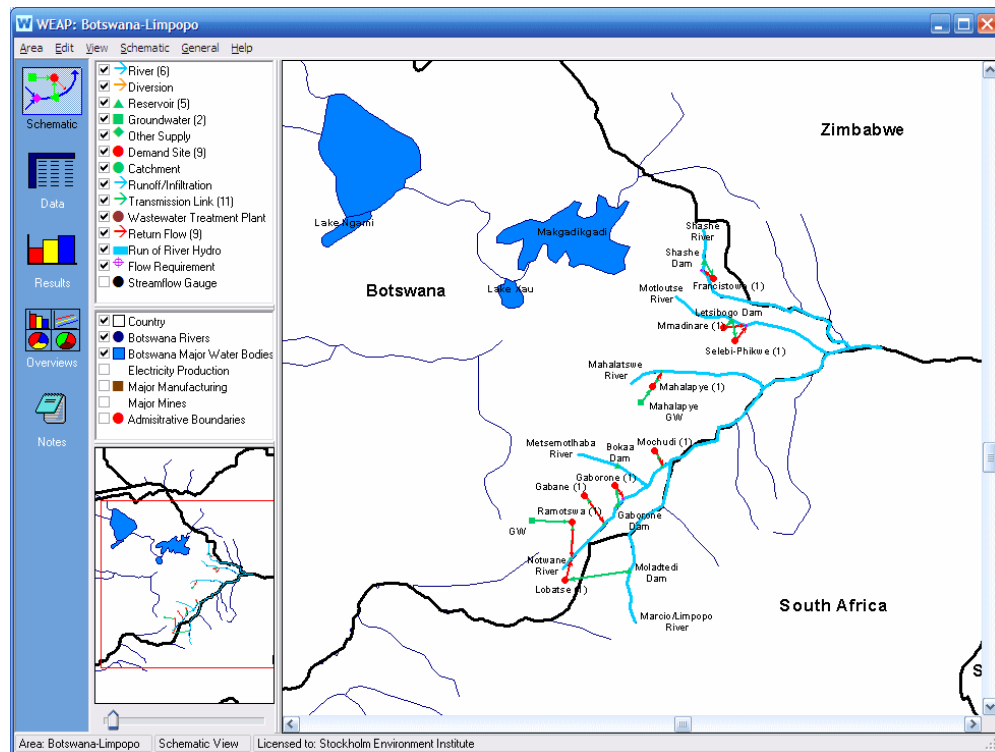




Water Evaluation And Planning System

## *USER GUIDE*





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# **WEAP**

**Water Evaluation And Planning System**

## **USER GUIDE**

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# 1 Introduction

## 1.1 Background

Many regions are facing formidable freshwater management challenges. Allocation of limited water resources, environmental quality and policies for sustainable water use are issues of increasing concern. Conventional supply-oriented simulation models are not always adequate. Over the last decade, an integrated approach to water development has emerged which places water supply projects in the context of demand-side issues, as well as issues of water quality and ecosystem preservation.

The Water Evaluation and Planning System (WEAP) aims to incorporate these values into a practical tool for water resources planning. WEAP is distinguished by its integrated approach to simulating water systems and by its policy orientation. WEAP places the demand side of the equation--water use patterns, equipment efficiencies, re-use, prices, hydropower energy demand, and allocation--on an equal footing with the supply side--streamflow, groundwater, reservoirs and water transfers. WEAP is a laboratory for examining alternative water development and management strategies.

WEAP is comprehensive, straightforward and easy-to-use, and attempts to assist rather than substitute for the skilled planner. As a database, WEAP provides a system for maintaining water demand and supply information. As a forecasting tool, WEAP simulates water demand, supply, flows, and storage, and pollution generation, treatment and discharge. As a policy analysis tool, WEAP evaluates a full range of water development and management options, and takes account of multiple and competing uses of water systems.

See also: [Overview](#), [WEAP Approach](#), [Getting Started](#)

## 1.2 Overview

Operating on the basic principle of water balance accounting, WEAP is applicable to municipal and agricultural systems, single subbasins or complex river systems. Moreover, WEAP can address a wide range of issues, e.g., sectoral demand analyses, water conservation, water rights and allocation priorities, groundwater and streamflow simulations, reservoir operations, hydropower generation and energy demands, pollution tracking, ecosystem requirements, and project benefit-cost analyses.

The analyst represents the system in terms of its various supply sources (e.g., rivers, creeks, groundwater, reservoirs); withdrawal, transmission and wastewater treatment facilities; ecosystem requirements, water demands and pollution generation. The data structure and level of detail may be easily customized to meet the requirements of a particular analysis, and to reflect the limits imposed by restricted data.

WEAP applications generally include several steps. The study definition sets up the time frame, spatial boundary, system components and configuration of the problem. The [Current Accounts](#) provide a snapshot of actual water demand, pollution loads, resources and supplies for the system. Alternative sets of future assumptions are based on policies, costs, technological development and other factors that affect demand, pollution, supply and hydrology. Scenarios are constructed consisting of alternative sets of assumptions or policies. Finally, the scenarios are evaluated with regard to water sufficiency, costs and benefits, compatibility with environmental targets, and sensitivity to uncertainty in key variables.

## 1.3 The WEAP Approach

Computer modeling in the field of water resources has a long history. Many sophisticated models have faltered by being mathematically obscure and overly ambitious in attempting to "optimize" solutions to real-life problems. Experience shows that the best approach is to build a straightforward and flexible tool to assist, but not substitute for, the user of the model. WEAP represents a new generation of water planning software that utilizes the powerful capability of today's personal computers to give water professionals everywhere access to appropriate tools.

The design of WEAP is guided by a number of methodological considerations: an integrated and comprehensive planning framework; use of scenario analyses in understanding the effects of different development choices; Demand-management capability; Environmental assessment capability; and Ease-of-use. These are discussed in turn below.

### 1.3.1 Integrated and Comprehensive Planning Framework

WEAP places the evaluation of specific water problems in a comprehensive framework. The integration is over several dimensions: between demand and supply, between water quantity and quality, and between economic development objectives and environmental constraints.

### 1.3.2 Scenario Analysis

With WEAP, you first create a [Current Accounts](#) of the water system under study. Then, based on a variety of economic, demographic, hydrological, and technological trends, a "reference" or "business-as-usual" [scenario](#) projection is established, referred to as a Reference Scenario. You can then develop one or more policy scenarios with alternative assumptions about future developments.

The scenarios can address a broad range of "what if" questions, such as: What if population growth and economic development patterns change? What if reservoir operating rules are altered? What if groundwater is more fully exploited? What if water conservation is introduced? What if ecosystem requirements are tightened? What if new sources of water pollution are added? What if a water-recycling program is implemented? What if a more efficient irrigation technique is implemented? What if the mix of agricultural crops changes? What if climate change alters the hydrology? These scenarios may be viewed simultaneously in the results for easy comparison of their effects on the water system.

### 1.3.3 Demand Management Capability

WEAP is unique in its capability of representing the effects of demand management on water systems. Water requirements may be derived from a detailed set of final uses, or "water services" in different economic sectors. For example, the agricultural sector could be broken down by crop types, irrigation districts and irrigation techniques. An urban sector could be organized by county, city, and water district. Industrial demand can be broken down by industrial subsector and further into process water and cooling water. This approach places development objectives--providing end-use goods and services--at the foundation of water analysis, and allows an evaluation of effects of improved technologies on these uses, as well as effects of changing prices on quantities of water demanded. In addition, priorities for allocating water for particular demands or from particular sources may be specified by the user.

### 1.3.4 Environmental Effects

WEAP scenario analyses can take into account the requirements for aquatic ecosystems. They also can provide a summary of the pollution pressure different water uses impose on the overall system. Pollution is tracked from generation through treatment and outflow into surface and underground bodies of water. Concentrations of water quality constituents are modeled in rivers.

### 1.3.5 Ease of Use

An intuitive graphical interface provides a simple yet powerful means for constructing, viewing and modifying the system and its data. The main functions--loading data, calculating and reviewing results--are handled through an interactive screen structure that prompts the user, catches errors and provides on-screen guidance. The expandable and adaptable data structures of WEAP accommodate the evolving needs of water analysts as better information becomes available and planning issues change. In addition, WEAP allows users to develop their own set of variables and equations to further refine and/or adapt the analysis to local constraints and conditions.

### 1.3.6 Urban Water Management

One of the strengths of WEAP is that it is adaptable to whatever data is available to describe a water resources system. That is, it can use daily, weekly, monthly, or annual time-steps to characterize the system's water supplies and demands. This flexibility means that it can be applied across a range of spatial and temporal scales. Indeed, WEAP has been used throughout the world to analyze a diverse set of water management issues for small communities and large managed watersheds alike.

Historically, WEAP has been used primarily to assess the reliability of water deliveries and the sustainability of surface water and groundwater supplies under future development scenarios. This type of application of WEAP has focused on the water supply implications of proposed management and/or infrastructural changes, but has overlooked the impacts of these changes on the management of storm water and wastewater. Recent advancement of the model, however, has allowed for the holistic, comprehensive consideration of each of these facets of managing local water resources. The updated model can now be used to address questions surrounding the integration of storm water, waste water, and water supply. These include:

- How will water supply and wastewater treatment facilities be affected by the retention and/or diversion of storm waters?
- How will improvements in water collection systems affect water supply and wastewater treatment?
- How will modifications of combined sewer overflow systems affect wastewater treatment?
- How can reclaimed wastewater be used to augment water supply?

The enhanced WEAP model includes updated features that allow the user to include the following:

- **Infiltration and Inflow** from groundwater to sewage collection systems. These inflows can stress rivers and streams by removing clean water from watersheds and place additional burden on wastewater treatment by taking up valuable plant capacity and limiting future sewer connections.
- **Infiltration Basins & Retention Ponds** as management practices. These can be used to offset the impacts of urbanization, where water demands increase and potentially threaten water supplies as more rainfall runs off of expanding impervious surfaces, rather than recharging local aquifers. They can also serve to attenuate non-point source pollution.

- [\*\*Display of User-Defined Performance Measures as Results\*\*](#). This will allow for the output of site-specific performance measures and criteria, which are commonly guided by the objectives of individual studies and systems configuration and local conditions.
- [\*\*Tiered Water Pricing\*\*](#) policies as a means of promoting demand management.
- [\*\*Combined Sewer Overflows\*\*](#) (CSOs) that pose potential risks to public health and aquatic life, because they discharge chemicals and disease-causing pathogens directly into waterways.

## 1.4 Getting Started

Each WEAP analysis is conducted in a single area. An area is typically a watershed, but could also be a larger or smaller geographic region. The last viewed area will open automatically when WEAP starts.

These help files contain comprehensive information on using the WEAP software. To get started, we suggest you familiarize yourself with some of the major concepts:

- **Help:** Use the Help menu to get access to WEAP's online documentation. Press the **F1** key to get context-sensitive help anywhere in WEAP.
- **Views:** WEAP is structured as a set of five different "views" onto your Area: Schematic, Data, Results, Scenario Explorer, and Notes. These views are listed as graphical icons on the View Bar, located on the left of the screen.
- **Current Accounts:** The Current Accounts represent the basic definition of the water system as it currently exists, and forms the foundation of all scenarios analysis.
- **Scenario analysis** is at the heart of using WEAP. Scenarios are self-consistent story-lines of how a future system might evolve over time in a particular socio-economic setting and under a particular set of policy and technology conditions. The comparison of these alternative scenarios proves to be a useful guide to development policy for water systems from local to regional scales.
- **User Interface:** This documentation assumes you are familiar with Windows-based programs. The main screen of the WEAP system consists of the [View Bar](#) on the left of the screen and a [main menu](#) at the top providing access to the most important functions of the program, and a status bar at the bottom of the screen showing the current area name, current view, licensing information and other status information. The layout of the rest of the screen will depend on which view is selected.
- **Calculation Algorithms:** WEAP calculates a water and pollution mass balance for every node and link in the system on a monthly time step. Water is dispatched to meet instream and consumptive requirements, subject to demand priorities, supply preferences, mass balance and other constraints.
- **Sample Data:** WEAP comes with a sample data set for a fictional area called the Weaping River Basin. The User Guide refers to this data set when describing data entry screens and reports. It is worthwhile exploring this data set, as it illustrates most of the features of WEAP and the types of analysis that WEAP facilitates. Essentially, the area depicts a river basin with growing problems of water shortages, groundwater depletion and environmental pressures. These problems of the Reference Scenario are addressed in a series of scenarios employing a variety of both demand- and supply-oriented measures.

## 1.4 Getting Started

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- **Importing Data:** If you have a full sequence of annual or monthly data, for example on streamflows or municipal demands, the [Read From File](#) function allows you read this data from an ASCII data file.
- **Additional Information** on the [hardware and software](#) requirements for using WEAP, and on how to license the system and obtain technical support is also available.

**See also:** [Background](#), [Overview](#), [WEAP Approach](#)



# 2 WEAP Structure

## 2.1 Main Menu

The main menu in WEAP provides access to the most important functions of the program. There are seven sub-menus:

### 2.1.1 Area Menu

The area menu provides options for creating, opening, saving and managing areas (typically river basins), as well giving access to Area-wide operations such as managing scenarios, setting print options and exiting WEAP.

Click on Manage Areas to see all recent WEAP areas, associated planning periods, date and time of last changes, initials of person who made changes, directory size of the area, and zip status. An accompanying image of each WEAP area is shown in the inset in the lower left. A notes field is also provided. In Manage Areas, a new WEAP area can be created, areas can be opened, renamed, deleted, backed-up, e-mailed, and zipped. To open a previously backed-up WEAP area not listed, click on Restore. The Repair button will check and repair the database files of the highlighted area.

### 2.1.2 Edit Menu

The edit menu gives access to standard Windows editing operations: cut (Ctrl-X), copy (Ctrl-C), paste (Ctrl-V) and undo (Ctrl-Z). Note that the Undo feature is limited to a single undo operation and only within a given text editing box. WEAP does not currently support undoing of operations that affect data structures, nor does it support multi-level undo.

### 2.1.3 View Menu

The View menu allows you to switch between the five basic views in the WEAP system. It also lets you show or hide the View Bar, which by default is shown on the left of the screen. If the View Bar is hidden (to make more room on screen), use the View menu to switch views. See the [View Bar](#) help topic for a description of each view.

### 2.1.4 General Menu

The general menu gives access to basic parameters, such as the [time horizon](#) and [units](#) used for your analysis and the [water quality constituents](#) to be modeled. The user also has the option to determine whether or not individual demand branches within a demand site have the same monthly variation.

### 2.1.5 Schematic View

Various formatting options are available for the Schematic View. The user can set the area boundaries, change the size of the demand nodes and labels, hide all WEAP objects, and choose among a variety of priority views (e.g., demand site priorities, supply preferences).

### 2.1.6 Tree Menu

The tree menu is used to edit and navigate through the Tree which appears in the [Data View](#). Options on this menu allow you to add, rename, delete, move and organize branches. See "[Editing the Tree](#)" for more information. Many of these functions are also available by right-clicking on the Tree.

### 2.1.7 Favorites Menu

The Favorites menu, which is only displayed when in the [Results View](#), lets you save favorite charts including all settings for the axes, type of chart, and formatting. This feature is similar to the bookmark/favorites features found on popular Internet browsing software. In the [Scenario Explorer View](#), you can group together favorite charts to create overviews of different results. Use the "[Save Chart as Favorite](#)" option to bookmark the current highlighted chart. You will be asked to give the favorite a name. Use the "Delete Favorite" option to delete a saved favorite. To switch to a favorite chart, select its name from the favorites menu.

### 2.1.8 Explorer Menu

The Explorer menu covers all aspects of displaying and formatting the data (inputs) and results (outputs) in the [Scenario Explorer View](#).

### 2.1.9 Help Menu

The Help menu gives access to the contents, index and search pages of WEAP's help system. You can also press the **F1** key at any time to access context-sensitive help appropriate to the screen you are working in.

The Help menu also gives access to the WEAP web site (this requires an Internet connection) and lets you send an email to SEI requesting technical assistance. This feature requires that you have a MAPI compliant email system installed on your PC, such as Microsoft Outlook or Netscape Navigator. An "About" screen gives you contact information should you wish to contact SEI by mail, phone or fax. This screen also gives you system information which can be useful in identifying problems you may encounter while running WEAP. An option labeled "**Check on Internet for Updates**" automatically checks for newer versions of WEAP over the Internet, and installs them onto your PC. This is the preferred method of updating the software as it requires a much smaller download compared to a full download and re-installation of the system. WEAP will automatically check for a newer version on startup, if there is an active Internet connection at the time.

NB: the versions of WEAP available on the Internet work by default in "evaluation" mode (i.e., with the "Save" feature disabled). For those using this version, the "Register WEAP" option can be used to enter a user name and registration code to fully unlock the software. User names and registration codes are distributed by SEI to licensed users of the system. Visit the [WEAP web site](#) for more information on licensing WEAP.

## 2.2 View Bar

WEAP is structured as a set of five different "views" of your area. These views are listed as graphical icons on the "View Bar", located on the left of the screen. Click an icon in the View Bar to select one of the views. For the Results and Scenario Explorer view, WEAP will calculate scenarios before the view is displayed, if any changes have been made to the system or the scenarios.



## 2.3 Schematic View



The **Schematic View** is the starting point for all activities in WEAP. A central feature of WEAP is its easy-to-use "drag and drop" graphical interface used to describe and visualize the physical features of the water supply and demand system. This spatial layout is called the **schematic**. You can create, edit and view it in the Schematic View. GIS layers can be added for clarity and impact. The Schematic View provides you with one-click access to your entire analysis--right click on any element in the schematic to access its data or results.



The **Data View** is the place where you create your data structures, models and assumptions in WEAP. In the Data View, the screen is divided into four panes. On the top left, a hierarchical tree is used to create and organize data structures under six major categories Key Assumptions, Demand Sites, Hydrology, Supply and Resources, Environment, and Other Assumptions. The tree is also used to select the data to be edited, which is shown on the right of the screen. For example, clicking on the "Demand Sites" tree branch on the left of the screen, will display the data for all demand sites on the right of the screen. On the bottom left is a data inset schematic. Clicking on an element in the schematic will result in a jump to its place on the tree. On the top-right of the screen, a data entry table is used to edit data and create modeling relationships. The information you enter here is displayed graphically in the bottom right pane.




The **Results View** displays a wide variety of charts and tables covering each aspect of the system: demand, supply, costs, and environmental loadings. Customizable reports can be viewed for one or more scenarios. You can also use the "Favorites" option to bookmark the most useful charts for your analysis.



The **Scenario Explorer View** is used to group together "Favorite" charts (created earlier in the "Results" view) into "Overviews" for simultaneous display. With Overviews, you can get a birds-eye perspective on different important aspects of your system, such as demands, coverage, flows, storage levels, environmental impacts and costs. You can create multiple Overviews, each of which can display up to 25 different Favorites. In addition to showing Results, the Scenario Explorer View can display selected Data across many scenarios, to help demonstrate the impact of various assumptions and policies on results. These input values can be changed on the spot and WEAP will recalculate and update the results.



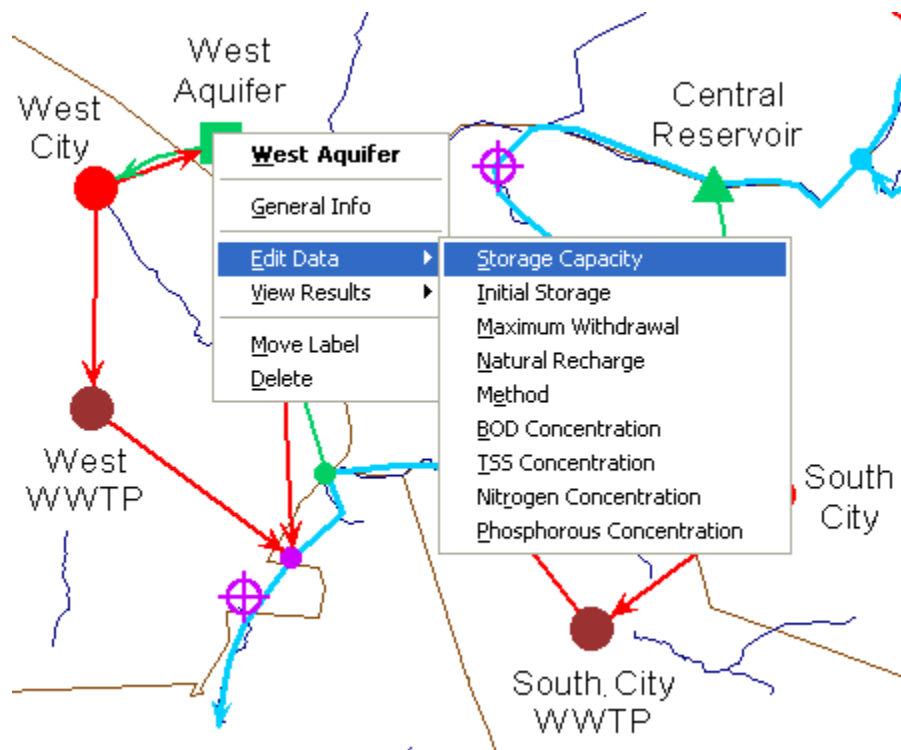
The **Notes View** is a simple word processing tool with which you can enter documentation and references for each branch of the tree. To edit the notes, either type directly into the Notes Window, or select **Edit** to display a larger window with additional word-processing features. Notes can include formatting (bold, underline, fonts, etc.) and can also include standard Windows "objects" such as spreadsheets. Use the **Print** and **Print All** buttons () to print one or all of the notes or the **Word** buttons to export one or all of the notes to Microsoft Word. We highly recommend extensive use of notes to document each scenario.

*Tip: If you are working on a low-resolution screen, we suggest that you hide the View Bar to make more space on the screen. Use the menu option **View: View Bar** to do this. You will then need to use the **View** menu to select the different views.*

## 2.3 Schematic View

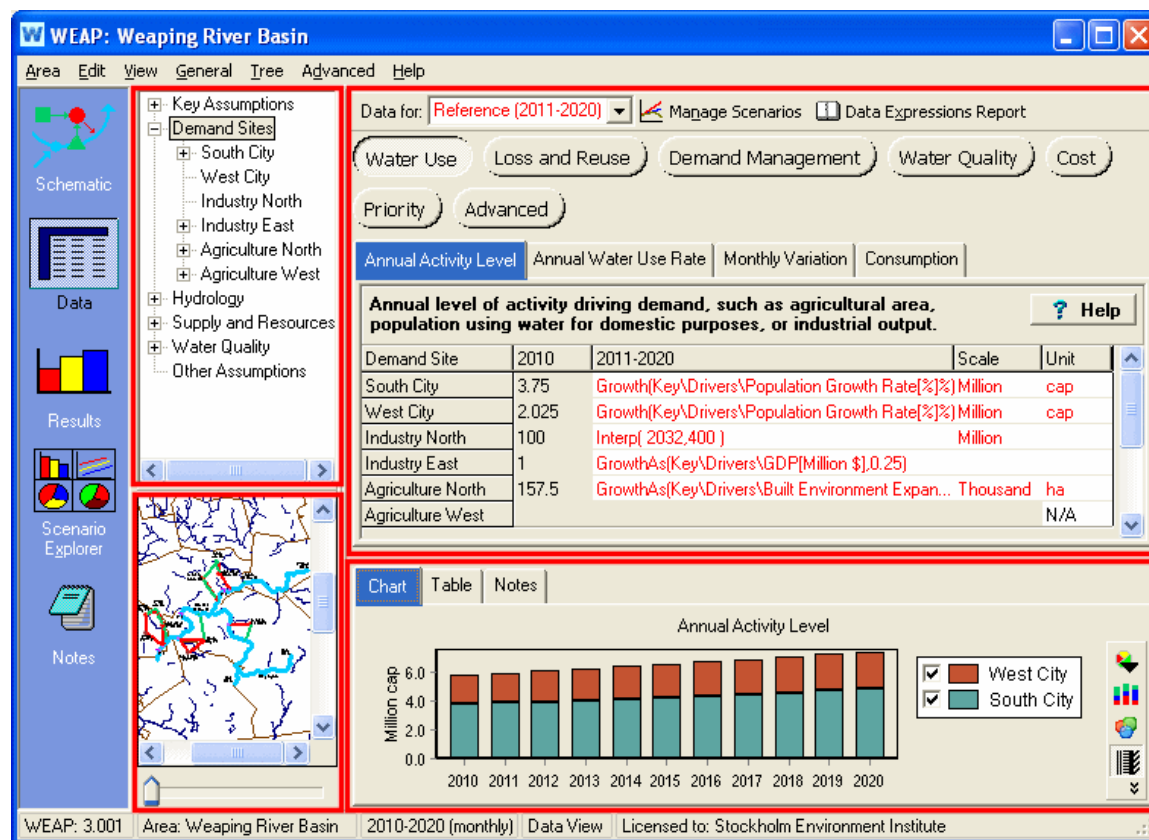
The Schematic View is the starting point for all activities in WEAP. A central feature of WEAP is its easy-to-use "[drag and drop](#)" graphical interface used to describe and visualize the physical features of the water supply and demand system. This spatial layout is called the **schematic**. You can create, edit and view it in the Schematic View. [GIS layers](#) can be added to provide clarity and impact.

The schematic also provides you with one-click access to your entire analysis. Right click on any element in the Main Schematic, and choose the data variable to edit under Edit Data, or the result table to view under View Results. In the example at the right, the user is about to edit Storage Capacity data for the groundwater node named West Aquifer.



## 2.4 Data View

In the **Data View** you build the model of your system, entering the data structures, data, assumptions, modeling relationships and documentation for the [Current Accounts](#) and for each scenario. The screen is divided into four panes (marked by red boxes in figure below):



### 2.4.1 Tree

On the top left, a hierarchical tree is used to create and organize data structures under six major categories: Key Assumptions, Demand Sites, Hydrology, Supply and Resources, Environment, and Other Assumptions. The tree is also used to select the data to be edited, which is shown on the right of the screen. For example, clicking on the "Demand Sites" tree branch on the left of the screen will display the data for all demand sites on the right of the screen. Note that when you click on a tree branch, the associated object in the schematic will flash on the map. See [Tree Overview](#) for more information.

### 2.4.2 Inset Schematic

A small schematic of your area is located on the bottom left. When you click on an element, it will be highlighted in the tree (above) and its data will be displayed in the data entry tables to the right. Conversely, when you click on a branch in the tree, the associated element on the Schematic will flash briefly. Move the **zoom bar** (below the schematic) to zoom in or out. Alternatively, hold down the **Ctrl** key and click and drag to define a region to zoom in to. Hold down the **Shift** key and click and drag on the schematic to pan. When the mouse cursor is positioned over the inset schematic, rotating the mouse wheel will zoom in or out.

### 2.4.3 Data Entry Tables

The data entry tables on the top right are used to enter expressions that define Current Accounts and Scenario values of variables. Each data variable appears on its own tab; related variables are grouped into categories (selected via buttons). Above the data entry tables is a set of buttons giving access to the different variable categories associated with each branch. The buttons and tabs you see will vary depending on what part of the data set you are working on. For example, when editing demand sites you will see buttons giving access to "Water Use," "Loss and Reuse," "Demand Management," "Cost," "Priority," and "Advanced," while for reservoirs you will see buttons for "Physical," "Operation," "Hydropower," "Water Quality," "Cost," and "Priority." Click on one of these buttons to see the variables in that category. For example, "Water Use" has three variables: "Annual Activity Level," "Annual Water Use Rate," and "Monthly Variation." There are wizards to help you construct the expressions--see [Expression Builder](#), [Yearly Time-Series Wizard](#) and [Monthly Time-Series Wizard](#). There is a "Help" button next to the description of each variable that can be clicked on to retrieve more information about that variable.

Immediately above the data entry tables is a toolbar containing a selection box and the Manage Scenarios button. Use the selection box to choose which data to edit--Current Accounts or one of the Scenarios. Click on [Manage Scenarios](#) to create, rename or delete scenarios, or to change their inheritance relationships.

### 2.4.4 Data Entry Results and Notes

The bottom right pane displays the data you entered in the top pane as either a chart or a table. These let you quickly examine the values generated by the expressions you have entered above. A toolbar on the right of the pane gives access to a range of options for formatting charts and tables (e.g. picking chart type and stacking options, colors, 3D effects, grids, number of decimal places, etc.) and for printing and copying charts and tables and exporting tables to Microsoft Excel.

The bottom pane also gives access to a notes screen: a word processing tool in which you can enter documentation and references for each branch of the tree. To edit the notes, right-click and select **Edit** to display the notes in a larger window, which includes a basic set of word processing controls. Notes can include formatting (bold, underline, fonts, etc.) and can also include standard Windows "objects" such as spreadsheets.

You may resize each of these four panels by dragging the dividing bars between them.

A record of all changes made to data in the order the changes were made are recorded in the text file Changes.txt (stored in the subdirectory for a WEAP area). Users enter their initials upon logging in when WEAP starts so that any changes can be catalogued in this file and attributed to a specific user.

See also: [View Bar](#)

## 2.5 Results View

Once you have entered data for your area, click on the Results View. WEAP can run its monthly simulation and report projections of all aspects of your system, including demand site requirements and coverage, streamflow, instream flow requirement satisfaction, reservoir and groundwater storage, hydropower generation and energy demands, evaporation, transmission and return flow losses, wastewater treatment, pollution loads, and costs. Calculations can be interrupted by pressing the Cancel button.

## 2.7 Scenario Explorer View

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The Results View is a general purpose reporting tool for reviewing the results of your scenario calculations in either chart or table form, or displayed on your schematic. Monthly or yearly results can be displayed for any time period within the study horizon. The reports are available either as graphs, tables or maps and can be saved as text, graphic or spreadsheet files. You may customize each report by changing: the list of nodes displayed (e.g., demand sites), scenarios, time period, graph type, unit, gridlines, color, or background image. (See [Charts, Tables and Maps](#) for more details.) Once you have customized a report, you can save it as a "[favorite](#)" for later retrieval. Up to 25 "favorites" can be displayed side by side by grouping them into an "[overview](#)". Using favorites and overviews, you can easily assemble a customized set of reports that highlight the key results of your analysis.

In addition to its role as WEAP's main reporting tool, the Results View is also important as the main place where you analyze your intermediate results to ensure that your data, assumptions and models are valid and consistent.

The reports are grouped into three main categories: [Demand](#), [Supply and Resources](#), and [Environment](#).

## 2.6 Scenario Explorer View

The Scenario Explorer View is used to group together multiple "Favorite" charts and tables (created earlier in the [Results View](#)) into "Overviews." With Overviews, you can simultaneously examine different important aspects of your system, such as demands, coverage, flows, storage levels, environmental impacts and costs.


In addition to showing Results, the Scenario Explorer View can display selected Data across many scenarios, to help demonstrate the impact of various assumptions and policies on results. These input values can be changed on the spot and WEAP will recalculate and update the results.

For details on choosing and configuring the Data Variables and Results Charts in the Scenario Explorer, see [Scenario Explorer](#).

See also: [View Bar](#), [Scenario Explorer](#)

## 2.7 Notes View

The notes screen is a simple word processing tool with which you can enter documentation and references for each branch of the [tree](#). To edit the notes, either type directly into the Window, or right-click and select **Edit** to display a larger window with additional word-processing features.

Notes can include formatting (bold, underline, fonts, etc.) and can also include standard Windows "objects" such as spreadsheets. Use the Print and Print All buttons () to print one or all of the notes or the **Word** buttons to export one or all of the notes to Microsoft Word.



# 3 Setting Up Your Analysis

To setup an area, the problem under study is characterized by defining physical elements comprising the water demand-supply system and their spatial relationships, the study time period, units, hydrologic pattern, and, when needed, water quality constituents and cost parameters. A central feature is an easy-to-use "drag and drop" graphical interface used to lay out and visualize the physical features of the water supply and demand system. This spatial layout represents the Schematic.

## 3.1 Creating an Area

### 3.1.1 Create Area

An "area" in WEAP is defined as a self-contained set of data and assumptions. Its geographical extent is typically a river basin. The data is separated into [Current Accounts](#) and any number of alternative [scenarios](#). An area is sometimes referred to as a "data set."

A study area can be a set of demand sites defined by political or geographic boundaries. It can also be defined as a specific water supply system such as a river basin or a groundwater aquifer. In one case, the point of focus will be the demand sites, while in another, it will be the water supplies in a region of interest. In yet other cases, it may be necessary to conceive of both a set of demand sites and the specific river system together as the study area. Study area boundaries could be somewhat more flexible than the rigid definition of the hydrologic boundaries in order to include the adjacent demand areas served by water supplies from within the hydrologic supply system, or possibilities of importing or exporting water from or to sites outside the study area.

Whichever you choose, ultimately the study area in WEAP will contain a distinct set of information and assumptions about a system of linked demands and supplies. Several different study areas as defined in WEAP could actually be used to represent the same geographic area or watershed, each under alternative configurations or different sets of demand data or operating assumptions. In this way, study areas can be thought of as representing separate databases where different sets of water supply and demand data are stored, managed and analyzed.

To begin your analysis, you will first create a new area. To do so, choose Area, New Area... from the Main Menu. When creating a new area, you can begin with a copy of an existing area or start fresh with a blank area. If starting from a blank area, you will be prompted to [Set Area Boundaries](#).

Another way to create an area as a copy of an existing area is from the Main Menu: Area, Save As....

**See also:** [Manage Areas](#)

### 3.1.2 Set Area Boundaries

Here you can change the geographical extent of your study area. The Set Area Boundaries dialog shows an inset schematic on the lower left, which controls what is shown on the main schematic on the right. The main schematic has a green box that indicates the current area boundaries. To change, click and drag on the main schematic to specify the new boundaries.

**Menu Option:** Schematic: Set Area Boundaries

## 3.2 Schematic

The Schematic View is the starting point for all activities in WEAP. A central feature of WEAP is its easy-to-use "drag and drop" graphical interface used to describe and visualize the physical features of the water supply and demand system. This spatial layout is called the **schematic**. You can create, edit and view it in the Schematic View. GIS layers can be added to add clarity and impact.

### 3.2.1 Screen Layout

## WEAP Legend

The **legend**, shown in the upper left corner of the Schematic View, lists the symbols used to represent each type of WEAP component. The checkbox next to each symbol can be used to hide or show all elements of that type on the schematic. To create a new element, simply click on its symbol in the legend and drag to the schematic on the right.

## Background Maps

You may display GIS layers as overlays or backgrounds on your WEAP Schematic. These **background maps** are listed on the left side of the Schematic View, below the legend. The checkbox next to each layer can be used to hide or show it on the schematic.

To add a layer, right click on the list of background layers and choose **Add Vector Layer** (e.g. ArcView Shape files: \*.shp) or **Add Raster Layer** (e.g. ArcView GRID or GeoTIFF). This menu also allows you to edit, delete, set labels or reorder the background maps. For instance, to view or edit the attribute data associated with a GIS layer, right-click on the layer name, then select Edit to go to the Map Layer window (shortcut: double click on the layer name to edit). On the **Map Layer** window that appears, click on an element in the map to see its data (displayed in the table to the left of the map). In Split or Table view, click the Edit button (below the map) to be able to edit the attribute values.

Vector layers display geographic features using discrete X-Y locations. Lines are constructed from strings of points, and polygons (regions) are built from lines which close. Vector methods are sometimes contrasted with raster techniques which record geographic features within a matrix of grid cells. A raster display builds an image from pixels, pels, or elements of coarse or fine resolution, from centimeters to kilometers. Many satellites, like Landsat, transmit raster images of the earth's surface.

## Inset Schematic

On the left side of the Schematic View, below the list of background maps, you will find the **inset schematic**. This small schematic always shows your complete area, and may be used to zoom in and out of the display on the main schematic. The area currently shown in the main schematic is indicated by a red box on the inset schematic. Click and drag on the inset schematic to change what is shown on the main schematic. You can also move the **zoom bar** (below the inset schematic) or use the mouse wheel to zoom in or out on the main schematic.

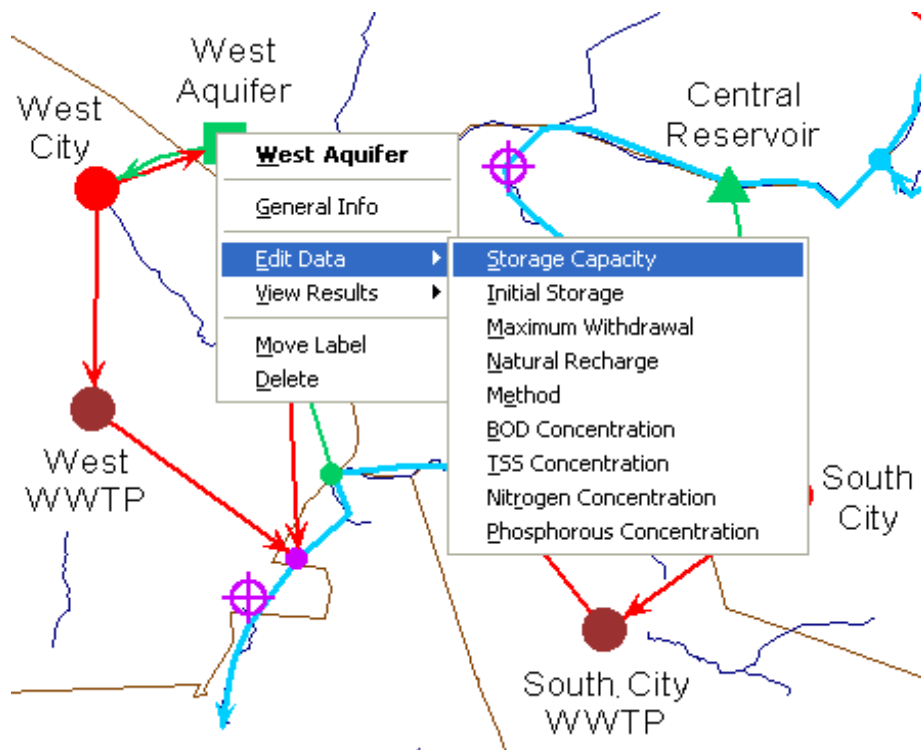


## Main Schematic

The large area on the right side of the Schematic View shows the **Main Schematic**. It is here that you will create and edit the schematic. Click and drag a symbol from the WEAP legend on the left and drop it on the main schematic on the right to create a new object. You can also click and drag an object on the main schematic to move it. Right click an object on the main schematic to edit general properties or data, view results, delete, or to move the label. These actions are described in more detail below.

The schematic has scroll bars for moving side to side. You may also hold down the **Shift** key and click and drag on the schematic to pan. To zoom in, hold down the **Ctrl** key and click and drag to define a region to zoom in to.

The schematic also provides you with one-click access to your entire analysis. Right click on any element in the Main Schematic, and choose the data variable to edit under Edit Data, or the result table to view under View Results. In the example at the right, the user is about to edit Water Use Rate data for the demand site Industry North.



### 3.2.2 Elements of a WEAP Schematic

A node represents a physical component such as a demand site, wastewater treatment plant, groundwater aquifer, reservoir or special location along a river. Nodes are linked by lines that represent the natural or man-made water conduits such as river channels, canals and pipelines. These lines include rivers, diversions, transmission links and return flow links. A river reach is defined as the section of a river or diversion between two river nodes, or following the last river node. WEAP refers to a reach by the node above it.

Each node (except demand sites and tributary nodes) may have a startup year, before which it is not active. With this feature you can include nodes in the analysis that may be built after the Current Accounts Year, or selectively exclude nodes from some scenarios. To exclude a node from a scenario

entirely, set it to be not active in the [Current Accounts](#), and then enter 0 for the startup year. WEAP will ignore any nodes (not active in the Current Accounts) with startup year equal to 0.

To capture the features of most water systems, different types of components (or nodes) are incorporated in WEAP. Below we present detailed descriptions of each type of component. In [Calculation Algorithms](#) we present the set of rules defining system water allocation and storage in successive time periods.

## Demand Sites

A demand site is best defined as a set of water users that share a physical distribution system, that are all within a defined region, or that share an important withdrawal supply point. You also must decide whether to lump demands together into aggregate demand sites (e.g., counties) or to separate key water uses into individual demand sites. The level of aggregation generally is determined by the level of detail of water use data available. Demand data may not be available for individual sites, but may only be available for a larger unit such as a city or county. In addition to data, your definition of demand sites may also depend on the level of detail desired for your analysis.

When defining demand sites, it is useful to inventory the actual physical infrastructure, such as pumping stations, withdrawal facilities, wastewater treatment plants and well fields. You should think carefully about the configuration of the entire demand and supply system, including the links between supplies and demands. You should also take into consideration the details of the water accounting picture you wish to present, any key water uses, and any key supply sources and river points that need to be tracked, described and evaluated. You might want to define demand sites according to the following groupings:

- major cities or counties
- individual user which manages a surface or groundwater withdrawal point, such as an industrial facility
- irrigation districts
- demands which return to a unique wastewater treatment plant
- water utilities

Each demand site needs a transmission link from its source, and where applicable, a return link either directly to a river, wastewater treatment plant or other location. The demand site cannot be placed directly on the river. The [user-defined priority system](#) determines the order of allocations to demand sites.

## Catchments

A catchment is a user-defined area within the schematic in which you can specify processes such as precipitation, evapotranspiration, runoff, irrigation and yields on agricultural and non-agricultural land. When you create a catchment in the schematic, a window pops up in which you can select a number of options which will apply for this catchment. In addition to requesting whether the runoff from the catchment will contribute headflow to a river, this box also asks whether irrigation will occur in the catchment (and if so, the demand priority). If irrigation is selected for a catchment, the user will be required to create transmission links from a supply to the catchment for the irrigation water and to input additional variables that parameterize the irrigation activity.

For a catchment, the user can choose one of [three different methods](#) to compute water use (both rainfed and irrigated), runoff and infiltration from agricultural and other land cover.

The **FAO Crop Requirements** (either rainfed or irrigated) method focuses on crop growth, and assumes simplified hydrological and agri-hydrological processes (non-agricultural crops can be included as well). Runoff from these processes can be diverted back to a river or to a groundwater node.

The **Soil Moisture** method includes a one dimensional, 2-compartment (or "bucket") soil moisture accounting scheme for calculating evapotranspiration, surface runoff, sub-surface runoff (i.e., interflow), and deep percolation for a watershed unit. This method allows for the characterization of land use and/or soil type impacts to these processes. The deep percolation within the watershed unit can be transmitted to a surface water body as baseflow or directly to groundwater storage if the appropriate link is made between the catchment node and a groundwater node. If the latter link is made, the method essentially becomes a 1-compartment model, where the runoff from the upper compartment is divided among runoff to the river and infiltration directly to groundwater.

## Rivers, Diversions and River Nodes

Both rivers and diversions in WEAP are made up of river nodes connected by river reaches. Other rivers may flow in (tributaries) or out (diversions) of a river. There are seven types of river nodes:

- **Reservoir** nodes, which represent reservoir sites on a river. A river reservoir node can release water directly to demand sites or for use downstream, and can be used to simulate hydropower generation.
- **Run-of-river hydropower** nodes, which define points on which run-of-river hydropower stations are located. Run-of-river stations generate hydropower based on varying streamflows but a fixed water head in the river.
- **flow requirement** nodes, which defines the minimum instream flow required at a point on a river or diversion to meet water quality, fish & wildlife, navigation, recreation, downstream or other requirements.
- **Withdrawal** nodes, which represent points where any number of demand sites receive water directly from a river.
- **Diversion** nodes, which divert water from a river or other diversion into a canal or pipeline called a diversion. This diversion is itself, like a river, composed of a series of reservoir, run-of-river hydropower, flow requirement, withdrawal, diversion, tributary and return flow nodes.
- **Tributary** nodes define points where one river joins another. The inflow from a tributary node is the outflow from the tributary river.
- **Return flow** nodes, which represent return flows from demand sites and wastewater treatment plants. (You may actually have return flows enter the river at any type of river node: reservoir, run-of-river, tributary, diversion, flow requirement, withdrawal, or return flow node.)
- **Streamflow gauges**, which are placed on river reaches and represent points where actual streamflow measurements have been acquired and can be used as points of comparison to simulated flows in the river. Streamflow data is typically added using the ReadFromFile function. In results, look at Supply and Resources, River, Streamflow Relative to Gauge to view the report comparing actual and simulated streamflow.

## Groundwater

**Groundwater** nodes can have natural inflow, infiltration from Catchments, demand site and wastewater treatment plant returns, inflows from transmission and return flow link leakage, river interactions and storage capability between months.

A groundwater supply node can be linked to any number of demand sites. The user must assign a preference to each link to order withdrawals. Demand site and wastewater treatment plant return flows can be returned to groundwater sources.

## Non-River Supplies

A **local reservoir** source can have predetermined monthly inflows, receive runoff from catchments, and demand site and wastewater treatment plant returns, can have storage capability between months and hydropower generation capability. In contrast to river reservoir nodes, they are managed *independently* of any river system.

"**Other**" sources have predetermined water quantities available on a monthly basis, but with no storage capability between months (e.g., streams or other unconnected rivers, inter-basin transfers or other imports, and desalination plants).

Local reservoirs and other sources can be linked to any number of demand sites. The user must assign a preference to each link to order withdrawals. Demand site and wastewater treatment plant return flows can be returned to local reservoir sources, but since "other" sources do not have storage capability, WEAP does not capture the water returned to them.

## Transmission Links

Transmission links deliver water from surface water (reservoir nodes, and withdrawal nodes), groundwater and other supplies to satisfy final demand at demand sites. In addition, transmission links can deliver wastewater outflows from demand sites and wastewater treatment plants to other demand sites for reuse. WEAP uses two user-defined systems to determine the water allocation along each transmission link in each month, as described in [Priorities for Water Allocation](#).

## Runoff/Infiltration Links

Runoff/infiltration links carry runoff and infiltration from catchments to rivers, reservoirs, and groundwater nodes. Catchment runoff and infiltration is water from precipitation, snow melt, irrigation and soil moisture storage that is not consumed by evapotranspiration or losses to increased soil moisture. Catchment Runoff can also be designated as runoff as the headflow to a river--this option can be selected in the window that opens when the catchment runoff link is created.

## Return Flow Links

Water that is not consumed at a demand site can be directed to one or more demand sites, wastewater treatment plants, surface or groundwater nodes. Return flows are specified as a percentage of outflow.

Wastewater treatment plant return flow can be directed to one or more demand sites, river nodes or local supply sources. Like demand site return flows, they are specified as a percentage of outflow.

### Wastewater Treatment Plants

Wastewater treatment plants receive water from demand sites, remove pollutants, and then return treated effluent to one or more demand sites, river nodes or local supply sources. A wastewater treatment plant can receive wastewater from multiple demand sites.

### Priorities for Water Allocation

Two user-defined priority systems are used to determine allocations from supplies to demand sites and catchments (for irrigation), for instream flow requirements, and for filling reservoirs and generating hydropower.

Competing demand sites and catchments, reservoir filling and hydropower generation, and flow requirements are allocated water according to their **demand priorities**. The demand priority is attached to the demand site, catchment, reservoir (priority for filling or hydropower), or flow requirement, and can be changed by right clicking on it and selecting General Info. Priorities can range from 1 to 99, with 1 being the highest priority and 99 the lowest. Reservoir filling priorities default to 99, meaning that they will fill only if water remains after satisfying all other higher priority demands. (Hydropower priorities for individual reservoirs are set in the Data View under [Reservoir, Hydropower](#). To set a system hydropower priority, go to the Supply and Resources branch in the Data View.) Many demand sites can share the same priority. These priorities are useful in representing a system of water rights, and are also important during a water shortage, in which case higher priorities are satisfied as fully as possible before lower priorities are considered. If priorities are the same, shortages will be equally shared. Typically, you would assign the highest priorities (lowest priority number) to critical demands that must be satisfied during a shortfall, such as a municipal water supply. You may change the priorities over time or from one scenario to another.

If a demand site or catchment is connected to more than one supply source, you may rank its choices for supply with **supply preferences**. The supply preferences are attached to [transmission links](#), and can be changed by right clicking on a link in the Schematic View and selecting General Info, or Edit Data, Supply Preference.

Using the demand priorities and supply preferences, WEAP determines the **allocation order** to follow when allocating the water. The allocation order represents the actual calculation order used by WEAP for allocating water. All transmission links and instream flow requirements with the same allocation order are handled at the same time. For example, flows through transmission links with allocation order 1 are computed, while temporarily holding the flows in other transmission links (with higher allocation order numbers) at zero flow. Then, after order 1 flows have been determined, compute flows in links with allocation order 2, while temporarily setting to zero flows in links ordered 3 and higher.

In general, if a source is connected to many demand sites with the same demand priority, WEAP attempts to allocate these flows simultaneously, regardless of the supply preferences on the links. For example, demand site DS1 is connected to both a river and a groundwater source, with preference for the groundwater, while demand site DS2 is only connected to the river. Both demand sites have the same demand priority. The allocation orders would be 1 for DS1's link to the groundwater, and 2 for both demand sites' links to the river. In calculations, first DS1 is allocated water from groundwater, and then both DS1 and DS2 are allocated water from the river. In this way, both demand sites have an equal chance to receive water from the river in the case of a water shortage. Note: in some unusual configurations, the supply preferences may be inconsistent with this rule. In those cases, a supply preference of 1 is used for all demand sites.

You may switch among viewing demand priorities, supply preferences or allocation orders on the schematic: from the Main Menu, select Schematic, Change Priority View.

**Tip:** If WEAP is not allocating water as you would expect, change the priority view on the Schematic to "Allocation Order" to make sure that it is allocating in the order you intend.

### 3.2.3 Creating and Editing WEAP Elements

## Creating

To create a **new node** (demand site, groundwater node, river node, wastewater treatment plant or flow requirement), merely click on the node's symbol in the [WEAP legend](#) and drag it anywhere inside the main schematic. To create a **new river** or diversion, click on the symbol (a line segment) in the legend and drag onto the main schematic, then release the mouse button to specify the headflow. Next, single click once for each intermediate point on the river, then double click to specify the endpoint of the river, as modeled in this particular system.

When you create a node or river, you will be prompted to enter the object's Name, a Schematic Label (used only for display on the schematic), and whether or not it is Active in the [Current Accounts](#). The label can be displayed as multi-line text--use semicolons to indicate line breaks. The label will be displayed below the object. However, you can move the label anywhere you want to enhance the legibility of the Schematic. Right click on the object and choose the Move Label option. When you create a demand site or flow requirement, you will be prompted to enter its [Demand Priority](#).

A river consists of a headflow point, an endpoint, and zero or more points in between. You may add as many bends in the river as you wish, to more closely approximate the actual shape of the river. To add a new bend in the river, just click on any straight section of the river and drag to create a bend.

To add a **new transmission (i.e., withdrawal) or return link**, click on the symbol (a line segment) in the legend for the desired type of link and drag onto the main schematic, releasing the mouse button on the node or river where the link originates. Next, single click once for each intermediate point on the link, then double click on the destination node. You will be prompted to enter the demand site's [supply preference](#) for the supply connected to this transmission link.

For instance, to create a transmission link from a local reservoir to a demand site, click on the transmission link symbol in the legend, drag it to the local reservoir and release, then double click on the demand site. To later add new bends in the link, just click on any straight section of the link and drag to create a bend.

River **withdrawal nodes** will automatically appear if you start a transmission link from a previously unused place along the river. Similarly, a **return flow node** will automatically appear if you end a return flow link on a previously unused place along the river, and a **catchment inflow node** will automatically appear if you end a runoff/infiltration link on a previously unused place along the river.

Catchment Runoff Links are created in a similar way; drag the symbol from the legend first to the particular Catchment, single click, then double click on the river or groundwater node where the Catchment Runoff is to be directed. If you position the Catchment Runoff anywhere above the first node of a river, the dialog box that appears will ask if you wish this runoff to represent headflow to the river. If you do select the Catchment Runoff as headflow to the river, the Headflow variable for that river will be set/locked to "Inflow from Catchment" in the Data view. No other sources of headflow can be input for that river using the direct input methods (for example, the Read from File method). This is in contrast to groundwater nodes, where sources of inflow in addition to Catchment Runoff can be input from Read from File or Expressions.

### Moving

To move an existing node in the schematic, merely click and drag the object to its new location. When you move a river node, the river underneath the node will not move with the node. For instructions on moving a river node along with the river underneath, see [Moving Multiple Elements at Once](#) below.

You may move a node from one river to another. Because reservoirs can exist both on (river reservoir) or off (local reservoir) a river, you may move a river reservoir off of a river, or a local reservoir onto a river.

### Moving Multiple Elements at Once

For convenience, there is a way to move more than one object at a time. To select multiple objects, hold down the Alt key as you click and drag on the main schematic to draw a grouping box around the intended objects. After a moment, a red box will appear. Click inside this red box and drag to move all objects, including river points.

### Deleting

To delete any object (node, link, river point), simply right click on it and select Delete. You will be prompted for confirmation before the object is deleted (except for river points). Transmission and return flow links to the deleted object will also be deleted. If you delete a river, all its river nodes will also be deleted.

### Edit General Info

To edit information associated with a node, link or river (name, schematic label, active in Current Accounts, demand priority, supply preference), right click on the object and choose the General Info option. A dialog will pop up with the relevant information.

### Connecting and Disconnecting Rivers and Diversions

To have one river flow into another (a tributary), move the endpoint from the first river onto a previously unused place along the second river. A tributary node will appear, connecting the two rivers. To disconnect a tributary, right click on it and choose Disconnect Endpoint.

To have one river flow out of another (a diversion), move the headflow point from the first river onto a previously unused place along the second river. A diversion node will appear, connecting the two rivers. To disconnect a diversion, right click on it and choose Disconnect Headflow.

To have a river flow into a groundwater node, move the endpoint from river onto the groundwater node. This will cause all water flowing out of the last reach on the river to flow into the groundwater node.

### Catchment Setup

When a catchment node is created in a schematic, a window appears in which the user is required to select a number of options appropriate for the catchment. In addition to the name and label for the catchment, the user must select a river to which runoff from the catchment will be directed. One and only one river can be selected to direct runoff to for each catchment.

Once a river is selected, the text "Represents Headflow?" and associated toggle box will appear out of shadow, and the user can click this box if the runoff is to represent headflow to this river. The user can also choose a groundwater node to direct infiltration from the catchment to--selecting a groundwater node for infiltration, unlike runoff, is not required, though. Selecting a groundwater node to which to direct infiltration will modify the Soil Moisture model from that of a two soil layer formulation to one layer (see [Overview of Catchment Calculation Methods](#)).

Finally, if the catchment is to include irrigated areas, click on the box associated with "Includes Irrigated Areas?". If this box is clicked, a box requesting input of the Demand Priority will appear. Only if this box is selected will the window associated with inputting irrigation variables (such as irrigated fraction) appear for that catchment in the Data view.

The catchment node will then appear in the schematic view, along with an associated Runoff/Infiltration Link that connects the node to the indicated river and, if appropriate, to a groundwater node. If the catchment runoff was selected to represent headflow to the river, the link will terminate at the first node of the river.

Automatically created Runoff/Infiltration Links that do not represent headflow to the river can be moved to another location along the river if desired. If you try to move a Runoff/Infiltration Link that does represent headflow to a river, a dialog box will appear asking if you no longer want this catchment inflow to represent headflow to that river.

Runoff/Infiltration Links can also be created manually by using the drag-and-drop feature. The appropriate details for link will be set accordingly (in General Info).

When you go to the Data view and select, for the first time, from the data tree the created catchment, a dialog box will automatically appear requesting that you select the desired catchment simulation method (such as Rainfall Runoff, Irrigation Demand Only, or Soil Moisture Methods--see [Overview of Catchment Calculation Methods](#)).

## Viewing Changes History

A record of every change made to a WEAP area is logged in the text file "Changes.txt," which is stored in the subdirectory for a WEAP area. Each change is tagged with the date and time of the change, as well as who made it.

### 3.2.4 Schematic Options

## Set Area Boundaries

Here you can change the geographical extent of your study area. The Set Area Boundaries dialog shows an inset schematic on the lower left, which controls what is shown on the main schematic on the right. The main schematic has a green box that indicates the current area boundaries. To change, click and drag on the main schematic to specify the new boundaries.

**Menu Option:** Schematic: Set Area Boundaries

## Set WEAP Node and Label Size

You may change the size of the WEAP symbols and labels. These options are available either from the **General** menu or by right clicking on the WEAP Legend. The dialog has a slider bar to make the nodes or labels either larger or smaller.



**Menu Option:** Schematic: Set WEAP Node Size or Set WEAP Node Label Size

### Priority Views

You may view demand priorities (for demand sites, flow requirements and reservoirs), supply preferences (for transmission links) or allocation orders (for transmission links and flow requirements) on the schematic. See [Priorities for Water Allocation](#) for more information.

**Menu Option:** Schematic: Change Priority View

### Show or Hide by Element Type

In some cases, you may wish to temporarily hide certain types of objects from display, such as all demand sites or wastewater treatment plants. Uncheck the box on the WEAP legend next to the type you want to hide. You may hide all objects at once: choose the **Hide All WEAP Objects** option from the General menu or from the right-click menu on the WEAP legend. Once some or all WEAP objects are hidden, an option to **Show All WEAP Objects** will be available.

### Printing a Schematic

A schematic can be saved or printed as a graphic. You can copy the schematic to the Windows clipboard for pasting into Word or other applications. In the Schematic View, go to the main menu and select: Schematic, Copy Schematic to Clipboard. You will be asked to choose the level of detail to include--as you move the slider bar, WEAP will tell you how large the graphic will be, both in pixels (width and height) and megabytes. More detail will yield a sharper image, but files will be much larger.

## 3.3 General Area Parameters

### 3.3.1 Years and Time Steps

#### Time Horizon

Enter the **Current Accounts Year** and **Last Year of Scenarios**. WEAP performs a monthly analysis from the first month of the Current Accounts Year through the last month of the Last Year. The Current Accounts Year is usually the most recent year for which reasonably reliable and complete data are available and from which future demand projections can be made. The Current Accounts year data comprise the **Current Accounts**, which all scenarios use as the basis for their projections.

#### Time Steps per Year

The time step can be set anywhere from one day to 365 days. Each year and scenario in an area must have the same time step.

Checking **Add Leap Days?** will add an extra day in leap years (e.g., 2000, 2004, 2008) to the timestep that includes February 28 (e.g., the February timestep in a monthly analysis). For daily models there will be 366 time steps in leap years, 365 time steps in all other years. This would be useful if you have datasets, such as river streamflow gauges, that include data for leap days.

## Time Step Boundary

The user has the option to have time steps be based on (a) the calendar year, (b) all time steps are equal, or (c) the time step lengths are entered manually.

## Water Year Start

Any particular time step (for example, a particular month) can be designated as the starting point for the "Water Year."

## Time Step Names

In the grid on the right, the user can change the title and abbreviation of the time steps. If the Time Step Boundary is set to "Set time step length manually," the length can be set in the grid.

**Menu Option:** General: Years and Time Steps

### 3.3.2 Units

Here you choose the units for data entry. The units can be set for the following components: Rivers, Reservoirs, Groundwater, Other Supplies, Land Use, Wastewater Treatment, and Monetary. The exception is the **Default Water Use Rate** set on the **Demand** tab. The Default Water Use Rate you set will be the default data entry unit, but you will be able to change the units individually for each branch. Also, the system **Discount Rate** is entered on the Monetary tab.

## Units Definition

Regardless of the unit used for data entry, you can view results in any units. User-defined units can be added by clicking on the **Units Definition** button.

**Menu Option:** General: Units

### 3.3.3 Water Quality Constituents

## Water Quality Constituents

WEAP tracks water quality, including pollution generation at demand sites, waste removal at wastewater treatment plants, effluent flows to surface and groundwater sources, and water quality modeling in rivers. On the water quality constituents setup screen, turn on water quality modeling by checking the **Enable water quality modeling** checkbox. You may then define up to 20 constituents to track in your application. Set the **scale** and **load unit** as appropriate for entering the annual production of the pollutant by the demand site, per unit of activity. Set the **concentration** unit appropriate for entering data on concentrations of constituents in demand site outflows, and in headflows, reservoir outflows and groundwater outflows.

For each constituent, specify which method WEAP should use to calculate surface water quality concentrations, in the **Calculate By** column:

### 3.3 General Area Parameters

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**Conservative:** There is no decay of this constituent--the instream concentration will be computed using simple mixing and weighted average of the concentration from all inflows.

**First-Order Decay:** This constituent decays following an exponential decay function. Enter the daily decay rate here.

**BOD:** WEAP will use its built-in BOD model to simulate the changes in the biochemical oxygen demand (BOD) in the river. In order to model BOD, you will need to include temperature as one of your water quality constituents (with unit = Celsius), and either enter as data the temperature of water in the river for each reach, or model it in WEAP.

**DO:** WEAP will use its built-in DO model to simulate the changes in dissolved oxygen (DO) in the river. Because the DO model uses BOD as an input, you will also need to simulate BOD.

For temperature values (required by WEAP to implement the BOD and DO modeling), one can choose from either of two methods:

**Temperature (Modeled in WEAP):** WEAP will calculate water temperature for each river reach based on climate data (air temperature, humidity, wind, and latitude) input in the Data view (under the Climate tab for the reach).

**Temperature (Data):** the user specifies the water temperature for each reach. If this option is selected and temperature for a particular reach is left blank, WEAP will assign to that reach the temperature of the immediate upstream reach. Water temperature is needed by the BOD model.

**Modeled in QUAL2K:** Link to the US EPA water quality model QUAL2K and let it model water quality for some or all water quality constituents. See [below](#) for details.

**Menu Option:** General: Water Quality Constituents

## Linking to QUAL2K

[QUAL2K](#) is a 1-dimensional, steady state, instream water quality model for well mixed channels (laterally and vertically). Constituents modeled include: ammonia, nitrate, organic and inorganic phosphorous, algae, sediment, pH and pathogens. QUAL2K was developed by Dr. Steve Chapra and his grad students at Tufts University.

To model a WEAP constituent using QUAL2K, choose "Modeled in QUAL2K" in the **Calculate By** column. If you want to model any constituents in QUAL2K, you must also model water temperature in QUAL2K. QUAL2K will calculate water temperature for each river reach based on WEAP climate data (air temperature, dew point, wind speed, and cloud cover and shade fractions) input in the Data view (under the Climate tab for the reach). For each constituent that will be modeled in QUAL2K, choose the corresponding QUAL2K constituent in the **Link to QUAL2K Constituent** column. Note: you can choose to model just a subset of your constituents in QUAL2K, with the others modeled in WEAP.

QUAL2K has many parameters and options, too many to include in WEAP. Therefore, you will need to first create a QUAL2K data file (.q2k) with the appropriate parameters. Use the Excel file QUAL2K.xls in the WEAP directory to create and edit QUAL2K data files. Put that .q2k input file into the WEAP area's subdirectory and select it using the .q2k data file drop down in the lower left of the Water Quality Constituents window. Alternatively, choose < Copy file from another directory > from the drop down to copy the .q2k file from another directory.

If the QUAL2K data file (.q2k) includes more than one river, you will need to match the rivers in the QUAL2K data file with those in WEAP. Click the "Link WEAP Rivers to QUAL2K Rivers" button below the .q2k data file drop down (the button will only appear if the .q2k file has multiple rivers). Note: you do not need to model all WEAP rivers in QUAL2K--you may choose to model some and not others.

When WEAP calculates, it will read in the specified .q2k data file, add to it the data specified in WEAP (headflows, point and diffuse sources of water and pollution, climate data), write the new .q2k file and run QUAL2K. Because QUAL2K provides for more detailed water quality modeling than is available in WEAP, you may want to take the .q2k file created by WEAP and examine, modify and run it yourself in the QUAL2K Excel interface. To do so, check the **Save every .q2k file created (for each time step)** checkbox, and specify **Where to save** each .q2k file. After WEAP calculates, you will find a new .q2k file in this directory for every scenario and time step (e.g., for a monthly time step over 20 years for 4 scenarios, there will be 960 .q2k files created). Each .q2k file occupies about 20K of disk space. You may then load any of these files yourself in QUAL2K and change data (e.g., add diurnal variation to climate data) and view results in the many graphs available in the QUAL2K Excel interface.

See [QUAL2K Overview](#) for more information about QUAL2K, and [Running QUAL2K](#) in the Calculation Algorithms section for more information about the linkage from WEAP.

### 3.3.4 Basic Parameters

The user can choose whether all the branches within a demand site will have the same [monthly variation](#) in demand, or whether each branch can have a different monthly variation.

Separately, the user can choose whether all land use branches within a catchment will have the same **climate** data ([Soil Moisture Method Climate](#), [FAO Climate](#) or [MABIA Climate](#)), or whether each branch can have different climate data. This second option might be necessary if there is a large variation in the elevation among different land uses within a catchment. Alternatively, the catchment could be divided into several different catchment nodes according to elevation, so that the climate within each catchment did not vary by land use.

Before December 2010, WEAP incorrectly used the **Latent Heat of Vaporization** (2260 kJ/kg, at 100 C) instead of the **Latent Heat of Fusion** (334 kJ/kg) for calculating **snow melt** in the [soil moisture method](#). Although we recommend that you use Latent Heat of Fusion, if you have a previously calibrated model that used Latent Heat of Vaporization, you might want to use that setting instead.

If you have [linked your WEAP model to a MODFLOW model](#), you can choose whether all land use branches within a catchment will pump from the same MODFLOW layer or set of layers (see the Pump Layer variable under [Soil Moisture Method Irrigation](#) or [FAO Irrigation](#)), or whether each land use branch can pump from a different layer or set of layers.

**Menu Option:** General: Basic Parameters

## 3.4 Advanced

### 3.4.1 MODFLOW Link

*Note: linking WEAP to MODFLOW is an advanced feature.*

For situations where the built-in WEAP groundwater model is not sufficiently complex, there is the option to link a WEAP model to a MODFLOW model. MODFLOW is a three-dimensional finite-difference groundwater model created by the U.S. Geological Survey (USGS). When properly linked, data and results flow back and forth between WEAP and MODFLOW for each calculation timestep. With this tight coupling between the models, it is possible to study how changes in local groundwater levels affect the overall system (e.g., groundwater-stream interactions, pumping problems due to drawdown, lateral groundwater recharge) and vice versa (e.g., infiltration and abstraction). However, be advised that building and calibrating a MODFLOW model is not a trivial task, and the linkage to WEAP requires

### 3.4 Advanced

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creating a GIS shape file to connect the WEAP elements to the MODFLOW cells. The version of MODFLOW that WEAP is designed to link to is MODFLOW 2000.

For more information, please see the Appendix on [linking WEAP to MODFLOW](#).

#### 3.4.2 MODPATH Link

*Note: linking WEAP to MODPATH is an advanced feature.*

MODPATH is a groundwater particle tracking post-processing package that was developed to compute three-dimensional flow paths using output from steady-state or transient groundwater flow simulations by [MODFLOW](#), the U. S. Geological Survey (USGS) finite-difference groundwater flow model. Its purpose is to evaluate advective transport through a model. MODPATH uses a semi-analytical particle tracking scheme that allows an analytical expression of the particle's flow path to be obtained within each finite-difference grid cell. Particle paths are computed by tracking particles from one cell to the next until the particle reaches a boundary, an internal sink/source, or satisfies some other termination criterion. The version of MODPATH that WEAP is designed to link to is MODPATH 5.0.

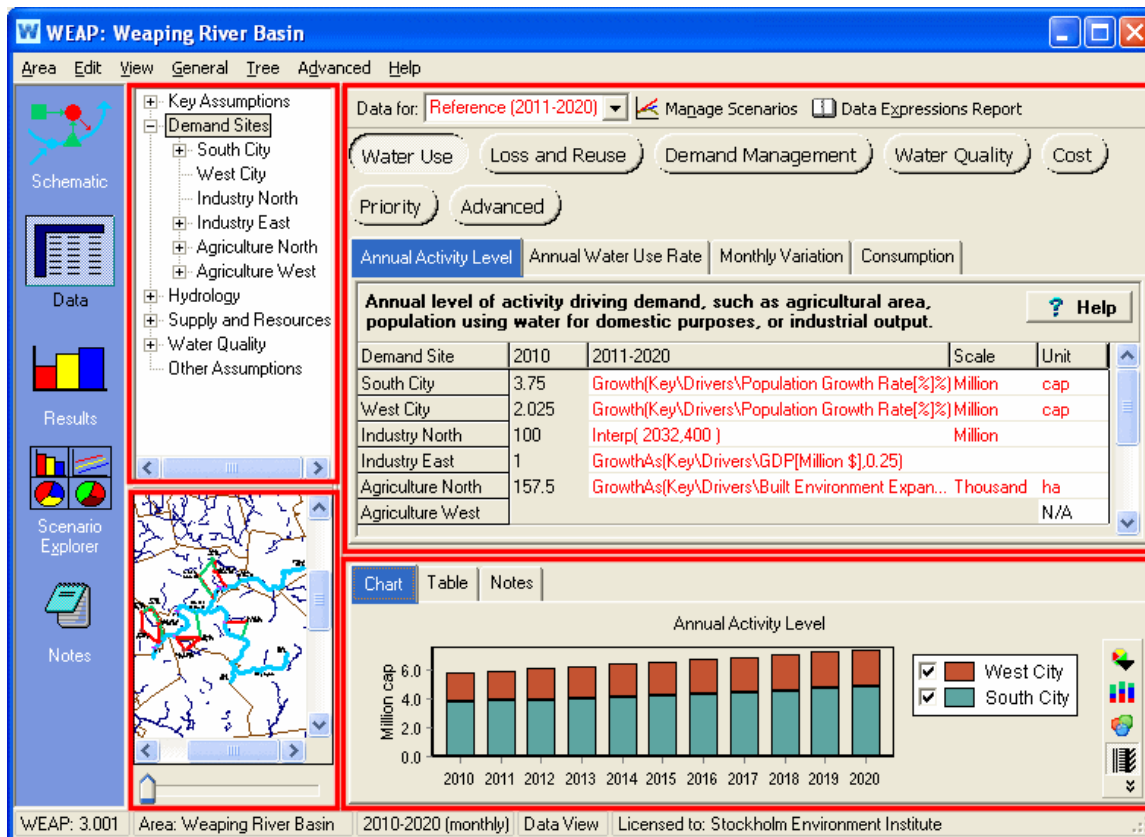
For more information, please see the Appendix on [linking WEAP to MODPATH](#).



# 4 Data

## 4.1 Data View

In the **Data View** you build the model of your system, entering the data structures, data, assumptions, modeling relationships and documentation for the [Current Accounts](#) and for each scenario. The screen is divided into four panes (marked by red boxes in figure below):



### 4.1.1 Tree

On the top left, a hierarchical tree is used to create and organize data structures under six major categories: Key Assumptions, Demand Sites, Hydrology, Supply and Resources, Environment, and Other Assumptions. The tree is also used to select the data to be edited, which is shown on the right of the screen. For example, clicking on the "Demand Sites" tree branch on the left of the screen will display the data for all demand sites on the right of the screen. Note that when you click on a tree branch, the associated object in the schematic will flash on the map. See [Tree Overview](#) for more information.

### 4.1.2 Inset Schematic

A small schematic of your area is located on the bottom left. When you click on an element, it will be highlighted in the tree (above) and its data will be displayed in the data entry tables to the right.

Conversely, when you click on a branch in the tree, the associated element on the Schematic will flash briefly. Move the **zoom bar** (below the schematic) to zoom in or out. Alternatively, hold down the **Ctrl** key and click and drag to define a region to zoom in to. Hold down the **Shift** key and click and drag on the schematic to pan. When the mouse cursor is positioned over the inset schematic, rotating the mouse wheel will zoom in or out.

### 4.1.3 Data Entry Tables

The data entry tables on the top right are used to enter expressions that define Current Accounts and Scenario values of variables. Each data variable appears on its own tab; related variables are grouped into categories (selected via buttons). Above the data entry tables is a set of buttons giving access to the different variable categories associated with each branch. The buttons and tabs you see will vary depending on what part of the data set you are working on. For example, when editing demand sites you will see buttons giving access to "Water Use," "Loss and Reuse," "Demand Management," "Cost," "Priority," and "Advanced," while for reservoirs you will see buttons for "Physical," "Operation," "Hydropower," "Water Quality," "Cost," and "Priority." Click on one of these buttons to see the variables in that category. For example, "Water Use" has three variables: "Annual Activity Level," "Annual Water Use Rate," and "Monthly Variation." There are wizards to help you construct the expressions--see [Expression Builder](#), [Yearly Time-Series Wizard](#) and [Monthly Time-Series Wizard](#). There is a "Help" button next to the description of each variable that can be clicked on to retrieve more information about that variable.

Immediately above the data entry tables is a toolbar containing a selection box and the Manage Scenarios button. Use the selection box to choose which data to edit--Current Accounts or one of the Scenarios. Click on [Manage Scenarios](#) to create, rename or delete scenarios, or to change their inheritance relationships.

### 4.1.4 Data Entry Results and Notes

The bottom right pane displays the data you entered in the top pane as either a chart or a table. These let you quickly examine the values generated by the expressions you have entered above. A toolbar on the right of the pane gives access to a range of options for formatting charts and tables (e.g. picking chart type and stacking options, colors, 3D effects, grids, number of decimal places, etc.) and for printing and copying charts and tables and exporting tables to Microsoft Excel.

The bottom pane also gives access to a notes screen: a word processing tool in which you can enter documentation and references for each branch of the tree. To edit the notes, right-click and select **Edit** to display the notes in a larger window, which includes a basic set of word processing controls. Notes can include formatting (bold, underline, fonts, etc.) and can also include standard Windows "objects" such as spreadsheets.

You may resize each of these four panels by dragging the dividing bars between them.

A record of all changes made to data in the order the changes were made are recorded in the text file Changes.txt (stored in the subdirectory for a WEAP area). Users enter their initials upon logging in when WEAP starts so that any changes can be catalogued in this file and attributed to a specific user.

See also: [View Bar](#)



### 4.2 Current Accounts

The Current Accounts represent the basic definition of the water system as it currently exists. Establishing Current Accounts requires the user to "calibrate" the system data and assumptions to a point that accurately reflects the observed operation of the system. The Current Accounts are also assumed to be the starting year for all scenarios. Note that the Current Accounts Year is not meant to be an "average" year, but the best available estimate of the current system in the present. The Current Accounts include the specification of supply and demand data (including definitions of reservoirs, pipelines, treatment plants, pollution generation, etc.) for the first year of the study on a monthly basis.

### 4.3 Scenarios

At the heart of WEAP is the concept of scenario analysis. Scenarios are self-consistent story-lines of how a future system might evolve over time in a particular socio-economic setting and under a particular set of policy and technology conditions. Using WEAP, scenarios can be built and then compared to assess their water requirements, costs and environmental impacts. All scenarios start from a common year, for which you establish your [Current Accounts](#) data.

The scenarios can address a broad range of "what if" questions, such as: What if population growth and economic development patterns change? What if reservoir operating rules are altered? What if groundwater is more fully exploited? What if water conservation is introduced? What if ecosystem requirements are tightened? What if new sources of water pollution are added? What if a water recycling program is implemented? What if a more efficient irrigation technique is implemented? What if the mix of agricultural crops changes? What if climate change alters the hydrology?

Scenarios in WEAP encompass any factor that can change over time, including those factors that may change because of particular policy interventions, and those that reflect different socio-economic assumptions. Sensitivity analyses may also be done by varying uncertain factors through their range of plausible values and comparing the results.

#### 4.3.1 Manage Scenarios

Use the Manage Scenarios screen, to create, delete, organize and set the properties of the scenarios in an Area.

The tool bar at the top of the Scenario Manager lets you add, copy, delete and rename scenarios. Click on **Add** (+) to add a new scenario, immediately under the current scenario. Click on **Delete** (■) to delete a scenario. Bear in mind that deleting a scenario will also delete all data associated with that scenario. Click on **Copy** (■) to make a copy of a scenario with a different name, and click on **Rename** to rename the scenario.

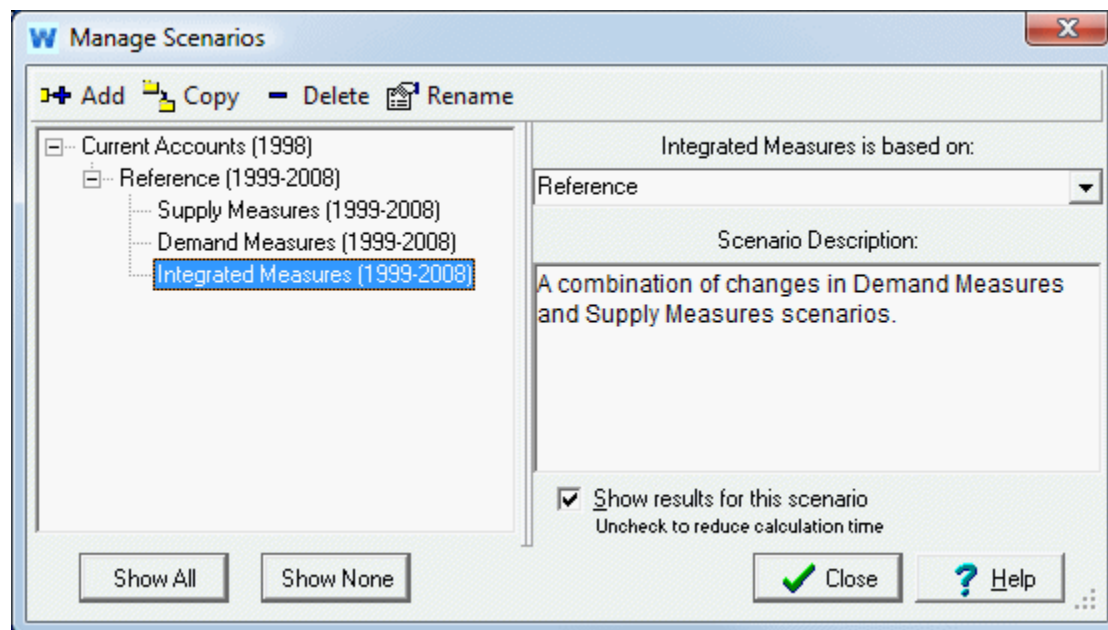
On the left side of the screen, the Area's scenarios are listed in a hierarchical tree showing the main scenario inheritance structure. Scenario inheritance describes how each scenario inherits the expressions from the scenarios above it in the hierarchy. For more information, refer to [Scenario Inheritance](#). Click on a scenario in the tree to edit it or to add a new scenario beneath it.

On the right of the screen, you can edit a scenario's inheritance and description. Use the **is based on** selection box to change the scenario's "parent." For those branch/variable combinations in the scenario for which no expression has been explicitly defined, a default expression is inherited from one of its ancestor scenarios. First the parent is checked for an expression. If none is found, then the parent's parent is

searched. This continues until an expression is found, either in an ancestor scenario or in the [Current Accounts](#).

To show or hide results for individual scenarios, check or uncheck "Show Results for Scenario" for each scenario. If this box is unchecked, then WEAP will not calculate results for that scenario. Click "Show All" to check all scenarios; "Show None" to uncheck all.

In the example shown below, there are four scenarios defined--a Reference scenario, and three variants of the Reference scenario.



**Menu Option:** Area: Manage Scenarios (also on Data View toolbar)

**See also:** [Scenarios](#), [Data View](#)

### 4.3.2 Scenario Inheritance

An important concept in using scenarios is the idea of scenario inheritance. In WEAP's [Data View](#), you create mathematical expressions that define the data values of each branch/variable combination in your analysis. Scenario inheritance allows you to create hierarchies of scenarios that inherit default expressions from their parent scenario. Initially, you create expressions for the [Current Accounts](#). These can either be constant expressions, or expressions that generate a time-series of values. Then, you can create additional scenarios, with expressions that either simply inherit the Current Accounts expressions, or override these for particular branches and variables. So, for example, you might create a scenario that examines an irrigation efficiency program, that inherits most of its expression from a baseline "business as usual" scenario. Because the efficiency scenario inherits from the baseline scenario, when initially created it will contain exactly the same expressions as the baseline scenario, and hence will yield exactly the same results. To fully define the scenario you only need to type in expressions to reflect the branches and variables affected by the irrigation efficiency program. The inherited expressions for all other branches stay the same. You can define any number of levels of inheritance. So for example you could make an irrigation efficiency scenario that inherits from the first, with slightly revised assumptions. This approach makes it very easy to edit and organize scenarios, since a) they can be created with a minimum of data entry and b) common assumptions in families of scenarios can be edited by just editing the parent scenario. The ability to establish scenario inheritance is demonstrated in [Manage Scenarios](#).

## 4.4 Tree

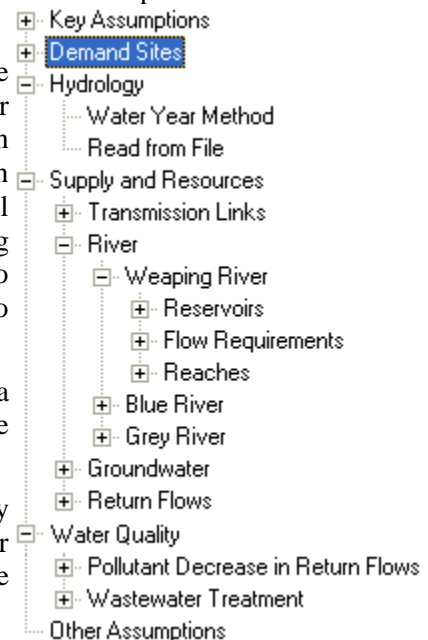
When editing scenario data in WEAP's [Data View](#), the expression fields in data entry tables are **color coded** to show which expressions have been entered explicitly in the current scenario, and which are inherited either from a parent scenario or from the data specified for Current Accounts. **Red text** indicates a value entered explicitly in the current scenario, while black text indicates an inherited value (or data entered in Current Accounts).

## 4.4 Tree

The tree is a hierarchical outline used to organize and edit the main data structures in a WEAP analysis. You can edit the tree structure underneath the branches for Demand Sites, Key Assumptions, and Other Assumptions (by right-clicking with the mouse on a tree branch, or by using the Tree menu options), and you also click on the tree to select the data you want to view and edit. (See [Editing the Tree](#) for details.) You cannot add or remove schematic nodes (e.g., reservoirs, wastewater treatment plants) by editing the tree; all schematic changes must be done through the Schematic View

Data in the tree are organized under six major categories, which appear as the top level of branches in the tree:


- **Key Assumptions:** under which you create and organize independent variables used to "drive" the calculations in your analyses. Driver variables are not directly calculated in WEAP, but they are useful as intermediate variables that can be referenced in your modeling calculations. It is very useful to create variables here for all your major modeling assumptions, especially those that will vary from scenario to scenario. Less important intermediate variables should go under **Other Assumptions** (see below).
- **Demand Sites:** Demand analysis in WEAP is a disaggregated, end-use based approach for modeling the requirements for water consumption in an area.
- **Hydrology:** under which future inflows for each supply source are projected using either the Water Year Method or the Read From File Method. You specify the details of these two methods under the Hydrology section.
- **Supply and Resources:** given the monthly supply requirement from Demand and definitions of Hydrology, the Supply and resources section determines the amounts, availability and allocation of supplies, simulates monthly river flows, including surface/groundwater interactions and instream flow requirements, and tracks reservoir and groundwater storage.
- **Environment:** the Environment section tracks pollution from generation to treatment to its outflow and accumulation in surface and underground bodies of water.
- **Other Assumptions:** user-defined intermediate variables are created, similar to Key Assumptions (see above).




### 4.4.1 Editing the Tree

The branch structure underneath the top-level branches **Key Assumptions** and **Other Assumptions**, and under each demand site under the top-level branch **Demand Sites**, is edited directly from the tree, much

like the tree in Windows Explorer. You can rename branches by clicking once on them and typing, and you can expand and collapse the outline by clicking on the +/- symbols to the left of each branch icon. Additional options to edit the tree are accessed by right-clicking on the tree and selecting an option from the pop-up menu that appears, or by using Tree menu.



 **Add** is used to add a new branch as a "child" of the highlighted branch.


**Rename** allows you to rename a branch. Alternatively, you may click on the branch, wait a second, then click again to be put into edit mode.

 **Delete** is used to delete the current highlighted branch and all branches underneath it. You will be asked to confirm the operation before the branch is deleted, but bear in mind that a delete cannot be undone. Note, however, that you can exit WEAP without saving your data set to restore it to its status prior to the previous Save operation.

**Sort by Name (all levels below):** orders all branches alphabetically at all levels below the selected branch.

**Sort by Name (just one level below):** orders only the one level of branch that is below the selected branch. For example, to order the list of demand sites alphabetically but leave each demand site's sector branches unsorted, this option would be selected when right-clicking on the "Demand Sites" branch.

 **Cut Branches** is used to mark a branch and all branches below it to be cut. Later when you select **Paste Branches** () , the marked branches will be moved to the new position selected in the tree. Notice that, unlike a conventional cut operation in a standard Windows program, the cut operation does not actually delete the branches, nor does it copy the branches to the Windows clipboard.

 **Copy Branches** is similar to the Cut operation except that on the Paste operation, branches are subsequently copied not moved.

**Auto-Expand** specifies whether the branches in the tree automatically expand and collapse as you click on them.

**Expand All** fully expands the tree.

**Collapse All** fully collapses the tree.

**Outline Level** expands or collapses the tree to show all branches up to the selected level of depth.

 **Font** is used to change the typeface and size of displayed tree.

## Drag and Drop Editing of Branches

You can also move branch (and all branches below it) by dragging and dropping it onto another branch. To copy rather than move a branch, hold down the **Ctrl** key and then click and drag the branches. This approach allows you to rapidly create data sets, especially those containing many similar groups of branches (for example a household subsector with many similar disaggregated end-uses).

See also: [Tree Overview](#)

### 4.5 Key Assumptions and Other Assumptions


You can create **Key Assumptions** and **Other Assumptions**, which you can reference in expressions elsewhere in WEAP. It is very useful to create variables here for all your major modeling assumptions, especially those that will vary from scenario to scenario, as it will organize and highlight the most important parts of your model, help ensure that consistent assumptions are used throughout your model, and make it convenient to view and edit them. (Less important intermediate variables should go in the Other Assumptions section.) You may create a multilevel, hierarchical structure for your Key Assumption and Other Assumption branches, grouping together related concepts. For example, the categories of Key Assumptions in the Weaping River Basin dataset are Drivers, Monthly Variation, and Elasticity. You can create any number of levels of grouping.

Although Key Assumptions can be thought of as *variables*, they are actually added as new *branches* to the Data View Tree under the Key Assumptions and Other Assumptions sections. Alternatively, you can also add your own [User-Defined Variables](#) under the sections for Demand Sites, Supply and Resources, and Water Quality. As opposed to Key Assumptions, which are added as new branches to the tree, User-Defined Variables are added as new variable tabs to existing branches. Key Assumptions are best if you are using the same expression in multiple places in your model, or to highlight a major modeling assumption. User-defined variables are better if you want to create a variable whose values will vary by demand site (or groundwater node, or reservoir, etc.). See the [Customizing Data Variables](#) section for more information about them.

To **create** a Key Assumption branch, right click on the branch under which you want to add the new branch (on or under the Key Assumptions and Other Assumptions top level branches), and choose **Add** from the context menu. A new branch will appear, with the name "New Branch" highlighted for you to type a new name. To create a multilevel structure, first create the branch that will hold the other branches (e.g., "Drivers"), then create the other branches underneath it (e.g., "GDP," "Price of Water," and "Technical Innovation").

For example, suppose you wanted to model the population of your demand sites by using a simple growth rate. If the growth rate was the same for all municipal demand sites, it would be best to create a single Key Assumption branch called Population Growth Rate, and then reference this in the [Annual Activity Level](#) expression for the municipal demand sites (e.g., `Growth(\Key\Population Growth Rate)`). However, if you wanted to use a different growth rate for each demand site, to do this with Key Assumptions would require adding a different Key Assumption branch for each demand site. It would be better to create a single [user-defined variable](#) called Population Growth Rate in the Demand Sites section of the tree. After entering the growth rate value for each demand site, the expression for Annual Activity Level would be `Growth(Population Growth Rate)`.

Because the values of [Key Assumption variables can be displayed in the Results View](#), these variables can also be used to create new result variables or alternative indicators. For example, you could perform a social cost-benefit analysis by creating indicators such as the social cost of unmet demand (shortages), or the environmental cost of low river flows. The shortage cost key assumption could refer to the unmet demand at one or more demand sites (using the [PrevTSValue](#) function), with an increasing cost associated with increasing unmet demands. A complete "triple bottom line" analysis could be done, involving financial, social and environmental costs. You could create a key assumption group for each of these types of costs, with individual cost items under each. (The financial costs Key Assumption Variables would reference the [Financial Results](#) variables using `PrevTSValue`.)

**Entered on:**  Data View, Branches: Key Assumptions, Other Assumptions

## 4.6 Customizing Data Variables

### 4.6.1 User-Defined Variables

You can create user-defined variables under the sections for Demand Sites, Supply and Resources, and Water Quality, which you can reference in expressions elsewhere in WEAP. This is a very powerful feature, as it allows you to easily create your own models within WEAP. For example, SEI researchers created an experimental glacier module in WEAP, tracking accretion, depletions and runoff from glaciers, using user-defined variables for WEAP's catchment objects.

As opposed to [Key Assumptions](#), which are added as new *branches* to the tree, User-Defined Variables are added as new *variable* tabs to existing branches. Key Assumptions are best if you are using the same expression in multiple places in your model, or to highlight a major modeling assumption. User-defined variables are better if you want to create a variable whose values will vary by demand site (or groundwater node, or reservoir, etc.). See the [Key Assumptions](#) section for more information about them.

To create a user-defined variable, go to the Data View, right click on any of the existing variable tabs, and choose **Create**. (Alternatively, for Create and all other user-defined variable actions, you can use the main menu: Edit, Data Variable.) To edit an existing variable, make sure it is the active variable, then right click on the variable tab and choose **Edit**. When you create a variable, it will initially take on the properties (described below) of the highlighted variable.

## Definition

Each variable needs a Name and Category; Unit and Comment are optional.

## Scope

The Scope section determines where and how the variable will appear. Choose between **Monthly** or **Annual**. Select whether the variable will appear in both **Current Accounts and Scenarios**, **Current Accounts Only**, or **Scenarios Only**. Finally, for variables under Demand Sites and Catchments, whether the variable appears at the **Top Level Only** (the Demand Site level), the **Lowest Level Only**, or at **All Levels**. For comparison, Annual Activity Level appears at All Levels, Annual Water Use Rate appears at the Lowest Level Only, and Monthly Variation appears at the Top Level Only.

## Values

The Values section determines how to constrain the values of the variable. You can specify **Minimum** or **Maximum** limits for values of the variable, or leave them blank if there are no limits. If it makes sense to sum the values across the branches (e.g., Land Area can be summed, but not Consumption), check **Sum Across Branches**.

## Default Value or Expression

Data variables will typically default to 0, but in some cases to another value (e.g., Consumption defaults to 100%, Demand Priority defaults to 1). You can also create variables that are calculated, which will have a default expression that is not a constant. For example, to model population you might add two variables: Population Growth Rate, and Population. Population Growth Rate is data, and will contain the



## 4.6 Customizing Data Variables

annual growth rate, whereas Population is calculated (in the Scenario). In this case, the scope of Population Growth Rate is Scenarios Only, with a default of 0. Population will appear in both Current Accounts and Scenarios, but the default expressions will be different--the default for the Current Accounts is 0 (entered as data), and for the Scenarios the default will be `Growth(Population Growth Rate)`.

To delete a user-defined variable, right click on its tab and choose **Delete**.

You can reorder the variables tabs--right click on a tab and choose **Move Left** or **Move Right**.

### 4.6.2 Built-In Data Variables

You may customize WEAP's built-in variables (such as Demand Site Annual Activity Level or Consumption) to some extent. You are allowed to edit (right click on the variable and choose Edit) a variable's Unit, Category, Minimum and Maximum Values and Default Value or Expression. (Changing the default expression can be especially useful if you have created your own model using user-defined variables and you want to link a built-in WEAP variable to the result from a user-defined variable.) You may not change the name, comment or scope. You are not allowed to change the unit here if the unit is chosen on the main menu [General Units](#) screen (e.g., Reservoir storage volume) or independently for each branch (e.g., Demand Site Annual Activity Level).

Although you are not allowed to delete a built-in variable, you may hide it. Right click on the variable and choose **Hide**. To unhide previously hidden variables, right click and choose **Unhide**, and then choose the variable to show, or **All Variables** to unhide all previously hidden variables. Hiding unused variables can be a useful way to simplify a model's appearance, perhaps for display to stakeholders. Note: variables can still be used in calculations even when hidden (e.g., if you enter 50% for a demand site's consumption and then hide the Consumption variable, WEAP will still use the hidden value of 50% in determining how much water is consumed by the demand site). Therefore, to prevent confusion, it is best not to hide variables which currently hold data.

### 4.6.3 Data Variables Report

To see a list of all (unhidden) data variables along with their definitions (the information listed above), from the main menu choose Edit, Data Variable, **Report**. Variables for non-existent objects (e.g., catchments variables if the area has no catchments) are not shown. The report can be exported to a CSV, ASCII, Excel, Word, HTML or XML file, or to the Windows clipboard. This report will not include any data expressions--for those, you will need to see the [Data Expressions Report](#) or [Export Expressions to Excel](#).

**Note:** If you want to perform an action on a variable (Edit, Delete, Move Left, Move Right, or Hide), you must first make sure that the variable is the current, highlighted variable. If it is not, left click on the variable tab to select it, then right click on it and choose the desired action.

**Note:** Customizing data variables only applies to the current WEAP dataset. If you want to add or customize variables in other datasets, you will need to do it separately for each one.

**See also:** [Customizing Result Variables](#)

**Menu Option:** Edit: Data Variable

## 4.7 Startup Year

Most WEAP elements (Demand Sites, Wastewater Treatment Plants, Groundwater nodes, Reservoirs, Other Supply nodes, Transmission Links, Return Flow Links, Run of River Hydropower nodes, and Diversions) can be specified as not being active in the Current Accounts. (To view or change this setting, see [Edit General Info.](#)) For elements that are not active in the Current Account, you can specify the **Startup Year** in which it becomes active in a scenario. The startup year can vary by scenario. Set the startup year to 0 in a scenario to have it never be active in that scenario. Elements which are not active yet will have no effect on calculations. For example, Demand Sites that are not active will not have any demand, reservoirs will not store any water, transmission and return flow links will not have any water flowing through them, wastewater treatment plants will not treat any water (water routed to it will flow to its return flow links untreated).

## 4.8 Demand

Demand analysis in WEAP is a disaggregated, end-use based approach for modeling the requirements for water consumption in an Area. Using WEAP you can apply economic, demographic and water-use information to construct alternative scenarios that examine how total and disaggregated consumption of water evolve over time in all sectors of the economy. Demand analysis in WEAP is also the starting point for conducting integrated water planning analysis, since all Supply and Resource calculations in WEAP are driven by the levels of final demand calculated in the demand analysis.

WEAP provides a lot of flexibility in how you structure your data. These can range from highly disaggregated end-use oriented structures to highly aggregate analyses. Typically a structure would consist of sectors including households, industry and agriculture, each of which might be broken down into different subsectors, end-uses and water-using devices. You can adapt the structure of the data to your purposes, based on the availability of data, the types of analyses you want to conduct, and your unit preferences. Note also that you can create different levels of disaggregation in each demand site and sector.

In each case, demand calculations are based on a disaggregated accounting for various measures of social and economic activity (number of households, hectares of irrigated agriculture, industrial and commercial value added, etc.). In the simplest cases, these [activity levels](#) are multiplied by the [water use rates](#) of each activity (water use per unit of activity). Each activity level and water use rate can be individually projected into the future using a variety of techniques, ranging from applying simple exponential growth rates and interpolation functions, to using sophisticated modeling techniques that take advantage of WEAP's powerful built-in modeling capabilities. More advanced approaches can incorporate hydrologic processes to determine demand (e.g. crop evapotranspiration calculations to determine irrigation requirements).

### 4.8.1 Getting Started

The following types of data are often useful:

- Basic water requirements data, categorized by sector and/or specific water users
- Existing water use studies for the study area, and data from national, state, county or municipal agencies
- Population projections for cities and towns, production activity level projections for industry and agriculture



## 4.8 Demand

- Water consumption (water consumed by a demand site that is lost to the system, lost to evaporation, embodied in products, or otherwise unaccounted for)

Note: Agricultural irrigation demands can either be calculated using activity levels and water use rates as described above, or by simulating catchment processes such as evapotranspiration, runoff, infiltration and irrigation demands. See [Overview of Catchment Calculation Methods](#) for more information.

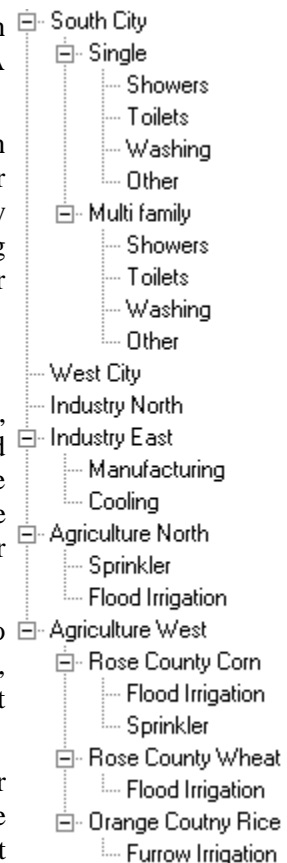
### 4.8.2 Demand Tree

WEAP uses a hierarchical structure to disaggregate water demand data. You can easily adapt this structure to the nature of your problem and data availability. A hypothetical example of a multilevel demand structure is shown on the right.

The first level corresponds to the demand sites (from the Schematic created on the Schematic View). Below this, you can create as many levels as you wish. For example, South City is broken down into single and multi-family, and further by end use, while West City has no disaggregation. WEAP is flexible in allowing you to enter aggregated data initially, and to refine the demand projections later as more detailed data becomes available or necessary.

Examples of disaggregation:

- **Sector:** A sample sectoral partition could include agriculture, industry, urban domestic and rural domestic. The sector categories can be used flexibly to correspond to the particular problem under analysis. The example at the right has no sectoral breakdown within a demand site--the demand sites themselves each represent one sector (two each for municipal, industry and agriculture).
- **Subsector:** For example, the industrial sector could be divided into industrial classifications, e.g., steel and iron, petroleum, chemistry, textile, pulp and paper, and food processing. The agriculture sector might be broken down by crop type, livestock or another appropriate subsector.
- **End-use:** For example, a crop end-use might be characterized by water requirements in different soil conditions or in different locations in the study area, or different irrigation techniques. Industrial end-uses might include processing, cooling and sanitary amenities.
- **Device:** For example, sprinkler, drip or flooding irrigation in agricultural sectors, or showers, toilets, and washing for domestic sectors.



You can organize the demand tree along the lines of the available data. For example, under the agricultural sector, the irrigation area for each crop can be identified at the subsector level. One level down, the percentage of each irrigation technique in each crop may be assigned at the end-use level. Another equally valid way to organize the agriculture sector would be to identify irrigation districts at the subsector level and the crops grown within the irrigation districts at the end-use level.

### 4.8.3 Methods for Calculating Demands

## Methods for Calculating Demands

The method for determining demands can be selected here. Currently three options are available: (1) standard water use method (2) FAO crop requirements approach and the (3) direct method.

## Standard Water Use Method

In the simplest case, the user determines an appropriate [activity level](#) (e.g. persons, households, hectares of land) for each disaggregated level and multiplies these by the appropriate [annual water use rate](#) for each activity. Monthly variation is applied to this rate.

## FAO Crop Requirements Approach

The FAO crop requirements approach is typically used to represent agricultural demand nodes. This approach assumes for each demand site a set of simplified hydrological and agro-hydrological processes such as precipitation, evapotranspiration, and crop growth emphasizing irrigated and rainfall agriculture. Obviously non-agricultural crops can be included as well. These processes are used to determine the irrigation requirements for each demand site. Some of the basic assumptions are:

- water balance is calculated at a monthly base
- no carrying over capacity between months of soil water
- water shortage is divided equally over the irrigated land classes
- crop factors specified by month
- yield response factor constant for entire growing season

See FAO Irrigation and Drainage Paper 56 (1998) for more details. This method can also be used to directly determine runoff contributions to rivers and groundwater supplies.

## Direct Method

Demands can be directly read into WEAP from a file or monthly water use rates can be inputted.

**Entered on:**  Data View, Branch: Demand Sites, Category: Advanced, Tabs: Methods

## Overview of Demand Calculation Methods

Several options exist to input and calculate demand within WEAP. For a particular demand site branch within the Data Tree, you can click on the "Advanced" button at the top of the Data Entry window to select among the following options:

(1) Monthly Demand - this option allows you to input month by month demand values for the demand site, or you may use the ReadFromFile function to read in monthly demands from a file.

(2) Annual Demand with Monthly Variation - this option allows you to express demands on an annual level. It requires you to input an activity level (e.g., number of people) and a water use rate associated with that activity level (e.g., an annual volume used per person). Monthly variation can then be described either with some user-defined expression or variation weighted by days in each month. If you want the monthly variation to differ by branches within a demand site, WEAP can accommodate this--just go to the main menu at the top of the schematic, select General, Basic Parameters to indicate this option.

Losses, reuse, and efficiency are accounted for separately. Water demand is calculated by multiplying the overall level of activity by a water use rate. Activity Levels are used in WEAP's Demand analysis as a measure of social and economic activity.

Note: Agricultural irrigation demands can either be calculated using activity levels and water use rates as described above, or by simulating catchment processes such as evapotranspiration, runoff, infiltration and irrigation demands. See [Overview of Catchment Calculation Methods](#) for more information.

## Monthly Demand Option

### Monthly Demand

Specify the demand for each month, typically using the [ReadFromFile](#) function.

**Entered on:**  Data View, Branch: Demand Sites, Category: Water Use, Tab: Monthly Demand

## Annual Demand with Monthly Variation Option


### Annual Activity Levels

The annual demand represents the amount of water required by each demand. Losses, reuse, and efficiency are accounted for separately. Water consumption is calculated by multiplying the overall level of activity by a water use rate. Activity Levels are used in WEAP's Demand analysis as a measure of social and economic activity.

Annual Activity Level					
Annual level of activity driving demand, such as agricultural area, population using water for domestic purposes, or industrial output.					
Demand Site	1998	1999-2008	Scale	Unit	
South City	3.75	Growth(3%)	Million	person	
Single family	42	Interp( 2020,50 )	Percent	share	of people
Showers	90	Interp( 2020,98 )	Percent	saturation	of people
Toilets	99	99	Percent	saturation	of people
Washing	75	Interp( 2020,85 )	Percent	saturation	of people
Other	80	Interp( 2020,90 )	Percent	saturation	of people

Activity levels for one of the hierarchical levels are typically described in absolute terms (in this case, the number of people in South City is 3.75 million in the [Current Accounts](#)), while the other levels are described in proportionate (i.e., percentage share or percentage saturation) terms. In the example shown above, 42% of the population lives in single-family households in 1998 and of these, 90% have showers. Notice that at the top level, the user chooses an absolute unit for the activity level (person). At lower levels, WEAP keeps track of the units, and hence knows that the percentage number entered at the second level is the share "of people". In general, WEAP lets you choose the numerator units for activity levels, while automatically displaying the denominator unit. When selecting an activity level unit, you can choose from any of the standard units. WEAP multiplies activity levels down each chain of branches to get a total activity. (See [Calculation Algorithms](#) for details.) For example, the total number of single-family dwellers in South City with showers in 1998 = 3.75 million people \* 42% \* 90% = 1.42 million people. Multiply this value by the water use rate per person per shower per year to get the total annual demand for South City single-family showers.

All values can be altered for future years in scenarios. This allows the planner to capture the combined effects of separate changes at many levels, such as, for example, the growth in the total population (shown above growing at 3%), the change in household structure, the growing penetration of washing machines (from 75% to 85%), and the market share of less efficient vs. more efficient washing machines. To project these data, you first use the Manage Scenarios option to create one or more scenarios. Then, in the Data View, you override the default (constant) expressions entered in Current Accounts for each branch, with new expressions that describe how each value changes over time. See [Expressions](#) for more information.

**Entered on:**  Data View, Branch: Demand Sites, Category: Water Use, Tab: Annual Activity Level

## Annual Water Use Rate

The Water Use Rate is the average annual water consumption per unit of activity. WEAP displays the denominator (person, in the example below) to emphasize that this is a rate per unit, not the total amount of water used by all showers.

Annual Activity Level   Annual Water Use Rate   Monthly Variation   Consumption					
Annual water use rate per unit of activity					
Single family	1998	1999-2008	Scale	Unit	
Showers	62.62	GrowthAs(Key\Drivers\Technical Innovation,-0.25)	m <sup>3</sup>	/person	
Toilets	70.5	GrowthAs(Key\Drivers\Technical Innovation,-0.25)	m <sup>3</sup>	/person	
Washing	44.1	44.1	m <sup>3</sup>	/person	
Other	30.8	30.8	m <sup>3</sup>	/person	

**Entered on:** Data View, Branch: Demand Sites, Category: Water Use, Tab: Annual Water Use Rate

## Monthly Variation

In some demand sites, such as industrial sites, water use may remain constant throughout the year, while other demands may vary considerably from month to month. If the demand is constant throughout the year, leave this line blank. Otherwise, enter the percentage of annual water used in each month. The percentages will also be used to convert the annual pollution generated into monthly amounts. The variation should reflect the weighted effects of all users within the demand site. In estimating monthly variations for a demand site, historical patterns can be reviewed. If such records are unavailable, the user can reference demand sites with similar properties. The twelve monthly coefficients must sum to one hundred percent. If demand does not vary, all months are assumed to use the same amount, according to the number of days in the month. For example, the default annual share for January is  $31/365=8.49\%$ , whereas February is  $28/365=7.67\%$ . Depending on the setting in [Basic Parameters](#), either the monthly variation is the same for all branches underneath a demand site or each branch within a demand site can have a different monthly variation.

Annual water demands are the requirements for final water services in industry, agriculture, domestic and other purposes. WEAP allows for three adjustments--demand site losses and reuse, and transmission link losses--to reflect more accurately the actual supply requirement needed to meet the demand for water services.

**Entered on:** Data View, Branch: Demand Sites, Category: Water Use, Tab: Monthly Variation


## Demand Management

If you want to model the effects of various demand-side management (DSM) strategies for reducing demand, you can use either a **disaggregated** or **aggregated** approach. The disaggregate approach would make changes to the water use rates on individual branches. For example, to model a program to promote efficient washing machines, you would either decrease the water use rate for washing machines (if there was only one branch for washing machines), or increase the share of efficient washing machines (if there were two branches--one for traditional washing machines and one for more efficient ones). Another example would be a tiered pricing strategy that charged more per unit water for higher usage rates, thus encouraging individuals to reduce their consumption. The benefits generated by this pricing strategy could be modeled using the [BlockRate](#) function. However, you would need to separately estimate the reduction in [activity level](#) or [water use rate](#) due to increased prices.

## 4.8 Demand


The disaggregated approach works well if your demand data is already disaggregated to the level of end-uses or devices. However, most demand analyses will not be so disaggregated. With the aggregated approach for DSM, you estimate the fraction of total demand for a demand site that could be reduced by DSM programs, and enter that fraction under **DSM Savings**. For example, if efficient washing machines and toilets consume 60% less water than traditional ones, and those end uses account for 4% of overall water consumption for a demand site, enter 2.4% for the DSM Savings.

If there are costs associated with these DSM programs, enter the cost per unit of water saved on the **DSM Cost** tab.

**Entered on:**  Data View, Branch: Demand Sites, Category: Demand Management, Tabs: DSM Savings, DSM Cost

### 4.8.4 Consumption

Enter the consumptive losses for the demand site--water that is lost to evaporation or treatment, embodied in products, or otherwise unaccounted for. These amounts are lost from the system. Consumption is entered as a fraction of the demand site inflow (supply).

**Entered on:**  Data View, Branch: Demand Sites, Category: Water Use, Tab: Consumption

### 4.8.5 Pumping

## Pump Layer

Groundwater layer or layers (as defined in linked MODFLOW model) from which to pump. Specify layer=255 for a cell to have pumping come equally from all layers in that cell. To have withdrawals handled instead as negative recharge, specify layer=0. If pump layer>0, WEAP will add cells to the well file if they are not already there. Use the [PumpLayer](#) function to specify fractions to pump from several layers. If blank, will default to 0 (negative recharge).

*Note: Pump Layer is only used when [linked to MODFLOW](#).*

**Entered on:**  Data View, Branch: Demand Sites, Category: Pumping, Tab: Pump Layer

### 4.8.6 Loss and Reuse

## Loss Rate (%)


**Loss Rate** includes distribution losses within a demand site and otherwise unaccounted for demands. For example, in municipal systems, distribution losses could represent physical leaks, unmetered water use in public parks and buildings, clandestine connections, water used for line flushing, or water use for firefighting. The effect of distribution losses is to increase the supply requirement by the factor  $1 / (1 - \text{loss rate})$ . NB: Do not include losses that are already accounted for as [transmission link losses](#). Also, do not confuse these losses with [Consumption](#)--**Loss Rate** increases supply requirements but is not lost from the system, whereas **Consumption** is lost from the system and will decrease the return flow of the amount supplied.

## Reuse Rate (%)

**Reuse Rate** accounts for water recycling or reuse. This adjustment refers to processes by which water is used in more than one application before discharge. For example, irrigation water may be routed for reuse in more than one field. In industry, water may be recycled for multiple uses. The effect of reuse is to reduce the supply requirement by the factor  $(1 - \text{reuse rate})$ . NB: This internal reuse should not be confused with the direct reuse by one demand site of wastewater from another demand site. See Return Flow Routing for more information on this non-internal reuse. The internal reuse happens within one demand site.

Taking all these factors into account (and [DSM Savings](#)),

$$\text{MonthlySupplyRequirement} = \text{MonthlyDemand} \times (1 - \text{ReuseRate}) \times (1 - \text{DSMSavings}) / (1 - \text{LossRate})$$


**Entered on:**  Data View, Branch: Demand Sites, Category: Loss and Reuse, Tabs: Loss Rate, Reuse Rate

### 4.8.7 Demand Management

If you want to model the effects of various demand-side management (DSM) strategies for reducing demand, you can use either a **disaggregated** or **aggregated** approach. The disaggregate approach would make changes to the water use rates on individual branches. For example, to model a program to promote efficient washing machines, you would either decrease the water use rate for washing machines (if there was only one branch for washing machines), or increase the share of efficient washing machines (if there were two branches--one for traditional washing machines and one for more efficient ones). Another example would be a tiered pricing strategy that charged more per unit water for higher usage rates, thus encouraging individuals to reduce their consumption. The benefits generated by this pricing strategy could be modeled using the [BlockRate](#) function. However, you would need to separately estimate the reduction in [activity level](#) or [water use rate](#) due to increased prices.

The disaggregated approach works well if your demand data is already disaggregated to the level of end-uses or devices. However, most demand analyses will not be so disaggregated. With the aggregated approach for DSM, you estimate the fraction of total demand for a demand site that could be reduced by DSM programs, and enter that fraction under **DSM Savings**. For example, if efficient washing machines and toilets consume 60% less water than traditional ones, and those end uses account for 4% of overall water consumption for a demand site, enter 2.4% for the DSM Savings.

If there are costs associated with these DSM programs, enter the cost per unit of water saved on the **DSM Cost** tab.

**Entered on:**  Data View, Branch: Demand Sites, Category: Demand Management, Tabs: DSM Savings, DSM Cost


### 4.8.8 Demand Site and Catchment Water Quality

## Inflow: Maximum Allowed Inflow Concentration

In order to set a minimum water quality standard for supply to a demand site or catchment, enter the maximum allowed concentration for each constituent. This maximum will be a constraint during allocation, such that the inflow from all supplies to a demand site will not exceed the maximum concentration entered. If a demand site is connected to more than one source, then the concentration of



the mixed inflows (weighted average) must not exceed the maximum. Note: when computing the concentration of the inflow, the concentrations from the previous time step of the supplies will be used.

**Entered on:**  Data View, Branch: Demand Sites and Catchments, Category: Water Quality, Tabs: <Constituent Name> Inflow

### Outflow: Pollution Generation


Demand Sites may generate pollution, which is carried in their wastewater return flows to treatment plants and local and river sources; catchments may generate non-point source pollution, which runs off to surface water and infiltrates to groundwater. There are two different methods to use to enter pollution generation data.

The first method to enter pollution data is similar to that of water demands. The data is broken down into activity level and pollution **intensity** (amount of production) per activity. The activity level used is that which was entered for Water Use. WEAP computes the annual wastewater or non-point source pollution generated over time by multiplying activity levels with unit pollution intensities. Projected unit pollution intensities can be based on several methods. Annual pollution generated is converted to monthly values, using the [Monthly Variation](#) entered under Annual Water Use.

Using the second method, enter the **concentration** of each constituent in the demand site return flow or catchment runoff. WEAP will multiply this concentration by the volume of wastewater return flow or runoff to calculate the volume of pollution generated. Do not enter the pollution activity level or intensity.

For both the intensity and concentration methods, you may enter the data at any level of disaggregation. For example, for a city, you might enter the kg BOD per person per year (at the top, demand site, level of the tree), whereas the pollution generated from agricultural lands might be disaggregated by crop type or irrigation method, and thus data entered at a level below the catchment branch.

To edit the list of water quality constituents, go to the menu option [General, Water Quality Constituents](#).

**Entered on:**  Data View, Branch: Demand Sites and Catchments, Category: Water Quality, Tabs: <Constituent Name> Intensity, <Constituent Name> Concentration

#### 4.8.9 Priority

Determines the demand site's priority for supply. Note: if there is a transmission link carrying wastewater for reuse from one demand site to another demand site, the receiving demand site must have a lower priority than the supplying demand site. Otherwise, no water will be reused. This is due to the fact that demand sites with higher priorities are processed first by the WEAP allocation algorithm. Therefore, a higher priority receiving demand site would not receive any wastewater from the supplying demand site because the supplying demand site has not yet received any water nor returned any wastewater by the time the receiving demand site is processed. See [Demand Priority, Supply Preferences and Allocation Order](#) for more information.

**Entered on:**  Data View, Branch: Demand Sites, Category: Priority, Tab: Demand Priority

## 4.9 Catchments

There is a choice among four methods to simulate catchment processes such as evapotranspiration, runoff, infiltration and irrigation demands. These methods include (1) the Rainfall Runoff and (2) Irrigation

Demands Only versions of the FAO Crop Requirements Approach, (3) the Soil Moisture Method, and (4) the MABIA Method. You can click on the "Advanced" button at the top of the Data Entry window for a particular catchment to select among these options. Your choice of method should depend on the level of complexity desired for representing the catchment processes and data availability.

## **Irrigation Demands Only Method (FAO Crop Requirements Method)**

Of these four methods, the Irrigation Demands Only method is the simplest. It uses crop coefficients to calculate the potential evapotranspiration in the catchment, then determines any irrigation demand that may be required to fulfill that portion of the evapotranspiration requirement that rainfall cannot meet. It does not simulate runoff or infiltration processes, or track changes in soil moisture.

## **Rainfall Runoff Method (FAO Crop Requirements Method)**

The Rainfall Runoff method also determines evapotranspiration for irrigated and rainfed crops using crop coefficients, the same as in the Irrigation Demands Only method. The remainder of rainfall not consumed by evapotranspiration is simulated as runoff to a river, or can be proportioned among runoff to a river and flow to groundwater via catchment links.

## **Rainfall Runoff Method (Soil Moisture Method)**

The Soil Moisture method is the most complex of the four methods, representing the catchment with two soil layers, as well as the potential for snow accumulation. In the upper soil layer, it simulates evapotranspiration considering rainfall and irrigation on agricultural and non-agricultural land, runoff and shallow interflow, and changes in soil moisture. This method allows for the characterization of land use and/or soil type impacts to these processes. Baseflow routing to the river and soil moisture changes are simulated in the lower soil layer. Correspondingly, the Soil Moisture Method requires more extensive soil and climate parameterization to simulate these processes.

Note that the deeper percolation within the catchment can also be transmitted directly to a groundwater node by creating a Runoff/Infiltration Flow Link from the catchment to the groundwater node. The method essentially becomes a 1-layer soil moisture scheme if this link is made. See [Groundwater-Surface Water Interactions](#) for more information.

## **MABIA Method (FAO 56, Dual Kc, Daily)**

The MABIA Method is a daily simulation of transpiration, evaporation, irrigation requirements and scheduling, crop growth and yields, and includes modules for estimating reference evapotranspiration and soil water capacity. It was derived from the MABIA suite of software tools, developed at the [Institut National Agronomique de Tunisie](#) by Dr. Ali Sahli and Mohamed Jabloun. For more information about MABIA and to download standalone versions of the software, visit <http://www.mabia-agrosoftware.net>. The algorithms and descriptions contained here are for the combined MABIA-WEAP calculation procedure.

The MABIA Method uses the 'dual' Kc method, as described in [FAO Irrigation and Drainage Paper No. 56 \(Spanish version of FAO 56\)](#), whereby the Kc value is divided into a 'basal' crop coefficient,  $K_{cb}$ , and a separate component,  $K_e$ , representing evaporation from the soil surface. The basal crop coefficient represents actual ET conditions when the soil surface is dry but sufficient root zone moisture is present to



support full transpiration. In this way, MABIA is an improvement over [CROPWAT](#), which use a single Kc method, and hence, does not separate evaporation and transpiration.

See also: [FAO Method Calculation Algorithms](#), [Soil Moisture Method Calculation Algorithms](#), [MABIA Method Calculation Algorithms](#).

### 4.9.1 FAO Crop Requirements Method

## Land Use

(These parameters apply to the FAO Method. For the Soil Moisture Method, see [Soil Moisture, Land Use](#); for the MABIA Method, see [MABIA, Land Use](#).)

### Area

The land area for a catchment or subcatchment, or the share of land area from the branch above.

### Kc

The crop coefficient, relative to the reference crop, is given here for each land class type. There is a special case involving Kc and double cropping. In cases where there are two different crops planted on the same land at different times of the year (double cropping), you can choose to model this with two separate branches on the demand tree, one for each crop. In this case, set the Kc = 0 for branch 2 when branch 1 is active and Kc = 0 for branch 1 when branch 2 is active. For example, if winter wheat was planted November through March and corn was planted May through September, the Kc's may look something like this:

Wheat: Kc = MonthlyValues( Jan, 1.15, Feb, 1.15, Mar, 0.4, Apr, 0.05, May, 0, Jun, 0, Jul, 0, Aug, 0, Sep, 0, Oct, 0, Nov, 0.4, Dec, 0.7 )


Corn: Kc = MonthlyValues( Jan, 0, Feb, 0, Mar, 0, Apr, 0, May, 1, Jun, 1.15, Jul, 1.15, Aug, 1.05, Sep, 1.05, Oct, 0.05, Nov, 0, Dec, 0 )

Double cropping could also be modeled with one branch, where the various crop and land use parameters would change over the year to reflect the two different crops. The important point to remember is that Kc should not be set to 0 unless you are double cropping. When Kc = 0, WEAP will ignore that land entirely, including no precipitation, evaporation or runoff. For fallow land, set Kc to a small but non-zero value, such as 0.05.

## Effective Precipitation

The percentage of rainfall available for evapotranspiration. The remainder is available for runoff.

See also: [FAO Method Calculation Algorithm](#)

**Entered on:**  Data View, Branch: Catchments, Category: Land Use, Tab: Area, Kc, Effective Precipitation.

## Climate

(These parameters apply to the FAO Method. For the Soil Moisture Method, see [Soil Moisture, Climate](#); for the MABIA Method, see [MABIA, Climate](#).)

Depending on the setting in [General: Basic Parameters](#), the values for precipitation and ETref can **either** be entered once for each catchment and will apply to all the land use branches within that catchment, **or** they will be entered separately for each branch within each catchment. This second option might be necessary if there is a large variation in the elevation among different land uses within a catchment. Alternatively, the catchment could be divided into several different catchment nodes according to elevation, so that the climate within each catchment did not vary by land use.

## Precipitation

The monthly precipitation time series can either be read in from a file or entered in manually.

## ETref

The monthly reference evapotranspiration can either be read in from a file or entered in manually.

**See also:** [FAO Method Calculation Algorithm](#)

**Entered on:**  Data View, Branch: Catchments, Category: Climate, Tab: Precipitation, ETreference.

## Irrigation

(These parameters apply to the FAO Method. For the Soil Moisture Method, see [Soil Moisture, Irrigation](#); for the MABIA Method, see [MABIA, Irrigation](#).)

If you indicate that irrigation is to occur in a Catchment at the time you create the Catchment in the Schematic, the Irrigation tab will appear under the particular Catchment in the Data View. The following irrigation-related variables will require input if the FAO method is chosen for the Catchment.

## Irrigated

Enter 1 if the land class is irrigated. Enter 0 otherwise.

## Irrigation Fraction

Irrigation fraction is the percentage of the supplied water available for ET consumption (i.e., irrigation efficiency).

## Pump Layer

Groundwater layer or layers (as defined in linked MODFLOW model) from which to pump for irrigation. Specify layer=255 for a cell to have pumping come equally from all layers in that cell. To have withdrawals handled instead as negative recharge, specify layer=0. If pump layer>0, WEAP will add cells to the well file if they are not already there. Use the [PumpLayer](#) function to specify fractions to pump from several layers. If blank, will default to 0 (negative recharge).

Depending on the setting in [General: Basic Parameters](#), the pump layer can **either** be entered once for each catchment and will apply to all the land use branches within that catchment, **or** can be entered separately for each branch within each catchment.

*Note: Pump Layer is only used when [linked to MODFLOW](#).*

**See also:** [FAO Method Calculation Algorithm](#)

**Entered on:**  Data View, Branch: Catchments, Category: Irrigation, Tabs: Irrigated, Irrigation Fraction, Pump Layer.

### Yield

(These parameters apply to the FAO Method. For the MABIA Method, see [MABIA, Yield.](#))

### Potential Yield

The maximum potential yield assuming an optimal supply of water.

### Yield Response Factor

Defines how the yield changes when the ETactual is less than the ETpotential.  $\text{ActualYield} = \text{PotentialYield} * (1 - \text{YieldResponseFactor}) * ((1 - \text{ETActual}) / \text{ETPotential})$

### Market Price

The market price of the crops.

See also: [FAO Method Calculation Algorithm](#)

**Entered on:**  Data View, Branch: Catchments, Category: Yield, Tab: Potential Yield, Yield Response Factor, Market Price.

## 4.9.2 Soil Moisture Method

### Land Use

(These parameters apply to the Soil Moisture method. For the FAO Method, see [FAO Method, Land Use](#); for the MABIA Method, see [MABIA, Land Use](#).)

### Area

Land area for land cover class within branch or basin catchment.

### Kc

The crop coefficient, relative to the reference crop, for a land class type.

### Root Zone Water Capacity

The effective water holding capacity of the top layer of soil, represented in mm.

### Deep Water Capacity

Effective water holding capacity of lower, deep soil layer (bottom "bucket"), represented in mm. This is given as a single value for the catchment and does not vary by land class type. This is ignored if the demand site has a return flow link to a groundwater node.

### Deep Conductivity

Conductivity rate (length/time) of the deep layer (bottom "bucket") at full saturation (when relative storage  $z2 = 1.0$ ), which controls transmission of baseflow. This is given as a single value for the catchment and does not vary by land class type. Baseflow will increase as this parameter increases. This is ignored if the demand site has a return flow link to a groundwater node.

**Runoff Resistance Factor**

Used to control surface runoff response. Related to factors such as leaf area index and land slope. Runoff will tend to decrease with higher values (range 0.1 to 10). This parameter can vary among the land class types.

**Root Zone Conductivity**

Root zone (top "bucket") conductivity rate at full saturation (when relative storage  $z1 = 1.0$ ), which will be partitioned, according to Preferred Flow Direction, between interflow and flow to the lower soil layer. This rate can vary among the land class types.

**Preferred Flow Direction**

Preferred Flow Direction: 1.0 = 100% horizontal, 0 = 100% vertical flow. Used to partition the flow out of the root zone layer (top "bucket") between interflow and flow to the lower soil layer (bottom "bucket") or groundwater. This value can vary among the land class types.

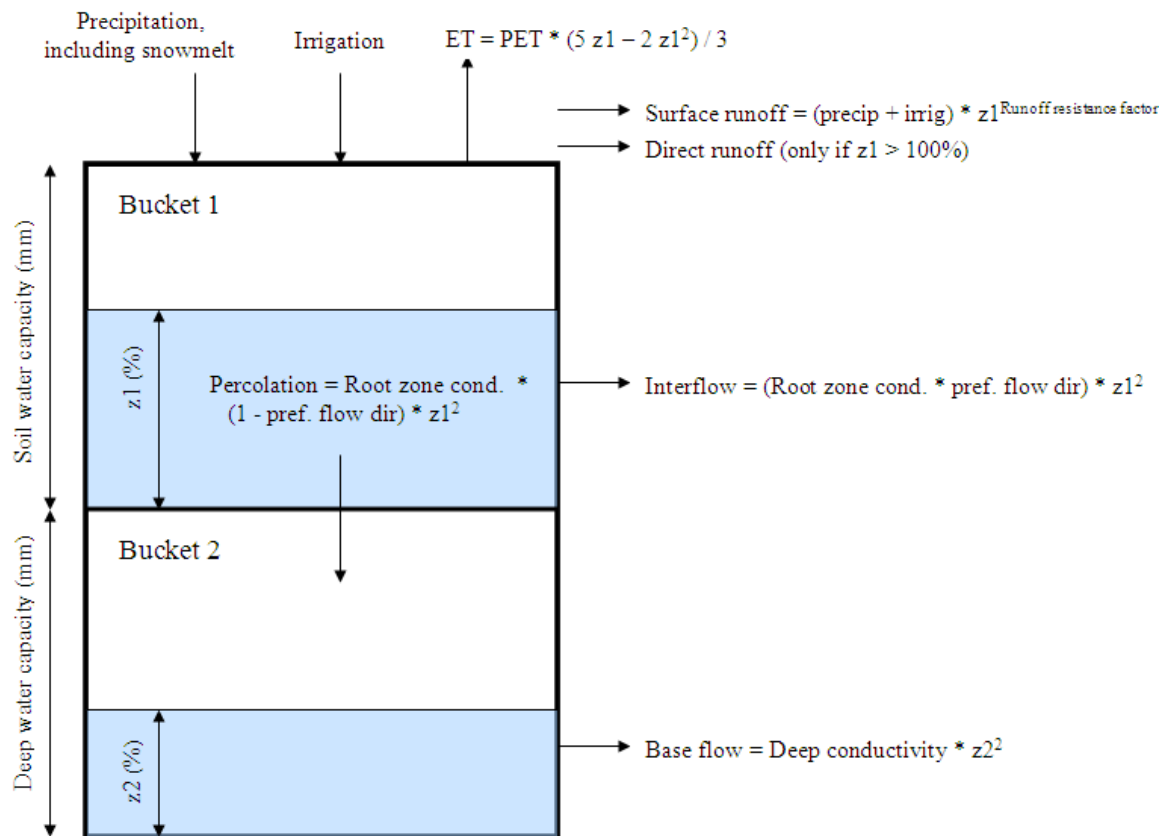
**Initial Z1**

Initial value of Z1 at the beginning of a simulation. Z1 is the relative storage given as a percentage of the total effective storage of the root zone water capacity.

**Initial Z2**

Initial value of Z2 at the beginning of a simulation. Z2 is the relative storage given as a percentage of the total effective storage of the lower soil bucket (deep water capacity). This parameter is ignored if the demand site has a runoff/infiltration link to a groundwater node. This rate cannot vary among the land class types.

## Conceptual diagram and equations incorporated in the Two-bucket model



See also: [Soil Moisture Method Calculation Algorithm](#)

**Entered on:** Data View, Branch: Catchments, Category: Land Use, Tabs: Area, Initial Z1, Initial Z2, Leaf Area Index, Kc, Root Zone Conductivity, Preferred Flow Direction, Root Zone Water Capacity, Deep Water Capacity, Deep Conductivity.

## Climate

(These parameters apply to the Soil Moisture method. For the FAO Method, see [FAO Method, Climate](#); for the MABIA Method, see [MABIA, Climate](#).)

Depending on the setting in [General: Basic Parameters](#), the values for all of these variables (except latitude) can **either** be entered once for each catchment and will apply to all the land use branches within that catchment, **or** they will be entered separately for each branch within each catchment. This second option might be necessary if there is a large variation in the elevation among different land uses within a catchment. Alternatively, the catchment could be divided into several different catchment nodes according to elevation, so that the climate within each catchment did not vary by land use.

## Precipitation

The monthly precipitation time series can either be [read in from a file](#) or entered in manually.

## Temperature

The weighted mean of high and low temperature on a monthly basis.

## Humidity

The average monthly relative humidity.

## Wind

The average monthly wind speed.

## Cloudiness Fraction

Fraction of daytime hours with no clouds (0.0=completely overcast, 1.0=no clouds). If blank, will default to 1 (no clouds).

## Latitude

The latitude in degrees.

## Initial Snow

The initial value for snow accumulation at the beginning of the first month of the simulation.

## Melting Point

Liquid water threshold for snow melt (defaults to +5 degrees Celsius).


## Freezing Point

Solid water threshold for snow accumulation (defaults to -5 degrees Celsius).

## Snow Accumulation Gauge

Historic data of snow accumulation (snowpack), to be used in [calibration](#). Measured in melt water equivalent (MWE) depth. For calibrating, see the "[Snow Accumulation vs. Gauge](#)" report, or use the [PEST Calibration Wizard](#).

**See also:** [Soil Moisture Method Calculation Algorithm](#)

**Entered on:**  Data View, Branch: Catchments, Category: Climate, Tabs: Precipitation, Temperature, Humidity, Wind, Melting Point, Freezing Point, Latitude, Initial Snow.

## Ponding

(These parameters apply to the Soil Moisture method. For the FAO Method, see [FAO Method, Climate](#).)

These variables are used to model flooding for rice cultivation, or for wetlands (managed or unmanaged).

## Maximum Depth

The maximum depth of water above ground. This is typically the height of the dike that contains the water. Once the water reaches this height, any additional water will run off. This height may vary from one timestep to the next. For example, if the rice fields are flooded in May and drained in September,

using a dike 150 mm high, the following expression would be used: MonthlyValues( Apr, 0, May, 150, Aug, 150, Sep, 0 ). In this case, any remaining above-ground storage from the end of August would become surface runoff in September.


### Minimum Depth, Target Depth

Minimum Depth is the minimum required depth for healthy plant growth. When the level of above-ground storage falls below this height, WEAP will irrigate with enough water to bring the level up to the Target Depth. If the level is between the Minimum Depth and the Target Depth, no irrigation will be applied. Leave Minimum Depth blank to have it default to the Target Depth--this will cause irrigation to be applied each month to maintain the level at exactly the target level. The Minimum Depth is analogous to the [Lower Threshold](#) variable for irrigation; Target Depth is analogous to the [Upper Threshold](#) variable.

For an unmanaged wetland, enter 0 for minimum and target depth so that irrigation will never be applied.

### Release Requirement

When modeling surface water storage on a land class, either for rice cultivation or a managed wetland, the Release Requirement is the amount of water to be released in the timestep, to be replaced with new supply. This is typically used to maintain proper water temperature for rice. The release requirement for the timestep will never exceed the amount of surface storage at the beginning of the timestep. For example, if the release requirement for August is 100 mm, but the amount of water at the beginning of August is only 75 mm, then the release requirement will be reduced to 75 mm. Therefore, all of the water will be released, and replaced by new supply.

**Entered on:**  Data View, Branch: Catchments, Category: Ponding, Tabs: Maximum Depth, Minimum Depth, Target Depth, Release Requirement.

## Irrigation

(These parameters apply to the Soil Moisture method. For the FAO Method, see [FAO Method, Irrigation](#); for the MABIA Method, see [MABIA, Irrigation](#).)

If you indicate that irrigation is to occur in a Catchment at the time you create the Catchment in the Schematic, the Irrigation tab will appear under the particular Catchment in the Data View. The following irrigation-related variables will require input if the Soil Moisture method is chosen for the Catchment.

### Irrigated Area

The percent of area that is irrigated.

### Lower Threshold

Irrigate when soil moisture falls below this percent level.

### Upper Threshold

Cease irrigation when soil moisture reaches this percent level.


## Pump Layer

Groundwater layer or layers (as defined in linked MODFLOW model) from which to pump for irrigation. Specify layer=255 for a cell to have pumping come equally from all layers in that cell. To have withdrawals handled instead as negative recharge, specify layer=0. If pump layer>0, WEAP will add cells to the well file if they are not already there. Use the [PumpLayer](#) function to specify fractions to pump from several layers. If blank, will default to 0 (negative recharge).

Depending on the setting in [General: Basic Parameters](#), the pump layer can **either** be entered once for each catchment and will apply to all the land use branches within that catchment, **or** can be entered separately for each branch within each catchment.

*Note: Pump Layer is only used when [linked to MODFLOW](#).*

**See also:** [Soil Moisture Method Calculation Algorithm](#)

**Entered on:**  Data View, Branch: Catchments, Category: Irrigation, Tabs: Irrigated Area, Lower Threshold, Upper Threshold, Pump Layer.

### 4.9.3 MABIA Method (FAO 56, dual Kc, daily)

## Land Use

(These parameters apply to the [MABIA Method](#). For the FAO Method, see [FAO Method, Land Use](#); for the Soil Moisture Method, see [Soil Moisture, Land Use](#).)

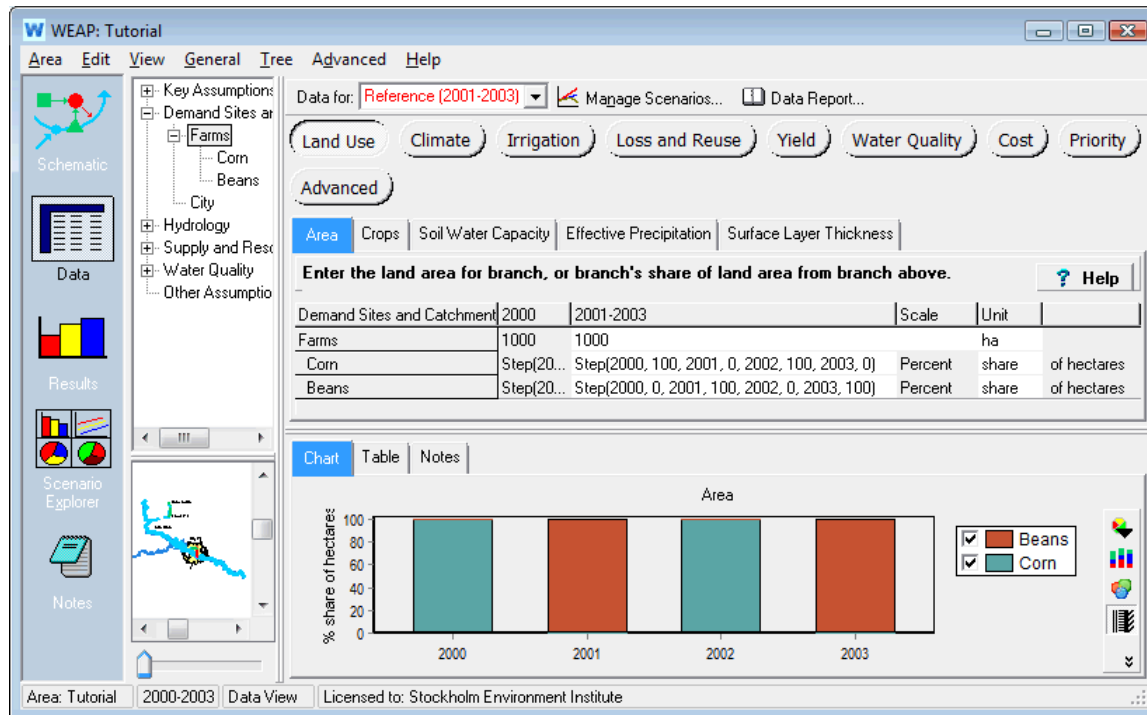
### Area

The land area for a catchment or subcatchment, or the share of land area from the branch above.

If you want to plant different crops on the same piece of land in different years (crop rotation), you can do this with two different branches under the catchment. For example, if you wanted to plant corn in even years and beans in odd years, create two branches (Corn and Beans) underneath the Catchment branch.

Enter the actual area for the Area variable on the catchment branch, and set the unit to percent share for the Corn and Beans branches. Use the Step function to alternate between 0% and 100% for each branch:





### Crops

Each catchment branch represents a piece of land on which one or more crops is planted each year. For each branch, you need to specify which crop or crops (from the [Crop Library](#)) are planted and the planting date. Given the planting date and the crop stage duration, WEAP can determine the end date. All days before the planting date or after the harvest date will use the characteristics of the crop named "Fallow" (in the Crop Library). Use the [Crop Scheduling Wizard](#) to choose crop and planting date, or choose one of the crop/planting dates already specified on another branch. Both of these options are available on the drop-down menu in the data grid. There is also an option here to view or edit the Crop Library. The expression created by the [Crop Scheduling Wizard](#) will use the [CropLibrary](#) function. It is not possible to edit the expression directly in the data grid cell--use the Crop Scheduling Wizard instead.

For perennial crops and land covers, choose the first day of the water year as the planting date, and make sure that the end date is the last day of the water year. If not, edit that crop in the Crop Library so that the stage lengths add up to 365 days.

Many crops grown for forage or hay receive multiple harvests during the growing season. Each harvest essentially terminates a "sub" growing season and associated  $K_{cb}$  curve and initiates a new "sub" growing season and associated  $K_{cb}$  curve. The resulting  $K_{cb}$  curve for the entire growing season is the aggregation of a series of  $K_{cb}$  curves associated with each sub cycle. To handle this situation, the crop library has different entries for the first cutting and subsequent cuttings. (Search for alfalfa in the crop library to see an example.) Specify multiple crops (in the [Crop Scheduling Wizard](#)) for a particular branch, where the first crop chosen is that for the first cutting, and the second (and third) crop is for the crop specifying the subsequent cutting's parameters.

### Soil Water capacity

Specify the water holding properties of the soil, including saturation, field capacity and wilt point. The available water capacity (AWC) will be field capacity minus wilt point. You have four options for specifying these parameters (all available on the drop-down menu in the data grid):

1. Enter soil properties directly: a window will appear into which you enter the saturation, field capacity and wilt point, and fraction of coarse fragments (if any).
2. Choose from [Soil Library](#): this will add the SoilLibrary function to the expression with the chosen texture class. Optionally, you can specify the fraction of coarse fragments. See the [SoilLibrary](#) function for more information.
3. Use the [Soil Profiles Wizard](#): a window will appear for entering, importing, or pasting information about one or more soil profiles, each containing one or more soil horizons (layers). Various pedotransfer functions are available for estimating soil water capacity. See [Soil Profiles Wizard](#) for details.
4. Paste an array of data (e.g., copy several rows and columns of data from Excel onto the Windows clipboard, and paste it into the data grid) representing soil profile data. A Paste Special wizard will appear to help you format the information.

If the soil properties of one branch are the same as those of another branch, you can copy and paste the expression from one branch to another.

## Maximum Infiltration Rate

Water depth that can infiltrate into the soil over a 24 hour period--this will vary according to soil type, slope, and rain or irrigation intensity. If daily precipitation exceeds this rate, the excess will run off. Leave blank to ignore.

## Effective Precipitation

The percentage of rainfall available for evapotranspiration. The remainder is direct runoff.


## Surface Layer Thickness

Depth of surface layer subject to drying by evaporation. If blank, will default to 100 mm.

## Initial Depletion

Initial value of soil moisture depletion. Zero depletion corresponds to field capacity. The maximum depletion is the available water capacity, as specified under Soil Water Capacity (above).

See also: [MABIA Calculation Algorithms](#)

**Entered on:**  Data View, Branch: Catchments, Category: Land Use, Tabs: Area, Crops, Soil Water Capacity, Effective Precipitation, Surface Layer Thickness, Initial Depletion.

## Irrigation

(These parameters apply to the [MABIA Method](#). For the FAO Method, see [FAO Method, Irrigation](#); for the Soil Moisture Method, see [Soil Moisture, Irrigation](#).)

Irrigation is required when rainfall is insufficient to compensate for the water lost by evapotranspiration. The primary objective of irrigation is to apply water at the right period and in the right amount. By calculating the soil water balance of the root zone on a daily basis, the timing and the depth of future irrigations can be planned. To avoid crop water stress, irrigations should be applied before or at the moment when the readily available soil water (RAW) is depleted ( $\text{Depletion} \leq \text{RAW}$ ).

If you indicate that irrigation is to occur in a Catchment at the time you create the Catchment in the Schematic, the Irrigation tab will appear under the particular Catchment in the Data View.

### Irrigation Schedule

Choose the irrigation methods and schedule, using the [Irrigation Scheduling Wizard](#), or choosing a schedule already in use for the same crop. These two options are available on the drop-down menu in the data grid. You may also edit the expression directly in the cell, for example, to change the value of one of the methods (e.g., % of Depletion, from 100% to 90%). Leave the expression blank if there is no irrigation for this crop or land cover.

The Irrigation Schedule can be set only once for a scenario. Therefore, to model a shift in irrigation methods over time (e.g., from furrow irrigation in early years to drip irrigation in later years), you will need to create two branches, one for each irrigation method. Enter the actual area for the Area variable on the catchment branch, and set the unit to percent share for the two branches. Change the percent shares for the two branches over time to model the change in irrigation method. The sum of the shares for the two branches should always equal 100%. (The easiest way to ensure this is by using the [Remainder](#) function on one branch.)

### Fraction Wetted

Many types of irrigation systems wet only a fraction of the soil surface. For example, for a trickle irrigation system, the fraction of the surface wetted,  $F_w$ , may be only 0.4. For furrow irrigation systems, the fraction of the surface wetted may range from 0.3 to 0.8.

### Irrigation Efficiency

Irrigation efficiency is the percentage of the supplied water available for ET consumption.


### Loss to Groundwater

Of the supplied water NOT available for evapotranspiration (100% - Irrigation Efficiency), Loss to Groundwater is the percent that infiltrates to groundwater. That which does not infiltrate or run off is assumed to evaporate.

### Loss to Runoff

Of the supplied water NOT available for evapotranspiration (100% - Irrigation Efficiency), Loss to Runoff is the percent that runs off to surface water. That which does not percolate or run off is assumed to evaporate.

See also: [MABIA Calculation Algorithms](#)

**Entered on:**  Data View, Branch: Catchments, Category: Irrigation, Tabs: Irrigation Schedule, Fraction Wetted, Irrigation Efficiency, Loss to Groundwater, Loss to Runoff.

## Climate

(These parameters apply to the [MABIA Method](#). For the FAO Method, see [FAO Method, Climate](#); for the Soil Moisture Method, see [Soil Moisture, Climate](#).)

The MABIA Method requires daily climate data for precipitation, reference evapotranspiration (known as  $ET_0$  or  $ET_{ref}$ ), wind speed and minimum daily relative humidity.

For ET<sub>ref</sub>, you have two options:

1. Enter ET<sub>ref</sub> directly (some climate stations provide derived ET<sub>ref</sub> as data), OR
2. Calculate it using the Penman-Monteith equation. This approach has its own data requirements, with various options. Penman-Monteith requires:
  - a. Minimum and maximum daily temperature.
  - b. Relative humidity. Depending on the availability of data, different equations are used. The following are the data requirements, in decreasing order of preference.
    - i. Minimum and maximum daily relative humidity, OR
    - ii. Maximum daily relative humidity, OR
    - iii. Average daily relative humidity, OR
    - iv. If humidity data is not available, and estimate can be obtained by assuming that the dew point temperature is the same as the daily minimum temperature.
  - c. Solar radiation. Depending on the availability of data, different equations are used. The following are the data requirements, in decreasing order of preference.
    - i. Enter solar radiation data directly, OR
    - ii. Hours of sunshine per day, OR
    - iii. Cloudiness fraction, OR
    - iv. If neither sunshine hours nor cloudiness fraction are available, solar radiation can be estimated using the Hargreaves formula, based on minimum and maximum daily temperature and an adjustment coefficient (K<sub>rs</sub>)
  - d. Wind speed. (An adjustment can be made if the wind speed measurement height is known.)
  - e. Latitude and altitude of the climate measurement station.

Depending on the setting in [General: Basic Parameters](#), the values for precipitation and ET<sub>ref</sub> can **either** be entered once for each catchment and will apply to all the land use branches within that catchment, **or** they will be entered separately for each branch within each catchment. This second option might be necessary if there is a large variation in the elevation among different land uses within a catchment. Alternatively, the catchment could be divided into several different catchment nodes according to elevation, so that the climate within each catchment did not vary by land use.

Because the MABIA method calculates on a daily timestep, you will need daily data for most climate parameters (which will typically be read from a text file). However, if you only have monthly data, it can be disaggregated into daily data using several different methods (Interpolate, Repeat, Divide, and Divide with Gaps). See the section titled "Disaggregating Annual Data to Monthly, or Monthly Data to Daily" under the [ReadFromFile](#) function for more information.

## Precipitation

The daily precipitation time series can either be read in from a file or entered in manually.

## ET<sub>ref</sub>

Evapotranspiration from the reference surface, the so-called reference crop evapotranspiration or reference evapotranspiration, denoted as ET<sub>o</sub>. The reference surface is a hypothetical grass reference crop with an assumed crop height of 0.12 m, a fixed surface resistance of 70 s m<sup>-1</sup> and an albedo of 0.23. The reference surface closely resembles an extensive surface of green, well-watered grass of uniform height,

## 4.9 Catchments

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actively growing and completely shading the ground. The fixed surface resistance of  $70 \text{ s m}^{-1}$  implies a moderately dry soil surface resulting from about a weekly irrigation frequency.

Leave blank to calculate  $ET_{ref}$  using the Penman-Monteith equation (as described above).

### **Min. Temperature**

Minimum daily temperature

### **Max. Temperature**

Maximum daily temperature

### **Latitude**

Latitude of the climate measurement station.

### **Altitude**

Altitude of the climate measurement station.

### **Min. Humidity**

Minimum daily relative humidity. Used to calculate  $K_{cb}$ . If blank, will default to 45%. Also used if calculating  $ET_{ref}$ --if blank, will use maximum relative humidity, or average humidity, or Hargreaves formula.

### **Max. Humidity**

Maximum daily relative humidity. Used if calculating  $ET_{ref}$ . If blank, will use average humidity, or dew point temperature estimate.

### **Average Humidity**

Average daily relative humidity. Used if calculating  $ET_{ref}$ . Only needed if no data for maximum humidity. If this and other humidity data are blank, an estimate will be made by assuming that the dew point temperature is the same as the daily minimum temperature.

### **Wind**

Average daily wind speed. If blank, will default to 2 m/s.

### **Wind speed measurement height**

An adjustment can be made if the wind speed measurement height is known.)

For the calculation of evapotranspiration, wind speed measured at 2 m above the surface is required. However, an adjustment can be made if the wind speed measurement height is known.

### **Solar Radiation**

Daily solar radiation. If blank, WEAP will calculate using Sunshine Hours, Cloudiness Fraction or Hargreaves formula.

## Sunshine Hours

Actual number of daytime hours with no clouds. If blank, WEAP will use Cloudiness Fraction. If both Sunshine Hours and Cloudiness Fraction are blank, WEAP will use Hargreaves formula.


## Cloudiness Fraction

Fraction of daytime hours with no clouds (0.0=completely overcast, 1.0=no clouds). If blank, WEAP will use Sunshine Hours. If both Sunshine Hours and Cloudiness Fraction are blank, WEAP will use Hargreaves formula.

## Krs

Adjustment coefficient for Hargreaves radiation formula. Only needed if neither sunshine hours nor cloudiness fraction are available. Typical range is 0.16 - 0.19.

See also: [MABIA Calculation Algorithms](#)

**Entered on:**  Data View, Branch: Catchments, Category: Climate, Tabs: Precipitation, ETref, Min. Temperature, Max. Temperature, Latitude, Min. Humidity, Max. Humidity, Average Humidity, Wind, Wind speed measurement Height, Altitude, Sunshine Hours, Cloudiness Fraction, Solar Radiation, Krs.

## Yield

(These parameters apply to the [MABIA Method](#). For the FAO Method, see [FAO, Yield](#).)

## Potential Yield

The maximum potential yield, assuming an optimal supply of water. Actual yields will be lower if the plant undergoes stress due to insufficient water (i.e., depletion falling below the Readily Available Water threshold). See [MABIA Calculation Algorithms](#) for details on the yield reduction calculation. If the branch has multiple crops, use the [MultiCropValues](#) function to specify the potential yield for each crop. The [Potential Yield Wizard](#) can help build the MultiCropValues expression.

## Market Price

The market price of the crops. If the branch has multiple crops, use the [MultiCropValues](#) function to specify the market price for each crop. The [Potential Yield Wizard](#) can help build the MultiCropValues expression.

See also: [MABIA Calculation Algorithms](#)

**Entered on:**  Data View, Branch: Catchments, Category: Yield, Tab: Potential Yield, Market Price.

## Supporting Screens

### Crop Library

This screen is used in conjunction with the [MABIA Method](#) for catchment hydrology and crop water requirements.

WEAP comes with a built-in library of crop data for over 100 crops and land use types, some with multiple entries for different climates or regions of the world. (Many of these data and the descriptions of them come from FAO Irrigation and Drainage Paper No. 56. This document is an excellent resource for

computing crop water requirements. Full text is available online at <http://www.kimberly.uidaho.edu/ref-et/fao56.pdf> (PDF) and <http://www.fao.org/docrep/X0490E/X0490E00.htm> (HTML).) These data are used to estimate evapotranspiration, irrigation requirements, and yields. You can edit this library or add to it. Buttons on the toolbar at the top allow you to **add**, **delete** or **rename** crops. The **Copy** button will create a new crop as a copy of the highlighted crop. You can **export** one or more crops to a comma separated value (CSV) file, which can be edited in Excel or a text editor. All the crops currently shown on screen will be exported. You can **import** crops from a CSV file--new crops can be added in this way, or data for existing crops can be updated. When reading in from the file, WEAP will match both the crop name and typical planting month. This is because there can be multiple entries for the same crop, but with different planting dates. The format for the CSV file to import must be the same format as is created when exporting--the same columns of data in the same order. Each WEAP area (dataset) has its own copy of the Crop Library. Therefore, changes made to the library in one area will not affect the library of another area. You can use import and export to move values from one area's library to another.

By default, the Crop Library screen will at first show you only the crops that are currently in use in your area (those that have been assigned to catchment branches in the Data View, under [Land Use](#)). To see all crops in the library, change the selection in the upper left from "Show Only Crops in Use" to "Show Entire Crop Library." You can also search for a crop by entering all or part of its name or the name of its category, in the search box on the upper right of the toolbar. For example, type Fruit into the search box. You can view multiple crops at once (List View) or one at a time (Single View).

The following columns of information exist for each crop:

### Crop or Land Use

The name of the crop or land use, including a specific climate or region to which the data are relevant. Note that you can use the MABIA Method to model both agricultural crops as wells as non-agricultural land classes, such as forests and grasslands. The first "crop" in the list is a special one named "Fallow," which will automatically be used to model the days before and after other crops are active. For example, if spinach was planted April 15 - July 23, "Fallow" would be used from January 1 - April 14, and July 24 - December 31. If you would prefer to differentiate the fallow period after different crops, e.g., the period after a spinach crop vs. after a wheat crop, you could create other "Fallow" crops, such as "Fallow after spinach" and "Fallow after wheat", assign the appropriate characteristics to these after-harvest states, and then choose those fallow "crops" after the main crops in the [Crop Scheduling Wizard](#).

### Category

The crops are grouped into categories, such as Small Vegetables, Legumes, and Oil Crops. You can change the category of a crop using the selection box in the grid. You can also edit the list of categories--click the "Category" button on the toolbar at the top.

### Typical Planting Month

This text field is for information only. You will need to specify the planting day and month for any crops you use in your analysis. Note that in some cases there are multiple entries for the same crop (e.g., Lettuce (Mediterranean)) with different typical planting months. For example, look at Lettuce (Mediterranean), whose entries for April and Nov/Jan have different stage lengths (the Winter crop has a longer season).

### Stage Length

Stage length provides general lengths for the four distinct growth stages for various types of climates and locations: Initial period (planting or green ground cover), Crop Development period (from 10% ground cover until about 70% ground cover and higher), Mid-season period (from 70% ground cover to the

beginning of the late season period and the onset of senescence), and Late Season period (beginning of senescence or mid grain or frost-kill, or full senescence). Perennial crops should have a total growing period of 365 days.

The lengths of the initial and development periods may be relatively short for deciduous trees and shrubs that can develop new leaves in the spring at relatively fast rates. The rate at which vegetation cover develops and the time at which it attains effective full cover are affected by weather conditions in general and by mean daily air temperature in particular. Therefore, the length of time between planting and effective full cover will vary with climate, latitude, elevation and planting date. It will also vary with cultivar (crop variety). Generally, once the effective full cover for a plant canopy has been reached, the rate of further phenological development (flowering, seed development, ripening, and senescence) is more dependent on plant genotype and less dependent on weather.

The end of the mid-season and beginning of the late season is usually marked by senescence of leaves, often beginning with the lower leaves of plants. The length of the late season period may be relatively short (less than 10 days) for vegetation killed by frost (for example, maize at high elevations in latitudes  $> 40^{\circ}\text{N}$ ) or for agricultural crops that are harvested fresh (for example, table beets and small vegetables).

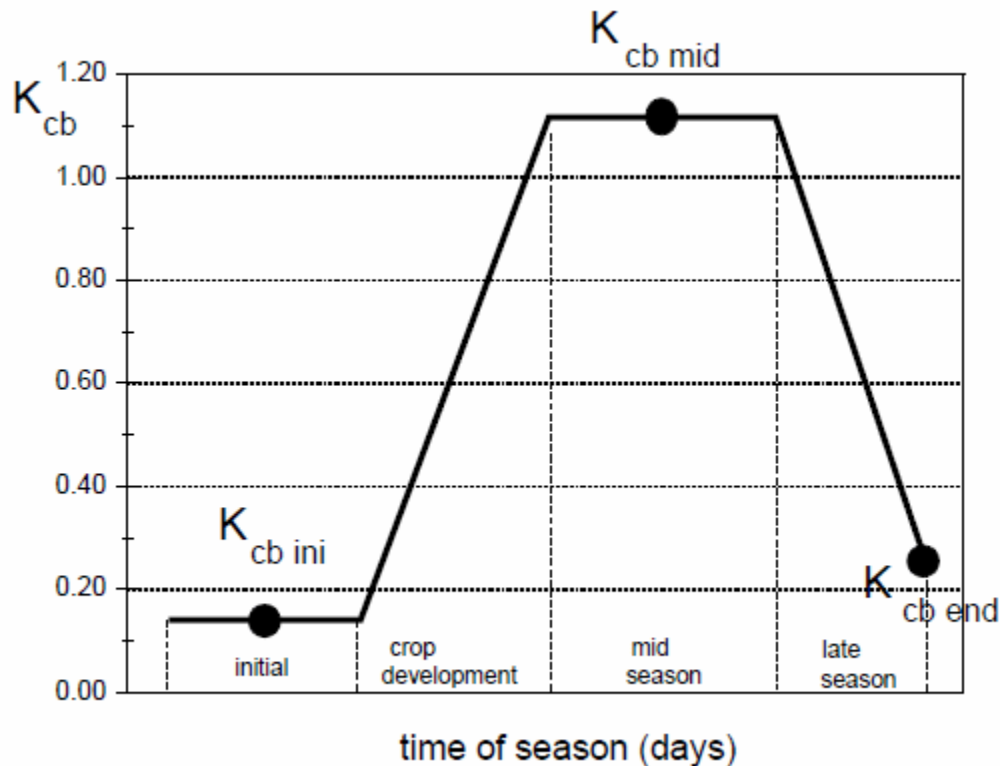
High temperatures may accelerate the ripening and senescence of crops. Long duration of high air temperature ( $> 35^{\circ}\text{C}$ ) can cause some crops such as turf grass to go into dormancy. If severely high air temperatures are coupled with moisture stress, the dormancy of grass can be permanent for the remainder of the growing season. Moisture stress or other environmental stresses will usually accelerate the rate of crop maturation and can shorten the mid and late season growing periods.

These values are useful only as a general guide and for comparison purposes. The listed lengths of growth stages are average lengths for the regions and periods specified and are intended to serve only as examples. Local observations of the specific plant stage development should be used, wherever possible, to incorporate effects of plant variety, climate and cultural practices.

### **$K_{cb}$**

The MABIA Method uses the 'dual'  $K_c$  method, whereby the  $K_c$  value is divided into a 'basal' crop coefficient,  $K_{cb}$ , and a separate component,  $K_e$ , representing evaporation from the soil surface. The basal crop coefficient represents actual ET conditions when the soil surface is dry but sufficient root zone moisture is present to support full transpiration. The crop coefficient curve represents the changes in  $K_{cb}$  over the course of the growing season, depending on changes in vegetation cover and physiology. During the initial period, shortly after planting of annuals or prior to the initiation of new leaves for perennials, the value of  $K_{cb}$  is often small. Only three values for  $K_{cb}$  are required to describe and construct the crop coefficient curve: those during the initial stage, the mid-season stage and at the end of the late season stage. A typical curve is illustrated below.





Many crops grown for forage or hay receive multiple harvests during the growing season. Each harvest essentially terminates a “sub” growing season and associated  $K_{cb}$  curve and initiates a new “sub” growing season and associated  $K_{cb}$  curve. The resulting  $K_{cb}$  curve for the entire growing season is the aggregation of a series of  $K_{cb}$  curves associated with each sub cycle. To handle this situation, the crop library has different entries for the first cutting and subsequent cuttings. (Search for alfalfa in the crop library to see an example.) Specify multiple crops (in the [Crop Scheduling Wizard](#)) for a particular branch, where the first crop chosen is that for the first cutting, and the second (and third) crop is for the crop specifying the subsequent cutting's parameters.

### Depletion Factor

The depletion factor is the fraction of total available water (TAW) that a crop can extract from the root zone without suffering water stress. The depletion factor normally varies from 0.30 for shallow rooted plants at high rates of  $ET_c$  ( $> 8$  mm d<sup>-1</sup>), to 0.70 for deep rooted plants at low rates of  $ET_c$  ( $< 3$  mm d<sup>-1</sup>). A value of 0.50 is commonly used for many crops.

### Yield Response Factor ( $K_y$ )

The response of yield to water supply is quantified by the yield response factor ( $K_y$ ) which relates relative yield decrease ( $1 - Y_a / Y_m$ ) to relative evapotranspiration deficit ( $1 - ET_a / ET_m$ ), where  $Y_a$ ,  $Y_m$ ,  $ET_a$  and  $ET_m$  represent actual and maximum yields and evapotranspiration. Hence, the  $K_y$  values for most crops are derived on the assumption that the relationship between relative yield ( $Y_a / Y_m$ ) and relative evapotranspiration ( $ET_a / ET_c$ ) is linear and is valid for water deficits of up to about 50% or  $1 - ET_a / ET_c = 0.5$ . The higher the yield response factor, the greater the decrease in yield for a given evapotranspiration deficit.

The yield response will vary according to the individual growth periods in which it occurs; these growth periods, ordered from least to most sensitive to evapotranspiration deficit, are: ripening, vegetative, yield

formation, and flowering. Although these growth periods do not exactly correspond to the four crop growth stages (initial, crop development, mid-season and late season), for the sake of simplicity they are considered the same. If you do not have data on  $K_y$  for individual growth periods, enter it in the column labeled "Overall."

### Maximum Height

The maximum height of the crop, which will occur in the mid-season stage.

### Minimum Root Depth

Initial depth of roots.

### Maximum Root Depth

Maximum depth of roots, which will occur in the mid-season stage. The rooting depth determines the total available water for evapotranspiration.

**See also:** [MABIA Calculation Algorithms](#)

**Menu Option:** General: Crop Library (only available if there is at least one catchment on the schematic whose method is "MABIA.")

## Soil Library (Texture Class)

This screen is used in conjunction with the [MABIA Method](#) for catchment hydrology and crop water requirements.

WEAP comes with a built-in library of soil data for the 12 standard texture classes defined by the US Department of Agriculture (USDA): Clay, Clay loam, Loam, Loamy sand, Sand, Sandy clay, Sandy clay loam, Sandy loam, Silt, Silt loam, Silty clay and Silty clay loam. (A thorough discussion of soil texture and these texture classes can be found at <http://edis.ifas.ufl.edu/SS169> . A more general discussion of soil and water can be found at <http://www.fao.org/docrep/r4082e/r4082e03.htm> .) In addition, a texture class named "Consolidated rock" represents a rocky surface that can hold no water. You can edit this library or add to it. Buttons on the toolbar at the top allow you to **add**, **delete** or **rename** texture classes. The **Copy** button will create a new texture class as a copy of the highlighted type. You can **export** all the texture classes to a comma separated value (CSV) file, which can be edited in Excel or a text editor. You can **import** texture classes from a CSV file--new texture classes can be added in this way, or data for existing texture classes can be updated. When reading in from the file, WEAP will match the texture class name to determine if the imported data represents a new texture class or changes to an existing texture class.

The format for the CSV file to import must be the same format as is created when exporting--the same columns of data in the same order. Each WEAP area (dataset) has its own copy of the Soil Library. Therefore, changes made to the library in one area will not affect the library of another area. You can use import and export to move values from one area's library to another.

The following columns of information exist for each texture class:

### Soil Type

The name of the texture class.

### Saturation

Fully saturated water, equivalent to effective porosity of the soil, where all the pore spaces are filled with water. Saturated soil quickly drains until it reaches field capacity.

### Field Capacity

Field capacity is defined as the amount of soil moisture or water content held in soil after excess water has drained away and the rate of downward movement has materially decreased. Irrigation or precipitation in excess of field capacity will quickly drain away (deep percolation), and is not available for crop evapotranspiration.

### Wilt Point

Minimum soil moisture at which a plant wilts, sometimes referred to as the "permanent wilting point." Once the soil moisture depletion reaches this level, the plant has died.

### Available Water Capacity

Available Water Capacity = Field Capacity - Wilt Point Available Water Capacity represents the available water that can be stored in soil and be available for growing crops.

Saturation, Field Capacity, Wilt Point and Available Water Capacity are all represented as the % of the total volume that contains water.

See also: [MABIA Calculation Algorithms](#)

**Menu Option:** General: Soil Library

## Crop Scheduling Wizard

This screen is used in conjunction with the [MABIA Method](#) for catchment hydrology and crop water requirements. It is accessible via the drop-down menu on the data grid for the Crops variable under [Land Use](#).

Each catchment branch represents a piece of land on which one or more crops is planted each year. For each branch, use the Crop Scheduling Wizard to specify which crop or crops (from the [Crop Library](#)) are planted and the planting date. (You can also choose one of the crop/planting dates already specified on another branch. This option is also available on the drop-down menu in the data grid.) Given the planting date and the crop stage duration, WEAP can determine the end date. Any days not under cultivation by a crop will automatically use the characteristics of the crop named "Fallow" in the Crop Library. You do not need to add Fallow in the Crop Scheduling Wizard.

At the top of the wizard, select the number of crops or cuttings per year. For example, if you had corn followed by winter wheat, you would enter 2; if you had an initial alfalfa crop with two subsequent cuttings, you would enter 3.

### Crop or Land Cover

Choose the crop from the crop library.

### Crop Season Length

The season length from the Crop Library (the sum of all four crop stages) will be displayed for information.

### Typical Planting Month

The typical planting month from the Crop Library will be displayed for information.

### Planting Date

Choose the day of the year on which the crop will be planted. For a subsequent cutting or harvest, typically the Planting Date would be the day after the previous crop's End Date.

### End Date

The Planting Date plus the season length determine the last day of the crop, and will be displayed for information.

Crops may not go past the end of the water year. Multiple crops or cuttings must not overlap dates. For perennial crops and land covers, choose the first day of the water year as the planting date, and make sure that the end date is the last day of the water year. If not, edit that crop in the Crop Library so that the stage lengths add up to 365 days.

See also: [MABIA Calculation Algorithms](#)

**Entered on:**  Data View, Branch: Catchments, Category: Land Use, Tab: Crops.

## Soil Profiles Wizard

This screen is used in conjunction with the [MABIA Method](#) for catchment hydrology and crop water requirements.

Because direct measurement of a soil's water holding capacity, including saturation, field capacity and wilt point, can be costly and time consuming, pedotransfer functions were developed to translate more easily obtainable data into these water holding capacity values. The [SoilProfiles](#) function estimates average soil water capacity (saturation, field capacity and wilt point) using one of seven available pedotransfer functions (PTF), in order to determine the Soil Water Capacity for catchment land use branches in the Data View, under [Land Use](#). This function can average over several soil profiles (sampling sites) and soil horizons (layers). Use the Soil Profiles Wizard, available on the drop-down menu in the data grid, to build this function. (As an alternative to using SoilProfiles, you can enter soil properties directly, or choose a texture class from the [Soil Library](#). These two options are also available on the drop-down menu in the data grid.)

A description of the seven pedotransfer functions and their parameters can be found in the description of the [SoilProfiles](#) function. Once you have entered the appropriate data into the Soil Profiles Wizard, click the Save button and WEAP will create the corresponding SoilProfiles expression that embodies this data. The following will describe how to enter this data into the wizard.

If you have soil profile data in a CSV file or Excel spreadsheet, you can read those in without having to retype the data. For a CSV file, click the Import button and browse to find the CSV file. To bring in the data from the Excel spreadsheet, copy the data from Excel onto the Windows clipboard and click the "Paste Special" button. In both of these cases, WEAP will read in the rows and columns of data (from CSV file or Windows clipboard), and display it in a new window, along with its best guess as to which variable each column represents. The data should be arranged so that each horizon of each layer is on its own row, and each column represents a different variable (e.g., profile number, horizon number, texture class, thickness, etc.). (If you are having problems getting the correct format for import, click the "Copy to Excel" button to see what a suitable structure would look like.)

Here is an example of the import structure for soil profile data if using the Particle Size pedotransfer function. (The columns for sand, saturation, field capacity, wilt point, and available water capacity are not required for import because they will be calculated by WEAP.)

Profile	Horizon	Thickness[m]	Coarse Fragments[%]	Clay[%]	Silt[%]
1	1	0.3	10	30	30

## 4.9 Catchments

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1	2	0.7	25	40	25
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If you do not have soil profile data already entered into a file, you can enter it into the wizard. First, choose the pedotransfer function to use in estimating soil water capacity. Next, indicate how many profiles (sampling sites) you have, and for each profile, how many horizons (layers) you have data for. The pedotransfer function you chose will determine which other data variables are required.

For each profile and horizon, WEAP will calculate and display the saturation, field capacity, wilt point, and available water capacity, and the weighted average across all profiles and horizons will be shown at the bottom on the row labeled "Average." These average values are what will be used for calculating soil moisture by the MABIA Method. Some data values will lead to numerical instability and will result in "error" being shown instead of calculated values. For example, the particle sizes (clay, silt and sand) cannot be too close to 0%.

After all the data is entered, you can click the Export button to save to a CSV file, or the "Copy to Excel" button to save it to an Excel file.

**See also:** [MABIA Calculation Algorithms](#)

**Entered on:**  Data View, Branch: Catchments, Category: Land Use, Tab: Soil Water Capacity.

### Irrigation Scheduling Wizard

This screen is used in conjunction with the [MABIA Method](#) for catchment hydrology and crop water requirements. It is accessible via the drop-down menu on the data grid for the "Irrigation Schedule" variable under [Irrigation](#).

A description of the irrigation methods can be found in the description of the [IrrigationSchedule](#) function. Once you have entered the appropriate data into the Irrigation Scheduling Wizard, click the Save button and WEAP will create the corresponding IrrigationSchedule expression that embodies this data. The following will describe how to enter this data into the wizard.

At the top of the wizard, select the number of irrigation schedules per year (for all crops combined). For example, if you had corn followed by winter wheat, and each had 1 irrigation schedule, you would enter 2. If the irrigation schedule expression was initially blank, when the Irrigation Scheduling Wizard starts WEAP will automatically add all crops defined for this branch, and set the default irrigation schedule for each: triggered at 100% of RAW, with an application of 100 % of Depletion. This will ensure that soil moisture depletion never goes below RAW so that no crop water stress will occur. Of course, you can make changes to these defaults.

Each row of the table defines one irrigation schedule, with the following columns of information:

#### Crop

Choose the crop for the irrigation schedule. Only the crops already chosen for this branch are available here for selection.

#### Crop Season Length

The season length from the Crop Library for this crop (the sum of all four crop stages) will be displayed for information.

#### Irrigation Start Date

Enter the number of the day on which this irrigation schedule takes effect, counting from the first day of the crop season. To start on the first day, enter 1.

**Irrigation End Date**

Enter the number of the day on which this irrigation schedule ends, counting from the first day of the crop season. To end on the last day, enter the crop season length.

**Irrigation Period**

The dates corresponding to the start and end days will be shown for information.

**Irrigation Trigger Method**

Select one of the four irrigation trigger methods, as described in the [IrrigationSchedule](#) function: Fixed Interval, % of RAW, % of TAW, Fixed Depletion. This will determine on which days irrigation will occur.

**Irrigation Trigger Value**

Enter the value that goes with the IrrigationTriggerMethod: days (fixed interval), % (% of RAW or % of TAW), mm (fixed depletion).

**Irrigation Amount Method**

Select one of the four irrigation amount methods, as described in the [IrrigationSchedule](#) function: % of Depletion, % of RAW, % of TAW, Fixed Depth. This will determine how much irrigation water to apply.

**Irrigation Amount Value**

Enter the value that goes with the IrrigationAmountMethod: % (% Depletion, % of RAW or % of TAW), mm (fixed depth).

Note: If there are gaps in the irrigation dates between schedules, there will be no irrigation during those periods. There is no irrigation in the fallow periods (before or after the crop season).

See also: [MABIA Calculation Algorithms](#)

**Entered on:**  Data View, Branch: Catchments, Category: Climate, Tab: Precipitation, ETreference.

**Potential Yield and Market Price Wizards**

This screen is used in conjunction with the [MABIA Method](#) for catchment hydrology and crop water requirements.

If you have any branches for which you have chosen multiple crops (see [Crop Scheduling Wizard](#)), you will need to use the [MultiCropValues](#) function to specify Potential Yield and Market Price. Use the Potential Yield and Market Price Wizards to enter this data. These two wizards are available on the drop-down menu in the data grid for the Potential Yield and Market Price variables, but only for those branches for which multiple crops have already been chosen.

See also: [MABIA Calculation Algorithms](#)

**Entered on:**  Data View, Branch: Catchments, Category: Climate, Tab: Precipitation, ETreference.

### 4.9.4 Linking Catchments to Rivers and Groundwater

#### Catchment Runoff to Rivers

Catchment Runoff can be directed to a river by dragging the Catchment Runoff symbol from the legend in the Schematic view to anywhere along the river. If the Catchment Runoff is to be Headflow to the river, the symbol can be placed anywhere above the first node of the river, and the dialog box that appears will ask you if the Catchment Runoff is to represent Headflow (See River Headflow for additional details).

Note that if you select a Catchment as a headflow source for a river, then under the Headflow variable tab for that river, it will be set/locked to "Inflow from Catchment".

Catchments must contribute runoff to one and only river node, and optionally to one groundwater node.

#### Catchment Runoff to Groundwater


Catchment Runoff can be directed to a groundwater node by dragging the Catchment Runoff symbol from the legend in the Schematic view to the particular node. A groundwater node can receive inflow from more than one Catchment, as well as other types of inflow input by Read from File or Expression methods (in contrast to Catchment Runoff designated as headflow to a river - other sources of headflow cannot be input for that river - see Catchment Runoff to Rivers).

If using the Soil Moisture (two-bucket) method to calculate Catchment Runoff, and Catchment Runoff is directed to a groundwater node from that Catchment, the Soil Moisture method becomes a "one-bucket" representation. (see Overview of Catchment Calculation Methods).

Catchments must contribute runoff to one and only river node, and optionally to one groundwater node.

#### Runoff Fraction

For catchments simulated with the Rainfall Runoff version of the FAO Crop Requirements Approach, the **Runoff Flow Routing** specifies the fraction of runoff generated by the catchment that is sent to each runoff flow destination. These flows must sum to 100% since they are a fraction of outflow.

**Entered on:**  Data View, Branch: Supply and Resources \ Runoff and Infiltration, Tab: Runoff Fraction

## 4.10 Supply and Resources

Given the monthly supply requirement established from the definitions of the system [Demand](#), and the definitions of Hydrology, the Supply and Resources section determines the amounts, availability and allocation of supplies, simulates monthly river flows, including surface/groundwater interactions and instream flow requirements, hydropower generation, and tracks reservoir and groundwater storage.

Supply and Resources include the following subsections:

- **Transmission Links:** transmission links carry water from local and river supplies to demand sites, subject to losses and physical capacity, contractual and other constraints.



- **Rivers and Diversions:** surface inflows to rivers, properties and operation of reservoirs and run-of-river hydropower facilities, instream flow requirements, surface water-groundwater interaction, and streamflow gauges.
- **Groundwater:** aquifer properties, storage and natural recharge..
- **Local Reservoirs:** reservoirs not on a river.
- **Other Supplies:** e.g., surface sources that are not modeled in your WEAP application, such as inter-basin transfers or desalination.
- **Return Flows:** wastewater from demand sites can be routed to one or more wastewater treatment plants, rivers, groundwater nodes or other supply sources; treated effluent from wastewater treatment plants can be routed to one or more rivers, groundwater nodes or other supply sources.

### 4.10.1 Getting Started

The following types of data are often useful:

- Streamflow gage records and their locations
- Estimates of streamflow for ungaged locations calculated using gage records, drainage area or other parameters
- Reservoir storage levels, volume-elevation relationships, net monthly evaporation rates, operating rules for fish and wildlife, recreation, hydropower, navigation, water supply and other conservation purposes
- Groundwater recharge rates, gains from and losses to rivers
- Instream flow requirements for recreation, water quality, fish and wildlife, navigation, other conservation purposes, and any downstream obligations
- Transmission link capacities and losses
- Wastewater and effluent routing
- Costs of delivered water

### 4.10.2 Specifying Hydrologic Inflows

## Specifying Hydrologic Inflows

An important aspect of modeling a water system is understanding how it operates under a variety of hydrologic conditions. Natural variations in hydrology--month to month and year to year--can have major effects on the results of your scenarios.

WEAP has four methods for projecting the surface water hydrology over the study period: [Water Year Method](#), [Expressions](#), [Catchments Runoff and Infiltration](#) and [Read From File Method](#). These methods may be used to project the inflow to every surface and groundwater inflow point in the system for every month in the study period. This includes river and tributary headflows, surface water inflows to river reaches, groundwater, local reservoir and other supply inflow.



### Water Year Method

The Water Year Method allows you to use historical data in a simplified form and to easily explore the effects of future changes in hydrological patterns. The Water Year Method projects future inflows by varying the inflow data from the [Current Accounts](#) according to the [Water Year Sequence](#) and [Definitions](#) specified in the Hydrology section. If you want to test a hypothetical event or set of events, or wish to approximate historic patterns, then you should probably select the Water Year Method. For example, you could use the Water Year Method to test the system under historic or hypothetical drought conditions. Hydrologic fluctuations are entered as variations from a Normal Water Year (the Current Accounts year is not necessarily a Normal water year). The Water Year Method requires data for defining standard types of water years ([Water Year Definition](#)), as well as defining the sequence of those years for a given set of scenarios ([Water Year Sequence](#)).


A **water year type** characterizes the hydrological conditions over the period of one year. The five types that WEAP uses--Normal, Very Wet, Wet, Dry, and Very Dry--divide the years into five broad categories based on relative amounts of surface water inflows.

### Water Year Definition

To define each non-Normal water year type (Very Dry, Dry, Wet, Very Wet), specify how much more or less water flows into the system in that year relative to a Normal water year. For example, if a Wet year has 25% more inflow than a Normal year, enter 1.25 for the Wet year. Typically, you would derive these fractions from a statistical analysis of historical flows. First you would group the years into five bins (quintiles), then compute how they vary from the norm, perhaps by month. Note: the [Current Accounts](#) year is not necessarily a Normal water year.

You may specify a single variation fraction for an entire water year type, or you may specify a different fraction for each month. Your data might show, for example, that the winter months of a Dry year average 50% of a Normal winter, while the summer months are closer to 75% of Normal summer inflows.

A simple way to explore sensitivity to climate change would be to define two scenarios. The first would use the Water Year Method to reproduce the observed variation in hydrology from the historical record. The second scenario would use the first as a starting point, but alter each water year type according to predicted effects of climate change (e.g., wetter winters and dryer summers).

**Entered on:**  Data View, Branch: Hydrology \ Water Year Method, Tab: Definitions (applies to scenarios only, not to the Current Accounts)


### Water Year Sequence

Once you have given definitions for each water year type ([Water Year Definition](#)), specify the sequence of water year types (Very Dry, Dry, Normal, Wet, Very Wet) in your study. The defined sequence of water year types will set inflow values for future years by applying the appropriate fluctuation coefficients to the Current Accounts inflows. Note: the Current Accounts year is not necessarily a Normal water year.

When using the Water Year Method, your assignment of water year types can be based upon a variety of considerations:

- past hydrologic patterns, for a simplified historical analysis (a frequency analysis of an annual inflow record at a representative river point may be useful)
- a specific future hydrologic occurrence, such as a 3-year drought, in which 3 Very Dry years occur sequentially

- climate change scenarios

**Entered on:**  Data View, Branch: Hydrology \ Water Year Method, Tab: Sequence

## Expressions

Inflows can be specified with a mathematical expression. Typical expressions include: constants (e.g., groundwater recharge that doesn't vary over time), a specified value for each month (this is usually how the Current Accounts inflow data is specified when you are using the Water Year Method to project future inflows--using the [Monthly Time-Series Wizard](#) can be helpful in establishing these data), or some other relationship (e.g., the headflow for an ungaged stream could be modeled as some fraction of the headflow in another river for which good data exists). You may also use the [ReadFromFile](#) function to read in data from a text file (not to be confused with the obsolete [Read from File Method](#), which uses a different ASCII file format).

WEAP allows you to mix these methods, using the Read From File method for some sources (e.g., one or two rivers for which you have historical streamflow data), the Water Year Method for others, and expressions for the rest. For example, the natural recharge for an aquifer might be relatively constant over time, so you would enter a constant for this value. As another example, you could use the Read From File method for the headflow and surface inflow of a major river, then use an expression for the minor rivers' inflows--perhaps a fraction of the flow in the main river. In this way, you could replicate the actual historical variation of the main river on the smaller rivers.

## Catchment Runoff and Infiltration

Catchment Runoff can be directed to rivers and groundwater nodes using a Runoff/Infiltration Link. These flows can be specified directly (for the Rainfall Runoff method) or WEAP can simulate, using the Soil Moisture Method, the amounts of runoff, soil moisture, and baseflow (groundwater inflow if a Runoff/Infiltration Link is created between the catchment and a groundwater node) generated by the catchment. See [Overview of Catchment Simulation Methods](#) for details.

## Read from File Method

**Note:** The Read from File Method is primarily of use for datasets created in older versions of WEAP. If you are creating a new text file for import into WEAP, use the [ReadFromFile](#) function instead.

If you have monthly data on inflows to some or all of your rivers and local supplies, the Read From File Method allows you to model the system using this sequence of inflows. The required file formats for these data files are given in [ASCII Data File Format for Monthly Inflows](#). You can export gaged inflow data from many conventional hydrologic databases into ASCII files, and then edit these files into the required format. (USGS has extensive streamflow data for the United States available for download from the Web at <http://water.usgs.gov>) For ungaged locations, you will have to calculate streamflow estimates prior to entering them into WEAP.

The monthly inflow data is not restricted to historical values. Your detailed projected monthly surface water assumptions can be based on historical data, or on projections from some external model, or a mixture of both. For example, you might want to modify historical flows to account for projected changes due to climate change. Or you could use outputs from a climate model to project future inflows.

You can choose different time intervals from the historical data files to simulate the system over various historical time periods. For instance, if your study period is twenty years and you have sixty years of

historical data, WEAP allows you to easily select any of the forty-one different twenty-year periods from the historical data, to explore the effects of various sequences of hydrologic conditions. Refer to ASCII Data File Format for Monthly Inflows for details.

**Entered on:** Data View, Branch: Hydrology \ Read from File

### 4.10.3 Transmission Links

## Linking Rules

Transmission links carry water from local and river supplies, as well as wastewater from demand sites and wastewater treatment plants, to demand sites, subject to losses and physical capacity, contractual and other constraints. A transmission link is also required to bring water to satisfy irrigation requirements in Catchments that have been indicated to have irrigation. Transmission links only transfer water in response to a demand. For example, if a transmission link connects a desalination plant (Other Supply) to a Demand Site, water will flow from the plant through the transmission link to the Demand Site only to satisfy demand, and only if the Demand Site did not get its supply requirement satisfied from other supplies.

Primarily, WEAP allocates water according to the demand priority associated with each demand site. The sites with the highest priorities (lowest numbers) get water first, followed by sites with lower priorities (higher numbers), as availability allows. This system is useful in times of shortage to ensure that the highest priority water uses (e.g., municipal or minimum instream flows) are satisfied. When there is plenty of water to satisfy everyone, demand priorities are unnecessary.

A secondary concern, in cases where a demand site is connected to more than one supply source, is determining the mix of supply from various sources. Perhaps a city prefers groundwater to surface water because of its quality, or a farmer prefers surface water to groundwater because of the pumping expense, yet they are connected to both sources to ensure reliability of supply. However, in many cases, you may not know the underlying reasons to explain a particular observed mix (e.g., 20% from groundwater, 80% from surface water), but you want to reproduce it.

WEAP includes **linking rules** to specify the mix of supply from multiple sources. These rules enable the analyst to match observed allocation patterns in the [Current Accounts](#) and model future changes in the scenarios.

## Supply Preference

Each demand site (and catchments with irrigation) with multiple sources can specify its preference for a source, due to economic, environmental, historical, legal or political reasons. In the above example, the agricultural site would have a preference of 1 for the river source, and 2 for the groundwater source. With no other constraints, the site would pull everything it could from the river, falling back on the aquifer only if there was a shortage of river water. See [Demand Priority, Supply Preferences and Allocation Order](#) for more information.

If there is no preference for sources (or a demand site has only one source), set the preference to 1.

## Maximum Flow: Volume

You can restrict the supply from a source, to model contractual or physical capacity limitations, or merely to match observations. For example, an agricultural site has a fixed allotment of river water, beyond which it must pump from groundwater. In this case, the demand site supply preference would be 1 for the

river and 2 for the aquifer, and the allotment would be entered for the river source under Maximum Flow: Volume.

The rate of restriction can be entered for any time scale. For example, physical capacities would be entered as cubic meters per second, while contractual limitations might be entered as million cubic meters per month or per year. If the time scale is year, then the demand site's [monthly variation](#) will be used to distribute the allotment monthly.

### Maximum Flow: % of Demand

You can also restrict the monthly flow along a transmission link by a percentage of the demand site's total monthly supply requirement. For instance, you might only know that a demand site got 20% of its yearly flow from one source and 80% from another. In this case, set the supply preferences for the sources to 1 and 2, respectively, then set the Maximum Flow: % of Demand for the preference 1 source to be its observed share (either 20% or 80%), and leave the preference 2 source unlimited. In general, you would choose the source more likely to experience shortages as the preference 1 source, in which cases the preference 2 source would meet the shortfall.


Another example for restricting flow as a percentage of demand would be for quality considerations. Perhaps one source is cheaper than another, but of inferior quality. You could estimate the maximum fraction of the poorer quality water you could use and still meet your water quality criteria. In this case, the cheaper source would have a higher preference than the more expensive one, and you would set its Maximum Flow: % of Demand accordingly.

In some cases, you might have restrictions both on Volume and % of Demand. For example, the volume constraint might represent a physical capacity, while the % of demand would model quality criteria (as mentioned above).

**Entered on:**  Data View, Branch: Supply and Resources \ Transmission Links, Category: Linking Rules, Tabs: Supply Preference, Maximum Flow Volume, Maximum Flow Percent of Demand

## Transmission Link Losses

**Loss from System (%)** and **Loss to Groundwater (%)** refer to the evaporative and leakage losses as water is carried by canals and/or conduits to demand sites and catchments. These loss rates are specified as a percentage of the flow passing through the link. Loss from System indicates water that disappears from WEAP's accounts, whereas Loss to Groundwater will flow into the groundwater node specified. You may include fractions for both, if, for example, there are both evaporative losses (Loss from System) as well as leakage losses that go to a groundwater node (Loss to Groundwater). NB: Do not include losses that are already accounted for as [demand site losses](#).


**Entered on:**  Data View, Branch: Supply and Resources \ Transmission Links, Category: Losses, Tabs: Loss from System, Loss to Groundwater

### 4.10.4 Groundwater

## Initial and Total Groundwater Storage Capacity

The **Storage Capacity** represents the maximum theoretically accessible capacity of the aquifer, while the **Initial Storage** is the amount of water initially stored there at the beginning of the first month of the Current Accounts Year. Among other factors, these data will depend on pump depths. Leave Storage Capacity blank to model unlimited capacity. WEAP maintains a mass balance of monthly inflows and


outflows in order to track the monthly groundwater storage volume. WEAP will not allow the storage volume to exceed the storage capacity (any excess will overflow, and be lost from the system). WEAP will not allow the storage volume to fall below zero (pumping will be restricted or stopped), unless you are [linking WEAP to MODFLOW](#), in which case the storage volume can be negative.

**Entered on:**  Data View, Branch: Supply and Resources \ Groundwater, Category: Physical, Tab: Initial and Total Storage Capacity

### Maximum Groundwater Withdrawal


The **Maximum Withdrawal** defines the maximum total amount that may be withdrawn from this aquifer in any month by all connected demand sites. In general, the maximum will be equal to the monthly pumping capacity of the well, although it may also depend on characteristics of the aquifer, such as hydraulic conductivity, aquifer specific yield, and hydraulic head (between the base and the rim of the pumping cone of depression).

If multiple demand sites are connected to a single aquifer each with their own wells (and thus their own individual constraints on pumping capacity), you could enter the individual pumping capacity limitations on the transmission links connecting the demand sites to the aquifer. In this case, the Maximum Withdrawal for the aquifer would be based on the above-mentioned hydraulic characteristics of the aquifer.

**Entered on:**  Data View, Branch: Supply and Resources \ Groundwater, Category: Physical, Tab: Maximum Withdrawal

### Natural Recharge

The **recharge** represents inflow to the groundwater source--inflows that are not explicitly modeled in WEAP (e.g., return flows). You may specify the inflow using the [Water Year Method](#), the [Read from File Method](#), or with an [expression](#). See [Specifying Inflow](#) for details. Note: do not use this variable if you are [linking WEAP to MODFLOW](#). Natural recharge is allowed to be less than zero, for example, to model lateral outflow from an aquifer to another aquifer outside the system.

**Entered on:**  Data View, Branch: Supply and Resources \ Groundwater, Category: Physical, Tab: Natural Recharge

### Groundwater Water Quality

#### <Constituent> Concentration

If you are [modeling water quality in a river](#) that has [inflow from a groundwater source](#), enter the concentration of each constituent in that inflow from groundwater to surface water. Note that the quality of water flowing **into** groundwater will not affect the quality of outflow specified here--groundwater quality is not modeled in WEAP due to the inherent complexities of such a system.

**Entered on:**  Data View, Branch: Supply and Resources \ Groundwater, Category: Water Quality, Tab: <Constituent> Concentration, Temperature

## Groundwater-Surface Water Interactions

In many watersheds, surface waters and groundwater are hydraulically connected. A stream can contribute to groundwater recharge (a "losing" stream) or can gain water from the aquifer (a "gaining" stream) depending on the level of groundwater in the aquifer. Groundwater levels respond to natural recharge from precipitation, but can also be influenced by irrigation in the watershed, where a portion of this water may recharge the aquifer rather than be taken up by the target crop.

To simulate groundwater interactions with surface waters, there are four options.

1. Specify directly the amount of groundwater inflow to a particular river or reach
2. Have WEAP model these interactions ([groundwater "wedge" connected to river](#))
3. Have WEAP model these interactions (deep soil layer of [Soil Moisture method](#) catchment)
4. [Link WEAP to MODFLOW](#)

To select option 1 or option 2, go to particular groundwater node in the Data view under the Groundwater branch of Supply and Resources, and click on the **Method** tab. For option 3, create one or more catchment nodes with infiltration links to the groundwater node and [enter data for the deep soil layer](#). If you are linking WEAP to MODFLOW, you should leave all surface water-groundwater interaction variables blank.

If you choose to specify the amount of groundwater inflow from or outflow to a river or reach (option 1), the values can input under the "Groundwater Inflow" and "Groundwater Outflow" tabs in the Inflows and Outflows section for that river or reach.

WEAP can also model groundwater-surface water interactions using a [stylized representation of the system](#) (option 2). Groundwater can be represented as a wedge that is symmetrical about the surface water body, such as a river; recharge and extraction from one side of the wedge will therefore represent half the total rate. The recharge or extraction volumes are dependent on the elevation between the groundwater table (the surface representing full saturation of aquifer pore spaces) relative to the wetted depth of the river (see definition below). The additional parameters required to use this method are:

**Wetted Depth:** the depth of the river. This value is used as the reference for comparison to the simulated groundwater elevation.


**Storage at River Level:** the groundwater storage volume at which the top of groundwater is level with the river.

**Specific Yield:** the porosity of the aquifer, represented as a fractional volume (a number greater than 0 and less than or equal to 1) of the aquifer.

**Hydraulic Conductivity:** a measure of the ability of the aquifer to transmit water through its pores, represented in units of length/time.

**Horizontal Distance:** a representative distance for the groundwater-river geometry, taken as the length from the farthest edge of the aquifer to the river.

In addition to these aquifer-specific parameters, you will need to enter the **Reach Length**--the horizontal length of the interface between the reach and linked groundwater--as data for each reach that is connected to the aquifer.

**Entered on:**  Data View, Branch: Supply and Resources \ Groundwater, Category: Physical, Tabs: Method, Hydraulic Conductivity, Specific Yield, Horizontal Distance, Wetted Depth, Storage at River Level



## Physical


### Local Reservoir Inflow

Local reservoirs by definition are modeled independently of river streamflow. For this reason, you must explicitly enter monthly inflows to local reservoir sources. The monthly inflows you enter should not include return flows from demand sites and wastewater treatment plants--WEAP will calculate the inflows from return flows separately. You may specify the inflow using the [Water Year Method](#), the [Read from File method](#), or with an [expression](#). See [Specifying Inflow](#) for details.

**Entered on:**  Data View, Branch: Supply and Resources \ Reservoir, Tabs: Inflow

### Reservoir Initial and Total Storage Capacity

The **Storage Capacity** represents the total capacity of the reservoir, while the **Initial Storage** is the amount of water initially stored there at the beginning of the first month of the [Current Accounts](#) year. WEAP maintains a mass balance of monthly inflows and outflows in order to track the monthly storage volume.

**Entered on:**  Data View, Branch: Supply and Resources \ Local or River \ Reservoir, Category: Physical, Tabs: Initial Storage (Current Accounts only), Storage Capacity

### Reservoir Volume Elevation Curve

In order to calculate the amount of evaporation and/or the amount of energy production from hydropower, WEAP must have a function to convert between volume and elevation. This function is defined by the points on the **Volume Elevation Curve**. Values between the points are interpolated. You must enter at least one point, corresponding to the total storage capacity of the reservoir. If you choose to model the reservoir as a box with straight sides, you do not need to enter any other points.

Click on **Add (+)** to add a new point. After you have at least one point (other than 0, 0), you can create or move points by clicking on the graph.

**Tip:** You can copy a two-column or two-row array of Volume-Elevation points from Excel and paste into the Volume-Elevation table in WEAP. Optionally, you can apply conversion factors to the volume or elevation data. When you do this paste, all existing data in the V-E table in WEAP will be erased, and replaced with the pasted data.

**Entered on:**  Data View, Branch: Supply and Resources \ Local or River \ Reservoir, Category: Physical, Tab: Volume Elevation Curve ([Current Accounts](#) only)

### Reservoir Maximum Hydraulic Outflow


Maximum reservoir outflow during the timestep due to hydraulic constraints. Typically this will be function of reservoir elevation at beginning of timestep (PrevTSValue(Storage Elevation)). Optional--no constraint if blank (i.e., no limit on outflow). Also, no constraint in timesteps when reservoir is completely full--water will overtop the reservoir at an unlimited rate. Normally, when there is no maximum hydraulic outflow constraint, WEAP will never allow reservoir storage to exceed the top of conservation. However, if there is a maximum hydraulic outflow constraint, it is possible for the reservoir storage to exceed the top of conservation in timesteps where releases from the reservoir equal the maximum hydraulic outflow.

See [River Reservoir Flows](#) for calculation algorithms.

**Entered on:** Data View, Branch: Supply and Resources \ Local or River \ Reservoir, Category: Physical, Tab: Maximum Hydraulic Outflow

## Reservoir Evaporation


The monthly evaporation rate can be positive or negative to account for the difference between evaporation and precipitation on the reservoir surface. A positive (negative) net evaporation represents a net loss from (gain to) the reservoir.

**Entered on:**  Data View, Branch: Supply and Resources \ Local or River \ Reservoir, Category: Physical, Tab: Net Evaporation

## Reservoir Losses to Groundwater


Seepage losses from reservoirs can be significant, particularly in lakes and unlined reservoirs. To model these losses, specify the groundwater node and flow to it for each timestep. Net gains from groundwater to the reservoir should be entered as negative numbers.

Reservoir losses to groundwater can also be used to model infiltration ponds and retention basins. This type of structure, one of several "Best Management Practices" (BMPs), is useful for holding stormwater runoff to allow it to recharge the aquifer, and as a means for reducing non-point source pollution runoff into surface water. Typically, this would be represented in WEAP by a catchment (to model the stormwater runoff) that runs off into a reservoir (with no operations--set the top of inactive equal to the total storage), which has losses to groundwater and overflows to a river (which flows into the received surface water body).

**Entered on:**  Data View, Branch: Supply and Resources \ Local or River \ Reservoir, Category: Physical, Tab: Loss to Groundwater

## Reservoir Observed Volume

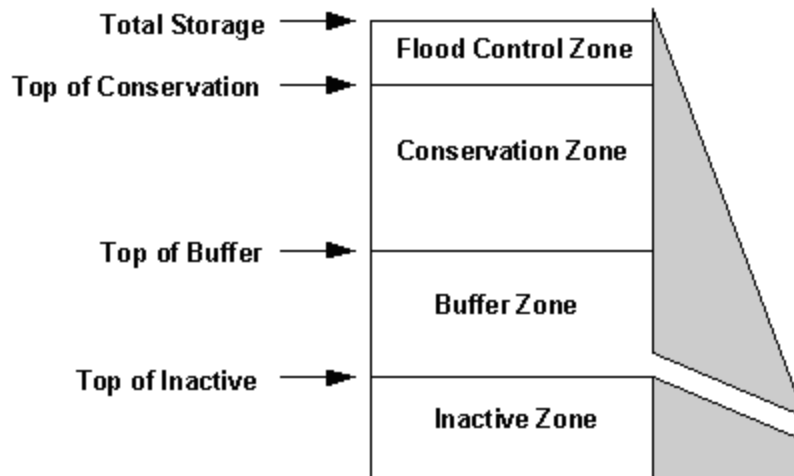
The **Observed Volume** represents

**Entered on:**  Data View, Branch: Supply and Resources \ Local or River \ Reservoir, Category: Physical, Tab: Observed Volume

## Reservoir Zones and Operation

Reservoir storage is divided into four zones, or pools. These include, from top to bottom, the flood-control zone, conservation zone, buffer zone and inactive zone. The conservation and buffer pools, together, constitute the reservoir's active storage. WEAP will ensure that the flood-control zone is always kept vacant, i.e., the volume of water in the reservoir cannot exceed the top of the conservation pool.






WEAP allows the reservoir to freely release water from the conservation pool to fully meet withdrawal and other downstream requirements, and demand for energy from hydropower. Once the storage level drops into the buffer pool, the release will be restricted according to the buffer coefficient, to conserve the reservoir's dwindling supplies. Water in the inactive pool is not available for allocation, although under extreme conditions evaporation may draw the reservoir into the inactive pool.

To define the zones, you enter the volumes corresponding to the top of each zone (**Top of Conservation**, **Top of Buffer** and **Top of Inactive**). WEAP uses the **Buffer Coefficient** to slow releases when the storage level falls into the buffer zone. When this occurs, the monthly release cannot exceed the volume of water in the buffer zone multiplied by this coefficient. In other words, the buffer coefficient is the fraction of the water in the buffer zone available each month for release. Thus, a coefficient close to 1.0 will cause demands to be met more fully while rapidly emptying the buffer zone, while a coefficient close to 0 will leave demands unmet while preserving the storage in the buffer zone. Essentially, the top of buffer should represent the volume at which releases are to be cut back, and the buffer coefficient determines the amount of the cut back. **Note:** The buffer coefficient determines how much of the water that is in the buffer zone at the *beginning* of a timestep is available for release during that timestep. However, this doesn't restrict WEAP from releasing some or all of water that flows into the reservoir *during* the timestep. Even if the buffer coefficient is 0, WEAP can still release any water that flows into the reservoir that timestep if needed to meet downstream or hydropower demands--in this case, the storage level will not decrease, but it may not increase either.

See [River Reservoir Flows](#) for calculation algorithms.

**Entered on:**  Data View, Branch: Supply and Resources \ Local or River \ Reservoir, Category: Operation, Tabs: Top of Conservation, Top of Buffer, Top of Inactive, Buffer Coefficient

## Hydropower Generation

*If the reservoir does not generate hydropower, simply leave this entire section blank.*


Hydropower will only be generated for flows up to the **Maximum Turbine Flow**. *Note: you must enter a non-zero value for maximum turbine flow in order to generate hydropower.* **Tailwater Elevation** defines the working water head on the turbine. The power generated in a given month depends on the head available, which is computed as the drop from the reservoir elevation (as computed by WEAP, using the [Volume Elevation Curve](#) and the storage volume at the beginning of the month) to the tailwater elevation. The **Plant Factor** specifies the percentage of each month that the plant is running. The plant **Generating**

**Efficiency** defines the generator's overall operation effectiveness in converting the energy of the falling water into electricity.

Optionally, to accommodate situations in which you want to prioritize reservoir releases to generate hydropower, there are two methods for specifying hydropower energy demands in WEAP: as individual energy demands for each reservoir or run of river hydropower, or as an aggregate energy demand at the system level. You can choose either method, or even use both at the same time. See [Supply and Resources\System Hydropower Demand](#) for more information about system-level aggregate energy demands.


If you specify a non-zero **Hydropower Priority** and **Energy Demand**, WEAP will convert the energy demand into an equivalent volume of water that must be released from the reservoir that month to satisfy that demand. (Because hydropower generation is a function of the distance the water falls, this required volume will vary as the reservoir elevation varies each month.) Depending on the hydropower priority, this release requirement will be satisfied either before, after or at the same time as other demands for water on the river. If the hydropower priority is zero, WEAP will not release water solely to generate hydropower. You may change the priority over time or from one scenario to another.

See [Hydropower Calculations](#) for calculation algorithms.

**Entered on:**  Data View, Branch: Supply and Resources \ Local or River \ Reservoir, Category: Hydropower, Tabs: Max. Turbine Flow, Tailwater Elevation, Plant Factor, Generating Efficiency, Hydropower Priority, Energy Demand

## Reservoir Water Quality

WEAP does not model water quality in lakes or reservoirs, due to uncertainties in vertical and longitudinal stratification and other processes. Therefore, if you are [modeling water quality in a river](#) (except if using QUAL2K), you must enter as data the concentrations of each constituent in water released from the river's reservoirs. (Leave blank if not modeling water quality in the river.) When using QUAL2K to model water quality in the river, you do not need to enter reservoir outflow water quality. In this case, the outflow water quality will be calculated by QUAL2K.

**Entered on:**  Data View, Branch: Supply and Resources \ River \ <River name> \ Reservoirs \ <reservoir name>, Category: Water Quality, Tabs: <Constituent Name> Concentration

## Reservoir Filling Priority

Determines the priority for filling of the reservoir. This priority can change over time or from scenario to scenario. Typically, this priority is set to 99 (the lowest possible priority), so that it will fill only after all other demands have been satisfied. If you had two reservoirs, you could fill one before the other by setting its priority to 98. Note: a reservoir can also have a priority for generating hydropower--see [Reservoir Hydropower](#) for details. See [Demand Priority, Supply Preferences and Allocation Order](#) for more information.


**Entered on:**  Data View, Branch: Supply and Resources \ River, Category: Reservoir, Tab: Priority

### 4.10.6 Other Supplies

"Other" supplies represent non-river supplies that have no storage capacity. Examples include streams or other unconnected rivers, inter-basin transfers or other imports, and desalination plants. Since these sources have no carry-over storage, unused supply from one month cannot be stored for next month's use.

However, the supply from an Other Supply can be stored in a reservoir, e.g., to model a desalination plant whose output is stored in a reservoir. To do this, use a transmission link to connect the Other Supply to the Reservoir. Alternatively, the Other Supply could be fed directly into a river or diversion (via a transmission link) for use downstream. The flow in the Other Supply will not flow along the transmission link unless there is a downstream demand that requests it, including a reservoir filling demand.

You may specify the monthly inflow using the [Water Year Method](#), the [Read from File Method](#), or with an [expression](#). See [Specifying Inflow](#) for details.


**Entered on:**  Data View, Branch: Supply and Resources \ Other Supplies, Tab: Inflow

### 4.10.7 Rivers and Diversions

## River Headflow

**Headflow** represents the average inflow to the first node on a river. Headflow can be specified either (1) as originating from a Catchment, with values calculated by the FAO or Soil Moisture Methods (see Overview of Catchment Calculation Methods), or (2) with values directly input with the Water Year Method, the Read from File Method, or an Expression (See [Specifying Hydrologic Inflows](#) for details). Note that if you select a Catchment as a headflow source for a river, then under the Headflow variable tab for that river, it will be set/locked to "Inflow from Catchment". You will not be able to enter additional headflow values for that river with the other methods.


With the direct input methods (such as the Read from File Method), the monthly inflows you enter should not include return flows from demand sites and wastewater treatment plants--WEAP will calculate the inflows from return flows separately.

**Entered on:**  Data View, Branch: Supply and Resources \ River \ <River Name>, Category: Inflows and Outflows, Tab: Inflow

## Maximum Diversion

Diversion nodes withdraw water from a river (or another diversion), and this diverted flow becomes the headflow for a diversion. A diversion is modeled in WEAP as a separate river, complete with river nodes, demands and return flows. WEAP will divert only as much water as needed to satisfy the demand sites connected to the diversion, and its instream flow requirements.

Typically, a diversion is an artificial conduit, such as a canal or pipeline. The **Maximum Diversion** represents the maximum amount that can be diverted, due to physical capacity, contractual or other constraints.

**Entered on:**  Data View, Branch: Supply and Resources \ River \ <Diversion Name>, Tab: Maximum Diversion

## Water Quality

WEAP can model the concentration of water quality constituents in a river using simple mixing and assuming conservative behavior, or with first-order decay and built-in BOD, temperature, and DO models, or by linking to QUAL2K. To indicate whether simulation of water quality parameters is desired, go to the *Data View* and click on *River* under *Supply and Resources*. Clicking on the *Water Quality* Category will access a window where you can select rivers for which you want to simulate water quality

parameters. For instance, you may choose to model water quality only on the main river but not on its tributaries. Here, you can also enter data for **BOD**, **temperature**, and other water quality constituents determined by the user--these data pertain to the headflow for a river. If you choose not to model water quality in a river, a concentration or temperature input here will be used as a value for the outflow of the river.

## Model Water Quality?

If you want to model water quality in a river, check off the box on the "Model Water Quality?" tab. In order to model water quality, you will also need to enter data on headflow (see "<Constituent> Concentration" below), [groundwater](#) and [other surface water inflow concentrations](#), reservoir outflow concentrations, [reach lengths](#), [flow-stage-width relationships](#) and [temperature](#) (for the BOD model). For example, you may choose to model water quality in only the main stem river, but not in its tributaries. In this case, check off "Model Water Quality?" for only the main river. Note: If linking to QUAL2K, you may only model water quality in one river.

## <Constituent> Concentration


For rivers that you have selected for WEAP to model water quality, enter the concentrations of each constituent in the headflow. This will serve as the initial condition for water quality in the river.

Alternatively, for any tributaries that WEAP will **not** model (the box for "Model Water Quality?" is not checked) but that flow into other rivers that WEAP **will** model, enter the concentration of each constituent in the tributary's outflow.

**Entered on:**  Data View, Branch: Supply and Resources \ River \ <River Name>, Category: Water Quality, Tabs: Model Water Quality?, <Constituent> Concentration

## Streamflow Gauge

Use the streamflow gauge object to facilitate comparing simulated and observed streamflows, both in terms of quantity and quality. On the schematic, place a gauge on the river of interest. Enter the data to specify the observed flow and water quality concentrations, typically using the [ReadFromFile](#) function. In Results, look at the Supply and Resources \ River \ Streamflow Relative to Gauge report to compare simulated and observed flows, and Water Quality \ Surface Water Quality to compare calculated and observed concentrations for each water quality constituent. The comparison is made between the gauge data and the simulated results at the river node immediately **above** the gauge.

**Entered on:**  Data View, Branch: Supply and Resources \ River \ Streamflow Gauges, Category: Inflows and Outflows, Water Quality, Tab: Streamflow Data, <Constituent> Concentration Data

## Reservoirs

River reservoirs provide storage of river water, provide a source of water for demand sites and downstream requirements, and generate hydropower. The reservoir simulation in WEAP takes into account net evaporation on the reservoir, priorities of downstream requirements and for hydropower energy demands, and the reservoir's operating rules.


## Physical

### Reservoir Initial and Total Storage Capacity

## 4.10 Supply and Resources

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The **Storage Capacity** represents the total capacity of the reservoir, while the **Initial Storage** is the amount of water initially stored there at the beginning of the first month of the [Current Accounts](#) year. WEAP maintains a mass balance of monthly inflows and outflows in order to track the monthly storage volume.

**Entered on:**  Data View, Branch: Supply and Resources \ Local or River \ Reservoir, Category: Physical, Tabs: Initial Storage (Current Accounts only), Storage Capacity

### Reservoir Volume Elevation Curve

In order to calculate the amount of evaporation and/or the amount of energy production from hydropower, WEAP must have a function to convert between volume and elevation. This function is defined by the points on the **Volume Elevation Curve**. Values between the points are interpolated. You must enter at least one point, corresponding to the total storage capacity of the reservoir. If you choose to model the reservoir as a box with straight sides, you do not need to enter any other points.

Click on **Add** (+) to add a new point. After you have at least one point (other than 0, 0), you can create or move points by clicking on the graph.

**Tip:** You can copy a two-column or two-row array of Volume-Elevation points from Excel and paste into the Volume-Elevation table in WEAP. Optionally, you can apply conversion factors to the volume or elevation data. When you do this paste, all existing data in the V-E table in WEAP will be erased, and replaced with the pasted data.

**Entered on:**  Data View, Branch: Supply and Resources \ Local or River \ Reservoir, Category: Physical, Tab: Volume Elevation Curve ([Current Accounts](#) only)

### Reservoir Maximum Hydraulic Outflow


Maximum reservoir outflow during the timestep due to hydraulic constraints. Typically this will be function of reservoir elevation at beginning of timestep (PrevTSValue(Storage Elevation)). Optional--no constraint if blank (i.e., no limit on outflow). Also, no constraint in timesteps when reservoir is completely full--water will overtop the reservoir at an unlimited rate. Normally, when there is no maximum hydraulic outflow constraint, WEAP will never allow reservoir storage to exceed the top of conservation. However, if there is a maximum hydraulic outflow constraint, it is possible for the reservoir storage to exceed the top of conservation in timesteps where releases from the reservoir equal the maximum hydraulic outflow.

See [River Reservoir Flows](#) for calculation algorithms.

**Entered on:** Data View, Branch: Supply and Resources \ Local or River \ Reservoir, Category: Physical, Tab: Maximum Hydraulic Outflow

### Reservoir Evaporation


The monthly evaporation rate can be positive or negative to account for the difference between evaporation and precipitation on the reservoir surface. A positive (negative) net evaporation represents a net loss from (gain to) the reservoir.

**Entered on:**  Data View, Branch: Supply and Resources \ Local or River \ Reservoir, Category: Physical, Tab: Net Evaporation

### Reservoir Losses to Groundwater


Seepage losses from reservoirs can be significant, particularly in lakes and unlined reservoirs. To model these losses, specify the groundwater node and flow to it for each timestep. Net gains from groundwater to the reservoir should be entered as negative numbers.

Reservoir losses to groundwater can also be used to model infiltration ponds and retention basins. This type of structure, one of several "Best Management Practices" (BMPs), is useful for holding stormwater runoff to allow it to recharge the aquifer, and as a means for reducing non-point source pollution runoff into surface water. Typically, this would be represented in WEAP by a catchment (to model the stormwater runoff) that runs off into a reservoir (with no operations--set the top of inactive equal to the total storage), which has losses to groundwater and overflows to a river (which flows into the received surface water body).

**Entered on:**  Data View, Branch: Supply and Resources \ Local or River \ Reservoir, Category: Physical, Tab: Loss to Groundwater

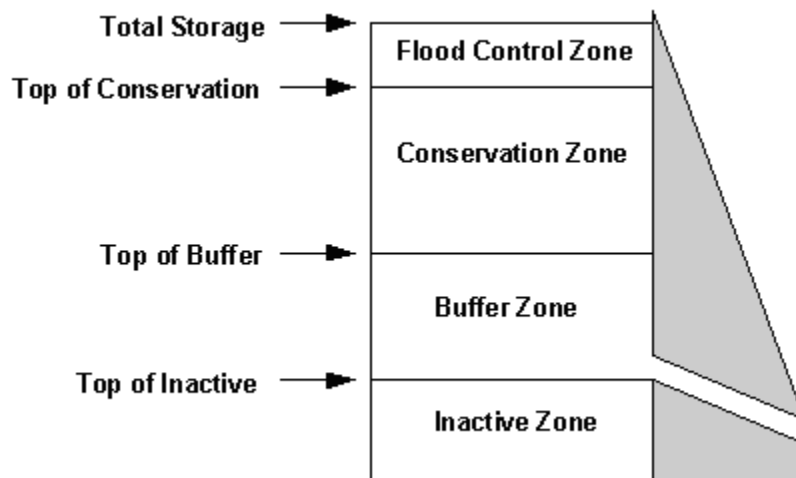
### Reservoir Observed Volume

The **Observed Volume** represents

**Entered on:**  Data View, Branch: Supply and Resources \ Local or River \ Reservoir, Category: Physical, Tab: Observed Volume

### Reservoir Zones and Operation

Reservoir storage is divided into four zones, or pools. These include, from top to bottom, the flood-control zone, conservation zone, buffer zone and inactive zone. The conservation and buffer pools, together, constitute the reservoir's active storage. WEAP will ensure that the flood-control zone is always kept vacant, i.e., the volume of water in the reservoir cannot exceed the top of the conservation pool.



WEAP allows the reservoir to freely release water from the conservation pool to fully meet withdrawal and other downstream requirements, and demand for energy from hydropower. Once the storage level drops into the buffer pool, the release will be restricted according to the buffer coefficient, to conserve the reservoir's dwindling supplies. Water in the inactive pool is not available for allocation, although under extreme conditions evaporation may draw the reservoir into the inactive pool.

To define the zones, you enter the volumes corresponding to the top of each zone (**Top of Conservation**, **Top of Buffer** and **Top of Inactive**). WEAP uses the **Buffer Coefficient** to slow releases when the storage level falls into the buffer zone. When this occurs, the monthly release cannot exceed the volume of water in the buffer zone multiplied by this coefficient. In other words, the buffer coefficient is the fraction of the water in the buffer zone available each month for release. Thus, a coefficient close to 1.0 will cause demands to be met more fully while rapidly emptying the buffer zone, while a coefficient close




## 4.10 Supply and Resources

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to 0 will leave demands unmet while preserving the storage in the buffer zone. Essentially, the top of buffer should represent the volume at which releases are to be cut back, and the buffer coefficient determines the amount of the cut back. **Note:** The buffer coefficient determines how much of the water that is in the buffer zone at the *beginning* of a timestep is available for release during that timestep.

However, this doesn't restrict WEAP from releasing some or all of water that flows into the reservoir *during* the timestep. Even if the buffer coefficient is 0, WEAP can still release any water that flows into the reservoir that timestep if needed to meet downstream or hydropower demands--in this case, the storage level will not decrease, but it may not increase either.

See [River Reservoir Flows](#) for calculation algorithms.

**Entered on:**  Data View, Branch: Supply and Resources \ Local or River \ Reservoir, Category: Operation, Tabs: Top of Conservation, Top of Buffer, Top of Inactive, Buffer Coefficient

### Hydropower Generation


*If the reservoir does not generate hydropower, simply leave this entire section blank.*

Hydropower will only be generated for flows up to the **Maximum Turbine Flow**. *Note: you must enter a non-zero value for maximum turbine flow in order to generate hydropower.* **Tailwater Elevation** defines the working water head on the turbine. The power generated in a given month depends on the head available, which is computed as the drop from the reservoir elevation (as computed by WEAP, using the [Volume Elevation Curve](#) and the storage volume at the beginning of the month) to the tailwater elevation. The **Plant Factor** specifies the percentage of each month that the plant is running. The plant **Generating Efficiency** defines the generator's overall operation effectiveness in converting the energy of the falling water into electricity.

Optionally, to accommodate situations in which you want to prioritize reservoir releases to generate hydropower, there are two methods for specifying hydropower energy demands in WEAP: as individual energy demands for each reservoir or run of river hydropower, or as an aggregate energy demand at the system level. You can choose either method, or even use both at the same time. See [Supply and Resources\System Hydropower Demand](#) for more information about system-level aggregate energy demands.

If you specify a non-zero **Hydropower Priority** and **Energy Demand**, WEAP will convert the energy demand into an equivalent volume of water that must be released from the reservoir that month to satisfy that demand. (Because hydropower generation is a function of the distance the water falls, this required volume will vary as the reservoir elevation varies each month.) Depending on the hydropower priority, this release requirement will be satisfied either before, after or at the same time as other demands for water on the river. If the hydropower priority is zero, WEAP will not release water solely to generate hydropower. You may change the priority over time or from one scenario to another.


See [Hydropower Calculations](#) for calculation algorithms.

**Entered on:**  Data View, Branch: Supply and Resources \ Local or River \ Reservoir, Category: Hydropower, Tabs: Max. Turbine Flow, Tailwater Elevation, Plant Factor, Generating Efficiency, Hydropower Priority, Energy Demand

### Reservoir Water Quality

WEAP does not model water quality in lakes or reservoirs, due to uncertainties in vertical and longitudinal stratification and other processes. Therefore, if you are [modeling water quality in a river](#) (except if using QUAL2K), you must enter as data the concentrations of each constituent in water released from the river's reservoirs. (Leave blank if not modeling water quality in the river.) When using

QUAL2K to model water quality in the river, you do not need to enter reservoir outflow water quality. In this case, the outflow water quality will be calculated by QUAL2K.

**Entered on:**  Data View, Branch: Supply and Resources \ River \ <River name> \ Reservoirs \ <reservoir name>, Category: Water Quality, Tabs: <Constituent Name> Concentration

## Reservoir Filling Priority

Determines the priority for filling of the reservoir. This priority can change over time or from scenario to scenario. Typically, this priority is set to 99 (the lowest possible priority), so that it will fill only after all other demands have been satisfied. If you had two reservoirs, you could fill one before the other by setting its priority to 98. Note: a reservoir can also have a priority for generating hydropower--see [Reservoir Hydropower](#) for details. See [Demand Priority, Supply Preferences and Allocation Order](#) for more information.

**Entered on:**  Data View, Branch: Supply and Resources \ River, Category: Reservoir, Tab: Priority


## Run of River Hydropower

Hydropower will only be generated for flows up to the **Maximum Turbine Flow**. *Note: you must enter a non-zero value for maximum turbine flow in order to generate hydropower.* The **Fixed Head** defines the working water head on the turbine--the distance the water falls. The **Plant Factor** specifies the percentage of each month that the plant is running. The plant **Generating Efficiency** defines the generator's overall operation effectiveness in converting the energy of the falling water into electricity.

Optionally, to accommodate situations in which you want to prioritize reservoir releases to generate hydropower, there are two methods for specifying hydropower energy demands in WEAP: as individual energy demands for each reservoir or run of river hydropower, or as an aggregate energy demand at the system level. You can choose either method, or even use both at the same time. See [Supply and Resources\System Hydropower Demand](#) for more information about system-level aggregate energy demands.

**Individual energy demands:** If you specify a non-zero **Hydropower Priority** and **Energy Demand**, WEAP will convert the energy demand into an equivalent volume of water that must flow through the hydropower plant that month to satisfy that demand. Depending on the hydropower priority, this flow requirement will be satisfied either before, after or at the same time as other demands for water on the river. If the hydropower priority is zero, WEAP will not release water from upstream reservoirs solely to generate hydropower at this run of river plant. You may change the priority over time or from one scenario to another. See [Demand Priority, Supply Preferences and Allocation Order](#) for more information.

See [Hydropower Calculations](#) for calculation algorithms.

**Entered on:**  Data View, Branch: Supply and Resources \ River \ <River Name> \ Run of River Hydro, Tabs: Max. Turbine Flow, Plant Factor, Generating Efficiency, Fixed Head, Hydropower Priority, Energy Demand

## Minimum Flow Requirement


A **Minimum Flow Requirement** defines the minimum monthly flow required along a river to meet water quality, fish & wildlife, navigation, recreation, downstream or other requirements. Depending on its demand priority, a flow requirement will be satisfied either before, after or at the same time as other demands on the river.



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You may change the **Priority** over time or from one scenario to another. See [Demand Priority, Supply Preferences and Allocation Order](#) for more information.

**Entered on:**  Data View, Branch: Supply and Resources \ River \ <River Name> \ Flow Requirements, Tab: Minimum Flow Requirement

## Reaches

### Inflows and Outflows

In many watersheds, surface waters and groundwater are hydraulically connected. A stream can contribute to groundwater recharge (a "losing" stream) or can gain water from the aquifer (a "gaining" stream) depending on the level of groundwater in the aquifer. These flows between surface water and groundwater can be handled in WEAP in one of two ways.

Either

you can **specify directly** how much flows from surface to groundwater (**Groundwater Outflow**) and from groundwater to surface water (**Groundwater Inflow**),

or

**WEAP can model** these flows based on the level of the groundwater table and the **Reach Length**. For more information, see [Groundwater-Surface Water Interactions](#).


In addition to flows to and from groundwater, flow on river reaches can be reduced by **Evaporation** and increased by **Surface Water Inflow**.

Both **evaporation** losses and **groundwater outflow** are specified as percentages of streamflow, while **surface water inflow** and **groundwater inflow** are entered as volumes.

Surface water inflow represents either non-point runoff into the river, or the confluence of streams or rivers not otherwise modeled. You may specify this inflow using the [Water Year Method](#), the [Read from File Method](#), or with an [expression](#). See [Specifying Inflow](#) for details.

For groundwater interactions, you must specify to which Groundwater Source each reach is connected.

If a reach is connected to a groundwater node for which you've chosen to model the flows based on the level of the water table, then you will need to enter the **Reach Length**--the horizontal length of the interface between the reach and linked groundwater.

**Entered on:**  Data View, Branch: Supply and Resources \ River \ <River Name> \ Reaches, Category: Inflows, Tabs: Surface Water Inflow, Groundwater Inflow, Groundwater Outflow, Evaporation, Reach Length.

### Climate Data

Climate data is needed for each reach if you want WEAP to model water temperature. The climate parameters include:


- **Air Temperature** - the weighted mean of high and low temperature.
- **Humidity** - relative humidity
- **Wind** - average wind speed in m/s. Default is 2 m/s.
- **Cloudiness Fraction** - fraction of daytime hours with no shade from clouds, vegetation or topography (0.0=completely overcast or shaded, 1.0=no clouds or shade). Default is 1 (no shade).

- **Latitude** - in degrees

If you are using QUAL2K to model water temperature, the following climate parameters are required:

- **Air Temperature** - the weighted mean of high and low temperature for the timestep.
- **Dew Point Temperature** - temperature to which the air would have to cool in order to reach saturation. The closer dew point is to the air temperature, the higher the relative humidity. Dew point cannot be higher than air temperature.
- **Wind** - average wind speed
- **Cloud Cover** - average percent of daytime that the river is shaded by clouds
- **Shade** - percent of solar radiation that is blocked because of shade from topography and vegetation.

Whether modeled by WEAP or QUAL2K, if any of the climate data for a reach are left blank, the values from the immediate upstream reach will be used. Therefore, if the climate is the same for all reaches, you only need to enter the data for the first reach.

**Entered on:**  Data View, Branch: Supply and Resources \ River \ <River Name> \ Reaches, Category: Climate, Tabs: Air Temperature, Humidity, Wind, Latitude, Dew Point Temperature, Cloud Cover, Shade.

## River Reach Water Quality Parameters

If you are [modeling water quality in a river](#), you must enter the following data:

### Distance Marker

In order to model decay within a reach, WEAP must know how long that reach is. Enter the distance marker for the top of each reach. The distance markers should be increasing as you go downstream. The first reach does not need to start with 0. Finally, enter the distance marker for the bottom of the river (the bottom of the last reach). If you leave any reaches blank, WEAP will use the relative lengths from the schematic to estimate the reach lengths. At a minimum, you must enter the distance for the top of the first reach and the bottom of the last reach. To change the distance marker unit, go to the "Rivers" tab of the [General, Units](#) screen. Note: this data is entered only for Current Accounts.

### Flow Stage Width

WEAP uses a flow-stage-width function to derive the velocity (e.g., m/s) of a stream from its flow rate (e.g., m<sup>3</sup>/s). Using the FlowStageWidthCurve function, you will enter data points relating flow to stage (depth) and width. The "FlowStageWidth wizard" will facilitate data entry. The wizard will calculate the corresponding velocity at each data point, which is useful as an error check, since the velocity should increase as the flow rate increases. If the characteristics of a reach are similar to the reach above, you can leave it blank and it will use the FlowStageWidthCurve from the reach above. To change the stage and width unit, go to the "Rivers" tab of the [General, Units](#) screen. Note: this data is entered only for Current Accounts. Note: If you are using QUAL2K to calculate water quality, you do not enter flow-stage-width data in WEAP but in QUAL2K.

### Water Temperature

If you have chosen to model BOD and DO but have chosen not to model river water temperature (the method for the temperature water quality constituent is "Temperature (Data)"), you will need to enter the water temperature for each reach. WEAP will use values from the immediate upstream reach if you leave


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this value If you are modeling BOD, you must enter the water temperature of each reach. To use the value from the upstream reach, leave blank.

### <Constituent> Concentration

For reaches on which you have specified [Surface Water Inflow](#), enter the concentration of each constituent.

**Entered on:**  Data View, Branch: Supply and Resources \ River \ <River Name>, Category: Water Quality, Tabs: Distance Marker (Current Accounts only), Flow Stage Width (Current Accounts only), <Constituent> Concentration

## Other River Nodes

The following river nodes have no data associated with them--they serve to mark the points of inflow and outflow from a river.

**Withdrawal nodes**, which represent points where any number of demand sites receive water directly from a river.

**Diversion nodes**, which divert water from a river or other diversion into a canal or pipeline called a diversion. This diversion is itself, like a river, composed of a series of reservoir, run-of-river hydropower, flow requirement, withdrawal, diversion, tributary, catchment inflow and return flow nodes.

**Tributary nodes** define points where one river joins another. The inflow from a tributary node is the outflow from the tributary river.

**Return flow nodes**, which represent return flows from demand sites and wastewater treatment plants. (You may actually have return flows enter the river at any type of river node: reservoir, run-of-river, tributary, diversion, flow requirement, withdrawal, catchment inflow or return flow node.)


**Catchment Inflow flow nodes**, which represent runoff inflow from catchments. (You may actually have catchment inflows enter the river at any type of river node: reservoir, run-of-river, tributary, diversion, flow requirement, withdrawal, catchment inflow or return flow node.)

### 4.10.8 Return Flows

## Return Flow Routing

There is a distinction between wastewater that is routed to and directly reused by another demand site (green transmission links) and wastewater return flow that is routed to one or more wastewater treatment plants, rivers, groundwater nodes or other supply sources (red return flow links). These data in this section pertain to the latter (red return flow links). Even if the outflow from a demand site or wastewater treatment plant is being reused directly by another demand site, there must still be at least one return flow link to carry away any wastewater that is not reused.

The **Return Flow Routing** specifies the fraction of demand site outflow (water supplied to the demand site minus consumptive losses and minus reuse by other demand sites) or wastewater treatment plant outflow (inflow to the treatment plant minus any water lost in processing and minus reuse by other demand sites) that is sent to each return flow destination. The percentages should sum to 100%. Note: the routing fractions do not include any losses along the return flow link--these are specified below in [Return Flow Losses](#).

**Entered on:**  Data View, Branch: Supply and Resources \ Return Flows \ <Demand Site Name>, Tab: Return Flow Routing

## Losses and Gains in Return Links

**Loss from System** and **Loss to Groundwater** refer to the evaporative and leakage losses as wastewater is carried by canals and/or conduits from demand sites and wastewater treatment plants. These loss rates are specified as a percentage of the flow passing through the link. Loss from System indicates water that disappears from WEAP's accounts, whereas Loss to Groundwater does not disappear, but will flow into the groundwater node specified. You may include fractions for both, if, for example, there are both evaporative losses (Loss from System) as well as leakage losses that go to a groundwater node (Loss to Groundwater). Losses to groundwater in which there is no groundwater node defined in WEAP should be entered as Loss from System.

**Gain from Groundwater** deals with infiltration from groundwater into the return flow link. Infiltration, typically via cracked pipes, can lead to sewer overflows and increased wastewater treatment costs. To model infiltration, specify the groundwater node and the amount of inflow.

**Entered on:**  Data View, Branch: Supply and Resources \ Return Flows \ <Demand Site Name>, Tabs: Loss from System, Loss to Groundwater, Gain from Groundwater

## 4.11 System Hydropower Demand

To accommodate situations in which you want to prioritize reservoir releases to generate hydropower, there are two methods for specifying hydropower energy demands in WEAP: as individual energy demands for each reservoir, or as an aggregate energy demand at the system level. You can choose either method, or even use both at the same time, even setting different priorities for the system demand and the individual demands. See [Reservoir Hydropower](#) for more information about individual reservoir hydropower demands.

If you specify a non-zero **System Hydropower Priority** and **System Hydropower Energy Demand**, WEAP will attempt to release water from **Selected Reservoirs** in order to meet that demand. Depending on the priority, this release requirement will be satisfied either before, after or at the same time as other demands for water on the river. You may change the priority over time or from one scenario to another. See [Demand Priority, Supply Preferences and Allocation Order](#) for more information.

See [Hydropower Calculations](#) for calculation algorithms.

**Entered on:**  Data View, Branch: Supply and Resources, Category: Hydropower, Tabs: System Hydropower Priority, System Hydropower Energy Demand, Selected Reservoirs

## 4.12 Water Quality

### 4.12.1 Getting Started

The Water Quality section tracks point and non-point source pollution from generation to treatment to its accumulation in surface and underground bodies of water and transport and decay in rivers. Instream water quality can be modeled within WEAP, or by linking to QUAL2K.

On the [Water Quality Constituents](#) screen you can turn on or off water quality modeling, and specify the list of constituents and how they are modeled.

## 4.12 Water Quality

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The Water Quality section of the Data View includes data on [Pollutant Decrease in Return Flows](#) and [Wastewater Treatment](#), both described below. Other water quality data are describe above in the Demand and Supply sections: [Pollution generation by demand sites and catchments](#), [River Water Quality](#), [Reach Water Quality Parameters](#), [Reservoir Water Quality](#) and [Groundwater Water Quality](#).

The following types of data are often useful:

- Pollution discharges, their locations and quantities.
- Non-point source pollution concentrations
- Minimum water quality standards
- Wastewater treatment plant ratings for pollutant removal
- River water temperature in river reaches
- Climate data
- River flow-stage-width relationships
- River length
- Concentrations of water quality constituents in headflows, reservoir outflows, groundwater and surface water inflows

### 4.12.2 Pollutant Decrease in Return Flows

Some pollutants decay or are otherwise lost en route from demand sites, catchments or wastewater treatment plants to their destinations. For each return flow link, enter the % decrease of each pollutant while flowing through the link. If no change, enter 0 or leave blank.

**Entered on:**  Data View, Branch: Water Quality \ Pollutant Decrease in Return Flows, Tabs: <Constituent Name> Decrease

### 4.12.3 Wastewater Treatment

In WEAP, a wastewater treatment plant accepts wastewater from demand sites and treats it to remove pollutants. The treated effluent can be reused directly by other demand sites (green transmission links) or routed to rivers, aquifers and other supplies (red return flow links). You may also model combined sewer overflow (CSO) of stormwater. To do this, use a catchment to model stormwater runoff, and route the catchment's runoff to the wastewater treatment plant. Enter a daily capacity for the plant. In timesteps where the combined runoff and wastewater inflow to the treatment plant exceeds its capacity, the excess will overflow, causing untreated wastewater mixed with stormwater to flow through the wastewater return flow links.

## Daily Capacity

Enter the maximum daily processing capacity of the treatment plant, or leave blank for no capacity limitation. Flows exceeding this limit will not be treated, flowing untreated through the wastewater return flow links.

## Consumption

Enter the consumptive losses for the treatment plant--water that is lost to evaporation or treatment or otherwise unaccounted for. These amounts are lost from the system. Consumption is entered as a fraction of the treatment plant inflow.


Treatment can be specified by two different methods: removal rate or outflow concentration. For each constituent, specify either removal rate or outflow concentration, but not both.

## Removal Rate

The removal rates will typically vary among wastewater treatment plants and among the different types of pollutants. Enter the % (by weight) of each pollutant that is removed by treatment.

## Outflow Concentration

Enter the concentration of the constituent in the outflow.

**Entered on:**  Data View, Branch: Water Quality \ Wastewater Treatment, Tabs: Daily Capacity, Consumption, <Constituent Name> Removal, <Constituent Name> Concentration

## 4.13 Financial Analysis

The financial planning module within WEAP provides a method for calculating costs and benefits associated with scenarios. Fixed and variable costs and fixed and variable benefits can be associated with each item in a WEAP schematic, including: reservoirs, transmission links, rivers, diversions, return links, groundwater supplies, other supplies, hydroelectric plants, wastewater treatment plants, and demand nodes. In addition, capital cost, fixed operating cost and benefits can be entered for the entire system.

Three report types are provided that present the output of the financial analysis:

- **Net costs** - Data from the net costs report can be used to create a ledger showing costs and benefits associated with planning scenarios.
- **Net present value** - With the use of a discount rate, the results can also be presented in the form of net present value, providing a method for comparing future infrastructure projects or demand management programs with different completion dates.
- **Average cost of water** - The average cost of water report divides total costs by the total volume of water delivered to demands and provides a way to compare the per unit costs across various scenarios.

For each item in a WEAP schematic, costs can be subdivided into capital and operations costs. Operations costs can be further subdivided into fixed (per year) and variable (per unit of water) costs. Benefits for each item can be subdivided into fixed and variable categories as well. All financial data entered for capital costs, fixed operations costs, and fixed benefits must be annual values. For instance, if a user enters a capital cost that represents loan payments, the total annual payments are entered. Financial data can also be entered for the entire supply and resources system--see [Entering System Costs and Benefits](#).

### 4.13.1 Entering System Costs and Benefits

Financial data can be entered for the entire supply and resources system as a whole, in addition to individual items. Capital Costs, Operations Costs, and Benefit can be entered either as a single value for application in all years, or by using a function such as [Interp](#) or [LoanPayment](#) to calculate the value. The system variables can be used to enter costs and benefits not directly associated with an individual item in the model, to enter sunk costs, or if you choose not to disaggregate costs. Note that these values are represented as fixed costs or benefits - they do not vary with the flows that are calculated during a simulation. To enter costs that do vary with flows, data must be input at the level of the individual item.

These system-wide variables include:

- Capital Costs
- Operations and Management costs
- Benefit

**Entered on:**  Data View, Branch: Supply and Resources, Tabs: Capital Costs, O and M Costs, Benefit.

### 4.13.2 Entering Item Costs and Benefits

#### Costs

For each individual item (such as demand nodes, transmission links, treatment plants and reservoirs), costs can be entered as capital, fixed operation, and variable operation costs. These variables can be accessed by right clicking on an item in the Schematic View. The dropdown menu provides a list of all the variables associated with the item. These variables can also be accessed by navigating through the **Data View** screen to the item of interest, then clicking on the **Cost** tab.

Cost variables include:


- **Capital Costs** - the principal of the loan, in dollars. Capital costs represent the investment in project construction and are often financed. WEAP provides the [LoanPayment](#) function for calculation of the annual payment on a loan. This feature can be used in the expression builder, and includes variables such as the principal value, length of loan and year to initiate payments, and interest rate. For example, for a wastewater treatment plant built in 2005 for \$50,000,000 and financed with a 30-year loan at 5% interest, the expression would be `LoanPayment(50000000, 2005, 30, 5%)`.
- **Fixed Operating Costs** - costs from annual operations and management that are not a function of the volume of water produced, transmitted, or consumed by an item. For example, the labor cost of running the wastewater treatment plant does not vary according to how much wastewater is treated. Therefore, labor would be a fixed annual cost.
- **Variable Operating Costs** - costs from operations and management that are represented as per unit of water produced, transmitted, or consumed by an item. The quantities of water subject to these costs can include demand site supply inflows, reservoir releases, river headflow, flows in river reach transmission links and return flow links, groundwater pumping, wastewater treatment plant inflows (outflows may differ if in-plant losses occur), flows into tops of diversions from rivers, and flow requirements (total flow at that point). For example, processing costs at a wastewater treatment plant, including chemicals, filters and energy costs, will vary according to the volume of wastewater treated. Therefore, these costs are considered variable operating costs and entered as a cost per volume of water (e.g., cubic meter) treated.

#### Benefits



Benefit variables can be accessed in a similar manner as the cost variables. You can right click on an item in the Schematic View or by navigating the Data View. Three types of benefits can be modeled in WEAP:


- Fixed Benefit--this value represents the total annual benefit produced by an item that is not a function of the volume of water produced, transmitted, or consumed by an item.
- Variable Benefit--benefit expected per unit of water produced, transmitted, or consumed by a model item. Use the [BlockRate](#) function to model a tiered pricing structure, where the unit cost of water supplied to each consumer can increase with increasing consumption.
- Electricity Revenue--this variable is available for the case of reservoirs and run-of-river hydropower plants, where revenue produced by electricity generation can be calculated as a separate variable. Electricity revenues are entered per unit of electricity generated.

**Entered on:**  Data View, Branch: Demand Sites and Catchments, Category: Cost, Tabs: Capital Costs, Fixed Operating Costs, Variable Operating Costs, Fixed Benefit, Variable Benefit.


**Or**

**Entered on:**  Data View, Branch: Supply and Resources \ Groundwater, Category: Cost, Tabs: Capital Costs, Fixed Operating Costs, Variable Operating Costs, Fixed Benefit, Variable Benefit.

**Or**

**Entered on:**  Data View, Branch: Supply and Resources \ River \ "river name" \ Reservoirs, Category: Cost, Tabs: Capital Costs, Fixed Operating Costs, Variable Operating Costs, Fixed Benefit, Variable Benefit, Electricity Benefit.

**Or**

**Entered on:**  Data View, Branch: Supply and Resources \ River \ "river name" \ Reaches, Category: Cost, Tabs: Capital Costs, Fixed Operating Costs, Variable Operating Costs, Fixed Benefit, Variable Benefit.

## 4.14 Data Expressions Report

In Data view, click the "Data Expressions Report" button in the upper right corner of the screen (or on the menu: Edit, Data Expressions Report) to create a text report listing all data for all branches for the active scenario. You may print the report or copy to the clipboard and then paste into a word processing program. Tip: because the lines are wide, you will probably want to print the report in landscape orientation. An alternative method for reviewing your data is by [Exporting to Excel](#).



## 5 Results

Once you have entered data for your area, click on the Results View. WEAP can run its monthly simulation and report projections of all aspects of your system, including demand site requirements and coverage, streamflow, instream flow requirement satisfaction, reservoir and groundwater storage, hydropower generation and energy demands, evaporation, transmission and return flow losses, wastewater treatment, pollution loads, and costs. Calculations can be interrupted by pressing the Cancel button.

The Results View is a general purpose reporting tool for reviewing the results of your scenario calculations in either chart or table form, or displayed on your schematic. Monthly or yearly results can be displayed for any time period within the study horizon. The reports are available either as graphs, tables or maps and can be saved as text, graphic or spreadsheet files. You may customize each report by changing: the list of nodes displayed (e.g., demand sites), scenarios, time period, graph type, unit, gridlines, color, or background image. (See [Charts, Tables and Maps](#) for more details.) Once you have customized a report, you can save it as a "[favorite](#)" for later retrieval. Up to 25 "favorites" can be displayed side by side by grouping them into an "[overview](#)". Using favorites and overviews, you can easily assemble a customized set of reports that highlight the key results of your analysis.

In addition to its role as WEAP's main reporting tool, the Results View is also important as the main place where you analyze your intermediate results to ensure that your data, assumptions and models are valid and consistent.

The reports are grouped into three main categories: [Demand](#), [Supply and Resources](#), and [Environment](#).

### 5.1 Available Reports

#### 5.1.1 Key Assumption Results

Because the values of [Key Assumption](#) variables can be displayed in the Results View, these variables can also be used to create new result variables or alternative indicators. For example, you could perform a social cost-benefit analysis by creating indicators such as the social cost of unmet demand (shortages), or the environmental cost of low river flows. The shortage cost key assumption could refer to the unmet demand at one or more demand sites (using the [PrevTSValue](#) function), with an increasing cost associated with increasing unmet demands. A complete "triple bottom line" analysis could be done, involving financial, social and environmental costs. You could create a key assumption group for each of these types of costs, with individual cost items under each. (The financial costs Key Assumption Variables would reference the [Financial Results](#) variables using PrevTSValue.)

To view the value of Key Assumptions and Other Assumptions variables in the Results View, choose Input Data \ Key Assumptions as the title of the report. Select a branch using the Branch combo box. For multilevel branch structures, all branches underneath the chosen branch will be shown. As with any other report, Key Assumption reports can be saved as [Favorites](#) for display in the [Scenario Explorer View](#).

#### 5.1.2 Demand Results

Demand results cover requirements by and allocations to demand sites. The following reports are available:

## Water Demand

The requirement at each demand site, **before** demand site losses, reuse and demand-side management savings are taken into account.

## Supply Requirement

The requirement at each demand site, **after** demand site losses, reuse and demand-side management savings are taken into account.

## Supply Delivered

The amount of water supplied to demand sites, listed either by source (supplies) or by destination (demand sites). When listed by destination, the amounts reported are the actual amounts reaching the demand sites, after subtracting any transmission losses.

## Unmet Demand

The amount of each demand site's requirement that is not met. When some demand sites are not getting full coverage, this report is useful in understanding the magnitude of the shortage.

## Coverage

The percent of each demand site's requirement (adjusting for demand site losses, reuse and demand-side management savings) that is met, from 0% (no water delivered) to 100% (delivery of full requirement). The coverage report gives a quick assessment of how well demands are being met.

## Reliability

The percent of the timesteps in which a demand site's demand was fully satisfied. For example, if a demand site has unmet demands in 6 months out of a 10-year scenario, the reliability would be  $(10 * 12 - 6) / (10 * 12) = 95\%$ .

## Demand Site Inflow and Outflow

The mass balance of all water entering and leaving one or more demand sites. Inflows (from local and river supplies) are represented as positive amounts, outflows (either consumed or routed to wastewater treatment plants, rivers, groundwater nodes and other supplies) as negative amounts.

## Instream Flow Requirement

The prescribed minimum flow requirement (given in units of a volumetric flux) for social or environmental purposes.

### Instream Flow Requirement Delivered

The amount of water supplied to flow requirements listed by destination.

### Unmet Instream Flow Requirement

The difference between the instream flow requirement and the amount actually delivered.

### Instream Flow Requirement Coverage

The ratio of the amount delivered divided by the flow requirement.

### Flow Requirement Reliability

The percent of the timesteps in which a flow requirement's demand was fully satisfied. For example, if a flow requirement has unmet demands in 12 months out of a 10-year scenario, the reliability would be  $(10 * 12 - 12) / (10 * 12) = 90\%$ .

See also: [Charts and Tables](#), [Chart Toolbar](#), [Favorites](#), [Scenario Explorer](#)

## 5.1.3 Supply and Resources Results

### Inflows to Area

Water entering the system (river headflows, surface water inflows to reaches, groundwater recharge, local reservoir inflows, other local supply inflows, catchment precipitation).

### Outflows from Area

Water leaving the system (consumption at demand sites, catchment evapotranspiration (ET Actual), evaporation on river reaches and reservoirs, losses in transmission and return flow links, groundwater and local reservoir overflow, losses in wastewater treatment, and outflows from the end of rivers and diversions that do not flow into other rivers or groundwater nodes).

**Note:** Inflows to area may not equal total outflows from area due to changes in storage in reservoirs and groundwater.

### River

**Streamflow:** The streamflow at selected nodes and reaches along a river. You can plot a line for each point on the river over time (choose Year for the X Axis), or a line for each month plotted along the river (choose River Nodes and Reaches for the X Axis).

**Streamflow Relative to Gauge (absolute):** The absolute difference between streamflow gauge data (observed streamflow) and the simulated streamflow at the node immediately above the gauge (simulated minus observed).

**Streamflow Relative to Gauge (%):** The relative difference between streamflow gauge data (observed streamflow) and the simulated streamflow at the node immediately above the gauge (simulated divided by observed, where 100% means the simulated value is the same as the observation).

**Stage:** The depth of water at selected nodes and reaches along a river.

**Velocity:** The velocity of water flow at selected nodes and reaches along a river.

**Reach Length:** The length of the reach.

## Groundwater

**Storage:** The aquifer storage levels at the end of each month.

**Inflows and Outflows:** A mass balance of all water entering and leaving a specified aquifer. Inflows (from recharge, inflow from river reaches, and return flows from demand sites and wastewater treatment plants) are represented as positive amounts, outflows (withdrawals by demand sites and outflows to river reaches) as negative amounts.

**Overflow:** Groundwater overflow occurs when the aquifer storage is at its maximum, and there is net inflow. Any overflow is lost from the system.

**Height Above River:** The difference in elevation between the water table and the wetted depth of the river, based on the reference groundwater elevation equal to the wetted depth that is specified when setting up the groundwater-surface water interactions.

**Outflow to River:** The volume of groundwater flowing to a river through the streambed.

**MODFLOW and MODPATH:** See [MODFLOW Results](#) and [MODPATH Results](#)

## Reservoir

**Storage Volume:** The reservoir storage volume at the end of each month.

**Storage Elevation:** The elevation of the reservoir level at the end of each month.

**Inflows and Outflows:** All water entering and leaving a specified reservoir. Inflows (either from upstream (river reservoirs) or monthly inflow (local reservoirs) or return flows from demand sites and wastewater treatment plants) are represented as positive amounts, outflows (to downstream, evaporation, local reservoir overflow, or withdrawals by demand sites) as negative amounts. For local reservoirs, evaporation and overflow are lumped together.

**Evaporation:** The volume of net evaporation for each month.

**Refills:** For each reservoir, a value of 0 means that the reservoir did NOT refill completely after its lowest point; a value of 1 means that it did refill. Some algorithms for determining reservoir safe yield mandate that the reservoir must refill completely after its lowest point in order to be considered a safe yield.

**Hydropower Generation:** The power generated by reservoirs and hydropower nodes.

**Hydropower Turbine Flow:** Actual flow through turbines. (Any flow exceeding the [maximum turbine flow](#) will bypass the turbines.)

**Hydropower Demand (Energy):** The energy demand specified (as data) for each reservoir and run of river hydropower node.

**Hydropower Demand (Flow):** The equivalent flow required to produce the hydropower energy demand.

**Hydropower Unmet Demand:** How much of the hydropower energy demand that was not met.

**Hydropower Coverage:** The percentage of the hydropower energy demand that was met.

**Hydropower Reliability:** The percent of the timesteps in which a reservoir's hydropower energy demand was fully satisfied. For example, if a reservoir has unmet hydropower energy demands in 18 months out of a 10-year scenario, the reliability would be  $(10 * 12 - 18) / (10 * 12) = 85\%$ .

**System Hydropower Generation:** The total power generated by all reservoirs and hydropower nodes which are contributing to the [system hydropower demand](#).

**System Hydropower Demand:** The power generated by reservoirs and hydropower nodes.

**System Hydropower Unmet Demand:** The energy demand specified (as data) for the system as a whole.

Note: Reports related to hydropower demand will only be available if [hydropower demand data](#) has been entered.

## Transmission Link

**Flow:** The flow through each transmission link.

**Inflows and Outflows:** Includes amounts lost to evaporation and leakage.

## Other Supply

**Inflows and Outflows:** A mass balance of all water entering and leaving a specified other supply source. Inflows are represented as positive amounts, outflows as negative amounts.

## Return Link

**Flow:** The flow through each return link.

**Inflows and Outflows:** Includes amounts lost to evaporation and leakage.

### 5.1.4 Catchment Results

Catchment results cover all processes and variables related to the method chosen to simulate Catchments (FAO Crop Requirements, Soil Moisture, or MABIA). Reports will not be available unless catchments have been created in the schematic.

## FAO Method Results

The following reports are available for catchments using the FAO Method:

### Runoff from Precipitation

The amount of runoff from the catchment derived from precipitation

**Observed Precipitation**

The amount of rainfall that actually fell on the catchment area.

**Infiltration/Runoff Flow**

Volume of flows from catchments to surface and groundwater.

**ETPotential**

The amount of water that would be consumed by evapotranspiration in the catchment if no water limitations exist.

**ETActual (including irrigation)**

The actual amount of water consumed by evapotranspiration in the catchment, including water supplied by irrigation

**ET Shortfall**

The amount of water that was needed, but was not available from precipitation and irrigation, for evapotranspiration in the catchment

**Total Yield**

The total yield from crops cultivated in the catchment

**Total Market Value**

The total yield multiplied by the market price for the crops

See also: [FAO Method Calculation Algorithm](#)

**Soil Moisture Method Results**

Most reports can be displayed in either volume (e.g.,  $m^3$ ) , flow (e.g., CMS) or depth (e.g., mm) units. Depth units are derived by dividing the water volume by the area of each catchment or land class.

**Land Class Inflows and Outflows**

A detailed breakdown of inflows to and outflows from catchments and their sub land classes, including precipitation, snow melt, snow accumulation, surface runoff, irrigation, interflow, evapotranspiration, increase or decrease in soil moisture and base flow.

**Observed Precipitation**

The volume of precipitation that fell in the catchment

**Snow Accumulation**

The accumulated depth of snow pack in the catchment (snow depth is the same for all land classes within a catchment), in melt water equivalent (MWE) depth.

### **Snow Gauge**

Historical observations for accumulated depth of snow pack in the catchment, if entered in the [Snow Accumulation Gauge](#) data variable. The accumulated depth of snow pack in the catchment. Depending on the setting of (snow depth is the same for all land classes within a catchment)

### **Snow Accumulation vs. Gauge**

A side by side graph of Snow Accumulation results and Snow Gauge data, in melt water equivalent (MWE) depth.

### **Ponded Depth**

For land classes with ponding, such as rice paddies, the depth of water on the surface of the land class

### **Infiltration/Runoff Flow**

Volume of flows from catchments to surface and groundwater

### **Effective Precipitation for ET (including snowmelt)**

The monthly precipitation that is available for evapotranspiration (minus snow accumulation or plus snow melt)

### **Area**

The area for each of the land classes designated in the catchment

### **Temperature**

The air temperature in the catchment

### **Albedo**

Fraction of solar radiation striking a land class that is reflected--albedo increases as snow accumulates

### **Solar Radiation**

Maximum theoretical daily incident solar insolation per unit area--a function of latitude and day of year

### **Net Solar Radiation**

The daily net energy per unit area from sunlight falling on each catchment, including effects of albedo, air temperature and relative humidity

### **Reference PET**

The value of the Penman-Monteith reference crop potential evapotranspiration

### **ETPotential**

The amount of water that would be consumed by evapotranspiration in the catchment if no water limitations exist.

**ETActual (including irrigation)**

The actual amount of water consumed by evapotranspiration in the catchment, including water supplied by irrigation

**Relative Soil Moisture 1 (%)**

The amount of water in the top soil layer, as a percent of its maximum water holding capacity.

**Relative Soil Moisture 2 (%)**

The amount of water in the lower soil layer, as a percent of its maximum water holding capacity.

**Flow to River No Irrigation**

The total volume of flow from the catchment to the river, including runoff, interflow, and baseflow, assuming no irrigation of irrigated land.

**Flow to River Full Irrigation**

The total volume of flow from the catchment to the river, including runoff, interflow, and baseflow, assuming full irrigation of irrigated land.

**Flow to GW No Irrigation**

The total volume of flow from precipitation infiltrating to groundwater from the catchment, assuming no irrigation of irrigated land.

**Flow to GW Full Irrigation**

The total volume of flow from precipitation and irrigation infiltrating to groundwater from the catchment, assuming full irrigation of irrigated land.

**Irrigation Return Flow Fraction to Surface Water**

The average fraction of irrigation water supplied that flows to surface water.

**Irrigation Return Flow Fraction to Groundwater**

The average fraction of irrigation water supplied that flows to groundwater.

See also: [Soil Moisture Method Calculation Algorithm](#)

**MABIA Method Results**

The following reports are available for catchments using the [MABIA Method](#). The most important reports are Land Class Inflows and Outflows, Depletion and Available Water, ET Actual and Potential, Precipitation and Irrigation, and Crop Yield. Because the MABIA Method operates on a daily timestep, most reports are daily.



### **Land Class Inflows and Outflows**

A detailed breakdown of inflows to and outflows from catchments and their sub land classes, including precipitation, irrigation, surface runoff, evaporation, transpiration, flow to groundwater, increase or decrease in soil moisture.

### **Infiltration/Runoff Flow**

Volume of flows from catchments to surface and groundwater

### **Area**

The area for each of the land classes designated in the catchment

### **Depletion and Available Water**

View soil moisture depletion against the Readily Available Water (RAW) and Total Available Water (TAW) thresholds. Choose "All Variables" on the legend to see them all graphed at once.

### **ET Actual and Potential**

Actual and potential evapotranspiration. Choose "All Variables" on the legend to see them both graphed at once.

### **Precipitation and Irrigation**

Choose "All Variables" on the legend to see both precipitation and irrigation graphed at once.

### **ET, Precip, Irrigation and Depletion**

Choose "All Variables" on the legend to see them all graphed at once.

### **Crop Yield**

The total yield from crops cultivated in the catchment. Choose "All Crops" on the legend to see the breakdown by crop.

### **Market Value**

The total yield multiplied by the market price for the crops. Choose "All Crops" on the legend to see the breakdown by crop.

### **Reference PET**

The value of the Penman-Monteith reference crop potential evapotranspiration

### **Effective Precipitation**

The daily precipitation that is available for evaporation and transpiration (the remainder is direct runoff).

### **Solar Radiation**

Maximum daily incident solar insolation per unit area.

**K<sub>c</sub> Potential**

Potential crop coefficient, including K<sub>cb</sub> and K<sub>e</sub> (transpiration and evaporation).

**K<sub>c</sub> Actual**

Actual crop coefficient, including K<sub>cb</sub> and K<sub>e</sub> (transpiration and evaporation).

**ET Potential**

The amount of water that would be consumed by evapotranspiration in the catchment if no water limitations exist.

**ET Actual (including irrigation)**

The actual amount of water consumed by evapotranspiration in the catchment, including water supplied by irrigation

**Evaporation**

The portion of ET that is evaporation

**Transpiration**

The portion of ET that is transpiration

**Effective Irrigation**

Amount of Irrigation available for ET consumption (i.e., actual irrigation \* irrigation efficiency).

**Soil Moisture Depletion**

The depletion of soil moisture, ranging from 0 (no depletion) to Total Available Water (total depletion--wilt point).

**Readily Available Water**

Readily available water represents the threshold beyond which the crop will suffer water stress, reducing its yield.

**Total Available Water**

Total available water represents the threshold beyond which the crop will reach permanent wilt point.

**Flow to River No Irrigation**

The total volume of flow from the catchment to the river, including runoff, interflow, and baseflow, assuming no irrigation of irrigated land.

**Flow to River Full Irrigation**

The total volume of flow from the catchment to the river, including runoff, interflow, and baseflow, assuming full irrigation of irrigated land.

### **Flow to GW No Irrigation**

The total volume of flow from precipitation infiltrating to groundwater from the catchment, assuming no irrigation of irrigated land.

### **Flow to GW Full Irrigation**

The total volume of flow from precipitation and irrigation infiltrating to groundwater from the catchment, assuming full irrigation of irrigated land.

### **Irrigation Return Flow Fraction to Surface Water**

The average fraction of irrigation water supplied that flows to surface water.

### **Irrigation Return Flow Fraction to Groundwater**

The average fraction of irrigation water supplied that flows to groundwater.

See also: [MABIA Calculation Algorithms](#)

## **5.1.5 Water Quality Results**

Water Quality results cover pollution generation by demand sites, pollution loads at receptors, wastewater treatment, and surface water quality.

### **Pollution Generation**

Pollution generated by each demand site. If you have disaggregated by demand branches below the demand site level, you may disaggregate the results as well.

### **Pollution Loads**

Pollutant loads carried by return flow links from demand sites and wastewater treatments (sources) into rivers, groundwater nodes and other supplies (receptors).

### **Pollution Inflow to Treatment Plants**

Total pollution flowing in to wastewater treatment plants.

### **Wastewater Treatment Plant Inflows and Outflows**

Details of all inflows and outflows from wastewater treatment plants, including water lost during treatment.

### **Surface Water Quality**

Concentrations of water quality constituents at all river nodes and reaches.

### 5.1.6 Financial Results

There are three financial reports in WEAP that users can access to view the results of a financial analysis. To access reports after a simulation, click on the *Results View*. Use the dropdown menu at the top of the screen to select the financial reports. There, the user can choose between the **Net Cost**, **Net Present Value**, and **Average Cost of Water** reports.

#### Net Cost Report

This report can be used to generate graphs or tables showing the net cost of financing and operating infrastructure in one or more scenarios. Using the menus and checkbox arranged around the edge of the screen, the user can choose how the data are presented. The menu on the bottom of the screen determines the data type for the x-axis. Choices include model items, simulation years, scenarios, and cost/benefit types. The menus at the top and right side of the screen can be used to further adjust the information in the graph or table. If both costs and benefits are selected for display, the sum of these is shown with costs assumed to be positive and benefits to be negative. For example, if benefits exceed costs, the resulting sum displayed in the graph or table will be negative. If results for all items are displayed, the values will account for the costs and/or benefits of all items and the system costs and/or benefits described in the "Entering System Costs and Benefits" section.

#### Net Present Value Report

This report represents the net present value of future expenditures for capital and operations costs, net of any benefits. The values presented in the report are the sums of the net present value calculation of the net costs for each of the future years modeled in the scenario. As an example, consider the WEAP River Basin area provided with WEAP and assume the current accounts year is 1998, the North Reservoir is built in 2003 for 100 million dollars, and the financing is for 30 years at 4% interest. The net present value is calculated as the present value of the annual loan payment of 5.7 million dollars for year 2003, plus the present value of the payments for the remaining years in the simulation (2005-2008). The net present value of future operations costs for North Reservoir is calculated using the same approach. Operations costs for the years 2003-2008 are discounted back to 1998 dollars on a year-by-year basis, using the system discount rate; and the sum of the annual totals is presented in the report. Note that loan payments scheduled after the end of the simulation (for example, the remaining 24 years on the 30-year loan for North Reservoir) will not be included in the net present value calculation.

The menu at the bottom of the screen can be used to set the type of information to display on the x-axis of the graph. Options include: cost and benefit types, scenarios, and model items. The menus located at the top and right side of the screen can adjust the data presented on the graph further.

An example of the utility of the net present value report is illustrated through an analysis of the cost tradeoffs associated with effectively creating a new supply either through construction of a new reservoir or implementation of a new treatment technology at a demand node. This example was created by modifying the Weaping River Basin area provided with the WEAP software. In the Supply Measures scenario, the North Reservoir was given a capital cost of 100 million dollars financed over 30 years at 4% interest. Payments were to begin in 2003 - this is also the year the reservoir began operation. A variable operations cost of \$0.005 per cubic meter was also entered. In the Demand Measures scenario, a capital cost of 1 million dollars per year was entered for the Industry North demand node. An operations cost of \$0.005 per cubic meter was also entered. The net present value of the capital and operations costs shown in Figure 1 represent:

1. The discounted annual payments on the loan for North Reservoir for the years 2003 to 2008.
2. The discounted annual capital payments for the treatment technology at Industry North for years 1999-2008.

## 5.2 Viewing Options

3. The discounted annual operations costs for the North Reservoir for year 2003 to 2008, and
4. The discounted annual operation costs for treatment technology at Industry North for 1999 to 2008.

### Average Cost of Water Report

This report provides a calculation of the average cost of water in a given scenario. It is calculated by dividing the sum of the net cost associated with all model items and system costs by the total volume of water delivered to demand nodes. It can be used as another comparison between scenarios to determine relative benefits and costs. Similar to the net cost report, a negative value implies that benefits are larger than costs. Menus located around the screen can be used to select the months(s) and/or year(s) for which data will be displayed.

### 5.1.7 Input Data Results

Most variables from the Data View can be displayed in the Results View. From the results selection box at the top, select the category "Input Data" to choose from the available variables.

### 5.1.8 Customizing Result Variables

You may customize WEAP's result variables (e.g., Unmet Demand or Inflows to Area) to some extent.

You are allowed to edit the title of a variable or hide it entirely. In the Result View, right click on the result variable selection box at the top and choose **Edit Name** or **Hide**. (Or from the Main Menu: Edit: Result Variable) If you have changed the name of a variable and want to reset it to its original value, right click and choose **Reset Name to Default**. To unhide previously hidden variables, right click and choose **Unhide**, and then choose the variable to show, or **All Variables** to unhide all previously hidden variables. Hiding unused variables can be a useful way to simplify a model's appearance, perhaps for display to stakeholders. Note: result variables can still be used in calculations even when hidden (via the [PrevTSValue](#) function).

**Note:** Customizing result variables only applies to the current WEAP dataset. If you want to customize variables in other datasets, you will need to do it separately for each one.

**See also:** [Customizing Data Variables](#)

**Menu Option:** Edit: Result Variable

## 5.2 Viewing Options

### 5.2.1 Charts and Tables

Three tabs at the top of the Results View let you switch among **Chart**, **Table** and **Map**. Charts and tables contain the same basic information, while maps contain a subset. (Maps are discussed in more details [below](#).) You can change any of the selection boxes at any time, but typically you will follow these steps to create a new report.

1. First, use the selection box at the top of the screen (the chart or table title) to choose a particular report, such as Monthly Supply Requirement, Groundwater Storage or Streamflow.
2. Next, use the selection boxes attached to the chart's X axis (or at the bottom of the table) and the chart or table legend to pick the data dimensions you want to see on each axis of the chart or in the columns of the table. Different categories of results will have different data dimensions. For

example, the Supply Delivered report has the following dimensions: years, demand sites, sources and scenarios, so you can therefore create a chart (or table) that has any two of these dimensions on the X axis (or in the table columns) and legend of the chart (or table). Examples of charts and tables you can create include: demand site by year (for one or more sources and a given scenario), source by year (for one or more demand sites and a given scenario), demand site by source (for a given year and scenario), demand site by scenario (for one or more sources and a given year). Some restrictions do apply. When picking a dimension for the chart's X axis or legend or the table's columns, you will also be able to specify whether you want to show all items in the dimension or only selected items. If you choose "selected" you will be shown a dialog box in which you can check off the items to be displayed. Also, you can select the level of aggregation or disaggregation of demands for the Water Demand and Supply Requirement reports by using the "Levels" button (located underneath the report title). For example, on Weaping River Basin results, choose "All Branches" for the legend. Level 1 shows demand for each demand site; Level 2 disaggregates demand by agricultural county and crop type (Agriculture West), industrial water use (Industry East), irrigation technology (Agriculture North), and single and multi-family (South City). When Levels is greater than 1, a "Match Names" checkbox appears; selecting this checkbox will group together branches with the same name. Set Levels = 3 and check "Match Names" to see that Flood Irrigation consumes nearly a third of the total Weaping River Basin demand in the Current Accounts.

3. Next, you can use the various additional on-screen controls to further customize your chart or table.
  - Use the **Units** selection box to pick the unit for the chart or table data. The class of the unit (volume, flow, energy, monetary, etc.) is determined by the category of result you are examining. WEAP handles scaling and units conversion automatically.
  - Use the **Scale** selection box to change the scale (thousand, million, billion) for the chart or table data. Normally, WEAP will automatically select the scale so that numbers on the chart or table are not too large or too small. If you override the automatic scale, it will stay fixed until you change the unit or go to another result variable.
  - When viewing cost results, an additional **Costs** selection box appears, letting you choose either real (i.e. constant value) costs or [discounted](#) costs.
  - When viewing the results charts with time along the x-axis, or the table with time dictating the column content, click the Monthly Average checkbox to see the average for each month. Furthermore, you can sum monthly results to see annual totals - just check the "Annual Total" box in the chart subtitle (units of years must be selected for the x-axis).
  - Additionally, when the x-axis is time you can see an "exceedance" graph, in which the values are sorted in descending order. Check the checkbox "Percent of time exceeded" below the X axis to turn on the exceedance graph. This will tell you what fraction of the time a particular value was exceeded. An exceedance graph for streamflow is often called a flow duration curve.
4. Finally, you can use the [Toolbar](#) on the right of the screen (or right-click on a chart) to customize the appearance of the chart or the table, to copy results to the Windows clipboard, and to print or export results to Microsoft Excel. Options on the toolbar let you select the type of chart, type of stacking, and formatting options such as 3D effects, log scales, grid lines, and the number of decimal places reported in numeric values. For charts that show results for just one year (i.e., the X axis dimension is not time), the animate button will play a movie showing the results for each year. Note that when more than twenty items appear on a chart, the legend uses patterns to

differentiate the items. Lastly, click on the Stats button on the [Toolbar](#) to see the minimum, maximum, average, standard deviation, and root mean square for tabulated data.

## Saving Favorite Charts

If you want to save a particular chart with all your formatting choices for later retrieval, you can save it as a "favorite." See [Favorites](#) for details. Combining favorites to form "overviews" in the Scenario Explorer View are a powerful way to get an overall perspective of your system. See [Scenario Explorer](#) for details.

### 5.2.2 Maps

Results are shown on the map both as numeric labels and by varying the thickness of lines or size of nodes. On the toolbar to the right of the map, click on the # symbol to turn on or off the numeric labels; click on "Size" to turn on or off the display of results as varying thickness of lines or size of nodes. You may increase or decrease the precision for the numeric labels using the buttons on the toolbar on the right. Another button will copy the map with results to the Windows clipboard.

**Tip:** Results displayed for links (transmission links, return flow links and runoff/infiltration links) may not always be placed for easy reading. However, you can reposition where the results appear: on the Schematic View, right click on each link and choose "Move Label." A sample number ("000") will appear--move the mouse to the place you would like the result value to appear, then click the left mouse button to save the position. When you next view results on the map, they will use this new position. Unfortunately, you cannot reposition where river reach results appear.

A map displays results for just one snapshot in time. To get a better sense for how the results vary over time, you can display the corresponding chart below the map. To show or hide the chart, click on the chart icon, just below the "Size" button on the toolbar. The current time slice mapped will be marked with a black vertical line on the chart. Click anywhere on the chart to see that particular time mapped above. In addition, there is a "slider bar" below the map which ranges from the first timestep to the last timestep (these will be years, if "Annual Total" is checked). Click and drag the slider to quickly change from one time period to another. You can also click and drag on the chart to animate the map over time, or click and hold down the arrows to the left or right of the slider. A toolbar to the right of the chart gives the standard options to customize the appearance of the chart. Double click on the chart to zoom into it; this will switch to the Chart tab, with this chart loaded. The splitter bar between the map and chart can be repositioned to enlarge one and shrink the other.


To choose which result to map, check the appropriate box to the left of the map, under the heading "Results to Map." Nearly every result available on the [Chart and Table](#) tabs is available to map. If you do not see a result listed, click the "Add" button below the checkboxes to choose a new result for the list. Clicking the Delete button only removes the variable from this list--you can always click Add later to add it back.


You can display more than one result at a time, as long as they have the same units. For example, check off Supply Requirement, Transmission Link Flow, and Return Link Flow to see the flow of water to and from demand sites. When mapping multiple results, only one can be charted at once. The chart title is a dropdown box from which you may select the variable (of those that are mapped) to chart.


The combination of the map and the chart is a powerful way to visualize your results. The chart shows you the full expanse of time, in which the maximum and minimums are revealed. Click on an interesting point on the graph below (such as a low streamflow or high unmet demand) to instantly see the state of the system (on the map above) at that time period. You can export these results to Google Earth--see [Export to Google Earth](#) for details.


### 5.2.3 Chart, Table and Map Toolbar


The toolbar is used to customize, print and export the charts, tables and maps displayed in WEAP. It consists of the following buttons:

 **Chart Type** selects the type of chart (bar, horizontal bar, line, step, area, area without vertical lines, and pie). Some restrictions apply to the types of charts you can choose. In particular, you can only pick line charts when the X-Axis is time (years or months), and you can only pick area charts when values are summable. Choosing pie when there are multiple items on the X-Axis will produce multiple pies--one for each X-Axis item (e.g., month or year).

 **Stack Type** is used in area, bar and horizontal bar charts to pick how series are formatted. The options are: side by side, stacked, stacked to 100%, and grouped behind. This last option displays series behind one another in a 3D effect. Note that stacking of charts is only available when it makes sense to stack the variable or dimension. So for example, a variable such as water use rate cannot be stacked, and nor can values from different scenarios.

 Change the **color palette** of the chart. Choose "Grayscale" for shades of gray--suitable for printing on a black and white printer.

 Toggles whether symbols are displayed on line and step charts for each data point.

 Toggles whether patterns are displayed instead of solid colors. Useful when printing in black and white.


**Y=0** Toggles whether the Y-Axis value of 0 is displayed. Turning this off helps magnify variations between values graphed.


**3D** Toggles whether charts are shown with a **3-dimensional** effect. Note that due to software limitations, any charts with negative values cannot currently be shown with 3D effects.


**Log** Toggles the use of a **logarithmic scale** on the chart. Note that log scales do not work well if the chart contains negative values.

**Grp Group** If there are more than 12 items in the results legend, you can click the **Grp** button to group the smallest items together into "All Others." For pie charts, this will group all items less than 3% into one pie slice called "All Others."


 **Gridlines** toggles the display of gridlines on a chart.


 Show or hide marks (values, names or percentages) for points in the chart.

 Rotate X-Axis labels (horizontal, vertical or diagonal).


 Export the table to **Excel**.


**csv** Export the table to a **comma separated value** file, which can be read by Excel or WEAP's [ReadFromFile](#) function. There are options to include the table and column titles, to transpose rows and columns, and to format the file according to the ReadFromFile format.


 **Print** lets you preview a chart and set basic printer options before printing.


 **Copy** charts and maps are copied to the Windows clipboard in metafile format. Images can be pasted into any Windows program that supports image objects. Tables are copied to the Windows clipboard in tabular format, suitable for pasting into Excel or Word.





 **Save chart or map** as a graphic file (e.g., Acrobat, BMP, JPG, GIF, Google Earth, PNG). See [Export to Google Earth](#) for information about saving as Google Earth format.


 **Show a movie** of the chart, going from the first timestep of the first year to the last timestep of the last year. This option is only available if the X-axis is **not** years.


 **Select Background Image** lets you insert a background image behind your chart. You will be prompted to select a JPG, GIF or BMP file, and given the chance to preview the image before selecting it. Several water-related pictures come with WEAP, located in the \_Pictures subdirectory. Background image settings are saved along with your other settings when you save a "Favorite" chart, and can then be displayed when you use WEAP's Overview feature.

 **Clear Background Image** removes the background image from the current chart.

 **Advanced chart options** Change any aspect of how the chart is displayed. Note: these changes cannot be saved in a Favorite.

 **Legend** toggles whether a legend is displayed on the chart. Legends are always displayed in the [Results View](#).


 **Increase Decimals** increases the number of decimal places displayed in a table.


 **Decrease Decimals** decreases the number of decimal places displayed in a table.

 **Transpose** transposes rows and columns in the table.

 **Choose the font** for the table.

**Stat View summary statistics** in the last rows and columns of the table: minimum, maximum, mean, standard deviation (SD) and root mean square (RMS).

 **Move forward to the next timestep** for the chart or table. This option is only available if the X-axis is **not** years.

 **Move backwards to the previous timestep** for the chart or table. This option is only available if the X-axis is **not** years.

# **Display results as labels** turns on or off the display of results as labels on the map.

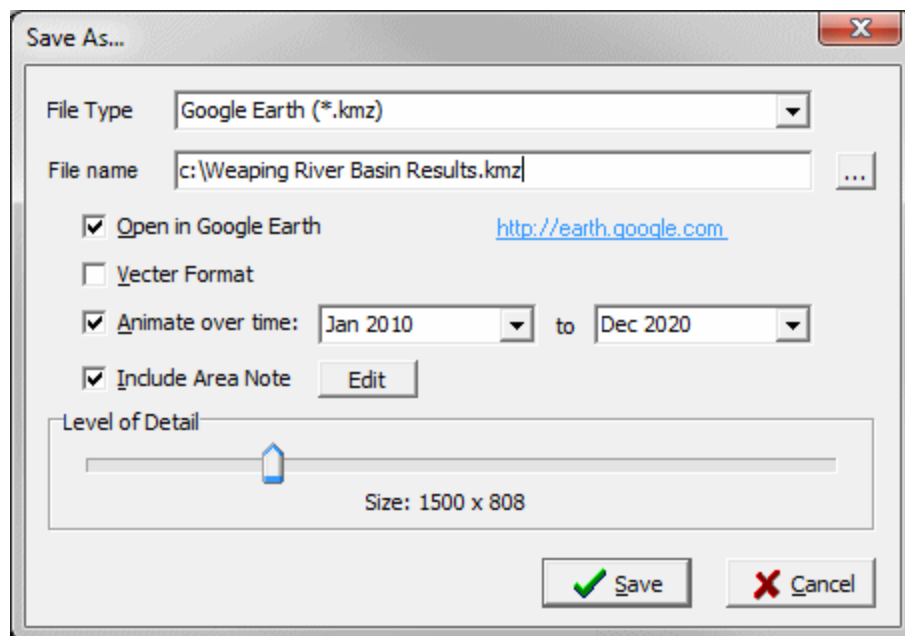
Size **Display results as varying line widths and node sizes** turns on or off the display of results on the map by resizing lines and nodes.

 **Display chart below map** shows or hides the chart in the Map tab.

### 5.2.4 Export to Google Earth

WEAP can export the area schematic and results in [Google Earth](#) format (.kmz). This provides a powerful and convenient way to package the results from a WEAP analysis to share with others--everything is saved in one file that can be sent via email or posted on a web site for others to download and open in Google Earth. Here are two examples from the Weaping River Basin (click to open in Google Earth): [Results for each WEAP object](#), [Animated movie of results](#). Google Earth is free and can be downloaded from <http://earth.google.com>. To export to Google Earth requires that the WEAP area uses the WGS84 (lat/lon) or UTM GIS projections. If using the UTM projection, you will need to specify the UTM zone (1-60) and hemisphere (north or south) on the "Save As" screen.

When saving to Google Earth, a representation of the schematic will be displayed in Google Earth, georeferenced so that it appears in the correct position over the Google Earth satellite maps. In the **Schematic View** (menu: Schematic, Save Schematic to File), a schematic can be saved to Google Earth either in "vector" or "raster" format. Vector format will create individual clickable Google Earth elements for each WEAP object (e.g., Rivers, Demand Sites,



Reservoirs, Groundwater Nodes), each of which can include any notes you've entered in the [Notes View](#).

If you uncheck "Vector Format," a single graphic image will be exported to Google Earth, using the level of detail you choose. The raster image will have a white background, and show the same spatial extent as is currently shown in the Schematic window. (If you are zoomed in, it will only show the zoomed in portion of the Schematic.) Additionally, you can choose whether or not to include the note describing the entire area; click the "Edit" button to see and edit the note. The **area note** and the **object notes** can include HTML formatting codes, which Google Earth will display as if in a web browser. For example, to include an image with a hyperlink (in this example, the WEAP logo, linked to the WEAP web site), you would add the following text to the note in WEAP: `<a href="http://www.weap21.org"></a>`

In the Results and Scenario Explorer Views, you can include results with the schematic. Click the icon in the [Chart Toolbar](#) to open the Save As window. When saving from the **Chart tab of the Results View**, WEAP will export the currently displayed chart, customized for each relevant object. For example, if the current chart is "Unmet Demand," then WEAP will create a separate chart of Unmet Demand for each Demand Site and attach each chart to the associated Demand Site. Click on the Demand Site in Google Earth to see the chart. Because each object must be clickable in Google Earth, only the vector format is allowed.

When saving from the **Map tab of the Results View**, WEAP will take whatever result variables that are currently displayed on the WEAP map and create an **animated movie** of results in Google Earth. Each timestep is a single frame in the movie. Results are shown on the map both as numeric labels and by varying the thickness of lines or size of nodes, just as in WEAP. Increasing the **Level of Detail** will yield sharper images, but will cause the Google Earth kmz file to be larger. Because the movie frames are raster images, only the raster format is allowed.

When saving from the **Scenario Explorer View**, WEAP will export every currently displayed chart, customized for each relevant object. If there are several charts for a given WEAP object type, each will appear in the Google Earth note. For example, if both "Supply Requirement" and "Unmet Demand" are selected, then WEAP will create separate charts for Supply Requirement and Unmet Demand for each

## 5.3 Scenario Explorer

Demand Site and attach them both to the each Demand Site. Because each object must be clickable in Google Earth, only the vector format is allowed.

To summarize, here are the options for exporting to Google Earth:

Schematic View	Schematic only (no results); choice of vector or raster format.
Results View, Chart Tab	The current chart attached to every relevant WEAP object (in the notes for each object); vector format.
Results View, Map Tab	Animated movie of results; raster format.
Scenario Explorer View	The current charts attached to every relevant WEAP object (in the notes for each object); vector format.

### 5.2.5 Favorites

You can save your favorite charts including all settings for the axes, type of chart, and formatting, using the Favorites menu. This feature is similar to the bookmark/favorites features found on popular Internet browsing software. Later, in the [Scenario Explorer View](#), you can group together favorite charts to create "overviews" of different results. Use the **Save Chart as Favorite** menu option to bookmark the current highlighted chart. You will be asked to give the favorite a name. Use the **Delete Favorite** menu option to delete a saved favorite. To switch to a favorite chart, select its name from the favorites menu.

## 5.3 Scenario Explorer

The Scenario Explorer View is used to group together multiple "Favorite" charts and tables (created earlier in the [Results View](#)) into "Overviews." With Overviews, you can simultaneously examine different important aspects of your system, such as demands, coverage, flows, storage levels, environmental impacts and costs. In addition to showing Results, the Scenario Explorer View can display selected Data across many scenarios. This serves to distinguish each scenario from the others, and helps demonstrate the impact of various assumptions and policies on results. These input values can be changed on the spot and WEAP will recalculate and update the results. Scenarios can be created on the spot, allowing the user to perform a very quick sensitivity analysis.

The Scenario Explorer is split between a Data Section and a Results Section, with each section displaying information from their respective Views (the Data View and the Results View). Use the "Show Data Variables?" checkbox to show or hide the Data Section.

### 5.3.1 Results Section

## Adding and organizing charts

You can create multiple Overviews in the Results Section, each of which can display up to 25 different charts and table. The first time you go to the Scenario Explorer View, WEAP will display a standard set of charts, grouped into an overview named "All". You can add, remove or reorder the charts. You can **add** a chart either by first [defining a Favorite](#) in the Results View (which gives you the opportunity to filter the results and format the chart) and then adding that Favorite to the Overview, or by simply choosing a result from the all-inclusive list of result charts. Right click on any existing chart and select **Add Chart** (or from the Main Menu: Explorer, Chart, Add Chart). The menu that appears will list (on top) all Favorites you have defined (not including those already shown in the Overview), and (on bottom)

the all-inclusive list of result charts, categorized and ordered as in the Results View. The selected chart will appear as the last chart in the Overview--to **reorder** the charts, right click on a chart and choose **Move Left** or **Move Right**. To **remove** a chart from an Overview, right click it and choose **Remove Chart**. Note: If you added a chart by choosing from the list of all results (not from an already-defined Favorite), WEAP will automatically create a new Favorite (named with the chart's title) and add it to the Overview.



You may want to create several Overviews to highlight different aspects of your analysis. For example, one Overview could contain charts with financial results, a second could display water supply results, and a third could show water quality results. You can select which overview to display from the drop down list of Overviews in the upper left corner of the Results Section of the Scenario Explorer View. To **create** a new overview, right click on the drop down list and select **Create Overview**. From this menu, you can also **rename** or **delete** the current overview--select **Rename Overview** or **Delete Overview**.

An alternate method for selecting and ordering charts and creating overviews is to use the [Overview Manager](#), although here you will be restricted to adding only Favorites already defined. The Overview Manager can be accessed by right clicking on the Overview drop down list and selecting **Manage**, or by clicking the Manage button next to the drop down list, or from the Main Menu (Explorer, Overview, Manage).


## Formatting

By default, each chart will show values for each scenario for all years, to make it easy to compare results across scenarios. The scenarios are colored consistently in all charts, and the legend is displayed below the charts. You can also choose to display more in-depth results for a single scenario. Use the drop down list at the top of the Results Section, between the "Show Data Variables?" and "Annual Total?" checkboxes, to choose among "All Scenarios" or an individual scenario. A final option in the drop down list, "From Favorite," will display each chart exactly as it appeared when it was saved as a Favorite, including all filtering options in effect (such as a subset of years to display).

The **Annual Total** checkbox above the charts will determine whether the charts display annual totals or monthly values. (For storage reports, such as groundwater or reservoir storage, it does not make sense to total the monthly storage values--instead, the storage at the end of each water year will be displayed.)

You can apply a few formatting options across all charts shown in the Overview: change the color palette () , show or hide all legends () , show or hide titles and axis labels (**Labels**), or set the 3D effect for all charts (**3D**).

To see the numbers behind the charts, select the Table tab at the top of the Results Section. You will see the results from each chart organized into one large table. The toolbar on the right allows you to export the table to **Excel**, or save it to the Windows **clipboard**.

To zoom in to one of the charts shown in an Overview, right click and choose **Zoom In**, or click it and select the zoom button () on the toolbar to the right. You will then switch to the [Results View](#) with this chart displayed. If you change the formatting of the chart and want to save these customizations, choose the Main Menu option: Favorite, Save Chart as Favorite. After saving, return to the Scenario Explorer View and you should see that the Overview chart will include your changes. (Note: some formatting will only be shown when "From Favorite" is the selection.)

Click the **Axis Scale** button on the right to use the same scale for the Y axes on each chart, so that values on different charts can be easily compared.

## 5.3.2 Data Section

The Data Section displays values for selected scenarios and selected variables from the Data View. It is a good idea to choose for display major assumptions that vary from one scenario to another, such as climate, infrastructure (building a reservoir) and demographic scenarios. These data variables are organized in a grid, with variables across the columns and scenarios down the rows. You choose which variables and which scenarios to display (you can even create a new scenario here). For each cell in the grid, corresponding to a single variable in a single scenario, the value is displayed either by a horizontal "slider" or by a drop down selection. This represents the value of that variable for all years and timesteps in that scenario. For example, if the WEAP model you built included an assumption for the annual average population growth rate, this single value would be a good choice for a slider in the Data Section.

However, you could not create a slider for the changing population in a scenario, as this would be more than one value and not representable on a slider bar. However, you could create a slider for the value of the population in the last year of your scenario, in which case the model could interpolate between the Current Accounts population and this final population to get the population in each intermediate year.

## Creating, editing and organizing data variables

To **add** a data variable, right click on the grid and choose **Add Data Variable** (or from the Main Menu: Explorer, Data Variable, **Add Data Variable**). (To **edit** an existing variable, right click on it in the grid and choose **Edit Data Variable**.) On the Add (or Edit) Data Variable screen, choose the Data View **Branch** and **Variable** you want to display. Remember, this variable should be one you've already defined in your model that will have a single value per scenario for all years and timesteps. Some examples are annual growth rates, annual efficiency improvements, startup year for new infrastructure (such as a new reservoir), or the size of a new reservoir. Give a **Title** for the grid and a **Description** (which will be displayed when the mouse moves over the data variable in the grid). The **Control Type** can either be a **Slider** or a **Drop-down list**. A slider is more appropriate for selecting a continuous value (such as a growth rate), whereas the drop-down list works best for discrete choices (such as the startup year or a qualitative measure such as high, medium and low).

For a slider, enter the **Lower Bound** and **Upper Bound** (e.g., 0 and 5) and the corresponding **Label** to display on the grid (e.g., 5% and 0%). Make sure to choose the bounds so that all existing values are within bounds. Specify the **Increment** that the slider will move by (e.g., 0.5, to allow minimum changes of 0.5%). If increment is left blank, WEAP will use a very small value to approximate the continuity of choices.

For a drop-down list, enter the list of values to display (number or text) and the corresponding expression for each. (Click **Add Row** or **Insert Row** to add new rows to the list). You could even make each choice in the list represent a different model (e.g., exponential growth using the Growth function as one choice, and linear growth using the Interp function for the other choice). Note: If the variable you have chosen is Startup Year, then WEAP will automatically create a drop-down list with every year as an item in the list.

You can add an unlimited number of data variables here. The list will scroll horizontally if there are too many to fit. To change the order of display for the variables, right click the variable in the grid and choose **Move Left** or **Move Right**.


If you have many different variables that you want to include here, you may want to divide them into different categories, e.g., climate variables and demographic variables. The drop-down list of data variable categories is in the upper left. Right click it to **add**, **rename** or **delete** categories (or use the Main Menu: Explorer, Data Category). To move an existing data variable to another category, right click it in the grid and choose **Move to Category**.

## Data variable values

The Data Section displays the values of each data variable for each scenario. This provides a quick way to see how each scenario differs from the others for the most important assumptions. To explore the impact from changing the value of an assumption, you can move the slider or change the selection from the drop-down list to see how the results (shown in the Results Section) will change. If the **Auto Calculate** checkbox is checked, WEAP will calculate results for the affected scenario as soon as you change the value of an assumption in the grid. If Auto Calculate is not checked, WEAP will not recalculate until you click the **Calculate Now** button. (This button is only active if any changes have been made.) If the value for a variable in scenario B *inherits* its value from scenario A, then changing the value in scenario A will also make the same change in scenario B. (Scenario B inherits from A if B is a child of A, and the expression in B is blank.) If you change the value in Scenario B by moving the slider, then it will no longer inherit the value from A, and a later change to the value in A will not affect the value in B.

## Choosing scenarios to display, including creating new scenarios

The Data Section shows values for every existing scenario that is currently selected for display. To **create** a new scenario, right click on the scenario name that you want to be the parent of the new scenario and choose **Create New Scenario**. You can **rename** or **delete** an existing scenario by right clicking on it and choosing that option from the menu. (or use the Explorer, Scenario option on the Main Menu) To **hide** a scenario, right click on it and choose **Hide Scenario**. To **show** hidden scenarios, right click on any scenario and choose **Show Scenario**. Together, these options provide a powerful and convenient method for exploring new scenarios. For example, in the Weaping River Basin, to understand the impact of a smaller North Reservoir in the Integrated Measures scenario: right click on Integrated Measures and choose Create New Scenario (name it "Smaller Reservoir"); move the slider for North Reservoir Capacity on this new scenario from 1000 MCM to 500 MCM. Click the Calculate Now button and look at the charts. You should see a difference in the Reservoir Storage Volume result for this new scenario. However, it appears that there are no additional unmet demands in this scenario over the Integrated Measures scenario, indicating that, at least for the hydrology of this 10 year period, the smaller reservoir was sufficient. Note: The functionality for creating, renaming, deleting, showing or hiding scenarios available here is also available on the [Manage Scenarios](#) screen.

Each scenario is shown with a different **color**, and the color for a scenario in the Data Section matches the color for that scenario's results in the Results Section. You can change the color palette by clicking the  button on the chart toolbar to the right of the charts.

The parent-child relationships among scenarios are shown, using indentation and lines, in the layout of the scenarios in the Data Section. For example, in the Weaping River Basin, the Reference scenario is the parent to the other three scenarios (Supply Measures, Demand Measures, and Integrated Measures), which are shown below and indented from Reference.

See also: [View Bar](#)



# 6 Expressions

## 6.1 Overview

WEAP borrows an approach made popular in spreadsheets: the ability for users to enter data and construct models using mathematical expressions. Expressions are standard mathematical formulae used to specify the values of variables in WEAP's [Data View](#). In the [Current Accounts](#) an expression defines the initial value for a given variable at a branch, while in scenarios, the expression defines how that variable changes over time (from one year after the Current Accounts to the end of the study period).

Expressions can range from simple numeric values to complex mathematical formulae. Each formula can optionally use WEAP's many built-in functions, as well as referencing the values of other branches, both data and result variables. Expressions can even create dynamic links to the values stored in an external Microsoft Excel spreadsheet.

WEAP provides a number of ways of editing expressions. The most common are:

- Typing directly into the expression field in one of the data entry table's in WEAP's [Data View](#).
- Using the [Yearly Time-Series Wizard](#) (a tool for easily entering time-series functions such as Interpolation, Step, and Smooth Curve functions) or the [Monthly Time-Series Wizard](#).
- Using the [Expression Builder](#) tool: a tool for creating expressions by dragging-and-dropping functions and WEAP data and result variables.

### 6.1.1 Color Coding of Expressions

When editing scenario data in WEAP's Data View, expressions are color coded to show which expressions have been entered explicitly, and which are inherited from another scenario. **Red** text indicates a value entered explicitly, whereas black text indicates an inherited value. To reset an expression back to its inherited default, highlight the expression and press the Delete key. For more information, see [Scenario Inheritance](#).

If no data has been entered yet for an expression, either for the current scenario or any of its parent scenarios or Current Accounts, a default value will be shown in light gray. For most variables the default value is 0, although there are a few exceptions, such as Demand Site Consumption, which defaults to 100%.

### 6.1.2 Referencing Variables in Expressions

- **Data Variables:** In an expression, the values of other branches/variables are referenced by typing the branch name followed by a colon followed by the variable name. For example, the value of the consumption variable in the Demand Sites\West City branch (of the [Weaping River Basin](#) dataset) would be referenced by typing Demand Sites\West City:Consumption. Note: Expressions are not case-sensitive. You can enter variable and function names in any combination of upper and lower-case letters. When you have finished entering the formula, WEAP will put the names in a standard format: capitalizing the names. When referencing branches that are immediate siblings or parents of the current branch, you need only specify the last part of the branch name (e.g. South City). When referencing more distant branches, include the full path name (e.g. Supply and Resources\River\Weaping River\Reservoirs\Central Reservoir:Storage Capacity). When referencing a different variable at the same branch, you need not enter the branch name.

Similarly, when referencing the same variable at a different branch you need not enter the variable name. When you specify a reference to another variable in an expression, WEAP will automatically append the scale and units of the referenced variable to the expression text using square brackets written immediately following the variable name. For example, if you enter a branch/variable reference to an Activity Level variable with a scale and units of Million Person as:

West City:Annual Activity Level

WEAP will change this to read

West City:Annual Activity Level[Million Person]

Thus the general syntax of branch/variable references is:

Branch:Variable[Scale Unit]

Notice that some variables will have no scaling factor and thus the square bracket will simply contain the unit name. You can subsequently edit the scale and units specified within the square brackets and WEAP will **convert** the values returned to the scale and units you specify. Note however, that you must specify a unit of the same class as the one specified for the referenced variable. For example, if the referenced variable is measured in a mass unit (e.g. "Tonne"), you may specify another mass unit (e.g. "kg") but using a volume unit such as liters, or any a unit of any other class will generate an error message. You can specify units either using their long names (e.g. Kilogram) or using their abbreviations (kg). Refer to the [General: Units](#) screen for a full list of available units. The allowable scaling factors values are: % (10E-2), Hundred (10E2), Thousand (10E3), Million (10E6), Billion (10E9) and Trillion (10E12). Note that you can reset an expression to use the default scaling factors (those used in the referenced variable) by simply deleting the contents of the square brackets.

- **Result Variables:** In addition to including references to data variables in your expression, you can also include references to results from a previous timestep using the [PrevTSValue](#) function. These are the values that are evaluated during WEAP's calculation routines. When you reference them in Data View or in the Expression Builder, WEAP will show the most recently calculated results for these variables. Note however, that following a calculation the value may change (because of any edits you made in Data View). Referencing a result variable before it has been calculated will return a zero value when displayed in Data View, but the value will ultimately be resolved when WEAP is calculated. Just as with referencing data variables, WEAP will automatically add the variable's scale and unit in square brackets. Similarly, you can convert from the default unit to another by changing the unit name within the brackets.

*Tip: Using the [Expression Builder](#) tool is the easiest way to create expressions that reference other branches and variables.*

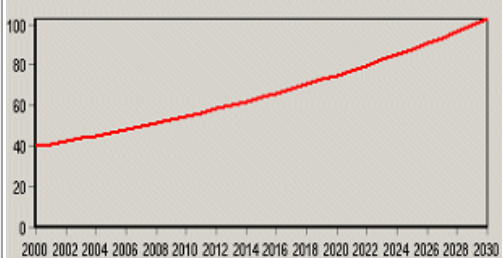
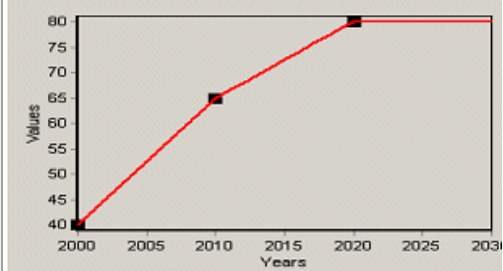
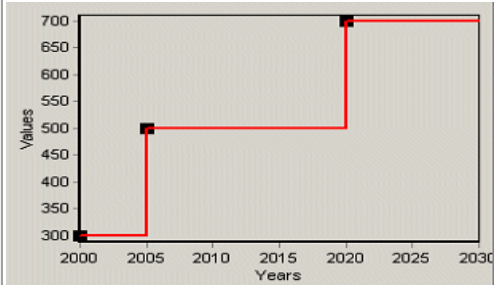
**See also:** [Functions](#), [Data View](#), [Examples of Expressions](#), [Expression Builder](#)

## 6.2 Examples of Expressions

Type of Expression.	Description	Example Syntax and Graph
Simple Number	Calculates a constant value in all scenario years	3.1415



## 6.2 Examples of Expressions




Type of Expression.	Description	Example Syntax and Graph
Simple Formula	Calculates a constant value in all scenario years	$0.1 * 5970$
Growth Rate	Calculates exponential growth over time from a <a href="#">Current Accounts</a> value. NB: only valid in scenario expressions - not in Current Account expressions.	Growth(3.2%) 
Interpolation	Calculates straight-line change between specified pairs of data years and values. An optional final parameter lets you specify an exponential growth rate after the last data year. The function can include any number of year/value pairs, which need to be entered in ascending chronological order. Notice that the value parameters in this function can themselves be specified as mathematical functions.	Interp(2000, 40, 2010, 65, 2020, 80)  Interp(2000, 0.9 * BaseYearValue, 2030, 0.7 * BaseYearValue)
Step	Similar to the Interpolation function except that it calculates discrete changes between specified pairs of data years and values.	Step(2000, 300, 2005, 500, 2020, 700) 
Remainder	Calculates remaining value in one branch by subtracting values of all other neighboring branches from the function parameter. This function is useful for “share” branches, for example where you want to specify some branches as changing percentage share, and have one branch account for the remaining share.	Remainder(100)
Branch and Variable	Any WEAP variable can be calculated as a function of another variable (with some	Weaping River:Headflow * 0.25

Type of Expression.	Description	Example Syntax and Graph
References	restrictions)	
GrowthAs	Calculates a value in any given year based on its previous year's value and the rate of growth in another named branch, raised to the power of an elasticity.	GrowthAs(Drivers\Income,1.1)

## 6.3 Expression Builder

The Expression **Builder** is a general purpose tool that helps you construct WEAP's [expressions](#) by dragging and dropping the functions and WEAP Branches into an editing box. To access the wizard, either right-click on the data table or click on the down arrow on the right side of the expression box, and choose Expression Builder from the menu.

The screen of the Expression Builder is divided into two resizable panes. At the top are a set of tabs that are used to access the names of the mathematical, logical and modeling functions built-in to WEAP, as well as to access the names of all branches in WEAP. At the bottom of the screen is an editing box, into which you can directly type to edit an expression, or into which you can add an item from the top pane, either by dragging-and-dropping or by double-clicking on an item. At the right of the editing box is a set of buttons that give quick access to the most common mathematical operators (+, -, \*, /, ^, etc.).

A toolbar at the top of the expression builder gives quick access to the most common editing options such as **Cut** () , **Copy** () , **Paste** () , etc. When constructing an expression, you can check whether the expression is valid by clicking on the **Verify** button. Finally, when you have finished with the expression, click on **Finish** to put the expression back into the data entry table you came from, or click on **Cancel** to abandon the edit.

There are two tabbed pages in the Expression Builder:

- **Functions** contain the list of [functions](#) built in to WEAP. You can see a list of ALL functions or filter the list to show the modeling, mathematical and logical functions. On the right of the tab, each function is fully documented with notes describing syntax and usage, as well as examples of how to apply each function. The modeling functions are the main functions used for defining and calculating variables in WEAP. The mathematical functions are standard mathematical functions (log, exp, max, min, etc.). Wherever possible the names and syntax of these functions are the same as equivalent functions in Microsoft Excel. The logical functions are standard logical operators (IF, AND, NOT, OR, LessThan, etc.) used to construct conditional expressions that yield different results depending on the values of variables.
- **Branches** contain a tree outline listing all WEAP branches. When you drag and drop a branch to add it to the expression, a pop-up box will appear prompting you to pick a variable from the branch to which you wish to refer. Data variables are listed first, followed by result variables (which all include "(calculated result from previous timestep)" after the result variable's name).

**See also:** [Data View](#), [Expressions](#), [Examples of Expressions](#), [Export to Excel](#), [Functions](#), [Import from Excel](#)

## 6.4 Operators

In addition to WEAP's built-in library of functions, you can also write your own functions in standard scripting languages, such as VBScript and JavaScript. These functions can be accessed from your expressions using the [Call](#) function. The [script editor](#) lets you edit the default VBScript file (functions.txt), which is stored in the current area folder. Thus, you can have different functions specified in different areas. See [Scripting](#) for more information.

## 6.5 Reserved Words

The following words are reserved for use in WEAP's expressions and cannot be included as part of a WEAP branch or variable name:

%	GrowthFrom	PrevTSValue
Abs	Hundred	PrevYear
And	If	PrevYearValue
Arccos	Int	PumpLayer
Arcsin	Interp	Random
Arctan	IrrigationSchedule	RandomDistribution
BaseYear	IsBlank	RandomInteger
Between	January or Jan or any month	ReadFromFile
Billion	name	Remainder
BlockRate	JulianDaysBefore	Round
Call	LastYear	Seconds
CAY	LessThan	Sin
Ceiling	LessThanOrEqual	Sinh
Cos	LinForecast	Smooth
Cosh	Ln	SoilLibrary
CropLibrary	LoanPayment	SoilProfiles
CurrentAccountsYear	Log	Sqr
CurrentAccountsValue	LogN	Sqrt
Days	Log10	Step
DaysBefore	LogisticForecast	Tan
ElevationToVolume	Max	Tanh
EndYear	Million	Thousand
Equal	Min	TotalChildren
Exp	Mod	TS
ExpForecast	Month	Trillion
False	MonthlyValues	True
Floor	MultiCropValues	Trunc
Frac	Not	VolumeElevation
GreaterThan	NotEqual	WaterYearMethod
GreaterThanOrEqual	Or	WaterYearSequence
Growth	Parent	Year
GrowthAs	Pi	

In addition, branch names are limited to no more than 50 characters, and may only contain alphabetic and numeric characters as well as the following additional characters: `_ . ? $ # { }` All branch names must begin with an alphabetic character.

See also: [Expressions](#)

## 6.6 Import Expressions from Excel

Use this option in conjunction with the [Export to Excel](#) option to import large amounts of data into WEAP from a previously saved Excel template spreadsheet. Each row of the spreadsheet refers to the data associated with one branch/variable/scenario combination.

Before using this option you must have created and opened a spreadsheet in Excel containing the data you wish to import. This spreadsheet must be strictly formatted with the names of branches, scenarios and variables as the rows of the spreadsheet. The only practical way to create such a spreadsheet is to first use the Export to Excel option.

Once you have exported this template, you can use standard Excel functions (fill, copy/paste, and making equations to link to other cells) to fill in the expressions with the correct values. When you import, the **text** from the Excel cell for every expression in the worksheet will overwrite the corresponding expression in WEAP. WEAP will **not** create a link to the Excel worksheet.

### Tips:

1. **What Sheet is Imported?** WEAP always imports from the current open Excel spreadsheet.
2. **Importing from Filtered Excel Spreadsheets:** By default, WEAP's export option will set up a spreadsheet that can be easily filtered to show only selected branches, variables, or scenarios. You can use the auto-filter buttons in the spreadsheet to selectively hide rows of the spreadsheet. However, when importing, WEAP will import data from all rows of the spreadsheet, whether they are visible or not.
3. **Resetting to Inherited Expressions:** To reset many expressions in a scenario to the ones used in the parent scenario, first export the scenario to Excel, then in the spreadsheet blank out the expressions you wish to reset (but do not delete the row of the spreadsheet), then import the sheet back into WEAP.
4. **How the Import option works:** In order to work correctly, the import function needs to match-up the rows in the spreadsheet with the data stored in WEAP for a given branch, variable and scenario. It is important to understand that during the import WEAP does NOT make use of the names stored in the branch, variable and scenario columns. Instead it makes use of 3 hidden columns in the spreadsheet (columns A-C) that contain unique the ID codes used for these items in WEAP. Please bear these warnings in mind:
  - Do not edit any of the hidden ID codes. Editing these codes may cause unpredictable results and can even cause your WEAP data to become corrupted and unusable. Bear in mind also that you cannot add rows to the sheet--WEAP can only import data that corresponds to an existing branch/variable/scenario,
  - You may delete any rows in the spreadsheet. WEAP simply imports any remaining contiguous rows that exist in the spreadsheet
  - Make sure you have a backup of your data set before importing any data.

## 6.7 Export Expressions to Excel

Use this option to export to Excel some or all of the data expressions in WEAP. This process will allow you to link your WEAP expressions to Excel values for later import back into WEAP. See [Import from](#)

## 6.7 Export Expressions to Excel

[Excel](#) for details of importing. In addition, Excel, with its filtering capabilities, provides a convenient way to view your data

There are various options that allow you to control exactly what is exported and to where.

### Export to

Choose to export to a new Excel workbook, or a new worksheet in the active workbook. The second option is only available if a workbook is open in Excel.

### Branches

Choose whether to export only the current branch and all branches below it (e.g., all demand sites), or all branches.

### Variables

Choose whether to export only the current variable (e.g., Annual Activity Level) or all variables.

### Scenarios

You can export just the active scenario, or all scenarios.

### Export rows for blank expressions

When this option is unchecked, WEAP will only create rows in Excel where the data expression is not blank. If you are primarily interested in viewing the data you have entered in WEAP, leave this unchecked. However, if you intend to link your expressions to Excel values (in which case the expressions are currently blank) for later import into WEAP, you will want to turn this on. This option works in combination with **Export inherited expressions**, as explained next.

### Export inherited expressions

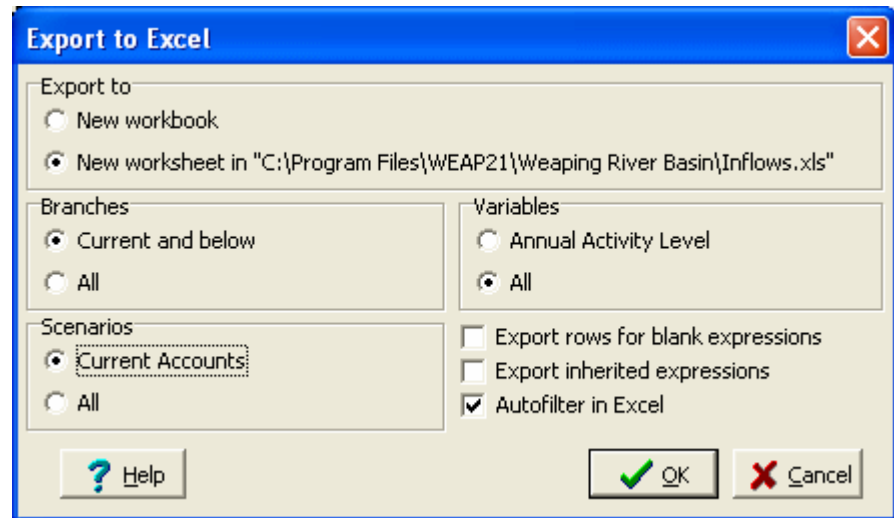
This option lets you either export all data, or only data that is not inherited (i.e., is explicitly entered) for a given scenario. For example, in Weaping River Basin, the consumption rate for South City is 25%. This value is entered in the Current Accounts, and every scenario inherits this value. Therefore, if you were exporting expressions from the Reference scenario, the expression for \Demand Sites\South City:Consumption would be "25" only if **Export inherited expressions** was checked. If it was not checked, since the expression is blank in the Reference scenario, the row would be exported only if **Export rows for blank expressions** was checked. (See [Scenario Inheritance](#) for more information.)

### Autofilter in Excel

Finally, WEAP can optionally set up Excel's auto-filtering feature, to help you quickly sort through and filter the resulting spreadsheet. If you don't want Excel to auto-filter the resulting spreadsheet, uncheck the Autofilter checkbox.

Once you have set these options, click OK to export to Excel, or Cancel to abort the export operation.

**Menu Option:** Edit: Export to Excel...



## 6.8 Functions

WEAP borrows an approach made popular in spreadsheets--the ability for users to enter data and construct models using mathematical expressions. Expressions are standard mathematical formulae used to specify the values of variables in WEAP's Data View. WEAP supports a comprehensive set of functions that you can include in your expressions to create your models. For more information, see [Expressions](#) for an introduction to expressions. Functions are divided into three groups:

- **Modeling functions:** the major functions used to help you model data.
- **Mathematical functions:** standard mathematical functions, similar in syntax to the ones used in Microsoft Excel.
- **Logical functions:** which can be used to create complex conditional modeling expressions.

In addition to WEAP's built-in library of functions, you can easily write your own functions in standard scripting languages, such as VBScript, JavaScript, Perl, Python, Ruby and PHP. These functions can be accessed from your expressions using the [CALL](#) function. See [Scripting](#) for more information.

### 6.8.1 Modeling Functions

## BaseYear

### Syntax

CurrentAccountsYear or CAY or BaseYear

### Description

The Current Accounts year as a numeric value (as specified in the [General, Years and Time Steps](#) screen).

### Example

Interp(BaseYear, 100, LastYear, 200)

Will do a linear interpolation between 100 and 200 over the entire study period.

## BlockRate

### Syntax

BlockRate(Customers, TimestepsPerBillingPeriod, Rate\_1, RateDenomUnit\_1, UpperLimit\_1, UpperLimitUnit\_1, Rate\_2, RateDenomUnit\_2, UpperLimit\_2, UpperLimitUnit\_2, ..., Rate\_N, RateDenomUnit\_N)

### Description

Tiered water pricing policies are often touted as a means of promoting demand management. Water conservation practices are motivated by increasing unit costs on higher usage of water. The BlockRate function allows for the approximation of revenues generated by such a block rate pricing structure. There is no limit to the number of blocks.

**Customers:** The number of customers included in the demand site. Note: the block rate is calculated for the average customer use--actual rates will differ slightly, because some customers will use more than the average and some will use less, and the block rate structure is inherently non-linear. WEAP will take the total water used by the demand site and divide by the number of customers to derive the average usage

per customer. The block rates will be applied to this average usage to get the average cost per customer. This average cost will then be multiplied by the number of customers to get the total customer cost.

**TimestepsPerBillingPeriod:** The length of the billing period, in timesteps. E.g., for quarterly billing and a monthly timestep, enter 3. WEAP will calculate the cost for each timestep, by dividing the block sizes by this number of timesteps. For example, instead of one bill every 3 months, there will be a bill every month, but each will be approximately 1/3 of the quarterly bill.

The following four parameters are repeated for each block, except for the final block, which includes only the first two parameters (because it has no upper limit).

**Rate\_i:** The cost of water for block i, either a unit cost or a flat rate. See RateDenomUnit\_i

**RateDenomUnit\_i:** The denominator unit for Rate\_i (e.g., "gallons," or "cubic meters"), or "flat" to indicate a fixed cost regardless of usage within this block. A flat rate, or "base rate," is often charged for the first block.

**UpperLimit\_i:** The upper limit water volume for this block. This parameter is not included for the last block, because it has no upper limit.

**UpperLimitUnit\_i:** The unit for the upper limit water volume. This parameter is not included for the last block, because it has no upper limit.

### **Example**

The 100,000 households in South City are billed every 6 months, using the following block structure:

Base charge of \$29.20 per bill includes up to 20,000 gallons  
20,000 - 30,000 gallons at \$1.40/1000 gallons  
30,000 - 50,000 gallons at \$1.65/1000 gallons  
50,000 - 70,000 gallons at \$1.90/1000 gallons  
70,000 - 90,000 gallons at \$2.25/1000 gallons  
Over 90,000 gallons at \$2.60/1000 gallons

The following expression should be entered in the "Variable Benefit" data tab for South City:

BlockRate(100000, 6, 29.20, flat, 20000, gal, 0.00140, gal, 30000, gal, 0.00165, gal, 50000, gal, 0.00190, gal, 70000, gal, 0.00225, gal, 90000, gal, 0.00260, gal)

Note that WEAP calculates the cost for each month, but because the bill covers 6 months, WEAP will divide the size of each block by 6. Also, the flat rate would be divided evenly over each of the 6 months. If, for example, the average customer use in January was 4000 gallons, this would fall in the second block: 20,000 - 30,000 gallons for 6 months is equivalent to 3333 - 5000 gallons for 1 month. 4000 gallons would be charged a flat rate of \$4.87 for the first 3333 gallons, and \$0.0014/gallon for the next 667 gallons. The cost per customer =  $\$29.20/6 + (4000 - 3333) * \$0.0014 = \$5.80$ , or a total cost for all customers of \$580,047.

## **Call**

### **Syntax**

Call( ScriptFunctionName, parameter1, parameter2, ...)  
or Call( ScriptFileName ! ScriptFunctionName, parameter1, parameter2, ...)  
or Call( DLLFileName ! DLLFunctionName, parameter1, parameter2, ...)

### **Description**

Call a function in an external script (e.g., Visual Basic Script or JavaScript) or DLL with any number of parameters.

## Calling Scripts

A script is a text file containing user-defined functions written in a scripting language, such as Visual Basic Script (.vbs), JScript (.js), Perl (.pl), Python (.py), PHP (.php) or Ruby (.rb). VBScript and JScript come with Windows and are always available, whereas other scripting languages must be installed by you on your computer before you can use them in WEAP.

WEAP will look in ScriptFileName for the function ScriptFunctionName. As a convenience, if ScriptFileName is omitted, WEAP will look for a file called "functions.vbs" in the current area folder.

You can put commonly used functions into functions.vbs to make it easier to call them. For example, two trivial examples:

```
Function Add(x, y)
    Add = x + y
End Function

Function Multiply(x, y)
    Multiply = x * y
end Function
```

Notice that each function starts with the keyword Function and ends with the Keywords End Function.

Function results are set by assigning values to the function name. WEAP functions should always return numeric values (integer or floating point) and should always use numeric parameters. Functions can have any number of parameters, but the burden is on the user to pass the correct number of parameters in a comma separated list in the Call statement.

The following example expressions in WEAP could be used to call these two functions:

CALL(Add, 5, 4)  
would return a value of 9

CALL(Multiply, 5, 4)  
would return a value of 20

An error will be reported if the number or type of parameters are incorrect, or if you call a function that does not exist in the script file.

WEAP has its own built-in [script editor](#) that can be used to edit, interactively debug and run scripts.

## Calling DLLs

A DLL is a Microsoft Windows "dynamic link library" file that contains one or more functions. A DLL is a compiled executable program written in a standard programming language, such as C, Visual Basic or Delphi. The ability of WEAP to call DLL functions is very powerful, as it allows the user to add new functions or even complete models to WEAP.

The DLL function should expect a parameter that is an array of double precision numbers, and should return one double precision number as the result.

### Examples

Call( C:\DLLTest.dll ! Sum, 1, 2, 3, 4, 5) ; will call a function called Sum in the DLL file c:\DLLTest.dll, passing it an array of 5 numbers. (See Delphi source below)



## 6.8 Functions

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Call( C:\DLLTest.dll ! Cos, month \* 30) ; a Cosine wave, going from 30 degrees to 360 degrees over the year (See Delphi source below)

The parameters can include WEAP variables and functions, e.g.,

```
Call( ReservoirOperations.dll ! CalculateRelease,  
  \Demand Sites\Agriculture North:Monthly Demand,  
  PrevTSValue( \Supply and Resources\River\Weaping River\Reservoirs\Central Reservoir:Storage  
  Volume[m^3] ) )
```

**Sample Delphi source code listing for test.dpr, which can be compiled (using the free [Turbo Delphi compiler](#)) into test.dll**

```
library DLLTest;  
  
{  
Simple Delphi program for testing calling dlls from WEAP  
Example calls from WEAP  
Call( C:\DLLTest.dll ! Sum, 1, 2, 3, 4, 5)  
Call( C:\DLLTest.dll ! Cos, 90)  
Call( C:\DLLTest.dll ! Sin, month * 30)  
}  
  
{$R *.res}  
  
// Sum up all the parameters  
function Sum(Parameters: array of double): double; stdcall;  
var  
i: integer;  
begin  
result := 0;  
  
for i := 0 to Length(Parameters) - 1 do  
result := result + Parameters[i];  
end;  
  
const  
DegreeToRadianConversion = 2 * Pi / 360; // Convert from degrees to  
radians  
  
// Cosine of an angle expressed in degrees.  
function Cos(Parameters: array of double): double; stdcall;  
begin  
result := System.Cos(Parameters[0] * DegreeToRadianConversion);  
end;  
  
// Sine of an angle expressed in degrees.  
function Sin(Parameters: array of double): double; stdcall;  
begin  
result := System.Sin(Parameters[0] * DegreeToRadianConversion);  
end;
```

```
// These are the functions that can be called by WEAP or other
programs
exports Sum, Cos, Sin;

begin
// nothing in the body
end.
```

**Sample C source code listing for test.c, which can be compiled (using a standard C compiler, such as the free [Turbo C++ compiler](#)) into test.dll**

```
#include <stdlib.h>
#include <windows.h>

#define DLLEXPORT __declspec(dllexport)

DLLEXPORT double Sum(double *Parameters, int LastElementIndex);

# When Delphi programs, such as WEAP, pass an array to a C program,
there is a parameter following the array which is the index of the
last element in the 0-based array. In other words, this will equal the
length of the array minus 1. For example, if the array has 5 elements,
LastElementIndex = 4.

DLLEXPORT double Sum(double *Parameters, int LastElementIndex) {
int i;
double result;
result = 0;
for (i = 0; i <= LastElementIndex; i++)
    result += Parameters[i];
return result;
}

BOOL APIENTRY DllMain (HINSTANCE hInst /* Library instance handle. */
,
DWORD reason /* Reason this function is being called. */ ,
LPVOID reserved /* Not used. */ )
{
switch (reason)
{
case DLL_PROCESS_ATTACH:
break;

case DLL_PROCESS_DETACH:
break;

case DLL_THREAD_ATTACH:
break;
}
```

```
case DLL_THREAD_DETACH:
break;
}

/* Returns TRUE on success, FALSE on failure */
return TRUE;
}
```

# CAY

### Syntax

CurrentAccountsYear or CAY or BaseYear

### Description

The Current Accounts year as a numeric value (as specified in the [General, Years and Time Steps](#) screen).

### Example

Interp(CAY, 100, LastYear, 200)

Will do a linear interpolation between 100 and 200 over the entire study period.

# CropLibrary

### Syntax

CropLibrary("Crop1", Planting Date1, "Crop2", Planting Date2, ...)

### Description

This function is used in conjunction with the [MABIA Method](#) for catchment hydrology and crop water requirements.

The CropLibrary function is used to specify one or more crops (from the [Crop Library](#)) and planting dates for catchment branches in the Data View, under [Land Use](#). Use the [Crop Scheduling Wizard](#) to build an expression containing CropLibrary, available in the drop-down menu in the data grid.

### Examples

CropLibrary("Tomato (Arid Region)", Jan 13)

Crop "Tomato (Arid Region)" is planted on January 13.

CropLibrary("Maize (grain) (Arid Climate)", Jan 10, "Onion (green) (Arid Region)", Sep 25)

Crop "Maize (grain) (Arid Climate)" is planted on January 10, and later in the year on the same land, crop "Onion (green) (Arid Region)" is planted on September 25.

# CurrentAccountsYear

### Syntax

CurrentAccountsYear or CAY

### Description

The Current Accounts year as a numeric value (as specified in the [General, Years and Time Steps](#) screen).

**Example**

Year - CurrentAccountsYear

Evaluated for a Current Accounts year of 1995

2000 = 5.0

2020 = 25.0

## CurrentAccountsValue

**Syntax**

CurrentAccountsValue or

CurrentAccountsValue(BranchName)

**Description**

Calculates the Current Accounts value of either the current branch, or of another branch referred to as a parameter to the function.

**Examples**

10+CurrentAccountsValue for a Current Accounts value of 100

Evaluated in any year = 110

10+CurrentAccountsValue(Households\Urban)

for branch "Household\Urban" with a Current Accounts value of 1000.

Evaluated in any year = 1010

## Days

**Syntax**

Days

**Description**

The number of days in the current month (as specified in the [General, Years and Time Steps](#) screen).

**Example**

Days

Evaluated in January 2000 = 31

Evaluated in February 2000 = 28 (if leap days are turned off)

Evaluated in February 2000 = 29 (if leap days are turned on)

## DaysBefore

**Syntax**

DaysBefore

### **Description**

The number of days in the **water** year preceding the current month. This depends on the Water Year Start (as specified in the [General, Years and Time Steps](#) screen).

### **Example**

DaysBefore

Evaluated in January 2001 = 0 (assuming the water year starts in January)

Evaluated in January 2001 = 92 (assuming the water year starts in October)

## **ElevationToVolume**

### **Syntax**

ElevationToVolume(Elevation) or  
ElevationToVolume(Reservoir, Elevation)

### **Description**

Converts a reservoir elevation to a reservoir volume, using the [Reservoir Volume Elevation Curve](#). If the reservoir parameter is not included, then the current reservoir will be used. A typical use would be to specify reservoir [operating zones](#), such as top of conservation, using elevation instead of volume units. Note: the elevation given must be in the unit specified for reservoir elevation and the resulting volume will be in the unit specified for reservoir volume (see [General Area Parameters, Units](#)).

### **Examples**

Your data for the top of conservation pool is in meters, not cubic meters. Because you are referring to the volume elevation curve from a variable (top of conservation) from the same reservoir, you can omit the reservoir parameter. Here is the expression to put into the top of conservation data variable, than includes the elevation data (from 20 - 30 m):

```
ElevationToVolume( MonthlyValues(Jan, 20, Feb, 20, Mar, 20, Apr, 30, May, 30, Jun, 28, Jul, 25, Aug, 22, Sep, 20, Oct, 20, Nov, 20, Dec, 20) )
```

You want to model a water conservation program that starts (reducing demand by 15%) when the reservoir elevation drops below a critical level (20 m). Here is the expression for \Demand Sites\South City:DSM Reduction

```
If( ElevationToVolume( Supply and Resources\River\Weaping River\Reservoirs\Central Reservoir, 20 )  
< PrevTSValue(Supply and Resources\River\Weaping River\Reservoirs\Central Reservoir:Storage  
Volume[Million m^3]),  
15%,  
0)
```

Note: for this example, it would actually be easier to get the result value for elevation directly (no need to convert elevation to volume), using PrevTSValue(Supply and Resources\River\Weaping River\Reservoirs\Central Reservoir:Storage Elevation.

## **EndYear**

### **Syntax**

EndYear

### **Description**

The last year of the analysis as a numeric value (as specified in the [General, Years and Time Steps](#) screen). Synonymous with LastYear

### **Example**

EndYear - Year

Evaluated for an last year of 2020:

2000 = 20.0

2018 = 2.0

Interp(BaseYear, 100, EndYear, 200)

Will do a linear interpolation between 100 and 200 over the entire study period.

## **ExpForecast**

### **Syntax**

ExpForecast(Year1, Value1, Year2, Value2,... YearN, ValueN) or  
ExpForecast(XLRange(Filename, Rangenam))

### **Description**

Exponential forecasting is used to estimate future values based on a time series of historical data. The new values are predicted using linear regression to an exponential growth model ( $Y = m + X^c$ ) where the Y terms corresponds to the variable to be forecast and the X term is years. Exponential forecasting is most useful in cases where certain values can be expected to grow at constant growth rates over the period in question (e.g. population levels).

Use this function with caution. You may need to first use a spreadsheet or some other package to test the statistical validity of the forecast (i.e. test how well the regression "fits" the historical data). Moreover, bear in mind that future trends may be markedly different from historical ones, particularly if structural or policy shifts in the economy are likely to have an impact on future trends.

Using the above two alternatives syntaxes the time-series data required by the function can either be entered explicitly in WEAP as year/value pairs or it can be specified as a range in an Excel spreadsheet. Use the yearly time-series wizard to input these values or to link to the Excel data. In either case, years do not need to be in any particular order, but duplicate years are not allowed, and must be in the range 1990-2200.

When linking to a range in Excel, you must specify the directory and filename of a valid Excel worksheet or spreadsheet (an XLS or XLW) file, followed by a valid Excel range. A range can be either a valid named range (e.g. "Import") or a range address (e.g. "Sheet1!A1:B5"). The Excel range must contain pairs of years and values in its cells arranged into 2 columns. Use the WEAP Yearly Time-series Wizard to select a worksheet, to choose among the valid named ranges in the worksheet, and to preview the data that will be imported.

NB: The result of this function will be overridden by any value calculated for the Current Accounts. In some cases this may lead to a marked "jump" from the Current Accounts value to the succeeding year's value. This may reflect the fact that the Current Accounts year you have chosen is not a good match of the long-term trends in your scenario, or it may reflect a poor fit between the regression and the historical data.

### **Tip**

Use the Yearly Time-Series Wizard to enter the data for this function.

## **Growth**

### **Syntax**

Growth(Expression)

### **Description**

Calculates a value in any given year using a growth rate from the previous year's value (exponential growth). Because it references a previous year's value, this function is only available when editing scenarios.

### **Examples**

Growth(0.05) or Growth(5%)

Evaluated from a Current Accounts value of 100 in 2000

2001 = 105.00

2002 = 110.25

If the water use rate is growing annually by 3%, but will start to decline at a rate of 1% per year once you implement water-saving measures in 2012, the expression would be:

If( Year < 2012, Growth(3%), Growth(-1%) )

## **GrowthAs**

### **Syntax**

GrowthAs(BranchName) or

GrowthAs(BranchName, Elasticity) or

### **Description**

Calculates a value in any given year using the previous value of the current branch and the rate of growth in another named branch. This is equivalent to the formula:

$$\text{Current Value}(t) = \frac{\text{Current Value}(t-1) * \text{NamedBranchValue}(t)}{\text{NamedBranchValue}(t-1)}$$

In the second form of the function, the calculated growth rate is adjusted to reflect an elasticity. More precisely, the change in the current (dependent) branch is related to the change in the named branch raised to the power of the elasticity. This is a common approach in econometric modeling, in which the growth in one variable is estimated as a function of the growth in another (independent) variable.

$$\text{Current Value}(t) = \text{Current Value}(t-1) * ( (\text{NamedBranchValue}(t) / \text{NamedBranchValue}(t-1)) ^ \text{Elasticity} )$$

### **Examples**

GrowthAs(Household\Rural)

GrowthAs(GDP, 1)

In this example (elasticity = 1), the current branch grows at the same rate as the named branch (GDP). When GDP doubles, so does the current branch. This is equivalent to GrowthAs(GDP) without the elasticity parameter.

GrowthAs(GDP, 0.9)

In this example (elasticity = 0.9), the current branch grows more slowly than GDP.

GrowthAs(GDP, 1.2)

In this example (elasticity = 1.2), the current branch grows more rapidly than GDP.

GrowthAs(GDP, 0)

In this example (elasticity = 0), the current branch is constant (i.e. independent of GDP).

### **Determining the value for Elasticity**

To derive the elasticity, substitute your assumptions into the equation above. Suppose you think that demand will decrease by 25% as the price of water doubles. (This is an inverse relationship--as one increases, the other decreases--and will have an elasticity less than 0.) The expression for demand (the "water intensity" variable) will be

GrowthAs(\Key Assumptions\Price of Water, elasticity).

(This assumes that you had created a Key Assumption variable called Price of Water, and had specified the current and future values of the price. WEAP will not do this for you.)

To derive the elasticity, let's use our assumptions. NamedBranchValue doubles:

NamedBranchValue(t) = 2 \* NamedBranchValue(t-1)

Current Value decreases by 25%:

Current Value(t) = 0.75 \* Current Value(t-1)

Using the definition of GrowthAs with elasticity

Current Value(t) = Current Value(t-1) \* ( (NamedBranchValue(t) / NamedBranchValue(t-1)) ^ Elasticity )

substitute our assumptions:

0.75 \* Current Value(t-1) = Current Value(t-1) \* ( (2 \* NamedBranchValue(t-1) / NamedBranchValue(t-1)) ^ Elasticity )

Simplifying:

0.75 = 2 ^ Elasticity

Take the log base 2 of each side:

Elasticity = log2(0.75) = -0.415

Therefore, the expression to use for the water intensity would be GrowthAs(\Key Assumptions\Price of Water, -0.415)

In modeling demand, in addition to looking at the price elasticity of demand (demand decreases as price increases), you might also want to explore the income elasticity of demand (demand increases as income or GDP increases). For more information on elasticities, consult a basic economics textbook.



# GrowthFrom

### Syntax

GrowthFrom(*GrowthRate*, *StartYear*, *StartValue*)

### Description

Calculates a value in any given year using a growth rate from the *StartValue* in the *StartYear*. The *StartYear* can be any year, past, present or future.

### Example

GrowthFrom(5%, 1990, 100)

2000 = 162.89

2002 = 171.03

GrowthFrom(5%, 2010, 100)

2001 = 61.39

2002 = 64.46

# Interp

### Syntax

Interp(*Year1*, *Value1*, *Year2*, *Value2*,... *YearN*, *ValueN*, [*GrowthRate*]) or  
Interp(*ExcelFilename*, *ExcelRangeName*, [*GrowthRate*])

### Description

Calculates a value in any given year by linear interpolation of a time-series of year/value pairs.

Using the above two alternatives syntaxes year/value pairs can either be entered explicitly or linked to a range in an Excel spreadsheet. Use the WEAP [Yearly Time-series Wizard](#) to input these values or specify the Excel data. In either case, years do not need to be in any particular order, but duplicate years are not allowed, and must be in the range 1990-2200. The final optional parameter to the function is a growth rate that is applied after the last specified year. If no growth rate is specified zero growth is assumed (i.e. values are not extrapolated).

When linking to a range in Excel, you specify the full path name of a valid Excel worksheet or spreadsheet (an XLS or XLW) file, followed by a valid Excel range. A range can be either a valid named range (e.g. "Import") or a range address (e.g. "Sheet1!A1:B5"). The Excel range must contain pairs of years and values in its cells arranged into 2 columns. Use the Yearly Time-series Wizard to select a worksheet, to choose among the valid named ranges in the worksheet, and to preview the data that will be imported.

NB: the [Current Accounts](#) value is always implicit in the above function, and will override any value explicitly entered for that year by the user. So for example, if the Current Accounts year is 1998 and the Current Accounts value (entered in Current Accounts) is 6.0 then the above function will result in the value 8.0 1999.

### Example

Interp(2000, 10.0, 2010, 16.0, 2020, 30.0, 2%)

2000 = 10.0  
 2005 = 13.0  
 2020 = 30.0  
 2021 = 30.6

### **Tips**

- For users of older versions of WEAP: this function is similar to the old "Interpolation" method for projecting data.
- Use the Yearly Time-Series Wizard to enter the data for this function.
- You may also import many data expressions at once from Excel. See [Export to Excel](#), [Import from Excel](#) for details.

## **IrrigationSchedule**

### **Syntax**

IrrigationSchedule(CropNumber1, IrrigationStartDate1, IrrigationEndDate1, IrrigationTriggerMethod1, IrrigationTriggerValue1, IrrigationAmountMethod1, IrrigationAmountValue1, CropNumber2, IrrigationStartDate2, IrrigationEndDate2, IrrigationTriggerMethod2, ...)

### **Description**

This function is used in conjunction with the [MABIA Method](#) for catchment hydrology and crop water requirements.

Irrigation is required when rainfall is insufficient to compensate for the water lost by evapotranspiration. The primary objective of irrigation is to apply water at the right period and in the right amount. By calculating the soil water balance of the root zone on a daily basis, the timing and the depth of future irrigation can be planned. To avoid crop water stress, irrigation should be applied before or at the moment when the readily available soil water (RAW) is depleted (Depletion  $\geq$  RAW).

The IrrigationSchedule function specifies the timing and amount of irrigation. Each crop can have many different schedules for non-overlapping periods of the crop season. For example, you may want to irrigate more frequently during the sensitive flowering and yield formation stages. If a branch has more than one crop in rotation, you can specify the irrigation schedules for all crops. Use the [Irrigation Scheduling Wizard](#) to help you fill in the parameters for the IrrigationSchedule function.

**CropNumber\_i:** To which crop does schedule i apply. 1 is the first crop in the rotation, 2 is the second crop (if any), and so forth. The same crop can have multiple schedules

**IrrigationStartDate\_i:** The date on which schedule i begins, in Month Day format, e.g., "Jan 1" for January 1st.

**IrrigationEndDate\_i:** The date on which schedule i ends.

**IrrigationTriggerMethod\_i:** The method for determining when irrigation will occur. There are four "trigger" methods:

- Fixed Interval: Irrigate every N days, where N is specified in the IrrigationTriggerValue.
- % of RAW: Irrigate when soil moisture depletion is greater than or equal to a specified % of Readily Available Water (RAW). To prevent crop water stress, depletion should never exceed RAW.

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- % of TAW: Irrigate when soil moisture depletion is greater than or equal to a specified % of Total Available Water (TAW). To prevent crop death (permanent wilt point), depletion should never equal or exceed TAW.
- Fixed Depletion: Irrigate when soil moisture depletion is equal to or exceeds a specified depth (in mm).

**IrrigationTriggerValue\_i:** The value that goes with the IrrigationTriggerMethod: days (fixed interval), % (% of RAW or % of TAW), mm (fixed depletion).

**IrrigationAmountMethod\_i:** The method for determining how much water to apply on days when irrigation occurs. There are four methods:

- % Depletion: Apply a specified % of the current soil water depletion.
- % of RAW: Apply a specified % of the Readily Available Water (RAW) level, regardless of the current soil water depletion.
- % of TAW: Apply a specified % of the Total Available Water (TAW) level, regardless of the current soil water depletion.
- Fixed Depth: Apply a specified depth of water. Note: the value entered should be the average depth of water applied to the entire area. If the fraction wetted ( $F_w$ ) < 1, then the amount actually delivered to the crop will be higher:  $I/F_w$ . For example, for a drip irrigation system with  $F_w=0.3$ , a fixed depth application of 10 mm of water would be mean that  $10/0.3 = 33.3$  mm of water was applied to that 30% of the land area, and would be available for ET by the crop.

**IrrigationAmountValue\_i:** The value that goes with the IrrigationAmountMethod: % (% Depletion, % of RAW or % of TAW), mm (fixed depth).

The optimal irrigation schedule and amount would use % of RAW (100% of RAW) as the trigger method, and % of Depletion (100% of Depletion) as the irrigation amount method, which would apply irrigation at the last moment before crop stress would occur, and irrigate just enough to get back up to field capacity. However, in reality, it will be difficult for a farmer to know exactly when depletion reaches the RAW threshold

For the first three irrigation amount methods (% of Depletion, RAW or TAW), the amount calculated will be the actual amount delivered to the crop. If the fraction wetted ( $F_w$ ) < 1, then the average amount over the entire area will be less:  $I * F_w$ . For example, a drip irrigation system with  $F_w=0.3$ , a % of depletion amount method (100%), and a depletion of 40 mm, would require an average depth of irrigation of  $40 * 0.3 = 12$  mm. For a 1 hectare plot of land, this would be  $1 \text{ ha} * 12 \text{ mm} = 120 \text{ m}^3$  of water. When the  $120 \text{ m}^3$  of water was applied to the 30% of the 1 hectare, the crop would receive  $120 \text{ m}^3 / (30\% * 1 \text{ ha}) = 40\text{mm}$ .

If there are gaps in the irrigation dates between schedules, there will be no irrigation during those periods. There is no irrigation in the fallow periods (before or after the crop season).

Note: the irrigation amount is the amount available for evapotranspiration. If the irrigation efficiency is less than 100%, then the supply requirement for irrigation will be increased. For example, if the irrigation efficiency is 75% (which means that 25% is lost to evaporation, runoff or deep percolation) and the irrigation amount is 100% of depletion, and the depletion is 40mm, then the amount applied will be  $40 / 0.75 = 53.3$  mm, of which 40 mm will effectively reach the crop and be available for ET, and 13.3 will evaporate, runoff or percolate (as specified by Loss to Groundwater and Loss to Runoff fractions [entered as data](#)).

### **Examples**

IrrigationSchedule(1, Mar 1, Nov 25, % of RAW, 100, % Depletion, 100)

This example has 1 irrigation schedule, triggering irrigation when soil moisture depletion reaches 100% of RAW, and will apply enough water erase 100% of the current soil moisture depletion.

IrrigationSchedule(1, Mar 1, Mar 30, Fixed Interval, 3, Fixed Depth, 80, 1, Mar 31, Sep 11, % of RAW, 100, % Depletion, 100, 2, Sep 12, Jan 29, % of RAW, 100, % Depletion, 90)

This example has 3 irrigation schedules--2 for the first crop and 1 for the second crop. The first crop will be irrigated every 3 days to a depth of 80 mm from March 1 to March 30, and from March 31 to September 11 will irrigation when depletion reaches 100% of RAW and apply an amount to eliminate all the soil moisture depletion (i.e., up to field capacity). The second crop will be irrigated from September 12 to January 29 when depletion reaches 100% of RAW and apply an amount equal to 90% of the soil moisture depletion (not quite enough to get back to field capacity).

See also: [MABIA Irrigation](#), [Irrigation Scheduling Wizard](#)

## January (or any other month name)

### Syntax

January or Jan or February or Feb or ... or December or Dec

### Description

The number of the month in the water year, from 1 - 12 (as specified in the [General, Years and Time Steps](#) screen). Only available if the timestep is monthly. Note: the number of the month depends on when the water year starts. For example, if the water year starts in October, then the value of October is 1, not 10.

### Example

If( Month = April, 10, 2)  
= 10 in April, and 2 in every other month

## JulianDaysBefore

### Syntax

JulianDaysBefore

### Description

The number of days in the **calendar** year preceding the current month, regardless of the Water Year Start.

### Example

JulianDaysBefore

Evaluated in January 2001 = 0  
Evaluated in February 2001 = 31

## LastYear

### Syntax

LastYear

### Description

The last year of the analysis as a numeric value (as specified in the [General, Years and Time Steps](#) screen). Synonymous with EndYear

### **Examples**

LastYear - Year

Evaluated for an last year of 2020:

2000 = 20.0

2018 = 2.0

Interp(BaseYear, 100, LastYear, 200)

Will do a linear interpolation between 100 and 200 over the entire study period.

## **LinForecast**

### **Syntax**

LinForecast(Year1, Value1, Year2, Value2,... YearN, ValueN) or  
LinForecast(XLRange(Filename, Rangenam))

### **Description**

Linear forecasting is used to estimate future values based on a time-series of historical data. The new values are predicted using linear regression assuming a linear trend ( $y = mx + c$ ) where the Y term corresponds to the variable to be forecast and the X term is years. Linear forecasting is most suitable in cases where exponential growth in values is not expected: for example when forecasting how market shares or technology penetration rates might change over time.

Use this function with caution. You may need to first use a spreadsheet or some other package to test the statistical validity of the forecast (i.e. test how well the regression "fits" the historical data). Moreover, bear in mind that future trends may be markedly different from historical ones, particularly if structural or policy shifts in the economy are likely to have an impact on future trends.

Using the above two alternatives syntaxes the time-series data required by the function can either be entered explicitly in WEAP as year/value pairs or it can be specified as a range in an Excel spreadsheet. Use the yearly time-series wizard to input these values or to link to the Excel data. In either case, years do not need to be in any particular order, but duplicate years are not allowed, and must be in the range 1900-2200.

When linking to a range in Excel, you must specify the directory and filename of a valid Excel worksheet or spreadsheet (an XLS or XLW) file, followed by a valid Excel range. A range can be either a valid named range (e.g. "Import") or a range address (e.g. "Sheet1!A1:B5"). The Excel range must contain pairs of years and values in its cells arranged into 2 columns. Use the WEAP Yearly Time-series Wizard to select a worksheet, to choose among the valid named ranges in the worksheet, and to preview the data that will be imported.

NB: The result of this function will be overridden by any value calculated for the [Current Accounts](#). In some cases this may lead to a marked "jump" from the Current Accounts value to the succeeding year's value. This may reflect the fact that the Current Accounts year you have chosen is not a good match of the long-term trends in your scenario, or it may reflect a poor fit between the regression and the historical data.

### **Tip**

Use the Yearly Time-Series Wizard to enter the data for this function.

## LoanPayment

### Syntax

LoanPayment(CapitalCost, FirstYear, LoanTerm) or

LoanPayment(CapitalCost, FirstYear, LoanTerm, InterestRate)

### Description

The LoanPayment function returns the value of the annual loan payment divided by the number of timesteps in a year. The arguments are:

**CapitalCost:** The principal of the loan, in dollars.

**FirstYear:** The first simulation year in which payments will be made.

**LoanTerm:** The length of the loan, in years.

**InterestRate:** The interest rate expressed in decimal form or as a percent, e.g., for six percent enter either "0.06" or "6% ". This item is not required. If left blank, the *Discount Rate* set under the menu option *General, Units, Monetary* will be used.

### Example

LoanPayment(10000000, 2005, 20, 6%)

This example calculates the annual loan payment for 10 million dollars financed over 20 years at 6% interest. The annual payment, \$871,845 is divided by the number of timesteps in a year before appearing in the financial reports.

## LogisticForecast

### Syntax

LogisticForecast(Year1, Value1, Year2, Value2,... YearN, ValueN) or

LogisticForecast(XLRange(Filename, Rangenam))

### Description

Logistic forecasting is used to estimate future values based on a time series of historical data. The new values are predicted using an approximate fit of a logistic function by linear regression.

A logistic function takes the general form:

$$Y = A + \frac{B - A}{1 + e^{(-a \cdot X + b)}}$$

where the Y terms corresponds to the variable to be forecast and the X term is years. A, B, a, b are constants and e is the base of the natural logarithm (2.718...). A logistic forecast is most appropriate when a variable is expected to show an "S "shaped curve over time. This makes it useful for forecasting shares, populations and other variables that are expected to grow slowly at first, then rapidly and finally more slowly, approaching some final value (the "B" term in the above equation).

Use this function with caution. You may need to first use some other package to test the statistical validity of the forecast (i.e. test how well the regression "fits" the historical data).

Using the above two alternatives syntaxes the time-series data required by the function can either be entered explicitly in WEAP as year/value pairs or they can be specified as a range in an Excel spreadsheet. Use the yearly time-series wizard to input these values or to link to the Excel data. In either case, years do not need to be in any particular order, but duplicate years are not allowed, and must be in the range 1990-2200.

When linking to a range in Excel, you must specify the directory and filename of a valid Excel worksheet or spreadsheet (an XLS or XLW) file, followed by a valid Excel range. A range can be either a valid named range (e.g. "Import") or a range address (e.g. "Sheet1!A1:B5"). The Excel range must contain pairs of years and values in its cells arranged into 2 columns. Use the WEAP Yearly Time-series Wizard to select a worksheet, to choose among the valid named ranges in the worksheet, and to preview the data that will be imported.

NB: The result of this function will be overridden by any value calculated for the [Current Accounts](#). In some cases this may lead to a marked "jump" from the Current Accounts value to the succeeding year's value. This may reflect the fact that the Current Accounts year you have chosen is not a good match of the long-term trends in your scenario, or it may reflect a poor fit between the regression and the historical data.

### **Tip**

Use the Yearly Time-Series Wizard to enter the data for this function.

## **MissingValue**

### **Syntax**

MissingValue

### **Description**

Internally, WEAP uses a value of -9999 to represent missing values when [reading from a file](#), and does not include them on charts or tables. Note: most WEAP calculations will not accept MissingValue and will cause an error. For example, if your climate data has gaps, you must fill these gaps in order to use the data for catchment calculations. The gaps can be filled by one of the [ReadFromFile](#) methods above (Interpolate, Repeat, Replace), or you can edit the file yourself to fill the gaps. One exception is the comparison of streamflow gauge data to calculated streamflow. No comparison will be made for any timestep for which the gauge data is missing.

### **Example**

```
If( ReadFromFile(Climate.csv, , , , Mark) = MissingValue, \Key\Default Wind Speed,  
ReadFromFile(Climate.csv) )
```

If the value for a timestep in Climate.csv is missing, use instead the value from the key assumption \Key\Default Wind Speed.

## **Month**

### **Syntax**

Month or M or TS

**Description**

The number of the current month, where the first month in the Water Year is 1 and the last month is 12 (as specified in the [General, Years and Time Steps](#) screen). Synonymous with TS (timestep).

**Example**

Month

Evaluated in January = 1 (assuming the water year starts in January)

Evaluated in January = 4 (assuming the water year starts in October)

## MonthlyValues

**Syntax**

MonthlyValues(Month1, Value1, Month2, Value2,... MonthN, ValueN)

Note: The name of this function will correspond to the timestep. For example, if the timestep is a week, then the name of this function will be WeeklyValues; if timestep is a day, then DailyValues.

**Description**

Specify values for each month. If some months are not specified, their values will be calculated by interpolating the values before and after.

**Example**

MonthlyValues(Jan, 10, Feb, 15, Mar, 17, Apr, 20, May, 21, Jun, 22, ...)

Values are specified for each month.

MonthlyValues(Jan, 10, July, 40)

Values are specified for two months--the others are interpolated.

Jan = 10

Feb = 15

Mar = 20

Apr = 25

May = 30

Jun = 35

Jul = 40

Aug = 35

Sep = 30

Oct = 25

Nov = 20

Dec = 15

MonthlyValues(Jan, 8.3333)

The values do not change month to month, so only need to be specified for one month. (You could also just enter the constant 8.3333 without the MonthlyValues function.)

Jan = 8.3333

Feb = 8.3333

Mar = 8.3333

Apr = 8.3333



May = 8.3333  
Jun = 8.3333  
Jul = 8.3333  
Aug = 8.3333  
Sep = 8.3333  
Oct = 8.3333  
Nov = 8.3333  
Dec = 8.3333

**Tip:** the WEAP Monthly Time-Series Wizard makes it easy to enter these values.

## MultiCropValues

### Syntax

MultiCropValues(ValueForCrop1, ValueForCrop2, ...)

### Description

If you have any branches for which you have chosen multiple crops (see [Crop Scheduling Wizard](#)), you will need to use the MultiCropValues function to specify Potential Yield and Market Price. Use the [Potential Yield and Market Price Wizards](#) to enter this data.

### Examples

Cabbage and onions are growing in rotation within each year on one piece of land, with cabbage yielding 30 t/ha and onions yielding 40 t/ha. Here is the expression for Potential Yields:

MultiCropValues(30, 40)

## Parent

### Syntax

Parent  
Parent(BranchName)  
Parent(VariableName)  
Parent(BranchName, VariableName)

### Description

The current value of the specified variable in the parent branch of named branch. Both BranchName and VariableName are optional parameters so that, when used without any parameters, the function returns the value of the current variable in the parent branch of the current branch.

### Tip

Because the simple form of this function points, not to a named branch, but to a relative branch address (the parent), it can be safely used in cases where you want to write a model for a particular set of subsectoral branches, and then copy branches for use elsewhere in the tree. See also: the "TotalChildren" function.

## PrevTSValue

### Syntax

PrevTSValue  
 or PrevTSValue(Branch:VariableName)  
 or PrevTSValue(Branch:VariableName, TimeStepsPrevious)  
 or PrevTSValue(Branch:VariableName,TimeStepsPrevious,EndOfPreviousTSInterval)  
 or PrevTSValue(Branch:VariableName,TimeStepsPrevious,EndOfPreviousTSInterval,  
 FunctionToCompute)  
 or PrevTSValue(Branch:VariableName,TimeStepsPrevious,EndOfPreviousTSInterval,  
 FunctionToCompute, PercentileValue)  
 or PrevTSValue(MODFLOWVariableName[layer, row, column], TimeStepsPrevious,...)

### **Description**

The PrevTSValue function can be used in two ways. One is to return results calculated in previous timesteps. The other is to return past or future values from *Data* variables. The parameters are:

**Branch:VariableName:** Name of branch and variable from which to read previous results. If omitted, then the result will be the value from the previous timestep of the current Branch:Variable.

**TimeStepsPrevious:** Number of previous time steps to look back. For example, a value of 1 returns the result from the previous time step, 2 returns the value from 2 time steps previous to the current time step, etc.. If omitted, the function will default to 1 time step previous.

**EndOfPreviousTSInterval:** The other end of the interval of time steps previous to use. For example, if TimeStepsPrevious is 1 and EndOfPreviousTSInterval is 4, then results are returned from the previous 4 time steps. If TimeStepsPrevious is 2 and EndOfPreviousTSInterval is 5, then results are returned from the interval from 2 time steps previous to 5 time steps previous (a total of 4 time steps). If omitted, the function will default to just the one time step specified by TimeStepsPrevious.

**FunctionToCompute:** Operation to execute on results: Sum, Average, Min, Max, Median, CV, Percentile. The function can be specified either by its name or by its numerical code: 0 for Sum, 1 for Average, 2 for Minimum, 3 for Maximum, 9 for Median, 8 for CV (coefficient of variation), and 7 for percentile. If omitted, the operation will be Sum.

**PercentileValue:** Only used if FunctionToCompute is Percentile. Values range from 0 to 100. If omitted, 0 will be used.

**MODFLOWVariableName[layer, row, column]:** To access [MODFLOW results](#) for individual cells, replace Branch:VariableName with MODFLOWVariableName[layer, row, column].

### **Examples**

If( PrevTSValue > 15, PrevTSValue / 2, PrevTSValue + 1)

This example looks at the previous value of the current branch:variable. If it is greater than 15, then reduce by half. Otherwise, increase by 1.

PrevTSValue(Supply and Resources\River\Weaping River\Reservoirs\Central Reservoir:Storage Volume)

This example calculates Central Reservoir's storage from the previous month.

PrevTSValue(Supply and Resources\River\Weaping River\Reservoirs\Central Reservoir:Storage Volume,  
3)

This example calculates Central Reservoir's storage from three months ago.

PrevTSValue(Demand Sites\South City:Unmet Demand, 1, 4)

This example calculates the sum of all unmet demands at South City for the previous 4 months.

## 6.8 Functions

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PrevTSValue(Supply and Resources\River\Weaping River\Reservoirs\Central Reservoir:Storage Volume, 1, 4, Average)

This example calculates the storage in Central Reservoir, averaged over the previous four months (a moving average).

PrevTSValue(Supply and Resources\River\Weaping River\Reservoirs\Central Reservoir:Storage Volume, 1, 4, Minimum)

This example calculates the minimum storage in Central Reservoir over the previous four months.

PrevTSValue(Supply and Resources\River\Weaping River\Reservoirs\Central Reservoir:Storage Volume, 1, 4, Maximum)

This example calculates the maximum storage in Central Reservoir over the previous four months.

PrevTSValue(Supply and Resources\River\Weaping River\Reservoirs\Central Reservoir:Storage Volume, 1, 12, Median)

This example calculates the median (50% percentile) storage in Central Reservoir over the previous twelve months.

PrevTSValue(Supply and Resources\River\Weaping River\Reservoirs\Central Reservoir:Storage Volume, 1, 12, Percentile, 5)

This example calculates the 5% percentile storage value in Central Reservoir over the previous twelve months.

PrevTSValue(Cell Head[1,57,30], 1, 12, Minimum)

This example calculates the minimum groundwater head elevation of cell at layer 1, row 57, column 30 over the previous twelve months, as calculated by a [linked MODFLOW model](#).

This function can also be used to return values from data variables found in the *Data* view, such as the "Top of Conservation" for reservoirs.

PrevTSValue(Supply and Resources\River\Weaping River\Reservoirs\North Reservoir:Top of Conservation, 1, 4, Average).

This example returns the average of the Top of Conservation variable for the North Reservoir over the four previous months.

The function can also be used to "look ahead" at a data variable. In this case, specify the time steps to look ahead as negative numbers for TimeStepsPrevious and EndOfPreviousTSInterval (because a negative number of timesteps previous means a positive number of timesteps ahead).

PrevTSValue(Supply and Resources\River\Weaping River:Headflow, -1, -4, Average)

This example returns the average headflow over the future four months.

### **Tip**

To find out which result variables are available to use with PrevTSValue, go to the Branches tab of the [Expression Builder](#), and drag a branch, such as a reservoir or groundwater node, to the expression area at the bottom. A menu will appear that lists all the available variables--data variables first, followed by the result variables. The result variables will include the notation "calculated result from previous timestep."

## **PrevYear**

### **Syntax**

PrevYear

**Description**

The year previous to the one being evaluated as a numeric value. This function is not available when entering [Current Accounts](#).

**Examples**

Evaluated in 2000 = 1999.0

Evaluated in 2020 = 2019.0

## PrevYearValue

**Syntax**

PrevYearValue or

PrevYearValue(BranchName)

**Description**

Calculates the previous year's value of either the current branch or of another branch referred to as a parameter to the function. This function is not available when entering [Current Accounts](#).

**Examples**

10+PrevYearValue

Evaluated for a value of 100 in 2000

2001 = 110

2002 = 120

2003 = 130

0.3+PrevYearValue(Households\Urban\Cooking)

Evaluated for a value of 30 in 2000 in a branch named "Household\Urban\Cooking".

2001 = 30.3

2002 = 30.6

2003 = 30.9

## PumpLayer

**Syntax**

PumpLayer(Layer\_1, LayerFraction\_1, Layer\_2, LayerFraction\_2, ..., Layer\_N, LayerFraction\_N)

**Description**

*Note: PumpLayer is only used when [linking to MODFLOW](#).*

When a demand site, catchment, or land use branch pumps water from more than one MODFLOW layer, the PumpLayer function allows you to specify how much should be pumped from each layer.

Additionally, the fractions can differ by scenario or change over time. For each layer pumped, include 2 parameters to the PumpLayer function that give the layer number and the fraction pumped from that layer. These fractions are used for every MODFLOW row, column cell that the demand site, catchment, or land use branch is linked to.

**Layer\_i:** The number of the MODFLOW layer from which to pump. Use layer=0 to handle pumping as negative recharge.

**LayerFraction\_i:** The fraction to pump from Layer\_i, from 0 to 1.

You do not need to include a layer if there is no pumping from it. The sum of all the LayerFractions for all layers must equal 1. Note: you may not use Interp or other time-series function to specify changes over time. Instead, use the "If" function in conjunction with the "Year" variable. An example below illustrates this.

### Examples

Pump 50% as negative recharge, 50% from layer 1:

```
PumpLayer(0, 0.5, 1, 0.5)
```

Pump 25% from layer 3 and 75% from layer 4:

```
PumpLayer(3, 0.25, 4, 0.75)
```

Start off pumping 25% from layer 3 and 75% from layer 4, but in 2005 go to 50% from each layer:

```
PumpLayer(3, If( Year < 2005, 0.25, 0.5), 4, If( Year < 2005, 0.75, 0.5) )
```

Read in pump layer fractions from a file:

```
PumpLayer( 1, ReadFromFile(LayerFraction.csv, 1), 2, ReadFromFile(LayerFraction.csv, 2) )
```

See [Demand Site Pumping](#)

## ReadFromFile

The ReadFromFile function allows one to read annual, monthly (or whatever your timestep is) or daily data from a text, comma-separated value (CSV) file into any WEAP variable. In cases where aggregate data needs to be disaggregated, such as extracting a daily time series from monthly climate data, one of many disaggregation methods can be used. Alternatively, daily data can be aggregated to match your timestep (e.g., monthly), or monthly data can be aggregated to annual, using one of many aggregation methods. Missing values can be filled in using one of several missing value methods. You may refer to files in any directory on your computer, although, it is best practice to place the files in the same directory of the WEAP area, or in a subdirectory of the WEAP area directory, so that the files will be included when the area is backed up or transferred to another computer. In this case, do not include the full directory path ("absolute" reference)--just include the file name ("relative" reference).

A text file can contain one or more columns of data for each year, month or day. The format of the WEAP expression is:

```
ReadFromFile(FileName) or  
ReadFromFile(FileName, DataColumnNumber) or  
ReadFromFile(FileName, DataColumnNumber, YearOffset) or  
ReadFromFile(FileName, DataColumnNumber, YearOffset, Aggregation or Disaggregation Method,  
Disaggregation Method Parameter) or  
ReadFromFile(FileName, DataColumnNumber, YearOffset, Aggregation or Disaggregation Method,  
Disaggregation Method Parameter, Missing Value Method, Missing Value Method Parameter)
```

Only the FileName parameter is required; all others are optional. If you do not specify a data column number, the first data column will be used. The numbering of the data columns starts after the year and month columns. If the other parameters are omitted, the following defaults will be used: YearOffset = 0, Aggregation Method = Average, Disaggregation Method = Repeat, Missing Value Method = Replace

with 0. Each parameter is described in detail below. You can leave parameters empty, e.g., `ReadFromFile(DailyPrecipitation.csv, , , Sum)`. WEAP can export its results in a format compatible with `ReadFromFile`--click the CSV button on the table toolbar when viewing tabular results in the Data or Results View and choose the **ReadFromFile Format** option.

## Year Offset

The optional **YearOffset** parameter can be used to use data from different years. For example, to use historical stream flow data (starting in 1950) for future values (2005-2025), the YearOffset would be -55.

In general, the YearOffset should equal the first year of data in the CSV file minus the Current Account Year. In the previous example,  $\text{YearOffset} = 1950 - 2005 = -55$ . When WEAP is looking for 2005 data, it will offset -55 years, so will read in data 55 years previous to 2005 (1950). When looking for 2006 data, it will read in data from 1951, etc.

To repeat a block of data over and over, you can use this expression for Year Offset:  $-1 * n * \text{Floor}((y - y1) / n)$ , where  $1/1/y1$  to  $12/31/y2$  are the dates of the data to repeat, and  $n = y2 - y1 + 1 = \text{number of years to repeat}$ . For example, if you have temperature data for 1960-1999 (40 years) in column 2 of `climate.csv` and want to use it over and over for 2000-2100, the expression would be:

`ReadFromFile(Climate.csv, 2, -1 * 40 * Floor((y - 1960) / 40))`

## Aggregating daily data to monthly (or other timestep)

In cases where you have daily data but your WEAP model is not daily, you may specify an **Aggregation Method**. Available methods are Sum, Average, Median, Minimum and Maximum.

- Sum: Total the daily values for each month.
- Average: Divide the monthly total of the daily values by the number of non-missing values to get the average.
- Median: The 50% percentile value.
- Minimum: The minimum daily value from each month. You can abbreviate this as "Min"
- Maximum: The maximum daily value from each month. You can abbreviate this as "Max"

## Disaggregating monthly (or other timestep) data to daily

In cases where you have annual data but need a monthly time series for your WEAP model, or have monthly data but need a daily time series (e.g., for a daily model, or for the [MABIA catchment method](#), which requires daily data), you may specify a **Disaggregation Method**. Available methods are Interpolate, Repeat, Divide, and Divide with Gaps.

- Interpolate: Assume the monthly values are the values for mid-month; interpolate between them to derive daily values. Typical use would be to derive daily temperature or humidity values from monthly averages. For example, if the January value was 3 and the February value was 10, the "Interpolate" method would come up with the following daily values: January 16 = 3, January 17 =  $3 + (1/29) * (10 - 3) = 3.24$  (29 days between Jan 16 and Feb 14, so Jan 17 would be 1/29th of the way from the Jan 16 value to the Feb 14 value), January 18 =  $3 + (2/29) * (10 - 3) = 3.48$ , ..., February 13 =  $3 + (28/29) * (10 - 3) = 9.76$ , February 14 =  $3 + (29/29) * (10 - 3) = 10$ .
- Repeat: Repeat the monthly value for each day.
- Divide: Divide the monthly value evenly across each day of the month, for example, to divide the monthly precipitation evenly onto every day. For example, if the January rainfall was 62 mm, each day in January would have 2 mm.

- **Divide with Gaps:** Divide the monthly value into a sequence of evenly spaced "events," such as rainstorms. The frequency of events is specified by the **Disaggregation Method Parameter**. For example, if the January rainfall was 70 mm and the Disaggregation Method Parameter was 5 (rainstorms every 5 days), there would be rainfall on these days: Jan 1, Jan 6, Jan 11, Jan 16, Jan 21, Jan 26 and Jan 31. The 70 mm of January rainfall would be evenly split across these seven events; therefore, each event would have 10 mm. Note that the last event was January 31, which means that the next event would occur on February 5 (5 days later). The first event will always occur on the first day of the Current Accounts year. In the unlikely case that the frequency is larger than the length of each timestep (e.g., rainstorms every 10 days in a weekly model), WEAP will have a single event in the middle of the timestep (e.g., day 4 of the week for a weekly model).

### Handling Missing Data

In cases where there are gaps in the data, either because of missing rows (timesteps) in the text file, or from values marked as missing in the file, you need to tell WEAP how to interpret the missing data. You may specify a **Missing Value Method**. Available methods are Interpolate, Repeat, Replace, Mark and Error. The method will default to Replace if none is specified, which means that missing values will be replaced with 0.

- **Interpolate:** Linear interpolation between the previous and next (non-missing) values. You can abbreviate this as "Interp"
- **Repeat:** Repeat the previous (non-missing) value.
- **Replace:** The number given as the 7th parameter (**Missing Value Method Parameter**) will be used in place of the missing value. If the 7th parameter is not specified, 0 will be used.
- **Mark:** Will fill in any gaps in the data with the [MissingValue](#) (-9999). These will not show up on charts or tables. Note: most WEAP calculations will not accept MissingValue and will cause an error. For example, if your climate data has gaps, you must fill these gaps in order to use the data for catchment calculations. The gaps can be filled by one of the methods above (Interpolate, Repeat, Replace), or you can edit the file yourself to fill the gaps. One exception is the comparison of streamflow gauge data to calculated streamflow. No comparison will be made for any timestep for which the gauge data is missing.
- **Error:** Will display an error if any Divide the monthly value evenly across each day of the month, for example, to divide the monthly precipitation evenly onto every day. For example, if the January rainfall was 62 mm, each day in January would have 2 mm.

### Comments

Comment lines (any line that does not begin with a number) are ignored. Also, any part of a line after a semicolon (;) or number sign (#) will be ignored, so can be used to include comments on the same line with data. It is good practice to have a few comment lines at the beginning of the file, documenting where the data came from, units used, and which data are in each data column.

### List separator

WEAP assumes that the values in the CSV file will be separated by the Windows ListSeparator character (set in the "Regional and Language Options" Windows Control Panel). However, you can override this setting by placing a **\$ListSeparator** directive into the CSV file, on a line before any data values. (You may not use ; or # as the list separator, because these denote comment lines.) For example, to specify , (comma) as the separator, include the following line at the top of the file:

`$ListSeparator = ,`

Because the list separator varies from country to country, it is a good practice to always include the `$ListSeparator` directive in the CSV file so that WEAP can read the file, regardless of the setting of the Windows ListSeparator character. This is helpful if the dataset is shared between users in different countries.

## Date Format (for daily data)

By default, WEAP will use the Windows system "Short date" format (set in the "Regional and Language Options" Windows Control Panel) for interpreting daily dates, e.g., mm/dd/yyyy or dd/mm/yyyy.

However, because you may want to share your WEAP area with someone in another country (whose regional settings are different), it is best practice to include in the file a line that specifies the date format used. To do this, place a **\$DateFormat** directive into the CSV file, on a line at the top before the data values. For example, to specify mm/dd/yyyy as the date format, include the following line at the top of the file:

```
$DateFormat = mm/dd/yyyy
```

Some other examples:

```
$DateFormat = d-m-y
```

```
$DateFormat = m d y
```

```
$DateFormat = d/m/y
```

```
$DateFormat = yyyy/m/d
```

When specifying the date format, you do not need to repeat the 'm', 'd', or 'y', .e.g., mm/dd/yyyy is equivalent to m/d/y. The two separator characters must be the same, e.g., m-d-y is fine, but m d, y is not.

For the date values in the CSV file, single-digit month and day numbers do not need to have a leading zero, but it is allowed, e.g., 1/3/1990 or 01/03/1990 are both fine. Years must have 4 digits.

## Examples

```
ReadFromFile(GroundwaterRecharge.txt)
```

will read in data from the first data column of file GroundwaterRecharge.txt in the directory for the current WEAP area (e.g., if the area was Weaping River Basin, the file would be C:\Program Files\WEAP21\Weaping River Basin\GroundwaterRecharge.txt).

```
ReadFromFile(DemandActivity.txt, 2)
```

will read in data from the second data column of file DemandActivity.txt.

```
ReadFromFile(DemandActivity.txt, 1, -50)
```

will read in data from the first data column of file DemandActivity.txt, shifting the years by 50 (year 1950 data in the file will be interpreted as 2000 data).

## Aggregating Daily Data to Monthly (or other timestep)

```
ReadFromFile(DailyTemperature.csv, 1, 0, Average)
```

will read in daily air temperature data from the first data column of file DailyTemperature.csv, not shifting the years at all (offset = 0), and deriving monthly values by averaging the daily temperature values. Because the parameter values in this example are actually the same as the defaults, you could omit them and get the same result (monthly average of daily values):

```
ReadFromFile(DailyTemperature.csv)
```



`ReadFromFile(DailyPrecipitation.csv, , , Sum)`

will read in daily precipitation data from `DailyPrecipitation.csv` and derive monthly values by totaling the daily precip values. Because `Column` and `YearOffset` parameters were not specified, their defaults are used (`Column = 1`, `YearOffset = 0`).

`ReadFromFile(Streamflow.csv, , , Median)`

will read in daily streamflow data from `Streamflow.csv` and derive monthly values by finding the median value for each month.

`ReadFromFile(Streamflow.csv, , , Minimum)`

will read in daily streamflow data from `Streamflow.csv` and derive monthly values by finding the minimum value for each month.

`ReadFromFile(Streamflow.csv, , , Maximum)`

will read in daily streamflow data from `Streamflow.csv` and derive monthly values by finding the maximum value for each month.

### **Disaggregating Monthly (or other timestep) Data to Daily**

`ReadFromFile(Climate.txt, 1, 0, Interpolate)`

will read in monthly air temperature data from the first data column of file `Climate.txt`, not shifting the years at all (`offset = 0`), and deriving daily values by interpolating the monthly values

`ReadFromFile(Climate.txt, 2, 0, Divide with Gaps, 5)`

will read in monthly precipitation data from the second data column of file `Climate.txt`, not shifting the years at all (`offset = 0`), and deriving daily values by splitting the monthly precipitation data into storms every 5 days

`ReadFromFile(Climate.txt, 2, 0, Divide)`

will read in monthly precipitation data from the second data column of file `Climate.txt`, not shifting the years at all (`offset = 0`), and deriving daily values by splitting the monthly precipitation data evenly across every day in that month (e.g., if total January rainfall was 31 mm, each day would have 1 mm)

`ReadFromFile(Climate.txt, 3, 0, Repeat)`

will read in monthly mean wind speed data from the third data column of file `Climate.txt`, not shifting the years at all (`offset = 0`), and deriving daily values by repeating the monthly value for every day in that month

### **Handling Missing Data**

`ReadFromFile(Climate.txt, 1, 0, , , Interpolate)`

will fill in any gaps in the data by a linear interpolation of the previous and next values.

`ReadFromFile(Climate.txt, 1, 0, , , Repeat)`

will fill in any gaps in the data by repeating the previous value.

`ReadFromFile(Climate.txt, 1, 0, , , Replace, 2)`

will fill in any gaps in the data with a 2. (If the number is omitted, the default will be 0.)

`ReadFromFile(Climate.txt, 1, 0, , , Mark)`

will fill in any gaps in the data with the MissingValue (-9999). These will not show up on graphs, but will cause an error if the value is needed for a calculation.

```
ReadFromFile(Climate.txt, 1, 0, , , Error)
```

will display an error if any gaps are found.

### Annual Data

For annual data, each line of the file contains data for one year, in the format:

```
Year, DataColumn1, DataColumn2, ..., DataColumnN
```

e.g.,

```
2000, 15.123, 43.01
2001, 10.321, 35.835
2002, 12.423, 38.922
...
```

Data years must be in chronological order, although gaps are allowed (a zero will be added for missing values).

### Monthly (or other timestep) Data

For monthly (or other timestep) data, each line of the file contains data for one month, in the format:

```
Year, Month, DataColumn1, DataColumn2, ..., DataColumnN
```

e.g.,

```
2000, 1, 44.29, 64.77
2000, 2, 59.12, 74, 55
...
2000, 12, 61.11.78.74
2001, 1, 24.29, 44.77
...
```

Data months must be in chronological order, although gaps are allowed (a zero will be added for missing values).

### Daily Data

For daily data (which can be used if the WEAP's timestep is daily, or when aggregating daily data to monthly or other timestep, or when using the [MABIA method for catchment runoff](#)), each line of the file contains data for one day, in the format:

```
Date, DataColumn1, DataColumn2, ..., DataColumnN
```

e.g.,

```
1/1/2000, 44.29, 64.77
1/2/2000, 59.12, 74, 55
...
12/30/2000, 23.1, 88.22
12/31/2000, 61.11.78.74
1/1/2001, 24.29, 44.77
...
```

Note: See the "Date Format" section above for information about the format of the date (e.g., mm/dd/yyyy or dd/mm/yyyy).

Data for leap days (e.g., 2/29/2000) will be ignored unless the "Add Leap Days?" option is selected on the [Years and Timesteps](#) screen. If data for leap days are missing and the "Add Leap Days?" option is selected, a zero will be used for those days.

## Remainder

### Syntax

Remainder(Expression)

### Description

Calculates the remainder between an Expression and the sum of the values of neighboring (sibling) branches.

### Example

Consider two neighboring branches in a demand tree in which you are specifying the split between urban and rural households (in percent):

Branch	Expression
Urban	Interpolate(2000, 50, 2020, 30)
Rural	Remainder(100)

Remainder(100) is evaluated as follows:

2000 = 50.0  
2010 = 60.0  
2020 = 70.0

## Seconds

### Syntax

Seconds

### Description

The number of seconds in the current month (as specified in the [General, Years and Time Steps](#) screen).

### Example

Seconds

Evaluated in January 2000 =  $31 * 24 * 60 * 60 = 2,678,400$   
Evaluated in February 2000 =  $28 * 24 * 60 * 60 = 2,419,200$  (if leap days are turned off)  
Evaluated in February 2000 =  $29 * 24 * 60 * 60 = 2,505,600$  (if leap days are turned on)

## Smooth

### Syntax

Smooth (Year1, Value1, Year2, Value2,... YearN, ValueN) or  
Smooth (ExcelFilename, ExcelRangeName)

### **Description**

Estimates a value in any given intermediate year based on the year/value pairs specified in the function and a smooth curve polynomial function of the form

$$Y = a + b.X + c. X^2 + d. X^3 + e.X^4 + \dots$$

When more points are available, a higher degree polynomial is used to give a more accurate fit.

NB: A minimum of 4 year/value pairs are required in order for the curve to be estimated.

Using the above two alternatives syntaxes year/value pairs can either be entered explicitly or linked to a range in an Excel spreadsheet. Use the Yearly Time-series Wizard to input these values or to specify the Excel data. In either case, years do not need to be in any particular order, but duplicate years are not allowed, and must be in the range 1990-2200.

When linking to a range in Excel, you specify the full pathname of a valid Excel worksheet or spreadsheet (an XLS or XLW) file, followed by a valid Excel range. A range can be either a valid named range (e.g. "Import") or a range address (e.g. "Sheet1!A1:B5"). The Excel range must contain pairs of years and values in its cells arranged into 2 columns. Use the WEAP Yearly Time-series Wizard to select a worksheet, to choose among the valid named ranges in the worksheet, and to preview the data that will be imported.

NB: The [Current Accounts](#) value is always implicit in the function, and will override any value explicitly entered for that year by the user. So for example, if the Current Accounts year is 1997 and the Current Accounts value (entered in Current Accounts) is 200.0 then the above function will results in the value 200.0 for both 1998 and 1999.

### **Tip**

Use the Yearly Time-Series Wizard to enter the data for this function.

## **SoilLibrary**

### **Syntax**

SoilLibrary(Texture Class)

### **Description**

This function is used in conjunction with the [MABIA Method](#) for catchment hydrology and crop water requirements.

The SoilLibrary function is used to choose a texture class (from the [Soil Library](#)), in order to determine the Soil Water Capacity for catchment branches in the Data View, under [Land Use](#). Use the "Select from Soil Library" option in the drop-down menu in the data grid. (As an alternative to choosing from the Soil Library, you can enter soil properties directly, or use the [Soil Profiles Wizard](#). These two options are also available on the drop-down menu in the data grid.)

### **Example**

SoilLibrary(Clay loam)

Use the texture class named "Clay loam" from the Soil Library.

## SoilProfiles

### Syntax

SoilProfiles(PedotransferFunction, NumProfiles, P1NumLayers, P1H1Thickness, P1H1CoarseFragments, P1H1Parm1, P1H1Parm2, ..., P1h2Thickness, P1h2CoarseFragments, P1H2Parm1, ...)

### Description

This function is used in conjunction with the [MABIA Method](#) for catchment hydrology and crop water requirements.

Because direct measurement of a soil's water holding capacity, including saturation, field capacity and wilt point, can be costly and time consuming, pedotransfer functions were developed to translate more easily obtainable data into these water holding capacity values. The SoilProfiles function estimates average soil water capacity (saturation, field capacity and wilt point) using one of six available pedotransfer functions (PTF), in order to determine the Soil Water Capacity for catchment branches in the Data View, under [Land Use](#). This function can average over several soil profiles (sampling sites) and soil horizons (layers). Use the [Soil Profiles Wizard](#), available on the drop-down menu in the data grid, to build this function. (As an alternative to using SoilProfiles, you can enter soil properties directly, or choose a texture class from the [Soil Library](#). These two options are also available on the drop-down menu in the data grid.)

**PedotransferFunction:** Of the seven available pedotransfer functions, one is based on texture class and the other six use particle size (sand, silt and clay), optionally with data on bulk density or organic matter content. The PTF names (which include references to the original author and date) used in the SoilProfiles function, along with the parameters required by that function, are:

1. "Texture class": texture class, from the [Soil Library](#)
2. "Particle size (Jabloun and Sahli 2006)": silt[%] and clay[%] fraction (sand is calculated as 100 - silt - clay, so does not need to be entered)
3. "Particle size Bulk density (Jabloun and Sahli 2006)": silt[%], clay[%] and bulk density[g/cm<sup>3</sup>]
4. "Particle size Organic matter (Jabloun and Sahli 2006)": silt[%], clay[%] and organic matter[g/kg]
5. "Particle size Bulk density Organic matter (Jabloun and Sahli 2006)": silt[%], clay[%], bulk density[g/cm<sup>3</sup>] and organic matter[g/kg]
6. "Particle size Bulk density Organic matter (Vereecken et. al. 1989)": silt[%], clay[%], bulk density[g/cm<sup>3</sup>] and organic matter[g/kg]
7. "Particle size Bulk density Organic matter (Wösten et. al. 1999)": silt[%], clay[%], bulk density[g/cm<sup>3</sup>] and organic matter[g/kg]

**NumProfiles:** The number of soil profiles (sampling sites) included.

**PiNumLayers:** The number of horizons (layers) in profile i.

**PiHjThickness:** The thickness (in meters) of profile i, horizon j.

**PiHjCoarseFragments:** Fraction of profile i, horizon j that is coarse fragments. Coarse fragments (rock) cannot hold any moisture--therefore, the higher the fraction of coarse fragments, the lower the water holding capacity.

**PiHjParm\_k:** PTF parameter k for profile i, horizon j. Each PTF has its own parameters, described above.

Note: The MABIA Method will NOT use rooting depth to determine which soil horizons are in contact with the roots. Instead, the average soil water properties will be used regardless of root depth.

### **References**

Jabloun, M. and Sahli, A., [Development and comparative analysis of pedotransfer functions for predicting characteristic soil water content for Tunisian soil](#), *Tunisia-Japan Symposium on Society, Science and Technology proceeding*, 7th Edition, 2006, pp. 170-178.

Vereecken, H., Maes, J., Feyen, J., Darius, P., [Estimating the soil moisture retention characteristic from texture, bulk density and carbon content](#), *Soil Science*, 148 (1989), pp. 389–403.

Wösten, J.H.M., Lilly, A., Nemes, A., Le Bas, C., 1999, [Development and use of a database of hydraulic properties of European soils](#), *Geoderma*, 90, July 1999, pp. 169-185.

### **Examples**

SoilProfiles("Texture class", 1, 2, 0.5, 5, Loam, 0.5, 10, Clay loam)

This example specifies one soil profile with two horizons, each 0.5m thick. The top horizon is Loam with 5% coarse fragments; the lower horizon is Clay loam, with 10% coarse fragments. The average soil properties are: Saturation = 38.17%, Field Capacity = 27.01%, Wilt Point = 12.64%, Available Water Capacity = 14.37%

SoilProfiles("Particle size Organic matter (Jabloun and Sahli 2006)", 2, 2, 0.3, 10, 20, 40, 5, 0.7, 20, 35, 35, 3, 1, 1, 15, 15, 70, 2)

This example specifies two soil profiles, the first with two horizons and the second with one horizon. The method used to compute soil water capacity is from Jabloun and Sahli, 2006, and requires particle size and organic matter content, in addition to thickness and coarse fragments. Profile 1, top horizon: 0.3m thick, 10% coarse fragments, 20% clay, 40% silt, 5 g/kg Organic Matter. Profile 1, lower horizon: 0.7m thick, 20% coarse fragments, 35% clay, 35% silt, 3 g/kg Organic Matter. Profile 2: 1.0m thick, 15% coarse fragments, 15% clay, 70% silt, 2 g/kg Organic Matter. The average soil properties are: Saturation = 35.03%, Field Capacity = 37.54%, Wilt Point = 13.20%, Available Water Capacity = 24.34%

## **Step**

### **Syntax**

Step(Year1, Value1, Year2, Value2,... YearN, ValueN) or  
Step(ExcelFilename, ExcelRangeName)

### **Description**

Calculates a value in any given year using a step function between a time-series of year/value pairs.

Using the above two alternatives syntaxes year/value pairs can either be entered explicitly or linked to a range in an Excel spreadsheet. Use the [Yearly Time-series Wizard](#) to input these values or to specify the Excel data. In either case, years do not need to be in any particular order, but duplicate years are not allowed, and must be in the range 1990-2200.

When linking to a range in Excel, you specify the full path name of a valid Excel worksheet or spreadsheet (an XLS or XLW) file, followed by a valid Excel range. A range can be either a valid named range (e.g. "Import") or a range address (e.g. "Sheet1!A1:B5"). The Excel range must contain pairs of years and values in its cells arranged into 2 columns. Use the WEAP Yearly Time-series Wizard to select a worksheet, to choose among the valid named ranges in the worksheet, and to preview the data that will be imported.

NB: The [Current Accounts](#) value is always implicit in the function, and will override any value explicitly entered for that year by the user. So for example, if the Current Accounts year is 1997 and the Current Accounts value (entered in Current Accounts) is 200.0 then the above function will results in the value 200.0 for both 1998 and 1999.

### **Example**

Step (2000, 300.0, 2010, 500.0, 2020, 900.0)

2000 = 300.0

2012 = 500.0

2022 = 900.0

### **Tip**

Use the Yearly Time-Series Wizard to enter the data for this function.

## **TotalChildren**

### **Syntax**

TotalChildren

TotalChildren(BranchName)

TotalChildren(VariableName)

TotalChildren(BranchName, VariableName)

### **Description**

The sum of the specified variable across all children of the named branch. Both BranchName and VariableName are optional parameters so that, when used without any parameters, the function returns the sum of the current variable across the children of the current branch.

### **Tip**

Because the simple form of this function points, not to a named branch, but to a relative branch address (all children), it can be safely used in cases where you want to write a model for a particular set of subsectoral branches, and then copy branches for use elsewhere in the tree. See also: the "Parent" function

## **TotalDaysBefore**

### **Syntax**

TotalDaysBefore

### **Description**

The total number of days, starting from the first month of the Current Accounts year, in the current month.

### **Example**

TotalDaysBefore

Evaluated in January 2002 = 730 (with a Current Accounts Year of 2000 and a Water Year Start of January)

Evaluated in January 2002 = 824 (with a Current Accounts Year of 2000 and a Water Year Start of October)

## TS

### Syntax

Month or M or TS

### Description

The number of the current month, where the first month in the Water Year is 1 and the last month is 12 (as specified in the [General, Years and Time Steps](#) screen). Synonymous with Month. Available whether the timestep is monthly or not.

### Example

TS

Evaluated in January = 1 (assuming the water year starts in January)

Evaluated in January = 4 (assuming the water year starts in October)

## VolumeToElevation

### Syntax

VolumeToElevation(Volume) or  
VolumeToElevation(Reservoir, Volume)

### Description

Converts a reservoir volume to a reservoir elevation, using the [Reservoir Volume Elevation Curve](#). If the reservoir parameter is not included, then the current reservoir will be used. Note: the volume given must be in the unit specified for reservoir volume and the resulting elevation will be in the unit specified for reservoir elevation (see [General Area Parameters, Units](#)).

### Examples

You want to model a water conservation program that starts (reducing demand by 15%) when the reservoir elevation drops below a critical level (20 m). Here is the expression for \Demand Sites\South City:DSM Reduction

```
If( VolumeToElevation( Supply and Resources\River\Weaping River\Reservoirs\Central Reservoir,
PrevTSValue(Supply and Resources\River\Weaping River\Reservoirs\Central Reservoir:Storage
Volume[Million m^3] )) < 20,
  15%,
  0)
```

Note: for this example, it would actually be easier to get the result value for elevation directly (no need to convert volume to elevation), using PrevTSValue(Supply and Resources\River\Weaping River\Reservoirs\Central Reservoir:Storage Elevation.

## Year

### Syntax

Year or Y



### **Description**

The year being evaluated as a numeric value.

### **Example**

Evaluated in 2000 = 2000.0

Evaluated in 2020 = 2020.0

## 6.8.2 Mathematical Functions

### **Abs**

#### **Syntax**

Abs(Expression)

#### **Description**

The absolute value of the expression.

#### **Example**

Abs(-2.8) = 2.8

Abs(2.8) = 2.8

### **Arccos**

#### **Syntax**

Arccos(x)

#### **Description**

Arccos(x) returns the inverse cosine of x, that is, the angle (expressed in degrees, not radians) whose cosine is x.

#### **Example**

Arccos(0.7071) = 45

Arccos(-1) = 180

### **Arcsin**

#### **Syntax**

Arcsin(x)

#### **Description**

Arcsin(x) returns the inverse sine of x, that is, the angle (expressed in degrees, not radians) whose sine is x.

#### **Example**

Arcsin(1) = 90  
Arcsin(0) = 180

## Arctan

### Syntax

Arctan(x)

### Description

Arctan(x) returns the inverse tangent of x, that is, the angle (expressed in radians, not degrees) whose tangent is x. The range is  $-\pi/2$  to  $\pi/2$ .

### Example

Arctan(1) = 0.78540 = ( $\pi$  / 4)

Arctan(0) = 0

## Between

### Syntax

Between(x, LowerBound, UpperBound)

### Description

Test if a value is between two other values. Between(x, LowerBound, UpperBound) is equivalent to And((x >= LowerBound), (x <= UpperBound))

### Examples

Between(1, 0, 2) = True

Between(0, 0, 2) = True

Between(-1, 0, 2) = False

Between(1, 2, 0) = True      LowerBound and UpperBound can be reversed.

Between(Year, 2005, 2010) = True if the year is in the range 2005-2010.

## Ceiling

### Syntax

Ceiling(Expression)

### Description

The expression rounded up toward positive infinity. Use Ceiling to obtain the lowest integer greater than or equal to X.

### Example

Ceiling(-2.8) = -2

Ceiling(2.8) = 3

Ceiling(1.5) = 2

Ceiling(-1.5) = -1

## Cos

### Syntax

Cos(Angle)

### **Description**

The cosine of Angle, where Angle is expressed in degrees (not radians).

### **Example**

$\text{Cos}(45) = 0.7071$

$\text{Cos}(180) = -1$

## **Cosh**

### **Syntax**

$\text{Cosh}(X)$

### **Description**

The hyperbolic cosine of X.

## **Exp**

### **Syntax**

$\text{Exp}(\text{Expression})$

### **Description**

The constant e raised to the power of Expression. The constant e equals 2.71828182845904, the base of the natural logarithm. EXP is the inverse of LN, the natural logarithm of number.

### **Examples**

$\text{Exp}(1) = 2.718282$  (the approximate value of e)

$\text{Exp}(2) = 7.389056$

$\text{Exp}(\text{Ln}(3)) = 3$

### **Tip**

To calculate the powers of other bases, use the exponentiation operator (^).

## **Floor**

### **Syntax**

$\text{Floor}(\text{Expression})$

### **Description**

The expression rounded toward negative infinity. Use Floor to obtain the highest integer less than or equal to X. Note: Floor is not the same as the Int function

### **Example**

$\text{Floor}(-2.8) = -3$

$\text{Floor}(2.8) = 2$

$\text{Floor}(1.5) = 1$

$\text{Floor}(-1.5) = -2$

## Frac

### Syntax

Frac(Expression)

### Description

The fractional part of Expression.  $\text{Frac}(\text{Expression}) = \text{Expression} - \text{Int}(\text{Expression})$ .

### Examples

$\text{Frac}(2.3) = 0.3$

$\text{Frac}(-2.5) = -0.5$

## Int

### Syntax

Int(Expression)

### Description

The integer part of the expression (the expression rounded toward zero). Note: Int is not the same as the Floor function.

### Example

$\text{Int}(-2.8) = -2$

$\text{Int}(2.8) = 2$

$\text{Int}(1.5) = 1$

$\text{Int}(-1.5) = -1$

## Ln

### Syntax

Ln(Expression)

### Description

The natural logarithm of the expression

### Example

$\text{Ln}(2.7182) = 1$

$\text{Ln}(10) = 2.3026$

## Log

### Syntax

Log(Expression)

### Description

The base 10 logarithm of the expression. This is the same as the [Log10](#) function.

### **Example**

$\text{Log}(10) = 1$   
 $\text{Log}(100) = 2$

## **LogN**

### **Syntax**

$\text{LogN}(\text{Base}, \text{Expression})$

### **Description**

The logarithm of the expression with a specified base

### **Example**

$\text{LogN}(10, 100) = 2$   
 $\text{LogN}(2.7182, 100) = 4.605$

## **Log10**

### **Syntax**

$\text{Log10}(\text{Expression})$

### **Description**

The base 10 logarithm of the expression. This is the same as the [Log](#) function.

### **Example**

$\text{Log10}(10) = 1$   
 $\text{Log10}(100) = 2$

## **Max**

### **Syntax**

$\text{Max}(\text{Expression1}, \text{Expression2})$  or  
 $\text{Max}(\text{Expression1}, \text{Expression2}, \text{Expression3})$

### **Description**

Returns the maximum value of the list of parameters. Accepts up to 3 parameters.

### **Example**

$\text{Max}(3,4,5) = 5$

## **Min**

### **Syntax**

$\text{Min}(\text{Expression1}, \text{Expression2})$  or  
 $\text{Min}(\text{Expression1}, \text{Expression2})$

### **Description**

Returns the minimum value of the list of parameters. Accepts up to 3 parameters.

**Example**

Min(3,4,5) = 3

## Mod

**Syntax**

Min(Number, Divisor)

**Description**

Returns the remainder after a number is divided by the divisor.

**Examples**

Mod(8,	3)	=	2
Mod(9, 3)	= 0		

## Pi

**Syntax**

Pi

**Description**

The value of Pi (3.14159265).

**Example**

Pi \* Sqr(R) will give the area of a circle of radius R

## Random

**Syntax**

Random

Random(UpperBound)

Random(LowerBound, UpperBound)

**Description**

Returns a different random real number, between LowerBound and UpperBound, for each timestep. If not specified, the lower and upper bounds default to 0 and 1. The value is a real number--to get random integers, use the [RandomInteger](#) function.

The value returned is a random but repeatable value for any given branch, scenario, year and month. This means that the numbers will be the same each time a scenario is calculated (for a given branch, year and timestep).

**Examples**

Random = some value between 0 and 1, e.g., 0.407

Random(100) = some value between 0 and 100, e.g., 83.12

Random(-10, 10) = some value between -10 and 10, e.g., -4.74

## RandomDistribution

### Syntax

RandomDistribution(Mean, StandardDeviation)

### Description

Generates random numbers with a Gaussian distribution about the mean, different for each timestep. This is useful for simulating data with sampling errors and expected deviations from the mean.

### Example

RandomDistribution(100, 20) = Random distribution of values whose mean is 100 and standard deviation is 20.

## RandomInteger

### Syntax

RandomInteger

RandomInteger(UpperBound)

RandomInteger(LowerBound, UpperBound)

### Description

Returns a different random integer, between LowerBound and UpperBound, for each timestep. If not specified, the lower and upper bounds default to 0 and 1. The value is a integer--to get random real numbers, use the [Random](#) function.

The value returned is a random but repeatable value for any given branch, scenario, year and month. This means that the numbers will be the same each time a scenario is calculated (for a given branch, year and timestep).

### Example

RandomInteger = either 0 or 1

RandomInteger(100) = some integer between 0 and 100, e.g., 83

RandomInteger(-10, 10) = some integer between -10 and 10, e.g., -5

## Round

### Syntax

Round(Expression)

### Description

Round returns the nearest whole number to the expression. If expression is exactly halfway between two whole numbers, the result is always the even number.

### Example

Round(25.4) = 25

Round(25.5) = 26

Round(25.6) = 26

Round(26.5) = 26

## Sin

### Syntax

Sin(Angle)

### Description

The sine of Angle, where Angle is expressed in degrees (not radians).

### Example

Sin(90)	=	1
Sin(180)	=	0

## Sinh

### Syntax

Sinh(X)

### Description

The hyperbolic sine of X.

## Sqr

### Syntax

Sqr(Expression)

### Description

The square of the expression, equivalent to Expression \* Expression or (expression ^ 2).

### Example

Sqr(3) = 9  
Sqr(10) = 100

## Sqrt

### Syntax

Sqrt(Expression)

### Description

The square root of the expression.

### Example

Sqrt(9) = 3  
Sqrt(100) = 10



## Tan

### Syntax

Tan(Angle)

### Description

The tangent of Angle, where Angle is expressed in degrees (not radians).

### Example

Tan(45)	=	1
Tan(180)	=	0

## Tanh

### Syntax

Tanh(X)

### Description

The hyperbolic tangent of X.

## 6.8.3 Logical Functions

## And

### Syntax

And(Expression1, Expression2, ..., ExpressionN)

### Description

Performs a logical "AND" operation. Returns a value of one (true) if all of the expressions are non-zero (true). Otherwise returns a value of zero (false). You can have any number of expressions, each of which can be a complex logical expression.

### Examples

And( 5 > 4, 10 < 20) = 1

And( 5 > 4, 10 < 20, 15 < 10) = 0

And( Year < 2005, \Demand Sites\South City:Activity Level[million cap] > 4 )  
= 1 (true) for years before 2005 in which the South City population is greater than 4 million  
= 0 (false) otherwise

## Equal

### Syntax

Equal(Expression1, Expression2)

### Description

Returns a value of 1 if parameter 1 is equal to parameter 2. Otherwise returns a value of zero.

**Note:** This function is included for backwards compatibility with earlier versions of WEAP. In the latest versions of WEAP you can now use the standard equals operator "=" directly in your expressions. This helps to simplify your expressions and make them easier to understand.

**Example**

Equal(-1,3) = 0

Equal(3,3) = 1

## False

**Syntax**

False

**Description**

Used in logical tests. Has a value of zero.

**Examples**

If( PrevTSValue(Demand Sites\South City:Unmet Demand) > 10000, True, False)

## GreaterThan

**Syntax**

GreaterThan(Expression1, Expression2)

**Description**

Returns a value of 1 if parameter 1 is greater than parameter 2. Otherwise returns a value of zero.

**Note:** This function is included for backwards compatibility with earlier versions of WEAP. In the latest versions of WEAP you can now use the standard greater than operator ">" directly in your expressions. This helps to simplify your expressions and make them easier to understand.

**Example**

GreaterThan(-1,3) = 0

GreaterThan(3,1) = 1

GreaterThan(1,1) = 0

## GreaterThanOrEqual

**Syntax**

GreaterThanOrEqual(Expression1, Expression2)

**Description**

Returns a value of 1 if parameter 1 is greater than or equal to parameter 2. Otherwise returns a value of zero.

**Note:** This function is included for backwards compatibility with earlier versions of WEAP. In the latest versions of WEAP you can now use the standard greater than or equal to operator ">=" directly in your expressions. This helps to simplify your expressions and make them easier to understand.

### **Example**

```
GreaterThanOrEqual(-1,3) = 0  
GreaterThanOrEqual(3,1) = 1  
GreaterThanOrEqual(1,1) = 1
```

## **If**

### **Syntax**

If(TestExpression1, ResultIfTrue1, ..., TestExpressionN, ResultIfTrueN, ResultIfAllFalse)

### **Description**

The If function evaluates each TestExpression in sequence, and for the first one that is not FALSE ( $\neq 0$ ), returns the value of its associated ResultIfTrue. If all TestExpressions are FALSE, then the value of ResultIfAllFalse is returned, or 0 if ResultIfAllFalse is omitted.

TestExpression is any value or expression that can be evaluated to TRUE or FALSE. Test expressions are generally made up of two or more terms which are compared according to standard logical operators. If there are more than one TestExpression, they are evaluated in order from left to right until the first TRUE one is found.

ResultIfTrue1 is an expression that is evaluated if TestExpression1 is TRUE ( $\neq 0$ ).

ResultIfFalse is an expression that is evaluated if all TestExpressions are FALSE ( $=0$ ).

### **Examples**

```
If(Income > 1000, 10, 20)
```

If the branch named Income has a value greater than 1000 then the function evaluates to 10. Otherwise, is it 20.

```
If( year >= 2005, 30, 0)
```

= 30 in years 2005 and after, 0 before 2005

```
If( year < 2005, 0, year < 2010, 10, year < 2020, 15, 20)
```

= 0 in years before 2005, 10 in years 2005-2009, 15 in 2010-2019, and 20 in years 2020 and after.

## **IsBlank**

### **Syntax**

IsBlank(Branch:VariableName)

### **Description**

The IsBlank function returns True if there is no expression entered for the named Branch:VariableName.

Note: if there is an expression entered for a parent scenario (or Current Accounts), IsBlank will be false.

### **Examples**

```
If( IsBlank(Central Reservoir:Top of Conservation), Central Reservoir:StorageCapacity, Central Reservoir:Top of Conservation)
```

If there is no expression for Top of Conservation, get the value of Storage Capacity, otherwise, use value of Top of Conservation.

## LessThan

### Syntax

LessThan(Expression1, Expression2)

### Description

Returns a value of 1 if parameter 1 is less than parameter 2. Otherwise returns a value of zero.

**Note:** This function is included for backwards compatibility with earlier versions of WEAP. In the latest versions of WEAP you can now use the standard less than operator "<" directly in your expressions. This helps to simplify your expressions and make them easier to understand.

### Example

LessThan(-1,3) = 1

LessThan(3,1) = 0

LessThan(1,1) = 0

## LessThanOrEqual

### Syntax

LessThanOrEqual(Expression1, Expression2)

### Description

Returns a value of 1 if parameter 1 is less than or equal to parameter 2. Otherwise returns a value of zero.

**Note:** This function is included for backwards compatibility with earlier versions of WEAP. In the latest versions of WEAP you can now use the standard less than or equal to operator "<=" directly in your expressions. This helps to simplify your expressions and make them easier to understand.

### Example

LessThanOrEqual (-1,3) = 1

LessThanOrEqual (3,1) = 0

LessThanOrEqual (1,1) = 1

## Not

### Syntax

Not(Expression)

### Description

Reverses the logic of the parameter. Returns a 1 (true) if the parameter is zero (false). Returns a zero (false) if the parameter is non-zero (true).

### Example

Not(1) = 0  
Not(-1) = 0  
Not(0) = 1

# NotEqual

### Syntax

NotEqual(Expression1, Expression2)

### Description

Returns a value of 1 if parameter 1 is not equal to parameter 2. Otherwise returns a value of zero.

**Note:** This function is included for backwards compatibility with earlier versions of WEAP. In the latest versions of WEAP you can now use the standard not equals operator "<>" directly in your expressions. This helps to simplify your expressions and make them easier to understand.

### Example

NotEqual(-1,3) = 1  
NotEqual(3,3) = 0

# Or

### Syntax

Or(Expression1, Expression2, ..., ExpressionN)

### Description

Performs a logical "OR" operation. Returns a value of one (true) if any one of the parameters is non-zero. Otherwise returns a value of zero (false). You can have any number of expressions, each of which can be a complex logical expression.

### Examples

Or( 5 > 4, 10 < 20 ) = 1  
Or( 5 > 4, 10 < 20, 15 < 10 ) = 1  
Or( 15 < 10, 20 > 30 ) = 0  
Or( Year > 2005, \Demand Sites\South City\Single Family:Annual Activity Level[% share] > 50 )  
= 1 (true) if either the year is after 2005 or the Single Family share is greater than 50 percent  
= 0 (false) otherwise

# True

### Syntax

True

### Description

Used in logical tests. Has a value of one.

### Examples

If( PrevTSValue(Demand Sites\South City:Unmet Demand) > 10000, True, False)

#### 6.8.4 User-Defined Functions

In addition to WEAP's built-in library of functions, you can also write your own functions in standard scripting languages, such as VBScript and JavaScript. These functions can be accessed from your expressions using the [Call](#) function. The [script editor](#) lets you edit the default VBScript file (functions.txt), which is stored in the current area folder. Thus, you can have different functions specified in different areas. See [Scripting](#) for more information.

# 7 Calculation Algorithms

WEAP calculates a water and pollution mass balance for every node and link in the system on a monthly time step. Water is dispatched to meet instream, consumptive and hydropower requirements, subject to demand priorities, supply preferences, mass balance and other constraints. Point loads of pollution into receiving bodies of water are computed, and instream water quality concentrations are calculated.

WEAP operates on a monthly time step, from the first month of the [Current Accounts](#) year through the last month of the last scenario year. Each month is independent of the previous month, except for reservoir and aquifer storage, and catchment soil moisture levels (soil moisture method only). Thus, all of the water entering the system in a month (e.g., headflow, groundwater recharge, or runoff into reaches) is either stored in an aquifer, reservoir or catchment, or leaves the system by the end of the month (e.g., outflow from end of river, demand site consumption, reservoir or river reach evaporation, transmission and return flow link losses). Because the time scale is relatively long (monthly), all flows are assumed to occur instantaneously. Thus, a demand site can withdraw water from the river, consume some, return the rest to a wastewater treatment plant that treats it and returns it to the river. This return flow is available for use in the same month by downstream demands.

Each month the calculations follow this order:

1. [Annual demand and monthly supply requirements](#) for each demand site and flow requirement. Catchment potential evapotranspiration, snow accumulation, and runoff and infiltration, assuming no irrigation inflow (yet).
2. [Inflows and outflows](#) of water for every node and link in the system. This includes calculating withdrawals from supply sources to meet demand, and dispatching reservoirs. This step is solved by a linear program (LP), which attempts to optimize coverage of demand site and instream flow requirements, subject to demand priorities, supply preferences, mass balance and other constraints.
3. [Hydropower generation](#).
4. [Capital and Operating Costs and Benefits](#).
5. If a [MODFLOW model](#) is linked, WEAP results (groundwater pumping and recharge, and river stage) will be loaded into the MODFLOW input files, MODFLOW will be run for one timestep, and MODFLOW results (cell heads, and flows between surface and groundwater) will be read into WEAP.
6. [Pollution generation by demand sites, flows and treatment of pollutants, and loadings on receiving bodies, concentrations in rivers](#).

## 7.1 Annual Demand and Monthly Supply Requirement Calculations

### 7.1.1 Annual Demand

A demand site's (*DS*) demand for water is calculated as the sum of the demands for all the demand site's bottom-level branches (*Br*). A bottom-level branch is one that has no branches below it. For example, in the structure shown at the right, Showers, Toilets, Washing and Other (and four others underneath Multifamily that are not shown) are the bottom-level branches for South City.

$$AnnualDemand_{DS} = \sum_{Br} ( TotalActivityLevel_{Br} \times WaterUseRate_{Br} )$$

The total activity level for a bottom-level branch is the product of the activity levels in all branches from the bottom branch back up to the demand site branch (where Br is the bottom-level branch, Br' is the parent of Br, Br'' is the grandparent of Br, etc.).

$$TotalActivityLevel_{Br} = ActivityLevel_{Br} \times ActivityLevel_{Br'} \times ActivityLevel_{Br''} \times \dots$$

For the example above, this becomes

$$TotalActivityLevel_{Showers} = ActivityLevel_{Showers} \times ActivityLevel_{SingleFamily} \times ActivityLevel_{SouthCity}$$

= percent of people in single family homes who have showers x percent of people who live in single family homes x number of people in South City

The activity level for a branch, and the water use rate for a bottom-level branch, are entered as data. (See [Demand\Annual Water Use\Activity Level](#) and [Demand\Annual Water Use\Water Use Rate](#).) Note that those branches marked as having "No data" (unit = N/A) are treated as having an activity level of 1.



### 7.1.2 Monthly Demand

The demand for a month (*m*) equals that month's fraction (specified as data under [Demand\Monthly Variation](#)) of the adjusted annual demand.

$$MonthlyDemand_{DS,m} = MonthlyVariationFraction_{DS,m} \times AdjustedAnnualDemand_{DS}$$

### 7.1.3 Monthly Supply Requirement

The monthly demand represents the amount of water needed each month by the demand site for its use, while the **supply requirement** is the actual amount needed from the supply sources. The supply requirement takes the demand and adjusts it to account for internal reuse, demand side management strategies for reducing demand, and internal losses. These three adjustment fractions are entered as data-- see [Demand\Loss and Reuse](#) and [Demand\Demand Side Management](#).

$$MonthlySupplyRequirement_{DS,m} = (MonthlyDemand_{DS,m} \times (1 - ReuseRate_{DS}) \times (1 - DSMSavings_{DS})) / (1 - LossRate_{DS})$$

## 7.2 Evapotranspiration, Runoff, Infiltration and Irrigation

There is a choice among four methods to simulate catchment processes such as evapotranspiration, runoff, infiltration and irrigation demands. These methods include (1) the Rainfall Runoff and (2) Irrigation Demands Only versions of the FAO Crop Requirements Approach, (3) the Soil Moisture Method, and (4) the MABIA Method. You can click on the "Advanced" button at the top of the Data Entry window for a particular catchment to select among these options. Your choice of method should depend on the level of complexity desired for representing the catchment processes and data availability.



### **Irrigation Demands Only Method (FAO Crop Requirements Method)**

Of these four methods, the Irrigation Demands Only method is the simplest. It uses crop coefficients to calculate the potential evapotranspiration in the catchment, then determines any irrigation demand that may be required to fulfill that portion of the evapotranspiration requirement that rainfall cannot meet. It does not simulate runoff or infiltration processes, or track changes in soil moisture.

### **Rainfall Runoff Method (FAO Crop Requirements Method)**

The Rainfall Runoff method also determines evapotranspiration for irrigated and rainfed crops using crop coefficients, the same as in the Irrigation Demands Only method. The remainder of rainfall not consumed by evapotranspiration is simulated as runoff to a river, or can be proportioned among runoff to a river and flow to groundwater via catchment links.

### **Rainfall Runoff Method (Soil Moisture Method)**

The Soil Moisture method is the most complex of the four methods, representing the catchment with two soil layers, as well as the potential for snow accumulation. In the upper soil layer, it simulates evapotranspiration considering rainfall and irrigation on agricultural and non-agricultural land, runoff and shallow interflow, and changes in soil moisture. This method allows for the characterization of land use and/or soil type impacts to these processes. Baseflow routing to the river and soil moisture changes are simulated in the lower soil layer. Correspondingly, the Soil Moisture Method requires more extensive soil and climate parameterization to simulate these processes.

Note that the deeper percolation within the catchment can also be transmitted directly to a groundwater node by creating a Runoff/Infiltration Flow Link from the catchment to the groundwater node. The method essentially becomes a 1-layer soil moisture scheme if this link is made. See [Groundwater-Surface Water Interactions](#) for more information.

### **MABIA Method (FAO 56, Dual Kc, Daily)**

The MABIA Method is a daily simulation of transpiration, evaporation, irrigation requirements and scheduling, crop growth and yields, and includes modules for estimating reference evapotranspiration and soil water capacity. It was derived from the MABIA suite of software tools, developed at the [Institut National Agronomique de Tunisie](#) by Dr. Ali Sahli and Mohamed Jabloun. For more information about MABIA and to download standalone versions of the software, visit <http://www.mabia-agrosoftware.net>. The algorithms and descriptions contained here are for the combined MABIA-WEAP calculation procedure.

The MABIA Method uses the ‘dual’ Kc method, as described in [FAO Irrigation and Drainage Paper No. 56 \(Spanish version of FAO 56\)](#), whereby the Kc value is divided into a ‘basal’ crop coefficient,  $K_{cb}$ , and a separate component,  $K_e$ , representing evaporation from the soil surface. The basal crop coefficient represents actual ET conditions when the soil surface is dry but sufficient root zone moisture is present to support full transpiration. In this way, MABIA is an improvement over [CROPWAT](#), which use a single Kc method, and hence, does not separate evaporation and transpiration.

See also: [FAO Method Calculation Algorithms](#), [Soil Moisture Method Calculation Algorithms](#), [MABIA Method Calculation Algorithms](#).

### 7.2.1 FAO Crop Requirements Methods (Rainfall Runoff & Irrigation Demands Only)

Crop requirements are calculated assuming a demand site with simplified hydrological and agro-hydrological processes such as precipitation, evapotranspiration, and crop growth emphasizing irrigated and rainfall agriculture. Non-agricultural land classes can be included as well. The following equations were used to implement this approach where subscripts  $_{LC}$  is land cover,  $_{HU}$  is hydro-unit,  $_I$  is irrigated, and  $_{NI}$  is non-irrigated:

$$PrecipAvailableForET_{LC} = Precip_{HU} * Area_{LC} * 10^{-5} * PrecipEffective_{LC}$$

$$ETpotential_{LC} = ETreference_{HU} * Kc_{LC} * Area_{LC} * 10^{-5}$$

$$PrecipShortfall_{LC,I} = \text{Max} ( 0, ETpotential_{LC,I} - PrecipAvailableForET_{LC,I} )$$

$$SupplyRequirement_{LC,I} = ( 1 / IrrFrac_{LC,I} ) * PrecipShortfall_{LC,I}$$

$$SupplyRequirement_{HU} = \sum_{LC,I} SupplyRequirement_{LC,I}$$

The above four equations are used to determine the additional amount of water (above the available precipitation) needed to supply the evapotranspiration demand of the land cover (and total hydro unit) while taking into account irrigation efficiencies.

Based on the system of priorities, the following quantities can be calculated:

$$Supply_{HU} = \text{Calculated by WEAP allocation algorithm}$$

$$Supply_{LC,I} = Supply_{HU} * ( SupplyRequirement_{LC,I} / SupplyRequirement_{HU} )$$

$$ETActual_{LC,NI} = \text{Min} ( ETpotential_{LC,NI} , PrecipAvailableForET_{LC,NI} )$$

$$ETActual_{LC,I} = \text{Min} ( ETpotential_{LC,I} , PrecipAvailableForET_{LC,I} ) + IrrFrac_{LC,I} * Supply_{LC,I}$$

$$EF_{LC} = ETActual_{LC} / ETpotential_{LC}$$

As a result, the actual yield can be calculated with the following equation:

$$ActualYield_{LC} = PotentialYield_{LC} * \text{Max} ( 0, ( 1 - YieldResponseFactor_{LC} * ( 1 - EF_{LC} ) ) )$$

In the Irrigation Demands Only method, runoff is not calculated. In the Rainfall Runoff method, runoff to both groundwater and surface water can be calculated with the following equations:

$$Runoff_{LC} = \text{Max} ( 0, PrecipAvailableForET_{LC} - ETpotential_{LC} )$$

$$+ ( Precip_{LC} * ( 1 - PrecipEffective_{LC} ) )$$

$$+ ( 1 - IrrFrac_{LC,I} ) * Supply_{LC,I}$$

$$RunoffToGW_{HU} = \sum_{LC} ( Runoff_{LC} * RunoffToGWFraction_{LC} )$$

$$RunoffToSurfaceWater_{HU} = \sum_{LC} ( Runoff_{LC} * ( 1 - RunoffToGWFraction_{LC} ) )$$

Units and definitions for all variables above are:

Area [HA] - Area of land cover

Precip [MM] - Precipitation

PrecipEffective [%] - Percentage of precipitation that can be used for evapotranspiration

PrecipAvailableForET [MCM] - Precipitation available for evapotranspiration

Kc [-] - FAO crop coefficient

## 7.2 Evapotranspiration, Runoff, Infiltration and Irrigation

ETreference [MM] - Reference crop evapotranspiration  
 ETpotential [MCM] - Potential crop evapotranspiration  
 PrecipShortfall [MCM] - Evapotranspiration deficit if only precipitation is considered  
 IrrFrac [%] - Percentage of supplied water available for ET (i.e. irrigation efficiency)  
 SupplyRequirement [MCM] - Crop irrigation requirement  
 Supply [MCM] - Amount supplied to irrigation (calculated by WEAP allocation)  
 EF [-] - Fraction of potential evapotranspiration satisfied  
 YieldResponseFactor [-] - Factor that defines how the yield changes when the ETactual is less than the ETpotential.  
 PotentialYield [KG/HA] - The maximum potential yield given optimal supplies of water  
 ActualYield [KG/HA] - The actual yield given the available evapotranspiration  
 Runoff [MCM] - Runoff from a land cover  
 RunoffToGW [MCM] - Runoff to groundwater supplies  
 RunoffToSurfaceWater [MCM] - Runoff to surface water supplies

### 7.2.2 Soil Moisture Method

This one dimensional, 2-compartment (or "bucket") soil moisture accounting scheme is based on empirical functions that describe evapotranspiration, surface runoff, sub-surface runoff (i.e., interflow), and deep percolation for a watershed unit (see Figure 1). This method allows for the characterization of land use and/or soil type impacts to these processes. The deep percolation within the watershed unit can be transmitted to a surface water body as baseflow or directly to groundwater storage if the appropriate link is made between the watershed unit node and a groundwater node.

A watershed unit can be divided into N fractional areas representing different land uses/soil types, and a water balance is computed for each fractional area, j of N. Climate is assumed uniform over each sub-catchment, and the water balance is given as,

$$Rd_j \frac{dz_{1,j}}{dt} = P_e(t) - PET(t)k_{e,j}(t)\left(\frac{5z_{1,j} - 2z_{1,j}^2}{3}\right) - P_e(t)z_{1,j}^{RRF_j} - f_j k_{z,j} z_{1,j}^2 - (1 - f_j)k_{z,j} z_{1,j}^2 \quad \text{Eqn. 1}$$

where  $z_{1,j} = [1,0]$  is the relative storage given as a fraction of the total effective storage of the root zone,  $Rd_j$  (mm) for land cover fraction, j. The effective precipitation,  $P_e$ , includes snowmelt from accumulated snowpack in the sub-catchment, where  $m_c$  is the melt coefficient given as,

$$m_c = \begin{cases} 0 & T_i < T_s \\ \frac{T_i - T_s}{T_l - T_s} & \text{if } T_s \leq T_i \leq T_l \\ 1 & T_i > T_l \end{cases} \quad \text{Eqn. 2}$$

where  $T_i$  is the observed temperature for month  $i$ , and  $T_l$  and  $T_s$  are the melting and freezing temperature thresholds. Snow accumulation,  $Ac_i$ , is a function of  $m_c$  and the observed monthly total precipitation,  $P_i$ , by the following relation,

$$Ac_i = Ac_{i-1} + (1 - m_c)P_i \quad \text{Eqn. 3}$$

with the melt rate,  $m_r$ , defined as,

$$m_r = A c_i m_e \text{Eqn. 4}$$

The effective precipitation,  $P_e$ , is then computed as

$$P_e = P_i m_e + m_r \text{Eqn. 5}$$

In Eqn. 1, PET is the Penman-Monteith reference crop potential evapotranspiration, where  $k_{c,j}$  is the crop/plant coefficient for each fractional land cover. The third term represents surface runoff, where  $RRF_j$  is the Runoff Resistance Factor of the land cover. Higher values of  $RRF_j$  lead to less surface runoff. The fourth and fifth terms are the interflow and deep percolation terms, respectively, where the parameter  $k_{s,j}$  is an estimate of the root zone saturated conductivity (mm/time) and  $f_j$  is a partitioning coefficient related to soil, land cover type, and topography that fractionally partitions water both horizontally and vertically. Thus total surface and interflow runoff, RT, from each sub-catchment at time  $t$  is,

$$RT(t) = \sum_{j=1}^N A_j \left( P_e(t) z_{1,j}^{RRF_j} + f_j k_{s,j} z_{1,j}^2 \right) \text{Eqn. 6}$$

For applications where no return flow link is created from a catchment to a groundwater node, baseflow emanating from the second bucket will be computed as:

$$S_{\max} \frac{dz_2}{dt} = \left( \sum_{j=1}^N (1 - f_j) k_{s,j} z_{1,j}^2 \right) - k_{s,2} z_2^2 \text{Eqn. 7}$$

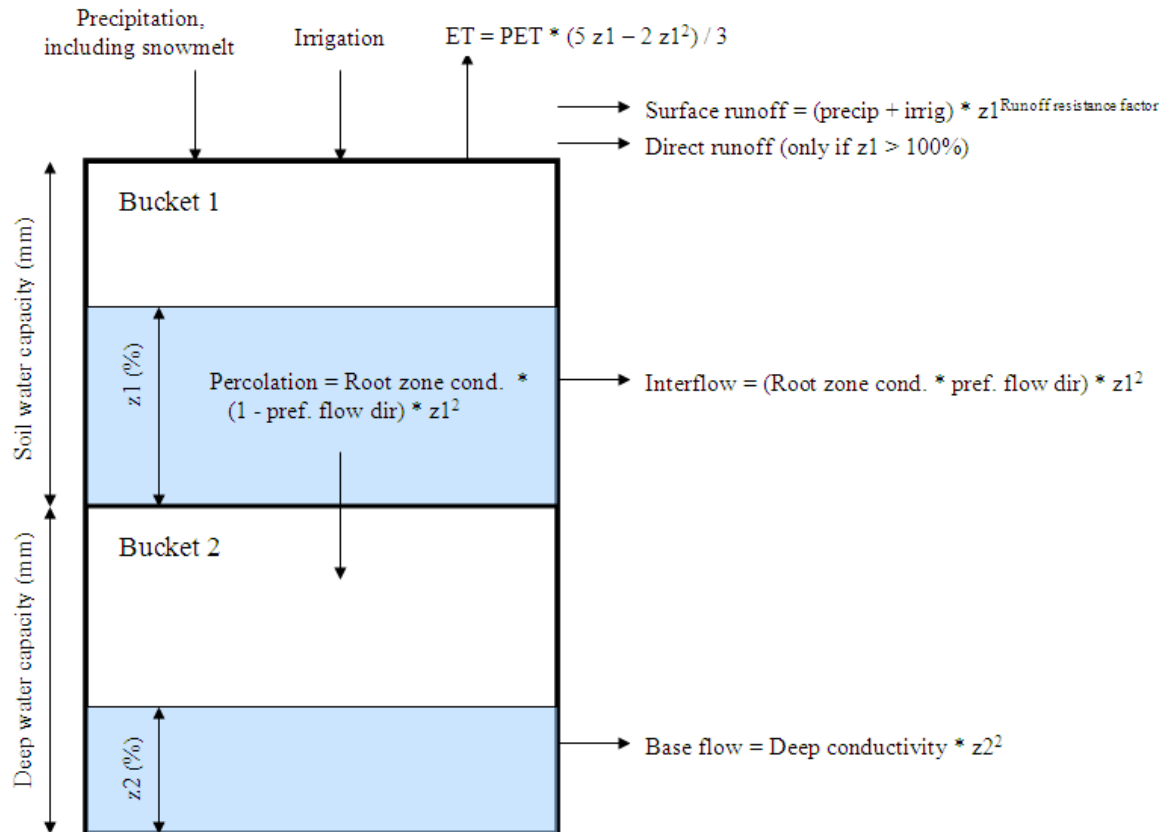
where the inflow to this storage,  $S_{\max}$  is the deep percolation from the upper storage given in Eqn. 1, and  $K_{s,2}$  is the saturated conductivity of the lower storage (mm/time), which is given as a single value for the catchment and therefore does not include a subscript,  $j$ . Equations 1 and 7 are solved using a predictor-corrector algorithm.

When an alluvial aquifer is introduced into the model and a runoff/infiltration link is established between the watershed unit and the groundwater node, the second storage term in Eqn. 7 is ignored, and recharge  $R$  (volume/time) to the aquifer is

$$R = \sum_{j=1}^N A_j (1 - f_j) k_{s,j} z_{1,j}^2 \text{Eqn. 8}$$

where  $A$  is the watershed unit's contributing area. The stylized aquifer characterizes the height of the water table relative to the stream, where individual river segments can either gain or lose water to the aquifer (see [Groundwater-Surface water Interactions](#)).

**Figure 1. Conceptual diagram and equations incorporated in the Soil Moisture model**



## Runoff Flows from Irrigation

Irrigation runoff can be included in total runoff emanating from a catchment. WEAP calculates this irrigation runoff by first assuming no irrigation exists and calculating flows accordingly. WEAP then performs the calculations incorporating irrigation, assuming all requested irrigation is supplied. Knowing how much more runoff would flow due solely to irrigation, WEAP calculates an "average" irrigation runoff fraction (that goes to a river and/or groundwater). This fraction is then applied to the quantity of irrigation that was actually supplied, and essentially becomes the runoff fraction. Note: this irrigation runoff fraction is specified as data by the user when simulating a catchment with the Rainfall Runoff method.

### 7.2.3 MABIA Method

## MABIA Method

The MABIA Method is a daily simulation of transpiration, evaporation, irrigation requirements and scheduling, crop growth and yields, and includes modules for estimating reference evapotranspiration and soil water capacity. It was derived from the MABIA suite of software tools, developed at the [Institut National Agronomique de Tunisie](http://www.mabia-agrosoftware.net) by Dr. Ali Sahli and Mohamed Jabloun. For more information about MABIA and to download standalone versions of the software, visit <http://www.mabia-agrosoftware.net>. The algorithms and descriptions contained here are for the combined MABIA-WEAP calculation procedure.

The MABIA Method uses the 'dual'  $K_c$  method, as described in [FAO Irrigation and Drainage Paper No. 56 \(Spanish version of FAO 56\)](#), whereby the  $K_c$  value is divided into a 'basal' crop coefficient,  $K_{cb}$ , and a separate component,  $K_e$ , representing evaporation from the soil surface. The basal crop coefficient represents actual ET conditions when the soil surface is dry but sufficient root zone moisture is present to support full transpiration. In this way, MABIA is an improvement over [CROPWAT](#), which use a single  $K_c$  method, and hence, does not separate evaporation and transpiration. This method can be used to model both agricultural crops as wells as non-agricultural land classes, such as forests and grasslands.

Although the timestep for MABIA is daily, the timestep for the rest of your WEAP analysis does not need to be daily (although it can be daily). For each WEAP timestep (e.g., monthly), MABIA would run for every day in that timestep and aggregate its results (evaporation, transpiration, irrigation requirements, runoff, and infiltration) to that timestep. For example, in January, MABIA would run from January 1 to 31, and sum up its results as January totals, including most importantly, the supply requirement for irrigation. WEAP would then solve its supply allocations, using this monthly irrigation requirement from the MABIA catchments. In the case where the supply delivered to the catchments was less than the requirement, MABIA would rerun its daily simulation, this time using only the reduced amount of irrigation to determine actual evaporation, transpiration, irrigation requirements, runoff, and infiltration.

The steps in the MABIA calculations are as follows:

1. [Reference Evapotranspiration](#) (ET<sub>ref</sub>)
2. [Soil Water Capacity](#)
3. [Basal Crop Coefficient](#) ( $K_{cb}$ )
4. [Evaporation Coefficient](#) ( $K_e$ )
5. [Potential and Actual Crop Evapotranspiration](#) (ET<sub>c</sub>)
6. [Irrigation](#)
7. [Yield](#)

## Reference Evapotranspiration (ET<sub>ref</sub>)

Reference crop evapotranspiration or reference evapotranspiration, denoted as ETo or ET<sub>ref</sub>, is the estimation of the evapotranspiration from the "reference surface." The reference surface is a hypothetical grass reference crop with an assumed crop height of 0.12 m, a fixed surface resistance of 70 s/m and an albedo of 0.23. The reference surface closely resembles an extensive surface of green, well-watered grass of uniform height, actively growing and completely shading the ground. The fixed surface resistance of 70 s/m implies a moderately dry soil surface resulting from about a weekly irrigation frequency.

For ET<sub>ref</sub>, you have two options:

1. Enter ET<sub>ref</sub> directly (some climate stations provide derived ET<sub>ref</sub> as data), OR
2. Calculate it using the Penman-Monteith equation. This approach has its own data requirements, with various options. Penman-Monteith requires:
  - a. Minimum and maximum daily temperature.
  - b. Relative humidity. Depending on the availability of data, different equations are used. The following are the data requirements, in decreasing order of preference.
    - i. Minimum and maximum daily relative humidity, OR
    - ii. Maximum daily relative humidity, OR
    - iii. Average daily relative humidity, OR

- iv. If humidity data is not available, and estimate can be obtained by assuming that the dew point temperature is the same as the daily minimum temperature.
- c. Solar radiation. Depending on the availability of data, different equations are used. The following are the data requirements, in decreasing order of preference.
  - i. Enter solar radiation data directly, OR
  - ii. Hours of sunshine per day, OR
  - iii. Cloudiness fraction, OR
  - iv. If neither sunshine hours nor cloudiness fraction are available, solar radiation can be estimated using the Hargreaves formula, based on minimum and maximum daily temperature and an adjustment coefficient (Krs)
- d. Wind speed. (An adjustment can be made if the wind speed measurement height is known.)
- e. Latitude and altitude of the climate measurement station.

Depending on the setting in [General: Basic Parameters](#), the values for climate data can **either** be entered once for each catchment and will apply to all the land use branches within that catchment, **or** they will be entered separately for each branch within each catchment. This second option might be necessary if there is a large variation in the elevation among different land uses within a catchment. Alternatively, the catchment could be divided into several different catchment nodes according to elevation, so that the climate within each catchment did not vary by land use.

The calculation methods implemented in the MABIA Method are those of the FAO Penman-Monteith equation as outlined in the FAO Irrigation and Drainage Paper 56. This equation can be written as follows:

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T_{mean} + 273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34 u_2)}$$

where

- ET<sub>o</sub> = reference evapotranspiration [mm/day],
- R<sub>n</sub> = net radiation at the crop surface [MJ/m<sup>2</sup>/day],
- G = soil heat flux density [MJ/m<sup>2</sup>/day] which can be neglected (G=0),
- T<sub>mean</sub> = mean air temperature [°C],
- u<sub>2</sub> = wind speed measured at 2 m height [m/s],
- e<sub>s</sub> = saturation vapor pressure [kPa],
- e<sub>a</sub> = actual vapor pressure [kPa],
- e<sub>s</sub>-e<sub>a</sub> = saturation vapor pressure deficit [kPa],
- Δ = slope vapor pressure curve [kPa/°C],
- γ = psychrometric constant [kPa/°C].

### Net radiation

The net radiation, R<sub>n</sub>, is the difference between the incoming net shortwave radiation (R<sub>ns</sub>) and the outgoing net long wave radiation (R<sub>nl</sub>):

$$R_n = R_{ns} - R_{nl}$$

## Net solar or net shortwave radiation

The net shortwave radiation resulting from the balance between incoming and reflected solar radiation is given by:

$$R_{ns} = (1-\Delta) R_s$$

where

$R_{ns}$  = net shortwave radiation [MJ/m<sup>2</sup>/day],

$\Delta$  = albedo or canopy reflection coefficient for the reference crop [dimensionless] (a fixed value of 0.23 is used),

$R_s$  = solar radiation [MJ/m<sup>2</sup>/day].

## Net long wave radiation

The net long wave radiation,  $R_{nl}$ , is given by:

$$R_{nl} = \sigma \left[ \frac{T_{max,K}^4 + T_{min,K}^4}{2} \right] (0.34 - 0.14\sqrt{e_a}) \left( 1.35 \frac{R_s}{R_{so}} - 0.35 \right)$$

where

$R_{nl}$  = net long wave radiation [MJ/m<sup>2</sup>/day],

$\sigma$  = Stefan-Boltzmann constant [4.903 10<sup>-9</sup> MJ/K<sup>4</sup>/m<sup>2</sup>/day],

$T_{max}$  = K maximum absolute temperature during the 24-hour period [K = °C + 273.16],

$T_{min}$  = K minimum absolute temperature during the 24-hour period [K = °C + 273.16],

$e_a$  = actual vapor pressure [kPa],

$R_s/R_{so}$  = relative shortwave radiation (limited to ≤ 1.0)

$R_s$  = solar radiation [MJ/m<sup>2</sup>/day],

$R_{so}$  = clear-sky radiation [MJ/m<sup>2</sup>/day]

## Solar radiation

If the solar radiation,  $R_s$ , is not measured, it can be calculated with the Angstrom formula, which relates solar radiation to extraterrestrial radiation and relative sunshine duration:

$$R_s = (a_s + b_s \frac{n}{N}) R_a$$

where

$R_s$  = solar or shortwave radiation [MJ/m<sup>2</sup>/day],

$n$  = actual duration of sunshine [hour],

$N$  = maximum possible duration of sunshine or daylight hours [hour],

$n/N$  = relative sunshine duration [fraction],

$R_a$  = extraterrestrial radiation [MJ/m<sup>2</sup>/day],

$a_s$  = regression constant, expressing the fraction of extraterrestrial radiation reaching the earth on overcast days ( $n = 0$ ),

$a_s + b_s$  = fraction of extraterrestrial radiation reaching the earth on clear days ( $n = N$ ).

The default values for  $a_s$  and  $b_s$  are 0.25 and 0.50.

An alternative to entering the actual duration of sunshine ( $n$ ) is to enter the cloudiness fraction, which is used in place of  $n/N$ . When neither  $n$  nor cloudiness fraction is available,  $R_s$  can be estimated using the Hargreaves formula:



$$R_s = k_{Rs} \sqrt{T_{max} - T_{min}} R_a$$

where

$R_a$  = extraterrestrial radiation [MJ/m<sup>2</sup>/day],

$T_{max}$  = maximum air temperature [°C],

$T_{min}$  = minimum air temperature [°C],

$k_{Rs}$  = adjustment coefficient (between 0.16 and 0.19) [°C<sup>-0.5</sup>].

### Clear-sky solar radiation

The calculation of the clear-sky radiation,  $R_{so}$ , when  $n = N$ , is required for computing net long wave radiation.

$$R_{so} = (0.75 + 2 \cdot 10^{-5} z) R_a$$

where

$R_{so}$  = clear-sky solar radiation [MJ/m<sup>2</sup>/day],

$z$  = station elevation above sea level [m],

$R_a$  = extraterrestrial radiation [MJ/m<sup>2</sup>/day].

### Extraterrestrial radiation

The extraterrestrial radiation,  $R_a$ , for each day of the year and for different latitudes is estimated from the solar constant, the solar declination and the time of the year by:

$$R_a = \frac{24(60)}{\pi} G_{sc} d_r [\omega_s \sin(\varphi) \sin(\delta) + \cos(\varphi) \cos(\delta) \sin(\omega_s)]$$

where

$R_a$  = extraterrestrial radiation [MJ/m<sup>2</sup>/day],

$G_{sc}$  = solar constant = 0.0820 MJ/m<sup>2</sup>/min,

$d_r$  = inverse relative distance Earth-Sun,

$\omega_s$  = sunset hour angle [rad],

$\varphi$  = latitude [rad],

$\delta$  = solar declination [rad].

The latitude,  $\varphi$ , expressed in radians is positive for the northern hemisphere and negative for the southern hemisphere. The conversion from decimal degrees to radians is given by:

$$\varphi = \frac{\pi}{180} \left( \text{Lat}_{deg} + \frac{\text{Lat}_{min}}{60} \right)$$

The inverse relative distance Earth-Sun,  $d_r$ , and the solar declination,  $\delta$ , are given by:

$$d_r = 1 + 0.033 \cos\left(\frac{2\pi J}{365}\right)$$

$$\delta = 0.409 \sin\left(\frac{2\pi J}{365} - 1.39\right)$$

where

J = number of the day in the year between 1 (1 January) and 365 or 366 (31 December).

The sunset hour angle,  $\omega_s$ , is given by:

$$\omega_s = \arccos(-\tan(\varphi) \tan(\delta))$$

## Daylight hours

The daylight hours, N, are given by:

$$N = 24 * \omega_s / \pi$$

## Psychrometric constant

The psychrometric constant,  $\gamma$ , is given by:

$$\gamma = \frac{c_p P}{\varepsilon \lambda} = 0.665 \cdot 10^{-3} P$$

where

$\gamma$  = psychrometric constant [kPa/°C],

P = atmospheric pressure [kPa],

$\lambda$  = latent heat of vaporization = 2.45 [MJ/kg],

$c_p$  = specific heat at constant pressure = 1.013  $\cdot 10^{-3}$  [MJ/kg/°C],

$\varepsilon$  = ratio molecular weight of water vapor/dry air = 0.622.

The value of the latent heat varies as a function of temperature. However, because  $\lambda$  varies only slightly over normal temperature ranges, a single value of 2.45 MJ/kg is used. (This value corresponds to an air temperature of about 20°C.)

## Atmospheric pressure

The atmospheric pressure, P, is the pressure exerted by the weight of the earth's atmosphere:

$$P = 101.3 \left( \frac{293 - 0.0065z}{293} \right)^{5.26}$$

where

P = atmospheric pressure [kPa],

z = elevation above sea level [m]

## Mean Daily air temperature

$$T_{mean} = (T_{max} + T_{min}) / 2$$

where

$T_{mean}$  = mean daily air temperature [°C],

$T_{min}$  = minimum daily air temperature [°C],

$T_{max}$  = maximum daily air temperature [°C].

### Wind speed

For the calculation of evapotranspiration, wind speed measured at 2 m above the surface is required. To adjust wind speed data obtained from instruments placed at elevations other than the standard height of 2 m, a logarithmic wind speed profile may be used for measurements above a short grassed surface:

$$u_2 = u_z \frac{4.87}{\ln(67.8 z - 5.42)}$$

where

- $u_2$  = wind speed at 2 m above ground surface [m/s],
- $u_z$  = measured wind speed at  $z$  m above ground surface [m/s],
- $z$  = height of measurement above ground surface [m].

### Mean saturation vapor pressure

The mean saturation vapor pressure is the mean of the saturation vapor pressures at maximum and minimum air temperatures for the day:

$$e_s = \frac{e^o(T_{max}) + e^o(T_{min})}{2}$$

where

- $e_s$  = saturation vapor pressure [kPa],
- $e^o(T_{max})$  = saturation vapor pressure at the mean daily maximum air temperature [kPa],
- $e^o(T_{min})$  = saturation vapor pressure at the mean daily minimum air temperature [kPa].

### Saturation vapor pressure

The saturation vapor pressure,  $e^o$ , is a function of air temperature:

$$e^o(T) = 0.6108 \exp((17.27 T) / (T + 237.3))$$

where

- $e^o(T)$  = saturation vapor pressure at the air temperature  $T$  [kPa],
- $T$  = air temperature [ $^{\circ}\text{C}$ ].

### Actual vapor pressure

The actual vapor pressure,  $e_a$  can also be calculated from the relative humidity. Depending on the availability of the humidity data, different equations are used:

1. Using  $RH_{max}$  and  $RH_{min}$ :

$$e_a = \frac{e^o(T_{min}) \frac{RH_{max}}{100} + e^o(T_{max}) \frac{RH_{min}}{100}}{2}$$

2. Using  $RH_{max}$  :

$$e_a = e^o(T_{min}) \frac{RH_{max}}{100}$$

3. Using  $RH_{\text{mean}}$ :

In the absence of  $RH_{\text{max}}$  and  $RH_{\text{min}}$ ,  $RH_{\text{mean}}$  can be used to estimate  $e_a$ :

$$e_a = \frac{RH_{\text{mean}}}{100} \left[ \frac{e^{\circ}(T_{\text{max}}) + e^{\circ}(T_{\text{min}})}{2} \right]$$

where  $RH_{\text{mean}}$  is the mean relative humidity, defined as the average between  $RH_{\text{max}}$  and  $RH_{\text{min}}$ .

## 4. If Humidity data is not available

An estimate of actual vapor pressure,  $e_a$ , can be obtained by assuming that dew point temperature ( $T_{\text{dew}}$ ) is near the daily minimum temperature ( $T_{\text{min}}$ ) then,

$$e_a = e^{\circ}(T_{\text{min}}) = 0.611 \exp \left[ \frac{17.27 T_{\text{min}}}{T_{\text{min}} + 237.3} \right]$$

where

$e_a$  = actual vapor pressure [kPa],  
 $e^{\circ}(T_{\text{min}})$  = saturation vapor pressure at daily minimum temperature [kPa],  
 $e^{\circ}(T_{\text{max}})$  = saturation vapor pressure at daily maximum temperature [kPa],  
 $RH_{\text{max}}$  = maximum relative humidity [%],  
 $RH_{\text{min}}$  = minimum relative humidity [%].

## Slope vapor pressure curve

For the calculation of evapotranspiration by mean of various methods, the slope of the relationship between saturation vapor pressure and temperature,  $\Delta$ , is required. The slope of the curve at a given temperature is given by:

$$\Delta = \frac{4098 \left[ 0.6108 e^{\left( \frac{17.27 T_{\text{mean}}}{T_{\text{mean}} + 237.3} \right)} \right]}{(T_{\text{mean}} + 237.3)^2}$$

where

$\Delta$  = slope of saturation vapor pressure curve at air temperature  $T$  [kPa/°C],  
 $T_{\text{mean}}$  = mean air temperature [°C].

## Soil Water Capacity

The MABIA method requires data on water holding capacity at field capacity and wilt point, for each catchment land use. Because direct measurement of a soil's water holding capacity, including saturation, field capacity and wilt point, can be costly and time consuming, pedotransfer functions were developed to translate more easily obtainable data into these water holding capacity values. The [SoilProfiles](#) function estimates average soil water capacity (saturation, field capacity and wilt point) using one of six available pedotransfer functions (PTF), in order to determine the Soil Water Capacity for catchment land use branches. This function can average over several soil profiles (sampling sites) and soil horizons (layers). (As an alternative to using [SoilProfiles](#), you can enter field capacity and wilt point directly, or choose a texture class from the [Soil Library](#).)

### Averaging over multiple profiles and horizons

If there are multiple profiles (sampling sites), the average field capacity and wilt point over all the profiles is the **simple** average over all the profiles:

$$FC = \frac{\sum_{p=1}^{NumProfiles} FC_p}{NumProfiles} \quad WP = \frac{\sum_{p=1}^{NumProfiles} WP_p}{NumProfiles}$$

where

FC = field capacity averaged over all profiles  
 FC<sub>p</sub> = average field capacity for profile p,  
 WP = wilt point averaged over all profiles  
 WP<sub>p</sub> = average wilt point for profile p,  
 NumProfiles = number of profiles to average

If there are multiple horizons (layers) in a profile, the average field capacity and wilt point for the profile is the **weighted** average over all the horizons (weighted by horizon thickness):

$$FC_p = \frac{\sum_{h=1}^{NumHorizons_p} (z_{p,h} FC_{p,h})}{\sum_{h=1}^{NumHorizons_p} z_{p,h}} \quad WP_p = \frac{\sum_{h=1}^{NumHorizons_p} (z_{p,h} WP_{p,h})}{\sum_{h=1}^{NumHorizons_p} z_{p,h}}$$

where

FC<sub>p</sub> = average field capacity for profile p,  
 FC<sub>p,h</sub> = field capacity of horizon h in profile p,  
 WP<sub>p</sub> = average wilt point for profile p,  
 WP<sub>p,h</sub> = wilt point of horizon h in profile p,  
 NumHorizons<sub>p</sub> = number of horizons in profile p,  
 z<sub>p,h</sub> = thickness of horizon h in profile p

### Coarse fragments

The presence of coarse fragments (e.g., rocks) will reduce the water hold capacity of the soil.

$$FC'_{p,h} = FC_{p,h} * (1 - CF_{p,h}) \quad WP'_{p,h} = WP_{p,h} * (1 - CF_{p,h})$$

where

FC'\_{p,h} = field capacity of horizon h in profile p, corrected for coarse fragments,  
 FC\_{p,h} = field capacity of horizon h in profile p,  
 WP'\_{p,h} = wilt point of horizon h in profile p, corrected for coarse fragments,  
 WP\_{p,h} = wilt point of horizon h in profile p,  
 CF\_{p,h} = coarse fragment fraction of horizon h in profile p

### Estimation of horizon properties using pedotransfer functions

Field capacity and wilt point for each horizon in each profile are estimated using pedotransfer functions.

The pedotransfer functions are commonly categorized into “class” and “continuous” PTFs, based on the parameters to use in estimating the water content. The “class” PTFs are defined based on the soil texture class to which the soil sample belongs, while the “continuous” PTFs predict the soil properties as a continuous function of one or more measured variables. This latter type of pedotransfer function can be used either to predict the soil water content at a special point of the water retention curve or to predict the parameters of an hydraulic model. The most widely used is the Van-Genuchten hydraulic model:

$$\theta(h) = \theta_r + \frac{\theta_s - \theta_r}{[1 + (\alpha h)^n]^m}$$

where

$\theta_r$  and  $\theta_s$  are the residual and saturated water content, respectively,  
 $h$  is the matric potential (kPa), for Saturation point ( $h=0$  kPa), Field Capacity ( $h=100$  kPa) and Wilting Point ( $h=1500$  kPa)  
 $\alpha$  is the scaling parameter,  
 $n$  is the curve shape factor,  
 $m$  is an empirical constant, which can be related to  $n$ , by  $m = 1 - 1/n$ .

Six continuous pedotransfer functions are available in the MABIA method. They were chosen to accommodate varying data availability, in terms of which of the following were available: particle size fractions, dry bulk density and organic matter content.

1. "Particle size (Jabloun and Sahli 2006)": silt[%], clay[%], and sand[%] fraction
2. "Particle size Bulk density (Jabloun and Sahli 2006)": silt[%], clay[%], and sand[%] and bulk density[g/cm<sup>3</sup>]
3. "Particle size Organic matter (Jabloun and Sahli 2006)": silt[%], clay[%], and sand[%] and organic matter[g/kg]
4. "Particle size Bulk density Organic matter (Jabloun and Sahli 2006)": silt[%], clay[%], and sand[%], bulk density[g/cm<sup>3</sup>] and organic matter[g/kg]
5. "Particle size Bulk density Organic matter (Vereecken et. al. 1989)": silt[%], clay[%], and sand[%], bulk density[g/cm<sup>3</sup>] and organic matter[g/kg]
6. "Particle size Bulk density Organic matter (Wösten et. al. 1999)": silt[%], clay[%], and sand[%], bulk density[g/cm<sup>3</sup>] and organic matter[g/kg]

In the following equations,

Cl = Clay [%]  
Si = Silt [%]  
Sa = Sand [%] = 100% - Cl - Si  
BD = Bulk density [g/cm<sup>3</sup>]  
OM = Organic matter [g/kg]

#### **"Particle size (Jabloun and Sahli 2006)": silt[%], clay[%], and sand[%] fraction**

This model is defined by three specific equations to estimate water content at saturation, field capacity and wilting point.

$$\begin{aligned}\theta_{SAT} &= 0.6658(Si) + 0.1567(Sa) - 0.0079(Si^2) - 12.31121/Sa - 6.4756 \ln(Sa) - 0.0038(Cl)(Si) + \\ &0.0038(Cl)(Sa) - 0.0042(Si)(Sa) + 52.7526 \\ \theta_{FC} &= 118.932(Cl) + 119.0866(Si) + 119.1104(Sa) + 162.31731/Cl - 46.21921/Si - 5.12991/Sa + \\ &18.1733 \ln(Cl) + 0.0013(Cl)(Si) + 0.0022(Si)(Sa) - 11939.3493 \\ \theta_{WP} &= -1.5722(Si) - 0.5423(Sa) - 0.0072(Cl^2) + 0.0072(Si^2) - 0.0059(Sa^2) + 160.14591/Cl + \\ &6.60011/Sa + 0.0022(Cl)(Si) - 0.0039(Cl)(Sa) + 92.3851\end{aligned}$$

#### **"Particle size Bulk density (Jabloun and Sahli 2006)": silt[%], clay[%], and sand[%] and bulk density[g/cm<sup>3</sup>]**

## 7.2 Evapotranspiration, Runoff, Infiltration and Irrigation

This model is defined by three specific equations to estimate water content at saturation, field capacity and wilting point.

$$\begin{aligned}\theta_{SAT} &= 0.4602(Cl) + 1.1343(Si) - 86.8963(BD) - 0.011(Si^2) - 9.4193 \ln(Si) + 110.5222 \ln(BD) - \\ &0.256(Cl)BD - 0.002(Si)(Sa) + 0.0405(Sa)(BD) + 135.5837 \\ \theta_{FC} &= 148.39031/Cl - 43.85161/Si - 5.17411/Sa + 16.6718 \ln(Cl) + 0.0011(Cl)(Si) - \\ &0.0999(Cl)(BD) + 0.0025(Si)(Sa) - 24.1522 \\ \theta_{WP} &= -1.2152(Si) - 0.4877(Sa) - 0.0057(Cl^2) + 0.0087(Si^2) + 85.84361/Cl - 88.0331/Si + \\ &0.0012(Cl)(Si) + 0.2129(Cl)(BD) + 59.6137\end{aligned}$$

### "Particle size Organic matter (Jabloun and Sahli 2006)": silt[%], clay[%], and sand[%] and organic matter[g/kg]

This model is defined by three specific equations to estimate water content at saturation, field capacity and wilting point.

$$\begin{aligned}\theta_{SAT} &= 0.7264(Si) + 0.2026(Sa) - 0.0083(Si^2) - 13.75491/Sa - 7.7387 \ln(Sa) + 2.2103 \ln(OM) - \\ &0.0043(Cl)(Si) + 0.0051(Cl)(Sa) - 0.0047(Si)(Sa) + 53.4646 \\ \theta_{FC} &= 0.2239(Cl) - 57.95441/Si - 11.69741/Sa + 6.90031/OM - 3.5324 \ln(Sa) + 24.0966 \ln(OM) \\ &+ 0.0031(Cl)(Sa) - 0.1886(Cl)(OM) + 36.7918 \\ \theta_{WP} &= -181.7238(Cl) - 183.5092(Si) - 182.4525(Sa) - 0.0048(Cl^2) + 0.0114(Si^2) - 0.0031(Sa^2) + \\ &128.78961/Cl - 83.0451/Si + 6.52931/Sa + 9.18951/OM + 27.4919 \ln(OM) + 0.0043(Cl)(Si) - \\ &0.2411\end{aligned}$$

### "Particle size Bulk density Organic matter (Jabloun and Sahli 2006)": silt[%], clay[%], and sand[%], bulk density[g/cm^3] and organic matter[g/kg]

This model is defined by three specific equations to estimate water content at saturation, field capacity and wilting point.

$$\begin{aligned}\theta_{SAT} &= -0.8667(Cl) - 1.426(Sa) - 84.2817(BD) - 0.0151(Si^2) + 0.0012(Sa^2) - 7.9188 \ln(Si) + \\ &112.0333 \ln(BD) - 0.0064(Cl)(Si) - 0.2835(Cl)(BD) - 0.0068(Si)(Sa) + 0.177(Si)(OM) + 266.768 \\ \theta_{FC} &= 0.0023(Si^2) - 8.491(BD^2) - 3.2498(OM^2) + 153.59021/Cl - 101.21431/Si - 9.02181/Sa + \\ &8.52011/OM + 20.9002 \ln(OM) + 0.355(Cl)(BD) - 0.2388(Cl)(OM) + 10.1357(BD)(OM) + 16.4788 \\ \theta_{WP} &= -0.7409(Si) + 0.0126(Si^2) - 7.4396(BD^2) - 2.8807(OM^2) + 136.151/Cl - 98.33231/Si - \\ &23.99671/Sa + 9.03681/OM + 20.7999 \ln(OM) + 0.4598(Cl)(BD) - 0.2579(Cl)(OM) + \\ &9.1905(BD)(OM) + 9.8444\end{aligned}$$

### "Particle size Bulk density Organic matter (Vereecken et. al. 1989)": silt[%], clay[%], and sand[%], bulk density[g/cm^3] and organic matter[g/kg]

The water content at saturation, field capacity and wilting point are obtained by calculating the Van-Genuchten model for  $h = 0, 100$  and  $1500$ , respectively.

$$\begin{aligned}\theta_{SAT} &= \theta_r + (\theta_s - \theta_r) / (1 + (\Delta * 0)^n)^{1/m} = \theta_s \\ \theta_{FC} &= \theta_r + (\theta_s - \theta_r) / (1 + (\Delta * 100)^n)^{1/m} \\ \theta_{WP} &= \theta_r + (\theta_s - \theta_r) / (1 + (\Delta * 1500)^n)^{1/m}\end{aligned}$$

where

$$\begin{aligned}\theta_s &= 0.81 - 0.283(BD) + 0.001(Cl) \\ \theta_r &= 0.015 + 0.005(Cl) + 0.014(OM) \\ \Delta &= \exp(-2.486 + 0.025(S) - 0.351(OM) - 2.617(BD) - 0.023(Cl)) \\ n &= \exp(0.053 - 0.009(S) - 0.0135(Cl) + 0.00015(S)^2) \\ m &= 1\end{aligned}$$

**"Particle size Bulk density Organic matter (Wösten et. al. 1999)": silt[%], clay[%], and sand[%], bulk density[g/cm<sup>3</sup>] and organic matter[g/kg]**

The water content at saturation, field capacity and wilting point are obtained by calculating the Van-Genuchten model for  $h = 0, 100$  and  $1500$ , respectively.

$$\begin{aligned}\theta_{SAT} &= \theta_r + (\theta_s - \theta_r) / (1 + (\Delta * 0)^n)^m = \theta_s \\ \theta_{FC} &= \theta_r + (\theta_s - \theta_r) / (1 + (\Delta * 100)^n)^m \\ \theta_{WP} &= \theta_r + (\theta_s - \theta_r) / (1 + (\Delta * 1500)^n)^m\end{aligned}$$

where

$$\begin{aligned}\theta_s &= 0.7919 + 0.001691(Cl) - 0.29619(BD) - 0.000001491(Si^2) + 0.0000821(OM^2) + (0.02427 \\ &)/Cl + 0.01113/Si + 0.01472 \ln(Si) - 0.0000733(OM)(Cl) - 0.000619(BD)(Cl) - 0.001183(BD)(OM) - \\ &0.0001664(Si) \\ \theta_r &= 0.01 \\ \Delta &= \exp[-14.96 + 0.03135(Cl) + 0.0351(Si) + 0.646(OM) + 15.29(BD) - 0.192 - 4.671(BD^2) - \\ &0.000781(Cl^2) - 0.00687(OM^2) + 0.0449/OM + 0.0663 \ln(Si) + 0.1482 \ln(OM) - \\ &0.04546(BD)(Si) - 0.4852(BD)(OM) + 0.00673(Cl)] \\ n &= \exp[-25.23 - 0.02195(Cl) + 0.0074(Si) - 0.194(OM) + 45.5(BD) - 7.24(BD^2) + 0.0003658(Cl^2) \\ &+ 0.002885(OM^2) - 12.81/BD - 0.1524/Si - 0.01958/OM - 0.2876 \ln(Si) - 0.0709 \ln(OM) - 44.6 \\ &\ln(BD) - 0.02264(BD)(Cl) + 0.0896(BD)(OM) + 0.00718(Cl)] + 1 \\ m &= 1 - 1/n\end{aligned}$$

## Basal Crop Coefficient ( $K_{cb}$ )

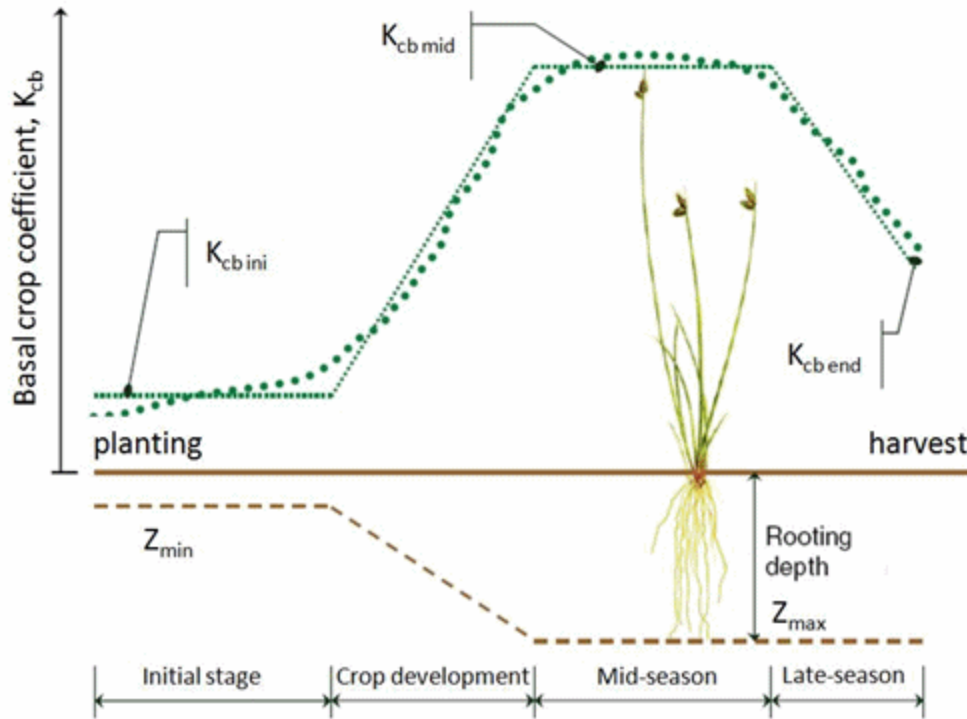
The MABIA Method uses the 'dual'  $K_c$  method, as described in [FAO Irrigation and Drainage Paper No. 56](#), whereby the  $K_c$  value is divided into a 'basal' crop coefficient,  $K_{cb}$ , and a separate component,  $K_e$ , representing evaporation from the soil surface. The basal crop coefficient represents actual ET conditions when the soil surface is dry but sufficient root zone moisture is present to support full transpiration.

## Basal Crop Coefficient Curve

The crop coefficient curve represents the changes in  $K_{cb}$  over the course of the growing season, depending on changes in vegetation cover and physiology. During the initial period, shortly after planting of annuals or prior to the initiation of new leaves for perennials, the value of  $K_{cb}$  is often small.

Definitions for three  $K_{cb}$  values ( $K_{cb \text{ ini}}$ ,  $K_{cb \text{ mid}}$  and  $K_{cb \text{ end}}$ ) required to construct the curve and associated definitions for growth stage periods and relative ground cover are illustrated below.





The linear  $K_{cb}$  approximation curve is constructed by the following steps:

1. Divide the growing period into four general growth stages describing crop canopy development and phenology for a regional specific developmental crop calendar. The four stages are (1) Initial period (planting or green-up until about 10% ground cover); (2) Crop Development period; from 10% ground cover until about 70% ground cover and higher; (3) Mid Season period; from 70% ground cover to the beginning of the late season period (the onset of senescence); and (4) Late Season period (beginning of senescence or mid grain or fruit fill until harvest, crop death, frost-kill, or full senescence).
2. Specify the three  $K_{cb}$  values corresponding to  $K_{cb\ ini}$ ,  $K_{cb\ mid}$  and  $K_{cb\ end}$ , where  $K_{cb\ ini}$  represents the average  $K_{cb}$  during the initial period,  $K_{cb\ mid}$  represents the average  $K_{cb}$  during the mid-season period and  $K_{cb\ end}$  represents the  $K_{cb}$  at the end of the late season period.
3. Connect straight line segments through each of the four growth stage periods, with horizontal lines drawn through  $K_{cb\ ini}$  during the initial period and through  $K_{cb\ mid}$  during the mid-season period. Diagonal lines are drawn from  $K_{cb\ ini}$  to  $K_{cb\ mid}$  within the domain of the development period and from  $K_{cb\ mid}$  to  $K_{cb\ end}$  within the domain of the late season period.

### Numerical determination of $K_{cb}$

The  $K_{cb}$  coefficient for any period of the growing season can be derived by considering that during the initial and mid-season stages  $K_{cb}$  is constant and equal to the  $K_{cb}$  value of the growth stage under consideration. During the crop development and late season stage,  $K_{cb}$  varies linearly between the  $K_{cb}$  at the end of the previous stage ( $K_{cb\ prev}$ ) and the  $K_{cb}$  at the beginning of the next stage ( $K_{cb\ next}$ ), which in the case of the late season stage is  $K_{cb\ end}$ :

$$K_{cb\ i} = K_{cb\ prev} + \left[ \frac{i - \sum L_{prev}}{L_{stage}} \right] (K_{cb\ next} - K_{cb\ prev})$$

Where

- $i$  = day number within the growing season [1..length of the growing season],
- $K_{cb\ i}$  = crop coefficient on day  $i$ ,
- $L_{stage}$  = length of the stage under consideration [days],
- $\Sigma(L_{prev})$  = sum of the lengths of all previous stages [days].

Values for  $K_{cb\ i}$  and  $L_{stage}$  come from the [Crop Library](#).

## **$K_{cb}$ Curves for Forage Crops**

Many crops grown for forage or hay receive multiple harvests during the growing season. Each harvest essentially terminates a “sub” growing season and associated  $K_{cb}$  curve and initiates a new “sub” growing season and associated  $K_{cb}$  curve. The resulting  $K_{cb}$  curve for the entire growing season is the aggregation of a series of  $K_{cb}$  curves associated with each sub cycle.

## **The climatic correction of $K_{cb}$ values ( $K_{cb\ mid}$ and $K_{cb\ end}$ )**

The  $K_{cb\ mid}$  and  $K_{cb\ end}$  values are typical values expected under a standard climatic condition defined in FAO 56 as a sub-humid climate having average daytime minimum relative humidity ( $RH_{min} = 45\%$ ) and having calm to moderate wind speeds averaging 2 m/s. For specific adjustment in climates where  $RH_{min}$  and  $u_2$  are larger or smaller than the standard values, the  $K_{cb\ mid}$  as well as  $K_{cb\ end}$  values are adjusted as:

$$K_{cb} = K_{cb\ (lib)} + [0.04(u_2 - 2) - 0.004(RH_{min} - 45)] \left( \frac{h_{max}}{3} \right)^{0.3}$$

where

- $K_{cb}$  = the corrected value for  $K_{cb\ mid}$  or  $K_{cb\ end}$ ,
- $K_{cb\ (lib)}$  = value for  $K_{cb\ mid}$  or  $K_{cb\ end}$  taken from [Crop Library](#),
- $u_2$  = wind speed measured at 2 m height [m/s],
- $RH_{min}$  = minimum relative humidity [%],
- $h_{max}$  = maximum plant height [m]

Note:  $RH_{min}$  is used rather than  $RH_{mean}$  because it is easier to approximate  $RH_{min}$  from  $T_{max}$  where relative humidity data are unavailable.

## **Plant Height**

Plant height can be estimated as follows:

$$h_i = \frac{K_{cb\ i}}{K_{cb\ mid}} h_{max}$$

where

- $i$  = day number within the growing season [1..length of the growing season],
- $h_i$  = height of the crop on day  $i$  [m],
- $K_{cb\ i}$  = crop coefficient on day  $i$ ,
- $K_{cb\ mid}$  = corrected value of the  $K_{cb\ mid}$ ,
- $h_{max}$  = maximum crop height [m].

## Evaporation Coefficient (K<sub>e</sub>)

The MABIA method adopts the ‘dual’ K<sub>c</sub> method, where the K<sub>c</sub> value is divided into a ‘basal’ crop coefficient, K<sub>cb</sub>, and a separate component, K<sub>e</sub>, representing evaporation from the soil surface that is not under the crop canopy.

When the soil surface layer is wet, following rain or irrigation, K<sub>e</sub> is at some maximum rate where K<sub>cb</sub> + K<sub>e</sub> is limited by a maximum value K<sub>c max</sub>, and when the soil surface layer is dry, K<sub>e</sub> is small and can approach zero.

$$K_e = \min \left\{ \begin{array}{l} K_r(K_{c \max} - K_{cb}); \\ f_{ew} K_{c \max} \end{array} \right\}$$

where

K<sub>c max</sub> = the maximum value of K<sub>c</sub> following rain or irrigation,

K<sub>r</sub> = a dimensionless evaporation reduction coefficient (defined later) and is dependent on the cumulative depth of water depleted (evaporated), and

f<sub>ew</sub> = the fraction of the soil that is both exposed to solar radiation and that is wetted.

The evaporation rate is restricted by the estimated amount of energy available at the exposed soil fraction, i.e., K<sub>e</sub> cannot exceed f<sub>ew</sub> K<sub>c max</sub>

The calculation procedure consists in determining:

- The upper limit K<sub>c max</sub>;
- The soil evaporation reduction coefficient K<sub>r</sub>; and
- The exposed and wetted soil fraction f<sub>ew</sub>.

### Upper limit (K<sub>c max</sub>)

$$K_{c \max} = \max \left\{ \frac{1.2 + [0.04(u_2 - 2) - 0.004(RH_{\min} - 45)] \left(\frac{h}{3}\right)^{0.3}}{K_{cb} + 0.05} \right\};$$

where

u<sub>2</sub> = wind speed measured at 2 m height [m/s],

RH<sub>min</sub> = minimum relative humidity [%],

h = plant height during the current day [m]

This Equation ensures that K<sub>c max</sub> is always greater than or equal to the sum K<sub>cb</sub> + 0.05, suggesting that wet soil increases the K<sub>c</sub> value above K<sub>cb</sub> by 0.05 following complete wetting of the soil surface, even during periods of full ground cover.

### Soil evaporation reduction coefficient (K<sub>r</sub>)

Soil evaporation from the exposed soil can be assumed to take place in two stages: an energy limiting stage, and a falling rate stage. When the soil surface is wet, K<sub>r</sub> is 1. When the water content in the upper soil becomes limiting, K<sub>r</sub> decreases. K<sub>r</sub> becomes zero when the total amount of water that can be evaporated (TEW) from the topsoil is depleted. Readily evaporable water (REW) is the water content that can be evaporated in the first stage (energy limiting).

The amount of water that can be removed by evaporation during a complete drying cycle is estimated as:

$$TEW = 10 (\theta_{FC} - 0.5 \theta_{WP}) Z_e$$

where

TEW = total evaporable water, the maximum depth of water that can be evaporated from the surface soil layer assuming that the soil was completely wetted [mm],

$\theta_{FC}$  = field capacity [% vol]

$\theta_{WP}$  = wilt point [% vol]

$Z_e$  = the effective depth of the surface soil subject to drying to 0.5  $\theta_{WP}$  by way of evaporation [m].

$Z_e$  is an empirical value based on observation. Some evaporation or soil drying will be observed to occur below the  $Z_e$  depth. A fixed value of 0.08 m is used in the MABIA method.

The readily evaporable water (REW), which is the maximum depth of water that can be evaporated from the topsoil layer without restriction, is defined as:

$$REW = (3.121 TEW + 22.896) Z_e$$

The  $K_r$  coefficient is calculated as:

$$K_r = \begin{cases} 1.0, & \text{for } D_{e,i-1} \leq REW \\ \frac{TEW - D_{e,i-1}}{TEW - REW}, & \text{for } D_{e,i-1} > REW \end{cases}$$

where

$D_{e,i-1}$  = cumulative depletion from the soil surface layer at the end of day i-1 (the previous day) [mm],

TEW = total evaporable water [mm],

REW = readily evaporable water [mm]

Evaporation from the soil beneath the crop canopy, occurring at a slower rate, is assumed included in the basal  $K_{cb}$  coefficient.

### Exposed and wetted soil fraction ( $f_{ew}$ )

$$f_{ew} = \min \left\{ \frac{1 - f_c}{f_w} \right\}$$

where

$f_w$  = fraction of the surface wetted by irrigation and/or precipitation,

$f_c$  = fraction of soil surface effectively covered by vegetation

$f_w$  defines the potential spatial extent of evaporation. Common values for  $f_w$  are listed in lookup tables. When the soil surface is completely wetted, as by precipitation or sprinkler irrigation,  $f_{ew}$  is set equal to (1 -  $f_c$ ). For irrigation systems where only a fraction of the ground surface ( $f_w$ ) is wetted,  $f_{ew}$  is limited to  $f_w$ .

Both (1 -  $f_c$ ) and  $f_w$ , for numerical stability, have limits of [0.01-1]. In the case of drip irrigation, Allen et al. (1998) suggest that where the majority of soil wetted by irrigation is beneath the crop canopy and is shaded,  $f_w$  be reduced to about one-half to one-third of that given in lookup tables. Their general recommendation for drip irrigation is to multiply  $f_w$  by [1 - (2/3)  $f_c$ ].

### Soil fraction covered by vegetation ( $f_c$ )

The value for  $f_c$  ranges between 0 and 0.99 for numerical stability and is generally determined by visual observation. For purposes of estimating  $f_{ew}$ ,  $f_c$  can be estimated from  $K_{cb}$  as:

$$f_c = \left( \frac{K_{cb} - K_{c \min}}{K_{c \max} - K_{c \min}} \right)^{(1+0.5h)}$$

where

$K_{c \min}$  = the minimum  $K_c$  for dry bare soil with no ground cover,

$h$  = plant height during the current day [m].

The difference  $K_{cb} - K_{c \min}$  is limited to  $\geq 0.01$  for numerical stability. The value for  $f_c$  will change daily as  $K_{cb}$  changes.  $K_{c \min}$  ordinarily has the same value as  $K_{cb \min}$  used for annual crops under nearly bare soil conditions (i.e.,  $K_{c \min} = 0.15$ ). However,  $K_{c \min}$  is set to 0 or nearly zero under conditions with large time periods between wetting events, for example in applications with natural vegetation in deserts. The value for  $f_c$  decreases during the late season period in proportion to  $K_{cb}$  to account for local transport of sensible heat from senescing leaves to the soil surface.

### Fraction Wetted ( $f_w$ )

If the most recent wetting event is irrigation,  $f_w = f_{w \text{ irr}}$ , which is [entered as data](#). If the most recent wetting event is precipitation,  $f_w = 1$ .

### Water Balance of the Soil Surface Layer

Estimation of  $K_c$  requires a daily water balance for the  $f_{ew}$  fraction of the surface soil layer. The daily soil water balance equation is:

$$D_{s,i} = D_{s,i-1} - (P_i - RO_i) - \frac{I_i}{f_w} + \frac{E_i}{f_{ew}} + T_{s,i} + DP_{s,i}$$

where

$D_{e,i-1}$  and  $D_{e,i}$  = cumulative depletion depth at the ends of days  $i-1$  and  $i$  [mm],

$P_i$  and  $RO_i$  = precipitation and precipitation runoff from the soil surface on day  $i$  [mm],

$I_i$  = the irrigation depth on day  $i$  that infiltrates the soil [mm],

$E_i$  = evaporation on day  $i$  (i.e.,  $E_i = K_e ETo$ ) [mm],

$T_{e,i}$  = the depth of transpiration from the exposed and wetted fraction of the soil surface layer on day  $i$  [mm],

$DP_{e,i}$  = the deep percolation from the  $f_{ew}$  fraction of the soil surface layer on day  $i$  if soil water content exceeds field capacity [mm].

Assuming that the surface layer is at field capacity following heavy rain or irrigation, the minimum value for  $D_{e,i}$  is zero. The limits imposed on  $D_{e,i}$  are consequently  $0 \leq D_{e,i} \leq TEW$ . It is recognized that water content of the soil surface layer can exceed TEW for short periods of time while drainage is occurring. However, because the length of time that this occurs varies with soil texture, wetting depth, and tillage,  $D_{e,i} \geq 0$  is assumed. The irrigation depth  $I_i$  is divided by  $f_w$  to approximate the infiltration depth to the  $f_w$  portion of the soil surface. Similarly,  $E_i$  is divided by  $f_{ew}$  because it is assumed that all  $E_i$  (other than residual evaporation implicit to the  $K_{cb}$  coefficient) is taken from the  $f_{ew}$  fraction of the surface layer.

The amount of transpiration extracted from the  $f_{ew}$  fraction of the evaporating soil layer is generally a small fraction of total transpiration, and is generally ignored ( $T_{e,i} = 0$ ).  $DP_{e,i}$  is not to be confused with deep percolation from the root zone.

## Effective Precipitation

Many factors influence how much precipitation can infiltrate the soil and be available for evapotranspiration (so-called "effective" precipitation), including rainfall rate, terrain slope, and soil type and compaction. Any precipitation which is not available for ET will become surface runoff.

$$RO_i = \text{Min}(MIR, P_i (1 - EP))$$

where

MIR = water depth that can infiltrate over a 24 hour period [mm/day],

EP = effective precipitation rate [%],

$P_i$  and  $RO_i$  = precipitation and precipitation runoff from the soil surface on day  $i$  [mm],

## Potential and Actual Crop Evapotranspiration ( $ET_c$ and $ET_a$ )

### Potential Crop Evapotranspiration ( $ET_c$ )

The potential crop evapotranspiration under standard field conditions is calculated as follows:

$$ET_c = (K_{cb} + K_e) ET_{ref}$$

### Actual Crop evapotranspiration ( $ET_a$ )

Precipitation and irrigation amounts are often not sufficient to supply the full  $ET_c$  requirement. In these situations, soil water content in the root zone is reduced to levels too low to permit plant roots to extract the full  $ET_c$  amount. Under these conditions, water stress is said to occur, and  $ET_a$  is less than  $ET_c$ . The reduction in  $ET_a$  can be estimated using a daily soil water balance, as follows. When field-specific estimates of  $ET_a$  are needed, they can be estimated by:

$$ET_a = K_{act} ET_{ref}$$

where

$K_{act}$  = actual  $K_c$  value =  $K_s K_{cb} + K_e$ .

The stress coefficient,  $K_s$  is estimated as:

$$K_s = \begin{cases} 1, & D_r \leq RAW \\ \frac{TAW - D_r}{TAW - RAW} = \frac{TAW - D_r}{(1-p)TAW}, & D_r > RAW \end{cases}$$

where

$D_r$  = root zone depletion, defined as the water shortage relative to field capacity [mm],

RAW = 'readily' available water [mm],

TAW = total available soil water in the root zone [mm],

$p$  = depletion factor, the fraction of TAW that a crop can extract from the root zone without suffering water stress [0..1].

When  $D_r \leq RAW$ ,  $K_s = 1$ . At field capacity,  $D_r = 0$ . The degree of stress is presumed to progressively increase as  $D_r$  increases past RAW, the depth of readily available water in the root zone. The value for  $p$  varies by crop and crop growth stage, and typically ranges from about 0.4 for shallow-rooted crops to 0.6 for deep rooted crops. The [Crop Library](#) includes values for  $p$  ("depletion factor").

TAW is estimated as the difference between the water content at field capacity and wilting point (% vol):

$$TAW = 10(\theta_{FC} - \theta_{WP})Z_r$$

where

$Z_r$  = effective rooting depth [m]

For crop stage 1,  $Z_r = Z_{r \min}$  For crop stages 3 and 4,  $Z_r = Z_{r \max}$  For crop stage 2,  $Z_r$  is estimated as:

$$Z_r = \frac{K_{cb \ i} - K_{cb \ ini}}{K_{cb \ mid} - K_{cb \ ini}} (Z_{r \ max} - Z_{r \ min}) + Z_{r \ min}$$

where

$Z_{r \ min}$  = minimum rooting depth for crop [m]

$Z_{r \ max}$  = maximum rooting depth for crop [m]

RAW is estimated as:

$$RAW = p \ TAW$$

The calculation of  $K_s$  requires a daily water balance computation for the root zone.

### Water Balance of the Root Zone

A daily water balance, expressed in terms of depletion at the end of the day, is:

$$D_{r,i} = D_{r,i-1} - P_i + RO_i - I_i - CR_i + ET_{a,i} + SR_i + DP_i$$

where

$D_{r,i}$  = root zone depletion at the end of day i [mm]

$D_{r,i-1}$  = depletion in the root zone at the end of the previous day, i-1 [mm]

$P_i$  = precipitation on day i [mm], limited by maximum daily infiltration rate [mm]

$RO_i$  = surface runoff from the soil surface on day i [mm]

$I_i$  = net irrigation depth on day i that infiltrates the soil [mm]

$CR_i$  = capillary rise from the groundwater table on day i [mm]

$ET_{a,i}$  = actual crop evapotranspiration on day i [mm]

$DP_i$  = water flux out of the root zone by deep percolation on day i [mm]

The capillary rise,  $CR_i$ , can normally be assumed to be zero when the water table is more than about 1 m below the bottom of the root zone. Although following heavy rain or irrigation, soil water content might temporally exceed field capacity, the total amount of water exceeding field capacity is assumed to be lost the same day via deep percolation or surface runoff, following any  $ET_a$  for that day. This does permit the extraction of one day's  $ET_a$  from this excess before percolation. The root zone depletion will gradually increase as a result of  $ET_a$ . In the absence of a wetting event, the root zone depletion will reach the value TAW. At that moment no water is left for  $ET_a$ , and  $K_s$  and  $ET_a$  become zero.

Following heavy rain or irrigation, the soil water content in the root zone may exceed field capacity or even saturation. The amount above saturation goes to surface runoff, whereas the amount between field capacity and saturation goes to deep percolation within the same day of a wetting event, and depletion  $D_{r,i}$  becomes zero. As long as the soil water content in the root zone is below field capacity (i.e.,  $D_{r,i} > 0$ ), the soil is assumed to not drain and  $DP_i = 0$  and  $RO_i = 0$ . The  $DP_i$  term is not to be confused with the  $DP_{e,i}$  term used for the evaporation layer. Both terms can be calculated at the same time, but are independent of one another.

### Irrigation

Irrigation is required when rainfall is insufficient to compensate for the water lost by evapotranspiration. The primary objective of irrigation is to apply water at the right period and in the right amount. By



calculating the soil water balance of the root zone on a daily basis, the timing and the depth of future irrigation can be planned. To avoid crop water stress, irrigation should be applied before or at the moment when the readily available soil water is depleted ( $D_{r,i} \leq \text{RAW}$ ).

An irrigation schedule specifies the timing (which day) and amount (depth) of irrigation. Each crop can have many different schedules for non-overlapping periods of the crop season. For example, you may want to irrigate more frequently during the sensitive flowering and yield formation stages. If a branch has more than one crop in rotation, you can specify the irrigation schedules for all crops. Use the [Irrigation Scheduling Wizard](#) to help you fill in the parameters for the [IrrigationSchedule](#) function.

There are various methods available to determine both the timing and amount of irrigation.

## Irrigation Timing (Trigger)

There are four methods for determining on which days irrigation will occur:

- Fixed Interval: Irrigate every N days, where N is specified in the IrrigationTriggerValue.
- % of RAW: Irrigate when soil moisture depletion is greater than or equal to a specified % of Readily Available Water (RAW). To prevent crop water stress, depletion should never exceed RAW.
- % of TAW: Irrigate when soil moisture depletion is greater than or equal to a specified % of Total Available Water (TAW). To prevent crop death (permanent wilt point), depletion should never equal or exceed TAW.
- Fixed Depletion: Irrigate when soil moisture depletion is equal to or exceeds a specified depth (in mm).

## Irrigation Amount

There are four methods for determining how much water to apply on days when irrigation occurs:

- % Depletion: Apply a specified % of the current soil water depletion.
- % of RAW: Apply a specified % of the Readily Available Water (RAW) level, regardless of the current soil water depletion.
- % of TAW: Apply a specified % of the Total Available Water (TAW) level, regardless of the current soil water depletion.
- Fixed Depth: Apply a specified depth of water. Note: the value entered should be the average depth of water applied to the entire area. If the fraction wetted ( $F_w$ ) < 1, then the amount actually delivered to the crop will be higher:  $I/F_w$ . For example, for a drip irrigation system with  $F_w=0.3$ , a fixed depth application of 10 mm of water would be mean that  $10/0.3 = 33.3$  mm of water was applied to that 30% of the land area, and would be available for ET by the crop.

The optimal irrigation schedule and amount would use % of RAW (100% of RAW) as the trigger method, and % of Depletion (100% of Depletion) as the irrigation amount method, which would apply irrigation at the last moment before crop stress would occur, and irrigate just enough to get back up to field capacity. However, in reality, it will be difficult for a farmer to know exactly when depletion reaches the RAW threshold

For the first three irrigation amount methods (% of Depletion, RAW or TAW), the amount calculated will be the actual amount delivered to the crop. If the fraction wetted ( $F_w$ ) < 1, then the average amount over the entire area will be less:  $I * F_w$ . For example, a drip irrigation system with  $F_w=0.3$ , a % of depletion amount method (100%), and a depletion of 40 mm would require an average depth of irrigation of  $40 * 0.3 = 12$  mm. For a 1 hectare plot of land, this would be  $1 \text{ ha} * 12 \text{ mm} = 120 \text{ m}^3$  of water. When the



## 7.2 Evapotranspiration, Runoff, Infiltration and Irrigation

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120 m<sup>3</sup> of water was applied to the 30% of the 1 hectare, the crop would receive 120 m<sup>3</sup> / (30% \* 1 ha) = 40mm.

If there are gaps in the irrigation dates between schedules, there will be no irrigation during those periods. There is no irrigation in the fallow periods (before or after the crop season).

### Irrigation Efficiency and Losses to Groundwater, Runoff and Evaporation

The irrigation amount is the amount available for evapotranspiration. If the irrigation efficiency is less than 100%, then the supply requirement for irrigation will be increased.

$$\text{Irrigation Supply Requirement} = \text{Irrigation Crop Requirement} / \text{Irrigation Efficiency}$$

For example, if the irrigation efficiency is 75% (which means that 25% is lost to evaporation, runoff or deep percolation) and the irrigation amount is 100% of depletion, and the depletion is 40mm, then the amount applied will be 40 / 0.75 = 53.3 mm, of which 40 mm will effectively reach the crop and be available for ET, and 13.3 will evaporate, runoff or percolate (as specified by Loss to Groundwater and Loss to Runoff fractions [entered as data](#)).

The Loss to Groundwater and Loss to Runoff fractions determine how much of the irrigation that is not available for evapotranspiration will infiltrate, runoff or evaporate.

$$\text{Irrigation Loss to Groundwater} = \text{Irrigation Supply Requirement} * (1 - \text{Irrigation Efficiency}) * \text{Loss to Groundwater}\%$$

$$\text{Irrigation Loss to Runoff} = \text{Irrigation Supply Requirement} * (1 - \text{Irrigation Efficiency}) * \text{Loss to Runoff}\%$$

$$\text{Irrigation Loss to Evaporation} = \text{Irrigation Supply Requirement} * (1 - \text{Irrigation Efficiency}) * (1 - \text{Loss to Groundwater}\% - \text{Loss to Runoff}\%)$$

See also: [MABIA Irrigation](#), [Irrigation Scheduling Wizard](#)

## Yield

### Yield Response to Water Shortage

Water is essential for crop production and best use of available water must be made for efficient crop production and high yields. This requires a proper understanding of the effect of water rainfall and/or irrigation on crop growth and yield under different growing conditions.

For application in planning, design and operation of irrigation schemes, it is possible to analyze the effect of water supply on crop yields. Water deficits in crops, and the resulting water stress on the plant, have an effect on crop evapotranspiration and crop yield. The relationship between crop yield and water supply can be determined when crop water requirements and actual crop water use, on the one hand, and maximum and actual crop yield on the other, can be quantified.

In the FAO 56 approach, the response of yield to water supply is quantified by the yield response factor ( $K_y$ ), which relates the relative yield decrease ( $1 - Y_a/Y_m$ ) to relative evapotranspiration deficit ( $1 - ET_a/ET_c$ ). Hence, the  $K_y$  values for most crops are derived on the assumption that the relationship between relative yield ( $Y_a/Y_m$ ) and relative evapotranspiration ( $ET_a/ET_c$ ) is linear and is valid for water deficits of up to about 50% or  $1 - ET_a/ET_c = 0.5$ .

In field conditions, water deficit of a given magnitude, expressed in the ratio of actual crop evapotranspiration ( $ET_a$ ) to potential crop evapotranspiration ( $ET_c$ ), may either occur continuously over the total growing period of the crop or it may occur during any stage of the individual growth periods.

[FAO Irrigation and Drainage Paper No. 33](#) empirically derived yield-response factors ( $K_y$ ) for individual growth stages (i.e. establishment, vegetative, flowering, yield formation, or ripening period) as well as for the total growing period. These factors are yield response factors for water stress in specified physiological growth stage (i) and over the total growing period of crops, and are given by:

$$\left(1 - \frac{Y_a}{Y_m}\right) = K_y \left(1 - \frac{ET_a}{ET_c}\right)$$

where

$Y_a$  = actual yield (corresponding to  $ET_a$ ) [kg/ha]

$Y_m$  = maximum theoretical yield (corresponding to  $ET_c$ ) [kg/ha]

$ET_a$  = actual crop evapotranspiration

$ET_c$  = potential crop evapotranspiration

$K_y$  = yield response factor to water stress, which comes from the [Crop Library](#).

$Y_a/Y_m$  is the relative yield fraction. Solving for  $Y_a/Y_m$ :

$$\frac{Y_a}{Y_m} = \left(1 - K_y \left(1 - \frac{ET_a}{ET_c}\right)\right)$$

However, if water stress cannot be considered as constant throughout the growing period but occurs with different magnitude at different periods of the growing season, the expected total relative yield fraction should be calculated at a smaller timestep and aggregated for the season. In the MABIA method, relative yield fractions will be calculated on a daily timestep, and the multiplicative product of the yield fractions from all days will be used as the relative yield fraction for the season. (For details and justification for this approach, see Dirk Raes, Sam Geerts, Emmanuel Kipkorir, Joost Wellens, and Ali Sahli, [Simulation of yield decline as a result of water stress with a robust soil water balance model](#), *Agricultural Water Management*, 81: 335-357, 2006.)

$$1 - K_y \left(1 - \frac{ET_a}{ET_c}\right) = \prod_{i=1}^N \left[1 - K_{y,s} \left(1 - \frac{ET_{a,i}}{ET_{c,i}}\right)\right]^{1/L_s}$$

where

$\Pi$  indicates the product of the N terms within the square brackets,

N = length of the growing season [days]

i = day number within the growing season [1..N]

s = crop stage corresponding to day i [1-4]

$K_{y,s}$  = yield-response factor for crop stage s, from the Crop Library

$L_s$  = length of crop stage s

$ET_{a,i}$  = actual evapotranspiration at day i

$ET_{c,i}$  = potential evapotranspiration at day i.

To obtain the actual yield, multiply the seasonal relative yield fraction by the maximum theoretical yield:

$$Y_a = Y_m \left(1 - K_y \left(1 - \frac{ET_a}{ET_c}\right)\right)$$

## Market Value

$$\text{Market Value} = Y_a * \text{Area} * \text{Price}$$

where

Market Value = Total market value for crop [\$]

$Y_a$  = actual yield [kg/ha]

Area = cultivated area [ha]

Price = unit market price for crop [\$/kg]

## 7.3 Inflows and Outflows of Water

This step computes water inflows to and outflows from every node and link in the system for a given month. This includes calculating withdrawals from supply sources to meet demand. A linear program (LP) is used to maximize satisfaction of requirements for demand sites, user-specified instream flows, and hydropower generation, subject to demand priorities, supply preferences, mass balance and other constraints. The LP solves the set of simultaneous equations explained below. For details of how demand priorities and supply preferences affect calculations, see [Priorities for Water Allocation](#).

Mass balance equations are the foundation of WEAP's monthly water accounting: total inflows equal total outflows, net of any change in storage (in reservoirs, aquifers and catchment soil moisture). Every node and link in WEAP has a mass balance equation, and some have additional equations which constrain their flows (e.g., inflow to a demand site cannot exceed its supply requirement, outflows from an aquifer cannot exceed its maximum withdrawal, link losses are a fraction of flow, etc.).

### 7.3.1 Inflows and Outflows of Water

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### 7.3.2 Demand Site Flows

The amount supplied to a demand site ( $DS$ ) is the sum of the inflows from its transmission links. (The inflow to the demand site from a supply source ( $Src$ ) is defined as the outflow from the transmission link connecting them, i.e., net of any leakage along the transmission link).

$$DemandSiteInflow_{DS} = \sum_{Src} TransLinkOutflow_{Src,DS}$$

Every demand site has a monthly supply requirement for water, as computed in [Demand Calculations](#). The inflow to the demand site equals this requirement, unless there are water shortages due to hydrological, physical, contractual or other constraints.

$$DemandSiteInflow_{DS} \leq SupplyRequirement_{DS}$$

Some fraction of the water received by a demand site will be unavailable for use elsewhere in the system (i.e., because the water is consumed--lost to evaporation, embodied in products, or otherwise unaccounted for--it disappears from the system.) This consumption fraction is entered as data.

$$Consumption_{DS} = DemandSiteInflow_{DS} \times DemandSiteConsumption_{DS}$$

Of the inflow that is not consumed, the remainder flows out of the demand site, either to another demand site for reuse, to a wastewater treatment plant for treatment, or to surface or groundwater. Any demand sites directly reusing this outflow will take what they need. The remainder is sent to the various return flow destinations. (These return flow routing fractions are entered as data--see [Supply and Resources\Return Flows\Routing](#).)

$$DemandSiteReuseOutflow_{DS1} = \sum TransLinkOutflow_{DS1,DS2}$$

$$DemandSiteReturnFlow_{DS} = DemandSiteInflow_{DS} - Consumption_{DS} - DemandSiteReuseOutflow_{DS}$$

### 7.3.3 Transmission Link Flows

In a transmission link from a supply source (*Src*) to a demand site (*DS*), the amount delivered to the demand site (i.e., the outflow from the transmission link) equals the amount withdrawn from the source (i.e., the inflow to the transmission link) minus any losses along the link.

$$TransLinkOutflow_{Src,DS} = TransLinkInflow_{Src,DS} - TransLinkLoss_{Src,DS}$$

The losses in the transmission link are a fraction of its inflow, where the loss rates are entered as data (see [Supply and Resources\Transmission Links\Transmission Losses](#)).

$$TransLinkLoss_{Src,DS} = ( TransLinkLossFromSystem_{Src,DS} + TransLinkLossToGroundwater_{Src,DS} ) \times TransLinkInflow_{Src,DS}$$

You may set constraints to model the physical, contractual or other limits on the flow from a source to a demand site, using one of two types of constraints. One type of constraint is a fixed upper bound (*MaximumFlowVolume*) on the amount of water flowing into the link. For example, this might represent a pipeline capacity, or a contractually limited allotment.

$$TransLinkInflow_{Src,DS} \leq MaximumFlowVolume_{Src,DS}$$

The other type of constraint allow you to set the maximum fraction (*MaximumFlowPercent*) of the demand site's supply requirement that can be satisfied from a particular source. Both of these constraints are entered as data (see [Supply and Resources\Transmission Links\Linking Rules](#)).

$$TransLinkOutflow_{Src,DS} \leq MaximumFlowPercent_{Src,DS} \times SupplyRequirement_{DS}$$

### 7.3.4 Demand Site Return Link Flows

Demand site return flow links transmit wastewater from demand sites (*DS*) to destinations (*Dest*), which may be either wastewater treatment plants or receiving bodies of water. The amount that flows into the link is a fraction of demand site return flow (outflow minus the flow to demand sites for reuse).

$$DSReturnLinkInflow_{DS,Dest} = DSReturnFlowRoutingFraction_{DS,Dest} \times DemandSiteReturnFlow_{DS}$$

The amount that reaches the destination (i.e., the outflow from the link) equals the outflow from the demand site (i.e., the inflow to the link) minus any losses along the link.

$$DSReturnLinkOutflow_{DS,Dest} = DSReturnLinkInflow_{DS,Dest} - DSReturnLinkLoss_{DS,Dest}$$

### 7.3 Inflows and Outflows of Water

The losses along the link are a fraction of its inflow, where the loss rates, both from the system and to a named groundwater node, are entered as data (see [Supply and Resources\Return Flows\Losses](#)).

$$DSReturnLinkLoss_{DS, Dest} = ( DSReturnLinkLossFromSystem_{DS, Dest} + DSReturnLinkLossToGroundwater_{DS, Dest} ) \times DSReturnLinkInflow_{DS, Dest}$$

#### 7.3.5 Wastewater Treatment Plant Flows

A wastewater treatment plant (TP) receives wastewater inflows from one or more demand sites (DS) and stormwater from one or more catchments (Catch). (The inflow to the treatment plant from a demand site is defined as the outflow from the return flow link connecting them, from a catchment as the outflow from the runoff link connecting them.)

$$TreatmentPlantInflow_{TP} = \sum_{DS} DSReturnLinkOutflow_{DS, TP} + \sum_{Catch} CatchmentRunoffLinkOutflow_{Catch, TP}$$

If the inflow exceeds the plant's capacity, then the excess will overflow untreated.

$$FractionTreated_{TP} = Minimum( 1, TreatmentPlantCapacity_{TP} / TreatmentPlantInflow_{TP} )$$

The treatment plant treats wastewater inflows, removes a fraction of the pollution, then returns the treated effluent to one or more receiving bodies of water (Dest), less any water lost in processing. (See Pollution Calculations for details on the generation, treatment and flow of pollution.)

$$\sum_{Dest} TPReturnLinkInflow_{TP, Dest} = TreatmentPlantInflow_{TP} - TreatmentLoss_{TP}$$

The amount consumed in processing, which disappears from the system, is assumed to be a fraction of the water received by the treatment plant. This consumption fraction is entered as data

$$Consumption_{TP} = TreatmentPlantInflow_{TP} \times TreatmentPlanConsumption_{TP}$$

Of the inflow that is not consumed, the remainder flows out of the treatment plant, either to demand sites or catchments for reuse, or to surface or groundwater.

$$TreatmentPlantOutflow_{TP} = TreatmentPlantInflow_{TP} - Consumption_{TP}$$

Any demand sites or catchments directly reusing this outflow will take what they need. The remainder is sent to the various return flow destinations. (These return flow routing fractions are entered as data--see [Supply and Resources\Return Flows\Routing](#).)

$$TreatmentPlantReuseOutflow_{TP} = \sum TransLinkOutflow_{TP, DS}$$
$$TreatmentPlantReturnFlow_{TP} = TreatmentPlantOutflow_{TP} - TreatmentPlantReuseOutflow_{TP}$$

#### 7.3.6 Wastewater Treatment Plant Return Link Flows

The treatment plant return links transmit treated wastewater from treatment plants (TP) to surface and groundwater (Dest). (Outflow to demand sites for reuse flows through transmission links, not return flow links.) The amount that flows into the link is a fraction of treatment plant return flow (outflow minus the flow to demand sites for reuse).

$$TPReturnLinkInflow_{TP, Dest} = TPReturnFlowRoutingFraction_{TP, Dest} \times TreatmentPlantReturnFlow_{TP}$$

The amount that reaches the destination (i.e., the outflow from the link) equals the outflow from the treatment plant (i.e., the inflow to the link) minus any losses along the link.

$$TPReturnLinkOutflow_{TP, Dest} = TPReturnLinkInflow_{TP, Dest} - TPReturnLinkLoss_{TP, Dest}$$

The losses along the link are a fraction of its inflow, where the loss rates is entered as data (see [Supply and Resources\Return Flows\Losses](#)).

$$TPReturnLinkLoss_{TP, Dest} = ( TPReturnLinkLossFromSystem_{TP, Dest} + TPReturnLinkLossToGroundwater_{TP, Dest} ) \times TPReturnLinkInflow_{TP, Dest}$$

### 7.3.7 Groundwater Flows

A groundwater node's (GW) storage in the first month ( $m$ ) of the simulation is specified as data (see [Supply and Resources\Groundwater\Initial Storage](#)).

$$BeginMonthStorage_{GW, m} = InitialStorage_{GW} \text{ for } m = 1$$

Thereafter, it begins each month with the storage from the end of the previous month.

$$BeginMonthStorage_{GW, m} = EndMonthStorage_{GW, m-1} \text{ for } m > 1$$

The storage at the end of the month equals the storage at the beginning plus inflows from natural recharge (entered as data: [Supply and Resources\Groundwater\Natural Recharge](#)), demand site (DS) and treatment plant (TP) [return flows](#), [transmission losses](#) and [return flow losses](#) to groundwater, [reservoir losses to groundwater](#) (Res), [river tailflow into groundwater](#), and [subsurface flow from river reaches](#) (Rch), minus [withdrawals by demand sites](#), [subsurface flow to river reaches](#) and groundwater overflow (net inflow. In addition, if [linking to MODFLOW](#), there will be subsurface inflows from and outflows to other groundwater nodes.

$$\begin{aligned} EndMonthStorage_{GW} = & BeginMonthStorage_{GW} + NaturalRecharge_{GW} + \sum_{DS} DSReturnFlow_{DS, GW} + \\ & \sum_{TP} TPReturnFlow_{TP, GW} + \sum_{DS} DSTransLinkLossToGroundwater_{DS, GW} + \\ & \sum_{DS} DSReturnFlowLinkLossToGroundwater_{DS, GW} + \sum_{TP} TPReturnFlowLinkLossToGroundwater_{TP, GW} + \\ & \sum_{Res} ReservoirLossToGroundwater_{Res, GW} + \sum_{River} RiverTailflowIntoGroundwater_{River, GW} + \\ & \sum_{Rch} ReachFlowToGroundwater_{Rch, GW} + \sum_{Src} OtherGroundwaterFlowToGroundwater_{Src, GW} - \\ & \sum_{DS} DSTransLinkInflow_{GW, DS} - GroundwaterFlowToReach_{GW, Rch} - \\ & \sum_{Dest} GroundwaterFlowToOtherGroundwater_{GW, Dest} \end{aligned}$$

The  $EndMonthStorage$  cannot exceed the groundwater node's [storage capacity](#). Any excess will overflow, and be lost from the system. (If no data is entered for storage capacity, the capacity is unlimited and there cannot be any overflow.)

$$\begin{aligned} & \text{IF } EndMonthStorage_{GW} > StorageCapacity_{GW} \text{ THEN} \\ & \quad Overflow_{GW} = EndMonthStorage_{GW} - StorageCapacity_{GW} \\ & \quad EndMonthStorage_{GW} = StorageCapacity_{GW} \\ & \text{ELSE} \\ & \quad Overflow_{GW} = 0 \end{aligned}$$

## 7.3 Inflows and Outflows of Water

The amount withdrawn from the aquifer to satisfy demand requirements is determined in the context of all other demands and supplies in the system. The maximum withdrawals from an aquifer can be set (see [Supply and Resources\Groundwater\Maximum Withdrawal](#)), to model the monthly pumping capacity of the well or other characteristics of the aquifer that could limit withdrawals.

$$\sum_{DS} TransLinkInflow_{GW,DS} \leq MaximumGroundwaterWithdrawal_{GW}$$

### 7.3.8 River

## River Headflow

Headflow is defined as the flow into the first reach (*Rch*) of a river (*River*), and is entered as data (see [Supply and Resources\River\Headflow](#)).

$$UpstreamInflow_{Rch} = RiverHeadflow_{River}$$

## Reach Flows

The inflow to a reach (*Rch*) from upstream (other than the first reach) is defined as the amount flowing downstream from the node (*Node*) immediately above the reach.

$$UpstreamInflow_{Rch} = DownstreamOutflow_{Node}$$

The flow out of a reach into the downstream node equals the flow into the reach from upstream plus surface water runoff and groundwater inflows to the reach minus evaporation and outflow to groundwater (inflows from runoff and groundwater are entered directly--see [Supply and Resources\River\Reaches](#)). This downstream outflow from the reach will become the upstream inflow to the node immediately below the reach (or the outflow from the river as a whole if there are no more nodes downstream of the reach).

$$DownstreamOutflow_{Rch} = UpstreamInflow_{Rch} + SurfaceWaterInflow_{Rch} + \\ GroundwaterFlowToReach_{GW,Rch} - ReachFlowToGroundwater_{GW,Rch} - Evaporation_{Rch}$$

Outflows to groundwater are a fraction (entered as data--see [Supply and Resources\River\Reaches](#)) of upstream inflows to the reach.

$$ReachFlowToGroundwater_{Rch} = ReachFlowToGroundwaterFraction_{Rch} \times UpstreamInflow_{Rch}$$

Evaporation is calculated as a fraction (entered as data--see [Supply and Resources\River\Reaches](#)) of upstream inflow to the reach.

$$Evaporation_{Rch} = EvaporationFraction_{Rch} \times UpstreamInflow_{Rch}$$

## River Reservoir Flows

A reservoir's (*Res*) storage in the first month (*m*) of the simulation is specified as data (see [Supply and Resources\River\Reservoir\Storage](#)).

$$BeginMonthStorage_{Res,m} = InitialStorage_{Res} \text{ for } m = 1$$

Thereafter, it begins each month with the storage from the end of the previous month.

$$BeginMonthStorage_{Res,m} = EndMonthStorage_{Res,m-1} \text{ for } m > 1$$



This beginning storage level is adjusted for evaporation. Since the evaporation rate is specified as a change in elevation (see [Supply and Resources\River\Reservoir\Physical\Net Evaporation](#)), the storage level must be converted from a volume to an elevation. This is done by a simple linear interpretation between adjacent points on the volume-elevation curve (specified as data--see [Supply and Resources\River\Reservoir\Physical\Volume Elevation Curve](#)).

$$\text{BeginMonthElevation}_{Res} = \text{VolumeToElevation}(\text{BeginMonthStorage}_{Res})$$

The elevation is reduced by the evaporation rate.

$$\text{AdjustedBeginMonthElevation}_{Res} = \text{BeginMonthElevation}_{Res} - \text{EvaporationRate}_{Res}$$

Then the adjusted elevation is converted back to a volume.

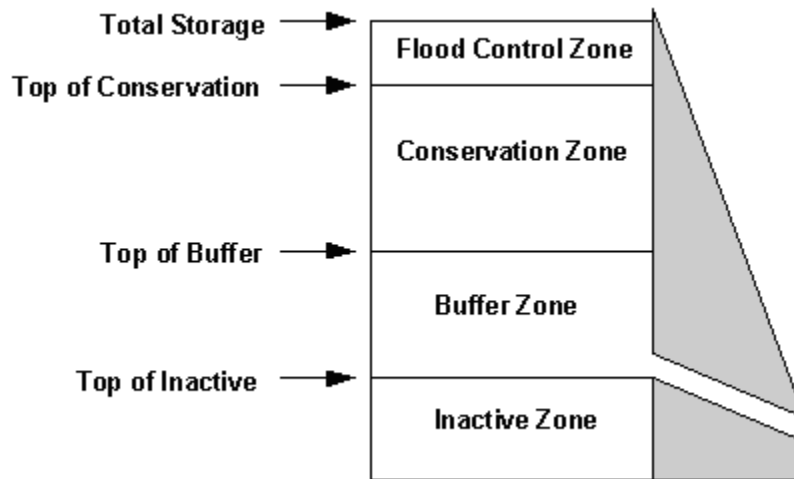
$$\text{AdjustedBeginMonthStorage}_{Res} = \text{ElevationToVolume}(\text{AdjustedBeginMonthElevation}_{Res})$$

A reservoir's operating rules determine how much water is available in a given month for release, to satisfy demand, instream flow and hydropower requirements, and for flood control. These rules operate on the available resource for the month. This "storage level for operation" is the adjusted amount at the beginning of the month, plus inflow from upstream, and demand site (DS) and treatment plant (TP) return flows that come in at that point.

$$\text{StorageForOperation}_{Res} = \text{AdjustedBeginMonthStorage}_{Res} + \text{UpstreamInflow}_{Res} + \sum_{DS} \text{DSReturnFlow}_{DS,Res} + \sum_{TP} \text{TPReturnFlow}_{TP,Res}$$

The amount available to be released from the reservoir is the full amount in the conservation and flood control zones and a fraction of the amount in the buffer zone (the buffer coefficient fraction is entered as data--see [Supply and Resources\River\Reservoir\Operation](#)). Each of these zones is given in terms of volume (i.e. not elevation). The water in the inactive zone is not available for release.

$$\text{StorageAvailableForRelease}_{Res} = \text{FloodControlAndConservationZoneStorage}_{Res} + \text{BufferCoefficient}_{Res} \times \text{BufferZoneStorage}_{Res}$$



All of the water in the flood control and conservation zones is available for release, and equals the amount above Top Of Buffer (TOB) and other reservoir zones levels are entered as data--see [Supply and Resources\River\Reservoir\Operation](#)),

$$\text{FloodControlAndConservationZoneStorage}_{Res} = \text{StorageForOperation}_{Res} - \text{TopOfBuffer}_{Res}$$

or zero if the level is below Top Of Buffer.



### 7.3 Inflows and Outflows of Water

$$FloodControlAndConservationZoneStorage_{Res} = 0$$

Buffer zone storage equals the total volume of the buffer zone if the level is above Top Of Buffer,

$$BufferZoneStorage_{Res} = TopOfBufferZone_{Res} - TopOfInactiveZone_{Res}$$

or the amount above Top Of Inactive if the level is below Top of Buffer,

$$BufferZoneStorage_{Res} = StorageForOperation_{Res} - TopOfInactiveZone_{Res}$$

or zero if the level is below Top Of Inactive.

$$BufferZoneStorage_{Res} = 0$$

WEAP will release only as much of the storage available for release as is needed to satisfy demand, instream flow and hydropower requirements, in the context of releases from other reservoirs and withdrawals from rivers and other sources. (As much as possible, the releases from multiple reservoirs with the same [reservoir filling priority](#) are adjusted so that each will have the same fraction of their conservation zone filled. For example, the conservation zone in a downstream reservoir will not be drained while an upstream reservoir remains full. Instead, each reservoir's conservation zone would be drained halfway. If, however, you would like to drain reservoir A before reservoir B, set reservoir A's priority lower than B's priority.)

$$Outflow_{Res} = DownstreamOutflow_{Res} + \sum_{DS} TransLinkInflow_{Res,DS}$$

where

$$Outflow_{Res} \leq StorageAvailableForRelease_{Res}$$

The storage at the end of the month is the storage for operation minus the outflow.

$$EndMonthStorage_{Res} = StorageForOperation_{Res} - Outflow_{Res}$$

The change in storage is the difference between the storage at the beginning and the end of the month. This is an increase if the ending storage is larger than the beginning, a decrease if the reverse is true.

$$IncreaseInStorage_{Res} = EndMonthStorage_{Res} - BeginMonthStorage_{Res}$$

## Run-of-River Hydropower Flows

A run-of-river hydropower facility (*ROR*) generates hydropower from a fixed head on the river (see [Hydropower Calculations](#) for details). It does not have any storage nor does it remove water from the river. The flow out of the facility equals the flow in from upstream, plus demand site (*DS*) and treatment plant (*TP*) return flows that come in at that point. (See [Hydropower Calculations](#) for details of hydropower generation.)

$$DownstreamOutflow_{ROR} = UpstreamInflow_{ROR} + \sum_{DS} DSReturnFlow_{DS,ROR} + \sum_{TP} TPReturnFlow_{TP,ROR}$$

## Minimum Flow Requirement Node Flows

A minimum instream flow requirement (*FR*), which is entered as data (see [Supply and Resources\River\Flow Requirement](#)), specifies a minimum flow required at a point on the river, to meet water quality, fish & wildlife, navigation, recreation, downstream or other requirements. Depending on its priority, a flow requirement will be satisfied either before, after or at the same time as other requirements

in the system. (The minimum flow is achieved either by restricting upstream withdrawals from the river or by releasing water from upstream reservoirs.) The flow out of the node equals the flow in from upstream, plus demand site (*DS*) and treatment plant (*TP*) return flows that come in at that point.

$$DownstreamOutflow_{FR} = UpstreamInflow_{FR} + \sum_{DS} DSReturnFlow_{DS,FR} + \sum_{TP} TPReturnFlow_{TP,FR}$$

## River Withdrawal Nodes Flows

Water is withdrawn from withdrawal nodes (*WN*) and delivered via transmission links to satisfy supply requirements at demand sites. The amount to withdraw, from zero up to the full supply requirement, is computed within the context of all demand and instream flow requirements, available supplies, demand priorities, supply preferences and other constraints. The downstream outflow from the withdrawal node equals the inflows from upstream, plus demand site (*DS*) and treatment plant (*TP*) return flows that come in at that point, minus the withdrawal to all connected demand sites.

$$DownstreamOutflow_{WN} = UpstreamInflow_{WN} + \sum_{DS} DSReturnFlow_{DS,WN} + \sum_{TP} TPReturnFlow_{TP,WN} - \sum_{DS} TransLinkInflow_{WN,DS}$$

## Diversion Node Flows

Diversion nodes (*DN*) withdraw water from a river (or another diversion), and this diverted flow becomes the headflow for a diversion. A diversion is modeled in WEAP as a separate river, complete with river nodes, demands and return flows. WEAP will divert only as much water as needed to satisfy the demand sites connected to the diversion, and its instream flow requirements. The downstream outflow from the diversion node equals the inflows from upstream, plus demand site (*DS*) and treatment plant (*TP*) return flows that come in at that point, minus the amount diverted.

$$DownstreamOutflow_{DN} = UpstreamInflow_{DN} + \sum_{DS} DSReturnFlow_{DS,DN} + \sum_{TP} TPReturnFlow_{TP,DN} - AmountDiverted_{DN}$$

## Return Flow Node Flows

Return flow nodes (*RFN*) are a point at which demand sites (*DS*) and treatment plants (*TP*) returns enter the river. The downstream outflow from the return flow node equals the inflows from upstream, plus demand site (*DS*) and treatment plant (*TP*) return flows that come in at that point.

$$DownstreamOutflow_{RFN} = UpstreamInflow_{RFN} + \sum_{DS} DSReturnFlow_{DS,RFN} + \sum_{TP} TPReturnFlow_{TP,RFN}$$

## Tributary Inflow Node Flows

A tributary inflow node (*TN*) is the point at which one or more rivers or diversions flow into another river or diversion. The downstream outflow from the tributary inflow node equals the inflows from upstream of the node on the main river plus the outflow from the last reach (*Rch*) on the tributary.

### 7.3 Inflows and Outflows of Water

$$DownstreamOutflow_{TN} = UpstreamInflow_{TN} + DownstreamOutflow_{Rch}$$

#### 7.3.9 Groundwater-Surface Water Interactions

In many watersheds, surface waters and groundwater are hydraulically connected. A stream can contribute to groundwater recharge (i.e., a losing stream) or can gain water from the aquifer (i.e., a gaining stream) depending on the level of groundwater in the aquifer. Groundwater levels respond to natural recharge from precipitation, but can also be influenced by irrigation in the watershed, where a portion of this water may recharge the aquifer rather than be taken up by the target crop. Pumping, of course, can draw down groundwater levels.

Of the [four options to simulate groundwater-surface water interactions](#), the following describes the option where WEAP models these interactions by using a groundwater "wedge" connected to the river.

To simulate groundwater interactions with surface waters, a stylized representation of the system can be used. Groundwater can be represented as a wedge that is symmetrical about the surface water body, such as a river; recharge and extraction from one side of the wedge will therefore represent half the total rate.

Total groundwater storage is first estimated using the assumption that the groundwater table is in equilibrium with the river; equilibrium storage for one side of the wedge,  $GS_e$ , can be given as,

$$GS_e = (h_d)(l_w)(A_d)(S_y)$$

where  $h_d$  (m) represents the distance that extends in a direction horizontally and at a right angle to the stream,  $l_w$  (m) is the wetted length of the aquifer in contact with the stream,  $S_y$  is the specific yield of the aquifer, and  $A_d$  is the aquifer depth at equilibrium. An estimate of the height above which the aquifer lies or is drawn below the equilibrium storage height is given by  $y_d$ , so the initial storage  $GS(0)$  in the aquifer at  $t=0$  is given as,

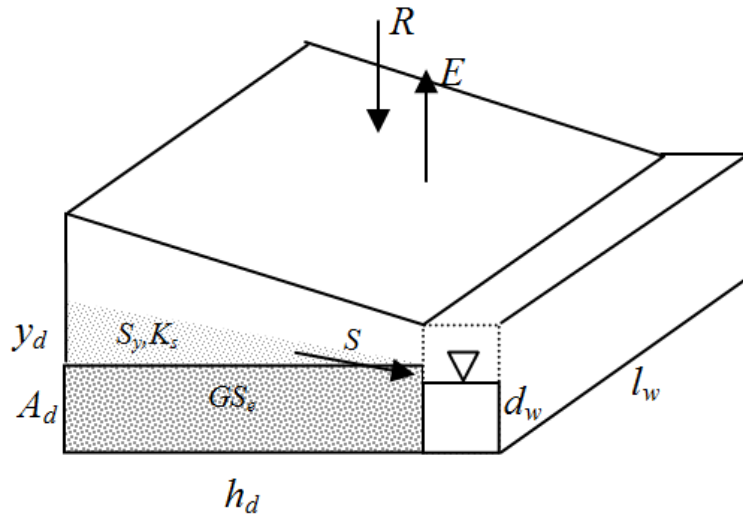
$$GS(0) = GS_e + (y_d)(h_d)(l_w)(S_y)$$

The vertical height of the aquifer above or below the equilibrium position is given as,

$$y_d = \frac{GS - GS_e}{(h_d)(l_w)(S_y)}$$

The more the water table rises relative to the stream channel, the greater the seepage becomes to the stream. The more the water table falls relative the stream channel, the greater the loss of water from the stream channel to the aquifer. Total seepage from both sides of the river ( $m^3/time$ ) is defined by,

$$S = 2 \left( K_s \frac{y_d}{h_d} \right) (l_w)(d_w)$$



where  $K_s$  (m/time) is an estimate of the saturated hydraulic conductivity of the aquifer and  $d_w$  is an estimate of the wetted depth of the stream, which is time invariant. The wetted depth, together with the wetted length, approximate the area through which the seepage takes place. The saturated hydraulic conductivity controls the rate at which water moves toward or away from this seepage area. Once seepage is estimated, the groundwater storage at the end of the current time step is estimated as,

$$GS_{(i)} = GS_{(i-1)} + 0.5(R - E - S)$$

where  $E$  is the anthropogenic extraction from the aquifer that is associated with meeting water demand and  $R$  is recharge from precipitation.

### 7.3.10 Local Supply

## Local Reservoir Flows

Local reservoirs are identical to river reservoirs, except that they are not located along a river, tributary or diversion and therefore do not have inflow from these sources. All other properties of the local reservoir calculations are the same as river reservoirs. In detail, a local reservoir's ( $Res$ ) storage in the first month ( $m$ ) of the simulation is specified as data (see [Supply and Resources\Local Reservoirs\Storage](#)).

$$BeginMonthStorage_{Res,m} = InitialStorage_{Res} \text{ for } m = 1$$

Thereafter, it begins each month with the storage from the end of the previous month.

$$BeginMonthStorage_{Res,m} = EndMonthStorage_{Res,m-1} \text{ for } m > 1$$

This beginning storage level is adjusted for evaporation. Since the evaporation rate is specified as a change in elevation (see [Supply and Resources\Local Reservoirs\Physical\Net Evaporation](#)), the storage level must be converted from a volume to an elevation. This is done using the volume-elevation curve (specified as data--see [Supply and Resources\Local Reservoirs\Physical\Volume Elevation Curve](#)).

$$BeginMonthElevation_{Res} = VolumeToElevation( BeginMonthStorage_{Res} )$$

The elevation is reduced by the evaporation rate.

$$AdjustedBeginMonthElevation_{Res} = BeginMonthElevation_{Res} - EvaporationRate_{Res}$$

Then the adjusted elevation is converted back to a volume.

$$AdjustedBeginMonthStorage_{Res} = ElevationToVolume( AdjustedBeginMonthElevation_{Res} )$$

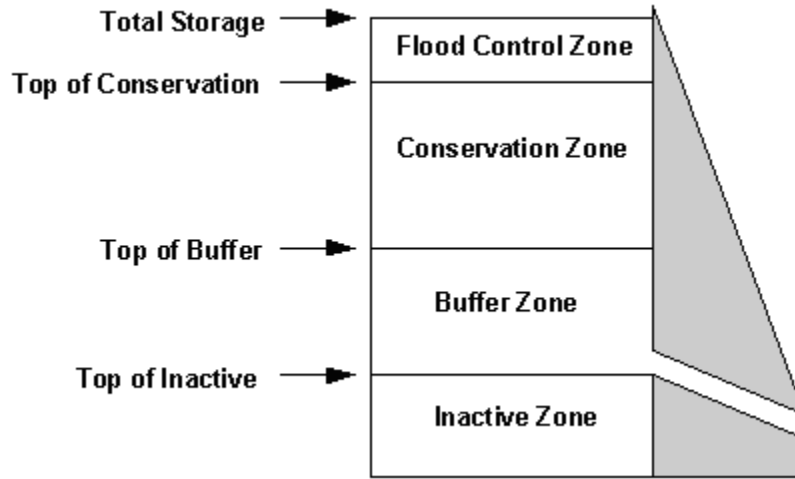
A reservoir's operating rules determine how much water is available in a given month for release, to satisfy demand and hydropower requirements and for flood control. These rules operate on the available resource for the month. This "storage level for operation" is the adjusted amount at the beginning of the month, plus demand site ( $DS$ ) and treatment plant ( $TP$ ) return flows that come in at that point.

$$StorageForOperation_{Res} = AdjustedBeginMonthStorage_{Res} + \sum_{DS} DSReturnFlow_{DS,Res} + \sum_{TP} TPReturnFlow_{TP,Res}$$

The amount available to be released from the reservoir is the full amount in the conservation and flood control zones and a fraction (the buffer coefficient fraction is entered as data--see [Supply and Resources\Local Reservoirs\Operation](#)) of the amount in the buffer zone. Each of these zones is given in terms of volume (i.e. not elevation). The water in the inactive zone is not available for release.

### 7.3 Inflows and Outflows of Water

$$StorageAvailableForRelease_{Res} = FloodControlAndConservationZoneStorage_{Res} + BufferCoefficient_{Res} \times BufferZoneStorage_{Res}$$



All of the water in the flood control and conservation zones is available for release, and equals the amount above Top Of Buffer (TOB and other reservoir zones levels are entered as data--see [Supply and Resources\Local Reservoirs\Operation](#)),

$$FloodControlAndConservationZoneStorage_{Res} = StorageForOperation_{Res} - TopOfBufferZone_{Res}$$

or zero if the level is below Top Of Buffer.

$$FloodControlAndConservationZoneStorage_{Res} = 0$$

Buffer zone storage equals the total volume of the buffer zone if the level is above Top Of Buffer,

$$BufferZoneStorage_{Res} = TopOfBufferZone_{Res} - TopOfInactiveZone_{Res}$$

or the amount above Top Of Inactive if the level is below Top of Buffer,

$$BufferZoneStorage_{Res} = StorageForOperation_{Res} - TopOfInactiveZone_{Res}$$

or zero if the level is below Top Of Inactive.

$$BufferZoneStorage_{Res} = 0$$

WEAP will release only as much of the storage available for release as is needed to satisfy demand and hydropower requirements, in the context of releases from other reservoirs and withdrawals from rivers and other sources. *Note: because a local reservoir is not on a river, any water released to satisfy a hydropower energy demand will disappear from the system.*

$$Outflow_{Res} = \sum_{DS} TransLinkInflow_{Res,DS} + ExtraOutflowForHydropowerRequirement$$

where

$$Outflow_{Res} \leq StorageAvailableForRelease_{Res}$$

The storage at the end of the month is the storage for operation minus the outflow.

$$EndMonthStorage_{Res} = StorageForOperation_{Res} - Outflow_{Res}$$

The change in storage is the difference between the storage at the beginning and the end of the month. This is an increase if the ending storage is larger than the beginning, a decrease if the reverse is true.

$$IncreaseInStorage_{Res} = EndMonthStorage_{Res} - BeginMonthStorage_{Res}$$

## Other Supply Flows

"Other" supplies (OS) have no storage capacity. The full amount of the monthly inflow (entered as data-- see [Supply and Resources\Other Supply\Inflow](#)) is available for withdrawal by demand sites. What is not withdrawn is assumed to flow out of the system, and therefore is not available for use in the system.

$$Outflow_{OS} = Inflow_{OS} - \sum_{DS} TransLinkInflow_{OS,DS}$$

### 7.3.11 Formulation for LP

## Formulation for LP

A linear program (LP) is used to maximize satisfaction of requirements for demand sites, user-specified instream flows and hydropower, subject to demand priorities, supply preferences, mass balance and other constraints. The LP solves all the simultaneous equations listed above. WEAP uses an open source linear program solver called LPSolve. The program and its documentation can be found online: <http://sourceforge.net/projects/lpsolve>.

## Mass Balance Constraints

Mass balance equations are the foundation of WEAP's monthly water accounting: total inflows equal total outflows, net of any change in storage (in reservoirs and aquifers). Every node and link in WEAP has a mass balance equation, and some have additional equations which constrain their flows (e.g., inflow to a demand site cannot exceed its supply requirement, outflows from an aquifer cannot exceed its maximum withdrawal, link losses are a fraction of flow, etc.).

Each mass balance equation becomes a constraint in the LP.

$$\sum Inflow = \sum Outflow + AdditionToStorage$$

which can be rewritten as

$$\sum Inflow - \sum Outflow - AdditionToStorage = 0$$

AdditionToStorage only applies to reservoirs and aquifers. AdditionToStorage is positive for an increase in storage and negative for a decrease in storage. Outflow includes consumption and losses.

Every flow from one point to another is represented by a variable in the LP.

For example, assume Demand Site A draws from Supplies B and C, and returns water to those same supplies, as well as consuming some of the water. The mass balance equation would be

$$Inflow_{B,A} + Inflow_{C,A} - Outflow_{A,B} - Outflow_{A,C} - Consumption_A = 0$$

Where Inflow<sub>B,A</sub> is the inflow from supply B to demand site A. The LP constraint would be a row in the LP matrix, with coefficients of 1 for the inflow variables and -1 for the outflow variables. The entire row would be set equal to 0.

### 7.3 Inflows and Outflows of Water

As another example, if there were losses in transmission link D, which transmits supply from supply B to demand site A, the mass balance equation for the transmission link would be:

$$Inflow_{B,D} - Outflow_{D,A} - Losses_D = 0$$

And the first example would be rewritten as

$$Inflow_{D,A} + Inflow_{C,A} - Outflow_{A,B} - Outflow_{A,C} - Consumption_A = 0$$

## Coverage Variables and Constraints

A new LP variable is created for each demand (demand site, instream flow requirement or hydropower demand), which will equal its "coverage" (percent of demand satisfied). The coverage (for demand D) cannot exceed 100%

$$Coverage_D \leq 100\%$$

The inflow to a demand site (DS) from all its transmission links (Src) will equal its supply requirement times its coverage.

$$\sum_{Src} Inflow_{Src,DS} = SupplyRequirement_{DS} \times Coverage_{DS}$$

which can be rewritten as

$$\sum_{Src} Inflow_{Src,DS} - SupplyRequirement_{DS} \times Coverage_{DS} = 0$$

Whereas demand sites cannot receive more water than their supply requirement, instream flow requirements (IFR) and hydropower requirements (H) **can** be exceeded by actual flows. Therefore, the equation is written as an **inequality**.

$$Flow_{IFR} \geq SupplyRequirement_{IFR} \times Coverage_{IFR}$$

$$VolumeThroughTurbine_H \geq SupplyRequirement_H \times Coverage_H$$

which can be rewritten as

$$Flow_{IFR} - SupplyRequirement_{IFR} \times Coverage_{IFR} \geq 0$$

$$VolumeThroughTurbine_H - SupplyRequirement_H \times Coverage_H \geq 0$$

The LP constraint would be a row in the LP matrix, with coefficients of 1 for the flow variables (inflow to demand sites, streamflow at the instream flow requirement node, or turbine flow), and -1 times the supply requirement as the coefficient for the coverage variable. The entire row would be set equal to 0 (demand sites) or greater than or equal to 0 (instream flow and hydropower requirements).

For example, if Demand Site A had a requirement of 100 units, but in solving the LP was allocated only 30, the coverage would be 30%:

$$30 = 100 \times 30\%$$

If a [system hydropower priority and energy demand](#) has been set, WEAP will create LP variables and constraints for each reservoir or run of river hydropower contributing to the system hydropower demand, representing the hydropower energy generated at each hydropower plant (H).

$$EnergyGenerated_H = VolumeThroughTurbine_H \times HydroGenerationFactor_H$$

For the coverage constraint, the system hydropower energy generated by all contributing hydropower plants (H) will equal or exceed the system hydropower energy demand times the system hydropower energy coverage.

$$\sum_H \text{EnergyGenerated}_H \geq \text{SystemHydropowerEnergyRequirement}_D \times \text{Coverage}_D$$

which can be rewritten as

$$\sum_H \text{EnergyGenerated}_H - \text{SystemHydropowerEnergyRequirement}_D \times \text{Coverage}_D \geq 0$$

Because WEAP tries to satisfy all demands with the same priority equally (in terms of percentage of demand), additional constraints are added to the LP. Each coverage variable is set equal to a new variable that represents the final coverage ( $\text{Coverage}_{\text{Final}}$ ). In this way, all the coverages being solved for must be equal.

$$\text{Coverage}_{\text{Final}} = \text{Coverage}_{D1}$$

$$\text{Coverage}_{\text{Final}} = \text{Coverage}_{D2}$$

## Hydropower Constraints

For individual reservoirs with If a demand and priority for hydropower energy has been set for an , WEAP will calculate the supply requirement (volume of water through the turbines) necessary to generate the energy demand.

In order to limit the flow through the hydropower turbines to the maximum turbine flow, two new LP variables are created for each reservoir and run of river hydropower that either have individual hydropower priorities and demands, or that contribute to a system hydropower energy demand, representing the flow through the turbine and the flow that bypasses the turbine. A constraint is added, which equates these two variables with the total release from the reservoir or run of river hydropower.

$$\text{Release}_H = \text{VolumeThroughTurbine}_H + \text{VolumeNotThroughTurbine}_H$$

And a constraint is set for the maximum turbine flow.

$$\text{VolumeThroughTurbine}_H \leq \text{MaxTurbineFlow}_H$$

## Objective Function and Iterations

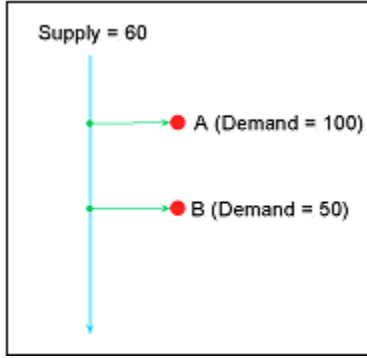
WEAP strives to maximize supply to demands sites, subject to all constraints and priorities. Demand sites are allocated water depending on demand priorities and supply preferences. WEAP iterates for each priority and preference, so that demands with priority 1 are allocated water before those with priority 2. Thus, the LP is solved at least once for each priority for each time step. When solving for priority 1, WEAP will temporarily turn off (in the LP) allocations to demands with priority 2 and lower. Then, after priority 1 allocations have been made, priority 2 demands are turned on (but 3 and lower are still turned off).

Because the goal is to maximize the coverage rate for all demand sites, the objective function maximizes  $\text{Coverage}_{\text{Final}}$ .

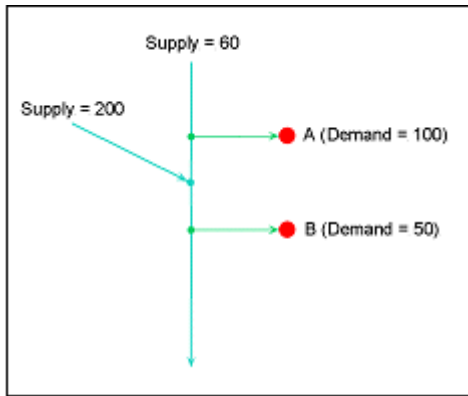
In cases where there is not enough water to satisfy all demands with the same priority, WEAP tries to satisfy all demands to the same percentage of their demand. (The coverage constraints, as described above, ensure this.)



### 7.3 Inflows and Outflows of Water



For example, if Demand Site A has a supply requirement of 100 and Demand Site B has a supply requirement of 50 (assume both are the same priority), and there is only 60 units of river water available this time step, then A will get 40 units (40%) and B will get 20 units (40%).



However, in some cases, some demand sites may have access to more water than others. For example, between the withdrawal points for Demands Sites A and B is a tributary inflow, such that there is always enough water for B. In this case, Demand Site B should be able to withdraw its full requirement, even though Demand Site A cannot. In this case, the WEAP LP must iterate. The first time it solves, both A and B will get 60%-A gets all 60 units (60%) flowing past its withdrawal point, and Demand Site B will get 30 units (60%) 50 units that flowed in from the tributary. (The equity constraints ensure that both Demand Sites get the same percent coverage.) The LP indicates that there is slack (see below) in the coverage variable for B, because it could get more water than it is getting (as opposed to A, which cannot get any more water). Therefore, the allocation to Demand Site A is fixed at 60, and the equity constraint

$$Coverage_{Final} = Coverage_A$$

is deleted. The LP runs again, and this time Demand Site B will get its full demand of 50 satisfied (100%).

## Determining Slack

In the second example above, Demand Site B was able to receive a higher percentage of its demand than Demand Site A, due to the tributary inflow between the two withdrawal points for the two demand sites. In order for WEAP to determine which coverages are constrained from going higher due to unavailability of supply (e.g., 60% for Demand Site A), and which can get more water (e.g., 100% for Demand Site B), a new variable, epsilon, is defined for each demand site and added to the coverage constraints:

$$Coverage_{Final} = Coverage_{DS1} + Epsilon_{DS1}$$

$$Coverage_{Final} = Coverage_{DS2} + Epsilon_{DS2}$$

The epsilons are also added to the objective function, but with a negative sign, so that they are minimized.

$$\text{Maximize: } Coverage_{Final} - k * Epsilon_{DS1} - k * Epsilon_{DS2}$$

The values for each epsilon must be between 0 and 0.0001. The value for k is chosen to insure that the values for the epsilons will never overwhelm the value for  $Coverage_{Final}$ . The value chosen is  $1 / (n + 1)$ , where n = the number of demand sites.

The effect of the epsilons is to determine which demand sites are supply limited and which are not. In the second example above, here are the values of the variables after the first iteration of the LP:

$$Coverage_{DS1} = 0.6$$

$$Epsilon_{DS1} = 0.0001$$

$$Coverage_{DS2} = 0.6001$$

$$Epsilon_{DS2} = 0$$

$$Coverage_{Final} = 0.6001$$

$$\text{Objective function} = 0.6001 - (1/3) * 0.0001 - (1/3) * 0 = 0.60006666$$

Because  $Epsilon_{DS1} = 0$ , we know that DS1 cannot get any more water than 0.6. Assume DS1 **could** get more than 0.6, say 0.6001. In that case, the following values

$$Coverage_{DS1} = 0.6001$$

$$Epsilon_{DS1} = 0.0001$$

$$Coverage_{DS2} = 0.6001$$

$$Epsilon_{DS2} = 0.0001$$

$$Coverage_{Final} = 0.6002$$

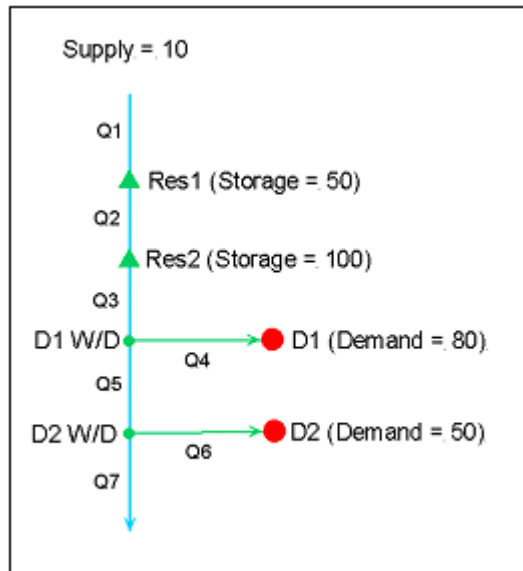
$$\text{Objective function} = 0.6002 - (1/3) * 0.0001 - (1/3) * 0.0001 = 0.60013333$$

would yield a better value for the objective function and hence would have been the solution. Therefore, DS1 cannot get more than 0.6, while DS2 can get more than 0.6.

## Reservoirs

Reservoirs with storage levels below the top of conservation pool are treated like demand sites so that WEAP will not drain them unless to meet downstream demands, and to try to fill them up when there is surplus surface water. Where multiple reservoirs with the same demand priority exist, WEAP will try to fill them up to same level (as a % of the top of conservation pool), just as it will try to satisfy demand sites to the same percentage of their demand.

### Example 1



In the first example, the river headflow is insufficient to meet the two demands. Therefore, the reservoirs will need to release water to satisfy the demands. Both reservoirs have a top of conservation pool (TOC) of 200, although their initial storages are different: 50 and 100, as shown. Both reservoirs have the same demand priority (99). Therefore, after allocating water, the goal will be to have both reservoirs finish with the same fraction of the top of conservation pool filled.

Since the demand is 130, and the available water is 160, there will be 30 remaining, after allocating to the demand sites. This 30 is split evenly between the two reservoirs-each will have 15. WEAP will solve first for the allocations to the demand sites, and second to fill up the reservoirs. Here is the LP formulation for the first:

$$\begin{aligned}
 Q1 &= Add1 + Q2 & Q4 &= 80 C1 & S1 &= 50 + Add1 \\
 Q2 &= Add2 + Q3 & Q6 &= 50 C2 & S2 &= 100 + Add2 \\
 Q3 &= Q4 + Q5 & S1 &= 200 C3 & C1 + E1 &\geq FC \\
 Q5 &= Q6 + Q7 & S2 &= 200 C4 & C2 + E2 &\geq FC \\
 Obj\ fn: & FC - 0.2 E1 - 0.2 E2 - 0.2 E3 - 0.2 E4
 \end{aligned}$$

Upper and lower bounds:

$$\begin{aligned}
 Q1 &= 10 & Add1 &\geq -50 & 0 &\leq C4 \leq 1 \\
 Q2 &\geq 0 & Add2 &\geq -100 & 0 &\leq E1 \leq 0.0001 \\
 C3 &\geq 0 & 0 &\leq S1 \leq 200 & 0 &\leq E2 \leq 0.0001 \\
 Q4 &\geq 0 & 0 &\leq S2 \leq 200 & 0 &\leq E3 \leq 0.0001 \\
 Q5 &\geq 0 & 0 &\leq C1 \leq 1 & 0 &\leq E4 \leq 0.0001 \\
 Q6 &\geq 0 & 0 &\leq C2 \leq 1 & 0 &\leq FC \leq 1 \\
 Q7 &\geq 0 & 0 &\leq C3 \leq 1
 \end{aligned}$$

Where:

*Add1 = addition to reservoir 1 storage (negative "additions" represent releases, which cannot exceed the initial storage)*

*Add2 = addition to reservoir 2 storage*

*S1 = final storage in reservoir 1*

*S2 = final storage in reservoir 1*

*C1 = D1 coverage*

*C2 = D2 coverage*

*C3 = Coverage for "demand" to fill reservoir 1 to top of conservation (TOC) pool*

*C4 = Coverage for "demand" to fill reservoir 2 to top of conservation (TOC) pool*

*E1 = D1 epsilon*

*E2 = D2 epsilon*

*E3 = Res 1 TOC epsilon*

*E4 = Res 2 TOC epsilon*

*FC = Final Coverage*

Here is the solution:

$Q1 = 10$	$Q6 = 50$	$S2 = 0$
$Q2 = 30$	$Q7 = 0$	$C1 = C2 = FC = 1$
$Q3 = 130$	$Add1 = -20$	$C3 = C4 = 0$
$Q4 = 80$	$Add2 = -100$	$E1 = E2 = E3 = E4 = 0$
$Q5 = 50$	$S1 = 30$	

Note that Reservoir 1 has storage of 30 while reservoir 2 has 0. This inequity will be rectified next. For the second LP iteration, to solve for equalizing the reservoir releases, here is the LP formulation:

$Q1 = Add1 + Q2$	$Q4 = 80 \ C1$	$S1 = 50 + Add1$
$Q2 = Add2 + Q3$	$Q6 = 50 \ C2$	$S2 = 100 + Add2$
$Q3 = Q4 + Q5$	$S1 = 200 \ C3$	$C3 + E3 \geq FC$
$Q5 = Q6 + Q7$	$S2 = 200 \ C4$	$C4 + E4 \geq FC$
<i>Obj fn: <math>FC - 0.2 \ E1 - 0.2 \ E2 - 0.2 \ E3 - 0.2 \ E4</math></i>		

Upper and lower bounds:

$Q1 = 10$	$Add1 \geq -50$	$0 \leq C4 \leq 1$
$Q2 \geq 0$	$Add2 \geq -100$	$0 \leq E1 \leq 0.0001$
$C3 \geq 0$	$0 \leq S1 \leq 200$	$0 \leq E2 \leq 0.0001$
$Q4 = 80$	$0 \leq S2 \leq 200$	$0 \leq E3 \leq 0.0001$
$Q5 \geq 0$	$C1 = 1$	$0 \leq E4 \leq 0.0001$
$Q6 = 50$	$C2 = 1$	$0 \leq FC \leq 1$
$Q7 \geq 0$	$0 \leq C3 \leq 1$	

Here is the solution:

$$Q1 = 10$$

$$Q2 = 45$$

$$Q3 = 130$$

$$Q4 = 80$$

$$Q5 = 50$$

$$Q6 = 50$$

$$Q7 = 0$$

$$Add1 = -35$$

$$Add2 = -85$$

$$S1 = 15$$

$$S2 = 15$$

$$C1 = C2 = 1$$

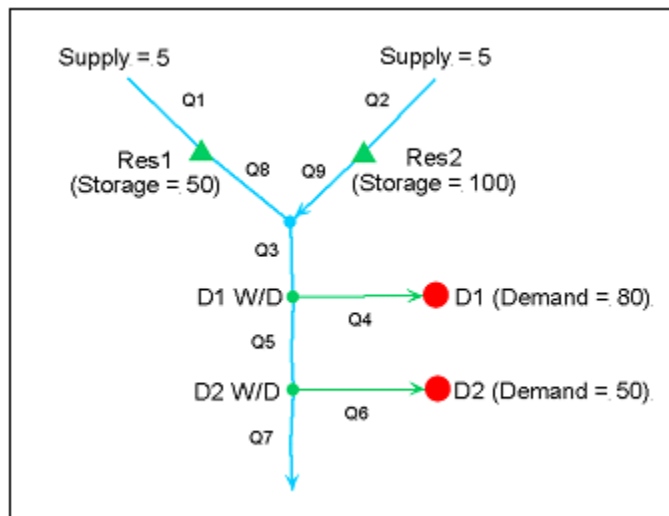
$$C3 = C4 = 0.075$$

$$FC = 0.0751$$

$$E1 = E2 = 0$$

$$E3 = E4 = 0.0001$$

## Example 2



The second example is identical to the first, except that the two reservoirs are on different rivers. The river headflow is insufficient to meet the two demands. Therefore, the reservoirs will need to release water to satisfy the demands. Both reservoirs have a top of conservation pool (TOC) of 200, although their initial storages are different: 50 and 100, as shown. Both reservoirs have the same demand priority (99). Therefore, after allocating water, the goal will be to have both reservoirs finish with the same fraction of the top of conservation pool filled.

Since the demand is 130, and the available water is 160, there will be 30 remaining, after allocating to the demand sites. This 30 is split evenly between the two reservoirs-each will have 15. WEAP will solve first for the allocations to the demand sites, and second to fill up the reservoirs. Here is the LP formulation for the first:

$$Q1 = Add1 + Q8$$

$$Q2 = Add2 + Q9$$

$$Q3 = Q8 + Q9$$

$$Q3 = Q4 + Q5$$

$$Q5 = Q6 + Q7$$

$$Q6 = 50 \ C2$$

$$S1 = 200 \ C3$$

$$S2 = 200 \ C4$$

$$S1 = 50 + Add1$$

$$S2 = 100 + Add2$$

$$C1 + E1 \geq FC$$

$$C2 + E2 \geq FC$$

$$Obj\ fn: FC - 0.2 \ E1 - 0.2 \ E2 - 0.2 \ E3 - 0.2 \ E4$$

Upper and lower bounds:

$Q1 = 5$	$Q9 \geq 0$	$0 \leq C4 \leq 1$
$Q2 = 5$	$Add1 \geq -50$	$0 \leq E1 \leq 0.0001$
$C3 \geq 0$	$Add2 \geq -100$	$0 \leq E2 \leq 0.0001$
$Q4 \geq 0$	$0 \leq S1 \leq 200$	$0 \leq E3 \leq 0.0001$
$Q5 \geq 0$	$0 \leq S2 \leq 200$	$0 \leq E4 \leq 0.0001$
$Q6 \geq 0$	$0 \leq C1 \leq 1$	$0 \leq FC \leq 1$
$Q7 \geq 0$	$0 \leq C2 \leq 1$	
$Q8 \geq 0$	$0 \leq C3 \leq 1$	

Where:

$Add1$  = addition to reservoir 1 storage (negative "additions" represent releases, which cannot exceed the initial storage)

$Add2$  = addition to reservoir 2 storage

$S1$  = final storage in reservoir 1

$S2$  = final storage in reservoir 1

$C1$  = D1 coverage

$C2$  = D2 coverage

$C3$  = Coverage for "demand" to fill reservoir 1 to top of conservation (TOC) pool

$C4$  = Coverage for "demand" to fill reservoir 2 to top of conservation (TOC) pool

$E1$  = D1 epsilon

$E2$  = D2 epsilon

$E3$  = Res 1 TOC epsilon

$E4$  = Res 2 TOC epsilon

$FC$  = Final Coverage

Here is the solution:

$Q1 = 5$	$Q7 = 0$	$S2 = 0$
$Q2 = 5$	$Q8 = 25$	$C1 = C2 = FC = 1$
$Q3 = 130$	$Q9 = 105$	$C3 = C4 = 0$
$Q4 = 80$	$Add1 = -20$	$E1 = E2 = E3 = E4 = 0$
$Q5 = 50$	$Add2 = -100$	
$Q6 = 50$	$S1 = 30$	

Note that Reservoir 1 has storage of 30 while reservoir 2 has 0. This inequity will be rectified next. For the second LP iteration, to solve for equalizing the reservoir releases, here is the LP formulation:

$Q1 = Add1 + Q8$	$Q3 = Q8 + Q9$	$Q4 = 80$
$Q2 = Add2 + Q9$	$Q3 = Q4 + Q5$	$Q5 = Q6 + Q7$

### 7.3 Inflows and Outflows of Water

$$\begin{array}{lll}
 Q6 = 50 & S1 = 50 + Add1 & C4 + E4 \geq FC \\
 S1 = 200 C3 & S2 = 100 + Add2 & \\
 S2 = 200 C4 & C3 + E3 \geq FC & \\
 Obj\ fn: FC - 0.2 E1 - 0.2 E2 - 0.2 E3 - 0.2 E4 & & 
 \end{array}$$

Upper and lower bounds:

$$\begin{array}{lll}
 Q1 = 5 & Q9 \geq 0 & 0 \leq C4 \leq 1 \\
 Q2 = 5 & Add1 \geq -50 & 0 \leq E1 \leq 0.0001 \\
 C3 \geq 0 & Add2 \geq -100 & 0 \leq E2 \leq 0.0001 \\
 Q4 = 80 & 0 \leq S1 \leq 200 & 0 \leq E3 \leq 0.0001 \\
 Q5 \geq 0 & 0 \leq S2 \leq 200 & 0 \leq E4 \leq 0.0001 \\
 Q6 = 50 & C1 = 1 & 0 \leq FC \leq 1 \\
 Q7 \geq 0 & C2 = 1 & \\
 Q8 \geq 0 & 0 \leq C3 \leq 1 & 
 \end{array}$$

Here is the solution:

$$\begin{array}{lll}
 Q1 = 5 & Q7 = 0 & S2 = 15 \\
 Q2 = 5 & Q8 = 40 & C1 = C2 = 1 \\
 Q3 = 130 & Q9 = 90 & C3 = C4 = 0.075 \\
 Q4 = 80 & Add1 = -35 & FC = 0.0751 \\
 Q5 = 50 & Add2 = -85 & E1 = E2 = 0 \\
 Q6 = 50 & S1 = 15 & E3 = E4 = 0.0001
 \end{array}$$

## Water Quality Constraints

If maximum water quality concentrations on demand site inflow from supplies have been set, then additional water quality constraints are created. The basic relationship states that the weighted average mixed concentration from all supplies must not exceed the maximum allowed concentration.

$$(Q_1 C_1 + Q_2 C_2 + \dots) / (Q_1 + Q_2 + \dots) \leq C_{max} \quad Eqn. 1$$

which can be transformed into

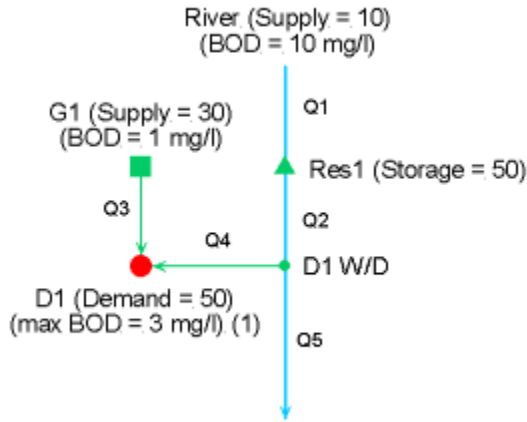
$$Q_1 (1 - C_1 / C_{max}) + Q_2 (1 - C_2 / C_{max}) + \dots \geq 0 \quad Eqn. 2$$

where  $Q_i$  is the flow into the demand site from source  $i$ ,  $C_i$  is the concentration of source  $i$  in the previous timestep, and  $C_{max}$  is the maximum allowed concentration. Because the water quality calculations in the river are inherently non-linear, the concentrations used in the equation above must come from the previous time step. Thus, the  $(1 - C_i / C_{max})$  terms are constants, and this equation (Eqn. 2) is a suitable form for a LP constraint.

## Example

As an example, consider a Demand Site that is connected to both surface water and groundwater sources. The demand site has no treatment facilities, and requires the concentration of BOD to be 3 mg/l or less. The concentrations of BOD in the previous time step are 10 mg/l in the river and 1 mg/l in the groundwater. The demand is 50; the river supply is 10, the groundwater supply (considering pumping

capacity) is 30, and the reservoir has 50 units available for release. The reservoir's top of conservation pool (TOC) is 200.



WEAP will need to choose a mix from the two sources such that the average BOD concentration does not exceed 3 mg/l.

Substituting into the above equations, where  $Q_1$  is the supply from groundwater ( $Q_G$ ),  $C_1$  is the groundwater BOD concentration (1 mg/l),  $Q_2$  is the supply from the river ( $Q_R$ ),  $C_2$  is the river BOD concentration (10 mg/l), and  $C_{\max}$  is the demand site's maximum BOD concentration (3 mg/l):

$$(1Q_3 + 10Q_4) / (Q_3 + Q_4) \leq 3 \text{ (from Eqn. 1)} \quad \text{Eqn. 3}$$

$$Q_3 (1 - 1/3) + Q_4 (1 - 10/3) \geq 0 \text{ (from Eqn. 2)} \quad \text{Eqn. 4}$$

$$(2/3) Q_3 - (7/3) Q_4 \geq 0 \quad \text{Eqn. 5}$$

$$(2/3) Q_3 \geq (7/3) Q_4 \quad \text{Eqn. 6}$$

$$Q_3 \geq (7/2) Q_4 \quad \text{Eqn. 7}$$

This equation gives the minimum ratio of river water to groundwater that will satisfy the demand site's water quality constraint.

The demand (50) will come from the two sources:

$$Q_3 + Q_4 = 50 \quad \text{Eqn. 8}$$

$$Q_3 = 50 - Q_4 \quad \text{Eqn. 9}$$

Substituting into Eqn. 7:

$$50 - Q_4 \geq (7/2) Q_4 \quad \text{Eqn. 10}$$

$$50 \geq (9/2) Q_4 \quad \text{Eqn. 11}$$

$$Q_4 \leq 11.11 \quad \text{Eqn. 12}$$

therefore,

$$Q_3 = 50 - 11.11 = 38.89 \quad \text{Eqn. 13}$$

Substituting into Eqn. 3:

$$(38.89 * 1 + 11.11 * 10) / (38.89 + 11.11) \leq 3 \quad \text{Eqn. 14}$$

$$(38.89 * 1 + 11.11 * 10) / (38.89 + 11.11) \leq 3 \quad \text{Eqn. 15}$$



### 7.3 Inflows and Outflows of Water

$$149.99 / 50 \leq 3 \quad \text{Eqn. 16}$$

We see that the maximum water quality constraint is satisfied.

The water quality constraint will be added as a new constraint to the LP. WEAP will solve first for the allocations to the demand site, and second to fill up the reservoir. Here is the LP formulation for the first:

$$\begin{aligned} Q1 &= Add1 + Q2 & Q3 + Q4 &= 50 \quad C1 & S1 &= 50 + Add1 \\ Q2 &= Q4 + Q5 & S1 &= 200 \quad C2 & C1 + E1 &\geq FC \\ (1 - 1/3) * Q3 + (1 - 10/3) * Q4 &\geq 0 & & & & \text{(Water quality constraint)} \\ \text{Obj fn: } &FC - 0.33 E1 - 0.33 E2 & & & & \end{aligned}$$

Upper and lower bounds:

$$\begin{aligned} Q1 &= 10 & Q5 &\geq 0 & 0 &\leq C2 \leq 1 \\ Q2 &\geq 0 & Add1 &\geq -50 & 0 &\leq E1 \leq 0.0001 \\ Q3 &\geq 0 & 0 &\leq S1 \leq 200 & 0 &\leq E2 \leq 0.0001 \\ Q4 &\geq 0 & 0 &\leq C1 \leq 1 & 0 &\leq FC \leq 1 \end{aligned}$$

Where:

*Add1 = addition to reservoir 1 storage (negative "additions" represent releases, which cannot exceed the initial storage)*

*S1 = final storage in reservoir 1*

*C1 = D1 coverage*

*C2 = Coverage for "demand" to fill reservoir 1 to top of conservation (TOC) pool*

*E1 = D1 epsilon*

*E2 = Res 1 TOC epsilon*

*FC = Final Coverage*

Here is the solution:

$$\begin{aligned} Q1 &= 10 & Q5 &= 1.43 & C2 &= 0 \\ Q2 &= 10 & Add1 &= 0 & E1 = E2 &= 0.0001 \\ Q3 &= 30 & S1 &= 50 & FC &= 0.7701 \\ Q4 &= 8.57 & C1 &= 0.77 & & \end{aligned}$$

Note that Reservoir 1 has plenty of storage to satisfy the demand, but because of the water quality constraint for D1 and the low water quality of the river, only 8.57 units of water can be supplied from the river. For the second LP iteration, to filling the reservoir, here is the LP formulation:

$$\begin{aligned} Q1 &= Add1 + Q2 & S1 &= 200 \quad C2 & C2 + E2 &\geq FC \\ Q2 &= Q4 + Q5 & S1 &= 50 + Add1 & & \\ (1 - 1/3) * Q3 + (1 - 10/3) * Q4 &\geq 0 & & & & \end{aligned}$$

$$\text{Obj fn: } FC - 0.33 E1 - 0.33 E2$$

Upper and lower bounds:

$Q1 = 10$	$Q5 \geq 0$	$0 \leq E1 \leq 0.0001$
$Q2 \geq 0$	$Add1 \geq -50$	$0 \leq E2 \leq 0.0001$
$Q3 = 30$ (set after first LP iteration)	$0 \leq S1 \leq 200$	$0 \leq FC \leq 1$
$Q4 = 8.57$ (set after first LP iteration)	$0 \leq C1 \leq 1$	
	$0 \leq C2 \leq 1$	

Where:

$Add1$  = addition to reservoir 1 storage (negative "additions" represent releases, which cannot exceed the initial storage)

$S1$  = final storage in reservoir 1

$C1$  = D1 coverage

$C2$  = Coverage for "demand" to fill reservoir 1 to top of conservation (TOC) pool

$E1$  = D1 epsilon

$E2$  = Res 1 TOC epsilon

$FC$  = Final Coverage

Here is the solution:

$Q1 = 10$	$Q5 = 0$	$C2 = 0.01$
$Q2 = 8.57$	$Add1 = 1.43$	$E1 = E2 = 0.0001$
$Q3 = 30$	$S1 = 51.43$	$FC = 0.0101$
$Q4 = 8.57$	$C1 = 0.77$	

The reservoir can add 1.43 to storage, because the demand site can only use 8.57 of the poor quality river water.

## 7.4 Hydropower Calculations

Hydropower generation is computed from the flow passing through the turbine, based on the reservoir release or run-of-river streamflow, and constrained by the turbine's maximum flow capacity. Note that the amount of water that flows through the turbine is calculated differently for local reservoirs, river reservoirs and run-of-river hydropower. For river reservoirs, all water released downstream is sent through the turbines, but water pumped from the reservoir to satisfy direct reservoir withdrawals is not sent through the turbines.

$$Release_H = DownstreamOutflow_H$$

For local reservoirs, all linked demand sites are assumed to be downstream of the reservoir, so all reservoir releases are sent through the turbines.

$$Release_H = \sum_{DS} TransLinkInflow_{H,DS} + ExtraOutflowForHydropowerRequirement$$

For run-of-river hydropower nodes, the "release" is equal to the downstream outflow from the node.

## 7.5 Water Quality

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$$Release_H = DownstreamOutflow_H$$

The volume of water that passes through the turbines is bounded by the maximum turbine flow (entered as data--see [Supply and Resources\Reservoir\Hydropower](#)). Note that if there is too much water, extra water is assumed to be released through spillways that do not generate electricity.

$$VolumeThroughTurbine_H = \text{Min}(Release_H, MaxTurbineFlow_H)$$

The gigajoules (GJ) of energy produced in a month,

$$EnergyFullMonthGJ_H = VolumeThroughTurbine_H \times HydroGenerationFactor_H$$

is a function of the mass of water ( $1000 \text{ kg} / \text{m}^3$ ) through the turbines multiplied by the drop in elevation, the plant factor (fraction of time on-line), the generating efficiency, and a conversion factor ( $9.806 \text{ kN/m}^3$  is the specific weight of water, and from joules to gigajoules). The plant factor and efficiency are entered as data (see [Supply and Resources\Reservoir\Hydropower](#)).

$$HydroGenerationFactor_H = 1000 (\text{kg} / \text{m}^3) \times DropElevation_H \times PlantFactor_H \times PlantEfficiency_H \times 9.806 / (1,000,000,000 \text{ J} / \text{GJ})$$

For reservoirs, the height that the water falls in the turbines is equal to the elevation at the beginning of the month minus the tailwater elevation (entered as data--see [Supply and Resources\Reservoir\Hydropower](#)).

$$DropElevation_H = \text{BeginMonthElevation}_H - \text{TailwaterElevation}_H$$

For run-of-river hydropower nodes, the drop in elevation is entered as data (see [Supply and Resources\River\Run of River Hydropower](#)).

$$DropElevation_H = \text{FixedHead}_H$$

If a demand priority for hydropower energy has been set for an individual reservoir, WEAP will calculate the supply requirement (volume of water through the turbines) necessary to generate the energy demand.

$$SupplyRequirement_H = \text{EnergyDemandFullMonthGJ}_H / HydroGenerationFactor_H$$

## 7.5 Water Quality

WEAP includes descriptive models of point source pollutant loadings that can simulate the impact of wastewater on receiving waters from demand sites and wastewater treatment plants. Water quality parameters that can be considered in WEAP include conservative substances, constituents that decay according to an exponential decay function, dissolved oxygen (DO) and biological oxygen demand (BOD) from point sources, and instream water temperature. These parameters are not modeled in reservoirs, though; all reservoir outflow concentrations must be entered as data.

In the first-order DO model, water quality is simulated in select rivers, chosen via the WEAP user interface. Mass balance equations are written for each stream segment of the selected rivers, with hydrologic inflows from rivers and groundwater sources automatically input to simulate the water balance and mixing of DO, BOD and other constituents along each reach. The river network is the same for the water resources and water quality simulations and assumes complete mixing.

First, all pollution loads into a river are calculated from demand site return flows, wastewater treatment plant return flows, groundwater inflows, headflows, upstream inflows, and other surface water inflows. WEAP assumes complete mixing of all inflows. As each constituent (other than conservative constituents) moves downstream, its decay is calculated.

### 7.5.1 Routing Pollution Generation

The pollution generated by a demand site is carried in the wastewater return flows to wastewater treatment plants and receiving bodies of water. Wastewater flows distributed from a given demand site to multiple destinations are assumed to have approximately the same concentrations. Therefore, the pollution streams flowing from a single source are proportional to the volume of flow. Thus, the amount of pollution that flows out of a demand site into a return flow link is a fraction of the pollution generated.

$$DSReturnLinkPollInflow_{DS, Dest, p} = DSOutflowRoutingFraction_{DS, Dest} \times MonthlyPollGenerated_{DS, p}$$

For example, if the routing fraction from Demand Site North Agriculture to North Aquifer was 35%, and the routing fraction from Agriculture North to the Weaping River was 25% (with 40% of water consumed by the demand site), the fraction of Agriculture North's pollution that flow towards North Aquifer would be  $0.35 / (0.35 + 0.25) = 0.58$ .

Stormwater runoff from catchments can also be routed to wastewater treatment plants, in order to model combined sewer overflow (CSO). In this case, non-point source pollution generated by the catchment is carried in the runoff to the treatment plant. The Soil Moisture Model determines the split between surface runoff and infiltration, with the non-point source pollution generated assumed to follow the same split.

$$CatchmentRunoffLinkPollInflow_{Catch, Dest, p} = CatchmentSurfaceRunoffFraction_{Catch, Dest} \times MonthlyNonPointSourcePollution_{Catch, p}$$

Some of the pollutant might decay or otherwise be lost as it passes through the return flow or runoff links. The pollution that flows out of the return flow or runoff link is a fraction (entered as data-see Water Quality\Pollutant Decrease in Return Flows) of the inflow.

$$DSReturnLinkPollOutflow_{DS, Dest, p} = (1 - DSReturnLinkPollDecreaseRate_{DS, Dest, p}) \times DSReturnLinkPollInflow_{DS, Dest, p}$$

$$CatchmentRunoffLinkPollOutflow_{Catch, Dest, p} = (1 - CatchmentRunoffLinkPollDecreaseRate_{Catch, Dest, p}) \times CatchmentRunoffLinkPollInflow_{Catch, Dest, p}$$

### 7.5.2 Wastewater Treatment

The pollution that flows into a wastewater treatment plant (TP) is the sum of the flows from all connected demand site (DS) return flow links and catchment (Catch) runoff links.

$$TreatmentPlantPollInflow_{TP, p} = \sum_{DS} DSReturnLinkPollOutflow_{DS, TP, p} + \sum_{Catch} CatchmentRunoffLinkPollOutflow_{Catch, TP, p}$$

Treatment can be specified by two different methods: removal rate or outflow concentration

#### Removal Rate

Some fraction of the pollution will be removed by the plant (entered as data--see [Water Quality\Wastewater Treatment](#)), and the rest will flow out. Note that if the plant's inflow exceeds its capacity, not all of the inflow will be treated.

$$TreatmentPlantPollOutflow_{TP, p} = (1 - RemovalRate_{TP, p} \times FractionTreated_{TP}) \times TreatmentPlantPollInflow_{TP, p}$$

## Outflow Concentration

The concentration of the outflow will be as specified in the [outflow concentration data](#) (see Water Quality\Wastewater Treatment). Note that if the plant's inflow exceeds its capacity, the treated effluent at the specified concentration will be mixed with the untreated overflow.

$$TreatmentPlantPollOutflow_{TP,p} = OutflowConcentration_{TP,p} \times TreatmentPlantOutflow_{TP} \times FractionTreated_{TP} + TreatmentPlantPollInflow_{TP,p} \times (1 - FractionTreated_{TP})$$

### 7.5.3 Pollution Routing from Treatment Plants

The pollution remaining in the treatment plant effluent is carried by the treatment plant return flow links to receiving bodies of water. Flows from a given plant to multiple destinations are assumed to have approximately the same concentrations. Therefore, the pollution streams flowing from a single source are proportional to the volume of flow. Thus, the amount of pollution that flows out of a treatment plant into a return flow link is a fraction of the pollution remaining in the effluent.

$$TPReturnLinkPollInflow_{TP, Dest, p} = ( TPOutflowRoutingFraction_{TP, Dest} / \sum_{Dest} TPOutflowRoutingFraction_{TP, Dest} ) \times TreatmentPlantPollOutflow_{TP}$$

Some of the pollutant might decay or otherwise be lost as it passes through the return flow link. The pollution that flows out of the return flow link is a fraction (entered as data-see [Environment\Pollutant Decrease in Return Flows](#)) of the inflow.

$$TPReturnLinkPollOutflow_{TP, Dest, p} = (1 - TPReturnLinkPollDecreaseRate_{TP, Dest, p}) \times TPReturnLinkPollInflow_{TP, Dest, p}$$

### 7.5.4 Groundwater Pollution

Groundwater inflows to the river can bring pollution, specified by the concentration of each constituent in the groundwater inflow.

$$GroundwaterPollutionFlowToReach_{GW, Rch, p, m} = GroundwaterFlowToReach_{GW, Rch} \times GroundwaterPollutionConcentration_{GW, p, m}$$

### 7.5.5 Headflow Pollution

River headflow can bring pollution, specified by the concentration of each constituent in the headflow.

$$HeadflowPollutionRiver_{River, p, m} = Headflow_{River} \times HeadflowPollutionConcentration_{River, m, p}$$

### 7.5.6 Other Surface Water Inflow Pollution

Any other surface water inflow to a reach can bring pollution, specified by the concentration of each constituent in the inflow.

$$OtherSWInflowPollutionToReach_{Rch, p, m} = OtherSWInflowToReach_{Rch} \times OtherSWInflowPollutionConcentration_{Rch, p, m}$$

### 7.5.7 Pollutant Loads

The pollutant load to a river node or reach is the sum of all the pollution from all connected demand site return flow links, catchment runoff links, treatment plant return flow links, groundwater inflows, headflows, upstream inflows, and other surface water inflows. WEAP assumes complete mixing of all inflows.

$$\begin{aligned} \text{PollutionLoad}_{Node,p} = & \sum_{DS} \text{DSReturnLinkPollOutflow}_{DS,Node,p} + \sum_{Catch} \text{CatchmentRunoffLinkPollOutflow}_{DS,Node,p} \\ & + \sum_{TP} \text{TPReturnLinkPollOutflow}_{TP,Node,p} + \sum_{GWS} \text{GWPollutionFlow}_{GW,Node,p} + \text{HeadflowPollution}_{River,p} + \\ & \text{OtherSWInflowPollutionToReach}_{Rch,p} + \text{UpstreamInflowPollutionToReach}_{Rch,p} \end{aligned}$$

### 7.5.8 Surface Water Quality Modeling

WEAP can model the concentration of water quality constituents in a river using simple mixing, first-order decay, and built-in temperature, BOD and DO models, or by linking to QUAL2K. Note that water quality in reservoirs and groundwater is not modeled by WEAP, but the user can specify the water quality of outflows from them into river reaches, demand sites and catchments.

#### Simple Mixing

Starting with the simplest assumptions, that the effects of diffusion and dispersion are negligible relative to the effects of advection, the stream may be represented as a plug-flow system. The initial concentration of a pollutant at the point of injection into the stream is calculated from a mass balance:

$$c = \frac{Q_w c_w + Q_r c_r}{Q_w + Q_r} \quad \text{Eqn. 1}$$

Where:

$c$  is the new concentration (mg/l)

$Q_w$  is the flow of wastewater discharged (m<sup>3</sup>/time)

$C_w$  is the concentration of pollutant in the wastewater (mg/l)

$Q_r$  is the flow of receiving water (m<sup>3</sup>/time)

$C_r$  is the concentration of pollutant in the receiving water (mg/l)

This is the simplest case of representing the spatial and temporal variation of pollution in a system. One possible candidate that could be modeled as a conservative pollutant would be salinity.

#### Exponential First-Order Decay

The modeling of the in-stream concentration below the point of discharge depends on the nature of the pollutant: for example, is the pollutant conservative and is settling a dominant process? For a conservative pollutant with negligible settling, the concentration can be determined simply from the equation above for  $c_0$ . For pollutants assumed to follow first order decay, the stream velocity and decay parameters must be

estimated. For a known cross-sectional area,  $A_c$  and flow rate,  $Q$ , the stream velocity  $U$  can be estimated as follows:

$$U = \frac{Q}{A_c} \quad \text{Eqn. 2}$$

$A_c$  is calculated based on user-entered data correlating stage to flow and width. The concentration of the pollutant at some distance downstream,  $L$ , from the point of discharge is the concentration as calculated in equation above for  $c_0$ , multiplied by a first order decay term, based on the decay parameter  $k$  (/day), as shown in the following equation.

$$c = c_0 e^{-\frac{kL}{U}} \quad \text{Eqn. 3}$$

## Dissolved Oxygen and Biochemical Oxygen Demand

First, the oxygen saturation  $OS$  for each segment is estimated as a function of water temperature  $T$ ,

$$OS = 14.54 - (0.39T) + (0.01T^2) \quad \text{Eqn. 4}$$

and an analytical solution of the classic Streeter-Phelps model is used to compute oxygen concentrations from point source loads of BOD.

$$O = OS - \left( \frac{k_a}{k_a - k_r} \right) \left( \exp^{-k_r(L/U)} - \exp^{-k_a(L/U)} \right) BOD_{IN} - \left( (OS - O_{IN}) \exp^{-k_a(L/U)} \right) \quad \text{Eqn. 5}$$

where  $k_d=0.4$ ;  $k_a = 0.95$ ; and  $k_r = 0.4$  are the decomposition, the reaction, and the re-aeration rates, respectively (1/day).  $L$  is the reach length (m),  $U$  the velocity of the water in the reach.  $O_{IN}$  is the oxygen concentration (mg/l) at the top of the reach and  $BOD_{IN}$  is the concentration of the pollutant loading (mg/l) at the top of the reach.

BOD removal is given as,

$$BOD = BOD_{IN} \left( \exp^{-k_{BOD}(L/U)} \right) \quad \text{Eqn. 6}$$

The removal rate,  $k_{BOD}$ , is influenced by several factors, including temperature, settling velocity of the particles, and water depth. Chapra (1997) provides an expression for  $k_{BOD}$  as,

$$k_{BOD} = k_{d20}^{(1.047(T-20))} + \frac{v_s}{H} \quad \text{Eqn. 7}$$

where  $T$  is the water temperature (in degrees Celsius),  $H$  is the depth of the water, and  $v_s$  is the settling velocity. In addition,  $k_{d20}$  is defined (at a reference temperature of 20 degrees Celsius) as,

$$k_{d20} = 0.3 \left( \frac{H}{8} \right)^{-0.434} \quad 0 \leq H \leq 2.4m$$

$$k_{d20} = 0.3$$

$$H > 2.4m$$

## Water Temperature

Water temperature for a river node is computed using simple mixing--a weighted average of the water temperatures in the inflows from upstream, tributaries, return flows, and groundwater inflows.

As water flows downstream, the water temperature can change due to gains of heat from net solar short-wave radiation and atmospheric long-wave radiation, and losses of heat due to conduction, convection and evaporation.

The volume for a reach is defined by its length and average cross sectional area, and the assumption of steady state during the time step. A heat balance equation is written for each reach on the river.

$$\begin{aligned} \frac{dT}{dt} = & \frac{Q_i}{V} T_i + \frac{Rn}{\rho C_p H} + \left( \frac{\sigma (T_{air} + 273)^4 a \sqrt{e_{air}}}{\rho C_p H} \right) - \frac{Q_i}{V} T_{i+1} \\ & - \frac{\varepsilon \sigma (T_{i+1} + 273)^4}{\rho C_p H} - \frac{f(u)(T_{i+1} - T_{air})}{\rho C_p H} - \frac{g(u)D}{\rho C_p H} \end{aligned}$$

where the first term on the right-hand side is the upstream heat input to the stream segment with constant volume,  $V$  (m<sup>3</sup>) expressed as a relationship of flow,  $Q_i$  (m<sup>3</sup>/time) and temperature,  $T_i$  at the upstream node. The second term is the net radiation input,  $Rn$ , to the control volume with density  $\rho$ , and  $C_p$  the specific heat of water and  $H$  (m), the mean water depth of the stream segment. The third term is the atmospheric long-wave radiation into the control volume, with the Stefan-Boltzmann constant,  $T_{air}$  the air temperature (C),  $a$ , a coefficient to account for atmospheric attenuation and reflection and the air vapor pressure,  $e_{air}$ . The fourth term is the heat leaving the control volume, while the fifth term is the long-wave radiation of the water that leaves the control. The sixth and seventh terms are the conduction of heat to the air and the removal of heat from the river due to evaporation. The terms  $f(u)$  and  $g(u)$  are wind functions, and  $D$  is the vapor pressure deficit. The temperature,  $T_{i+1}$  is solved for the downstream node with a fourth-order Runge-Kutta and is the boundary condition temperature for the next reach (after mixing of any other inflows into the downstream node is considered).

## QUAL2K

Surface water quality can be modeled using the US EPA model QUAL2K, version 2.04. QUAL2K, developed by Dr. Steve Chapra and his grad students at Tufts University, provides for much more detailed water quality modeling than WEAP--including diurnal simulations and modeling of nitrogen, phosphorous, sedimentation, algae, pH and pathogens. QUAL2K consists of an Excel workbook (QUAL2K.xls) that provides the front-end to the model and a Fortran executable (Q2KFortran2\_04.exe) that runs the calculations. You may use the workbook to create and edit QUAL2K datasets (saved in files with the extension .q2k), run the model, and view the results, in tables and graphs. The full details of QUAL2K and its use are beyond the scope of this document. Refer to the QUAL2K User Guide (Q2KDocv2\_04.pdf) for full details of the model and Excel interface.

In order to link QUAL2K to WEAP, you will first need to prepare and calibrate a QUAL2K file outside of WEAP, using the QUAL2K interface (an Excel spreadsheet, provided in the WEAP directory). Because QUAL2K is so detailed, preparation of an initial QUAL2K data file will entail significant effort.

The following description comes from the official QUAL2K page on the US EPA website: <http://www.epa.gov/ATHENS/wwqtsc/html/qual2k.html>



QUAL2K (or Q2K) is a river and stream water quality model that is intended to represent a modernized version of the QUAL2E (or Q2E) model (Brown and Barnwell 1987). Q2K is similar to Q2E in the following respects:

One dimensional. The channel is well-mixed vertically and laterally.

- Steady state hydraulics. Non-uniform, steady flow is simulated.
- Diurnal heat budget. The heat budget and temperature are simulated as a function of meteorology on a diurnal time scale.
- Diurnal water-quality kinetics. All water quality variables are simulated on a diurnal time scale.
- Heat and mass inputs. Point and non-point loads and abstractions are simulated.

The QUAL2K framework includes the following new elements:

Software Environment and Interface. Q2K is implemented within the Microsoft Windows environment. It is programmed in the Windows macro language: Visual Basic for Applications (VBA). Excel is used as the graphical user interface.

- Model segmentation. Q2E segments the system into river reaches comprised of equally spaced elements. In contrast, Q2K uses unequally-spaced reaches. In addition, multiple loadings and abstractions can be input to any reach.
- Carbonaceous BOD speciation. Q2K uses two forms of carbonaceous BOD to represent organic carbon. These forms are a slowly oxidizing form (slow CBOD) and a rapidly oxidizing form (fast CBOD). In addition, non-living particulate organic matter (detritus) is simulated. This detrital material is composed of particulate carbon, nitrogen and phosphorus in a fixed stoichiometry.
- Anoxia. Q2K accommodates anoxia by reducing oxidation reactions to zero at low oxygen levels. In addition, denitrification is modeled as a first-order reaction that becomes pronounced at low oxygen concentrations.
- Sediment-water interactions. Sediment-water fluxes of dissolved oxygen and nutrients are simulated internally rather than being prescribed. That is, oxygen (SOD) and nutrient fluxes are simulated as a function of settling particulate organic matter, reactions within the sediments, and the concentrations of soluble forms in the overlying waters.
- Bottom algae. The model explicitly simulates attached bottom algae.
- Light extinction. Light extinction is calculated as a function of algae, detritus and inorganic solids.
- pH. Both alkalinity and total inorganic carbon are simulated. The river's pH is then simulated based on these two quantities.
- Pathogens. A generic pathogen is simulated. Pathogen removal is determined as a function of temperature, light, and settling.

### Distance Markers

[Distance markers](#) are used to match WEAP and QUAL2K reaches, as well as point and diffuse inflows and outflows. You must be careful that the locations in the .q2k file (entered on the "Reach" worksheet in QUAL2K) match the distance markers entered in WEAP, especially for tributary inflow points. However, the reach boundaries in QUAL2K do not need to match the reach boundaries in WEAP, because point and diffuse source data are entered according to locations, not reaches.

Each QUAL2K reach is subdivided into 1 or more equal-length computational elements. Results are calculated for each element. When WEAP is reading the QUAL2K results, it must find the closest matching QUAL2K computational element for each WEAP node and reach. For nodes, WEAP chooses the closest computational element at or downstream of the node. For reaches, WEAP chooses the closest element to the middle of the WEAP reach, as long as it isn't upstream of the reaches upstream boundary.

## **Point Sources**

Point sources correspond to inflows to and outflows from river nodes, including inflows from demand sites, wastewater treatment plants, tributaries (only if that tributary is not also modeled in QUAL2K) and net decreases in reservoir storage, and outflows to demand site (withdrawals), diversions, reservoir evaporation, and net increases in reservoir storage. The location of the QUAL2K point source is the distance marker for the WEAP node. For inflows, QUAL2K needs to know the concentration of each constituent in the inflow; for outflows, the concentration is irrelevant. See [Reservoirs and QUAL2K](#) for details on how reservoirs are handled.

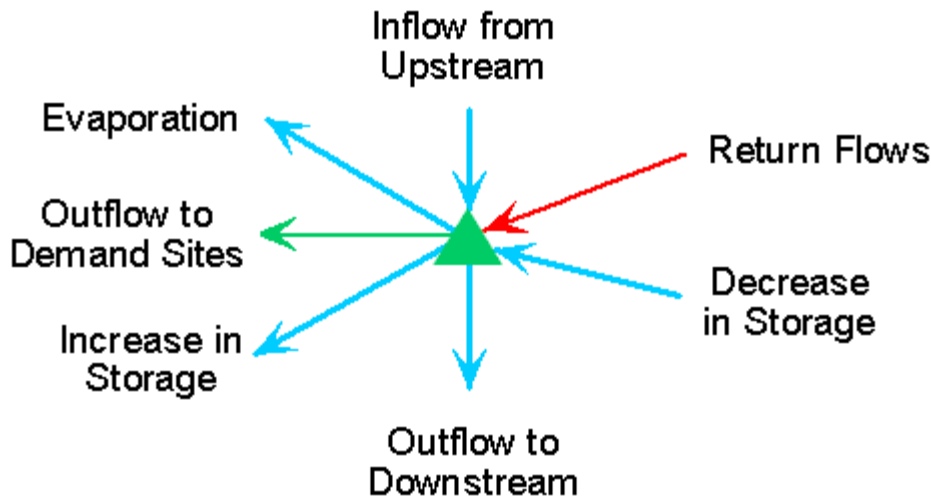
## **Diffuse Sources**

Diffuse sources correspond to inflows to and outflows from river reaches, including inflows from groundwater and surface water (not tributaries), and outflows to groundwater and evaporation. The upstream and downstream boundaries of a QUAL2K diffuse source are the upstream and downstream distance markers of the corresponding WEAP reach. For inflows, QUAL2K needs to know the concentration of each constituent in the inflow; for outflows, the concentration is irrelevant.

## **Reservoirs and QUAL2K**

No attempt is made in either WEAP or QUAL2K to model water quality in reservoirs and lakes, due to uncertainties in vertical and longitudinal stratification and other complex processes. Additionally, QUAL2K does not allow for operable reservoirs whose storage can vary over time. (It does include sharp-crested weirs, but these are simple structures that are not operated.) For these reasons, when modeling water quality on a river with a reservoir, you might want to consider modeling it in two sections--above the reservoir and below the reservoir.

Because QUAL2K does not consider reservoir storage and its effects on water quality, outflow concentrations are calculated simply as the weighted average of the inflows in a single time step, as described in [Simple Mixing](#). Inflows include inflows from upstream and demand site and wastewater treatment plant return flows into the reservoir; outflows include outflows to downstream, evaporation and withdrawal by demand sites. A net decrease in storage is considered to be an inflow; a net increase in storage is an outflow. For purposes of mixing, the water quality concentration of the "inflow" from a decrease in storage is assumed to be the water quality flowing out of the reservoir from the previous time step.



Here is the simple mass balance equation (inflow = outflow):

$$\begin{aligned}
 & UpstreamInflow_{Res} + \sum_{DS} DSReturnFlow_{DS,Res} + \sum_{TP} TPReturnFlow_{TP,Res} + StorageDecrease_{Res} \\
 & = DownstreamOutflow_{Res} + Evaporation_{Res} + \sum_{DS} DSTransLinkInflow_{Res,DS} + StorageIncrease_{Res}
 \end{aligned}$$

## Running QUAL2K

Once you have [selected QUAL2K as the calculation method and linked WEAP's constituents to QUAL2K's](#), and entered water quality data for river [headflows](#), [surface water](#) and [groundwater](#) inflows, [climate](#), [distance markers](#) and wastewater [generation](#) and [treatment](#), WEAP will be able to send data to QUAL2K, run QUAL2K, and retrieve results for each time step.

WEAP will send the following data to QUAL2K (listed by worksheet name):

- **QUAL2K:** River name, Month, Day and Year of simulation
- **Headwater:** flow rate and water quality of headflow
- **Air Temperature**
- **Dew Point Temperature**
- **Wind Speed**
- **Cloud Cover**
- **Shade**
- **Point Sources:** inflow rates and water quality from demand sites, wastewater treatment plants, tributaries (only if that tributary is not also modeled in QUAL2K) and net decreases in reservoir storage, and outflow rates from demand site withdrawals, diversions, reservoir evaporation, and net increases in reservoir storage.
- **Diffuse Sources:** inflow rates and water quality from groundwater and surface water (not tributaries), and outflow rates to groundwater and evaporation.

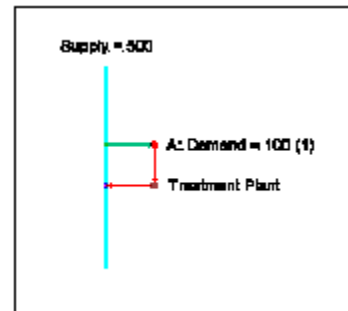
After running the QUAL2K calculations, WEAP will read the following results (listed by worksheet name):

- **Temperature Output:** mean water temperature
- **WQ Output:** all other water quality constituents

## Water Quality Example Calculations

This example illustrates how WEAP calculates instream water quality. The section of the river modeled is 100 km, with a water temperature throughout of 15 °C. The river headflow of 500 units contains initial concentrations of BOD ( $BOD_{IN} = 5$  mg/l), DO ( $O_{IN} = 8$  mg/l), Salt (2 mg/l) and TSS (20 mg/l). Salt is a conservative

constituent, so it will not decay. TSS follow first-order decay, with a decay rate of 0.25 (/day). The demand site withdraws 100 units, consumes 50%, and returns 50% (50 units) to the wastewater treatment plant, with the following concentrations: BOD (20 mg/l), DO (3 mg/l), Salt (10 mg/l) and TSS (5 mg/l). The wastewater treatment plant removes 90% of the BOD, 0% of salt and TSS, and the outflow concentration of DO is 4 mg/l. 10% of the water evaporates in processing, so 90% of the inflow (45 units) returns to the river.



### Reach Below Headflow

The initial concentrations of non-conservative pollutants will decay along the reach below the headflow. If the reach is 38.8 km long, and the water velocity is 15.61 m/s, it will take 25 seconds to traverse the reach.

### Salinity

Salt is conservative, so it will not decay. Therefore, the concentration at the end of the first reach will be the same as at the beginning: 2 mg/l.

### TSS

TSS is simulated with first-order decay. In Eqn. 3, if  $c_0 = 20$  mg/l,  $k = 0.25/\text{day}$ ,  $L = 38.8$  km, and  $U = 196.36$  km/day; then  $c = 19.036$  mg/l.

### DO

In Eqn. 4, if  $T = 15$ ; then  $OS = 10.94$ .

It follows from Eqn. 5 that if  $k_d = 0.4/\text{day}$ ,  $k_a = 0.95/\text{day}$ ,  $k_r = 0.4/\text{day}$ ,  $L = 38.8$  km,  $U = 196.36$  km/day,  $BOD_{IN} = 5$  mg/l, and  $O_{IN} = 8$  mg/l; then  $O = 8.157$  mg/l.

### BOD

Using Eqn. 7 with  $\nu_s = 0.25$ ,  $H = 4\text{m}$  (i.e.,  $k_{d20} = 0.3$ ), and  $T = 15^\circ\text{C}$ ;  $k_{rBOD} = 0.288$

Then, using Eqn. 6 with  $k_{rBOD} = 0.288$ ,  $L = 38.8$  km,  $U = 196.36$  km/day, and  $BOD_{IN} = 5$  mg/l; then  $BOD = 4.72$  mg/l

### Withdrawal Node

## 7.5 Water Quality

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Removing water from the river does not change the concentration of the water, it just reduces the volume. Therefore, the concentrations immediately below this node will be the same as flowed into the node from the reach above.

### Salinity

Salt is conservative, so it will not decay. Therefore, the concentration at the end of the reach will be the same as at the beginning: 2 mg/l.

### TSS

Using Eqn. 3, with  $c_0 = 19.036$  mg/l,  $k = 0.25$ /day,  $L = 20.4$  km, and  $U = 180$  km/day; then  $c = 18.504$  mg/l

### DO

Using Eqn. 4 with  $T = 15$ ;  $OS = 10.94$

Then, using Eqn. 5 with  $k_d = 0.4$ /day;  $k_a = 0.95$ /day,  $k_r = 0.4$ /day,  $L = 20.4$  km,  $U = 180$  km/day,  $BOD_{\infty} = 4.72$  mg/l,  $O_{\infty} = 8.157$  mg/l; then  $O = 8.243$  mg/l

### BOD

Using Eqn. 7 with  $v_s = 0.25$ ,  $H = 3.6$  m (i.e.,  $k_{d20} = 0.3$ ),  $T = 15^\circ\text{C}$ ; then  $k_{\text{rBOD}} = 0.288$ .

### Demand Site

Concentrations of pollution in demand site return flows does not depend on concentrations of inflows to the demand site. Therefore, the concentration of the river water supply is irrelevant.

In this example, demand site pollution generation is specified as the concentration in the return flow. The demand site withdraws 100 units, consumes 50%, and returns 50% (50 units) to the wastewater treatment plant with the following concentrations: BOD (20 mg/l), DO (3 mg/l), Salt (10 mg/l) and TSS (5 mg/l).

The mass of each pollutant is calculated as,

$$\text{MonthlyPollutionGenerated}_{DS,p,m} = \text{DemandSiteReturnFlow}_{DS,m} \times \text{ReturnFlowConcentration}_{DS,m,p}$$

### Salinity

$$\text{Mass} = 50 * 10 = 500$$

### TSS

$$\text{Mass} = 50 * 5 = 250$$

### DO

$$\text{Mass} = 50 * 3 = 150$$

### BOD

$$\text{Mass} = 50 * 20 = 1000$$

### Wastewater Treatment Plant

The wastewater treatment plant removes 90% of the BOD, 0% of salt and TSS, and the outflow concentration of DO is 4 mg/l. 10% of the water evaporates in processing, so 90% of the inflow (45 units) returns to the river. Evaporation concentrates the pollutants somewhat, causing the concentrations to be higher (by 11% in this case) than they would with no evaporation. The removal rate (e.g., 90% of BOD) refers to the mass of pollutant, not the concentration.

### Salinity

$$\text{TreatmentPlantPollOutflow}_{TP,p} = (1 - \text{RemovalRate}_{TP,p}) \times \text{TreatmentPlantPollInflow}_{TP,p}$$

$$\text{Mass outflow} = (1 - 0) \times 500 = 500$$

**TSS**

$$\text{Mass outflow} = (1 - 0) \times 250 = 250$$

**BOD**

$$\text{Mass outflow} = (1 - 0.9) \times 1000 = 100$$

**DO**

DO is specified as a concentration, rather than a removal rate. Therefore, the inflow of DO is not used.

$$\text{TreatmentPlantPollOutflow}_{TP,p} = \text{OutflowConcentration}_{TP,p} \times \text{TreatmentPlantReturnFlow}_{TP,p}$$

$$\text{Mass outflow} = 4 \times 45 = 180$$

**Reach below Withdrawal Node****Salinity**

Salt is conservative, so it will not decay. Therefore, the concentration at the end of the reach will be the same as at the beginning: 2 mg/l.

**TSS**

Using Eqn. 3, with  $c_0 = 19.036$  mg/l,  $k = 0.25/\text{day}$ ,  $L = 20.4$  km,  $U = 180$  km/day; then  $c = 18.504$  mg/l.

**DO**

Using Eqn. 4, with  $T = 15$ ; then  $OS = 10.94$ .

Using Eqn. 5 with  $k_d = 0.4/\text{day}$ ,  $k_a = 0.95/\text{day}$ ,  $k_r = 0.4/\text{day}$ ,  $L = 20.4$  km,  $U = 180$  km/day,  $BOD_{\infty} = 4.72$  mg/l, and  $O_{\infty} = 8.157$  mg/l; then  $O = 8.243$  mg/l

**BOD**

Using Eqn. 7 with  $v_s = 0.25$ ,  $H = 3.6$  m (i.e.,  $k_{d20} = 0.3$ ),  $T = 15^\circ\text{C}$ ; then  $k_{rBOD} = 0.288$ .

Using Eqn. 6 with  $k_{rBOD} = 0.288$ ,  $L = 20.4$  km,  $U = 180$  km/day,  $BOD_{\infty} = 4.72$  mg/l; then  $BOD = 4.57$  mg/l

**Return Flow Node**

Treated effluent from the wastewater treatment plant mixes with the river water, using the following weighted average:

$$c = \frac{Q_w c_w + Q_r c_r}{Q_w + Q_r} = \frac{M_w + Q_r c_r}{Q_w + Q_r} \quad \text{Eqn. 8}$$

$c$  is the new concentration (mg/l)

$Q_w$  is the inflow of wastewater = 45

$Q_r$  is the flow from upstream = 400

$C_w$  is the concentration of pollutant in the wastewater

$C_r$  is the concentration of pollutant in the flow from upstream

$M_w = Q_w C_w$ , the mass of pollutant in wastewater

## 7.5 Water Quality

### Salinity

With  $M_w = 500$  and  $C_r = 2$  mg/l; then  $c = 2.92$  mg/l in Eqn. 8.

### TSS

With  $M_w = 250$  and  $C_r = 18.5$  mg/l; then  $c = 17.2$  mg/l

### DO

With  $M_w = 180$  and  $C_r = 8.24$  mg/l; then  $c = 7.81$  mg/l

### BOD

With  $M_w = 100$  and  $C_r = 4.57$  mg/l; then  $c = 4.33$  mg/l

### Reach below Return Flow Node

#### Salinity

Salt is conservative, so it will not decay. Therefore, the concentration at the end of the reach will be the same as at the beginning: 2.92 mg/l.

#### TSS

TSS uses first-order decay. Using Eqn. 3 with  $c_0 = 17.2$  mg/l,  $k = 0.25$ /day,  $L = 40.8$  km, and  $U = 187.92$  km/day; then  $c = 16.29$  mg/l

#### DO

Using Eqn. 4 with  $T = 15$ ; then  $OS = 10.94$

Using Eqn. 5 with  $k_d = 0.4$ /day,  $k_a = 0.95$ /day,  $k_r = 0.4$ /day,  $L = 40.8$  km,  $U = 187.92$  km/day,  $BOD_{\infty} = 4.33$  mg/l, and  $O_{\infty} = 7.81$  mg/l; then  $O = 8.07$  mg/l

#### BOD

Using Eqn. 7 with  $\nu_s = 0.25$ ,  $H = 3.78$ m (i.e.,  $k_{d20} = 0.3$ ), and  $T = 15$ C; then  $k_{rBOD} = 0.291$

Using Eqn. 6 with  $k_{rBOD} = 0.288$ ,  $L = 40.8$  km,  $U = 187.92$  km/day, and  $BOD_{\infty} = 4.33$  mg/l; then  $BOD = 4.066$  mg/l

Here is a summary of surface water quality:

Node or Reach	Volume	Reach Length (km)	Velocity (m/s)	Velocity (km/day)	Temp (°C)	Salinity (mg/l)	TSS (mg/l)	DO (mg/l)	BOD (mg/l)
Headflow	500					2	20	8	5
At End of Reach below headflow	500	38.8	2.27	196.36	15	2	19.04	8.16	4.72
Withdrawal Node	400					2	19.04	8.16	4.72
At End of Reach below	400	20.4	2.08	180	15	2	18.51	8.24	4.57
Return flow node	445					2.92	17.20	7.81	4.33
At End of Reach below	445	40.8	2.17	187.92	15	2.92	16.29	8.07	4.07

## 7.6 Cost Calculations

### 7.6.1 Costs

For each individual item (such as demand nodes, transmission links, treatment plants and reservoirs), costs can be entered as capital, fixed operating, and variable operating costs. Capital and fixed operating costs are entered as an annual cost stream (capital costs typically use the [LoanPayment](#) function), whereas fixed operating costs are entered as a cost per unit of water (e.g., delivered, pumped, released or treated).

$$Cost_{Item} = CapitalCost_{Item} + FixedOperatingCost_{Item} + VariableOperatingCost_{Item}$$

$$VariableOperatingCost_{Item} = VariableCostRate_{Item} * Flow_{Item}$$

where CapitalCost and FixedOperatingCost are data.

Annual capital and fixed operating costs are spread evenly over the time steps of the year to get a cost per time step.

### 7.6.2 Benefits

Benefits can also be entered for each individual item, both as fixed (annual) and variable (per unit flow).

$$Benefit_{Item} = FixedBenefit_{Item} + VariableBenefit_{Item}$$

$$VariableBenefit_{Item} = VariableBenefitRate_{Item} * Flow_{Item}$$

where FixedBenefit is data.

Annual Benefits are spread evenly over the time steps of the year to get a Benefit per time step.

### 7.6.3 System Costs and Benefits

In addition to itemized costs and Benefits, overall uncategorized system capital and operating costs and benefits can be entered as a whole.

### 7.6.4 Net Cost

Net cost is the total cost, net of any benefit.

$$NetCost = SystemCost + \sum Cost_{Item} - SystemBenefit - \sum Benefit_{Item}$$

### 7.6.5 Net Present Value (NPV)

The net present value of future expenditures for capital and operations costs, net of any benefits. The NPV is the sum of the net present value calculation of the net costs for each of the future years modeled in the scenario

NPV is the future stream of benefits and costs converted into equivalent values today. This is done by discounting future benefits and costs using an appropriate discount rate, and subtracting the sum total of discounted benefits from the sum total of discounted costs. The discount rate is specified under the menu option General, Units, Monetary.



## 7.6 Cost Calculations

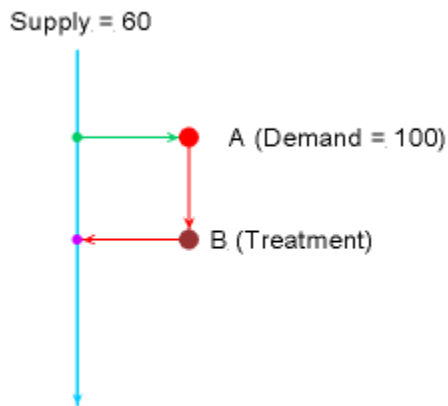
$$NPV = \sum [ NetCost_{Year} / ((1 + DiscountRate)^{(Year - BaseYear)}) ]$$

### 7.6.6 Average Cost of Water

The average cost of water is the net total cost per unit of water delivered to all demand site.

$$AverageCost = NetCost / \sum DS DemandSiteInflow_{DS}$$

### 7.6.7 Example



Costs are incurred for transmission of supply and treatment of wastewater. Demand Site A has a demand of 100 units, of which only 60 is satisfied from the river. Of the 60 units of supply, half are consumed by the demand site. The other half are sent to Treatment Plant B for treatment, which returns the treated wastewater to the river.

The cost to transmit supply from the river through the transmission link to the demand site is \$1000 per unit of water transmitted. The treatment plant was built in 2005 at a cost of \$50,000,000, financed through a 30-year loan with a fixed interest rate of 5%. In addition to capital costs (loan payments), the treatment plant incurs ongoing operating and maintenance costs every year. The fixed operating cost is \$200,000 per year for labor and maintenance fees; the variable operating cost is \$5000 per unit of water treated.

## Capital Cost

$$AnnualTreatmentCapitalCost = LoanPayment(50000000, 2005, 30, 5\%) = \$3,252,571.75$$

$$MonthlyTreatmentCapitalCost = AnnualTreatmentCapitalCost / 12 = \$271,047.65$$

## Operating Cost

### Transmission Link

$$MonthlyTransmissionOperatingCost = 60 * \$1000 = \$60,000$$

### Wastewater Treatment

$$\text{MonthlyTreatmentOperatingCost} = (\text{AnnualFixedTreatmentOperatingCost} / 12) + \text{MonthlyVariableTreatmentOperatingCost}$$

$$\text{AnnualFixedTreatmentOperatingCost} = \$200,000$$

$$\text{MonthlyVariableTreatmentOperatingCost} = 30 * \$5000 = \$150,000$$

$$\text{MonthlyTreatmentOperatingCost} = (\$200,000 / 12) + \$150,000 = \$166,666.67$$

### **Total Operating Cost**

$$\begin{aligned} \text{MonthlyTotalOperatingCost} &= \text{MonthlyTransmissionOperatingCost} + \\ \text{MonthlyTreatmentOperatingCost} &= \$60,000 + \$166,666.67 = \$226,666.67 \end{aligned}$$

### **Net Cost**

$$\begin{aligned} \text{MonthlyNetCost} &= \text{MonthlyTreatmentCapitalCost} + \text{MonthlyTotalOperatingCost} = \$271,047.65 + \\ &\$226,666.67 = \$497,714.32 \end{aligned}$$

$$\text{AnnualNetCost} = \text{MonthlyNetCost} * 12 = \$497,714.32 * 12 = \$5,972,571.80$$

### **Net Present Value (NPV)**

Assuming a base year of 2005, a time horizon of 30 years, a discount rate of 3%, and a constant demand and supply,

$$\text{NPV} = \text{AnnualNetCost}_{2005} / (1 + 3\%)^{(2005 - 2005)} + \text{AnnualNetCost}_{2006} / (1 + 3\%)^{(2006 - 2005)} + \dots + \text{AnnualNetCost}_{2034} / (1 + 3\%)^{(2034 - 2005)}$$

$$\text{NPV} = \$5,972,571.80 / 1.03^0 + \$5,972,571.80 / 1.03^1 + \dots + \$5,972,571.80 / 1.03^{29} = \$120,576,994.57$$

### **Average Cost of Water**

$$\text{AverageCost} = \$497,714.32 / 60 = \$8295.24 \text{ per unit of water supplied to demand site}$$

# 8 Advanced Topics

## 8.1 Linking to MODFLOW

*Note: linking WEAP to MODFLOW is an advanced feature.*

For situations where the built-in WEAP groundwater model is not sufficiently complex, there is the option to link a WEAP model to a MODFLOW model. MODFLOW is a three-dimensional finite-difference groundwater modeling platform created by the U.S. Geological Survey (USGS). When properly linked, data and results flow back and forth between WEAP and MODFLOW for each calculation timestep. With this tight coupling between the models, it is possible to study how changes in local groundwater levels affect the overall system (e.g., groundwater-stream interactions, pumping problems due to drawdown, lateral groundwater recharge) and vice versa (e.g., infiltration and abstraction). However, be advised that building and calibrating a MODFLOW model is not a trivial task, and the linkage to WEAP requires creating a GIS shape file to connect the WEAP elements to the MODFLOW cells.

The version of MODFLOW that can be linked to WEAP is MODFLOW-2000. (See <http://water.usgs.gov/nrp/gwsoftware/modflow2000/modflow2000.html> or <http://en.wikipedia.org/wiki/MODFLOW> for more information.) MODFLOW-2000 simulates steady and nonsteady flow in an irregularly shaped flow system in which aquifer layers can be confined, unconfined, or a combination of confined and unconfined. Flow from external stresses, such as flow to wells, areal recharge, evapotranspiration, flow to drains, and flow through river beds, can be simulated. Hydraulic conductivities or transmissivities for any layer may differ spatially and be anisotropic (restricted to having the principal directions aligned with the grid axes), and the storage coefficient may be heterogeneous. Specified head and specified flux boundaries can be simulated as can a head dependent flux across the model's outer boundary that allows water to be supplied to a boundary block in the modeled area at a rate proportional to the current head difference between a "source" of water outside the modeled area and the boundary block. MODFLOW is currently the most used numerical model in the U.S. Geological Survey for groundwater flow problems. In addition to simulating ground-water flow, the scope of MODFLOW-2000 has been expanded to incorporate related capabilities such as solute transport and parameter estimation.

In order to link a MODFLOW model to a WEAP model, you will first need to prepare and calibrate a MODFLOW model outside of WEAP. Because MODFLOW is so detailed, preparation of an initial MODFLOW model will entail significant effort. There are various software packages, both free and commercial, that can help you create a MODFLOW model:

- MODFLOW-GUI (USGS): <http://water.usgs.gov/nrp/gwsoftware/mfgui4/modflow-gui.html>
- Processing Modflow: <http://www.pmwin.net>
- Groundwater Modeling System (GMS): [http://en.wikipedia.org/wiki/GMS\\_\(software\)](http://en.wikipedia.org/wiki/GMS_(software))
- Visual MODFLOW: [http://en.wikipedia.org/wiki/Visual\\_MODFLOW](http://en.wikipedia.org/wiki/Visual_MODFLOW)

The ground-water flow equation is solved using the finite-difference approximation. The flow region is subdivided into blocks in which the medium properties are assumed to be uniform. In plan view the blocks are made from a grid of mutually perpendicular lines that may be variably spaced. Model layers can have varying thickness. A flow equation is written for each block, called a cell. Several solvers are provided for solving the resulting matrix problem; the user can choose the best solver for the particular problem. Flow-rate and cumulative-volume balances from each type of inflow and outflow are computed

for each time step. For more information about MODFLOW, see the [USGS MODFLOW-2000 home page](#), [Online Guide to MODFLOW](#), or the [MODFLOW User Guide](#).

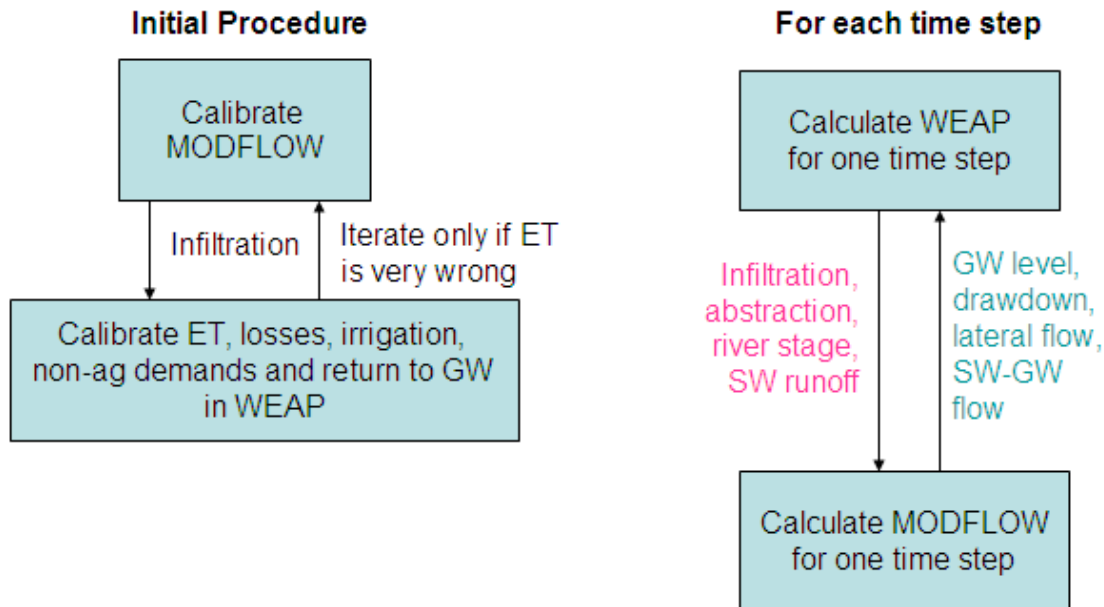
A MODFLOW model consists of many different "packages," most of which are optional. However, not all packages are used or allowed by WEAP.

- **Used by WEAP:** [BAS6](#) (Basic), [BCF6](#) (Block-Centered Flow), [CHD](#) (Constant-Head), [DIS](#) (Discretization), [DRN](#) (Drain), [HUF2](#) (Hydrogeologic Unit Flow), [LPF](#) (Layer Property Flow), [NAM](#) (Name), [OC](#) (Output Control), [RCH](#) (Recharge), [RIV](#) (River), [WEL](#) (Well). WEAP reads information from each of these, and will write new versions of the following: NAM, DIS, OC, RCH, RIV, WEL, as explained in [MODFLOW Link Technical Details](#). (The original files will not be changed.) WEAP only requires NAM, DIS, BAS6 and one of BCF6/HUF2/LPF--all other packages are optional.
- **Allowed but not used by WEAP:** [ADV2](#) (Advective-Transport Observation), [DE4](#) (Direct Solution), [ETS](#) (Evapotranspiration Segments), [GAGE](#), [GHB](#) (Ground-Water Flow Process General-Head Boundary), [HFB6](#) (Ground-Water Flow Process Horizontal Flow Barrier), [HYD](#) (HYDMOD), [IBS](#) (Interbed-Storage), [KDEP](#) (Hydraulic-Conductivity Depth-Dependence Capability of the HUF2), [LMG](#) (Link-AMG), [LVDA](#) (Model-Layer Variable-Direction Horizontal Anisotropy capability of the HUF2), [MNW1](#) (Multi-Node, Drawdown-Limited Well), [MULT](#) (multiplier), [PCG](#) (Preconditioned Conjugate-Gradient), [RES](#) (Reservoir), [SIP](#) (Strongly Implicit Procedure), [SOR](#) (Slice-Successive Over-Relaxation), [SUB](#) (Subsidence and Aquifer-System Compaction), [ZONE](#).
- **Commented out in new name file:** (Observation files might reference stress periods after the first, which no longer exist) [CHOB](#) (Constant-Head Flow Observation), [DROB](#) (Drain Observation), [DFOB](#) (Drain Return Observation), [GBOB](#) (General-Head-Boundary Observation), [HOB](#) (Head-Observation), [OBS](#) (Observation Process), [RVOB](#) (River Observation), [STOB](#) (Streamflow-Routing Observation), [LMT6](#) (Link-MT3DMS)
- **Not allowed:** ASP, [DAF](#) (DAFLOW surface-water), [DAFG](#) (DAFLOW ground-water), [DRT](#) (Drain Return), [LAK](#) (Lake), [EVT](#) (Evapotranspiration), [FHB](#) (Flow and Head Boundary), [PES](#) (Parameter Estimation), [SEN](#) (Sensitivity Process), [STR](#) (Streamflow-Routing). (Because DRT, EVT, LAK and STR duplicate calculations done by WEAP, allowing them would cause errors.)

For details on how each package is linked to WEAP, see [MODFLOW Link Technical Details](#).

The following flow chart illustrates the flow of information between WEAP and MODFLOW.

## WEAP-MODFLOW Linkage

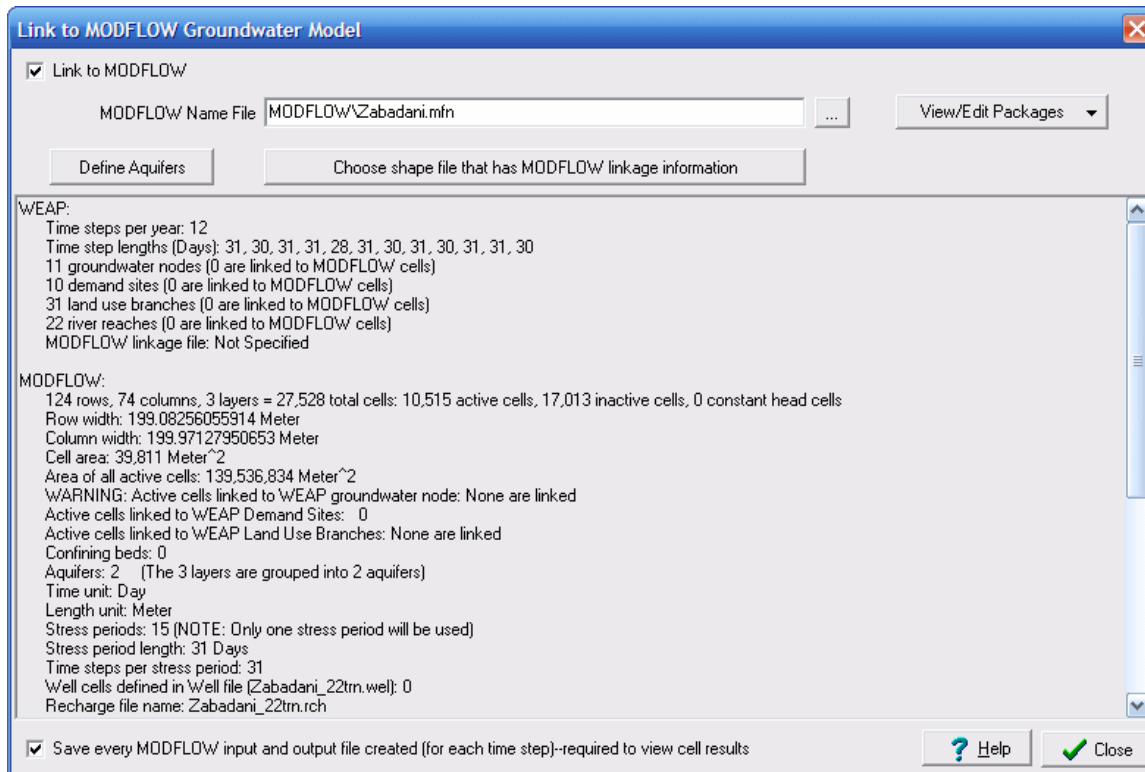


The following topics describe the steps required to link WEAP to MODFLOW: [Loading MODFLOW Model](#), [Linking MODFLOW Cells to WEAP Elements](#) and [Running the Models and View Results](#). Also, see [MODFLOW Link Technical Details](#).

### 8.1.1 Load MODFLOW Model

Create a subdirectory within your WEAP area's subdirectory and copy the MODFLOW input files into it. For example, for the Weaping River Basin area, you would create a directory C:\Program Files\WEAP\Weaping River Basin\MODFLOW (assuming WEAP was installed in C:\Program Files\WEAP), and copy the MODFLOW name file and all other package files into this MODFLOW directory. It is best not to copy any MODFLOW results files--any files in a subdirectory of a WEAP area will be included in WEAP's automatic version backup, and MODFLOW result files can be very large.

On the menu, choose Advanced, MODFLOW Link. Check the "Link to MODFLOW" check box, and then type in or browse for the [MODFLOW Name](#) filename. Typically the "Name" file has an extension of .NAM or .MFN. After WEAP loads the MODFLOW name file and its packages, it will display information about the MODFLOW model.



Make sure to check the box at the bottom ("Save every MODFLOW input and output file created") so that the results will be available to view in WEAP. (Because a complete set of new input files are created and kept for each timestep and scenario, you will be able to run them yourself in MODFLOW outside of WEAP, if you want to examine the results in more detail, or to make slight changes to the inputs. Note that any changes you make directly to these temporary input files will be lost the next time WEAP does its calculations, so you are advised to save them in another directory if you want to preserve them. The temporary filenames all start with "!MF!" to distinguish them from other files.)

The name file lists the other files that contain data for the various aspects of the MODFLOW model, such as recharge, pumping or river interactions. These files are called "packages." Use the "View/Edit Packages" button to view or edit the text file packages.

Note that initially WEAP does not know how to link the MODFLOW model to the WEAP model, as can be seen in the screen above, e.g., "WARNING: Active cells linked to WEAP groundwater node: None are linked."

If the MODFLOW model includes confined layers, you can group one or more layers into distinct aquifers for reporting purposes. For example, suppose that layer 2 in a 3-layer model has a confining bed below it. In this case, you would define two aquifers in WEAP: aquifer 1 containing layers 1 and 2, and aquifer 2 containing layer 3. Click the "Define Aquifers" button (see above) to specify how many aquifers exist and which layers correspond to which aquifers. This option is not available if the model has only one layer.

### 8.1.2 Link MODFLOW Cells to WEAP Elements

Each active MODFLOW cell is linked to one and only one WEAP groundwater node. (For a given row and column, every layer will be linked to the same groundwater node.) The linkage is established by a GIS shape file (.shp) that relates MODFLOW cells (by row and column number) with WEAP groundwater nodes (by name). The polygon shape file has one rectangular feature for each MODFLOW

## 8.1 Linking to MODFLOW

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cell (row, column) and must be loaded as a background layer on the Schematic. For example, for a MODFLOW model with 20 rows, 40 columns and 3 layers, there would be 800 features in the shape file. The attribute table for the shape file must have fields for row number, column number and WEAP groundwater node name. Other optional fields are described below. This shape file will also be used to display MODFLOW results in WEAP.

In its most simple mode, you can have all withdrawals from and returns to a groundwater node be distributed evenly from/to all linked cells. For example, the water pumped by a demand site from a groundwater node could come evenly from all cells linked to the groundwater node. Similarly, all return flow to the groundwater node could be spread evenly to all linked cells. If cells areas are not uniform, then water will be spread proportionally to area. Inactive cells would not be linked to a WEAP groundwater node.

Optionally, you may link WEAP demand sites or catchments to subsets of MODFLOW cells. In this case, the demand site pumping will be spread evenly over only the cells linked to that demand site, and the return flow will only go to those linked cells. This linkage is made in the same shape file, with each demand site or catchment name listed for each cell it is linked to. Because demand sites may overlap catchment areas, there will be two additional fields in the shape file's attribute table, one for WEAP demand site names and one for WEAP catchment names. In this way, a cell could be linked to both a demand site and a catchment. If two or more demand sites (or catchments) are linked to the same groundwater node, and each demand is linked to a different group of cells, then the pumping from one demand site will be evenly distributed to its linked cells, while the pumping from the other demand site will come from its cells.

For even more precision, you may link WEAP catchment land classes to smaller subsets of MODFLOW cells. In this case, flows to and from these branches will go to only the cells linked to those branches. These linkages are made in the same shape file, in an additional attribute field for the land use branch name. Land use branch names are listed for linked cells. For this option, the catchment must also be listed in its attribute field.

Pumping to satisfy demand sites or catchment land classes (irrigation) can either be handled as pumping in the well file, or as negative recharge in the recharge file. The pump layer is specified in the Data View--see [Demand Site Pump Layer](#) and [Land Use Pump Layer](#) variables. Specify layer=255 for a cell to have pumping come equally from all layers in that cell. To have withdrawals handled instead as negative recharge, specify layer=0. For all cells with pumping layer>0, WEAP will add cells to the well file if they are not already there. Use the [PumpLayer](#) function to specify fractions pumped from different layers, and to describe how these fractions vary by scenario and over time.

This GIS shape file can either be created by WEAP (see [Create MODFLOW Linkage Shape File](#)), or outside of WEAP using GIS software such as ArcGIS. If you create it using GIS software, copy it to the WEAP area subdirectory, and then load it as a vector layer on the Schematic. Now that you have added this shape file as a background layer and specified the MODFLOW name file, you are ready to link MODFLOW and WEAP. On the "Link to MODFLOW Groundwater Model" screen, click the "Choose shape file that has MODFLOW linkage information" button.

WEAP will try to guess which shape file layer contains the linkage information, by looking for a polygon layer with the number of features equal to the number of MODFLOW rows times the number of MODFLOW columns. Note that it should include every MODFLOW cell, including inactive cells. If it finds this layer, it will further try to guess which fields, based on their names, contain information for MODFLOW rows and columns and WEAP groundwater, river reach, catchment, land use branch, demand sites and pumping layers, based on the names of the fields in the shape files attribute table (.dbf).



If WEAP does not guess the correct shape file, choose it yourself by clicking on "Background Shape File with MODFLOW Linkage Information." In addition to the option here to create a new GIS layer (see next topic), you can also choose "Add existing shape file as new map layer". Once you had chosen or created a shape file, WEAP will display its contents in the grid below. If WEAP does not correctly guess any or all of the fields, choose them yourself. For the choice of Demand Site fields, you may choose more than one field. This would be necessary in cases where multiple demand sites withdrew or returned water to the same cells. As discussed above, only the Cell Row, Cell Column and Groundwater Name fields are required, depending on your model.

Choose shape file that has MODFLOW linkage information

Background Shape File with MODFLOW Linkage Information: linkage.shp

MODFLOW Cell Row Field: ROW

MODFLOW Cell Column Field: COL

Groundwater Name Field: Gw\_NODE

River Reach Name Field: RIVERREACH

Catchment Name Field: CATCHMENT

Land Use Name Field: LAND\_CLASS

Demand Sites Name Fields: DEMANDSITE

Buttons: Guess Groundwater Linkages, Guess Demand Site Linkages, Guess River Point Linkages, Guess Drain Cell Linkages

ROW	COL	R_C	Gw_NODE	DEMANDSITE	CATCHMENT	LAND_CLASS	DRAIN	RIVERREACH	HECTARES
16	17	16_17	groundwater		catchment	Forest		100	
16	18	16_18	groundwater		catchment	Forest		100	
16	19	16_19	groundwater		catchment	Forest		100	
16	20	16_20	groundwater		catchment	Forest		100	
15	1	15_1						100	
15	2	15_2						100	
15	3	15_3	groundwater		catchment	Grass		100	
15	4	15_4	groundwater		catchment	Grass		100	
15	5	15_5	groundwater		catchment	Grass		100	
15	6	15_6	groundwater	Artificial Recharge	catchment	Grass		100	
15	7	15_7	groundwater		catchment	Grass		100	
15	8	15_8	groundwater		catchment	Grass		100	

Buttons: ? Help, OK

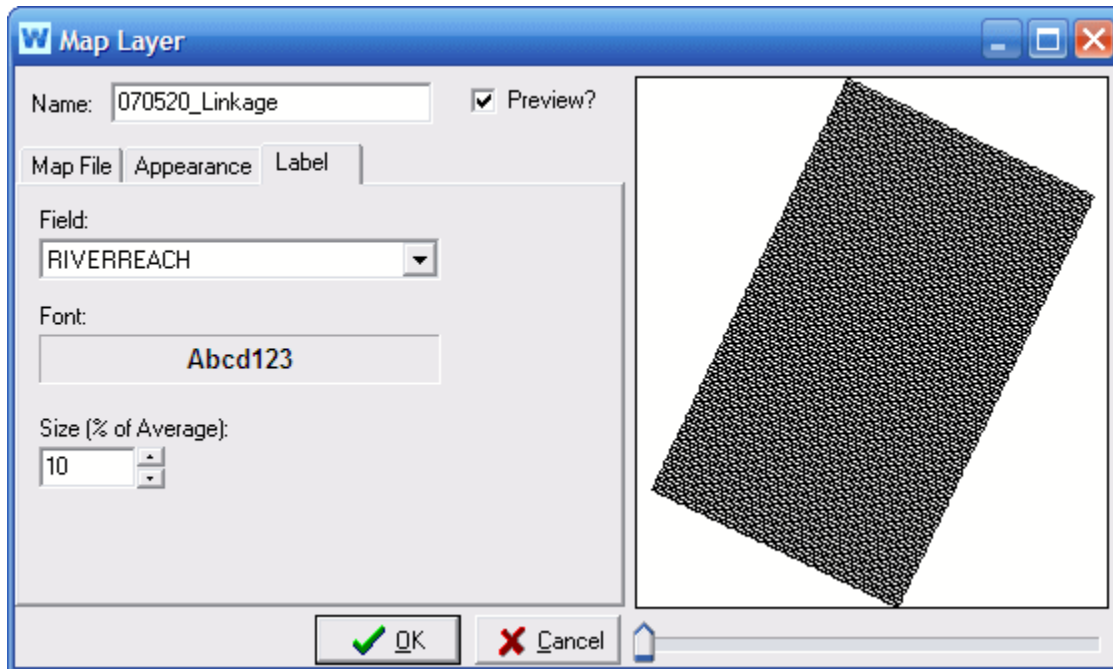
## Automatically Linking Groundwater Nodes, Demand Sites, River and Drain Cells

As a convenience, WEAP can try to guess which MODFLOW cells the WEAP groundwater nodes, demand sites and river reaches are linked to, based on proximity on the Schematic. Click the "Guess Groundwater Linkages" button for WEAP to assign the closest WEAP groundwater node to each active MODFLOW cell, which it will write into the shape file field specified by "Groundwater Name Field." (Every active cell will be linked.) Click the "Guess Demand Site Linkages" button for WEAP to assign the closest active MODFLOW cell to each WEAP Demand Site, which it will write into the shape file field specified by "Demand Site Names Field." (Each Demand Site will be linked to only one cell.) Click the "Guess River Point Linkages" button for WEAP to make its guesses for the cells in the River package, and "Guess Drain Cell Linkages" to have it guess WEAP river reaches for cells in the Drain package (if the [River \(RIV\)](#) and [Drain \(DRN\)](#) packages are included), which it will write into the shape file field specified by "River Reach Name Field." You are strongly advised to check which nodes and cells WEAP has guessed to make sure that they are correct. The easiest way to do this is to display the linkages on the Schematic. Go back to the Schematic and right click the MODFLOW Linkage shapefile (in the list of

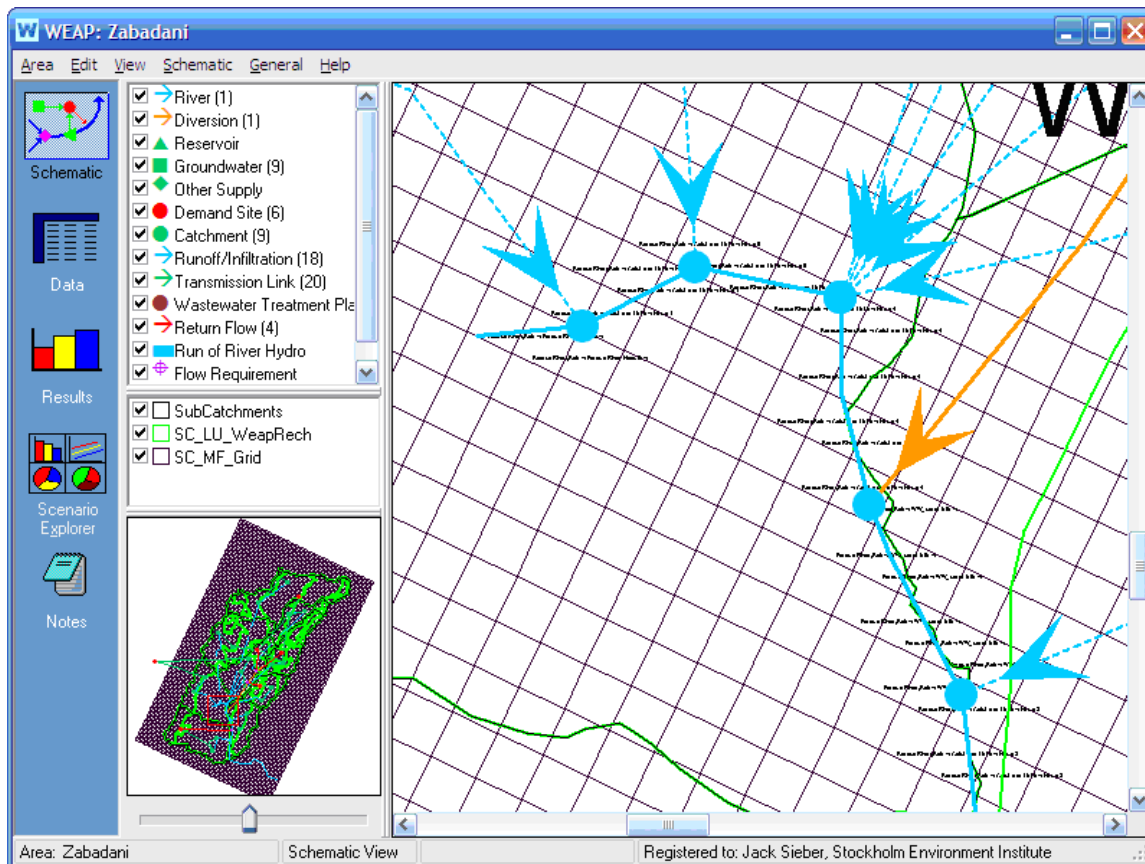


## 8.1 Linking to MODFLOW

background layers on the left), and choose "Set Label to," then select each of the fields corresponding to groundwater name, demand site name or river reach name.



When you return to the Schematic, you will now see the river cells labels with the WEAP reach. Zoom in so that you can verify that the cells are correctly labeled. If they are not correct, you must edit the shape file's attribute table (.dbf), either within WEAP ([Map Layer window](#)) or outside of WEAP (ArcView or Excel), to enter the correct reach names, in the format: River name, Reach name.



## Filling in Attribute Table to Link MODFLOW Cells to WEAP Elements

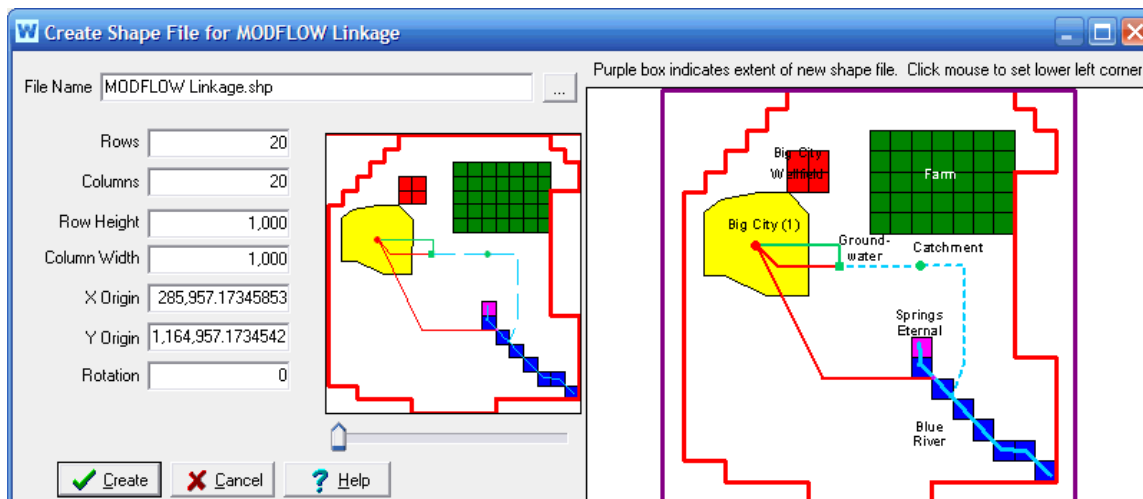
The shape file's associated attribute table has fields for row, column, and for linking various WEAP elements to each cell: GW, Catchment, Land\_Use, DemandSite and RiverReach. You will need to fill in this table, specifying which cells are linked to which WEAP elements. For example, the name of the WEAP groundwater node (in the Tutorial, the node is named "Groundwater") must be entered in the table in the column labeled GW for each cell that corresponds to the WEAP groundwater node. For the tutorial dataset, row 1, columns 6 through 17 correspond to the WEAP groundwater node, so you would enter "Groundwater" in table column GW for those cells. (As mentioned above, WEAP can guess which river reaches go with which cells, automatically filling values for the RiverReach column.)

There are several different ways to edit this table. To edit inside WEAP, go to the Map Layer window (double click on the layer name in the Schematic's Background Layer list), click the Edit button and type the values directly in the table. You can also edit the table in Microsoft Excel (the attribute table has the extension .dbf, e.g., "MODFLOW Linkage.dbf") or in any GIS program, such as ArcGIS. If you do have access to GIS software, this will be the easiest way to edit the table, but it *can* be done in WEAP. In order to edit the .dbf table in Excel or GIS, you must first close WEAP so that the file is not locked.

After you have chosen the shape file, specified which fields within it contain the linkage information and manually linked MODFLOW Cells to WEAP Elements, WEAP will be able to link the MODFLOW cells to the WEAP items. Verify on the MODFLOW linkage screen that all cells are linked.

### 8.1.3 Create MODFLOW Linkage Shape File

On the MODFLOW Link screen, click the "Choose shape file that has MODFLOW linkage information" button. On the next window, for "Background Shape File with MODFLOW Linkage Information," choose "< Create New Shape File >". The following window will appear:



WEAP automatically fills in the number of rows and columns, and the row height and column width, which it read from the MODFLOW [discretization file \(.DIS\)](#). However, the MODFLOW model does not contain information about the X,Y position (latitude and longitude) or the rotation angle of the cells. Therefore, you will need to enter this information yourself.

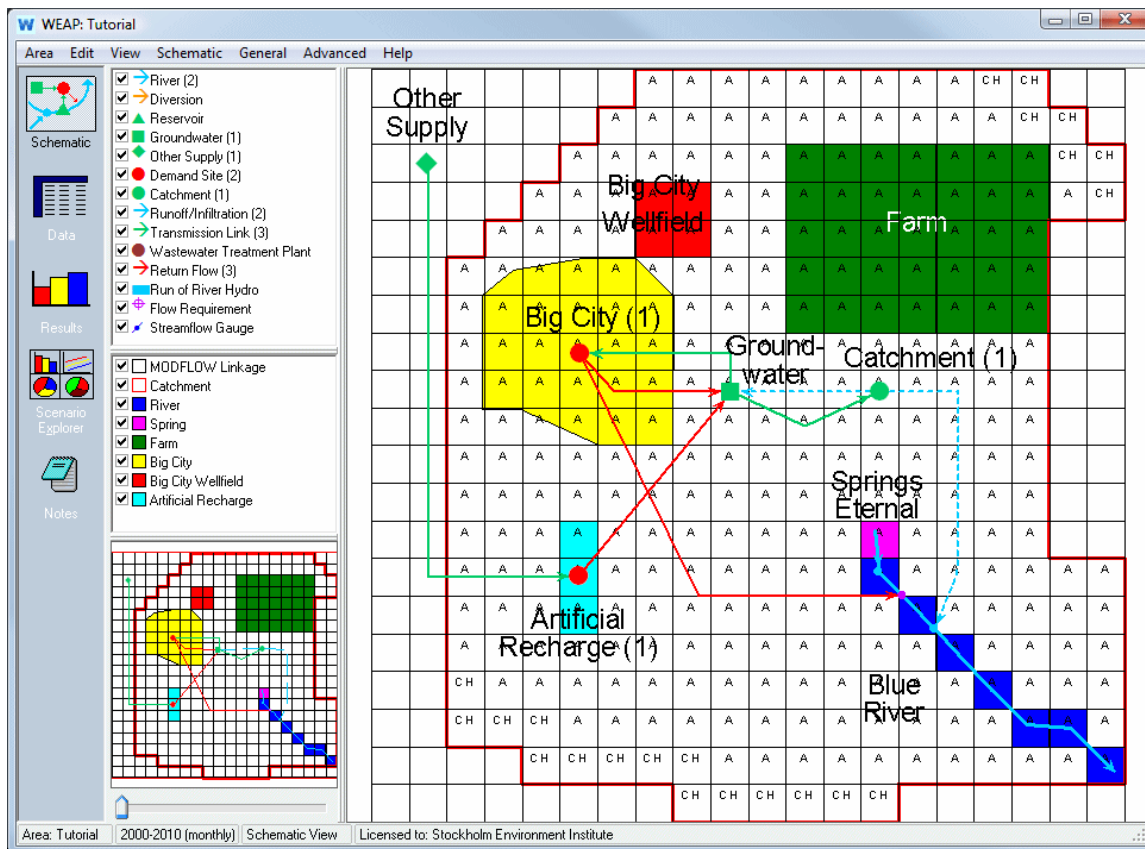
If you know the values for latitude, longitude and rotation, you can enter the numbers directly. If you do not know the values, you can click on the map to set the origin (lower left corner). You will see a purple box on the map that indicates the area of all the cells. As long as you hold down the left mouse key, the purple box will move with the mouse; release when the box is correctly positioned. You can zoom in on the map (using the zoom slider below the inset map on the left, the mouse wheel, or control-click and drag on the map) to help achieve greater precision in placement of the area.

The File Name box contains the filename for the new shape file. Either use the default filename ("MODFLOW Linkage.shp") or enter another name. Shape files always have a .shp extension. Click the Create button to create it.

After the shape file has been created, WEAP will display it and allow you to customize its appearance on the schematic. You will also need to fill in values in the shape file's attribute table for each linked cell--see ["Filling in Attribute Table to Link MODFLOW Cells to WEAP Elements"](#) above for information.

After customizing its appearance and possibly editing the attribute table, click the OK button. WEAP will add this layer to your Schematic and return you to the "Choose shape file that has MODFLOW linkage information " window.

**Tip:** Using information from the MODFLOW Basic (BAS) package, WEAP will create columns in the attribute table for each layer in the MODFLOW model, indicating which cells are active, inactive or have constant head. The column names are Is\_Active<N>, where <N> is the layer number (e.g., Is\_Active1, Is\_Active2). Active cells are marked with "A," constant head cells are marked with "CH," and inactive cells are blank. You can choose one of these columns to display as the label on the Schematic View to get a quick idea of the MODFLOW model.

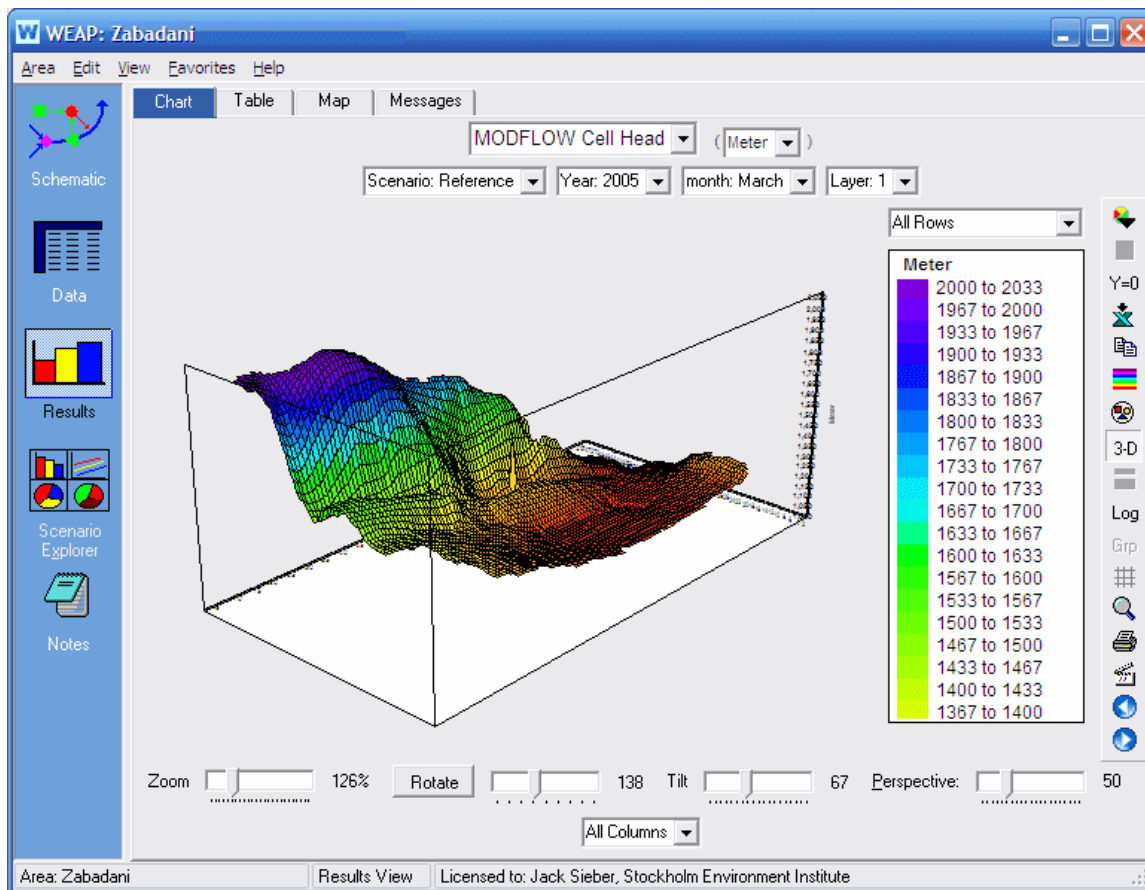


### 8.1.4 Run the Models and View Results

WEAP and MODFLOW are now dynamically coupled. WEAP will pause during calculations after each time step to load information (groundwater pumping and recharge, and river stage, disaggregated to cells) into newly created, temporary MODFLOW input files, run MODFLOW for one stress period/timestep, and then retrieve results (cell heads, and flows between surface and groundwater ([RIV](#) and [DRN](#) packages), aggregating cells to river reaches and groundwater nodes) from the MODFLOW output files.

Cell head and other MODFLOW results can be overlaid on the map, or displayed as a 3-dimensional surface. In the Results View, choose the variable Supply and Resources \ Groundwater \ MODFLOW \ Cell Head. On the chart tab, this will display by default as a 3-D surface showing head elevations for one layer, timestep, and scenario, with cells color coded by elevation. Using the mouse, click and drag on the surface to rotate it, or move the sliders below to manipulate it. Click the "Rotate" button to start it spinning.

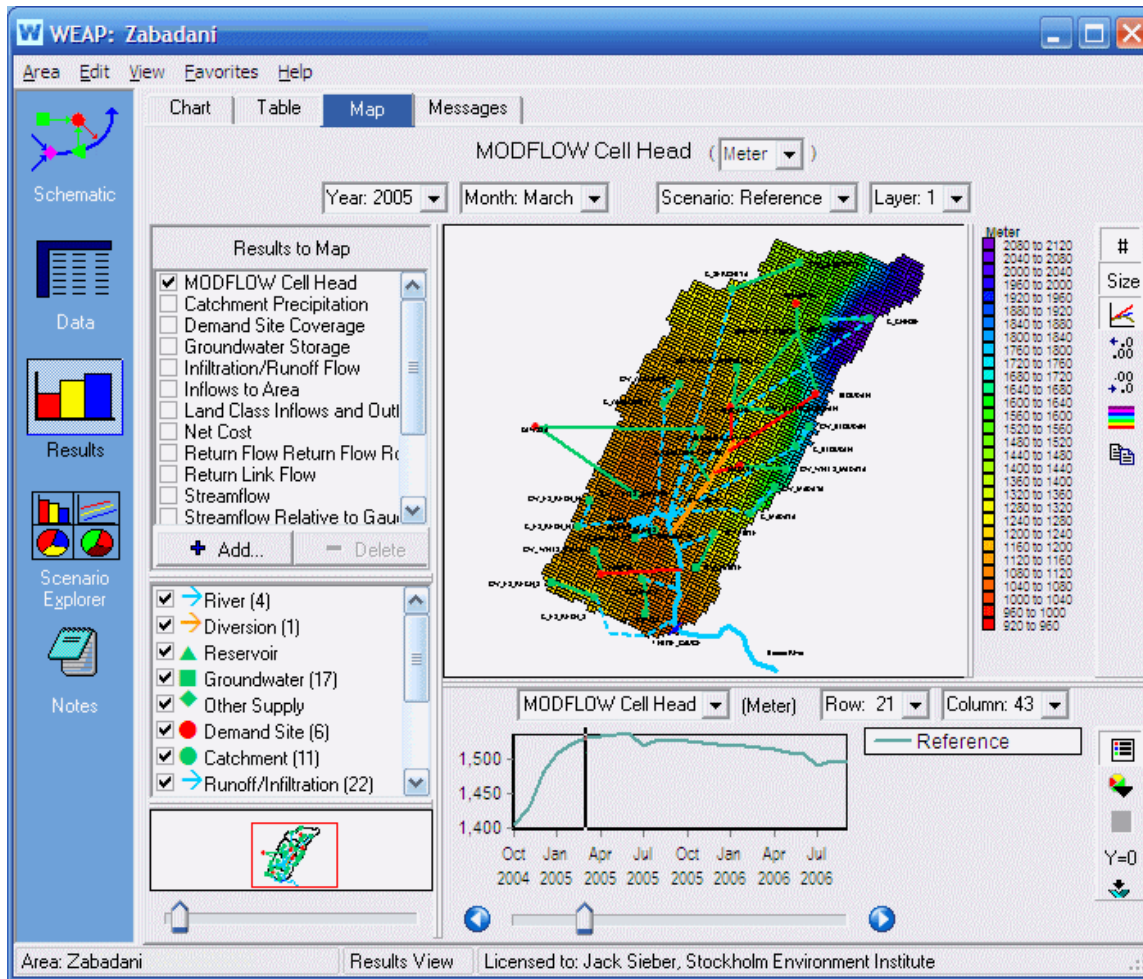
## 8.1 Linking to MODFLOW



To advance through time, click the blue arrows (in the toolbar to the right of the legend) to go forward or backward by a timestep, or click the animation icon just above the blue arrows to have it step through every timestep.

Click the Map tab to see cell head results displayed on the Schematic, again for one layer, timestep and scenario. Below the map, a chart shows how head results for a single cell vary over time, one line for each scenario. (It is recommended that you turn off the "Y=0" button to the right of this chart to magnify the changes in elevation over time.) Click any cell on the map to see it charted below. (Click and drag on the map and the chart will update as you move the mouse.) Click on any point in the chart to see all the cell heads for that timestep displayed on the map above. (Click and drag on the chart and the map will update as you move the mouse.) Click the blue arrows below the chart to step forward or back one timestep.

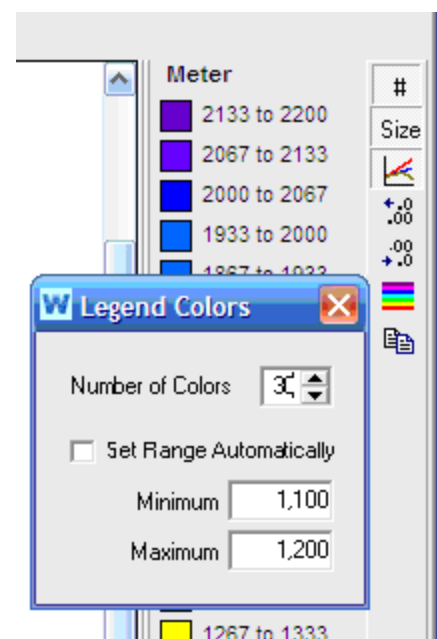




Even though the map only shows results for one timestep, the elevations associated with each color (e.g., green = 1600-1640 meters) do not change as you view other timesteps. This makes it easy to see how head changes over time.

By default, WEAP will automatically choose a rainbow of colors to span the entire range of values. If you would like to focus on a smaller range, you can set the range yourself manually. You may also change the number of colors used. Click the rainbow icon to the right of the chart or map to make changes.

In addition to cell head, you can also look at the following results from MODFLOW: Recharge, Pumping, Leakage to River, Drain flow, Flow Right Face (flow from the column to the right--higher column number), Flow Front Face (flow from the row below--higher row number), Flow Lower Face (flow from layer below--higher layer number), Constant Head Flow, Pump Head, and Number of Dry Cells. For each of these, you can see either the total volume per cell, or the depth in each cell (volume divided by cell area). For recharge, positive values represent inflow into the cell, whereas for pumping, drain flow and leakage to river, positive values represent outflow from the cell. For models with more than one layer, you can see the



## 8.1 Linking to MODFLOW

groundwater inflows and outflows (for WEAP groundwater nodes) reported by layer, on the "Groundwater Inflows and Outflows by Layer" report. For models with confining layers (and if you have [grouped layers into aquifers](#)), you can see the groundwater inflows and outflows (for WEAP groundwater nodes) reported by aquifer, on the "Groundwater Inflows and Outflows by Aquifer" report.

You can access MODFLOW results for individual cells in WEAP expressions using the `PrevTSValue` function. For example, `PrevTSValue(Cell Head[1,57,30])`. See [PrevTSValue](#) for more information.

### 8.1.5 MODFLOW Link Technical Details

When properly linked, data and results flow back and forth between WEAP and MODFLOW for each calculation timestep. The following description provides details of exactly what information is passed between WEAP and MODFLOW, and how the process happens.

WEAP reads information from the MODFLOW packages before calculations begin, along with the linkage information that links MODFLOW cells to WEAP objects. Thereafter, at each calculation timestep, WEAP will write out a new set of MODFLOW package files, run MODFLOW, then read the results from the MODFLOW output files. (If you select the option to save all MODFLOW input and output files, the new MODFLOW package files created will be named with !MF! as a prefix and a suffix unique for each scenario, year and timestep. For example, if the original Recharge filename is Zabadani.rch, the new Recharge file written for the Current Accounts (scenario number 1) for March 2000 would be !MF!Zabadani\_S01\_2000\_03.rch. This allows you to inspect or modify the input files and rerun MODFLOW yourself, outside of WEAP. This could be an aid in debugging. However, keep in mind that all these files will be deleted and recreated the next time WEAP calculates results.)

A MODFLOW model consists of many different "packages," most of which are optional. However, not all packages are used or allowed by WEAP.

- **Used by WEAP:** [BAS6](#) (Basic), [BCF6](#) (Block-Centered Flow), [CHD](#) (Constant-Head), [DIS](#) (Discretization), [DRN](#) (Drain), [HUF2](#) (Hydrogeologic Unit Flow), [LPF](#) (Layer Property Flow), [NAM](#) (Name), [OC](#) (Output Control), [RCH](#) (Recharge), [RIV](#) (River), [WEL](#) (Well). WEAP reads information from each of these, and will write new versions of the following: NAM, DIS, OC, RCH, RIV, WEL, as explained in [MODFLOW Link Technical Details](#). (The original files will not be changed.) WEAP only requires NAM, DIS, BAS6 and one of BCF6/HUF2/LPF--all other packages are optional.
- **Allowed but not used by WEAP:** [ADV2](#) (Advective-Transport Observation), [DE4](#) (Direct Solution), [ETS](#) (Evapotranspiration Segments), [GAGE](#), [GHB](#) (Ground-Water Flow Process General-Head Boundary), [HFB6](#) (Ground-Water Flow Process Horizontal Flow Barrier), [HYD](#) (HYDMOD), [IBS](#) (Interbed-Storage), [KDEP](#) (Hydraulic-Conductivity Depth-Dependence Capability of the HUF2), [LMG](#) (Link-AMG), [LVDA](#) (Model-Layer Variable-Direction Horizontal Anisotropy capability of the HUF2), [MNW1](#) (Multi-Node, Drawdown-Limited Well), [MULT](#) (multiplier), [PCG](#) (Preconditioned Conjugate-Gradient), [RES](#) (Reservoir), [SIP](#) (Strongly Implicit Procedure), [SOR](#) (Slice-Successive Over-Relaxation), [SUB](#) (Subsidence and Aquifer-System Compaction), [ZONE](#).
- **Commented out in new name file:** (Observation files might reference stress periods after the first, which no longer exist) [CHOB](#) (Constant-Head Flow Observation), [DROB](#) (Drain Observation), [DTOB](#) (Drain Return Observation), [GBOB](#) (General-Head-Boundary Observation), [HOB](#) (Head-Observation), [OBS](#) (Observation Process), [RVOB](#) (River Observation), [STOB](#) (Streamflow-Routing Observation), [LMT6](#) (Link-MT3DMS)
- **Not allowed:** ASP, [DAF](#) (DAFLOW surface-water), [DAFG](#) (DAFLOW ground-water), [DRT](#) (Drain Return), [LAK](#) (Lake), [EVT](#) (Evapotranspiration), [FHB](#) (Flow and Head Boundary), [PES](#)

(Parameter Estimation), [SEN](#) (Sensitivity Process), [STR](#) (Streamflow-Routing). (Because DRT, EVT, LAK and STR duplicate calculations done by WEAP, allowing them would cause errors.)

The following describes how WEAP interacts with the MODFLOW packages from the "Used by WEAP" group:

## Name (NAM):

The Name File specifies the names of the input and output files, associates each file name with a unit number and identifies the packages that will be used in the model. WEAP reads the name file first to know which packages are used and which file each one is in. WEAP will write a new NAM file for each timestep it calculates, and include in it new entries for an initial head file, output head file, and a cell-to-cell-flow (CCF) file.

## Discretization (DIS):

WEAP reads the following information from the Discretization file:

Number of rows, columns and layers

Row and column widths

Time and length units

Number and length of stress periods. Models with more than one stress period are allowed, but only data from the first stress period will be used by WEAP. Time-varying parameters and multiple stress periods are fundamentally opposed to the WEAP-MODFLOW linkage approach, which is that MODFLOW will be run for one stress period, then the results will go back to WEAP, which will write new MODFLOW input files, and then run MODFLOW for the next stress period. When WEAP writes the new DIS package, the length of the stress period will be changed to match the length of the WEAP timestep being calculated. The number of MODFLOW timesteps is not changed. Tip: If the original MODFLOW stress period length is much longer than the WEAP timestep (e.g., annual vs. monthly), you probably want to reduce the number of MODFLOW timesteps per stress period—it will calculate faster and create smaller files. For example, if the MODFLOW stress period is 365 days and the number of timesteps per stress period is 12 (one per month), because WEAP will change the stress period length to monthly, you probably want to reduce the number of timesteps per stress period to 1 so that it is still monthly.

Which layers have Quasi-3d confining beds below. This information is only used to initially establish individual aquifers in a multi-aquifer system. However, it is up to the user to decide how many aquifers exist and which layers are in which aquifers.

A MODFLOW model can be either transient or steady state. A steady state model is not a good fit to link to WEAP, because it cannot fully capture the changes from the WEAP model.

## Basis (BAS6):

WEAP reads from the Basic package the locations of active, inactive, and specified head cells and the initial heads in all cells. In addition, BAS specifies if FREE or FIXED formats are used in other packages, and the numeric code to use for no-flow cells (e.g., -999). WEAP writes the initial cell heads to a new binary file, for use in the first WEAP timestep as the initial head for the simulation, and changes the BAS file to refer to this EXTERNAL file. Thereafter, the head results from one WEAP timestep will



be used in the next timestep as the initial heads, and the BAS file will be changed to refer to the newly created head file.

The XSECTION tag is not allowed.

### **Well (WEL):**

The Well package is used to simulate a specified flux to individual cells and specified in units of volume/time. WEAP reads from the Well package the number and location of well cells, to which it adds any other cells that are linked to land use or demand site pumping in WEAP but not already included in the Well file. You may choose to model some or all pumping, such as pumping for irrigation, as negative recharge in the Recharge package instead of as pumping in the Well package. When writing the pumping flows in the new Well file for each WEAP timestep, cells that are linked to land use or demand site pumping will have pumping rates calculated by WEAP, whereas cells that are not linked will have the flow rate as specified in the original Well file. The Well package is also modified so that cell-by-cell flow terms will be written to the new CCF file. It is OK if the Well package does not exist in the original MODFLOW model--WEAP will create a new one.

### **Recharge (RCH):**

The Recharge package is used to simulate a specified flux distributed over the top of the model and specified in units of length/time. Within MODFLOW, these rates are multiplied by the horizontal area of the cells to which they are applied to calculate the volumetric flux rates. You may choose to model some or all pumping, such as pumping for irrigation, as negative recharge in the Recharge package instead of as pumping in the Well package. Initial values of recharge from the Recharge package are ignored, to be replaced by recharge values calculated by WEAP. The Recharge package is also modified so that cell-by-cell flow terms will be written to the new CCF file. It is OK if the Recharge package does not exist in the original MODFLOW model--WEAP will create a new one. In this case, the recharge will be applied to the highest active cell in each vertical column.

### **Drain (DRN):**

The Drain package is used to simulate head-dependent flux boundaries. In the Drain package if the head in the cell falls below a certain threshold, the flux from the drain to the model cell drops to zero. WEAP reads from the Drain package the number and location of drain cells. The only change made to the Drain package is to specify the new CCF file that cell-by-cell flow terms will be written to.

### **River (RIV):**

The River package is used to simulate head-dependent flux boundaries. In the River package if the head in the cell falls below a certain threshold, the flux from the river to the model cell is set to a specified lower bound. The River package includes stage height and river bottom elevation, which are used by MODFLOW to calculate fluxes. In each timestep, WEAP will calculate the stage in the river at each reach linked to a river cell and write a new River file with this new stage value. WEAP's flow-stage-width curve can either specify the stage in relative (where 0 is the river bottom) or absolute terms. If in relative terms, WEAP will add the elevation of the river bottom (RBOT) from the original River file to the calculated stage to derive the absolute stage level. River cells that are not linked to WEAP reaches are written back out unchanged. The River package is also modified so that cell-by-cell flow terms will be written to the new CCF file.

## **Block-Centered Flow (BCF6), Hydrogeologic Unit Flow (HUF2) and Layer Property Flow (LPF):**

One and only one of these packages may be used. The only information that WEAP needs from these files is the numeric code for dry cells, e.g., -888. The only change made is to specify the new CCF file that cell-by-cell flow terms will be written to.

## **Constant Head (CHD):**

WEAP does not read from or write to the Constant Head package, but its presence indicates that WEAP should read constant head results from the CCF file, which will be added to the WEAP groundwater mass balance results.

## **Output Control (OC):**

WEAP ignores the original Output Control package (if it exists) and instead creates a new Output Control file, specifying that head and budget results should be saved (for the final MODFLOW timestep), and the file unit to which they are saved.

## **General Notes on Packages**

Parameter are handled in all packages, but will not be written to the new package files. This is because time-varying parameters and multiple stress periods are fundamentally opposed to the WEAP-MODFLOW linkage approach, which is that MODFLOW will be run for one stress period, then the results will go back to WEAP, which will write new MODFLOW input files, and then run MODFLOW for the next stress period.

All MODFLOW format options are supported: FREE and FIXED formats, as well as CONSTANT, INTERNAL, EXTERNAL, LOCAT (fixed) and OPEN/CLOSE.

## 8.2 Linking to MODPATH

*Note: linking WEAP to MODPATH is an advanced feature.*

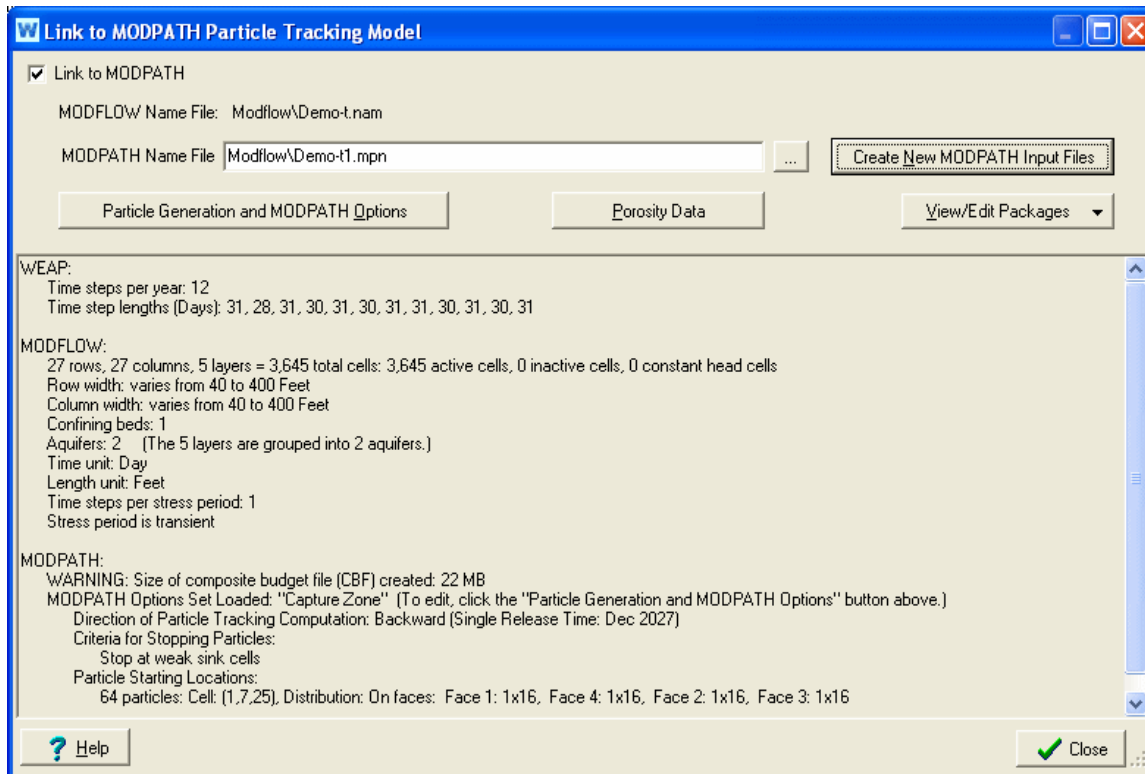
MODPATH is a groundwater particle tracking post-processing package that was developed to compute three-dimensional flow paths using output from steady-state or transient groundwater flow simulations by [MODFLOW](#), the U. S. Geological Survey (USGS) finite-difference groundwater flow model. Its purpose is to evaluate advective transport through a model. MODPATH uses a semi-analytical particle tracking scheme that allows an analytical expression of the particle's flow path (from the flow field results from MODFLOW) to be obtained within each finite-difference grid cell. Particle paths are computed by tracking particles from one cell to the next until the particle reaches a boundary, an internal sink/source, or satisfies some other termination criterion. The version of MODPATH that WEAP is designed to link to is MODPATH 5.0. (See <http://water.usgs.gov/nrp/gwsoftware/modpath5/modpath5.html>, or the [MODPATH User Guide](#), for more information.) MODPATH tracks the trajectory of a set of particles from user-defined starting locations using the MODFLOW solution as the flow field. The particles can be tracked either forward or backward in time. Particle tracking solutions have a variety of applications, including the determination of zones of influence for injection and extraction wells.

In order to link a WEAP model to MODPATH, you must have already [linked your WEAP model to a MODFLOW model](#). With an existing MODFLOW model, the only additional data that are required for MODPATH is porosity and where recharge should be applied.

The following topics describe the steps required to link WEAP to MODPATH: [Load MODPATH Model](#), [MODPATH Options and Particle Generation](#), [MODPATH Porosity](#) and [Run the Models and View Results](#). See also [MODPATH Link Technical Details](#).

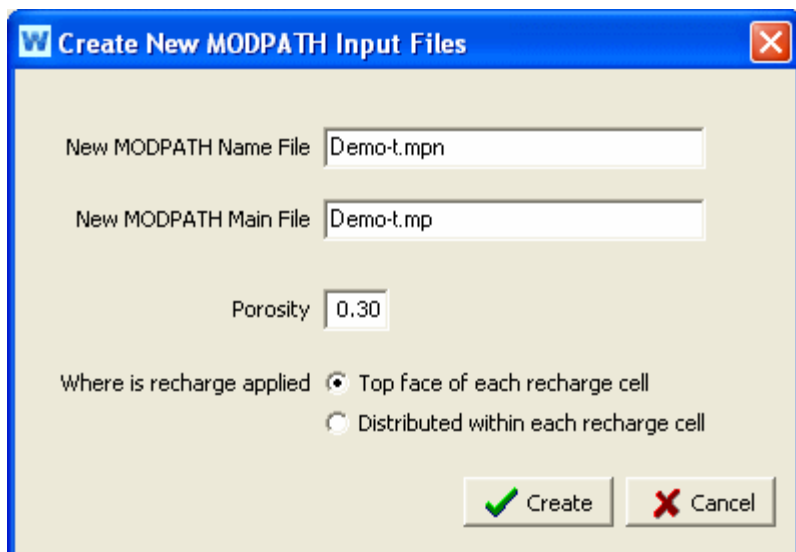
### 8.2.1 Load MODPATH Model

On the menu, choose Advanced, MODPATH Link. Check the "Link to MODPATH" check box.



You can either link to an existing MODPATH model or create a new one from scratch. To **link to an existing model**, enter the MODPATH Name filename, or click the Browse button (“...”) to browse for it. The Name file must be in the same directory as the linked MODFLOW model. Typically, the “Name” file has an extension of .mpn

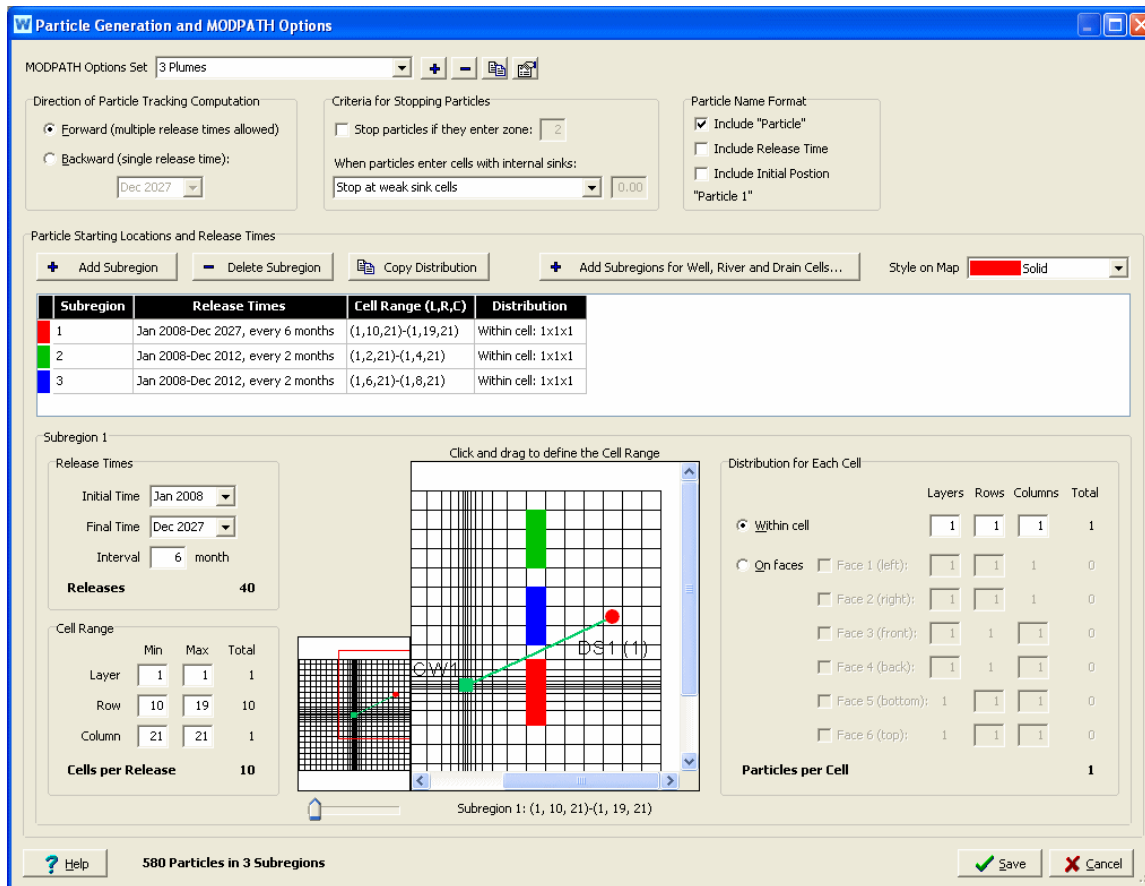
To **create a new model**, click “Create New MODPATH Input Files,” which will use details from the linked MODFLOW model (e.g., number of layers, rows and columns, IBOUND array) to create a new MODPATH model. A window will pop up, asking for the filenames to use for creating the MODPATH Name and Main files, the default porosity, and whether recharge is distributed within a cell or applied to the top face. The distributed source approximation for areal recharge is usually only appropriate for two-dimensional areal flow models. You can later edit the Porosity (see instructions below); to change where recharge is distributed, you can later edit the Main file package (click the “View/Edit Packages” button and choose the Main file). The MODPATH Name file created will only include the Main package--all other packages will be added when [WEAP runs MODPATH](#).



Information about the WEAP and MODFLOW models is displayed, along with the current MODPATH options and particle generation. You may [edit the particle generation and MODPATH options](#) by clicking the "Particle Generation and MODPATH Options" button. Note: you must have at least one particle generated in order to run MODPATH. Click the "Porosity Data" button to [edit the porosity data](#) for each cell. Use the "View/Edit Packages" button to view or edit the Name and Main files. (Other files may be listed in the Name file, but they are either output files or binary input files--in either case, they cannot be viewed here.)

### 8.2.2 Edit Particle Generation and MODPATH Options

It is on this screen that you will set the main options for your MODPATH analysis, including the starting position for particles that will be tracked over time. As a convenience, you may store many different sets of options, so that you can quickly switch from one to another. For example, you could have different Option Sets for different capture zone analyses (backward tracking from each of several wells or drains), and other Options Sets to look at the plume resulting from particle releases in different locations or release times (forward tracking from particle release points). When you exit this screen, whichever Options Set is listed in the MODPATH Options Set drop down list at the top will be active. (You will also be able to change the active Options Set from the [Results View](#).) You may use the buttons to the right to Add, Delete, Copy or Rename the current Options Set.



## Direction of particle tracking computation

MODPATH provides the option of tracking particles forward in the direction of groundwater flow, or backward toward points of recharge. Backward tracking is accomplished by multiplying all velocity components by -1. Once the sign of the velocity components has been changed, computations are carried out in exactly the same way as for forward tracking. For backward tracking, particles terminate at points of recharge, rather than points of discharge. The backward tracking option often provides an efficient means of delineating the source of recharge to localized points of discharge, such as well fields or drains.

For a forward tracking analysis, you may release particles at different times, whereas for a backward tracking analysis particles are traced backwards in time from a single release time (typically the last time step of the WEAP model).

## Criteria for stopping particles

A particle terminates when it:

- reaches a cell face that is a boundary of the active grid,
- enters a cell with a strong sink from which there is no outflow to other cells (or, for backward tracking, a strong source cell with no inflow from other cells),
- reaches an external boundary or internal sink/source cell that captures the particle,
- enters a cell with a special zone code that is designated as a stopping point, or

- is stranded in a dry cell.

If a special zone code is given, MODPATH will terminate a particle if it enters a cell that has been assigned that zone code value. This option can be used to map out the recharge area for a hydrogeologic unit by setting the zone code for the cells that contain that unit equal to the special zone code for terminating particles. If you select this option, you will need to edit the IBOUND array in the MODPATH Main file. The zone code is an integer greater than one.

A weak sink is a model cell (representing a well, for example) that does not discharge at a sufficiently large rate to capture all of the flow entering the cell; thus, some of the flow leaves the cell across one or more of the cell faces. Because of this limitation of model discretization, flow paths to weak sink cells cannot be uniquely defined, as it is impossible to know whether a specific water particle discharges to the sink or passes through the cell. For cells with weak sinks, an arbitrary decision must be made by the user about whether to stop particles. MODPATH provides three options, which apply for backward tracking as well as forward tracking:

- particles pass through cells with weak sinks.
- particles are stopped when they enter cells with weak sinks.
- particles are stopped when they enter cells where discharge to sinks is larger than a specified fraction of the total inflow to the cell. For this last option, enter a fraction between 0 and 1.

## Particle Name Format

These options determine the name shown in the chart legend in the Results View for each particle pathline. As you change the options, an example of how the name will appear is shown below the checkboxes, e.g., "Particle 1."

## Particle starting locations and release times

Starting locations for particles can be generated in one or more rectangular blocks of cells. Each subregion represents one rectangular block of cells--you must have at least one subregion, although it can contain as few as one cell. Use the "Add Subregion" and "Delete Subregion" buttons to add and delete subregions.

### Release Times

In the case of forward tracking analyses, particles also can be assigned a "release time," which allows particles to be released into the flow system over a range of times rather than simply as a single, instantaneous release. Using Initial Time, Final Time and Interval, choose the times in which particles for this subregion will be released. These options are not available for backward tracking.

### Cell Range

Specify the extent of the subregion, by specifying the Minimum and Maximum Layer, Row and Column. Each release time specified above will release particles into the same block of cells. (MODFLOW occasionally refers to these three dimensions by the letters I, J, K, with row being the I-axis, column the J-axis, and layer the K-axis, and sometimes by the letters X, Y, Z, with row being the Y-axis, column the X-axis, and layer the Z-axis (elevation). When shown as three numbers together, such as (1, 13, 24), the order is (Layer, Row, Column).) The total number of cells will be the product of the number of layers, rows and columns. For example, if particles will be released in 2 layers, 4 rows and 12 columns, the total number of cells will be  $2 * 4 * 12 = 96$ . As a special case, when Minimum and Maximum Layer = 0,

particles are placed in the first **active** layer for each areal cell location within the subregion. Particles can be draped over the water table surface by placing them on face 6 of all the cells in the subregion.

The cell ranges for every subregion are shown on the map, color coded by subregion. Use the dropdown box labeled "Style on Map" to change whether the cells are displayed with a solid color or with a pattern on the map on this screen. You can also select the cells by clicking and dragging with the mouse on the map--this method is used to choose the rows and columns; to choose the layers, you must use the keyboard.

For a typical backwards analysis, particles are released at sinks, such as well, river or drain cells. Click the ["Add Subregions for Well, River and Drain Cells..."](#) button to select which of these cells to add and the distribution for each cell.

## Distribution for Each Cell

You can release one or more particles per cell. Locations of particles for each cell can be generated either as a 3-dimension array of particles inside the cell ("within cell"), or as a 2-dimension array around one or more of the six faces of the cell ("on faces").

If you choose "within cell," specify the number of particles within each cell along the layer, row and column dimensions. The number of particles within the cell is the product of these three numbers.

If you choose "on faces," select which faces on which you would like to place particles. For each selected face (Face 1 = left face, Face 2 = right face, Face 3 = front face, Face 4 = back face, Face 5 = bottom face, and Face 6 = top face), specify the other two dimensions of particles. For example, for Face 1, a 2x3 array (2 layers, 3 rows) would place 6 particles on the left face of each cell in the subregion.

If you want to use the same distribution in all subregions, you can copy the Distribution from the selected subregion to the others by clicking the "Copy Distribution" button. For example, if you want to analyze the capture zones from several non-contiguous well cells, define a subregion for each well cell, specify the distribution for one subregion, then copy this distribution to the other subregions.

If you are backtracking from a cell with a well, river or drain to define a capture area, it is generally best to place particles on the cell faces rather than distribute them internally within the cell. For example, 16 particles on each of the faces 1-4.

## Total Particles Released

The total number of particles released in each subregion is Number of Releases \* Number of Cells per Release \* Number of Particles per Cell. The total for all subregions is shown at the bottom of the window. Note: the more particles you have defined, the longer it will take for MODPATH to run and for WEAP to display results.

### 8.2.3 Add Subregions for Well, River and Drain Cells

For a typical backwards analysis, particles are released at sinks, such as well, river or drain cells. On this screen, you can choose in which of those cells particles should be released and the distribution for each cell.



**Add Subregions for Well, River and Drain Cells**

**Cells**

- ☒ Demand Sites (5)
  - ☒ DS1 (5)
    - ☒ (1, 7, 25)
    - ☒ (2, 7, 25)
    - ☒ (3, 7, 25)
    - ☒ (4, 7, 25)
    - ☒ (5, 7, 25)
  - ☐ Rivers (0)
  - ☐ Unlinked River Cells (0)
    - ☐ (1, 1, 27)
    - ☐ (1, 2, 27)
    - ☐ (1, 3, 27)
    - ☐ (1, 4, 27)
    - ☐ (1, 5, 27)
    - ☐ (1, 6, 27)
    - ☐ (1, 7, 27)

**Selected Cells: 5**

**80 Particles**

**Distribution for Each Cell**

	Layers	Rows	Columns	Total
<input type="radio"/> Within cell	1	1	1	0
<input checked="" type="radio"/> On faces				
<input checked="" type="checkbox"/> Face 1 (left):	1	4	1	4
<input checked="" type="checkbox"/> Face 2 (right):	1	4	1	4
<input checked="" type="checkbox"/> Face 3 (front):	1	1	4	4
<input checked="" type="checkbox"/> Face 4 (back):	1	1	4	4
<input type="checkbox"/> Face 5 (bottom):	1	4	4	0
<input type="checkbox"/> Face 6 (top):	1	4	4	0

**Particles per Cell** **16**

For Well cells, WEAP will try to guess which layers are pumped by examining the expression for [Pump Layer](#) for each demand site and catchment land use. However, in cases where the Pump Layer expression changes over time, WEAP will just select all layers. Therefore, you should review the layers selected and decide which to include. Even well or river cells from the original MODFLOW files that are not linked to WEAP groundwater nodes or river reaches will be listed and can be included for particle generation.

Click the Add button to create subregions for the selected cells. If multiple cells are selected, WEAP will try to group adjacent cells into rectangular subregions, so that the total number of subregions created is minimized (i.e., not one subregion for every cell).

## Distribution for Each Cell

You can release one or more particles per cell. Locations of particles for each cell can be generated either as a 3-dimension array of particles inside the cell ("within cell"), or as a 2-dimension array around one or more of the six faces of the cell ("on faces").

If you choose "within cell," specify the number of particles within each cell along the layer, row and column dimensions. The number of particles within the cell is the product of these three numbers.

If you choose "on faces," select which faces on which you would like to place particles. For each selected face (Face 1 = left face, Face 2 = right face, Face 3 = front face, Face 4 = back face, Face 5 = bottom face, and Face 6 = top face), specify the other two dimensions of particles. For example, for Face 1, a 2x3 array (2 layers, 3 rows) would place 6 particles on the left face of each cell in the subregion.

When backtracking from a cell to define a capture area, it is generally best to place particles on the cell faces rather than distribute them internally within the cell. For example, 16 particles on each of the faces 1-4.

The same distribution will apply to all cells added. If you want to use different distributions for different cells, first add the cells with the first distribution, then come back and add the cells with the other distribution.

## Total Particles Released

The total number of particles released in each subregion is Number of Cells \* Number of Particles per Cell, and is shown at the bottom of the window. Note: the more particles you have defined, the longer it will take for MODPATH to run and for WEAP to display results.

### 8.2.4 Edit MODPATH Porosity

From the MODPATH Link screen, click the "Porosity Data" button to view or edit porosity data for each layer and cell. Choose the layer to display using the drop down box at the top. For each layer, you can set the porosity to either be the same value for all rows and columns ("Constant porosity"), or set each row and column individually ("Set porosity for every cell").

Porosity

Layer 1

☒ Constant porosity: 0.30

☐ Set porosity for every cell:

	Col 1	Col 2	Col 3	Col 4	Col 5	Col 6	Col 7	Col 8	Col 9	Col 10	Col 11	Col 12	Col 13
Row 1	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Row 2	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Row 3	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Row 4	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Row 5	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Row 6	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Row 7	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Row 8	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Row 9	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Row 10	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30

Help Save Cancel

### 8.2.5 Run the Models and View Results

After WEAP does its calculations for each scenario, including running MODFLOW at each timestep, WEAP combines all the individual MODFLOW input files for a scenario (one set for each WEAP time step--each set represents one MODFLOW stress period) into one set of files that covers all WEAP time steps (the set has as many MODFLOW stress periods as there are WEAP time steps in the entire simulation). WEAP runs this large MODFLOW model, and then runs MODPATH, using the currently loaded [MODPATH Options Set](#). Just as it does when [running MODFLOW](#), WEAP creates temporary MODPATH files for each scenario it calculates. (Because a complete set of new input files are created and kept for each scenario, you will be able to run them yourself in MODPATH outside of WEAP, if you want to examine the results in more detail, or to make slight changes to the inputs. Note that any changes you make directly to these temporary input files will be lost the next time WEAP does its calculations, so you are advised to save them in another directory if you want to preserve them. The temporary filenames all start with "!MP!" to distinguish them from other files.) MODPATH can only calculate particles in

## 8.2 Linking to MODPATH

active cells. If a cell goes dry, any particles in that cell will not exist. Check the MODFLOW report on dry cells to determine if this is happening.

In the Results View, choose Supply and Resources \ Groundwater \ MODFLOW \ Particle Pathline. On the Chart tab, WEAP displays particle pathlines as 3-dimensional vectors. Each particle will display as a line showing its path over time in three dimensions. Using the mouse, click and drag on the chart to rotate it, or move the sliders below to manipulate it. Shift-click and drag to pan the chart, or use the mouse wheel to zoom in or out. Click the "Rotate" button to start it spinning. Position the mouse on or near a point on a 3-D pathline to see a description of it in the status bar at the bottom of the WEAP window. Click the "Top," "Front" or "Left" buttons to switch to a 2-D view showing a cross-section as seen from the chosen face (top, front or left).

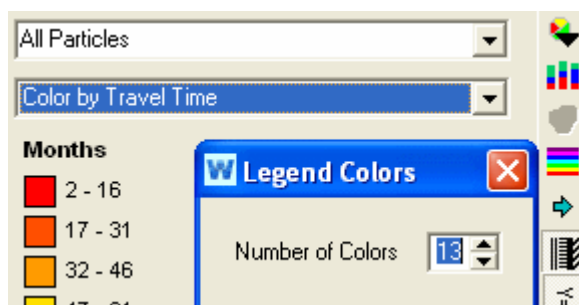
The lines are plotted in one of two coordinate spaces, depending on the setting of the "Show X,Y" checkbox at the top. If "Show X,Y" is checked, the coordinates are X,Y,Z, all in length units (e.g., feet or meters) selected at the top. X is the distance from the left face of column 1, Y is the distance from the front face of the last row, and Z is the elevation. These are based on column and row widths, and cell elevations, from the MODFLOW Discretization file. If "Show X,Y" is not checked, the coordinates are Column, Row, Elevation, where Column and Row are fractional positions within a cell (e.g., Row=5.5 is the middle of row 5), and Elevation is in length units selected at the top. Go to the Table tab to see the 3-D coordinates for each particle and time step. The coordinates are shown either as (Row, Column, Z) or (X, Y, Z). You can turn off the "Y=0" button to the right of this chart to magnify the changes in elevation over time.

Each particle is listed in the legend (using the format chosen for the current [MODPATH Options Set](#)). For example, it might include the Layer, Row, Column coordinates where it was released: "Particle 1: (1, 10, 22)". Note: If there are multiple particles per cell or multiple releases times, there will be particles with the same starting coordinates in their names.

The 3-D pathlines are made up of connected 3-D line segments, each of which connects the position of a particle on two successive time steps. Each point shown corresponds to the position of the particle at the end of that timestep. You may select to see all months and years and all particles, or select subsets of them. Tip: You can speed up the display by selecting just one month from each year to display. For example, select December only and each line segment will show the jump in the position from the end of December in one year to the end of December in the next year. (See chart below for an example of this.) Click the Arrowhead icon on the right tool bar to show or hide arrowheads on each line segment.

You can change the MODPATH options or starting particles positions without leaving the Results View--click the "Particle Generation and MODPATH Options" dropdown button on the upper right to quickly switch from one options set to another. When you change it, MODPATH will automatically recalculate using the new particles and MODPATH options. You can also edit or add Options Sets--click the "Edit" button to the right of the dropdown box to go to the [Edit Particle Generation and MODPATH Options](#) screen. When you exit that screen, MODPATH will automatically recalculate if you had made any changes. Because the normal WEAP or MODFLOW calculations do not need to be re-run when the MODPATH options have changed, this process is very quick.

The color of each line segment represents one of several different types of information, selected by the "Color by" dropdown box just above the legend (in the example below, it is set to "Color by Particle"). In two cases, the entire pathline for a particle will have a single color (Color by Pathline, Color by Release Time); in the other cases, each line segment of each particle pathline can have a different color, representing information about the particle either



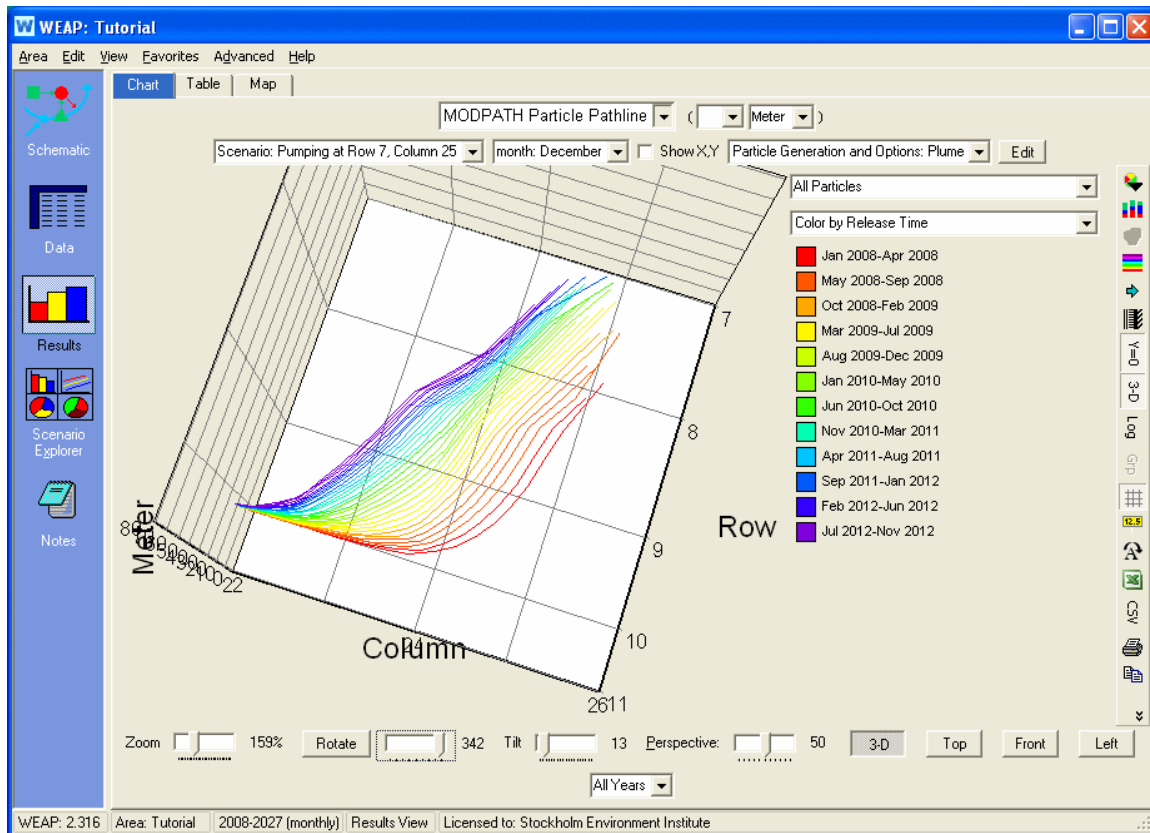
during the time it moved from the beginning of the line segment to the end of the line segment (Color by Velocity) or at the moment when it was at the end of the line segment (Color by Travel Time, Color by Absolute Time, Color by Travel Distance, Color by Elevation, Color by Layer, Color by Layer (fractional)).

- Color by Particle: Each particle pathline has a different color.
- Color by Travel Time: Each line segment has a color corresponding to the number of timesteps the particle has traveled since its release to the position of the end of the line segment, e.g., 6 months.
- Color by Absolute Time: Each line segment has a color corresponding to the date when the particle had reached the position of the end of the line segment, e.g., December 2015.
- Color by Release Time: Each particle pathline has a color corresponding to its release time, e.g., January 2008.
- Color by Travel Distance: Each line segment has a color corresponding to the cumulative distance the particle has traveled from its release point to the position of the end of the line segment, e.g., 10 meters. The length unit can be changed in the unit dropdown box to the right of the chart title.
- Color by Velocity: Each line segment has a color corresponding to the velocity of the particle during its travel from the beginning of the line segment to the end of the line segment, e.g., 108 meters/year. The length unit can be changed in the unit dropdown box to the right of the chart title.
- Color by Elevation: Each line segment has a color corresponding to the elevation of the particle when the particle had reached the position of the end of the line segment, e.g., 200 meters. The length unit can be changed in the unit dropdown box to the right of the chart title.
- Color by Layer: Each line segment has a color corresponding to the MODFLOW model layer of the particle when the particle had reached the position of the end of the line segment.
- Color by Layer (fractional): Each line segment has a color corresponding to the MODFLOW model layer of the particle when the particle had reached the position of the end of the line segment. The layer is given as a decimal number, indicating the distance between the layer's top and bottom, e.g., layer 1.5 means that the particle is halfway between the top and bottom of layer 1.

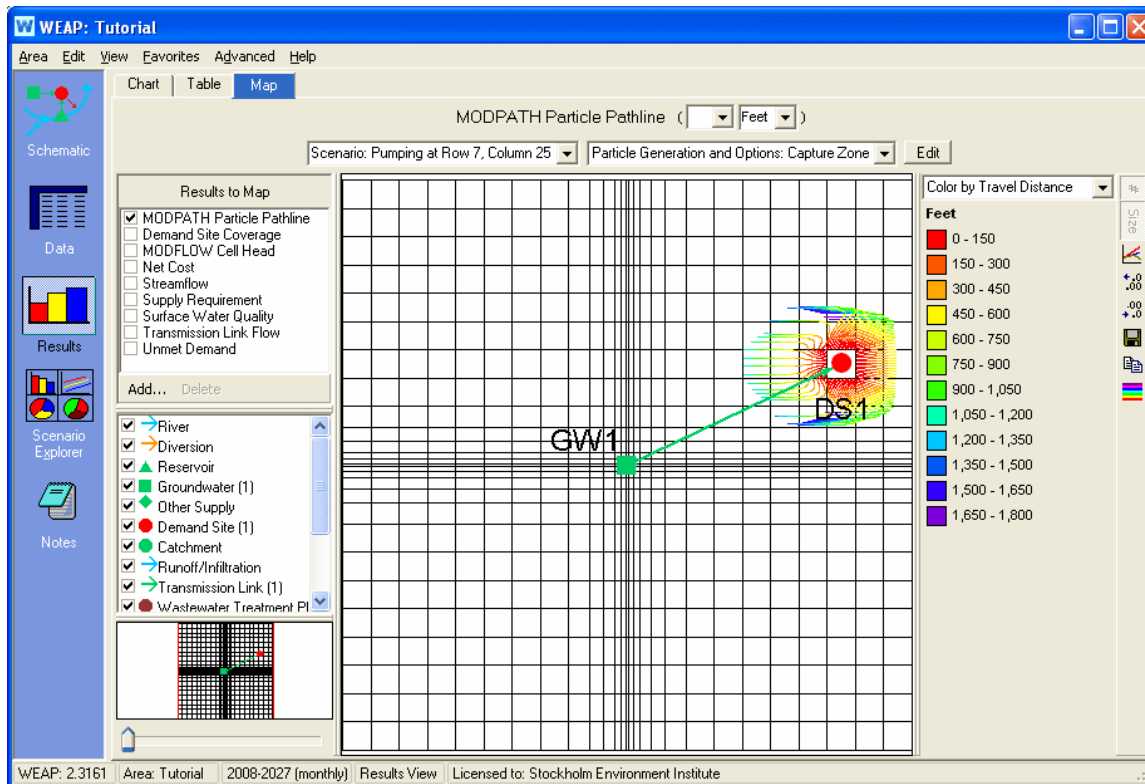
For "Color by Particle," you can change the color scheme and whether or not to use patterns for the lines; the other choices all use the rainbow palette, without patterns. For choices other than "Color by Particle," you can set how many different colors to use--click the rainbow button on the toolbar on the right (see above).


Here is an example showing the plume that results from releasing particles at the same location over successive time steps, using a forward tracking analysis. In this scenario, pumping rates increase over time, which causes the particles released later (shown in blue and purple) to move more quickly towards the well (at row 7, column 25).

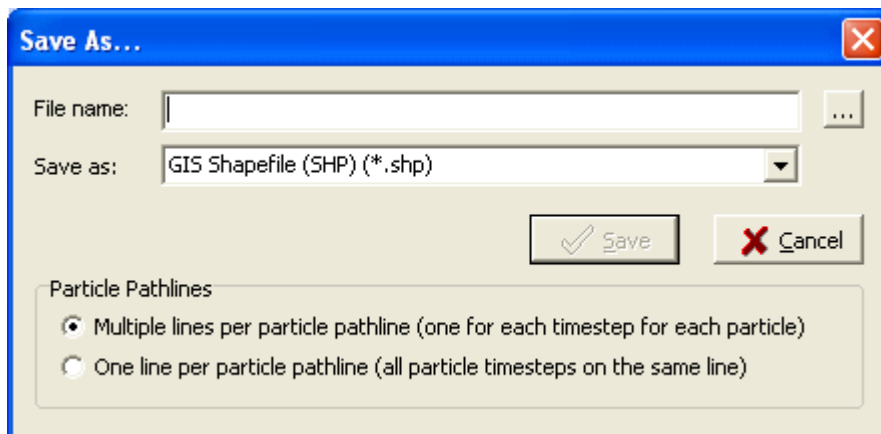
## 8.2 Linking to MODPATH



On the Map tab, WEAP overlays 2-dimensional particle pathlines on top of the Schematic. Here is an example showing the capture zone for a well, using a backward tracking analysis of particles arranged on faces 1, 2, 3 and 4 of the well cell (at row 7, column 25), all released at the end of the simulation (December 2027) and traced backwards in time. By choosing Color by Travel Time, the colors show how long it takes each particle to reach the well.

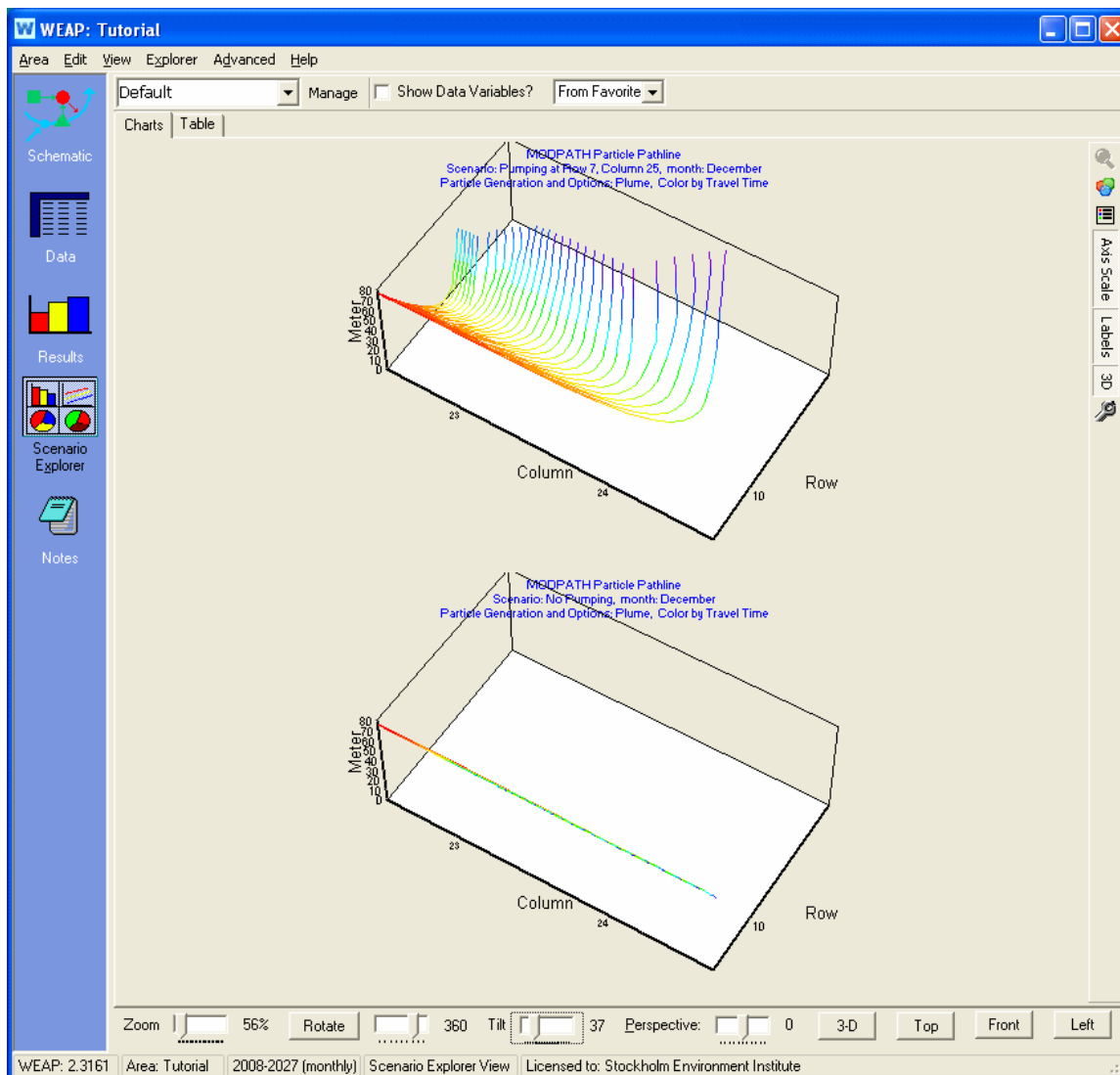


From the Map tab, the pathlines can be saved as a GIS Shapefile. Click the  button on the toolbar to the right and choose save as "GIS Shapefile (SHP)". You can choose to create a separate line in the shapefile for each particle pathline line segment (there is a line segment for each timestep for each particle), or group together all the line segments for each particle into one line. When saving lines segments separately, WEAP will include information in the shapefile's attribute table for each particle timestep, such as distance traveled and velocity. This information will be useful if you later want to display the shapefile in a GIS program, such as ArcGIS, and color code the line segments by these attributes.



The [Scenario Explorer View](#) can display multiple pathline results (saved as Favorites) for different Particle Generation and MODPATH Options, or for different scenarios. In this example, favorites have been saved for the same variable but for different scenarios, showing how the particle plume is strongly affected by pumping (one scenario has pumping; the other scenario does not). Choose "From Favorite" to see both scenarios. Click the "Axis Scale" button on the right to use the same scales for the axes so that the different charts can be easily compared.

## 8.2 Linking to MODPATH



### 8.2.6 MODPATH Link Technical Details

Just as it does when [running MODFLOW](#), WEAP creates temporary MODPATH files for each scenario it calculates. The temporary filenames all start with "IMP!" to distinguish them from other files. Each of these is described below. For files that appear in the Name file, the file type is given in all caps in parentheses, e.g., "(MAIN)". Unless otherwise noted, a different file is created for each scenario. The input files are created by WEAP or MODFLOW; the output files are created by MODPATH.

#### Name:

The only file from the original Name file that will be listed in the new Name file is the Main file. All others are discarded or replaced. WEAP adds each of the following files: DIS, LOCATIONS, TIME, LIST, HEAD(BINARY), BUDGET, ENDPOINT, CBF, and TIME-SERIES.

WEAP links the Options Set to the Name file--it has the same filename as the Name file, but with a file extension of .mpo. Therefore, each Name file can have a different group of Options Sets.

## Main (MAIN):

A new Main file is created from the original Main file, but the only change made is for a transient analysis, in which values for BeginPeriod BeginStep EndPeriod EndStep are changed, according to the [Options Set](#) for when the particles are released. This file does not vary by scenario, so there is only one temporary Main file for all scenarios. Note: if the user [edits Porosity Data](#), the changes are made to the original Main file.

## Discretization (DIS):

WEAP creates a new Discretization file by combining all the individual MODFLOW Discretization files from the scenario run into one Discretization file that includes all WEAP time steps (each WEAP time step is a MODFLOW stress period).

## Starting locations file (LOCATIONS):

WEAP creates this file of starting particles locations and release times from the currently loaded [Options Set](#). This file does not vary by scenario, so there is only one temporary Main file for all scenarios.

## Time data file (TIME):

This file specifies the values of tracking time at which output is required for the time series results. So that results are available for each WEAP time step, WEAP creates this file by listing every time step in the simulation. This file does not vary by scenario, so there is only one temporary Time file for all scenarios.

## Summary output file (LIST):

The summary output file, with detailed information about the MODPATH run. It is shown to the user only if there is a problem and the TIME-SERIES file is not created.

## Head (HEAD(Binary)):

Head file created by MODFLOW, for all stress periods.

## Cell-to-cell flow (BUDGET):

Cell-to-cell flow file (.ccf) created by MODFLOW, for all stress periods.

## Endpoint (ENDPOINT):

The Endpoint file is created by MODPATH as a result. It is not used by WEAP, but is required to be in the Name file.



### Composite budget file (CBF):

MODPATH creates this file from flow data in the MODFLOW BUDGET file, for use in backward tracking analysis.

### Time series file (TIME-SERIES):

This is the main MODPATH results file, which lists the location for each particle (in the LOCATIONS file) at each time (in the TIME file) in the simulation. WEAP display the 3-D vector pathlines from the results in this text file.

### Response:

The Response file tells MODPATH which Name file and which options to use in the run. WEAP creates it based on the currently loaded Options Set.

There are some response file options on which WEAP does not give the user a choice. They are listed, along with the choice made by WEAP:

```
* STOP COMPUTING PATHS AT A SPECIFIED VALUE OF TRACKING TIME?
```

```
No
```

```
* SELECT THE OUTPUT MODE:
```

```
*      1 = ENDPOINTS
```

```
*      2 = PATHLINE
```

```
*      3 = TIME SERIES
```

```
3
```

```
* DO YOU WANT TO COMPUTE VOLUMETRIC BUDGETS FOR ALL CELLS ?
```

```
No
```

```
* DO YOU WANT TO CHECK DATA CELL BY CELL ?
```

```
No
```

```
* SUMMARIZE FINAL STATUS OF PARTICLES IN SUMMARY.PTH FILE ? (This is  
the LIST file.)
```

```
Yes
```

### Notes

MODPATH uses advective transport to plot the particle paths. It does not model diffusion or dispersion of particles.

If the contrast in hydraulic conductivity between adjacent cells changes too abruptly, MODPATH may not be able to compute particle paths and will crash. In such cases, you may wish to adjust the hydraulic conductivity specification to reduce the contrast between adjacent cells. Such problems may occur if the contrast exceeds three orders of magnitude. The Horizontal Flow Barrier package has the potential to cause similar problems.

MODPATH does not continue to track particles once they have entered surface water bodies such as streams or lakes. If you are using MODPATH to delineate the well-head protection area and a stream or lake is part of the recharge area, you may need to consider the sources of water for the stream or lake when delineating the well-head protection area.

MODPATH expects the MODFLOW CCF file to have results for all MODFLOW time steps in each stress period. If there are several MODFLOW time steps, this file could become quite large. Reducing the number of timesteps per stress period will reduce the file size. If the original MODFLOW stress period length is much longer than the WEAP timestep (e.g., annual vs. monthly), you probably want to reduce the number of MODFLOW timesteps per stress period--it will calculate faster and create smaller files. For example, if the MODFLOW stress period is 365 days and the number of timesteps per stress period is 12 (one per month), because WEAP will change the stress period length to monthly, you probably want to reduce the number of timesteps per stress period to 1 so that it is still monthly.

MODPATH reserves file unit numbers between 80-99 for internal use. Therefore, do not use these numbers in your MODFLOW Name file.

MODPATH file comment lines start with @.

The particle tracking algorithm used by MODPATH can be implemented for either steady state or transient flow fields. However, when used with a steady state MODFLOW model, MODPATH will not consider any changes in pumping or recharge that occur after the first timestep. Therefore, **a steady state model is a poor choice for one to link to WEAP.**

### 8.3 Scripting

A script is a simple computer program which uses Microsoft's [Windows Script](#) technology. Scripts are text files written in one of the many different script languages that support Windows Script, such as VBScript, JScript (JavaScript), Perl, Python, Ruby and PHP. VBScript and JScript come with Windows and are always available, whereas other scripting languages must be installed by you on your computer before you can use them. (See below for links to free versions of these scripting languages.) Because scripts are text files, they are easy to create and modify.

Scripts can be used with WEAP in two different ways:

1. Internally: to create more powerful expressions and functions for a WEAP model (e.g., create a script to calculate reservoir water quality, and [Call](#) the script from a WEAP expression).
2. Externally: to automate WEAP via its [Application Programming Interface \(API\)](#) to perform a sequence of actions (e.g., create and run 100 WEAP scenarios by varying the value of several parameters (sensitivity analysis), and export the results to Excel for further analysis);

WEAP has its own built-in [script editor](#) that can be used to edit, interactively debug and run scripts. You may also use any text editor to create or edit your scripts.

When used internally, scripts can either be called from the [Call](#) function in an expression, or associated with [events](#) that will run at various times before, during and after WEAP's calculations.

You may also run a script from the main menu: Advanced, Scripting, Run.

A trivial example function is shown here (written in VBScript):

```
Function Add(x,y)
  Add = x + y
End Function

Function Multiply(x,y)
  Multiply = x * y
End Function
```

Notice that each function starts with the keyword `Function` and ends with the keywords `End Function`. Function results are set by assigning values to the function name (in this case `Add` or `Multiply`). WEAP functions should always return numeric values (integer or floating point) and should always use numeric parameters. Functions can have any number of parameters, but it is the user's responsibility to pass the correct number of parameters in a comma separated list in the [Call](#) statement.

Some other internet-based resources you may find useful:

[Windows Script Information](#)

[VBScript tutorial](#)

[VBScript reference guide](#)

[JScript reference guide](#)

Free versions of [Python](#), [Perl](#), [PHP](#) and [Ruby](#)

### 8.3.1 Script Editor

The script editor is used to edit, interactively debug and run scripts that automate WEAP and connect it with other Windows programs using standard "COM Automation Server" programming techniques. The script editor uses Microsoft's [Windows Script](#) technology, which directly supports scripts written in VBScript and JScript (JavaScript). VBScript and JScript come with Windows and are always available, whereas other scripting languages, such as Perl, Python, Ruby and PHP, must be installed by you on your computer before you can use them in WEAP.

The script editor is divided into three panes.

- At the top left is the edit pane where you edit your scripts. Use the Open button to open a script to be edited. You can open scripts stored in the current area folder ("Area scripts") or in the common "\_SCRIPTS" folder ("Shared scripts"). (The area script named Functions.vbs is a special script that can be called using [Call](#) without specifying the name.) Use the Save or Save As buttons to save the script. Use the Clear button to delete the current script. The editor also supports standard editing options such as cut, copy, paste, undo, find (Ctrl-F) and find again (F3). Use the Run Script button or press Ctrl-Enter to run the script. The script editor supports integrated debugging. Syntax or run-time errors in the script will cause the script to stop running. The type of error, and the line and column at which it occurred will be reported, and the edit cursor will be placed at the place in the script where the error occurred, helping you to fix the problem. "Autocompletion" for WEAP API classes is available. For example, type WEAP. After you type the dot after "WEAP," a window will pop up, listing all the properties and methods of the WEAPApplication class. Type the first few letters of the item, such as "B" for BaseYear, and the cursor will move down to that item. Hit Enter to add it to your script. Autocomplete works with any WEAP API class. For example, type WEAP.ActiveArea. to see a list of properties and methods for the WEAPArea class.
- At the bottom of the window is a PRINT output pane. Any PRINT messages in your script will appear here. You can clear this pane using the Clear button on the right of the pane or by issuing a CLS or CLEAR command in your script.
- On the right of the window is a pane with two tabs. These tabs give access to WEAP API objects and to WEAP Branch and variable names, which you may want to include in your scripts. Select an object in the tree and then click the Add button, or double click it, to add it to the edit pane on the left. Bear in mind that in addition to referring to WEAP objects you can also create references to many other COM objects. Many Windows based programs support COM, allowing you to connect WEAP to other programs such as Excel, Word, PowerPoint, etc.

The editor has standard editing functions: Undo (Ctrl-Z), Redo (Ctrl-Y), Find (Ctrl-F), and Find Next (F3).

The script "timeout" is the maximum time a script can run before WEAP asks if you want to stop it. The timeout is useful in cases either of an infinite loop in the script or where the script is taking much longer than expected. The default timeout is 30 seconds and can be changed in the toolbar. This timeout applies to all scripts in the current area. (Each area can have a different timeout value.)

**Menu option:** Advanced, Scripting, Edit Scripts

**See also:** [Scripting](#), [Automating WEAP \(API\)](#)

### 8.3.2 Event Scripts

Use the **Event Scripts** screen to specify scripts (VBScript or JScript, or any other script languages that you have installed on your computer, such as Python, Perl or Ruby) that will run at various times before,

## 8.3 Scripting

---

during and after WEAP's calculations. You can use these scripts to do additional calculations or perform other processing of data or results. Use the browse buttons to select a script file for each event. Optionally, you can specify a specific function to run within each script file, using the [Call](#) syntax, e.g., `Call( ReservoirTemperature.vbs ! Initialize )`. If no function is specified, WEAP will run the module-level commands in the script (i.e., those that are not inside a function or sub). Each script has access to all of the objects in [WEAP's API](#). Leave one or more of the edit boxes blank if you do not want scripts to run during certain calculation events.

The names of the event scripts are saved along with the rest of your data for each area (data set). Thus, a different set of scripts can be run for each area. It is recommended that you store the actual scripts (typically .VBS or .JS files) in the current area folder so that they will be backed-up and can be moved along with the rest of the area data.

The order in which the events occur within WEAP's calculations is indicated by the indentation of the text boxes on the Event Scripts screen, and is as follows:

Before Calculation (once before entire calculation)

    Before Scenario (for each scenario)

        Before Year (for each scenario/year)

            Before Month (for each scenario/year/month)

                Before Demand calculations

                Before Supply calculations

                Before Cost calculations

                Before running MODFLOW

                Before Water Quality calculations

            After Month

        After Year

    After Scenario

After Calculation (once after entire calculation)

**Menu option:** Advanced, Scripting, Events

**See also:** [Scripting](#), [Script Editor](#), [Automating WEAP \(API\)](#)

## 8.4 Automating WEAP (API)

WEAP can act as a standard "COM Automation Server," meaning that other programs (e.g., Excel via VBA), programming languages (e.g., Visual Basic, C) or scripts (e.g., VB script, JavaScript, Perl, Python) can control WEAP directly--changing data values, calculating results, and exporting them to text files or Excel spreadsheets. This can be enormously powerful. For example, you could write a 10-line script that would run WEAP calculations 100 times, each time with a different value of an input assumption, and output the results to Excel for later analysis. WEAP can also call scripts directly (from the [Call](#) function in an expression, or from the Advanced, Scripting menu item), and these scripts can use the WEAP API.

The WEAP Application Programming Interface (API) consists of several "classes," each with their own "properties" and "methods." Properties are values that can be inspected or changed, whereas methods are functions that do something.

The following classes are defined:

[WEAPApplication](#): top-level properties and methods, including access to all other classes

[WEAPArea](#): a WEAP Area (dataset)

[WEAPAreas](#): collection of all WEAP Areas

[WEAPScenario](#): a WEAP Scenario in the active area

[WEAPScenarios](#): collection of all Scenarios in the active area

[WEAPBranch](#): a specific Branch on the data tree (e.g., \Demand Sites\South City )

[WEAPBranches](#): collection of all child Branches for a specified Branch (e.g., Branch("\Demand Sites").Children )

[WEAPVariable](#): a Variable for a given Branch (e.g., Consumption for Branch \Demand Sites\South City)

[WEAPVariables](#): collection of all Variables for a single Branch (e.g., all variables for \Demand Sites\South City )

[WEAPVersion](#): a named version of the active area

[WEAPVersions](#): collection of all Versions in the active area

Each class is discussed below, followed by tips on [exploring the API](#) and an [example](#).

WEAP has its own built-in [script editor](#) that can be used to edit, interactively debug and run scripts that automate WEAP using its API. WEAP uses Microsoft's Windows Script (aka ActiveScript) technology which directly supports scripts written in VBScript and JScript (JavaScript). VBScript and JScript come with Windows and are always available, whereas other scripting languages, such as Perl, Python, Ruby and PHP, must be installed by you on your computer before you can use them in WEAP.

### 8.4.1 WEAPApplication API Class

The WEAPApplication class contains top-level properties and methods, including access to all other classes.

Note: in the following examples, a reference to WEAP, as in WEAP.ActiveArea, assumes that there is an object named WEAP of class WEAPApplication. This can be created in VBScript by:

```
SET WEAP = CreateObject("WEAP.WEAPApplication")
```

## 8.4 Automating WEAP (API)

However, this is not necessary when running scripts inside WEAP (e.g. using the [Call](#) function in an expression, from the menu (Advanced, Scripting, Run), or from the script editor) because an object named WEAP is automatically added to the internal scripting environment.

WEAPApplication Properties and Methods	Example (using VB script)
<b>ActiveArea:</b> Set or get the active WEAP area (i.e., dataset). Read or write.	<pre>WEAP.ActiveArea = "Weaping River Basin" 'Note: This is equivalent to WEAP.Areas("Weaping River Basin").Open PRINT WEAP.ActiveArea.Name</pre>
<b>ActiveScenario:</b> Set or get the active scenario. Read or write.	<pre>WEAP.ActiveScenario = WEAP.Scenarios("Current Accounts")  Note: This is equivalent to WEAP.Scenarios("Current Accounts").Activate  PRINT WEAP.ActiveScenario.Name</pre>
<b>Areas:</b> Get the collection of all WEAP areas. See <a href="#">WEAPAreas</a> for details. Read only.	<pre>WEAP.Areas("Weaping River Basin").Open PRINT WEAP.Areas(1).Name</pre>
<b>AreaSetting(Key, Section):</b> Set or get a text value associated with a key (text). Value is stored in file area.ini in the area subdirectory. If Section is not specified, will look in section User. The area.ini file can be a convenient place for the user to store settings that apply to one area. WEAP-wide settings can also be saved--see Setting and DeleteSetting.	<pre>WEAP.AreaSetting("Custom hydrology model") = "SWAT" WEAP.AreaSetting("Model directory", "SWAT") = "C:\Program Files\SWAT" IF WEAP.AreaSetting("Custom hydrology model") = "SWAT" THEN     ... END IF</pre>
<b>AutoCalc:</b> Set or get the Auto Calculation setting. If AutoCalc is FALSE, WEAP will not calculate any expressions in the Data View. Read or write.	<pre>WEAP.AutoCalc = FALSE ' Turn off automatic calculations</pre>
<b>BaseYear:</b> Set or get the first year of the study period. Read or write.	<pre>WEAP.BaseYear = 2000 PRINT WEAP.BaseYear</pre>
<b>Branch(BranchName):</b> Get the <a href="#">WEAPBranch</a> object for the specified branch. Read only.	<pre>WEAP.Branch("\Demand Sites\South City").Variables("Consumption").Expression = "30"</pre>
<b>Branches:</b> Get the collection of all visible branches in the tree. Returns a <a href="#">WEAPBranches</a> object. Read only.	
<b>BranchExists(BranchName):</b> Check if a branch exists. Read only.	<pre>IF WEAP.BranchExists("\Demand Sites\South City") THEN</pre>

WEAPApplication Properties and Methods	Example (using VB script)
	<pre>WEAP.Branch("\Demand Sites\South City").Variables("Consumption").Expres sion = "30" END IF</pre>
<p><b>BranchVariable</b>(BranchName:VariableName): Get the <a href="#">WEAPVariable</a> object for the specified branch and variable. VariableName can be omitted if BranchName only has one variable (e.g., Key Assumptions branches have one variable). Note: This is equivalent to Branch(BranchName).Variables(VariableName). Read only.</p>	<pre>WEAP.BranchVariable("\Demand Sites\South City:Consumption").Expression = "30"</pre> <p>Note: This is equivalent to Branch(BranchName).Variable(VariableName)</p>
<p><b>Calculate</b>(LastYear, LastTimestep): Force WEAP to calculate all scenarios marked for calculation, even if WEAP thinks the calculations are up to date. This is useful if you have changed values in an input file that WEAP is reading via ReadFromFile. If <b>optional</b> parameters LastYear and LastTime are given, only calculate up to that year and timestep.</p>	<pre>WEAP.Calculate WEAP.Calculate(2000, 6)</pre>
<p><b>CalculationErrors</b>: Get the number of WEAP calculation errors from the just-run WEAP calculation. Read only.</p>	<pre>IF WEAP.CalculationErrors &gt; 0 THEN PRINT WEAP.CalculationErrors, " calculation errors"</pre>
<p><b>CalculationTime</b>: Get the calculation time from the just-run WEAP calculation, in seconds. Read only.</p>	<pre>PRINT WEAP.CalculationTime, " seconds to calculate"</pre>
<p><b>CalcTS</b>: Get the timestep being calculated. Read only.</p>	<pre>IF WEAP.CalcYear = WEAP.BaseYear and WEAP.CalcTS = WEAP.NumTimeSteps THEN ' Do something in the last timestep of the Current Accounts END IF</pre>
<p><b>CalcYear</b>: Get the year being calculated. Read only.</p>	<pre>IF WEAP.CalcYear = WEAP.BaseYear THEN Initialize END IF</pre>
<p><b>CalledByBranch</b>: If the script containing this statement was called from an expression using the <a href="#">Call</a> function, this will get the <a href="#">WEAPBranch</a> object for the branch that made the call. Read only.</p>	<pre>PRINT WEAP.CalledByBranch.FullName</pre>



## 8.4 Automating WEAP (API)

WEAPApplication Properties and Methods	Example (using VB script)
<p><b>CalledByScenario:</b> If the script containing this statement was called from an expression using the <a href="#">Call</a> function, this will get the <a href="#">WEAPScenario</a> object for the scenario that made the call. Read only.</p>	<pre>PRINT WEAP.CalledByScenario.Name</pre>
<p><b>CalledByTimeStep:</b> If the script containing this statement was called from an expression using the <a href="#">Call</a> function, this will get the timestep number (from 1 to NumTimeSteps) for the timestep that made the call. Read only.</p>	<pre>IF WEAP.CalledByTimeStep = 6 THEN ... </pre>
<p><b>CalledByVariable:</b> If the script containing this statement was called from an expression using the <a href="#">Call</a> function, this will get the <a href="#">WEAPVariable</a> object for the variable that made the call. Read only.</p>	<pre>PRINT WEAP.CalledByVariable.Name</pre>
<p><b>CalledByYear:</b> If the script containing this statement was called from an expression using the <a href="#">Call</a> function, this will get the year number (between BaseYear and EndYear) for the year that made the call. Read only.</p>	<pre>IF WEAP.CalledByYear &gt; WEAP.BaseYear THEN ... </pre>
<p><b>DataExpression</b>(BranchVariableName, InheritIfNecessary): Set or get the data expression for the branch:variable. Because a blank expression will default to the expression from the parent scenario, use FALSE for the optional parameter InheritIfNecessary to prevent inheriting from the scenario.</p>	<pre>WEAP.DataExpression("\Demand Sites\South City:Annual Activity Level") = "Growth(3%)"  PRINT WEAP.DataExpression("\Demand Sites\South City:Annual Activity Level")  IF WEAP.DataExpression("\Demand Sites\South City:Annual Activity Level", FALSE) = "" THEN 'check if blank in active scenario     WEAP.DataExpression("\Demand Sites\South City:Annual Activity Level") = "Growth(3%)" END IF</pre>
<p><b>DeleteAreaSetting</b>(Key, Section): Delete a text value associated with a key (text) (previously saved by WEAP.AreaSetting), from file area.ini in the area subdirectory. If Section is not specified, will look in section User. The area.ini file can be a convenient place for the user to store settings that apply to one area. WEAP-wide settings can also be saved--see Setting and DeleteSetting.</p>	<pre>WEAP.DeleteAreaSetting("Custom hydrology model")</pre>

WEAPApplication Properties and Methods	Example (using VB script)
<p><b>DeleteSetting</b>(Key, Section): Delete a text value associated with a key (text) (previously saved by WEAP.Setting), from file weap.ini in the WEAP main directory. If Section is not specified, will look in section User. The weap.ini file can be a convenient place for the user to store settings that apply to all of WEAP. Area-specific settings can also be saved--see AreaSetting and DeleteAreaSetting.</p>	<pre>WEAP.DeleteSetting("PEST directory")</pre>
<p><b>DictionaryVersion</b>: Get the WEAP data dictionary version number. Read only.</p>	<pre>PRINT "WEAP data dictionary version "; WEAP.DictionaryVersion</pre>
<p><b>Directory</b>: Get the directory where the WEAP program is located. Read only.</p>	<pre>PRINT "WEAP is located in "; WEAP.Directory</pre>
<p><b>EndYear</b>: Set or get the last year of the study period. Read or write.</p>	<pre>WEAP.EndYear = 2020 PRINT WEAP.EndYear</pre>
<p>If the filename has the .xls extension, the table will be exported to an Excel file. Otherwise, it will be exported to a CSV file.</p> <p><b>ExportResults</b>(CSVFilename, IncludeTitle, IncludeColumnTitles, Transpose, ReadFromFileFormat): Save active results table to a comma separated value (CSV) file. Will switch to Results View if necessary, calculating results as needed. If IncludeTitle = FALSE, do not include a title in the file. If IncludeColumnTitles = FALSE, do not have a row with column titles. If Transpose is TRUE, transpose the rows and columns. If ReadFromFileFormat is TRUE, save in the format expected by the <a href="#">ReadFromFile</a> function (one line per timestep). IncludeTitle, IncludeColumnTitles, Transpose and ReadFromFileFormat are optional parameters; IncludeTitle and IncludeColumnTitles default to TRUE if omitted, whereas Transpose and ReadFromFileFormat default to FALSE if omitted.</p> <p><b>ExportResults</b>(ExcelFilename): Save active results table to an Excel (XLS) file. Will switch to Results View if necessary, calculating results as needed. If there are more than 256 columns (e.g., 30 years of</p>	<pre>WEAP.ExportResults("C:\Groundwater.csv") WEAP.ExportResults("C:\Groundwater.csv", FALSE) WEAP.ExportResults("C:\Groundwater.csv", TRUE, FALSE) WEAP.ExportResults("C:\Groundwater.csv", TRUE, FALSE, TRUE) WEAP.ExportResults("C:\Groundwater.csv", TRUE, FALSE, TRUE, TRUE)  WEAP.LoadOverview("Default") WEAP.ExportResults("C:\Overview.xls")</pre>

## 8.4 Automating WEAP (API)

WEAP Application Properties and Methods	Example (using VB script)
monthly results would be $30 \times 12 = 360$ columns), the table will be transposed.  Note: ExportResults works in both the Results View and the Scenario Explorer View.	
<b>FirstTimeStep</b> : Get the calendar index for the first timestep of the water year. Read only.	PRINT WEAP. <b>FirstTimeStep</b> ' if the water year begins in October, this would be 10  Note: FirstTimeStep is equivalent to Timesteps(1).CalendarIndex
<b>IncludeLeapDays</b> : True if the timestep which includes February 29 will have an extra day in leap years. Read only.	IF WEAP. <b>IncludeLeapDays</b> Then ...
<b>IsCalculating</b> : True if WEAP is calculating, False if not. Read Only.	IF WEAP. <b>IsCalculating</b> Then ...
<b>LoadFavorite</b> (FavoriteName): Load predefined report format, which had been previously saved as a WEAP "favorite." Will switch to Results View if necessary, calculating results as needed.	WEAP. <b>LoadFavorite</b> ("Groundwater Storage")
<b>LoadOverview</b> (OverviewName): Load previously saved WEAP "overview." Will switch to Scenario Explorer View if necessary, calculating results as needed. Tip: Once an overview has been loaded, you may use WEAP.ExportResults to save all the tables to a CSV or Excel file.	WEAP. <b>LoadOverview</b> ("Default")
<b>Logfile</b> : Set or get the file to which errors and warnings are logged (only if Verbose is 0, 1 or 2)	WEAP. <b>Logfile</b> = WEAP.Directory + "WEAPErrors.txt"
<b>NumErrors</b> : Get or reset the number of errors this session from using API property and method calls..	IF WEAP. <b>NumErrors</b> > 0 THEN PRINT WEAP. <b>NumErrors</b> ; " Errors"
<b>NumTimeSteps</b> : Get the number of time steps in each year (e.g., 12). Read only.	PRINT WEAP. <b>NumTimeSteps</b> Note: This is equivalent to WEAP.Timesteps.Count
<b>PrevTSCalcTS</b> : Integer: Get the timestep of the previous calculation timestep. Read only	PRINT WEAP.BranchVariable("\Demand Sites\South City:Supplied").Value(WEAP.PrevTSCalcYear, WEAP.PrevTSCalcTS)

WEAPApplication Properties and Methods	Example (using VB script)
<b>PrevTSCalcYear:</b> Integer: Get the year of the previous calculation timestep. Read only.	<pre>PRINT WEAP.BranchVariable("\Demand Sites\South City:Supplied").Value(WEAP.PrevTSCa lcYear, WEAP.PrevTSCalcTS)</pre>
<b>Print</b> (Number or text): Prints a number or a text string. Print statements are sent to the APIPrint.txt file. This file is automatically monitored and displayed in WEAP's Script Editor.	<pre>WEAP.<b>Print</b>("The current calculation year is " &amp; WEAP.CalcYear)</pre>
<b>PrintToFile</b> (FileName, Number or text, Append): Prints a number or a text string to a named text file. The value of the optional parameter Append will determine what WEAP will do if the file already exists: if Append is TRUE (or not specified), WEAP will add the number or text to the end of the existing file. Otherwise, the file will be cleared before writing the number or text to it.	<pre>WEAP.PrintToFile("C:\Results.txt", "</pre>
<b>ProgramDirectory:</b> Gets the full path of the folder in which WEAP is installed. Read only.	
<b>ProgramStarted:</b> Determine if WEAP has finished starting up. Can be used to make sure WEAP is loaded before continuing in the script. Read only.	<pre>WEAP = CreateObject("WEAP.WEAPApplication") WHILE NOT WEAP.<b>ProgramStarted</b> ' do nothing WEND</pre>
<p><b>ResultValue</b>(BranchName:VariableName, Year, TimeStepNumber, Scenario, Year2, TimeStep2, FunctionType, PercentileValue): Get a single result value or an aggregate result value (e.g., sum or average over time). TimeStepNumber is the index of the timestep, e.g., for June, the TimeStepNumber is 6 (assuming the water year begins in January). The Year and TimeStepNumber parameters are omitted for variables that have a single value for the entire study period (e.g., Demand Site Reliability). Omit Year2 and TimeStepNumber2 to get a single value. Available functions for FunctionType are: <b>Total, Average, Median, Minimum, Maximum, Percentile</b> and <b>CV</b> (coefficient of variation). If FunctionType is omitted, the Total will be calculated. PercentileValue is only used if FunctionType is Percentile. If the</p>	<pre>PRINT WEAP.<b>ResultValue</b>(\Demand Sites\South City:Reliability") 'Reliability is for the entire study period, so doesn't have a year or time step parameter PRINT WEAP.<b>ResultValue</b>(\Supply and Resources\River\Weaping River\Reservoirs\Central Reservoir:Storage Volume", 1998, 7) PRINT WEAP.<b>ResultValue</b>(\Supply and Resources\River\Weaping River\Reservoirs\Central Reservoir:Storage Volume", 2005, 7, "Reference") PRINT WEAP.<b>ResultValue</b>(\Demand Sites\West City:Unmet Demand", 2005, 1, "Reference",</pre>

## 8.4 Automating WEAP (API)

WEAPApplication Properties and Methods	Example (using VB script)
<p>Scenario parameter is omitted, the active scenario will be used. Will switch to Results View if necessary, calculating results as needed. Read only.</p> <p>To access MODFLOW cell results, the cell's layer, row and column is given instead of the BranchName:  ResultValue(MODFLOWVariableName[layer, row, column], Year, TimeStepNumber, Scenario, Year2, TimeStep2, FunctionType, PercentileValue)</p> <p>Note:  WEAP.Branch(BranchName).Variables(VariableName).Value(Year, TimeStepNumber, ....) is equivalent to  WEAP.ResultValue(BranchName:VariableName, Year, TimeStepNumber, ...)</p>	<pre> 2005,WEAP.NumTimeSteps) ' total unmet demand for 2005  PRINT WEAP.ResultValue (\Demand Sites\West City:Unmet Demand", WEAP.BaseYear, 1, "Reference", WEAP.EndYear, WEAP.NumTimeSteps) ' total unmet demand for entire study period  PRINT WEAP.ResultValue (\Demand Sites\West City:Unmet Demand", WEAP.BaseYear, 1, "Reference", WEAP.EndYear, WEAP.NumTimeSteps, "Average") ' average unmet demand for entire study period  PRINT WEAP.ResultValue (\Demand Sites\West City:Unmet Demand", WEAP.BaseYear, 1, "Reference", WEAP.EndYear, WEAP.NumTimeSteps, "Percentile", 90) ' the 90th percentile value for unmet demand for entire study period  PRINT WEAP.ResultValue ("Cell Head[1, 57, 30]", 2005, 1, "Reference", 2009, 12, "Minimum") ' The minimum groundwater head elevation of cell layer 1, row 57, column 30 in the period 2005-2009 in scenario Reference, as calculated by a linked MODFLOW model. </pre>
<p><b>SaveArea:</b> Save all changes to current area. NOTE: If you close WEAP without calling <b>SaveArea</b>, the changes will <b>not</b> be saved.</p>	<pre>WEAP.SaveArea</pre>
<p><b>SaveVersion</b>(comment): Create a new version of the active area with the given comment.</p>	<pre>WEAP.SaveVersion ("Scenario 'Reference' is finished")</pre>
<p><b>Scenarios:</b> Get the collection of all scenarios in the active area. See <a href="#">WEAPScenarios</a> for details. Read only.</p>	<pre> FOR EACH s IN WEAP.Scenarios PRINT WEAP.ResultValue ("\Demand Sites\South City:Reliability", , , s.Name) NEXT </pre>
<p><b>Setting</b>(Key, Section): Set or get a text value associated with a key (text). Value is stored in file weap.ini in the WEAP main directory.</p>	<pre> WEAP.Setting("Custom hydrology model") = "SWAT"  WEAP.Setting("Model directory", </pre>

WEAPApplication Properties and Methods	Example (using VB script)
If Section is not specified, will look in section User. The weap.ini file can be a convenient place for the user to store settings that apply to all of WEAP. Area-specific settings can also be saved--see AreaSetting and DeleteAreaSetting.	<pre>"SWAT") = "C:\Program Files\SWAT" IF WEAP.Setting("Custom hydrology model") = "SWAT" THEN ... END IF</pre>
<b>SoftwareVersion:</b> Get the WEAP version number. Read only.	<pre>PRINT "WEAP version: "; WEAP.<b>SoftwareVersion</b></pre>
<b>Status:</b> Determine whether the previous property or method call was successful, returning a logical value of TRUE or FALSE. Read only.	<pre>IF WEAP.<b>Status</b> = FALSE THEN EXIT FOR</pre>
<b>TimeStepName</b> (TimeStepNumber): Get the name of a time step (e.g., "May" or "Oct 15"). Read only.	<pre>PRINT WEAP.<b>TimeStepName</b>(12)</pre> <p>Note: This is equivalent to WEAP.Timesteps(12).Name</p>
<b>UserID:</b> Set or get the 3-letter User ID (the user's initials).	<pre>WEAP.<b>UserID</b> = "JGS"</pre>
<b>UserName:</b> Get the current user's full name.	<pre>PRINT WEAP.<b>UserName</b></pre>
<b>Verbose:</b> Set or get level of information and interaction, from 0-4. 0 = display no messages; 1 = display errors only; 2 = ask questions; 3 = show warnings; 4 = show all messages. The default level is 1.	<pre>WEAP.<b>Verbose</b> = 0 WEAP.<b>Verbose</b> = 2</pre>
<b>Versions:</b> Get the collection of versions for the active area. See <a href="#">WEAPVersions</a> for details. Read only.	<pre>WEAP.<b>Versions</b>("Finished Reference Scenario").Revert</pre>
<b>View:</b> Set or get the active view (one of "Schematic", "Data", "Results", "Scenario Explorer" or "Notes")	<pre>WEAP.<b>View</b> = "Data" WEAP.<b>View</b> = "Results" IF WEAP.<b>View</b> &lt;&gt; "Results" THEN do something</pre>
<b>Visible:</b> Show or hide WEAP	<pre>WEAP.<b>Visible</b> = TRUE WEAP.<b>Visible</b> = FALSE</pre>
<b>WorkingDirectory:</b> Gets the full path of the WEAP working directory. Read only.	<pre>PRINT WEAP.<b>WorkingDirectory</b></pre>
<b>YearTimeStepName</b> (Year, TimeStepNumber): Get the name of a year and time step (e.g., "May 2000" or "Oct 15	<pre>PRINT WEAP.<b>YearTimeStepName</b>(2000, 12)</pre>

WEAPApplication Properties and Methods	Example (using VB script)
2001"). Read only.	

### 8.4.2 WEAPArea and WEAPAreas API Classes

The WEAPArea class represents a single WEAP area (dataset), whereas WEAPAreas is the collection of all WEAP areas.

The WEAPAreas collection is a property of the [WEAPApplication](#) class, e.g., WEAP.Areas

You can get access to a WEAPArea in three different ways:

1. WEAPApplication.Areas(AreaName or Index), specifying either the name of the area or a number from 1 to WEAP.Areas.Count, e.g., WEAP.Areas("Weaping River Basin") or WEAP.Areas(1)
2. WEAPApplication.ActiveArea, e.g., WEAP.ActiveArea
3. Iterate through the collection of areas, e.g., For Each Area in WEAP.Areas

WEAPAreas Properties and Methods	Example (using VB script)
<b>Count:</b> Get the number of WEAP areas. Read only.	<pre>PRINT "There are "; WEAP.Areas.Count;     " areas."  FOR i = 1 to WEAP.Areas.Count     PRINT WEAP.Areas(i).Name NEXT</pre>
<b>Exists:</b> Returns true if the area exists.	<pre>IF WEAP.Areas.Exists("Weaping River     Basin") THEN     WEAP.ActiveArea := "Weaping River     Basin"  END IF</pre>
<b>Item</b> (AreaName or Index): Get the area identified by name or index (from 1 to Areas.Count).	<pre>WEAP.Areas.Item("Weaping River     Basin").Open  WEAP.Areas("Weaping River Basin").Open</pre> <p>Note: the Item property is the "default" property, and therefore is usually omitted. Thus, the two examples above are equivalent.</p>

WEAPArea Properties and Methods	Example (using VB script)
<b>Directory:</b> Get the folder for the area (e.g. C:\Program Files\WEAP21\Weaping River Basin). Read Only.	<pre>FOR EACH Area IN WEAP.Areas     PRINT Area.Directory NEXT</pre>
<b>Name:</b> Get the name of the area. Read only.	<pre>PRINT WEAP.Areas(1).Name</pre>

<b>Open:</b> Make this area the active area.	<code>WEAP.Areas("Weaping River Basin").Open</code> Note: This is equivalent to <code>WEAP.ActiveArea = "Weaping River Basin"</code>
<b>Save:</b> Save all changes to the area. This only works if the area is the active area.	<code>WEAP.ActiveArea.Save</code> Note: This is equivalent to <code>WEAP.SaveArea</code>

### 8.4.3 WEAPScenario and WEAPScenarios API Classes

The `WEAPScenario` class represents a single WEAP scenario, whereas `WEAPScenarios` is the collection of all scenarios in the active area (including Current Accounts).

The `WEAPScenarios` collection is a property of the [WEAPApplication](#) class, e.g., `WEAP.Scenarios`

You can get access to a `WEAPScenario` in three different ways:

1. `WEAPApplication.Scenarios(ScenarioName or Index)`, specifying either the name of the scenario or a number from 1 to `WEAPApplication.Scenarios.Count`, e.g., `WEAP.Scenarios("Current Accounts")` or `WEAP.Scenarios(1)`
2. `WEAPApplication.ActiveScenario`, e.g., `WEAP.ActiveScenario`
3. Iterate through the collection of scenarios, e.g., For Each Scenario in `WEAP.Scenarios`

WEAPScenarios Properties and Methods	Example (using VB script)
<b>Count:</b> Get the number of WEAP scenarios in the active area. Read only.	<pre>FOR i = 1 TO WEAP.Scenarios.Count;     PRINT WEAP.Scenarios(i).Name NEXT</pre>
<b>Item(ScenarioName or Index):</b> Get the scenario identified by name or index (from 1 to <code>Scenarios.Count</code> ).	<pre>WEAP.Scenarios.Item("Current Accounts").Activate WEAP.Scenarios("Current Accounts").Activate WEAP.Scenarios(1).Activate</pre> <p>Note: the <code>Item</code> property is the "default" property, and therefore is usually omitted. Thus, the first two examples above are equivalent.</p>
<b>ResultsShown:</b> Set or get for all the scenarios whether their results will be shown in the Results View (calculating if necessary).	<pre>WEAP.Scenarios.ResultsShown = FALSE</pre>

WEAPScenario Properties and Methods	Example (using VB script)
<b>Activate:</b> Make this scenario the active scenario.	<pre>WEAP.Scenarios("Current Accounts").Activate</pre> <p>Note: This is equivalent to <code>WEAP.ActiveScenario =</code></p>



WEAPScenario Properties and Methods	Example (using VB script)
	"Current Accounts"
<b>Name:</b> Get the name of the scenario. Read only.	<code>PRINT WEAP.Scenarios(1).Name</code>
<b>ID:</b> Get WEAP's internal ID code of the scenario. Most users will not ever need this information. Read only.	<code>PRINT "ID code for "; WEAP.ActiveScenario.Name; "is "; WEAP.ActiveScenario.ID</code>
<b>IsCurrentAccounts:</b> Is TRUE if the scenario is the Current Accounts, FALSE otherwise. Read only.	<code>IF WEAP.ActiveScenario.IsCurrentAccount s = FALSE THEN WEAP.ActiveScenario.ResultsShown = TRUE</code>
<b>ResultsShown:</b> Set or get whether the scenario's results will be shown in the Results View (calculating if necessary).	<code>WEAP.ActiveScenario.ResultsShown = TRUE</code>

#### 8.4.4 WEAPBranch and WEAPBranches API Classes

The WEAPBranch class represents a specific Branch on the data tree (e.g., \Demand Sites\South City ), whereas WEAPBranches is a collection of all child Branches for a specified Branch (e.g., all child branches of \Demand Sites ).

You can get access to a WEAPBranches collection in two different ways:

1. The Branches property of the [WEAPApplication](#) class, giving all branches, WEAP.Branches
2. From the Children property of a WEAPBranch, e.g., WEAP.Branch("\Demand Sites").Children

You can get access to a WEAPBranch in three different ways:

1. WEAPApplication.Branch(FullBranchPath), e.g., WEAP.Branch("\Demand Sites\South City")
2. WEAPBranches(Index), specifying a number from 1 to WEAPBranches.Count, e.g., WEAP.Branch("\Demand Sites").Children(1)
3. Iterate through the collection of all branches, e.g., For Each Branch in WEAP.Branches

WEAPBranches Properties and Methods	Example (using VB script)
<b>Count:</b> Get the number of WEAP branches in the collection. Read only.	<code>FOR i = 1 to WEAP.Branch("\Demand Sites").Children.Count; PRINT WEAP.Branch("\Demand Sites").Children(i).Name NEXT</code>
<b>Item(Index):</b> Get the branch identified by index (from 1 to Count).	<code>PRINT WEAP.Branch("\Demand Sites").Children.Item(2) PRINT WEAP.Branch("\Demand Sites").Children(2).Name</code>

Note: the Item property is the "default" property, and therefore is usually omitted. Thus, the two examples above are equivalent.

WEAPBranch Properties and Methods	Example (using VB script)
<b>ActiveInCurrentAccounts:</b> Get or set whether the branch is active in the Current Accounts. The following types can be set as not active in the Current Accounts (all other types are always active in the Current Accounts): Demand Site, Wastewater Treatment Plant, Groundwater Node, Reservoir, Other Supply, Transmission Link, Return Flow Link, Run of River Hydro, Diversion.	<pre>WEAP.Branch("\Demand Sites\South City").ActiveInCurrentAccounts = FALSE FOR EACH Branch IN WEAP.Branch("\Demand Sites").Children IF Branch.ActiveInCurrentAccounts THEN ... END IF NEXT</pre>
<b>Children:</b> Get the collection of all branches underneath this branch. See <a href="#">WEAPBranches</a> for details. Read only.	<pre>PRINT WEAP.Branch("\Demand Sites").Children(2).Name FOR EACH Branch IN WEAP.Branch("\Demand Sites").Children PRINT Branch.Name NEXT</pre>
<b>FullName:</b> Get the full path of the current branch. Each level is separated by the "\" character. (e.g. Demand Sites\South City) Read only.	<pre>FOR EACH Branch IN WEAP.Branches PRINT Branch.FullName NEXT</pre>
<b>ID:</b> Get the internal unique numeric ID of the branch. Each branch in the tree has a unique ID. It is not displayed in WEAP's normal interface but may be useful when automating WEAP. Read only.	
<b>Name:</b> Get the name of the branch. Read only.	<pre>PRINT WEAP.Branch("\Demand Sites").Children(2).Name</pre>
<b>Order:</b> Get the order of the branch among its siblings, where the order of the first sibling is one. Read only.	<pre>PRINT WEAP.Branch("\Demand Sites\South City").Order</pre>
<b>Parent:</b> Get the WEAPBranch object for the parent of the current branch. Read only.	<pre>PRINT WEAP.Branch("\Demand Sites\South City").Parent.Name ' This will be "Demand Sites"</pre>
<b>ParentID:</b> Get the numeric ID of the Parent of the current branch. Equivalent to Branch.Parent.ID. Read only.	<pre>IF Branch.ParentID = WEAP.Branch("\Demand Sites").ID THEN</pre>

## 8.4 Automating WEAP (API)

WEAPBranch Properties and Methods	Example (using VB script)																																
	...																																
<b>TypeID:</b> Get the numeric code indicating the type of branch. Read only.	<pre>FOR EACH Branch IN WEAP.Branch("\Demand Sites").Children   IF Branch.TypeID = 1 THEN ' Demand site or catchment?   ... NEXT</pre>																																
<b>TypeName:</b> Get the name of the type of branch. Read only.  Valid branch type IDs and their associated names: <div> <table> <tr> <th>Type Name</th><th>TypeID</th></tr> <tr><td>River</td><td>6</td></tr> <tr><td>Diversion</td><td>15</td></tr> <tr><td>Reservoir</td><td>4</td></tr> <tr><td>Groundwater</td><td>3</td></tr> <tr><td>Other Supply</td><td>5</td></tr> <tr><td>Demand Site</td><td>1</td></tr> <tr><td>Catchment</td><td>21</td></tr> <tr><td>Runoff/Infiltration Link</td><td>22</td></tr> <tr><td>Transmission Link</td><td>7</td></tr> <tr><td>Wastewater Treatment Plant</td><td>2</td></tr> <tr><td>Return Flow Link</td><td>8</td></tr> <tr><td>Run of River Hydro</td><td>14</td></tr> <tr><td>Flow Requirement</td><td>9</td></tr> <tr><td>Streamflow Gauge</td><td>20</td></tr> <tr><td>River Reach</td><td>16</td></tr> </table> </div>	Type Name	TypeID	River	6	Diversion	15	Reservoir	4	Groundwater	3	Other Supply	5	Demand Site	1	Catchment	21	Runoff/Infiltration Link	22	Transmission Link	7	Wastewater Treatment Plant	2	Return Flow Link	8	Run of River Hydro	14	Flow Requirement	9	Streamflow Gauge	20	River Reach	16	<pre>FOR EACH Branch IN WEAP.Branch("\Demand Sites").Children   IF Branch.TypeName = "Demand Site" THEN ' Demand site or catchment? NEXT</pre>
Type Name	TypeID																																
River	6																																
Diversion	15																																
Reservoir	4																																
Groundwater	3																																
Other Supply	5																																
Demand Site	1																																
Catchment	21																																
Runoff/Infiltration Link	22																																
Transmission Link	7																																
Wastewater Treatment Plant	2																																
Return Flow Link	8																																
Run of River Hydro	14																																
Flow Requirement	9																																
Streamflow Gauge	20																																
River Reach	16																																
<b>Variable</b> (VariableName): Get the named variable for this branch. See <a href="#">WEAPVariable</a> for details. Read only	<pre>WEAP.Branch("\Demand Sites\South City").Variable("Consumption").Expression = 40</pre>																																
<b>VariableExists:</b> Returns true if the specified variable exists for this branch.	<pre>IF WEAP.Branch("\Demand Sites\South City").VariableExists("Consumption") THEN</pre>																																

WEAPBranch Properties and Methods	Example (using VB script)
	<code>PRINT "Variable exists"</code>
<b>Variables:</b> Get the collection of all variables associated with this branch. See <a href="#">WEAPVariables</a> for details. Read only	<pre>FOR i = 1 to WEAP.Branch("\Demand Sites\South City").Variables.Count;   PRINT WEAP.Branch("\Demand Sites\South City").Variables(i).Name NEXT  WEAP.Branch("\Demand Sites\South City").Variables("Consumption").Expr ession = 30</pre>
<b>VariableExists(VariableName):</b> Check if a variable exists for this branch. Read only.	<pre>' Set the wind speed for every catchment to be 3.3 m/s FOR EACH Branch IN WEAP.Branch("\Demand Sites and Catchments").Children   IF Branch.VariableExists("Wind") THEN ' This variable only exists for catchment branches   Br.Variable("Wind").Expression = 3.3   END IF NEXT</pre>

#### 8.4.5 WEAPTimeStep and WEAPTimeSteps API Classes

The WEAPTimeStep class represents a single WEAP Timestep, whereas WEAPTimeSteps is the collection of all Timesteps in the active area.

The WEAPTimeSteps collection is a property of the [WEAPApplication](#) class, e.g., WEAP.TimeSteps

You can get access to a WEAPTimeStep in two different ways:

1. WEAPApplication.TimeSteps(TimestepName or Index), specifying either the name of the Timestep or a number from 1 to WEAPApplication.TimeSteps.Count, e.g., WEAP.TimeSteps("January") or WEAP.TimeSteps(1)
2. Iterate through the collection of timesteps, e.g., For Each TS in WEAP.TimeSteps

WEAPTimeSteps Properties and Methods	Example (using VB script)
<b>Count:</b> Get the number of WEAP TimeSteps in the active area. Read only.	<pre>FOR i = 1 to WEAP.TimeSteps.Count;   PRINT WEAP.TimeSteps(i).Name NEXT</pre>
<b>Item(TimestepName or Index):</b> Get the Timestep identified by name or index (from 1 to TimeSteps.Count).	<pre>PRINT WEAP.TimeSteps.Item("January").NumDays PRINT WEAP.TimeSteps("January").NumDays PRINT WEAP.TimeSteps(1).Abbrev</pre>

## 8.4 Automating WEAP (API)

	Note: the Item property is the "default" property, and therefore is usually omitted. Thus, the first two examples above are equivalent.
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WEAP Timestep Properties and Methods	Example (using VB script)
<b>Abbrev:</b> The abbreviation for the timestep, e.g., "Jan" for "January".	<pre>PRINT WEAP.Timesteps("January").Abbrev</pre>
<b>CalendarIndex:</b> Get the index of this timestep, from 1 to Timesteps.Count, where January is 1.	<pre>PRINT   WEAP.Timesteps("October").CalendarIndex ' If FirstTimestep is October,   then this = 10</pre>
<b>ContainsLeapDay:</b> True if the timestep contains February 29 and WEAP.IncludeLeapDays is true. Read only.	<pre>PRINT   WEAP.Timesteps("October").ContainsLeapDay ' False  PRINT   WEAP.Timesteps("February").ContainsLeapDay ' True (if   WEAP.IncludeLeapDays is true)</pre>
<b>DaysBefore:</b> Get the total number of days in the water year before this timestep. For example, if Read only.	<pre>PRINT   WEAP.Timesteps("January").DaysBefore   ' If FirstTimestep is October, then   this = 92 (October + November +   December). If FirstTimestep is   January, then this = 0.</pre>
<b>Name:</b> Get the name of the Timestep. Read only.	<pre>FOR Each Timestep in WEAP.Timesteps   PRINT Timestep.Name NEXT</pre>
<b>Index:</b> Get the index of this timestep, from 1 to Timesteps.Count, where FirstTimestep is 1. For example, if FirstTimestep is October, then Timesteps("October").Index = 1. Read only.	<pre>PRINT WEAP.Timesteps("October").Index   ' If FirstTimestep is October, then   this = 1</pre>
<b>NumDays:</b> Get the number of days in the timestep, which could be a fractional number. Read only.	<pre>PRINT WEAP.Timesteps(2).NumDays ' If   FirstTimestep is October, then this   = 30 (Timestep 2 is November)</pre>
<b>ResultsShown:</b> Set or get whether the Timestep's results will be shown in the Results View (calculating if necessary).	<pre>WEAP.ActiveTimestep.ResultsShown = TRUE</pre>

### 8.4.6 WEAPVariable and WEAPVariables API Classes

The WEAPVariable class represents a Variable for a single Branch (e.g., Consumption for Branch \Demand Sites\South City), whereas WEAPVariables is a collection of all Variables for a given Branch (e.g., all variables for \Demand Sites\South City).

A WEAPVariables collection comes from the Variables property of a [WEAPBranch](#):

1. WEAPBranch.Variables, e.g., WEAP.Branch("\Demand Sites\South City").Variables

You can get access to a WEAPVariable from the Variables collection:

1. WEAPVariables(VariableName or Index), specifying either the name of the variable or a number from 1 to WEAPVariables.Count, e.g., WEAP.Branch("\Demand Sites\South City").Variables("Consumption") or WEAP.Branch("\Demand Sites\South City").Variables(1)

WEAPVariables Properties and Methods	Example (using VB script)
<b>Count:</b> Get the number of variables in the collection. Read only.	<pre>FOR i = 1 to WEAP.Branch("\Demand Sites\South City").Variables.Count;   PRINT WEAP.Branch("\Demand Sites\South City").Variables(i).Name NEXT</pre>
<b>Item(Index):</b> Get the variable identified by name or number (from 1 to Count).	<pre>PRINT WEAP.Branch("\Demand Sites\South City").Variables.Item(2).Name PRINT WEAP.Branch("\Demand Sites\South City").Variables(2).Name  PRINT WEAP.Branch("\Demand Sites\South City").Variables.Item("Consumption").Name PRINT WEAP.Branch("\Demand Sites\South City").Variables("Consumption").Name</pre> <p>Note: the Item property is the "default" property, and therefore is usually omitted. Thus, the first two examples above are equivalent, as are the third and fourth examples.</p>

WEAPVariable Properties and Methods	Example (using VB script)
<b>Expression(InheritIfNecessary):</b> Set or get the data expression for the variable. Because a blank expression will default to the expression from the parent scenario, use FALSE for the optional parameter InheritIfNecessary to prevent inheriting from the scenario.	<pre>V = WEAP.Branch("\Demand Sites\South City").Variables("Annual Activity Level") ' So we don't have to specify branch and variable every time  V.Expression = "Growth(3%)"  PRINT V.Expression  IF V.Expression(FALSE) = "" THEN 'check if blank in active scenario V.Expression = "Growth(3%)"</pre>

## 8.4 Automating WEAP (API)

WEAPVariable Properties and Methods	Example (using VB script)
	END IF
<b>IsResultVariable:</b> Is this a result variable (vs. a data variable). Read only.	<pre>PRINT WEAP.Branch("\Demand Sites\South City").Variables("Consumption").IsResultVariable ' This is false  PRINT WEAP.Branch("\Demand Sites\South City").Variables("Reliability").IsResultVariable ' This is true</pre>
<b>Name:</b> Get the name of the variable. Read only.	<pre>PRINT WEAP.Branch("\Demand Sites\South City").Variables(1).Name</pre>
<b>ScaleUnitText:</b> Gets a string containing the scale and units of the variable (works with both data and results variables). Read only.	<pre>PRINT WEAP.Branch("\Demand Sites\South City").Variables("Annual Activity Level").ScaleUnitText ' This is "Million cap"  PRINT WEAP.Branch("\Supply and Resources\River\Weaping River\Reservoirs\Central Reservoir:Storage Volume").ScaleUnitText ' This is m^3</pre>
<p><b>Value</b>(Year, TimeStepNumber, Scenario, Year2, TimeStep2, FunctionType, PercentileValue): Get a single result value or an aggregate result value (e.g., sum or average over time). TimeStepNumber is the index of the timestep, e.g., for June, the TimeStepNumber is 6 (assuming the water year begins in January). The Year and TimeStepNumber parameters are omitted for variables that have a single value for the entire study period (e.g., Demand Site Reliability). Omit Year2 and TimeStepNumber2 to get a single value. Available functions for FunctionType are: <b>Total, Average, Median, Minimum, Maximum, Percentile</b> and <b>CV</b> (coefficient of variation). If FunctionType is omitted, the Total will be calculated. PercentileValue is only used if FunctionType is Percentile. If the Scenario parameter is omitted, the active scenario will be used. Will switch to Results View if necessary, calculating results as needed. Read only.</p> <p>Note:</p>	<pre>PRINT WEAP.Branch("\Demand Sites\South City").Variables("Reliability").Value 'Reliability is for the entire study period, so doesn't have a year or time step parameter  V = WEAP.Branch("\Supply and Resources\River\Weaping River\Reservoirs\Central Reservoir").Variables("Storage Volume") ' So we don't have to specify branch and variable every time  PRINT V.Value(1998, 7) PRINT V.Value(2005, 7, "Reference")  V = WEAP.Branch("\Demand Sites\Industry East").Variables("Unmet Demand") ' So we don't have to specify branch and variable every time  PRINT V.Value(2005, 1, "Reference", 2005, WEAP.NumTimeSteps) ' total unmet demand for 2005  PRINT V.Value(WEAP.BaseYear, 1,</pre>

WEAPVariable Properties and Methods	Example (using VB script)
<code>bleName).Value(Year, ....)</code> is equivalent to <code>WEAP.ResultValue(BranchName:VariableName, Year, ...)</code>	<pre> "Reference", WEAP.EndYear, WEAP.NumTimeSteps) ' total unmet demand for entire study period  PRINT V.Value(WEAP.BaseYear, 1, "Reference", WEAP.EndYear, WEAP.NumTimeSteps, "Average") ' average unmet demand for entire study period  PRINT V.Value(WEAP.BaseYear, 1, "Reference", WEAP.EndYear, WEAP.NumTimeSteps, "Percentile", 90) ' the 90th percentile value for unmet demand for entire study period </pre>

### 8.4.7 WEAPVersion and WEAPVersions API Classes

The WEAPVersion class represents a single WEAP version, whereas WEAPVersions is the collection of all versions in the active area. (To see the list of versions in WEAP, on the menu choose Area, Revert to Version. The versions will be listed in the following format: AreaName: VersionDateTime - VersionName.)

The WEAPVersions collection is a property of the [WEAPApplication](#) class:

1. WEAPApplication.Versions, e.g., WEAP.Versions

You can get access to a WEAPVersion in two different ways:

1. WEAPVersions(VersionComment or Index), specifying either the comment associated with a version or a number from 1 to WEAPApplication.Versions.Count, e.g., WEAP.Versions("Finished with Current Accounts") or WEAP.Versions(1)
2. Iterate through the collection of versions, e.g., For Each Version in WEAP.Versions

WEAPVersions Properties and Methods	Example (using VB script)
<b>Count:</b> Get the number of WEAP versions in the active area. Read only.	<pre> FOR i = 1 to WEAP.Versions.Count;   PRINT WEAP.Versions(i).Name NEXT </pre>
<b>Item</b> (VersionComment or Index): Get the version identified by comment or index (from 1 to Versions.Count). If more than one version has the same comment, then the <b>latest</b> version is chosen. Read only.	<pre> PRINT WEAP.Versions.Item(1).Date PRINT WEAP.Versions(1).Date </pre> <p>Note: the Item property is the "default" property, and therefore is usually omitted. Thus, the two examples above are equivalent.</p>

WEAPVersion Properties and Methods	Example (using VB script)
<b>Comment:</b> Set or get the comment associated	<code>WEAP.Versions(1).Comment = "Finished"</code>



## 8.4 Automating WEAP (API)

WEAPVersion Properties and Methods	Example (using VB script)
with the version. The comment can be blank.	Reference Scenario" PRINT WEAP.Versions(1). <b>Comment</b>
<b>Date:</b> Get the date the version was saved. Read only.	PRINT WEAP.Versions(1). <b>Date</b>
<b>Filename:</b> Get the filename, including path, of the version. Read only.	PRINT WEAP.Versions(1). <b>Filename</b>
<b>Name:</b> Get the full name (both date and comment) of the version. Read only.	FOR Each Version in WEAP.Versions PRINT Version. <b>Name</b> END IF
<b>Revert:</b> Revert to this "version" of the active area. <b>Use with caution:</b> when you revert to a version, it will overwrite everything in the active area, so that the area will be just as it was when the version was originally saved.	WEAP.Versions("Finished Reference Scenario"). <b>Revert</b>

### 8.4.8 Exploring the API

Microsoft Excel provides a wonderful environment for exploring the WEAP API, using its Visual Basic Editor. In Excel, first create a new blank workbook, then go to Tools, Macros, Visual Basic Editor. (For Excel 2010, commands that you use to edit and run macros are found in the Code group of the Developer tab, which is hidden by default. To make the Developer tab visible, do the following: 1.Click the File tab, and then click Options. 2.Click the Customize Ribbon category. 3.Under Customize the Ribbon, in the Main Tabs list on the right, click Developer, and then click OK. Then, Developer tab, Visual Basic (on ribbon).)

Once you are in the Excel Visual Basic Editor, go to Tools, References. Scroll down to find "WEAP" and make sure the check box is checked. You will only need to do this once for each workbook. Go to View, Immediate Window to open the "Immediate" window, a place for you to type in commands and see their results instantly. Try to following in the Immediate Window, one at a time:

```
Set W = CreateObject("WEAP.WEAPApplication") ' This will open WEAP and  
set the local variable W to reference it
```

```
? W.Areas.Count ' how many areas do you have? The question mark is VB  
shorthand for PRINT
```

```
W.ActiveArea = "Weaping River Basin" ' open it
```

```
W.View = "Data"
```

```
? W.ActiveScenario.Name
```

```
W.ActiveScenario = "Current Accounts"
```

```
W.Branch("\Demand Sites\South  
City").Variables("Consumption").Expression = 20
```

```
W.LoadFavorite("Groundwater Storage") ' it will calculate at this
point
```

```
W.LoadFavorite("Unmet Demand")
```

```
W = nil ' This will close WEAP without saving any changes
```

Excel can also remind you what are the properties, methods and classes in the WEAP API, via its "Intellisense" technology. Intellisense only works when editing a macro, not in the Immediate Window. On the left side of the Excel Visual Basic Editor, double click on "ThisWorkbook" to open the code window. Then on the menu, choose Insert, Procedure. Give it a name ("Test"), and you can now start adding code to it. On the first line, type

```
Dim W As
```

After you type "As" and a space, Excel should pop up a list from which to choose. You can either scroll down to choose WEAPApplication, but it's easier to start typing. After you type WE, Excel should jump to that section of the list. Press the down arrow once to highlight WEAPApplication, then hit Enter to select it. For this to work, you must have already done the Tools, References step mentioned above. (If Excel isn't showing this list, hit Ctrl-space to pop it up.)

Now that Excel knows that W is of type WEAPApplication, you can type W. (that's W followed by a period) and a list will pop up of all the WEAP API properties and methods for the [WEAPApplication](#) class. On the next line, type W. and choose ActiveArea from the list. Excel will move to the next line, but that line is not finished yet. Go back up to the W.ActiveArea line and type = "Weaping River Basin" to finish it.

Another way that Excel can show the details of the API is in the "Object Browser." On the menu, choose View, Object Browser. In the top left of this window, change from <All Libraries> to WEAP. Now, you should see all the classes listed on the left. Click on a class, and its properties and methods will be listed on the right. Click on the property or method on the right and information about it will be displayed below. For example, click on WEAPApplication on the left, then ResultValue on the right. Below, you should see all the parameters that ResultValue needs, including which are optional.

### 8.4.9 API Example

Here is an example using VB script. Save the following lines as a text file (e.g., test.vbs), then double-click on the text file in Windows Explorer to run it.

```
' Run WEAP as a COM Automation Server
' Do a sensitivity analysis on the Supply Measures scenario to the
population growth rate of South City
' Vary the population growth for South City from 0 to 5%, saving
groundwater storage results for each run in c:\GWN.csv
```

```
Set WEAP = CreateObject("WEAP.WEAPApplication")
```

```
WEAP.Verbose = 1 ' 0 = no dialogs, 1 = errors only, 2 = questions and
errors, 3 = warnings, questions and errors, 4 = all dialogs
WEAP.Logfile = WEAP.Directory + "WeapErrors.txt" ' log all errors and
warnings to this text file
```

```
WEAP.ActiveArea = "Weaping River Basin"
WEAP.ActiveScenario = "Supply Measures"
```

## 8.4 Automating WEAP (API)

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```
FOR GrowthRate = 0 to 5
WEAP.Branch("\Demand Sites\South City").Variables("Annual Activity
Level").Expression = "Growth(" + FormatNumber(GrowthRate, 0) + "%)"
CALL WEAP.LoadFavorite("Groundwater Storage") ' This will calculate
first
IF WEAP.Status = FALSE THEN ' If the user cancels the calculations,
exit the FOR loop
EXIT FOR
END IF

CALL WEAP.ExportResults("c:\GW" + FormatNumber(GrowthRate, 0) +
".csv", FALSE, TRUE)
NEXT

' WEAP will close automatically when the script is done, and the
changes will NOT be saved to the area
```

## 8.5 PEST Calibration

WEAP includes a linkage to a parameter estimation tool (PEST) that allows the user to automate the process of comparing WEAP outputs to historical observations and modifying model parameters to improve its accuracy. You can use PEST to help calibrate one or more variables in your WEAP model, which can be particularly useful when using the [Soil Moisture method](#) of catchment hydrology. PEST (**Parameter ESTimation**) is a free software package for Model-Independent Parameter Estimation and Uncertainty Analysis. The basic PEST tool (pest.exe) is included in the WEAP installation. For more information about PEST, and to download documentation or other PEST modules, see <http://www.pesthomepage.org>.

### 8.5.1 Calibration Sets

WEAP can keep track of multiple sets of PEST Calibration settings. For example, you might want to have one Set for calibrating snowpack in the mountains, and another Set for calibrating runoff in the lowlands. Each set comprises all the following information: **Parameters to Calibrate**, **Observations to Calibrate to**, and **Options**. The buttons to the right of the Calibration Set drop-down list let you add, delete or rename the Sets.

### 8.5.2 Parameters to Calibrate

Choose one or more parameters (variables in your model) to calibrate, giving allowable ranges for each. PEST will find the values for these parameters that give the best fit to the observations specified (see below).

To **add** a parameter, click the **Add Parameter** button. (To **edit** an existing parameter, click the **Edit Parameter** button.) On the "Parameter to Calibrate" screen, choose the Data View **Branch** and **Variable** you want to calibrate. In each calibration iteration, this variable will be given a single value for all years and timesteps. For example, if you were calibrating a catchment that used the Soil Moisture method, you might want to calibrate the Root Zone Conductivity and Preferred Flow Direction variables. (If you had several land classes, you might need to calibrate these variables for each land class.) Enter the **Title** and **Description**, which will be displayed on the Scenario Explorer Overview that the PEST Calibration Wizard will create. The **Parameter Name Abbreviation for PEST File** will be used as the name of the parameter in the PEST control file. The name can be up to 12 characters long, consisting of letters, numbers, and the underline character (e.g., "Pref\_Flo\_Dir", or "PFD\_Forest"). You cannot have two parameters with the same 12 character name. To specify the allowable range of values for this variable, enter the **Lower Bound** and **Upper Bound**, and the **Initial Value** to test. PEST solutions can be sensitive to the initial value of a parameter, so you might want to experiment with different initial values. Click the **Save** button to save your changes.

The table lists all the parameters defined so far. You can edit the Lower Bound, Upper Bound and Initial Value directly in the table, or click the Edit Parameter button to edit on the "Parameter to Calibrate" screen.

### 8.5.3 Observations to Calibrate to

There are three different types of observations to which you can calibrate: **Streamflow**, **Reservoir storage** and **Catchment** snowpack. You may select one or more types to calibrate to, and one or more

## 8.5 PEST Calibration

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within each selected type. For Streamflow, PEST will compare the streamflow gauge data entered in the Data View, with streamflow results for the node immediately upstream of the gauge. For Reservoir storage, PEST will compare the reservoir storage data entered in the Observed Volume variable for the reservoir in the Data View, with the reservoir storage results. For Catchment snowpack, PEST will compare the snowpack data entered in the Snow Accumulation Gauge variable for the catchment in the Data View, with the Snow Accumulation results for the catchment.

You can choose to calibrate all **Years** and **Months**, or a subset of either.

### 8.5.4 Options

Choose one or more **Scenarios to Calibrate**. PEST will run once for each selected scenario.

If you uncheck **Modify parameters in Current Accounts also**, then PEST will only modify the parameters in the selected scenarios. If checked, the parameters will be modified in both Current Accounts and Scenarios.

If you choose **Normalize observation data**, PEST will use the reciprocal of each observation value as its weight. For example, if the observations were 10, 30 and 25, the weights would be 1/10, 1/30 and 1/25. This weighting will ensure that the larger values, such as flood flows in the river, do not outweigh the smaller values, such as low flows. Also, this option is essential when simultaneously calibrating different types of observations (e.g., streamflow and reservoir storage), because the two types are not comparable (different units, or could be many orders of magnitude different). If you are unsure about this option, you should try it both ways and compare the calibrations.

You can choose to have WEAP build the PEST input files and then run PEST automatically, or just build the files but not run PEST. This second option would allow you to edit the PEST control file directly in order to set advanced options before running PEST. (The PEST control files that WEAP creates will be placed into a subdirectory named PEST of the area subdirectory, e.g., My Documents\WEAP Areas\Weaping River Basin\PEST.) Choose the setting for the **Run PEST after building PEST input files** checkbox accordingly.

### 8.5.5 Running PEST

When you click the **Build Files and Run PEST** button, WEAP will run PEST once for each scenario selected. In a single PEST run, PEST will repeatedly cycle through: modifying WEAP data variables, running WEAP calculations, then examining the results. After PEST has run for each selected scenario, WEAP will go to the [Scenario Explorer](#) View, displaying each parameter to calibrate in the Data Section, and each Observation to calibrate to in the Results Section, for the selected scenarios.

**Menu option:** Advanced, PEST Calibration

## 8.6 Safe Yield Wizard

The Safe Yield Wizard can help optimize and evaluate tradeoffs among human and environmental water supply needs by finding the maximum safe yield for a given WEAP model. For example, you could explore different policies for reservoir release, instream flow requirements and demand management to see what impact they had on the maximum safe yield from the reservoir and on instream flow.

The Wizard will attempt to maximize the "goal variable" in each selected scenario, such that all selected demand sites and flow requirements have 100% reliability (no unmet demand) for all years in the study period, and all selected reservoirs refill completely at least once after their lowest point.

The first step in the Safe Yield Wizard is to select the **Goal Variable** that you want to maximize, along with its bounds (minimum and maximum values, and an initial value to try). This variable should be linked to water demand, such that increasing the value of the variable will increase demand. For example, the variable could represent the population (or any other activity level, such as units of production or land area under cultivation), or it could be an absolute volume of water demand. When WEAP varies this value to find the maximum safe yield, it will have a single value for all years and timesteps. If it is population, for example, each iteration of the Safe Yield calculation will set the population to some value for all years of each scenario. Rather than model a rising population over time, the idea here is to find the maximum population that can be supported by the water system modeled.

Next, select the **Demand Sites** and **Flow Requirements** that you want to ensure have 100% reliability. You must select at least one demand site or flow requirement.

Next, select one or more **Reservoirs** that must refill at least once after their lowest point. The lowest point may correspond to the drought of record. The requirement about refilling after the lowest point ensures that there is not an unsustainable trend in reservoir use that would eventually drain the reservoir.

If instead you want to track the reservoir storage but not require that they refill, uncheck the "Require reservoirs to refill at least once after their lowest point" checkbox.

Finally, choose one or more **Scenarios** to evaluate. For each scenario selected, the Wizard will find the maximum value of the goal variable that has 100% reliability and reservoirs refilling.

The **Iterations** setting dictates how many calculation iterations will be made for each scenario in searching for the maximum safe yield. The Safe Yield Wizard uses a "binary search" algorithm to find the maximum safe yield within the bounds given for the goal variable. For example, if the bounds were 0 and 16, with an initial value of 8, and the maximum safe yield corresponded to a value of 10.23, here is the sequence of guesses that would be tested: 8, 16, 12, 10, 11, 10.5, 10.25, 10.125, 10.1875, 10.21875, 10.234375, .... Each guess divides by half the distance to the maximum safe yield. If a guess results in reliability less than 100%, or a reservoir that does not refill, the next guess will be lower.

Conversely, if reliability = 100% and the reservoirs refill, then the next guess will be higher. Therefore, the greater the number of guesses, the more precise the answer, but also the longer the time to calculate.

Keep in mind that the WEAP model of your system has many different uncertainties and inaccuracies, so a precision for the goal variable of 1% or 2% is probably sufficient. This can be achieved in 6 iterations.

If the **Include Current Accounts** box is checked, then the value for the goal variable will be set in the Current Accounts as well as the scenarios, and WEAP will check that the yield is safe in the Current Accounts as well as in the scenarios.

Click the **Calculate** button at the bottom to start the calculations. The status bar at the bottom of the WEAP window will show the current status, in terms of the scenario and iteration being calculated, the

## 8.6 Safe Yield Wizard

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value of the goal variable being tested and the maximum safe goal variable value found so far. Once the wizard has iterated the chosen number of times for each scenario to find the maximum safe yield for each, it will create a view in the [Scenario Explorer](#) showing the value of the goal variable in each scenario (in the upper Data Section), and the corresponding yield (Supply Requirements and Instream Flow Requirements) and the reservoir storage for each scenario (in the lower Results Section).

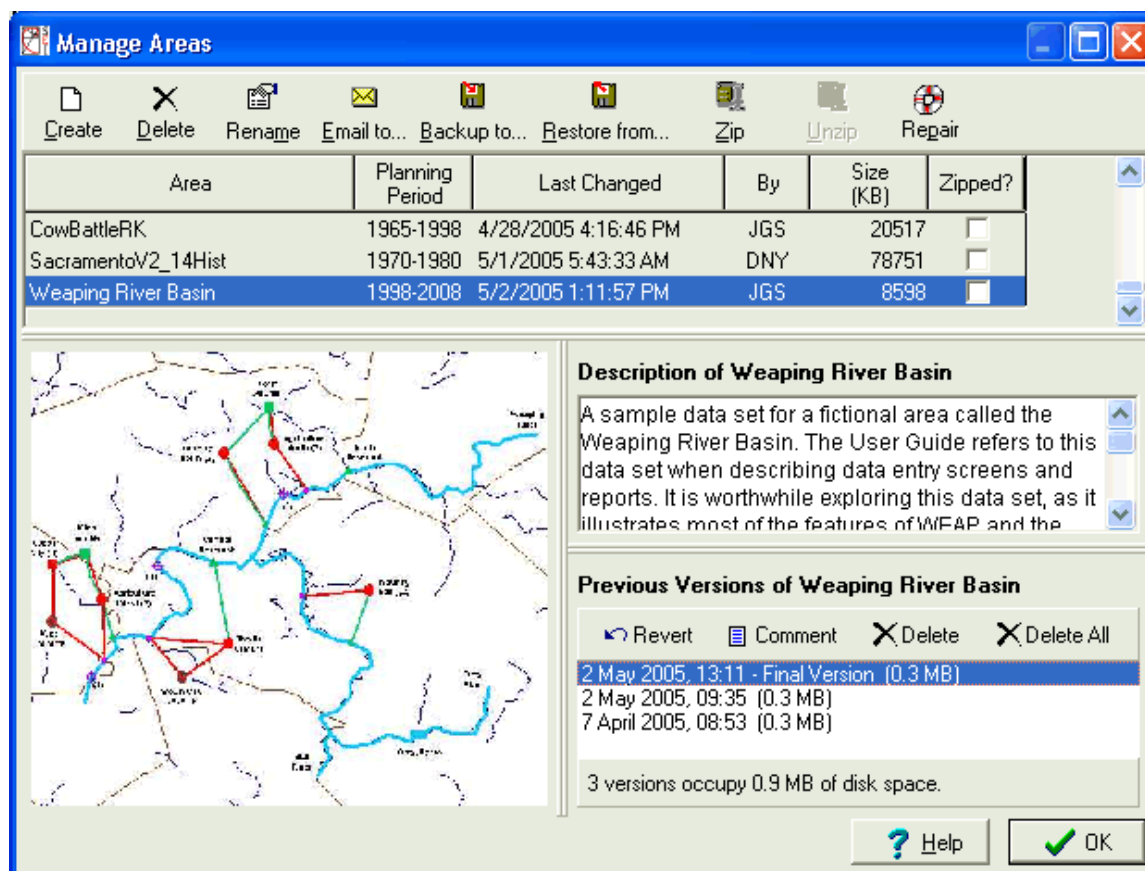
**Menu option:** Advanced, Safe Yield Wizard





# 9 Supporting Screens

## 9.1 Manage Areas











Use the Manage Areas screen, to create, delete, and organize the data sets ("Areas") on your computer. The Manage Area screen is divided into four panes. The table in the top pane shows the areas installed on your computer, along with various details about each area (planning period, when and by whom it was last changed, directory size, and whether it is currently "zipped"). You may click on the column titles to sort the table according to values in that area. For example, click on "Area" to order the areas alphabetically; click on "Last Changed" to sort chronologically, with the most recent areas at the bottom.

The lower three panes display information for the area currently highlighted in the table: the area's Schematic on the left, an overall description of the area in the upper right (which can be edited), and the list of previous versions of the area in the lower right (more on this below).

### 9.1.1 Toolbar

The toolbar at the top gives access to a variety of options for managing areas:

- **Create:** Use this option to create a new Area data set. The new area can either be blank or a copy of an existing Area.

-  **Delete:** Use this option to delete the highlighted area. NB: deleted areas are permanently deleted from your hard disk, and unless previously backed up, cannot be restored.
-  **Rename:** Use this option to change the name of the highlighted area (and the subdirectory in which it is stored).
-  **Email to...** Use this option to send the highlighted area as an email attachment. WEAP will automatically archive the data set into a single zip file and then attach the file to an email message. Since the results files can occupy a large amount of space, you will have the option of including or excluding them from the zip file. Note: this feature requires that you have a MAPI-compliant email system installed on your PC, such as Microsoft Outlook or Mozilla Thunderbird.
-  **Backup to...:** Use this option to make a backup copy of the highlighted area. The area will first be archived into a single zip file. You can backup to any drive or folder on your PC or on a local area network.
-  **Restore from...:** Use this option to restore a previously backed up data set, or to load an area sent to you by another person. You will be prompted to select the name of a zip file. WEAP will check the zip file to ensure that it is a valid WEAP Area data set. Tip: You can also restore a file from an FTP site--just enter the FTP site in the "File Name" box to browse for a WEAP file to restore, e.g., <ftp://sei-us.org/WEAP/Data>.
-  **Zip:** Use this option to compress the highlighted area in order to save disk space (it will automatically expand to normal size when next selected from the Main Menu: Area, Open). Typically, you would only use this for inactive areas.
-  **Unzip:** Use this option to uncompress the highlighted area. Since a compressed area is automatically uncompressed when it is next selected (Main Menu: Area, Open), you do not normally need to unzip it here in Manage Areas.
-  **Repair:** Use this option to check the highlighted area data set for errors, including corrupted data files and orphaned data. Where possible, WEAP will attempt to fix these errors. If it cannot it will report the problem to you. If errors cannot be fixed, contact the staff of SEI-Boston for assistance. This option will also "pack" the data files of your area, removing unused space and compacting the data files. (this is different from the Zip option)






### 9.1.2 Versions

WEAP saves multiple previous versions of each area, in case you decide you want to go back to an earlier version of your data. (Think of it as a large undo function.) Backup versions of Areas are automatically created every time the area is saved (containing all files in the area directory except for result files). You may also manually create a version from the Main Menu: Area, Save Version, along with a comment describing that version. If results exist, you will be asked if you want to include them in the version. These previous versions are placed in the \_backup folder and named with the area name and the backup date and time. For example, a version of Weaping River Basin from 2.30 PM on March 2, 2009 would be named Weaping River Basin\_2009\_03\_02\_14\_30\_00.zip

As versions accumulate, WEAP will selectively and automatically **delete** some of the previous versions saved, trying to balance the need to keep several previous versions, with the reality of limited hard disk space. WEAP will keep more versions from the recent past, on the theory that you may realize that a recent change you made was a mistake and want to go back to a previous version. Several versions will be preserved from the previous 24 hours, then one per day for the last seven days, then one per week for the last month, then one per month for the last year, then one per year before that. Note: **WEAP will never automatically delete a version for which you have given a comment. You may treat these versions as**

**milestones.** For example, once you have finished entering and calibrating the Current Accounts for an area, you may create a version with the comment "Current Accounts complete." As another example, suppose you had just finished a study using WEAP and written a paper. You might want to create a milestone version, with the comment "Data set corresponding to March 2009 paper."

Versions for the highlighted area are displayed in the bottom-right pane, along with the disk space they occupy. The panel has its own toolbar containing five options:

-  **Revert:** This option lets you revert to the highlighted version of a data set. Use this option with great care as it will overwrite the current version of your data set. The Revert option is also available from the Main Menu: Area, Revert to Version.
-  **Comment:** allows you to add or edit a comment for the highlighted version. For example, you may wish to mark versions made after important events such as project milestones. Note: any version with a comment will NOT be automatically removed by WEAP.
-  **Delete:** deletes the highlighted version.
-  **Delete All:** delete all versions for this area.
-  **Email to...** Use this option to send the highlighted version as an email attachment. Note: this feature requires that you have a MAPI-compliant email system installed on your PC, such as Microsoft Outlook or Mozilla Thunderbird.

**Menu Option:** Area: Manage Areas

## 9.2 Water Quality Constituents

WEAP tracks water quality, including pollution generation at demand sites, waste removal at wastewater treatment plants, effluent flows to surface and groundwater sources, and water quality modeling in rivers. On the water quality constituents setup screen, turn on water quality modeling by checking the **Enable water quality modeling** checkbox. You may then define up to 20 constituents to track in your application. Set the **scale** and **load unit** as appropriate for entering the annual production of the pollutant by the demand site, per unit of activity. Set the **concentration** unit appropriate for entering data on concentrations of constituents in demand site outflows, and in headflows, reservoir outflows and groundwater outflows.

For each constituent, specify which method WEAP should use to calculate surface water quality concentrations, in the **Calculate By** column:

**Conservative:** There is no decay of this constituent--the instream concentration will be computed using simple mixing and weighted average of the concentration from all inflows.

**First-Order Decay:** This constituent decays following an exponential decay function. Enter the daily **decay rate** here.

**BOD:** WEAP will use its built-in BOD model to simulate the changes in the biochemical oxygen demand (BOD) in the river. In order to model BOD, you will need to include temperature as one of your water quality constituents (with unit = Celsius), and either enter as data the temperature of water in the river for each reach, or model it in WEAP.

**DO:** WEAP will use its built-in DO model to simulate the changes in dissolved oxygen (DO) in the river. Because the DO model uses BOD as an input, you will also need to simulate BOD.

For temperature values (required by WEAP to implement the BOD and DO modeling), one can choose from either of two methods:

**Temperature (Modeled in WEAP):** WEAP will calculate water temperature for each river reach based on climate data (air temperature, humidity, wind, and latitude) input in the Data view (under the Climate tab for the reach).

**Temperature (Data):** the user specifies the water temperature for each reach. If this option is selected and temperature for a particular reach is left blank, WEAP will assign to that reach the temperature of the immediate upstream reach. Water temperature is needed by the BOD model.

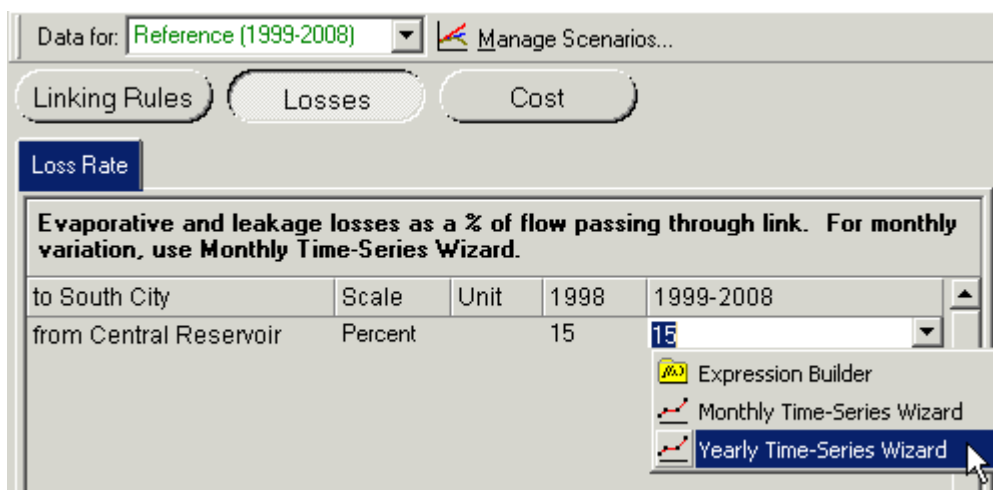
**Modeled in QUAL2K:** Link to the US EPA water quality model QUAL2K and let it model water quality for some or all water quality constituents. See [below](#) for details.

**Menu Option:** General: Water Quality Constituents

## 9.3 Yearly Time-Series Wizard

The Yearly Time-Series Wizard is a tool that helps you construct the various time-series expressions supported by WEAP's [Data View](#). These expressions include functions for interpolation, step functions, smooth curves and linear, exponential and logistic projections. (You may also import many data expressions at once from Excel. See [Export to Excel](#), [Import from Excel](#) for details.)

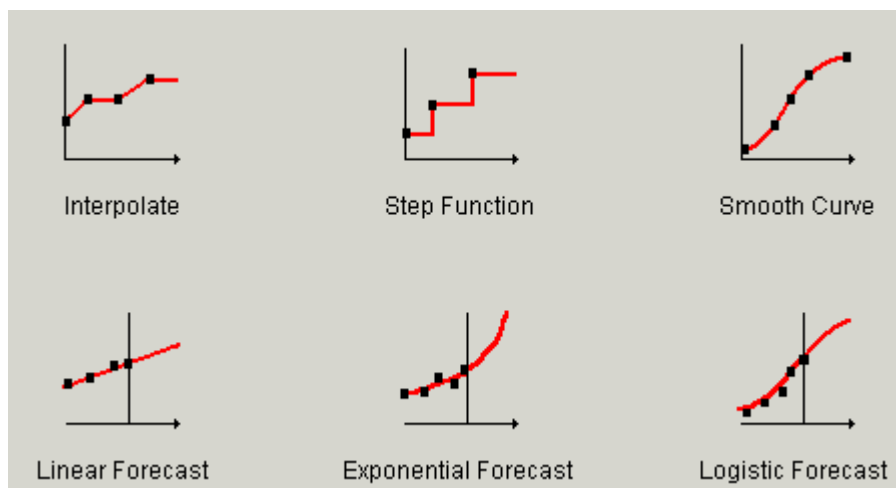
To access the wizard, either right-click on the data table or click on the down arrow on the right side of the expression box, and choose Yearly Time-Series Wizard from the menu.



The wizard is divided into three pages, which you step through using the **Next** (→) and **Previous** (←) buttons.

### 9.3.1 Page 1: Projection Method

Use this page to select the type of function you want to create. The functions are summarized in graph form on screen as shown below, and are grouped into two main types.



The three functions on the top row allow you to specify data points for various future years, and the function then calculates the values for intervening years:

- The **interpolation** function calculates values based on a linear (straight line) interpolation between the values you specify.
- The **step** function assumes that values change discretely at the specified data years. In other words, values stay constant after a specified data year, until the next specified data year.
- The **smooth curve** function calculates a best-fit smooth curve based on a polynomial least-squares fit of the specified data points. To achieve a good fit, the smooth curve function requires at least 3 data points.

The interpolation and smooth curve functions are most useful when you expect data to change gradually (for example when modeling the gradual penetration of some common device such as refrigerators or vehicles). The step function is most useful for specifying "lumpy" changes to your system, such as the construction of new transmission links.

The last three functions allow you to specify historic data values (i.e., values before the [Current Accounts](#)). The different functions are then used to extrapolate data forward to calculate future values. Extrapolations are based on **linear**, **exponential** or **logistic** least-squares curve fits. Use these functions with care. The onus is on you to ensure that the projections are reasonable, both in terms of how a) well the estimated curve fits the historical data, and b) how policies and other structural factors may change in the future. In other words, **be sure to consider how well you can identify past trends, but also if it is reasonable to expect these past trends to continue into the future**. WEAP helps you with task a) by providing various statistics describing the curve-fit: the  $R^2$  value, the standard error, and the number of observations. If you need to do a more detailed analysis, we suggest you use the data analysis features built-in to Microsoft Excel, and then link your results to your WEAP analysis (see below).

### 9.3.2 Page 2: Data Source

On page 2, you select the source of the data for the expression. Select whether you want to enter the data directly (*i.e.*, type it in) or whether you want to link to the values in an external Excel spreadsheet.

### 9.3.3 Page 3: Data Entry

Depending on your choice on page 2, in page 3 you either enter the data used by the function or select an Excel spreadsheet and range from which to extract the data for the selected time-series function.

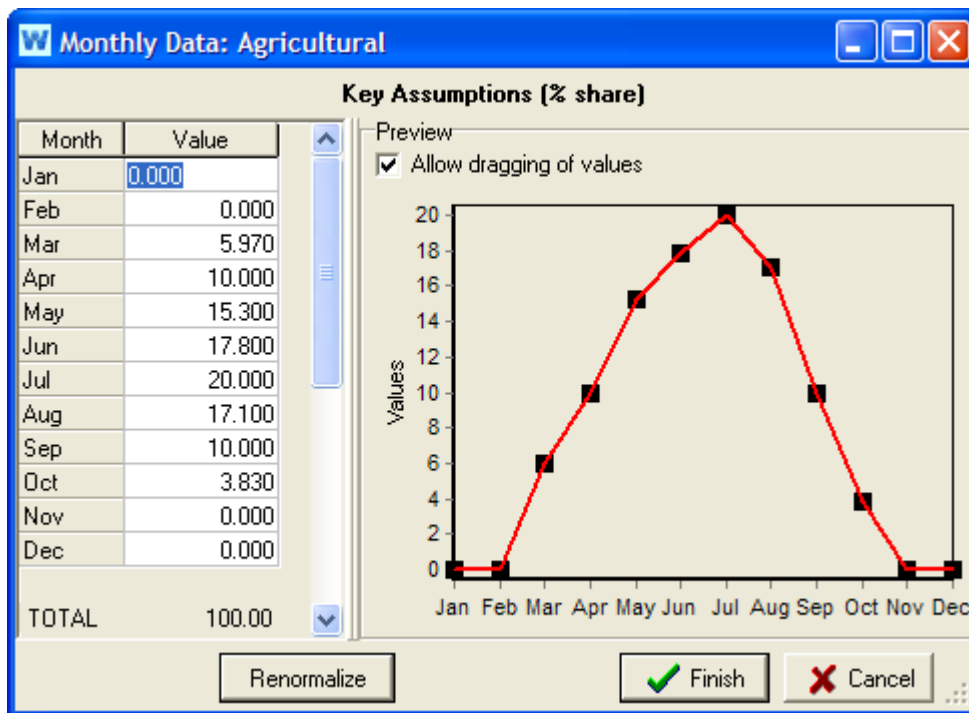
- When entering data directly, use the **Add (+)** and **Delete (-)** buttons to add or delete new year/value pairs, or click and drag data points on the adjoining graph to enter values graphically. For the Interpolation function, an additional data field is shown allowing you to specify a percentage growth rate, which is applied after the last specified data year. By default this value is zero. In other words, by default values are not extrapolated past the last interpolation data year. The data you entered will be shown as the points on the adjoining chart, while the line drawn on the chart will reflect the projection method you chose on page one.
- When linking to a Microsoft Excel sheet, first enter the name of the worksheet file (.XLS or .XLW) or use "..." button to browse your PC and local area network for the file. Next enter the range name from which the data will be extracted, or click the button attached to the field to select from the named ranges in the worksheet. Ranges can be specified either as names, or as Excel range formulae (e.g. Sheet1!A1:B16). NB: ranges must contain only two columns of data. The first column must contain years, arranged in chronological order (with the earliest at the top), and the second must contain data values. Click on the **Get Excel Data** button to extract the data from Excel and preview the values in the adjoining graph. Notice that the points on the chart will be the values in the Excel spreadsheet, while the line drawn on the chart will reflect the projection method you chose on page one.

**See also:** [Data View](#), [Expressions](#), [Examples of Expressions](#), [Export to Excel](#), [Import from Excel](#)

## 9.4 Monthly Time-Series Wizard

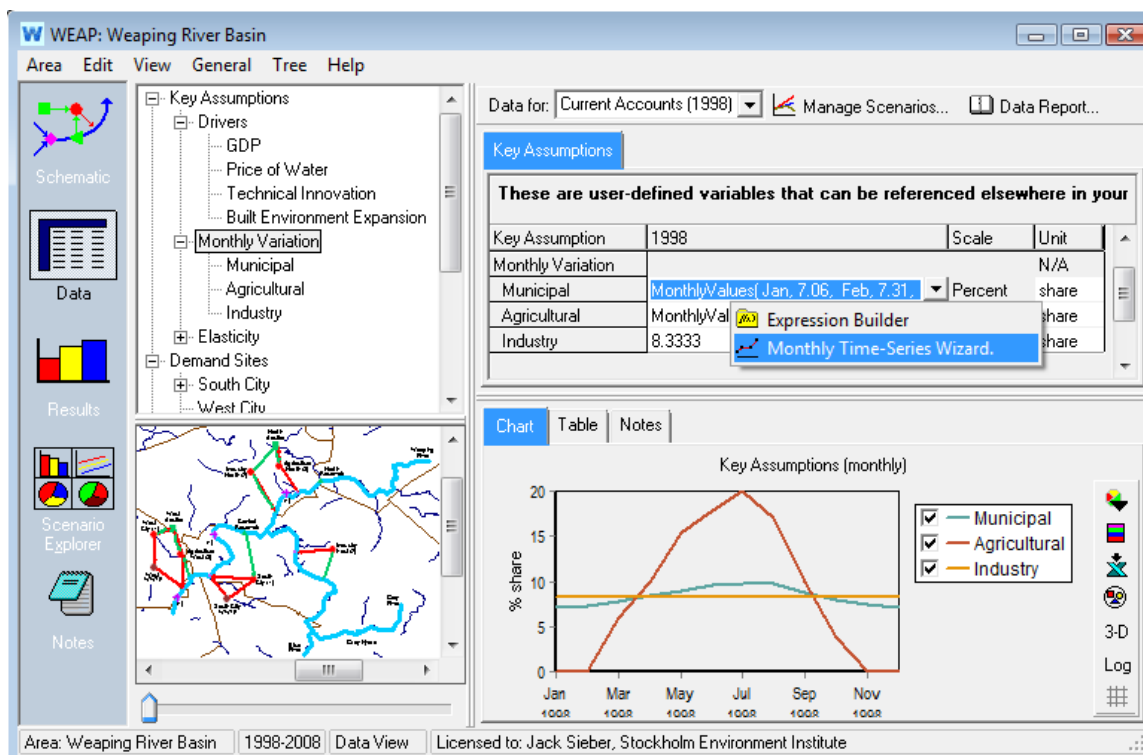
The Monthly Time-Series Wizard helps you enter values that vary monthly but not yearly, e.g., monthly variation of demand. Enter monthly values in the table on the left and they will be graphed on the right. If you leave some months blank, WEAP will interpolate using adjacent points. The total of all months should be 100%. If it is not, click the Renormalize button to scale all values so that they sum to 100%.

## 9.4 Monthly Time-Series Wizard






After clicking the Finish button to close the wizard, WEAP will construct a [MonthlyValues](#) function to represent the monthly values you entered, e.g., `MonthlyValues(Jan, 5, Feb, 5, Mar, 10, ...)`



To access the wizard, either right-click on the data table or click on the down arrow on the right side of the expression box, and choose Monthly Time-Series Wizard from the menu.



## 9.5 Overview Manager

Use the Overview Manager (accessed from the Scenario Explorer Toolbar) to

- Add (  ), delete (  ) and rename (  ) overviews, and to
- quickly select which favorite charts are to be included in an overview, and the order in which they appear.

Use the selection box to select which overview you wish to manage, and then click the check boxes next to the list of favorite charts to include or exclude charts. When you click the close button, the edited overviews will be displayed on screen. Use the up (  ) and down (  ) arrows on the right side to re-order how the favorites are displayed in the overview.

Note: In addition to using the Overview Manager, you can also select and order Overview charts directly from the Scenario Explorer screen. Right click on a chart to get options. See [Scenario Explorer](#) for details.

**See Also** [Scenario Explorer View](#)



# 10 Sample Data Set

**Weaping River Basin** is the sample data set that is installed with WEAP. The goal of the data set is to give the user the opportunity to explore some of WEAP's capabilities, and to illustrate the problems and solutions that WEAP can help identify.

The Weaping River Basin is a river basin consisting of rivers, aquifers, reservoirs, demand sites, flow requirements, wastewater treatment facilities and the links among them. The data are compiled for a 11-year (2010-2020) monthly time series. There are four scenarios presented in this data set: Reference, Demand Measures, Supply Measures, and Integrated Measures (a combination of the Demand and Supply scenarios).

## 10.1 Reference

Demands increase steadily over time, while the supply infrastructure remains static--no improvements are made that might increase availability of supply. As demands increase and groundwater sources are depleted, there are increasing shortfalls in meeting demand and instream flow requirements. Pollution generation and loads follow demand trend, increasing over time. Identification of problems guides creation of scenarios to alleviate them. The following three scenarios implement measures designed to reduce demand or increase available supply.

## 10.2 Demand Measures

The Demand Measures Scenario slows the increasing rate of the demands by decreasing water use rates in the future. Supply coverage is improved in all areas because the supply requirement is decreased, although still less than 100%. This scenario also slows, but does not halt, the depletion rate of the groundwater. Costs increase due to demand efficiency measures.

## 10.3 Supply Measures

The Supply Measures Scenario consists of building the North Reservoir in 2015. This reservoir allows the storage of surplus surface water from winter and spring, to be made available in the drier summer and fall. Supply coverage is improved due to the increased supply available, although still less than 100%. This scenario slows the depletion of groundwater and allows all flow requirements to be met. Costs increase due to construction of a new reservoir.

## 10.4 Integrated Measures

The Integrated Measures Scenario combines measures from Demand Measures and Supply Measures Scenarios. This scenario decreases demand and provides excellent supply coverage. Combining Demand and Supply Scenarios increases groundwater storage and fulfills all flow requirements. Costs increase due to demand efficiency measures and construction of new reservoir.



# 11 Technical Support

Limited technical support is provided at no charge to licensed users of the system. Various options are available for obtaining support. We request that you first make use of the [WEAP technical support forum](#). This site provides a moderated forum for users to request and receive technical support and to discuss WEAP-related issues with other users.

When requesting technical support by email, we strongly suggest that you send your data set as an attachment and include the system information from the Help: About WEAP screen. To do this easily, use the Email option on the [Manage Areas](#) screen on the Area menu.

Finally, before requesting help, be sure to check to see if a [more recent version of WEAP](#) is available. Use the "**Check on Internet for Updates**" on the Help menu to check for a newer version over the Internet, and then install it onto your PC. Note that this is the preferred method of updating the software as it requires a much smaller download compared to a full download and installation of the system.

The full set of technical support options are as follows:

- **Technical Support Forum:** <http://www.weap21.org/forum>
- **WEAP Web Site:** <http://www.weap21.org>
- **Email:** [info@weap21.org](mailto:info@weap21.org)

## 11.1 Hardware and Software Requirements

WEAP runs on all versions of Microsoft Windows from Windows 98 to Windows 7, including 64-bit Windows, with a minimum of 256 MB of RAM and 100 MB of free hard disk space (2 GB of RAM is recommended, especially for larger models).

To install WEAP on Windows 2000 or later, either your user account must have Administrator privileges or you must run the installer with Administrator privileges (right click on the installer and choose "Run as Administrator").

Your computer screen should be set to a minimum resolution of 1024x768, but preferably even higher (e.g., 1280x1024), to maximize the presentation of data and results.

An Internet connection is not required, but is useful for tasks such as [emailing data sets](#) and receiving [automatic updates to the software](#).

WEAP can interact with [MODFLOW](#), [MODPATH](#), [QUAL2K](#) and [PEST](#), all of which are installed with WEAP. WEAP can also communicate with Microsoft Excel and Microsoft Word, but they are not required.

Note: WEAP is designed as a single-user system. It is not intended as a multi-user system and we do not recommend running it from a shared network drive.

## 11.2 WEAP Updates

When WEAP starts up, it will automatically check the WEAP ftp site for software updates (if your computer has an active internet connection). If any updates are found, you will be asked if you want to download and install them. If you do, the download and install process is automatic. In addition to its automatic check on startup, you can have WEAP check by choosing the menu option: Help, Check on Internet for New Version.



# 12 ASCII Data File Format for Monthly Inflows (Obsolete)

**Note:** The file format described here, used in conjunction with the [Read from File Method](#), is primarily of use for datasets created in **older** versions of WEAP. If you are creating a new text file for import into WEAP, use the [ReadFromFile](#) function instead.

If you have monthly data on inflows to some or all of your rivers and other supplies, the [Read From File Method](#) allows you to model the system using this sequence of inflows. You can export gaged inflow data from many conventional hydrologic databases (USGS has extensive streamflow data for the United States available for download from the Web at <http://water.usgs.gov>.) into ASCII files, and then edit these files into the required format described below. The following discussion is provided as a courtesy to those users that are using the older versions of WEAP that support data input by ASCII files.

These data may come from a historical record, or they may be outputs from some other model, such as a physically-based hydrologic model. A single ASCII file is meant to be a consistent set of data, both spatially and temporally. You may have many different ASCII import files, but each WEAP scenario can reference only one. For example, if you were investigating the sensitivity to climate change, you could have a different file for each of your climate scenarios.

You may include in these files data for years and supplies not included in a particular WEAP area. Thus, you could use one set of data files for several different WEAP areas, which might include different sets of rivers and supplies. Or you can easily run the WEAP calculations using different historical time periods to test a scenario's sensitivity to a particular hydrological sequence. WEAP will ignore any data extraneous to its current analysis. In this way, the file can comprise a master database of historic flow data that you will use for all your analyses.

The files should be named with the extension .FLO, and placed in the subdirectory corresponding to the WEAP area (e.g., WEAP\Weeping River Basin\ ). Then, in the Hydrology \ Read from File branch, select this file in the drop-down box.

## 12.1 Sections

The ASCII file is divided into six sections.

Section Name	Description
[OPTIONS]	Set water flow unit and first year
[HEADFLOW]	River headflows
[REACH]	Surface water runoff to reaches
[RESERVOIR]	Local Reservoir inflows
[GROUNDWATER]	Groundwater inflows
[OTHER]	Other Supply inflows

In the options section you specify the first year of data to use and the units.

## 12.2 First Year

When using historical datasets, you need to specify which historical year to use. If your analysis is longer than the entered dataset, WEAP will loop through the historical sequence up to the number of years specified in the model time horizon. For example, if the historical dataset spanned 1950-1959, and your WEAP time horizon was 1998-2017, you would specify 1950 as the first year. In this case, the ten years of data from the file would be used twice--for 1998-2007 and for 2008-2017. You can choose different time intervals to simulate the system over various historical time periods. For instance, if your study period is twenty years and you have sixty years of historical data, WEAP allows you to easily select any of the forty-one different twenty-year periods from the historical data, to explore the effects of various sequences of hydrologic conditions.

The first year is specified in the [OPTIONS] section, in the following format:

FIRST YEAR = <year>

If you do not specify the first year, WEAP will assume the Current Accounts year is the first year to use.

## 12.3 Units

You may use any unit for your data and WEAP will automatically convert it. To set the unit to be used in reading the file, include the optional first section [OPTIONS] in your data file. If you do not specify the unit, WEAP will assume cubic meters per second. However, to avoid any potential confusion, we recommend that you always include the specification of unit in the file.

The unit is specified in the [OPTIONS] section, in the following format:

UNIT = [optional scale] <volume unit> per <time unit>

The scale is optional and can be either a word (thousand, million, etc.) or a number. For volume unit and time unit, select from the tables below. You may use either the word 'per' or a slash (/) to separate them. You may also use the following flow unit abbreviations: CFS, CMS, CFM and MGD. If you use month as the time unit, WEAP will take into account the variable number of seconds in each of the twelve months when converting into its per second flow rate. You may use a mixture of upper or lower case.

The following are examples of valid units:

CUB. METERS/SECOND  
1000 M<sup>3</sup>/min  
MGD  
CFS  
million acre-inch per day

Time Unit	Abbreviation
second	sec
minute	min
hour	hr
day	day
month	mon

Volume Unit	Abbreviation
-------------	--------------

cubic meters	m <sup>3</sup>
cubic feet	ft <sup>3</sup>
liter	ltr
gallon	gal
acre-inch	AI
acre-foot	AF

Flow Unit	Abbreviation
-----------	--------------

cubic feet per second	CFS
cubic feet per minute	CFM
cubic meters per second	CMS
million gallons per day	MGD

## 12.4 Data Sections

The other five sections contain monthly flow data for river headflow, river reach inflow, local reservoir inflow, groundwater and other supply inflow. Enter the section name in square brackets to define a section, i.e., [HEADFLOW], [REACH], [RESERVOIR], [GROUNDWATER] AND [OTHER]. To specify the flows for a particular element, first give its name on a line by itself. The name must match exactly the name given in the WEAP schematic (except for differences in upper or lower case). Because the name is used to match the Schematic element to its data, all supply elements in the Schematic must have unique names. Note: the name of an element is not its Schematic label, but its "name", as specified on General Info for the node.

On the lines following the name, enter the monthly inflows to this element, one year per line. Each line of data must contain thirteen pieces of data: the year, followed by data for each of the twelve months.

The years must be listed in increasing order, although there may be gaps in the years. During calculations, the flows for the Current Accounts Year will be taken from the data year specified with the First Year option (or the Current Account year if not specified). Inflows for each subsequent year will be taken from the next sequential year in the data file. If there is no data for the next year, WEAP will cycle back to the first year of the contiguous block of yearly data, which might be before the First Year. In this way, you can use a subset of historical data as a cycle. For example, if the time horizon is 2000 to 2020, the First Year is 1930, and there is historical data for years 1925 through 1934, the sequence of historical data used will be: 1930, 1931, 1932, 1933, 1934, 1925, 1926, 1927, 1928, 1929, 1930, 1931, 1932, 1933, 1934, 1925, 1926, 1927, 1928, 1929, 1930.

## 12.5 Numeric Format

Numbers can be entered in either floating point or fixed point notation or a mixture of the two. Floating point format is as follows: <mantissa>E<exponent>, with no spaces before or after the E. The following numbers are all equivalent:

```
3421.032
3.421032E+3
0.3421032E+4
3421032E-3
```

## 12.6 Data Delimiters

Numbers can be separated by commas, tabs or spaces. Names of rivers and nodes can be enclosed in quotes or not, although you must use quotes if a name itself includes a comma.

Tip: It may be convenient to collect and format your data in Excel, then export them as tab-delimited or comma separated value (CSV) files. WEAP will be able to read these exported files without any further reformatting.

## 12.7 Comments

Any line that begins with a semicolon (;) will be treated as a comment line and ignored. Comments can be very useful for documenting your historical data. Blank lines are also ignored and can be used to enhance readability.

## 12.8 Example

The following example comes from the file HIST.FLO in Weaping River Basin. (To save space, ellipses are shown in place of data for months 4-11.)

```
; Sample historical data file for 1950-59
; All flows are in cubic meters per second
[OPTIONS]
Unit = CMS
FirstYear = 1950

[GROUNDWATER]

"West Aquifer"
1950, 8.606448, 7.03752, 21.57701, ..., 3.302112
1951, 2.659248, 7.360368, 4.820064, ..., 4.77192
1952, 11.20906, 14.1515, 8.38272, ..., 11.22038
1953, 7.921104, 11.92838, 10.63699, ..., 13.91928
1954, 9.116208, 11.15242, 10.50389, ..., 5.22504
1955, 4.684128, 9.413568, 5.468592, ..., 5.32416
1956, 3.981792, 3.86568, 4.664304, ..., 8.546976
1957, 8.173152, 9.484368, 11.54606, ..., 4.004448
1958, 7.402848, 5.151408, 4.075248, ..., 2.832
```



## 12.8 Example

---

1959, 5.669664, 5.641344, 8.532816, ..., 7.836144

[HEADFLOW]

"Blue River"

1950, 17.22706, 10.33397, 41.10081, ..., 3.22848  
1951, 2.982096, 17.88408, 8.844336, ..., 6.125616  
1952, 16.66632, 38.58034, 11.5489, ..., 22.04995  
1953, 13.7437, 20.48669, 19.41619, ..., 33.88488  
1954, 15.88469, 15.91584, 17.83027, ..., 7.252752  
1955, 6.68352, 21.81206, 7.921104, ..., 9.031248  
1956, 5.06928, 6.105792, 8.207136, ..., 8.051376  
1957, 20.75856, 10.43592, 16.96085, ..., 4.505712  
1958, 10.50955, 9.184176, 4.910688, ..., 2.560128  
1959, 5.740464, 6.842112, 11.5489, ..., 12.37584

[REACH]

"Blue River", "Below Industry East With."

1950, 3.205824, 1.948416, 7.765344, ..., .620208  
1951, .555072, 3.188832, 1.523616, ..., 1.229088  
1952, 2.928288, 6.366336, 1.945584, ..., 3.664608  
1953, 2.319408, 3.460704, 3.726912, ..., 6.493776  
1954, 2.829168, 3.007584, 3.29928, ..., 1.57176  
1955, 1.365024, 3.234144, 1.416, ..., 1.67088  
1956, 1.050672, 1.084656, 1.6992, ..., 2.248608  
1957, 3.404064, 2.741376, 3.474864, ..., .674016  
1958, 1.951248, 2.118336, .982704, ..., .75048  
1959, 1.07616, 1.333872, 1.710528, ..., 2.509152

[RESERVOIR]

; No local reservoirs exist

[OTHER]

; No other supplies exist



# 13 History and Credits

## 13.1 History

WEAP was created in 1988, with the aim to be a flexible, integrated, and transparent planning tool for evaluating the sustainability of current water demand and supply patterns and exploring alternative long-range scenarios.

The first major application of WEAP was in the Aral Sea region 1989 with the sponsorship of the newly formed [Stockholm Environment Institute \(SEI\)](#). SEI continued to support the development of WEAP through its [Boston center](#) (SEI-Boston), which was established in 1989 and hosted by the [Tellus Institute](#). Over the years WEAP has been applied in [scores of countries and river basins](#). The software has been transferred to water planners throughout the world.

## 13.2 Credits

The development and distribution of the WEAP software is managed by [Jack Sieber](#) of the [U.S. Center](#) of the Stockholm Environment Institute (SEI).

WEAP was conceived by Paul Raskin, President of Tellus Institute, and developed under his supervision until 2001. Many have contributed to the development and application of WEAP since its inception. We would like to acknowledge, in particular, Paul Raskin, Eugene Stakhiv, Ken Strzepek, Zhongping Zhu, Bill Johnson, Evan Hansen, Charlie Heaps, Dmitry Stavisky, Mimi Jenkins, Jack Sieber, Paul Kirshen, Tom Votta, David Purkey, Jimmy Henson, Alyssa Holt McClusky, Eric Kemp-Benedict, Annette Huber-Lee, David Yates, Peter Droogers, Pete Loucks, Jeff Rosenblum, Winston Yu, Chris Swartz, Sylvain Hermon, Kate Emans, Dong-Ryul Lee, David Michaud, Chuck Young, Martha Fernandes, Brian Joyce, Chayanis Krittasudthacheewa, Andre Savitsky, Daene McKinney, Marisa Escobar, Vishal Mehta, Johannes Wolfer, Markus Huber, Mahmoud Al Sibai, Abdullah Droubi, Ali Sahli, Mohamed Jabloun, Issam Nouri and Alex Bedig.

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Many organizations have generously contributed major funding for the development of WEAP. We gratefully acknowledge:

- [Stockholm Environment Institute \(SEI\)](#)
- [Tellus Institute](#)
- [Hydrologic Engineering Center \(HEC\)](#) of the [U.S. Army Corps of Engineers](#)
- [Swedish International Development Cooperation Agency \(SIDA\)](#)
- [International Water Management Institute \(IWMI\)](#)
- [Global Change Research Program \(GCRP\)](#) of the [United States Environmental Protection Agency \(US EPA\)](#)
- [California Department of Water Resources \(DWR\)](#)
- [CGIAR Challenge Program on Water and Food \(CPWF\)](#)

- [Dutch Ministry of Foreign Affairs \(DGIS\)](#)
- [Korea Institute of Construction Technology \(KICT\)](#)
- [American Water Works Association Research Foundation \(AwwaRF\)](#)
- [World Bank](#)
- [GLOWA Program](#) of the [German Federal Ministry of Education and Research \(BMBF\)](#)
- [EU Global Water Initiative](#)
- [Arab Center for the Studies of Arid Zones and Dry Lands \(ACSAD\)](#), a center of expertise and training in the Arab region
- [German Federal Institute for Geosciences and Natural Resources \(BGR\)](#), via the [BGR-ACSAD cooperation project](#)
- [Riverways Program](#) of the [Commonwealth of Massachusetts](#)

## 13.4 Translation

Language translations have been contributed by:

- Arabic: Wael Seif
- Chinese: Guoyi Han, Ying Li
- Farsi: Mehdi Mirzaee
- French: Sylvain Hermon, David Michaud, Cyrille Faugeras, Issam Nouiri, Keita Kobélé
- Greek: Spyros Michas
- Korean: Dong-Ryul Lee
- Portuguese: Lineu Rodrigues
- Russian: Andre Savitsky
- Spanish: Sebastian Vicuna
- Thai: Chayanis Krittasudthacheewa

# 14 Glossary

## A

**Activity Level:** A measure of social or economic activity. When used in WEAP's Demand analysis, activity levels are multiplied by water use rates to yield overall levels of annual water demand. See Water Use Rate.

**Aggregate:** To summarize by grouping together. See Disaggregate

**Albedo:** Fraction of solar radiation striking a land class that is reflected--albedo increases as snow accumulates.

**Allocation Order:** The actual calculation order, assigned to transmission links and instream flow requirements, used by WEAP for allocating water. WEAP automatically determines the allocation order based on the supply priorities and demand preferences. See Supply Priority, Demand Preference.

**API:** Application Programming Interface. WEAP can act as a "COM Automation Server," meaning that other programs (e.g., Excel via VBA), programming languages (e.g., Visual Basic, C) or scripts (e.g., Visual Basic Script (VB script), JavaScript, Perl, Python) can control WEAP directly--changing data values, calculating results, and exporting them to text files or Excel spreadsheets.

**Area:** The water system being studied, often a river basin.

**Attribute table:** A .dbf file associated with a GIS shape file (.shp) that contains one row for each geographic feature (point, line or polygon) and one or more columns of information about that feature.

## B

**Base flow:** Streamflow coming from ground-water seepage into a stream

**BOD:** "Biochemical Oxygen Demand" - a measurement of the oxygen consumption capacity in water brought about by the degradation of organic matter, typically from a wastewater source, by bacteria. It is expressed as a concentration.

**Branch:** An item on the tree, e.g., "Supply and Resources" or "Key Assumptions".

**Bucket:** A reference to a soil layer in the Soil Moisture Method, which contains two layers, or buckets

## C

**Catchment:** A land area with defined geographic boundaries that captures precipitation and partitions it into evapotranspiration, runoff to surface water and infiltration to groundwater.

**Current Accounts:** The Current Accounts represent the basic definition of the water system as it currently exists. Establishing Current Accounts requires the user to "calibrate" the system data and assumptions to a point that accurately reflects the observed operation of the system. The Current Accounts are also assumed to be the starting year for all scenarios. Note that the Current Accounts Year is not meant to be an "average" year, but the best available estimate of the current system in the present. The Current Accounts include the specification of supply and demand data (including definitions of reservoirs, pipelines, treatment plants, pollution generation, etc.) for the first year of the study on a monthly basis.

**Current Accounts Year:** The first year of the analysis period, and the year for which the system is 'calibrated.'

## D

**Deep Conductivity:** Conductivity rate (length/time) of the deep layer (bottom "bucket") at full saturation (when relative storage  $z2 = 1.0$ ), which controls transmission of baseflow. This is given as a single value for the catchment and does not vary by land class type. Baseflow will increase as this parameter increases.

**Demand-Side Management:** Demand-Side Management, or Demand Management, refers to strategies for reducing demand for water, such as a program to reduce leakage or unauthorized withdrawals from the system, a program to encourage reuse or more efficient use of water, or programs that use price as an incentive to reduce demands.

**Demand Priority:** A demand site's or instream flow requirement's area-wide priority for receiving water, ranging from 1 (highest preference) to 99 (lowest). These priorities represent the user's priorities for delivery of water for each demand site and instream flow requirement. See Demand Preference, Allocation Order.

**Demand Site:** A set of water users that share a physical distribution system, that are all within a defined region, or that share an important withdrawal supply point.

**Disaggregate:** To break something down into sub-categories (e.g. breaking a municipal demand site into urban and rural sectors). See Aggregate, Sector, Subsector.

**Diversion:** A canal or pipeline that is supplied by water diverted from a river. A diversion is represented as a river in WEAP--composed of a series of reservoirs, run-of-river hydropowers, flow requirements, withdrawals, diversions, tributaries and return flow nodes. See Diversion Node.

**Diversion Node:** A point at which water is diverted from a river or other diversion into a canal or pipeline called a diversion. See Diversion.

**DLL:** A DLL is a "dynamic link library" file that contains one or more functions. A DLL is a compiled executable program written in a standard programming language, such as C, Visual Basic or Delphi. The ability of WEAP to call DLL functions is very powerful, as it allows the user to add new functions or even complete models to WEAP. See WEAP's Call function.

**DO:** "Dissolved Oxygen" - the concentration of dissolved oxygen in water.

**DSM:** See Demand-Side Management

## E

**Endogenous:** Something calculated internally in a model.

**Exogenous:** A value explicitly specified (i.e., not calculated internally by the model).

**Expression:** A mathematical formula used to specify how the values of a variable changes over time.

## F

**Favorite:** A result chart saved by the user, complete with all formatting, for later retrieval, or inclusion in an Overview. See Overview.

**Flow Requirement:** Minimum instream flow required at a point on a river or diversion to meet water quality, fish & wildlife, navigation, recreation, downstream or other requirements.

## G

**GIS:** Geographic Information System. WEAP allows you to load GIS maps, in standard ArcView Shape and Grid format, as background layers for the Schematic.

## H

**Head:** Hydropower is generated when water falls from a height into a turbine. This height is called the head, or head difference. Also refers to the elevation of the groundwater table.

**Hydrology:** The time-series of monthly inflows to the system, specified using either the Water Year Method or the Read from File Method. See Inflow, Water Year Method, Read from File.

## I

**Infiltration:** precipitation or other sources of water (such as excess irrigation) that percolates into and through the soil, or, inflow of groundwater into return flow links

**Inflow:** Flows into the WEAP system: Groundwater recharge, River Headflow, and Inflow to River Reaches, Local Reservoirs and Other Local Supplies. See Hydrology.

## K

**Key Assumptions:** Independent user-defined variables used to "drive" the calculations in your analyses. See Tree.

## L

**Local Supply:** Supply sources not connected (or not modeled as connected) to a river, i.e., Groundwater, Local Reservoirs, and Other Local Supplies.

## M

**Main Stem:** The principal course of a river or stream.

**MODFLOW:** A three-dimensional finite-difference groundwater flow model created by the U.S. Geological Survey (USGS).

## N

**Net present value (NPV):** The future stream of benefits and costs converted into equivalent values today. This is done by assigning monetary values to benefits and costs, discounting future benefits and costs using an appropriate discount rate, and subtracting the sum total of discounted costs from the sum total of discounted benefits.

**Nonpoint Source:** A pollution source that cannot be defined as originating from discrete points such as pipe discharge. Areas of fertilizer and pesticide applications, atmospheric deposition, manure, and natural inputs from plants and trees are types of nonpoint source pollution.

**Normal Water Year Type:** A water year type that represents an average hydrological conditions. Note: the Current Accounts Year is not necessarily a Normal Water Year Type. See Water Year Type.

**Nutrients:** Element or compound essential for animal and plant growth. Common nutrients include nitrogen, phosphorus, and potassium.

## O

**Other Local Supply:** Sources with predetermined water quantities available on a monthly basis, but with no storage capability between months (e.g., streams or other unconnected rivers, inter-basin transfers or other imports, and desalination plants).

**Overview:** Side-by-side display of multiple result charts, constructed from user-defined "Favorites." See Favorite.

## P

**Point source:** A pollution source at a discrete location such as a discharge pipe, drainage ditch, tunnel, well, or concentrated livestock operation.

**Pool:** Synonym for Reservoir Zone. See Zone.

**Priority:** See Demand Priority

## R

**Raster GIS Layer:** Display of geographic features from grid cells in a matrix. A raster display builds an image from pixels, pels, or elements of coarse or fine resolution, from centimeters to kilometers. Many satellites, like Landsat, transmit raster images of the earth's surface.

**Read from File:** A detailed means for projecting inflows in the future. Inflow values for every month for one or more supply sources are read in from an ASCII file. Typically, this file contains either historical data or outputs from another model (e.g., a climate change model). See Inflow.

**Recharge:** The natural inflow to a groundwater source. This does not include return flows and inflows from a river.

**Reference Scenario:** A scenario that represents the changes that are likely to occur in the future, in the absence of any new policy measure. Sometimes called a "business as usual" scenario.

**Return Flow:** Wastewater flows from demand sites and wastewater treatment plants, to treatment plants and receiving bodies of water. See Return Flow Node.

**Return Flow Node:** Point at which a return flow enters a river. (You may actually have return flows enter the river at any type of river node: Reservoir, Run-of-River Hydropower, Tributary, Diversion, Flow Requirement, Withdrawal Node, or Return Flow Node.) See Return Flow.

**Revert:** WEAP automatically saves multiple versions of each area's data; you may revert to any previous version.

**River Node:** A point on a river, of the following types: Reservoir, Run-of-River Hydropower, Withdrawal Node, Return Flow Node, Tributary Node, Diversion Node, Flow Requirement.

**River Reach:** The portion of a river between two river nodes. See River Node.



**Run-of-River Hydro:** Points on which run-of-river hydropower stations are located. Run-of-river stations generate hydropower based on varying streamflows but a fixed water head in the river. They have no storage.

**Runoff:** Precipitation or other source of water (such as excess irrigation water) that travels overland

**Runoff Resistance Factor:** Used to control surface runoff response. Related to factors such as leaf area index and land slope. Runoff will tend to decrease with higher values of RRF (range 0.1 to 10).

## S

**Scenario:** A self-consistent storyline of how a future system might evolve over time in a particular socio-economic setting, for an assumed hydrologic sequence, and under a particular set of policy and technology conditions.

**Schematic:** A user-created spatial layout that encompasses the physical features of the water supply and demand system. The schematic is the starting point for all activities in WEAP--from here you have one-click access to all data and results.

**Script:** WEAP can act as an "COM Automation Server," meaning that other programs (e.g., Excel via VBA), programming languages (e.g., Visual Basic, C) or scripts (e.g., Visual Basic Script (VB script), JavaScript, Perl, Python) can control WEAP directly--changing data values, calculating results, and exporting them to text files or Excel spreadsheets. These scripts or programs would use WEAP's "Application Programming Interface" (API) to communicate and automate WEAP.

**Sector:** A water-using sector of society, e.g., Agricultural, Municipal or Industrial. See Subsector, Disaggregate, Aggregate.

**Sensitivity:** Changes that occur in a scenario because of different socio-economic, hydrologic or technology assumptions, rather than because of different policies.

**Subsector:** Detailed breakdown of a sector, e.g., urban and rural subsectors represent the municipal sector, or crop types, which represent subsectors for the agricultural sector. See Sector, Disaggregate, Aggregate.

**Supply Preference:** The preference a demand site has for a particular source. Each transmission link has a preference number, ranging from 1 (highest preference) to 99 (lowest). See also Demand Priority, Allocation Order.

**Surface Runoff:** Surface water inflow to river reaches represents either non-point runoff into the river, or the confluence of streams or rivers not otherwise modeled.

## T

**Transmission Link:** Transmission links deliver water from local supplies, reservoir nodes, and withdrawal nodes to satisfy final demand at demand sites.

**Tree:** A hierarchical structure for organizing data, under six major categories: Key Assumptions, Demand Sites, Hydrology, Supply and Resources, Environment, and Other Assumptions.

**Tributary Node:** Points where one river joins another.

## V

**Variable:** Data that can change over time.

**Vector GIS Layer:** Display geographic features from points, using discrete X-Y locations. Lines are constructed from strings of points, and polygons (regions) are built from lines which close. Vector methods are sometimes contrasted with raster techniques which record geographic features within a matrix of grid cells.

**Version:** WEAP automatically saves multiple versions of each area's data; you may revert to any previous version.

## W

**Wastewater Treatment Plant:** Treats wastewater from demand sites to remove pollutants, then returns treated effluent to one or more river nodes or local supply sources.

**Water Quality:** A term used to describe the chemical, physical, and biological characteristics of water, usually in respect to its suitability for a particular purpose.

**Water Use Rate:** The average water consumption of some device or end-use per unit of activity. See Activity Level.

**Water Year Method:** A simplified means for projecting inflows in the future. Enter Current Accounts inflow data, then define the fluctuations of each water year type from the norm, and specify the sequence of water year types in the future. See Water Year Type, Inflow.

**Water Year Type:** A water year type characterizes the hydrological conditions over the period of one year. The five types that WEAP uses-- Normal, Very Wet, Wet, Dry, and Very Dry--divide the years into five broad categories based on relative amounts of surface water inflows. See Water Year Method.

**Watershed:** See Catchment.

**Withdrawal Node:** Point where any number of demand sites receive water directly from a river.

## Z

**Zone:** Reservoir storage is divided into four zones, or pools. These include, from top to bottom, the flood-control zone, conservation zone, buffer zone and inactive zone. The conservation and buffer pools, together, constitute the reservoir's active storage.

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