

---

# **WEAP**

**Water Evaluation And Planning System**

# **Tutorial**

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

**August 2016**



---

# WEAP

Water Evaluation And Planning System

## Tutorial Modules

Tutorial Overview.....	5
WEAP in One Hour .....	15
Basic Tools .....	41
Scenarios .....	51
Refining the Demand Analysis.....	73
Refining the Supply .....	95
Data, Results and Formatting.....	115
Reservoirs and Power Production.....	135
Water Quality .....	149
The WEAP/ QUAL2K Interface .....	173
Hydrology .....	181
Snow Hydrology and PEST Calibration.....	201
Financial Analysis.....	217
Linking WEAP to MODFLOW.....	229
Linking WEAP to LEAP.....	257





---

# WEAP

Water Evaluation And Planning System

## Tutorial Overview

<i>Introduction .....</i>	<i>6</i>
<i>Background .....</i>	<i>6</i>
<i>WEAP Development .....</i>	<i>7</i>
<i>The WEAP Approach .....</i>	<i>7</i>
<i>Program Structure .....</i>	<i>8</i>
<i>The Tutorial Structure .....</i>	<i>11</i>

August 2016

## Introduction

WEAP<sup>®</sup> 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, 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.

## 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 over one hundred countries.

## 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*

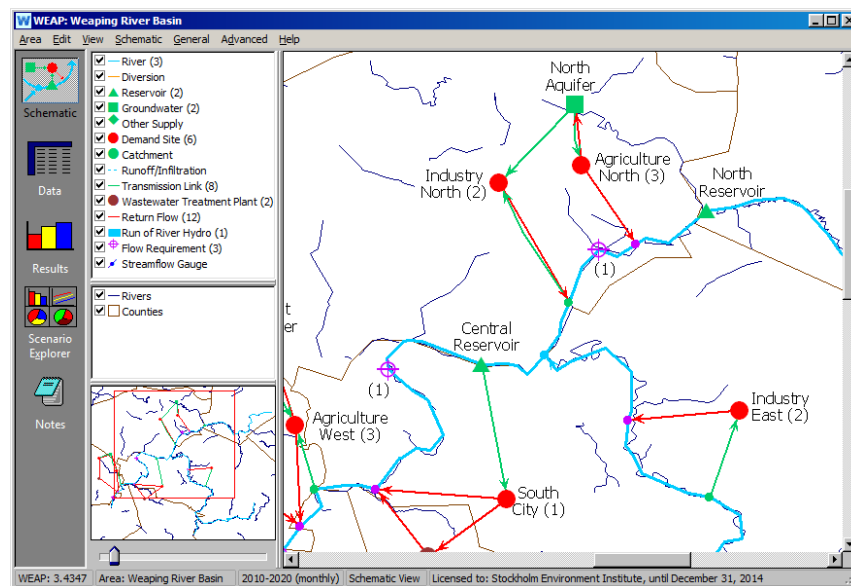
with regard to water sufficiency, costs and benefits, compatibility with environmental targets, and sensitivity to uncertainty in key variables.

## Program Structure

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

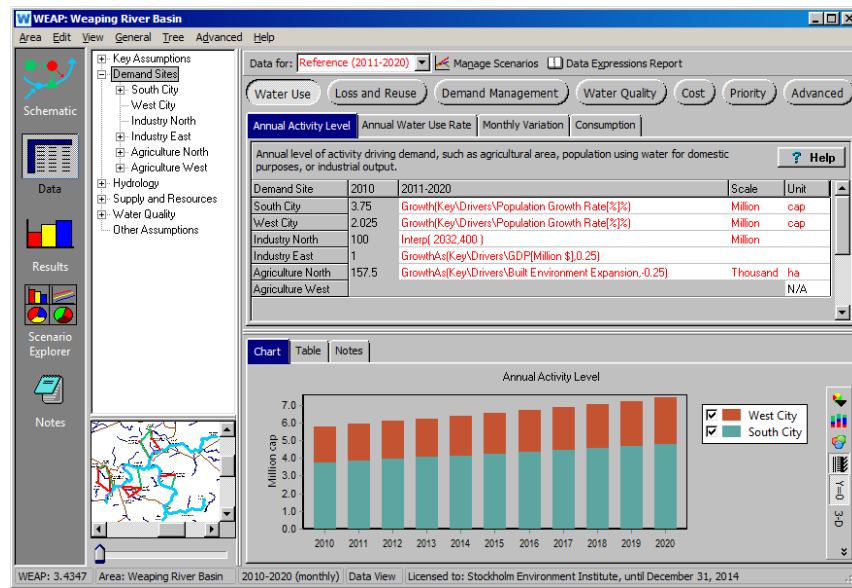
### Schematic:

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.



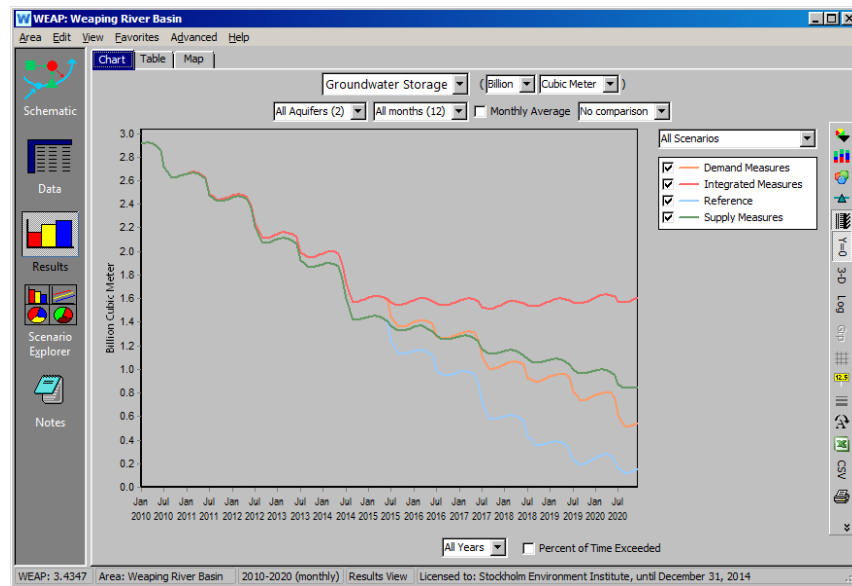
### Data:

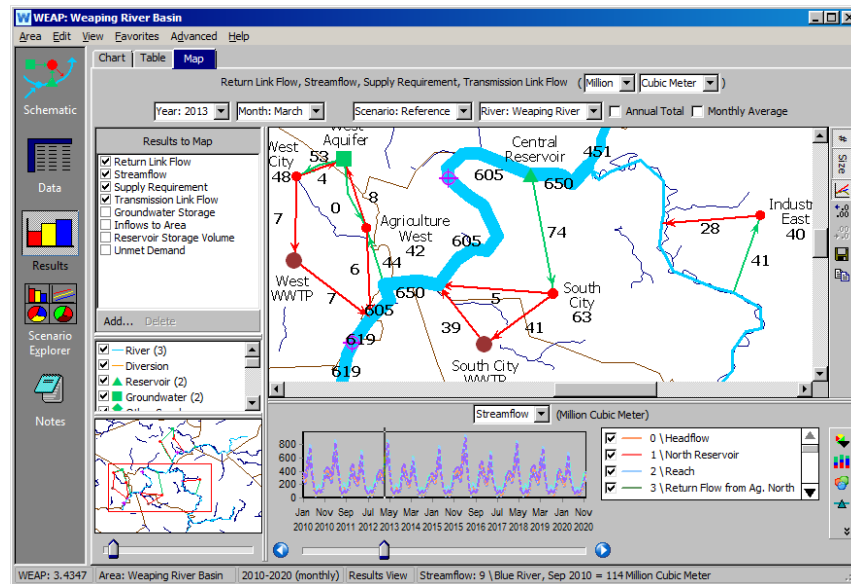
The Data view allows you to create variables and relationships, enter assumptions and projections using mathematical expressions, and dynamically link to Excel.



## Results:

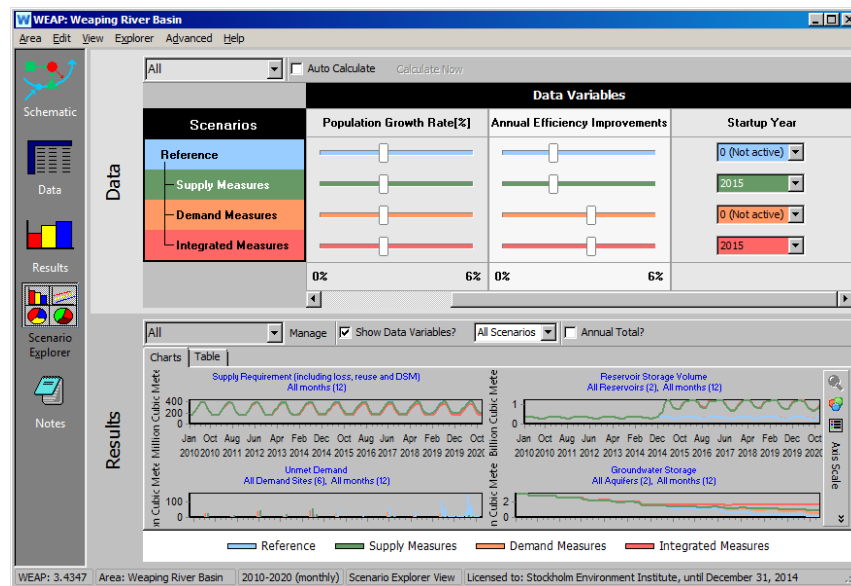
The Results view allows detailed and flexible display of all model outputs, in charts and tables, and on the Schematic.





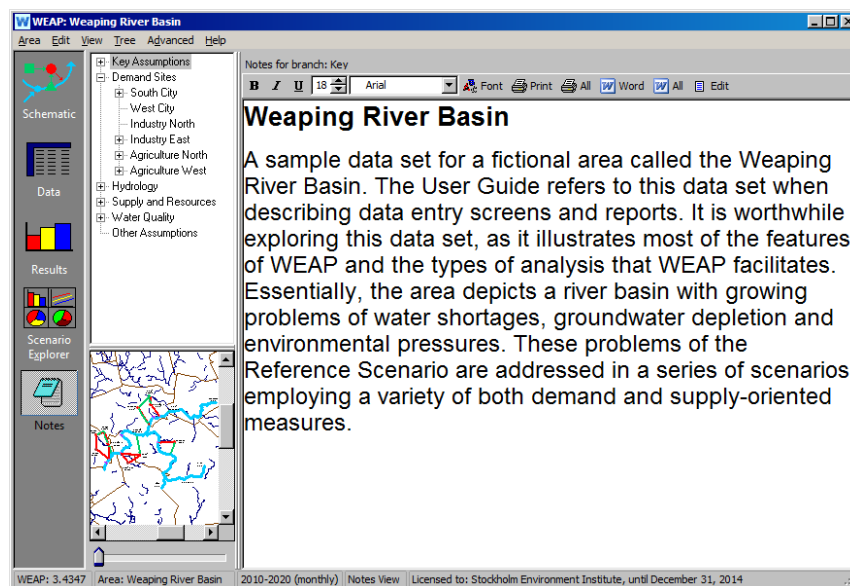
### Scenario Explorer:

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 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 Reservoir Supply
- Adding Flow Requirements
- Modeling Groundwater Resources

***Data, Results and Formatting***

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

***Reservoirs and Power Production***

- Modeling Reservoir Operation
- 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

***Snow Hydrology and PEST Calibration***

- Explore the Pre-Existing Model
- Enter Catchment Climate and Calibration Data
- Explore the Model Sensitivity
- Calibrate with PEST
- Appendix

***Financial Analysis***

- Setting up the Cost and Benefit Model
- Modeling Cost
- Modeling Benefits

***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

Water Evaluation And Planning System

# WEAP in One Hour

## ***A TUTORIAL ON***

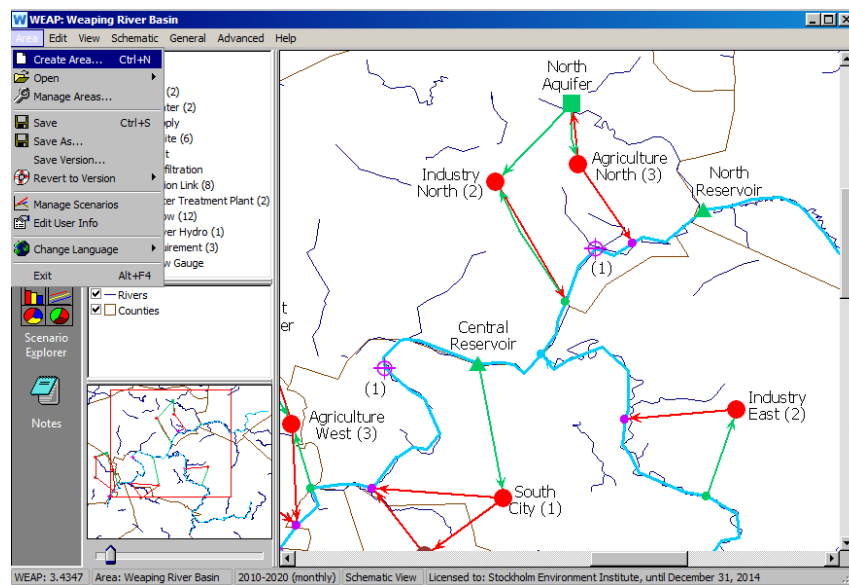
<i>Creating a New, Blank Study Area.....</i>	<i>16</i>
<i>Setting General Parameters .....</i>	<i>20</i>
<i>Entering Elements into the Schematic .....</i>	<i>23</i>
<i>Getting First Results.....</i>	<i>36</i>

**August 2016**

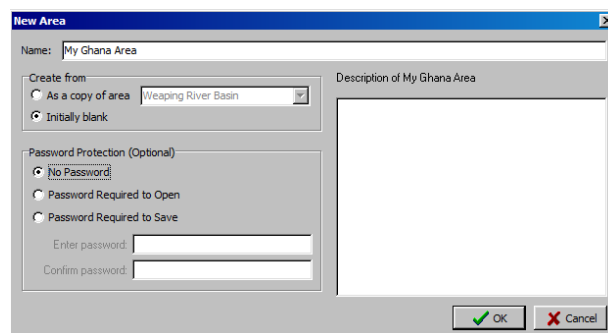
# Creating a New, Blank Study Area

## 1. Establish a New, Blank Area.

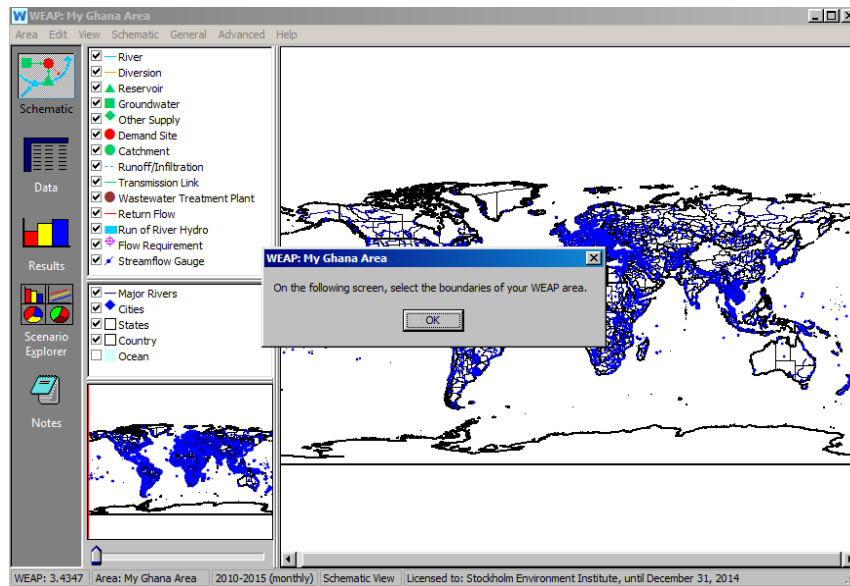
You are now going to practice creating a new, blank area. When you open WEAP for the first time, a project area called “Weeping River Basin” will appear. Use the Area, Create Area menu option to make a new, blank area.



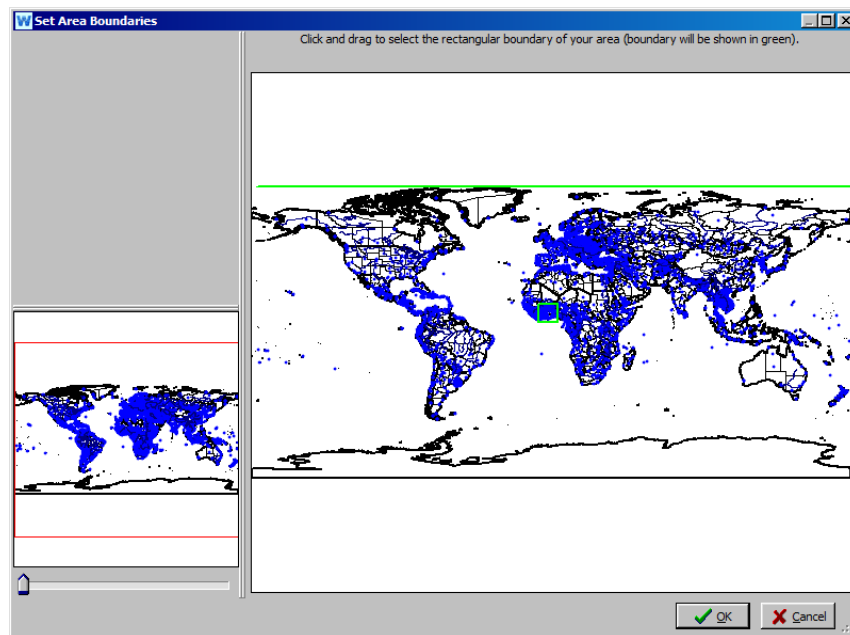
A window, as shown below, will appear in which you should click on the “Initially Blank” option. In the next steps, you will be defining this area for a specific geographic area of the world - so you can name the area based on this selection if you like (e.g., My Ghana Area). You can also save it as another version of model under construction, in the event you wanted multiple versions. Note that you can choose whether to have it password protected.



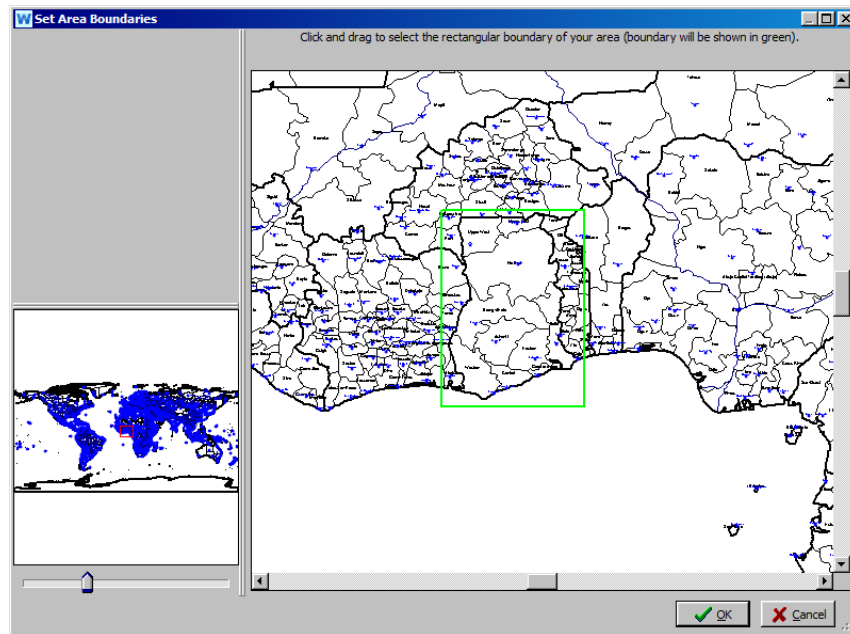
After clicking “OK” you may be prompted to save changes to the Weeping River Basin. After clicking yes or no, you will get the following screen:



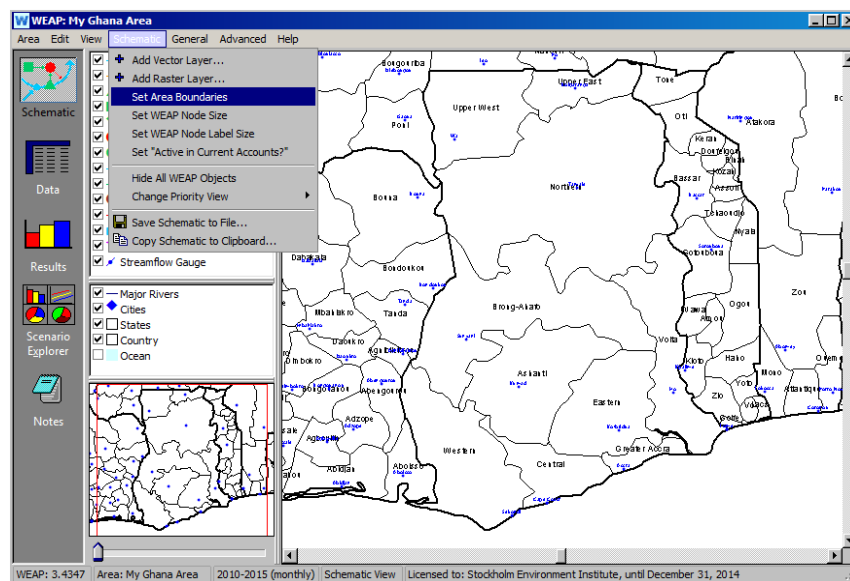
Click “OK” again. In the next screen, you will select the geographic area for your project from the world map that appears. Use your cursor to draw a rectangle around the area that your project will represent. The boundaries will appear as a green rectangle.



You can then use the slider bar on the lower left of the window to zoom into this selected area.



You can redraw your green rectangle to best capture the area you want in this view. 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.”

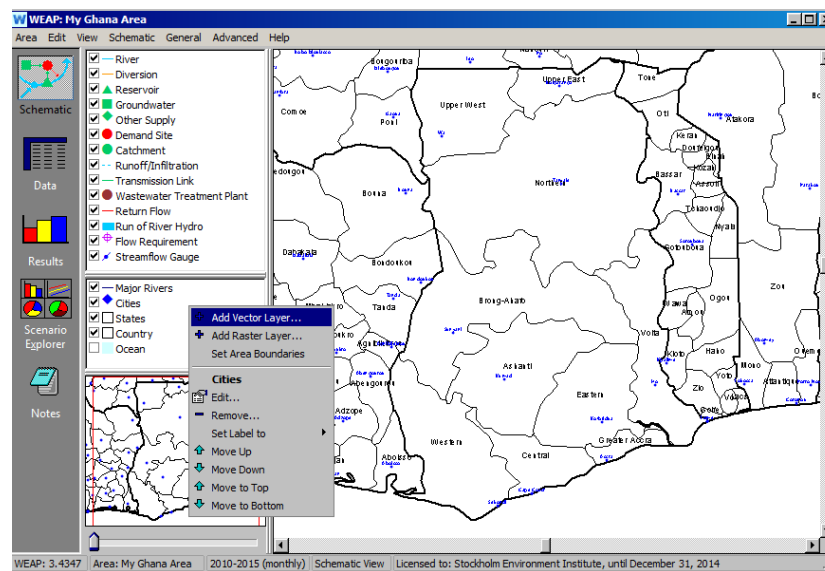


Areas are limited by boundaries, which define the extent of the project area. If you create a new area by copying an existing one, the boundary is kept identical to that of the existing area. To modify boundaries once you have established a New Area, go to Schematic on the menu, and choose “Set Area 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.

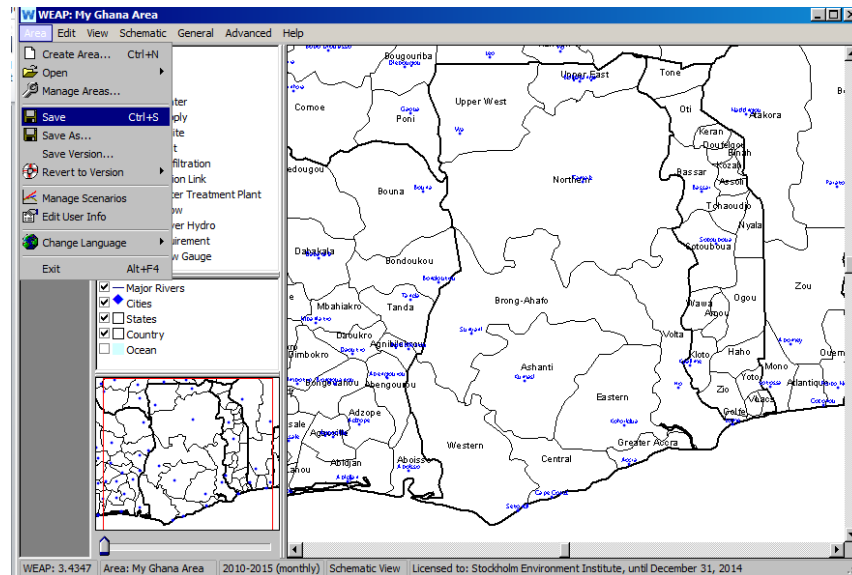
Background vector data can be added by clicking “Add Vector Layer.” WEAP reads vector information in the SHAPEFILE format. This format can be created by most GIS software.



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

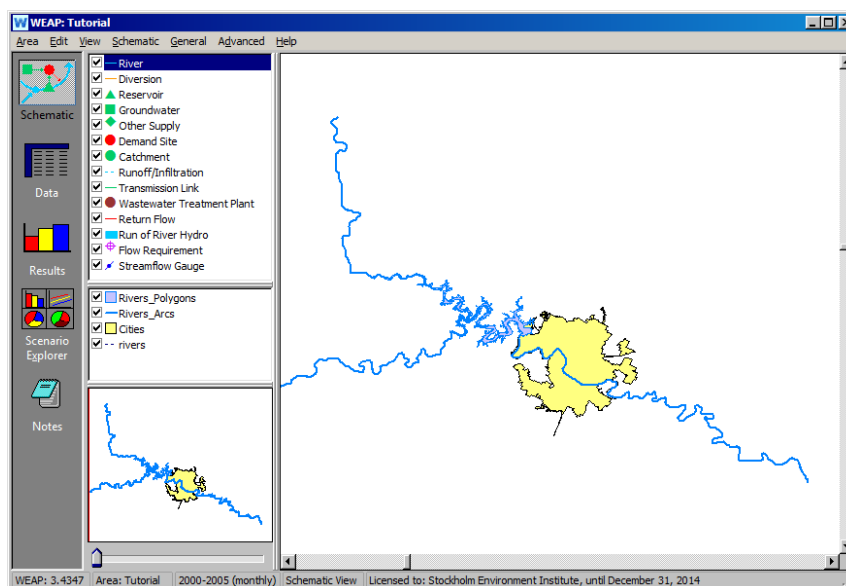
If you want to save this Area for your own use later, Use the “Area”, “Save...” menu or press Ctrl+S.



## 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 Area Menu, select “Revert to Version” and choose the version named “Starting Point for ‘WEAP in One Hour’ module” (it will have a date and time before the title).

## 4. Set the General Parameters

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

*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 (see below) Keep the default (SI units) for now.*

**Years and Time Steps**

Time Horizon

Current Accounts Year: 2000

Last Year of Scenarios: 2005

Time Steps per Year

12

☐ Add Leap Days?

Time Step Boundary

☒ Based on calendar month

☐ All time steps are equal length

☐ Set time step length manually

Water Year Start

January

#	Title	Abbrev.	Length	Begins	Ends
1	January	Jan	31	Jan 1	Jan 31
2	February	Feb	28	Feb 1	Feb 28
3	March	Mar	31	Mar 1	Mar 31
4	April	Apr	30	Apr 1	Apr 30
5	May	May	31	May 1	May 31
6	June	Jun	30	Jun 1	Jun 30
7	July	Jul	31	Jul 1	Jul 31
8	August	Aug	31	Aug 1	Aug 31
9	September	Sep	30	Sep 1	Sep 30
10	October	Oct	31	Oct 1	Oct 31
11	November	Nov	30	Nov 1	Nov 30

Time Step Name Format: October / Oct

The study period will run from January, 2000 to December, 2005.

? Help

✓ Close

Under “General”, the units also be set. We will leave them in the default (SI units) for now.



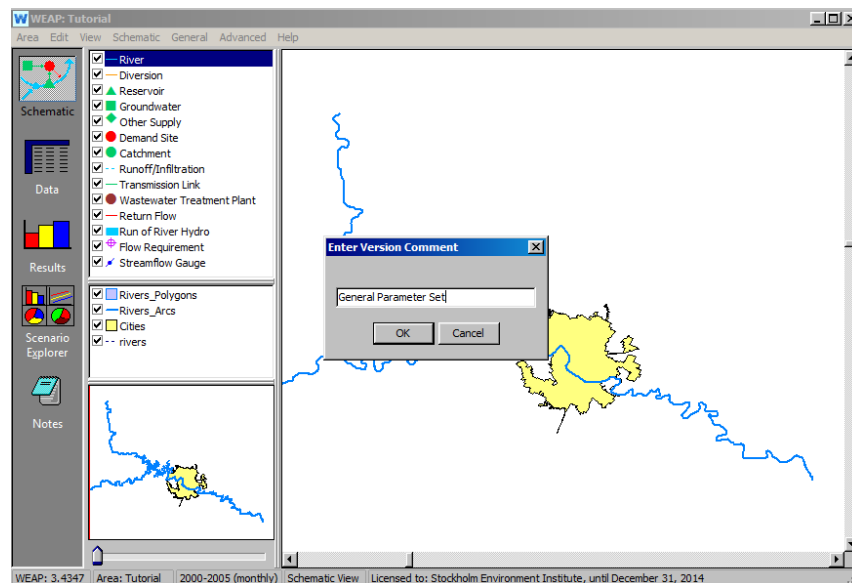
The year 2000 will serve as the “Current Accounts” year for this project. The Current Accounts year is chosen to serve as the base year for the model, and all system information (e.g., demand, supply data) is input into the Current Accounts. The Current Accounts is the dataset from which scenarios are 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.

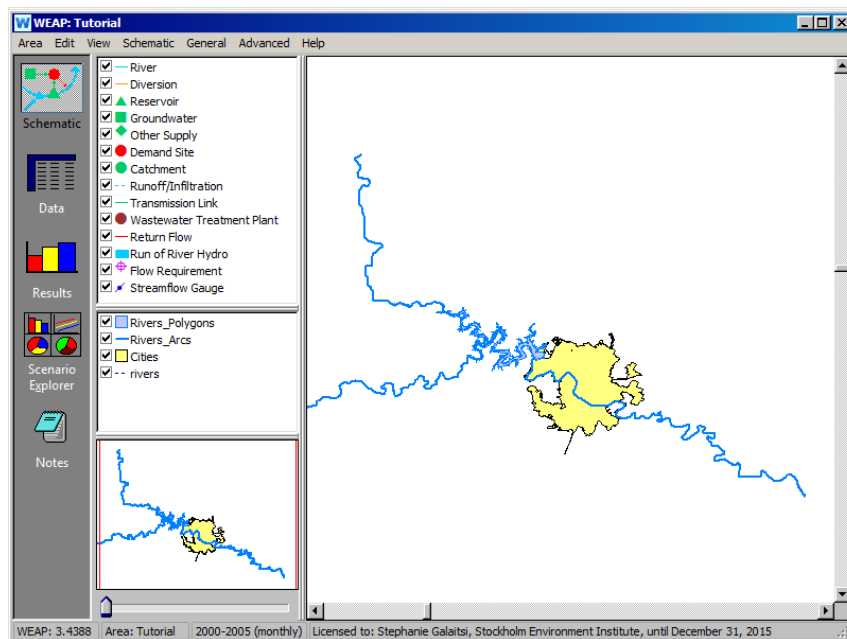


WEAP also has a very convenient versioning feature that allow saving versions of a model within the same area. Use the “Area”, “Save Version...” menu to save a version, and the “Area”, “Revert to Version” to switch to another version. You can switch between recent and older versions without losing data. 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.

# Entering Elements into the Schematic

## 6. Draw a River

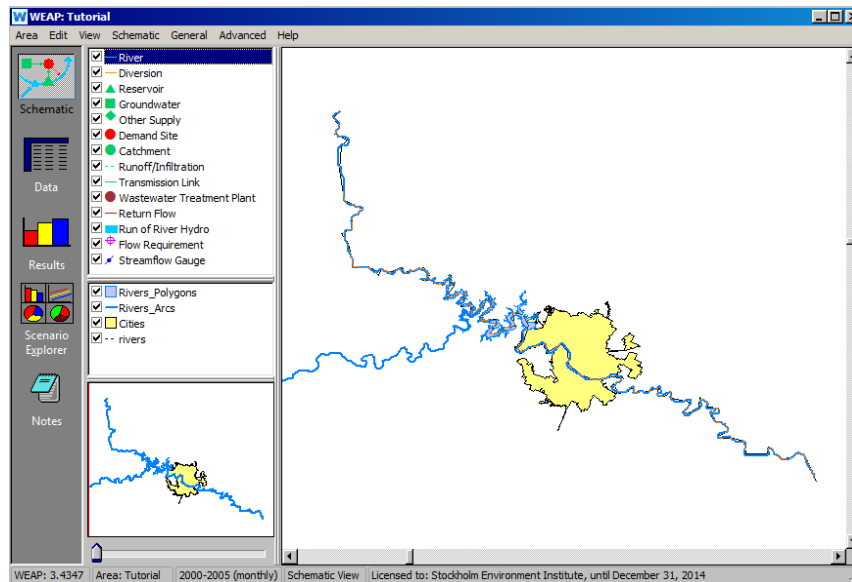
Click on the “River” symbol in the Element window and hold the click as you drag the symbol over to the map. Release the click when you have positioned the cursor over the upper left starting point of the main section of the river. Move the cursor, and you will notice a line being generated from that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

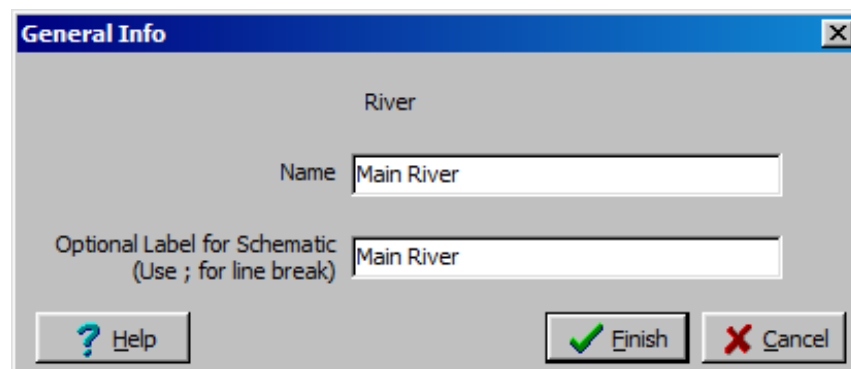
*Follow the main river, drawing from the upstream (upper left) to the downstream (lower right), clicking once to end each segment that you draw. You can follow the line of the river as closely as you like, or you can draw a less detailed representation (below). Note though, that how closely you follow 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.*



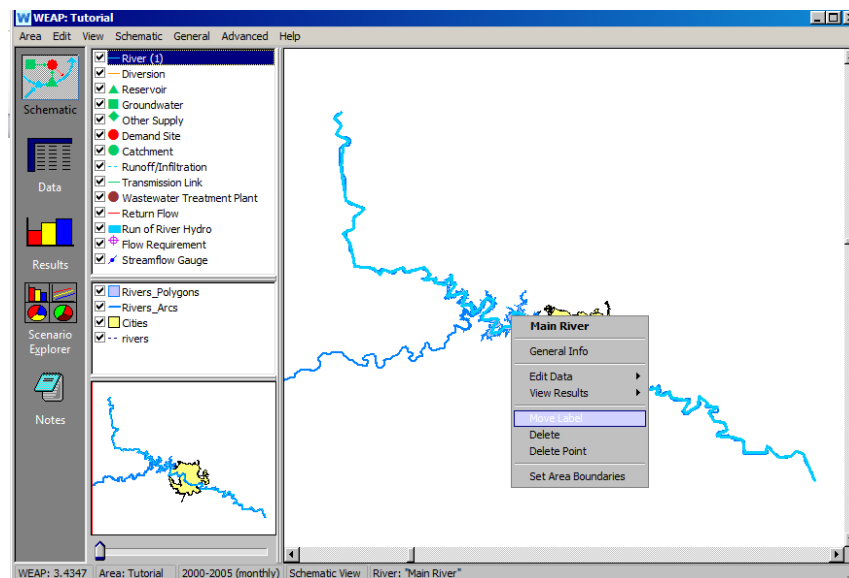
When you double click to finish drawing the river, a dialog box appears for naming the river (see below).

*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).

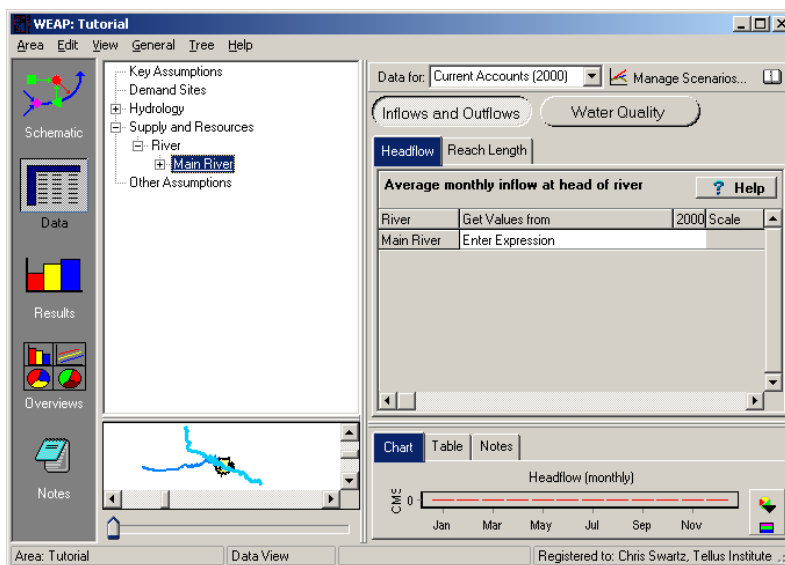
You can move the river label to another location by right clicking anywhere on the river and selecting "Move Label." The label will follow the cursor - single click when the label is in the desired location.



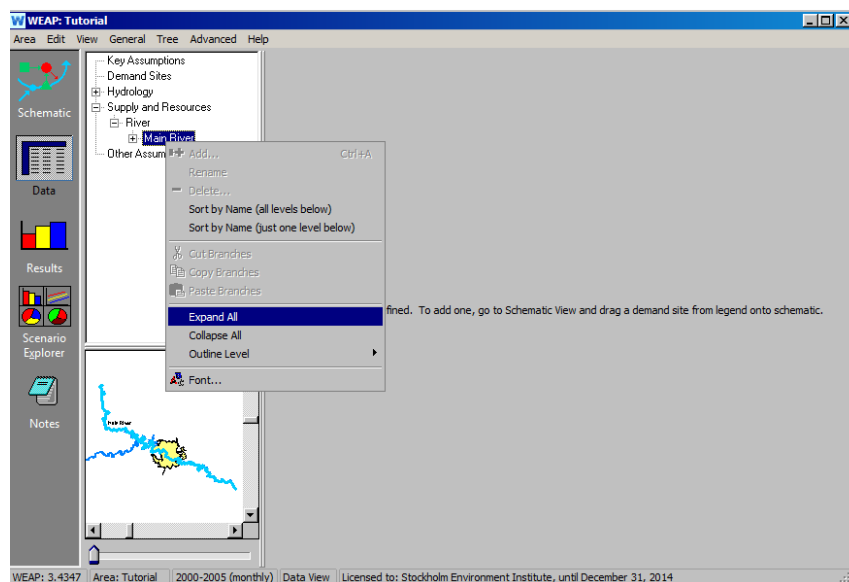
## 7. Enter Data for the Main River

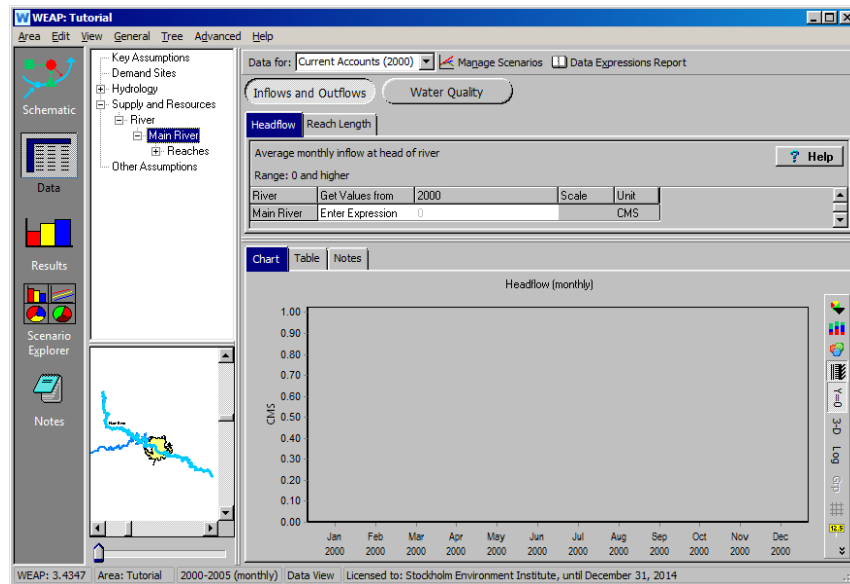
There are two ways to navigate to the data entry section of WEAP to enter data for the Main River.

- 1) Right-click on the Main River and select Edit data and any item in the list.
- 2) 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.

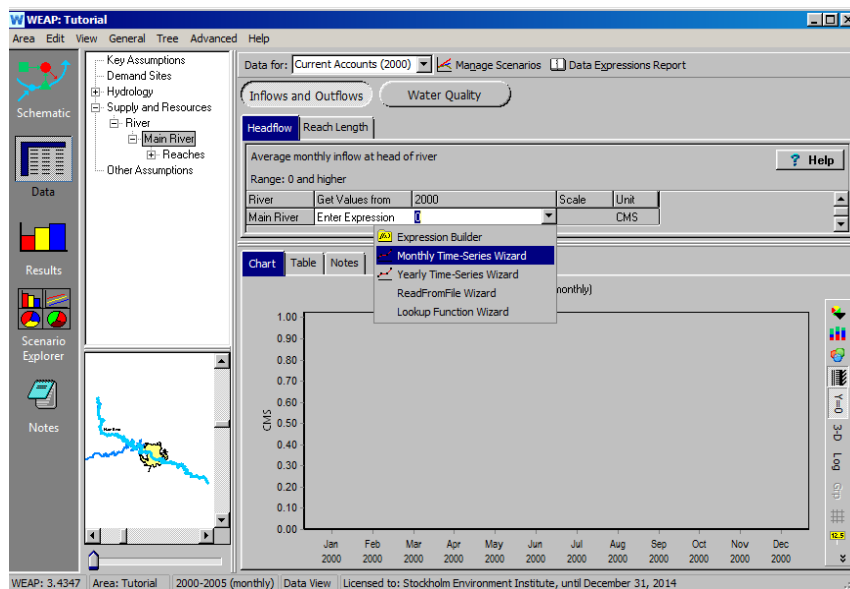


Alternatively, you can use the Tree pull-down menu and select “Expand All” to view all branches.



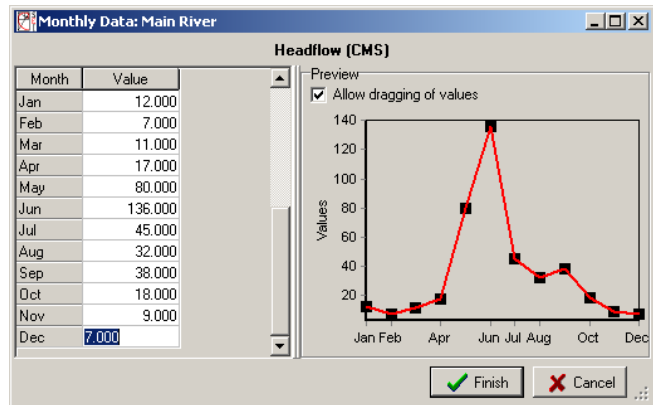


The "Inflows and Outflows" window should be open - if it isn't, click on the appropriate button. Click on the "Headflow" tab. Click on the area just beneath the bar labeled "2000" in the data input window to view a pull-down menu icon. Select the "Monthly Time-Series Wizard" from the drop-down menu.



Use the Monthly Time Series Wizard to enter the following data series:

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



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.



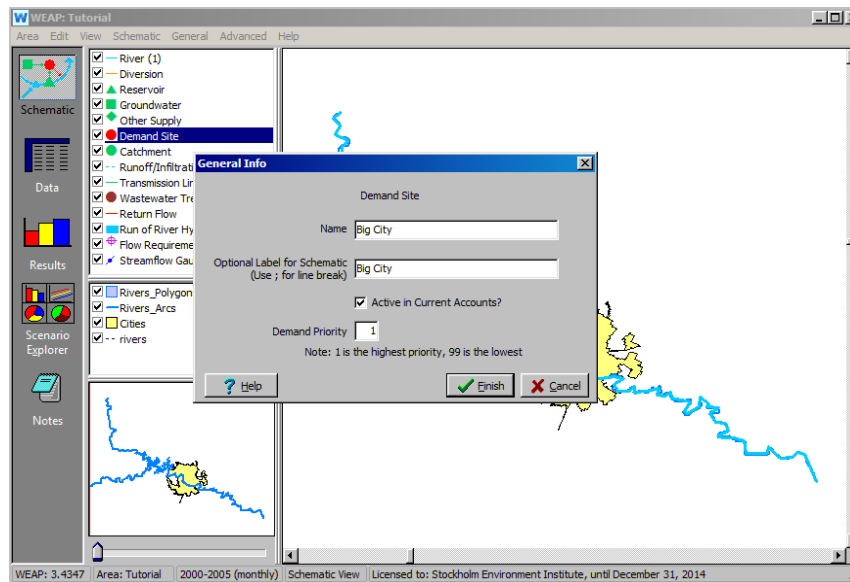
WEAP divides up rivers into reaches (segments). Originally your river has only one reach; as you add withdrawal and return points, WEAP will automatically create new reaches.

## 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.*

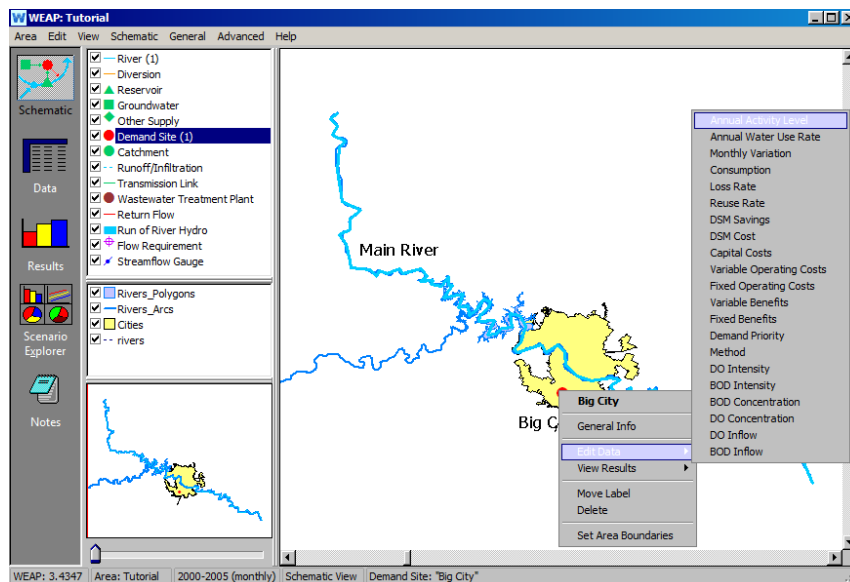




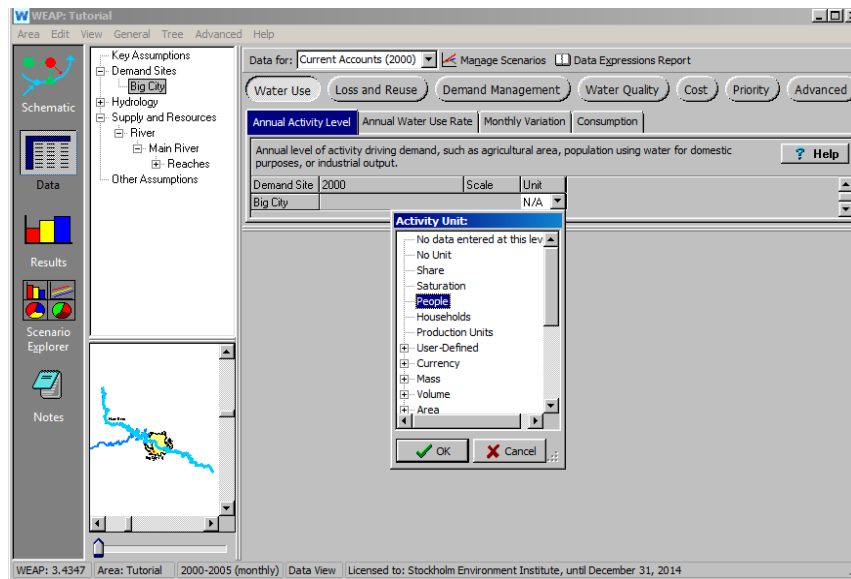
Right click on the Big City demand site and select "Edit data" and "Annual Activity Level." This is the alternative way to edit data, rather than clicking on the "Data" view icon on the side bar menu and searching through the data tree.



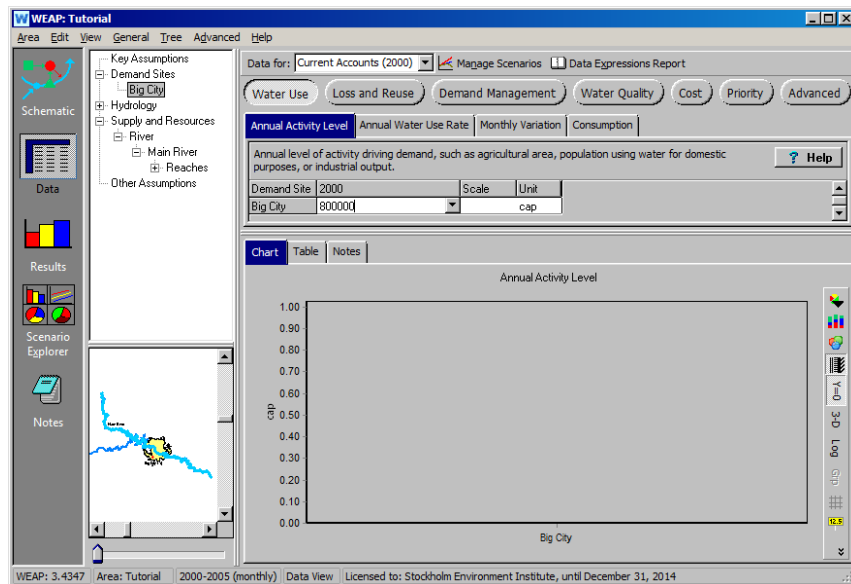
The Demand Priority represents the level of priority for allocation of constrained resources among multiple demand sites. WEAP will attempt to supply all demand sites with highest Demand Priority, then moving to lower priority sites until all of the demand is met or all of the resources are used, whichever happens first



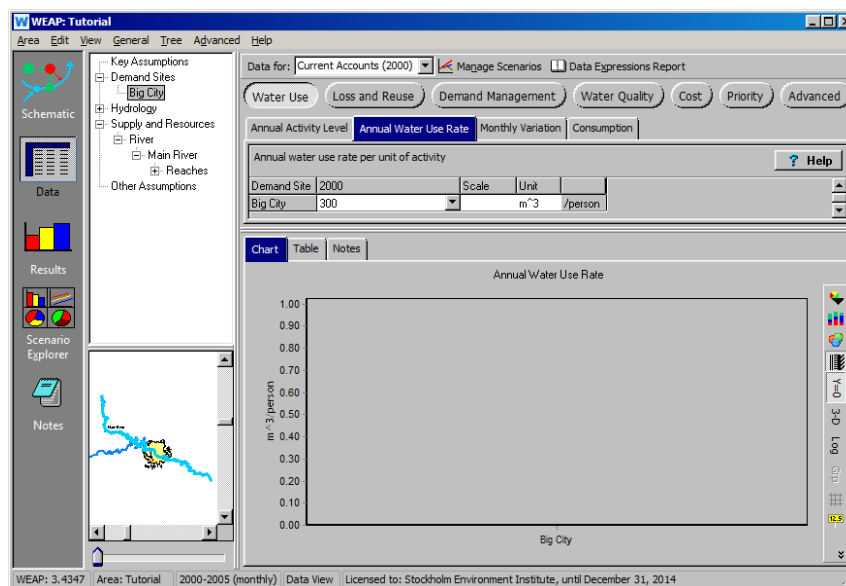
You must first select the units before entering data. Click on the “N/A” under Unit in the Annual Activity level tab. Pull down the arrow that appears, select "People", and click “OK.”



*In the space under the field labeled "2000", enter the Annual Activity Level as 800,000.*



*Next, click on the "Annual Water Use Rate" tab and enter 300 under the year 2000.*



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.

We will not edit these values for the city demand, but we will edit them later for the agricultural demand.

*Finally, click on the "Consumption" tab and enter 15. Note that the units are pre-set to "percent."*

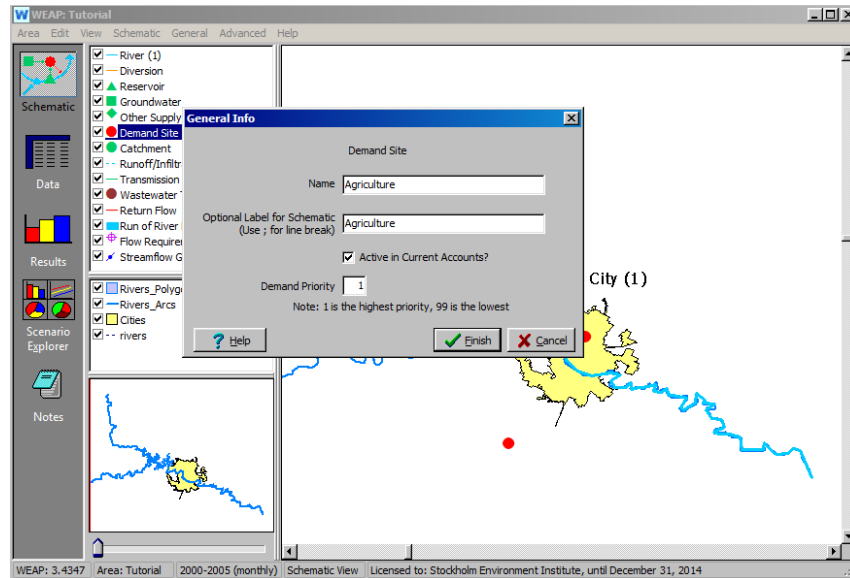
## 9. Create an Agriculture Demand Site

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.*

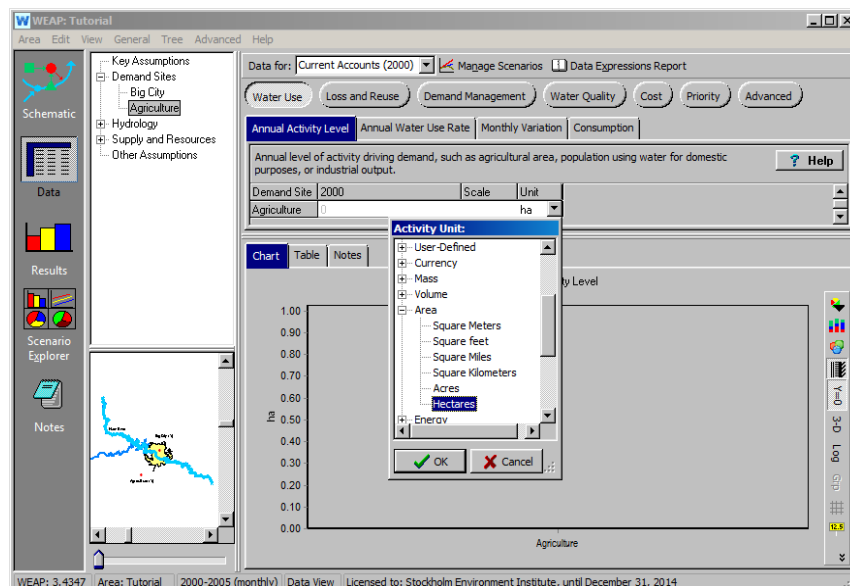


Consumption represents the amount of water that is actually consumed (i.e. is not returned in the form of wastewater).

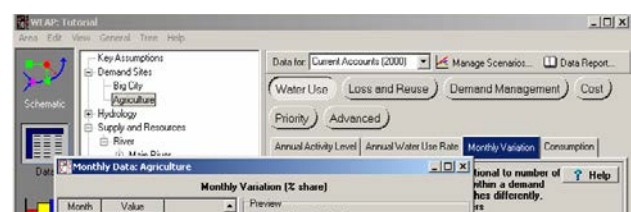


In the same manner as for Big City, enter the Annual Activity Level and Annual Water Use Rate in the Data View for the Agriculture demand site after first selecting "hectares" as the units (you may have to click on the “plus” sign to the left in the tree in order to see all of the options for area units).

*Annual Activity Level*      100,000 hectares  
*Annual Water Use rate*      3,500 m<sup>3</sup>/hectare

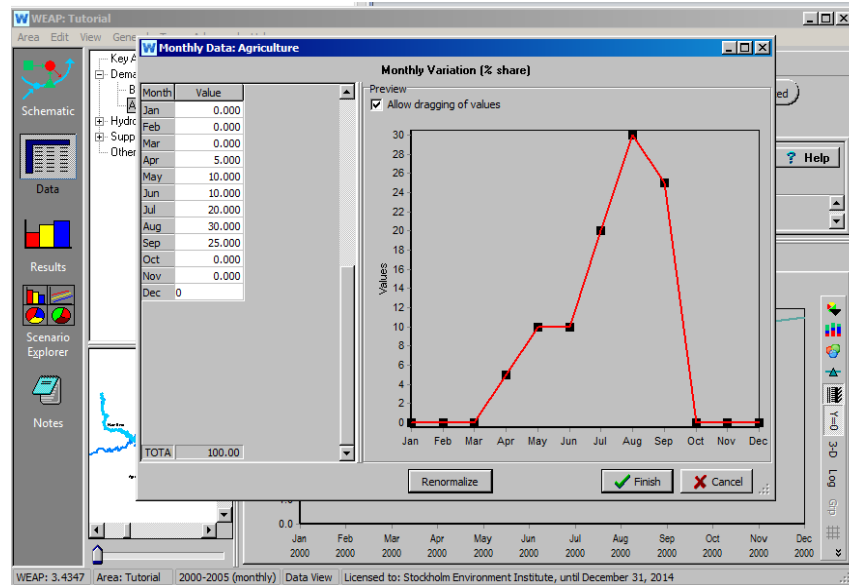


Select the Monthly Variation tab and the Monthly Time Series Wizard to enter the data below for the monthly variation in the water use rate.



*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.*

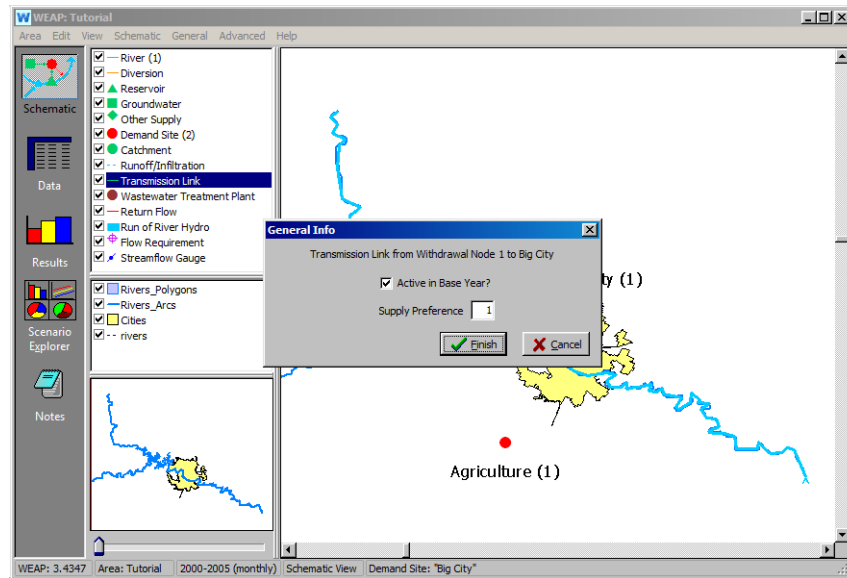


You could have created one single demand site integrating both urban and agriculture demand. However, we will see later that this removes some of the flexibility in the water supply priorities allocation.

## 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.*

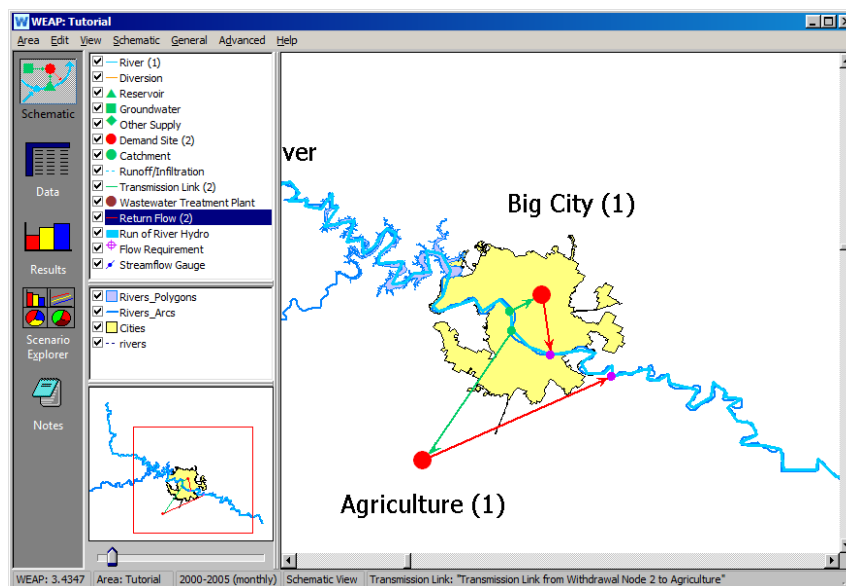


The Supply Preference parameter allows you to define which source should be used in priority to supply water to this Demand Site. WEAP will attempt to supply all of the demand with sources having the highest preference level, only using lower-level sources if the high-level sources do not have sufficient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



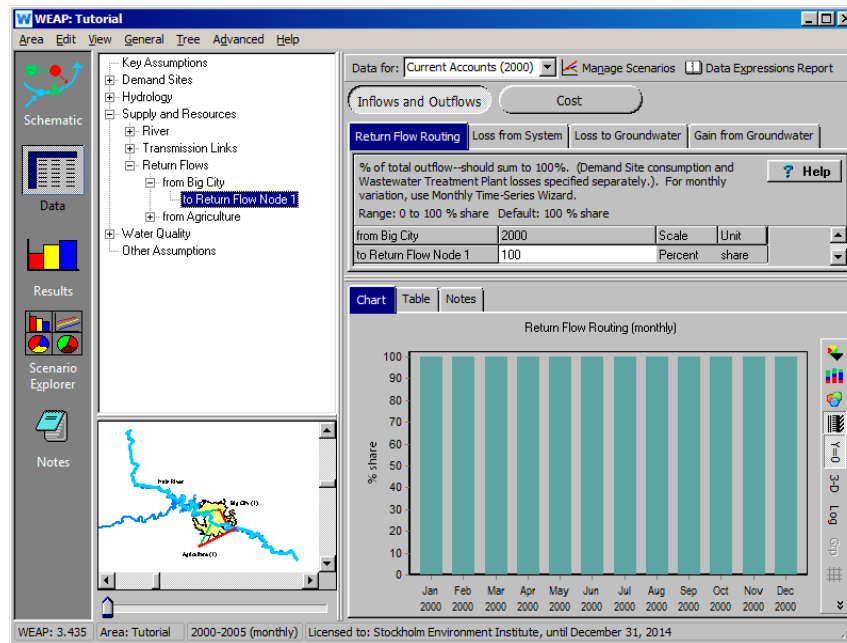
Next, set the Return Flow Routing for the Big City Return Flow. Do this by right-clicking on each Return Flow and selecting "edit data" and "Return Flow Routing" or by going to the Data view\Supply and Resources\Return Flows\from Big City.

*Set the Return Flow Routing to 100%.*

Do the same for the Agriculture Return Flow.

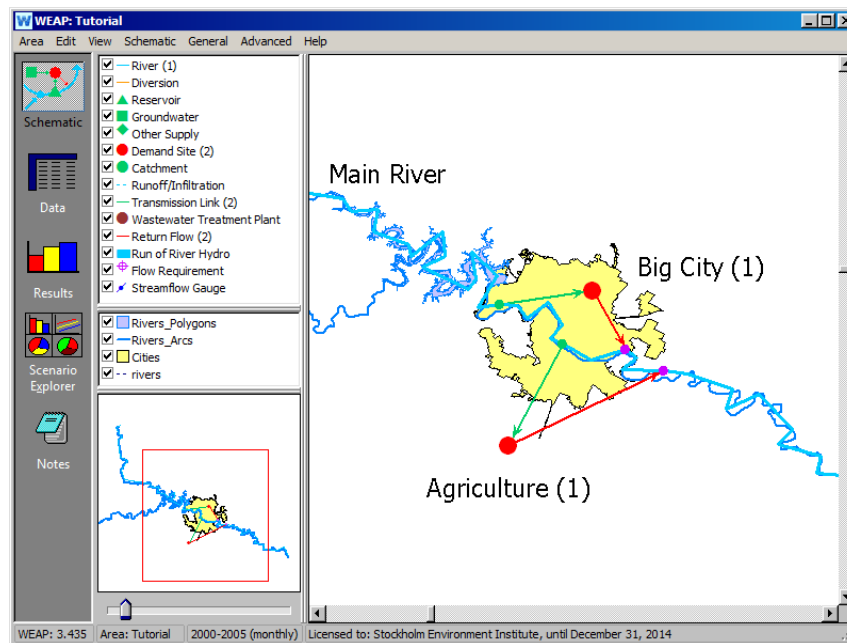


Return Flow Routing is the percent of total outflow from a demand site that is directed through a Return Flow Link. If only one Return Flow Link is created for a demand node, then the Return Flow Routing for that link must be 100%. Likewise, if multiple Return Flow links are created for a demand node, then Routing factors for all of the links must sum to 100%. Losses within the Return Flow Links are specified separately.



## 12. Check your Model

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



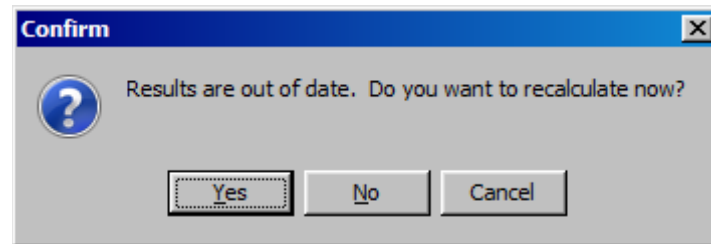
## Getting First Results

### 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

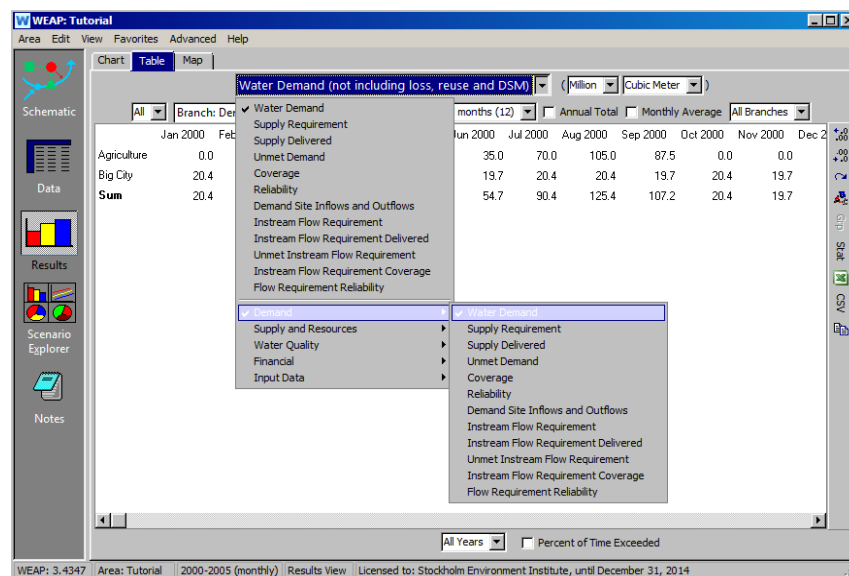


Reference Scenario - the default scenario that is generated using Current Accounts information for the period of time specified for the project (here, 2000 to 2005). When the computation is complete, the Results view will appear.



## 14. Check your Results

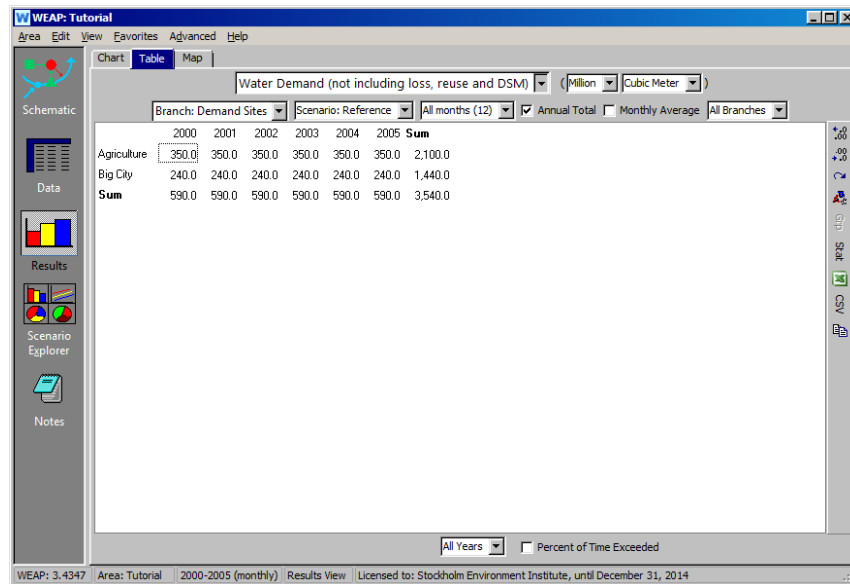
Click on the “Table” tab and select “Demand” and “Water Demand” from the primary variable pull-down menu in the upper center of the window (see below).



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:

<i>Annual Demand for Agriculture</i>	<i>350 M m<sup>3</sup></i>
<i>Annual Demand for Urban Area</i>	<i>240 M m<sup>3</sup></i>

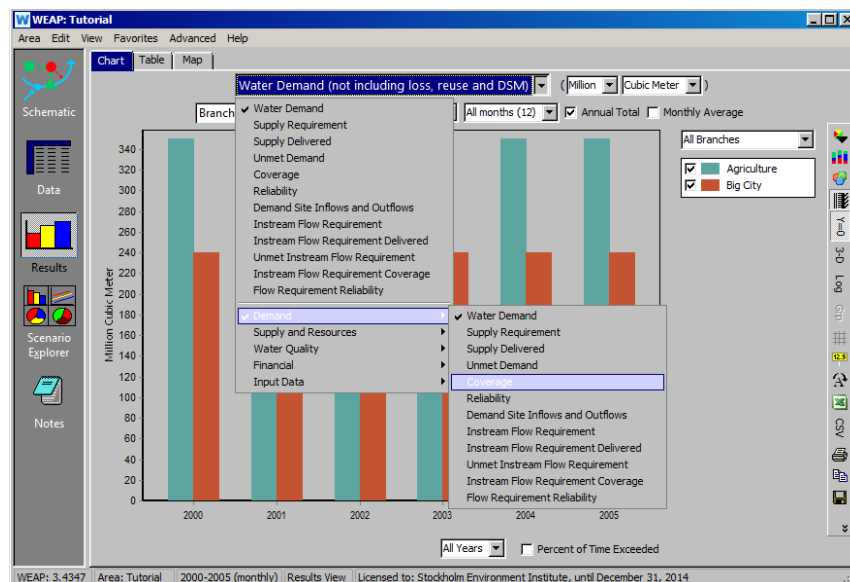


If you do not obtain those values go back to the “Data” view and check your inputs.

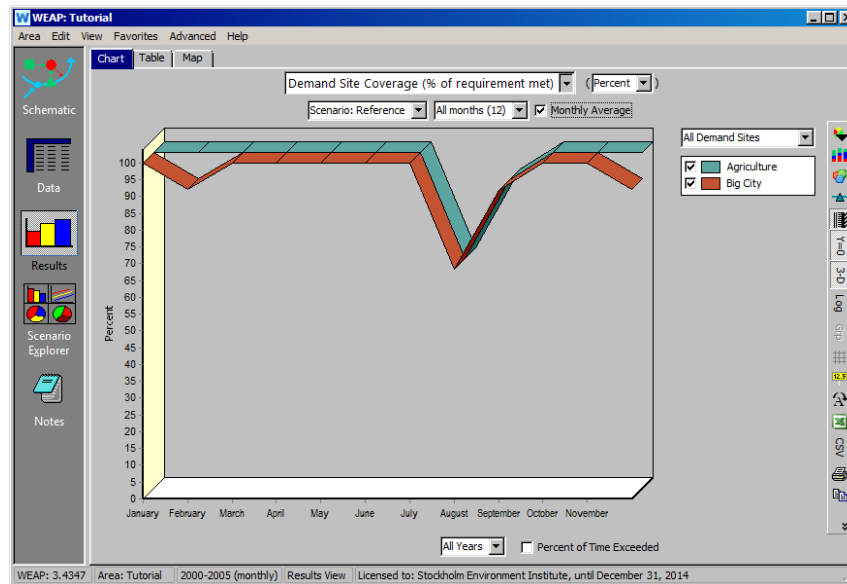
If you obtain an error or warning message read it carefully as it might reveal where in your inputs is the discrepancy, or which step you skipped.

## 15. Look at Additional Results

Now, look at the monthly Demand Coverage rates in graphical form. Click on the “Chart” tab. Select “Coverage” from the primary variable pull-down menu in the upper center of the window. Right now the Demand variables are shown at the top of the menu, since Demand is checked below. If you were in another variable subsection, such as Supply and Resources, you would have to go into Demand to find the Coverage variable.



Format the graph by selecting the 3-D option on the right 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). Note that the 3-D option allows the viewer to see both data sets even while they overlap. The graph should look like the one below.



*During the months of December and February, which have little flow in the river, Big City lacks water, and therefore demands go unmet. We modeled agriculture to only require water March-September, so it registers 100% coverage in the December-February shortage because it has no water demand. Agriculture only has a shortfall in supply in the month of August and September, when the plants require the most water. Note that because Agriculture and Big City both have a supply preference of 1, when there is water shortage they will have equal percentages of unmet demand, assuming they are both demanding water at that time.*



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.



---

# WEAP

Water Evaluation And Planning System

# Basic Tools

## ***A TUTORIAL ON***

*Creating and Using Key Assumptions* .....42

*Using the Expression Builder*.....45

August 2016

**Note:**

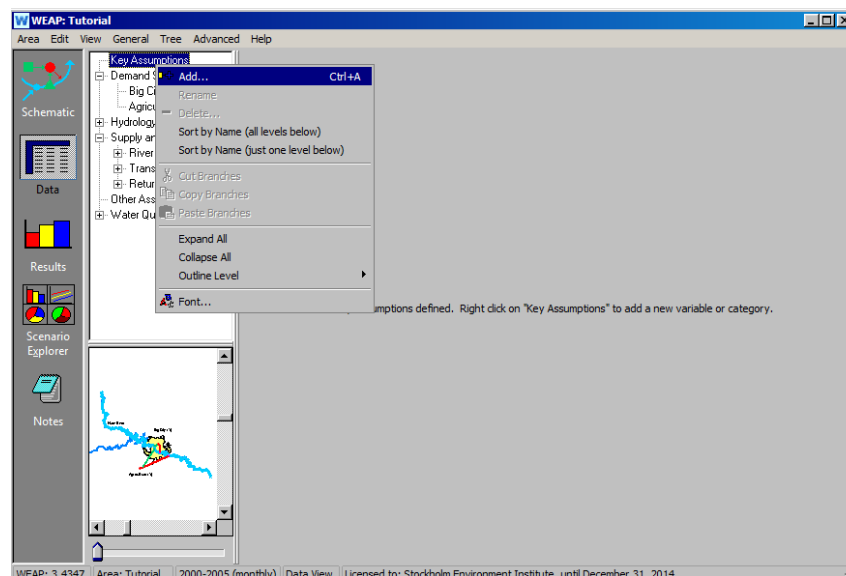
For this module you will need to have completed the previous module (“WEAP in one hour”) or have a basic knowledge of WEAP (creating an area, drawing a model, entering basic data, obtaining first results). To begin this module, go to the Main Menu, select “Revert to Version” and choose the version named “Starting Point for ‘Basic Tools’ module.”

## Creating and Using Key Assumptions

### 1. Using Key Assumptions

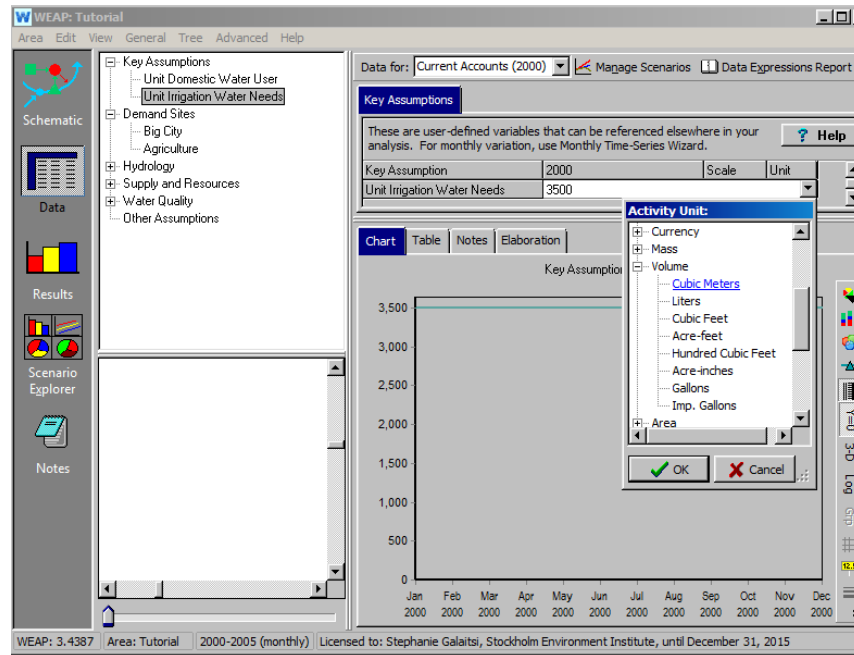
Key Assumptions are pieces of data that may be useful to apply across multiple elements. The use of key assumptions is especially worthwhile when the model has a large number of similar objects, for example demand sites, and when performing scenario analyses. In this case, you can easily set all your demand sites to have the same unit domestic consumption. Then, you can create scenarios to vary this consumption without having to edit each and every demand site – simply by changing the key assumption value.

Key Assumptions are created by going to the Data view and right-clicking on the Key Assumptions branch of the Data Tree. Select “Add” - this will create a new Key Assumption variable below the Key Assumption branch.



After clicking Add, you can name your Key assumptions in the Data Tree. Name them and enter the data as follows: (be sure to select the appropriate units from the Units pull-down menu. Cubic meters will be found under “Volume,”):

*Unit Domestic Water Use*                       $300 \text{ m}^3$   
*Unit Irrigation Water Needs*                 $3,500 \text{ m}^3$

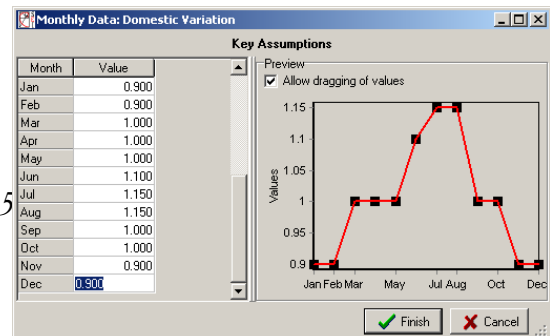


With Key Assumptions, it is important to ensure that the units designated in a Key Assumption variable match the units indicated for the variable as it occurs elsewhere in the data tree. In this case, the  $300 \text{ m}^3$  domestic water use matches the  $300 \text{ m}^3/\text{person}$  use specified in Big City/Water Use/Annual Use Rate. Similarly, the key assumption Unit Irrigation Water Needs matches the units in Agriculture/Water Use/Annual Water Use Rate.

Create one more Key Assumption, Domestic Variation, that is unitless (“No Unit”), and use the Monthly Time Series Wizard to populate it with values:

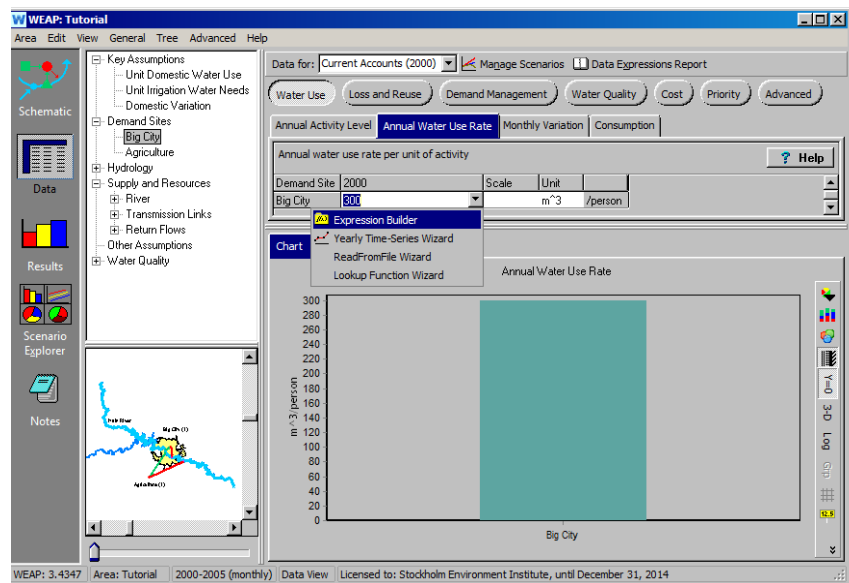
#### *Domestic Variation*

- Jan to Feb & Nov. to Dec.: 0.9  
 - Mar. to May & Sept. to Oct. 1.0  
 - June 1.1  
 - Jul, Aug 1.15



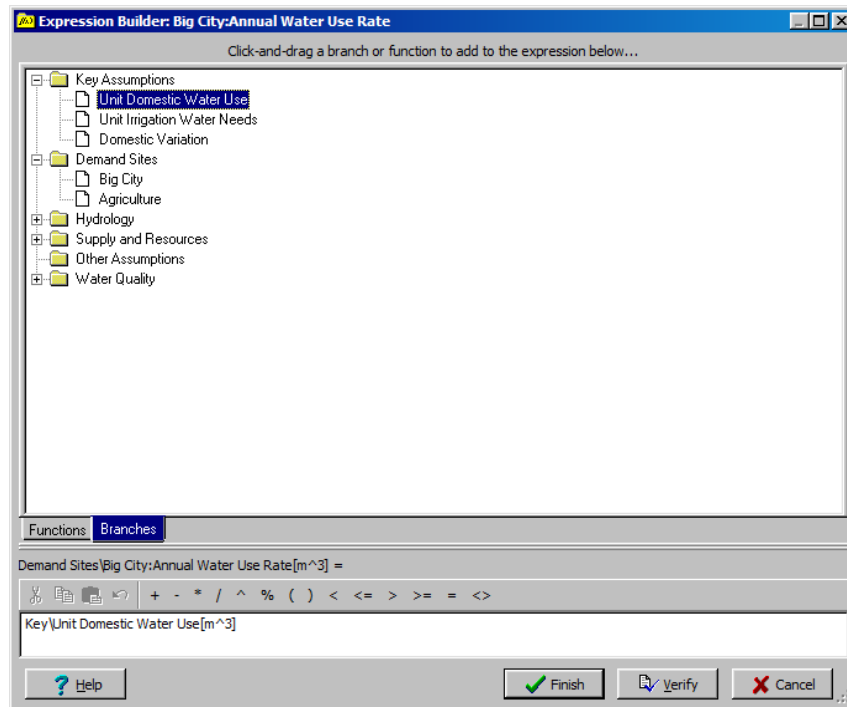
## 2. Creating References to Key Assumption

Create a Key Assumption reference for “Big City Annual Water Use.” Do this by going to the “Annual Water Use Rate” window for Big City in the Data view. Click on the Expression Builder pull-down menu in the space where you entered the “Annual Water Use Rate” (300 m<sup>3</sup>) previously.



In the Expression Builder window, delete the value of 300 from the text field at the bottom of the Expression Builder window, click on the “Branches” tab towards the bottom left of the screen, then click on the “Unit Domestic Water Rate” under Key Assumption (you may have to expand the data tree to see all of the branches) in the Data tree field and drag it down to the text field so it shows up as Key\Unit Domestic Use[m<sup>3</sup>]. Click on “Finish.”





Repeat this procedure to replace the 3500 m<sup>3</sup>/ha water use rate for the “Agriculture” Demand Site with the newly created “Unit Irrigation Water Needs” Key Assumption.

*If you check the results now by re-recalculating, you should have the same annual total values for demand as obtained in the WEAP in One Hour module:*

- Annual Demand for Agriculture 350 M m<sup>3</sup>
- Annual Demand for Urban Area 240 M m<sup>3</sup>

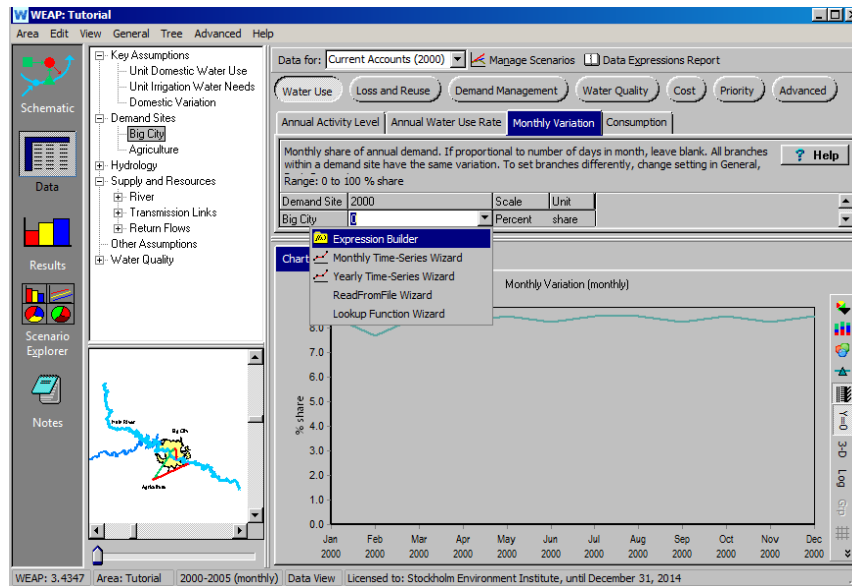


Using the same process, references to other objects’ data can also be created. This can be helpful in certain cases. Upon dragging and dropping the object to be referenced from the tree to the expression builder’s text field, a list of all available variables appears.

## Using the Expression Builder

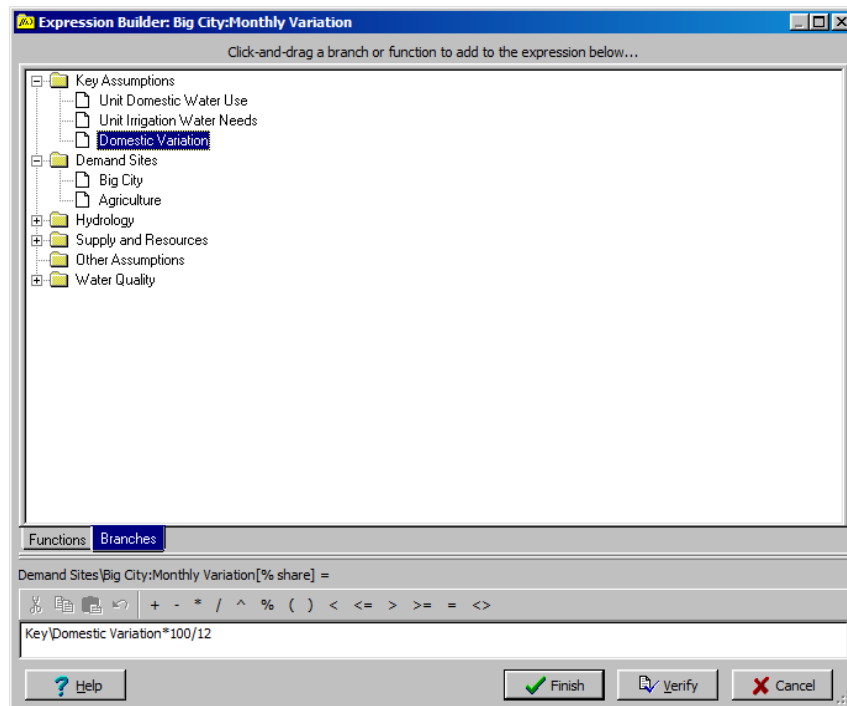
### 3. Creating Mathematical Expressions

You will now alter the monthly variation in water demand for Big City using a mathematical expression. In the Data view, click on the Big City demand site, then “Water Use” and the “Monthly Variation” tab and select the Expression Builder from the pull-down menu in the data entry bar.



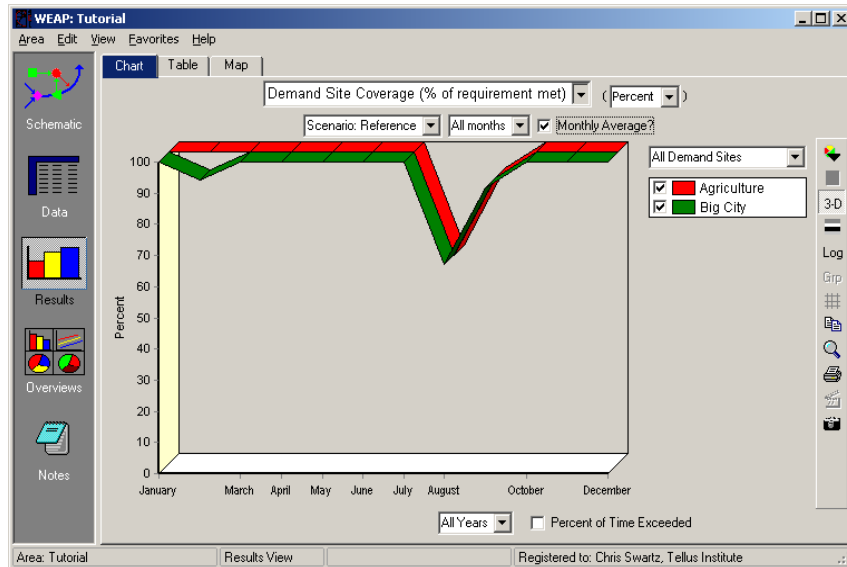
Create the following expression by pulling down the “Domestic Variation” Key Assumption and typing in the modifying terms:

$$\text{Key} \backslash \text{Domestic Variation} * 100 / 12$$

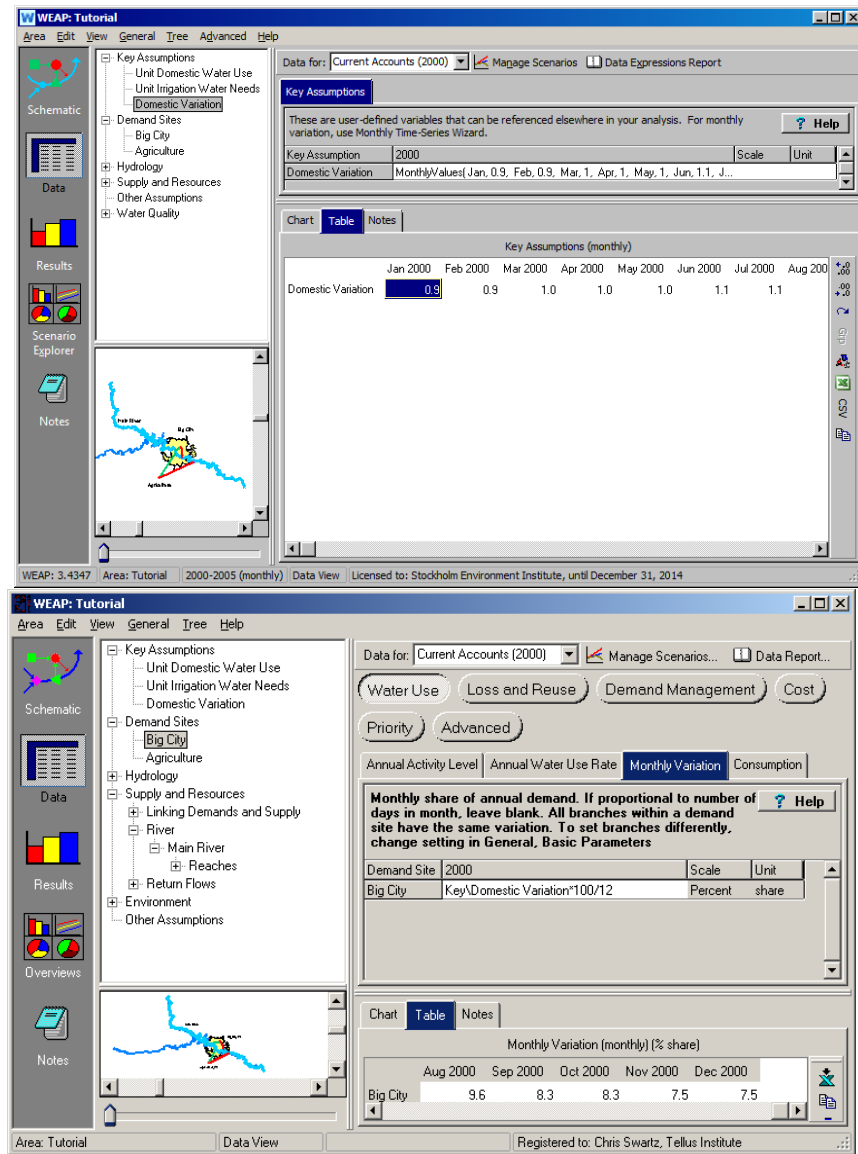


Note that if you had made a mistake in typing the expression, such as entering a space instead of a division sign, an error message would have appeared after clicking “Finish.” You would then be given the opportunity to review and correct the expression. After the correction of an error, you must click “Verify” before “Finish.”

View the new results for “Demand Site Coverage” after making these changes. Click on the Results view and click on “Yes” to recalculate. The results should appear as below:

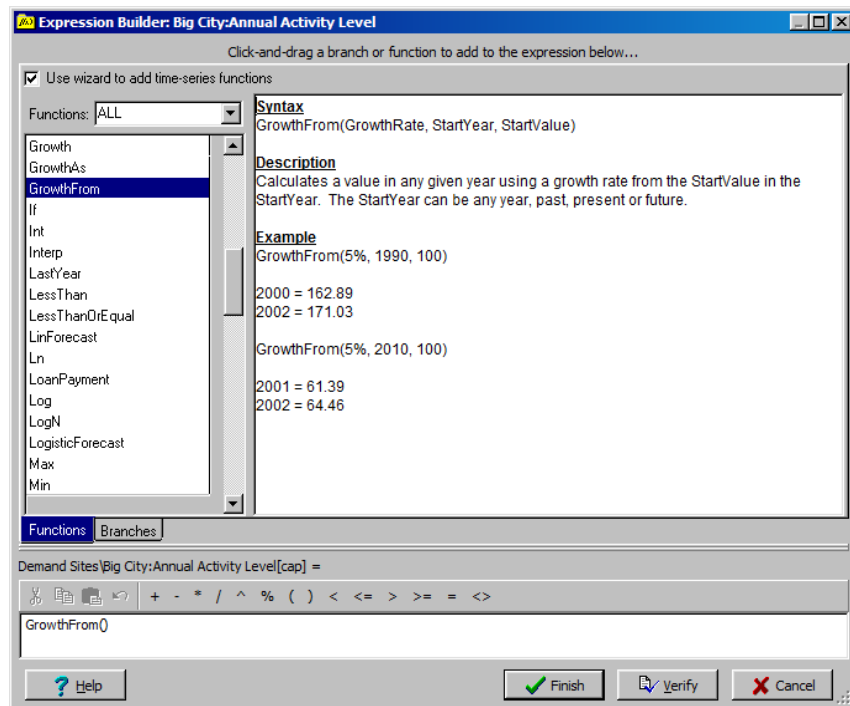
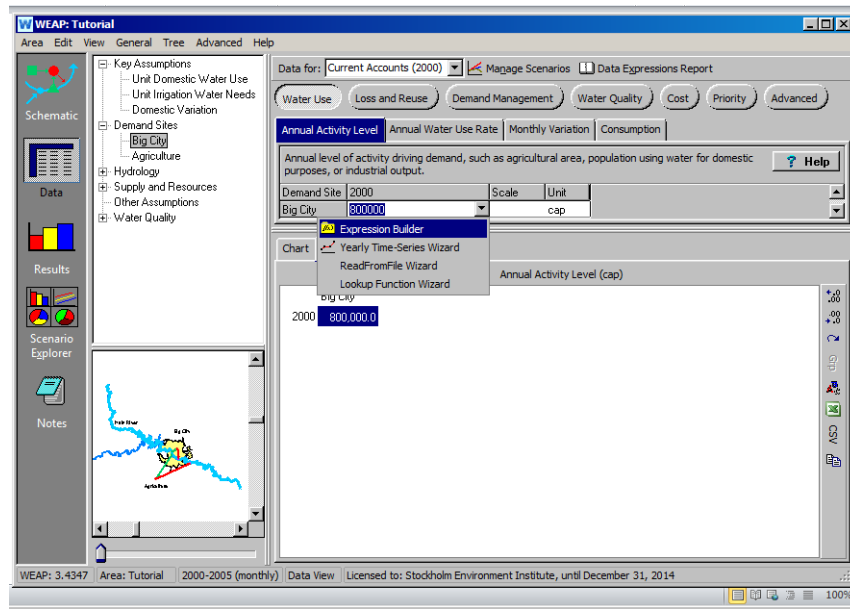


Note that there is no longer unmet demand in December for Big City because the fraction of demand in December decreased from 8.5% (originally based on the number of days in the month) to 7.5% (now based on the expression using the “Domestic Variation” Key Assumption). You can review the numerical values calculated from the “Monthly Variation” expression by selecting the “Table” tab in the data review panel at the bottom of the data window. Remember it is calculated from the original data we entered in the Key Assumptions/Domestic Variation, subjected to the equation we entered in the Expression Builder.



## 4. Using Built-In Functions

We will assume that the current population of Big City (2000) is not known, but we know its population during the last census and the growth estimate. We can use the built-in “GrowthFrom” function to compute the current population of Big City. Do this by selecting the Expression Builder from the pull-down menu in the year 2000 data input field within the “Annual Activity Level” window for Big City. Delete the present value of 800000, click on the “Function” tab rather than the “Branch” tab and drag down into the text field the “GrowthFrom” expression selected from the list of built in expressions.



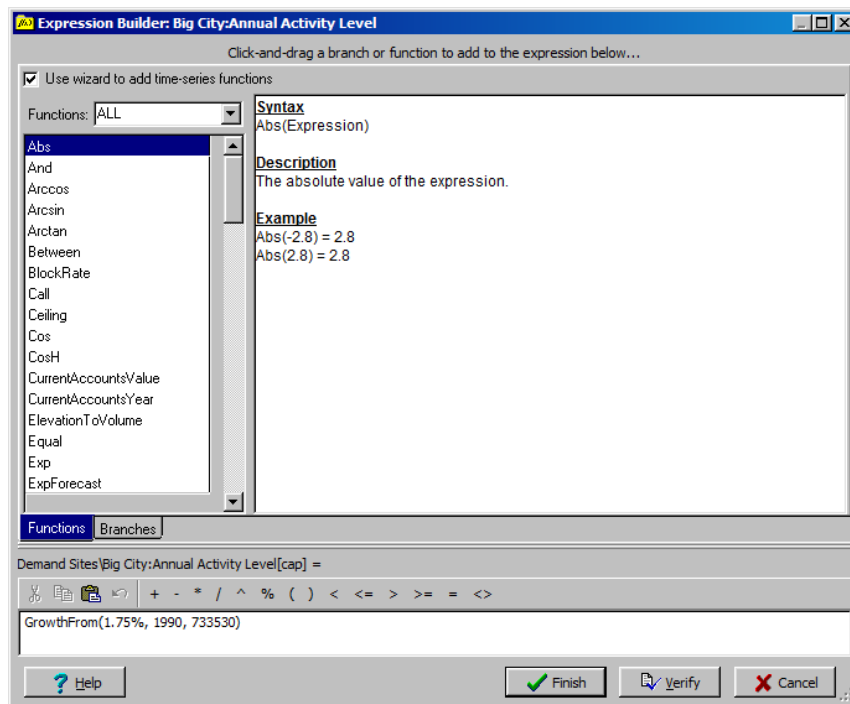
Input the following data into the “GrowthFrom” expression, using the format indicated in the description window next to the expression list.

<i>Date of last Census</i>	1990
<i>Population at last census</i>	733,530
<i>Estimated growth rate</i>	1.75%

This results in the following format for the expression:

*GrowthFrom(1.75%, 1990, 733530)*

Be sure to include the percentage sign in your expression.



The Expression Builder is only a simple way of entering expressions and functions. Savvy users can by-pass it and enter functions, references and mathematical expressions directly in the main Expression window.

---

# WEAP

Water Evaluation And Planning System

# Scenarios

## ***A TUTORIAL ON***

<i>Preparing the Ground for Scenarios .....</i>	<i>52</i>
<i>Creating the Reference Scenario.....</i>	<i>53</i>
<i>Creating and Running Scenarios.....</i>	<i>58</i>
<i>Using the Water Year Method.....</i>	<i>61</i>

**August 2016**

**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.

<i>Current Accounts Year</i>	<i>2000 (unchanged)</i>
<i>Last Year of Scenarios</i>	<i>2015</i>

### 3. Create an Additional Key Assumption

Create the following key assumption:

<i>Population Growth Rate</i>	<i>2.2</i>
-------------------------------	------------

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

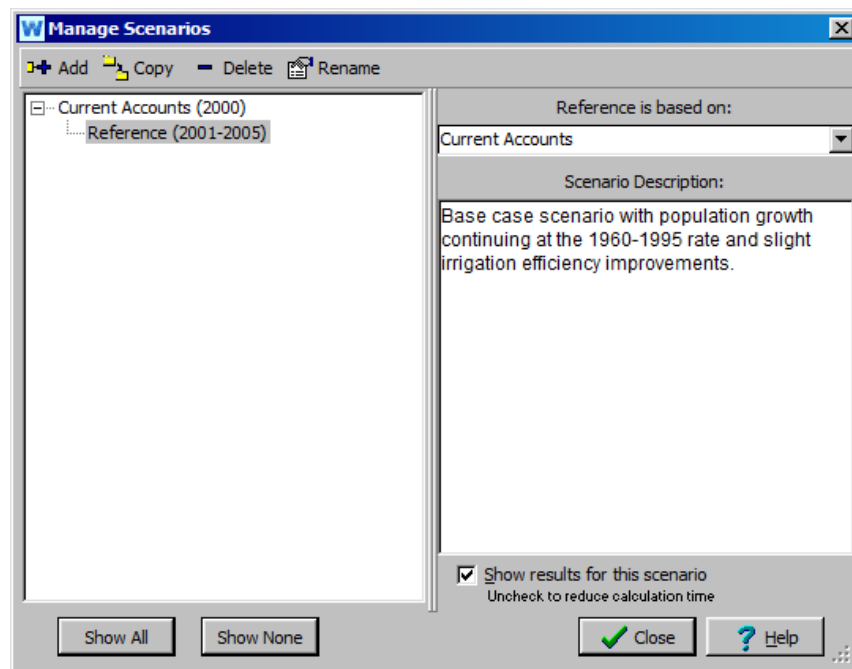


## Creating the Reference Scenario

### 4. Describe the Reference Scenario

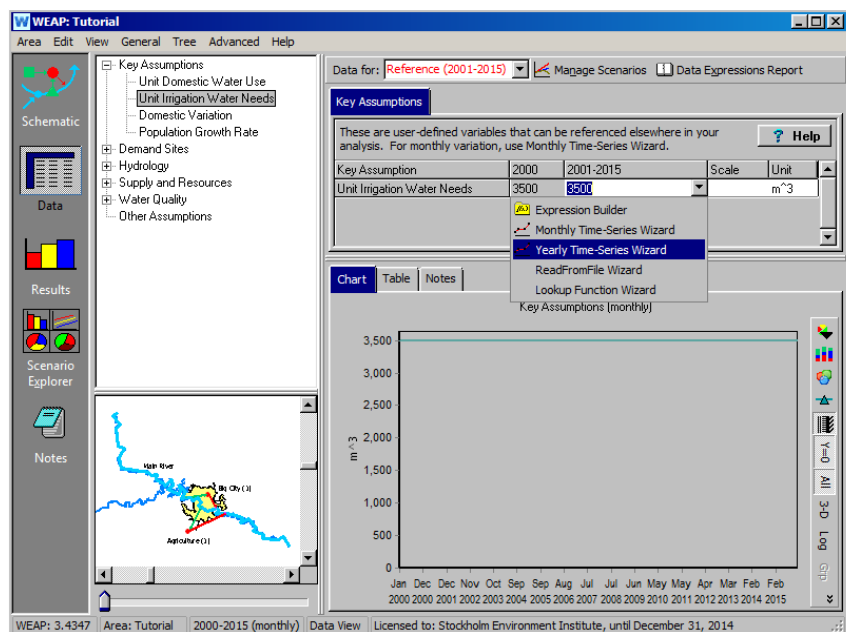
The “Reference” Scenario always exists. Change its description in the Area\Manage Scenarios menu to reflect its actual role. Note that you must be in the Data View or Schematic view to have access to the “Manage Scenarios” option in the Area menu.

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

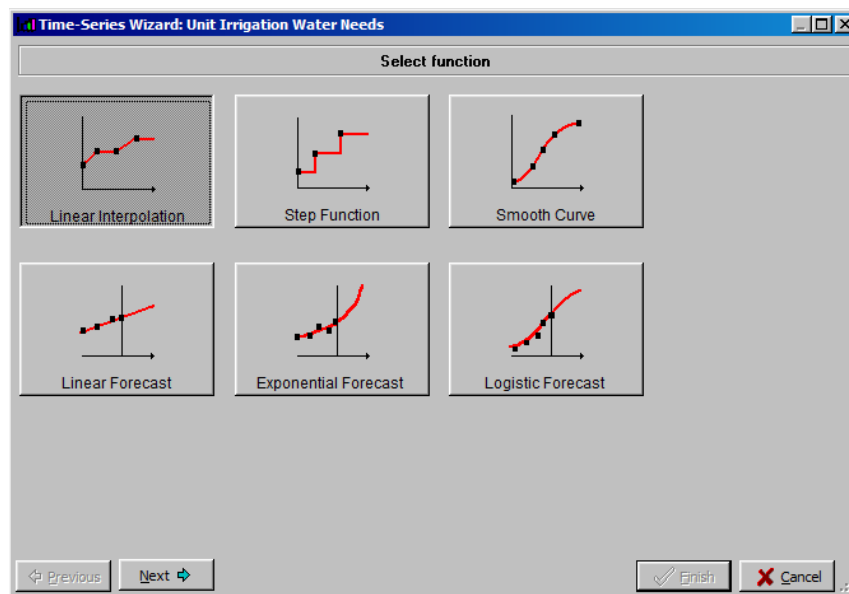


### 5. Change the Unit Irrigation Water Use

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 "Linear Interpolation" 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:

*Enter Time-Series Data: Linear Interpolation*

*Data:*

2000 3500

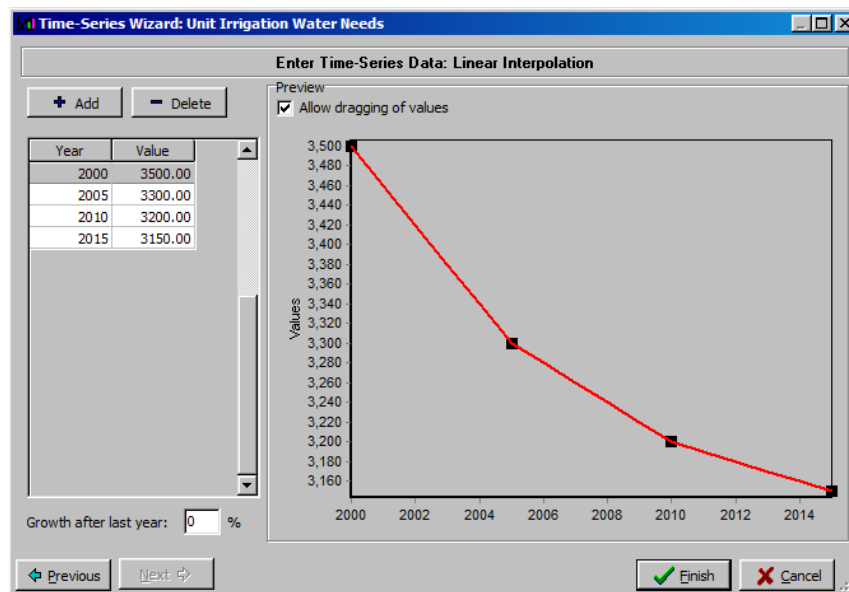
2005 3300

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.

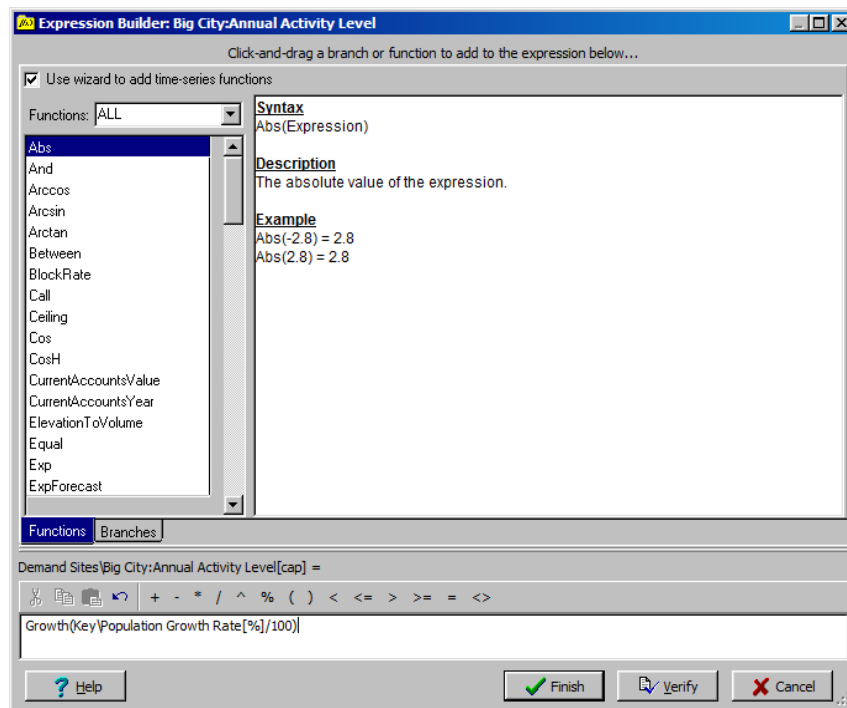
The Yearly Time Series Wizard helps you create expressions. You can also simply type or edit the expression (in this case, “Interp( 2000,3300, 2005,3300, 2010,3200, 2015,3150 )”) without running the wizard, either directly or through the Expression Builder.

## 6. Set the Population Growth

Change 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.*



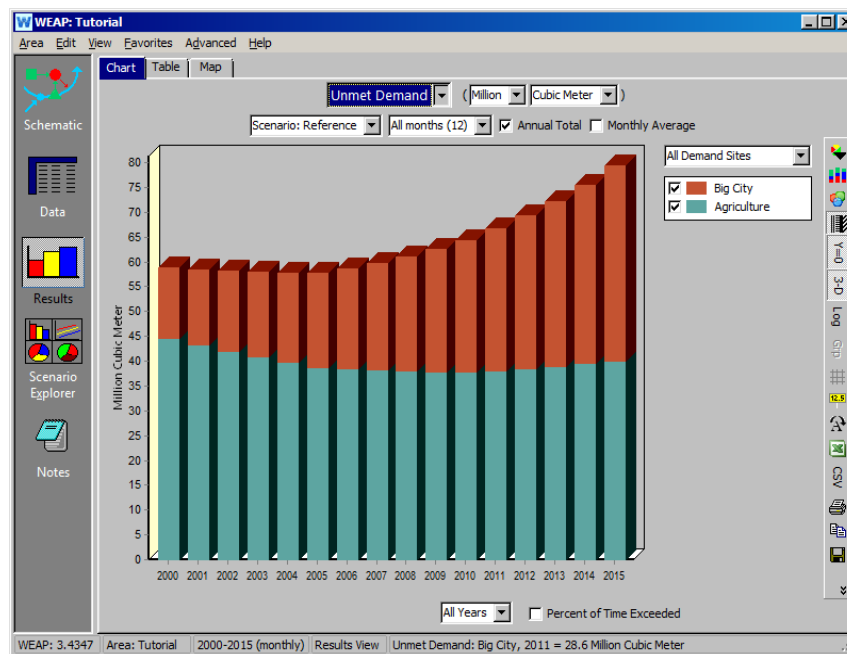
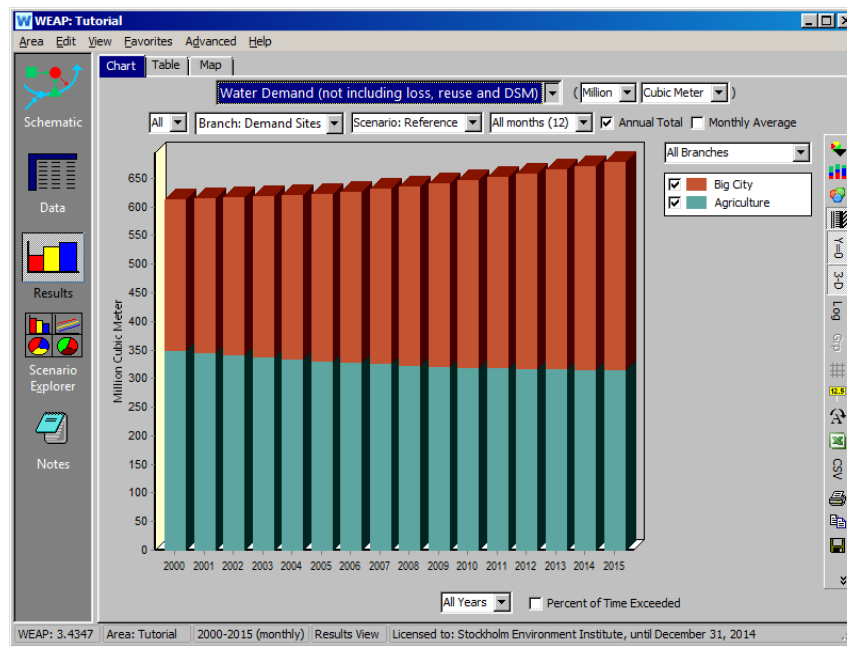
The same effect could have been modeled without creating a Key Assumption in the first place. We will see however that doing so provides more flexibility when adding other scenarios.

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?*

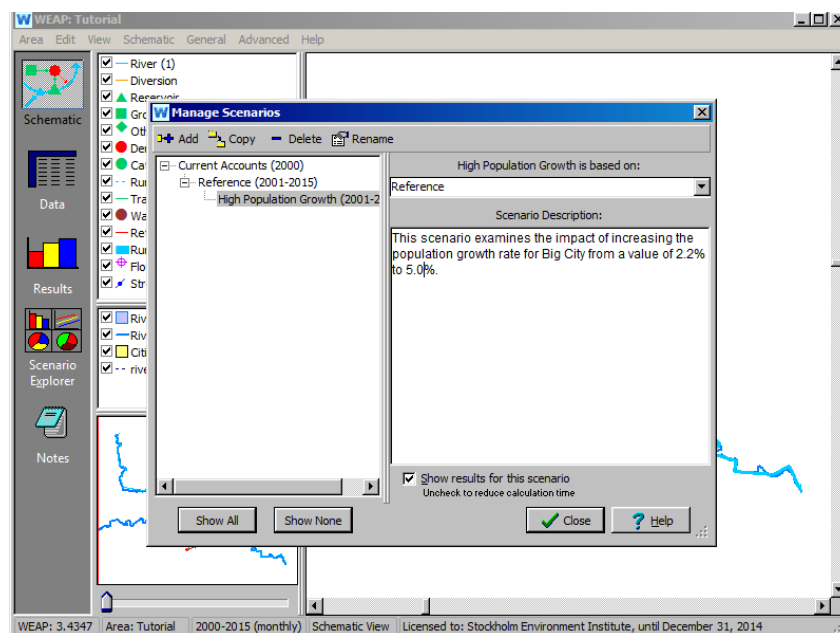


# Creating and Running Scenarios

## 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.

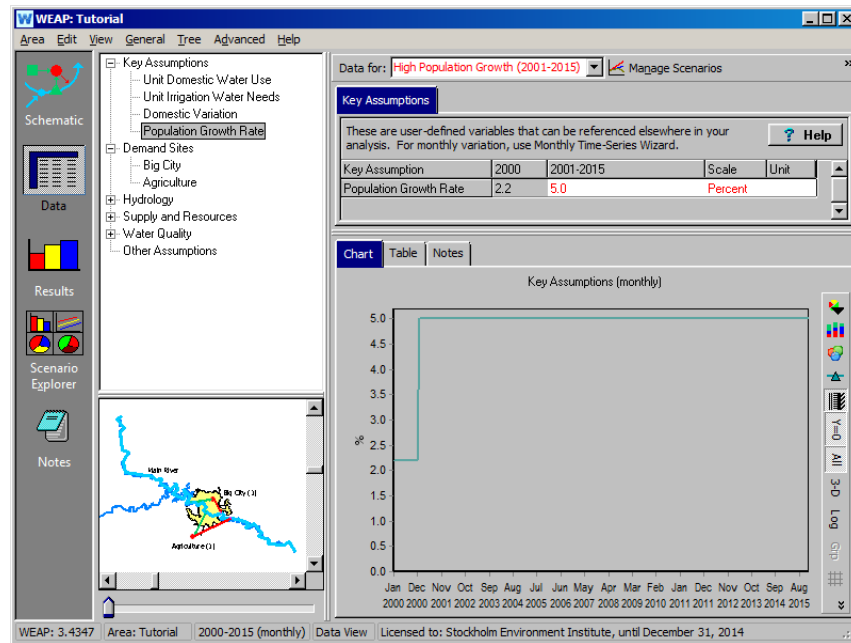
*For this you will have to return to the Data View or the Schematic View. Choose the menu “Area”, “Manage Scenario”, right-click the “Reference” scenario and select “Add.” Name this scenario “High Population Growth” and add the description “This scenario looks at the impact of increasing the population 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:

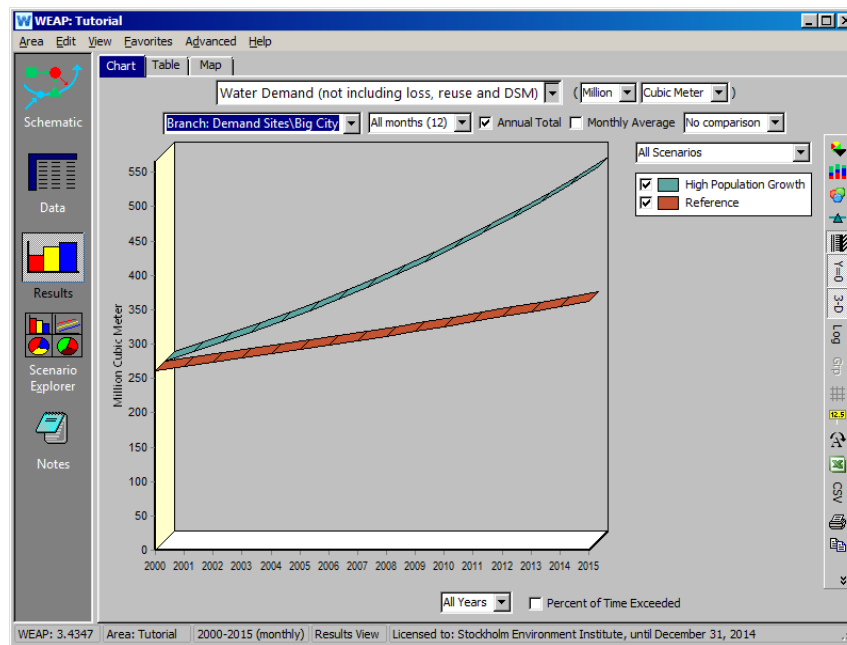
*Select the “Population Growth Rate” Key Assumption and change the value under the 2001-2015 field to 5.0. Note that the color of the data field changes to red after the change - this occurs for any values that are changed to deviate from the “Reference” scenario value.*



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

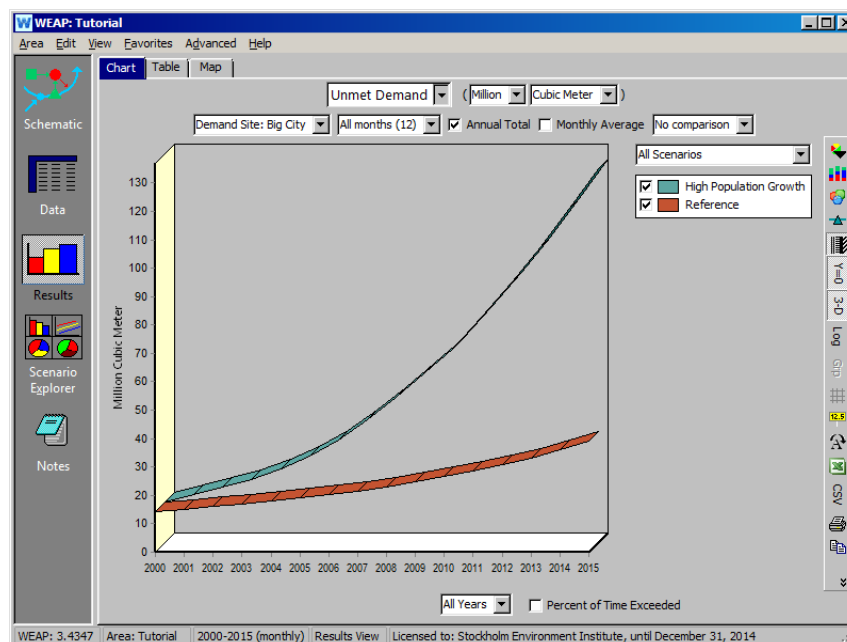
Compare, graphically, the results for the two scenarios we have established so far (Reference and Higher Population Growth).

*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.





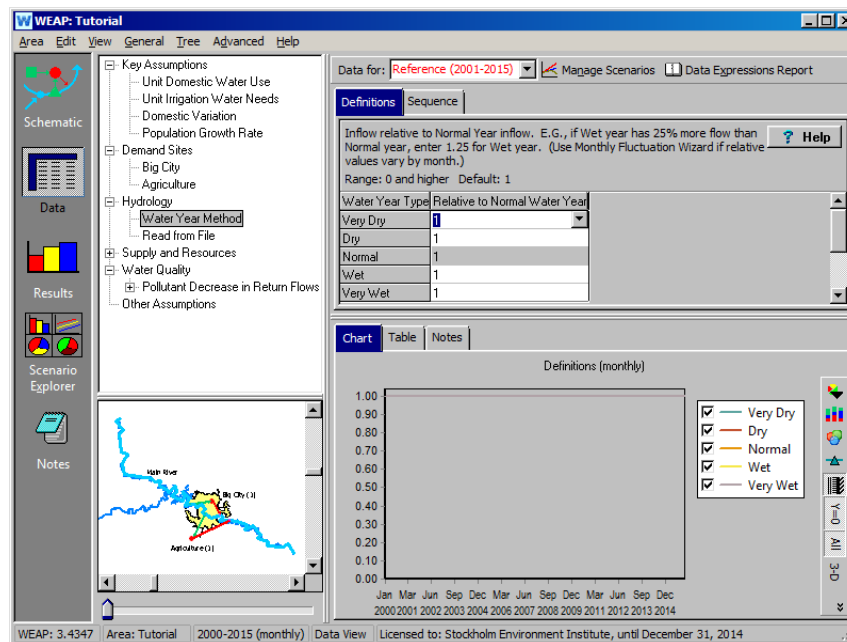
When creating many scenarios in the same area, the computation can become lengthy. In this case you can exclude some of the scenarios from the calculation by unchecking the “Show results for this scenario” box in the scenario manager for those scenarios.

## Using the Water Year Method

### 11. Create the Water Year Definitions

The previous exercise *only varied demand, not supply*. In this step we now want to see how natural variation in climate data (stream flow, rainfall etc.) can be taken into account in WEAP through scenario analyses. We will use the “Water Year Method” as an example. The Water Year Method is a simple means to represent variation in climate data such as streamflow, rainfall, and groundwater recharge. The method first involves defining how different climate regimes (e.g., very dry, dry, very wet) compare relative to a normal year, which is given a value of 1. Dry years have a value less than 1, very wet years have a value larger than 1.

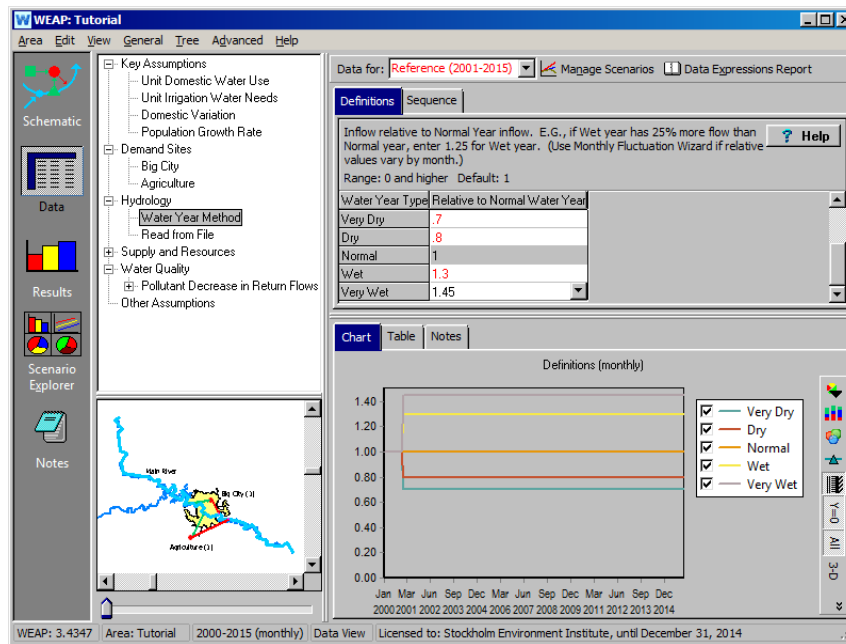
With the “Reference” scenario selected, go into the data view and click on the “Water Year Method” branch under “Hydrology” in the Data tree.



Select the "Definitions" tab and expand the window, if necessary, to see all five definitions. Enter the following data:

Very Dry 0.7  
Dry 0.8

*Normal*      1.0  
*Wet*          1.3  
*Very wet*    1.45

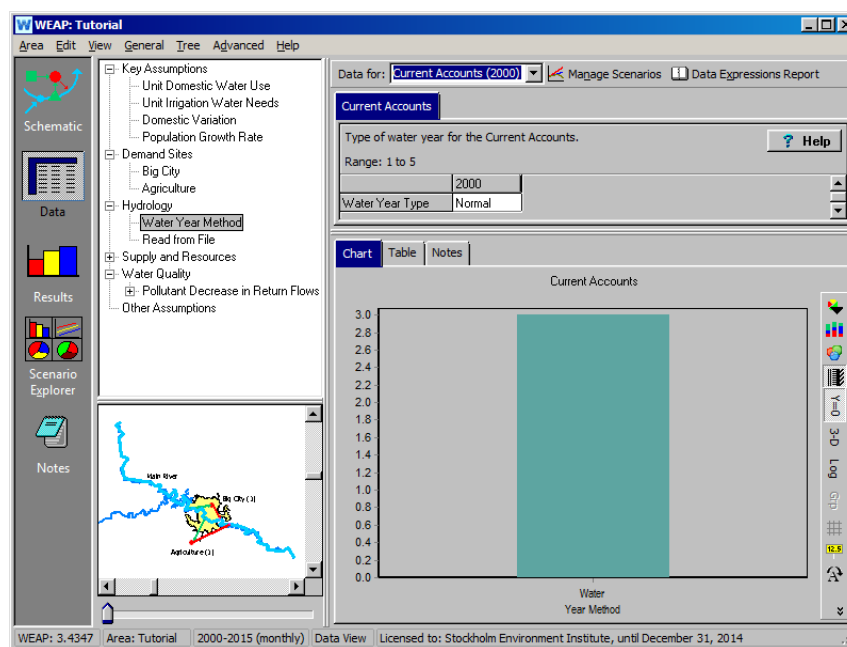


Monthly variations can be entered with the Water Year Monthly Fluctuation Wizard in the drop down menu.

## 12. Create the Water Year Sequence

The next step in using the “Water Year Method” is to create the sequence of climatic variation for the scenario period. Each year of the period is assigned one of the climate categories (e.g., wet). Select the "Sequence" tab under the "Water Year Method" branch.

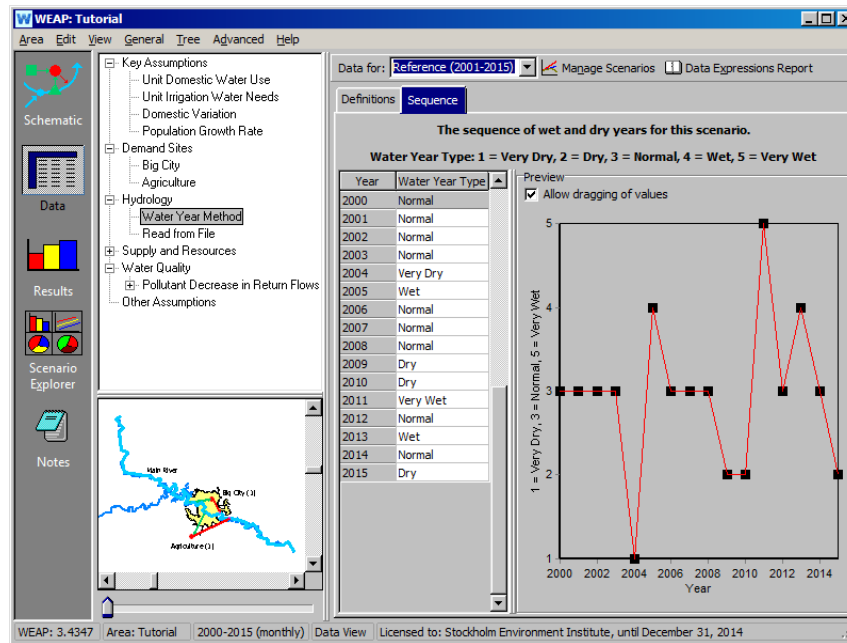
*Set the Current Account as Normal*



Then, select the “Reference” scenario and input the following sequence.

2001-2003	<i>normal</i>
2004	<i>very dry</i>
2005	<i>wet</i>
2006-2008	<i>normal</i>
2009-2010	<i>dry</i>
2011	<i>very wet</i>
2012	<i>normal</i>
2013	<i>wet</i>
2014	<i>normal</i>
2015	<i>dry</i>

To input this sequence

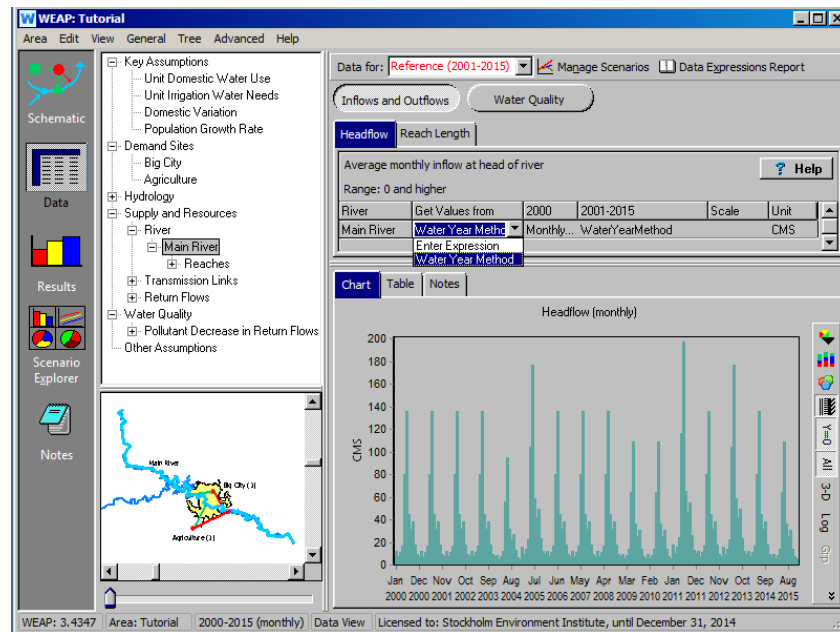


In order to let the inflows to the model (in our case, the headflow of the main river) vary in time, WEAP offers two strategies. If detailed forecasts are available, those can be read using the ReadFromFile function (refer to the Tutorial module on Format and Data for more details). Another method, which is the one presented here, is the “Water Year Method.” Under this method every year in the model’s duration can be defined as normal, wet, very wet, dry or very dry. Different scenarios can then alter the chosen sequence of dry and wet years to assess the impact of natural variation on water resources management.

### 13. Set up the Model to Use the Water Year Method

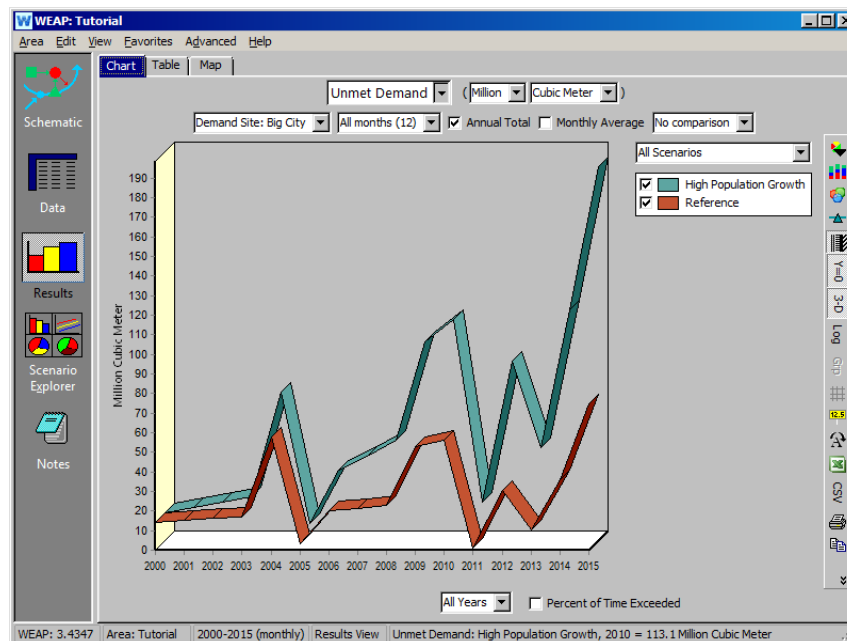
In the Data tree, change the “Headflow” for the Main River in the “Reference” scenario to use the “Water Year Method.” Note that before, the monthly values of Headflow were the same for the period 2001-2015 as for 2000, the Current Accounts year.

*Use the drop down menu in the “Get Values from” to select this method. You may have to scroll left in this window to get the “Get Values from” field to appear*



## 14. Re-run the Model

Run the model again and compare “Unmet Demand” for the “Reference” and “Higher Population Growth” scenarios, as before (of course, “Water Demand” will not have changed after altering the supply side of the model with the Water Year Method).



Note that Big City “Unmet Demand” for both scenarios is much more erratic using the Water Year Method than assuming a constant headflow to the Main River, as observed in the previous exercise. In the present case,

Unmet Demand varies as the future climate varies. During years wetter or much wetter than normal (2000, the Current Accounts year), Unmet Demand is actually lower than in 2000 for both scenarios, even with the increase in Water Demand from population growth (2.2% for the Reference and 5.0% for the Higher Population Growth scenarios). The increased precipitation, and headflow to the river, mitigates this increased demand in the wetter years.

The opposite occurs in the dry to very dry years, where the population growth is exacerbated by the lower precipitation and headflow in the river in these years. This leads to even higher Unmet Demand than is simulated assuming a constant climate (as performed in the previous exercise).

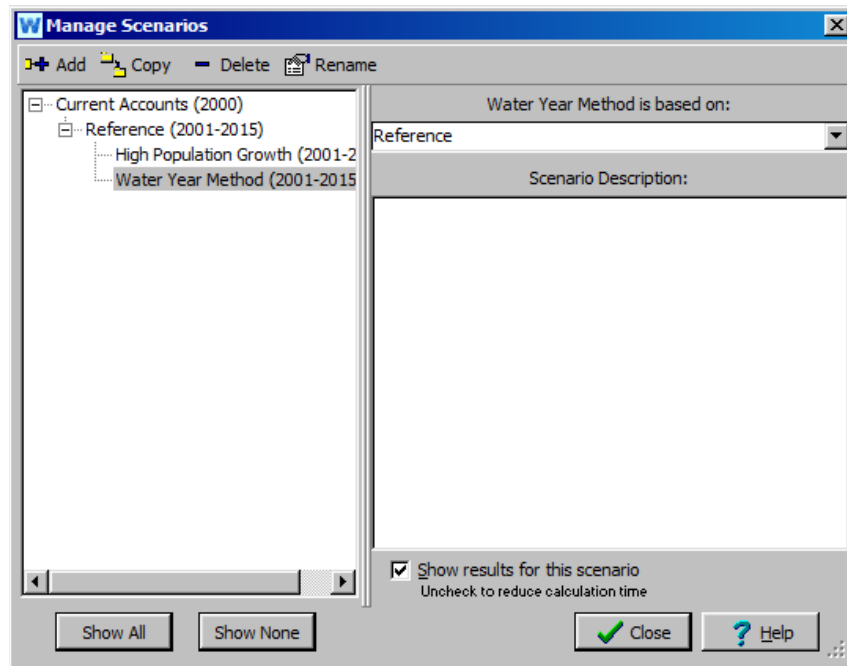


Since unmet demand is the difference between a large demand and a large supply, even a rather small change in the supply at nearly-constant demand can have a very large impact on the unmet demand.

This model does not take any kind of inter-year storage into consideration (reservoirs, groundwater). Therefore, there is no way that the shortage in a dry year can be alleviated by using surplus from previous, wetter years. For more details on how to model storage, refer to the “Refining the Supply” WEAP tutorial module.

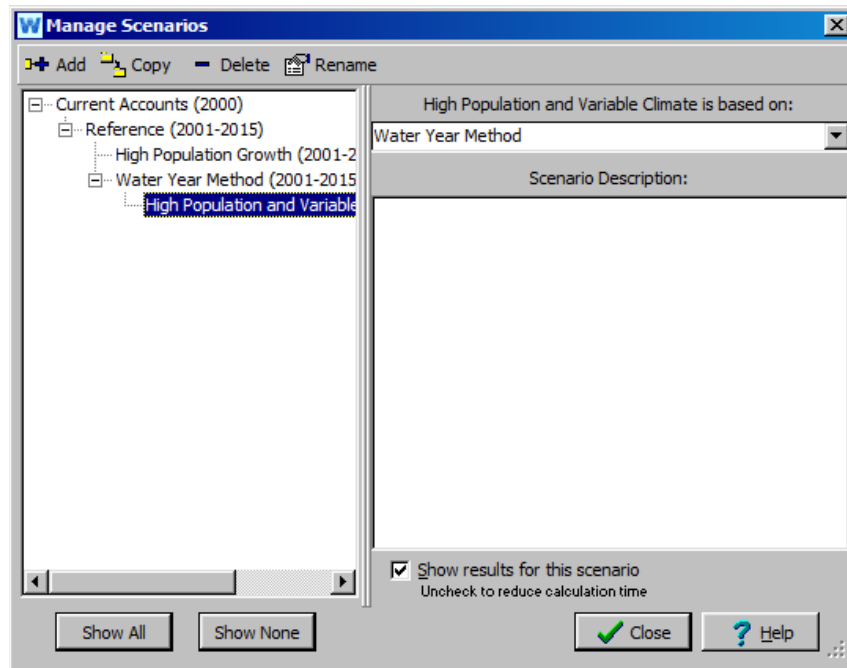
---

If you had wanted to compare, *in the same graph in WEAP*, results for the Water Year Method to that generated assuming a constant climate, you could have created a new scenario that used the Water Year Method rather than changing the data in the “Reference” scenario to accommodate the Water Year Method. This new scenario would be inherited from the “Reference” scenario, and the Scenario tree in the “Scenarios Manager” would look as follows:



Note that in this case, both the “Reference” (constant climate) and “Water Year Method” scenarios (variable climate) would use a Population Growth Rate equal to 2.2% for Big City, since the “Water Year Method” scenario is inherited from the “Reference” scenario.

If one wanted to compare, in the same WEAP graph, constant climate and variable climate using a 5% Population Growth Rate, you could create another new scenario inherited from the “Water Year Method” scenario and change the “Population Growth Rate” Key Assumption in this scenario to 5%. The tree structure would look as follows:



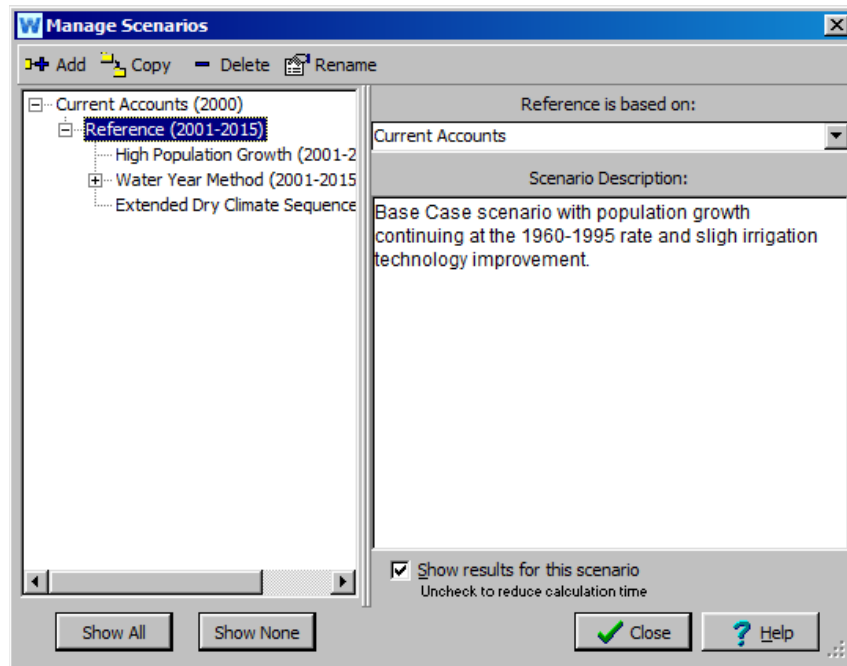
WEAP allows for unlimited versatility in the arrangement of scenarios. Note that you can output results to Excel, which also facilitates results comparisons among scenarios. This feature will be discussed in greater detail in the “Data, Results, and Formatting” module.

## 15. Change Scenario Inheritance

The following example demonstrates the utility of changing scenario inheritance within WEAP.

Create a new scenario inherited from the “Reference” scenario, and name it “Extended Dry Climate Sequence.” The scenario tree structure should look as follows:

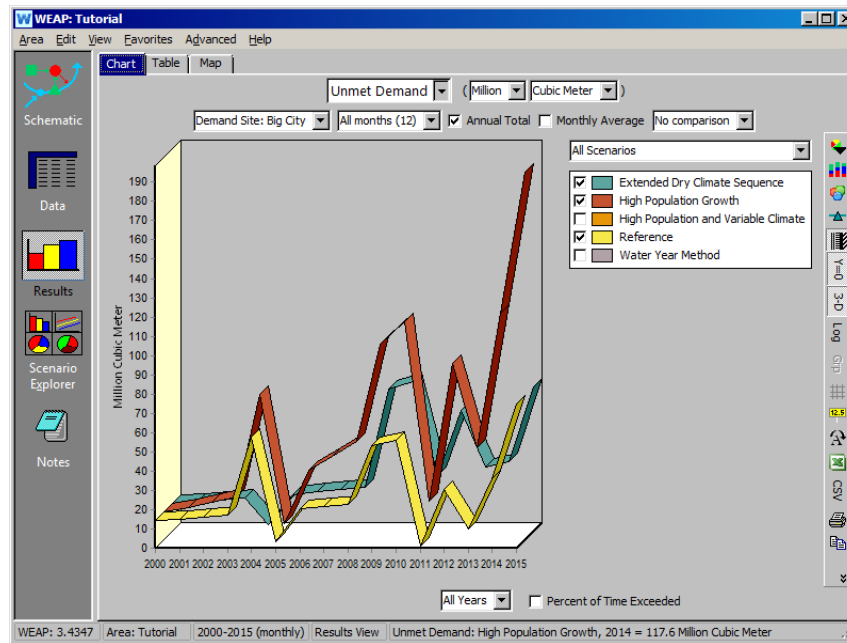




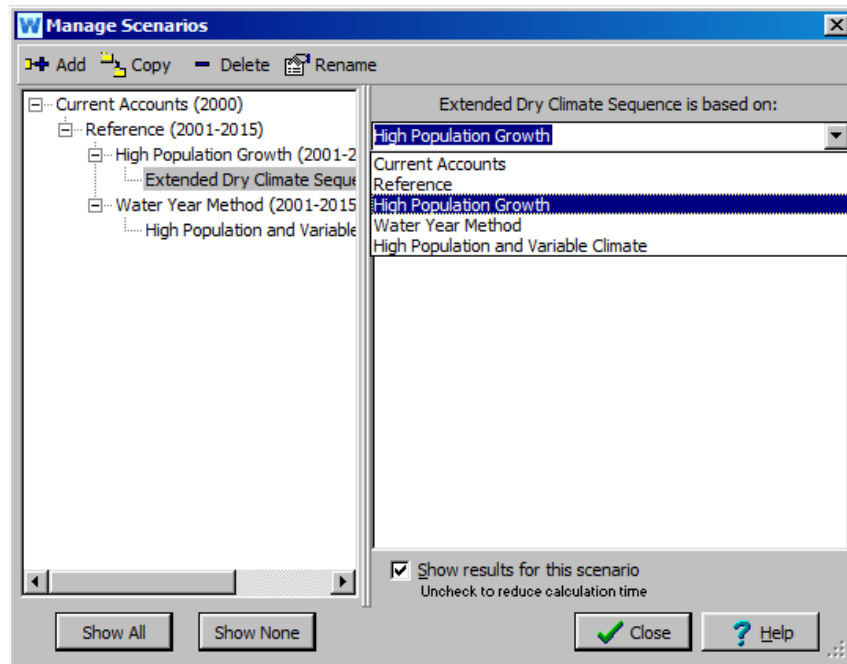
Go to the Data view and select this new scenario for editing. Click on the “Water Year Method” branch of the data tree (below Hydrology) to edit the climate sequence as follows:

2001-2003	<i>normal</i>
2004	<i>wet</i>
2005-2008	<i>normal</i>
2009-2010	<i>very dry</i>
2011	<i>normal</i>
2012	<i>dry</i>
2013	<i>normal</i>
2014	<i>normal</i>
2015	<i>dry</i>

The results (shown below) indicate that Big City “Unmet Demand” for the “Extended Dry Climate Sequence” (new climate sequence and a 2.2 % Population Growth Rate) falls somewhat in between those for the “Reference” scenario (original climate sequence and a 2.2 % Population Growth Rate) and the “Higher Population Growth Rate” scenario (original climate sequence, but a 5% Population Growth Rate).

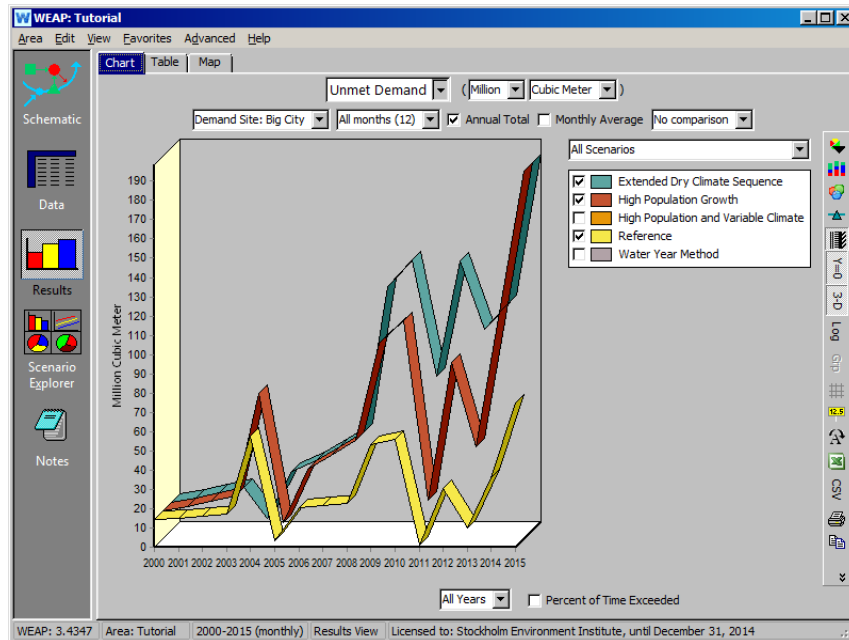


Now, we will change the Scenario Inheritance of the “Extended Dry Climate Sequence” scenario, placing it under the “Higher Population Growth Rate” scenario so that it inherits the 5% Population Growth Rate of that scenario. In the Scenario Manager, select the “Extended Dry Climate Sequence” scenario, click on the drop down list to the right (below the text saying “Extended Dry Climate Sequence is based on:”) and select “Higher Population Growth” as the new parent scenario.



Now, recalculate the results and look again at “Unmet Demand” for Big City.

*What changes do you notice to the unmet demand for the “Extended Dry Climate Sequence” scenario?*



With the higher population growth rate and dryer climate, Unmet Demand increases substantially.



---

**WEAP**

**Water Evaluation And Planning System**

# **Refining the Demand Analysis**

## ***A TUTORIAL ON***

*Disaggregating Demand* ..... 74

*Modeling Demand Side Management, Losses  
and Reuse*..... 81

*Setting Demand Allocation Priorities*..... 91

**August 2016**

**Note:**

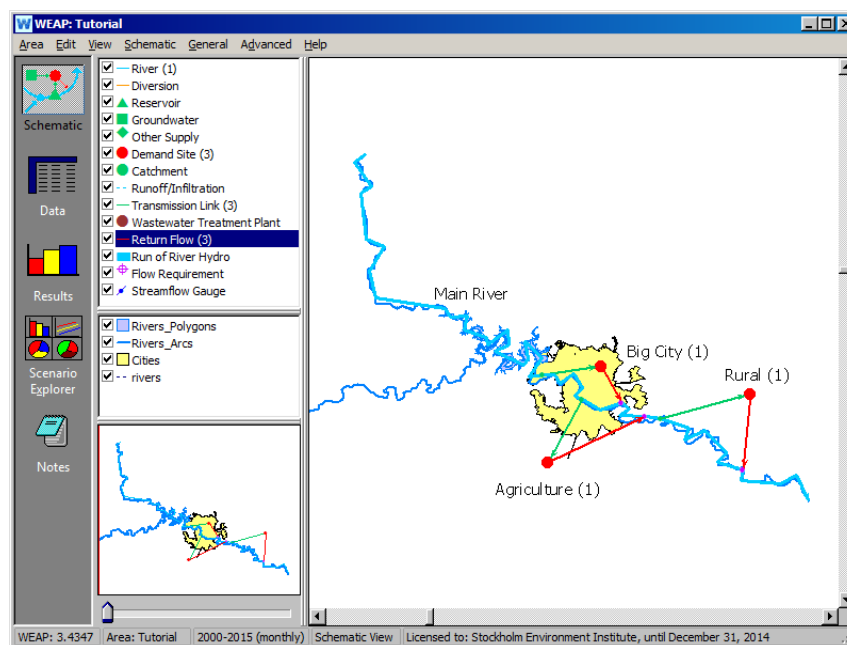
For this module you will need to have completed the previous modules (“WEAP in One Hour, Basic Tools, and Scenarios”) or have a fair knowledge of WEAP (data structure, Key Assumptions, Expression Builder, creating scenarios). To begin this module, go to the Main Menu, select “Revert to Version” and choose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

## Disaggregating Demand

### 1. Create a new Demand Site

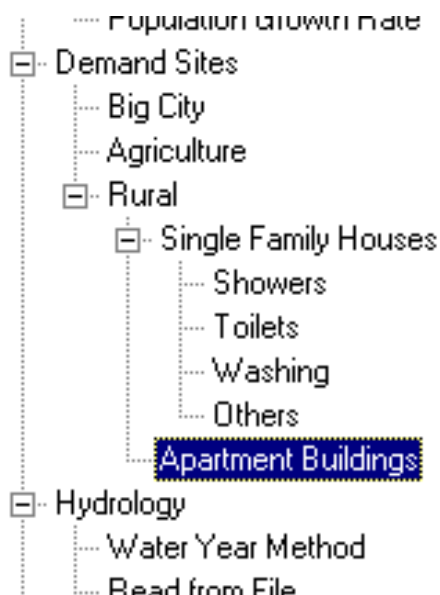
In the Current Accounts, create a new demand site downstream of Big City to simulate rural demand. Name this node “Rural” and give it a *Demand Priority = 1*. Provide a Transmission Link from the Main River positioned downstream of both the Big City and Agriculture Return Flows. *The Supply Preference should be set to 1*. Also provide a Return Flow for Rural that is positioned further downstream.

Your area should now look as follows:

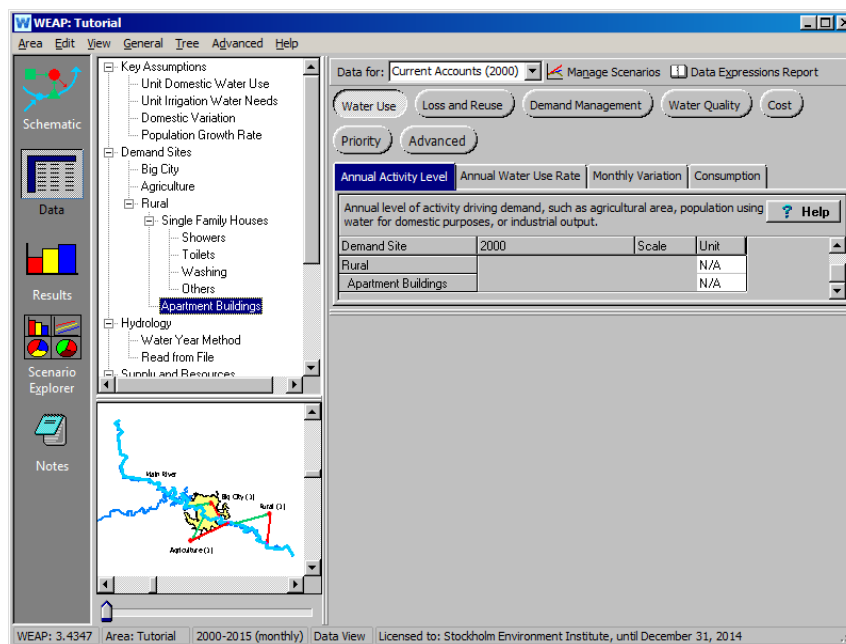


### 2. Create the Data Structure for “Rural” demand node

In order to create a data structure, right-click the “Rural” demand site in the data view tree, and select “Add” to implement the following structure (do not enter any data yet):



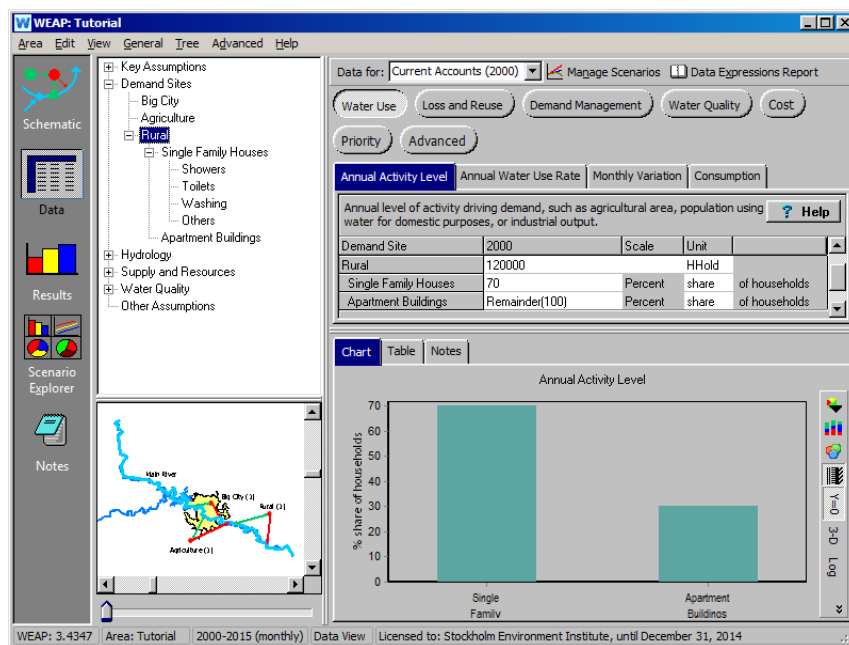
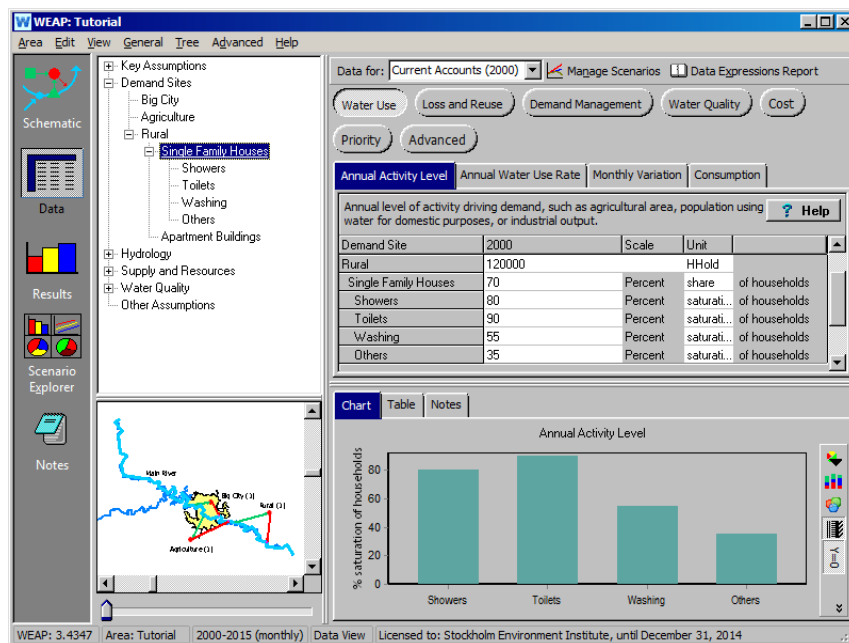
Note that “Showers”, “Toilets”, “Washing”, and “Others” are added as sub-branches below “Single Family Houses.”



### 3. Enter the Annual Activity Level data

Enter the following data under the Rural Demand Site, Annual Activity Level tab (You will have to click on Single Family House in the Data Tree):

<i>Rural</i>	<i>120,000 Households</i>
<i>Single Family Houses</i>	<i>70% Share</i>
<i>Showers</i>	<i>80% Saturation</i>
<i>Toilets</i>	<i>90% Saturation</i>
<i>Washing</i>	<i>55% Saturation</i>
<i>Others</i>	<i>35% Saturation</i>
<i>Apartment Buildings</i>	<i>Remainder share (use the Expression Builder)</i>







Share vs. Saturation: even though both types of percentages are treated mathematically the same by WEAP, they are conceptually different. At a given level of the tree, shares should always sum up to 100%. They also allow the use of the “remainder” function. Saturation indicates the penetration rate for a particular device and is independent of the penetration rate for other devices (i.e., saturation rates for all sub-branches within a given branch do not have to sum to 100.)

#### 4. Enter the Annual Water Use Rate data

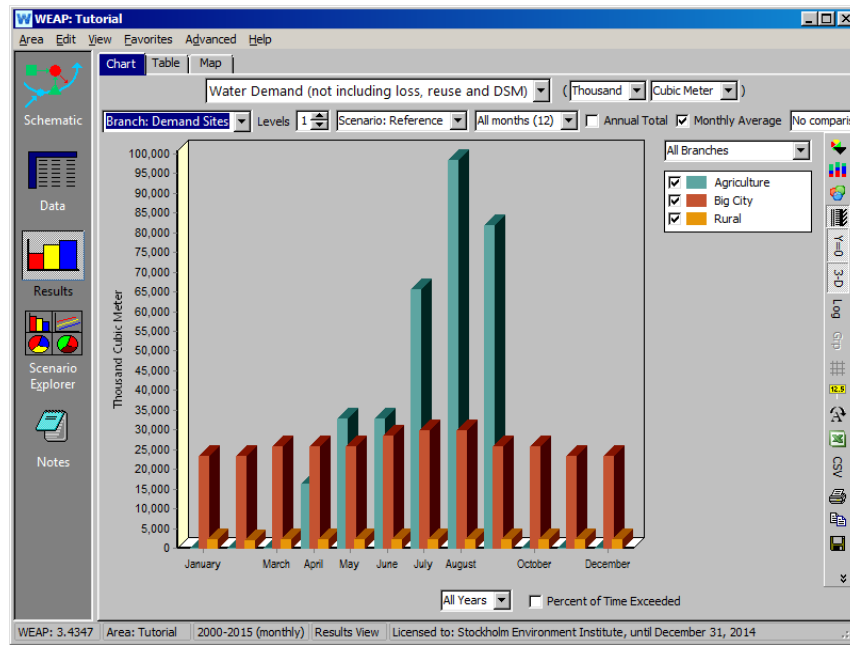
Enter the following data under the “Rural” demand site, “Annual Water Use Rate” tab.

<i>Rural</i>	
<i>Single Family Houses</i>	
<i>Showers</i>	<i>80 m<sup>3</sup> / household</i>
<i>Toilets</i>	<i>120 m<sup>3</sup> / household</i>
<i>Washing</i>	<i>60 m<sup>3</sup> / household</i>
<i>Others</i>	<i>40 m<sup>3</sup> / household</i>
<i>Apartment Buildings</i>	<i>220 m<sup>3</sup> / household</i>
<i>Consumption (in consumption tab)</i>	<i>80%</i>

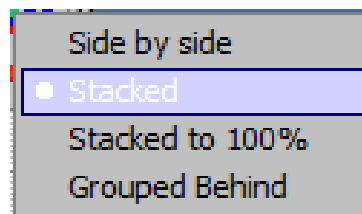
*Note that the “Consumption” value is entered for the entire Rural demand node, and not the sub-branches.*

#### 5. Check the results

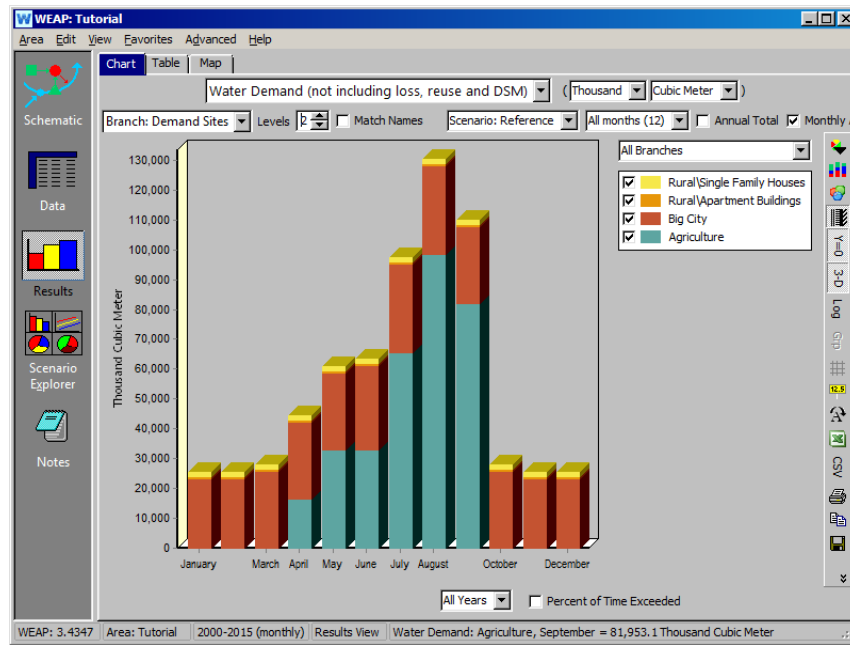
Recalculate your results. In the Results view, choose “Water Demand” as the primary variable from the pull down menu. Select “All Branches” from the pull-down menu directly above the graph legend. Select 3-D and bar graph as the format using the pull-down menu for the “Chart Type” icon on the vertical graphing toolbar (see first and second screen shot below). Select the Rural demand node from the pull down menu above the graph (see third screen shot below).



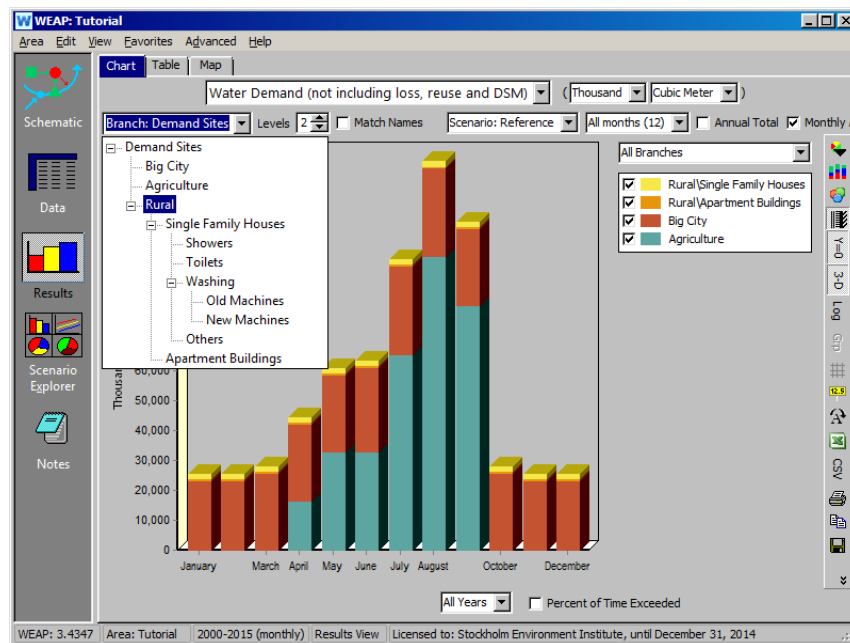
To see the results stacked, click on the bar icon in the far right menu, and click the option “stacked.”

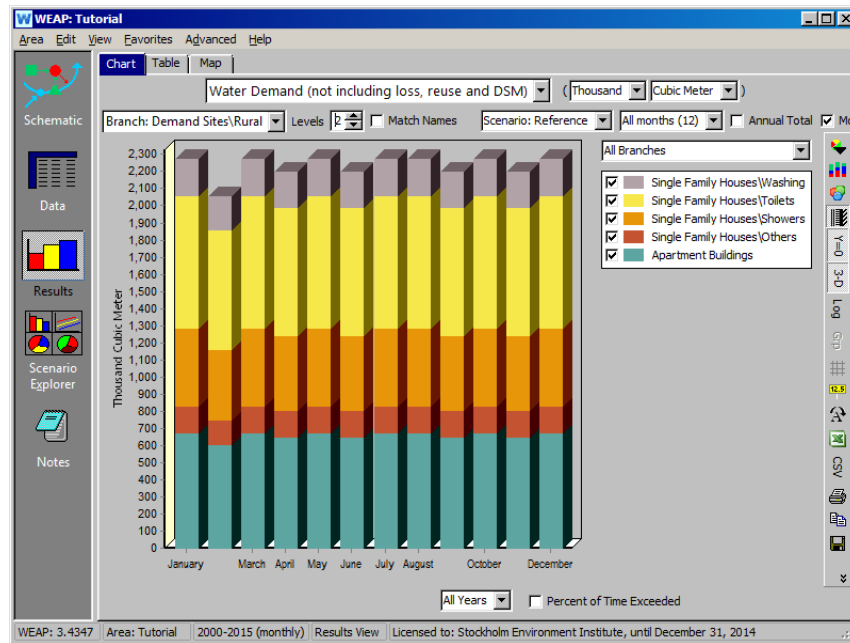


In order to view Water Demand results for all of the Rural sub-branches (e.g., Single Family Houses\Showers; Apartment Buildings), toggle up to Level 2 on the “Levels” selection field (directly above the center of the graph). The resulting graph should look like the one below:



Change the branch of demand to the Rural demand.



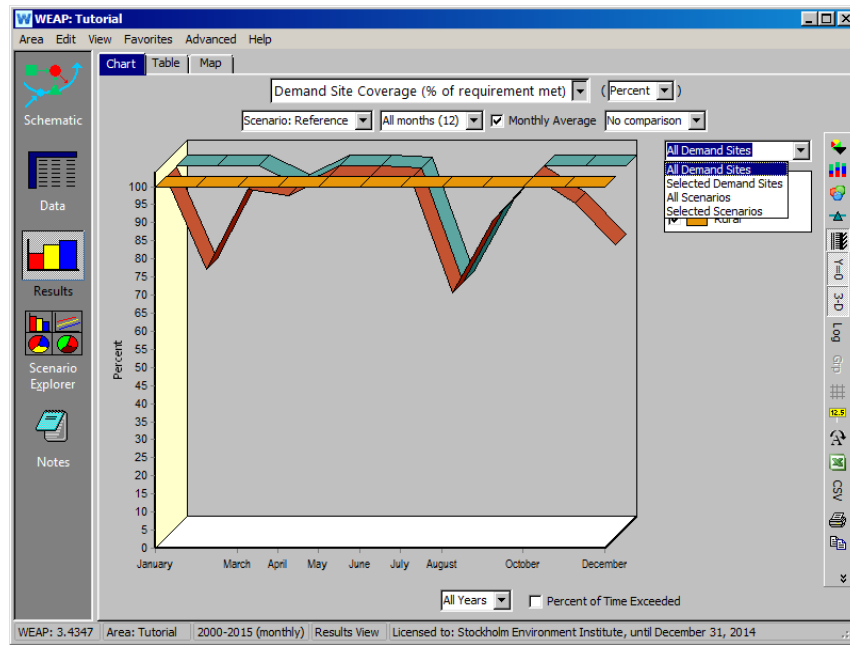


*Do you understand why the Rural demand varies along the year even though we have not entered any variation?*



The variation in Rural demand is due to the fact that WEAP assumes a constant daily demand per day (no monthly demand was specified by the user), so months that have less days (like February) have a lower demand than months that have more days (like January).

Now create a 3-D graph of “Demand Site Coverage” and select all demand sites for presentation (the pull-down menu to do the latter is to the right of the graph; see below).



*Do you understand why Coverage is always 100% for Rural but not for Big City and Agriculture, even though they all have the same demand priority level?*

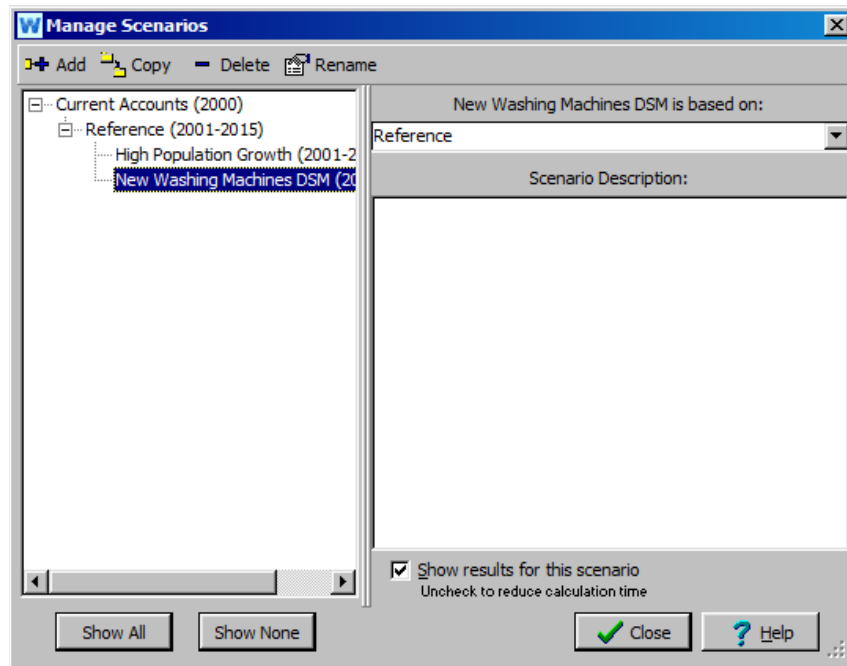


The Rural withdrawal point is downstream of the return flow point for the Big City, which means there is an additional volume of water available in the river; this return flow can easily cover the rather small Rural demand.

## Modeling Demand Side Management, Losses and Reuse

### 6. Implement Demand Side Management - the disaggregated approach

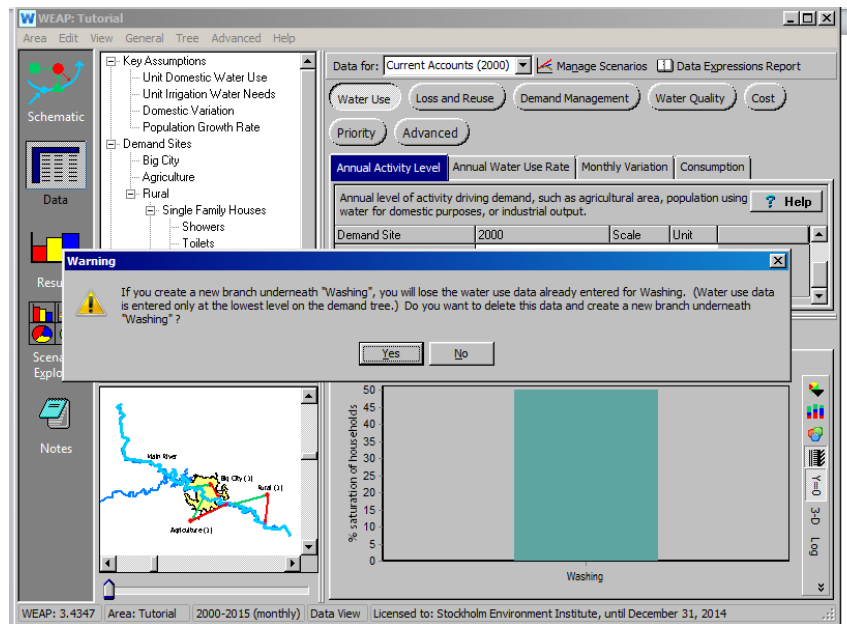
We will now create a new scenario that explores a demand side management strategy. Call this scenario “New Washing Machines DSM”; it is to be inherited from the “Reference” scenario so it will have the same climate and Big City population growth rate as the “Reference” scenario. We deleted the scenarios we are not using by clicking the “delete” button. The scenario tree in the Manage Scenarios window should look like this:



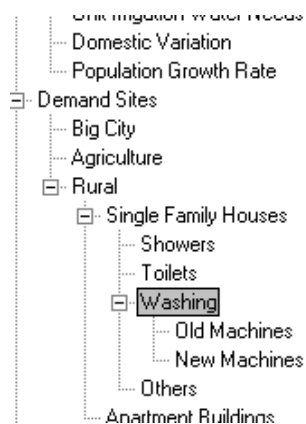
We will assume that a new type of washing machines allows a 1/3 reduction (33.3% less) in washing water consumption. This new scenario will evaluate the impact of this Demand Side Management measure if 50% of the households can be convinced to purchase the water-saving machine.

First, go back to Current Accounts in the Data view, where you will create two new branches (Old Machines and New Machines) in the Rural data structure. Effectively, you are disaggregating the “Washing” variable to now include two new sub-categories. *Note that you must return to Current Accounts because all new data structures have to be entered in Current Accounts, even if the variable is not to be activated (i.e., given non-zero activity levels) in the Current Accounts and “Reference” scenario.*

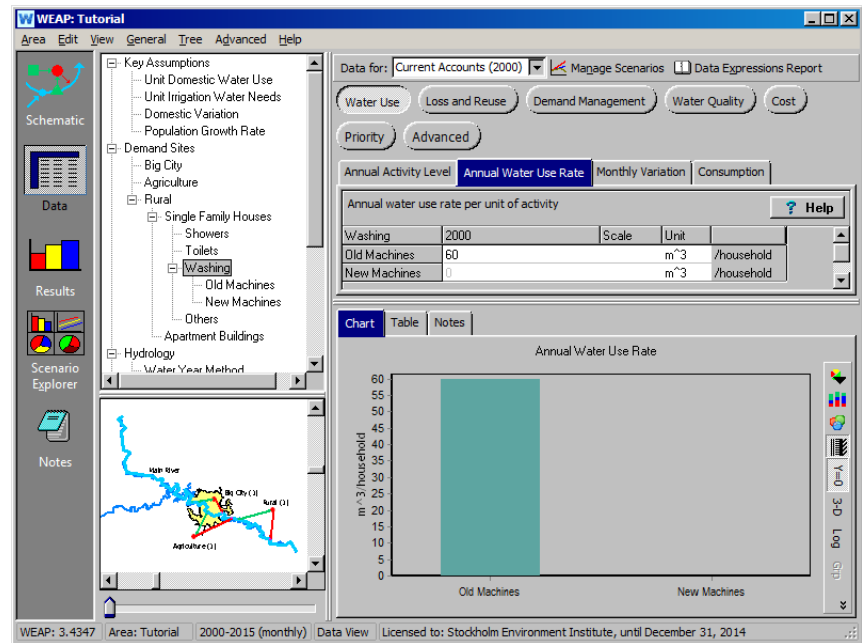
When you go to add the first sub-branch under Washing, you will get the following message:



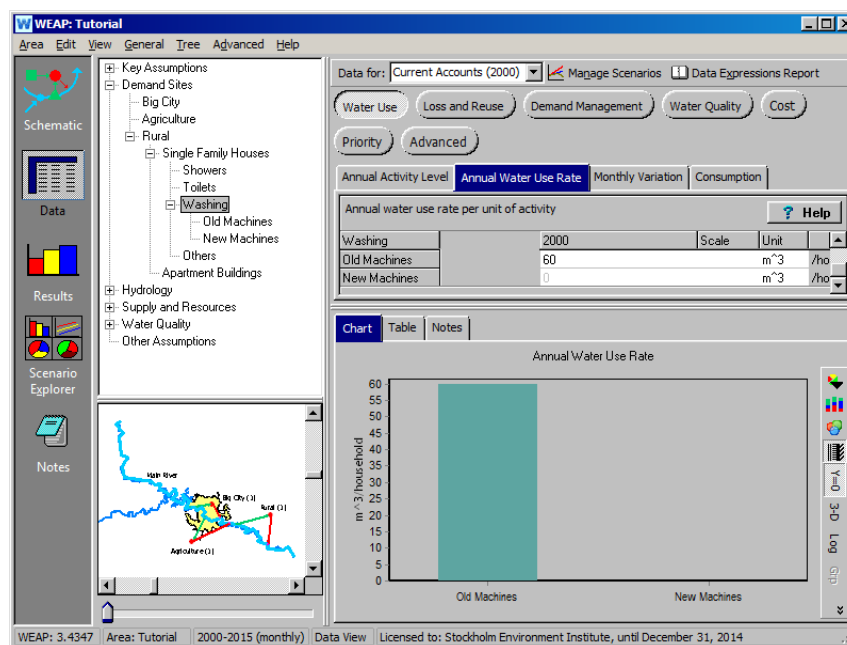
Click "Yes," and add the following structure:



*Change the units for "Old Machines" and "New Machines" to "Shares." Under Annual Water Use, reenter the Water Use Rate for Old Machines (60 m<sup>3</sup> / household), as was the value for the original higher level variable "Washing."*



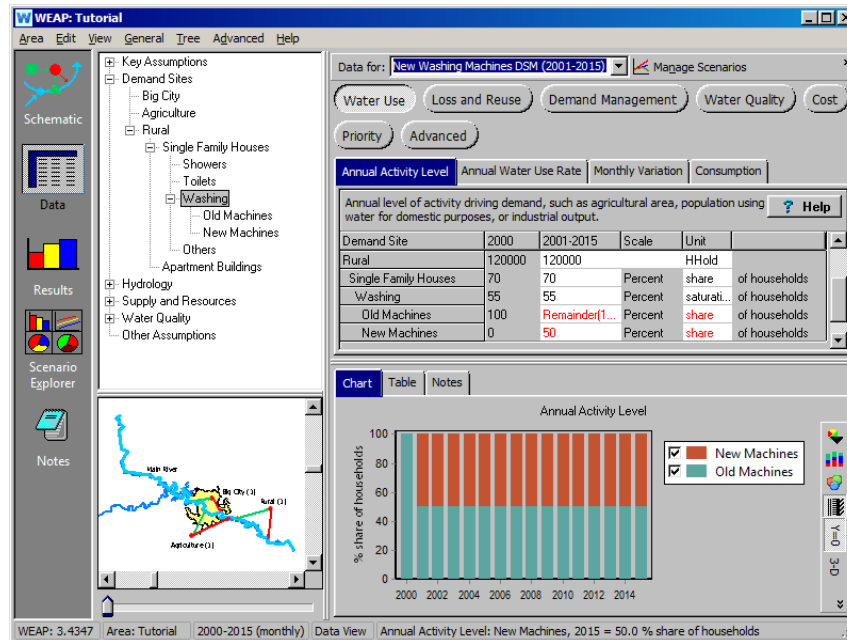
*Enter a value of 100% for the “Old Machines Annual Activity Level.” Leave blank the Annual Activity Level for “New Machines” - this is the same as entering a zero. Remember, you are entering these in the Current Accounts, so you want only the “Old Machines” to be active in the “Reference” scenario. This recreates the same effect as having the aggregated variable “Washing” in the original Current Accounts and “Reference” scenario. The “New Machines” variable will be activated in the “New Washing Machines DSM” scenario (see below).*





Now, switch to the “New Washing Machines DSM” scenario.

*Input a value of 50 for New Machines (50% of all washing machines will be this new variety) and Remainder(100) for Old Machines (use the Expression Builder for the latter).*



*You will have to input again the original Water Use Rate for the Old Machines ( $60 \text{ m}^3/\text{household}$ ) as well as the new Water Use Rate for the New Machines:*

*Old Machines  $60 \text{ m}^3/\text{household}$*

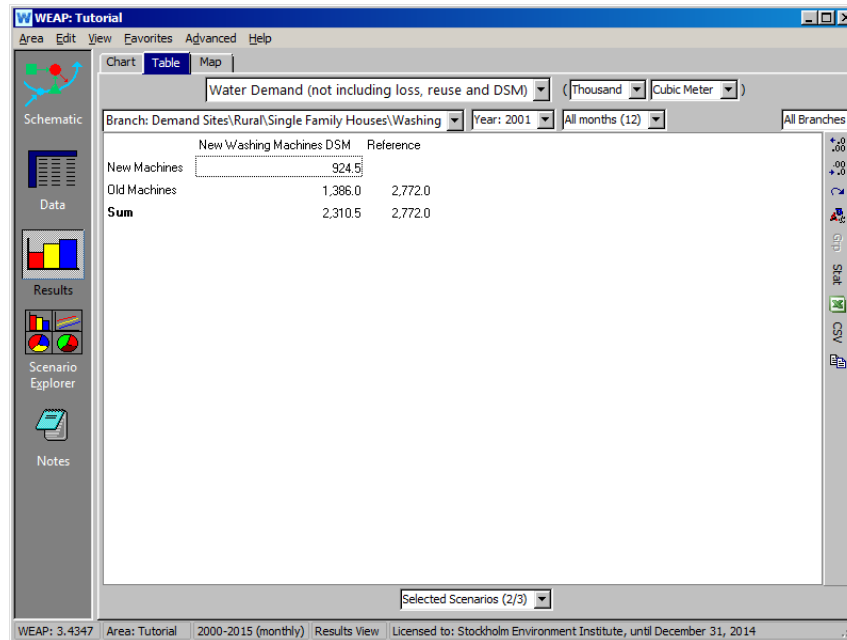
*New Machines  $60 \times 0.667 \text{ m}^3/\text{household}$*

*View the data on as “Bar,” selected on the right hand side from the top icon.*

(Note that you have to tell WEAP to make the chart a bar graph to see those results)

Now compare the numerical Water Demand results for the Washing branch of the Rural demand site for the “Reference” and “New Washing Machines DSM” scenarios. In the Results view, click on the Table tab and select the Water Demand variable. Also select “Annual Total” rather than “Monthly Average” and choose 2001 (you can only view numerical results for one individual year at a time when comparing scenarios in the Table view, but this does not present a difficulty for this example, as we do not try to model any growth with time for the Washing variable). Choose Demand Sites\Rural\Washing\Single Family Houses\Washing from the upper left pull-down menu and “All Branches” from the upper right pull-down menu. Select the “Reference” and “New Washing Machines DSM” scenarios from

the pull-down menu at the bottom of the window. The table should look like the following:



Note that the use of the New Machines in 2001 (and all subsequent years in the “New Washing Machines DSM” scenario period) results in about 460000 m<sup>3</sup> less water demand than if only Old Machines are used (Reference scenario).



**Demand-side management (DSM)** refers to measures that can be taken on the consumer’s side of the meter to change the amount or timing of water consumption (as compared to the utility company’s, or supply, side of the meter).

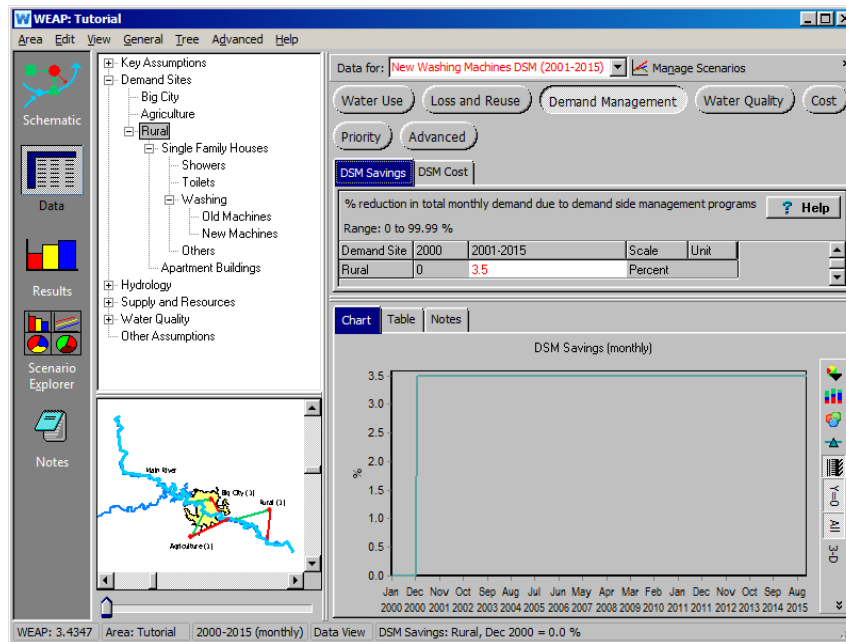
Another way of modeling disaggregated DSM is to reduce the unit consumption for the affected category (in this case washing). There is no right or wrong way to model DSM, although some ways can show more information than others within WEAP.

## 7. Implement Demand Side Management - the aggregated approach

If disaggregated data is not available, an equivalent value of DSM can be computed. In this example, assuming we had not disaggregated the Rural water demand, we could come to the same result by using the “Demand Management” option for this Demand Site in the Data view. In this case the reduction would amount to:

<i>Original contribution of washing to rural water use</i>	2,772/26,316 10.5%
<i>Share of New Machines</i>	50%
<i>Reduction of New Machines</i>	66.6%
<i>Multiplying all of these percentages together =</i>	3.5%

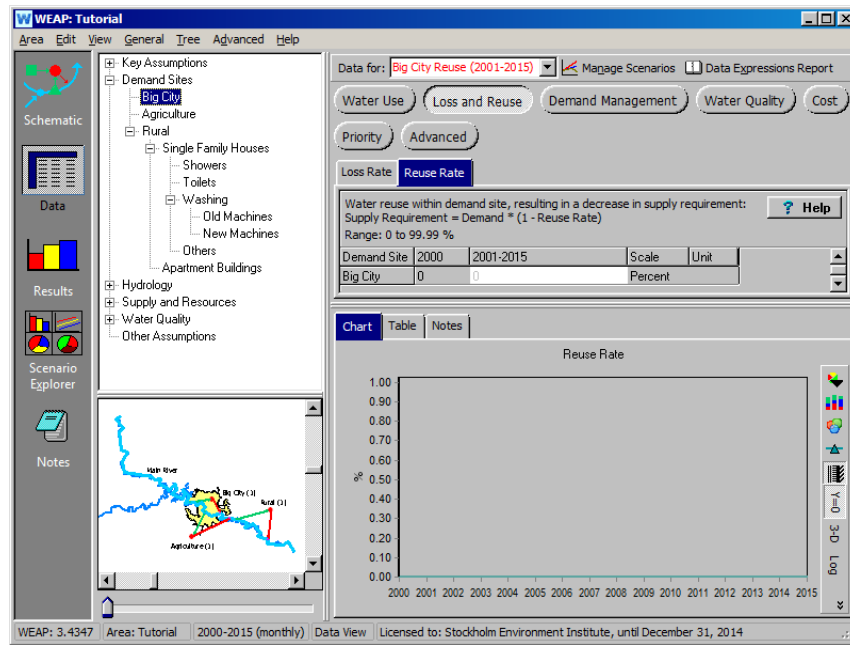
*This value could be entered in the “Demand Management/ Demand Savings” tab for the Rural branch of a Demand Side Management scenario.*



**Demand Side Management (DSM) measures are not taken into account in the demand view. To see the effect of a DSM measure, look at the change in Supply Requirement rather than Water Demand.**

## 8. Model Reuse

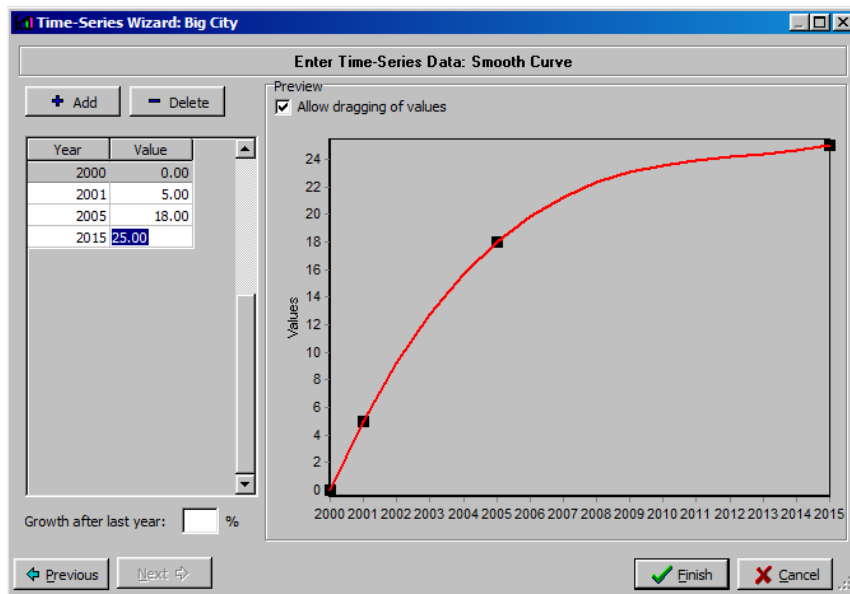
Another water conservation strategy that could be studied with scenarios is water reuse. Create a new scenario inherited from the “Reference” scenario and name it “Big City Reuse.” Make sure you are in this new scenario and click on the Big City branch. Click on the “Loss and Reuse” button and click the “Reuse Rate” tab.



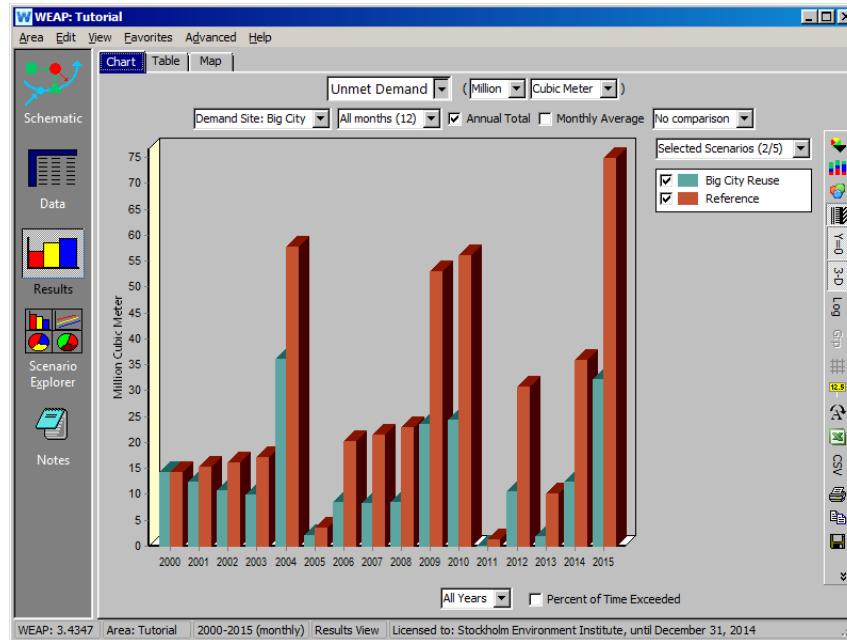
Enter the following expression in the 2001-2015 field using the Expression Builder:

$$\text{Smooth}(2001,5, 2005,18, 2015,25)$$

First, pull the “Smooth” function into the text field of the Expression builder and select “Smooth Curve” from the options. Click “Next” and enter the data values. You should get a plot like the one below. Note that Reuse in the Current Accounts (2000) remains zero. Click “Finish.”

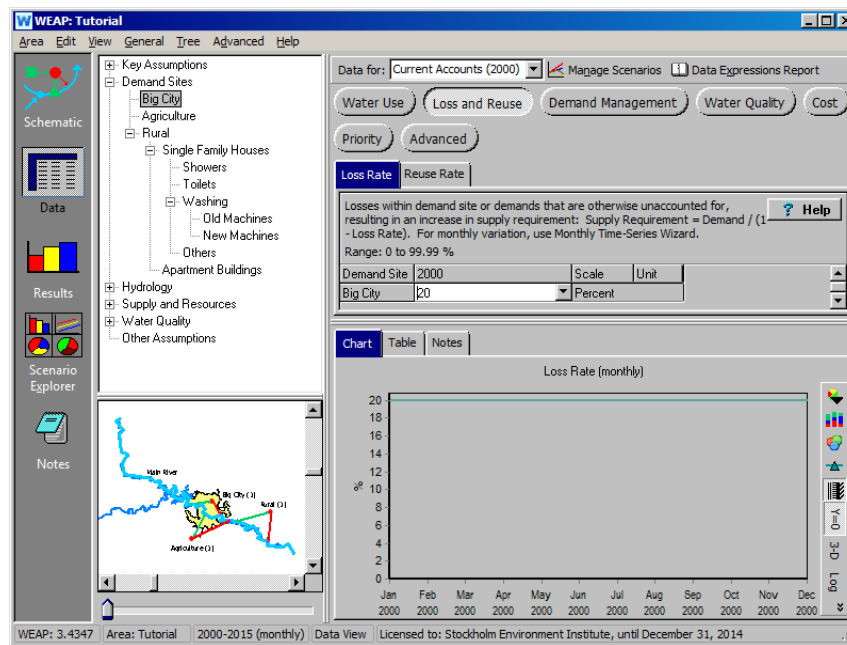


In the Results View, compare Unmet Demand for Big City before (Reference) and after (Big City Reuse) instituting this conservation strategy. You should get the graph below, which shows substantial reductions in Big City Unmet Demand when the water reuse strategy is used.

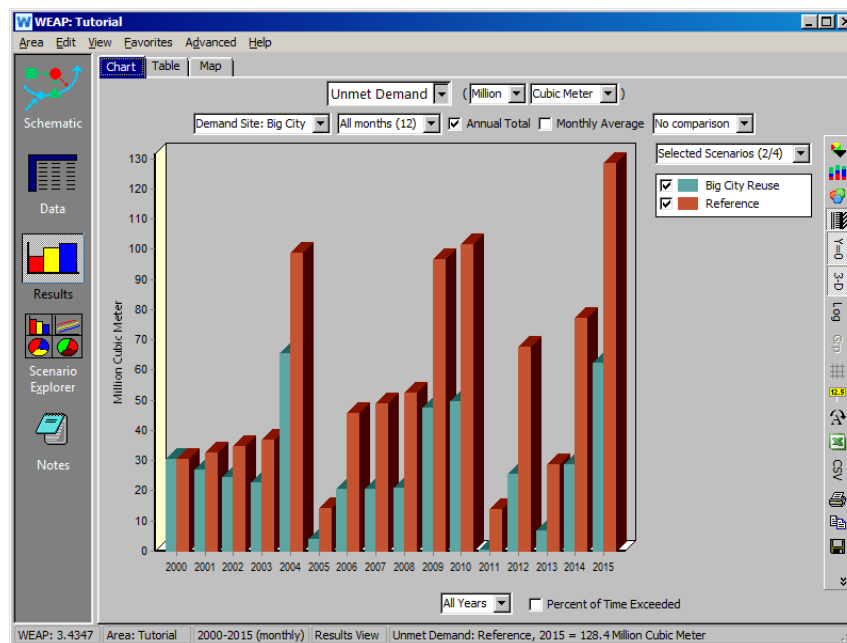


## 9. Model Losses

Re-edit the model to take into account the fact that there is a 20% loss rate in the network of Big City. Make this change for the Current Accounts so that it will be carried through the “Reference” scenario, and as a result of the inheritance feature, throughout all scenarios.



*What happens to the unmet demand for the Big City, both in the “Reference” scenario and the “Big City Reuse” scenario compared to the earlier exercise without losses?*



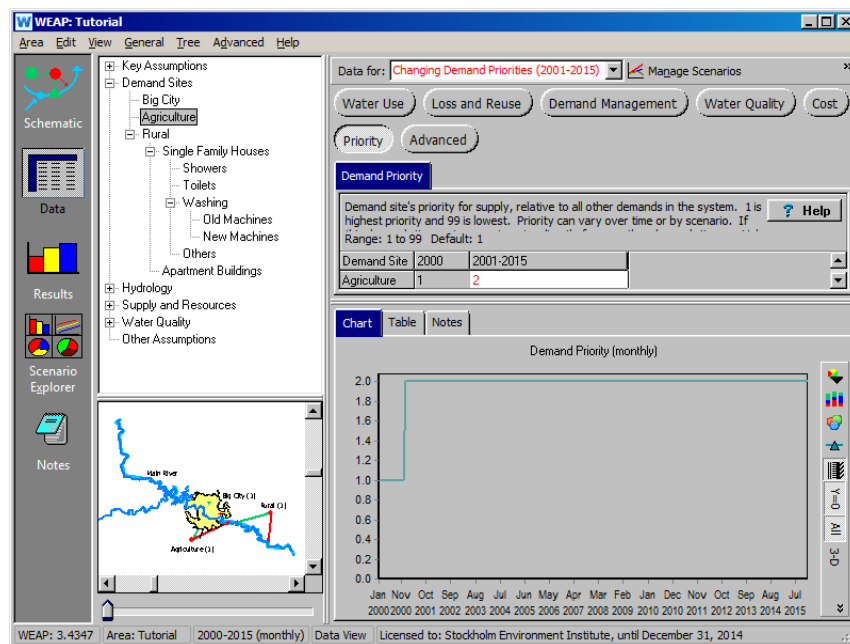
Losses can happen in Transmission Link, in the Demand Site itself or in the Return flow. Losses in the Transmission Link will affect the supply to the Demand Site. Losses in the Demand Site will affect the required Supply Requirements of this Demand Site. Losses in the Return Flow will only affect the flow returned.

# Setting Demand Allocation Priorities

## 10. Edit Demand Site Priority

Create a new scenario, inherited from the “Reference”, and name it “Changing Demand Priorities.” Change the Demand Priority of the Agriculture Demand Site in the Data view by clicking on the Agriculture branch and then clicking on the Priority button, or by clicking on the node in the Schematic View and selecting “General Info.”

*Change the Demand Priority from 1 to 2.*



A demand priority can be any whole number between 1 and 99 (1 is the default) and allows the user to specify the order in which the water requirements of demand sites are satisfied. WEAP will attempt to satisfy the water requirement of a demand site with a demand priority of 1 before a demand site with a demand priority of 2 or greater. If two demand sites have the same priority, WEAP will attempt to satisfy their water requirements equally. Absolute values have no significance for the priority levels; only the relative order matters. For example, if there are two demand sites, the same result will occur if demand priorities are set to 1 and 2 or 1 and 99.

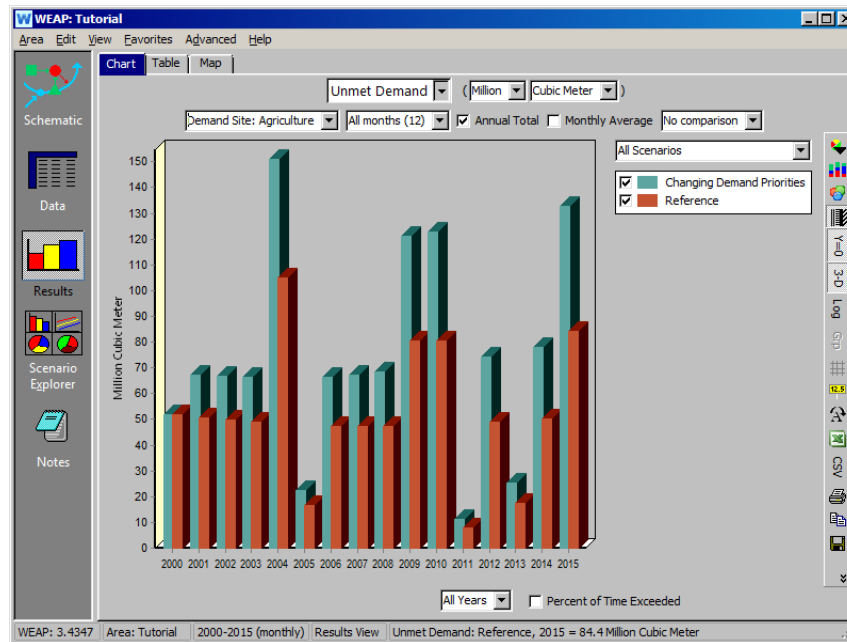


Demand Priorities allow the user to represent in WEAP water allocation as it actually occurs in their system. For example, a downstream farmer may have historical water rights to river water, even though another demand site positioned upstream could extract as much river water as it desired, leaving the farmer with little water in the absence of such water rights. The Demand Priority setting allows the user to set the farmer's priority for water above that of the upstream demand site. Demand Priorities can also change with time or change in a scenario - more advanced subject matter to be dealt with later in the tutorial.

You can also change the Demand Priority in the Data View\”Priority” screen\”Demand Priority” tab.

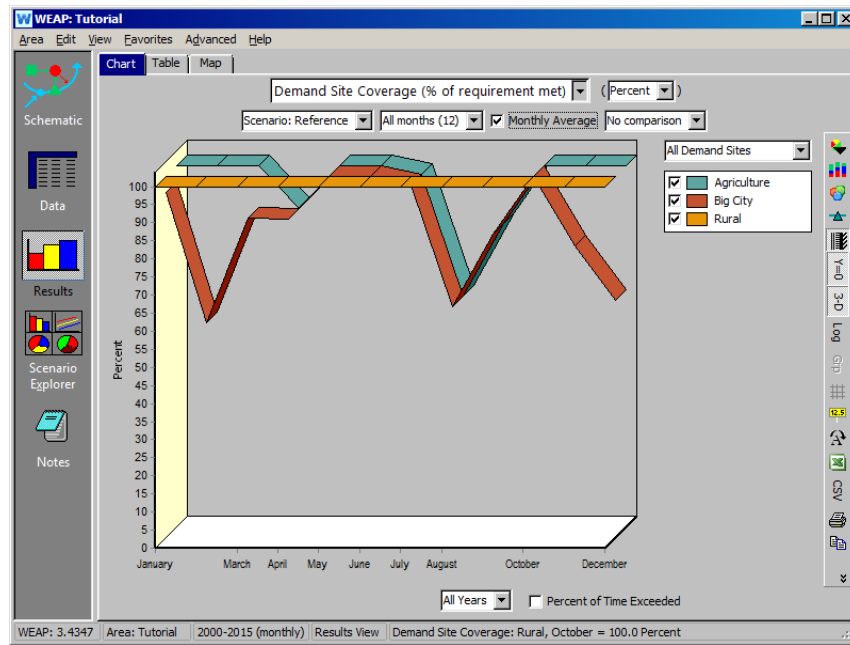
## 11. Compare Results

Display graphically the Unmet Demand for Agriculture for the “Reference” and “Changing Demand Priorities” scenarios. It should look like the graph below”:

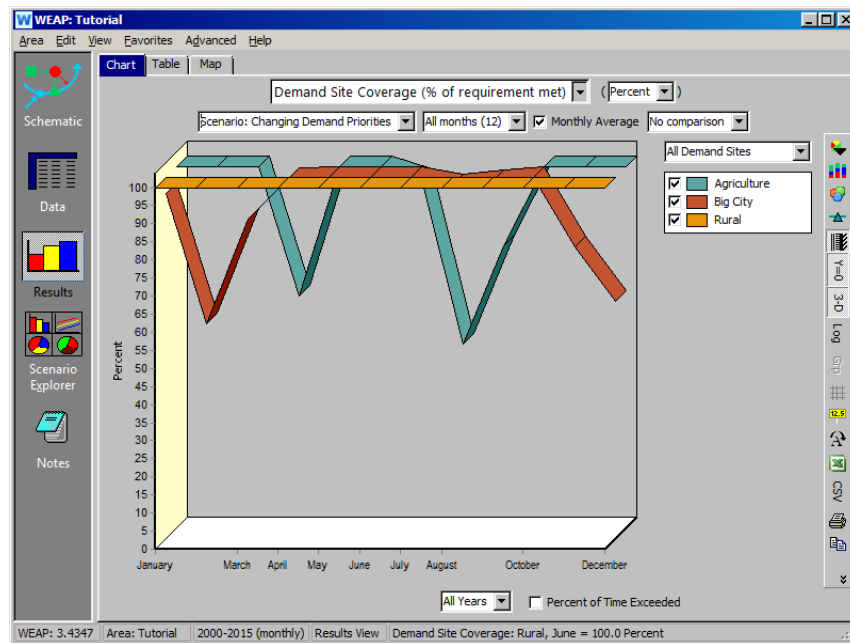


Notice that the Unmet Demand for Agriculture increases when its Demand Priority is raised to 2. This is because Big City now has preference for having its demand met first. Evidence of this can be observed by generating a graph of the monthly average Demand Coverage for Big City and Agriculture across all years of the Reference scenario.





Now compare these results to the same graph generated for the “Changing Demand Priorities” scenario.



Notice that in the “Reference” scenario, for April and August, both Big City and Agriculture do not get full coverage of their demand because they both compete equally for Main River flow. When Big City is given preference for meeting demand (Changing Demand Priorities scenario), however, its coverage improves relative to Agriculture. At times, coverage is 100% for Agriculture, but not for Big City - that is because there is no Agriculture demand (primarily observed for the winter months). Note that the Demand

Coverage for the Rural demand site is always 100% - this is because the return flows for Big City and Agriculture satisfy the water demand created by the Rural demand site.

---

# WEAP

Water Evaluation And Planning System

# Refining the Supply

## ***A TUTORIAL ON***

<i>Changing Supply Priorities.....</i>	<i>96</i>
<i>Modeling Reservoirs .....</i>	<i>99</i>
<i>Adding Flow Requirements.....</i>	<i>106</i>
<i>Modeling Groundwater Resources .....</i>	<i>110</i>

**August 2016**

**Note:**

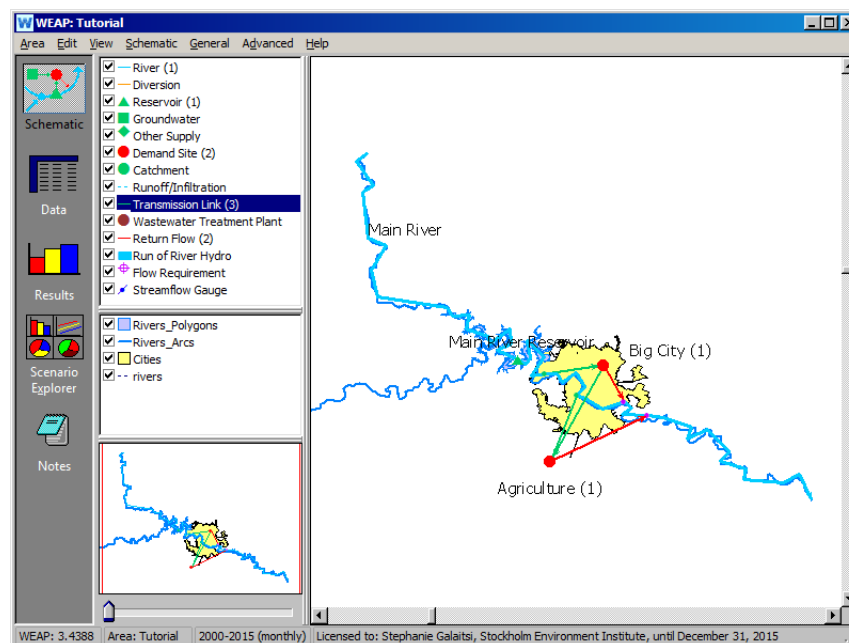
For this module you will need to have completed the previous modules (“WEAP in One Hour, Basic Tools, and Scenarios”) or have a fair knowledge of WEAP (data structure, Key Assumptions, Expression Builder, creating scenarios). To begin this module, go to the Main Menu, select “Revert to Version” and choose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

## 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.

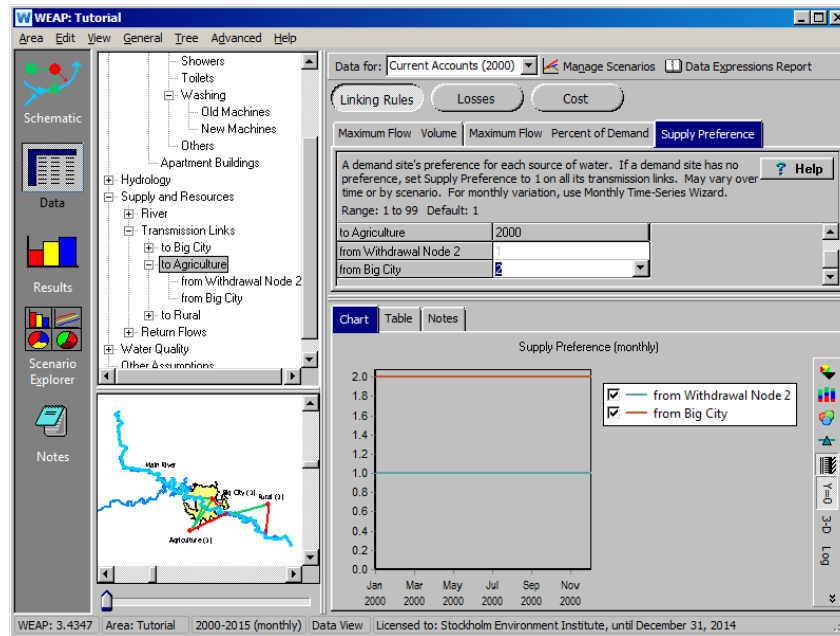
*Supply Preference*                      2



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.

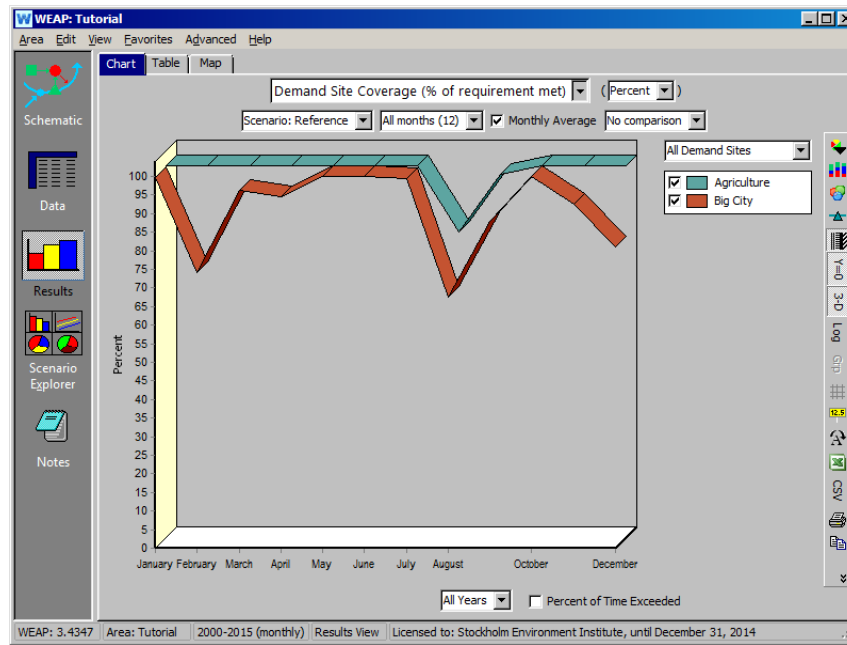
## 2. Results when you change Supply Preferences

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.

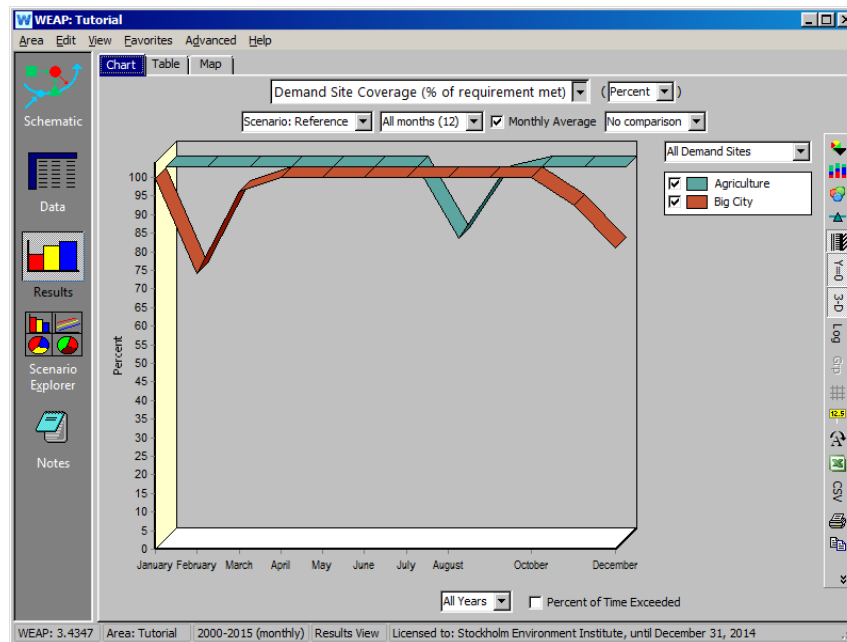


*Try the following combinations:*

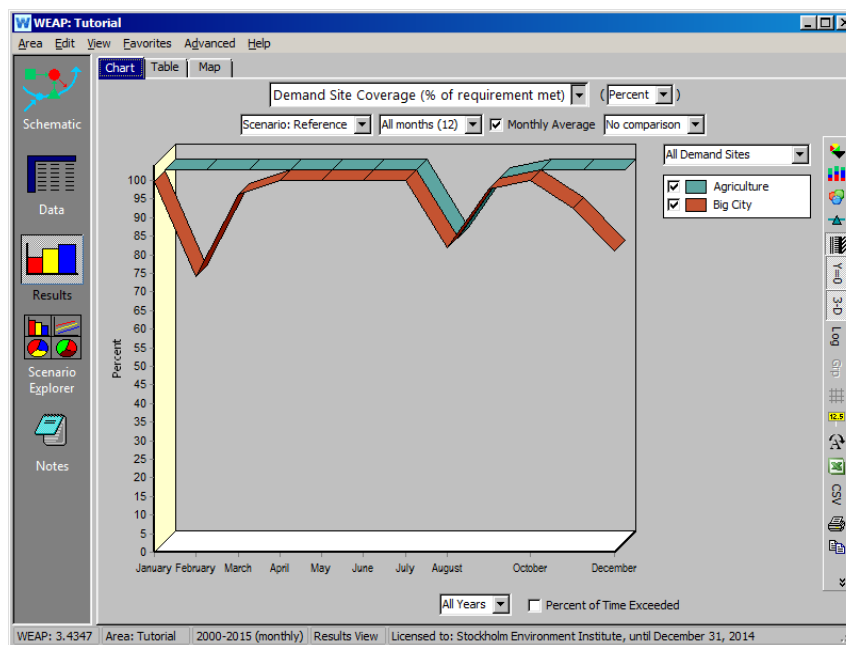
Supply Preferences = 1 from the Main River, 2 from Big City



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



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



*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

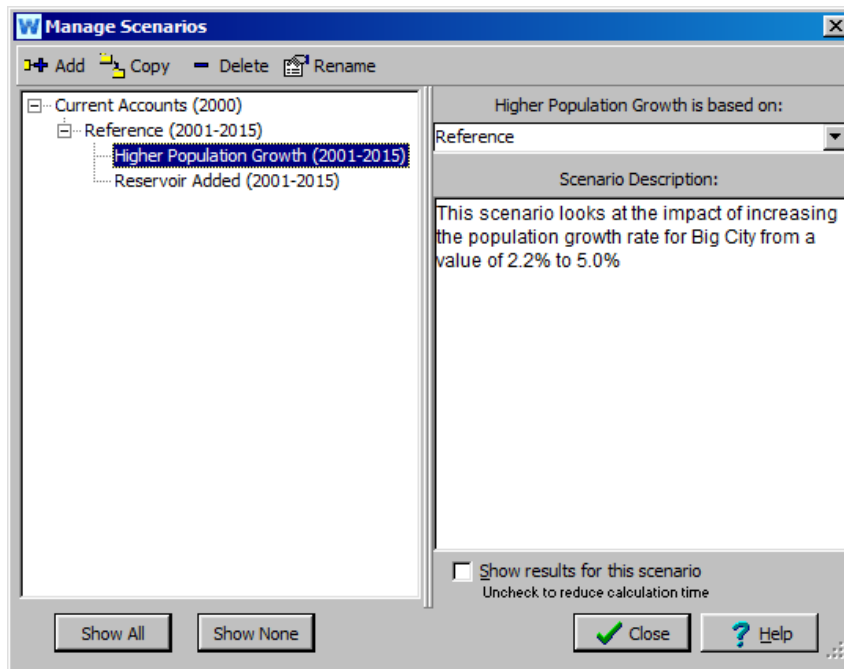
You can do this using the “Revert to Version” option under the Area menu. Choose “Starting point for all modules after “Scenarios” module” as you did at the beginning of this exercise.

## Modeling Reservoir Supply

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

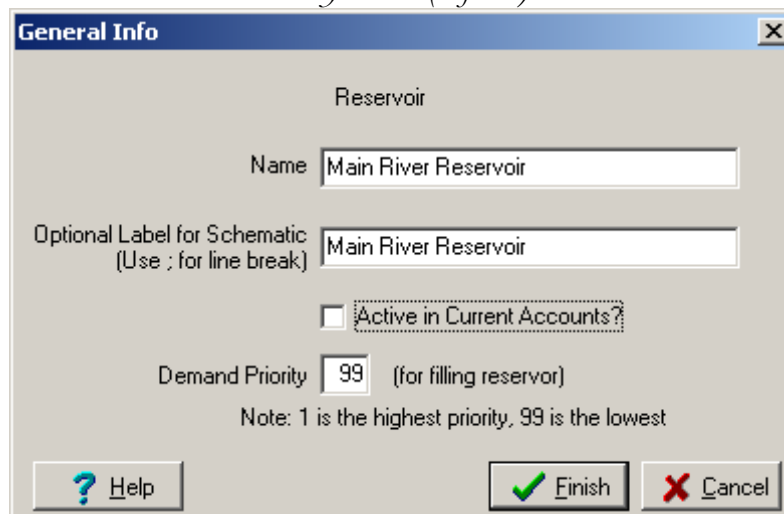
First, create a new scenario inherited from “Reference”, and name it “Reservoir Added.”

While in Manage Scenarios, highlight the High Population Growth scenario and uncheck the box “show results for this scenario.” This will enable WEAP to make calculations faster.

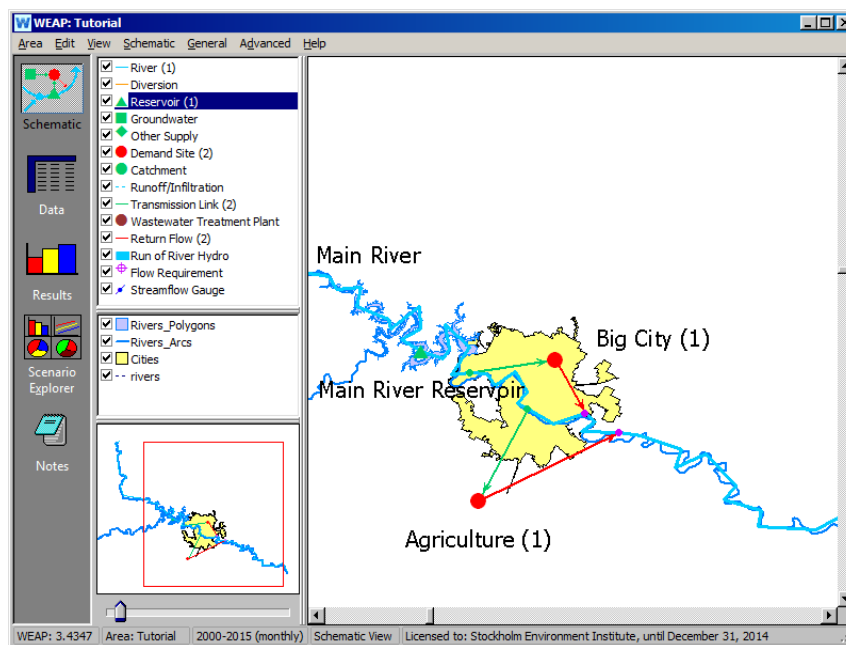


Then add a reservoir object on the Main River upstream of Big City, and name it "Main River Reservoir." Unclick the box where it asks if this object is active in Current Accounts.

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

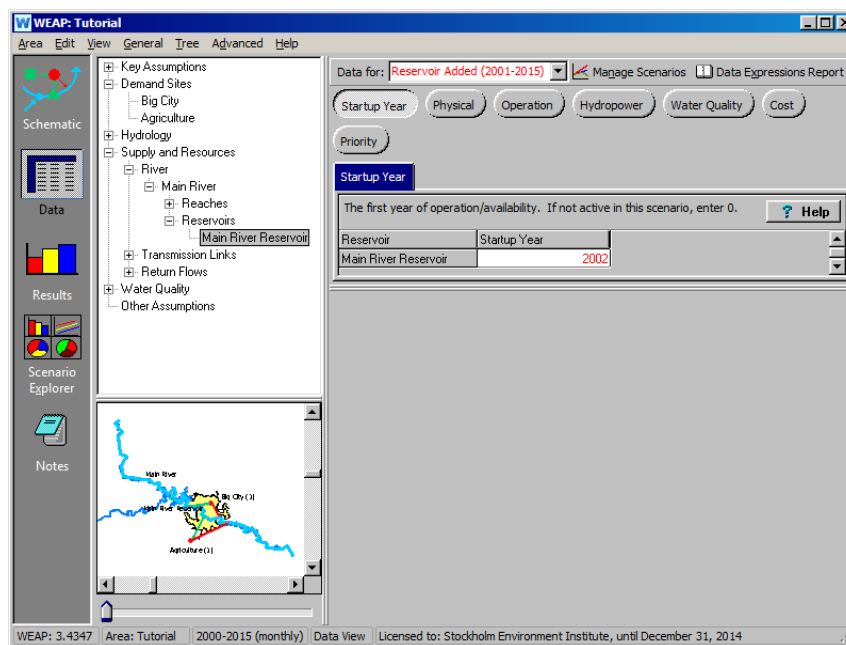






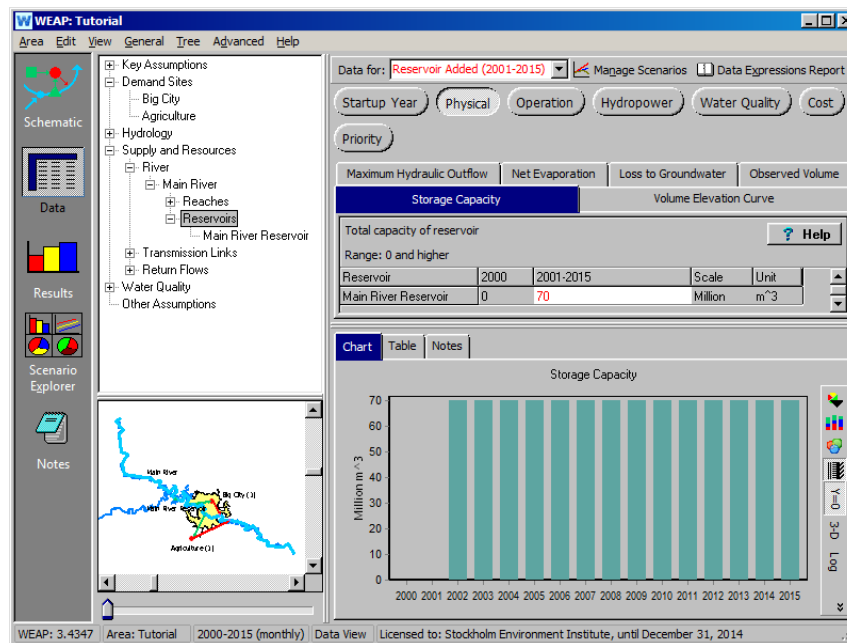
Right click on Main River Reservoir and select "Edit Data." Select the "Storage Capacity" variable to enter the Data view (Make sure you have the "Reservoir Added" scenario selected). Once you are in the Data view, you will first have to click on the "Startup Year" button before you can alter any other parameters. Note: you may have to click on the data tree before the year will save.

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



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

*Storage Capacity*                       $70 \text{ M m}^3$   
*Note that the Scale is set to "Million"*

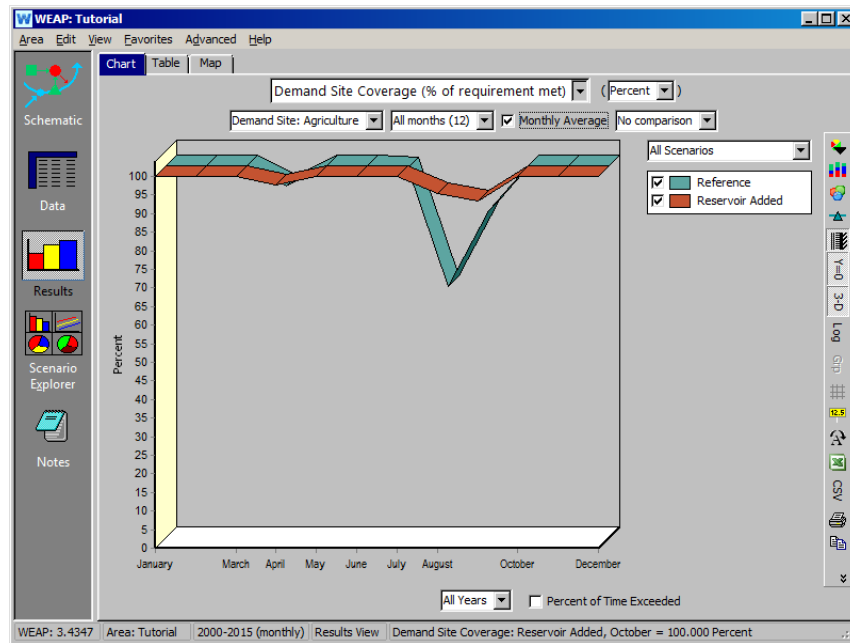


More details about reservoirs operation and hydropower production are provided in the “Reservoirs and Power Production” module of the WEAP tutorial.

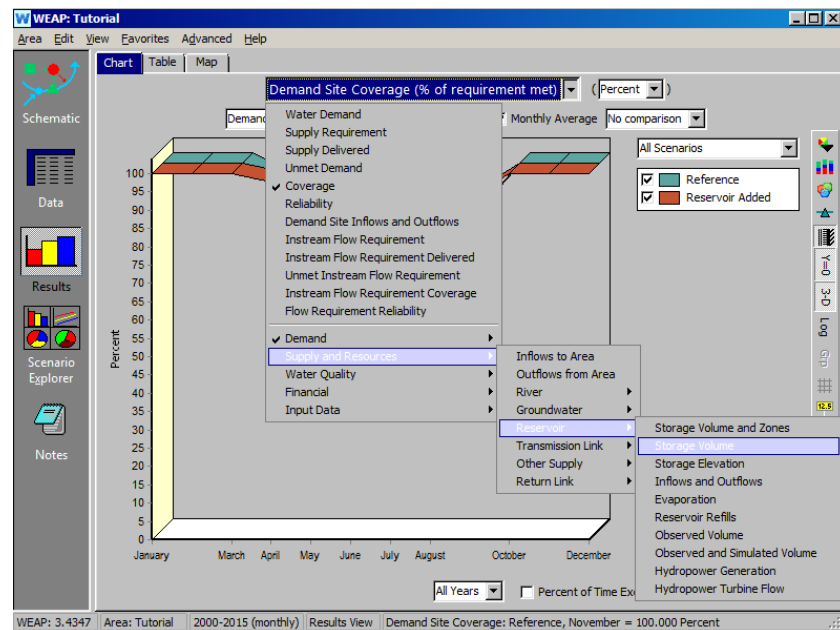
## 5. Run the Model and Evaluate the Results

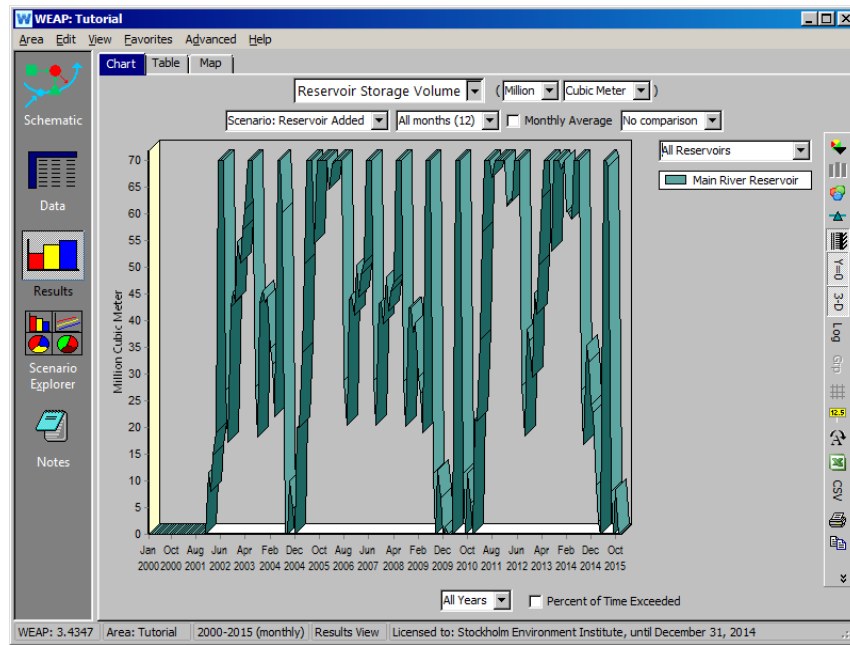
Compare the Demand Site Coverage for Agriculture in the “Reference” and “Reservoir Added” scenarios.

*- Demand Coverage: why does Agriculture have higher coverage with the Main River Reservoir in place?*

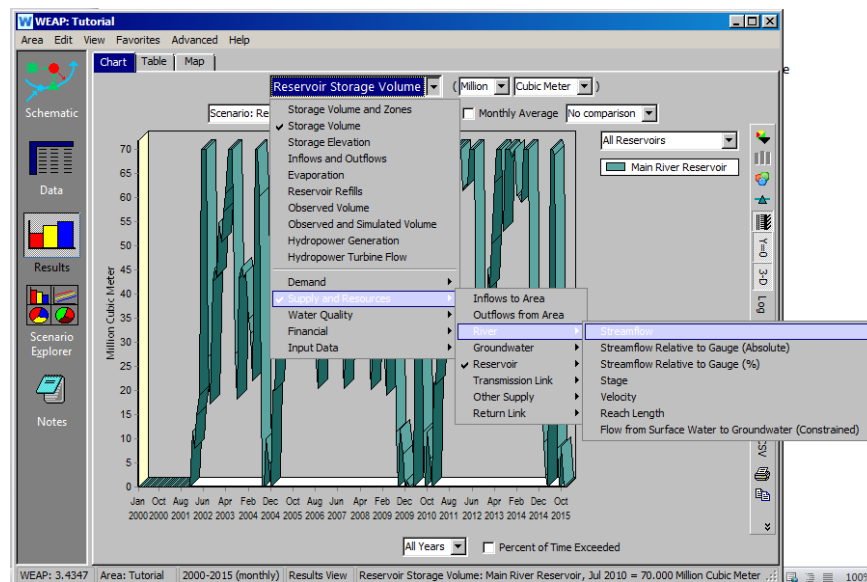


- *Reservoir Storage Volume*: does the solution of building a reservoir appear to be sustainable? Use the primary variable pull down menu to select *Reservoir Storage Volume* (under *Supply and Resources\Reservoir*), and select “All Years” from the pull down menu at the bottom of the graph.

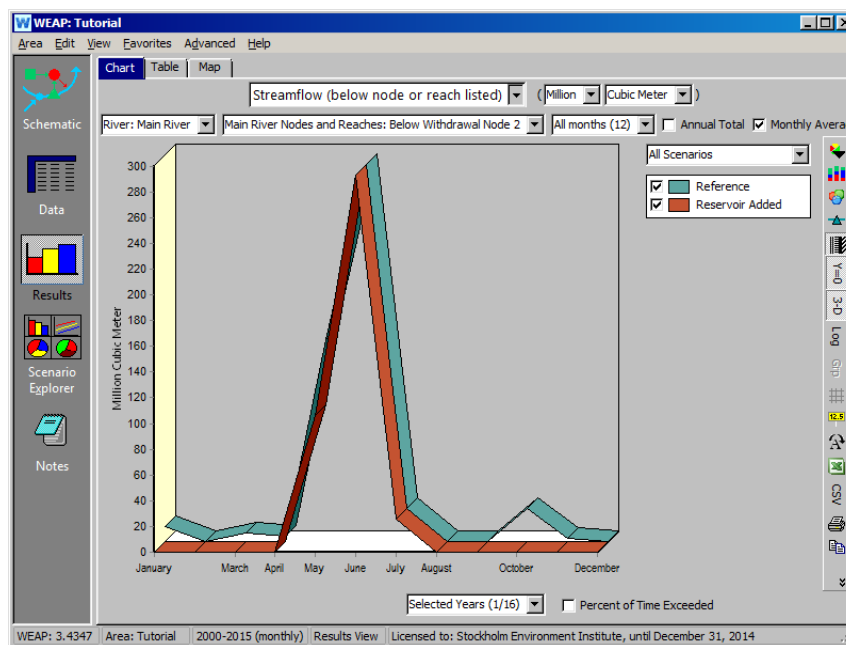




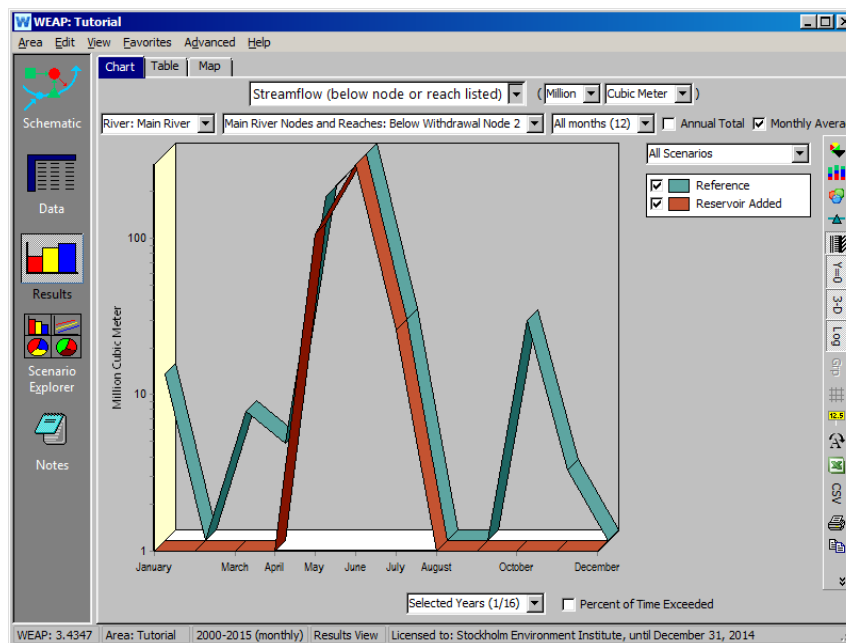
- *Flow in the River: how does having the reservoir on the Main River change the flow downstream compared to the Reference scenario? Select Streamflow (under Supply and Resources\River) from the primary variable pull-down menu and click on "Monthly Average."*



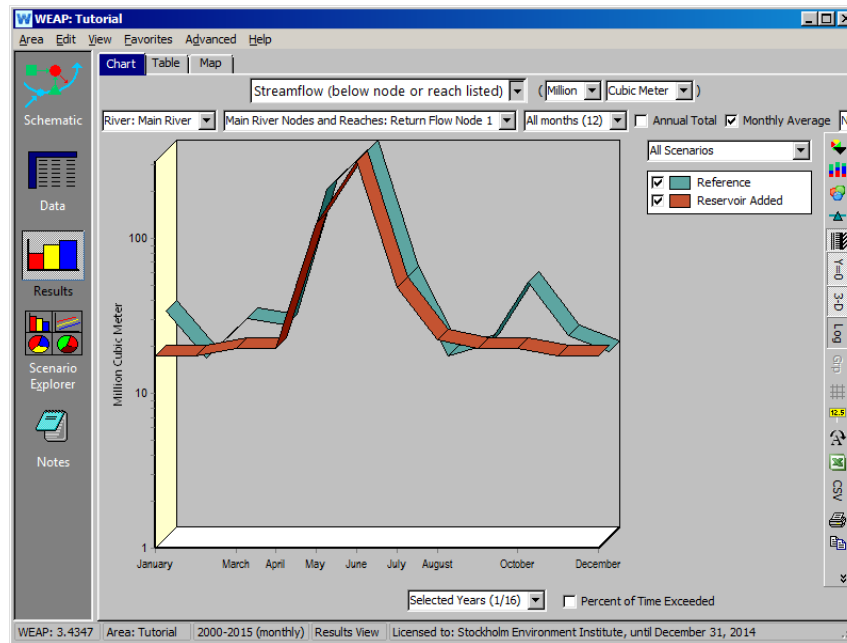
- *Choose the year 2002 from the "Selected Years" option on the bottom menu, and choose the reach below Withdrawal Node 2 for comparison.*



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?*

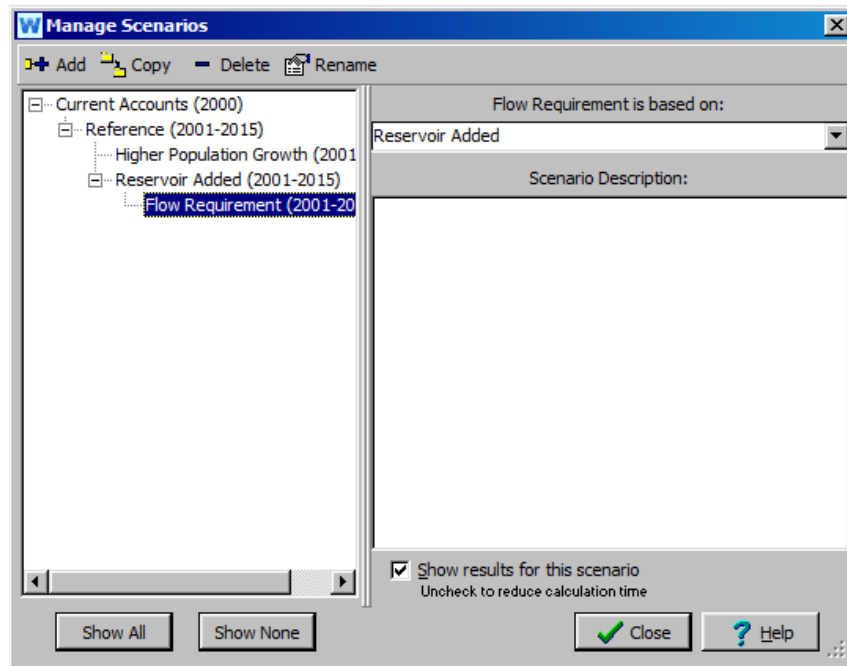


The creation of a large reservoir allows storage of “excess” water during high flow periods to cover water demand during low flow periods. The price to pay is, however, a potentially large impact on the hydrological regime of the river downstream of the reservoir. The Return Flows from Big City and Agriculture 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

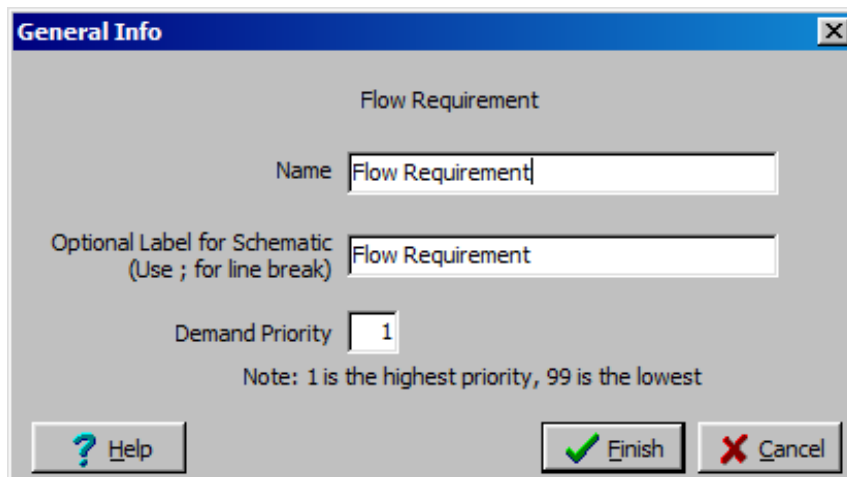
### 6. Create a Flow Requirements

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:



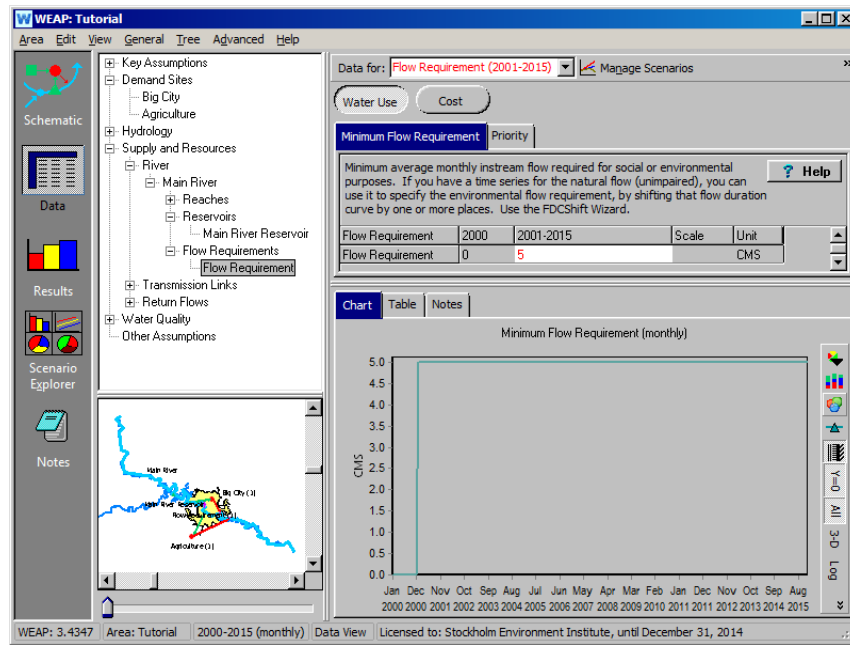
Now add a “Flow Requirement” to the Schematic view below the withdrawal node for the Big City, but upstream of the withdrawal node for Agriculture.

*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



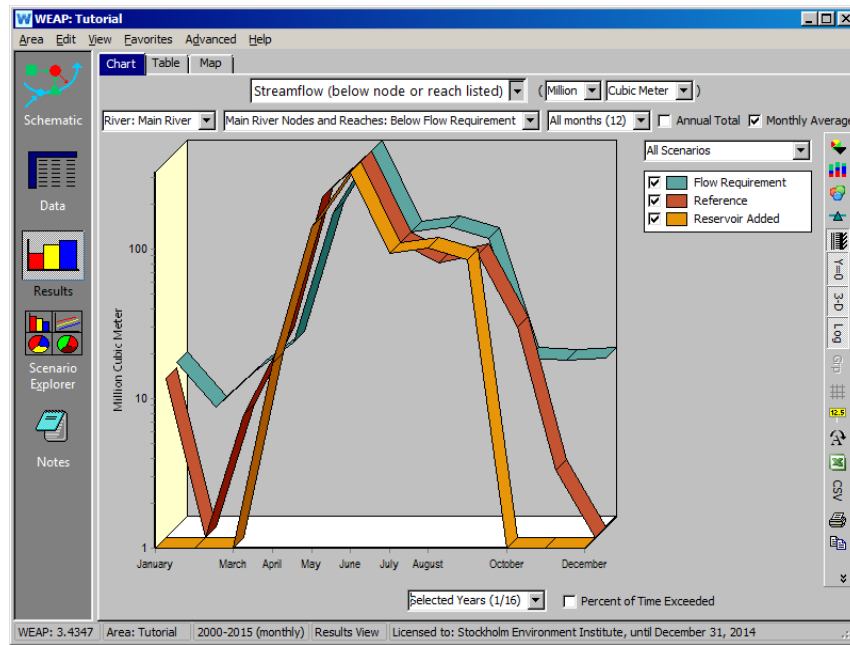
## 7. Run the Model and Evaluate the Results

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?

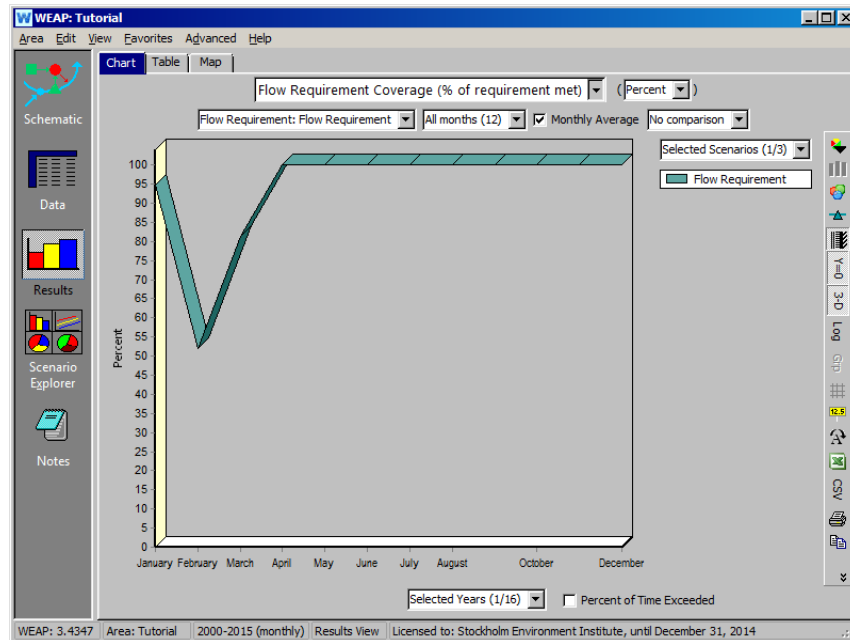
Compare streamflow below the flow requirement for the “Reference”, “Reservoir Added”, and “Flow Requirement Added” scenarios for the same year (2002). You should obtain a graph like the one below:





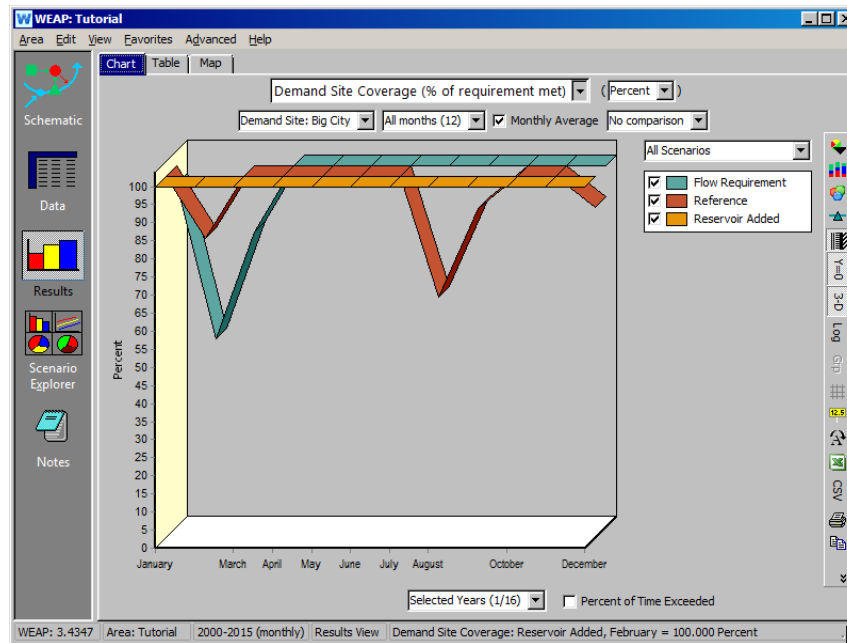
- *What is the Flow Requirement coverage?*

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?

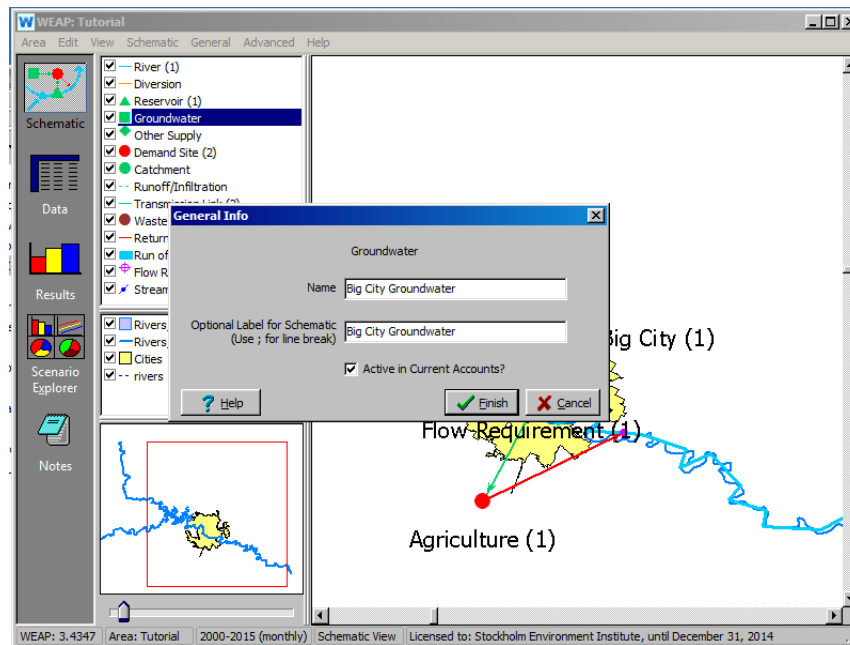


The relative level of Demand Priority for Big City, Agriculture and the Flow Requirement will determine which demand is covered first. To ensure that the Flow Requirement is covered first, change the Demand Priority of Big City to a higher number (lower priority) than for the Flow Requirement, since 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):

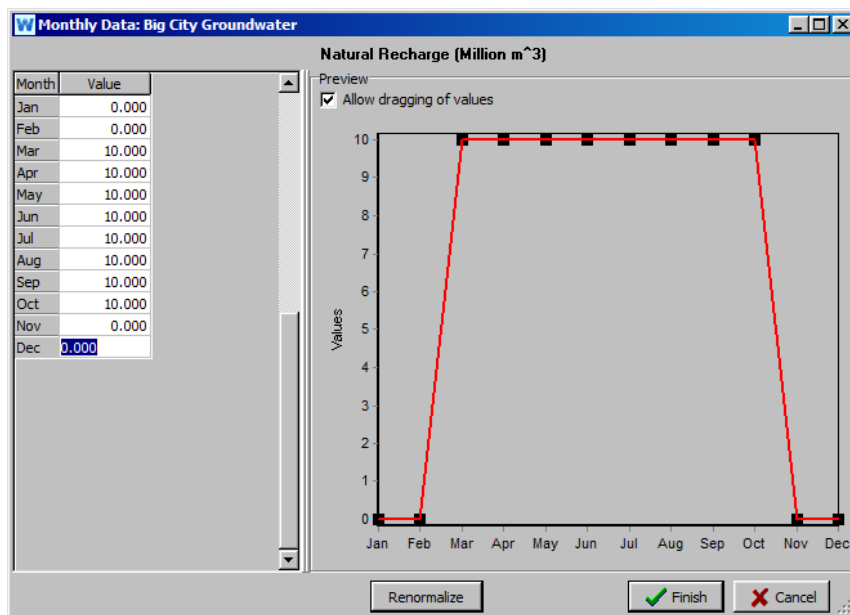
*Storage Capacity*      *Unlimited (default, leave empty)*

*Initial Storage*      *100M m<sup>3</sup>*

*Natural Recharge (use the Monthly Time Series Wizard, accessed in the field under "2000")*

- *Nov. to Feb. 0M m<sup>3</sup> / month*

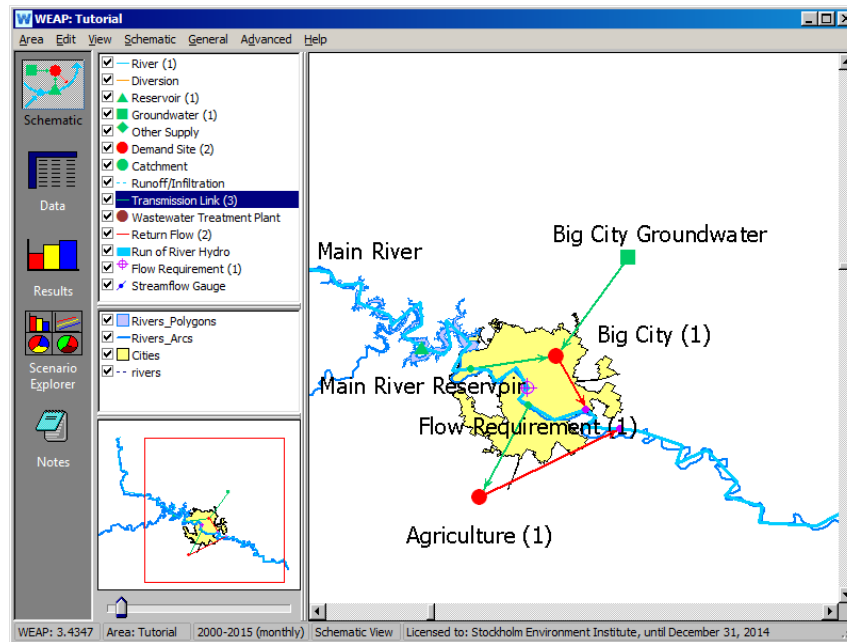
- *Mar. to Oct. 10M m<sup>3</sup> / month*



## 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:



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

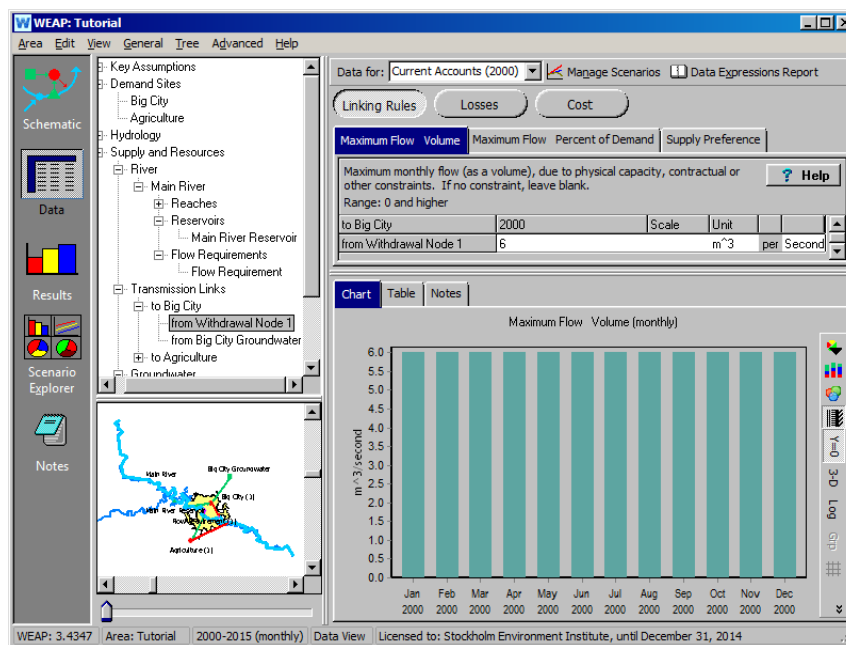
Change the characteristics of the Transmission Link connecting the Main



The Maximum Flow Volume or Percent of Demand parameter represents restrictions in the capacity of a resource (due, for example to equipment limits).

River (Withdrawal Node 1) and Big City (make sure you are in Current Accounts):

<i>Supply Preference</i>	1 (default)
<i>Maximum Flow Volume</i>	6 m <sup>3</sup> /sec

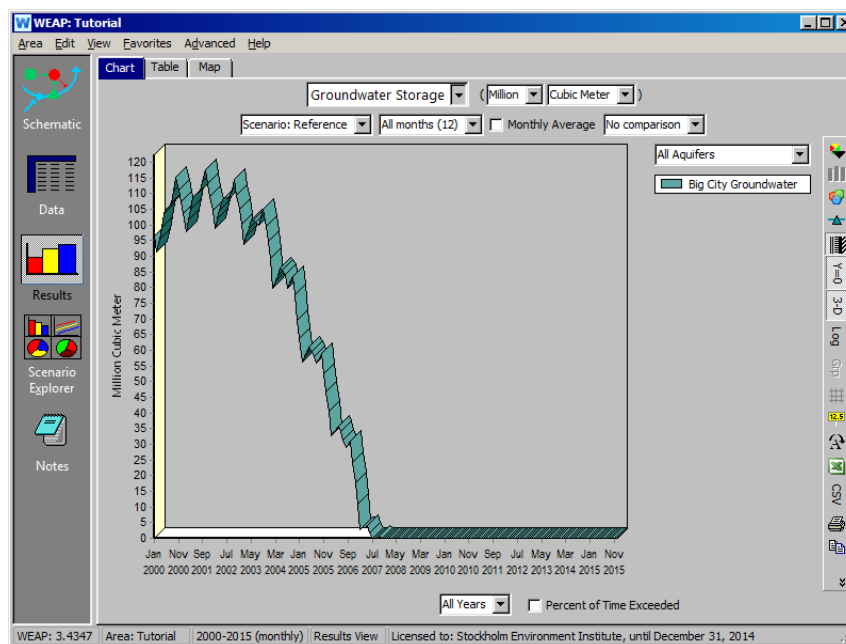


## 11. Run the Model and Evaluate the Results

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

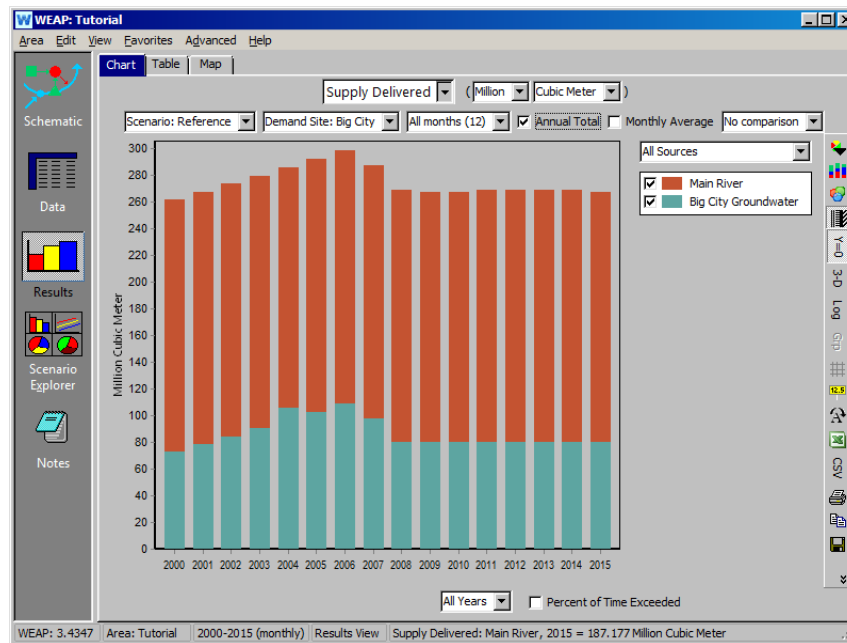
- *Is the groundwater extraction required to meet demands under these conditions sustainable?*

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



- 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 above the graph. Click on "Annual Total."



Groundwater recharge and interaction with rainfall and surface water can be modeled rather than 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

# Data, Results and Formatting

## ***A TUTORIAL ON***

*Exchanging Data* .....116

*Importing Time Series* .....119

*Working with Results* .....123

*Formatting* .....127

**August 2016**



**Note:**

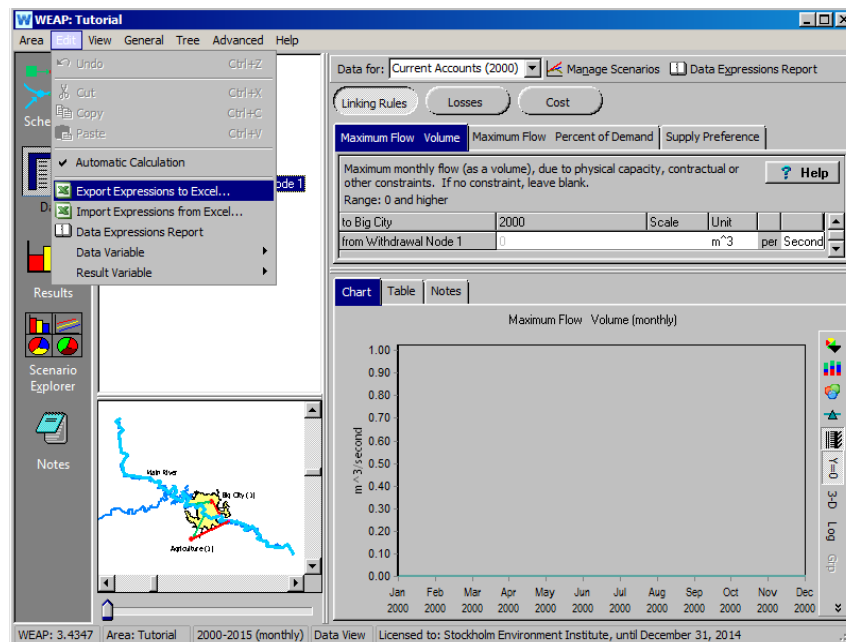
For this module you will need to have completed the previous modules (“WEAP in One Hour, Basic Tools, and Scenarios”) or have a fair knowledge of WEAP (data structure, Key Assumptions, Expression Builder, creating scenarios). To begin this module, go to the Main Menu, select “Revert to Version” and choose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

## Exchanging Data

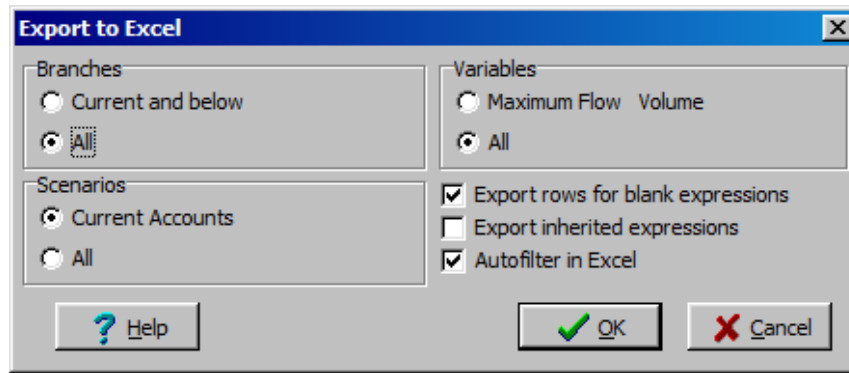
### 1. Export Data to Excel

Export the entire model to Excel by going to the Data view and selecting “Edit”, “Export Expressions to Excel.”

*Export all branches, and all variables of the “Current Accounts” only (don’t export any of the scenarios for this example) to a new workbook. Keep other options at default values.*





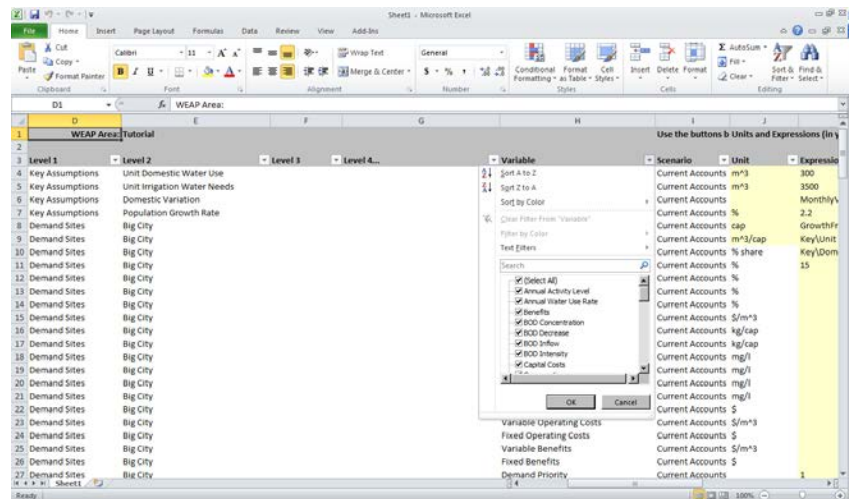


This instruction creates a new Excel workbook that contains all the variables that can be changed in the “Data” view, using the same structure as in the Data tree. In large models, you can choose to export only the current branch and/or variable.

## 2. Use Excel’s Auto Filtering Option

In the Excel Spreadsheet that was created in the previous steps, filter the content to display only the “Consumption” variable. You will probably have to scroll over to the right to see the column in the view.

*Use the arrow to the right of the “variable” header to unselect “select all” and the scroll down to select the “Consumption” variable in the drop-down list.*



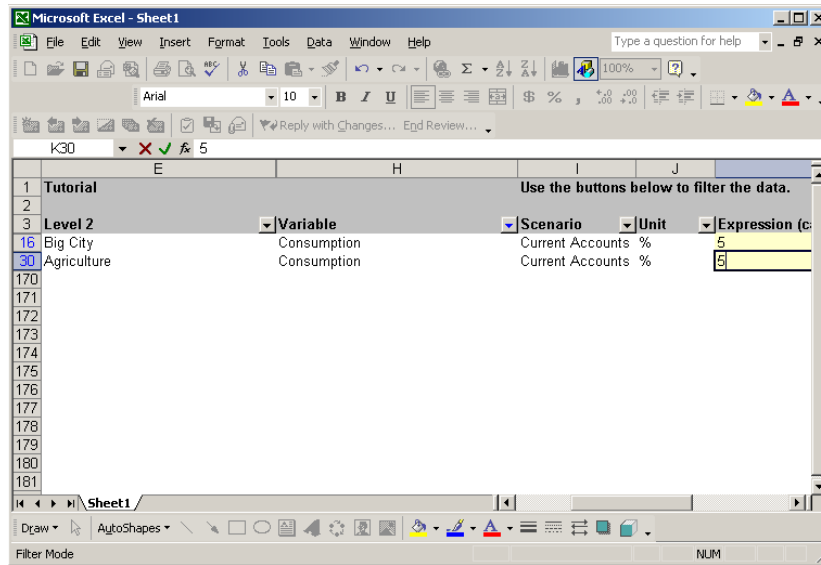
Auto-filtering does not change or erase the data; it only hides the rows that are not of interest. Multiple filters can be used.

## 3. Modify Data

In the Excel spreadsheet that was created in the previous steps, make the following changes in the yellow column (it may be good to hide a few of the

columns so that you can see both the variable values and the Demand Sites to which they belong in the same view):

*Big City Consumption*      5% (value was 15 originally)  
*Agriculture Consumption*      5% (value was 90 originally)



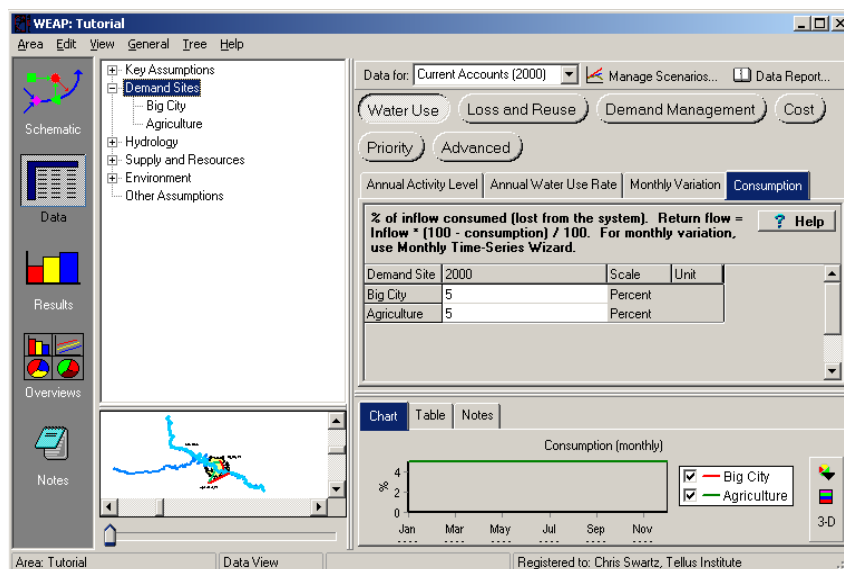
The values entered are not meant to be representative of realistic values, just examples.

When creating a large model, a quick way to enter a lot of data is to use the Excel Import and Export functions combined with the Excel lookup capabilities. This requires the user to have set up the model in a consistent way (data structure, names), however.

## 4. Import the Data from Excel

Re-import the modified data in Excel.

*In WEAP, choose “Edit”, “Import Expressions from Excel...”*  
*Check that the Consumption data have been changed in your model.*



WEAP always reads from the Excel file that had the focus last. If you have several Excel files open, you should ensure that the appropriate Excel file is selected before beginning the importation into WEAP.

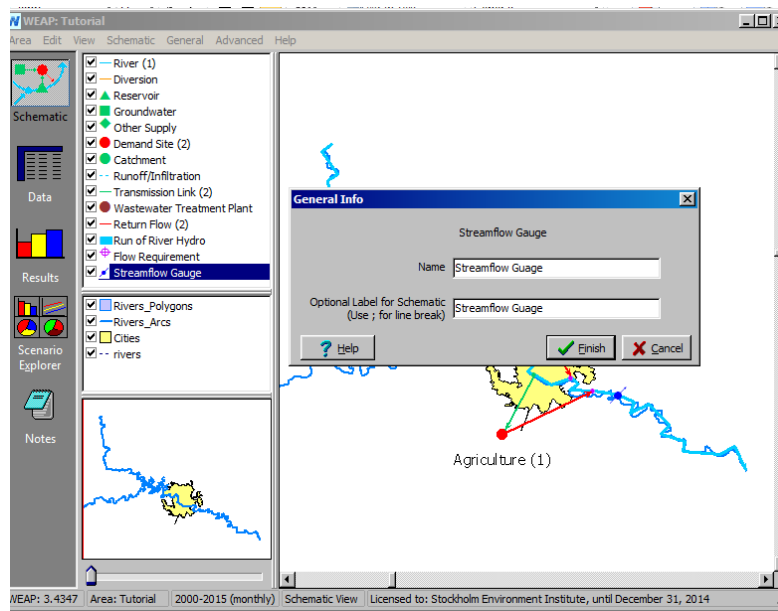
When re-importing into Excel, all rows are read, even those that are filtered out through the auto-filtering options.

## Importing Time Series

### 5. Create a Streamflow Gauge Object

Add a “Streamflow Gauge” object to the model.

*Insert the Streamflow Gauge downstream of the Big City, below the return flow nodes for Agriculture and Big City.*



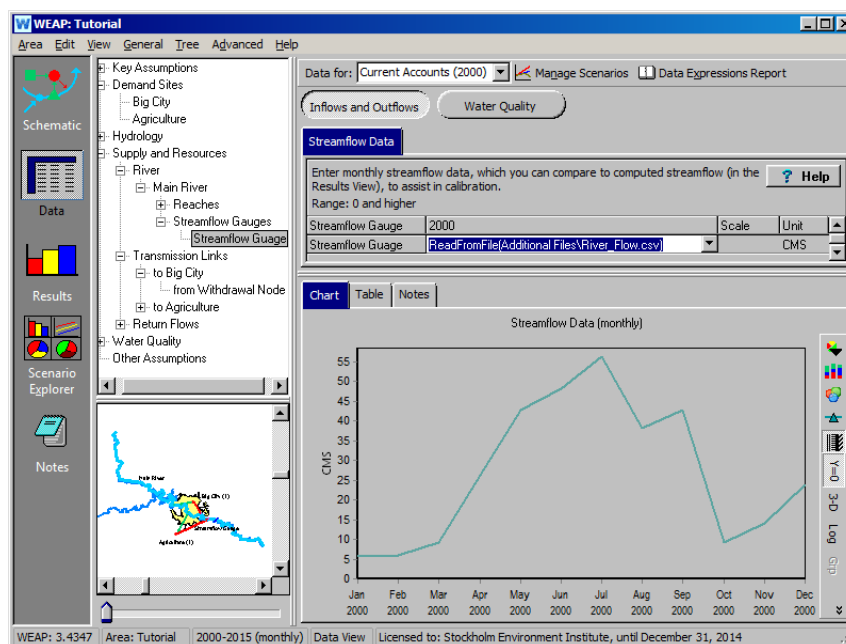
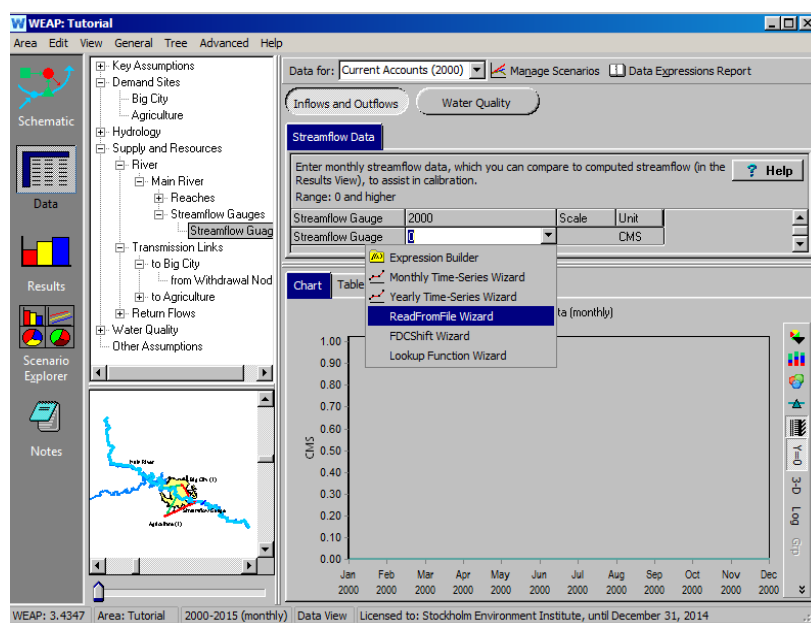
## 6. Import Text File Data

Import streamflow data from a comma-separated text file containing approximately 100 years of streamflow measurements up to 2003. To import the file, use the “ReadFromFile” function in the streamflow gauge’s data tab in the “Supply and Resources\River\Streamflow Gauges” branch of the Data tree.

*Type in the following function, which will read the file from a directory called “Additional Files” located in your area’s folder:*

*“ReadFromFile(Additional Files\River\_Flow.csv)”*

If WEAP cannot find the file, try searching for it using the “ReadFromFile Wizard” in the dropdown menu.



The ReadFromFile function can be used for any variable that requires a time series, monthly or yearly, such as headflow, groundwater recharge, etc.



WEAP will automatically locate the correct year and month and only use that data. If you change the years modeled, WEAP will automatically read the correct data.

More information about the syntax of this function and the format of the data file can be found in the “Read from File” help topic.

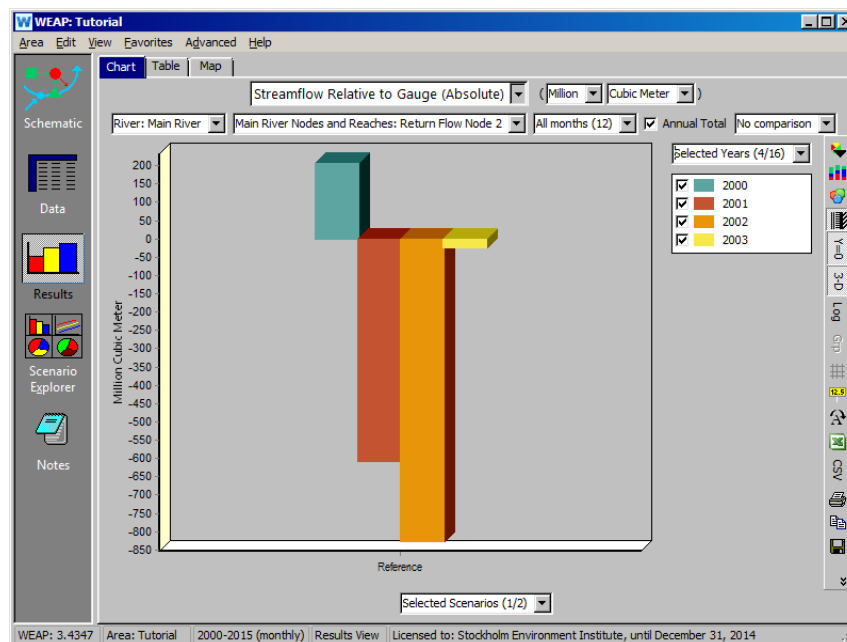
## 7. Compare the Actual and Modeled Streamflow

Recalculate the results and compare the historical streamflow data with the WEAP simulated streamflow. Do this by clicking on the “Chart” tab of the Results view and selecting from the primary variable pull-down menu: Supply and Resources\River\Streamflow Relative to Gauge (Absolute).



WEAP will compare the observed flow at the streamflow gauge to the nearest upstream node. In the case for this example, that node is Return Flow 2 (the Return Flow for Agriculture). Comparing observed and simulated streamflow is one means for the user to assess if the model is representing the system accurately.

Choose the “Selected Years” option from the pull-down menu below the chart and select only the years 2000, 2001, 2002, and 2003 (the Current Accounts is 2000, and the data file contains no stream gauge data beyond 2003). If the results display both scenarios, change it to the reference scenario only with the pull-down menu to the right of the chart above the legend. To display the years in different colors, use the same pull-down menu above the legend to select “Selected Years.” Choose the Reference scenario. You should obtain the graph below:



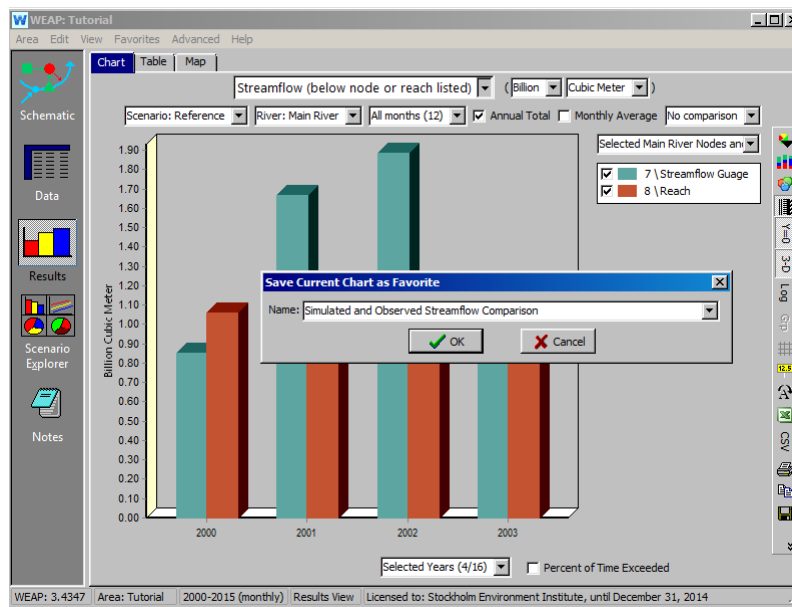
Notice that the simulated streamflow is greater than the observed streamflow in the Current Accounts year (2000) but is less than observed in subsequent years.

# Working with Results

## 8. Create a Favorite Graph

Create a graph of streamflow that shows both the actual flow as recorded at the streamflow gauge and the simulated streamflow at the appropriate node upstream of the streamflow gauge (in this example, below Return Flow Node 2). First, select “Streamflow” from the primary variable pull-down menu. Then select “7 \ Streamflow gauge (gauge)” and “8 \ Reach” from the list that appears when you choose “Selected Main River Nodes and Reaches” from the drop-down menu of the Supply and Resources\River\Streamflow chart above the graph legend (see below). Finally, select the years 2000, 2001, 2002, and 2003 to be represented in the graph using the pull-down menu at the bottom of the window.

Save this graph as a favorite by using the “Favorite”, “Save Chart as Favorite” option. Name the file “Simulated and Observed Streamflow Comparison.”



From this point forward, the chart will appear in the list of favorite charts of the Results view.

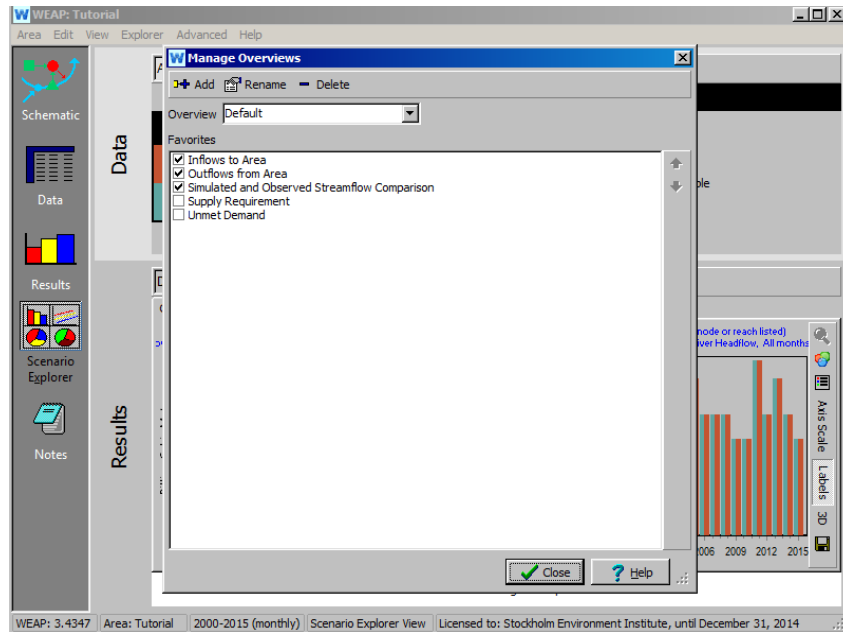


You can also export the data to Excel or to the clipboard, change the format and the display of figures and charts, calculate statistics, group series with the smallest values, etc. from the toolbar located at the right of the “Results” view.

## 9. Create an Overview

An overview displays important charts in the Scenario View like a dashboard. Create an “Overview” displaying the streamflow, inflow, and outflow to area charts.

*Select the “Scenario Explorer” view. Click “Manage.” In the window that appears, select “Inflows to Area”, “Outflows from Area” and the Favorite graph created in the previous step.*



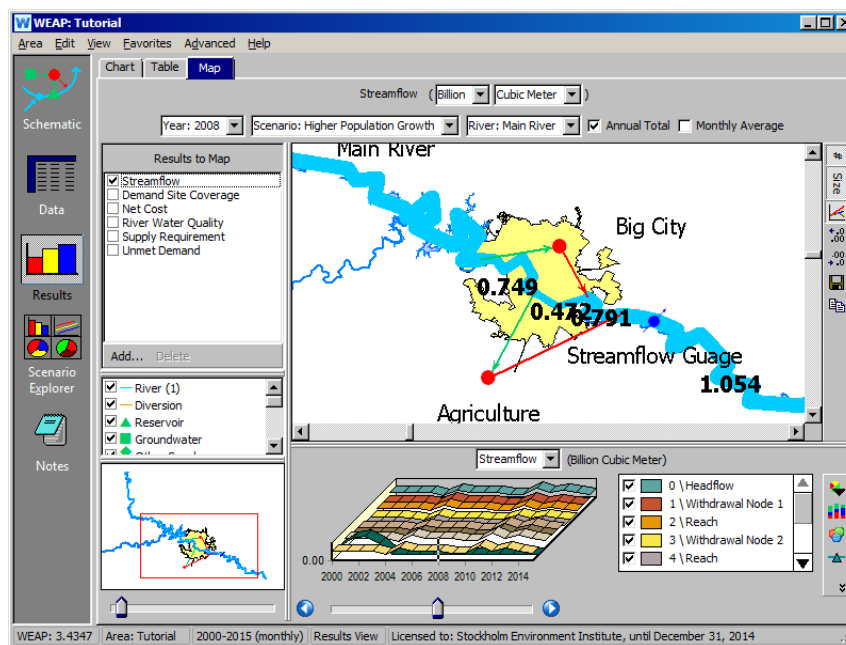
Overviews can be created from any combination of favorites, but the charts need to be created in the “Results” view prior to their integration in an overview. The data underlying overviews can also be displayed in tabular format (select the “Table” tab) and exported to Excel.

## 10. Use the Dynamic Map

Dynamic Results Maps are a quick way to obtain an overview of the results in their temporal context. In the “Results” view, select the “Map” tab and play with the time slider at the bottom of the display to see how the displayed parameters change.

*Try this by selecting the Main River’s streamflow.*






Note that as you pull the slider across the bar, an indicator appears in the graph above the bar to indicate the data selected (for this example, the year 2004 annual total is selected). In the smaller schematic view at the top of the window, the width of the river will increase and decrease with the changing data, and numerical values appear for each of the reaches.

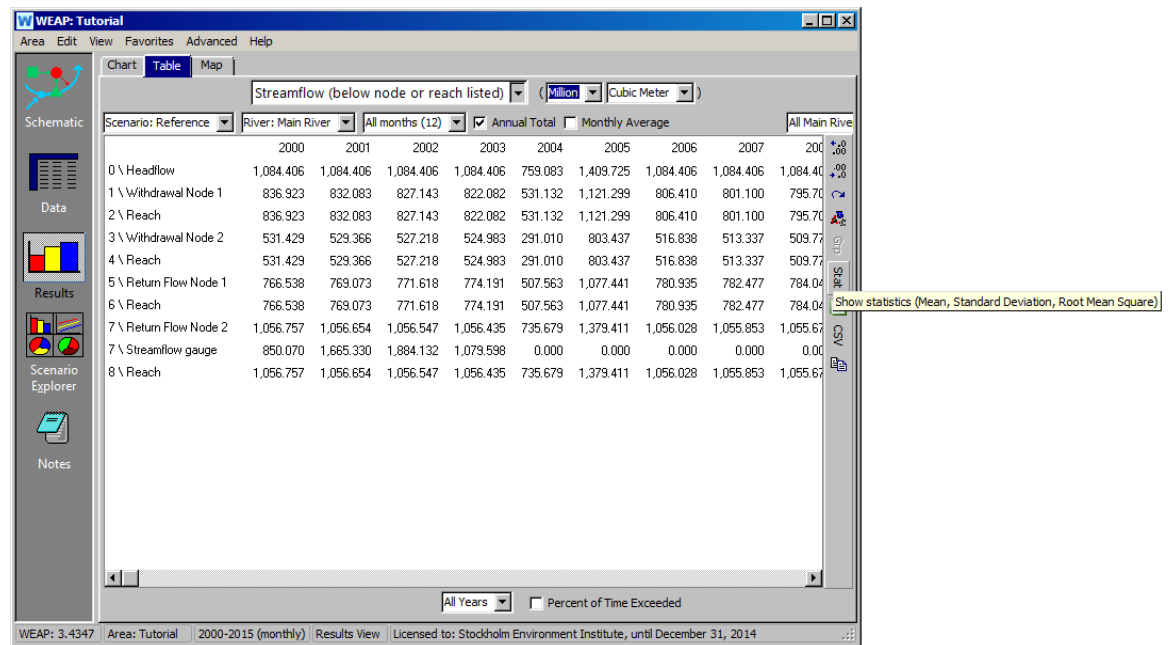
## 11. Export Results to Excel

All results can be readily exported to Excel from the “Results” view. A new workbook is created that contains the results in table format, with the same structure as in WEAP.

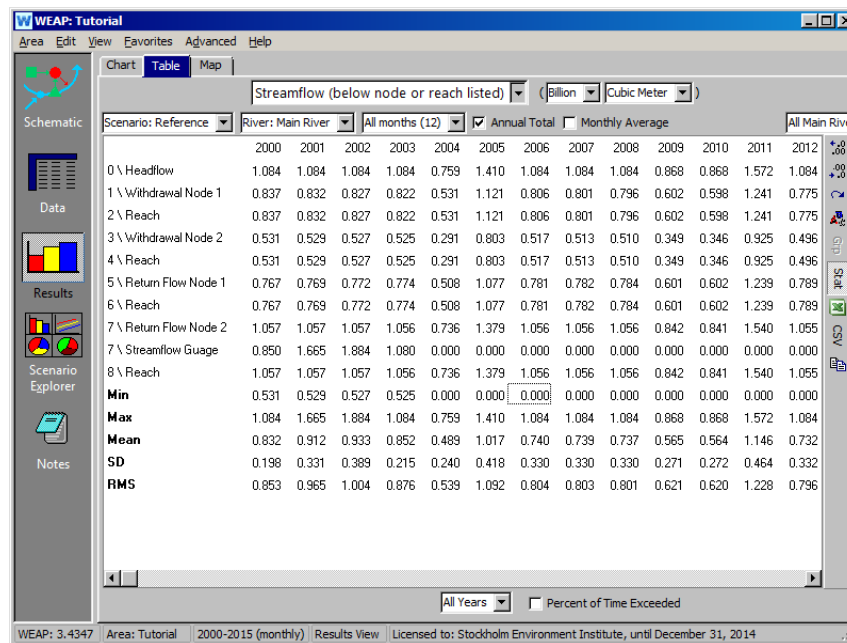
*Recall the favorite graph you have created a few steps before by selecting it in the “Favorite” menu of the Results View. Export the related data to Excel by switching to the “Table” tab and hitting the “Export Table to Excel” button (  ) to the right of the screen.*

## 12. Calculate Statistics

You can generate statistics in the Results view for any table. Under “Charts”, display the Reference Scenario Streamflow (annual total) for all reaches of the Main River for all years. Now click on the Table tab and then click on the “Stat” icon on the right vertical menu bar.



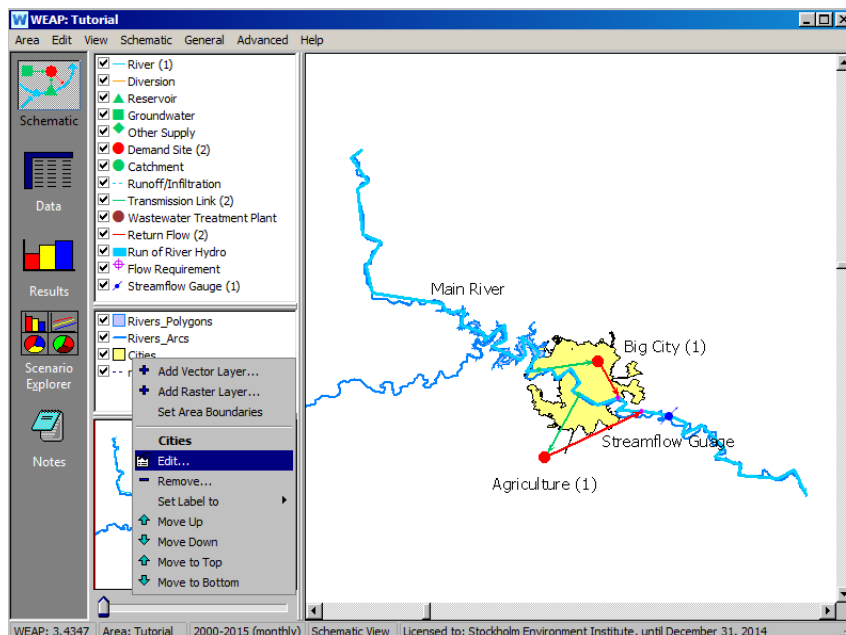
We are provided with statistical values of Min, Max, Mean, Standard Deviation (SD) and Root Mean Square (RMS).



# Formatting

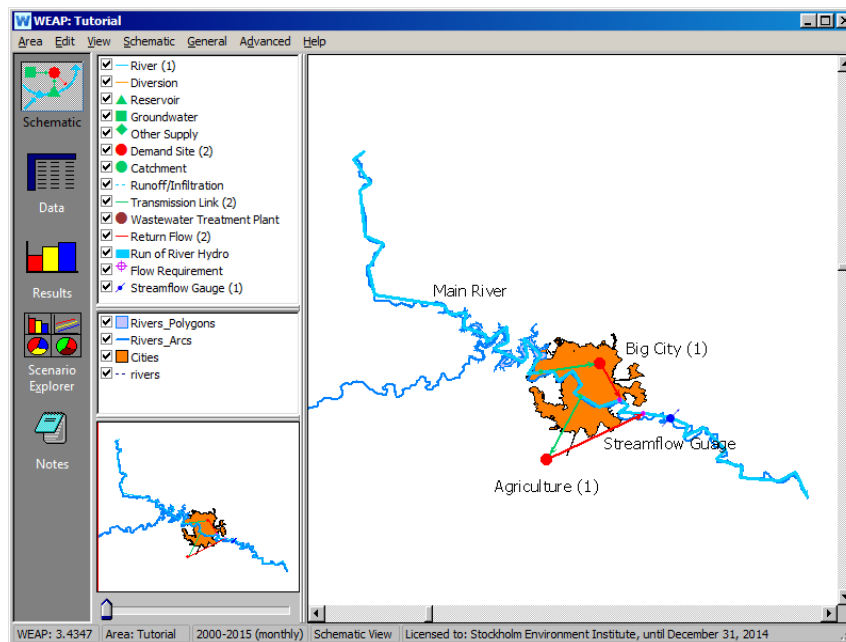
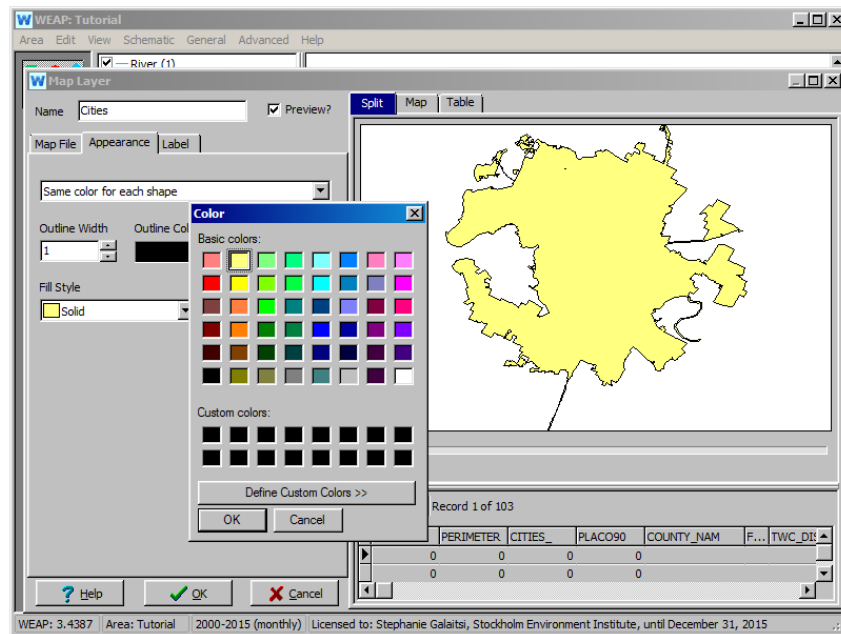
## 1. Change the Appearance of a Background Vector Layer

In the Schematic View, change the color of the polygon for Big City by right-clicking the “Cities” layer in the box below the Element Selection box (see example below), and selecting “Edit.”



In the window that appears, click on the Appearances tab, then click on the “Fill Color” field. A color palette will appear.

*Change the Background color to orange.*



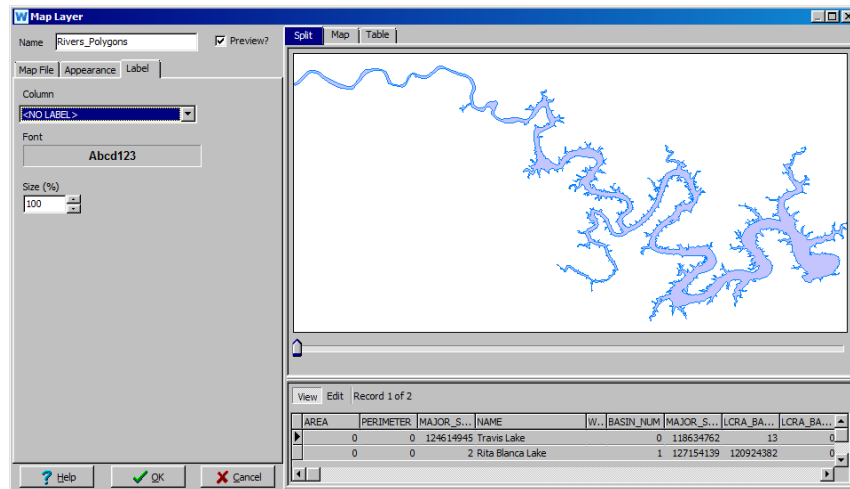
Background vector data can be added by clicking “Add Vector Layer.” WEAP reads vector information in the SHAPEFILE format. This format can be created by most GIS software.



A large amount of georeferenced data (both in vector and raster format) is available on the Internet, sometimes for free; websites such as [www.geographynetwork.com](http://www.geographynetwork.com) or [www.terraserver.com](http://www.terraserver.com) provide good starting points for a search. Keep in mind that some of the downloadable data might need GIS processing before being usable in WEAP, especially to adapt the projection and/or coordinate system.

## 2. Label a Vector Layer

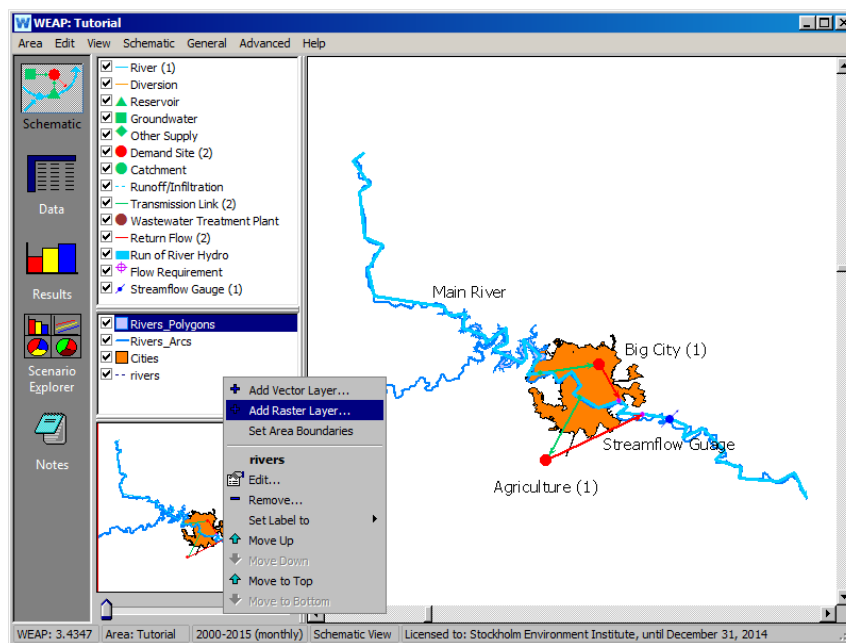
You can edit the labels for the layers - right click on the “Rivers Polygons” layer in the box to the right of the schematic, select “Edit” and choose the “Label” tab. You can also change the size of the labels in this tab by going to the Size field at the bottom of the window.



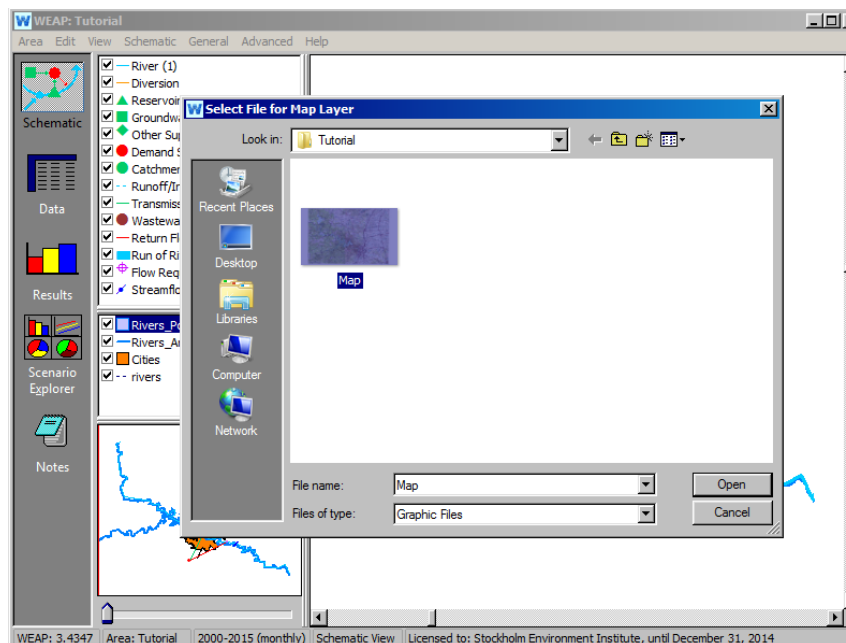
You can also hide layers in the Schematic view by clicking in the small box to the left of the layer name (this makes the check mark disappear also).

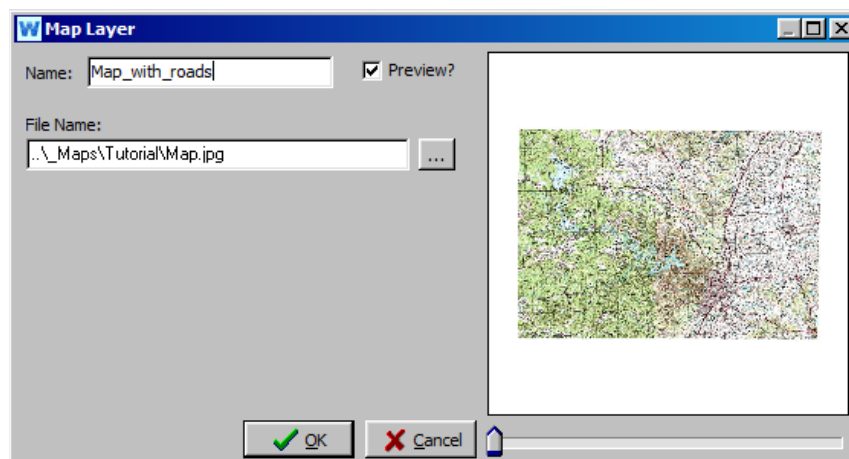
## 3. Add a Raster Layer

In the Schematic view, add a background map of the Big City region by right-clicking in the Layer window (see example below) and selecting “Add Raster Layer”

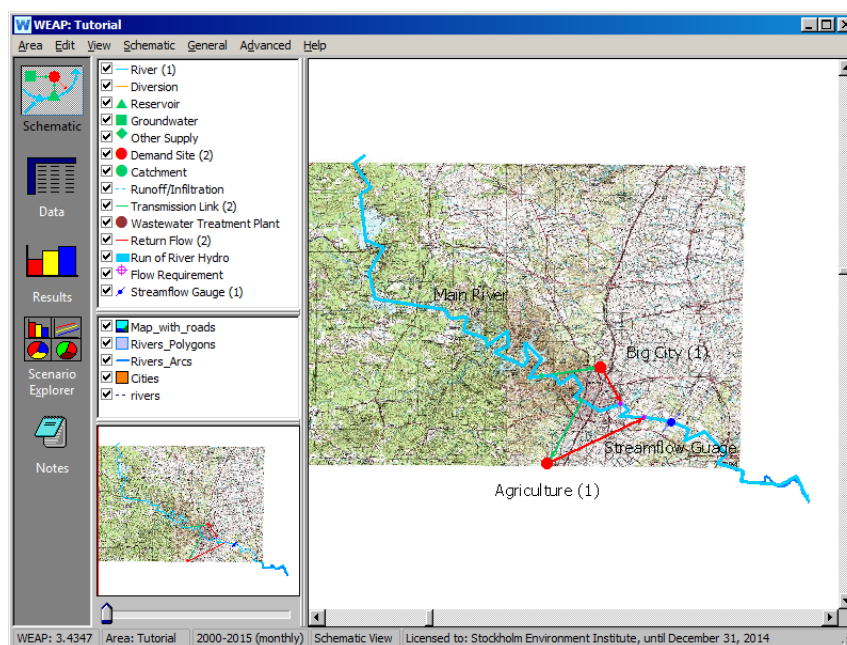


Select the file “Map.jpg” located in the “\_Maps\Tutorial” subdirectory of the WEAP directory (e.g., C:\Program Files\WEAP21\\_Maps\Tutorial). Also enter a descriptive name to appear in the Layer window.



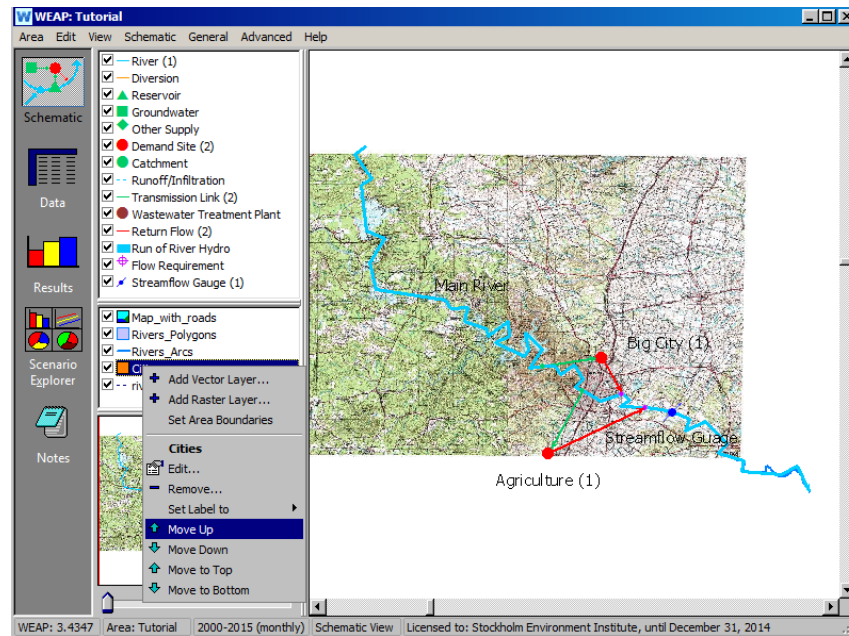


*Your map may show up as the first item in the window, placing it the other vectors and shapes.*

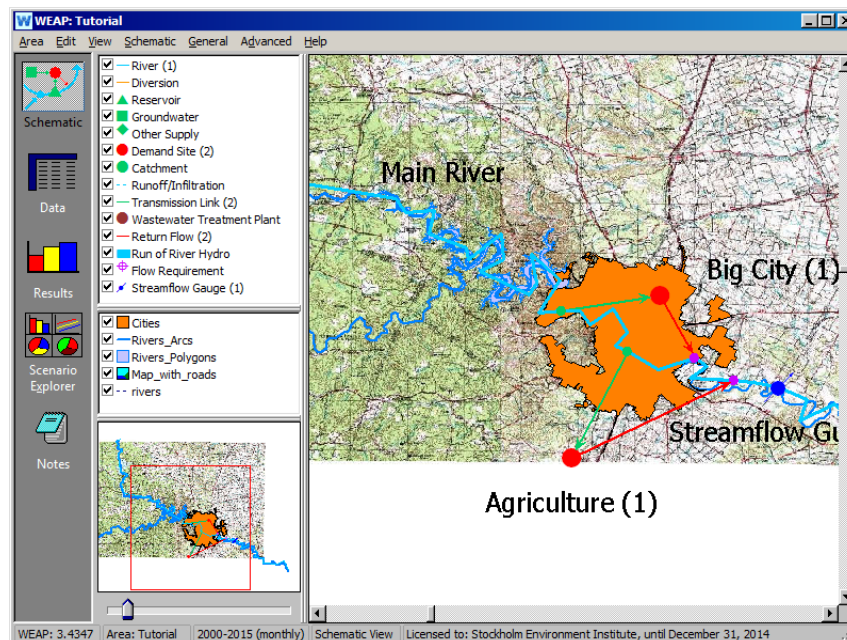


We want to see the rivers and roads. You can also move various layers above or below each other in the schematic. Do this by right clicking on a layer and selecting "Move Up" or "Move Down."





*After you have moved your layers, your model should now look similar to the figure below:*



WEAP uses a “world file” to correctly position your raster file for a specific map projection. Those files define the coordinate of one of the corners of the raster and the cell size. They can be created by many standard GIS programs such as ArcView.

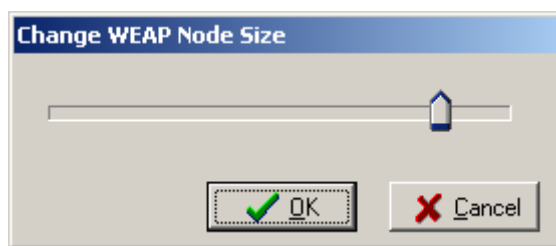
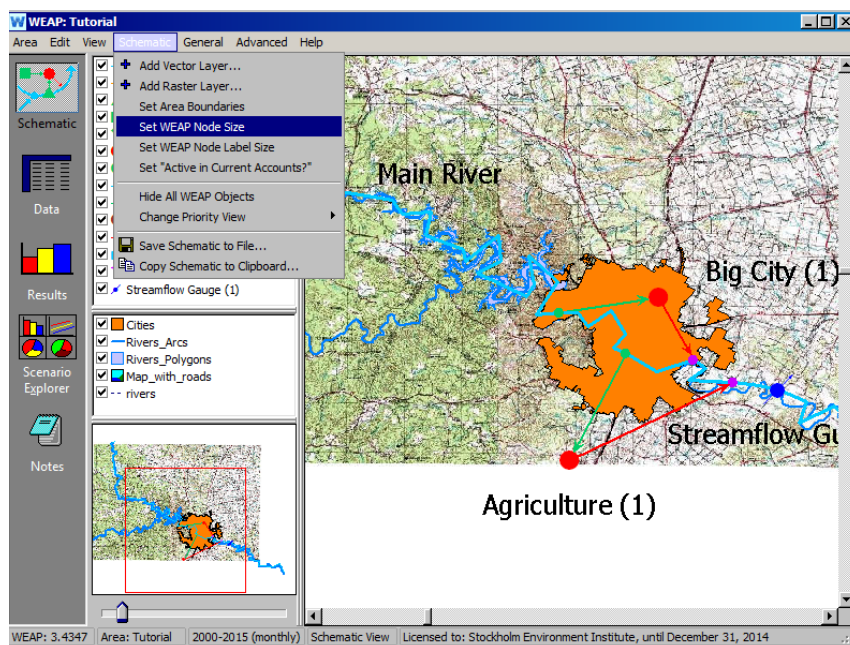
The world file must have the same name as the raster file with a “w” added to its extension and be in the same directory. For example, the world file for the above file is called “map.jgw.”



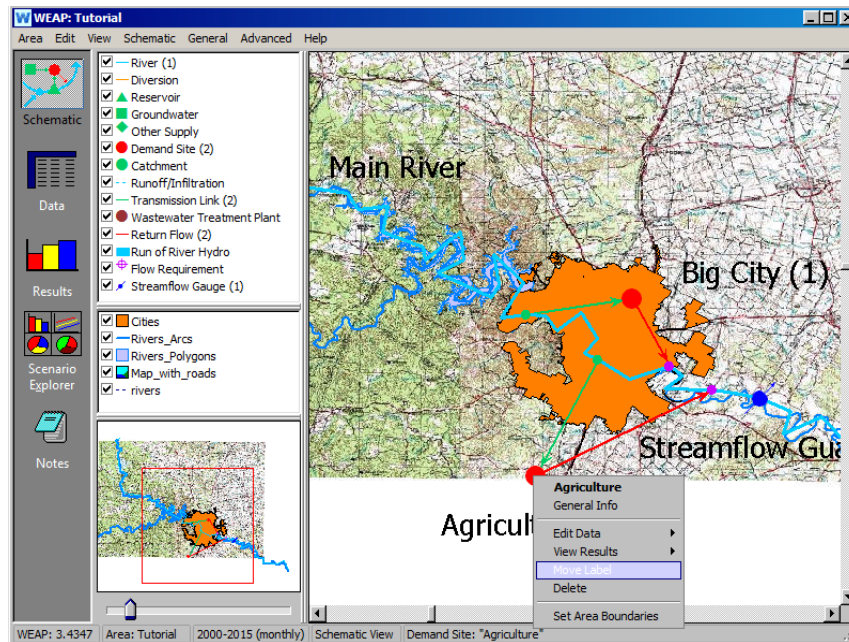
## 4. Move around Labels

Complete the formatting of your area by changing the node and label font size and moving around labels.

*Under the Schematic pull-down menu, the “Set WEAP Node Size” and “Set WEAP Node Label Size” menu options can be used to change the size of symbols and labels. For each of these actions, a window with a slider will appear for increasing and decreasing the size of these elements.*



Right-Click on any object and select “Move Label” to move its label.



If you don't want a label to appear for a given object, just right-click that object, select “General Info” and delete the optional label text.



You can copy your map to the clipboard for later use in reports and presentations by selecting “Copy Schematic to Clipboard...” in the “Schematic” menu. The file size indicated in the dialog box corresponds to an uncompressed format. It is usually safe to go with the default level of detail.

---

**WEAP**

**Water Evaluation And Planning System**

# **Reservoirs and Power Production**

***A TUTORIAL ON***

*Modeling Reservoir Operation.....136*

*Adding Hydropower Computation.....141*

*Modeling Run-of-River Power Plants.....144*

**August 2016**

**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 Reservoir Operation

### 1. Create a Reservoir

Create a Reservoir on the Lake located upstream of the Big City’s withdrawal from Main River. Name it “Big City Reservoir” and leave it active in Current Accounts.

*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<sup>3</sup>

*Initial Storage*                        25 M m<sup>3</sup>

*Volume Elevation Curve*

<u>Volume</u>	<u>Elevation</u>
---------------	------------------

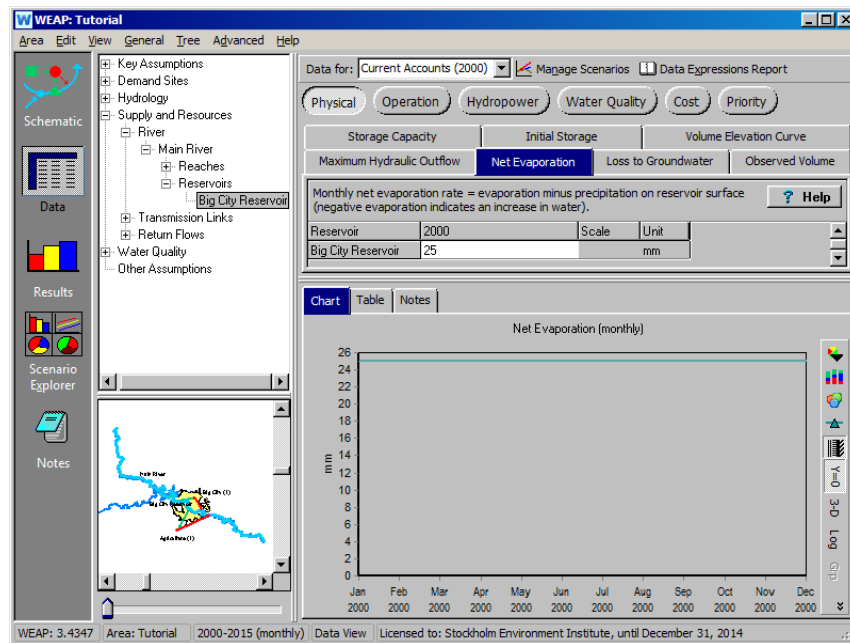
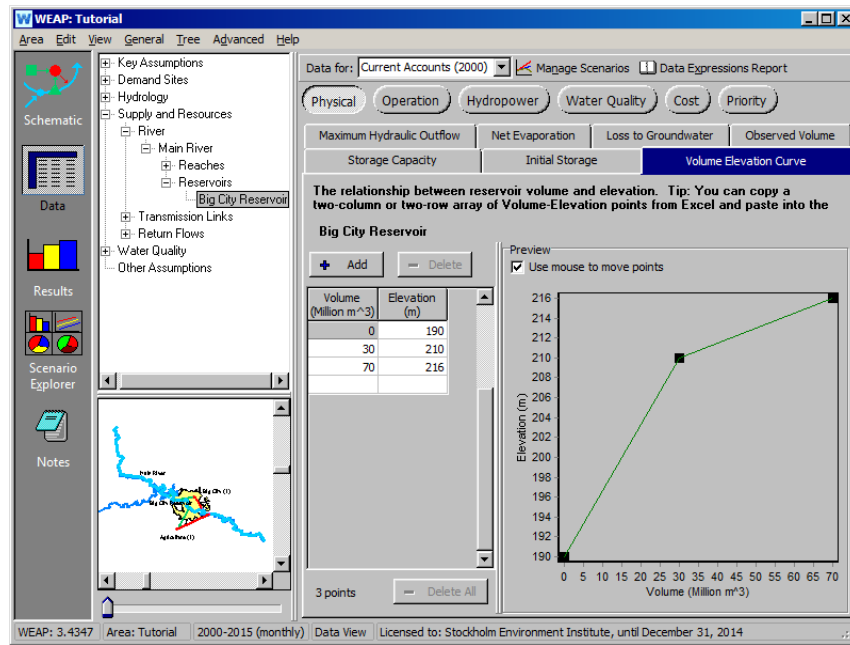
M m <sup>3</sup>	m
------------------	---

0.0	190
-----	-----

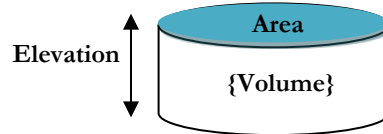
30.0	210
------	-----

70.0	216
------	-----

*Net Evaporation*                      25 mm/month (note that it defaults to monthly measurements).



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 reservoir volume and elevation into reservoir area.

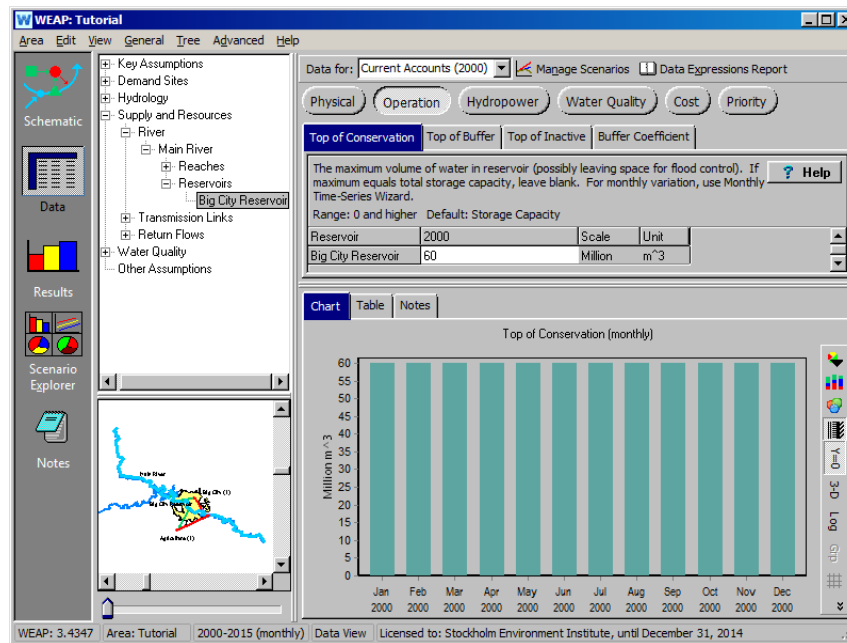


Net evaporation needs to account for both rainfall and evaporation. It can therefore be a positive or a negative number; monthly variations can be modeled using the “Monthly Time Series Wizard.”

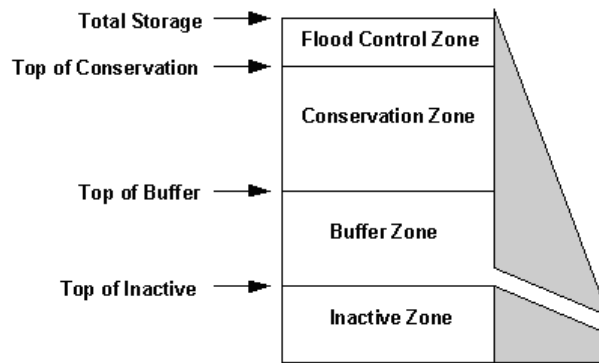
### 3. Enter the Operation Data

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

<i>Top of Conservation</i>	<i>60 M m<sup>3</sup></i>
<i>Top of Buffer</i>	<i>40 M m<sup>3</sup></i>
<i>Top of Inactive</i>	<i>5 M m<sup>3</sup></i>
<i>Buffer Coefficient</i>	<i>1.0</i>



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.

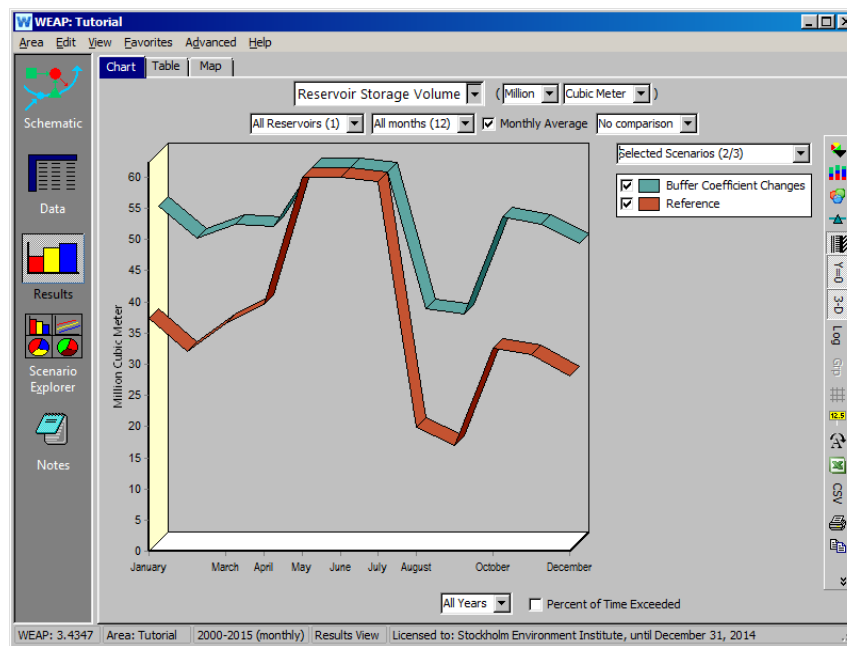


More can be learned through the Help file's "Reservoir Zones and Operation" screen or by clicking on the help button when in the Reservoir's Operation tab.

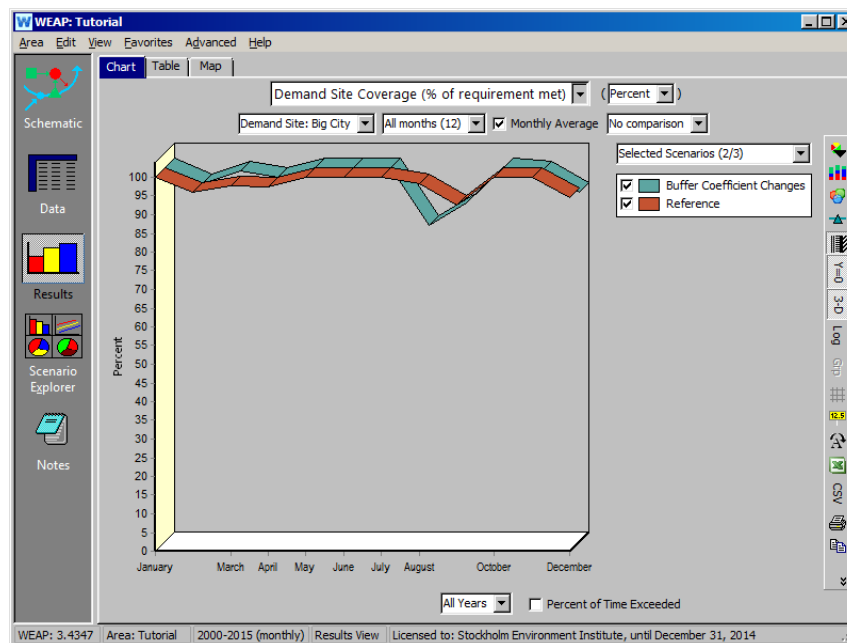
#### 4. Understanding the Impact of the Buffer Coefficient

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

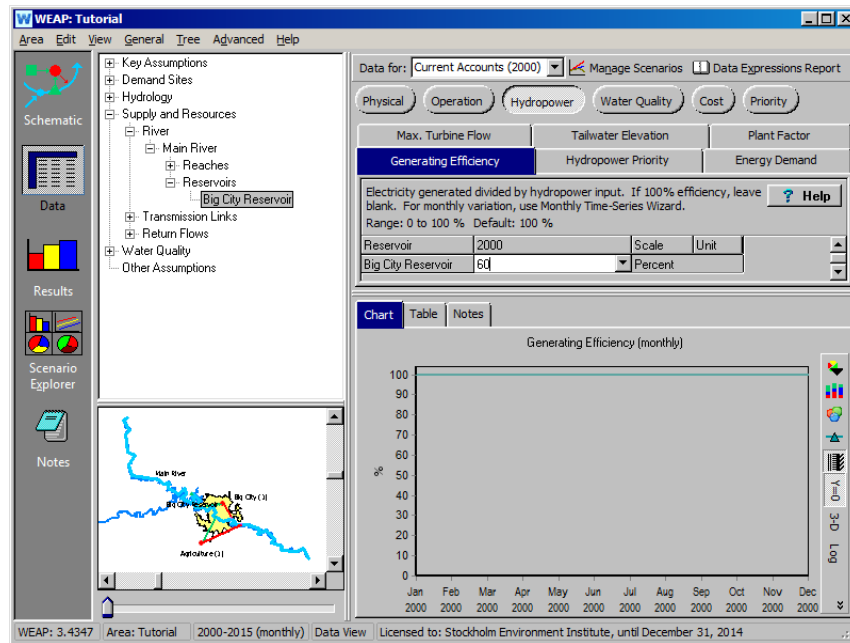
WEAP can model Power Production in three different ways: through on-line reservoirs, through off-line reservoirs, and through run-of-river hydropower plants. In a later module, we will also discuss linking WEAP with a Long-range Energy Alternatives Planning system (LEAP) energy modeling software.

*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 operating reservoir power plant. Enter the following data under the “Hydropower” window for Big City Reservoir in the Current Accounts.

<i>Max Turbine Flow</i>	<i>80 CMS</i>
<i>Tailwater Elevation</i>	<i>195m</i>
<i>Plant Factor</i>	<i>100%</i>
<i>Generating Efficiency</i>	<i>60%</i>

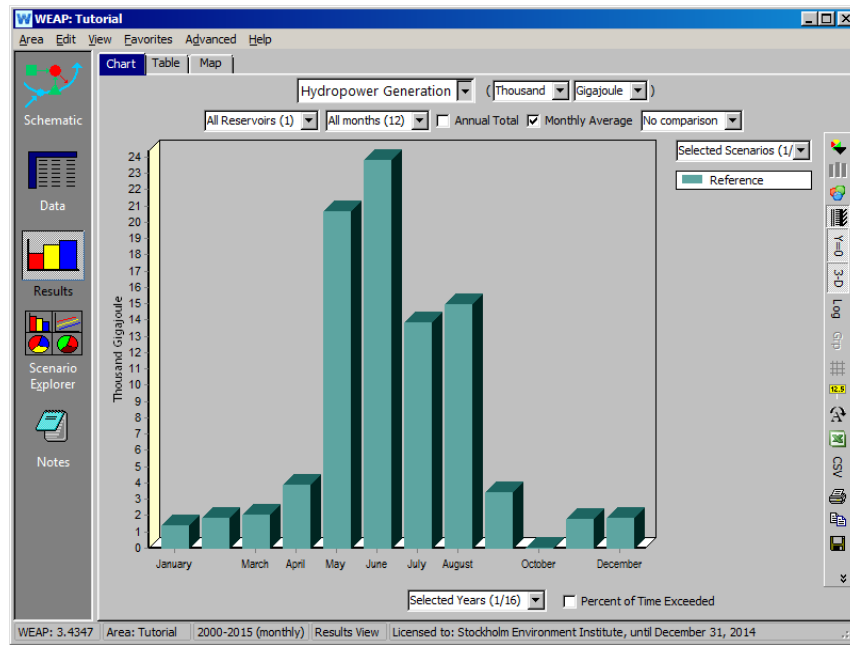


Look at the “Hydropower Calculations” help topic for more information about how WEAP computes power production.

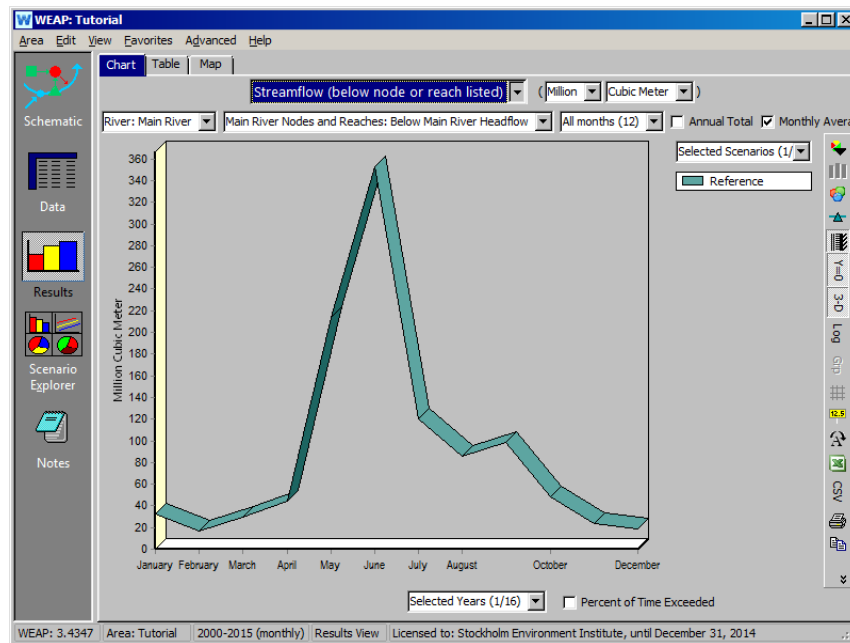
## 7. Compute Hydropower Production and Understand the Results

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 (Below Main River Headflow).*





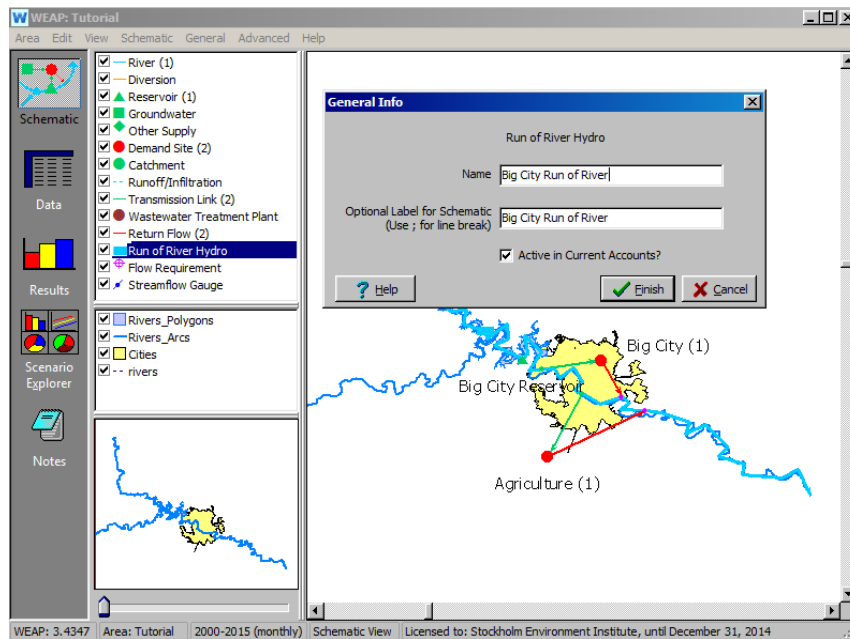
The streamflow that can be processed by the turbine has been capped to 80CMS (see previous step), meaning that even though there is a higher discharge in June, the excess quantity flows downstream without going through the turbine. Hydropower in June would be the same for May and June if not for the 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.

## Modeling Run-of-River Power Plants

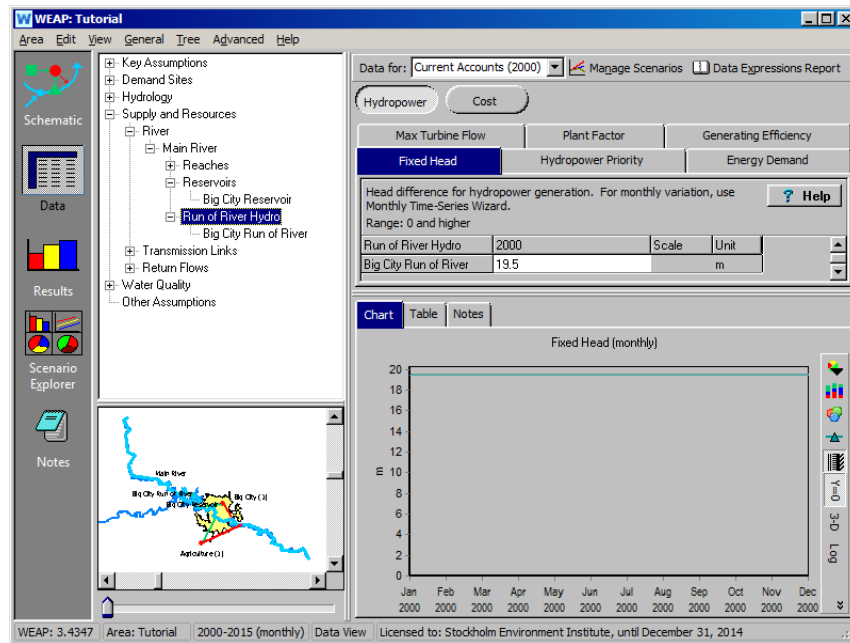
### 8. Create a Run-of-River Hydro Object

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:

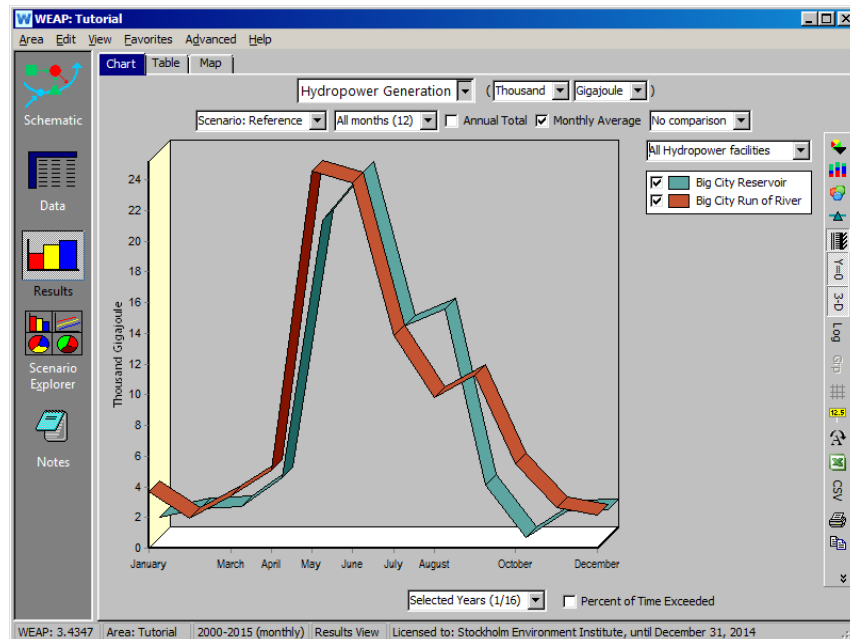
<i>Max Turbine Flow</i>	<i>80 CMS</i>
<i>Plant Factor</i>	<i>100%</i>
<i>Generating Efficiency</i>	<i>60%</i>
<i>Fixed Head</i>	<i>19.5 m</i>



## 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?*

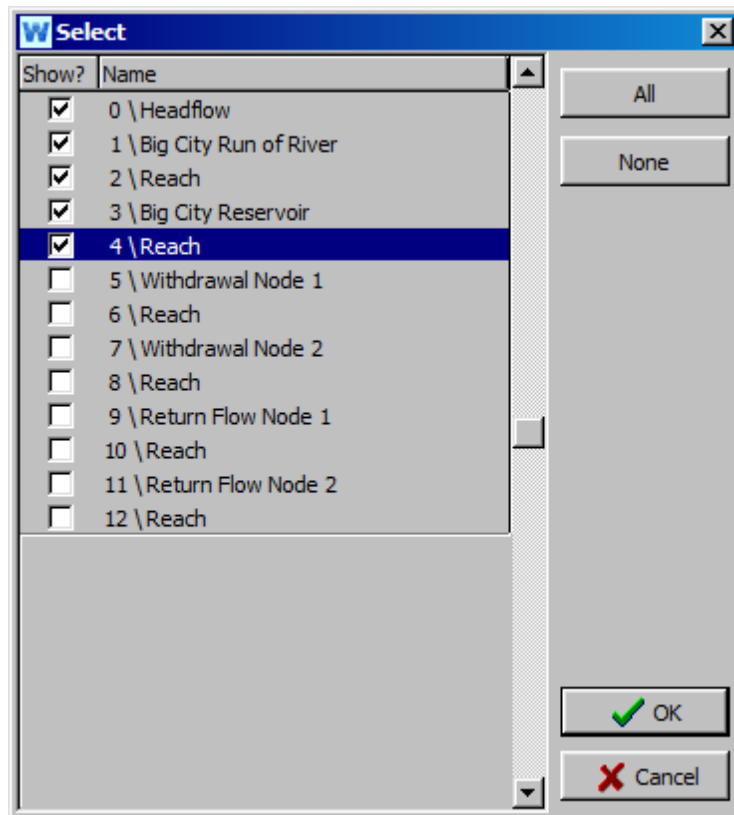




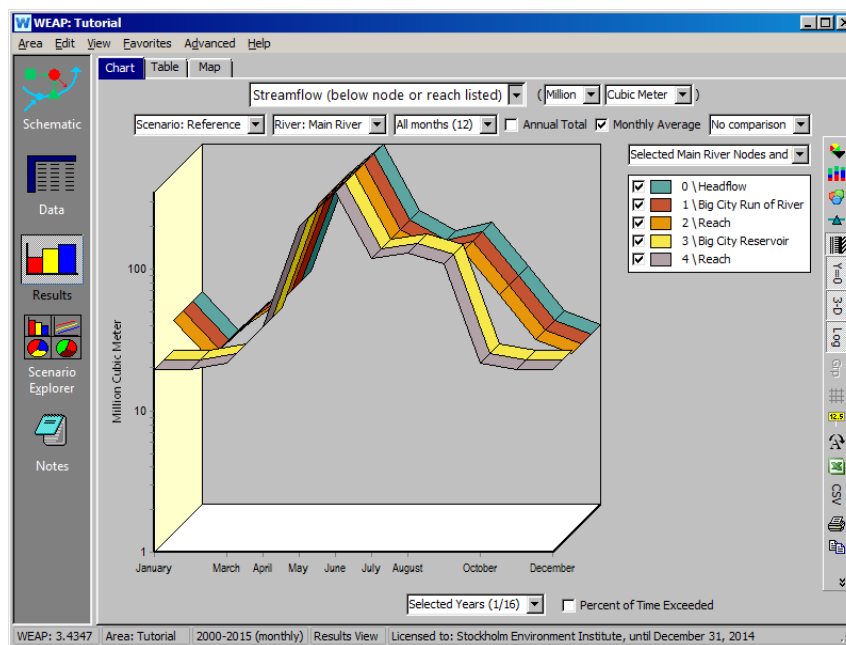
Note that the Run of River hydropower is slightly higher in May than June, in contrast to Big City Reservoir power production. This is due to the additional day available in May compared to June. Run of River hydropower production does not have Storage Elevation as limiting effect, whereas the Reservoir was still filling in May, which decreased 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: “0\Headflow”, “1\Big City Run of River”, “2\Reach”, “2\Big City Reservoir”, and “4\Reach” from the list.



We view the results (below) on a logarithmic scale, accessed by clicking on the “Log” icon on the bar on the right.



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.





---

# WEAP

Water Evaluation And Planning System

# Water Quality

## ***A TUTORIAL ON***

*Setting up Quality Modeling.....150*

*Entering Water Quality Data.....152*

*Using Water Quality Inflow Constraints for a  
Demand Site .....158*

*Entering Pollution Generating Activity for  
Demand Sites.....160*

*Modeling a Wastewater Treatment Plant.....164*

**August 2016**

**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.”

## Setting up Quality Modeling

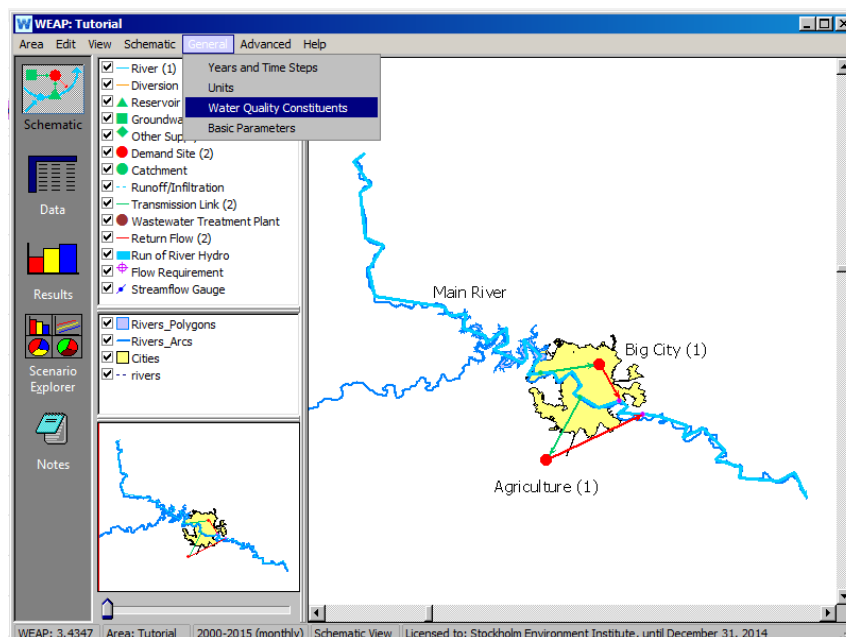
### 1. Understanding Water Quality Modeling in WEAP

WEAP can model both conservative and non-conservative pollutants. Conservative pollutants are modeled through a simple mass balance. Several models are offered for non-conservative pollutants.

*Read the Water Quality "Getting Started" help topic for a more detailed description of WEAP capabilities.*

### 2. Create a Set of Pollutants

Create a set of pollutants that will be modeled by going to the “General\Water Quality Constituents” menu.



In the dialog box, choose “Temperature” to be calculated by temperature modeled in WEAP, under the “Calculated By” down.

Name	Scale	Load Unit	Concentration	Calculate By	Decay Rate (per day)	Note
Temperature	C	C		Temperature (Modeled in WEAP)		Entered as data for each reach
BOD	kg	mg/l				Biochemical oxygen demand
DO	kg	mg/l				Dissolved Oxygen

Next, add “TSS” (Total Suspended Solids) and “Salt” to the list of constituents (“BOD” and “DO” should also already be listed):

<i>Name</i>	<i>Calculate by</i>	<i>Decay Rate</i>
<i>Temperature</i>	<i>Temperature (Modeled in WEAP)</i>	
<i>TSS</i>	<i>First-order Decay</i>	<i>0.25 per day</i>
<i>Salt</i>	<i>Conservative (No Decay)</i>	

Name	Scale	Load Unit	Concentration	Calculate By	Decay Rate (per day)	Note
Temperature	C	C		Temperature (Modeled in WEAP)		Entered as data for each reach
BOD	kg	mg/l		BOD Model		Biochemical oxygen demand
DO	kg	mg/l		DO Model		Dissolved Oxygen

Name	Scale	Load Unit	Concentration	Calculate By	Decay Rate (per day)	Note
Temperature	C	C		Temperature (Modeled in WEAP)		Entered as data for each reach
BOD	kg	mg/l		BOD Model		Biochemical oxygen demand
DO	kg	mg/l		DO Model		Dissolved Oxygen
TSS	kg	mg/l		First-Order Decay	0.25	
Salt	kg	mg/l		Conservative (No Decay)		



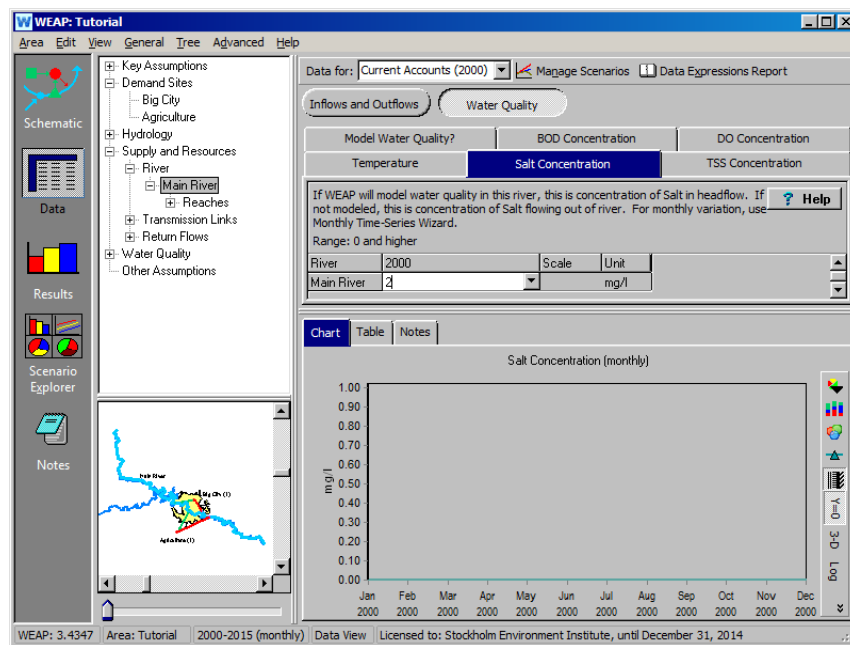
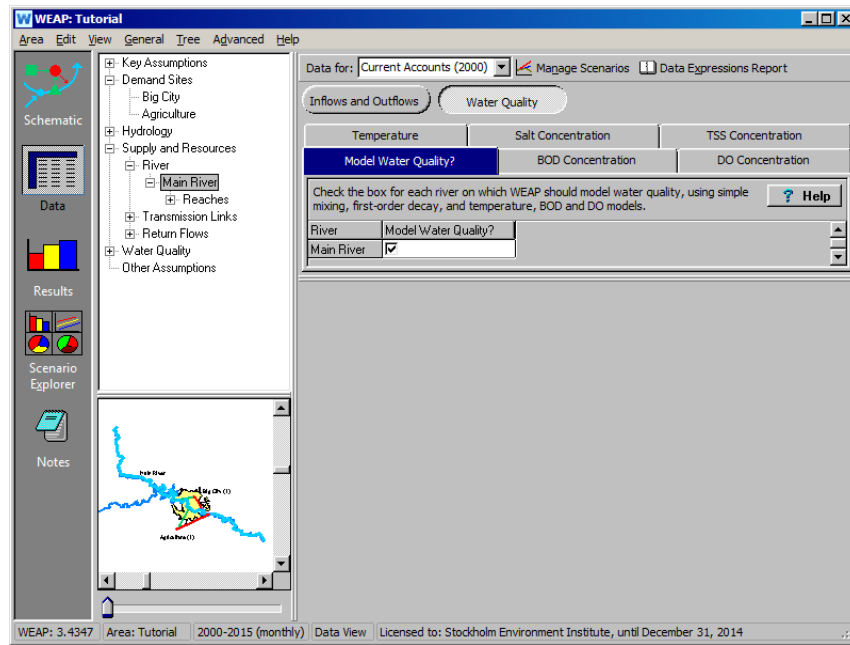
More details are provided on the different models used for BOD and DO models in the “Dissolved Oxygen and Biochemical Oxygen Demand” help topic.

## Entering Water Quality Data

### 3. Enter River Water Quality data

In the Data view tree, select “Supply and Resources\River” and click on the Main River. Then open the “Water Quality” screen and enter the following data, which will represent water quality at the headflow of the river:

<i>Model Water Quality?</i>	<i>YES (check the box)</i>
<i>Temperature</i>	<i>15°C</i>
<i>BOD concentration</i>	<i>5mg/l</i>
<i>DO concentration</i>	<i>8mg/l</i>
<i>TSS concentration</i>	<i>20mg/l</i>
<i>Salt concentration</i>	<i>2mg/l</i>

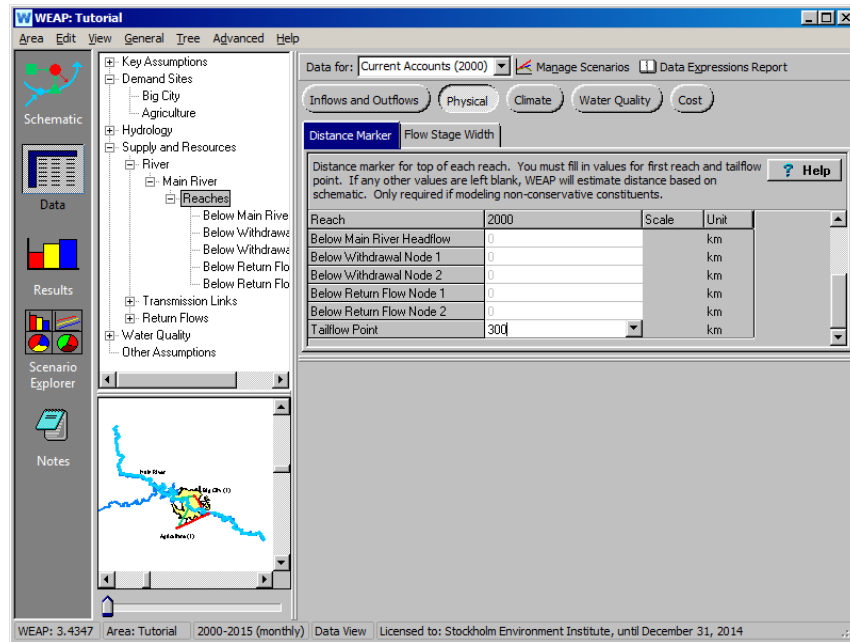


#### 4. Enter River Geometric Characteristics

River geometric characteristics are needed for the various water quality models. They are mainly used to compute velocity/residence time of the water along a reach. In the Data view, select the “Reaches” branch of the Main River and enter the following information under the “Physical” tabs.

*Headflow Distance Marker*      *0 km*  
*Tailflow Distance Marker*      *300 km*

*Note: intermediate reach lengths will be estimated by WEAP based on the schematic.*



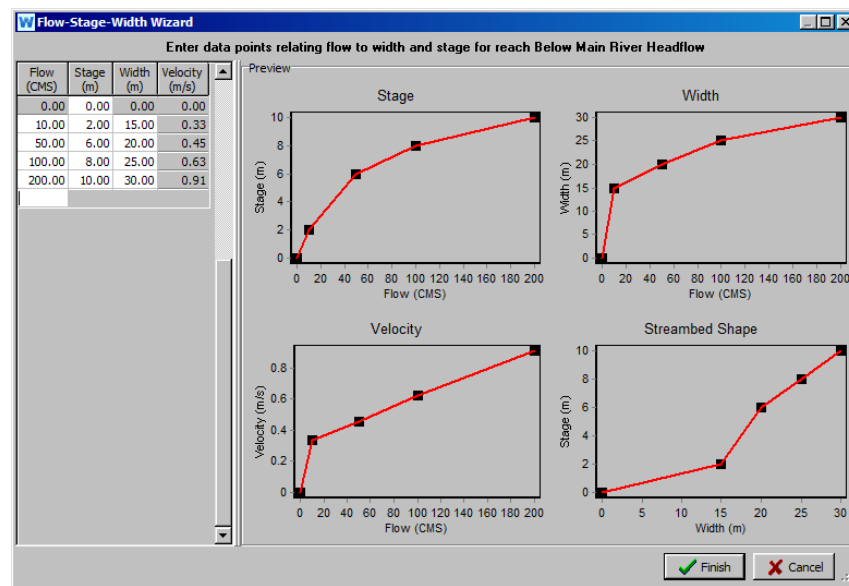
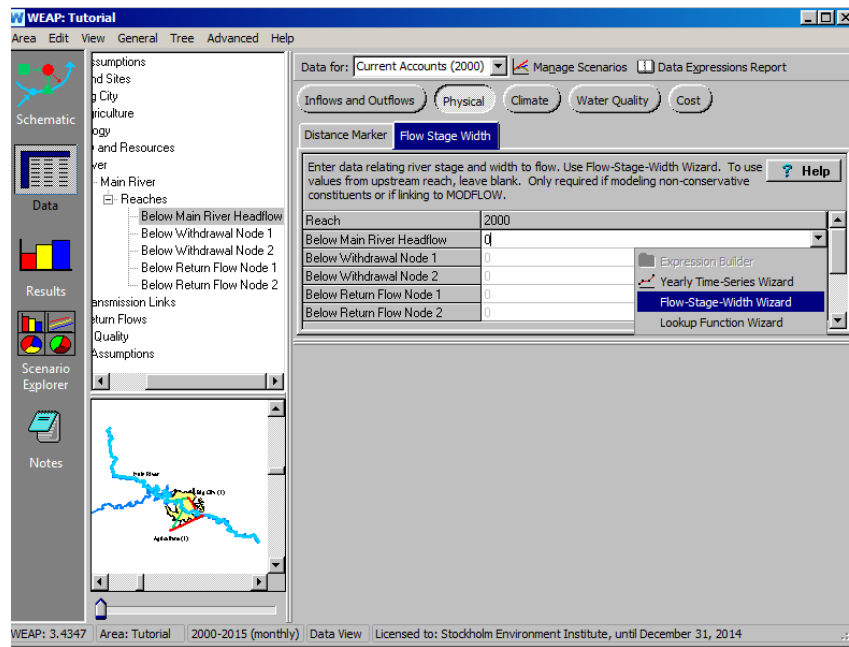
*In the Flow Stage Width tab, use the Wizard by clicking on the drop-down arrow for “Below Main River Headflow” to enter the following data:*

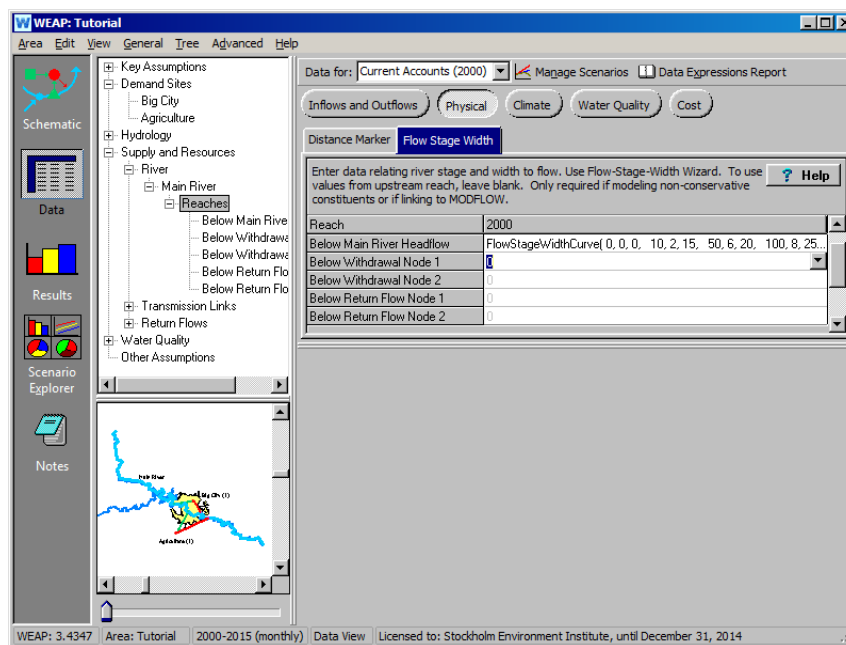
<i>Flow</i>	<i>Stage</i>	<i>Width</i>
0	0.00	0.00
10	2.00	15.00
50	6.00	20.00
100	8.00	25.00
200	10.00	30.00

*Your final formula should read:*

*FlowStageWidthCurve( 0, 0, 0, 10, 2, 15, 50, 6, 20, 100, 8, 25, 200, 10, 30 )*

*We will assume this section remains constant and leave other reaches empty.*





The “Reach Length” tab displayed under the “Inflows and Outflows” category is used only for modeling surface water-groundwater interactions. It represents the length of the reach connected to the groundwater, which may be less than the total length of that reach.

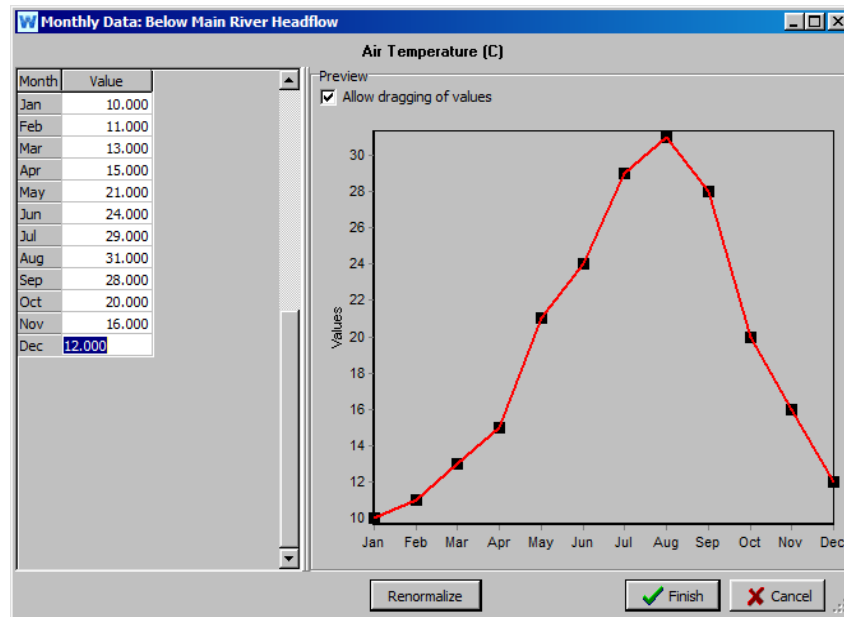
## 5. Enter the Climatic Data

Climatic Data are needed to compute water temperature. Click on the “Climate” button and again select the “Below Main River Headflow” reach. Enter the following climate data (for air temperature, use the Monthly Time Series Wizard):

### *Air Temperature*

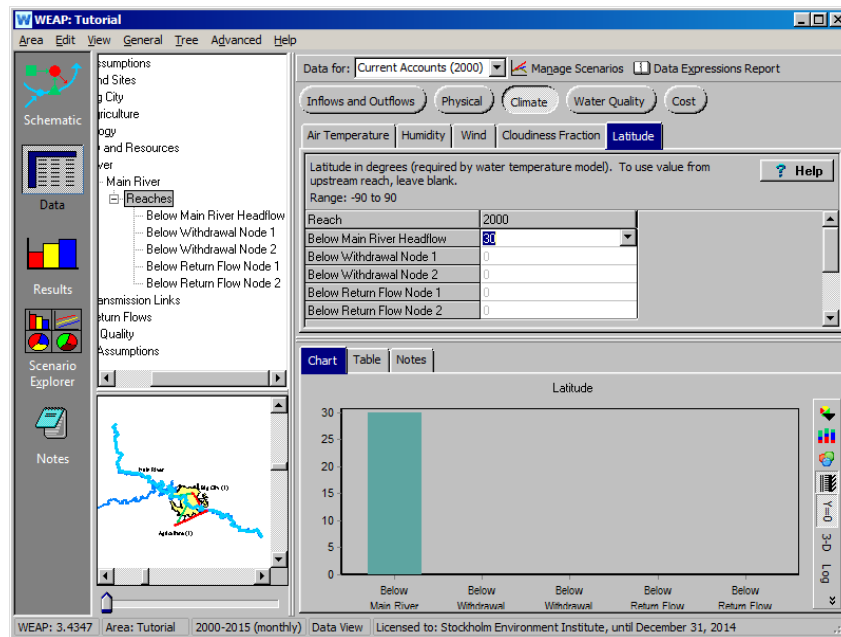
<i>Month</i>	<i>Value (°C)</i>
<i>Jan</i>	<i>10</i>
<i>Feb</i>	<i>11</i>
<i>Mar</i>	<i>13</i>
<i>Apr</i>	<i>15</i>
<i>May</i>	<i>21</i>
<i>Jun</i>	<i>24</i>
<i>Jul</i>	<i>29</i>
<i>Aug</i>	<i>31</i>
<i>Sep</i>	<i>28</i>
<i>Oct</i>	<i>20</i>
<i>Nov</i>	<i>16</i>
<i>Dec</i>	<i>12</i>





Humidity 65%  
 Wind 1 m/s  
 Cloudiness Fraction 1  
 Latitude 30°

*Note: you can enter these values for the first reach and leave the other reaches blank if you want the value to apply to all reaches.*



# Using Water Quality Inflow Constraints for a Demand Site

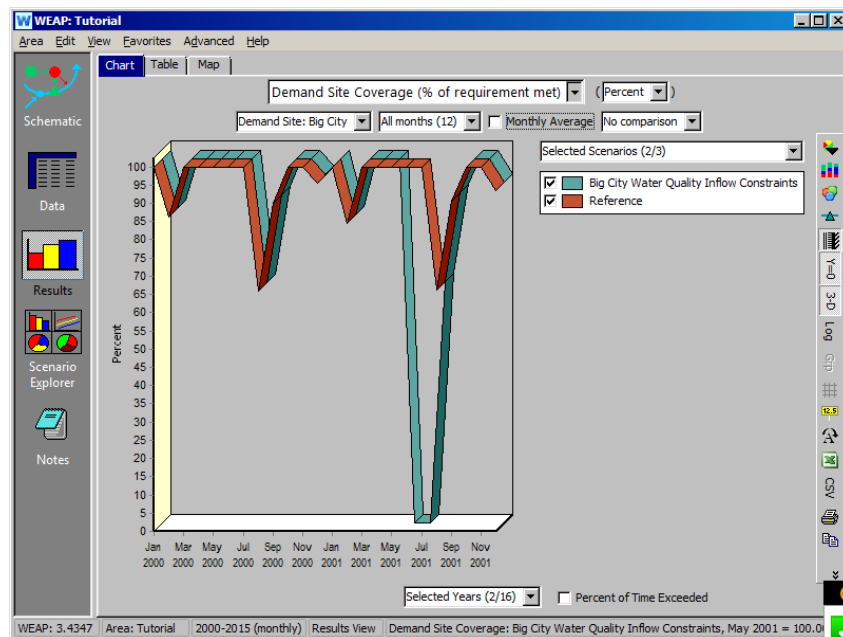
## 6. Enter Constraint Data

A demand site may require that its water supply meets certain quality criteria. Create a new scenario inherited from the “Reference” scenario and name it “Big City Water Quality Inflow Constraints.” In the Data view (make sure you are in this new scenario), select the Big City branch of the data tree, and click on the “Water Quality” button. Under the “BOD Inflow” tab, enter the following maximum allowed concentration of BOD:

$$\text{BOD inflow} \qquad 2 \text{ mg/L}$$

## 7. Compare Results

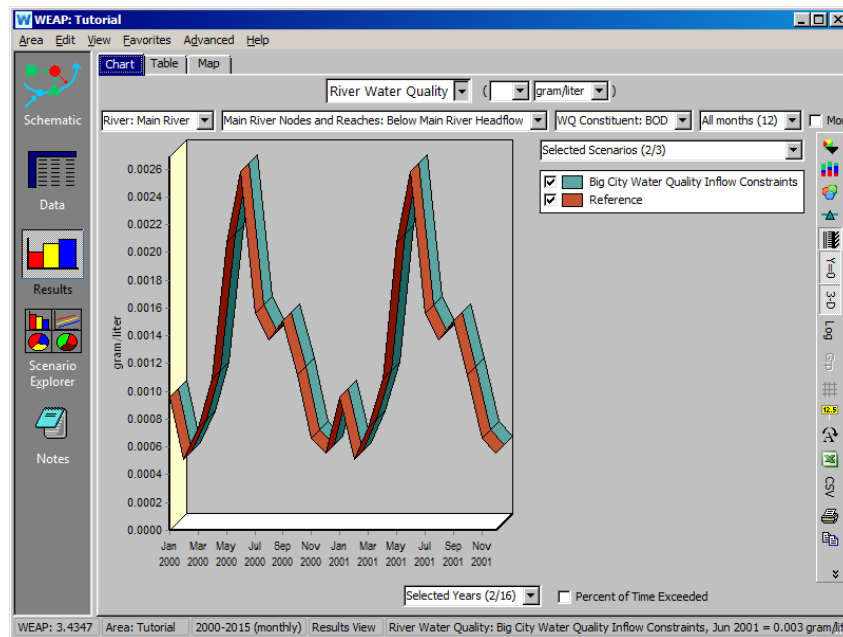
Note that you earlier entered a BOD concentration (5 mg/L) for the Main River Headflow (under Current Accounts), so you can now run the results and compare the output for Big City Demand Site Coverage, with and without this inflow constraint for Big City. For the period 2000 and 2001, a comparison of Big City Demand Site Coverage for the “Reference” and “Big City Water Quality Inflow Constraints” scenarios should look like the following:



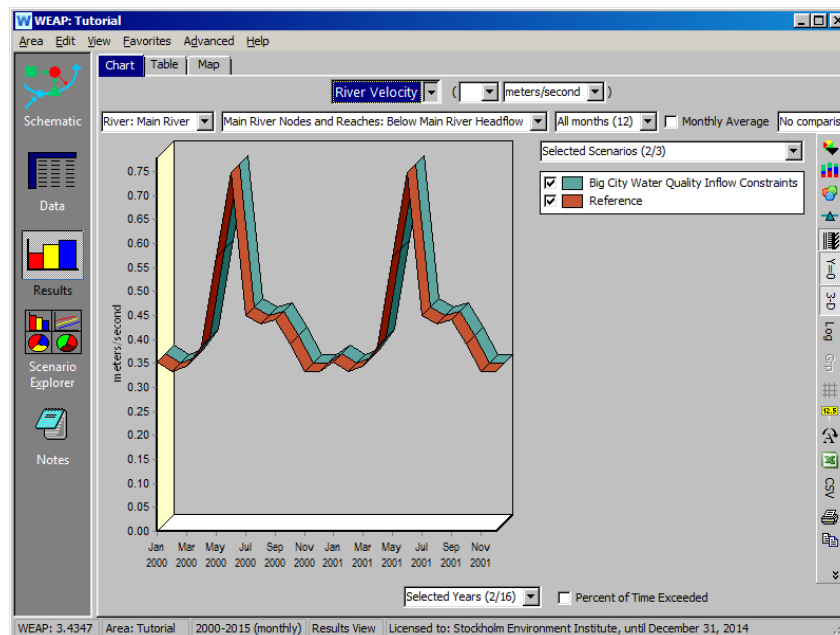
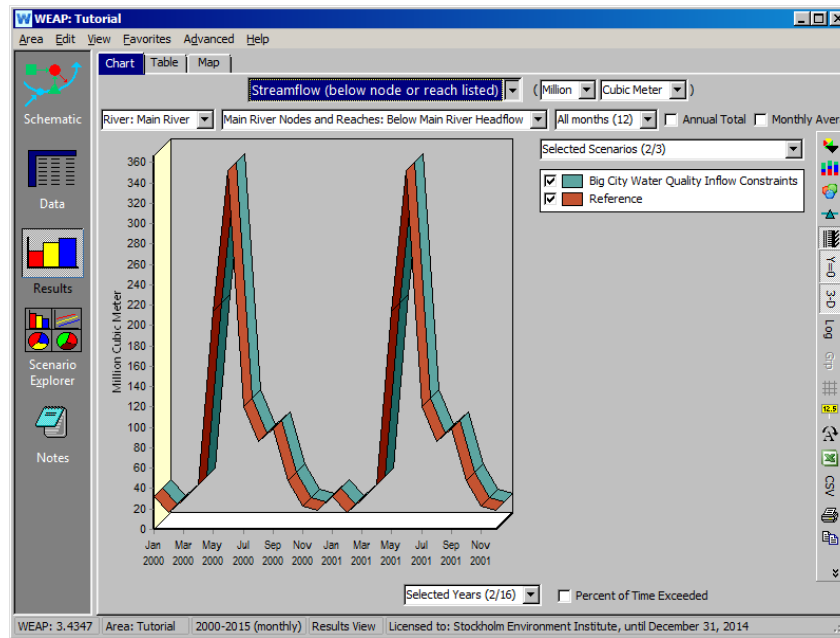
*Why does Big City Coverage drop to zero during June, 2001, in the Inflow Constraint scenario?*



If you look at the BOD concentration (Water Quality, River Water Quality) in the “Below Main River Headflow” reach (pictured below), you will see that BOD rises above the constraint (2 mg/L) for Big City intake during the month of June for both 2000 and 2001. Since the constraint is activated during the scenario period (starting in 2001), coverage for Big City decreases during June, 2001, because this demand site will not accept water that falls below the BOD constraint, and no other sources of water other than the Main River have been designated as supplies for Big City.



The simulated temporal pattern of the BOD concentration along this reach of the Main River is a function of degradation, the extent of which is controlled by the residence time of the water in the “Headflow” reach. The longer the residence time in this reach, the more degradation that occurs. The pattern for BOD thus mirrors that of the flow velocity, and streamflow, for the reach (both pictured below).

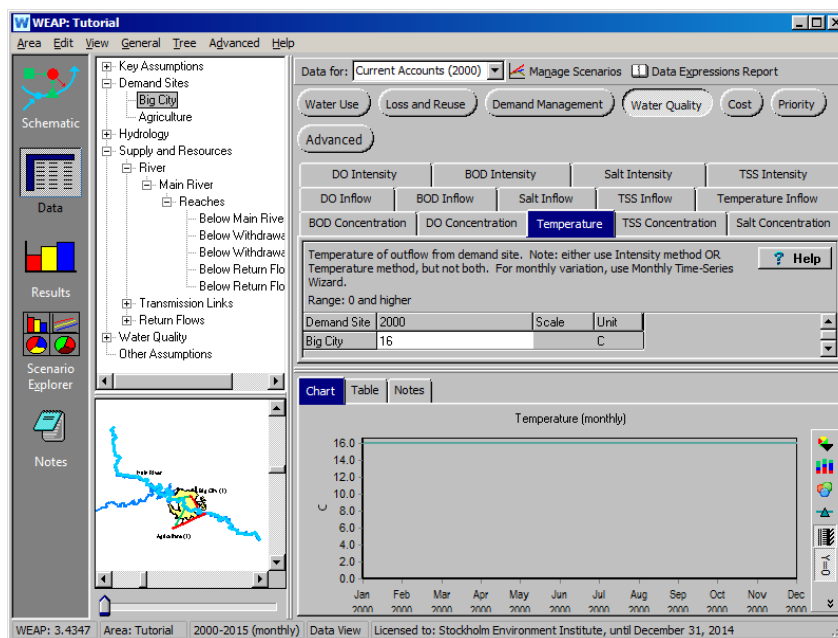


## Entering Pollution Generating Activity for Demand Sites

### 8. Entering Data

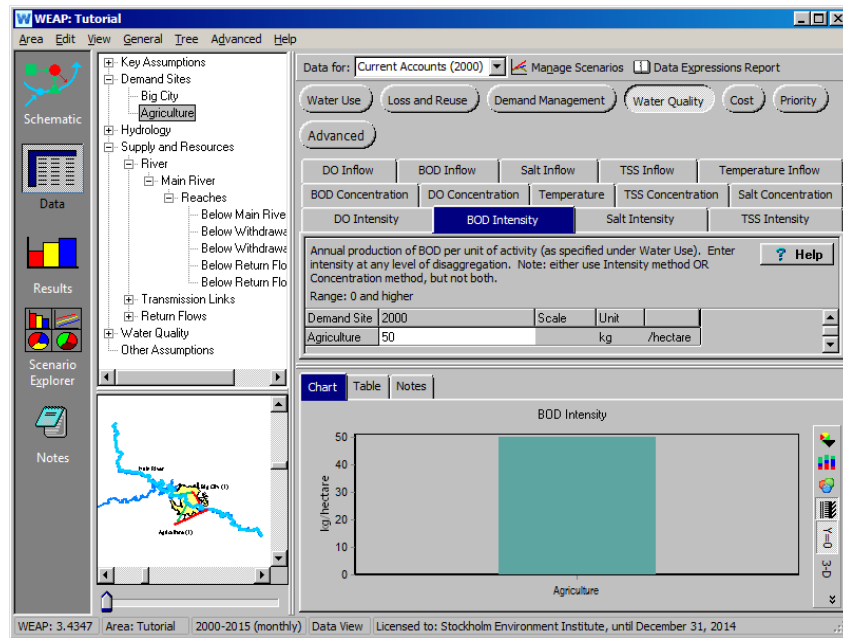
We will assume that we know the concentration of pollutants in the outflow (Return Flow) for Big City. Hence, we will use the “Concentration” series of tabs in the “Demand Sites\Big City” branch of the Data tree. Click on the “Water Quality” button and enter the following data (in Current Accounts):

<i>Temperature</i>	<i>16 °C</i>
<i>BOD Concentration</i>	<i>60 mg/l</i>
<i>DO Concentration</i>	<i>3 mg/l</i>
<i>TSS Concentration</i>	<i>5 mg/l</i>
<i>Salt Concentration</i>	<i>10 mg/l</i>



**For the Agriculture demand site, we will admit that we do not know the concentration at the outflow, but we do know the pollutant generation intensity. Enter the following data:**

<i>BOD intensity</i>	<i>50 kg/ ha</i>
<i>DO Intensity</i>	<i>30 kg/ ha</i>
<i>TSS Intensity</i>	<i>20 kg/ ha</i>
<i>Salt Intensity</i>	<i>2 kg/ ha</i>
<i>Temperature</i>	<i>15°C</i>



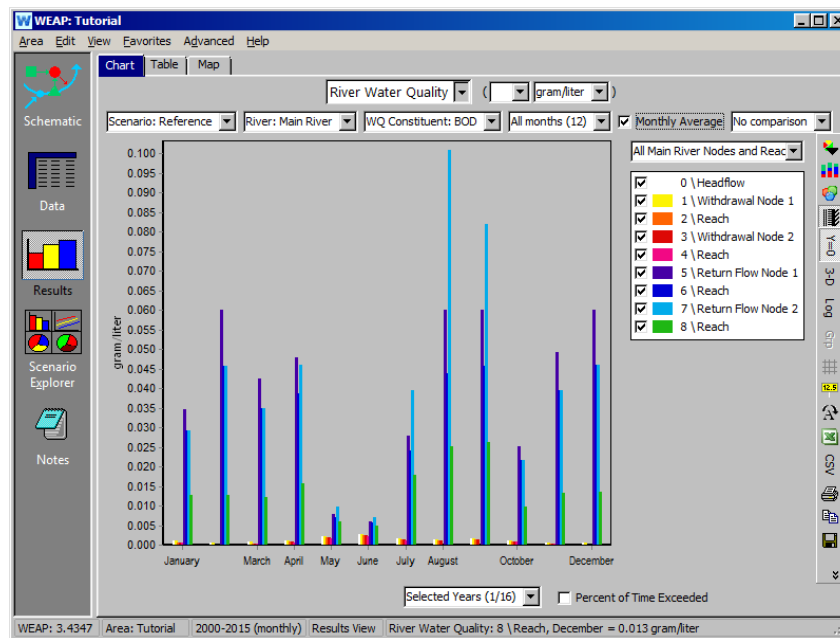
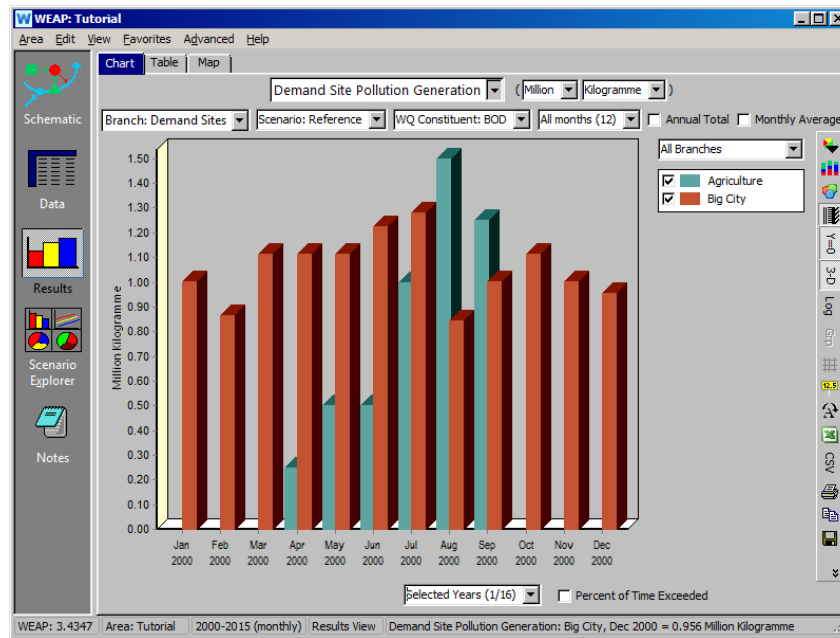
Pollution outflow from a demand site is only based on the each demand site's pollutant concentration or intensity data, not on the water quality of the inflow to the demand site. Note that temperature data can change over time.

## 9. Evaluate the Results

Run the model and look at the following results for various water quality constituents for the year 2000. Select “Pollution Generation” from the primary variable pull-down menu (under Water Quality):

*Demand Site Pollution Generation*

*River Water Quality (here we switched the colors to “Mac” in the colors option on the bar on the right of the screen)*

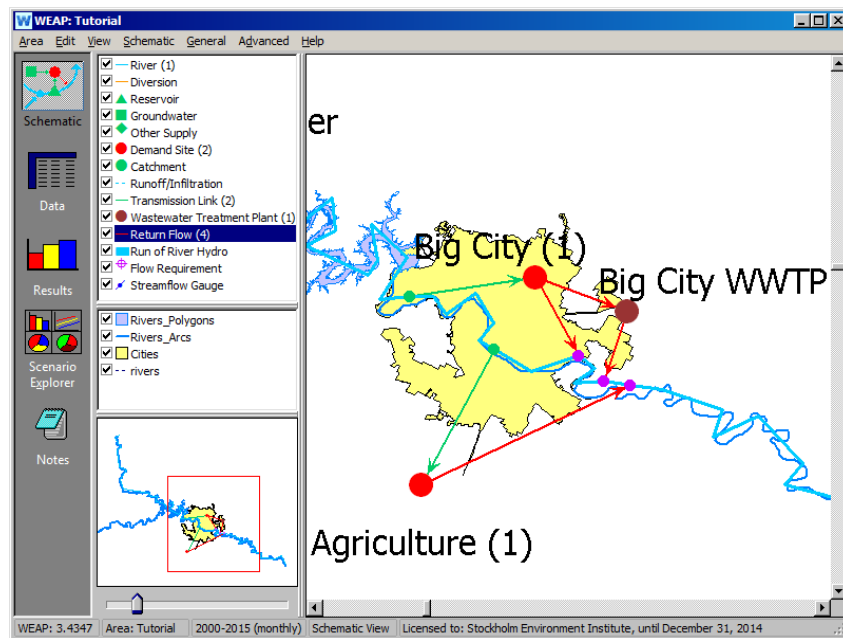


Note that Pollution Generation for Agriculture is confined to the spring and summer months when farming is active.

# Modeling a Wastewater Treatment Plant

## 10. Create a Wastewater Treatment Plant

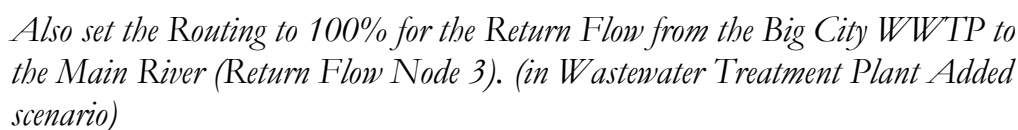
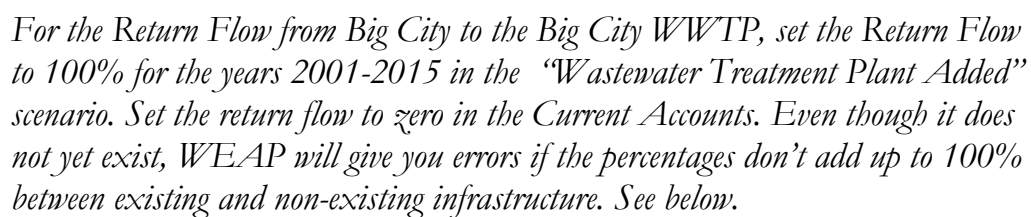
Create a new scenario named “Wastewater Treatment Plant Added”- this scenario is inherited from the “Reference.” Then, add a Wastewater Treatment Plant for Big City, name it “Big City WWTP” and make it inactive in Current Accounts, and create a Return Flow Link from the Big City to the WWTP. Keep the existing Return Flow Link from Big City to the river. Also create another return flow from the WWTP to the river. Your model should look similar to the figure below:

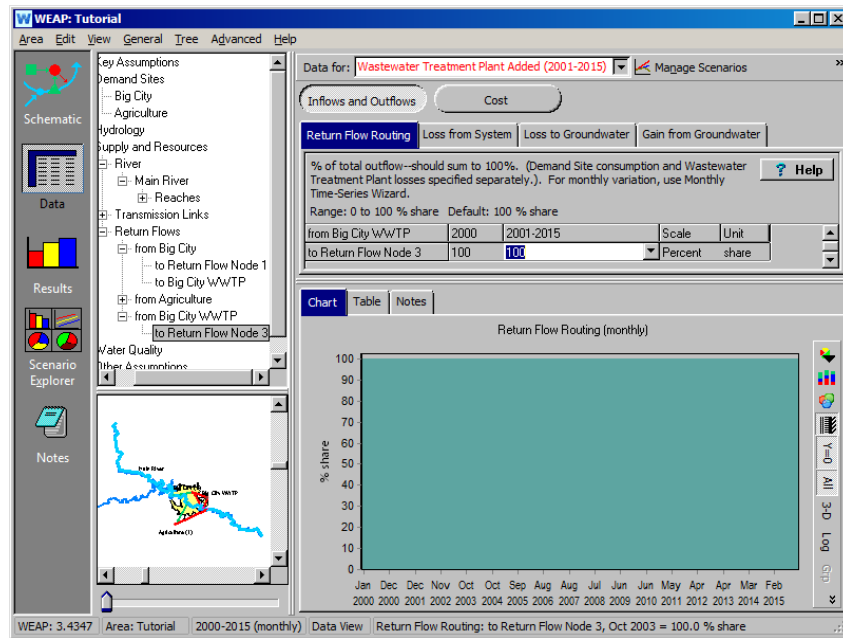


You will have to set the “Return Flow Routing” variables for both links.

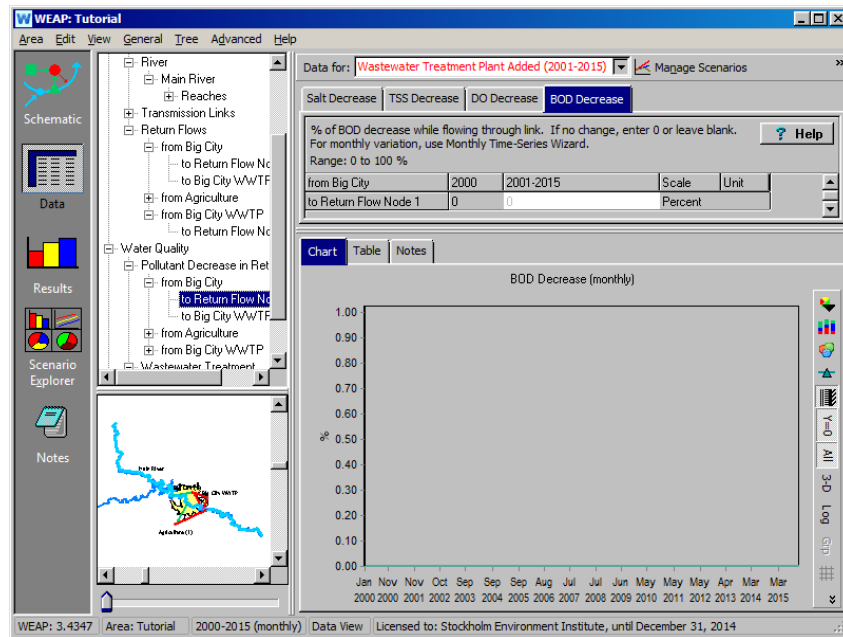
*For the Return Flow from Big City to Main River (Return Flow Node 1), set the Routing to 100% for the Current Accounts year and 0% for years 2001-2015 in the “Wastewater Treatment Plant Added” scenario.*







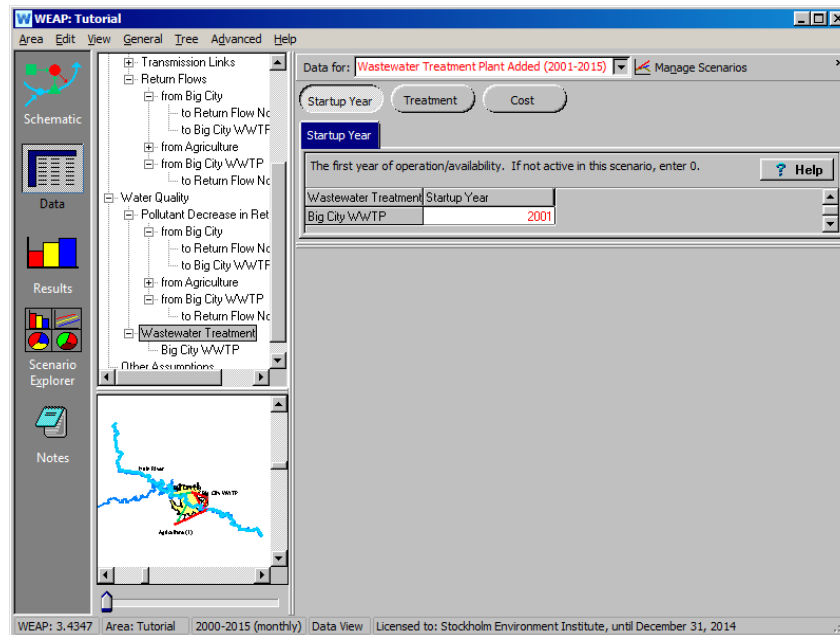
You also have the possibility to set removal rates in the various return flows. This would be useful if, for example, a given pollutant is decomposed by bacteria in the sewer system. These data can be entered under the “Water Quality\Pollutant Decrease in Return Flow” branches for the appropriate return flows (see figure below for example).



## 11. Enter WWTP Data

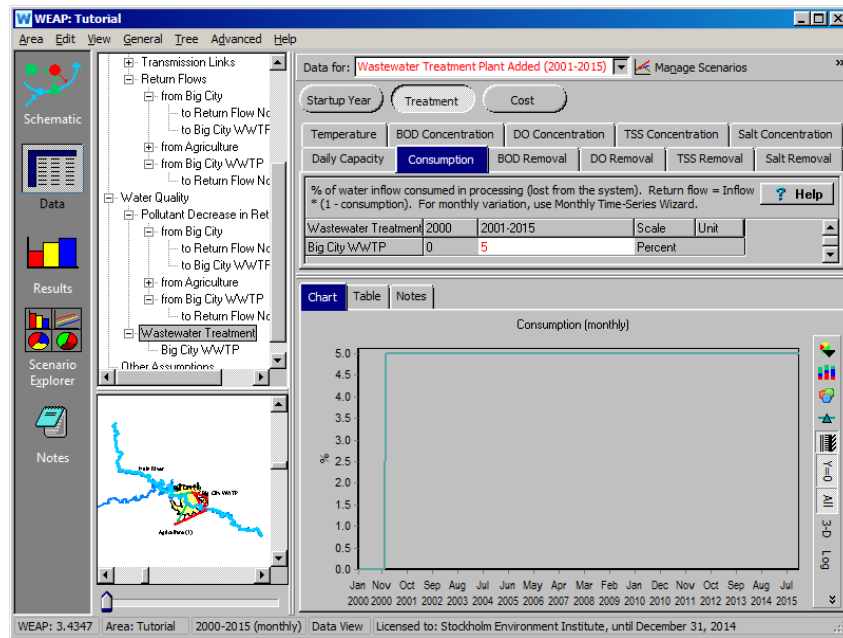
First, enter the “Start Year” by clicking on the “Start Year” button under the “Water Quality\Wastewater Treatment” branch of the data tree for Big City WWTP. Make sure you hit the enter key after entering 2001.

*Start Year*                      2001



Also enter the following data under the “Treatment” category (with the “Wastewater Treatment Plant Added” scenario selected):

<i>Consumption</i>	<i>5%</i>
<i>Daily Capacity</i>	<i>2M m<sup>3</sup></i>
<i>BOD Removal</i>	<i>90%</i>
<i>DO Concentration</i>	<i>5mg/l</i>
<i>TSS Removal</i>	<i>80%</i>
<i>Salt Removal</i>	<i>20%</i>
<i>Temperature</i>	<i>15°C</i>



If only part of the wastewater is treated through the WWTP, there are two modeling possibilities. One is to limit the Daily Capacity to whatever amount can actually be treated. In this case the wastewater in excess will be discharged without treatment. In this case, the share of untreated wastewater is not constant, but depends on the total flow.

Another solution is to create an additional return flow going from the demand site straight to the river, by-passing the WWTP. In this case, a constant share can be set to by-pass the WWTP by setting the return flow routing shares accordingly. A combination of both methods is also possible.

## 12. Evaluate the Results

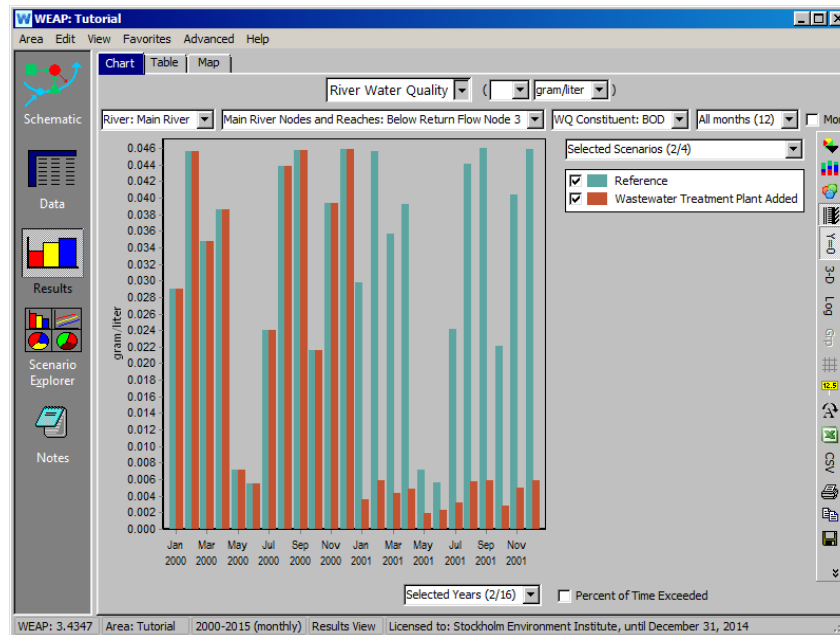
Run the model and look at the following results for BOD in the “Wastewater Treatment Plant Added” scenario, comparing them with the “Reference” scenario values (without a wastewater treatment plant).

*-RiverWater Quality (BOD downstream of Big City’s outflow into the river).*

To view these results, first select “River Water Quality” under “Water Quality” in the primary variable pull-down menu. Then choose “Selected Scenarios” under the pull-down menu above the chart legend and select the “Reference” and “Wastewater Treatment Plant Added” scenarios.

Using the pull-down menu at the bottom of the chart, select the years 2000 and 2001 for viewing. Select “Below Return Flow Node 3” (Return Flow

Node 3 is the return flow for the WWTP, so you will be looking at water quality in the river just downstream of the outflow from the WWTP) as the Main River reach to view. Select “BOD” as the water quality constituent from the pull-down menu directly above the chart, and unclick the “Monthly Average” button to the far right. Your screen should look like the one below:

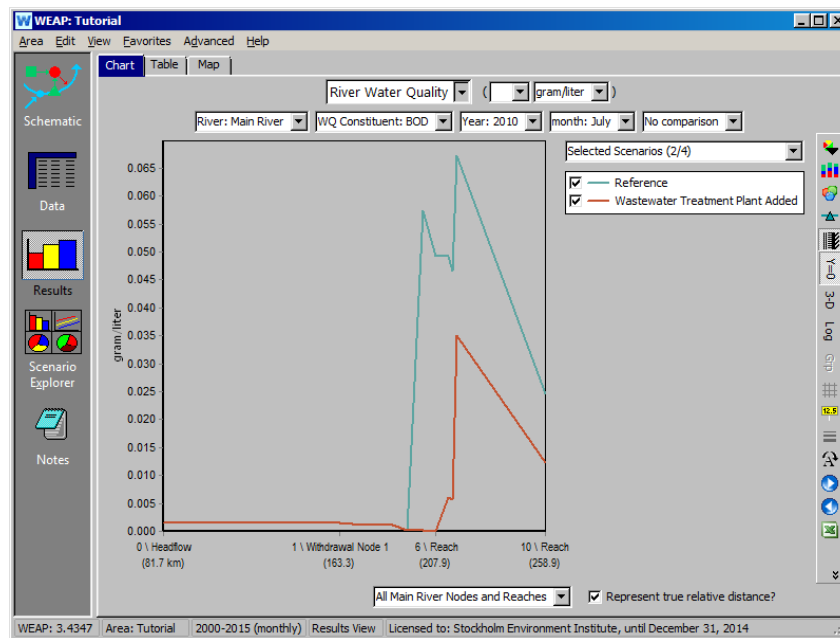


Note that BOD levels decrease substantially in 2001 compared to 2000 in the reach below the return flow from the treatment plant because the plant becomes active that year.

*-WEAP can also display water quality results from upstream to downstream.*

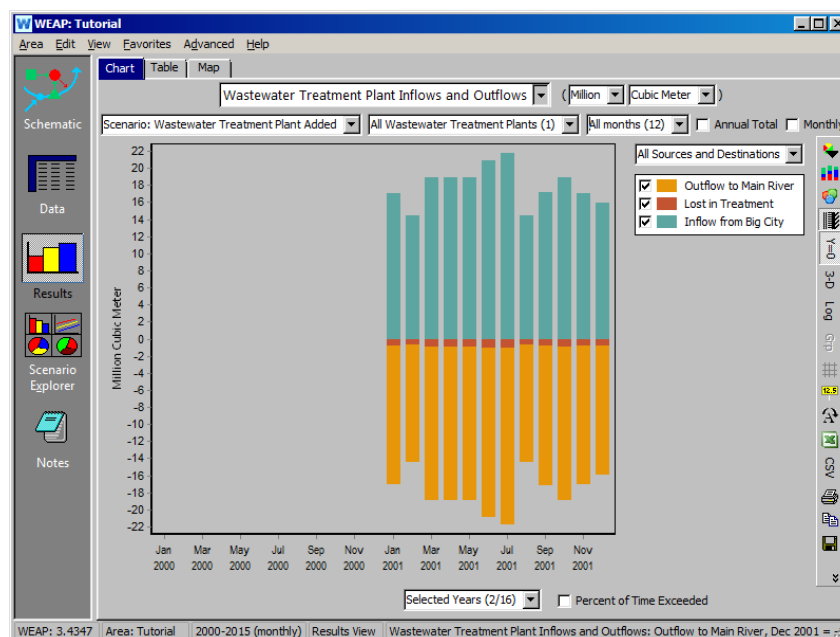
From the bottom menu, choose “All Main River Nodes and Reaches” and check “Represent true relative distance?” This will show all nodes and reaches along the X-axis, with their spacing proportional to their distance downstream (distances shown in parentheses). Select July, 2010, as the month and year. For the chart type, select “Line.”

The charts shows that BOD levels rise as BOD-laden return flows enter the river, and decline as the BOD decays as it moves downstream. The effect of the wastewater treatment plant can be clearly seen. Your chart should look like this:



### *-Wastewater Treatment Plant Inflows and Outflows.*

To view these results, select the “Wastewater Treatment Plant Inflows and Outflows” (under Water Quality) from the primary variable pull-down menu. Also select the “Wastewater Treatment Plant Added” scenario from the far upper left menu. View “All Months (12)” and in the second icon on the menu bar, select to have the bars stacked.





In this type of chart, the outflows are represented as negative values and inflows are positive values. Note also that the “Lost in Treatment” category represents the flow that is consumed - a consumption rate of 5% was input in the data view for the treatment plant.

---





---

# WEAP

Water Evaluation And Planning System

# The WEAP/ QUAL2K Interface

***A TUTORIAL ON***

*Linking to QUAL2K.....174*

*Running Scenarios .....180*

**August 2016**

**Note:**

For this module you will need to have completed the previous modules (WEAP in One Hour, Basic Tools, Scenarios, and Water Quality) 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 ‘Water Quality with QUAL2K’.” This version enacts necessary files to complete this module.

## Linking to QUAL2K

### 1. Using QUAL2K for Water Quality Modeling in WEAP

In addition to using WEAP’s in-built capacity for water quality modeling, it is possible to use the US EPA QUAL2K modeling framework. This module demonstrates how to use the WEAP/QUAL2K interface, taking the Water Quality module as a starting point. This module is not an introduction to QUAL2K, which requires specialized knowledge, but if you are already using QUAL2K, you should be able to link your QUAL2K file to WEAP after this module.



QUAL2K is a 1-dimensional, steady state, instream water quality model for well mixed channels (laterally and vertically). Constituents modeled include: ammonia, nitrate, organic and inorganic phosphorous, algae, sediment, pH and pathogens. QUAL2K was developed by Dr. Steve Chapra and his grad students at Tufts University. This module is not an introduction to QUAL2K. Considerable work is required outside of WEAP to calibrate and prepare a QUAL2K file. Refer to the QUAL2K manual for more information. Visit <http://www.epa.gov/athens/wwqtsc/html/qual2k.html> to download or for more information.

### 2. Differences Between QUAL2K and WEAP

QUAL2K and WEAP are compatible in their general approach to water quality modeling, but they do some things differently. The important differences are:

- QUAL2K measures distance along a reach from the tail of the reach, while WEAP measures distance from the head.
- QUAL2K allows for diurnal variations in water quality and climate, while WEAP applies the same value to all times of day.
- WEAP is more tolerant of zero or missing values than is QUAL2K.
- QUAL2K and WEAP use different climate parameters. For example, QUAL2K uses dew point, while WEAP uses humidity.

- QUAL2K models many more constituents in much more detail, including two separate CBOD constituents, ammonia, nitrate, organic and inorganic phosphorous, algae, sediment, pH and pathogens (see <http://www.epa.gov/athens/wwqtsc/html/qual2k.html> for more details).

QUAL2K and WEAP are similar in that each treats a river as a sequence of reaches, not necessarily of equal lengths. However, the reach boundaries as defined in QUAL2K and in WEAP need not match. Where reach boundaries do not match, WEAP handles the task of mapping water quality and climate variables, based on distance markers.

Reservoirs present special challenges for water quality modeling. WEAP includes reservoirs, but not for water quality, while QUAL2K includes weirs, but they are not operated. It is recommended that rivers with reservoirs not be linked to QUAL2K, or that they be modeled in two sections—above the reservoir and below the reservoir.

### 3. Link Pollutants to QUAL2K

This module uses the final result from the previous Water Quality module as a starting point. Open the WEAP tutorial (by selecting Area \ Open \ Tutorial from the menu), then selecting Area \ Revert to Version \ Starting point for 'Water Quality' from the menu.

Once the file is ready, change the water quality constituents to point to QUAL2K.

- From the menu, select “General | Water Quality Constituents.”
- For all of the constituents except Salt, select “Modeled in QUAL2K” in the “Calculated By” drop-down.
- Link each constituent in WEAP (except salt) to a corresponding QUAL2K constituent: “Temperature” → “Temperature”, “BOD” → “CBOD fast”, “DO” → “Dissolved Oxygen”, “TSS” → “Inorganic Solids.”

Salinity is not directly modeled in QUAL2K, so it is not linked to a QUAL2K constituent in this example. QUAL2K instead models conductivity, which is an easily measured indicator of salinity.

**Water Quality Constituents**

☒ Enable water quality modeling    **+** Add    **-** Delete

Name	Scale	Load Unit	Concentration	Calculate By	Link to Qual2K Constituent	Decay Rate (per day)	
Temperature	C	C	Modeled in QUAL2K	Temperature			Entered as data for
BOD	kg	mg/l	Modeled in QUAL2K	CBODfast			Biochemical oxygen
DO	kg	mg/l	Modeled in QUAL2K	Dissolved Oxygen			Dissolved Oxygen
TSS	kg	mg/l	Modeled in QUAL2K	Inorganic Solids		0.25	
Salt	kg	mg/l	Conservative (No Decay)				

QUAL2K Data File (.q2k)   ☐ Save every .q2k file created (for each time step)

Close

Next, search for a QUAL2K data file (a file ending in .q2k).

- Look for the new drop-down labeled “QUAL2K Data File (.q2k)” that has appeared at the bottom left of the Water Quality Constituents dialog.
- Select “< Copy file from another directory >” from the drop-down.
- Search the Tutorial\Additional Files for the file “Main\_River\_Tutorial.q2k.” If you want to view the QUAL2K file, click the “View” button to open it in the QUAL2K-formatted Excel spreadsheet.

The Water Quality Constituents Dialog should now look like the following:

Name	Scale	Load Unit	Concentration	Calculate By	Link to Qual2K Constituent	Decay Rate (per day)	
Temperature	C	C	Modeled in QUAL2K	Temperature			Entered as data for
BOD	kg	mg/l	Modeled in QUAL2K	CBODfast			Biochemical oxygen demand
DO	kg	mg/l	Modeled in QUAL2K	Dissolved Oxygen			Dissolved Oxygen
TSS	kg	mg/l	Modeled in QUAL2K	Inorganic Solids		0.25	
Salt	kg	mg/l	Conservative (No Decay)				



The QUAL2K file must initially be developed and edited outside of WEAP. WEAP will then modify some of the values, and extract values from QUAL2K after it is run. To view or edit the QUAL2K file, click on the “View” button next to the “QUAL2K Data File (.q2k)” drop-down on the Water Quality Constituents dialog.

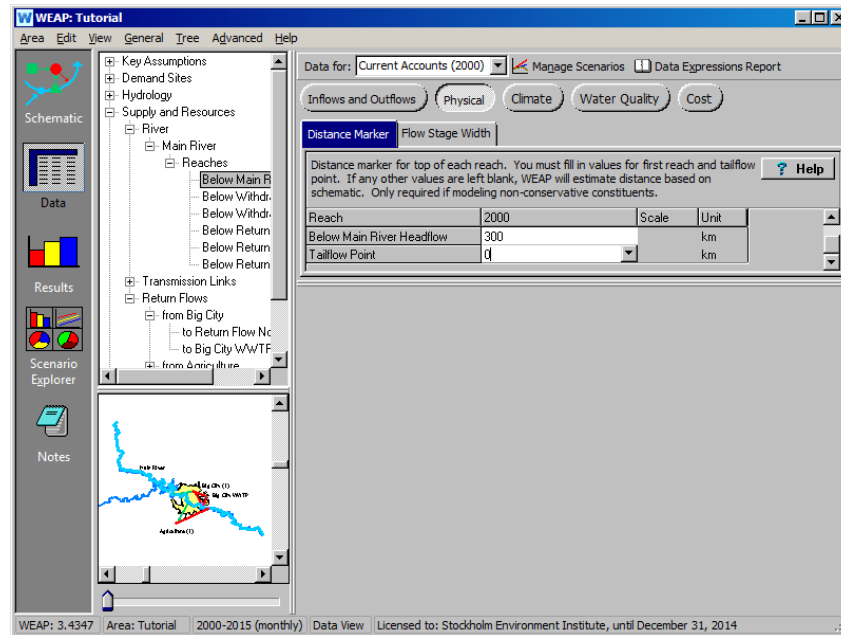
## 4. Change Reach Distance Markers

For marking reach distances, QUAL2K assigns the tail of the river a distance of 0, and distance increases upstream. WEAP can measure reach distances either downstream or upstream, but in the previous module distance was measured downstream, opposite the convention for QUAL2K, so the reach distance markers must be changed when linking to QUAL2K.

To set the reach distance markers:

- Go to Data View
- Navigate to the branch “Supply and Resources\River\Main River\Reaches\Below Main River Headflow.”
- Click on the “Physical” button.
- Select the “Distance Marker” tab. (This will only show up in Current Accounts: if you do not see it, switch to Current Accounts in the drop-down at the top of the page.)

- Set the distance for “Below Main River Headflow” to 300 km, and the distance for “Tailflow Point” to 0 km.



## 5. Set Dew Point and Cloud Cover

QUAL2K and WEAP use different climate parameters, so some additional climate parameters must be set for QUAL2K. When using QUAL2K for water quality calculations, WEAP changes the list of climate parameters automatically.

While each reach in QUAL2K can have a different climate, for most WEAP applications it is reasonable to assume that the climate is the same on all reaches. In this case, climate parameters only need to be set for the top reach, since for downstream reaches, upstream values are used by default. For this example, two climate parameters will be set: cloud cover and dew point.

Cloud cover is not a climate parameter in WEAP, so there is no corresponding value already in WEAP. For this example assume that average cloud cover is 30% along the river. To set this:

- Navigate to the branch “Supply and Resources\River\Main River\Reaches\Below Main River Headflow”, if you are not already there.
- Click on the “Climate” button.
- Select the “Cloud Cover” tab.

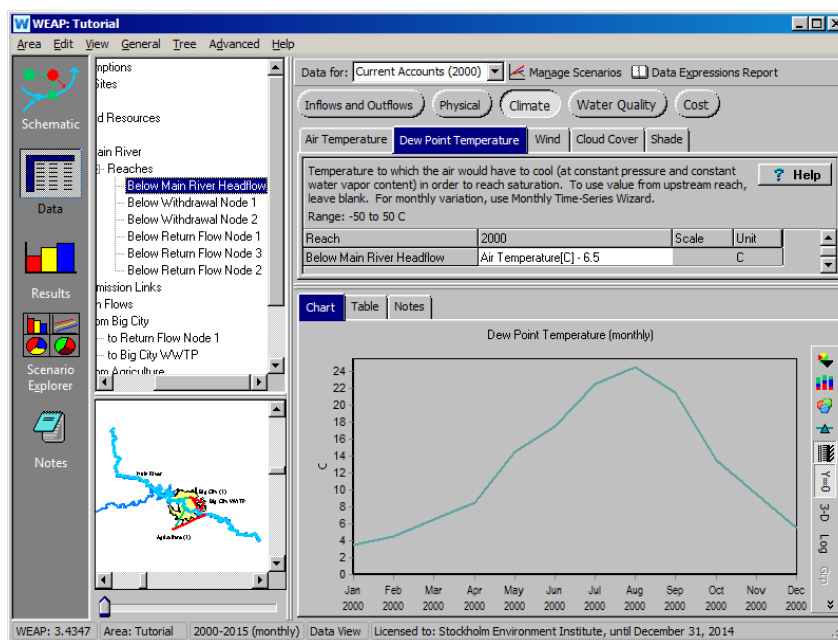
- Type “30” for the value.

Dew point is used by QUAL2K instead of WEAP’s relative humidity parameter. Dew point,  $T_d$ , can be calculated from the air temperature,  $T$ , and relative humidity,  $h_r$  doing the following calculation. First, instead of using air temperature  $T$  directly, use  $x = T/237.7$ . Then calculate dew point using:

$$T_d = 237.7 [17.3 x + (1 + x) \ln h_r] / [17.3 - (1 + x) \ln h_r]$$

Using this formula, and the values for air temperature (which are different for each month) and relative humidity (65% for every month) in the Water Quality module file, it turns out that dew point is about 6.5°C below air temperature for all months. So, to set dew point:

- Navigate to the branch “Supply and Resources\River\Main River\Reaches\Below Main River Headflow”, if you are not already there.
- Click on the “Climate” button.
- Select the “Dew Point Temperature” tab.
- Either use the Expression Builder or directly type in the formula “Air Temperature - 6.5”, and make sure the units are “C.” Do not type in the [C] as shown below – WEAP will populate that automatically.



# Running Scenarios

## 6. Run Scenarios

Run the scenario by going to Results View and answering “Yes” to the dialog asking whether to recalculate.

*Note that when using QUAL2K, running scenarios can take a long time. Consider reducing the number of scenarios that you calculate at any time.*

QUAL2K will not run for months in which streamflow is zero at any point in the river. If this situation occurs in one or more scenarios, add a (small) minimum flow requirement on reaches for which QUAL2K is used to force a flow greater than zero. Here is the error message you might see:

*“QUAL2K Error: Error Code 3. This error might be caused a streamflow of zero in the river, which QUAL2K does not allow. Perhaps use a flow requirement below to force a small flow at that point.”* Add a flow requirement to the river immediately upstream from the first return flow node (from Big City), and set the minimum flow requirement in Current Accounts to be 0.1 CMS. Re-run calculations.

## 7. Compare Results

When you have finished running your selected scenarios, compare the results with the results from the previous module. They should be similar, but not identical, because the built-in water quality calculations in WEAP make slightly different assumptions and use different approximations than QUAL2K.



---

# WEAP

Water Evaluation And Planning System

# Hydrology

## ***A TUTORIAL ON***

<i>Modeling Catchments: The Simplified Coefficient Method .....</i>	<i>182</i>
<i>Modeling Catchments: the Soil Moisture Model.....</i>	<i>187</i>
<i>Simulating Surface Water-Groundwater Interaction .....</i>	<i>192</i>

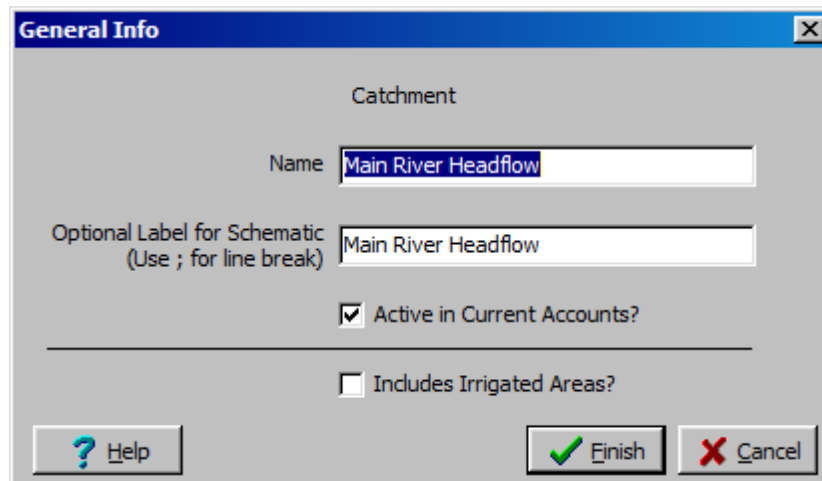
**Note:**

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.”

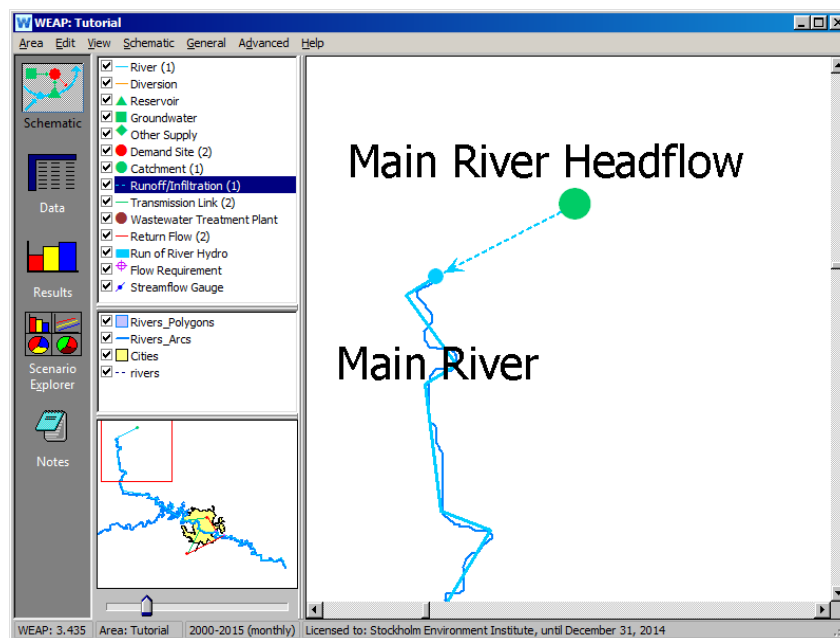
## Modeling Catchments: The Simplified Coefficient Method

### 1. Create a New Catchment

Create a “Catchment” object in the Schematic view to simulate headflow for Main River. Do this by pulling over a Catchment node and locating it near the starting point of the Main River. Name it “Main River Headflow.” Set it to be active in Current Accounts, and leave “Includes Irrigated Areas?” unchecked.

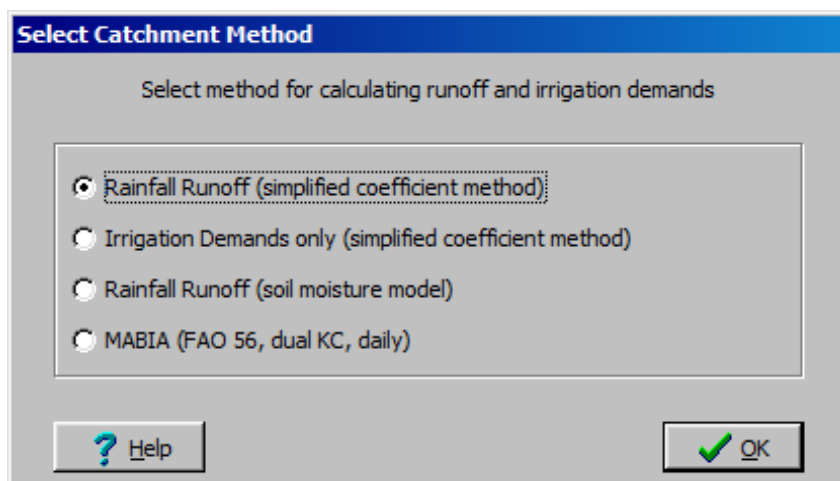


Next draw a Runoff/Infiltration path (dashed blue line) starting from the catchment into the beginning of the Main River.

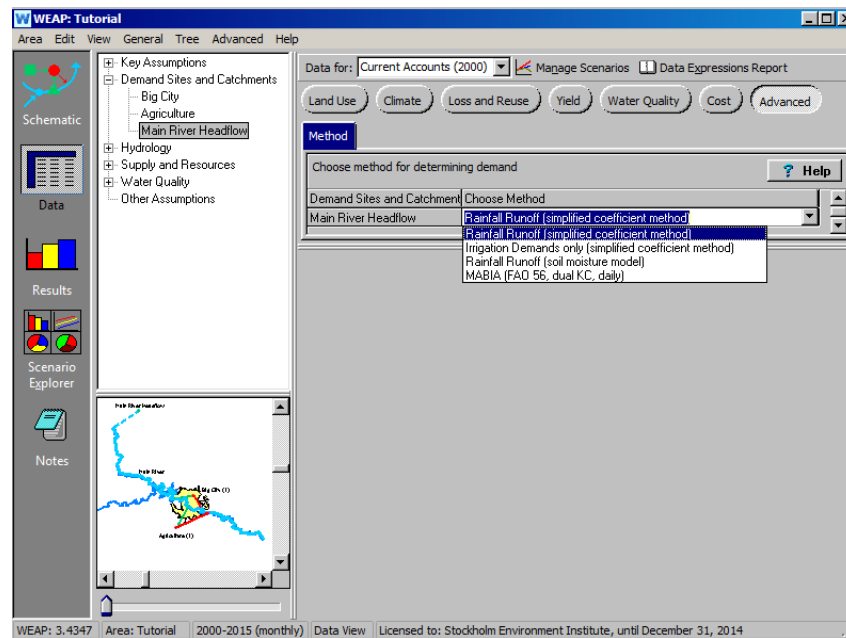


## 2. Create an Appropriate Substructure in the Basin

The first time you right click on the Catchment or select it in the Data Tree, you will get a window that asks you to select a model for the Catchment. Select *Rainfall Runoff (simplified coefficient method)*.

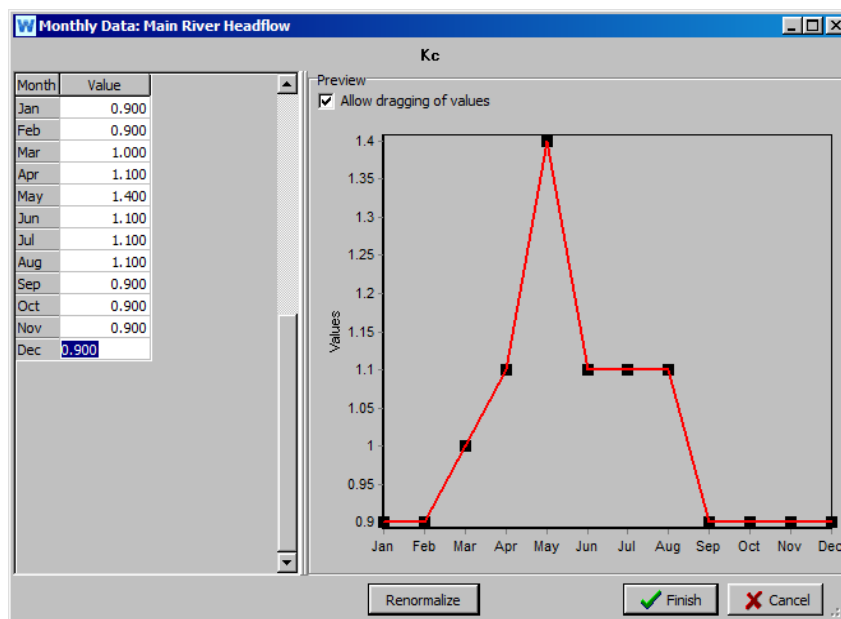


There is also the opportunity to change this selection later by clicking on the “Advanced” tab in the Data view:



In the Data View, select the new catchment under the “Demand Sites and Catchments” branch of the data tree. On the right, click on the “Land Use” button and enter the following data:

<i>Area</i>	<i>10M ha (you will have to choose the units first)</i>
<i>Effective Precipitation</i>	<i>98%</i>
<i>Kc (Crop Coefficients)</i>	<i>(use the Monthly Time Series Wizard to input these data)</i>
<i>Sep to Feb</i>	<i>0.9</i>
<i>March</i>	<i>1.0</i>
<i>April</i>	<i>1.1</i>
<i>May</i>	<i>1.4</i>
<i>Jun to Aug</i>	<i>1.1</i>



Note that if you had clicked “yes” when asked if irrigated areas were to be included in this catchment (under General Info when creating catchment), another button “Irrigation” would have appeared under the catchment in the Data view. This button would have two tabs under it: (1) “Irrigated”, where you would input either a “0” for not irrigated, or a “1” for irrigated for a particular land class; and (2) “Irrigated fraction” where you would specify the fraction of irrigation water supplied to the area that is available for evapotranspiration.

---

The Rainfall Runoff method is a simple method that computes runoff as the difference between precipitation and a plant’s evapotranspiration. A portion of the precipitation can be set to bypass the evapotranspiration process and go straight into runoff to ensure a base flow (through the “effective precipitation” parameter).

The evapotranspiration is estimated by first entering the reference evapotranspiration, then defining crop coefficients for each type of land use (Kc’s) that multiply the reference evapotranspiration to reflect differences occurring from plant to plant.



More information about this method can be obtained from the FAO Irrigation and Drainage Paper 56, called “Crop Evapotranspiration” and available from the FAO’s website ([www.fao.org](http://www.fao.org)).

Entering an effective precipitation other than 100% is one way of acknowledging the fact that part of the rainfall is not submitted to evapotranspiration during high intensity rainfall events, hence generating a minimal runoff to the river even when the rainfall is lower than the potential evapotranspiration. Another solution is to move to more developed models such as the 2-buckets soil moisture model coupled with Surface Water – Groundwater interaction modeling, as presented later in this module.

---

### 3. Enter the Climatic Data

Climatic Data are entered at the catchment level (Main River Headflow). Enter the following data under the “Climate” tab using the Monthly Time Series Wizard :

<i>Month</i>	<i>Precip.</i>	<i>ET<sub>ref</sub></i>
<i>Jan</i>	21	42
<i>Feb</i>	37	47
<i>Mar</i>	56	78
<i>Apr</i>	78	86
<i>May</i>	141	131
<i>Jun</i>	114	122
<i>Jul</i>	116	158
<i>Aug</i>	85	140
<i>Sep</i>	69	104
<i>Oct</i>	36	79
<i>Nov</i>	22	43
<i>Dec</i>	13	37



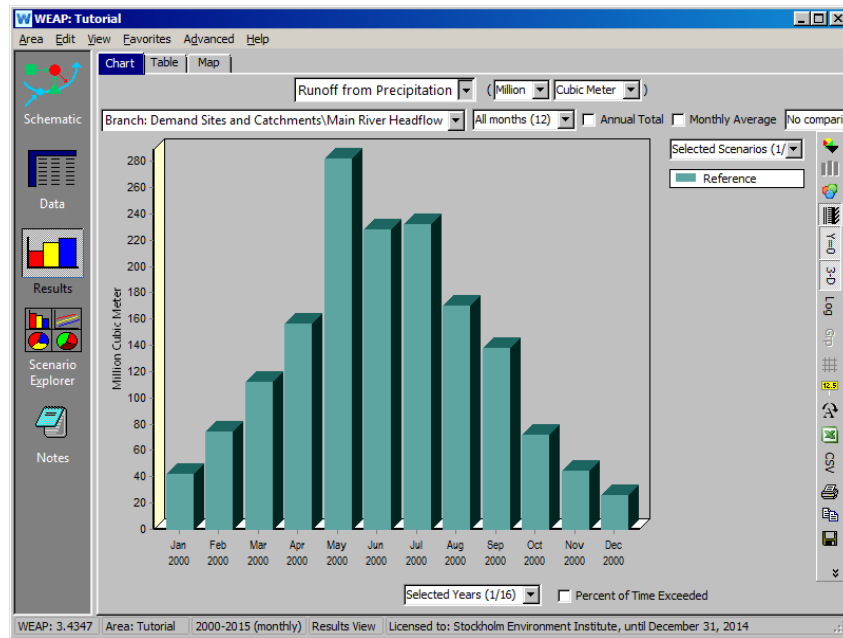
If not available from on-site stations, precipitation data can sometimes be derived from world-wide climate models such as the one developed by Tim Mitchell at the University of East Anglia (<http://www.cru.uea.ac.uk/~timm/data/index.html>). The use of GIS software to extract the appropriate data is required. Such models provide average data in opposition to actual data, implying that the calibration is much more delicate.

The Reference Evapotranspiration can be determined from a set of climatic and topographic parameters using the Penman-Monteith equation. More details are provided in the FAO publication mentioned earlier. Also, there exist global models of monthly reference evapotranspiration put together by the FAO, available from the FAO's website.

### 4. Look at the Results

Results for Catchments are located in the “Catchment” category in the primary variable pull-down menu.

*“Runoff from Precipitation” to the Main River should look similar to the graph below. Select “Selected Scenarios” from the pull-down menu above the graph legend and check off “Reference.” Select “Main River Headflow” as the Demand site/ branch from the menu to the upper left of the graph, and the year 2000 from the “Selected Years” option using the menu at the bottom of the graph. Make sure it is for “All Months.”*



## Modeling Catchments: The Soil Moisture Model

### 5. Replace the Agriculture Demand Site with a Catchment

Delete the Agriculture demand site and create a Catchment in its place. Name it “Agriculture Catchment” and set it Active in Current Accounts, Includes Irrigated Areas, and Demand Priority 1 (the demand priority only appears after you have selected “Includes Irrigated Areas”).

**General Info**

Catchment

Name: Agriculture Catchment

Optional Label for Schematic (Use ; for line break): Agriculture Catchment

☒ Active in Current Accounts?

☒ Includes Irrigated Areas?

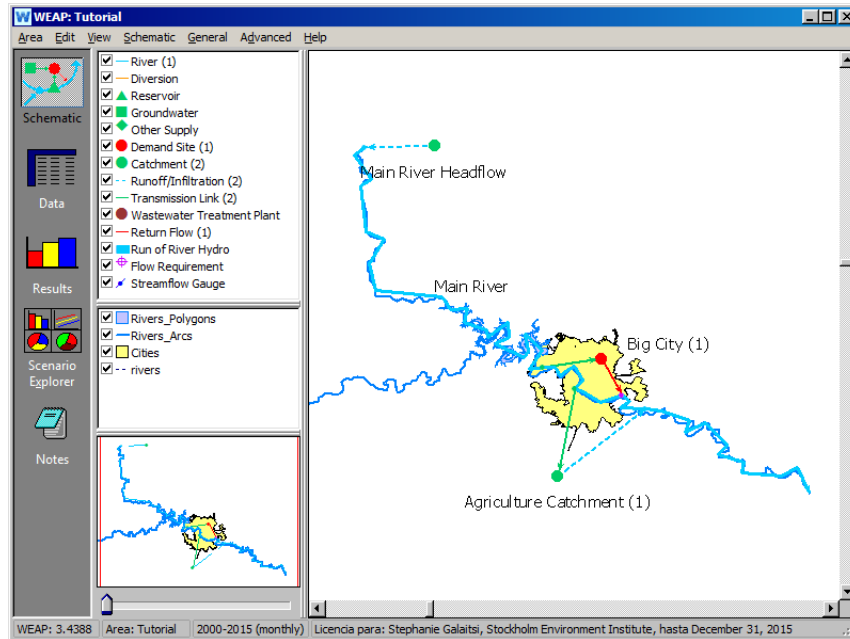
Demand Priority: 1

Note: 1 is the highest priority, 99 is the lowest

Buttons: ? Help, Finish, Cancel

## 6. Connect the New Catchment

Draw a Runoff/Infiltration Link to the Main River below the Return flow node from the Big City. Add a Transmission Link from the Main River (same starting point as the former Agriculture demand site), with a *Supply Preference of 1*. Your model should now look similar to the figure below:



The purpose of this transmission link is to allow supplying irrigated areas with water from the river in case rainfall is insufficient.

## 7. Create sub-structure in the Catchment

We will assume this catchment has three types of land use. In the Data View, add the following branches to your new catchment by right-clicking it in the data tree and selecting "Add." (If you select the catchment for editing by right clicking on the node in the schematic view rather than going through the Data view, you will be asked beforehand to choose a simulation method - pick the "Rainfall Runoff (soil moisture model)" method). Add the following branches:

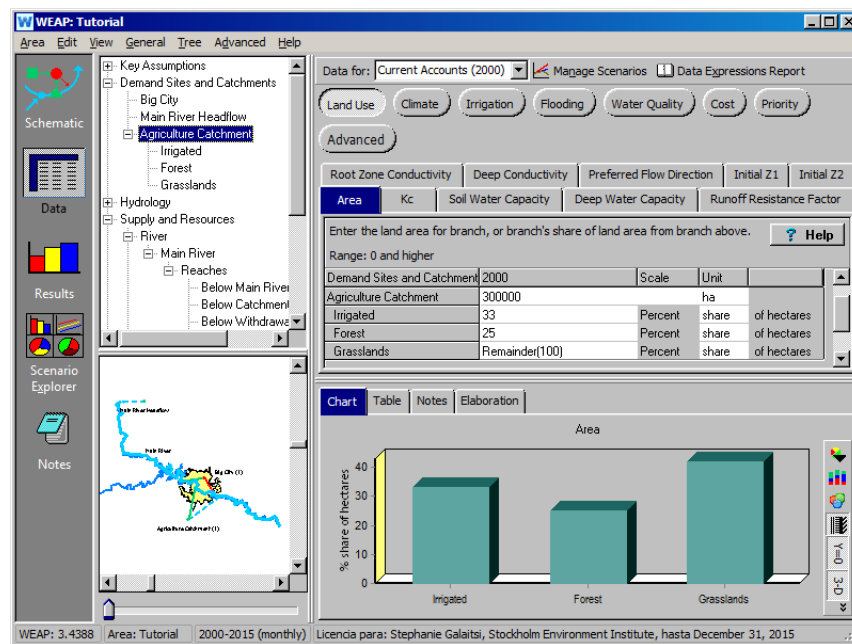
*Irrigated*  
*Forest*  
*Grasslands*



## 8. Enter the Appropriate Land Use Data

Select the Agricultural Catchment in the Data view and pick the “Rainfall Runoff (soil moisture model)” method by clicking on the “Advanced” button (click to the right of “Rainfall Runoff (simplified coefficient method)” and use the arrow to scroll down). Then enter the following data after clicking on the “Land Use” button:

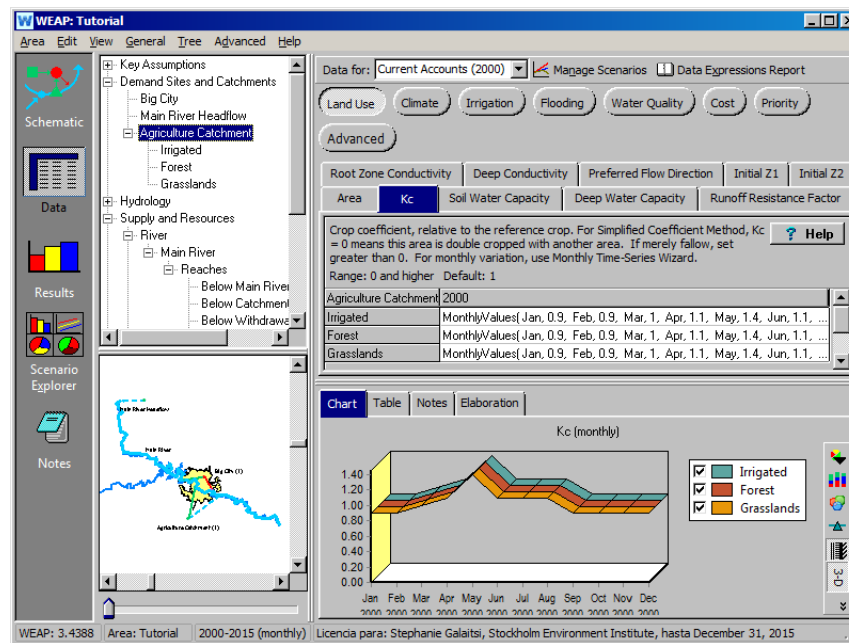
<i>Total Land Area</i>	<i>300,000 ha (you will have to select units first)</i>		
	<i>Irrigated</i>	<i>Forest</i>	<i>Grasslands</i>
<i>Share of Land Area</i>	<i>33%</i>	<i>25%</i>	<i>Remainder(100)</i>



	<i>Irrigated</i>	<i>Forest</i>	<i>Grasslands</i>
<i>Runoff Resistance Factor</i>	<i>3.6</i>	<i>3.0</i>	<i>1.7</i>
<i>Root Zone Conductivity</i>	<i>60</i>	<i>35</i>	<i>45 mm/month</i>
<i>Preferred Flow Dir.</i>	<i>0.15</i>	<i>0.15</i>	<i>0.15</i>
<i>Initial Z1</i>	<i>50%</i>	<i>20%</i>	<i>20%</i>

*The remaining variables are the same for all land classes in the catchment:*

*Initial Z2* 20%  
*Soil Water Capacity* 900 mm  
*Deep Water Capacity* 35,000 mm  
*Deep Conductivity* 240 mm/month  
*Kc* Use the same values as input for the Main River Headflow catchment in the previous exercise. You can simply copy and paste that expression into the Kc field for the Agriculture Catchment land classes.



The Rainfall Runoff (soil moisture model) method has been developed to provide a simple yet realistic way of modeling hydrological processes with a semi-physical representation. Details about the method and its parameters, as well as calibration procedures, can be found in articles posted to the “publication” section of WEAP’s website ([www.weap21.org](http://www.weap21.org)). The related WEAP help topic provides a description of each parameter and an overview of the model as well. The parameter values displayed above are for illustration purposes only.

## 9. Enter the Appropriate Climate Data

In the same view as in the previous step, select the “Climate” screen and enter the following data:

*Precipitation* Use the same precipitation values as input for the Main River Headflow catchment in the previous exercise.  
*Temperature* MonthlyValues(Jan, 9, Feb, 12, Mar, 16, Apr, 21, May, 24, Jun, 27, Jul, 29, Aug, 29, Sep, 27, Oct,

22, Nov, 16, Dec, 11 )

Humidity 65%  
Wind 1m/s  
Latitude 30°

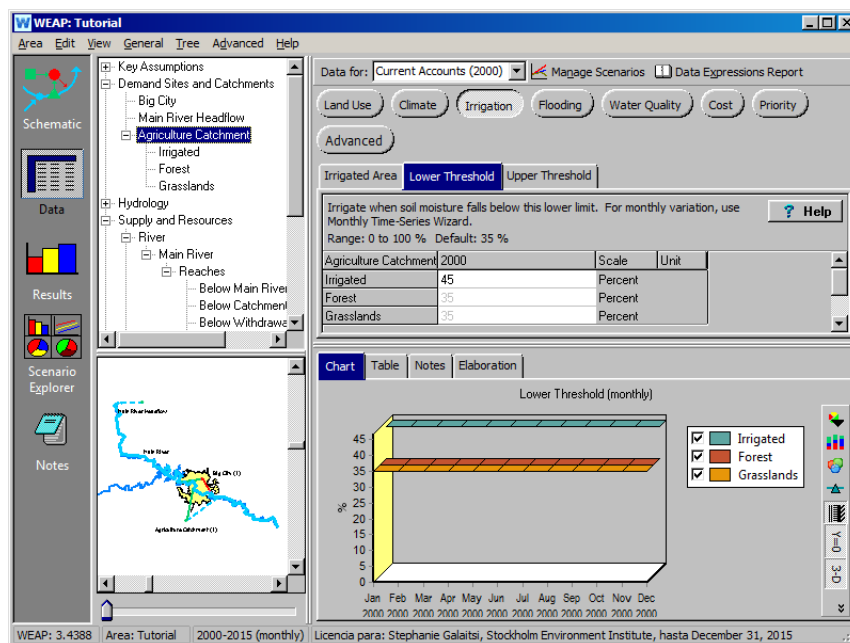


Data about snow coverage are not needed if the basin is not exposed to snow. WEAP determines the appearance of snow based on the temperature and the melting and freezing points parameters. If the last two are left empty, no snow will be allowed to accumulate.

## 10. Set up Irrigated Areas

In the same view as in the previous step, select the “Irrigation” screen and enter the following data:

	<i>Irrigated</i>	<i>Forest</i>	<i>Grasslands</i>
<i>Irrigated Area</i>	100%	0%	0%
<i>Lower Threshold</i>	45%	N/A	N/A
<i>Upper Threshold</i>	55%	N/A	N/A

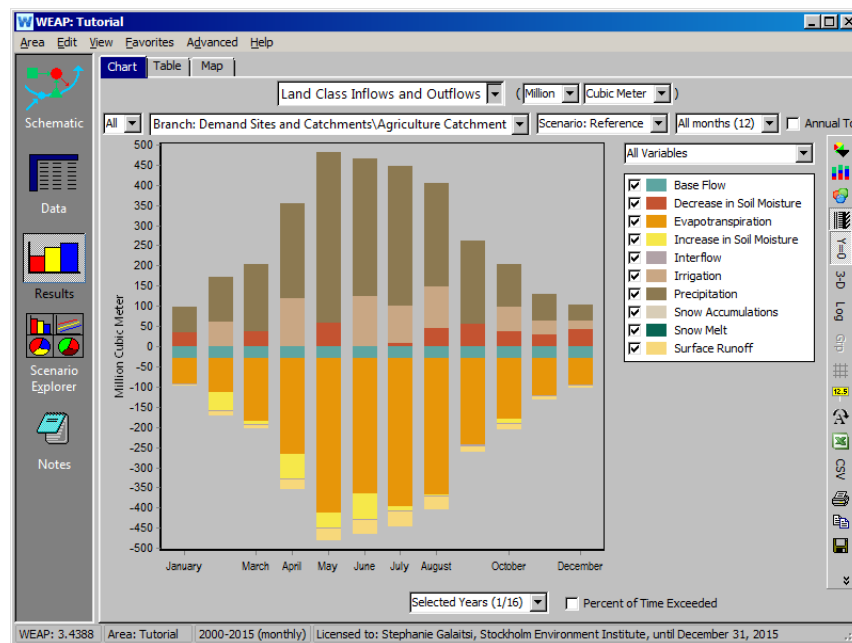


## 11. Look at Results

Look at the following results. Here again, the results are located in the “Catchment” category of the “Results” view. Select “Land Class Inflows and Outflows” under the primary variable pull-down menu. Click to view all variables above the chart legend. To view the “Irrigated” segment of the Agriculture catchment, select “Branch: Demand Sites and Catchments\Agriculture Catchment\Irrigated” from the pull-down menu to

the upper left of the chart. Choose the year 2000 from the “Selected Years” option using the pull-down menu at the bottom, and click on “Monthly Average” to the right of annual total (you may have to expand the screen to see it).

*“Land Class Inflows and Outflows” represents in a very detailed manner the water balance for each land use class. You should obtain a graph similar to the figure below for the “Irrigated” land class inflows and outflows graph:*



*Change the unit from Cubic Meter to mm. Depth units such as mm are typically more useful when examining or validating results catchment results. Note: you cannot change to a depth unit if “Monthly Average” is checked.*

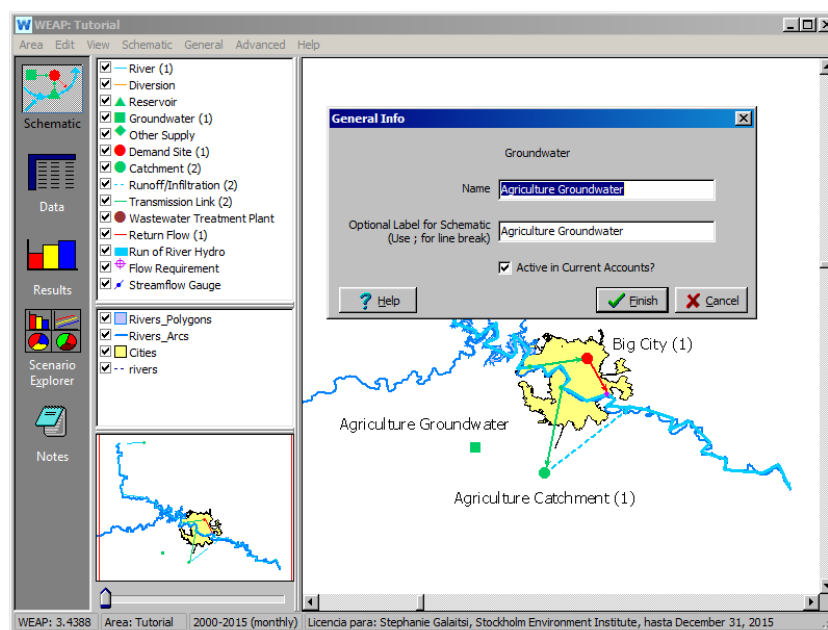
*You can also look at other parameters, such as “Soil Moisture in the upper bucket” (Relative Soil Moisture 1 (%)).*

## Simulating Surface Water-Groundwater Interaction

### 12. Create a Groundwater Object

Create a new “Groundwater” node.

*Locate this Groundwater object next to the Agriculture Catchment that you created in the previous exercise. Name it “Agriculture Groundwater.”*

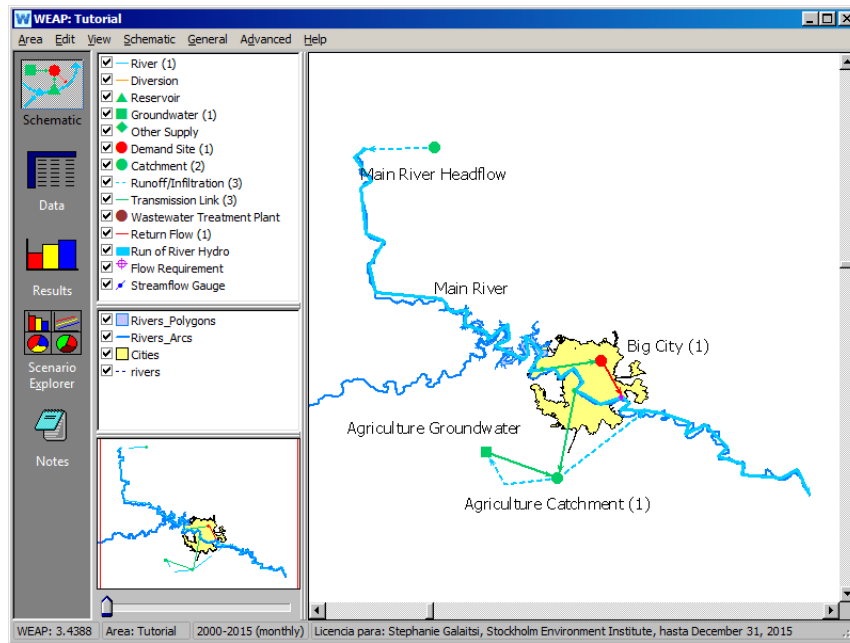


### 13. Connect the Groundwater Object to a Catchment

Create the following connections:

- 1) *Transmission Link from Agriculture Groundwater to Agriculture Catchment (Supply Preference 1)*
- 2) *Infiltration/Runoff Link from Agriculture Catchment to Agriculture Groundwater.*

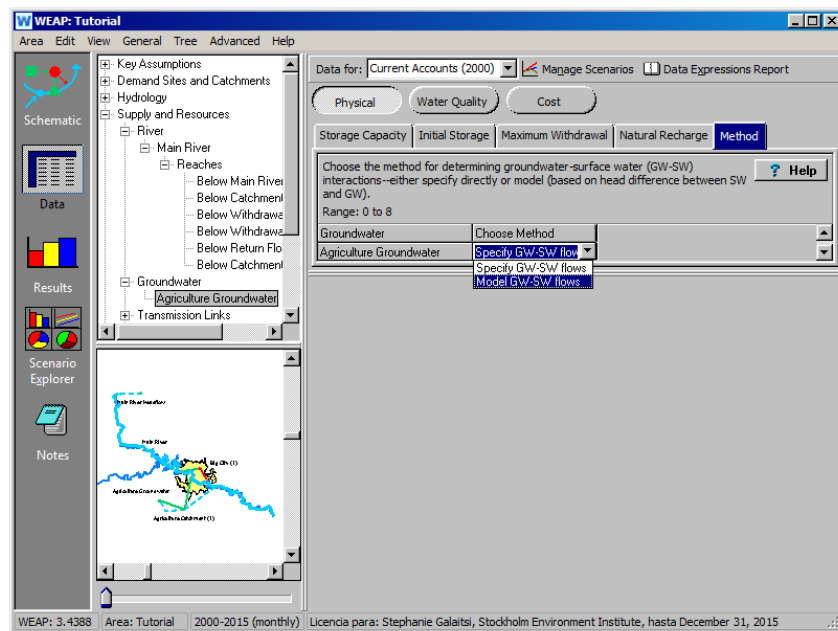
*Your model should look similar to the one below:*



You can also create the Infiltration/Runoff Link between the catchment and the groundwater node by right-clicking the catchment in the Schematic View, selecting “General Info” and then choosing the groundwater field in the “Infiltration to” drop-down menu.

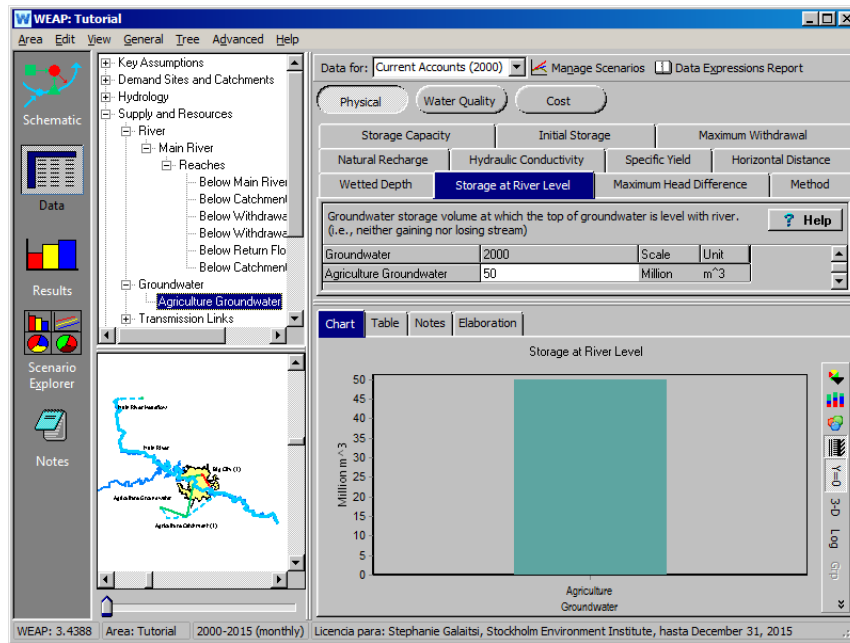
## 14. Enter the Appropriate Data

In the Data View, select Agriculture Groundwater, examine the “Physical” screen and select the “Model GW-SW flows” method from the “Method” tab.



Switch to the “Water Quality” window and then back to the “Physical” window for the change to take effect (you will now see several new tabs in the “Physical” window. If these do not populate, make sure you are in current accounts). Enter the following data (leave blank if nothing is specified) under the appropriate tabs:

<i>Initial storage</i>	<i>50M m<sup>3</sup></i>
<i>Hydraulic Conductivity</i>	<i>10m/day</i>
<i>Specific Yield</i>	<i>0.1</i>
<i>Horizontal Distance</i>	<i>260m (the extent of the aquifer perpendicular to the river)</i>
<i>Wetted Depth</i>	<i>5m</i>
<i>Storage at River Level</i>	<i>50M m<sup>3</sup></i>



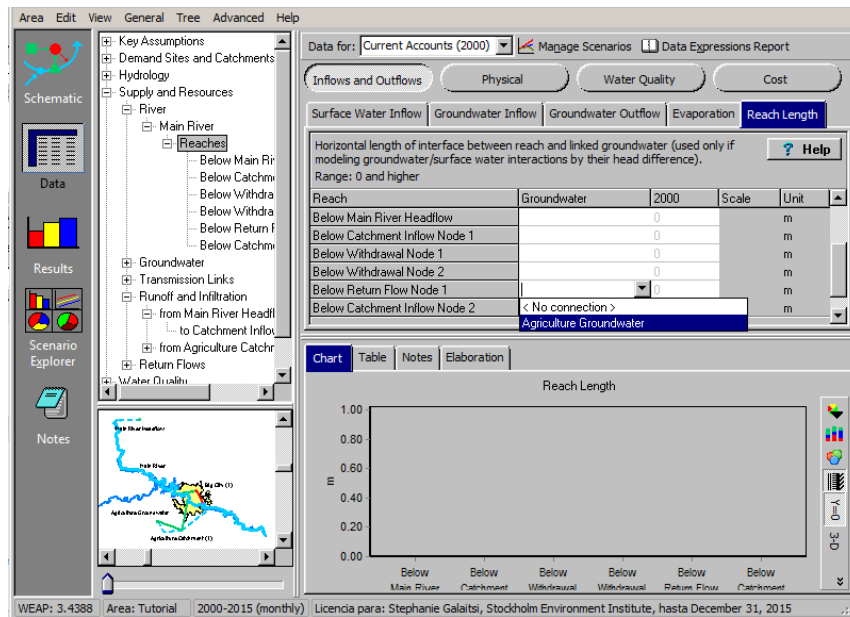
## 15. Select the Reaches that Interact with the Aquifer

In the Data View's tree, expand all the reaches of the Main River by clicking on the “+” icon next to it in the “Supply and Resources\River” branch. Select the reach that is below the return flow node from Big City (Return Flow Node 1; you might have to switch to the Schematic view and right-click on the nodes to find the name of that node in your model). Then enter the following data in the “Reach Length” tab for this reach:

*Groundwater*

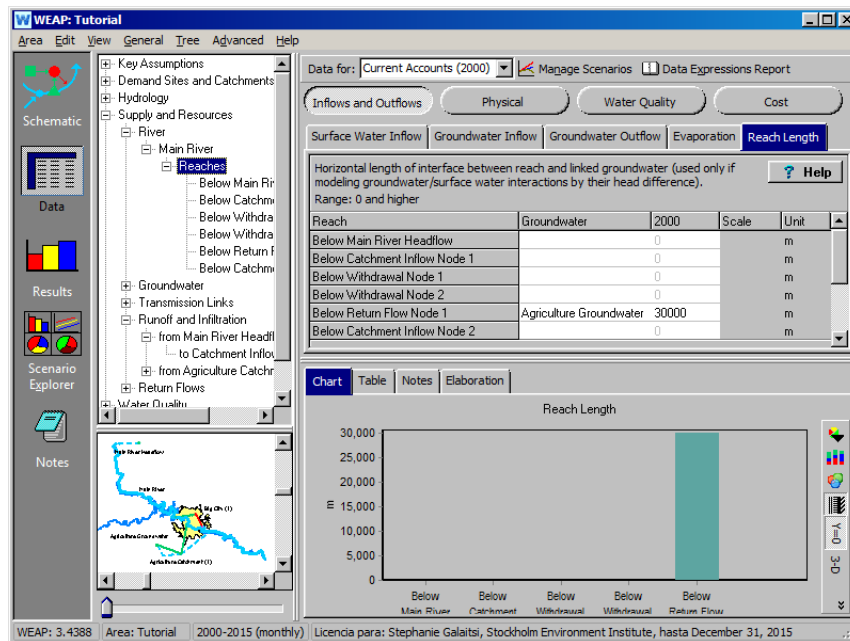
*Select “Agriculture Groundwater”*





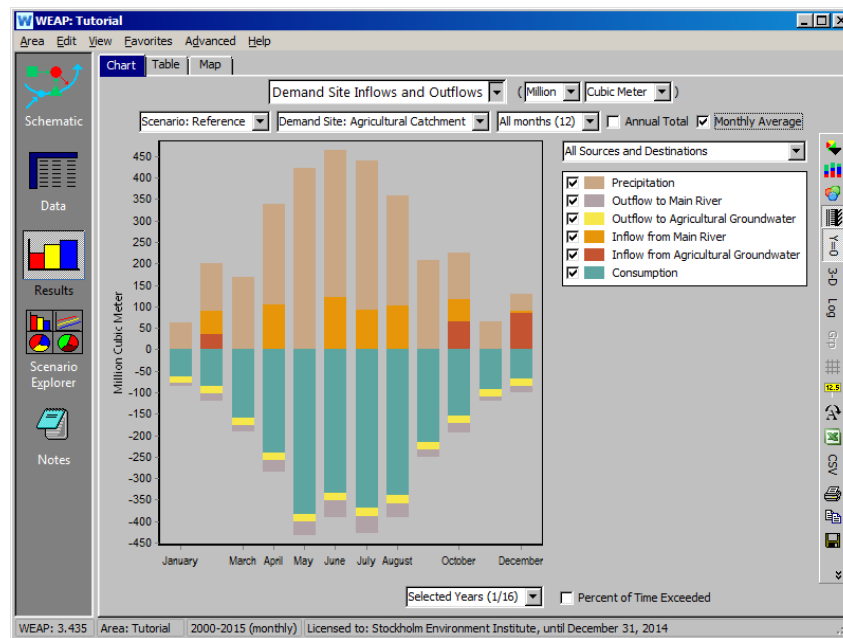
*Reach Length*

*30,000 m*



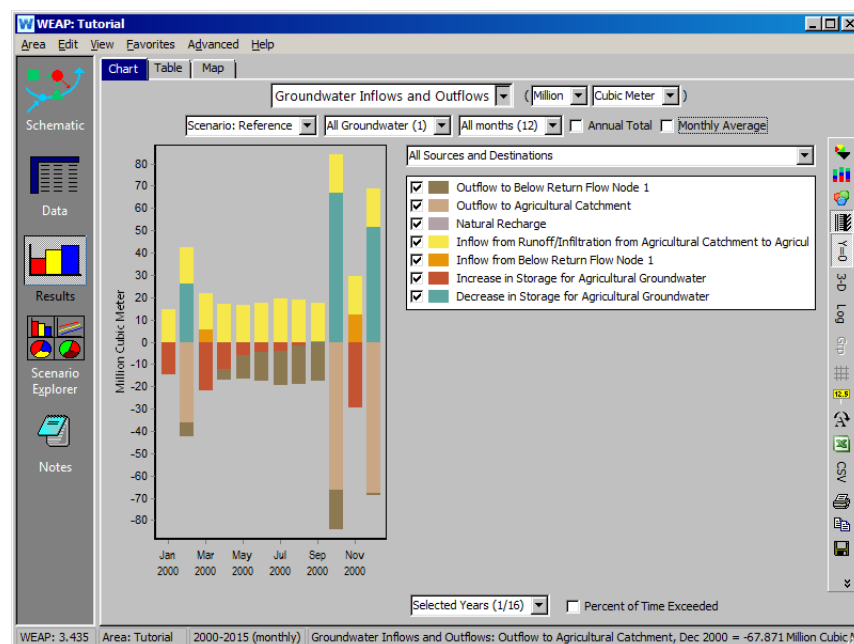
## 16. Look at the Results

Look at the “Demand Site Inflows and Outflows” in Demand for the Agriculture catchment, and select “All Sources and Destinations” for the year 2000.



Note that these results include “Inflow from Agriculture Groundwater” (due to the designation of the Agriculture Groundwater node as a source to supply irrigation water for the Agriculture Catchment) and “Outflow to Agriculture Groundwater” (due to the creation of a runoff/infiltration link between the two nodes).

Look also at “Groundwater Inflows and Outflows” (under Supply and Resources\Groundwater) for the year 2000.





Note that the “Inflow from Upstream” category indicates infiltration of Main River water to Agriculture Groundwater along the river reach you selected earlier. Likewise, “Outflow to Downstream” represents groundwater seepage into the Main River.

---

Look also at the height of groundwater above the river stage. This can be viewed by selecting “Supply and Resources\Groundwater\Height Above River” from the primary variable pull-down menu. Choose “Agriculture Groundwater” from the “Selected Aquifers” option in the pull-down menu above the chart legend.



Note that in the month where groundwater seepage to the Main River occurs (February), the groundwater elevation is higher than the wetted depth of the river as designated in the data (i.e., the difference in elevations is positive). Likewise, when Main River infiltration to groundwater is occurring, the elevation difference is negative.

---



---

**WEAP**

**Water Evaluation And Planning System**

# **Snow Hydrology and PEST Calibration**

## ***A TUTORIAL ON***

<i>Explore the Pre-Existing Model .....</i>	<i>202</i>
<i>Enter Catchment Climate and Calibration Data .....</i>	<i>204</i>
<i>Explore the Model Sensitivity.....</i>	<i>208</i>
<i>Calibrate with PEST .....</i>	<i>211</i>
<i>Appendix.....</i>	<i>214</i>

**August 2016**

**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 Snow Hydrology and PEST module.”

This exercise will familiarize you with WEAP’s snow accumulation and melt routines of the Soil Moisture Method (SMM). In addition, you will learn how to use PEST to help automate the model calibration process. For this exercise, we will model the streamflow produced in a nearby mountain that has snowfall. In general, it is a good idea to divide catchments by elevation bands for entering temperature data because temperature typically decreases with increasing elevation.<sup>1</sup> However, for this example, we assume that there is enough uniformity in the area to warrant building a single catchment, and that there is a snow gauge within the area of this catchment.

## Explore the Pre-Existing Model

When collaborating with other modelers, it is important to know how to explore pre-existing models.

The snow tutorial module is a historic model that uses weekly time steps. This means that we have entered data in the model to accommodate the weekly timestep instead of a monthly timestep.

Using a weekly model assumes that we are looking at a smaller spatial scale than a model with a monthly timestep, because WEAP assumes that it will take one week for water entering the headflow of the model to arrive at the outflow of the model. Weekly and monthly models thus should not be interchangeable; however we have made the switch for the purpose of this example.

---

<sup>1</sup> Dry air cools at about 10°C/km (the ‘dry adiabatic lapse rate’), while moist air usually cools at less than 6°C/km (the ‘moist adiabatic lapse rate’)

*Go to Main Menu> General/Year and Time Steps*

**Years and Time Steps**

**Time Horizon**  
 Current Accounts Year: 1982  
 Last Year of Scenarios: 2000

**Time Steps per Year**  
 52  
☐ Add Leap Days?

**Time Step Boundary**  
☒ Based on calendar month  
☐ All time steps are equal length  
☐ Set time step length manually

**Water Year Start**  
 Oct 1

**Time Step Name Format:** Oct 1 (first date)

#	Title	Abbrev.	Length	Begins	Ends
1	Oct 1	Oct 1	7	Oct 1	Oct 7
2	Oct 8	Oct 8	7	Oct 8	Oct 14
3	Oct 15	Oct 15	7	Oct 15	Oct 21
4	Oct 22	Oct 22	7	Oct 22	Oct 28
5	Oct 29	Oct 29	7	Oct 29	Nov 4
6	Nov 5	Nov 5	7	Nov 5	Nov 11
7	Nov 12	Nov 12	7	Nov 12	Nov 18
8	Nov 19	Nov 19	7	Nov 19	Nov 25
9	Nov 26	Nov 26	7	Nov 26	Dec 2

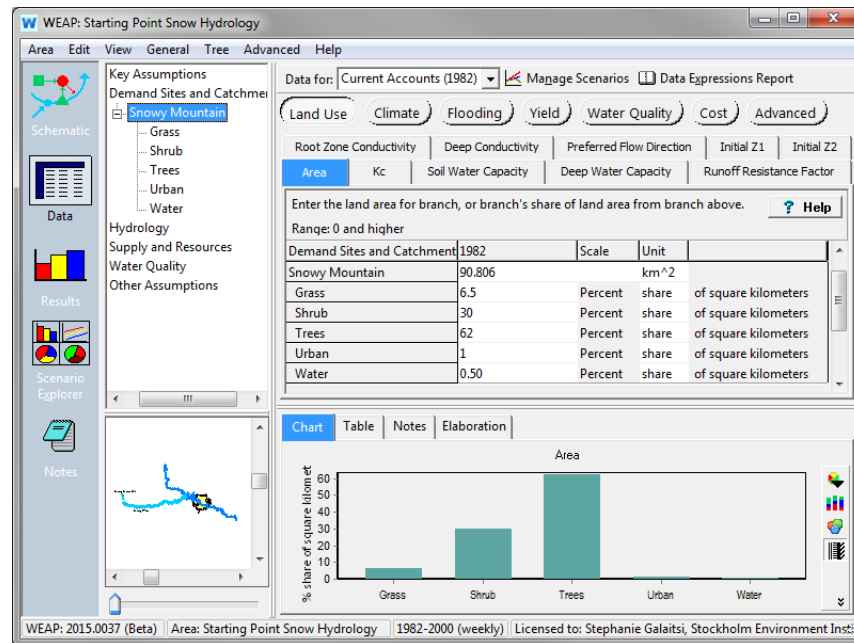
The study period will run from Oct 1, 1981 to Sep 24, 2000.

[? Help](#) [Close](#)

Not only is this a weekly model, but it starts on October 1, 1981. Water years in the United States typically start in October. In the dropdown menu “Time Step Name Format,” the format “Oct 1 (first date)” is selected, but there are other formats available to label the various weeks of the model.

*Close the Years and Time window and go into the Data View to see the data in the catchment “Snowy Mountain.”*

The catchment’s land area is dominated by tree cover (62%).



The variables Area, Kc, Soil Water Capacity, Deep Water Capacity, Deep Conductivity, Preferred Flow, Initial Z1, Initial Z2, Runoff Resistance Factor, and Root Zone Conductivity already have data entered. Most of the root zone (upper bucket) variables have the same value for the different land use types, with the notable exception of the Runoff Resistance Factor.

We also see that under Key Assumptions, there is a new assumption: Albedo, with both NewSnow and OldSnow values (explained below).

## Enter Catchment Climate and Calibration Data

### 1. Enter Climate Data

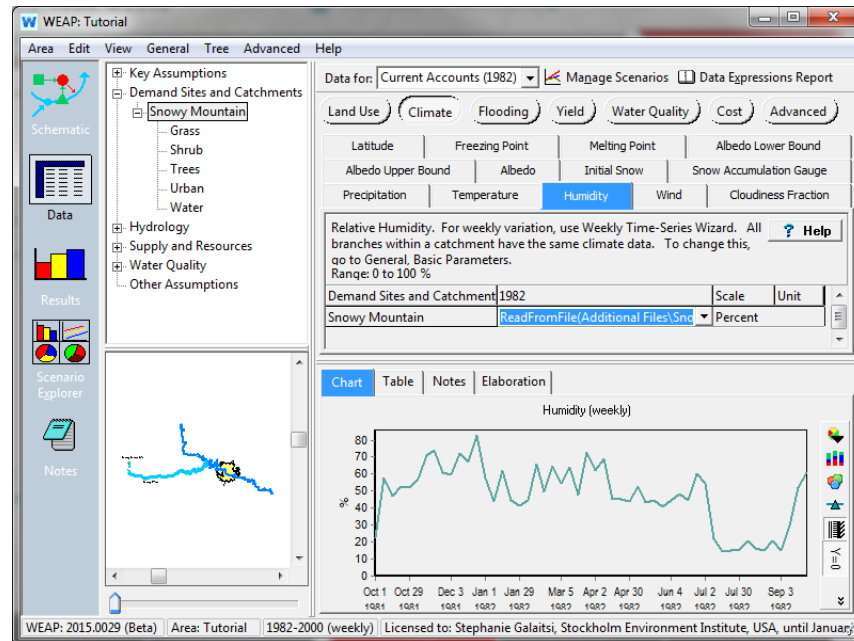
The climate data can be found in a file called SnowyMountain.csv in the WEAP Tutorial folder\Additional Files. You can look at this file as an example of a data format for a weekly model.

*Use the ReadFromFile function to enter data for precipitation (data column 1), temperature (data column 2) and humidity (data column 3) for Snowy Mountain. You may use the ReadFromFile wizard to help you build the expression, or type the expression in directly.*



Relative Humidity. For weekly variation, use Weekly Time-Series Wizard. All branches within a catchment have the same climate data. To change this, go to General, Basic Parameters. Range: 0 to 100 %

Demand Sites and Catchment	1982	Scale	Unit
Snowy Mountain	ReadFromFile(Additional Files\SnowyMountain.csv, "Humidity[%]")	Percent	



Enter the data for

Freezing Point       $-5^{\circ}\text{C}$  (default)

Melting Point       $10^{\circ}\text{C}$

Data for wind, cloudiness fraction and latitude are already entered.

Albedo (i.e., surface reflectance) is a very important parameter for snow routines. It controls the net radiation available for snow melt. In this region, albedo of old snow needs to be distinguished from albedo of new snow. Albedo of old snow is lower (as it gets dirtier) than new snow. You must have WEAP version 2016 or higher to access the albedo data tab to enter an expression to control the effect of age of snow on albedo.

Go to the Albedo data tab. Using the Expression Builder to make an expression. Enter the equation:

If(PrevTSValue(Snow Depth[m])=0, Albedo Lower Bound,  
PrevTSValue(Snow Depth[m],1)>PrevTSValue(Snow Depth[m],2),

Key\Albedo\NewSnow,  
 Max(PrevTSValue(Albedo)-0.1, Key\Albedo\OldSnow))

We have now given WEAP instructions for albedo values for three circumstances:

- 1) If previous time step had no snow, then Albedo = Albedo Lower Bound, which defaults to 0.15
- 2) Otherwise, if previous time step had new snow (the snow depth in the previous timestep is greater than two timesteps earlier), then Albedo = “NewSnow” = 0.8
- 3) Otherwise, Albedo = albedo in the previous timestep minus 0.1 (but not less than OldSnow = 0.4).

Note that NewSnow and OldSnow albedo values are in the Key Assumptions, and can be changed to help the model better fit the data. The Appendix for this module explains this equation in more detail.

## 2. Enter Observed Snow Data

We will now add snow accumulation data from the Snowy Mountain snow gauge. This gauge is located within the Snowy Mountain catchment.

In the Snowy Mountain Catchment, under Climate > Snow Accumulation Gauge.

*Use the ReadFromFile function to read the data from SnowGauge.csv (in Additional Files of the Tutorial folder)*

Note that this file has missing data, so in the ReadFromFile Wizard, where it says “Missing Value Method, WEAP defaults to the method “Mark” which leaves the data value empty. You can read about this topic in the Help menu about the ReadFromFile Wizard.

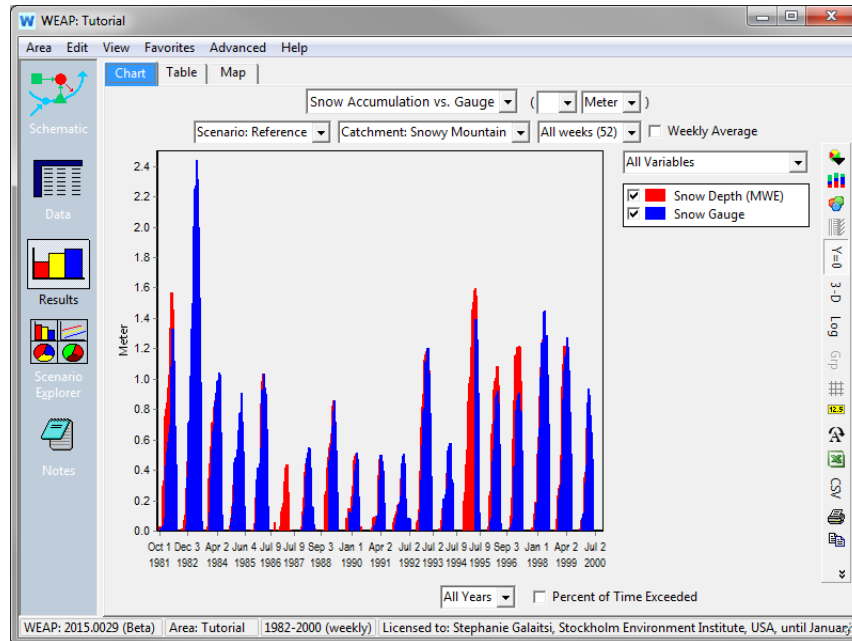
The expression will appear as:

Historic data of snow accumulation (snowpack), to be used in calibration. Measured in melt water equivalent (MWE) depth. For weekly variation, use Weekly Time-Series Wizard. All branches within a catchment have the same climate Range: 0 and higher				<a href="#">? Help</a>
Demand Sites and Catchment	1982	Scale	Unit	
Snowy Mountain	ReadFromFile(Additional Files\SnowGauge.csv, "SnowGauge[mm]", , , Mark)		mm	

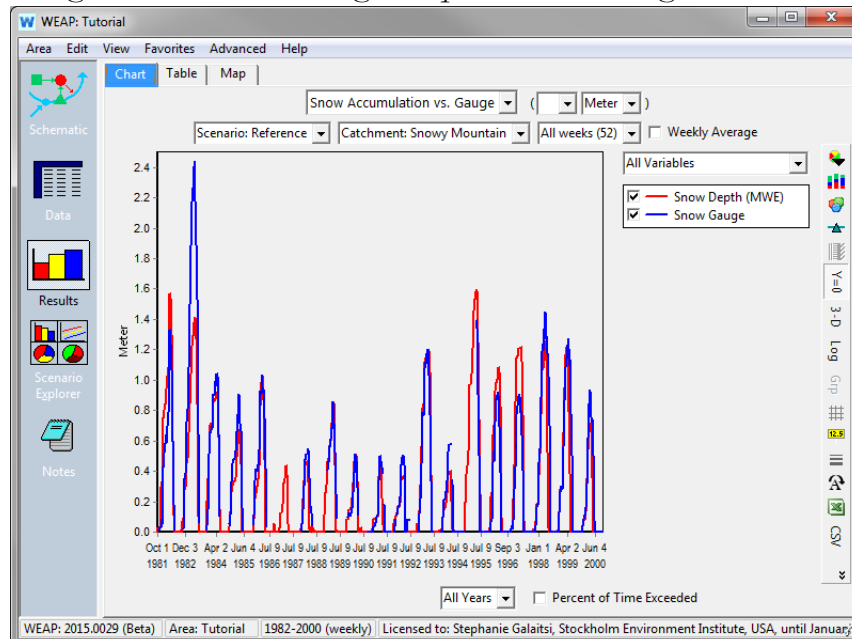
### 3. View the Results

Run the model results.

*View the result Catchments/Snow Accumulation vs. Gauge*

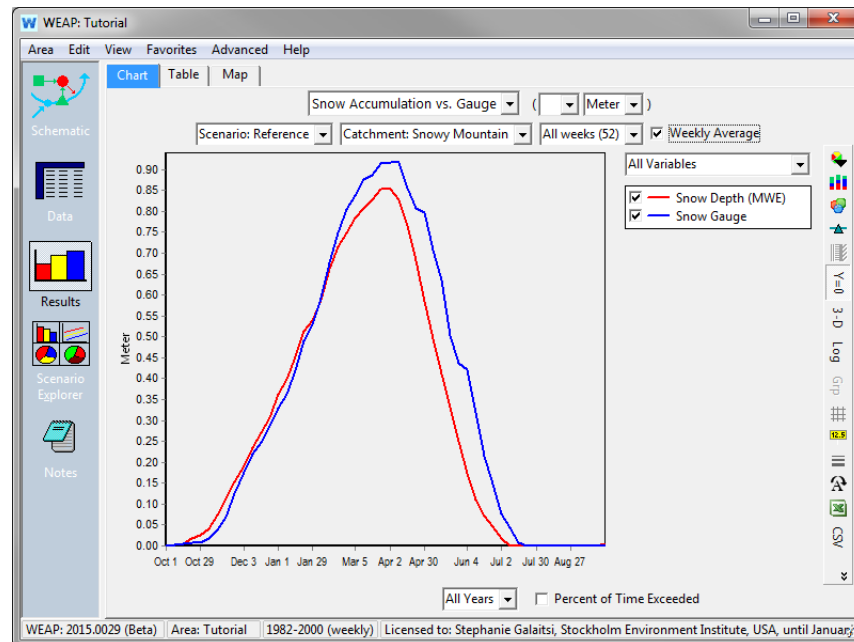


*Change the view to lines using the top button on the right toolbar.*



*Save the chart as a favorite (you can give it the name “Snow Accumulation vs. Gauge”)*

*Look at the same data as a weekly average.*



Here we can see that in general, WEAP’s modeled values for snow depth are too high between October to February and then too low until July, when the snow melts altogether. Compared to the gauge, the model is producing and melting snow too early.

## Explore the Model Sensitivity

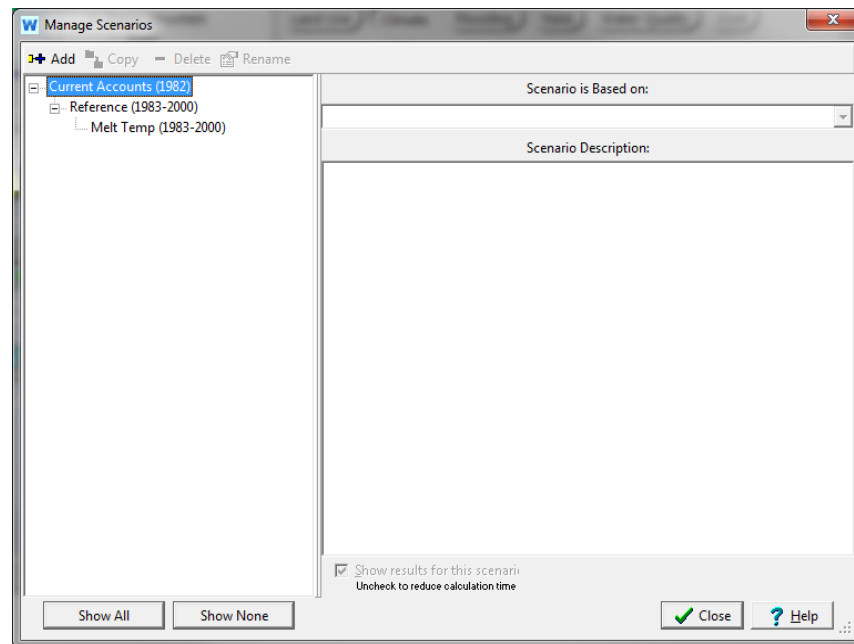
Now that you have a working model you can explore the sensitivity of model results to changes in the parameters.

To explore model sensitivity, you will first create a new scenario in which you will alter parameter values. You will then be able to compare the new scenario results to the “reference” scenario results and see the impacts of changing the parameter values.

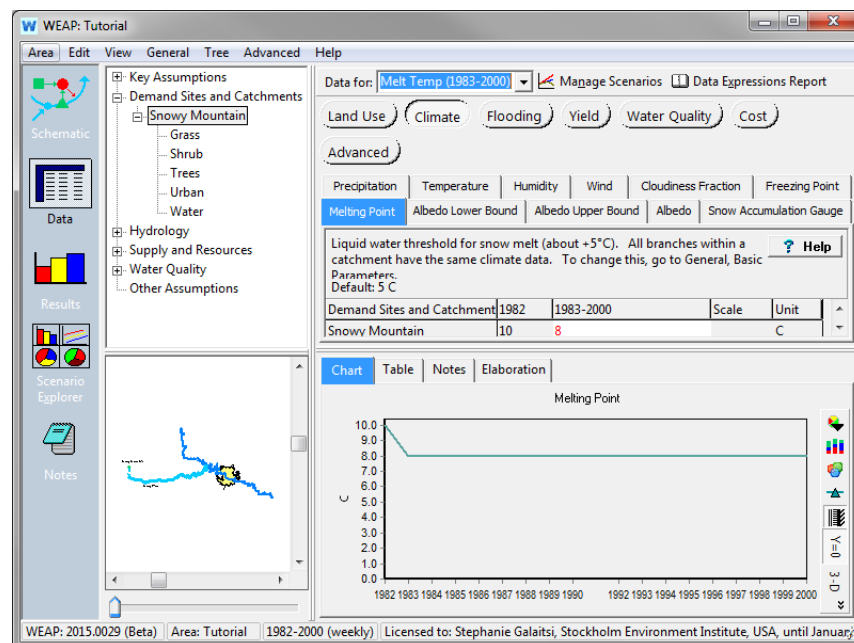
### 4. Manually changes within a scenario

We will first examine the impacts of changing the melting point parameter for snow.

*Add a new scenario that inherits from Reference called “Melt Temp.”*



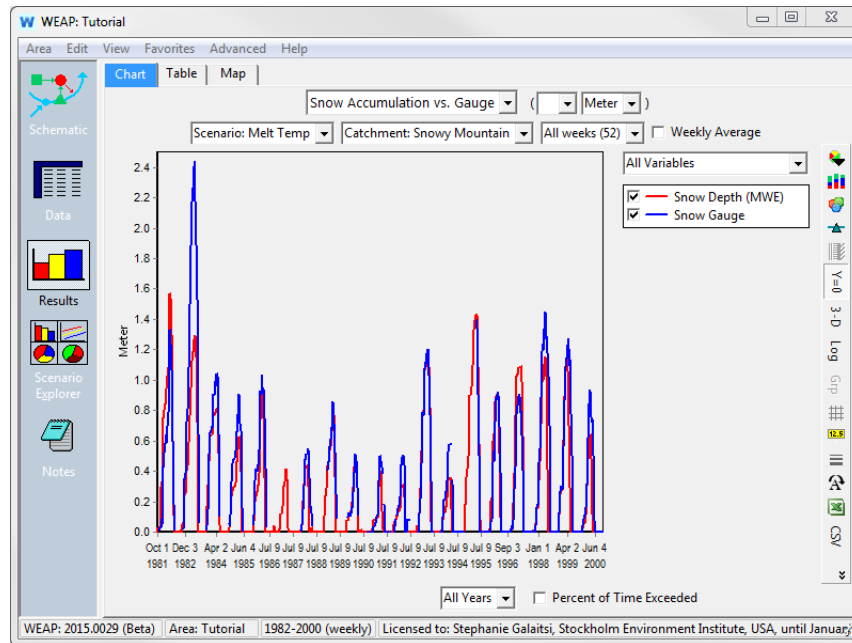
*In the Snowy Mountain catchment, in the Melt Temp scenario, change the “Melting Point” value to 8. Before you run the model, think about how you expect this to change the results.*



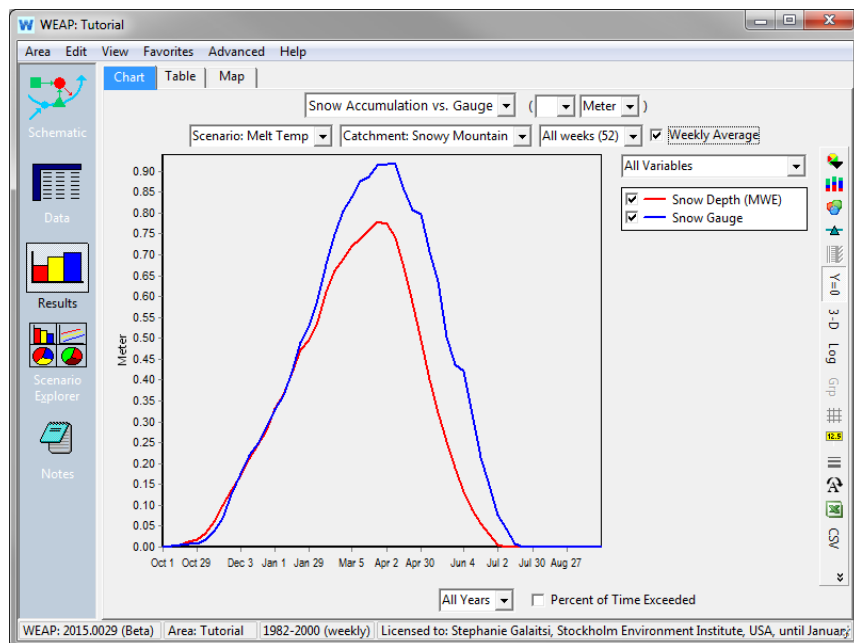
*Run the model by clicking on Results.*

We can compare snow accumulation to the modeled snow for both scenarios.

*Go to Favorites and choose the chart with snow accumulation vs. gauge. View the results for the Melt Temp Scenario*

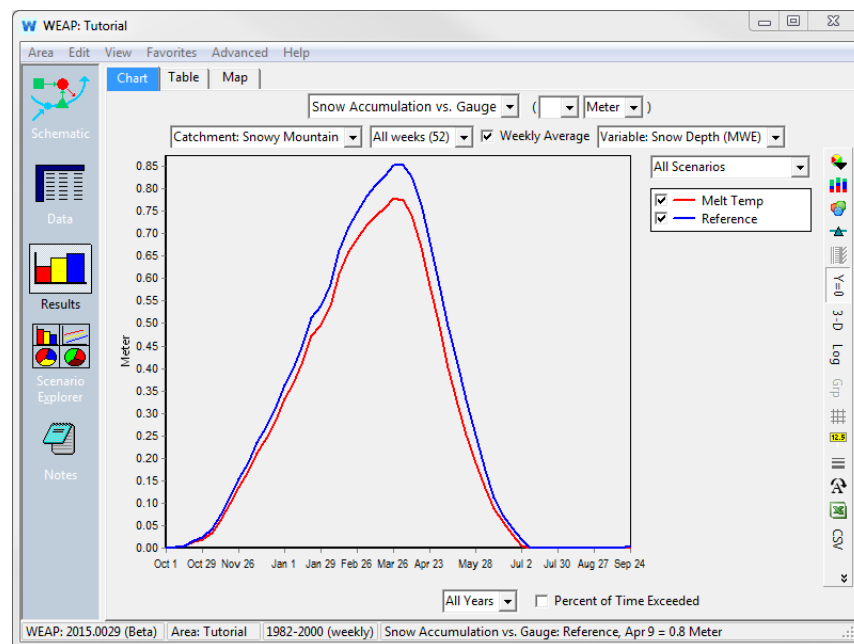


*View as a weekly average.*



The lowered melting temperature reduces the range of temperature in which water can exist as snow. Therefore, the snow accumulation is less. Between October and January, this produces similar results to the snow accumulation gauge, but after January, we see that the snow is melting too early, like the reference scenario. But how do they compare to each other?

*Choose “All Scenarios” from the dropdown on the right side of the screen.*



In our “Melt Temp” scenario, the snow is melting even earlier in the year than for the Reference scenario.

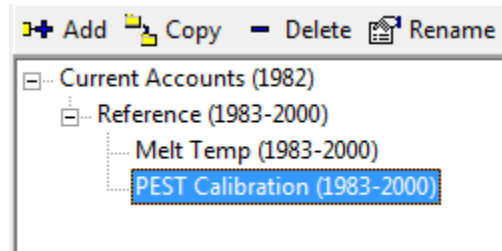
When examining the impacts of changing different parameters, it’s useful to start with a fairly substantial change (a few degrees C) to get a sense of how it will affect the model. Then you can select a more appropriate magnitude of change. This activity can be performed for the freezing temperature as well as for changes in other parameters.

## Calibrate with PEST

WEAP links to a parameter estimation tool (PEST) that can help produce results that match historical data records by examining a range of parameter values and combinations thereof. With PEST, the user can select which parameters to calibrate using the historical records available for entry in WEAP: streamflow gauges, catchments with snow depth data and reservoir

levels with volume data. A PEST calibration produces combinations of parameter values to enable the model results to approximate the observed data. PEST will not always find the best solutions, but can be a good place to start. To learn more about PEST, see the WEAP help menu: (PEST Calibration), or see [www.pesthomepage.org](http://www.pesthomepage.org).

*Create a new scenario called “PEST calibration” that inherits from Reference*



*Open PEST Calibration (Advanced > Pest Calibration).*

*Enter the following information*

<i>Variable</i>	<i>Lower Bound</i>	<i>Upper Bound</i>
<i>Melting Point</i>	<i>0</i>	<i>10</i>
<i>Freezing Point</i>	<i>-10</i>	<i>0</i>

*Catchments (with snowpack data):*      *Snowy Mountain*

*Years:*      *1983-2000 (Open the “Selected” menu, select all, then deselect ‘82)*

*Scenarios to Calibrate:*      *PEST Calibration*

*Modify Parameters in*

<i>Current Accounts</i>	<i>Unclick</i>
<i>Normalize Observation Data</i>	<i>Unclick</i>



Calibration using PEST

Calibration Set: PEST Calibration

Parameters to Calibrate

Parameter	Lower Bound	Upper Bound	Initial Value
Melting Point[C]	0	10	5
Freezing Point[C]	-10	0	-5

Observations to Calibrate To

Streamflow Gauges: None defined

Reservoirs (with observed data): None defined

Catchments (with snowpack data): Snowy Mountain

Years: Selected

Weeks: All

Options

Scenarios to Calibrate: PEST

☐ Modify parameters in Current Accounts also

☐ Normalize observation data

☒ Run PEST after building PEST input files

Buttons: ? Help, ✓ Build Files and Run PEST, ✗ Close

When WEAP normalizes observation data, PEST will use the reciprocal of each observation value as its weight. For example, if the observations were 10, 30 and 25, the weights would be  $1/10$ ,  $1/30$  and  $1/25$ . This weighting will ensure that the larger values, such as flood flows in the river, do not outweigh of the smaller values, such as low flows. This option is essential when simultaneously calibrating different types of observations (e.g., streamflow and reservoir storage), because the two types are not comparable (different units, or could be many orders of magnitude different). It is also helpful when calibrating streamflow, so that low flows will have equal weight as high flows. However, we currently have only one record of observation, and we will see what results PEST produces when it is not normalizing large and small flows.

*Click "Build Files and Run PEST".*

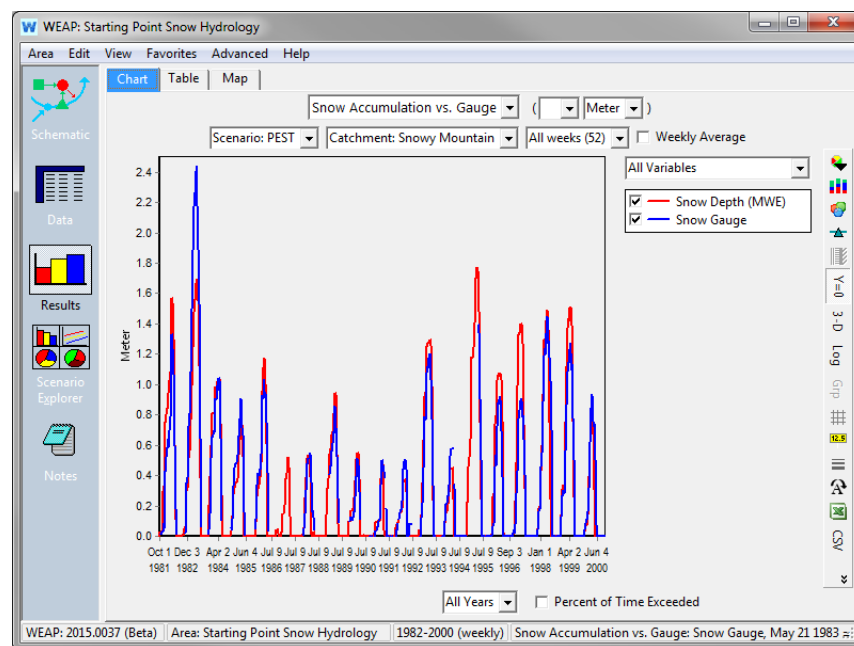
PEST will take control, running the model many times.

Once it stops, results for final parameter values found by PEST will show in the Scenarios Explorer. You can also see them in the Data View for the Pest Calibration Scenario.

What were the PEST values for these parameters? You may receive slightly different results. Our outputs were:

Parameter	PEST Calibration Value
Melting threshold	6.29
Freezing Threshold	-1.38

Run the results. How is the snow simulation vs the gauge? Is it better or worse than the Reference (uncalibrated) scenario?



## Appendix

This model used a custom equation for snow albedo evolution. **Note that the same equation should NOT be used in other model regions. You will have to figure out what makes sense in your own geographic region and timestep.**

First we will tell WEAP that if the previous time step had no snow, WEAP will use an Albedo value of Albedo Lower Bound (which defaults to 0.15). At the start of the model, there is no previous time step, but there is a parameter called “Initial Snow” which WEAP will use as the snow depth of the timestep before the model starts. The user can set this value according to the circumstances in their system at the start of the model’s time period.

To tell WEAP the albedo value for no snow, we will use the “If” statement, in the format *If(test 1, value if test 1 is true, test 2, value if test 2 is true, ..., value if all tests are false)*.

If(PrevTSValue(Snow Depth[m])=0, Albedo Lower Bound,

Now we have to tell WEAP what to do if there was snow in the previous timestep. We want to determine whether there was new snow or old snow, as they have different albedo values. As the *test 2* part of our “If” statement, we will ask WEAP if the snow depth in the previous timestep is greater than the snow depth in the time step prior to that. Values 1 and 2 in this PrevTSValue expression denote how many timesteps previous to look (one or two). In the event that the snow was greater in the most recent time step, WEAP will give Albedo the value of NewSnow from the Key Assumptions, which was 0.8 in this exercise.

If(PrevTSValue(Snow Depth[m])=0, Albedo Lower Bound,  
PrevTSValue(Snow Depth[m],1)>PrevTSValue(Snow Depth[m],2),  
Key\Albedo\NewSnow,

However, in the event that there was snow, but it was not new snow, we must tell WEAP how to calculate the Albedo value. This will be the *value if all tests are false* part of the “If” statement. We will ask it to choose the maximum of two values:

- 1) The albedo of the previous time step minus 0.1
- 2) The albedo of the Key Assumption OldSnow (0.4)

If(PrevTSValue(Snow Depth[m])=0, Albedo Lower Bound,  
PrevTSValue(Snow Depth[m],1)>PrevTSValue(Snow Depth[m],2),  
Key\Albedo\NewSnow,  
Max(PrevTSValue(Albedo)-0.1, Key\Albedo\OldSnow))

Therefore, if there is snow on the ground, the value of Albedo will be between 0.4-0.8, depending on how long it has been since the last new snow. After the last snow has melted, the albedo will fall to 0.15.

.

# Financial Analysis

## ***A TUTORIAL ON***

*Setting up the Cost and Benefit Model* .....218

*Modeling Cost* .....220

*Modeling Benefits*.....227

**August 2016**

**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.”

## Setting up the Cost and Benefit Model

### 5. Understanding Cost and Benefit Modeling in WEAP

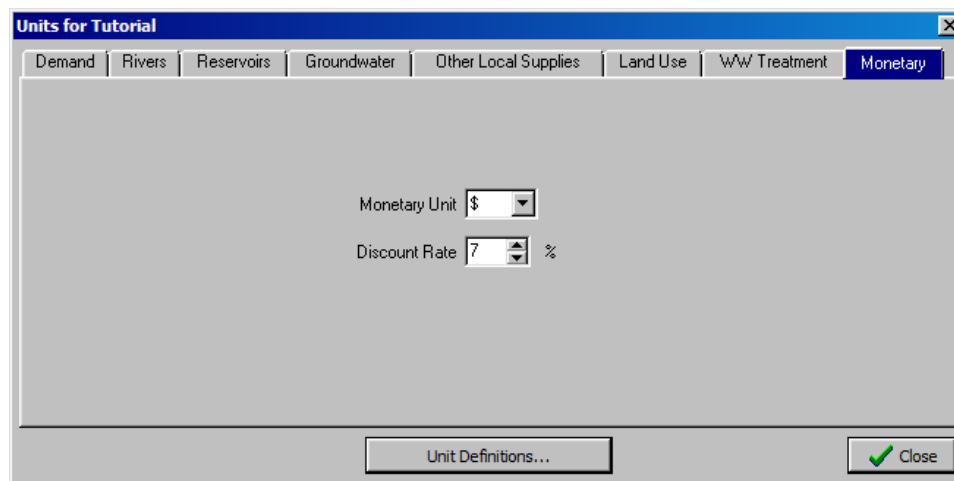
WEAP models three types of costs: Capital Costs, Fixed Operation & Maintenance (O&M) Costs, and Variable O&M Costs. It also models three types of benefits: fixed benefits, variable benefits and electricity revenues. Costs and Benefits can be assigned to any object (e.g., a demand site, river reach, groundwater node, reservoir or hydropower plant).

*For more information on Cost and Benefits, refer to the “Entering Item Cost and Benefits” topic in Help.*

### 6. Setting the Discount Rate

In the “General”, “Units” menu, select the “Monetary” tab and enter the Discount Rate.

*Discount Rate      7%*



The Discount Rate is used to compute net present value and accrue monetary quantities over time. It is different from the interest rate, which must be entered manually for each loan payment computation.



One needs to decide upfront whether the analysis will be done in real or in nominal dollars (with or without considering inflation) since this will have an effect on the discount rate, interest rates and cost & benefit growth.

Determining the Discount Rate is an important matter in economic analyses. Guidelines exist that are based on different methods such as the Weighted Average Cost of Capital (WACC) or Capital Asset Pricing Model (CAP-M). The US government currently recommends a discount rate of 7% for public sector projects (including inflation).

## 7. Changing the Modeling Duration

Cost modeling makes sense mainly if a long time period is being considered. Extend the time period being simulated in WEAP by opening the “General”, “Years and Time Steps” dialog box. Change the “Last Year of Scenarios” variable:

*Last Year of Scenarios*      2025

#	Title	Abbrev.	Length	Begins	Ends
1	January	Jan	31	Jan 1	Jan 31
2	February	Feb	28	Feb 1	Feb 28
3	March	Mar	31	Mar 1	Mar 31
4	April	Apr	30	Apr 1	Apr 30
5	May	May	31	May 1	May 31
6	June	Jun	30	Jun 1	Jun 30
7	July	Jul	31	Jul 1	Jul 31
8	August	Aug	31	Aug 1	Aug 31
9	September	Sep	30	Sep 1	Sep 30
10	October	Oct	31	Oct 1	Oct 31
11	November	Nov	30	Nov 1	Nov 30



Changing the “Last Year of Scenarios” will not affect the “Current Accounts”, the base year for all scenarios. It will only affect all the scenarios, including the “Reference” scenario. For more details about WEAP and scenarios, refer to the “Scenarios” module of the tutorial.

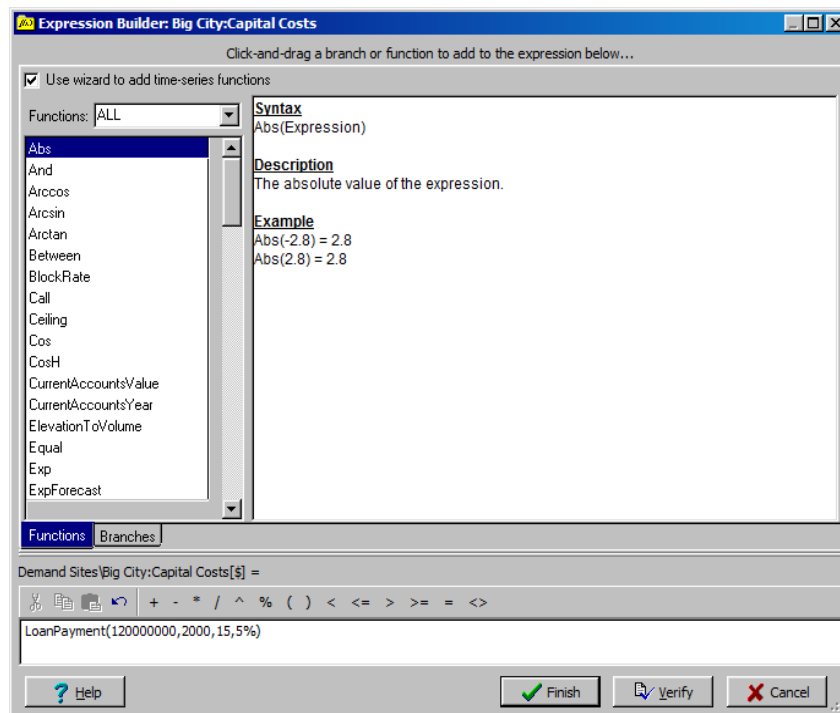
# Modeling Cost

## 8. Enter Demand Site Cost Data

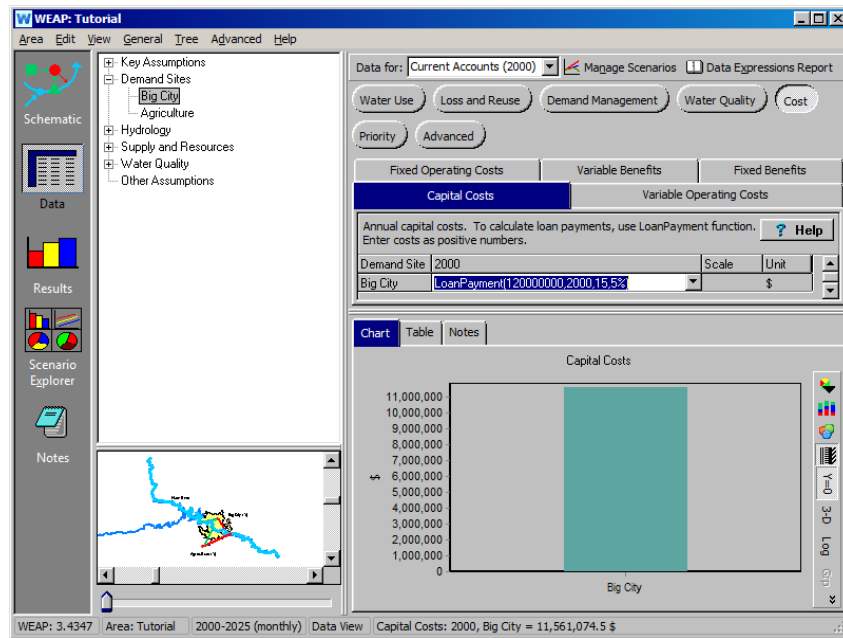
For the Big City demand site, enter the following data (in Current Accounts) in the “Demand Sites” branch of the data tree in the Data view. Click on the “Cost” button and enter under the “Capital Costs” tab:

*Capital Costs* *a loan of 120M\$, occurring in 2000, payback period 15 years, interest rate 5%*

*Use the Expression Builder to select the built-in function “LoanPayment”; pull this function into the expression window and type in the parameters 120000000, 2000, 15, 5% within the parentheses. The expression should look like: “LoanPayment(120000000,2000,15, 5%)”*

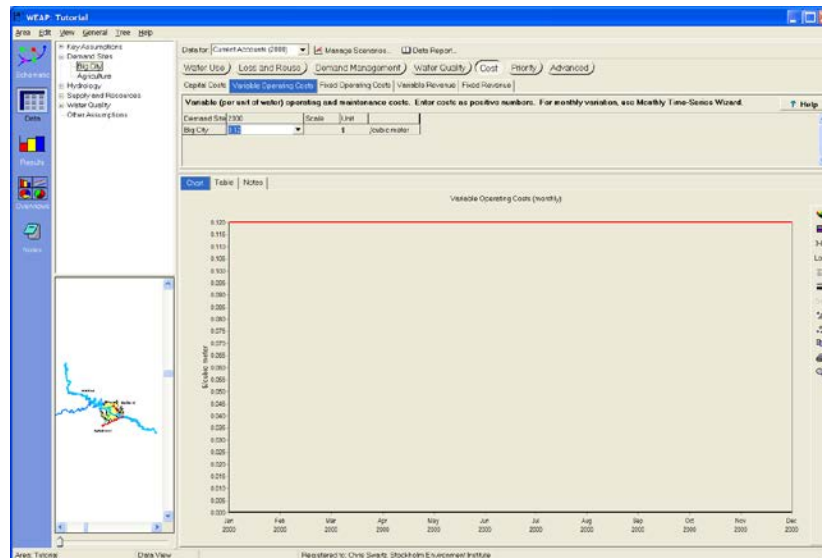






*Variable Operating Costs*

$0.12\$/m^3$

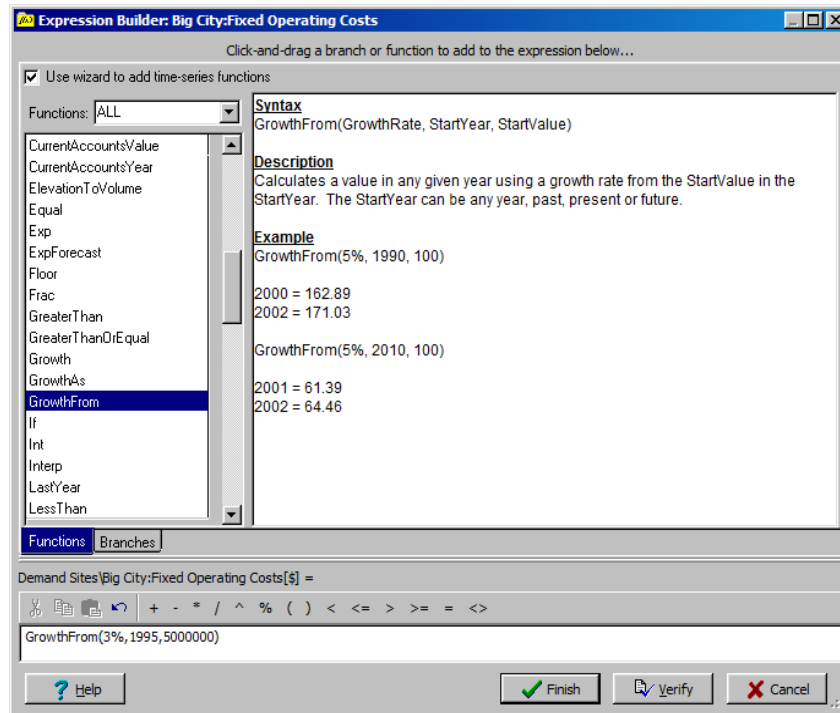


*Fixed Operating Costs*

*a yearly value of 5M\$, growing at a 3% rate starting in 1995*

*Use the Expression Builder again, selecting the built-in function "GrowthFrom"*

and entering the corresponding parameters in the parentheses. The formula should read: “GrowthFrom(3%,1995,5000000)”

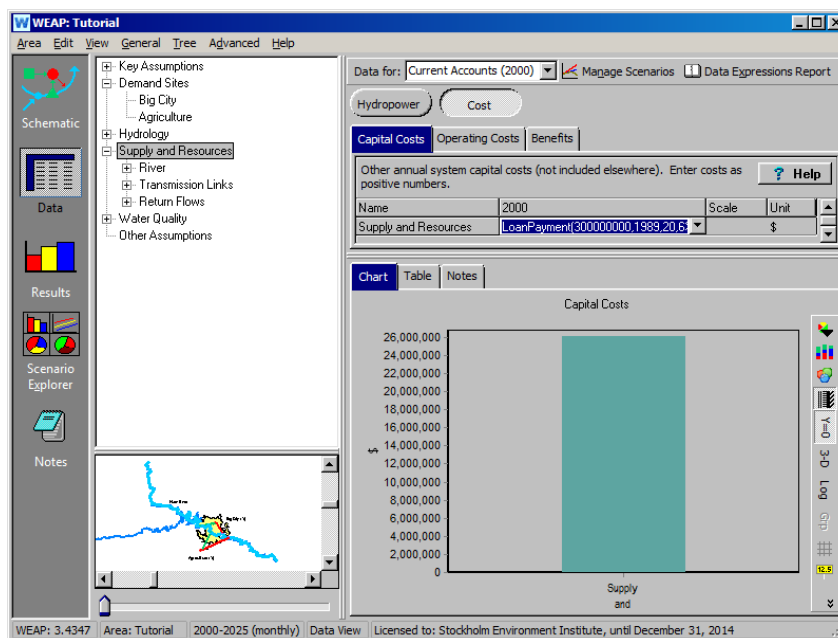


## 9. Enter System-Wide Cost Data

We'll assume that there was a loan made in years earlier than the Current Account (base) year which is still being paid back. We'll assign this cost to the entire system, rather than to a specific object. Enter the following data in the “Supply and Resources” branch of the data tree in the Data view.

*Capital Costs*                      *a loan of 300M\$, occurring in 1989, payback period 20 years, interest rate 6%*

*Again, use the Expression Builder and the “LoanPayment” function. The formula should read “LoanPayment(300000000,1989,20,6%)”*



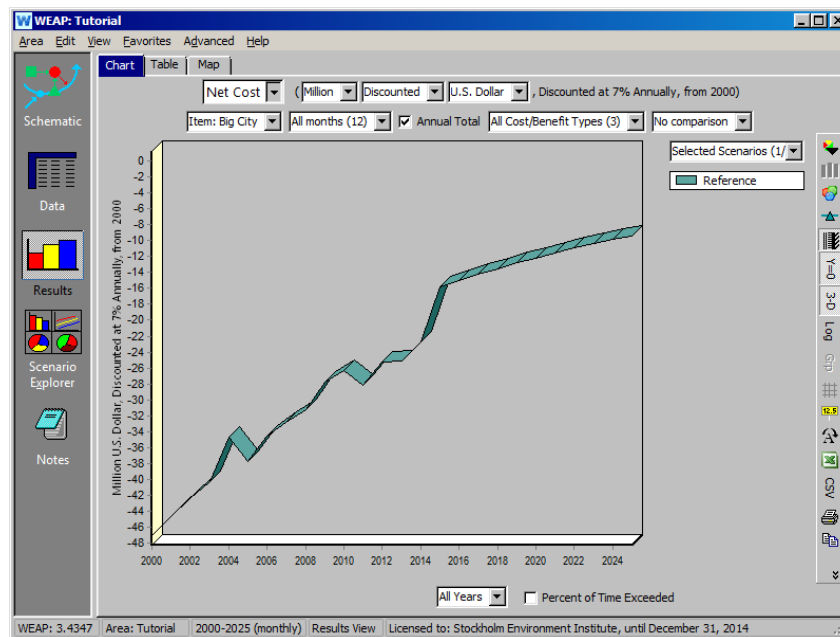
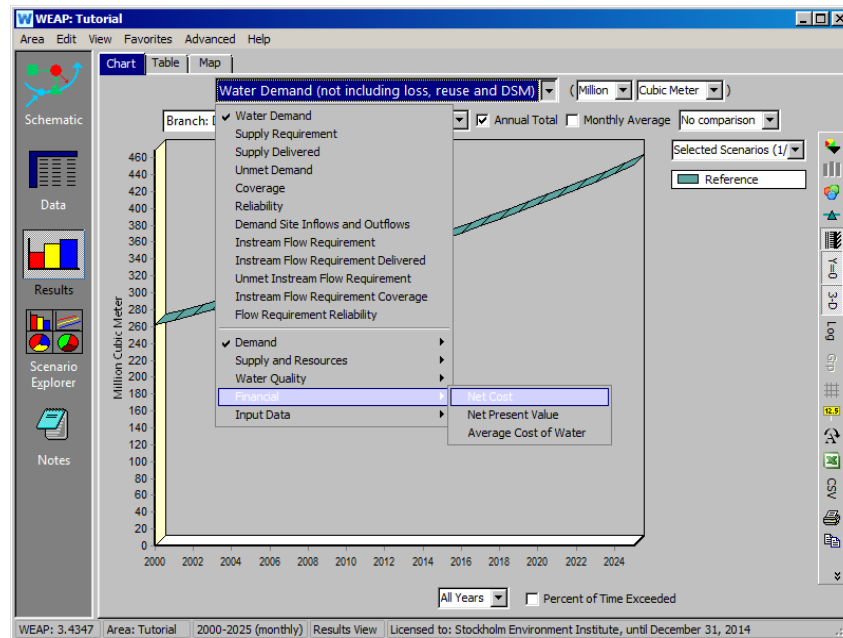
## 10. Evaluate Results

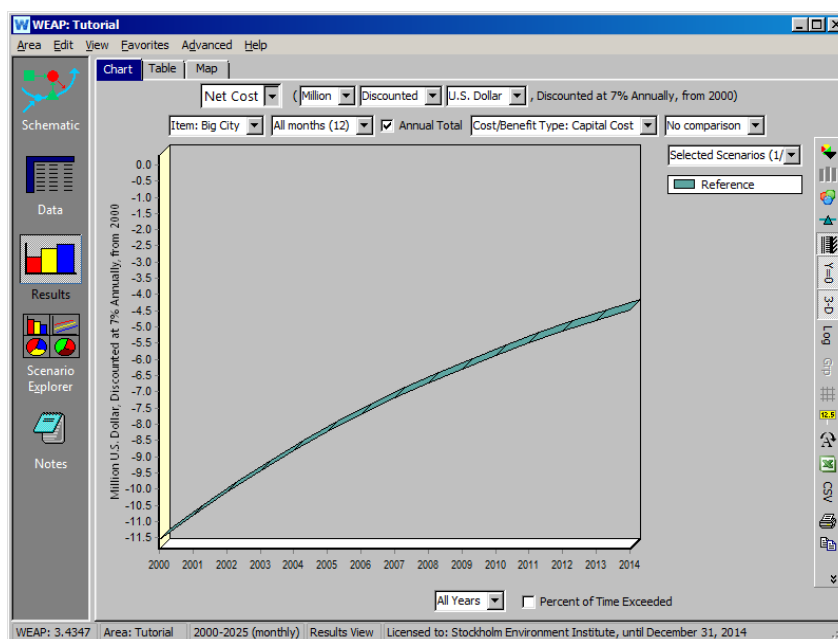
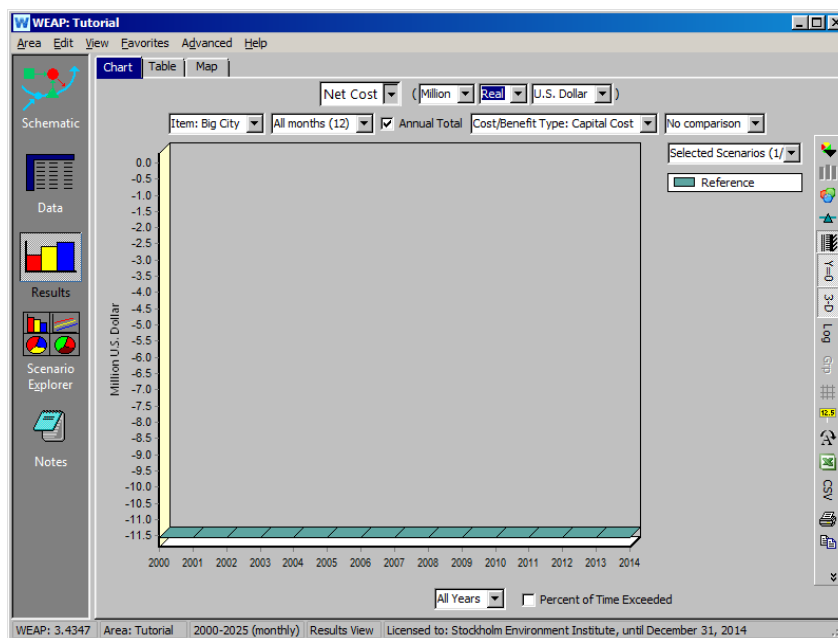
Run the model and look at the following results:

*Financial/Net Cost:*

*What is the difference between real and discounted dollar values for the Big City?*

*Select “Financial\Net Cost” from the primary variable pull-down menu and choose Big City from the list of items in the menu to the upper left of the chart. Select “Capital Cost” from the upper right menu. Make sure the “Reference” scenario is selected from the menu above the chart legend. Toggle between the “Real” and “Discounted” options using the menu just to the left of the unit menu (set at U.S. dollars).*



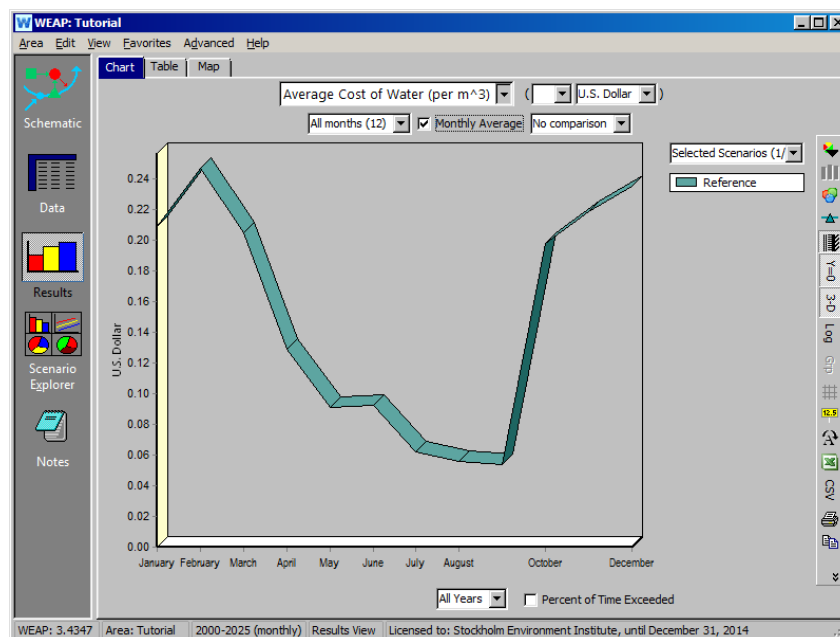
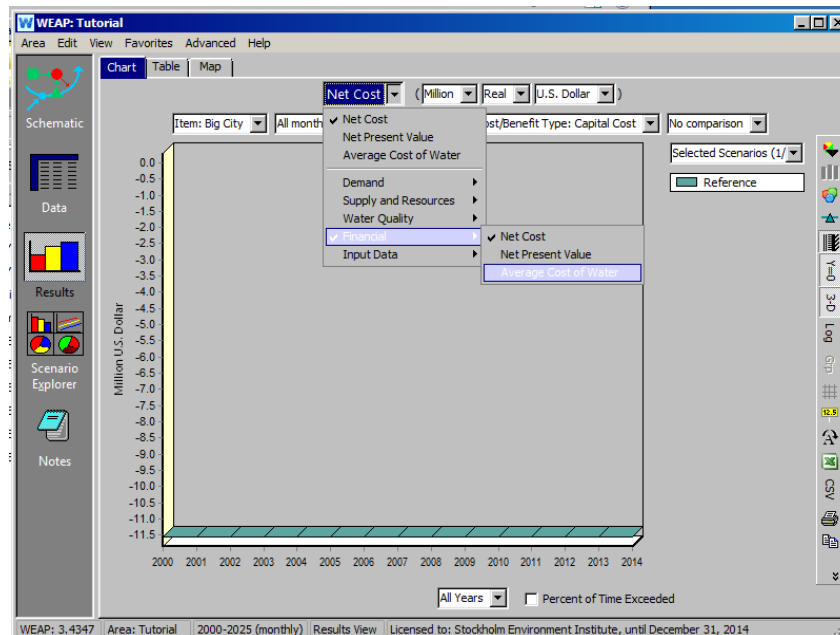


While real dollar are actual dollar values, discounted dollar values have been brought back to their present value using the discount rate. The further in the future the cost occurs, the lower its present value.

### *Average Cost of Water*

*What makes the cost vary on a monthly basis? On an annual basis?*

Select “Financial\Average Cost of Water” from the primary variable pull-down menu. Keep the “Reference” scenario selected and click on “Monthly Average.” You should have a chart like the one below:



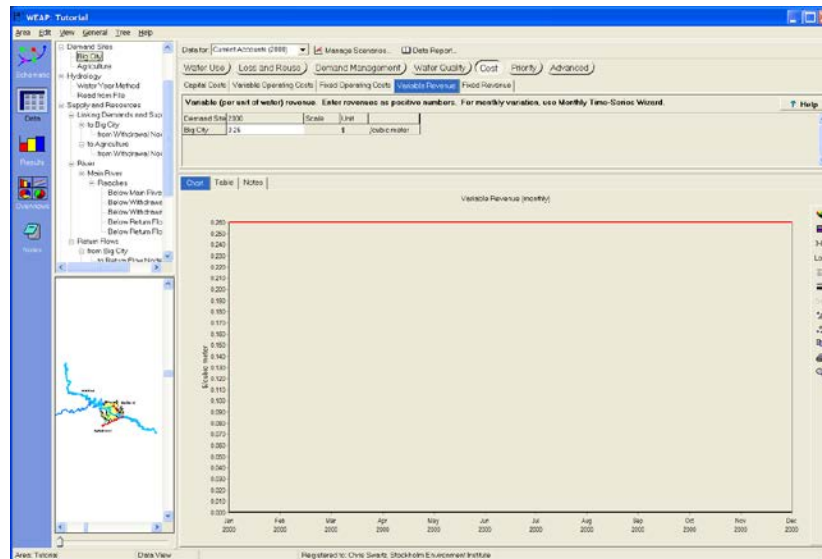
Monthly variations in average cost of water occur because of the largely varying consumption of water (especially in the Agriculture area), while fixed costs remain constant. Annual variations are mainly driven by changes in the capital costs (loans are paid back, new loans occur).

# Modeling Benefits

## 11. Enter Demand Site Benefit

In the “Cost” screen of the Big City Demand Site (Data View), enter the following data, which could, for example, correspond to the price water is sold for.

*Variable Benefit*  $0.26\$/m^3$



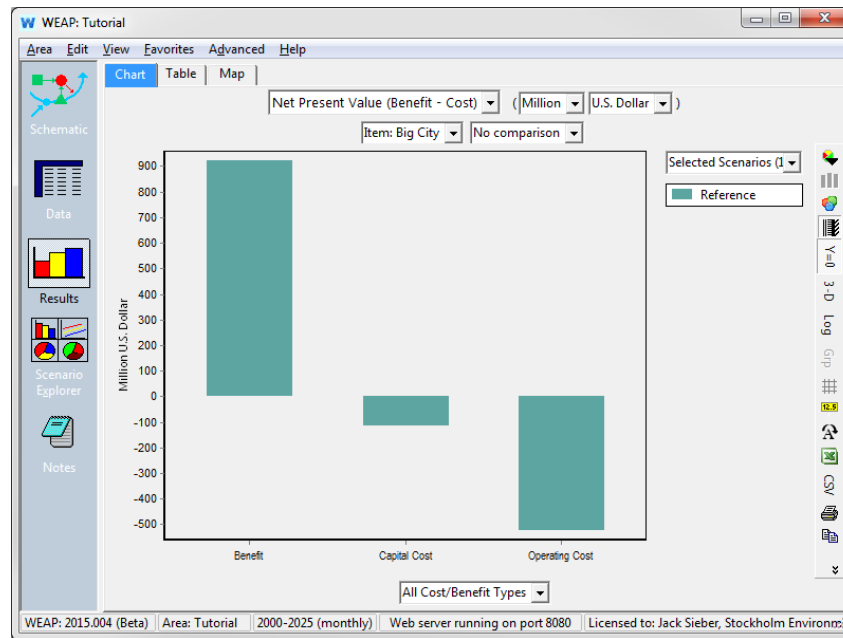
When modeling hydropower reservoirs (refer to the “Reservoir and Hydropower” WEAP tutorial module), one can also enter revenues from electricity generation. The related data-entry tab exists only when pertinent.

## 12. Compare Net Present Cost and Benefit

Display the Net Present Value of the project.

*How do the Net Present Value of the Costs compare to the Net Present Value of the Benefits?*

*In Results View, select “Financial\Net Present Value” from the primary variable pull-down menu, and choose Big City as the item for viewing. You should have a chart like the one below:*



*What does that comparison tell you?*



The Net Present Value of the costs can be compared to that of the benefit to obtain a sense of the economic viability of the system. If the NPV of the costs exceeds the NPV of the benefits, then the system is returning a lower profit than average projects (as defined by the discount rate). If the NPV of the benefits exceed that of the costs, then the systems is generating a profit higher than average projects.



---

# WEAP

Water Evaluation And Planning System

# Linking WEAP to MODFLOW

## ***A TUTORIAL ON***

<i>Linking to MODFLOW .....</i>	<i>230</i>
<i>Running MODFLOW and Viewing Results .....</i>	<i>240</i>
<i>Scenario: Increased Population.....</i>	<i>242</i>
<i>Scenario: Irrigation.....</i>	<i>244</i>
<i>Scenario: Artificial Recharge .....</i>	<i>250</i>

**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 'Linking WEAP to MODFLOW module'.”

## Linking to MODFLOW

### 1. Using MODFLOW for Groundwater Modeling in WEAP

For situations where the built-in WEAP groundwater model is not sufficiently complex, there is the option to link a WEAP model to a MODFLOW model. MODFLOW is a three-dimensional finite-difference groundwater model created by the U.S. Geological Survey (USGS). When properly linked, data and results flow back and forth between WEAP and MODFLOW for each calculation timestep. With this tight coupling between the models, it is possible to study how changes in local groundwater levels affect the overall system (e.g., groundwater-stream interactions, pumping problems due to drawdown, lateral groundwater recharge) and vice versa (e.g., infiltration and abstraction). However, be advised that building and calibrating a MODFLOW model is not a simple task. The version of MODFLOW that WEAP is designed to link to is MODFLOW 2000.



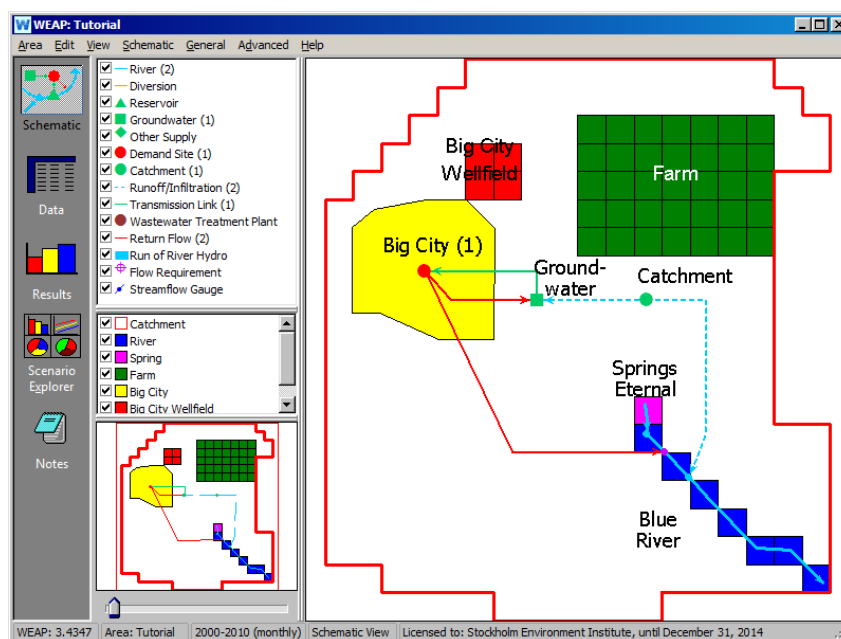
This module is not an introduction to MODFLOW, which requires specialized knowledge, but if you are already using MODFLOW, you should be able to link your MODFLOW model to WEAP after this module. Considerable work is required outside of WEAP to calibrate and prepare a MODFLOW model. Refer to the MODFLOW 2000 website for more information: <http://water.usgs.gov/nrp/gwsoftware/modflow2000/modflow2000.html>.

The groundwater models in MODFLOW and WEAP are very different. Whereas a WEAP groundwater node is represented as one large "bucket" with no parameters to describe internal flows, MODFLOW represents groundwater as a multilayered grid of independent cells, each with their own flow parameters and equations that are used to model flows between cells, and across the aquifer boundaries.

Once you have WEAP and MODFLOW models linked, WEAP values for groundwater infiltration (recharge) and abstraction (pumping), river stage, and surface water runoff will be sent to MODFLOW as inputs for its calculations, and MODFLOW results for groundwater level (head), lateral flow between aquifers, and surface water-groundwater flows will come back to WEAP as inputs for its calculations. This feedback between WEAP and MODFLOW happens at each calculation timestep.

## 2. Example WEAP model

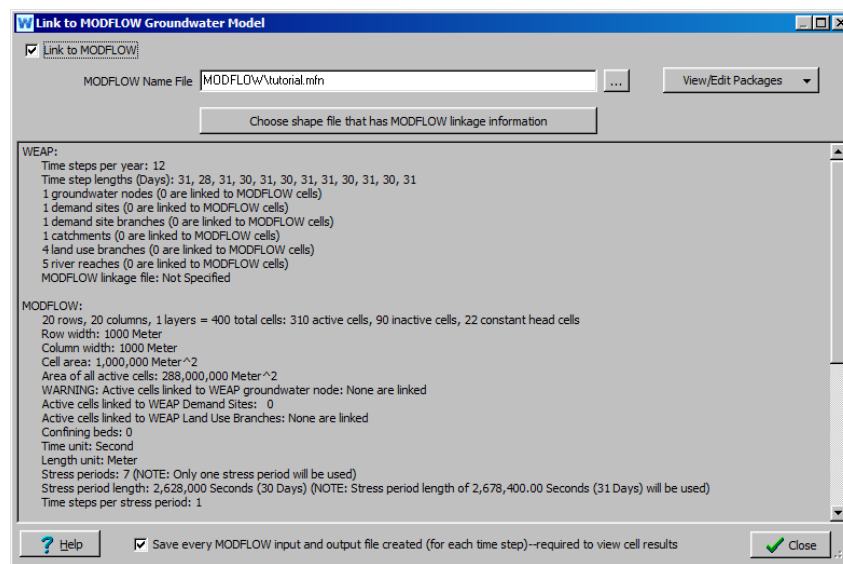
The sample area used for this module differs from those in previous modules. It includes a city whose supply comes entirely from groundwater, rainfed agriculture, a spring-fed river that receives surface runoff from the catchment and is hydraulically connected to groundwater. The catchment includes forests and grassland, in addition to agriculture and the city.



Note that because WEAP does not spatially disaggregate catchments or groundwater nodes, the one catchment node in this example represents the entire area inside the red outline without any information about where in the catchment the various land classes are. The one groundwater node represents the entire aquifer, which extends over the same area as the catchment, and does not include information about where the well field for the city is (the red squares labeled Big City Wellfield). (For your own applications, you are free to create multiple catchments and groundwater nodes, and link them to different groups of MODFLOW cells.)

### 3. Loading a MODFLOW model

To load a MODFLOW model, go to “Advanced\ MODFLOW Link (Groundwater Flow)” on the Main menu. Check the "Link to MODFLOW" checkbox and then type in or browse for the "MODFLOW Name File." Typically the "Name" file has an extension of .NAM or .MFN. For this example, all the MODFLOW files are contained in a subdirectory named MODFLOW underneath the Tutorial area subdirectory. (Keeping the MODFLOW files in a subdirectory of the WEAP area is a good practice.) The name file for this example is called **tutorial.mfn**. After you have specified the name file, WEAP will read in the MODFLOW model and display information about it.



The name file lists the other files that contain data for the various aspects of the MODFLOW model, such as recharge, pumping and river interactions. These files are called "packages." Take a look at some of the packages for this model—click on the "View/Edit Packages" button to and choose "MODFLOW Name File: tutorial.mfn." You will see the list of files/packages. Click the cancel button to close the name file and look at another package, such as the "MODFLOW Discretization file: tutorial.dis." The discretization file contains basic information about the model, such as the number of layers, row and columns, and the width of each row and column. As you can see in the screen above, WEAP has read in this information already: 20 rows, 20 columns, 1 layer, and 1000 meters width for both rows and columns.

Note that initially WEAP does not know how to link the MODFLOW model to the WEAP model, as can be seen in the screen above, e.g.,

"WARNING: Active cells linked to WEAP groundwater node: None are linked" and "1 groundwater nodes (0 are linked to MODFLOW cells)." The next step is to make this linkage.

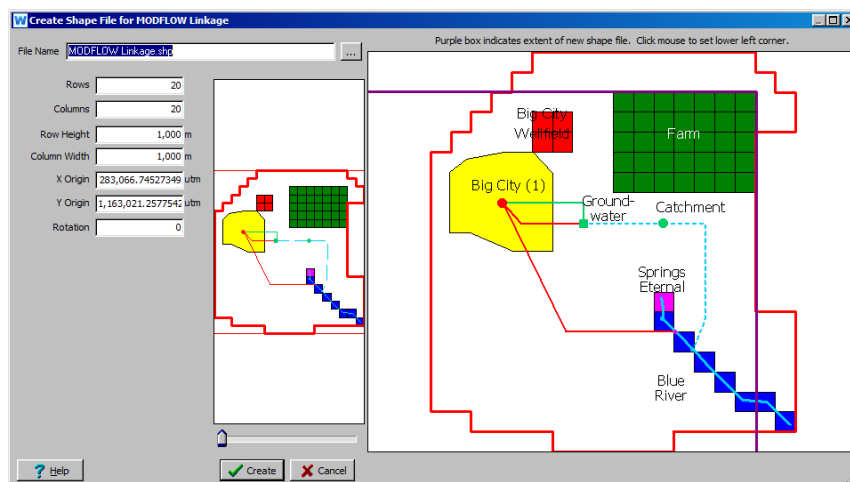
#### 4. Linking WEAP elements (groundwater nodes, demand sites, catchments, rivers) to MODFLOW cells

Each active MODFLOW cell is linked to one and only one WEAP groundwater node. (For a given row and column, every layer will be linked to the same groundwater node.) The linkage is established by a GIS shape file (.shp) that relates MODFLOW cells (by row and column number) with WEAP groundwater nodes (by name). The polygon shape file has one rectangular feature for each MODFLOW cell (row, column) and must be loaded as a background layer on the Schematic. For example, for a MODFLOW model with 20 rows, 20 columns and 3 layers, there would be 400 features in the shape file. The shape file's attribute table file (.dbf) must have fields for row number, column number and WEAP groundwater node name. Other optional fields are described below. This shape file will also be used to display MODFLOW results in WEAP.

To create this shape file, either use a GIS program such as ArcGIS, or WEAP's built-in tool that can create a shape file corresponding to a MODFLOW model as explained in the following section.

#### 5. Creating a new linkage shape file

On the Link to MODFLOW Groundwater Model screen (shown above), click the "Choose shape file that has MODFLOW linkage information" button. On the next window, for "Background Shape File with MODFLOW Linkage Information" choose "< Create New Shape File >" The following window will appear:



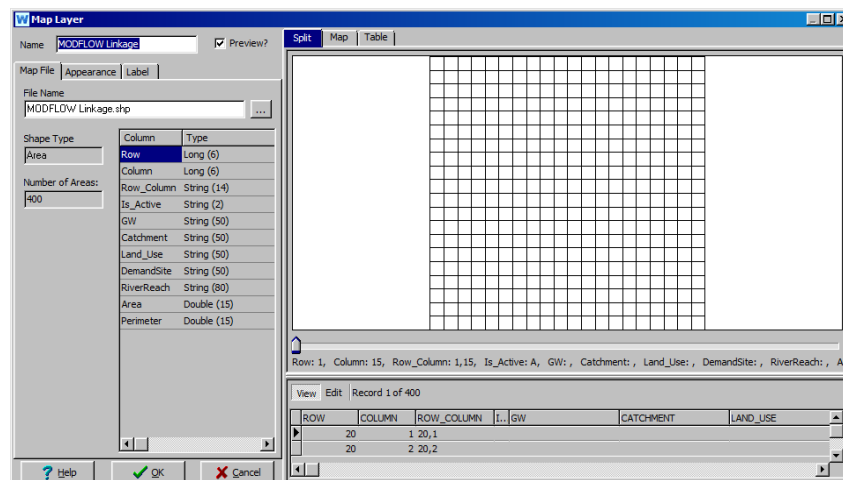
WEAP automatically fills in the number of rows and columns, and the row height and column width, which it read from the MODFLOW discretization file. However, the MODFLOW model does not contain information about the X,Y position (latitude and longitude) or the rotation angle of the cells. Therefore, you will need to enter this information yourself.

If you know the values for latitude, longitude and rotation, you can enter the numbers directly. If you do not know the values, you can click on the map to set the origin (lower left corner). You will see a purple box on the map that indicates the area of all the cells. As long as you hold down the left mouse key, the purple box will move with the mouse in the lower left corner; release when the box is correctly positioned. You can zoom in on the map (using the zoom slider below the inset map on the left, the mouse wheel, or control-click and drag on the map) to help achieve greater precision in placement of the area.

The **File Name** box contains the filename for the new shape file. Either use the default filename ("MODFLOW Linkage.shp") or enter another name. For now, enter "MODFLOW Created Linkage.shp" as the name. Shape files always have a .shp extension.

Click the **Create** button to create it.

After the shape file has been created, WEAP will display it and allow you to customize its appearance on the schematic. As you can see from the screen below, the new shape file is a 20x20 grid of 400 cells.



The associated attribute table has fields for row, column, and for linking various WEAP elements to each cell—GW, Catchment, Land\_Use, DemandSite and RiverReach. Your table will need to be filled in, specifying which cells are linked to which WEAP elements. For example, the name of

the WEAP groundwater node (in the Tutorial, the node is named "Groundwater") must be entered in the table in the column labeled GW for each cell that corresponds to the WEAP groundwater node. For example, in row 1, columns 6 through 17 correspond to the WEAP groundwater node, so the table should have "Groundwater" in table column GW for those cells.

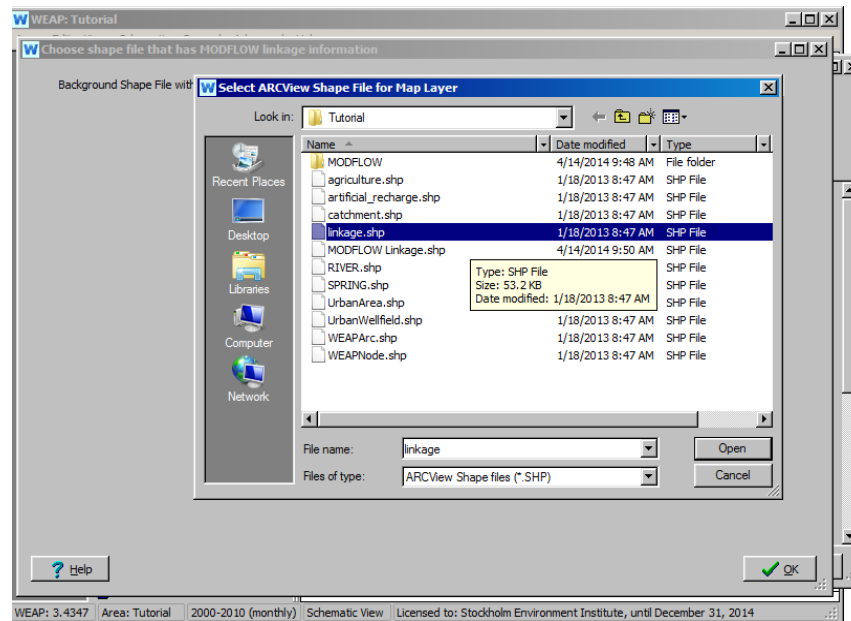
Although you do not need to do it for this tutorial, you may edit this table in several different ways. To edit inside WEAP, click the **Edit** button above the lower right table and type the values directly into the table. You can also edit the table in Microsoft Excel (the attribute table has the extension .dbf, e.g., MODFLOW Linkage.dbf, make sure WEAP is not open when you edit the attribute table file in Excel) or in any GIS program, such as ArcGIS. If you do have access to GIS software, this will be the easiest way to edit the table, but it can be done in WEAP. (WEAP can also attempt to guess which MODFLOW cells the WEAP groundwater nodes, demand sites and river reaches are linked to, based on proximity on the Schematic. (This is described more below.)

After customizing its appearance, click the **OK** button. WEAP will add this layer to your Schematic and return you to the "Choose shape file that has MODFLOW linkage information" window.

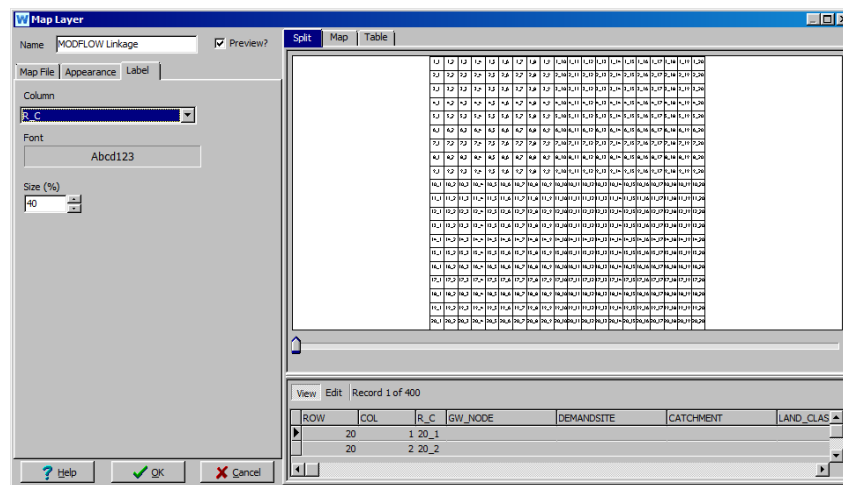
## 6. Use an existing shape file

Rather than spending the time now to fill in all the information in the attribute table, we will use an existing shape file with all this information already filled in. On the "Choose shape file that has MODFLOW linkage information" window, select "< Add existing shape file as new map layer >" for the "Background Shape File with MODFLOW Linkage Information." A dialog box will appear, asking you to select the

ArcView Shape File to use. Choose "Linkage.shp" (in the Tutorial directory) and click Open.



On the "Map Layer" screen, change the name to "MODFLOW Linkage." On the "Label" tab, choose "R\_C" for the Field and set the Size to 40%.



Click OK. Now we need to specify which of the fields in the Linkage attribute table will be used for the linkage, and to which MODFLOW and WEAP items they correspond. The required fields are MODFLOW Cell Row, MODFLOW Cell Column and Groundwater Name. Depending on your model, you may or may not also match some or all of the following: Catchment Name, Land Use Name, Demand Site Name and River Reach Name. Based on the attribute file column names, WEAP will try to guess which fields are used for what. For example, if it finds fields containing the



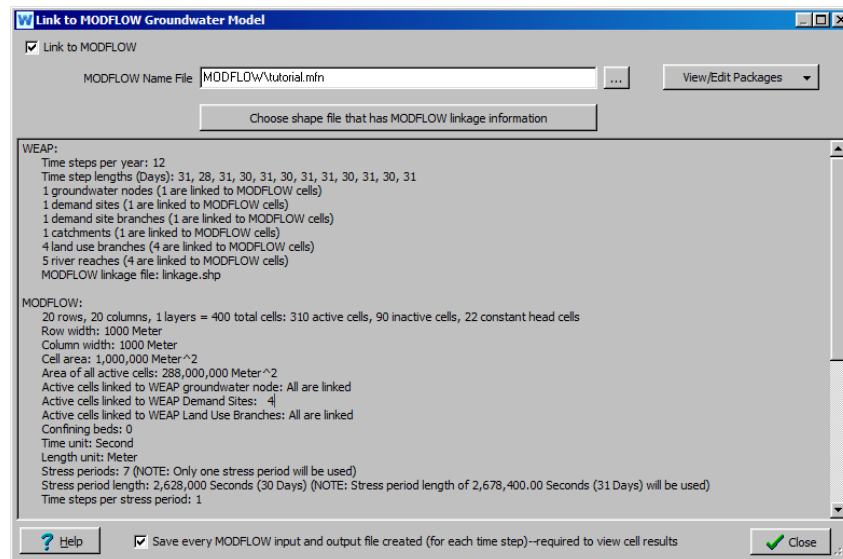
names "Row" and "Col", it will assume these contain the MODFLOW row and column values. In this example, WEAP is able to correctly guess all the fields:

ROW	COL	R_C	GW_NODE	DEMANDSITE	CATCHMENT	LAND_CLASS	DRAIN	RIVERREACH
20	1	20_1						
20	2	20_2						
20	3	20_3						
20	4	20_4						
20	5	20_5						
20	6	20_6						
20	7	20_7						
20	8	20_8						
20	9	20_9	groundwater		catchment	Forest		
20	10	20_10	groundwater		catchment	Forest		
20	11	20_11	groundwater		catchment	Forest		
20	12	20_12	groundwater		catchment	Forest		

If it didn't correctly guess, you would select the appropriate field for each item (e.g., Groundwater Name Field). WEAP can also attempt to guess which WEAP groundwater nodes, demand sites and river reaches correspond to the MODFLOW groundwater, pumping, river and drain cells, by clicking on the "Guess Groundwater Linkages" button, or the other "Guess" buttons. Click OK to close this window.

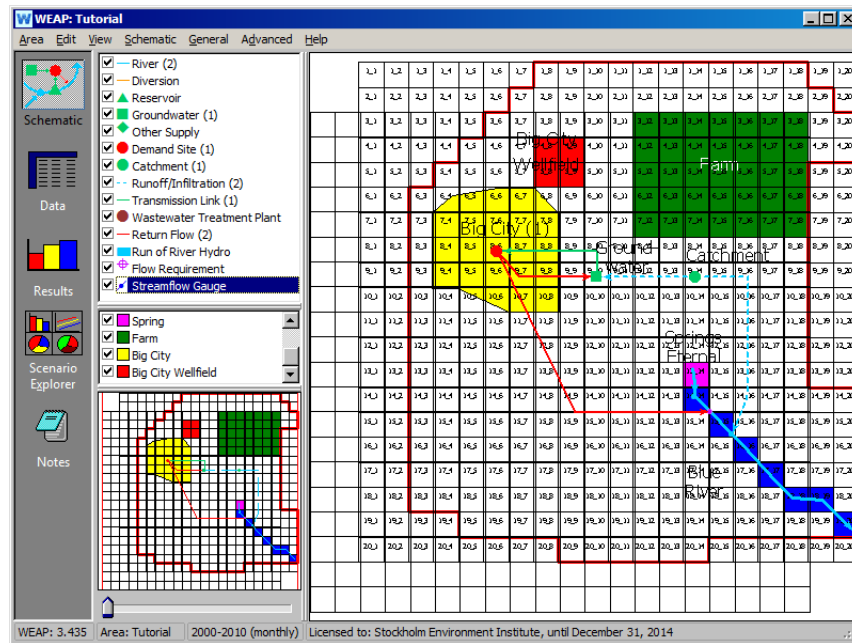
Note that WEAP now reports the linkage shape file and how many of the WEAP and MODFLOW items are linked together, e.g., "1 groundwater nodes (1 are linked to MODFLOW cells)" and "Active cells linked to

WEAP groundwater node: All are linked." Click Close to return to the WEAP Schematic.



The layers "MODFLOW Linkage" and "MODFLOW Created Linkage" are now in the list of background layers, ordered at the top. Note that WEAP can only link to one MODFLOW layer at a time, so even though both are shown, WEAP will only extract data from the layer specified in the "Choose Shape File that has MODFLOW Linkage Information" window (In Advanced/MODFLOW Link(Groundwater Flow)/Choose Shape file that has MODFLOW linkage button). In this case, WEAP is linked to linkage.shp, which is displayed in WEAP as MODFLOW Linkage.

If you want to change the order the layers in the element window, right-click on the layer name and choose "Move Down."

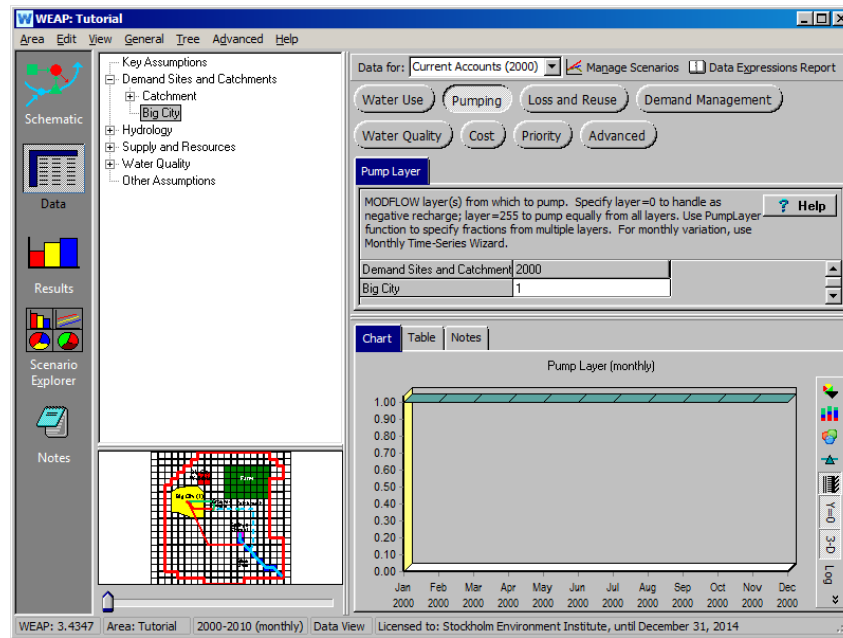


Take a moment now to view the other information contained in this linkage file. Right click on the name "MODFLOW linkage," choose "Set label to" and choose one of the other fields, such as "LAND\_CLASS." This will show you which of the four land classes (Grassland, City, Forest, Farm) each cell corresponds to. Choose the field "DEMANDSITE" to see from which cells the Big City demand site will pump from. Choose the field "GW\_NODE" to see which MODFLOW cells are linked to the WEAP groundwater node named "Groundwater." Finally, choose the field "RIVERREACH" to see which cells are linked to the WEAP river "Blue River."

## 7. Set Pump Layer

One final step to link the WEAP model to the MODFLOW model is to specify from which MODFLOW layer the Big City demand site will pump. In general, a demand site or catchment node can pump from a single layer, from many layers (in equal or different proportions), or have pumping be handled as negative recharge in the MODFLOW recharge file.

Our MODFLOW Linkage has only one data layer (which you can verify by going to Advanced/ MODFLOW Link (Groundwater Flow) to where it says "MODFLOW" and then lists the numbers of rows, columns and layers). Because there is only one layer, the pumping choices are from layer 1, or as negative recharge (enter pump layer = 0 for negative recharge). We want to pump from layer 1. Go to the Data View, select "Big City" on the data tree, then click on the "Pumping" category at the top and enter "1" for the expression.



You have now linked the WEAP model to the MODFLOW model.

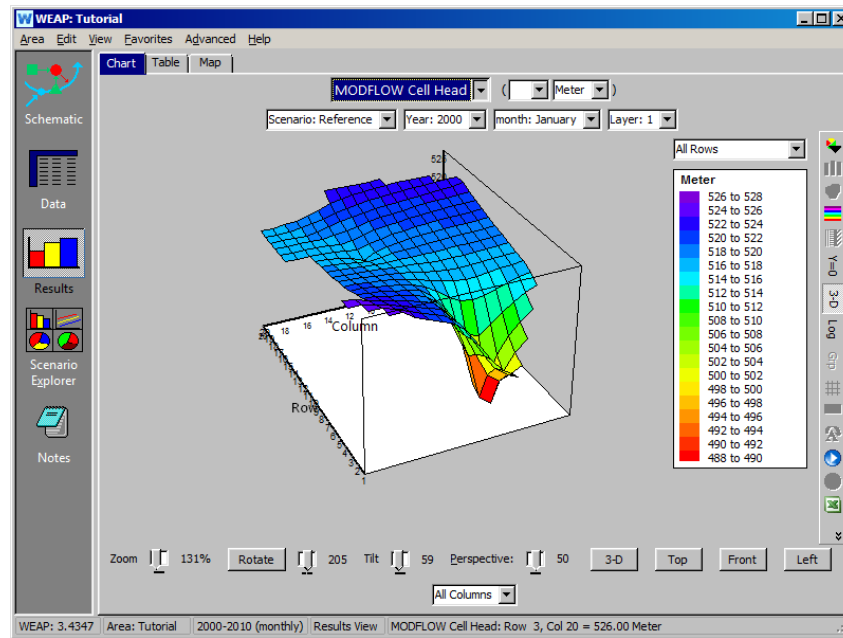
## Running MODFLOW and Viewing Results

### 8. View Results

Click the Results button to calculate and view results. Notice that at each calculation timestep, WEAP runs MODFLOW.

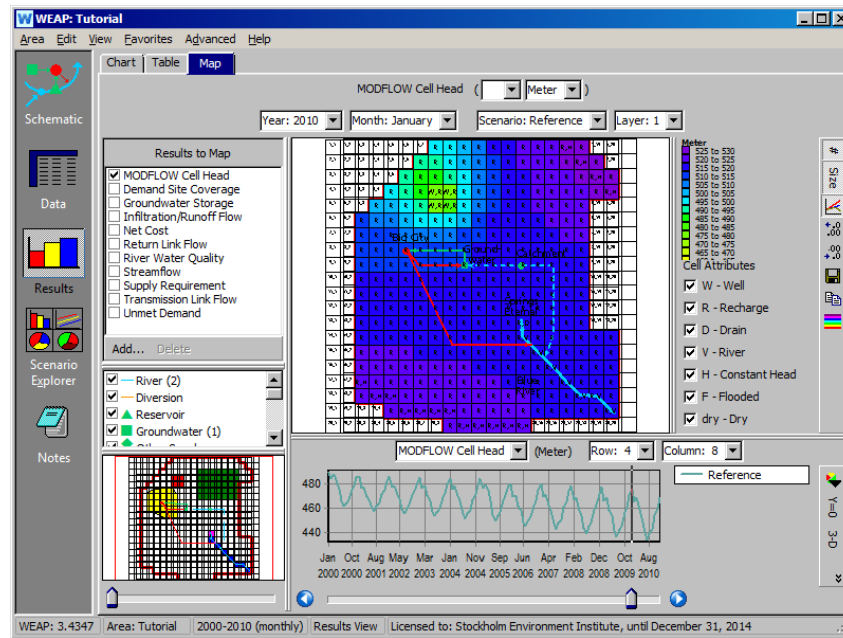
Results for MODFLOW are located in the “Supply and Resources / Groundwater / MODFLOW” category in the pull-down menu just above the chart.

Look at the results for Supply and Resources / Groundwater / MODFLOW / Cell Head. This report shows the vertical head for each MODFLOW cell. MODFLOW results utilize a 3-dimensional surface chart. Make sure that "Surface" is selected as the chart type (the first icon in the menu bar to the right of the screen), and that the "Y=0" button is not down. The cell head for one timestep is shown. Experiment with the sliders below the surface chart to rotate or tilt the surface. Click the "Rotate" button to animate the chart. Click the "3-D" button to switch between 3-D surface and 2-D plan views. You may also click on the 3-D surface and drag the mouse to rotate the view.



*Can you see the impact of pumping from the Big City Wellfield? (This view exaggerates the variation in head—click the "Y=0" button to see a more realistic view. It is usually better to turn off Y=0 in order to see the differences clearly.)*

Click on the Map tab to see the head values on the map, with a graph below. When you click on a grid cell, its value over time will be graphed below the map. Click on some of the cells at the Big City Wellfield to see how they vary. There is a seasonal fluctuation in cell head (higher in winter, lower in summer, due to increased pumping in the summer and lower rainfall in the summer), and an overall trend downward from 2000 to 2010. You can click and drag the mouse over many cells and the graph will update in real-time as you move the mouse. This is a good way to get a quick understanding of how cells in different areas of the model behave differently over time. Note that the option to turn Y=0 off is now at the bottom right menu.



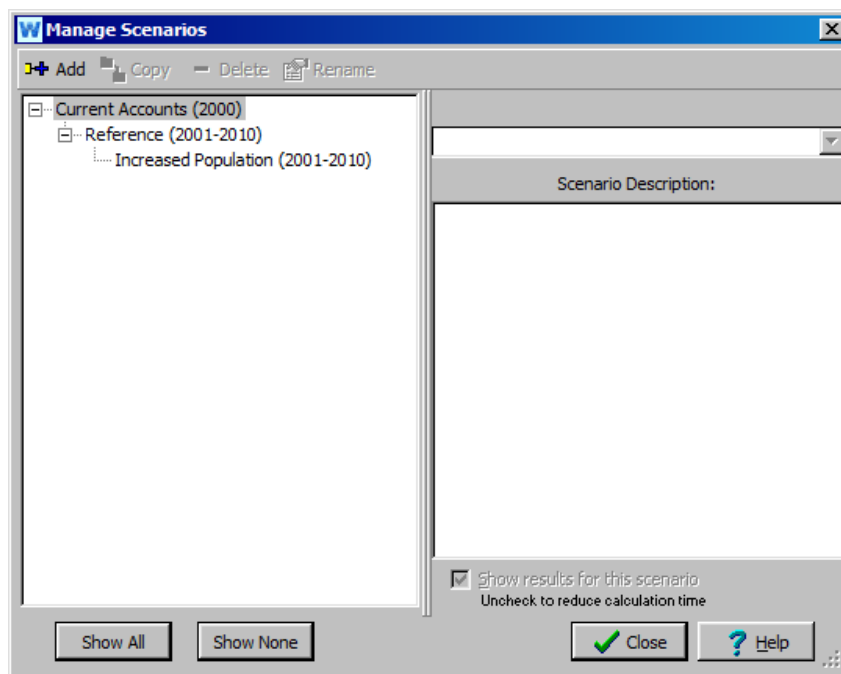
Look at a few other MODFLOW results, such as Recharge, Pumping, Drain Flow, and Leakage to River.

## Scenario: Increased Population

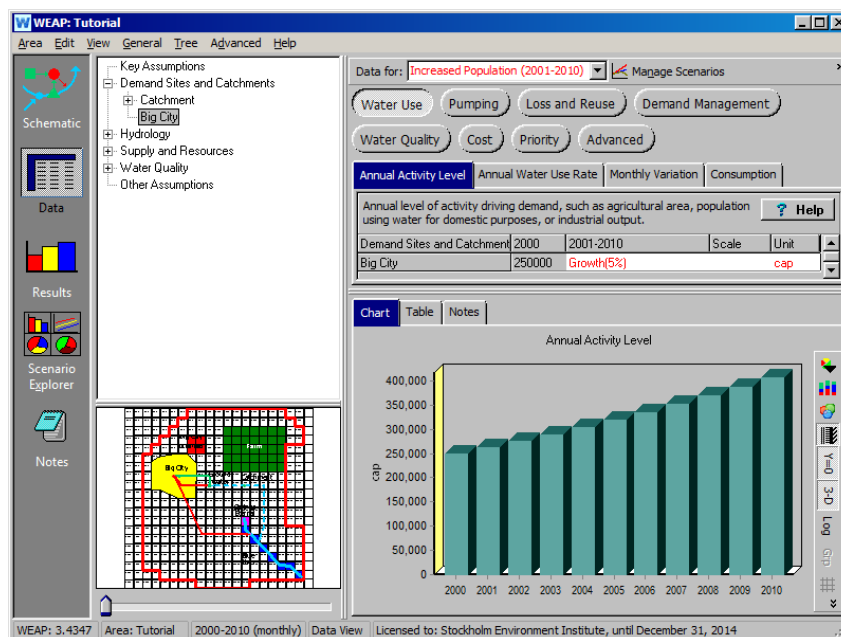
Now that we have a MODFLOW model linked to our WEAP model, we can create some WEAP scenarios and explore how they might affect groundwater.

### 9. Create scenario

Switch to the Data View and create a new scenario underneath "Reference," call it "Increased Population" (Main menu: Area, Manage Scenarios).



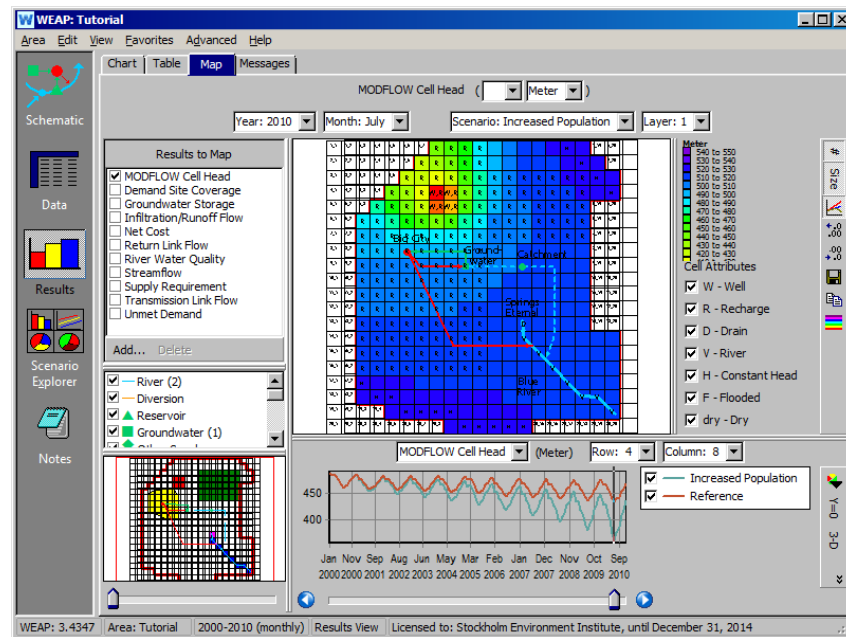
Under the Water Use tab, change the expression for the Annual Activity Level for Big City from "Growth(1%)" to "Growth(5%)."



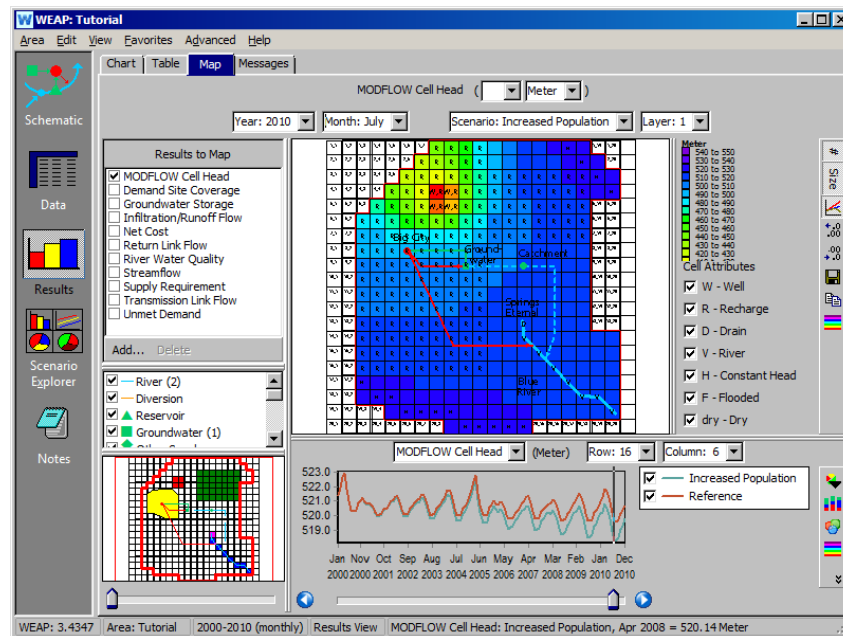
## 10. Evaluate results

Go to Results and look for the impact of the increased pumping from Big City on the groundwater levels. As you can see, the slow downward trend of the Reference scenario has now accelerated in the Increased Population

scenario. This is especially evident in the cells on or near the Big City Wellfield.



but an effect, although smaller, can even be seen far away from the wellfield, e.g., in Row 16, Column 6 (in the lower left corner of the model).

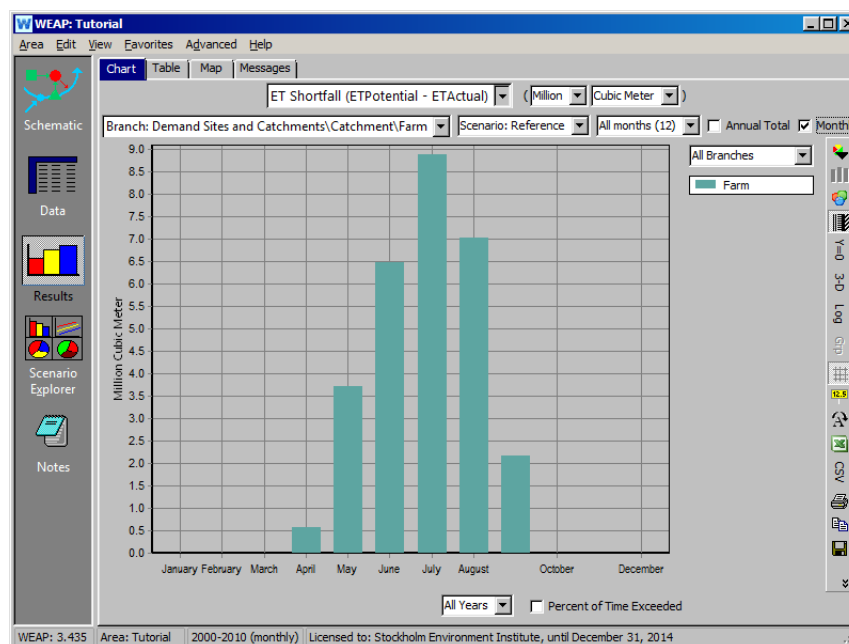


## Scenario: Irrigation

The crops on this Farm are currently rainfed, but there is not enough rainfall in the summer to meet their evapotranspirative demand. Look at



the results for Catchments / ET shortfall for the Farm branch of the catchment in the reference scenario



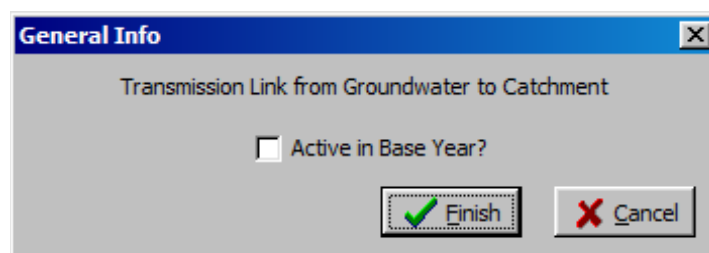
## 11. Create scenario

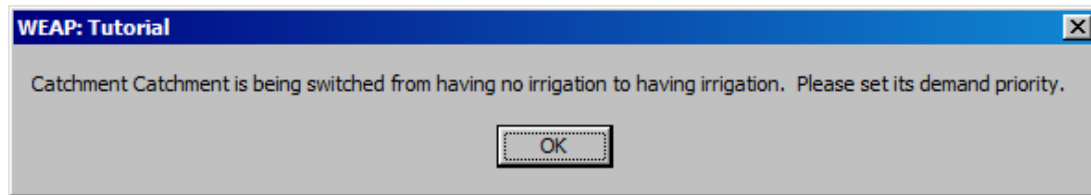
Let's investigate the impact of adding irrigation from groundwater pumping, both on the groundwater levels and on crop yields. Switch to the Schematic View and go to Areas/Manage Scenarios. Create a new scenario underneath "Reference," call it "Irrigation."

There are several steps to take to activate irrigation for the Farm land class and for the MODFLOW cells associated with the Farm.

## 12. Add transmission link

Add a transmission link from the groundwater node to the catchment, and uncheck "Active in Base Year?" When you add this link, WEAP will automatically set the catchment as having irrigation.

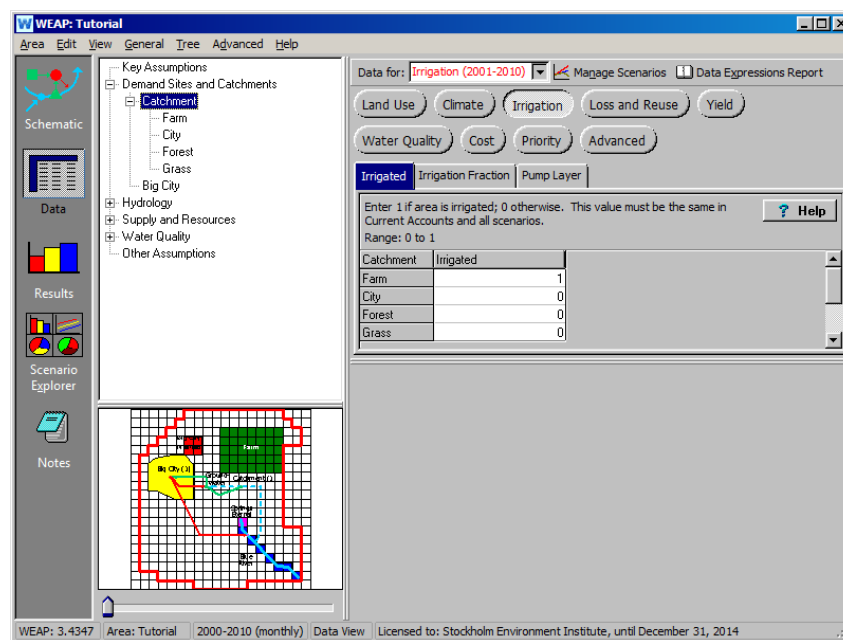




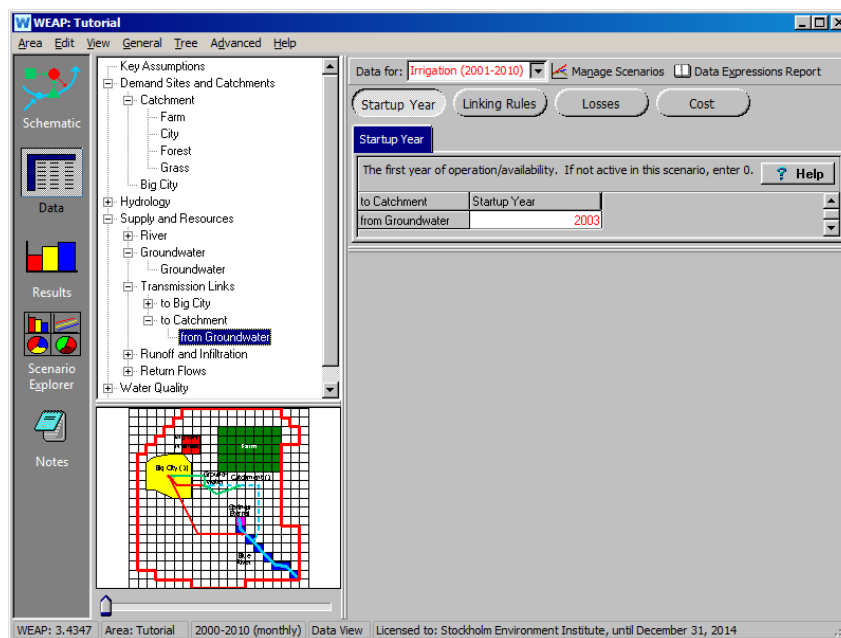
You can leave the priority as 1.

### 13. Set land class as irrigated

Go to the Data View and change "Irrigated" to 1 for the Farm, and "Irrigation Fraction" to 50 (50% irrigation efficiency). Make sure that the Irrigation scenario is selected in the "Data for" dropdown box at the top.

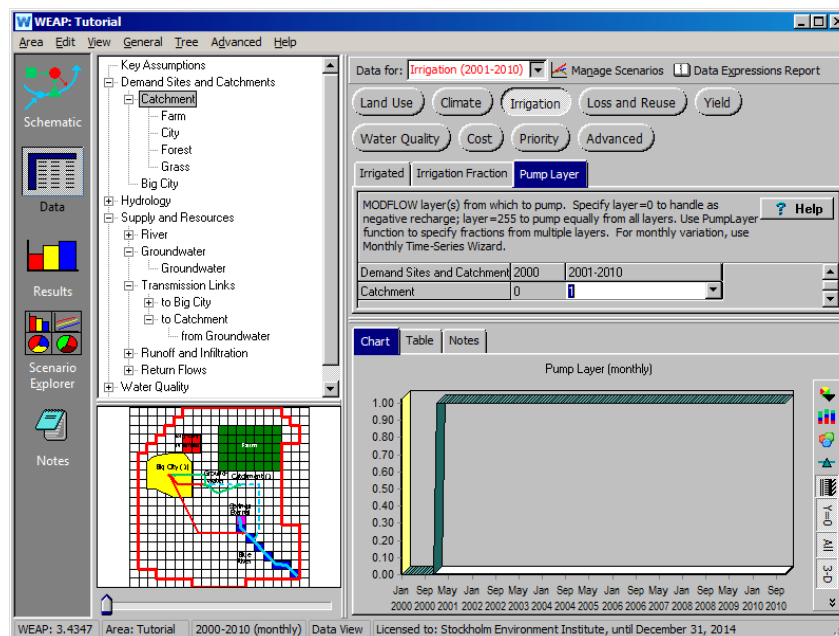


For the transmission link, set the Startup Year to 2003.



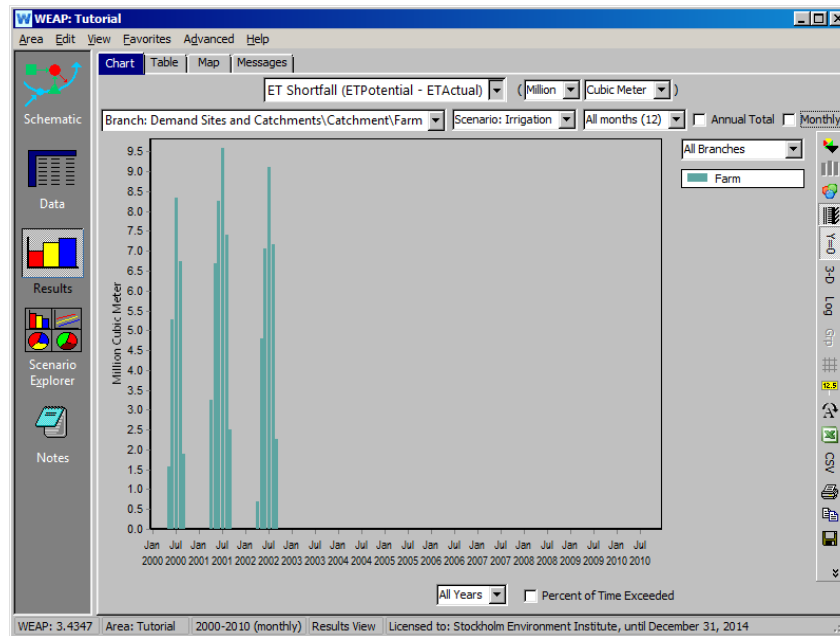
## 14. Set MODFLOW layer for irrigation

We want MODFLOW to pump the irrigation water from layer 1. Click on the "Catchment" branch in the data tree, then click on the "Irrigation" category at the top and the "Pump Layer" variable tab. Enter a value of 1.

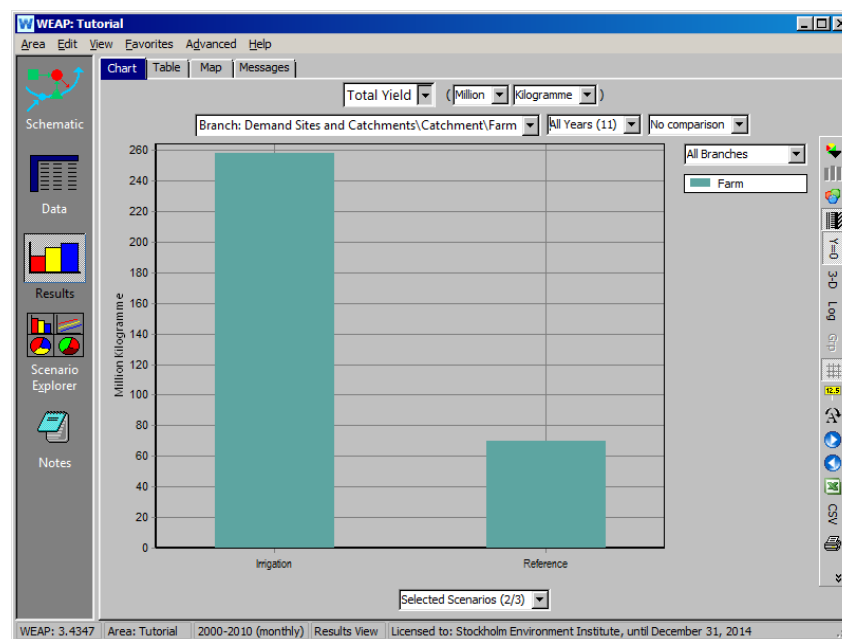


## 15. Evaluate results

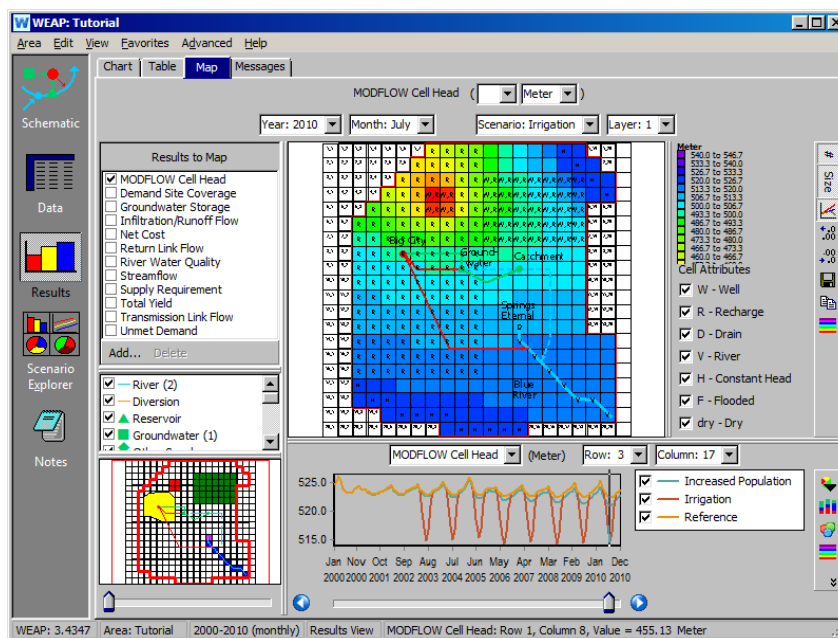
Go to the Results View. First, verify that irrigation begins in 2003, reducing the ET Shortfall to zero. (The report can be found in the Catchments category.)



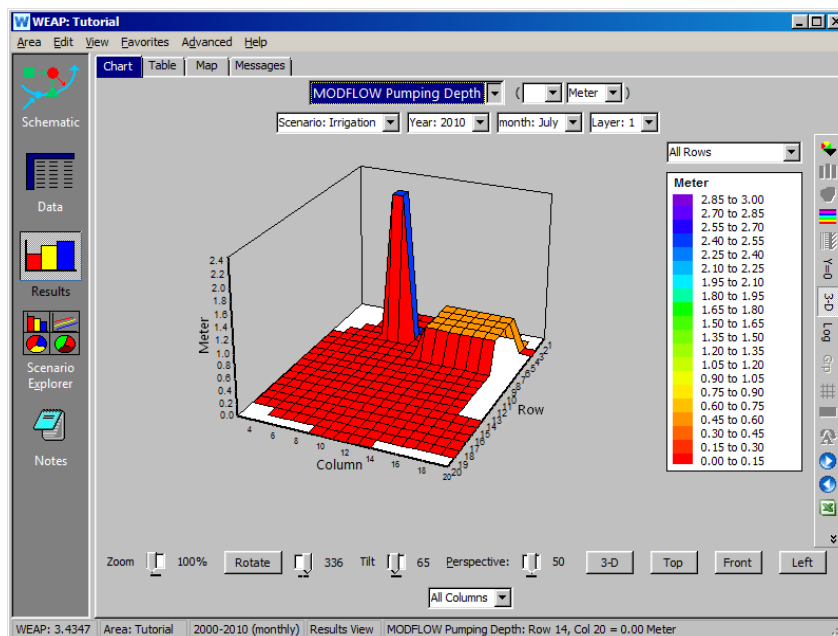
*What happens to crops yields, now that they receive all the water they need? Look at the Catchment report for yields, comparing the yield across scenarios for 2003 and later*



Now look at the impact of irrigation on groundwater. View the MODFLOW Cell Head Results on the Map tab. Click on a cell in the map in the Farm to see the largest effect, or a cell far away from the Farm to see the smaller effect.



Compare the pumping rates for the Farm and for Big City:



## Scenario: Artificial Recharge

For a final scenario, let's explore the impact of artificial recharge to groundwater.



Artificial recharge, or "Aquifer Storage and Recovery" (ASR), involves injecting water into an aquifer through wells or by surface spreading and infiltration and then pumping it out when needed. The aquifer essentially functions as a water bank. Deposits are made in times of surplus, typically during the rainy season, and withdrawals occur when available water falls short of demand.

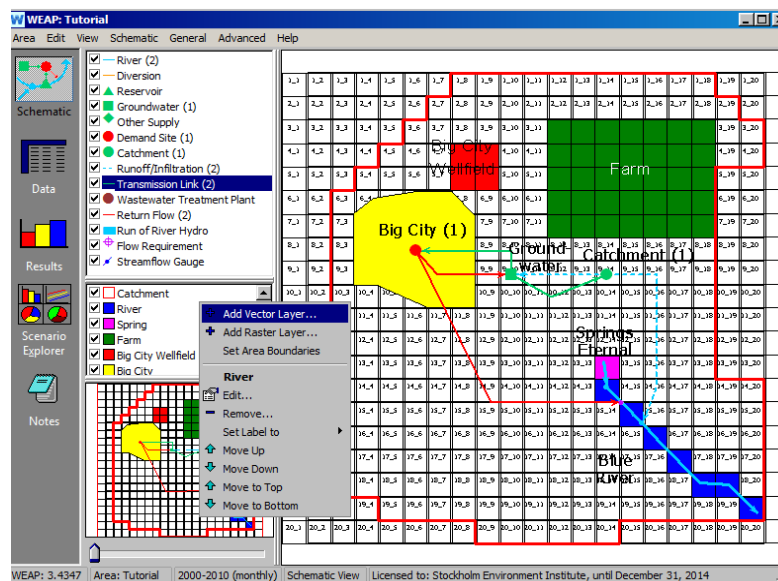
In this example, the water will come from outside the catchment area and not vary seasonally.

### 16. Create scenario

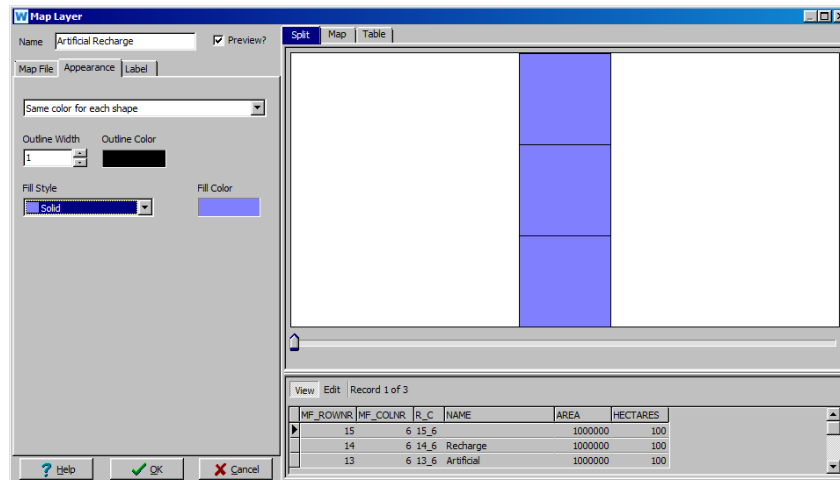
Switch to the Schematic View and create a new scenario underneath "Reference," call it "Artificial Recharge."

### 17. Load shape file layer

On the Main Menu, select Schematic, Add Vector Layer.

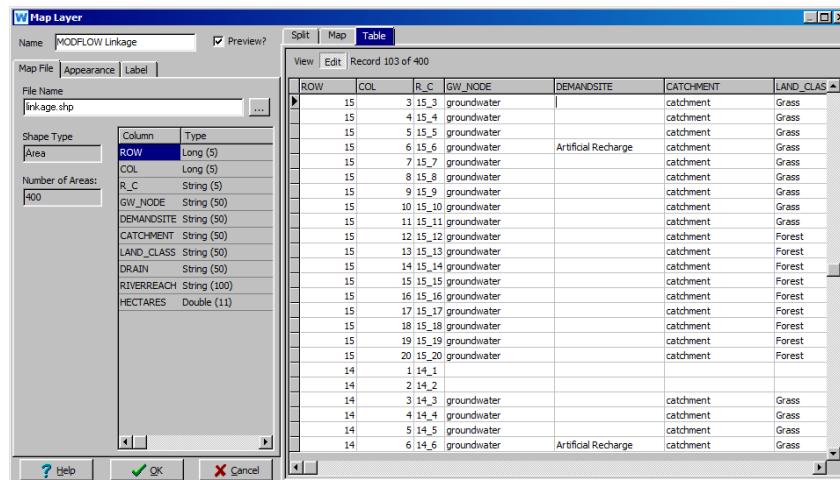


Choose the file `artificial_recharge.shp`. Give it the name "Artificial Recharge", and change its **appearance** so that the Style is "Solid" and the "Fill color" is light blue. Note that the cells are in column 6, rows 13-15.

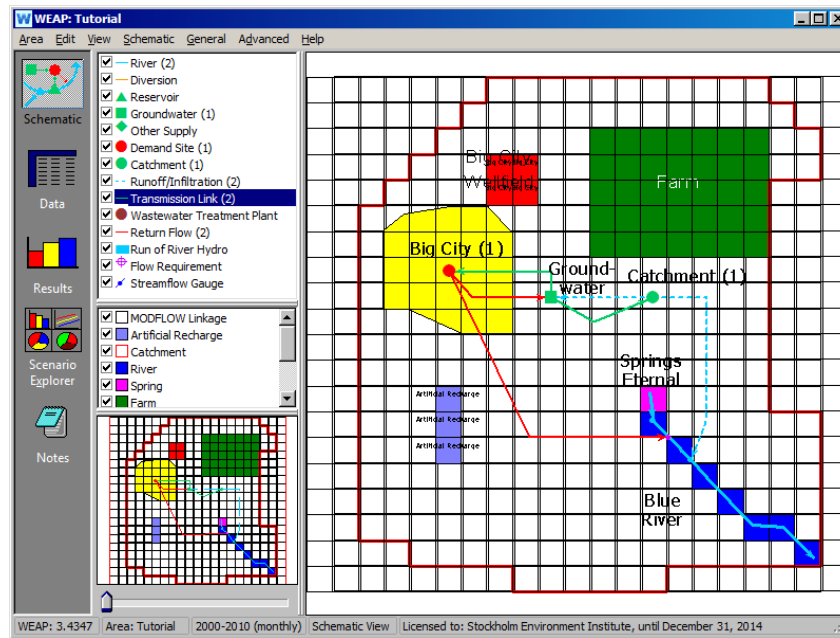


## 18. Edit linkage shape file

So that WEAP can tell MODFLOW which cells will receive the artificial recharge, we need to edit the linkage shape file. In the Schematic View, double-click on "MODFLOW Linkage", select the Table tab and click the Edit button. Scroll down to find the artificial recharge cells: column 6, rows 13, 14 and 15. For these three cells, type into the field labeled DEMANDSITE the name of the artificial recharge demand site: "Artificial Recharge."

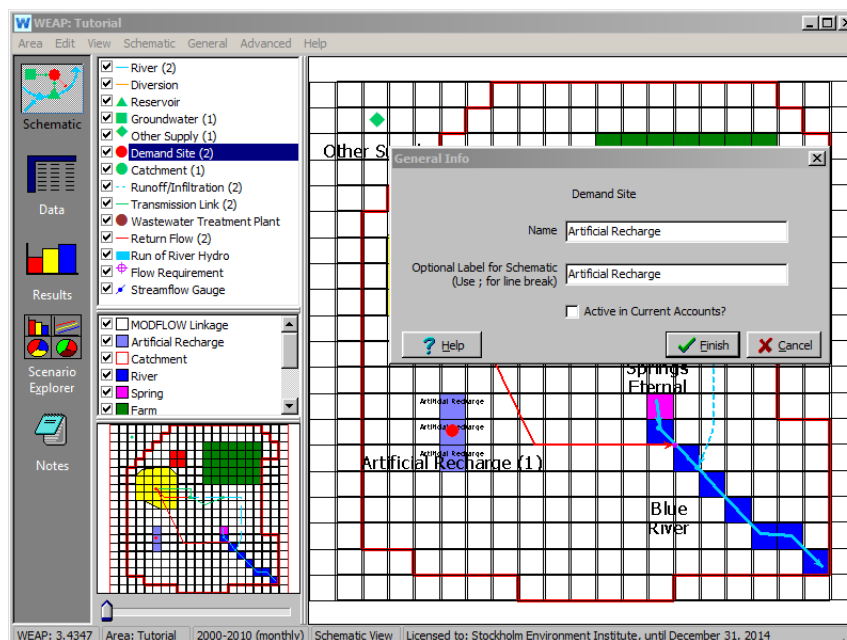


Return to the Schematic view and verify this new linkage information. Set the label for the MODFLOW Linkage layer to DEMANDSITE. You should see the artificial recharge cells labeled, as well as those for Big City Wellfield:



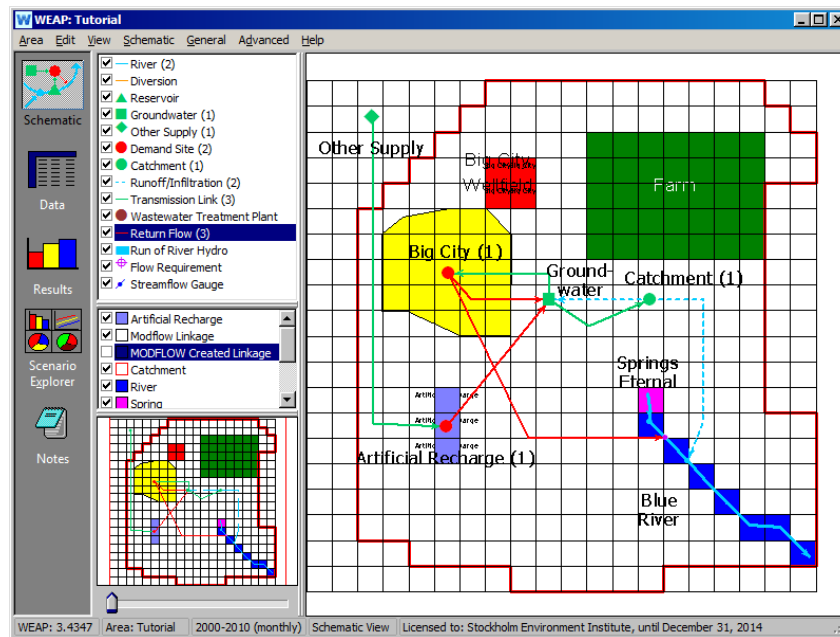
## 19. Create Other Supply and Demand Site

Create an "other supply" node called "Other Supply" in the upper right corner. Create a new demand site—place it on top of one of the blue artificial recharge cells. Call it "Artificial Recharge" and uncheck "Active in Current Accounts?"



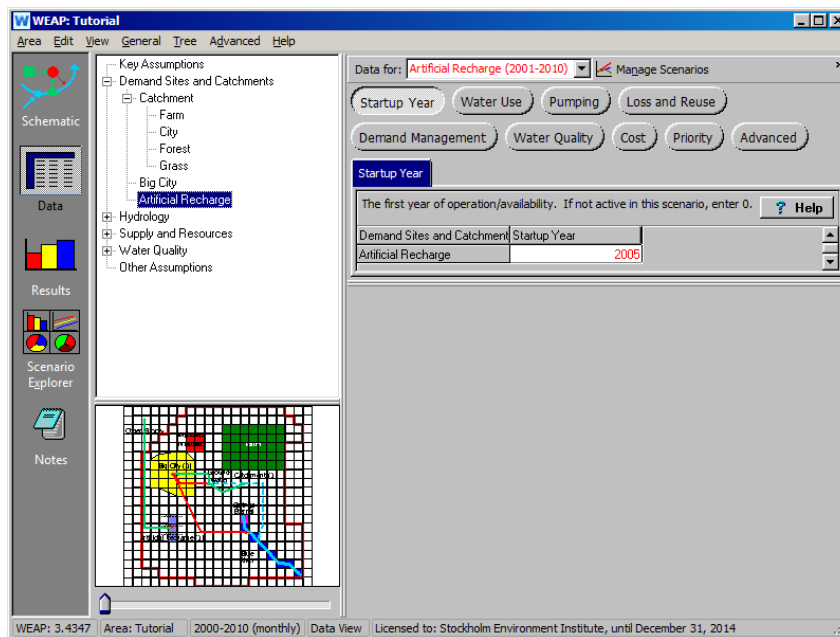


Add a transmission link from Other Supply to Artificial Recharge. Then add a Return Flow link from Artificial Recharge to the Groundwater node.

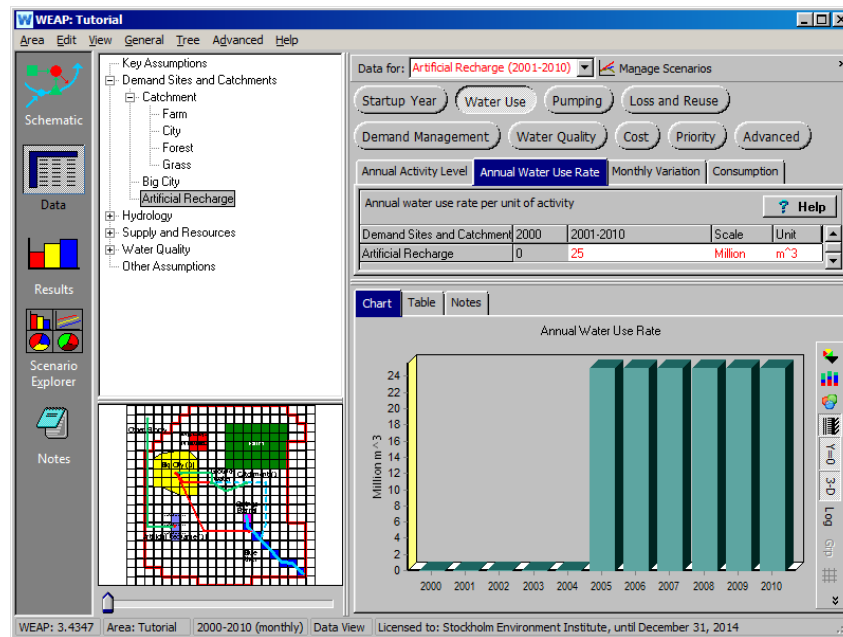


## 20. Enter supply and demand data

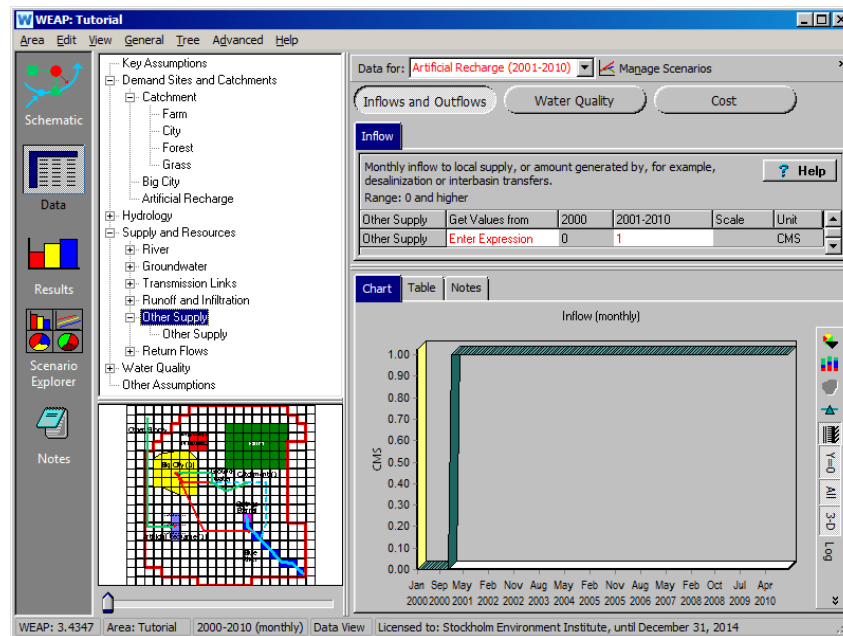
Go to the Data View, select scenario "Artificial Recharge," and then click on the branch for demand site Artificial Recharge in the tree. Set the Startup Year to 2005.



For Water Use, set the Annual Water Use Rate to 25 Million cubic meters (the annual capacity of the injection wells) and the Consumption to 0%.



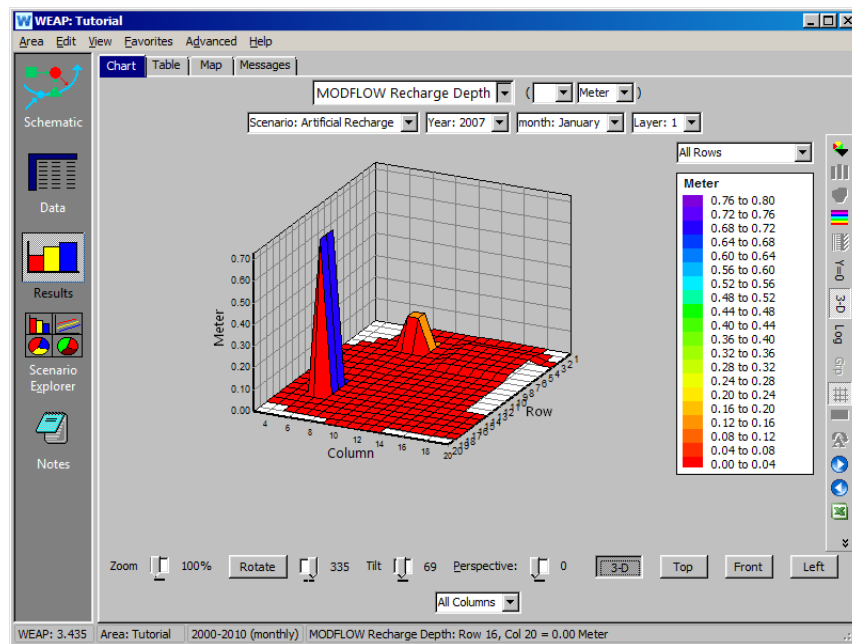
Click on the branch for the other supply, and then enter 1 CMS for the inflow.



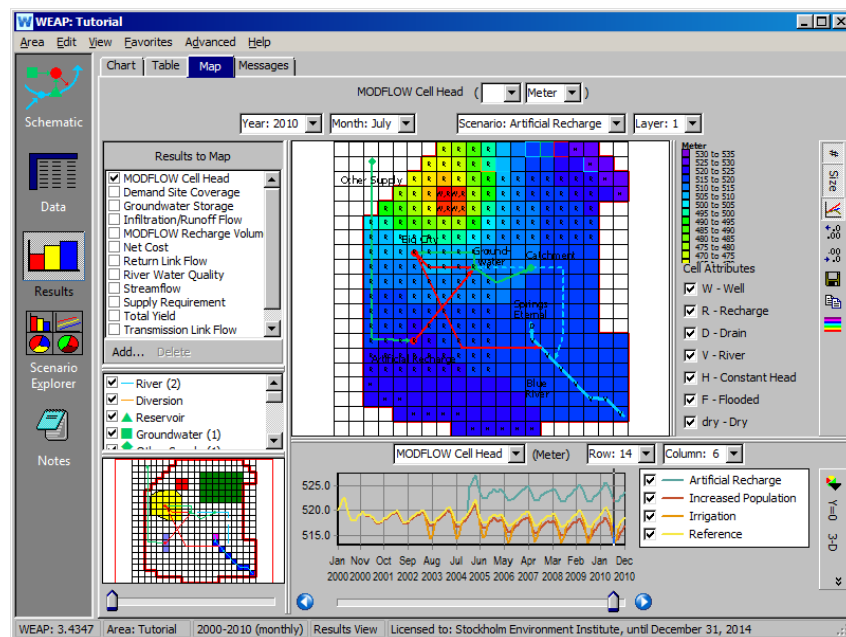
## 21. Evaluate Results

Run the model and look at results for recharge depth and cell head.

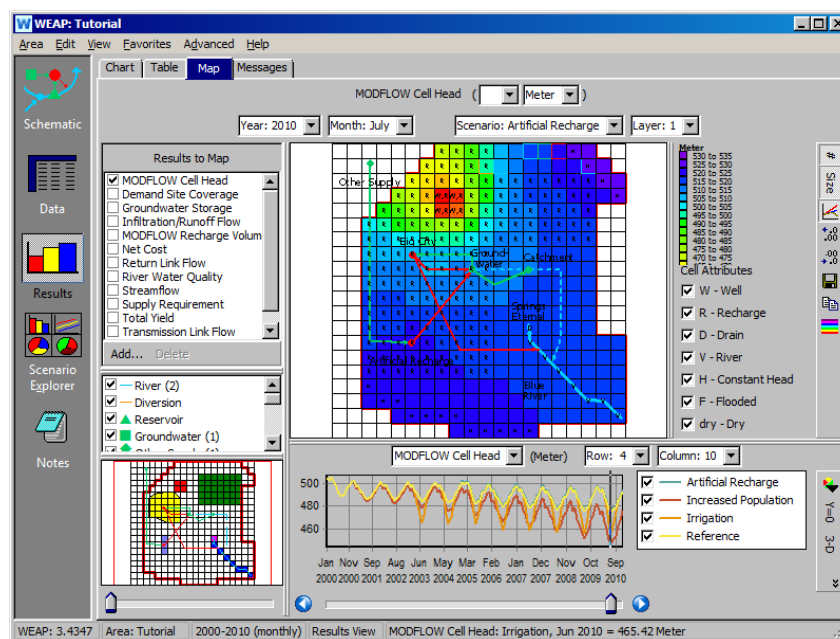
*Does the artificial recharge have much impact on groundwater levels at the recharge site? Is there much of an impact closer to the Big City Wellfield or irrigation? Can you think of another site for the artificial recharge that would better alleviate the drawdown from pumping?*



Groundwater levels at the recharge site are much higher than Reference:



Groundwater levels by the Wellfield are almost the same as in Reference:



---

# WEAP

Water Evaluation And Planning System

# Linking WEAP to LEAP

***A TUTORIAL ON***

<i>Linking WEAP and LEAP .....</i>	<i>258</i>
<i>Scenario: Hydropower Generation from WEAP .....</i>	<i>263</i>
<i>Scenario: Demand for Cooling Water from LEAP .....</i>	<i>274</i>
<i>Scenario: Electricity Demand from WEAP.....</i>	<i>280</i>

**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 'Linking WEAP to LEAP' module.”

## Linking WEAP and LEAP

### 1. Introduction to LEAP

LEAP, the Long-range Energy Alternatives Planning System, is a widely-used software tool for energy policy analysis and climate change mitigation assessment developed at the Stockholm Environment Institute.

LEAP is an integrated modeling tool that can be used to track energy consumption, production and resource extraction in all sectors of an economy. It can be used to account for both energy sector and non-energy sector greenhouse gas (GHG) emission sources and sinks. In addition to tracking GHGs, LEAP can also be used to analyze emissions of local and regional air pollutants, making it well-suited to studies of the climate co-benefits of local air pollution reduction.

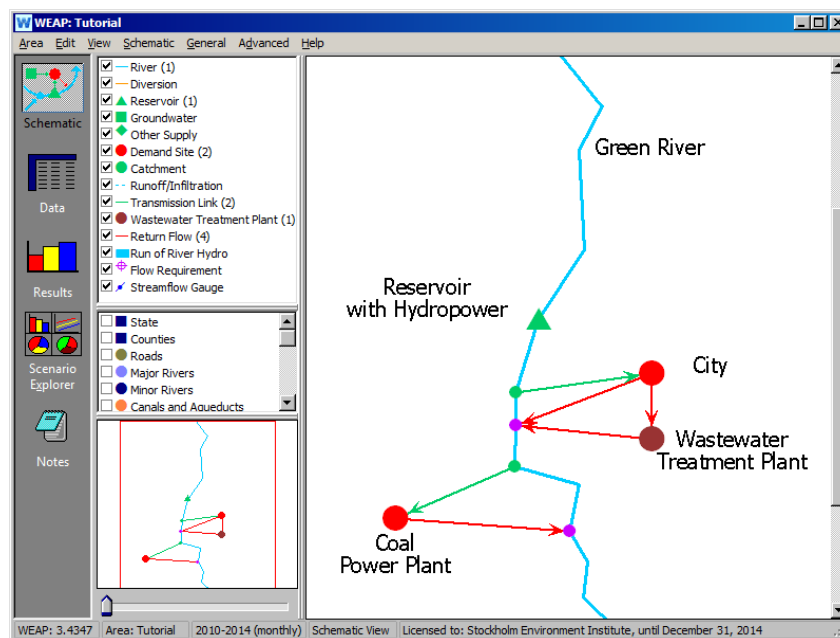
For more information on LEAP and to download the software, visit <http://www.energycommunity.org>.

### 2. Coupled water-energy models in WEAP and LEAP

We are going to examine a simple water-energy system; first the water side of the system using WEAP, then the energy side using LEAP. Then we will link the WEAP and LEAP models to examine the interaction between the two sides and see how this interaction influences the results we obtain.

### 3. WEAP Model

In the WEAP “Schematic” view there is a city situated near a river with its own wastewater treatment plant. A reservoir harnesses hydropower from the river. The demand for water comes from two sources: municipal demand from the city, and demand for thermal cooling from a coal power plant also situated near the river. The municipal demand has the first demand priority (1) compared to the thermal cooling demand (2).



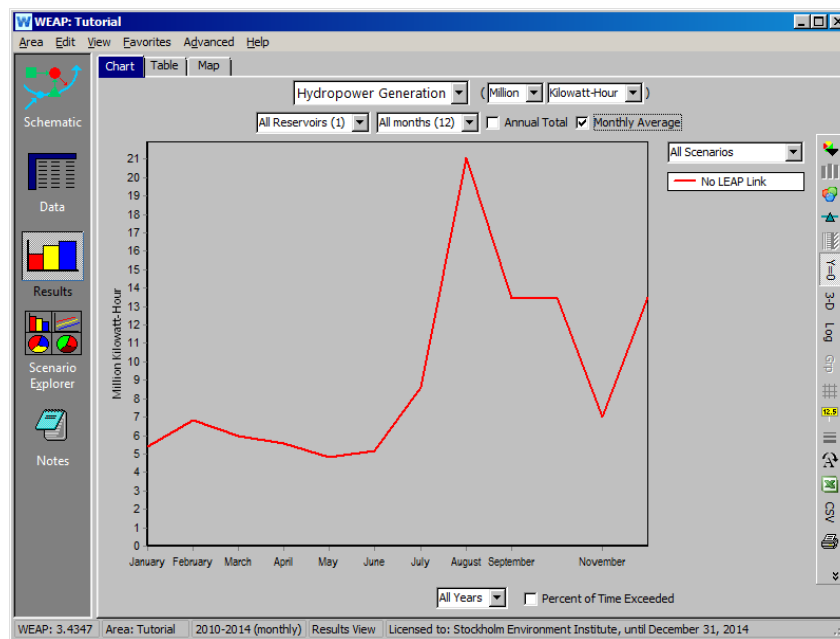
Already we can see links between the water and energy systems in this model. The reservoir and coal power plant utilize water to generate electricity. On the other hand, the wastewater treatment plant uses energy in its treatment process. Energy is also needed for processes like pumping for transmission.

#### 4. View WEAP results

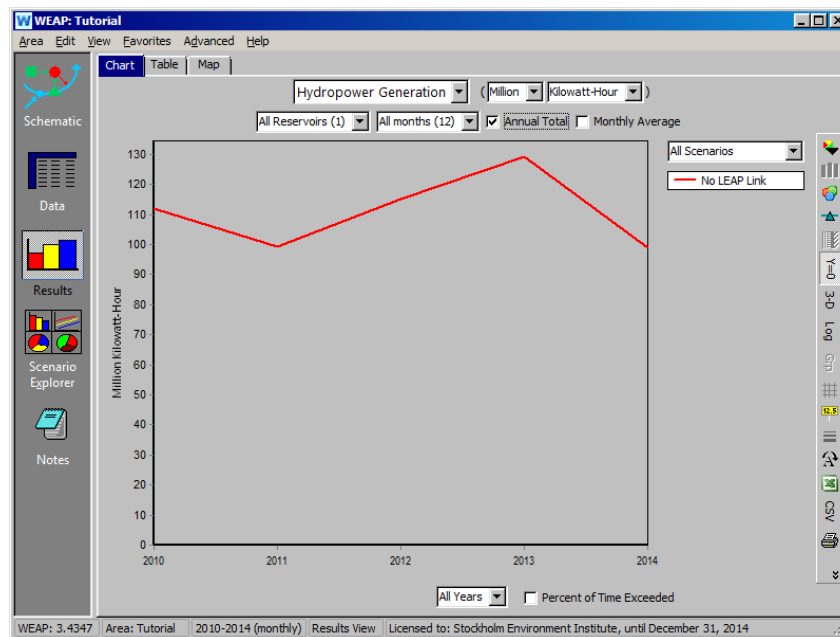
Switch to the “Results” view. Click the pull-down menu at the top left, select “Supply and Resources” > “Reservoir” > “Hydropower Generation.” This allows us to see the variation in hydropower generated by the reservoir over time. Change the unit to Kilowatt-Hour. Remember that you can change the chart type to a line or bar graph by clicking the “Chart Type” button on the right hand side of the window.

You can also view the monthly average or the annual total hydropower generated by checking the corresponding box at the top of the window. From these options, we can see that hydropower generation peaks during the summer, and varies from year to year.

### Monthly Average:



### Annual Total:



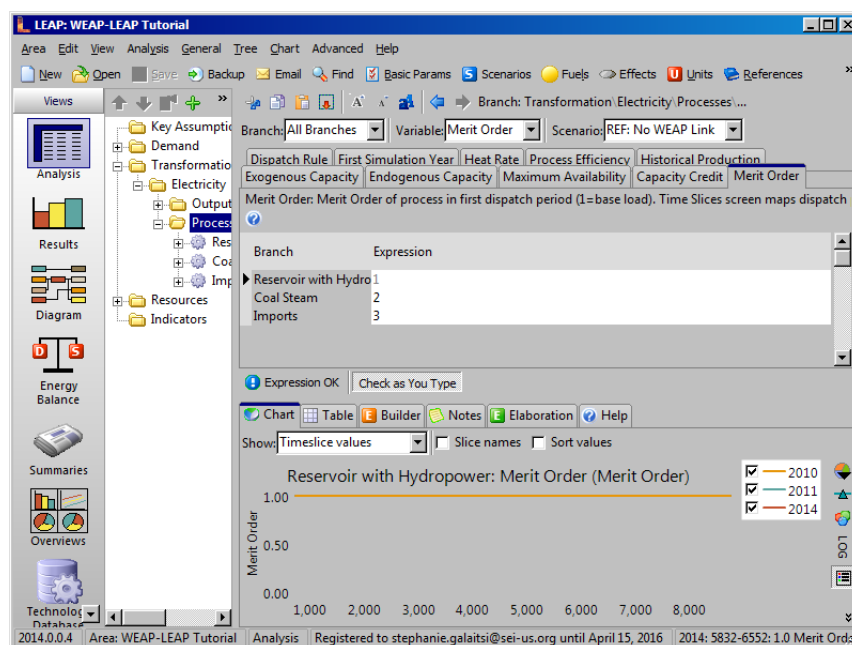
## 5. LEAP Model

Now we will open the energy modeling program, LEAP, to see the current sources of energy for Big City. Under the Area Menu, open the WEAP-LEAP Tutorial and revert to version “Starting point for WEAP-LEAP Tutorial.”

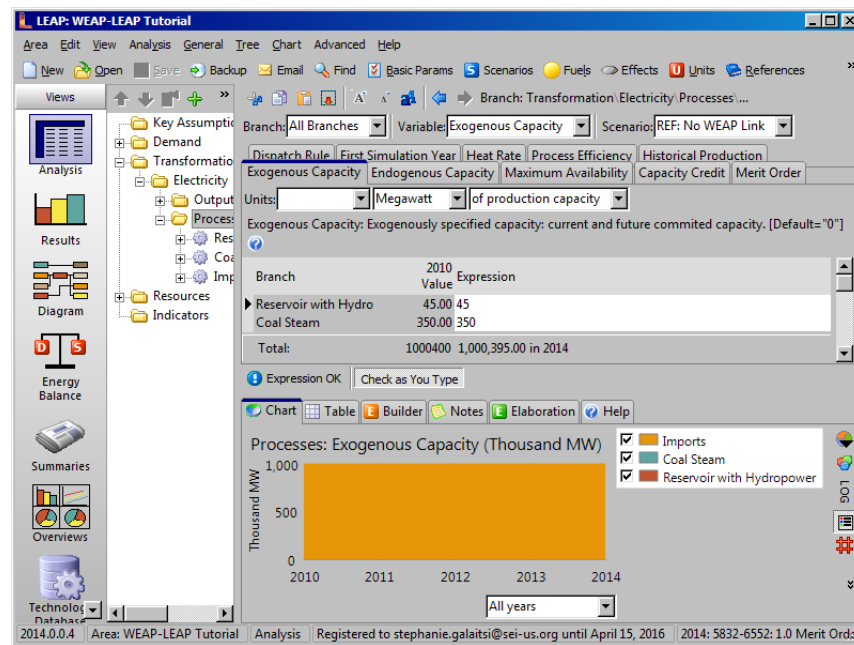


Open the “Analysis” view in LEAP, which can be found on the left-hand side of the window. This is similar to the “Data” view in WEAP. In the “Scenario” pull-down window toward the top, make sure the “REF: No WEAP Link” scenario is selected.

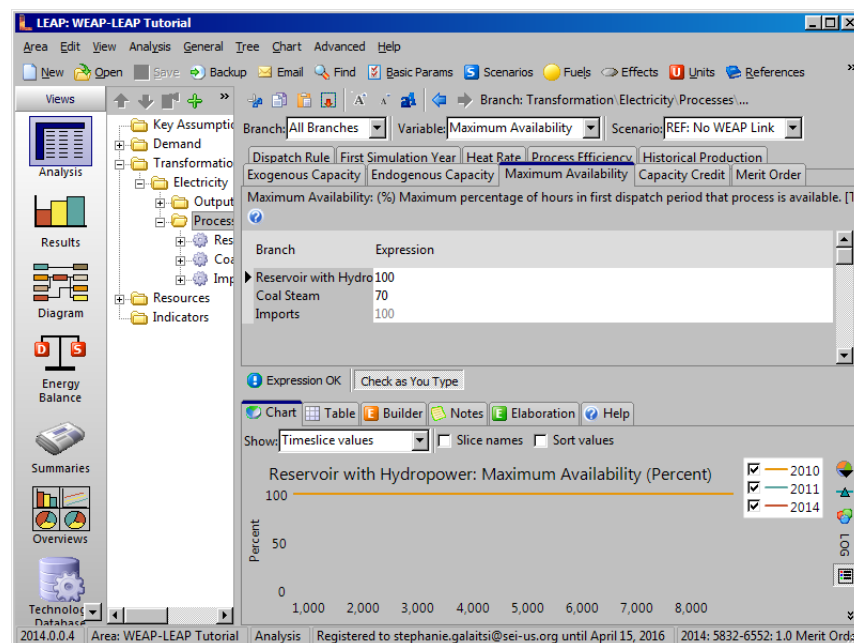
In the Data tree under “Transformation” > “Electricity” > “Processes,” there are three processes that generate electricity: hydropower from the reservoir, the coal steam power plant, and energy imports. If you select the “Merit Order” tab, you can see that hydropower is dispatched first, followed by energy from coal. Any remaining shortfalls are made up with imports, which is last in the merit order.



The energy production capacities for these plants are under the “Exogenous Capacity” tab.



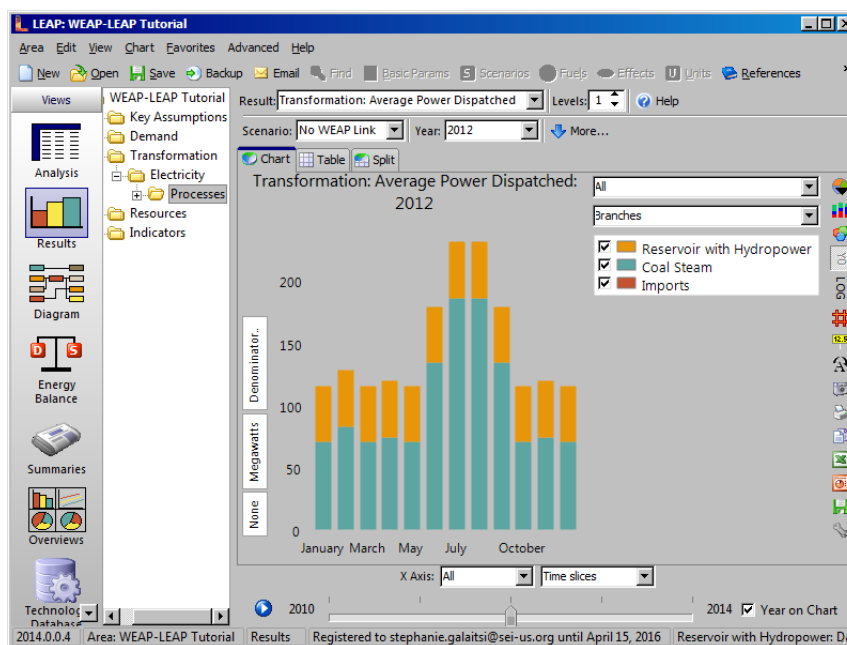
For each energy production process, the portion of maximum energy production that is available can be found under the “Maximum Availability” tab. In the “No WEAP Link” scenario, the maximum availability of the hydropower plant has been entered as 100%. LEAP is assuming that all water demand for hydropower will be met, as it has no information on the amount of water available for hydropower generation.



## 6. View LEAP results

Switch to the “Results” view, found under the “Analysis” button on the left-hand side of the window. From the top pull-down window, select the variable “Transformation: Average Power Dispatched.”

In 2014 (selected from the right dropdown menu or the bottom scroll bar), almost a third of all electricity produced comes from hydropower, running at its full rated capacity of 45 MW. This is unrealistic if there is insufficient water to satisfy the demand for electricity.

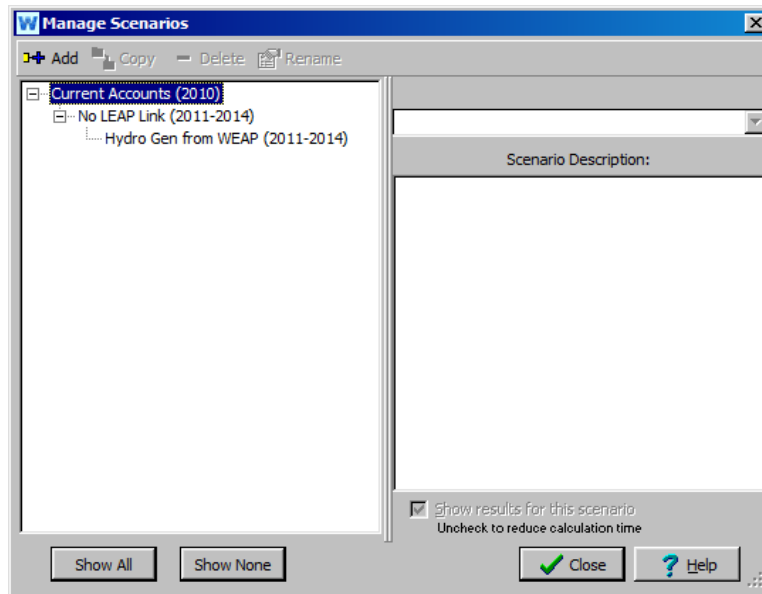


## Scenario: Hydropower Generation from WEAP

In order to have a more realistic representation of hydropower, we will now link LEAP to WEAP, so that LEAP can read the hydropower results calculated by WEAP. In this way, LEAP can determine how much electricity could, in reality, be generated from hydropower.

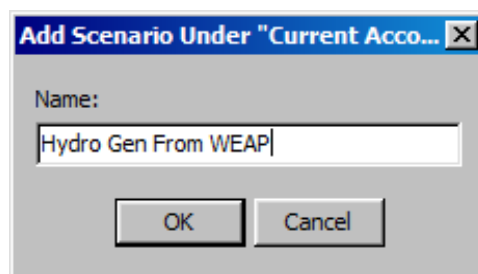
## 7. Create scenario in WEAP

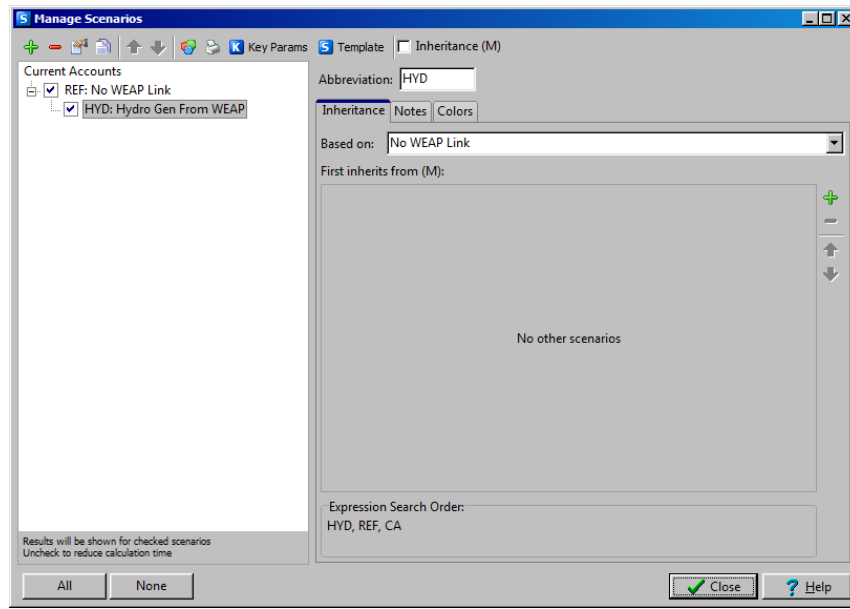
In WEAP, choose the menu item Area, Manage Scenarios to create a new scenario under the “No LEAP Link” scenario, and name it “Hydro Gen from WEAP.”



## 8. Create scenario in LEAP

In LEAP, return to the Analysis View and click the “Scenarios” button (with a blue S icon) toward the top of the window. Add a scenario by clicking the green plus button in the upper left corner, and name the scenario “Hydro Gen from WEAP.” In the “Based on” pull-down window under the Inheritance tab, select “No WEAP Link.” This will ensure that the new scenario inherits the characteristics of the “No WEAP Link” scenario. Close the window.





## 9. Linking WEAP and LEAP

In LEAP, go to the Analysis View and then, under the Advanced menu, select “Link to WEAP Water Model.” The window that pops up is the link manager. After checking the box in this window, you associate the LEAP area with the correct WEAP area. It is also where you match LEAP and WEAP scenarios and time steps.

Check the “Link to WEAP water model” box at the top. Where it says <Select a WEAP Area >, choose “Tutorial.” When first linked, LEAP or WEAP will attempt to match up the scenarios and timesteps from the two models if they have the same name. The timesteps should all be automatically matched, as well as the “Hydro Gen from WEAP” scenarios. The “No WEAP Link” and “No LEAP Link” scenarios will not link (their names are different), but this is correct—those two scenarios are not linked. You can click the Error Check button to double-check for any errors. Then, close the window.

**Link to WEAP water model**

☒ Link to WEAP water model [Visit WEAP web site](#)

WEAP Area:

	LEAP	WEAP
<b>Area</b>	WEAP-LEAP Tutorial	Tutorial
<b>Years</b>	2010 - 2014	2010 - 2014
<b>Scenarios</b>	Current Accounts	Current Accounts
	No WEAP Link	*** Not Linked ***
	Hydro Gen From WEAP	Hydro Gen from
	*** Not Linked ***	No LEAP Link
<b>Time slices</b>	January (31)	January (31)
	February (28)	February (28)
	March (31)	March (31)
	April (30)	April (30)
	May (31)	May (31)

1 LEAP scenarios are unlinked. 1 WEAP scenarios are unlinked.

Help Error Check Close

Now we shall follow the same steps for WEAP. In WEAP, under the Advanced menu, select “Link to LEAP Energy Model.” A window just like the LEAP link manager should pop up. Check the “Link to LEAP” box, and verify that the LEAP Area, scenarios and timesteps are linked correctly. Close the window.

**W Link to LEAP Energy Model**

☒ Link to LEAP: [LEAP Website](#)

LEAP Area: WEAP-LEAP Tutorial

	<b>WEAP</b>	<b>LEAP</b>
<b>Area</b>	Tutorial	WEAP-LEAP Tutorial
<b>Years</b>	2010 - 2014	2010 - 2014
<b>Scenarios</b>	Current Accounts	Current Accounts
	No LEAP Link	*** Not Linked ***
	Hydro Gen from WEAP	Hydro Gen From WEAP
	*** Not Linked ***	No WEAP Link
<b>Months (Days)</b>	January (31)	January (31)
	February (28)	February (28)
	March (31)	March (31)
	April (30)	April (30)
	May (31)	May (31)
	June (30)	June (30)
	July (31)	July (31)
	August (31)	August (31)
	September (30)	September (30)
	October (31)	October (31)
	November (30)	November (30)

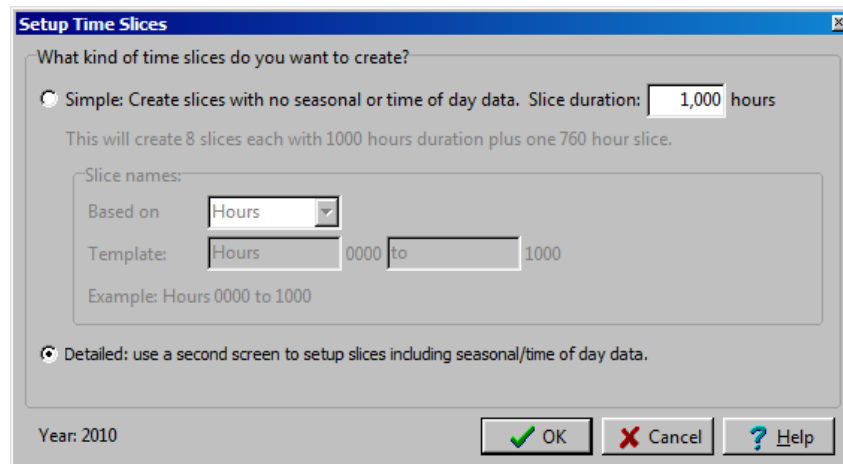
1 WEAP scenarios are unlinked. 1 LEAP scenarios are unlinked. This is OK--only linked scenarios will calculate.

[? Help](#) [Error Check](#) [Close](#)

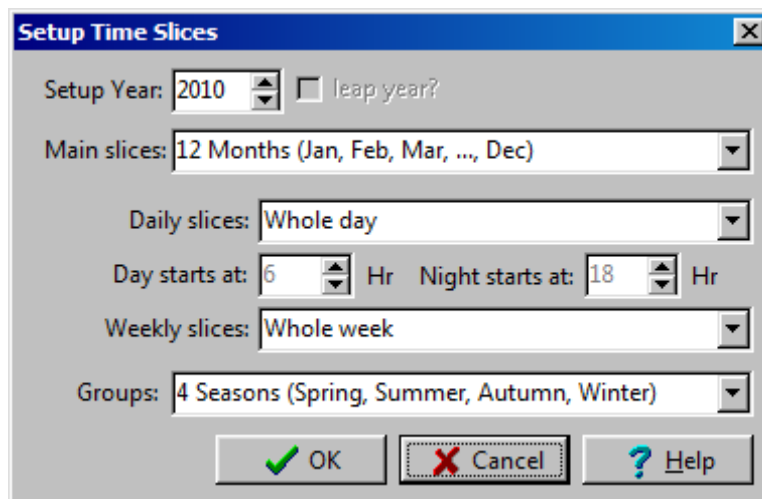
## 10. Time slices

In this example, the LEAP timeslices have already been set to monthly. But when you create your own LEAP area, you will need to setup the timeslices to match those in the WEAP area to be linked (typically, monthly). In the LEAP Analysis view, go to the “General” menu at the top of the window and select “Time Slices.” If this had been a new area, the default would be 8 seasonal day and night time slices. To change this, click “Setup.”

In the “Setup Time Slices” window that appears, choose “Detailed” and then OK.



Change “Main slices” to “12 Months.” Make sure “Daily slices” is “Whole day” and “Weekly slices” is “Whole week.” To save these settings, click OK. However, because the time slices are already monthly, you can just click Cancel.

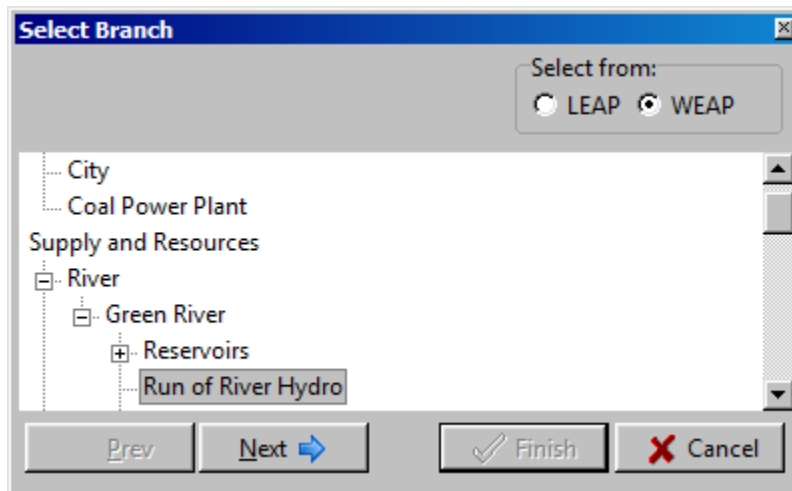


## 11. Reading WEAP Result into LEAP

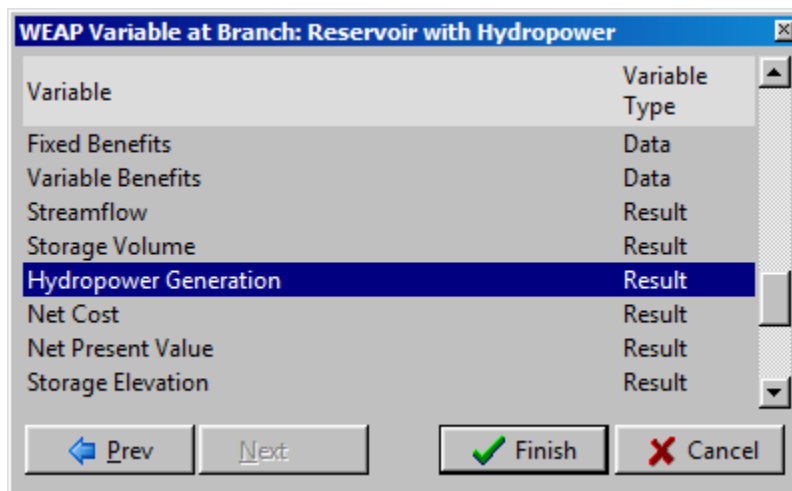
In the LEAP “Analysis” view, open the Data tree to “Transformation”>“Electricity”>“Processes.” Making sure that the new “Hydro Gen From WEAP” scenario is selected, choose the “Maximum Availability” tab. Select the Reservoir with Hydro branch and click on the Expression Builder tab (shown with an orange E) further down on the screen.



Use the “Branch/Variable” button below the Expressions Builder tab to enter branches from WEAP:



Choose the “Reservoir with Hydropower” branch and click Next.

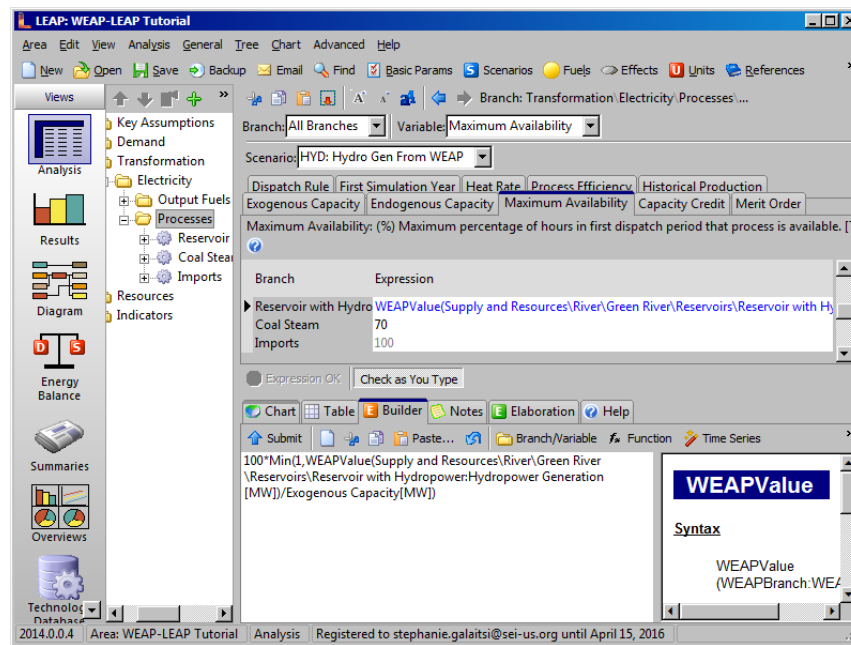


Select the “Hydropower Generation” result variable (you may need to scroll down) and click Finish. You might need to change the unit of “Hydropower Generation” from GJ to MW by specifying in the expression, as shown below.

Fill in the rest of the expression: put  $100 * \text{Min}(1, \text{WEAPValue}(\text{Supply and Resources} \backslash \text{River} \backslash \text{Green River} \backslash \text{Reservoirs} \backslash \text{Reservoir with Hydropower:Hydropower Generation}[\text{MW}]) / \text{Exogenous Capacity}[\text{MW}])$  after it. The completed expression should be:

$$100 * \text{Min}(1, \text{WEAPValue}(\text{Supply and Resources} \backslash \text{River} \backslash \text{Green River} \backslash \text{Reservoirs} \backslash \text{Reservoir with Hydropower:Hydropower Generation}[\text{MW}]) / \text{Exogenous Capacity}[\text{MW}])$$

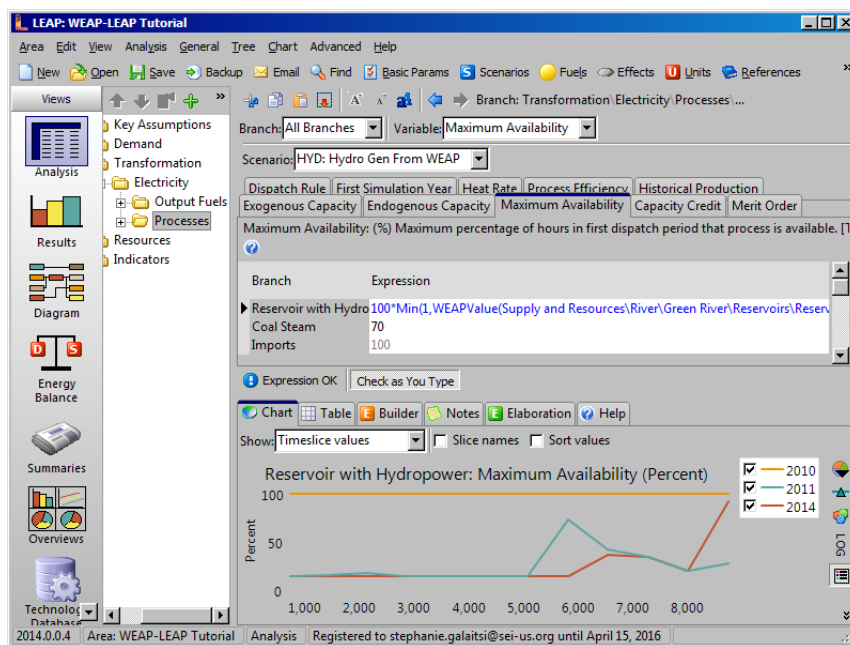
Click the “Submit” button at the top left corner of the Expression Builder.



*Note that you can also type this in. Spaces in names must be included for WEAP and LEAP to recognize the expression.*

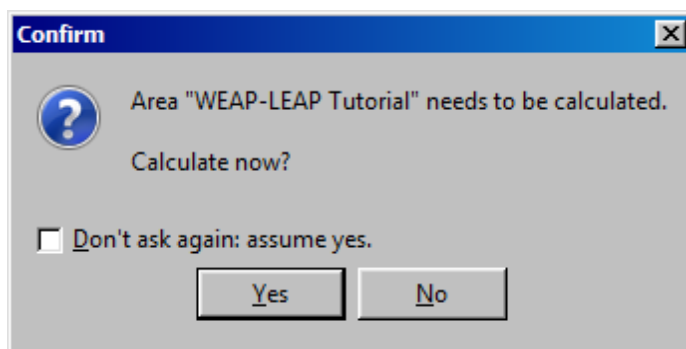
The WEAPValue function tells LEAP to look at data or results calculated by WEAP.

Run results in both WEAP and LEAP and then return to this Reservoir with Hydropower equation. The graph in the Chart tab below the expressions shows that the hydropower maximum availability in 2011 and 2014, as calculated by WEAP, is actually much lower than 100%. This restricts the amount of electricity LEAP can dispatch from hydropower.



## 12. View LEAP Results

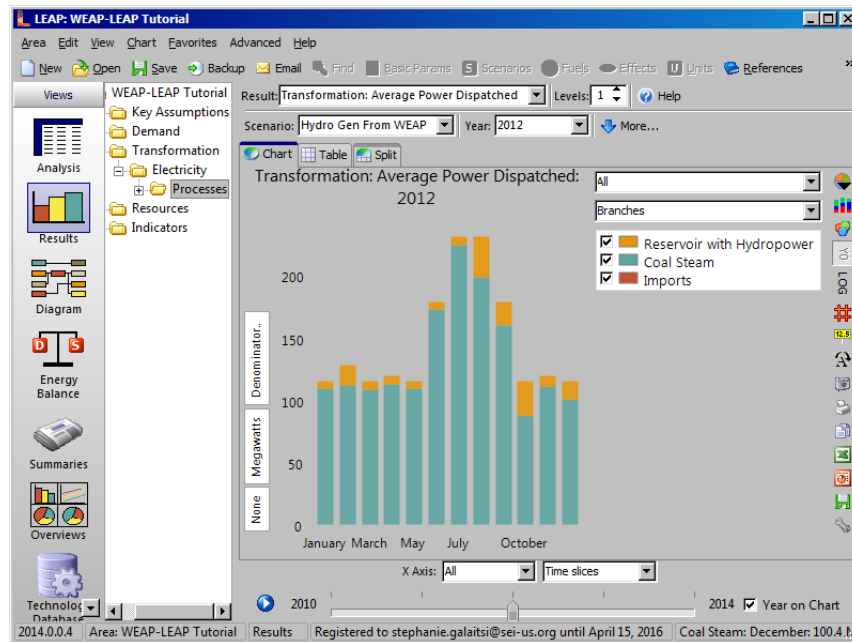
To see how hydropower results from WEAP affects the LEAP electricity dispatch, switch to the “Results” view. Now that WEAP and LEAP are linked and depend upon each other’s results, they will each need to make sure that the other’s results are up to date. In the LEAP confirmation dialog to run calculations, it notes that WEAP also needs to calculate and gives you the option to do that too.



In this initial version of the linked WEAP-LEAP modeling system, the flow of calculations is not fully automatic. In models which have links in both directions, the user is responsible for running the models several times until the system converges, or recognizing the cases where the results diverge or oscillate between two or more different states. We hope to automate this process in future versions.

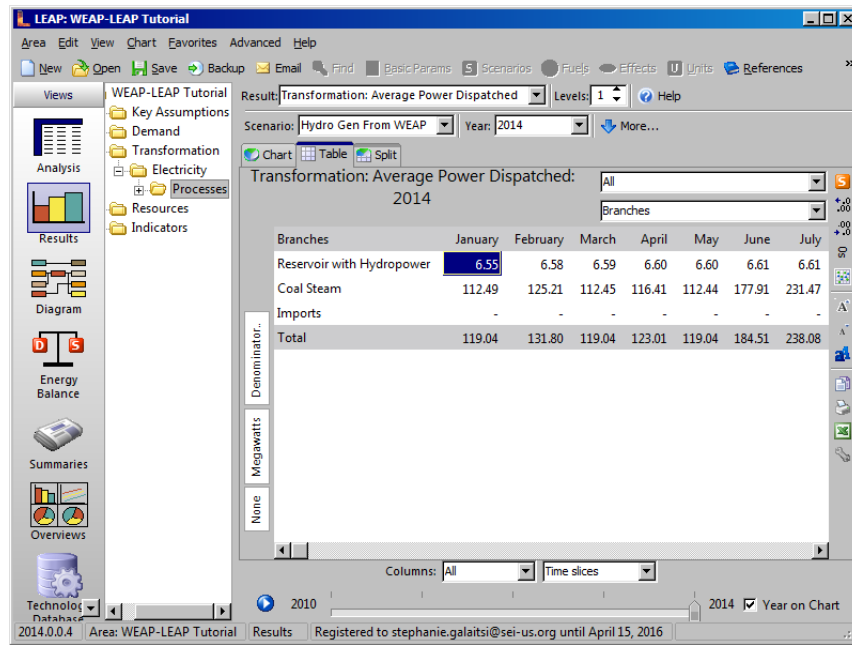
Note: Your results for this tutorial may not exactly match those shown here, depending on how many times you iterate the calculations in LEAP and WEAP.

Select the “Transformation: Average Power Dispatched” variable from the pull-down window under the Chart tab. Select the “Hydro Gen from WEAP” scenario from the “Scenario” pull-down window under that. Using the pull-down windows at the right and bottom of the window, select “All Branches” for the vertical axis of the chart, and “All Time Slices” for the horizontal axis.

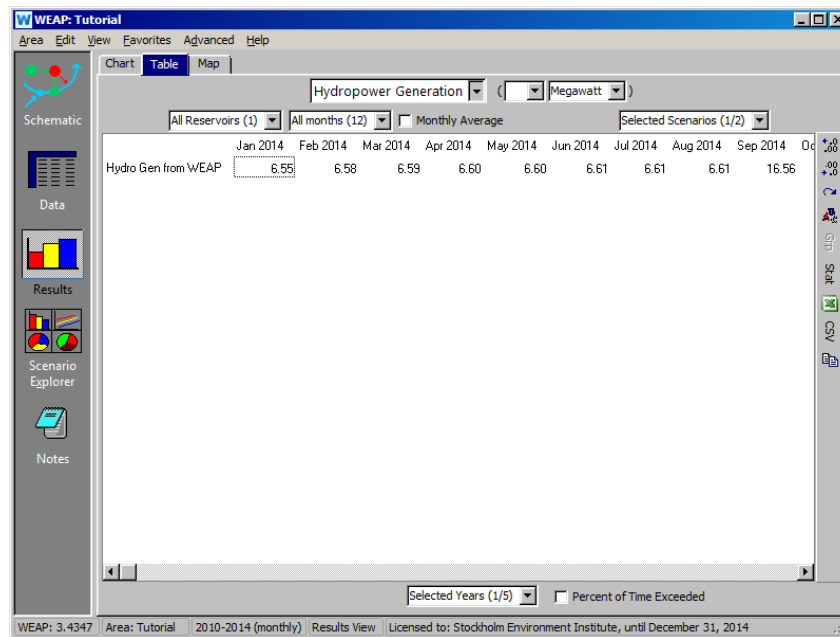


As we can see from the chart, there is much less hydropower and much more coal steam in this scenario due to the restriction given by WEAP.

We can verify that the outputs generated by WEAP indeed match the inputs to LEAP. Switching to the Table tab in the LEAP “Results” view, note that for January 2014, the amount of hydropower generated by the reservoir is 6.55 MW. Note that you may have to change the decimal display by clicking the button on the right. The units can be changed by clicking the vertical Megawatts tab on the left.



In WEAP, under the Table tab of the “Results” view, the value for January 2014 is also 6.55 MW (make sure the units displayed are MW by using the dropdown menu in the upper right).



## Scenario: Demand for Cooling Water from LEAP

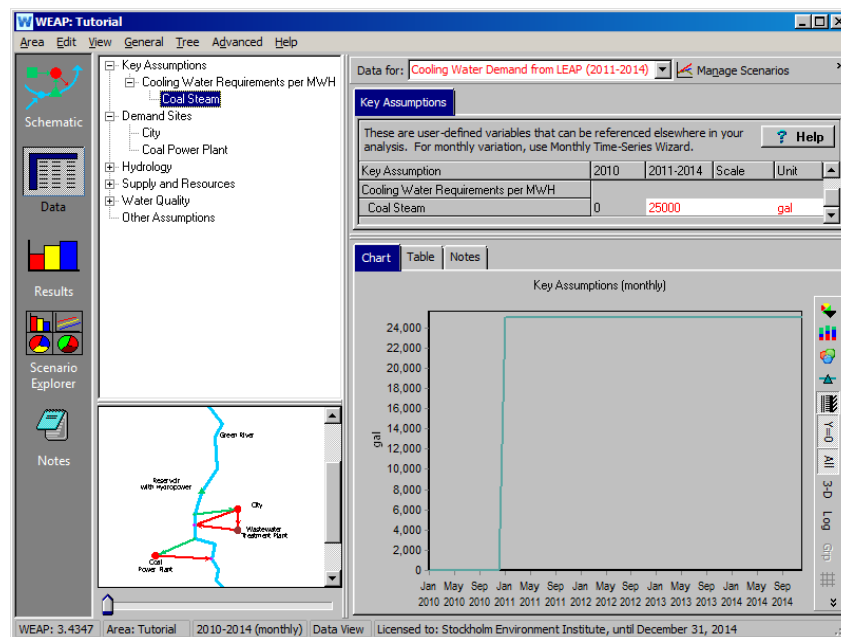
As mentioned before, the coal power plant downstream from the city uses cooling water in its electricity generation process. The demand for water from the coal plant is determined by how much electricity it generates in LEAP.

### 13. Create scenario

Create a new scenario in both WEAP and LEAP named “Cooling Water Demand from LEAP.” The new scenario should inherit the properties of the “Hydro Gen from WEAP” scenario. Check the link manager to ensure that these new scenarios are linked to each other (“Advanced”>”Link to WEAP” or “Link to LEAP” depending on whether you are in LEAP or WEAP).

### 14. Enter Water Use in WEAP

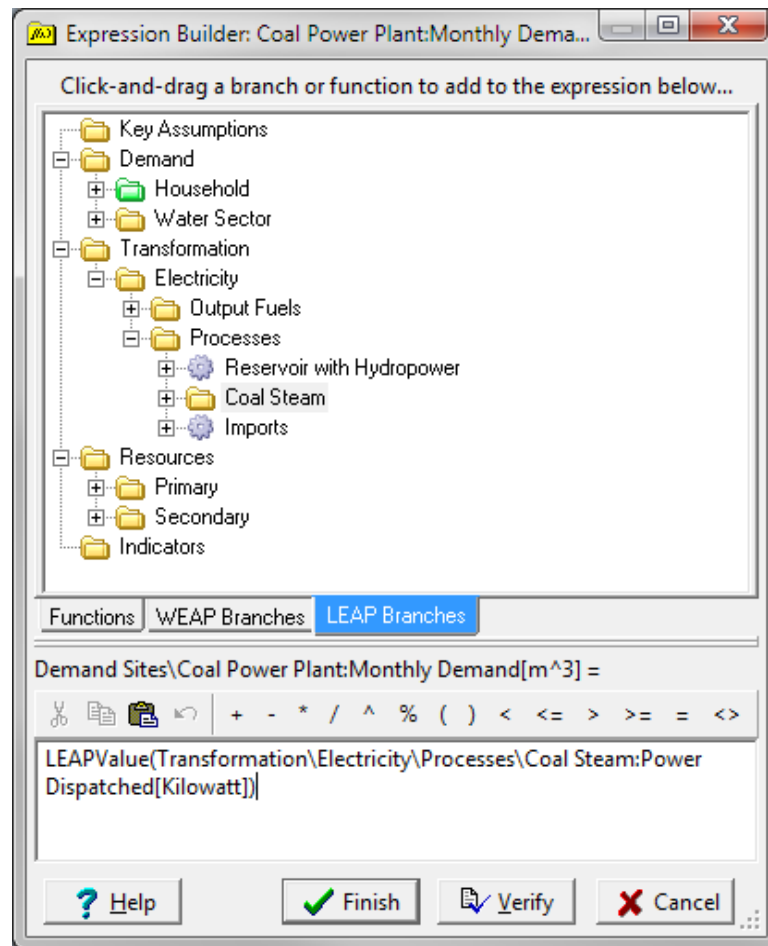
In the WEAP “Data” view, go to the Key Assumption for Cooling Water Requirements per MHW \ Coal Steam on the Data tree, and enter 25000 gal (make sure the “Cooling Water Demand from LEAP” scenario is selected):



Select Demand Sites \ Coal Power Plant on the tree. On the “Monthly Demand” tab under “Water Use,” enter the following LEAP function:

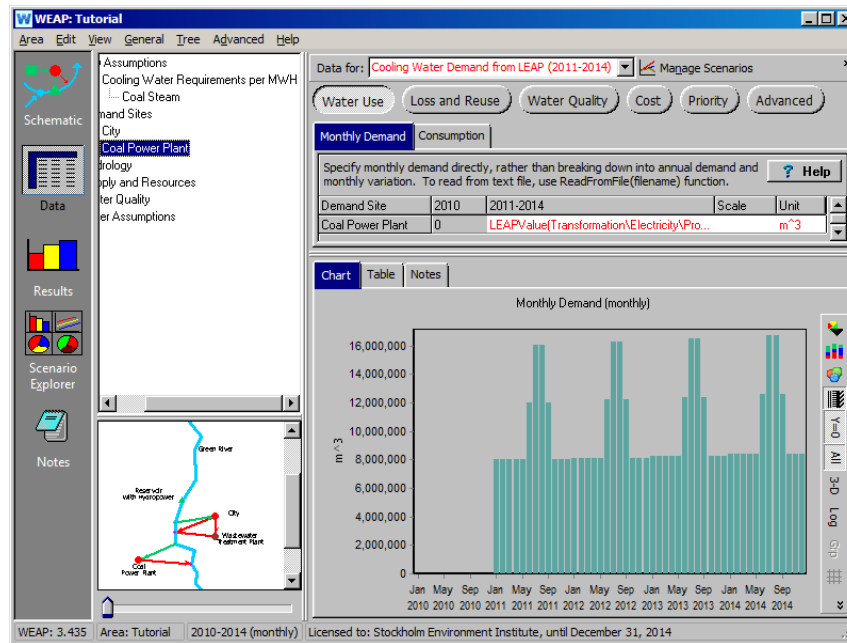
*LEAPValue(Transformation\Electricity\Processes\Coal Steam:Average Power Dispatched[MW]) \* Days \* 24 \* Key\Cooling Water Requirements per MWH\Coal Steam[m^3]*

Note: You may use the “LEAP Branches” tab on WEAP’s Expression Builder to help build the LEAPValue part of the expression. If you do, you will need to change the unit from Kilowatt to MW:



Multiplying by *Days \* 24* converts power (MW) to energy (Megawatt-hours); multiplying by the water requirement per MWH gives the volume of water needed by the coal power plant to function.

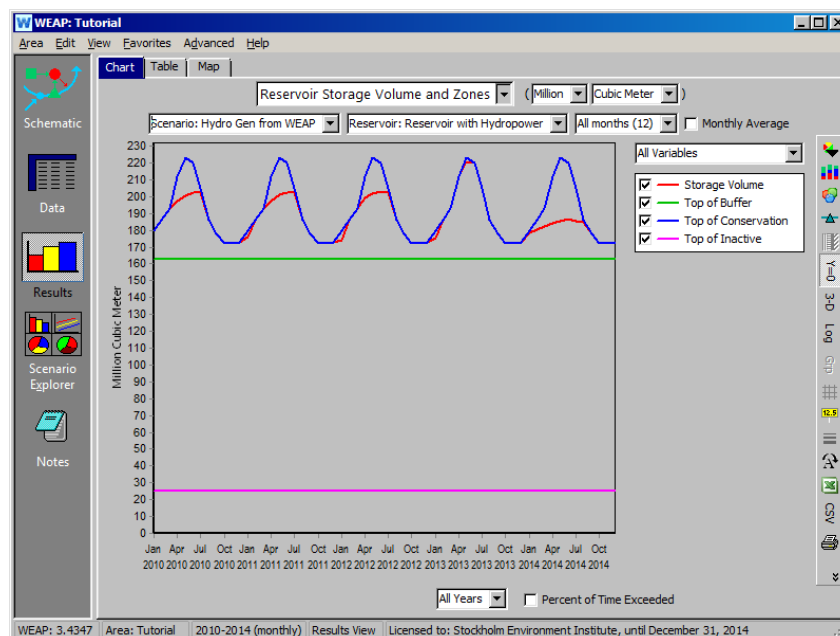
The chart shows the variation in cooling water demand, depending on how much electricity is generated by the coal power plant.



Note: If LEAP has not yet calculated this scenario, you will not see any results here.

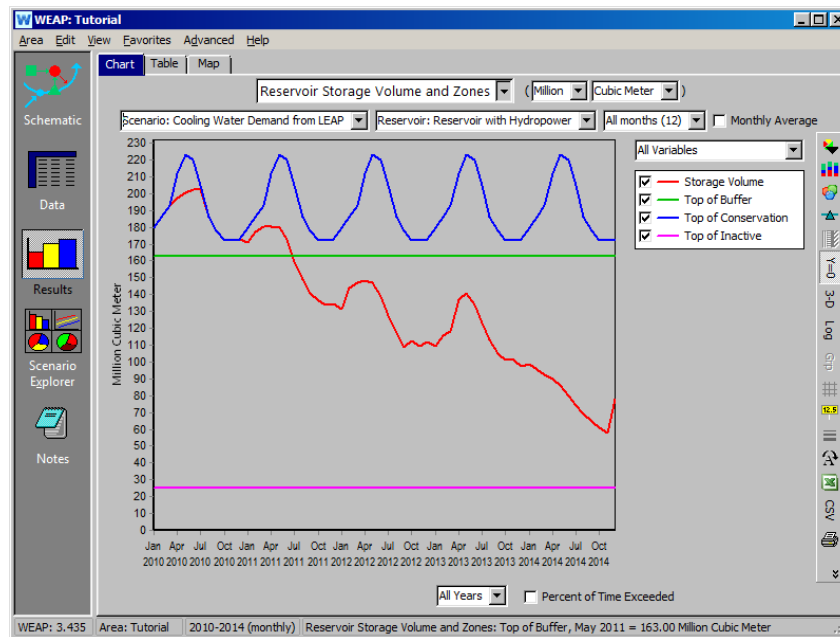
## 15. View WEAP results

In the “Results” view, select the “Reservoir Storage Volume and Zones” variable in the top pull-down window (“Supply and Resources”>”Reservoir”>“Storage Volume and Zones”). The graph shows the storage volume (red) against the different reservoir zones. Look at it first for Hydro Gen from WEAP for all years.

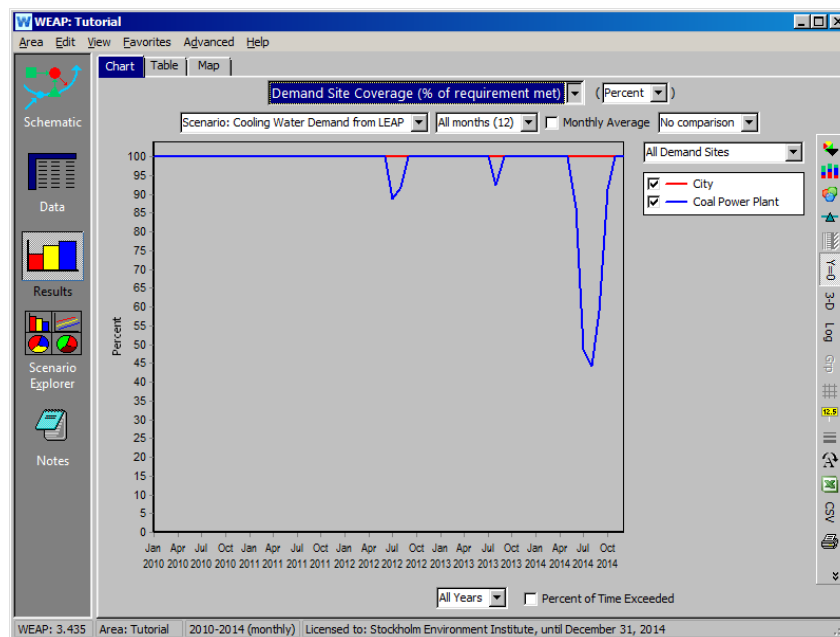




Change the scenario to “Cooling water demand from WEAP.” Now we can see that the reservoir level dropping lower over time due to the new demand for cooling water.



If we view the “Demand Site Coverage” variable (Demand>Coverage), we observe that demand coverage for the coal plant is less than 100% in several month. This means that there is not enough water to satisfy the coal plant’s demand.



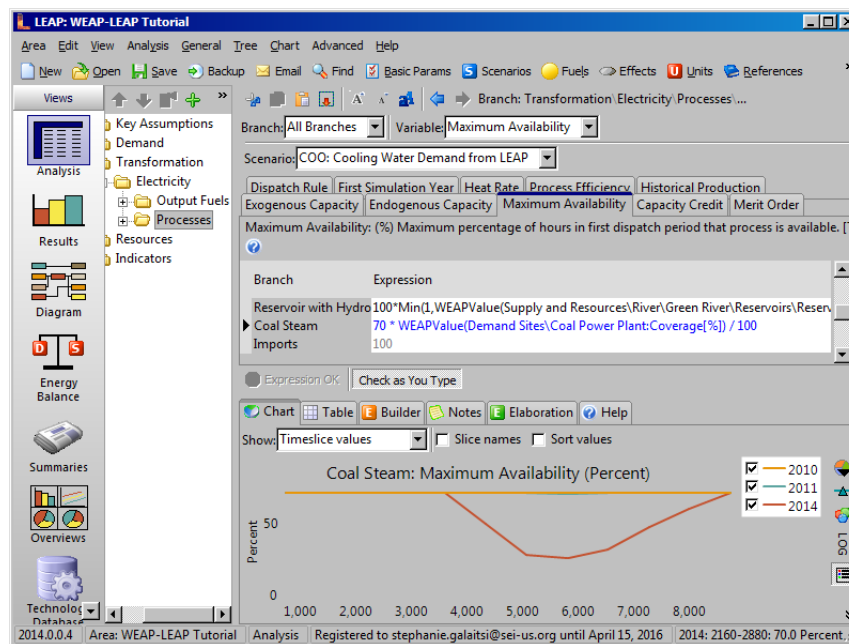
[Results vary]

## 16. Enter WEAP expression in LEAP

We will now see how this WEAP restriction affects the results in LEAP. Go to the LEAP “Analysis” view and select the “Cooling Water Demand from LEAP” scenario from the pull-down window. Under the “Maximum Availability” tab, enter the following WEAP input expression for the Coal Steam branch:

$$70 * WEAPValue(Demand Sites\Coal Power Plant:Coverage[\%]) / 100$$

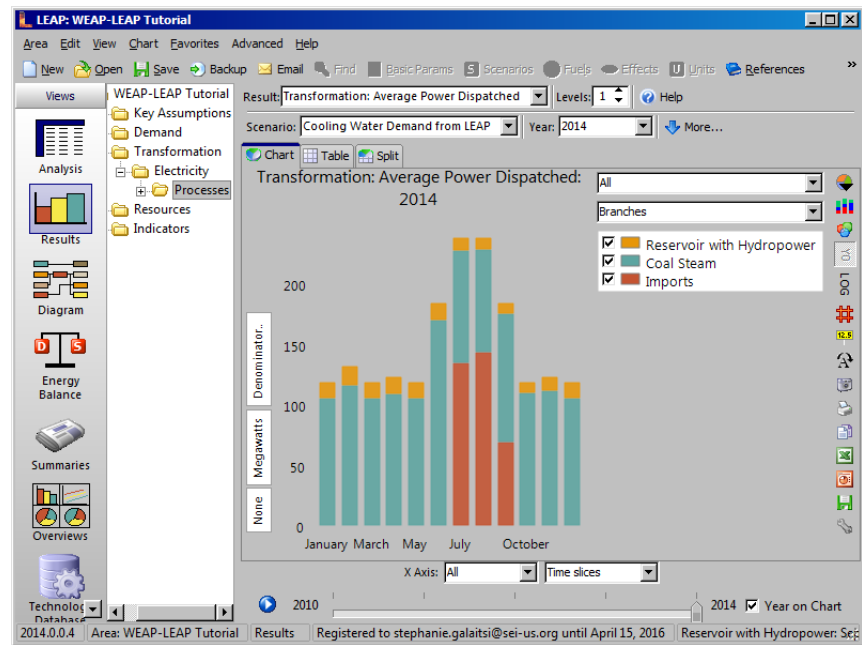
This is the demand coverage for the coal power plant. The chart shows that, in months where the coverage is below 100%, the maximum availability will be less than 70%.



## 17. View Results in LEAP

Switching to the “Results” view, select the “Cooling Water Demand from LEAP” scenario. In 2014, there is insufficient water to satisfy the cooling water demand, which reduces the generating capacity of the coal plant. We

can see that at times, imports (in red) are now required to make up for the lack in coverage by hydropower and coal steam.



## Scenario: Electricity Demand from WEAP

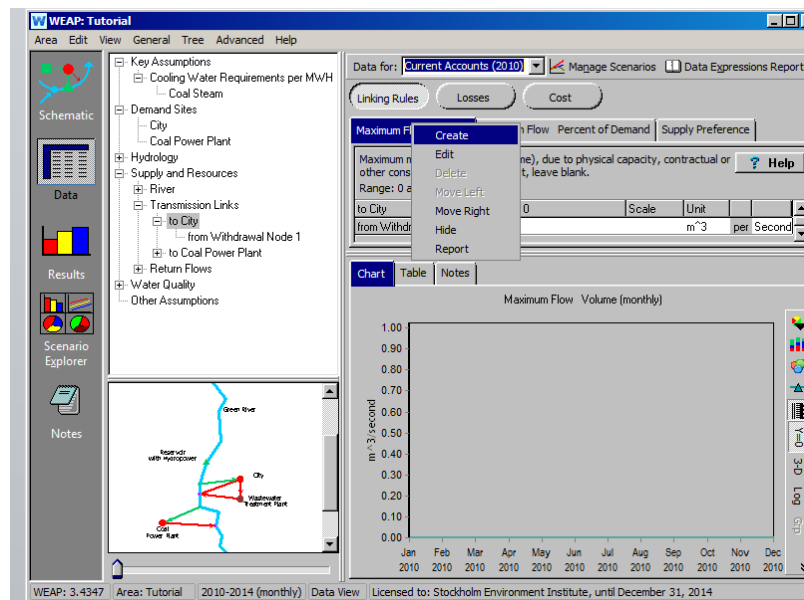
The water sector uses electricity to treat, pump and transmit water. Depending on how much water is used and treated, the demand for electricity changes accordingly.

### 18. Create scenario in WEAP

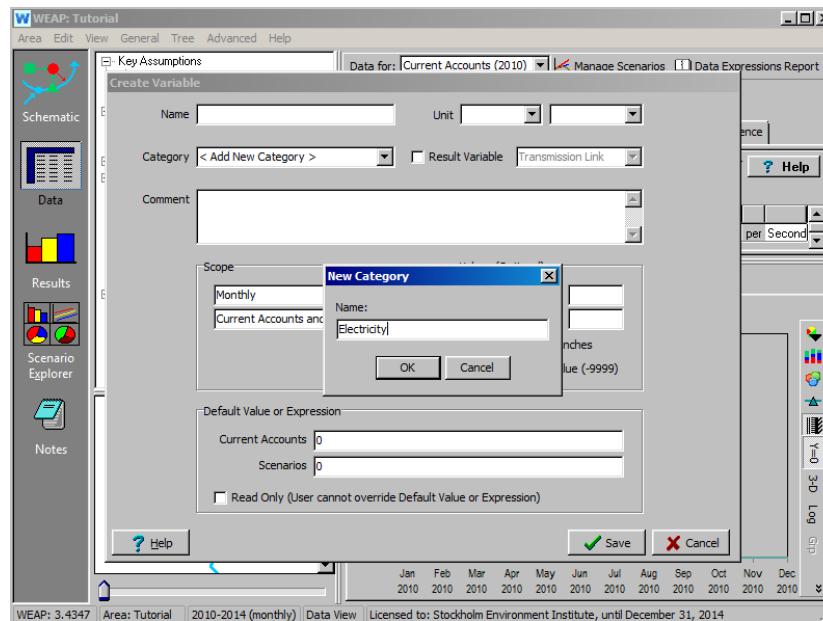
In WEAP, create a new scenario called “Electricity Demand from WEAP,” inheriting the characteristics of the “Cooling water demand from LEAP” scenario. Here we are going to focus on two demands for electricity by the water sector.

The first is the transmission link from the river to the city. In the Data tree, open “Supply and Resources,” “Transmission Links” and “to City.”

You will create two new user-defined variables, “Electricity per Cubic Meter” and “Total Electricity,” to model electricity used by water pumping and treatment. Right click on an existing variable tab (e.g., Maximum Flow Volume) and choose “Create.”



First, create a new category named “Electricity”—select < Add New Category> to add it.



Next, enter the following information and click Save:

**Create Variable**

Name:  Unit:

Category:  ☐ Result Variable

Comment:

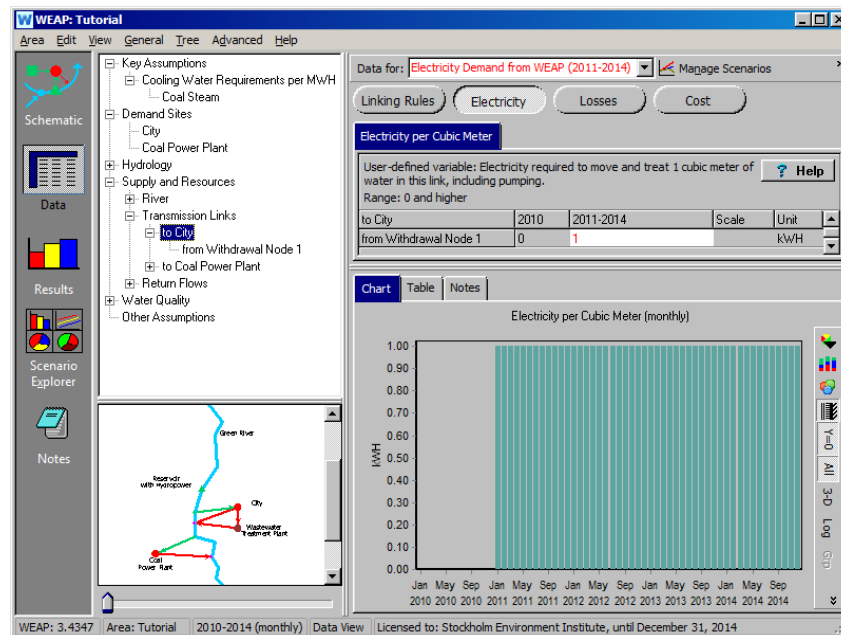
Scope:

Values (Optional):  
 Minimum Value:   
 Maximum Value:   
☒ Sum Across Branches  
☐ Allow Missing Value (-9999)

Default Value or Expression:  
 Current Accounts:   
 Scenarios:   
☐ Read Only (User cannot override Default Value or Expression)

Once you have created the variable, enter data in the “Electricity Demand from WEAP” scenario for the energy needed for pumping and treatment to the City (1 kWh / cubic meter) and the Coal Power Plant (0.2 kWh / cubic meter).

Tip: just click on the transmission link in the lower left map to jump to that branch in the tree.



Create another variable named “Total Electricity”:

The 'Create Variable' dialog box is shown. The 'Name' field is 'Total Electricity' and the 'Unit' is 'kWh'. The 'Category' is 'Electricity'. The 'Comment' field contains 'Electricity required to move and treat water flowing through this link, including pumping'. The 'Scope' is set to 'Monthly' and 'Current Accounts and Scenarios'. The 'Values (Optional)' section has 'Minimum Value' set to 0 and 'Maximum Value' set to an empty field. The 'Sum Across Branches' checkbox is checked. The 'Default Value or Expression' section shows the expression 'Electricity per Cubic Meter \* PrevTSValue(Flow)' for both 'Current Accounts' and 'Scenarios'. The 'Read Only' checkbox is checked. The 'Save' button is highlighted.

Note: This variable will be a read-only calculated result--the default expression you enter (*Electricity per Cubic Meter \* PrevTSValue(Flow)*) will calculate the total electricity used by the transmission link in the previous timestep. Because this is the default expression, it will be used for all transmission links.

The second electricity demand in this model is from the Wastewater Treatment Plant. Find this in the Data tree under “Water Quality” and “Wastewater Treatment.” We will model it the same way as we did the transmission links. Add two new user-defined variables: “Electricity per Cubic Meter” and “Total Electricity,” with the following definitions:

**Edit Variable**

Name:  Unit:

Category:  ☐ Result Variable

Comment:

Scope:

Values (Optional):  
 Minimum Value:   
 Maximum Value:   
☒ Sum Across Branches  
☐ Allow MissingValue (-9999)

Default Value or Expression:  
 Current Accounts:   
 Scenarios:   
☐ Read Only (User cannot override Default Value or Expression)

**Create Variable**

Name:  Unit:

Category:  ☐ Result Variable

Comment:

Scope:

Values (Optional):  
 Minimum Value:   
 Maximum Value:   
☒ Sum Across Branches  
☐ Allow MissingValue (-9999)

Default Value or Expression:  
 Current Accounts:   
 Scenarios:   
☒ Read Only (User cannot override Default Value or Expression)

The default expression for the read-only result variable Total Electricity is

$$\text{Electricity per Cubic Meter}[kWh] * \text{PrevTSValue}(\text{Wastewater Treatment Plant Total Inflow}[m^3])$$

Enter data in the “Electricity per Cubic Meter,” in the “Electricity Demand from WEAP” scenario: *0.1 kWh / cubic meter*.

## 19. Add Key Assumption in WEAP

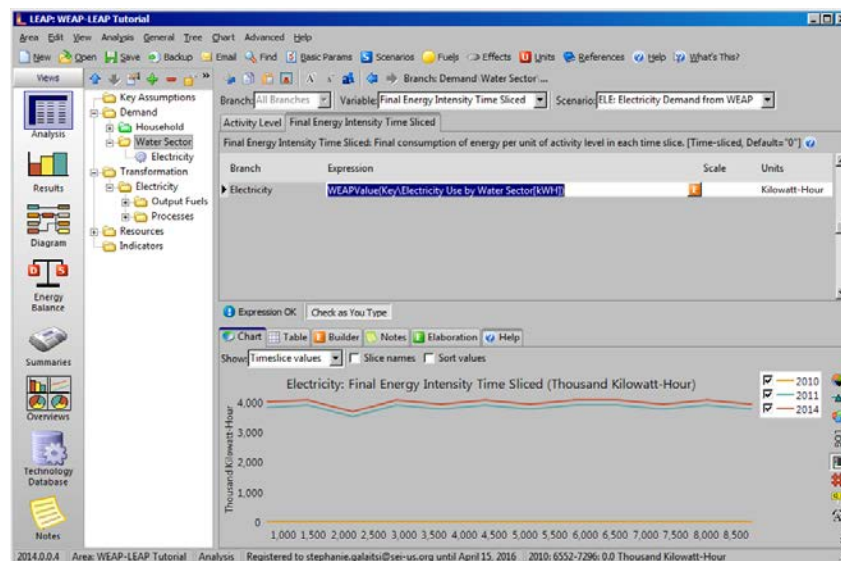
These two electricity demands can be summed up in one key assumption. Add a new key assumption in the Data tree and name it “Electricity Use by Water Sector.” (Right click on the “Key Assumptions” branch and choose “Add,” and select Kilowatt-Hours for the unit.). Enter the following expression in the Current Accounts:

$$(\text{Supply and Resources} \backslash \text{Transmission Links: Total Electricity}[kWh] + \text{Water Quality} \backslash \text{Wastewater Treatment: Total Electricity}[kWh])$$

## 20. Create scenario in LEAP

Open the “Analysis” view in LEAP and create a scenario named “Electricity Demand from WEAP.” Go to the Link to WEAP screen and link this scenario to the corresponding scenario in WEAP. In the Data tree, go to branch Demand \ Water Sector. Enter this expression in “Final Energy Intensity Time Sliced” (make sure the “Electricity Demand from WEAP” scenario is selected):

$$\text{WEAPValue}(\text{Key} \backslash \text{Electricity Use by Water Sector}[kWh])$$

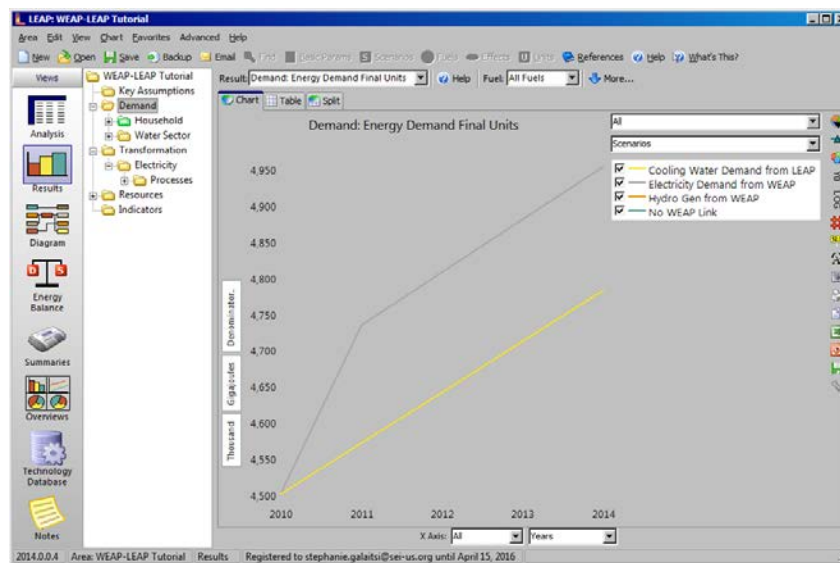




You will need to run calculations before you can see these results in the Data View.

## 21. View results and compare scenarios

In the “Results” view of LEAP, you can compare the energy demand across scenarios. Choose the “Energy Demand Final Units” variable from the top pull-down window, and “All Scenarios” for the legend. The “Electricity Demand from WEAP” scenario should show a variation in demand, while the other scenarios show straight lines because they do not take into account the changing electricity demand from the water sector. You may have to click the Y0 icon to the right to see the same view.



In WEAP, look at the results for Reservoir storage by scenario. You may have to run them to or three times to see the following chart. Because of the electricity demand from WEAP, LEAP must dispatch the coal plant more, which increases the cooling water requirement, which further reduces the reservoir level. Even in this simple example, you can see the complexity that can be modeled by linking WEAP and LEAP.

