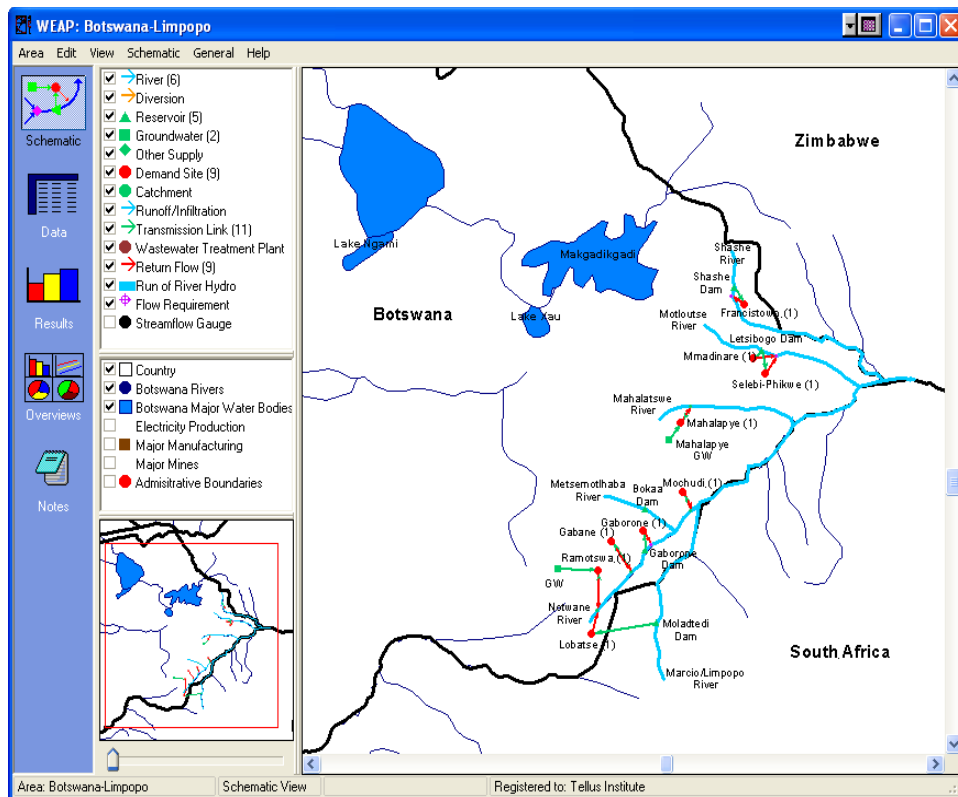# WEAP

Water Evaluation And Planning System

USER GUIDE

WEAP

Water Evaluation And Planning System

USER GUIDE

for WEAP21

Jack Sieber, M.S., Water Systems Modeler
Chris Swartz, Ph.D., Research Associate
Annette Huber-Lee, Ph.D., Director, Water Program

Stockholm Environment Institute
Tellus Institute
11 Arlington Street
Boston, MA   02116-3411   USA

Telephone: (617) 266-5400
Fax: (617) 266-8303
Email: weap@tellus.org
Web: http://www.seib.org/weap
                     http://www.tellus.org

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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 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, 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.

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.

1.4 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, Overview 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.

- **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

1.5 Acknowledgements

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 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 Overviews 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 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 Overviews view, WEAP will calculate scenarios before the view is displayed, if any changes have been made to the system or the scenarios.

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.
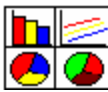
The Overviews View is used to group together "Favorite" charts (created earlier in the "Results" view) which can then be displayed on the screen simultaneously. With Overviews, you can get a birds-eye perspective on different important aspects of your system, such as demands, coverage, storage levels, environmental impacts and costs. You can create multiple Overviews, each of which can display up to 16 different Favorites.

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 Water Use Rate data for the demand site Industry North.
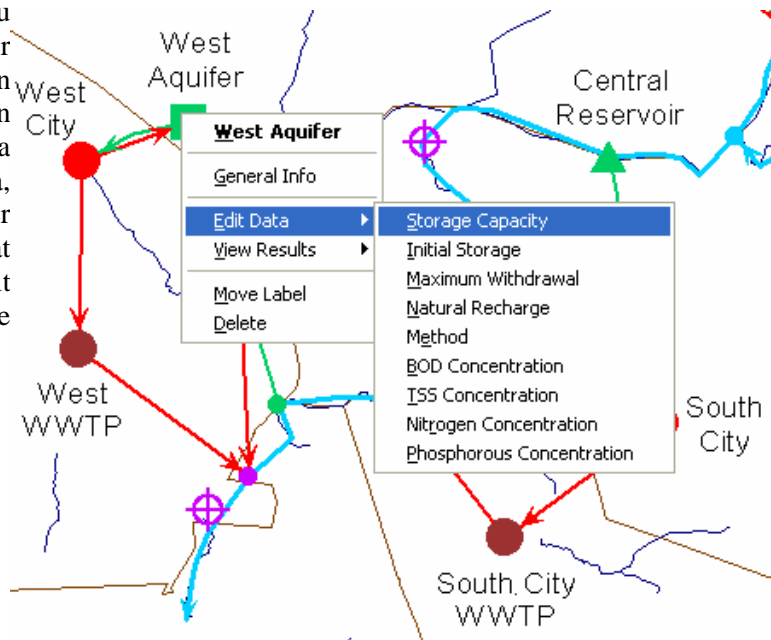
2.4 Data View

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):
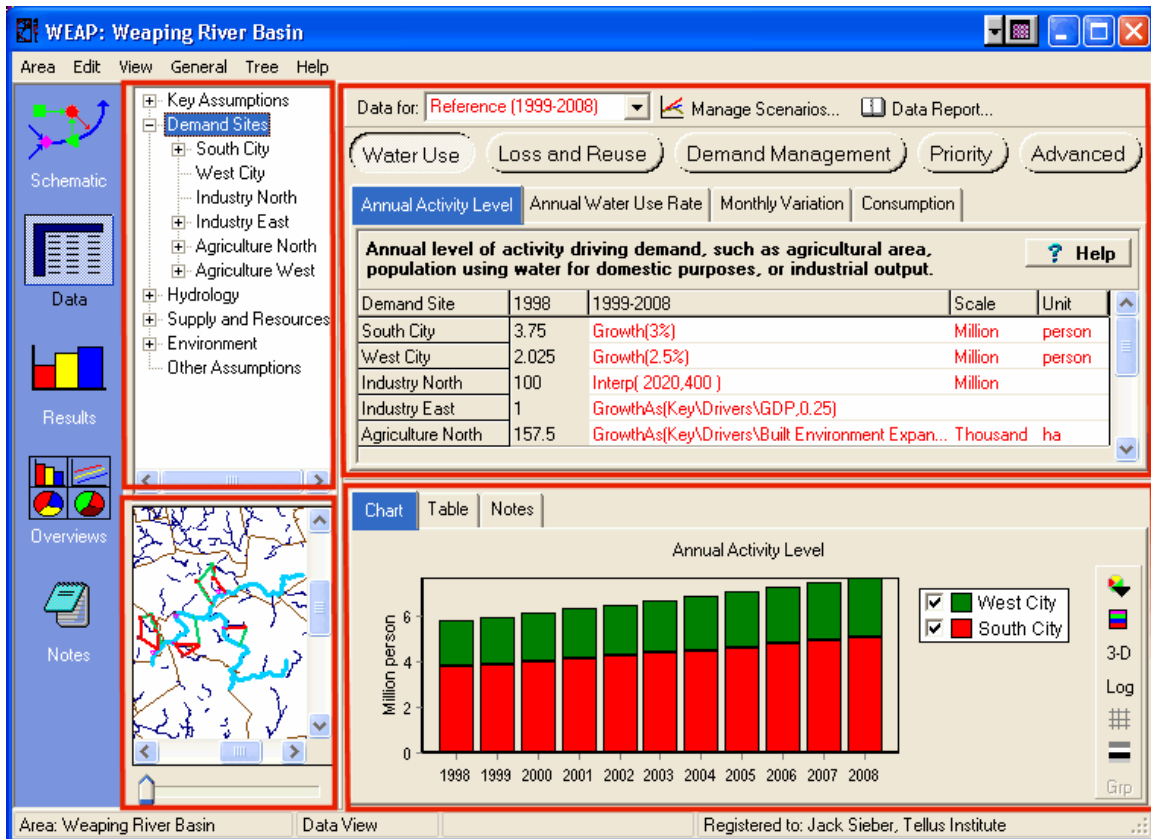
2.4.1 Tree

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 it 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, evaporation, transmission losses, wastewater treatment, pollution loads, and costs. Modeled runs 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.

2.6 Overviews View

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

You can create multiple Overviews, each of which can display up to 25 different charts and table sections. The first time you access the system, WEAP will display a standard set of charts. After you define your own favorites, you can use the Overview Manager to select which favorite charts and tables you want to include in your particular overview, and in which order to display them. You can also use the Overview manager to add, rename or delete overviews.

To zoom in to one of the charts shown in an Overview, double-click it or click the zoom button (🔍). 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 menu option Favorite, Save Chart as Favorite.

You can apply a couple of formatting options across all charts shown in the Overview: click on **3D** to set the 3D effect for all charts, or legend (▤) to show or hide all legends.

To see the numbers behind the charts, select the Table tab at the top. You will see the results from each chart organized into one large table.

See also: View Bar

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

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). This menu also allows you to edit, delete, or reorder the background maps. For instance, to view the data associated with a GIS layer, right-click on the layer name, then select Edit to go to the Edit Layer window. Click the Browse Data button to see data for all map elements, or click on an element in the map to see the data in the grid to the left of the map.

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.
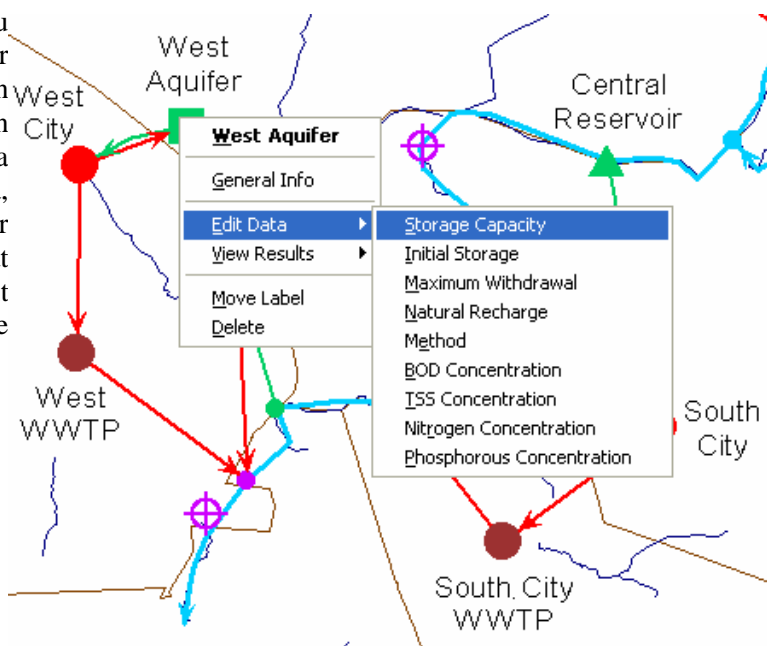
3.2.2 Elements of a WEAP Schematic

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, 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, 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.

Other 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 that 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.

Competing demand sites and catchments, the filling of reservoirs, 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 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 priorities default to 99, meaning that they will fill only if water remains after satisfying all other demands. 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, 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 General, Change Priority View.

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

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.

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.

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

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.

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.
Menu Option: General: Years and Time Steps

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

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, you may define up to 10 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:

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 enter as data the temperature of water in the river for each reach.

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): 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.

Menu Option: General: Water Quality Constituents

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.

Menu Option: General: Basic Parameters

4 Data

4.1 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.

4.2 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.

4.2.1 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 a 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.

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).

4.2.2   Create and 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.

In the example shown below, there are four scenarios defined--a Reference scenario, and three variants of the Reference scenario.
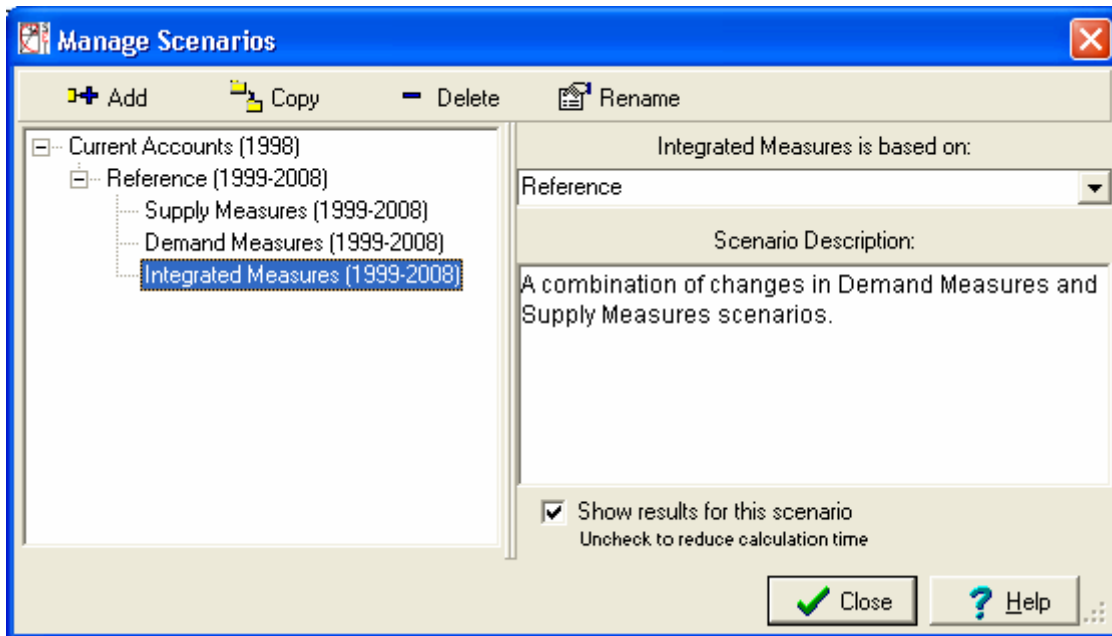
**Menu Option**: Area: Manage Scenarios (also on Data View toolbar)

See also: Scenarios, Data View

4.3 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
Demand Sites
Hydrology
    Water Year Method
    Read from File
Supply and Resources
    Linking Demands and Supply
    River
        Weaping River
            Reservoirs
            Flow Requirements
            Reaches
        Blue River
        Grey River
    Groundwater
    Return Flows
Environment
    Pollutant Generation
    Pollutant Decrease in Return Flows
    Wastewater Treatment
Other Assumptions

- **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 you 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).
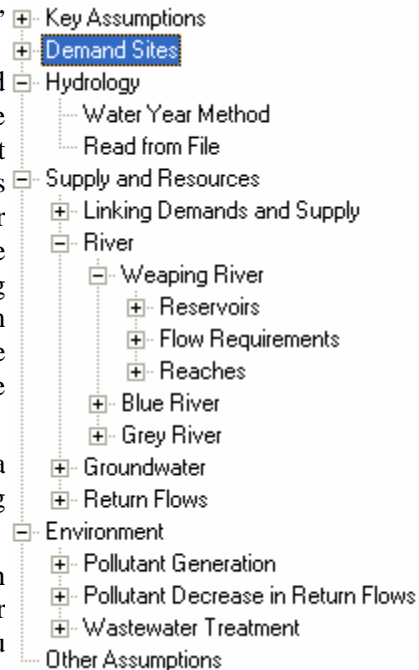
4.3.1 Editing the Tree

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

4.4 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).

4.4.1 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
- Water consumption (water consumed by a demand site that is lost to the system, lost to evaporation, embodied in products, or otherwise unaccounted for)

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.
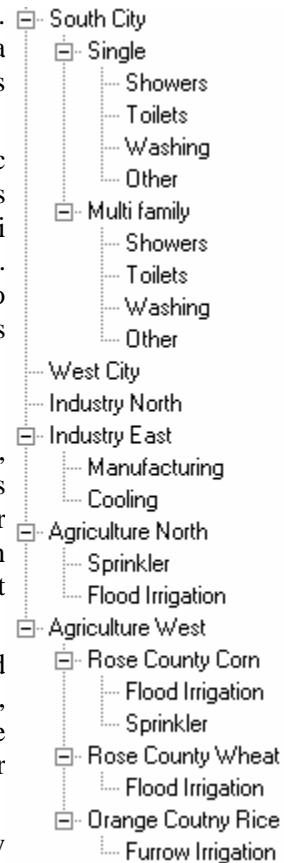
You can organize the demand tree along the lines of the available data. For example, under the agricultural sector, the irrigation area for each crop can be identified at the subsector level. One level down, the percentage of each irrigation technique in each crop may be assigned at the end-use level. 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.

4.4.3 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 multiples 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.
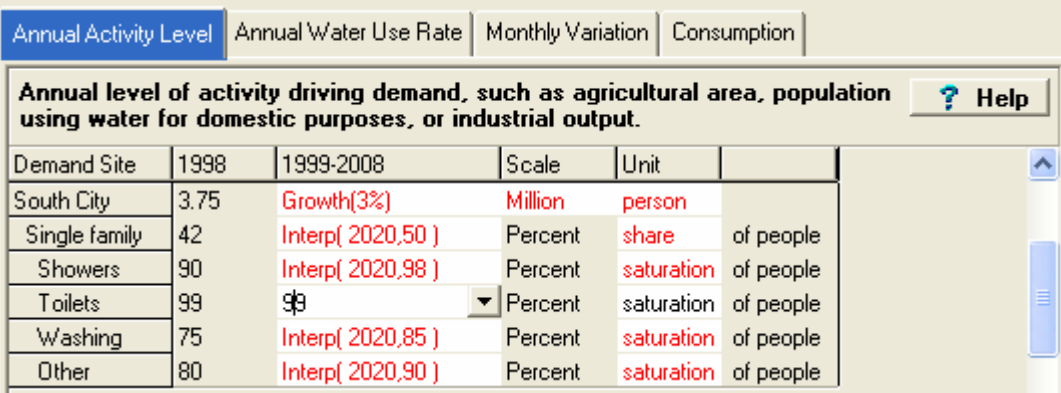
Monthly Demand Option

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 Water Use Rate	Monthly Variation	Consumption		
Annual level of activity driving demand, such as agricultural area, population using water for domestic purposes, or industrial output.				? Help	
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.

Single family	1998	1999-2008	Scale	Unit	
Showers	62.62	GrowthAs(Key\Drivers\Technical Innovation,-0.25) ▼		m^3	/person
Toilets	70.5	GrowthAs(Key\Drivers\Technical Innovation,-0.25)		m^3	/person
Washing	44.1	44.1		m^3	/person
Other	30.8	30.8		m^3	/person

Annual water use rate per unit of activity

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. Note that the twelve monthly coefficients entered on each screen must sum to one hundred percent. If demand does not vary, all months are assumed to use the same amount. Note that the monthly variation is the same for all branches underneath a demand site.

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 more accurately reflect 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).

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

4.4.4 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

4.4.5 Loss and Reuse

Loss Rate (%)

Loss Rate accounts for any distribution losses within each demand site. 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 fire fighting. The effect of distribution losses is to increase the supply requirement by the factor (1 + loss rate). NB: Do not include losses that are already accounted for as transmission link losses.

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 - 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

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

Inflow: Maximum Allowed Inflow Concentration

In order to set a minimum water quality standard for supply to a demand site, 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, Category: Water Quality, Tabs: <Constituent Name> Inflow

Outflow: Pollution Generation

Demand Sites may generate pollution, which is carried in its wastewater return flows to treatment plants and local and river sources. 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 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. WEAP will multiply this concentration by the volume of wastewater return flow 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 demand site 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, Category: Water Quality, Tabs: <Constituent Name> Intensity, <Constituent Name> Concentration

Determines the demand site's priority for supply. NB: 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.

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

4.5 Catchments

4.5.1 Overview of Catchment Simulation Methods

There is a choice among three 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, and (3) the Soil Moisture 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)

Of these three 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 can not meet. It does not simulate runoff or infiltration processes.

Rainfall Runoff Method (FAO)

The Rainfall Runoff method also determines evapotranspiration for irrigated and rainfed crops using crop coefficients. 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 Model)

The Soil Moisture Model is the most complex of the three 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 is link is made.

See also: FAO Method Calculation Algorithm, Soil Moisture Method Calculation Algorithm

Land Use

(These parameters apply to the FAO Method. 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.

Kc

The crop coefficient, relative to the reference crop, is given here for each land class type.

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.)

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.

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. ActualYield = Potential Yield*(1-YieldResponseFactor)*((1-ETActual)/ETPotential))

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, Price.

Irrigation

(These parameters apply to the FAO Method. For the Soil Moisture Method, see Soil Moisture, 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).

See also: FAO Method Calculation Algorithm

Entered on: ▦Data View, Branch: Catchments, Category: Irrigation, Tab: Irrigated, Irrigation Fraction.

<div style="text-align: right;">**4.5.3 Soil Moisture Method**</div>

Land Use

(These parameters apply to the Soil Moisture method. For the FAO Method, see FAO Method, 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.

Leaf Area Index

Used to control surface runoff response. Runoff will tend to decrease with higher values of LAI (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.
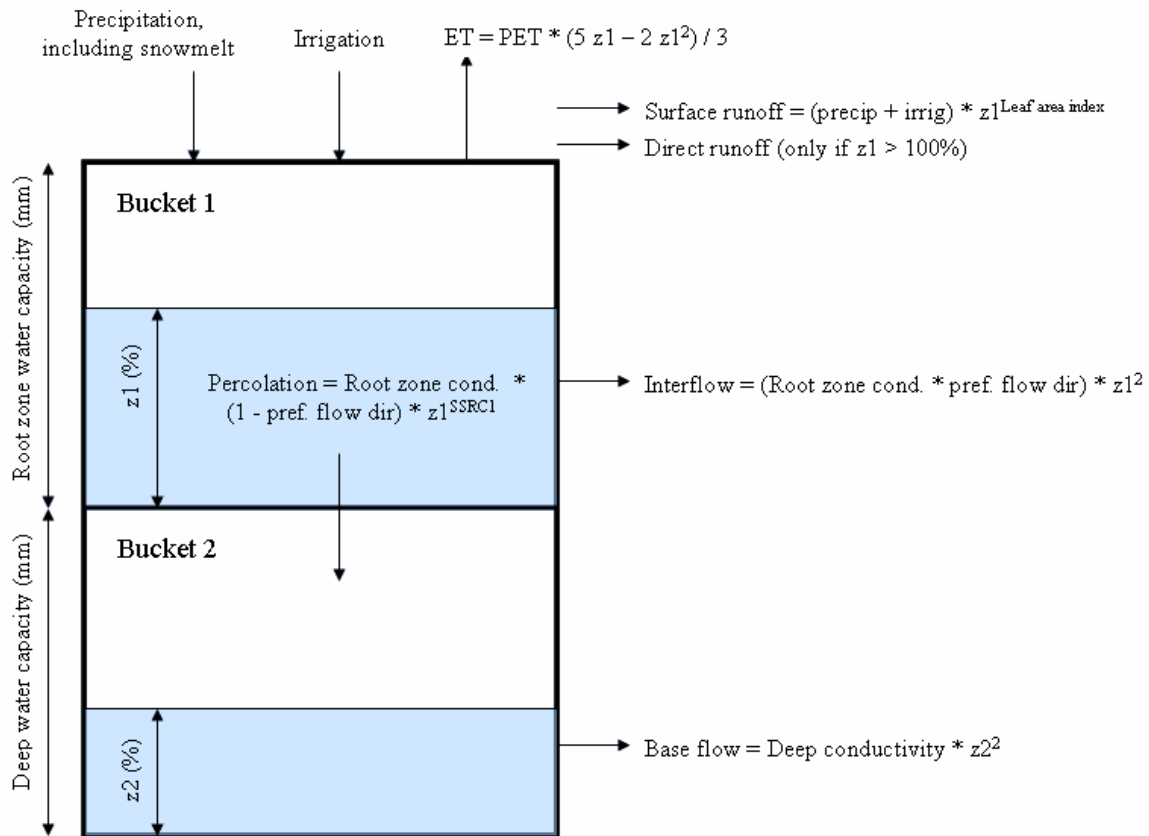
Initial Z1

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

Precipitation, including snowmelt   Irrigation $ET = PET * (5\,z1 - 2\,z1^2) / 3$

Surface runoff $= (precip + irrig) * z1^{\text{Leaf area index}}$

Direct runoff (only if z1 > 100%)

Bucket 1

Root zone water capacity (mm)

z1 (%)

Percolation $=$ Root zone cond. $*$ (1 - pref. flow dir) $* z1^{\text{SSRC1}}$

Interflow $= (\text{Root zone cond.} * \text{pref. flow dir}) * z1^2$

Bucket 2

Deep water capacity (mm)

z2 (%)

Base flow $=$ Deep conductivity $* z2^2$

See also: Soil Moisture Method Calculation Algorithm

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

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.

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).

Latitude

The latitude in degrees.

Initial Snow

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

See also: Soil Moisture Method Calculation Algorithm

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

Irrigation

(These parameters apply to the Soil Moisture method. For the FAO Method, see FAO Method, 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.

See also: Soil Moisture Method Calculation Algorithm

Entered on: ▦Data View, Branch: Catchments, Category: Irrigation, Tab: Irrigated Area, Lower Threshold, Upper Threshold.

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 can not 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

4.6 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, and tracks reservoir and

groundwater storage.

Supply and Resources include the following subsections:

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

- **Local Supplies**: non-river sources, including groundwater, reservoirs that are simulated as isolated facilities, and "other" sources (e.g., surface sources that are not modeled in your WEAP application, such as inter-basin transfers).

- **Rivers and Diversions**: surface inflows to rivers, properties and operation of reservoirs and run-of-river hydropower facilities, and instream flow requirements.

- **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.

4.6.1 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

4.6.2 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

Water Year Method Overview

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

4.6.3 Linking Demands and Supply

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.

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.

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 \ Linking Demands and Supply, Category: Linking Rules, Tabs: Supply Preference, Maximum Flow Volume, Maximum Flow Percent of Demand

Transmission Link Losses

The transmission losses refer to the evaporative and leakage losses as water is carried by canals and conduits to demand sites and catchments. The losses disappear from the system. This **Loss Rate** is specified as a percentage of the flow passing through a transmission link. NB: Do not include losses that are already accounted for as demand site losses.

Entered on: Data View, Branch: Supply and Resources \ Linking Demands and Supply, Category: Losses, Tab: Loss Rate

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. WEAP maintains a mass balance of monthly inflows and outflows in order to track the monthly groundwater storage volume.

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

Groundwater 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.

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

Groundwater 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 two options. One can specify the amount of groundwater inflow to a particular river or reach or you can have WEAP model these interactions. To select the desired method, go to particular groundwater node in the Data view under the Groundwater branch of Supply and Resources, and click on the **Method** tab.

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

WEAP can also model groundwater-surface water interactions using a stylized representation of the system. 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.

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

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, Tabs: Net Evaporation

Reservoir 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.

Entered on: ⊞ Data View, Branch: Supply and Resources/River, Category: Reservoir, Tab: Priority

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.
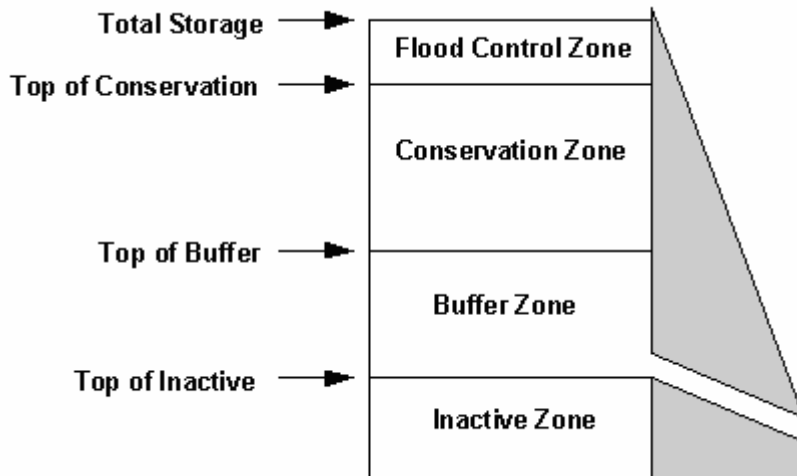
WEAP allows the reservoir to freely release water from the conservation pool to fully meet withdrawal and other downstream requirements. Once the storage level drops into the buffer pool, the release will be restricted according to the buffer coefficient, to conserve the reservoir's dwindling supplies. 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.

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

Maximum and **Minimum Turbine Flows** define the upper and lower capacity limits. When turbine flow exceeds the maximum, hydropower will only be generated up to the maximum flow. When turbine flow falls below the minimum, no hydropower will be generated. **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 current storage volume) 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 (electricity generated dived by hydropower input).

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

Entered on: ▦Data View, Branch: Supply and Resources \ Local or River \ Reservoir, Category: Hydropower, Tab: Min. Turbine Flow, Max. Turbine Flow, Tailwater Elevation, Plant Factor, Generating Efficiency

4.6.6 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.

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

4.6.7 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

Streamflow Gauge

Use the streamflow gauge object to facilitate comparing calculated 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 calculated and observed flows, and Water Quality \ Surface Water Quality to compare calculated and observed concentrations for each water quality constituent.

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

River and Reach 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 temperature, BOD, and DO models. 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.

If you want to model water quality constituents assuming other than conservative behavior, for example, using first order decay, several additional parameters are required. First, go to the *Data View* and click on *River* under *Supply and Resources*. Then click on the river name and then Reaches. The *Water Quality* category contains tabs for the following:

- **Distance Marker** - distance values for the top of the each reach and the tailflow point of the river. These parameters are not required if you are modeling water quality parameters assuming conservative behavior (only simple mixing is relevant). If you leave blank the distance values for any of the reaches other than the first reach, WEAP will estimate them based on the schematic.

- **Flow Stage Width** - data relating river stage and width to flow. WEAP will use values from the immediate upstream reach if you leave this value blank. This parameter is not

required if you are modeling parameters assuming conservative behavior.

- **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 this value blank.

If you have specified a volume of surface water inflow to a river along a reach, you can also specify water quality parameters (for example, temperature or phosphorus concentration) for that inflow.

Note that if you have specified inflow of groundwater to a river along a reach, the water quality parameters for that inflow are entered under the Groundwater data branch. In a similar fashion, the water quality of outflows from reservoirs is entered under the Reservoir data branch. Water quality in reservoirs and groundwater is not modeled by WEAP. Note also that WEAP models processes that add or withdraw water from a river or reach; such as groundwater inflow and outflow, reservoir outflows, return flows from demand nodes and wastewater treatment plants, tributary inflows and other surface inflows, and evaporation; with a simple mixing approach.

Entered on: ⊞Data View, Branch: Supply and Resources \ River \ <River Name> \ Reaches, Category: Water Quality, Tabs: <Constituent Concentration>, Temperature, Distance Marker, Climate, Flow Stage Width.

Reservoirs

River Reservoir Overview

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 the reservoir's operating rules.

Physical

Reservoir Water Quality

The quality of water outflow from reservoirs into river reaches can be indicated in WEAP. Selected constituent concentrations, as well as temperature, can be entered for the outflows from a reservoir. Note that the quality of water flowing into a reservoir will not affect the quality of outflow specified here--reservoir water quality is not modeled in WEAP due to the inherent complexities of such a system. Therefore, on rivers in which you are modeling water quality, any reservoir outflows will have to be parameterized for the selected water quality constituents.

Entered on: ⊞Data View, Branch: Supply and Resources \ River \ <River name> \ Reservoirs \ <reservoir name>, Category: Water Quality, Tab: Nitrogen Concentration, Phosphorus Concentration, BOD Concentration, TSS Concentration, Temperature

Run of River Hydropower

Maximum and **Minimum Turbine Flows** define the upper and lower capacity limits. When

turbine flow exceeds the maximum, hydropower will only be generated up to the maximum flow. When turbine flow falls below the minimum, no hydropower will be generated. 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 (electricity generated divided by hydropower input).

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

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 or after other demands on the river.

You may change the **Priority** over time or from one scenario to another.

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
- **Latitude** - in degrees

If any of the climate data for a reach are left blank, WEAP will use the values from the immediate upstream reach.

Entered on: ▦Data View, Branch: Supply and Resources \ River \ <River Name> \ Reaches, Category: Climate, Tabs: Air temperature, Humidity, Wind, Latitude.

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.)

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 in Return Links

The **Losses in Return Links** refer to the evaporative and leakage losses as wastewater is carried by canals and/or conduits from demand sites and wastewater treatment plants. This loss rate is specified as a percentage of the flow passing through the link.

Entered on: ▦Data View, Branch: Supply and Resources \ Return Flows \ <Demand Site Name>, Tab: Losses in Return Flows

4.7 Water Quality

4.7.1 Getting Started

The Water Quality section tracks pollution from generation to treatment to its accumulation in surface and underground bodies of water and transport and decay in rivers. Note: Pollution generation by demand sites is entered in the Demand Sites section of the tree.

The following types of data are often useful:

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

and surface water inflows

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: Environment \ Pollutant Decrease in Return Flows, Tabs: <Constituent Name> Decrease

4.7.3 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).

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: Environment \ Wastewater Treatment, Tabs: <Constituent Name> Removal, <Constituent Name> Concentration

4.8 Financial Analysis

The financial planning module within WEAP provides a method for calculating costs and revenues associated with scenarios. Fixed and variable costs and fixed and variable revenues 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 revenue, fixed revenue, and operation costs 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

revenues 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. Revenues 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 revenues 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 Revenues.

4.8.1 Entering System Costs and Revenues

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 Revenue 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 revenues 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 revenues - 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
- Revenue

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

4.8.2 Entering Item Costs and Revenues

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.

Revenues

Revenue 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 revenues can be modeled in WEAP:

- Fixed Revenue--this value represents the total annual revenue produced by an item that is not a function of the volume of water produced, transmitted, or consumed by an item.

- Variable Revenue--revenue expected per unit of water produced, transmitted, or consumed by a model item.

- Electricity Revenue--this variable is available for the case of reservoirs and run-of-the-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: Supply and Resources \ Groundwater \ "groundwater node name" \ Category: Costs, Tabs: Capital Costs, Fixed Operating Costs, Variable Operating Costs, Fixed Revenue, Variable Revenue.

Or

Entered on: Data View, Branch: Supply and Resources \ River \ "river name" \ Reservoirs \ "reservoir name", Category: Costs, Tabs: Capital Costs, Fixed O and M Costs, Variable O and M Costs, Fixed Revenue, Variable Revenue, Electricity Generation.

Or

Entered on: Data View, Branch: Supply and Resources \ River \ "river name" \ Reaches \ "reach name", Category: Costs, Tabs: Capital Costs, Fixed O and M Costs, Variable O and M Costs, Fixed Revenue, Variable Revenue, Electricity Generation.

4.9 Key Assumptions and Other Assumptions

Key Assumptions and Other Assumptions are user-defined variables that 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. Less important intermediate variables should go under **Other Assumptions** (see below). For example, you could

create variables that contain your projections of the unit cost of water by sector (municipal, agricultural, industrial). This would provide a convenient, consistent and transparent method for varying costs by scenario.

Another class of useful variables is macroeconomic drivers, such as population and GDP. For example, in Weaping River Basin, the expression for Industry East's Activity Level in the Reference scenario is "GrowthAs(Key\Drivers\GDP,0.25)". This means that the activity level will change as GDP changes, with an elasticity of 0.25. (When referenced in an expression Key "Assumptions\Drivers\GDP" is shortened to "Key\Drivers\GDP".)

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

4.10   Data Report

In Data view, click the "Data Report" button in the upper right corner of the screen 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.

4.11 Expressions

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 reference one of WEAP's many built-in functions, as well as referencing the values of other branches and variables entered elsewhere in the WEAP analysis. Expressions can even create dynamic links to the values stored in an external Microsoft Excel spreadsheet.
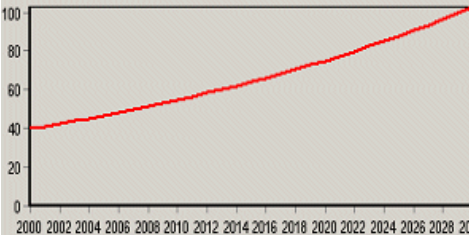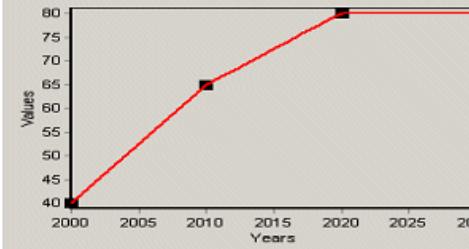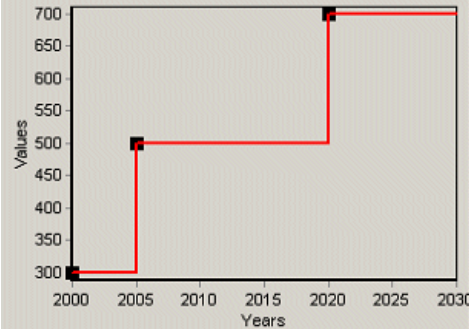
WEAP provides a number of ways of editing expressions. The most common are:

- Typing directly into the expression field in one of the data entry table's in WEAP's Data View.
- Selecting one of the most commonly used functions (Interpolation, Growth, Remainder) using the pop-up selection box attached to each expression field.
- Using the Yearly Time-Series Wizard: a tool for easily entering time-series functions (Interpolation, Step, and Smooth Curve functions)
- Using the Expression Builder tool: a tool for creating expressions by dragging-and-dropping functions and WEAP variables.

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 function names.

See also: Data View, Examples of Expressions, Expression Builder

Type of Expression.	Description	Example Syntax and Graph
Simple Number	Calculates a constant value in all scenario years	3.1415
Simple Formula	Calculates a constant value in all scenario years	0.1 * 5970
Growth Rate	Calculates exponential growth over time from a Current Accounts 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	Remainder(100)

	the remaining share.	
Branch and Variable References	Any WEAP variable can be calculated as a function of another variable (with some restrictions)	Weaping River:Headflow * 0.25
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)

4.11.2   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, or double-click on 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 (only if there are more than one variable associated with that branch).

See also: Data View, Expressions, Examples of Expressions, Export to Excel, Import from Excel

The following words are reserved for use in WEAP's expressions and cannot be included as part of a WEAP branch name:

> % Abs And CurrentAccountsYear CurrentAccountsValue Billion Ceiling Equal Exp ExpForecast Floor Frac GreaterThan GreaterThanOrEqual Growth GrowthAs GrowthFrom Hundred If Int Interp LastYear LessThan LessThanOrEqual LinForecast Ln LoanPayment Log Log10 LogisticForecast Max Million Min MonthlyValues Not NotEqual Or Parent PrevYear PrevYearValue ReadFromFile Remainder Round Smooth Sqr Sqrt Step Thousand TotalChildren Trillion Trunc VolumeElevation WaterYearMethod WaterYearSequence Year

In addition, branch names are limited to no more than 50 characters, and no less than 2 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

4.11.4   Export 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 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
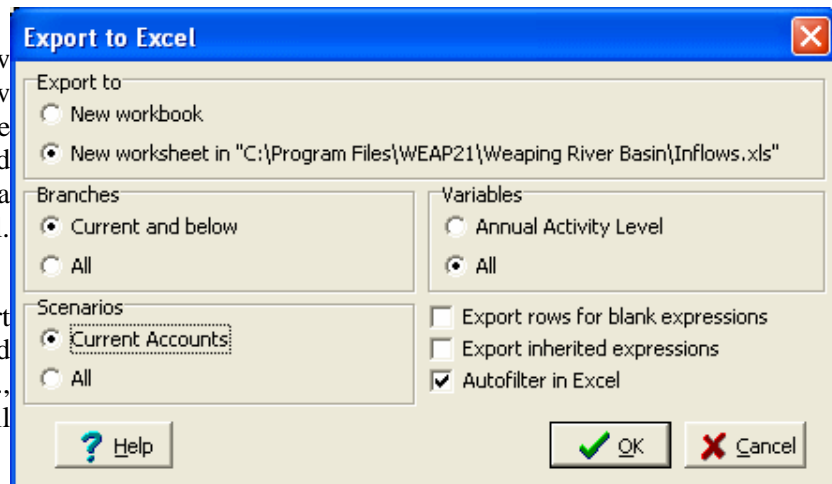
option works in combination with **Export inherited expressions**. as explained next**.**

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...

4.11.5   Import 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.

5 Results

5.1 Available Reports

5.1.1 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** distribution losses, reuse and demand-side management savings are taken into account.

Supply Requirement

The requirement at each demand site, **after** distribution 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 distribution 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.

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.

See also: Charts and Tables, , Chart Toolbar, Favorites, Overviews

5.1.2 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 to Area

Water leaving the system (consumption at demand sites, catchment evapotranspiration (ET Actual), evaporation on river reaches and reservoirs, losses in transmission 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).

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 simulated streamflow at selected nodes and reaches along a river compared to streamflow gauge data (measured streamflow).

Streamflow Relative to Gauge (%): The simulated streamflow expressed as a percent of streamflow indicated by streamflow gauge data (measured streamflow).

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 to 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.

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, or withdrawals by demand sites) as negative amounts.

Hydropower: The power generated by reservoirs and hydropower nodes.Transmission Link

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.

Catchment results cover all processes and variables related to the method chosen to simulate Catchments (FAO Crop Requirements Approach or Soil Moisture Approach). Reports will not be available unless catchments have been created in the schematic.

FAO method results

Variables which will appear in the results report for the FAO Crop Requirements Method include:

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

Soil Moisture Method Results

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

Infiltration/Runoff Flow

Volume of flows from catchments to surface and groundwater.

Effective Monthly 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.

Net Solar Radiation

The daily net energy per unit area from sunlight falling on each catchment

Reference Monthly PET

The value of the Penman-Montieth 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.

5.1.4 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.

5.1.5 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/revenue 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 revenues are selected for display, the sum of these is shown with costs assumed to be positive and revenues to be negative. For example, if revenues 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 revenues of all items and the system costs and/or revenues described in the "Entering System Costs and Revenues" section.

Net Present Value Report

This report represents the net present value of future expenditures for capital and operations costs, net of any revenues. 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 revenue 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.

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 revenues 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.

5.1.6 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.

5.2 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 of 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 "Group?" checkbox appears; selecting this checkbox will group together branches with the same name. Set Levels = 3 and check "Group?" to see that Flood Irrigation consumes nearly 50% 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.

   • 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. Favorites can be combined to form "overviews," which are a powerful way to get an overall perspective of your system. See Overviews 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.

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 (such as a low streamflow or high unmet demand) to instantly see the state of the system (on the map) at that time period.

5.2.3 Chart and Map Toolbar

The chart toolbar is used to customize and print the charts and tables displayed in WEAP. It consists of the following buttons:

Chart Type selects the type of chart (pie, bar, horizontal bar, area, line, and point). Some restrictions apply to the types of charts you can choose. In particular, you can only pick pie charts when there is a single set of summable values, and you can only pick area charts when values are summable.

Stack Type is used in area, bar and horizontal bar charts to pick how series are formatted. The options are: stacked, not stacked, grouped, percent stacked, and not stacked - 3D. This last option displays series behind one another in a 3D effect. Note that stacking of charts is only available when it makes to stack the variable or dimension. So for example, a variable such as water use rate cannot be stacked, and nor can different scenario values of any variable.

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.

Legend toggles whether a legend is displayed on the chart. Legends are always displayed in the Results View.

Shading toggles between colored charts and shaded charts. Depending on your type of printer, you may find that shaded charts work best in printed reports, while color charts work best while working with WEAP and for use in on-screen presentations.

Gridlines toggles the display of gridlines on a chart.

Increase Decimals increases the number of decimal places displayed in a table.

Decrease Decimals decreases the number of decimal places displayed in a table.

Copy copies the chart or map to the Windows clipboard in metafile format. Images can be pasted into any Windows program that supports image objects.

Print prints the chart or table. When printing tables you will be given the chance to set printer options such as print layout (landscape or portrait), print margins and how you want the table to be scaled to fit the page.

Print Preview lets you preview a chart and set basic printer options before printing.

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.

Grp lets you group small results into "All Others". If there are more than 12 items in the results legend, you can click the **Grp** button to group the smallest items together.

 # **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 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 Overviews 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.

6 Supporting Screens

6.1 Manage Areas
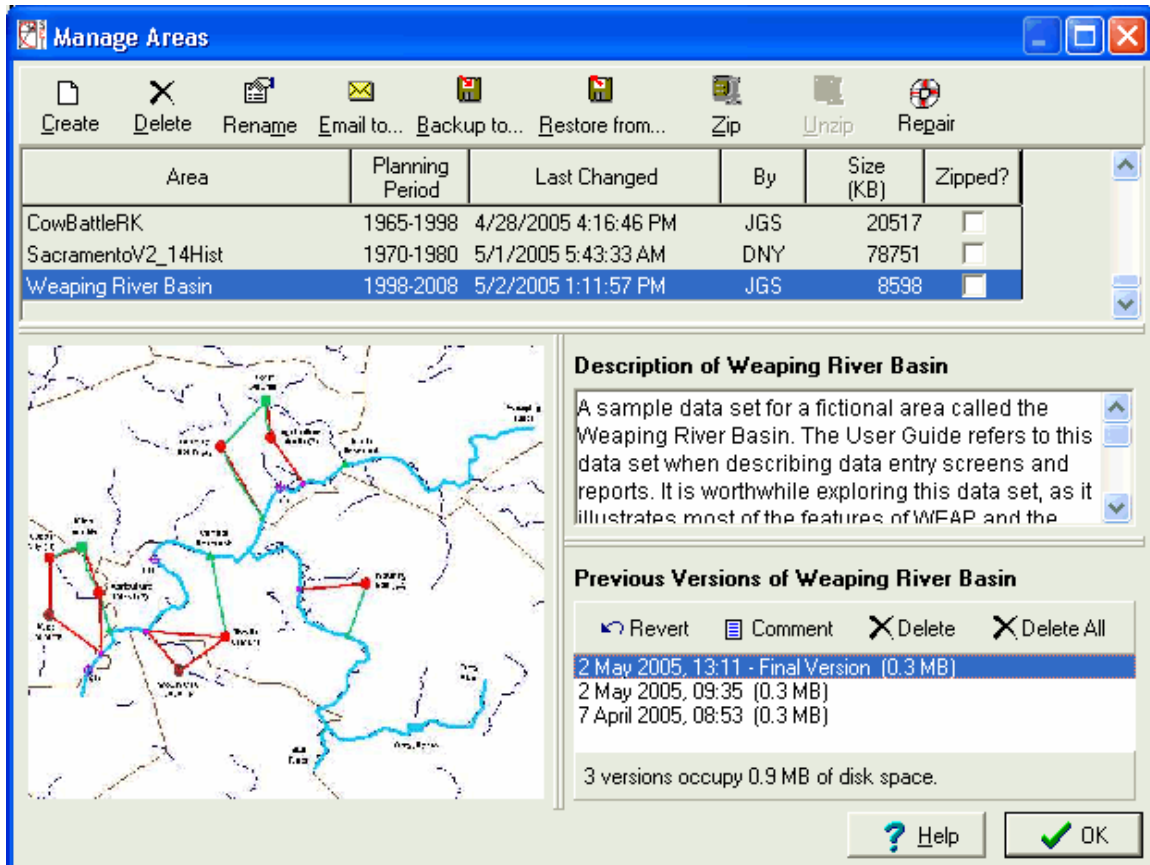
Use the Manage Areas screen, to create, delete, and organize the data sets ("Areas") on your computer. The Manage Area screen is divided into four panes. The table in the top pane shows the areas installed on your computer, along with various details about each area (planning period, when and by whom 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).

6.1.1 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 Netscape Navigator.

- **▦ 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://exchange.tellus.org/WEAPData.

- **▥ 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)

6.1.2 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. 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, 2005 would be named Weaping River Basin_2005_3_2_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 finite 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 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 2003 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 four 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.

Menu Option: Area: Manage Areas

6.2 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.
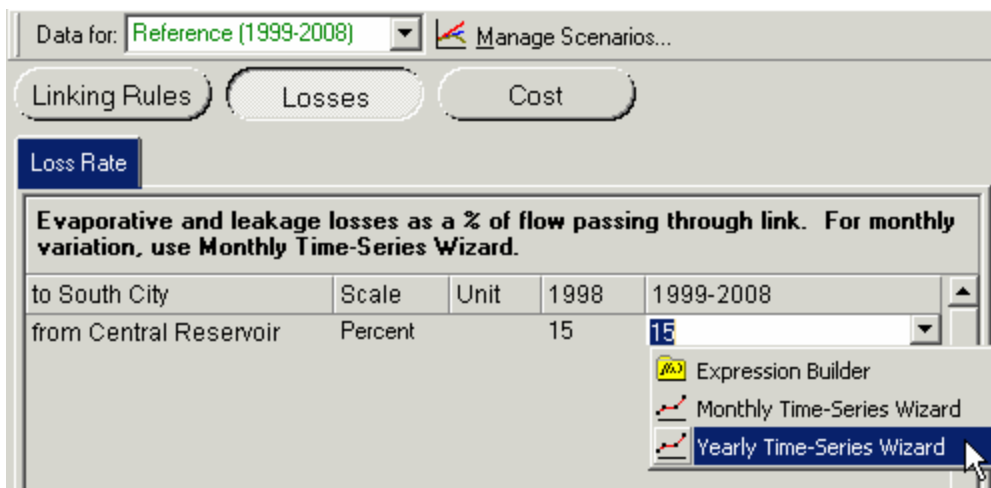
The wizard is divided into three pages, which you step through using the **Next** ( ) and **Previous** ( ) buttons.

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.
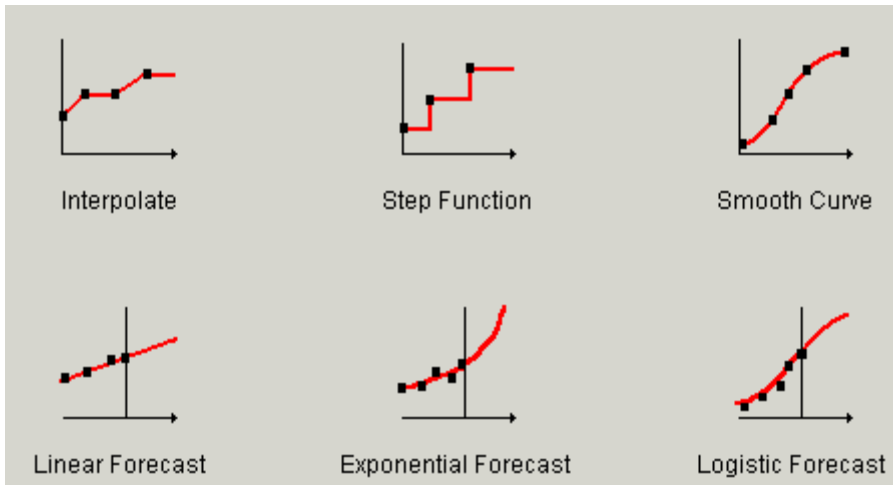
The three functions on the top row allow you to specify data points for various future years, and the function then calculates the values for intervening years:

• 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).

6.2.2 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.

6.2.3 Page 3: Data Entry

Depending on you 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

6.3   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.

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.
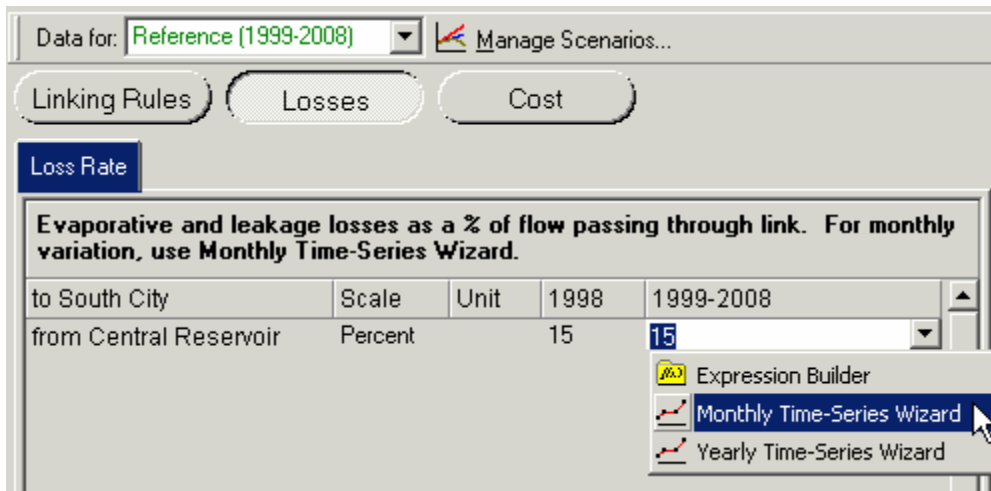
6.4 Overview Manager

Use the Overview Manager (accessed from the Overviews Toolbar) to

- Add (**+**), delete (**−**) and rename (🖻) overviews, and to
- quickly select which favorite charts are to be included in an overview.

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.

See Also Overviews View

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 and consumptive 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. 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 or reservoir, 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 to downstream demands.

Each month the calculations follow this order:

1. Annual demand and monthly supply requirements for each demand site and flow requirement.

2. Runoff and infiltration from catchments, assuming no irrigation inflow (yet).

3. 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.

4. Pollution generation by demand sites, flows and treatment of pollutants, and loadings on receiving bodies, concentrations in rivers.

5. Hydropower generation.

6. Capital and Operating Costs and Revenues.

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 Multi family that are not shown) are the bottom-level branches for South City.
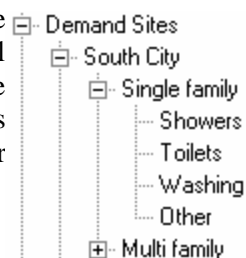
$$AnnualDemand_{DS} = \sum_{Br} (TotalActivityLevel_{Br} \text{ x } WaterUseRate_{Br})$$

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.).

$$TotalActivityLevel_{Br} = ActivityLevel_{Br} \text{ x } ActivityLevel_{Br'} \text{ x } ActivityLevel_{Br''} \text{ x } ...$$

For the example above, this becomes

$$TotalActivityLevel_{Showers} = ActivityLevel_{Showers} \text{ x } ActivityLevel_{SingleFamily} \text{ x } ActivityLevel_{SouthCity}$$

= 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.

$$MonthlyDemand_{DS,m} = MonthlyVariationFraction_{DS,m} \text{ x } AdjustedAnnualDemand_{DS}$$

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.

$$MonthlySupplyRequirement_{DS,m} = (MonthlyDemand_{DS,m} \text{ x } (1 - ReuseRate_{DS}) \text{ x } (1 - DSMSavings_{DS})) / (1 - LossRate_{DS})$$

7.2 Runoff, Infiltration and Irrigation

There is a choice among three 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, and (3) the Soil Moisture Method. Your choice of method depends on the level of complexity desired for representing the catchment processes and data availability.

Of these three 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 can not meet. It does not simulate runoff or infiltration processes.

The Rainfall Runoff method also determines evapotranspiration for irrigated and rainfed crops using crop coefficients. 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.

The Soil Moisture Method is the most complex of the three methods; it represents 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. 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. One can also link groundwater nodes to catchments simulated with the Soil Moisture Method. In this case, the lower soil layer is ignored and precipitation that passes through the upper soil layer is routed to the groundwater node rather than baseflow and increases in soil moisture in this lower layer.

7.2.1 FAO Crop Requirements

FAO 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. Obviously non-agricultural crops 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:

$PrecipAvailableForET_{LC} = Precip_{HU} * Area_{LC} * 10^{-5} * PrecipEffective_{LC}$

$ETpotential_{LC} = ETreference_{HU} * Kc_{LC} * Area_{LC} * 10^{-5}$

$PrecipShortfall_{LC,I} = Max (0, ETpotential_{LC,I} - PrecipAvailableForET_{LC,I})$

$SupplyRequirement_{LC,I} = (1 / IrrFrac_{LC,I}) * PrecipShortfall_{LC,I}$

$SupplyRequirement_{HU} = \sum_{LC,I} SupplyRequirement_{LC,I}$

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} = $ Calculated by WEAP allocation algorithm

$Supply_{LC,I} = Supply_{HU} * (SupplyRequirement_{LC,I} / SupplyRequirement_{HU})$

$ETActual_{LC,NI} = Min (ETpotential_{LC,NI} , PrecipAvailableForET_{LC,NI})$

$ETActual_{LC,I} = Min (ETpotential_{LC,I} , PrecipAvailableForET_{LC,I})$
$\qquad + IrrFrac_{LC,I} * Supply_{LC,I}$

$EF_{LC} = ETActual_{LC} / ETpotential_{LC}$

As a result, the actual yield can be calculated with the following equation:

$ActualYield_{LC} = PotentialYield_{LC} * Max (0, (1 - YieldResponseFactor_{LC}$
$\qquad * (1 - EF_{LC})))$

Runoff to both groundwater and surface water can be calculated with the following equations:

$Runoff_{LC} = Max (0, PrecipAvailableForET_{LC} - ETpotential_{LC})$
$\quad + (Precip_{LC} * (1 - PrecipEffective_{LC}))$
$\quad + (1 - IrrFrac_{LC,I}) * Supply_{LC,I}$

$$RunoffToGW_{HU} = \sum_{LC} (Runoff_{LC} * RunoffToGWFraction_{LC})$$

$$RunoffToSurfaceWater_{HU} = \sum_{LC} (Runoff_{LC} * (1 - RunoffToGWFraction_{LC}))$$

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
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,

$$Rd_j \frac{dz_{1,j}}{dt} = P_e(t) - PET(t)k_{c,j}(t)\left(\frac{5z_{1,j} - 2z_{1,j}^2}{3}\right) - P_e(t)z_{1,j}^{LAI_j} - (1 - f_j)k_j z_{1,j}^2 - f_j k_j z_{1,j}^2$$

Eq. 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,

$$m_c = \begin{cases} 0 & T_i < T_s \\ 1 & \text{if} \quad T_i > T_l \\ \dfrac{T_i - T_s}{T_l - T_s} & T_s \leq T_i \leq T_l \end{cases}$$
Eq. 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,

$$Ac_i = Ac_{i-1} + (1 - m_c)P_i$$
Eq. 3

with the melt rate, m_r, defined as,

$$m_r = Ac_i m_c$$
Eq. 4

The effective precipitation, P_e, is then computed as

$$P_e = P_i m_c + m_r$$
Eq. 5

In Eq. 1, PET is the Penman-Montieth 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 LAI_j is the Leaf Area Index of the land cover. Lower values of LAI_j lead to more surface runoff. The third and fourth 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 runoff, RT, from each sub-catchment at time t is,

$$RT(t) = \sum_{j=1}^{N} A_j \left(P_e(t) z_{1,j}^{LAI_i} - (1 - f_j) k_j z_{1,j}^2 \right)$$
Eq. 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:

$$S_{max} \frac{dz_2}{dt} = \left(\sum_{j=1}^{N} f_j k_j z_{1,j}^2 \right) - k_2 z_2^2$$
Eq. 7

where the inflow to this storage, S_{max} is the deep percolation from the upper storage given in Eq. 1, and K_{s2} 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 6 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 (given by Eq. 6) is ignored, and recharge R (volume/time) to the aquifer is

$$R = \sum_{j=1}^{N} A_j (f_j k_j z_{1,j}^2)$$
Eq. 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 Surface water-Groundwater Interactions).

Figure 1. Conceptual diagram and equations incorporated in the Soil Moisture model

Precipitation, including snowmelt   Irrigation $ET = PET * (5\,z1 - 2\,z1^2) / 3$

Surface runoff = (precip + irrig) * $z1^{\text{Leaf area index}}$
Direct runoff (only if $z1 > 100\%$)

Bucket 1

Root zone water capacity (mm)

$z1$ (%)

Percolation = Root zone cond. * (1 - pref. flow dir) * $z1^{SSRC1}$

Interflow = (Root zone cond. * pref. flow dir) * $z1^2$

Bucket 2

Deep water capacity (mm)

$z2$ (%)

Base flow = Deep conductivity * $z2^2$
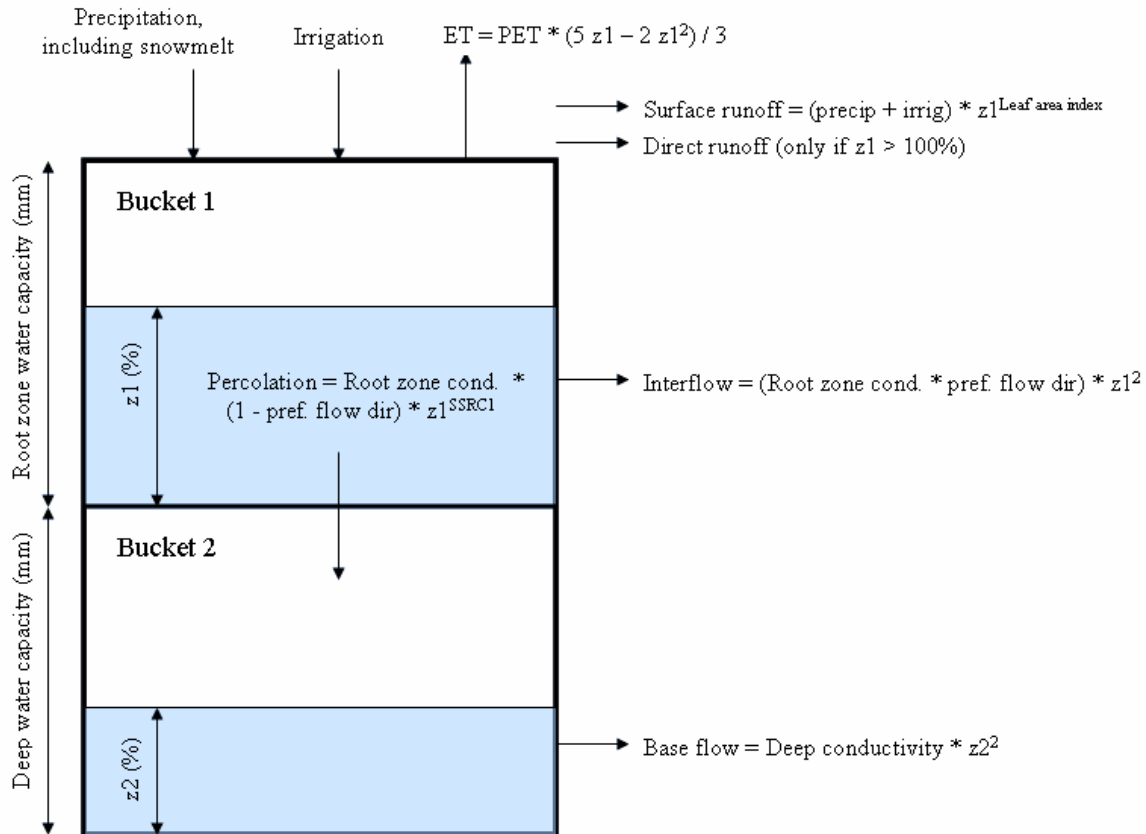
7.2.3 Runoff Flows from Irrigation

For the Soil Moisture Method, irrigation runoff can be included in total runoff emanating from a catchment. WEAP calculates this irrigation runoff by 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 by the user when simulating a catchment with the Rainfall Runoff method.

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 demand site and user-specified instream flow requirements, 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 and aquifers). Every node and link

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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 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.)

$$DemandSiteReuseOutflow_{DS1} = \sum TransLinkOutflow_{DS1,DS2}$$

$$DemandSiteReturnFlow_{DS} = DemandSiteInflow_{DS} - Consumption_{DS} - DemandSiteReuseOutflow_{DS}$$

7.3.2 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 rate is entered as data (see Supply and Resources\Linking Demand and Supply\Transmission Losses).

$$TransLinkLoss_{Src,DS} = TransLinkLossRate_{Src,DS} \times TransLinkInflow_{Src,DS}$$

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\Linking Demand and Supply\Linking Rules).

$$TransLinkOutflow_{Src,DS} \leq MaximumFlowPercent_{Src,DS} \times SupplyRequirement_{DS}$$

7.3.3 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.

$$DSReturnLinkOutflow_{DS,Dest} = DSReturnLinkInflow_{DS,Dest} - DSReturnLinkLoss_{DS,Dest}$$

The losses along the link are a fraction of its inflow, where the loss rate is entered as data (see Supply and Resources\Return Flows\Losses).

$$DSReturnLinkLoss_{DS,Dest} = DSReturnLinkLossRate_{DS,Dest} \times DSReturnLinkInflow_{DS,Dest}$$

7.3.4 Wastewater Treatment Plant Flows

A wastewater treatment plant (*TP*) receives wastewater inflows from one or more demand sites (*DS*). (The inflow to the treatment plant from a demand site is defined as the outflow from the return flow link connecting them.)

$$TreatmentPlantInflow_{TP} = \sum_{DS} DSReturnLinkOutflow_{DS,TP}$$

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 a demand site for reuse, 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.)

$$TreatmentPlantReuseOutflow_{TP} = \sum TransLinkOutflow_{TP,DS}$$

$$TreatmentPlantReturnFlow_{TP} = TreatmentPlantInflow_{TP} - Consumption_{TP} - TreatmentPlantReuseOutflow_{TP}$$

7.3.5 Wastewater Treatment Plant Return Link Flows

The treatment plant return link 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 rate is entered as data (see Supply and Resources\Return Flows\Losses).

$$TPReturnLinkLoss_{TP,Dest} = TPReturnLinkInflow_{TP,Dest} \times TPReturnLinkLossRate_{TP,Dest}$$

7.3.6 Groundwater Flows

A groundwater node's (*GW*) storage in the first month (*m*) of the simulation is specified as data (see Supply and Resources\Local\Groundwater\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\Local\Groundwater\Natural Recharge), demand site (*DS*) and treatment plant (*TP*) return flows, and subsurface flow from river reaches (*Rch*), minus withdrawals by demand sites and subsurface flow to river reaches. (For a description of groundwater/surface water interactions, see River Reach Flows.)

$$EndMonthStorage_{GW} = BeginMonthStorage_{GW} + NaturalRecharge_{GW} + \sum_{DS} DSReturnFlow_{DS,GW}$$

$$+ \sum_{TP} TPReturnFlow_{TP,GW} + ReachFlowToGroundwater_{GW,Rch} - \sum_{DS} TransLinkInflow_{GW,DS}$$
$$- GroundwaterFlowToReach_{GW,Rch}$$

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\Local\Groundwater\Maximum Withdrawal), to model the monthly pumping capacity of the well or other characteristics of the aquifer that could limit withdrawals.

$$\sum_{DS} TransLinkInflow_{GW,DS} \leq MaximumGroundwaterWithdrawal_{GW}$$

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.

$ReachFlowToGroundwater_{,Rch} = ReachFlowToGroundwaterFraction_{Rch} \ x \ UpstreamInflow_{Rch}$

Evaporation is calculated as a fraction (entered as data--see Supply and Resources\River\Reaches) of upstream inflow to the reach.

$Evaporation_{Rch} = EvaporationFraction_{Rch} \ x \ UpstreamInflow_{Rch}$

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).

$BeginMonthStorage_{Res,m} = InitialStorage_{Res}$ for m = 1

Thereafter, it begins each month with the storage from the end of the previous month.

$BeginMonthStorage_{Res,m} = EndMonthStorage_{Res,m-1}$ 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 using the volume-elevation curve (specified as data--see Supply and Resources\River\Reservoir\Physical\Volume Elevation Curve).

$BeginMonthElevation_{Res} = VolumeToElevation(BeginMonthStorage_{Res})$

The elevation is reduced by the evaporation rate.

$AdjustedBeginMonthElevation_{Res} = BeginMonthElevation_{Res} - EvaporationRate_{Res}$

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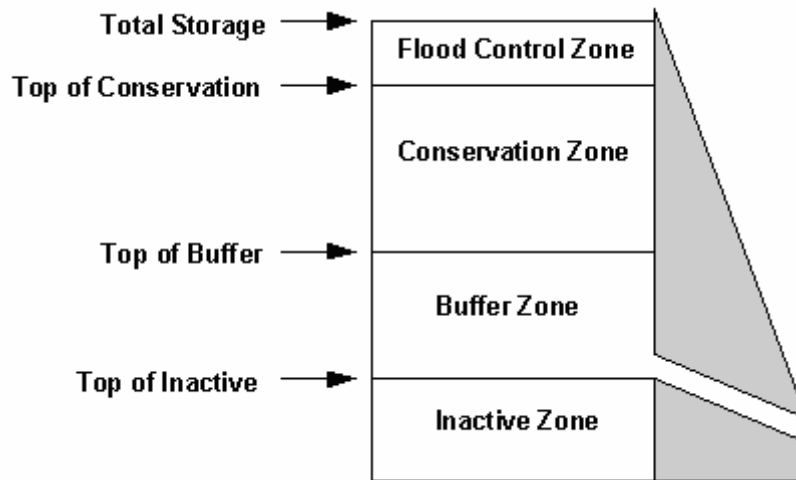Then the adjusted elevation is converted back to a volume.

$$AdjustedBeginMonthStorage_{Res} = ElevationToVolume(AdjustedBeginMonthElevation_{Res})$$

A reservoir's operating rules determine how much water is available in a given month for release, to satisfy demand and instream flow 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 return flows from demand sites (*DS*) and treatment plants (*TP*).

$$StorageForOperation_{Res} = AdjustedBeginMonthStorage_{Res} + UpstreamInflow_{Res} +$$
$$\sum_{DS} DSReturnFlow_{DS,Res} + \sum_{TP} TPReturnFlow_{TP,Res}$$

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\River\Reservoir\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.

$$StorageAvailableForRelease_{Res} = FloodControlAndConservationZoneStorage_{Res} +$$
$$BufferCoefficient_{Res} \times BufferZoneStorage_{Res}$$

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\River\Reservoir\Operation),

$$FloodControlAndConservationZoneStorage_{Res} = StorageForOperation_{Res} - TopOfBuffer_{Res}$$

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 instream flow 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 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.)

$$Outflow_{Res} = DownstreamOutflow_{Res} + \sum_{DS} TransLinkInflow_{Res,DS}$$

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*) returns. (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 or after other requirements in the system. (The minimum flow is achieved either by restricting withdrawals from the river or by releasing water from reservoirs.) The flow out of the node equals the flow in from upstream, plus demand site (*DS*) and treatment plant (*TP*) returns 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*) returns, 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*) returns, 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.

$$DownstreamOutflow_{RFN} = UpstreamInflow_{RFN} + \sum_{DS} DSReturnFlow_{DS,RFN} +$$
$$\sum_{TP} TPReturnFlow_{TP,RFN}$$

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.

$$DownstreamOutflow_{TN} = UpstreamInflow_{TN} + DownstreamOutflow_{Rch}$$

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\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\Local\Reservoir\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\Reservoir\Physical\Volume Elevation Curve).

$$BeginMonthElevation_{Res} = VolumeToElevation(BeginMonthStorage_{Res})$$

The elevation is reduced by the evaporation rate.

$$AdjustedBeginMonthElevation_{Res} = BeginMonthElevation_{Res} - EvaporationRate_{Res}$$

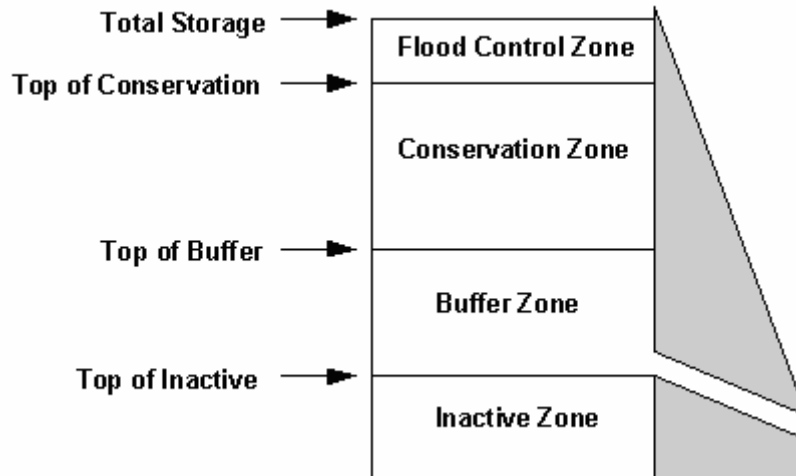Then the adjusted elevation is converted back to a volume.

$$AdjustedBeginMonthStorage_{Res} = ElevationToVolume(AdjustedBeginMonthElevation_{Res})$$

A reservoir's operating rules determine how much water is available in a given month for release, to satisfy demand 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 return flows from demand sites (*DS*) and treatment plants (*TP*).

$$StorageForOperation_{Res} = AdjustedBeginMonthStorage_{Res} + \sum_{DS} DSReturnFlow_{DS,Res} + \sum_{TP} TPReturnFlow_{TP,Res}$$

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\Reservoir\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.

$$StorageAvailableForRelease_{Res} = FloodControlAndConservationZoneStorage_{Res} + BufferCoefficient_{Res} \times BufferZoneStorage_{Res}$$

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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\Reservoir\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 requirements, in the context of releases from other reservoirs and withdrawals from rivers and other sources.

$$Outflow_{Res} = \sum_{DS} TransLinkInflow_{Res,DS}$$

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.

$$IncreaseInStorage_{Res} = EndMonthStorage_{Res} - BeginMonthStorage_{Res}$$

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.

$$Outflow_{OS} = Inflow_{OS} - \sum_{DS} TransLinkInflow_{OS,DS}$$

7.3.9 Surface Water-Groundwater 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.

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.

A linear program (LP) is used to maximize satisfaction of demand site and user-specified instream flow requirements, subject to demand priorities, supply preferences, mass balance and other constraints. The LP solves all the simultaneous equations listed above.

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.

$$\sum Inflow = \sum Outflow + AdditionToStorage$$

Or

$$\sum Inflow - \sum Outflow - AdditionToStorage = 0$$

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

$$Inflow_{B,A} + Inflow_{C,A} - Outlow_{A,B} - Outlow_{A,C} - Consumption_A = 0$$

Where InflowB,A 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.

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:

$$Inflow_{B,D} - Outlow_{D,A} - Losses_D = 0$$

And the first example would be rewritten as

$$Inflow_{\mathcal{D,A}} + Inflow_{C,A} - Outlow_{A,B} - Outlow_{A,C} - Consumption_A = 0$$

Coverage Variables and Constraints

A new LP variable is created for each demand site, which will equal its "coverage"- percent of demand satisfied.

$$\sum Inflow_{DS} = SupplyRequirement_{DS} \times Coverage_{DS}$$

or

$$\sum Inflow_{DS} - SupplyRequirement_{DS} \times Coverage_{DS} = 0$$

The LP constraint would be a row in the LP matrix, with coefficients of 1 for the inflow variables and -1 times the supply requirement as the coefficient for the coverage variable. The entire row would be set equal to 0.

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%:

$$30 = 100 \times 30\%$$

Because WEAP tries to satisfy all demand sites 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 ($Coverage_{Final}$). In this way, all the coverages being solved for must be equal.

$$Coverage_{Final} = Coverage_{DS1}$$

$$Coverage_{Final} = Coverage_{DS2}$$

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.

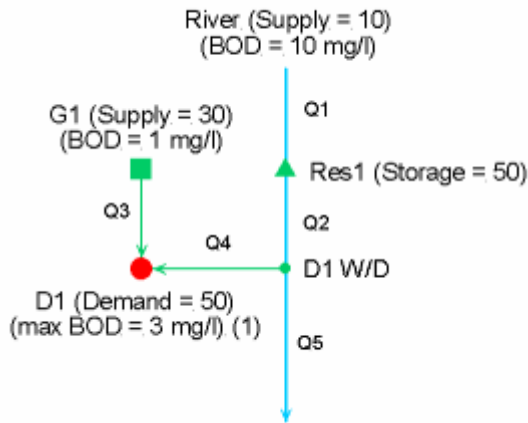$$(Q_1 C_1 + Q_2 C_2 + ...) / (Q_1 + Q_2 + ...) <= C_{max} \qquad Eq.\ 1$$

which can be transformed into

$$Q_1 (1 - C_1 / C_{max}) + Q_2 (1 - C_2 / C_{max}) + ... >= 0 \qquad Eq.\ 2$$

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 (Eq. 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.

River (Supply = 10)
(BOD = 10 mg/l)

G1 (Supply = 30)
(BOD = 1 mg/l)

Q1

Res1 (Storage = 50)

Q3

Q2

Q4

D1 W/D

D1 (Demand = 50)
(max BOD = 3 mg/l) (1)

Q5

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):

$(1Q_3 + 10Q_4) / (Q_3 + Q4) <= 3$ *(from Eq 1)*   *Eq. 3*

$Q_3 (1 - 1/3) + Q4 (1 - 10/3) >= 0$ *(from Eq 2)*   *Eq. 4*

$(2/3) Q_3 - (7/3) Q_R >= 0$ *Eq. 5*

$(2/3) Q_3 >= (7/3) Q_4$ *Eq. 6*

$Q_3 >= (7/2) Q_4$ *Eq. 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:

$Q_3 + Q_4 = 50$ *Eq. 8*

$Q_3 = 50 - Q_4$ *Eq. 9*

Substituting into Eq. 7:

$50 - Q_4 >= (7/2) Q_4$ *Eq. 10*

$50 >= (9/2) Q_4$ *Eq. 11*

$Q_4 <= 11.11$ *Eq. 12*

therefore,

$Q_3 = 50 - 11.11 = 38.89$ *Eq. 13*

Substituting into Eq. 3:

$(38.89 * 1 + 11.11 * 10) / (38.89 + 11.11) <= 3$ *Eq. 14*

$(38.89 * 1 + 11.11 * 10) / (38.89 + 11.11) <= 3$ *Eq. 15*

$149.99 / 50 <= 3$ *Eq. 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:

$Q1 = Add1 + Q2$

Q2 = Q4 + Q5

Q3 + Q4 = 50 C1

S1 = 200 C2

S1 = 50 + Add1

C1 + E1 >= FC

(1 - 1/3) * Q_3 + (1 - 10/3) * Q_4 >= 0 (Water quality constraint)

  Obj fn: FC - 0.33 E1 - 0.33 E2

Upper and lower bounds:

Q1 = 10	Q5 >= 0	0 <= C2 <= 1
Q2 >= 0	Add1 >= -50	0 <= E1 <= 0.0001
C3 >= 0	0 <= S1 <= 200	0 <= E2 <= 0.0001
Q4 >= 0	0 <= C1 <= 1	0 <= FC <= 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 = 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	

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:

Q1 = Add1 + Q2	S1 = 50 + Add1	10/3) * Q_4 >= 0
Q2 = Q4 + Q5	C2 + E2 >= FC	
S1 = 200 C2	(1 - 1/3) * Q_3 + (1 -	

  Obj fn: FC - 0.33 E1 - 0.33 E2

Upper and lower bounds:

Q1 = 10	0 <= S1 <= 200
Q2 >= 0	0 <= C1 <= 1
Q3 = 30 (set after first LP iteration)	0 <= C2 <= 1
Q4 = 8.57 (set after first LP iteration)	0 <= E1 <= 0.0001
Q5 >= 0	0 <= E2 <= 0.0001
Add1 >= -50	0 <= FC <= 1

 Where:

Add1 = addition to reservoir 1 storage (negative "additions" represent releases, which cannot

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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.

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 $Coverage_{Final}$.

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.)
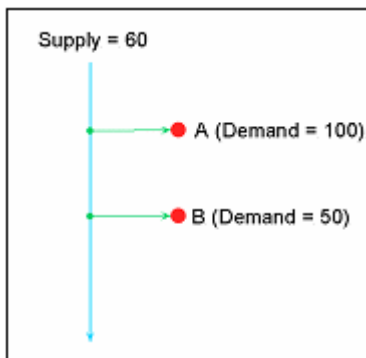
For example, if Demand Site A has a supply requirement of 100 and Demand Site B has a supply requirement of 50 (assume both are the same priority), and there is only 60 units of river water available this time step, then A will get 40 units (40%) and B will get 20 units (40%).

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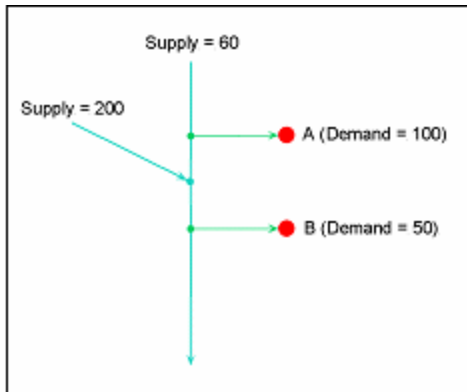
However, in some cases, some demand sites may have access to more water than others. For example, between the withdrawal points for Demands Sites A and B is a tributary inflow, such that there is always enough water for B. In this case, Demand Site B should be able to withdraw its full requirement, even 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 gets 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.

$Maximize: Coverage_{Final} - k * Epsilon_{DS1} - k * Epsilon_{DS2}$

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

*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

*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
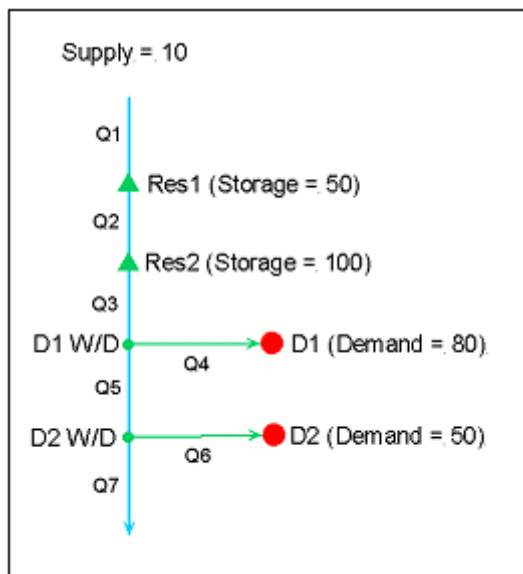
In the first example, the river headflow is insufficient to meet the two demands. Therefore, the reservoirs will need to release water to satisfy the demands. Both reservoirs have a top of conservation pool (TOC) of 200, although their initial storages are different: 50 and 100, as shown. Both reservoirs 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:

$Q1 = Add1 + Q2$	$Q4 = 80\ C1$	$S1 = 50 + Add1$
$Q2 = Add2 + Q3$	$Q6 = 50\ C2$	$S2 = 100 + Add2$
$Q3 = Q4 + Q5$	$S1 = 200\ C3$	$C1 + E1 >= FC$
$Q5 = Q6 + Q7$	$S2 = 200\ C4$	$C2 + E2 >= FC$

Obj fn: $FC - 0.2\ E1 - 0.2\ E2 - 0.2\ E3 - 0.2\ E4$

Upper and lower bounds:

$Q1 = 10$	$Add1 >= -50$	$0 <= C4 <= 1$
$Q2 >= 0$	$Add2 >= -100$	$0 <= E1 <= 0.0001$
$C3 >= 0$	$0 <= S1 <= 200$	$0 <= E2 <= 0.0001$
$Q4 >= 0$	$0 <= S2 <= 200$	$0 <= E3 <= 0.0001$
$Q5 >= 0$	$0 <= C1 <= 1$	$0 <= E4 <= 0.0001$
$Q6 >= 0$	$0 <= C2 <= 1$	$0 <= FC <= 1$
$Q7 >= 0$	$0 <= C3 <= 1$	

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:

$Q1 = 10$	$Q6 = 50$	$S2 = 0$
$Q2 = 30$	$Q7 = 0$	$C1 = C2 = FC = 1$
$Q3 = 130$	$Add1 = -20$	$C3 = C4 = 0$
$Q4 = 80$	$Add2 = -100$	$E1 = E2 = E3 = E4 = 0$
$Q5 = 50$	$S1 = 30$	

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:

$Q1 = Add1 + Q2$	$Q3 = Q4 + Q5$	$Q4 = 80\ C1$
$Q2 = Add2 + Q3$	$Q5 = Q6 + Q7$	$Q6 = 50\ C2$

S1 = 200 C3	*S1 = 50 + Add1*	*C3 + E3 >= FC*
S2 = 200 C4	*S2 = 100 + Add2*	*C4 + E4 >= FC*
Obj fn: FC - 0.2 E1 - 0.2 E2 - 0.2 E3 - 0.2 E4		

Upper and lower bounds:

Q1 = 10	*Add1 >= -50*	*0 <= C4 <= 1*
Q2 >= 0	*Add2 >= -100*	*0 <= E1 <= 0.0001*
C3 >= 0	*0 <= S1 <= 200*	*0 <= E2 <= 0.0001*
Q4 = 80	*0 <= S2 <= 200*	*0 <= E3 <= 0.0001*
Q5 >= 0	*C1 = 1*	*0 <= E4 <= 0.0001*
Q6 = 50	*C2 = 1*	*0 <= FC <= 1*
Q7 >= 0	*0 <= C3 <= 1*	

Here is the solution:

Q1 = 10	*Q7 = 0*	*C3 = C4 = 0.075*
Q2 = 45	*Add1 = -35*	*FC = 0.0751*
Q3 = 130	*Add2 = -85*	*E1 = E2 = 0*
Q4 = 80	*S1 = 15*	*E3 = E4 = 0.0001*
Q5 = 50	*S2 = 15*	
Q6 = 50	*C1 = C2 = 1*	

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:

$Q1 = Add1 + Q8$	$Q5 = Q6 + Q7$	$S1 = 50 + Add1$
$Q2 = Add2 + Q9$	$Q6 = 50\ C2$	$S2 = 100 + Add2$
$Q3 = Q8 + Q9$	$S1 = 200\ C3$	$C1 + E1 >= FC$
$Q3 = Q4 + Q5$	$S2 = 200\ C4$	$C2 + E2 >= FC$

Obj fn: $FC - 0.2\ E1 - 0.2\ E2 - 0.2\ E3 - 0.2\ E4$

Upper and lower bounds:

$Q1 = 5$	$Q9 >= 0$	$0 <= C4 <= 1$
$Q2 = 5$	$Add1 >= -50$	$0 <= E1 <= 0.0001$
$C3 >= 0$	$Add2 >= -100$	$0 <= E2 <= 0.0001$
$Q4 >= 0$	$0 <= S1 <= 200$	$0 <= E3 <= 0.0001$
$Q5 >= 0$	$0 <= S2 <= 200$	$0 <= E4 <= 0.0001$
$Q6 >= 0$	$0 <= C1 <= 1$	$0 <= FC <= 1$
$Q7 >= 0$	$0 <= C2 <= 1$	
$Q8 >= 0$	$0 <= C3 <= 1$	

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:

$Q1 = Add1 + Q8$

$Q2 = Add2 + Q9$

$Q3 = Q8 + Q9$

$Q3 = Q4 + Q5$

$Q4 = 80$

Obj fn: $FC - 0.2\ E1 - 0.2\ E2 - 0.2\ E3 - 0.2\ E4$

$Q5 = Q6 + Q7$

$Q6 = 50$

$S1 = 200\ C3$

$S2 = 200\ C4$

$S1 = 50 + Add1$

$S2 = 100 + Add2$

$C3 + E3 >= FC$

$C4 + E4 >= FC$

Upper and lower bounds:

$Q1 = 5$

$Q2 = 5$

$C3 >= 0$

$Q4 = 80$

$Q5 >= 0$

$Q6 = 50$

$Q7 >= 0$

$Q8 >= 0$

$Q9 >= 0$

$Add1 >= -50$

$Add2 >= -100$

$0 <= S1 <= 200$

$0 <= S2 <= 200$

$C1 = 1$

$C2 = 1$

$0 <= C3 <= 1$

$0 <= C4 <= 1$

$0 <= E1 <= 0.0001$

$0 <= E2 <= 0.0001$

$0 <= E3 <= 0.0001$

$0 <= E4 <= 0.0001$

$0 <= FC <= 1$

Here is the solution:

$Q1 = 5$

$Q2 = 5$

$Q3 = 130$

$Q4 = 80$

$Q5 = 50$

$Q6 = 50$

$Q7 = 0$

$Q8 = 40$

$Q9 = 90$

$Add1 = -35$

$Add2 = -85$

$S1 = 15$

$S2 = 15$

$C1 = C2 = 1$

$C3 = C4 = 0.075$

$FC = 0.0751$

$E1 = E2 = 0$

$E3 = E4 = 0.0001$

7.4 Water Quality

7.4.1 Overview

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 input as data. In addition, water temperatures are not modeled in stream reaches or reservoirs; these values must also be input as data for reaches and reservoir outflows.

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.

7.4.2 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.

$DSReturnLinkPollInflow_{DS,Dest,p} = (DSOutflowRoutingFraction_{DS,Dest}1 /$

$\sum_{Dest} DSOutflowRoutingFraction_{DS,Dest}$) x 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.

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.

$DSReturnLinkPollOutflow_{DS,Dest,p} = (1- DSReturnLinkPollDecreaseRate_{DS,Dest,p}$) x $DSReturnLinkPollInflow_{DS,Dest,p}$

7.4.3 Wastewater Treatment

The pollution that flows into a wastewater treatment plant (TP) is the sum of the flows from all connected demand site return flow links.

$TreatmentPlantPollInflow_{TP} = \sum_{DS} DSReturnLinkPollOutflow_{DS,TP}$

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 Environment\Wastewater Treatment), and the rest will flow out.

$TreatmentPlantPollOutflow_{TP,p} = (1 - RemovalRate_{TP,p})x TreatmentPlantPollInflow_{TP,p}$

Outflow Concentration

Some fraction of the pollution will be removed by the plant (entered as data-see Environment\Wastewater Treatment), and the rest will flow out.

$TreatmentPlantPollOutflow_{TP,p} = OutflowConcentration_{TP,p} x TreatmentPlantReturnFlow_{TP,p}$

7.4.4 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.

$TPReturnLinkPollInflow_{TP,Dest,p} = (TPOutflowRoutingFraction_{TP,Dest} /$

$\sum_{Dest} TPOutflowRoutingFraction_{TP,Dest}) \ x \ TreatmentPlantPollOutflow_{TP}$

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.

$TPReturnLinkPollOutflow_{TP,Dest,p} = (1 - TPReturnLinkPollDecreaseRate_{TP,Dest,p}) \ x$
$TPReturnLinkPollInflow_{TP,Dest,p}$

7.4.5 Groundwater Pollution

Groundwater inflows to the river can bring pollution, specified by the concentration of each constituent in the groundwater inflow.

$GroundwaterPollutionFlowToReach_{GW,Rch,p,m} = GroundwaterFlowToReach_{GW,Rch} \ x$
$GroundwaterPollutionConcentration_{GW,p,m}$

7.4.6 Headflow Pollution

River headflow can bring pollution, specified by the concentration of each constituent in the headflow.

$HeadflowPollutionRiver_{River,p,m} = Headflow_{River} \ x \ HeadflowPollutionConcentration_{River,m,p}$

7.4.7 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.

$OtherSWInflowPollutionToReach_{Rch,p,m} = OtherSWInflowToReach_{Rch} \ x$
$OtherSWInflowPollutionConcentration_{Rch,p,m}$

7.4.8 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, treatment plant return flow links, groundwater inflows, headflows, upstream inflows, and other surface water inflows. WEAP assumes complete mixing of all inflows.

$.PollutionLoad_{Node,p} = \sum_{DS} DSReturnLinkPollOutflow_{DS,Node,p} + \sum_{TP} TPReturnLinkPollOutflow_{TP,Node,p}$

$$+ \sum_{Dest}GWPollutionFlow_{GW,Node,p} + HeadflowPollution_{River,p} +$$

$OtherSWInflowPollutionToReach_{Rch,p}+ UpstreamInflowPollutionToReach_{Rch,p}$

Water Quality Modeling Overview

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. 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.

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:

$$c = \frac{Q_w c_w + Q_r c_r}{Q_w + Q_r}$$

Eq. 1

Where:

c is the new concentration (mg/l)
 Q_w is the flow of wastewater discharged (m3/time)
 C_w is the concentration of pollutant in the wastewater (mg/l)
 Q_r is the flow of receiving water (m3/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:

$$U = \frac{Q}{A_c}$$
Eq. 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.

$$c = c_0 e^{-\frac{kL}{U}}$$
Eq. 3

Dissolved Oxygen and Biochemical Oxygen Demand

First, the oxygen saturation OS for each segment is estimated as a function of water temperature T,

$$OS = 14.54 - (0.39T) + (0.01T^2)$$
Eq. 4

and an analytical solution of the classic Streeter-Phelps model is used to compute oxygen concentrations from point source loads of BOD.

$$O = OS - \left(\frac{k_a}{k_a - k_r}\right)\left(\exp^{-k_r(L/U)} - \exp^{-k_a(L/U)}\right)BOD_{IN} - \left((OS - O_{IN})\exp^{-k_a(L/U)}\right)$$
Eq. 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,

$$BOD = BOD_{IN}\left(\exp^{-k_{rBOD}(L/U)}\right)$$
Eq. 6

The removal rate, k_{rBOD}, is influenced by several factors, including temperature, settling velocity of the particles, and water depth. Chapra (1997) provides an expression for k_{rBOD} as,

$$k_{rBOD} = k_{d20}{}^{(1.047(T-20))} + \frac{v_s}{H}$$
Eq. 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,

$$k_{d20} = 0.3\left(\frac{H}{8}\right)^{-0.434} \qquad 0 \le H \le 2.4m$$

$$k_{d20} = 0.3 \qquad H > 2.4m$$

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.
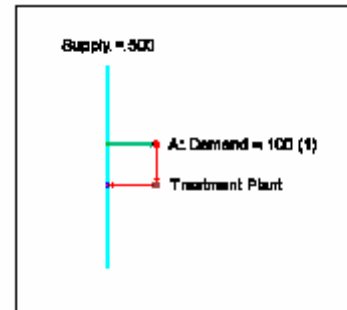
Reach Below Headflow

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 Eq. 3, if c_0 = 20 mg/l, k = 0.25/day, L = 38.8 km, and U = 196.36 km/day; then c = 19.036 mg/l.

DO

In Eq. 4, if T = 15; then OS = 10.94.

It follows from Eq. 5 that if k_d=0.4/day, k_a = 0.95/day, k_r = 0.4/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 Eq. 7 with v_s = 0.25, H = 4m (i.e., k_{d20} = 0.3), and T = 15C; k_{rBOD} = 0.288

Then, using Eq. 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

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 Eq. 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 Eq. 4 with T = 15; OS = 10.94

Then, using Eq. 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, $BODIN$ = 4.72 mg/l, OIN = 8.157 mg/l; then O = 8.243 mg/l

BOD

Using Eq. 7 with v_s = 0.25, H = 3.6 m (i.e., k_{d20} = 0.3), T = 15C; then k_{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,

$MonthlyPollutionGenerated_{DS,p,m} = DemandSiteReturnFlow_{DS,m}$ x $ReturnFlowConcentration_{DS,m,p}$

Salinity

Mass = 50 * 10 = 500

TSS

Mass = 50 * 5 = 250

DO

Mass = 50 * 3 = 150

BOD

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

$TreatmentPlantPollOutflow_{TP,p} = (1 - RemovalRate_{TP,p})$x $TreatmentPlantPollInflow_{TP,p}$

Mass outflow = (1 - 0) * 500 = 500

TSS

Mass outflow = (1 - 0) * 250 = 250

BOD

Mass outflow = (1 - 0.9) * 1000 = 100

DO

DO is specified as a concentration, rather than a removal rate. Therefore, the inflow of DO is not used.

TreatmentPlantPollOutflow$_{TP,p}$ = OutflowConcentration$_{TP,p}$ x TreatmentPlantReturnFlow$_{TP,p}$

Mass outflow = 4 * 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 Eq. 3, with c_0 = 19.036 mg/l, k = 0.25/day, L = 20.4 km, U = 180 km/day; then c = 18.504 mg/l.

DO

Using Eq. 4, with T = 15; then OS = 10.94.

Using Eq. 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_{IN} = 4.72 mg/l, and O_{IN} = 8.157 mg/l; then O = 8.243 mg/l

BOD

Using Eq. 7 with v_s = 0.25, H = 3.6 m (i.e., k_{d20} = 0.3), T = 15C; then k_{rBOD} = 0.288.

Using Eq. 6 with k_{rBOD} = 0.288, L = 20.4 km, U = 180 km/day, BOD_{IN} = 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:

$$c = \frac{Q_w c_w + Q_r c_r}{Q_w + Q_r} = \frac{M_w + Q_r c_r}{Q_w + Q_r} \quad \text{Eq. 8}$$

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

Salinity

With M_w = 500 and C_r = 2 mg/l; then c = 2.92 mg/l in Eq. 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 Eq. 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 Eq. 4 with T = 15; then OS = 10.94

Using Eq. 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_{IN} = 4.33 mg/l, and O_{IN} = 7.81 mg/l; then O = 8.07 mg/l

BOD

Using Eq. 7 with v_s = 0.25, H = 3.78m (i.e., k_{d20} = 0.3), and T = 15C; then k_{rBOD} = 0.291

Using Eq. 6 with k_{rBOD} = 0.288, L = 40.8 km, U = 187.92 km/day, and BOD_{IN} = 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

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.

$$\frac{dT}{dt} = \frac{Q_i}{V}T_i + \frac{Rn}{\rho C_p H} + \left(\frac{\sigma(T_{air}+273)^4 a\sqrt{e_{air}}}{\rho C_p H}\right) - \frac{Q_i}{V}T_{i+1}$$

$$- \frac{\varepsilon\sigma(T_{i+1}+273)^4}{\rho C_p H} - \frac{f(u)(T_{i+1}-T_{air})}{\rho C_p H} - \frac{g(u)D}{\rho C_p H}$$

where the first term on the right-hand side is the upstream heat input to the stream segment with constant volume, V (m3) expressed as a relationship of flow, Q_i (m3/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 steffan-boltzman 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 runga-kutta and is the boundary condition temperature for the next reach (after mixing of any other inflows into the downstream node is considered).

7.5 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 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.

$Release_{Node} = DownstreamOutflow_{Node}$

For local reservoirs, all linked demand sites are assumed to be downstream of the reservoir, so all reservoir releases are sent through the turbines.

$Release_{Node} = \sum_{DS} TransLinkInflow_{Node,DS}$

For run-of-river hydropower nodes, the "release" is equal to the downstream outflow from the node.

$Release_{Node} = DownstreamOutflow_{Node}$

The volume of water that passes through the turbines is bounded by the minimum and 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 which do not generate electricity. If the release is less than the minimum turbine flow, then no electricity is generated.

$VolumeThroughTurbine_{Node} = 0$ for $Release_{Node} < MinTurbineFlow_{Node}$

Otherwise, the turbine flow is the smaller of the reservoir release and the maximum turbine flow.

$VolumeThroughTurbine_{Node} = Min(Release_{Node} , MaxTurbineFlow_{Node})$ for $Release_{Node} \geq$ $MinTurbineFlow_{Node}$

The volume (in m^3) is converted to mass (in kg).

$$MassThroughTurbineKG_{Node} = VolumeThroughTurbine_{Node} \times 1000$$

The gigajoules (GJ) of energy produced in a month is a function of the mass of water 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 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).

$$EnergyFullMonthGJ_{Node} = MassThroughTurbineKG_{Node} * DropElevation_{Node} \times PlantFactor_{Node} \times$$
$$PlantEfficiency_{Node} * 9.806 / 1,000,000,000$$

For reservoirs, the height that the water falls in the turbines is equal to the average elevation of the reservoir during the month minus the tailwater elevation (entered as data--see Supply and Resources\Reservoir\Hydropower).

$$DropElevation_{Node} = AverageElevation_{Node} - TailwaterElevation_{Node}$$

where

$$AverageElevation_{Node} = (BeginMonthStorage_{Node} + EndMonthStorage_{Node}) / 2$$

For run-of-river hydropower nodes, the drop in elevation is entered as data (see Run of River Hydropower).

$$DropElevation_{Node} = FixedHead_{Node}$$

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 Revenues

Revenues can also be entered for each individual item, both as fixed (annual) and variable (per unit flow).

$$Revenue_{Item} = FixedRevenue_{Item} + VariableRevenue_{Item}$$

$$VariableRevenue_{Item} = VariableRevenueRate_{Item} * Flow_{Item}$$

where FixedRevenue is data.

Annual revenues are spread evenly over the time steps of the year to get a revenue per time step.

In addition to itemized costs and revenues, overall uncategorized system capital and operating costs and revenues can be entered as a whole.

7.6.4 Net Cost

Net cost is the total cost, net of any revenue.

$$NetCost = SystemCost + \sum Cost_{Item} - SystemRevenue - \sum Revenue_{Item}$$

7.6.5 Net Present Value (NPV)

The net present value of future expenditures for capital and operations costs, net of any revenues. 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 revenues and costs converted into equivalent values today. This is done by discounting future revenues and costs using an appropriate discount rate, and subtracting the sum total of discounted revenues from the sum total of discounted costs. The discount rate is specified under the menu option General, Units, Monetary.
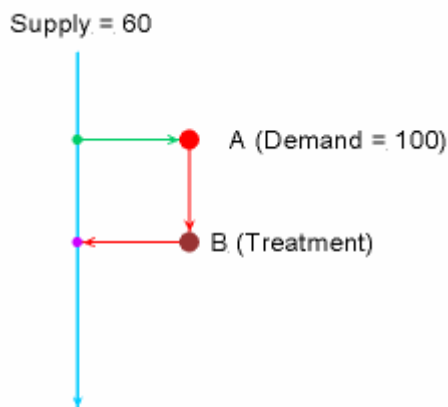
$$NPV = \sum (NetCost_{Year} * (1 - DiscountRate)^{(Year - BaseYear)})$$

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

MonthlyTreatmentOperatingCost = (AnnualFixedTreatmentOperatingCost / 12) +
      MonthlyVariableTreatmentOperatingCost

AnnualFixedTreatmentOperatingCost = $200,000

*MonthlyVariableTreatmentOperatingCost = 30 * $5000 = $150,000*

MonthlyTreatmentOperatingCost = ($200,000 / 12) + $150,000 = $166,666.67

Total Operating Cost

MonthlyTotalOperatingCost = MonthlyTransmissionOperatingCost +
      MonthlyTreatmentOperatingCost = $60,000 + $166,666.67 = $226,666.67

Net Cost

MonthlyNetCost = MonthlyTreatmentCapitalCost + MonthlyTotalOperatingCost = $271,047.65
      + $226,666.67 = $497,714.32

*AnnualNetCost = 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,

$NPV = AnnualNetCost_{2005} * (1 - 3\%)^{(2005 - 2005)} + AnnualNetCost_{2006} * (1 - 3\%)^{(2006 - 2005)} + ... + AnnualNetCost_{2034} * (1 - 3\%)^{(2034 - 2005)}$

$NPV = \$5,972,571.80 * 1 + \$5,972,571.80 * 0.97 + ... + \$5,972,571.80 * 0.97^{29} = \$64,942,250$

Average Cost of Water

AverageCost = $497,714.32 / 60 = $8295.24 per unit of water supplied to demand site

7.7 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.

7.7.1 Modeling Functions

CurrentAccountsYear

Syntax

CurrentAccountsYear or CAY

Description

The Current Accounts year as a numeric value.

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

ExpForecast

Syntax

ExpForecast(Year1, Value1, Year2, Value2,... YearN, ValueN) or
 ExpForecast(XLRange(Filename, Rangename))

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 ($Y = m + X^\wedge c$) 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 base year value. Because it references the Current Accounts value, this function is only available when editing scenarios.

Example

Growth(0.05) or Growth(5%)

Evaluated from a Current Accounts value of 100 in 2000

2001 = 105.00
 2002 = 110.25

Tip for users of older versions of WEAP: This function is equivalent to the old "Growth Rate" method for projecting data.

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:

Current Value(t) = $\dfrac{\text{Current Value(t-1) * NamedBranchValue(t)}}{\text{NamedBranchValue(t-1)}}$

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.

Tip for users of older versions of WEAP: This second form is equivalent to the old "Drivers and Elasticities" method for projecting data.

Examples

Growth(Household\Rural)

Growth(GDP, 1)

In this example (elasticity = 1), the current branch grows at the same rate as the named branch (GNP).

Growth(GDP, 0.9)

In this example (elasticity = 0.9), the current branch grows more slowly than GDP.

Growth(GDP, 1.2)

In this example (elasticity = 1.2), the current branch grows more rapidly than GDP.

Growth(GDP, 0)

In this example (elasticity = 0), the current branch is constant (i.e. independent of GDP).

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.

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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.

LastYear

Syntax

LastYear

Description

The last year of the analysis as a numeric value (as specified in the Areas: General Parameters screen).

Example

LastYear - Year

Evaluated for an last year of 2020

2000 = 20.0
 2018 = 2.0

LinForecast

Syntax

LinForecast(Year1, Value1, Year2, Value2,... YearN, ValueN) or
 LinForecast(XLRange(Filename, Rangename))

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.

Use the Yearly Time-Series Wizard to enter the data for this function.

LoanPayment

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, Rangename))

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:

$$Y = A + \frac{B - A}{1 + e^{(-a.X + b)}}$$

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.

MonthlyValues

Syntax

MonthlyValues(Month1, Value1, Month2, Value2,... MonthN, ValueN)

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, 10.0, July, 40.0)

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.

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(VariableName) or PrevTSValue(VariableName,TimeStepsPrevious) or
PrevTSValue(VariableName,TimeStepsPrevious,EndOfPreviousTSInterval) or
PrevTSValue(VariableName,TimeStepsPrevious,EndOfPreviousTSInterval,
FunctionToCompute)

Description

The PrevTSValue function can be used in two ways. One is to return results calculated in previous timesteps. The other is to return values from *Data* variables. The arguments are:

Variable Name: Name of variable from which previous results are required.

TimeStepsPrevious: Number of previous time steps to look back. 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. If omitted, the function will default to 1 time step look back.

EndOfPreviousTSInterval: Length of interval in time steps for which data is required. If TimeStepsPrevious is 1 and EndOfPreviousTSInterval is 4, then results are returned from the previous 4 time steps. If omitted, the function will default to 1 time step.

FunctionToCompute: Operation to execute on results: 0 for sum, 1 for average, 2 for minimum, and 3 for maximum. If omitted, the operation will be sum.

Example

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.

PrevTSValue(Supply and Resources\River\Weaping River\Reservoirs\Central Reservoir:Storage Volume, 1, 4, 1)

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, 2)

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, 3)

This example calculates the maximum storage in Central Reservoir over the previous four months.

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, 1).

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. To utilize this functionality, "minus sign" symbols need to be placed in the TimeStepsPrevious and EndOfPreviousTSInterval arguments.

PrevTSValue(Supply and Resources\River\Weaping River\Reaches\Below Weaping River Headflow:Surface Water Inflow, -1, -4, 1)

This example returns the average of surface water inflow over the future four months.

Tip

For results, "PrevTSValue" works with reservoir storage, reservoir elevation, streamflows, and

hydropower generation.

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

ReadFromFile

The ReadFromFile function allows one to read annual or monthly data from a text, comma-separated value (CSV) file into any WEAP variable.

A text file can contain one or more columns of data for each year or month. The format of the WEAP expression is:

 ReadFromFile(FileName) or
  ReadFromFile(FileName, DataColumnNumber) or
  ReadFromFile(FileName, DataColumnNumber, YearOffset)

If you do not specify a data column number, the first data column will be used.

For example,

  ReadFromFile(GroundwaterRecharge.txt)

will read in data from the first data column of file GroundwaterRecharge.txt in the directory for the WEAP area (e.g., if the area was Weaping River Basin, this directory would be C:\Program Files\WEAP21\Weaping River Basin).

  ReadFromFile(DemandActivity.txt, 2)

will read in data from the second data column of file DemandActivity.txt.

  ReadFromFile(DemandActivity.txt, 1, 10)

will read in data from the first data column of file DemandActivity.txt, shifting the years by 10 (year 2000 data in the file will be interpreted as 1990 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 and consecutive--no gaps are allowed.

For monthly 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 and consecutive--no gaps are allowed.

YearOffset 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.

Lines that begin with a semicolon (;) or number sign (#) will be ignored, so can be used for comments.

Tip: It is best to place the CSV files into the WEAP area subdirectory, so that when the area is backed up, archived, or sent to someone else, the CSV files are included.

Remainder

<u>Syntax</u>

Remainder(Expression)

<u>Description</u>

Calculates the remainder between an Expression and the sum of the values of neighboring (sibling)

branches.

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

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

$Y = a + b.X + c. X2 + d. X3 + e.X4 + \ldots$

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.

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

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

Abs

Syntax

Abs(Expression)

Description

The absolute value of the expression.

Example

Abs(-2.8) = 2.8
Abs(2.8) = 2.8

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

Exp

Syntax

Exp(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

Exp(1) = 2.718282 (the approximate value of e)
Exp(2) = 7.389056
Exp(Ln(3)) = 3

Tip

To calculate the powers of other bases, use the exponentiation operator (^).

Floor

Syntax

Floor(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

Floor(-2.8) = -3
Floor(2.8) = 2
Floor(1.5) = 1
Floor(-1.5) = -2

Frac

Syntax

Frac(Expression)

Description

The fractional part of Expression. Frac(Expression) = Expression - Int(Expression).

Examples

Frac(2.3) = 0.3
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

Int(-2.8) = -2
Int(2.8) = 2

Int(1.5) = 1
Int(-1.5) = -1

Ln

Syntax

Ln(Expression)

Description

The natural logarithm of the expression

Example

Ln(2.7182) = 1
Ln(10) = 2.3026

Log

Syntax

Log(Expression)

Description

The base 10 logarithm of the expression

Example

Log(10) = 1
Log(100) = 2

LogN

Syntax

LogN(Base, Expression)

Description

The logarithm of the expression with a specified base

Example

LogN(10, 100) = 2
LogN(2.7182, 100) = 4.605

Max

Syntax

Max(Expression1, Expression2) or
Max(Expression1, Expression2, Expression3)

Description

Returns the maximum value of the list of parameters. Accepts up to 3 parameters.

Example

Max(3,4,5) = 5

Min

Syntax

Min(Expression1, Expression2) or
 Min(Expression1, Expression2)

Description

Returns the minimum value of the list of parameters. Accepts up to 3 parameters.

Example

Min(3,4,5) = 3

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

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

And

Syntax

And(Expression1, Expression2) or
 And(Expression1, Expression2, Expression3)

Description

Performs a logical "AND" operation. Returns a value of 1 (true) if all of the parameters are non-zero. Otherwise returns a value of zero (false).

Example

And(1,2,4) = 1
 And(1,0,4) = 0

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

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.

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(TestExpression, ResultIfTrue, ResultIfFalse)

Description

Use the If function to return one value if a condition is TRUE (<> 0) and another value if it is FALSE (=0)

TestExpression is any value or expression that can be evaluated to TRUE or FALSE. Test expressions are generally made up of two or more statements which are compared using WEAP's logical functions (and, or, lessthan, greaterthan, equal, etc.).

ResultIfTrue is an expression that is evaluated if TestExpression is TRUE (<>0).

ResultIfFalse is an expression that is evaluated if TestExpression is FALSE (=0).

IF functions can be nested to construct more elaborate tests.

Examples

If(GreaterThan(Income,1000), 10, 20)

If the branch named Income has a value equal to 2000 then the function evaluates to value 20.

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) or
Or(Expression1, Expression2, Expression3)

Description

Performs a logical "OR" operation. Returns a value of 1 (true) if one or more of the parameters are non-zero. Otherwise returns a value of zero (false).

Example

Or(1,2,-1) = 1
Or(1,0,4) = 1
Or(0,0) = 0

8 ASCII Data File Format for Monthly Inflows

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\Weaping River Basin\ ). Then, in the Hydrology \ Read from File branch, select this file in the drop-down box.

8.1 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.

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.

8.3   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^3/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^3
cubic feet	ft^3
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

8.4 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.

8.5 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

8.6   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.

8.7   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.

8.8   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
   1959, 5.669664, 5.641344, 8.532816, ..., 7.836144

 [HEADFLOW]

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"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

9 Sample Data Set

Weaping River Basin is the sample data set associated 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 (1998-2008) 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).

9.1 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.

9.2 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.

9.3 Supply Measures

The Supply Measures Scenario consists of building the North Reservoir in 2003. 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.

9.4 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.

10 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:** weap@tellus.org
- **Mail:** Stockholm Environment Institute-Boston, Tellus Institute, 11 Arlington Street, Boston, MA 02116, USA
- **Phone:** +1 617 266 5400
- **Fax:** +1 617 266 8303

10.1 Hardware and Software Requirements

WEAP requires Microsoft Windows 98 or later, with a minimum of 256 MB of RAM and 50 MB of free hard disk space (512 MB of RAM is recommended). In addition Microsoft Internet Explorer version 4.0 is required for viewing WEAP's HTML Help. If you do not have it you can download it for free from the Microsoft web site. It is OK to install Internet Explorer after installing WEAP.

Your computer screen should be set to a minimum resolution of 800x600, but preferably even higher (e.g., 1024x768 or 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 also communicate with Microsoft Excel and Microsoft Word, but they are not required.

NB: 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.

10.2 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.

11 Glossary

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

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.

Area

The water system being studied, often a river basin.

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

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.'

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 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.

DO

"Dissolved Oxygen" - the concentration of dissolved oxygen in water.

DSM

Demand-Side Management--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.

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.

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.

GIS

Geographic Information System. WEAP allows you to load GIS maps, in standard ArcView Shape and Grid format, as background layers for the Schematic.

Head

Hydropower is generated when water falls from a height into a turbine. This height is called the head, or head difference.

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.

Infiltration

precipitation or other sources of water (such as excess irrigation) that percolates into and through the soil

Inflow

Flows into the WEAP system: Groundwater recharge, River Headflow, and Inflow to River Reaches, Local Reservoirs and Other Local Supplies. See Hydrology.

Key Assumptions

Independent user-defined variables used to "drive" the calculations in your analyses. See Tree.

Leaf Area Index

Used to control surface runoff response. Runoff will tend to decrease with higher values of LAI (range 0.1 to 10). Sometimes abbreviated as LAI.

Local Supply

Supply sources not connected (or not modeled as connected) to a river, i.e., Groundwater, Local Reservoirs, and Other Local Supplies.

Main Stem

The principal course of a river or stream

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.

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.

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

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

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.

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.

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.

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.

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.

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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