WEAP
Water Evaluation And Planning System

Tutorial

A collection of stand-alone modules to aid in learning the WEAP software

June 2013
Tutorial Modules

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Introduction

WEAP® is a microcomputer tool for integrated water resources planning. It provides a comprehensive, flexible, and user-friendly framework for policy analysis. A growing number of water professionals are finding WEAP to be a useful addition to their toolbox of models, databases, spreadsheets and other software.

This overview summarizes WEAP’s purpose, approach and structure. The contents of the WEAP tutorial are also introduced; the tutorial is constructed as a series of modules that takes you through all aspects of WEAP modeling capabilities. Although the tutorial itself is built on very simple examples, it covers most aspects of WEAP. A more complex model presenting those aspects in the context of a real situation is included with WEAP under the name “Weeping River Basin.” A detailed technical description is also available in a separate publication, the WEAP User Guide.

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 that places water supply projects in the context of demand-side issues, water quality and ecosystem preservation.

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, reuse, 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.

**WEAP Development**

The Stockholm Environment Institute provided primary support for the development of WEAP. The Hydrologic Engineering Center of the US Army Corps of Engineers funded significant enhancements. A number of agencies, including the World Bank, USAID and the Global Infrastructure Fund of Japan have provided project support. WEAP has been applied in water assessments in dozens of countries, including the United States, Mexico, Brazil, Germany, Ghana, Burkina Faso, Kenya, South Africa, Mozambique, Egypt, Israel, Oman, Central Asia, Sri Lanka, India, Nepal, China, South Korea, Thailand, Jordan, Syria, Lebanon, Iran, and Greece.

![Map of WEAP applications worldwide](image)

**The WEAP Approach**

Operating on the basic principle of a water balance, WEAP is applicable to municipal and agricultural systems, single catchments or complex transboundary 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, vulnerability assessments, and project benefit-cost analyses.
The analyst represents the system in terms of its various supply sources (e.g., rivers, creeks, groundwater, reservoirs, and desalination plants); 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, which can be viewed as a calibration step in the development of an application, provide a snapshot of actual water demand, pollution loads, resources and supplies for the system. Key assumptions may be built into the Current Accounts to represent policies, costs and factors that affect demand, pollution, supply and hydrology. Scenarios build on the Current Accounts and allow one to explore the impact of alternative assumptions or policies on future water availability and use. Finally, the scenarios are evaluated with regard to water sufficiency, costs and benefits, compatibility with environmental targets, and sensitivity to uncertainty in key variables.
Program Structure

WEAP consists of five main views: Schematic, Data, Results, Scenario Explorer and Notes. These five views are presented below.

Schematic:

This view contains GIS-based tools for easy configuration of your system. Objects (e.g., demand nodes, reservoirs) can be created and positioned within the system by dragging and dropping items from a menu. ArcView or other standard GIS vector or raster files can be added as background layers. You can quickly access data and results for any node by clicking on the object of interest.
**Data:**

The Data view allows you to create variables and relationships, enter assumptions and projections using mathematical expressions, and dynamically link to Excel.
Results:
The Results view allows detailed and flexible display of all model outputs, in charts and tables, and on the Schematic.
**Scenario Explorer:**

You can highlight key data and results in your system for quick viewing.

**Notes:**

The Notes view provides a place to document your data and assumptions.
The Tutorial Structure

This complete tutorial guides you through the wide range of applications that can be covered with WEAP. The first three modules (WEAP in one hour, Basic Tools and Scenarios) present the essential elements needed for any WEAP modeling effort. The other modules present refinements that may or may not apply to your situation.

Aside from the three basic modules, the tutorial modules are designed in a way that they can be completed in any order and independently, as you see fit. They all start with the same model that you will create after completing the first three modules.

Below is a list of all modules, starting with the three basic modules; the bulleted points indicate the aspects covered in each module.

**WEAP in One Hour**
- Creating a New, Blank Study Area
- Setting General Parameters
- Entering Elements into the Schematic
- Getting First Results

**Basic Tools**
- Creating and Using Key Assumptions
- Using the Expression Builder

**Scenarios**
- Preparing the Ground for Scenarios
- Creating the Reference Scenario
- Creating and Running Scenarios
- Using the Water Year Method

**Refining the Demand Analysis**
- Disaggregating Demand
- Modeling Demand Side Management, Losses and Reuse
- Setting Demand Allocation Priorities
Refining the Supply
- Changing Supply Priorities
- Modeling Reservoirs
- Adding Flow Requirements
- Modeling Groundwater Resources

Data, Results and Formatting
- Exchanging Data
- Importing Time Series
- Working with Results
- Formatting

Reservoirs and Power Production
- Modeling Reservoirs
- Adding Hydropower Computation
- Modeling Run-of-River Power Plants

Water Quality
- Setting up Quality Modeling
- Entering Water Quality Data
- Using Water Quality Inflow Constraints for a Demand Site
- Entering Pollution Generating Activity for Demand Sites
- Modeling a Wastewater Treatment Plant

The WEAP/QUAL2K Interface
- Linking to QUAL2K
- Running Scenarios

Hydrology
- Modeling Catchments: the Simplified Coefficient Method
- Modeling Catchments: the Soil Moisture Model
- Simulating Surface Water-Groundwater Interaction

Financial Analysis
- Setting up the Cost and Benefit Model
- Modeling Cost
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**Linking WEAP to MODFLOW**

- Linking to MODFLOW
- Running MODFLOW and Viewing Results
- Scenario: Increased Population
- Scenario: Irrigation
- Scenario: Artificial Recharge

**Linking WEAP to LEAP**

- Linking WEAP and LEAP
- Scenario: Hydropower Generation from WEAP
- Scenario: Demand for Cooling Water from LEAP
- Scenario: Electricity Demand from WEAP
WEAP
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WEAP in One Hour

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Creating a New, Blank Study Area

1. **Establish a New, Blank Area.**

   You are now going to practice creating a new, blank area. When you open WEAP for the first time, a project area called “Weaping River Basin” will appear. Use the Area, Create Area menu option to make a new, blank area.

   A window, as shown below, will appear in which you should click on the “Initially Blank” option. In the next steps, you will be defining this area for a specific geographic area of the world - so you can name the area based on this selection if you like (e.g., My_Ghana_Area).

   After clicking “OK”, you will get the following screen:
Click “OK” again. In the next screen, you will select the geographic area for
your project from the world map that appears. Click once where you want
to begin drawing a rectangle around the area that your project will represent.
A green rectangle will appear around the area selected.

You can then use the slider bar on the lower left of the window to zoom
into this selected area.
Click on “OK” when you are satisfied with your area boundaries. Note that you can modify these boundaries later by choosing “Set Area Boundaries” on the pull-down menu under Schematic on the top menu bar.
In WEAP, models are called “areas.” Areas are limited by boundaries, which define the extent of the project area. If you create a new area by copying an existing one, the boundary is kept identical to that of the existing area. To modify boundaries once you have established a New Area, go to Schematic on the menu, and choose “Set Area Boundaries.”

Note that if you want to start with a “blank” area, you can use the steps above to select a geographic area over one of the oceans instead of a land mass.

2. Add a GIS layer to the Area

You can add GIS-based Raster and Vector maps to your project area - these maps can help you to orient and construct your system and refine area boundaries. To add a Raster or Vector layer, right click in the middle window to the left of the Schematic and select “Add a Raster Layer” or “Add a Vector Layer.”

A window will appear in which you can input the name of this file and where WEAP can find it on your computer or on the internet. For now, close the window by pressing the “Cancel” button.

Background vector data can be added by clicking “Add Vector Layer.” WEAP reads vector information in the SHAPEFILE format. This format can be created by most GIS software.

A large amount of georeferenced data (both in vector and raster format) is available on the Internet, sometimes for free. Beware that some of the downloadable data might need GIS processing before being usable in WEAP, especially to adapt the projection and/or coordinate system.
3. **Saving an Area**

If you want to save this Area for your own use later, use the “Area”, “Save…” menu or press Ctrl+S.

[Image of WEAP interface]

**Setting General Parameters**

We are now going to proceed with learning how to navigate through WEAP and its functionalities. For the remaining exercises in this tutorial we will be using a pre-defined Area called “Tutorial.”

To open this Area, on the Main Menu, go to Area and select “Open.” You should see a list of Areas that includes “Tutorial”—select this Area. You should now see the Schematic as shown below—with blue lines for rivers and a yellow polygon for the city. If you do not see this, go to the Main Menu, select “Revert to Version” and choose the version named “Starting Point for ‘WEAP in One Hour’ module.”

4. **Set the General Parameters**

Once the Area opens, use the “General” menu to set Years and Time Steps and Units.

*Set the Current Accounts Year to 2000 and the Last Year of Scenarios to 2005. Set the Time Steps per year to 12. Set the Time Step Boundary to “Based on calendar month” and starting in January. Keep the default (SI units) for now.*
The year 2000 will serve as the “Current Accounts” year for this project. The Current Accounts year is chosen to serve as the base year for the model, and all system information (e.g., demand, supply data) is input into the Current Accounts. The Current Accounts is the dataset from which scenarios are built. Scenarios explore possible changes to the system in future years after the Current Accounts year. A default scenario, the “Reference Scenario” carries forward the Current Accounts data into the entire project period specified (here, 2000 to 2005) and serves as a point of comparison for other scenarios in which changes may be made to the system data. There will be a more detailed discussion of scenarios in an upcoming module.
The time steps should be chosen to reflect the level of precision of the data available. A shorter time step will increase the calculation time, especially when several scenarios have to be calculated.

5. **Save a version of your Area**

Select “Save Version” under the “Area” menu. A window will appear asking for a comment to describe this version. Type “general parameters set.”

As with any other program, it is usually a good idea to regularly save your work in WEAP. WEAP manages all the files pertaining to an area for you. Saving a new area will automatically save the related files. The files are saved in the WEAP program installation folder. You can manage the areas, export and import them, back them up and send them per email using the Area…, Manage Areas menu.

WEAP also has a very convenient versioning feature that allow saving versions of a model within the same area. Use the “Area”, “Save Version….” menu to save a version, and the “Area”, “Revert to Version” to switch to another version. You can switch between recent and older versions without losing data. WEAP will automatically create versions of your model every time you save. It is however better to manually create a version of a status you really want to keep since WEAP will eventually delete old automatic versions to save disk space, keeping only a few.
6. Draw a River

Click on the “River” symbol in the Element window and hold the click as you drag the symbol over to the map. Release the click when you have positioned the cursor over the upper left starting point of the main section of the river. Move the cursor, and you will notice a line being generated from that starting point.

The direction of drawing matters: the first point you draw will be the head of the river from where water will flow. You can edit the river course later on by simply clicking-moving any part of the river to create a new point, or right-clicking any point to delete it.

Follow the main river, drawing from the upstream (upper left) to the downstream (lower right), clicking once to end each segment that you draw. You can follow the line of the river as closely as you like, or you can draw a less detailed representation (below). Note though, that how closely you follow the actual course of the river will have implications for the performance of certain functionalities in WEAP. For example, if you plan to model water quality parameters along the river, it would be advantageous to construct the river element as closely as possible to the actual river course, because WEAP will need to calculate residence times in the river (a function of reach lengths) to perform water quality simulations. Zooming in on the river...
(using the zooming bar in the lower schematic window) can help if you want to follow the rivers path more closely. You do not need to draw a river on the branch coming horizontally from the left. You can also adjust the river later if you want to add more detail.

When you double click to finish drawing the river, a dialog box appears for naming the river (see below).

*Name the river "Main River."*
You may also enter an optional label for the schematic presentation (a shorter label can help to keep the schematic from becoming cluttered).

You can move the river label to another location by right clicking anywhere on the river and selecting "Move Label." The label will follow the cursor - single click when the label is in the desired location.

7. Enter Data for the Main River

To enter and edit data for the Main River, either right-click on the Main River and select Edit data and any item in the list, or switch to the Data view by clicking on the Data symbol on the left of the main screen. Select: Supply and Resources/ River /Main River in the Data tree. You may have to click on the “plus sign” icon beside the Supply and Resources branch in order to view all of the additional branches below it in the tree.
Alternatively, you can use the Tree pull-down menu and select “Expand All” to view all branches.

The "Inflows and Outflows" window should be open - if it isn't, click on the appropriate button. Click on the "Headflow" tab. Click on the area just beneath the bar labeled “2000” in the data input window to view a pull-down menu icon. Select the “Monthly Time-Series Wizard” from the drop-down menu.
Use the Monthly Time Series Wizard to enter the following data series:

<table>
<thead>
<tr>
<th>Month</th>
<th>Flow (CMS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan</td>
<td>12</td>
</tr>
<tr>
<td>Feb</td>
<td>7</td>
</tr>
<tr>
<td>Mar</td>
<td>11</td>
</tr>
<tr>
<td>Apr</td>
<td>17</td>
</tr>
<tr>
<td>May</td>
<td>80</td>
</tr>
<tr>
<td>Jun</td>
<td>136</td>
</tr>
<tr>
<td>Jul</td>
<td>45</td>
</tr>
<tr>
<td>Aug</td>
<td>32</td>
</tr>
<tr>
<td>Sep</td>
<td>38</td>
</tr>
<tr>
<td>Oct</td>
<td>18</td>
</tr>
<tr>
<td>Nov</td>
<td>9</td>
</tr>
<tr>
<td>Dec</td>
<td>7</td>
</tr>
</tbody>
</table>

Note that as you enter each data point, the data is shown graphically also. Do not input or change any other data yet. Push Finish to close the wizard.

WEAP divides up rivers into reaches (segments). Originally your river has only one reach; as you add withdrawal and return points, WEAP will automatically create new reaches.
8. Create an Urban Demand Site and Enter the Related Data

Creating a demand node is similar to the process you used to create a river. Return to the Schematic view and pull a demand node symbol onto the schematic from the Element window, releasing the click when you have positioned the node on the left bank of the river (facing downstream) in the yellow area that marks the city’s extent.

Enter the name of this demand node as "Big City" in the dialog box, and set the demand priority to 1.

The Demand Priority represents the level of priority for allocation of constrained resources among multiple demand sites. WEAP will attempt to supply all demand sites with highest Demand Priority, then moving to lower priority sites until all of the demand is met or all of the resources are used, whichever happens first.
Right click on the Big City demand site and select "Edit data" and "Annual Activity Level." This is the alternative way to edit data, rather than clicking on the "Data" view icon on the side bar menu and searching through the data tree.

You must first select the units before entering data. Pull down the "Activity Unit" window, select "People", and click “OK.”
In the space under the field labeled "2000", enter the Annual Activity Level as 800000.

Next, click on the "Annual Water Use Rate" tab and enter 300 under the year 2000.
Finally, click on the "Consumption" tab and enter 15. Note that the units are preset to "percent."

Consumption represents the amount of water that is actually consumed (i.e. is not returned in the form of wastewater).

9. Create an Agriculture Demand Site

Pull another demand node symbol into the project area and position it on the other side of the Main River opposite and downstream of Big City.

Name this demand node "Agriculture", and set the demand priority to 1.
In the same manner as for Big City, enter the Annual Activity Level and Annual Water Use Rate in the Data View for the Agriculture demand site after first selecting "hectares" as the units (you may have to click on the “plus” sign to the left in the tree in order to see all of the area options).

Annual Activity Level 100,000 hectares
Annual Water Use rate 3,500 m$^3$/hectare

Select the Monthly Variation tab and the Monthly Time Series Wizard to enter the data below for the monthly variation in the water use rate.

Monthly Variation:
- 5% in April
- 10% in May and June
- 20% in July
- 30% in August
- 25% in September
- 0% for the rest of the year

Finally, click on the Consumption tab and enter 90.

The monthly variation is expressed as a percentage of the yearly value. The values for all of the months have to sum up to 100% over the full year. If you don’t specify monthly variation, WEAP will prescribe a monthly variation based on the number of days in each month.
You could have created one single demand site integrating both urban and agriculture demand. However, we will see later that this removes some of the flexibility in the water supply priorities allocation.

10. **Connect the Demand with a Supply**

You now need to tell WEAP how demand is satisfied; this is accomplished by connecting a supply resource to each demand site. Return to the Schematic view and create a Transmission Link from the Main River to Big City and to Agriculture. Do this by dragging the Transmission Link first to a position on the river, releasing the click, then pulling the link to Big City and double clicking on this demand node. Do the same for Agriculture, but start the Transmission Link downstream of the one created for Big City.

**Select a Supply Preference of 1 for each Transmission Link.**

![Diagram of Transmission Links](image_url)

The Supply Preference parameter allows you to define which source should be used in priority to supply water to this Demand Site. WEAP will attempt to supply all of the demand with sources having the highest preference level, only using lower-level sources if the high-level sources do not have sufficient supply.

11. **Create Return Flow Links**

Now create a Return Flow from Big City to the Main River. Do the same for Agriculture to the Main River. Follow the same "drag and release" procedure as for the Transmission Links.
The return flow for the urban demand site should be positioned downstream of the agriculture withdrawal point. In the flow direction, the sequence should be: withdrawal for Big City, withdrawal for Agriculture, return from Big City, return from Agriculture.

Next, set the Return Flow Routing for the Big City Return Flow. Do this by right-clicking on each Return Flow and selecting "edit data" and "Return Flow Routing" or by going to the Data view\Supply and Resources\Return Flows\from Big City. Do the same for the Agriculture Return Flow.

*Set the Return Flow Routing to 100%.*
12. **Check your Model**

At this point, your model should look similar to the figure below.

---

![Model Image]

---

**Getting First Results**

13. **Run the Model**

Click on the “Results” view to start the computation. When asked whether to recalculate, click yes. This will compute the entire model for the Reference Scenario - the default scenario that is generated using Current
Accounts information for the period of time specified for the project (here, 2000 to 2005). When the computation is complete, the Results view will appear.

14. **Check your Results**

Click on the “Table” tab and select “Demand” and “Water Demand” from the primary variable pull-down menu in the upper center of the window (see below). Also, click the “Annual Total” Box.

If you have entered all data as listed in previous steps, you should obtain the following annual demand values for each year (2000 to 2005) of the Reference scenario:

- **Annual Demand for Agriculture**: 350 M $m^3$
- **Annual Demand for Urban Area**: 240 M $m^3$
15. Look at Additional Results

Now, look at the monthly Demand Coverage rates in graphical form. Click on the “Chart” tab. Select “Demand” and “Coverage” from the primary variable pull-down menu in the upper center of the window.

Format the graph by selecting the 3-D option on the left side-bar menu, and ensure that “All months” is selected in the pull-down menu above the graph (also keep the “Monthly Average” option checked). The graph should like the one below.

If you do not obtain those values go back to the “Data” view and check your inputs.

If you obtain an error or warning message read it carefully as it might reveal where in your inputs is the discrepancy, or which step you skipped.
During the months of December and February, which have little flow in the river, Big City lacks water, and therefore demands go unmet. Agriculture only has a shortfall in supply in the month of August and September, when the plants require the most water.

You can fully customize the way WEAP charts are displayed, as well as print or copy graphs to the clipboard using the toolbox located to the right of the graph.
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Scenarios

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Using the Water Year Method Error! Bookmark not defined.

June 2013
Scenarios

August 2012

WEAP Tutorial

Note:
For this module you will need to have completed the previous modules (WEAP in One Hour and Basic Tools) or have a fair knowledge of WEAP (data structure, Key Assumptions, Expression Builder). To begin this module, go to the Main Menu, select “Revert to Version” and choose the version named “Starting Point for ‘Scenarios' module.”

Preparing the Ground for Scenarios

1. Understand the Structure of Scenarios in WEAP

In WEAP the typical scenario modeling effort consists of three steps. First, a “Current Accounts” year is chosen to serve as the base year of the model; Current Accounts has been what you have been adding data to in the previous modules. A “Reference” scenario is established from the Current Accounts to simulate likely evolution of the system without intervention. Finally, “what-if” scenarios can be created to alter the “Reference Scenario” and evaluate the effects of changes in policies and/or technologies.

Read the “Scenarios” help topic (under the Data subheading in the Help Contents) for a more detailed description of the WEAP approach.

2. Change the Time Horizon for the Area

In the Data or Schematic view, under the General\Years and Time Steps menu, change the “Time Horizon” of the Area.

<table>
<thead>
<tr>
<th>Current Accounts Year</th>
<th>2000 (unchanged)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Last Year of Scenarios</td>
<td>2015</td>
</tr>
</tbody>
</table>

3. Create an Additional Key Assumption

Create the following key assumption:

Population Growth Rate  2.2

There is no unit for this Key Assumption, but remember to change the “Scale” field to Percent.
Creating the Reference Scenario

4. Describe the Reference Scenario

The “Reference” Scenario always exists. Change its description in the Area\Manage Scenarios menu to reflect its actual role. Note that you must be in the Data View or Schematic view to have access to the “Manage Scenarios” option in the Area menu.

For example, “Base Case Scenario with population growth continuing at the 1960-1995 rate and slight irrigation technology improvement.”

5. Change the Unit Irrigation Water Use

In the Data View, change the “Unit Irrigation Water Needs” Key Assumption to reflect a new annual pattern for the period (2001-2015) after the Current Accounts year. To make the change, you will need to select the “Reference” scenario from the drop-down menu at the top of the screen. Use the “Yearly Time-Series Wizard” to construct the time series.
First, select the function "Interpolate" by clicking on it, then click "Next."
Click on "Enter Data" in the next window, click "Next", then click "Add" to add the following data to the time series:

*Type of Time Series: Interpolate*

**Data:**
- 2000  3500
- 2005  3300
- 2010  3200
- 2015  3150

*Growth after last year: 0%*

Note that the first data point, for the year 2000, should already be listed in the data input window because it was input when the “Unit Irrigation Water Needs” Key Assumption was created in the Current Accounts (see Exercise 1 under Creating and Using Key Assumptions, Basic Tools Module).

As you can see while running the Yearly Time Series Wizard, WEAP offers a wide range of techniques to build time series, including importing from Excel files, creating step functions, using forecasting equations etc.

The Yearly Time Series Wizard helps you create expressions. You can also simply type or edit the expression (in this case, “Interp(2000,3300, 2005,3300, 2010,3200, 2015,3150)” without running the wizard, either directly or through the Expression Builder.
6. **Set the Population Growth**

Set the population of Big City to grow by the rate defined by the “Population Growth Rate” Key Assumption defined in an earlier step. Here again you will have to select the “Reference” scenario in the drop-down menu at the top of the Data view.

Make sure you have the Big City Demand Site and its Annual Activity Level tab selected. Delete the current expression and select the “Growth” function in the Expression Builder in the pull-down menu below the 2001-2015 field (Note that the present expression in this field is the same as that for the Current Accounts year). Then click on the “Branch” tab above the text field. Either double click on the "Population Growth Rate" Key Assumption in the Data Tree, or drag it down into the expression window. Your final function should read “Growth(Key\Population Growth Rate/100)”

*Note that you have to divide the “Population Growth Rate” by 100 in order for WEAP to recognize the value of 2.2 in the Key Assumption as 0.022 in the calculation.*

The same effect could have been modeled without creating a Key Assumption in the first place. We will see however that doing so provides more flexibility when adding other scenarios.

Any value for which no time series is defined for the “Reference” scenario is assumed to remain constant. In our case for example, the Agriculture demand will remain constant until 2015 unless we change this variable as well.
7. **Run the Reference Scenario**

Run the Reference Scenario by clicking the “Results” view. Look at a 3-D graph of “Unmet Demand” (select “Annual Total”) for both demand sites. It should be similar to the figure below. Think about the following points.

*How does the demand evolve compared to the unmet demand?*

*Why is the total unmet demand decreasing at first and then increasing?*
Creating and Running Scenarios

8. Create a New Scenario to Model High Population Growth

Create a new scenario to evaluate the impact of a population growth rate for Big City higher than 2.2% for the period 2001-2015.

For this, choose the menu “Area”, “Manage Scenario”, right-click the “Reference” scenario and select “Add.” Name this scenario “High Population Growth” and add the description “This scenario looks at the impact of increasing the population growth rate for Big City from a value of 2.2% to 5.0%.”

9. Enter the Data for this Scenario

Make the following changes in the Data view after having chosen your new scenario in the drop-down menu at the top of the screen:
Select the “Population Growth Rate” Key Assumption and change the value under the 2001-2015 field to 5.0. Note that the color of the data field changes to red after the change - this occurs for any values that are changed to deviate from the “Reference” scenario value.

10. Compare Results for the Reference and Higher Population Growth Scenarios

Compare, graphically, the results for the two scenarios we have established so far (Reference and Higher Population Growth).

For example, select “Water Demand” from the primary variable pull-down menu. Click in the drop-down menu to the right of the chart area (above the graph legend), and select “All Scenarios.” Choose to show only Big City demand by selecting it from the pull-down list in the upper left pull-down menu of the Results window. Your graph should be similar to the one below.
Note the higher Water Demand for Big City in the “Higher Population Growth” scenario, as expected.

Next, compare “Unmet Demand” for the two scenarios. Use the primary variable pull-down menu to select “Unmet Demand.”

Again, note the higher Unmet Demand for the Higher Population Growth scenario.

When creating many scenarios in the same area, the computation can become lengthy. In this case you can exclude some of the scenarios from the calculation by unchecking the “Show results for this scenario” box in the scenario manager for those scenarios.
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Refining the Supply

A TUTORIAL ON

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Changing Supply Priorities

1. Create a new Transmission Link for water reuse

Create a new transmission link starting at the Big City Demand Site and ending at the Agriculture Demand Site. This is a conceptual model of reuse of urban wastewater for agriculture purposes. Set the Supply Preference on this Transmission Link to 2.

Supply Preference 2

If water quality were a concern, a wastewater treatment plant could have been added to treat the water from Big City before Agriculture received it. Having the treatment plant in the schematic would make it possible to simulate the changes in water quality before and after treatment.
2. Results when you change Supply Preferences

Try changing the Supply Preferences of the two links that now supply Agriculture and look at the related results for Demand Site Coverage. To change Supply Preferences, either right click on the Transmission Link in the Schematic view or go to the Data view and click on the appropriate Transmission link below Supply and Resources\Linking Demands and Supply\Agriculture.

Try the following combinations:

Supply Preferences = 1 from the Main River, 2 from Big City
Supply Preferences = 2 from the Main River, 1 from Big City

![Diagram showing Demand Coverage]

Supply Preferences = 1 from the Main River and 1 from Big City

![Diagram showing Demand Coverage]

Do you understand why the differences in Demand Coverage occur when the Supply Preferences change?
You can modify the display of preferences on the schematic by using the “Schematic \ Change the Priority View” menu. The “View Allocation Order” option will display the actual priority order in which WEAP computes supply. This is a function of the Supply Preference of the link as well as the Demand Priority of the demand site.

Note that you can study the impact of changing Supply Preferences, like Demand Priorities, by creating alternative scenarios.

3. **Revert to original model**

   You can do this using the “Revert to Version” option under the Area menu. Choose “Starting Point for all modules after Scenarios module” as you did at the beginning of this exercise.

**Modeling Reservoirs**

4. **Create a Reservoir and enter the related data**

   First, create a new scenario inherited from “Reference”, and name it “Reservoir Added.” Then add a reservoir object on the Main River upstream of Big City, and name it "Main River Reservoir" Be sure to unclick the box where it asks if this object is active in Current Accounts.

   *Leave the Demand Priority at 99 (default).*

   ![General Info](image)
Right click on Main River Reservoir and select "Edit Data." Select the “Storage Capacity” variable to enter the Data view (Make sure you have the “Reservoir Added” scenario selected). Once you are in the Data view, you will first have to click on the “Startup Year” button before you can alter any other parameters.

*Choose 2002 as the startup year for Main River Reservoir*

Then click on the “Physical” button and change the following parameters:

- **Storage Capacity**: 70 M $m^3$
- *Note that the Scale is set to "Million"*
More details about reservoirs operation and hydropower production are provided in the “Reservoirs and Power Production” module of the WEAP tutorial.

5. Run the Model and Evaluate the Results

Compare the Demand Site Coverage for Agriculture in the “Reference” and “Reservoir Added” scenarios.

- Demand Coverage: why does Agriculture have higher coverage with the Main River Reservoir in place?
- Reservoir Storage Volume: does the solution of building a reservoir appear to be sustainable? Use the primary variable pull down menu to select Reservoir Storage Volume (under Supply and Resources\Reservoir), and select “All Years” from the pull down menu at the bottom of the graph.
Flow in the River: how does having the reservoir on the Main River change the flow downstream compared to the Reference scenario? Select Streamflow (under Supply and Resources\River) from the primary variable pull-down menu and click on “Monthly Average.” Choose the year 2002 from the “Selected Years” option on the bottom menu, and choose the reach below Withdrawal Node 2 for comparison.

You may want to switch to a logarithmic axis (the button is located on the vertical toolbar on the far right) to see more clearly the differences in flow upstream and downstream of the Main River Reservoir.
Now select the reach below Return Flow Node 1 for comparison. Why is streamflow along this reach more similar for the two scenarios?

The creation of a large reservoir allows storage of “excess” water during high flow periods to cover water demand during low flow periods. The price to pay, however, is a potentially large impact on the hydrological regime of the river downstream of the reservoir. The Return Flows from Big City and Agriculture provide the flow in the Main River during the spring and winter months. A reservoir’s operation variables and flow requirements can be used to mitigate the reservoir’s downstream impact.
Adding Flow Requirements

6. Create a Flow Requirements

Create another new scenario: “Flow Requirement Added.” This scenario is inherited from the “Reservoir Added” scenario. The scenario tree should look like the one below:

Now add a “Flow Requirement” to the Schematic view below the withdrawal node for the Big City, but upstream of the withdrawal node for Agriculture.

Demand Priority 1 (default)
Right click on the Flow Requirement and select Edit Data\Minimum Flow Requirement. Add the value below (make sure you still have the “Flow Requirement Added” scenario selected):

**Minimal Flow Requirement 5 CMS**

![Image of WEAP interface showing minimum flow requirement](image)

7. **Run the Model and Evaluate the Results**

Look at the results and think about the related questions.

- **How does adding the flow requirement change streamflow in the reach below the flow requirement?**

Compare streamflow below the flow requirement for the “Reference”, “Reservoir Added”, and “Flow Requirement Added” scenarios for the same year (2002). You should obtain a graph like the one below:
- **What is the Flow Requirement coverage?**

You can view these data by selecting "Instream Flow Requirement Coverage" under Demand. (Switch off the logarithmic display for the y axis, and select only the “Flow Requirement Added” scenario for viewing).

- **Why has the coverage now changed for the Big City?**

Select “Demand Coverage” from the primary variable pull-down menu, select the Big City demand site, and select the “Reference”, “Reservoir Added”, and “Flow Requirement Added” scenarios for viewing.
- Assuming this flow requirement was more important than supplying the Big City, how should the model be changed to ensure that the flow requirement is fulfilled?

The relative level of Demand Priority for Big City, Agriculture and the Flow Requirement will determine which demand is covered first. To ensure that the Flow Requirement is covered first, change the Demand Priority of Big City to a value higher than for the Flow Requirement, since it is upstream of the Flow Requirement.

Modeling Groundwater Resources

8. Create a Groundwater Resource

Create a Groundwater node next to the City and name it "Big City Groundwater." Also, make it active in Current Accounts.
Give Big City Groundwater the following properties (make sure you are in Current Accounts when entering these data - you will realize you are not if there is no tab for Initial Storage):

- **Storage Capacity**: Unlimited (default, leave empty)
- **Initial Storage**: 100M m³
- **Natural Recharge** (use the Monthly Time Series Window, accessed in the field under "2000")
  - Nov. to Feb.: 0M m³/month
  - Mar. to Oct.: 10M m³/month
9. Connect Big City Groundwater with Big City

Use a Transmission Link to connect Big City Groundwater to the Big City demand site, and provide it with a Supply Preference of 2.

Your model should look similar to the figure below:

![Diagram showing the connection between Big City Groundwater and Big City]

10. Update the characteristics of the Transmission Link between the Main River and Big City

Change the characteristics of the Transmission Link connecting the Main River (Withdrawal Node 1) and Big City (make sure you are in Current Accounts):

- Supply Preference: 1 (default)
- Maximum Flow Volume: 6 m³/sec
11. **Run the Model and Evaluate the Results**

Look at the following results and think about the related questions.

- Is the groundwater extraction required to meet demands under these conditions sustainable?

To view these results, select “Groundwater Storage” from the pull-down menu under “Supply and Resources\Groundwater.”

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The Maximum Flow Volume or Percent of Demand parameter represents restrictions in the capacity of a resource (due, for example, to equipment limits).
- How does the relative use of water from Big City Groundwater and the Main River evolve at the Big City demand site?

To view these graphical results for Big City specifically, first select "Supply Delivered" under Demand using the primary variable pull-down menu. Then choose "All Sources" in the pull-down menu on the right side of the window above the graph legend. Next, select Big City as the demand site to view using the pull-down menu centered above the graph and directly below primary variable field. Click on “Annual Total.”
Groundwater recharge and interaction with rainfall and surface water can be modeled rather that entered as inputs. Refer to the “Hydrological Modeling” tutorial for more details.

Other resources can be modeled using the “Other Supply” object, which is characterized by a monthly “production” curve. This object can be used to simulate a desalination plant or inter-basin transfers, for example.
WEAP
Water Evaluation And Planning System

Reservoirs and Power Production

A TUTORIAL ON

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Note:
For this module you will need to have completed the previous modules ("WEAP in One Hour, Basic Tools, and Scenarios) or have a fair knowledge of WEAP (data structure, Key Assumptions, Expression Builder, creating scenarios). To begin this module, go to the Main Menu, select “Revert to Version” and choose the version named “Starting Point for all modules after ‘Scenarios’ module.”

Modeling Reservoirs

1. **Create a Reservoir**
   
   Create a Reservoir on the Lake located upstream of the Big City. Name it "Big City Reservoir."

   **Demand Priority**  99 (default)

   Entering a Demand Priority of 99 ensures that the reservoir will only fill if all other needs are fulfilled, including downstream demand.

2. **Enter the Physical Data**

   Right click on Big City Reservoir to edit data. Enter the following data in the "Physical" window (make sure you are in Current Accounts).

   - **Storage Capacity**: 70 M $m^3$
   - **Initial Storage**: 25 M $m^3$
   - **Volume Elevation Curve**

<table>
<thead>
<tr>
<th>Volume ($M m^3$)</th>
<th>Elevation ($m$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
<td>190</td>
</tr>
<tr>
<td>30.0</td>
<td>210</td>
</tr>
<tr>
<td>70.0</td>
<td>216</td>
</tr>
</tbody>
</table>

   **Net Evaporation**: 25 mm/month.
The “Volume Elevation Curve” is used both to model the surface for evaporation and to compute the head in case hydropower production is simulated. A cylindrical shape is assumed in converting volume and elevation into area.

Net evaporation needs to account for both rainfall and evaporation. It can therefore be a positive or a negative number; monthly variations can be modeled using the “Monthly Time Series Wizard.”
3. Enter the Operation Data

In the same view, enter the following data in the “Operation” window.

- **Top of Conservation**: 60
- **Top of Buffer**: 40
- **Top of Inactive**: 5
- **Buffer Coefficient**: 1.0

As illustrated by the figure to the left, WEAP allows the modeling of advanced reservoir operation through the definition of several zones that have different operational constraints.

More can be learned through the Help file’s “Reservoir Zones and Operation” screen or by clicking on the help button when in the Reservoir’s Operation tab.

4. Understanding the Impact of the Buffer Coefficient

Now create a new scenario inherited from the “Reference” scenario. Name this scenario “Buffer Coefficient Changes.” Then go back to the Data view (make sure that you are in the new scenario you just created) and change the buffer coefficient to 0.1. Click on results to run the new model.
Compare, for the “Reference” and “Buffer Coefficient Changes” scenarios, the results for “Reservoir Storage Volume”, found under the “Supply and Resources\Reservoirs” branch of the primary variable pull-down menu. Select “All Years” from the pull-down menu at the bottom of the graph, and click on “Monthly Average” at the top of the graph. Choose the “Reference” scenario and “Buffer Coefficient Changes” scenario for viewing from the pull-down menu above the legend. You can choose “Big City Reservoir” from the pull-down menu directly above the graph.

Also compare results also for Demand Coverage (under the Demand branch). Select the “Reference” and “Buffer Coefficient Changes” scenarios from the pull-down menu above the graph legend. Select “Big City” as the demand site for viewing from the remaining pull-down menu directly above the graph.
The Buffer Coefficient provides a way to regulate water releases when the water level in the reservoir is within the buffer zone (see figure in the information box of the previous step). 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. This is why lower Demand Site Coverage is observed for results in the “Buffer Coefficient Changes” scenario above.

Adding Hydropower Computation

5. Understanding the way WEAP models Power Production

WEAP can model Power Production in three different ways: through on-line reservoirs, through off-line reservoirs, and through run-of-river hydropower plants.

Refer to the help for more information on each category.

6. Add Power Production Capabilities to Big City Reservoir

In this example we will model an on-line reservoir power plant. Enter the following data under the “Hydropower” window for Big City Reservoir in the Current Accounts.

- Max Turbine Flow: 80 CMS
- Tailwater Elevation: 195m
- Plant Factor: 100%
- Generating Efficiency: 60%
Look at the “Hydropower Calculations” help topic for more information about how WEAP computes power production.

7. **Compute Hydropower Production and Understand the Results**

Run the model and look at the results in the Reference scenario for power production for the year 2000.

*The results can be accessed under the Primary Variable pull-down menu under “Supply and Resources/Reservoir/Hydropower.”*
Do you understand why production levels between May and June are so similar, even though flow in Main River and downstream water release is much greater in June? To confirm this, look at the results for “Streamflow” in the reach above Big City Reservoir (Main River Headflow).

The streamflow that can be processed by the turbine has been capped to 80CMS (see previous step), meaning that even though there is a higher discharge in June, the excess quantity flows downstream without going through the turbine. Hydropower in June would be the same for May and June if not for the fact that the Storage Elevation in Big City Reservoir was slightly lower at the end of April than it was at the end of May (look at the Storage Elevation results to confirm this - these numbers represent the status at the end of each month indicated). This effect was slightly offset by the fact that May has 31 days to produce power, whereas June has 30 days, but June still ended up having slightly higher total production.

Off-line, “local” reservoirs’ hydropower production can be modeled in the same way.
8. Create a Run-of-River Hydro Object

Create a Run-of-River Hydro Object on the Main River upstream of the Big City Reservoir created in the previous exercise. Name it “Big City Run of River.”

Enter the following data in the “Supply and Resources\River\Run of River Hydro” branch of the Data tree in the Data View:

- **Max Turbine Flow**: 80 CMS
- **Plant Factor**: 100%
- **Generating Efficiency**: 60%
- **Fixed Head**: 19.5 m
9. Run and Compare Results

Run your model and create a graph comparing the power production for the run-of-river and the reservoir power plants. Do this by selecting “All Hydropower” from the pull-down menu above the legend.

What are the reasons for the differences between both curves?
Note that the Run of River hydropower is slightly higher in May than June, in contrast to Big City Reservoir power production. This is due to the additional day available in May compared to June. Run of River hydropower production does not have Storage Elevation as limiting effect, whereas the Reservoir was still filling in May, which decrease the Reservoir production for that month compared to June.

**How does the run-of-river plant influence the streamflow of the river, when compared to the Big City Reservoir plant?**

To view this on the chart, select “Streamflow” from the primary variable pull-down menu and choose “Selected Main River Nodes and Reaches” from the pull-down menu above the legend. Select the following reaches: “Headflow”, “Big City Run of River”, “Below Big City Run of River”, “Big City Reservoir”, and “Below Big City Reservoir” from the list.
A reservoir can store water during high flows and release during low flow, thus having a smoothing effect. A run-of-river operation, however, processes whatever water flows in the river at any given point in time. Therefore, it does not affect the shape of the streamflow curve.