CWEMF
IWFM v4.0 Workshop

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West Yost Associates, Davis, CA

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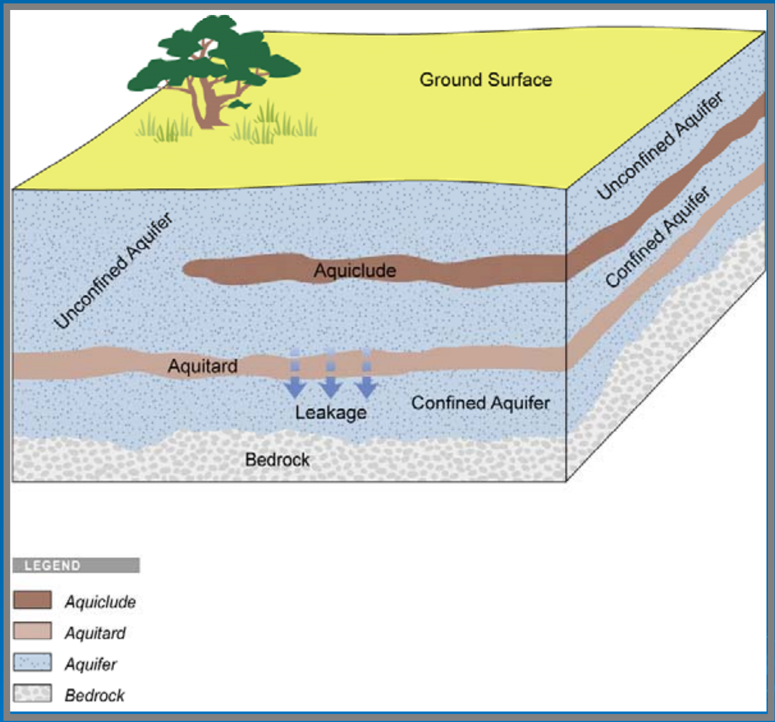
Session 1:
Groundwater Flow

Groundwater Flow: Overview

- Flow simulation for a combination of confined, unconfined, and leaky aquifer layers separated by aquitards or aquicludes
- Simulation of changing aquifer conditions
- Quasi 3-dimensional approach (exactly the same approach used in Modflow)
- Use of Galerkin finite element method for the spatial discretization of the governing conservation equation



Groundwater Flow Equation

$$\frac{\partial S_s h}{\partial t} - \vec{\nabla}\left(T\ \vec{\nabla} h\right) - I_u q_u - I_d q_d - Q = 0$$

S_s = Storativity, (dimensionless);

h = Groundwater head, (L);

T = Transmissivity = Kh_s, (L^2/T);

K = Hydraulic conductivity; (L/T);

h_s = Saturated thickness of aquifer, (L);

t = Time (T);

q_u, q_d = Flow from adjacent upper and lower aquifer layers, (L/T);

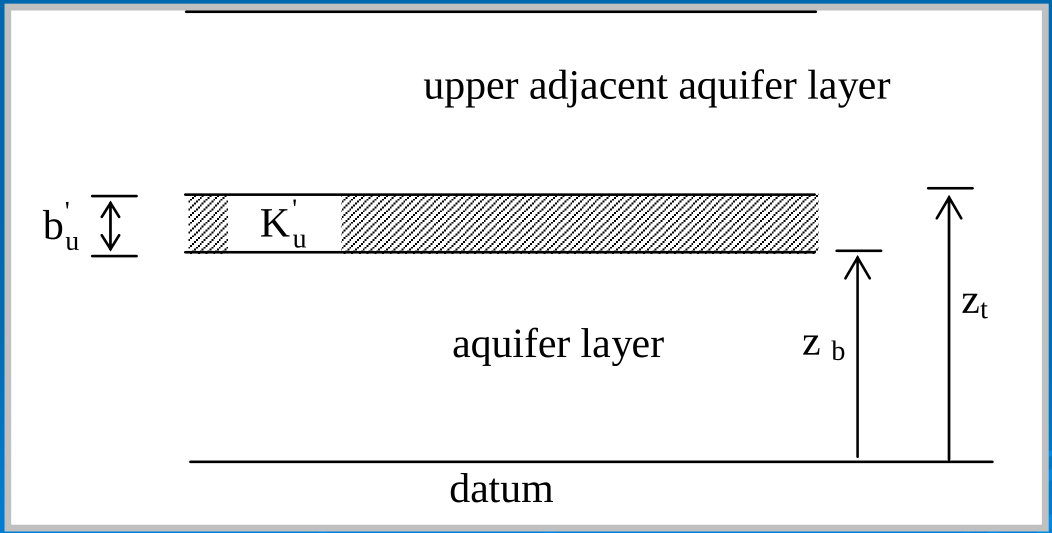
I_u, I_d = Indicator functions for top and bottom aquifer, (dimensionless);

Q = Source/sink term, (L/T).

Vertical Flow

(Aquifer Layers Separated by an Aquitard)

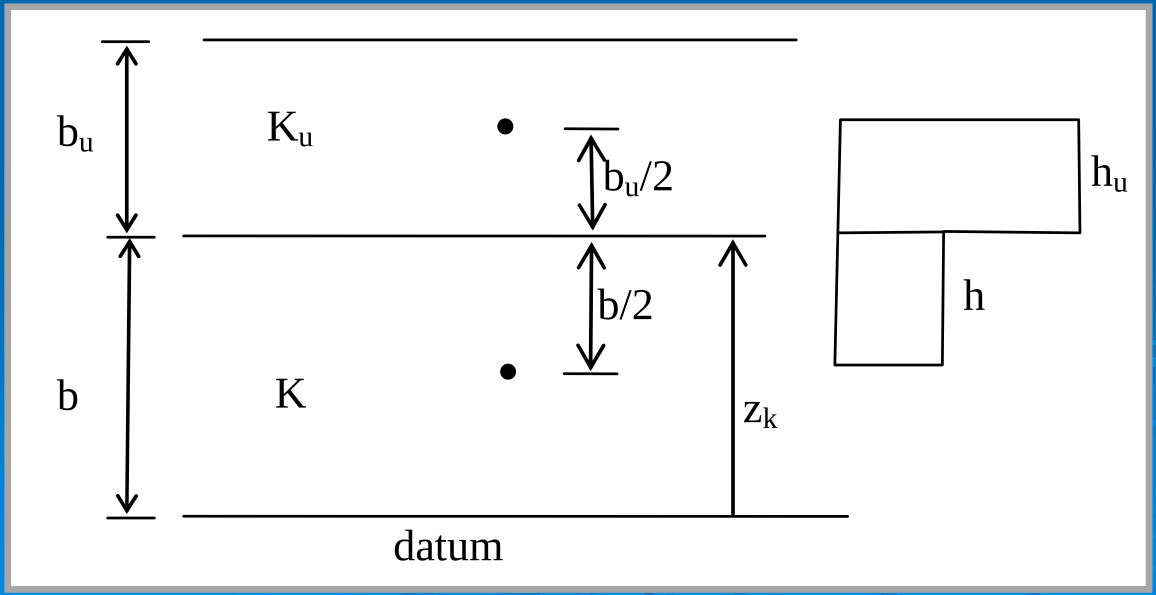
$$q_u = -L_u\left(h - h_u\right) = -\frac{K_u^{'}}{b_u^{'}}\left(h - h_u\right)$$



Vertical Flow

(Aquifer Layers not Separated by an Aquitard)

$$q_u = -L_u(h - h_u) = -\left[\frac{1}{0.5\left(\frac{b_u}{K_u} + \frac{b}{K}\right)}\right](h - h_u)$$



Groundwater Flow Equation *(after substitution)*

$$\frac{\partial S_s h}{\partial t} - \vec{\nabla}\left(T\ \vec{\nabla} h\right) + I_u L_u \left(h - h_u\right) + I_d L_d \left(h - h_d\right) - Q = 0$$

S_s = Storativity, (dimensionless);

h = Groundwater head, (L);

T = Transmissivity = Kh_s, (L^2/T);

K = Hydraulic conductivity; (L/T);

h_s = Saturated thickness of aquifer, (L);

t = Time (T);

I_u, I_d = Indicator functions for top and bottom aquifer, (dimensionless);

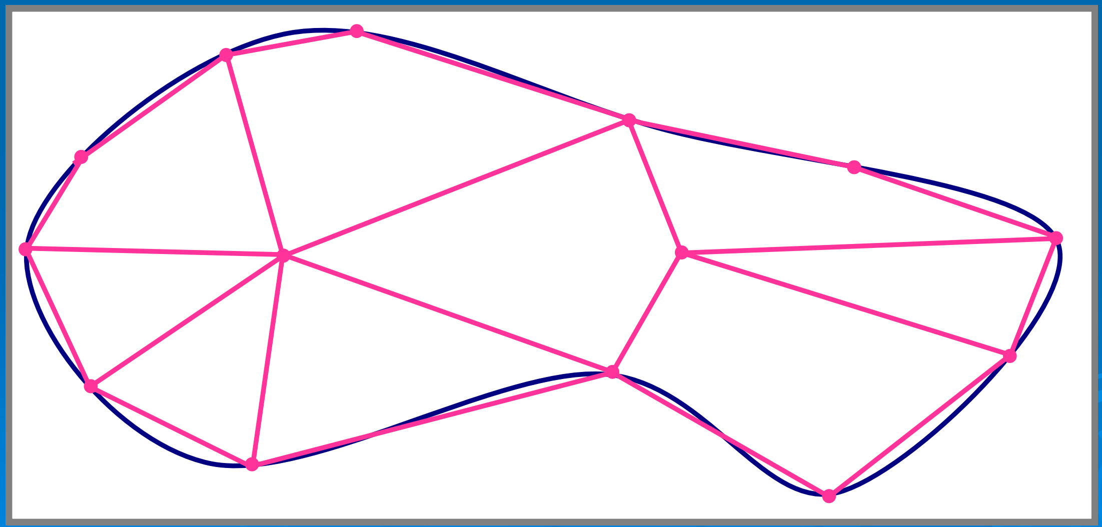
h_u, h_d = Groundwater head at adjacent upper and lower aquifer layers, (L/T);

L_u,L_d = Leakage coefficients of adjacent upper and lower aquifer layers, (1/T);

Q = Source/sink term, (L/T).

Discretization of Model Area

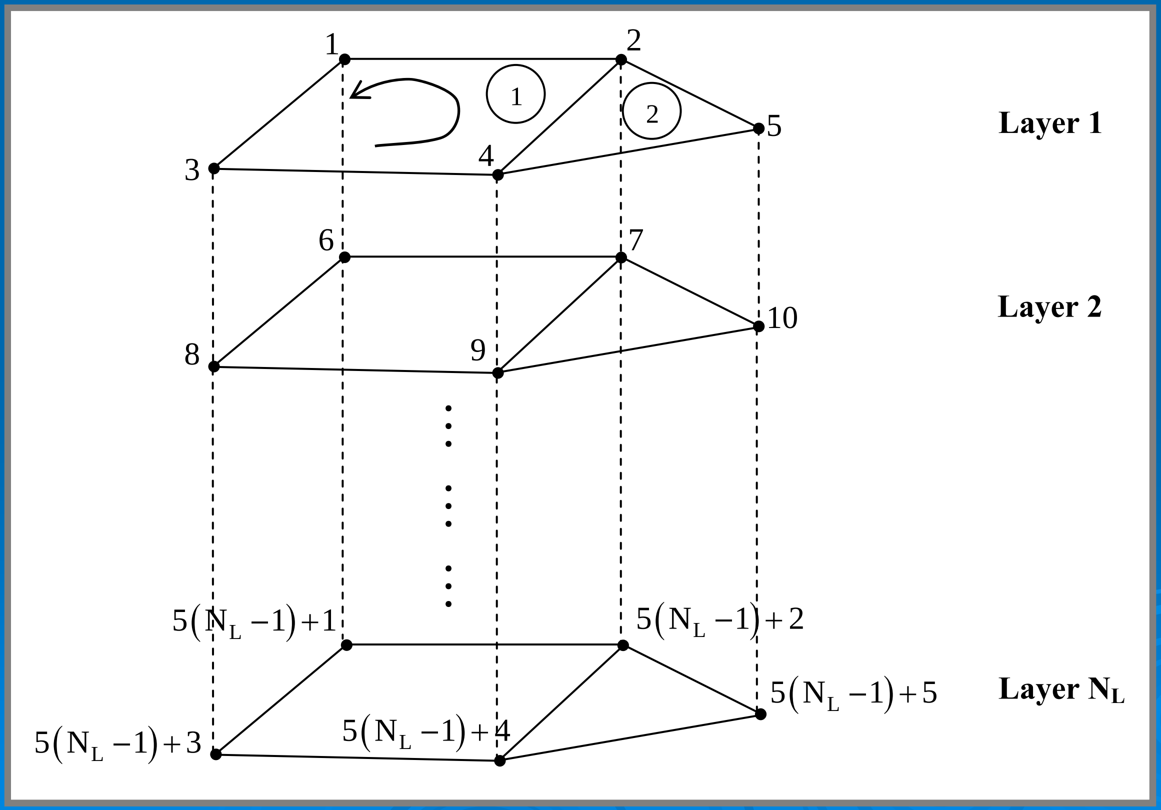
- Model area is discretized into linear triangular and bilinear quadrilateral elements
- Same finite element mesh is used for each layer of a multi-layer aquifer system



Node Numbering Convention

Nodes for layer m (N nodes in a layer):

$N(m-1)+1 \leq i \leq Nm$



Simulated Boundary Conditions

- Specified flow (Neumann); time-series or static
- Specified head (Dirichlet); time-series or static
- General head boundary condition; h_{GHB} can be time-series or static

$$Q_{GHB} = \frac{KA}{d}\left(h_{GHB} - h\right)$$

- Small stream watersheds as dynamically computed flow boundary conditions

Solution of the System of Equations

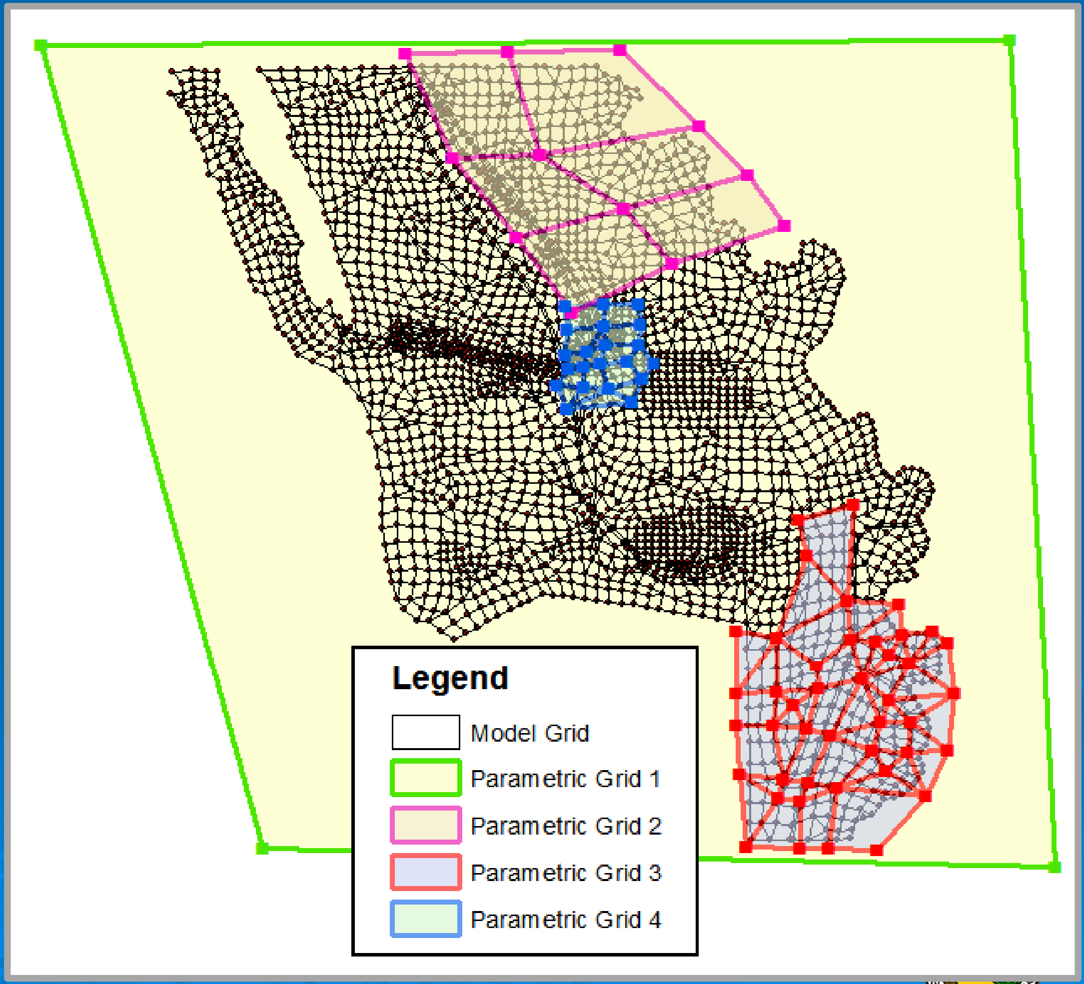
- Application of Newton-Raphson iteration method to linearize the spatially and temporally discretized groundwater equation
- Resulting set of linear algebraic equations are solved iteratively using either
  1. Point Successive Over-Relaxation method (SOR), or
  2. Modified pre-conditioned conjugate gradient method (PGMRES)
- Newton-Raphson convergence criteria:

$$\sqrt{\sum_i \left[\left(h_i^{t+1}\right)^{k+1} - \left(h_i^{t+1}\right)^{k} \right]^2} \leq \varepsilon \quad ; \quad i = 1, \cdots, N \times N_L$$

Specification of Aquifer Parameter Values

Aquifer parameters can be specified in two ways:

1. Enter parameter values for each node separately
2. Use parametric grid option to generate parameter values for each node (finite element interpolation is used to distribute parametric grid values to nodal values)



Preparing Input Files: File Types

File Type	Recognized File Name Extensions
ASCII	.DAT .TXT .OUT .IN .IN1 .IN2 .BUD
Fortran binary	.BIN
HEC-DSS	.DSS

Preparing Input Files: Comment Lines

- Comment lines in text input files start with *C*, *c* or *

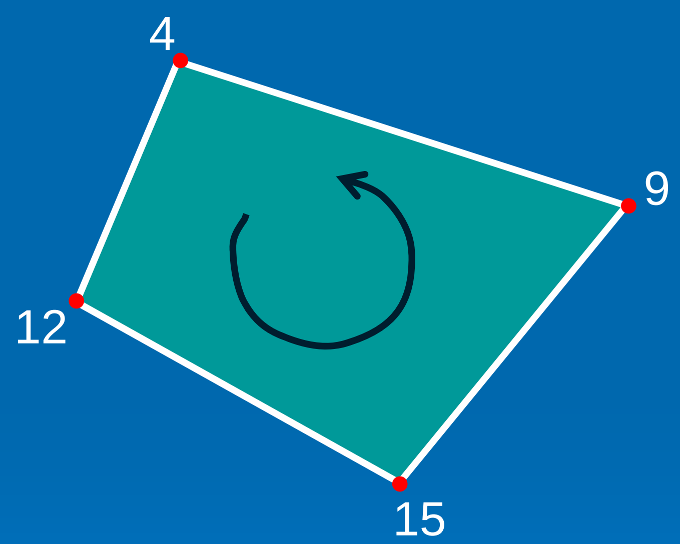
```
C*******************************************************************************
C
C                         IWFM DEMAND CALCULATOR (IDC)
C                              *** Version 4.0 ***
C
C*******************************************************************************
C
C                              MAIN INPUT FILE
C
C
C              Project :  IDC Workshop - December 11-12, 2013
C              Filename:  MAIN.in
C
C*******************************************************************************
C                             File Description
C
C    This file contains the control data for IDC that includes the names and
C    descriptions of all simulation files; simulation period and output conversion
C    factors.
C
C*******************************************************************************
C                             File Description
C
C   *Listed below are all input and output file names used when running the
C    utility.
C   *Each file name has a maximum length of 1000 characters
C   *If an optional file does not exist for a project, leave the filename blank
C
```


```
C*******************************************************************************
C                             File Description
C
C    This file contains the control data for IDC that includes the names and
C    descriptions of all simulation files; simulation period and output conversion
C    factors.
C
C*******************************************************************************
```


```
C    EDT   ; Ending simulation date and time.  Use MM/DD/YYYY_hh:mm format.
C              * Midnight is 24:00
C    UNITT  ; Time step length and unit. Choose one of the following:
C                   1MIN
```

Preparing Input Files: Cell Definitions

Quadrilateral

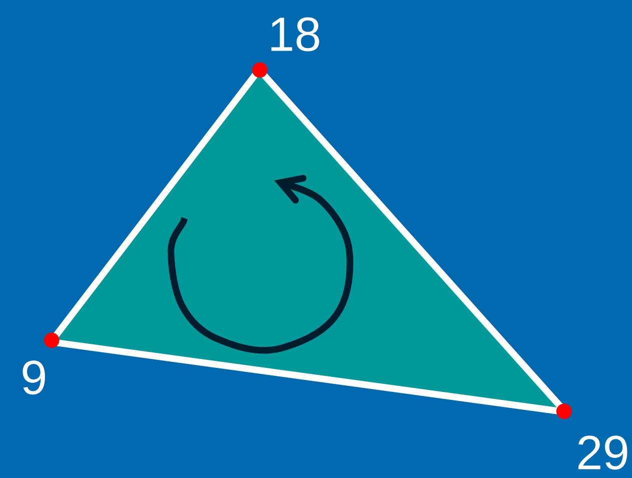


e.g.: 12, 15, 9 , 4

or

9, 4, 12, 15

Triangular



e.g.: 9, 29, 18, 0

or

18, 9, 29, 0

Preparing Input Files: Time-Tracking Simulations

- Aware of simulation date and time through simulation period
- Avoids translations between simulation time steps to calendar date and time
- Easy to update and maintain time series input data
- Easy to compare simulation data to measured data

Preparing Input Files: Time Step Length

Time Step Length	IWFM Notation
1 minute	1MIN
2 minutes	2MIN
3 minutes	3MIN
4 minutes	4MIN
5 minutes	5MIN
10 minutes	10MIN
15 minutes	15MIN
20 minutes	20MIN
30 minutes	30MIN
1 hour	1HOUR
2 hours	2HOUR
3 hours	3HOUR
4 hours	4HOUR
6 hours	6HOUR
8 hours	8HOUR
12 hours	12HOUR
1 day	1DAY
1 week	1WEEK
1 month	1MON
1 year	1YEAR

Preparing Input Files: Time Stamp Format

- Time stamp format:

  mm/dd/yyyy_hh:mm

- Examples:
  - 01/12/1973_06:00 = January 12, 1973, 6 o'clock in the morning
  - 12/31/2012_12:00 = December 31, 2012, noon
  - 09/30/2000_24:00 = September 30, 2000, midnight

- Incorrect time stamps:
  - 1/12/1973_06:00 (month must have 2 digits)
  - 12/1/73_2400 (day must have 2 digits, year must have 4 digits, missing colon to separate hour and minute)

Preparing Input Files: Time Stamp Format

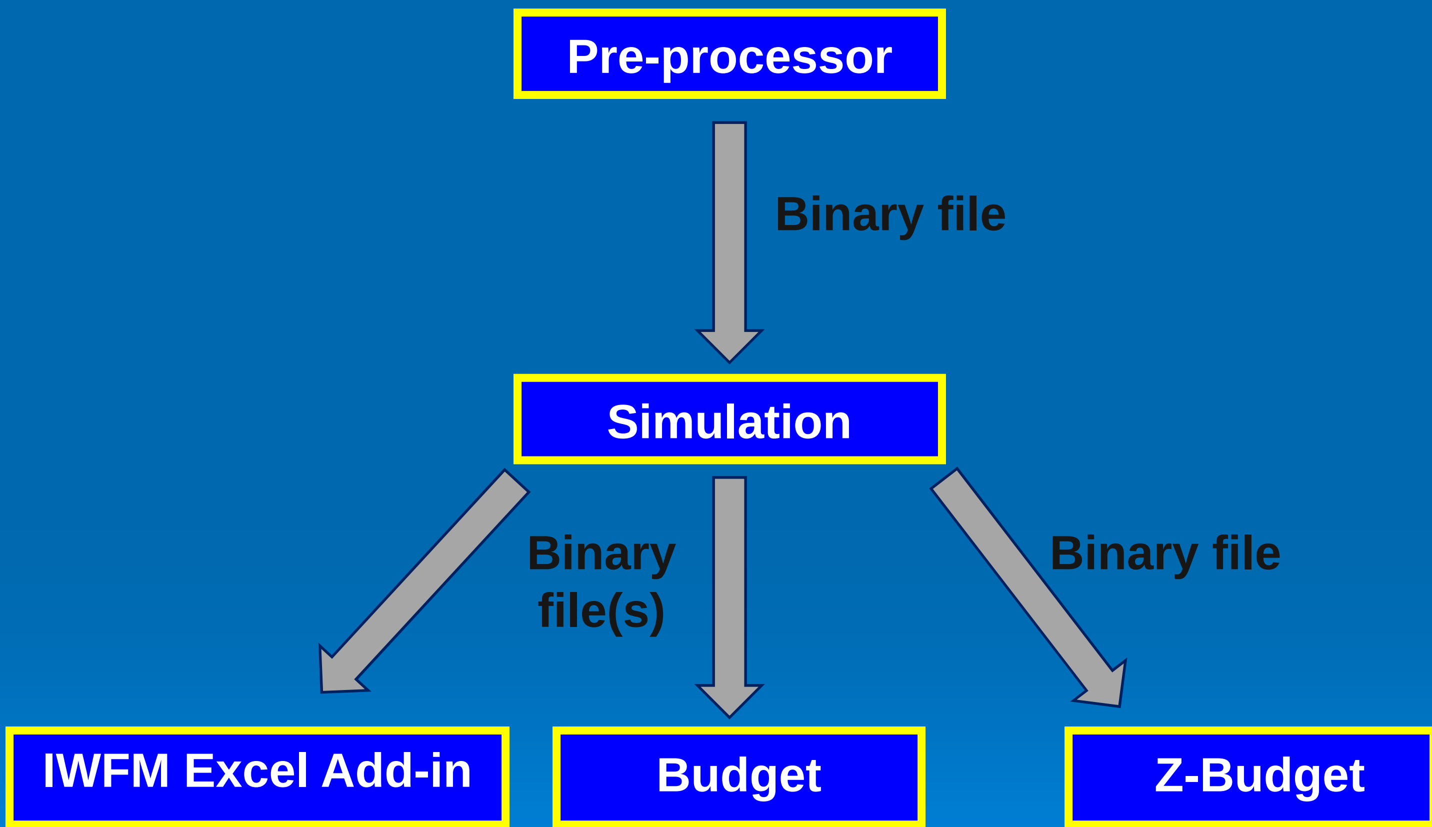
- Time series data with a given time stamp represents a value that is valid up to that time
  - e.g. precipitation rate with a time stamp 05/28/1973_24:00 is valid until midnight of May 28, 1973
  - e.g. land use acreages for water year 1980 (October 1, 1979 through September 30, 1980) should be time stamped as 09/30/1980_24:00
- Use year 4000 to recycle time series data
  - e.g. precipitation rate with a time stamp 05/28/4000_24:00 will be used for May 28th for all simulation years
- If simulation time step length is less than the time series data interval, flow-rate-type time series data will be distributed uniformly over time

Preparing Input Files: Time Stamp Format

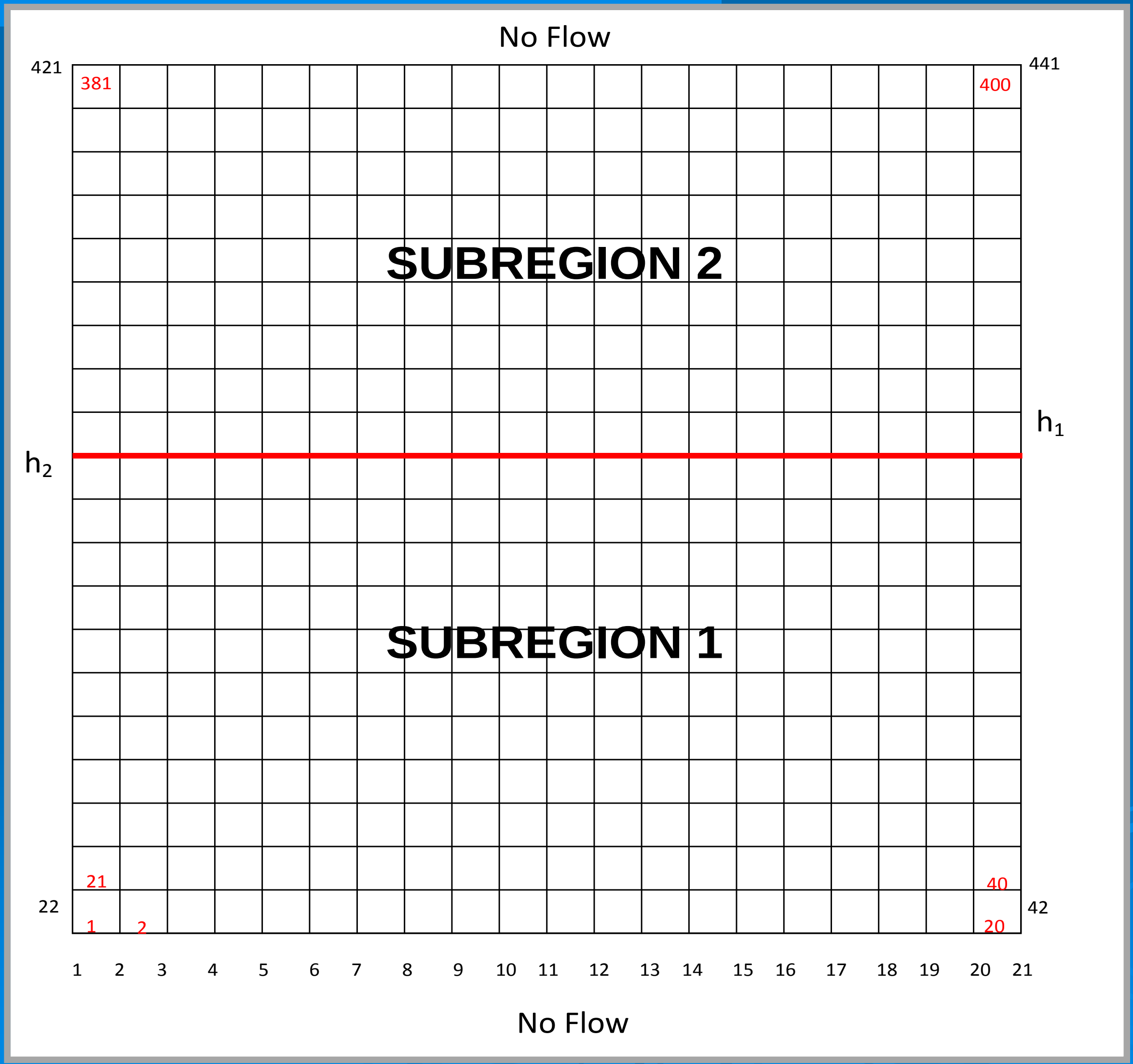
```
C*****************************************************************************
C                              Rainfall Data Specifications
C
C   NRAIN ;  Number of rainfall stations (or pathnames if DSS files are used)
C             used in the model
C   FACTRN;  Conversion factor for rainfall rate
C             It is used to convert only the spatial component of the unit;
C             DO NOT include the conversion factor for time component of the unit.
C             * e.g. Unit of rainfall rate listed in this
C                    Consistent unit used in simulation
C                    Enter FACTRN (INCHES/MONTH -> FEET/MO
C                     (conversion of MONTH -> DAY is perfo
C   NSPRN ;  Number of time steps to update the precipitat
C             * Enter any number if time-tracking option i
C   NFQRN ;  Repetition frequency of the precipitation dat
C             * Enter 0 if full time series data is suppli
C             * Enter any number if time-tracking option i
C   DSSFL ;  The name of the DSS file for data input (maxi
C             * Leave blank if DSS file is not used for da
C
C-----------------------------------------------------------
C        VALUE                                          DESCR
C-----------------------------------------------------------
          1602                                          / NRA
          0.08333                                       / FAC
          1                                             / NSP
          0                                             / NFQ
                                                          DSS
C-----------------------------------------------------------
C                              Rainfall Data
C                           (READ FROM THIS FILE)
C
C   List the rainfall rates for each of the rainfall stati
C   not be read from a DSS file (i.e. DSSFL is left blank
C
C   ITRN ;   Time
C   ARAIN;   Rainfall rate at the corresponding rainfall s
C
C-----------------------------------------------------------------------------
C ITRN     ARAIN(1)  ARAIN(2)  ARAIN(3)  ..
C-----------------------------------------------------------------------------
C   Time                  1        2        3        4        5
10/31/1921_24:00         1.34     1.34     1.32     1.27     1.
11/30/1921_24:00         3.64     3.62     3.59     3.49     3.
12/31/1921_24:00         8.15     8.14     7.86     7.49     8.
01/31/1922_24:00         1.32     1.46     1.62     1.80     1.
02/28/1922_24:00         7.61     7.95     7.98     8.02     7.25     7.23     7.09     6.63     6.66     6.56
03/31/1922_24:00         4.33     4.39     4.31     4.28     4.22     4.03     4.09     4.06     3.73     3.48
04/30/1922_24:00         0.94     0.91     0.92     0.91     0.94     0.93     0.93     0.94     0.92     0.79
05/31/1922_24:00         2.20     2.18     2.18     2.09     2.22     2.19     2.18     2.26     2.19     1.80
06/30/1922_24:00         0.71     0.72     0.67     0.62     0.76     0.58     0.74     0.82     0.65     0.36
07/31/1922_24:00         0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00
08/31/1922_24:00         0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00
[illegible]                                 0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00
10/31/1922_24:00         3.44     3.45     3.39     3.23     3.42     3.28     3.39     3.40     3.15     2.85
11/30/1922_24:00         3.54     3.64     3.74     3.79     3.47     3.51     3.41     3.22     3.22     3.40
12/31/1922_24:00         8.44     8.84     8.63     8.94     8.22     8.27     8.01     7.75     7.82     7.80
[illegible]
```


```
C
C    ITRN ;    Time
C    ARAIN;    Rainfall rate at the corre
C
C--------------------------------------
C ITRN     ARAIN(1)  ARAIN(2)  ARAIN(3)
C--------------------------------------
C    Time                  1        2
10/31/1921_24:00         1.34     1.34
11/30/1921_24:00         3.64     3.62
12/31/1921_24:00         8.15     8.14
01/31/1922_24:00         1.32     1.46
02/28/1922_24:00         7.61     7.95
03/31/1922_24:00         4.33     4.39
04/30/1922_24:00         0.94     0.91
05/31/1922_24:00         2.20     2.18
06/30/1922_24:00         0.71     0.72
07/31/1922_24:00         0.00     0.00
08/31/1922_24:00         0.00     0.00
```

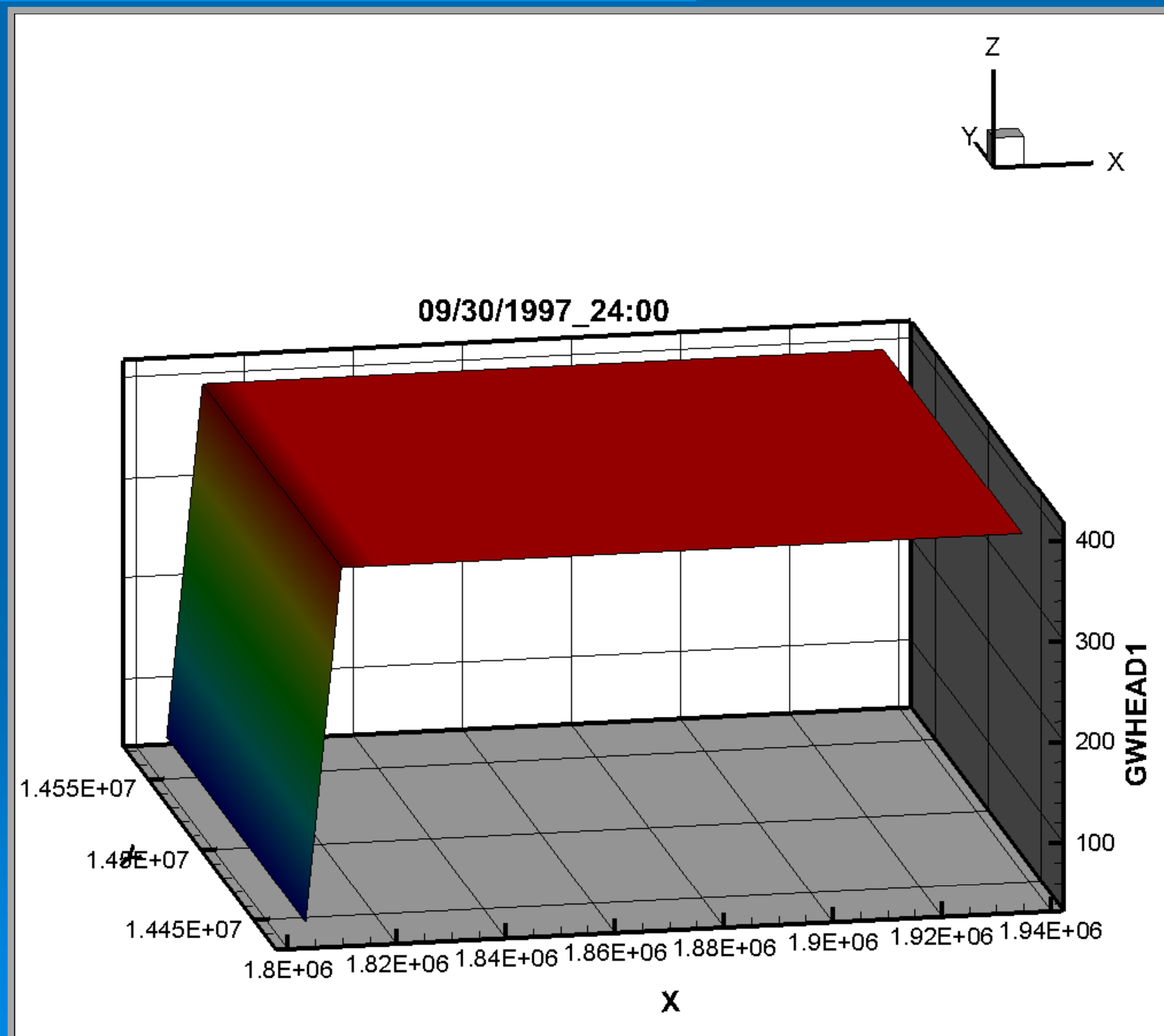
IWFM Program Execution



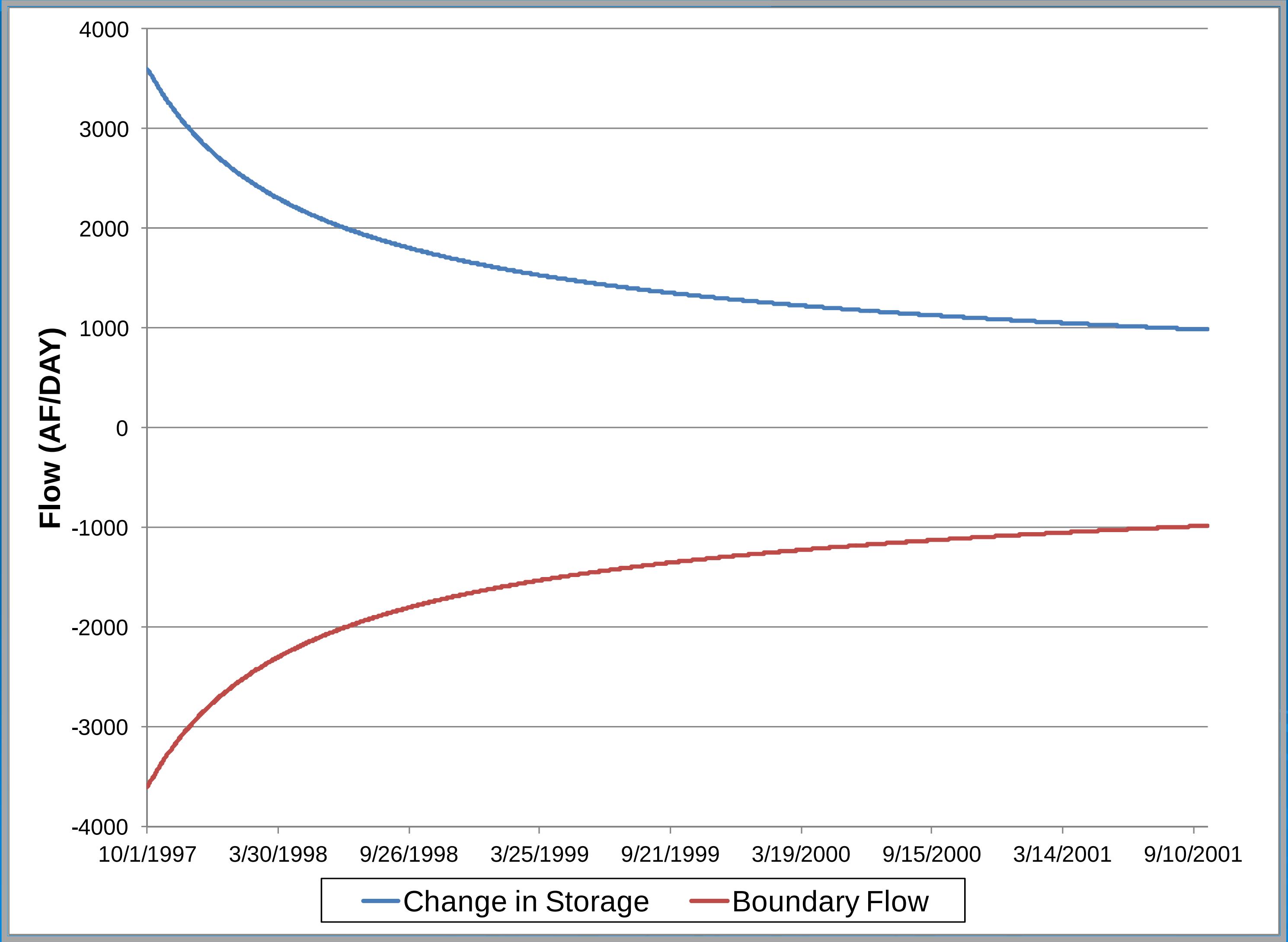
Example 1:
Groundwater Flow



Example 1:
Groundwater Flow – Results



Example 1:
Groundwater Flow – Mass Balance



Example 1:
Groundwater Flow – Mass Balance at Element 210