System Dynamics Modeling using Powersim Studio: Introductory Training Materials

Marissa D. Reno, Howard D. Passell, Jesse D. Roach, Leonard A. Malczynski, Vincent C. Tidwell

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National Nuclear Security Administration

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November 11-15, 2007
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Amman, Jordan

A Brief Overview of System Dynamics

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System dynamics modeling methodology

System dynamics (SD) models represent a structure of reservoirs or levels interconnected by controlled flows. SD models include three basic features:

1) reservoirs, or levels, that accumulate (water, money, people . . .)
2) flows into and out of the reservoir
3) constants and other variables that influence flows

SD modeling has been metaphorically described as “bathtub dynamics.”

Levels are the bathtubs themselves, decision functions are the automated or human-controlled valves on the flows to and from the bathtubs, and information channels serve as pipes between levels.

Feedback is an important feature of these systems.

What is System Dynamics?

Jay Forrester, the founder of systems dynamics, suggested that a model should have the following characteristics:

- Able to describe any statement of cause-effect relationships that we may wish to include.
- Simple in mathematical nature.
- Closely synonymous in nomenclature to industrial, economic and social terminology.
- Extendable to large numbers of variables (thousands) without exceeding the practical limits of digital computers.
- Able to handle continuous interactions in the sense that any artificial discontinuities introduced by solution-time intervals will not affect the results. It should, however, be able to generate discontinuous changes in decisions when these are needed.

System dynamics modeling software

- Powersim Studio — www.powersim.com
- Vensim — www.vensim.com
- iThink and Stella — www.iseesystems.com

System dynamics modeling resources

System Dynamics methodology web sites (free)

System Dynamics Society
www.systemdynamics.org
System Dynamics tutorial done for USA Department of Energy
www.albany.edu.cpr/sds/DL-IntroSysDyn/inside.htm
Cornell University System Dynamics sources
www.csdnet.aem.cornell.edu/index.html
Papers on System Dynamics and software engineering
www2.umass.edu/systemdynamics/papers.html
System Dynamics resources for children and young adults
www.clexchange.org
MIT course in system dynamics
www.ocw.mit.edu/OCWWeb/Sloan-School-of-Management/15-874Fall2003/CourseHome
Dr. Craig Kirkwood textbook on system dynamics using Vensim PLE
www.public.asu.edu/~kirkwood/sysdyn/SDRes.htm
Australian Powersim Studio site
http://www.argospress.com/books/system-dynamics/index.htm

Powersim Studio independent user group on Yahoo (free)

http://tech.groups.yahoo.com/group/powersimtools/

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Powersim Studio* Training Slides

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Starting a Model

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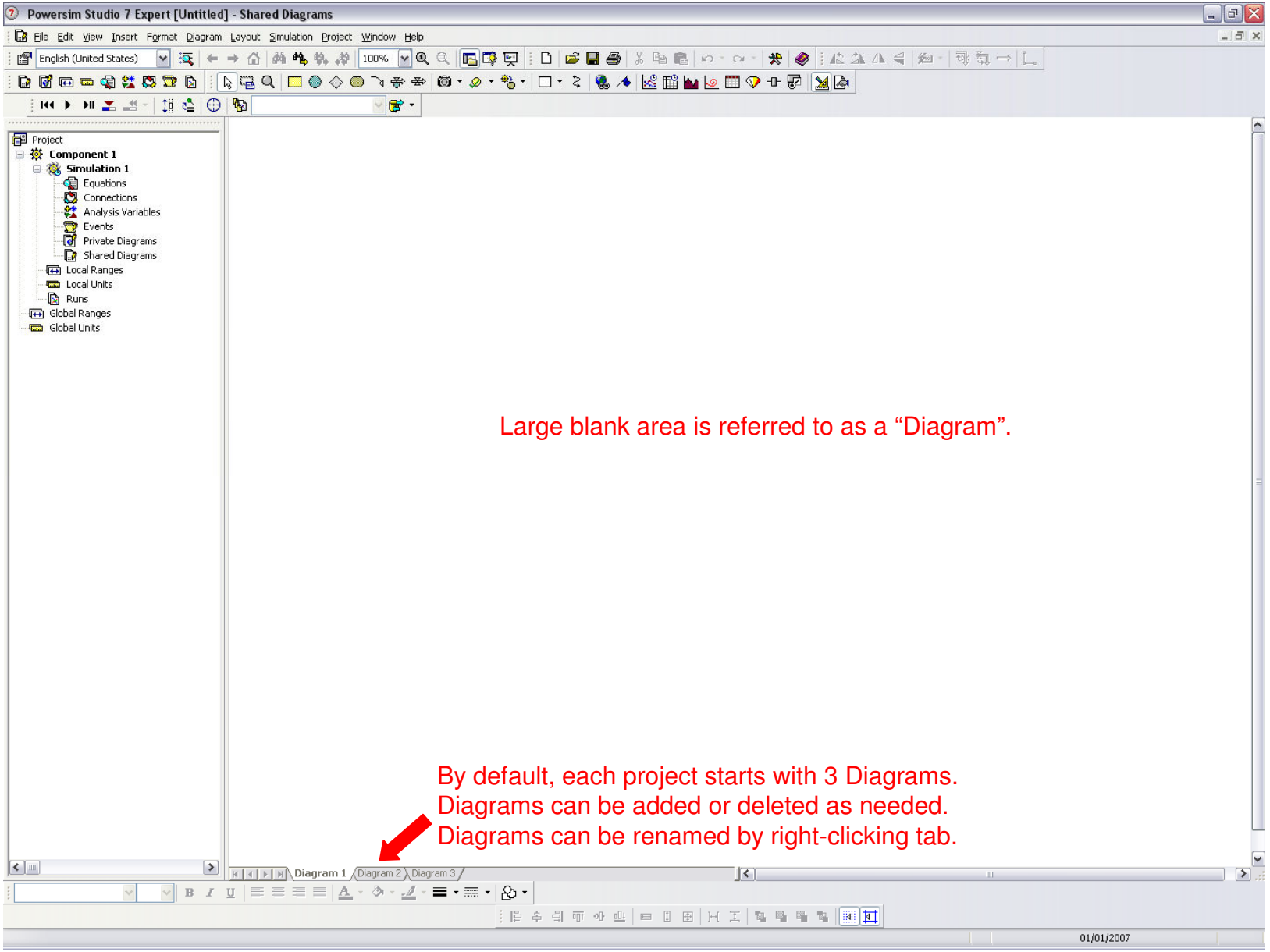
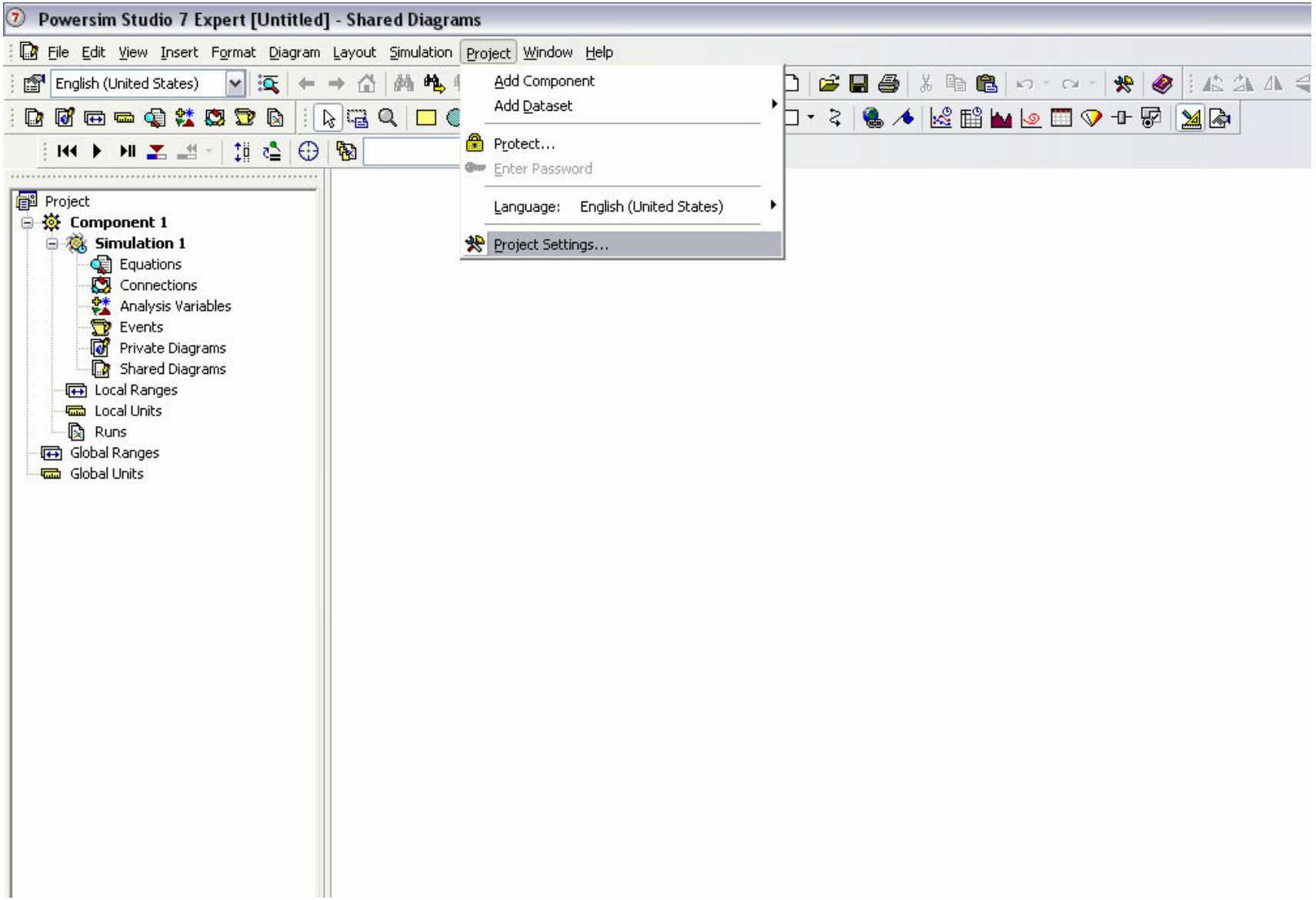
Blank Project



Project Settings



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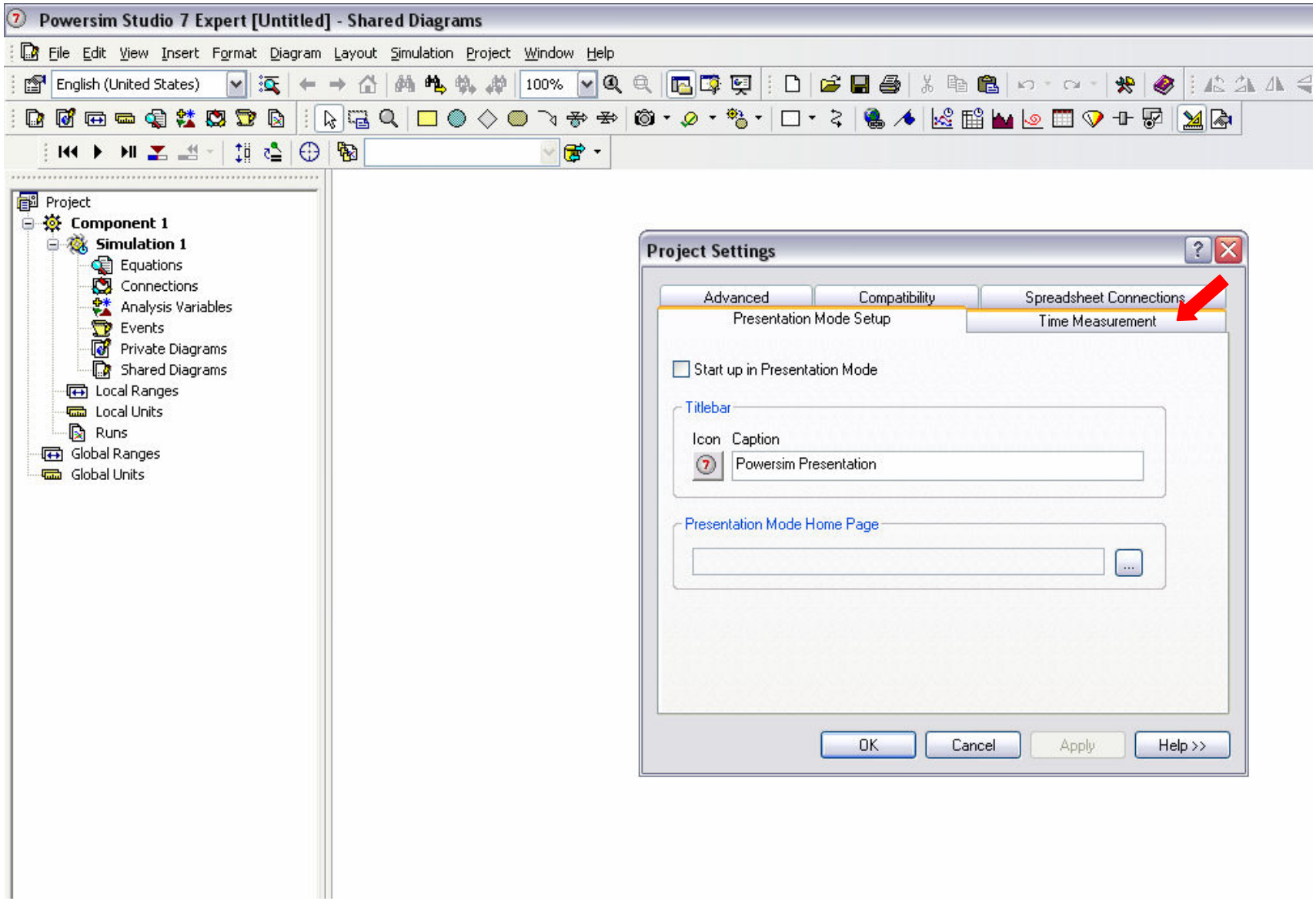


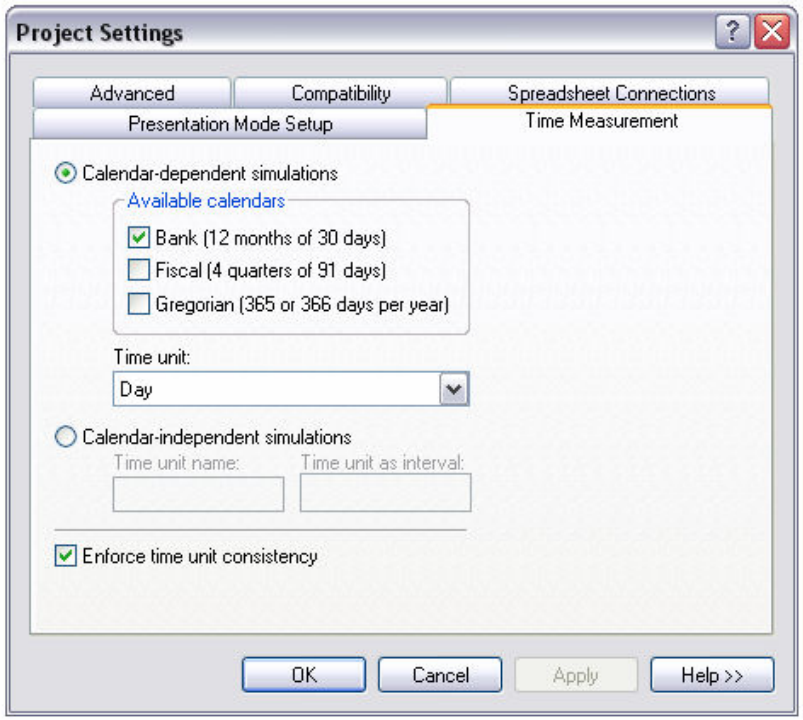
Project Settings

CALENDAR:

BANK – 12 months of 30 days each (second, minute, hour, day, week, month, quarter, and year are available units).

FISCAL – 4 quarters of 91 days each (month is no longer an available unit).

GREGORIAN – 365 or 366 days per year (month, quarter, and year are no longer available units).

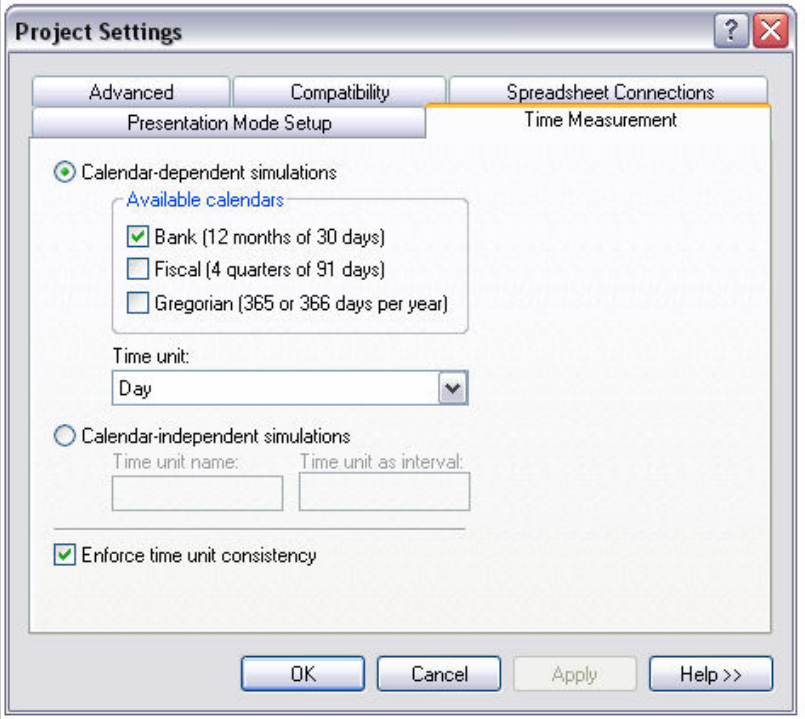


Project Settings

TIME UNIT:

-Select the time unit that you want Studio to use as a default when it displays any value involving time.

-Available time units will depend on the calendar that you select (see previous slide).

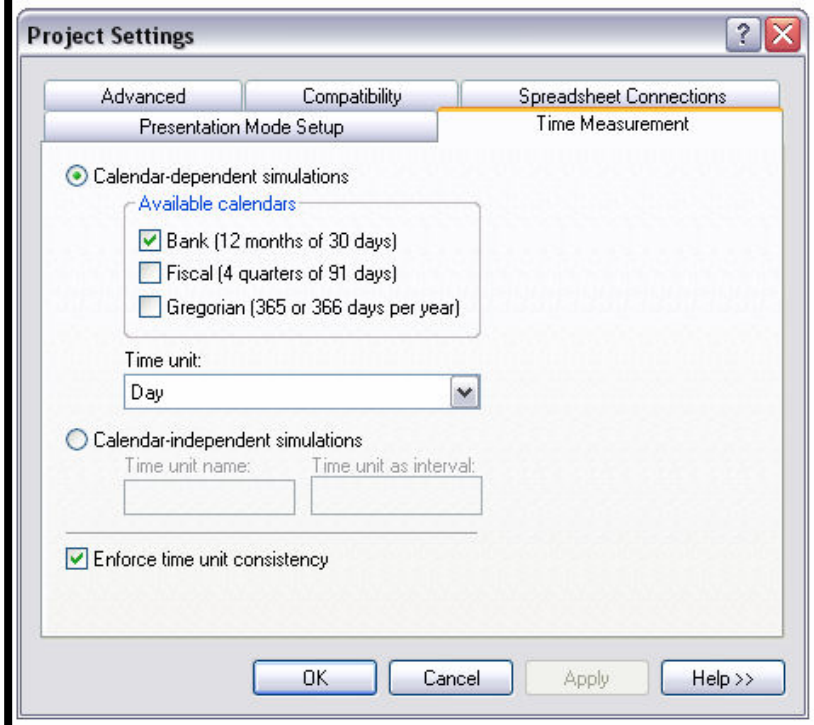


Project Settings

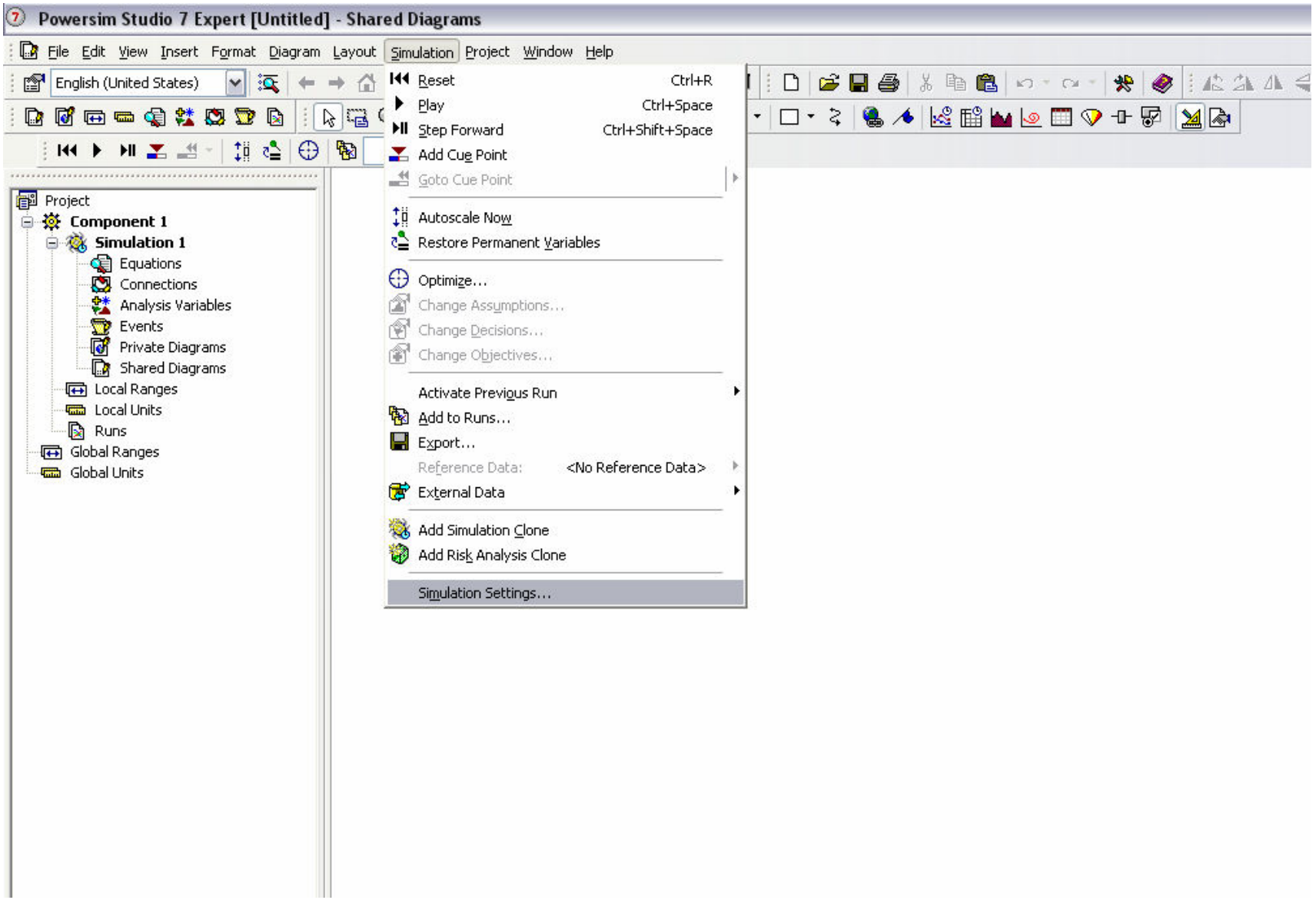
ENFORCE TIME UNIT CONSISTENCY:

-Leave checked if the measurement of time is important for the system that you are modeling. This is almost always true.

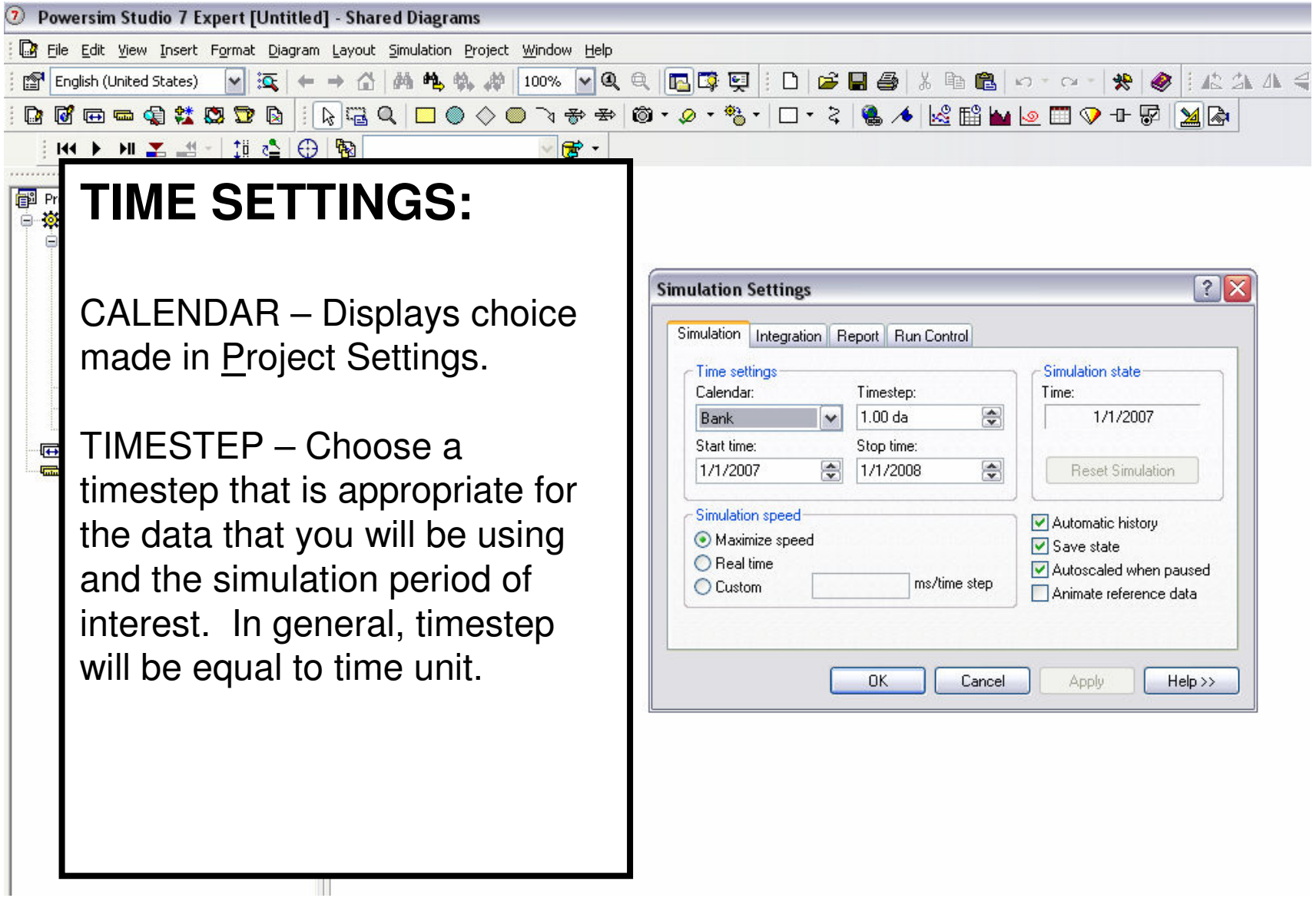
-If you choose to deselect this option, your simulation will no longer need time units in flow rates.



Simulation Settings



Simulation Settings

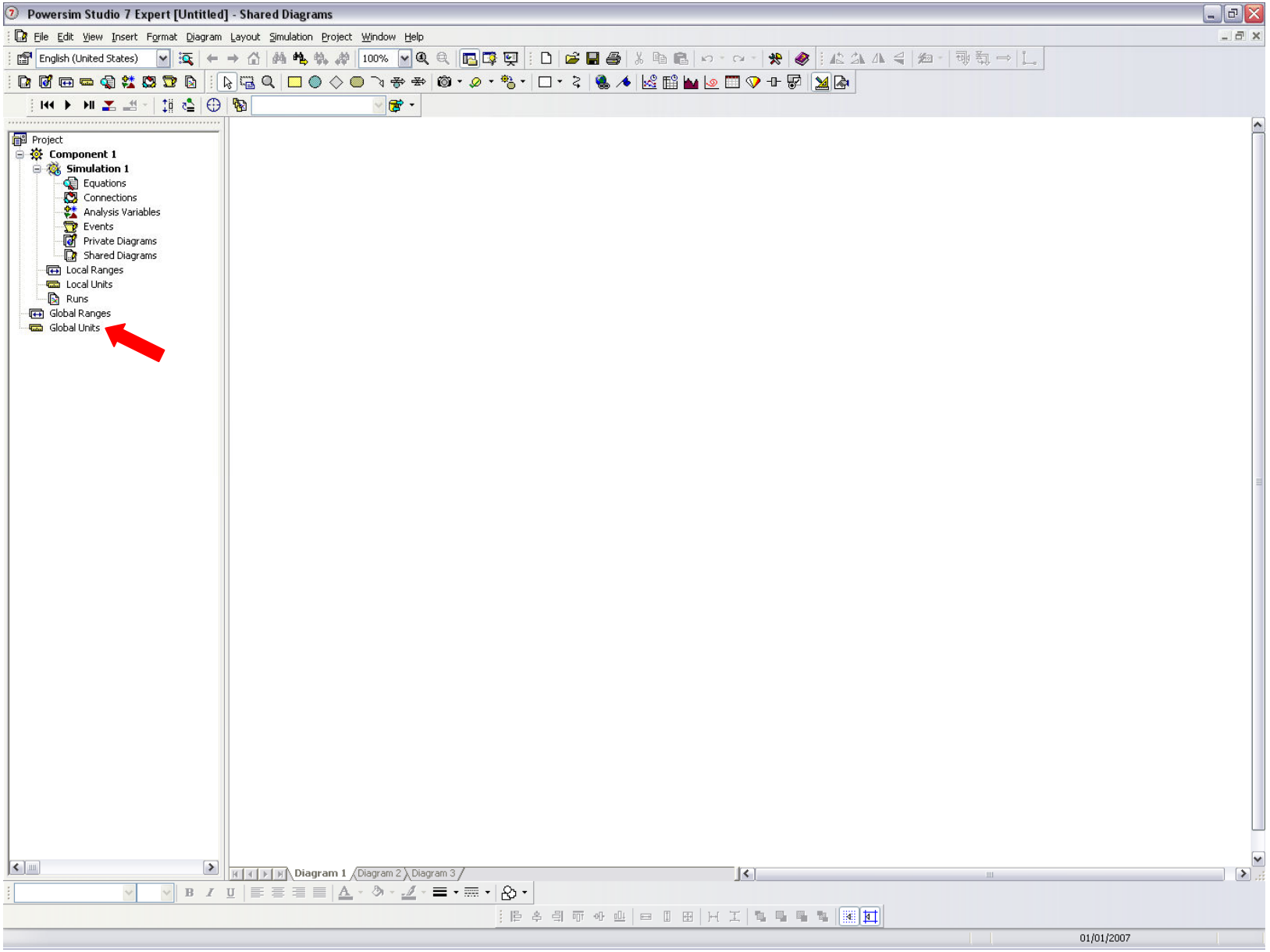


TIME SETTINGS:

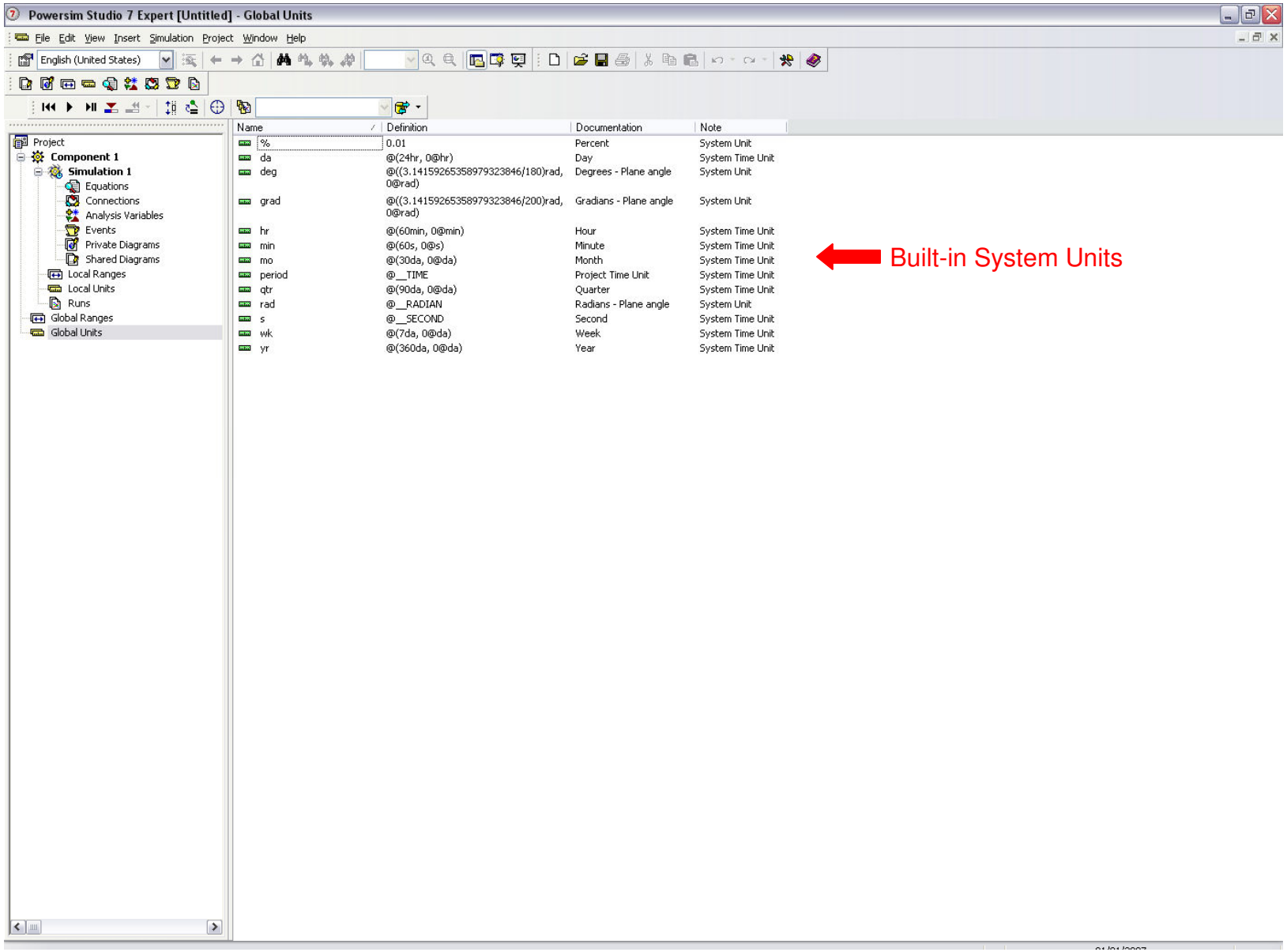
CALENDAR – Displays choice made in Project Settings.

TIMESTEP – Choose a timestep that is appropriate for the data that you will be using and the simulation period of interest. In general, timestep will be equal to time unit.

Units


Powersim Studio 7 Expert [Untitled] - Shared Diagrams
File Edit View Insert Format Diagram Layout Simulation Project Window Help
English (United States)
100%
Project
Component 1
Simulation 1
Equations
Connections
Analysis Variables
Events
Private Diagrams
Shared Diagrams
Local Ranges
Local Units
Runs
Global Ranges
Global Units
Diagram 1
Diagram 2
Diagram 3
01/01/2007

Units


Powersim Studio 7 Expert [Untitled] - Global Units
File Edit View Insert Simulation Project Window Help
English (United States)
Project
Component 1
Simulation 1
Equations
Connections
Analysis Variables
Events
Private Diagrams
Shared Diagrams
Local Ranges
Local Units
Runs
Global Ranges
Global Units
Name
Definition
Documentation
Note
% 0.01 Percent System Unit
da @(24hr, 0@hr) Day System Time Unit
deg @((3.14159265358979323846/180)rad, 0@rad) Degrees - Plane angle System Unit
grad @((3.14159265358979323846/200)rad, 0@rad) Gradians - Plane angle System Unit
hr @(60min, 0@min) Hour System Time Unit
min @(60s, 0@s) Minute System Time Unit
mo @(30da, 0@da) Month System Time Unit
period @__TIME Project Time Unit System Time Unit
qtr @(90da, 0@da) Quarter System Time Unit
rad @__RADIAN Radians - Plane angle System Unit
s @__SECOND Second System Time Unit
wk @(7da, 0@da) Week System Time Unit
yr @(360da, 0@da) Year System Time Unit
Built-in System Units

Unit types

ATOMIC – An atomic unit does not depend on other units (e.g., person, barrel of oil).

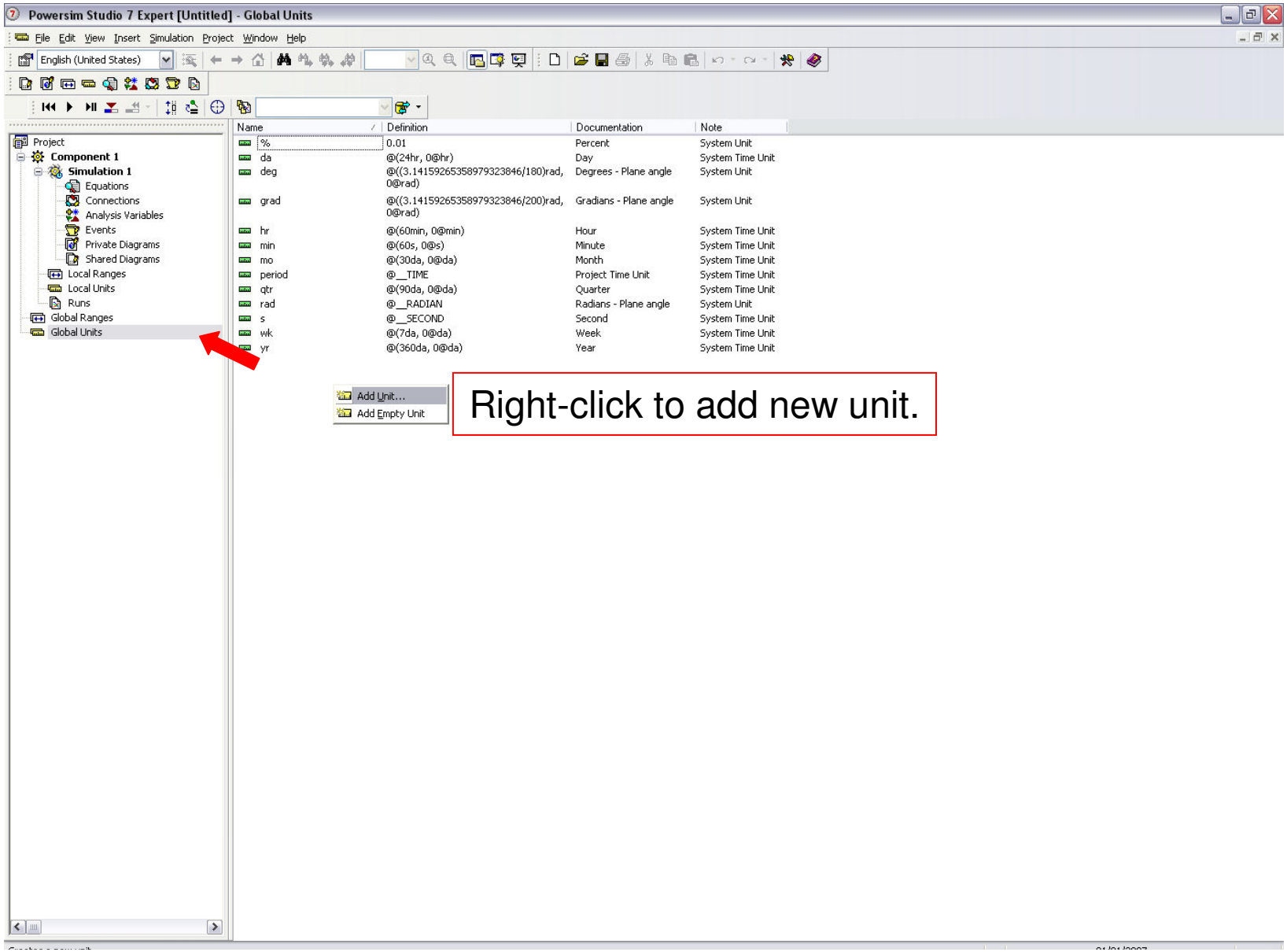
CURRENCY – Variables with currency units will be displayed with the corresponding currency symbol. Currency units can be defined relative to other currencies by an included exchange rate.

DERIVED – A derived unit is dependent upon another unit (it is derived from another unit).

CUSTOM – A custom unit is defined by a custom definition that you can enter freely.

STANDARD – A standard unit comes from Studio's list of built-in standard units.

Add new unit


Powersim Studio 7 Expert [Untitled] - Global Units
File Edit View Insert Simulation Project Window Help
English (United States)
Project
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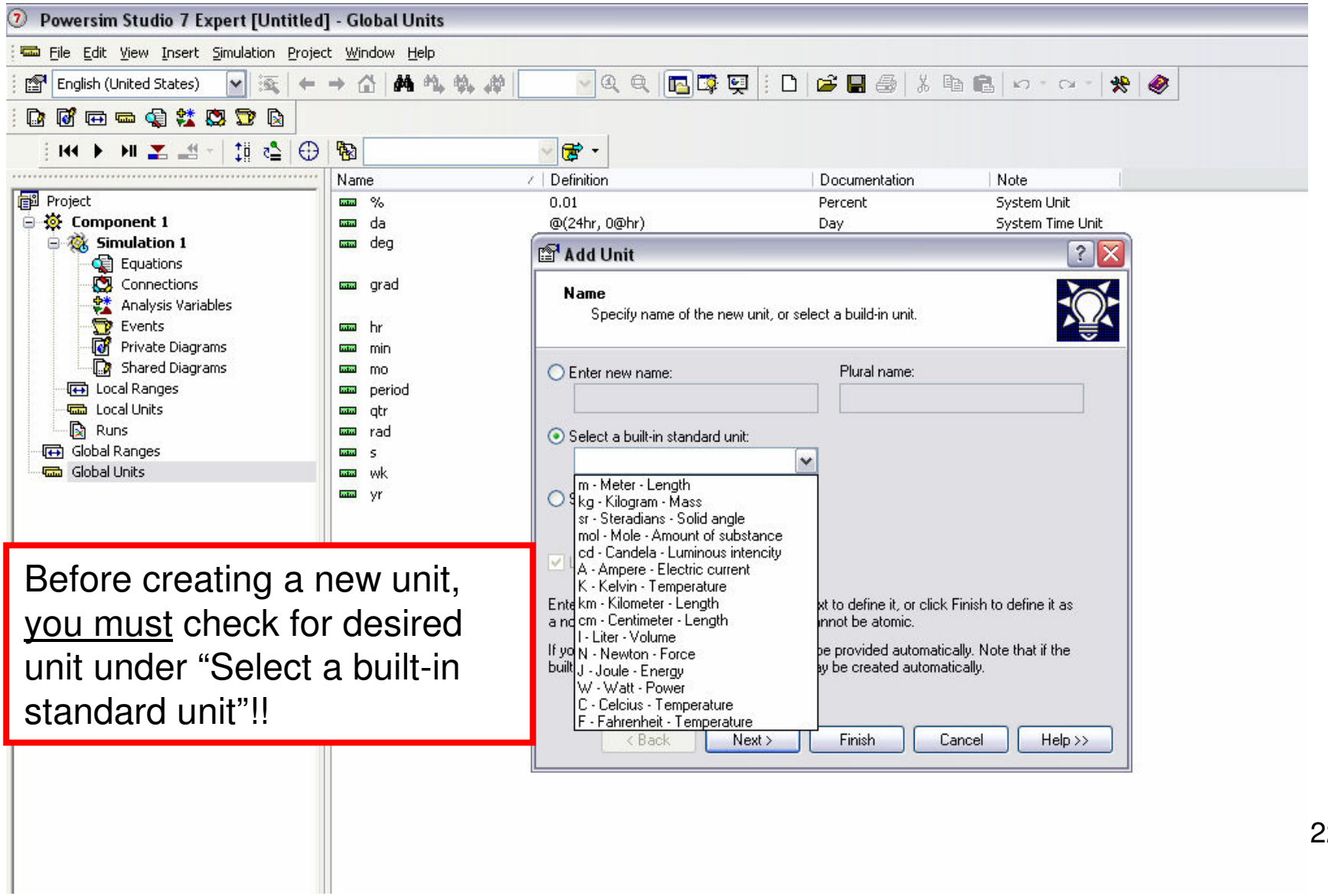
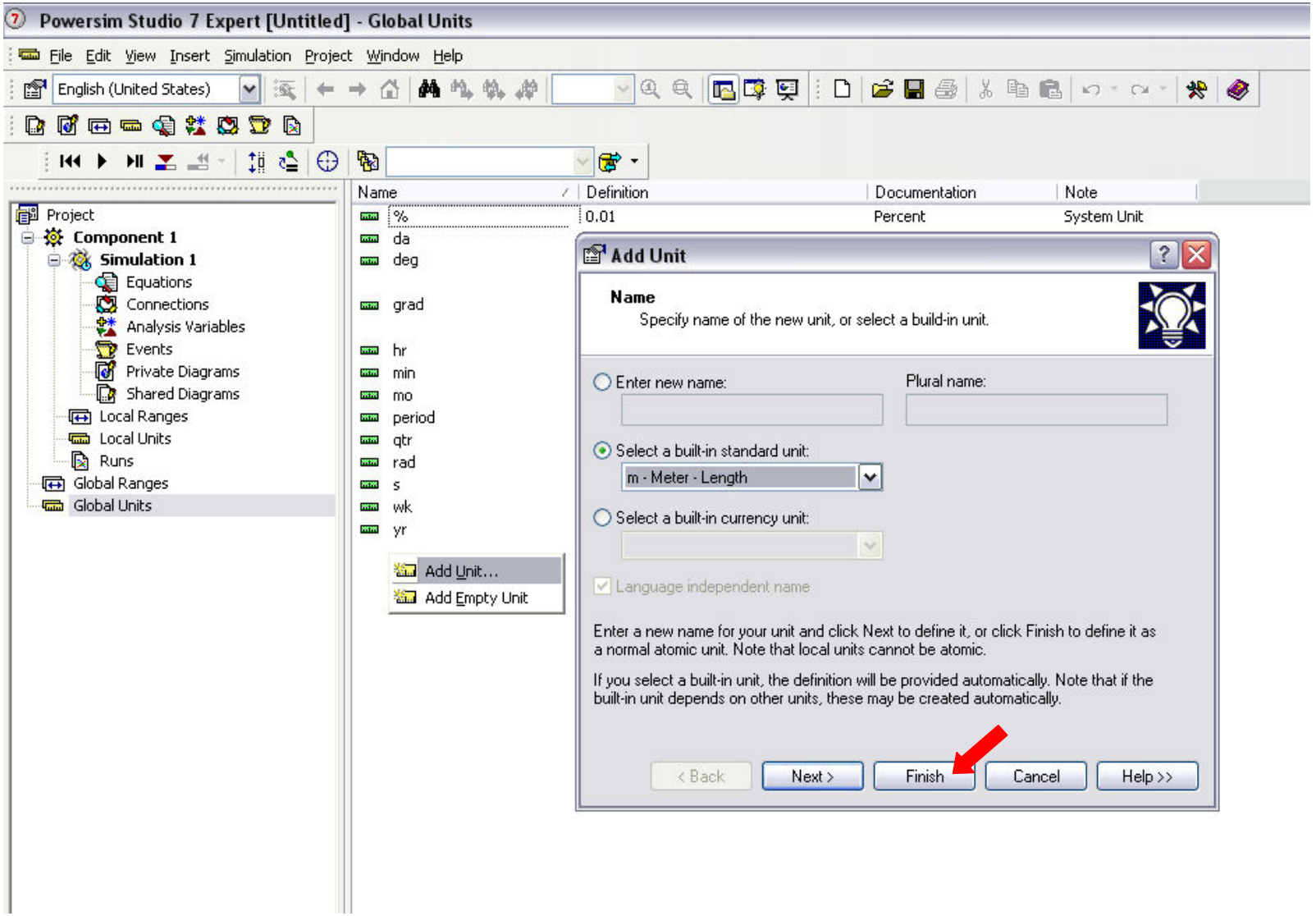
s @__SECOND Second System Time Unit
wk @(7da, 0@da) Week System Time Unit
yr @(360da, 0@da) Year System Time Unit
Add Unit...
Add Empty Unit
Right-click to add new unit.

Add new unit

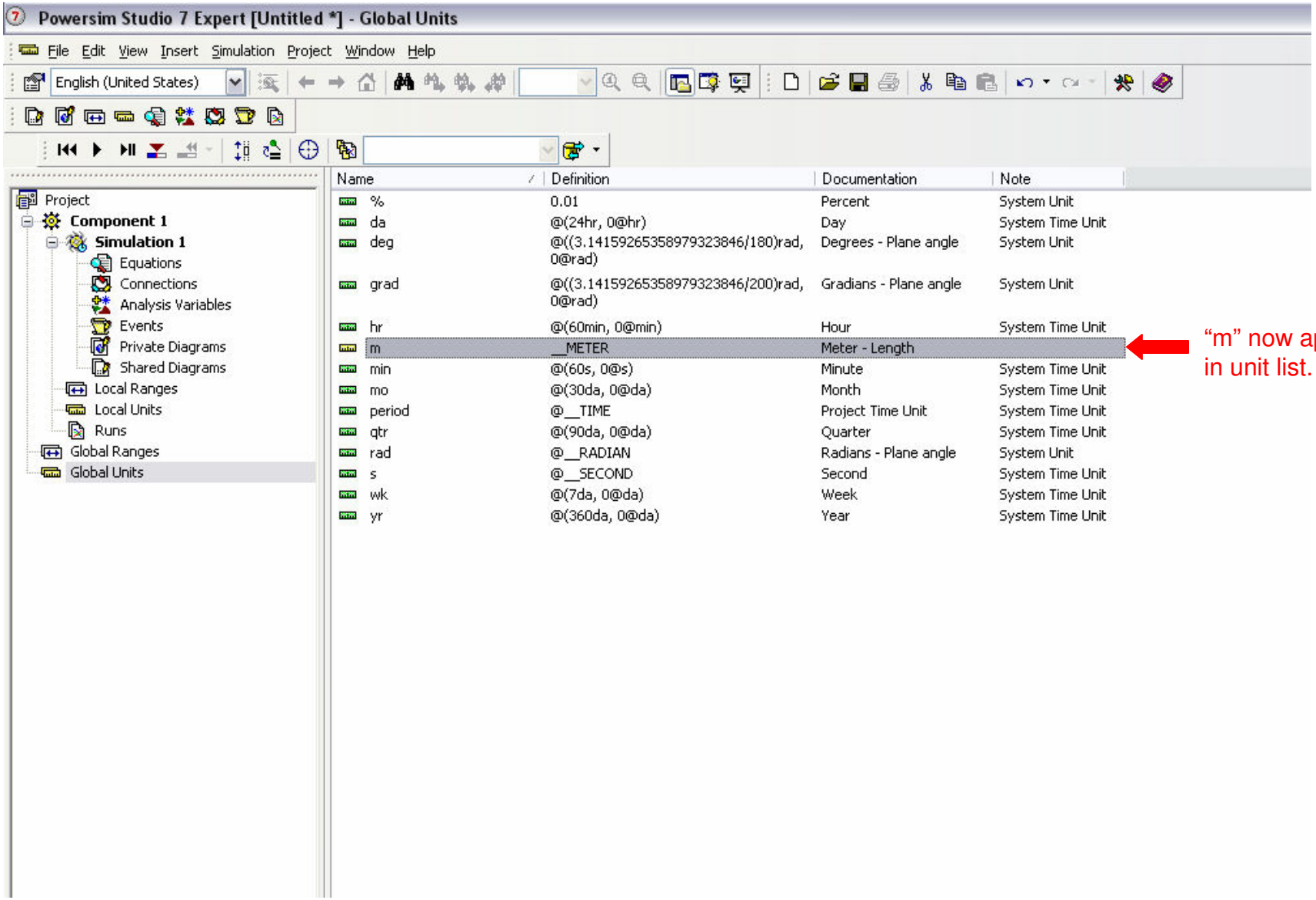


Before creating a new unit, <u>you must</u> check for desired unit under “Select a built-in standard unit”!!

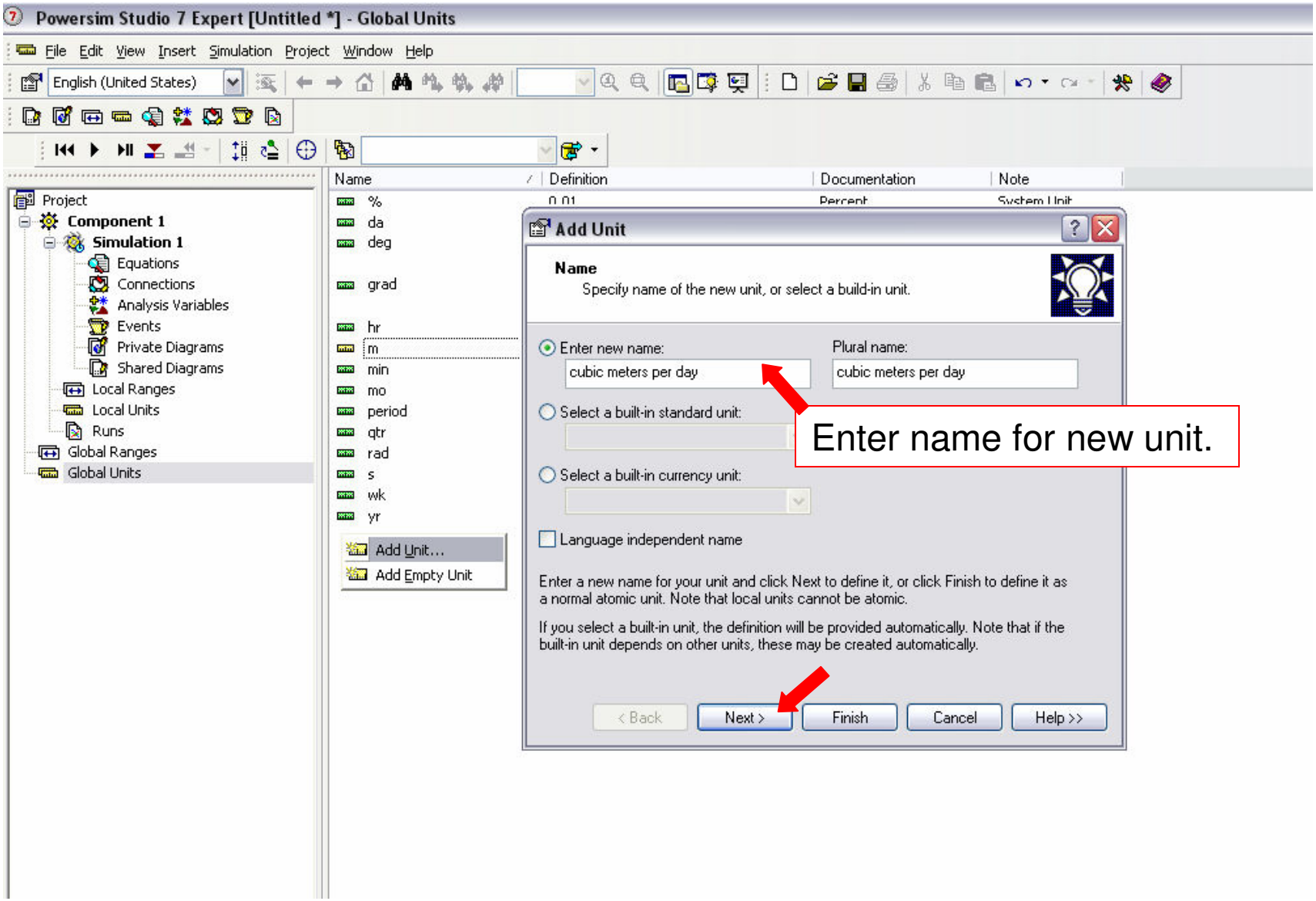
Create Unit "cubic meters per day"



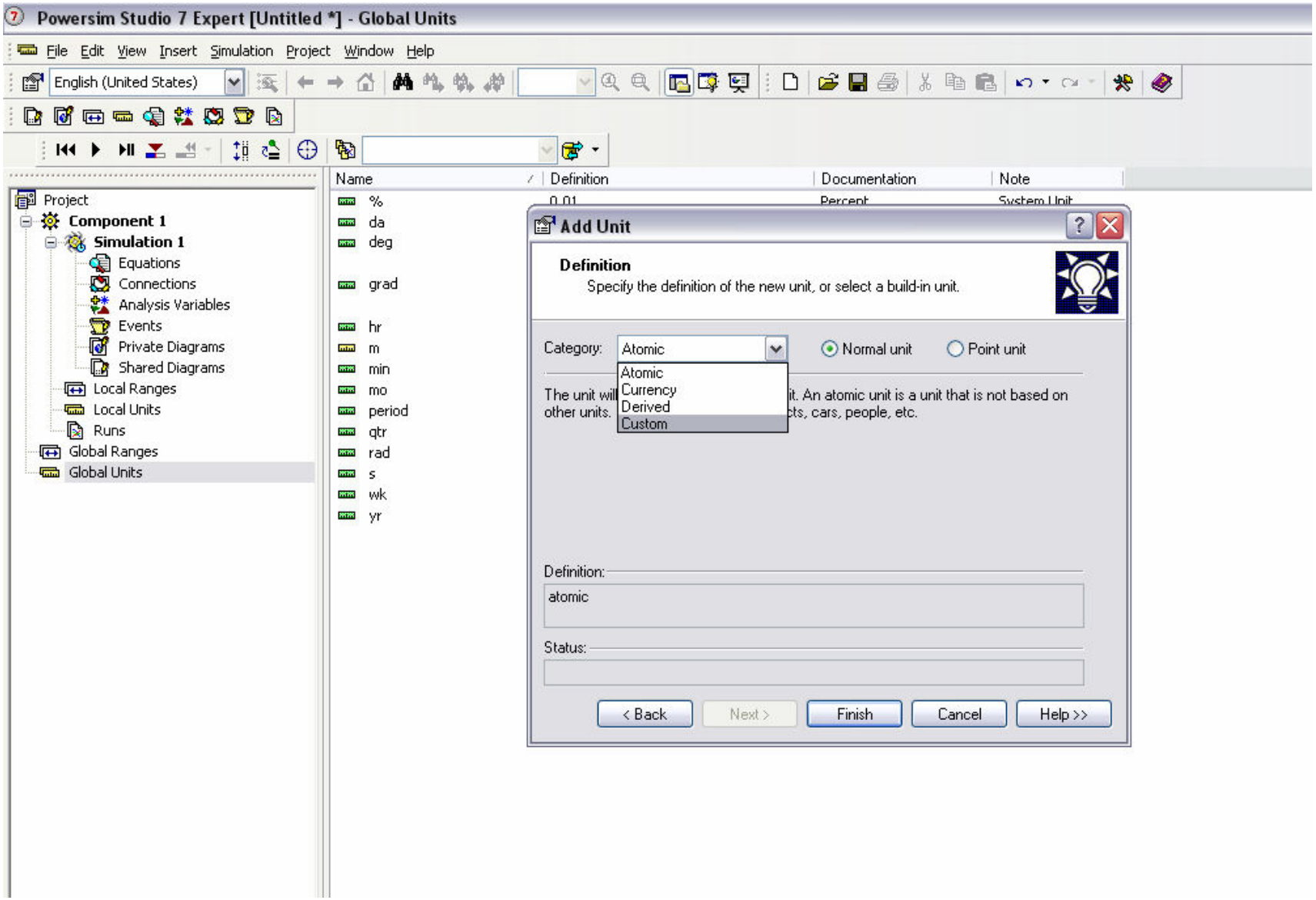
Create Unit "cubic meters per day"



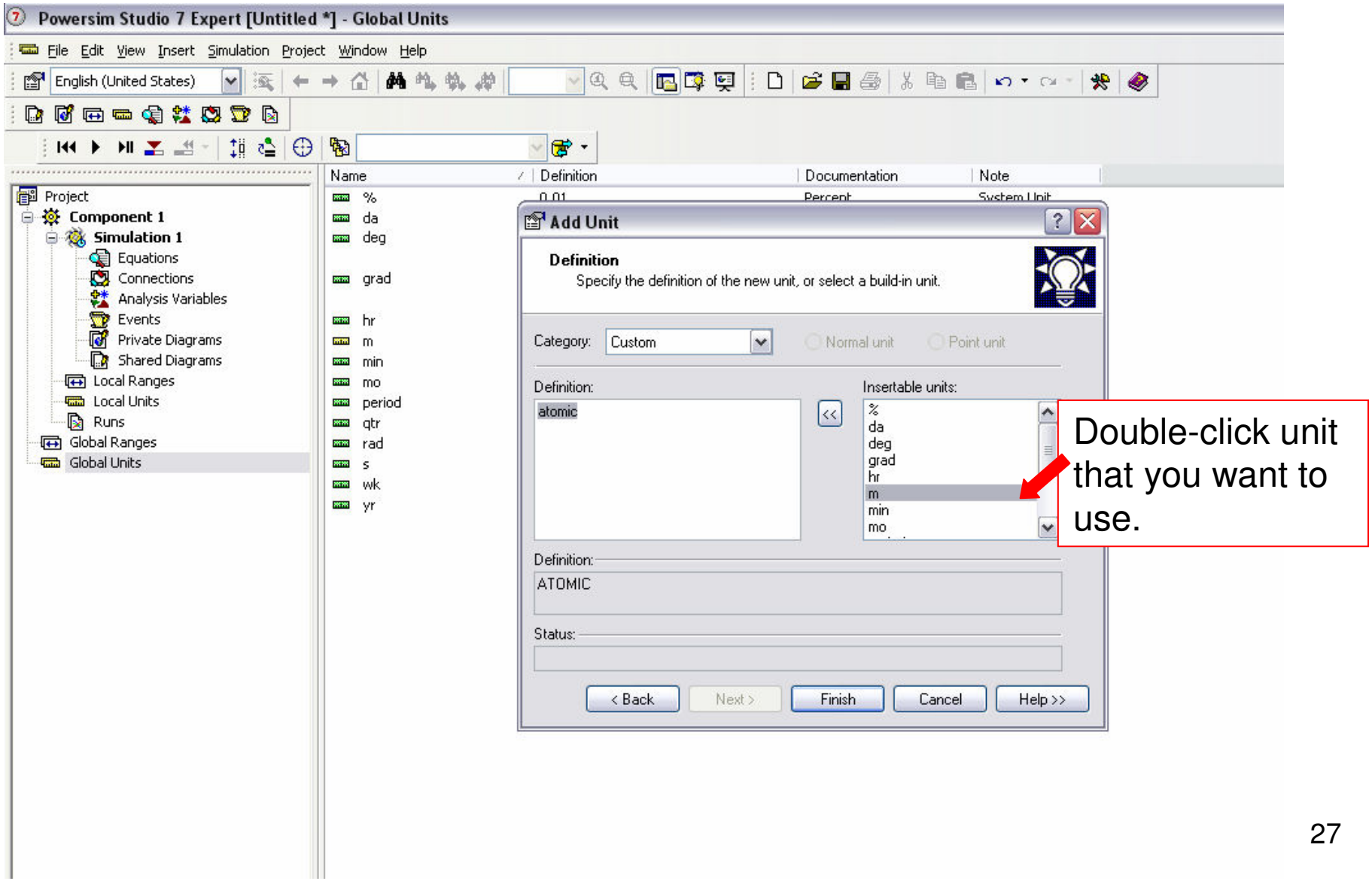
Create Unit "cubic meters per day"



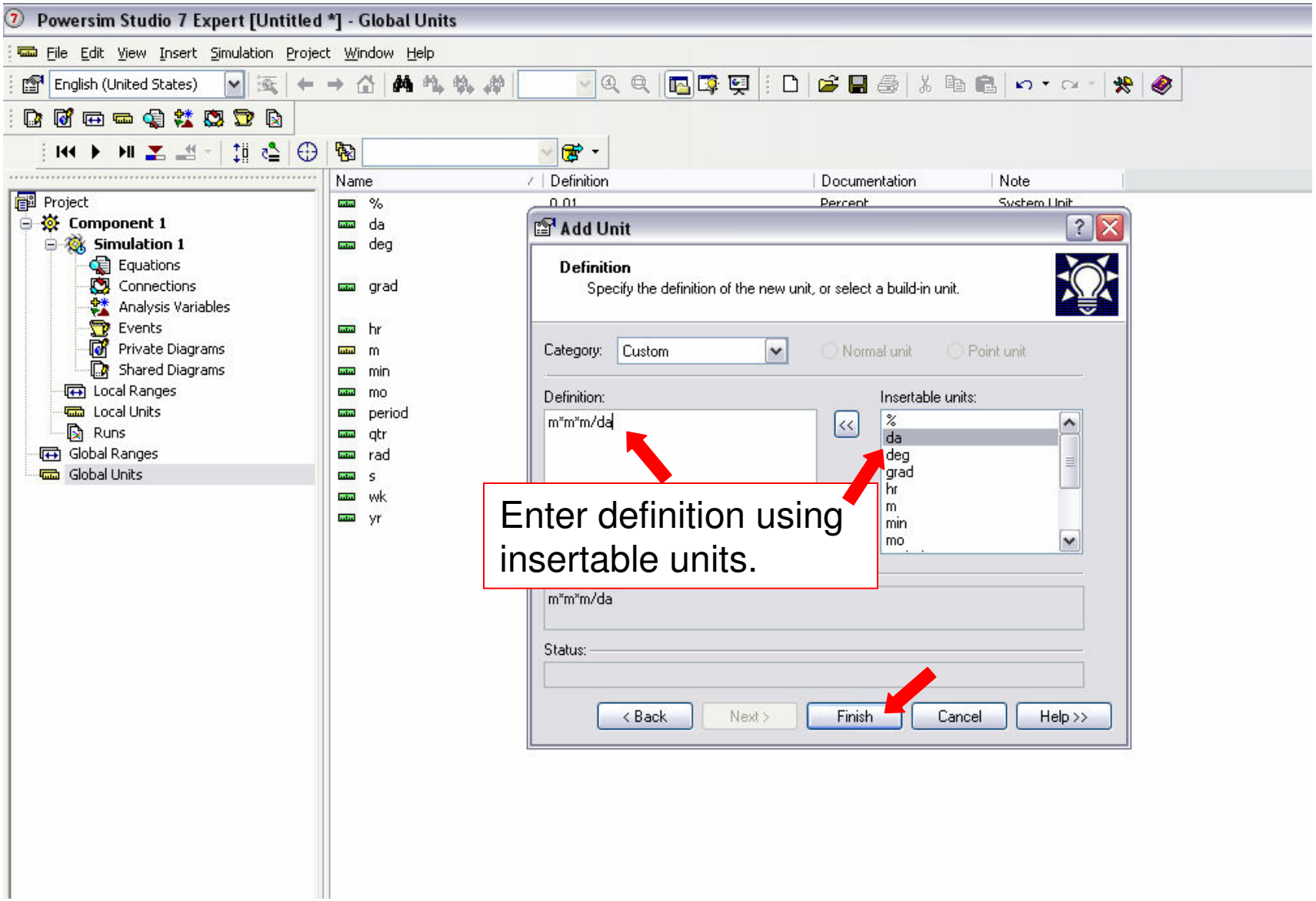
Create Unit "cubic meters per day"



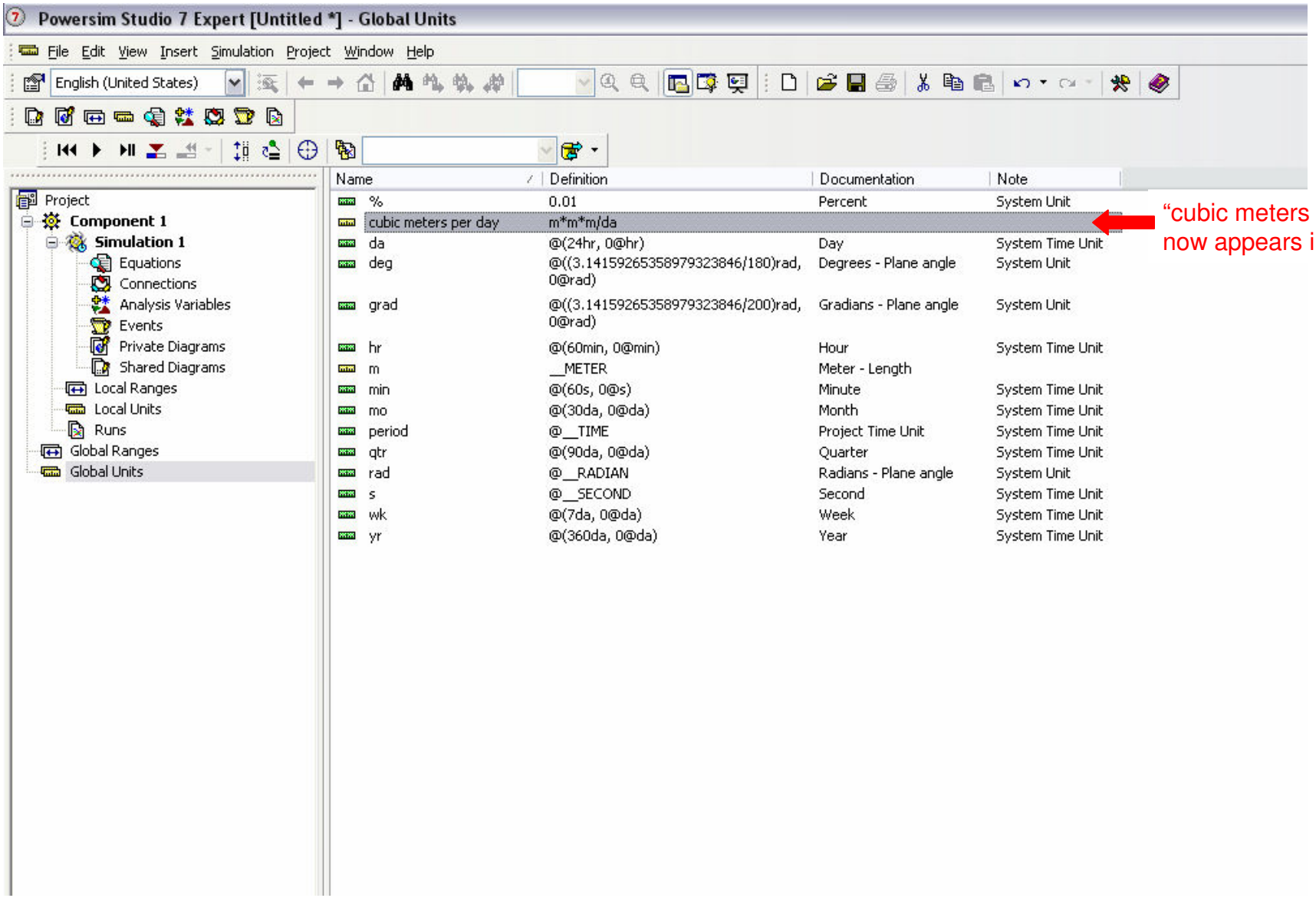
Create Unit "cubic meters per day"



Create Unit "cubic meters per day"

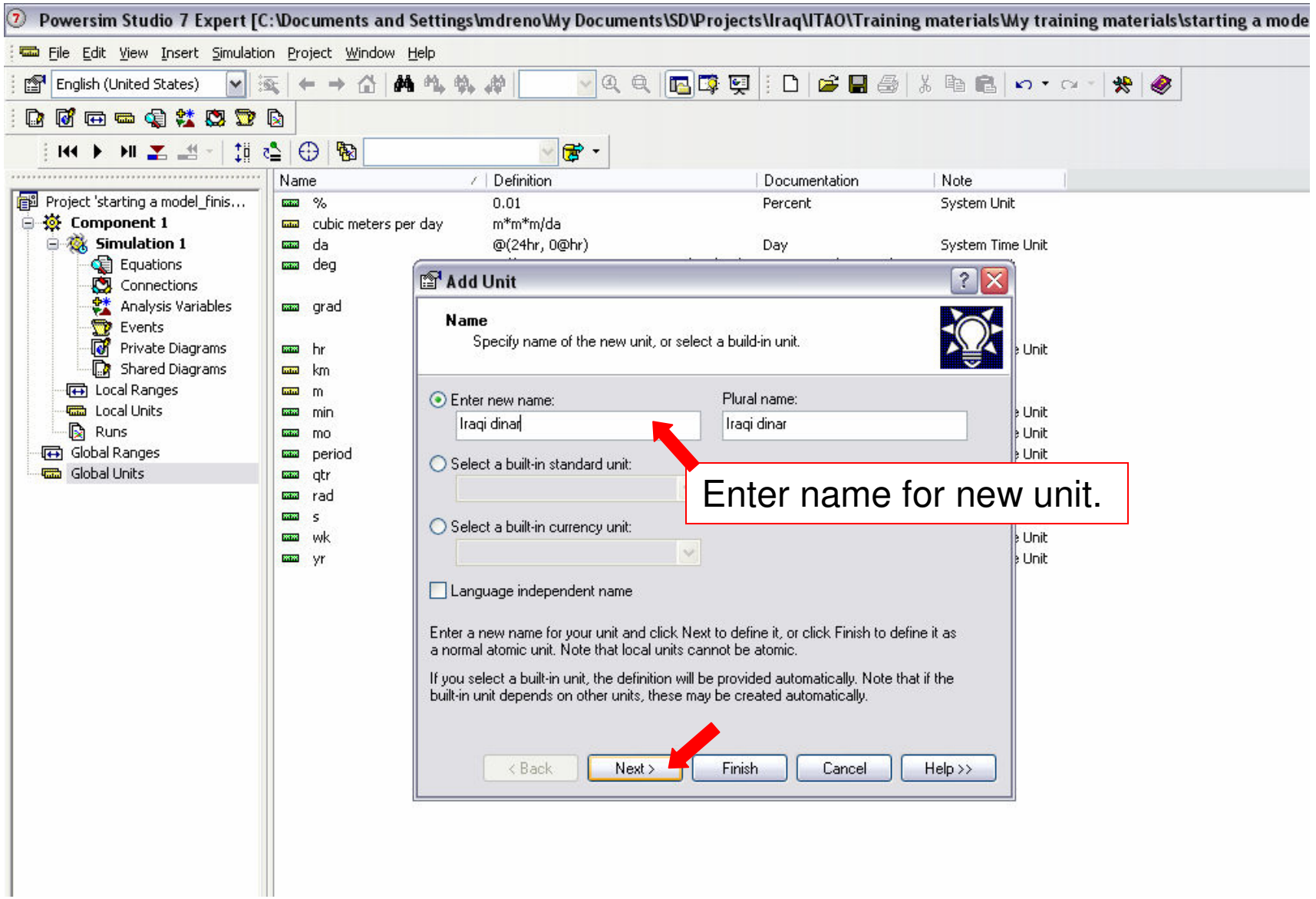


Create Unit "cubic meters per day"

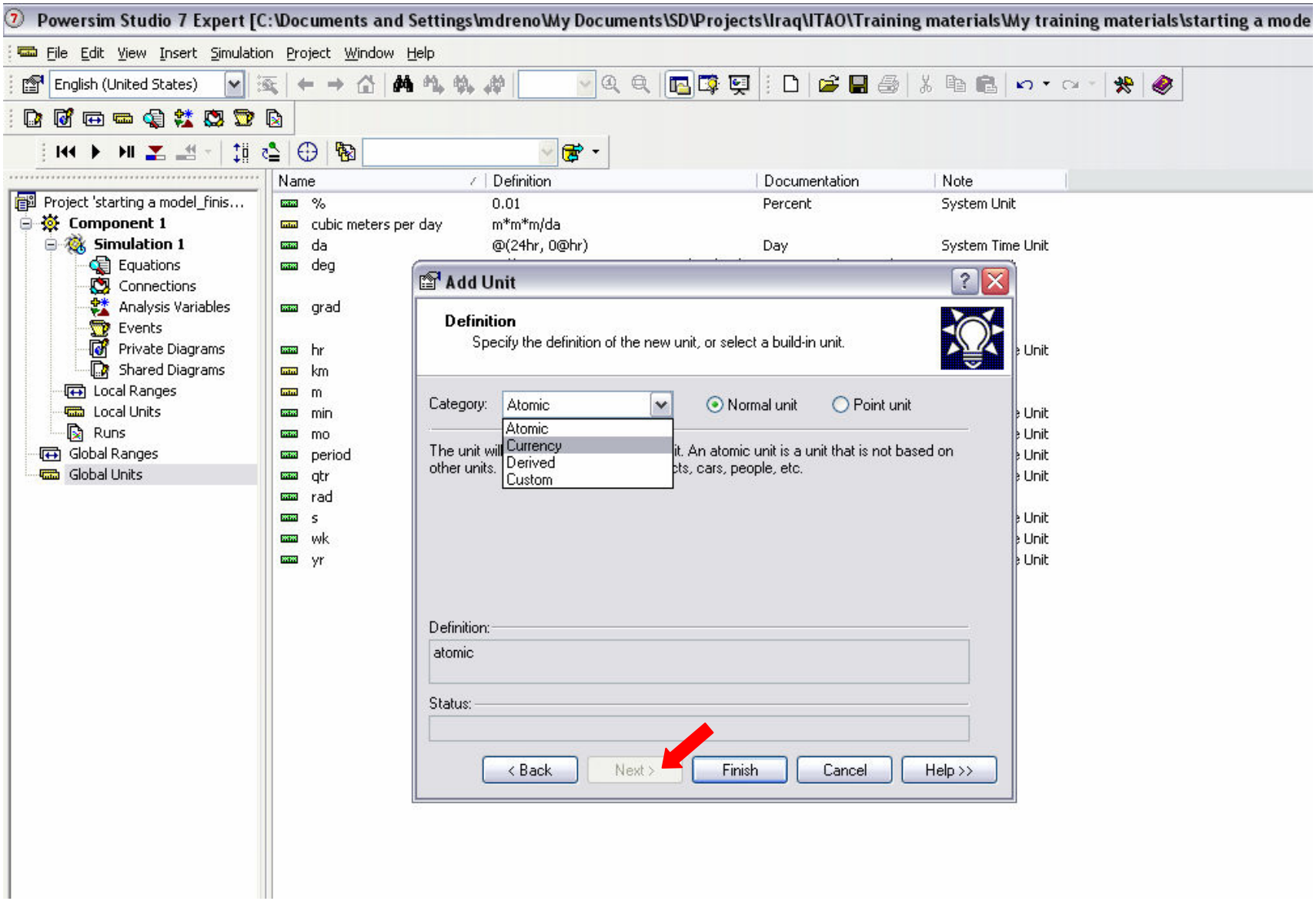


"cubic meters per day" now appears in unit list.

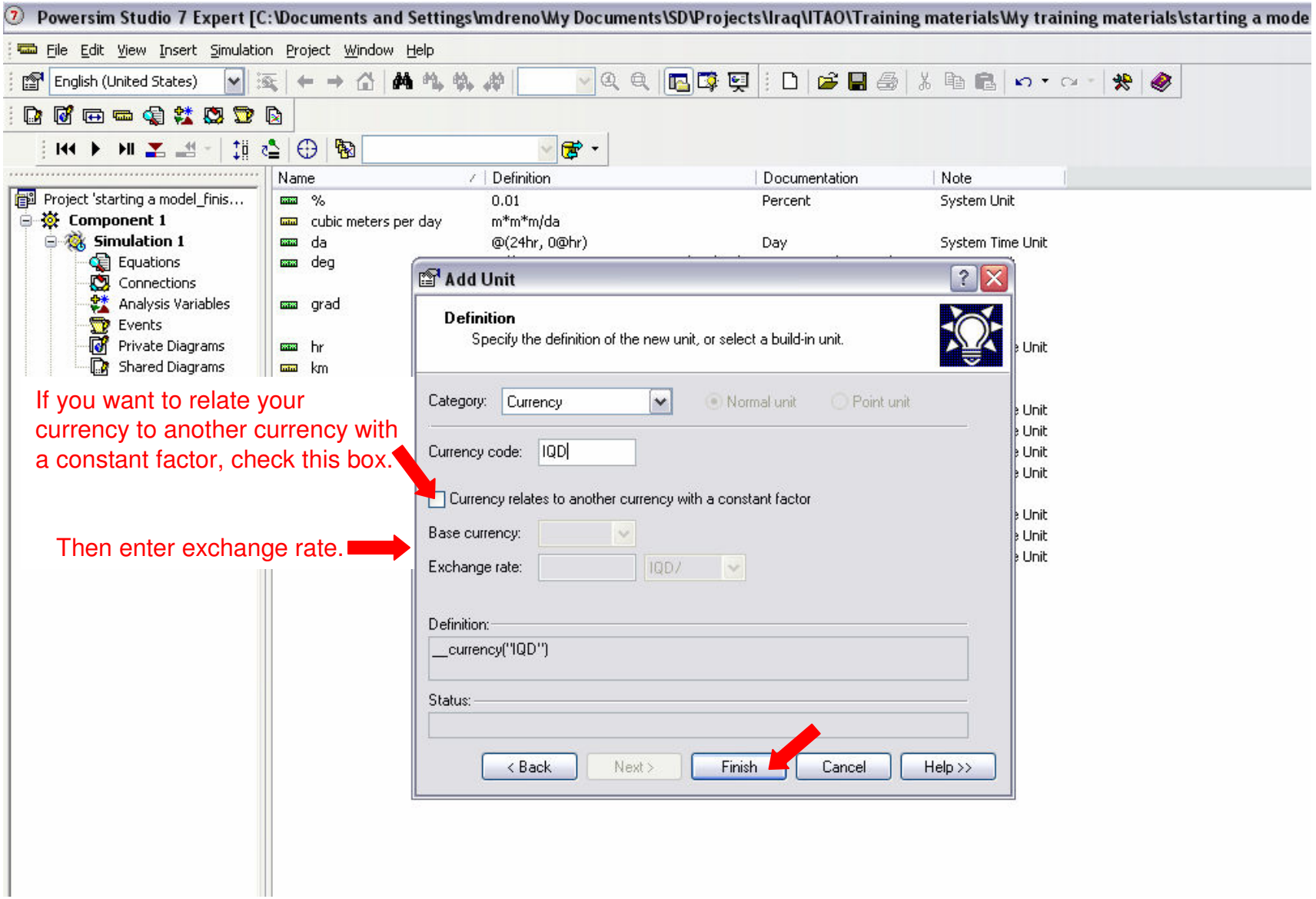
Create Unit "Iraqi dinar"



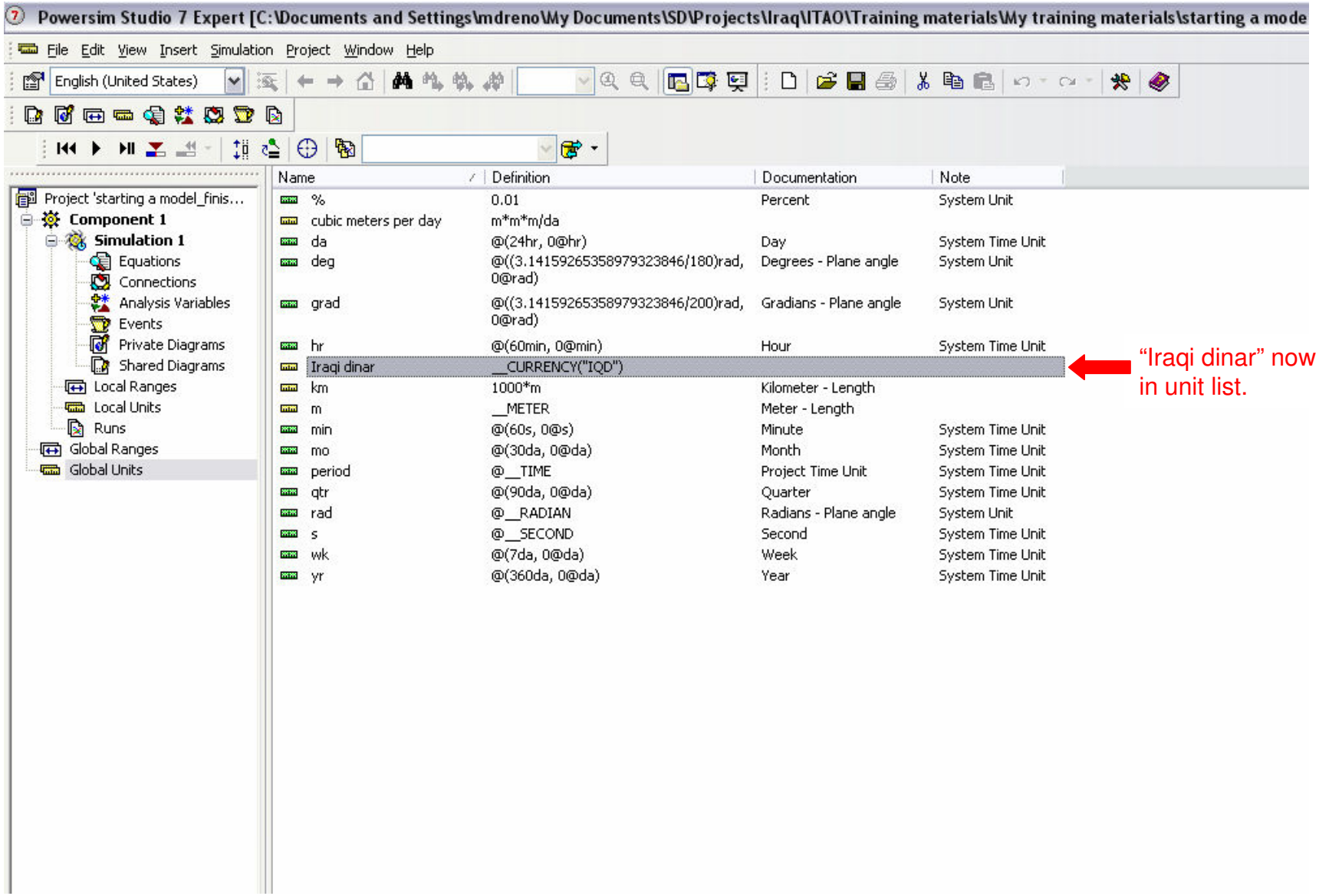
Create Unit "Iraqi dinar"



Create Unit "Iraqi dinar"

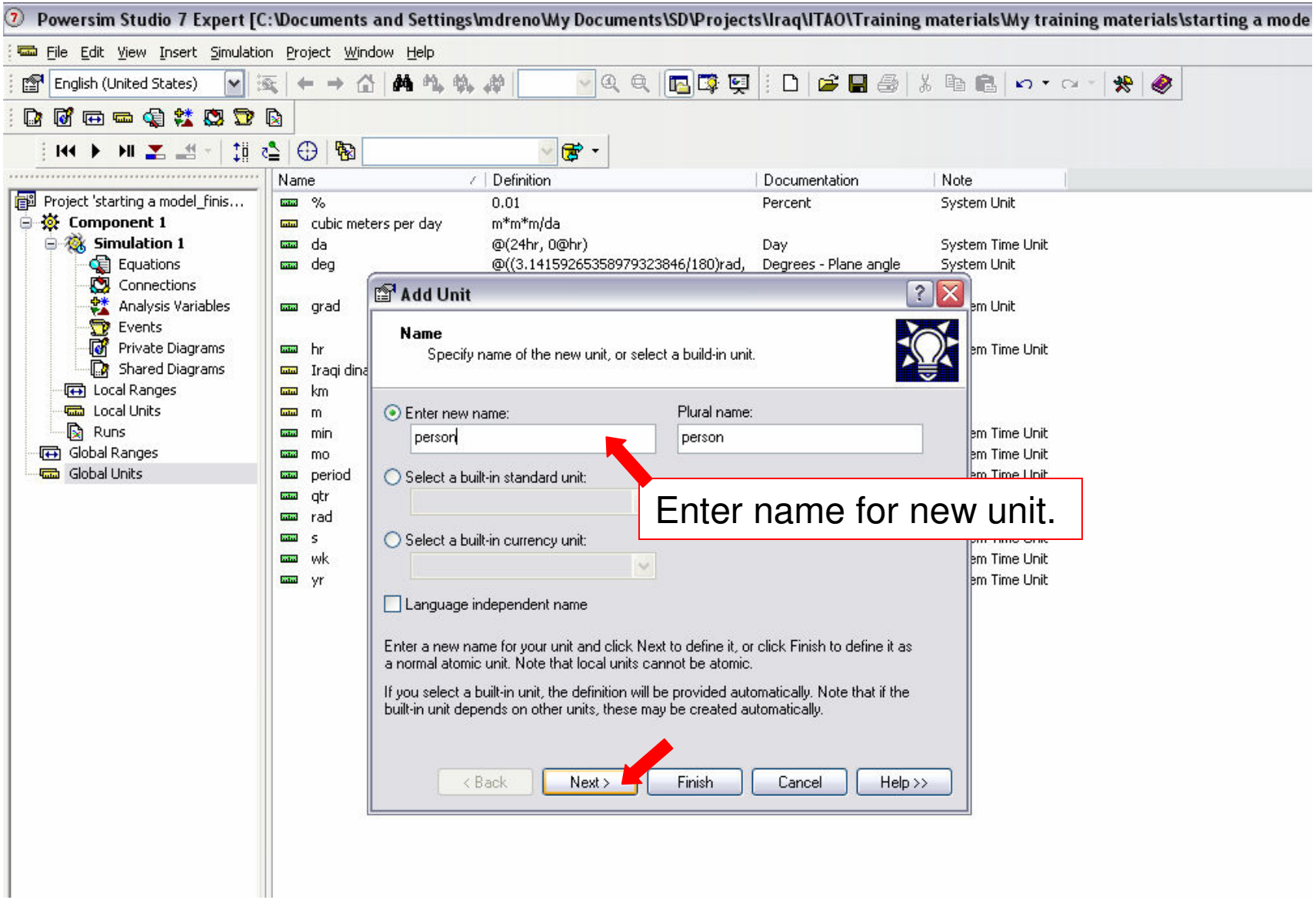


Create Unit "Iraqi dinar"

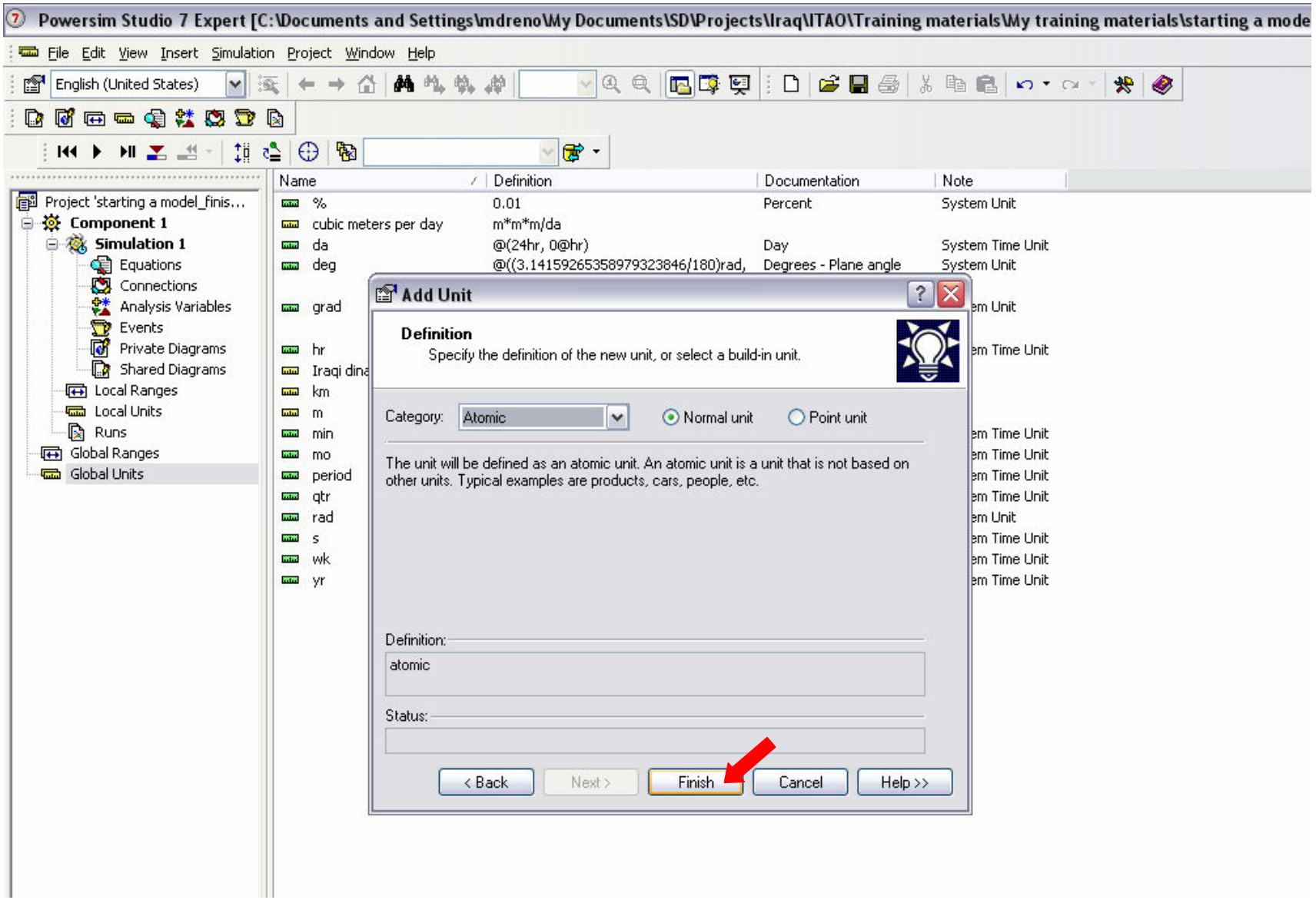


"Iraqi dinar" now appears in unit list.

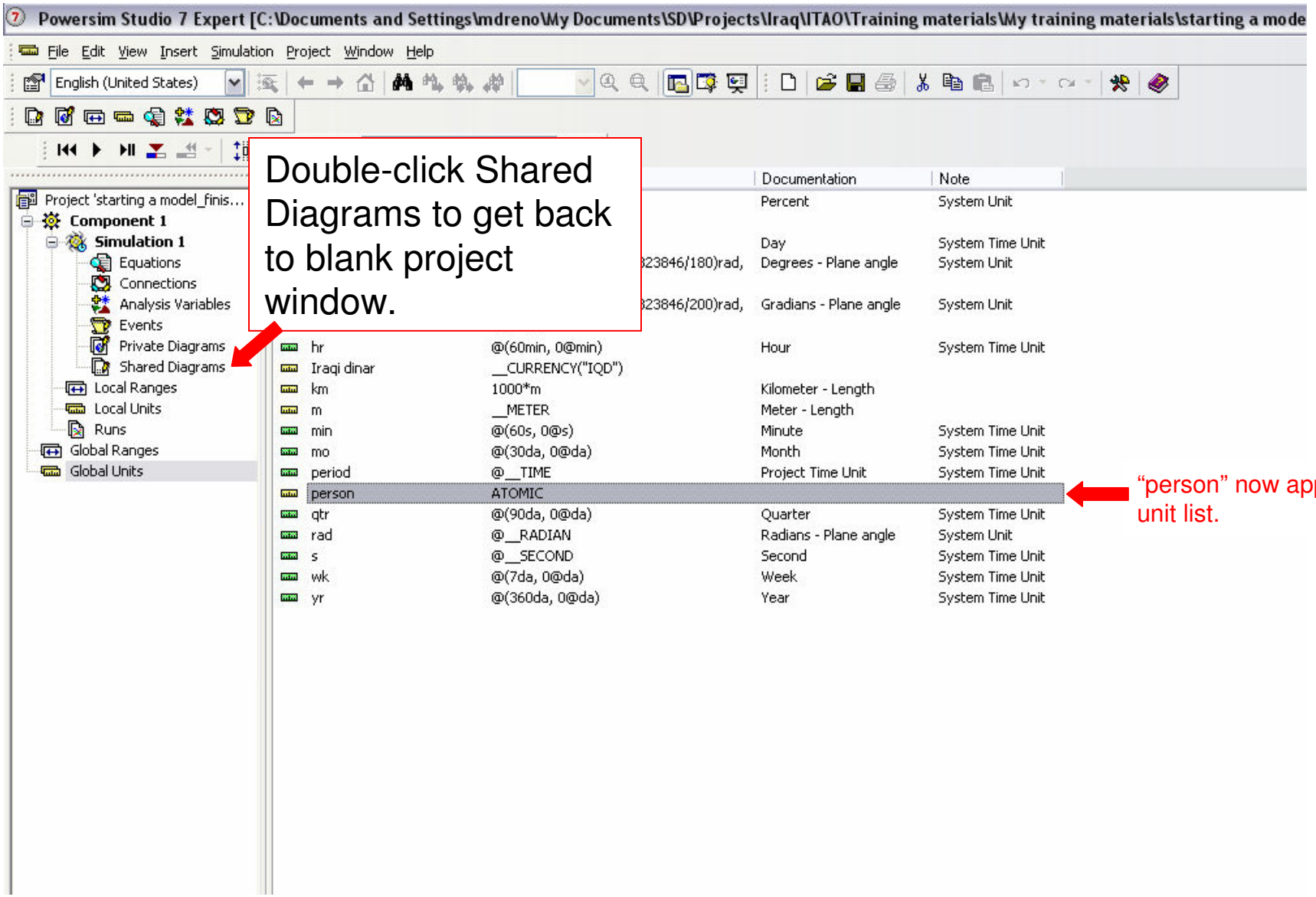
Create Unit "person"



Create Unit "person"

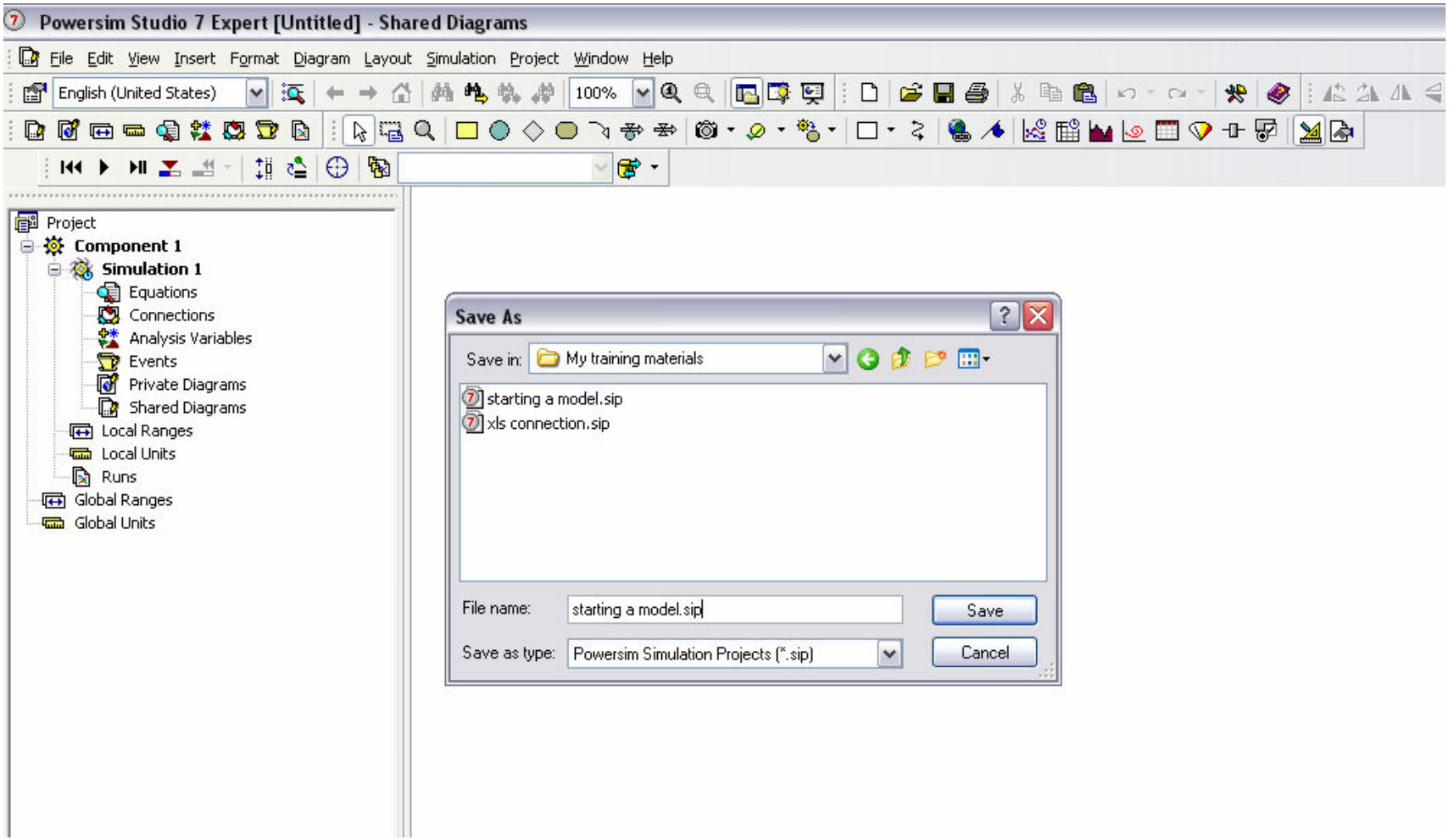


Create Unit "person"

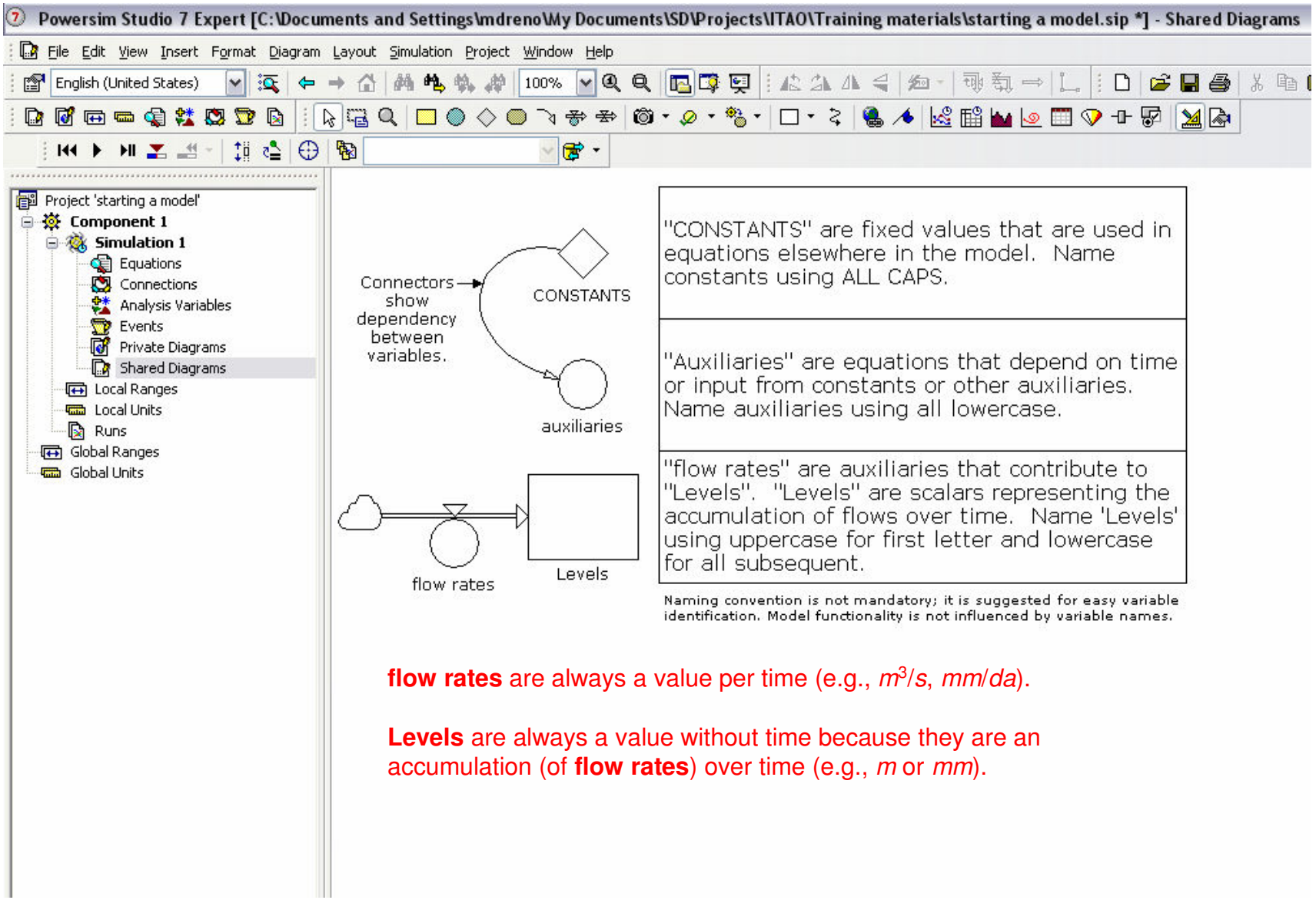


Save model

File → Save → *Enter name of your choice*.



Basic model building blocks

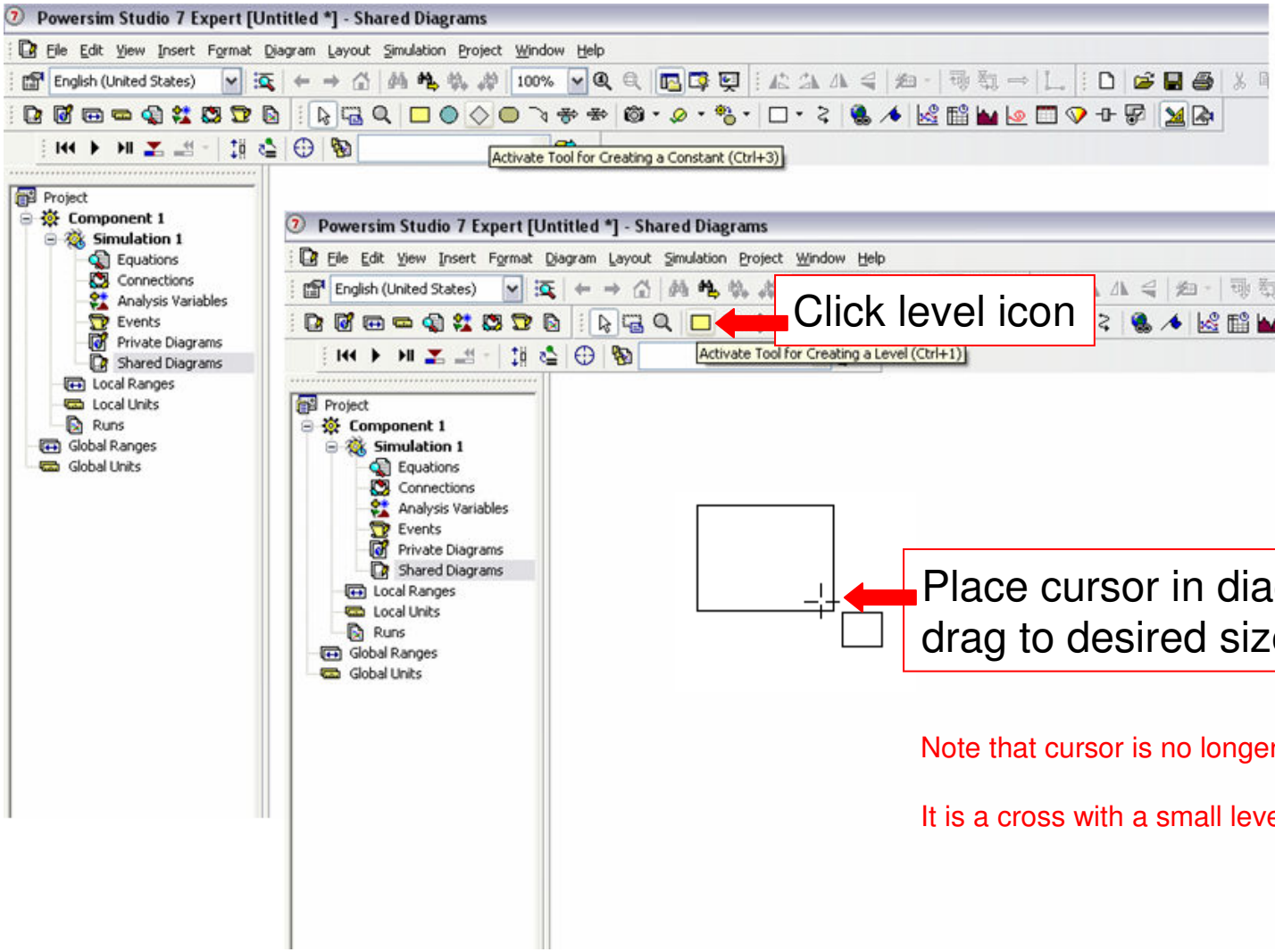


flow rates are always a value per time (e.g., m^3/s, *mm*/*da*).

Levels are always a value without time because they are an accumulation (of **flow rates**) over time (e.g., *m* or *mm*).

Basic model building blocks

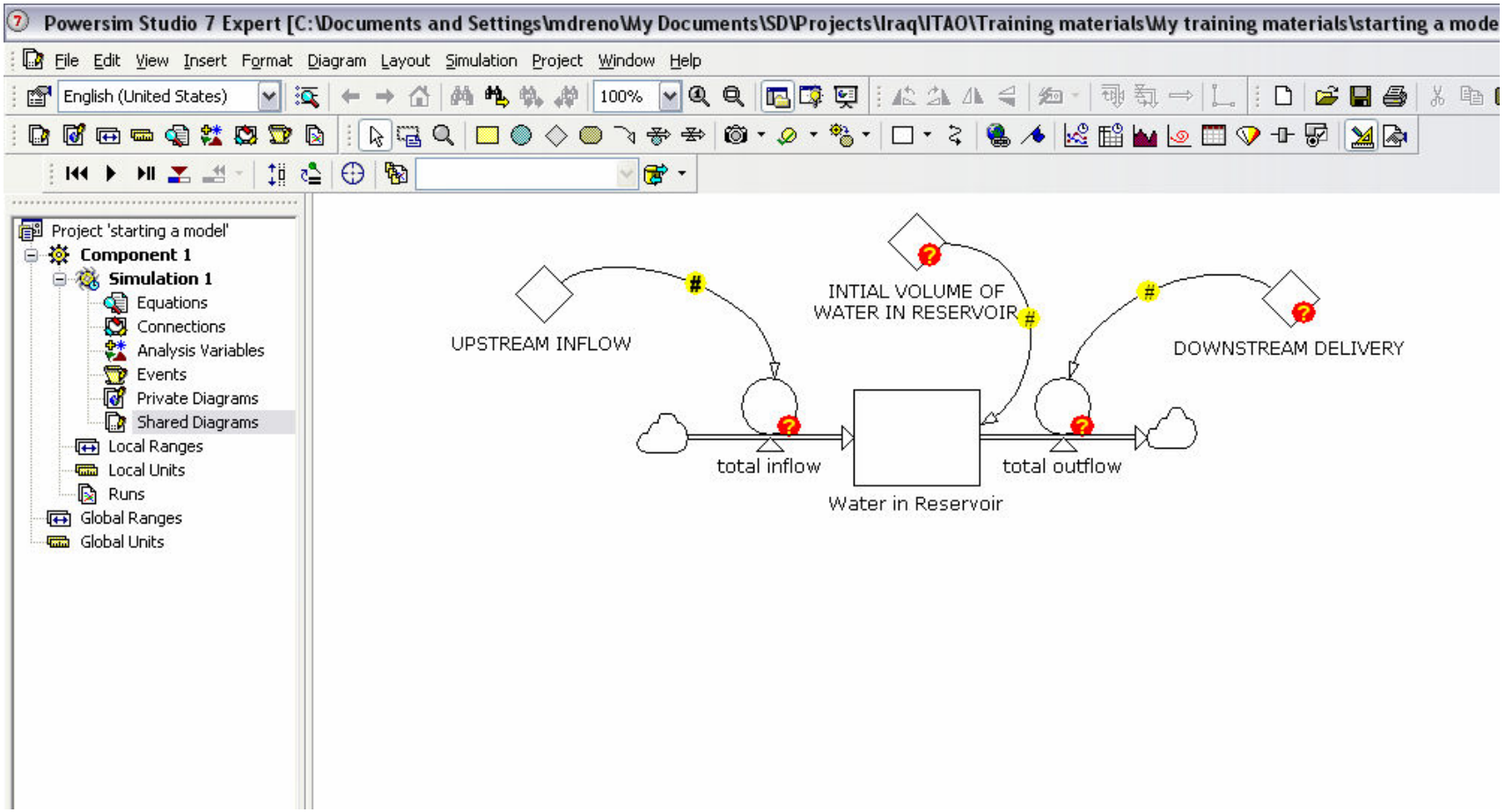
To add a constant, auxiliary, or level to your model, click the appropriate icon, place cursor in blank part of screen, hold down left mouse key, and drag to desired size.



Basic model building blocks

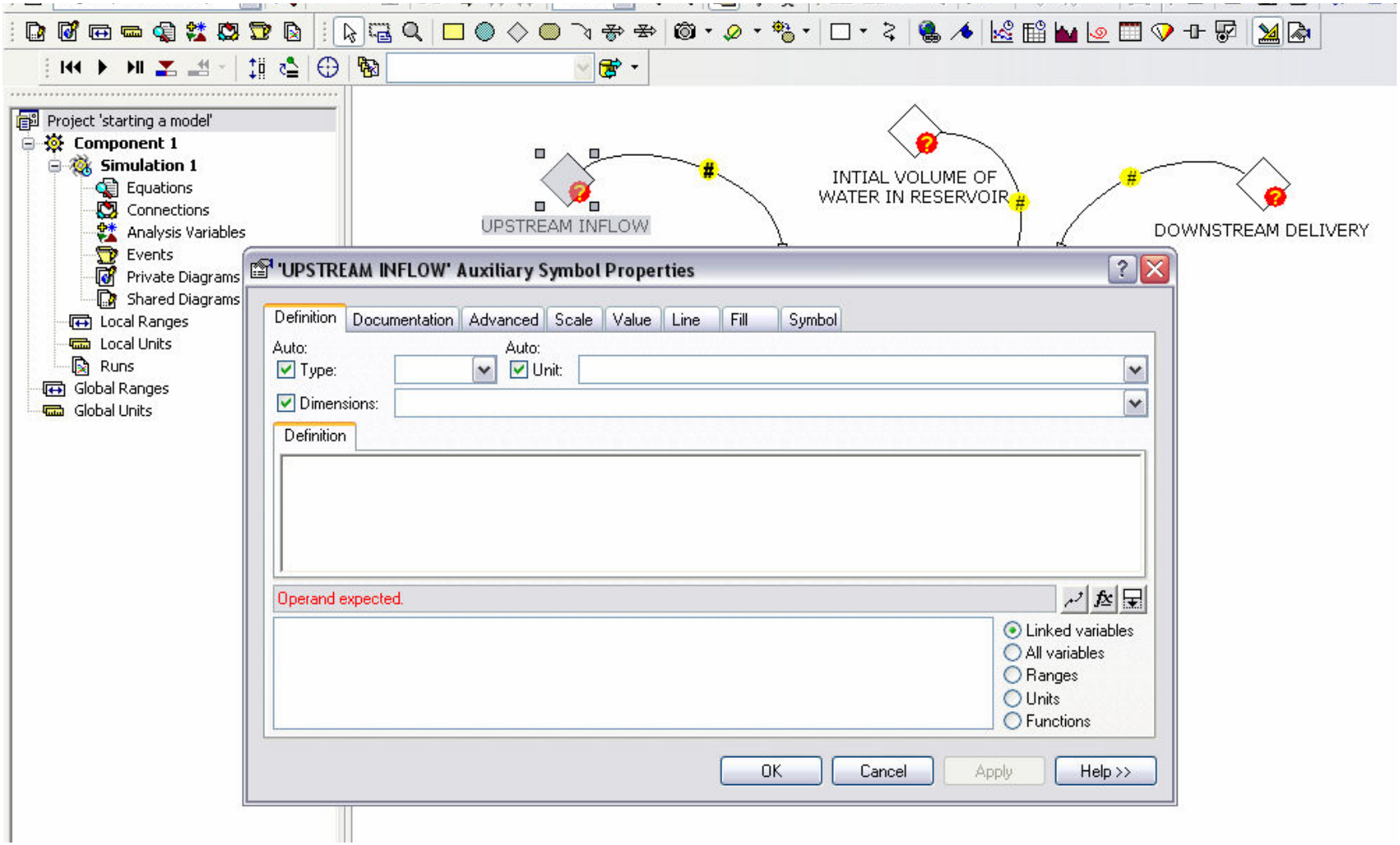
Suppose you want to model the volume of water in a reservoir. For now, we will consider greatly simplified inflow and outflow.

Step 1: Create model skeleton.



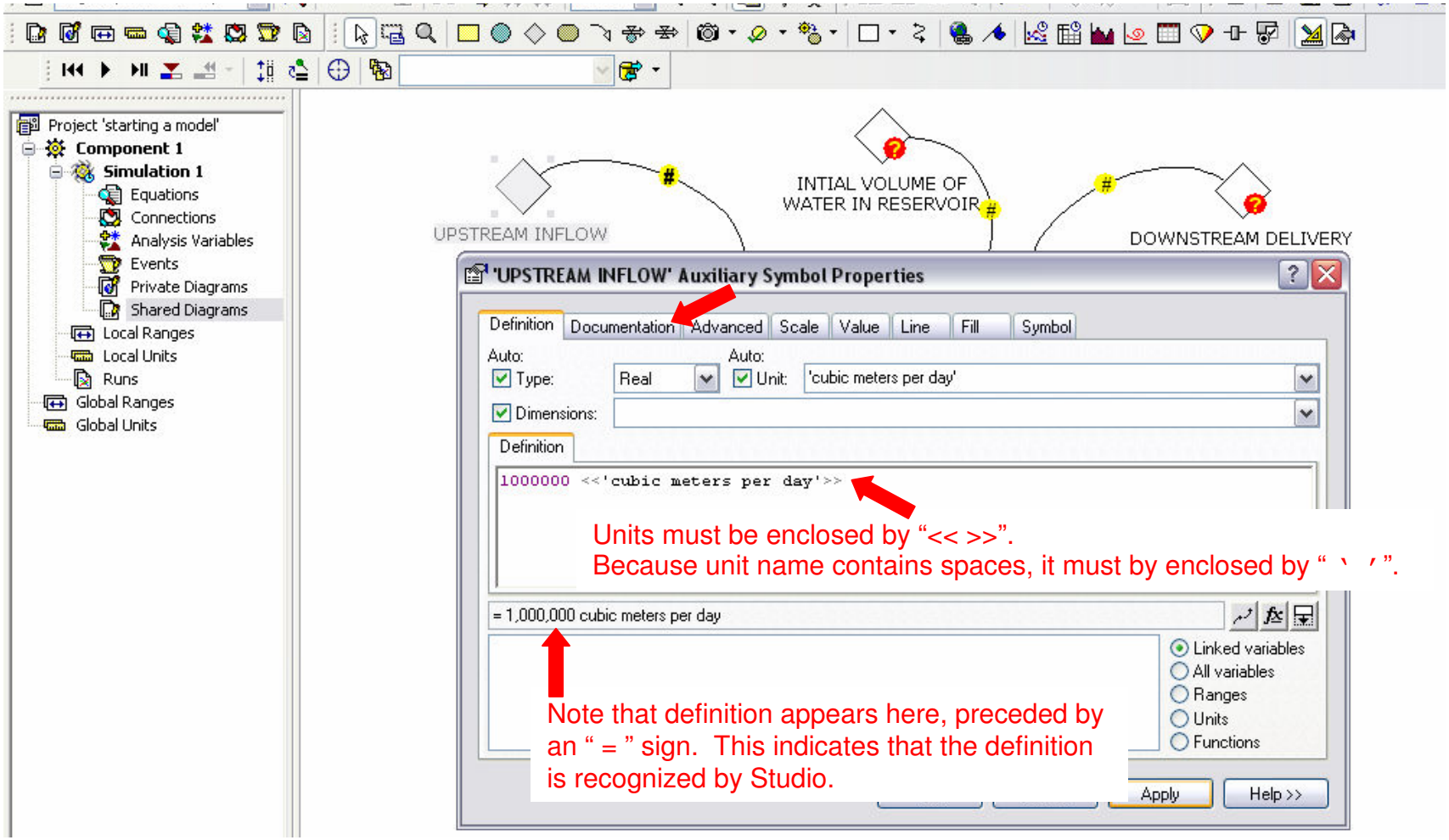
Basic model building blocks

Step 2: Define constants, auxiliaries, and level. Double-click variable to open it and add definition. Completing this step will make the warning (#) and error (?) symbols disappear.



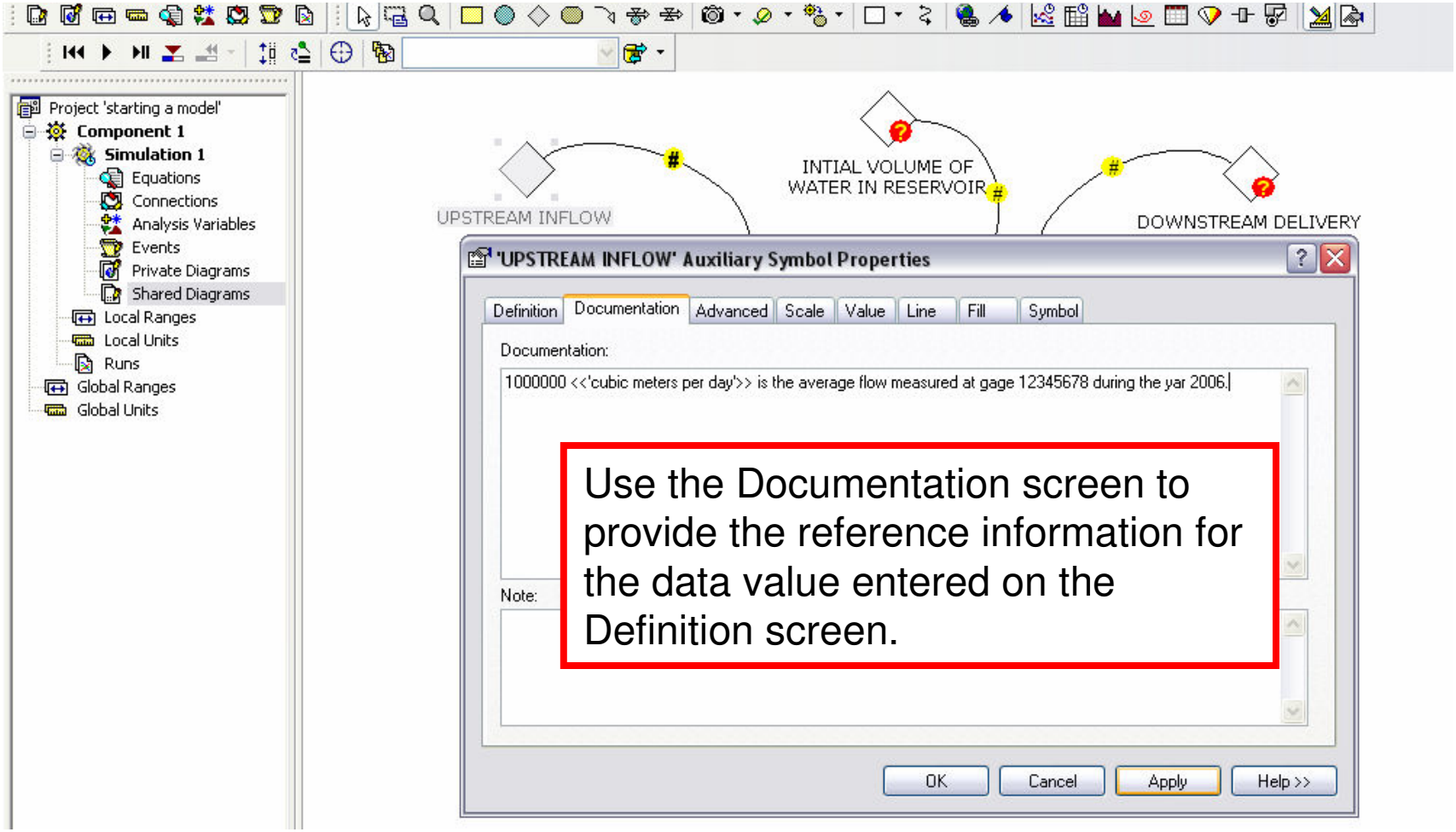
Basic model building blocks

Enter definition for **UPSTREAM INFLOW** and click “Apply”. Then go to Documentation tab.



Basic model building blocks

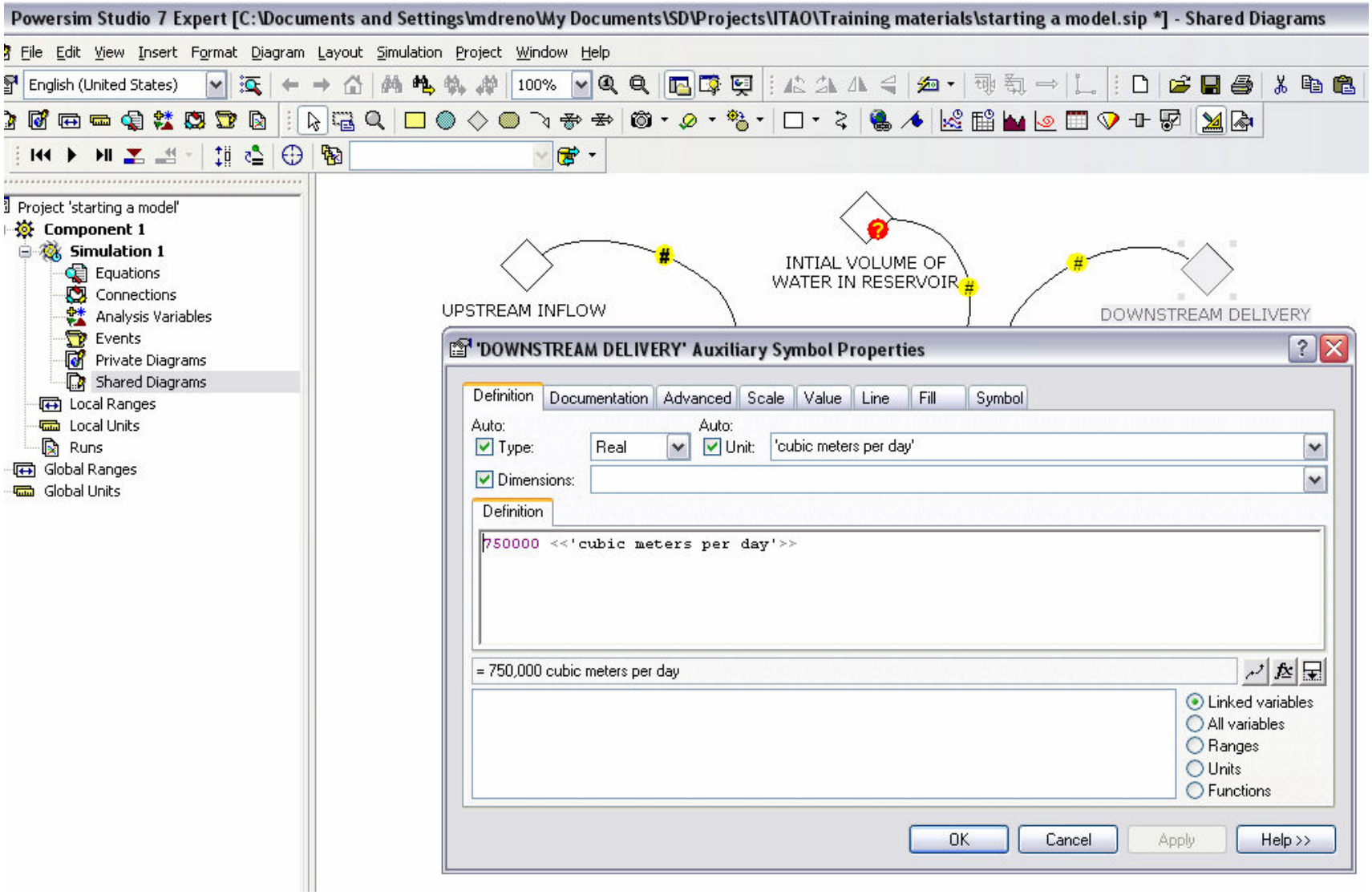
Add documentation text.



Use the Documentation screen to provide the reference information for the data value entered on the Definition screen.

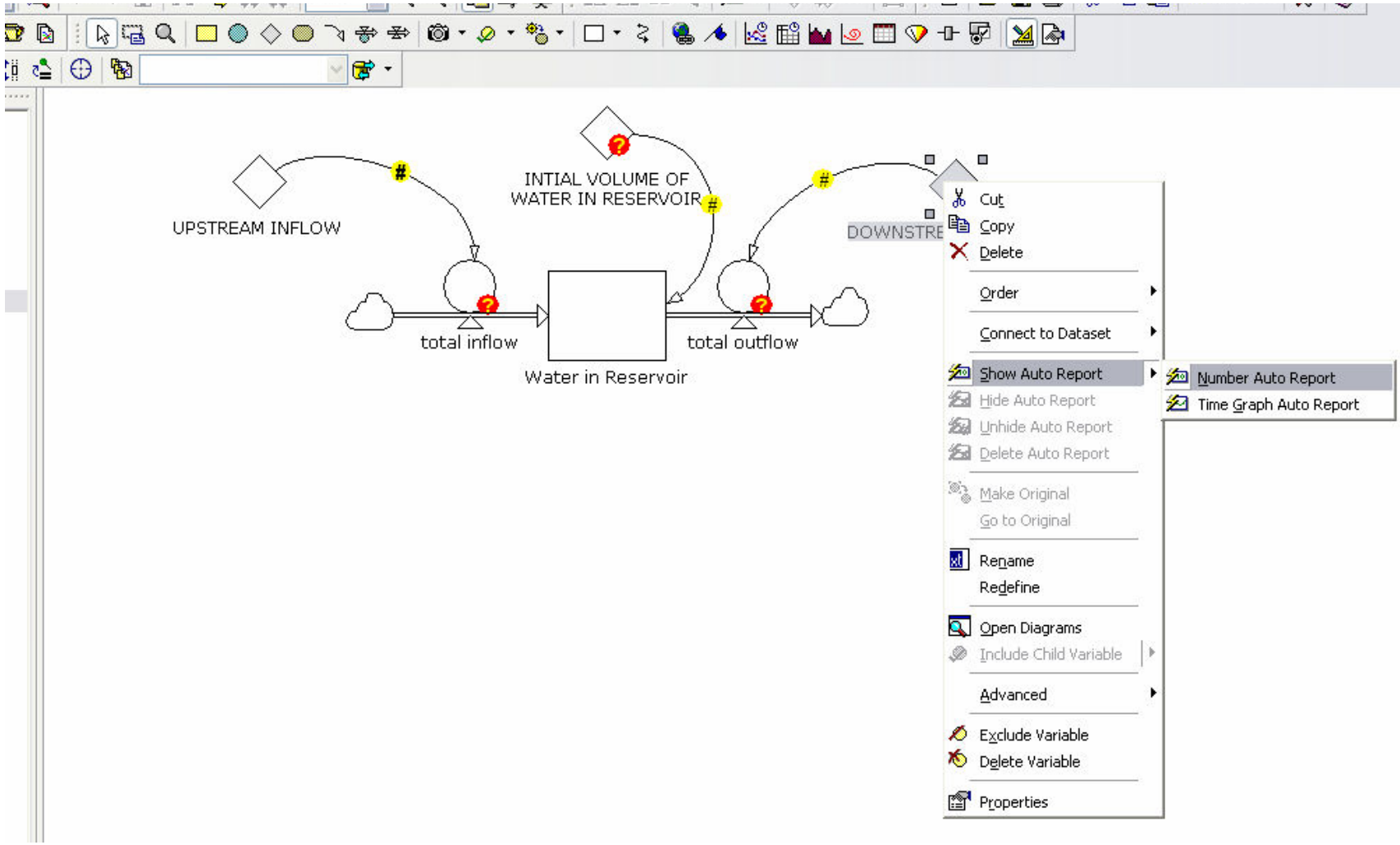
Basic model building blocks

Enter definition for **DOWNSTREAM DELIVERY** and click “OK”.



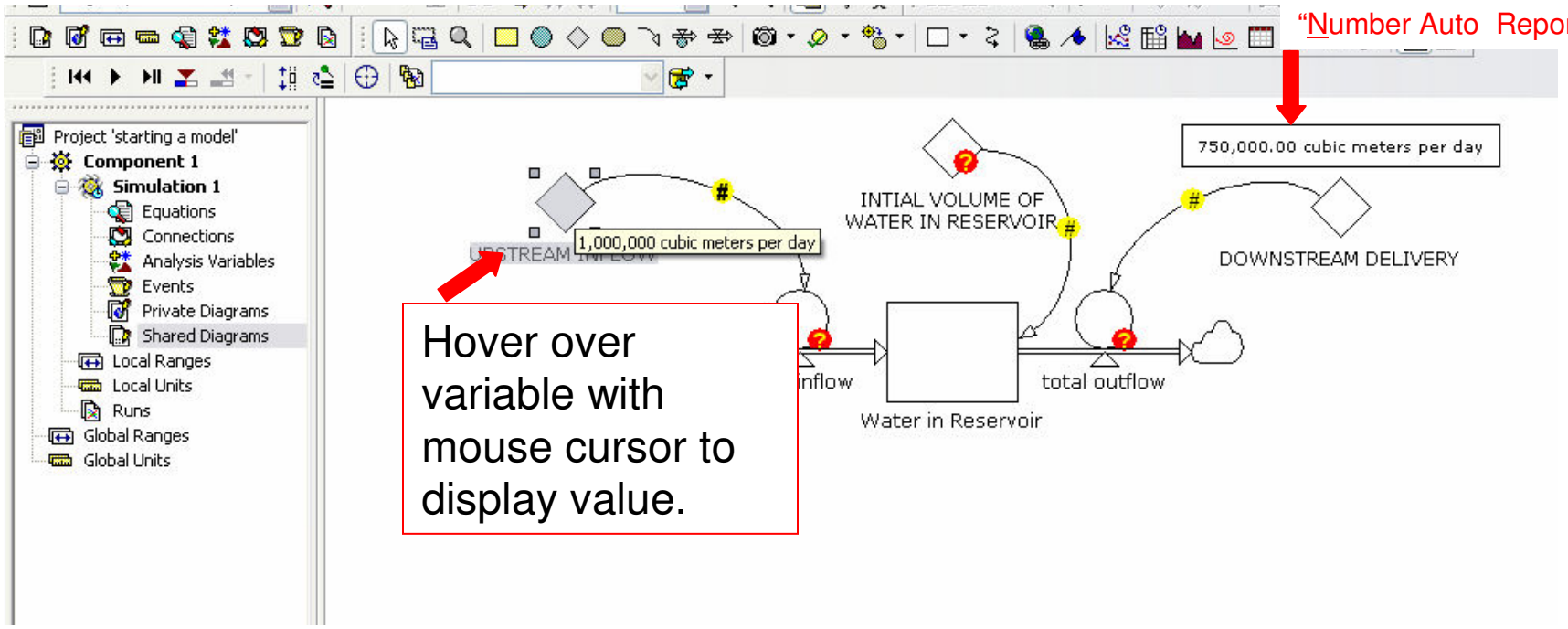
Basic model building blocks

To view value of any variable, right-click variable and select “Number Auto Report”.



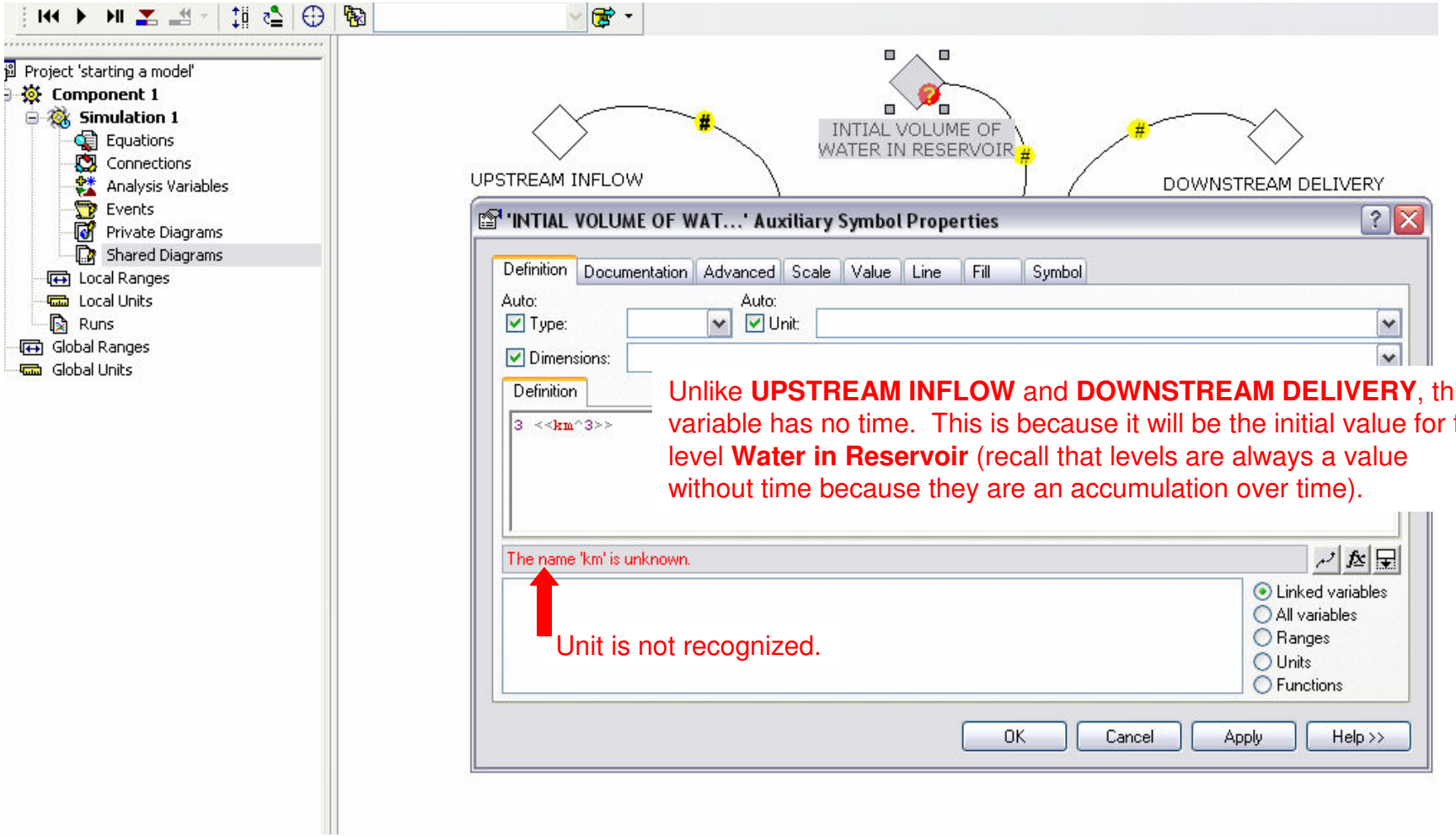
Basic model building blocks

To view value of any variable, you can also hover over variable of interest with mouse cursor.



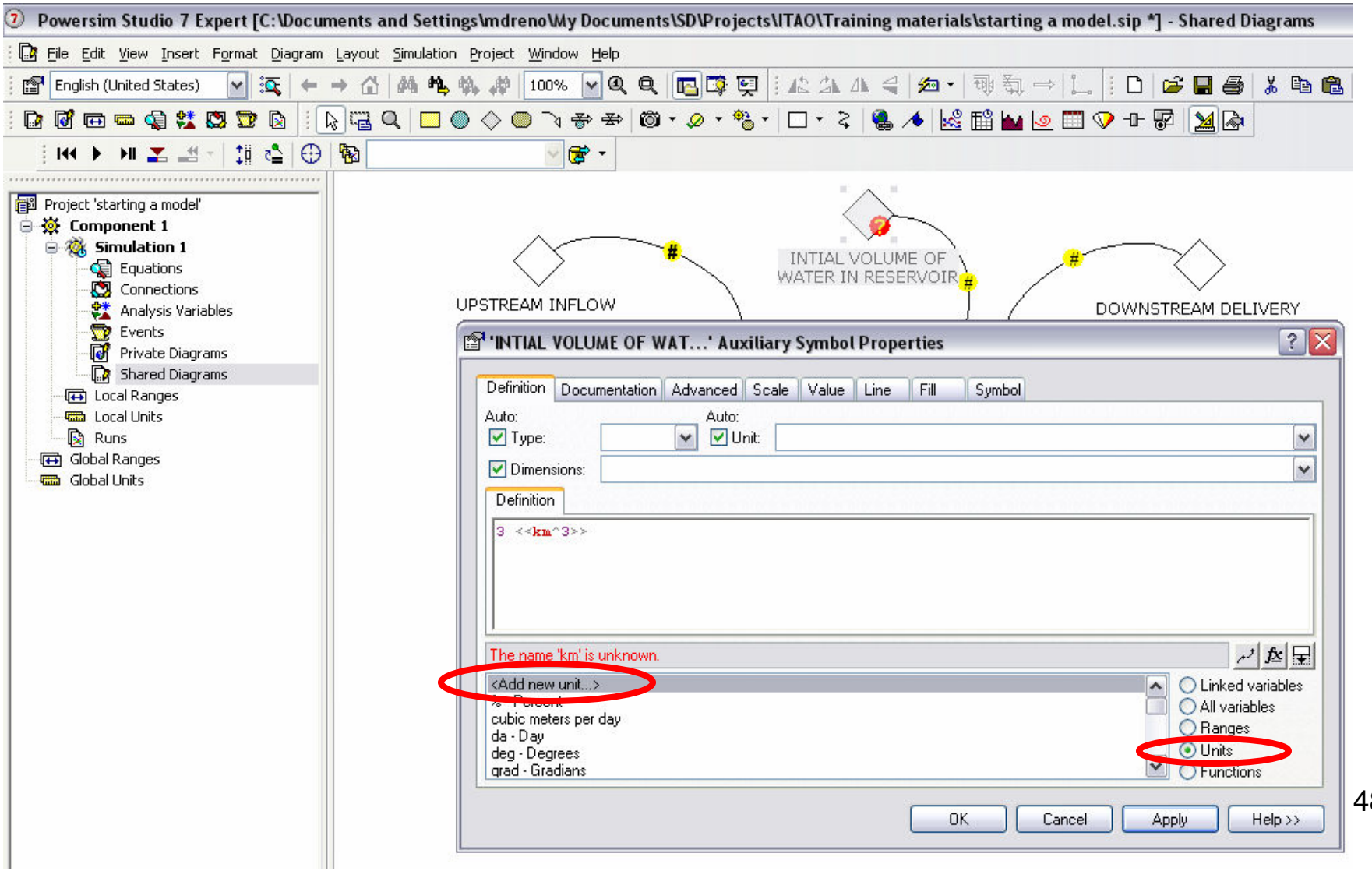
Basic model building blocks

Next, open **INITIAL VOLUME OF WATER IN RESERVOIR** and type “3 <<km^3>>”. Notice that Studio does not recognize “km”. This unit must be added before Studio will accept the definition.



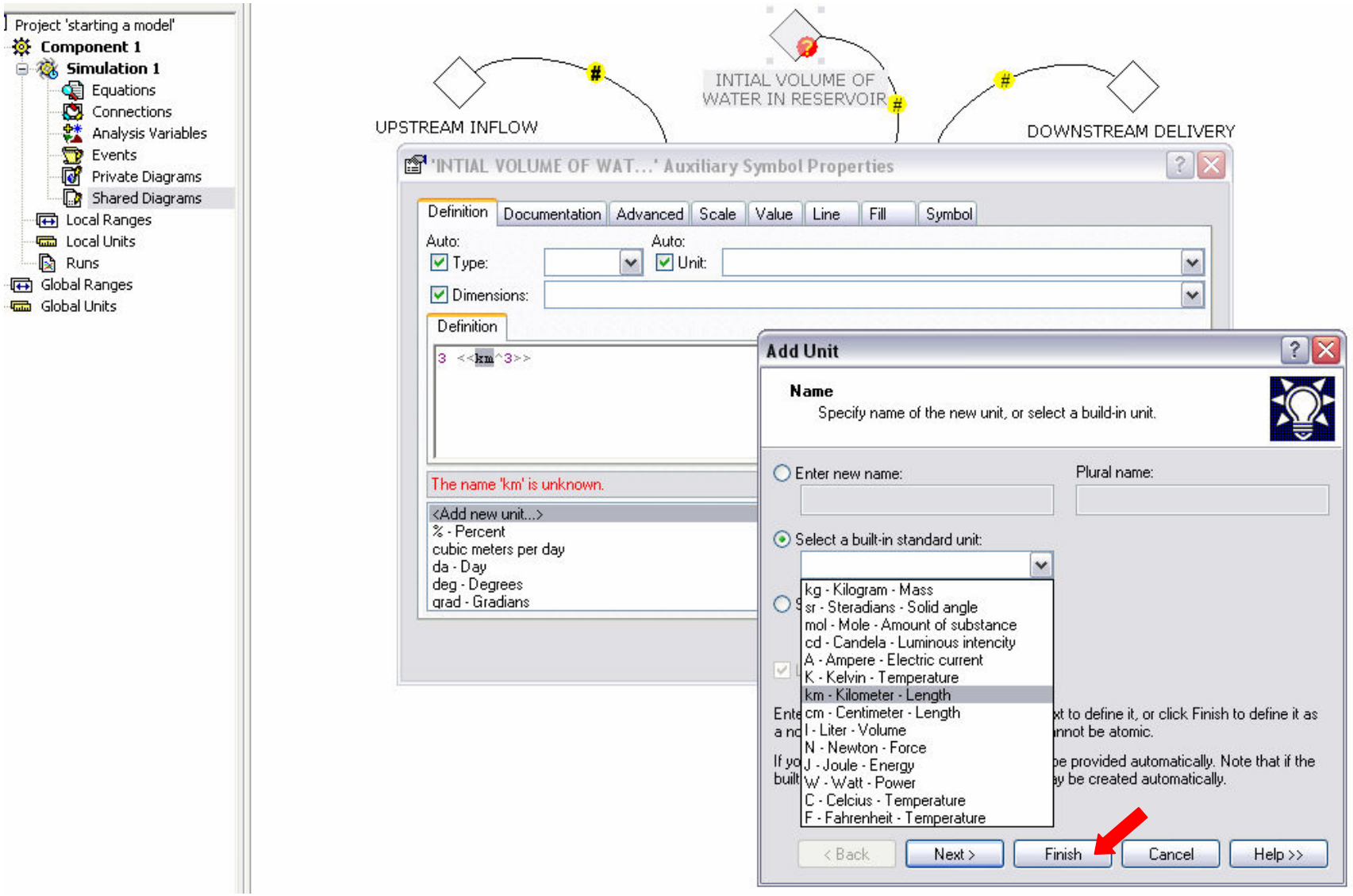
Basic model building blocks

Add “km” to units by toggling “Units”, then double-clicking “<Add new unit…>”.



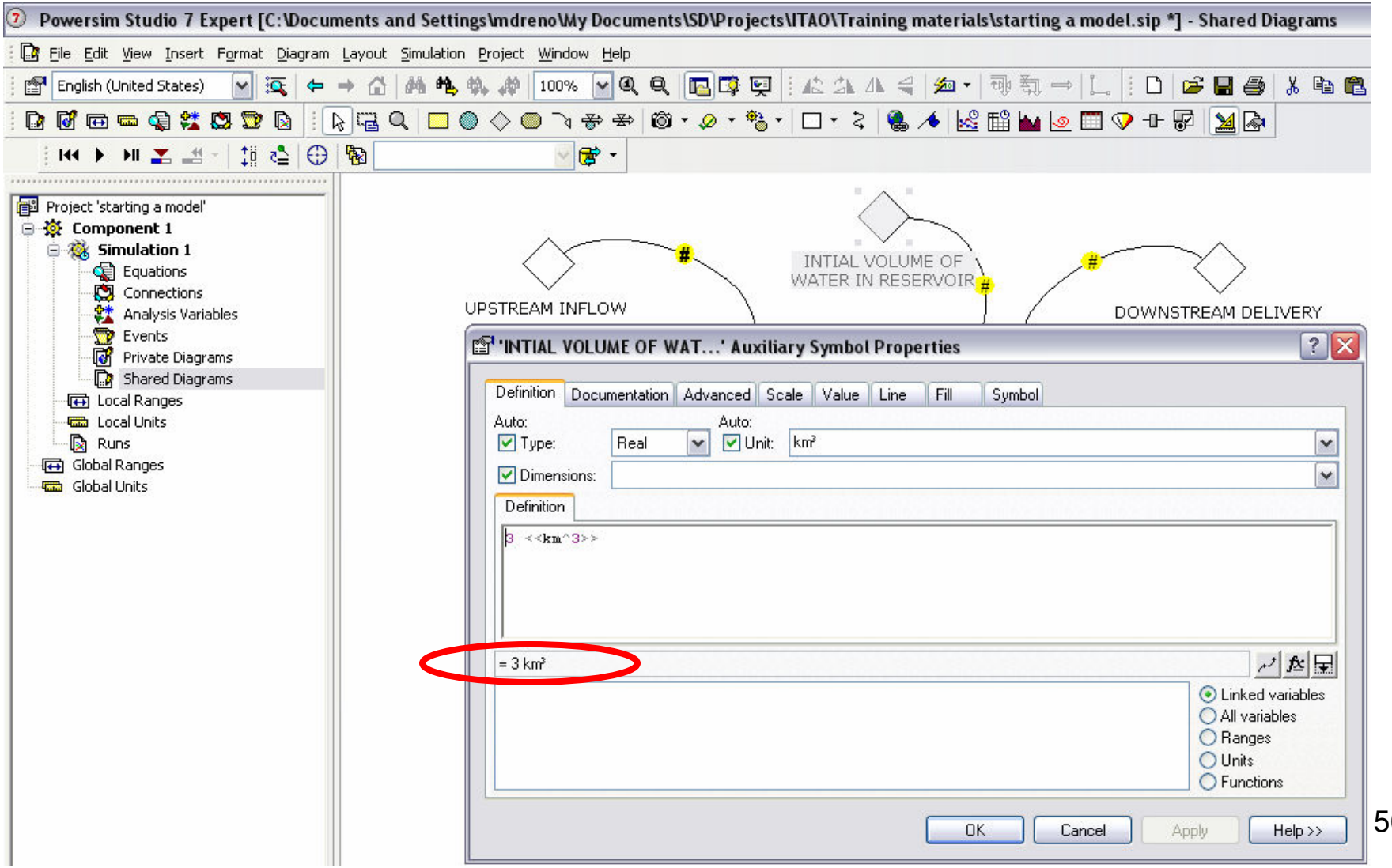
Basic model building blocks

"km" is a built-in standard unit. Add "km" using same method as for "m".



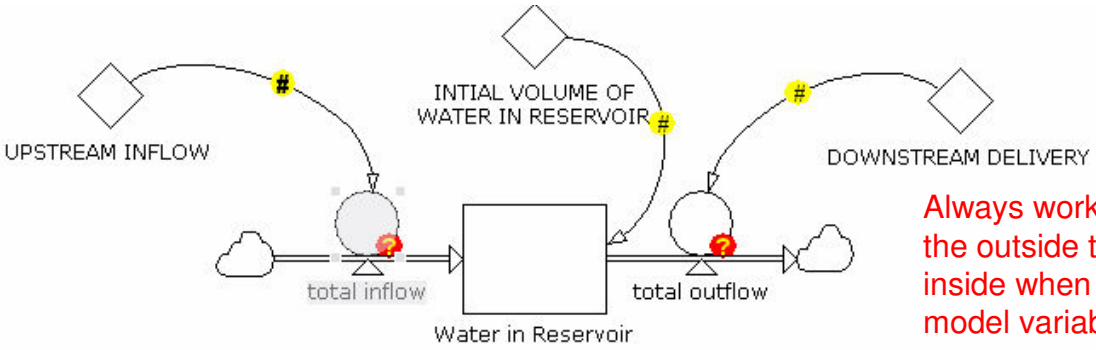
Basic model building blocks

Definition is now recognized.

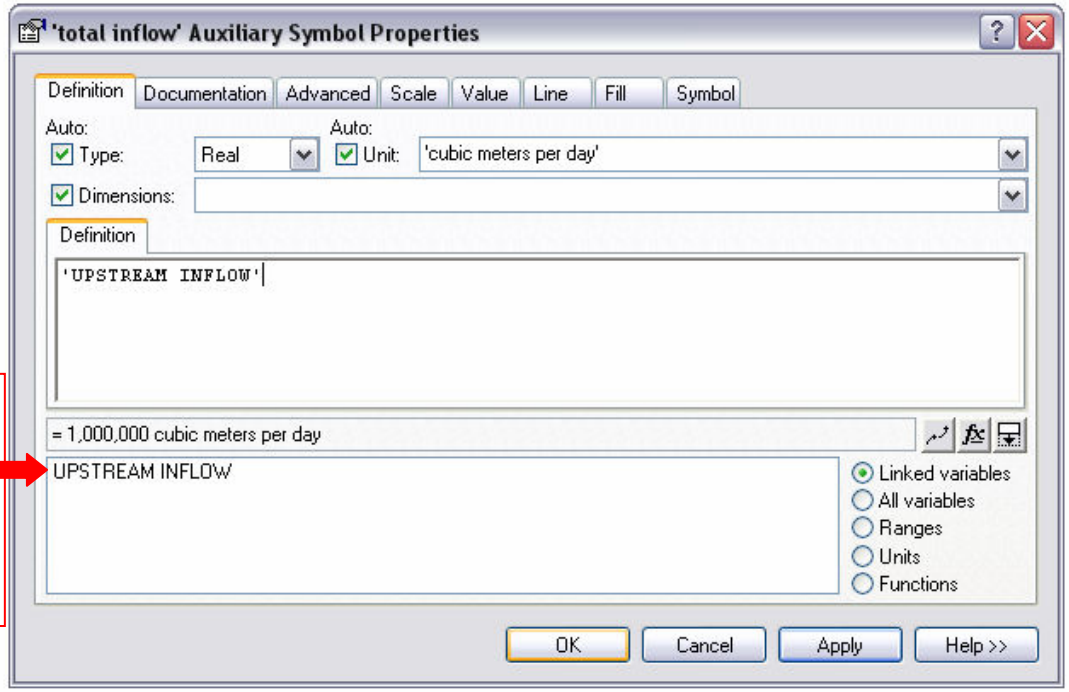


Basic model building blocks

Enter definition for **total inflow**. Notice that when you open this variable, **UPSTREAM INFLOW** appears in the box that lists available components for the variable definition. Any variable linked to **total inflow** with a connector will appear in this box. Double-click **UPSTREAM INFLOW** to use it in the definition of **total inflow**. Repeat these steps to enter definition for **total outflow** and **Water in Reservoir**.



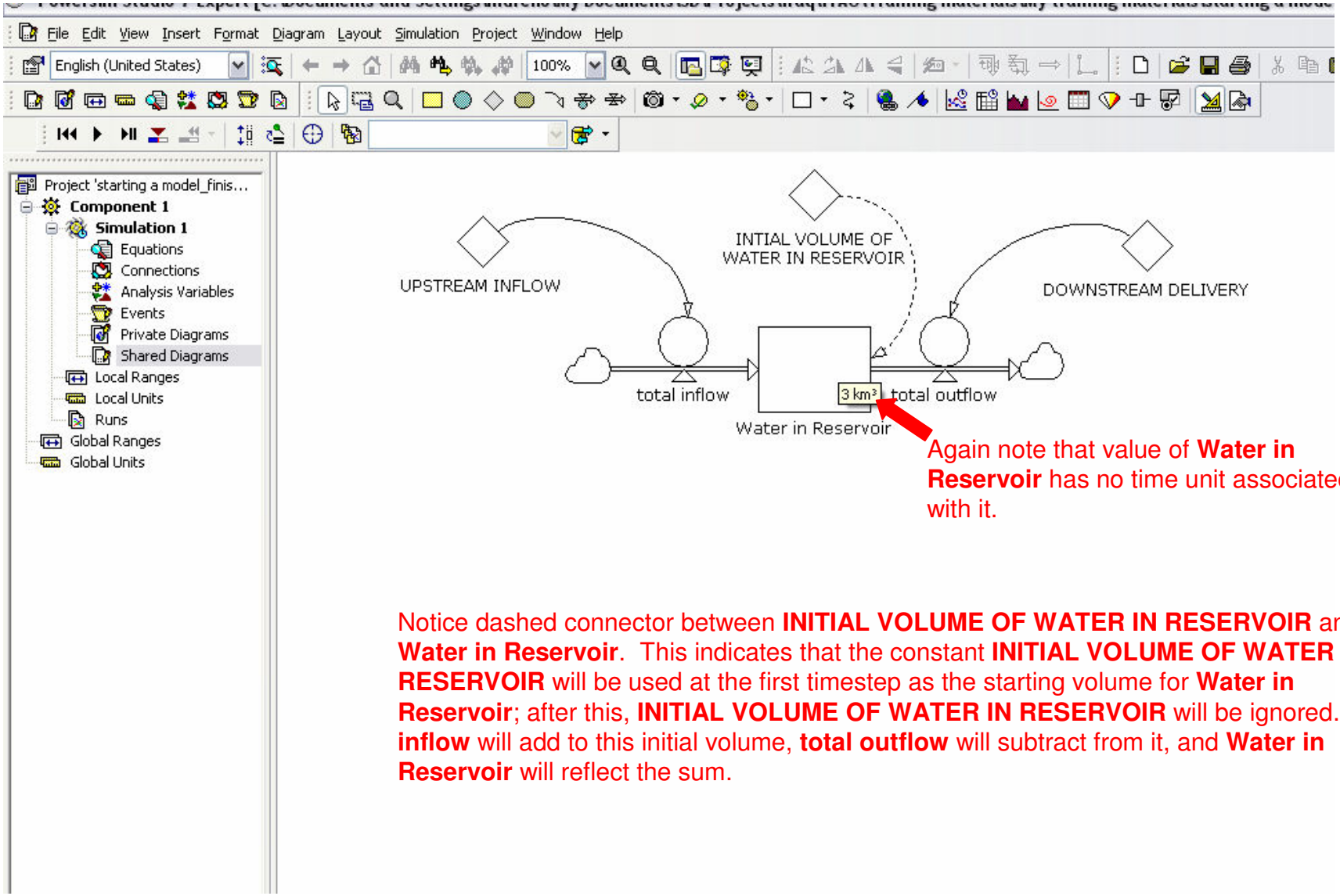
Always work from the outside to the inside when defining model variables.



Double-click **UPSTREAM INFLOW** to add it to the definition.

Basic model building blocks

Simple model complete.



Again note that value of **Water in Reservoir** has no time unit associated with it.

Notice dashed connector between **INITIAL VOLUME OF WATER IN RESERVOIR** and **Water in Reservoir**. This indicates that the constant **INITIAL VOLUME OF WATER IN RESERVOIR** will be used at the first timestep as the starting volume for **Water in Reservoir**; after this, **INITIAL VOLUME OF WATER IN RESERVOIR** will be ignored. **total inflow** will add to this initial volume, **total outflow** will subtract from it, and **Water in Reservoir** will reflect the sum.

Iraq National Water Modeling Workshop

November 11-15, 2007
United Nations University
Amman, Jordan

Using Graph Functions

National Nuclear Security Administration

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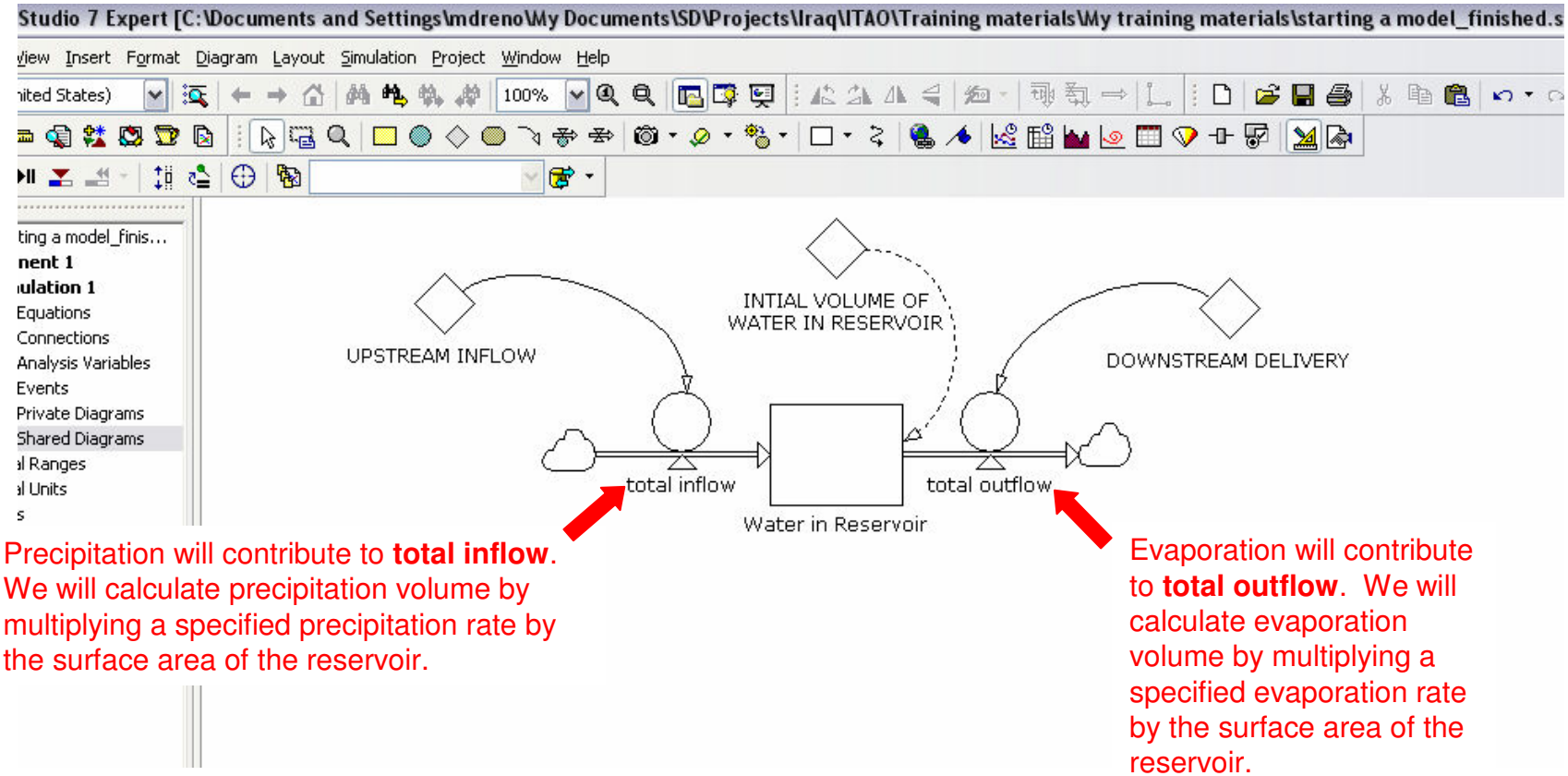
Using Graph Functions

Suppose you want to add complexity to your initial reservoir model by adding precipitation and evaporation.

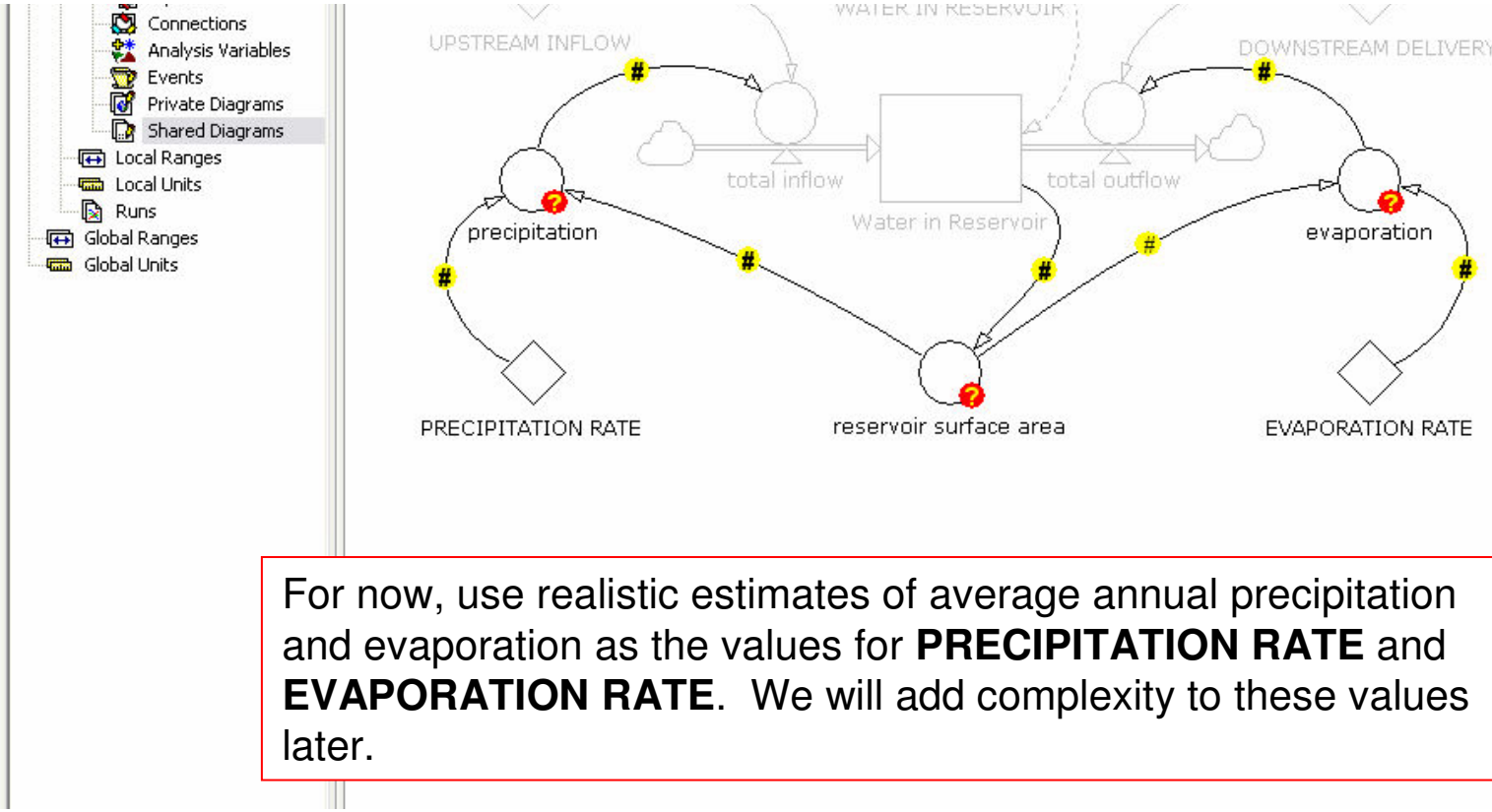


Precipitation will contribute to **total inflow**. We will calculate precipitation volume by multiplying a specified precipitation rate by the surface area of the reservoir.

Evaporation will contribute to **total outflow**. We will calculate evaporation volume by multiplying a specified evaporation rate by the surface area of the reservoir.

Using Graph Functions

Add additional variables. Define constants. If necessary, add new units (e.g., if you are entering precipitation in *mm/yr*, you will need to add the unit "mm"). **precipitation** and **evaporation** cannot be defined until **reservoir surface area** is defined. We will define **reservoir surface area** as a function of **Water in reservoir** using one of four Studio GRAPH functions.



For now, use realistic estimates of average annual precipitation and evaporation as the values for **PRECIPITATION RATE** and **EVAPORATION RATE**. We will add complexity to these values later.

Using Graph Functions

Studio offers four different graph functions: **GRAPH**, **GRAPHCURVE**, **GRAPHSTEP**, and **GRAPHLINAS**. We are going to demonstrate the use of **GRAPH**. The only difference between graph functions is the method of interpolation and extrapolation used. To define a variable using any graph function, the following syntax is used:

GRAPH FUNCTION NAME(X, X1, Dx, {Y(N)})

X: The input value for which a output value is to be found or computed.
X1: The first *x*-value of the graph.
Dx: The increment between fixed *x*-values.
Y(N): Vector of *y*-values.

For detailed information on each of the graph functions, search "graph" in Help (from Menu Bar, Help → Contents *or* press F1).

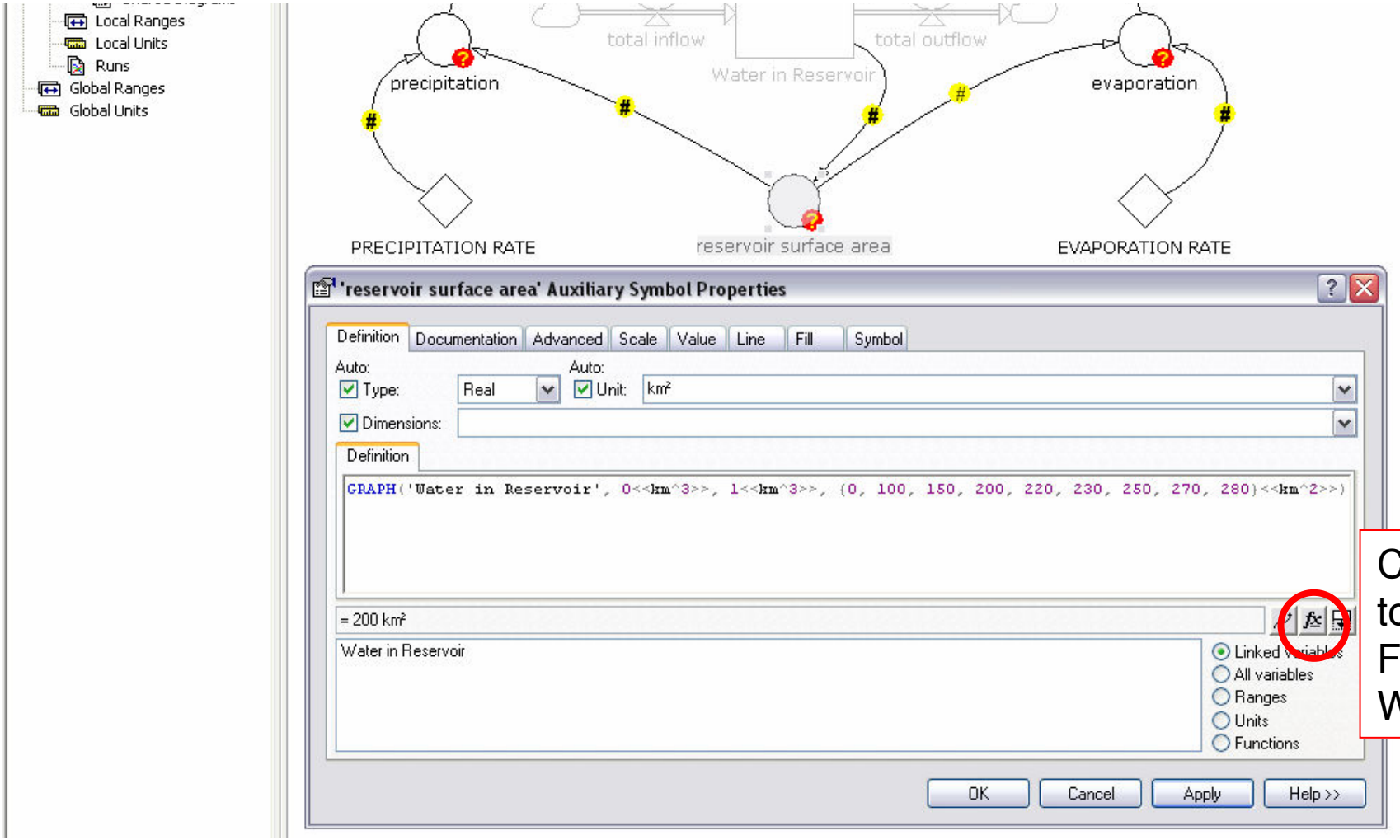
Using Graph Functions

To use the **GRAPH**, you should have several *x*,*y* data pairs and all *x*-values must be separated by the same increment. The table below gives hypothetical data that satisfy these criteria: there are several *x*,*y* pairs and *x* increases in increments of 1 km^3.

Volume (km^3)	Surface area (km^2)
0	0
1	100
2	150
3	200
4	220
5	230
6	250
7	270
8	280

Using Graph Functions

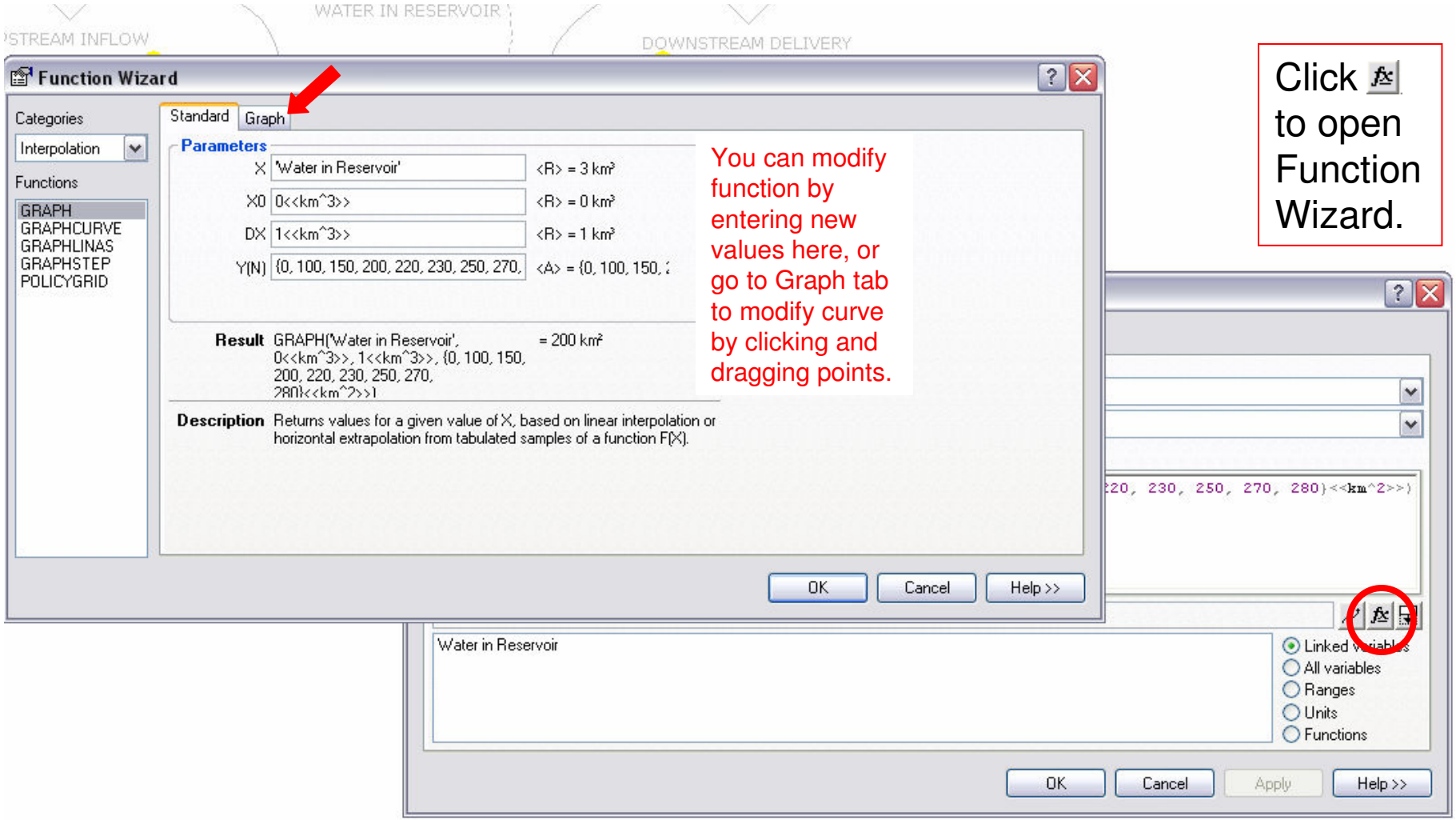
In definition box of **reservoir surface area**, enter data from previous slide using syntax guidelines from slide 56. Syntax guidelines can also be found by searching for "GRAPH" in Help (from Menu Bar, Help → Contents *or* press F1).



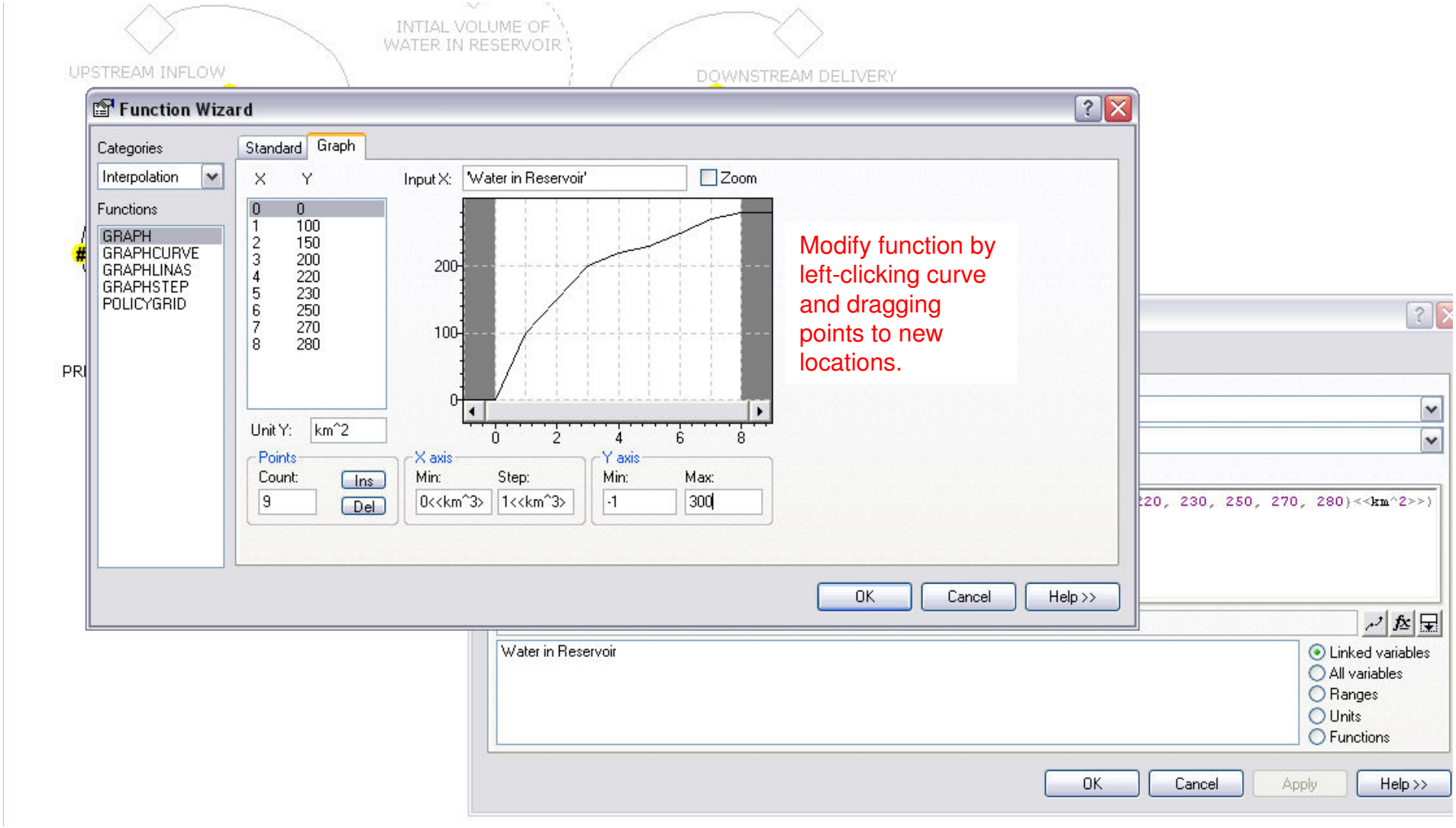
Click to open Function Wizard.

Using Graph Functions

The **GRAPH** function can also be used through the Function Wizard.

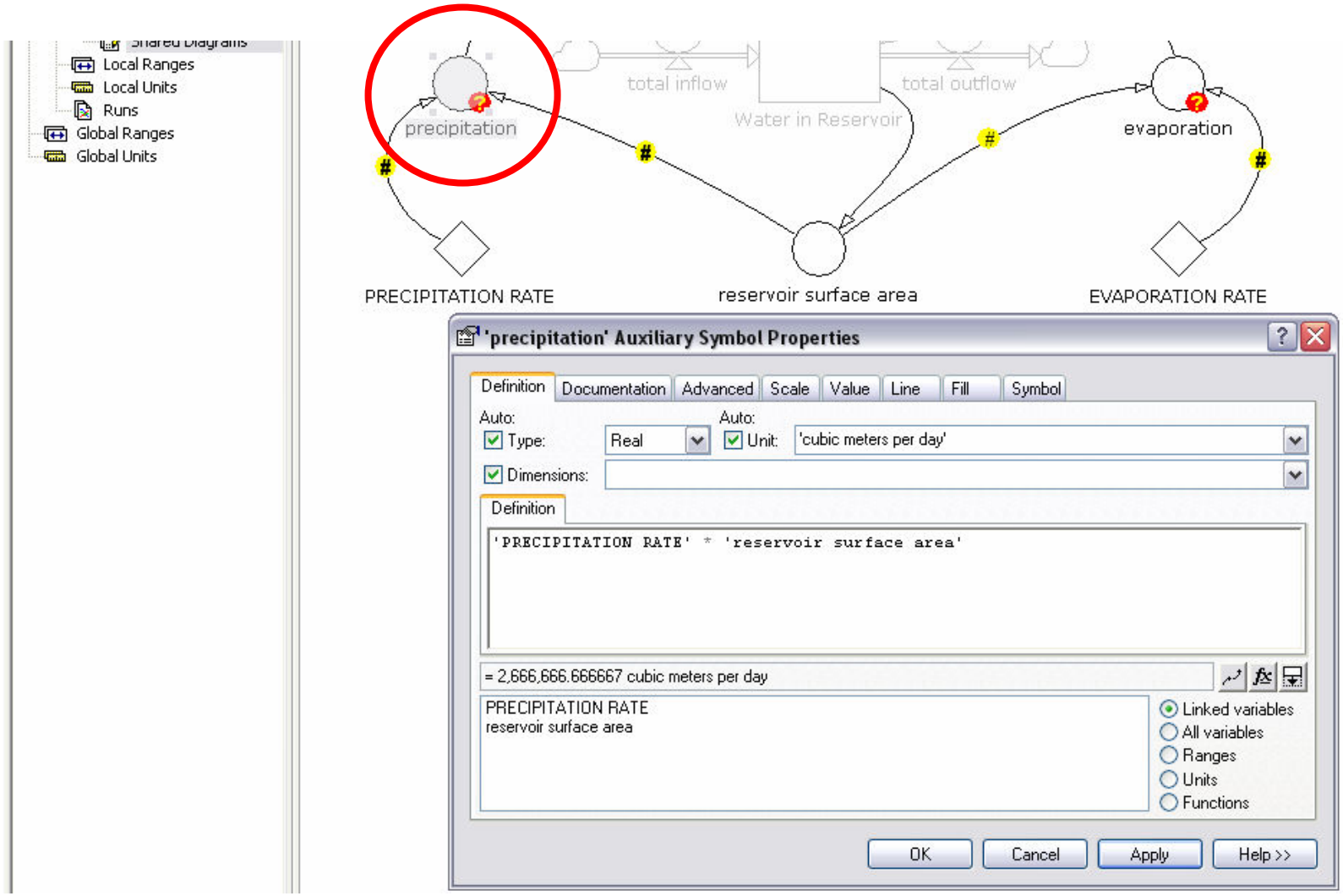


Using Graph Functions



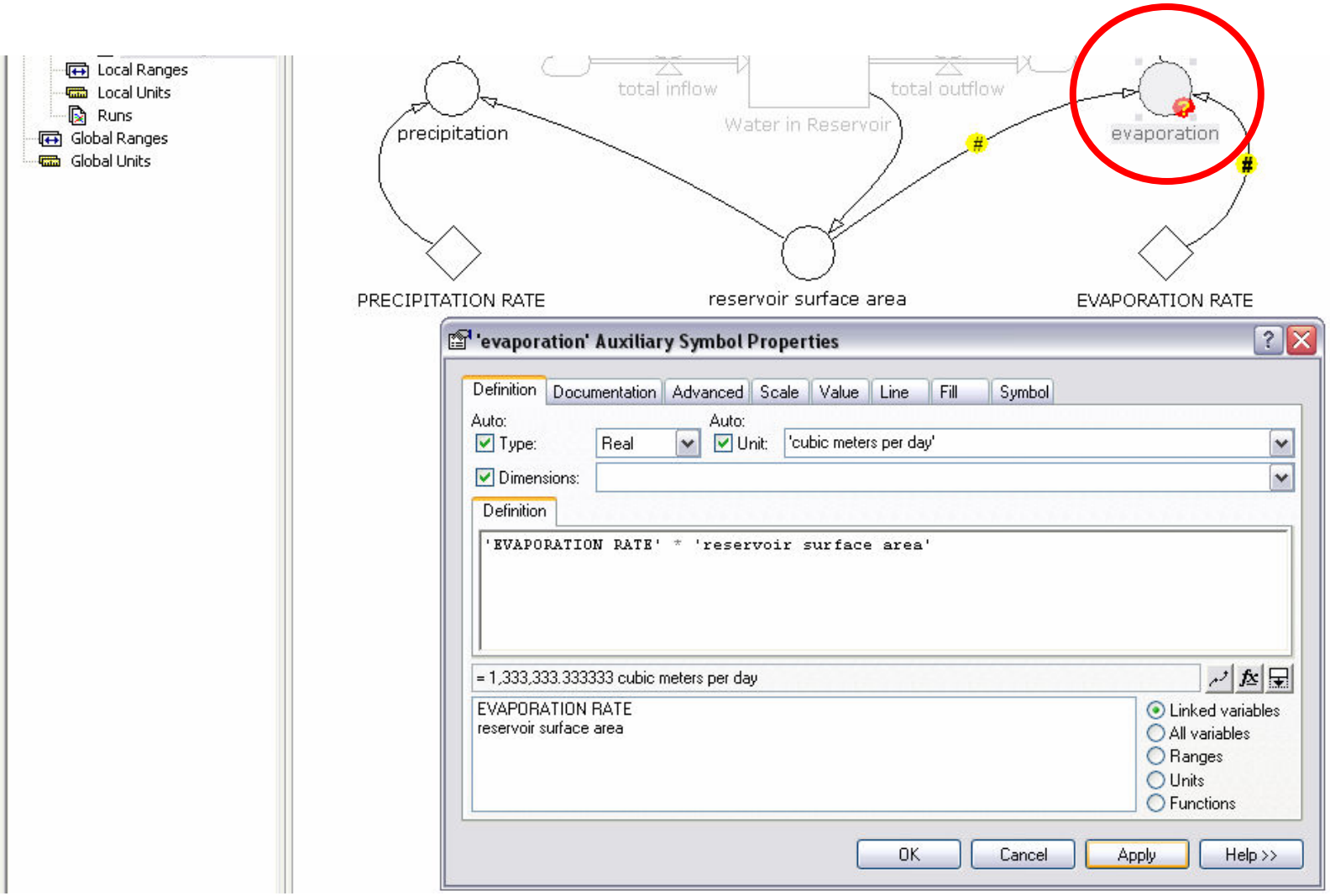
Using Graph Functions

Define **precipitation**.



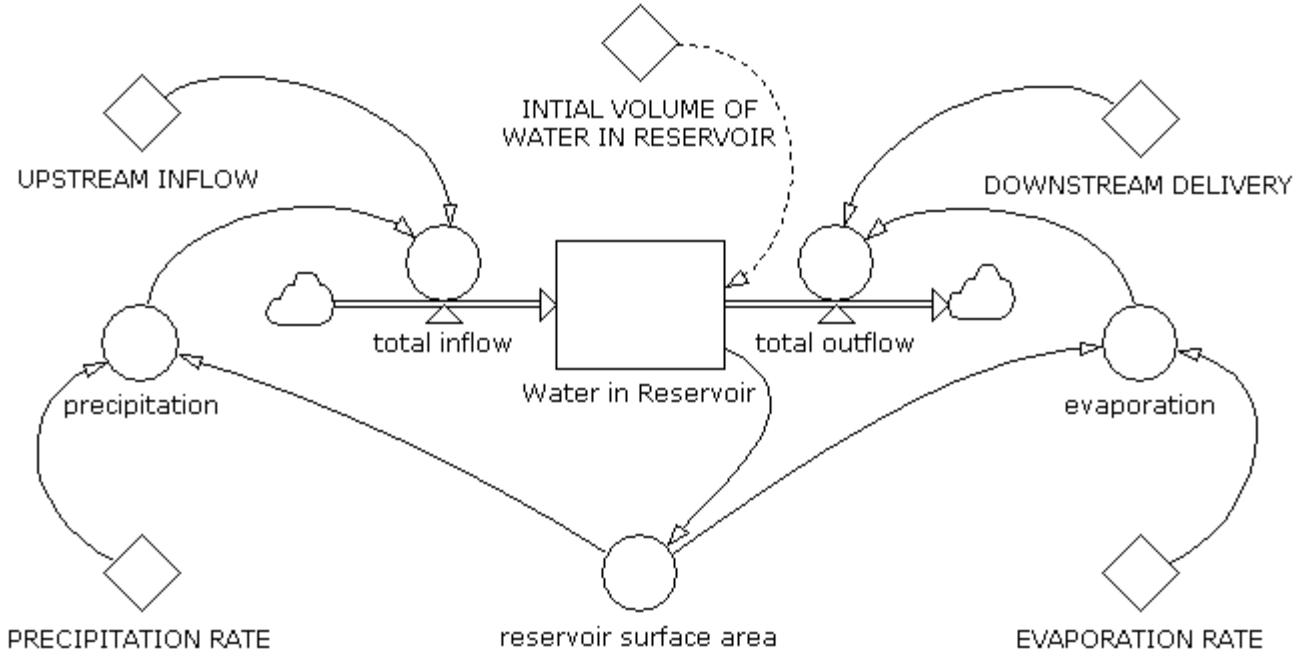
Using Graph Functions

Define **evaporation**.



Using Graph Functions

As in the initial reservoir model, **Water in Reservoir** is still defined by **INITIAL VOLUME OF WATER IN RESERVOIR**, **total inflow**, and **total outflow**. **total inflow** and **total outflow** have been revised and now include **precipitation** and **evaporation**. **precipitation** and **evaporation** are both calculated using **reservoir surface area**, which is calculated using **GRAPH** with **Water in Reservoir** as the *x*-value.



Iraq National Water Modeling Workshop I

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Arrays and Ranges

National Nuclear Security Administration

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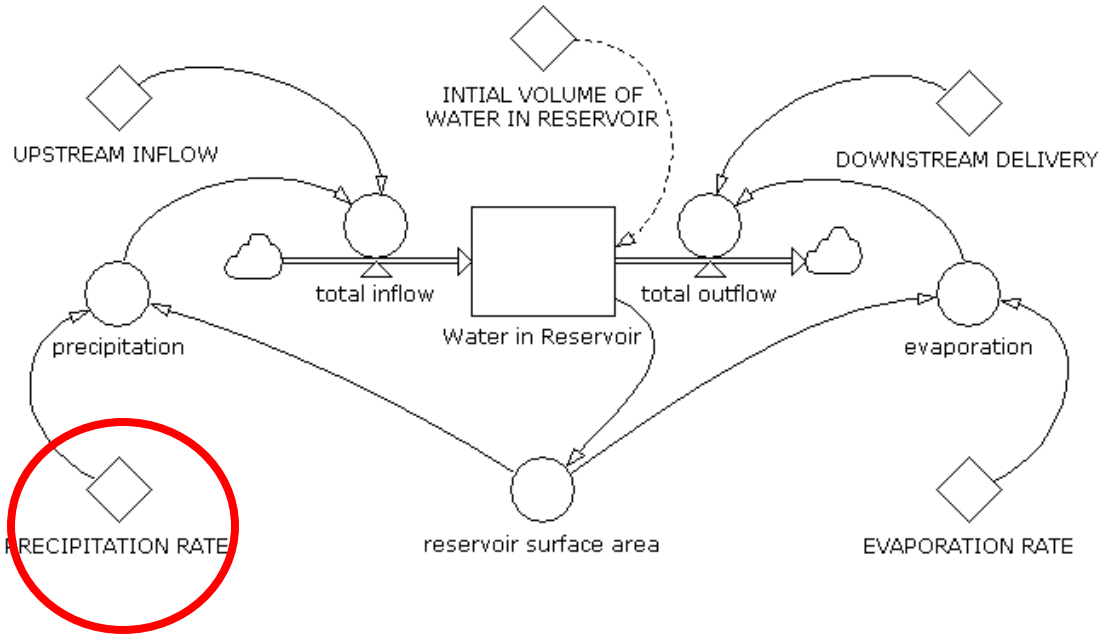
Creating Arrayed Variables

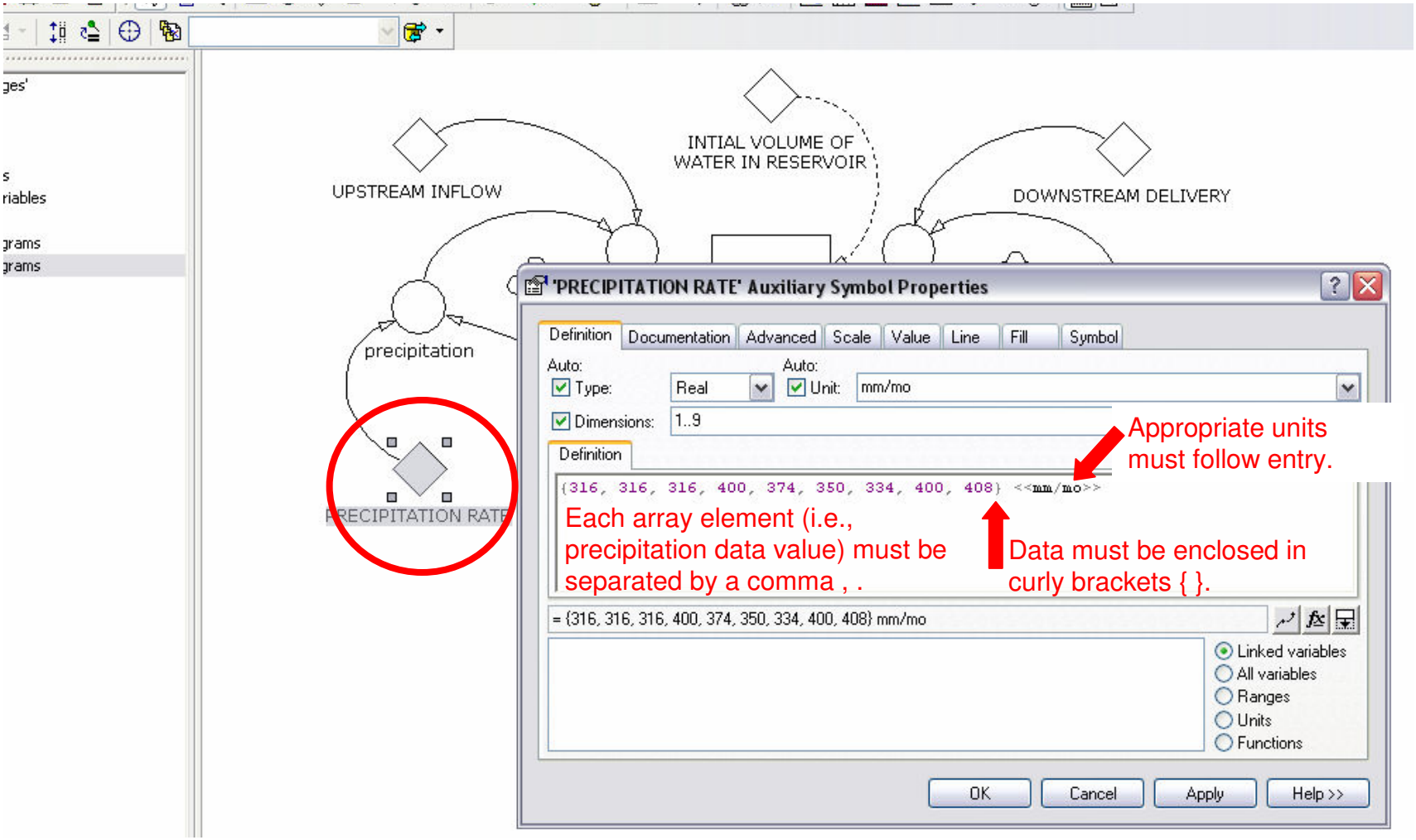


Suppose you have unique precipitation data for each of the reservoirs in the system that you are modeling. We will replace the scalar variable **PRECIPITATION RATE** with an arrayed variable.

Scalar variable: a variable holding a single numerical value.
Arrayed variable: a variable holding several distinct values at the same time.

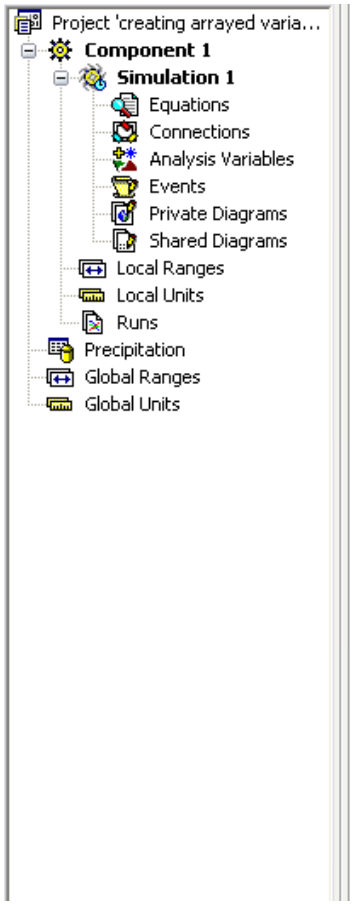
Creating Arrayed Variables

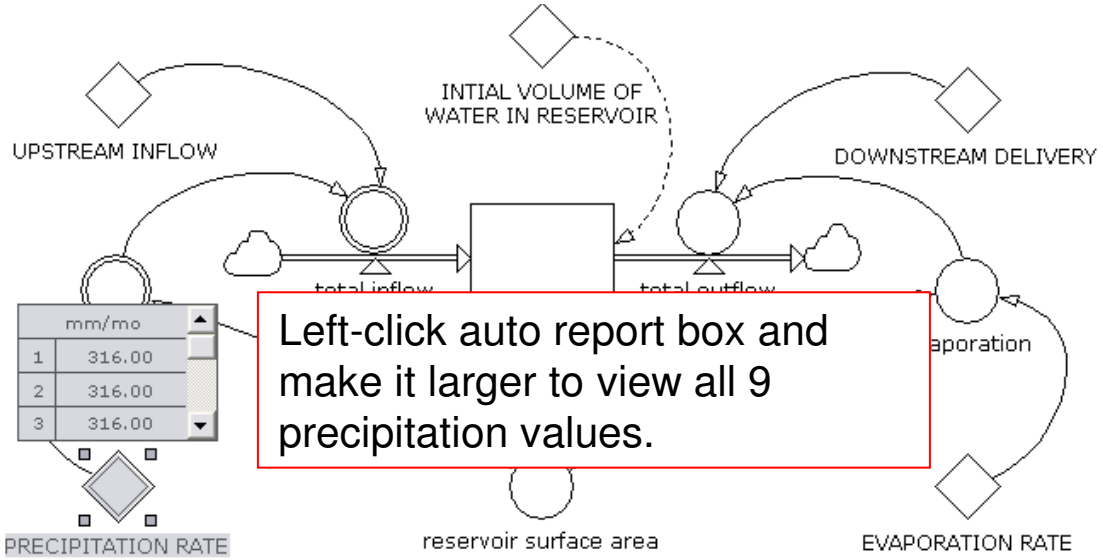
Double-click **PRECIPITATION RATE** and enter precipitation values corresponding to the average annual precipitation at each of the reservoirs in your model.



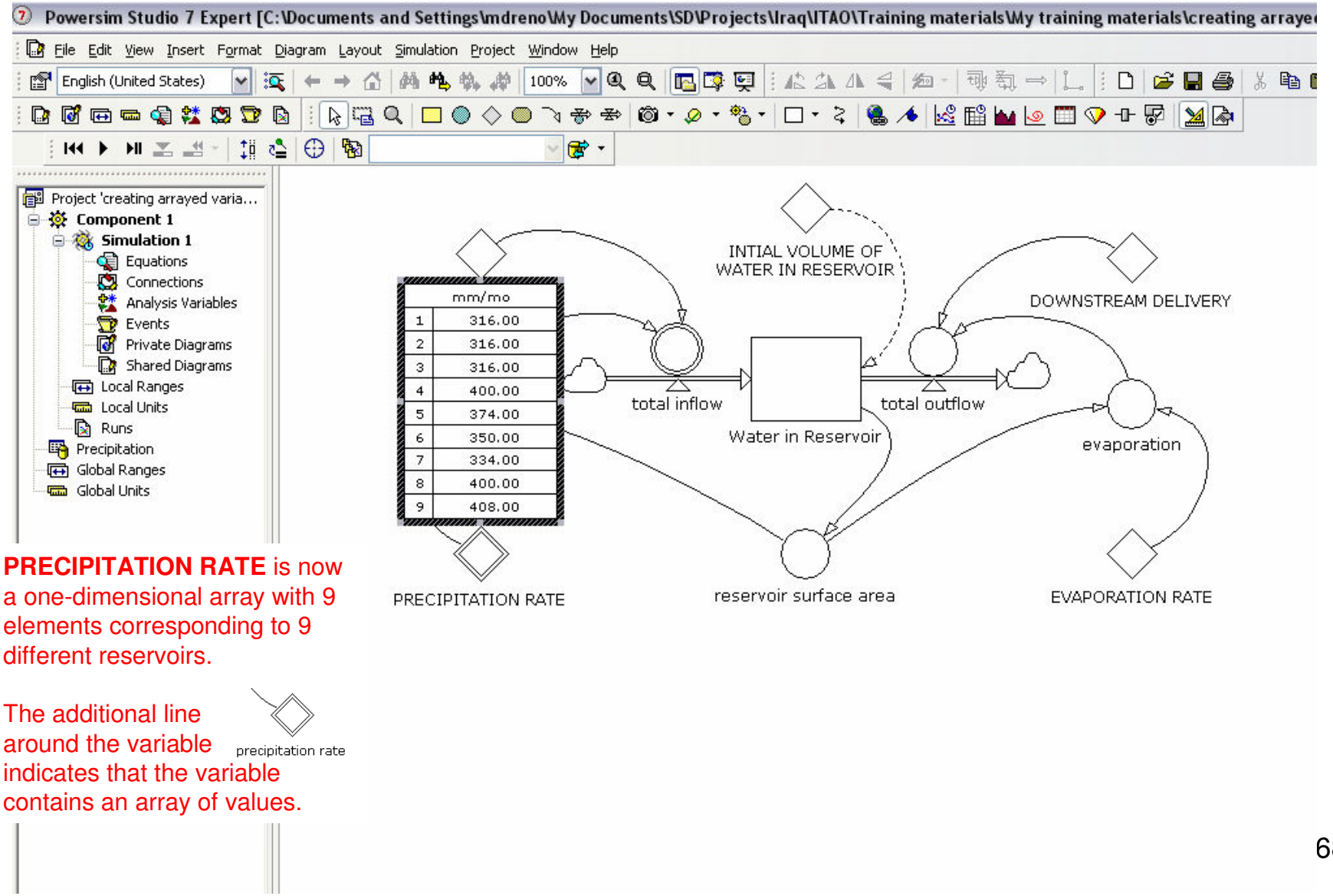
Creating Arrayed Variables

Right-click **PRECIPITATION RATE** and select “Number Auto Report” to view the definition that you just entered.





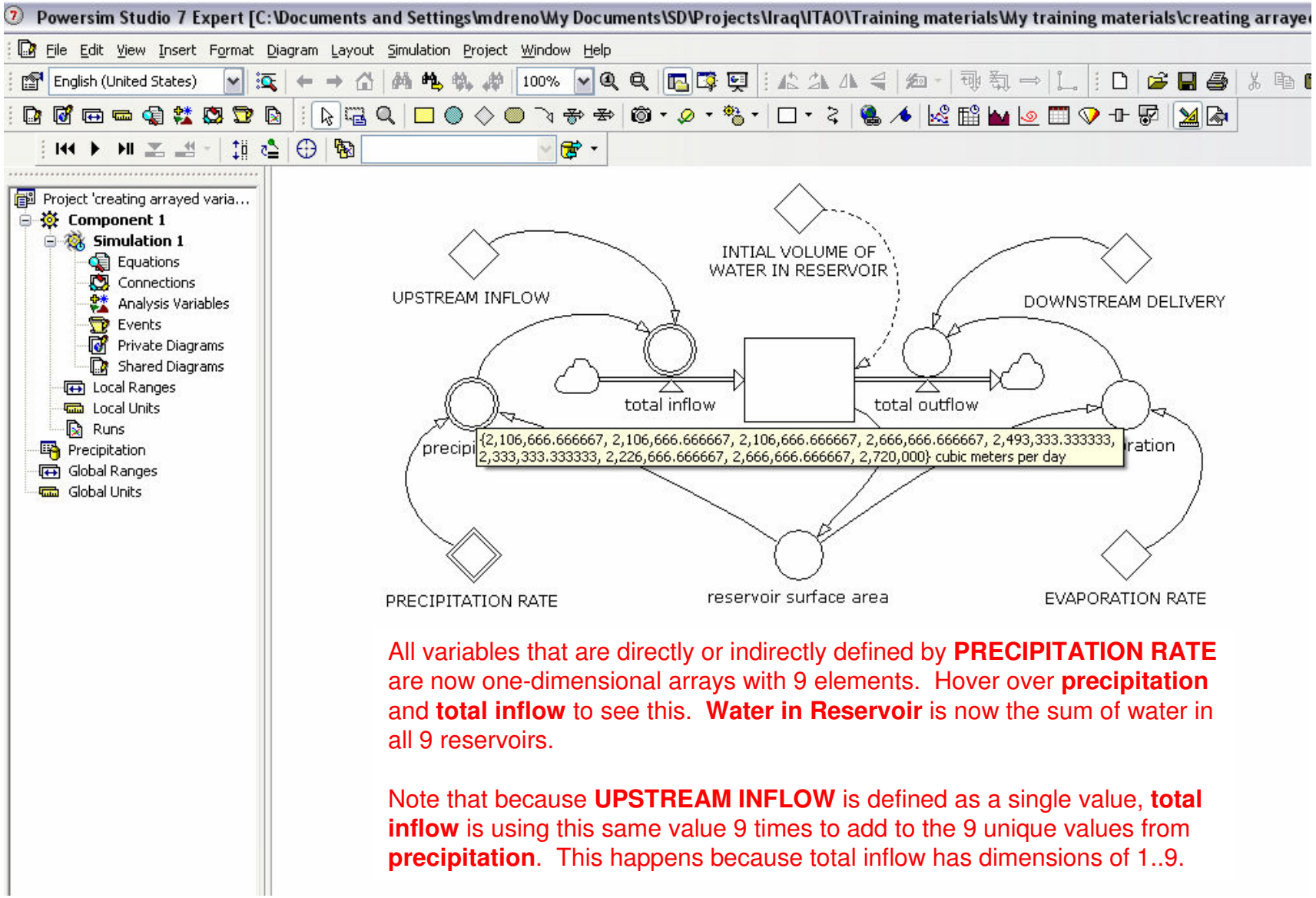
Creating Arrayed Variables



PRECIPITATION RATE is now a one-dimensional array with 9 elements corresponding to 9 different reservoirs.

The additional line around the variable indicates that the variable contains an array of values.

Creating Arrayed Variables

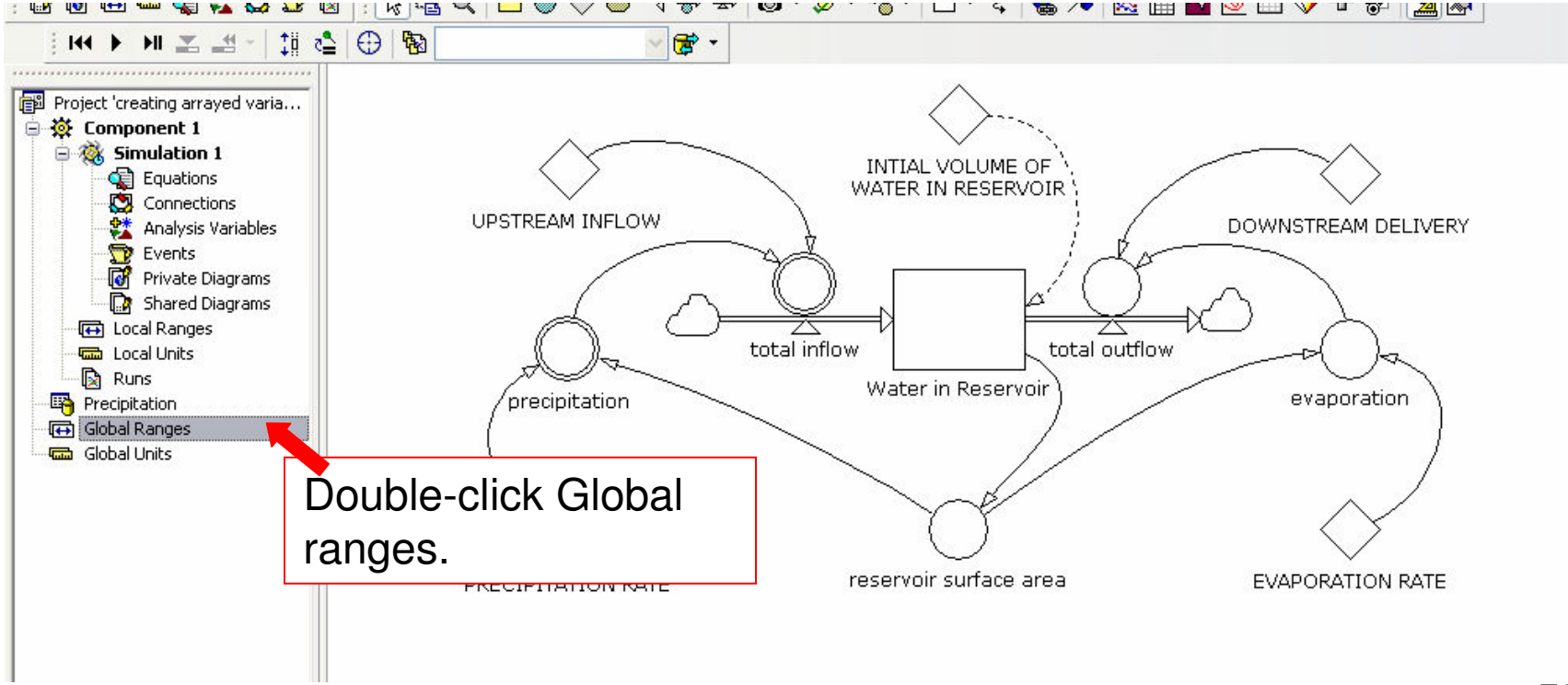


All variables that are directly or indirectly defined by **PRECIPITATION RATE** are now one-dimensional arrays with 9 elements. Hover over **precipitation** and **total inflow** to see this. **Water in Reservoir** is now the sum of water in all 9 reservoirs.

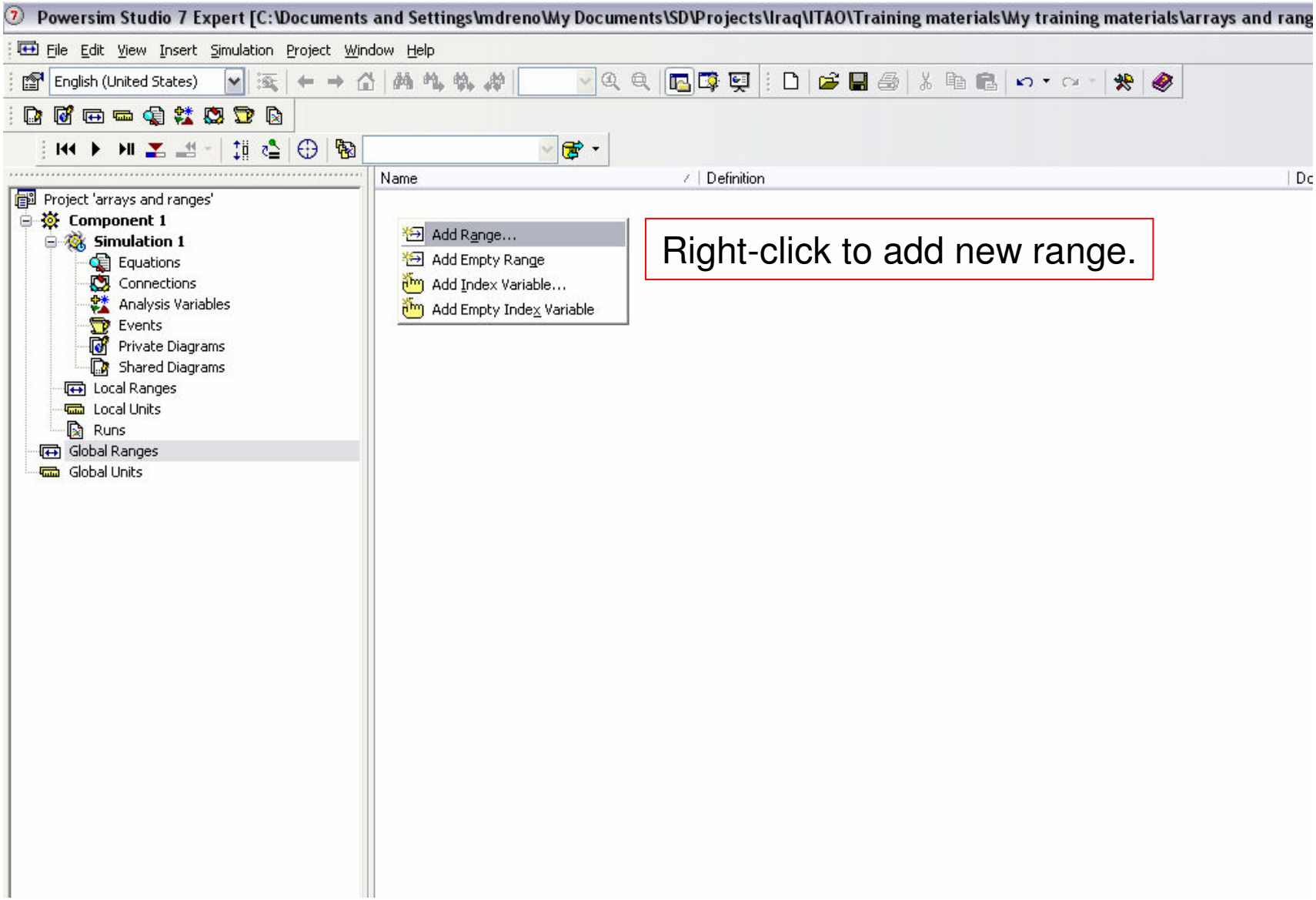
Note that because **UPSTREAM INFLOW** is defined as a single value, **total inflow** is using this same value 9 times to add to the 9 unique values from **precipitation**. This happens because total inflow has dimensions of 1..9.

Creating Ranges

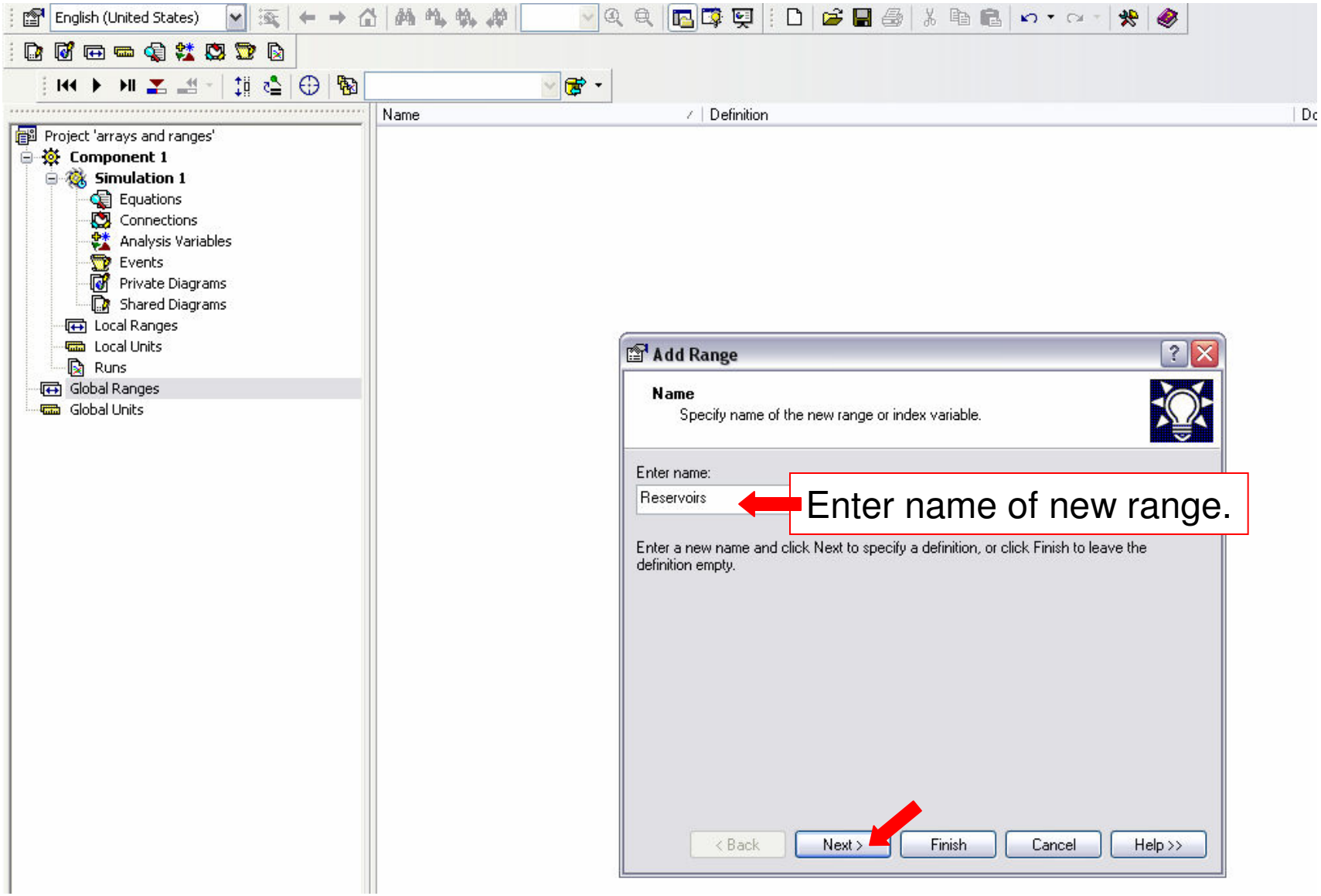
Ranges are used to access variable elements in an intuitive way. The precipitation data that we have entered corresponds to an estimate of average monthly precipitation (12 months of data) at Adhaim Reservoir, Derbendi Khan Reservoir, Dokan Reservoir, Habbaniyah Lake, Haditha Reservoir, Hemrin Reservoir, Mosul Reservoir, Razzaza Lake, and Tharthar Lake. We will create the a range called “Reservoirs” that includes the names listed above.



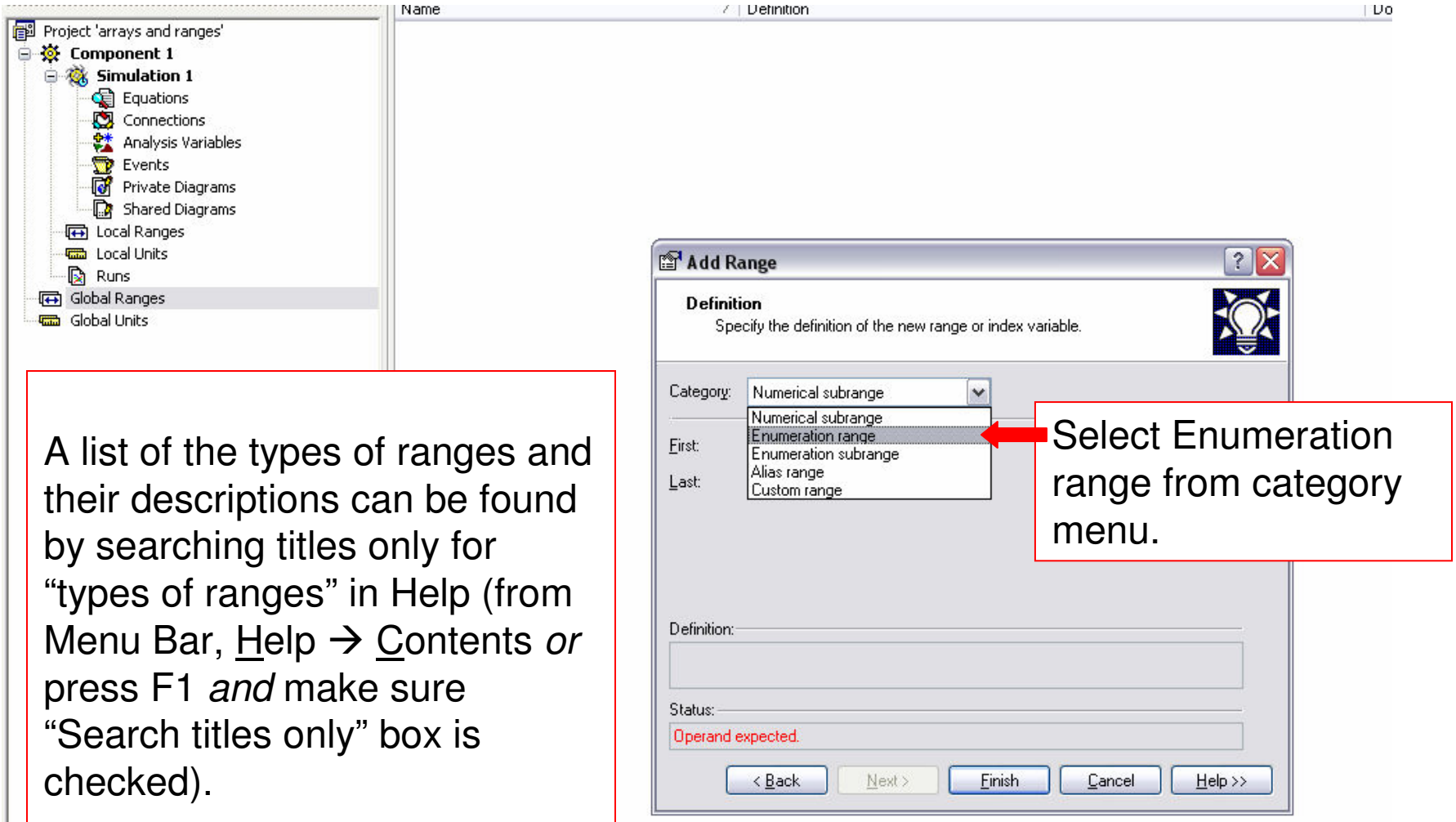
Creating Ranges



Creating Ranges



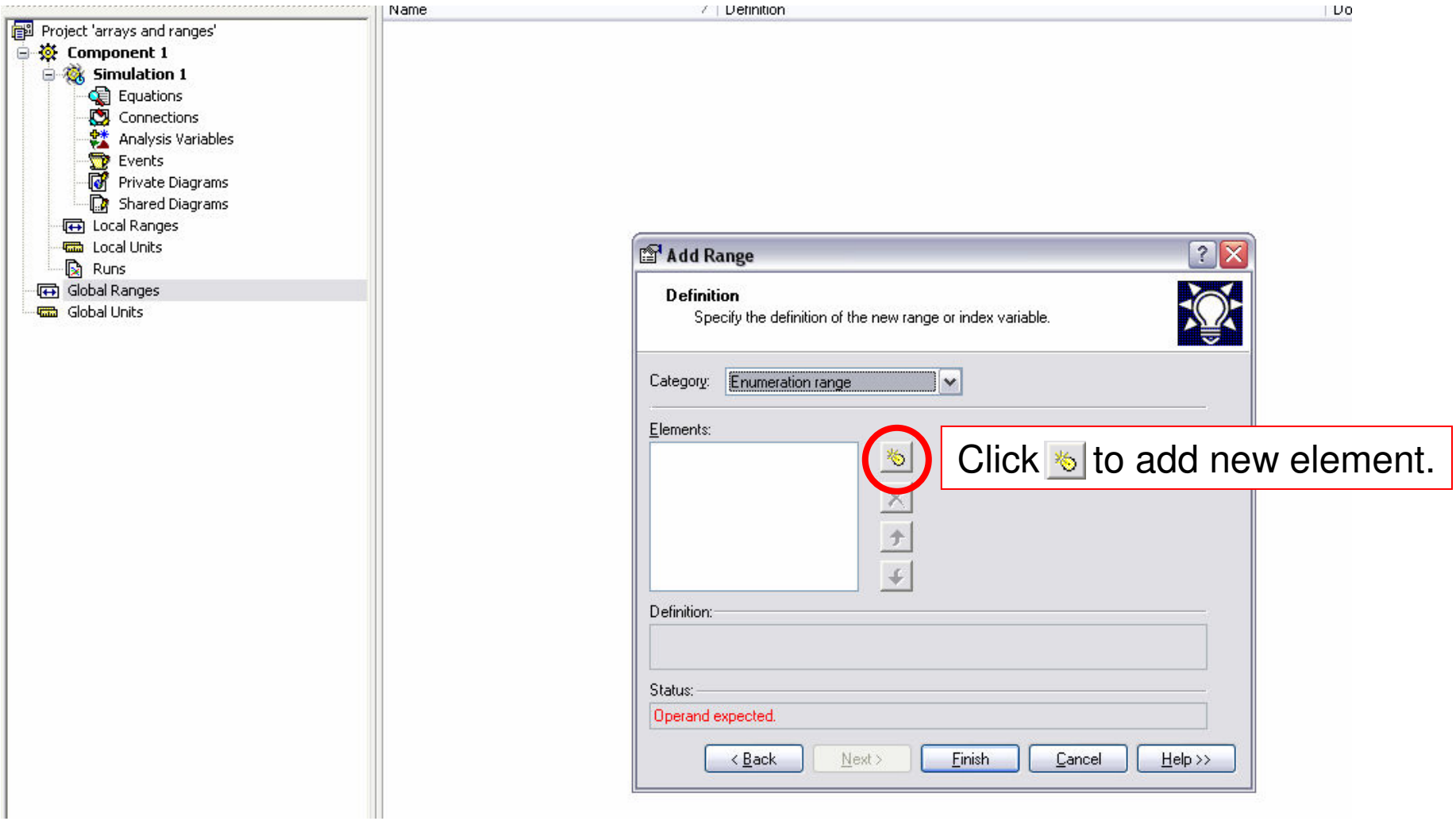
Creating Ranges



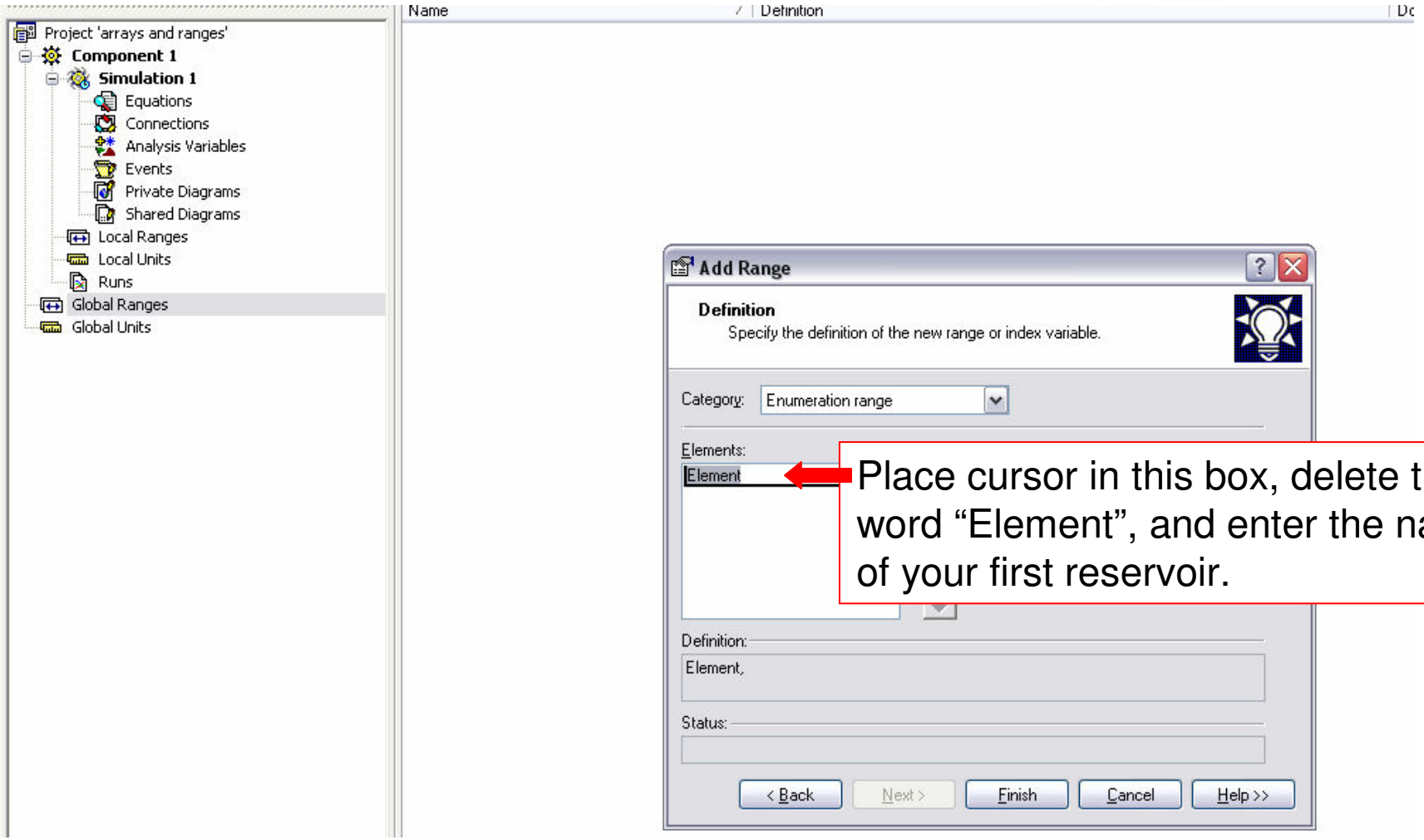
A list of the types of ranges and their descriptions can be found by searching titles only for "types of ranges" in Help (from Menu Bar, Help → Contents *or* press F1 *and* make sure "Search titles only" box is checked).

Select Enumeration range from category menu.

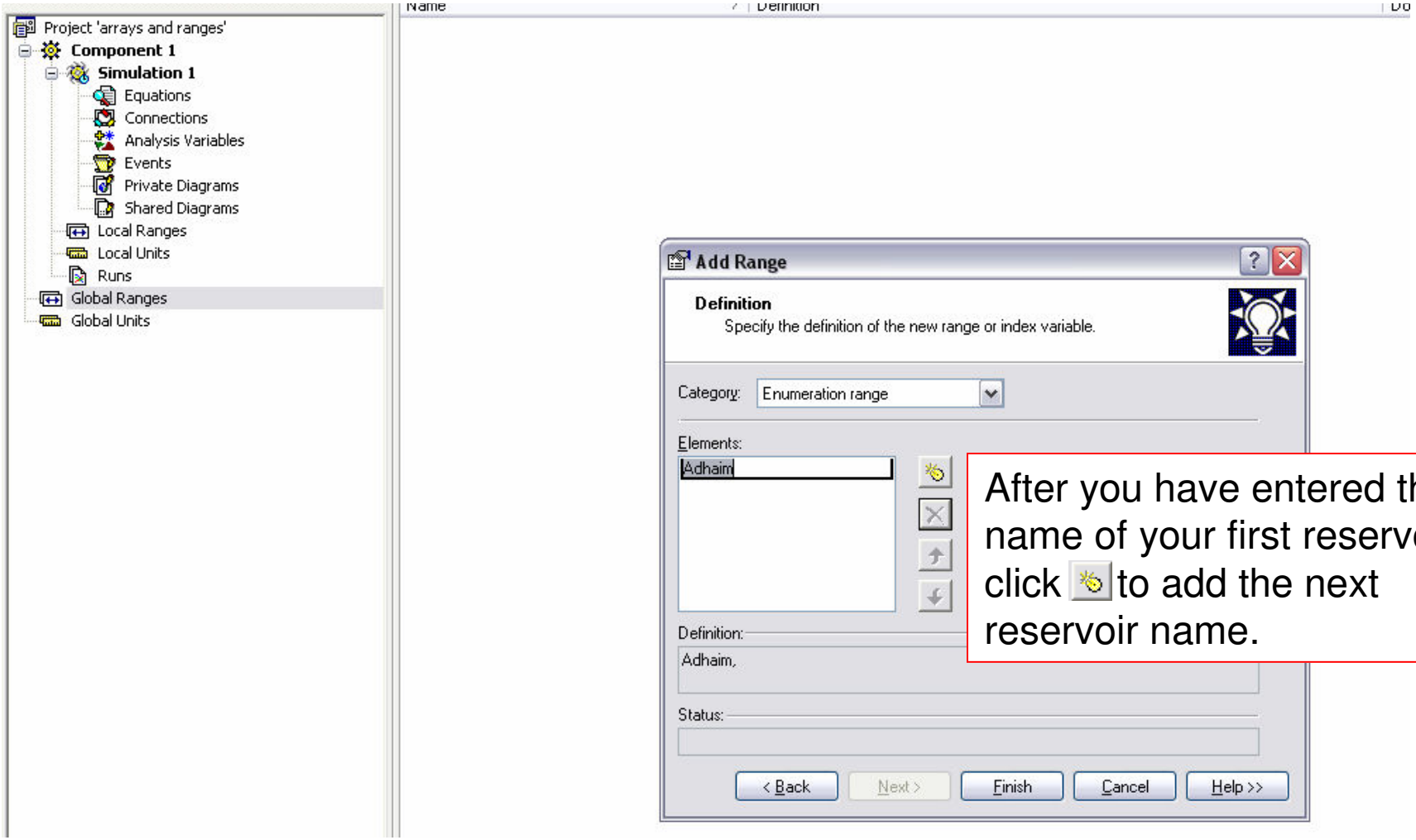
Creating Ranges



Creating Ranges

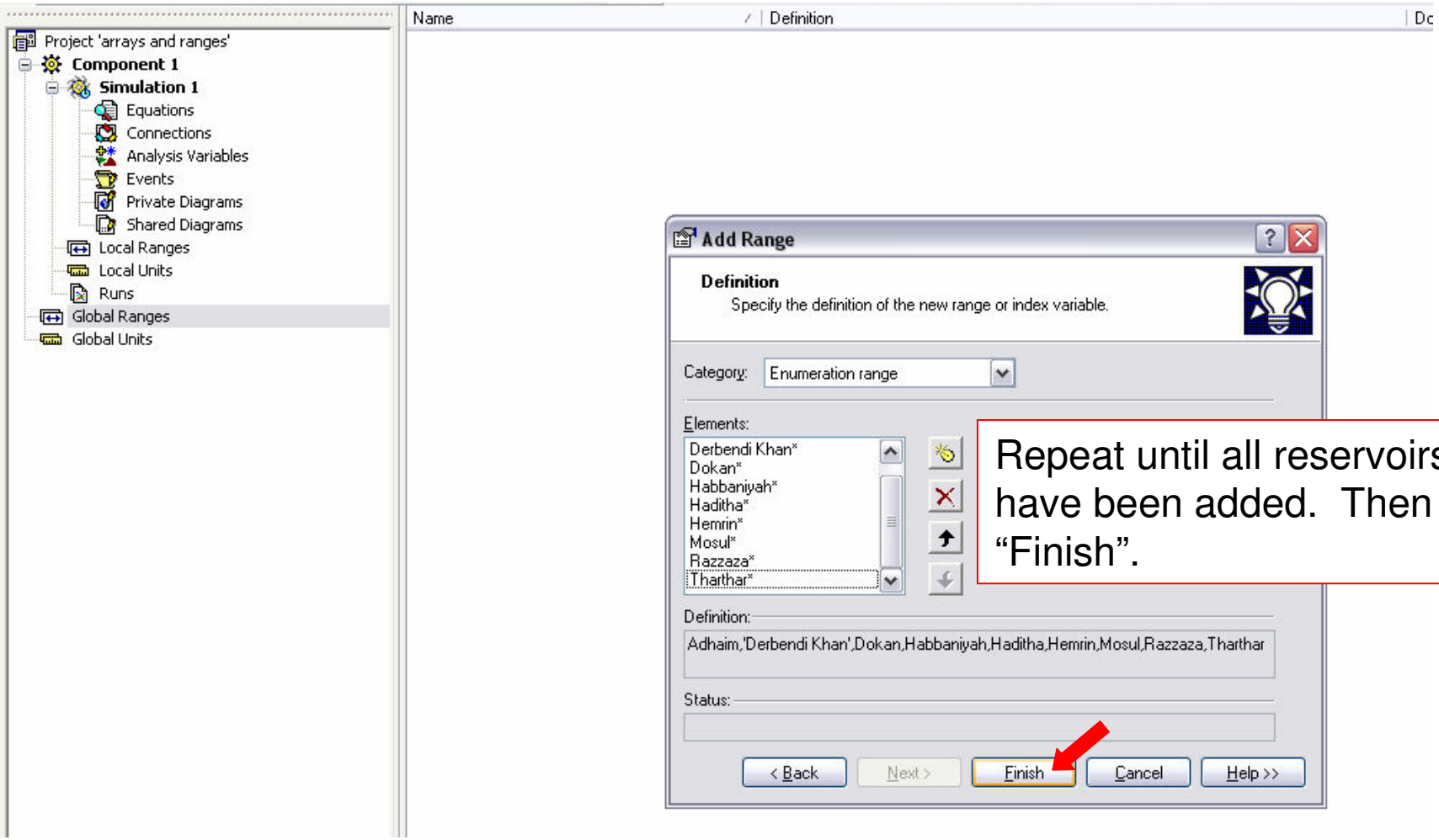


Creating Ranges



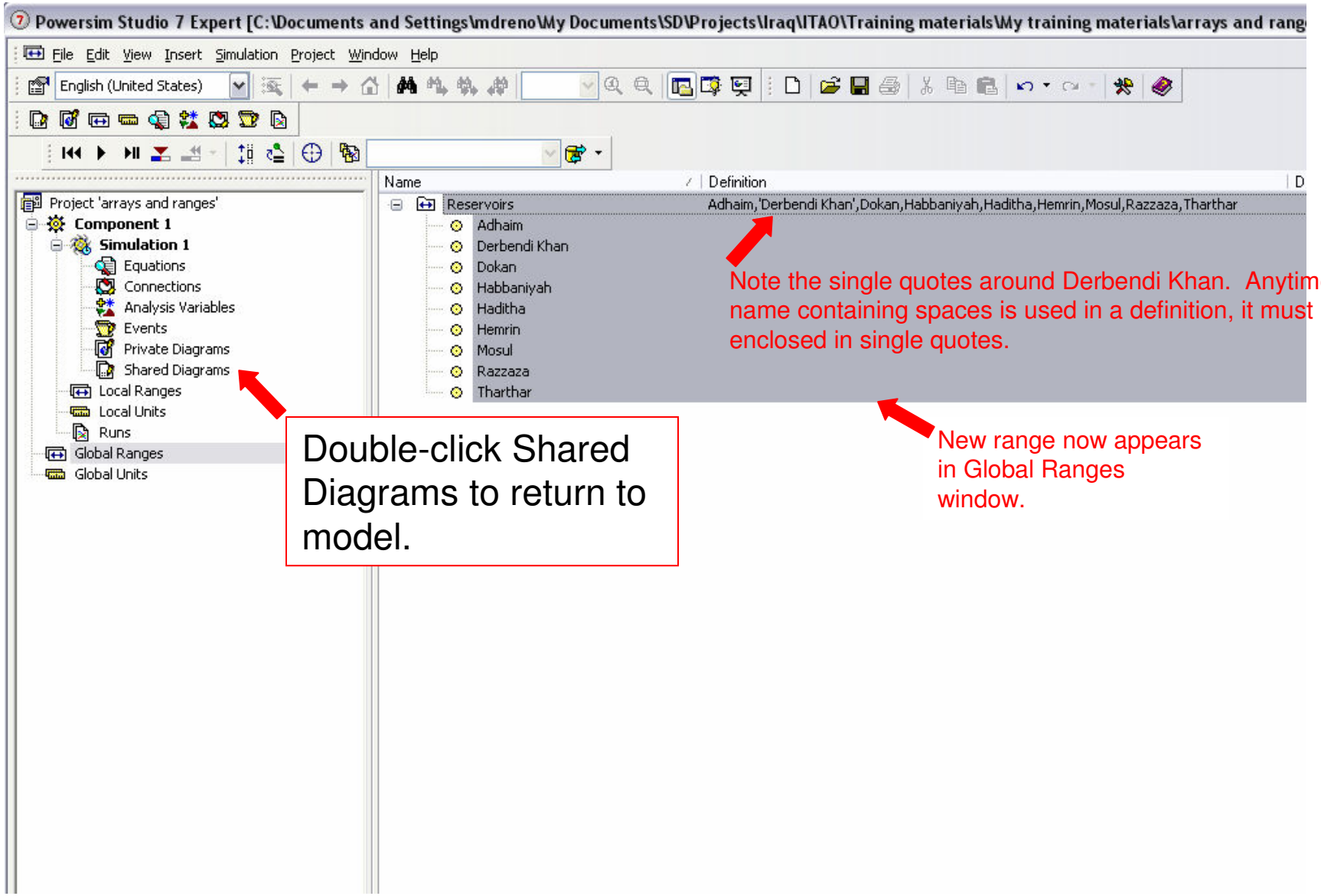
After you have entered the name of your first reservoir, click to add the next reservoir name.

Creating Ranges



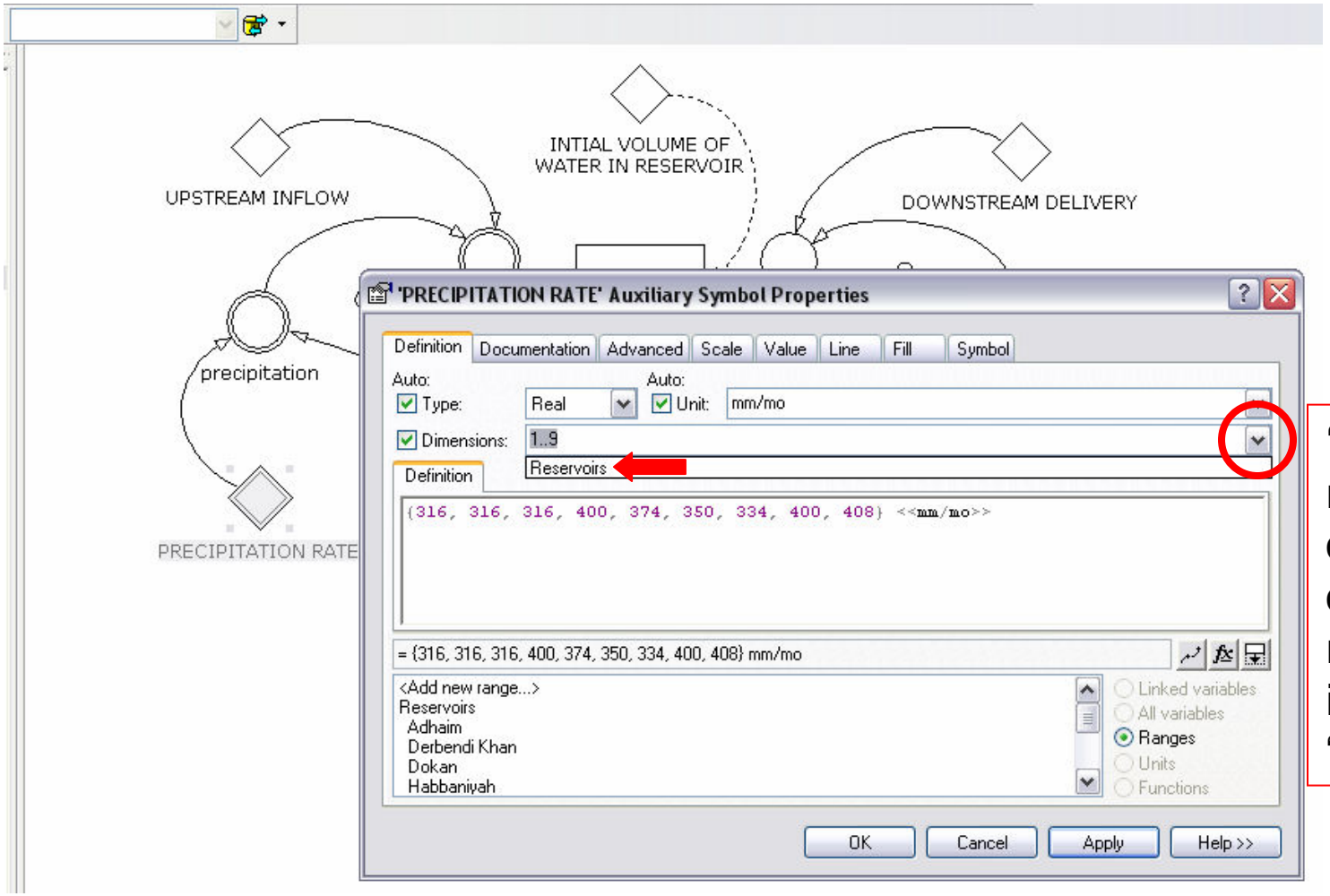
Repeat until all reservoirs have been added. Then click "Finish".

Creating Ranges



Creating Ranges

We will now modify the dimensions of **PRECIPITATION RATE** so that they relate to the newly created '**Reservoirs**' range.

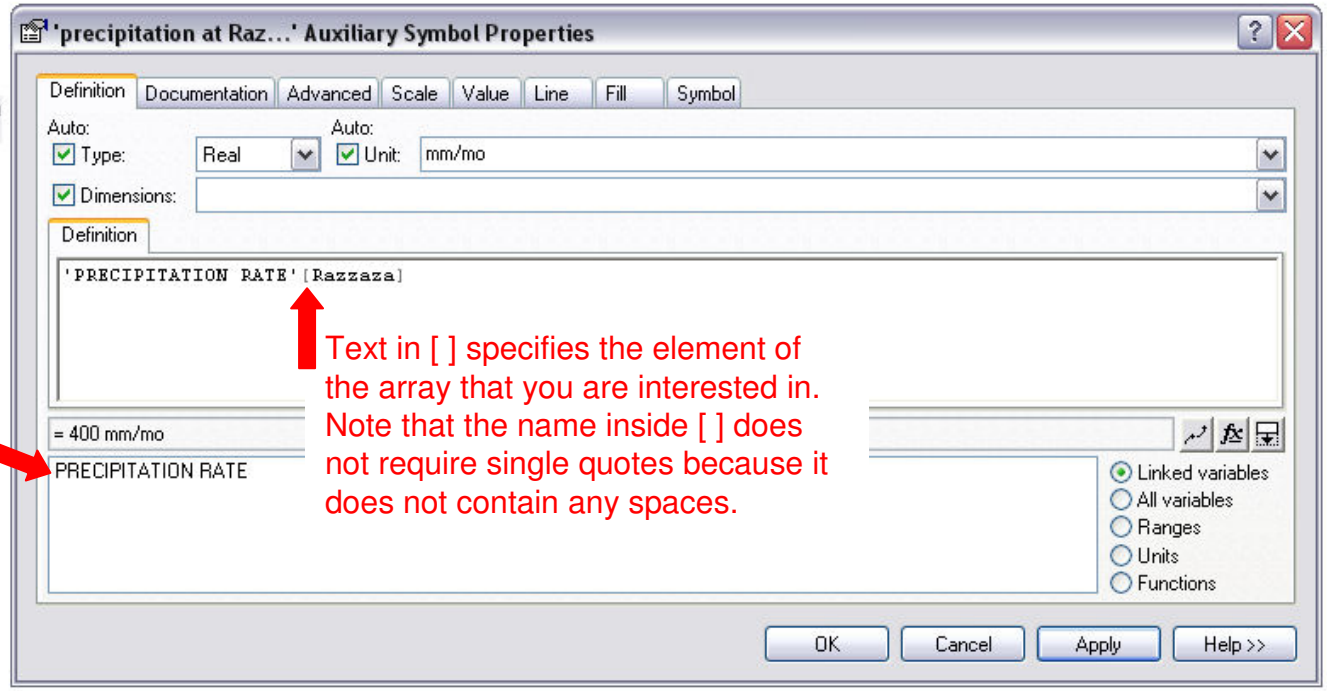


'**Reservoirs**' now appears in dimensions dropdown menu. Select it and click "OK".

Creating Ranges

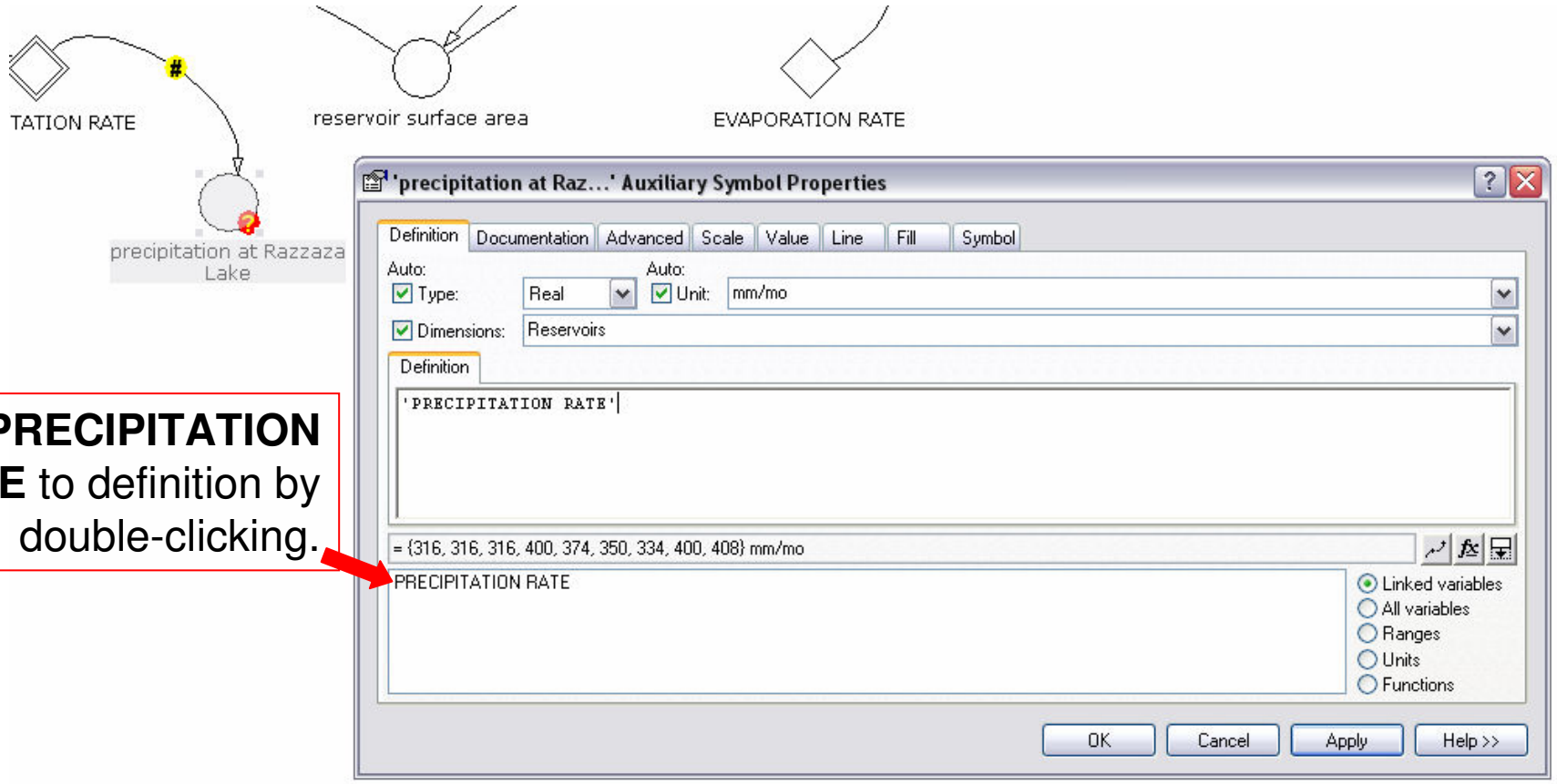
The elements contained in **PRECIPITATION RATE** can now be accessed using the reservoir names. Suppose we want to use the precipitation at Razzaza Lake for another calculation in the model. To pull this single value from the **PRECIPITATION RATE** array, we create a new variable **precipitation at Razzaza Lake**, connect it to **PRECIPITATION RATE**, and define it as shown below.

Add **PRECIPITATION RATE** to definition by double-clicking, then type "[Razzaza]".



Creating Ranges

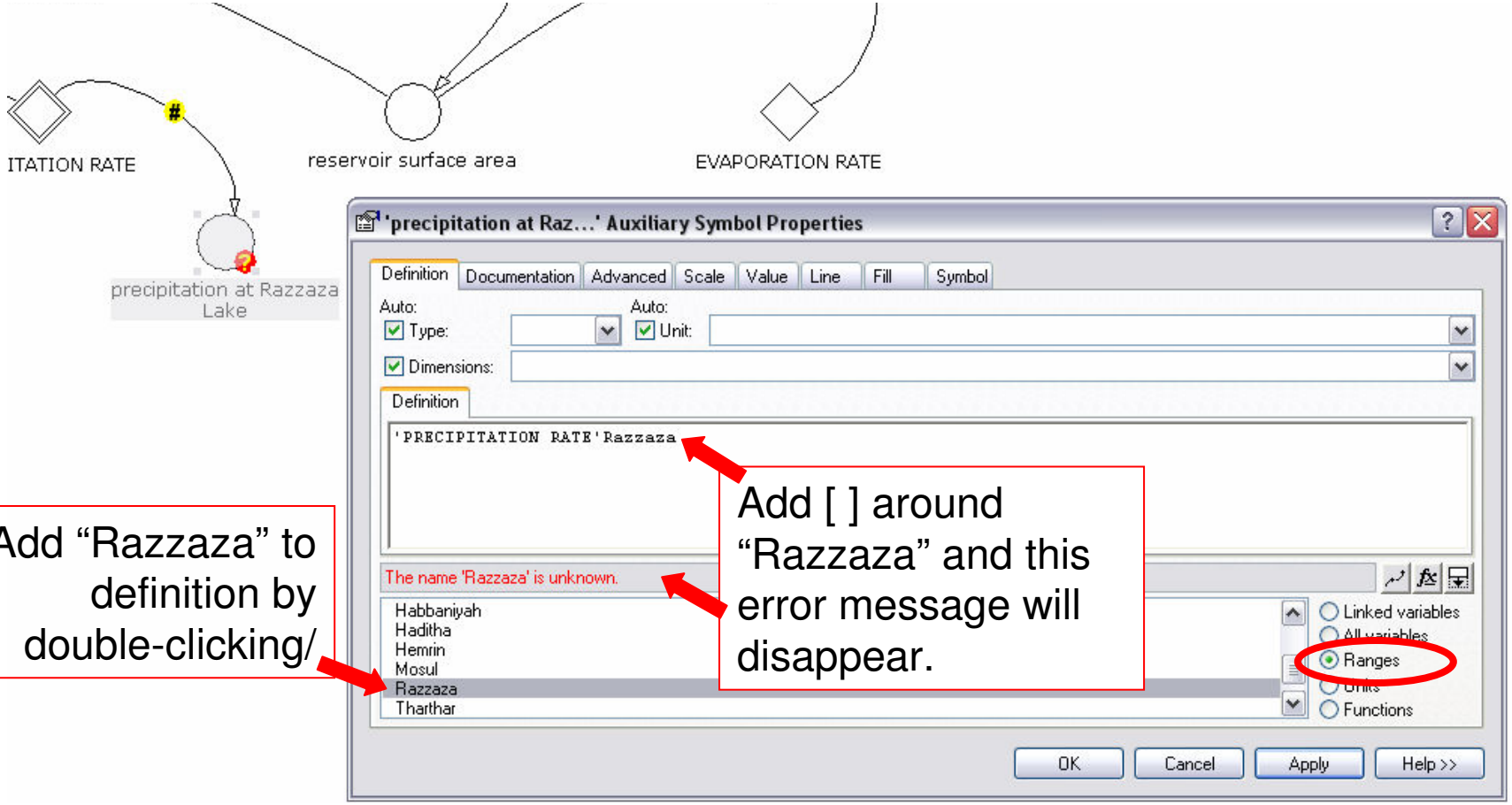
Another way to enter the definition from the previous slide is by double-clicking **PRECIPITATION RATE** as before…



Add **PRECIPITATION RATE** to definition by double-clicking.

Creating Ranges

…then toggle Ranges button and double-click “Razzaza” from list of ranges that appears. Note that [ ] must be manually added to the definition.



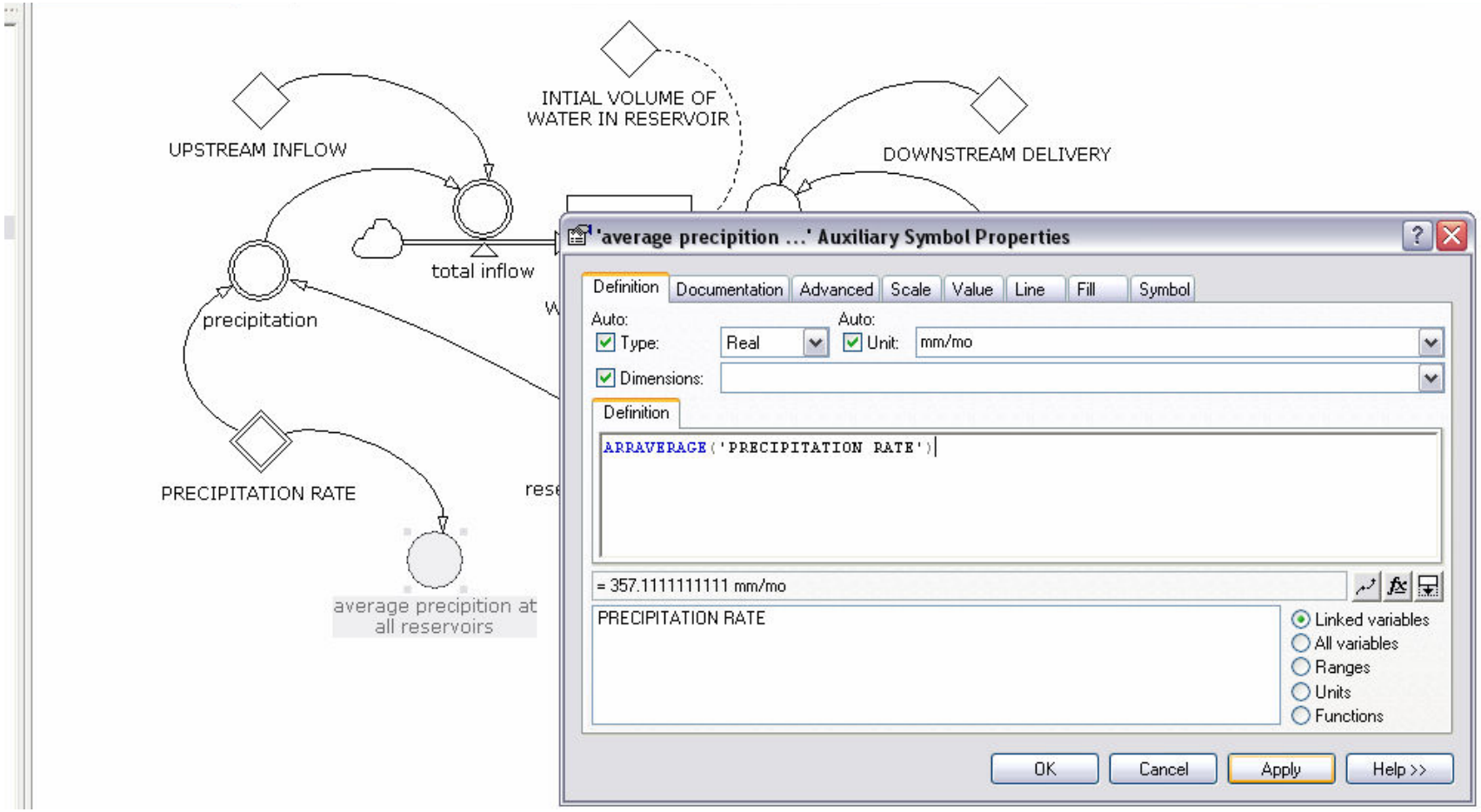
Array Functions

There are several functions available in Studio that enable you to perform various operations on array. These include ARRAVERAGE, ARRMAX, and ARRMIN, which calculate the average, maximum, and minimum of array elements. A list of array functions and their descriptions can be found by searching titles only for "about array functions" in Help (from Menu Bar, Help → Contents *or* press F1 *and* make sure "Search titles only" box is checked).

Array Functions	
ARRAVERAGE - Average of Array Elements	LOOKUP - Lookup Value of Array Element
ARRMAX - Maximum of Array Elements	MINVERSE - Inverse Square Matrix
ARRMIN - Minimum	NUMERICAL - Convert Range Element to Number
ARRPOLY - Array Polynomial	PRIORITYALLOCDISCRETE - Discrete Prioritized Resource Allocation
ARRPRODUCT - Product of Array Elements	PRIORITYALLOC - Prioritized Resource Allocation
ARRSTDEV - Standard Deviation of Infinite Population of Array Elements	PRODUCT - Product
ARRSTDEVP - Standard Deviation of Finite Population of Array Elements	REDIM - Redimension Array
ARRSUM - Sum of Array Elements	SCANEQ - Scan Vector for Equal Element
CONCAT - Concatenate Arrays	SCANGT - Scan Vector for Greater Element
COUNTEQ - Count Number of Equal Elements in Array	SCANGTEQ - Scan Vector for Greater or Equal Element
COUNTNTEQ - Count Number of Not Equal Elements in Array	SCANLT - Scan Vector for Smaller Element
COUNTGT - Count Number of Greater Elements in Array	SCANLTEQ - Scan Vector for Smaller or Equal Element
COUNTGTEQ - Count Number of Greater or Equal Elements in Array	SCANNEQ - Scan Vector for Unequal Element
COUNTLT - Count Number of Smaller Elements in Array	SCANNOTSAME - Scan Vector for Element with Different Representation
COUNTLTEQ - Count Number of Smaller or Equal Elements in Array	SCANSAME - Scan Vector for Element with Same Representation
COUNTNOTSAME - Count Number of Not Bit Equal Elements in Array	SORT - Sort Vector
COUNTSAME - Count Number of Bit Equal Elements in Array	SORTINDEX - Sort Vector Indices
CUMULATIVESUM - Cumulative Sum of Array Elements	SPARSESUM - Sparse Sum
DIM - Dimension of Variable	SPARSEVECTOR - Sparse Vectorize
DIMCOUNT - Dimension Count of Variable	SUM - Sum
ELEMCOUNT - Number of Elements in an Array	TRANSPOSE - Transpose Matrix
INDEX - Convert a Variable to an Index Variable	VECTOR - Vectorize Elements
LENGTH - Length of Array	XPROD - Vector Cross Product

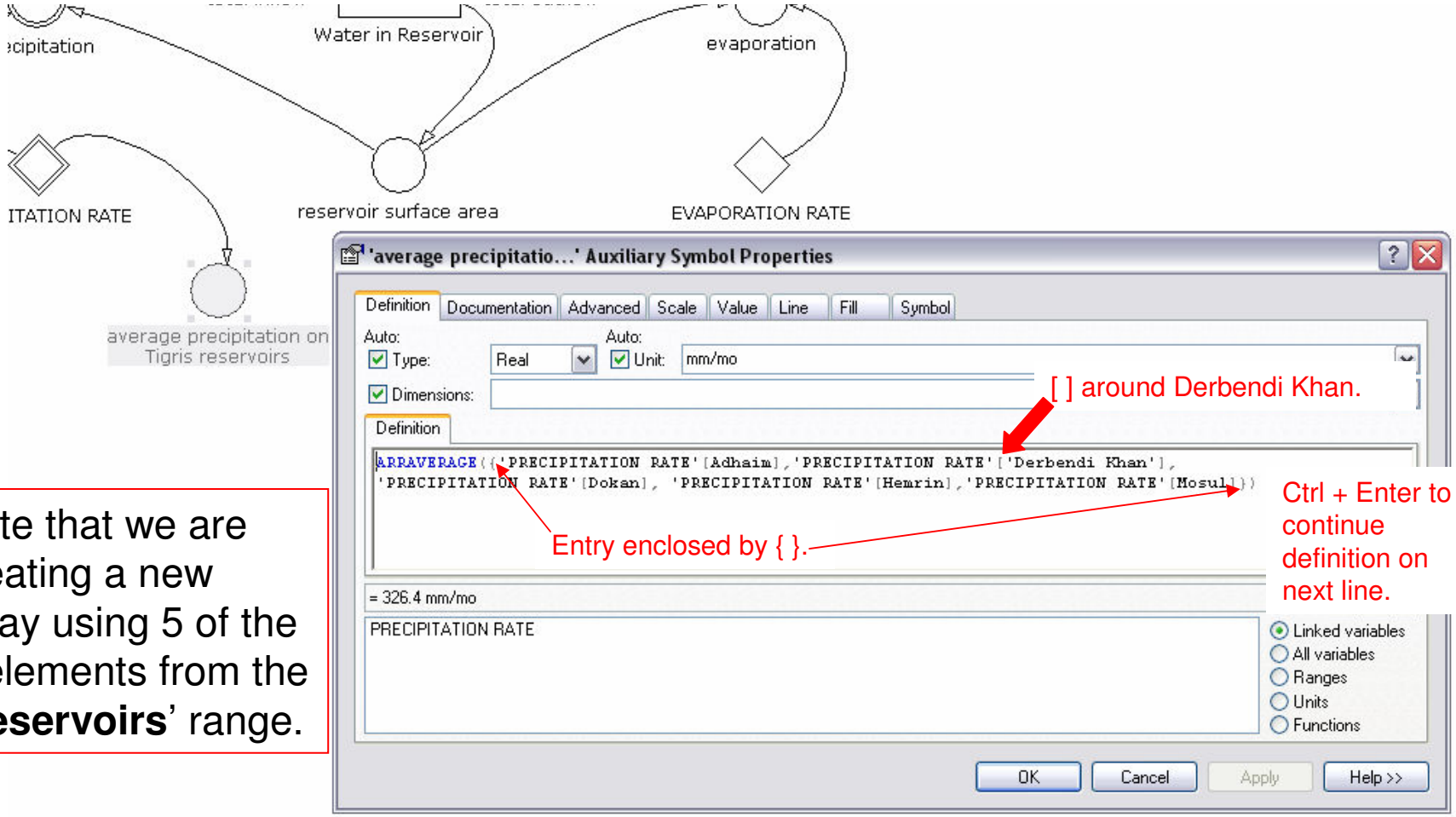
Array Functions

Calculate the average precipitation for all 9 reservoirs.



Array Functions

Calculate the average precipitation for reservoirs on the Tigris and its tributaries.



Note that we are creating a new array using 5 of the 9 elements from the '**Reservoirs**' range.

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Creating Datasets

National Nuclear Security Administration

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Dataset Types

Excel Spreadsheet Dataset

→ Requires link to an external Excel file (i.e., in order to work with this kind of dataset, Excel will have to be running in parallel with Studio).

→ Allows you to quickly import and work with large datasets.

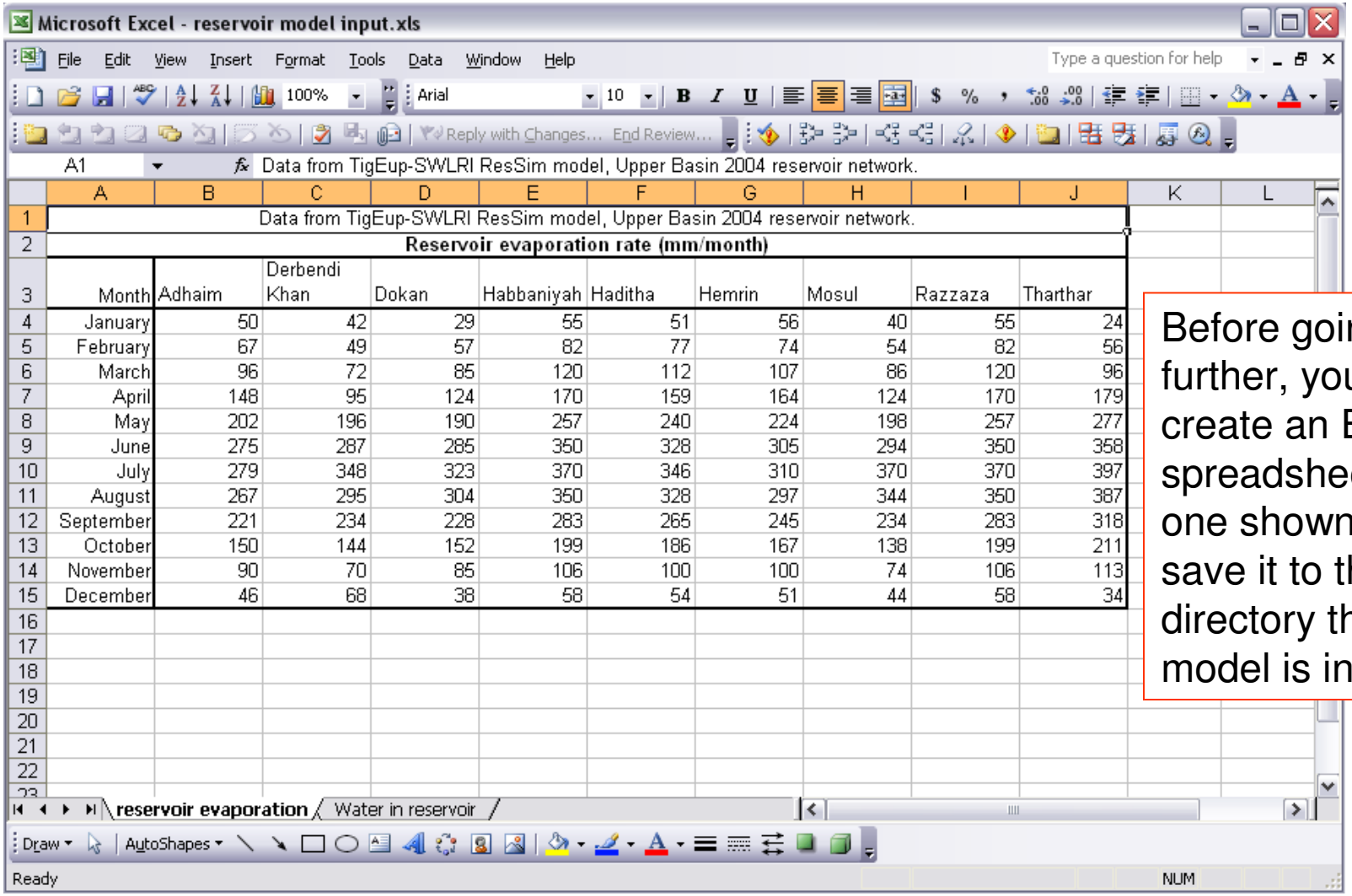
Manually-entered Dataset Array

→ If you have a small amount of data, it might be easier to manually enter it directly into the variable of interest rather than import it from Excel. We did this for **PRECIPITATION RATE** on slide 66.

→ Does not require link to external file.

Create Excel Dataset Connection

Suppose you want to use monthly evaporation data for each of the 9 reservoirs in place of the fixed annual average evaporation rate.



Microsoft Excel - reservoir model input.xls

A1: Data from TigEup-SWLRI ResSim model, Upper Basin 2004 reservoir network.

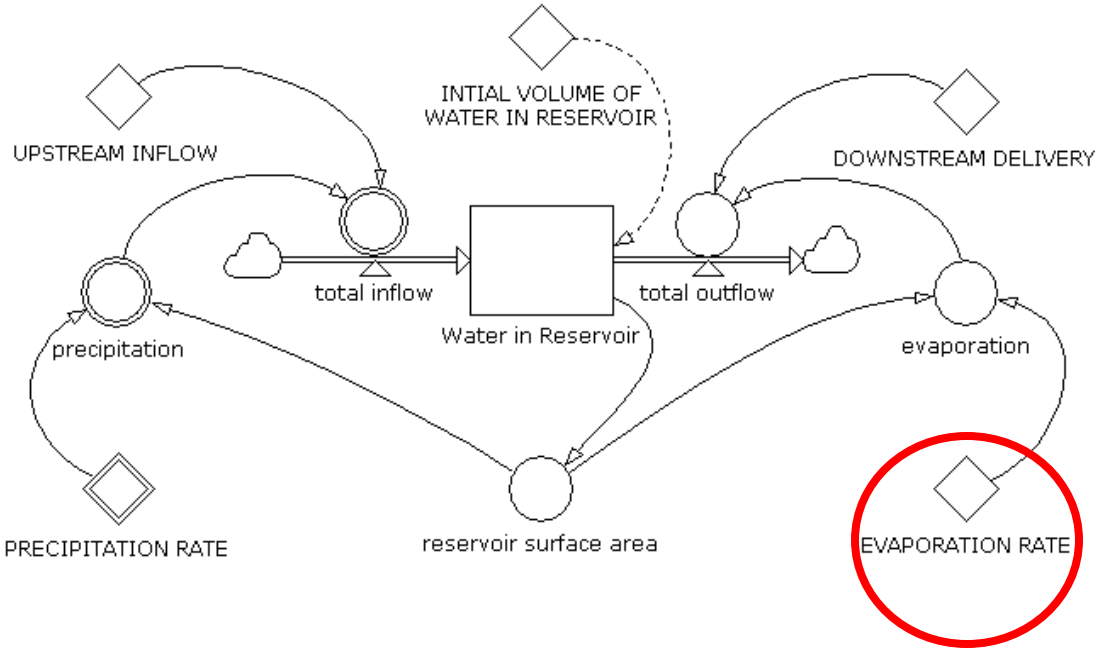
	A	B	C	D	E	F	G	H	I	J	K	L
1	Data from TigEup-SWLRI ResSim model, Upper Basin 2004 reservoir network.											
2	Reservoir evaporation rate (mm/month)											
3	Month	Adhaim	Derbendi Khan	Dokan	Habbaniyah	Haditha	Hemrin	Mosul	Razzaza	Tharthar		
4	January	50	42	29	55	51	56	40	55	24		
5	February	67	49	57	82	77	74	54	82	56		
6	March	96	72	85	120	112	107	86	120	96		
7	April	148	95	124	170	159	164	124	170	179		
8	May	202	196	190	257	240	224	198	257	277		
9	June	275	287	285	350	328	305	294	350	358		
10	July	279	348	323	370	346	310	370	370	397		
11	August	267	295	304	350	328	297	344	350	387		
12	September	221	234	228	283	265	245	234	283	318		
13	October	150	144	152	199	186	167	138	199	211		
14	November	90	70	85	106	100	100	74	106	113		
15	December	46	68	38	58	54	51	44	58	34		
16												
17												
18												
19												
20												
21												
22												

reservoir evaporation | Water in reservoir

Ready NUM

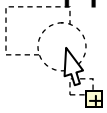
Before going any further, you need to create an Excel spreadsheet like the one shown here and save it to the same directory that your model is in.

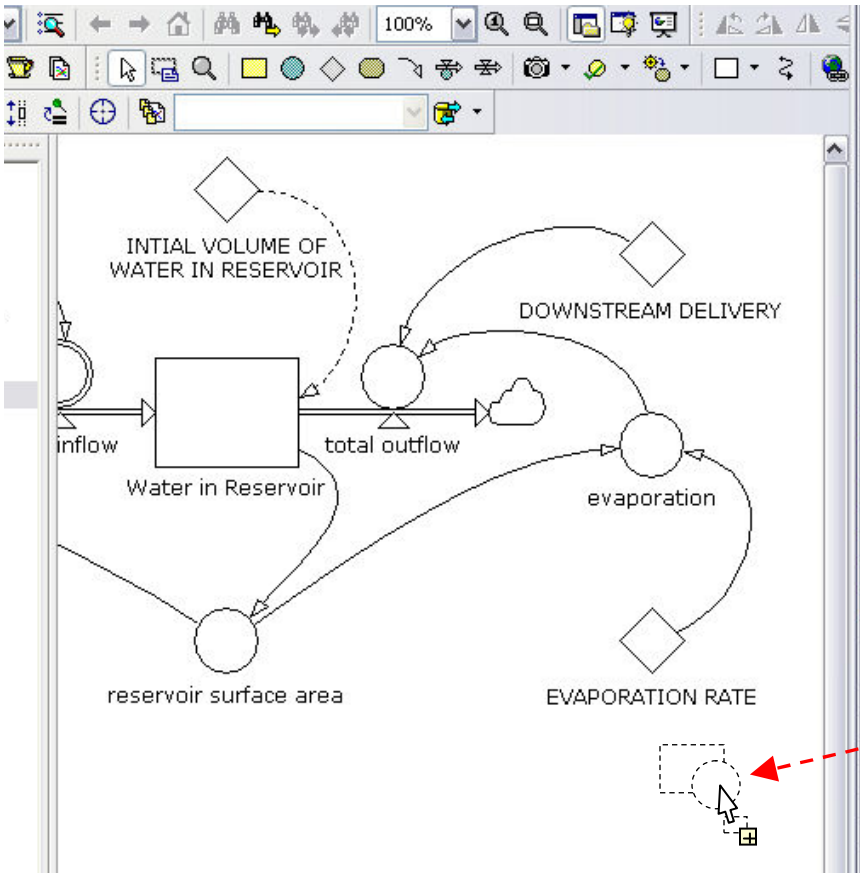
Create Excel Dataset Connection



We will replace the fixed value that currently defines **EVAPORATION RATE** with a series of monthly values (shown on the previous slide). These monthly values will be imported into Studio from an Excel spreadsheet using the function **XLDATA**. For additional information on this function, search for "XLDATA" in Help (from Menu Bar, Help → Contents *or* press F1).

Create Excel Dataset Connection

With Studio and Excel running side by side, highlight the data that you want to import. Move cursor to one of edges until  symbol appears. Left-click, hold mouse button down, and drag into Studio screen. When  symbol appears, let go of mouse button.

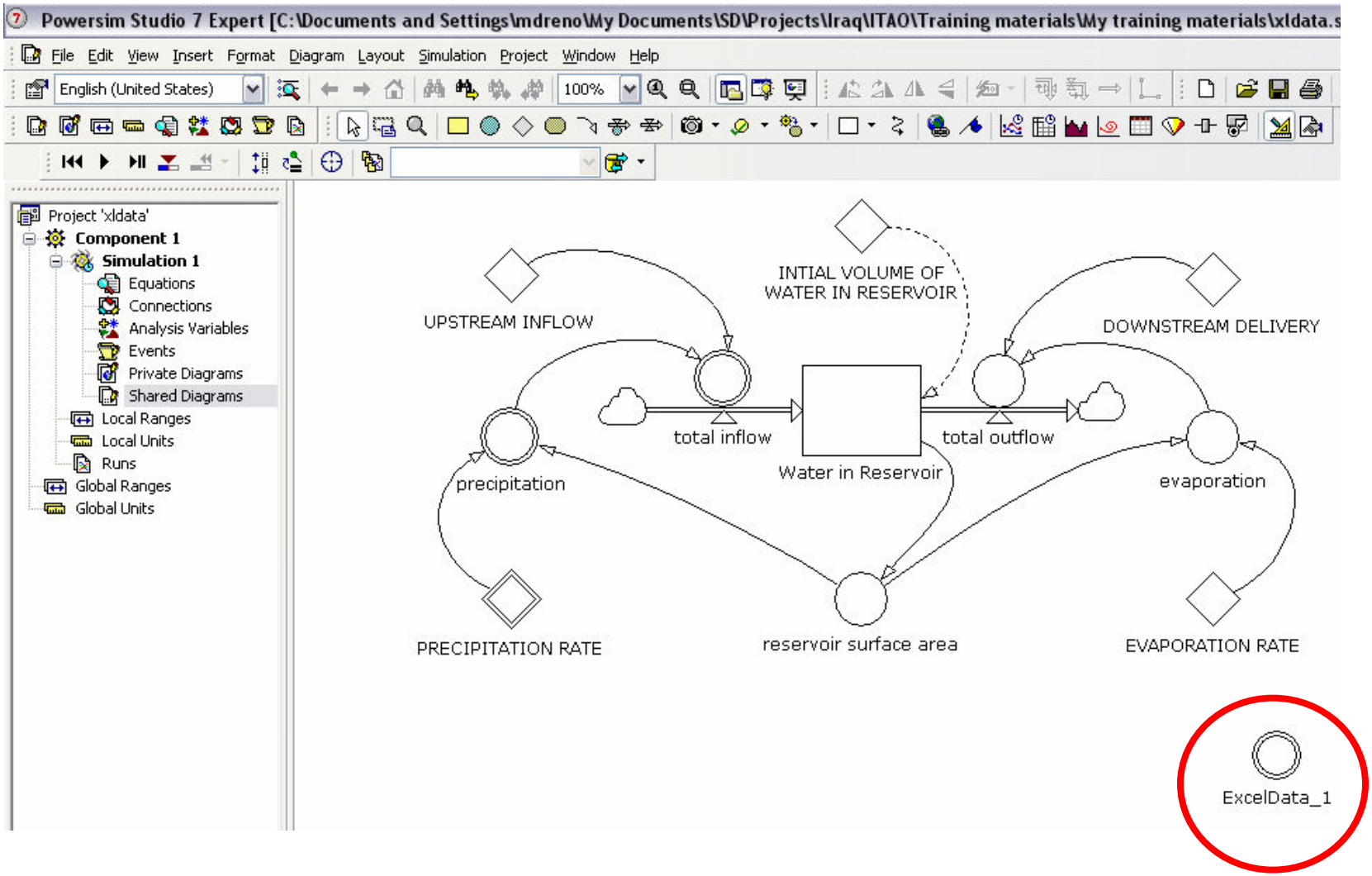


B4 | 50

	A	B	C	D	E	F	G	H	I	J
1	Data from TigEup-SWLRI ResSim model, Upper Basin 2004 reservoir network.									
2	Reservoir evaporation rate (mm/month)									
3	Month	Adhaim	Derbendi Khan	Dokan	Habbaniyah	Haditha	Hemrin	Mosul	Razzaza	Tharthar
4	January	50	42	29	55	51	56	40	55	24
5	February	67	49	57	82	77	74	54	82	56
6	March	96	72	85	120	112	107	86	120	96
7	April	148	95	124	170	159	164	124	170	179
8	May	202	196	190	257	240	224	198	257	277
9	June	275	287	285	350	328	305	294	350	358
10	July	279	348	323	370	346	310	370	370	397
11	August	267	295	304	350	328	297	344	350	387
12	September	221	234	228	283	265	245	234	283	318
13	October	150	144	152	199	186	167	138	199	211
14	November	90	70	85	106	100	100	74	106	113
15	December	46	68	38	58	54	51	44	58	34
16										
17										
18										
19										
20										
21										
22										
23										
24										

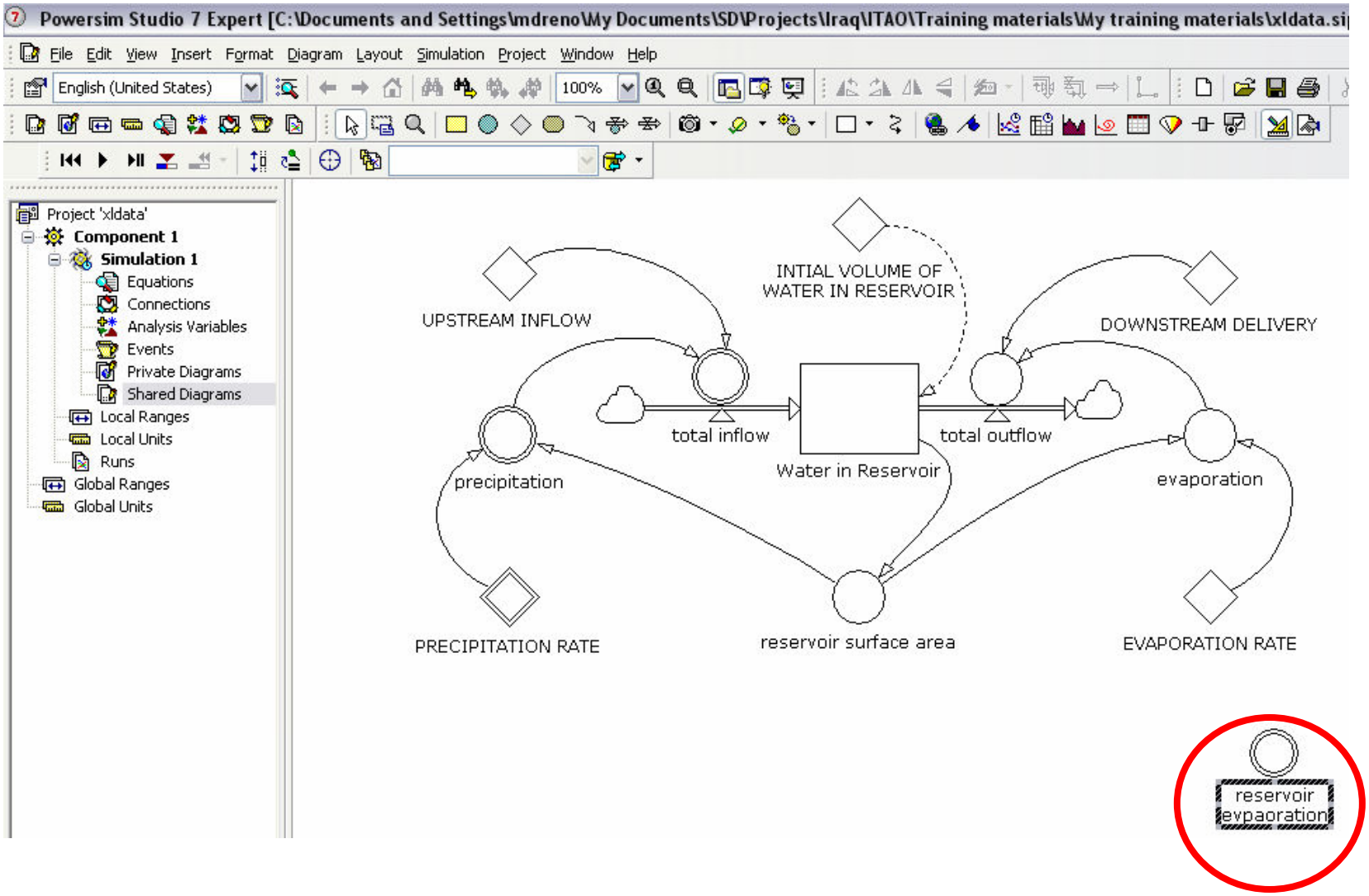
Create Excel Dataset Connection

New variable appears in diagram window.



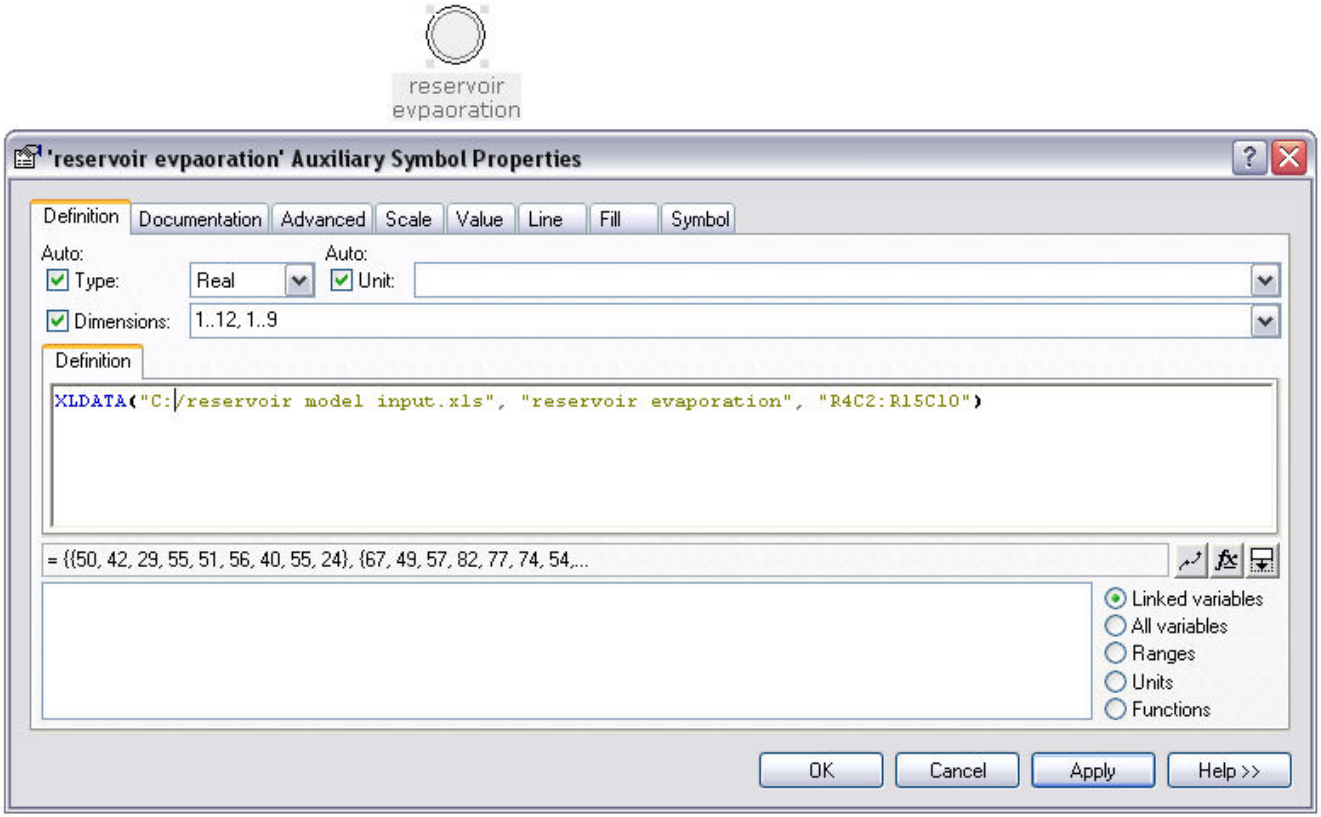
Use XLDATA Variable

Rename variable.



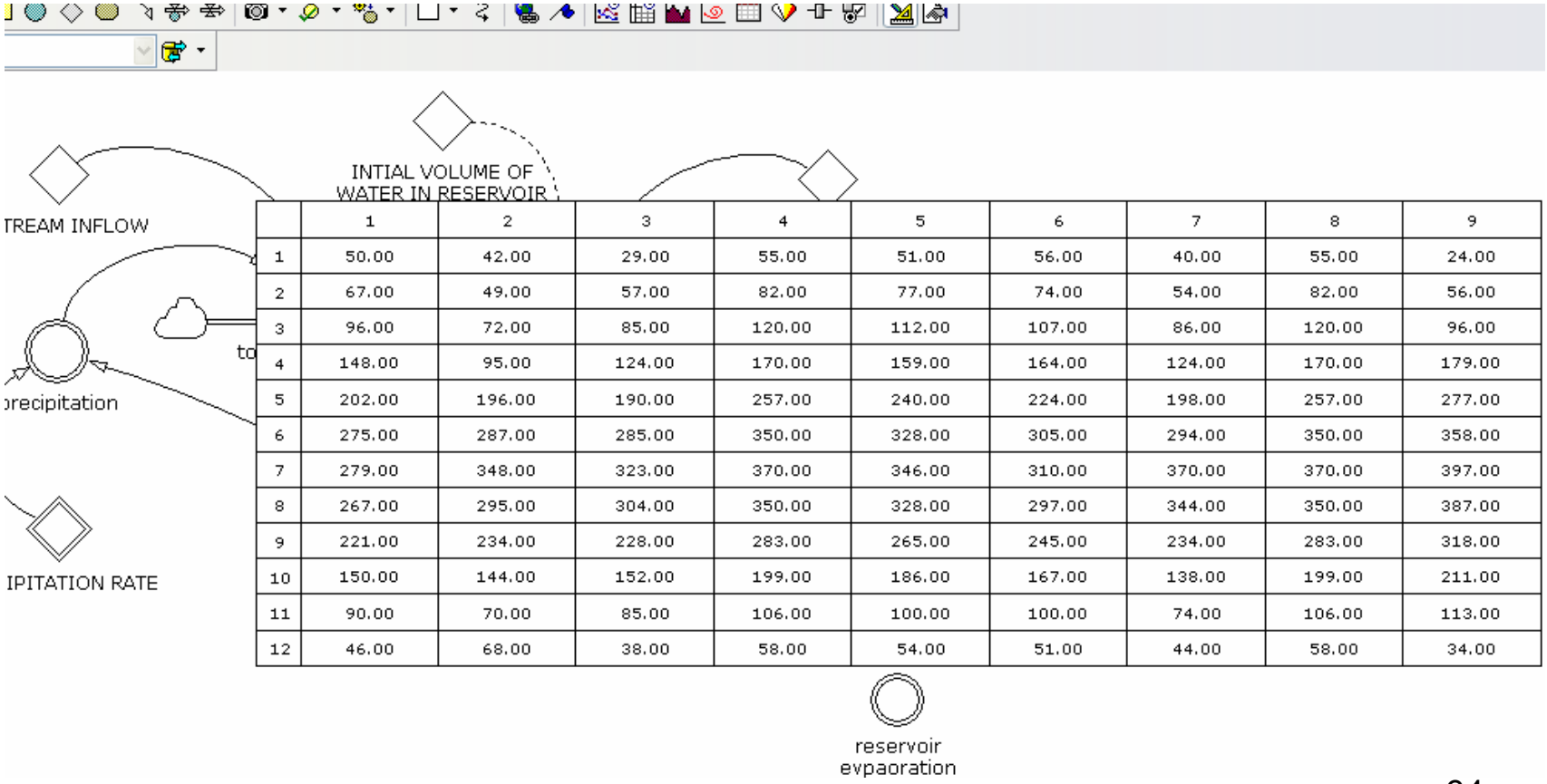
Use XLDATA Variable

Open **reservoir evaporation** and change path to "C:/*name of spreadsheet*.xls" (delete all text between "C:/" and *"name of spreadsheet*.xls"). Once you do this, you must keep your Studio model (.sip file) and spreadsheet in the same directory! This allows you to transfer the model and spreadsheet between computers or copy to other directories without breaking the data connection.



Use XLDATA Variable

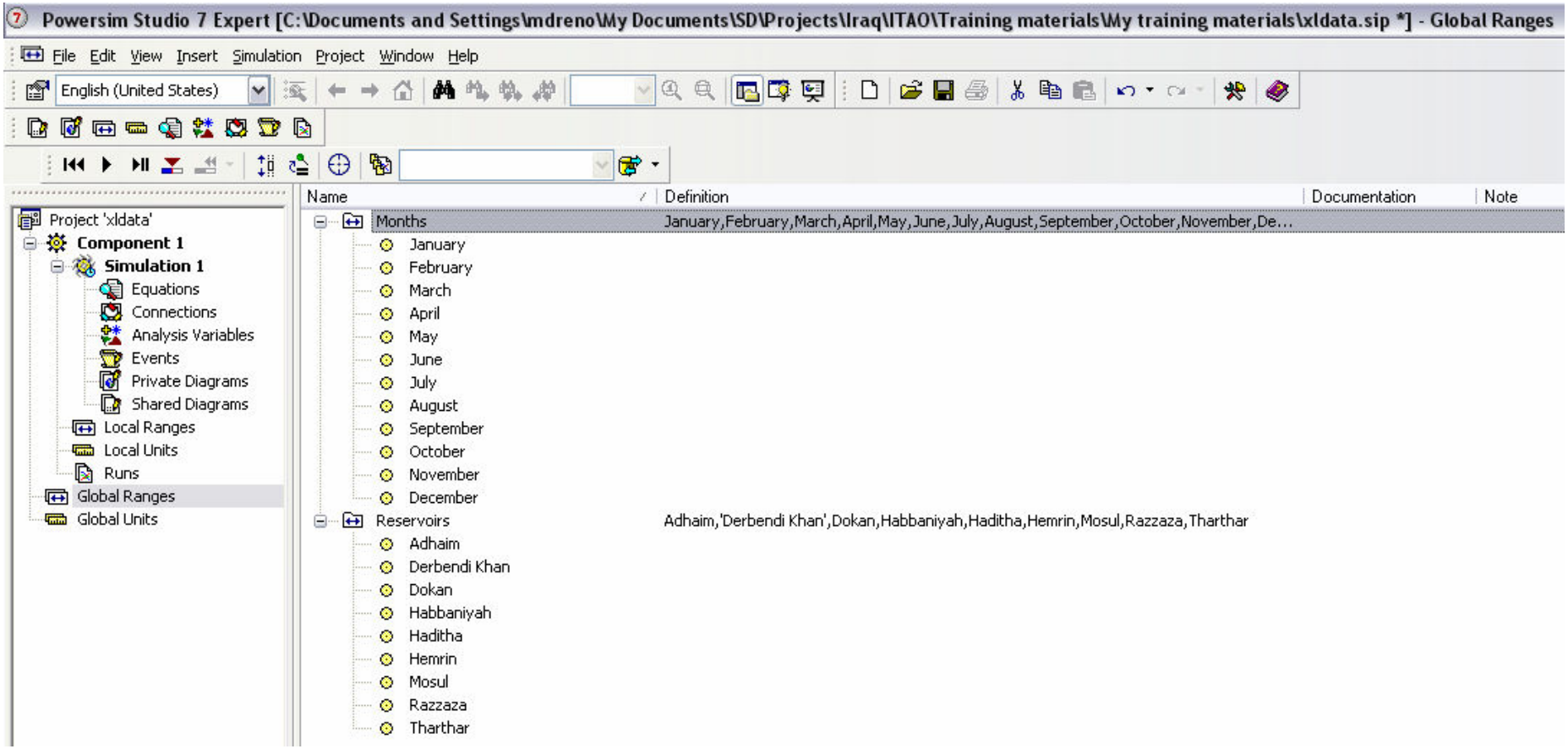
Show number auto report and observe that you have created a 12 x 9 array. The 12 rows correspond to the 12 months of a year. The 9 columns correspond to the 9 reservoirs.



	1	2	3	4	5	6	7	8	9
1	50.00	42.00	29.00	55.00	51.00	56.00	40.00	55.00	24.00
2	67.00	49.00	57.00	82.00	77.00	74.00	54.00	82.00	56.00
3	96.00	72.00	85.00	120.00	112.00	107.00	86.00	120.00	96.00
4	148.00	95.00	124.00	170.00	159.00	164.00	124.00	170.00	179.00
5	202.00	196.00	190.00	257.00	240.00	224.00	198.00	257.00	277.00
6	275.00	287.00	285.00	350.00	328.00	305.00	294.00	350.00	358.00
7	279.00	348.00	323.00	370.00	346.00	310.00	370.00	370.00	397.00
8	267.00	295.00	304.00	350.00	328.00	297.00	344.00	350.00	387.00
9	221.00	234.00	228.00	283.00	265.00	245.00	234.00	283.00	318.00
10	150.00	144.00	152.00	199.00	186.00	167.00	138.00	199.00	211.00
11	90.00	70.00	85.00	106.00	100.00	100.00	74.00	106.00	113.00
12	46.00	68.00	38.00	58.00	54.00	51.00	44.00	58.00	34.00

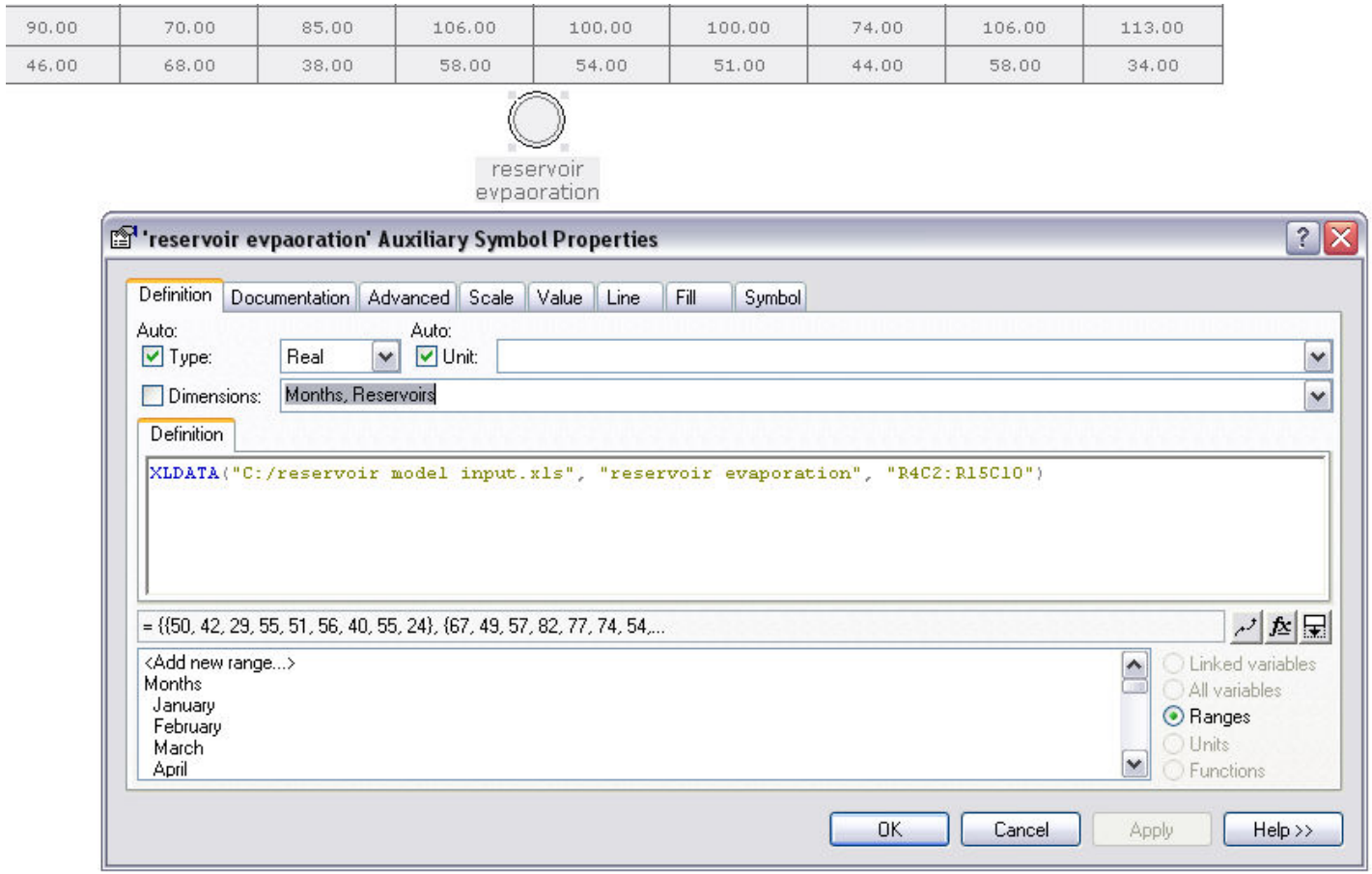
Use XLDATA Variable

We want to give this array dimensions of '**Months**' x '**Reservoirs**'. The '**Reservoirs**' range has already been created. Create a range called "Months". The Global Ranges screen should now look like this:



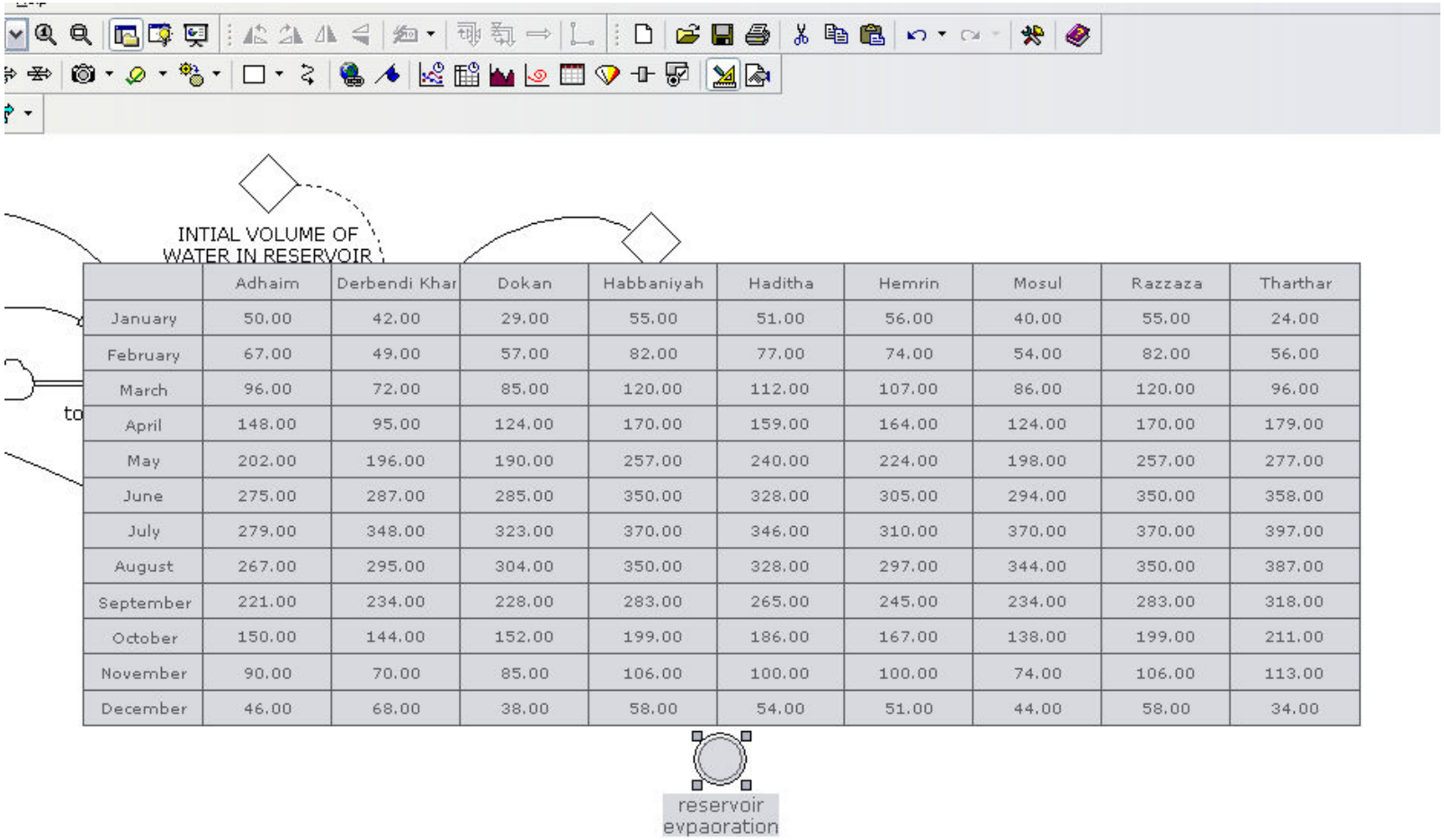
Use XLDATA Variable

Open **reservoir evaporation** and change the dimensions from “1..12, 1..9” to “Months, Reservoirs”. Click “Apply”.



Use XLDATA Variable

Notice that the row and column labels now reflect the appropriate months and reservoirs. Note also that no units appear (i.e., all of these values have units of *mm*/*mo*, but these do not appear anywhere). We will add these later.



	Adhaim	Derbendi Khar	Dokan	Habbaniyah	Haditha	Hemrin	Mosul	Razzaza	Tharthar
January	50.00	42.00	29.00	55.00	51.00	56.00	40.00	55.00	24.00
February	67.00	49.00	57.00	82.00	77.00	74.00	54.00	82.00	56.00
March	96.00	72.00	85.00	120.00	112.00	107.00	86.00	120.00	96.00
April	148.00	95.00	124.00	170.00	159.00	164.00	124.00	170.00	179.00
May	202.00	196.00	190.00	257.00	240.00	224.00	198.00	257.00	277.00
June	275.00	287.00	285.00	350.00	328.00	305.00	294.00	350.00	358.00
July	279.00	348.00	323.00	370.00	346.00	310.00	370.00	370.00	397.00
August	267.00	295.00	304.00	350.00	328.00	297.00	344.00	350.00	387.00
September	221.00	234.00	228.00	283.00	265.00	245.00	234.00	283.00	318.00
October	150.00	144.00	152.00	199.00	186.00	167.00	138.00	199.00	211.00
November	90.00	70.00	85.00	106.00	100.00	100.00	74.00	106.00	113.00
December	46.00	68.00	38.00	58.00	54.00	51.00	44.00	58.00	34.00

Use XLDATA Variable

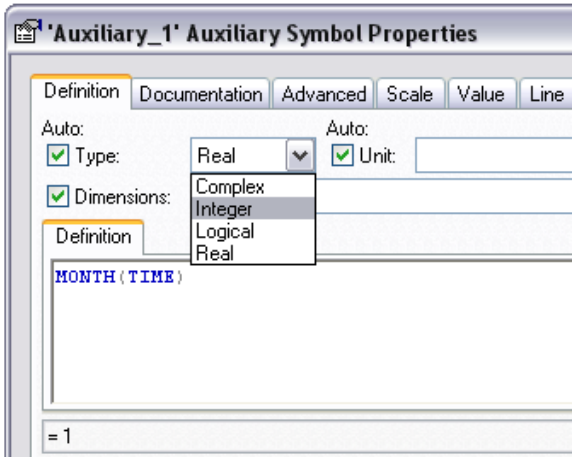
We will now link these data to the simulation time calculated by Studio when you run your model. We will do this by creating additional variables that use **INDEX** and **TIME** functions.

INDEX function

Used to access elements of an array. It allows you to use the integer value of any variable as an index when accessing an array element. For more information on this function, search "INDEX function" in Help (from Menu Bar, Help → Contents *or* press F1).

TIME function

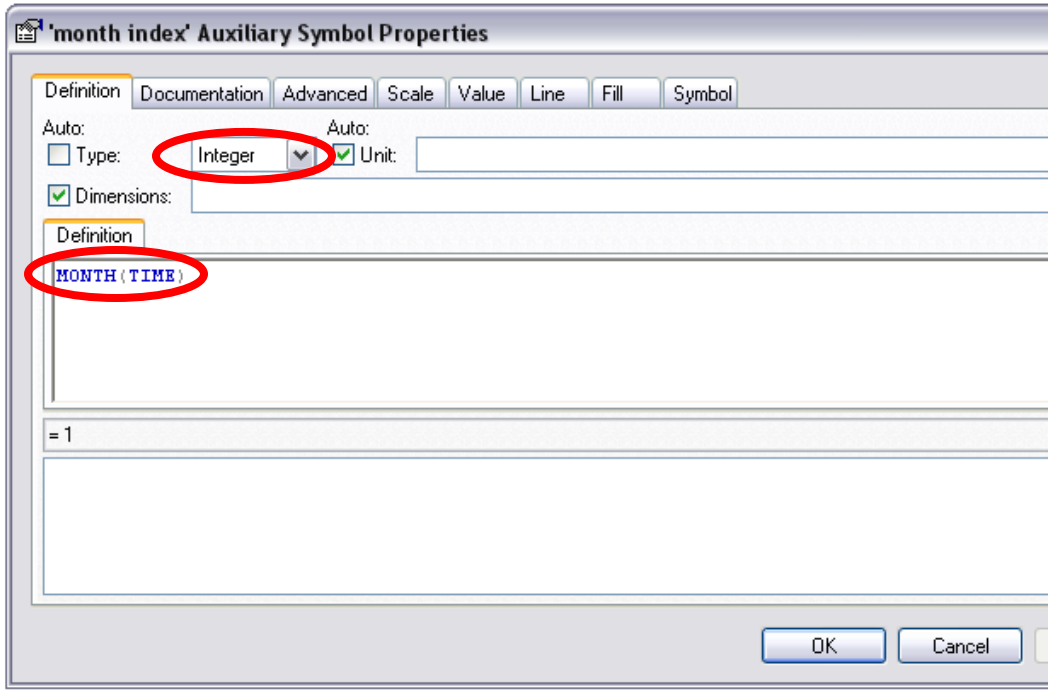
Returns the current time of the simulation. **DAY**(**TIME**) returns the current day of the simulation. **MONTH**(**TIME**) returns the current month of the simulation. **YEAR**(**TIME**) returns the current year of the simulation. In order to use any of these values in an **INDEX** function, you must specify "Integer" as variable type.



Use XLDATA Variable

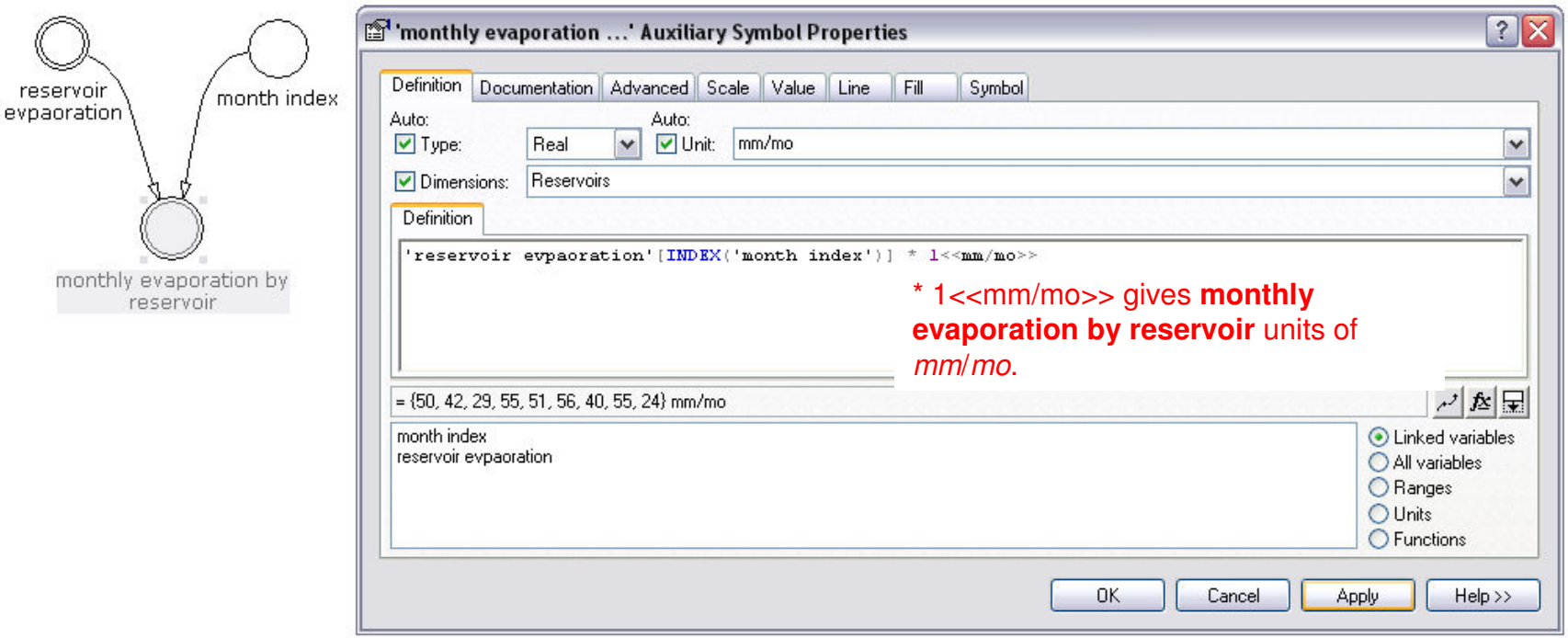
The data that we have imported are monthly and there is only 1 year of data. If we run our model for more than 1 year, we will need to reuse these data over and over again for the appropriate month. We will create a variable called “month index” to keep track of what the current month of the simulation is. Then we will use this variable to call the correct evaporation value.

Create a new variable **month index** and define it as shown here.



Use XLDATA Variable

Create a new variable **monthly evaporation by reservoir** and define it as shown here. Note that you must add the units “mm/mo”.

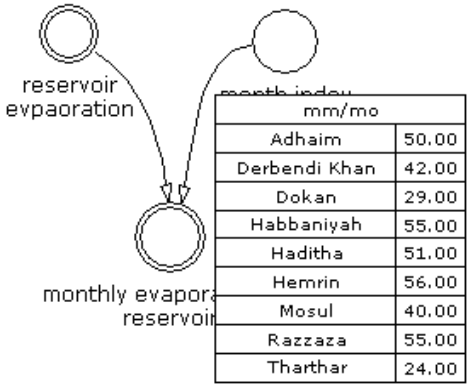


Use XLDATA Variable

Show auto report for **monthly evaporation by reservoir** and compare it to the auto report for **reservoir evaporation**.

	Adhaim	Derbendi Khar	Dokan	Habbaniyah	Haditha	Hemrin	Mosul	Razzaza	Tharthar
January	50.00	42.00	29.00	55.00	51.00	56.00	40.00	55.00	24.00
February	67.00	49.00	57.00	82.00	77.00	74.00	54.00	82.00	56.00
March	96.00	72.00	85.00	120.00	112.00	107.00	86.00	120.00	96.00
April	148.00	95.00	124.00	170.00	159.00	164.00	124.00	170.00	179.00
May	202.00	196.00	190.00	257.00	240.00	224.00	198.00	257.00	277.00
June	275.00	287.00	285.00	350.00	328.00	305.00	294.00	350.00	358.00
July	279.00	348.00	323.00	370.00	346.00	310.00	370.00	370.00	397.00
August	267.00	295.00	304.00	350.00	328.00	297.00	344.00	350.00	387.00
September	221.00	234.00	228.00	283.00	265.00	245.00	234.00	283.00	318.00
October	150.00	144.00	152.00	199.00	186.00	167.00	138.00	199.00	211.00
November	90.00	70.00	85.00	106.00	100.00	100.00	74.00	106.00	113.00
December	46.00	68.00	38.00	58.00	54.00	51.00	44.00	58.00	34.00

These values do not have any units.



mm/mo	
Adhaim	50.00
Derbendi Khan	42.00
Dokan	29.00
Habbaniyah	55.00
Haditha	51.00
Hemrin	56.00
Mosul	40.00
Razzaza	55.00
Tharthar	24.00

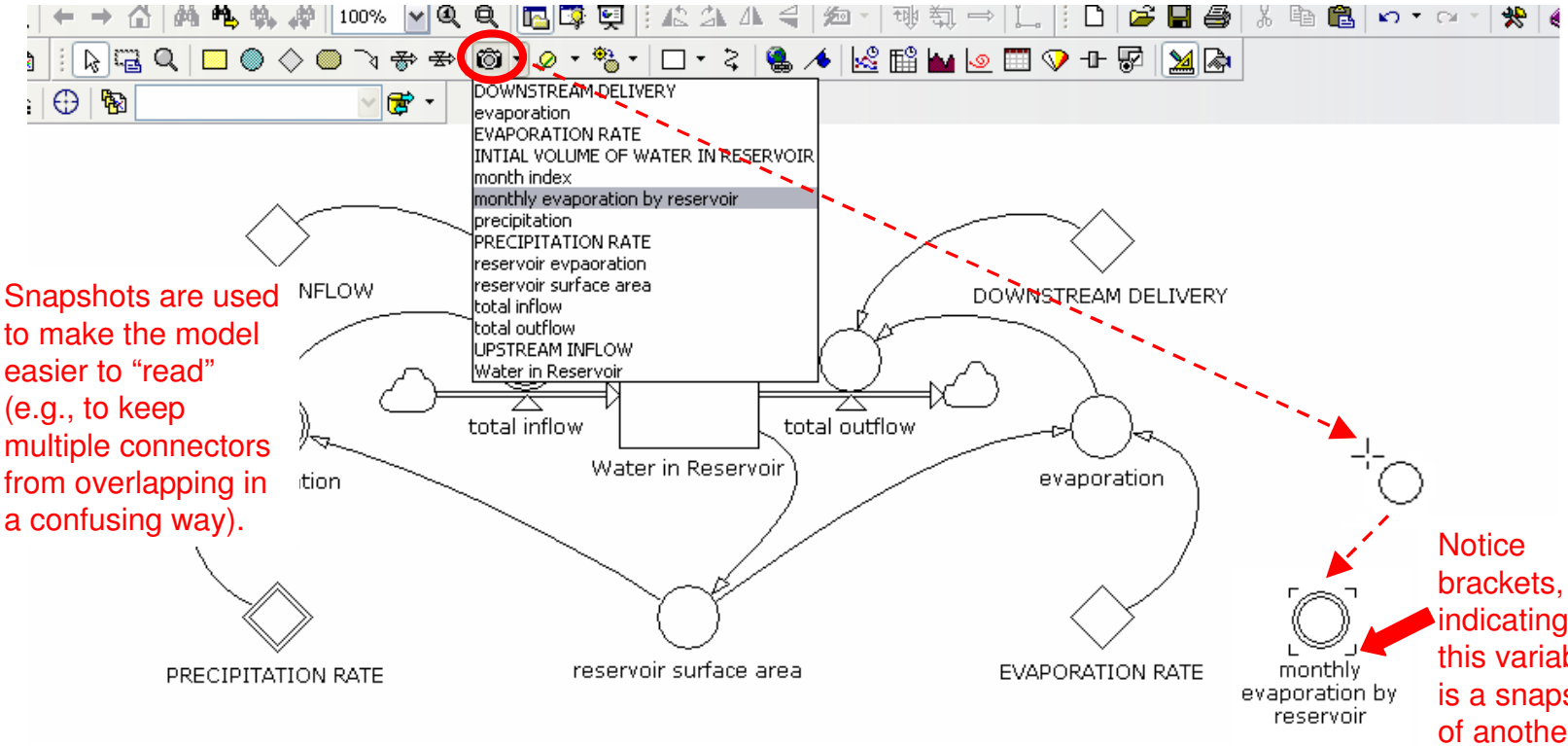
These values have units of *mm*/*mo*.

For every month of the simulation, **monthly evaporation by reservoir** calculates the evaporation at each reservoir for the current month of the simulation.

Use XLDATA Variable

Now we are going to replace **EVAPORATION RATE** with **monthly evaporation by reservoir**.

First, create a snapshot of **monthly evaporation by reservoir** by clicking the icon, selecting “monthly evaporation by reservoir”, placing the cursor in the part of the diagram window where you want the snapshot to appear, and clicking again.

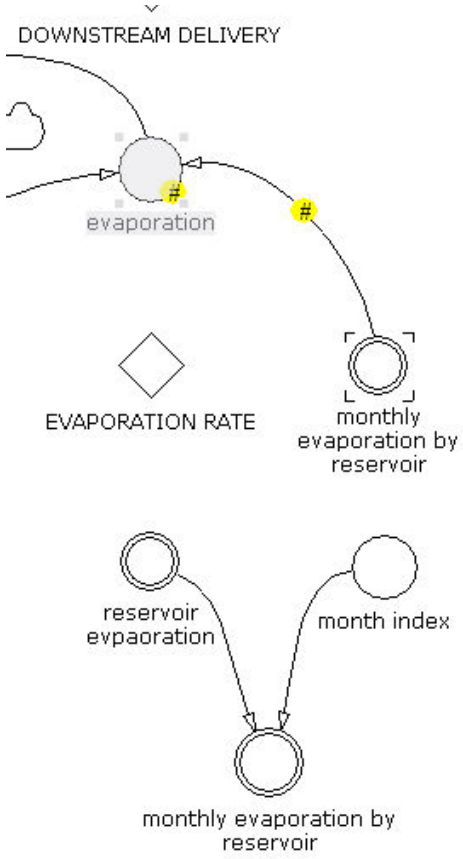


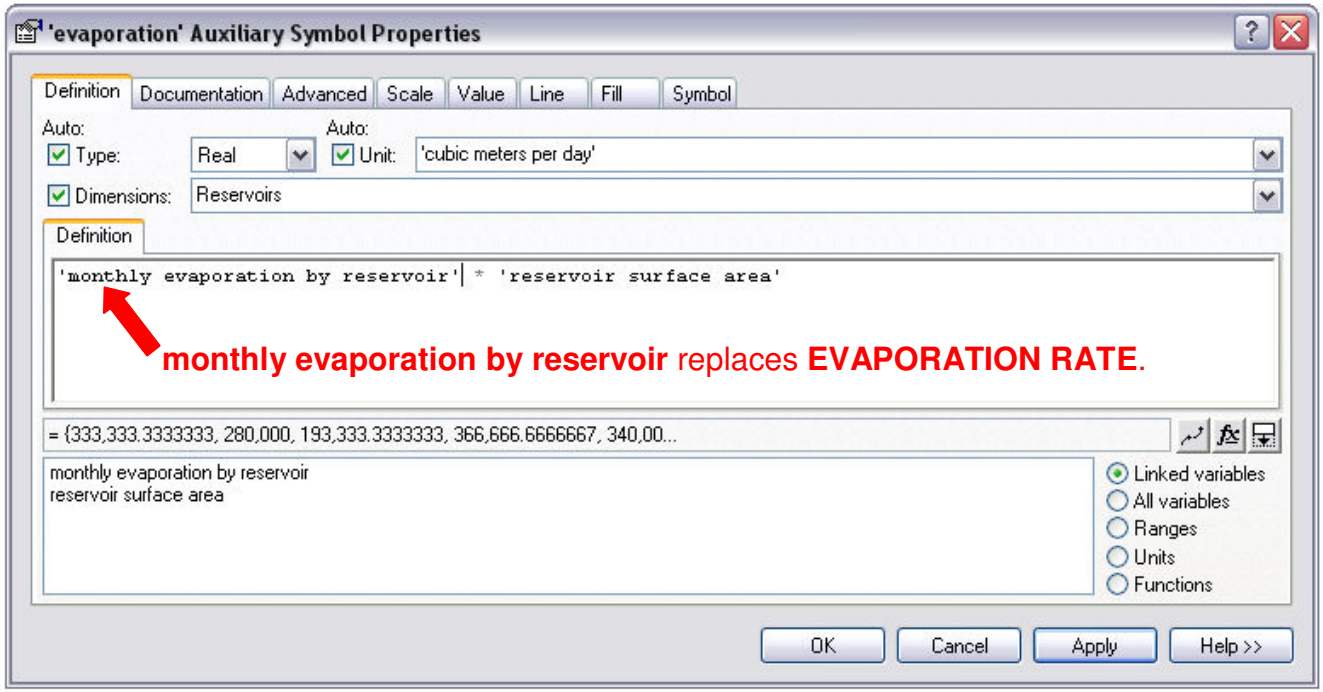
Snapshots are used to make the model easier to “read” (e.g., to keep multiple connectors from overlapping in a confusing way).

Notice brackets, indicating that this variable is a snapshot of another variable in the model.

Use XLDATA Variable

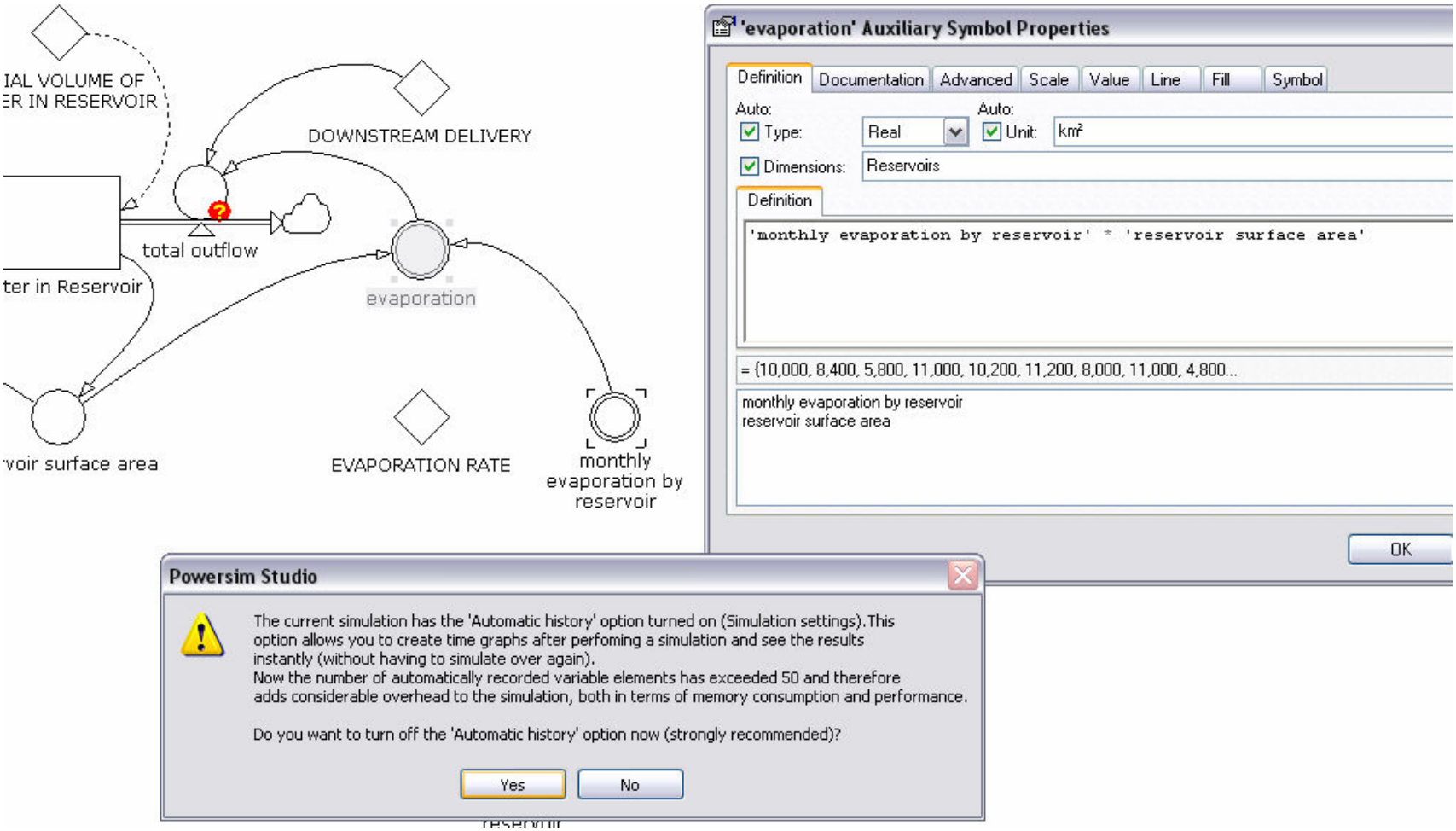
Delete connection between **EVAPORATION RATE** and **evaporation**. Create new connection between **monthly evaporation by reservoir** and **evaporation**. Redefine **evaporation**.





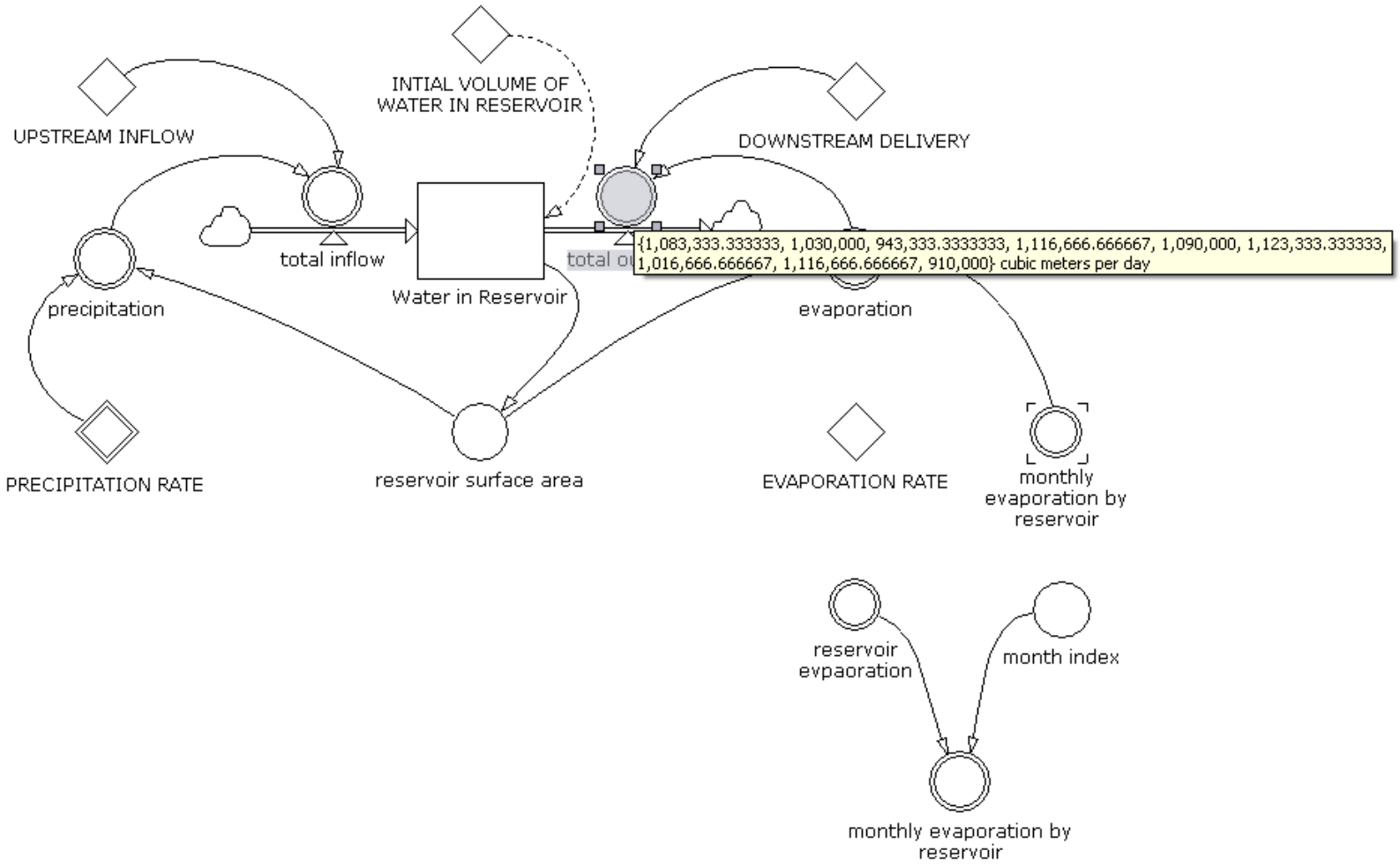
Use XLDATA Variable

A screen will appear asking if you want to turn off the ‘Automatic history’ option; click “Yes”. You can turn this option back on at any time through Simulation Settings. From Menu Bar, Simulation → Simulation Settings, then check the ‘Automatic history’ box.



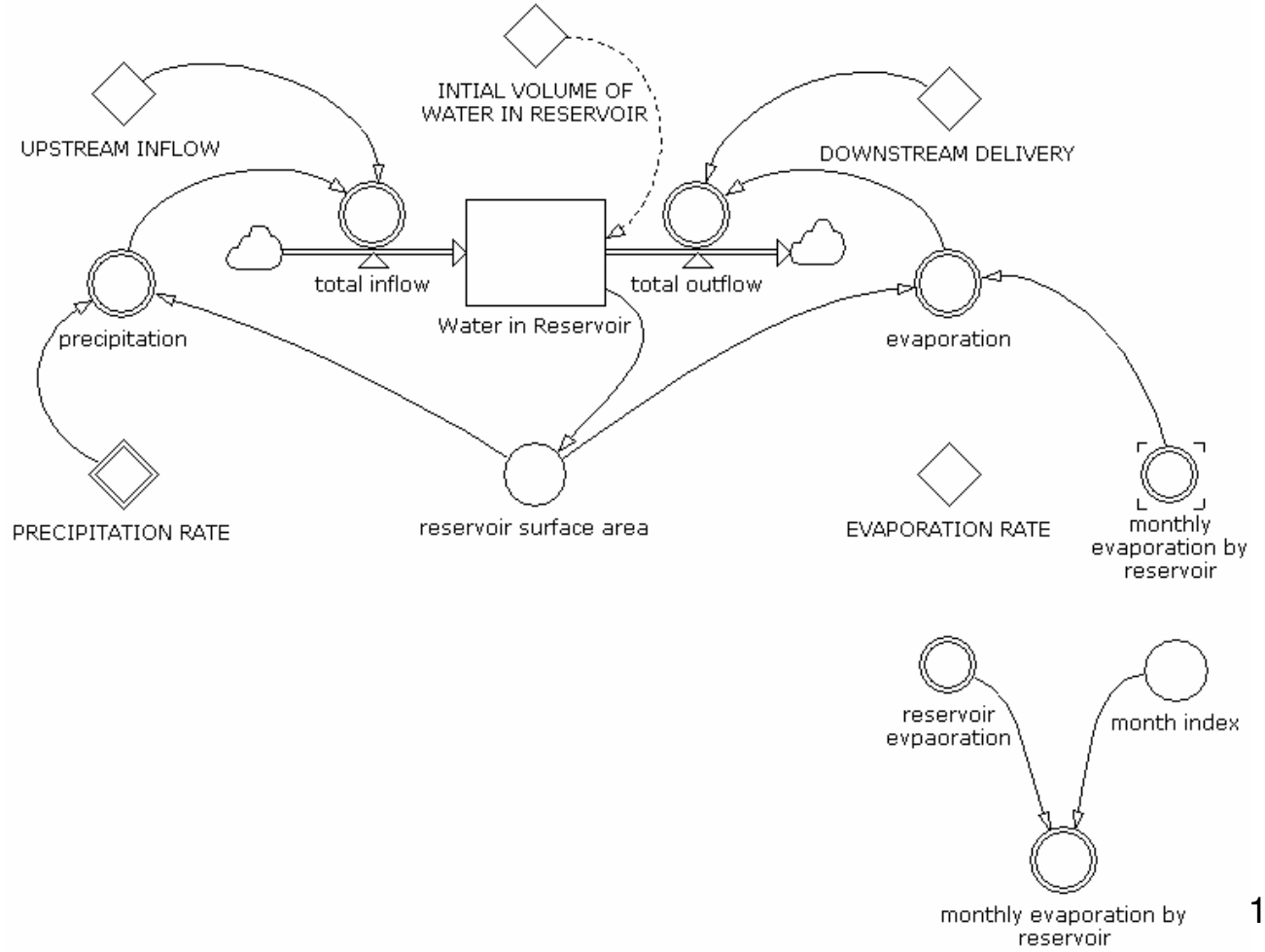
Use XLDATA Variable

total outflow now has dimensions of '**Reservoirs**' and **DOWNSTREAM DELIVERY** is used in the same way that **UPSTREAM INFLOW** is (see slide 69 for relevant details) **.**



Use XLDATA Variable

The reservoir model now includes reservoir-specific precipitation and evaporation data for the 9 reservoirs defined in the range '**Reservoirs**'. **precipitation** is a single average monthly value for each of the reservoirs, while **evaporation** uses a different value for every month of the year for each of the reservoirs. Because **evaporation** varies by month, we have to index it appropriately so that the model uses the correct value every month.



Iraq National Water Modeling Workshop I

November 11-15, 2007
United Nations University
Amman, Jordan

Other Useful Functions and Operators

IF

Description
The **IF** function is used to conduct conditional tests on values and formulas.

Syntax
IF(*Condition*, *A*, *B*, *C*)

Explanation
Condition is the statement that you are evaluating.
The IF statement returns *A* when *Condition* is true.
The IF statement returns *B* when *Condition* is false.
The IF statement returns *C* when *Condition* is indefinite.

Operator AND

Description

The **AND** operator is used to evaluate two arguments within the **IF** function.

Syntax

IF(*Condition1* **AND** *Condition2*, *A*, *B*, *C*)

Values

Condition1	*Condition2*	*Condition1* **AND** *Condition2*
FALSE	FALSE	FALSE
FALSE	TRUE	FALSE
TRUE	FALSE	FALSE
FALSE	INDEFINITE	FALSE
INDEFINITE	FALSE	FALSE
TRUE	TRUE	TRUE
TRUE	INDEFINITE	INDEFINITE
INDEFINITE	TRUE	INDEFINITE
INDEFINITE	INDEFINITE	INDEFINITE

Operator OR

Description

The **OR** operator is used to evaluate two arguments within the **IF** function.

Syntax

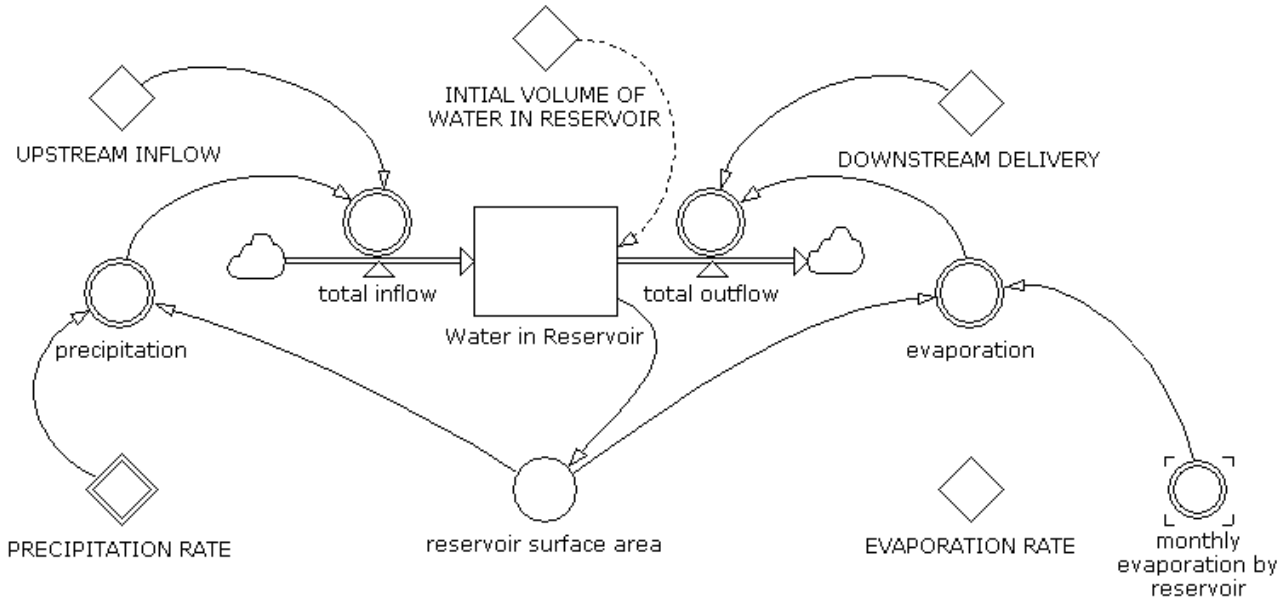
IF(*Condition1* **OR** *Condition2*, *A*, *B*, *C*)

Values

Condition1	*Condition2*	*Condition1* **OR** *Condition2*
FALSE	FALSE	FALSE
TRUE	FALSE	TRUE
FALSE	TRUE	TRUE
TRUE	TRUE	TRUE
INDEFINITE	FALSE	FALSE
INDEFINITE	TRUE	TRUE
TRUE	INDEFINITE	TRUE
FALSE	INDEFINITE	FALSE
INDEFINITE	INDEFINITE	INDEFINITE

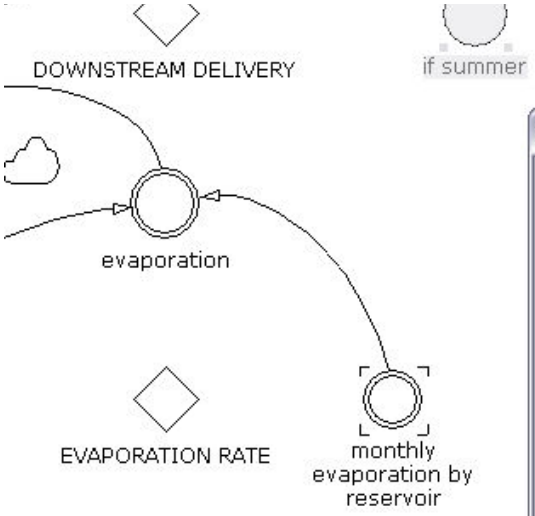
Apply IF to Reservoir Model

Suppose you want to change your downstream deliveries based on what time of year it is. Using the **IF** function, we will create a variable that calculates whether or not the current simulation date is during the summer season. If it is summer, downstream deliveries will increase. If it is not summer, downstream deliveries will decrease.

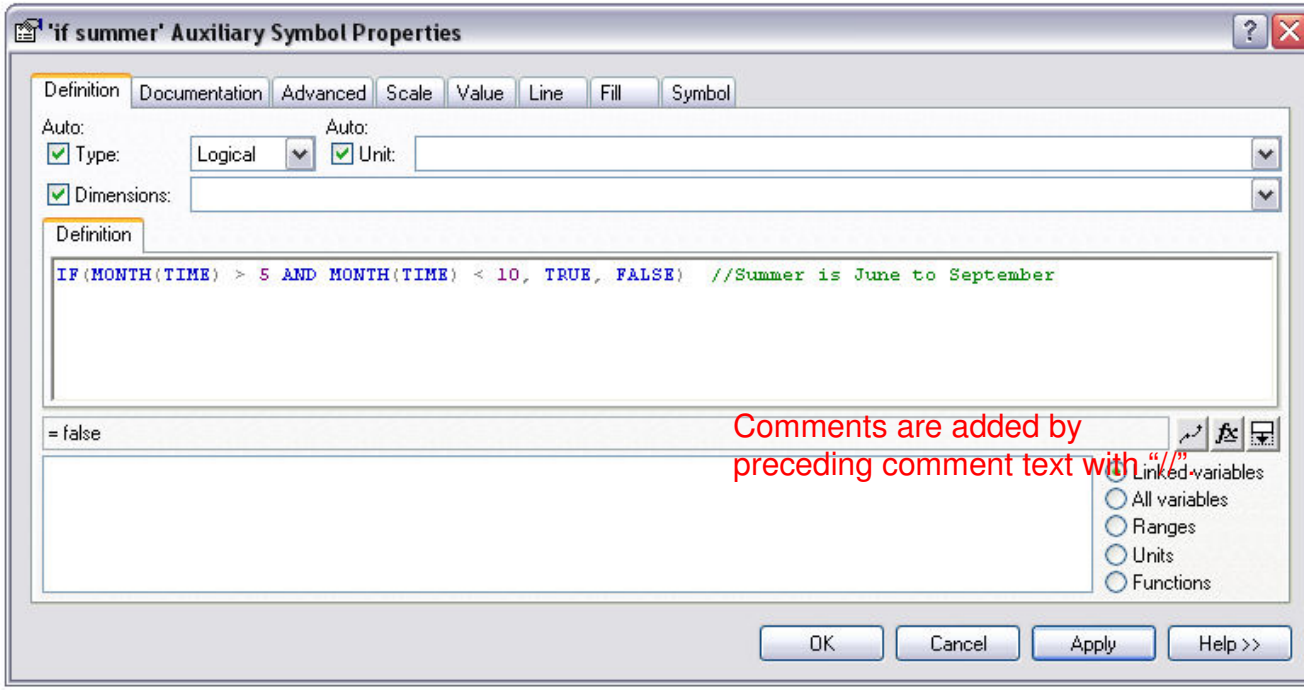


Apply IF to Reservoir Model

Create variable **if summer** and define it as shown below. This statement says that if the current simulation time is between June (greater than May) and September (less than October), then return the value TRUE, otherwise return the value FALSE.



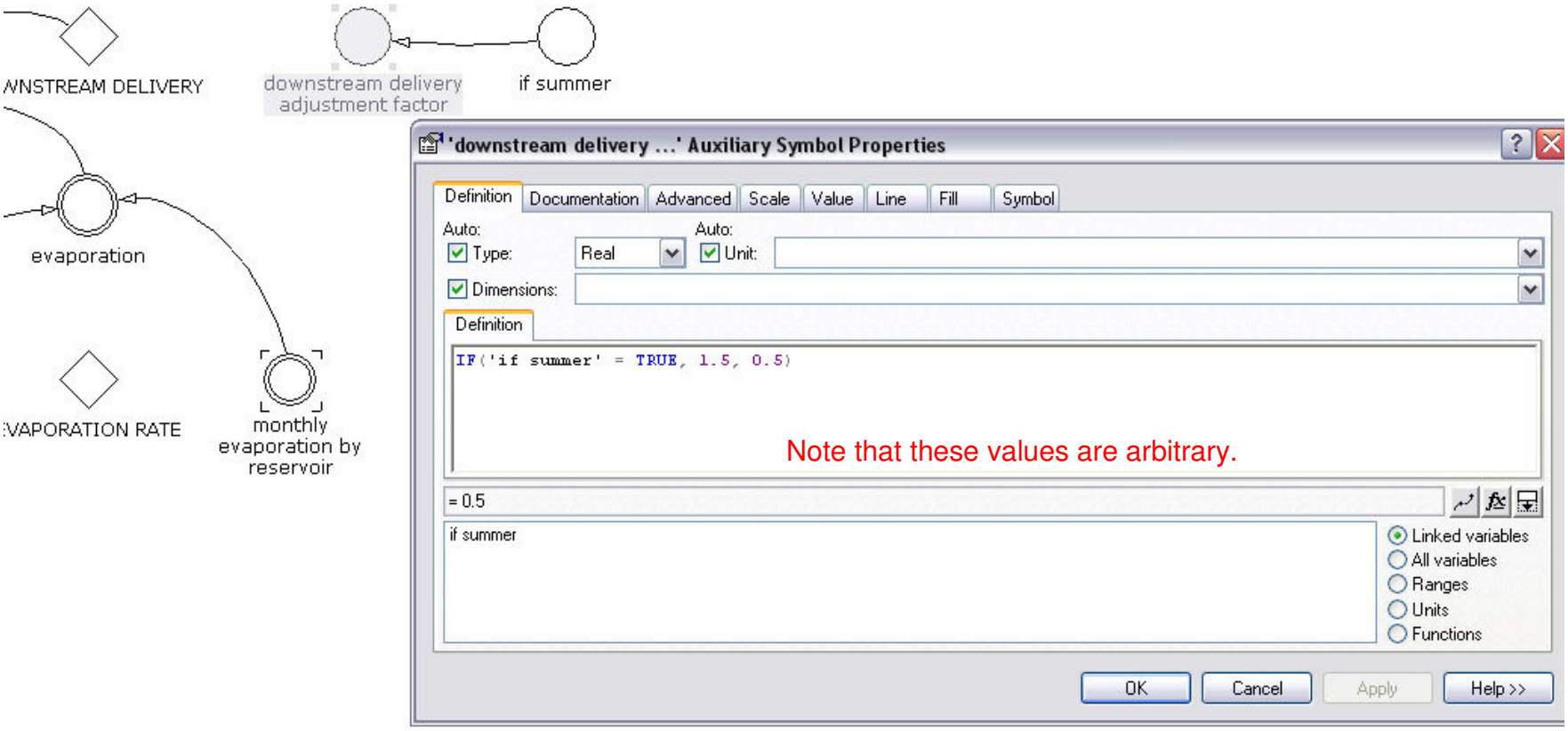
This definition could be embedded in the variable that uses it and still function properly. However, this is poor modeling practice because then **if summer** might be effectively "lost".



Comments are added by preceding comment text with "//".

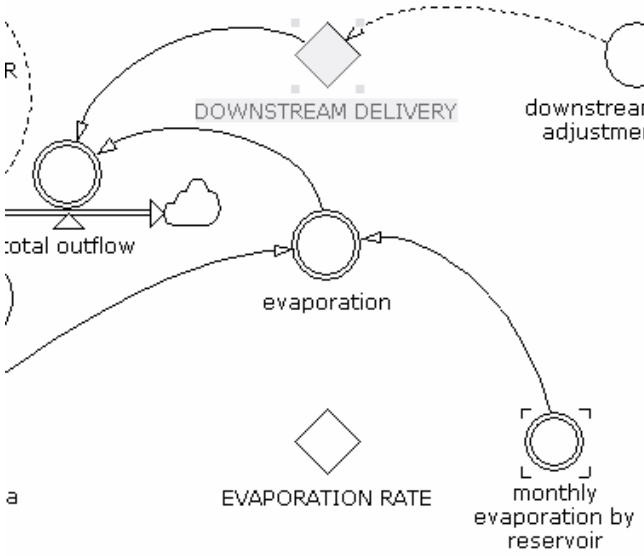
Apply IF to Reservoir Model

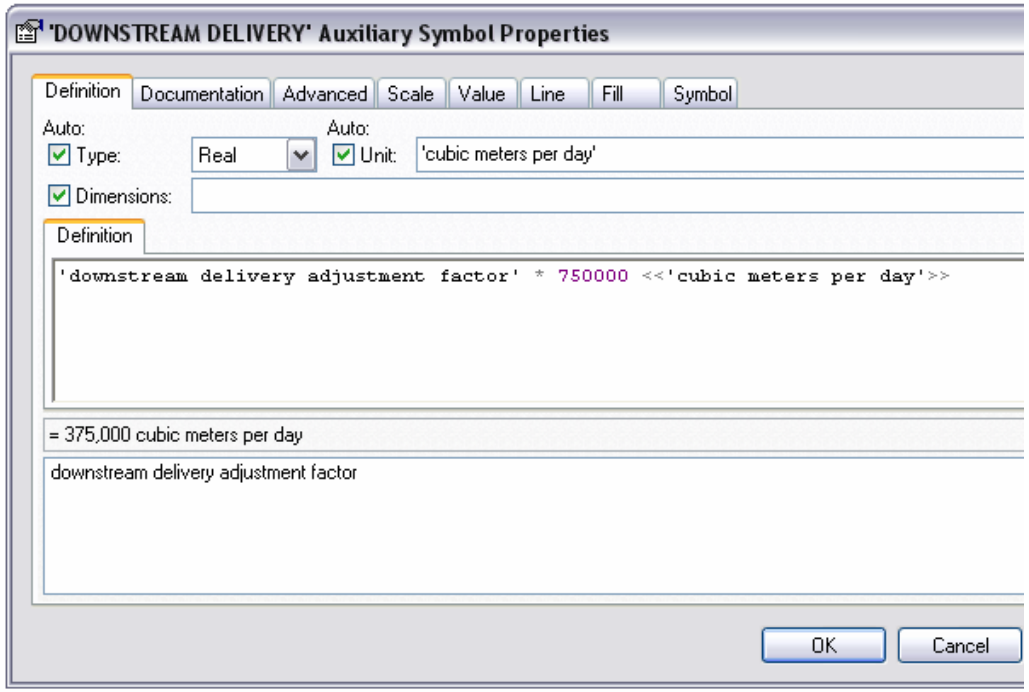
Create variable **downstream delivery adjustment factor** and define it as shown below. This statement says that if is summer (**if summer** is TRUE), return the value 1.5, otherwise return the value 0.5.



Apply IF to Reservoir Model

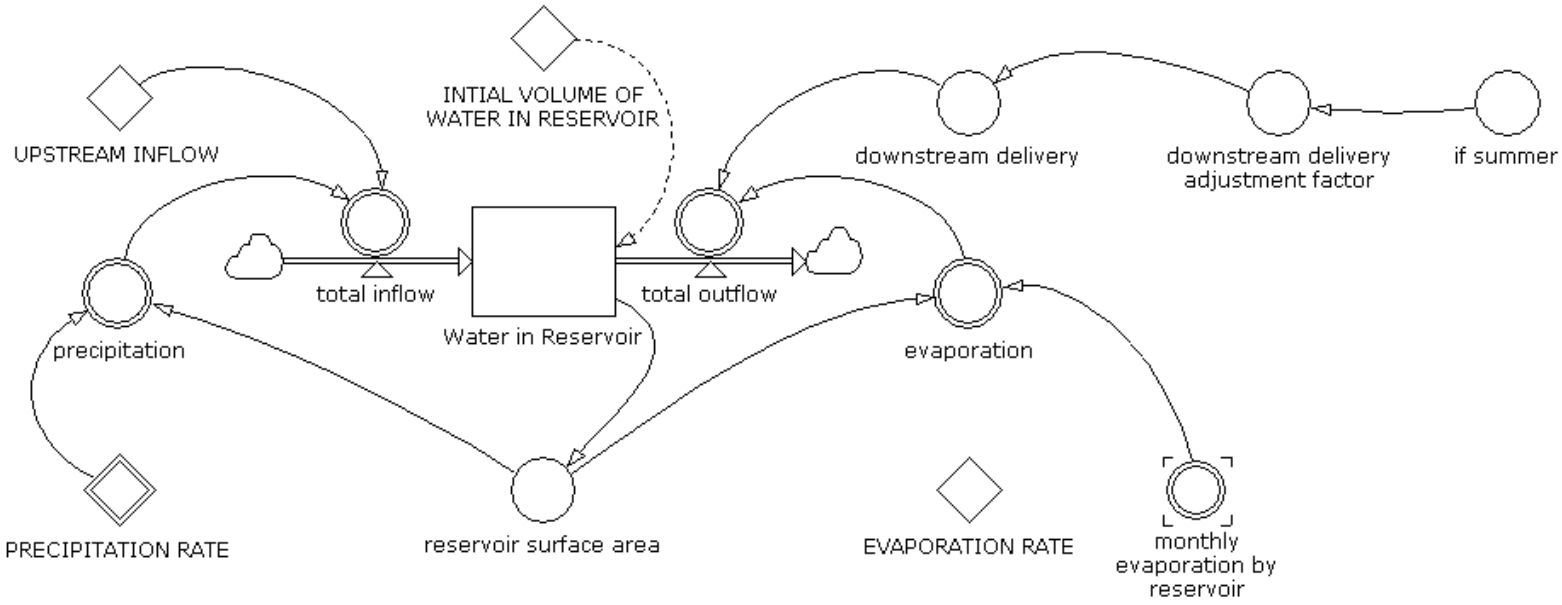
Attach **downstream delivery adjustment factor** to **DOWNSTREAM DELIVERY** and redefine **DOWNSTREAM DELIVERY** as shown below. You must change **DOWNSTREAM DELIVERY** to an auxiliary for this calculation to work properly. Go to the Advanced tab and make this change.





Apply IF to Reservoir Model

downstream delivery is now an auxiliary (circle icon and name in all lowercase). If the current simulation time is during the summer (between June and September), the original fixed value that defined **DOWNSTREAM DELIVERY** will be increased by 50%. Otherwise, the original fixed value will be decreased by 50%.



FOR

Description

The **FOR** function is used to perform operations on elements of an array.

Generic Examples

FOR(i =1..3 | i * 1<<m>>) = {1, 2, 3}m

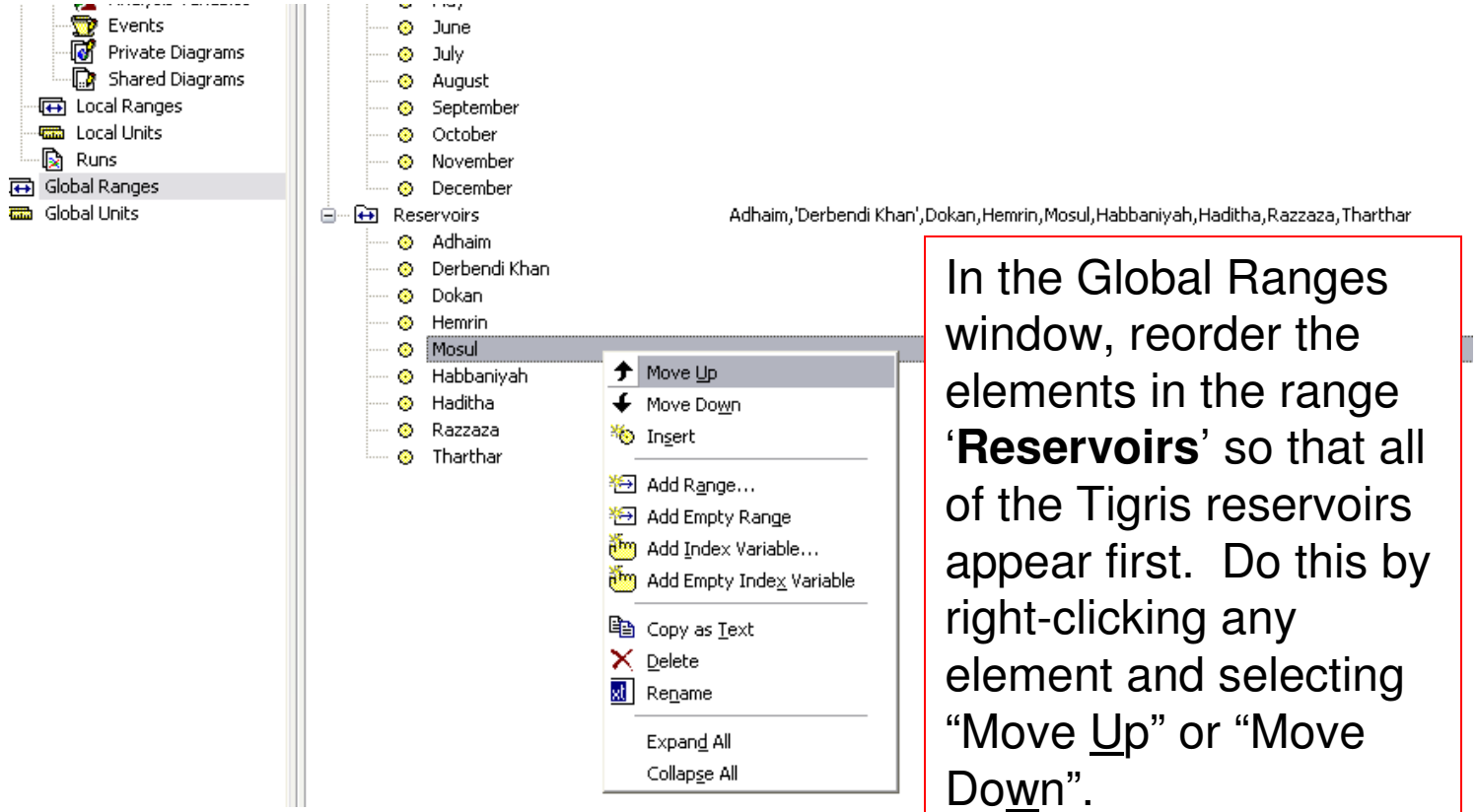
FOR(i =1..2, j =1..2 | i+j) = {{1+1, 1+2},{2+1, 2+2}} = {{2,3},{3,4}}

Important note

i, *j*, and *k* are internal index variables. Otherwise, you must use a variable that you have created.

Apply FOR to Reservoir Model

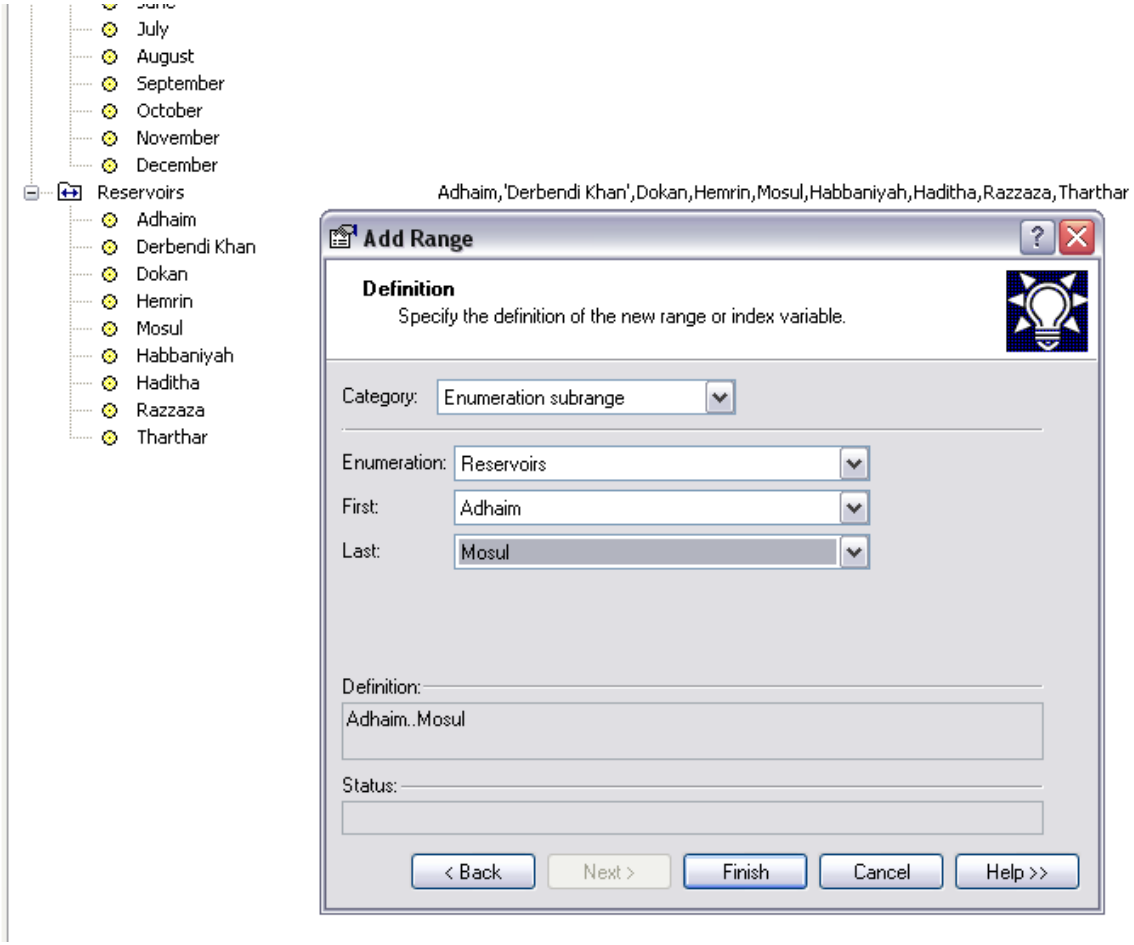
Suppose you want to perform calculations specific to the reservoirs on the Tigris and its tributaries. We did this on slide 85 by calling individual elements from the '**Reservoirs**' array. Now we want to create a range with the Tigris reservoirs only. This range can be used with the **FOR** function to calculate the same average that we did on slide 85.



In the Global Ranges window, reorder the elements in the range '**Reservoirs**' so that all of the Tigris reservoirs appear first. Do this by right-clicking any element and selecting "Move Up" or "Move Down".

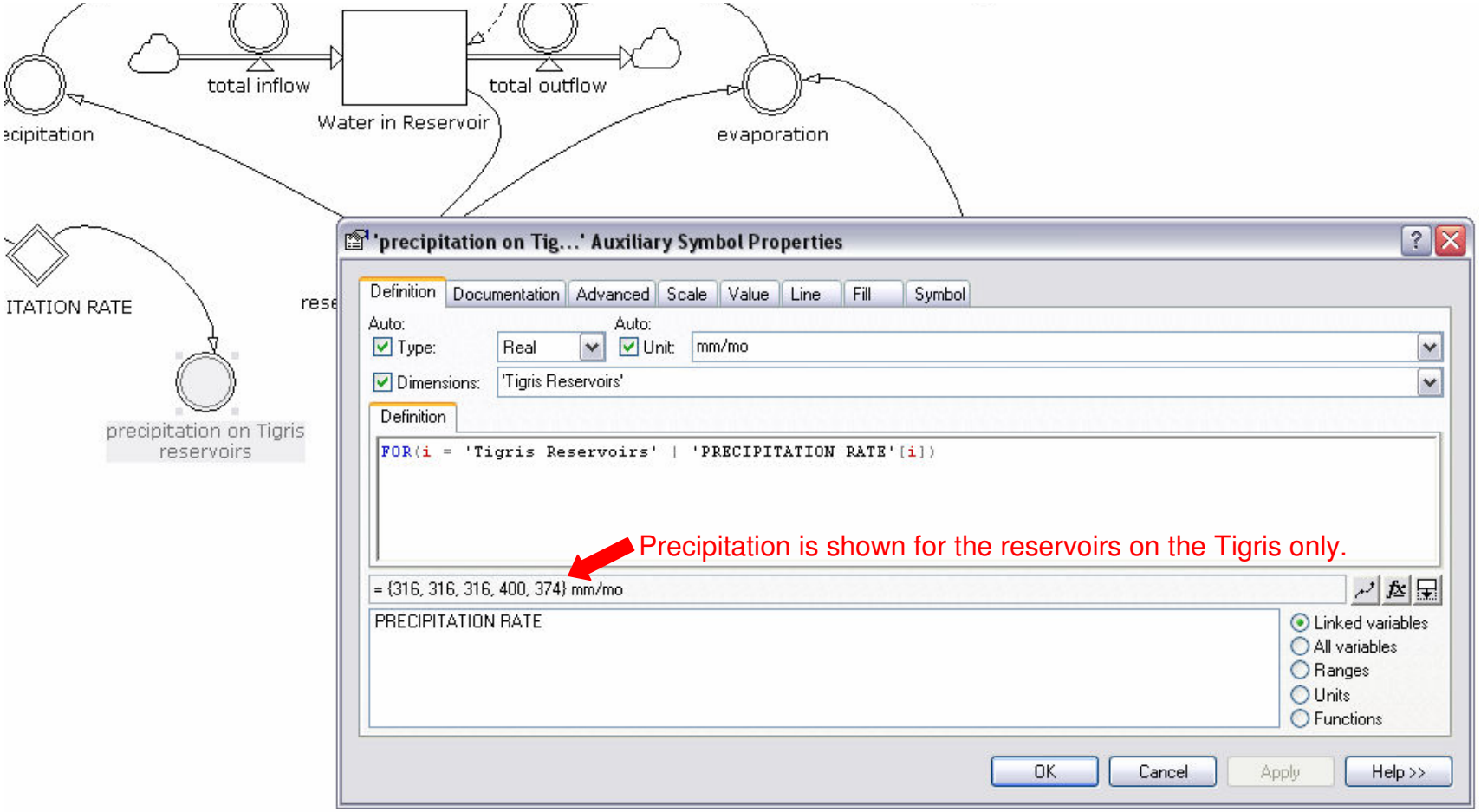
Apply FOR to Reservoir Model

Now, create and enumeration subrange called “Tigris Reservoirs” using Adhaim through Mosul from the ‘**Reservoirs**’ enumeration range.



Apply FOR to Reservoir Model

Create the variable **precipitation on Tigris reservoirs** and use the **FOR** function and the newly created '**Tigris Reservoirs**' subrange to define it.



MIN

Description

The **MIN** function returns the smallest of the elements in Input1, Input2, …. The function needs at least two input parameters. The minimum value is found element by element and the function returns an array of the same dimension as its input parameters.

Syntax

MIN(Input1, Input2, Input3, …)

Examples

MIN(1,2,3,4) = 1

MIN({4,5,2,3},{3,2,1,6}) = {3,2,1,3}

MAX

Description

The **MAX** function returns the largest of the elements in Input1, Input2, …. The function needs at least two input parameters. The maximum value is found element by element and the function returns an array of the same dimension as its input parameters.

Syntax

MAX(Input1, Input2, Input3, …)

Examples

MAX(1,2,3,4) = 4

MAX({4,5,2,3},{3,2,1,6}) = {4,5,2,6}

NUMERICAL

Description

For a range element in an enumeration range, the **NUMERICAL** function returns the numerical value of a corresponding element in a numerical subrange starting at 1.

Generic Example

Enumeration range = {‘RangeElement1’, ‘RangeElement2’, ‘RangeElement3’}

Numerical subrange corresponding to above enumeration range = {1, 2, 3}

NUMERICAL(‘RangeElement2’) = 2

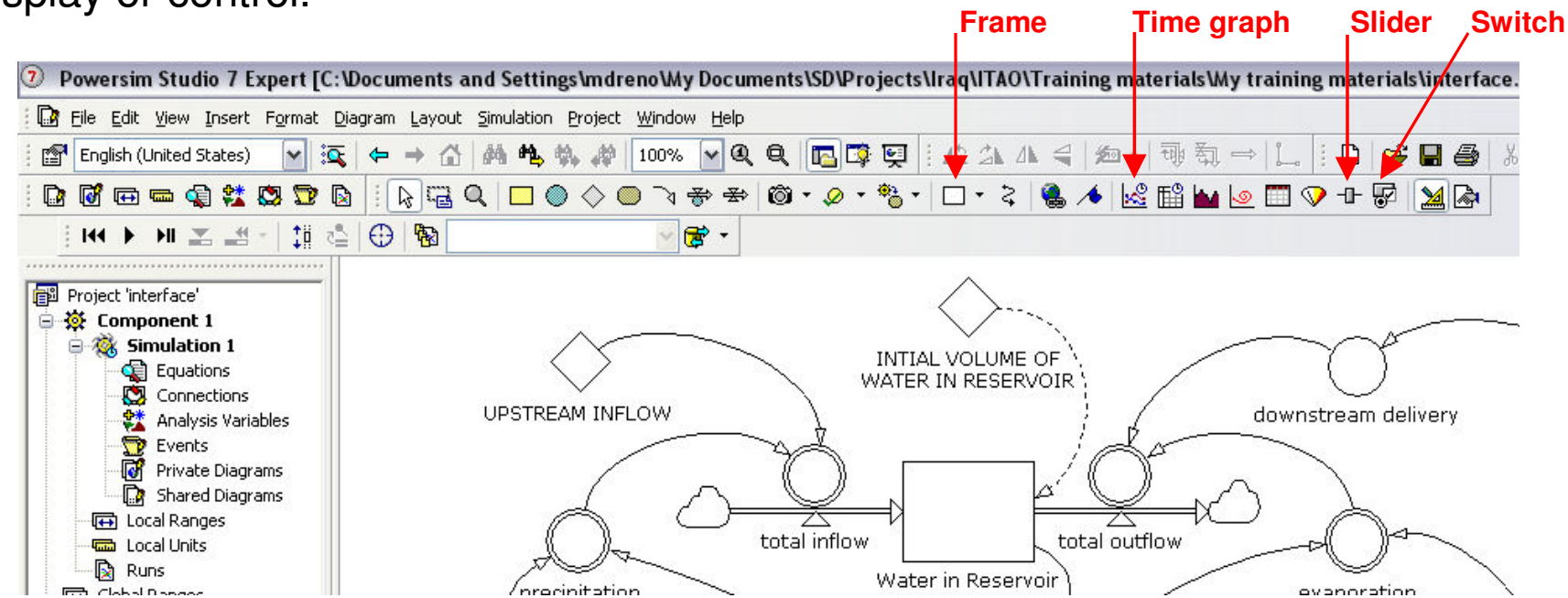
Iraq National Water Modeling Workshop I

November 11-15, 2007
United Nations University
Amman, Jordan

Building an Interface

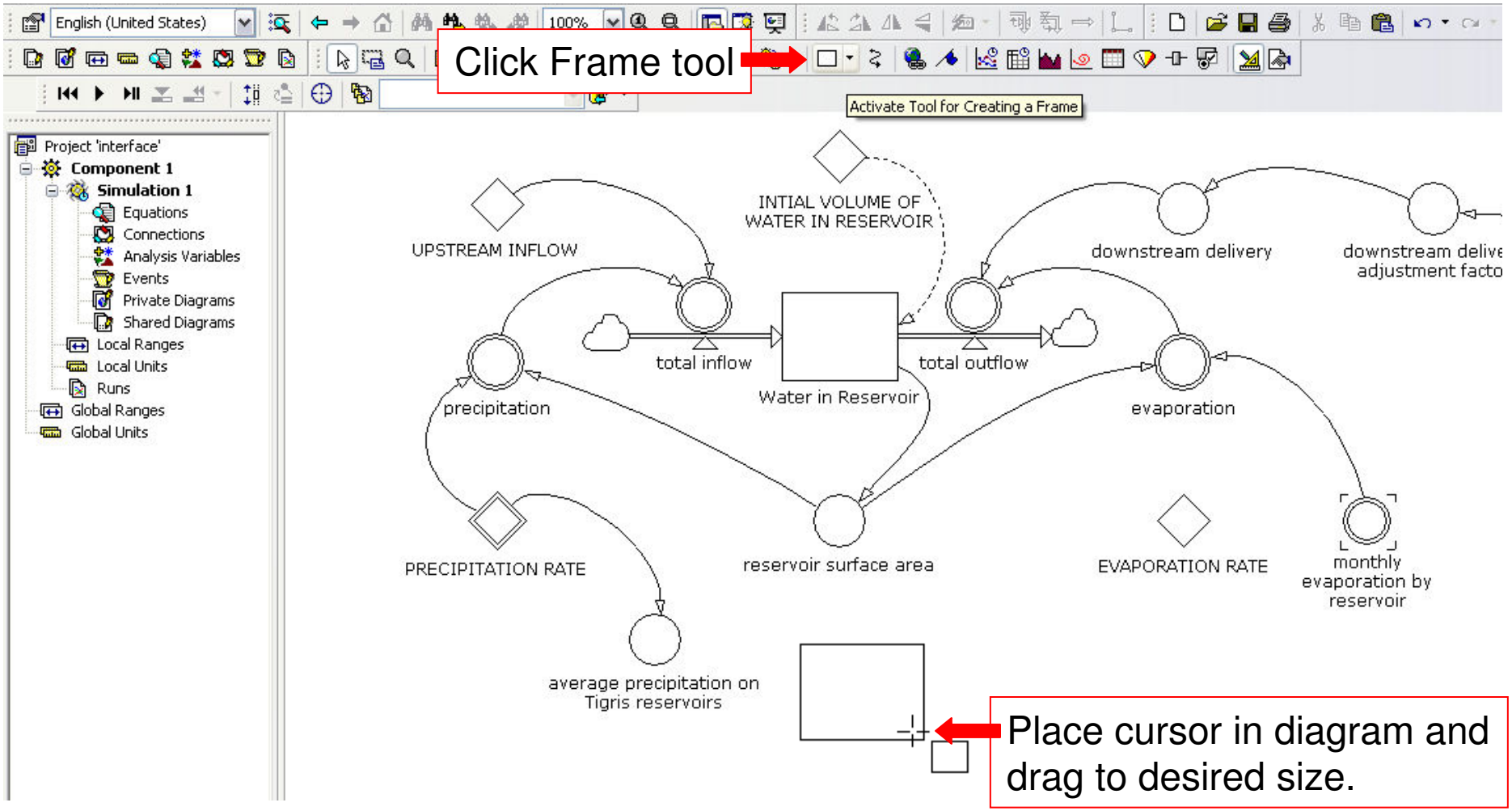
Basic Interface Components

Studio provides several interface components that are easily accessed by clicking the appropriate icon on the menu bar and adding the selected component to the diagram window in the same way that a Level is added (slide 39). The components that we will demonstrate are frames (commonly referred to as "text boxes"), time graphs , sliders , and switches . The easiest way to use any of these components is to add a blank copy to the diagram window and then drag and drop the variable that you want it to display or control.



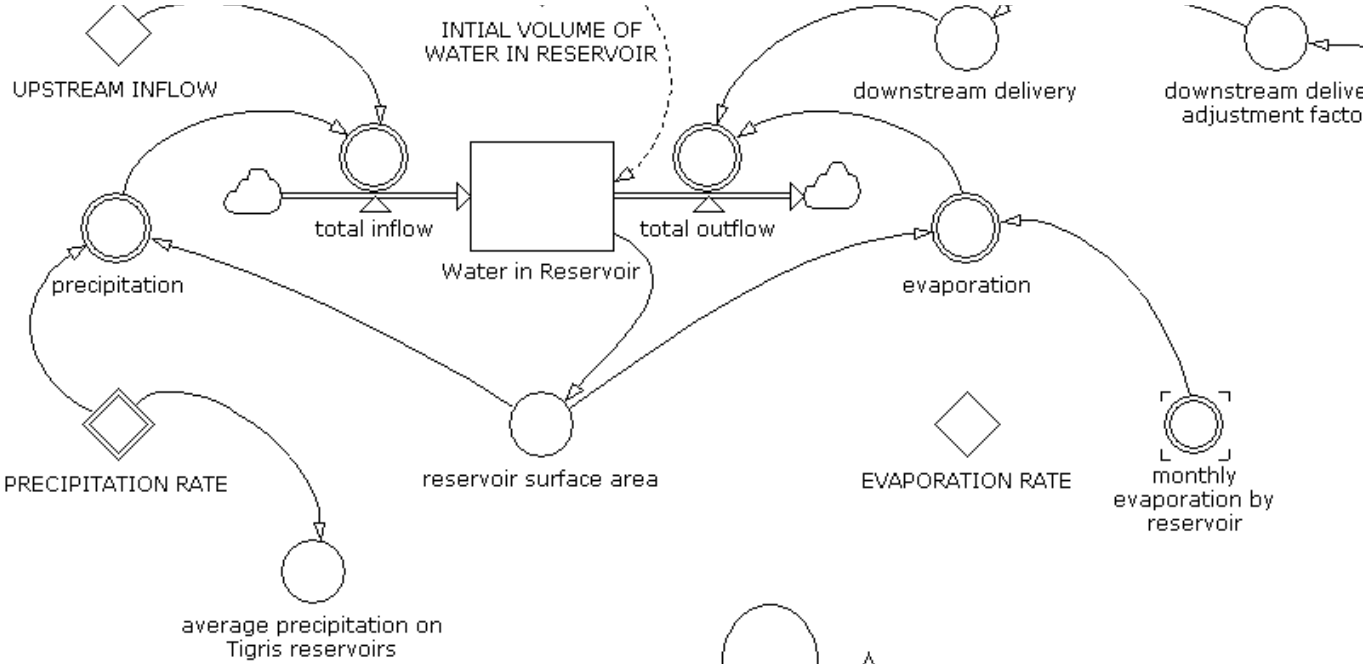
Basic Interface Components

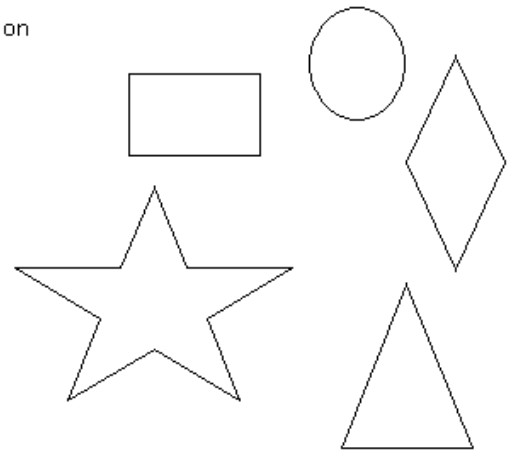
Create a frame.



Basic Interface Components

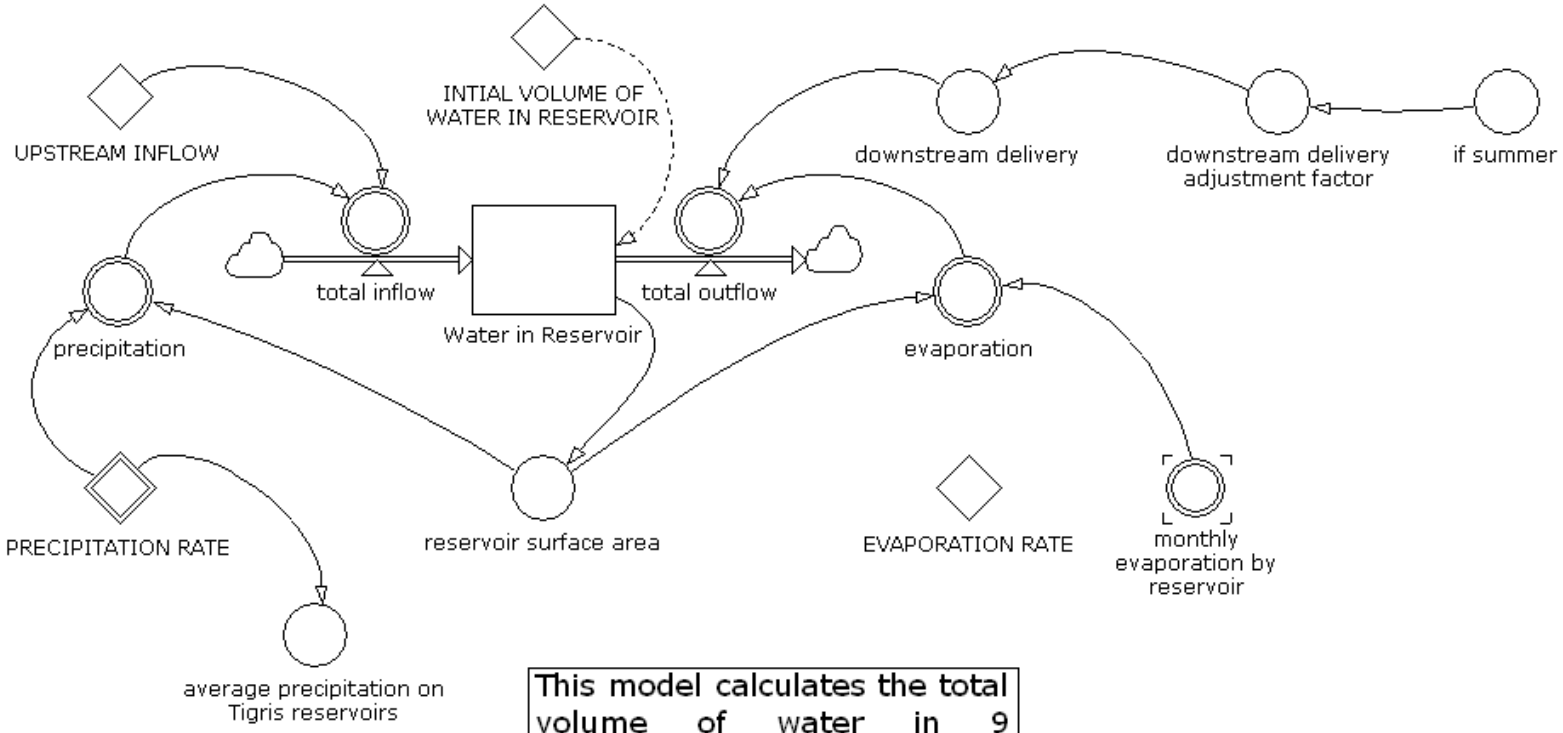
Create several small empty frames of various shapes to familiarize yourself with frame shape options.





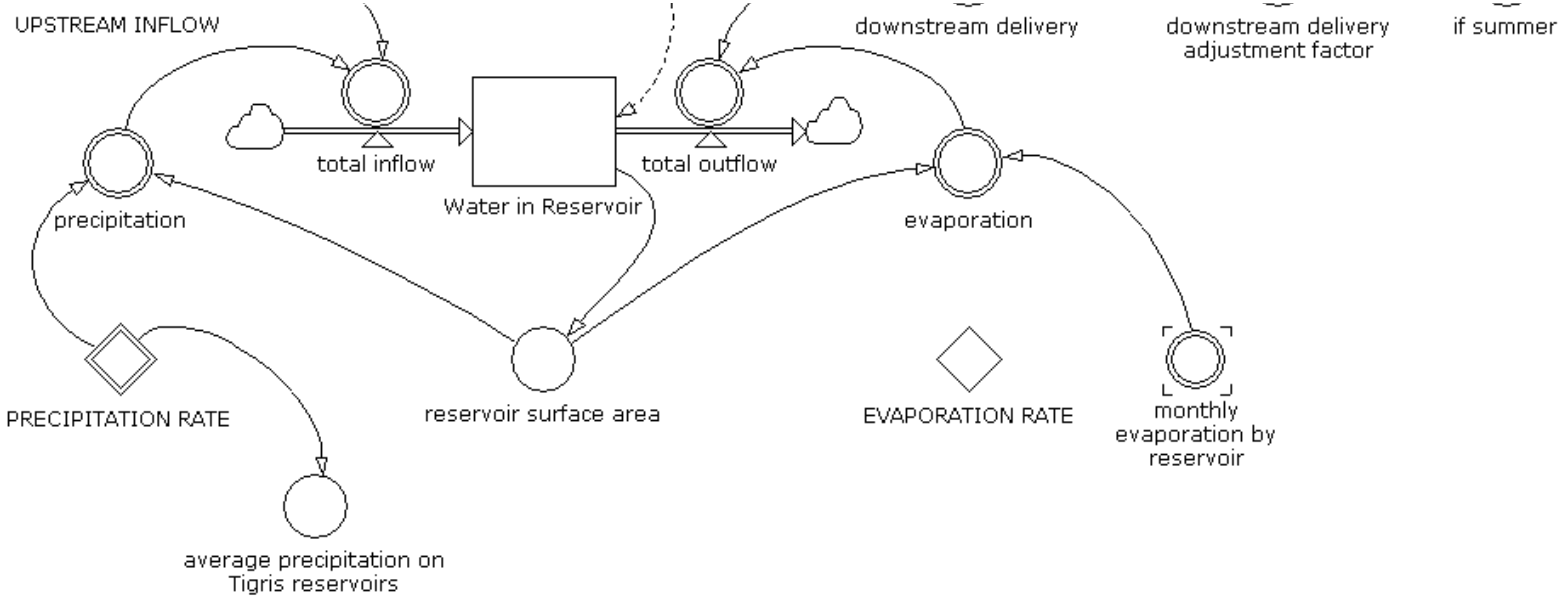
Basic Interface Components

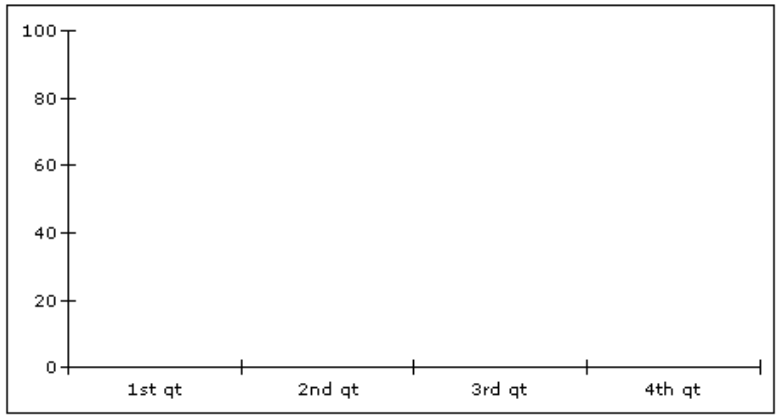
Use frame to display text, outline select variables, or enhance the appearance of other interface components. Frames can also be used to note important points as you are building a model.



Basic Interface Components

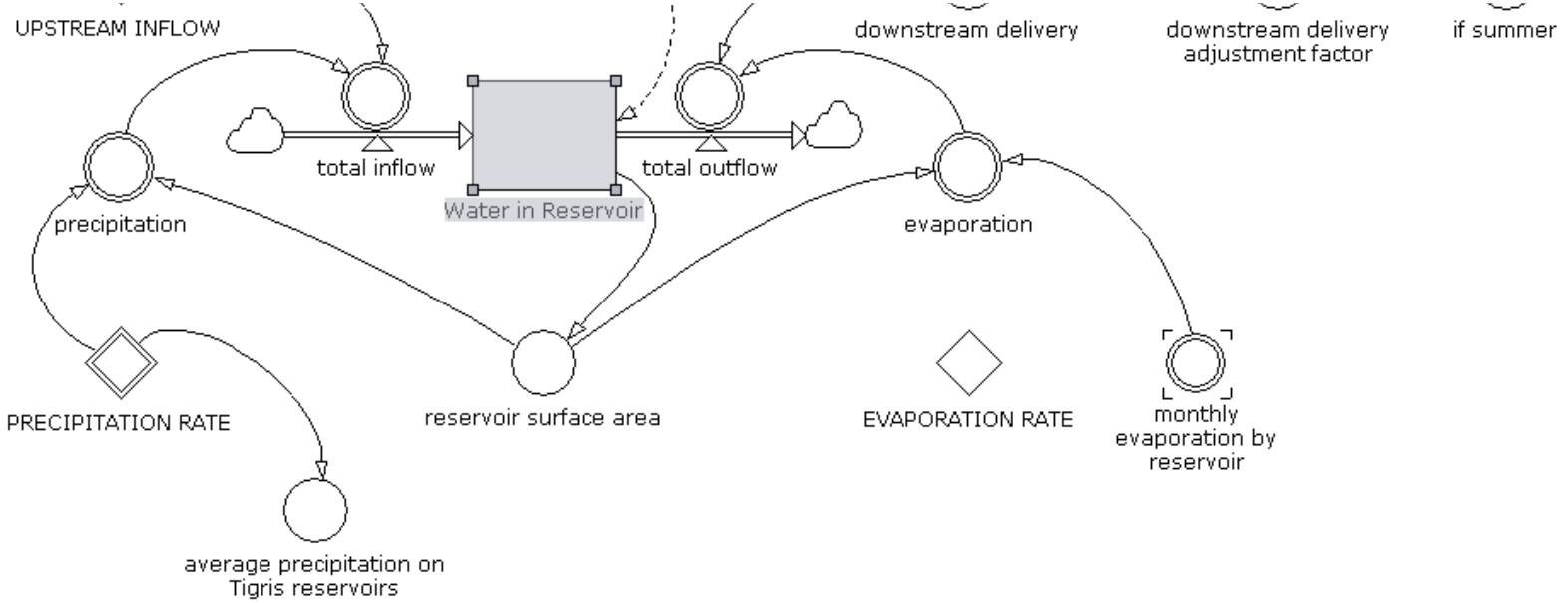
Create empty time graph in the same way that you created a frame. See slide 124 for time graph icon. See slide 125 for drag-and-drop method.



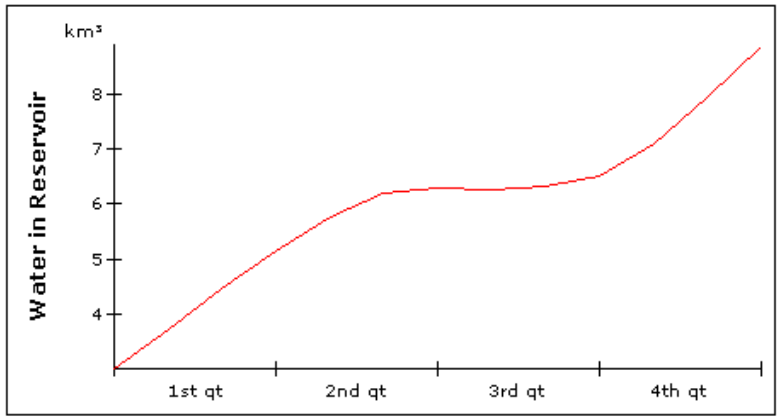


Basic Interface Components

Create time graph of **Water in Reservoir**.

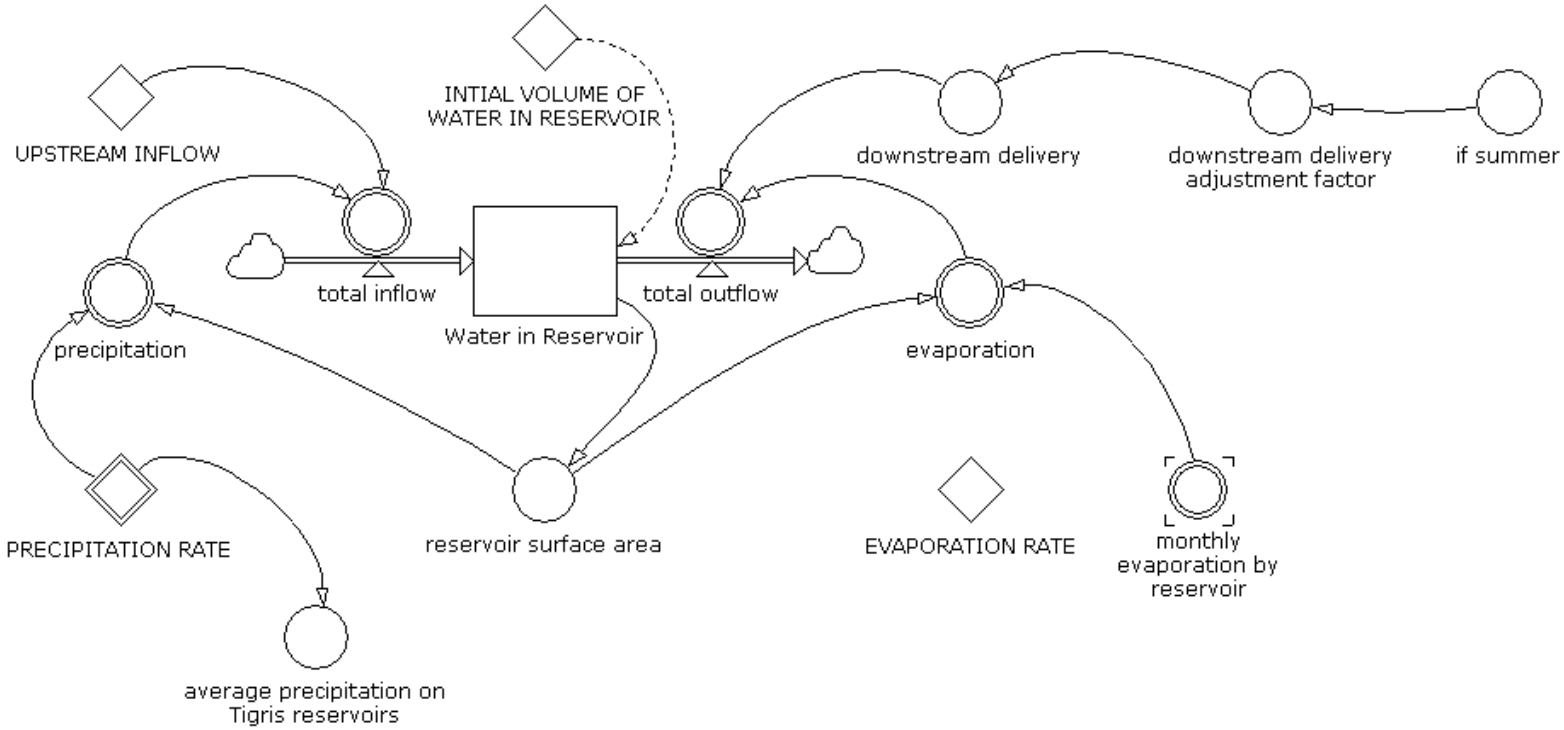


Draw empty Time Graph and then drag **Water in Reservoir** into it.



Basic Interface Components

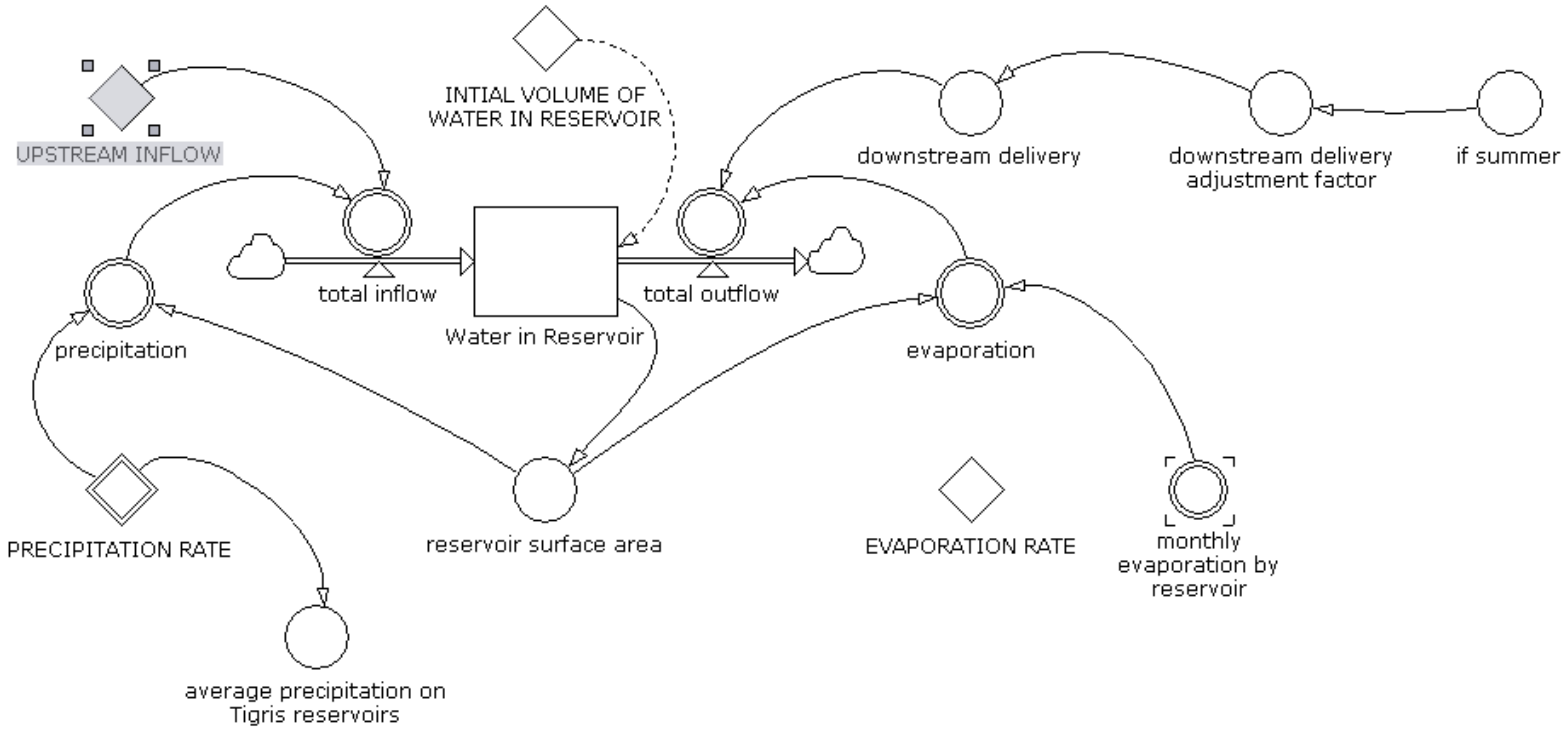
Create an empty slider. See slide 124 for slider icon. See slide 125 for drag-and-drop method.

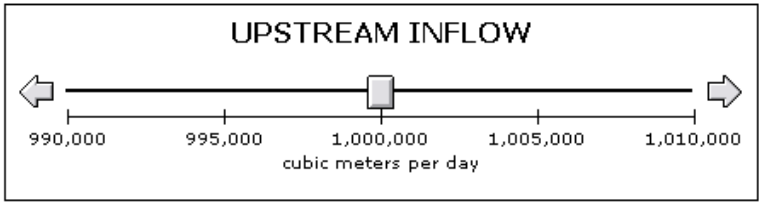


<No Parameter>

Basic Interface Components

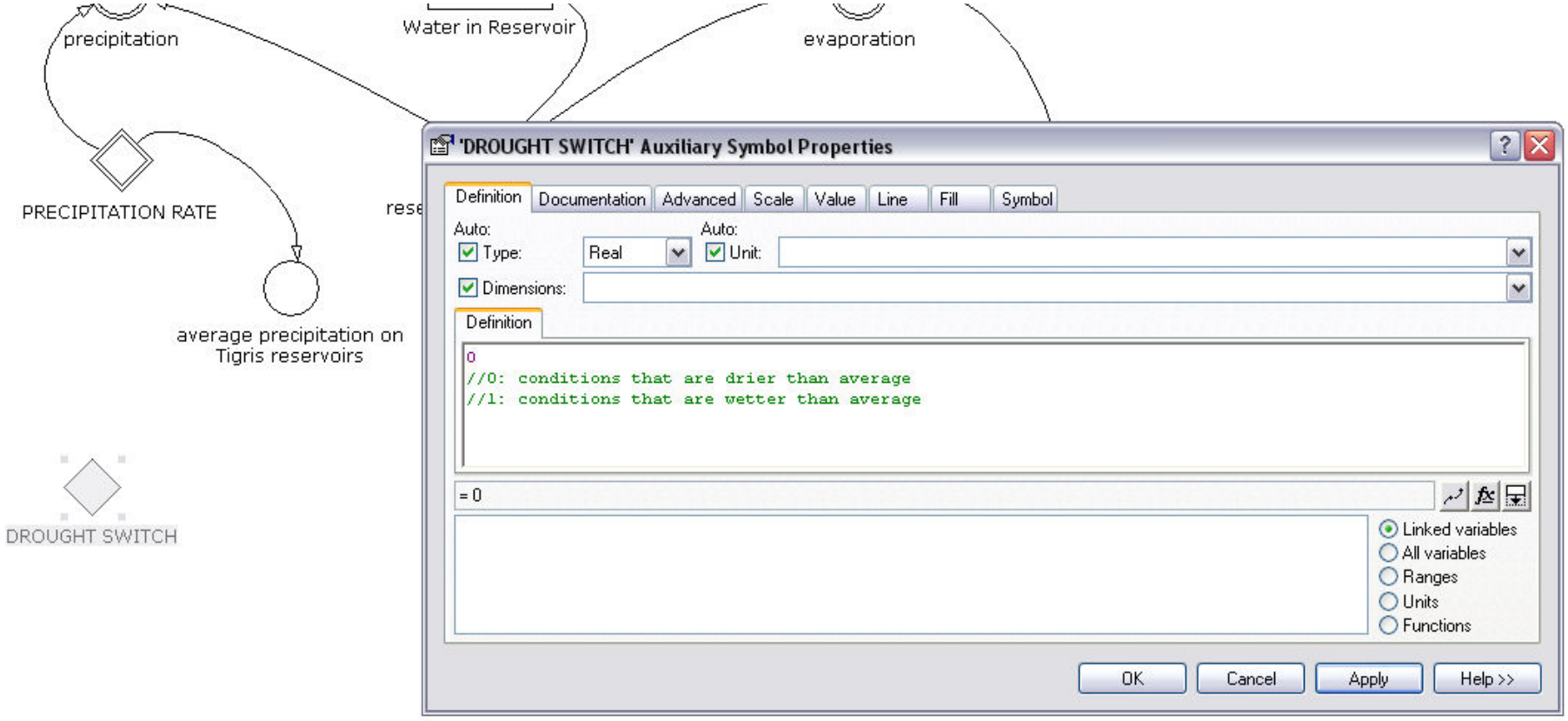
Drag and drop **UPSTREAM INFLOW** into slider.





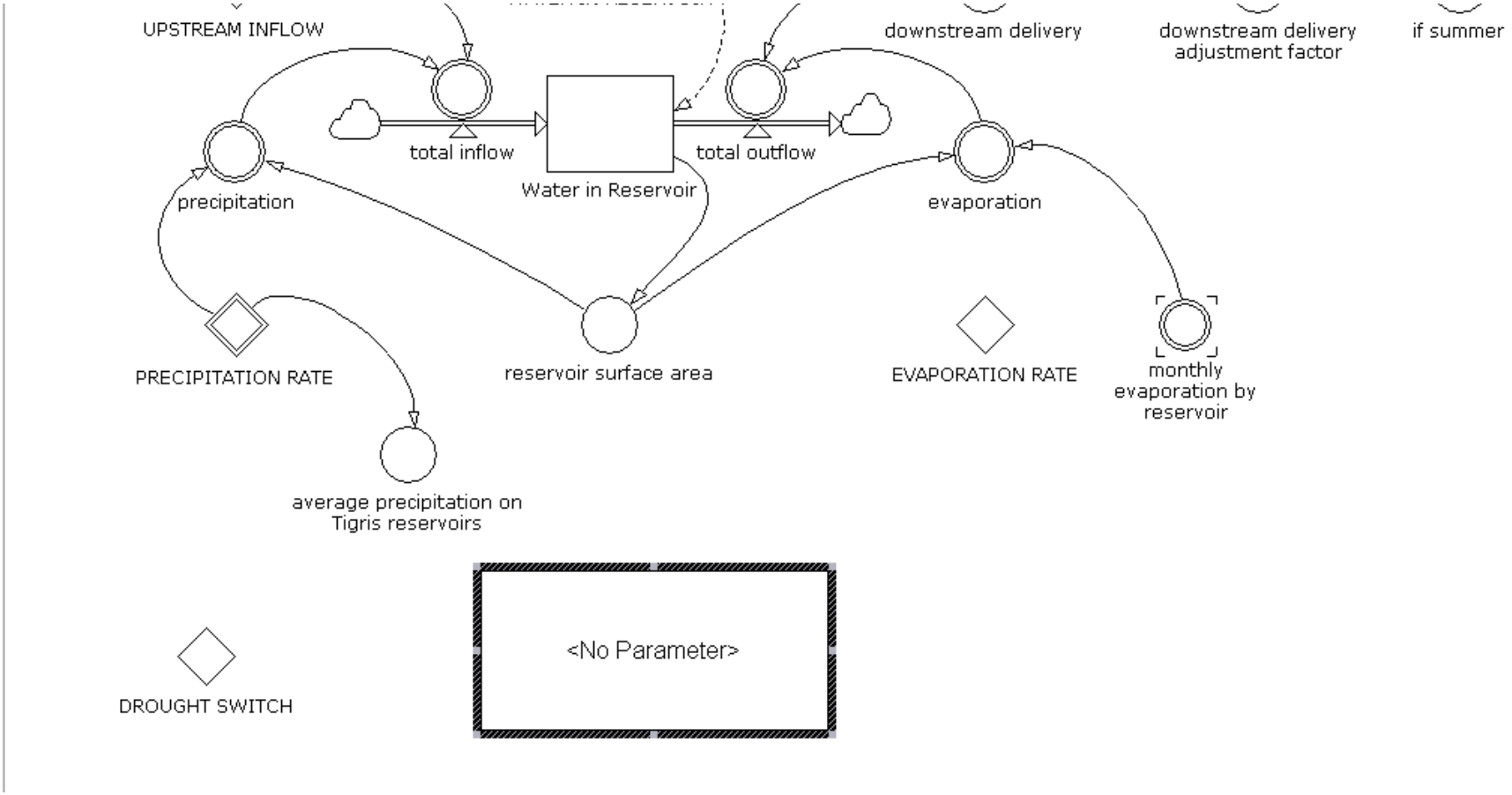
Basic Interface Components

To demonstrate the utility of the switch tool, we are going to create a new variable: **DROUGHT SWITCH**. This switch will have two values: 0 and 1. If 0 is selected, the simulation will assume precipitation conditions that are drier than normal. If 1 is selected, wetter than normal conditions will be assumed.



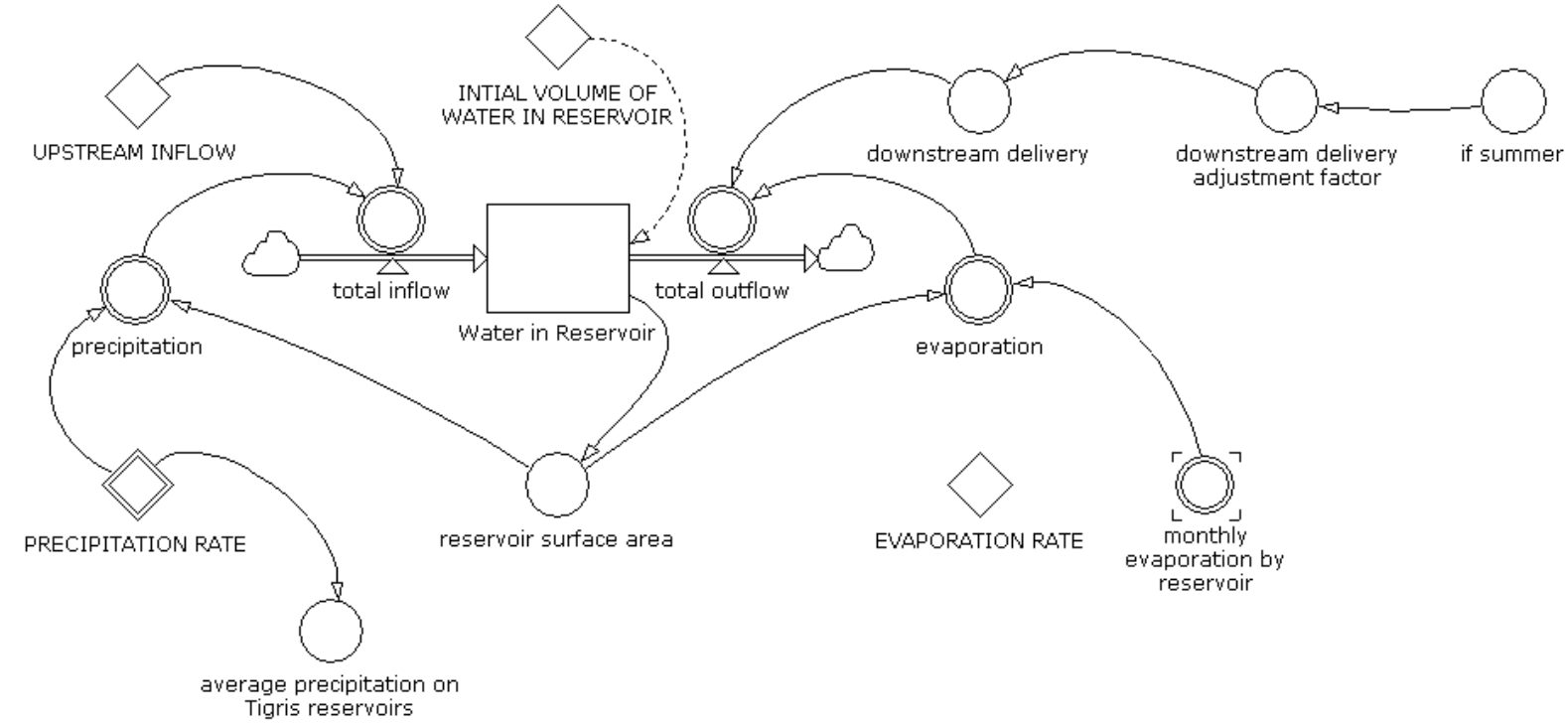
Basic Interface Components

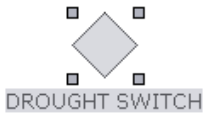
Create empty switch control. See slide 124 for switch icon. See slide 125 for drag-and-drop method.

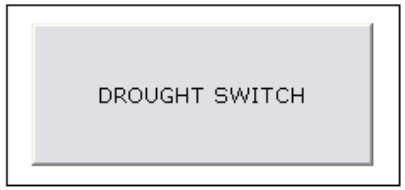


Basic Interface Components

Drag and drop **DROUGHT SWITCH** into switch control.

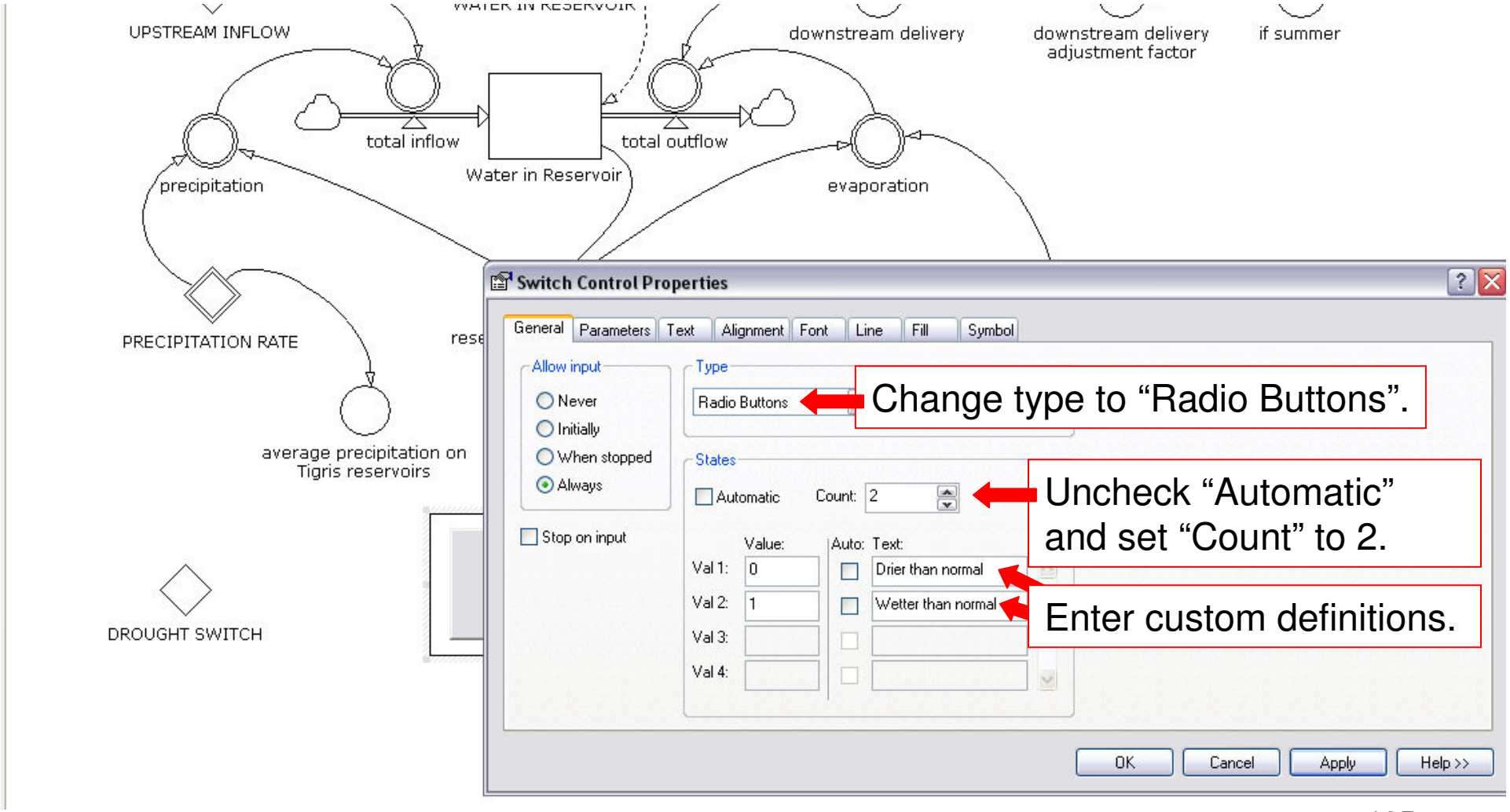






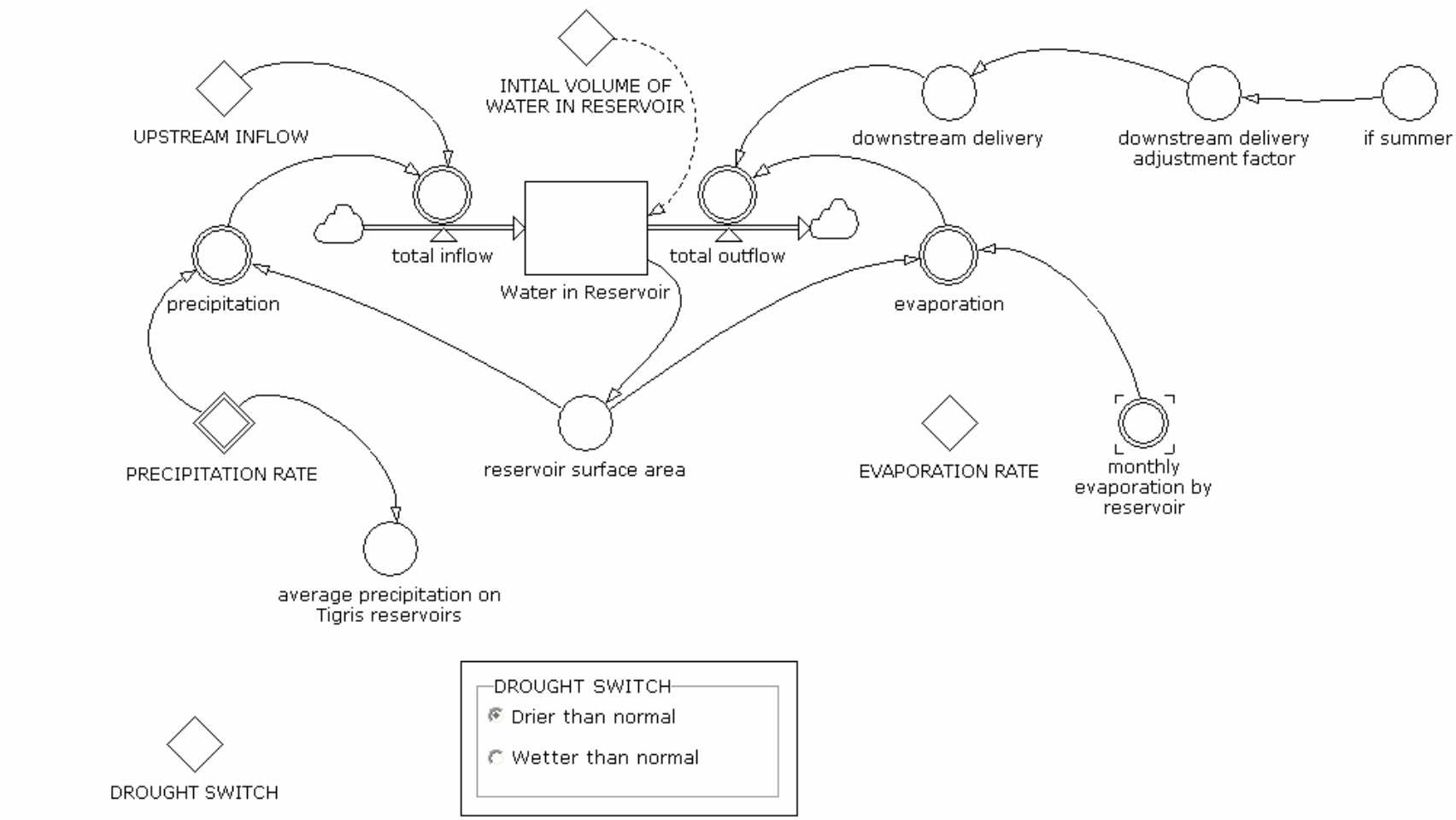
Basic Interface Components

Customize switch.



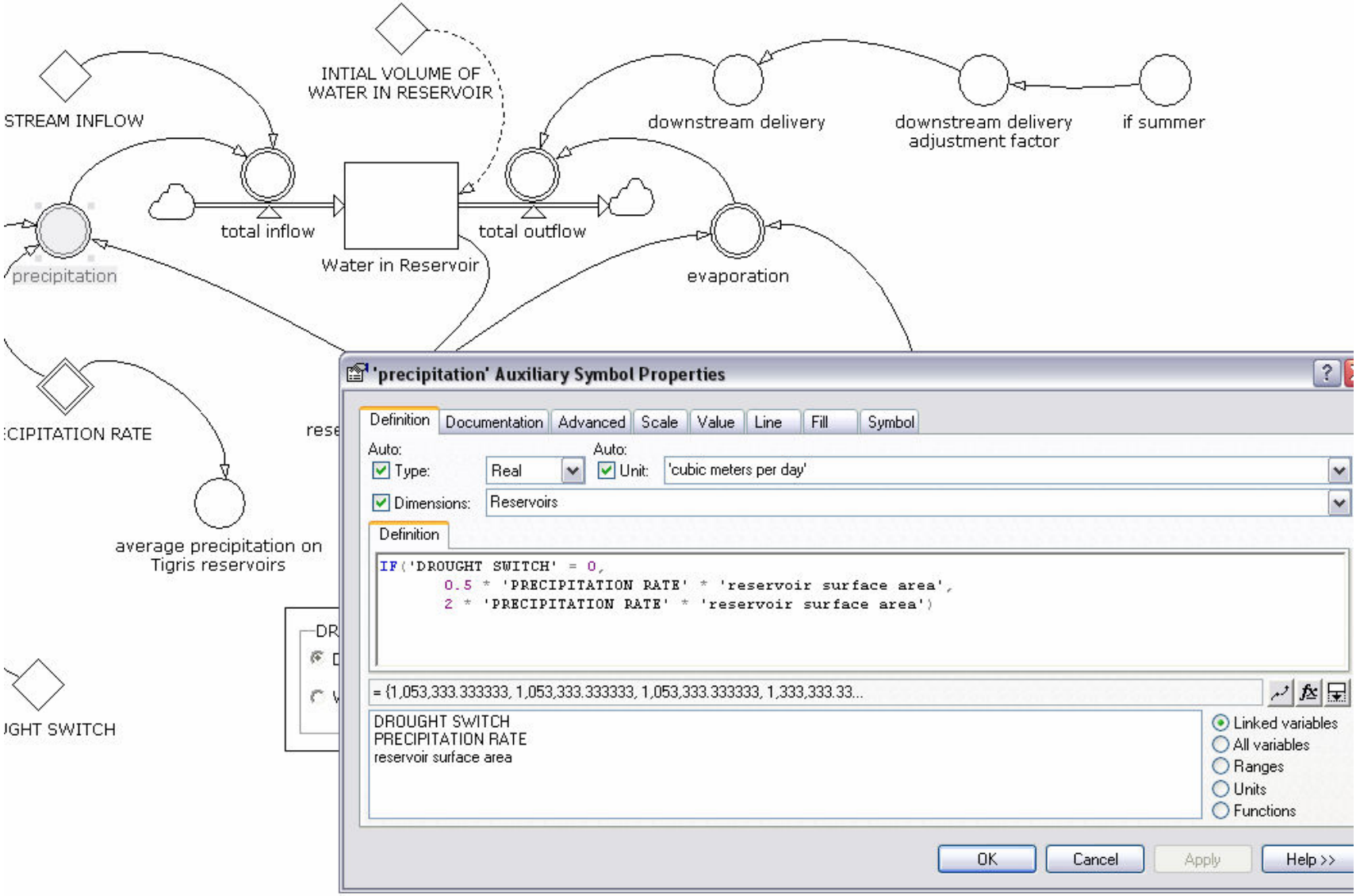
Basic Interface Components

You can now select “Drier than normal” or “Wetter than normal” precipitation conditions by toggling your choice on the switch control.



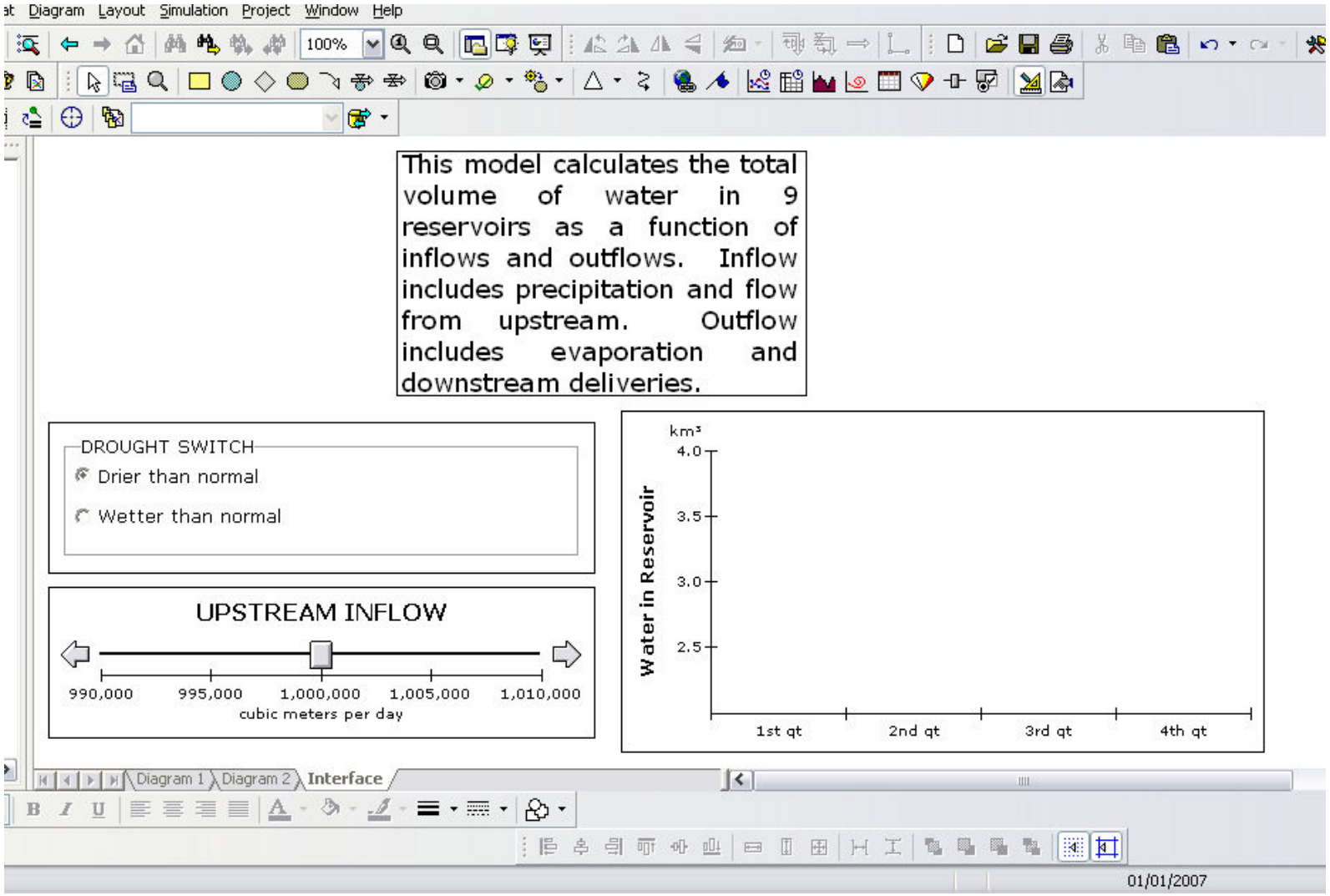
Basic Interface Components

Connect **DROUGHT SWITCH** to **precipitation** and redefine **precipitation** as shown.



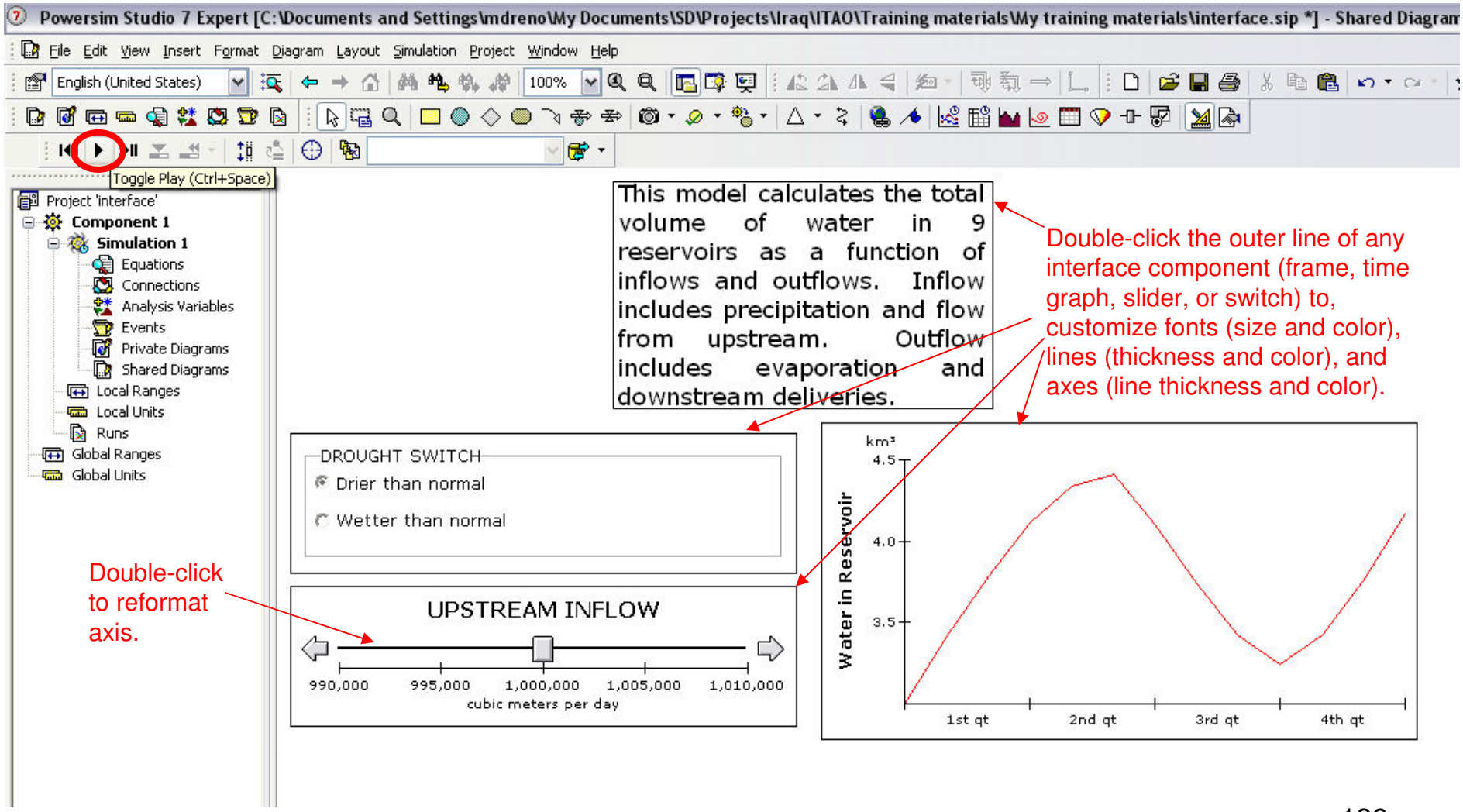
Reservoir Model Interface

Rename blank diagram “Interface” and cut and paste all interface components here.



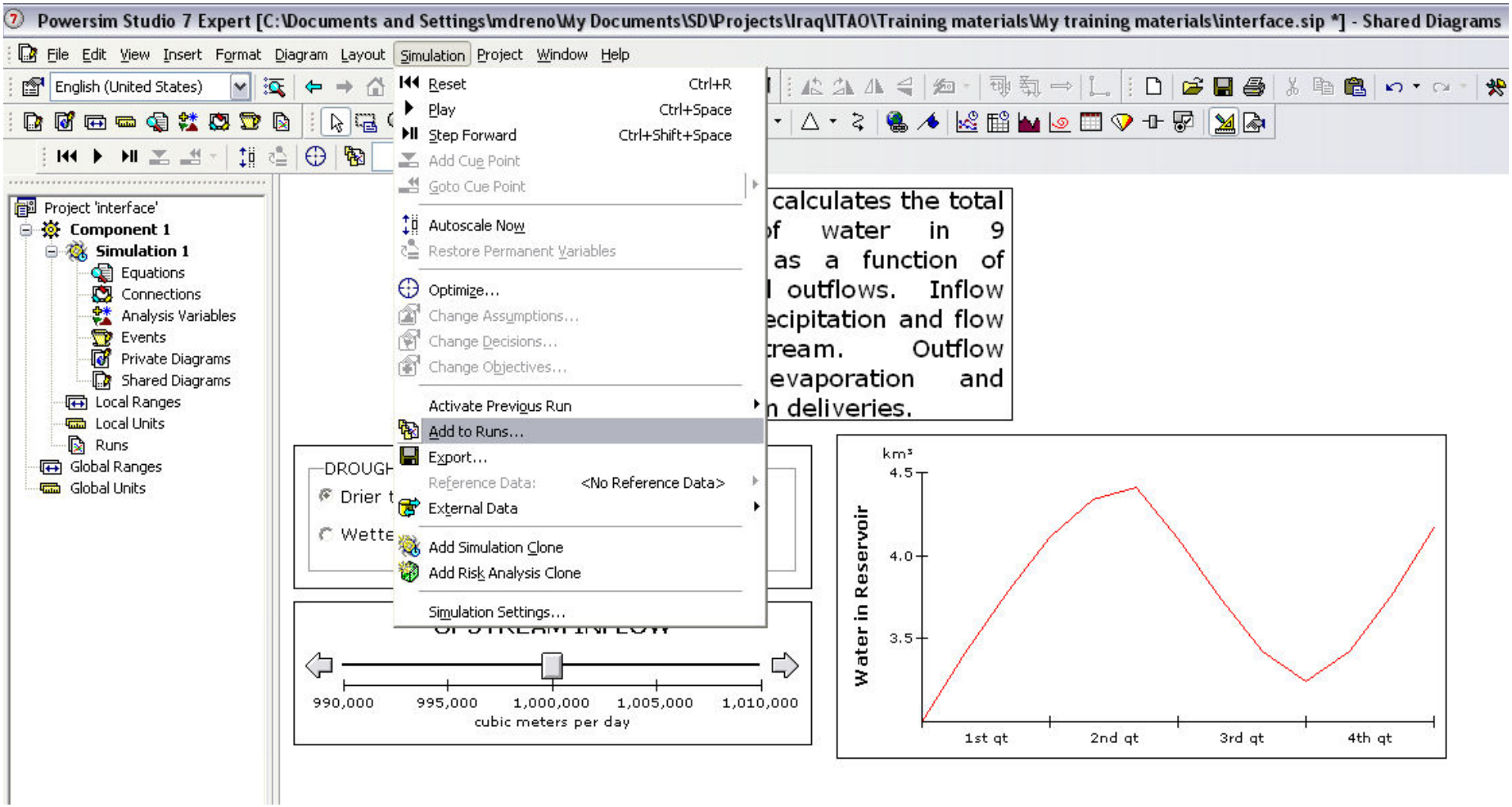
Reservoir Model Interface

Run model.

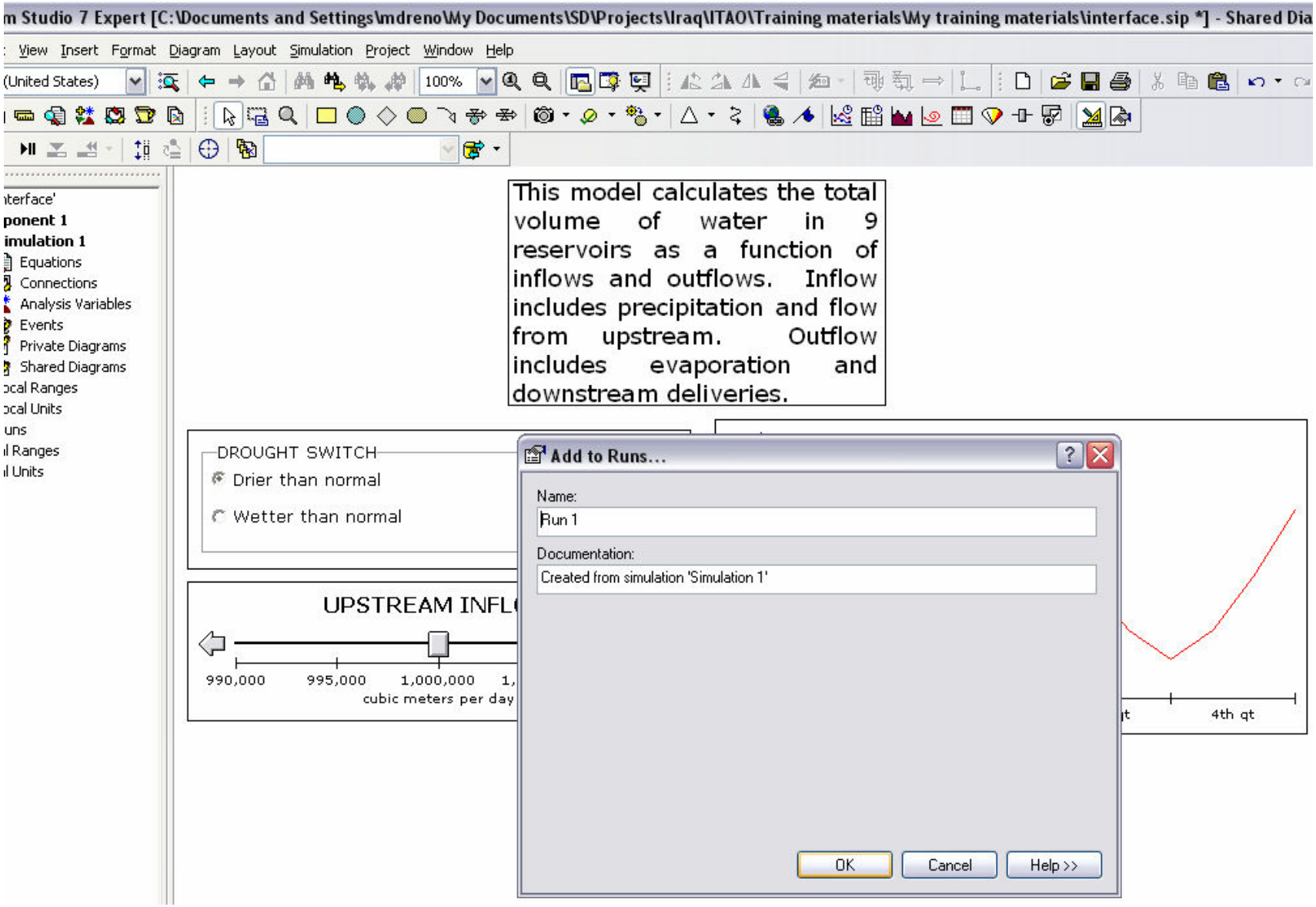


Create Reference Run

Add model run to reference runs.

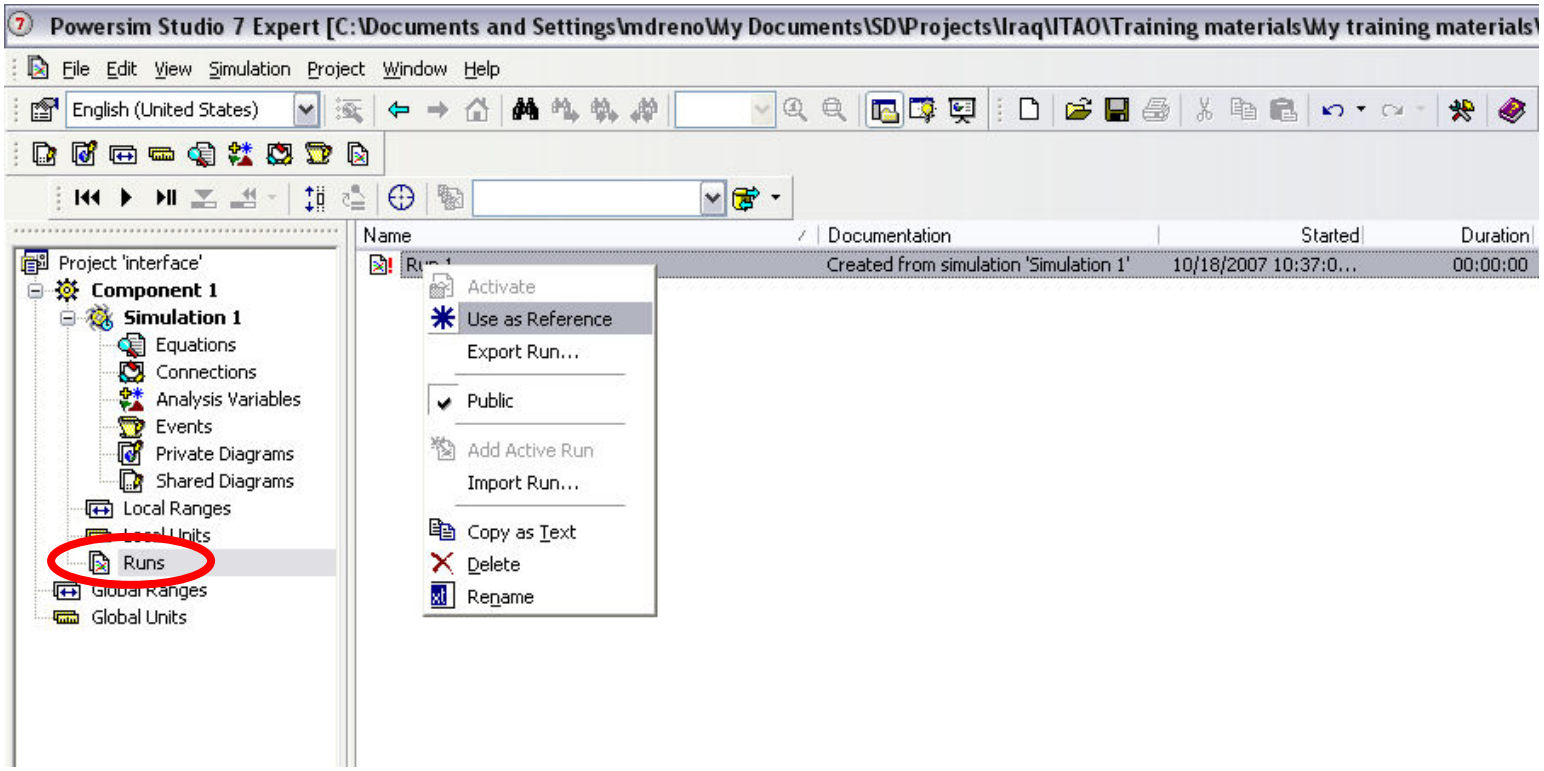


Create Reference Run



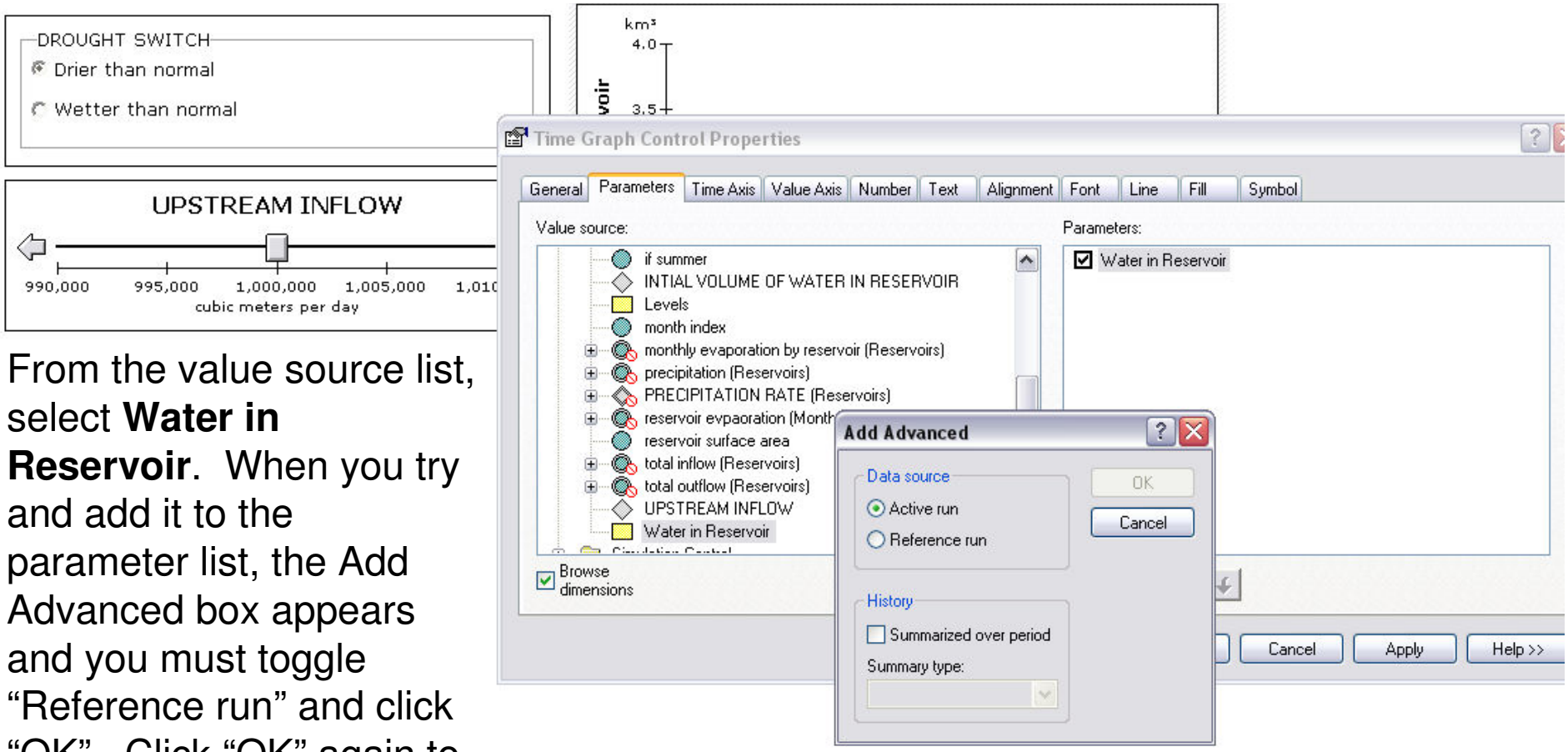
Create Reference Run

Saved run must now be set as “Reference”. Make this change by going to Runs window, right-clicking “Run 1”, and selecting “Use as Reference”. Then return to interface page (double-click Shared Diagrams).



Create Reference Run

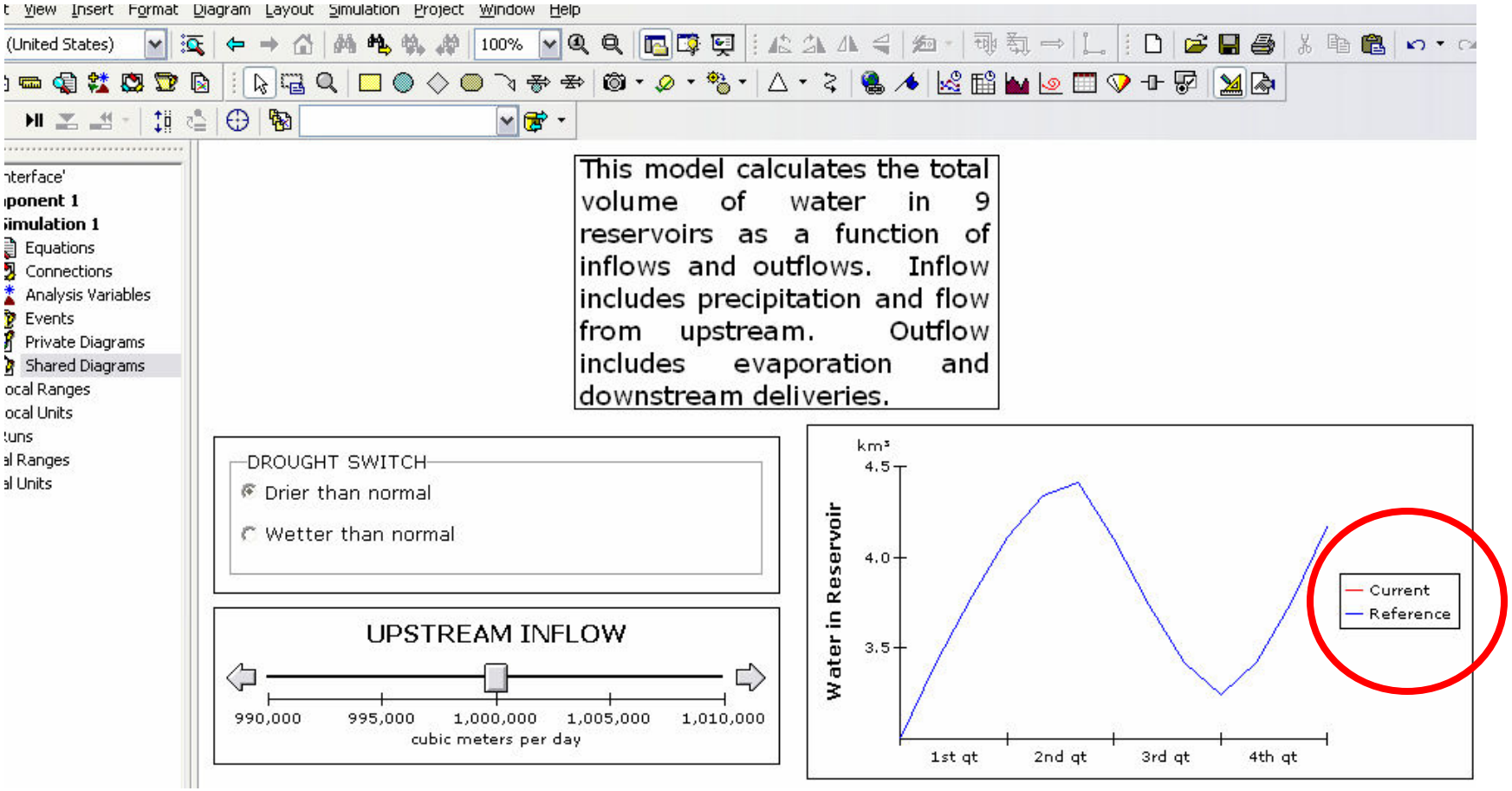
Reset model. Double-click time graph to view its properties. Click Parameters tab. **Water in Reservoir** will appear in the parameter list (this list shows the variables that the time graph will display).



From the value source list, select **Water in Reservoir**. When you try and add it to the parameter list, the Add Advanced box appears and you must toggle "Reference run" and click "OK". Click "OK" again to exit properties box.

Create Reference Run

Notice new legend on time graph.



Create Reference Run

Toggle “Wetter than normal” in **DROUGHT SWITCH**. Run model and note change in **Water in Reservoir**.