SWAT-MODFLOW Workshop

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Outline of Workshop

1. Overview and Theory of SWAT-MODFLOW
2. Setting up and running SWAT-MODFLOW
3. QSWATMOD: install, introduction, application
4. Work with your data and watersheds

Overview of SWAT-MODFLOW

Motivation Improve groundwater flow (and solute transport) processes in SWAT

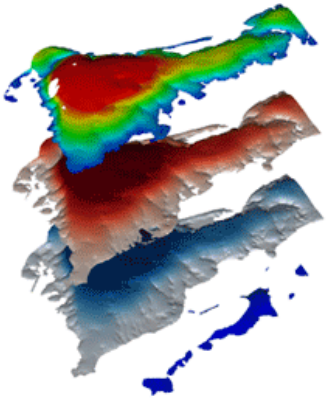
Method Link SWAT with physically-based, spatially-distributed groundwater models

Overview of SWAT-MODFLOW

Linking 3 Models:

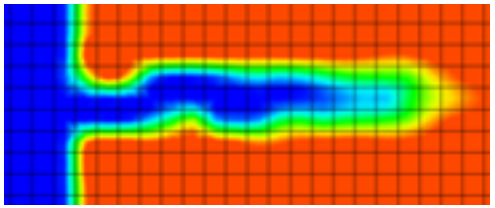
SWAT

MODFLOW



- Groundwater model
- 3D finite difference

RT3D



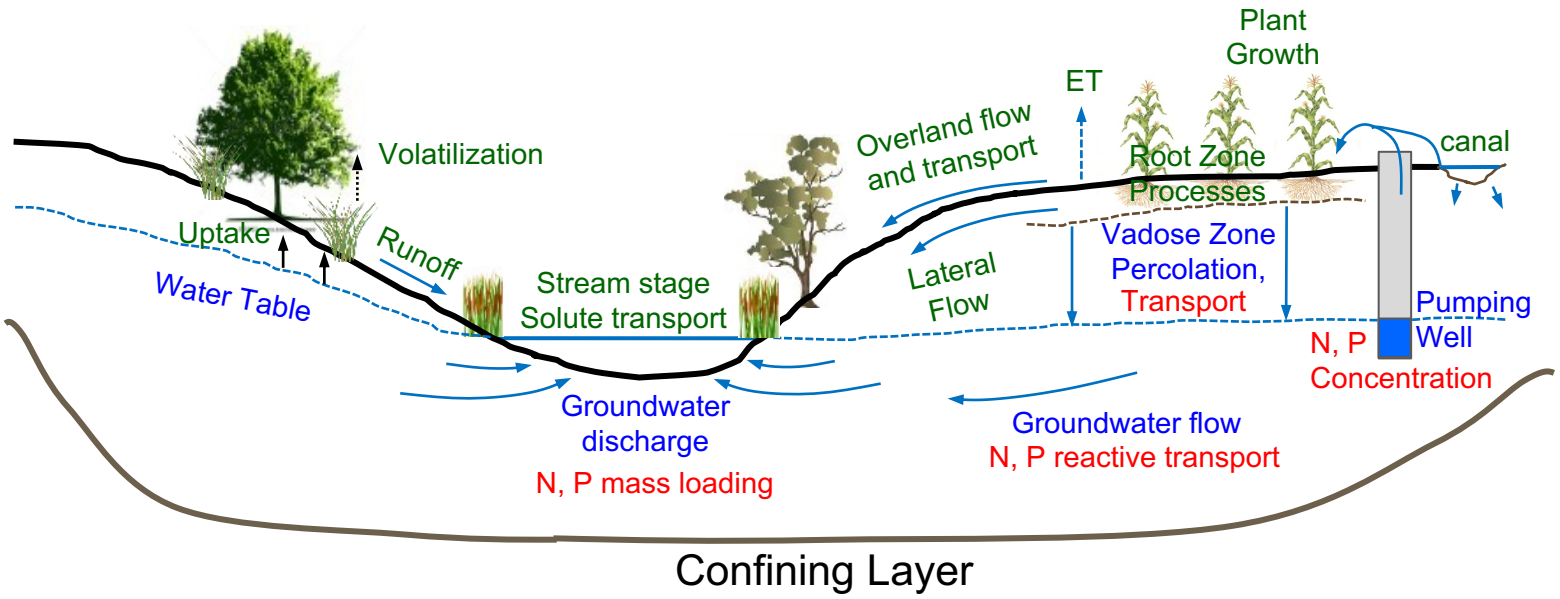
- Reactive transport
- 3D finite difference

Overview of SWAT-MODFLOW

Linking 3 Models: SWAT

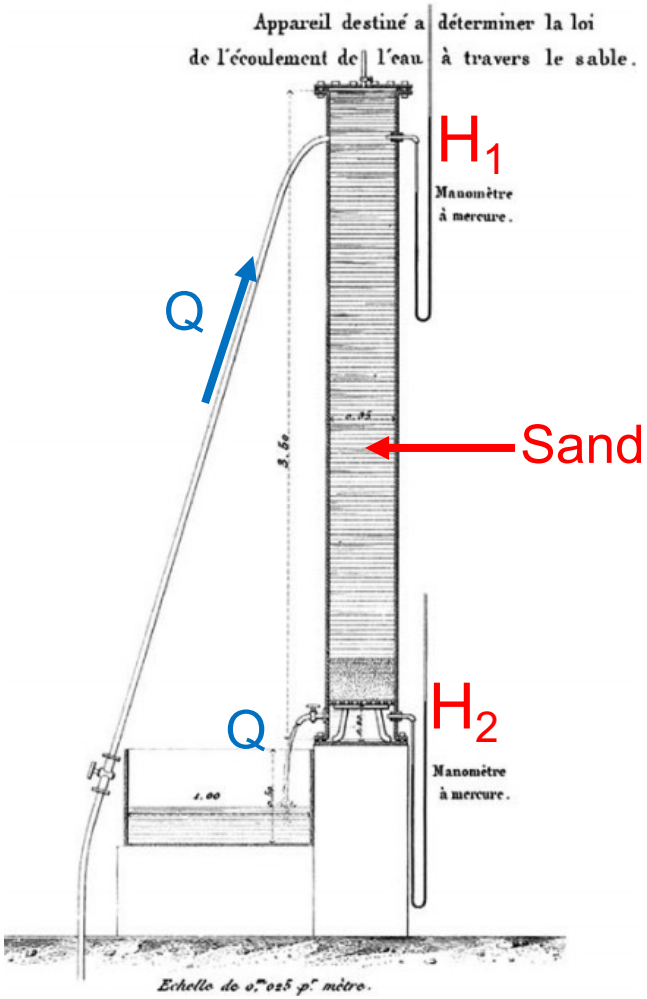
MODFLOW

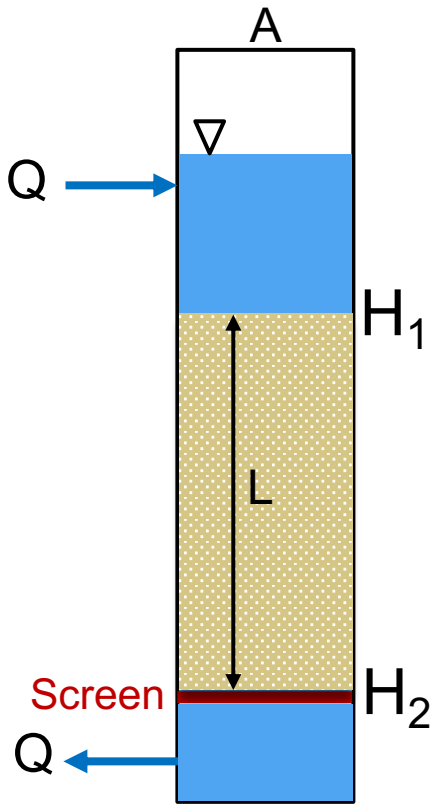
RT3D



MODFLOW

Introduction to Groundwater Modeling

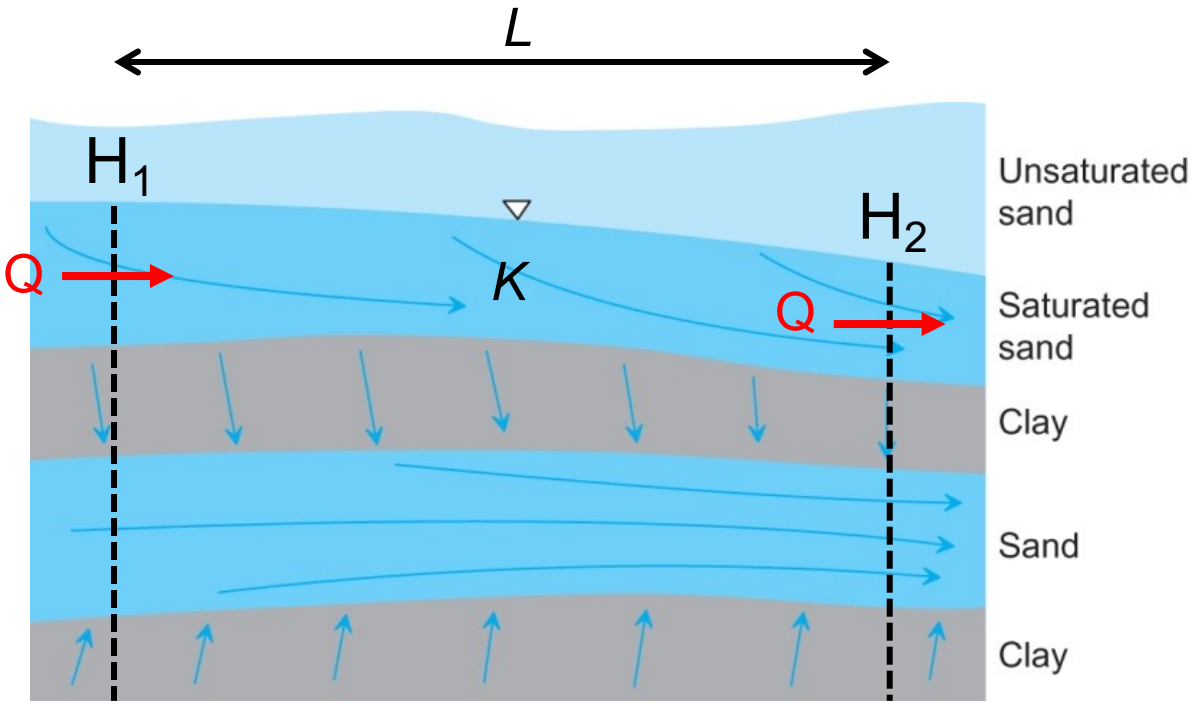




$$Q = KA\frac{\Delta H}{L}$$

MODFLOW

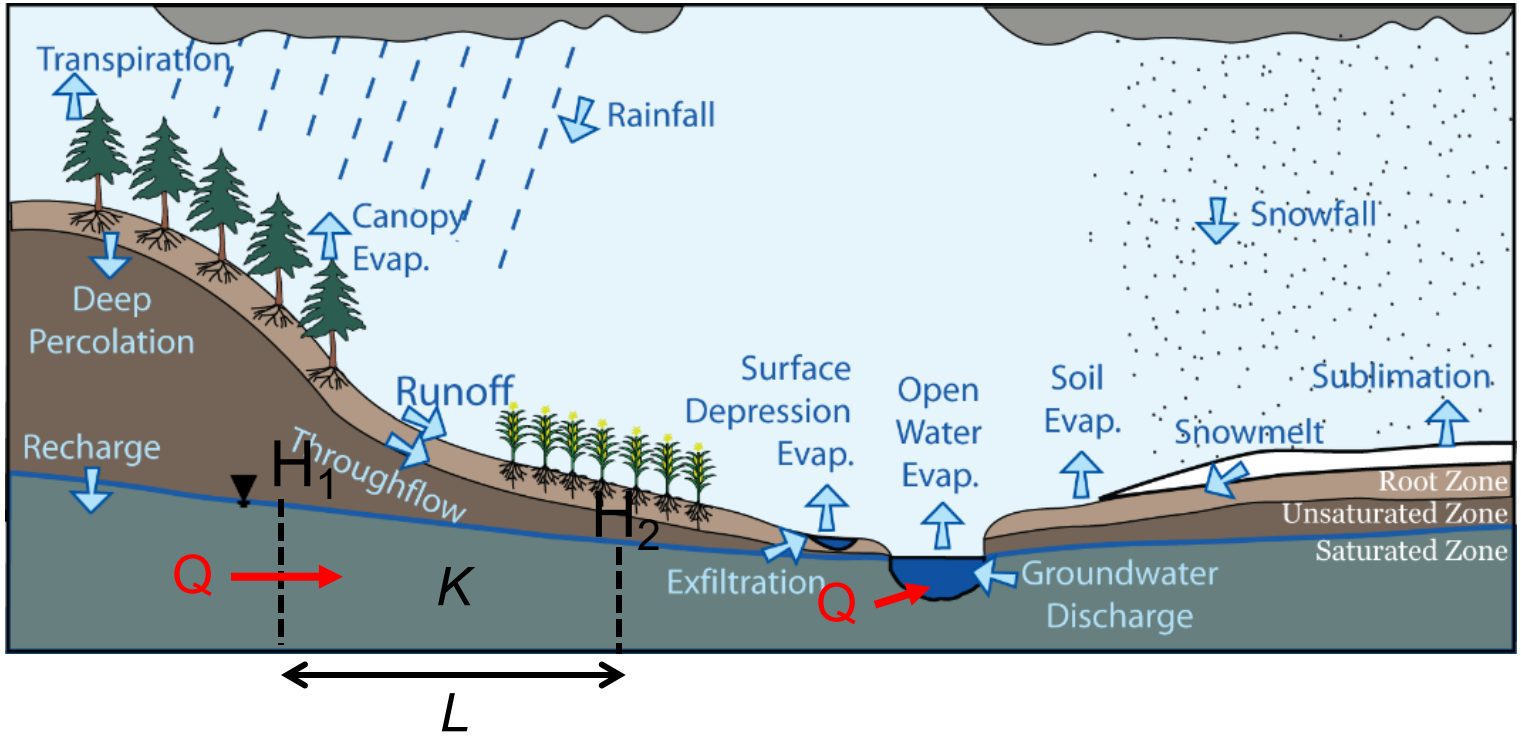
Introduction to Groundwater Modeling



$$Q = KA\frac{\Delta H}{L} = KA\frac{(H_2 - H_1)}{L}$$

MODFLOW

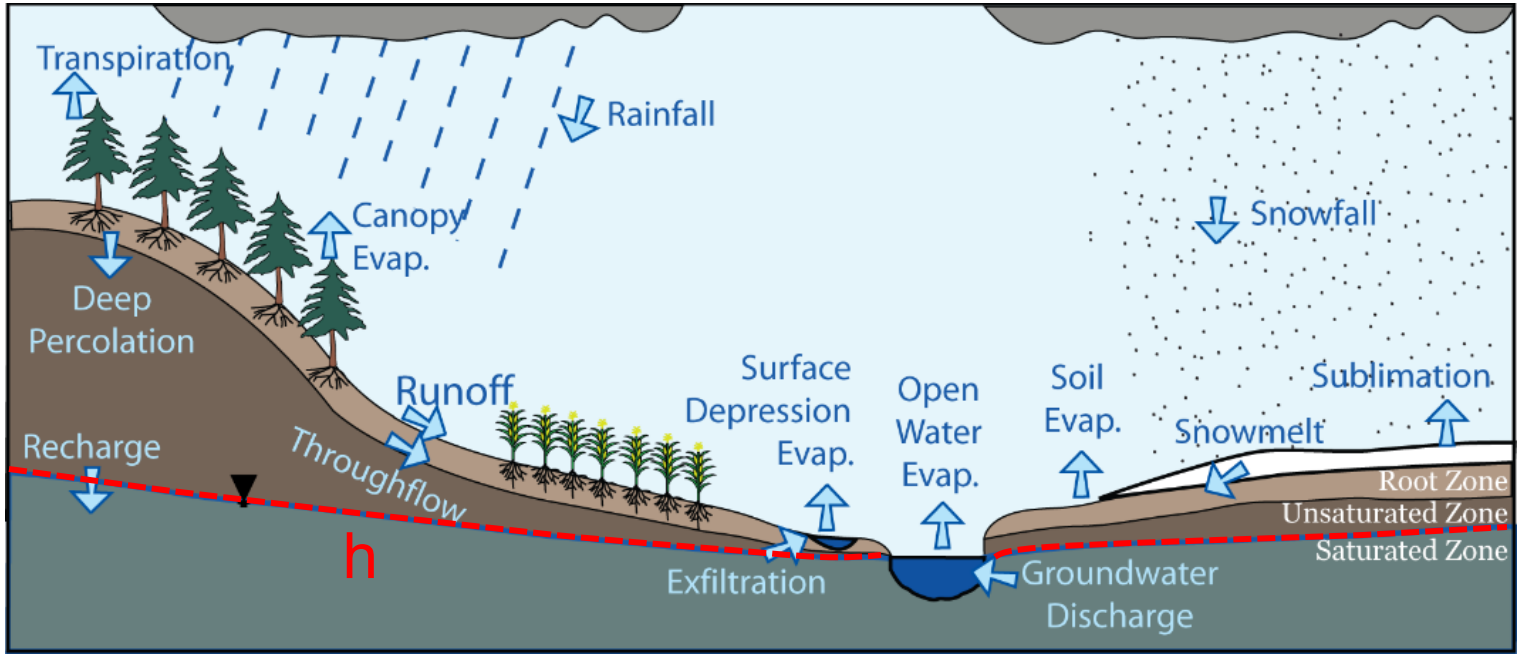
Introduction to Groundwater Modeling



$$Q = KA\frac{(H_2 - H_1)}{L}$$

MODFLOW

Introduction to Groundwater Modeling

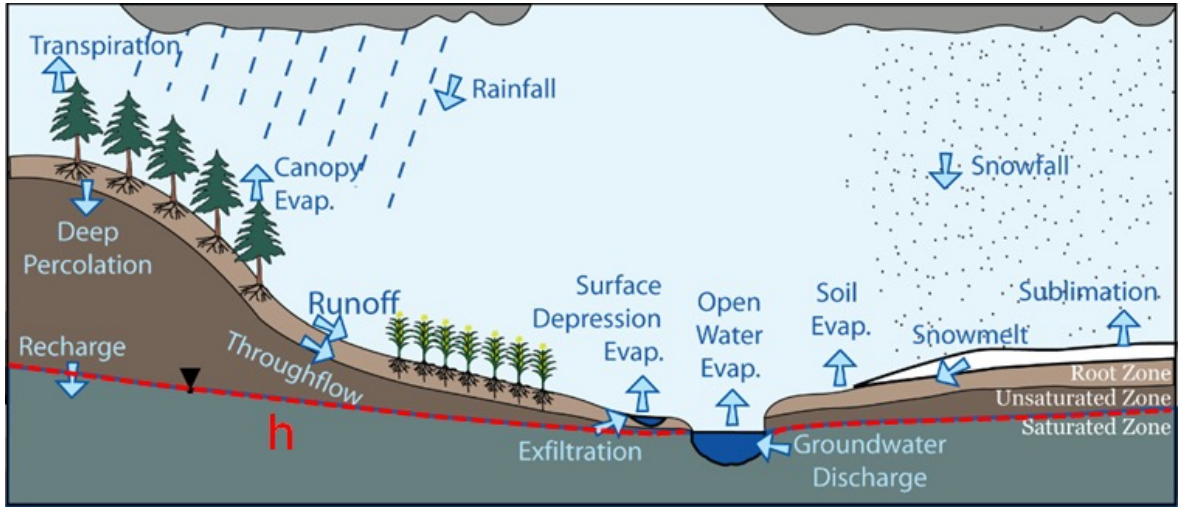


Objective: find *h* at every location (*x*,*y*,*z*) for all time (t_1, t_2, t_3…)
= *h*(*x*,*y*,*z*,*t*)

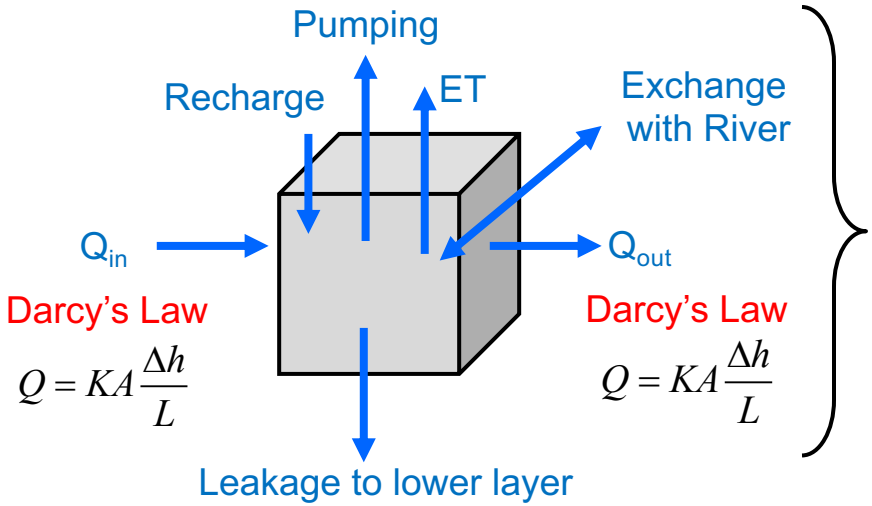
Secondary: use *h* to determine flow rate through the aquifer
use *h* to determine flow rate to/from aquifer (e.g. river)

MODFLOW

Introduction to Groundwater Modeling



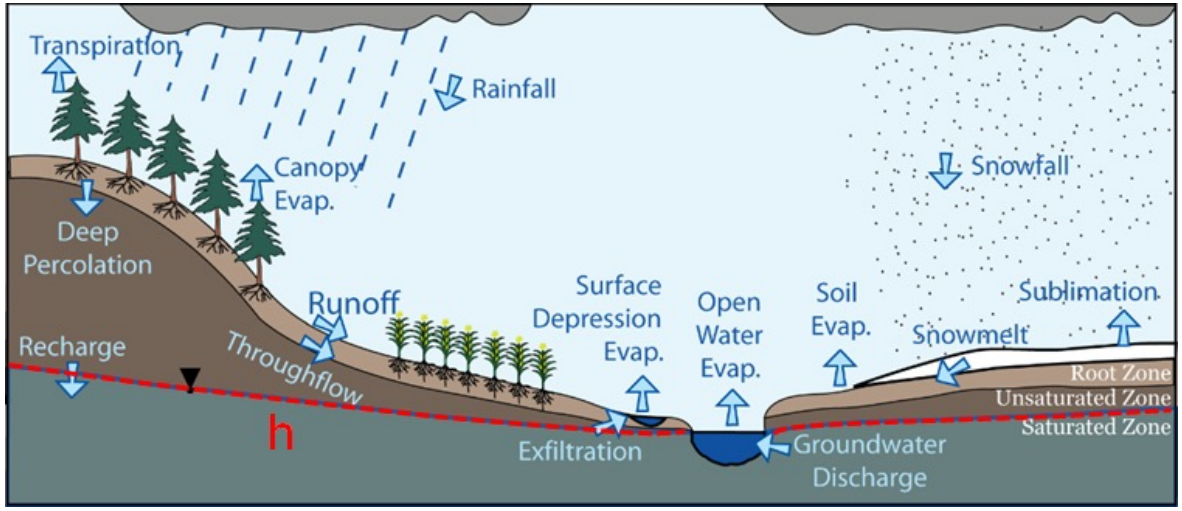
Strategy: develop water balance for each point (cell) in the aquifer



1. Divide aquifer into finite blocks
2. Write water balance for each block (*h* is unknown)
3. Solve the system of equations for *h*
4. Compute flow rates throughout aquifer

MODFLOW

Introduction to Groundwater Modeling



Strategy: develop water balance for each point (cell) in the aquifer

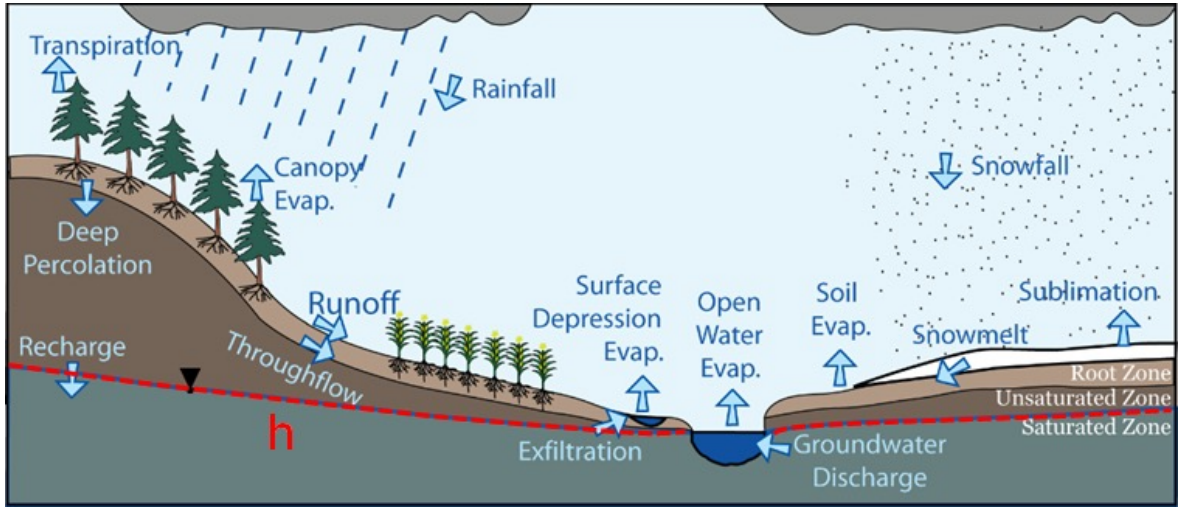
Water Balance Equation:

$$(Q_{in} - Q_{out})_x + (Q_{in} - Q_{out})_y + \text{Recharge} - \text{Pumping} - \text{ET} = \text{Change in Storage}$$

$(Q_{in} - Q_{out})_x$	$(Q_{in} - Q_{out})_y$	Recharge – Pumping – ET	Change in Storage
Q change in *x* direction	Q change in *y* direction	Sources & Sinks	Change in Storage

MODFLOW

Introduction to Groundwater Modeling



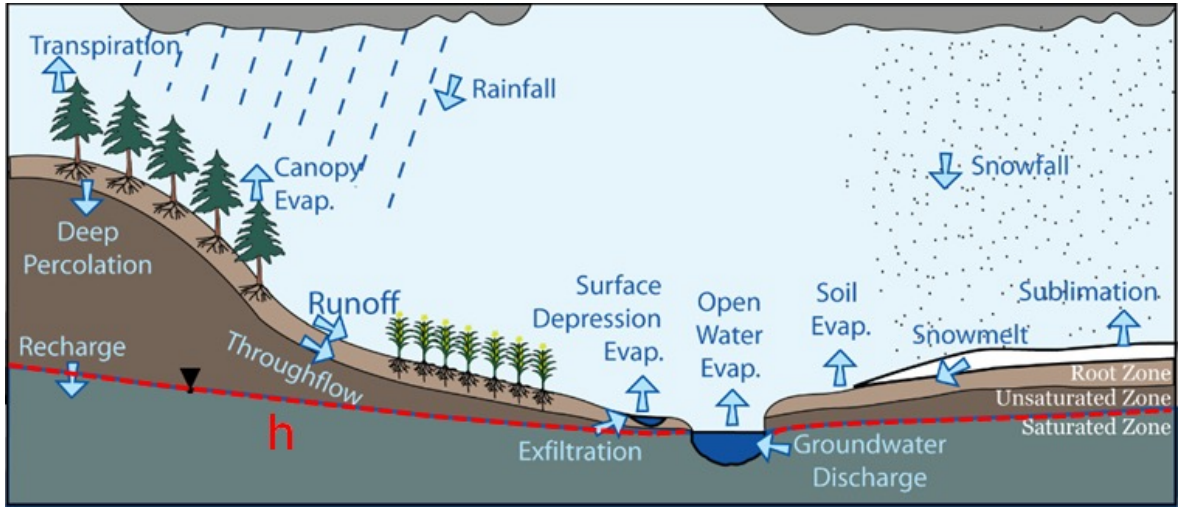
Strategy: develop water balance for each point (cell) in the aquifer

Partial Differential Equation:

$$\underbrace{\frac{\partial}{\partial x}\left(hK_x\frac{\partial h}{\partial x}\right)}_{\text{Q change in } x \text{ direction}}+\underbrace{\frac{\partial}{\partial y}\left(hK_y\frac{\partial h}{\partial y}\right)}_{\text{Q change in } y \text{ direction}}+\underbrace{Q_{rech}-Q_{pump}-Q_{ET}}_{\text{Sources \& Sinks}}=\underbrace{S_y\frac{\partial h}{\partial t}}_{\text{Change in Storage}}$$

MODFLOW

Introduction to Groundwater Modeling



Strategy: develop water balance for each point (cell) in the aquifer

Partial Differential Equation:

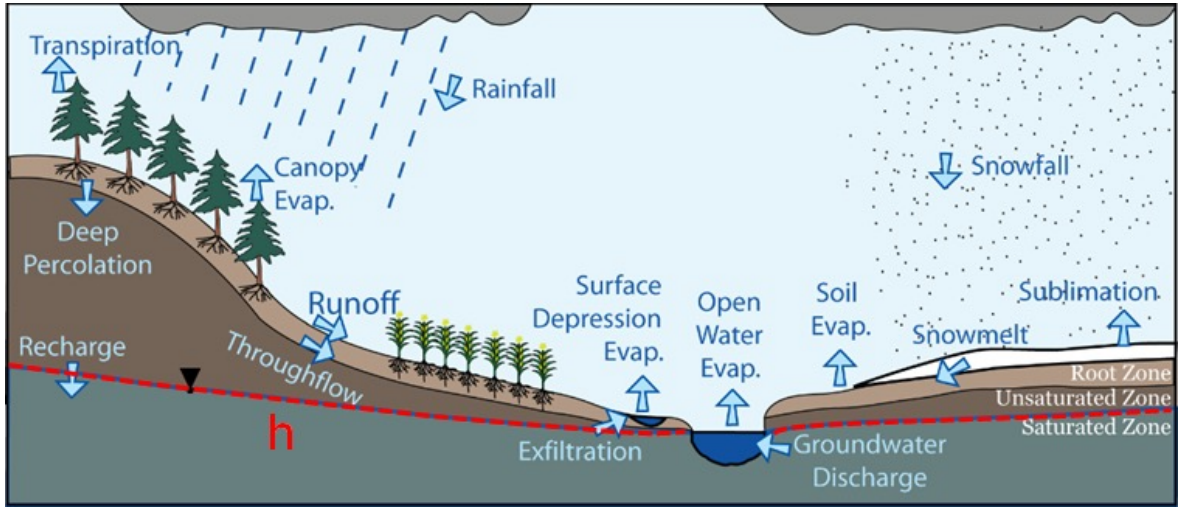
$$\frac{\partial}{\partial x}\left(hK_x\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(hK_y\frac{\partial h}{\partial y}\right)+Q_{rech}-Q_{pump}-Q_{ET}=S_y\frac{\partial h}{\partial t}$$

Hydraulic Conductivity

Specific Yield
(volume of groundwater that drains when water table lowers)

MODFLOW

Introduction to Groundwater Modeling



Strategy: develop water balance for each point (cell) in the aquifer

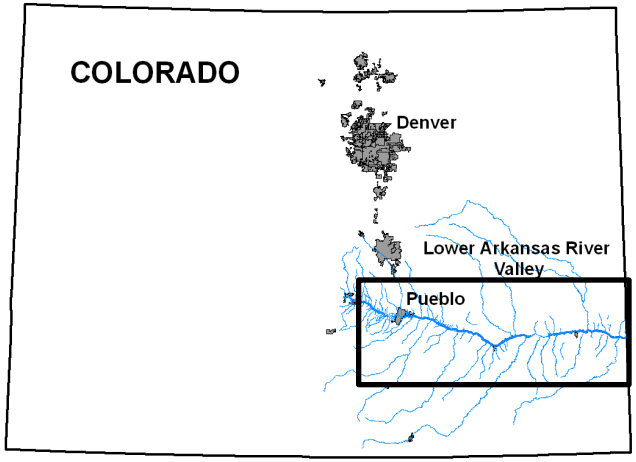
Partial Differential Equation:

$$\frac{\partial}{\partial x}\left(hK_x\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(hK_y\frac{\partial h}{\partial y}\right)+Q_{rech}-Q_{pump}-Q_{ET}=S_y\frac{\partial h}{\partial t}$$

Hydraulic Head = solve

MODFLOW

Example



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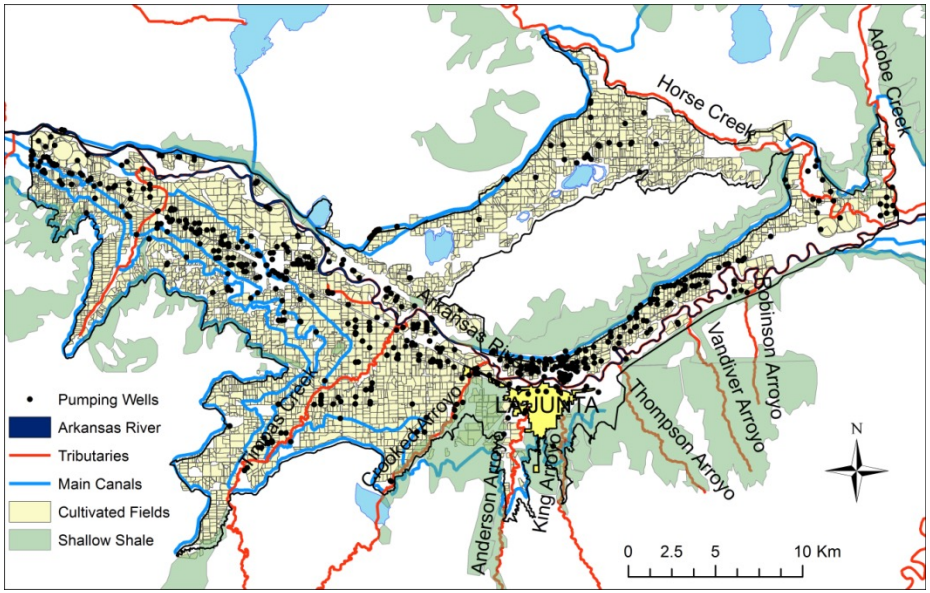
MODFLOW

Example



MODFLOW

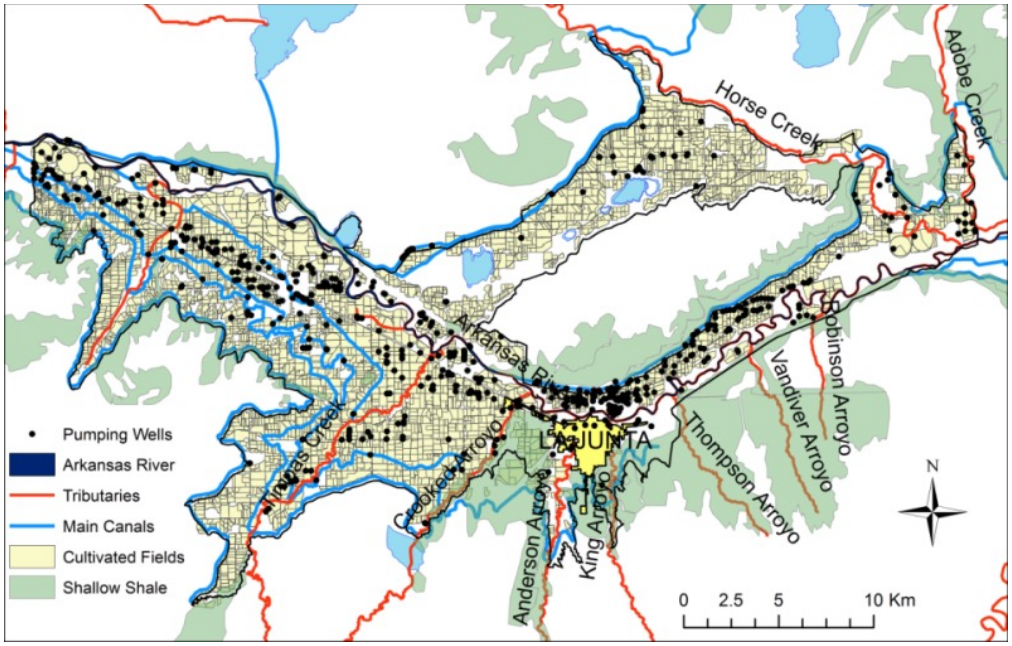
Example

Sources (+)

- Rainfall
- Irrigation water
- Canal seepage
- Stream seepage

Sinks (-)

- ET (crops)
- ET (vegetation)
- Pumping
- Discharge to streams



MODFLOW

Overview

MODFLOW

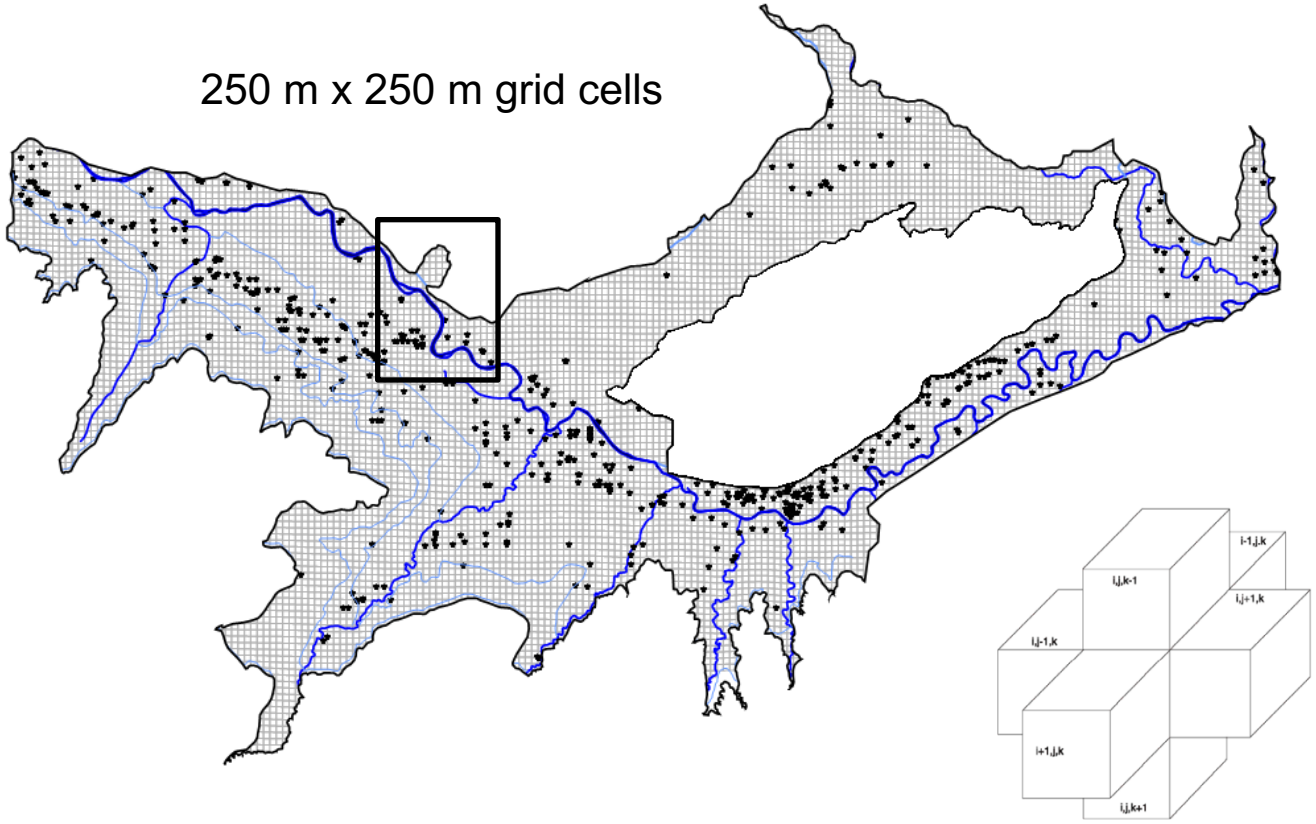
SWAT-MODFLOW

Setting up Simulation

RT3D

Example

1. Divide aquifer into finite blocks (= grid cells)
2. Write water balance for each block (*h* is unknown)
3. Solve the system of equations for *h*



MODFLOW

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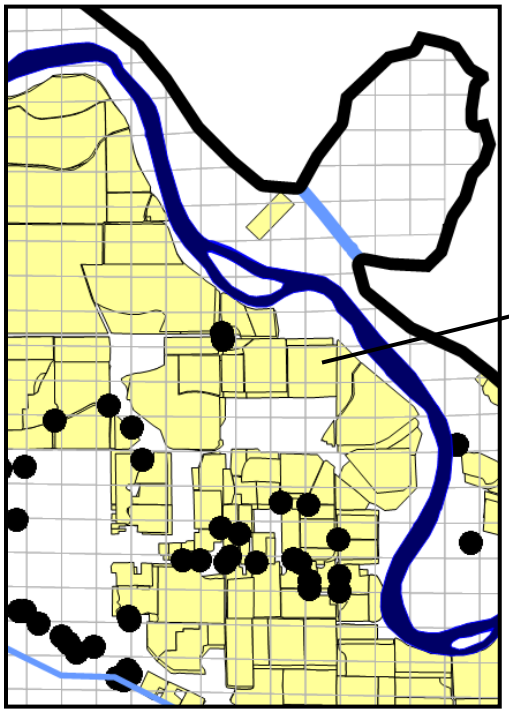
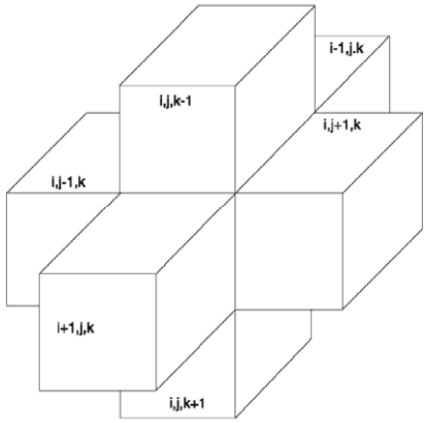




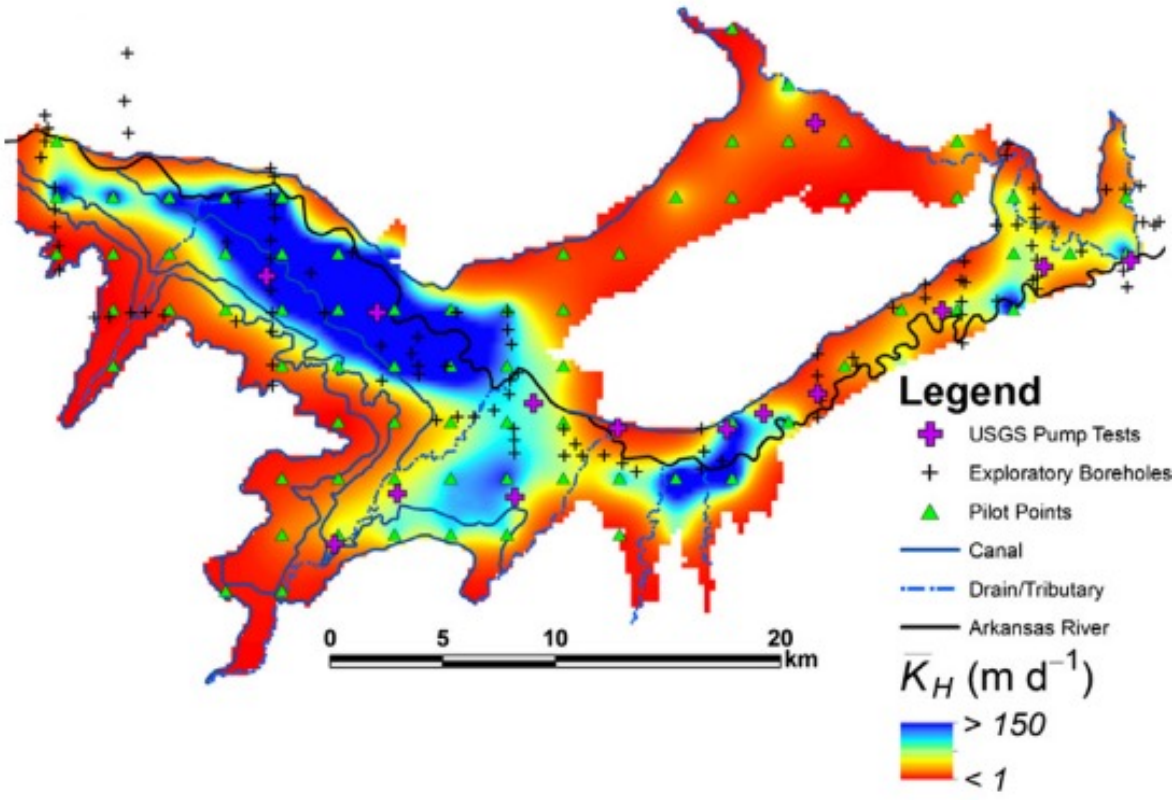
$$\sum Q_{in} - \sum Q_{out} = S_y \frac{\Delta h}{\Delta t}$$

Need *K* and S_y

MODFLOW

Example

1. Divide aquifer into finite blocks (= grid cells)
2. Write water balance for each block (*h* is unknown)
3. Solve the system of equations for *h*



MODFLOW

Overview

MODFLOW

SWAT-MODFLOW

Setting up Simulation

RT3D

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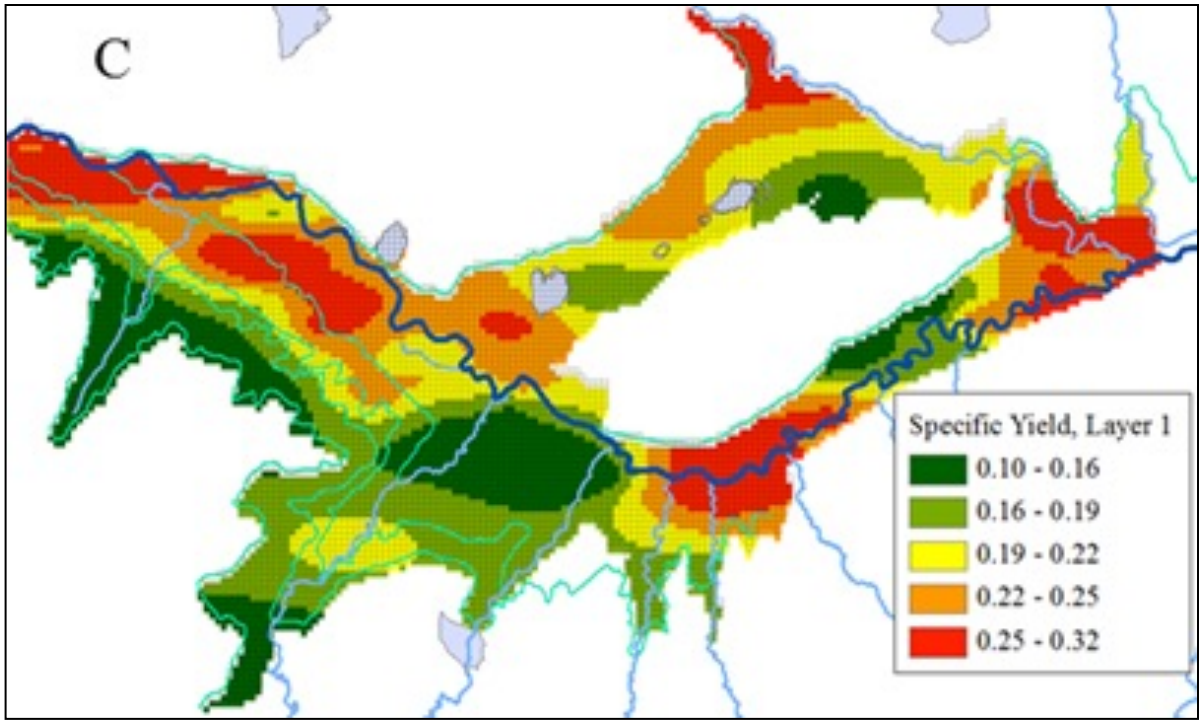

MODFLOW

Example

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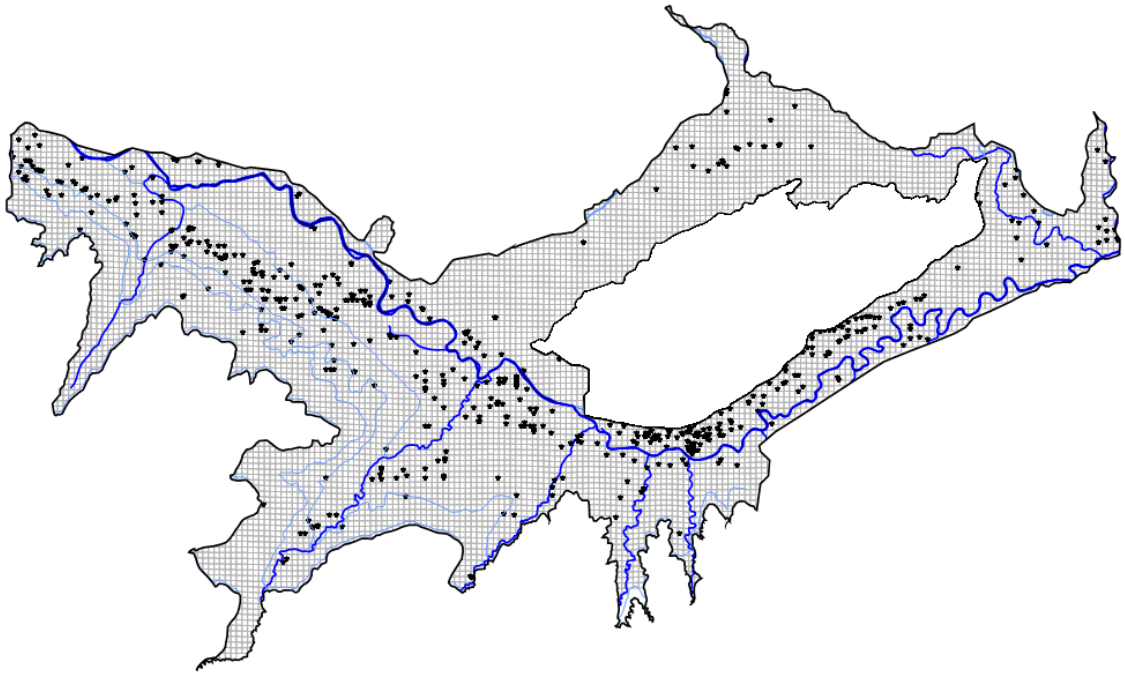

- 7776 Grid Cells
- 3 Layers

} 23328 Equations → Solve for *h* at each cell (repeat for each time step)

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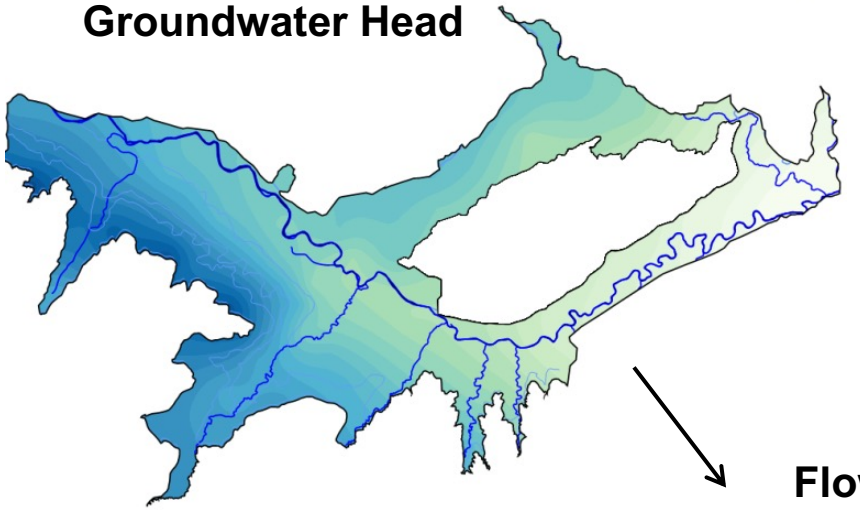
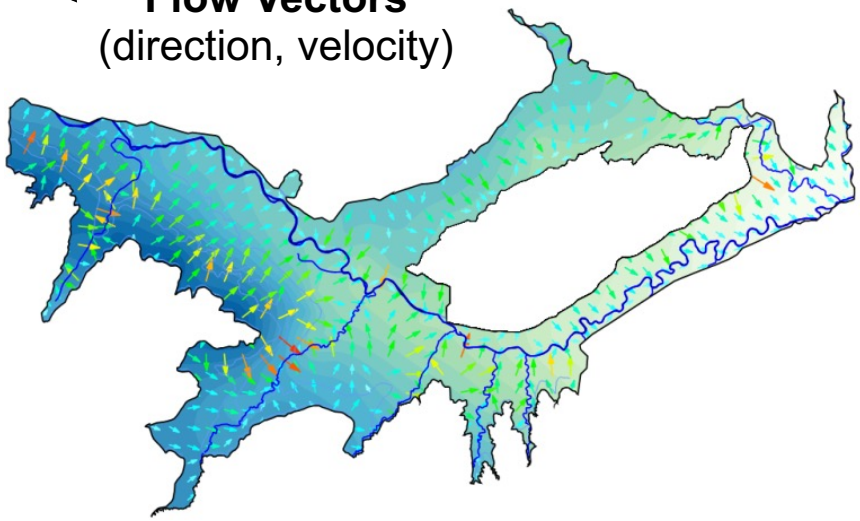
Example

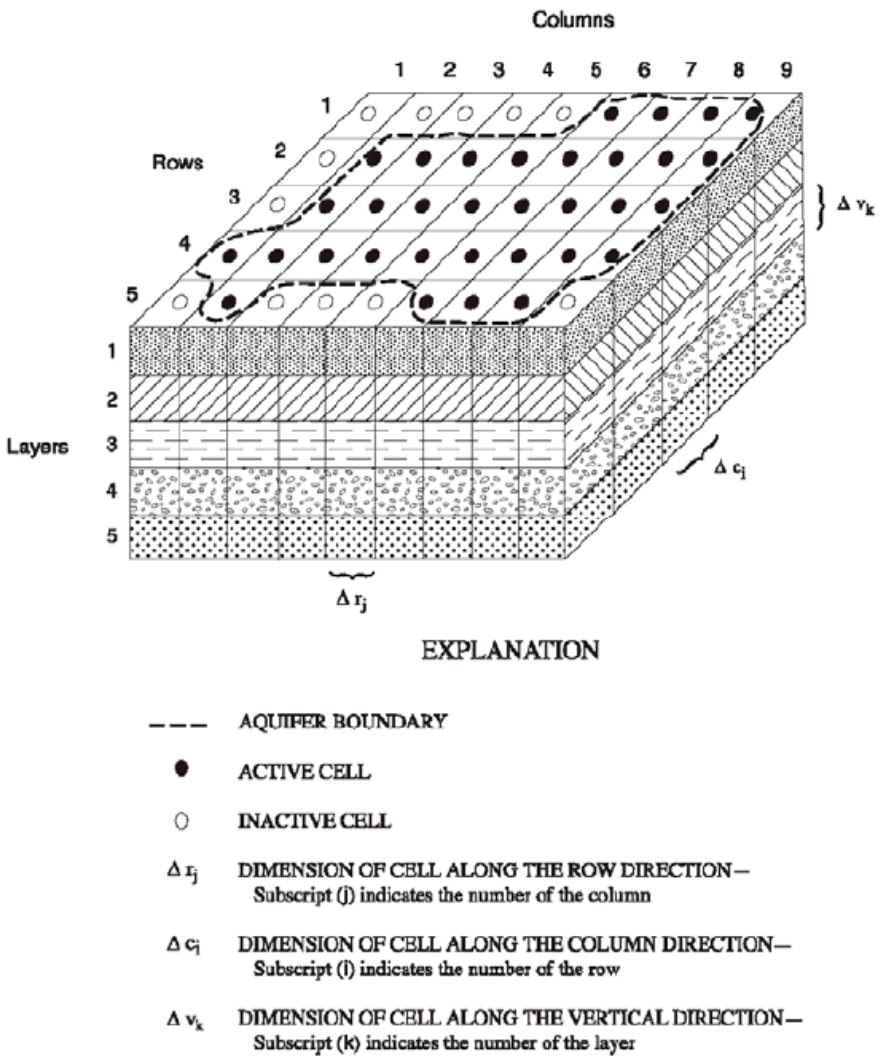
Groundwater Head



Flow Vectors
(direction, velocity)



MODFLOW



Most widely used groundwater flow model

3D Flow

- Layered systems
- Heterogeneous K
- Spatial sources/ sinks
- Time-variable sources/sinks
- Unconfined/Confined

MODFLOW

MODFLOW Packages

Package Name	Abbreviation	Package Category
Basic	BAS	Program Control
Block-Centered Flow	BCF	Hydrologic/Internal
Layer-Property Flow	LPF	Hydrologic/Internal
Horizontal Flow Barrier	HFB	Hydrologic/Internal
Well	WEL	Hydrologic/Stress
Recharge	RCH	Hydrologic/Stress
River	RIV	Hydrologic/Stress
General-Head Boundary	GHB	Hydrologic/Stress
Drain	DRN	Hydrologic/Stress
Evapotranspiration	EVT	Hydrologic/Stress
Strongly Implicit Procedure	SIP	Solver
Preconditioned Conjugate Gradient	PCG	Solver
Direct Solution	DE4	Solver

MODFLOW

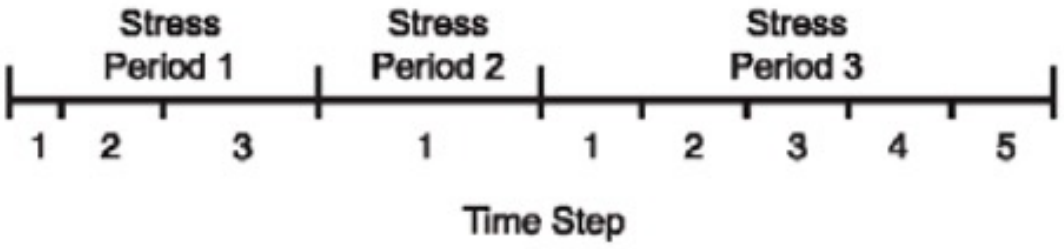
Additional MODFLOW Packages

- Streamflow routing
- Surface water routing
- Lake-Groundwater interaction
- Reservoir-Groundwater interaction
- Unsaturated zone flow
- Subsidence and aquifer-system compaction
- Seawater intrusion

Basic Inputs

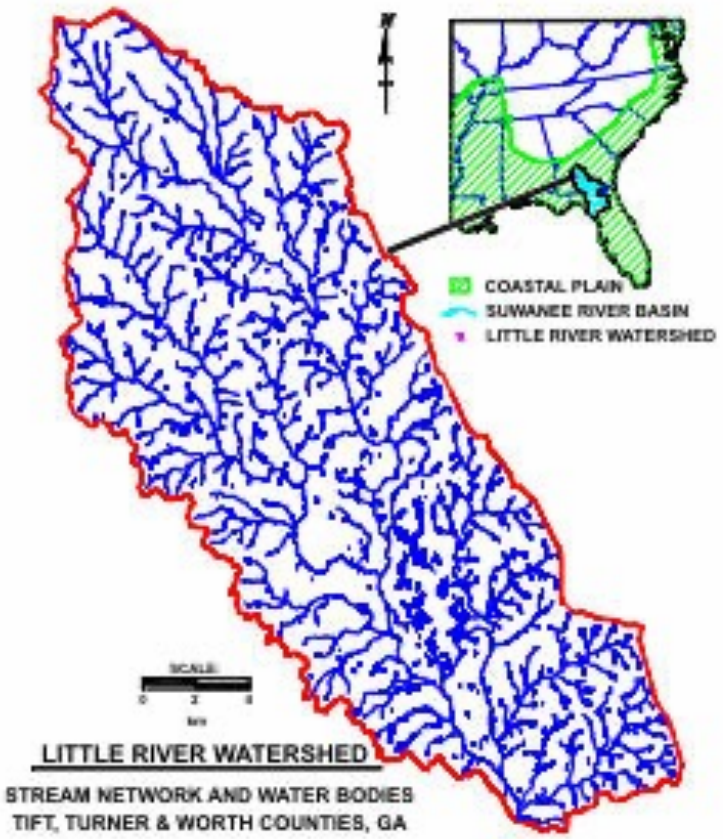
Time Step information

Stress Period: time interval during which input data for all external stresses are constant
(divided into time steps)



MODFLOW

Example – Little River Watershed

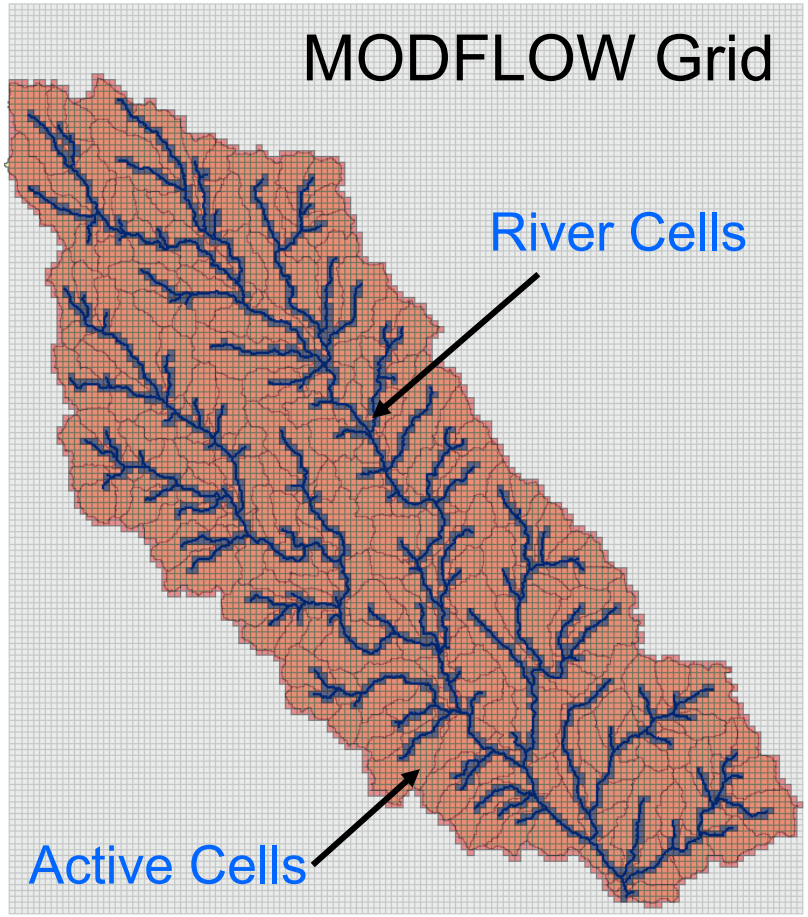


http://nsidc.org/data/docs/daac/nsidc0329_smex03_little_river_micronet_ga.html

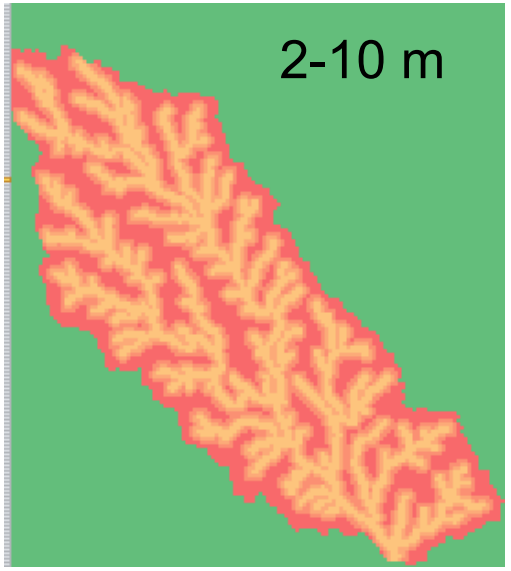
- 3D Steady flow model
- Homogeneous K

MODFLOW

Example – Little River Watershed



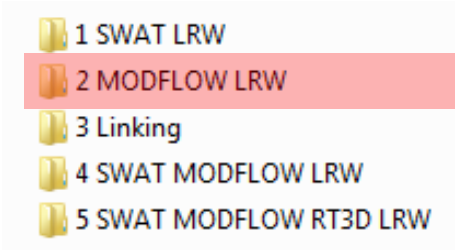
Aquifer Thickness

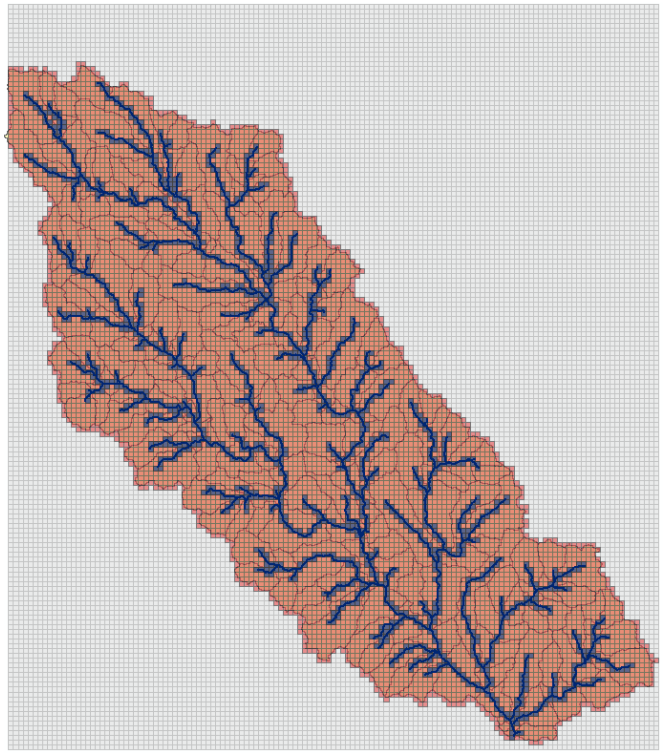


- K = 70 m/day
- R = 1.7 mm/day

MODFLOW

Input Files

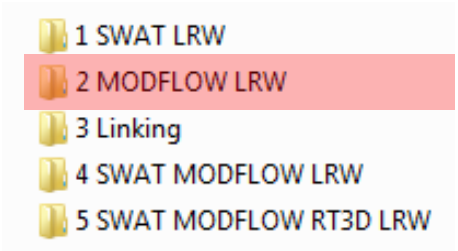


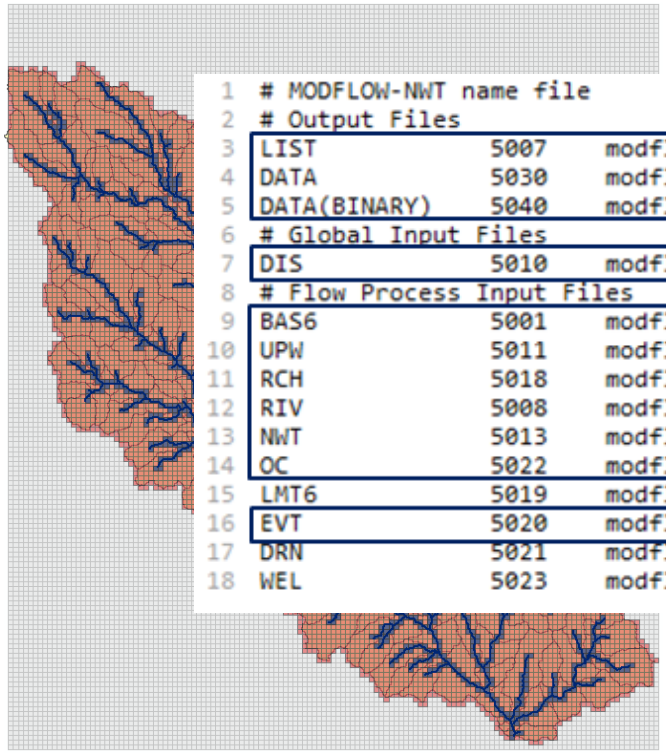


- .mfn
- .dis
- .bas
- .rch
- .upw
- .riv
- .wel
- .drn
- .evt
- .oc

MODFLOW

Input Files





- .mfn

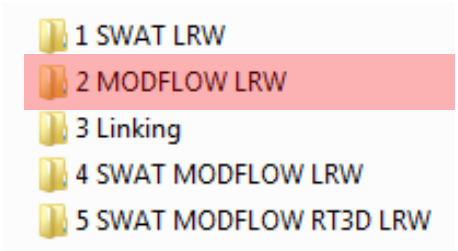
```
# MODFLOW-NWT name file
# Output Files
LIST            5007    modflow_LRW.out
DATA            5030    modflow_LRW.hed
DATA(BINARY)    5040    modflow_LRW.ccf
# Global Input Files
DIS             5010    modflow_LRW.dis
# Flow Process Input Files
BAS6            5001    modflow_LRW.bas
UPW             5011    modflow_LRW.upw
RCH             5018    modflow_LRW.rch
RIV             5008    modflow_LRW.riv
NWT             5013    modflow_LRW.nwt
OC              5022    modflow_LRW.oc
LMT6            5019    modflow_LRW.lmt
EVT             5020    modflow_LRW.evt
DRN             5021    modflow_LRW.drn
WEL             5023    modflow_LRW.wel
```

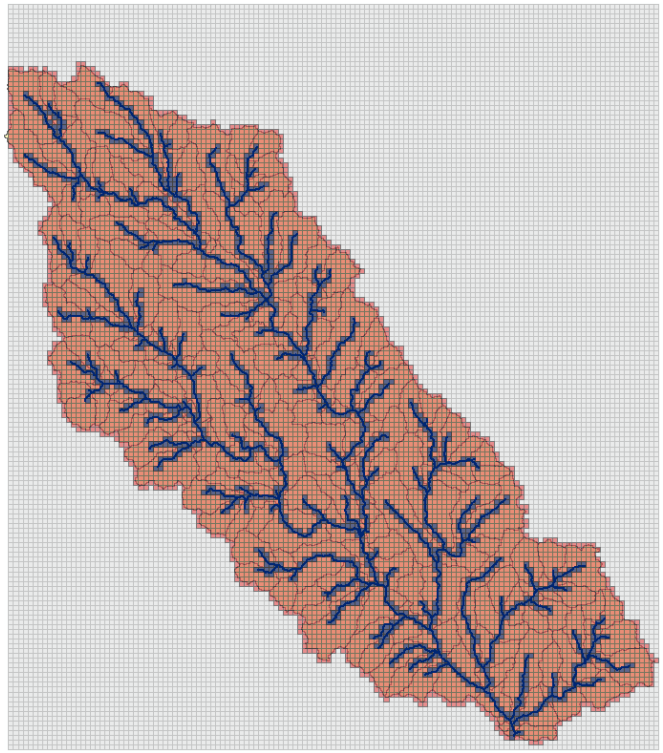
Discretization (grid, time steps)

Basic package (active cells, initial head)
Upstream Weighting package (aquifer properties)
Recharge package
River package
Newton solver
Output control
Linker file
Evapotranspiration package
Drain package
Well package (groundwater pumping)

MODFLOW

Input Files





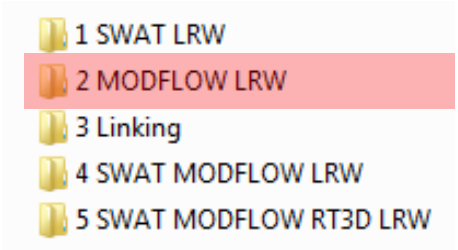
- .mfn
- .dis
- .bas
- .rch
- .upw
- .riv

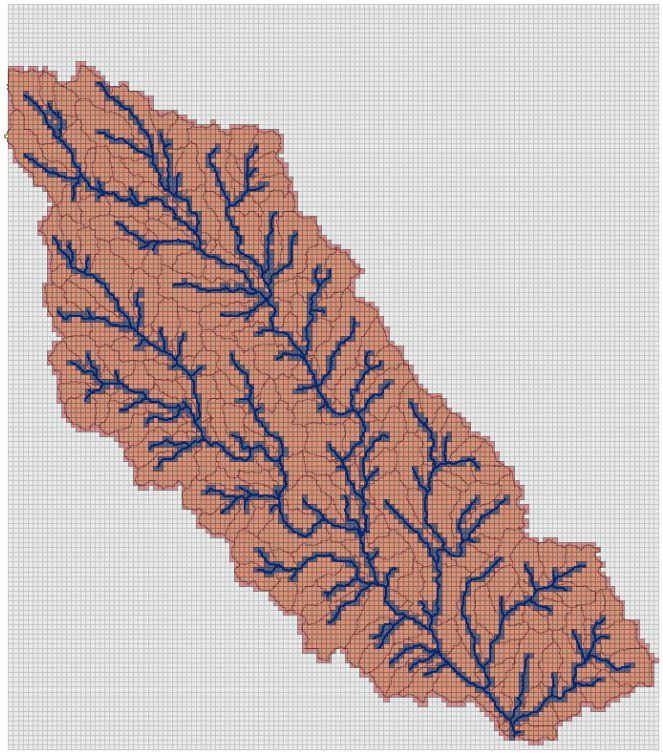
```
# Little River Watershed groundwater flow model
1633     0 Number of River Cells (maximum)
1633     0 Number of River Cells (current stress period)
1        5       20      126.3030        1786.6600       126.1400
1        5       21      126.6130        1804.0400       126.4500
1        6       21      125.2730        1835.0400       125.1100
1        6       22      127.9330        383.2590        127.7700
1        7        4      132.2580        98.9813         132.0400
1        7        5      131.9180        2027.6500       131.7000
1        7       22      125.0740        3560.2900       124.8700
1        8        5      131.6380        1409.7500       131.4200
1        8        6      130.0080        3635.3600       129.7900
1        8       22      127.1660        678.2110        126.9200
1        8       23      123.4660        4665.9300       123.2200
1        8       24      124.6260        1727.3500       124.3800
```

Cell Layer	Cell Row	Cell Column	River Stage [L]	Riverbed Conductance [L^2/T]	Riverbed Elevation [L]

MODFLOW

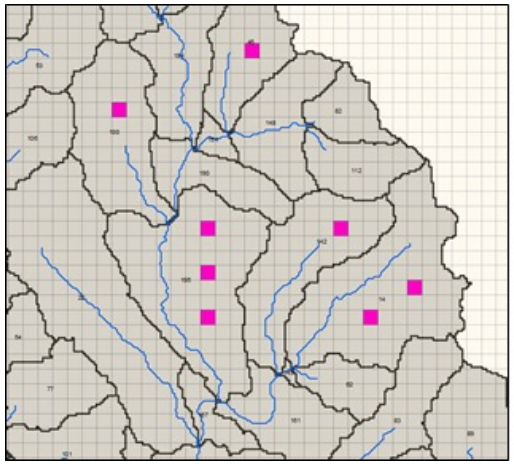
Input Files





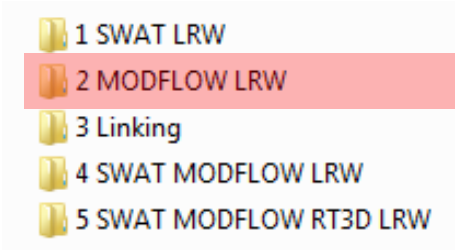
```
#Well package input file
8 0 AUX IFACE NAME  Number of Pumping Cells (maximum)
8 0                 Number of Pumping Cells (current stress period)
1       78      94      -1000
1       82      85      -1000
1       90      91      -1000
1       90      100     -1000
1       93      91      -1000
1       94      105     -1000
1       96      91      -1000
1       96      102     -1000
Cell    Cell    Cell    Pumping
Layer   Row     Column  Rate
                        [L³/T]
```

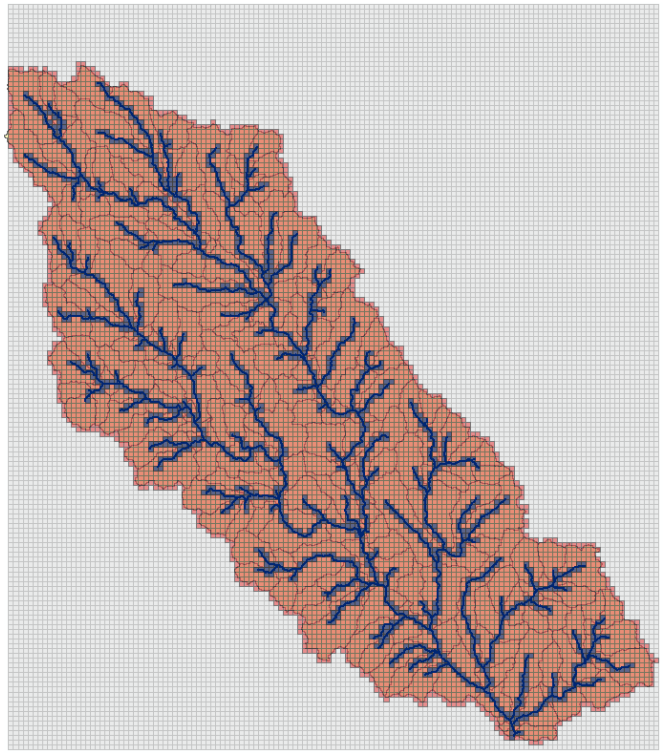
- .upw
- .riv
- .wel
- .drn
- .evt
- .oc



MODFLOW

Input Files

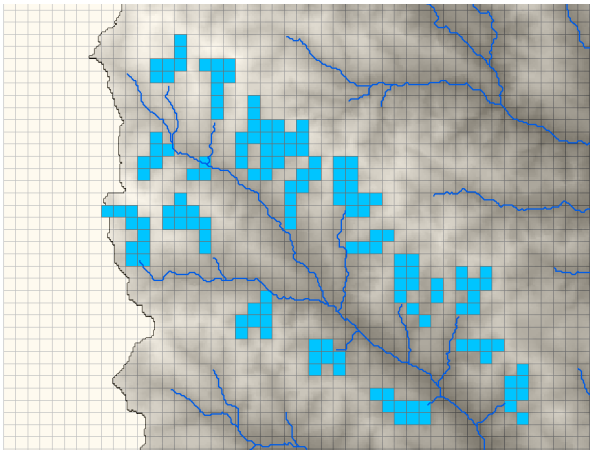




- .mfn
- .dis
- .bas
- .rch
- .upw
- .riv
- .wel
- .drn
- .evt
- .oc

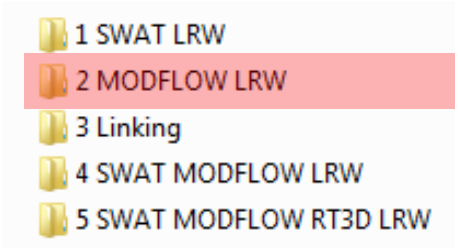
```
#Drain package input file
162      0 Number of Drain Cells (maximum)
162      0 Number of Drain Cells (current stress period)
1        34       15       134.27   100.00   0
1        36       19       133.34   100.00   0
1        37       19       130.56   100.00   0
1        34       15       134.27   100.00   0
1        35       15       131.34   100.00   0
1        36       13       133.35   100.00   0
1        36       14       128.83   100.00   0
1        36       15       129.07   100.00   0
1        37       13       130.03   100.00   0
1        37       14       126.85   100.00   0
```

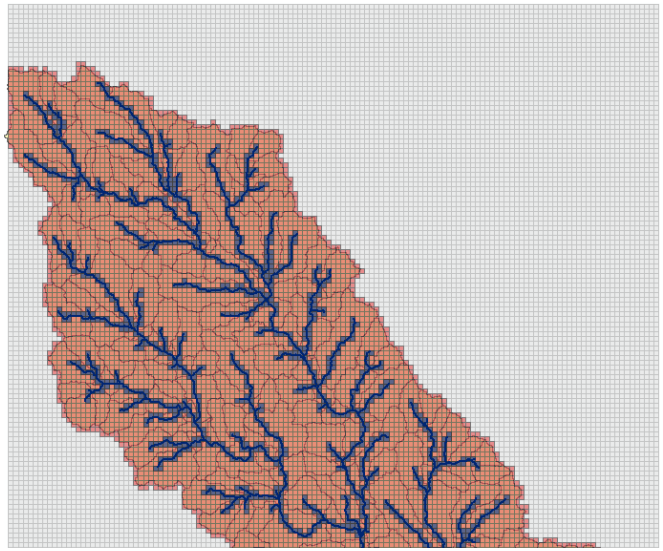
Cell Layer | Cell Row | Cell Column | Drain Elevation [L] | Drain Conductance [L^2/T]



MODFLOW

Input Files



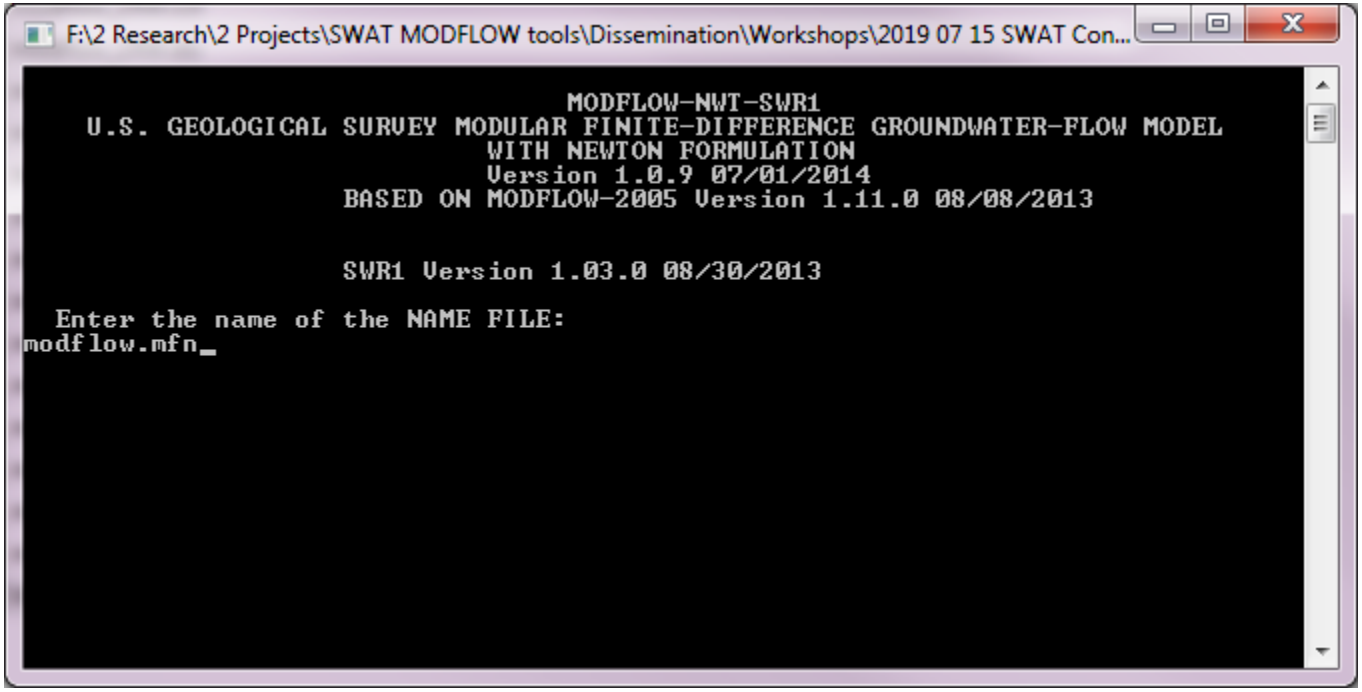


- .mfn
- .dis
- .bas
- .rch
- .upw
- .riv
- .wel
- .drn
- .evt
- .oc

```
1  # EVT: Evapotranspiration package file created on 7/6/2018 by ModelMuse version 3.10.0.0.
2       3     0 # DataSet 2: NEVTOP IEVTCB
3       1     1     1    -1 # Data Set 5: INSURF INEVTR INEXDP INIEVT Stress period 1
4  CONSTANT 0.000                  # Data Set 6: SURF Ground surface elevation [L]
5  CONSTANT 0.000                  # Data Set 7: EVTR Potential ET rate [L/T]
6  CONSTANT 2.000                  # Data Set 9: EXDP Extinction depth [L], below which no ET occurs
7
```

MODFLOW

Run MODFLOW



MODFLOW

View Results

- .out
- .hed
- .hff

Aquifer Water Balance

```
4288
4289      CUMULATIVE VOLUMES      L**3       RATES FOR THIS TIME STEP      L**3/T
4290      ------------------                 ------------------------
4291
4292           IN:                                IN:
4293           ---                                ---
4294             STORAGE =           0.0000           STORAGE =           0.0000
4295      CONSTANT HEAD =   134182112.0000    CONSTANT HEAD =       24463.4668
4296             WELLS =           0.0000           WELLS =           0.0000
4297            DRAINS =           0.0000           DRAINS =           0.0000
4298      RIVER LEAKAGE =   555737984.0000    RIVER LEAKAGE =      101319.5938
4299                 ET =           0.0000           ET =           0.0000
4300          RECHARGE =  3170628352.0000           RECHARGE =      578054.3750
4301
4302           TOTAL IN =  3860548352.0000           TOTAL IN =      703837.4375
4303
4304          OUT:                               OUT:
4305          ----                               ----
4306             STORAGE =           0.0000           STORAGE =           0.0000
4307      CONSTANT HEAD =    53309948.0000    CONSTANT HEAD =        9719.2246
4308             WELLS =    42112048.0000           WELLS =        7677.6748
4309            DRAINS =    49305436.0000           DRAINS =        8989.1406
4310      RIVER LEAKAGE =  3715820800.0000    RIVER LEAKAGE =      677451.3750
4311                 ET =           0.0000           ET =           0.0000
4312          RECHARGE =           0.0000           RECHARGE =           0.0000
4313
4314           TOTAL OUT =  3860548096.0000           TOTAL OUT =      703837.4375
4315
4316            IN - OUT =         256.0000            IN - OUT =           0.0000
4317
4318  PERCENT DISCREPANCY =           0.00     PERCENT DISCREPANCY =           0.00
```

MODFLOW

View Results

- .out
- .hed
- .hff

Groundwater Head for each Cell

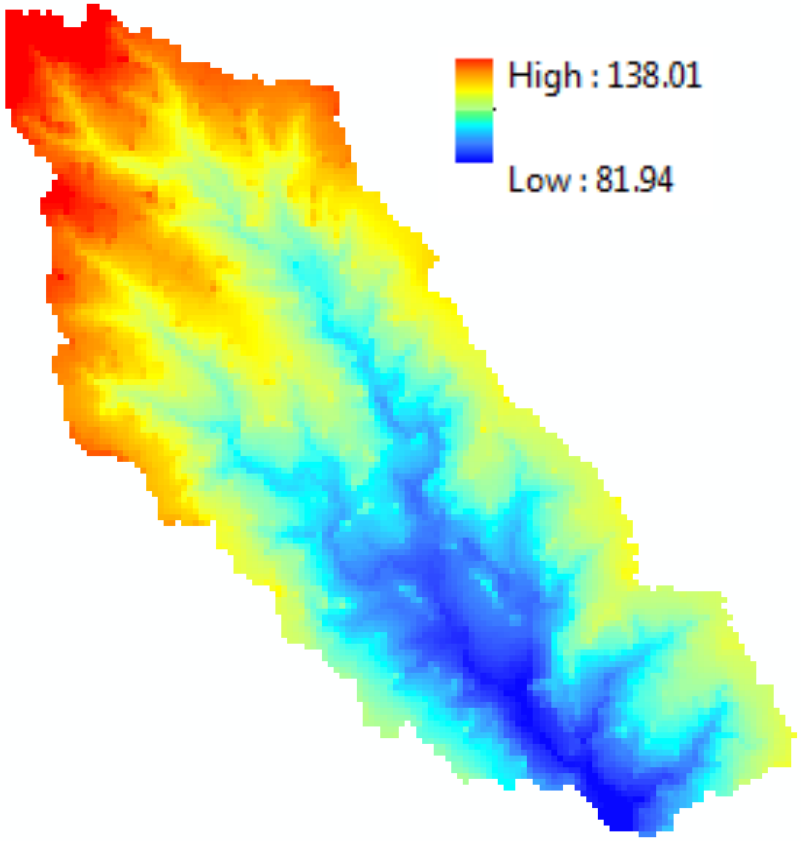
```
    1    1   5.485000E+03   5.485000E+03          HEAD   136   141     1 (213F10.2)
-999.00  -999.00  -999.00  -999.00  -999.00  -999.00  -999.00  -999.00  -999.00  -999.00  -999.00  -999.00  -999
-999.00   136.45   136.45   136.46  -999.00   136.88   136.90  -999.00   138.02  -999.00  -999.00  -999.00  -999
-999.00   136.31   136.28   136.30   136.31   136.37   136.48   136.80   137.04   136.70   137.17  -999.00  -999
-999.00   136.09   135.98   135.89   135.80   135.81   135.88   135.98   135.89   135.91   136.26  -999.00  -999
-999.00   135.74   135.63   135.48   135.29   135.21   135.36   135.46   135.39   135.38   135.42   135.23   134
-999.00   135.44   135.28   134.93   134.32   134.41   134.88   134.92   134.85   134.77   134.58   134.40   134
-999.00   135.20   134.83   134.06   132.44   133.21   134.21   134.46   134.32   134.18   133.98   133.37   133
-999.00   134.82   134.46   133.54   131.78   130.28   131.24   133.35   133.47   133.43   133.38   132.66   132
-999.00   134.39   134.19   133.45   131.50   130.13   128.78   130.70   131.80   132.26   132.11   131.69   131
-999.00   133.99   133.85   133.55   131.29   130.31   129.19   127.85   129.64   129.98   130.21   130.34   131
-999.00   133.17   133.23   133.39   132.78   130.60   129.28   127.85   126.84   127.88   126.51   127.91   129
-999.00   132.68   132.52   132.42   132.35   132.96   128.81   127.05   125.20   126.39   125.77   125.49   128
-999.00   132.25   132.04   131.73   131.03   129.89   128.83   127.24   125.16   125.12   124.65   124.12   125
-999.00   131.79   131.64   131.37   130.78   129.73   128.77   127.77   126.27   123.24   123.71   123.08   124
-999.00   131.39   131.33   131.16   130.55   129.77   129.11   128.24   126.11   123.53   121.55   121.53   123
-999.00   131.06   130.97   130.73   130.22   129.71   129.33   127.90   125.93   123.93   121.65   119.78   121
-999.00   130.75   130.55   130.26   129.86   129.51   129.29   128.38   127.01   126.54   123.84   120.00   119
-999.00   130.53   130.22   129.77   129.36   129.14   128.83   128.31   126.30   125.00   123.53   121.44   119
-999.00  -999.00   129.65   129.13   128.45   128.44   128.15   128.65   126.05   124.20   122.97   121.72   120
-999.00  -999.00   129.27   128.14   125.54   126.74   126.88   129.58   127.71   123.90   123.11   122.44   120
-999.00  -999.00   128.92   128.33   127.20   125.57   124.95   126.35   128.23   127.29   128.24   125.37   124
-999.00  -999.00  -999.00   128.78   128.98   126.20   124.94   123.54   124.83   125.39   127.44   126.37   124
-999.00  -999.00  -999.00  -999.00   128.43   126.58   126.04   124.61   122.27   122.92   123.73   123.08   122
-999.00  -999.00  -999.00  -999.00  -999.00   128.47   128.20   126.35   124.17   123.31   121.96   120.02   119
-999.00  -999.00  -999.00  -999.00  -999.00  -999.00   126.39   126.00   125.03   124.93   124.02   122.55   122
-999.00  -999.00  -999.00  -999.00  -999.00  -999.00   126.41   126.21   126.04   125.75   124.98   124.18   123
-999.00  -999.00  -999.00  -999.00  -999.00  -999.00  -999.00  -999.00   126.30   126.02   125.72   125.69   125
-999.00  -999.00  -999.00  -999.00  -999.00  -999.00  -999.00  -999.00  -999.00   126.57   126.49   126.66   127
-999.00  -999.00  -999.00  -999.00  -999.00  -999.00  -999.00  -999.00  -999.00   127.62   127.65   127.59   127
-999.00  -999.00  -999.00  -999.00  -999.00  -999.00  -999.00  -999.00  -999.00  -999.00   129.68   128.68   128
```

MODFLOW

View Results

- .out
- .hed
- .hff

Groundwater Head for each Cell

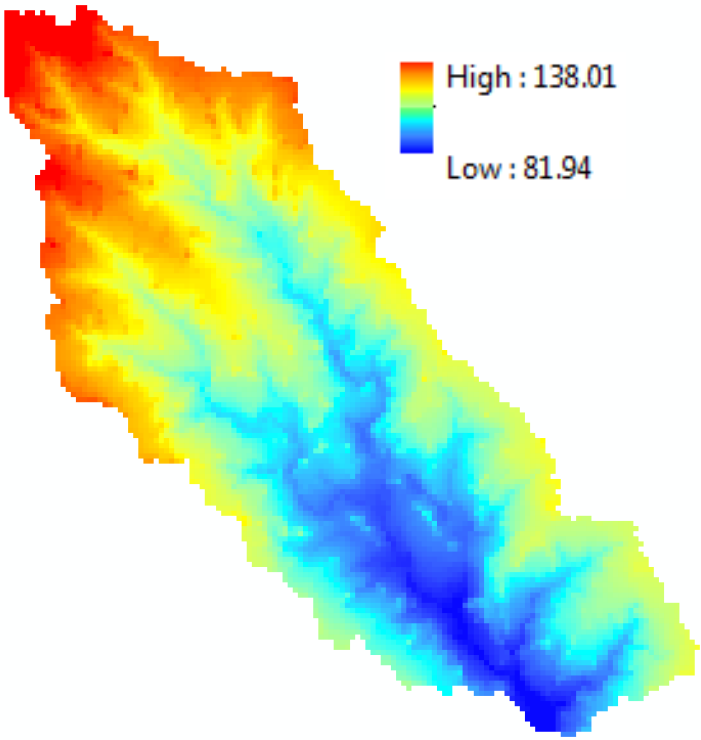


MODFLOW

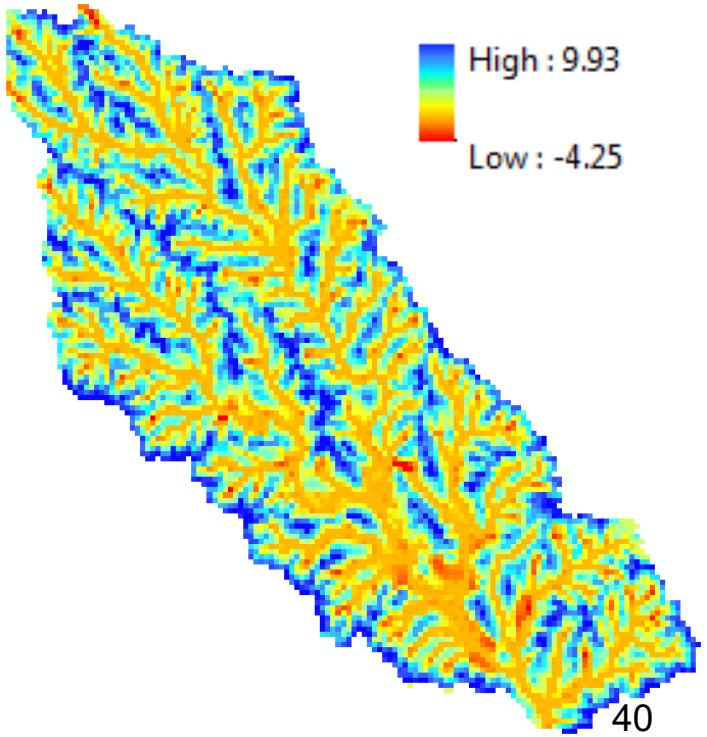
View Results

- .out
- .hed
- .hff

Groundwater Head



Depth to Water Table



40

MODFLOW

View Results

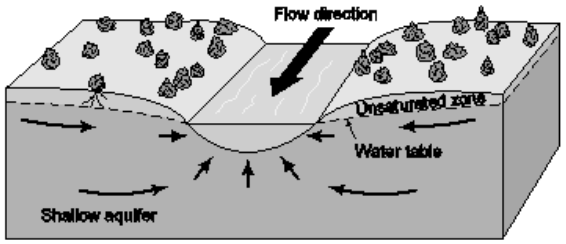
- .out
- .hed
- .hff

Aquifer-River Interaction

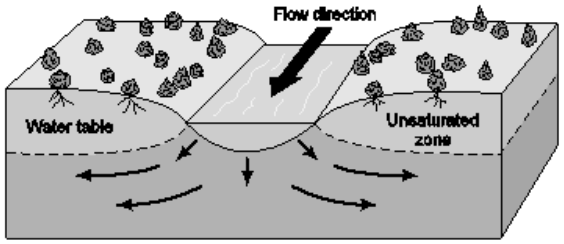
```
25784                1          1          136        141          1
25785   'RIV                 '
25786                1          5           20    -1614.715
25787                1          5           21    -287.0071
25788                1          6           21    -1017.541
25789                1          6           22     62.47199
25790                1          7            4    -178.8291
25791                1          7            5    -1066.438
25792                1          7           22    -692.8306
25793                1          8            5    -202.0663
25794                1          8            6    -997.8644
25795                1          8           22     166.8414
25796                1          8           23    -895.8528
25797                1          8           24     378.7040
25798                1          9            6    -155.4519
25799                1          9            7    -891.2577
25800                1          9            8     43.15596
25801                1          9           10     118.5494
25802                1          9           24    -976.2923
25803                1          9           25     151.3831
25804                1         10            8    -796.8106
25805                1         10           10    -34.12440
25806                1         10           25    -455.9524
25807                1         10           26    -1039.691
25808                1         10           27     421.9946
25809                1         11            8     184.1801
25810                1         11            9    -367.8575
25811                1         11           11    -694.4037
25812                1         11           12    -456.4211
25813                1         11           27    -999.4467
25814                1         12            9    -933.0735
25815                1         12           12    -541.0646
25816                1         12           27     283.7783
25817                1         12           28    -1145.911
25818                1         13            9    -872.2866
25819                1         13           10     307.3288
```

1633

Leaving Aquifer



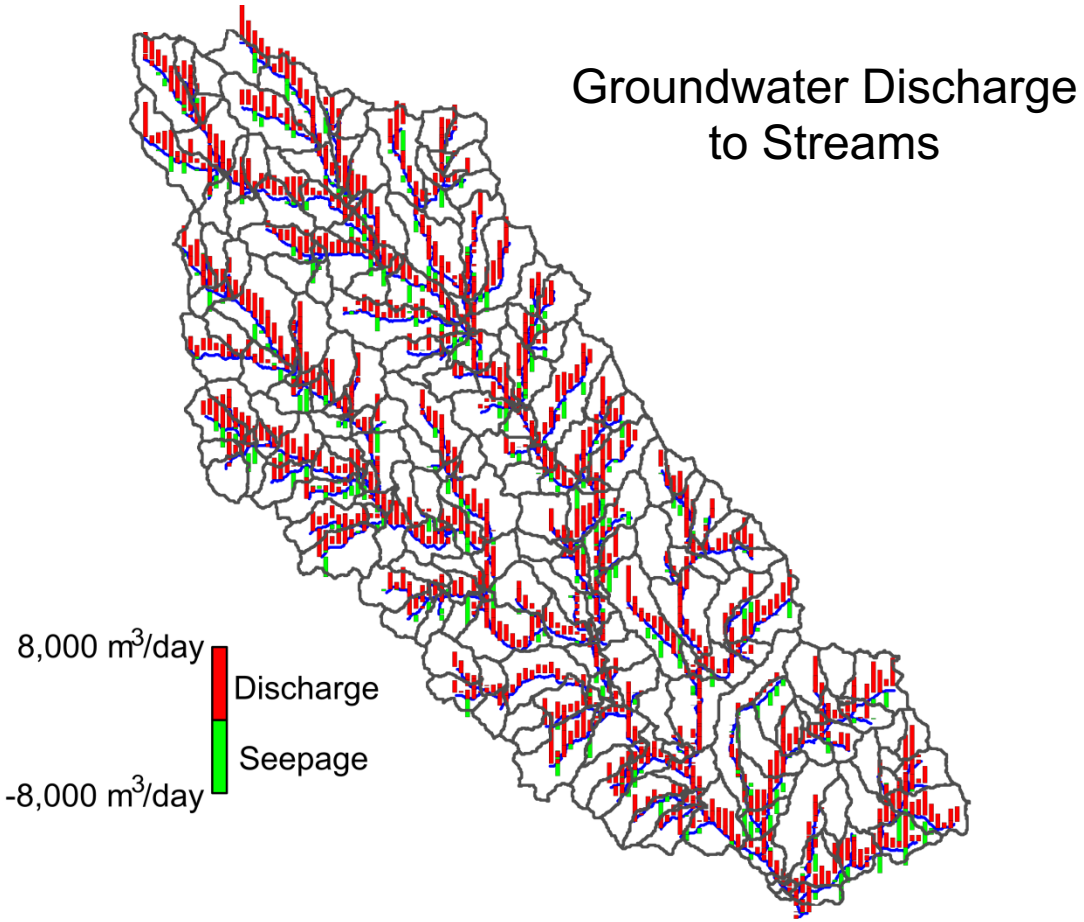
Entering Aquifer



MODFLOW

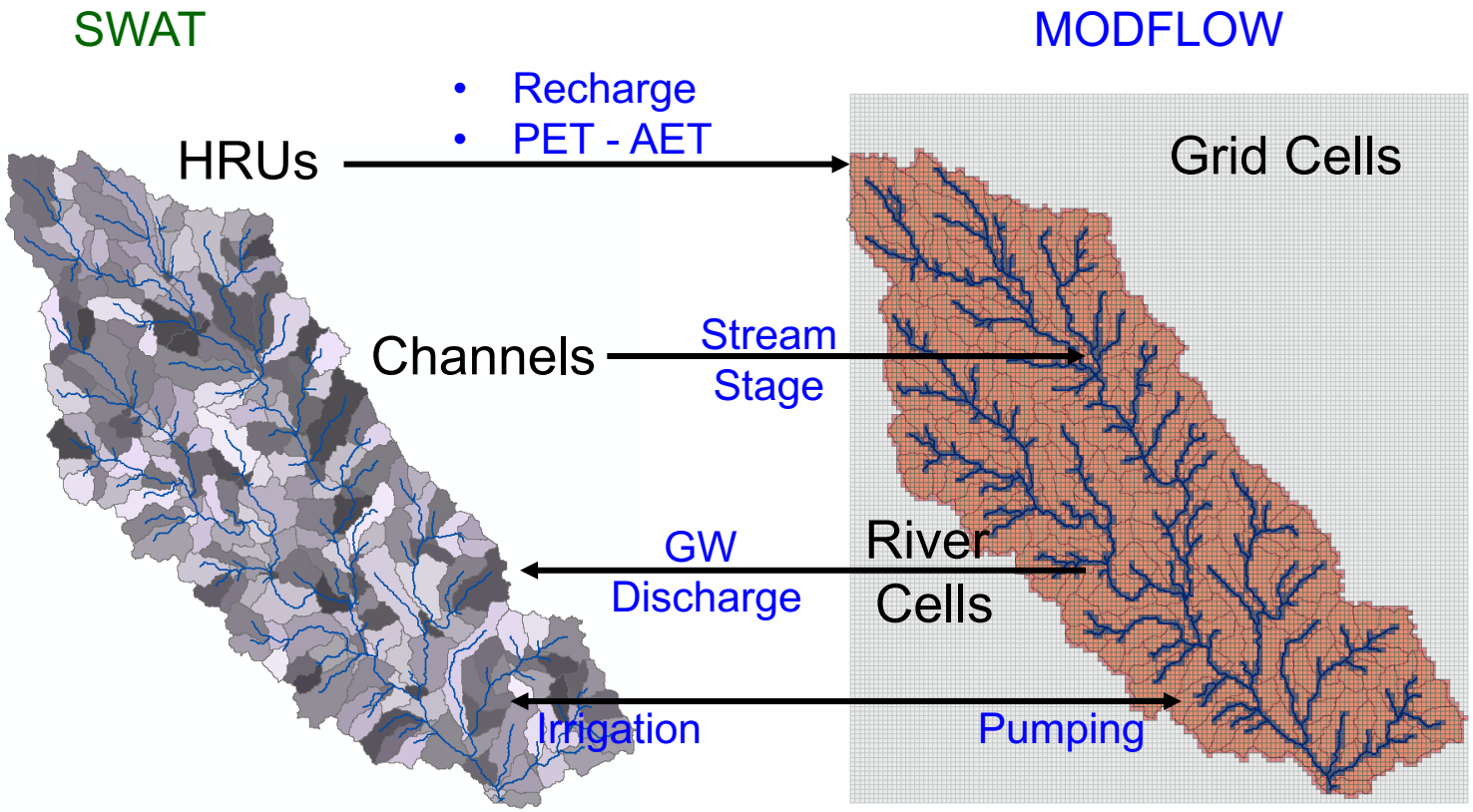
View Results

- .out
- .hed
- .hff



SWAT-MODFLOW

Objective: Pass data between SWAT and MODFLOW



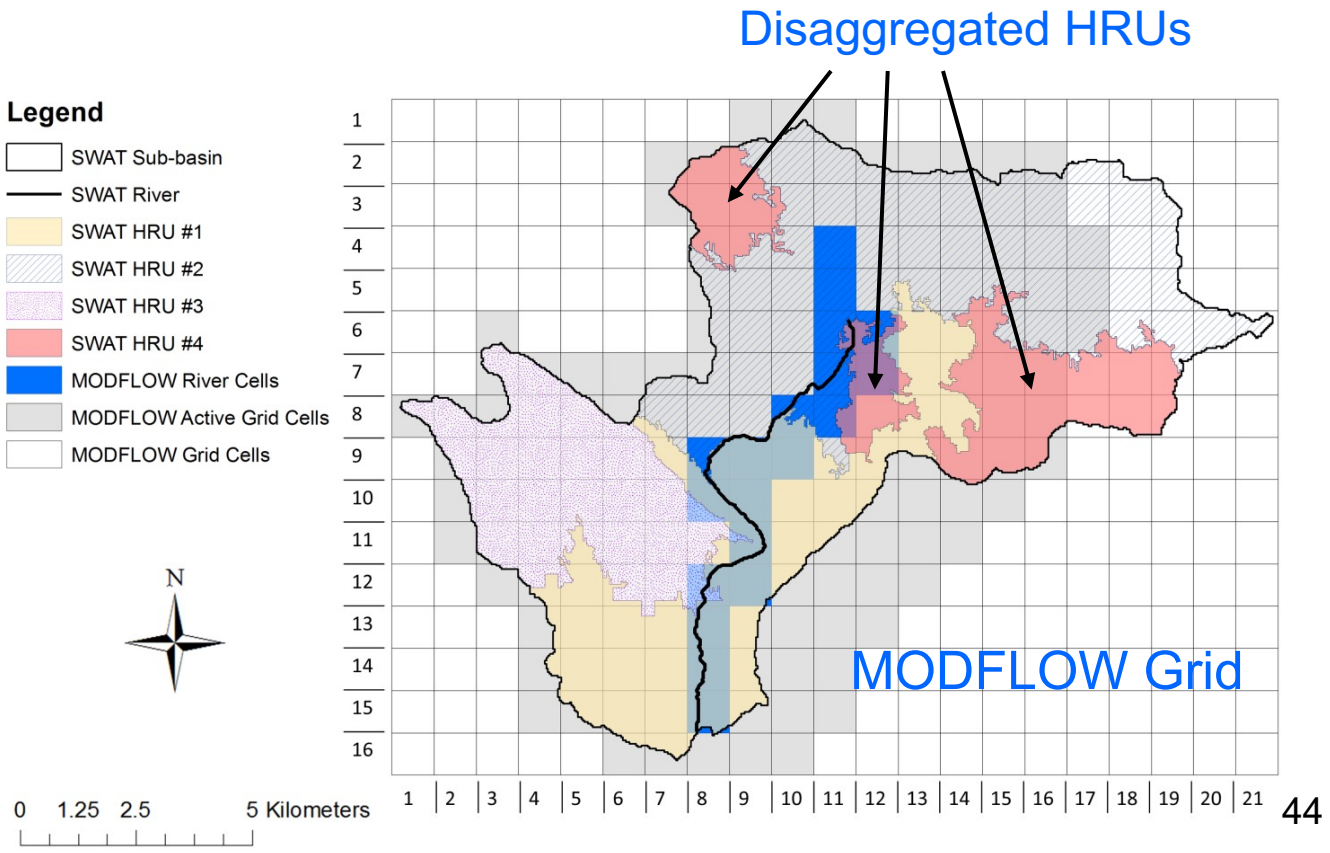
SWAT-MODFLOW

Linking Procedure:

HRU → DHRU → Grid Cells — Recharge

River Cells → Sub-basins — GW/SW exchange

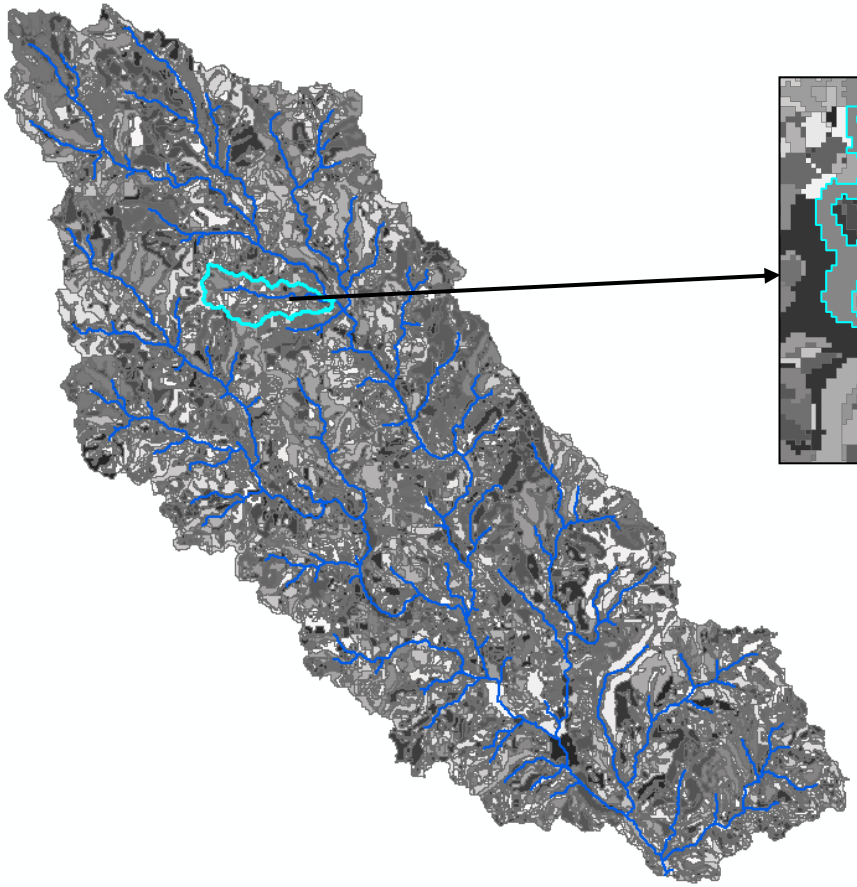
(Pre-processing in GIS)

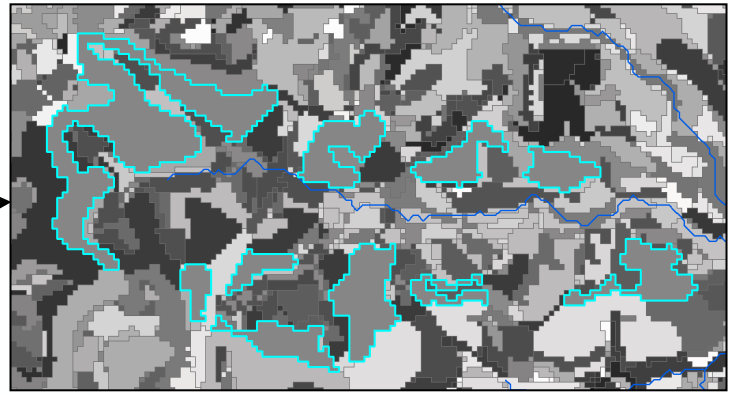


SWAT-MODFLOW

Linking Procedure: HRU → DHRU → Grid Cells — Recharge

River Cells → Sub-basins — GW/SW exchange





1 HRU → 11 DHRUs

hru_dhru

SWAT-MODFLOW

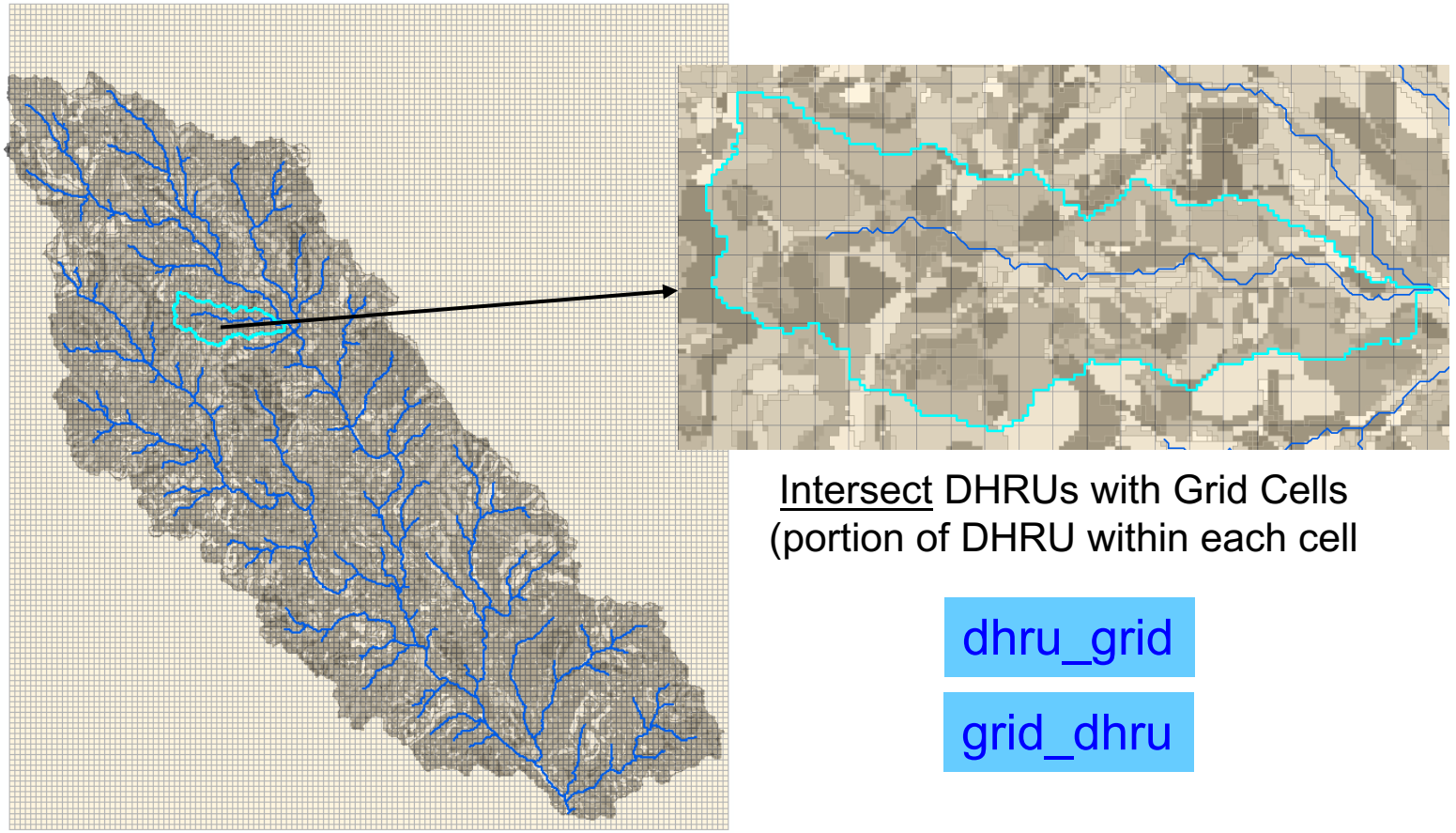
hru_dhru

```
27396  Number of DHRUs
6233 Number of HRUs
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
```

SWAT-MODFLOW

Linking Procedure: HRU → DHRU → Grid Cells — Recharge

River Cells → Sub-basins — GW/SW exchange



Intersect DHRUs with Grid Cells
(portion of DHRU within each cell

dhru_grid

grid_dhru

SWAT-MODFLOW

dhru_grid

```
1  61838  Number of Intersected polygons
2  19176  Number of cells
3  grid_id grid_area       dhru_id overlap_area    dhru_area
4  16      40000   27      3000.00000000000        9900.00000000000
5  16      40000   58      600.00000000000 900.00000000000
6  16      40000   63      1900.00000000000        31500.00000000000
7  17      40000   7       6000.00000000000        7200.00000000000
8  17      40000   27      6900.00000000000        9900.00000000000
9  17      40000   57      800.00000000000 4500.00000000000
10 17      40000   58      300.00000000000 900.00000000000
11 17      40000   63      800.00000000000 31500.00000000000
12 18      40000   57      400.00000000000 4500.00000000000
13 137     40000   1158    5600.00000000000        76500.00000000000
14 138     40000   1158    25100.00000000000       76500.00000000000
15 138     40000   1182    4500.00000000000        11700.00000000000
16 139     40000   1158    8600.00000000000        76500.00000000000
17 139     40000   1159    3300.00000000000        272700.00000000000
18 139     40000   1368    4200.00000000000        9000.00000000000
19 140     40000   1159    1400.00000000000        272700.00000000000
```

SWAT-MODFLOW

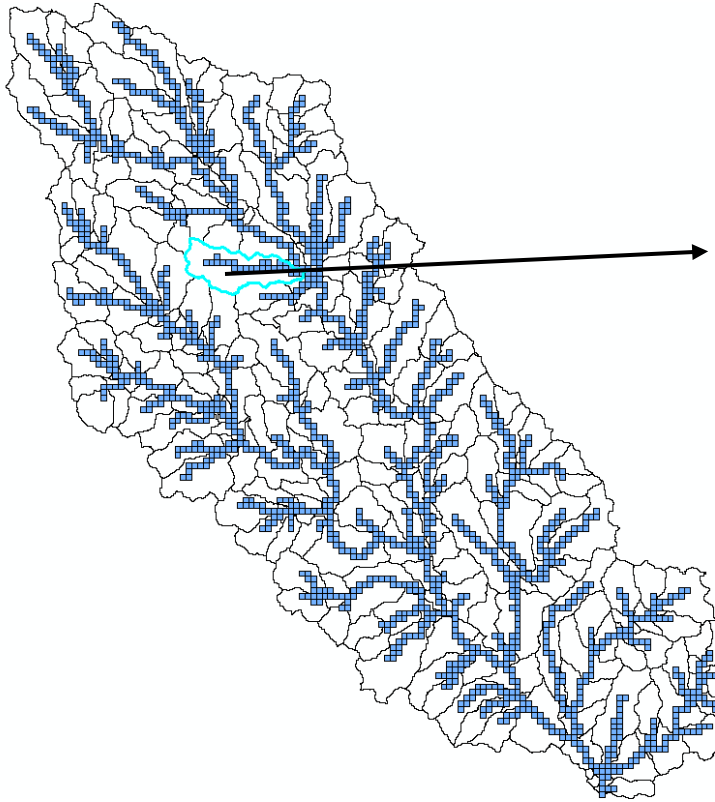
grid_dhru

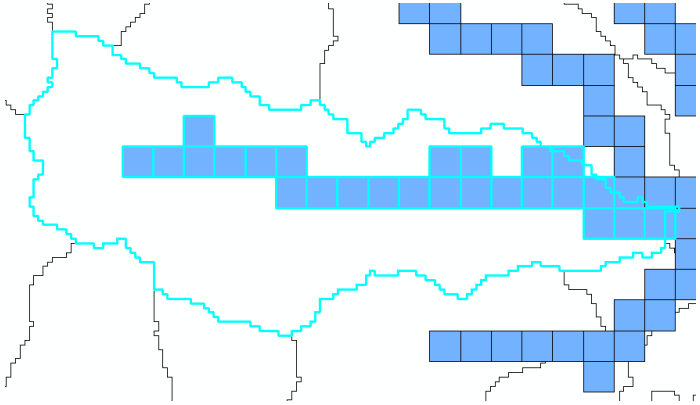
```
61838  Number of Intersected polygons
27396  Number of cells
141    Number of rows in MODFLOW grid
136    Number of columns in MODFLOW grid
grid_id grid_area        dhru_id overlap_area    dhru_area
702     40000   1        4500.00000000000        9000.00000000000
838     40000   1        4500.00000000000        9000.00000000000
702     40000   2        900.00000000000 900.00000000000
702     40000   3        900.00000000000 900.00000000000
560     40000   4        900.00000000000 900.00000000000
425     40000   5        9800.00000000000        45900.00000000000
426     40000   5        10900.00000000000       45900.00000000000
561     40000   5        15100.00000000000       45900.00000000000
562     40000   5        10100.00000000000       45900.00000000000
291     40000   6        16500.00000000000       89100.00000000000
292     40000   6        3300.00000000000        89100.00000000000
427     40000   6        7200.00000000000        89100.00000000000
428     40000   6        30300.00000000000       89100.00000000000
429     40000   6        14400.00000000000       89100.00000000000
565     40000   6        16800.00000000000       89100.00000000000
701     40000   6        600.00000000000 89100.00000000000
17      40000   7        6000.00000000000        7200.00000000000
153     40000   7        1200.00000000000        7200.00000000000
```

SWAT-MODFLOW

Linking Procedure: HRU → DHRU → Grid Cells — Recharge

River Cells → Sub-basins — GW/SW exchange





These cells interact with the sub-basin stream
(gw discharge / seepage)

river_grid

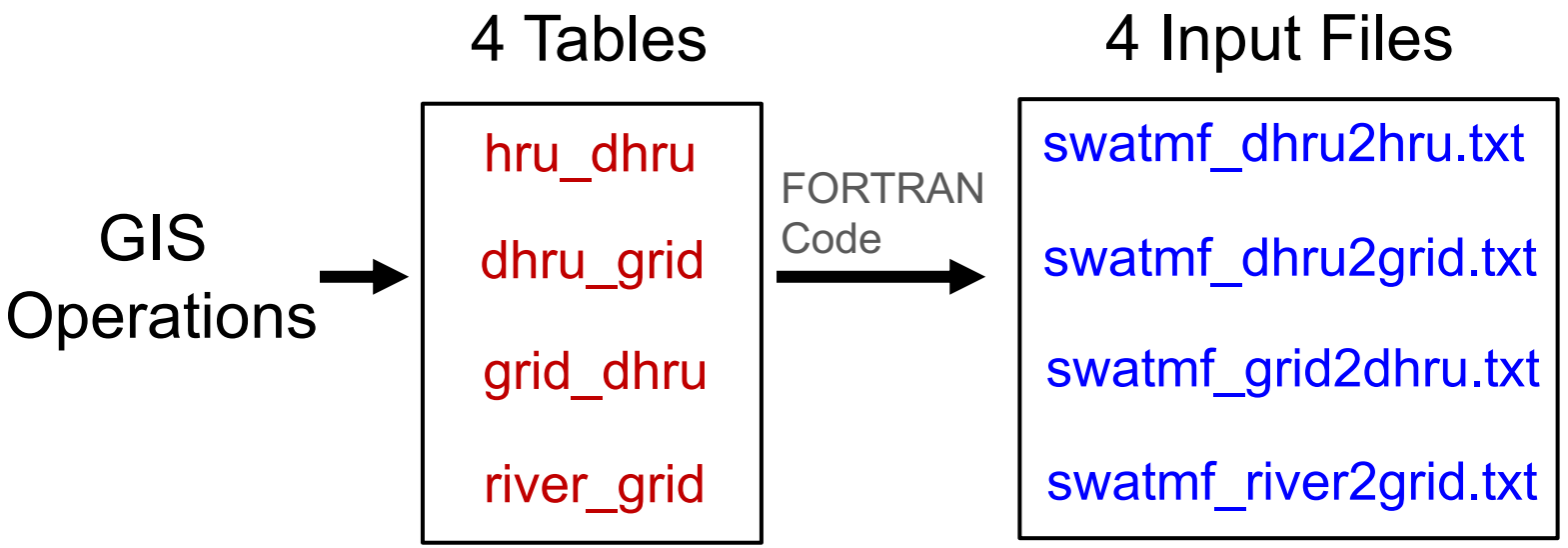
SWAT-MODFLOW

river_grid

```
1921 Number of Intersected River Cells
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
```

SWAT-MODFLOW

Linkage Files - Overview



SWAT-MODFLOW

swatmf_link.txt

```
1   1       SWAT-MODFLOW is activated
2   1       MODFLOW Pumping --> SWAT Irrigation
3   0       SWAT Auto-Irrigation --> MODFLOW Pumping
4   1       MODFLOW Drains --> SWAT subbasin channels
5   1       RT3D is active (N and P groundwater reactive transport)
6   1       Read in observation cells from "modflow.obs"
7   Optional output for SWAT-MODFLOW (0=no; 1=yes)
8   1       SWAT Deep Percolation (mm) (for each HRU)
9   1       MODFLOW Recharge (m3/day) (for each MODFLOW Cell)
10  1       SWAT Channel Depth (m) (for each SWAT Subbasin)
11  1       MODFLOW River Stage (m) (for each MODFLOW River Cell)
12  1       Groundwater/Surface Water Exchange (m3/day) (for each MODFLOW River Cell)
13  1       Groundwater/Surface Water Exchange (m3/day) (for each SWAT Subbasin)
14  1       Print out average values for SWAT-MODFLOW and RT3D output variables
15  Write SWAT-MODFLOW output only on specified days
16  7 number of output days for the 6 optional output variables
17  365
18  730
19  1095
20  1460
21  1825
22  3650
23  5475
24  Groundwater delay
25  0       0 = read in a single value for all HRUs; 1 = read in one value for each HRU
26  5       GW_DELAY : Groundwater delay [days]
27
```

flag (0 or 1): 1 if SWAT-MODFLOW is to be used

flag (0 or 1): see Section 7.1

flag (0 or 1): see Section 7.1

flag (0 or 1): see Section 7.2

flag (0 or 1): see Section 8

flag (0 or 1): see Section 4.3.9

flags (0 or 1) for output

flag (0 or 1) for monthly and annual average output

List of output days. On these days, daily values for variables listed under "Optional output for SWAT-MODFLOW" will be written to output files.

Groundwater delay value (the values in the HRU .gw files are not used)

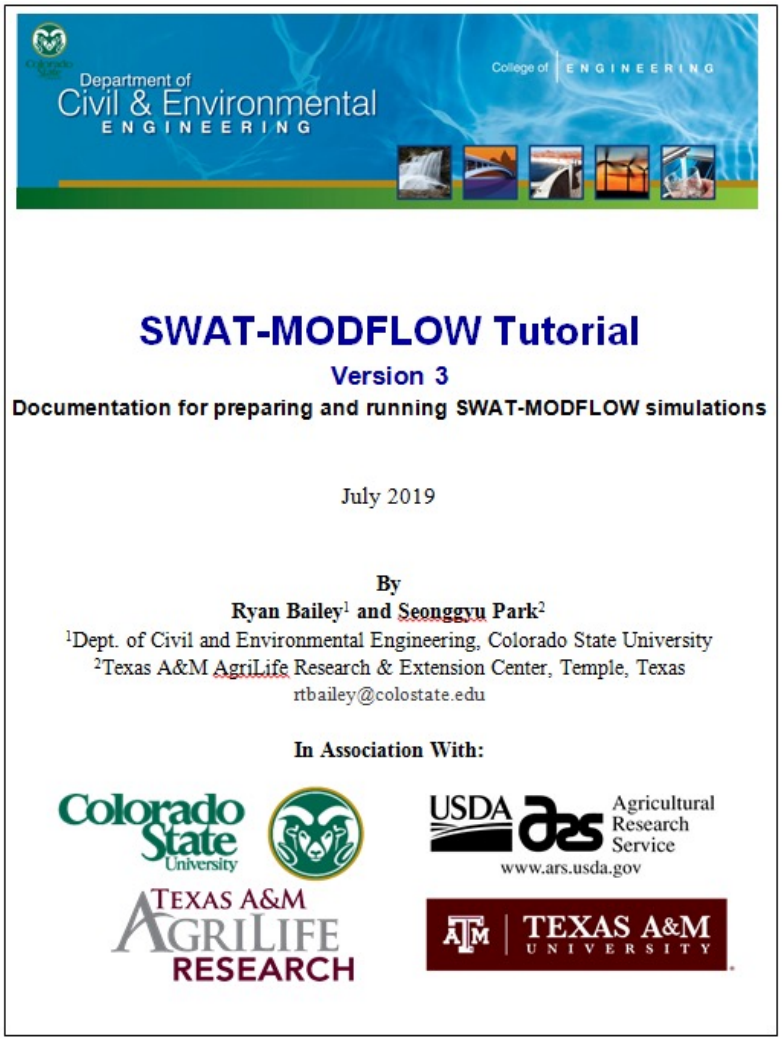
SWAT-MODFLOW

Running a Simulation

1. SWAT Input Files
2. MODFLOW Input Files
3. "*swatmf_link.txt*"
4. "*swatmf_*" linkage files
   - swatmf_dhru2hru.txt
   - swatmf_dhru2grid.txt
   - swatmf_grid2dhru.txt
   - swatmf_river2grid.txt
5. SWAT_MODFLOW.exe Run!

SWAT-MODFLOW

Linking Files


Department of Civil & Environmental ENGINEERING

College of ENGINEERING

SWAT-MODFLOW Tutorial

Version 3

Documentation for preparing and running SWAT-MODFLOW simulations

July 2019

By

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Colorado State University

USDA ARS Agricultural Research Service www.ars.usda.gov

Texas A&M AgriLife Research

Texas A&M University

SWAT-MODFLOW

Code Structure

Read/Allocate MODFLOW

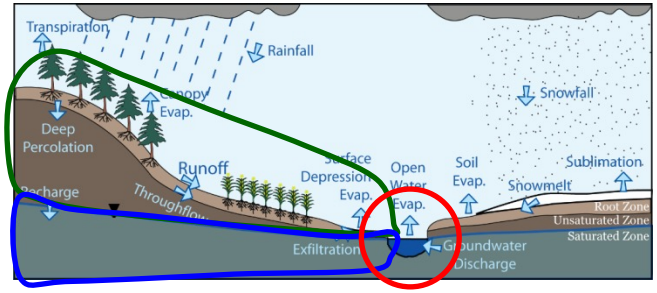
Read SWAT-MODFLOW linkage files

simulate

Years

Days

command



Surface 1: subbasin (hru calculations)

Aquifer 19: MODFLOW

Map SWAT → Grid Cells

HRU values → disaggregated HRUs (DHRUs)

DHRUs → Grid cells

River stage → MODFLOW River cells

Recharge

Run MODFLOW

Map Grid Cells → SWAT

GW Discharge → Subbasin streams

Routing 2: Route

Outline of Workshop

1. Overview and Theory of SWAT-MODFLOW
2. Setting up and running SWAT-MODFLOW
3. QSWATMOD: install, introduction, application
4. Work with your data and watersheds

Set Up, Run, View

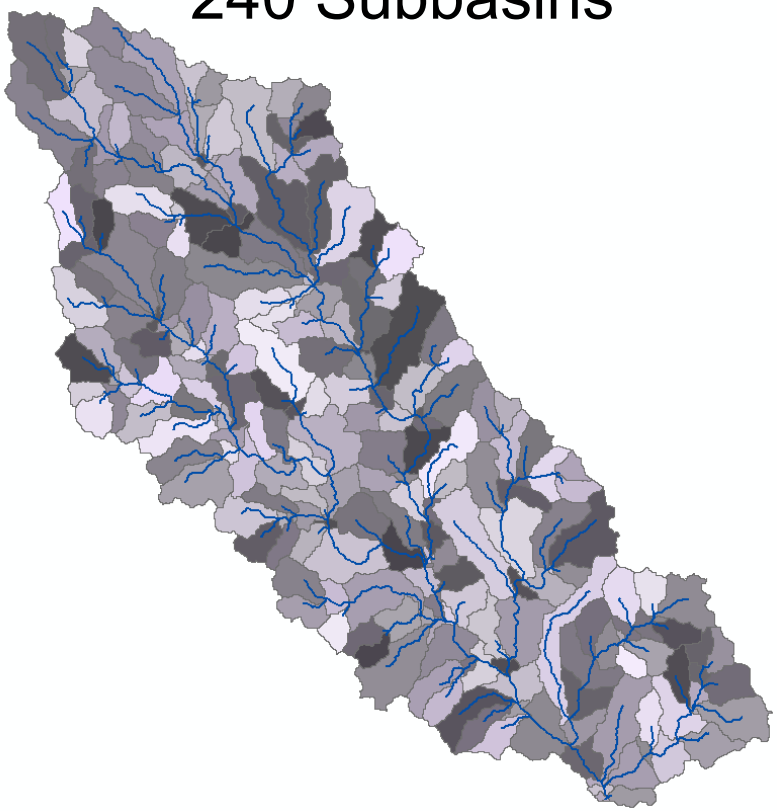
1. Assemble Model Input Files
2. Run SWAT-MODFLOW
3. Check and Analyze Output

1. SWAT input files — Files\1 SWAT LRW\SWAT Model\TxtInOut
2. MODFLOW input files
3. MODFLOW name file (modflow.mfn)
4. SWAT-MODFLOW linking file (swatmf_link.txt)
5. MODFLOW observation file (modflow.obs) (only if specified in swatmf_link.txt)
6. SWAT-MODFLOW Mapping files:
   a. swatmf_dhru2hru.txt
   b. swatmf_dhru2grid.txt
   c. swatmf_grid2dhru.txt
   d. swatmf_river2grid.txt
7. SWAT-MODFLOW executable (SWAT-MODFLOW3.exe)

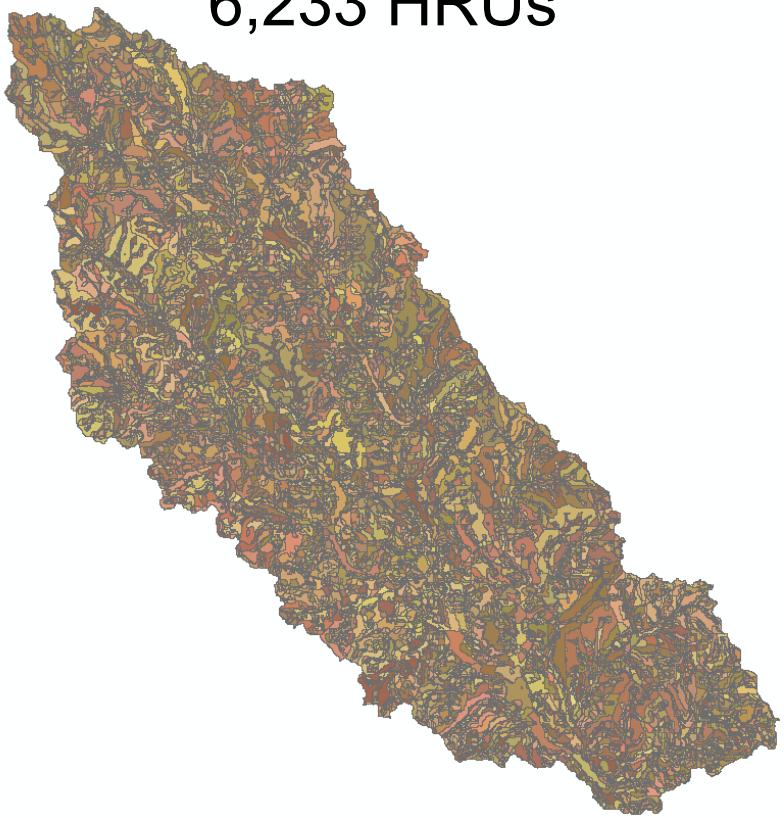
Setting up a Simulation

SWAT Model

240 Subbasins



6,233 HRUs



Set Up, Run, View

1. Assemble Model Input Files
2. Run SWAT-MODFLOW
3. Check and Analyze Output

1. SWAT input files
2. MODFLOW input files
3. MODFLOW name file (modflow.mfn)
4. SWAT-MODFLOW linking file (swatmf_link.txt)
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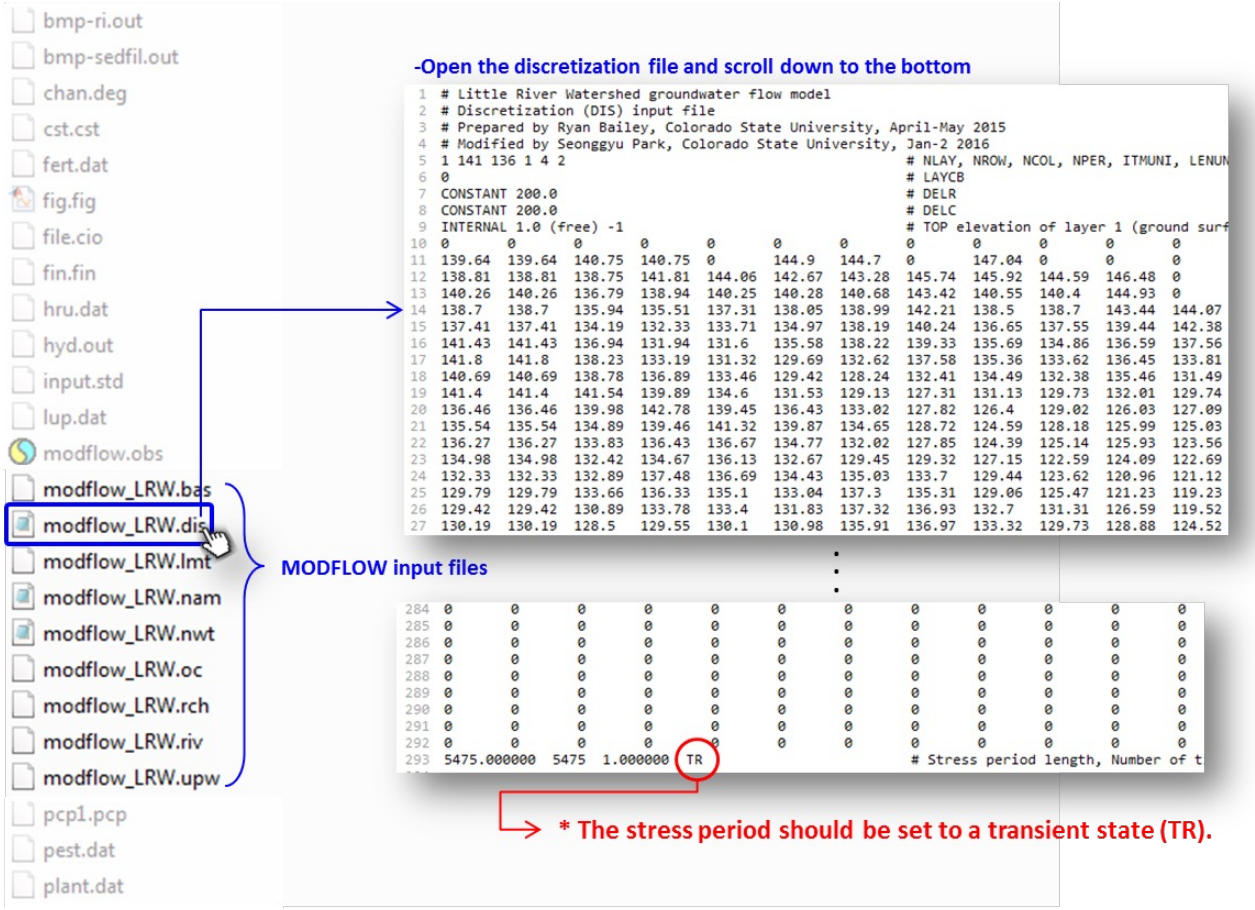
   a. swatmf_dhru2hru.txt
   b. swatmf_dhru2grid.txt
   c. swatmf_grid2dhru.txt
   d. swatmf_river2grid.txt
7. SWAT-MODFLOW executable (SWAT-MODFLOW3.exe)

Files\2 MODFLOW LRW\MODFLOW model

- Copy into TxtInOut folder
- Change .dis file

Set Up, Run, View

1. Assemble Model Input Files
2. Run SWAT-MODFLOW
3. Check and Analyze Output



Set Up, Run, View

1. Assemble Model Input Files
2. Run SWAT-MODFLOW
3. Check and Analyze Output

1. SWAT input files
2. MODFLOW input files
3. MODFLOW name file (modflow.mfn)
4. SWAT-MODFLOW linking file (swatmf_link.txt)
5. MODFLOW observation file (modflow.obs) (only if specified in swatmf_link.txt)
6. SWAT-MODFLOW Mapping files:
   a. swatmf_dhru2hru.txt
   b. swatmf_dhru2grid.txt
   c. swatmf_grid2dhru.txt
   d. swatmf_river2grid.txt
7. SWAT-MODFLOW executable (SWAT-MODFLOW3.exe)

Set Up, Run, View

1. Assemble Model Input Files
2. Run SWAT-MODFLOW
3. Check and Analyze Output

1. SWAT input files
2. MODFLOW input files
3. MODFLOW name file (modflow.mfn)
4. SWAT-MODFLOW linking file (swatmf_link.txt) Files\4 SWAT MODFLOW LRW
5. MODFLOW observation file (modflow.obs) (only if specified in swatmf_link.txt)
6. SWAT-MODFLOW Mapping files:
   a. swatmf_dhru2hru.txt
   b. swatmf_dhru2grid.txt
   c. swatmf_grid2dhru.txt
   d. swatmf_river2grid.txt
7. SWAT-MODFLOW executable (SWAT-MODFLOW3.exe)

Set Up, Run, View

1. Assemble Model Input Files
2. Run SWAT-MODFLOW
3. Check and Analyze Output

1. SWAT input files
2. MODFLOW input files
3. MODFLOW name file (modflow.mfn)
4. SWAT-MODFLOW linking file (swatmf_link.txt)
5. MODFLOW observation file (modflow.obs) (only if specified in swatmf_link.txt)
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   a. swatmf_dhru2hru.txt
   b. swatmf_dhru2grid.txt
   c. swatmf_grid2dhru.txt
   d. swatmf_river2grid.txt
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Set Up, Run, View

1. Assemble Model Input Files
2. Run SWAT-MODFLOW
3. Check and Analyze Output

1. SWAT input files
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5. MODFLOW observation file (modflow.obs) (only if specified in swatmf_link.txt)
6. SWAT-MODFLOW Mapping files:
   a. swatmf_dhru2hru.txt
   b. swatmf_dhru2grid.txt
   c. swatmf_grid2dhru.txt
   d. swatmf_river2grid.txt
7. SWAT-MODFLOW executable (SWAT-MODFLOW3.exe)

Files\3 Linking\2 Creating SWATMF files

Run *CreateSWATMF.exe*

Set Up, Run, View

1. Assemble Model Input Files
2. Run SWAT-MODFLOW
3. Check and Analyze Output

1. SWAT input files
2. MODFLOW input files
3. MODFLOW name file (modflow.mfn)
4. SWAT-MODFLOW linking file (swatmf_link.txt)
5. MODFLOW observation file (modflow.obs) (only if specified in swatmf_link.txt)
6. SWAT-MODFLOW Mapping files:
   a. swatmf_dhru2hru.txt
   b. swatmf_dhru2grid.txt
   c. swatmf_grid2dhru.txt
   d. swatmf_river2grid.txt
7. SWAT-MODFLOW executable (SWAT-MODFLOW3.exe) Run!

Set Up, Run, View

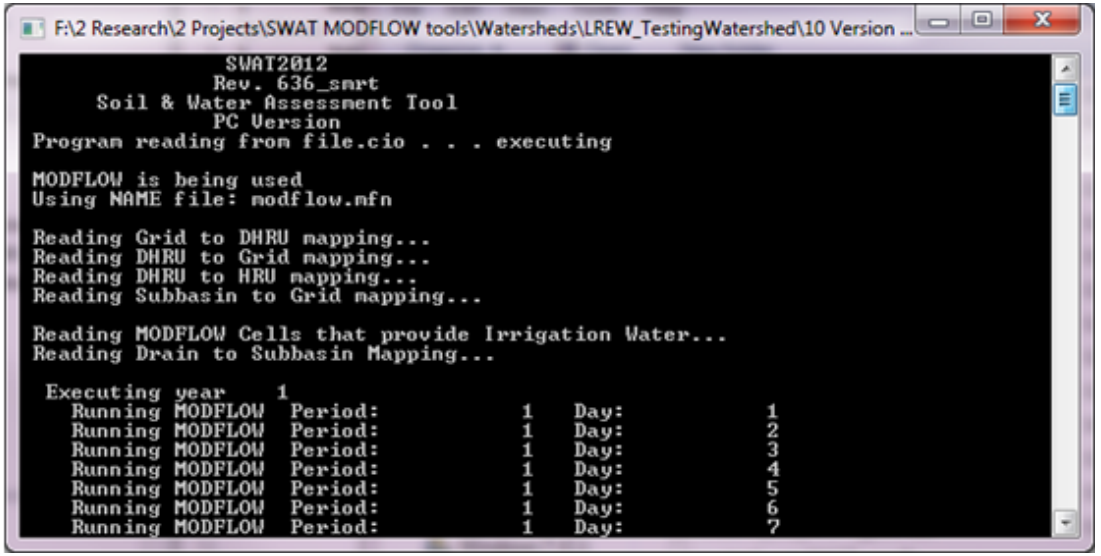
1. Assemble Model Input Files
2. Run SWAT-MODFLOW
3. Check and Analyze Output

MODFLOW is active

Read linking files

Additional MODFLOW packages

Daily MODFLOW execution



Set Up, Run, View

1. Assemble Model Input Files
2. Run SWAT-MODFLOW
3. Check and Analyze Output

```
VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP 5475, STRESS PERIOD   1
-------------------------------------------------------------------------------

   CUMULATIVE VOLUMES      L**3       RATES FOR THIS TIME STEP      L**3/T
   ------------------                 ------------------------

        IN:                                IN:
        ---                                ---
          STORAGE =  1292723712.0000         STORAGE =      174717.9219
    CONSTANT HEAD =   161053760.0000   CONSTANT HEAD =       26817.7773
            WELLS =           0.0000           WELLS =           0.0000
           DRAINS =           0.0000          DRAINS =           0.0000
    RIVER LEAKAGE =   372370304.0000   RIVER LEAKAGE =       56606.5039
               ET =           0.0000              ET =           0.0000
         RECHARGE =  1316383744.0000         RECHARGE =      194193.6406

         TOTAL IN =  3142531584.0000         TOTAL IN =      452335.8438

       OUT:                               OUT:
       ----                               ----
          STORAGE =  1151042176.0000         STORAGE =       49844.8984
    CONSTANT HEAD =    46418300.0000   CONSTANT HEAD =        9110.7969
            WELLS =    30376550.0000           WELLS =        6584.1978
           DRAINS =    17714204.0000          DRAINS =        3510.8010
    RIVER LEAKAGE =  1026437120.0000   RIVER LEAKAGE =      323870.0000
               ET =   870542144.0000              ET =       59415.1875
         RECHARGE =           0.0000         RECHARGE =           0.0000

        TOTAL OUT =  3142530304.0000        TOTAL OUT =      452335.8750

           IN - OUT =        1280.0000           IN - OUT =      -3.1250E-02

PERCENT DISCREPANCY =           0.00  PERCENT DISCREPANCY =           0.00
```

Groundwater entering the aquifer

Groundwater leaving the aquifer

Mass balance

Set Up, Run, View

1. Assemble Model Input Files
2. Run SWAT-MODFLOW
3. Check and Analyze Output

Troubleshooting

- The linkage files are not created properly
- The swatmf_link.txt file is not created properly
- The MODFLOW name file is not "modflow.mfn"
- The MODFLOW input files are not created properly
- The irrigation and drainage flags are set to "1" in swatmf_link.txt, but there is no corresponding MODFLOW input file for the Well package or Drain package, respectively
- The MODFLOW solution does not converge

Set Up, Run, View

1. Assemble Model Input Files
2. Run SWAT-MODFLOW
3. Check and Analyze Output

output.std

```
    SWAT Mar 17 2015    VER 2012/Rev 636_smrt                                   0/ 0/   0      0: 0: 0

    General Input/Output section (file.cio):
    5/20/2015 12:00:00 AM ARCGIS-SWAT interface AV

         Number of years in run:   15
         Area of watershed:      331.882 km2
1
    SWAT Mar 17 2015    VER 2012/Rev 636_smrt

    General Input/Output section (file.cio):
    5/20/2015 12:00:00 AM ARCGIS-SWAT interface AV

Annual Summary for Watershed in year    1 of simulation

UNIT                                          PERCO          TILE
TIME     PREC    SURQ    LATQ    GWQ    SWGW  LATE   RECH    Q       DRN     SW      GW      GWSTOR  GWCON  GWET   ET      P
         (mm)    (mm)    (mm)    (mm)   (mm)  (mm)   (mm)    (mm)    (mm)    (mm)    (mm)    mm      mm     mm     (mm)    (
    1    0.00    0.00    0.00    0.00   0.00  0.00   0.00    0.00    0.01    117.63  919.15  0.02    0.04   0.04   0.75    1
    2   10.20    0.10    0.04    0.00   0.29  0.00   0.00    0.00    0.02    126.09  919.48  0.32    0.05   0.02   1.28    1
    3   12.70    0.28    0.13    0.00   0.29  0.00   0.00    0.00    0.02    137.66  919.81  0.33    0.06   0.00   0.22    0
    4    9.10    0.11    0.18    0.00   0.55  0.00   0.00    0.00    0.03    145.80  914.36  0.59    0.06   0.00   0.37    0
```

The water balance for the aquifer is:

$$GWSTOR = RECH + SWGW + GWCON - GWQ - DRN - GWET$$

Set Up, Run, View

1. Assemble Model Input Files
2. Run SWAT-MODFLOW
3. Check and Analyze Output

output.std

```
AVE ANNUAL BASIN VALUES

     PRECIP =   1140.5 MM
     SNOW FALL =    1.56 MM
     SNOW MELT =     1.56 MM
     SUBLIMATION =     0.00 MM
     SURFACE RUNOFF Q =   233.28 MM
     LATERAL SOIL Q =   23.42 MM
     TILE Q =     0.00 MM
     DRAIN Q (MODFLOW) =     3.73MM
     GROUNDWATER (SHAL AQ) Q =   164.21 MM
     GROUNDWATER (DEEP AQ) Q =     0.00 MM
     CHANGE IN GW STORAGE (MODFLOW) =   -28.04 MM
     CONSTANT HEAD Q (MODFLOW) =    22.88 MM
     RIVER SEEPAGE Q =    20.46 MM
     REVAP (SHAL AQ => SOIL/PLANTS) =    0.00 MM
     DEEP AQ RECHARGE =     0.00 MM
     TOTAL AQ RECHARGE =  252.22 MM
     TOTAL WATER YLD =   404.13 MM
     PERCOLATION OUT OF SOIL =  252.84 MM
     ET =    639.4 MM
     ET FROM GROUNDWATER (MODFLOW) =   161.90 MM
     PET =   1390.3MM
     TRANSMISSION LOSSES =     0.00 MM
     SEPTIC INFLOW =       0.00 MM
     TOTAL SEDIMENT LOADING =     5.800 T/HA
     TILE FROM IMPOUNDED WATER =     0.000 (MM)
     EVAPORATION FROM IMPOUNDED WATER =     0.000 (MM)
     SEEPAGE INTO SOIL FROM IMPOUNDED WATER =    0.000 (MM)
     OVERFLOW FROM IMPOUNDED WATER =    0.000 (MM)
```

Set Up, Run, View

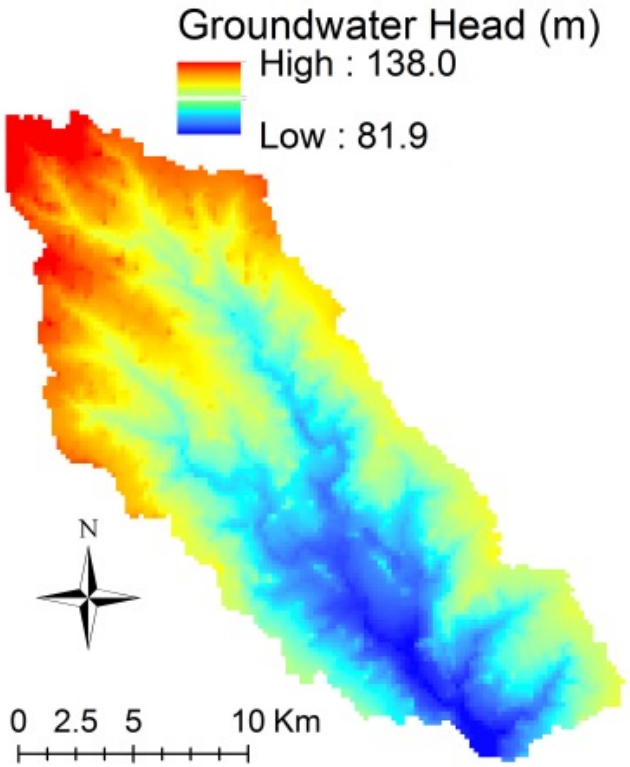
1. Assemble Model Input Files
2. Run SWAT-MODFLOW
3. Check and Analyze Output

SWAT-MODFLOW Output File		Units	Notes
MODFLOW: Groundwater-Surface Water Exchange			
	swatmf_out_MF_gwsw	L^3/T	Flow rate of water exchanged between the aquifer and the river, for each MODFLOW River cell; Positive: River-->Aquifer; Negative: Aquifer-->River
	swatmf_out_MF_gwsw_monthly	L^3/T	
	swatmf_out_MF_gwsw_yearly	L^3/T	
MODFLOW: Groundwater Head			
	swatmf_out_MF_head_monthly	L	Groundwater head values for each MODFLOW grid cell
	swatmf_out_MF_head_yearly	L	
MODFLOW: Recharge			
	swatmf_out_MF_recharge	L^3/T	Flow rate of water recharging the water table, for each MODFLOW grid cell
	swatmf_out_MF_recharge_monthly	L^3/T	
	swatmf_out_MF_recharge_yearly	L^3/T	
MODFLOW: River Stage			
	swatmf_out_MF_riverstage	L	River stage for each MODFLOW River cell
SWAT: Groundwater-Surface Water Exchange			
	swatmf_out_SWAT_gwsw	m^3/day	Flow rate of water exchanged between the aquifer and the river, for each SWAT subbasin (for River, Drain, Stream packages) Positive: Aquifer-->River ; Negative: River-->Aquifer
	swatmf_out_SWAT_gwsw_monthly	m^3/day	
	swatmf_out_SWAT_gwsw_yearly	m^3/day	
SWAT: Recharge			
	swatmf_out_SWAT_recharge	mm	Depth of water recharing the water table, for each SWAT HRU; for swatmf_out_SWAT_recharge, the soil percolation depth is also listed. *groundwater delay is used to simulate timing of recharge*
	swatmf_out_SWAT_recharge_monthly	mm	
	swatmf_out_SWAT_recharge_yearly	mm	
SWAT: River Stage			
	swatmf_out_SWAT_channel	m	Channel depth for each SWAT subbasin channel

Set Up, Run, View

1. Assemble Model Input Files
2. Run SWAT-MODFLOW
3. Check and Analyze Output

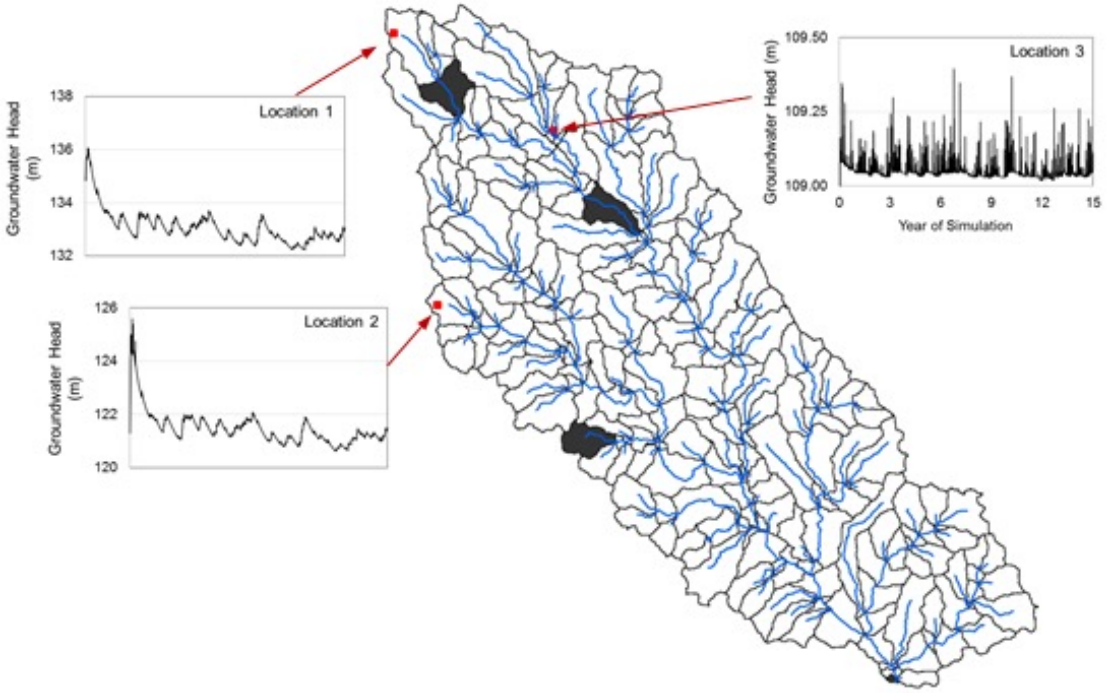
modflow_LRW.hed



Set Up, Run, View

1. Assemble Model Input Files
2. Run SWAT-MODFLOW
3. Check and Analyze Output

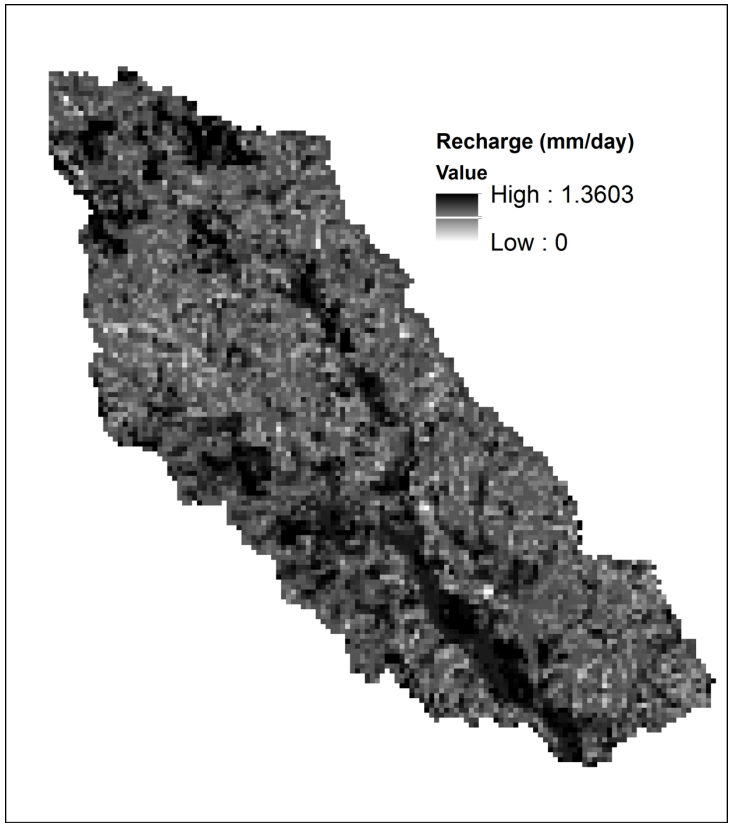
swatmf_out_MF_obs



Set Up, Run, View

1. Assemble Model Input Files
2. Run SWAT-MODFLOW
3. Check and Analyze Output

swatmf_out_MF_recharge



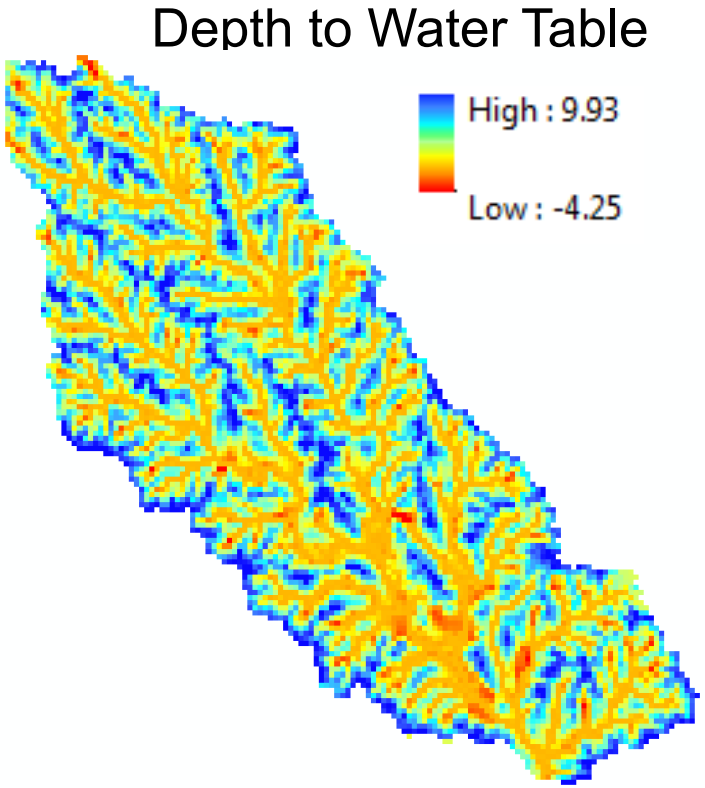
Set Up, Run, View

1. Assemble Model Input Files
2. Run SWAT-MODFLOW
3. Check and Analyze Output

modflow_LRW.hed

modflow_LRW.dis

Ground Surface Elevation
-
Hydraulic Head

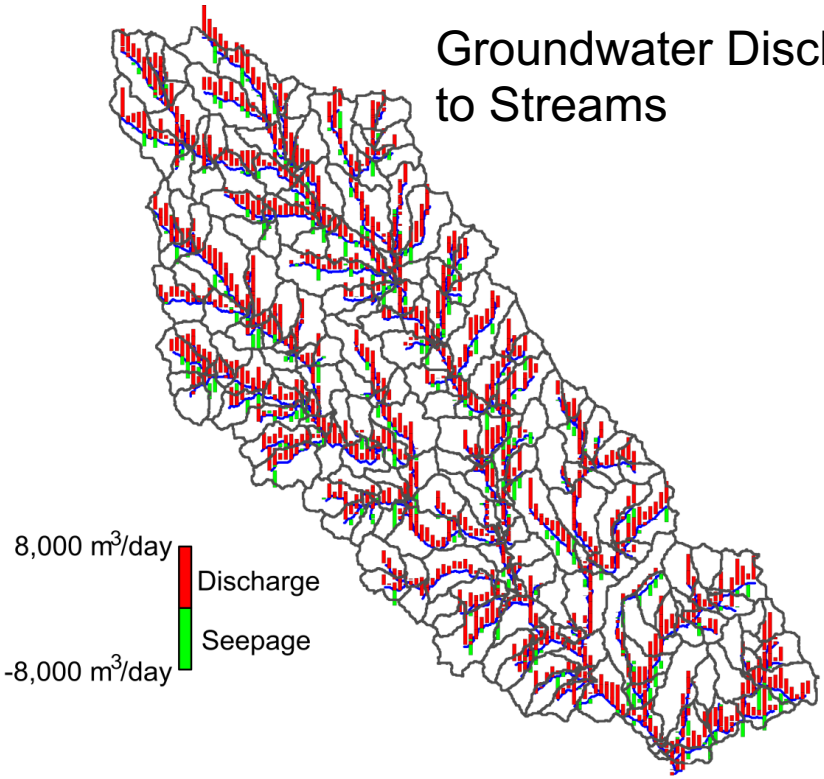


Set Up, Run, View

1. Assemble Model Input Files
2. Run SWAT-MODFLOW
3. Check and Analyze Output

swatmf_out_MF_gwsw

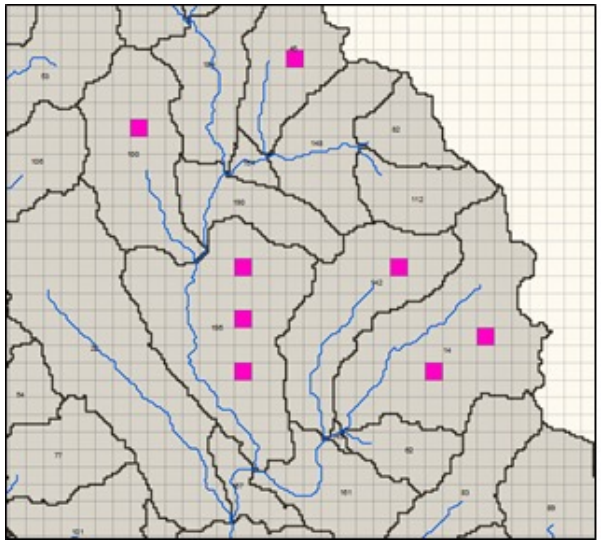
Groundwater Discharge to Streams



Additional Hydrological Linkages

SWAT Irrigation←→ MODFLOW Pumping

1. MODFLOW pumping controls SWAT irrigation
2. SWAT irrigation controls MODFLOW pumping



WELL package input file:

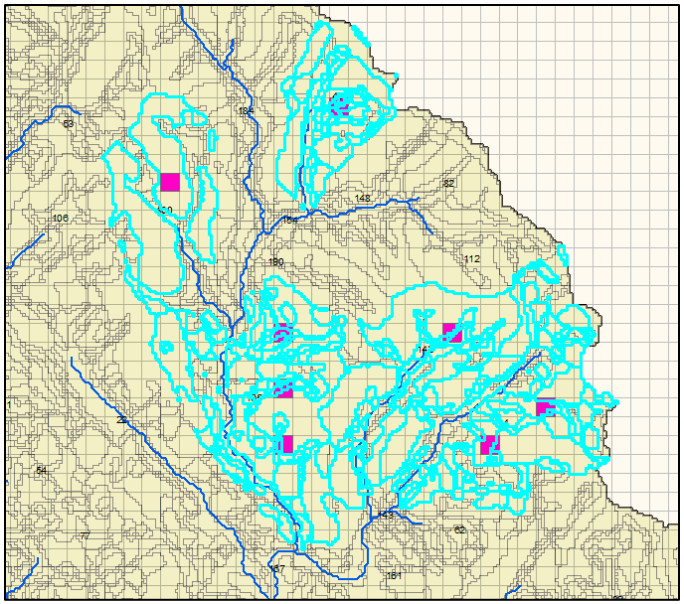
```
1  #Well package input file
2  8 0 AUX IFACE NAME
3  8 0
4  1        78       94       -1000
5  1        82       85       -1000
6  1        90       91       -1000
7  1        90       100      -1000
8  1        93       91       -1000
9  1        94       105      -1000
10 1        96       91       -1000
11 1        96       102      -1000
```

1. Calculate volume of pumped groundwater (m^3)
2. Determine subbasin that receives irrigation water
3. Determine the set of HRUs within the specified subbasin that receive the irrigation water
4. Use the spatial areas of the receiving HRUs to convert the pumped groundwater volume (m^3) to an irrigation depth (mm)
5. Apply the irrigation depth (mm) on the following day

Additional Hydrological Linkages

SWAT Irrigation←→ MODFLOW Pumping

1. MODFLOW pumping controls SWAT irrigation
2. SWAT irrigation controls MODFLOW pumping



1. Calculate volume of pumped groundwater (m^3)
2. Determine subbasin that receives irrigation water
3. Determine the set of HRUs within the specified subbasin that receive the irrigation water
4. Use the spatial areas of the receiving HRUs to convert the pumped groundwater volume (m^3) to an irrigation depth (mm)
5. Apply the irrigation depth (mm) on the following day

Additional Hydrological Linkages

SWAT Irrigation←→ MODFLOW Pumping

1. MODFLOW pumping controls SWAT irrigation
2. SWAT irrigation controls MODFLOW pumping

Files\4 SWAT MODFLOW LRW\Scenarios\MODFLOW pumping irrigation

swatmf_irrigate.txt

swatmf_link.txt

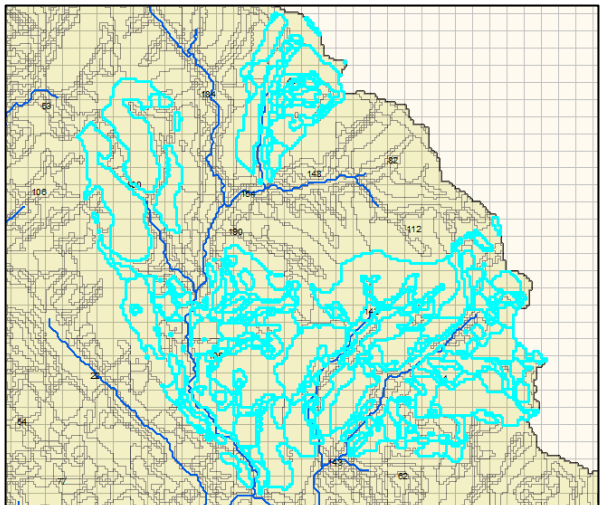
modflow.mfn

Additional Hydrological Linkages

SWAT Irrigation←→ MODFLOW Pumping

1. MODFLOW pumping controls SWAT irrigation
2. SWAT irrigation controls MODFLOW pumping

Receive irrigation using Auto-Irrigation



1. Irrigation depth (mm) for an HRU is specified using auto-irrigation routine
2. Convert the irrigation depth (mm) to volume (m^3) using the spatial area of the HRU
3. Find the MODFLOW cell that will provide the groundwater to the HRU
4. Check the available volume of groundwater in the MODFLOW cell; if the irrigation volume is greater than the available groundwater, then take the remainder and re-calculate the irrigation depth; otherwise, extract the full amount. The extracted volume becomes the pumping rates (m^3/day)
5. For each HRU, add a pumping cell to the MODFLOW WELL package with the calculated pumping rate (m^3/day)
6. MODFLOW uses the new set of pumping rates in its calculations for that day

Additional Hydrological Linkages

SWAT Irrigation←→ MODFLOW Pumping

1. MODFLOW pumping controls SWAT irrigation
2. SWAT irrigation controls MODFLOW pumping

Files\4 SWAT MODFLOW LRW\Scenarios\MODFLOW SWAT irrigation

swatmf_irrigate.txt

swatmf_link.txt

modflow_LRW.wel

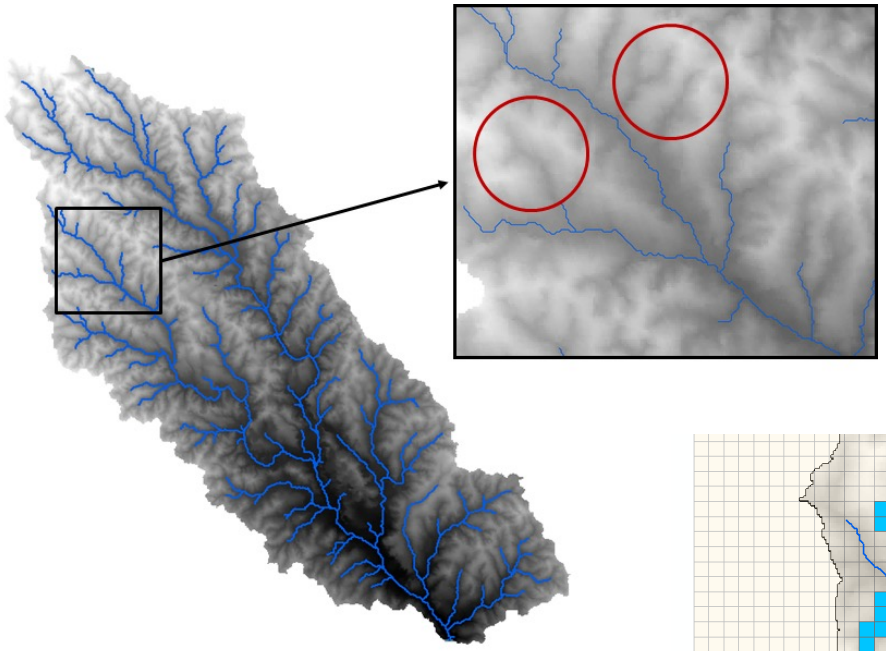
modflow.mfn

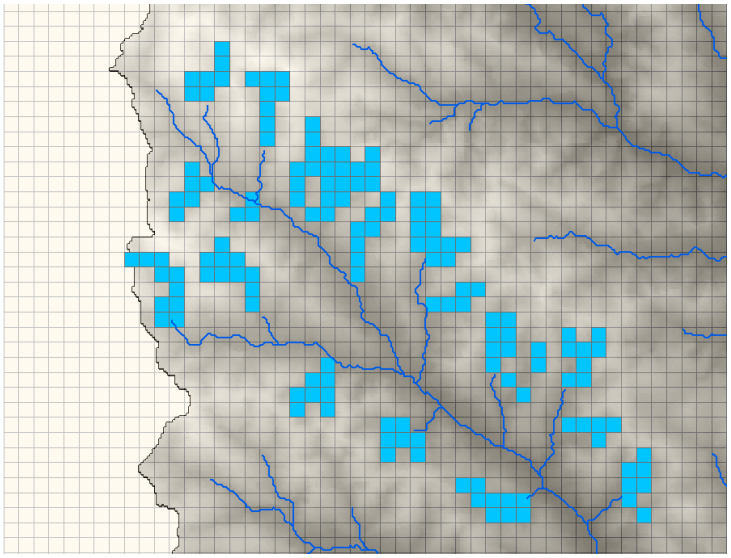
```
1  Irrigation Pumping File for SWAT-MODFLOW
2  40 Number of HRUs that receive irrigation water
3  Sub      Row      Column   Lay      HRU_ID
4  45       78       94       1        1193
5  45       78       94       1        1196
6  45       78       94       1        1198
7  45       78       94       1        1199
8  45       78       94       1        1212
9  45       78       94       1        1210
10 45       78       94       1        1211
11 100      82       85       1        2750
12 195      90       91       1        5136
13 195      90       91       1        5137
14 195      90       91       1        5139
15 195      90       91       1        5141
16 195      90       91       1        5157
17 195      90       91       1        5159
18 195      90       91       1        5166
19 142      90       100      1        3947
20 142      90       100      1        3949
```

Indices for the MODFLOW grid cell that provides pumped groundwater to HRU 1193 for irrigation.

Additional Hydrological Linkages

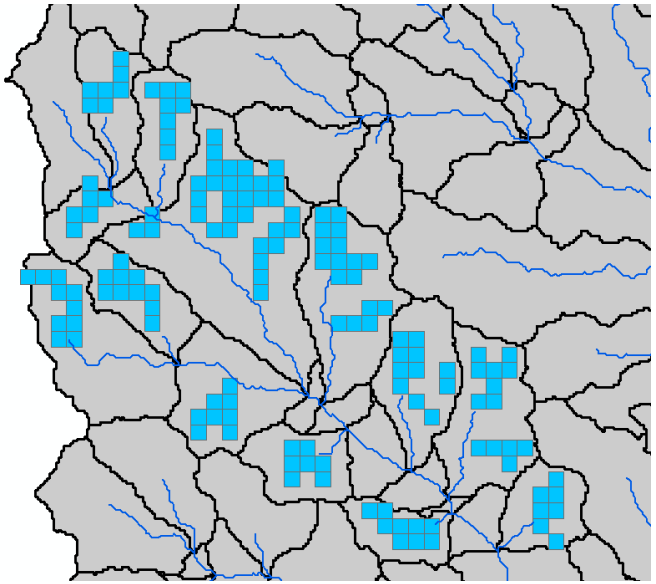
MODFLOW Drains → Subbasin Channels





Additional Hydrological Linkages

MODFLOW Drains → Subbasin Channels



1	162	Number of MODFLOW DRAIN cells the contribute water to SWAT subbasins	
2	Row	Column	Subbasin
3	34	15	85
4	36	19	97
5	37	19	97
6	34	15	19
7	35	15	19
8	36	13	19
9	36	14	19
10	36	15	19
11	37	13	19
12	37	14	19
13	36	17	43
14	36	18	43

List of 162 cells, with associated subbasin

Files\4 SWAT MODFLOW LRW\Scenarios\MODFLOW Drains

Simulating N and P Transport

Overview

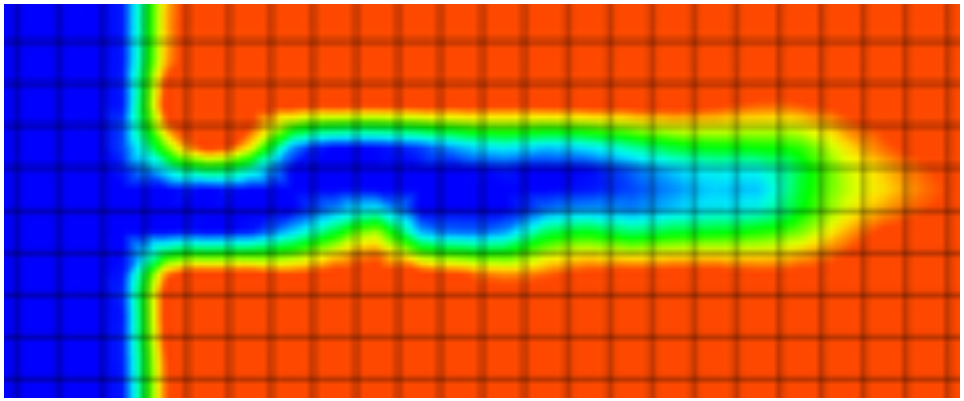
MODFLOW

SWAT-MODFLOW

Setting up Simulation

RT3D

Reactive Transport in 3 Dimensions



NO_3:

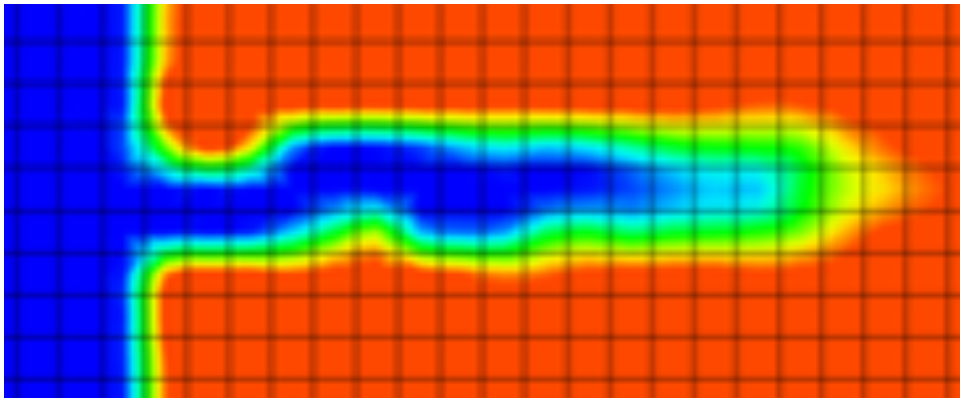
$$\underbrace{\frac{\partial C_{NO_3}}{\partial t}}_{} = \overbrace{-\frac{\partial}{\partial x_i}\left(v_i C_{NO_3}\right)}^{\text{Advection}} + \overbrace{\frac{\partial}{\partial x_i}\left(D_{ij}\frac{\partial C_{NO_3}}{\partial x_j}\right)}^{\text{Dispersion}} + \overbrace{\frac{q_s}{\phi}C_{s_{NO_3}}}^{\text{Source/Sink}} \overbrace{-k_{NO_3}C_{NO_3}\left(\frac{C_{NO_3}}{K_{NO_3}+C_{NO_3}}\right)}^{\text{Denitrification}}$$

P:

$$\underbrace{\frac{\partial C_P}{\partial t}R_P}_{\text{Sorption}} = \overbrace{-\frac{\partial}{\partial x_i}\left(v_i C_P\right)}^{\text{Advection}} + \overbrace{\frac{\partial}{\partial x_i}\left(D_{ij}\frac{\partial C_P}{\partial x_j}\right)}^{\text{Dispersion}} + \overbrace{\frac{q_s}{\phi}C_{s_P}}^{\text{Source/Sink}}$$

Simulating N and P Transport

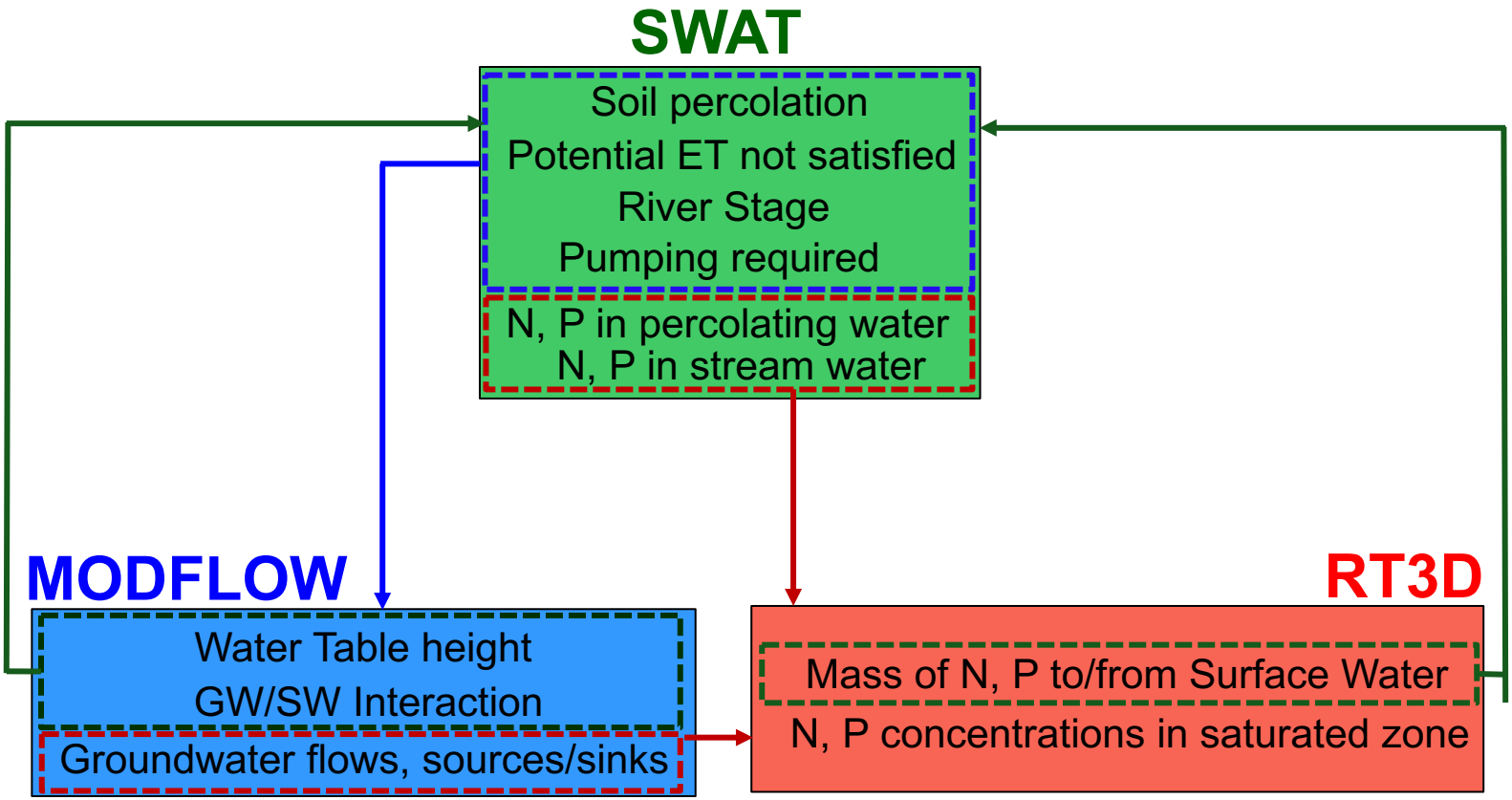
Reactive Transport in 3 Dimensions



- Finite Difference Method
- Same grid as MODFLOW
- Flows/SS from MODFLOW

SWAT-MODFLOW-RT3D

Linking 3 Models:



SWAT-MODFLOW-RT3D

RT3D Files

• Basic Transport package	Spatial / temporal discretization (i.e. grid, time steps)
• Advection package	Solute moves with groundwater flow
• Dispersion package	Solute mass is dispersed during transport
• Source-Sink Mixing package	Solute concentration in groundwater sources/sinks
• Reaction package	Chemical reactions (sorption, first-order kinetics)
• GCG package	Implicit solver

Example files for the LRW model are contained in **Files\5 SWAT MODFLOW RT3D LRW**. The input files are listed in the name file rt3d_filenames:

```
1  'rt3d.btn'          INBTN=1      Basic Transport Package
2  'rt3d.adv'          INADV=2      Advection Package
3  'rt3d.dsp'          INDSP=3      Dispersion Package
4  'rt3d.ssm'          INSSM=4      Source/Sink Mixing Package
5  'rt3d.rct'          INRCT=5      Reaction Package
6  'rt3d.gcg'          INGCG=6      Implicit Solver Package
7  'rt3d.restart'      OUTRES=10    Restart File
```

SWAT-MODFLOW-RT3D

RT3D Files

• Basic Transport package	Spatial / temporal discretization (i.e. grid, time steps)
• Advection package	Solute moves with groundwater flow
• Dispersion package	Solute mass is dispersed during transport
• Source-Sink Mixing package	Solute concentration in groundwater sources/sinks
• Reaction package	Chemical reactions (sorption, first-order kinetics)
• GCG package	Implicit solver

```
'PACKAGES USED: ADV,DSP,SSM,RCT,GCG,AGR,VST,IGR,--- --------------------------'
T T T T T F F F F F
'NCOMP, MCOMP -------------------------------------------------------------------'
2 2
'TYPE OF WRITING FOR OUTPUT FILES (0=ASCII/1=BINARY/2=BOTH) ------------------'
0
'SPECIES (MOBILE/IMMOBILE) -----------------------------------------------------'
'NO3' 1 1
'P' 1 1
'd'  'm'  'g'
'POROSITY FOR EACH LAYER -------------------------------------------------------'
0       0       0       0       0       0       0       0       0       0       0       0       0
0       0.2     0.2     0.2     0       0.2     0.2     0       0.2     0       0       0       0
0       0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2     0       0
0       0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2     0       0
0       0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2
0       0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2
0       0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2
0       0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2
0       0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2
0       0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2
0       0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2
0       0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2
0       0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2
0       0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2
0       0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2
0       0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2
```

Porosity for each active grid cell;

Repeat array for each layer in the grid

SWAT-MODFLOW-RT3D

RT3D Files

• Basic Transport package	Spatial / temporal discretization (i.e. grid, time steps)
• Advection package	Solute moves with groundwater flow
• Dispersion package	Solute mass is dispersed during transport
• Source-Sink Mixing package	Solute concentration in groundwater sources/sinks
• Reaction package	Chemical reactions (sorption, first-order kinetics)
• GCG package	Implicit solver

```
0       0       0       0       0       0       0       0       0       0       0       0       0       0       0
'INITIAL CONCENTRATIONS: EACH SPECIES ----------------------------------------'
0 0.00    CNO3  Initial concentration of NO3 in each grid cell in the layer (repeat line for the number of layers in the grid
0 0.00    CP    Initial concentration of P in each grid cell in the layer (repeat line for the number of layers in the grid
'VALUE INDICATING INACTIVE CELL CONCENTRATION --------------------------------'
 -999.0000
'IFMTCN(print), IFMTNP(particle), IFMTRF(R), IFMTDP(D), SAVUCN(binary) --------'
6       0       0       0       F
'NUMBER OF OUTPUT TIMES ------------------------------------------------------'
15  Number of times for which all cell concentration values will be written to swatmf_out_RT_CONC files
'OUTPUT TIMES   --------------------------------------------------------------'
365     730     1095    1460    1825    2190    2555    2920    3285    3650    4015    4380    4745    5110    5475   List of output times (days)
'OBSERVATION    CELLS:  I,J,K   --------------------------------------------'
2 1  Number of observation cells
100 50 1    Cells (row, column, layer) for which daily concentration of
50 50 1     NO3 and P will be written to swatmf_out_RT_OBS files
'OUTPUT MASS    BUDGET  FILES   ----------------------------------------------------'
F

```

SWAT-MODFLOW-RT3D

RT3D Files

• Basic Transport package	Spatial / temporal discretization (i.e. grid, time steps)
• Advection package	Solute moves with groundwater flow
• Dispersion package	Solute mass is dispersed during transport
• Source-Sink Mixing package	Solute concentration in groundwater sources/sinks
• Reaction package	Chemical reactions (sorption, first-order kinetics)
• GCG package	Implicit solver

```
'LONGITUDINAL DISPERSIVITY ----------------------------------------------------'
        0 2.000000 Constant value assigned to each grid cell in the layer (repeat line for the number of layers in the grid
'RATIO OF HORIZ. TRANSVERSE TO LONG. DISP. ------------------------------------'
        0 0.1000000 Constant value assigned to each cell in the model
'RATIO OF VERTIC. TRANSVERSE TO LONG. DISP. ------------------------------------'
        0 0.1000000 Constant value assigned to each cell in the model
'EFFECTIVE MOLECULAR DIFFUSION COEFFICIENT -------------------------------------'
        0 0.0000000 Constant value assigned to each cell in the model

```

SWAT-MODFLOW-RT3D

RT3D Files

• Basic Transport package	Spatial / temporal discretization (i.e. grid, time steps)
• Advection package	Solute moves with groundwater flow
• Dispersion package	Solute mass is dispersed during transport
• Source-Sink Mixing package	Solute concentration in groundwater sources/sinks
• Reaction package	Chemical reactions (sorption, first-order kinetics)
• GCG package	Implicit solver

```
1  'ISOTHM,IREACT,NCRXNDATA,NVRXNDATA,ISOLVER,IRCTOP ----------------------
2  1 10 2 0 1 0
3  Bulk density
4  0 1.855    Constant value assigned to each cell in the model
5  Sorption parameters
6  0 0.0            partition coefficient for NO3 (linear sorption)
7  0 3.5            partition coefficient for PO4 (linear sorption)
8  0 0.0            second parameter for NO3 (not used for linear sorption)
9  0 0.0            second parameter for PO4 (not used for linear sorption)
10 Spatially Constant Values for reaction rates
11 0.10             kden  First-order rate constant for denitrification (1/T: needs same units as MODFLOW simulation)
12 10.00            kno3  Monod half-saturation term for denitrification
13
```

Sorption parameters assigned to each cell in the model

SWAT-MODFLOW-RT3D

1. Assemble Model Input Files
2. Run SWAT-MODFLOW
3. Check and Analyze Output

1. SWAT input files
2. MODFLOW input files
   RT3D input files
3. MODFLOW name file (modflow.mfn)

```
1  1      SWAT-MODFLOW is activated
2  1      MODFLOW Pumping --> SWAT Irrigation
3  0      SWAT Auto-Irrigation --> MODFLOW Pumping
4  1      MODFLOW Drains --> SWAT subbasin channels
5  1      RT3D is active (N and P groundwater reactive transport)
6  1      Read in observation cells from "modflow.obs"
7  Optional output for SWAT-MODFLOW (0=no; 1=yes)
8  1      SWAT Deep Percolation (mm) (for each HRU)
```

4. SWAT-MODFLOW linking file (swatmf_link.txt)
5. MODFLOW observation file (modflow.obs) (only if specified in swatmf_link.txt)
6. SWAT-MODFLOW Mapping files:
   a. swatmf_dhru2hru.txt
   b. swatmf_dhru2grid.txt
   c. swatmf_grid2dhru.txt
   d. swatmf_river2grid.txt
7. SWAT-MODFLOW executable (SWAT-MODFLOW3.exe) Run!

SWAT-MODFLOW-RT3D

Overview

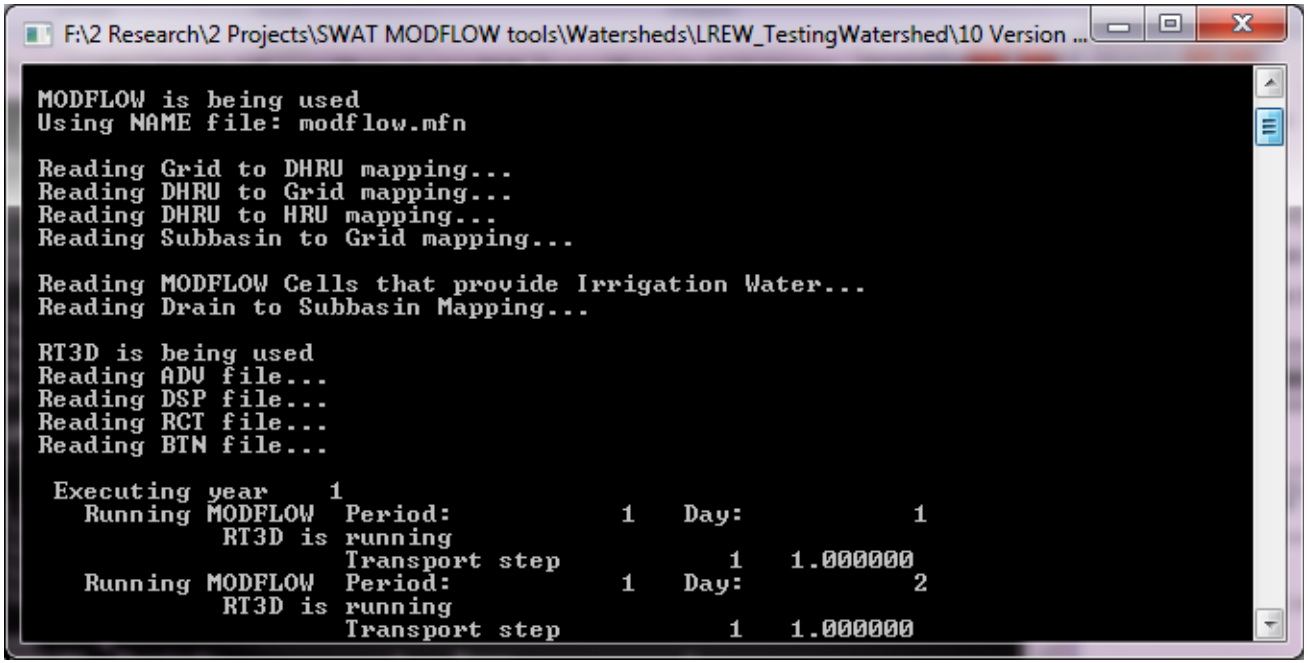
MODFLOW

SWAT-MODFLOW

Setting up Simulation

RT3D

1. Assemble Model Input Files
2. Run SWAT-MODFLOW
3. Check and Analyze Output



SWAT-MODFLOW-RT3D

1. Assemble Model Input Files
2. Run SWAT-MODFLOW
3. Check and Analyze Output

RT3D Output File		Units	Notes
RT3D: Groundwater Concentration of NO_3 and P			
	swatmf_out_RT_cno3_monthly	*mg/L*	Monthly averaged groundwater concentration for each active grid cell
	swatmf_out_RT_cp_monthly	*mg/L*	
	swatmf_out_RT_cno3_yearly	*mg/L*	Yearly averaged groundwater concentration for each active grid cell
	swatmf_out_RT_cp_yearly	*mg/L*	
	swatmf_out_RT_CONCNO3	*mg/L*	Cell-by-cell output for the output times specified in the *.btn file
	swatmf_out_RT_CONCP	*mg/L*	
	swatmf_out_RT_OBSNO3	*mg/L*	Output at each transport time step for the observation cells listed in the *.btn file
	swatmf_out_RT_OBSP	*mg/L*	
RT3D: Recharge Water			
	swatmf_out_RT_rechno3	*mg/L*	Solute concentration in recharge water, for each grid cell
	swatmf_out_RT_rechP	*mg/L*	
RT3D: Groundwater-Surface Water Loadings			
	swatmf_out_RT_rivno3	*kg/day*	Mass exchange between groundwater and surface water, for each River cell
	swatmf_out_RT_rivP	*kg/day*	
SWAT: Recharge Water			
	swatmf_out_SWAT_rechno3	*mg/L*	Solute concentration in recharge water, for each HRU
	swatmf_out_SWAT_rechP	*mg/L*	
SWAT: Groundwater-Surface Water Loadings			
	swatmf_out_SWAT_rivno3	*kg/day*	Mass exchange between groundwater and surface water for the RIVER package and the DRAIN package, for each subbasin
	swatmf_out_SWAT_rivP	*kg/day*	

SWAT-MODFLOW-RT3D

1. Assemble Model Input Files
2. Run SWAT-MODFLOW
3. Check and Analyze Output

output.std

NO3 GWQ:	Mass loading of NO_3 from the aquifer to the stream network, via MODFLOW River Cells
NO3 SWGW:	Mass loading of NO_3 from the stream network to the aquifer, via MODFLOW River Cells
NO3 DRN:	Mass loading of NO_3 from the aquifer to the stream network, via MODFLOW Drain cells.
P GWQ:	Mass loading of P from the aquifer to the stream network, via MODFLOW River Cells
P SWGW:	Mass loading of P from the stream network to the aquifer, via MODFLOW River Cells
P DRN:	Mass loading of P from the aquifer to the stream network, via MODFLOW Drain cells.

WATER YIELD (mm)	SED YIELD (mm)	NO3 SURQ	NO3 LATQ	NO3 GWQ	NO3 SWGW	NO3 PERC	NO3 CROP	N ORGANIC	P SOLUBLE	P ORGANIC	P TILENO3	P GWQ	P SWGW	NO3 DRN	P DRN
		(kg nutrient/ha)													
0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-0.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.13	0.01	0.00	0.01	0.00	0.01	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-0.22	0.00	0.00	0.01	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-0.36	0.00	0.00	0.01	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-0.13	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-0.16	0.00	0.00	0.01	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1.23	0.05	0.00	0.01	0.00	0.01	0.00	0.00	0.09	0.00	0.01	0.00	0.00	0.00	0.00	0.00
-0.80	0.00	0.00	0.01	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.04	0.00	0.00	0.01	0.00	0.14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.07	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

SWAT-MODFLOW-RT3D

1. Assemble Model Input Files
2. Run SWAT-MODFLOW
3. Check and Analyze Output

output.std

```
NUTRIENTS
     ORGANIC N =     7.250 (KG/HA)
     ORGANIC P =     1.059 (KG/HA)
     NO3 YIELD (SQ) =     2.357 (KG/HA)
     NO3 YIELD (LAT) =    0.564 (KG/HA)
     NO3 YIELD (TILE) =    0.000 (KG/HA)
     SOLP YIELD (TILE) =    0.000(KG/HA)
     SOLP YIELD (SURF INLET RISER) =    0.000 (KG/HA)
     SOL P YIELD (SQ) =    0.074 (KG/HA)
     NO3 LEACHED =    15.742 (KG/HA)
     P LEACHED =     0.100 (KG/HA)
     N UPTAKE =   104.846 (KG/HA)
     P UPTAKE =   18.795 (KG/HA)
     NO3 LOAD GW (RT3D) =     0.750 (KG/HA)
     NO3 SW-GW (RT3D) =     1.225 (KG/HA)
     NO3 LOAD DRAIN (RT3D) =     0.020 (KG/HA)
     P LOAD GW (RT3D) =     0.078 (KG/HA)
     P SW-GW (RT3D) =     0.019 (KG/HA)
     P LOAD DRAIN (RT3D) =     0.001 (KG/HA)
```

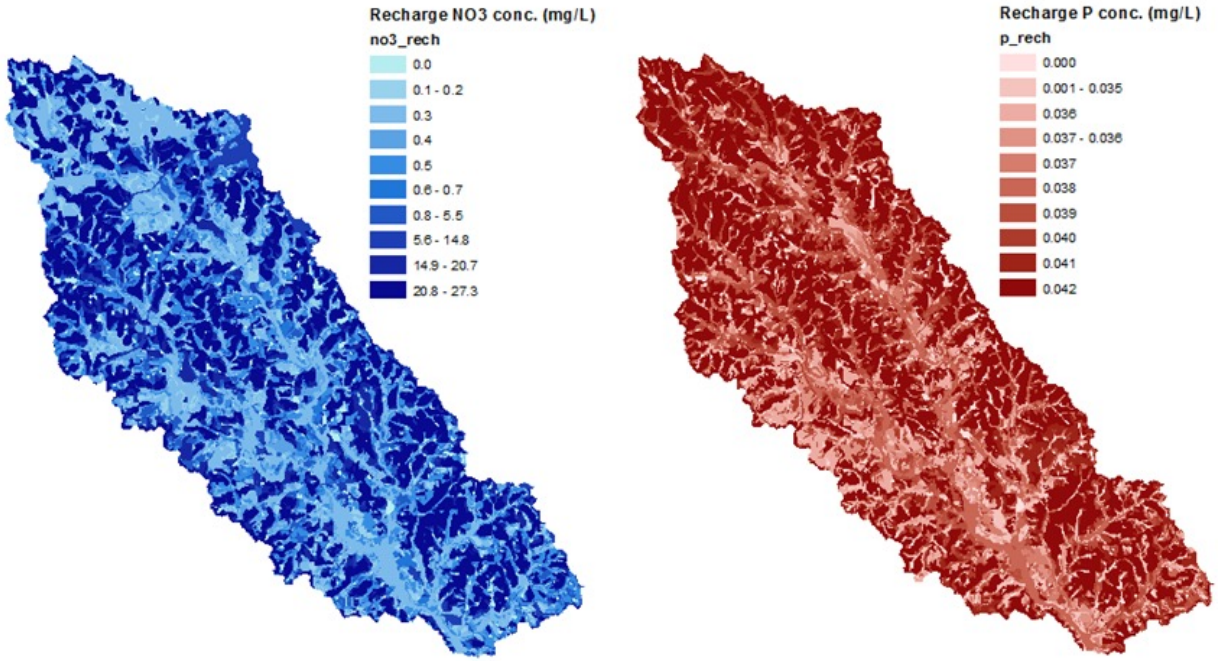
SWAT-MODFLOW-RT3D

1. Assemble Model Input Files
2. Run SWAT-MODFLOW
3. Check and Analyze Output

NO_3 and P Concentration in Recharge Water

Files that can be used:

- swatmf_out_RT_rechno3
- swatmf_out_RT_rechP
- swatmf_out_SWAT_rechno3
- swatmf_out_SWAT_rechP



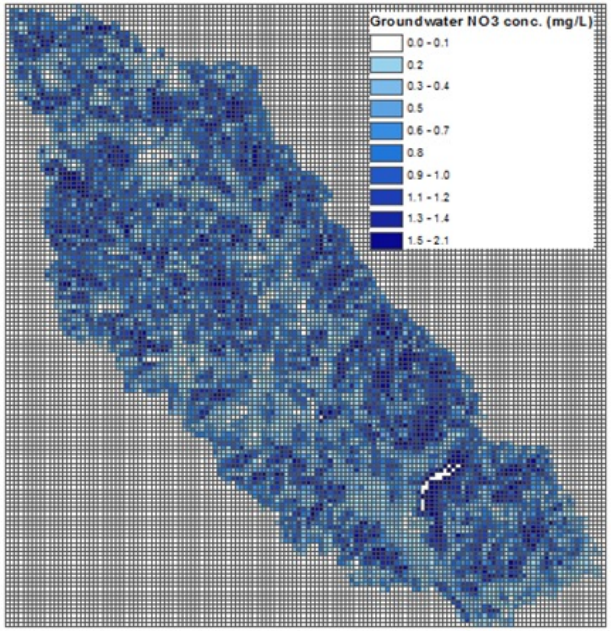
SWAT-MODFLOW-RT3D

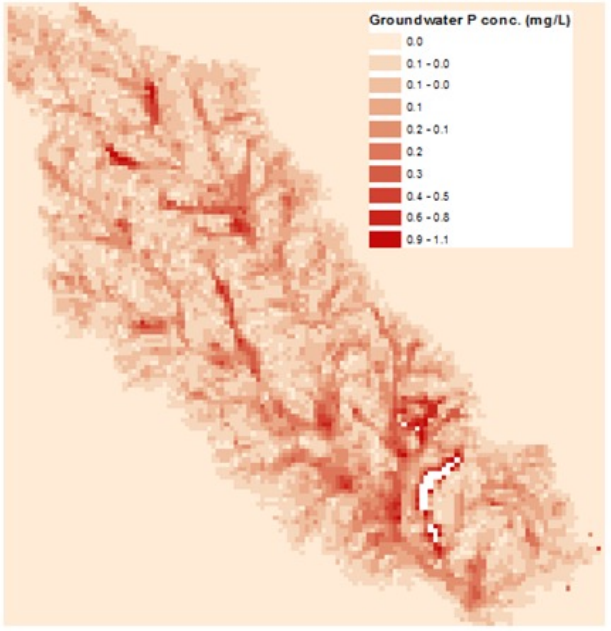
1. Assemble Model Input Files
2. Run SWAT-MODFLOW
3. Check and Analyze Output

NO_3 and P Concentration in Groundwater

Files that can be used:

- swatmf_out_RT_cno3_monthly
- swatmf_out_RT_cp_monthly
- swatmf_out_RT_cno3_yearly
- swatmf_out_RT_cp_yearly
- swatmf_out_RT_CONCNO3
- swatmf_out_RT_CONCP





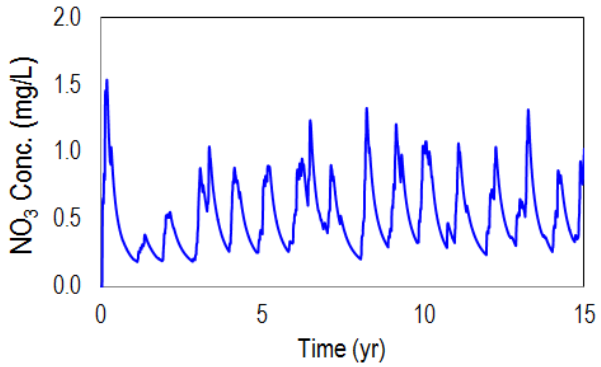
SWAT-MODFLOW-RT3D

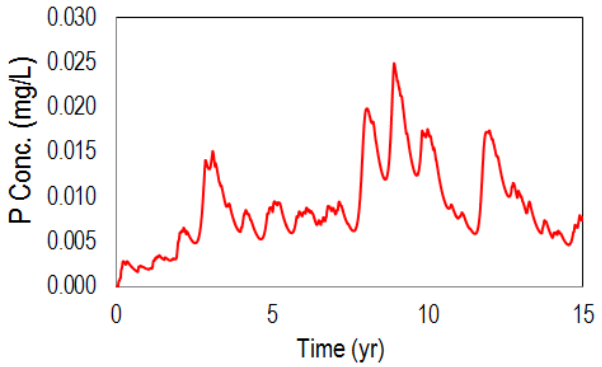
1. Assemble Model Input Files
2. Run SWAT-MODFLOW
3. Check and Analyze Output

NO_3 and P Concentration Time Series

Files that can be used:

- swatmf_out_RT_OBSNO3
- swatmf_out_RT_OBSP





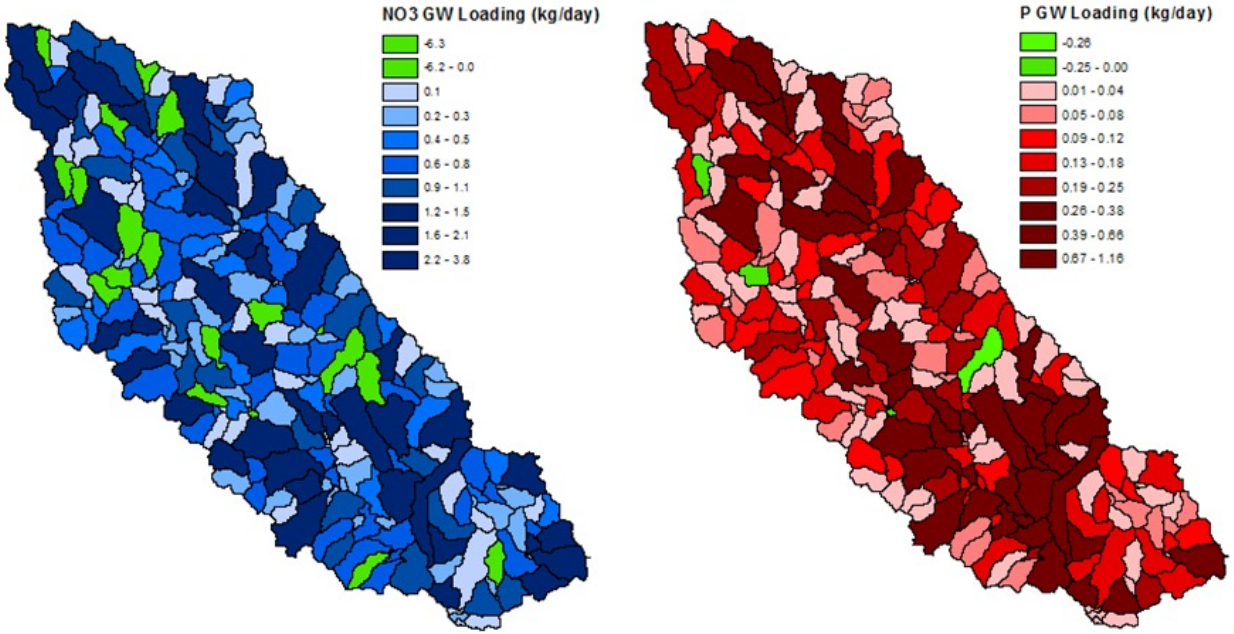
SWAT-MODFLOW-RT3D

1. Assemble Model Input Files
2. Run SWAT-MODFLOW
3. Check and Analyze Output

NO_3 and P Mass Exchanges in Subbasins

Files that can be used:

- swatmf_out_SWAT_rivno3
- swatmf_out_SWAT_rivP



Outline of Workshop

1. Overview and Theory of SWAT-MODFLOW
2. Setting up and running SWAT-MODFLOW
3. QSWATMOD: install, introduction, application
4. Work with your data and watersheds

Outline of Workshop

1. Overview and Theory of SWAT-MODFLOW
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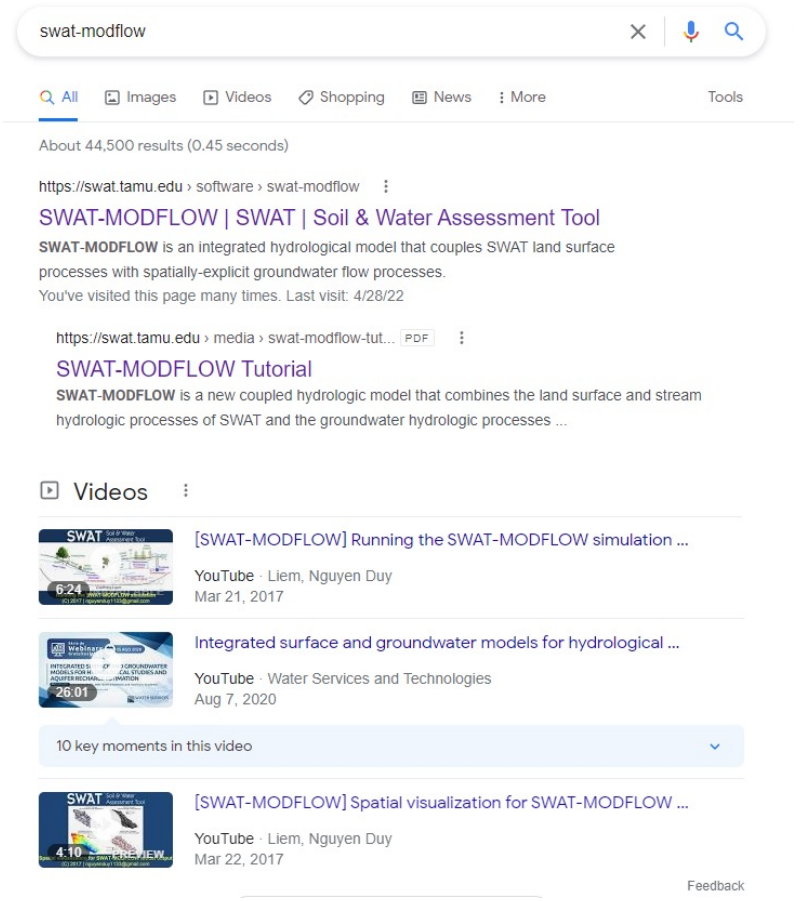
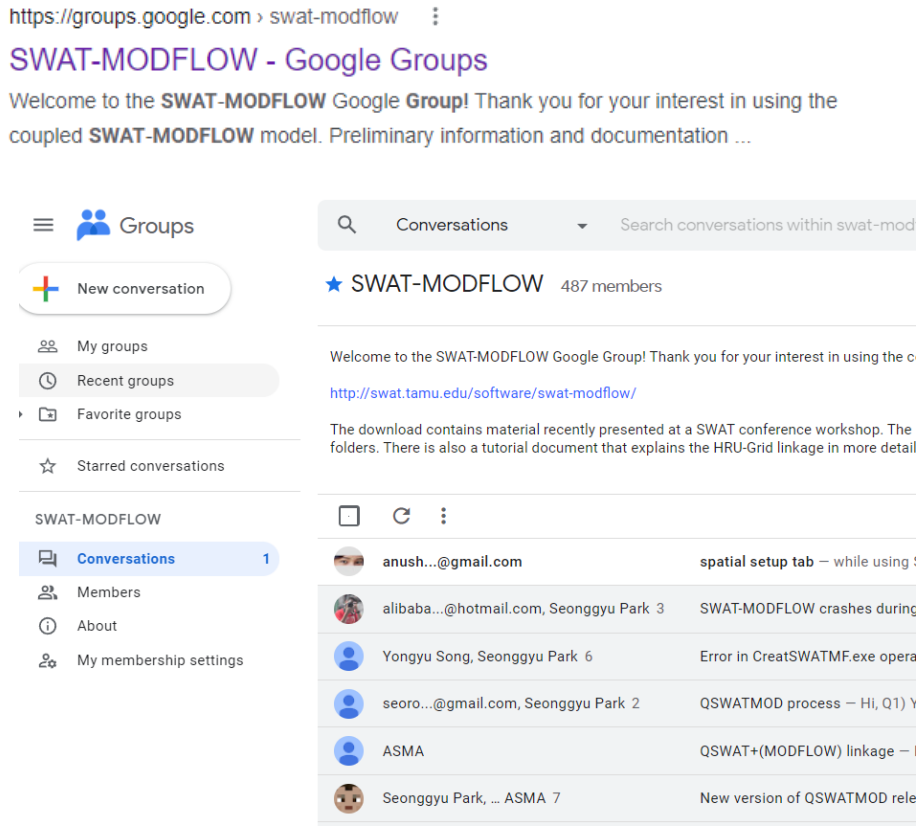
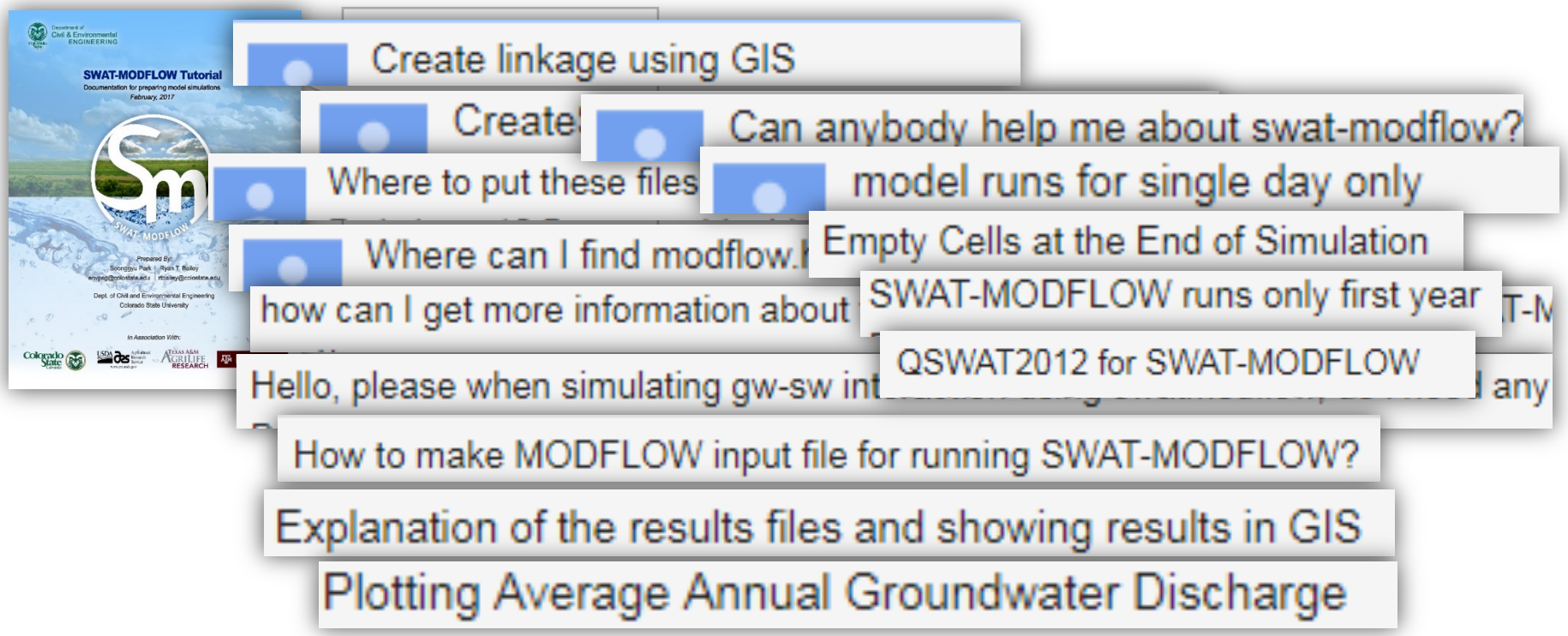
BACKGROUNDS | Technical needs





BACKGROUNDS | Technical needs



BACKGROUNDS | Technical needs

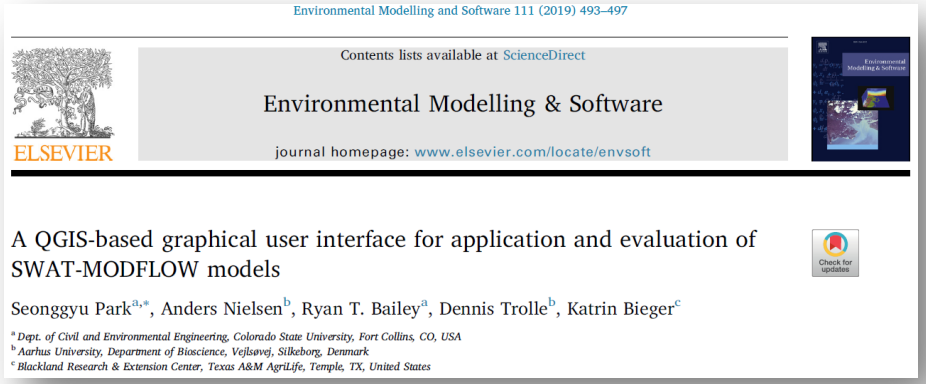
- **Provide an easy-to-use workflow for users**

I. Preparing input data through auto-linking process

II. Configuring simulation settings

III. Visualizing and interpreting results

IV. Handling a variety of scenarios for connecting MODFLOW river cells with SWAT subbasin channels



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ELSEVIER

A QGIS-based graphical user interface for application and evaluation of SWAT-MODFLOW models

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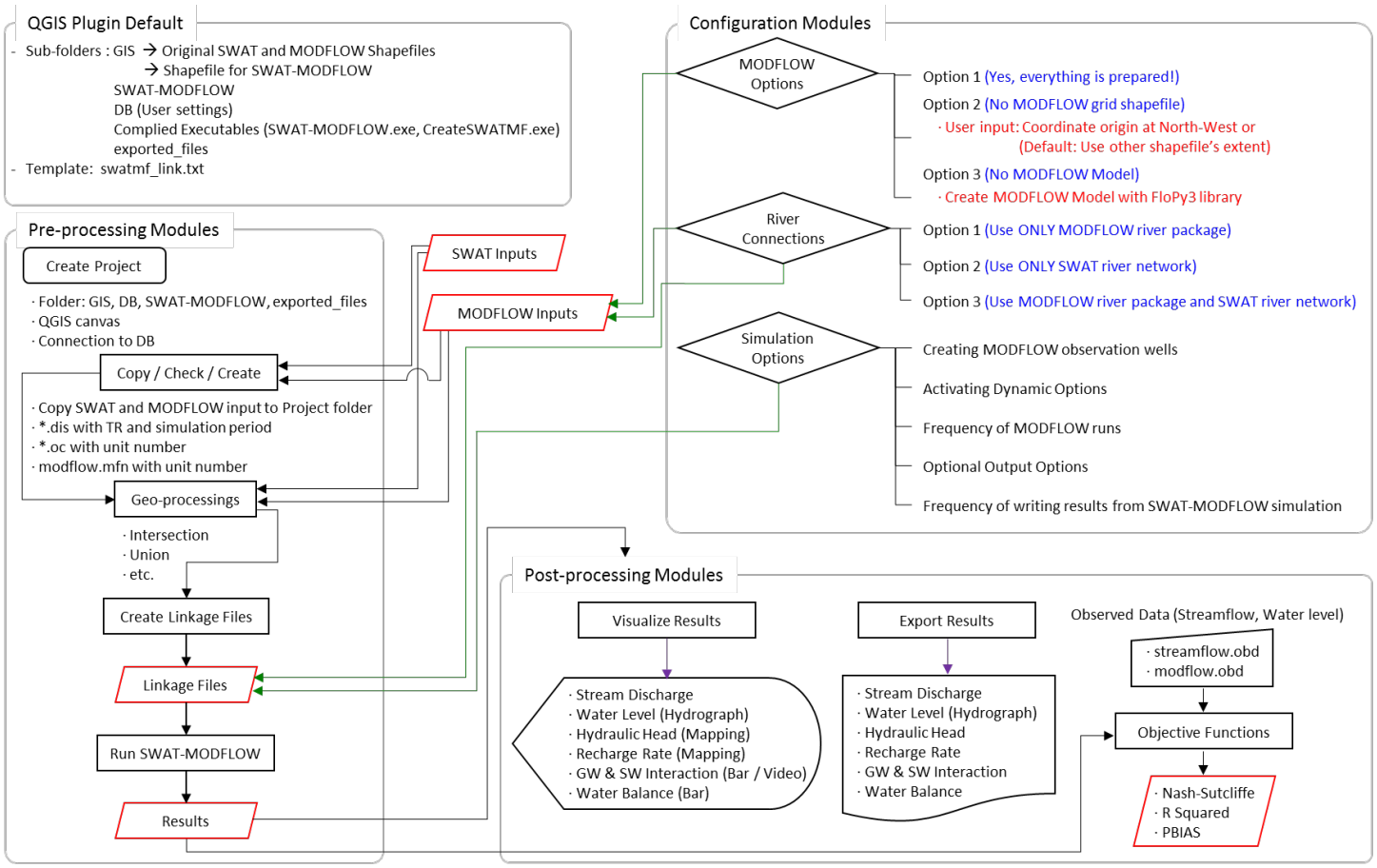
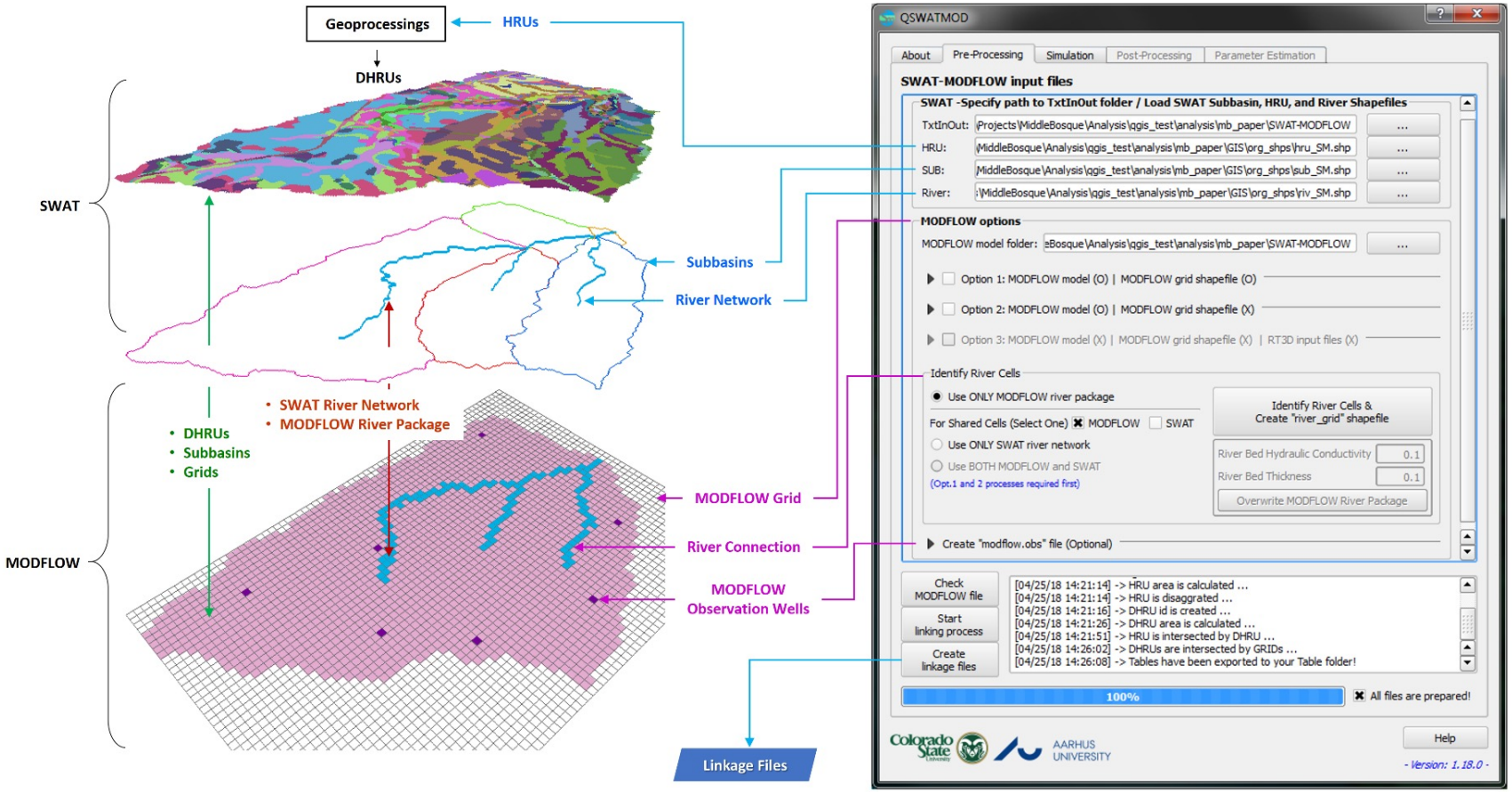
[c] Blackland Research & Extension Center, Texas A&M AgriLife, Temple, TX, United States

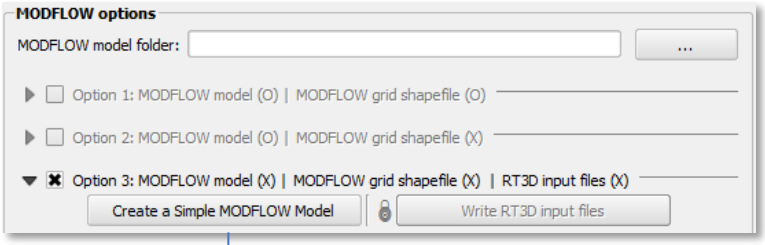
SOFTWARE | Approach

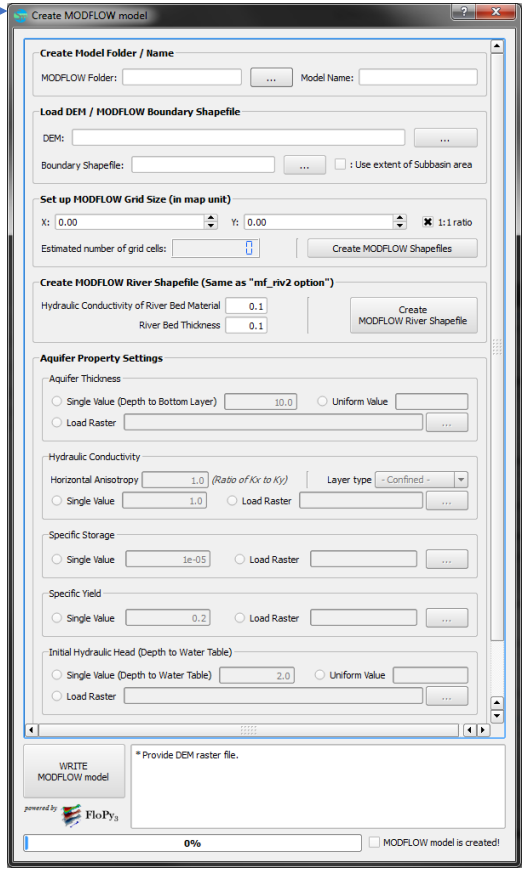


SOFTWARE | Approach



SOFTWARE | Approach

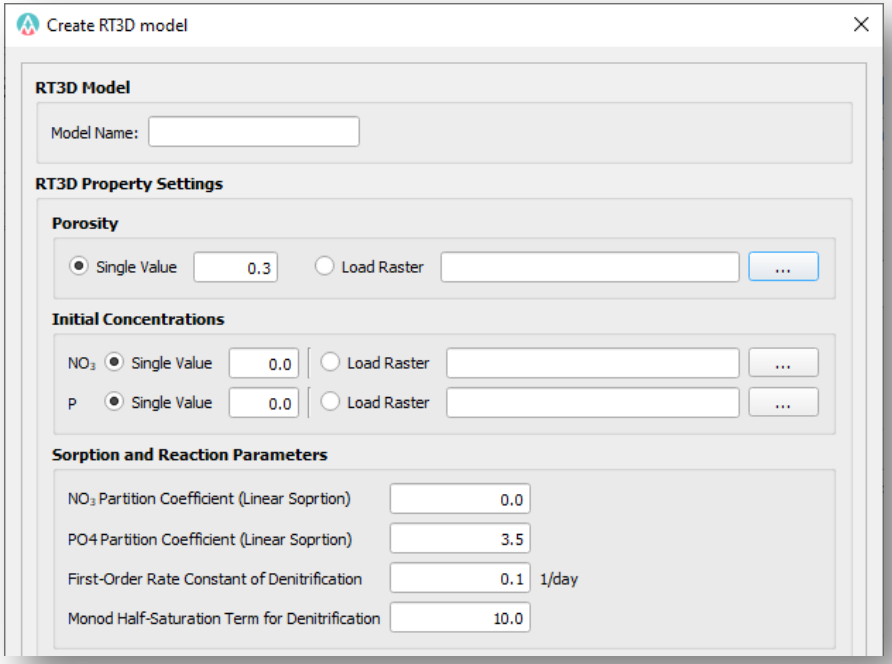


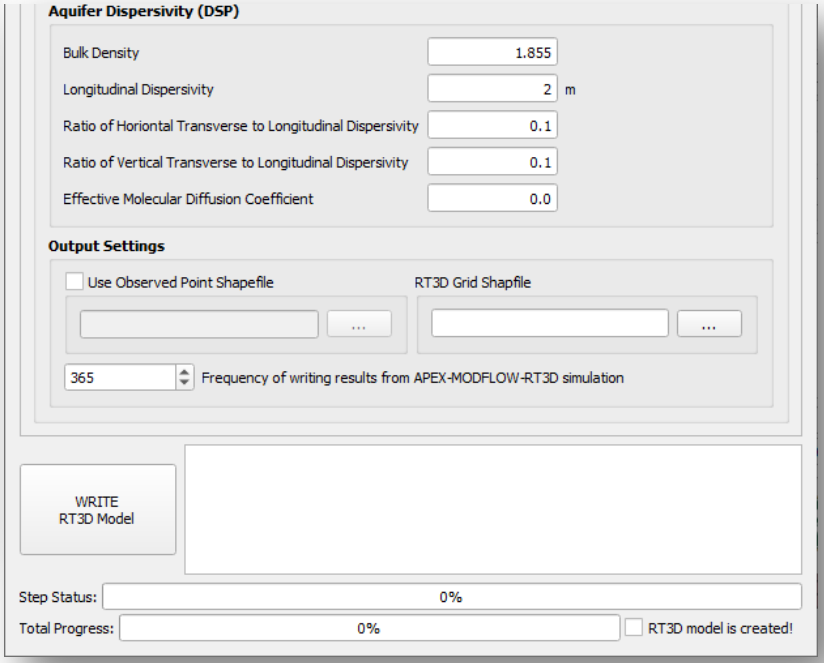


* Use “Freewat” or “ModelMuse”

- Land surface elevation from DEM (SWAT)
- MODFLOW boundary
- Grid size / River user inputs
- Aquifer Thickness / K / Ss / Sy / Initial head

SOFTWARE | Approach





Workshop Materials

https://github.com/spark-brc/QSWATMOD2-plugin

SWATMOD is a QGIS-based graphical user interface that facilitates linking SWAT and MODFLOW, running SWAT-MODFLOW simulations, and viewing results.

- **Installation**

1. The QGIS3 software must be installed on the system prior to the installation of SWATMOD. We've tested SWATMOD with the “long term release (LTR)” (3.24 ~ 3.34.7) versions of QGIS3. Install one of the versions of QGIS. It can be downloaded from https://qgis.org/en/site/forusers/download.html.
2. Download the QSWATMOD installer(https://github.com/spark-brc/QSWATMOD2-plugin/releases/download/v2.8.0/QSWATMOD2.exe) and install it by running SWATMOD 1.0.exe or a later version. The QSWATMOD is installed into the user's home directory *(~\AppData\Roaming\QGIS\QGIS3\profiles\default\python\plugins\QSWATMOD)*, which we will refer to as the SWATMOD plugin directory.
3. Download the workshop dataset and unzip it.

Thank you for your Participation!

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