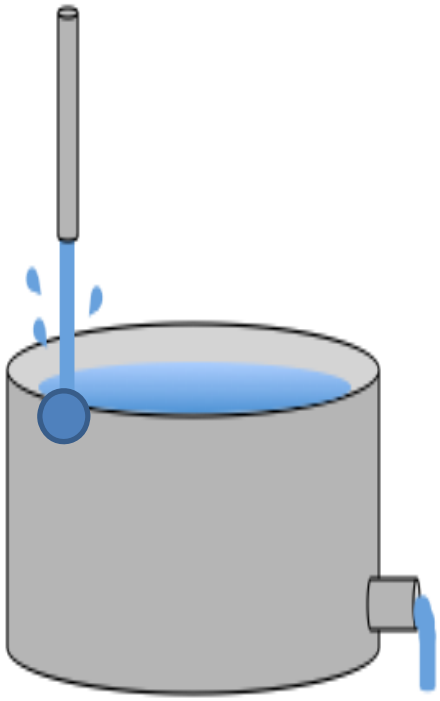
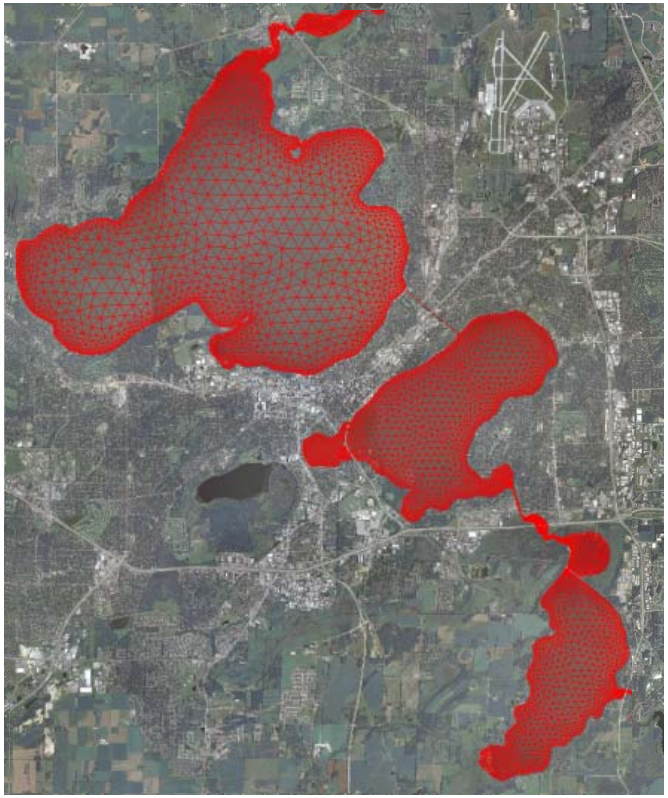
# Water Renewal Time Scales in a Lake-River Chain System





**Presented at:**

**AWRA-Wisconsin, 37th Annual Meeting**

**March 7th, 2012**


**John Reimer, Chin Wu**

**University of Wisconsin, Madison**

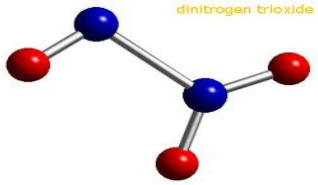
# Motivations

## Eutrophication

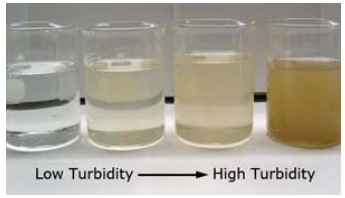
## Turbidity

## TMDL

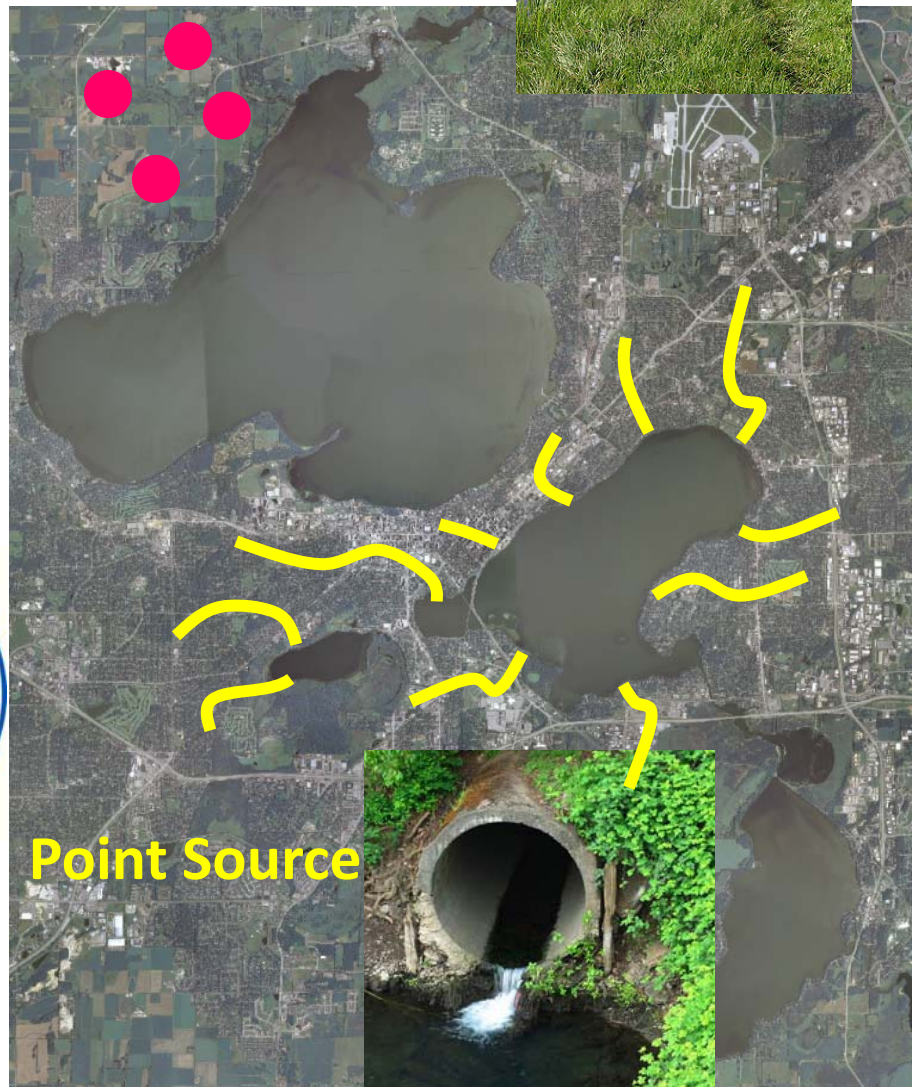
## Nutrients




## Sediment



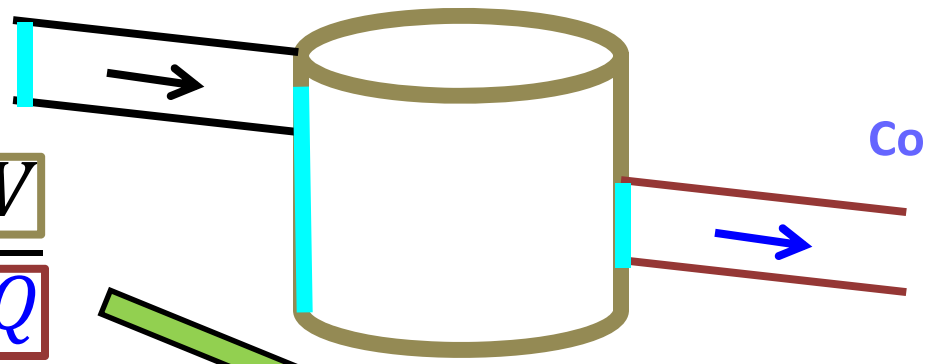

## Nonpoint Source



## Point Source

# Times

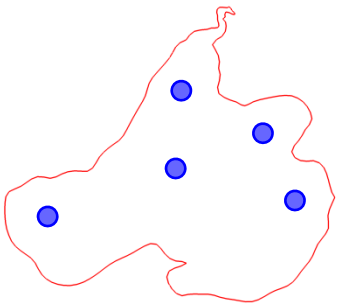
## Flushing Time



$$T_f = \frac{V}{Q}$$

**Assumption:**
**Continuous Stirred Tank Reactor (CSTR)**

## Residence Time

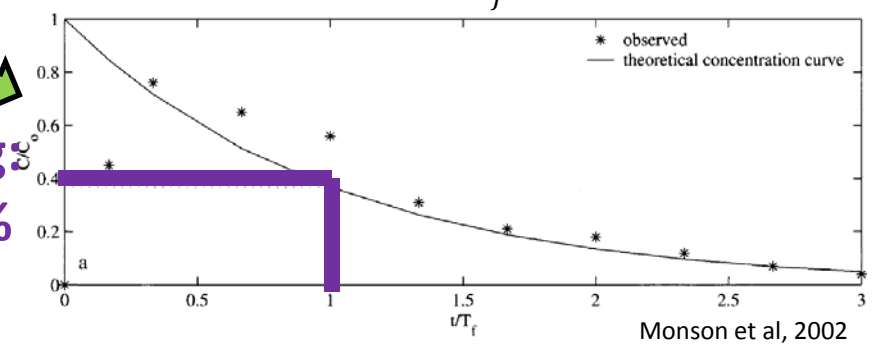


**Spatial Domain**

**Time to leave system**

$$\ln C(t) = -\left(\frac{1}{T_f}\right)t + \ln C_o$$

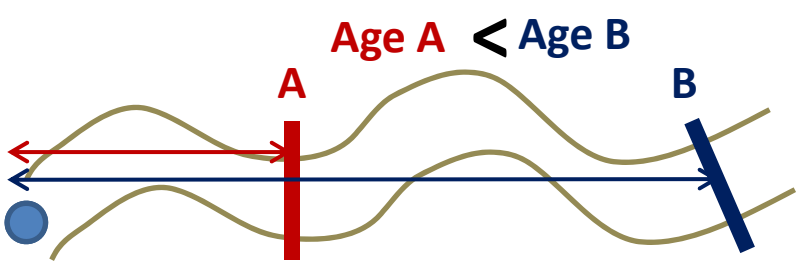
**e-folding: 37%**

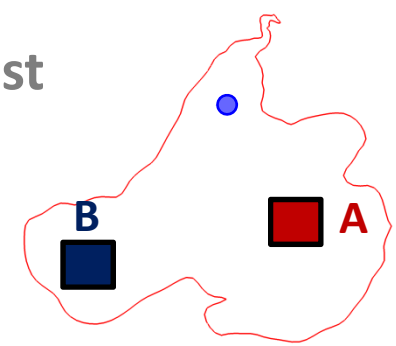



Monson et al, 2002

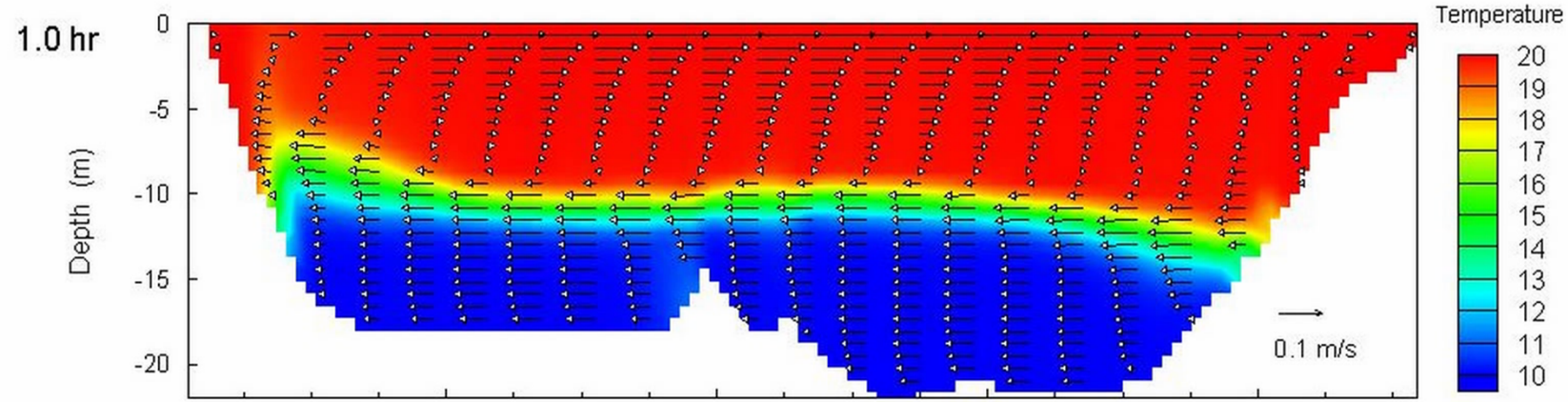
## Age

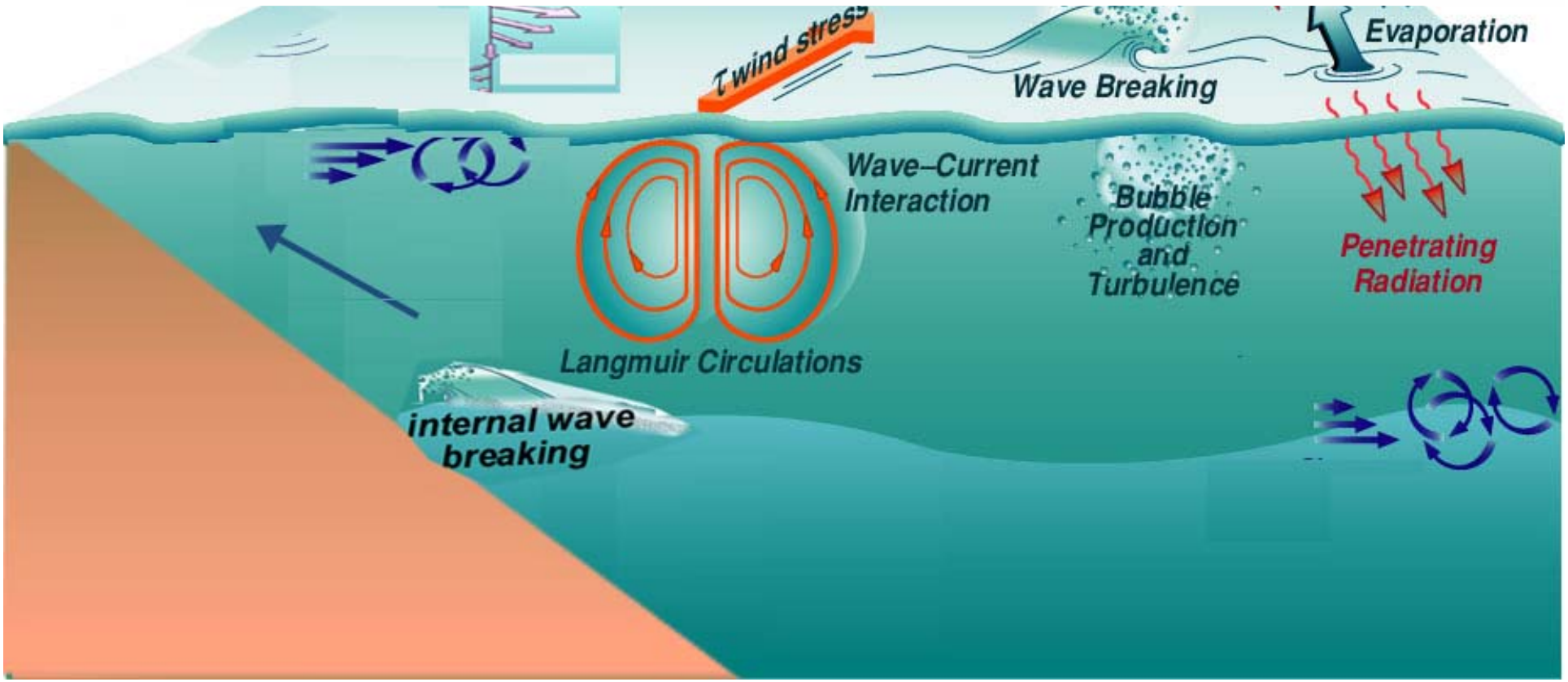
**Time to Reach Area of Interest**

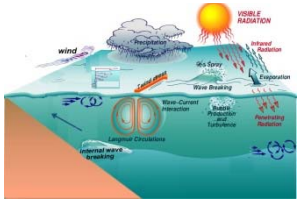


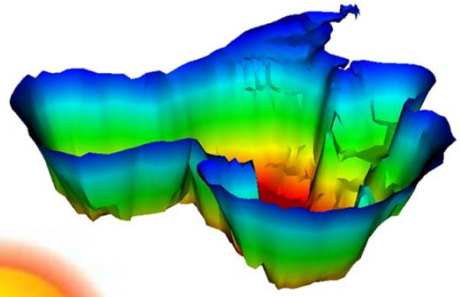
# Lake Hydrodynamics



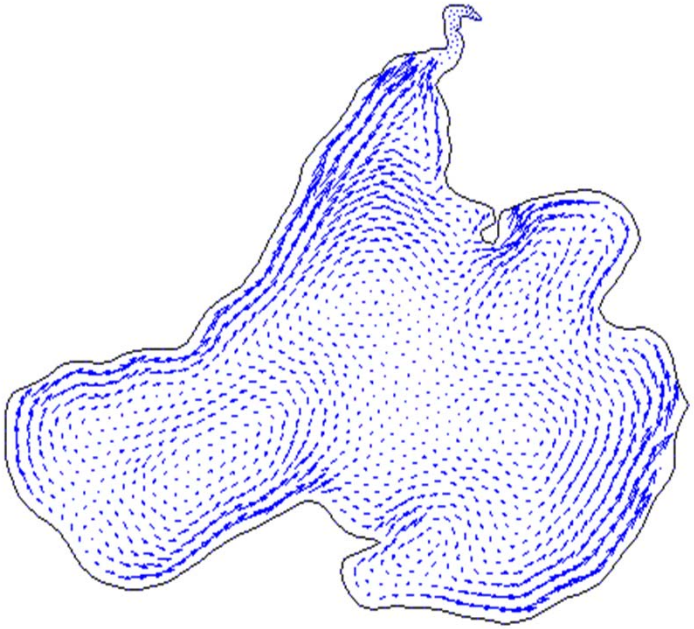


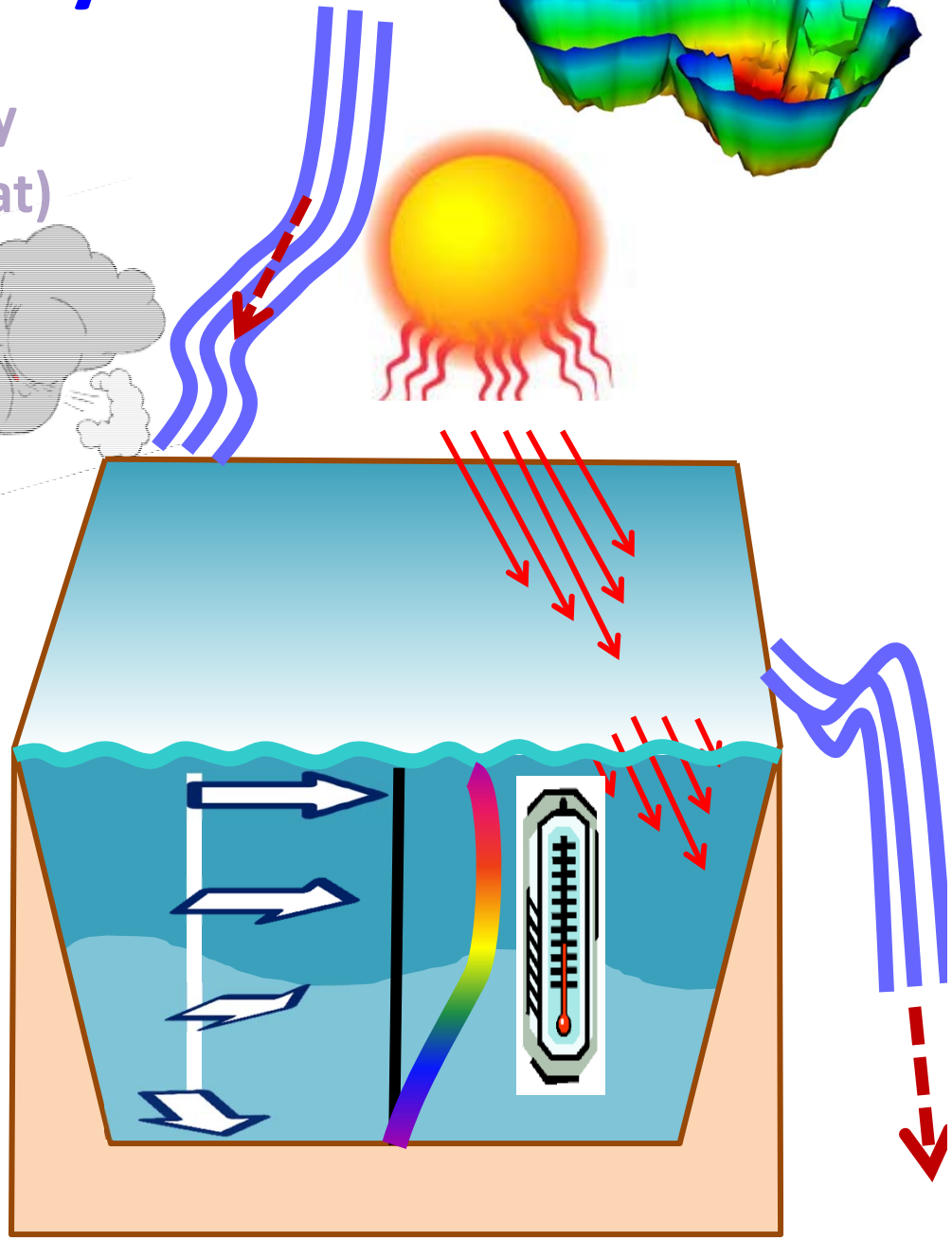
# Lake Hydrodynamics

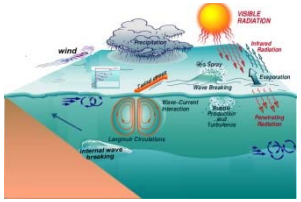


- Bathymetry/Morphometry
- Meteorological (Wind/Heat)
- Tributary

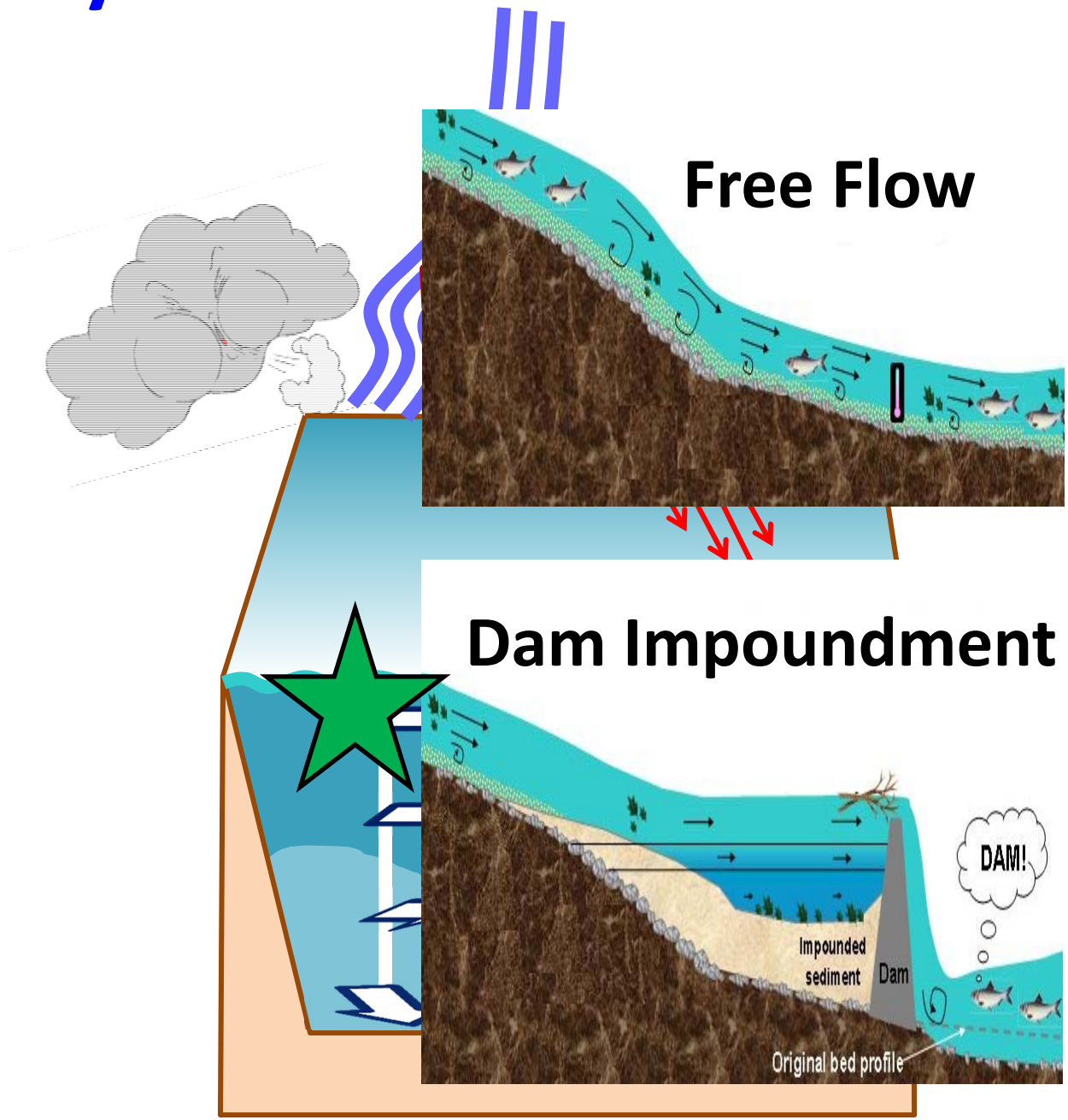
**Water Level**
**Circulation**





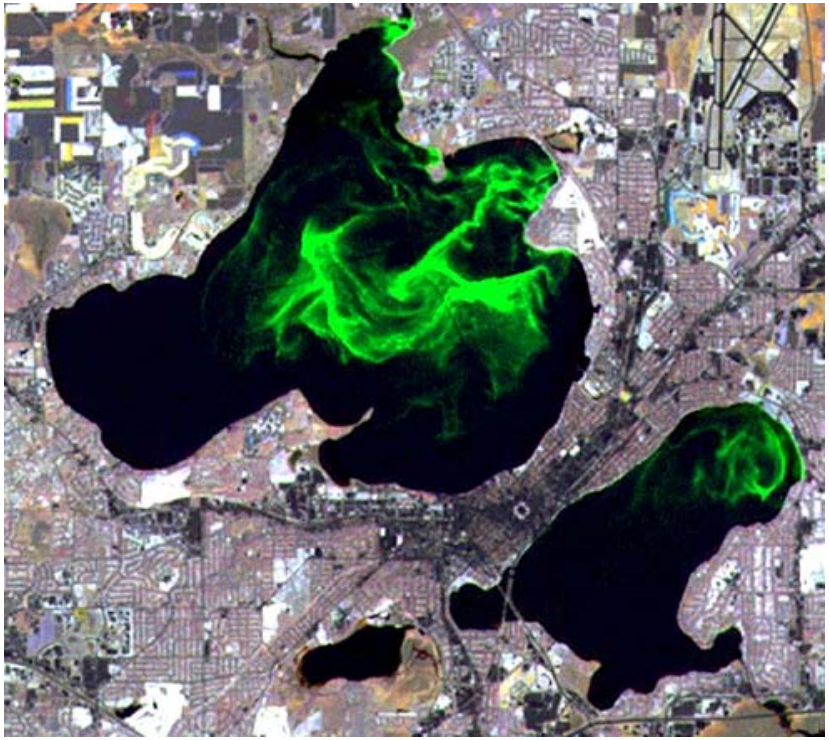


# River Dynamics



# Research Question

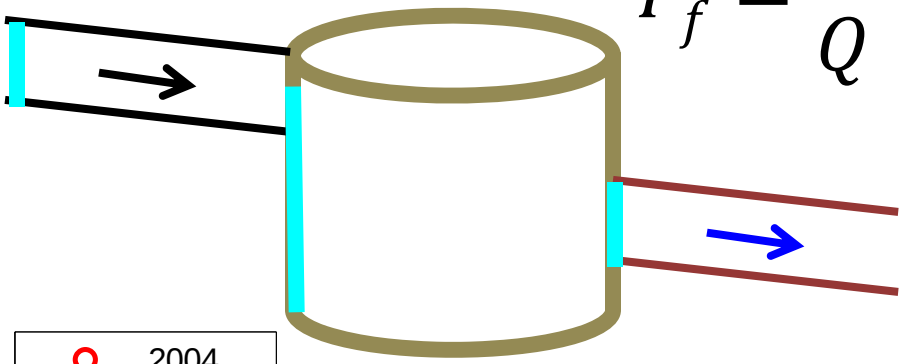
- **What are time scales (*flushing*, *residence*, *age*) for Lakes & Rivers driven by these hydrodynamics?**

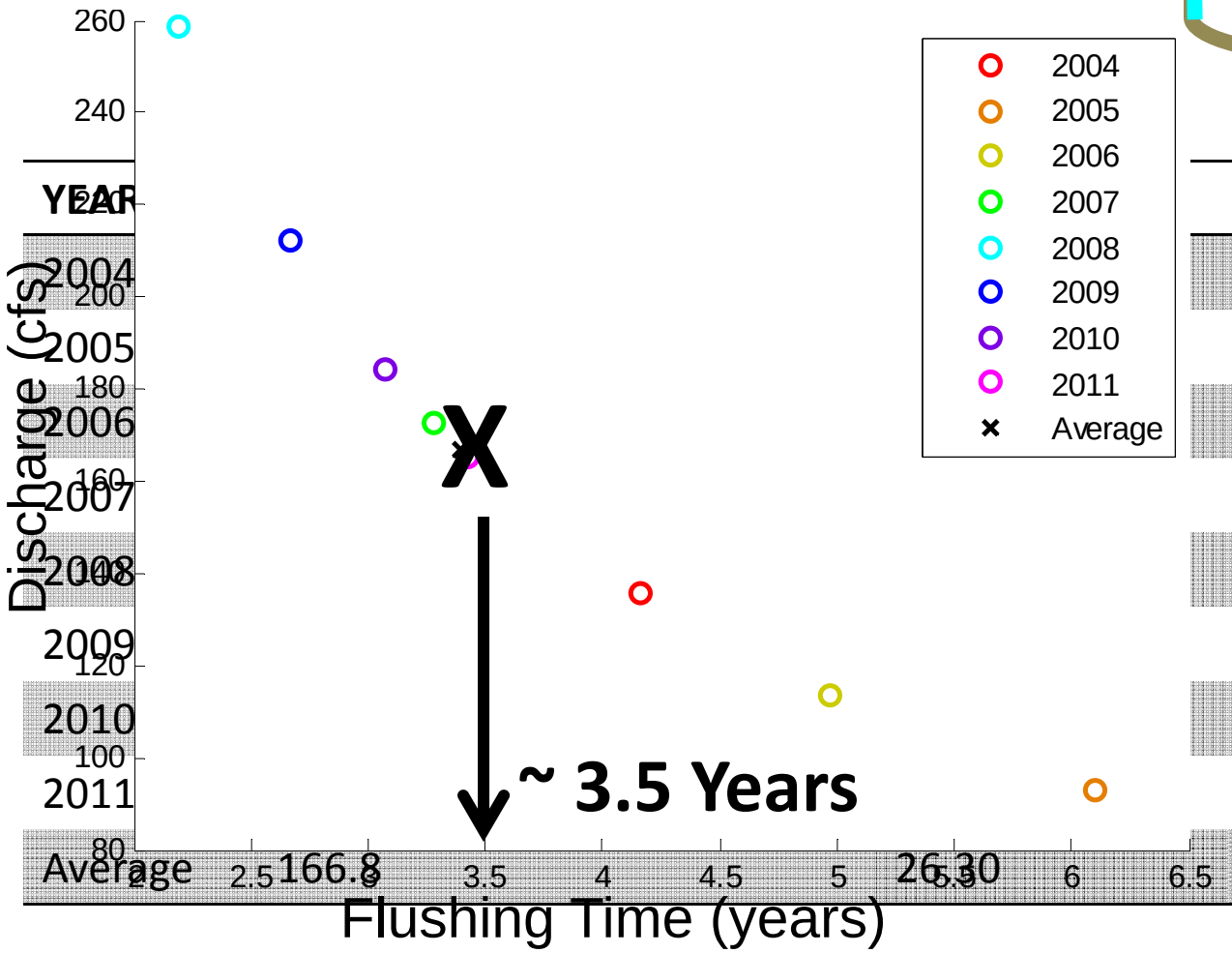



# Flushing Time

**RECALL:**

$$T_f = \frac{V}{Q}$$






| YEAR | FLUSHING TIME (years) |
|---|---|
| 2004 | 4.16 |
| 2005 | 6.10 |
| 2006 | 4.98 |
| 2007 | 3.28 |
| 2008 | 2.19 |
| 2009 | 2.67 |
| 2010 | 3.07 |
| 2011 | 3.42 |
| Average | 3.39 |

# Approach

## 1. Hydrodynamic model

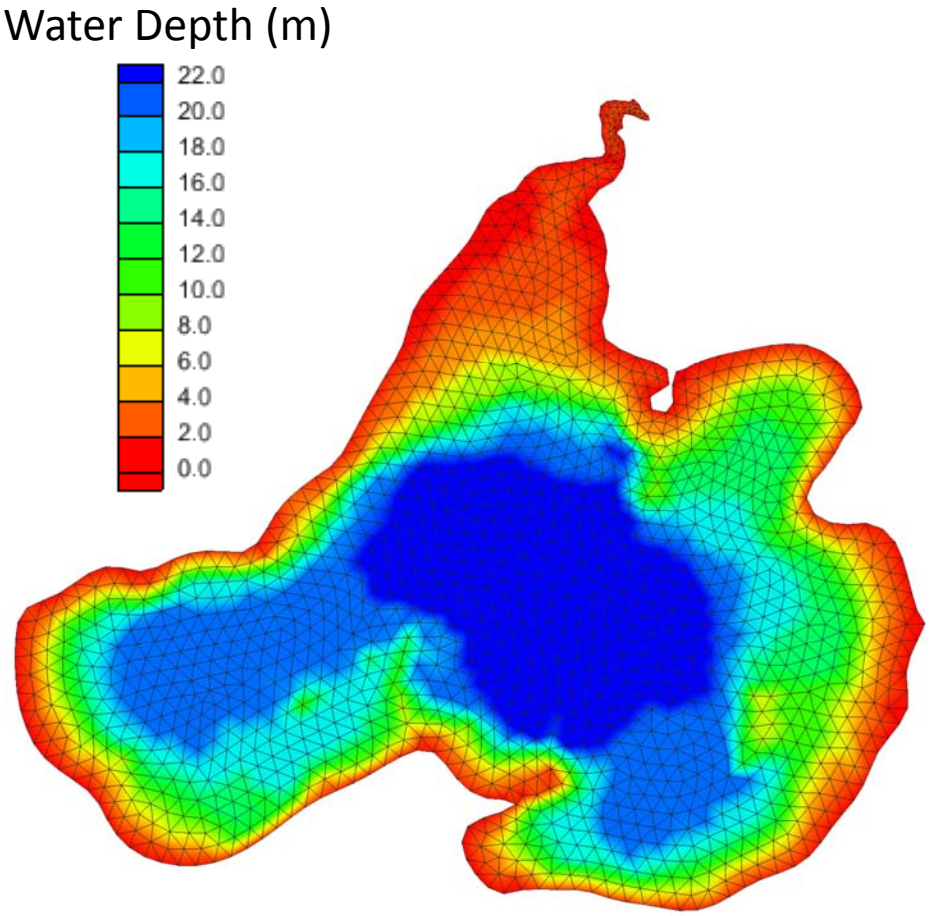
- Horizontal resolution: 100 meters
- Vertical layers: 52

**Model Execution**

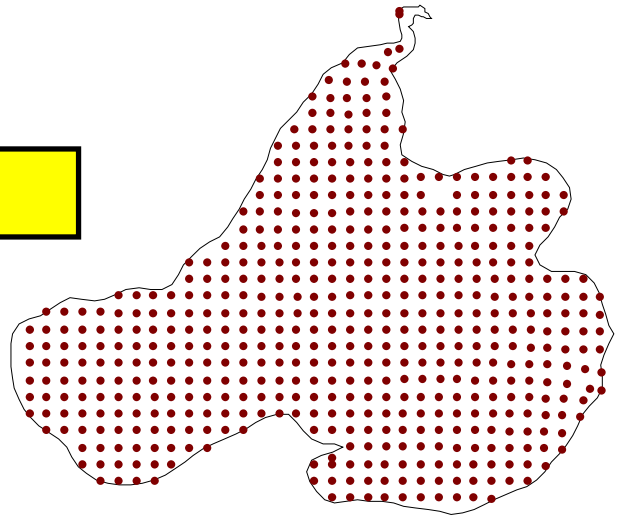
- AMD 64 processors (parallel computation)

**Model Setup**

- 8 Year Simulation
- Boundary Conditions
  - Wind Stress
  - Heat Flux
  - Inflow/Outflow



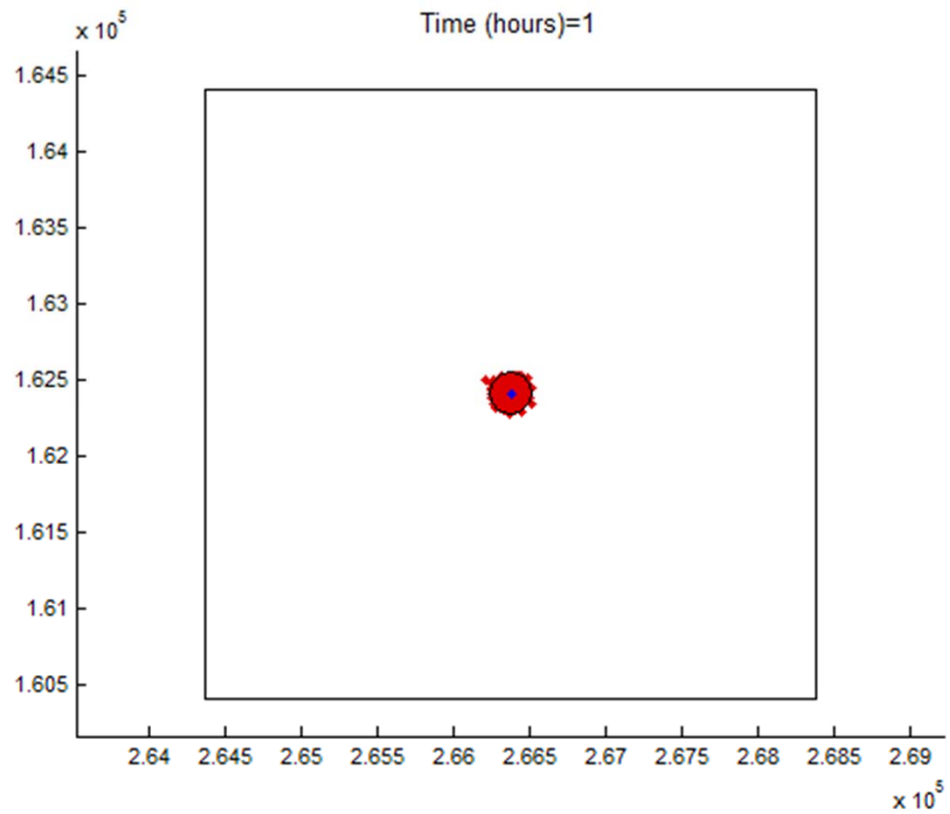

## 2. Particle Transport Model



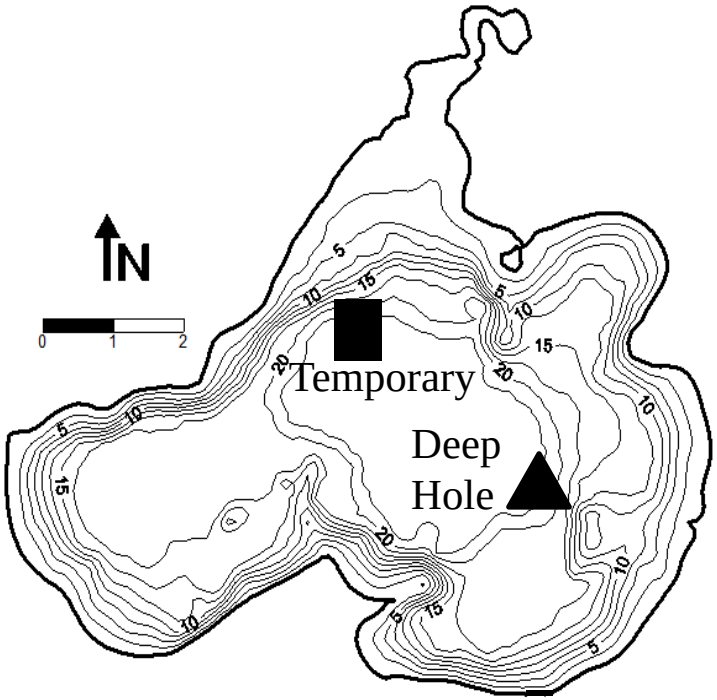
# Horizontal Dispersion Test

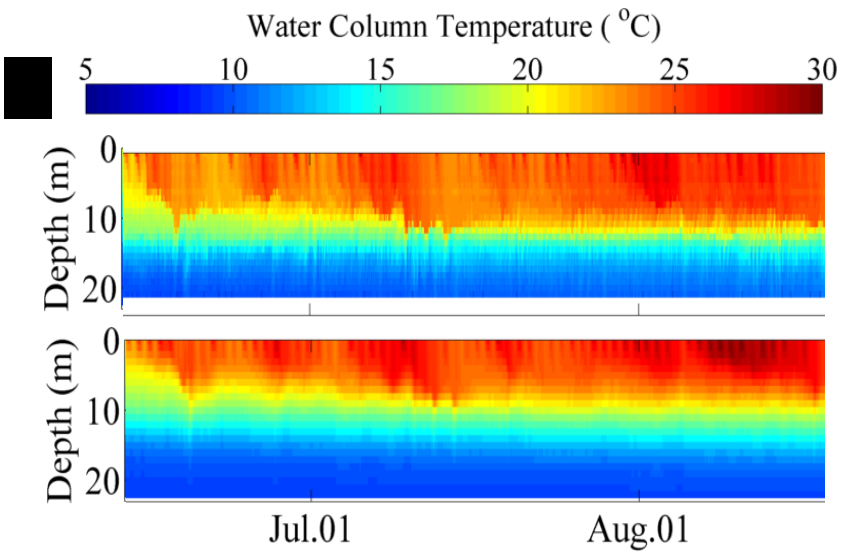
- Switch off advection term and release 1,000 particles at same time from center
- Check to see that particles remain within 3 times of standard deviation = $\sqrt{6Kt}$

  This means that 99.7% of total particles should be located within area

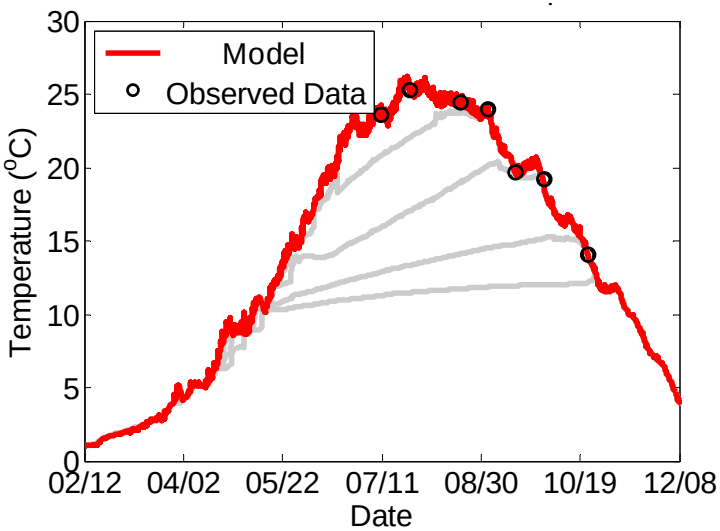


# 1. Hydrodynamic Model Calibration

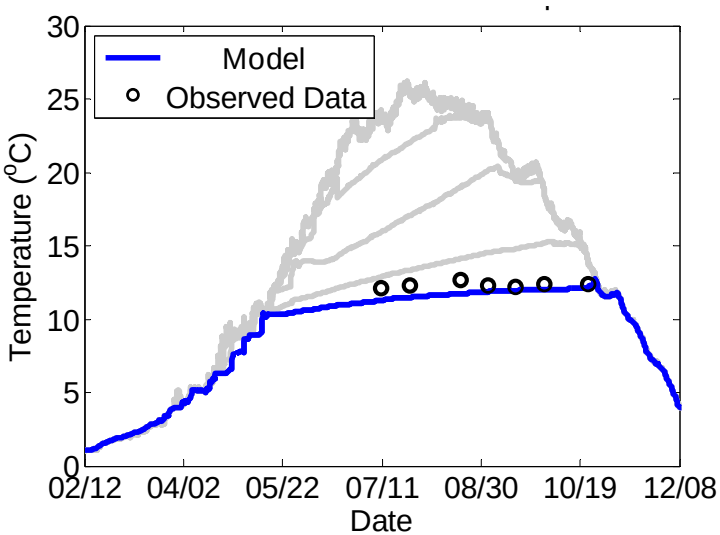



## ▲ Surface



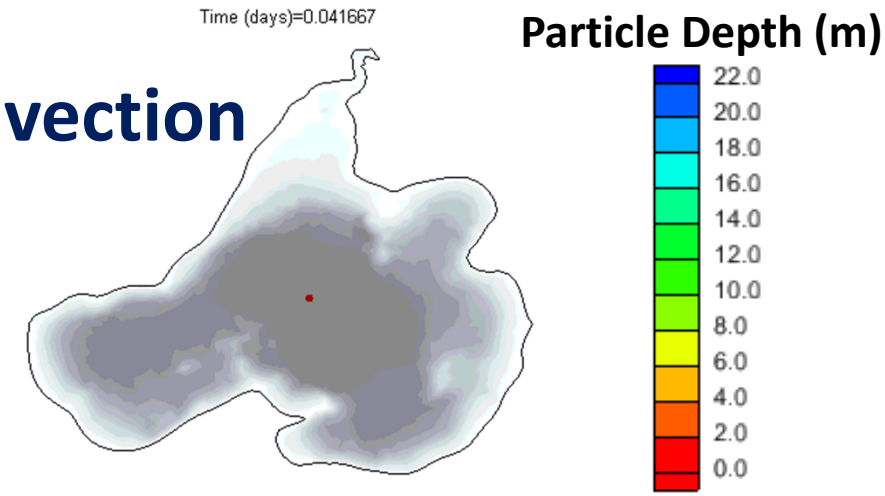

## ▲ Bottom



# 2. Particle Transport Model

$$X^{n+1} = X^{n} + \boxed{U\,\Delta t}$$

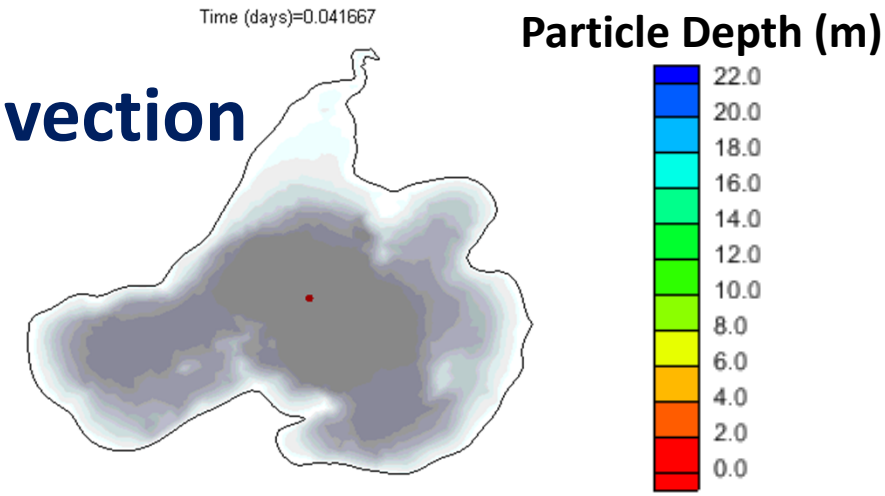
## Advection



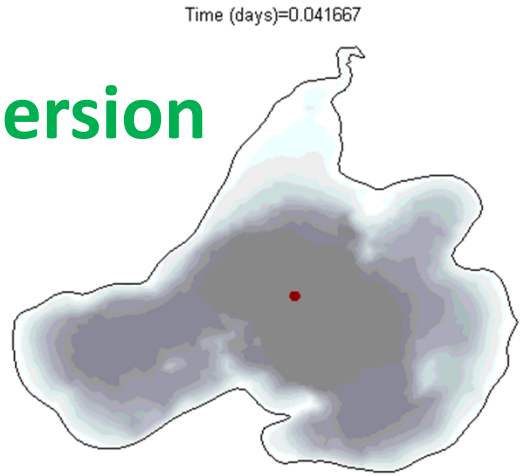
# 2. Particle Transport Model

$$X^{n+1} = X^{n} + \boxed{U\,\Delta t} + \boxed{R\sqrt{2\,K_x\,\Delta t}}$$

**Advection**




**Dispersion**



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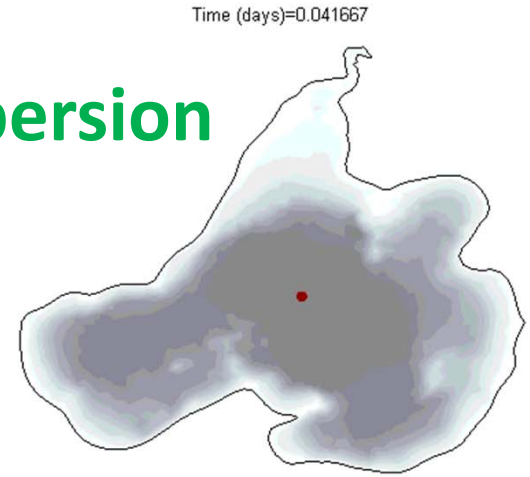
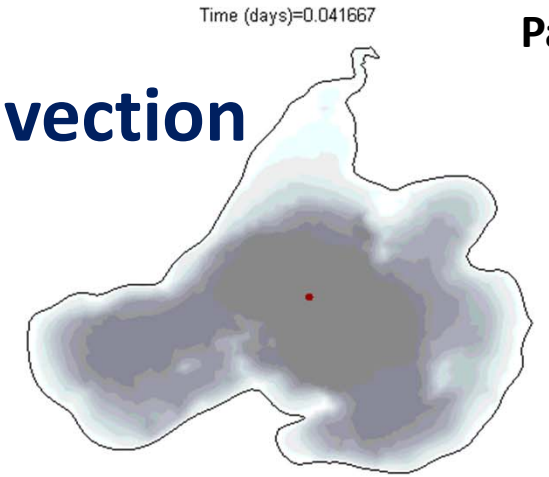
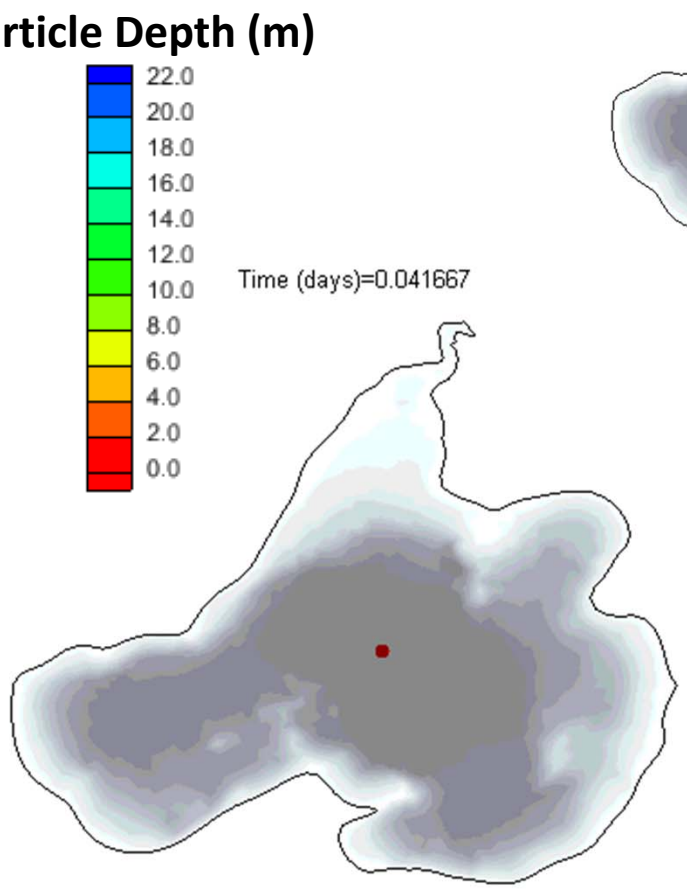
Dispersion



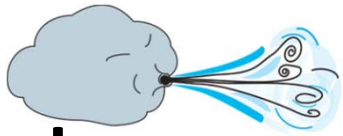

Advection



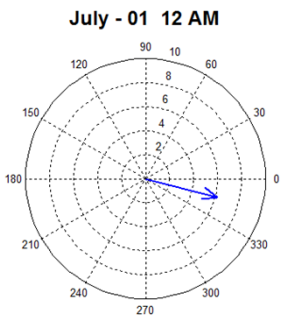



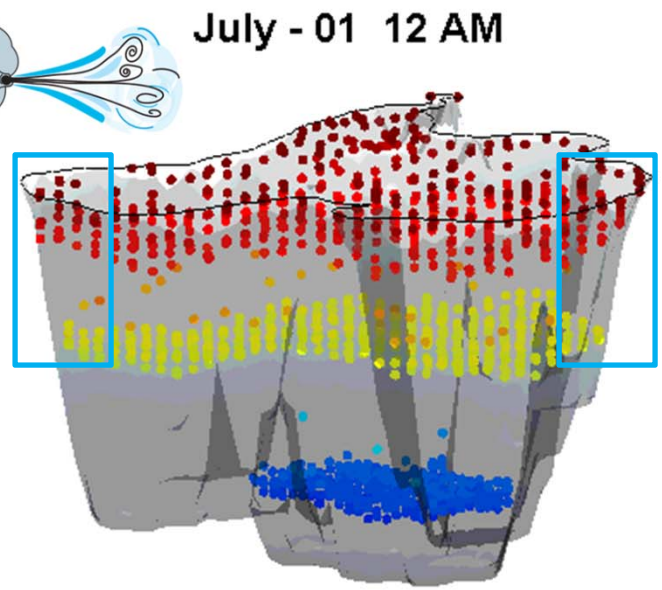

Advection-Dispersion

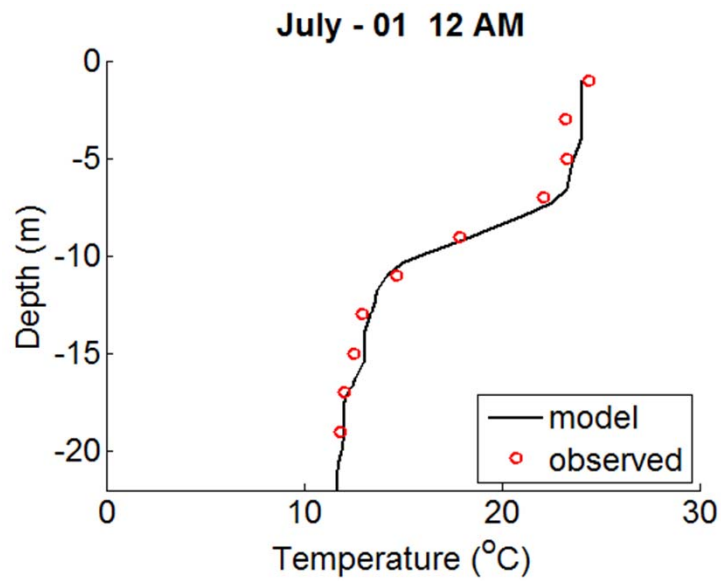
# Stratification



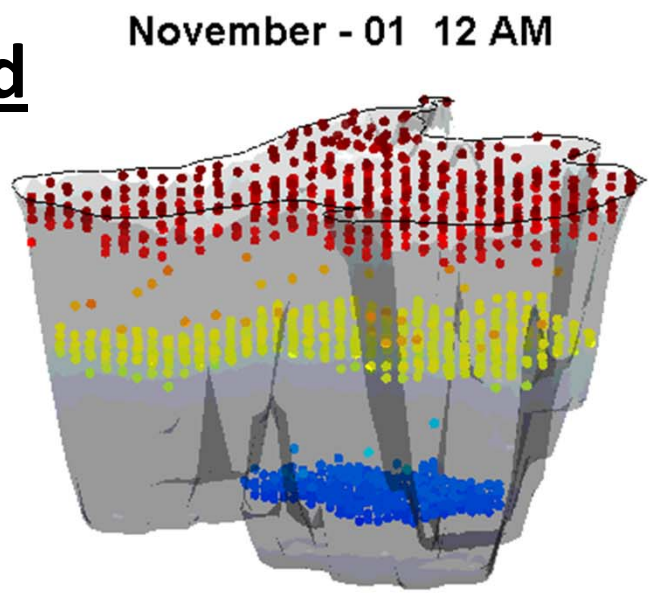
## Stratified

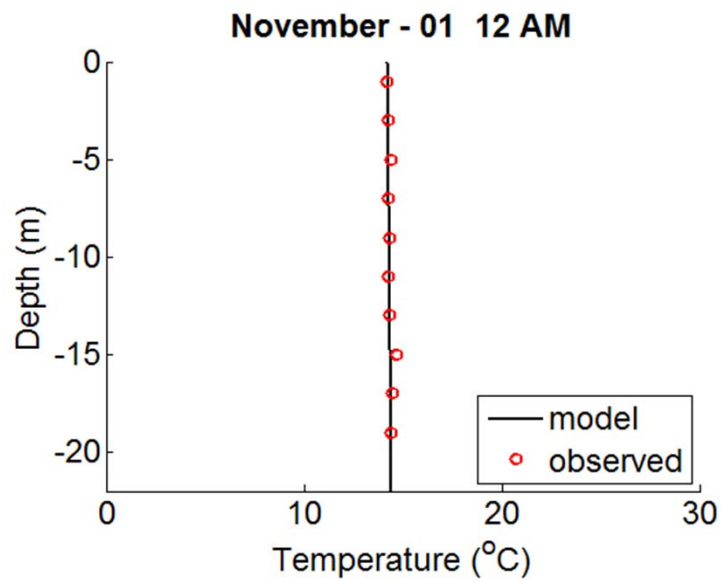


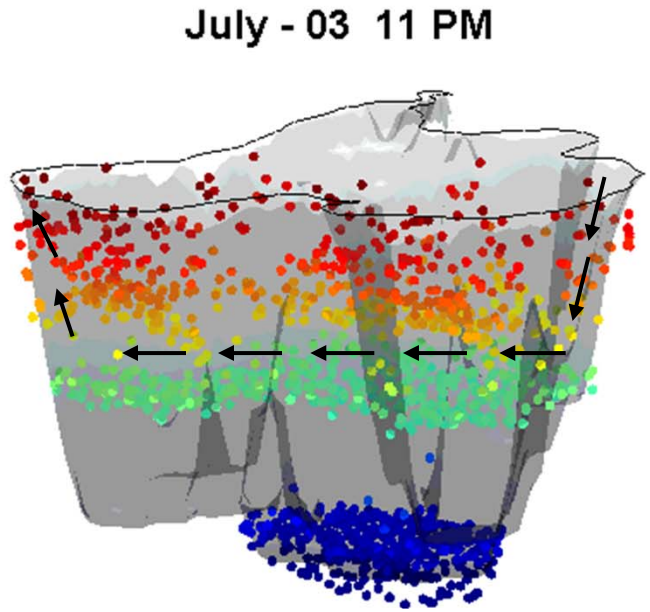

## Unstratified

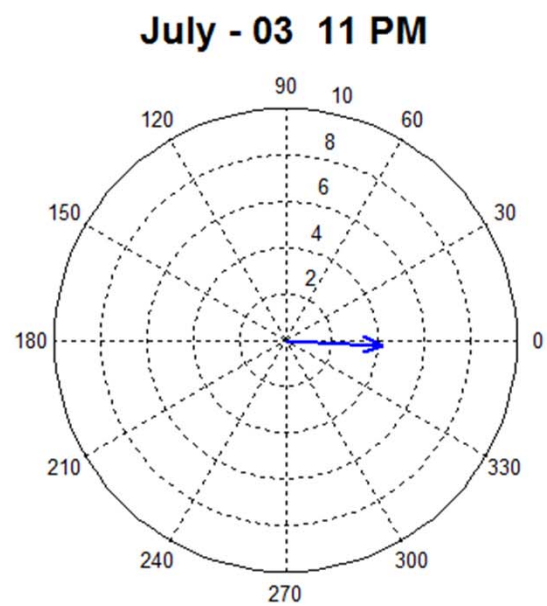


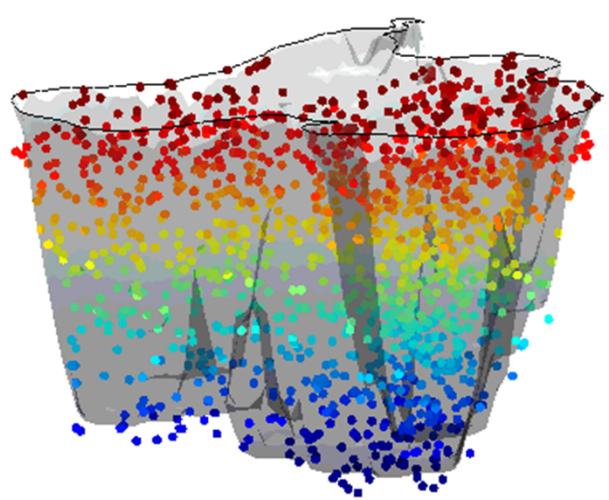
# Wind Up/Down welling

**Baroclinic**



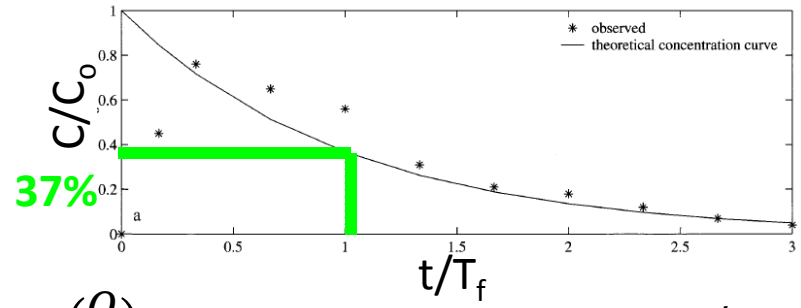




**Barotropic**



# Flushing Time

## Lake

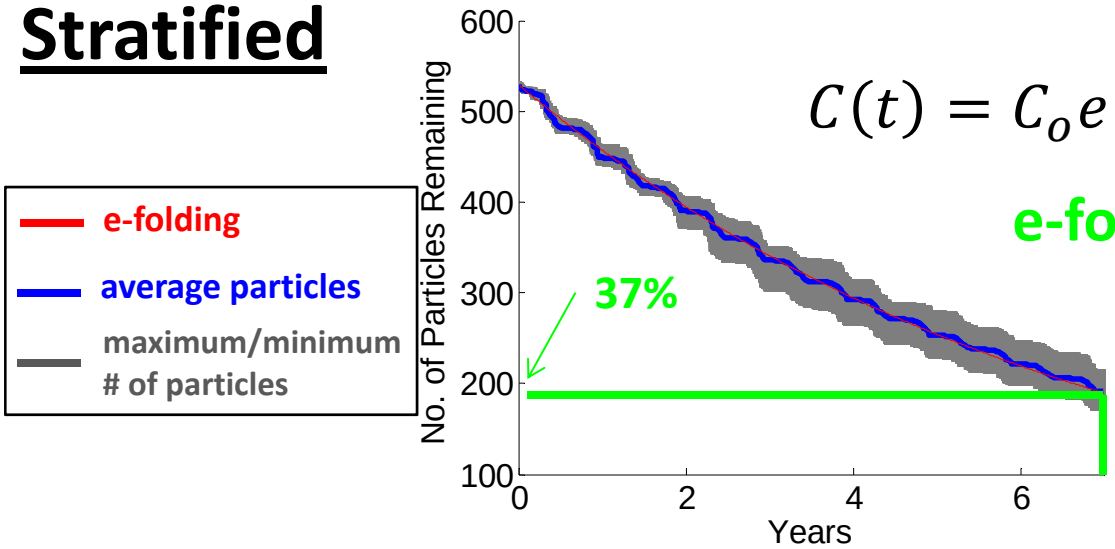



$$C(t) = C_o e^{-\left(\frac{Q}{V}\right)t} \longrightarrow C(t) = C_o e^{-t/T_f}$$

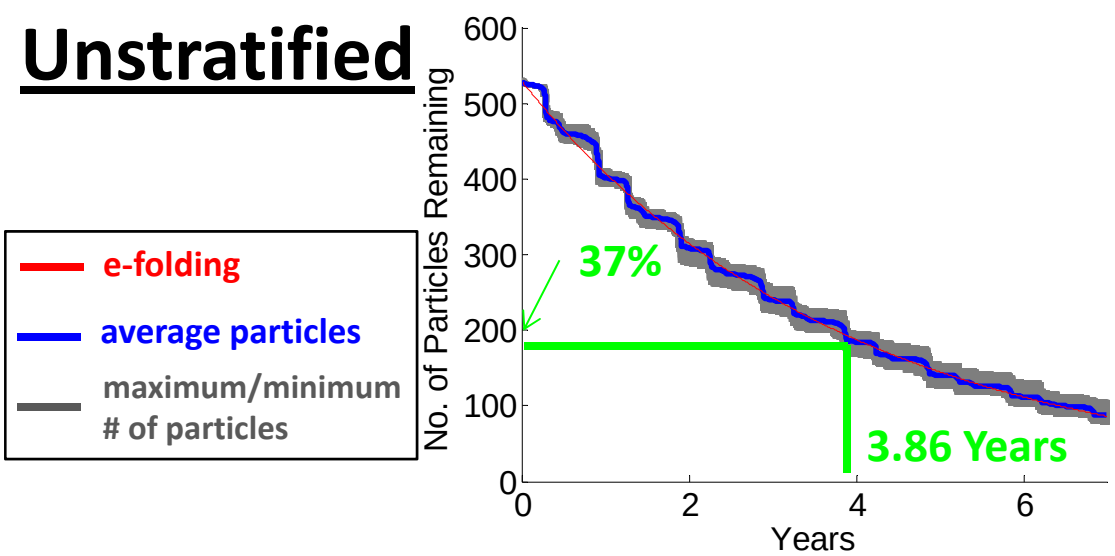
**e-folding:**

$$\ln C(t) = -\left(\frac{1}{T_f}\right)t + \ln C_o$$

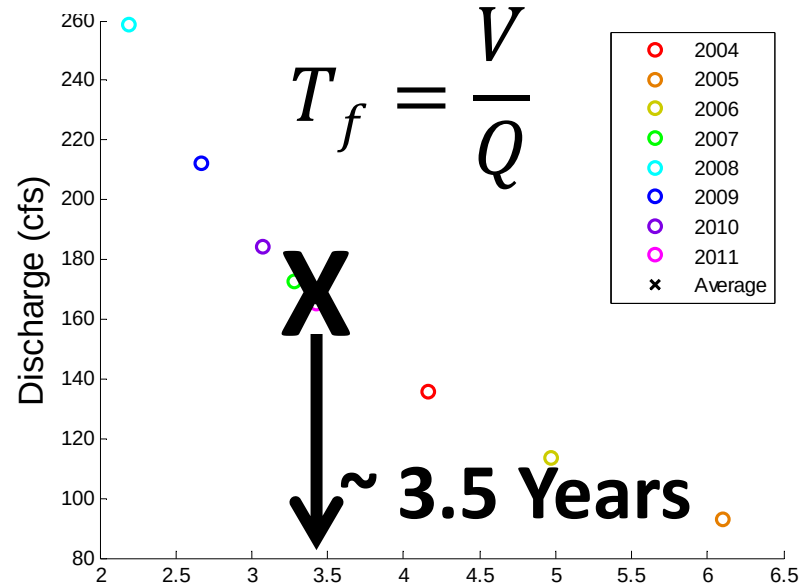
### Stratified




### Unstratified

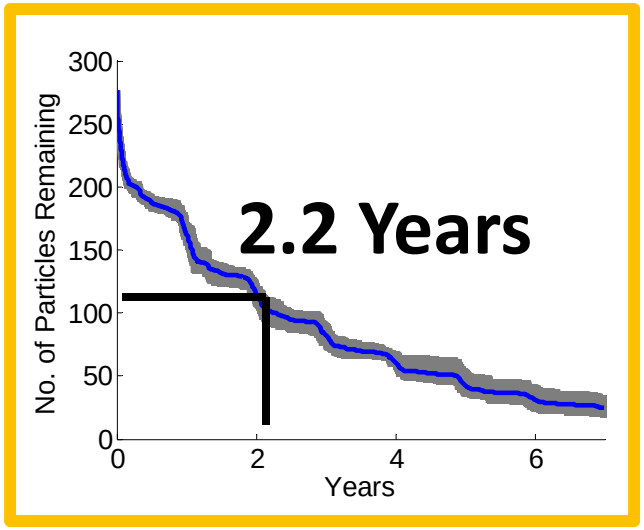


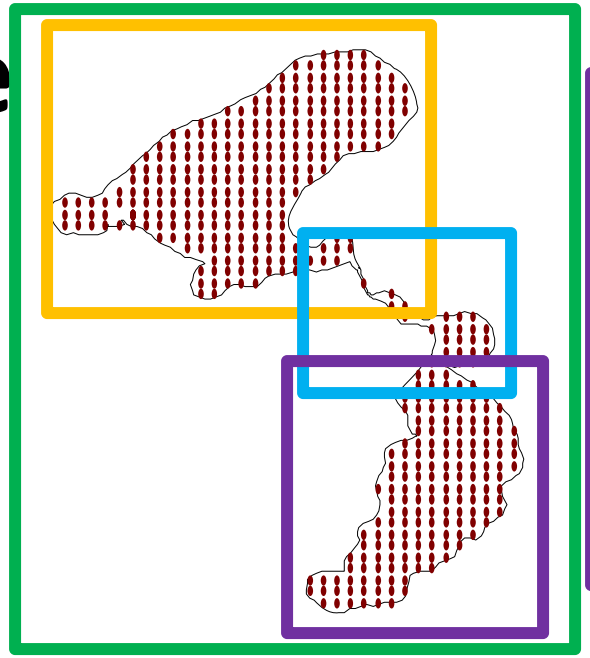

$$T_f = \frac{V}{Q}$$

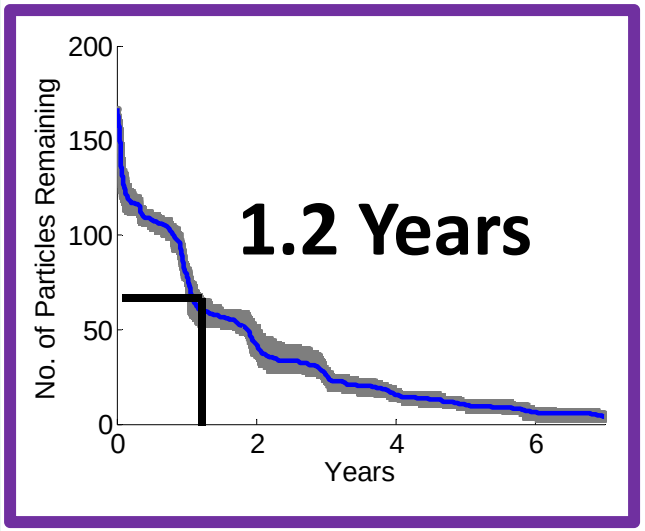


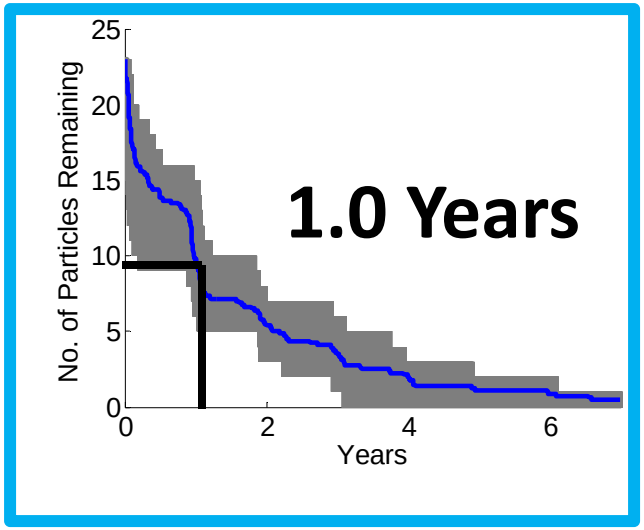
# Flushing Time

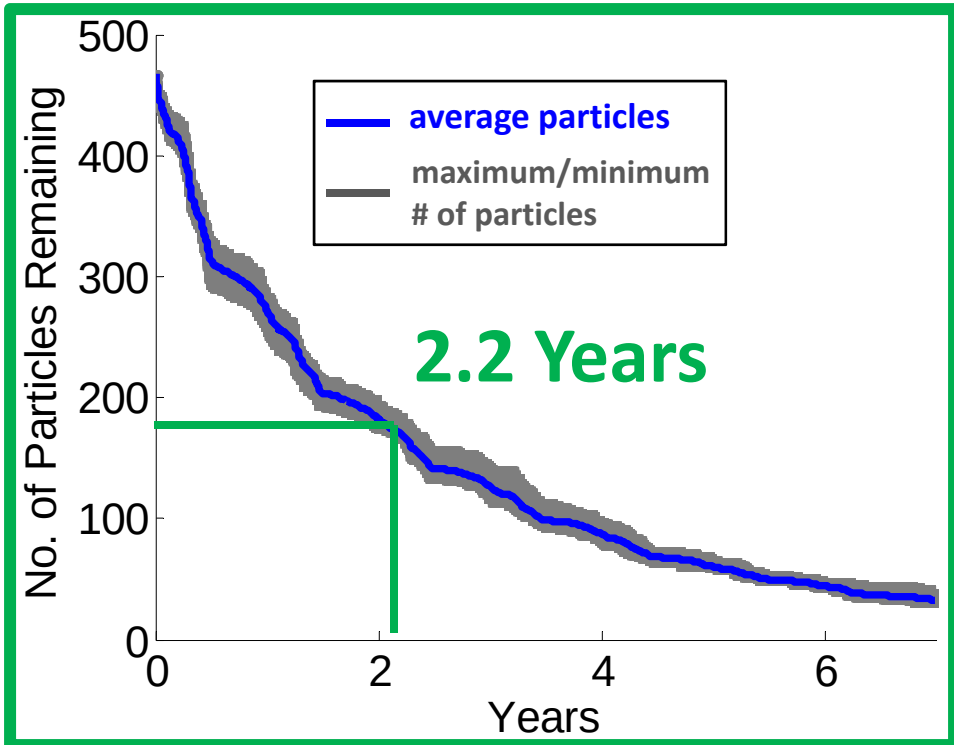
## Lake-River



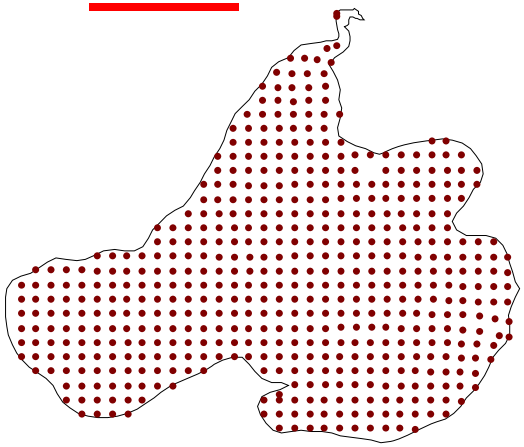


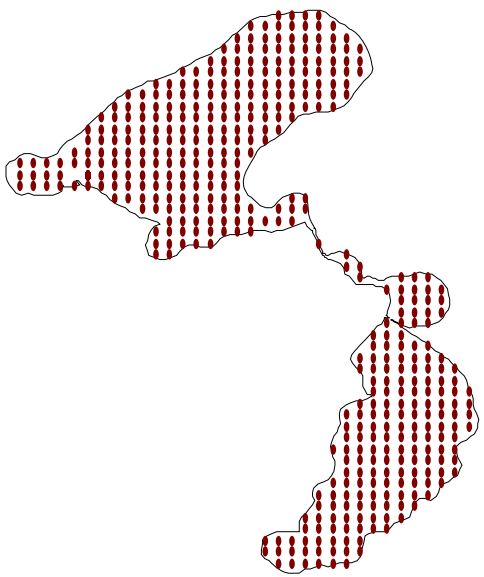



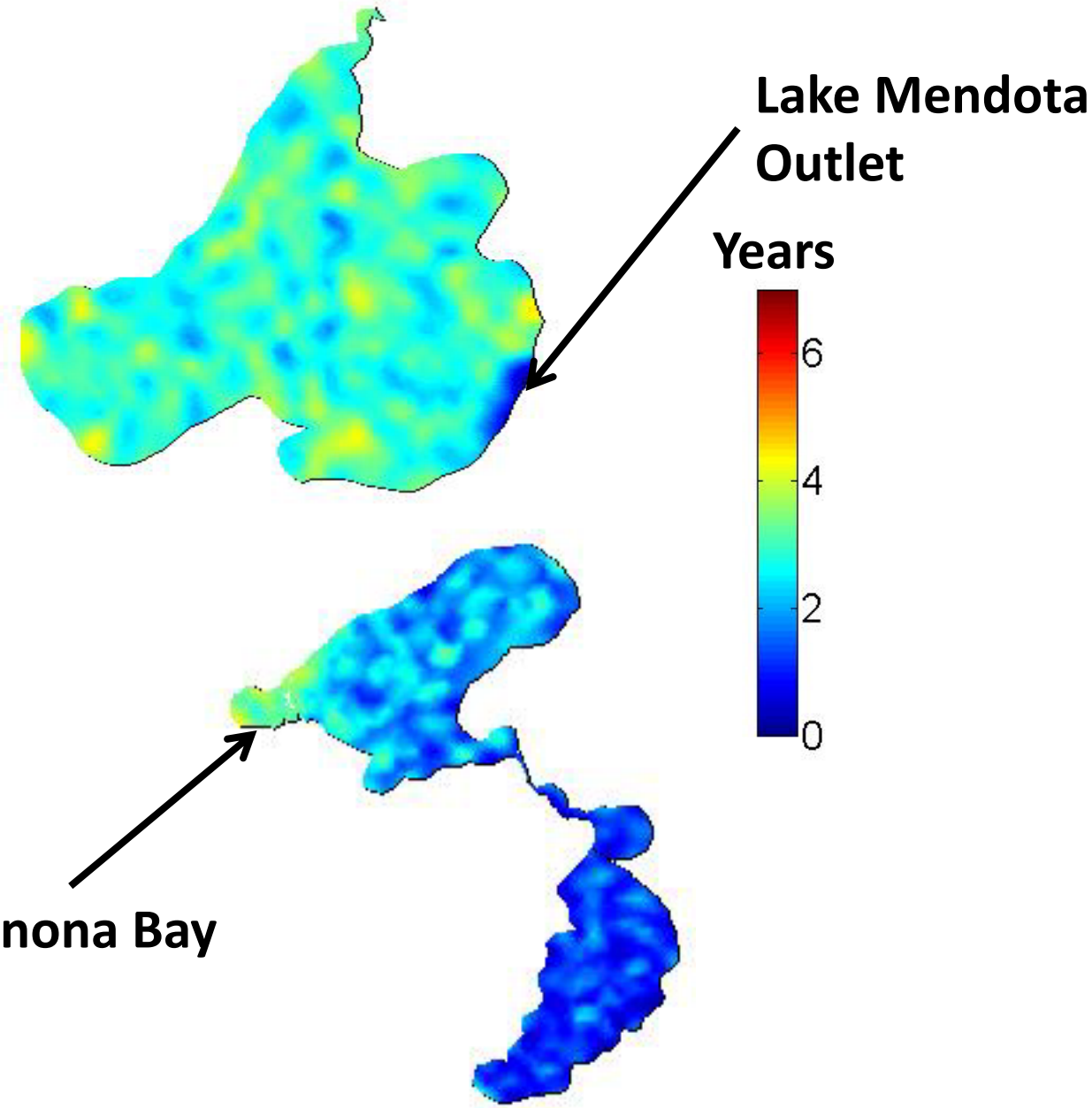
# Residence Time

**Lake**

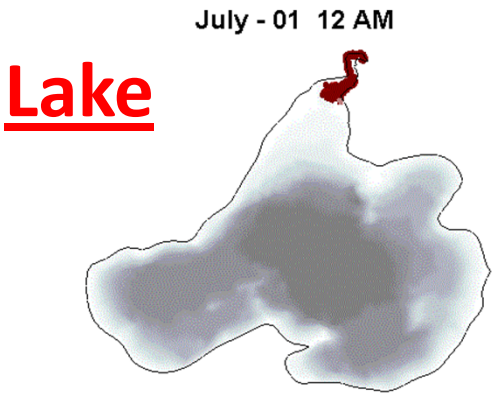


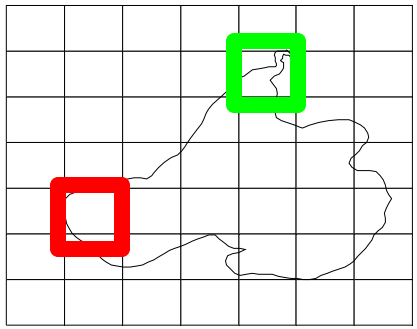
**Lake-River**

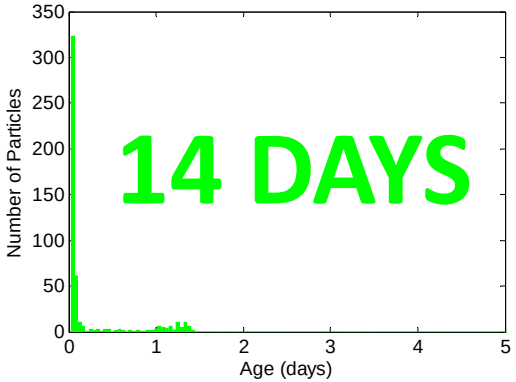


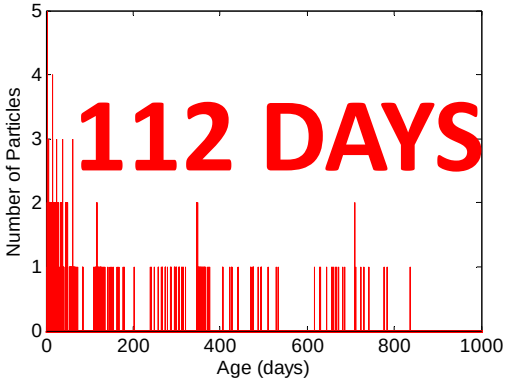


# Age


July - 01 12 AM
Lake

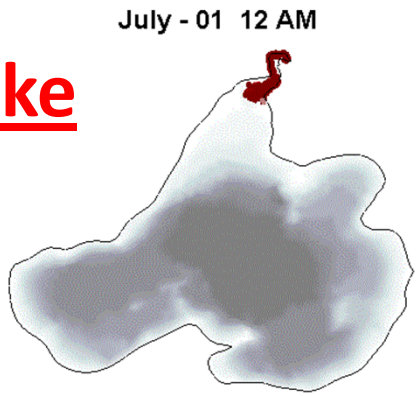


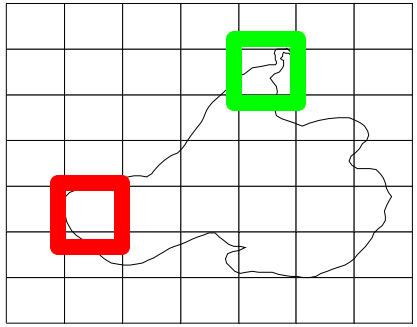

14 DAYS
Number of Particles
Age (days)
0
50
100
150
200
250
300
350
0
1
2
3
4
5

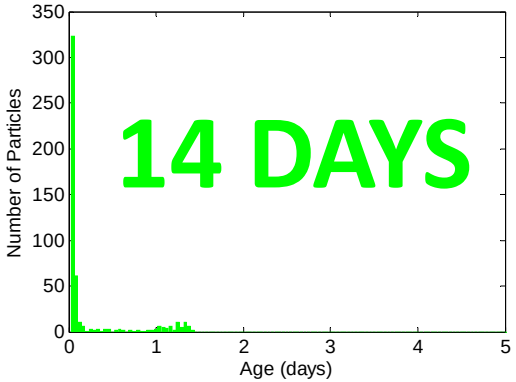

112 DAYS
Number of Particles
Age (days)
0
1
2
3
4
5
0
200
400
600
800
1000

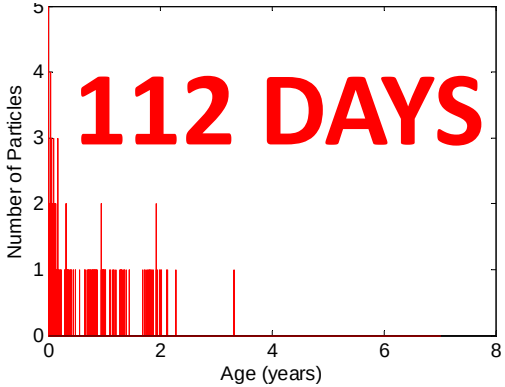
# Age

## Lake

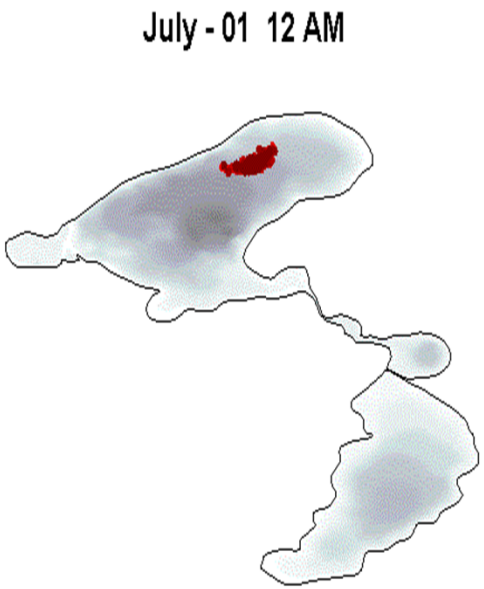


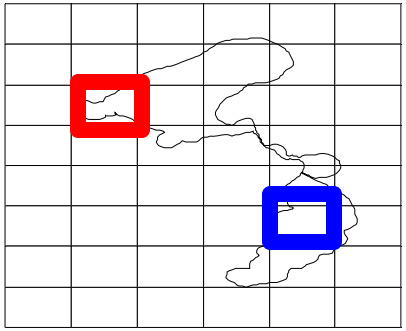



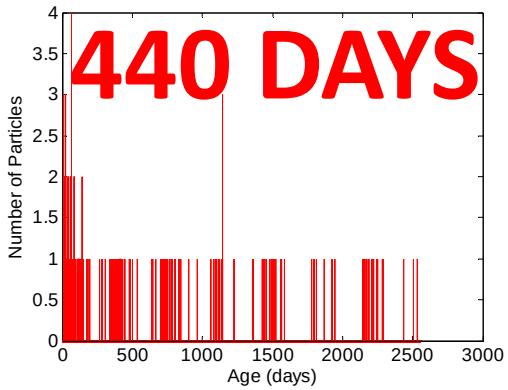


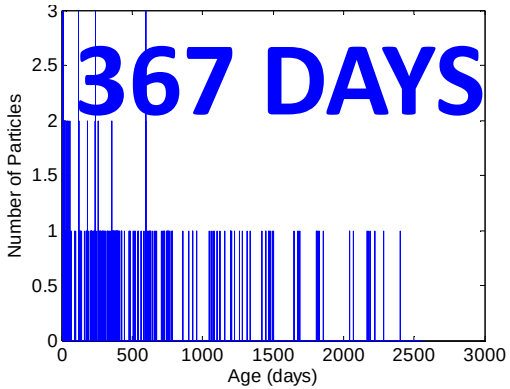




## Lake-River





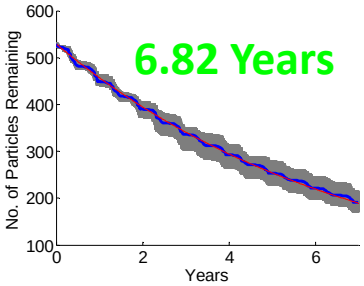



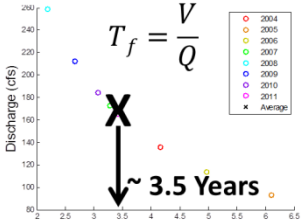
# Summary

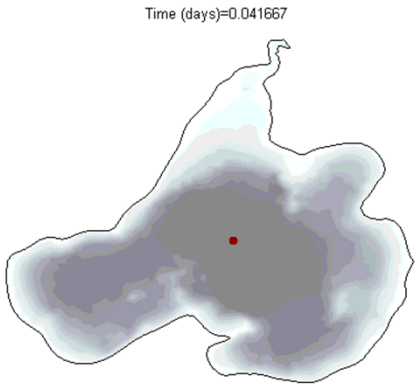
1. Hydrodynamic Model
2. Particle Transport Model

## Flushing Time

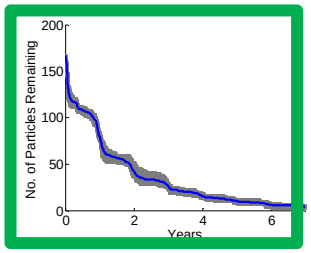
### Lake

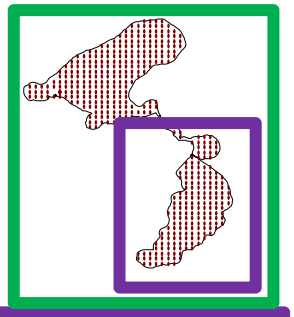


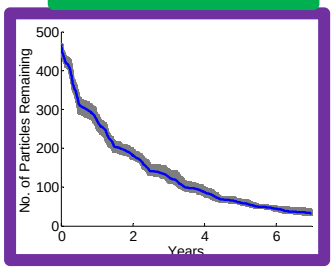




### Lake-River



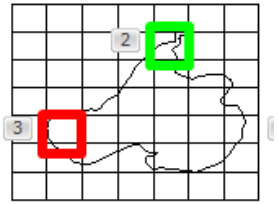


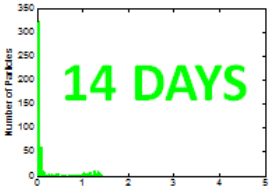

2.2 Years

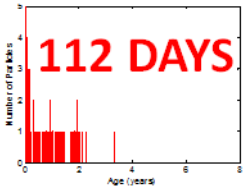
1.2 Years

## Age

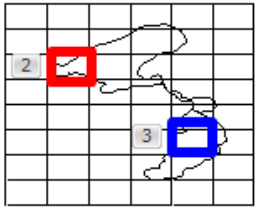
### Lake

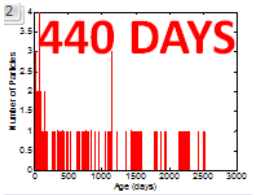


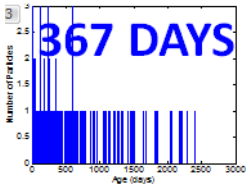




### Lake-River

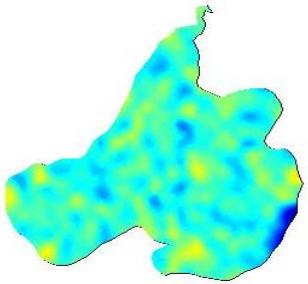


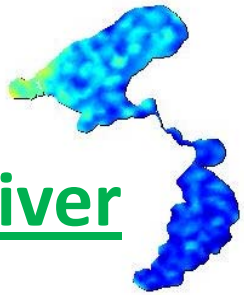




## Residence Time

### Lake



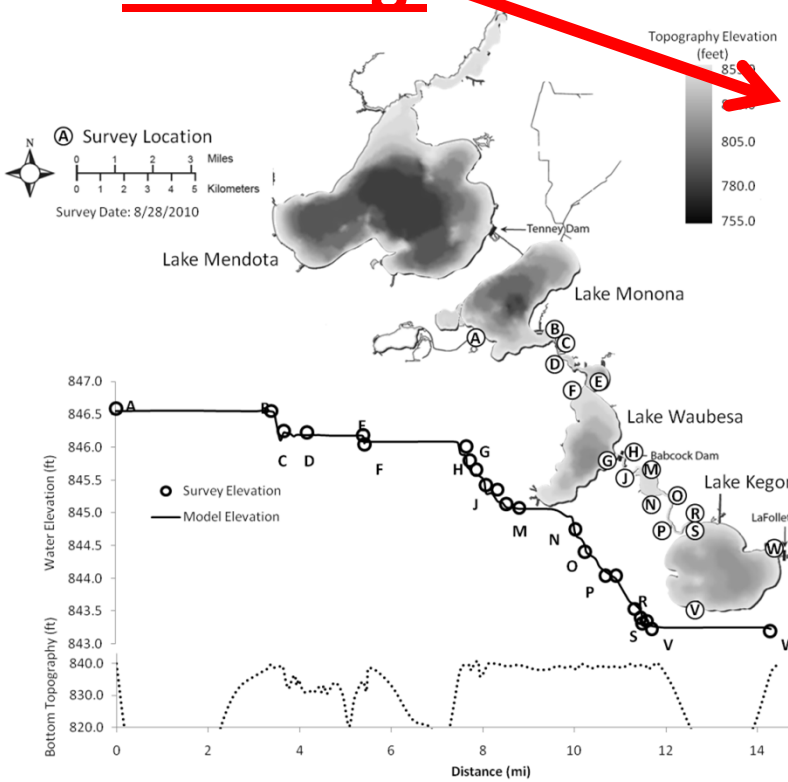
### Lake-River



# Future Work

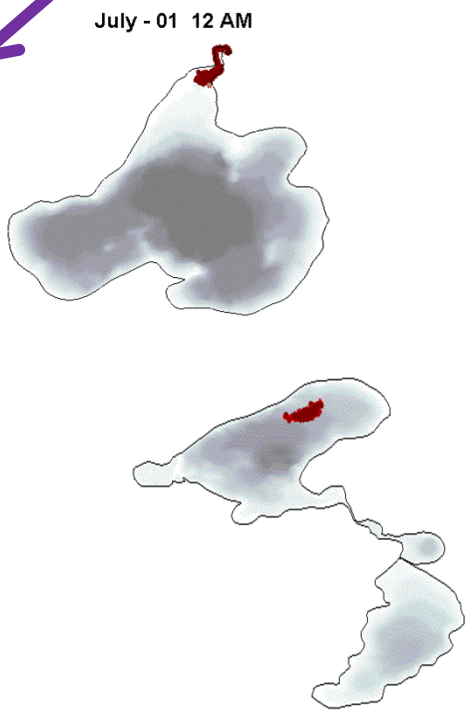
**Flooding**

**Quality**




## Optimization

### Lock/Dam Management




**Water Level RESPONSE**