Modeling Hydrodynamics and Water Quality for Wachusett Reservoir

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conducted for

MA Department of Conservation and Recreation (DCR)
Division of Water Supply Protection

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Acknowledgements

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- **MA Department of Conservation & Recreation**
  - **Division of Water Supply Protection**
  - **Consumers → MWRA → DCR**

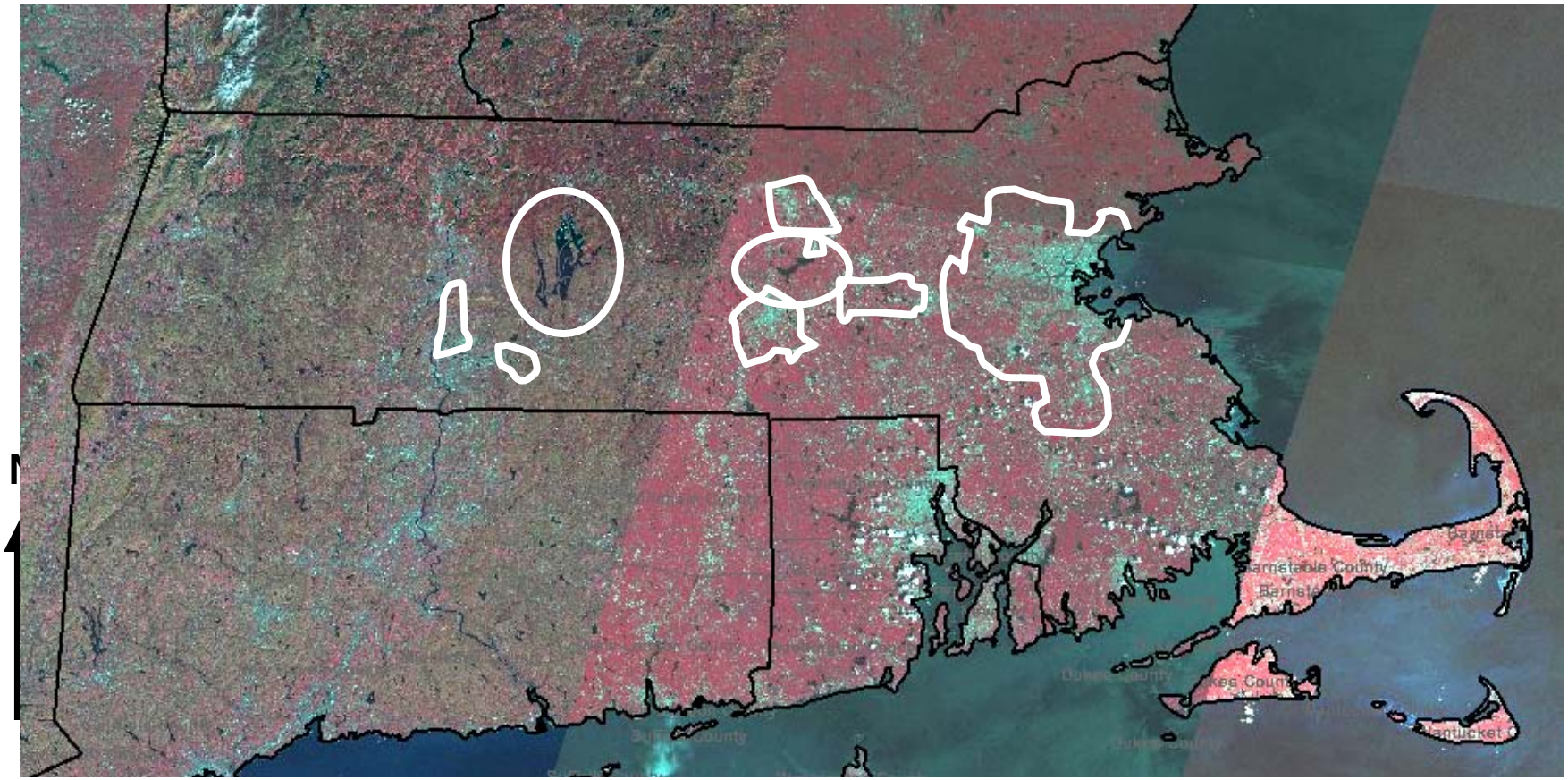
Essential Support:

- **DCR staff**
  - **Patricia Austin, Bill Pula, many others!**
- **MA Water Resources Authority (MWRA)**
- **UMass Faculty Colleagues**
  - **David Reckhow, Paula Rees, Sharon Long, Jim Edzwald, Jim Male**

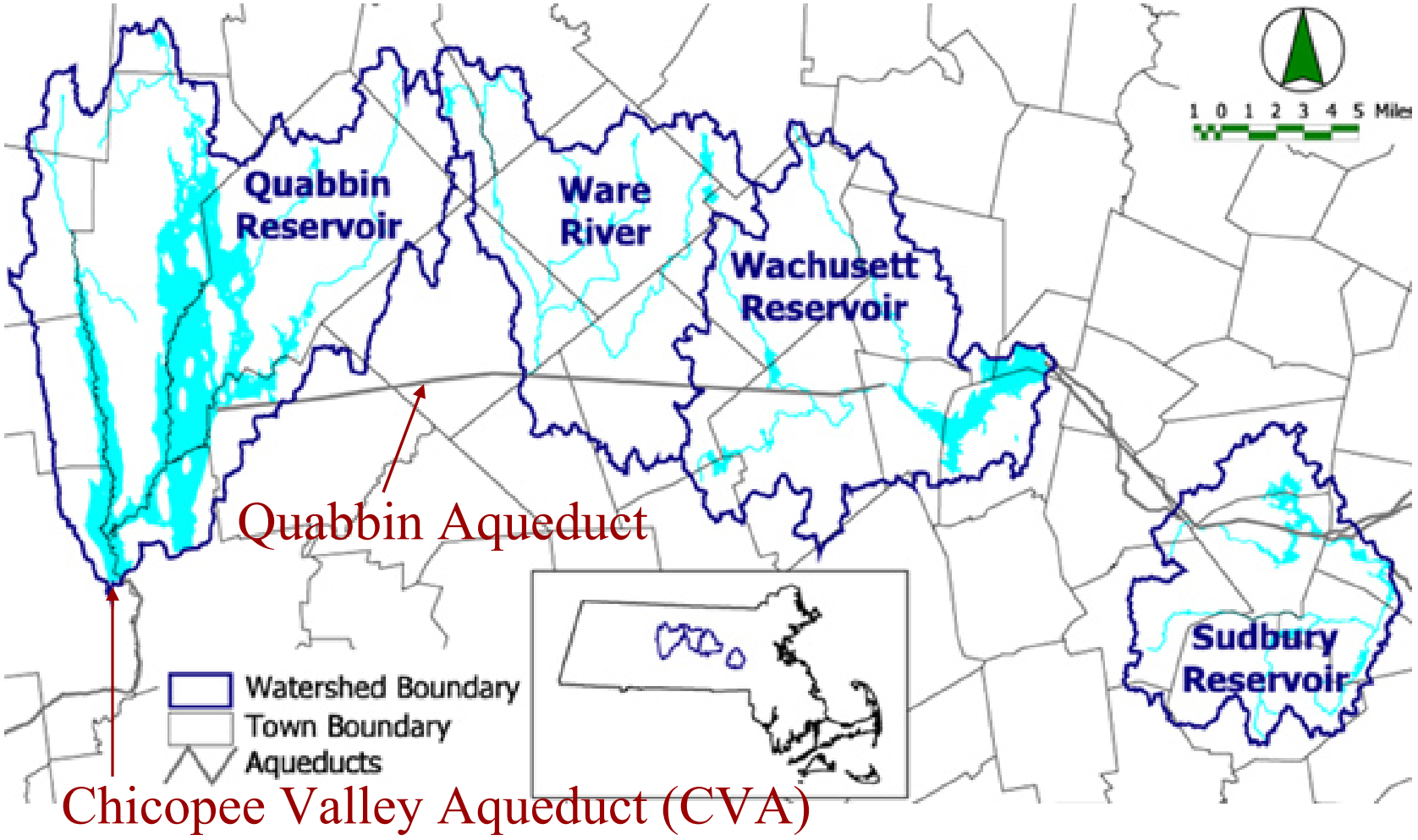
Real Work!

- **UMass graduate students (1995-2007)**
  - **Michael Hayes, Evelyn Wolfram, Elisa Garvey, Diane Mas, Alejandro Joaquin, Matt Kennedy, Meg Roberts, Rebecca Pease, Dan Buttrick, Thomas Matthews, Mary Serdakowski, Christina Stauber**

DCR/MWRA System



DCR/MWRA Reservoir System



DCR/MWRA System

- **Management**
  - DCR – watersheds & reservoirs
  - MWRA – transmission, treatment, bulk supply
- **Source Reservoirs (for about 2.5 million population)**
  - Quabbin – west central MA
  - Wachusett – central MA
- **Treatment**
  - Quabbin: free chlorination only, add UV in future
  - Wachusett: ozonation (7/05) & chloramination only, UV in future
  - pH and alkalinity adjustment
  - no coagulation/filtration; no removal of NOM/DBP precursors
- **Water Quality Management Strategies**
  - Watershed protection: best management practices; land use
  - Quabbin to Wachusett Transfer operation

System Quantity

Item	Quabbin Reservoir	Wachusett Reservoir	Unit
Capacity	412	65	BG
Watershed Area	187	117	mi^2
Average Depth	52	51	feet
Mean Hydraulic Residence time	5.9	0.6	years
Average Discharge	125	220	MGD
Discharge Range	0 - 300	170 - 325	MGD
Outlet	Swift River	Nashua River	
Destination	Wachusett and CVA	Metro-Boston	

System Quality

Item	Quabbin Reservoir	Wachusett Reservoir	Unit
Conductivity	40 - 50	70 - 110	µS/cm
Phosphorus	<5 - 9	<5 - 18	µg P/L
Ammonia	<5 - 21	<5 - 26	µg N/L
Nitrate	<5 - 21	15 - 130	µg N/L
Algae	≤ 900	≤ 1700	ASU/mL
TOC	1.5 - 2.5	1.8 - 3.5	mg/L
UV 254	0.015 - 0.030	0.03 - 0.09	cm^{-1}
Trophic State	Oligotrophic	Oligo-mesotrophic	

UMass/DCR Project Objectives

Long Term

- Maintain field/lab/modeling expertise directed at improved science-based watershed & reservoir management decisions
- Working from 1995 to present

Shorter Term

- Evaluate specific management issues
- Verify impact of management practices
- Respond to new/developing priority issues

Project Structure & Studies

- **Watershed Process Characterization**
  - Sources/type/amount of natural organic matter (NOM)
  - Assessment of storm-event based water quality sampling (with AwwaRF)
  - Tasks: field sampling, water quality analyses, laboratory experiments, modeling
- **Microbiological Issues**
  - Alternative indicator organisms for source tracking
  - Assessment of impacts of land use & sanitation changes
  - Understanding source/occurrence of reservoir coliforms
- **Reservoir Hydrodynamics and Water Quality**

Reservoir Modeling & Measurements

Hydrodynamics

- Water budget – data needs/ gaps
- Water velocities & transport time
- Water transfer impacts
- 2D CE-QUAL W2 & 3D Fluent CFD model
- Developing 3D GEMSS model

Water Quality

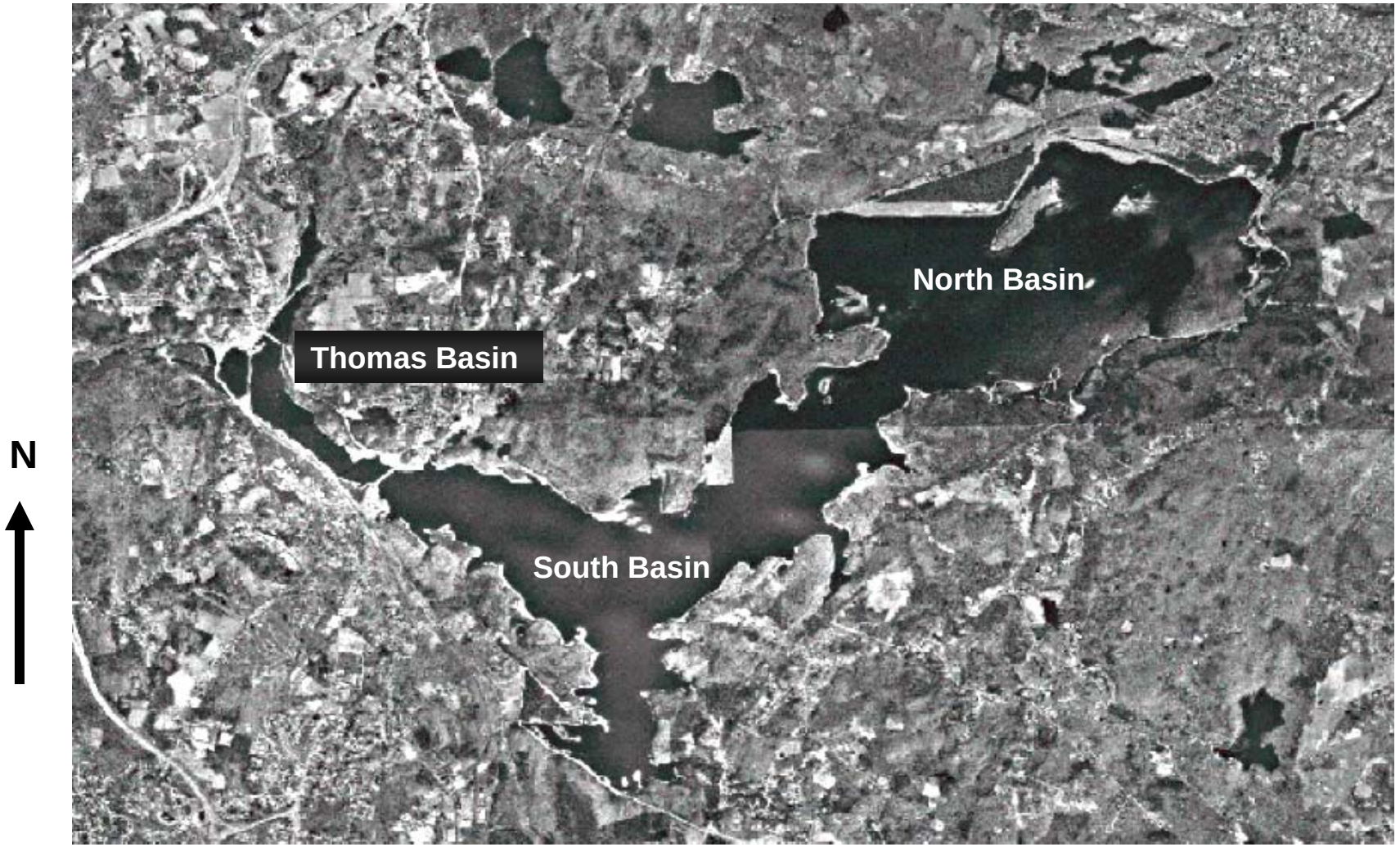
- Coliform
- NOM (algae, TOC, DOC, UV254, etc.)
- Nutrients (N,P)
- Contaminant Spills

Quabbin Reservoir

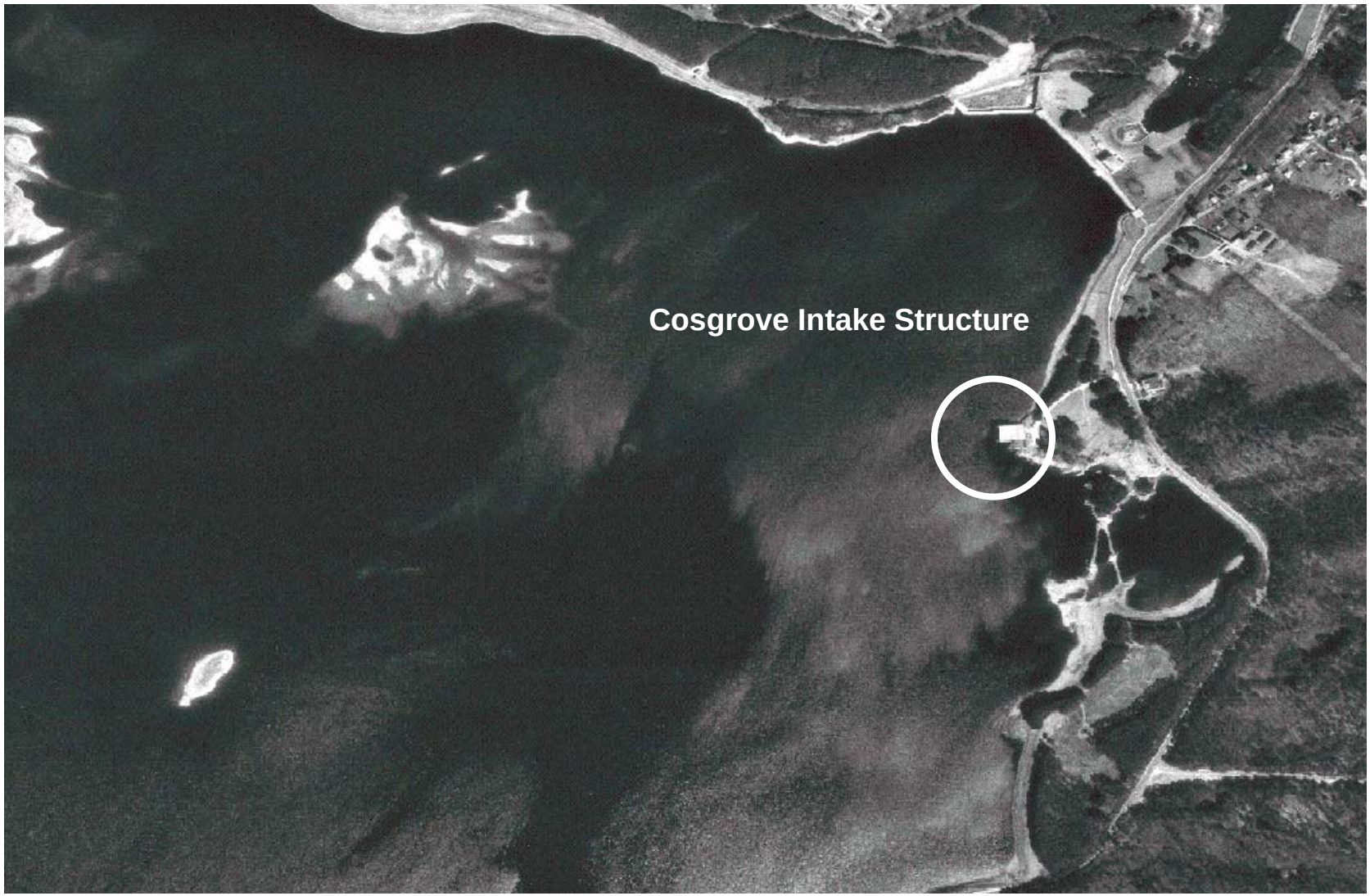
Quabbin Reservoir Studies

- **Impact of Gull Roosting on Coliforms**
  - **Confirmed need for DCR gull harassment to avoid coliform violations [important for filtration waiver]**
- **NOM: Inputs & Transformations**
  - **Assessed concentration & character of NOM, relationships between NOM measures, material flux balances**

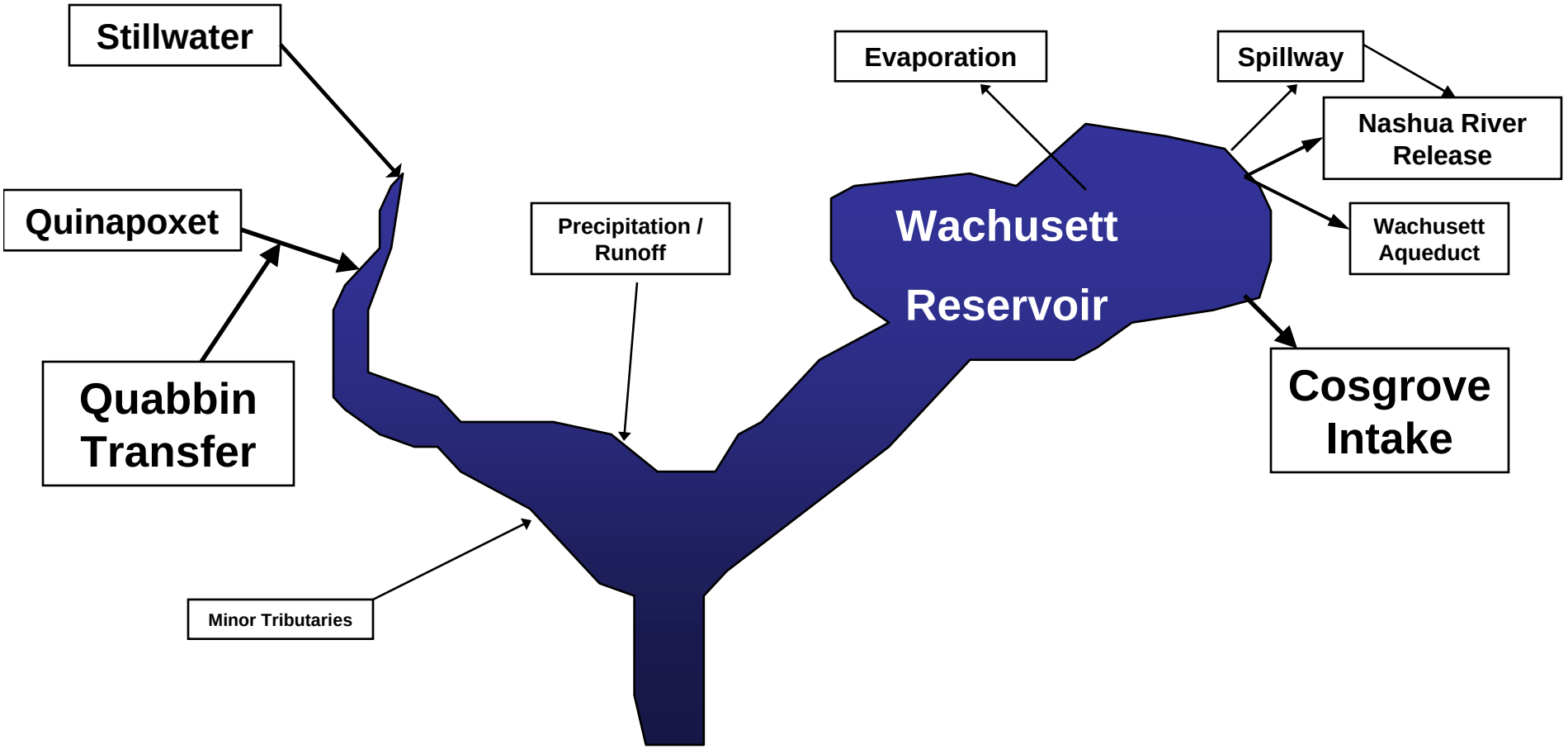
Wachusett Reservoir



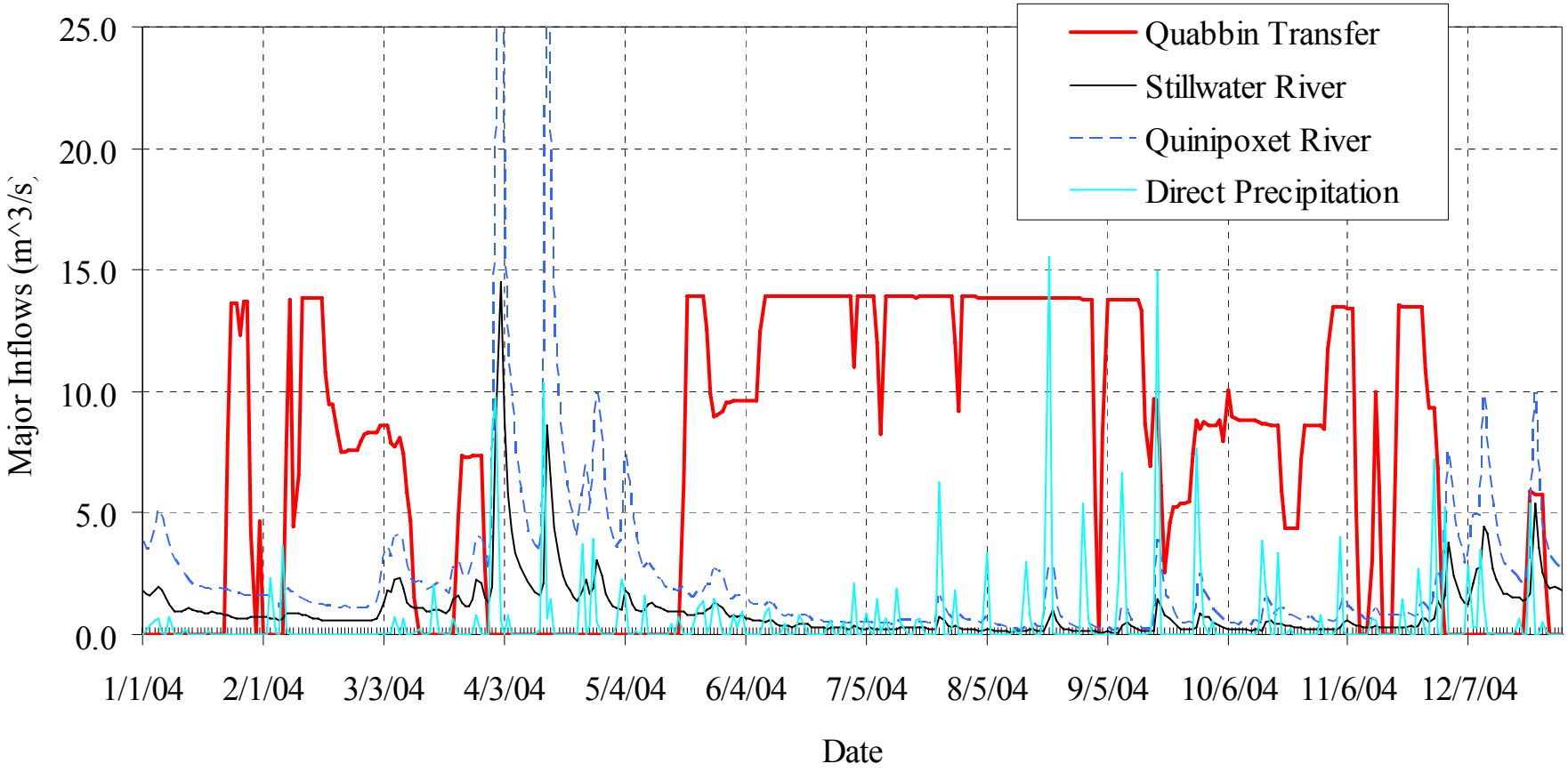
Cosgrove Withdrawal to WTP



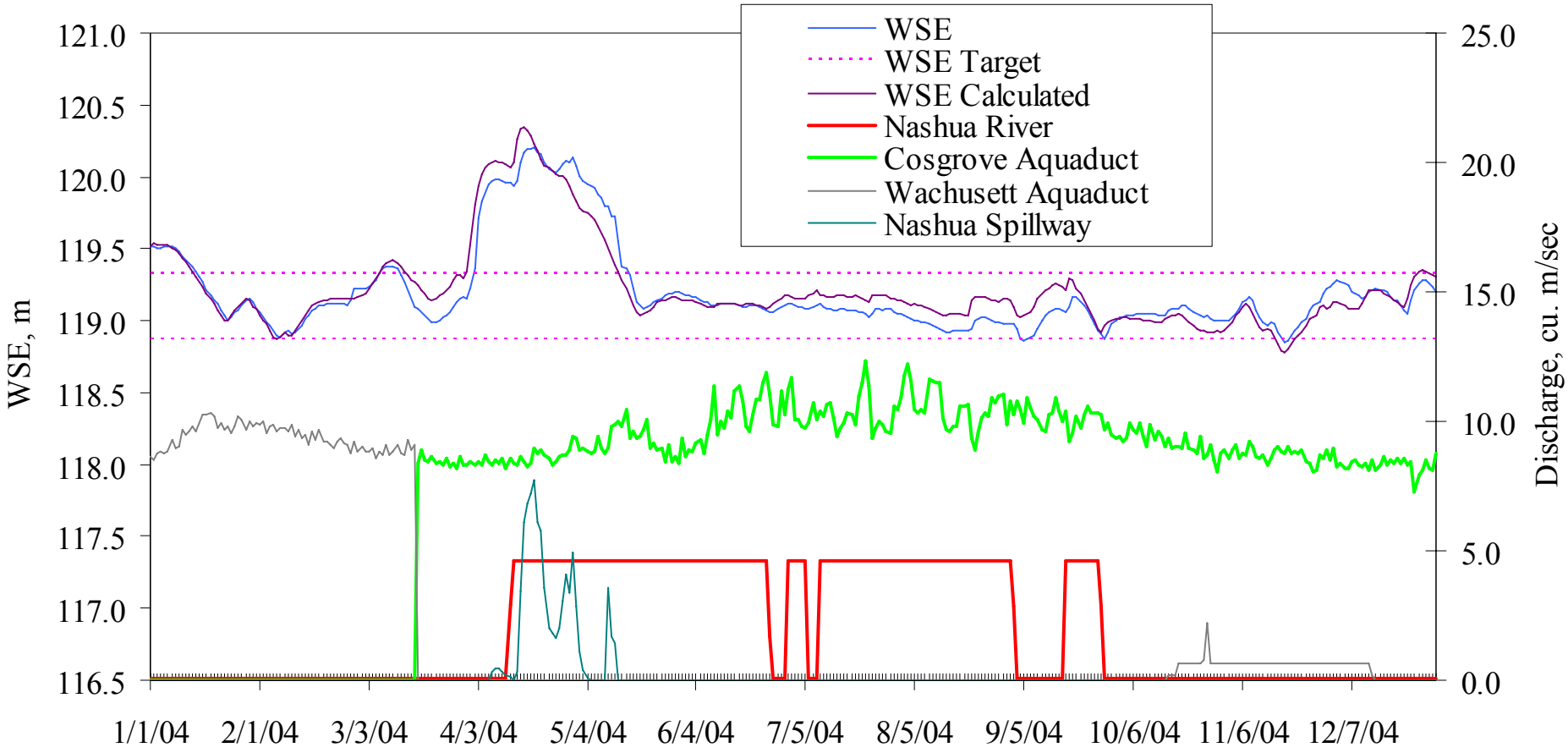
Wachusett Inputs/Outputs



2004 Inflow Hydrograph

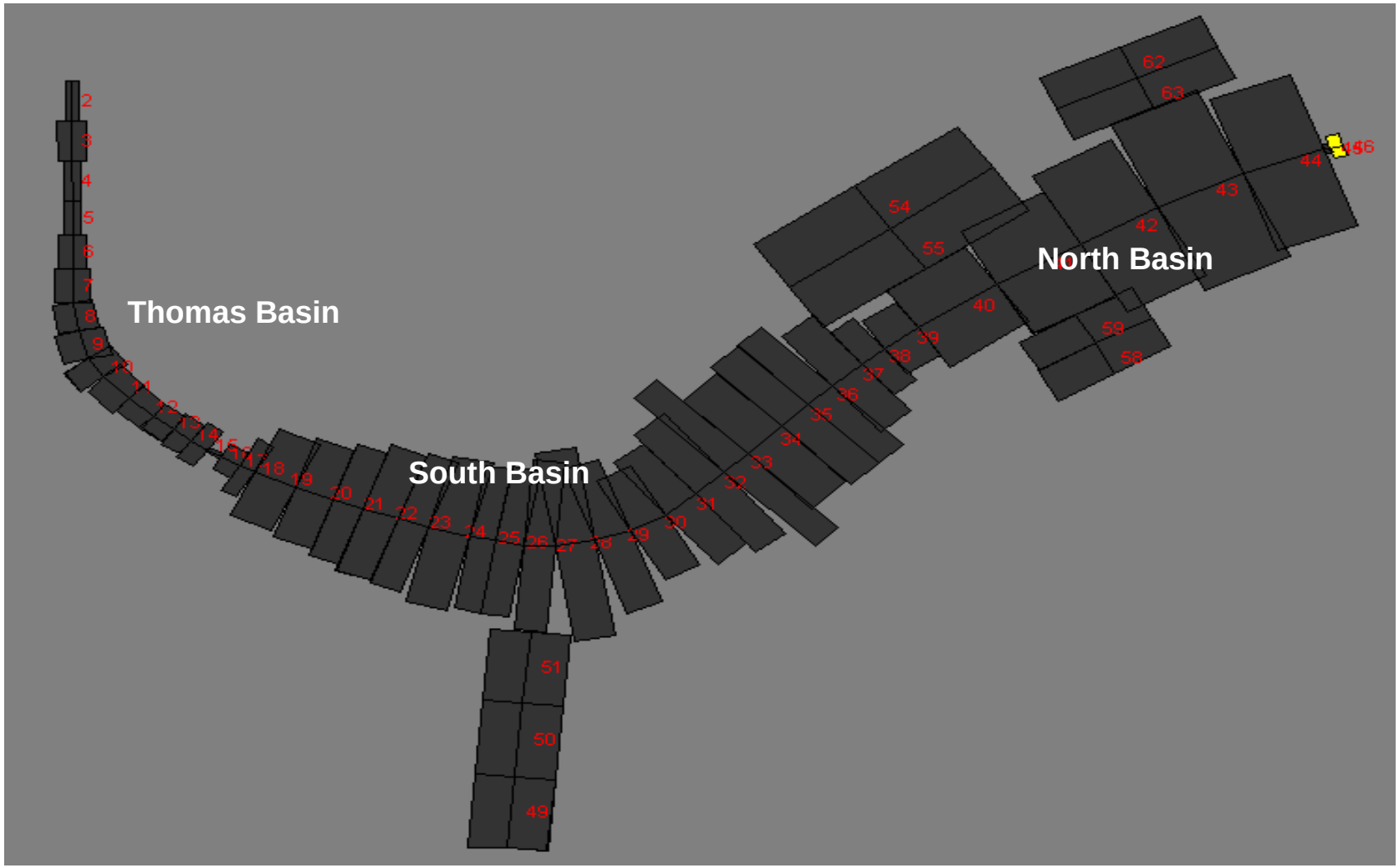


2004 Outflow Hydrograph & WSE

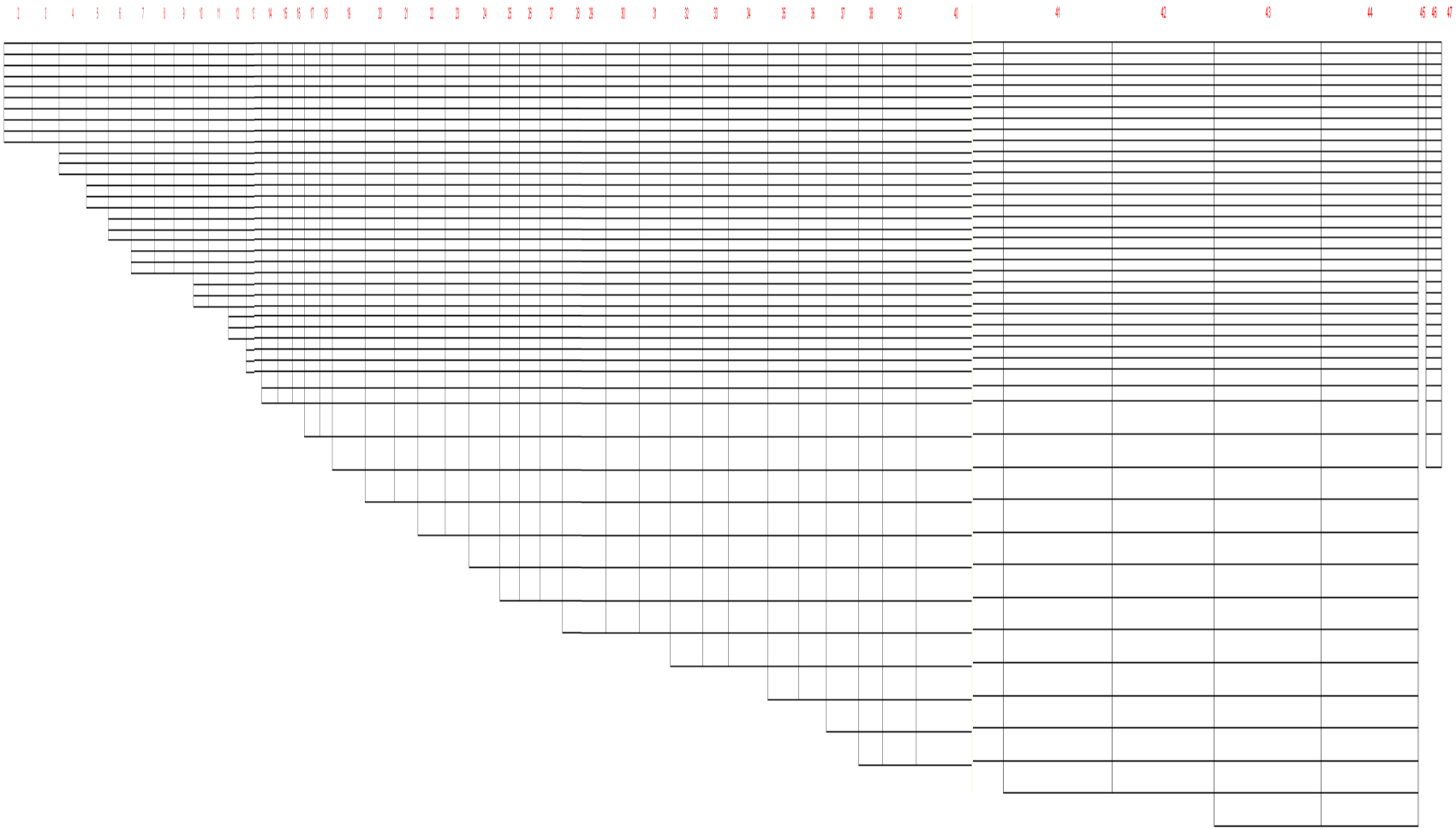


Spillway calibration
to 393.5 and 392.5 ft

CEQUAL W2 Wachusett Reservoir

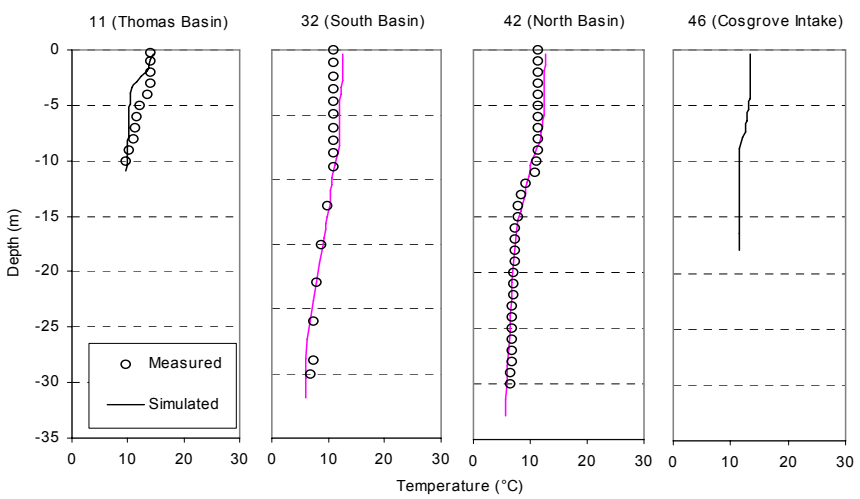


CEQUAL W2 Wachusett Reservoir – Layer Profile

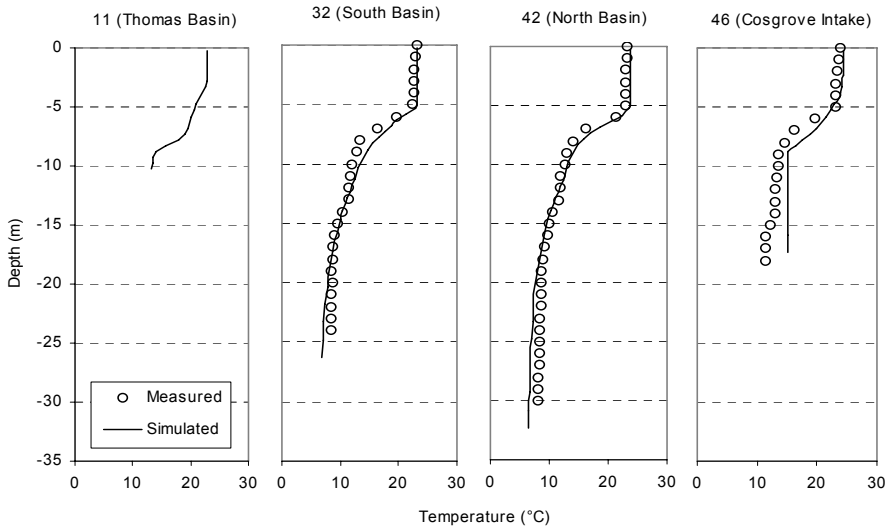


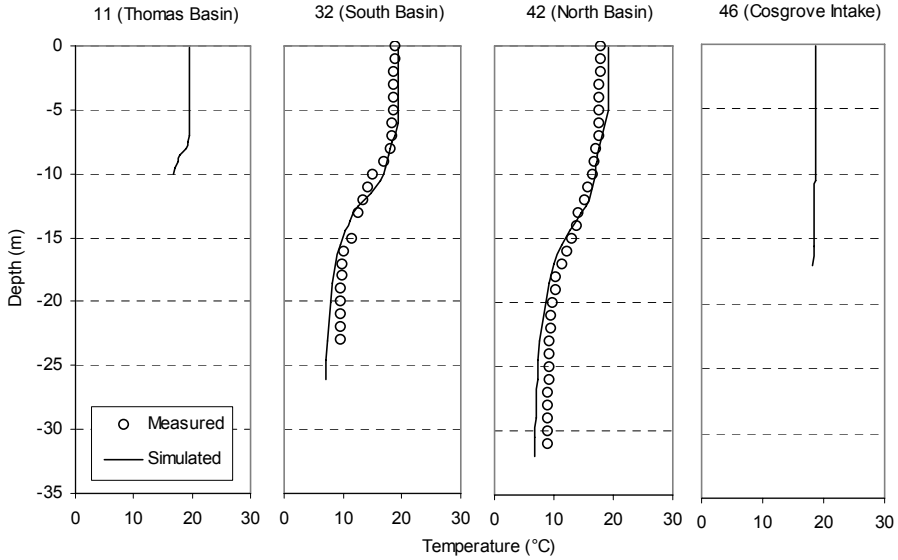
2004 Temperature Profiles

May 4, 2004



July 7, 2004

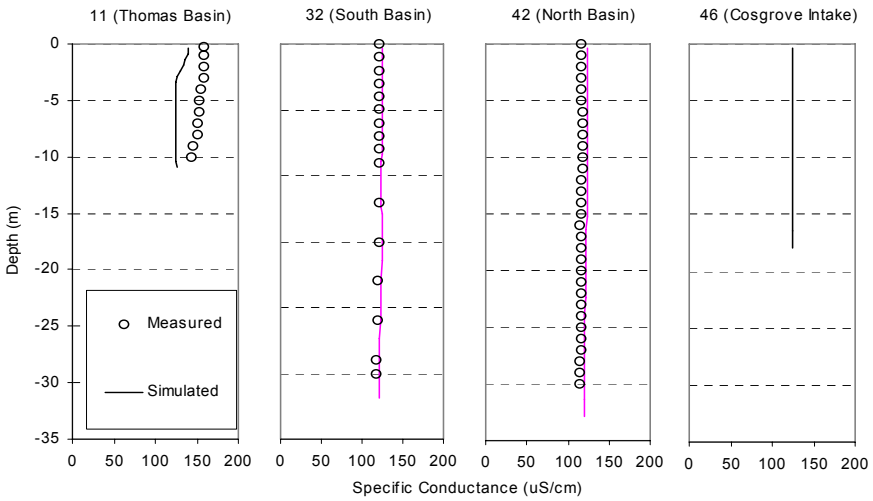




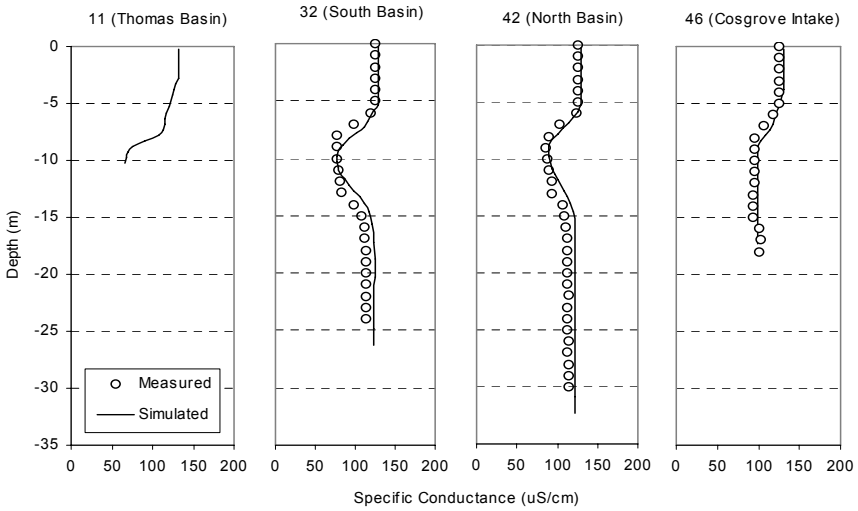
September 30, 2004

2004 Conductivity Profiles

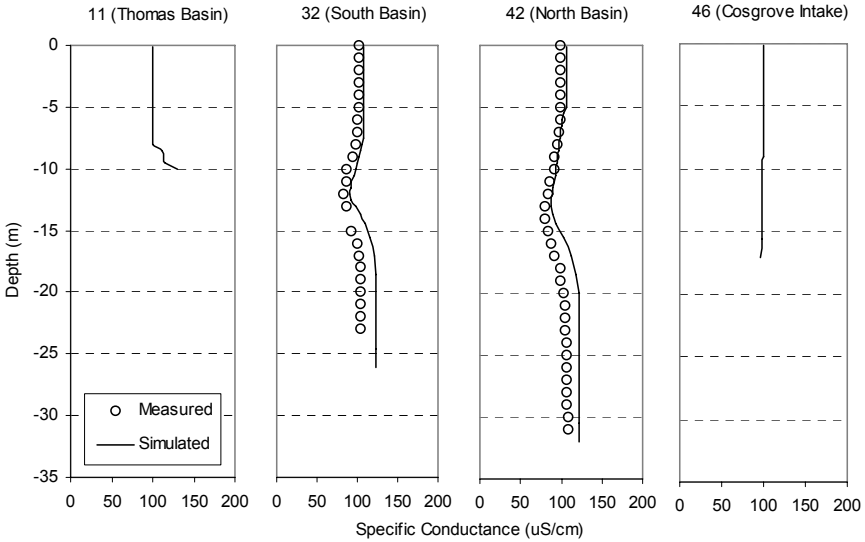
May 4, 2004



July 7, 2004

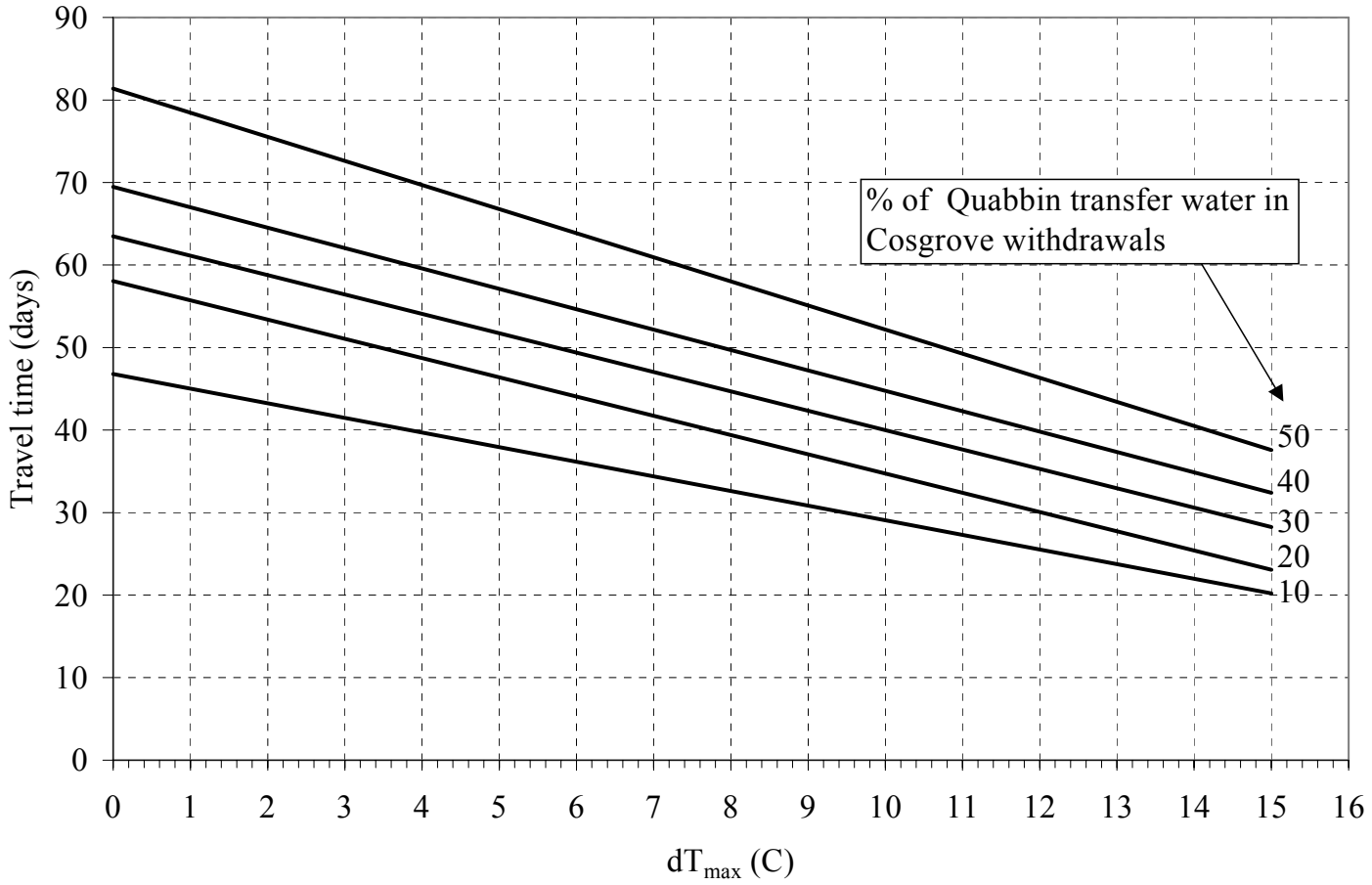


September 30, 2004



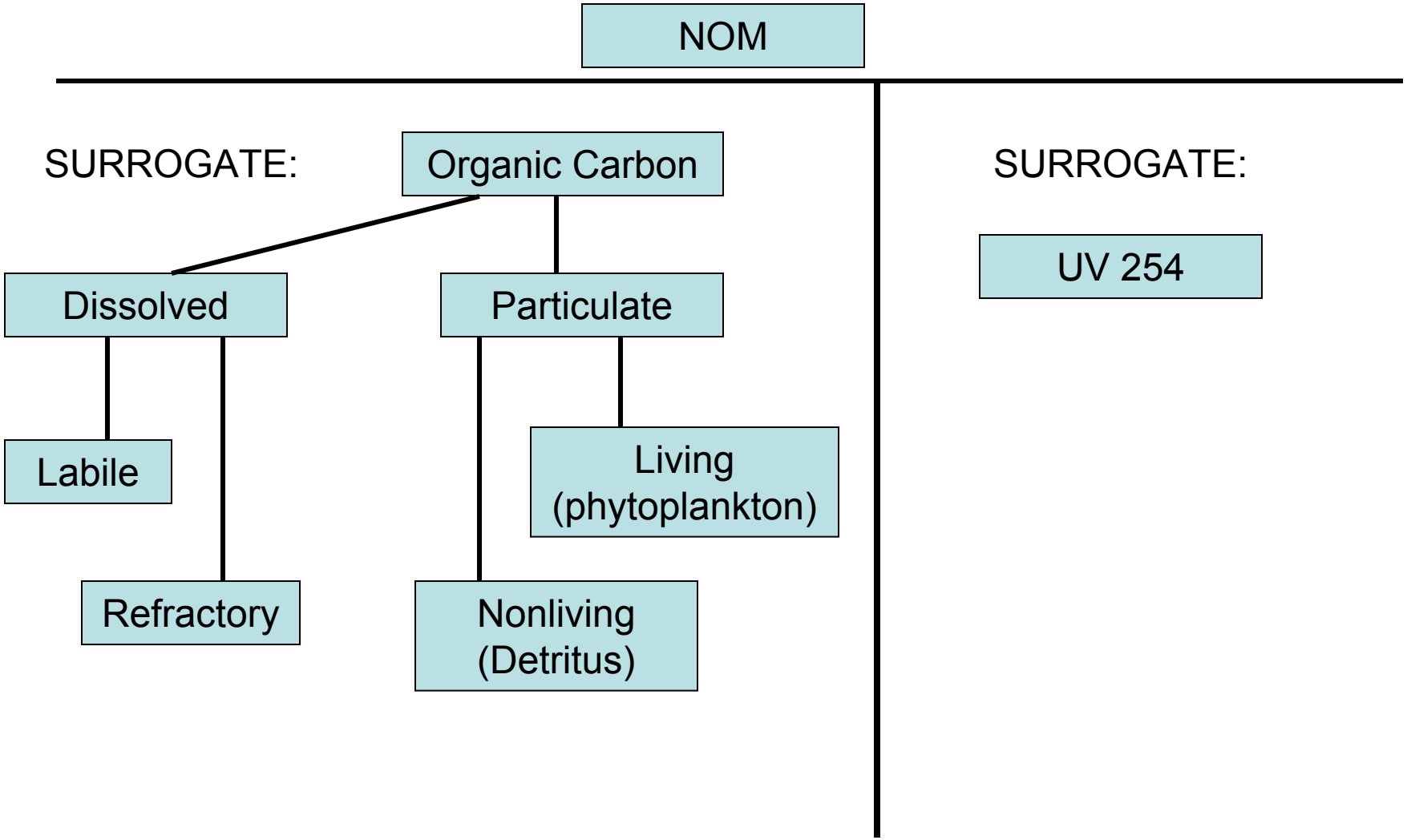
Travel Time vs Stratification Based on Simulation Results

(Alejandro Joaquin MSEVE 2001)



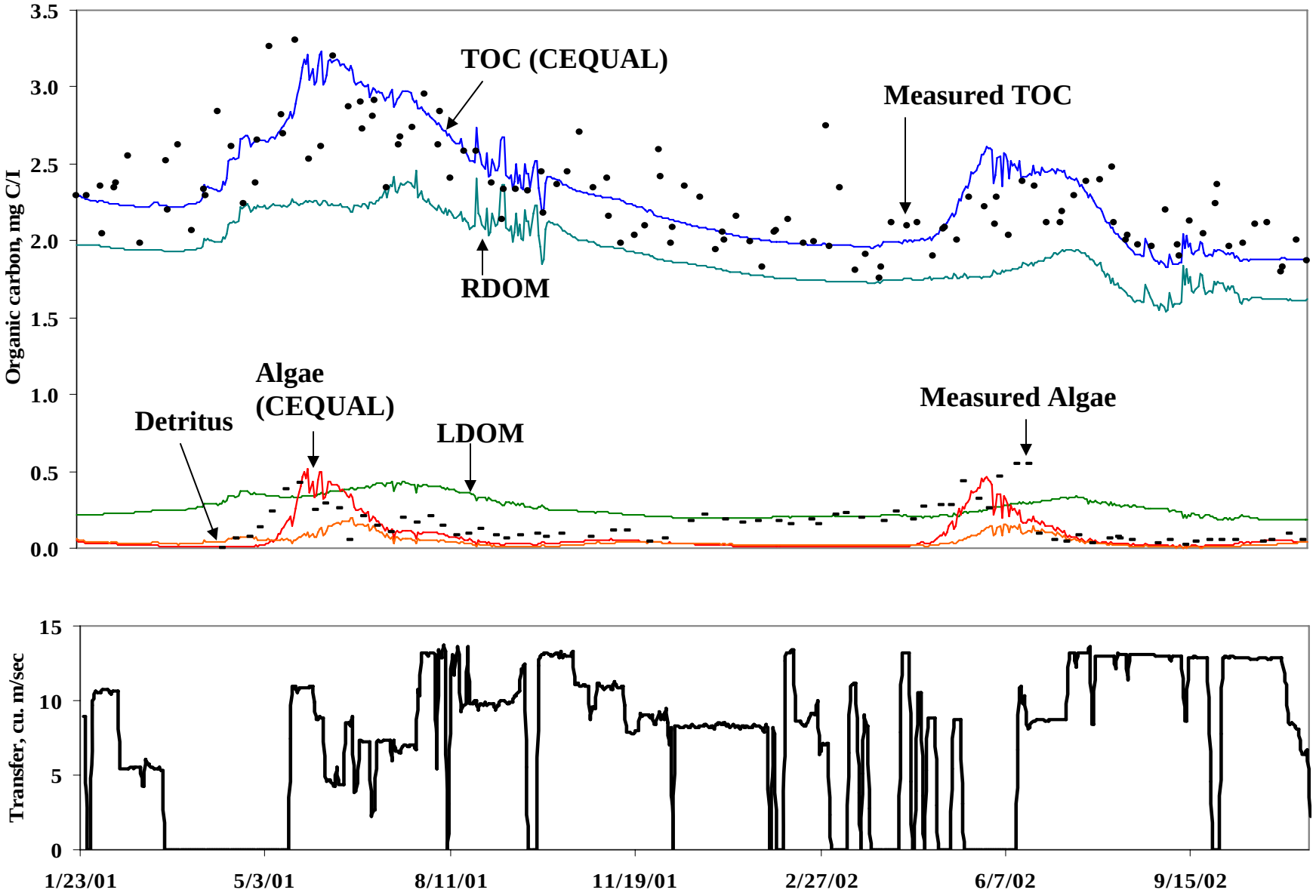
Epilimnion to Hypolimnion Temp Difference

Modeling NOM



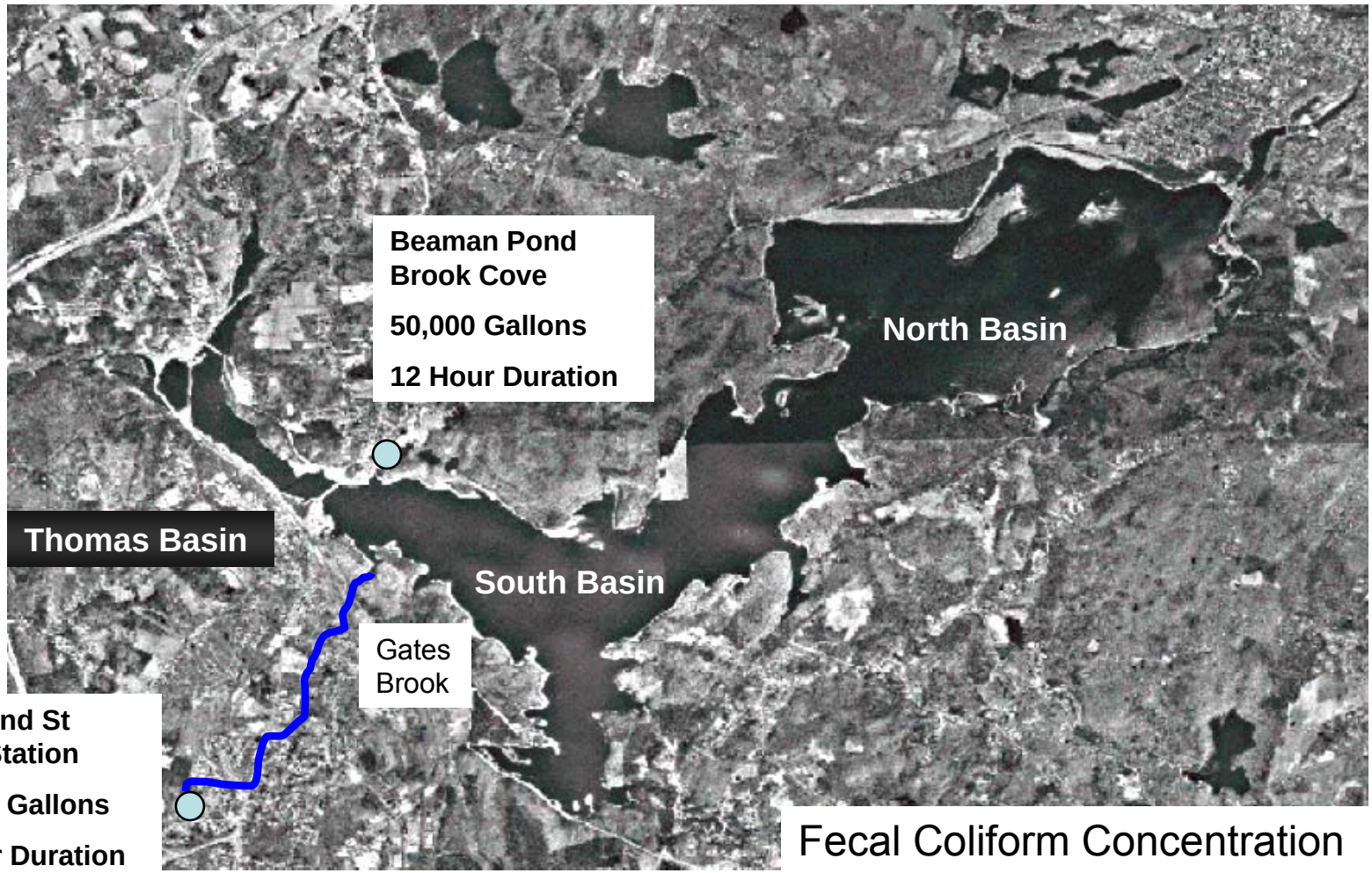
Wachusett TOC Calibration: 2001 – 2002

(Dan Buttrick, MS EVE 2005)



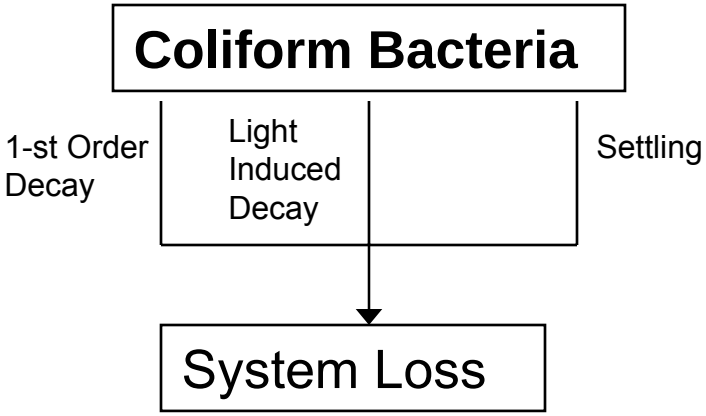
WW Pump Station Malfunction Scenarios

(Thomas Matthews, MS EVE 2007)



Fecal Coliform Concentration in Spill = 10^8 CFU/100 mL

Coliform Modeling



- **Problem: CEQUAL W2 does not include light induced decay when modeling coliform**
- **Solution: modify Fortran algorithm**

Coliform Decay

$$\frac{\partial(Coliform)}{\partial t} = -k_{Coliform}(Coliform)$$

$$k_{Coliform} = k_{Coliform,\ temp} + k_{Coliform,\ light} + k_{Settling}$$

$$k_{Coliform,temp} = k_{Coliform,\ 20}\ \theta^{(T-20)}$$

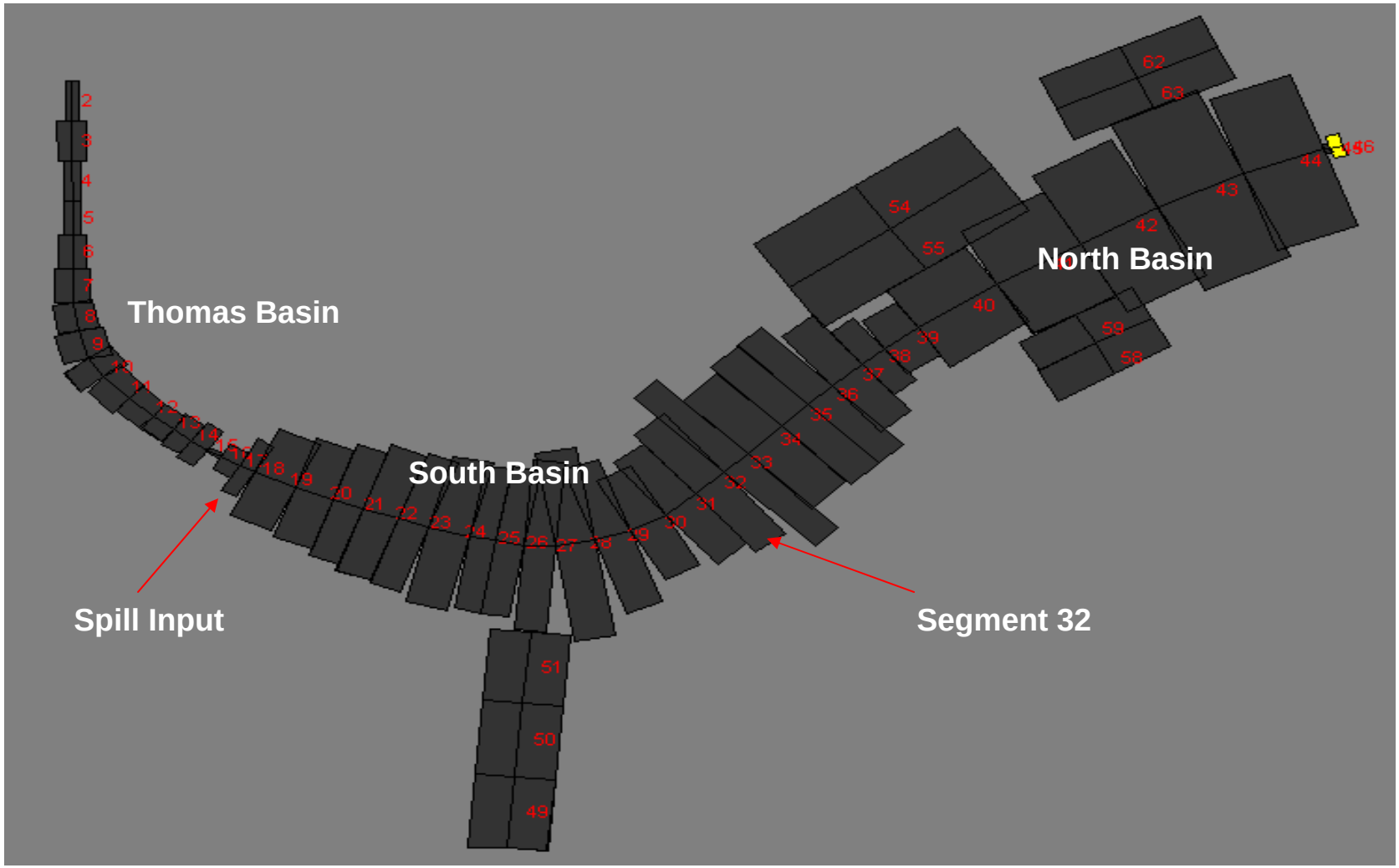
$$k_{Coliform,\ light} = a\ I_o\ e^{(-\gamma z)}$$

$$k_{settling} = \omega/\Delta Z$$

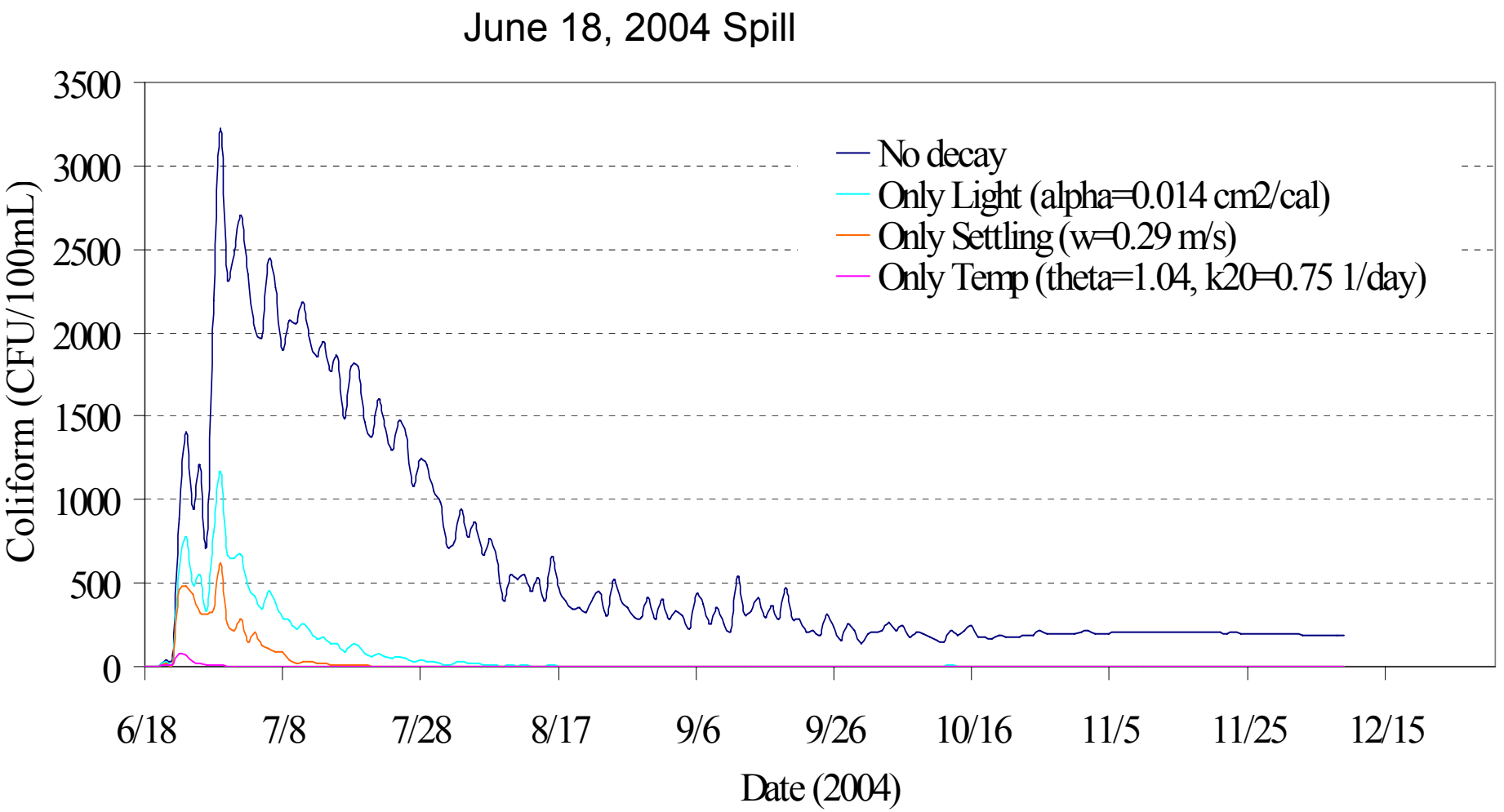
Baseline Fecal Coliform Decay Coefficients

CE QUAL W2 Parameter	Description	This Study
CGQ10	Arrhenius temperature rate multiplier, θ	1.04
CG1DK	Coliform dark decay at 20°C, k_{20}, day^{-1}	0.75
CGS	Settling rate, ω, m/day	0.29
LITDK	Proportionality constant relating irradiance-induced decay rate coefficient to irradiance, α, cm^2/cal	0.014

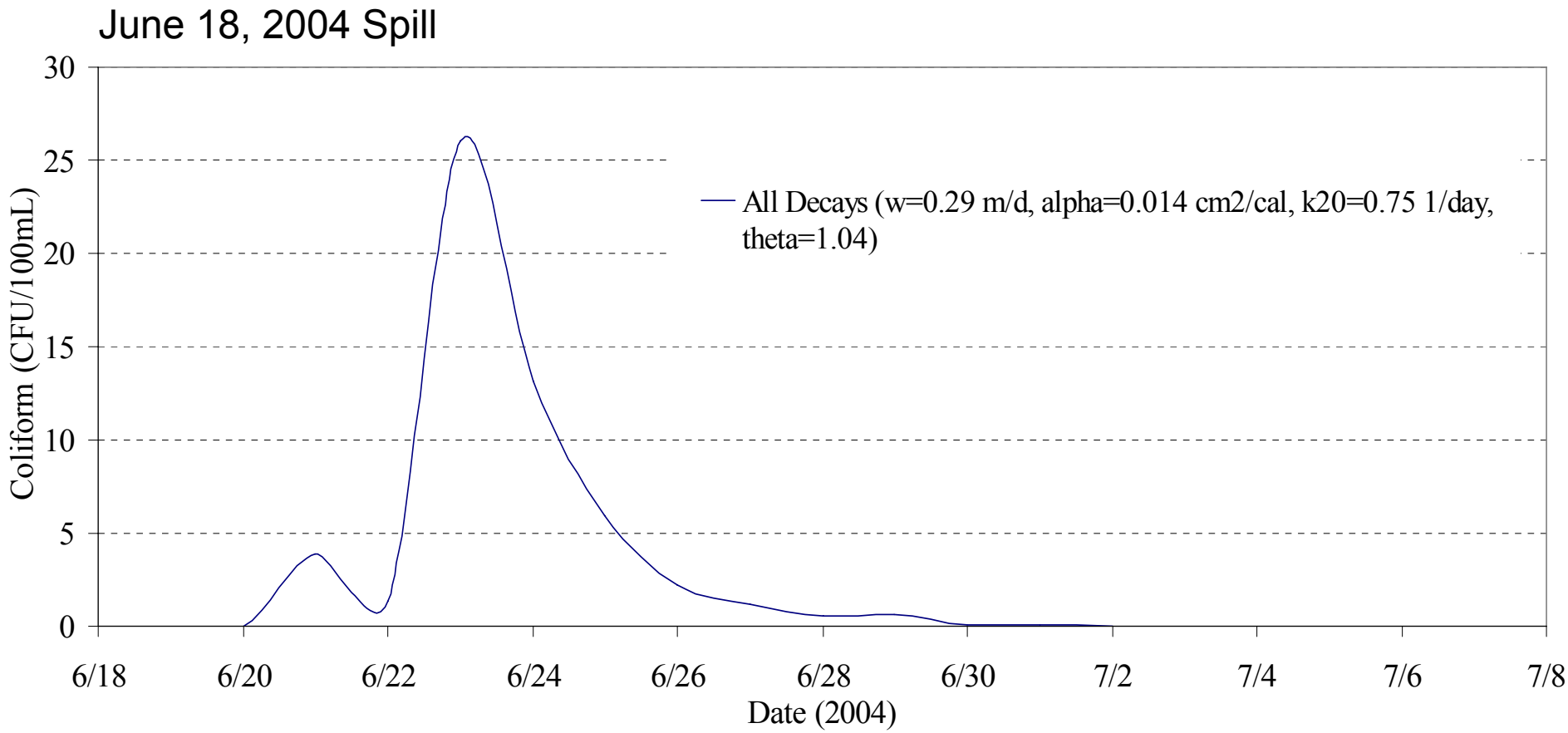
CEQUAL W2 Wachusett Reservoir



Individual Decay Mechanisms
Segment 32, Layer 31



Baseline Scenario, All Decay Mechanisms
Segment 32, Layer 31

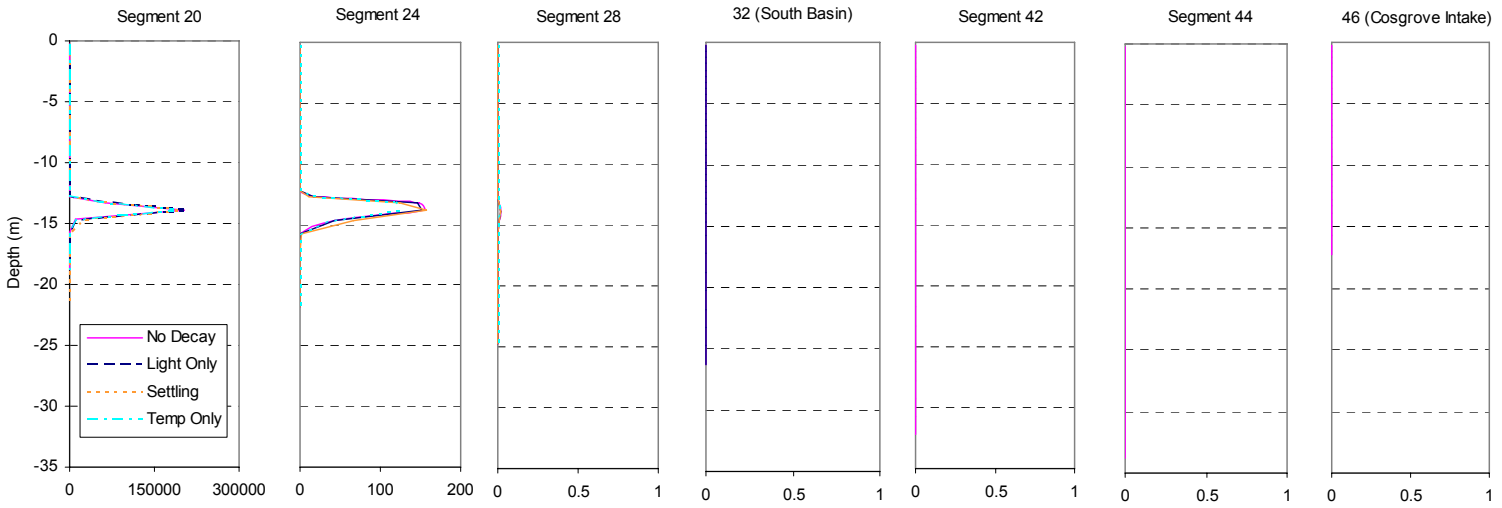


Peak concentration for first order temperature decay was 78 CFU/100 ml

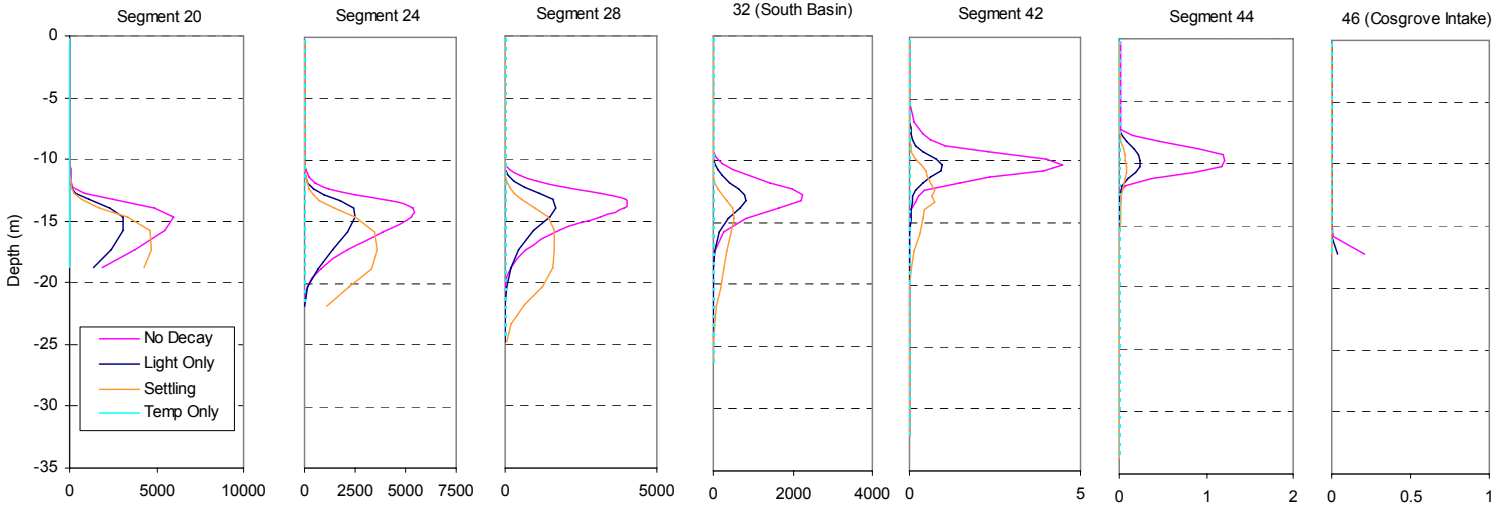
No evidence of fecal coliform at the Cosgrove Intake

Individual Decay Mechanisms
In-reservoir Profiles

June 19, 2004
(12 hours after beginning of spill)



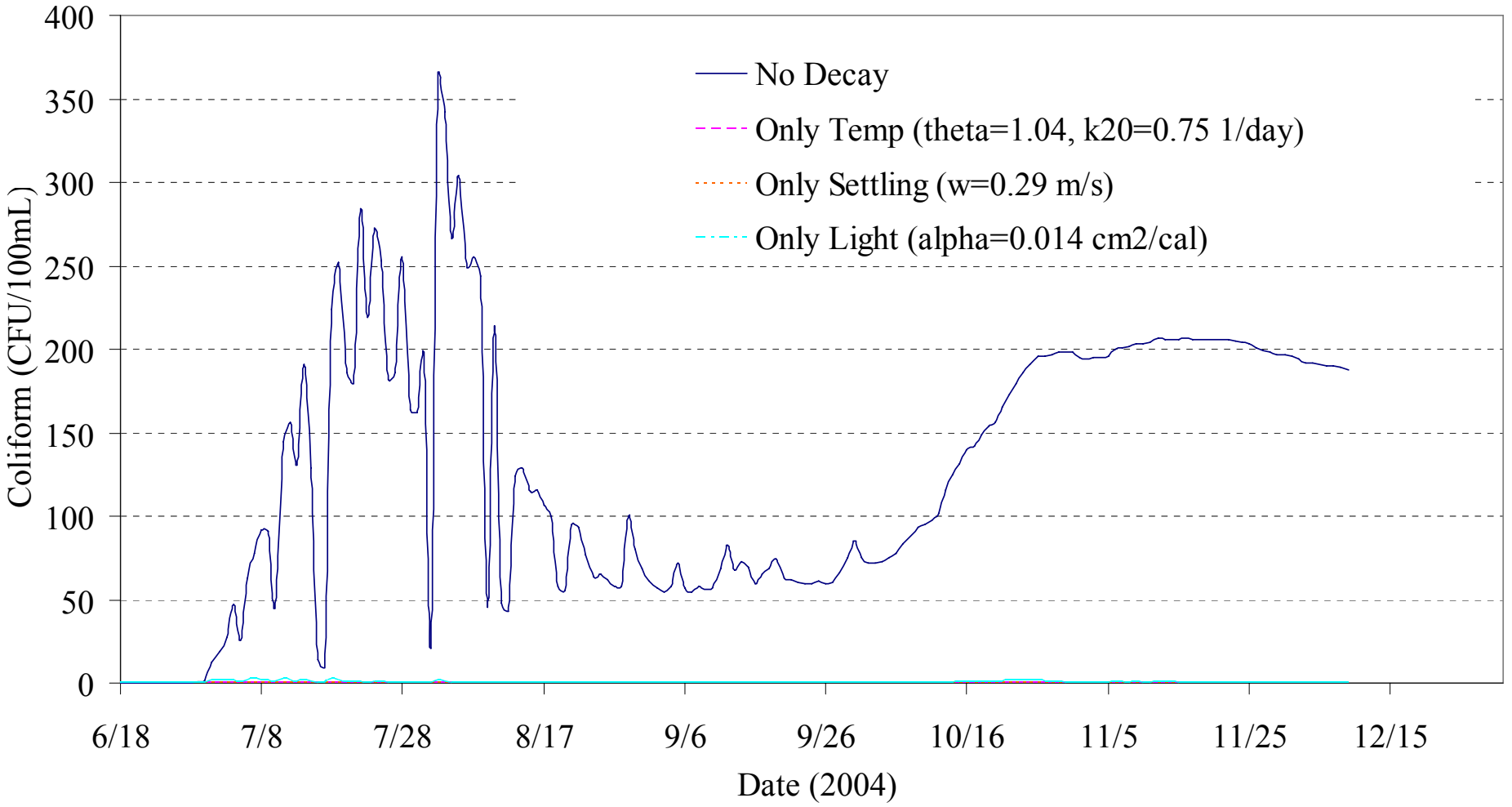
June 28, 2004
(10 days after beginning of spill)



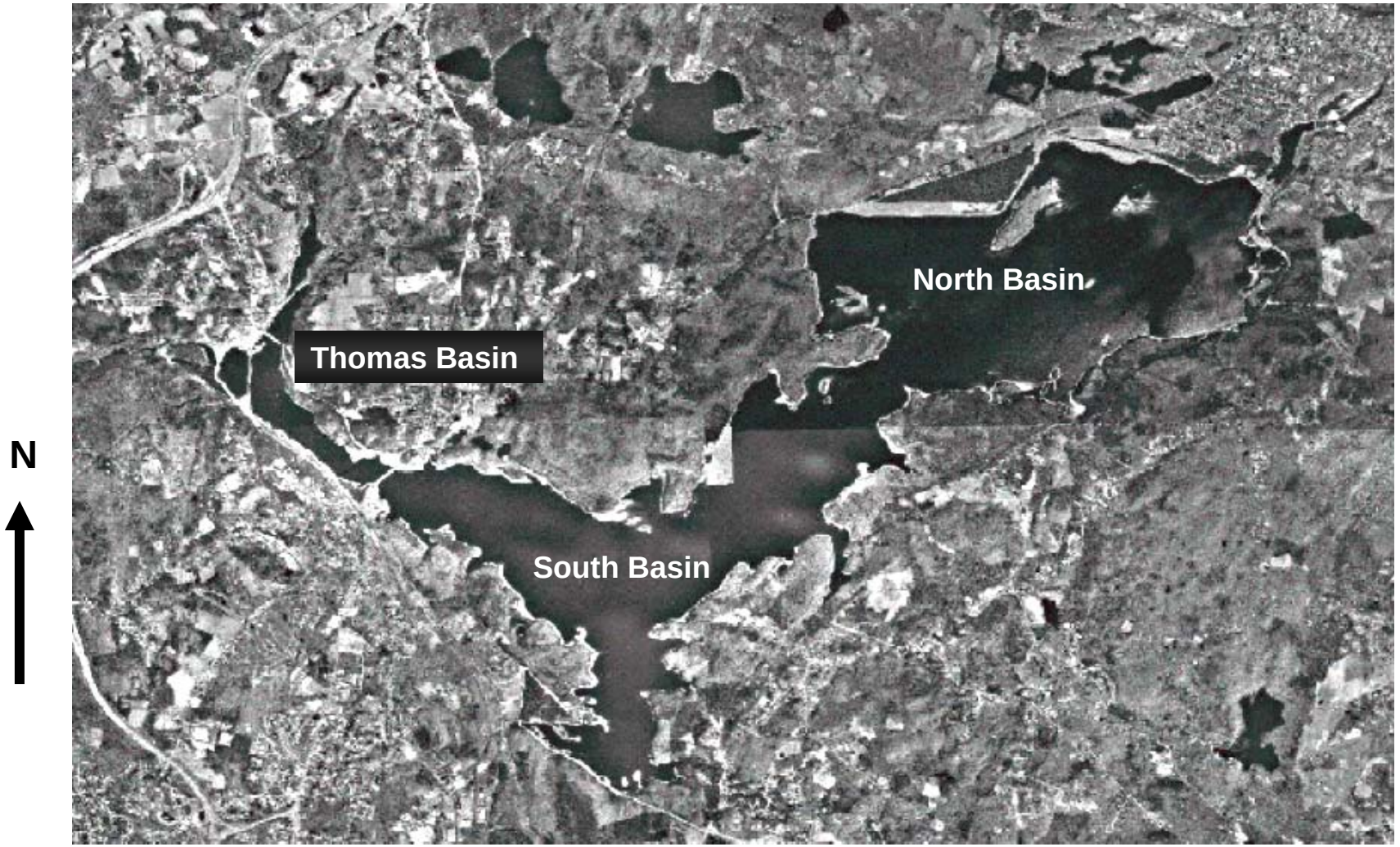
Individual Decay Mechanisms
Cosgrove Intake

No evidence of fecal coliform at the Cosgrove Intake if any decay occurs

June 18, 2004 Spill



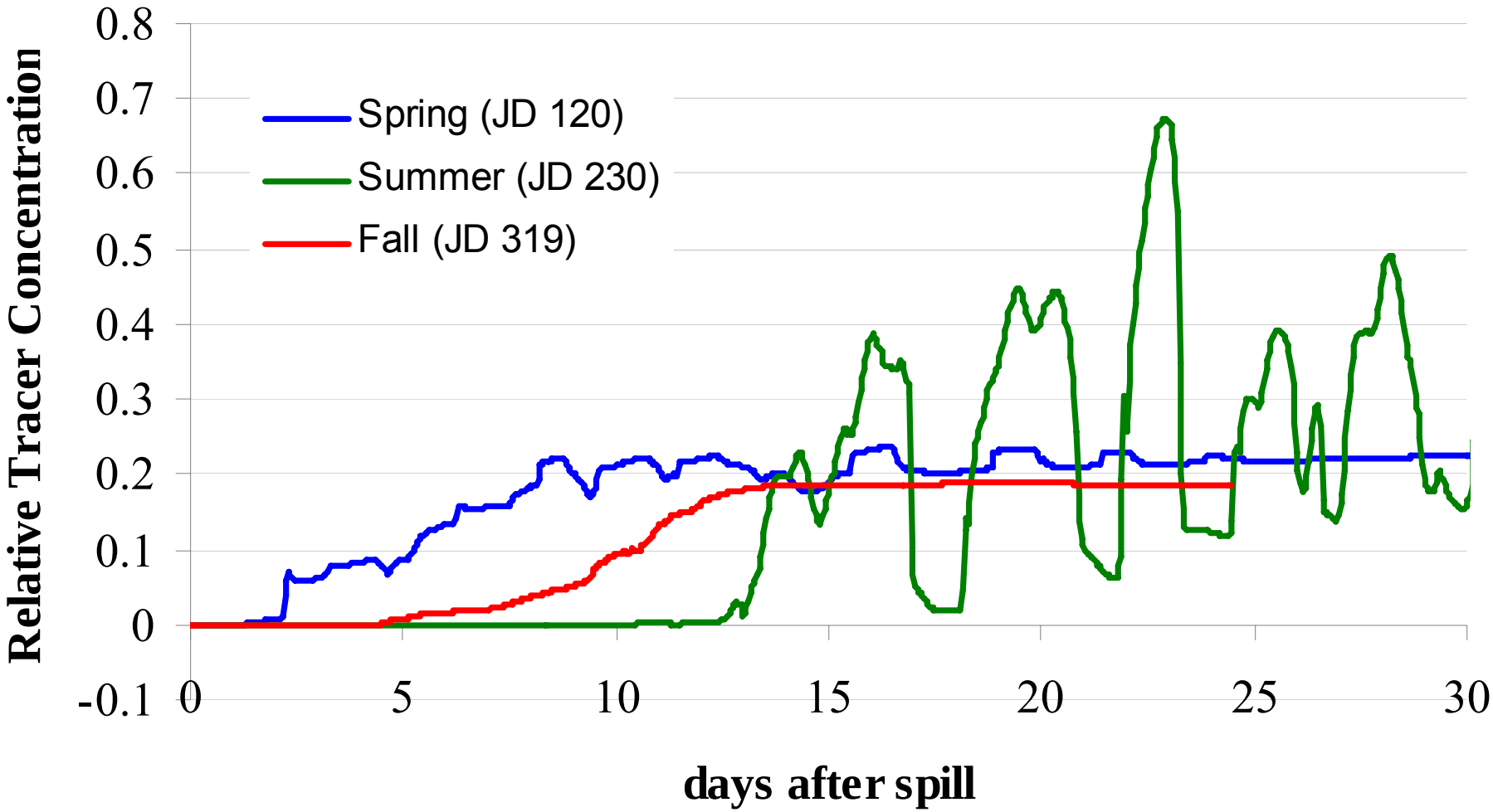
Wachusett Reservoir



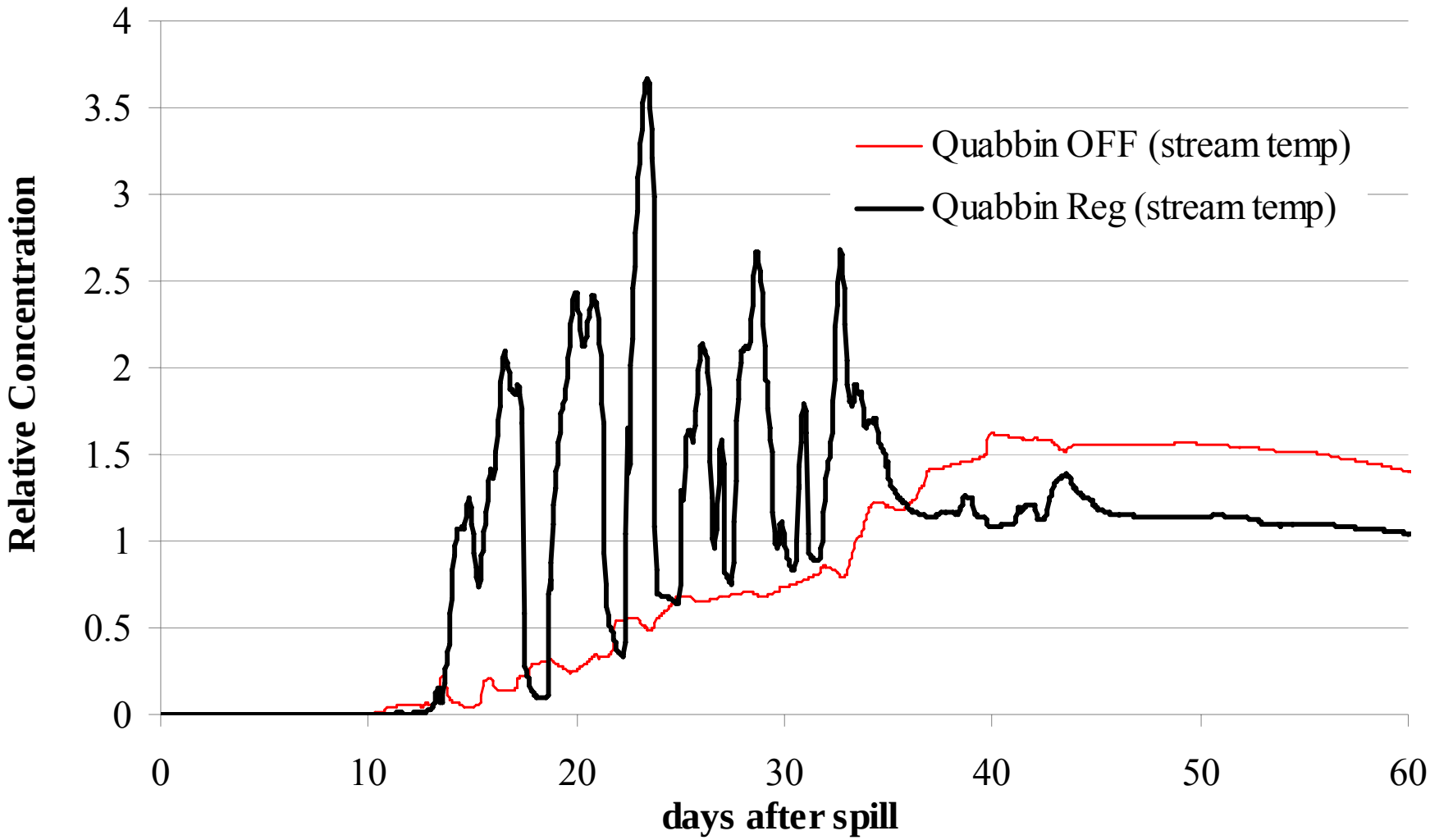
General Wachusett Spill Inputs

Vary location, date, wind, temp., magnitude, Quabbin transfer operation
(current work of Mary Serdakowski, Christina Stauber)

Ex: Rte 140 Bridge, tracer, 12 hr spill, Cosgrove Conc.

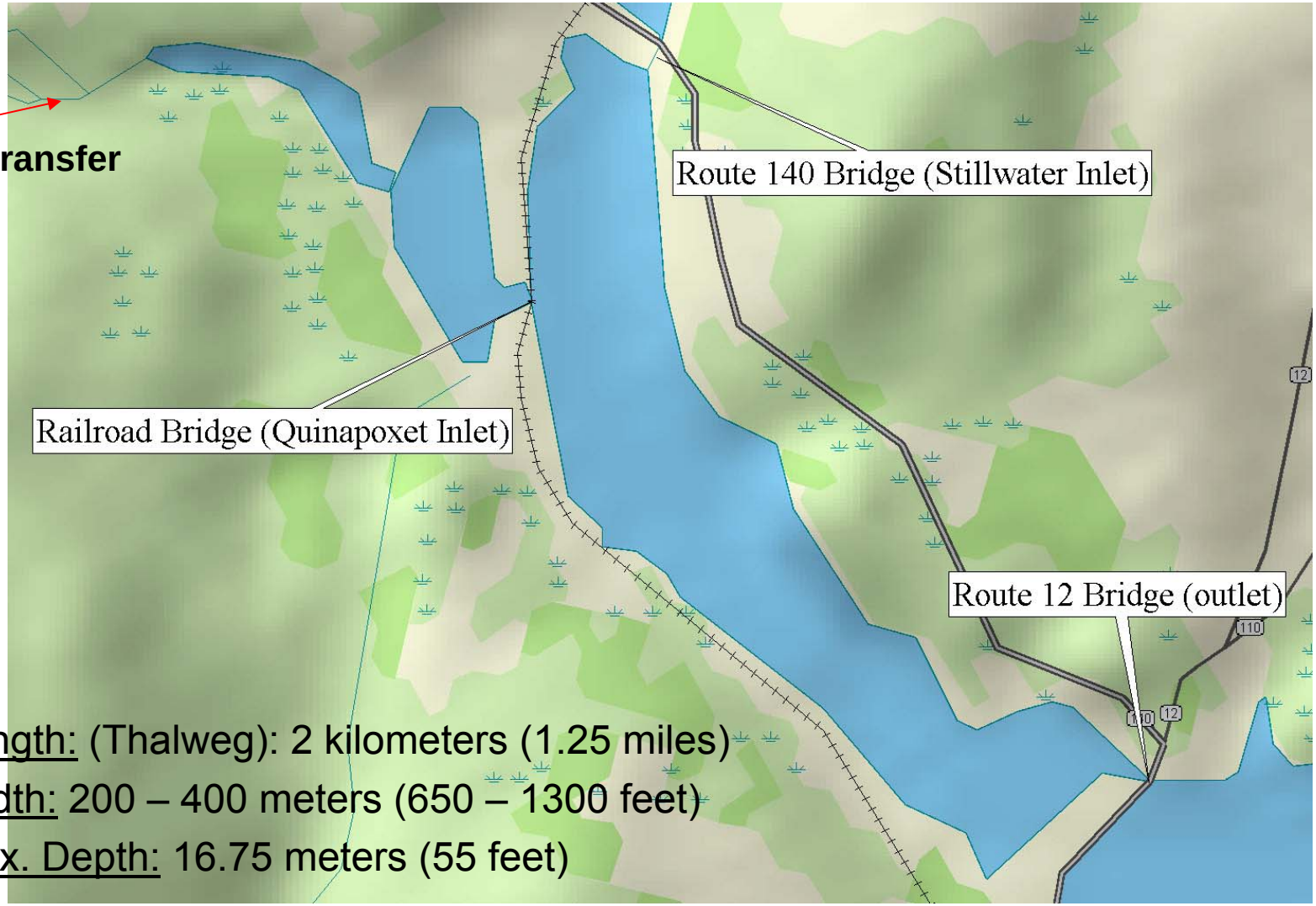


Summer JDAY 230, 2004 Spill at Seg 7 (Rt. 140)
Start at noon until midnight, Quabbin turned off within 12 hours
Tracer Concentrations at Cosgrove



Thomas Basin: need for 3-D model

(Matt Kennedy, MS EVE 2002; Rebecca Pease MS EVE 2003)

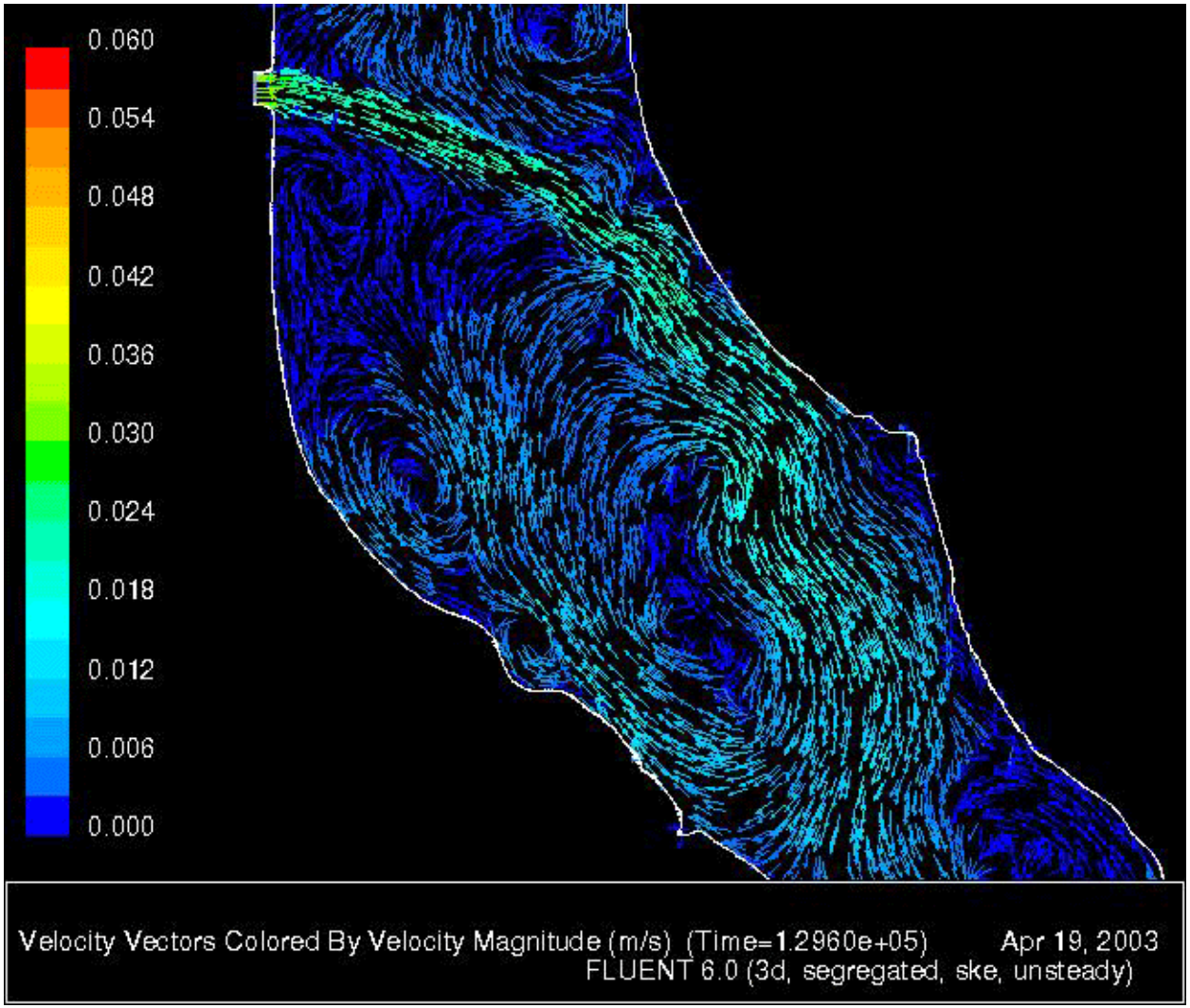


Length: (Thalweg): 2 kilometers (1.25 miles)

Width: 200 – 400 meters (650 – 1300 feet)

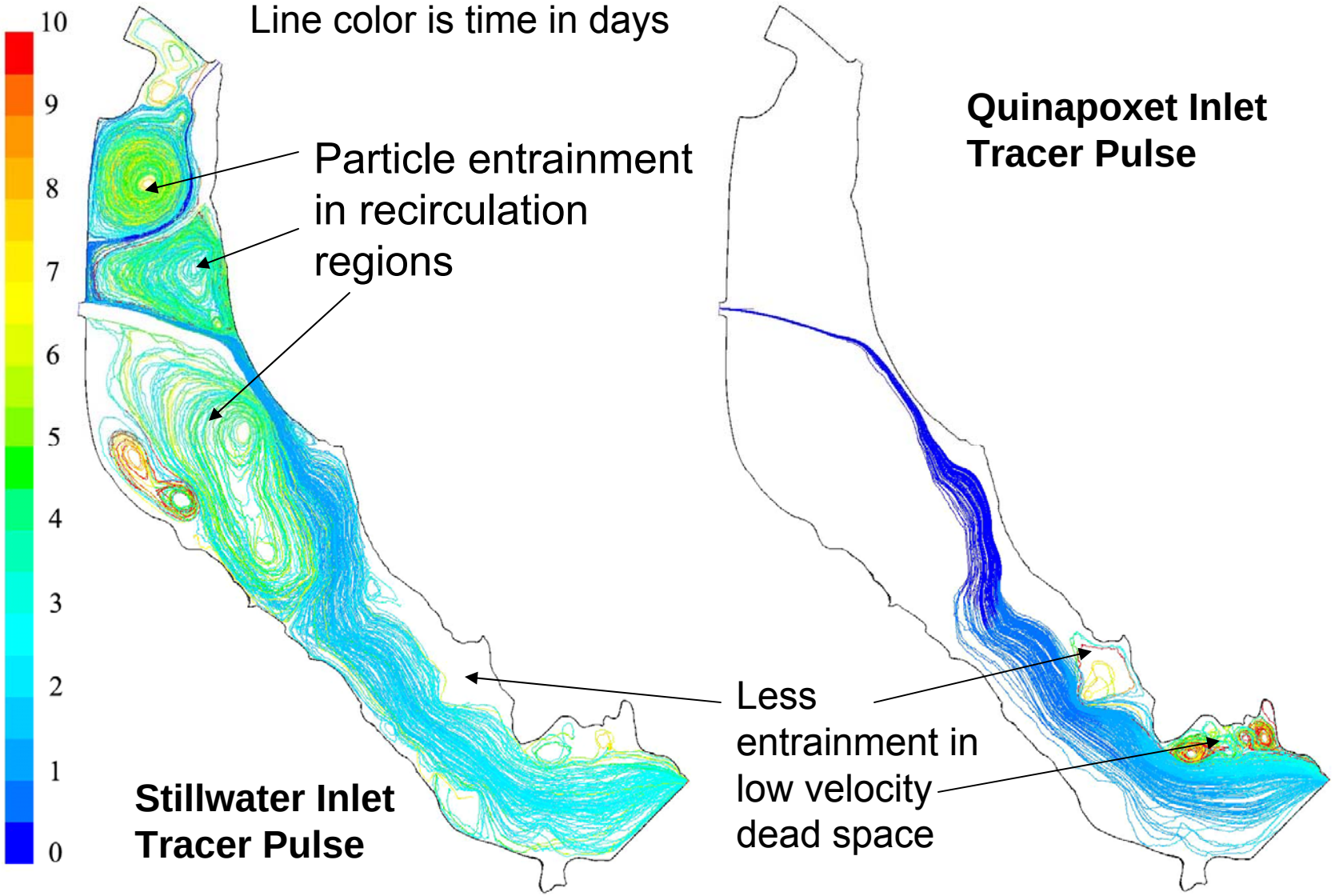
Max. Depth: 16.75 meters (55 feet)

CFD Result: Quabbin Transfer

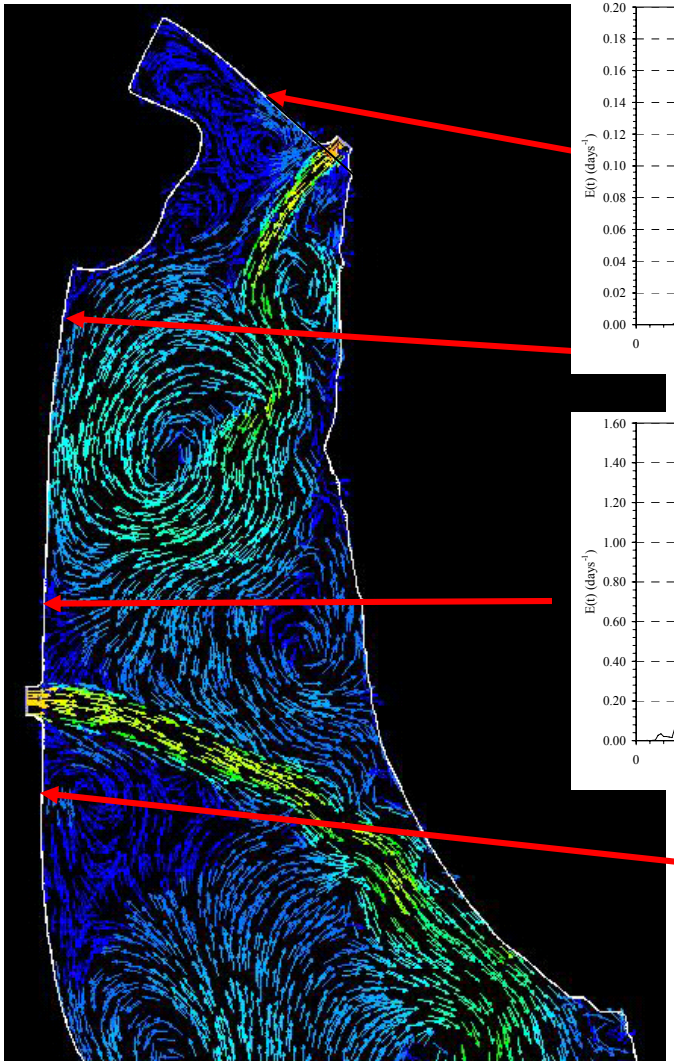


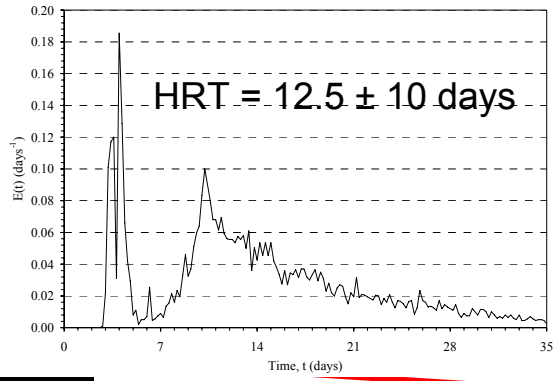
2-meters below surface

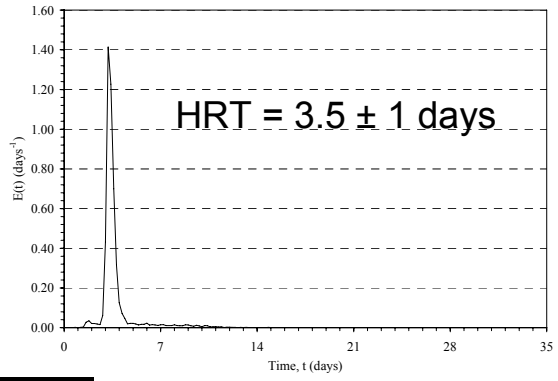
Quabbin Transfer Tracer Paths

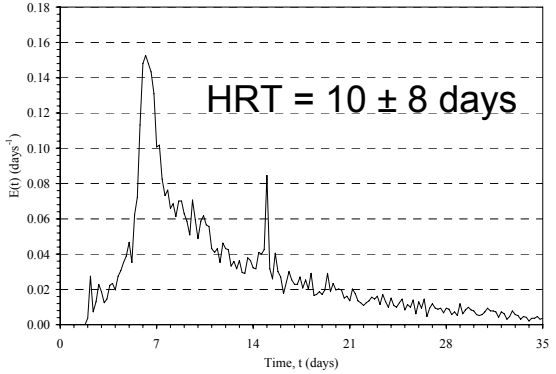


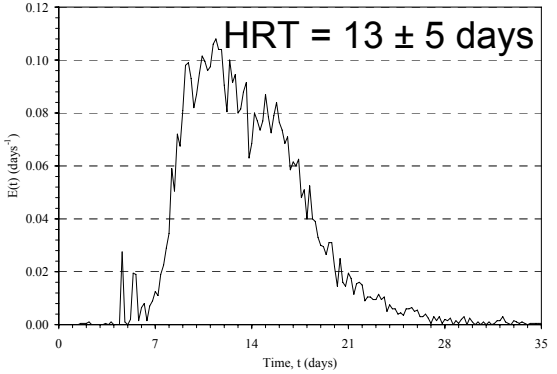
Spill Location Simulations: management action?











SUMMARY

- **DCR/UMass collaboration effective at addressing long-term questions and response to emergencies**
- ***Value of expertise/institutional knowledge for new/short term issues***
- **Foundation for rational basis for policy making**

Thank you!