PennState

# PIHM-GLM: A catchment-lake hydrological modeling framework

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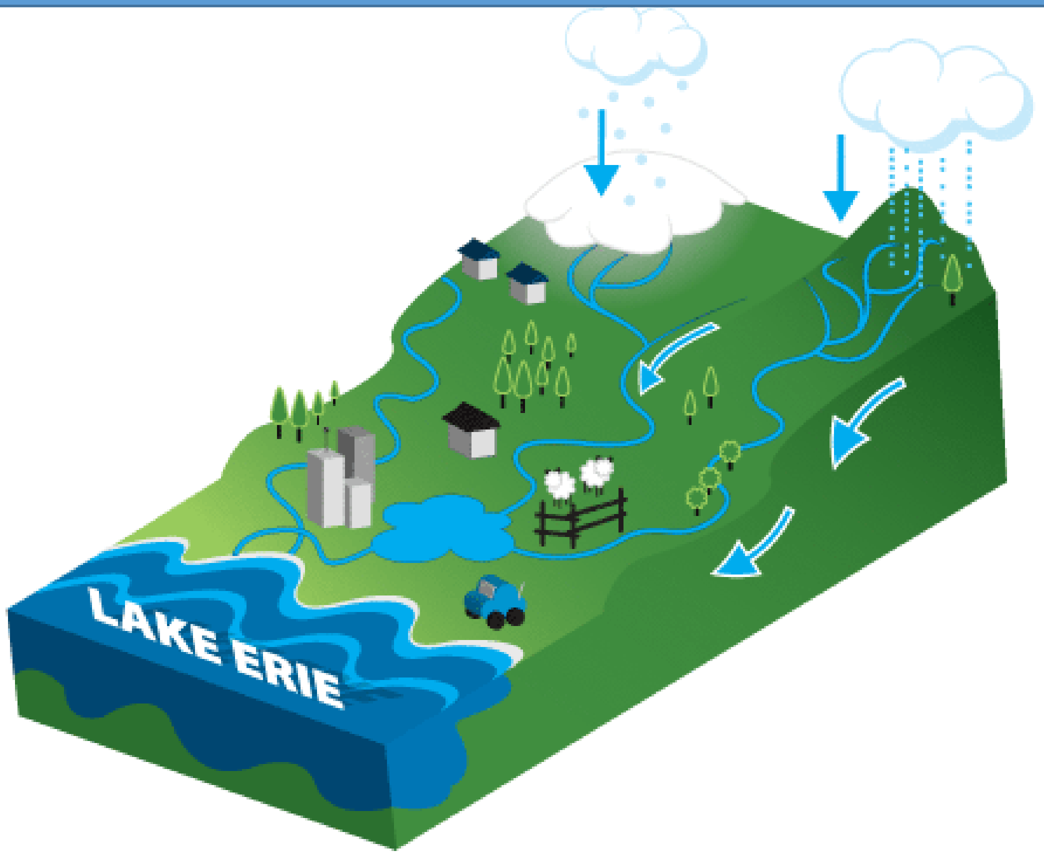
## Project Summary to Date

- a brief overview of the model and modeling activities
- Coupling PIHM and GLM
- Collaboration software for sharing

    -Organic Data Science - project WIKI
    -Prepare a sharable document with the details of catchment & lake data and model results with statistical analysis
    -Age and residence time of lake-catchment

- model calibration for the period 2003-2013;
- Preparation for passing data to cycles for the nitrogen scenario

# Motivation

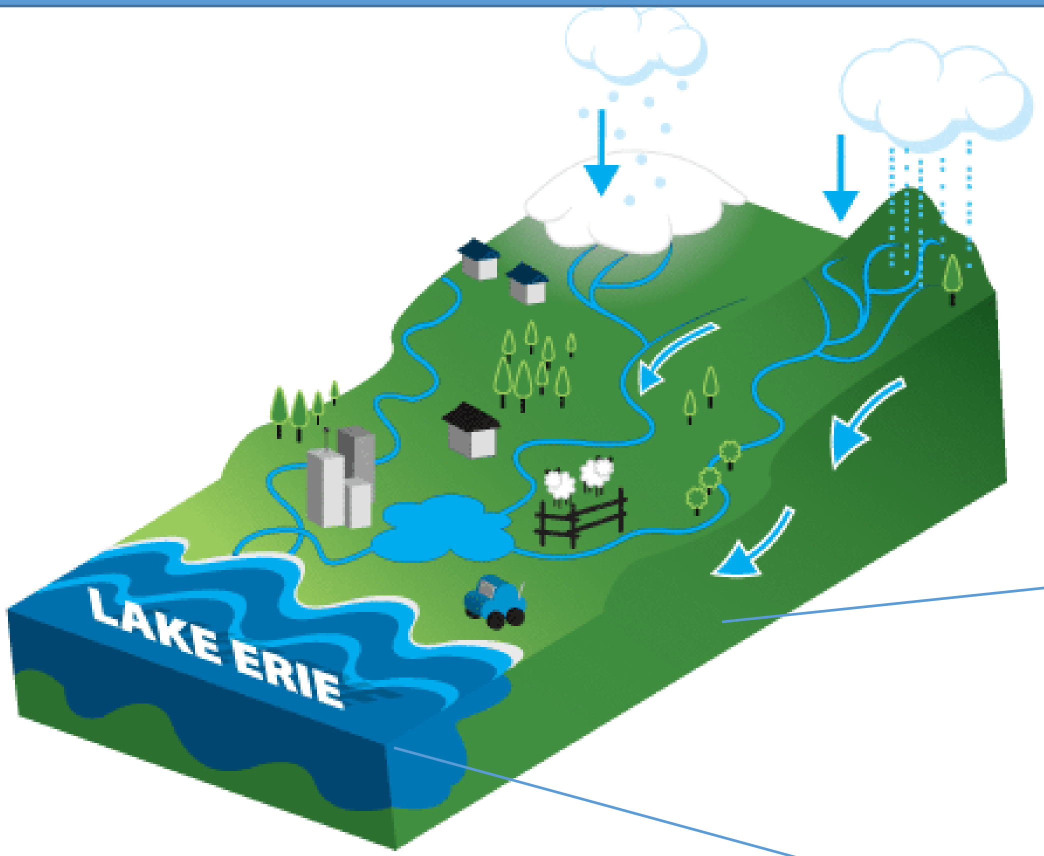


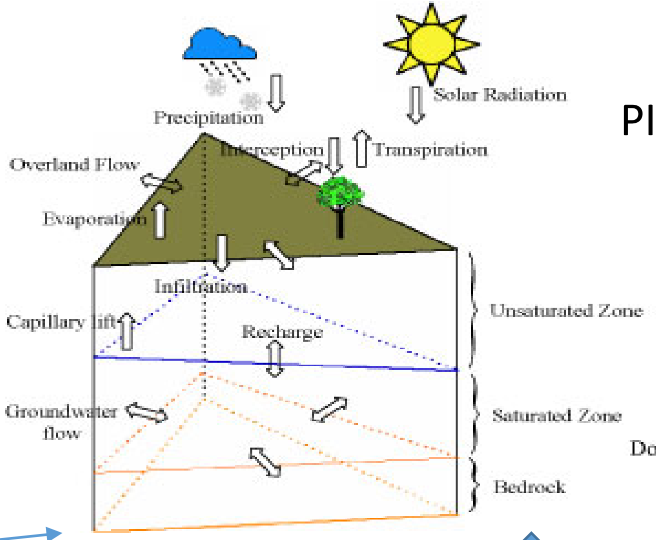

## Hydrologic Connectivity

- Surface subsurface interaction
- Nutrient transport
- Climate variability
- Sediment transport
- Age of water

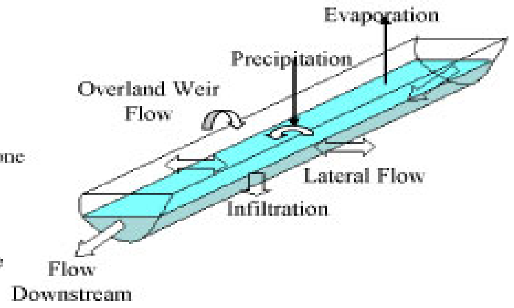
Need a model framework to understand the catchment-Lake interaction.

# Model coupling

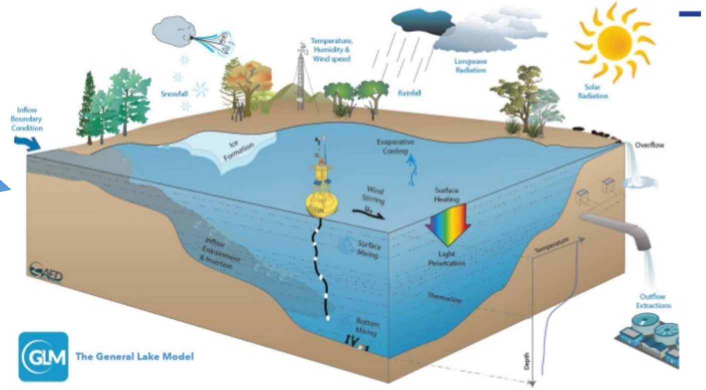



PIHM




**GLM** – General Lake Model

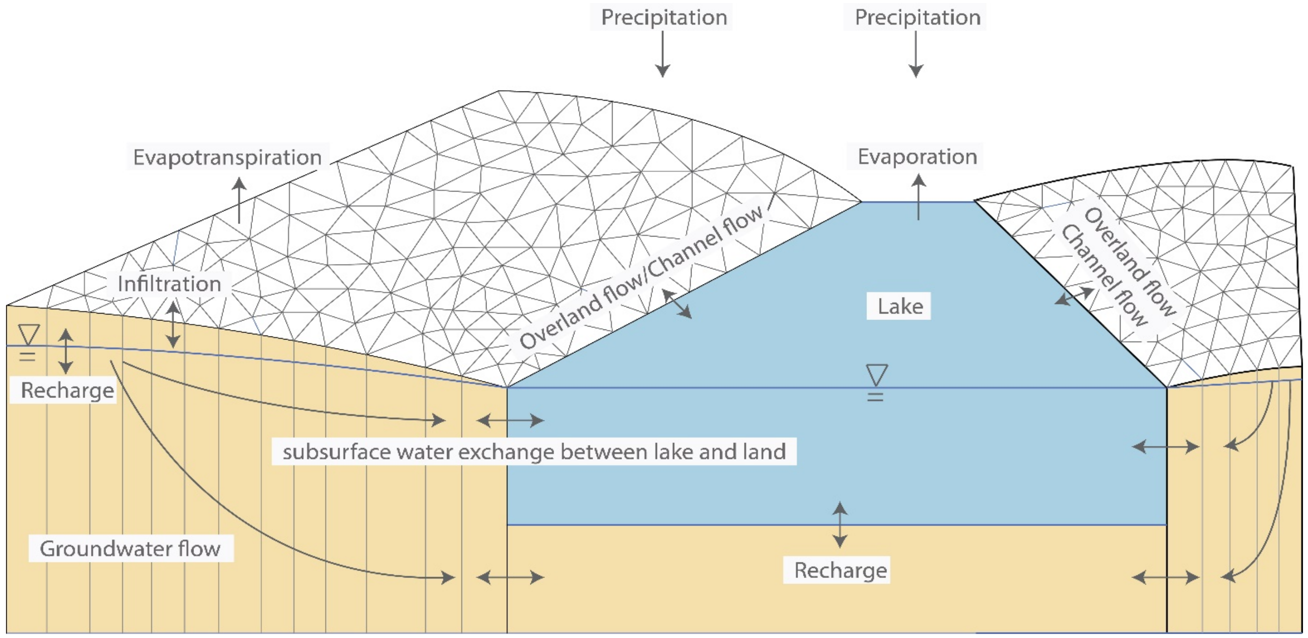


# Model coupling

## Sketch of PIHM-GLM model

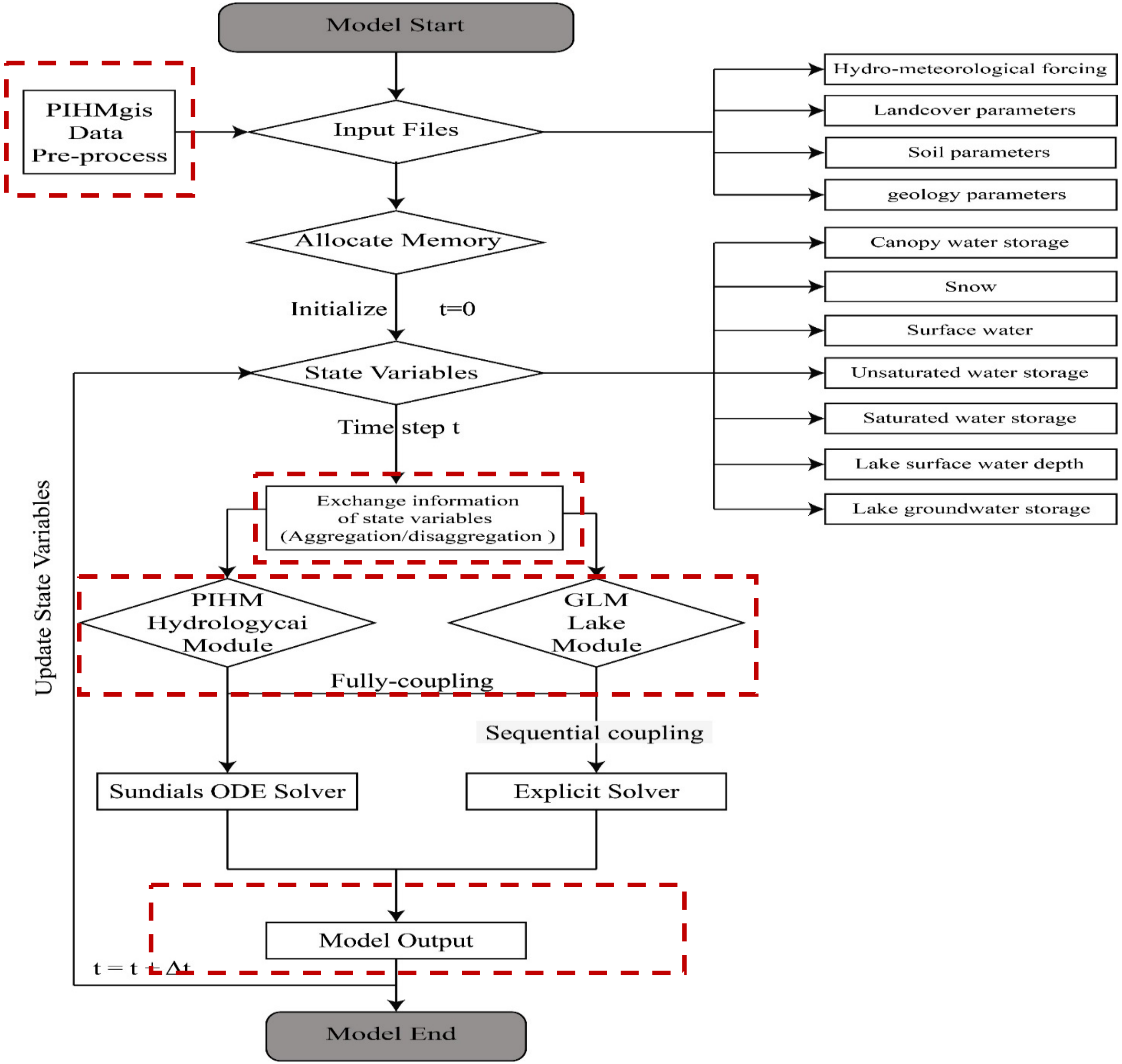
- **PIHM-GLM** is a hydrological model combining the hydrodynamic of lake surrounding watershed and lake itself.

- PIHM-GLM, like PIHM, tracks five variables/fluxes (surface water depth, unsaturated water storage, groundwater storage, snow, canopy interception, surface flow, subsurface flow, evapotranspiration, lake-catchment surface water /groundwater exchange)

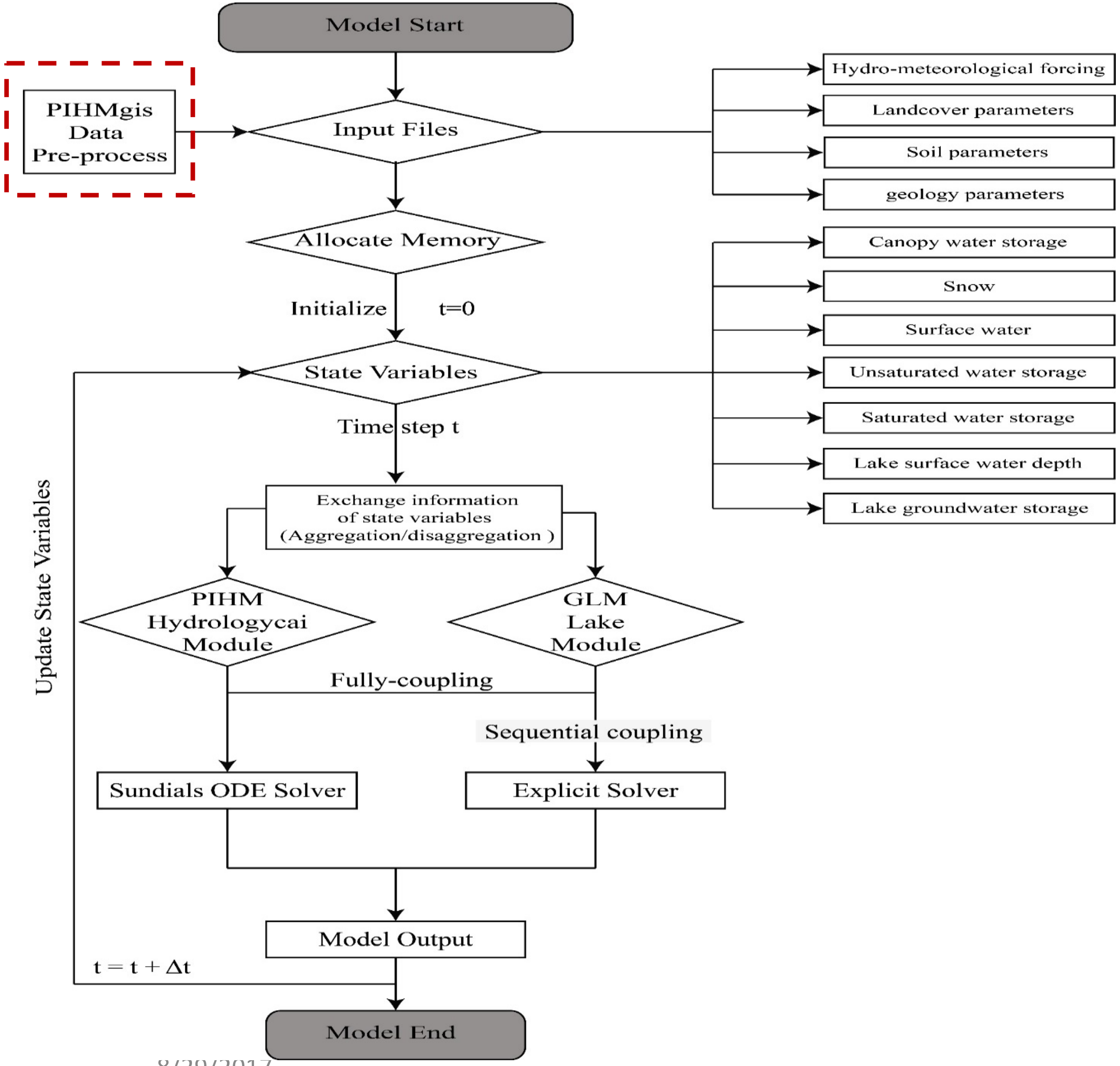



(Zhang, Duffy, Shu, et al…. 2017 in prep)

# Workflow of PIHM-GLM



# Data pre-processing




- Data needed for pre-processing
  - Watershed boundary (shp)
  - Lake boundary (shp)
  - Lake bathymetry

  Prepare separately

  - Topographic data (DEM)
  - Forcing data
  - Soil data
  - Land cover data

  PIHM Hydroterre

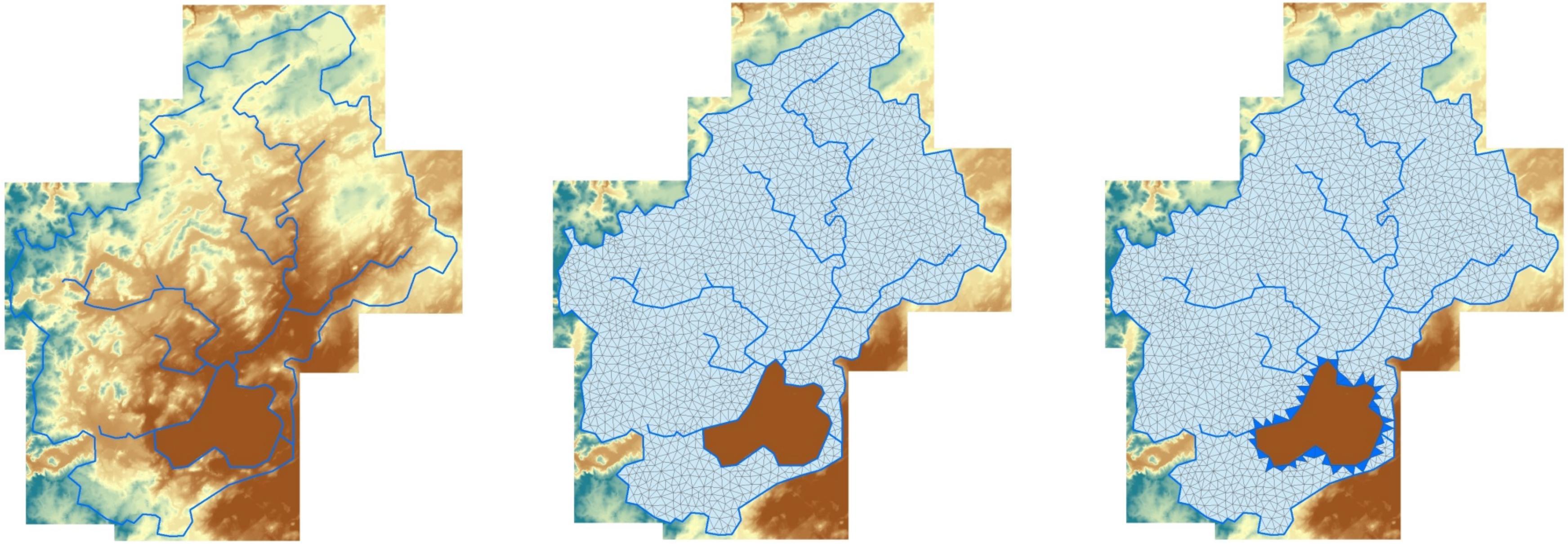
# Input data for the lake

.lakegeom .lakebathy .lakeatt  .lakesoil  .lakecalib

**Input files**

1.ProjectName.**lakegeom**: the geometry of lake and also the information of surrounding elements

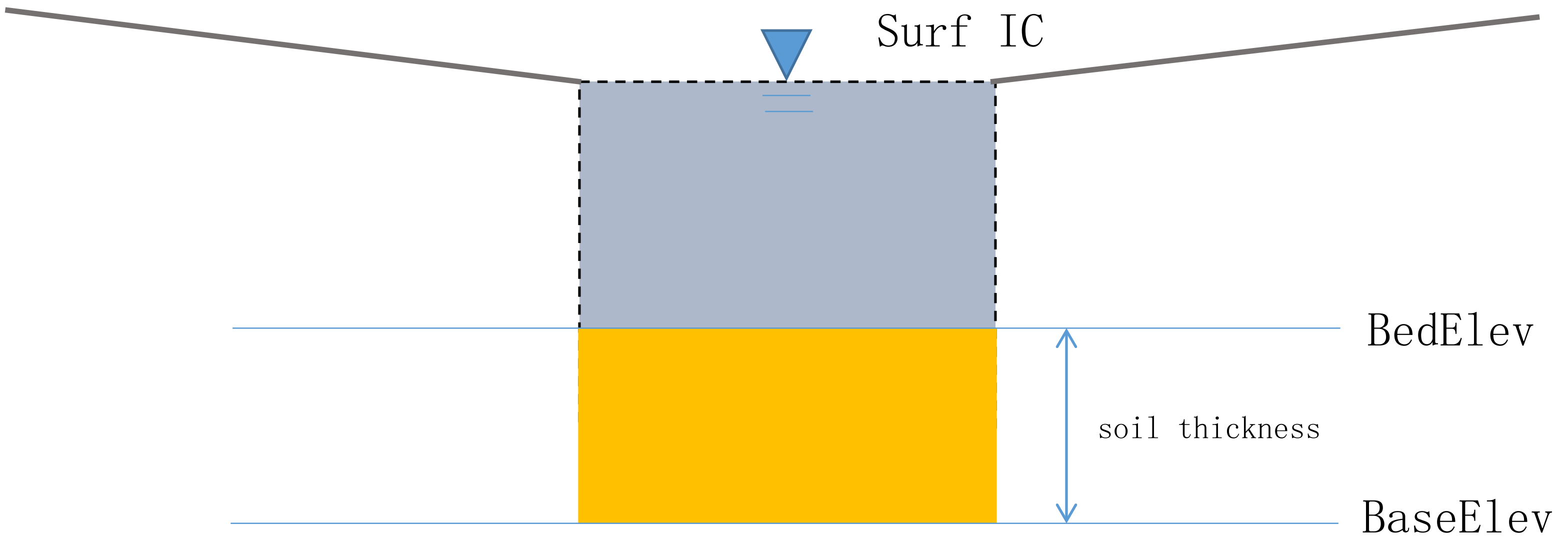
| | | |
|---|---|---|
| NumLake | | |
| Lake1 | NumBankEle | Surface area |
| BankElementID | BankElementID1 | BankElementID2 |
| Lake2 | StreamEle | BankElement |
| BankElementID | BankElementID1 | BankElementID2 |



## Input files

2. ProjectName.**lakebathy**: The bathymetry of lake and also the Bedrock elevation

| **NumLake** | Surface elevation when it is full of water | Lake Bed elevation | Bedrock elevation |
|---|---|---|---|
| **Lake1** | Surf_IC | BedElevL | BaseElev |



## Input files

3. ProjectName.**lakeatt**: Attribute table for the catogory of the Lake underlying materials

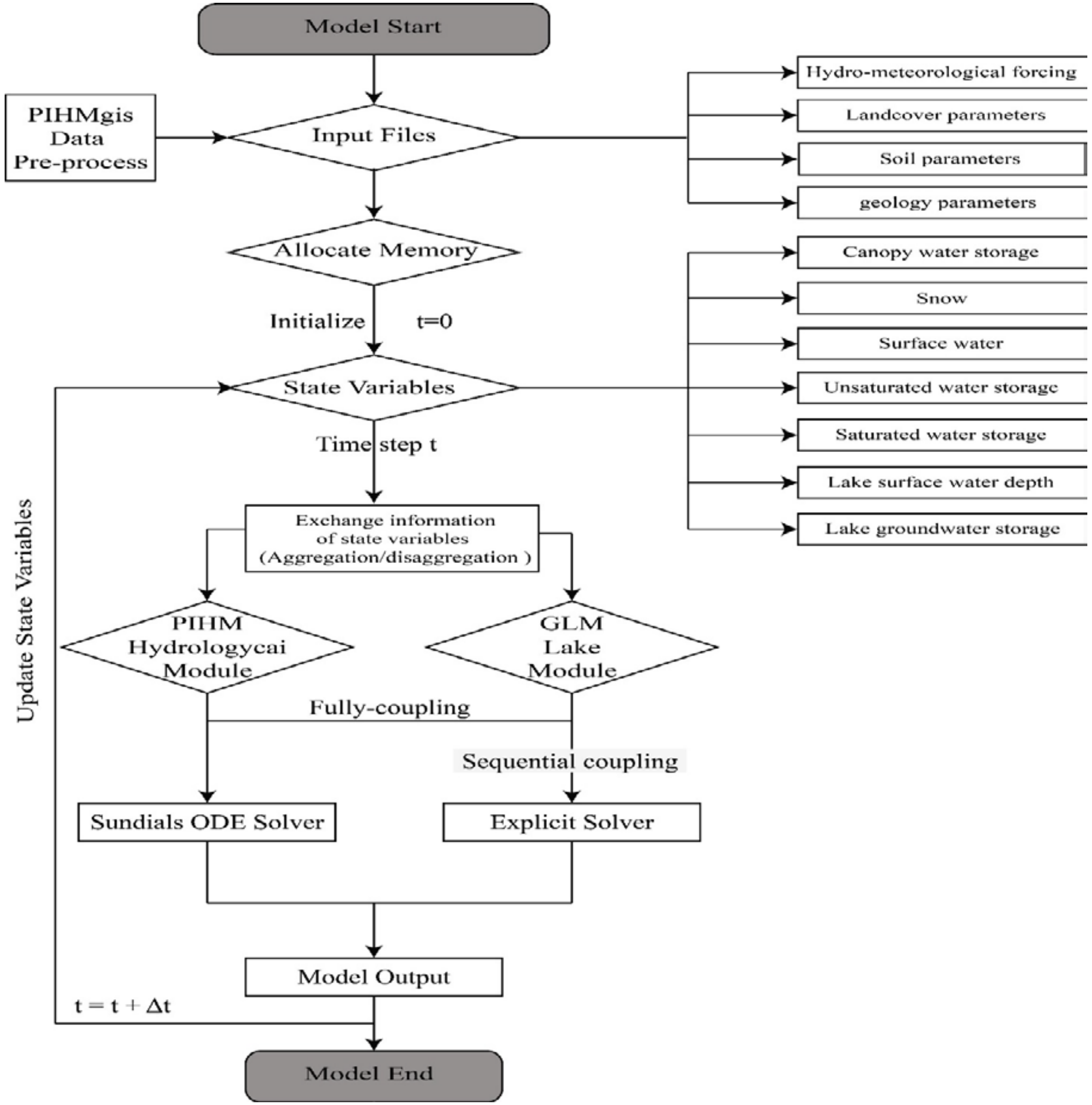
| LakeID | Soil_type | Meteorological type | macropore |
|---|---|---|---|
| 1 | 1 | 1 | 1 |
| | | | |

4. ProjectName.**lakesoil**: The soil properties of each of the soil type

| Number of Lake Soil Type | | | | | |
|---|---|---|---|---|---|
| NumID | Kh_matrix | Kv_matrix | ThetaS | ThetaR | macKsatH |

5. Projectname.**lakecalib**: calibrate five parameters

# All the inputs



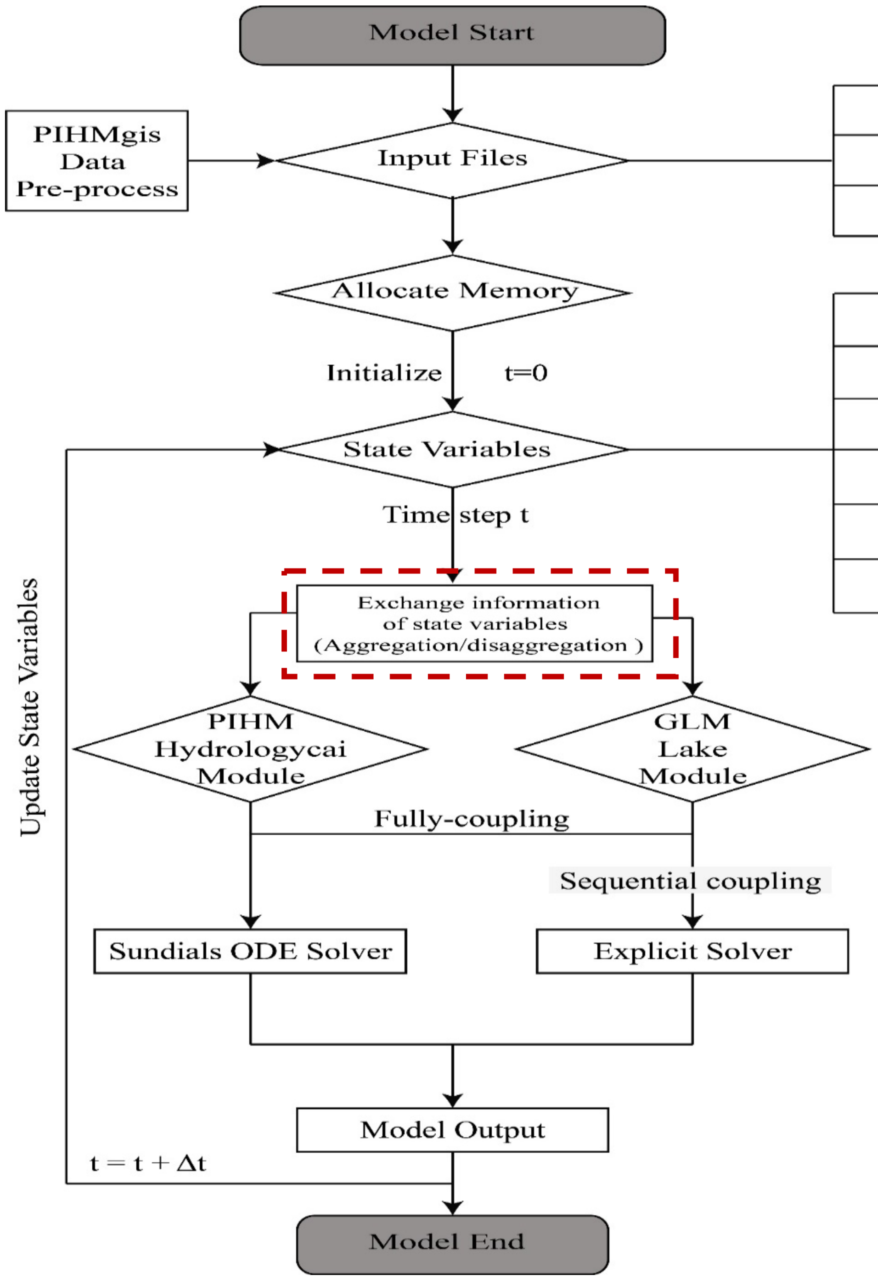

For watershed module

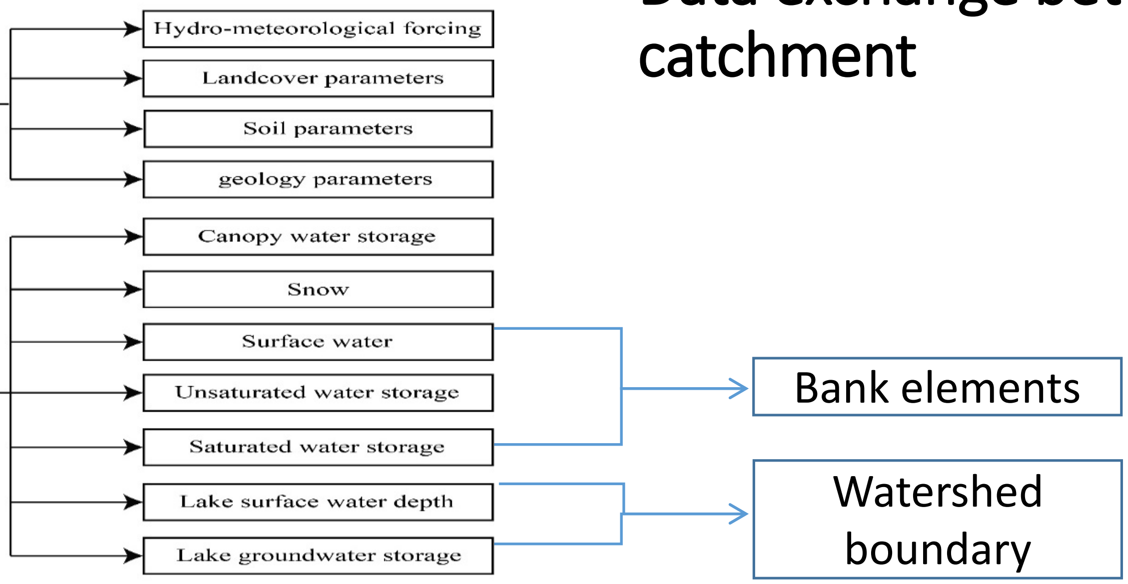
- .att
- .bid
- .calib
- .forc
- .geol
- .ibc
- .mesh
- .soil
- .para

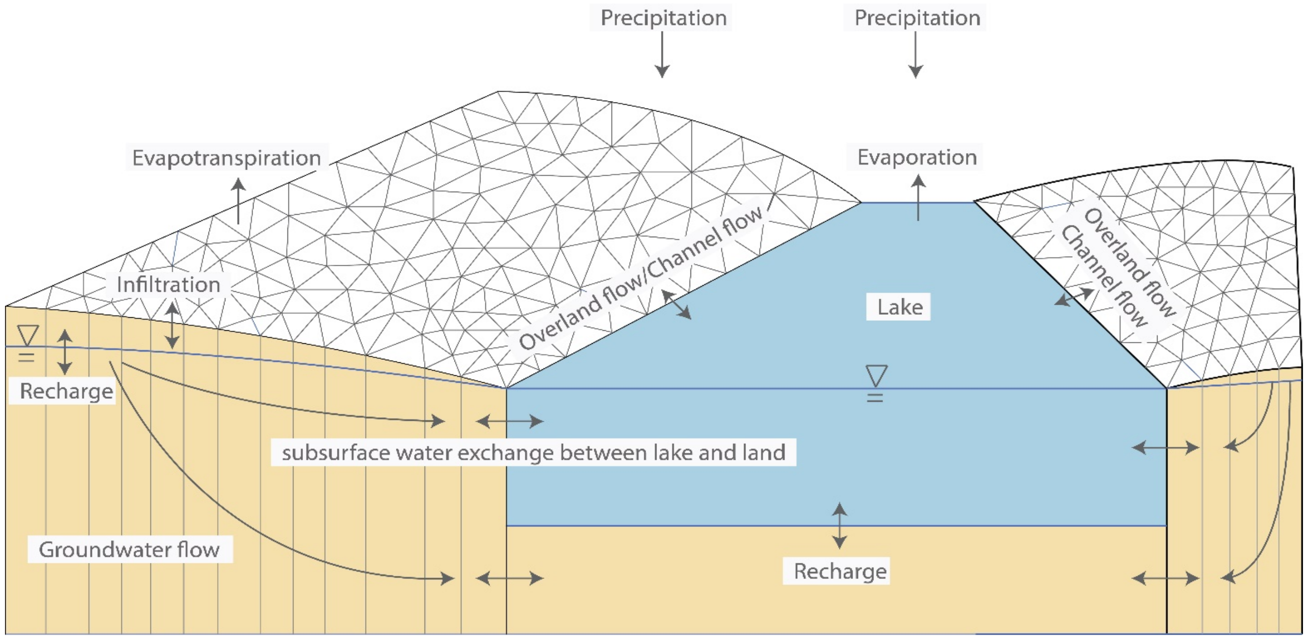
For lake module

- .lakeatt
- .lakebathy
- .lakegeom
- .lakesoil

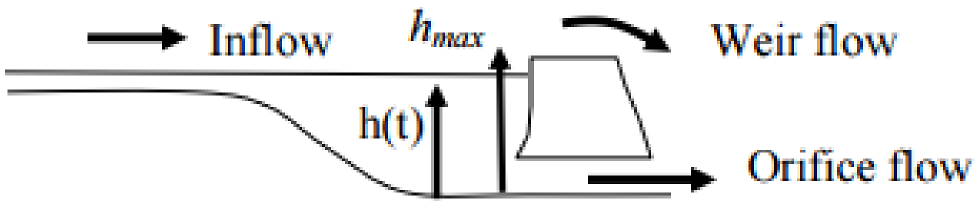
# Data exchange between lake and catchment

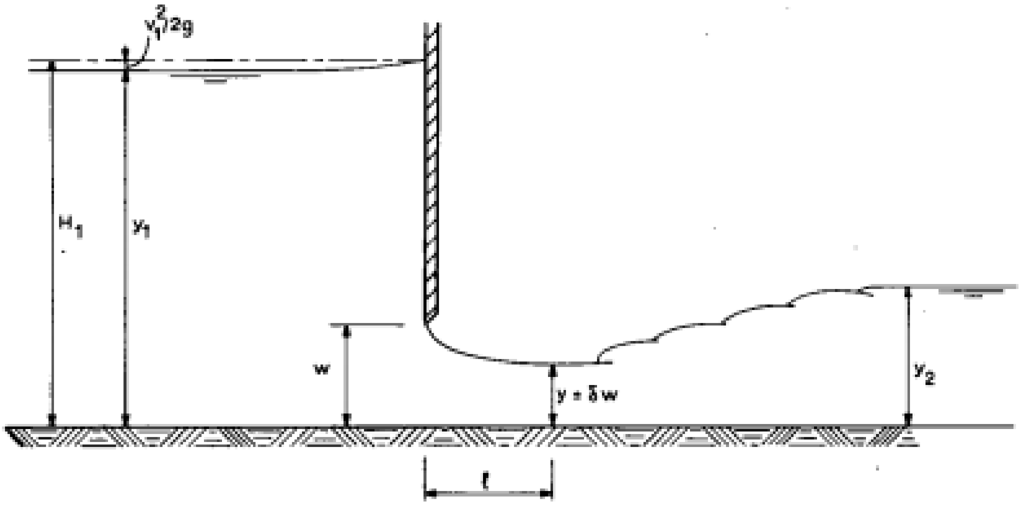


# Weir boundary condition



Weir (**Broad-Crested Weir**)

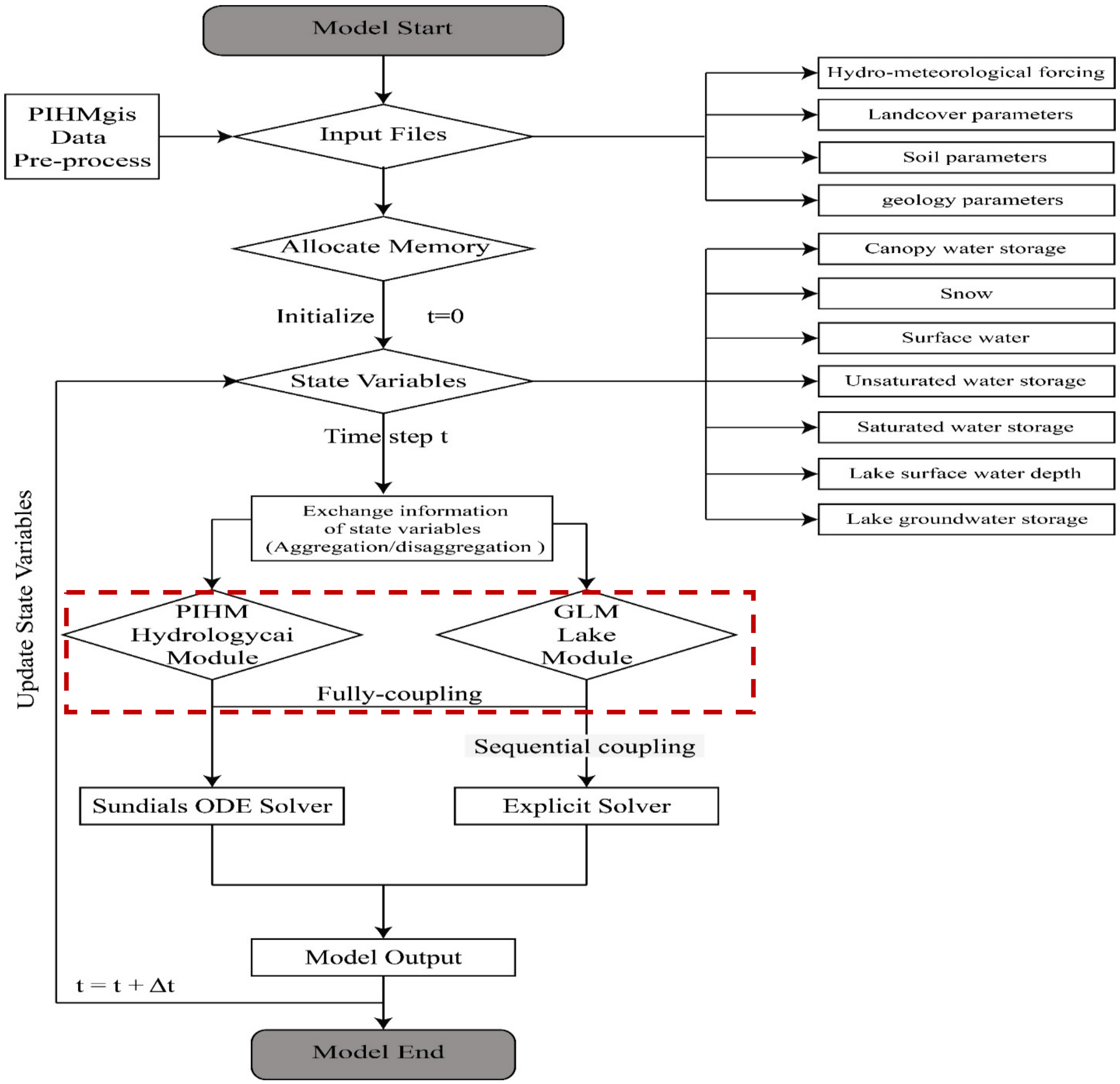
$Q_w = C_w L h^{3/2}$, $C_w$: Broad-Crested Weir coefficient (2.64 as default, details from http://epg.modot.org/files/b/bc/749_Broad-Crested_Weir_Coefficients.pdf)

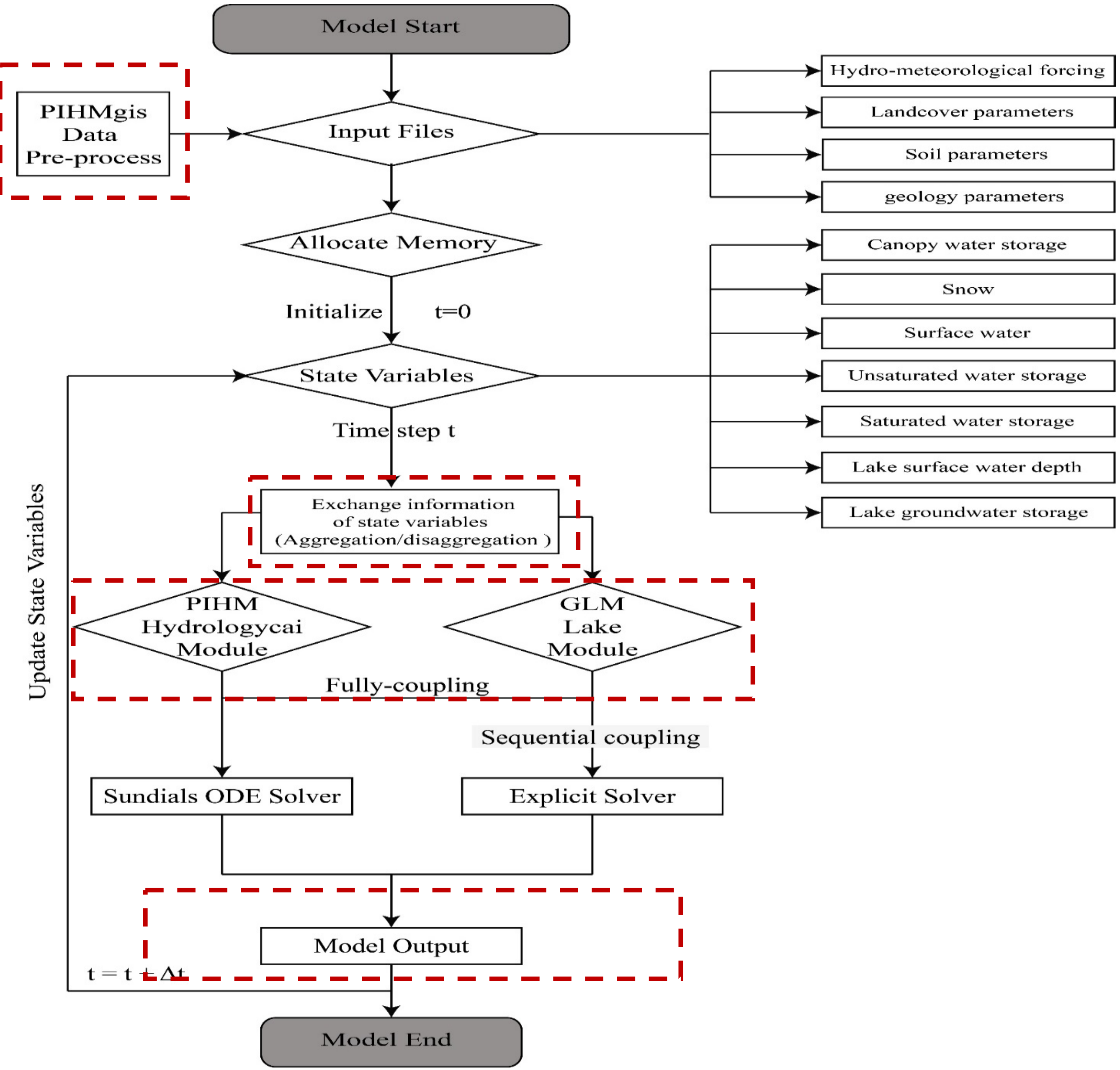
*L is the weir length, h is the water depth*

Orifice

$Q_w = C_0 O_a sqrt[2g(h_{\_before} - h_{\_after})]$. $C_0$: *orifice coefficient (default 0.61);* $O_a$ *is the orifice area; for details: http://content.alterra.wur.nl/Internet/webdocs/ilri-publicaties/publicaties/Pub20/pub20-h8.0.pdf*

# Explicit and implicit ODE solver






- Outputs from the lake module
  - lakeFluxStream
  - lakeFluxSurf
  - lakeFluxSub
  - lakeTemp
  - lakeFlux
  - lakeGW
  - lakeSurf
  - lakePrecip
  - lakeEp
  - lakeInfil

As input for GLM

# Output data-1

**Output files**

1.ProjectName. **lakesurf**: inflow from stream

| Output time (minute) | Water level for Lake1 (m) | Water Level for Lake2 (m^3/day) |
| --- | --- | --- |
| 1440 | 0 | 0 |

2. ProjectName. **lakeET**: inflow form bank

| Output time (minute) | ET for Lake1 (m/s) | ET for Lake2 (m/s) |
| --- | --- | --- |
| 1440 | 0 | 0 |

# Output data-2

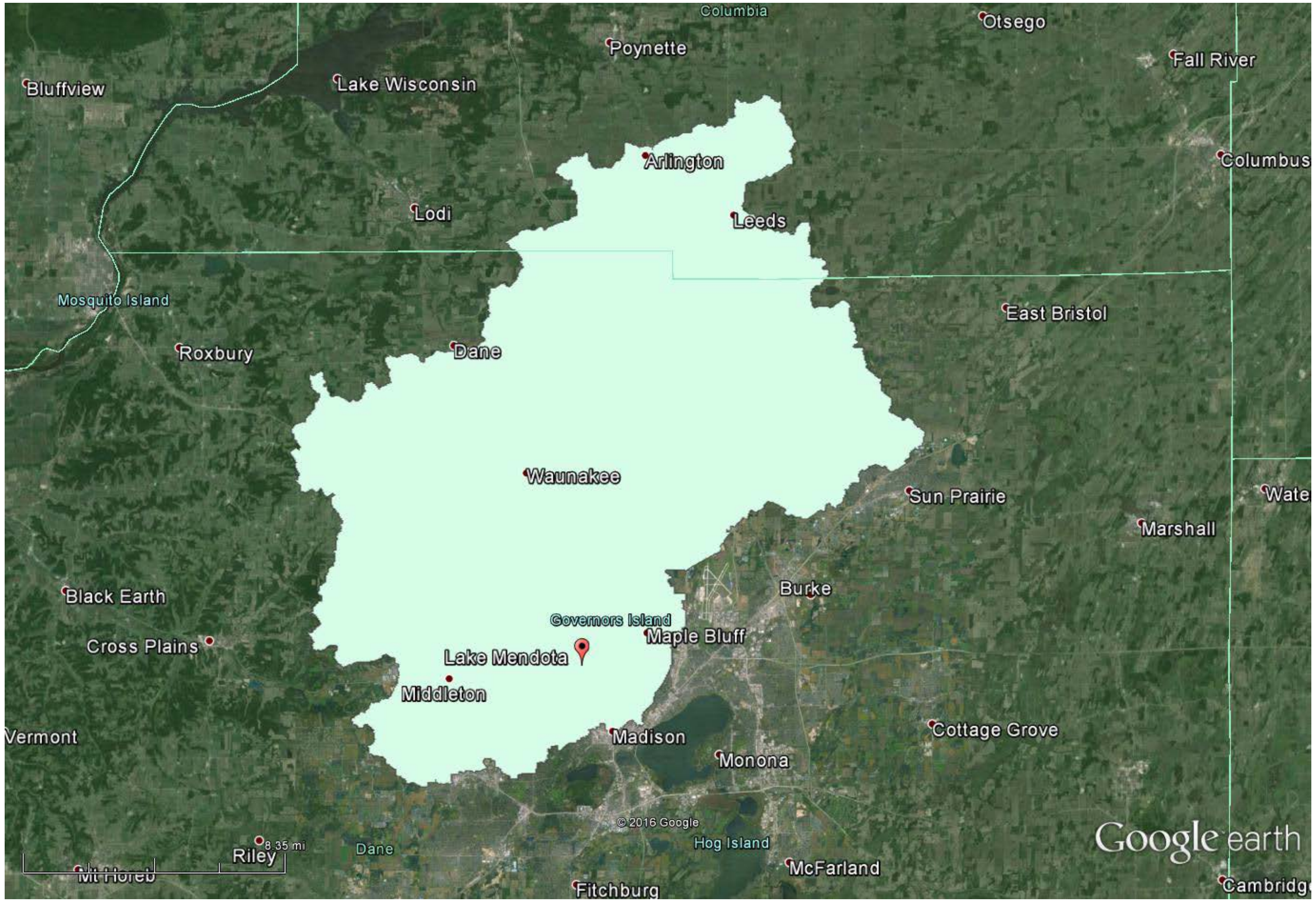
Standard format of the water flows passing along PIHM, GLM, and PIHM-CYCLES

| Date | iles-stream-inflow | -stream-in | _branch-stream-in | rbor-stream-in | Overland-inflow(cms | dwater-inflow | land-outflow | roundwater-outflow(cm | stream-outflow(cms) |
|---|---|---|---|---|---|---|---|---|---|
| 1/1/2000 | 0 | 0 | 0 | 0 | 94.88239934 | 0 | 0 | -0.025295999 | -448.8984637 |
| 1/2/2000 | 4.71172E-06 | 2.4E-06 | 2.9309E-06 | 8.74635E-06 | 36.96270769 | 0 | 0 | -0.021067423 | -166.9883839 |
| 1/3/2000 | 7.6009E-06 | 4.2E-06 | 1.01978E-05 | 2.93278E-05 | 20.3358009 | 0 | 0 | -0.015767273 | -100.6164594 |
| 1/4/2000 | 0 | 0 | 0 | 0 | 13.31189869 | 0 | 0 | -0.010370069 | -71.07612534 |
| 1/5/2000 | 0 | 0 | 0 | 0 | 9.542542685 | 0 | 0 | -0.005216391 | -54.68534703 |
| 1/6/2000 | 0 | 0 | 1.96096E-05 | 0.000273788 | 7.275094563 | 0.00059379 | 0 | -0.001015997 | -44.53156098 |
| 1/7/2000 | 9.87754E-06 | 8E-05 | 0.000132384 | 0.000708936 | 5.745108752 | 0.00402096 | 0 | -2.21316E-05 | -37.53712124 |
| 1/8/2000 | 0.000123007 | 0.00022 | 0.000264888 | 0.00111257 | 4.622760248 | 0.00806547 | 0 | 0 | -32.27913252 |
| 1/9/2000 | 0.000248159 | 0.00036 | 0.00173172 | 0.00996612 | 3.847779337 | 0.01179769 | 0 | 0 | -28.3876477 |
| 1/10/2000 | 0.000349594 | 0.00048 | 0.012355866 | 0.043819321 | 3.339828122 | 0.01528243 | 0 | 0 | -25.16835768 |
| 1/11/2000 | 0.000405482 | 0.00058 | 0.00317043 | 0.004551364 | 2.590234563 | 0.01854748 | 0 | 0 | -22.27803149 |
| 1/12/2000 | 0.000484277 | 0.00068 | 0.00125199 | 0.002424883 | 2.108699122 | 0.02155147 | 0 | 0 | -19.94083678 |
| 1/13/2000 | 0.000554801 | 0.00078 | 0.000792252 | 0.002688766 | 1.730910822 | 0.02430936 | 0 | 0 | -17.92243268 |
| 1/14/2000 | 0.000618159 | 0.00086 | 0.000875247 | 0.002932281 | 1.385979308 | 0.02685089 | 0 | 0 | -16.06965921 |
| 1/15/2000 | 0.000675191 | 0.00095 | 0.000952409 | 0.003157607 | 1.09176095 | 0.02919769 | 0 | 0 | -14.3969588 |
| 1/16/2000 | 0.000726576 | 0.00102 | 0.001024456 | 0.003366661 | 0.845969037 | 0.0313691 | 0 | 0 | -12.93711506 |
| 1/17/2000 | 0.00077288 | 0.00109 | 0.001092007 | 0.003560916 | 0.64728324 | 0.0333825 | 0 | 0 | -11.6974377 |
| 1/18/2000 | 0.000814626 | 0.00115 | 0.001155065 | 0.003741742 | 0.479454331 | 0.03525273 | 0 | 0 | -10.55600532 |
| 1/19/2000 | 0.000852109 | 0.00121 | 0.001213571 | 0.003910058 | 0.373920131 | 0.03698572 | 0 | 0 | -9.932402598 |

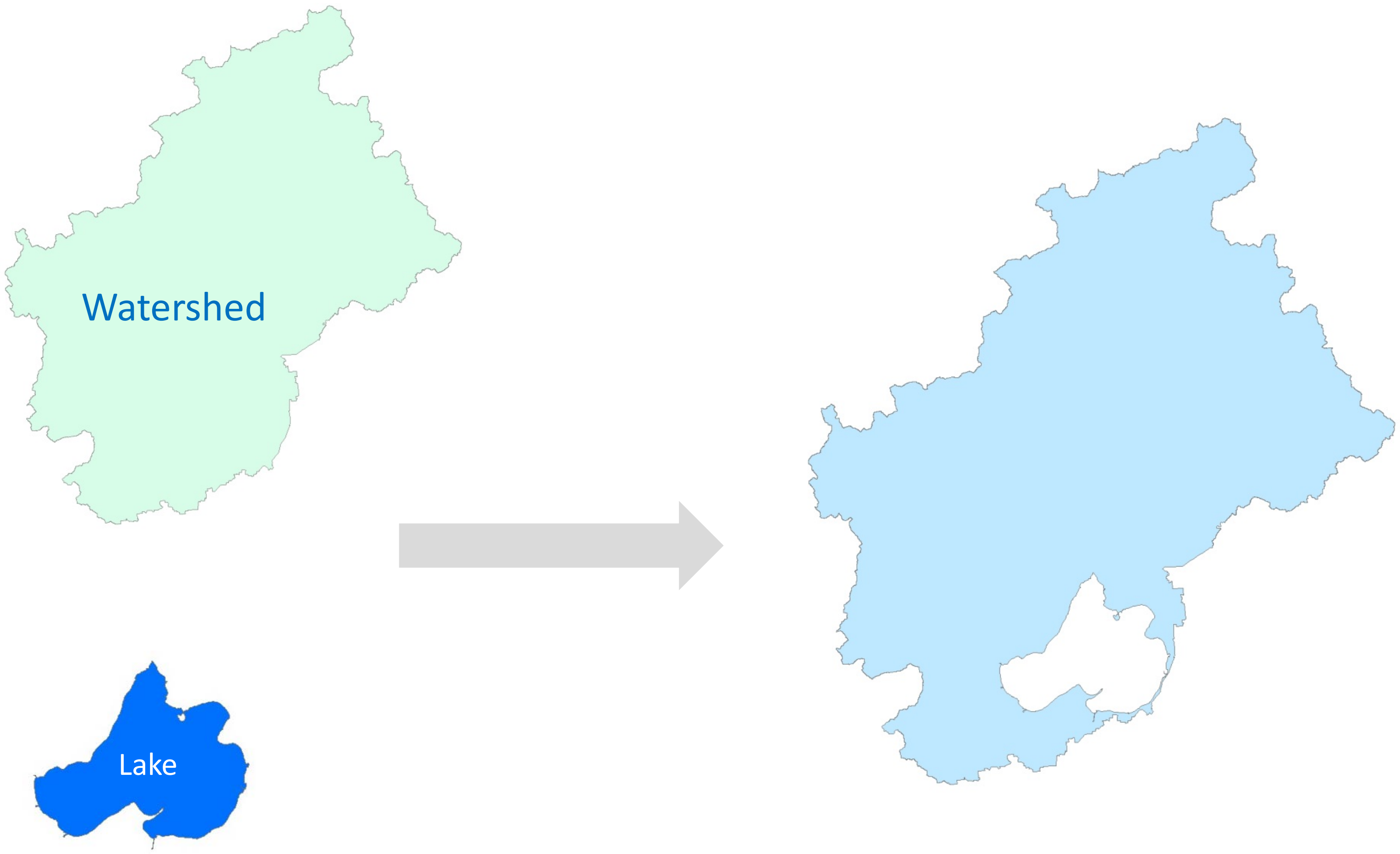
# Model simulation at Lake Mendota

# Application

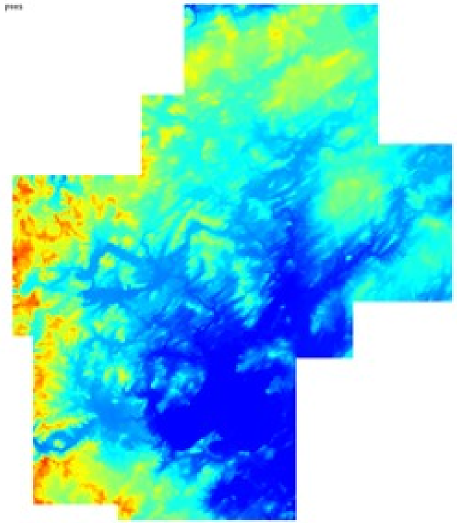
## Lake Mendota: at first glance



# Data pre-processing

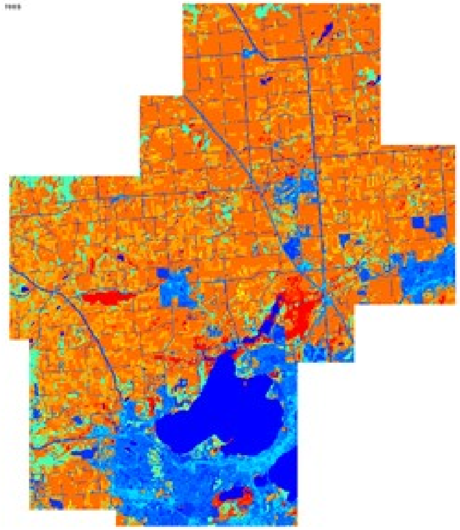


DEM



Soil type

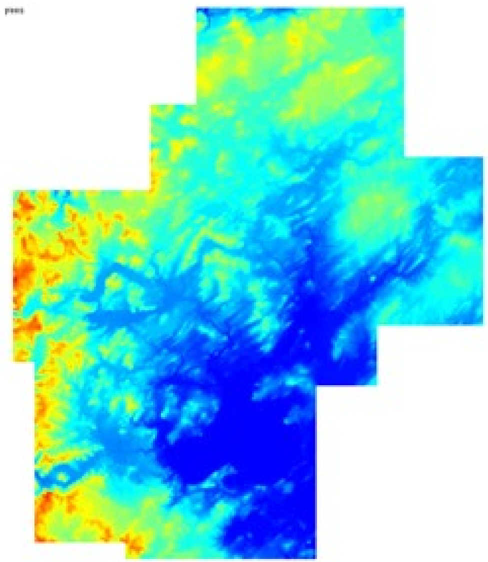
Land use type



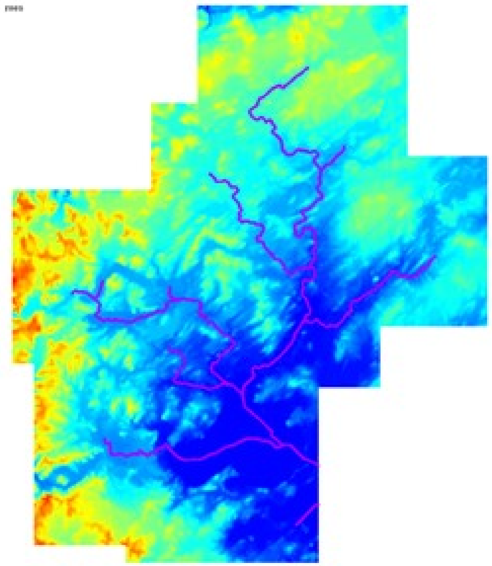
Precipitation

Precipitation type in lake

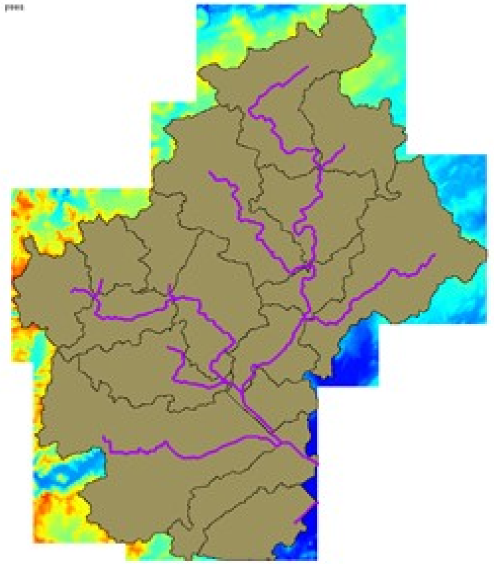
Fill DEM



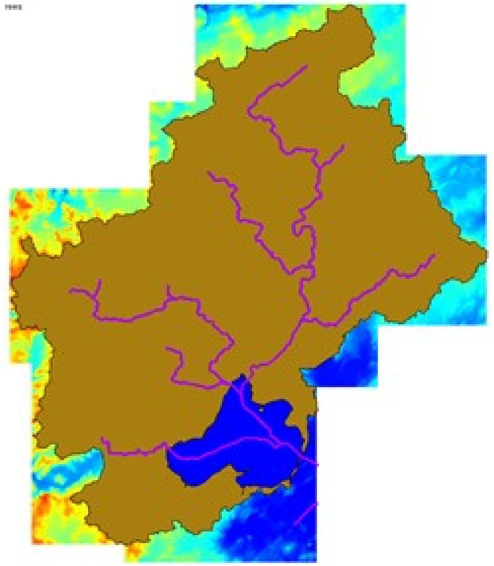
Find the stream line



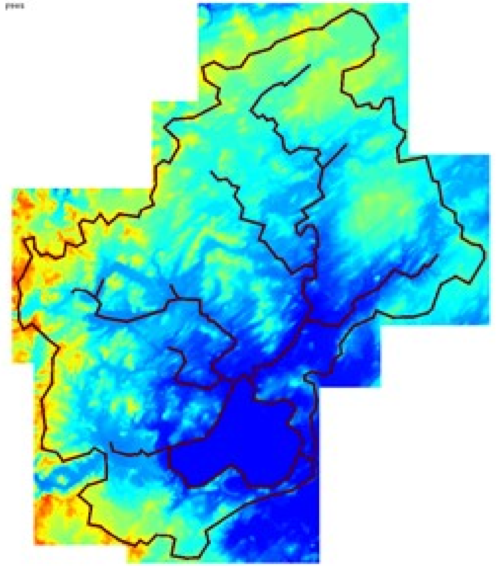
Watershed boundary



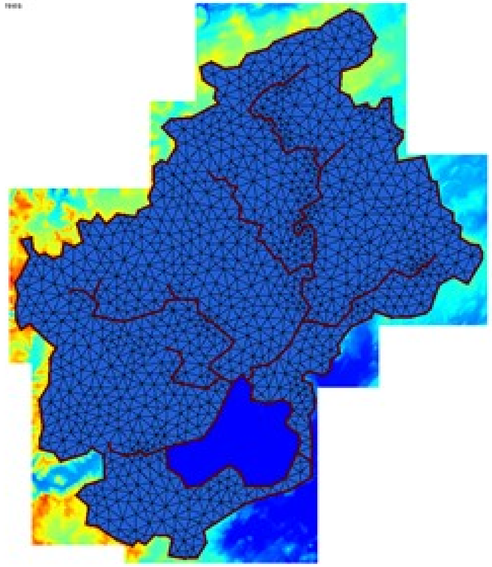
Watershed boundary without lake



Extract boundary line



Decompose model domain



# Gate of Lake Mendota

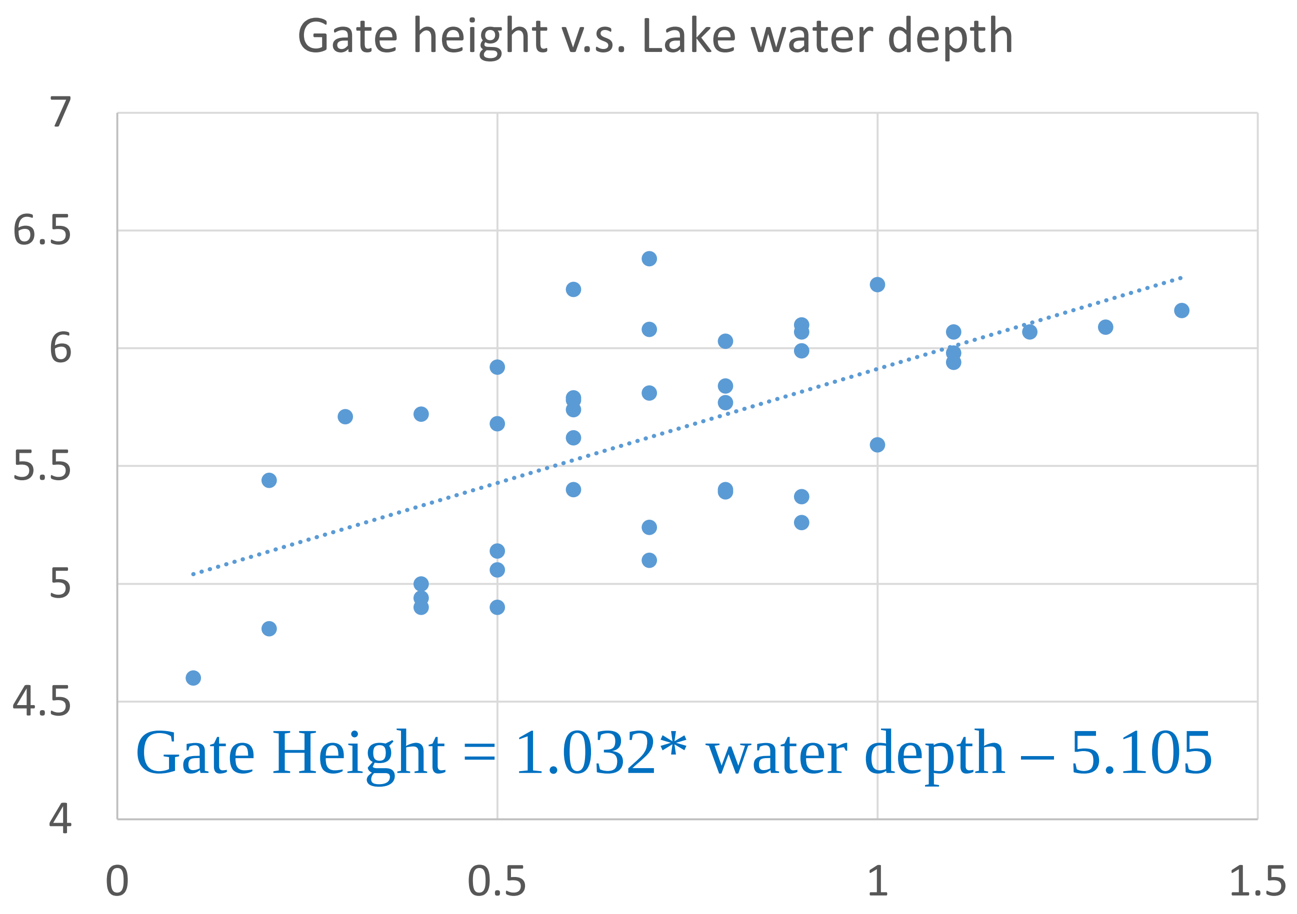

From Google Earth

# Gate information

| | |
|---|---|
| Thursday, October 30, 2008 | 0.7 |
| Thursday, November 13, 2008 | 0.9 |
| Monday, November 17, 2008 | 0.9 |
| Friday, December 12, 2008 | 0.7 |
| Friday, December 19, 2008 | 0.8 |
| Monday, December 29, 2008 | 0.6 |
| Monday, January 12, 2009 | 0.5 |
| Wednesday, January 21, 2009 | 0.5 |
| Thursday, January 22, 2009 | 0.4 |
| Friday, February 13, 2009 | 0.5 |
| Wednesday, February 18, 2009 | 0.4 |
| Friday, February 20, 2009 | 0.2 |
| Wednesday, February 25, 2009 | 0.1 |
| Saturday, March 7, 2009 | 0.4 |
| Tuesday, March 10, 2009 | 0.6 |
| Wednesday, March 11, 2009 | 0.8 |
| Friday, March 13, 2009 | 1.1 |

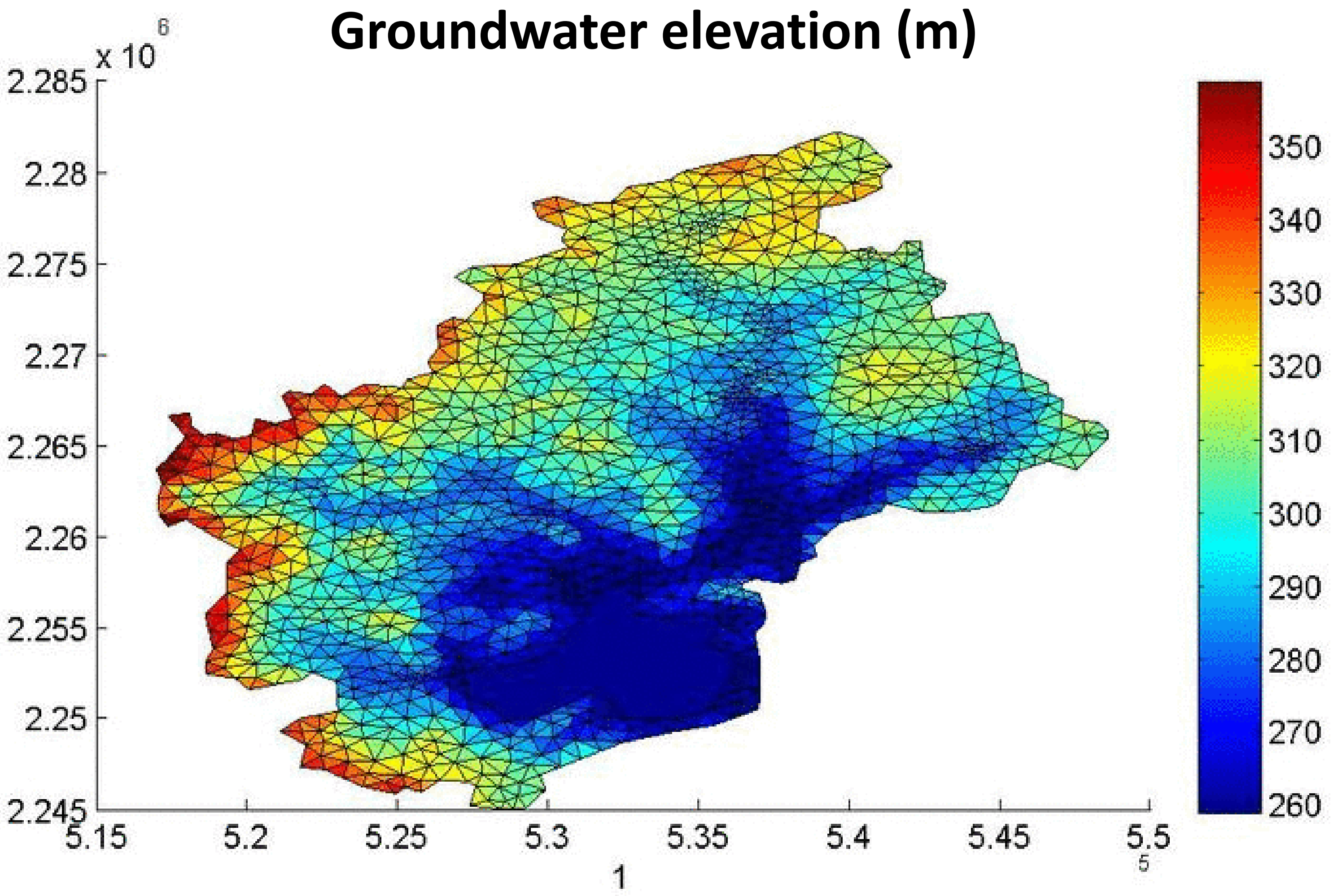
Gate data is available from 2008-2013

Average gate height: 0.67 ft
Maximum height: 1.6 ft
Minimum height: 0.2 ft

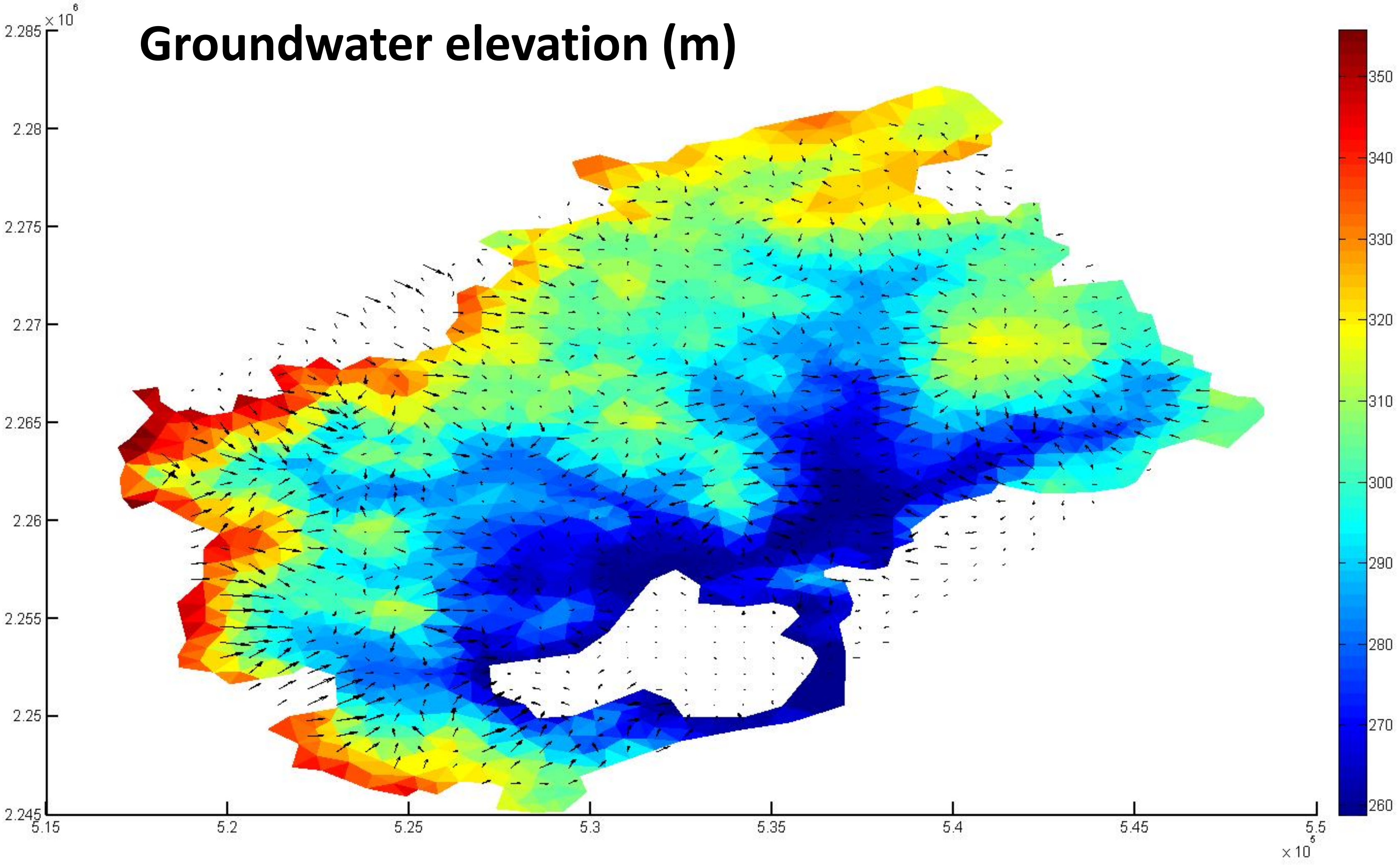



| | | |
|---|---|---|
| Tuesday, January 5, 2010 | 0.6 | 5.48 |
| Tuesday, January 12, 2010 | 0.4 | 5.24 |
| Tuesday, March 2, 2010 | 0.2 | 4.39 |
| Monday, April 12, 2010 | 0.3 | 4.64 |
| Wednesday, April 14, 2010 | 0.6 | 4.82 |
| Saturday, April 17, 2010 | 0.8 | 4.96 |
| Wednesday, April 21, 2010 | 0.8 | 5.07 |
| Thursday, April 22, 2010 | 0.6 | 5.02 |
| Friday, May 14, 2010 | 0.3 | 5.26 |
| Monday, May 17, 2010 | 0.6 | 5.34 |
| Tuesday, May 18, 2010 | 0.8 | 5.43 |
| Saturday, June 12, 2010 | 0.6 | 6.49 |
| Friday, July 2, 2010 | 0.7 | 6.77 |
| Sunday, July 4, 2010 | 0.8 | 6.75 |
| Monday, July 5, 2010 | 0.9 | 6.76 |
| Friday, July 9, 2010 | 1 | 6.83 |
| Thursday, July 22, 2010 | 0.8 | 6.89 |
| Friday, July 23, 2010 | 0.6 | 7.02 |
| Friday, August 13, 2010 | 0.4 | 7.33 |
| Saturday, August 14, 2010 | 0.2 | 7.42 |
| Sunday, August 15, 2010 | 0.3 | 7.41 |
| Sunday, August 22, 2010 | 0.4 | 7.26 |
| Thursday, August 26, 2010 | 0.5 | 7.12 |
| Thursday, September 16, 2010 | 0.7 | 6.84 |
| Saturday, September 18, 2010 | 0.5 | 6.91 |
| Friday, September 24, 2010 | 0.8 | 6.75 |
| Saturday, September 25, 2010 | 0.9 | 6.8 |
| Wednesday, September 29, 2010 | 1.1 | 6.84 |

# Groundwater elevation

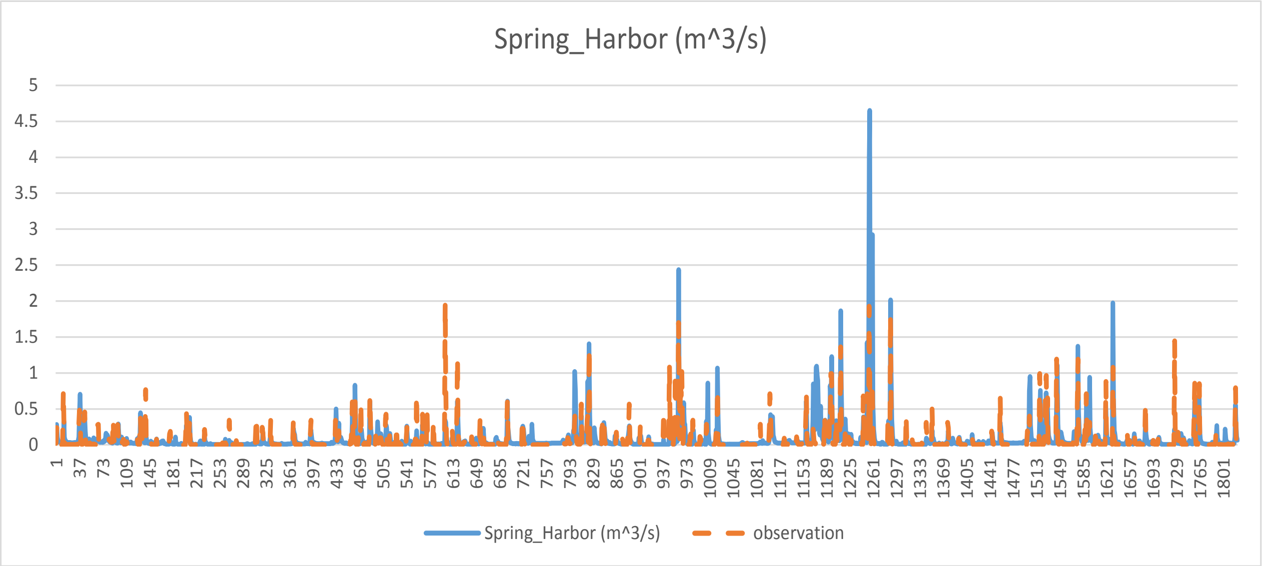


# Flow direction of groundwater



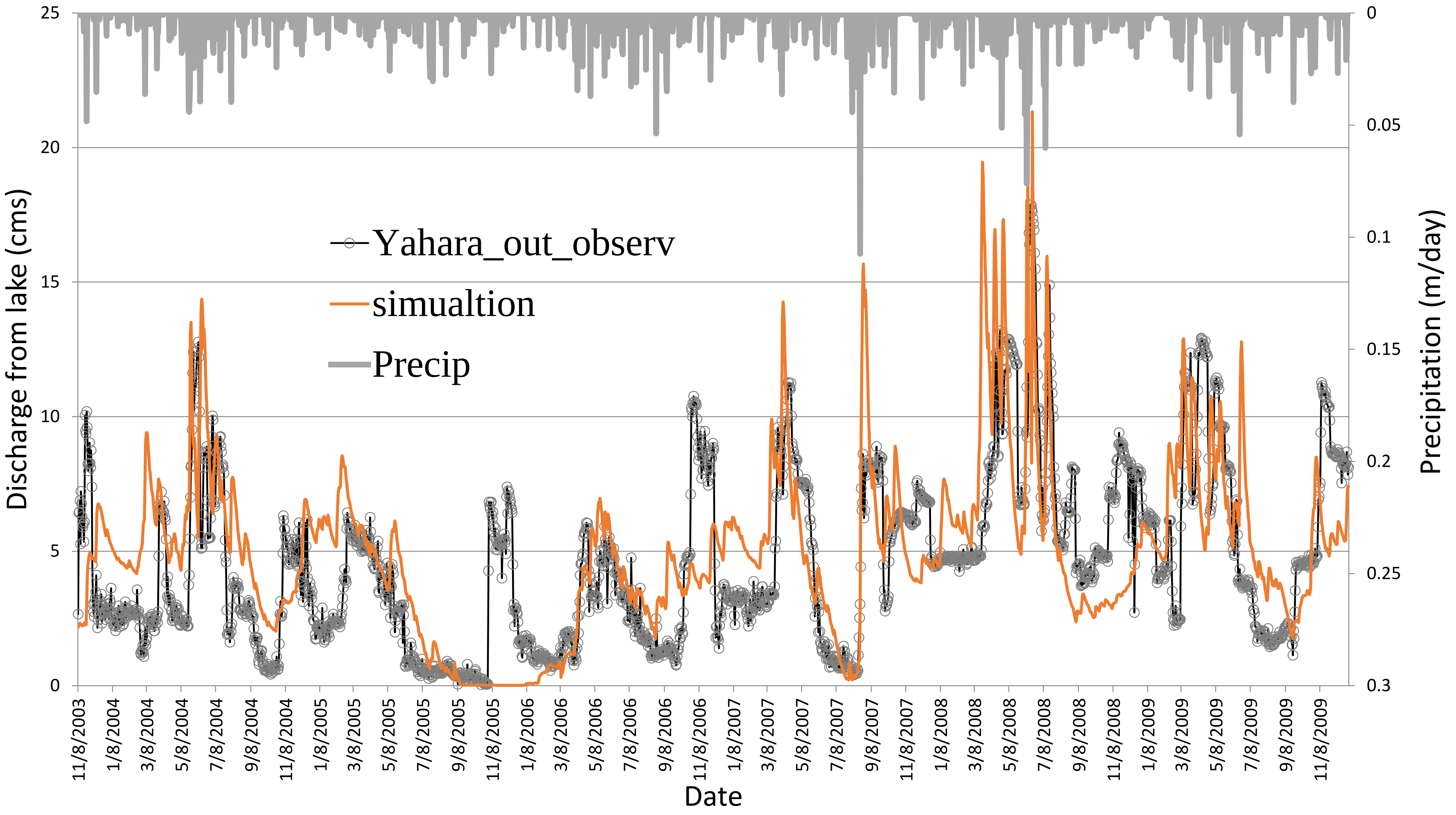
# Inflow

Yahara at Windsor 05427718
Q: 1976-1982, 1990-Present
P: 1990-Present
N: 2010-Present
6 Mile 05427910
Q: 2012-Present
P: NA
N: NA
Yahara at Highway 113 05427850
Q: 2002-Present
P: 2009-Present
N: NA
Pheasant Branch 05427948
Q: 1974-Present
P: 1992-Present
N: 2010-Present
Yahara Outlet 05428500
Q: 2003-Present
P: NA
N: NA
Spring Harbor 05427965
Q: 1976-Present
P: NA
Madison
Middleton
Sun Prairie
Windsor

Spring_Harbor (m^3/s)
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
Spring_Harbor (m^3/s)
observation

# Outflow



Yahara_out_observ
simualtion
Precip
Discharge from lake (cms)
Precipitation (m/day)
Date
25
20
15
10
5
0
0
0.05
0.1
0.15
0.2
0.25
0.3
11/8/2003
1/8/2004
3/8/2004
5/8/2004
7/8/2004
9/8/2004
11/8/2004
1/8/2005
3/8/2005
5/8/2005
7/8/2005
9/8/2005
11/8/2005
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5/8/2008
7/8/2008
9/8/2008
11/8/2008
1/8/2009
3/8/2009
5/8/2009
7/8/2009
9/8/2009
11/8/2009

# Analysis of the inflow and outflows

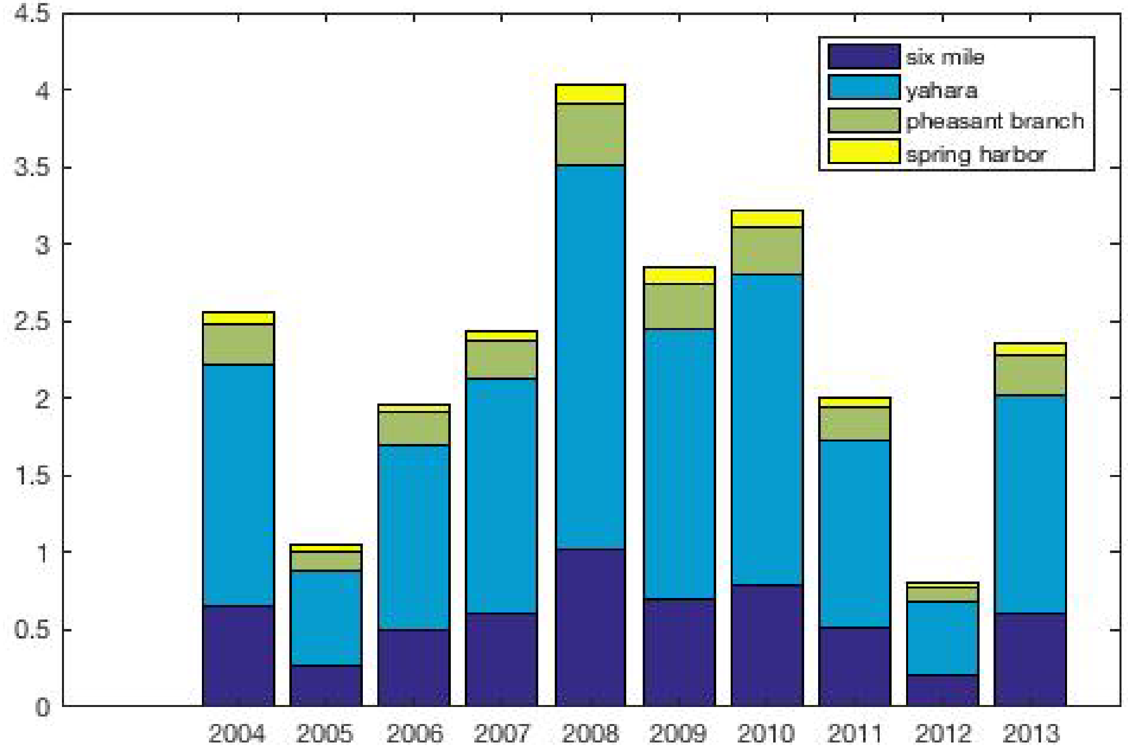
- Averaged stream inflow (10 years):2.01 cms

- Averaged overland inflow (10 years):0.75 cms

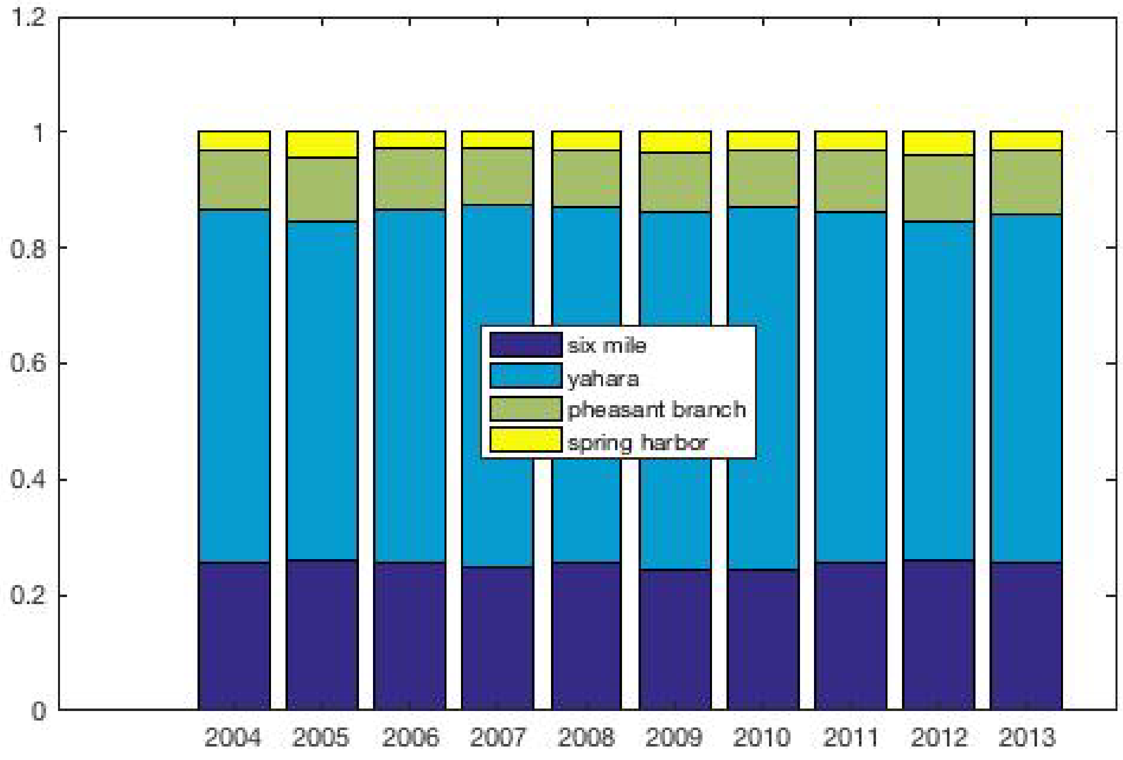
- Averaged groundwater flow (10 years):0.04 cms

# Inflow Stream Contribution

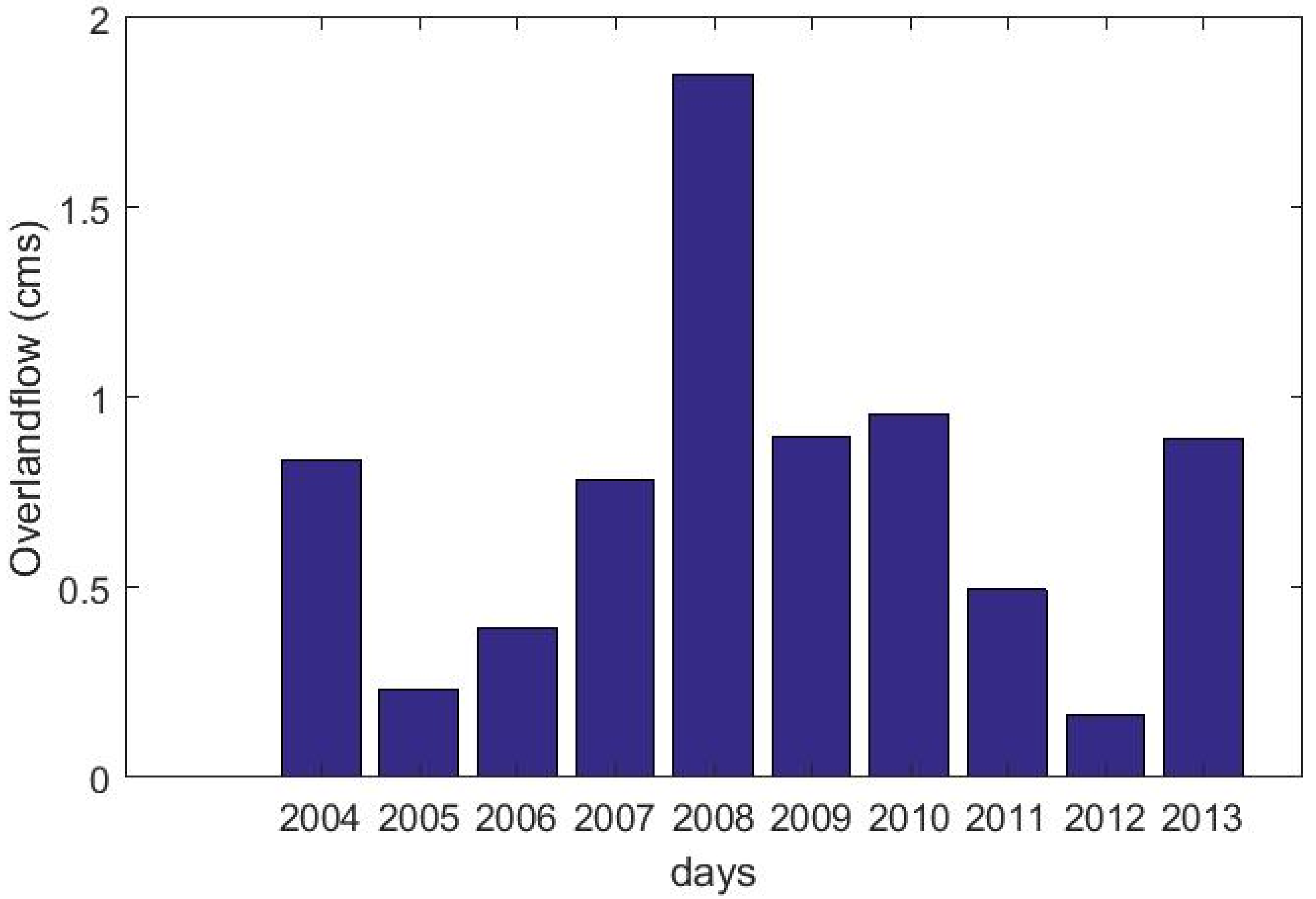
Bar plot of all the stream inflows



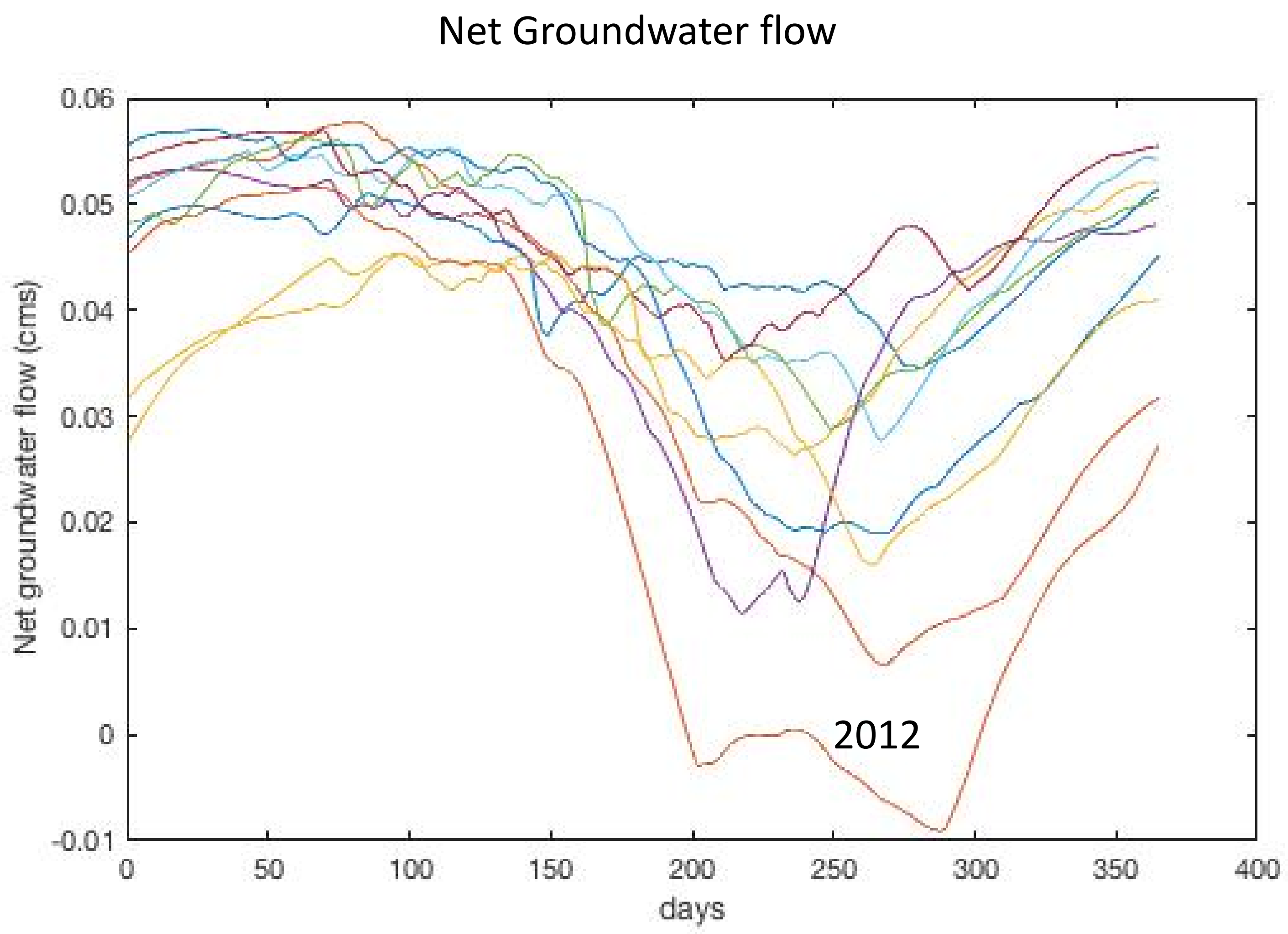

Proportion of each stream inflow respect to the total inflow



# Overland flow

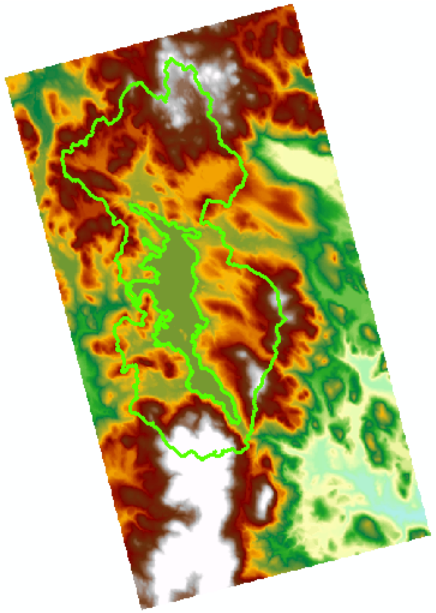


# Daily scale variation of net groundwater flow

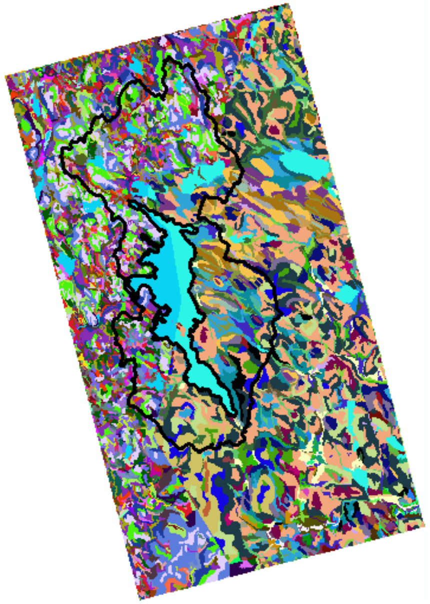


# Model simulation at Lake Sunapee

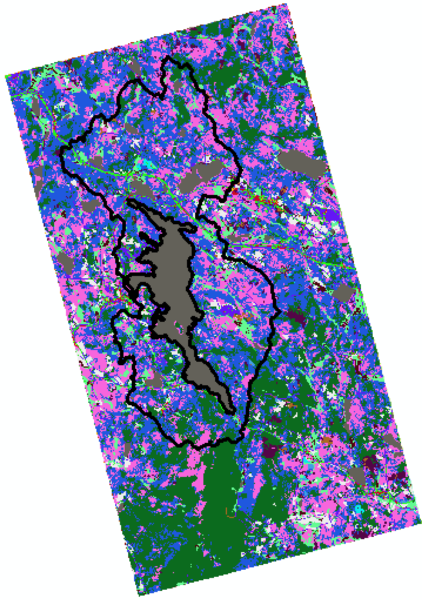
DEM



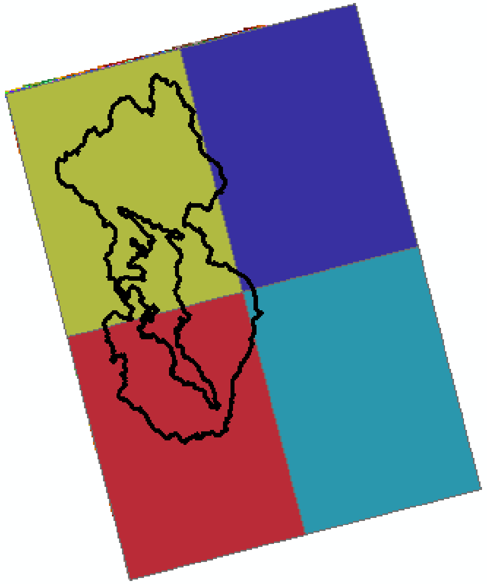
Soil type



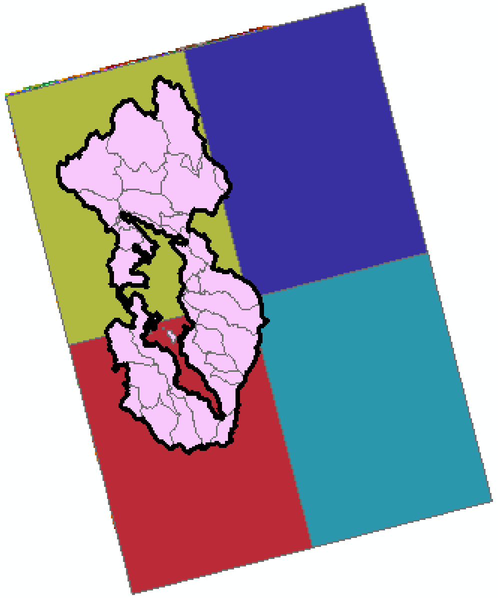
Land use type



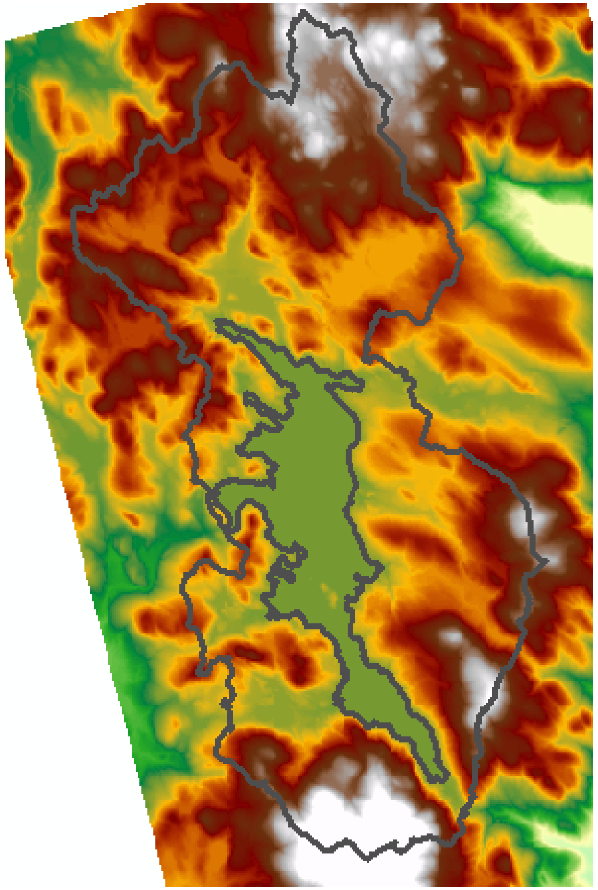
Precipitation

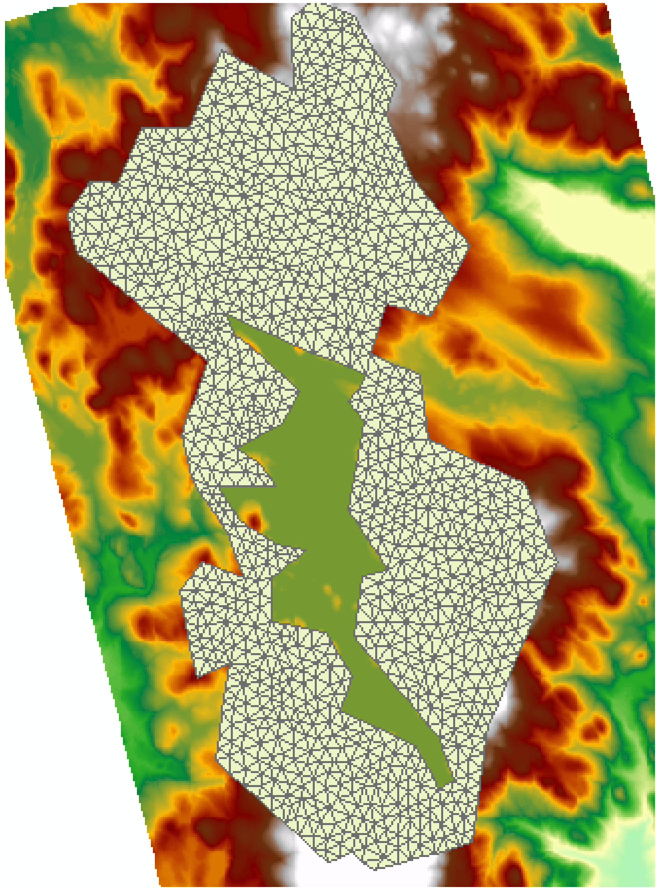


Precipitation type in lake

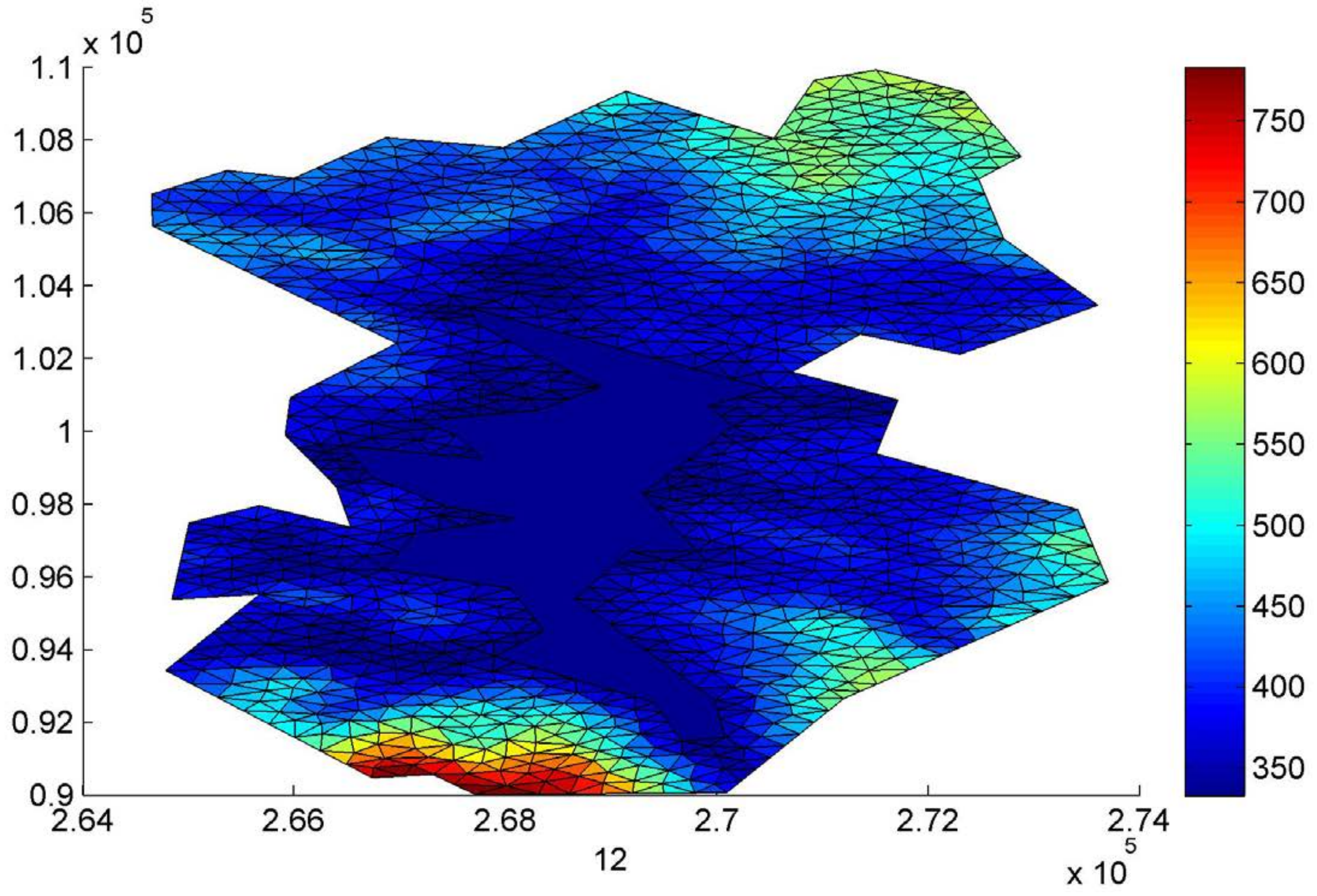


Domain decomposition (2224 elements)



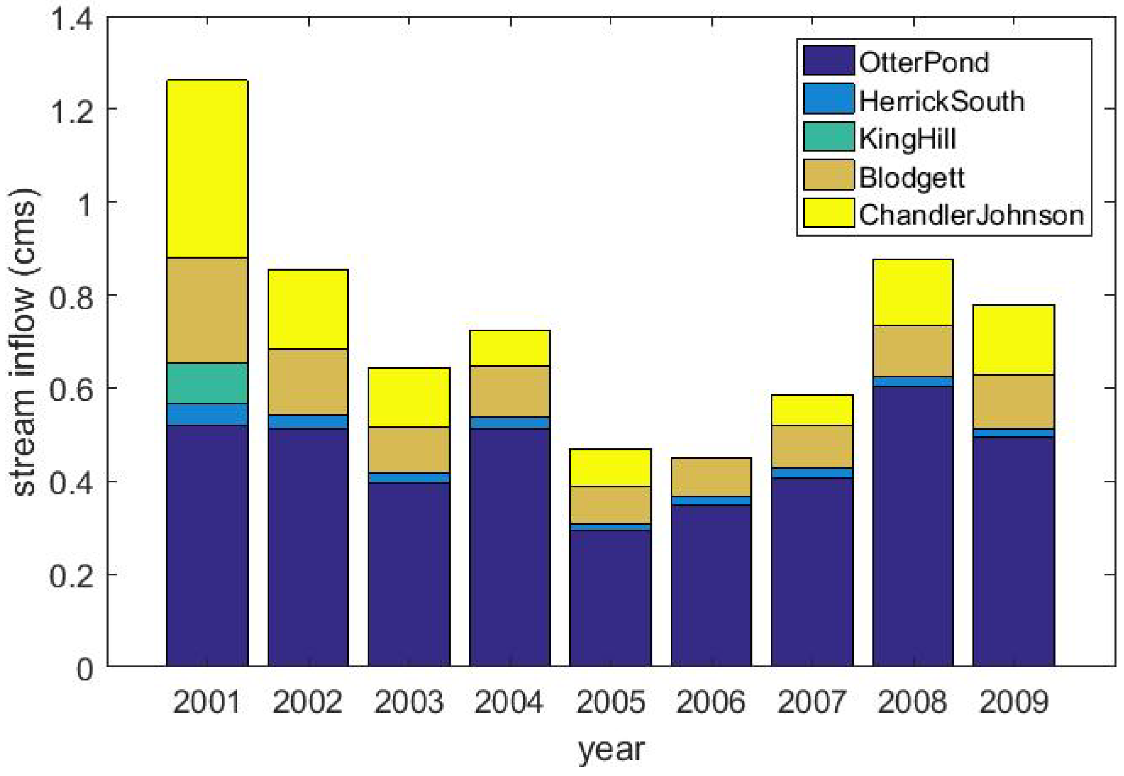


# Groundwater elevation

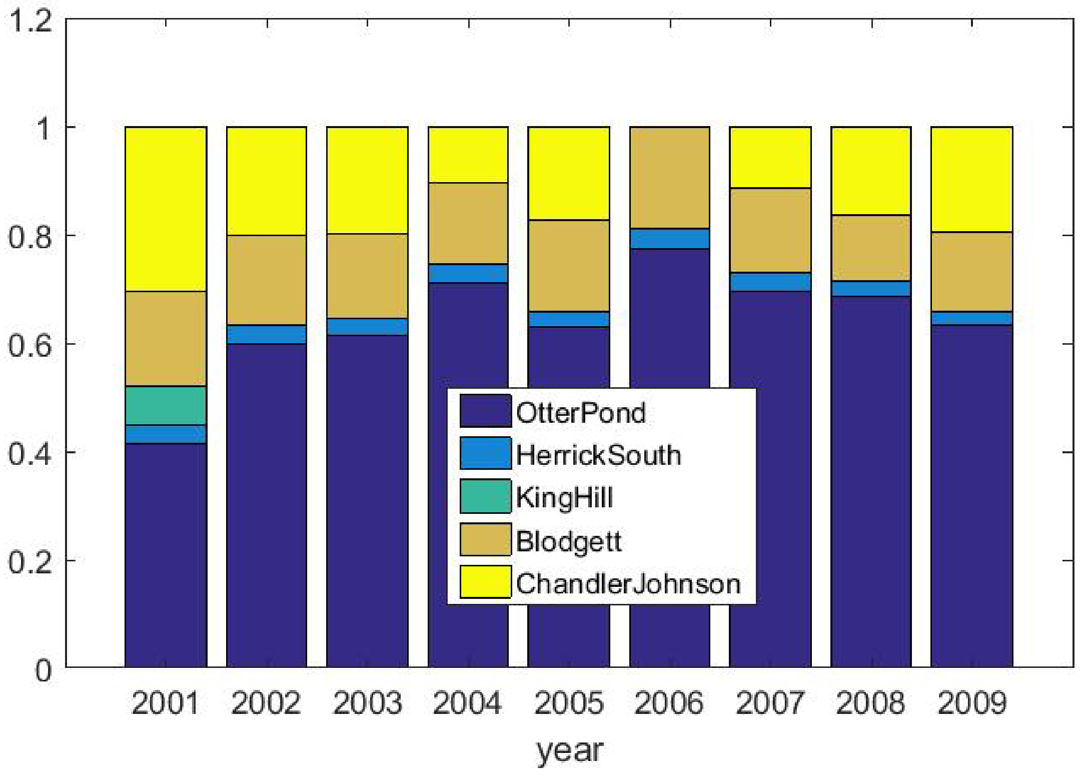


# Stream inflow

Bar plot of all the stream inflows




Proportion of each stream inflow respect to the total inflow



# Future work

- 1. Better calibrate the Mendota model and finish the long-term simulation (1979-present)
- 2. The calibration and validation of the NTL lake system
- 3. The calibration and validation of the Lake Sunapee

# Thank you!