PIHM-GLM: A catchment-lake hydrological modeling framework

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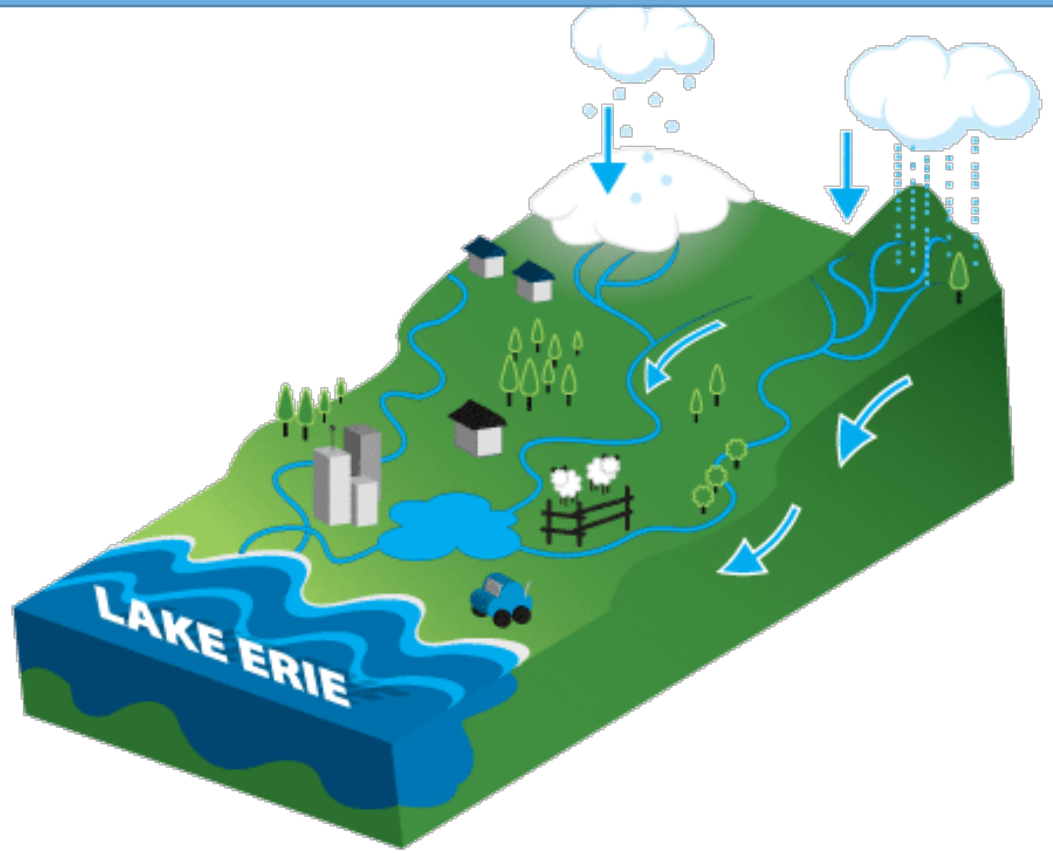
Outline

1. Motivation
2. Model coupling
3. Application
4. Future work

Motivation

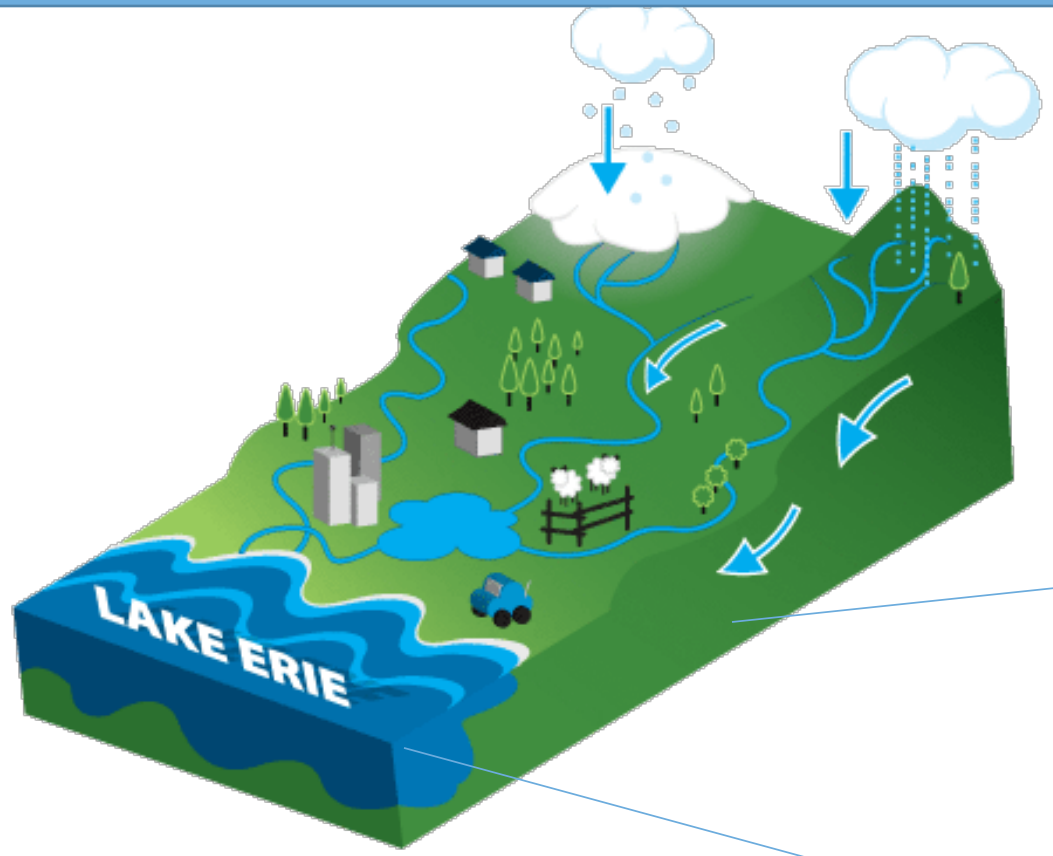


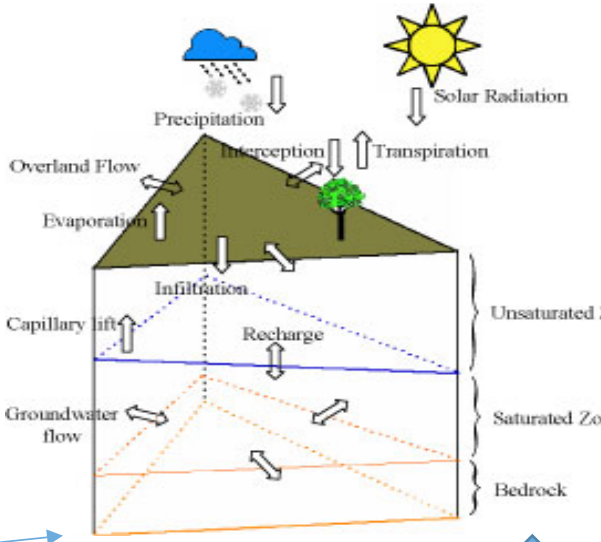
Hydrologic Connectivity

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

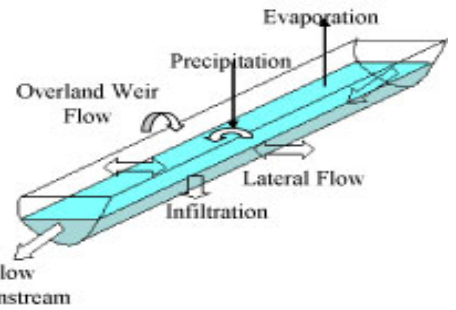
Need a model framework to understand the catchment-Lake interaction.

Model coupling

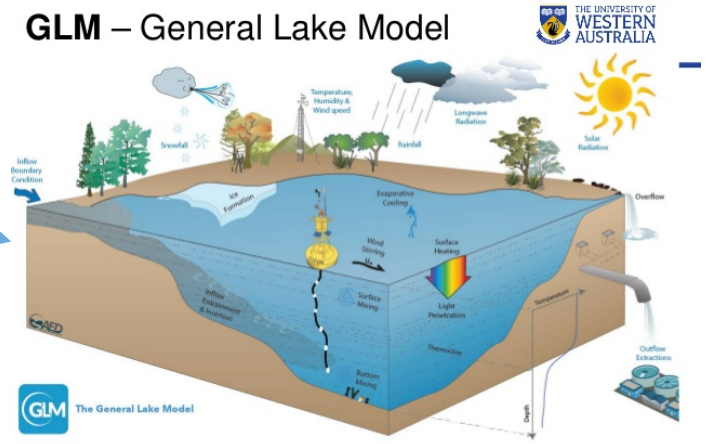




PIHM



GLM – General Lake Model

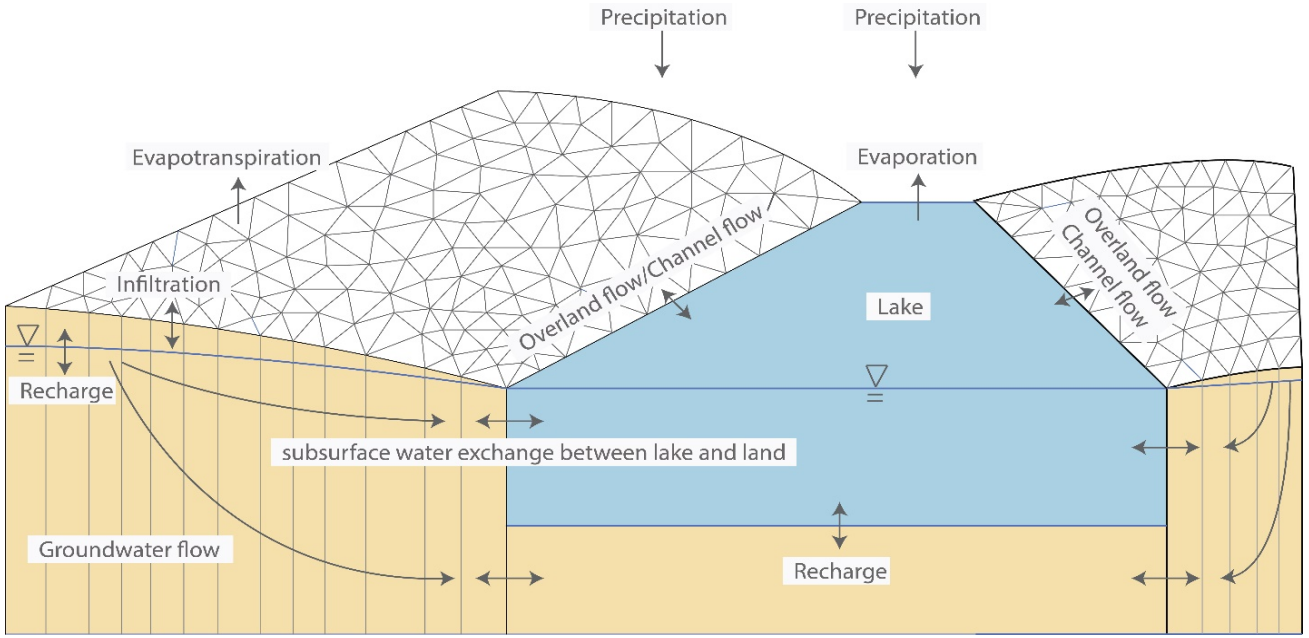


Model coupling

Sketch of PIHM-GLM model

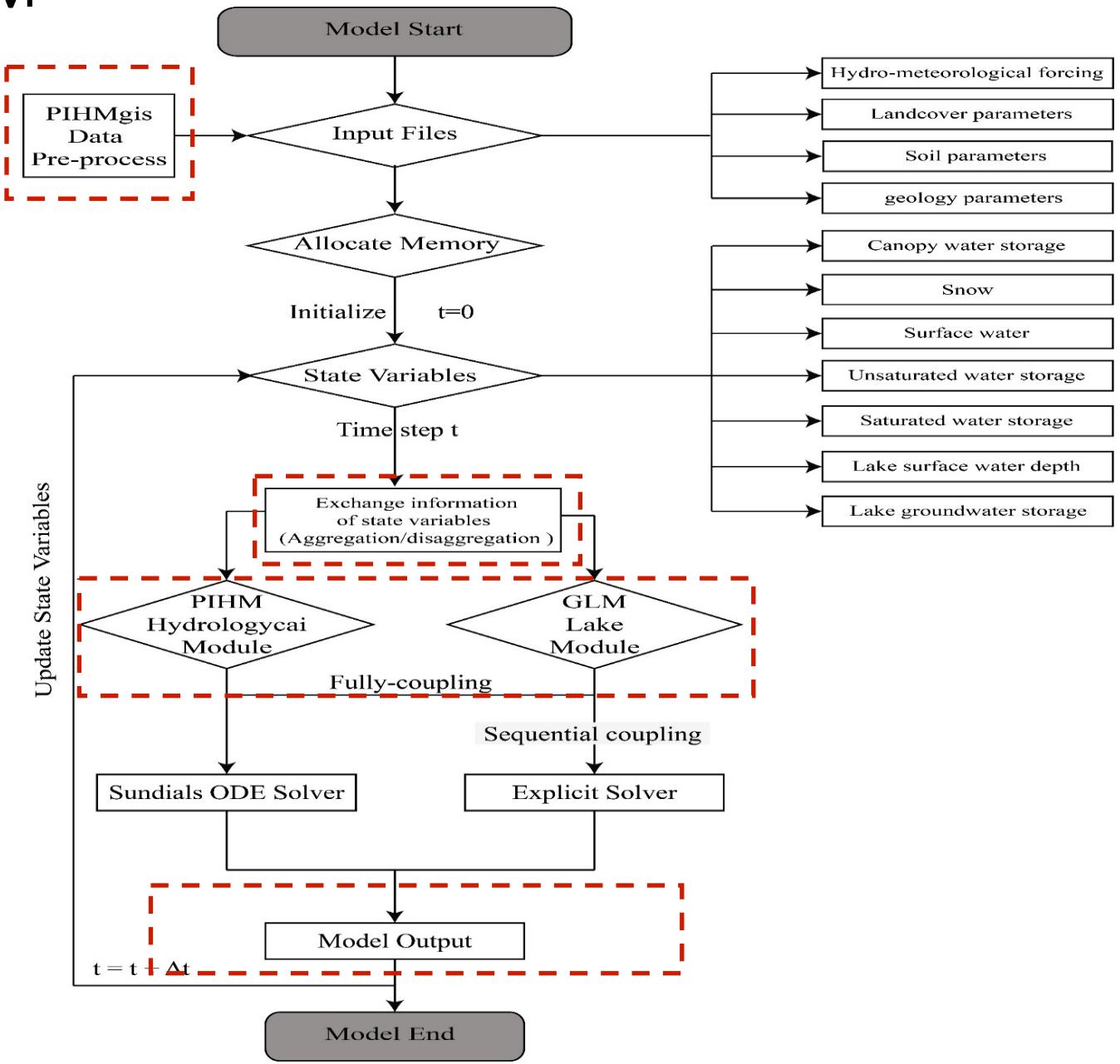
- **PIHM-GLM** is a hydrological model combining the hydrodynamic of lake surrounding watershed and lake itself.

- 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)

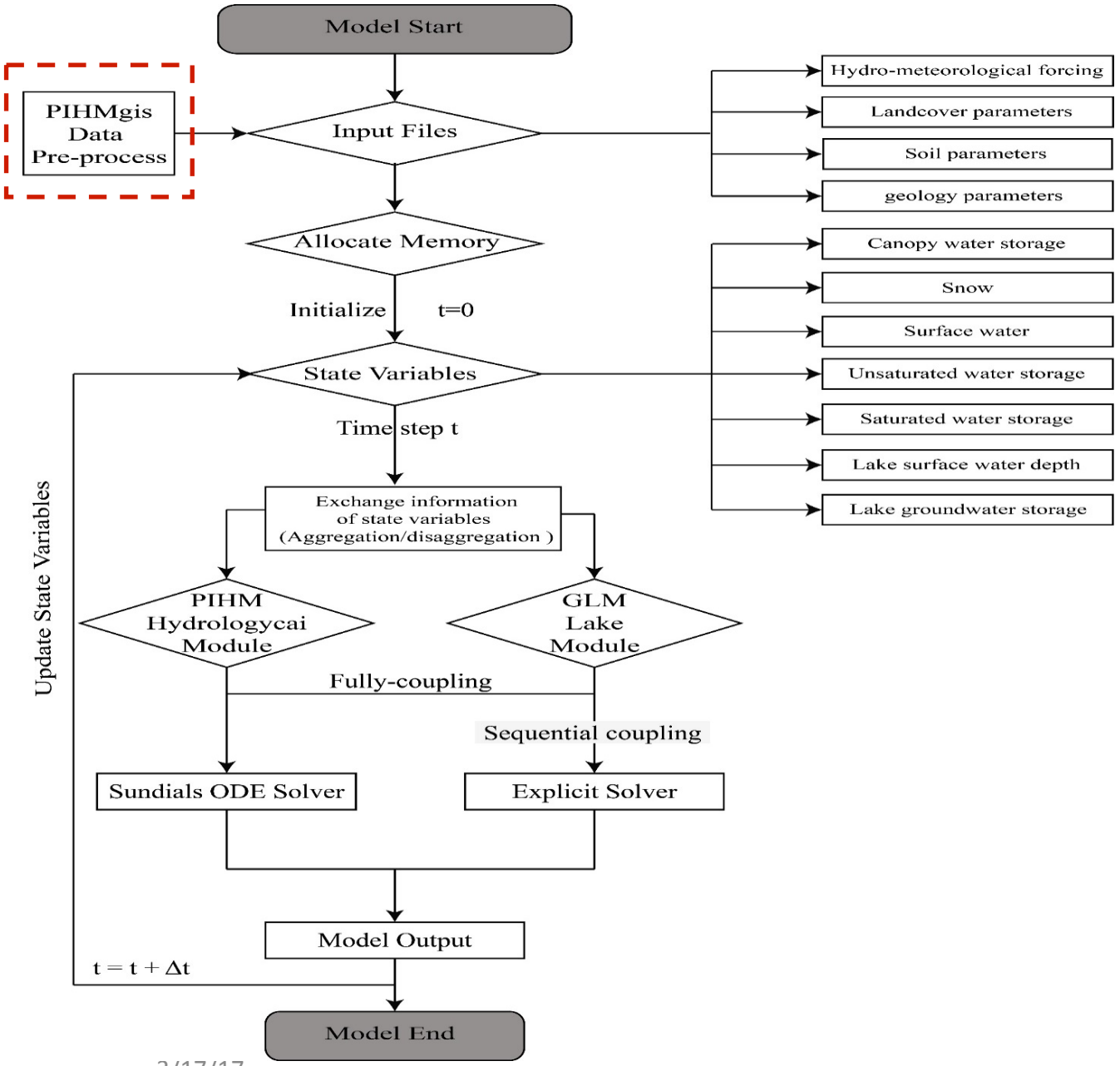


(paper in prep)

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

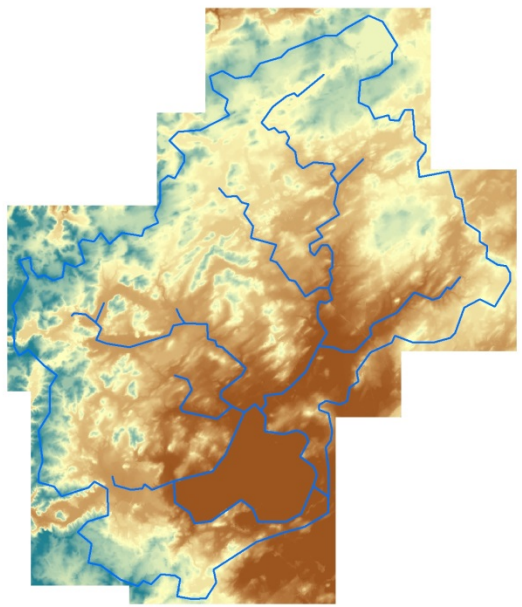
Input data for the lake

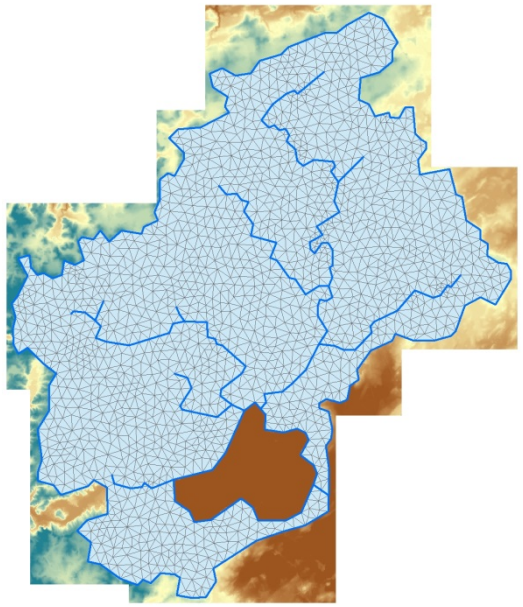
.lakegeom .lakebathy .lakeatt .lakesoil .lakecalib

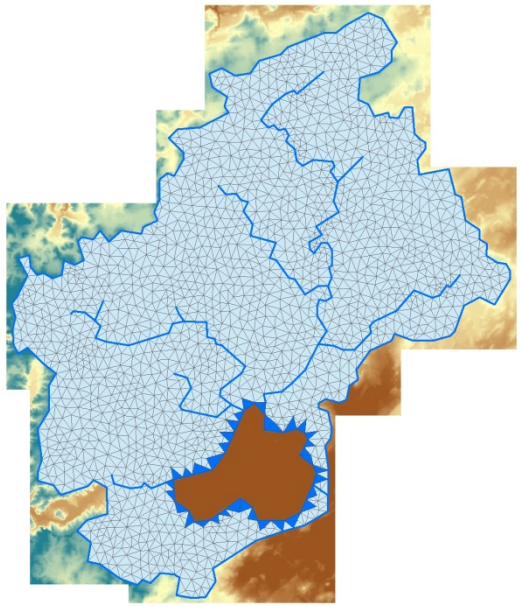
Input files

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



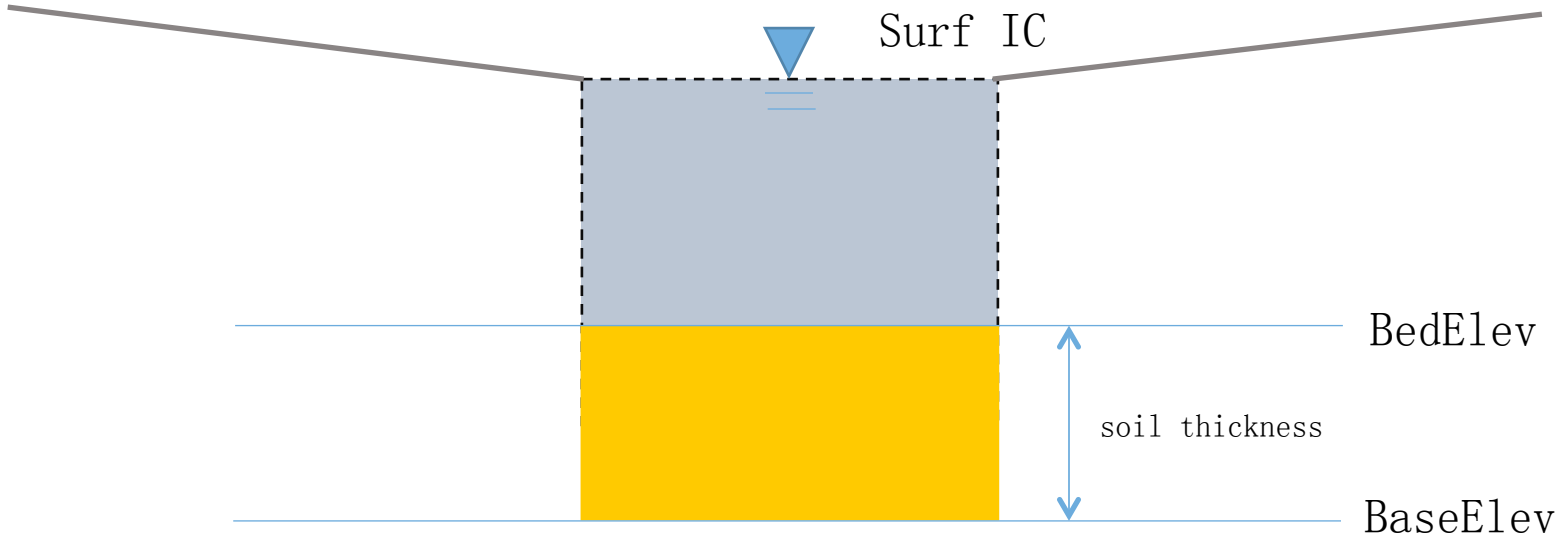




Input files

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

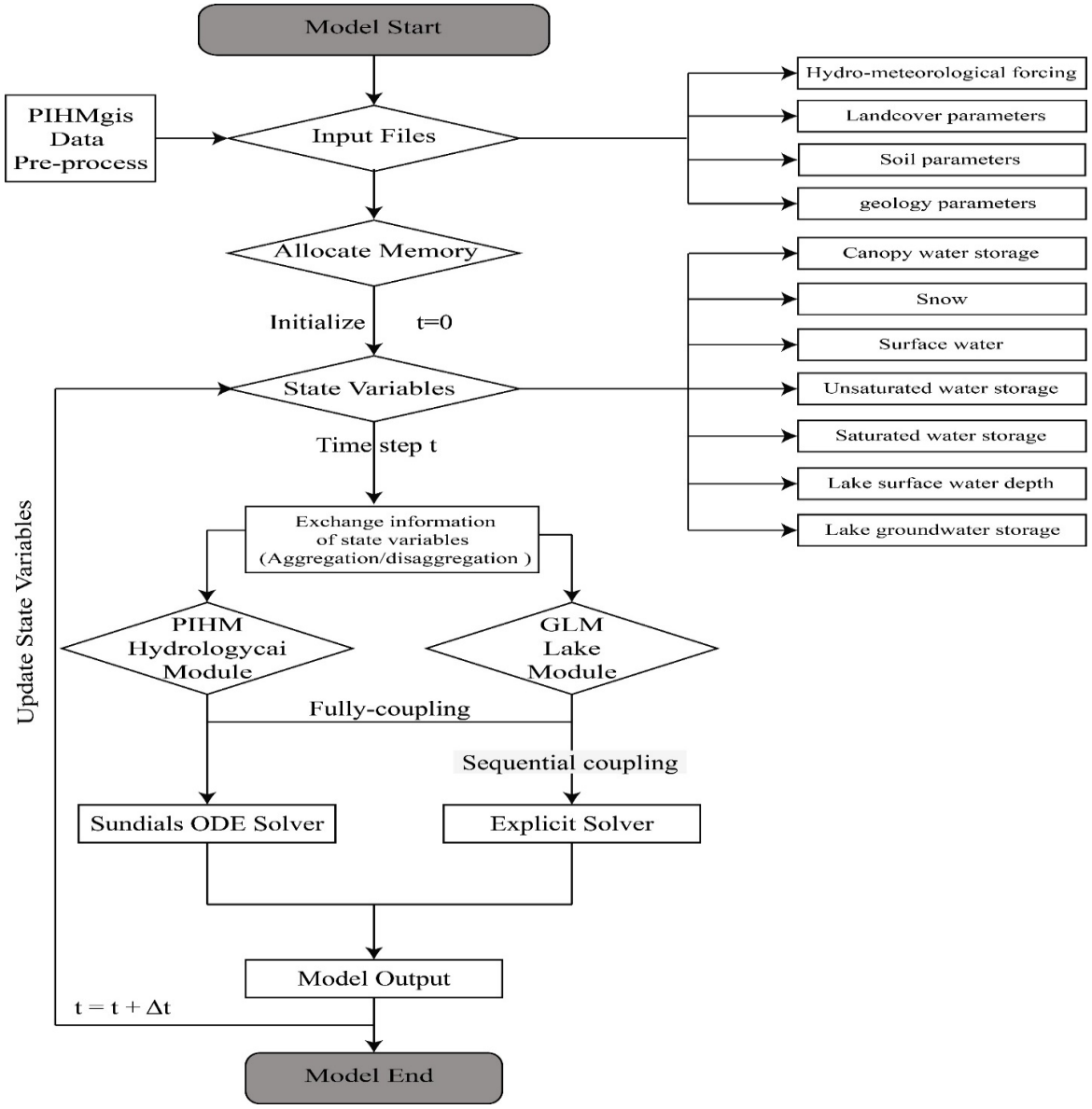
LakeID	Soil_type	Meteorological type	macropore
1	1	1	1

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

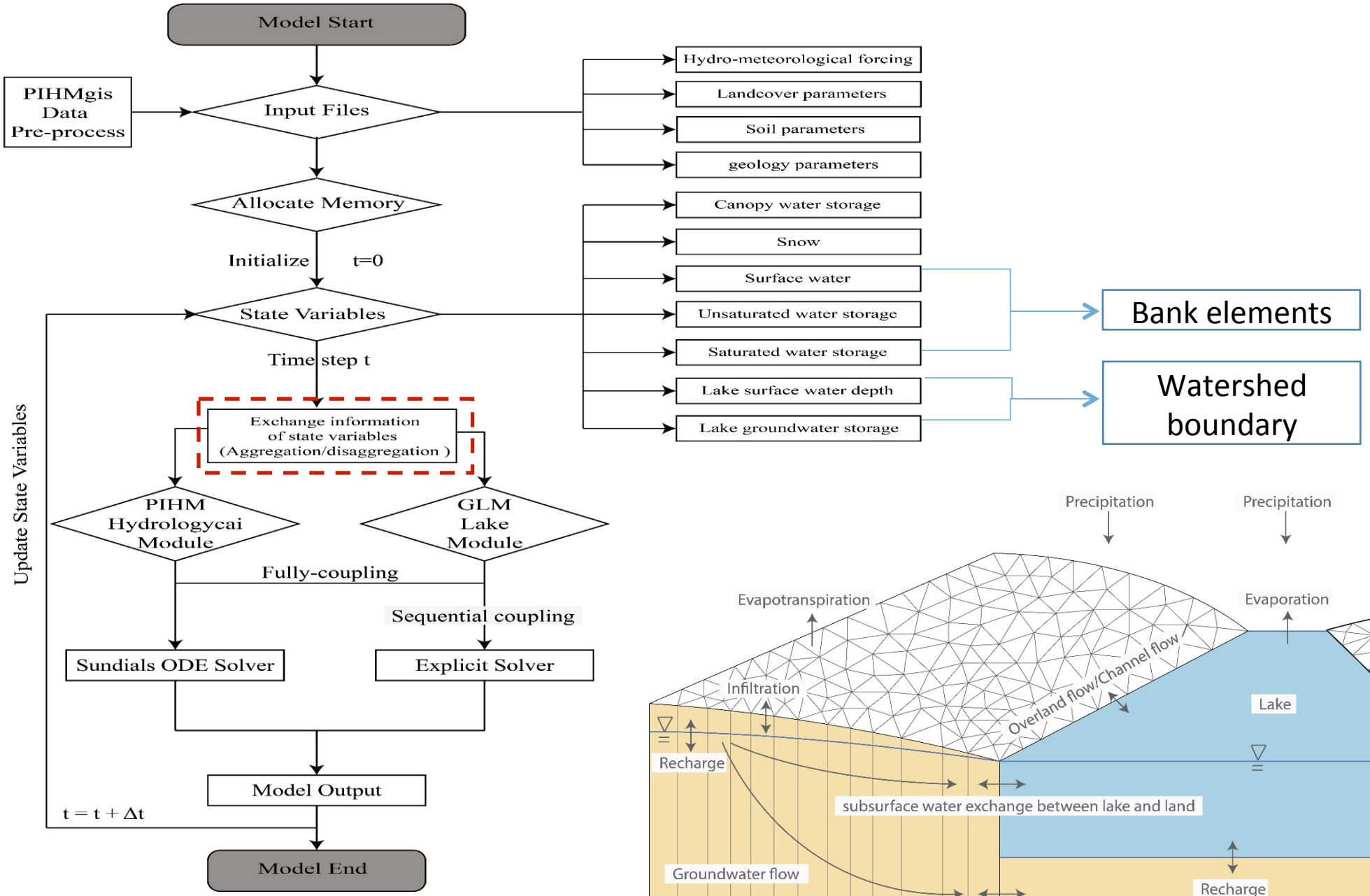


For watershed module

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

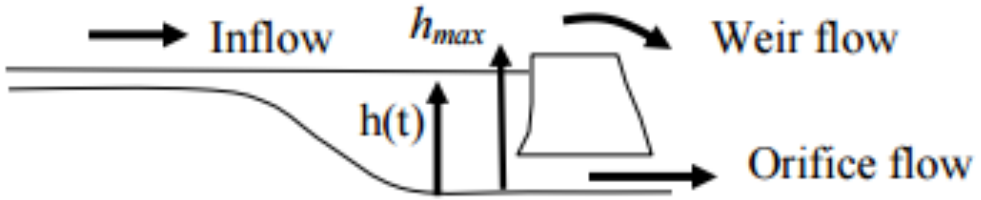
For lake module

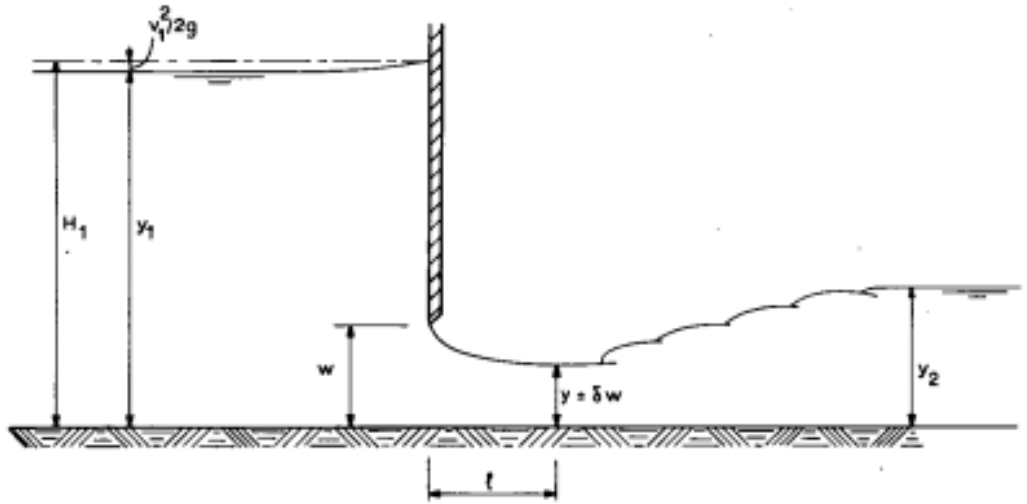
- .lakeatt
- .lakebathy
- .lakegeom
- .lakesoil


Model Start
PIHMgis Data Pre-process
Input Files
Hydro-meteorological forcing
Landcover parameters
Soil parameters
geology parameters
Allocate Memory
Initialize
t=0
State Variables
Canopy water storage
Snow
Surface water
Unsaturated water storage
Saturated water storage
Lake surface water depth
Lake groundwater storage
Bank elements
Watershed boundary
Time step t
Exchange information of state variables (Aggregation/disaggregation)
PIHM Hydrologycai Module
GLM Lake Module
Update State Variables
Fully-coupling
Sequential coupling
Sundials ODE Solver
Explicit Solver
Model Output
t = t + Δt
Model End

Precipitation
Precipitation
Evapotranspiration
Evaporation
Infiltration
Overland flow/Channel flow
Overland flow
Channel flow
Lake
Recharge
subsurface water exchange between lake and land
Groundwater flow
Recharge

Weir boundary condition





Weir (**Broad-Crested Weir**)

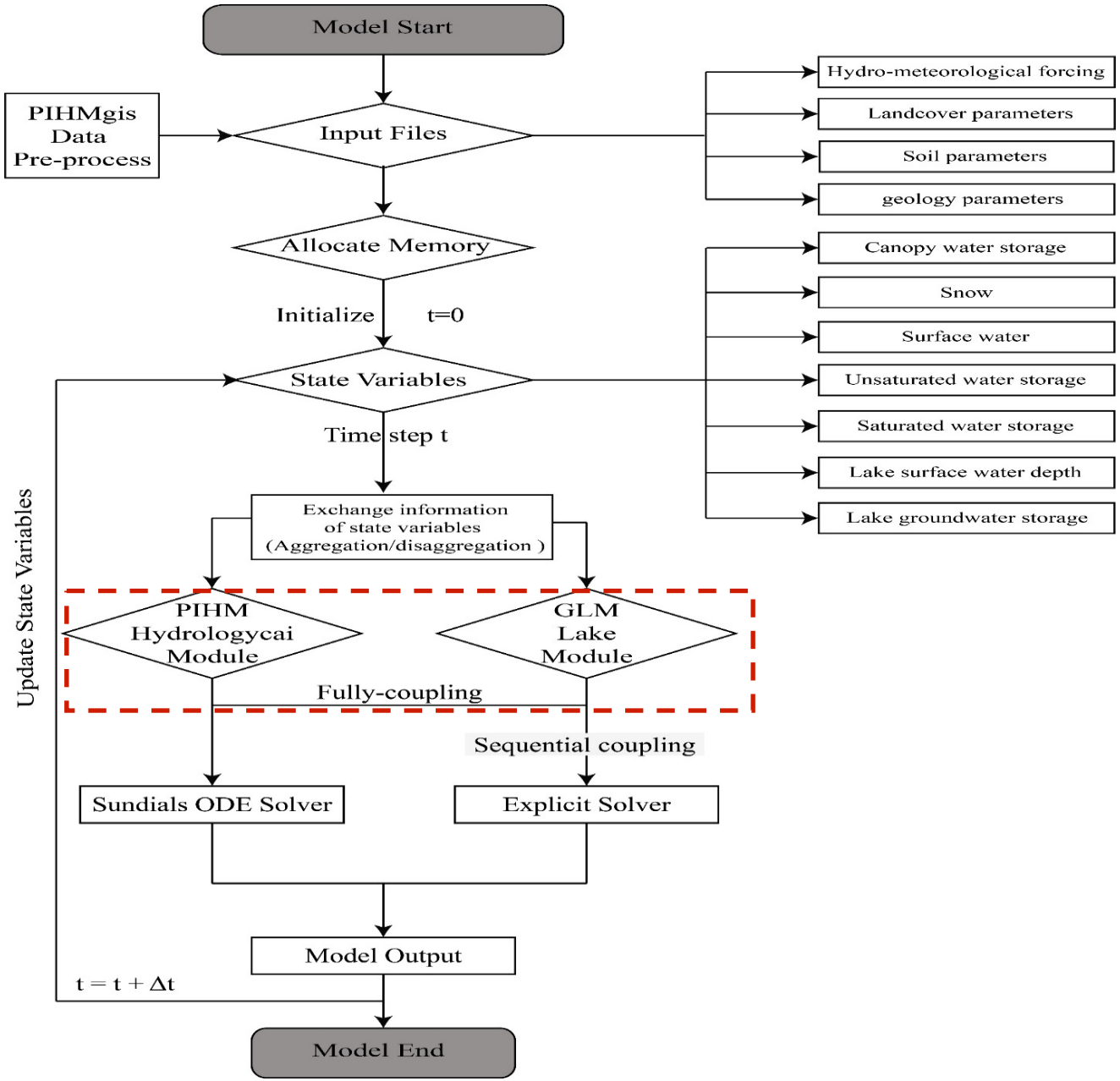
$Q_w = C_w L h^{3/2}$, C_w :Broad-Crested Weir coefficient (2.64 as default, details from http://epg.modot.org/files/b/bc/749_Broad-Crested_Weir_Coefficients.pdf)

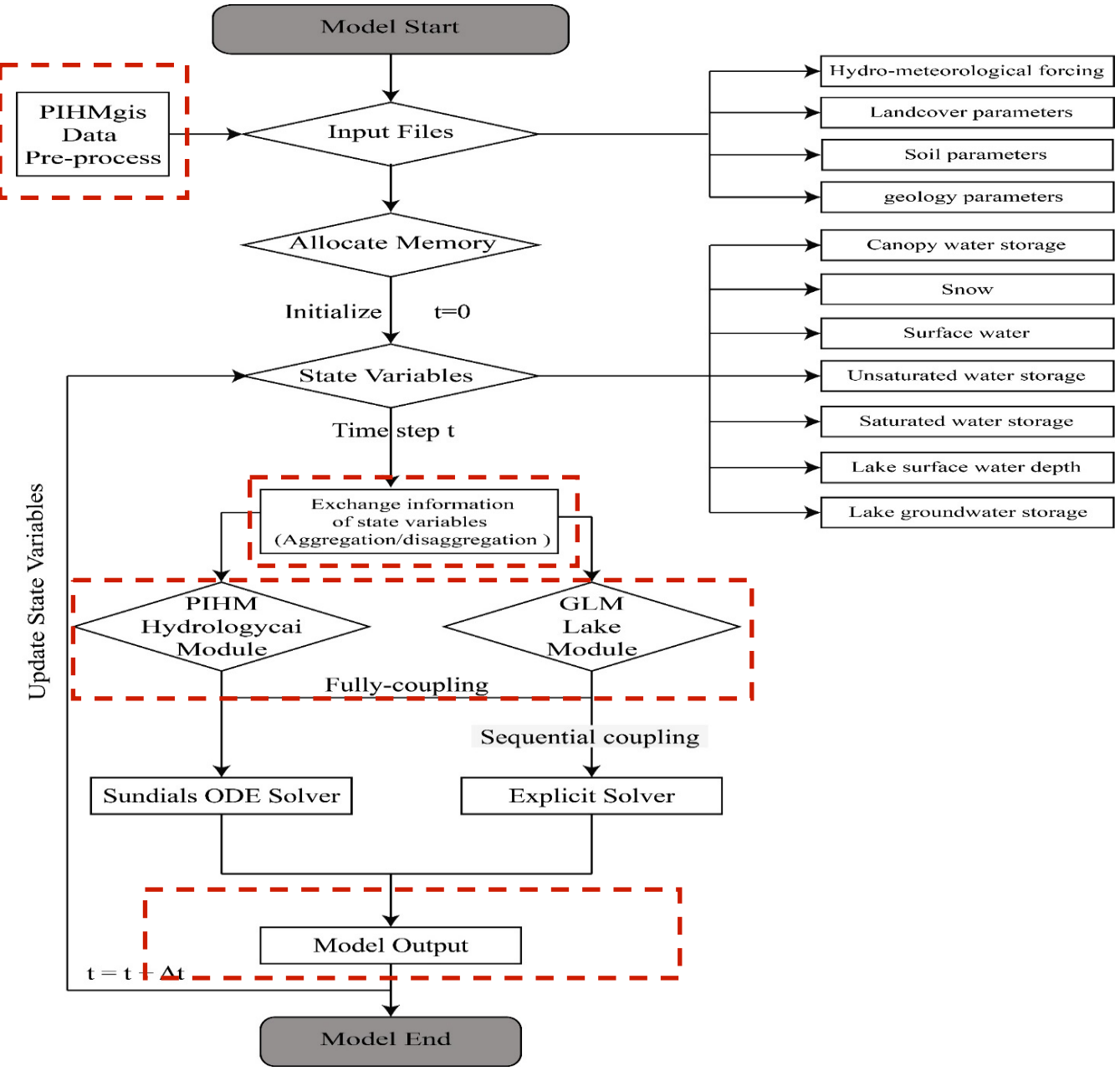
L is the weir length, h is the water depth

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

  As input for GLM
  - lakeGW
  - lakeSurf
  - lakePrecip
  - lakeEp
  - lakeInfil

Output data

Output files

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

Output time (minute)	Water Flux for Lake1 (m^3/day)	Water Flux for Lake2 (m^3/day)
1440	0	0

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

Output time (minute)	Water Flux for Lake1 (m^3/day)	Water Flux for Lake2 (m^3/day)
1440	0	0

3. ProjectName. **lakeFluxSub**: inflow form groundwater

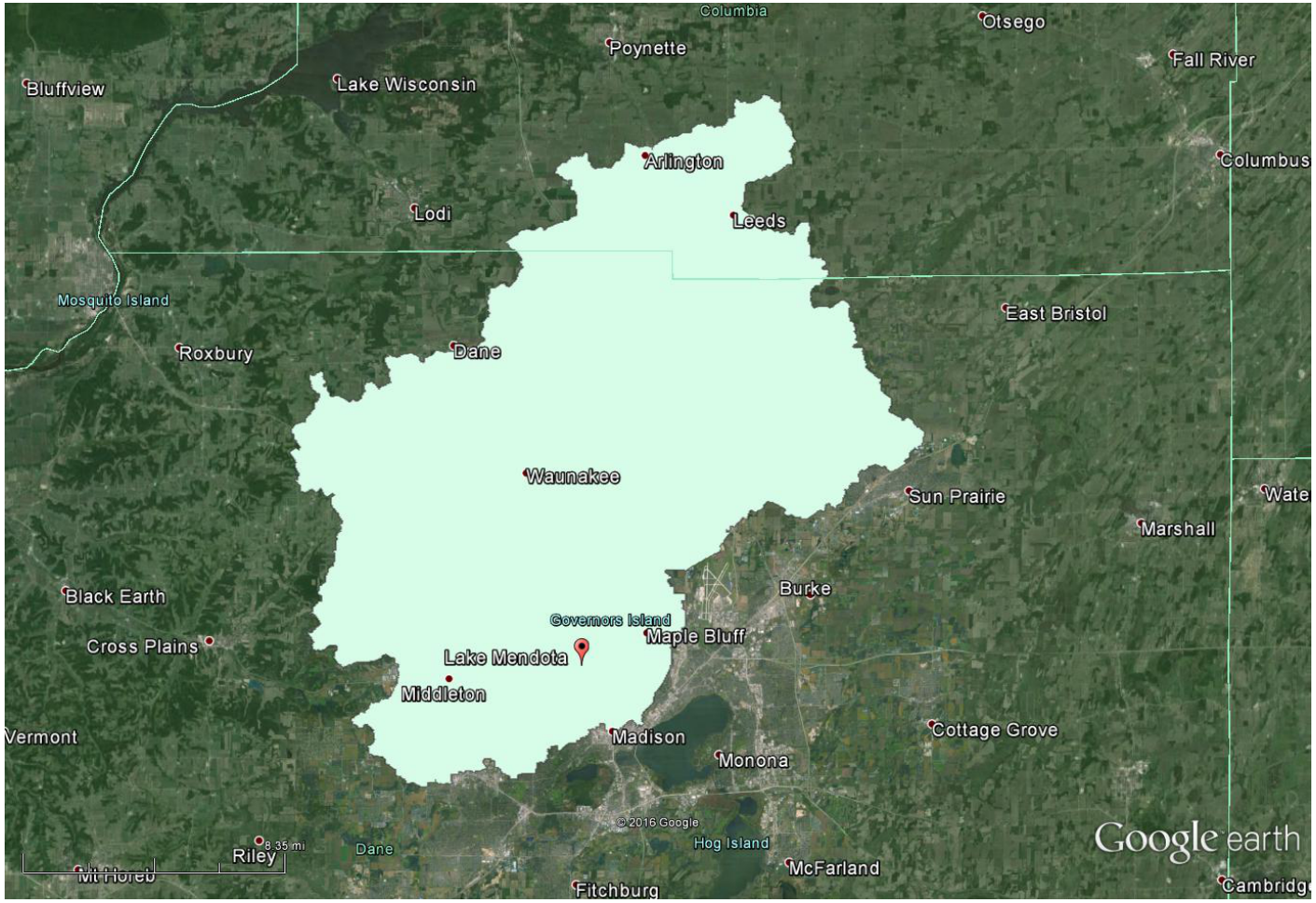
Output time (minute)	Water Flux for Lake1 (m^3/day)	Water Flux for Lake2 (m^3/day)
1440	0	0

4. ProjectName. **lakeTemp**: air temperature of bank

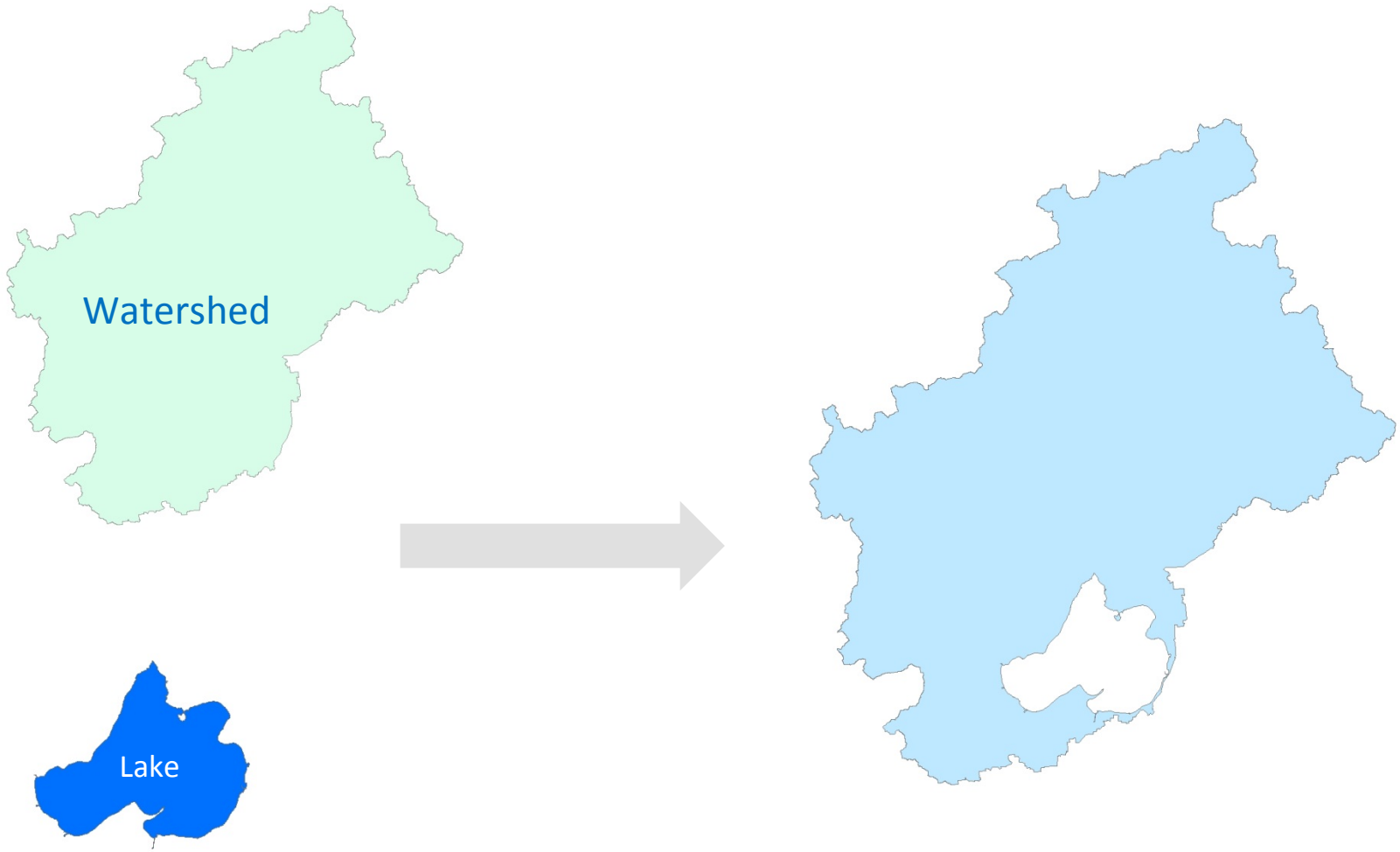
Output time (minute)	Temperature of lake1 (°C)	Temperature of lake2 (°C)
1440	0	0

Application

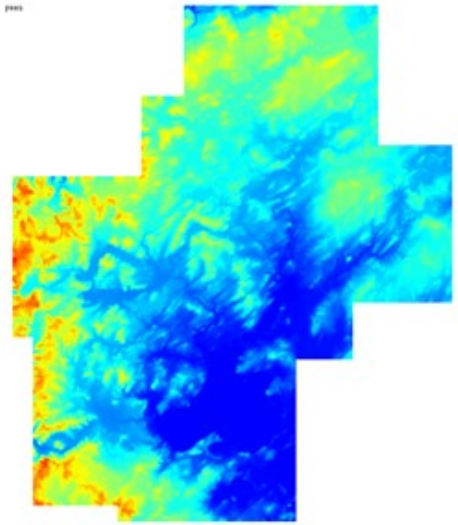
Lake Mendota: at first glance



Data pre-processing

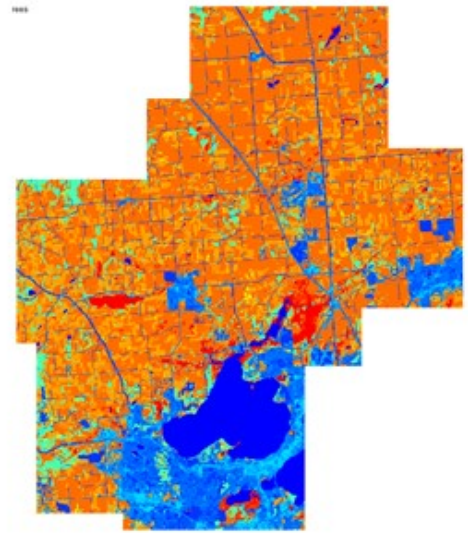


DEM



Soil type

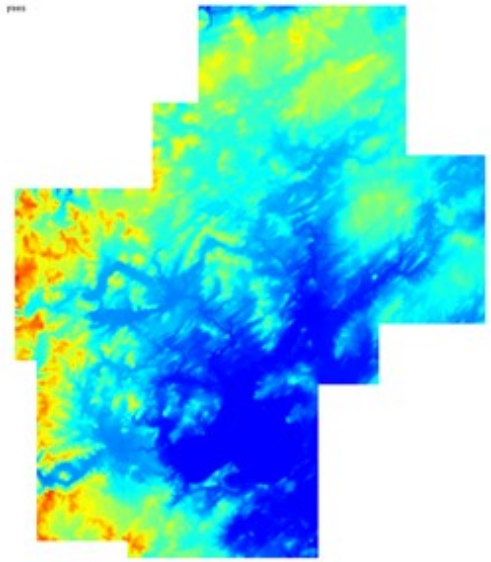
Land use type



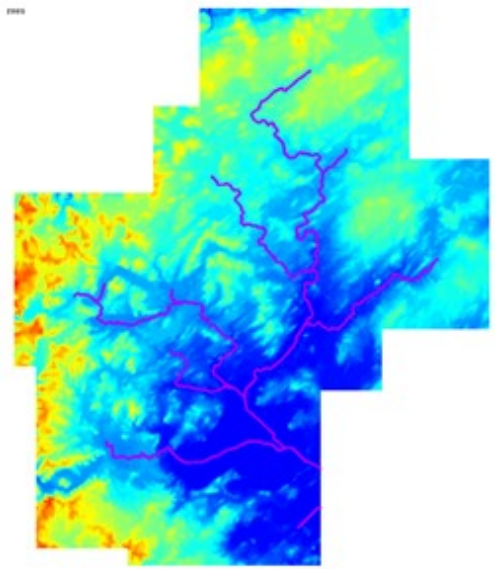
Precipitation

Precipitation type in lake

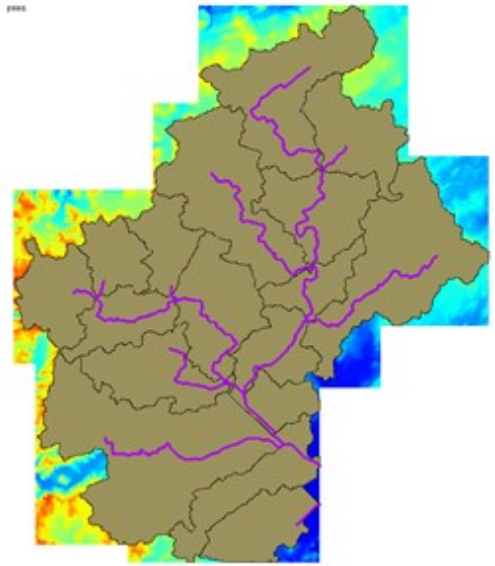
Fill DEM



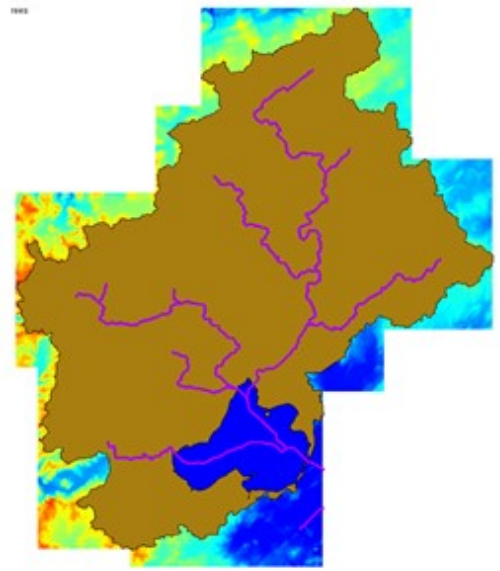
Find the stream line



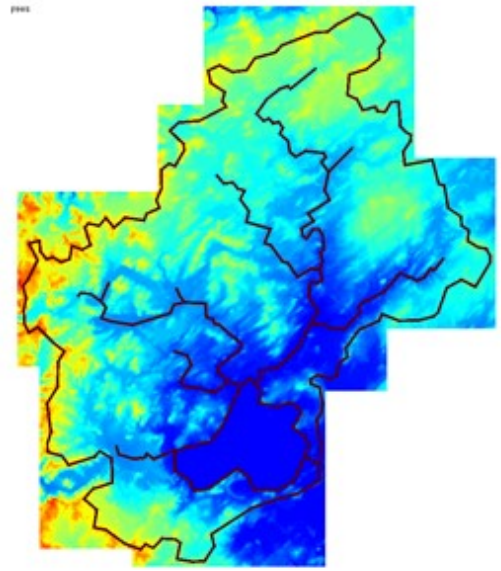
Watershed boundary



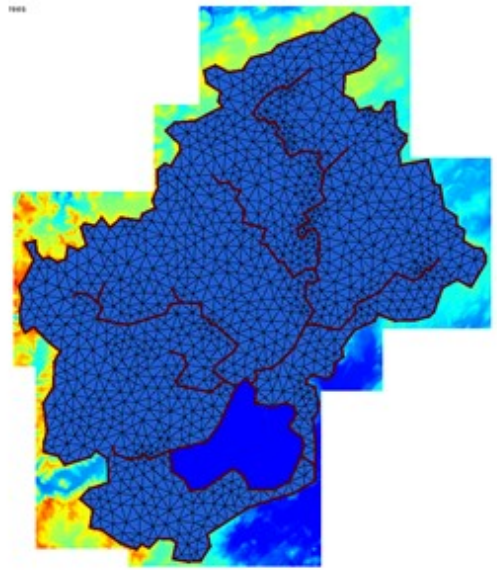
Watershed boundary without lake



Extract boundary line



Decompose model domain

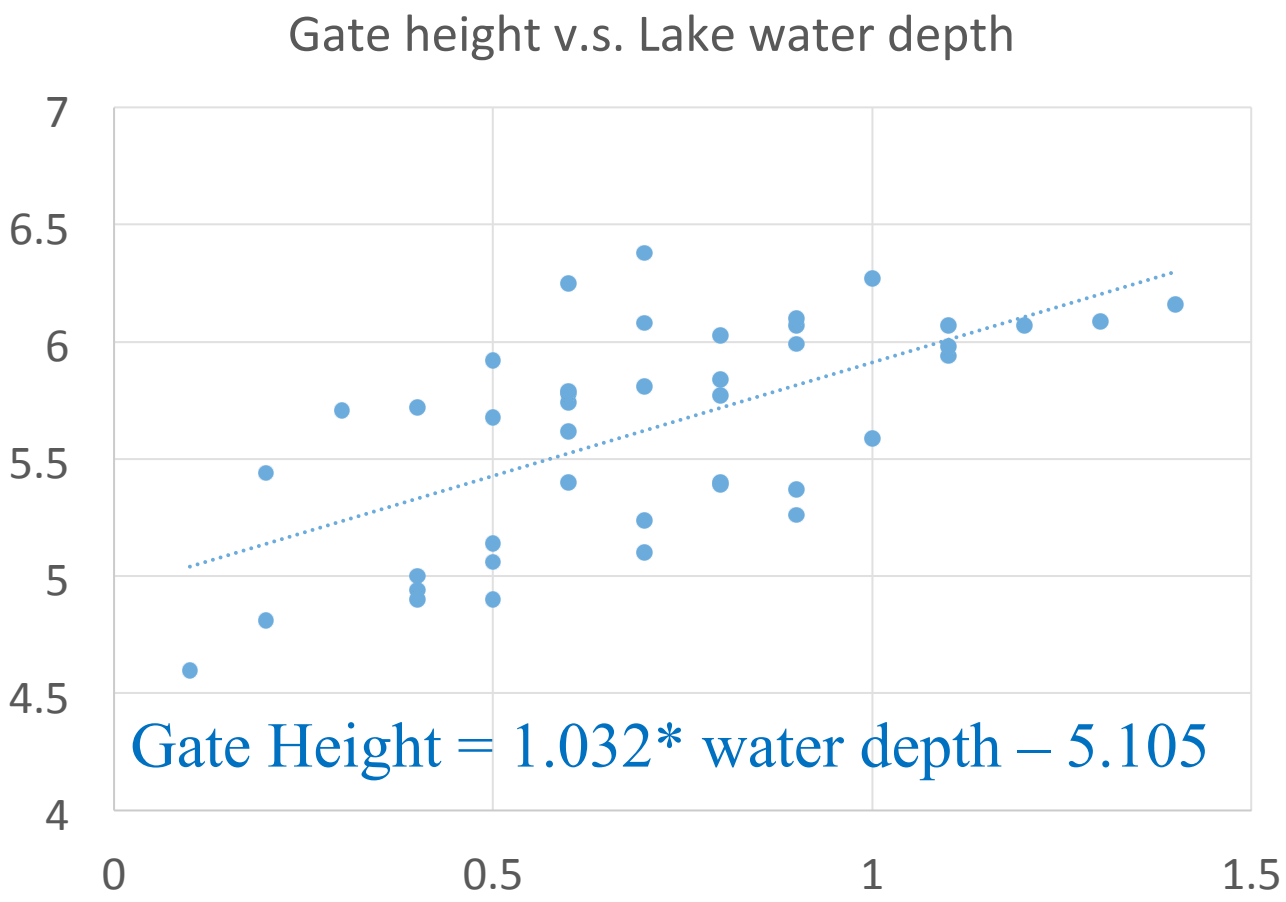


Gate information

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

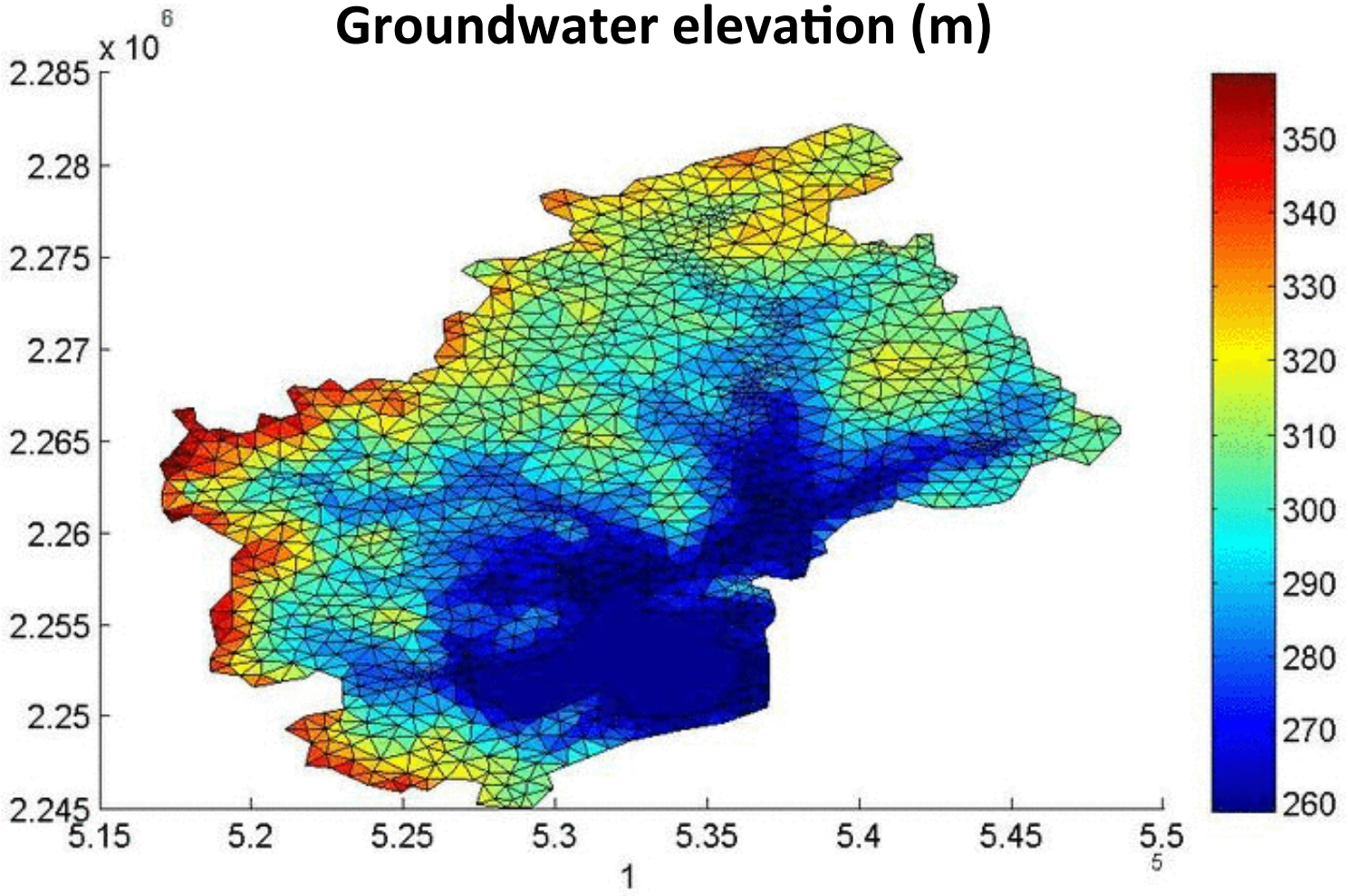
Average gate height: 0.67 ft
Maximum height: 1.6 ft
Minimum height: 0.2 ft



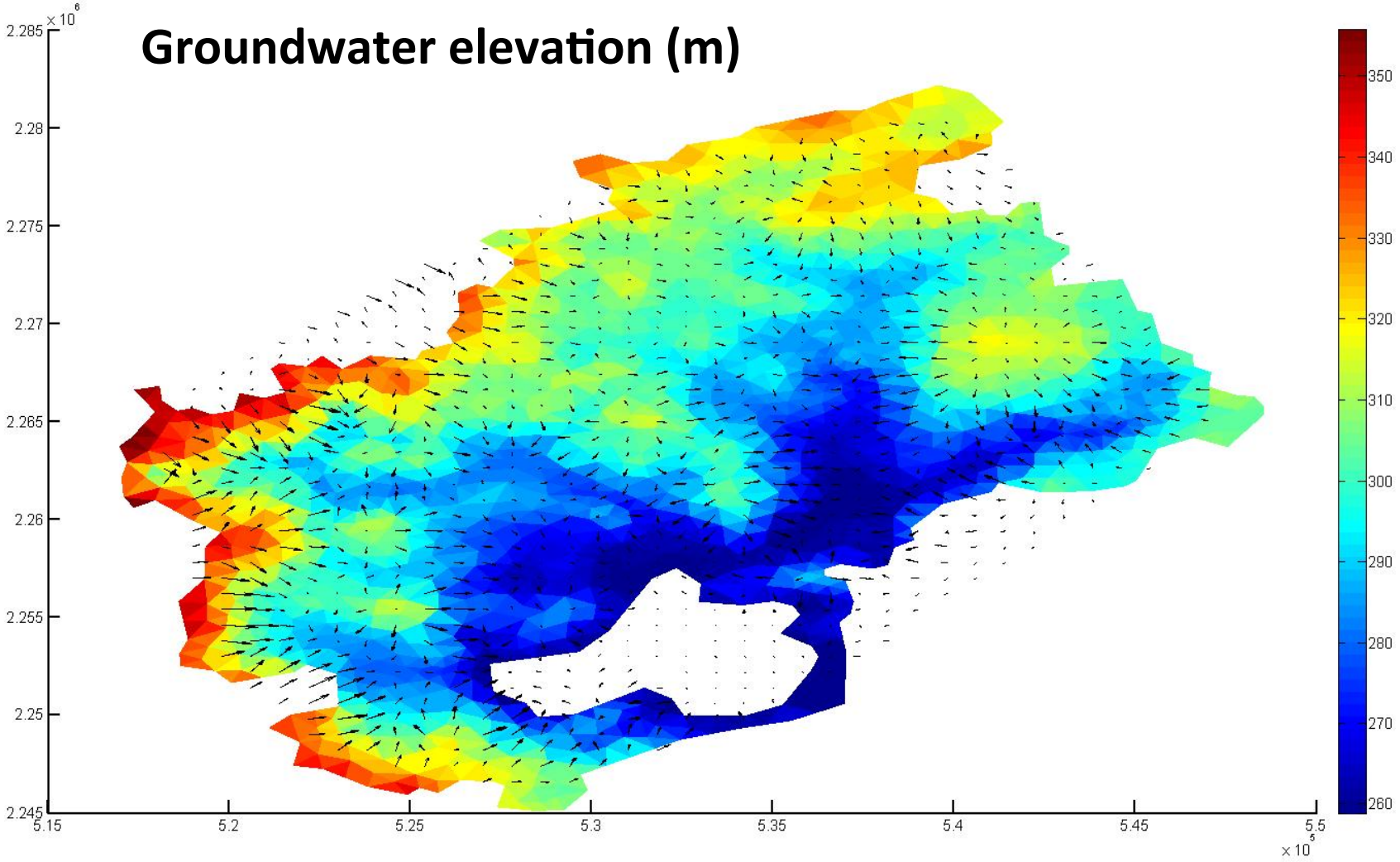
Tuesday, January 5, 2010	0.6	5.48
Tuesday, January 12, 2010	0.4	5.24
Tuesday, March 2, 2010	0.2	4.39
Monday, April 12, 2010	0.3	4.64
Wednesday, April 14, 2010	0.6	4.82
Saturday, April 17, 2010	0.8	4.96
Wednesday, April 21, 2010	0.8	5.07
Thursday, April 22, 2010	0.6	5.02
Friday, May 14, 2010	0.3	5.26
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

Simulated results

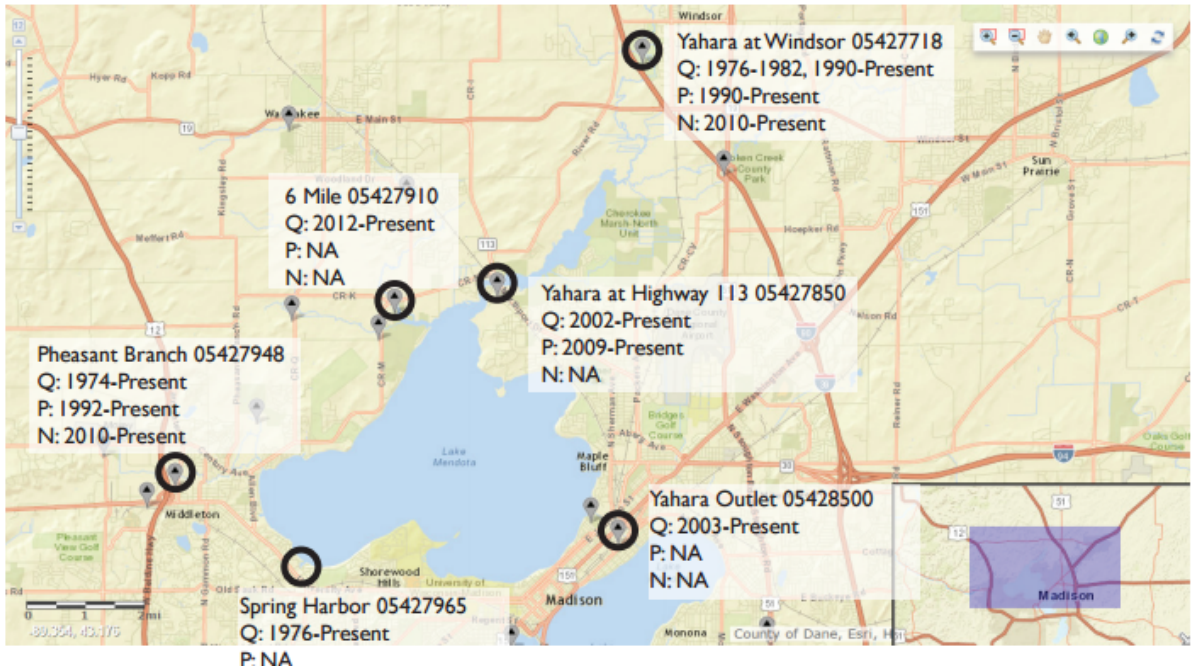
animation

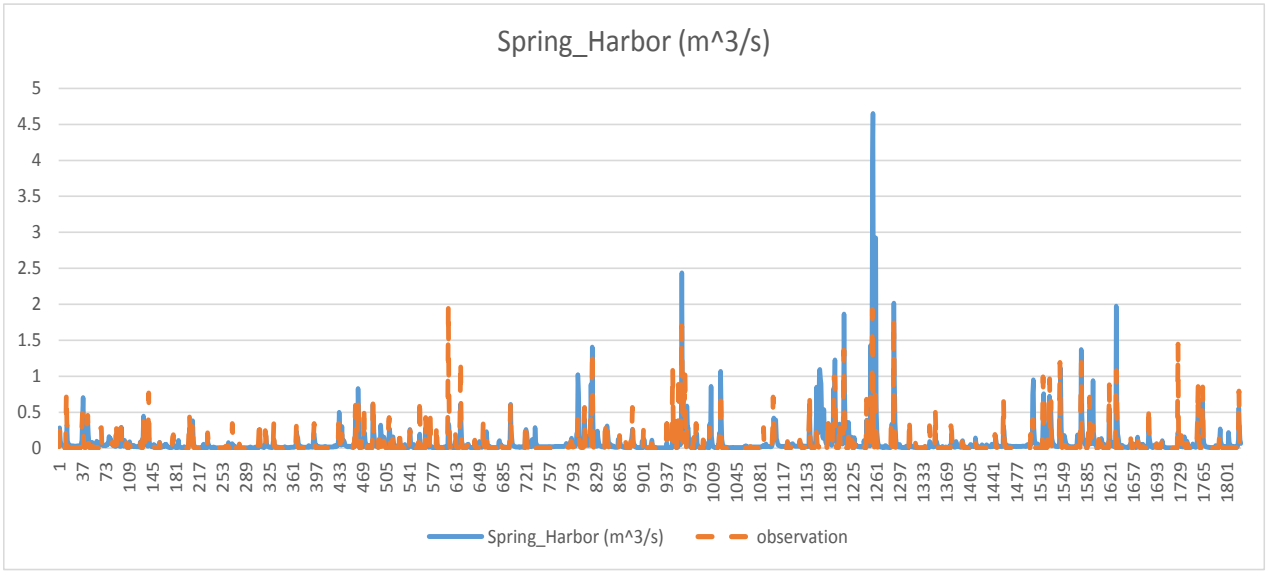


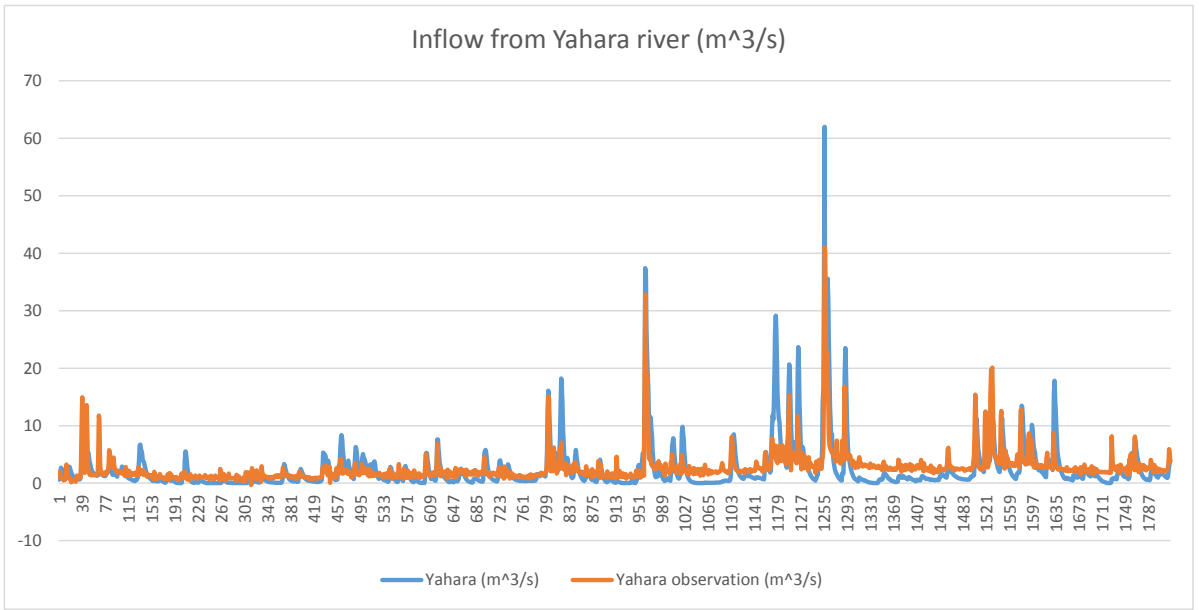
Groundwater flow vectors

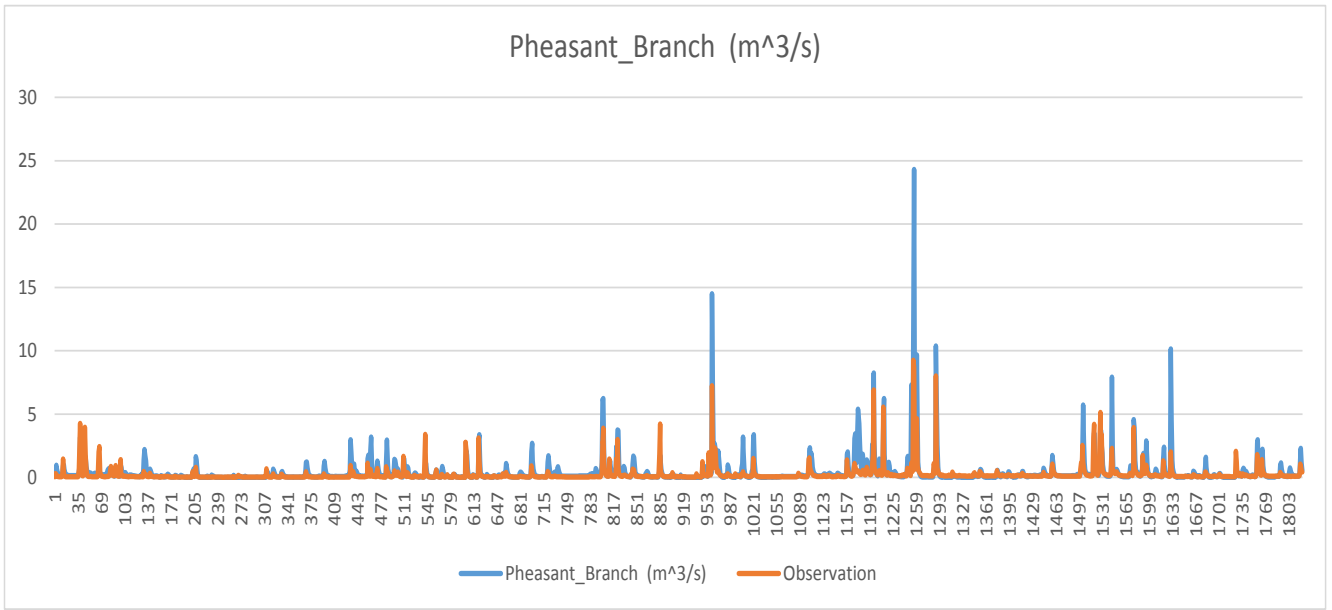


Inflow

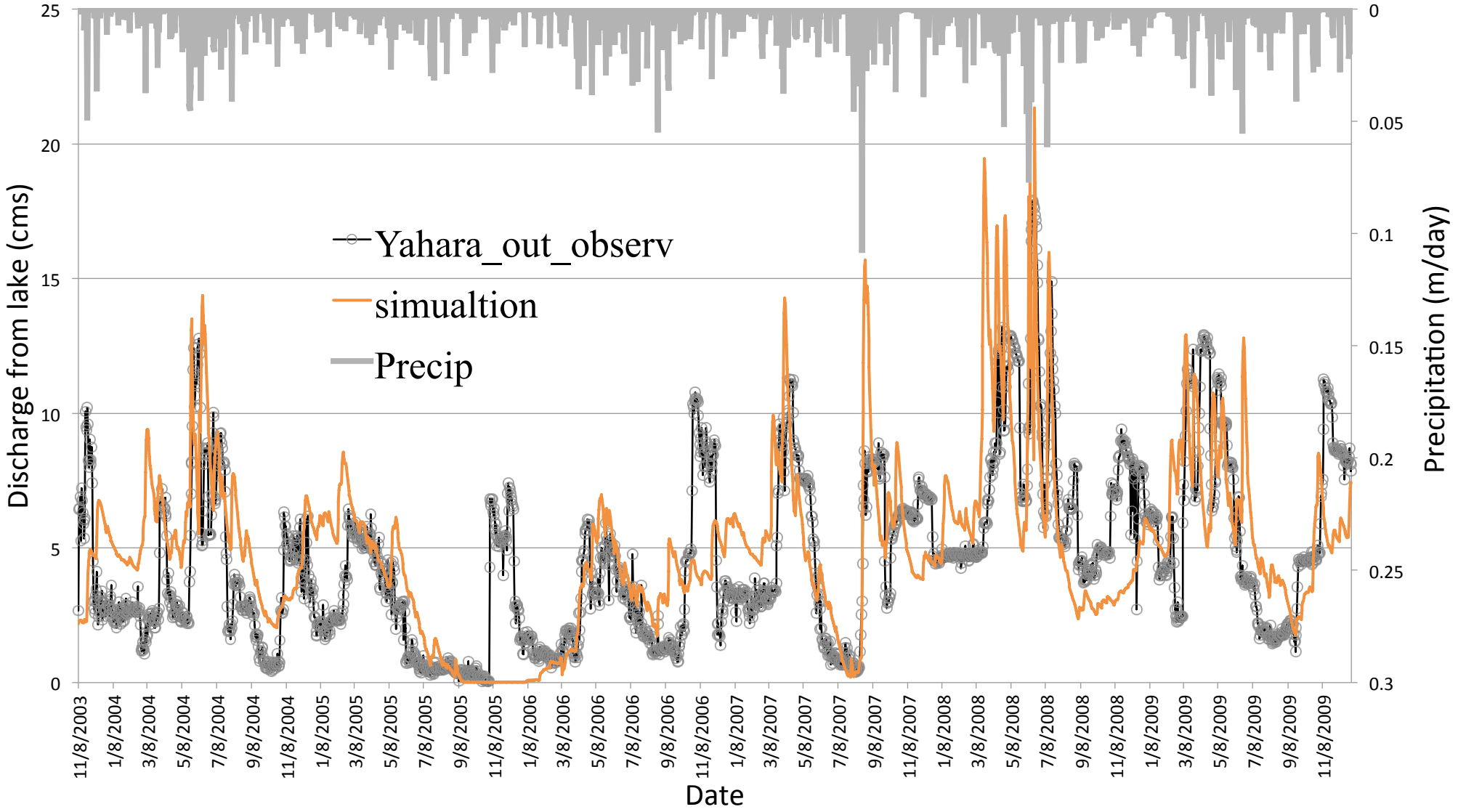

Yahara at Windsor 05427718
Q: 1976-1982, 1990-Present
P: 1990-Present
N: 2010-Present
6 Mile 05427910
Q: 2012-Present
P: NA
N: NA
Yahara at Highway 113 05427850
Q: 2002-Present
P: 2009-Present
N: NA
Pheasant Branch 05427948
Q: 1974-Present
P: 1992-Present
N: 2010-Present
Yahara Outlet 05428500
Q: 2003-Present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


Spring_Harbor (m^3/s)
Spring_Harbor (m^3/s)
observation


Inflow from Yahara river (m^3/s)
Yahara (m^3/s)
Yahara observation (m^3/s)


Pheasant_Branch (m^3/s)
Pheasant_Branch (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
1/8/2006
3/8/2006
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9/8/2007
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3/8/2008
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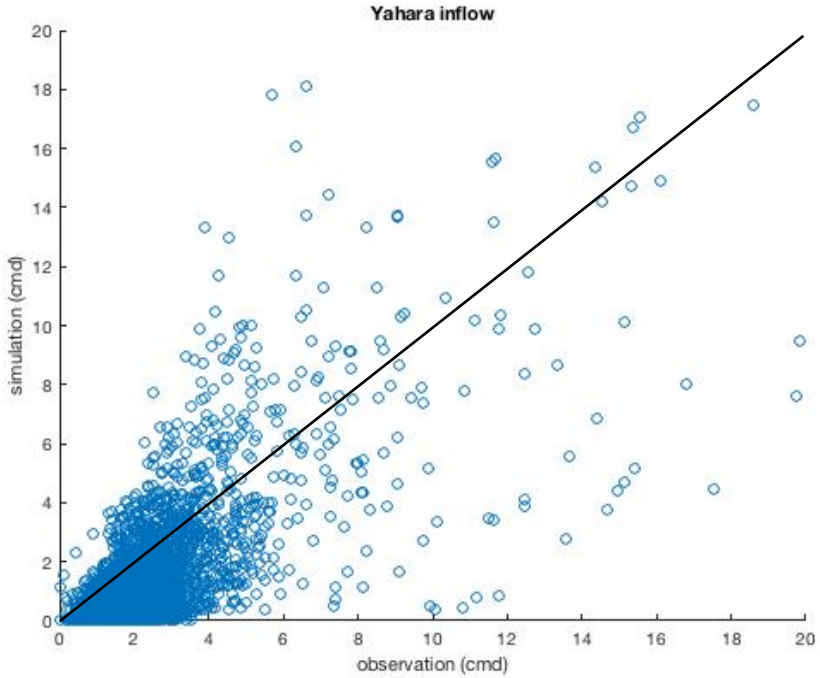
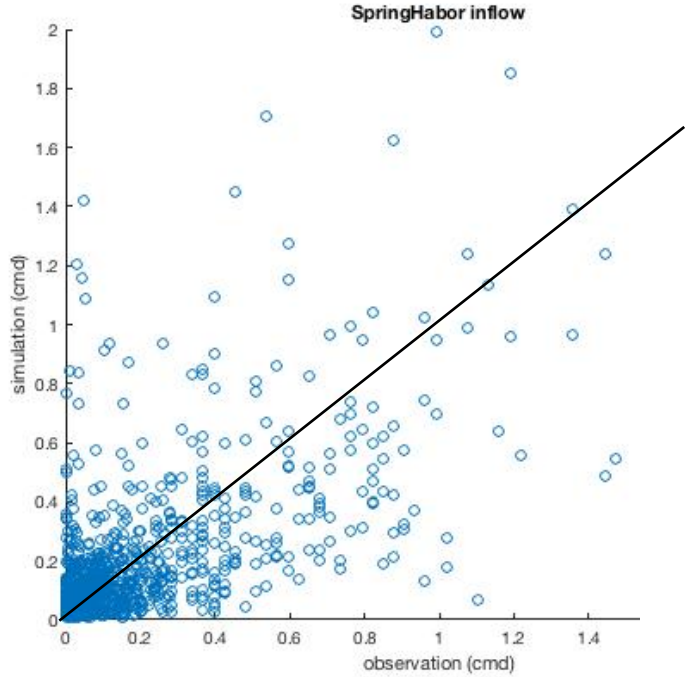
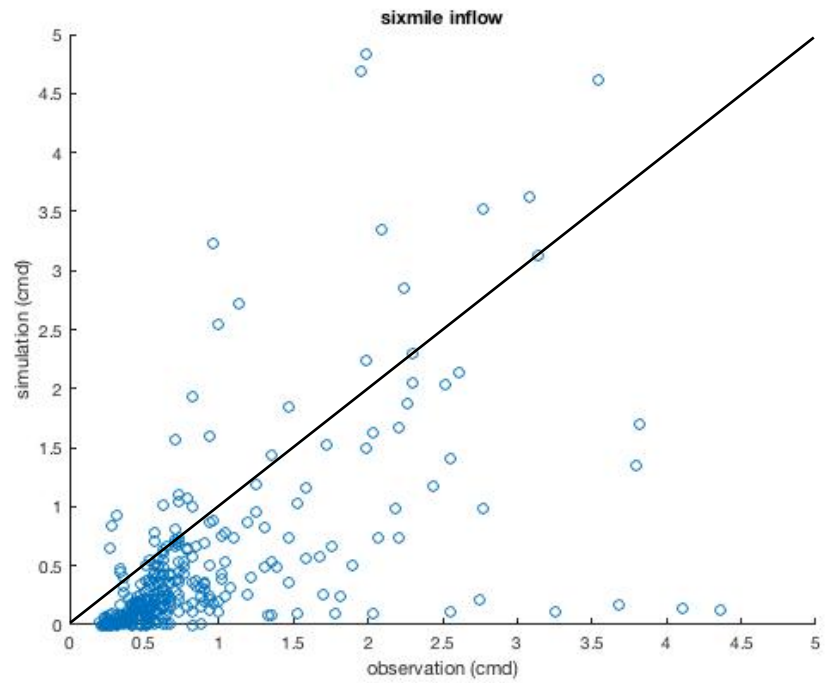
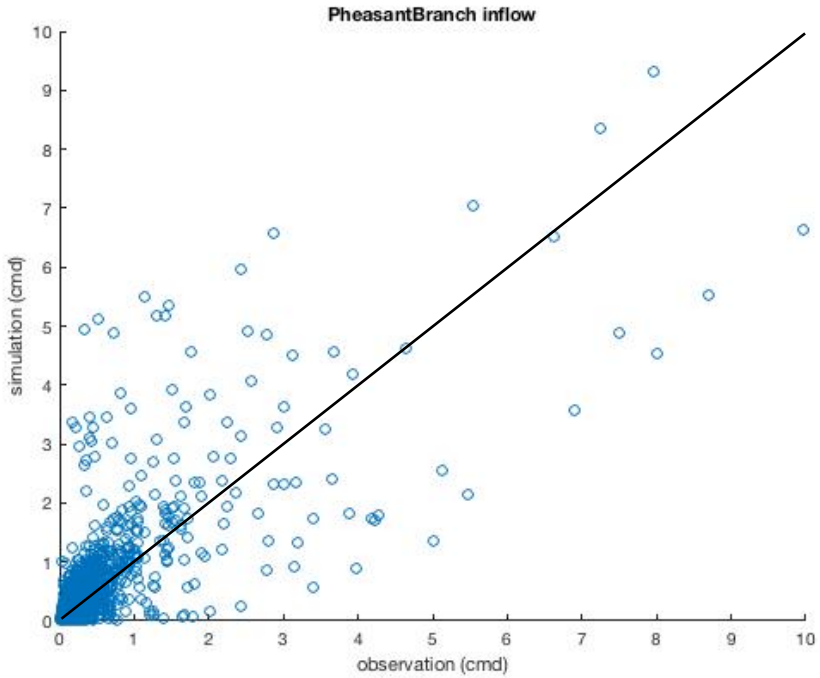
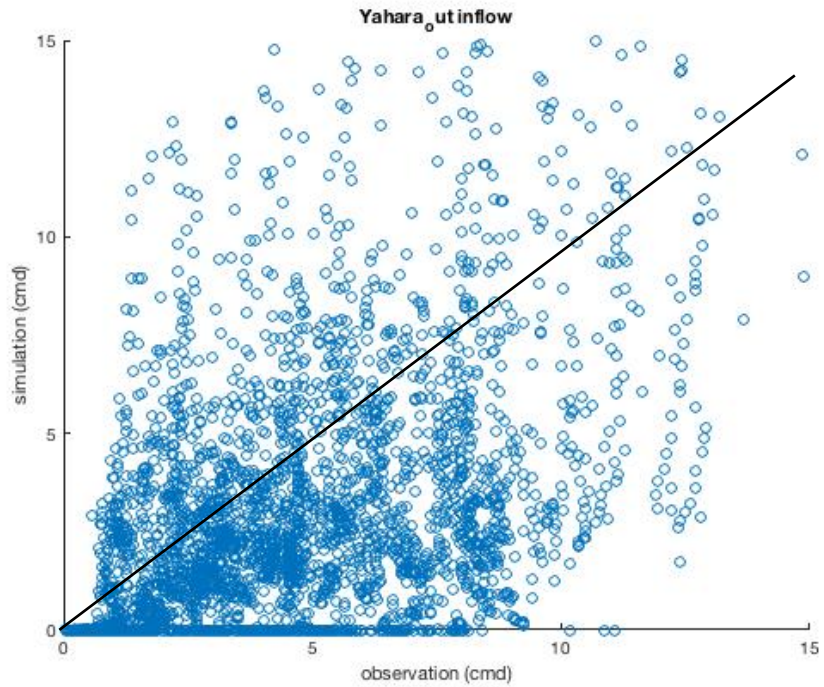
11/8/2008
1/8/2009
3/8/2009
5/8/2009
7/8/2009
9/8/2009
11/8/2009


Yahara inflow
simulation (cmd)
observation (cmd)
0
2
4
6
8
10
12
14
16
18
20


SpringHabor inflow
simulation (cmd)
observation (cmd)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2


sixmile inflow
simulation (cmd)
observation (cmd)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5


PheasantBranch inflow
simulation (cmd)
observation (cmd)
0
1
2
3
4
5
6
7
8
9
10


Yahara_out inflow
simulation (cmd)
observation (cmd)
0
5
10
15

Future work

1. Continue calibrating the simulation in Mendota lake
2. Conduct 1979-2016 simulation at Mendota Lake

Thank you!