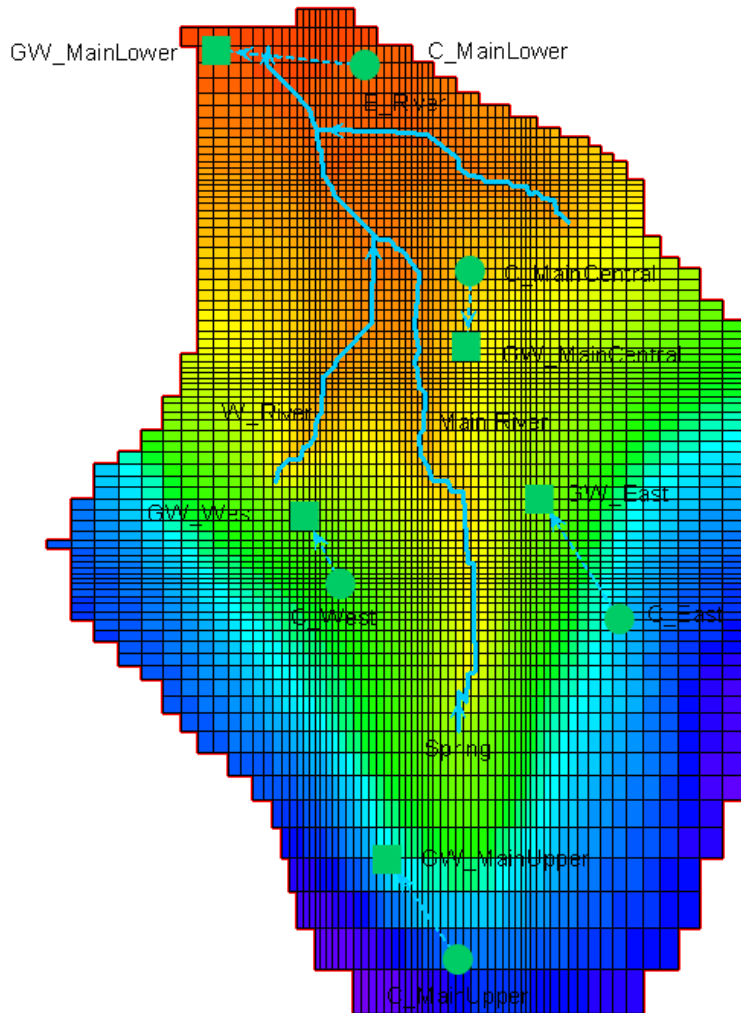


WEAP-MODFLOW Tutorial



WEAP-MODFLOW Tutorial

Version 2

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1 Introduction

The present tutorial intends to illustrate the idea of the dynamic link between WEAP and MODFLOW. The techniques presented are kept as simple as possible in order to make you familiar with the necessary steps for building up a WEAP model that is linked to MODFLOW and to give you an introduction to solving common water management problems.

The first part will guide you through building a WEAP model based on the data stored in a MODFLOW model (“Hard Data approach”). Despite this approach is not recommended in general, as flexibility is lost and many of WEAP’s powerful modelling options are not available, it might be useful in case measured data (e.g. precipitation) used to build and calibrate the existing MODFLOW model is unavailable for whatever reason.

The second part focusses on building and linking a model that makes use of WEAP’s internal functions to model groundwater recharge and surface runoff.

In the last part, you will learn how to cope with various challenges typical to modellers like implementing artificial recharge or changes in land use.

Before you start with the tutorial, be advised to have downloaded the associated shape files (Catchment.shp, Landuse.shp, Wellfields.shp) and the csv-file (InputData.csv).

This tutorial refers to WEAP Version 3.001 (Sep 2012) and LinkKitchen Version 1.00 (Sep 2012).

It is based on the WEAP-MODFLOW-Tutorial by BGR/ACSAD (2009) and includes contributions by M. Al-Sibai (Chapter 2).

2 MODFLOW Model

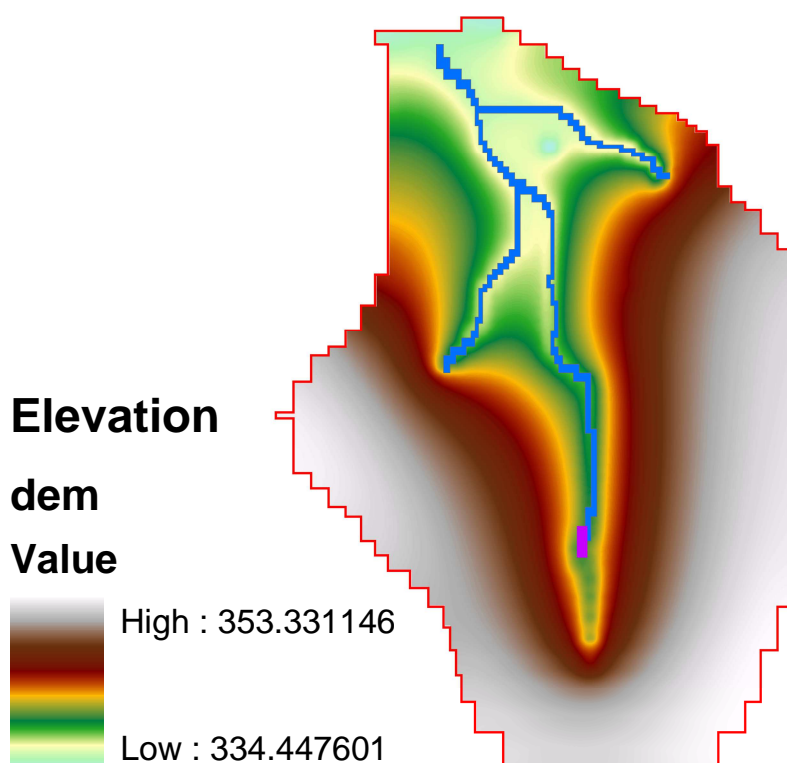
The MODFLOW model used in this tutorial was designed with the intention to make many planning options possible (dams, irrigation) and to remain easy to understand. It is a modification of the original GMS-Tutorial model and in the following named “Main River Basin”.

2.1 Model Area – “Main River Basin”

The Main River basin encompasses 783 square kilometres. It is located in a semi-arid climate, with precipitation only in the winter months. Most of this precipitation is lost by evapotranspiration. The aquifer consists of fractured crystalline bedrock and alluvial fills in the valleys, its saturated thickness varies between 35 m in the South to about 53 m in the North.

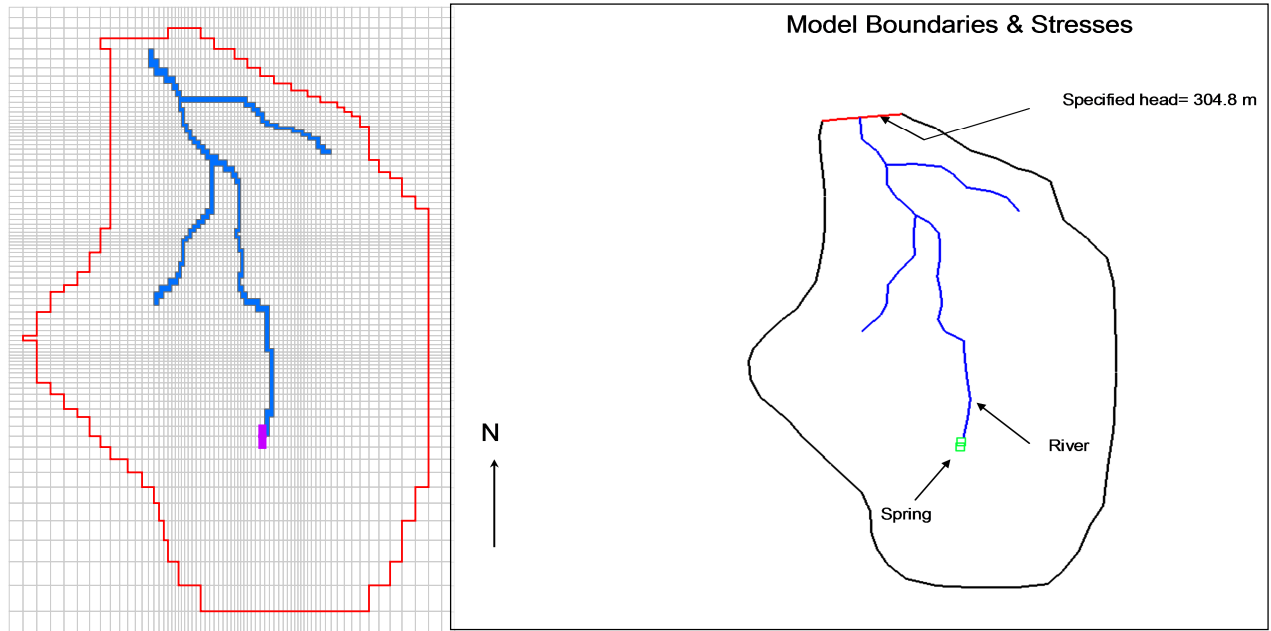
Groundwater flow is towards the spring, the Main River and its 2 tributaries. The spring represents the headflow of the Main river, with an average monthly discharge of about 320 000 m³. In the north, outside the model area the Main River finally drains into a reservoir lake with a constant water level of 304.8 m a.s.l.

The topography gradually decreases from South (353 m.a.s.l) to North (335 m.a.s.l).



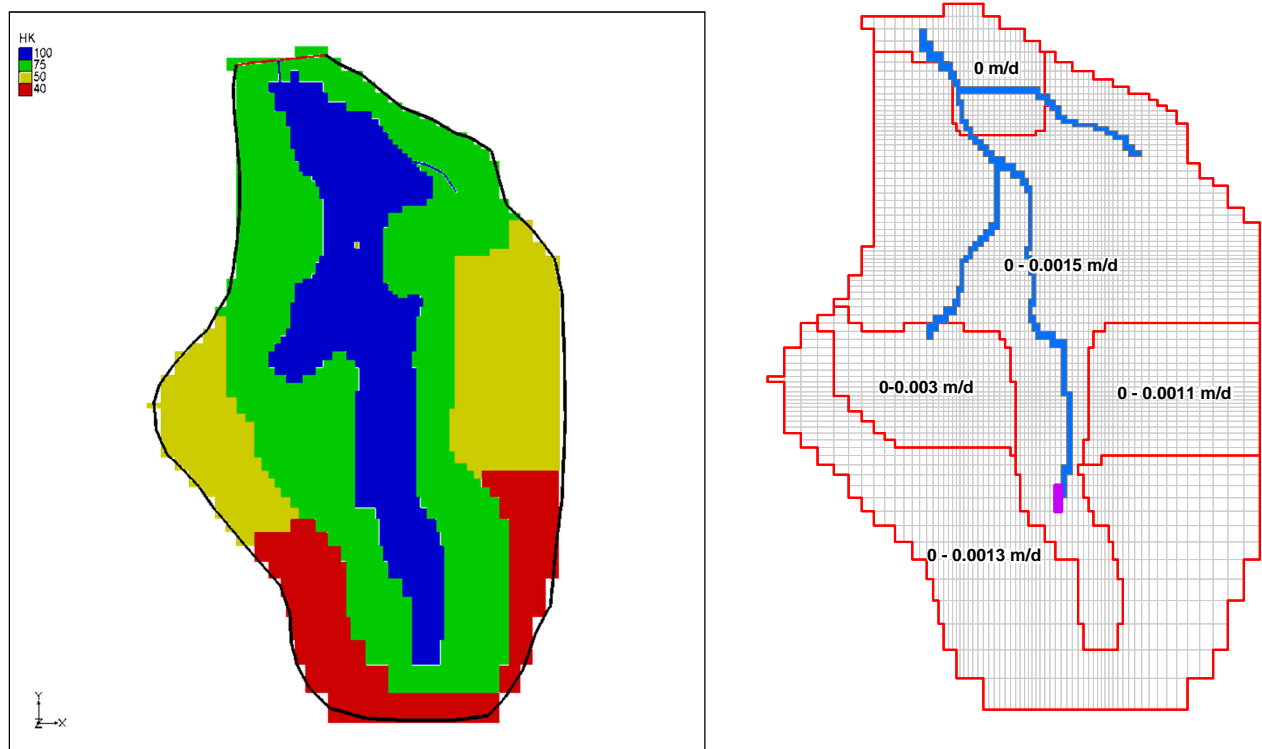
2.2 Mathematical Model

GRID: The model consists of one layer (1 unconfined aquifer, 60-80m layer thickness, 35m – 50m saturated thickness) with 88x70 cells. The cell sizes vary in width and height between 200 m to 1200 m (see figure below)



BOUNDARY CONDITIONS: Specified-Head boundary in the North (Reservoir Lake level). All other boundaries are No-Flow boundaries (see figure above).

HYDRAULIC CONDUCTIVITY: The 4 hydraulic conductivity zones for the model are shown in the figure below. The hydraulic conductivity of the aquifer varies between 100 m/day along the river valley to 40 m/day towards the basin boundary.

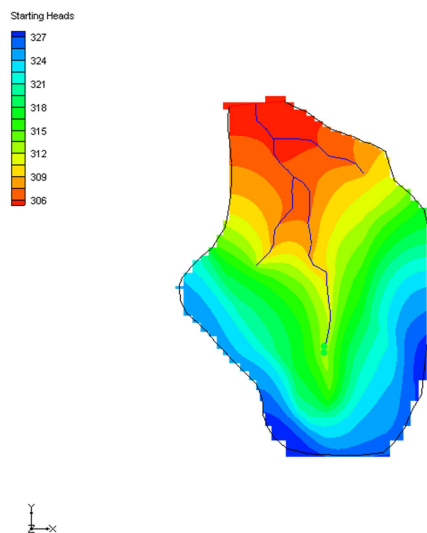


RECHARGE: 5 different recharge zones have been defined. The values in the zones ranging from 0 to 0.0015 m/d (see figure above).

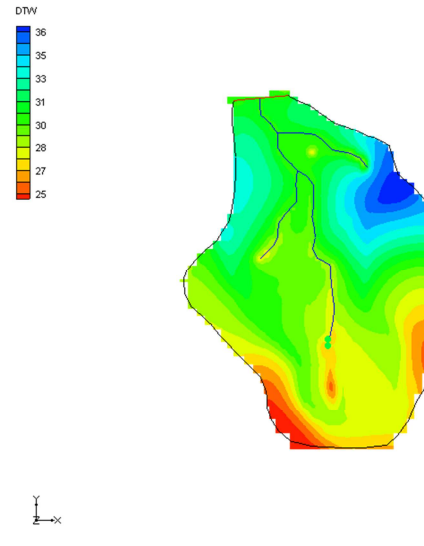
ADDITIONAL PACKAGES: The spring was modelled as 2 DRAIN-cells (pink in the figure above) and the rivers as RIVER-cells (blue in the figures above).

INITIAL HEAD: The initial head ranges from 306 – 327 m.a.s.l. resulting in a depth to water table of 25 to 36 m (see figures below).

Starting Heads:



Depth to groundwater table



The Model has been built and run on transient state in order to cover two years of recharge variation. It consists of 24 monthly stress periods, which contain 3 equal time steps each. The final balance (see figure below – units in m³ or m³/d) shows that the model is almost balanced or close to steady state, with recharge as the main inflow and river leakage as the main outflow fraction.

VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP 3 IN STRESS PERIOD 24			
CUMULATIVE VOLUMES		L**3	RATES FOR THIS TIME STEP
			L**3/T
IN:			

STORAGE =	158684992.0000		STORAGE = 25869.2949
CONSTANT HEAD =	0.0000		CONSTANT HEAD = 0.0000
DRAINS =	0.0000		DRAINS = 0.0000
RIVER LEAKAGE =	0.0000		RIVER LEAKAGE = 0.0000
RECHARGE =	357105632.0000		RECHARGE = 635431.5625
TOTAL IN =	515790624.0000		TOTAL IN = 661300.8750
OUT:			

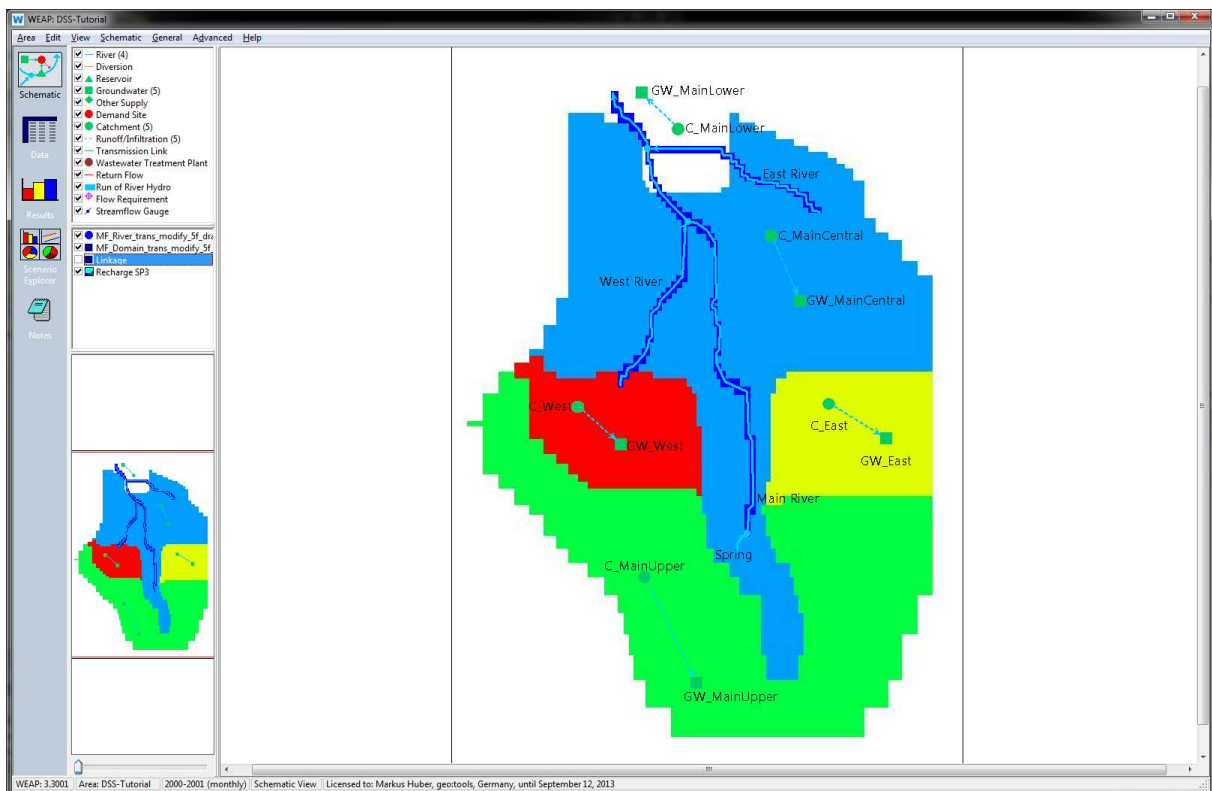
STORAGE =	160023184.0000		STORAGE = 248629.9062
CONSTANT HEAD =	5145124.0000		CONSTANT HEAD = 6988.5078
DRAINS =	7527779.5000		DRAINS = 10904.8906
RIVER LEAKAGE =	343096672.0000		RIVER LEAKAGE = 394787.0938
RECHARGE =	0.0000		RECHARGE = 0.0000
TOTAL OUT =	515792768.0000		TOTAL OUT = 661310.3750
IN - OUT =	-2144.0000		IN - OUT = -9.5000
PERCENT DISCREPANCY =	0.00		PERCENT DISCREPANCY = 0.00

3 Create and link a WEAP-model based on MODFLOW data

At the beginning, you will create a new WEAP Area and design the Schematic for it. The necessary tasks are:

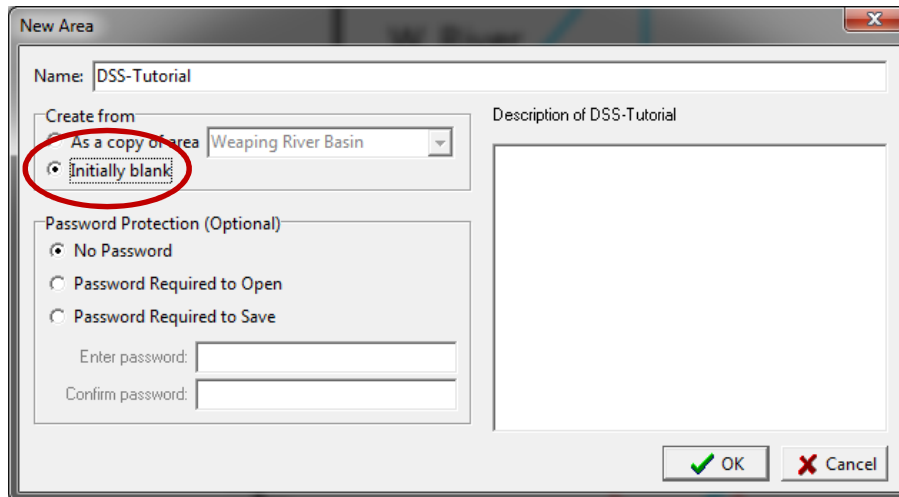
- Create a new WEAP area
- Set the area's spatial boundaries
- Load background layers
- Digitize 4 rivers
- Add 5 catchment and 5 groundwater nodes

The result will look similar to the image below.

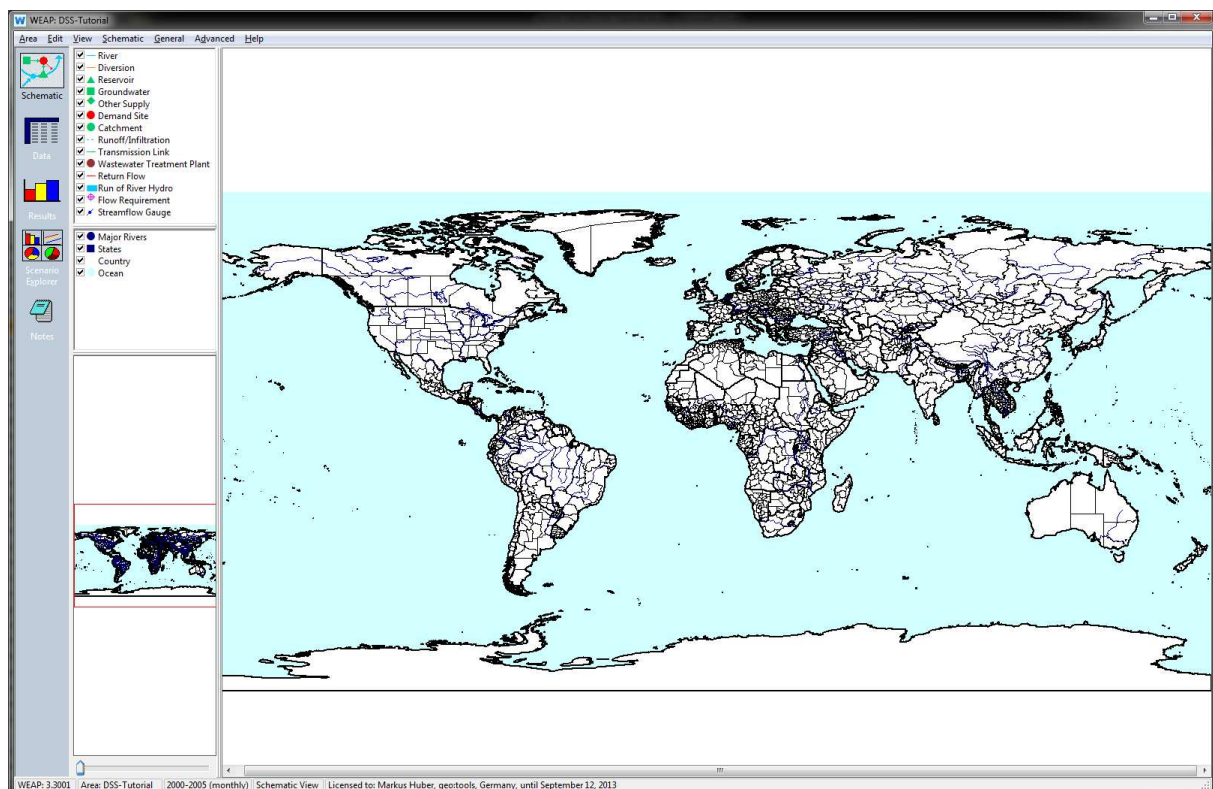


3.1 Create a new WEAP - Area

1. In the Main Menu in WEAP, go to *Area* → *Create Area*. In the following dialog, create a new Area, which is *initially blank* and give it the name: “DSS-Tutorial”:



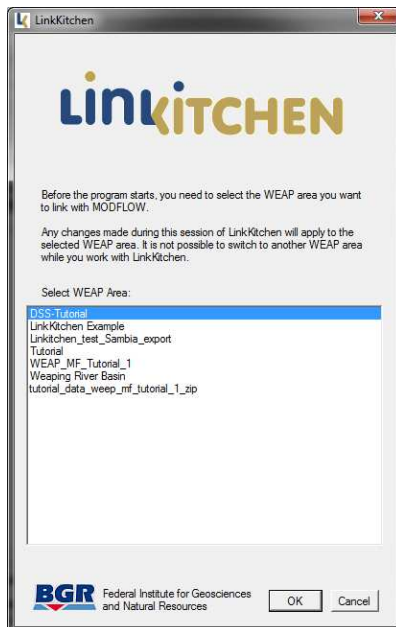
2. Click “OK” and ignore the following dialog (“Area boundary”) by clicking on “Cancel”. The model should look like below:



3.2 Start LinkKitchen

LinkKitchen is a GIS-alike tool designed to assist the setup of the Linkage Shapefile without the need of further GIS- and Spreadsheet-software. It provides all necessary functionality for producing the linkage file and for its attribution. Furthermore, it allows direct parameterization of the WEAP-model based on linkage file's attributes.

If you are not yet familiar with the use of LinkKitchen, please read its *User Manual* before you continue with the tutorial.



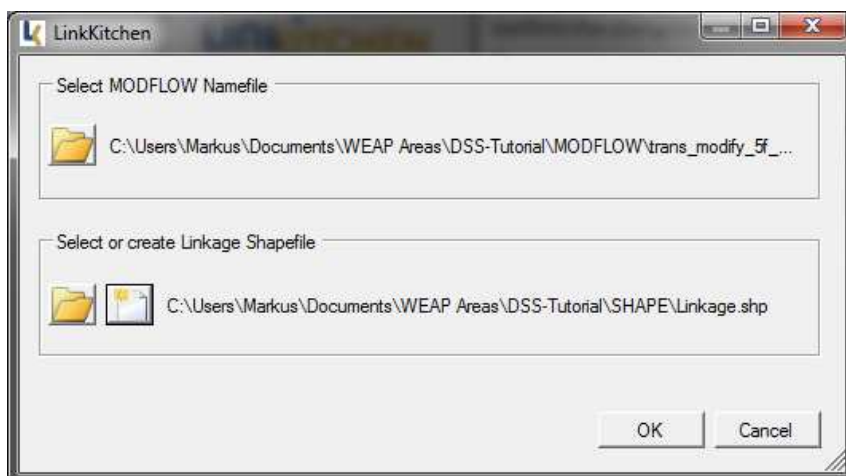
Remain WEAP open and start LinkKitchen in parallel.

At start-up, you are prompted to select the one of your WEAP models which you want to work on. Select *DSS-Tutorial* and confirm the dialog by click on *OK*.

In the following dialog, LinkKitchen prompts for the location of the MODFLOW model and the Linkage File. Browse for the MODFLOW model that comes with the Tutorial data and select the *Namefile*. As a linkage file does not yet exist, select to *create a new Linkage File*.

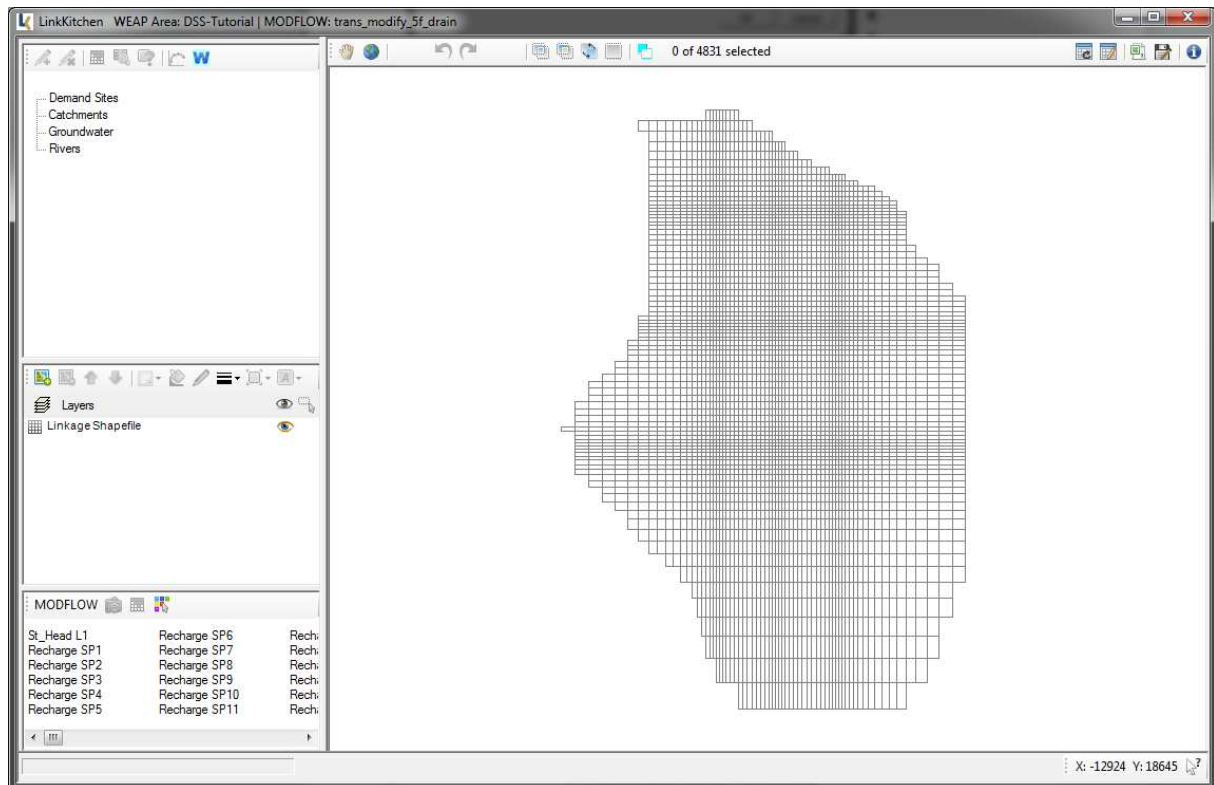
Once you confirm with OK, all MODFLOW files will be copied to the WEAP-Area's standard directory.

LinkKitchen produces the Linkage File as well as two other shapefiles in the background. Those will be used during the next steps.

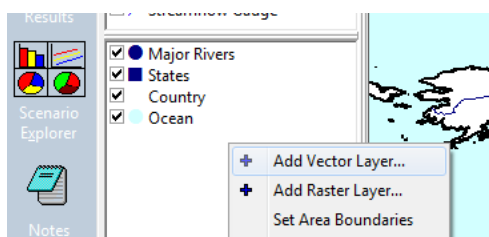


3.3 Set the WEAP Area's Boundary

Your LinkKitchen User Interface will show an empty grid that represents the geometry of your MODFLOW model. This is the linkage File.

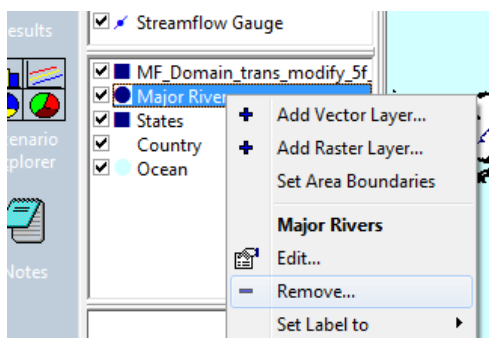


Switch back to WEAP (don't close LinkKitchen).

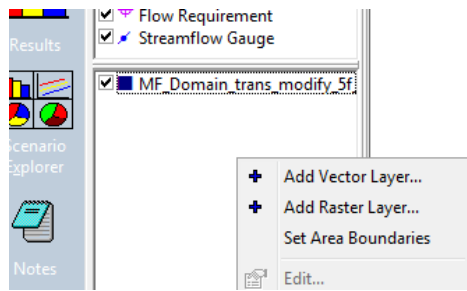


Right-click into the Layer-pane and select *Add Vector Layer* from the context menu.

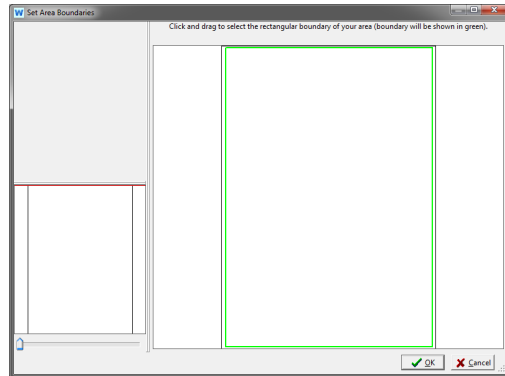
Browse to your WEAP Area directory/SHAPE/ and select the file *MF_Domain_trans_modify_5f_drain.shp*. This file was created at start-up and represents the spatial boundary of the MODFLOW model. You will use this file to define the area's boundaries.



Remove all other layers (Major Rivers, States, Country, Ocean) except *MF_Domain_trans_modify_5f_drain.shp*.




Right-click into the Layer-pane and select *Set Area Boundaries* from the context menu.

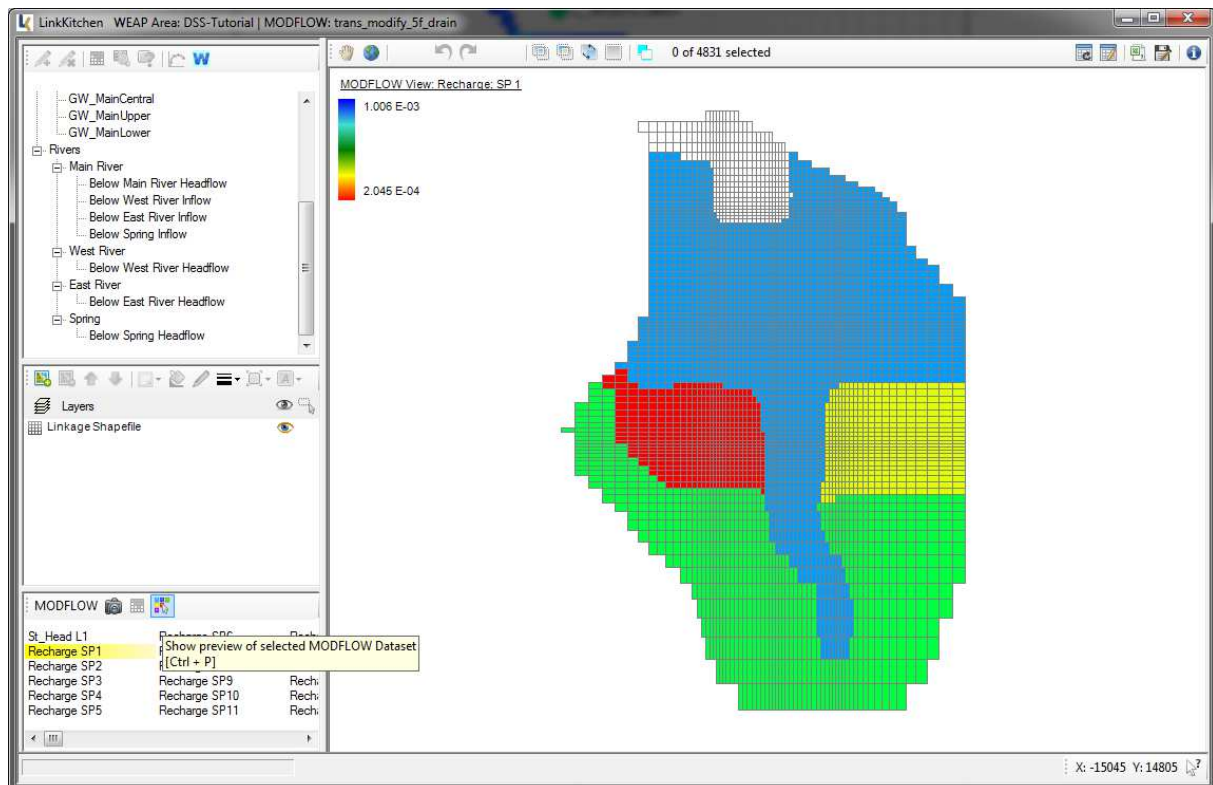



Draw the green rectangle (the area boundary) around the complete extent of the black rectangle (the MODFLOW model's extent) and confirm by click on OK.

3.4 Add Catchment and Groundwater Nodes to the Schematic

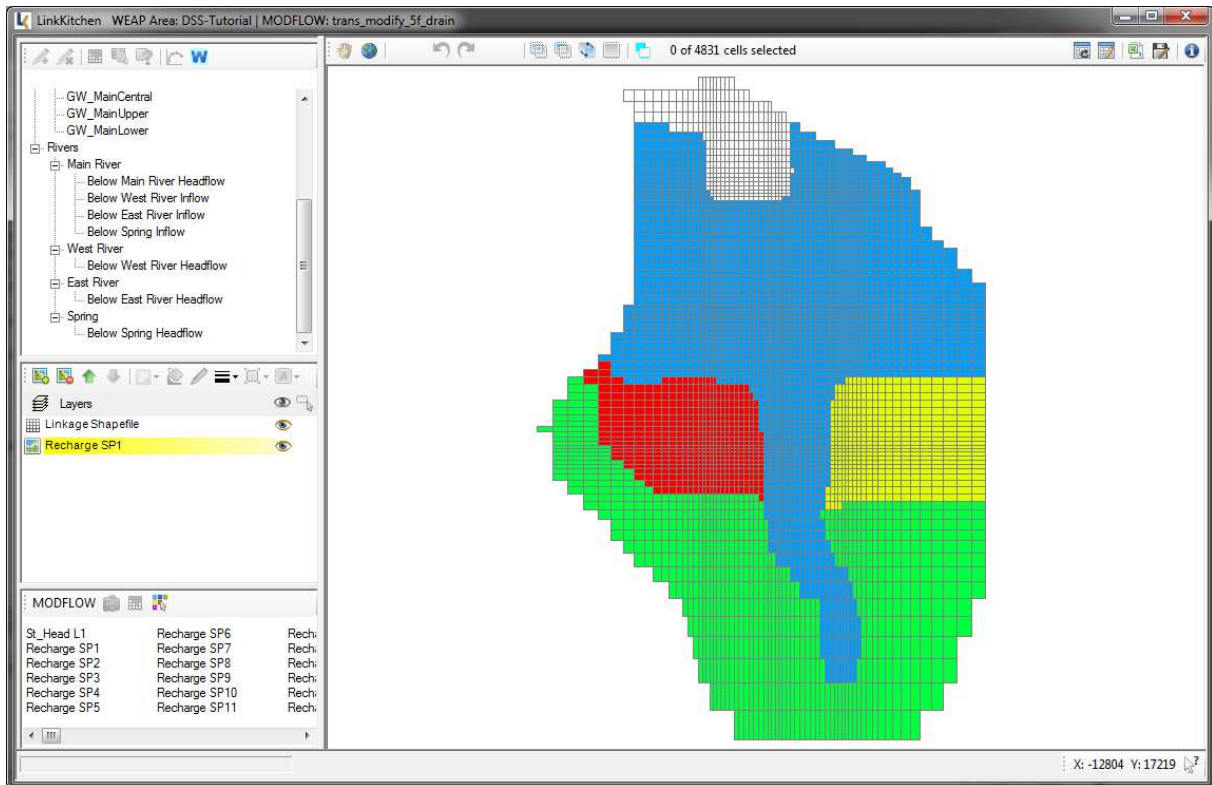
It is assumed, that MODFLOW is the only source of information about the model area. Catchments and Groundwater nodes are thus delineated by zones of equal recharge rate. You will use LinkKitchen to delineate the Catchment and Groundwater zones in WEAP.

1. Switch to LinkKitchen and browse to the MODFLOW-Layer *Recharge SP1* in the MODFLOW Viewer. Click the *Preview*-Button  to show the recharge zones.

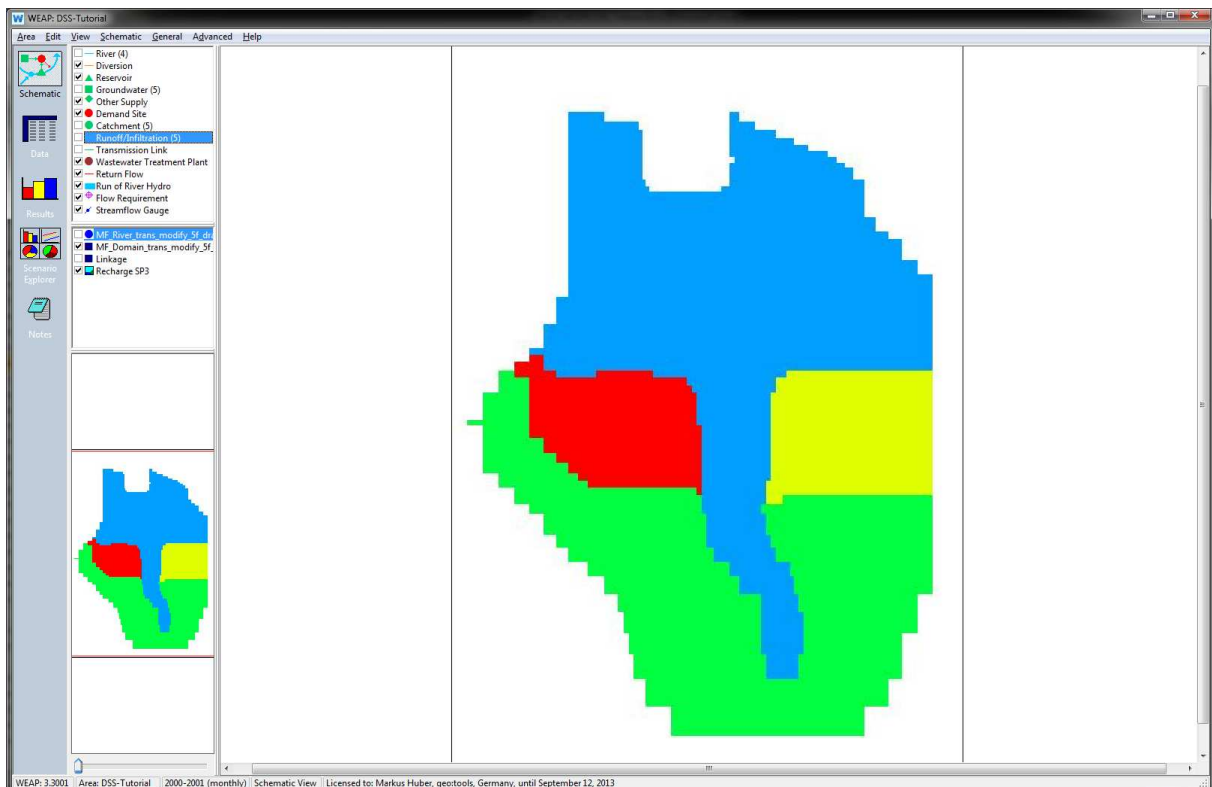


2. Click the *Make Snapshot*-button  to save the preview-image permanently to disc. The image appears in the List of Layers as a regular Background Layer.
- 3.

At this stage, the recharge zones are saved as a JPEG-image-file in the WEAP-area directory. The file doesn't store any information besides a different colour for each zone.



- Switch back to WEAP and load the file "Recharge_SP1.jpg" as a *background raster layer* to the Schematic.

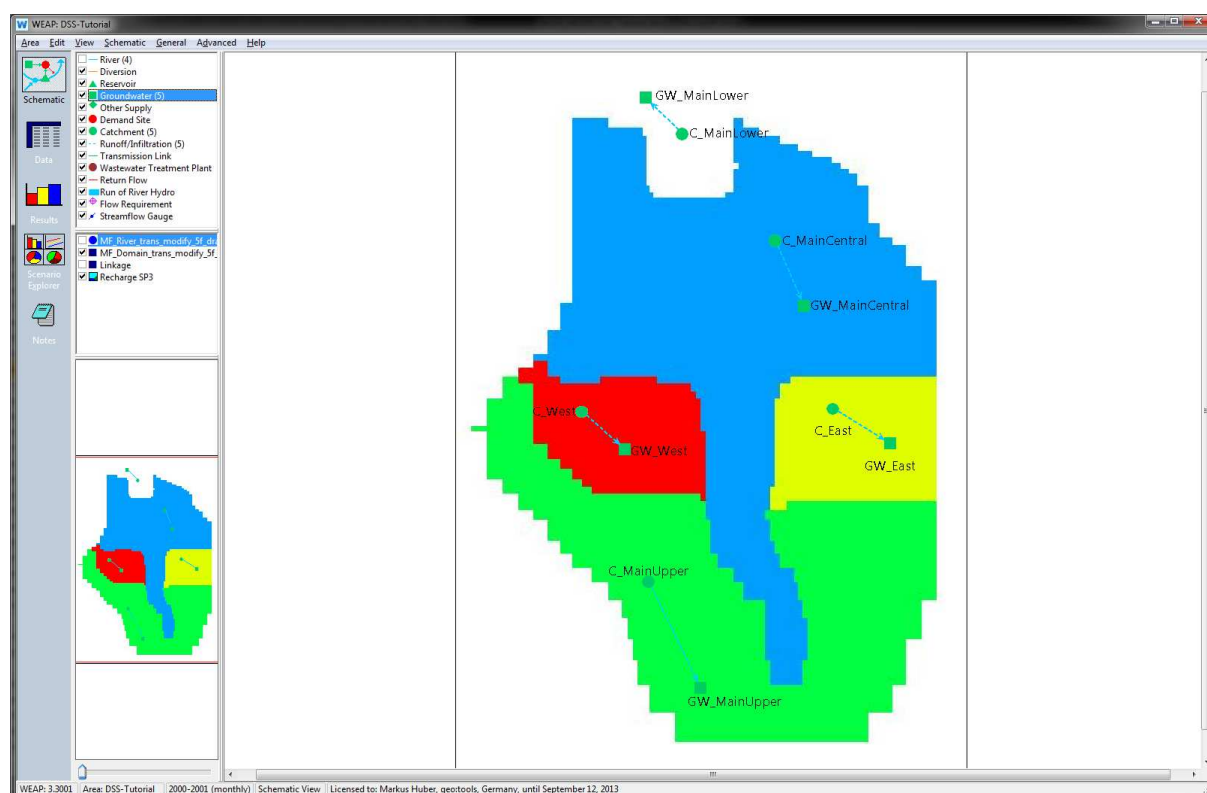


In the MODFLOW model, five zones of different recharge are defined. You will take these zones as blueprints for the delineation of WEAP-Catchments and groundwater nodes.

1. Drag and drop one Catchment and one Groundwater node for each recharge zone onto the schematic.
2. Connect the Groundwater and Catchment nodes by infiltration links.

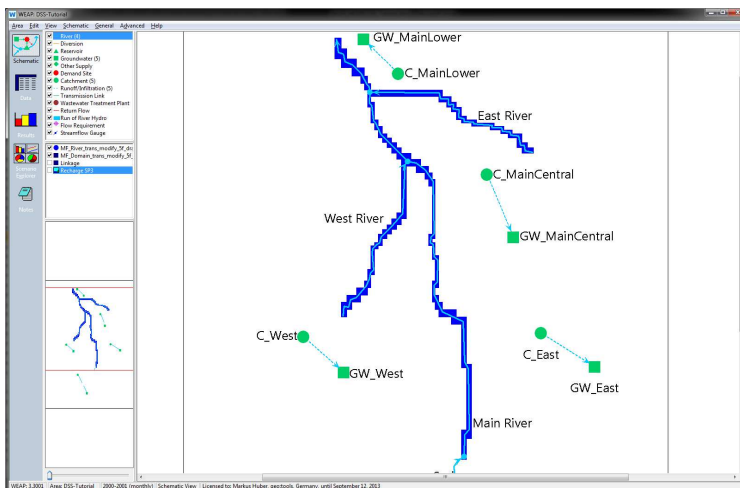
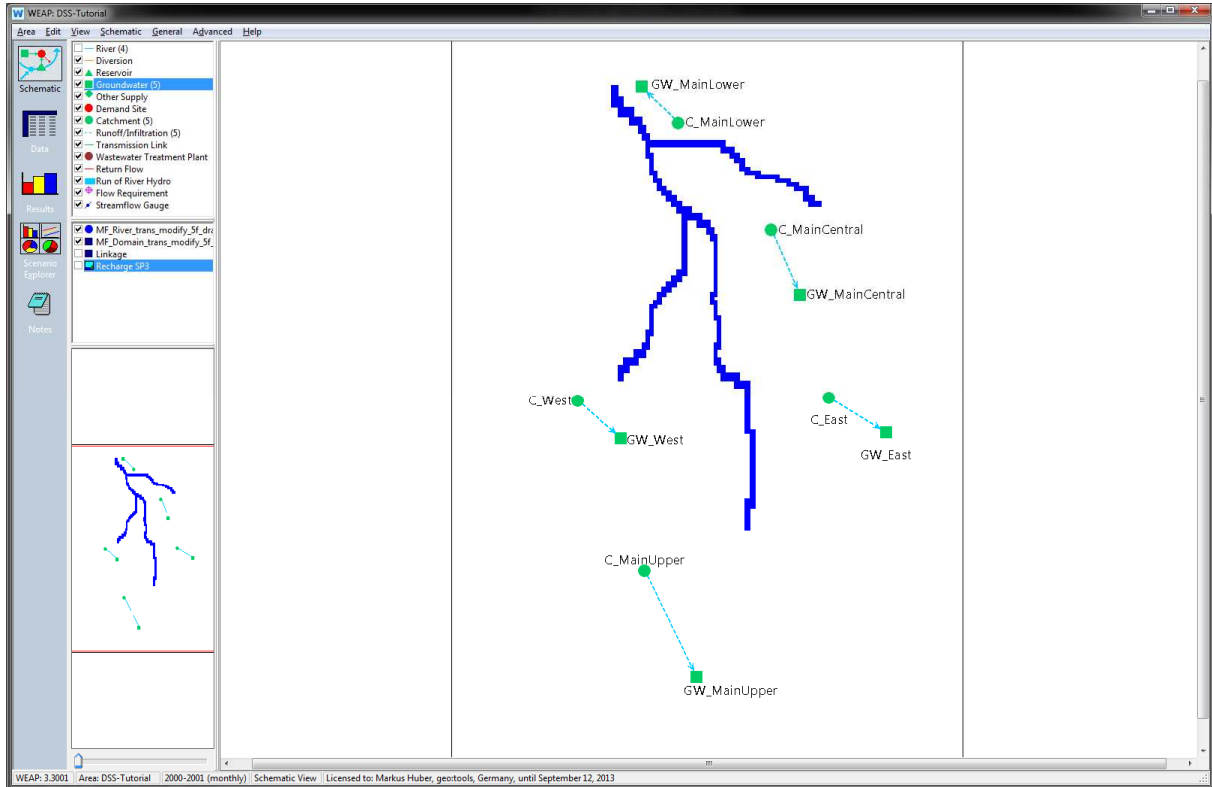
Catchment node name	connection	groundwater node name
C_East	infiltration link	GW_East
C_MainCentral	infiltration link	GW_MainCentral
C_MainLower	infiltration link	GW_MainLower
C_MainUpper	infiltration link	GW_MainUpper
C_West	infiltration link	GW_West

NOTE: It is good practice to add the prefix “C_” before the catchment’s name and the prefix “GW_” before groundwater nodes in order to avoid getting confused by identical names of groundwater nodes, catchments and demand sites.

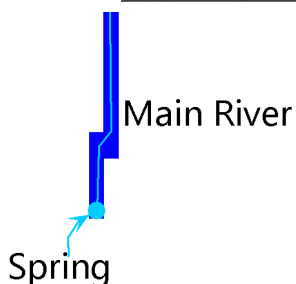


3.5 Add Rivers to the Schematic

1. Add the file *MF_River_trans_modify_5f_drain.shp* (located in the folder SHAPE in the area directory) to the Schematic and give it a solid blue colour.



2. Drag and Drop river nodes onto the Schematic and digitize each river, in flow direction, on top of the blue area. The rivers' names are *Main River*, *East River* and *West River*. East River and West River are tributaries to Main River.

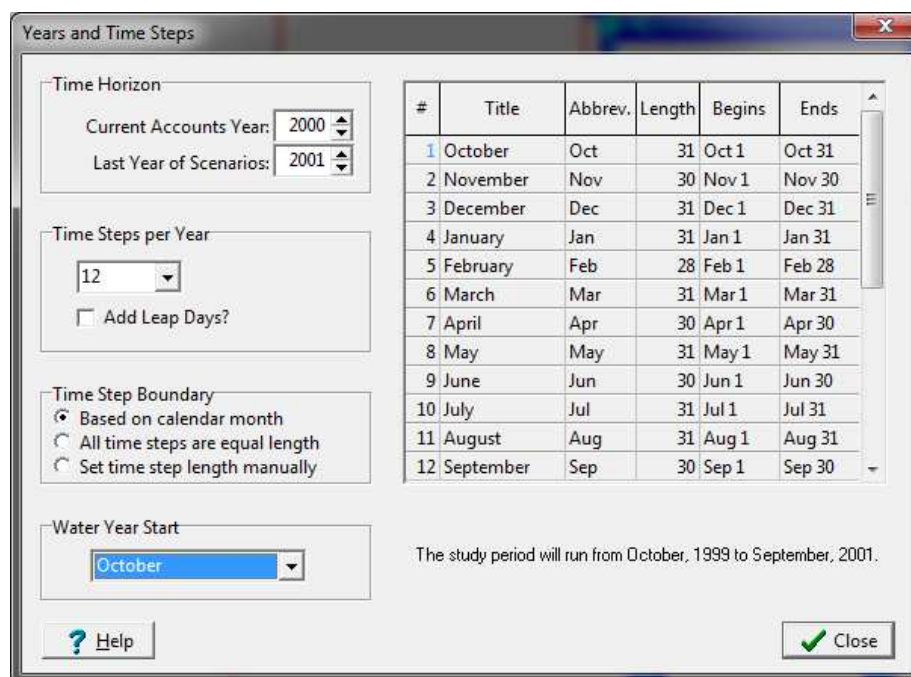


3. A fourth River needs to be digitized in addition to the three rivers. In MODFLOW, it is represented by two drain cells upstream of *Main River*. That River is named *Spring*.

3.6 Set the Model Runtime in WEAP

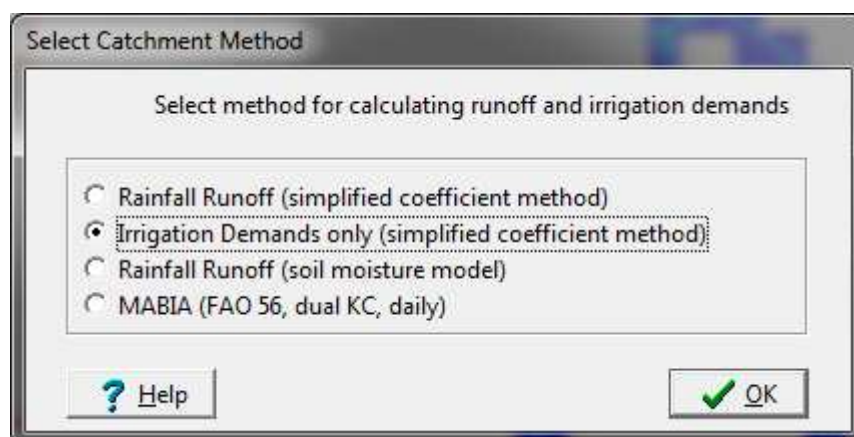
In order to ensure, the WEAP calculation correlates correctly with the MODFLOW model, adjust the WEAP time steps and the starting month according to the MODFLOW stress periods (here: October 1999 – September 2001).

This is done using the *General* menu item → *Years and Time Steps*



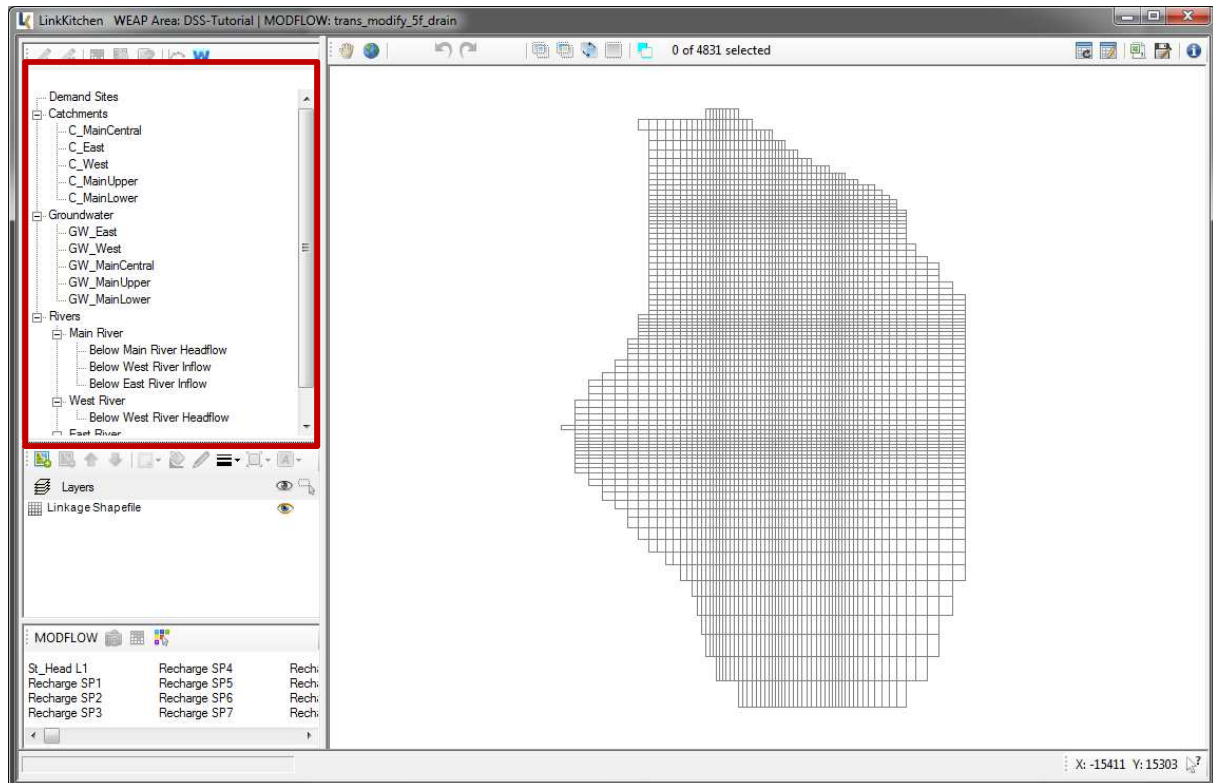
Initially you won't use any WEAP internal model to calculate surface runoff, groundwater recharge and irrigation demand, therefore choose in

Data View → *Demand Sites and Catchments* → *Advanced*



3.7 Define Catchment and Groundwater in the Linkage File

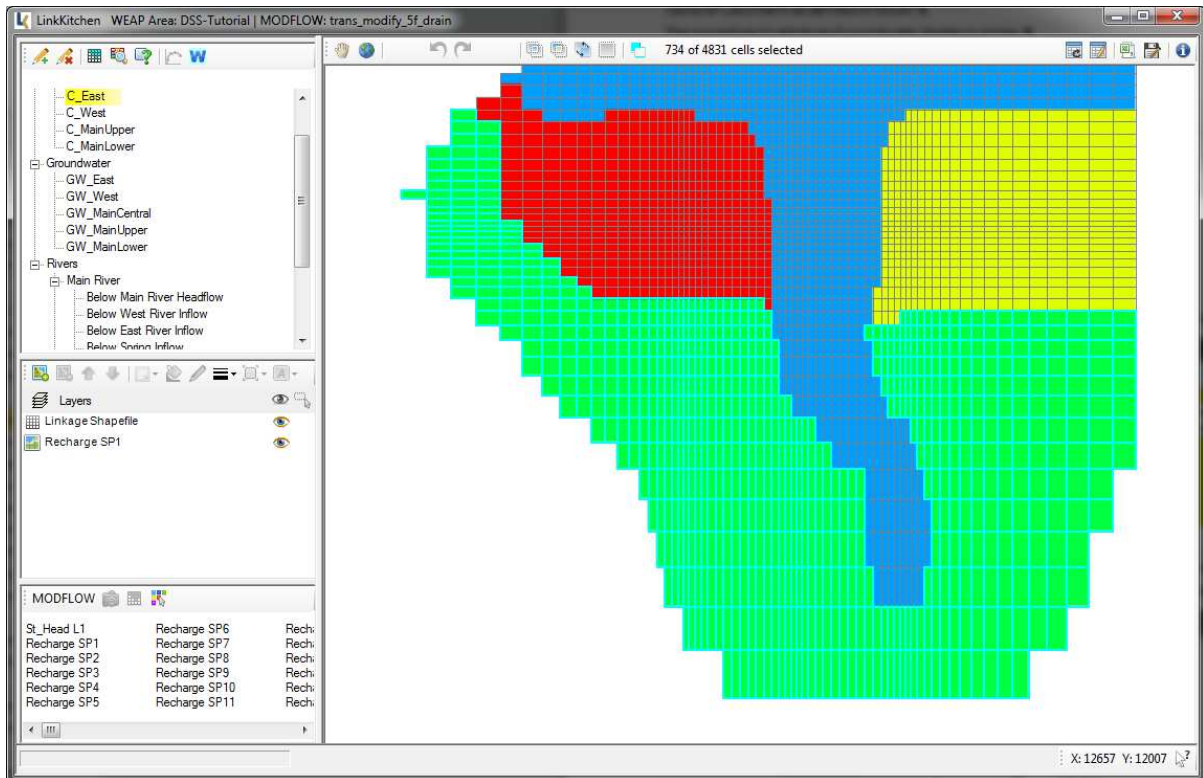
Switch back to LinkKitchen and see how it reflects the changes you made in WEAP. The Nodes you added to the Schematic are now visible in LinkKitchen's Branch Viewer. During the following steps, you will relate cells of the Linkage File to Catchments, Groundwater Nodes and Rivers.



As you have the recharge zones loaded in the background, you will use these zones as stencils for selecting cells. Use LinkKitchen's selection-tools (s. LinkKitchen User Manual) to select cells corresponding to recharge-zones. The thus selected cells are then attributed with the name of the catchment as defined in WEAP.

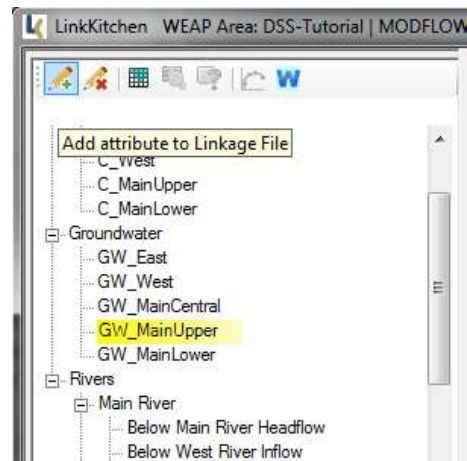
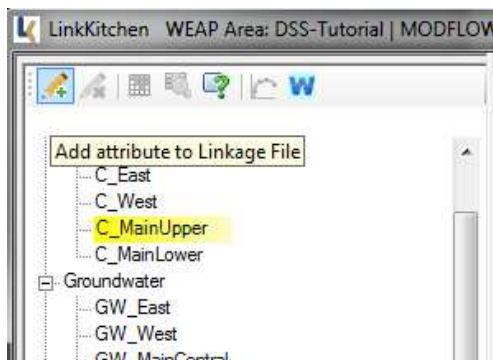
The procedure of attributing groundwater nodes is identical.

1. Select all cells located in the green area (C_Main Upper).



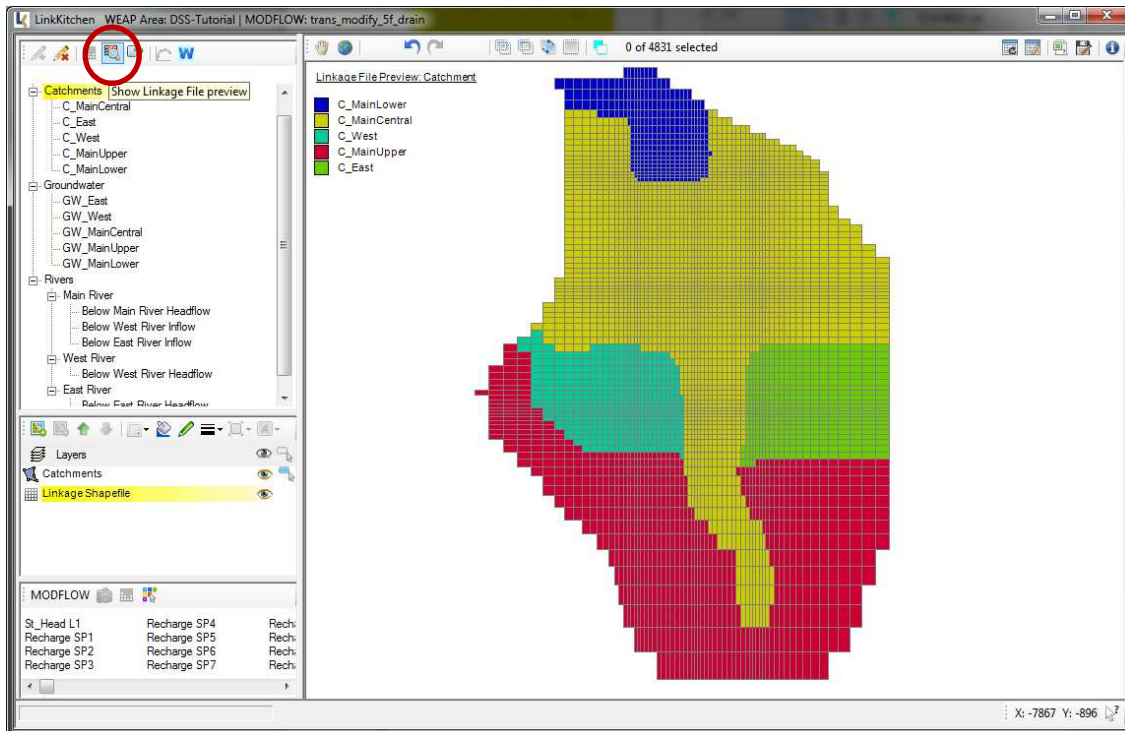
2. Highlight *C_MainUpper* in the Branch-Viewer and click *Add Attribute to Linkage File*. This will write the Branch's name to the linkage file.

3. Highlight *GW_MainUpper* and click *Add Attribute to Linkage File*.



3. Repeat Steps 1 and 2 for the other Catchments

4. Highlight the Parent-Branch *Catchments* and look at the Linkage File Preview:

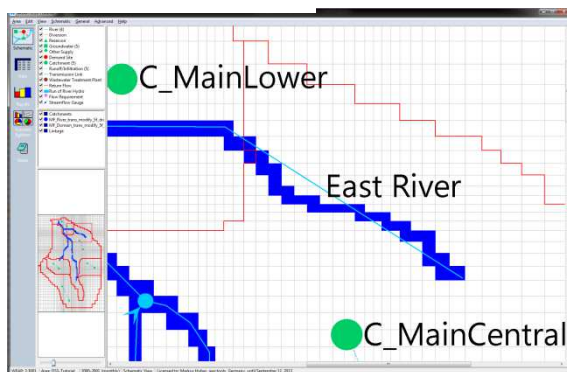


3.8 Define Rivers in the Linkage File

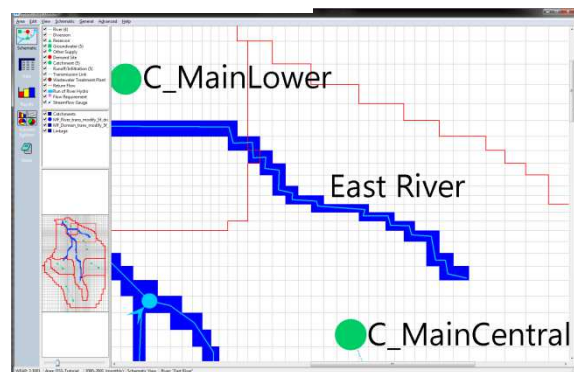
In WEAP, a river is defined as a “chain” of reaches, sections between inflow or outflow nodes. Any river reach requires to have a representation in the Linkage File.

There are two different ways to assign river reaches to the Linkage File. The method to choose depends on how accurate you digitized the rivers in the WEAP Schematic beforehand. If the WEAP-rivers are digitized very accurately with no overlaps of the river lines out of the blue river cells, you should opt for method 2. If the rivers are digitized only roughly around the river cells, choose the first method. Both methods are described in the following section.

Simplistic → Method 1



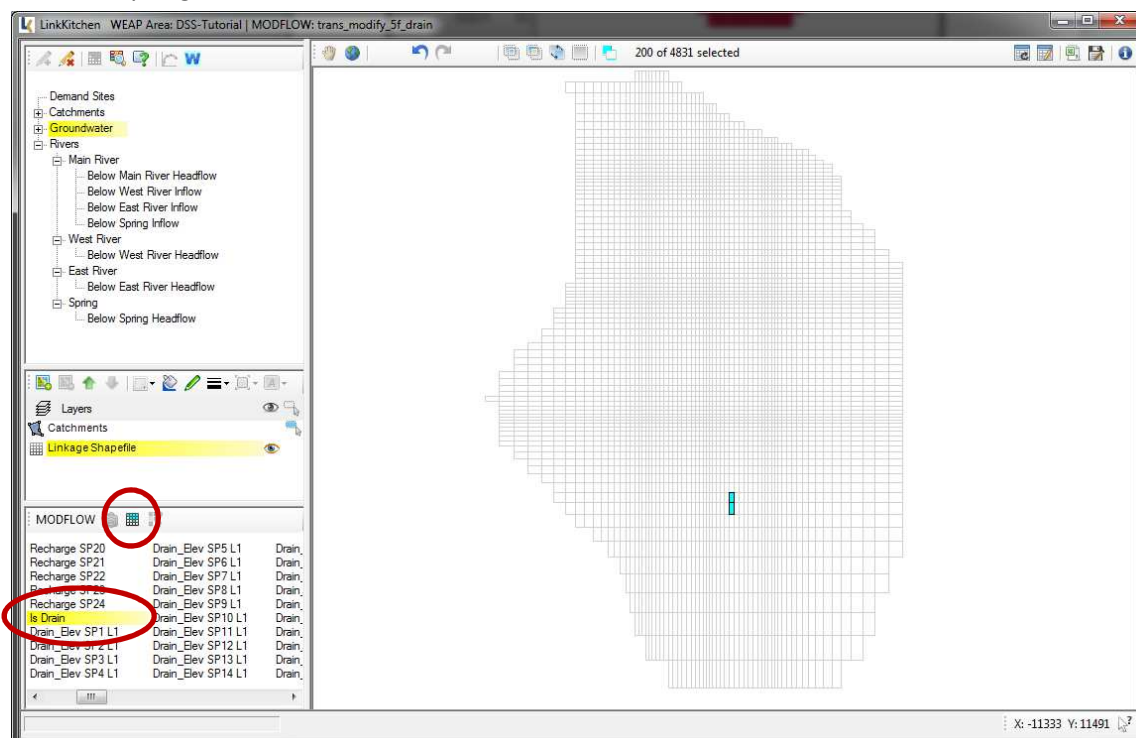
Accurate → Method 2



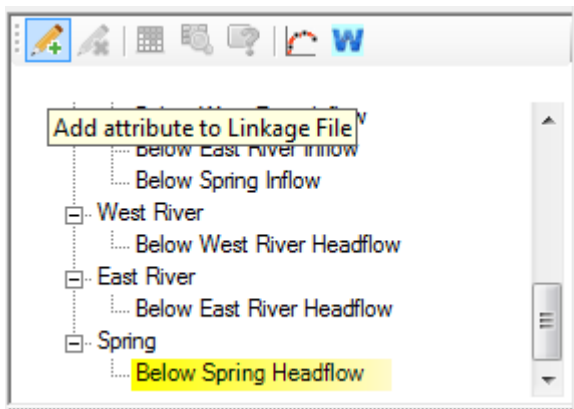
Method 1:

The procedure to assign river reaches to Linkage File cells is similar to the procedure to assign Catchments except that you start from Information you get from MODFLOW rather than from an overlay shapefile.

1. In the MODFLOW-Viewer, browse to the Layer *IsDrain* and click *select*. The drain cells represent the river *Spring* in WEAP.

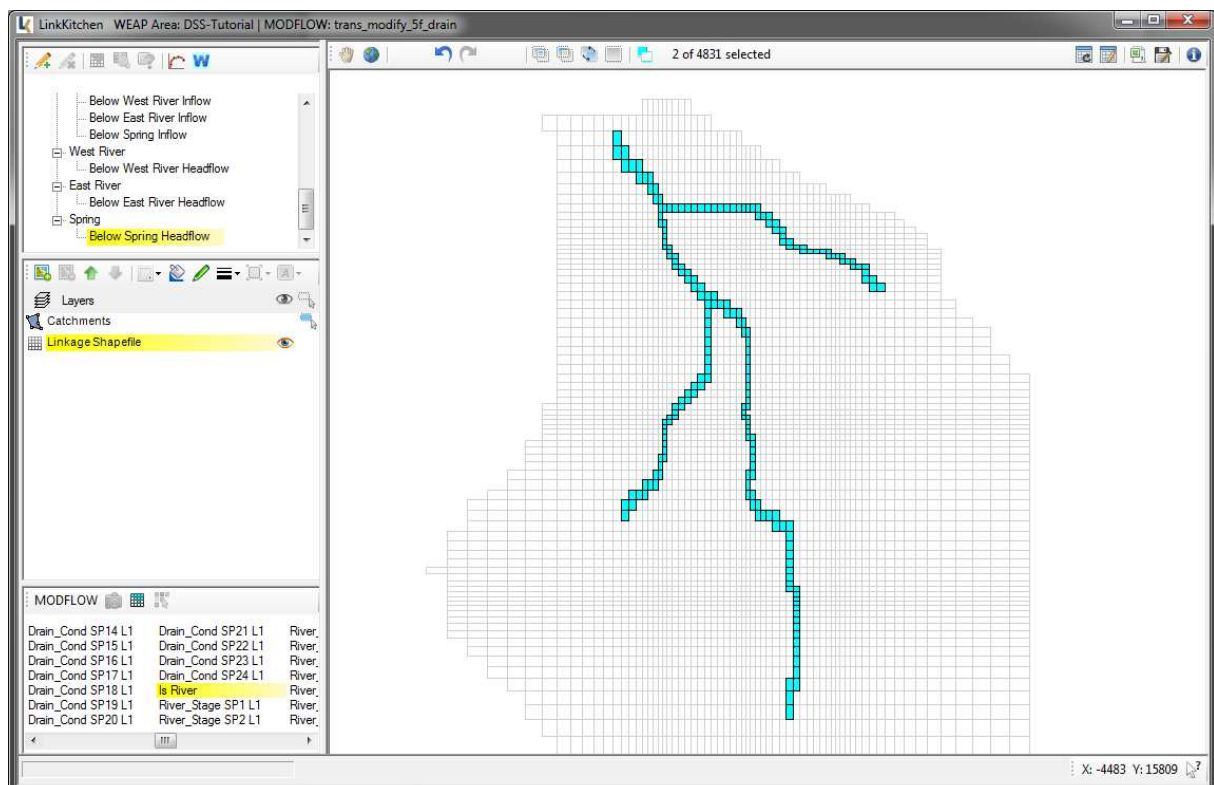


2. Highlight the River-branch *Below Spring Headflow* in the Branches-Viewer and click *Add Attribute to Linkage File*.

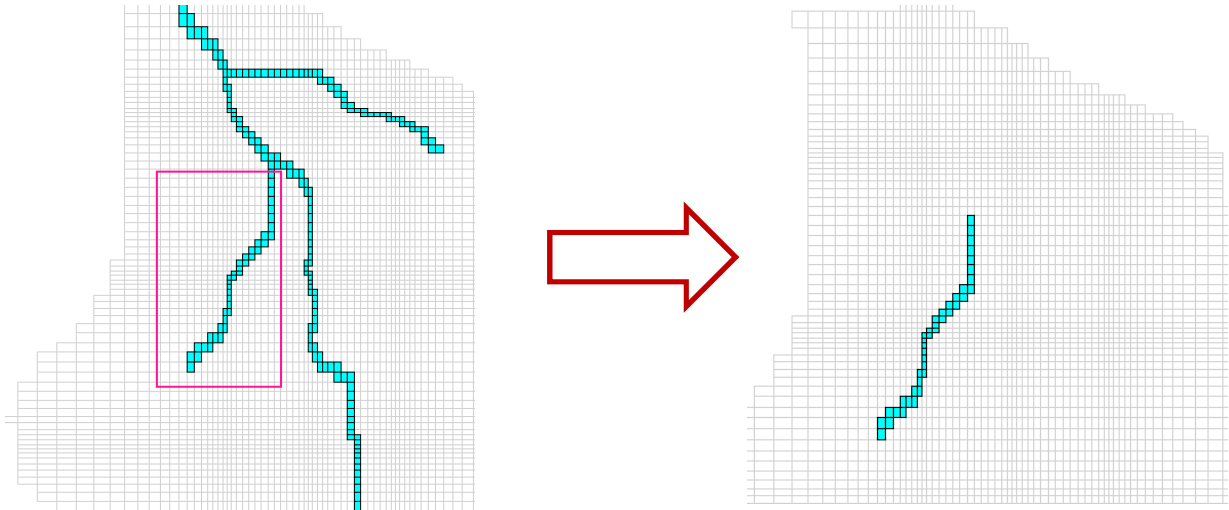


The two drain cells are now linked to the WEAP river reach *Below Spring Headflow*.

3. Browse to the layer *IsRiver* in the MODFLOW Viewer to select River cells.



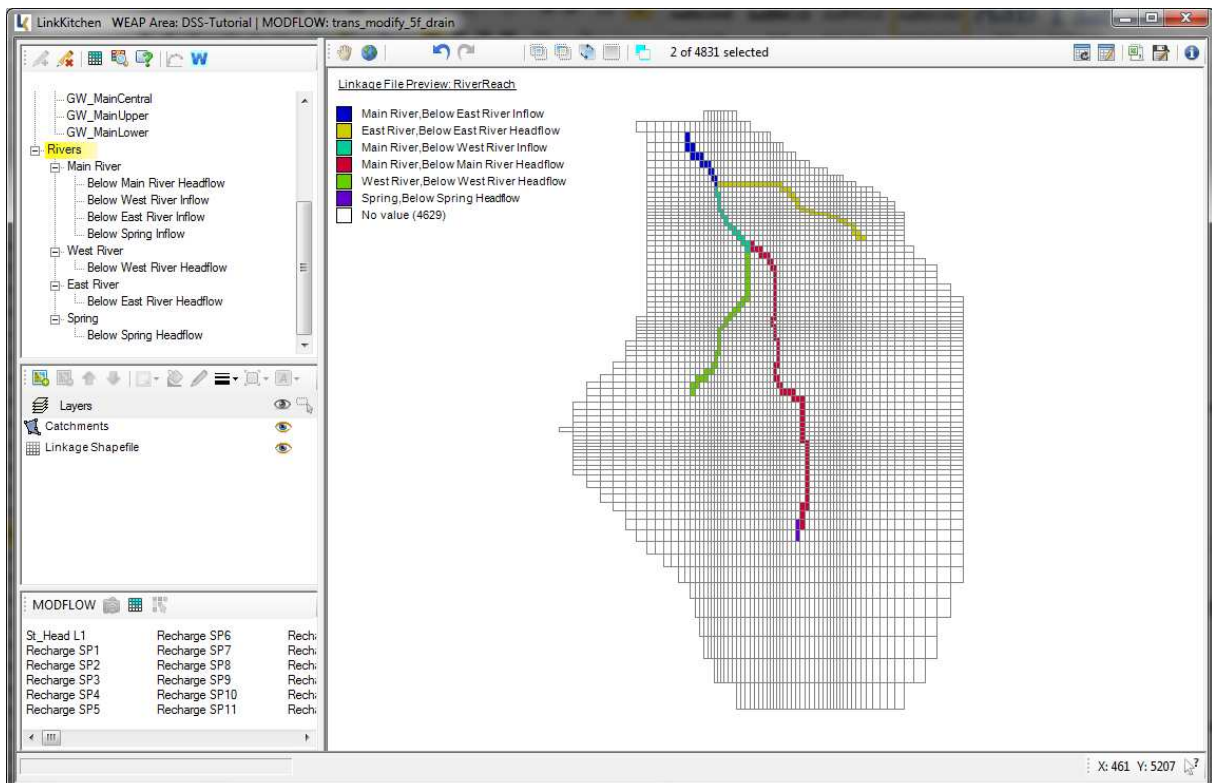
4. Use LinkKitchen's selection-tools to sub-select those cells corresponding to the WEAP-rivers. E.g. Click and hold the Alt-Key while drawing a rectangle around *West River* in order to select from selected river cells.



5. Highlight the River-branch *Below West River Headflow* in the Branches-Viewer and click *Add Attribute to Linkage File*.

6. Repeat the last two steps for all other river reaches.

The preview of the river-attribution should show an image similar to the image below:

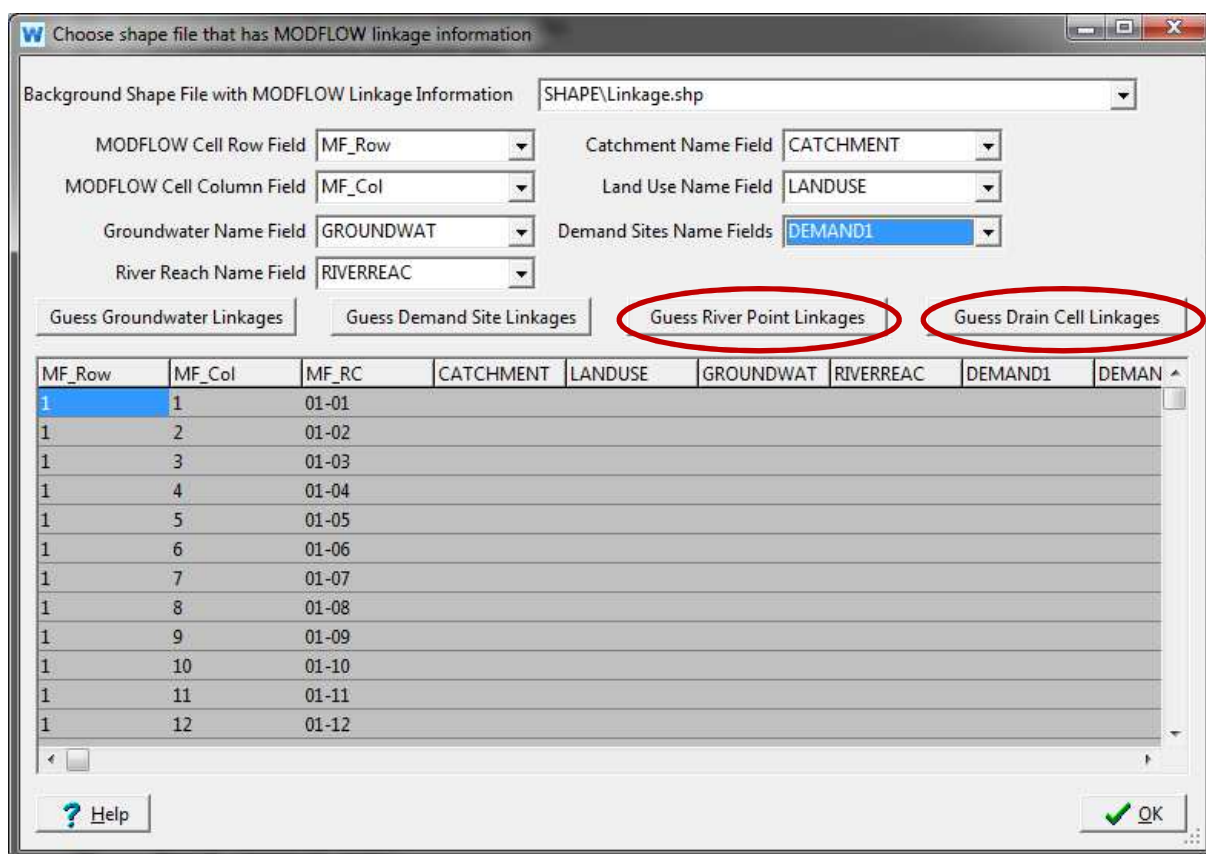


Save the Linkage File to disc by clicking on the *Write Linkage File* button



Method 2:

You can make WEAP “guess” the river reaches and drains in accordance to your digitizing rivers in the Schematic. In order to make this procedure work, it is necessary to **link WEAP and MODFLOW first**. Continue with the next chapter and once you are about to link with MODFLOW, click the *Guess River Point Linkages* and *Guess Drain Cell Linkages* – Buttons (Chapter 3.11).




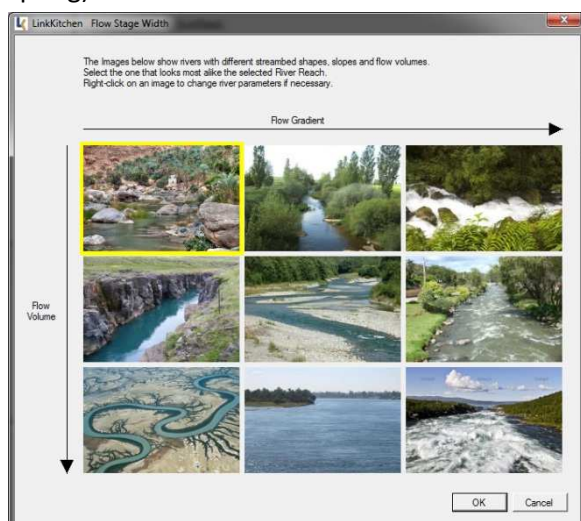
Note: it is good practice to save the linkage file frequently in order to not lose your edits. The file is overwritten every time you save it.

3.9 Set the FLOW-STAGE-WIDTH relationship

In order to allow WEAP to calculate river-related functions correctly, you need to assign a parameter called “Flow-Stage-Width relationship”. This parameter (or set of parameters) describes the physical properties of a river and its riverbed and is the basis for WEAP to calculate groundwater-river-interactions. If you set up a WEAP-model based on the information from a MODFLOW model, it is likely that the required information about rivers is missing.

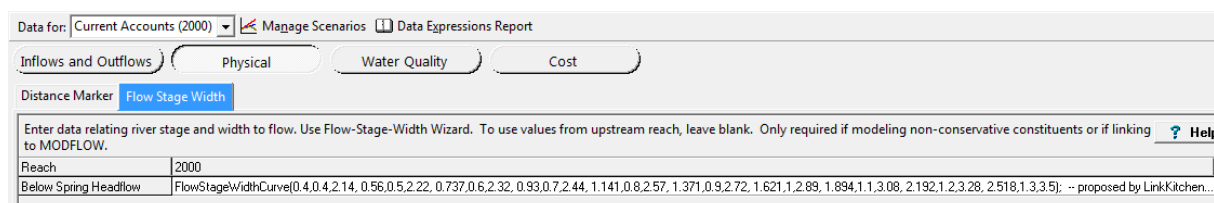
LinkKitchen provides a rather pragmatic method to assign the Flow-Stage-Width relationship with standardized parameters.

1. Switch to LinkKitchen and highlight the River Reach *Spring, Below Spring Headflow*.
2. Click the  - Command to open the Flow-Stage-Width-Dialog. The following Window shows nine images of rivers of various sizes. Left-click on the top left image (this one should come closest to a spring).



LinkKitchen will produce a Flow-Stage-Width-curve based on parameters stored with the image (see the LinkKitchen manual for further details).

3. Click the WEAP-button to send the curve to WEAP and check the result.
Supply and Resources → *River* → *Below Spring Headflow* → *Reaches* → *Physical* → *Flow Stage Width*



Note that the curve can be changed in WEAP using the Flow-Stage-Width-Wizard.

Repeat steps 1-3 for all other Rivers.

3.10 Send Linkage File Data to WEAP

In the currently used approach, you use the initial MODFLOW model inputs in WEAP rather than any of the WEAP built-in models for calculating groundwater recharge. The groundwater recharge retrieved from MODFLOW will be entered as input in WEAP instead.

Data View → Supply and Resources → Groundwater → Natural Recharge.

As a second obligatory parameter you need to enter catchment areas in WEAP

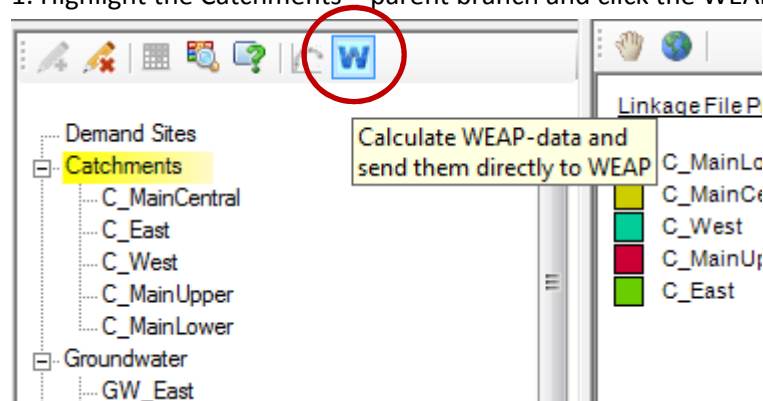
Data View → Demand Sites and Catchments → Landuse → Area

Both parameters are calculated by LinkKitchen and can be sent automatically to the correct input-position in WEAP.

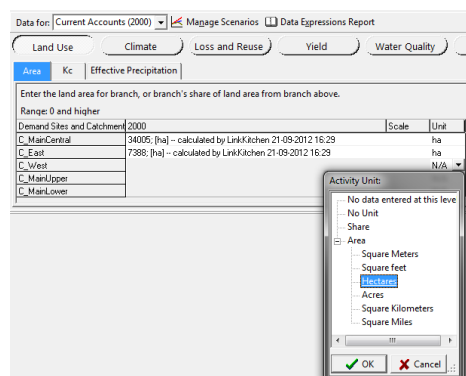
3.10.1 Send catchment areas to WEAP

Catchments' areas are calculated by LinkKitchen and can be sent to WEAP by a single mouse-click:

1. Highlight the Catchments – parent branch and click the WEAP-button on the top toolbar

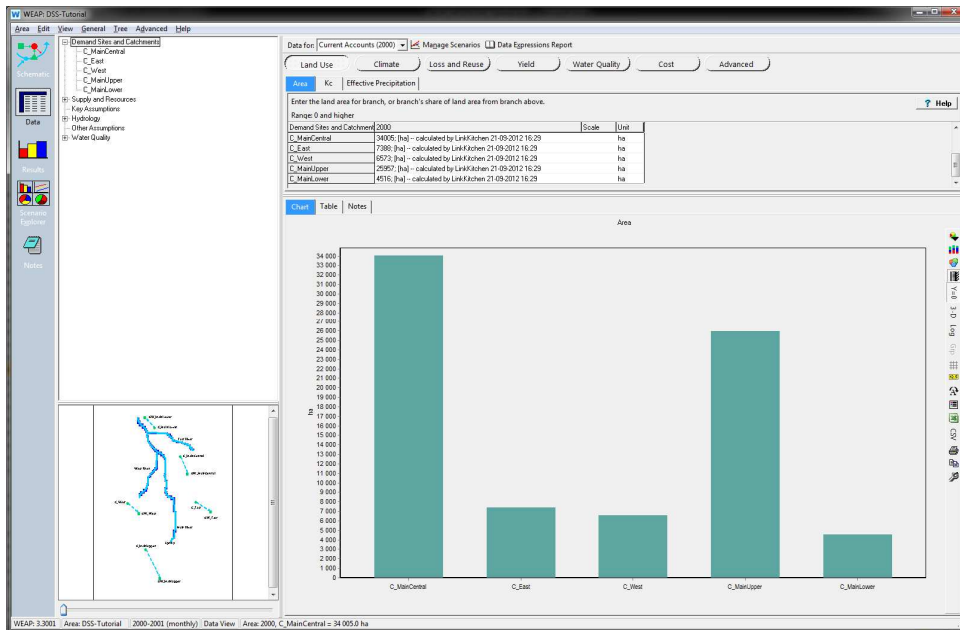


2. Switch to WEAP and browse to *Data View → Demand Sites and Catchments → Landuse → Area*



If the area's units are not yet defined, you need to select *hectares* as the area unit in order to make the entries visible.

The area distribution should look similar to the following:



3.10.2 Send groundwater recharge to WEAP

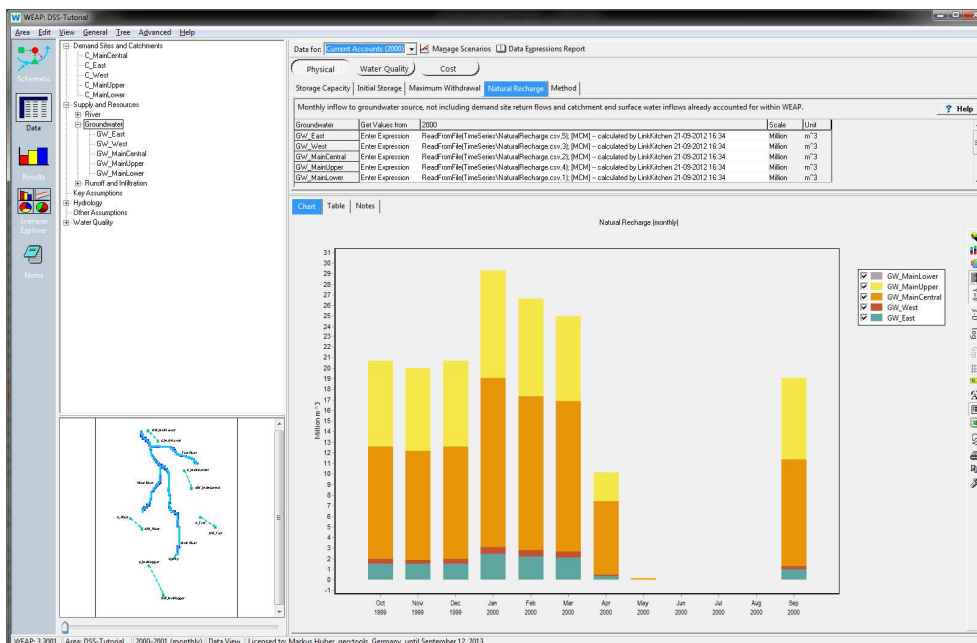
The procedure to send natural recharge to WEAP is similar to sending catchment areas.

1. Highlight the Groundwater – parent branch and click the WEAP-button on the top toolbar
2. Switch to WEAP and browse to *Data View* → *Supply and Resources* → *Groundwater* → *Natural Recharge*.

Note: LinkKitchen calculates all recharge-values as million m³ which is the default scale for natural recharge in WEAP. Check and change the scale if necessary!

General → *Units* → *Groundwater*: change the scale to Million m³.

The recharge values should look like:



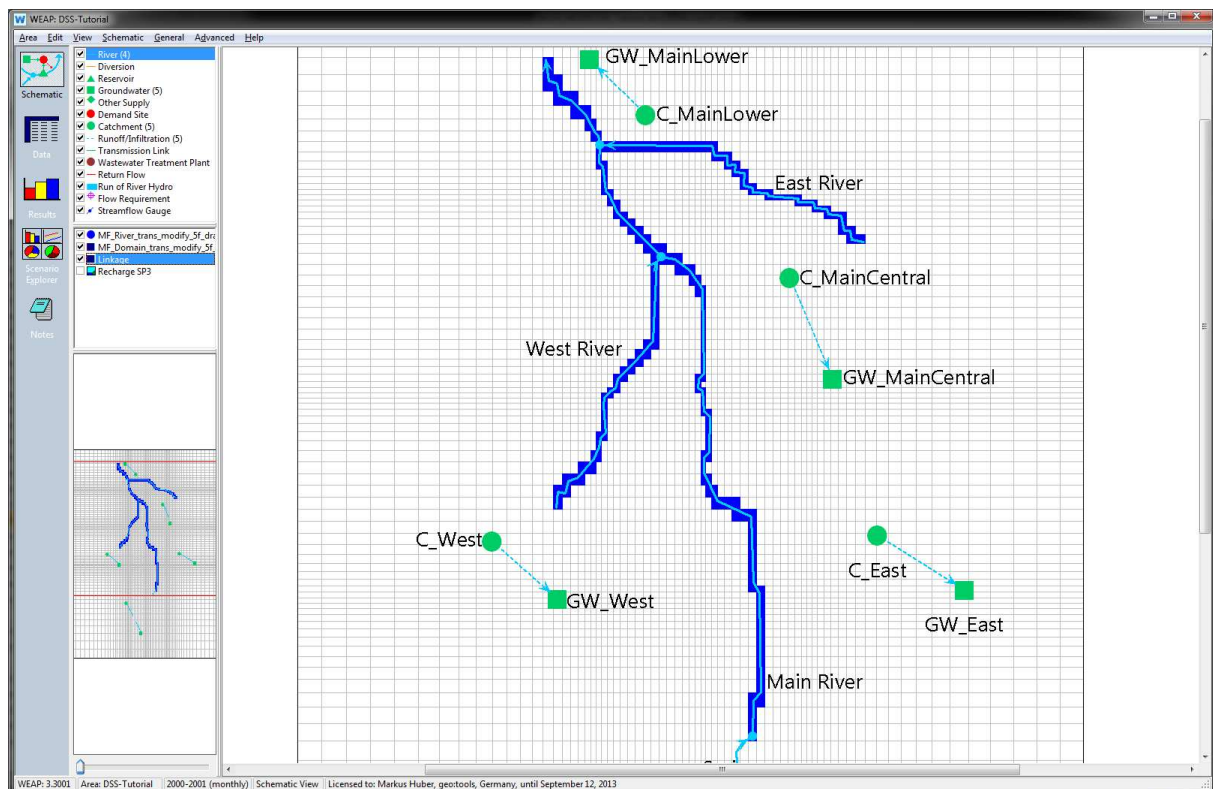
3.11 Link WEAP and MODFLOW

After having entered the required data in both the Linkage File and WEAP, you are now ready to link both models. This is done by:

- Loading the linkage shapefile to WEAP
- Set up the linkage in WEAP

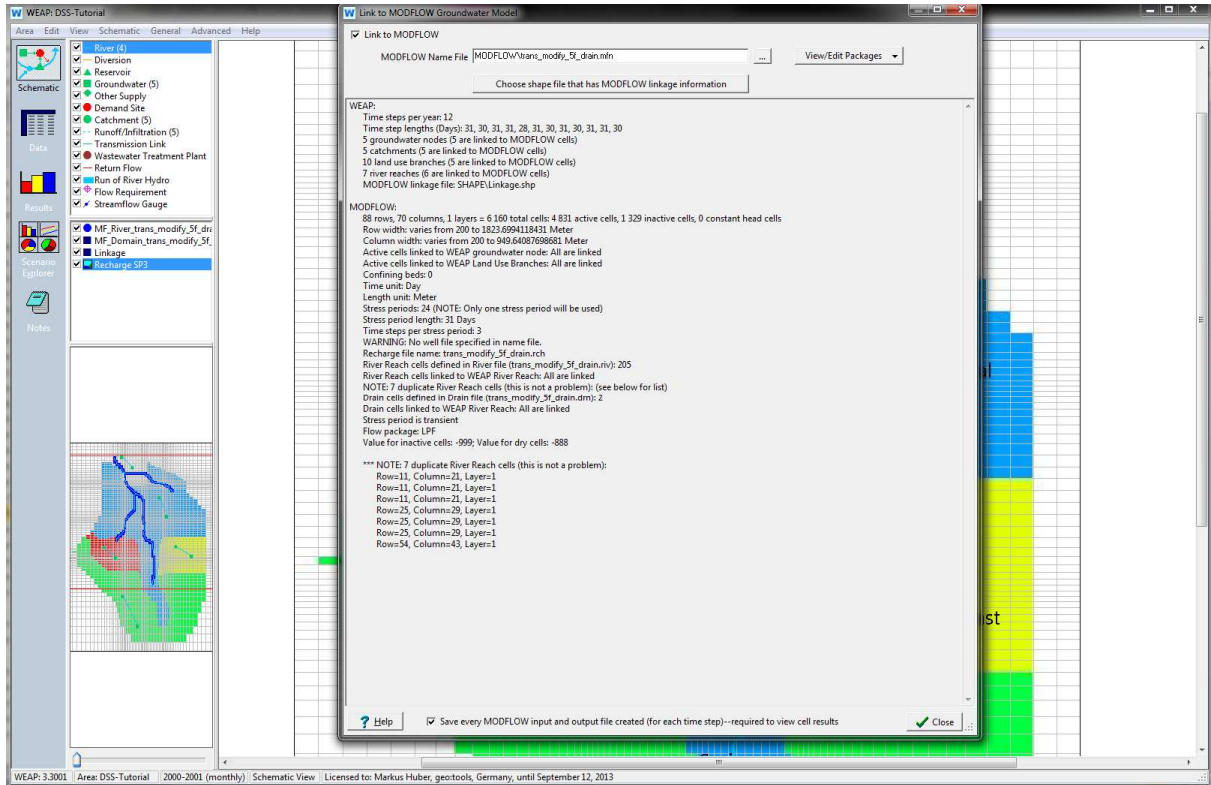
Load the linkage shapefile to the WEAP schematic:

Add Vector Layer → select the linkage file (linkage.shp)



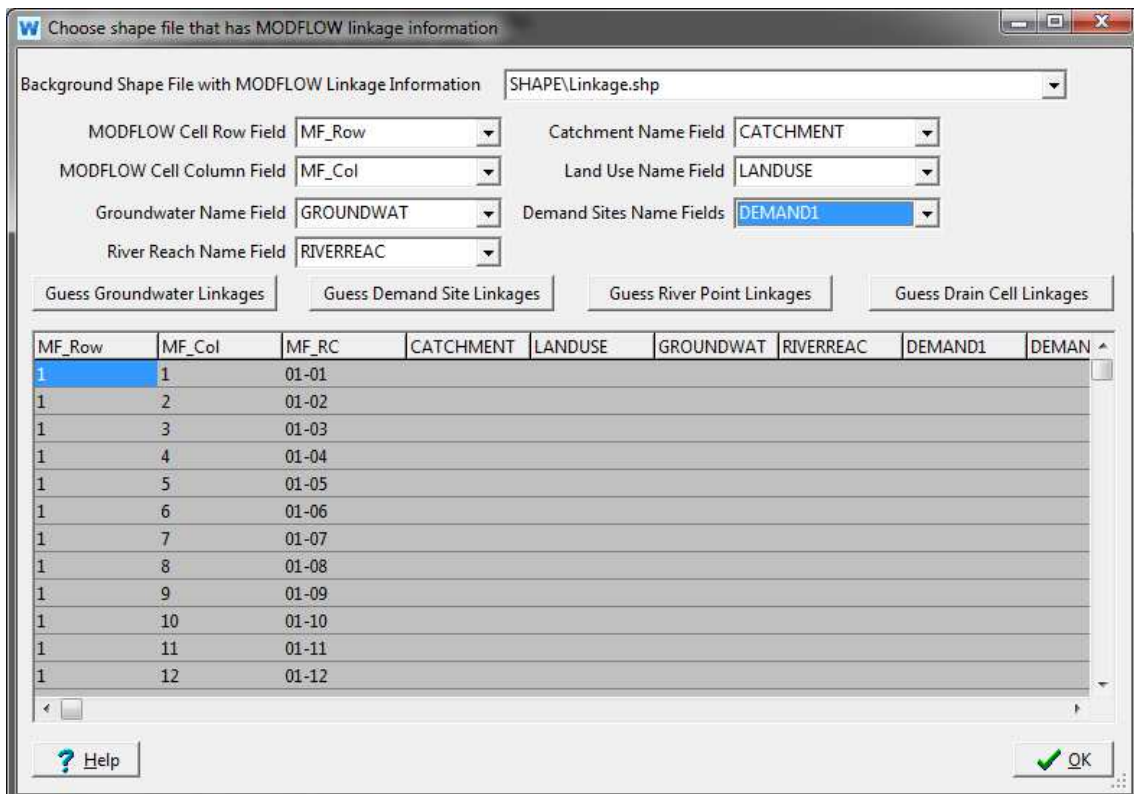
From the top menu, select:

Advanced → MODFLOW Link → MODFLOW Name File → MODFLOW/trans_modify_5f_drain.mfn

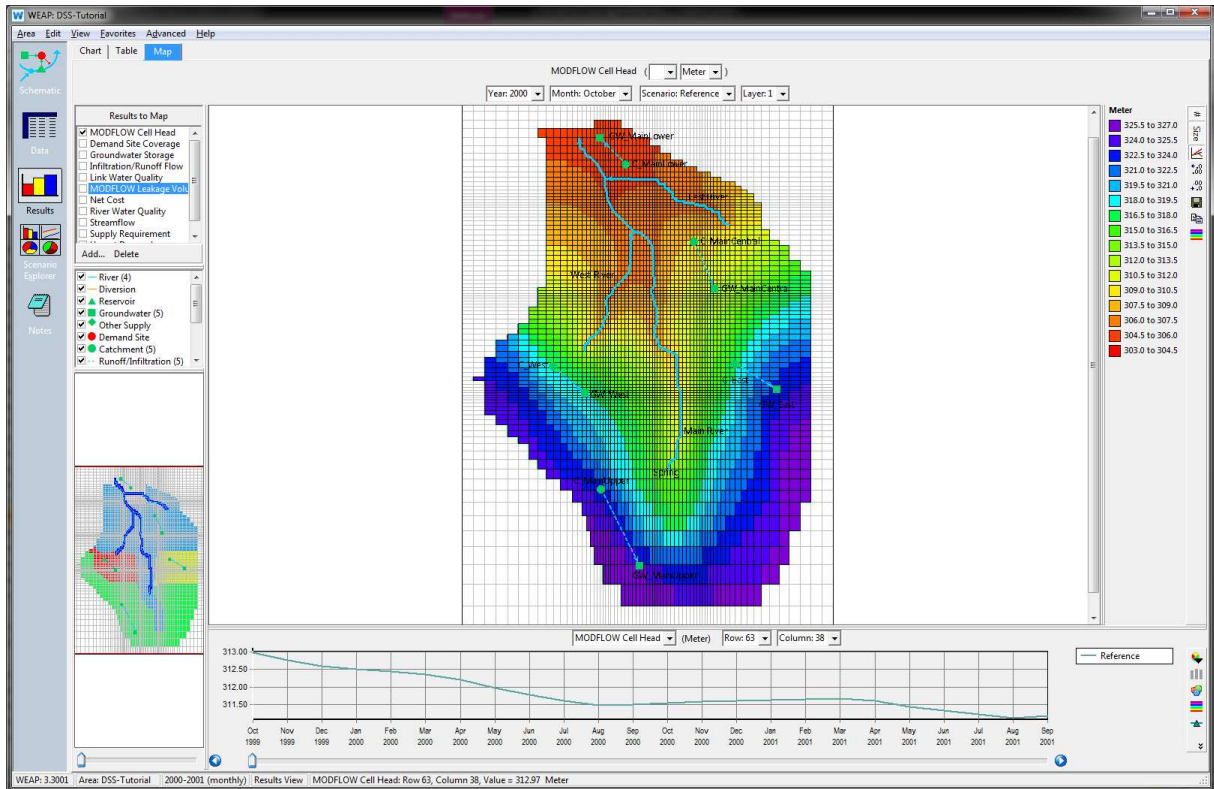


Choose your linkage shapefile and assign the respective attribute fields for Row and Column, Groundwater, River Reach and Catchment (this should be correct by default).

If you have not yet assigned river reaches (because you opted for Method 2 in chapter 3.8), you should now click on *Guess River Point Linkages* and *Guess Drain Cell Linkages*.



Click on the results-command and look at the result outputs like the groundwater levels (*Supply and Resources* → *Groundwater* → *MODFLOW* → *Cell Head*) etc.



4 WEAP-hydrology in linked models – Rainfall-Runoff

In the previous exercise, you entered groundwater recharge directly into WEAP as “Natural Recharge” and delimited the catchments according to recharge zones in MODFLOW.

In the following exercises, the catchment names remain the same, but they correlate to different spatial regions (surface water catchments). The Catchments are furthermore subdivided into Landuse classes in order to reflect various water needs.

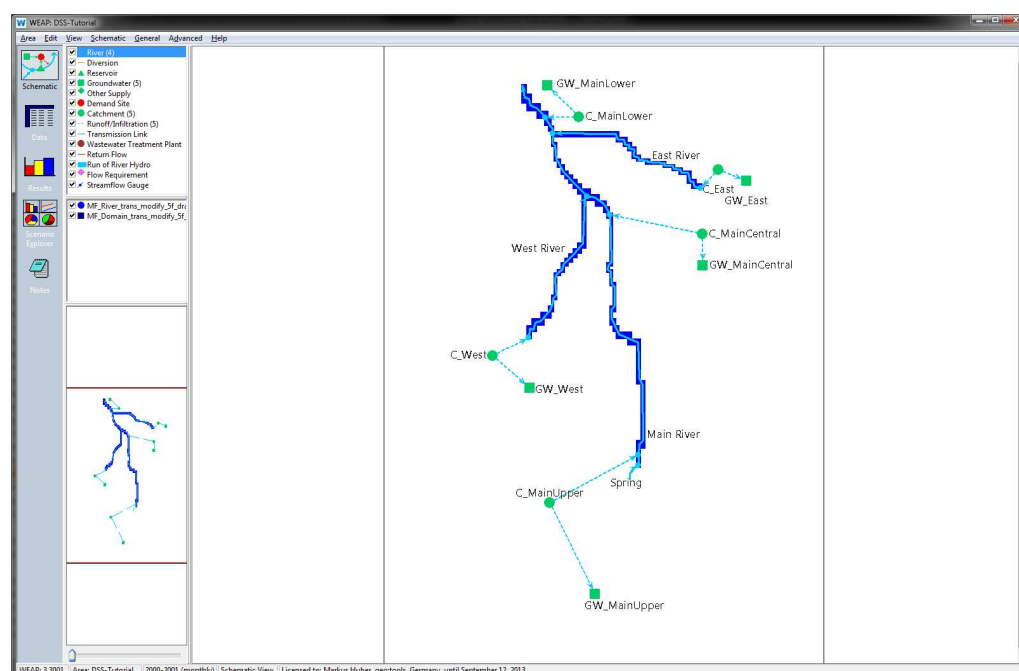
In addition, surface-runoff links are assigned to the catchment nodes (from the catchment to the river).

In this chapter, WEAP will calculate the groundwater recharge based on its internal *Rainfall Runoff (simplified coefficient method)* model.

4.1 Add Runoff links to the Schematic

In order to let WEAP calculate surface runoff, you need to add runoff-links from catchments to rivers in the WEAP Schematic. Drag and drop a runoff-link from each Catchment Node to its corresponding River.

Catchment	Runoff link to	Headflow yes/no
C_MainUpper	Main River	No
C_West	West River	Yes
C_East	East River	Yes
C_Central	Main River	No
C_Main Lower	Main River	No



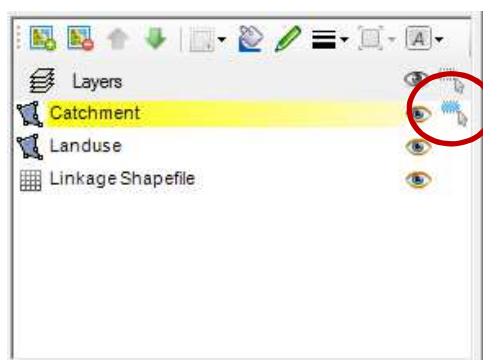
4.2 Assign catchments and Landuse Classes to the Linkage File.

1. Add Sub-branches to each of the Catchments.

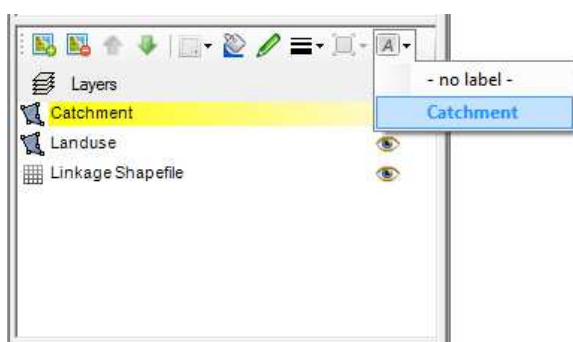
In the Data-View: right-click on the *Catchment* → *Add* → *type the name of the sub branch as specified in the table below:*

Catchment	Landuse class
C_East	unirrigated
C_East	urban
C_MainCentral	unirrigated
C_MainLower	unirrigated
C_MainLower	urban
C_MainUpper	forest
C_MainUpper	irrigated
C_MainUpper	pasture
C_MainUpper	shrub
C_West	forest
C_West	pasture
C_West	unirrigated


2. Switch to LinkKitchen and load the two files *Catchment.shp* and *Landuse.shp* as Overlays.

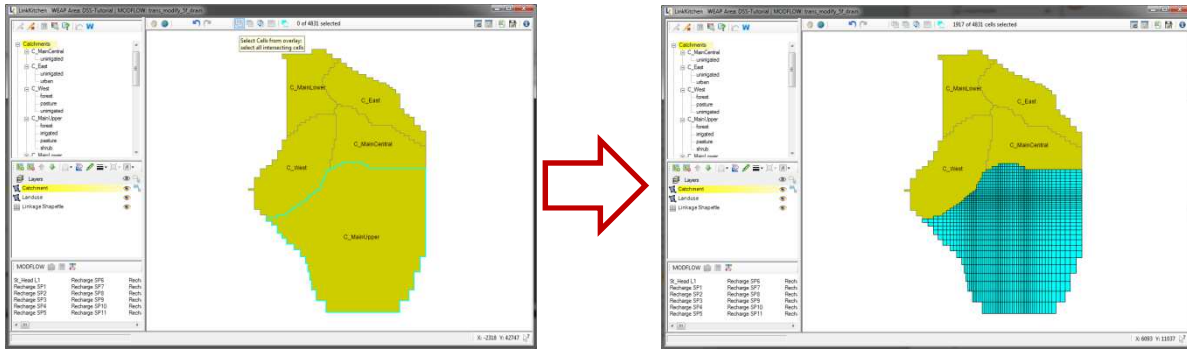


3. Set Layer *Catchment* to be *selectable*



4. Set Layer *Catchment*'s *Label* to "*Catchment*"

5. Right click into *C_MainUpper* and click on *Select Cells from Overlay* .



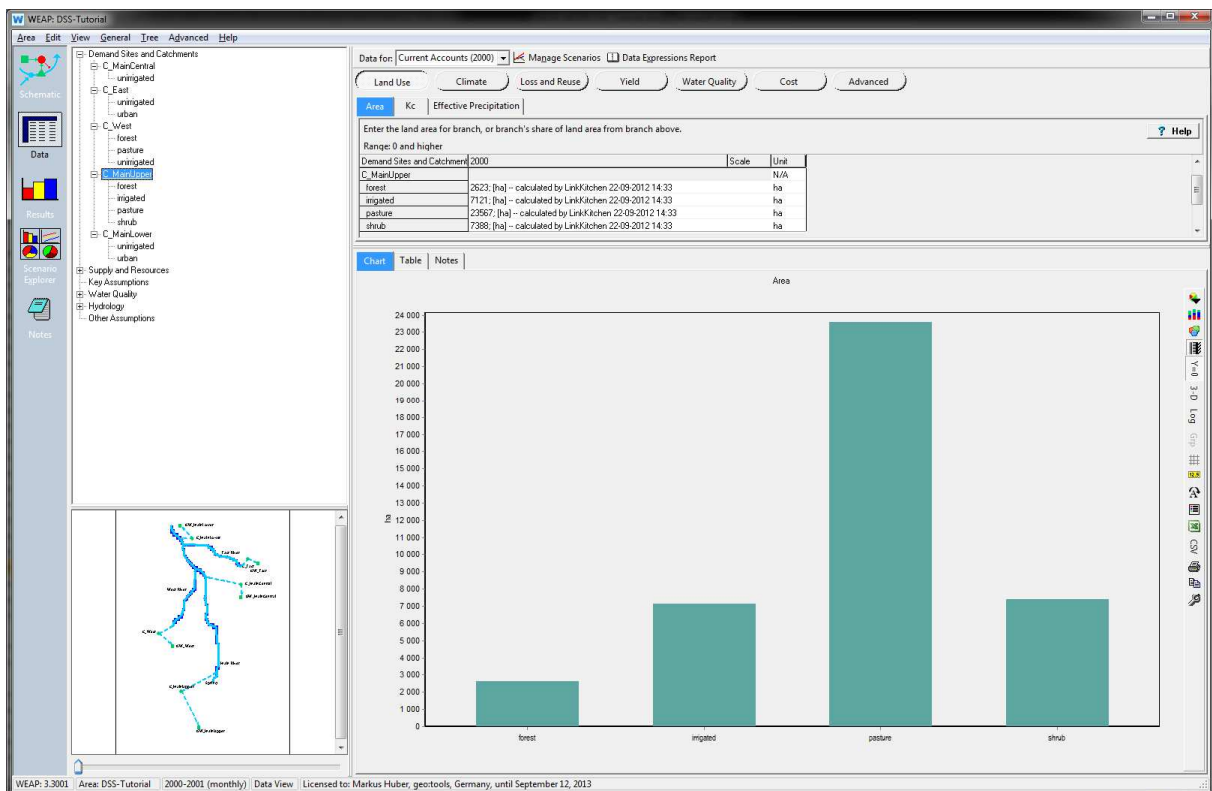
6. Highlight *C_MainUpper* in the Branch Viewer and click *Add Attribute to selected Cells*.

7. Highlight *GW_MainUpper* in the Branch Viewer and click *Add Attribute to selected Cells*.

Repeat steps 5-7 for the other Catchments and Groundwater nodes.

8. Set Layer *Landuse* selectable and assign *Landuse-Classes* to the Linkage File. The procedure is similar to steps 5-7.

9. Send the Area data to WEAP

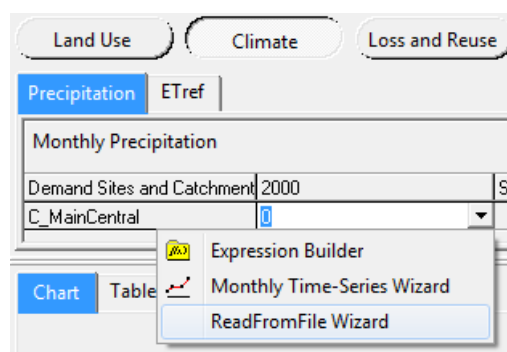


4.3 Data input in WEAP

Additional inputs at catchment level are precipitation and reference evapotranspiration (ETref). Crop coefficients (Kc) are entered at Landuse class level. These inputs are read into WEAP using the ReadFromFile-function. The file from which to read data is named *INPUT_DATA.csv*. Copy the file into the TimeSeries-Folder in the WEAP area-directory.

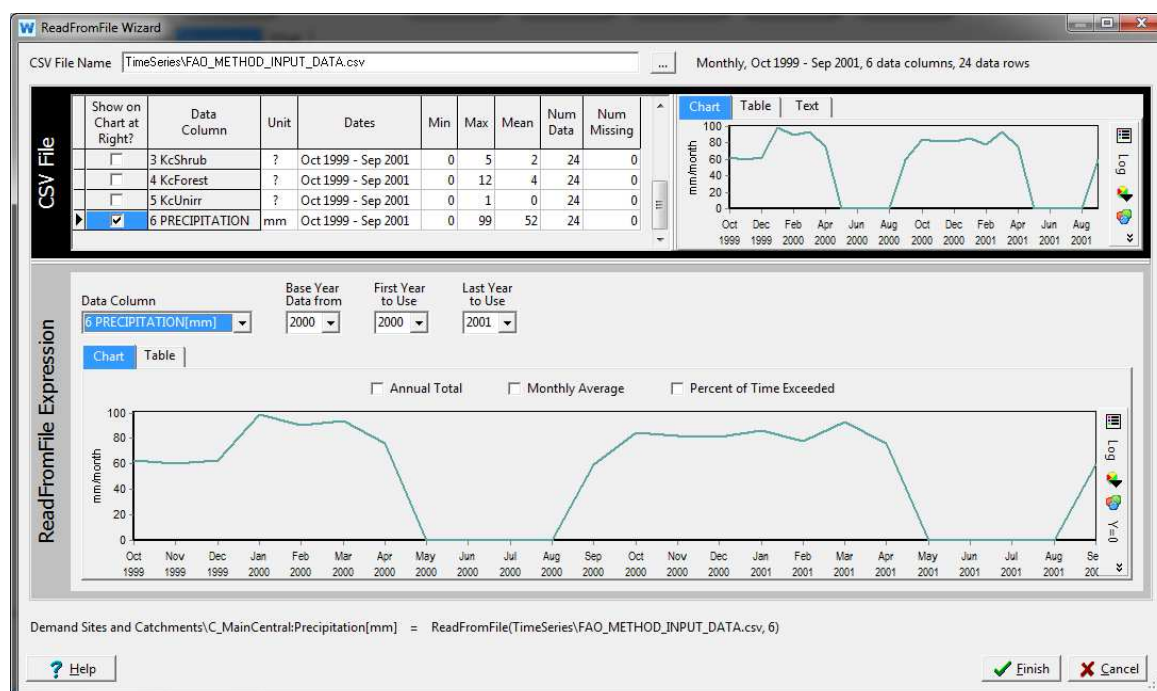
4.3.1 Enter precipitation

1. In the Data View, select *C_MainCentral* and activate *Climate* → *Precipitation*.
2. Click on the arrow besides the data-entry box and select the *ReadFromFile Wizard*.



3. Open the file *\TimeSeries\INPUT_DATA.csv*

4. In the lower pane, select the data column *Precipitation* and click *Finish*.



5. Repeat steps 2-4 for the other Catchments

4.3.2 Enter ETRef

ET_{Ref} is entered the same way as precipitation but with the data column [ET].

4.3.3 Enter Kc

Go to *Landuse – Kc* and enter Kc values for each Landuse Class the same way as precipitation and ET_{Ref}.

Landuse Classes *Irrigated* and *unirrigated* retrieve values from the same data column (unirrigated).

(For details on the Rainfall Runoff (simplified coefficient method)-model, see WEAP-help and FAO Irrigation and Drainage Paper No. 56 “Crop Evapotranspiration”).

4.3.4 Enter Runoff- and Infiltration fractions

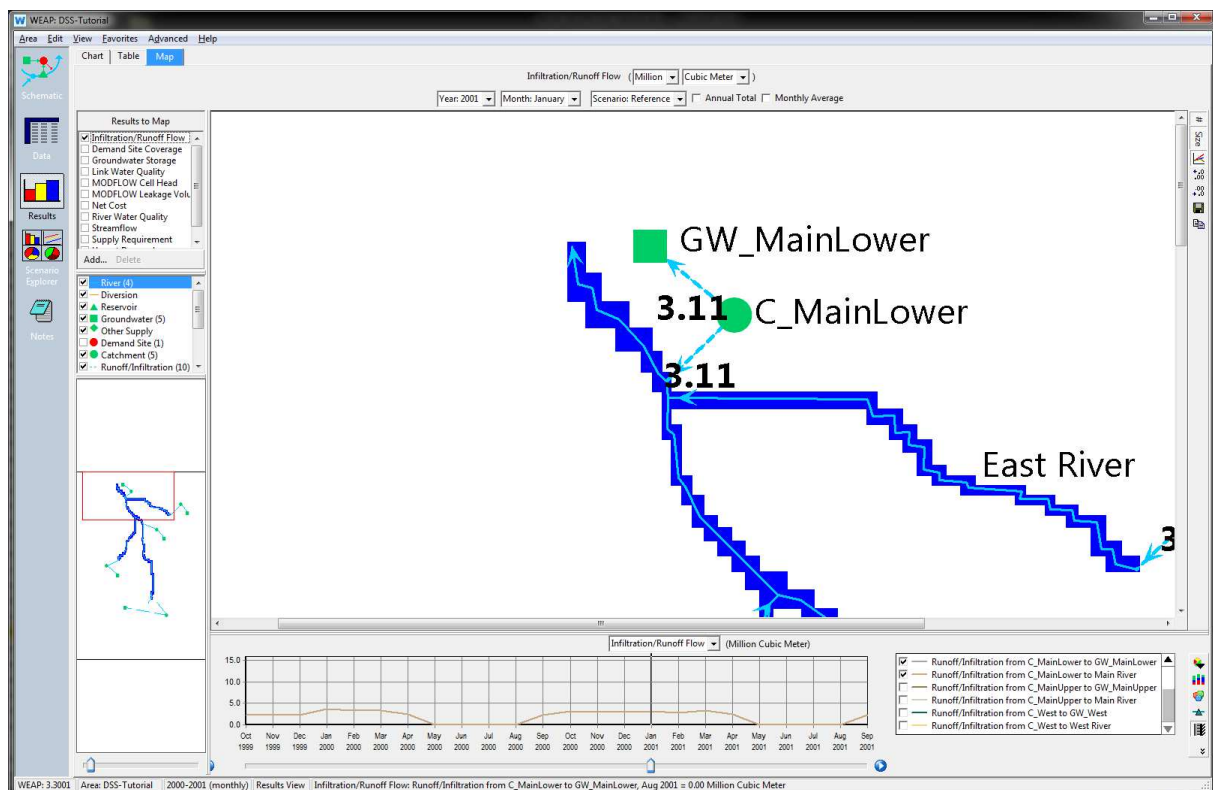
The total runoff volume can be fractioned to surface runoff and groundwater recharge:

Supply and Resources → *Runoff and Infiltration* → *from catchment (C_...)* → *to ...* → *Runoff Fraction*

Enter a value of 50% for each link.

4.3.5 Run the model and browse the results

The result below shows the calculated recharge- and runoff-flows from C_MainLower.



5 Common tasks

The following part of this tutorial will give you some workarounds for dealing with common modeling challenges. It does not make any claim to be complete nor does it pretend to show the one-and-only solution for any of the problems presented. But you might use some of the shown approaches as the starting point for your own modeling work.

The descriptions hereafter are reduced to the basic implementations and parameter setting. If you want to visualize the impacts of each task on the system, you should apply the changes on scenarios and compare the results with the reference.

5.1 Abstraction for irrigation

There are multiple ways to introduce irrigation abstraction. The two most commonly applied ways are:

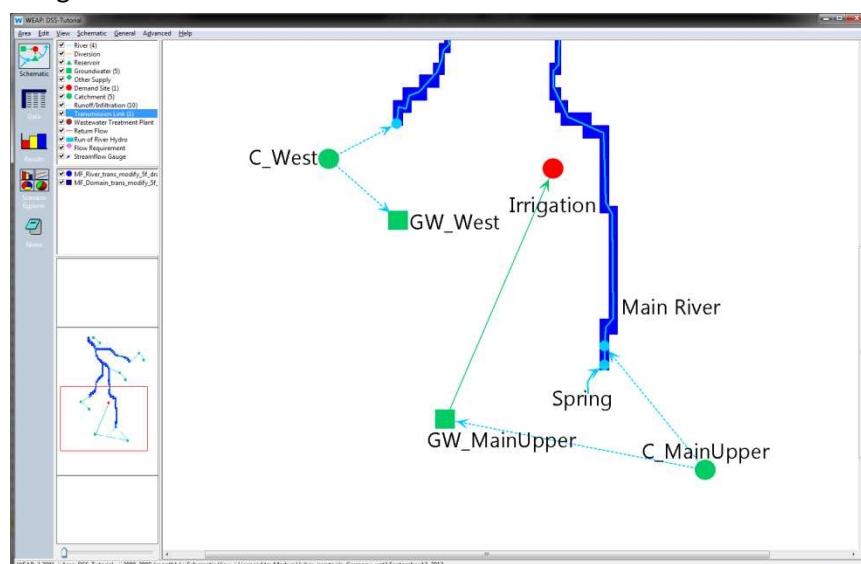
1. Define a Demand Site and enter the abstracted water directly
2. Let WEAP calculate irrigation demand based on climate and crop parameters

For the former, there is no need to care about the climate or what types of crop are grown. This method is easier to implement but very inflexible when it comes to build scenarios. The latter requires more data to enter but gives better performance for future planning.

The following chapters will show both approaches.

5.1.1 Add irrigation abstraction by demand site

1. Drag and drop a new demand site onto the Schematic View and name it "Irrigation".
2. Drag and drop a transmission link from groundwater *GW_MainUpper* to the new demand site "Irrigation".



3. Enter the water abstraction for irrigation under:

Data → *Demand sites and catchments* → *irrigation* → *water use* → *Annual water use*

The irrigation demand is 30 million m³ per year. As water is needed only during the months of May and June, the annual irrigation is fractioned with the percentage (40%) in May and (60%) in June. This is entered at

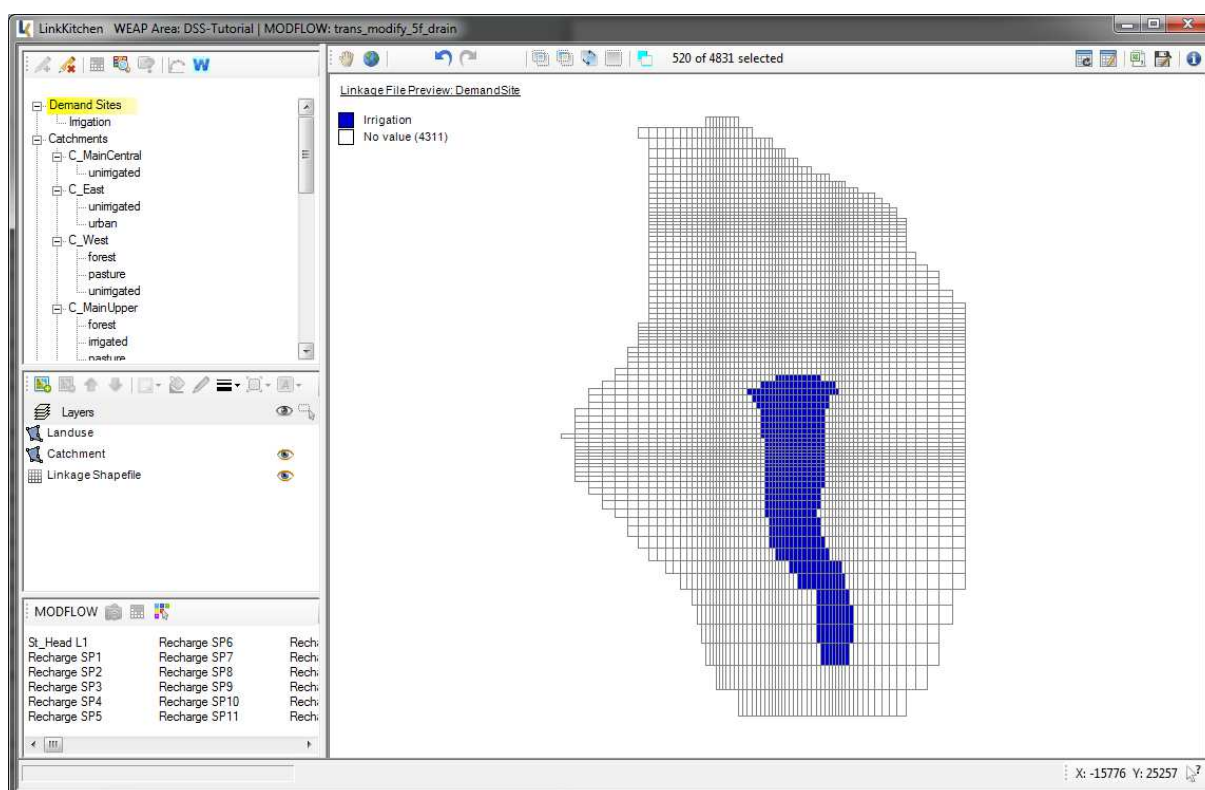
Data → Demand sites and catchments → irrigation → water use → Monthly Variation
Using the *Monthly Time Series Wizard*.

4. As WEAP needs to know from which cells to abstract water from, you need to update the Linkage File with that information. It is assumed, that water is abstracted from wells located all over the irrigated area.

Switch to LinkKitchen and highlight the Landuse Class *C_MainUpper/Irrigated* in the Branch Viewer.

5. Click the *Select Attributed Cells*-Button.

6. Highlight Demand Site *Irrigation* and click *Add Attribute to Linkage File*. Now, every cell located within the Landuse Class “Irrigated” supplies Demand Site *Irrigation*.



7. Save the Linkage File to disc and go back to WEAP.

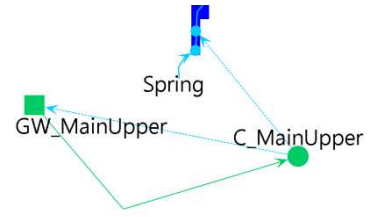
8. Re-load the Linkage File if necessary and run WEAP. Browse the results

5.1.2 Add irrigation abstraction to a Landuse Class

Modelling irrigation demand by a WEAP-internal model requires a connection from groundwater to the catchment. Further specifications, like from which cells to withdraw water and on which cells to apply water, are defined in the Linkage File.

The water demand is controlled by the crop parameter K_c and by the climate parameters precipitation and ET. WEAP will calculate water demand, if the plant evapotranspiration is higher than precipitation.

1. Drag and drop a transmission link from *GW_MainUpper* to *C_MainUpper*



2. Set the demand priority to 1

3. Switch the *irrigated* Landuse Class to *irrigated*:

Demand Sites and Catchments → *C_MainUpper* → *Irrigation* → *Irrigated* = 1

Data for: **Current Accounts (2000)** Manage Scenario

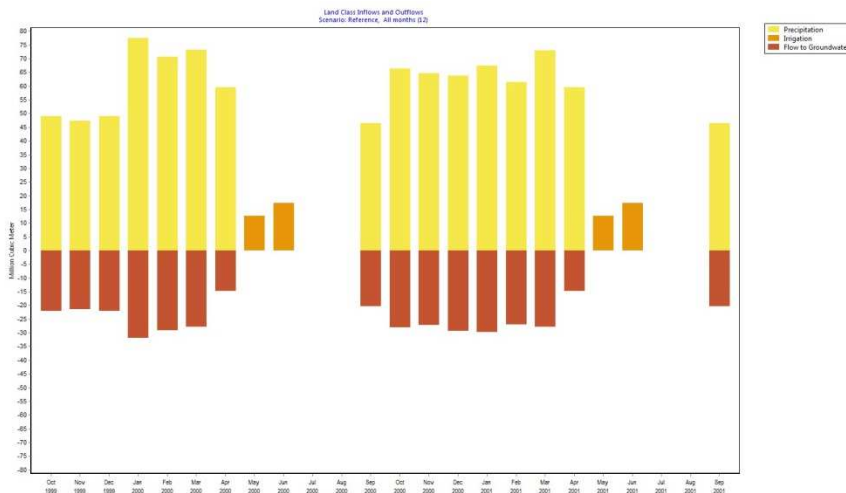
Land Use | Climate | Irrigation

Irrigated | Irrigation Fraction | Pump Layer

Enter 1 if area is irrigated; 0 otherwise. This value must be between 0 and 1.
Range: 0 to 1

C_MainUpper	Irrigated
forest	0
irrigated	1
pasture	0
shrub	0

4. Run the model and evaluate the results in the results view.



E.g. Land class inflows and outflows:

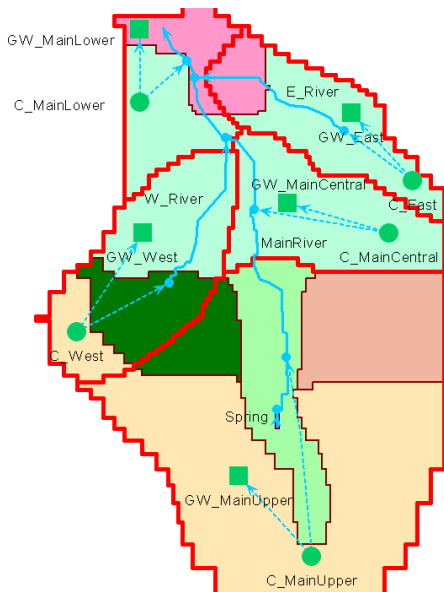
You can see irrigation taking place during the months May and June when ET is high and precipitation is low. Although precipitation remains low during July and August, there is no need to irrigate as the crops are already harvested.

5.2 Changes in Land Use

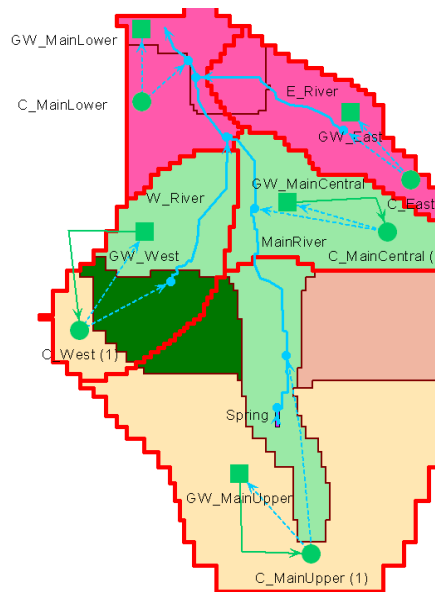
The purpose of this exercise is to investigate the impact of changes in land use on the groundwater recharge. In order to emphasize the changes, the total runtime of the model is extruded to 10 years.

General → *Years and time steps* → *last year of scenarios* = 2009

Land use 2000



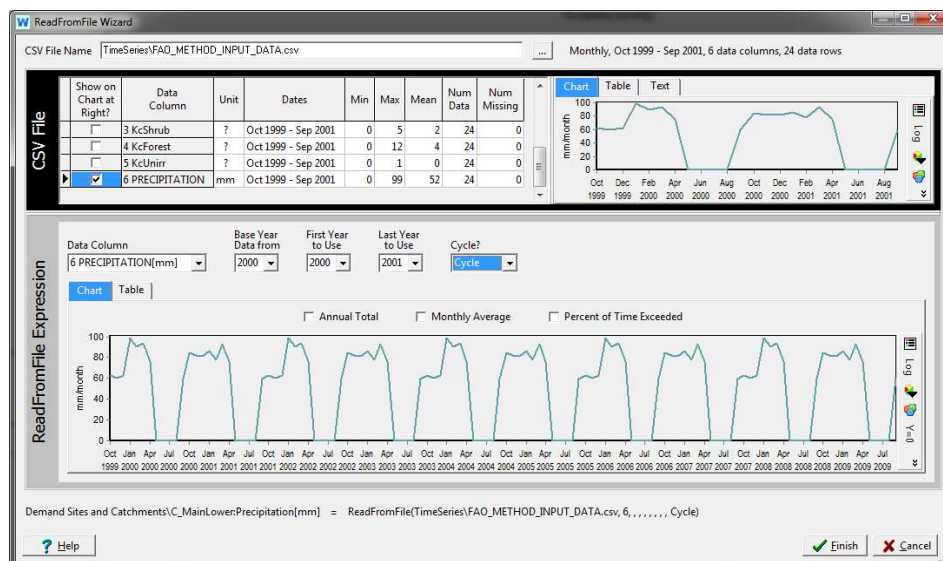
Land use 2010



5.2.1 Urbanization

Storyline: Urban areas grow towards extending over the entire catchment areas of *C_East* and *C_MainLower* until 2010. Infiltration vanishes and the entire precipitation runs off the rivers.

1. Let WEAP repeat time-dependant data each year (precipitation, ET, Kc):



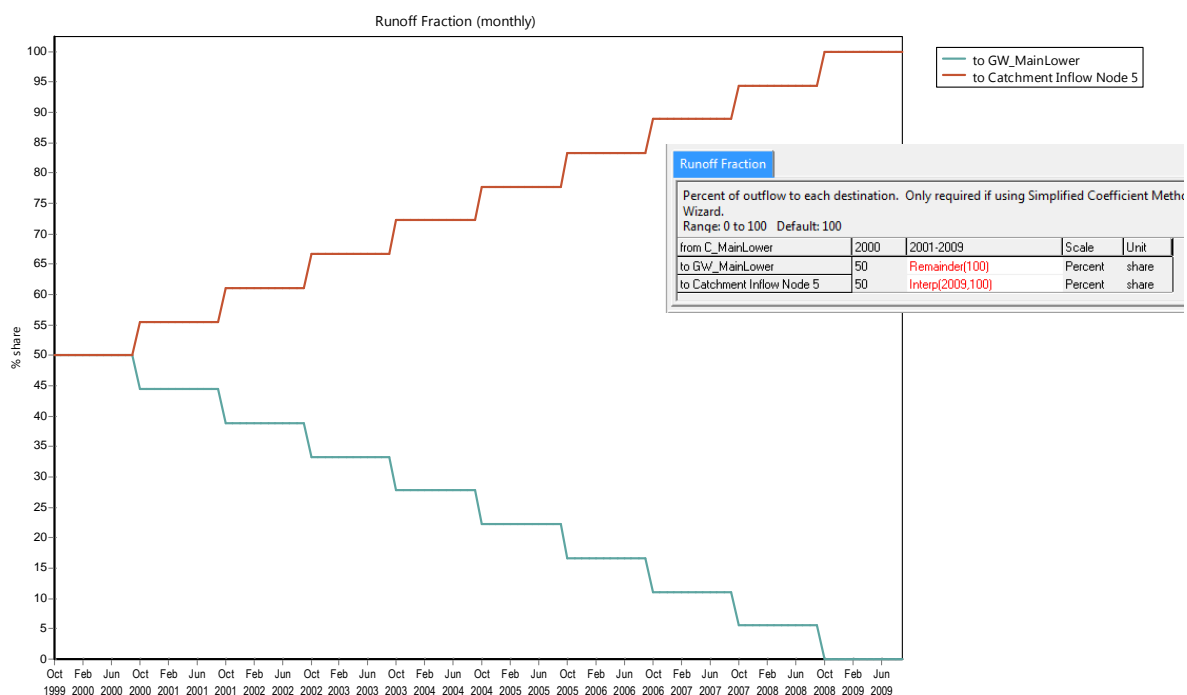
Chose "cycle"-option

2. Increase the surface runoff fraction from 50% in the year 2000 to 100% in 2009 and reduce the fraction for groundwater recharge accordingly:

Supply and Resources → *Runoff and Infiltration* → *from C_MainLower* → *Runoff Fraction*

Supply and Resources → *Runoff and Infiltration* → *from C_East* → *Runoff Fraction*

To interpolate the yearly fractions use the functions *Interp(2009, 100)* and *Remainder(100)*.



5.2.2 Irrigation growth

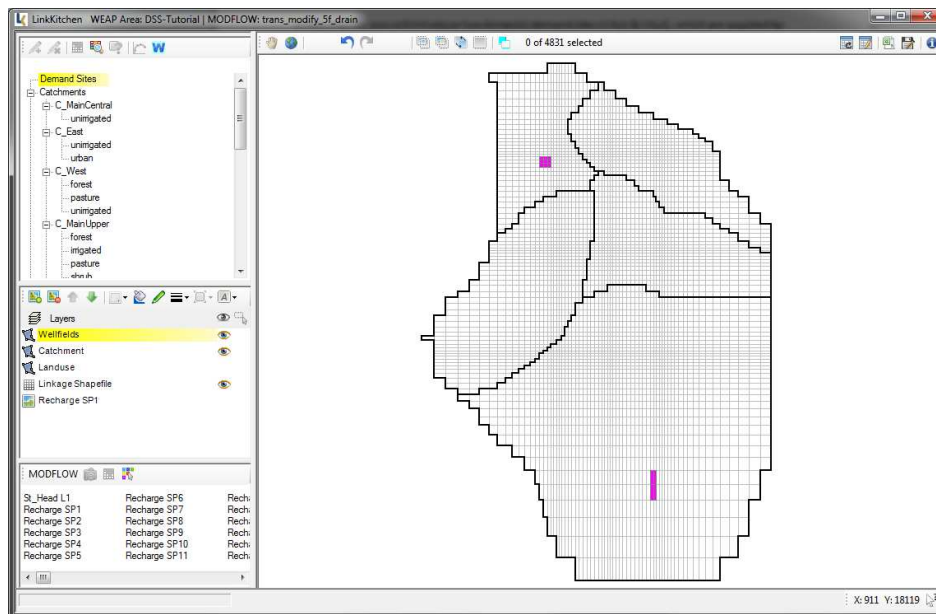
Land use class *unirrigated* is changed to be irrigated from the year 2001 onward.

1. Add transmission links from the groundwater to the catchment for the catchments *C_MainUpper*, *C_MainCentral* and *C_West*.
2. Within these catchments, set the land use classes *unirrigated* and *irrigated* to be irrigated (1)
3. Define an *irrigation fraction of 75%* (= overirrigation)
4. Run the model and browse the results

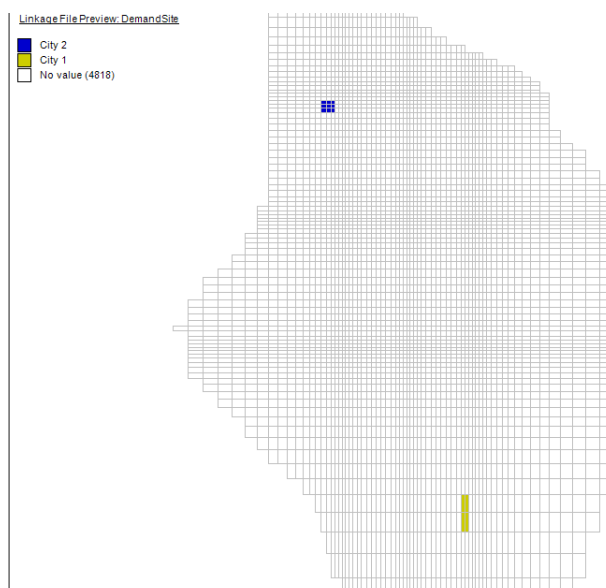
5.3 Domestic water supply from well fields

In this chapter, you will introduce two domestic demand sites (City1 & City2), which are supplied by local well fields. You need to make entries in both WEAP and the Linkage File for this to work.

1. Drag and drop two Demand Sites (*City 1* and *City 2*) onto the Schematic.
2. Add a Transmission link from *GW_MainUpper* to *City 1* and another transmission link from *GW_MainLower* to *City 2*.
3. Set the Annual Water Use Rate for both Cities to 20 Million m³.
4. Set the Consumption to 100%: *Demand Sites and Catchments* → *Water Use* → *Consumption*
5. Switch to LinkKitchen and load the overlay-layer *Wellfields.shp* which indicates the location of the two wellfields.



6. Select all cells of the top wellfields first and assign *City 2* to the selected cells. Repeat the step with the second wellfield. The preview should look like:

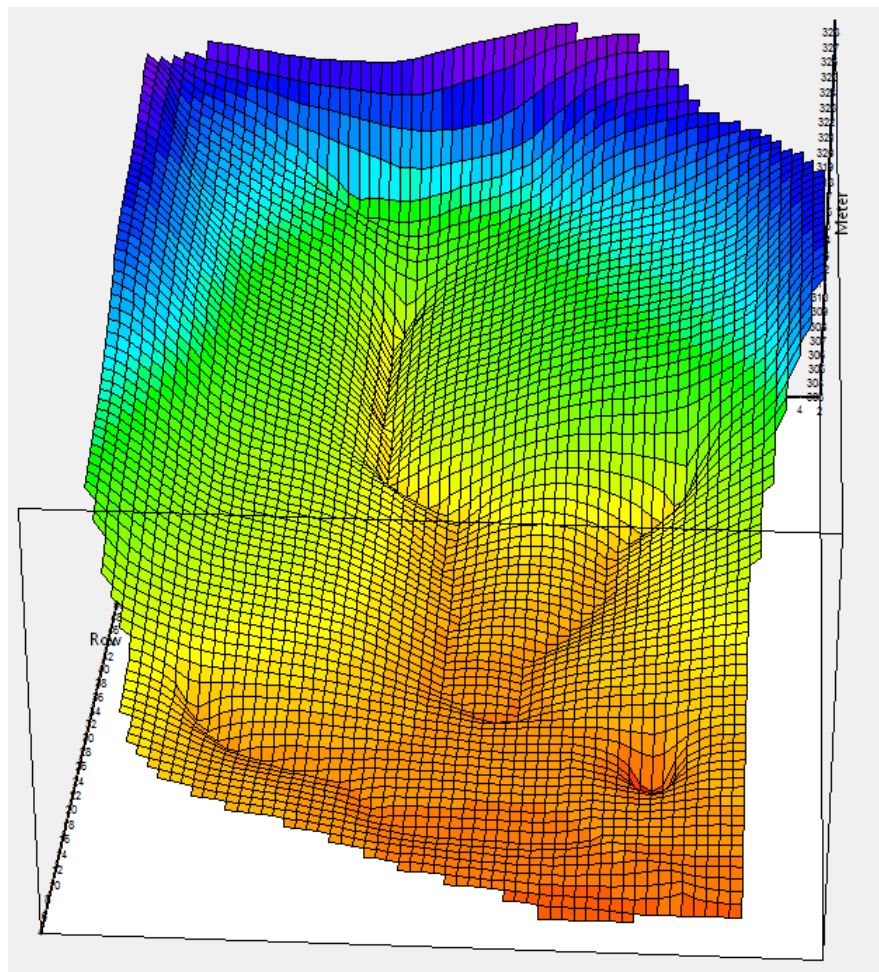
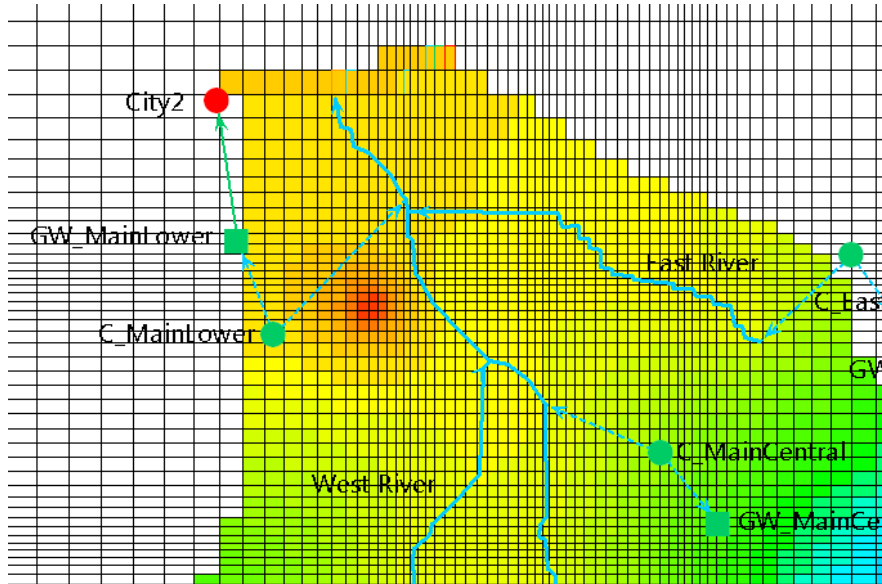


7. Save the Linkage File and reload it

into WEAP if necessary.

8. Run WEAP and browse for Cell-Head-results (Map-View)

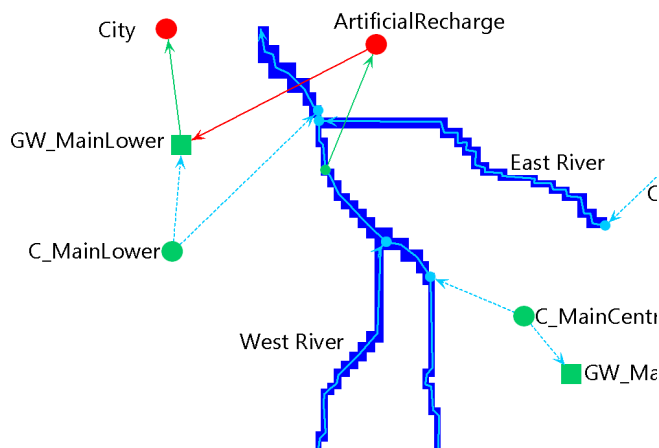
The result shows a significant cone of depression around the cells you defined as Demand Site “City2”.



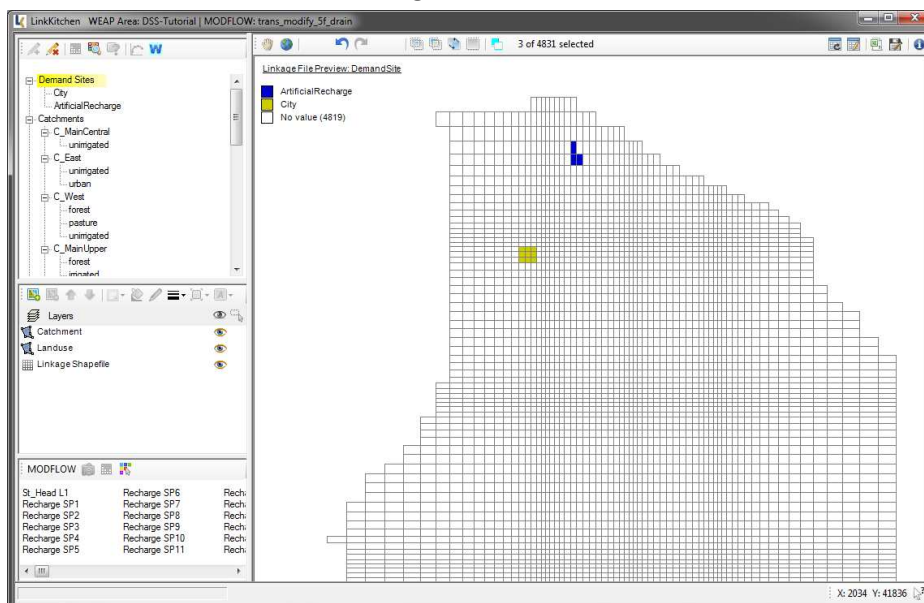
5.4 Artificial groundwater recharge

Modelling artificial recharge (e.g. injection wells) is similar to modelling abstraction. The only difference is that water is not consumed by the demand site but returned to a groundwater node. The location of the injection is defined by the demand-attribute in the Linkage File.

1. Add a Demand Site “Artificial Recharge” to the Schematic and set *Annual Water Use Rate* to 20 Million m³; set *Consumption* to 0%
2. Add a Transmission link from Main River to the new Demand Site and a Return Flow Link from the Demand Site to groundwater *GW_MainLower*

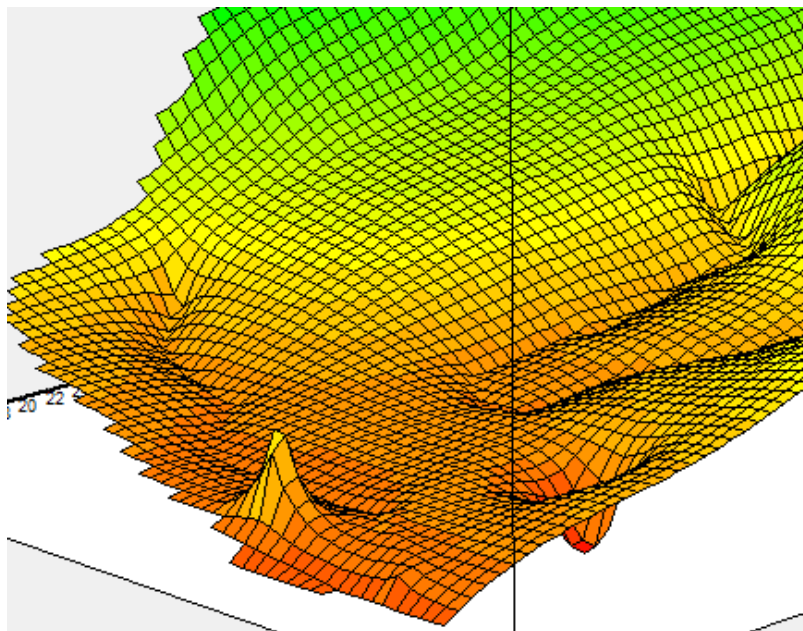
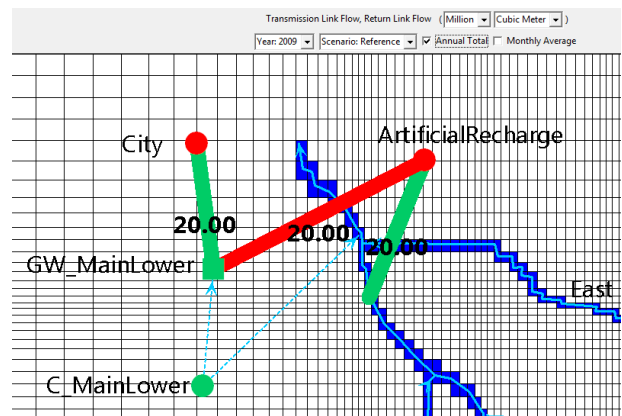
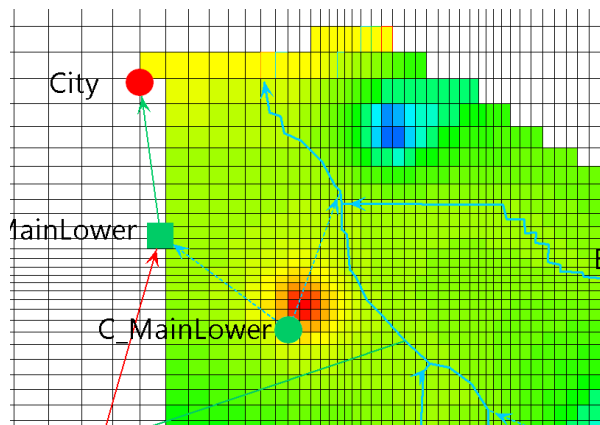


3. Switch to LinkKitchen and link some cells to Demand Site *ArtificialRecharge*. The preview should look similar to the image below:



4. Save the Linkage File and go back to WEAP
5. Browse to the Cell-Head-results

Injecting water has a similar effect on the groundwater table as withdrawal but in the opposite direction. The effects of withdrawal and artificial recharge are visualized in the Map Window and as 3D-chart (s. images below left and bottom). Image below right shows the annual flows as calculated by WEAP.



5.5 Climate Change

The possible impacts of climate change on surface runoff, groundwater levels and spring flow are (at a simplistic glance on that complex subject) driven by changes in the parameters precipitation and evaporation.

In order to visualize the impacts of climate change, create a new scenario "Climate Change" and change the following parameters for every single catchment:

- $ET_{Ref} \rightarrow Growth(3\%)$
- Precipitation $\rightarrow Growth(-3\%)$

Run WEAP and browse to the result for *groundwater storage*.

The comparison of the two scenarios *climate change* and *reference* shows the effect of climate change on groundwater storage over time

