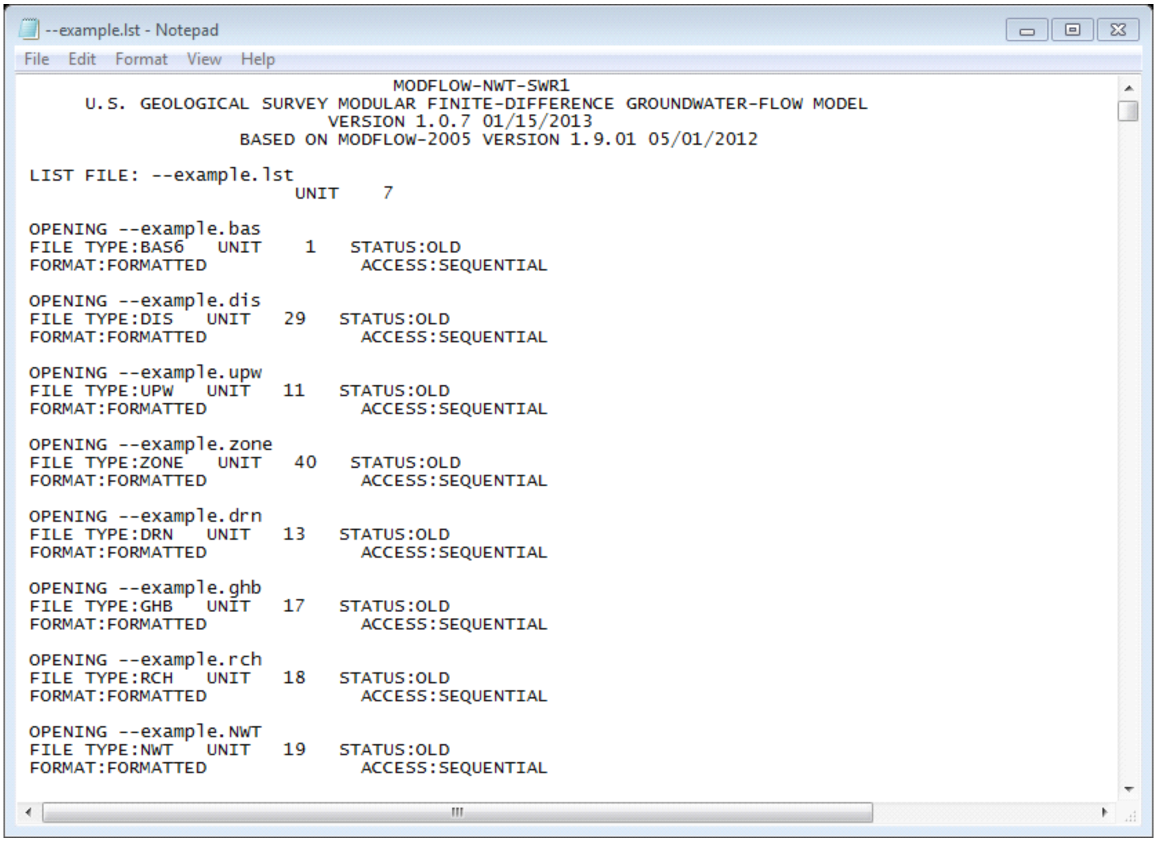


Note: If the Pause after Each MODFLOW run box is unchecked in the Advanced Model tab of Settings window (located by selecting Settings from Utilities menu in Wetbud home screen), the MODFLOW simulation window will automatically disappear. This option is not recommended because it does not give the user visual confirmation of a successful MODFLOW simulation.

c. Troubleshooting - Any MODFLOW simulation that does not conclude with the text ‘Normal termination of simulation’ has failed to execute. Since there are many possible causes of simulation failure, the most efficient way to identify the source of the error(s) is to view the MODFLOW listing file, which contains the output solutions for all time steps included in the MODFLOW simulation. When simulation failure occurs, the end of the MODFLOW listing file will display a description and/or grid location of the cell(s) for all errors that have occurred.

d. To view the MODFLOW listing file, click 

. The listing file will appear in a separate window (see figure below). Scroll to the end/bottom of the listing file window to view a description of the errors that have occurred. Make the necessary adjustments to the Advanced Scenario Model and repeat Step 1 (Generate Name Files) and Steps 2a-c (Solve) until ‘Normal termination of simulation’ has occurred. Next, proceed to Step e.

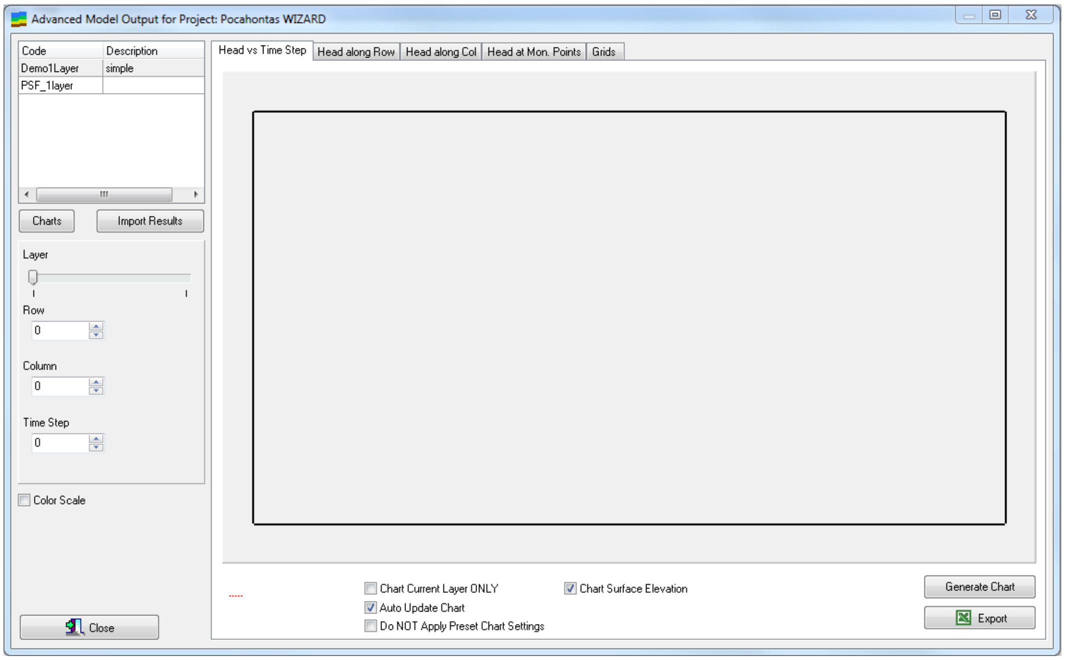


```
--example.lst - Notepad
File  Edit  Format  View  Help
                          MODFLOW-NWT-SWR1
      U.S. GEOLOGICAL SURVEY MODULAR FINITE-DIFFERENCE GROUNDWATER-FLOW MODEL
                          VERSION 1.0.7 01/15/2013
                  BASED ON MODFLOW-2005 VERSION 1.9.01 05/01/2012

 LIST FILE: --example.lst
                         UNIT    7

 OPENING --example.bas
 FILE TYPE:BAS6   UNIT    1   STATUS:OLD
 FORMAT:FORMATTED              ACCESS:SEQUENTIAL

 OPENING --example.dis
 FILE TYPE:DIS   UNIT   29   STATUS:OLD
 FORMAT:FORMATTED              ACCESS:SEQUENTIAL

 OPENING --example.upw
 FILE TYPE:UPW   UNIT   11   STATUS:OLD
 FORMAT:FORMATTED              ACCESS:SEQUENTIAL

 OPENING --example.zone
 FILE TYPE:ZONE   UNIT   40   STATUS:OLD
 FORMAT:FORMATTED              ACCESS:SEQUENTIAL

 OPENING --example.drn
 FILE TYPE:DRN   UNIT   13   STATUS:OLD
 FORMAT:FORMATTED              ACCESS:SEQUENTIAL

 OPENING --example.ghb
 FILE TYPE:GHB   UNIT   17   STATUS:OLD
 FORMAT:FORMATTED              ACCESS:SEQUENTIAL

 OPENING --example.rch
 FILE TYPE:RCH   UNIT   18   STATUS:OLD
 FORMAT:FORMATTED              ACCESS:SEQUENTIAL

 OPENING --example.NWT
 FILE TYPE:NWT   UNIT   19   STATUS:OLD
 FORMAT:FORMATTED              ACCESS:SEQUENTIAL
```

e. After pressing any key to continue, the MODFLOW simulation window will disappear. Next, click [4. Show Advanced Model Output], which will automatically display the Advanced Model Output window, where the results can be viewed and/or exported as an Excel spreadsheet.

Note: The additional buttons in the Solve tab, [Edit Cell Zone Parameters] and [Edit Grid Zone Parameters], serve as shortcuts to Advanced Parameters 1 – Cell Zones and Advanced Parameters 2 – Grid Zones. If any changes are made to Cell Zones and/or Grid Zones in an Advanced Model the user must re-create the MODFLOW Input files and re-execute the MODFLOW simulation for the changes to be reflected in output for the selected Scenario. See Advanced Parameters 1 – Cell Zones (Boundary Conditions) and Advanced Parameters 2 – Grid Zones (Properties) for details and information about setting up Cell Zones and Grid Zones.

Before results can be viewed in the Advanced Model Output window they must be imported and a chart must be generated. To import results, click [Import Results]. A progress bar of the import will appear in the lower left corner of the Advanced Model Output window. Once the import is complete the message ‘data import complete’ will be displayed in red text. Now, click [Generate Chart] to view results. See the next section, Viewing Advanced Model Results, for instructions and details about viewing Advanced Model results in the Advanced Model Output window.



10.6.1 Viewing Advanced Model Results

Once the user has successfully completed the MODFLOW simulation for an Advanced Model, results can be viewed in a variety of formats in the five tabs of the Advanced Model Output window using the slider bars, display tools, and chart settings options. At this point, the user usually wants to view overall results quickly, so the procedure for doing this is explained first in this section. Explanations and functions of slider bars, chart settings options, and additional tools follow.

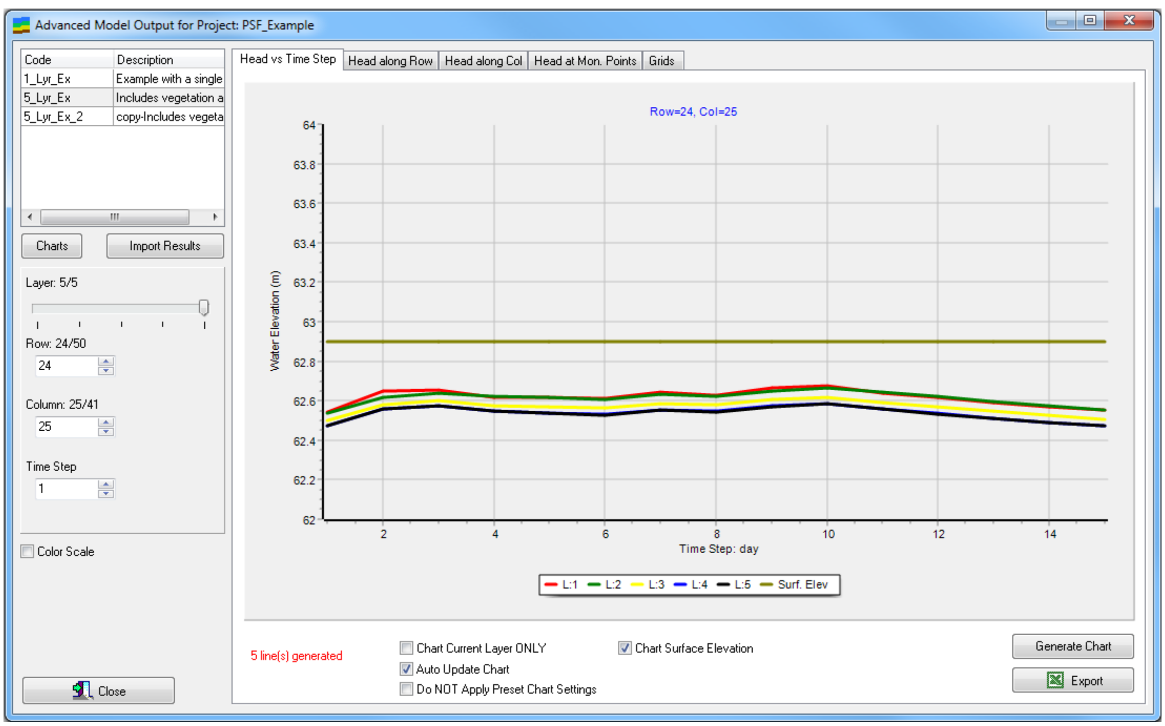
Note: In addition to being automatically directed to the Advanced Model Output window as described in step 2e of the previous section, users may also access this window by selecting Advanced Output from the Advanced Models drop-down menu in the Wetbud home screen.

Before results can be viewed in the Advanced Model Output window they must be imported. To import results, click Import Results. A progress bar of the import will appear in the lower left corner of the Advanced Model Output window. Once the import is complete the message ‘data import complete’ will be displayed in red text. Now, select one of the tabs at the top of the window and click Generate Chart, or Generate plot if Grids tab is selected, to view a graph of results. Each time a different tab is selected, the user must click Generate Chart to view results.

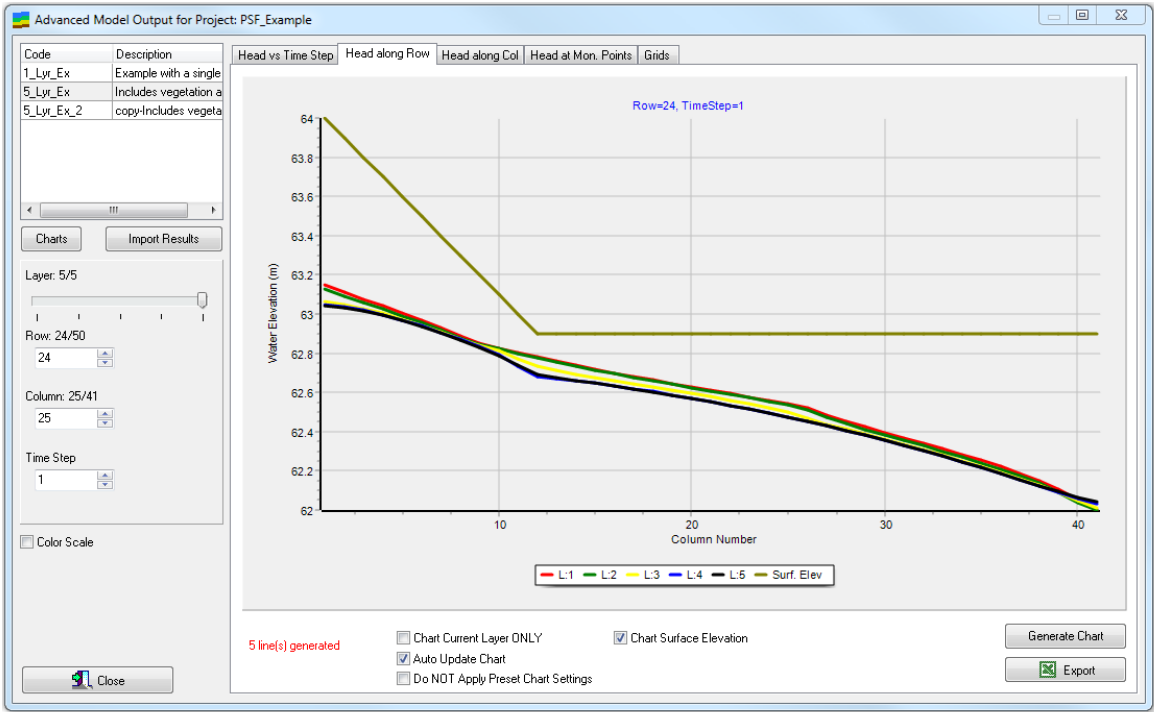
Slider Bars and Additional Display Tools

There are four slider bars in the Advanced Model Output window: Layer, Row, Column, and Time Step. By adjusting the position of a slider bar, the user can adjust the data displayed in the selected tab.

1. Layer bar: The layer of the head elevation data displayed in any of the tabs can be adjusted by using the Layer slider bar when viewing data in any tab but the Log tab. By default, the Current Layer ONLY box is unchecked, which allows the user to view data for multiple layers on the same graph. The red text under the bottom left corner of the graph will display the number of lines being generated. To only display data for the current layer, check the Current Layer ONLY box, which is located under the graph.
2. Row bar and Column boxes: These boxes are used to adjust the row and column, respectively, of the data being displayed in the Head vs. Time Step, Head along Row, or Head along Col (column) tab.
    a. If the Head vs. Time Step tab is selected (see figure below), the data displayed are those for the individual cell specified in the row box and column box. The row and column of the selected cell are displayed within each box and also at the top of the graph.



    b. If the Head along Row tab is selected, the row and time step will be displayed in each corresponding box and also at the top of the graph (see figure below). When the Head along Row tab is selected the selection in the Column box is ignored.
    c. If the Head along Col (column) tab is selected, the column and time step will be displayed above in each box and also at the top of the graph. When the Head along Col tab is selected, the selection in the Row box is ignored.

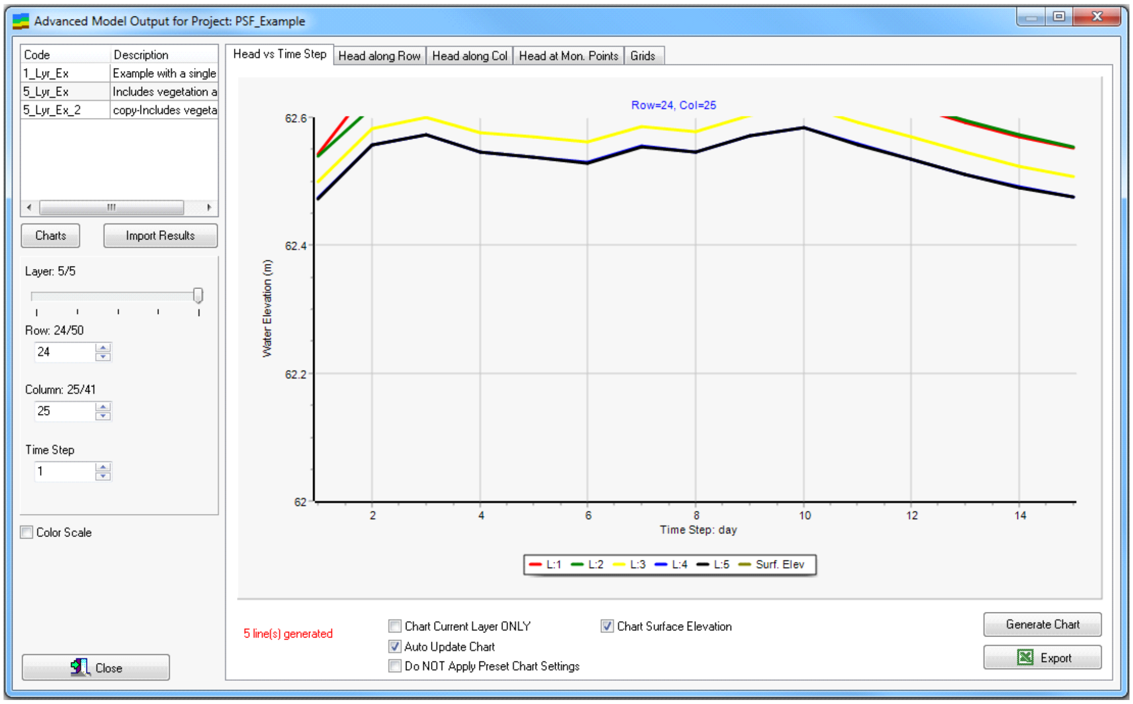


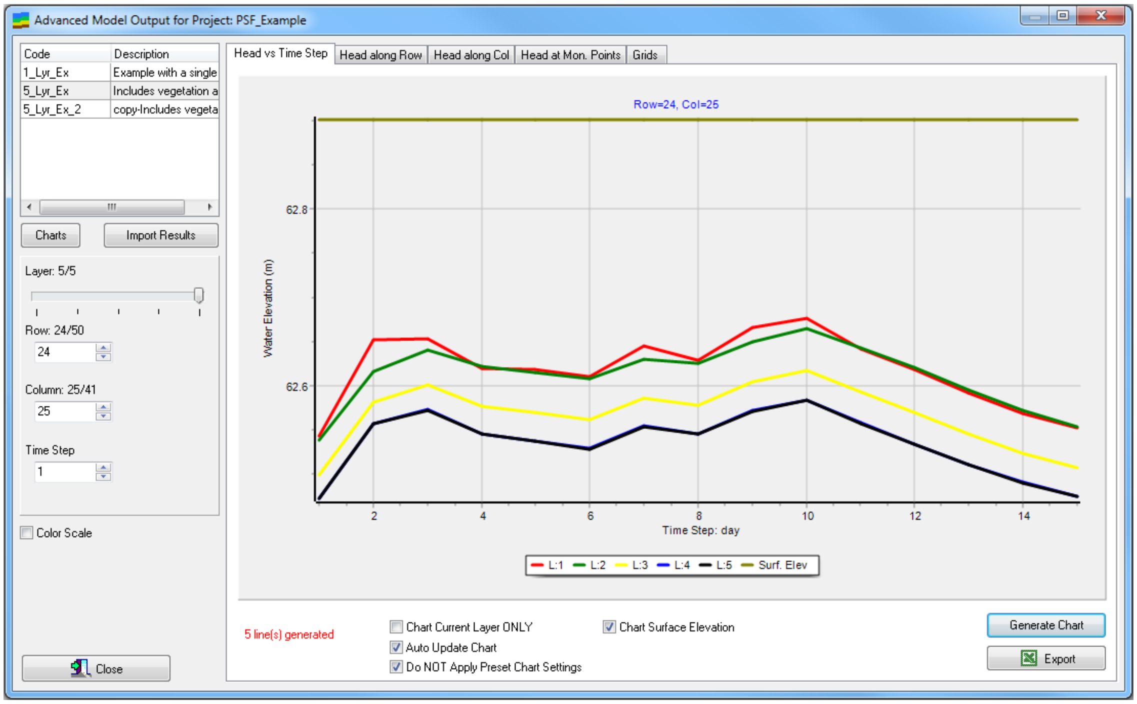
3. Time Step box: The Time Step box is used to adjust the time step of the data being displayed in any tab except the Head vs. Time Step tab, which displays a hydrograph for a given cell for the entire simulation period.

The additional display tools in the Advanced Model Output window are displayed with check boxes below the data being displayed in the selected tab:

Note: See the Grids tab for information about the tools only available in the Grids tab.

1. The Current Layer ONLY tool (unchecked by default) is used to display the data for the layer selection in the Layer slider bar. If left unchecked, the data for the current layer selection and all layers above will be displayed. The Current Layer ONLY tool is not available in the Head at Mon. Points or Grids tab.
2. If the Auto Update Chart box is checked (default), the auto update tool will automatically update the graph in the selected tab when the selection in any of the slider bars is adjusted. Uncheck the Auto Update Chart box to disable the auto update function.
3. The Do NOT Apply Preset Chart Settings box (unchecked by default) can be used to disable the preset chart settings (Chart Formatting data set) that have been assigned in the Setup tab during Advanced Scenario setup. This tool is useful when the head elevations in the model output fall outside the range specified for the y-axis in the chart formatting data set. An example of this situation is provided in the figures below, which show the initial graph generated with preset chart settings and the graph generated without the preset chart settings. When the Do NOT Apply Preset Chart Settings box is checked, the user must regenerate the chart, the new chart will automatically display a y-axis range that captures all of the data on the same graph.





Advanced Model Output Tabs

Results of an Advanced Model simulation can be displayed in a variety of formats using the tabs in the Advanced Model Output window:

- Head vs Time Step
- Head along Row
- Head along Column

- [Head at Monitoring Points]
- [Grids]

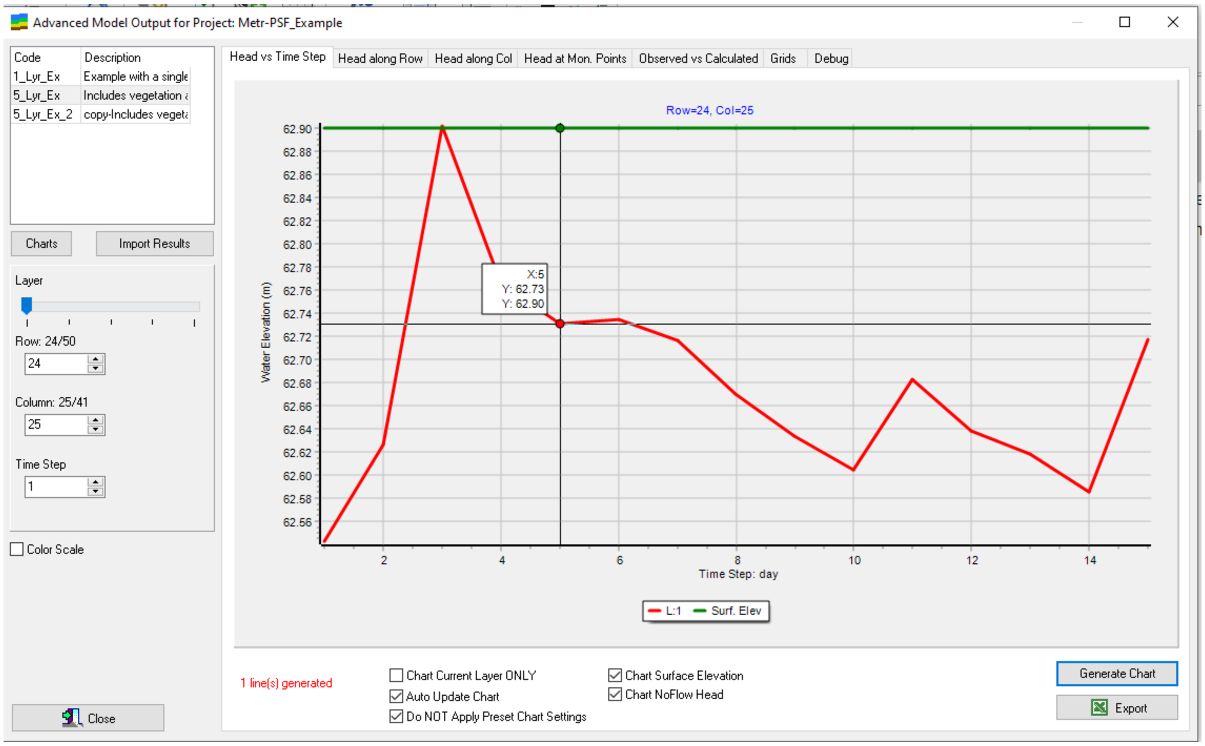
10.6.2 Head vs Time Step

This tab is used to display the hydrograph of the entire simulation period for a given cell in any layer of the model grid. The data displayed can be adjusted using the slider bars. The selection in the Time Step slider bar does not apply to this tab. To display the hydrograph for the layer selected in the Layer slider bar, check the Current Layer Only box. To export data for the displayed hydrograph(s) click 

, then name and save the file.

Wetbud will chart output using a specified chart definition (if already defined at model setup). This is important to ensure that different output charts are created using the same layout. The user can disable this default behavior.

The user can optionally plot surface elevations with the heads calculated for each monitoring point. Note: If multiple curves are displayed, the annotation tool will display all Y values in the sequence they appear in the legend.



10.6.3 Head along Row

This tab is used to display a head elevation profile across a row in one or all layers in the model grid for a given time step. The displayed data can be adjusted using the Row and Layer slider bars. The selection in the Column slider bar does not apply to this tab. To display the hydrograph for the layer selected in the Layer slider bar, check the Current Layer Only box. To export data for the displayed profile(s) click 

, then name and save the file.

Wetbud will chart output using a specified chart definition (if already defined at model setup). This is important to ensure that different output charts are created using the same layout. The user can disable this default behavior.

The user can optionally plot surface elevations with the heads calculated for each monitoring point. Note: If multiple curves are displayed, the annotation tool will display all Y values in the sequence they appear in the legend.

10.6.4 Head along Column

This tab is used to display a head elevation profile across a column in one or all layers in the model grid for a given time step. The displayed data can be adjusted using the Column and Layer slider bars. The selection in the Row slider bar does not apply to this tab. To display the hydrograph for the layer (s) selected in the Layer slider bar, check the Current Layer Only box. To export data for the profile(s) being displayed click 

, then name and save the file.

Wetbud will chart output using a specified chart definition (if already defined at model setup). This is important to ensure that different output charts are created using the same layout. The user can disable this default behavior.

The user can optionally plot surface elevations with the heads calculated for each monitoring point. Note: If multiple curves are displayed, the annotation tool will display all Y values in the sequence they appear in the legend.

10.6.5 Head at Monitoring Points

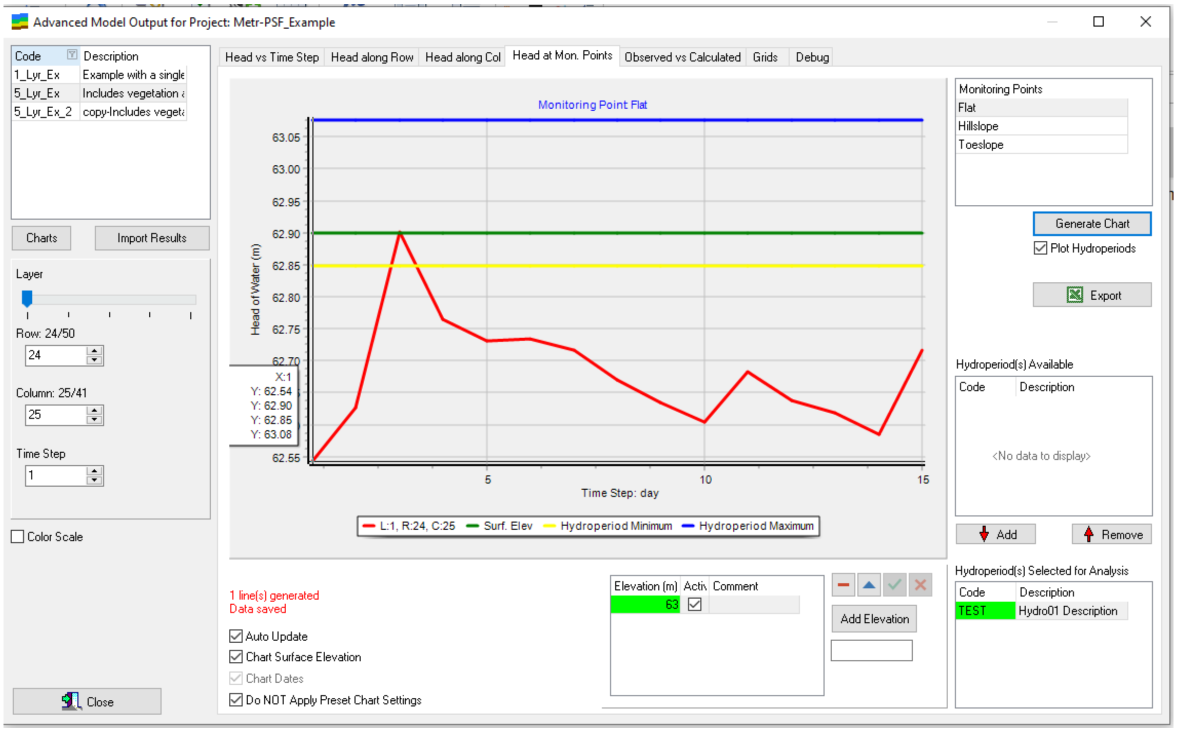
This tab is used to display a hydrograph of the entire simulation period for the cell assigned as a monitoring point. The slider bars do not apply to this tab. To export data for the profile(s) being displayed, click 

, then name and save the file.

Wetbud will chart output using a specified chart definition (if already defined at model setup). This is important to ensure that different output charts are created using the same layout. The user can disable this default behavior.

The user can optionally plot surface elevations with the heads calculated for each monitoring point.

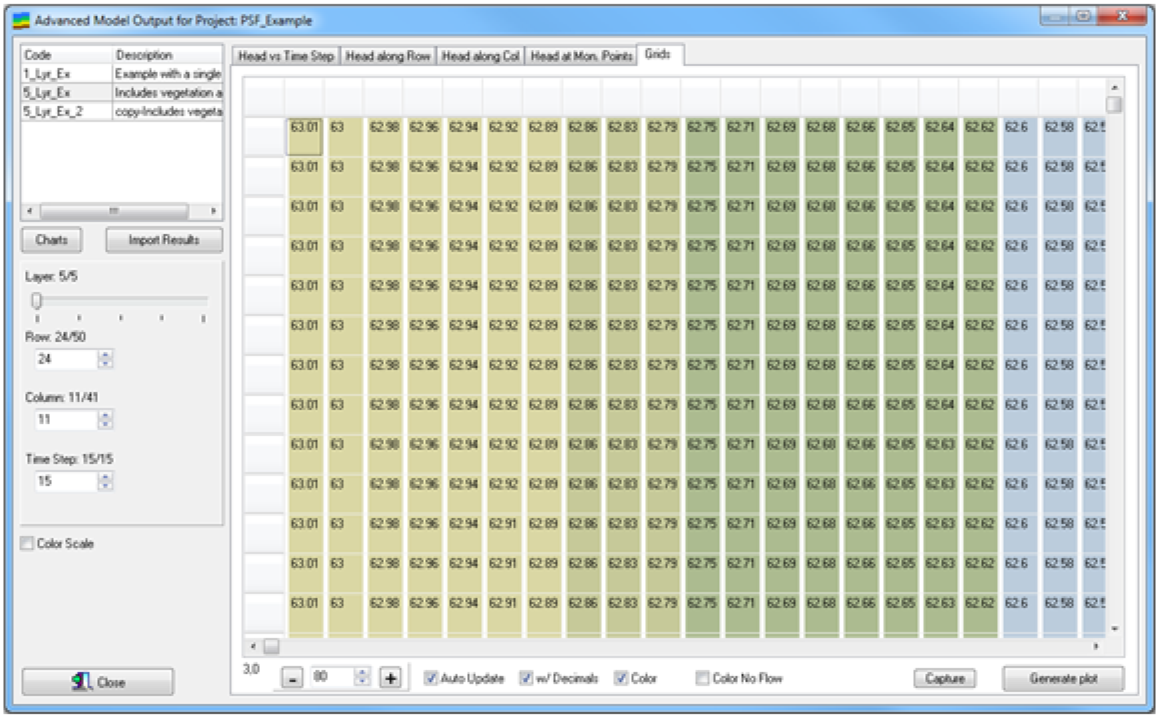
If a sensitivity analysis for hydroperiods is enabled, then the user can select different hydrioperiod-reference elevation combinations and plot them together with the heads calculated for each monitoring point.



Note: If multiple curves are displayed, the annotation tool will display all Y values in the sequence they appear in the legend.

10.6.6 Grids

The Grids tab is used to display a color contoured grid of head elevations for each cell in the selected layer for a specific time step. Head elevation data for the time step displayed can be adjusted using the Time Step slider bar. The Row and Column slider bars do not apply to this tab. The Grids tab can also be used to generate an AVI file that will display the head elevation grid for each time step as an animation. To capture an animation of all time steps, first make sure time step 1 is selected in the Time Step slider bar. Next, click Capture and select 'YES' from the prompt to initiate AVI file generation.


Advanced Model Output for Project: PSF_Example
Code
Description
1_Lyr_Ex
Example with a single
5_Lyr_Ex
Includes vegetation a
5_Lyr_Ex_2
copy-Includes vegeta
Charts
Import Results
Layer: 5/5
Row: 24/50
24
Column: 11/41
11
Time Step: 15/15
15
Color Scale
Close
Head vs Time Step
Head along Row
Head along Col
Head at Mon. Points
Grids
Auto Update
w/ Decimals
Color
Color No Flow
Capture
Generate plot

11

Advanced User Features

11 Advanced User Features

This portion of the manual shows users how to take advantage of advanced features that are not necessary for most water budgets. Some examples of Advanced User Features include: graphically comparing model output to observed head values or exporting data produced by the effective monthly recharge model for further review or use in other models.

11.1 Export WEM head values

The Effective Monthly Recharge model (WEM) produces estimates of groundwater head elevation based on a calibration curve that establishes a relationship between observed head elevations and the decaying influence of monthly precipitation and evapotranspiration rates. Wetbud then uses the head values predicted by WEM, for years that lack observations of head, to calculate a groundwater flux through the wetland via Darcy's Law. The Export WEM Values feature allows users to export the head values predicted by WEM. These head values can then be used to generate General Head Boundaries for Advanced Scenario groundwater flow models or for further evaluation outside of Wetbud.

There are several steps that a user would need to take before attempting to export WEM values. These steps include:

1. Enable WEM at the Project level (see Projects).
2. Create data sets within Wetbud of observed head values as well data sets (see Wells).
3. Set up WEM data and run the Effective Monthly Recharge Model calculations (see WEM Calculations).
4. Set the groundwater in/out option to Calculated by Wetbud using WEM in the Water Inputs/Outputs tab(s) (see Setting Up a Basic Scenario).
5. Run the Basic Model that includes WEM (see Basic Analysis and Output).

Once the above steps have been completed, Exporting the WEM values is quite simple. The following steps describe how to Export WEM Values from a Basic Model:

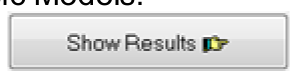
1. Enable Export of Calculated WEM Values in the Basic Model Settings tab. See Settings.
2. Return to the Basic Scenario Analysis window and click 

.
3. Click the 

button to generate an Excel file containing the WEM predicted head values used to calculate groundwater fluxes within that Basic Scenario.

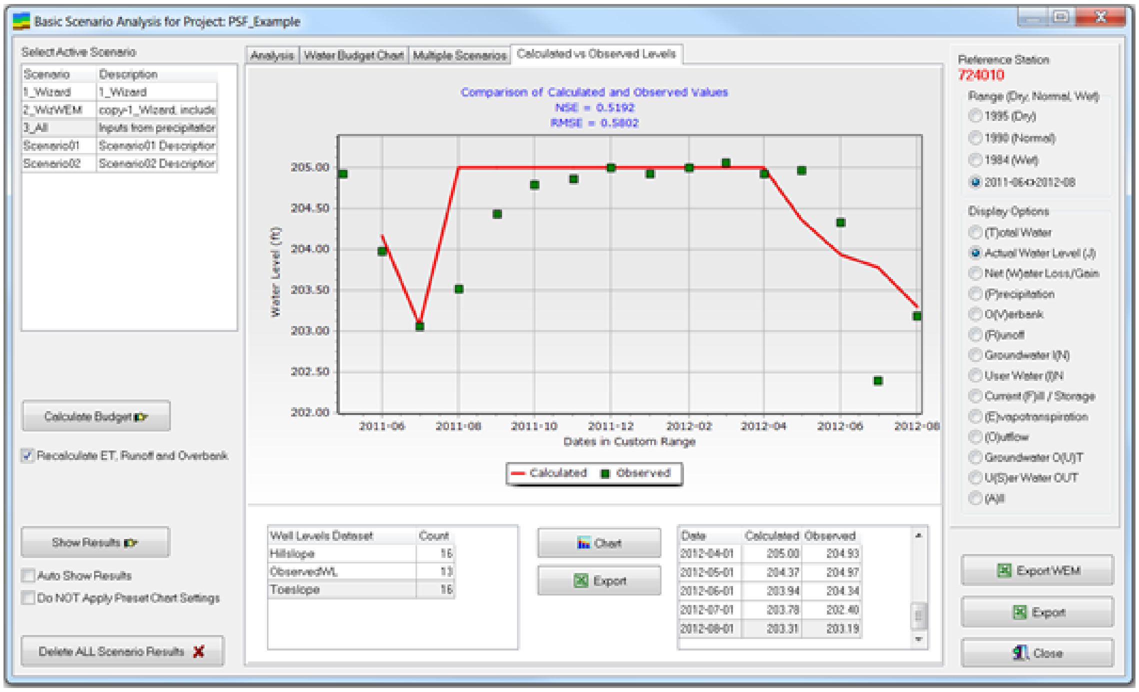
11.2 Enable Comparison of Predicted and Observed Water Levels

Users that have collected water level data for their site prior to developing water budgets may wish to compare those observed levels to levels predicted by Wetbud for a corresponding time period. Wetbud has the ability to plot predicted and observed values together, as well as statistically evaluate model performance. Both the Basic and Advanced Models have this functionality. To use this feature, the user will need to take the following steps:

1. Create data sets within Wetbud of observed head values as well data sets. See Project Specific Parameters.
2. Create models that run for time periods that correspond to the Well data sets.
   a. In Basic Models, the model should include a Custom Time Period that overlaps the Well data set(s) (see Setting Up a Basic Scenario).
   b. For Advanced Models, create a Time Step Array that overlaps the Well data set(s) (see Advanced Parameters 3 – Time Step Arrays).
3. Under Settings, in the Basic Model tab check the box beside Enable Comparison of Calculated Levels to Well Measurements (Custom Range Only). In the Advanced Model tab, check the box beside Enable Comparison of Predicted Heads to Well Measurements. Return to the Model Output window of the Model type for which you wish to view comparisons.
4. For Basic Models:
   a. Click 

and then select the Calculated vs Observed Levels tab. Select the Custom time period from the Range (Dry, Normal, Wet) list in the upper right side of the window. Select Actual Water Level (J) from the Display Options on the right side of the window (this is the water level after it has been adjusted to account for soil storage space). Select the Well Levels data set from the list in the lower left center of the window.
   b. Click 

to plot observed and predicted values (see figure below).
   c. The model-calculated Actual Water Level (J) will be plotted as a red line. The Observed levels, from the selected well data set, will be plotted as green squares.
   d. Above the plot there are two statistical values: 1) the Nash-Sutcliffe Efficiency parameter (NSE, negative infinity to 1, 0 = model is as good as average of observed, the closer to 1 the better the model is at predicting head values). 2) the Root Mean Square Error (RMSE) is the average error of any value predicted by the model, reported in the units in which the model was run.



5. The process is nearly the same for Advanced Models:
   a. Select the model from the list in the upper left corner of the window, click the Import Results button (in the Advanced Model Output window). Select the Head at Mon. Points tab and load the data for the monitoring point by clicking Generate Chart. Select the Observed vs Calculated tab and choose the well data set that corresponds to the Monitoring Point well you just imported (in the list on the lower right of the window).
   b. Then choose the Well data set from the list on the lower left of the screen, and click Chart.
   c. The model-calculated water level will be plotted as a line. The Observed levels, from the selected well data set, will be plotted as squares (see figure below).
   d. Above the plot there are two statistical values: 1) the Nash-Sutcliffe Efficiency parameter (NSE, negative infinity to 1, 0 = model is as good as average of observed, the closer to 1 the better the model is at predicting head values). 2) the Root Mean Square Error (RMSE) is the average error of any value predicted by the model, reported in the units in which the model was run.

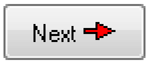

Advanced Model Output for Project: Huntley_metric
Head vs Time Step
Head along Row
Head along Col
Head at Mon. Points
Observed vs Calculated
Grids
Debug
Comparison of Calculated and Observed Values
Line: 1, NSE = 0.7730, RMSE = 0.0586
Water Level (m)
L:1
Observed
Charts
Import Results
Layer
Color Scale
Close
Monitoring Points
Chart
Export
Auto Update
Date Range Set by Calculated Values
Chart All Observed Points
Result set reset.

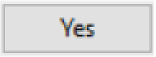
12

Reports

12 Reports

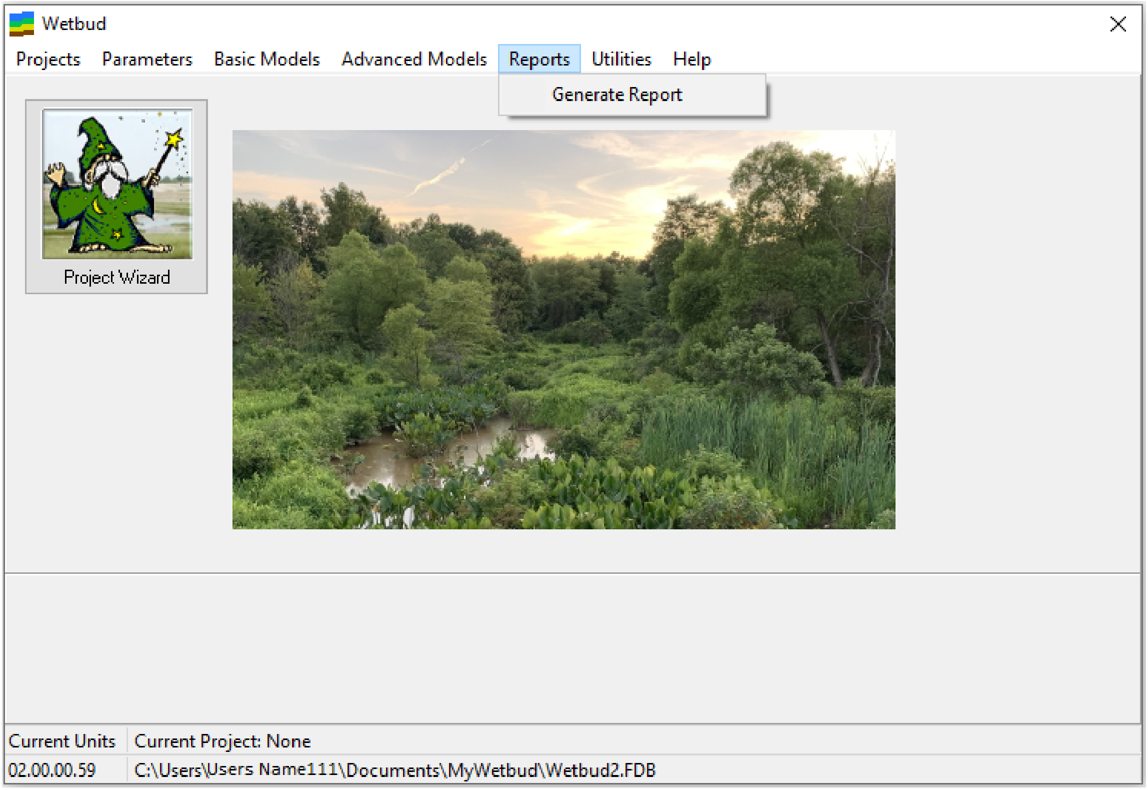
Reports summarizing the inputs and outputs of models created in Wetbud can be quickly exported for use in design narratives, plan sets, or other documents needing records of the components of the water budget that has been prepared by Wetbud. Reports can be exported as Word documents, Notepad files, or Excel spreadsheets. Instructions for generating reports are provided below.

There are two ways to access the Report Templates window. One way to access the Report Templates window is by using the Project Wizard to generate and run a Basic Model water budget. After running the model, close the Basic Scenario Analysis for Project: […] window and return to the Project Setup Wizard window. Click 

and then click 

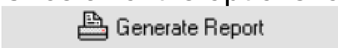
when notified that a new report template will be created.

The second way to access the Report Templates window is to select Reports from the Wetbud home screen and choose Generate Report from the drop-down menu.



12.1 Generate Report

Complete Reports can only be generated for Models that have been run in Wetbud using the Basic Scenario Analysis and Output tools or the tools in the Solve tab of the Advanced Scenarios for Project.

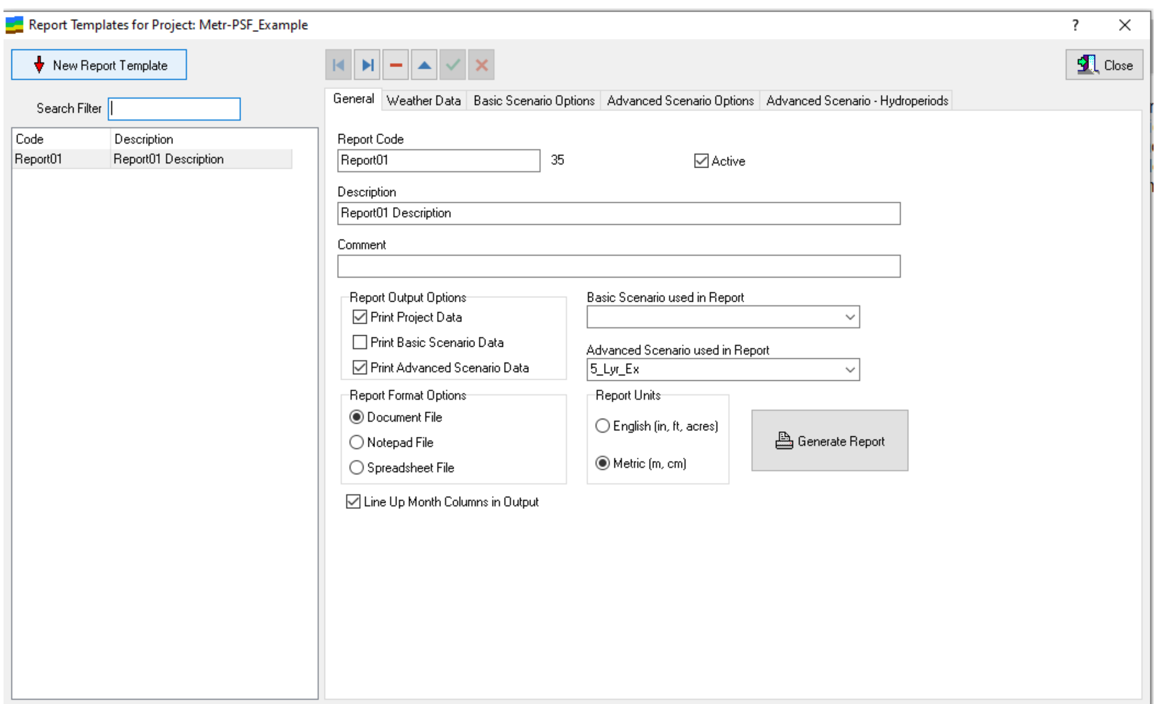
Once all of the options for the Report have been decided on, click , then click the 

button to have Wetbud produce a Report summarizing the inputs and outputs associated with the Model(s) you have produced.

12.2 General

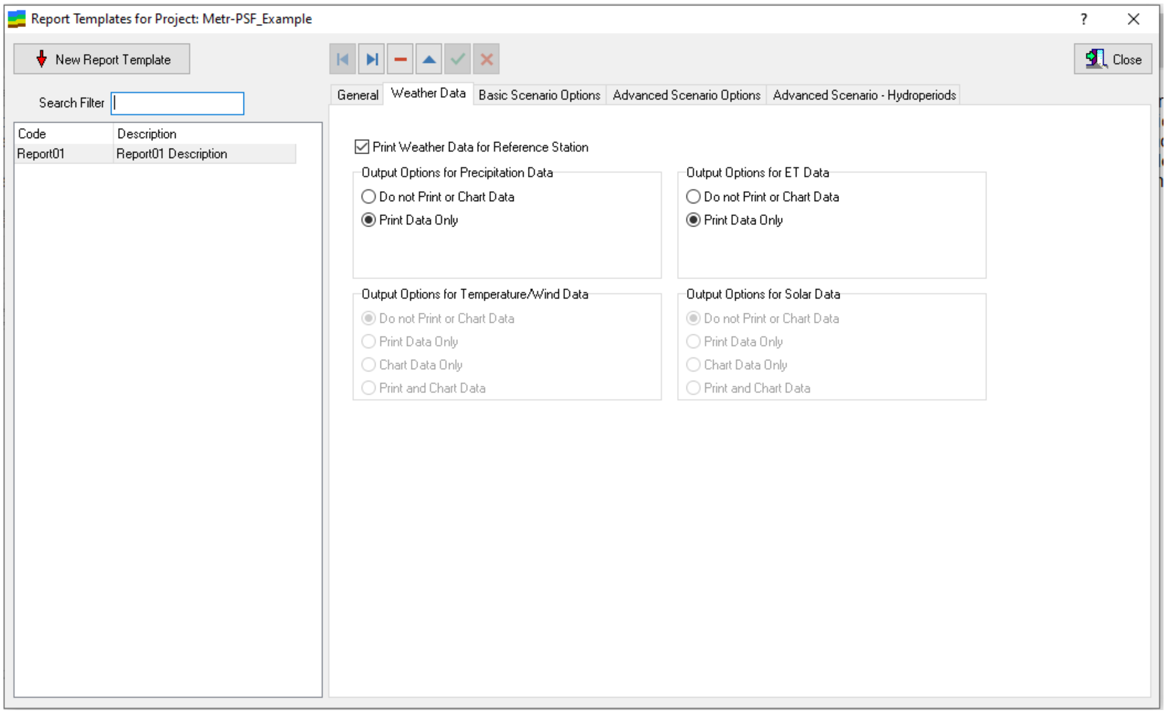
Click the 

button (button will be grayed out if you are generating a report from Project Wizard output). Update the Report Code, Description, and Comment boxes so that they accurately describe the report you are generating. In the Output Scenario/Model Data choose the model output data you wish to include in your Report. Use the drop-down menus to choose which Basic and/or Advanced Scenario data will be included in the Report. The check boxes below the Output Scenario/Model Data section allow the user to select whether or not to include Project Data, Basic Scenario Data, and Advanced Scenario Data. Use the radio buttons in the Report Units section to determine which unit system you would like to data in the report to be compiled in. Wetbud stores all of the values used in a Project in both English and Metric units. While a Project, and Models within, may have been constructed in English units, the Report can be generated in Metric units and vice versa. Under Report Options choose the format of the file generated by Wetbud that will contain the Report.



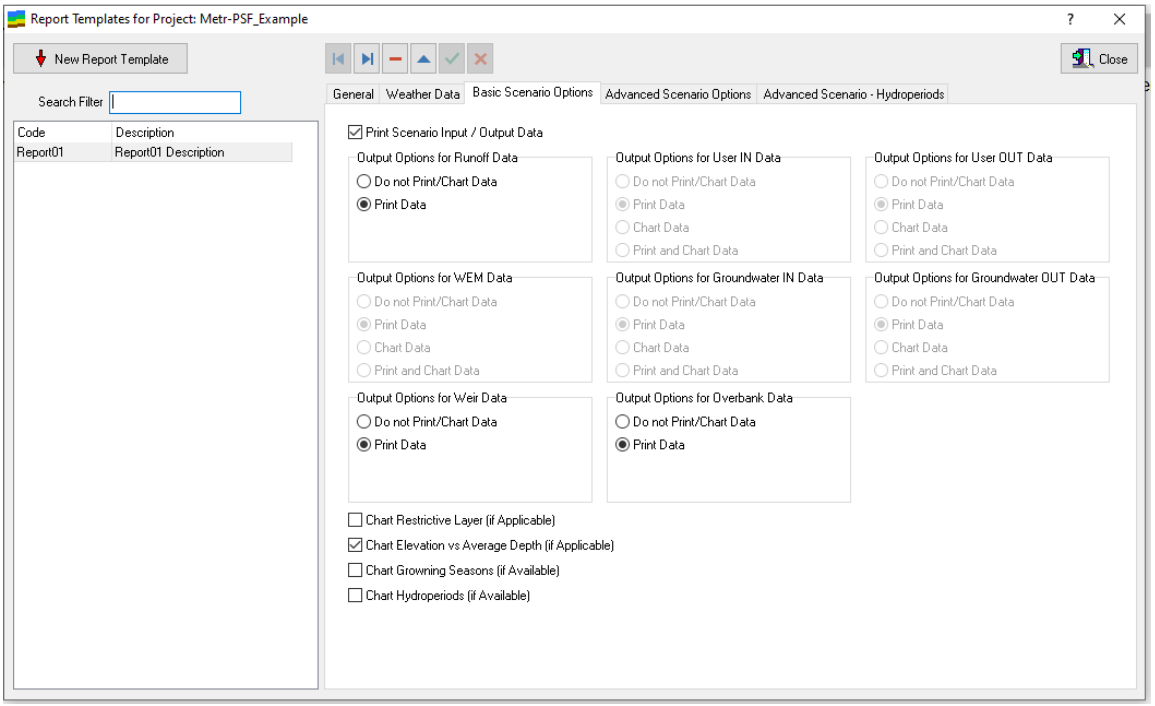
12.3 Weather Data

The Weather Data tab contains options for choosing which weather station data will be included in the Report and how that data will be presented.

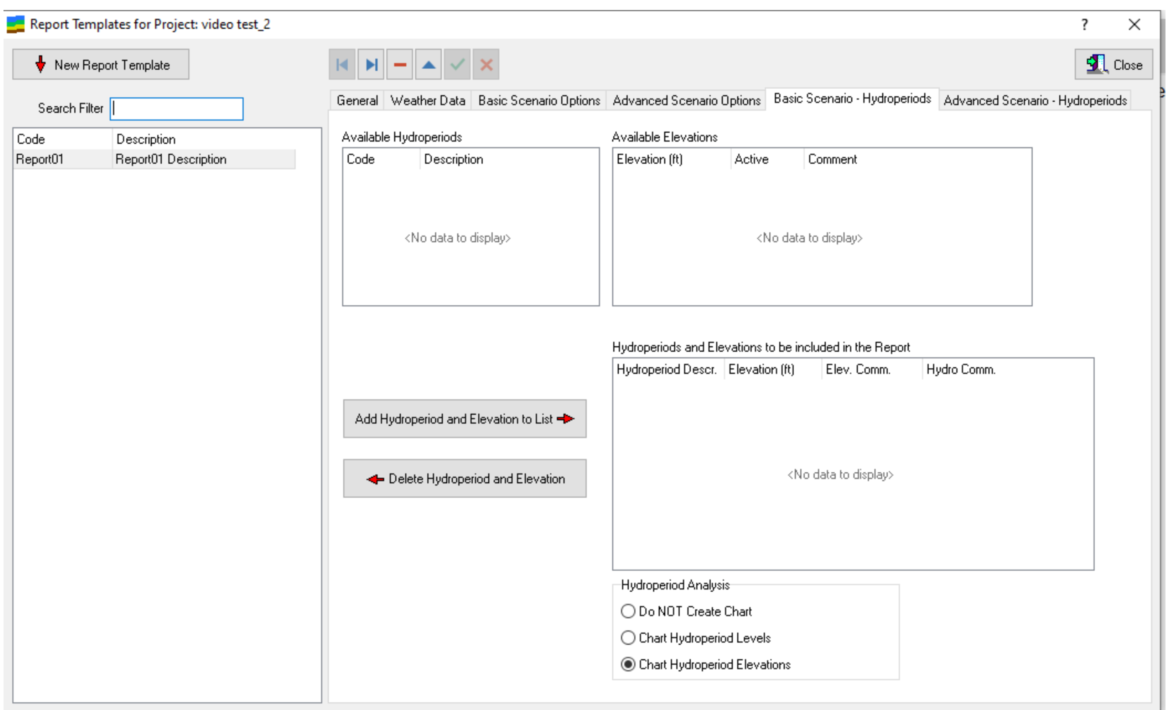


12.4 Basic Scenario Options

The Basic Scenario Options tab contains options for choosing which parameters will be included in the Report and how that data for each of the parameters will be presented.

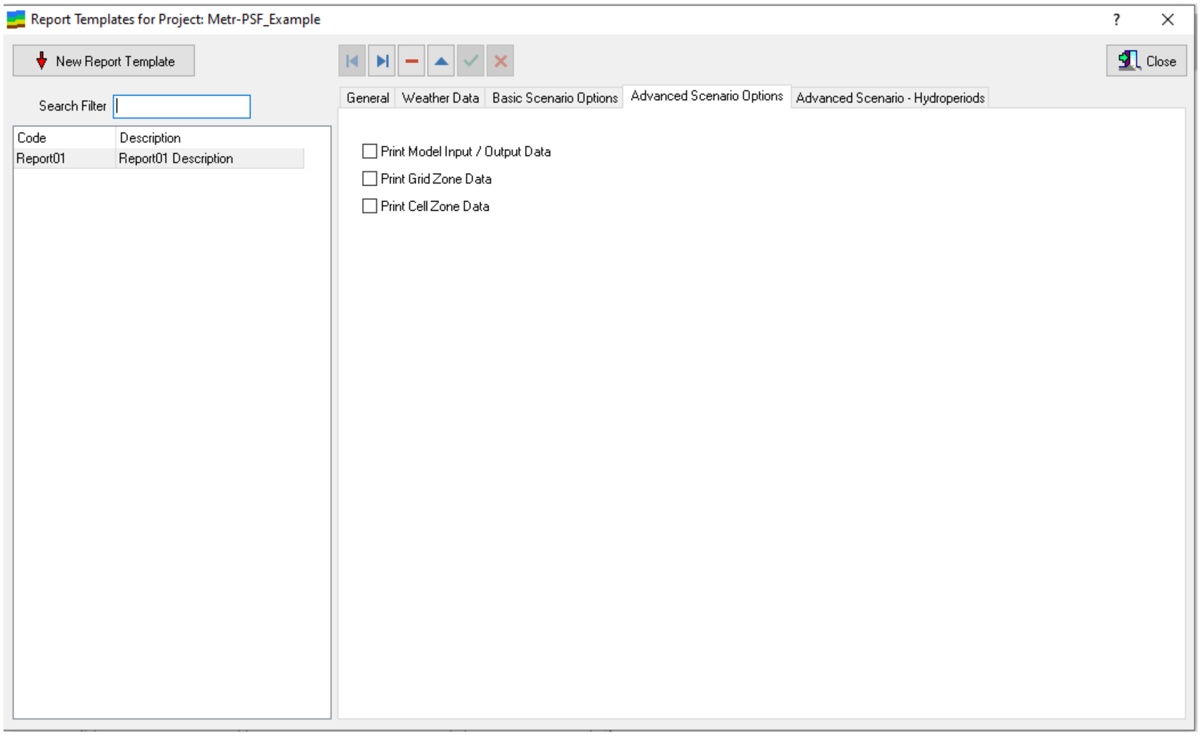


If the user has specified a sensitivity analysis with respect to hydroperiods and elevations (this is specified in the basic scenario definition), then the Basic Scenario Hydroperiod tab will be visible, where the user can specify hydroperiod and elevation combinations that will be charted in the report.

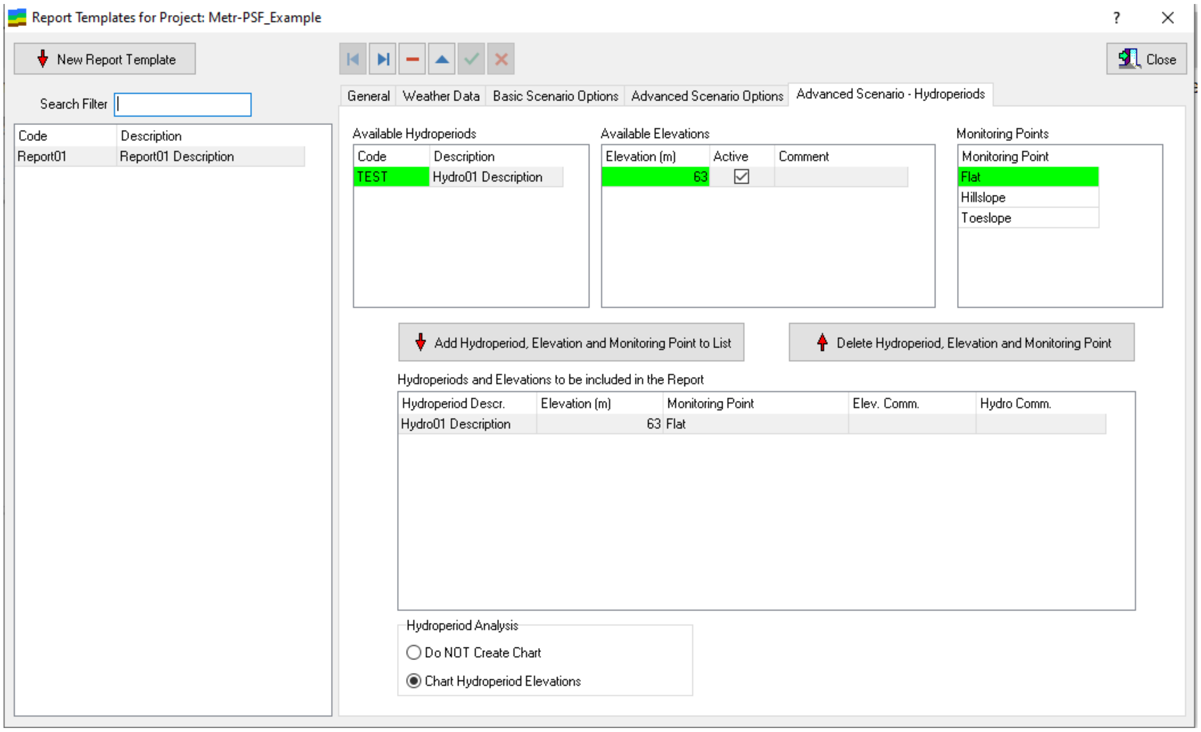


12.5 Advanced Scenario Options

The Advanced Scenario Options tab contains options for choosing which data from the Advanced Scenario will be included in the Report.



If the user has specified a sensitivity analysis with respect to hydroperiods and elevations (this is specified in the advanced scenario definition), then the Advanced Scenario Hydroperiod tab will be visible, where the user can specify hydroperiod, elevation and monitoring point combinations that will be charted in the report. If a hydroperiod sensitivity analysis was not specified, the report will print the hydrographs for all monitoring points and the respective surface elevations.


Report Templates for Project: Metr-PSF_Example
New Report Template
Close
Search Filter
Code Description
Report01 Report01 Description
General Weather Data Basic Scenario Options Advanced Scenario Options Advanced Scenario - Hydroperiods
Available Hydroperiods
Code Description
TEST Hydro01 Description
Available Elevations
Elevation (m) Active Comment
63
Monitoring Points
Monitoring Point
Flat
Hillslope
Toeslope
Add Hydroperiod, Elevation and Monitoring Point to List
Delete Hydroperiod, Elevation and Monitoring Point
Hydroperiods and Elevations to be included in the Report
Hydroperiod Descr. Elevation (m) Monitoring Point Elev. Comm. Hydro Comm.
Hydro01 Description 63 Flat
Hydroperiod Analysis
Do NOT Create Chart
Chart Hydroperiod Elevations

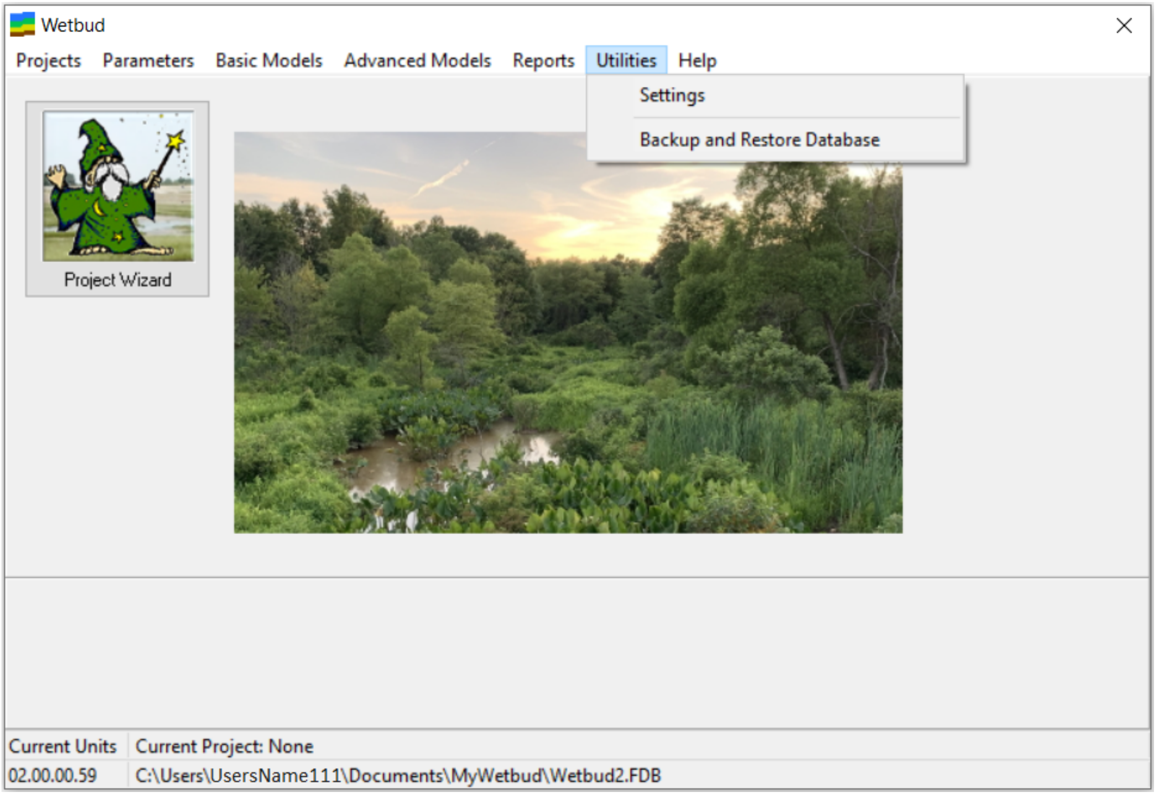
13

Utilities

13 Utilities

The Utilities menu includes two options:

- Settings
- Backup and Restore Database



13.1 Settings

The user can customize Wetbud through a number of settings options.

Settings options are grouped in different tabs as follows:

- General Options
- Download and Import Options
- Station Data Options
- Basic Model Options
- Advanced Model Options
- Appearance Options
- Video Options
- Backup Options

13.1.1 General

The General tab is used to assign the database file, the MODFLOW executable file, and the MODFLOW version. These options allow Wetbud to interface with different databases (i.e., the current database and a backup database). Database specification does not need to change in typical Wetbud installations.

Database Full Filename displays the location and file name of the current database file used by Wetbud. To change the database file, click the browse button and select the desired database file. If the Try to connect to DB (database) upon exit from Settings box is checked, Wetbud will automatically try to connect to the specified database file. The specification of the database file currently connected to Wetbud appears at the bottom of the Wetbud home screen.

Wetbud also allows the user to specify whether the database would be local (on the same computer) or on a database server over LAN. In the latter case, the specification will need to include the IP address of the server where the database file resides as shown below.

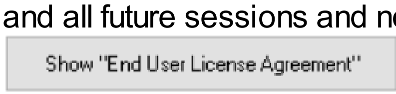
The MODFLOW Executable Full Filename field displays the location and file name of the current MODFLOW executable file being used to compute Advanced Model simulations. Four MODFLOW executable files are included in the Wetbud download, MODFLOW-NWT.exe as a 32bit and 64bit executable and mf2005.exe (MODFLOW 2005) as a single and double precision executable. MODFLOW-NWT is assigned as the default solution engine because it is more appropriate for simulating sites with large water level fluctuations such as wetlands. To change the MODFLOW executable file, click the browse button and select the desired MODFLOW executable.

Note: The selected MODFLOW Version Option must correspond to the MODFLOW executable file.

The Wetbud Log Files option can be used to control whether Wetbud log files will be kept or periodically deleted. Log files are kept under Documents/MyWetbud/logs.

The Default Project Units setting specifies the units that will be pre-selected when defining a new project as well as the units used for displaying precipitation, weather (e.g., temperature), ET and other data under Parameters.

Through the Show Disclaimer Options the user can select to either display the disclaimer form every time the program starts or to accept the disclaimer for the current and all future sessions and not show the disclaimer at program start up. Click



to display the disclaimer.

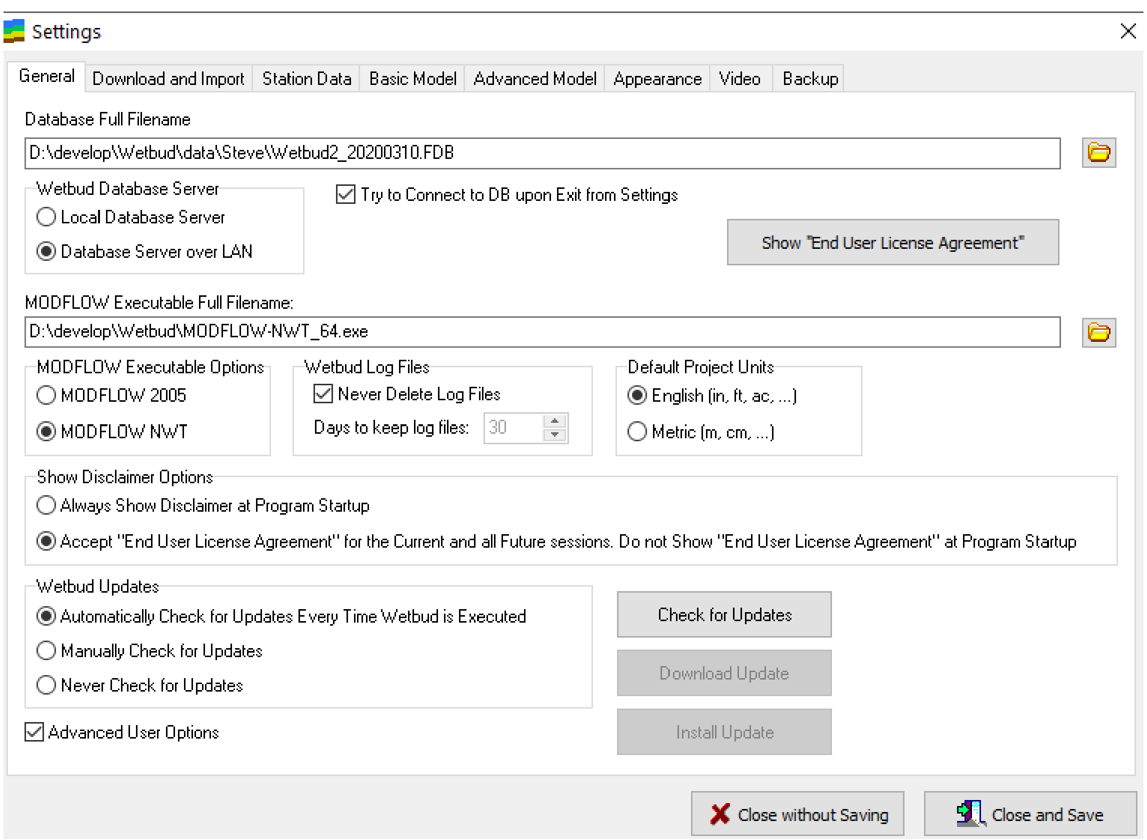
Wetbud Updates

- If the *Wetbud Updates* option is set to *Automatically Check for Update Every Time Wetbud is Executed*, Wetbud will check the website for any updates and if a newer version is found, Wetbud will prompt the user to install the updates.
- If the *Wetbud Updates* option is set to *Manually Check for Updates*, the user can click 

to check whether an update is available on the website. If an update is found, the Download Update button will be enabled and the user can download the update. Once the update is downloaded, the Install Update button will be enabled and the user will be able to install the update. Note that Wetbud will invoke the update installer and then close. The installer should automatically install any updates to the database and to the program itself.
- If the *Wetbud Updates* option is set to *Never Check for Updates*, the program will never check for any updates. This option is not recommended.

Note on download of Wetbud updates: The user may change the default download path to an alternate path if there are issues saving files to the default download path. For more information see Download and Import.

When Advanced User Options is enabled, additional options will appear under different menus and forms.



13.1.2 Download and Import

The Download and Import tab is used to manage the files downloaded by Wetbud (e.g., station data, precipitation, solar, weather).

The folder assigned under Data Folder for Downloads will be used to save the raw data files for all files downloaded by Wetbud. Wetbud uses the MyWetbud folder as the default storage location for these files. If "Application" is selected under Data Folder for Downloads then all data will be stored in the Wetbud installation directory, i.e., C: \Wetbud. If "Alternate" is selected in the Data Folder for Downloads drop-down list, then the user must specify the location of the data folder in the text box under Alternate Data Folder Specification.

Important: Wetbud does not check if the current Windows user has permission to save files in a specified directory. MyWetbud is created under "My documents" or "Documents" which ensures read/write permissions for the current Windows user.

The Virtual Drive for Download drop-down list is used to select the virtual drive used for downloading files in Wetbud. The use of virtual or mapped network drive is necessary especially when downloading to network or shared folders. For this task a drive letter should be assigned here which is **not already in use** in the computer. To ensure that a free drive letter is selected consult the drive letter showing under "Computer" or "My Computer." Wetbud will only use the drive letter when downloading and release it when downloading is completed.

If the Pause after each download call (Debug) box is checked, Wetbud will pause after each download. This function is helpful to identify whether the connection with the FTP server is successful and whether any data is being downloaded.

As a default, Wetbud deletes temporary download files such as "724007-03719-2005.op" under "….\MyWetbud\Data\precip\724007". Uncheck the Delete Temporary Download Files box to disable deletion of the temporary download files. This function is helpful when trying to identify the source of erroneous data and aid with quality assurance and quality control of data used by Wetbud.

As a default, Wetbud uses passive FTP mode, which enables Wetbud to bypass all router or internet service provider restrictions that may inhibit Wetbud from downloading files from the web. Uncheck the Use Passive FTP mode box to disable passive FTP mode. A quick summary of the pros and cons of active vs. passive FTP is given below:

- The main problem with active mode FTP actually falls on the client side. The FTP client doesn't make the actual connection to the data port of the server--it simply tells the server what port it is listening on and the server connects back to the specified port on the client. From the client side firewall this appears to be an outside system initiating a connection to an internal client--something that is usually blocked.
- While passive mode FTP solves many of the problems from the client side, it opens up a whole range of problems on the server side. The biggest issue is the need to allow any remote connection to high numbered ports on the server. If Active FTP

access to the NOAA sites seems to be blocked, try to use FTP in passive mode by selecting this option.

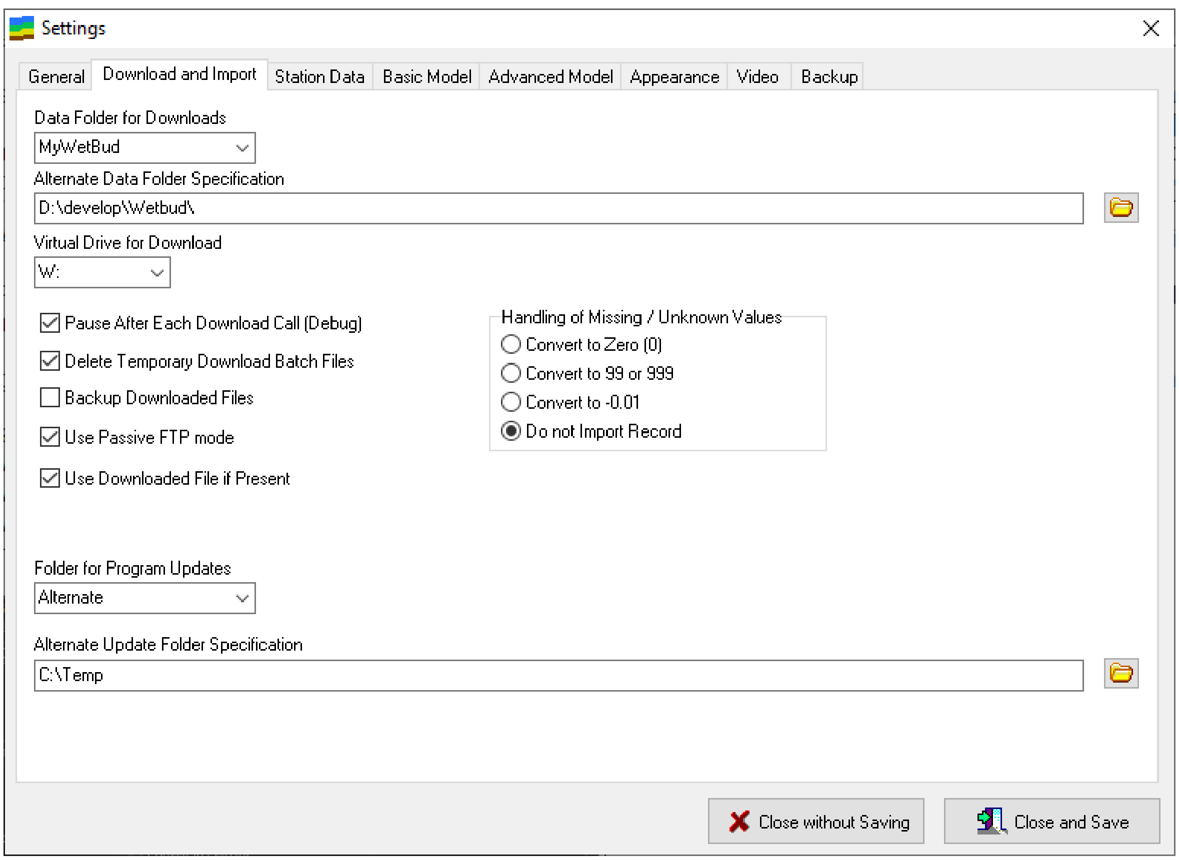
If the Use Downloaded File if Present box is checked, Wetbud will search the Documents\MyWetbud\Data folder for previously downloaded data before accessing the internet when attempting to download weather station data. This option will prioritize a local search but still permit Wetbud to access the internet if the data is not available locally.

The Handling of Missing/Unknown Values options have been provided so that the user may choose the best method for their approach to inspecting data imported from the web and correcting missing or null values.

Wetbud can handle Missing and/or Unknown values in different ways:

- By converting unknown values to 0.
- By converting unknown values (i.e., precipitation) to 99 or 999.
- By converting unknown values (i.e., precipitation) to small negative values, (-0.01).
- By completely disregarding that date record.

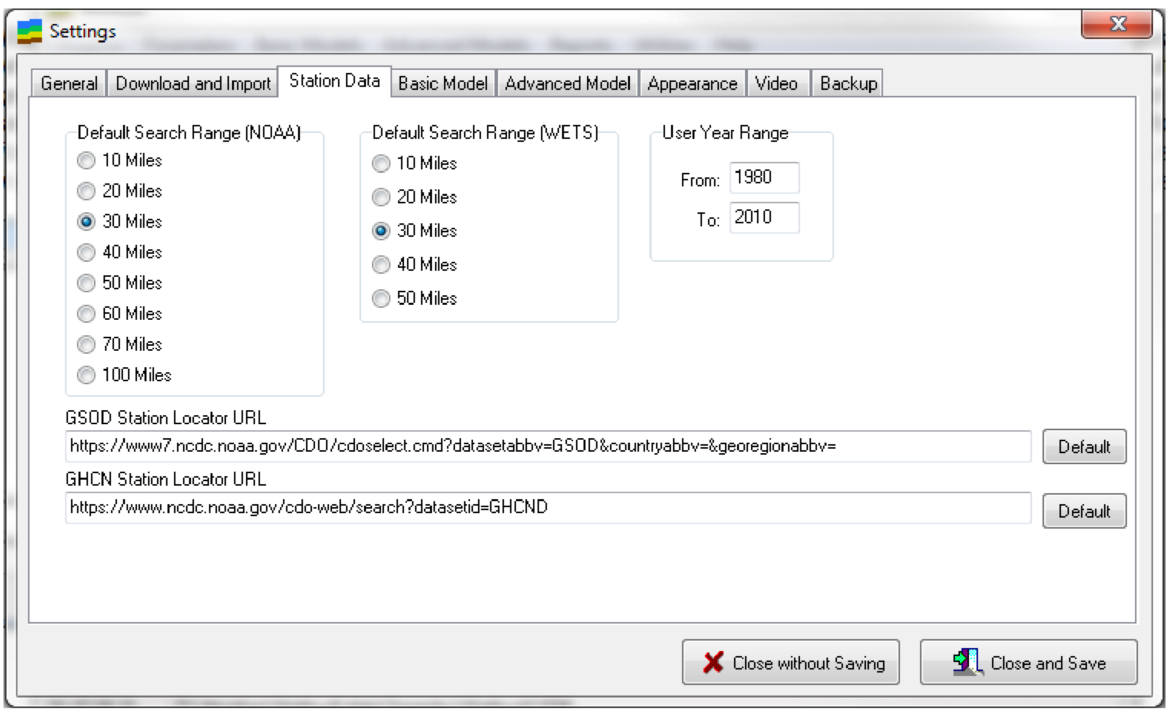
The user can also specify an alternate folder for downloading program updates, if the default folder specification is inaccessible due to permission issues.



13.1.3 Station Data

The Station Data tab is used to adjust the default search range and set the user year range in the weather parameters, as follows:

1. Default Search Range (miles) – This setting is used to adjust the default search range for Google map displays and for nearest NOAA (GSOD and GHCN) and WETS station searches.
2. User Year Range – This setting is used to adjust the range of years to be included when 'User Default' is selected in the Web Retrieval tab of the Solar, Weather, or Precipitation data windows. Instead of downloading all available data for a station, the 'User Default' option is useful for those who wish to download data for a specific range of years.
3. The GSOD Station Locator URL is a user defined URL that is used to access the GSOD Station Locator web page. This URL should not be changed unless the actual locator URL changes.
4. The GHCN Station Locator URL is a user defined URL that is used to access the GHCN Station Locator web page. This URL should not be changed unless the actual locator URL changes.



13.1.4 Basic Model

The Basic Model tab is used to adjust settings for Basic Model setup and output, as described below:

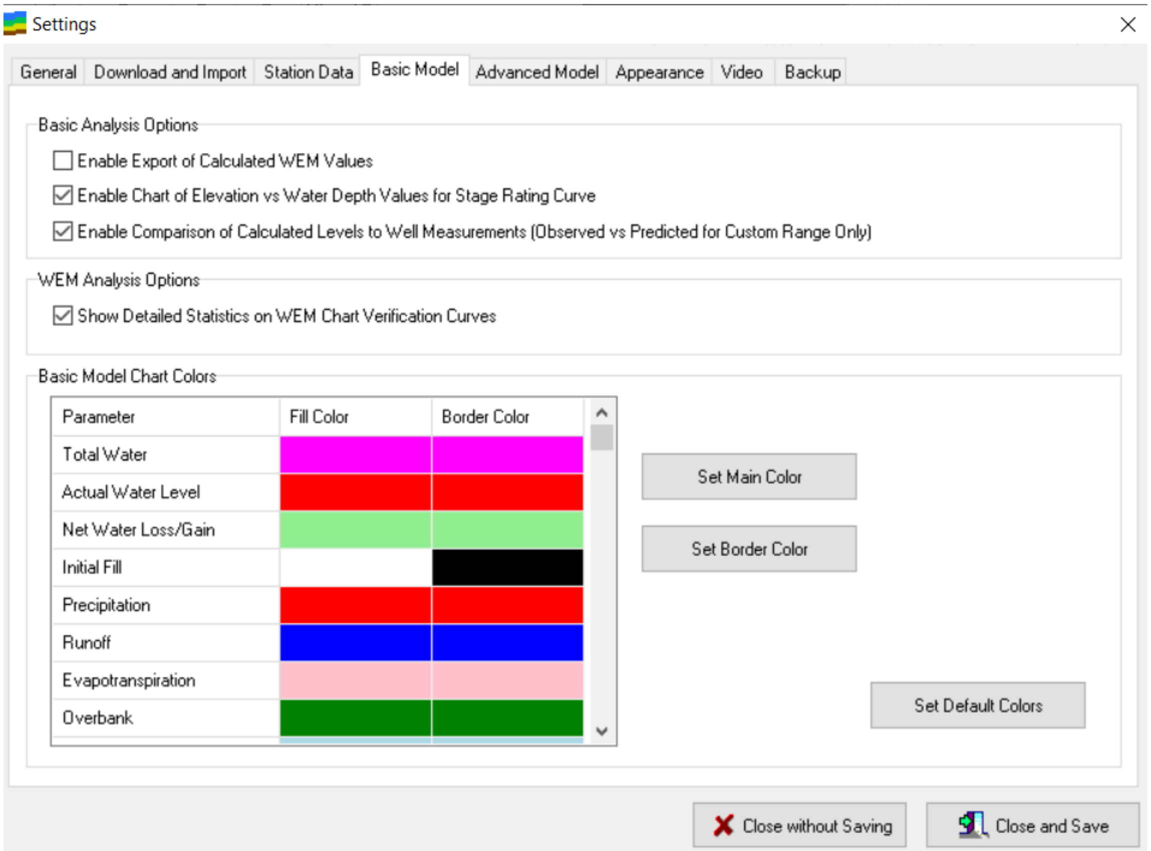
1. Enable Export of Calculated WEM Values – When this checkbox is checked, an Export button will be activated under Basic Scenario Analysis to allow exporting of WEM predicted head values. Once exported, these values could be used to generate General Head Boundaries for the Advanced Model for years that lack observed head values. This is an Advanced User option.
2. Enable Chart of Elevation vs Water Depth Values for Stage Rating Curve - When this checkbox is checked a Chart button will be activated under Basic Scenario Analysis to allow charting Elevation vs Average Water Depth for these scenarios that employ stage rating curves.
3. Enable Comparison of Calculated Levels to Well Measurements (Observed vs Predicted for Custom Range Only) – When this checkbox is checked, an additional tab will be activated under Basic Analysis to allow comparison of Observed and Predicted values for the custom range of calculations. These statistics include the standard error of the slope, the t-statistic, and the p-value of calibration curve. This is an Advanced User option.
4. Show Detailed Statistics on WEM Chart Verification Curves – When this checkbox is checked, additional statistics will be shown when the Chart Verification Curves are displayed under WEM. This is an Advanced User option.

Basic Model Chart Colors can be set by the user as described:
1. Click the colored boxes of the row of the Parameter to change.
2. Click 

and use the color picker to set the fill color for the chosen Parameter.
3. Click 

and use the color picker to set the border color for the chosen Parameter.
4. Click 

to return all colors to the defaults.

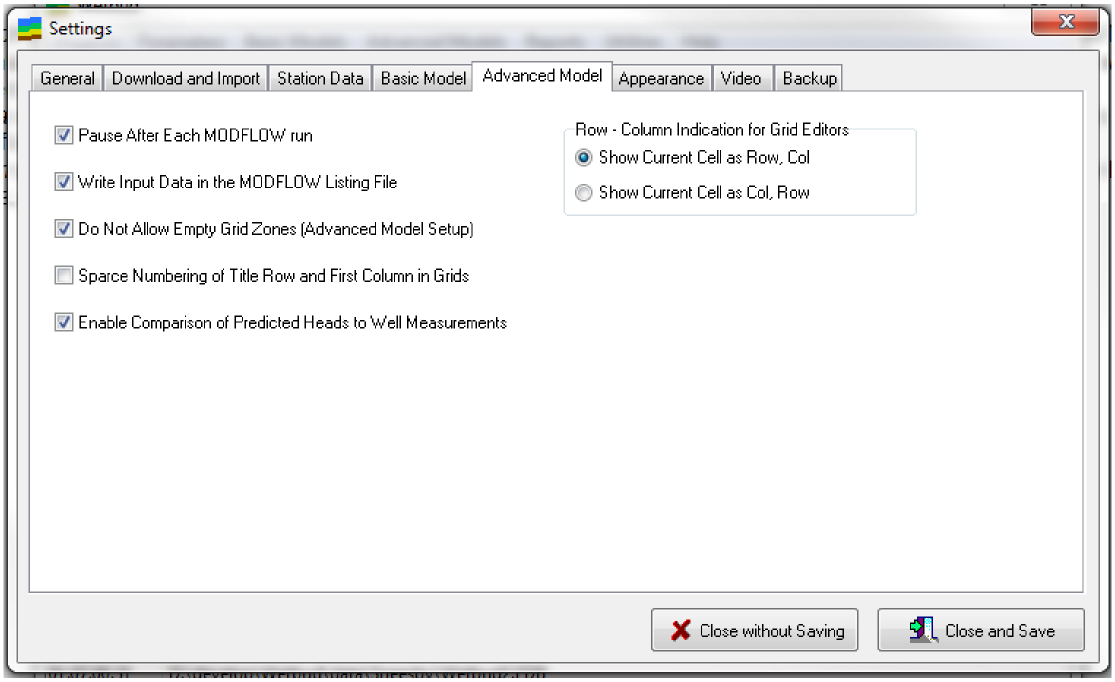


13.1.5 Advanced Model

The Advanced Model tab is used to adjust settings for Advanced Model setup and output, as described below:

1. Pause After Each MODFLOW run – When this checkbox is checked (recommended), each MODFLOW simulation of an Advanced Model is followed by a pause with a 'press any key to continue' prompt in the MODFLOW simulation window. If the Pause after MODFLOW run box is unchecked, then the MODFLOW simulation window will automatically disappear at the end of the MODFLOW simulation. Unchecking this box is not recommended because it does not give the user visual confirmation of a successful MODFLOW simulation.
2. Write Input Data in the MODFLOW Listing File – When this box is checked (recommended), all Advanced Model input data is written in to the MODFLOW listing file. Including input data in the MODFLOW listing file is useful for debugging MODFLOW runs in cases of non-convergence or erroneous input.
3. Do Not Allow Empty Grid Zones (Advanced Model Setup) – This option ensures that all Grid Zones under the Advanced Model grid zone setup are fully populated. Under this condition, Wetbud will not exit a grid edit form if a grid zone number is not assigned to all cells in the model grid.
4. Space Numbering of Title Row and First Column in Grids – When this checkbox is checked the first column enumerates the row number and the top row enumerates the column number. Numbers may not be fully visible for large grids

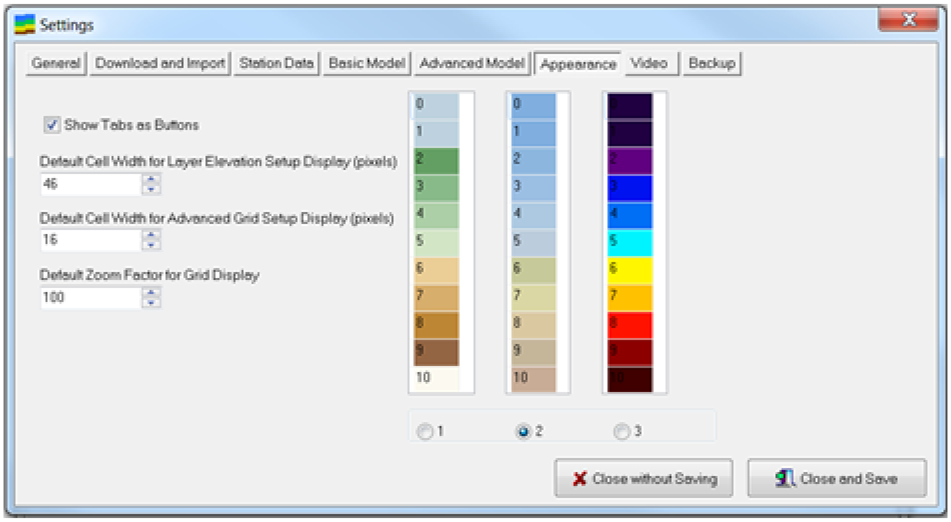
5. Enable Comparison of Predicted Heads to Well Measurements – When this checkbox is checked an additional tab will be available under Model Output to allow users to compare model results to actual measurements. This is considered an advanced feature
6. Row - Column Indication for Grid Editors – The default setting is to show the current cell position as row, col. The user has to option to select the current cell position indicator to be shown as column, row.



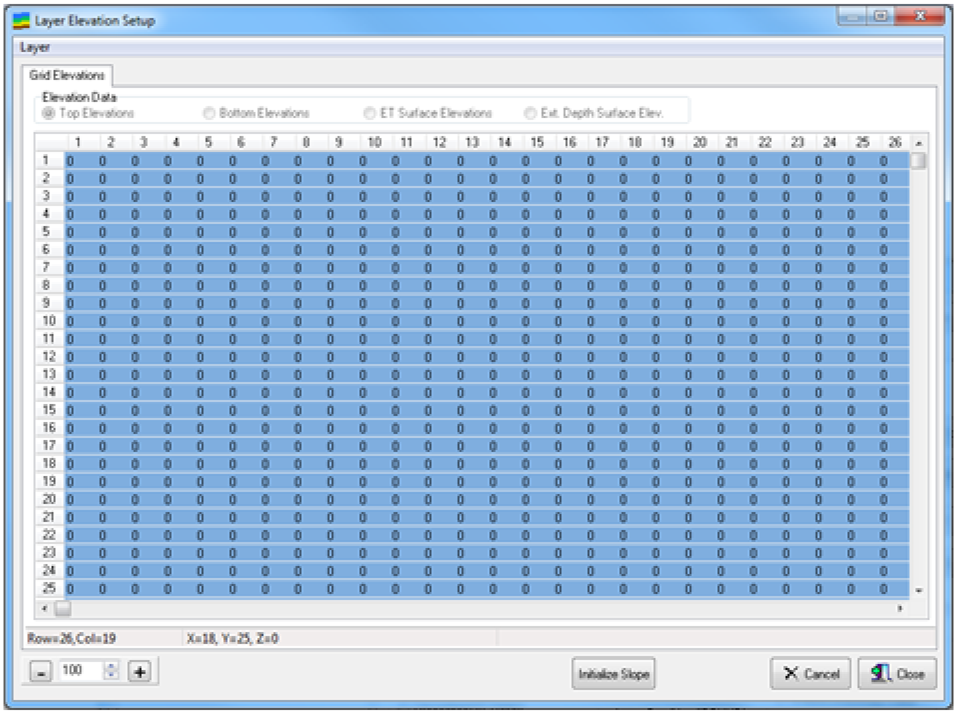
13.1.6 Appearance

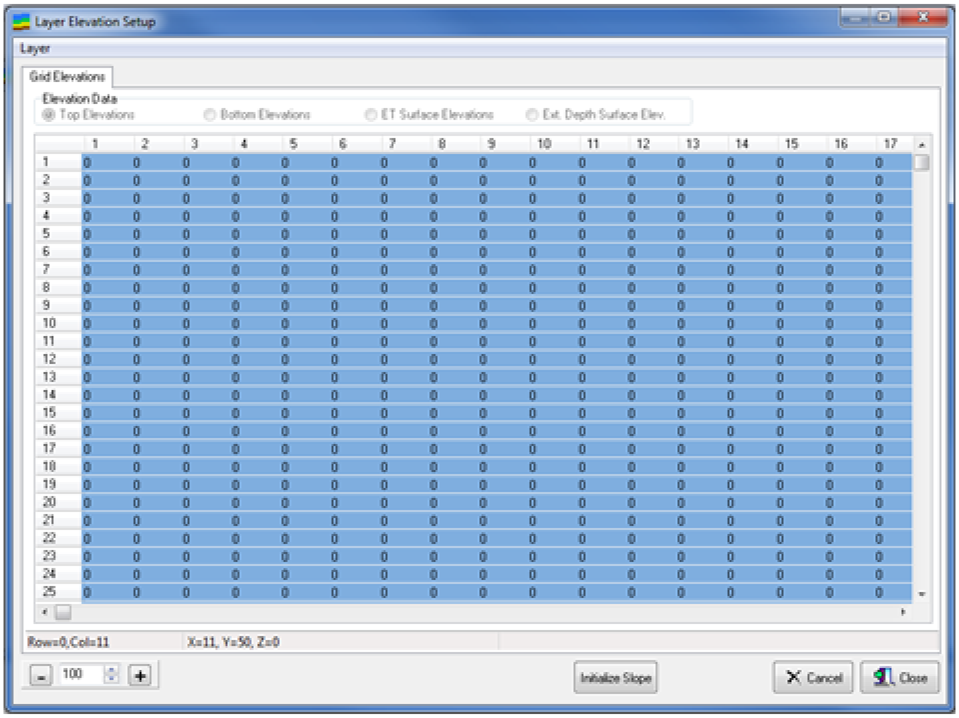
The Appearance tab is used to adjust display settings for windows in Wetbud and for the Advanced Model grid, as follows:

1. Show Tabs as Buttons – To display tabs as buttons, check the Show Tabs as Buttons box and then click OK. Tabs in all windows will be displayed as buttons as shown in the figure below.

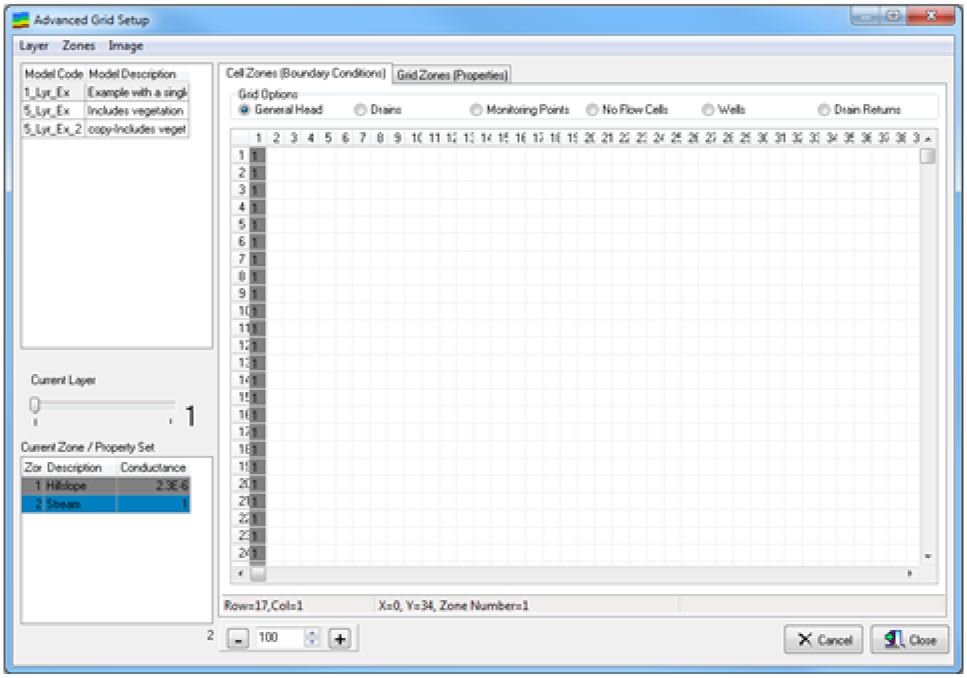


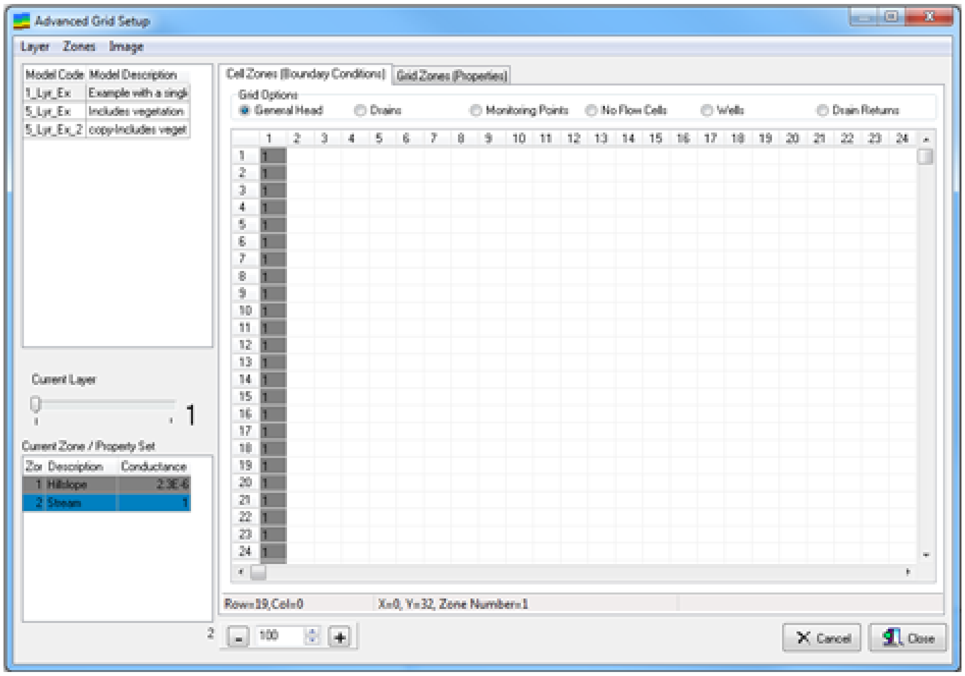
2. Default Cell Width for Layer Elevation Setup Display (pixels) – This setting is used to adjust the default cell width displayed in the Layer Elevation Setup window. The following two figures show grids with different cell widths of 30 and 46 pixels, respectively.





3. Default Cell Width for Advanced Grid Setup Display (pixels) - This setting is used to adjust the default cell width displayed in the Advanced Grid Setup window. The following two figures show grids with different cell widths of 16 and 26 pixels, respectively.



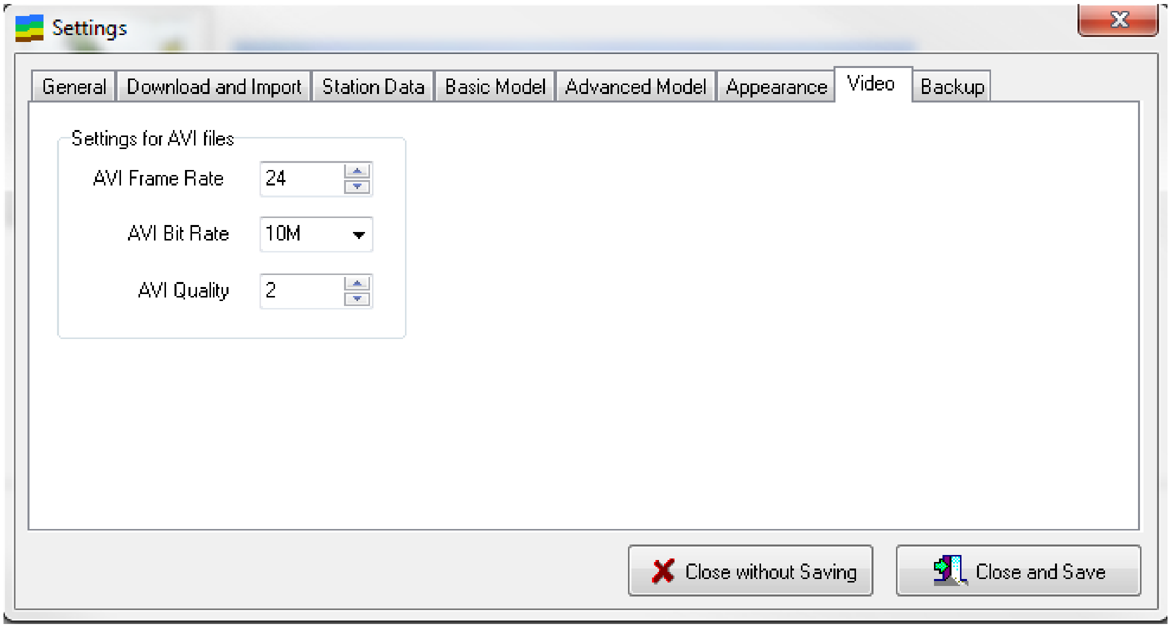


4. Default Zoom Factor for Grid Display – This setting is used to adjust the default zoom when displaying a Layer Elevation grid and Advanced Model setup grid. Since the zoom can be adjusted manually when viewing either type of grid, it is not recommended that users change the default zoom of 100.
5. Color scale options – The display of color-contoured layer elevation grids (Layer Elevation Setup window) and head elevation grids (Grids tab in Advanced Model output) can be adjusted by selecting from the three color scale options in the Appearance tab of the Settings window (default – color option 2). See the first figure in this section for details.

13.1.7 Video

Wetbud can generate short videos of the Advanced Model results displayed in the Grids tab of Advanced Model Output window. In general, the bitrate and frame rate of a digital video file give an indication of the video's quality level. The higher the bitrate of an AVI video file, the more data per second the video contains. A higher frame rate leads to smoother movement in the video.

In Wetbud, the solution for every time step corresponds to a frame. Thus, a solution with 360 time steps will produce a video sequence with 360 frames. If 20 frames per second are selected as the default frame rate (typical frame rates range between 18 and 24), then the video will last for 18 seconds. The AVI bit rate and quality are parameters required by the AVI movie generator. Default values are shown below.

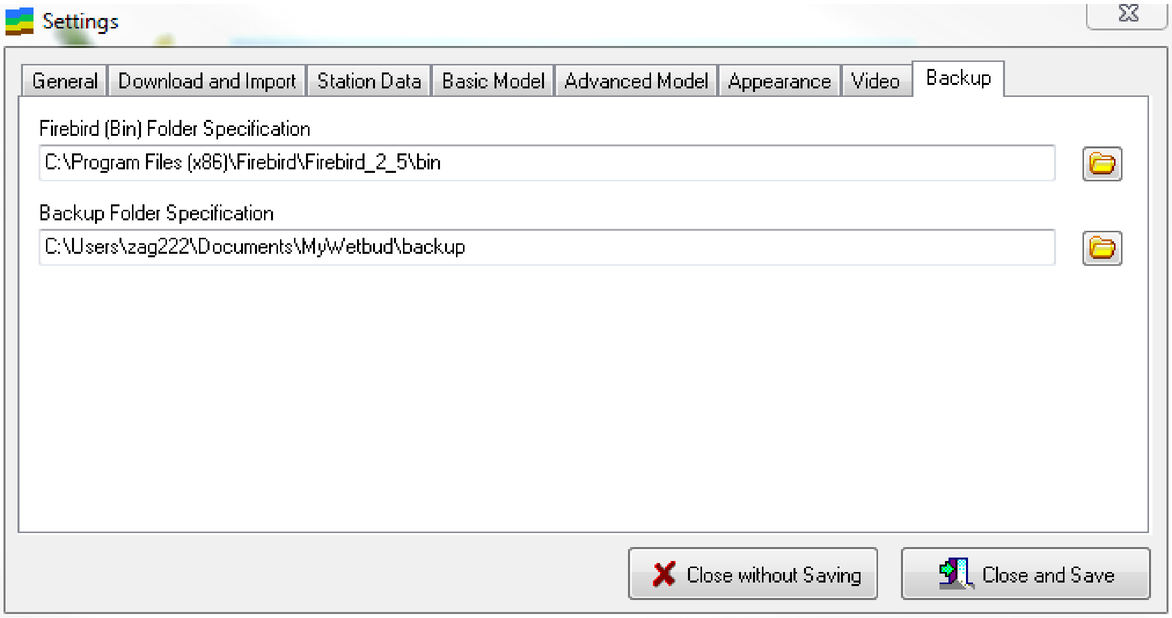


13.1.8 Backup

The Backup tab allows the user to setup the engine (program) and location for creating a backup file. The backup and restore functions are run through a different Settings menu option (see Backup and Restore).

Under Firebird (bin) Folder Specification the user should specify the location of the Firebird bin directory. This is usually C:\Program Files\Firebird\Firebird_2_5\bin. Under Backup Folder Specification the user should specify where to store the backup file.

Important: Wetbud does not check if the current Windows user has permission to save files in a specified directory when a backup folder is specified. If permission is not granted, then the backup process will fail.



13.2 Backup and Restore

These functions are useful for multi-user environments and to fix corrupt database files. To access the backup and restore options, select Backup and Restore from the Settings drop down menu in the Wetbud home screen.

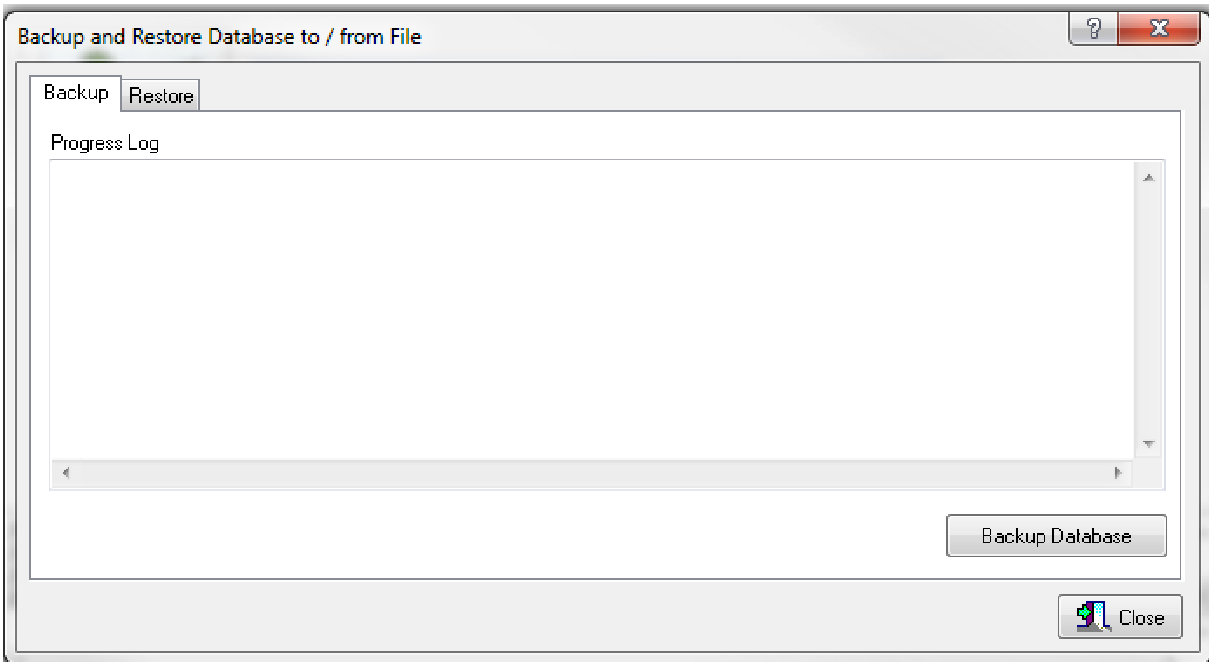
The Backup and Restore Database to/from File window has two tabs: Backup and Restore.

13.2.1 Backup

The Backup tab is used to create a backup of the database and store it in the folder specified under Settings/Backup. The parameters for backing up a database should be set under Utilities - Settings - Backup.

To create a backup database (DB) in this tab, click 

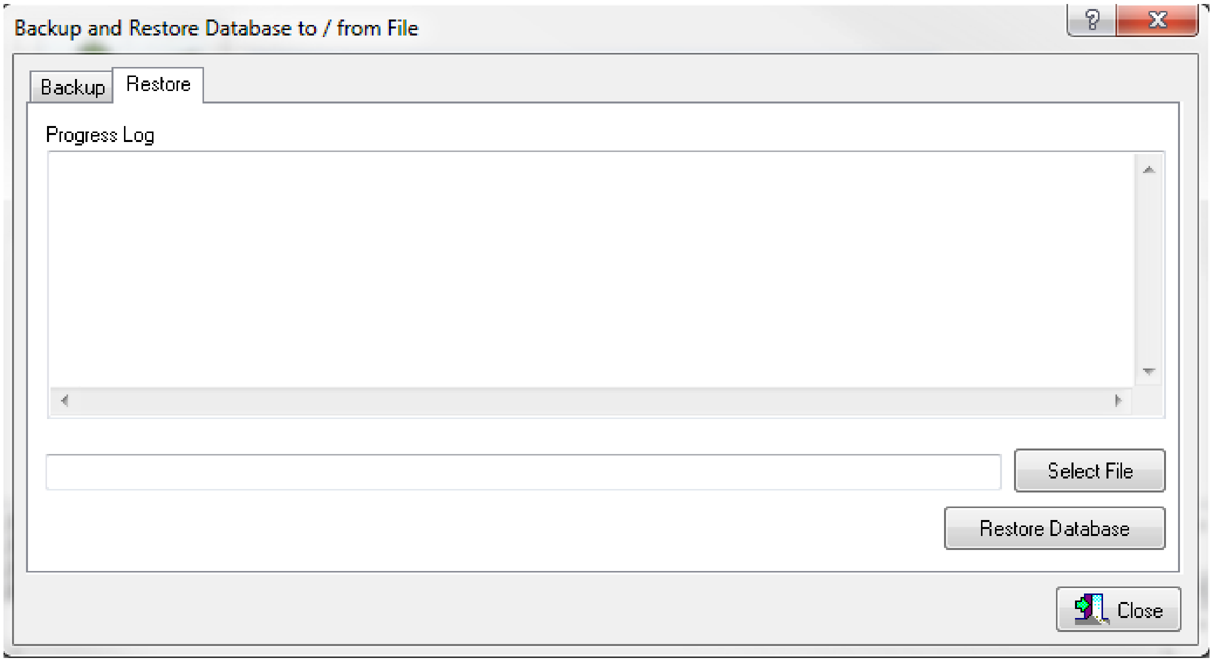
. The backup process will be initiated and a DOS window will appear temporarily. Once the backup file has been created, the DOS window will disappear. The file name of the backup DB will reflect the date and time the backup was created (timestamp).



13.2.2 Restore

The Restore tab is used to restore a backup image of the database to an actual database. The parameters for restoring a database should be set under [Utilities - Settings - Backup]

To restore a database, first select the file and then click Restore Database. Once the backup file has been created, the DOS window will disappear. The restored database will not overwrite the current database. It will be given a name with a timestamp.



14

Supplementary Material

14 Supplementary Material

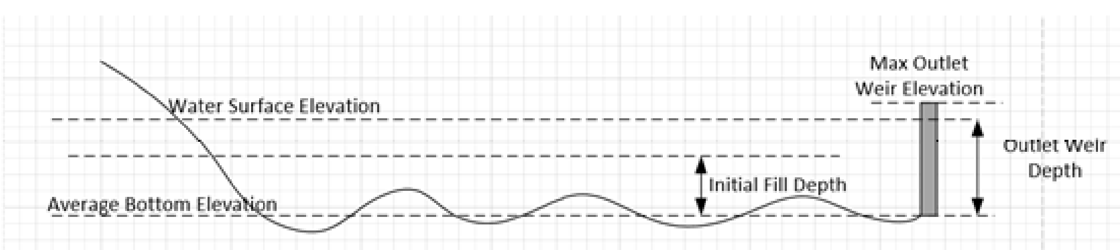
This section contains reference material for the operation of Wetbud.

14.1 Reference Hydroperiods

1. Wetbud is a wetland water budget modeling tool that can be used to help you predict what the range of hydroperiods is expected for a particular site and design for a range of precipitation years that represent Wet, Normal and Dry years. Wetbud was developed for specific application to created wetlands, but has other applications as well.
2. The hydroperiod is the major determinant of the type of wetlands you restore and create. It represents the depth, duration, and timing (i.e., seasonality) of surface and/or groundwater water levels in a wetlands system over an annual period (usually January to December).
3. To determine if the water budget you develop with Wetbud, or other methods, predicts the hydroperiod you need to achieve, it is usually necessary (or required by regulations) to compare your modeling result to a Reference or Design Target Hydroperiod ("Reference Hydroperiod").
4. There are currently only a few primary sources of data or approaches for establishing Reference Hydroperiods:
   a. Regulatory – e.g., Target Hydrology and Performance Standards for Compensatory Mitigation Sites, St. Paul District USACE, Version 6.0, March 20, 2019.
   b. Best Professional Judgement (BPJ).
   c. Published Literature Studies of Individual Sites.
   d. Wetbud Hydroperiod Reference Library.
5. RPG has sponsored a literature review and via contact with state and federal agencies and other sources (NGO's), developed a hydroperiod database for over 90 sites that was used to develop a Hydroperiod Reference Library for selected sites that met a range of criteria including continuity of data, multiple years of monitoring and disturbance history. The thesis that resulted from this effort is: Evaluation of a Water Budget Model for Created Wetland Design and Comparative Natural Wetland Hydroperiods (https://vtechworks.lib.vt.edu/handle/10919/88836) by Ethan Sneesby, M.S. thesis, Virginia Tech, 2019. Selected data sets from that effort have been distilled into 12 reference hydroperiods for a range of mid-Atlantic PFO wetlands that are stored in Wetbud. Details on the individual site characteristics including compiled graphics of all years (2-6) for each site can be found in the Appendix. We anticipate that additional hydroperiods for other types of non-tidal wetlands will be added over time.
6. For Wetbud and most other applications, the Reference Hydroperiod establishes a range of monthly high and low expected/possible water levels for each month. Thus, the Reference Hydroperiod reflects the range of water levels expected over time and not a single average. Thus, to enter a Reference Hydroperiod into Wetbud – you need a Maximum water level and a Minimum water level (relative to the average ground elevation) for the end of each month (the program uses the end of December value to start the graphs on Jan 1).

a. You can use this data entry portal to enter values from regulatory sources, BPJ or Literature.
b. Alternatively, you can select one of the data sets (all regional PFO's) provided in the Reference Hydroperiod Library. But you must review the related site-specific supporting data in the next section to ensure it matches your desired wetlands type and climate (i.e. – the data library may need to be adjusted using BPJ). Import a reference hydroperiod in the Project Specific Hydroperiod Data as explained in the Reference Hydroperiod Data section. See Basic Scenarios on how to define a hydroperiod curve for a specific scenario and on how to run a sensitivity analysis with different hydroperiod data sets and different elevations.

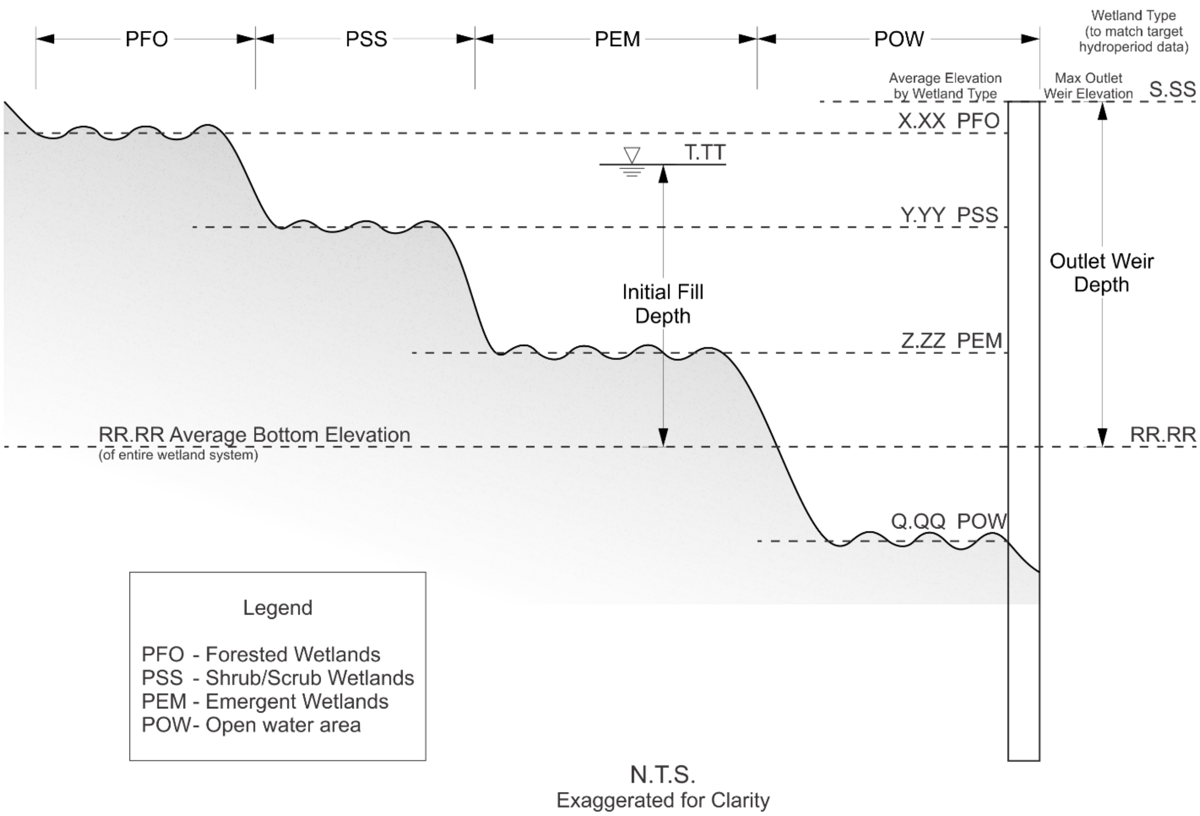
7. It is also recommended that you determine and input the appropriate beginning and end of Growing Season into Wetbud so that you can determine visually on the water budget output graph whether the predicted water levels during the growing season confirm you are meeting the minimum duration necessary to be a jurisdictional wetland – as well as see how the seasonal levels relate to your targeted type of wetlands system. For example, it has been our collective experience that many created forested wetland designs result in excessive surface ponding during the summer months and do not replicate the deep summer/fall drawdown that is clearly illustrated in our Reference Hydroperiods. This may lead to development of "wetter" wetland systems than desired. See "Growing Season" in Projects - General.
8. Selecting the appropriate reference elevation for the Hydroperiod:
   a. Reference Hydroperiod data is typically obtained from a groundwater well located in a wetland of a specified type. The data collected is usually expressed as a distance above/below the top of the soil surface (the well datum of 0.0) at the subject well. All Hydroperiod data in Wetbud is collected and managed in this manner.
   b. In a simple wetlands restoration system, where there is a relatively uniform soil surface elevation with microtopography variation such that most of the wetland's system is expected to be of the same type (e.g., PFO1A in Cowardin classification system) in terms of hydroperiod – the datum (0.0 elevation) of the reference hydroperiod should be the same elevation of the "Average Bottom Elevation" – as defined in Projects - General and shown graphically below:



For the actual water elevation (which is adjusted by Wetbud to reflect the proposed topographic variation of the site using a rating curve that is user input (see Stage Storage Rating Data)) provided in Reports to be comparable to the Reference Hydroperiod – you must input the elevation of the Hydroperiod Datum that matches the elevation of the proposed wetlands type. In the case shown above (where there is a relatively uniform soil surface elevation with microtopography variation such that most of the wetland's system is expected to be of the same type) it would be the "Average Bottom Elevation".

c. In a restoration with more significant topographic relief – such that there would be more than one expected type of wetlands systems within the area being modeled – different Reference Hydroperiods must be provided if you want to compare the projected hydroperiod from the Wetbud Model to an appropriate Reference Hydroperiod – AND a unique vertical elevation assigned to each selected reference hydroperiod datum that is the average elevation of that specific wetlands type you desire to restore or create on a particular project site. For example – in the wetland system depicted below:

i. The Forested Wetlands (PFO) have an average soil surface elevation of XX.XX feet.
ii. The Shrub/Scrub Wetlands (PSS) have an average soil surface elevation of YY.YY feet.
iii. The Emergent wetlands (PEM) have an average soil surface elevation of ZZ.ZZ feet.
iv. The Open water area (POW) have an average soil surface elevation of QQ.QQ feet.



In this example you would need four (4) different reference Hydroperiods (either from the library, regulatory sources, Literature or BPJ). After inputting into Wetbud the average elevation for the desired wetlands communities determined from your design plan as the datum of each specific related reference hydroperiod, you can then instruct Wetbud to plot out a comparison between the Reference Hydroperiod and the model output for each selected wetlands area in your project.

Wetbud can then plot out the modeled water elevation for D/N/W years against a plot of the min/max of the Reference Hydroperiod for each different wetland community. Each plot would be a unique graph for each wetlands community with the same modeled water elevation but different reference hydroperiods that use as their datum the average soil surface elevation of their respective communities.

As stated previously, Wetbud hydroperiod data sets contain the maximum and minimum values for each month. As such, they provide a range of possible water levels for each month. When comparing hydroperiods to model output note that Wetbud's Basic Model sums inputs and outputs and calculates a water level for each month. The output could be interpreted as real world end-of-the-month water levels compared to the hydroperiod values representing the highest and lowest possible water levels for the entirety of each month from a well in the reference community.

When modeled time periods contain partial months, the bands will have flat sections representing the max and min values for the whole month derived from the hydroperiod data set for the partial month (for example, the hydroperiod band would have the same value on January 1st as it would on January 31st for a single year, not an interpolated value from December 31st to January 31st). Custom time periods containing more than one year may appear to have interpolated values between Dec. and Jan., but in reality the predicted December value is to be compared to the maximum and minimum hydroperiod values observed for the entire month of December and the same would be true for January.

Note that Hydroperiod bands will typically look like step functions in Advanced Models as the source data is monthly and applied at user-specified scales (seconds, hours, days, etc.).

14.2 Reference Hydroperiod Datasets

The twelve “design target hydroperiods” that appear in this supplement were drawn from a large regional data set compiled by Sneesby (2019; https://vtechworks.lib.vt.edu/handle/10919/88836) as part of a Wetbud related M.S. thesis project at Virginia Tech. Over 90 Regional hydroperiod data sets were obtained, primarily from agency (e.g. USACE, NC DEQ) reference monitoring sites and non-governmental organization sites (e.g. The Nature Conservancy). We also reviewed a range of unpublished data sets associated with research projects conducted by Virginia Tech, Old Dominion University and other cooperators. All data sets reviewed were identified by their suppliers as being “reference sites”, or in some instances, long-term onsite monitoring for well-established restoration sites.

Final selected sites (~20) all met the following criteria:

- At least two complete years of data with appropriate well design.

- Full annual data sets with at least one reading per month, with higher frequency preferred. Certain gaps in summer/fall data were allowed if all other criteria were met.
- Relatively undisturbed via ditching, recent (<10 years) logging, and/or fully surrounding recent development.
- Supported an appropriate vegetative cover for their mapped Cowardin/NWI type.
- Occurring on hydric soil map units on readily identifiable topographic landforms that would allow HGM classification (where possible).
- Wherever possible, confirming data on vegetation, soils and overall jurisdictional status was available in reports and/or confirmed by contributors.

The twelve sites presented here are dominantly classified as PFO's (Cowardin/NWI) and Mineral Soil Flats (by HGM). Graphical hydroperiods and supporting site maps for several Riverine sites are included in Sneesby (2019) along with an Appendix listing all primary sites contributed for initial review. That document also includes D/N/W year classification for six of these sites.

This supplement contains the full multi-year hydroperiod data set for each site along with a determination of the monthly maximum and minimum observed water levels. **It is important that users of these reference hydroperiods understand the following data attributes:**

- The monthly maximum and minimum water levels are taken as the **absolute highest and lowest elevation** obtained in each month across all years in the data set. **They are not average values.**
- For many sites, this procedure generated very low minimum values in December which do not reflect the majority of monitoring years.
- Several extremely high outliers (presumably hurricane events) were removed.
- Several extremely low outliers (immediately following well installation) were removed.
- Summer water levels at the most sites frequently dropped below the lowest well/logger elevation and therefore appear as "flat line" data segments. Thus, the minimum levels projected for those sites do not reflect the actual lowest elevations achieved.

14.2.1 BP Amoco

Site location:	Seaford VA; NE of Newport News
NWI Classification:	PFO1B
HGM Classification:	Mineral Soil Flats
Geology:	Tabb Formation, Lynnhaven Member; Late Pleistocene
Soil Type:	Tomotley series; fine-loamy, mixed, semiactive thermic Typic Endoaquults
Elevation:	10'
Notes:	Based on regional reference well data provided by USACE Norfolk District upon specific request. Data span nine years, but

are not complete in all years due to wells and or loggers being periodically withdrawn and replaced.

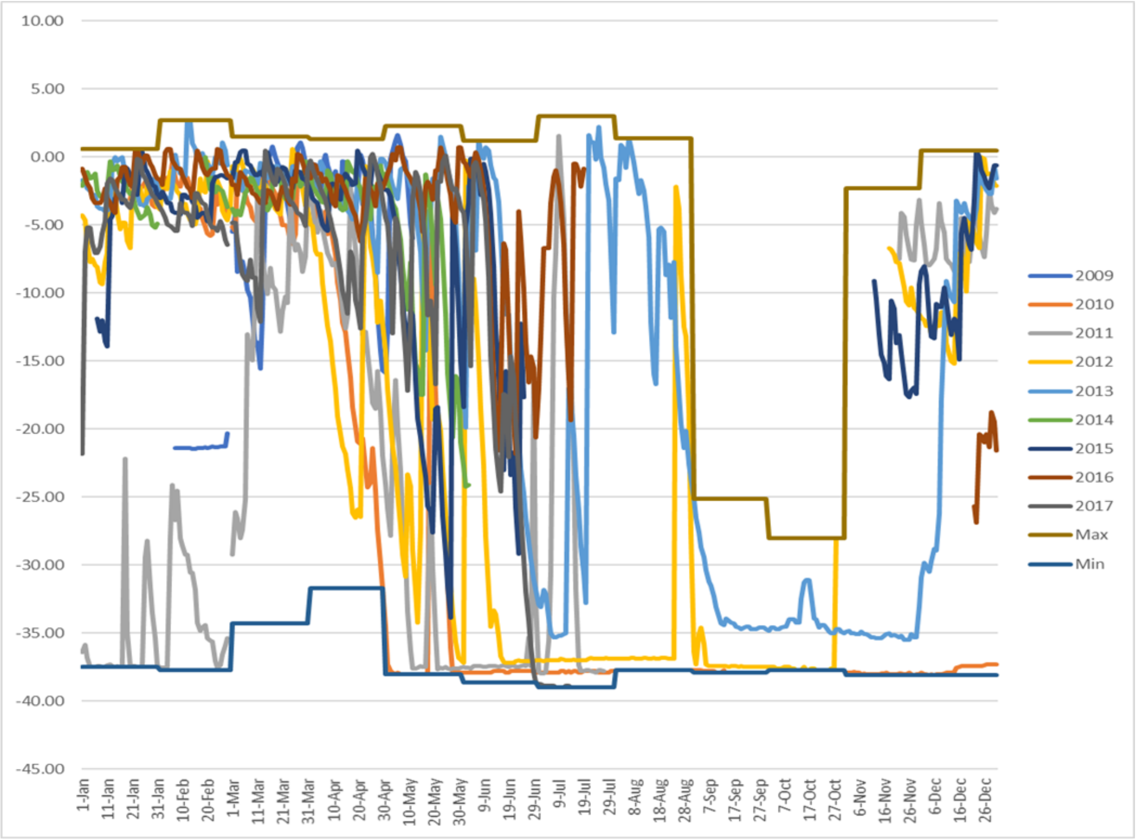


Figure 1. BP Amoco reference hydroperiod data (inches) for nine years (partial) based on daily level logger readings. The bottom of the well was ~38 inches, thus actual summer drawdown in some months may have been greater than shown here. Wells were removed/replaced in certain years and dry seasons where data gaps are obvious The max and min lines reflect levels achieved in all wells over a given month across all years.

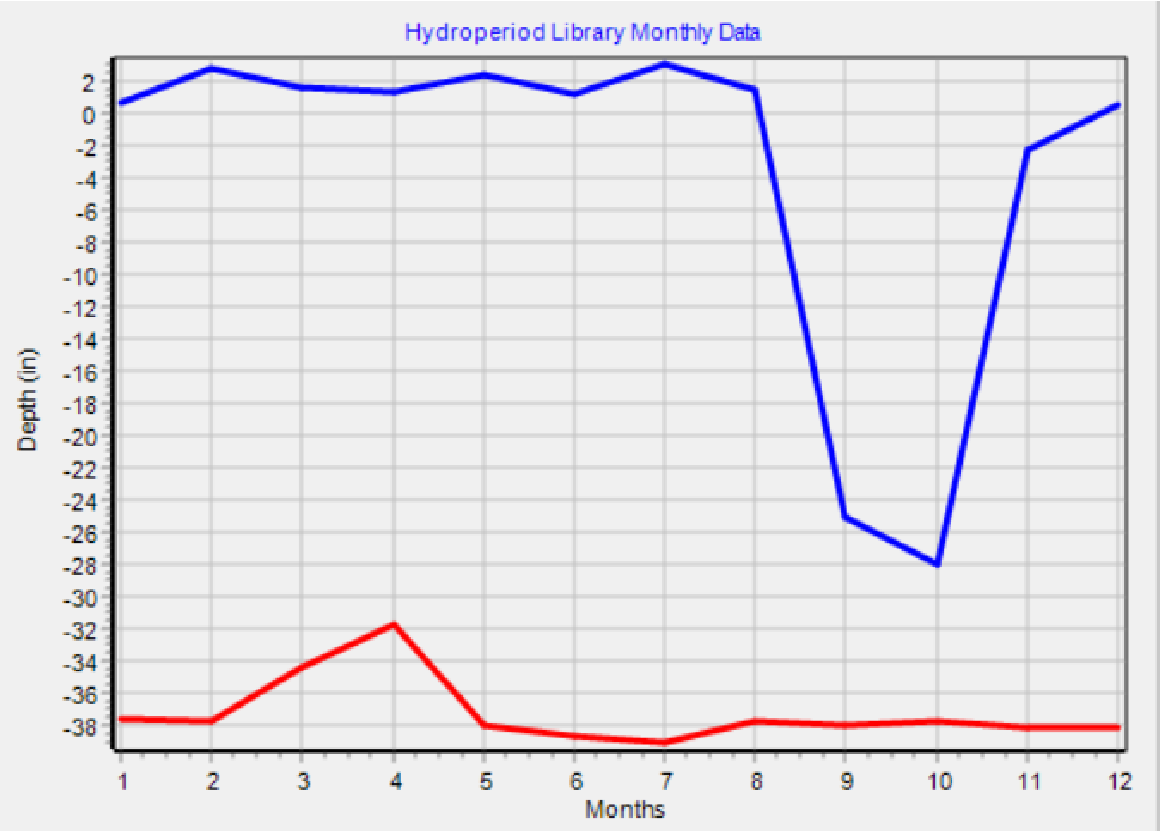
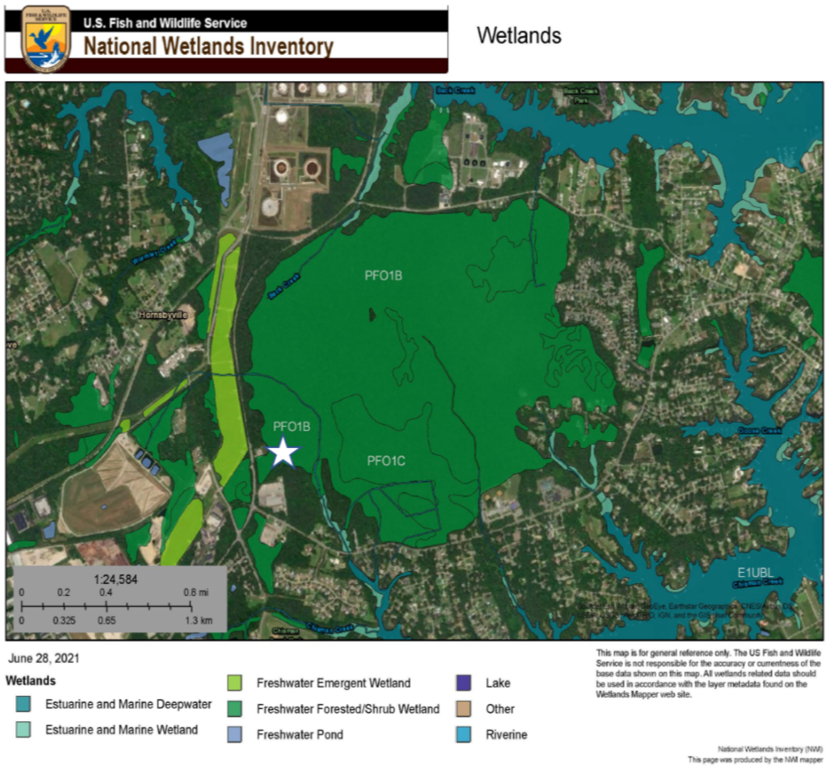


Figure 2. BP Amoco reference hydroperiod maximum and minimum levels observed over a nine year period (partial) displayed as a spline chart. Caution should be taken interpreting December minimum levels since per Figure 1 above, water levels were substantially higher in five of six years where data was available.



PFO1B – SE VA

BP Amoco reference hydroperiod site in Seaford VA; NE of Newport News.

Approximate monitoring well location indicated with a ★

Figure 3. NWI Map of BP Amoco Reference Hydroperiod Site Location.

14.2.2 Bishop Road 14

Site location:	Hyde County, NC; N of Scranton between US 264 and Pungo River
NWI Classification:	PFO4Cd
HGM Classification:	? Organic Soil Flats (possible riverine influenced)
Geology:	Not determined; most likely late Pleistocene/Holocene
Soil Type:	Belhaven series; Loamy, mixed, dysic, thermic Terric Haplosaprists
Elevation:	4-5'
Notes:	Site data (2 wells) provided by NC DEQ monitoring programs associated with a forested wetland restoration project to the east of these monitoring wells. Soils are mucks and mapped in a frequently flooded phase and probably accumulate a combination of runoff and groundwater discharge from uplands in addition to precipitation.

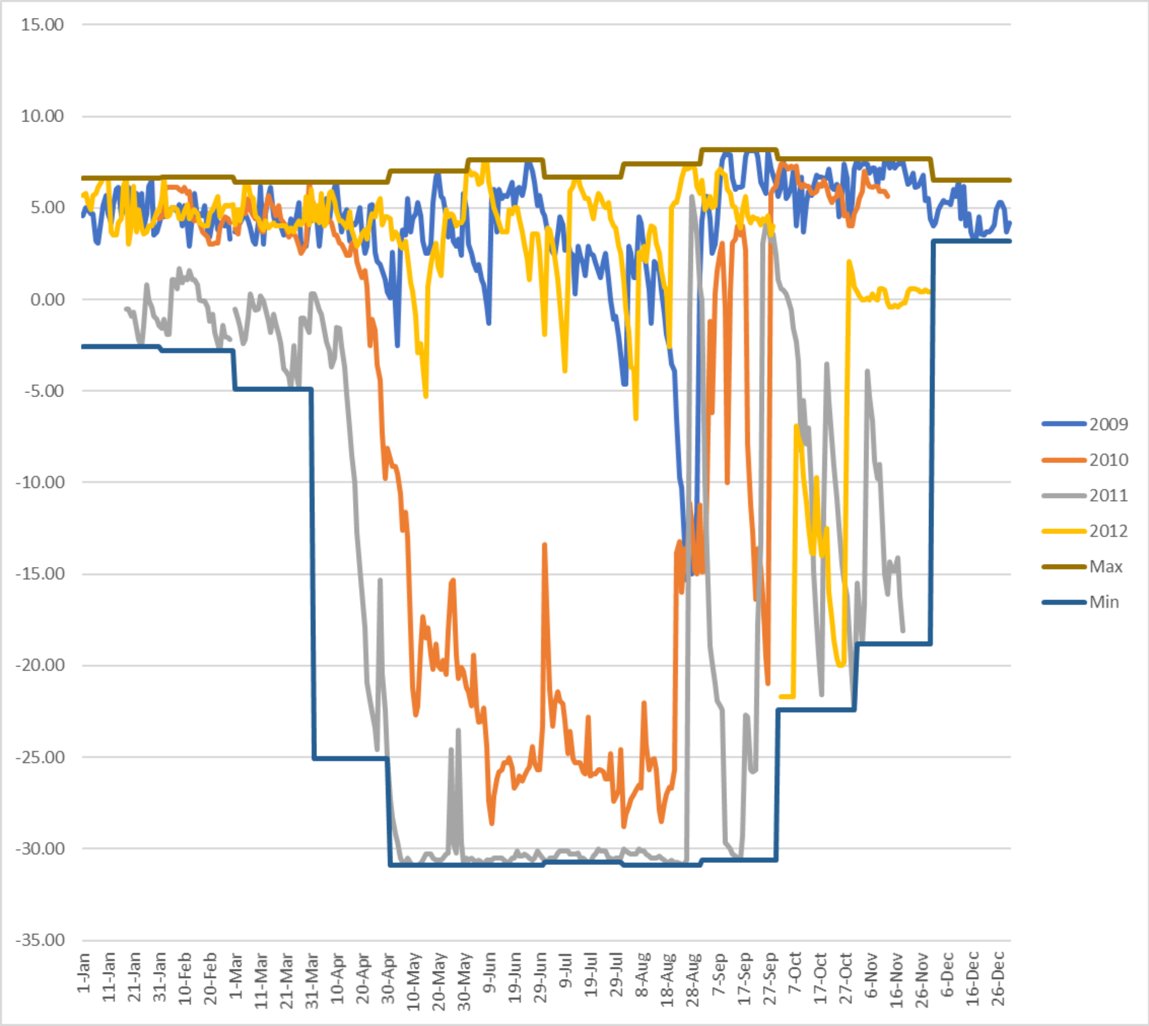


Figure 1. Bishop Road 14 reference hydroperiod data (inches) for four years based on daily well logger readings. The bottom of the well was ~30 inches. The max and min lines reflect levels achieved in all wells over a given month across all years. The soil here is a muck and the surface stayed ponded for the majority of the summer in two of four years.

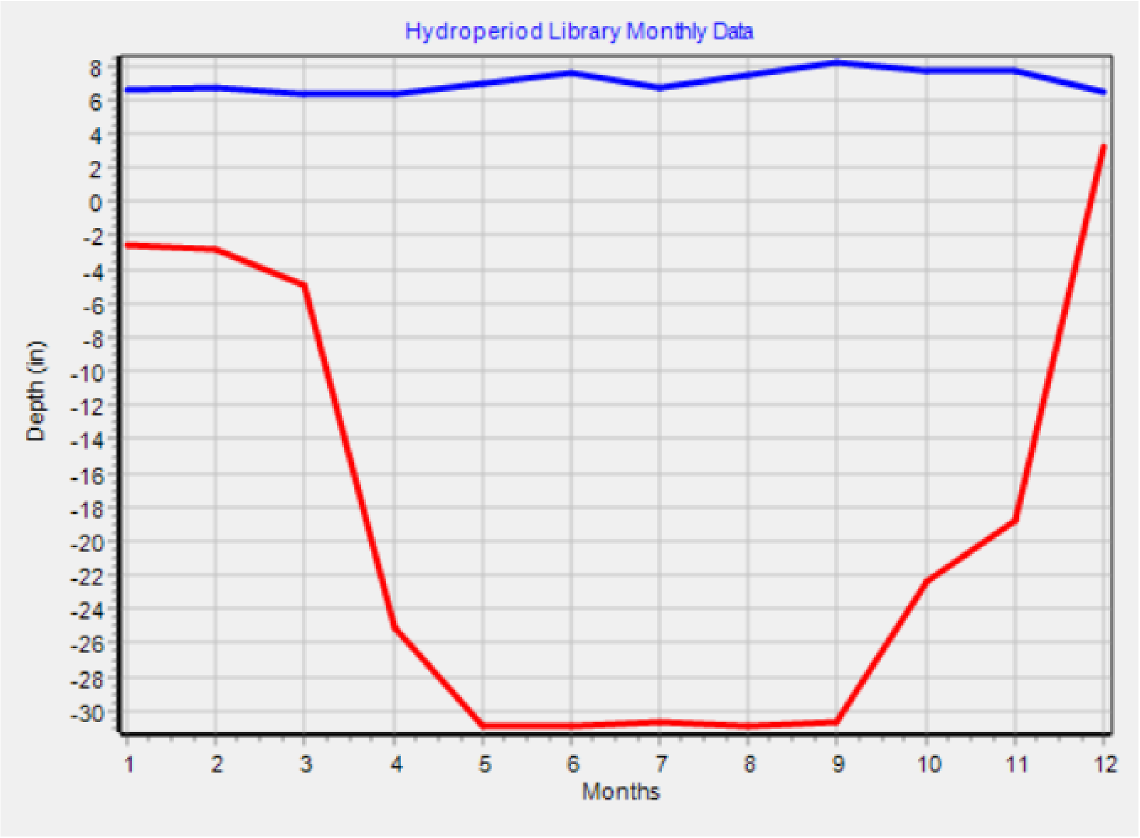
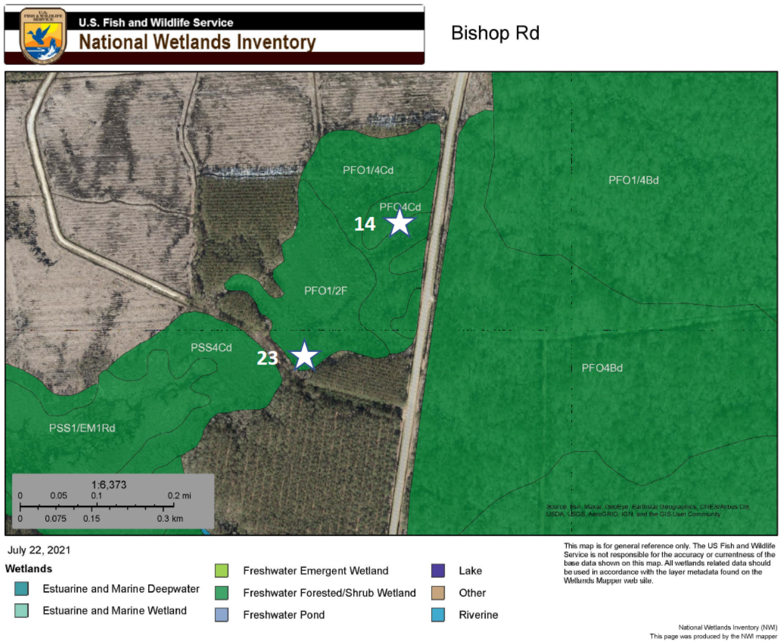


Figure 2. Bishop Road 14 reference hydroperiod maximum and minimum levels observed over a four year period displayed as a spline chart.



PFO1/2F and PFO4Cd – E NC

Current NWI map of Bishop Road reference hydroperiod sites in Hyde County, NC; N of Scranton. Between US 264 and Pungo River.

Approximate monitoring well locations indicated with a ★

Figure 3. NWI Map of Bishop Road 14 and 23 Reference Hydroperiod Site Location.

14.2.3 Bishop Road 23

Site location:	Hyde County, NC; N of Scranton between US 264 and Pungo River
NWI Classification:	PFO1/2F
HGM Classification:	? Organic Soil Flats (possible riverine influenced)
Geology:	Not determined; most likely late Pleistocene/Holocene
Soil Type:	Belhaven series; Loamy, mixed, dysic, thermic Terric Haplosaprists
Elevation:	4-5'
Notes:	Site data (2 wells) provided by NC DEQ monitoring programs associated with a forested wetland restoration project to the east of these monitoring wells. Soils are mucks and mapped in a frequently flooded phase and probably accumulate a combination of runoff and groundwater discharge from uplands in addition to precipitation.

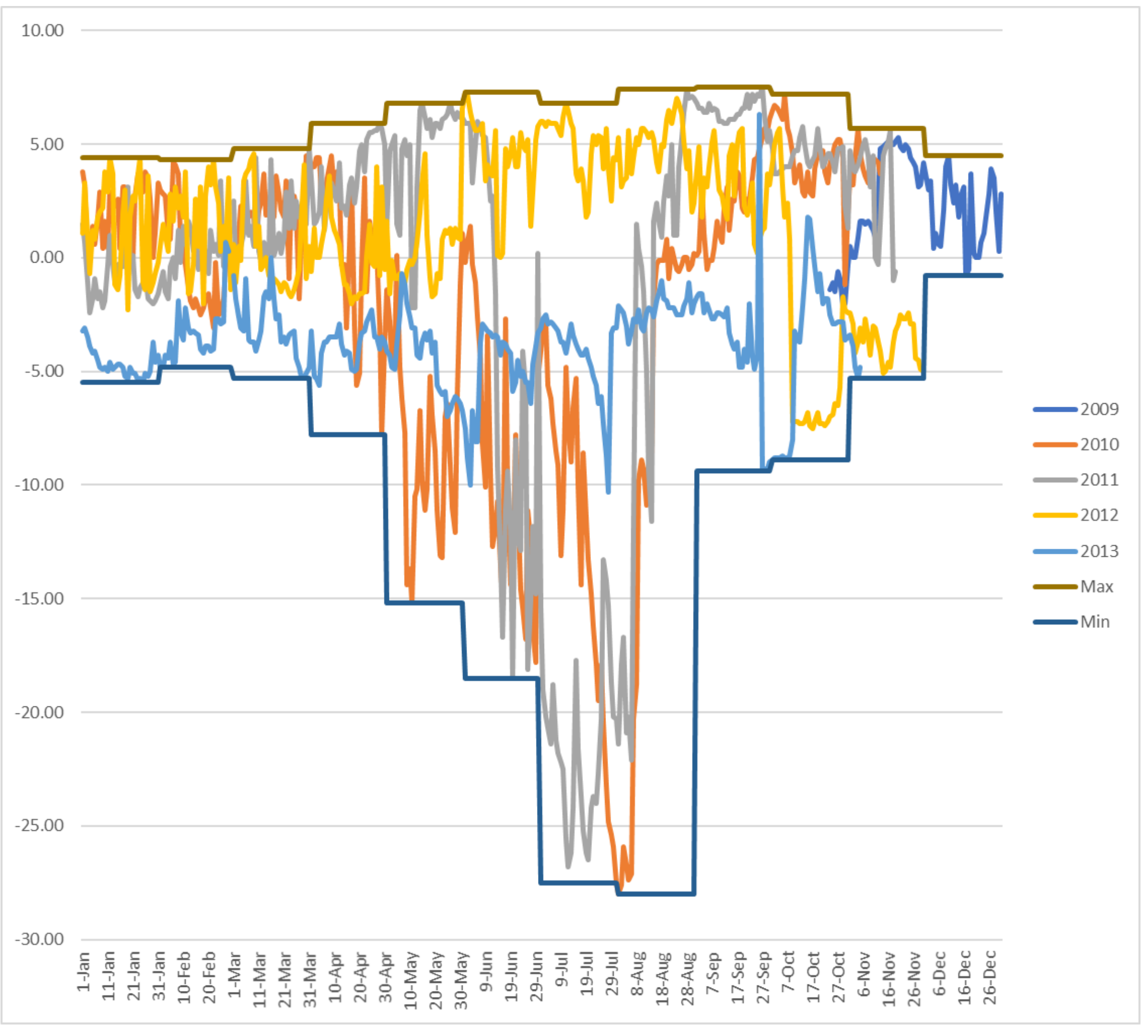


Figure 1. Bishop Road 23 reference hydroperiod data (inches) for four years based on daily well logger readings. The bottom of the well was ~30 inches. The max and min lines reflect levels achieved in all wells over a given month across all years. The soil here is a muck and the surface stayed ponded for the majority of the summer in two of four years.

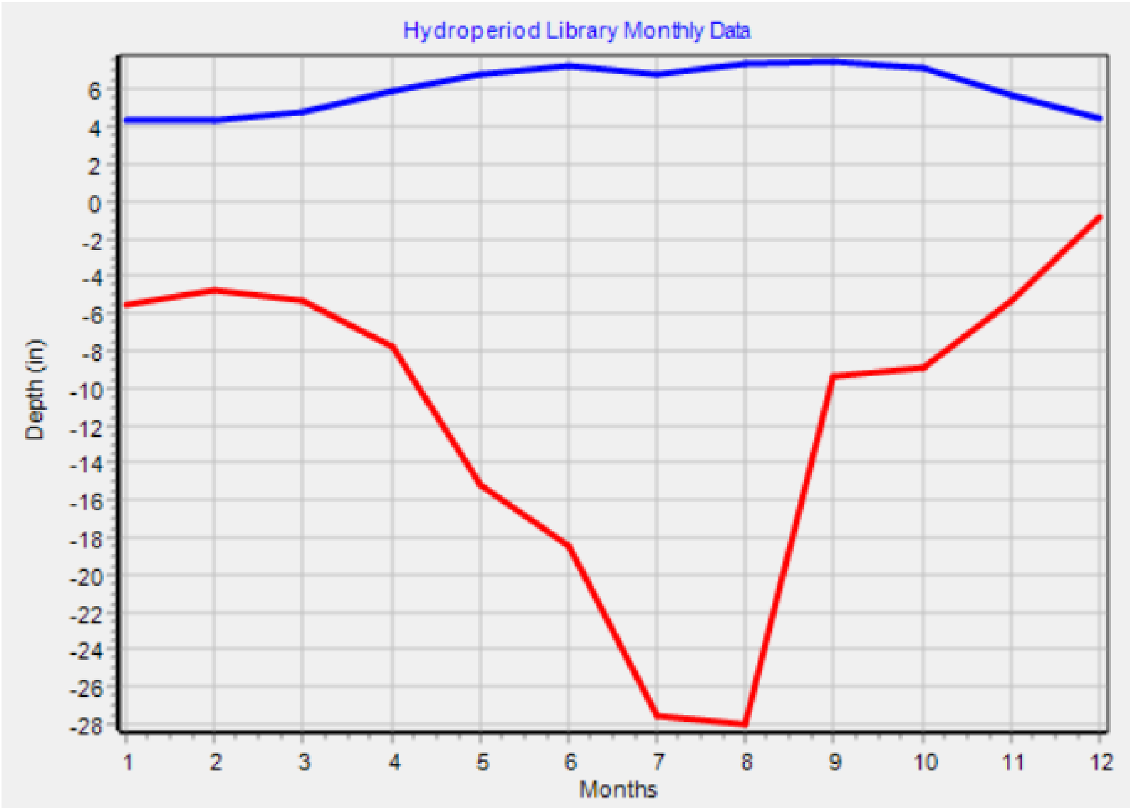
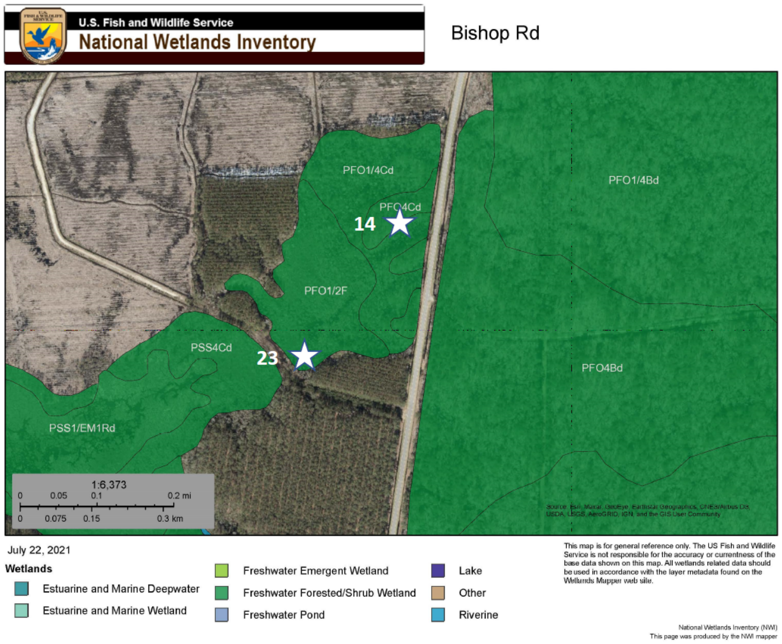


Figure 2. Bishop Road 23 reference hydroperiod maximum and minimum levels observed over a four year period displayed as a spline chart.



PFO1/2F and PFO4Cd – E NC

Current NWI map of Bishop Road reference hydroperiod sites in Hyde County, NC; N of Scranton. Between US 264 and Pungo River.

Approximate monitoring well locations indicated with a ★

Figure 3. NWI Map of Bishop Road 14 and 23 Reference Hydroperiod Site Location.

14.2.4 Level Ponds

Site location:	Accomack County VA, ~1 mile NE of Bayside (on VA Eastern Shore)
NWI Classification:	PFO4/1B
HGM Classification:	Mineral Soil Flats
Geology:	Kent Island Formation; late Pleistocene
Soil Type:	Nimmo series; Coarse-loamy, mixed, semiactive, thermic Typic Endoaquults
Elevation:	6-7'
Notes:	This data set was provided by The Nature Conservancy and covers approximately six years of daily water level data. The mature forested wetland preservation area sits on a broad mineral flat landscape. This site is about 100 m from an intermittent section of Doe Creek to the north of the well. The base level of the data set shifts over several years which may indicate well replacement and/or variations in the logger depth.

Considerably more detail on this site is available in Sneesby (2019) including D/N/W year determinations at https://vtechworks.lib.vt.edu/handle/10919/88836.

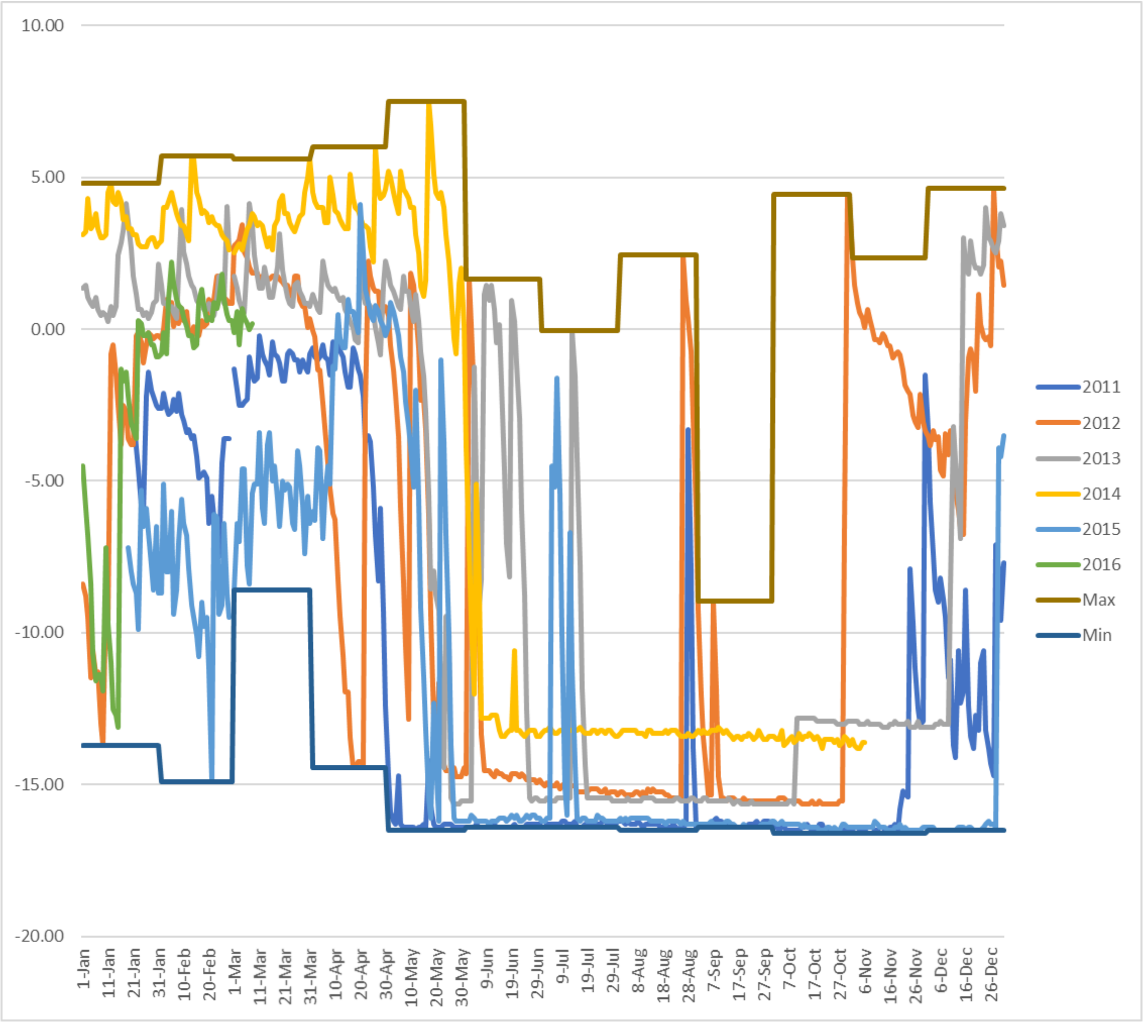


Figure 1. Level Ponds reference hydroperiod data (inches) for six years based on daily water level logger readings. The bottom of the well (or logger height) was ~16 inches, thus actual summer drawdown in most years was most likely greater than shown here. However, the baseline summer depth shifted in most years reflecting well and/or logger replacement. The max and min lines reflect levels achieved in all wells over a given month across all years.

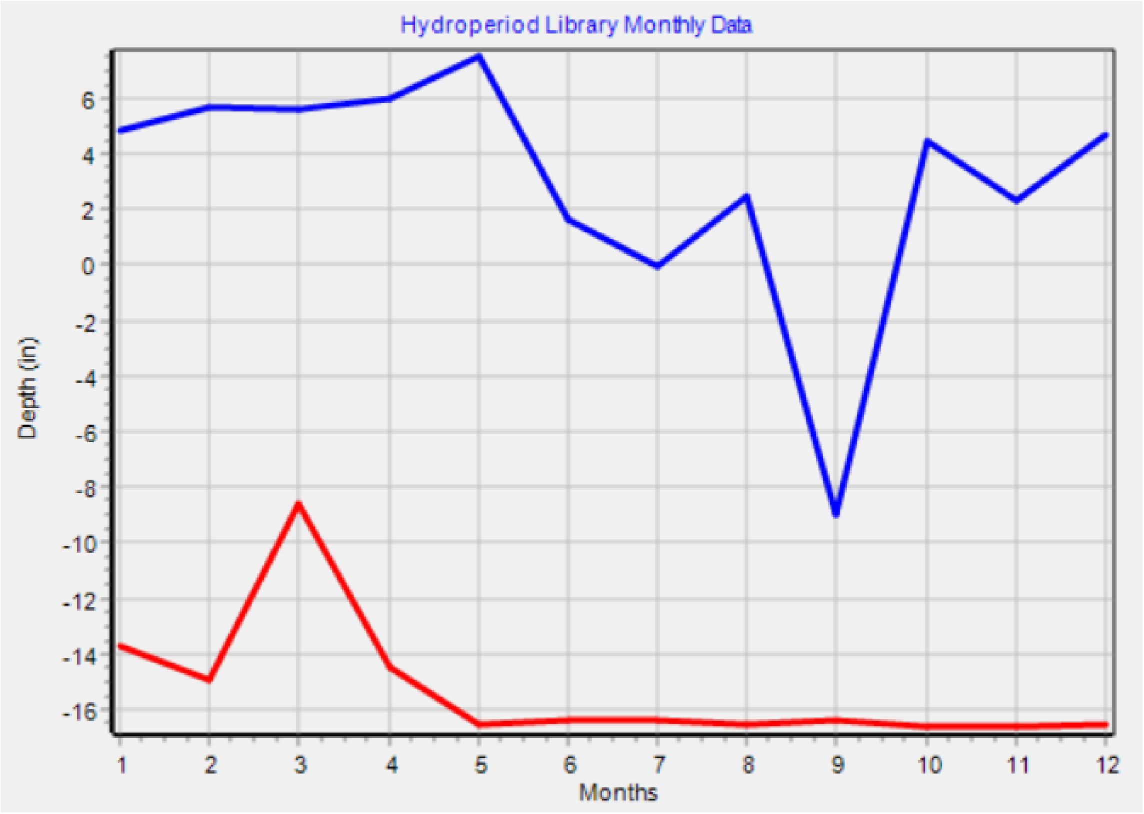
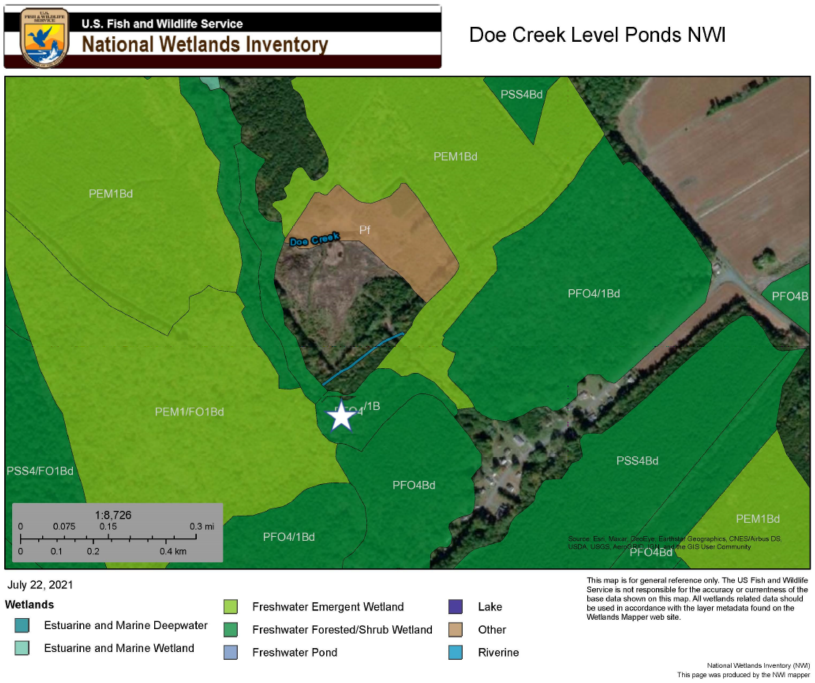


Figure 2. Level Ponds reference hydroperiod maximum and minimum levels observed over a six year period displayed as spline chart. Caution should be taken interpreting December minimum levels since per Figure 1 above, water levels were substantially higher in most years and the minimum shown here was only observed in December in one year.



PFO4/1B – E VA

Current NWI map of Level Ponds reference hydroperiod site in Accomack County, VA; N of Bayside.

Approximate monitoring well location indicated with a ★

Figure 3. NWI Map of Level Ponds Reference Hydroperiod Site Location.

14.2.5 Iluka

Site location:	Dinwiddie County Virginia, approximately 10 miles west of Stony Creek and 1 mile north of Route 40
NWI Classification:	PFO4B
HGM Classification:	Depressional (Carolina Bay)
Geology:	Pliocene sand & gravel
Soil Type:	Roanoke series; Fine, mixed, semiactive, thermic Typic Endoaquults
Elevation:	~215'
Notes:	This site was monitored by Virginia Tech for four years as a reference wetland for a research program supported by a nearby mineral sands mining operation conducted by Iluka Resources Inc. The site is a small Carolina Bay occurring in a landscape surrounded by numerous larger Carolina Bays, the vast majority of which have been drained for agriculture. While loblolly pine (P.Taeda L. growing on “hummocks”) commonly occurs in the overstory, deciduous species occupy approximately 50% of the canopy and dominate the understory.

Considerably more detail on this site is available in Sneesby (2019) including classification of D/N/W years at https://vtechworks.lib.vt.edu/handle/10919/88836.

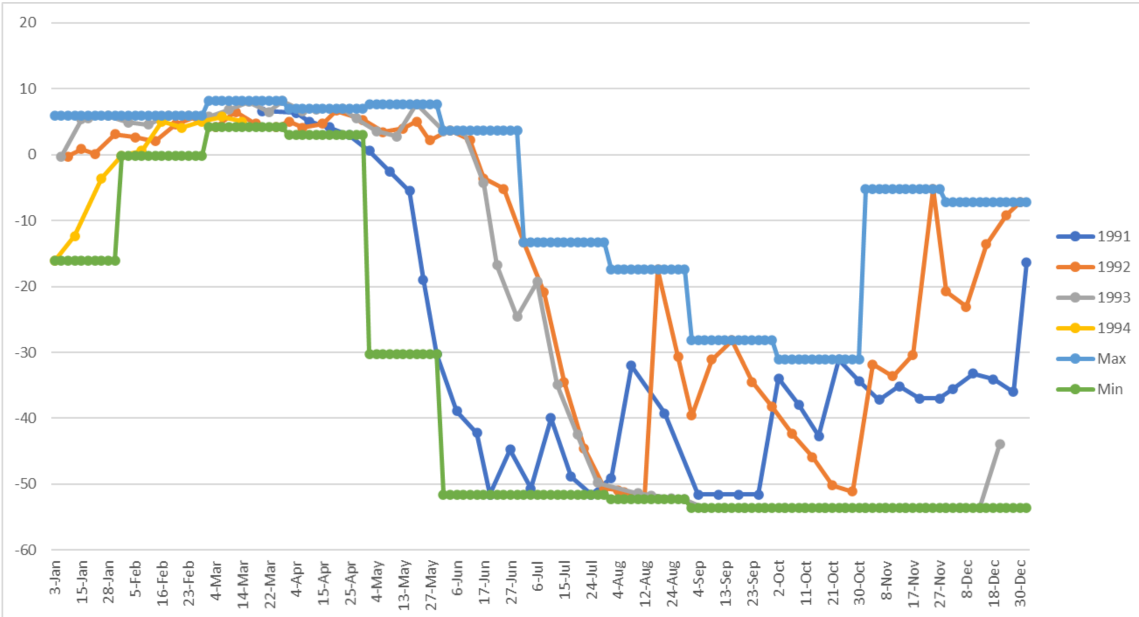


Figure 1. Iluka reference hydroperiod data (inches) for four years based on weekly manual level readings. The bottom of the well was ~50 inches, thus actual summer drawdown in some months may have been greater than shown here. The max and min lines reflect levels achieved in all wells over a given month across all years.

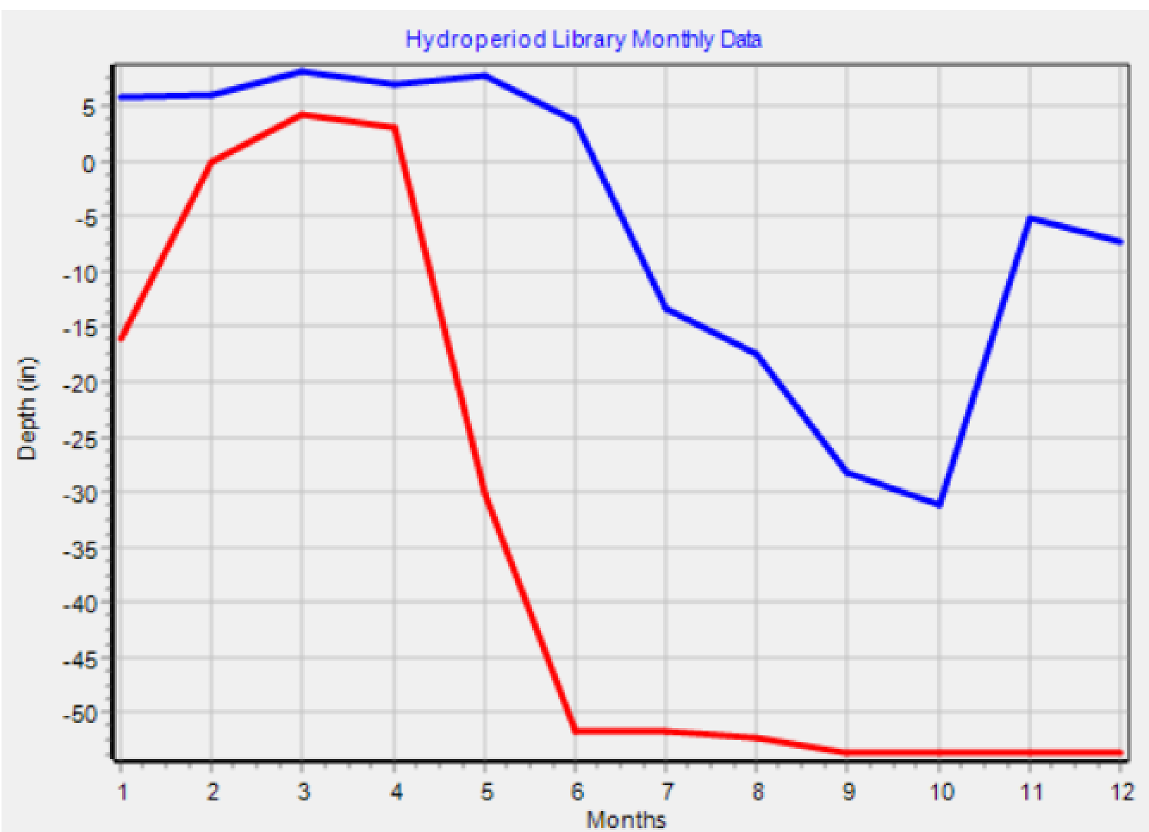
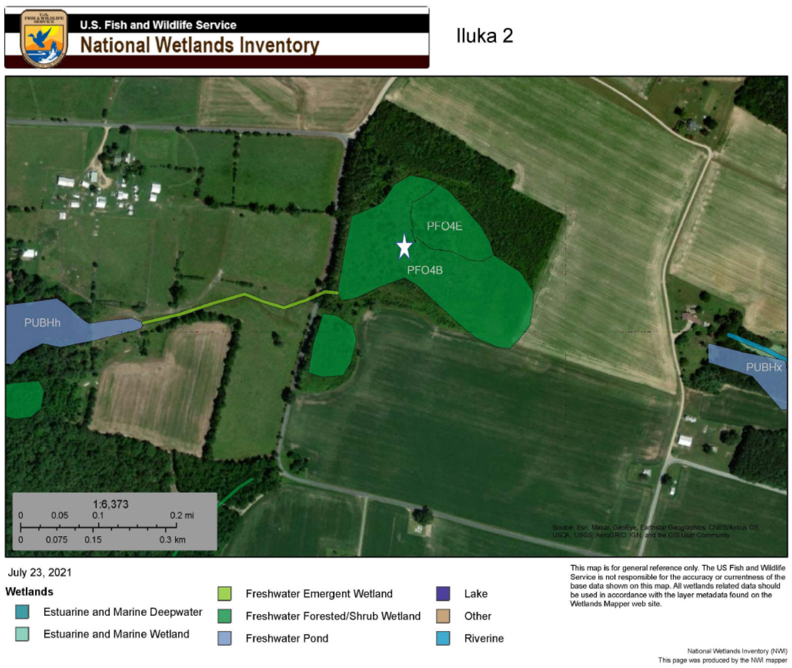


Figure 2. Iluka reference hydroperiod maximum and minimum levels observed over a four year period displayed as spline chart. Caution should be taken interpreting December minimum levels since per Figure 1 above, water levels were substantially higher in two out of three years and the minimum shown here was only observed in early December in one well.



PFO4B – E VA

Current NWI map of Iluka reference hydroperiod site in Dinwiddie County, VA; ~ 10 miles W of Stony Creek and 1 mile N of Rt. 40.

Approximate Monitoring well location indicated with a ★

Figure 3. NWI Map of Iluka Reference Hydroperiod Site Location.

14.2.6 Roquist

Site location:	Bertie County, NC; SE of Lewiston and east of Route 11
NWI Classification:	PFO1A
HGM Classification:	Mineral Soil Flats; (Pocosin), possibly relict Carolina Bay (depressional)?
Geology:	Yorktown and Duplin Formations, undifferentiated; Pliocene
Soil Type:	Leaf series; fine, mixed, active, thermic Typic Albaquults
Elevation:	25-30'
Notes:	Site data provided by NC DEQ monitoring programs. Most of the site was logged in 2003, at which point the area was left to regenerate naturally until site restoration began in 2007. Restoration included the plugging of logging ditches between 2007 and 2008 and planting > 15 tree species. The general topography and overall NW-SE orientation of the Roquist Pocosin suggest that it may the remnant of a weakly expressed Carolina Bay. However, the system does not have the typically

well expressed sandy rim (particularly to the SE) where it has been broached by drainage into Roquist Creek.

Considerably more detail on this site including hydroperiods for four additional wells and categorization of D/N/W years is available in Sneesby (2019) at https://vtechworks.lib.vt.edu/handle/10919/88836.

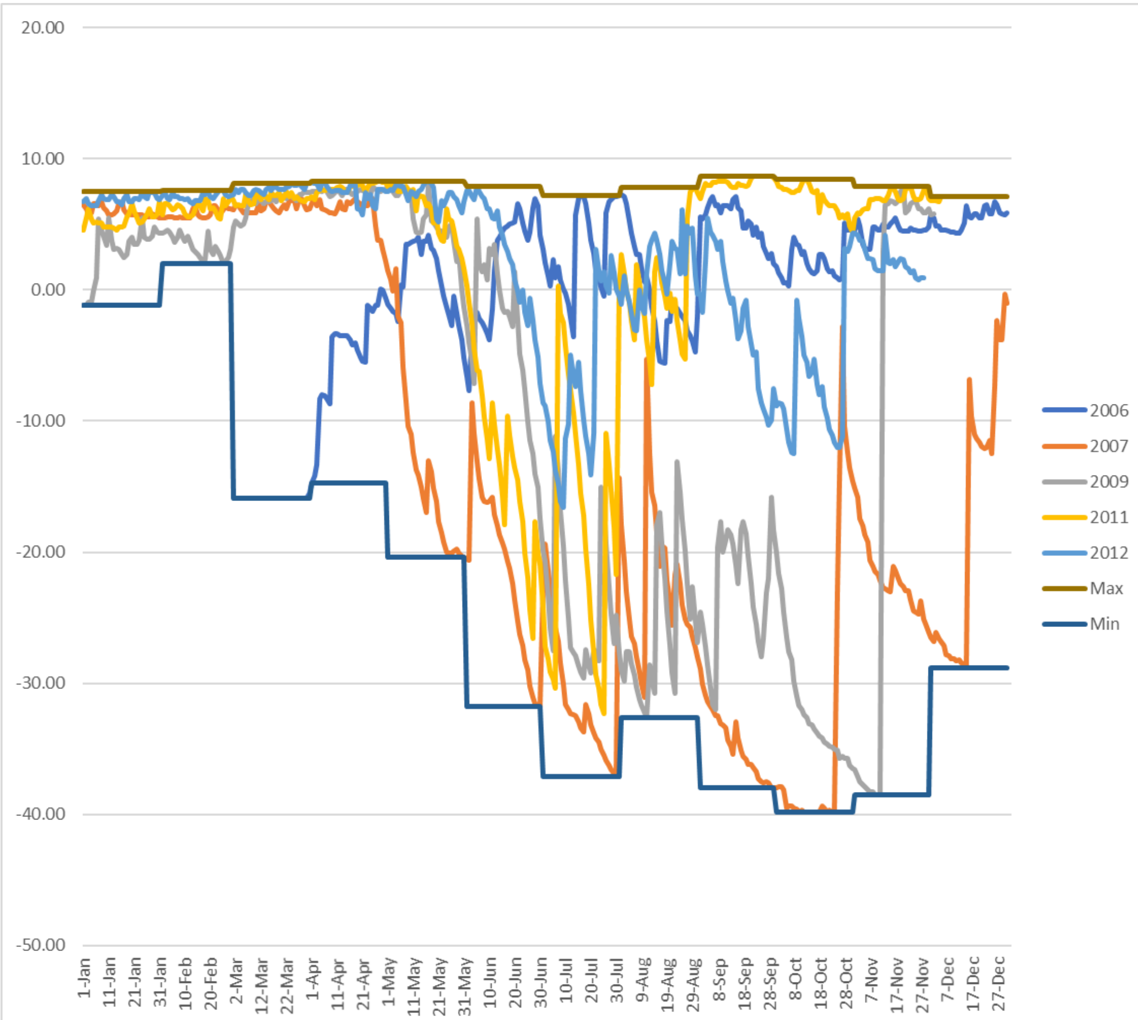


Figure 1. Roquist reference hydroperiod data (inches) for five years based on daily well logger readings. The bottom of the well was ~40 inches, thus actual summer drawdown in some months may have been greater than shown here for 2007. The max and min lines reflect levels achieved in all wells over a given month across all years. As noted above, hydroperiod graphs for four other wells at this site are available in Sneesby (2019). Abrupt spikes in Fall 2007 and 2009 may reflect well or logger replacement.

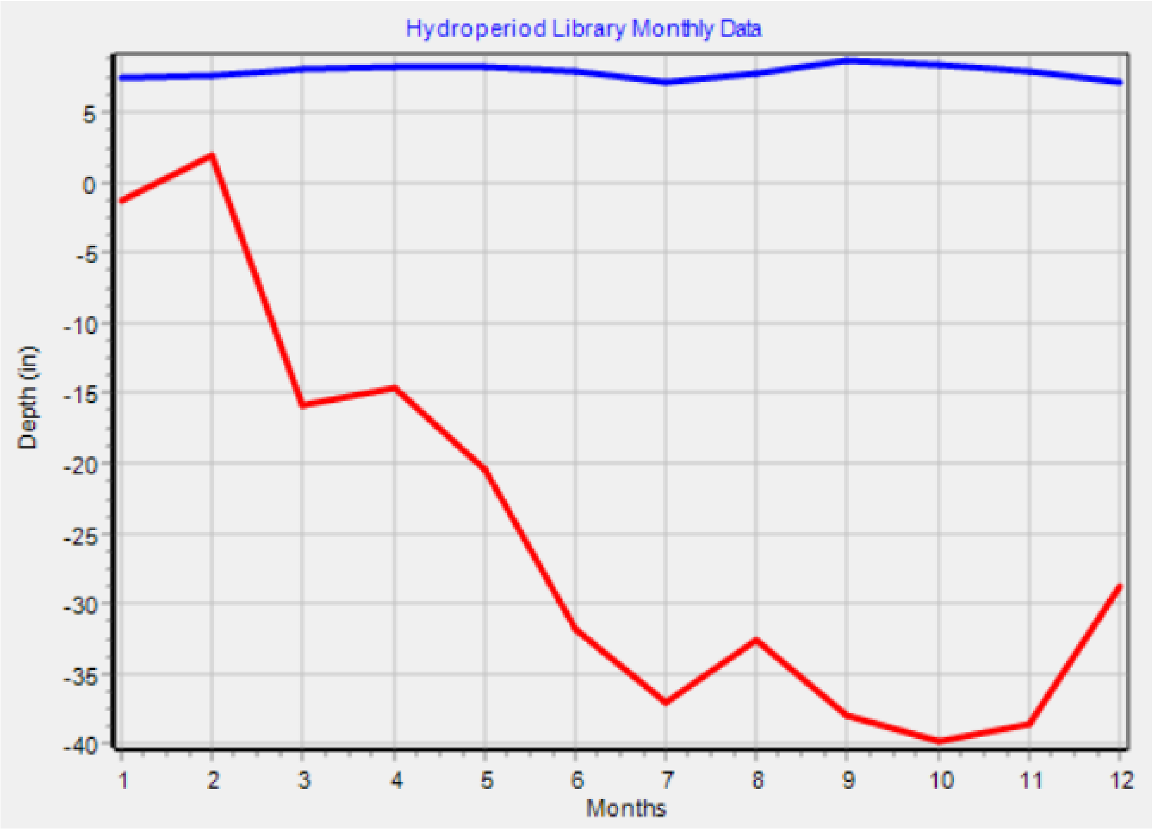
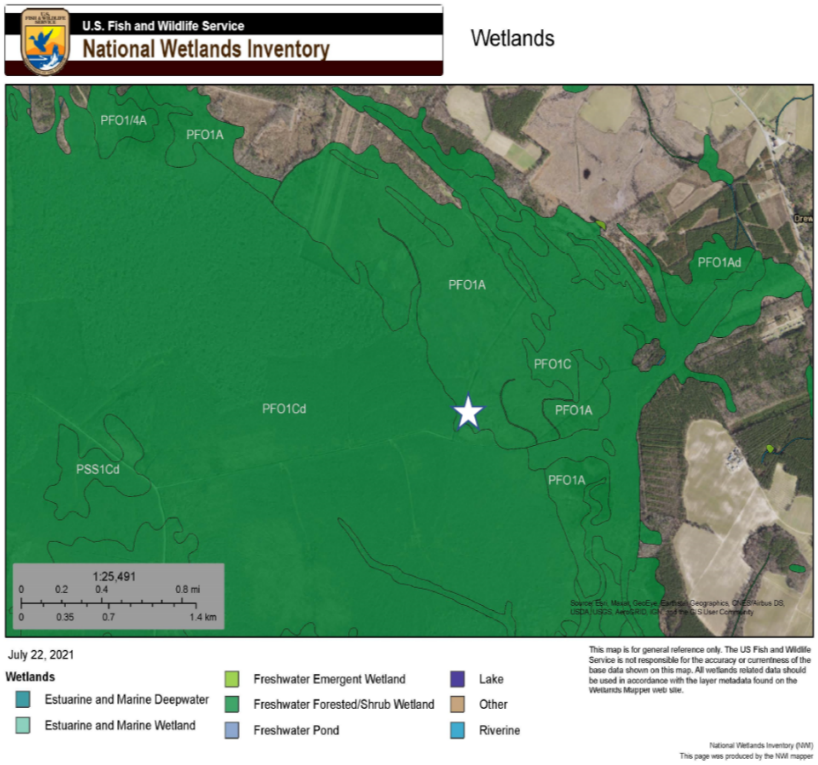


Figure 2. Roquist reference hydroperiod maximum and minimum levels observed over a five year period displayed as spline chart.



PFO1A – NE NC

Current NWI map of Roquist reference hydroperiod site in Bertie County, NC; SE of Windsor.

Approximate monitoring well location indicated with a ★

Figure 3. NWI Map of Roquist Reference Hydroperiod Site Location.

14.2.7 Su 17 (W)

Site location:	Chesapeake VA; E of Cornland and just N of NC border
NWI Classification:	PFO1Bd
HGM Classification:	Mineral Soil Flats
Geology:	Tabb Formation; Sedgefield member; Late Pleistocene
Soil Type:	Tomotley series (Fine-loamy, mixed, semiactive, thermic Typic Endoaquults) and Nimmo series (Coarse-loamy, mixed, semiactive, thermic Typic Endoaquults) complex
Elevation:	10-12'
Notes:	This wetland has one of the largest data sets analyzed by Sneesby (2019) and was provided by specific request from the USACE Norfolk District [Su (W) 17; 2009-2017] and by The Nature Conservancy (Su 23; 2002-2005). The data set includes continuous data for 2002-2005 for Site 23. Excluding 2012, the site (W) 17 data (2009 – 2017) spans the winter through early summer of each year with well/logger removal for several summer/fall months.

Considerably more detail on this site including hydroperiods for three additional TNC wells in the same general area along with categorization of D/N/W years is available in Sneesby (2019) at https://vtechworks.lib.vt.edu/handle/10919/88836.

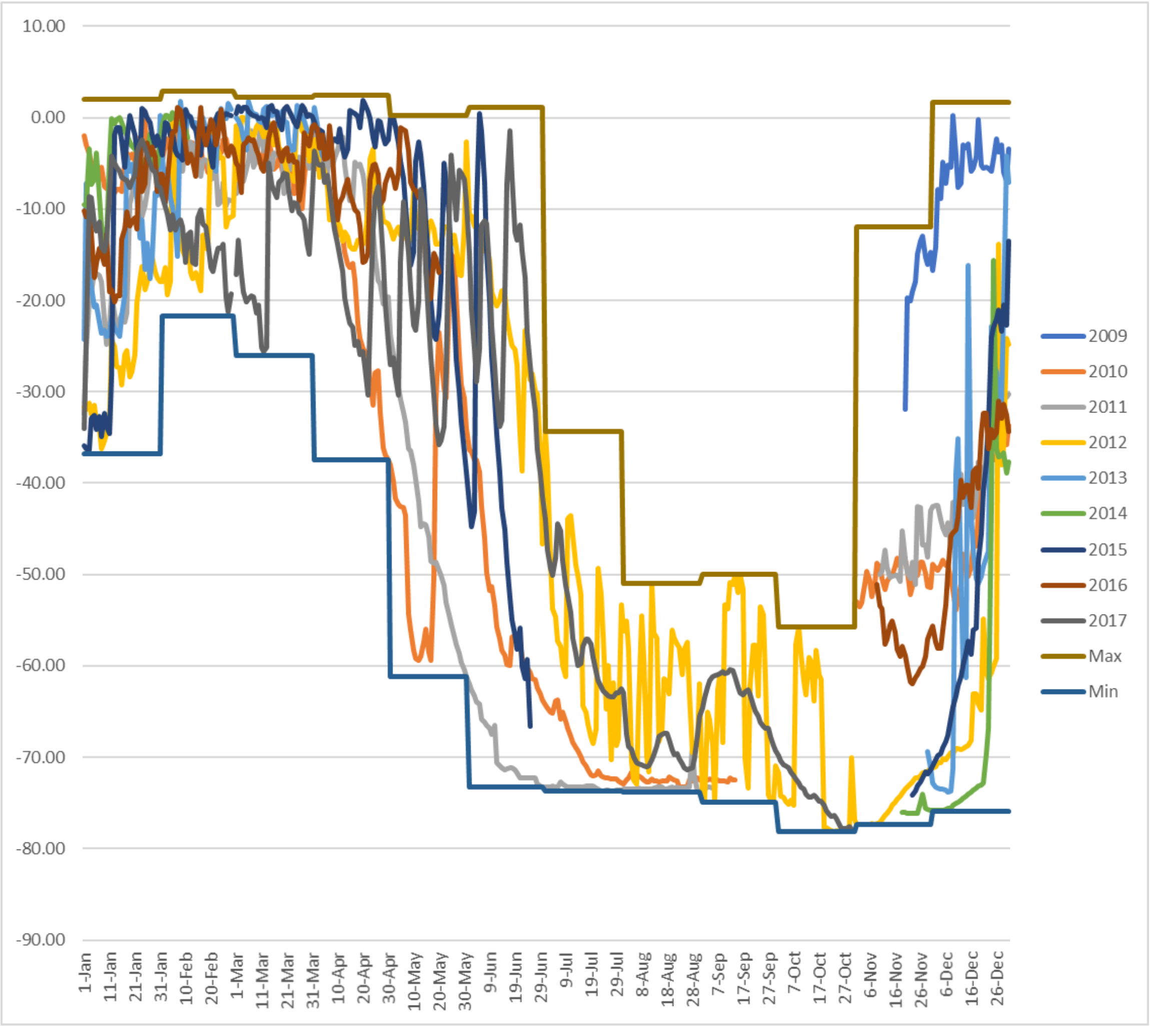


Figure 1. Su (W) 17 reference hydroperiod data (inches) for nine years based on daily well logger readings. The bottom of the well was ~75inches, thus actual summer drawdown in some months may have been greater than shown here. However, wells/loggers were removed for several summer/fall months in all years but 2012. The max and min lines reflect levels achieved in all wells over a given month across all years, thus the relatively low minimum level for December reflects only one brief duration at one well.

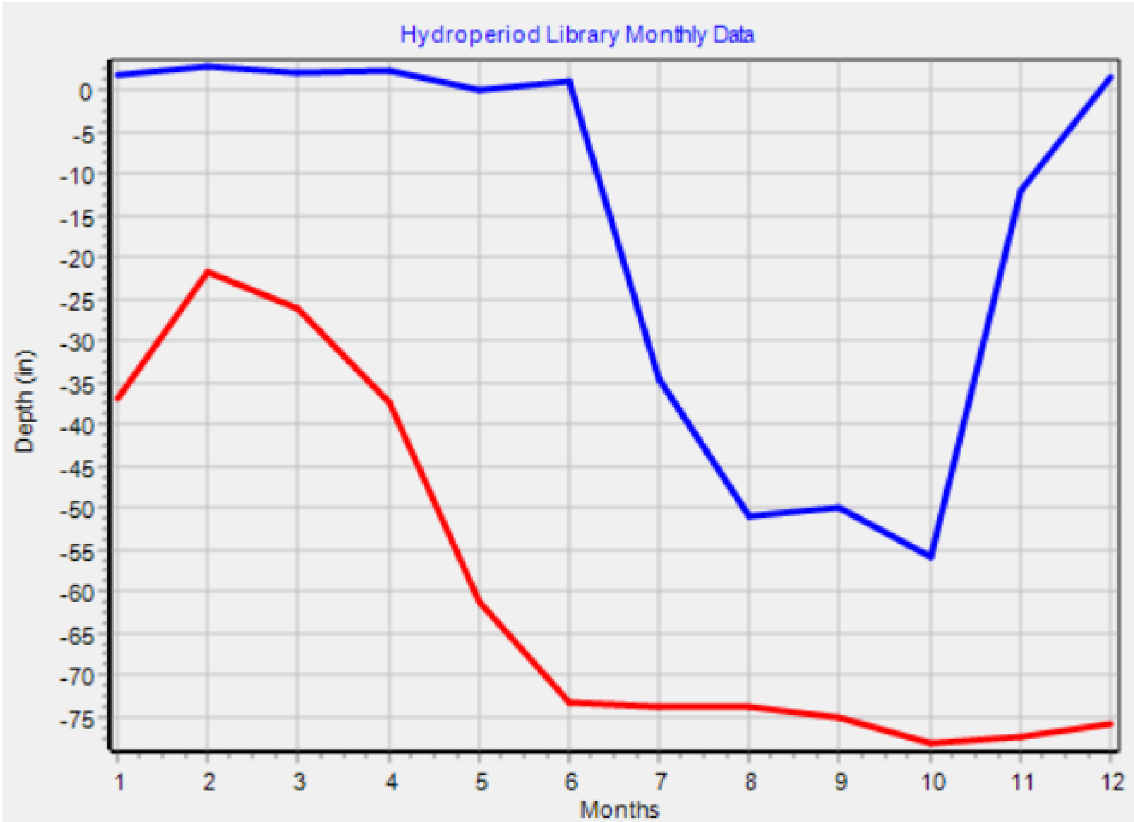
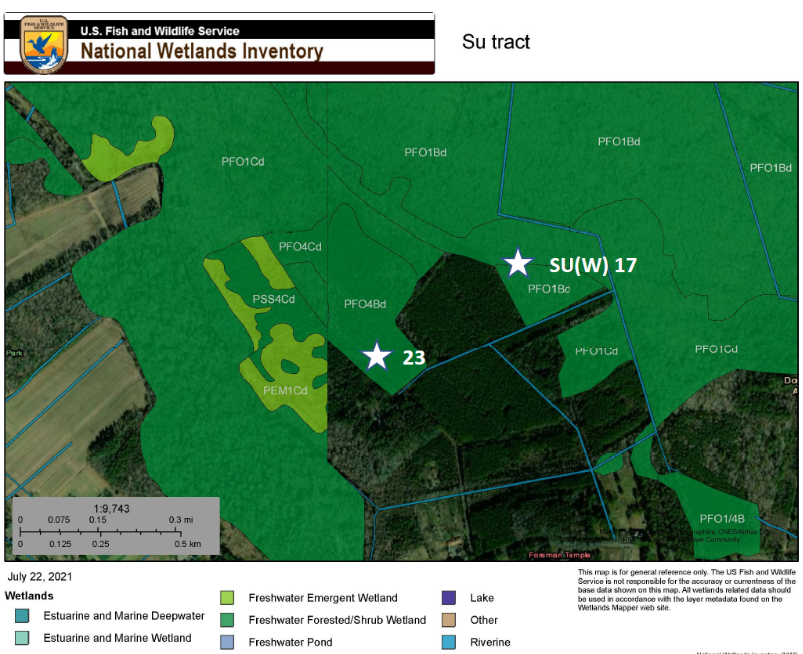


Figure 2. Su (W) 17 reference hydroperiod maximum and minimum levels observed over a nine year period (not complete in most summers) displayed as a spline chart.



PFO4Bd and PFO1Bd – SE VA

Current NWI map of Su reference hydroperiod sites in Chesapeake VA; E of Cornland.

Approximate monitoring well locations indicated with a ★

Figure 3. NWI Map of Su 17 (W) and Su 23 Reference Hydroperiod Site Location.

14.2.8 Su Tract 23

Site location:	Chesapeake VA; E of Cornland and just N of NC border
NWI Classification:	PFO4Bd
HGM Classification:	Mineral Soil Flats
Geology:	Tabb Formation; Sedgefield member; Late Pleistocene
Soil Type:	Tomotley series (Fine-loamy, mixed, semiactive, thermic Typic Endoaquults) and Nimmo series (Coarse-loamy, mixed, semiactive, thermic Typic Endoaquults) complex
Elevation:	10-12'
Notes:	This wetland has one of the largest data sets analyzed by Sneesby (2019) and was provided by specific request from the USACE Norfolk District [Su (W) 17; 2009-2017] and by The Nature Conservancy (Su 23; 2002-2005). The data set includes continuous data for 2002-2005 for Site 23. Excluding 2012, the site (W) 17 data (2009 – 2017) spans the winter through early summer of each year with well/logger removal for several summer/fall months.

Considerably more detail on this site including hydroperiods for three additional TNC wells in the same general area along with categorization of D/N/W years is available in Sneesby (2019) at https://vtechworks.lib.vt.edu/handle/10919/88836.

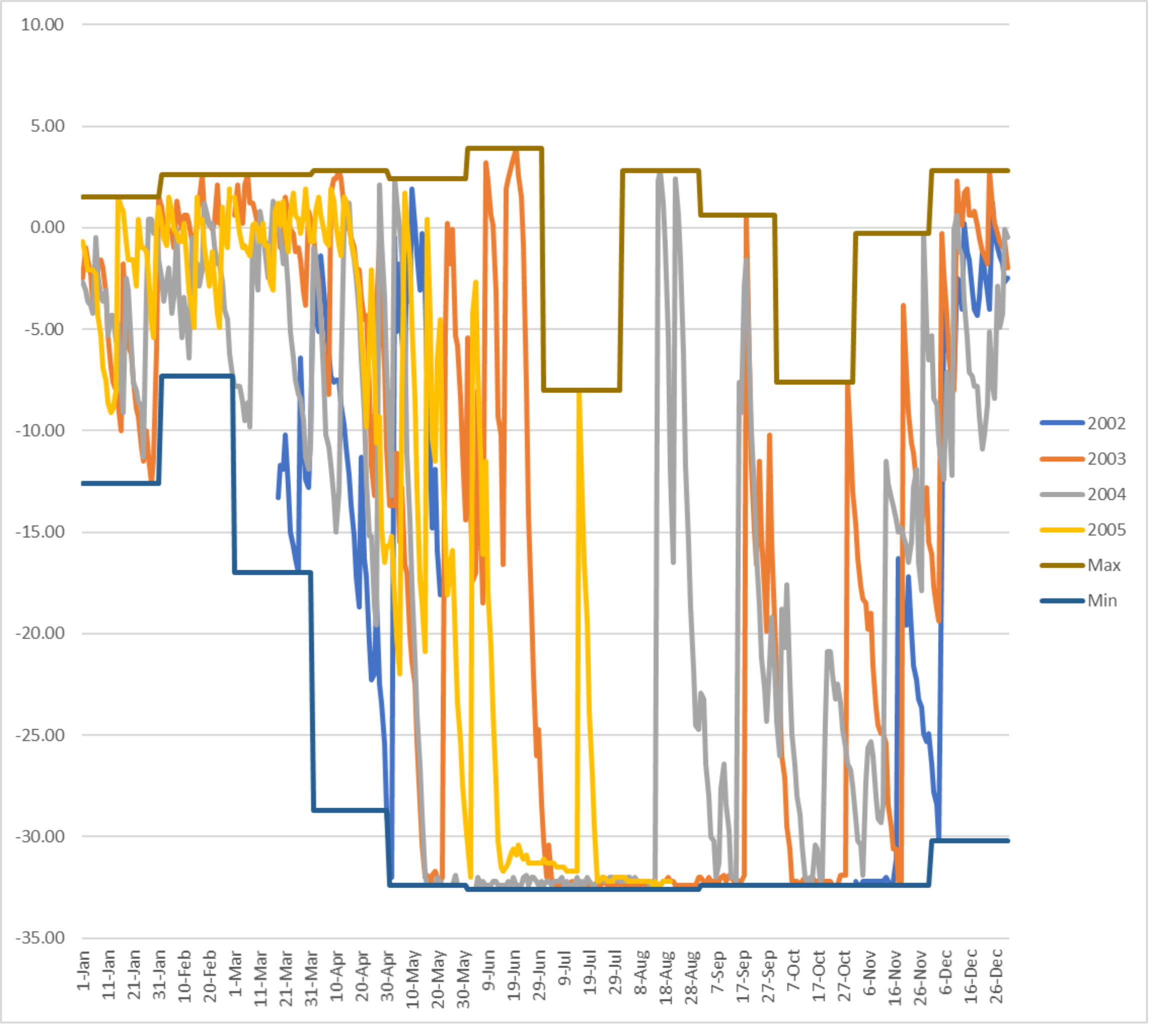


Figure 1. Su 23 reference hydroperiod data (inches) for four years based on daily well logger readings. The bottom of the well was ~32 inches, thus actual summer drawdown in some months may have been greater than shown here. The max and min lines reflect levels achieved in all wells over a given month across all years, thus relatively low level for December reflects only one brief duration at one well. As noted above, hydroperiod graphs for three other wells in this general site area are available in Sneesby (2019).

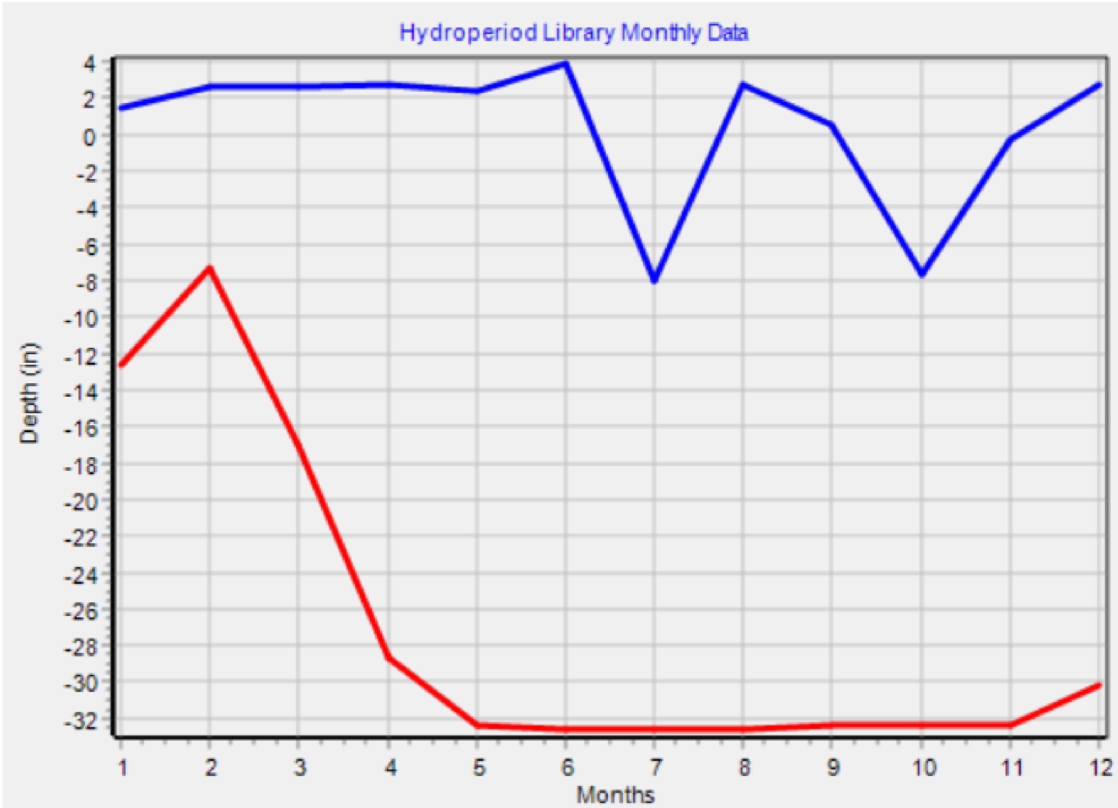
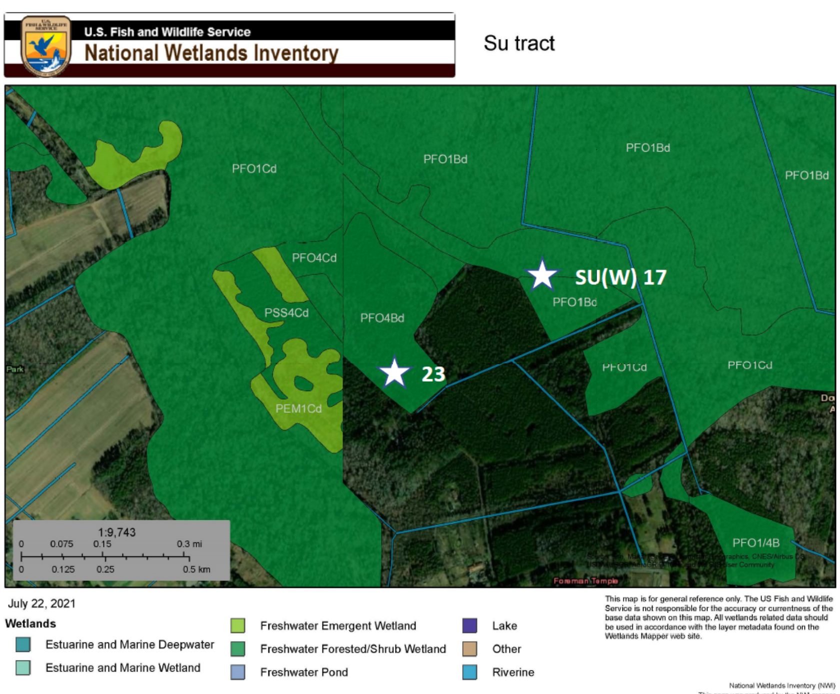


Figure 2. Su 23 reference hydroperiod maximum and minimum levels observed over a four year period displayed as spline chart.



PFO4Bd and PFO1Bd – SE VA

Current NWI map of Su reference hydroperiod sites in Chesapeake VA; E of Cornland.

Approximate monitoring well locations indicated with a ★

Figure 3. NWI Map of Su 17 (W) and Su 23 Reference Hydroperiod Site Location.

14.2.9 Sandy Bottom

Site location:	Hampton VA; W of Big Bethel Road and S of I-64 in Sandy Bottom Nature Park
NWI Classification:	PFO1B and PFO4B
HGM Classification:	Mineral Soil Flats
Geology:	Tabb Formation, Sedgefield Member, Late Pleistocene
Soil Type:	Tomotley series; Fine-loamy, mixed, semiactive, thermic Typic Endoaquults
Elevation:	25-26'
Notes:	This site was monitored by Virginia Tech and Old Dominion University for four years as a reference wetland for a research program supported by VDOT associated with an adjacent wetland restoration/creation project. The three monitoring wells reported here were monitored every two weeks by manual methods. The site is part of a broad mineral flat, portions of which were excavated in the 1960's for the construction of I-64 which bounds the site to the north. Two of the three monitoring locations reported here occur within a PFO1/4E mapping unit, but our frequent onsite observations never confirmed "flooding" per se. Thus, we have reclassified that unit for this project as PFO1/4B. However, two of three locations did support shallow surface ponding during the winter due to formation of the regional water table mound.

Considerably more detail on this site is available in Sneesby (2019) including classification of D/N/W years at https://vtechworks.lib.vt.edu/handle/10919/88836.

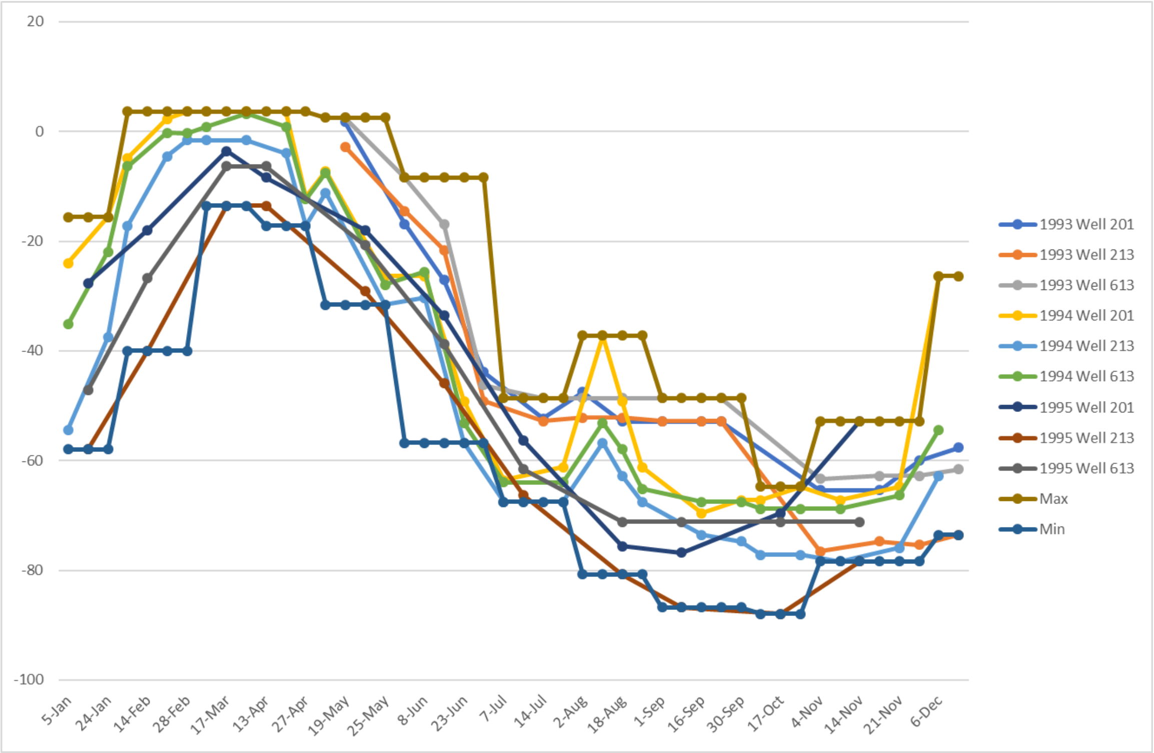


Figure 1. Sandy Bottom reference hydroperiod data (inches) for three locations over three years based on manual level readings every two weeks. The max and min lines reflect levels achieved in all wells over a given month across all years.

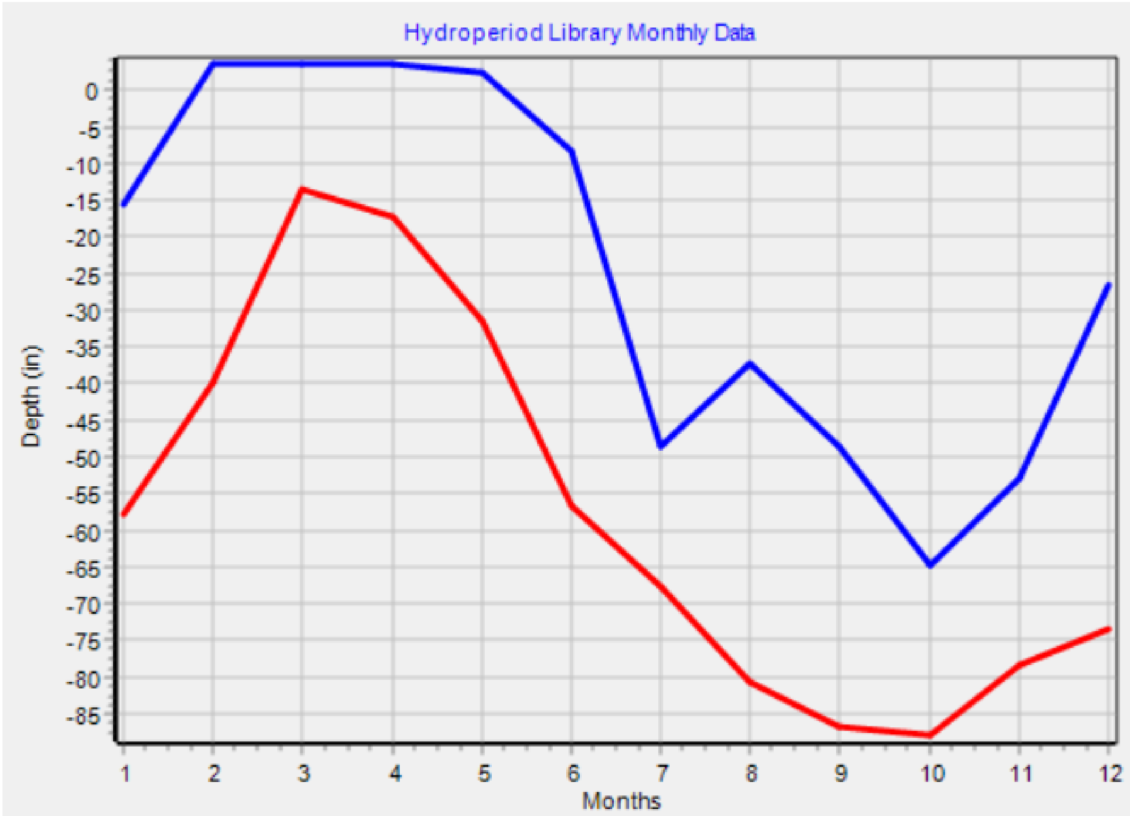
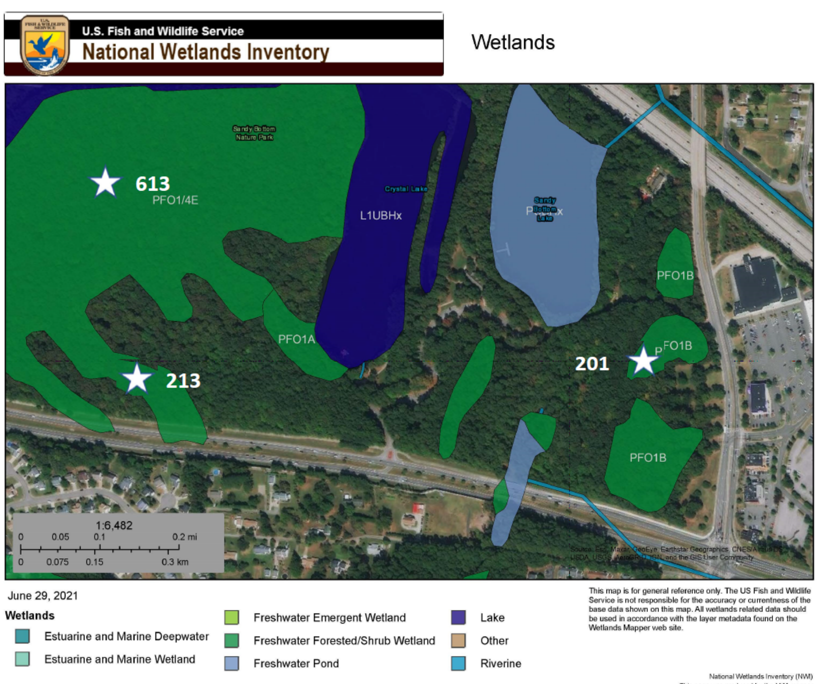


Figure 2. Sandy Bottom reference hydroperiod maximum and minimum levels observed over a three year period displayed as a spline chart.



PFO1/4B and PFO1B – SE VA

Current NWI map of Sandy Bottom reference hydroperiod site in Hampton VA; W of Big Bethel Rd.

Approximate monitoring well locations indicated with a ★

Figure 3. NWI Map of Sandy Bottom Reference Hydroperiod Site Location.

14.2.10 Stumpy Lake

Site location:	SW Virginia Beach, Virginia. West of Stumpy Lake GC
NWI Classification:	PFO1Bd
HGM Classification:	Mineral Soil Flats
Geology:	Tabb Formation, Lynnhaven Member; Late Pleistocene
Soil Type:	Acredale series; Fine-silty, mixed, active, thermic Typic Endoaqualfs
Elevation:	11'
Notes:	Based on regional reference well data provided by USACE Norfolk District upon specific request.

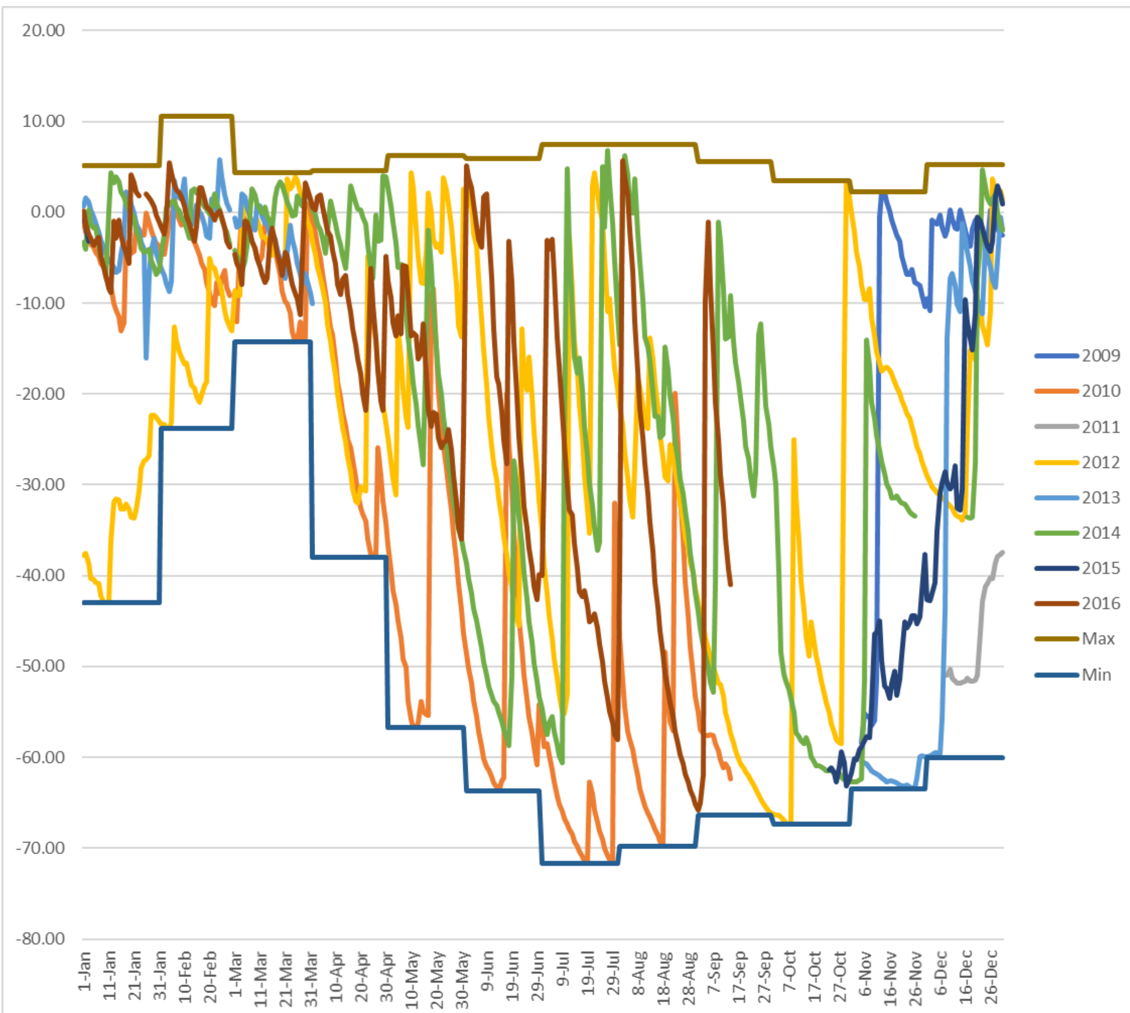


Figure 1. Stumpy Lake reference hydroperiod data (inches) for eight years based on daily level logger readings provided by the USACE Norfolk District. Wells were removed/replaced in certain years and dry seasons where data gaps are obvious The

max and min lines reflect levels achieved in all wells over a given month across all years.

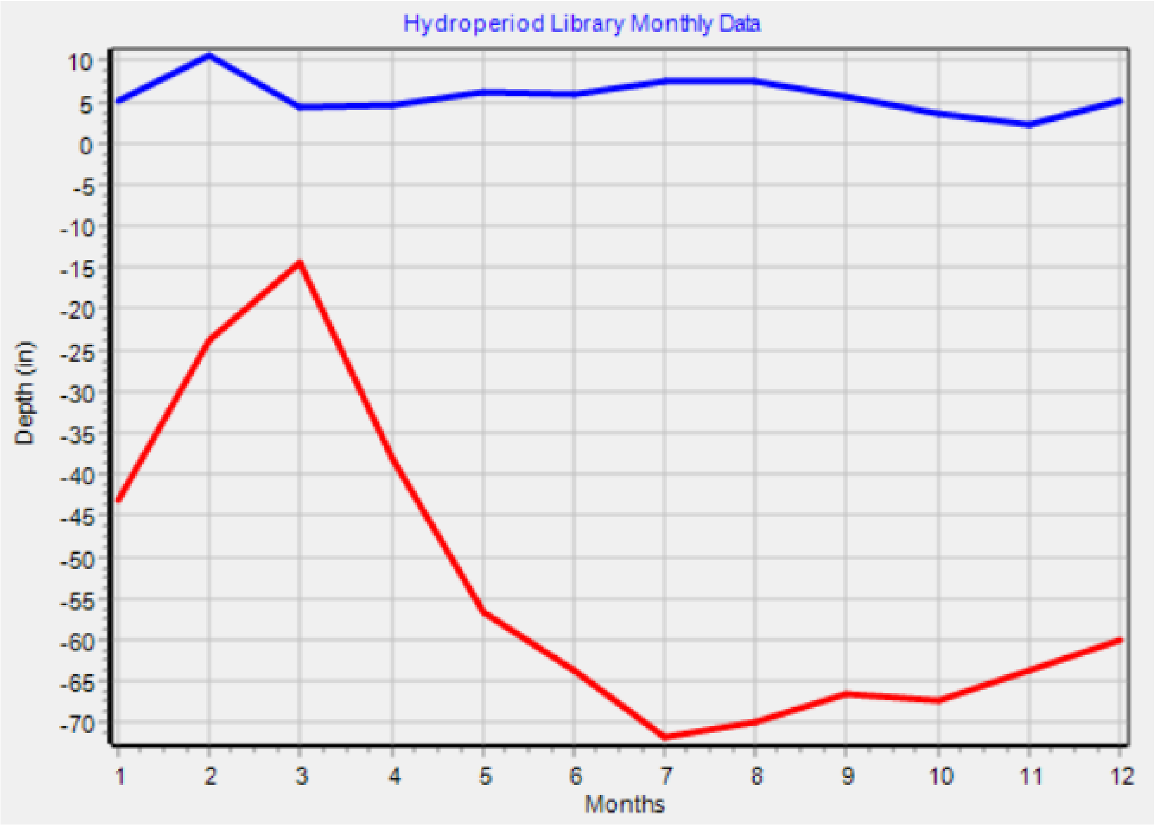
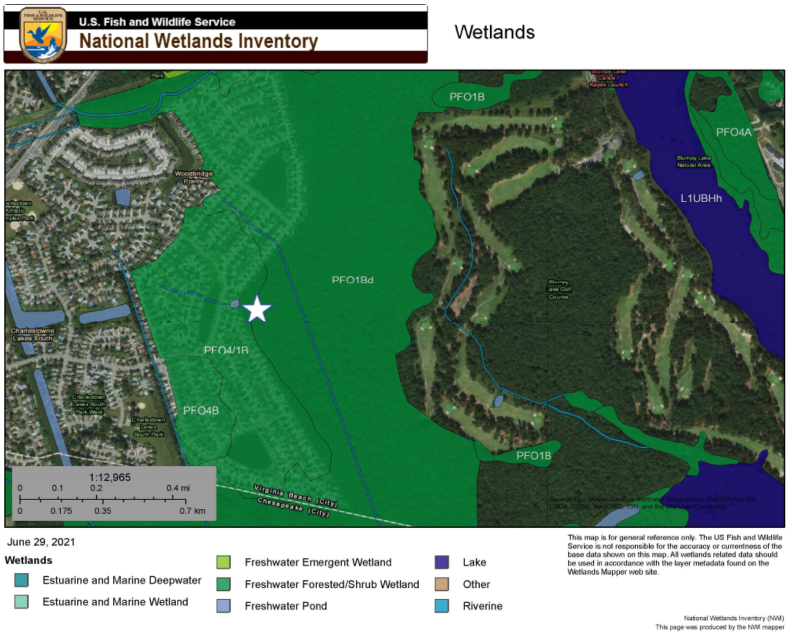


Figure 2. Stumpy Lake reference hydroperiod maximum and minimum levels observed over an eight year period (some years partial) displayed as a spline chart. Caution should be taken interpreting December minimum levels since water levels were substantially higher in six years of seven years where data was available.



PFO1Bd – SE VA

Current NWI map of Stumpy Lake reference hydroperiod site in SW Virginia Beach, VA.

Approximate monitoring well location indicated with a ★

Figure 3. NWI Map of Stumpy Lake Reference Hydroperiod Site Location.

14.2.11 Whitelace Creek 1

Site location:	Lenoir County, NC; E of LaGrange, on Mosely Creek
NWI Classification:	PFO1A
HGM Classification:	? - Mixture of riverine and possibly slope discharge influences
Geology:	Black Creek Formation; Cretaceous
Soil Type:	Pamlico series; Sandy or sandy-skeletal, siliceous, dysic, thermic Terric Haplosaprists
Elevation:	19'
Notes:	Based on reference well data provided by NC DEQ with six years of daily well logger data. The site was used as a reference location for a nearby stream and wetland restoration project (to S) on Whitelace Creek. The site occurs below a toeslope and adjacent to Mosely Creek. Differing project reports provide slightly different locations for this monitoring well; all within the Pamlico muck soil mapping unit and on this local riparian landform.

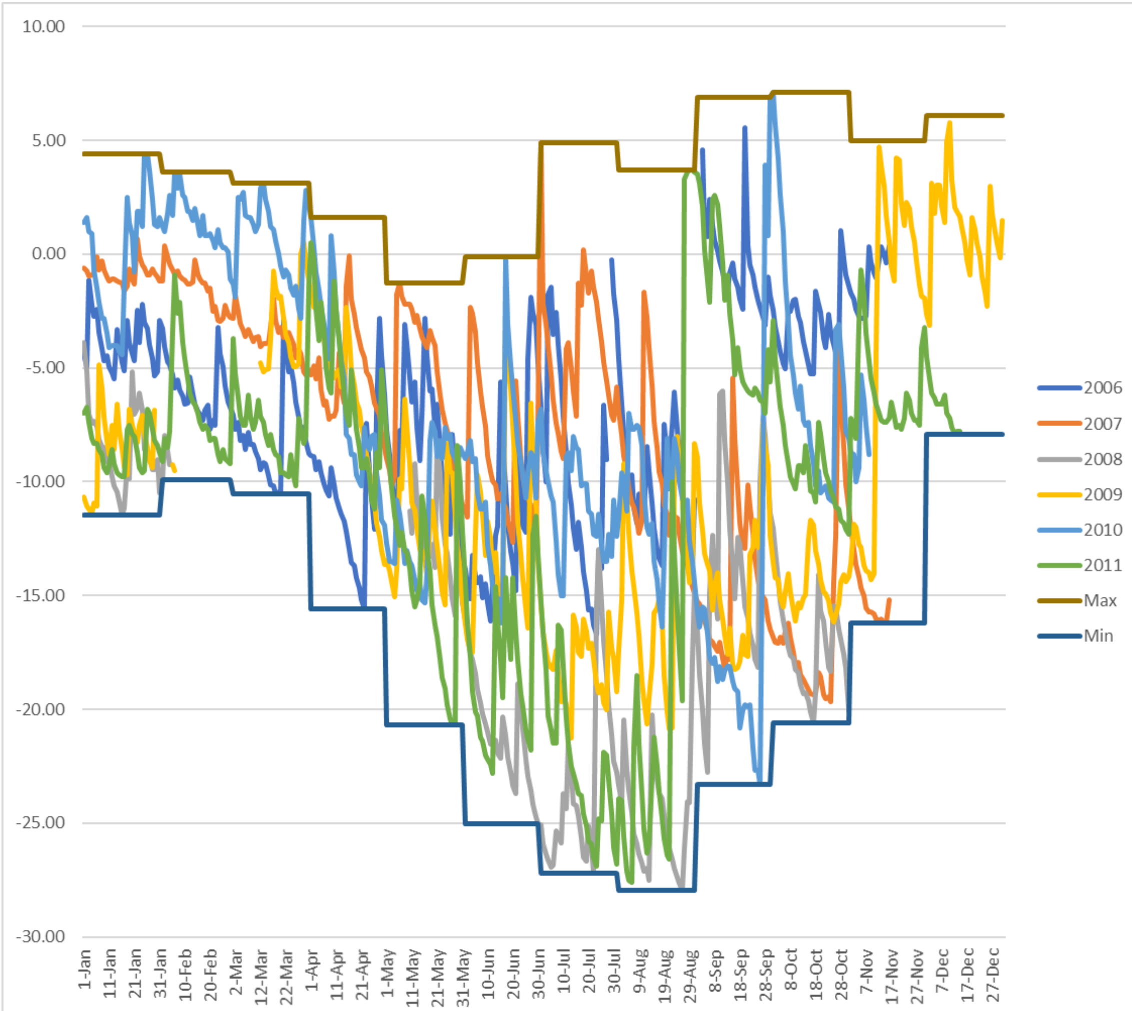


Figure 1. Whitelace Creek 1 reference hydroperiod data (inches) for six years based on daily level logger readings. Data provided by NC DEQ monitoring program. The max and min lines reflect levels achieved in all wells over a given month across all years.

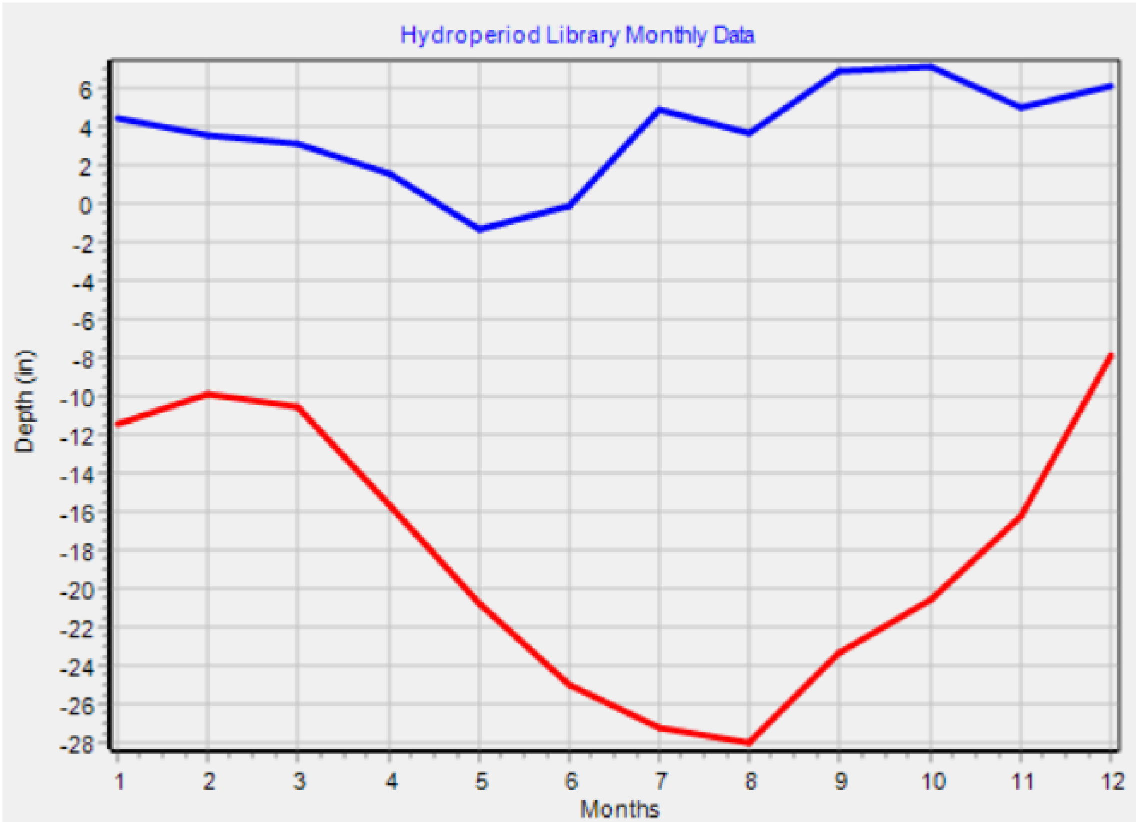
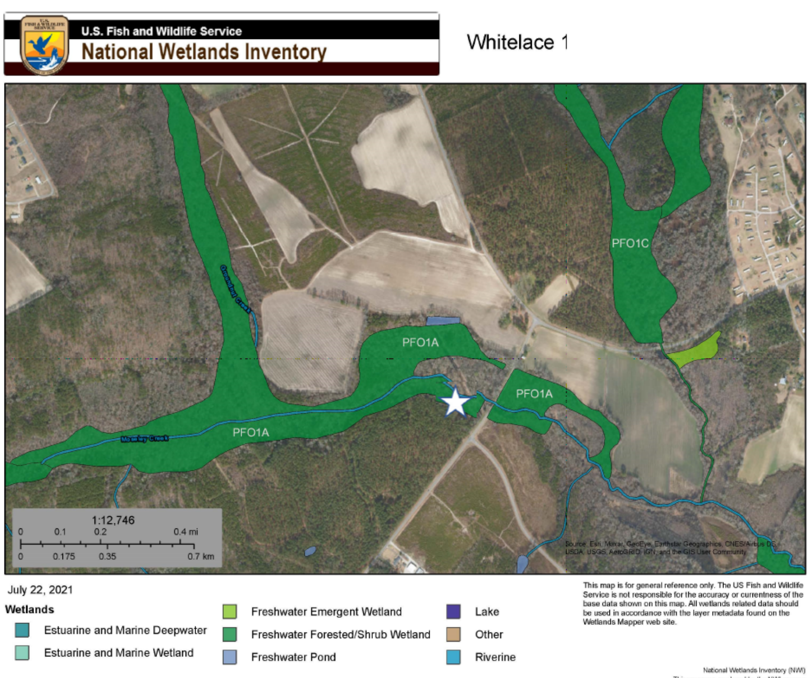


Figure 2. Whitelace Creek 1 reference hydroperiod maximum and minimum levels observed over a six year period displayed as a spline chart.



PFO1A – E NC

Current NWI map of Whitelace Creek 1 reference hydroperiod site in Lenoir County, NC; E of LaGrange.

Approximate monitoring well location indicated with a ★

Figure 3. NWI Map of Whitelace Creek 1 Reference Hydroperiod Site Location.

14.2.12 Whitelace Creek 3

Site location:	Lenoir County, NC; E of LaGrange, on Falling Creek
NWI Classification:	PFO1C
HGM Classification:	? Mineral Soil Flats with riverine influences
Geology:	Black Creek Formation; Cretaceous
Soil Type:	Johnston, Coarse-loamy, siliceous, active, acid, thermic Cumulic Humaquepts
Elevation:	~12'
Notes:	Based on reference well data provided by NC DEQ with six years of daily well logger data. The site was used as a reference location for a nearby stream and wetland restoration project (to S) on Whitelace Creek. The site occurs on a broad riparian flat associated with Falling Creek.

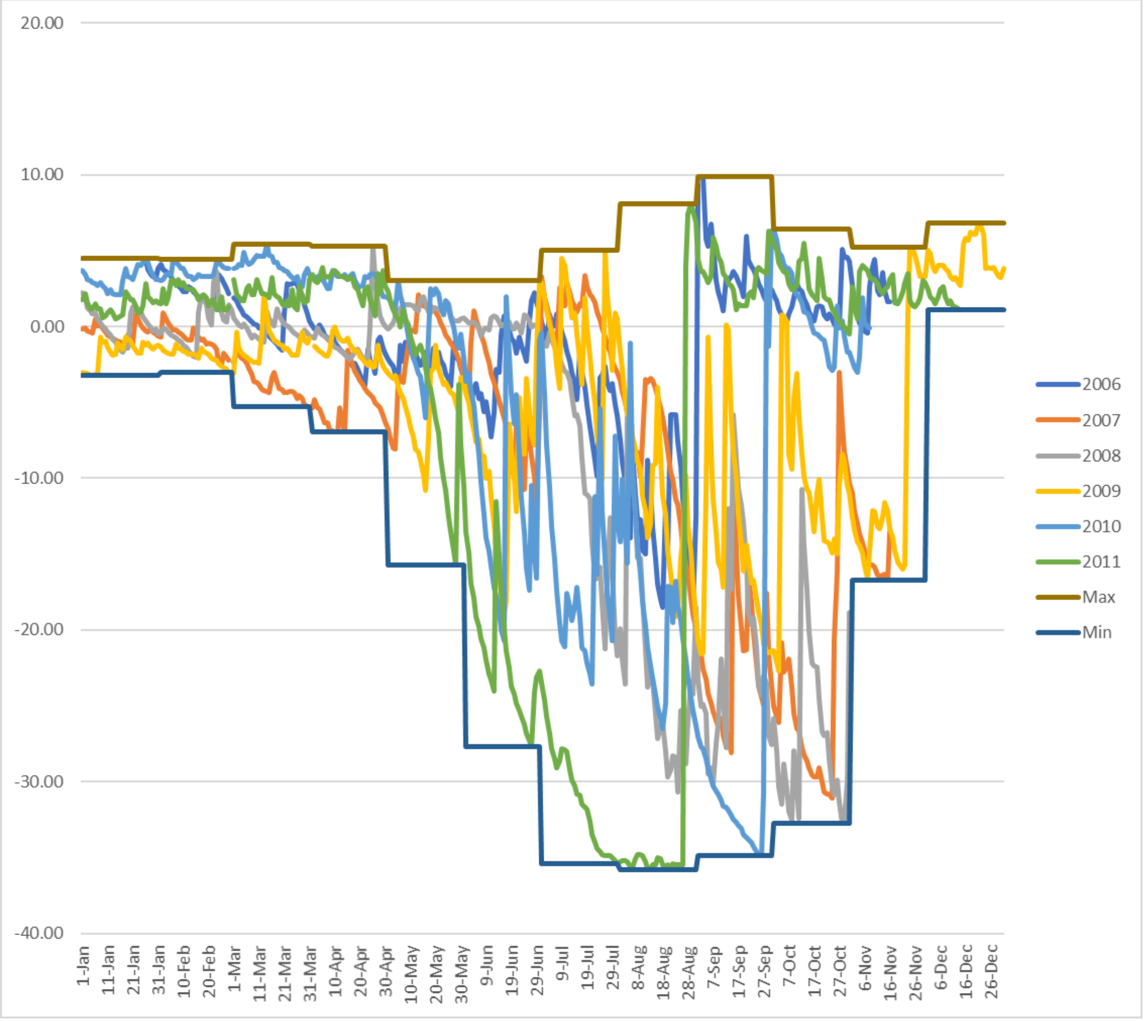


Figure 1. Whitelace Creek 3 reference hydroperiod data (inches) for six years based on daily level logger readings. Data provided by NC DEQ monitoring program. The max and min lines reflect levels achieved in all wells over a given month across all years.

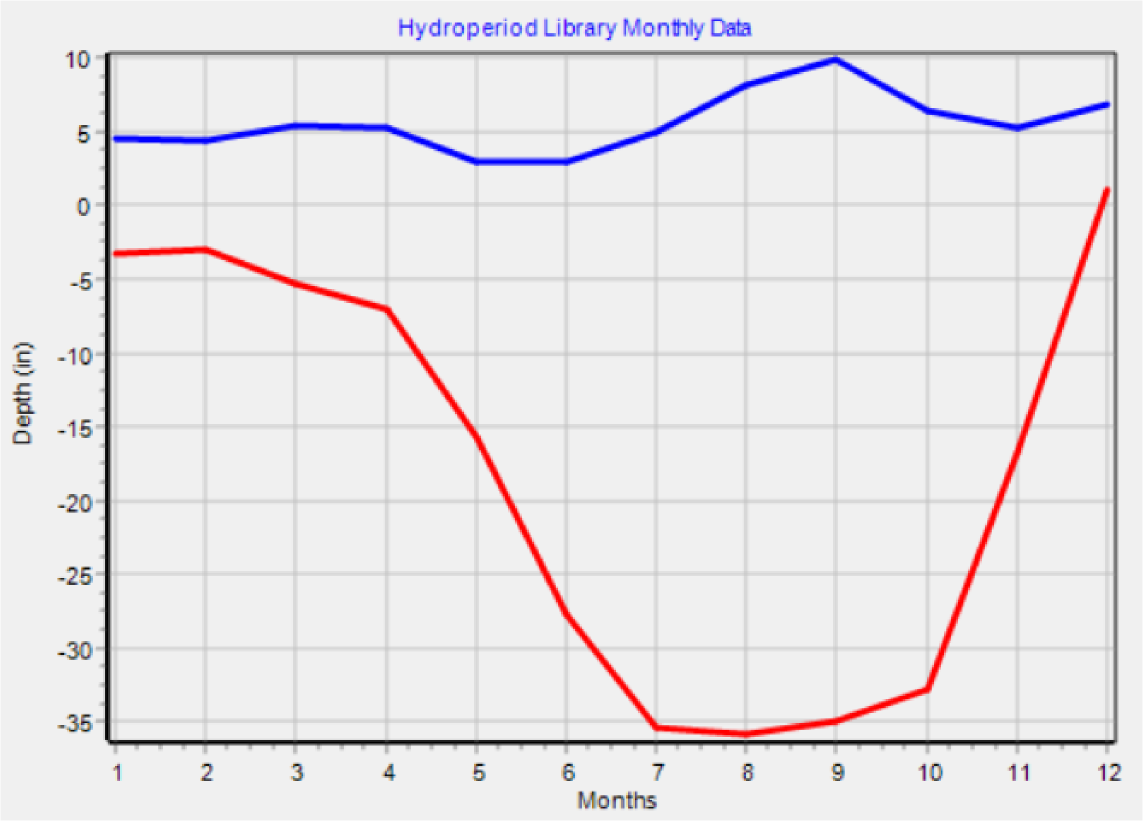
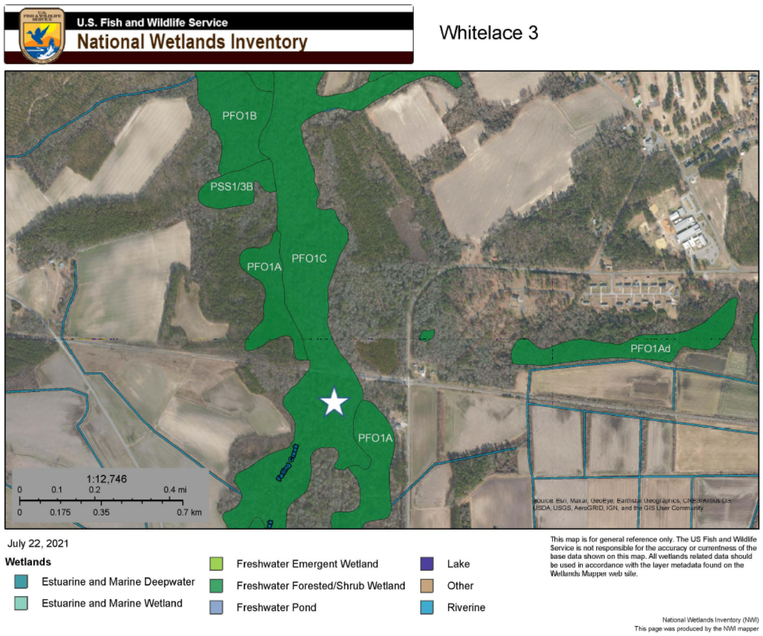


Figure 2. Whitelace Creek 3 reference hydroperiod maximum and minimum levels observed over a six year period displayed as a spline chart.



PFO1C – E NC

Current NWI map of Whitelace Creek 3 reference hydroperiod site in Lenoir County, NC; E of LaGrange.

Approximate Monitoring well location indicated with a ★

Figure 3. NWI Map of Whitelace Creek 3 Reference Hydroperiod Site Location.

15

References and Bibliography

15 References and Bibliography

References

1. Allen, R.G., L.S. Pereira, D. Raes, and M. Smith, 1998. Crop evapotranspiration: Guidelines for computing crop water requirements. Irrigation and Drainage Paper 56. UN-FAO, Rome, Italy.
2. Burdt, A.C, J.M. Galbraith, and W.L. Daniels, 2005. Season Length Indicators and Land-Use Effects in Southeast Virginia Wet Flats, Wetland Soils, Soil Fertility & Plant Nutrition. Soil Sci. Soc. Am. J. 69:1551–1558, https://doi.org/10.2136/sssaj2004.0124.
3. Chaubey, I., and G.M. Ward, 2006. Hydrologic budget analysis of a small natural wetland in southeast USA. Journal of Environmental Informatics 8: 10-21, https://doi.org/10.3808/jei.200600073.
4. Cowardin, L.M., V. Carter, F.C. Golet, and E.T. LaRoe, 1979. Classification of wetlands and deepwater habitats of the United States. U.S. Fish and Wildlife Service. FWS/OBS-79/31. Washington, DC.
5. Dobbs, K.M., 2013. Evaluating the contribution of groundwater to wetland water budgets, Central Piedmont, Virginia. M.S. Thesis. Department of Ocean, Earth, and Atmospheric Sciences, Old Dominion University, Norfolk, VA.
6. U.S. FHWA, 2006. Geotechnical aspects of pavements reference manual. U.S. DOT Publication FHWA-NHI-05-037. National Highway Institute, Federal Highway Administration, U.S. Department of Transportation, Washington D.C.
7. Harbaugh, A.W., E.R. Banta, M.C. Hill, and M.G. McDonald, 2000. MODFLOW-2000, the U.S. Geological Survey modular ground-water model - User guide to modularization concepts and the ground-water flow process. USGS Open-File Report 00-92, U.S. Geological Survey, Reston, VA, https://pubs.usgs.gov/of/2000/0092/report.pdf (accessed May 30, 2020)
8. Harbaugh, A.W., 2005. MODFLOW-2005, the U.S. Geological Survey modular ground-water model - the ground water flow process. USGS Techniques and Methods 6-A16. U.S. Geological Survey, Reston, VA.
9. Jensen, M.E., R.D. Burman, and R.G. Allen, 1990. Evapotranspiration and irrigation water requirements. American Society of Civil Engineers, New York, NY.
10. Johnson, A.I., 1967, Specific yield - Compilation of specific yields for various materials. U.S. Geological Survey Water Supply Paper 1662-D. U.S. Geological Survey, Denver, CO.
11. Maidment, D.R., 1993. Handbook of hydrology. McGraw-Hill, New York.
12. McDonald, M.G., A.W. Harbaugh, B.R. Orr, and D.J. Ackerman, 1992. A method of converting no-flow cells to variable head cells for the U.S. Geological Survey modular finite-difference groundwater flow model. USGS Open-File Report 91-536. U.S. Geological Survey, Reston, VA.
13. McLeod, J.M., 2013, Hydrogeologic analysis of factors that influence pitcher plant bog viability at the Joseph Pines Preserve, Sussex, Virginia. M.S. Thesis. Department of Ocean, Earth, and Atmospheric Sciences, Old Dominion University, Norfolk, VA.
14. NASA Atmospheric Science Data Center, 2021. POWER Data Methodology. National Air and Space Administration. https://power.larc.nasa.gov/docs/methodology/ (accessed June 24, 2021).

15. Niswonger, R.G., S. Panday, and M. Ibaraki, 2011. MODFLOW-NWT, A Newton formulation for MODFLOW-2005. U.S. Geological Survey Techniques and Methods 6-A37. U.S. Geological Survey, Reston, VA.
16. Pierce, G.J., M.N. Gilbert and R.J. Pierce, 2015. Wetland Mitigation: Planning Hydrology, Vegetation and Soils for Constructed Wetlands. Wetland Training Institute, Inc., Glenwood, New Mexico, pp. 99 to 116. https://wetlandtraining.com/product/wetland-mitigation-book/.
17. Sneesby, E.P., 2019. Evaluation of a Water Budget Model for Created Wetland Design and Comparative Natural Wetland Hydroperiods. M.S. Thesis, Virginia Tech, Blacksburg, Feb. 21, 2019. 203 p, http://hdl.handle.net/10919/88836.
18. Sneesby, E., W.L. Daniels, T. Thompson, Z. Agioutantis, G.R. Whittecar and S. Klopf., 2019. Evaluation of a Wetland Water Budget Model for Design of Created Non-tidal Wetlands. In: Abstracts, 2019 National Meeting of the Society of Wetland Scientists, May 27 to 31, 2019, Baltimore, Maryland. Society of Wetland Scientists, 1818 Parmenter St., Suite 300, Middleton, WI 53562, USA.
19. Stone, S.F., 2017. Hydrologic response caused by wetland expansion at Huntley Meadows Park in Hybla Valley, Virginia. M.S. Thesis, Old Dominion University, Norfolk, VA. https://doi.org/10.25777/ry2e-qf42.
20. Thornthwaite, C.W., 1948. An approach towards a rational classification of climate: Geographical Review 38: 55-94.
21. USACE, 2012. Regional Supplement to the Corps of Engineers Wetland Delineation Manual: Eastern Mountains and Piedmont Region (Version 2.0), ERCD/EL TR-12-9.
22. USACE, 1987. Corps of Engineers Wetlands Delineation Manual, Wetlands Research Program Technical Report Y-87-1 (on-line edition).
23. USACE, 2018. Exhibit F, Norfolk District Mitigation Banking Instrument, 2018. https://ribits.ops.usace.army.mil/ords/f?p=107:150:10913124681958::NO::P150_DOCUMENT_ID:78271 (to access the document, first access https://ribits.ops.usace.army.mil/ords/f?p=107:2::::: and then click on the actual document link).
24. USDA-NRCS, 1986. Urban hydrology for small watersheds. Technical Release 55. U.S. Department of Agriculture, Natural Resources Conservation Service, Washington DC, https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1044171.pdf (accessed June 1, 2020).
25. USDA-NRCS, 2004. Estimation of direct runoff from storm rainfall. Chapter 10. National engineering handbook, Part 630 Hydrology. U.S. Department of Agriculture, Natural Resources Conservation Service, Washington, DC, https://directives.sc.egov.usda.gov/OpenNonWebContent.aspx?content=17752.wba (accessed June 1, 2020).
26. USDA-NRCS, 2007. Hydrographs. Chapter 16. National engineering handbook, Part 630 Hydrology. U.S. Department of Agriculture, Natural Resources Conservation Service, Washington, DC, https://directives.sc.egov.usda.gov/OpenNonWebContent.aspx?content=17755.wba (accessed June 1, 2020).
27. USDA-NRCS, 2010. Time of concentration. Chapter 15. National engineering handbook, Part 630 Hydrology. U.S. Department of Agriculture, Natural Resources Conservation Service, Washington, DC,

https://directives.sc.egov.usda.gov/OpenNonWebContent.aspx?content=27002.wba (accessed June 1, 2020).
28. Whittecar, G.R., K.M. Dobbs, S.F. Stone, J.M. McLeod, T.L. Thornton and J.C. Smith, 2017. Use of the effective monthly recharge model to assess long-term water-level fluctuations in and around groundwater-dominated wetlands, Ecological Engineering, 99: 462 - 472, https://doi.org/10.1016/j.ecoleng.2016.11.038.

Bibliography

1. Dunne, T. and L.B. Leopold, 1978. Water in environmental planning, W.H. Freeman and Co, San Francisco, CA.
2. Mansell, R.S., S.A. Bloom, and G. Sun, 2000. A model for wetland hydrology: Description and validation. Soil Science 165(5):384-397, https://www.fs.usda.gov/treesearch/pubs/2083.
3. Neuhaus, E., 2013. Evaluation of a Water Budget Model for Use in Wetland Design. M.S. Thesis. Virginia Polytechnic Institute and State University. http://hdl.handle.net/10919/23741.
4. Stone, S., Z. Agioutantis, G.R. Whittecar, W.L. Daniels, T. Thompson and K. Dobbs, 2017. Wetbud – A free water budget modeling tool for created wetland design, Proceedings, SDIMI 2017, June 26-29, 2017, Beijing, China, http://dx.doi.org/10.15273/gree.2017.02.033.

16

Updates July 2020

16 Updates July 2020

2020-05-10

The Wetbud team has released version 2.0. This version included 114 preloaded stations covering the states of DE, FL, GA, IN, KY, MD, NC, NJ, NY, OH, PA, SC, TN, VA, VT, WV.

The data are available in the database with pre-loaded stations and the database with pre-loaded stations and examples. If you are updating your existing installation from Wetbud version 1.0 the new data will not automatically be imported in your existing database. Importing the data takes a very long time (i.e., between 6 and 9 hours depending on your system).

Please contact the Wetbud development team through the Wetbud users Google group to help you import the data in your database.

https://groups.google.com/forum/#!forum/wetbudplus

17

Updates April 2022

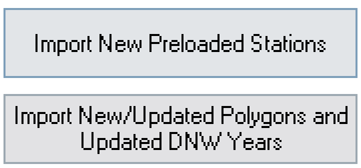
17 Updates April 2022

2022-04-15

The Wetbud team has released version 3.0. This version includes 138 preloaded stations covering the states of CT, DE, FL, GA, IN, KY, MA, MD, MN, MS, NC, NH, NJ, NY, OH, PA, RI, SC, TN, VA, VT, WV.

The data are available in the database with pre-loaded stations and the database with pre-loaded stations and examples. If you are updating your existing installation from Wetbud version 2.0 the new data will not automatically be imported in your existing database.

To import the data distributed with Wetbud version 3.0 which are not included in the data released with version 2.0 please navigate to the GSOD Stations form and use the buttons shown below:



In addition to many new weather stations, a wide range of improvements were completed including but not limited to:

1) More options were added to the overbank flow management calculation module.
2) A Hydroperiod Library was added. Dr. Lee Daniels and his team have developed reference hydroperiods for many forested wetlands in Virginia and North Carolina. The datasets have been made available for comparison to predicted water levels. A summary of the methods used to develop the datasets, as well as the characteristics of the sites from which the data came, is available in the Supplemental Material section of the Help documents.
3) Project specific hydroperiod curves can now be plotted as part of the results. Basic and Advanced Model output can be compared against reference hydroperiod curves from the library or user-generated curves. Tools have been developed to allow parametric analyses comparing predicted water levels to user-specified combinations of hydroperiod curves and design elevations.
4) Reporting for both the Basic and Advanced Models have been enhanced: (a) Hydroperiod analyses have been incorporated into the reports, (b) Numerous improvements have been made to unit conversion and graphing functions in the reports, (c) Advanced Model reports now provide a summary of parameters used to develop the numerical models as well as model output from user-defined monitoring points.
5) Revisions to many existing preloaded weather stations: (a) DNW year calculation ranges were extended to include longer time periods for several stations. (b) Influence area polygons for many existing stations were improved as new stations

were added. (c) A polygon version counter has been added to track changes to influence area polygons.

6) Various bugs and typos were corrected.
7) Twelve video tutorials have been prepared and made available through www.ResourceProtectionGroup.org.

The wetbud forum is still active for questions:

https://groups.google.com/forum/#!forum/wetbudplus

18

Updates October 2022 - July 2023

18 Updates October 2022 - July 2023

2022-10-22

version 3.0.0.6 was released on Oct 22, 2022 with minor bug fixes

2023-06-18

version 3.0.0.8 was released on June 18, 2023 with improvements on the google maps interface and other minor changes in the program and help file.

Also the latest modflow-NWT compile (version 1.3.0) is included in this distribution.

2023-07-01

version 3.0.0.9 was released on July 01, 2023 with minor bug fixes in the program and help file.

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