Department of
Civil & Environmental
ENGINEERING

SWAT-MODFLOW Tutorial

Documentation for preparing model simulations

February, 2017

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Overview of Tutorial

This tutorial provides the basic procedure of linking a SWAT model and a MODFLOW model to provide a coupled surface-subsurface hydrologic model. The theory and procedures of coupling the two models is discussed, followed by a step-by-step process of the linking procedure within the context of an example watershed. Necessary files for linking the two models and running the coupled model accompany this document. These files include ArcGIS shapefiles and rasters, SWAT model input files, and MODFLOW input files. This documentation can assist with creating a coupled SWAT-MODFLOW model for a given watershed.

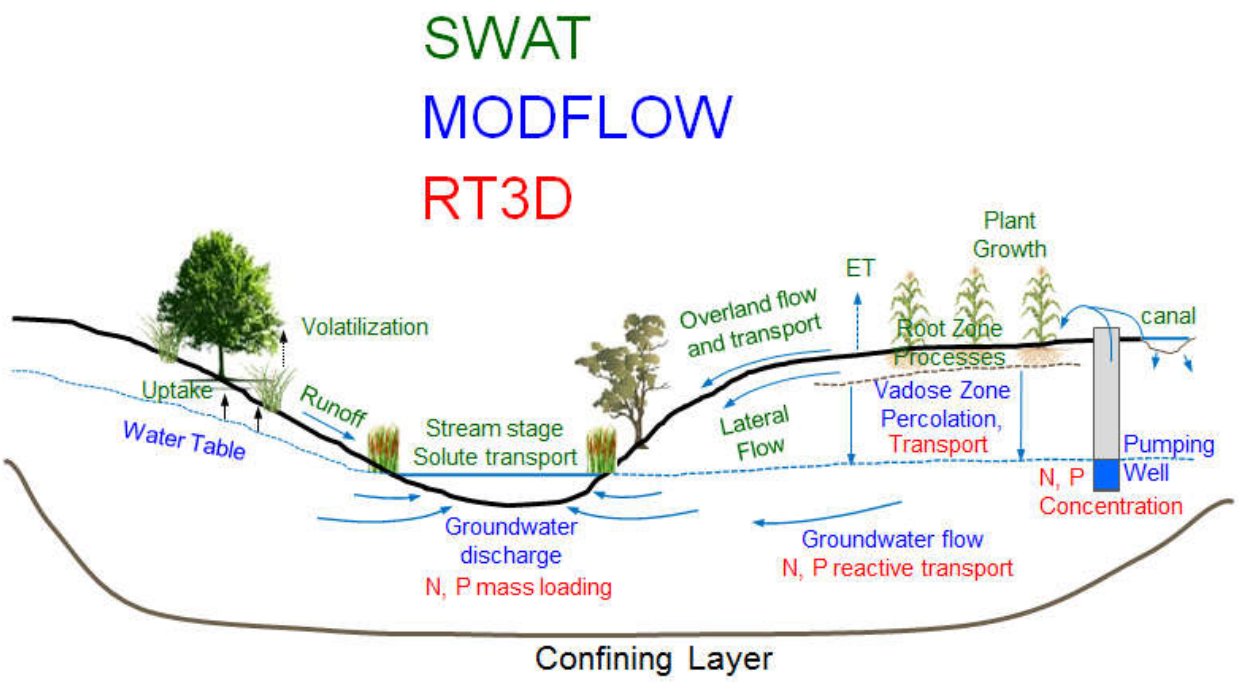
This documentation assumes that SWAT and MODFLOW models have already been constructed for the study area.

Tutorial Contents

1. OVERVIEW OF SWAT-MODFLOW

SWAT-MODFLOW is a new coupled hydrologic model that combines the land surface and stream hydrologic processes of SWAT and the groundwater hydrologic processes of MODFLOW to provide a comprehensive coupled hydrologic model for watershed systems. Transport of contaminants in this coupled system also can be simulated by including the RT3D (Reactive Transport in 3 Dimensions) model into the MODFLOW groundwater routines. The inclusion of RT3D is not documented in this tutorial (see Section 8 for more information).

The processes simulated by each model are shown in the following figure. Processes simulated by SWAT are shown with green text, those simulated MODFLOW in blue text, and those simulated by RT3D (if desired) in red text. SWAT performs operations for land surface hydrology, soil hydrology, and surface water hydrology; MODFLOW performs operations for groundwater hydrology and interactions between groundwater and surface water; and RT3D performs operations for solute transport in the aquifer and solute mass exchange between groundwater and surface water.



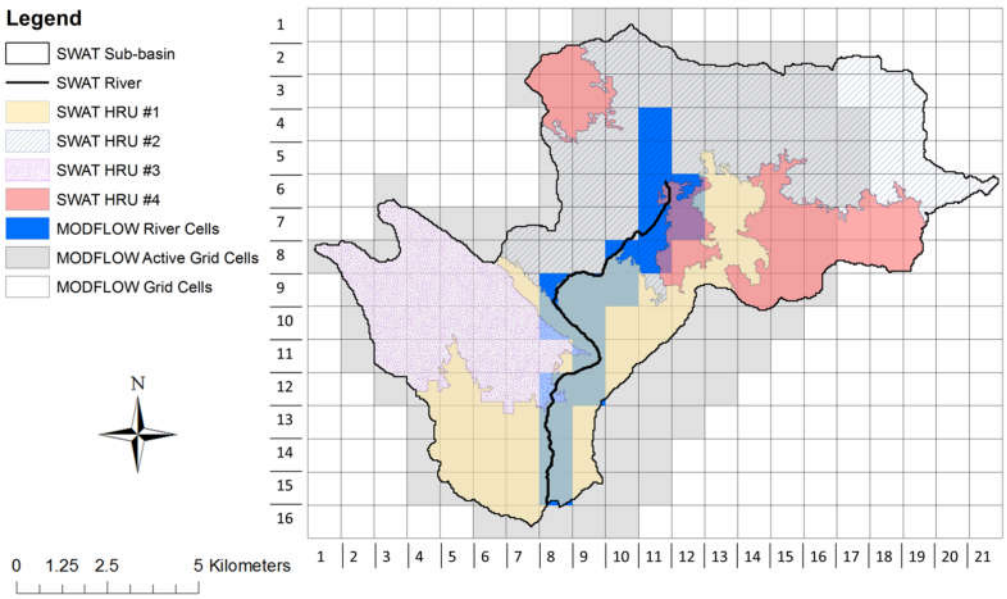
The remaining sections of this tutorial detail the code structure of SWAT-MODFLOW and the process for linking SWAT features (HRUs, subbasins) with MODFLOW grid cells. A new graphical user interface (SWATMOD-Prep) for facilitating the preparation of SWAT-MODFLOW simulations is described in Section 9. However, a detailed tutorial for SWATMOD-Prep has also been developed and is available on the SWAT-MODFLOW website (http://swat.tamu.edu/software/swat-modflow/).

2. OVERVIEW OF LINKING PROCEDURE

Running a coupled SWAT-MODFLOW model requires that values of state variables be passed ("mapped") from the SWAT model to the MODFLOW model and from the MODFLOW model back to the SWAT model. The following state variables are passed between the two models:

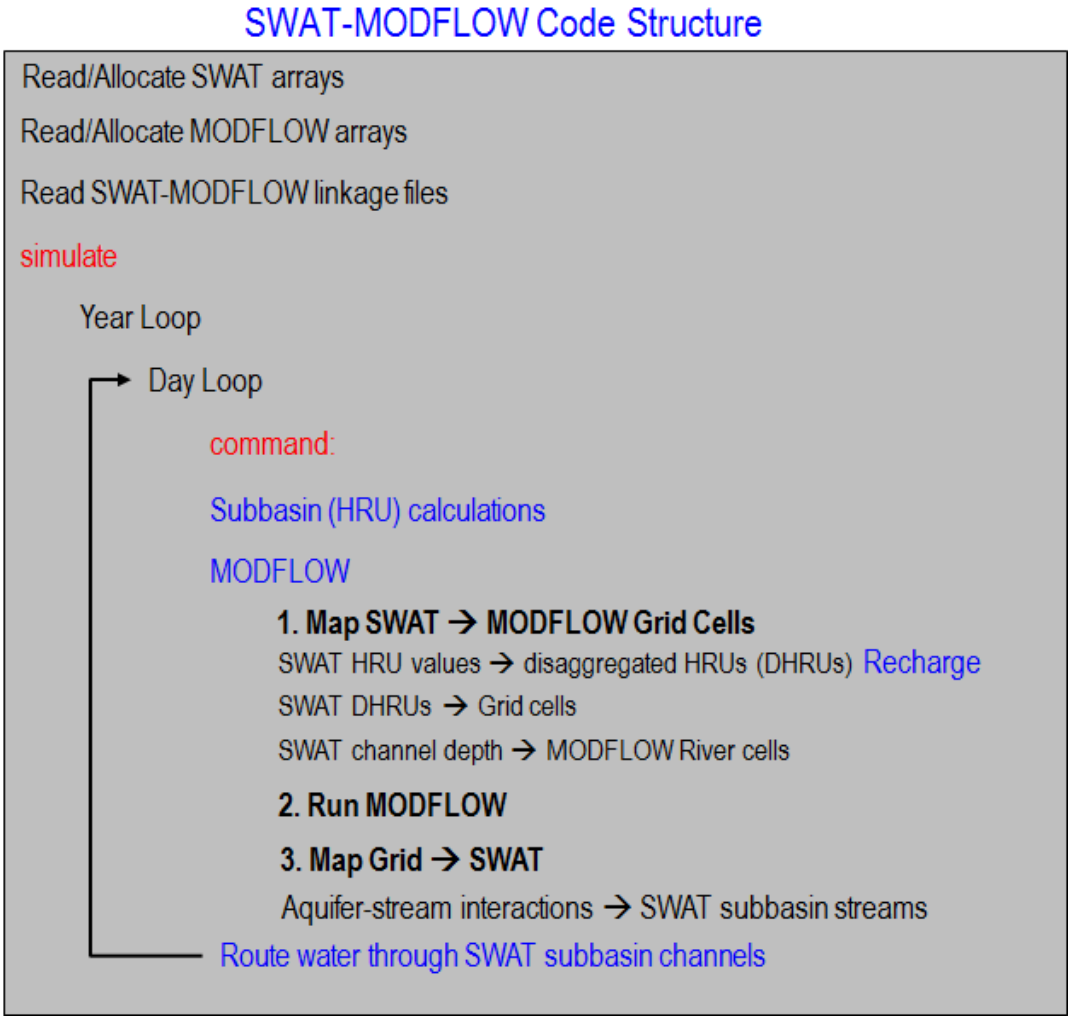
- Soil deep percolation (from SWAT HRUs to MODFLOW grid cells)
- Subbasin stream stage (from SWAT subbasins to MODFLOW river cells)
- Groundwater discharge (from MODFLOW river cells to SWAT subbasins)
- Water table elevation (from MODFLOW grid cells to SWAT HRUs)

As SWAT HRUs do not have a designated geographic location, HRUs are disaggregated in pre-processing GIS routines. Disaggregation splits apart an HRU into individual polygons that have a specific geographic location. These Disaggregated HRUs (DHRUs) are then intersected with MODFLOW grid cells in order to pass variables between SWAT and MODFLOW. Also, MODFLOW River Cells, for which volumetric flow exchange rates between the aquifer and the stream are estimated, are intersected with SWAT subbasins for transferring groundwater return flow rates to the correct subbasin stream. The following figure shows a MODFLOW grid (16 rows, 21 columns) and a SWAT subbasin with 4 HRUs (each in a different color). HRU #4 can be split apart to create 3 DHRUs, each with a specific geographic location. These DHRUs then are intersected with the MODFLOW grid, with the resulting weighted areas used to pass information between SWAT and MODFLOW. The subbasin also contains 19 MODFLOW River Cells (shaded in blue). These River Cells will be linked with the subbasin, so that volumetric flow rates of groundwater return flows to the stream will be given to this subbasin in the watershed.



3. OVERVIEW OF SWAT-MODFLOW CODE STRUCTURE

Both SWAT and MODFLOW are written in the FORTRAN programming language. The MODFLOW model is called as a subroutine within the SWAT code. It replaces the original SWAT groundwater subroutines, and hence these subroutines are not active when MODFLOW is being used. By default, the MODFLOW model is called daily. However, any frequency can be specified in the *swatmf_link.txt* file (see next section). The following figure shows the structure of the code. Within the daily SWAT loop, all subbasins calculations are performed first, followed by mapping variables to the MODFLOW grid cell, running MODFLOW, and then mapping variables back to SWAT. Routing of surface return flow and groundwater return flow through the watershed stream network then can be performed for that day.



4. CREATING THE SWAT-MODFLOW LINKAGE

The information required to link HRUs, DHRUs, SWAT subbasins, and MODFLOW grid cells is contained in 4 text files that are read in at the beginning of the SWAT-MODFLOW simulation. These text files are:

1. swatmf_dhru2hru.txt (relates HRUs to DHRUs)
2. swatmf _dhru2grid.txt (relates DHRUs to Grid Cells)
3. swatmf _grid2dhru.txt (relates Grid Cells to DHRUs)
4. swatmf _river2grid.txt (relates River Cells to Subbasins)

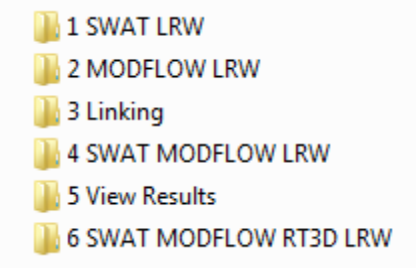
The linkage information is stored in memory during the simulation and used when variables are passed between the two models. The process of creating each of the 4 text files is as follows:

1. Perform basic intersection/extraction routines in a GIS
2. Prepare tables that contain results of the GIS routines
3. Run a FORTRAN program that creates the 4 SWAT-MODFLOW input files

This process is now described in more detail. Example tables and SWAT-MODFLOW input files are provided with this documentation.

4.1 LINKING PROCEDURE USING ARCGIS ROUTINES

This section describes the process to link SWAT features (HRUs, subbasins) with the MODFLOW grid cells. The files used in this process are contained in the folder "Workshop Materials\Example Simulation – LRW", which contains all files necessary to create a SWAT-MODFLOW model for the Little River Watershed near Tifton, Georgia. The files are contained in the following 6 sub-folders:



- The 1st folder contains the SWAT model input files and the SWAT shape files (HRU, River, Subbasin).
- The 2nd folder contains the MODFLOW simulation input files
- The 3rd folder contains the 4 linking tables that will be created using GIS routines. These files are placed here for your convenience. The process of creating these files is described in this section.
- The 4th folder contains files necessary for running a SWAT-MODFLOW simulation
- The 5th folder contains files for viewing results of a SWAT-MODFLOW simulation
- The 6th folder contains files for running a SWAT-MODFLOW-RT3D simulation

In the following procedures, the following two symbols are use frequently:

 : Left click  : Right click

4.1.1 Linkage between HRUs and Disaggregated HRUs (DHRUs)

File to create: **hru_dhu**. This file has the following structure:

At the top of the file:

Number of DHRUs
Number of HRUs

Then, the following columns:

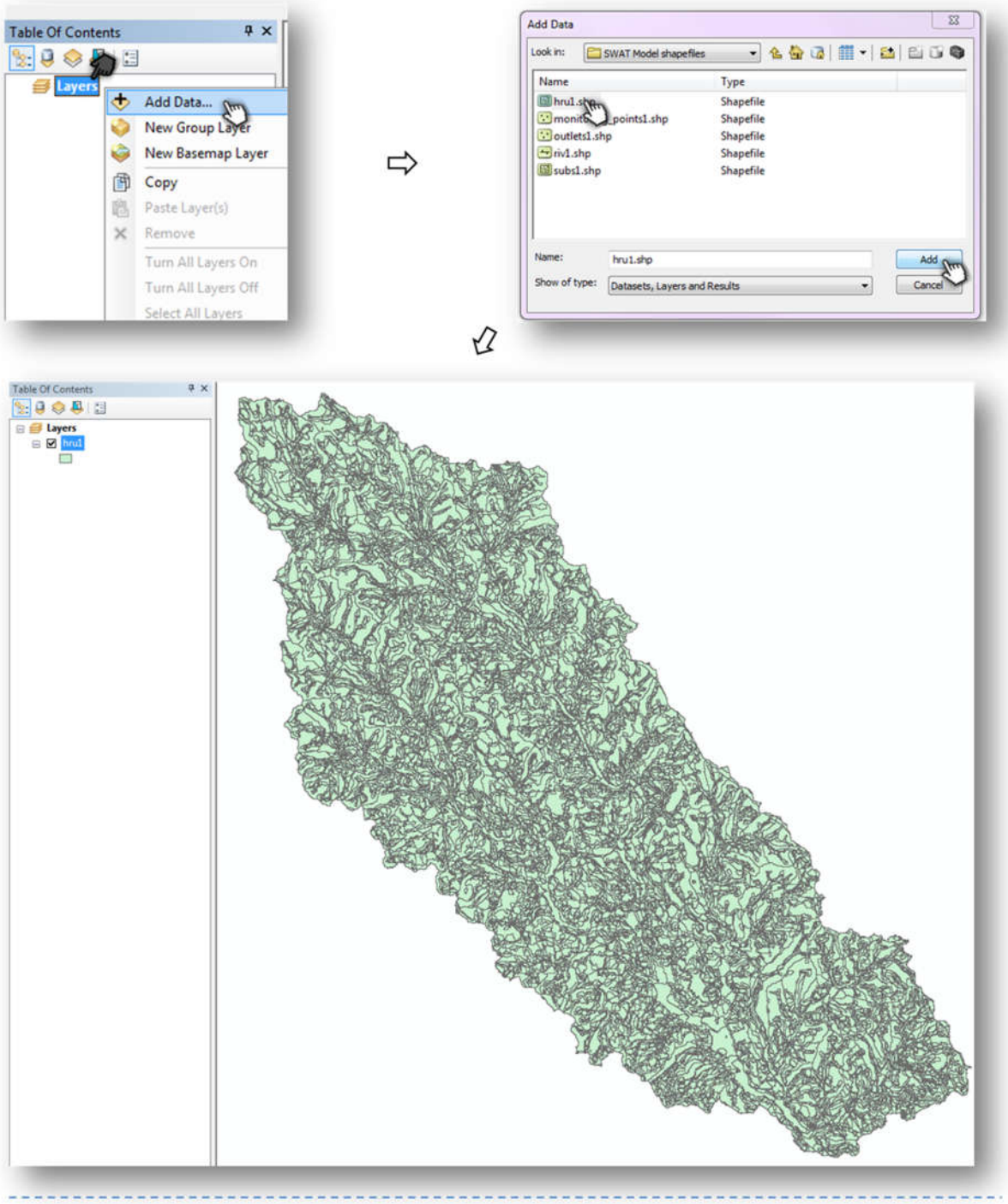
dhru_id: ID of DHRU (sequential numbering)
dhru_area: Spatial Area (m^2) of the DHRU
hru_id: ID of the HRU from which the DHRU originates
subbasin: ID of the Subbasin
hru_area: Spatial area (m^2) of the original HRU

For example:

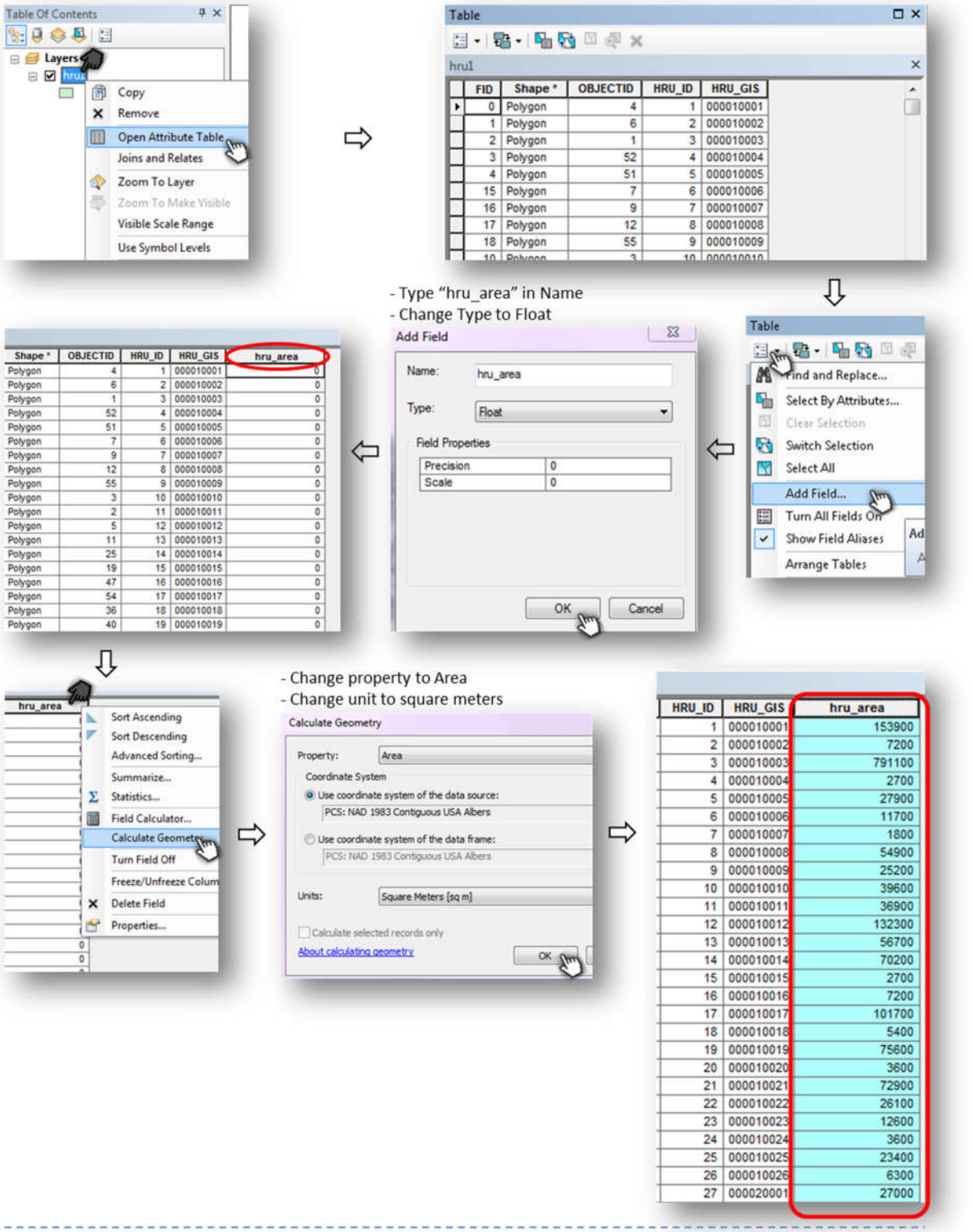
```
1  27396
2  6233
3  dhru_id dhru_area  hru_id   subbasin hru_area
4  1       9000    1       1       153900
5  2       900     1       1       153900
6  3       900     1       1       153900
7  4       900     1       1       153900
8  5       45900   1       1       153900
9  6       89100   1       1       153900
10 7       7200    1       1       153900
11 8       900     2       1       7200
12 9       900     2       1       7200
13 10      900     2       1       7200
14 11      900     2       1       7200
15 12      1800    2       1       7200
16 13      1800    2       1       7200
17 14      54000   3       1       791100
18 15      423000  3       1       791100
19 16      900     3       1       791100
20 17      900     3       1       791100
21 18      63900   3       1       791100
22 19      5400    3       1       791100
23 20      1800    3       1       791100
24 21      900     3       1       791100
25 22      900     3       1       791100
26 23      900     3       1       791100
27 24      900     3       1       791100
28 25      225900  3       1       791100
29 26      1800    3       1       791100
30 27      9900    3       1       791100
31 28      2700    4       1       2700
```

1. Begin with HRU shapefile (no thresholds)

① Import the “hru1” shapefile (1 SWAT LRW folder) into ArcMap

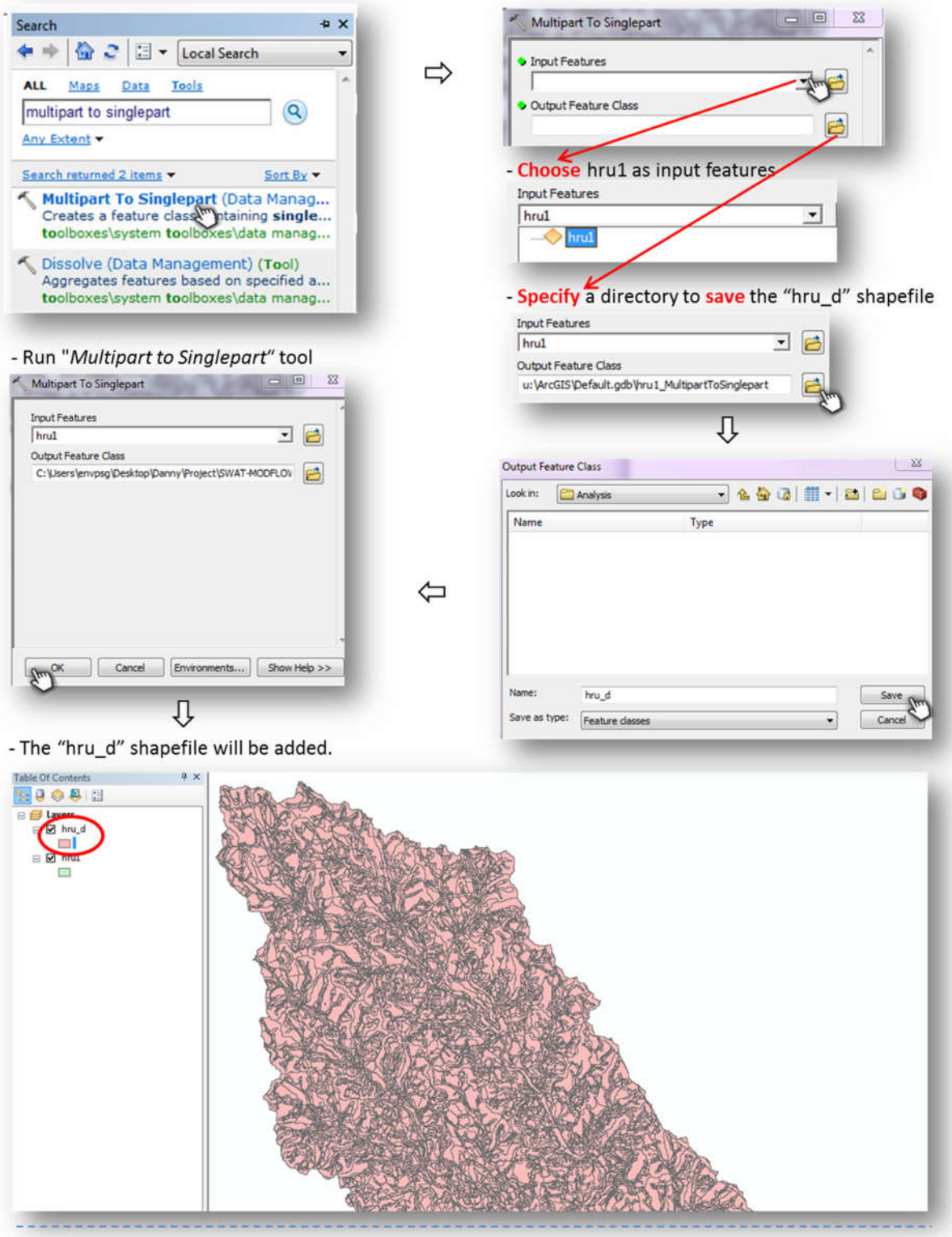


② Add the spatial area (m^2) of the HRUs in the "hru area" field



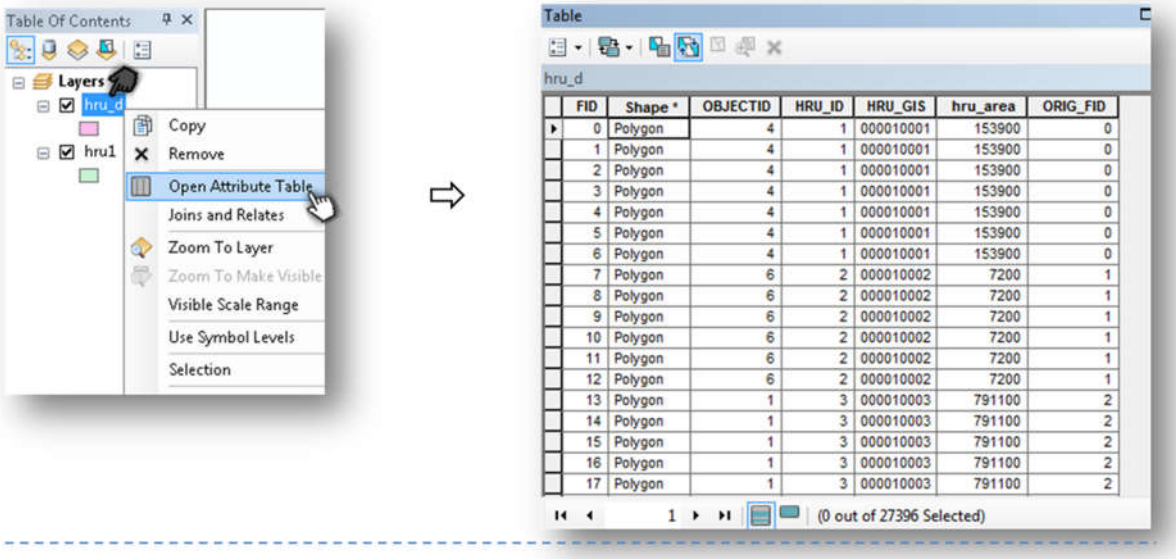
2. Apply the GIS operation "*Multipart to Singlepart*" to create the DHRU shape file

① Open “Multipart to Singlepart” tool



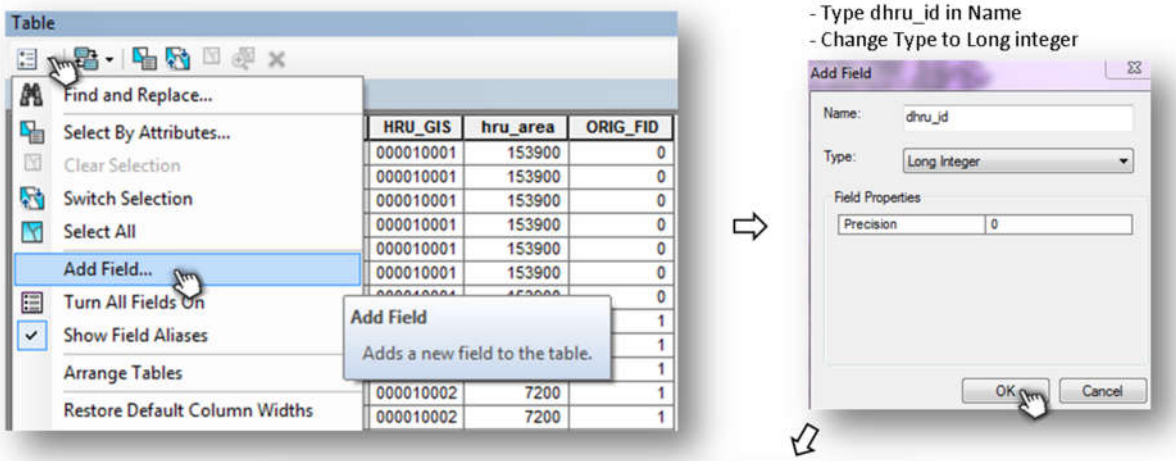
3. Get Area, unique ID, and subbasin for each DHRU

① Open the attribute table of the “hru_d” shapefile



FID	Shape *	OBJECTID	HRU_ID	HRU_GIS	hru_area	ORIG_FID
0	Polygon	4	1	000010001	153900	0
1	Polygon	4	1	000010001	153900	0
2	Polygon	4	1	000010001	153900	0
3	Polygon	4	1	000010001	153900	0
4	Polygon	4	1	000010001	153900	0
5	Polygon	4	1	000010001	153900	0
6	Polygon	4	1	000010001	153900	0
7	Polygon	6	2	000010002	7200	1
8	Polygon	6	2	000010002	7200	1
9	Polygon	6	2	000010002	7200	1
10	Polygon	6	2	000010002	7200	1
11	Polygon	6	2	000010002	7200	1
12	Polygon	6	2	000010002	7200	1
13	Polygon	1	3	000010003	791100	2
14	Polygon	1	3	000010003	791100	2
15	Polygon	1	3	000010003	791100	2
16	Polygon	1	3	000010003	791100	2
17	Polygon	1	3	000010003	791100	2

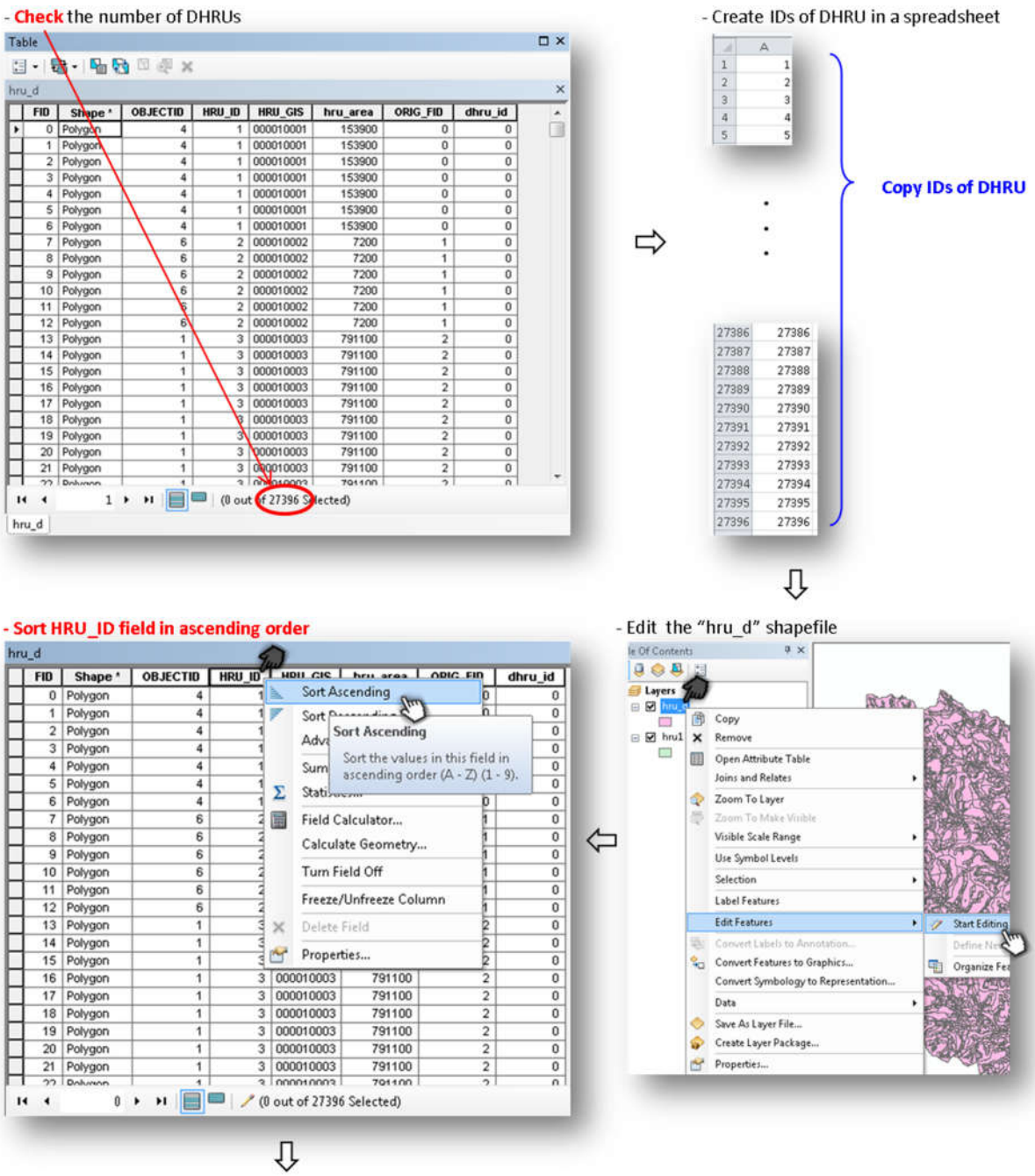
② Create “dhru_id” field with long integer type



hru_d

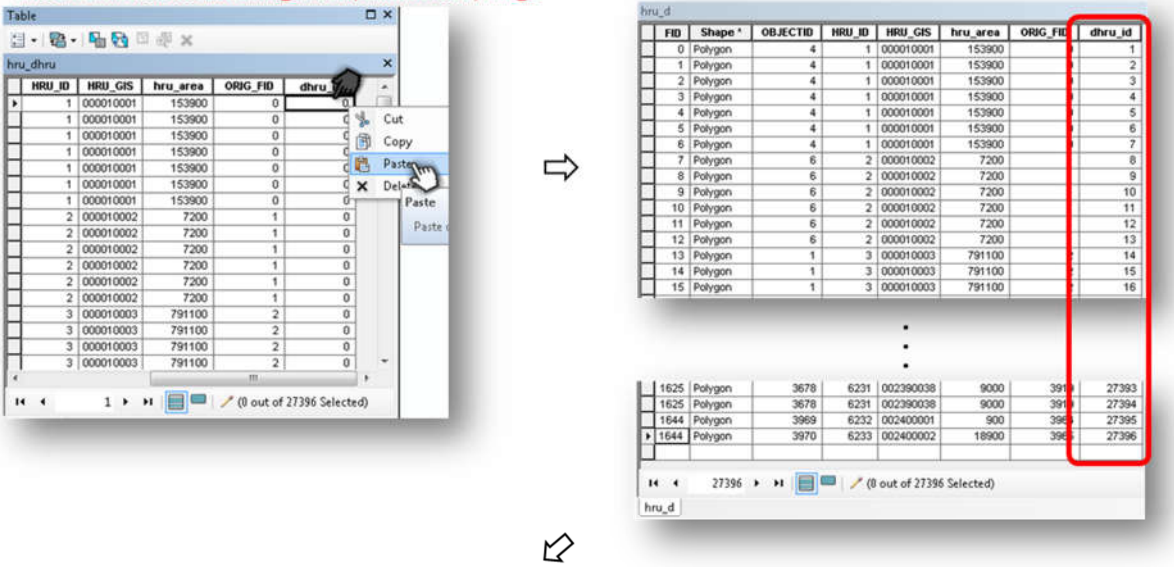
FID	Shape *	OBJECTID	HRU_ID	HRU_GIS	hru_area	ORIG_FID	dhru_id
0	Polygon	4	1	000010001	153900	0	0
1	Polygon	4	1	000010001	153900	0	0
2	Polygon	4	1	000010001	153900	0	0
3	Polygon	4	1	000010001	153900	0	0
4	Polygon	4	1	000010001	153900	0	0
5	Polygon	4	1	000010001	153900	0	0
6	Polygon	4	1	000010001	153900	0	0
7	Polygon	6	2	000010002	7200	1	0
8	Polygon	6	2	000010002	7200	1	0
9	Polygon	6	2	000010002	7200	1	0
10	Polygon	6	2	000010002	7200	1	0
11	Polygon	6	2	000010002	7200	1	0
12	Polygon	6	2	000010002	7200	1	0
13	Polygon	1	3	000010003	791100	2	0
14	Polygon	1	3	000010003	791100	2	0
15	Polygon	1	3	000010003	791100	2	0
16	Polygon	1	3	000010003	791100	2	0
17	Polygon	1	3	000010003	791100	2	0

③ Create IDs for the DHRUs in a spreadsheet of Excel. *It is important that the HRUs are sorted by ID before providing IDs to each DHRU. This will be described in this step.*



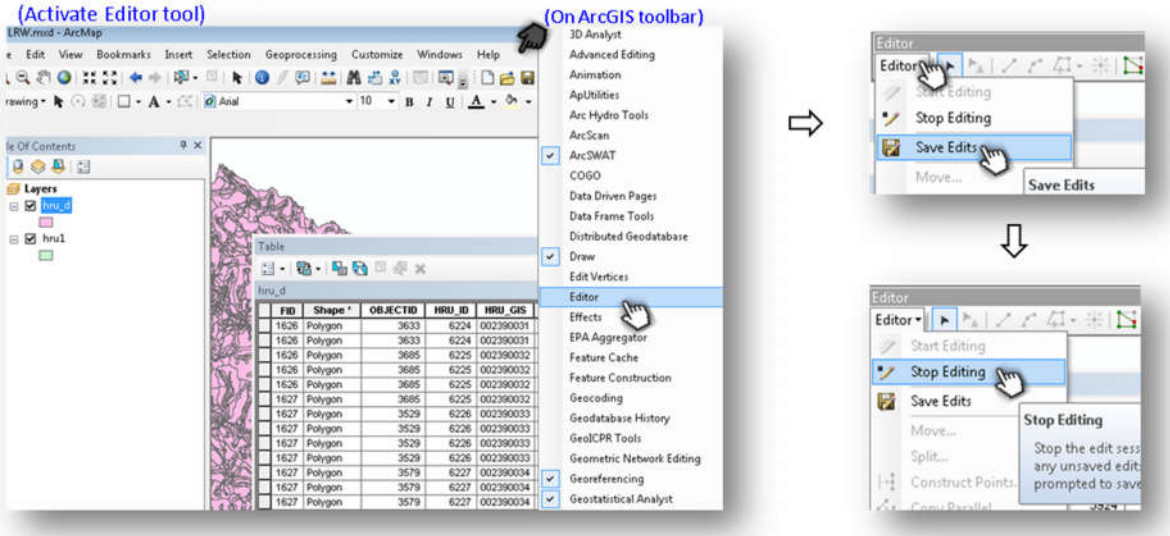
- Paste the IDs of DHRU copied from the spreadsheet into "dhru_id" field

* First Check the attribute table of hru_dhru shapefile is sorted by HRU_ID

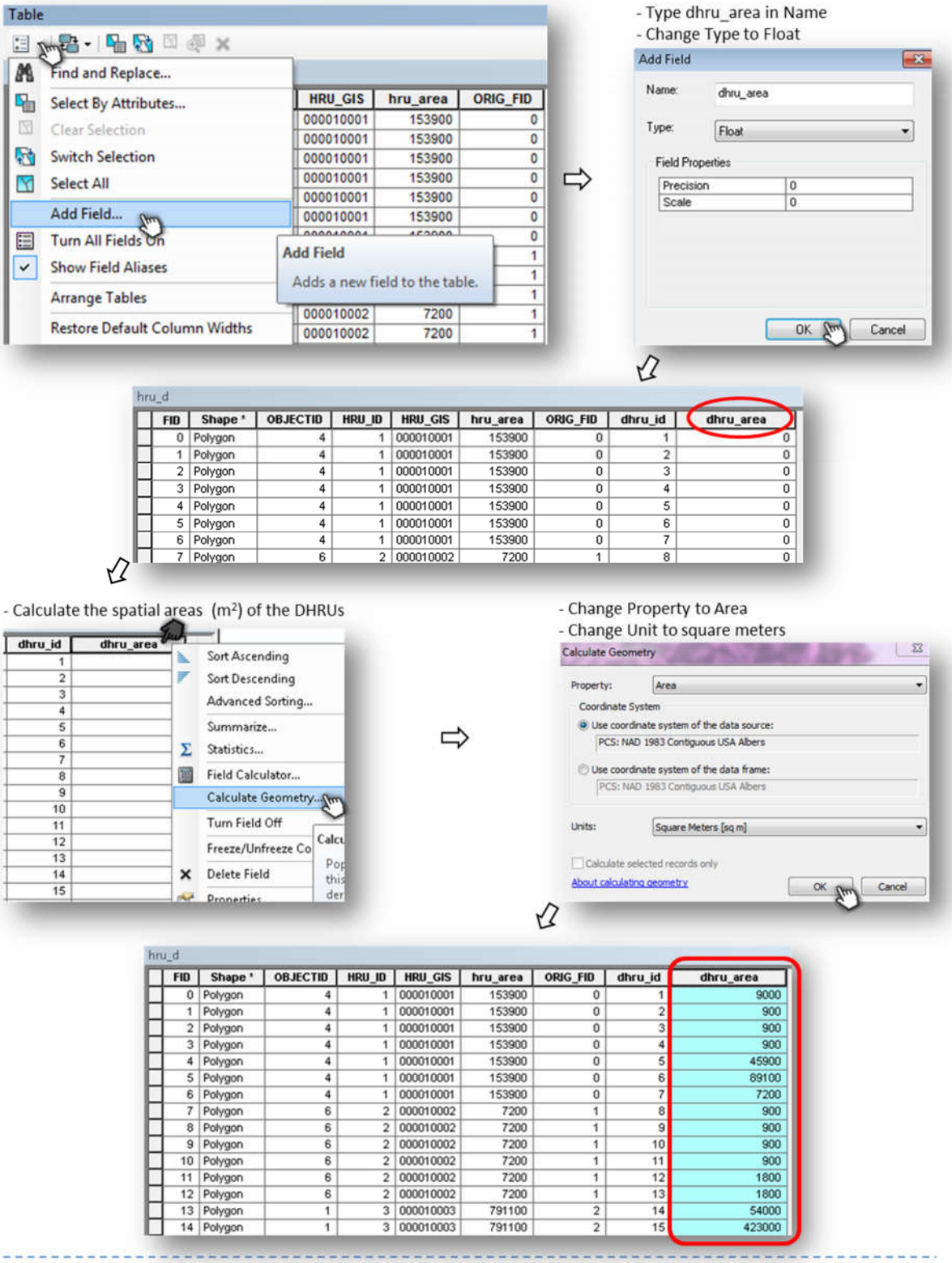


- Save the edited hru_d shapefile

(Activate Editor tool) (On ArcGIS toolbar)

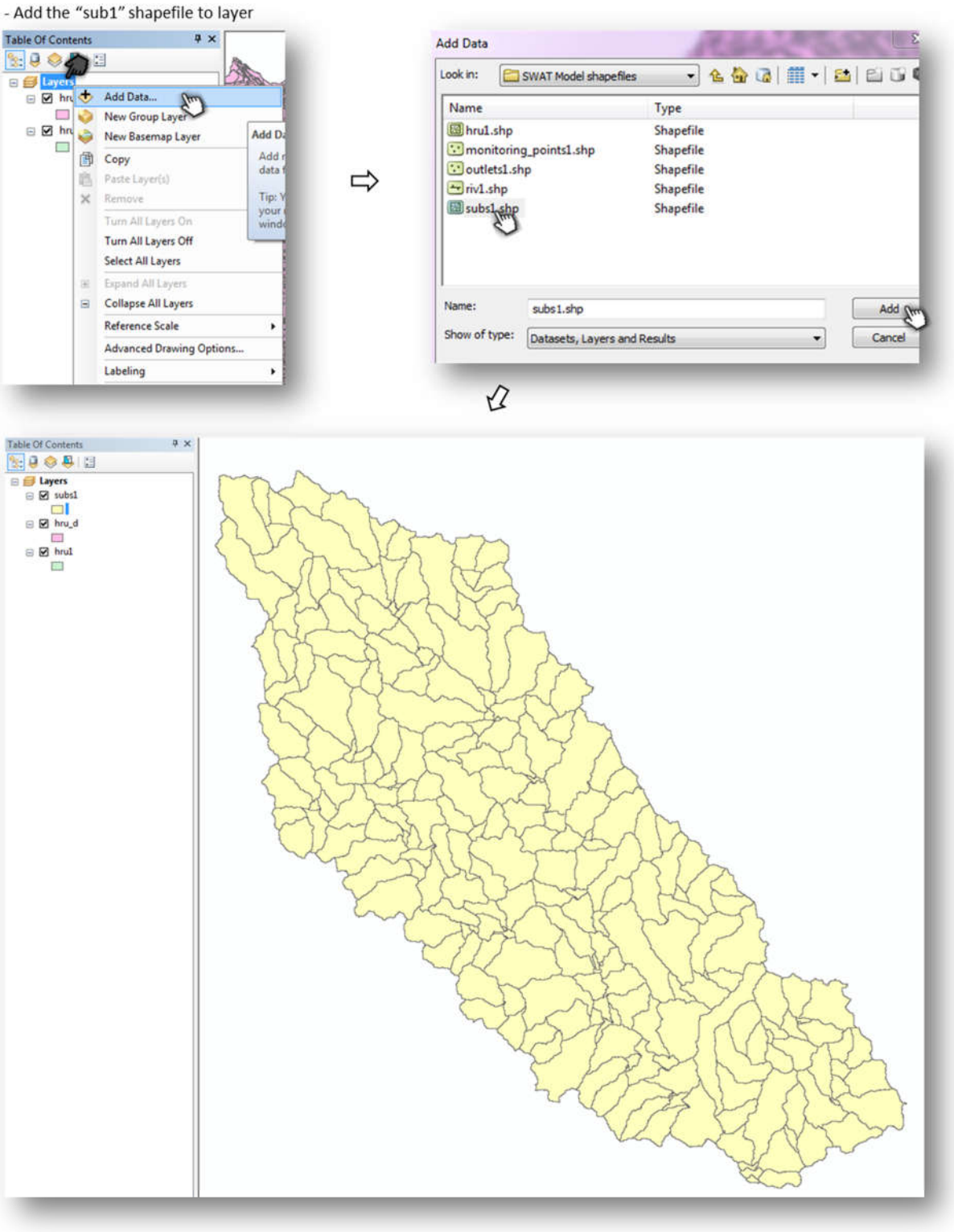


④ Create “dhru_area” field with float type

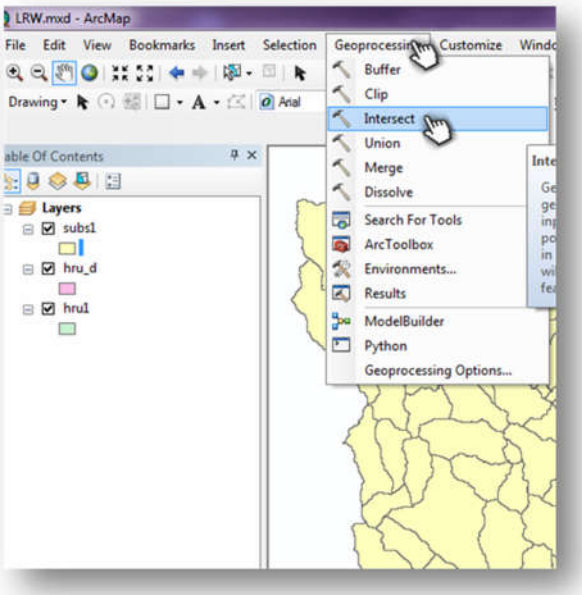


FID	Shape *	OBJECTID	HRU_ID	HRU_GIS	hru_area	ORIG_FID	dhru_id	dhru_area
0	Polygon	4	1	000010001	153900	0	1	9000
1	Polygon	4	1	000010001	153900	0	2	900
2	Polygon	4	1	000010001	153900	0	3	900
3	Polygon	4	1	000010001	153900	0	4	900
4	Polygon	4	1	000010001	153900	0	5	45900
5	Polygon	4	1	000010001	153900	0	6	89100
6	Polygon	4	1	000010001	153900	0	7	7200
7	Polygon	6	2	000010002	7200	1	8	900
8	Polygon	6	2	000010002	7200	1	9	900
9	Polygon	6	2	000010002	7200	1	10	900
10	Polygon	6	2	000010002	7200	1	11	900
11	Polygon	6	2	000010002	7200	1	12	1800
12	Polygon	6	2	000010002	7200	1	13	1800
13	Polygon	1	3	000010003	791100	2	14	54000
14	Polygon	1	3	000010003	791100	2	15	423000

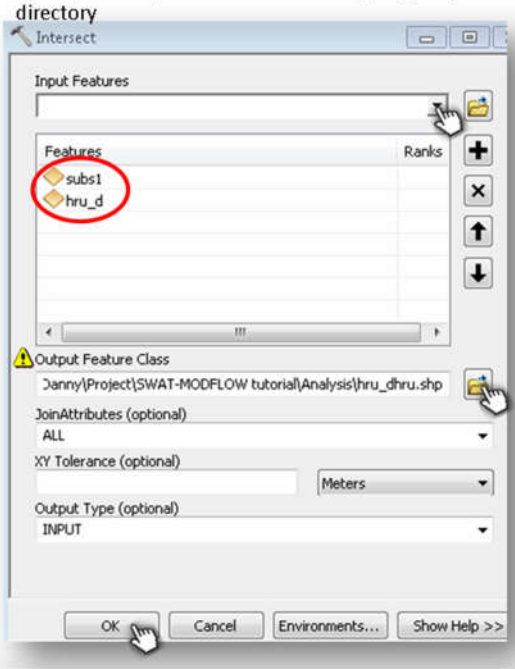
⑤ Intersect the “hru_d” with the “sub1” shapefile

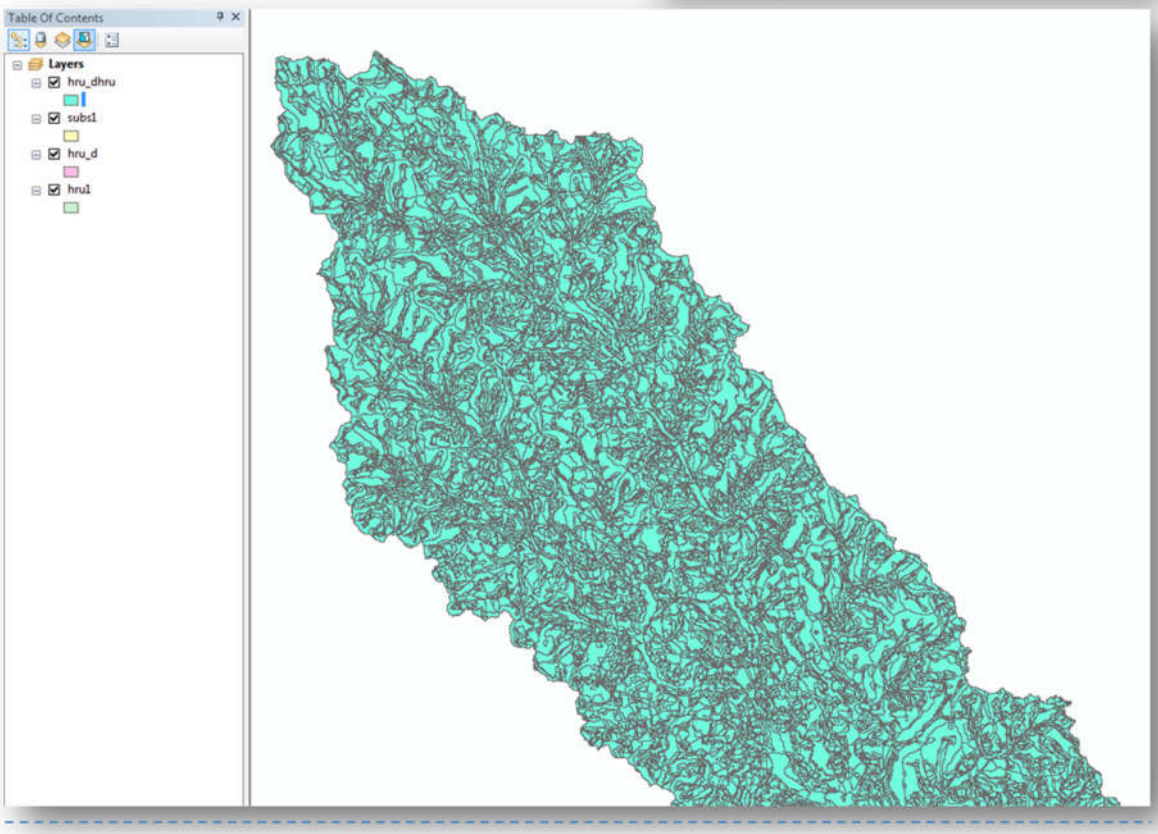


- Run Intersect tool

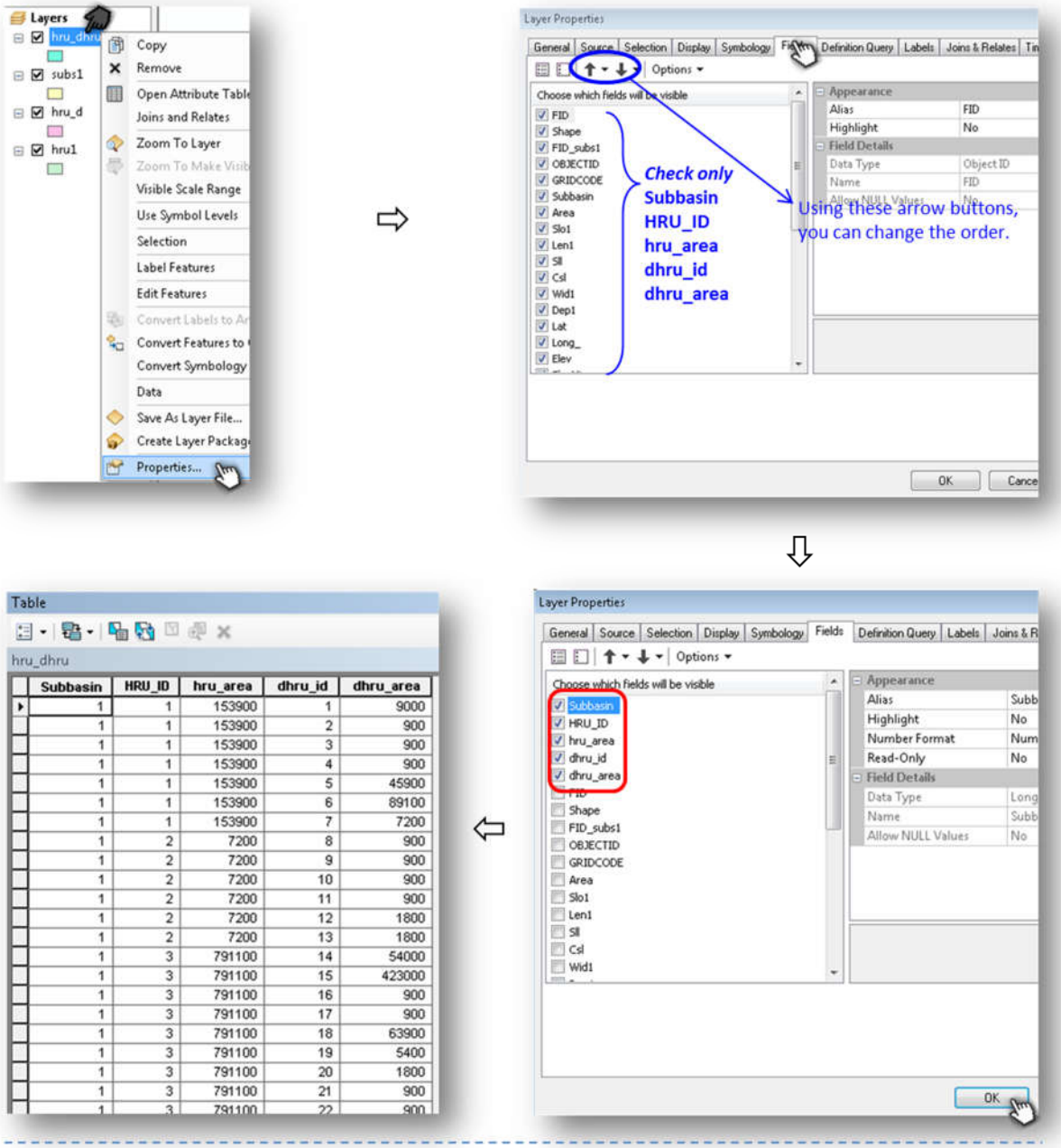


- Add the "sub1" and "hru_d" shapefiles in Input Features
- Specify the output feature class name (hru_dhru) and directory





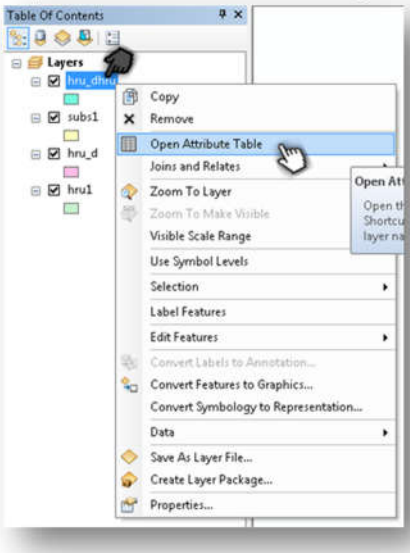
⑥ Select only the necessary fields (You can either turn off or delete an unnecessary field)

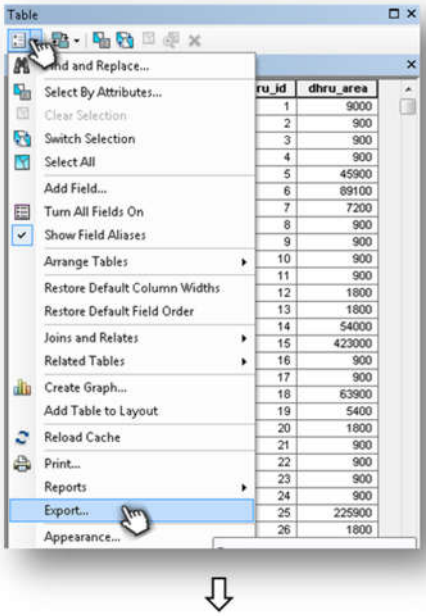


Subbasin	HRU_ID	hru_area	dhru_id	dhru_area
1	1	153900	1	9000
1	1	153900	2	900
1	1	153900	3	900
1	1	153900	4	900
1	1	153900	5	45900
1	1	153900	6	89100
1	1	153900	7	7200
1	2	7200	8	900
1	2	7200	9	900
1	2	7200	10	900
1	2	7200	11	900
1	2	7200	12	1800
1	2	7200	13	1800
1	3	791100	14	54000
1	3	791100	15	423000
1	3	791100	16	900
1	3	791100	17	900
1	3	791100	18	63900
1	3	791100	19	5400
1	3	791100	20	1800
1	3	791100	21	900
1	3	791100	22	900

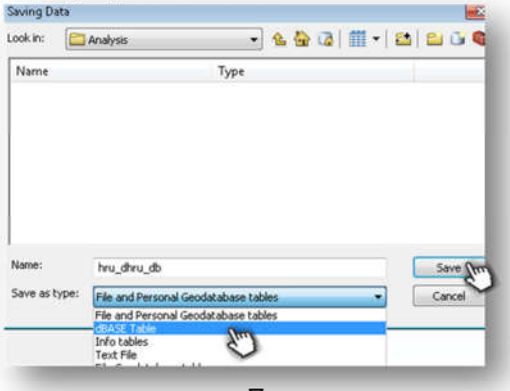
⑦ Provide text file: **hru_dhru** (This file is sorted by the HRU and DHRU IDs)

- Export the attribute table of the "hru_dhru" shapefile as dBASE table (*.dbf).

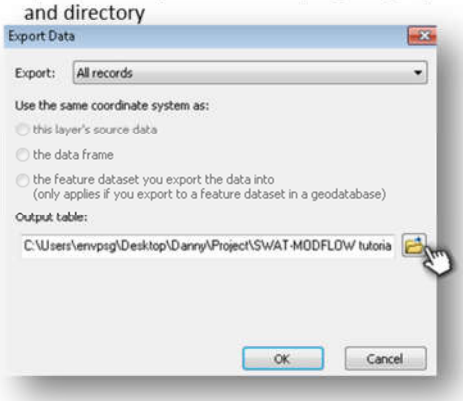




- Change Type to dBASE Table



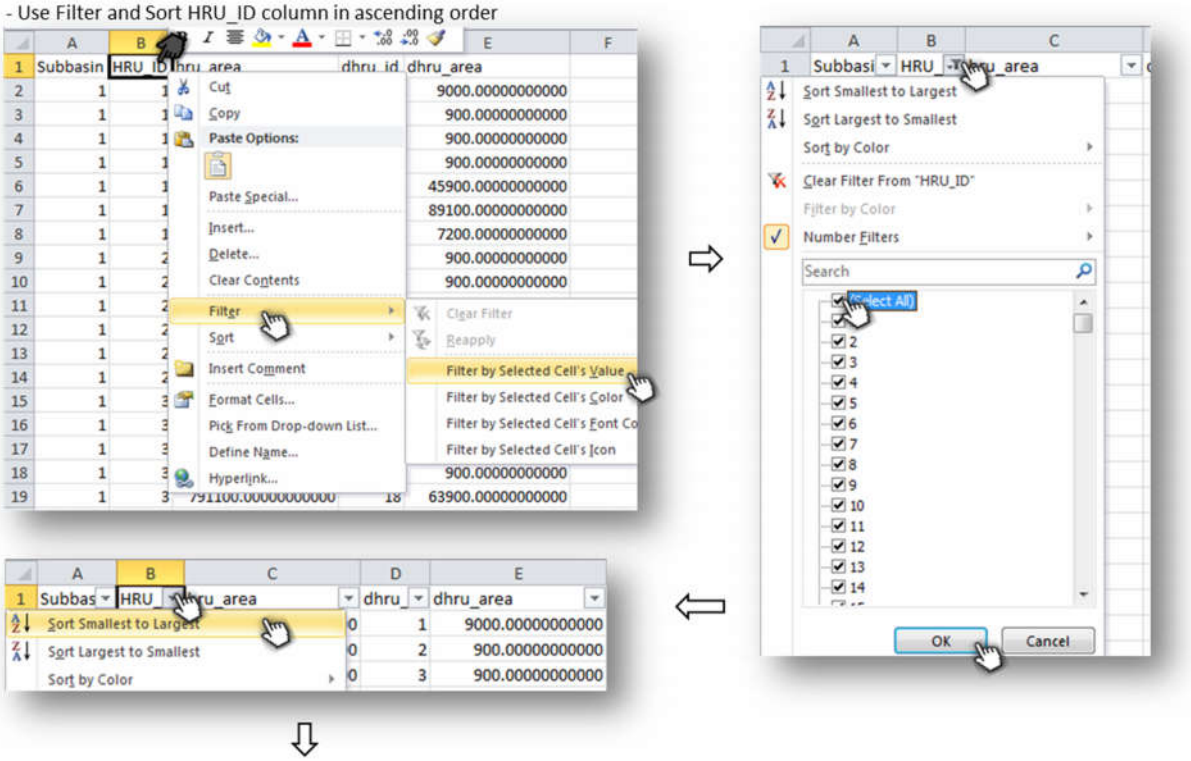
- Specify the output table name (hru_dhru_db) and directory



- Open the "hru_dhru_db" file with Excel

	A	B	C	D	E
1	Subbasin	HRU_ID	hru_area	dhru_id	dhru_area
2	1	1	153900.00000000000	1	9000.00000000000
3	1	1	153900.00000000000	2	900.00000000000
4	1	1	153900.00000000000	3	900.00000000000
5	1	1	153900.00000000000	4	900.00000000000
6	1	1	153900.00000000000	5	45900.00000000000
7	1	1	153900.00000000000	6	89100.00000000000
8	1	1	153900.00000000000	7	7200.00000000000
9	1	2	7200.00000000000	8	900.00000000000
10	1	2	7200.00000000000	9	900.00000000000
11	1	2	7200.00000000000	10	900.00000000000

- Use Filter and Sort HRU_ID column in ascending order



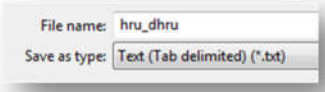
- Change the order of the columns and correct the column names

- Insert two rows at the top of the spreadsheet and write the numbers of DHRUs in 1st and HRUs in 2nd row

- Reduce the number of digits after decimal point if desired

	A	B	C	D	E
1	27396				
2	6233				
3	dhru_id	dhru_area	hru_id	subbasin	hru_area
4	1	9000	1	1	153900
5	2	900	1	1	153900
6	3	900	1	1	153900
7	4	900	1	1	153900
8	5	45900	1	1	153900
9	6	89100	1	1	153900
10	7	7200	1	1	153900
11	8	900	2	1	7200
12	9	900	2	1	7200
13	10	900	2	1	7200
14	11	900	2	1	7200
15	12	1800	2	1	7200
16	13	1800	2	1	7200
17	14	54000	3	1	791100
18	15	423000	3	1	791100
19	16	900	3	1	791100
20	17	900	3	1	791100
21	18	63900	3	1	791100

- Save the spreadsheet as “hru_dhru” with text file format




```
27396
6233
dhru_id dhru_area  hru_id   subbasin hru_area
1       9000    1       1       153900
2       900     1       1       153900
3       900     1       1       153900
4       900     1       1       153900
5       45900   1       1       153900
6       89100   1       1       153900
7       7200    1       1       153900
8       900     2       1       7200
9       900     2       1       7200
10      900     2       1       7200
11      900     2       1       7200
12      1800    2       1       7200
13      1800    2       1       7200
14      54000   3       1       791100
15      423000  3       1       791100
16      900     3       1       791100
17      900     3       1       791100
18      63900   3       1       791100
19      5400    3       1       791100
20      1800    3       1       791100
21      900     3       1       791100
```

4.1.2 Linkage between DHRUs and MODFLOW Grid cells

File to create: **dhru_grid**. This file has the following structure:

At the top of the file:

Number of lines with information (starting on Line 4)
Number of MODFLOW grid cells

Then, the following columns (sorted by *grid_id*, then by *dhru_id*):

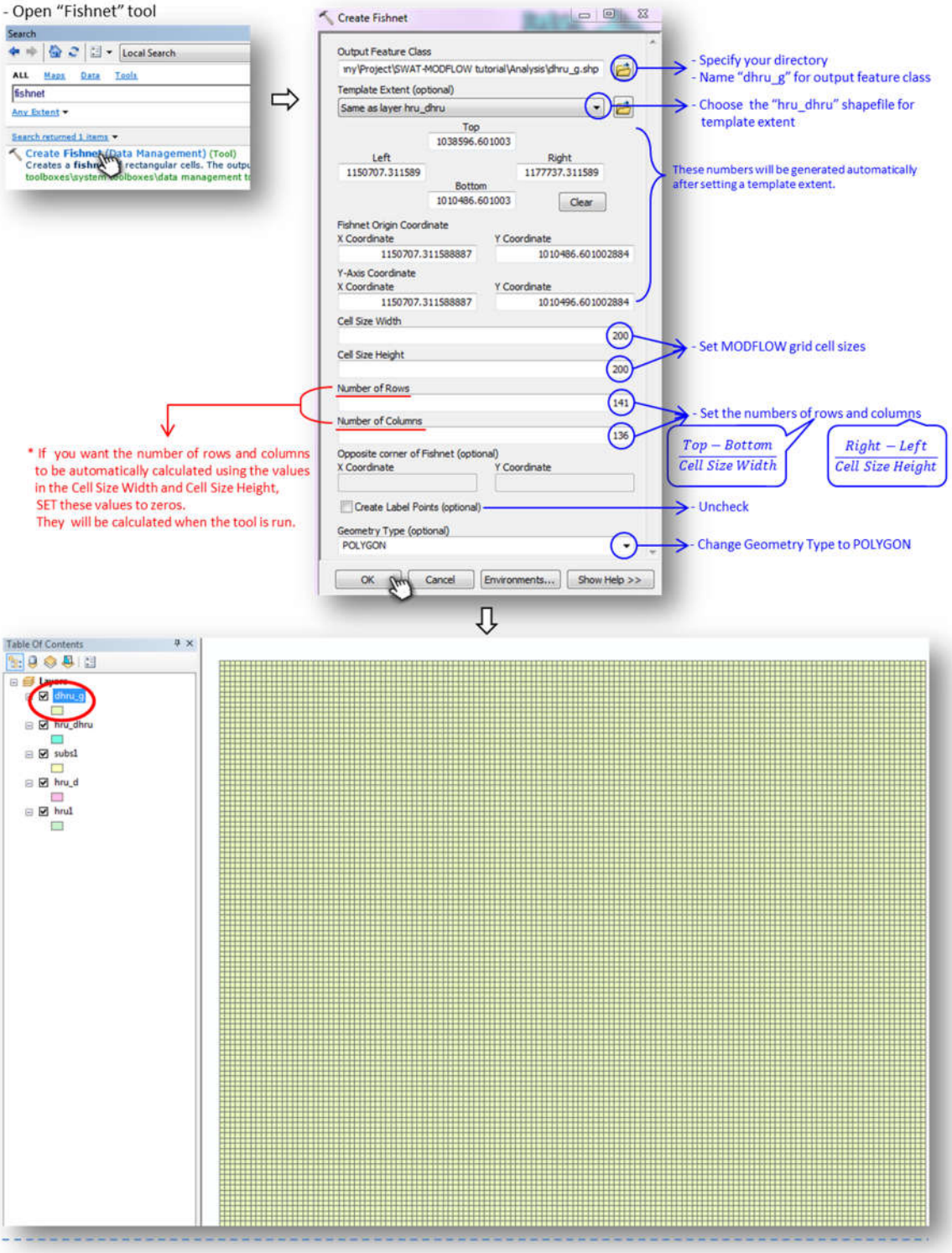
grid_id: ID of the MODFLOW grid cell (only cells intersecting DHRUs)
grid_area: Spatial Area (m^2) of the grid cell
dhru_id: ID of the DHRU
overlap_area: Overlap area (m^2) between the cell and the DHRU
dhru_area: Spatial area (m^2) of the DHRU

For example:

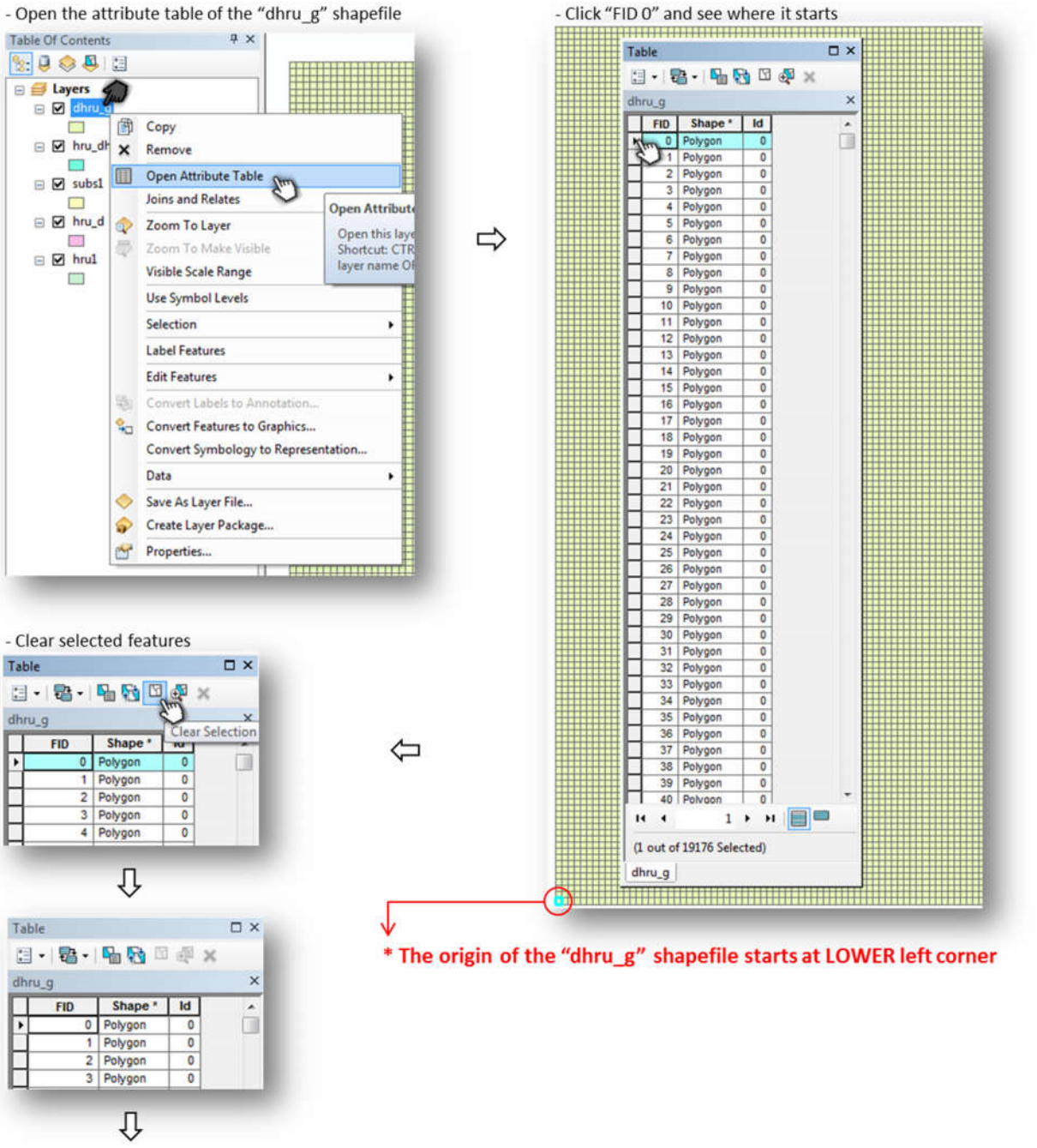
```
61838
19176
grid_id grid_area       dhru_id overlap_area    dhru_area
16      40000   27      3000    9900
16      40000   58      600     900
16      40000   63      1900    31500
17      40000   7       6000    7200
17      40000   27      6900    9900
17      40000   57      800     4500
17      40000   58      300     900
17      40000   63      800     31500
18      40000   57      400     4500
137     40000   1158    5600    76500
138     40000   1158    25100   76500
138     40000   1182    4500    11700
139     40000   1158    8600    76500
139     40000   1159    3300    272700
139     40000   1368    4200    9000
140     40000   1159    1400    272700
141     40000   1159    8300    272700
142     40000   1148    900     900
142     40000   1159    21800   272700
142     40000   1261    300     53100
143     40000   1145    900     900
143     40000   1146    900     900
143     40000   1155    3200    68400
143     40000   1159    900     272700
143     40000   1261    1500    53100
144     40000   1147    2700    5400
144     40000   1155    400     68400
144     40000   1156    900     900
144     40000   1157    700     7200
144     40000   1163    900     6300
145     40000   2356    1800    200700
145     40000   1147    2700    5400
145     40000   1157    1700    7200
152     40000   63      1100    31500
```

1. Create MODFLOW shapefile

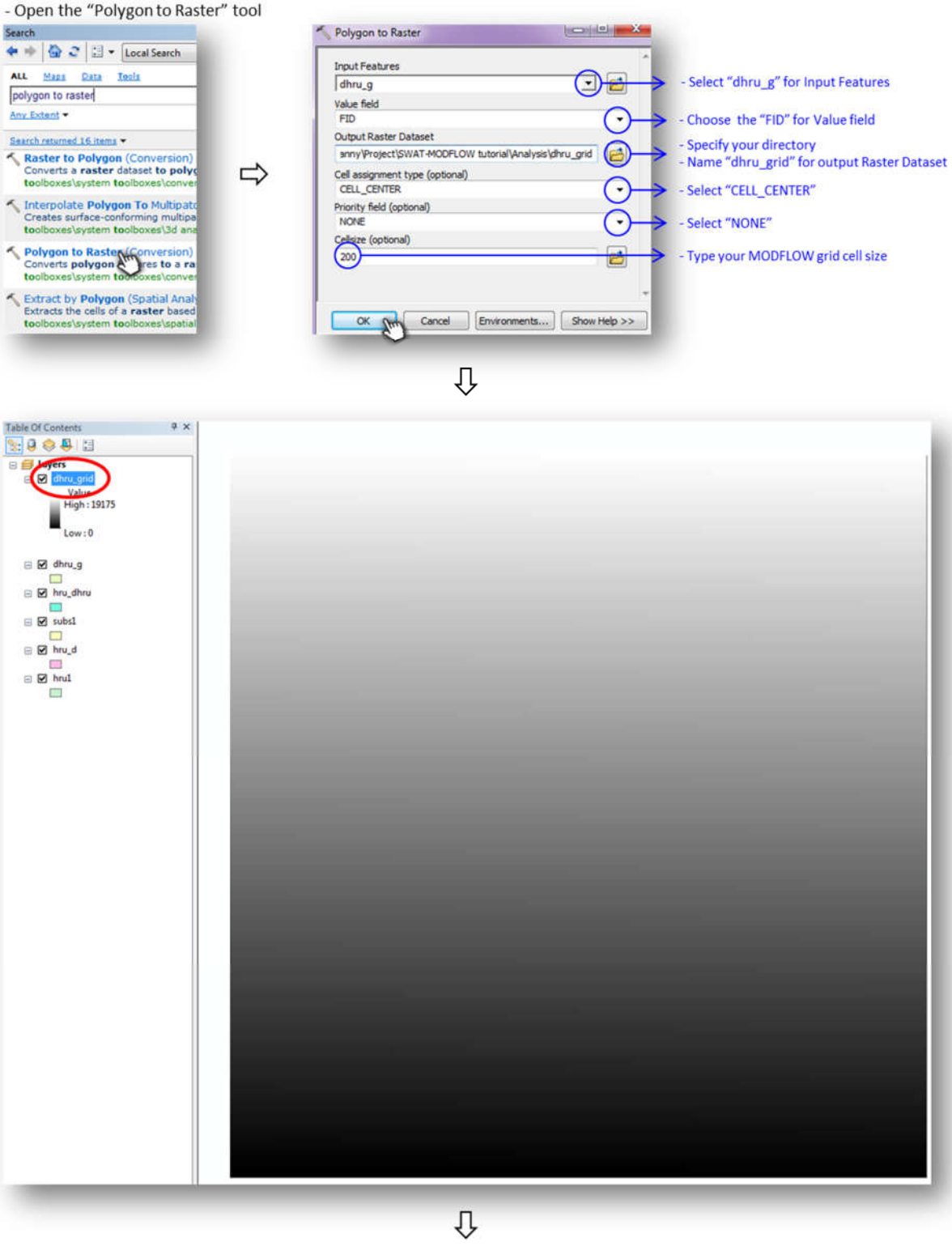
① Create a fishnet of rectangular cells as MODFLOW Grid cells



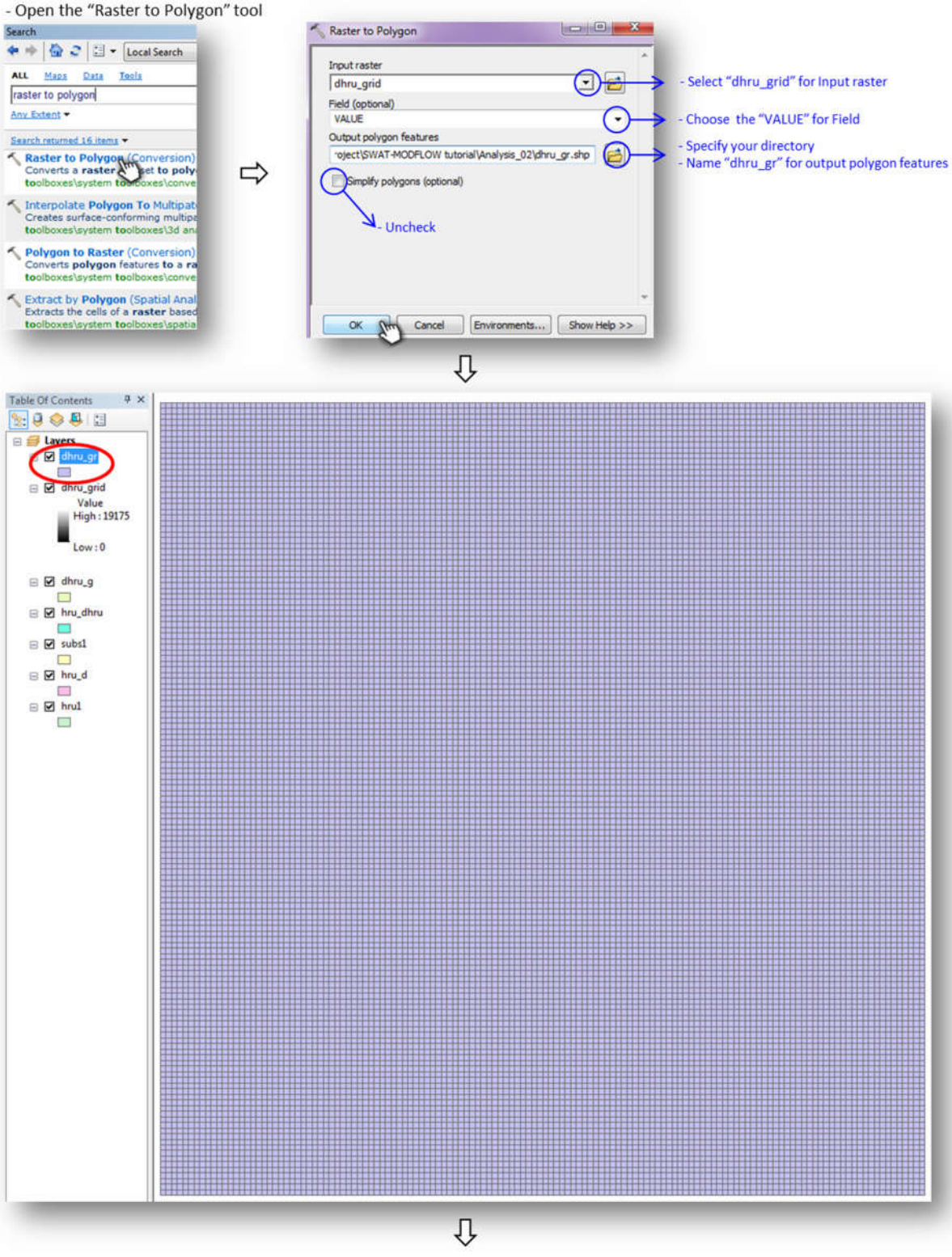
② Generate IDs of the MODFLOW grid cell (The origin of MODFLOW grid starts at upper left corner)



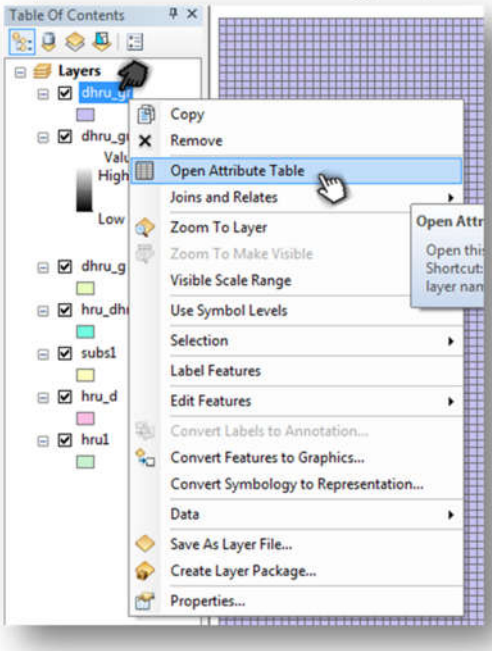
- Open the "Polygon to Raster" tool



- Open the "Raster to Polygon" tool

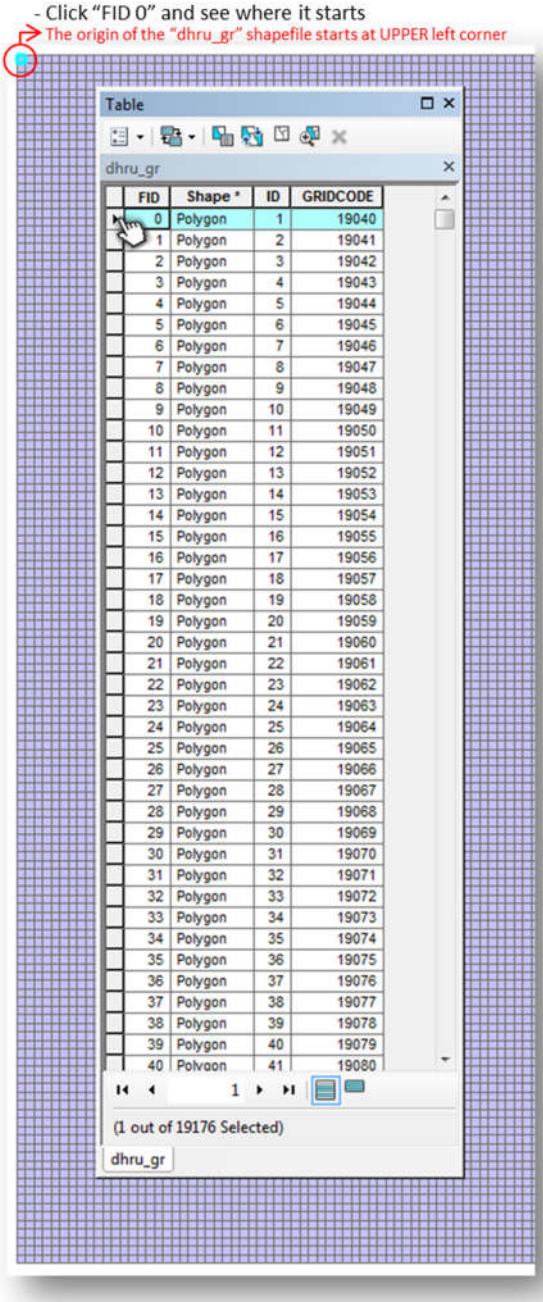


- Open the attribute table of the “dhru_gr” shapefile



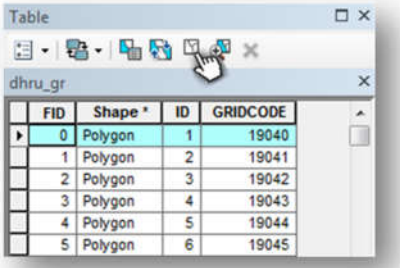
- Click “FID 0” and see where it starts

The origin of the “dhru_gr” shapefile starts at UPPER left corner

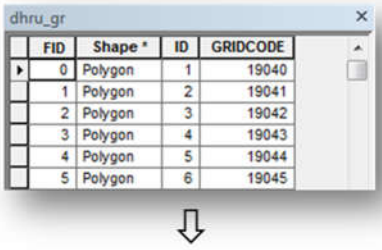


FID	Shape *	ID	GRIDCODE
0	Polygon	1	19040
1	Polygon	2	19041
2	Polygon	3	19042
3	Polygon	4	19043
4	Polygon	5	19044
5	Polygon	6	19045
6	Polygon	7	19046
7	Polygon	8	19047
8	Polygon	9	19048
9	Polygon	10	19049
10	Polygon	11	19050
11	Polygon	12	19051
12	Polygon	13	19052
13	Polygon	14	19053
14	Polygon	15	19054
15	Polygon	16	19055
16	Polygon	17	19056
17	Polygon	18	19057
18	Polygon	19	19058
19	Polygon	20	19059
20	Polygon	21	19060
21	Polygon	22	19061
22	Polygon	23	19062
23	Polygon	24	19063
24	Polygon	25	19064
25	Polygon	26	19065
26	Polygon	27	19066
27	Polygon	28	19067
28	Polygon	29	19068
29	Polygon	30	19069
30	Polygon	31	19070
31	Polygon	32	19071
32	Polygon	33	19072
33	Polygon	34	19073
34	Polygon	35	19074
35	Polygon	36	19075
36	Polygon	37	19076
37	Polygon	38	19077
38	Polygon	39	19078
39	Polygon	40	19079
40	Polygon	41	19080

- Clear selected features

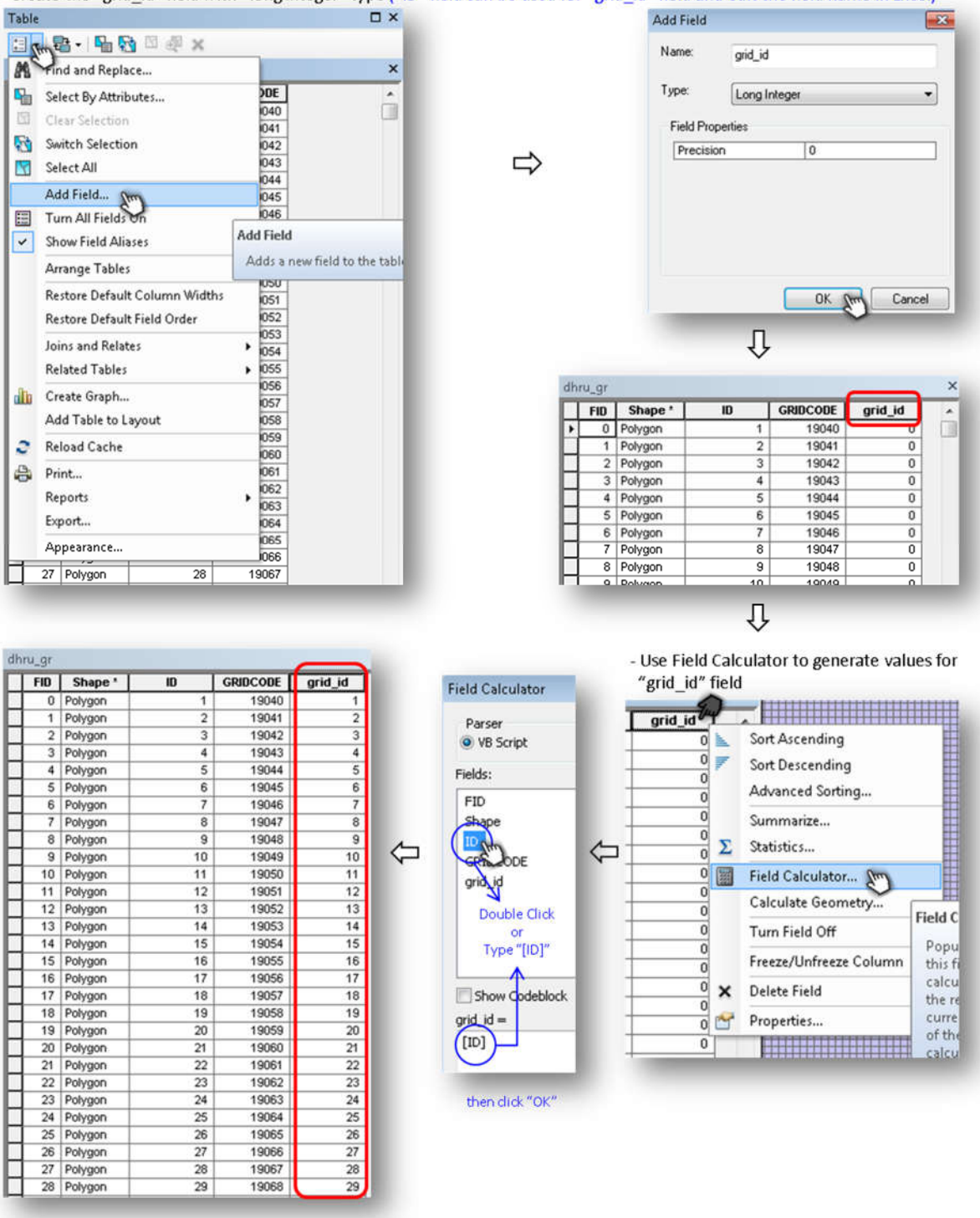


FID	Shape *	ID	GRIDCODE
0	Polygon	1	19040
1	Polygon	2	19041
2	Polygon	3	19042
3	Polygon	4	19043
4	Polygon	5	19044
5	Polygon	6	19045



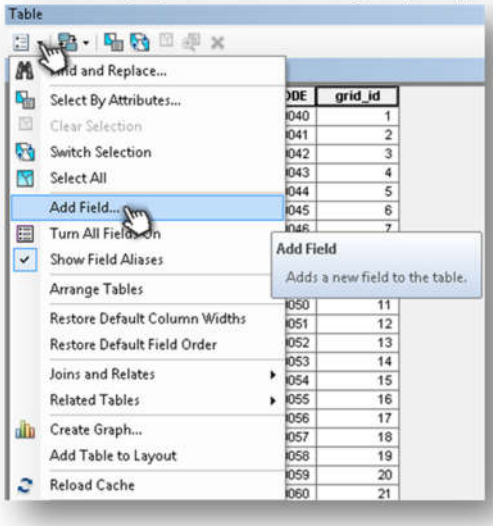
FID	Shape *	ID	GRIDCODE
0	Polygon	1	19040
1	Polygon	2	19041
2	Polygon	3	19042
3	Polygon	4	19043
4	Polygon	5	19044
5	Polygon	6	19045

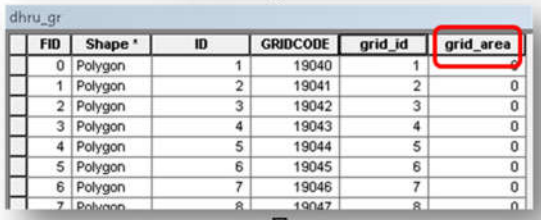
- Create the "grid_id" field with "long integer" type ("ID" field can be used for "grid_id" field and edit the field name in Excel)



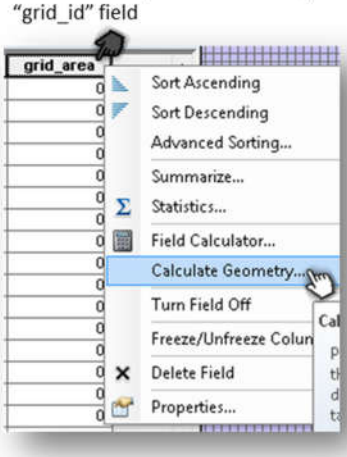
③ Calculate the spatial area of the grid cell

- Create the “grid_area” field with “long integer” type

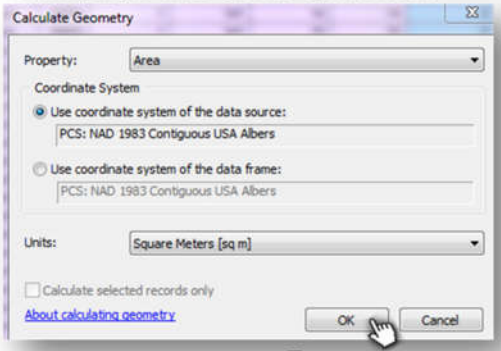




- Calculate the spatial area of the grid cell for “grid_id” field



- Set Property to “Area” & Units “Square Meters”

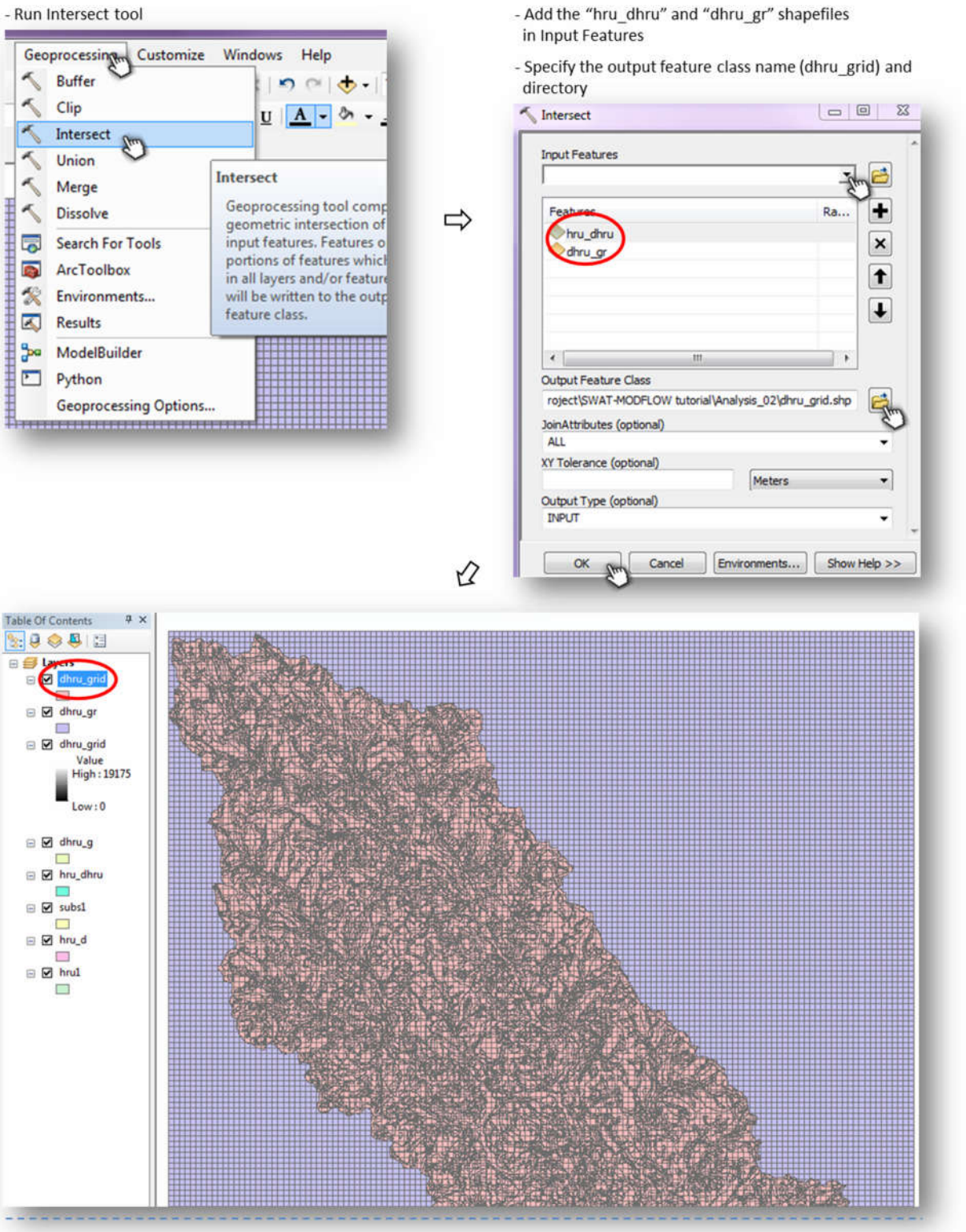


dhru_gr

FID	Shape *	ID	GRIDCODE	grid_id	grid_area
0	Polygon	1	19040	1	40000
1	Polygon	2	19041	2	40000
2	Polygon	3	19042	3	40000
3	Polygon	4	19043	4	40000
4	Polygon	5	19044	5	40000
5	Polygon	6	19045	6	40000
6	Polygon	7	19046	7	40000
7	Polygon	8	19047	8	40000
8	Polygon	9	19048	9	40000
9	Polygon	10	19049	10	40000
10	Polygon	11	19050	11	40000
11	Polygon	12	19051	12	40000
12	Polygon	13	19052	13	40000
13	Polygon	14	19053	14	40000
14	Polygon	15	19054	15	40000
15	Polygon	16	19055	16	40000
16	Polygon	17	19056	17	40000
17	Polygon	18	19057	18	40000
18	Polygon	19	19058	19	40000
19	Polygon	20	19059	20	40000

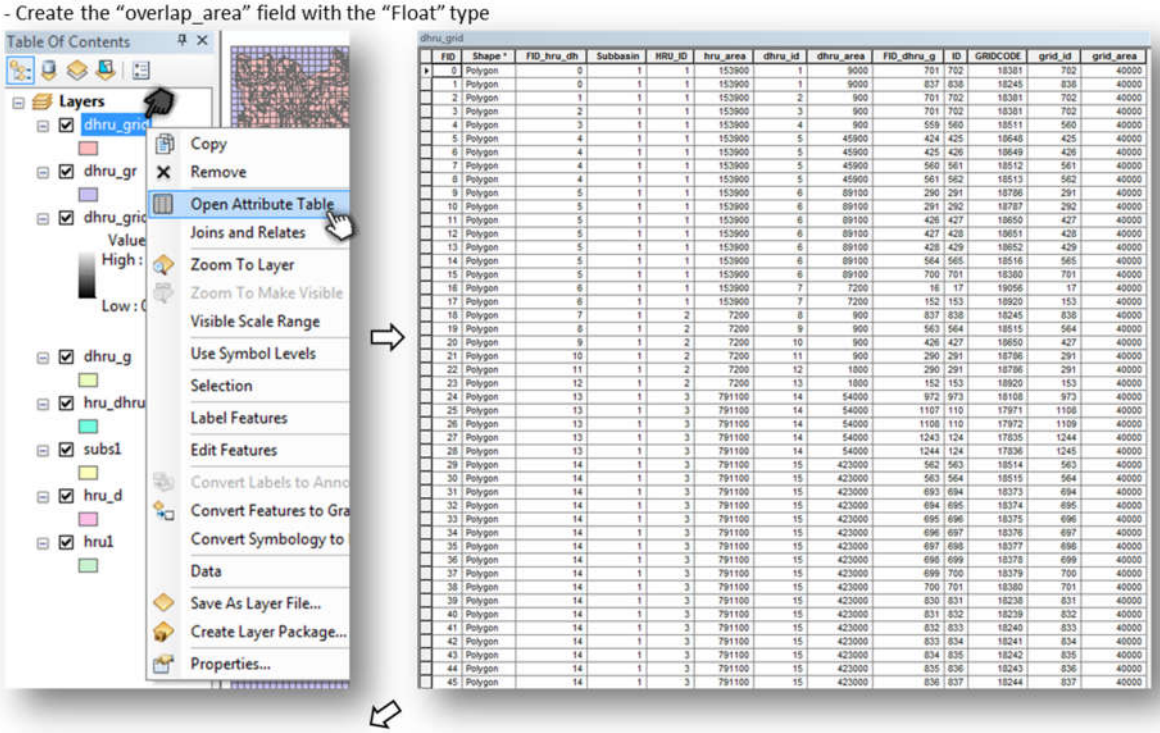
2. Intersect the “dhru_gr” shapefile with “hru_dhru” shapefile

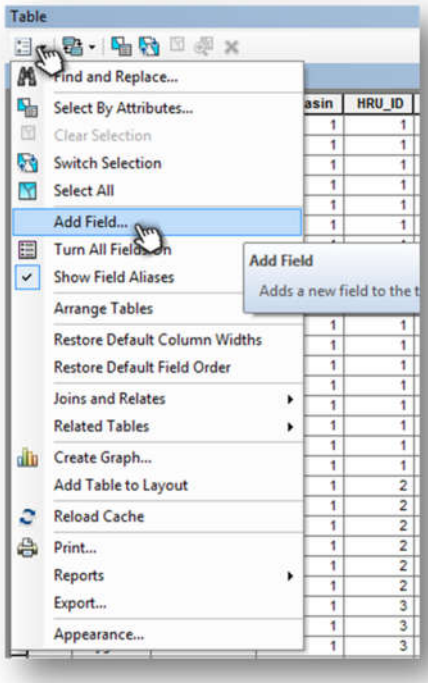
① Intersect the “dhru_gr” shapefile with “hru_dhru” shapefile



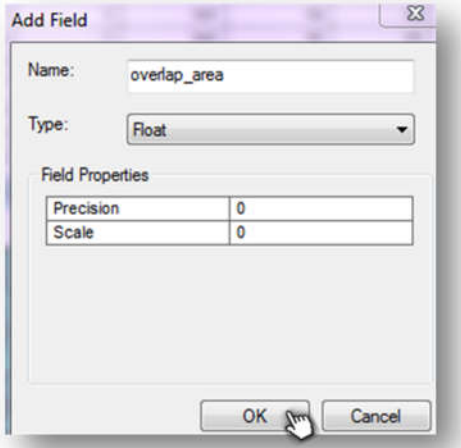
② Calculate the overlap area between Grid cells and DHRUs

- Create the “overlap_area” field with the “Float” type

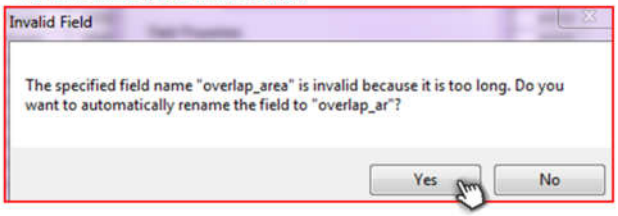




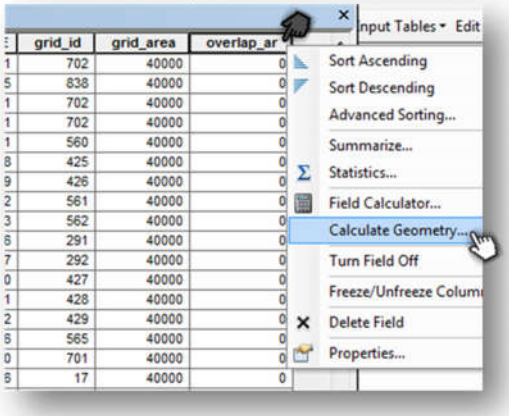
- Type “overlap_area” in Name
- Change Type to Float



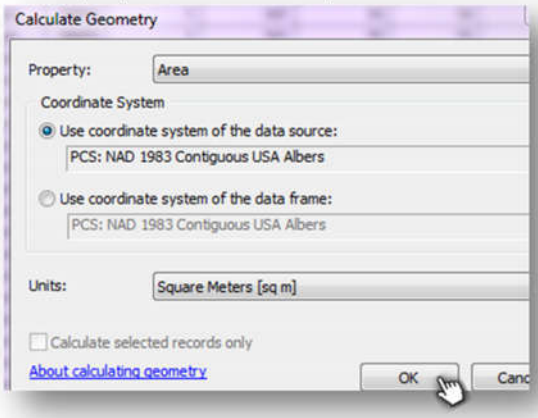
* Warning will be shown as the following figure. Click “Yes”.
The name will be edited with Excel later.



- Calculate the overlap area between Grid cells and DRHUs

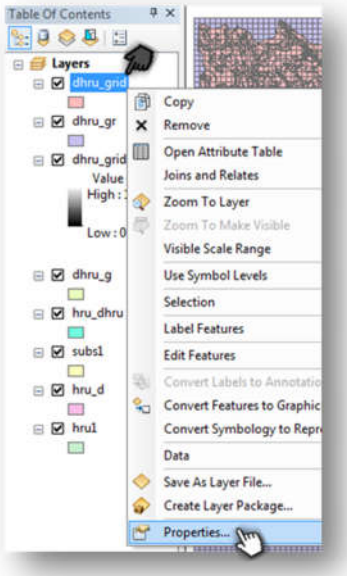


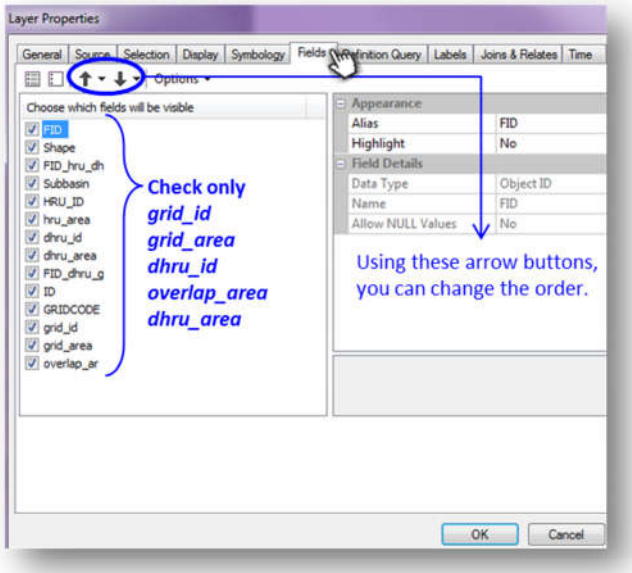
- Set Property to "Area" & Units "Square Meters"

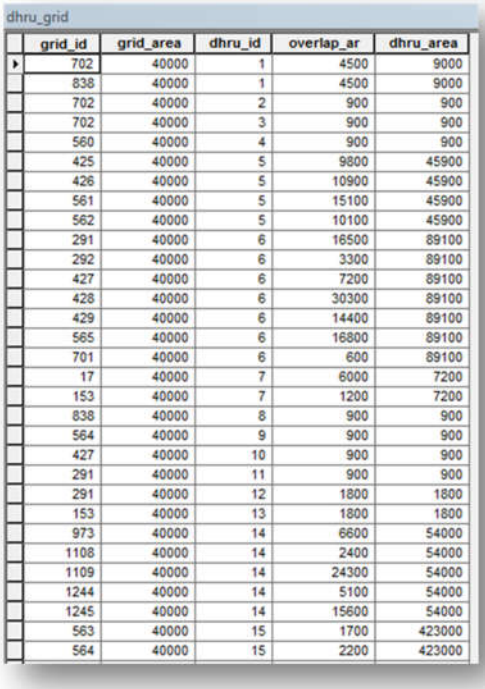


Subbasin	HRU_ID	hru_area	dhru_id	dhru_area	FID_dhru_g	ID	GRIDCODE	grid_id	grid_area	overlap_ar
1	1	153900	1	9000	701	702	18381	702	40000	4500
1	1	153900	1	9000	837	838	18245	838	40000	4500
1	1	153900	2	900	701	702	18381	702	40000	900
1	1	153900	3	900	701	702	18381	702	40000	900
1	1	153900	4	900	559	560	18511	560	40000	900
1	1	153900	5	45900	424	425	18648	425	40000	9800
1	1	153900	5	45900	425	426	18649	426	40000	10900
1	1	153900	5	45900	560	561	18512	561	40000	15100
1	1	153900	5	45900	561	562	18513	562	40000	10100
1	1	153900	6	89100	290	291	18786	291	40000	16500
1	1	153900	6	89100	291	292	18787	292	40000	3300
1	1	153900	6	89100	426	427	18650	427	40000	7200
1	1	153900	6	89100	427	428	18651	428	40000	30300
1	1	153900	6	89100	428	429	18652	429	40000	14400
1	1	153900	6	89100	564	565	18516	565	40000	16800
1	1	153900	6	89100	700	701	18380	701	40000	600
1	1	153900	7	7200	16	17	19056	17	40000	6000
1	1	153900	7	7200	152	153	18920	153	40000	1200
1	2	7200	8	900	837	838	18245	838	40000	900
1	2	7200	9	900	563	564	18515	564	40000	900
1	2	7200	10	900	426	427	18650	427	40000	900
1	2	7200	11	900	290	291	18786	291	40000	900
1	2	7200	12	1800	290	291	18786	291	40000	1800
1	2	7200	13	1800	152	153	18920	153	40000	1800
1	3	791100	14	54000	972	973	18108	973	40000	6600
1	3	791100	14	54000	1107	110	17971	1108	40000	2400
1	3	791100	14	54000	1108	110	17972	1109	40000	24300
1	3	791100	14	54000	1243	124	17835	1244	40000	5100
1	3	791100	14	54000	1244	124	17836	1245	40000	15600
1	3	791100	15	423000	562	563	18514	563	40000	1700
1	3	791100	15	423000	563	564	18515	564	40000	2200
1	3	791100	15	423000	693	694	18373	694	40000	2400
1	3	791100	15	423000	694	695	18374	695	40000	14700
1	3	791100	15	423000	695	696	18375	696	40000	14100
1	3	791100	15	423000	696	697	18376	697	40000	1200
1	3	791100	15	423000	697	698	18377	698	40000	4500
1	3	791100	15	423000	698	699	18378	699	40000	35500
1	3	791100	15	423000	699	700	18379	700	40000	34700
1	3	791100	15	423000	700	701	18380	701	40000	8700
1	3	791100	15	423000	830	831	18238	831	40000	9900
1	3	791100	15	423000	831	832	18239	832	40000	38400
1	3	791100	15	423000	832	833	18240	833	40000	35600

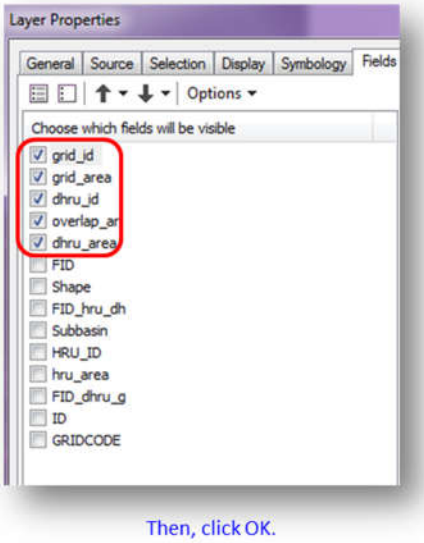
③ Select only the necessary fields (You can either turn off or delete an unnecessary field)






dhru_grid

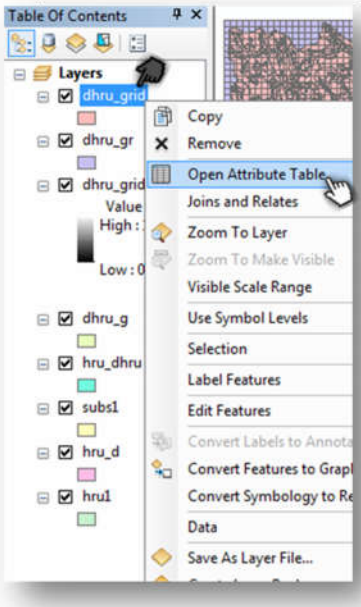
grid_id	grid_area	dhru_id	overlap_ar	dhru_area
702	40000	1	4500	9000
838	40000	1	4500	9000
702	40000	2	900	900
702	40000	3	900	900
560	40000	4	900	900
425	40000	5	9800	45900
426	40000	5	10900	45900
561	40000	5	15100	45900
562	40000	5	10100	45900
291	40000	6	16500	89100
292	40000	6	3300	89100
427	40000	6	7200	89100
428	40000	6	30300	89100
429	40000	6	14400	89100
565	40000	6	16800	89100
701	40000	6	600	89100
17	40000	7	6000	7200
153	40000	7	1200	7200
838	40000	8	900	900
564	40000	9	900	900
427	40000	10	900	900
291	40000	11	900	900
291	40000	12	1800	1800
153	40000	13	1800	1800
973	40000	14	6600	54000
1108	40000	14	2400	54000
1109	40000	14	24300	54000
1244	40000	14	5100	54000
1245	40000	14	15600	54000
563	40000	15	1700	423000
564	40000	15	2200	423000

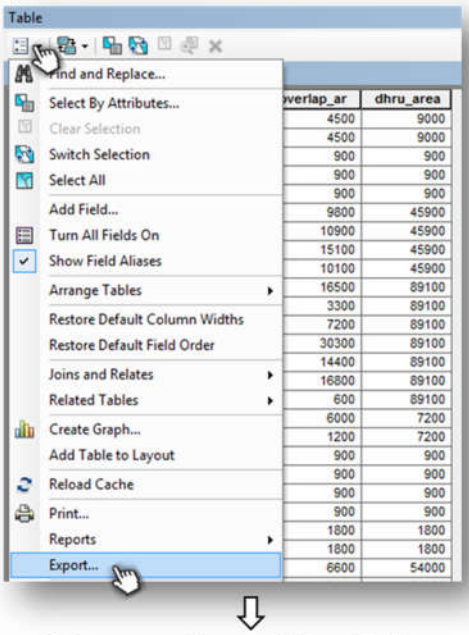


Then, click OK.

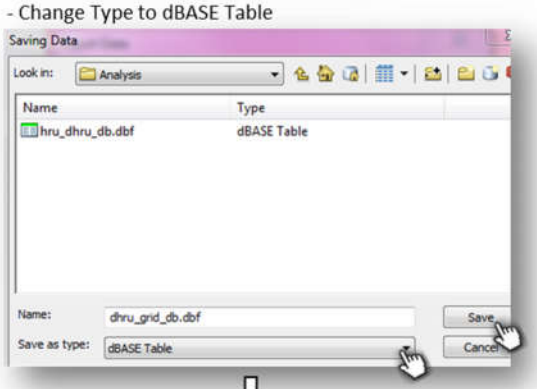
④ Provide text file: **dhru_grid** (This file is sorted by the "grid_id", then by "dhru_id")

- Export the attribute table of the "dhru_grid" shapefile as dBASE table (*.dbf)

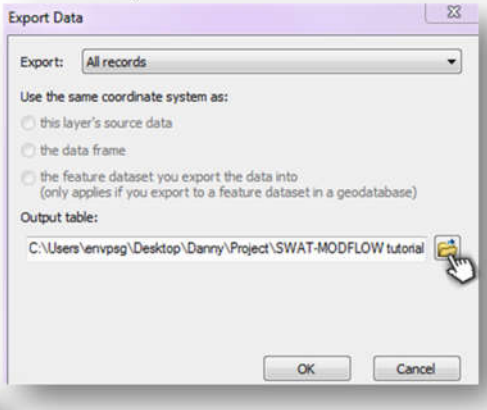




- Change Type to dBASE Table



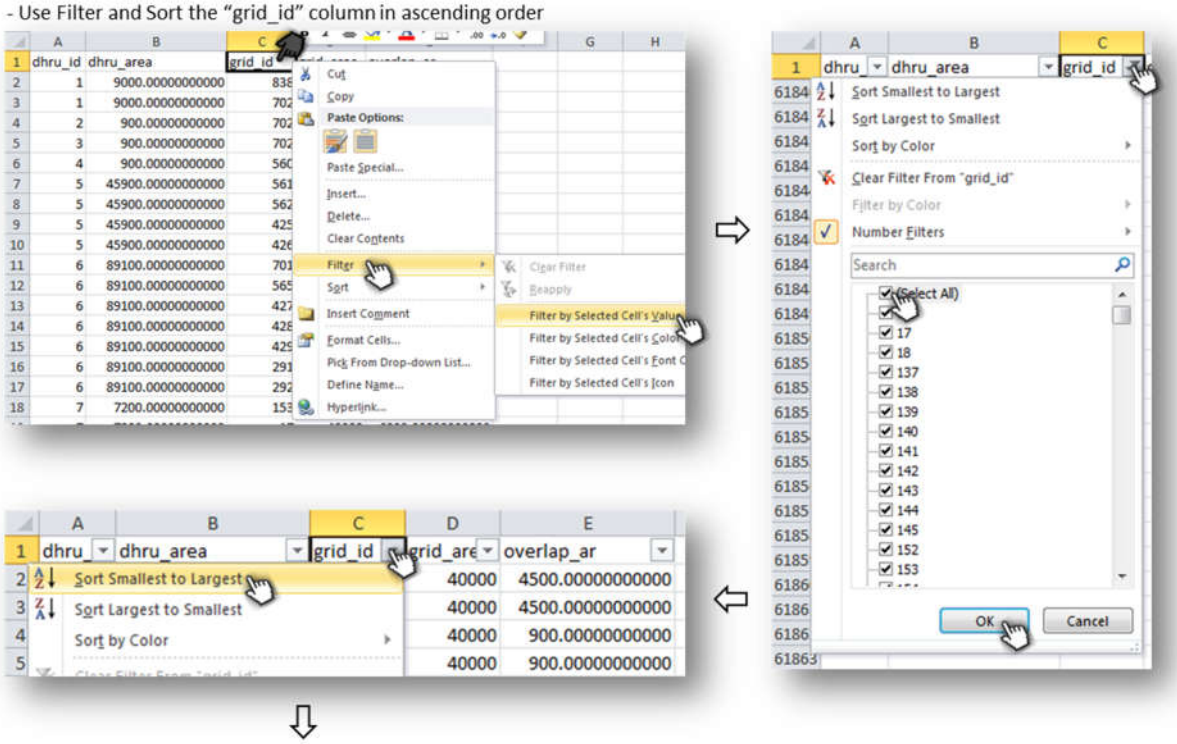
- Specify the output table name (dhru_grid_db) and directory



- Open the "dhru_grid_db" file with Excel

	A	B	C	D	E
1	dhru_id	dhru_area	grid_id	grid_area	overlap_ar
2	1	9000.00000000000	838	40000	4500.00000000000
3	1	9000.00000000000	702	40000	4500.00000000000
4	2	900.00000000000	702	40000	900.00000000000
5	3	900.00000000000	702	40000	900.00000000000
6	4	900.00000000000	560	40000	900.00000000000
7	5	45900.00000000000	561	40000	15100.00000000000
8	5	45900.00000000000	562	40000	10100.00000000000
9	5	45900.00000000000	425	40000	9800.00000000000
10	5	45900.00000000000	426	40000	10900.00000000000
11	6	89100.00000000000	701	40000	600.00000000000
12	6	89100.00000000000	565	40000	16800.00000000000
13	6	89100.00000000000	427	40000	7200.00000000000
14	6	89100.00000000000	428	40000	30300.00000000000

- Use Filter and Sort the "grid_id" column in ascending order



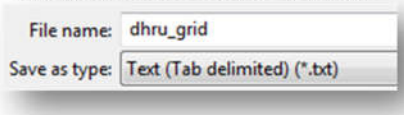
- Change the order of the columns and correct the column names

- Insert two rows at the top of the spreadsheet and write the number of lines with information (starting on Line 4) and number of MODFLOW grid cells

- Reduce the number of digits after decimal point if desired

	A	B	C	D	E
1	61838				
2	19176				
3	grid_id	grid_area	dhru_id	overlap_area	dhru_area
4	16	40000	27	3000	9900
5	16	40000	58	600	900
6	16	40000	63	1900	31500
7	17	40000	7	6000	7200
8	17	40000	27	6900	9900
9	17	40000	57	800	4500
10	17	40000	58	300	900
11	17	40000	63	800	31500
12	18	40000	57	400	4500
13	137	40000	1158	5600	76500
14	138	40000	1158	25100	76500
15	138	40000	1182	4500	11700
16	139	40000	1158	8600	76500
17	139	40000	1159	3300	272700
18	139	40000	1368	4200	9000
19	140	40000	1159	1400	272700
20	141	40000	1159	8300	272700
21	142	40000	1148	900	900
22	142	40000	1159	21800	272700
23	142	40000	1261	300	53100

- Save the spreadsheet as text file format




```
61838
19176
grid_id grid_area       dhru_id overlap_area    dhru_area
16      40000   27      3000    9900
16      40000   58      600     900
16      40000   63      1900    31500
17      40000   7       6000    7200
17      40000   27      6900    9900
17      40000   57      800     4500
17      40000   58      300     900
17      40000   63      800     31500
18      40000   57      400     4500
137     40000   1158    5600    76500
138     40000   1158    25100   76500
138     40000   1182    4500    11700
139     40000   1158    8600    76500
139     40000   1159    3300    272700
139     40000   1368    4200    9000
140     40000   1159    1400    272700
141     40000   1159    8300    272700
142     40000   1148    900     900
142     40000   1159    21800   272700
142     40000   1261    300     53100
143     40000   1145    900     900
143     40000   1146    900     900
143     40000   1155    3200    68400
143     40000   1159    900     272700
143     40000   1261    1500    53100
144     40000   1147    2700    5400
144     40000   1155    400     68400
144     40000   1156    900     900
144     40000   1157    700     7200
144     40000   1163    900     6300
```

4.1.3 Linkage between DHRUs and MODFLOW Grid cells (sorted by dhru_id)

File to create: **grid_dhru**. The same content as in **dhru_grid**, except sorted by *dhru_id*, then by *grid_id*. Also, the following information is needed at the beginning of the file:

At the top of the file:

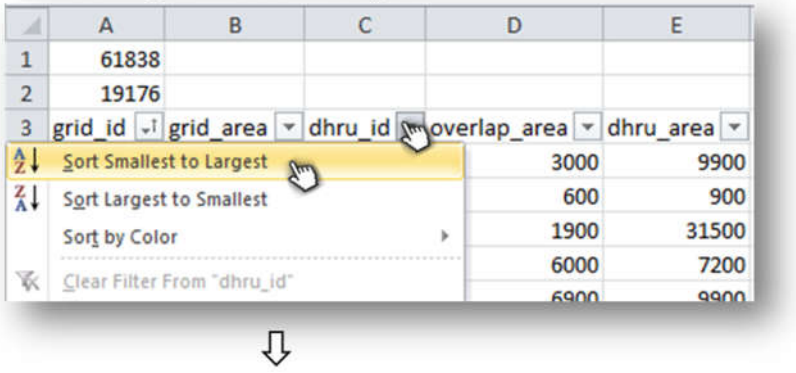
Number of lines with information (starting on Line 6)
Number of DHRUs
Number of rows (in the MODFLOW grid)
Number of columns (in the MODFLOW grid)

For example:

```
1  61838
2  27396
3  141
4  136
5  grid_id grid_area       dhru_id overlap_area    dhru_area
6  702     40000   1       4500    9000
7  838     40000   1       4500    9000
8  702     40000   2       900     900
9  702     40000   3       900     900
10 560     40000   4       900     900
11 425     40000   5       9800    45900
12 426     40000   5       10900   45900
13 561     40000   5       15100   45900
14 562     40000   5       10100   45900
15 291     40000   6       16500   89100
16 292     40000   6       3300    89100
17 427     40000   6       7200    89100
18 428     40000   6       30300   89100
19 429     40000   6       14400   89100
20 565     40000   6       16800   89100
21 701     40000   6       600     89100
22 17      40000   7       6000    7200
23 153     40000   7       1200    7200
24 838     40000   8       900     900
25 564     40000   9       900     900
26 427     40000   10      900     900
27 291     40000   11      900     900
28 291     40000   12      1800    1800
29 153     40000   13      1800    1800
30 973     40000   14      6600    54000
31 1108    40000   14      2400    54000
32 1109    40000   14      24300   54000
33 1244    40000   14      5100    54000
34 1245    40000   14      15600   54000
35 563     40000   15      1700    423000
36 564     40000   15      2200    423000
37 694     40000   15      2400    423000
38 695     40000   15      14700   423000
39 696     40000   15      14100   423000
```

① Provide text file: **grid_dhru** (This file is sorted by the "*dhru_id*", then by "*grid_id*")

- Sort the "dhru_id" column in ascending order

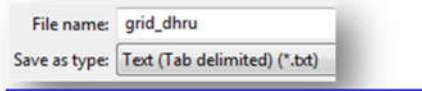


- Insert two more rows above the row with the names of the columns

- Keep the value in 1st row, change the value to the number of DHRUs in 2nd row, add the number of rows (in the MODFLOW grid) in 3rd row, and the number of columns (in the MODFLOW grid) in 4th row.

	A	B	C	D	E
1	61838				
2	27396				
3	141				
4	136				
5	grid_id	grid_area	dhru_id	overlap_area	dhru_area
6	702	40000	1	4500	9000
7	838	40000	1	4500	9000
8	702	40000	2	900	900
9	702	40000	3	900	900
10	560	40000	4	900	900
11	425	40000	5	9800	45900
12	426	40000	5	10900	45900
13	561	40000	5	15100	45900
14	562	40000	5	10100	45900
15	291	40000	6	16500	89100
16	292	40000	6	3300	89100
17	427	40000	6	7200	89100
18	428	40000	6	30300	89100
19	429	40000	6	14400	89100
20	565	40000	6	16800	89100
21	701	40000	6	600	89100
22	17	40000	7	6000	7200
23	153	40000	7	1200	7200
24	838	40000	8	900	900
25	564	40000	9	900	900
26	427	40000	10	900	900
27	291	40000	11	900	900
28	291	40000	12	1800	1800
29	153	40000	13	1800	1800
30	973	40000	14	6600	54000
31	1108	40000	14	2400	54000
32	1109	40000	14	24300	54000
33	1244	40000	14	5100	54000
34	1245	40000	14	15600	54000

- Save the spreadsheet as the text file format




```
61838
27396
141
136
grid_id grid_area       dhru_id overlap_area    dhru_area
702     40000   1       4500    9000
838     40000   1       4500    9000
702     40000   2       900     900
702     40000   3       900     900
560     40000   4       900     900
425     40000   5       9800    45900
426     40000   5       10900   45900
561     40000   5       15100   45900
562     40000   5       10100   45900
291     40000   6       16500   89100
292     40000   6       3300    89100
427     40000   6       7200    89100
428     40000   6       30300   89100
429     40000   6       14400   89100
565     40000   6       16800   89100
701     40000   6       600     89100
17      40000   7       6000    7200
153     40000   7       1200    7200
838     40000   8       900     900
564     40000   9       900     900
427     40000   10      900     900
291     40000   11      900     900
291     40000   12      1800    1800
153     40000   13      1800    1800
973     40000   14      6600    54000
1108    40000   14      2400    54000
1109    40000   14      24300   54000
1244    40000   14      5100    54000
1245    40000   14      15600   54000
563     40000   15      1700    423000
564     40000   15      2200    423000
694     40000   15      2400    423000
695     40000   15      14700   423000
696     40000   15      14100   423000
697     40000   15      1200    423000
698     40000   15      4500    423000
```

4.1.4 Linkage between MODFLOW River Cells and Subbasins

File to create: **river_grid**.

At the top of the file:

Number of lines with information (starting on Line 3)

Then, the following columns (sorted by grid column, then by grid row):

grid_id: ID of the MODFLOW grid cell
subbasin: ID of the Subbasin
rgrid_len: Length of the stream in the grid cell

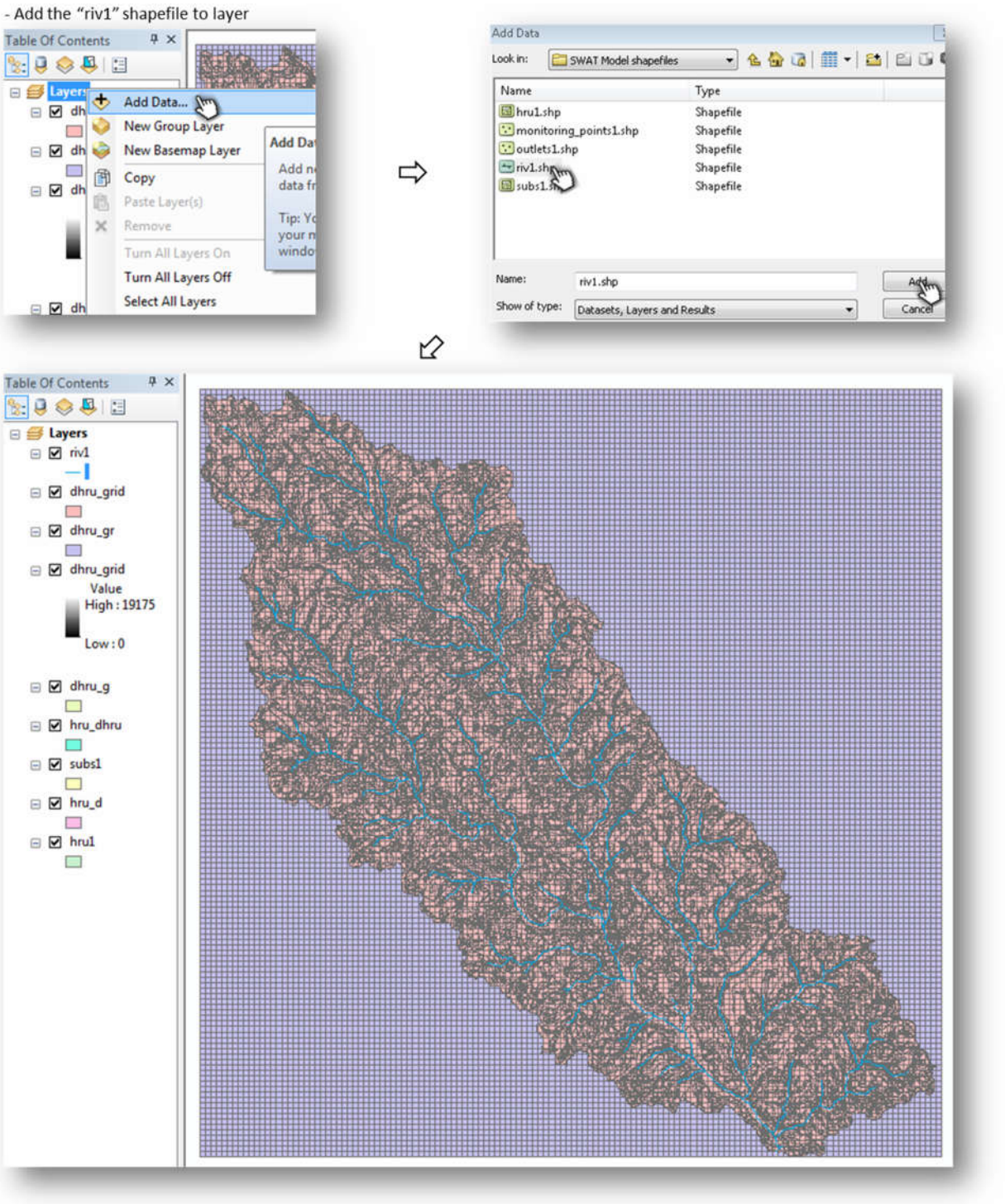
Note: the SWAT-MODFLOW code uses the *grid_id* of each cell to link with River Cells specified in the MODFLOW River package. The code matches this *grid_id* and the ID of the River Cells to provide groundwater return flow rates to the correct SWAT subbasin.

For example:

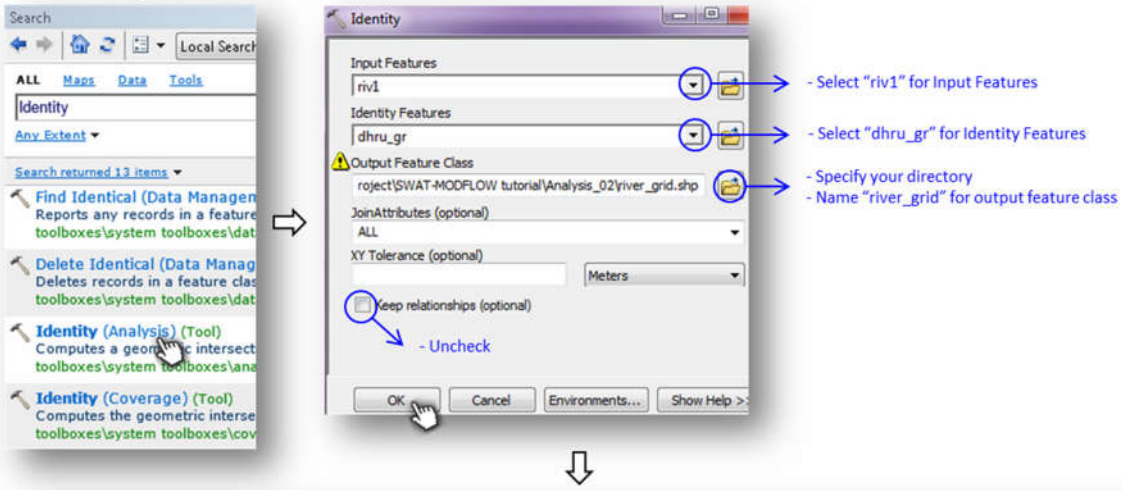
```
1921
grid_id subbasin        rgrid_len
564     1       197.78200000000
565     1       199.70600000000
701     1       203.13700000000
702     1       42.42640000000
820     9       7.07105000000
821     9       144.85300000000
838     1       123.64000000000
838     57      151.92400000000
957     9       100.71100000000
958     9       259.70600000000
974     57      40.35530000000
975     57      277.63500000000
976     57      102.78200000000
1094    9       28.28430000000
1095    9       287.99000000000
1096    9       14.14210000000
1098    17      153.64000000000
1112    57      215.20800000000
1113    57      114.85300000000
1232    9       257.99000000000
1234    17      245.56300000000
1249    57      173.13700000000
1250    57      245.56300000000
1251    57      102.07100000000
1368    9       60.35530000000
1369    9       217.27900000000
1371    49      35.35530000000
1371    25      55.00000000000
1371    17      282.63500000000
1372    25      119.85300000000
```

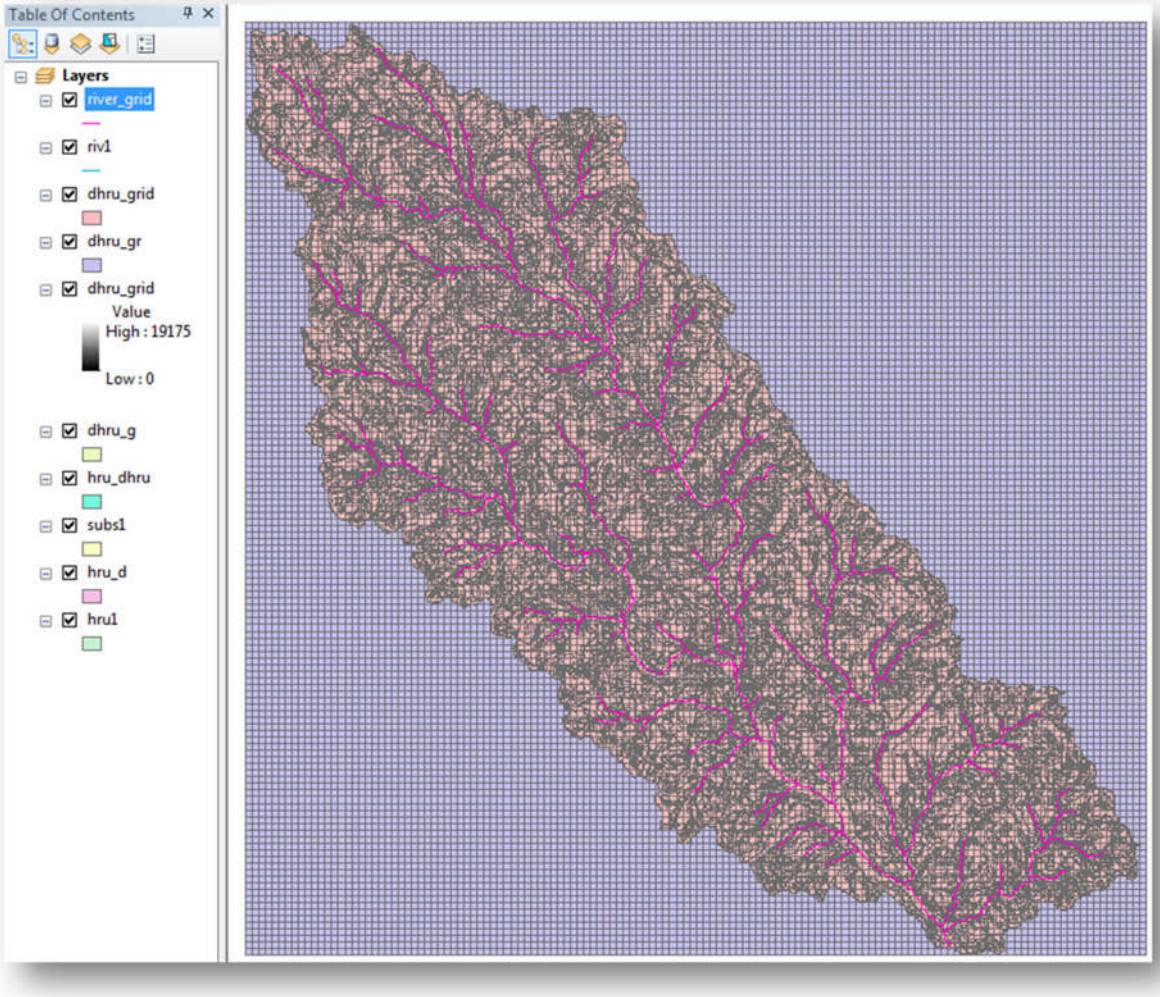
1. Compute SWAT stream network in the MODFLOW Grid

① Calculate each length of the stream in each grid cell

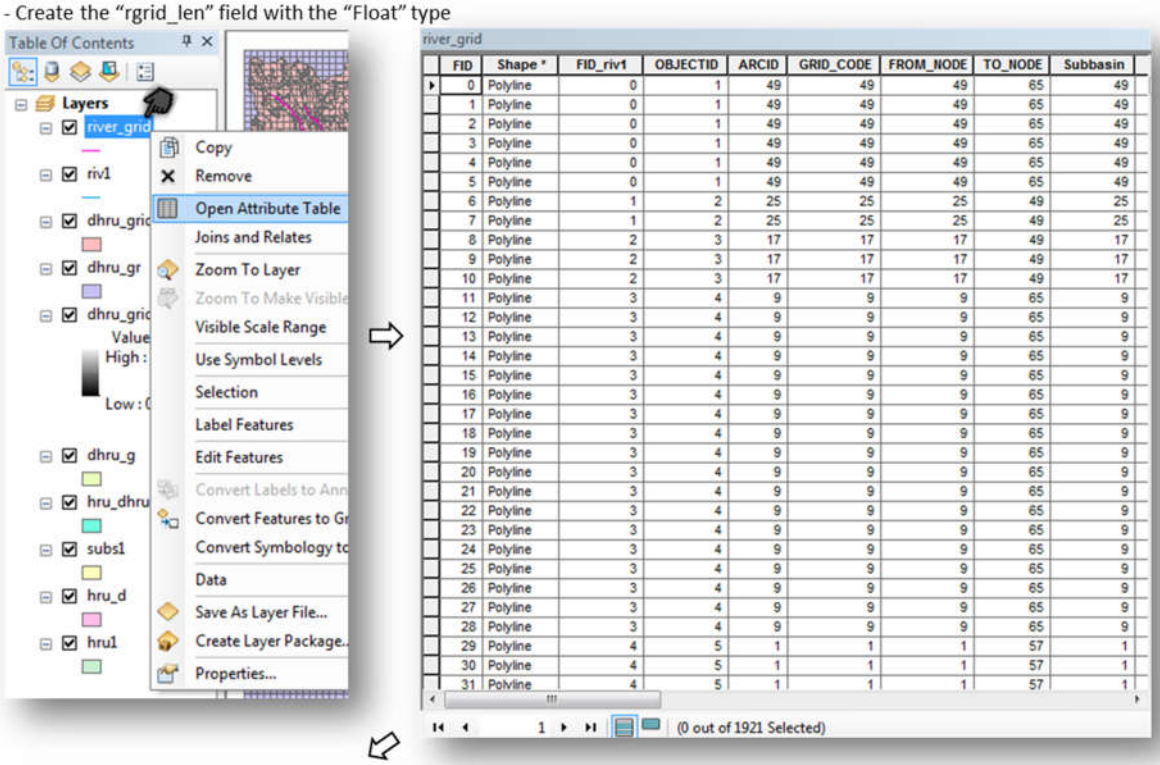


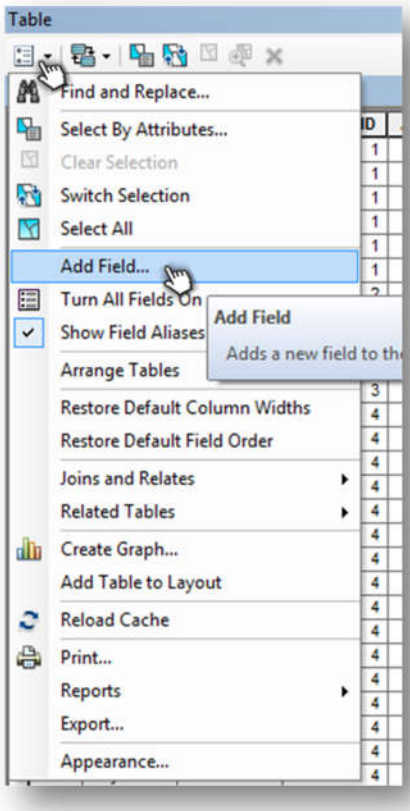
- Open "Identity" tool



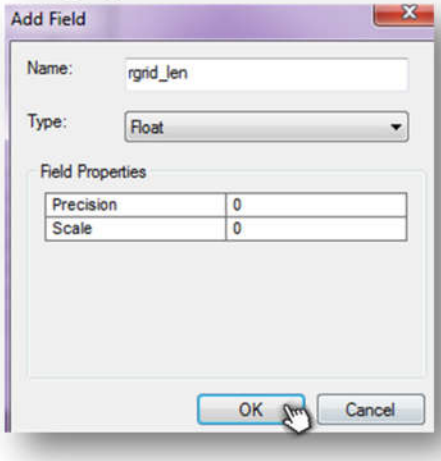


- Create the “rgrid_len” field with the “Float” type

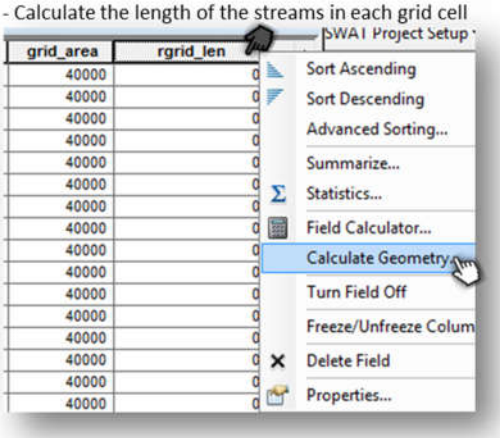




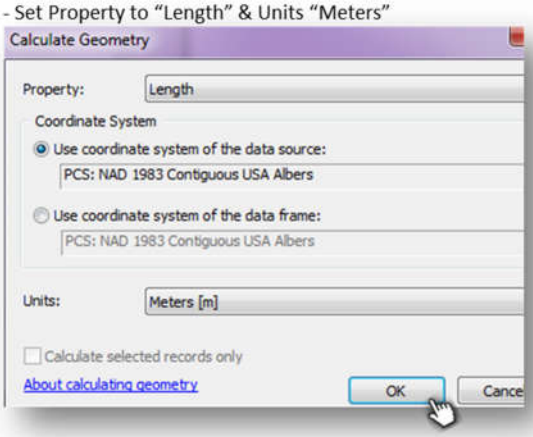
- Type “rgrid_len” in Name
- Change Type to Float



- Calculate the length of the streams in each grid cell



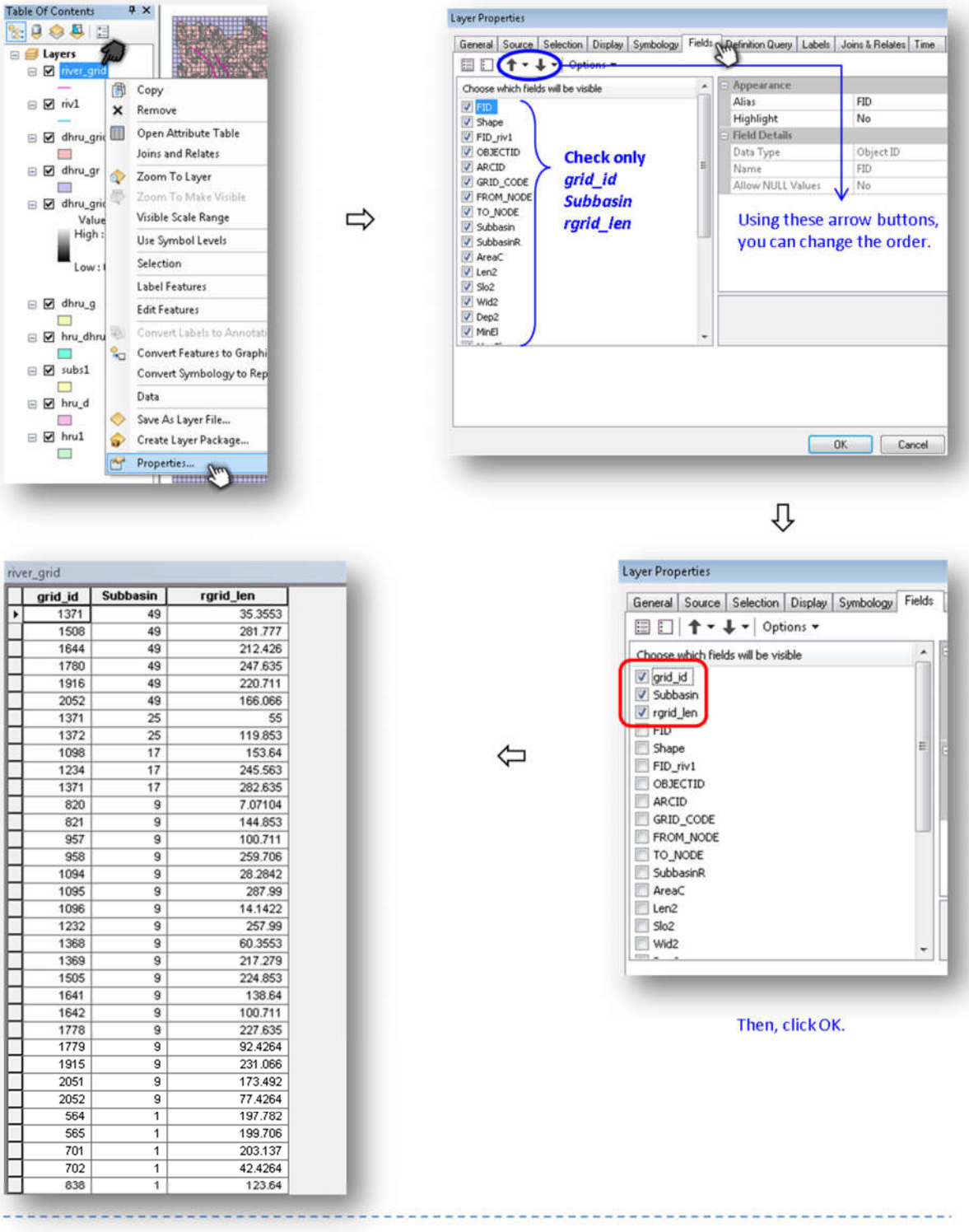
- Set Property to "Length" & Units "Meters"



river_grid

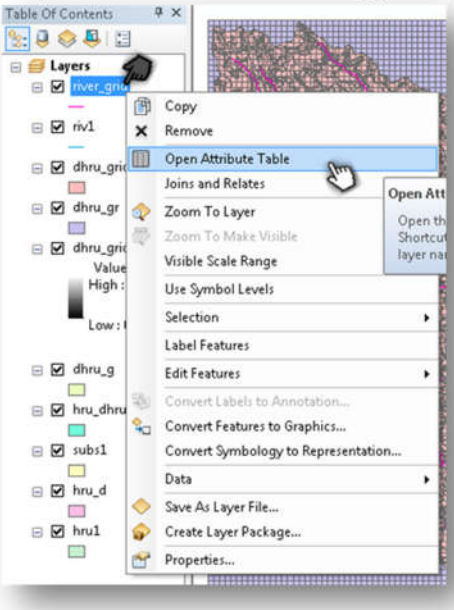
MinEl	MaxEl	Shape_Leng	HydroID	OutletID	FID_dhru_g	ID	GRIDCODE	grid_id	grid_area	rgrid_len
118.375839	124.356331	1163.969696	200001	100001	1370	137	17690	1371	40000	35.3553
118.375839	124.356331	1163.969696	200001	100001	1507	150	17555	1508	40000	281.777
118.375839	124.356331	1163.969696	200001	100001	1643	164	17419	1644	40000	212.426
118.375839	124.356331	1163.969696	200001	100001	1779	178	17283	1780	40000	247.635
118.375839	124.356331	1163.969696	200001	100001	1915	191	17147	1916	40000	220.711
118.375839	124.356331	1163.969696	200001	100001	2051	205	17011	2052	40000	166.066
124.356331	124.82679	174.852814	200002	100002	1370	137	17690	1371	40000	55
124.356331	124.82679	174.852814	200002	100002	1371	137	17691	1372	40000	119.853
124.356331	130.780838	681.837662	200003	100003	1097	109	17961	1098	40000	153.64
124.356331	130.780838	681.837662	200003	100003	1233	123	17825	1234	40000	245.563
124.356331	130.780838	681.837662	200003	100003	1370	137	17690	1371	40000	282.635
118.375839	130.102158	2644.629868	200004	100004	819	820	18227	820	40000	7.07104
118.375839	130.102158	2644.629868	200004	100004	820	821	18228	821	40000	144.853
118.375839	130.102158	2644.629868	200004	100004	956	957	18092	957	40000	100.711
118.375839	130.102158	2644.629868	200004	100004	957	958	18093	958	40000	259.706
118.375839	130.102158	2644.629868	200004	100004	1093	109	17957	1094	40000	28.2842
118.375839	130.102158	2644.629868	200004	100004	1094	109	17958	1095	40000	287.99
118.375839	130.102158	2644.629868	200004	100004	1095	109	17959	1096	40000	14.1422
118.375839	130.102158	2644.629868	200004	100004	1231	123	17823	1232	40000	257.99
118.375839	130.102158	2644.629868	200004	100004	1367	136	17687	1368	40000	60.3553
118.375839	130.102158	2644.629868	200004	100004	1368	136	17688	1369	40000	217.279
118.375839	130.102158	2644.629868	200004	100004	1504	150	17552	1505	40000	224.853
118.375839	130.102158	2644.629868	200004	100004	1640	164	17416	1641	40000	138.64
118.375839	130.102158	2644.629868	200004	100004	1641	164	17417	1642	40000	100.711
118.375839	130.102158	2644.629868	200004	100004	1777	177	17281	1778	40000	227.635
118.375839	130.102158	2644.629868	200004	100004	1778	177	17282	1779	40000	92.4264
118.375839	130.102158	2644.629868	200004	100004	1914	191	17146	1915	40000	231.066
118.375839	130.102158	2644.629868	200004	100004	2050	205	17010	2051	40000	173.492
118.375839	130.102158	2644.629868	200004	100004	2051	205	17011	2052	40000	77.4264
124.310143	125.786995	766.690476	200005	100005	563	564	18515	564	40000	197.782
124.310143	125.786995	766.690476	200005	100005	564	565	18516	565	40000	199.706
124.310143	125.786995	766.690476	200005	100005	700	701	18380	701	40000	203.137
124.310143	125.786995	766.690476	200005	100005	701	702	18381	702	40000	42.4264
124.310143	125.786995	766.690476	200005	100005	837	838	18245	838	40000	123.64
106.066887	109.088539	1978.233765	200006	100006	3837	383	15261	3838	40000	195.208
106.066887	109.088539	1978.233765	200006	100006	3838	383	15262	3839	40000	244.497
106.066887	109.088539	1978.233765	200006	100006	3839	384	15263	3840	40000	235.208
106.066887	109.088539	1978.233765	200006	100006	3840	384	15264	3841	40000	277.279
106.066887	109.088539	1978.233765	200006	100006	3971	397	15123	3972	40000	4.99998
106.066887	109.088539	1978.233765	200006	100006	3972	397	15124	3973	40000	210.355
106.066887	109.088539	1978.233765	200006	100006	3973	397	15125	3974	40000	86.5686
106.066887	109.088539	1978.233765	200006	100006	3976	397	15128	3977	40000	98.6395
106.066887	109.088539	1978.233765	200006	100006	3977	397	15129	3978	40000	217.279
106.066887	109.088539	1978.233765	200006	100006	3978	397	15130	3979	40000	42.4264
106.066887	109.088539	1978.233765	200006	100006	4113	411	14993	4114	40000	88.2842

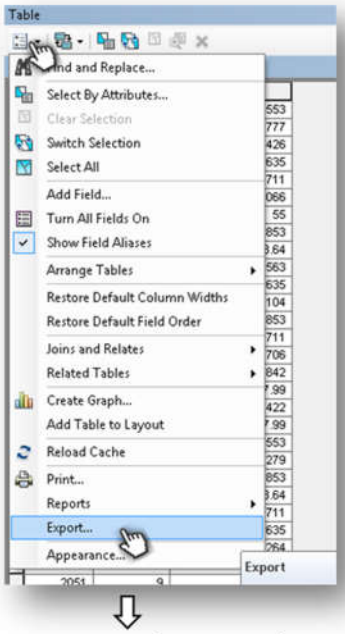
② Select only the necessary fields (You can either turn off or delete unnecessary fields)



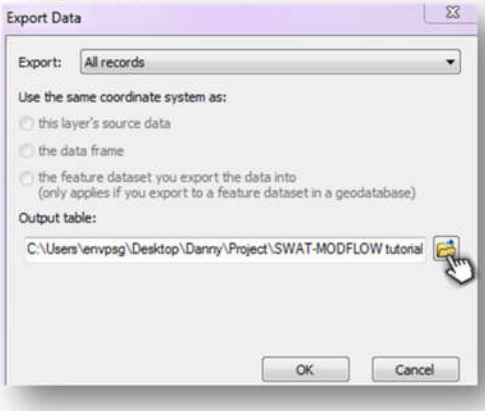
③ Provide text file: **river_grid**

- Export the attribute table of the "river_grid" shapefile as dBASE table (*.dbf)

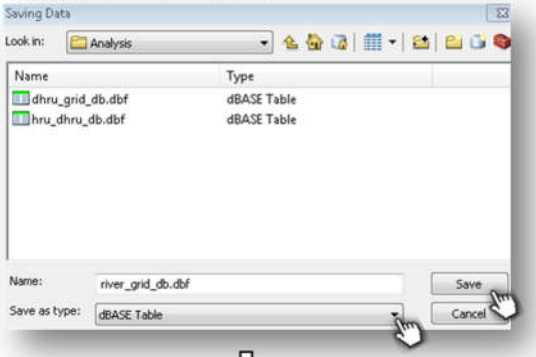




- Specify the output table name (river_grid_db) and directory



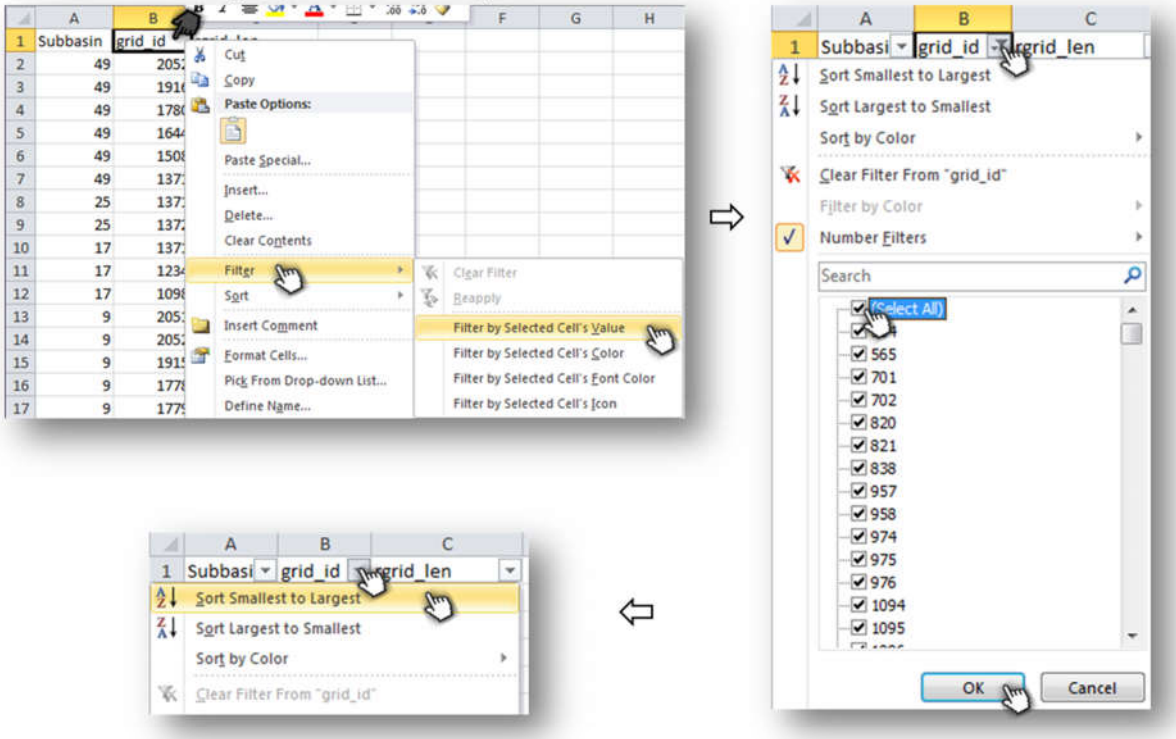
- Change Type to dBASE Table



- Open the "river_grid_db" file with Excel

	A	B	C
1	Subbasin	grid_id	rgrid_len
2	49	2052	166.06600000000
3	49	1916	220.71100000000
4	49	1780	247.63500000000
5	49	1644	212.42600000000
6	49	1508	281.77700000000
7	49	1371	35.35530000000
8	25	1371	55.00000000000
9	25	1372	119.85300000000
10	17	1371	282.63500000000
11	17	1234	245.56300000000
12	17	1098	153.64000000000
13	9	2051	173.49200000000
14	9	2052	77.42640000000

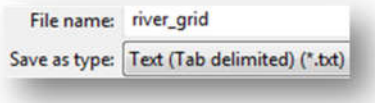
- Use Filter and Sort the “grid_id” column in ascending order



- Change the order of the columns and correct the column names
- Insert one row at the top of the spreadsheet and write the number of lines with information (starting on Line 3)
- Reduce the number of digits after decimal point if desired

	A	B	C
1	1921		
2	grid_id	subbasi	rgrid_len
3	564	1	197.78200000000
4	565	1	199.70600000000
5	701	1	203.13700000000
6	702	1	42.42640000000
7	820	9	7.07105000000
8	821	9	144.85300000000
9	838	1	123.64000000000
10	838	57	151.92400000000
11	957	9	100.71100000000
12	958	9	259.70600000000
13	974	57	40.35530000000
14	975	57	277.63500000000
15	976	57	102.78200000000
16	1094	9	28.28430000000
17	1095	9	287.99000000000
18	1096	9	14.14210000000

- Save the spreadsheet as text file format

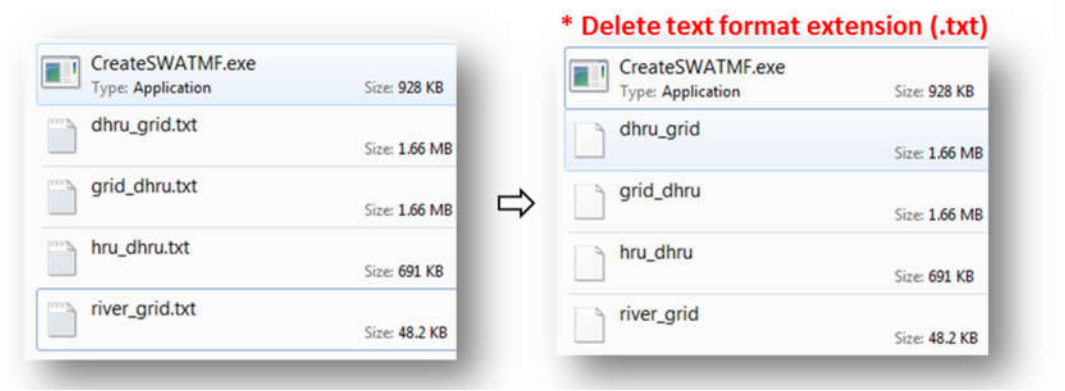



```
1  1921
2  grid_id subbasin        rgrid_len
3  564     1       197.78200000000
4  565     1       199.70600000000
5  701     1       203.13700000000
6  702     1       42.42640000000
7  820     9       7.07105000000
8  821     9       144.85300000000
9  838     1       123.64000000000
10 838     57      151.92400000000
11 957     9       100.71100000000
12 958     9       259.70600000000
13 974     57      40.35530000000
14 975     57      277.63500000000
15 976     57      102.78200000000
16 1094    9       28.28430000000
17 1095    9       287.99000000000
18 1096    9       14.14210000000
19 1098    17      153.64000000000
20 1112    57      215.20800000000
21 1113    57      114.85300000000
22 1232    9       257.99000000000
23 1234    17      245.56300000000
24 1249    57      173.13700000000
25 1250    57      245.56300000000
26 1251    57      102.07100000000
27 1368    9       60.35530000000
28 1369    9       217.27900000000
29 1371    49      35.35530000000
30 1371    25      55.00000000000
31 1371    17      282.63500000000
32 1372    25      119.85300000000
33 1387    57      267.27900000000
```

4.2 CREATE SWAT-MODFLOW INPUT FILES

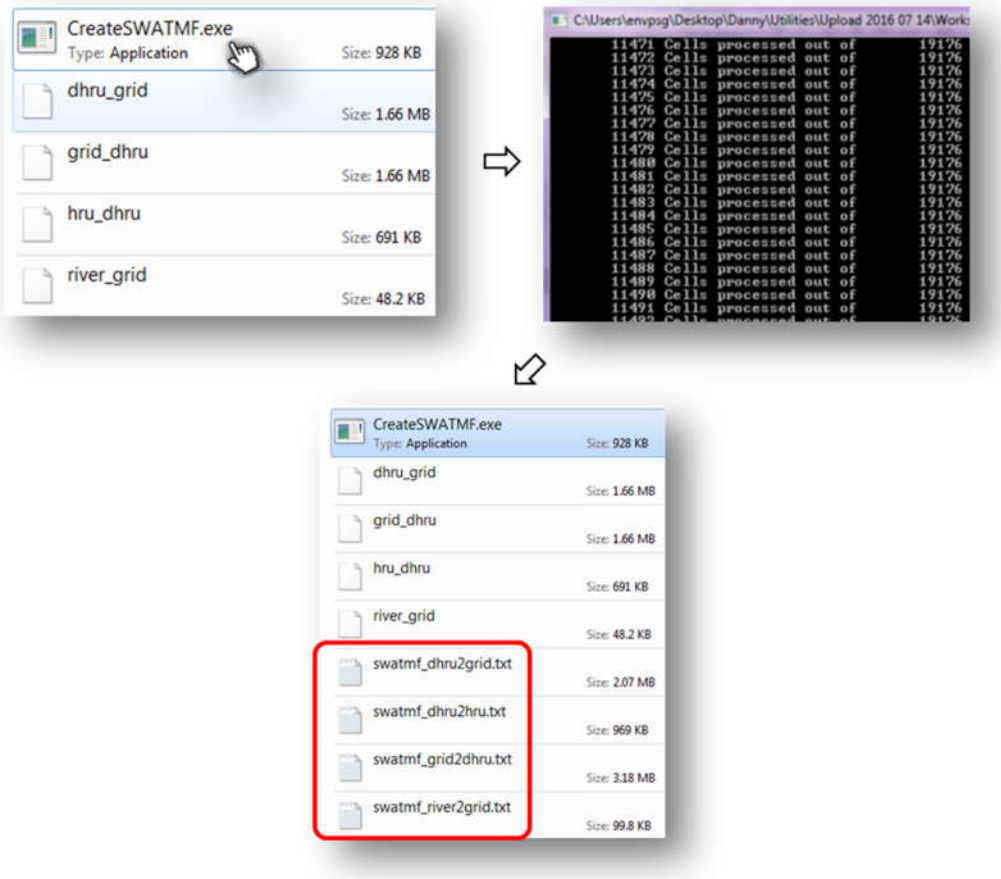
Now that the four linkage files have been created, the four SWAT-MODFLOW text input files can be created:

1. Place the **hru_dhru.txt**, **dhru_grid.txt**, **grid_dhru.txt**, and **river_grid.txt** files into the folder with the *CreateSWATMF.exe* FORTRAN program. Before running, make sure that the .txt extensions are deleted for each of the files.



2. Run *CreateSWATMF.exe*. Even for large watersheds with thousands of HRUs and MODFLOW grid cells, this program should only take 10-30 seconds to run. This will create the following files:

   - swatmf _dhru2hru.txt
   - swatmf _dhru2grid.txt
   - swatmf _grid2dhru.txt
   - swatmf _river2grid.txt


CreateSWATMF.exe
Type: Application
Size: 928 KB
dhru_grid
Size: 1.66 MB
grid_dhru
Size: 1.66 MB
hru_dhru
Size: 691 KB
river_grid
Size: 48.2 KB
C:\Users\envpsg\Desktop\Danny\Utilities\Upload 2016 07 14\Work
11471 Cells processed out of 19176
11472 Cells processed out of 19176
11473 Cells processed out of 19176
11474 Cells processed out of 19176
11475 Cells processed out of 19176
11476 Cells processed out of 19176
11477 Cells processed out of 19176
11478 Cells processed out of 19176
11479 Cells processed out of 19176
11480 Cells processed out of 19176
11481 Cells processed out of 19176
11482 Cells processed out of 19176
11483 Cells processed out of 19176
11484 Cells processed out of 19176
11485 Cells processed out of 19176
11486 Cells processed out of 19176
11487 Cells processed out of 19176
11488 Cells processed out of 19176
11489 Cells processed out of 19176
11490 Cells processed out of 19176
11491 Cells processed out of 19176
CreateSWATMF.exe
Type: Application
Size: 928 KB
dhru_grid
Size: 1.66 MB
grid_dhru
Size: 1.66 MB
hru_dhru
Size: 691 KB
river_grid
Size: 48.2 KB
swatmf_dhru2grid.txt
Size: 2.07 MB
swatmf_dhru2hru.txt
Size: 969 KB
swatmf_grid2dhru.txt
Size: 3.18 MB
swatmf_river2grid.txt
Size: 99.8 KB

3. Create the swatmf _link.txt file (see example file in the "Example Simulation - LRW\4 SWAT MODFLOW LRW" folder). This text file contains basic information for the SWAT-MODFLOW simulation:

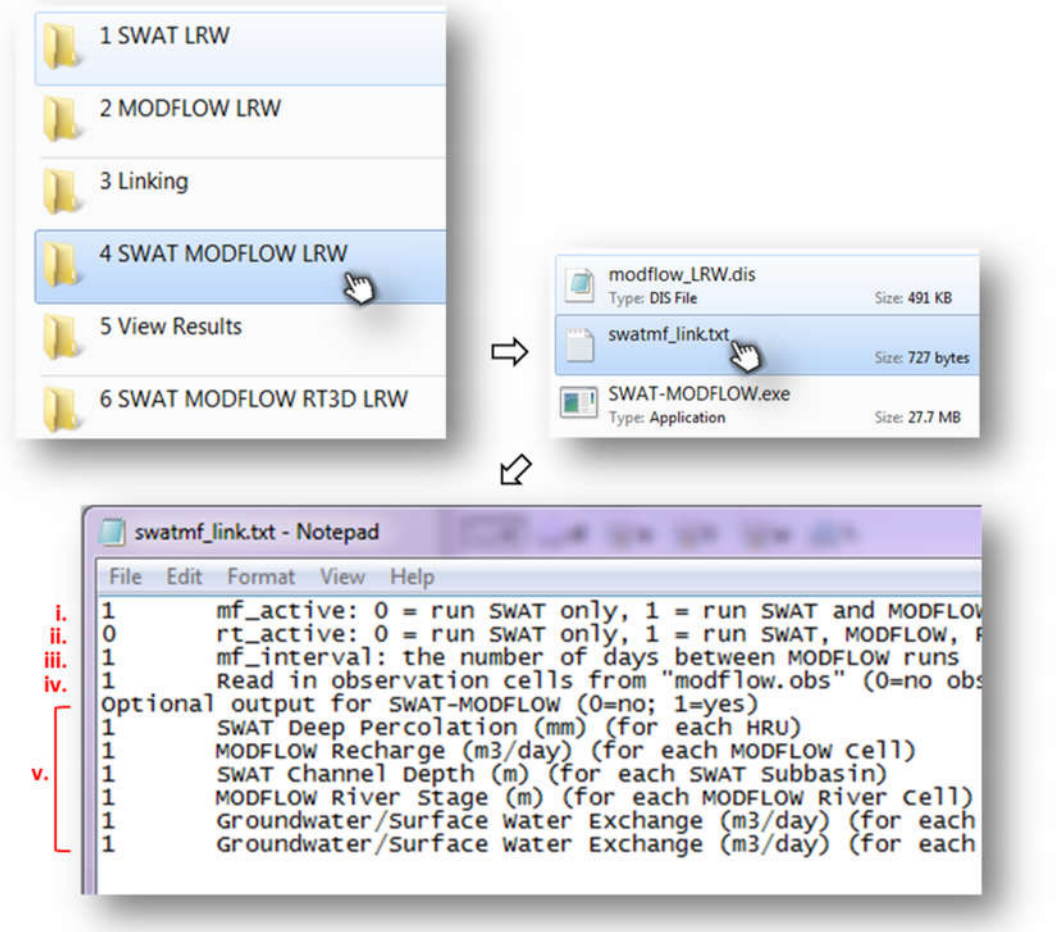
    i. Flag for including MODFLOW (0 or 1)

    ii. Flag for including RT3D (0 or 1) (for RT3D linkage, see Section 8)

    iii. Frequency of MODFLOW runs (# of days between MODFLOW calls)

    iv. Flag for reading observation cells (observation file was created). If desired, a modflow.obs file can be created. This file contains indices (I,J,K) for grid cells for which groundwater head data will be output for each time step. An example file is located in the "Example Simulation - LRW\2 MODFLOW LRW\MODFLOW model" folder.

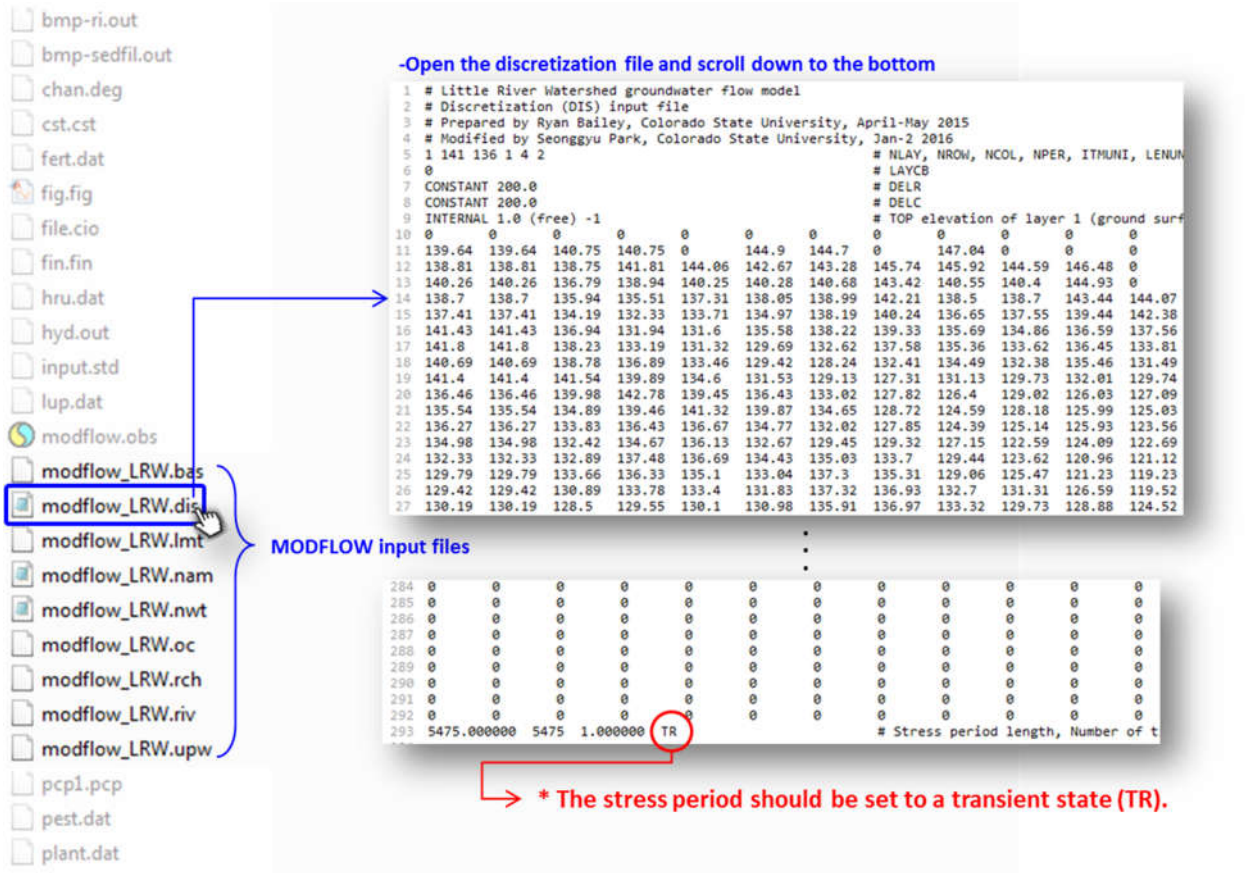
    v. Flags for optional model output (0 or 1)



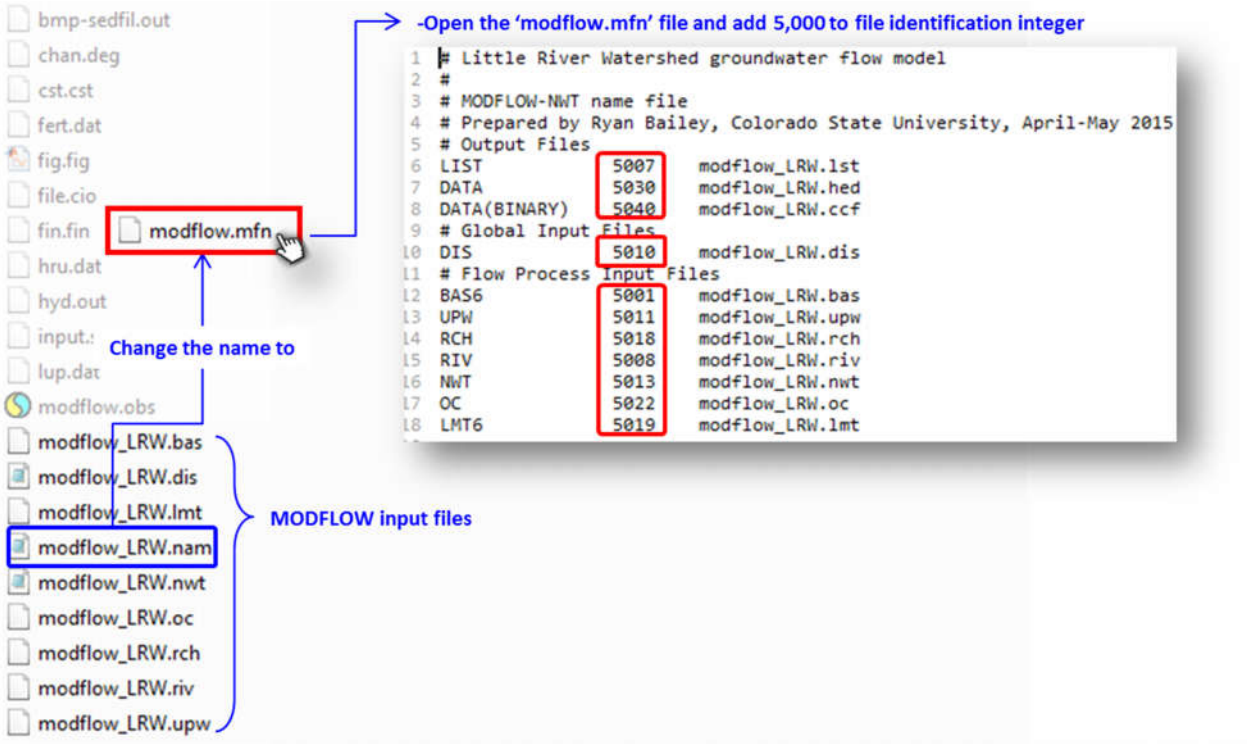
5. RUNNING THE SWAT-MODFLOW SIMULATION

5.1 Place the following files in the folder containing the original SWAT model:

- MODFLOW input files. Be sure to set your MODFLOW model to transient mode within the discretization file (*.dis):

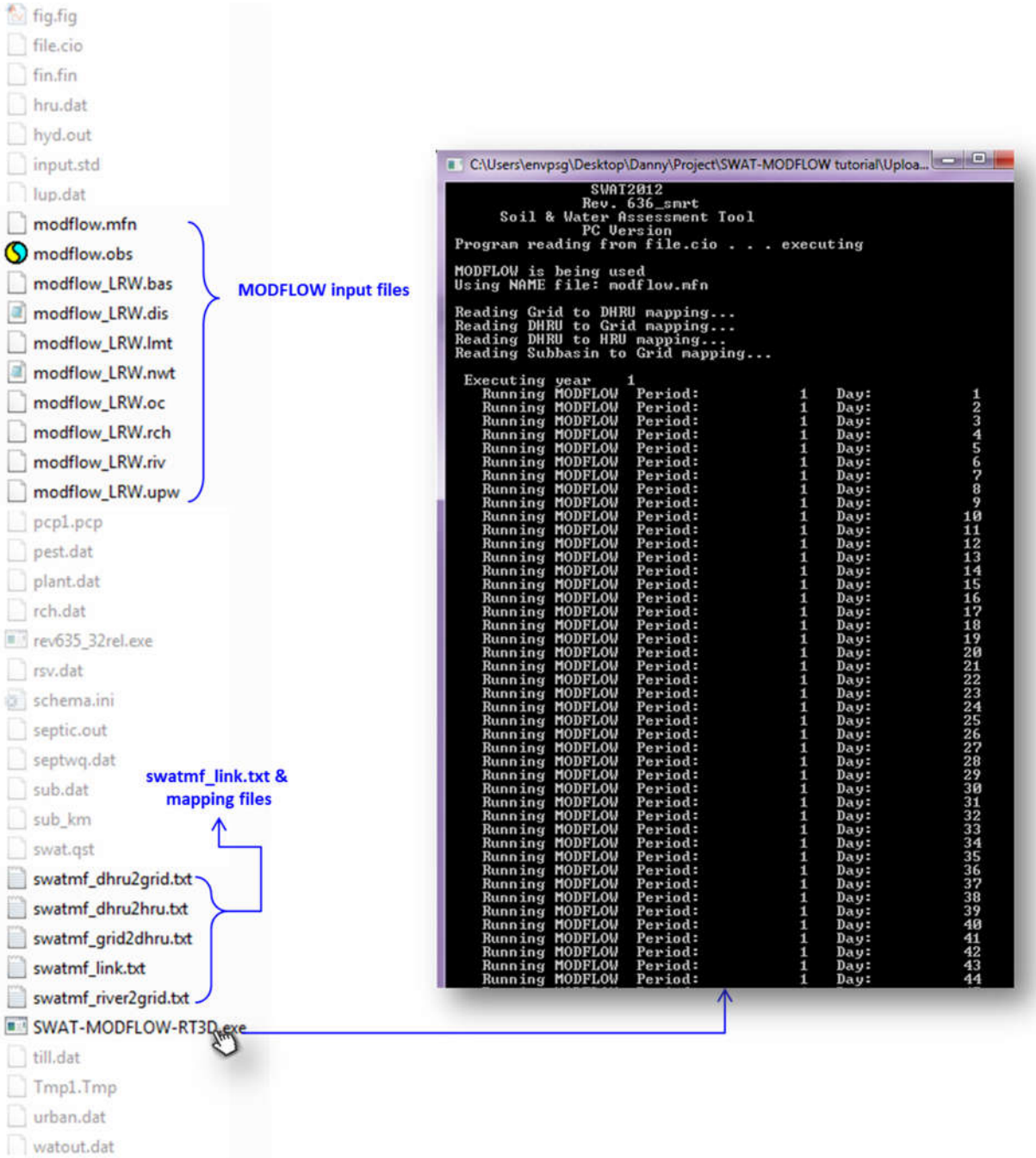


- MODFLOW name file (change name to modflow.mfn). Within the name file, add 5,000 to each file identification integer. This is done so that file integers do not conflict with SWAT input/output files.



- swatmf_link.txt
- Mapping files:
  - swatmf _dhru2hru.txt
  - swatmf _dhru2grid.txt
  - swatmf _grid2dhru.txt
  - swatmf _river2grid.txt

5.2 Run *SWAT_MODFLOW.exe* (rather than the original SWAT executable)

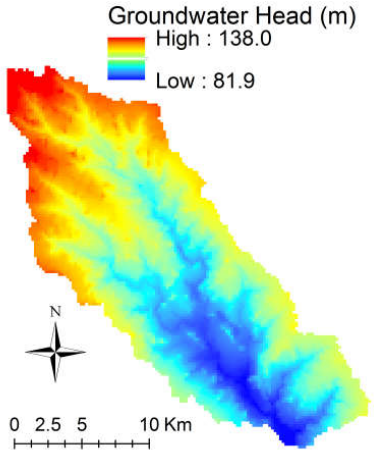


6. VIEWING RESULTS

The SWAT-MODFLOW simulation will produce several primary output files and, if selected in the *Simulation* tab, up to 6 additional output files:

modflow.hed

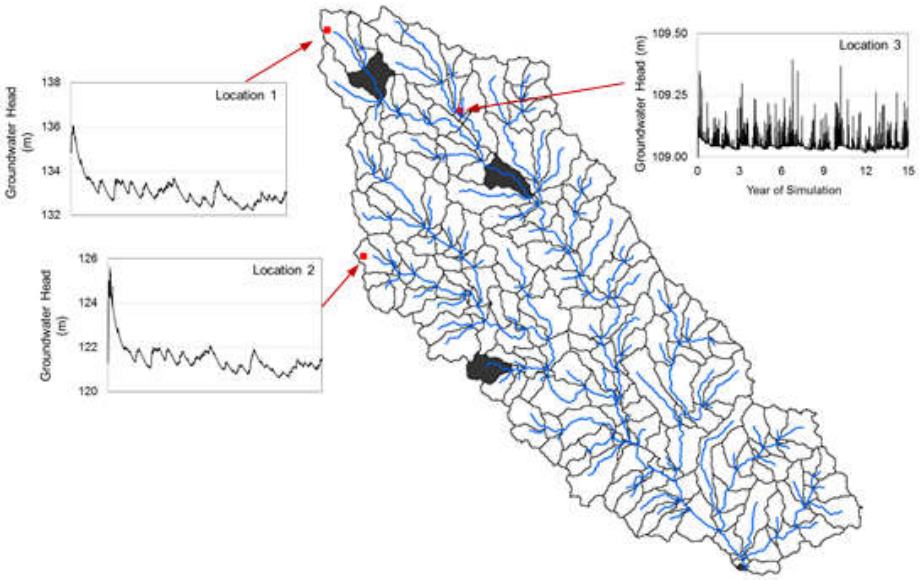
This file contains the calculated groundwater hydraulic head for each MODFLOW grid cell, for each specified time step of the simulation (the time steps at which values will be written are specified in the modflow.oc file). For each output time, there is a header line (time step, stress period), followed by the hydraulic head values written by row and column. No-data values (i.e. cells outside of the watershed boundary) are represented by "-999.0".



swatmf_out_MF_obs

Created only if flag is set in swatmf_link.txt

This file contains the groundwater hydraulic head of the observation cells specified in "modflow.obs", for each MODFLOW time step. For each time step, the head values for each observation cell are printed on a single line, in the same order as the cells listed in "modflow.obs". These results can be used to create time series of hydraulic head for locations within the aquifer:



swatmf_out_SWAT_recharge

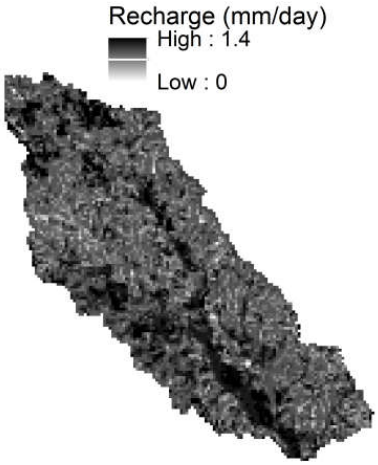
Created only if flag is set in swatmf_link.txt

This file contains the depth (mm) of deep percolation (= recharge to MODFLOW) calculated for each HRU, for each day of the simulation. Following the header line ("SWAT deep percolation (mm) (for each HRU)"), the deep percolation values for each HRU (beginning with HRU #1) are written for the first day, followed by a blank line, followed by the values for the next day, etc.

swatmf_out_MF_recharge

Created only if flag is set in swatmf_link.txt

This file contains the volumetric flow rate of recharge (m^3/day) of recharge provided to each MODFLOW grid cell, for each day of the simulation. The values are written in a 2D format according to the number of rows and columns in the MODFLOW grid. These values can be displayed as raster datasets in GIS to display the recharge to the water table:



swatmf_out_SWAT_channel

Created only if flag is set in swatmf_link.txt

This file contains the channel depth (m) for each sub-basin channel, for each day of the simulation. For each day, the depths are written on a single line, with the depth for sub-basin #1 in the first column, depth for sub-basin #2 in the second column, etc. up to the last sub-basin.

swatmf_out_MF_riverstage

Created only if flag is set in swatmf_link.txt

This file contains the river stage (= channel depth) (m) for each MODFLOW river cell, for each day of the simulation. These values are obtained from the sub-basin channel depths computed by SWAT. Output from consecutive days is separated by a blank line.

swatmf_out_SWAT_gwsw

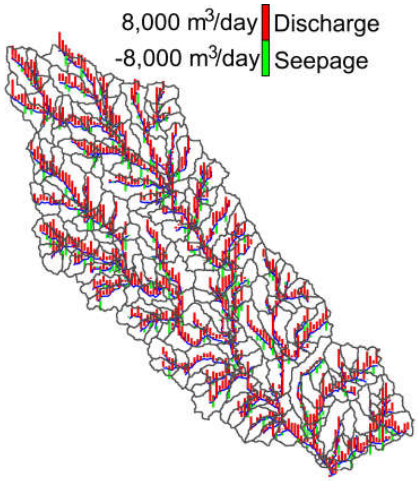
Created only if flag is set in swatmf_link.txt

This file contains the volumetric exchange rates (m^3/day) between the stream network and the aquifer for each SWAT sub-basin (numbered consecutively), for each day of the simulation. Positive values signify groundwater flow to the channel, whereas negative values signify stream seepage to the aquifer. Output from consecutive days is separated by a blank line.

swatmf_out_MF_gwsw

Created only if flag is set in swatmf_link.txt

This file contains the volumetric exchange rate (m^3/day) between the stream network and the aquifer for each MODFLOW River cell (numbered consecutively), for each day of the simulation. *Negative* values signify groundwater flow to the channel (MODFLOW treats the aquifer as the control volume, and water leaving the aquifer is denoted by a negative value), whereas positive values signify stream seepage to the aquifer (i.e. a source to the aquifer). Output from consecutive days is separated by a blank line.



7. WATERSHED WATER BALANCE IN SWAT-MODFLOW

For standard SWAT model simulations, the *output.std* file contains daily-averaged depths for the principal water balance variables in the watershed (e.g. rainfall, surface runoff, groundwater flow to streams, etc.). The *output.std* file for the SWAT-MODFLOW simulations has the same general format as the original SWAT model, but with several key additions that provide more information regarding groundwater and groundwater-surface water interactions. These additions are summarized as follows:

Variables in original SWAT simulations

PREC:	Rainfall in the watershed
SURQ:	Surface runoff to streams
LATQ:	Lateral flow to streams
GWQ:	Groundwater flow to streams (using original SWAT groundwater module)
PERCO LATE:	Deep percolation (recharge) to groundwater
TILE Q:	Tile drain flow to streams
SW:	Total soil water contained in the watershed
WATER YIELD:	Total water added to streams (= SURQ + LATQ + GWQ + TILE Q)

New Variables (and changes to original variables) in SWAT-MODFLOW simulations

GWQ:	Groundwater flow to streams (as calculated by the River package in MODFLOW)
SWGW:	Seepage from streams to the aquifer (as calculated by the River package in MODFLOW)
GW:	Total groundwater contained in the watershed
WATER YIELD:	Total water added to streams (= SURQ + LATQ + GWQ – SWGW + TILE Q) (notice that this takes into account the water that leaves the stream and seeps into the aquifer)

8. WATER QUALITY USING SWAT-MODFLOW-RT3D

SWAT-MODFLOW can also be used in conjunction with the RT3D (Reactive Transport in 3 Dimensions) model to simulate the reactive transport of solutes through the aquifer system and the solute mass exchange between the aquifer and the stream network. RT3D is called as a subroutine within the MODFLOW code during each groundwater flow time step. RT3D uses the same finite difference grid as MODFLOW.

In the current version of the code, Nitrate (NO_3) is included as a groundwater solute. Nitrate mass in deep percolation water as simulated for each SWAT HRU is passed to RT3D grid cells using the same HRU-Cell mapping procedures as described in the previous sections of this tutorial. MODFLOW provides the cell-by-cell flow rates for each grid cell, and then RT3D calculates the cell-by-cell NO_3 concentration in the aquifer and the NO_3 mass loading from the aquifer to the stream network. Using the River Cell – Subbasin linking procedure as described in Section 2.1.4, the NO_3 mass loading from the aquifer to the stream is provided to the correct sub-basin, which then can be routed through the watershed streams using the SWAT N-routing algorithms.

If solute transport with RT3D is desired, the "rt_active" flag in the swatmf_link.txt input file must be set to "1". There are also several RT3D input files required. These files are not described in this tutorial. If the user desires to use RT3D, please contact Dr. Ryan Bailey at Colorado State University for help in setting up a SWAT-MODFLOW-RT3D model.

9. SWATMOD-PREP: GRAPHICAL USER INTERFACE FOR CREATING SWAT-MODFLOW SIMULATIONS

SWATMOD-Prep is a graphical user interface that facilitates the linkage of SWAT and MODFLOW simulations to run a coupled SWAT-MODFLOW simulation. The executable for installing SWATMOD-Prep on a PC and an accompanying tutorial using the Little River Watershed dataset are provided on the SWAT-MODFLOW website (http://swat.tamu.edu/software/swat-modflow/).

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