Total phosphorus calibration of the Simple Refuge Screening Model Version 4 using optimization

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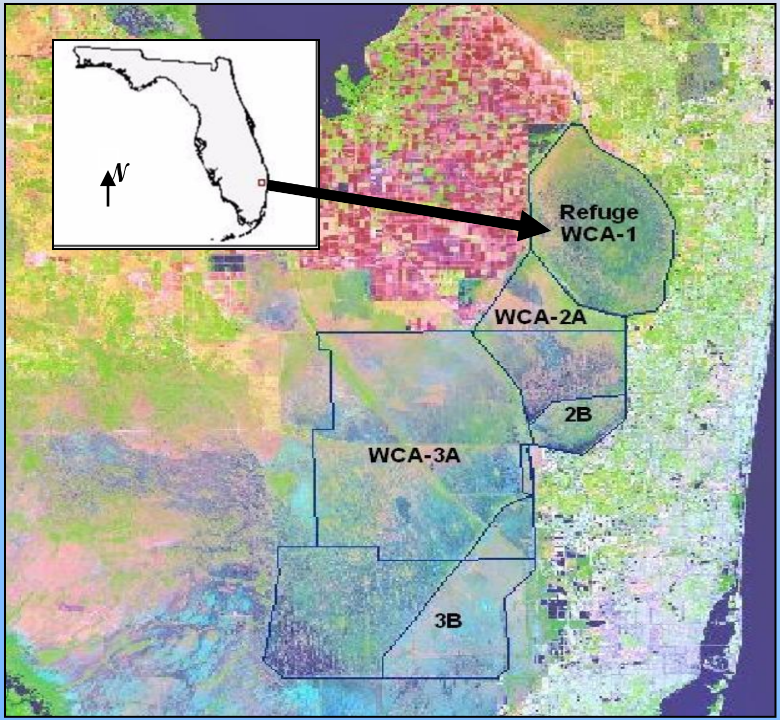
Center for Louisiana Water Studies
Institute of Coastal Ecology and Engineering

U.S. Fish & Wildlife Service
Arthur R. Marshall
Loxahatchee National Wildlife Refuge

Introduction

- Study Area
  - Freshwater remnant of the Northern Everglades
  - Located in Palm Beach County, Florida
  - Overlays Water Conservation Area 1 (WCA-1)
- Need for Modeling
  - Alterations to water quantity, quality, and timing have had various impacts on the Refuge
  - Assessment of various scenarios will guide future restoration efforts



Location of the Arthur R. Marshall Loxahatchee National Wildlife Refuge and other Everglades Water Conservation Areas (SFWMD, 2000).

Introduction

- Characteristics
  - Hydraulically isolated system
  - Area is approximately 58,275 ha
  - Two important features
    - Canal (4.03 km^2)
    - Marsh (560 km^2)
  - High concentrations enter via pumped inflows

Refuge marsh area (top) and rim canal (bottom). Photo Credit J. Arceneaux.

Modeling Suite -
4 models with varying levels of spatial aggregation

MODEL	Version / Status	Canal Cells	Marsh Cells	Stage	Water Quality
SRSM	4.0 Completed	1	1 / 3	Y	Y
9-Compartment	1.0 Completed	3	6	Y	Y
39-Comartment	1.0 Update in development	11	28	Y	Y
Mike-Flood HD	2.0 Completed	Distributed	3,494	Y	
Mike-Flood AD	2.0 Completed	Distributed	3,494		Y

Modeled Attributes

- **Stage, Volume, and Flow**
- **Chloride (Cl)** – Conservative (non-reactive) constituent, tracer
- **Sulfate (SO_4)** – Nearly constant areal mass disappearance
- **Total Phosphorus (TP)** – Model surface water concentration and storage using DMSTA2 kinetics

DMSTA2

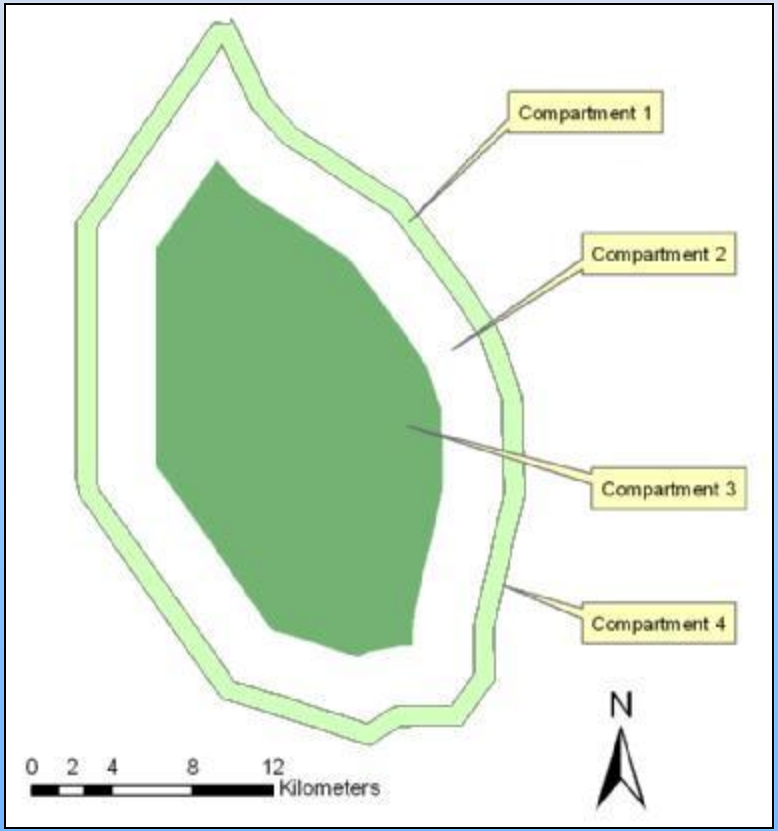
- Developed by Drs. Bill Walker and Bob Kadlec
- Simulates TP removal in constructed wetlands
- Simple kinetic formulation
- Has pre-calibrated parameter sets (PEW, EM, …)
- Primarily used as a design tool, but has other uses
- For more information

  http://www.wwwalker.net/

WQ Compartment Arrangement

- Model Structure
  - 4 compartments (cells)
    - 3 marsh
    - 1 canal
  - Nested concentrically

Compartment	Area (km^2)
1	89.36
2	224.1
3	246.6
4	4.033



SRSM Water Quality cell arrangement.

Model Characteristics

- SRSM results represent spatially-aggregated canal and marsh values for all state variables (e.g. volume and mass)
- Model appropriate for applications with time scale of one day or longer
- Due to the spatially-aggregated compartment design of the model, it is of limited value in analysis of site specific events
- Concentric compartment design displays average propagation of constituents from canal to marsh interior

Model Attributes

- Assumptions
  - Average soil elevations are used for canal and marsh compartments
  - Water surface of canal and marsh are flat
  - Canal surface area is constant
  - Precipitation is uniform
  - Chloride is a conservative constituent
  - TP and SO4 are conservative constituents in the Canal compartment
- SRSM V4 runs under Berkeley-Madonna

  http://www.berkeleymadonna.com/
- Runtime information
  - Time step
    - dt = 0.005 day
  - Simulation period extended
    - Start: Jan-95
    - End: Dec-07
  - Completes 13-year simulation in ~ 7 minutes

Phosphorus Equations

Storage

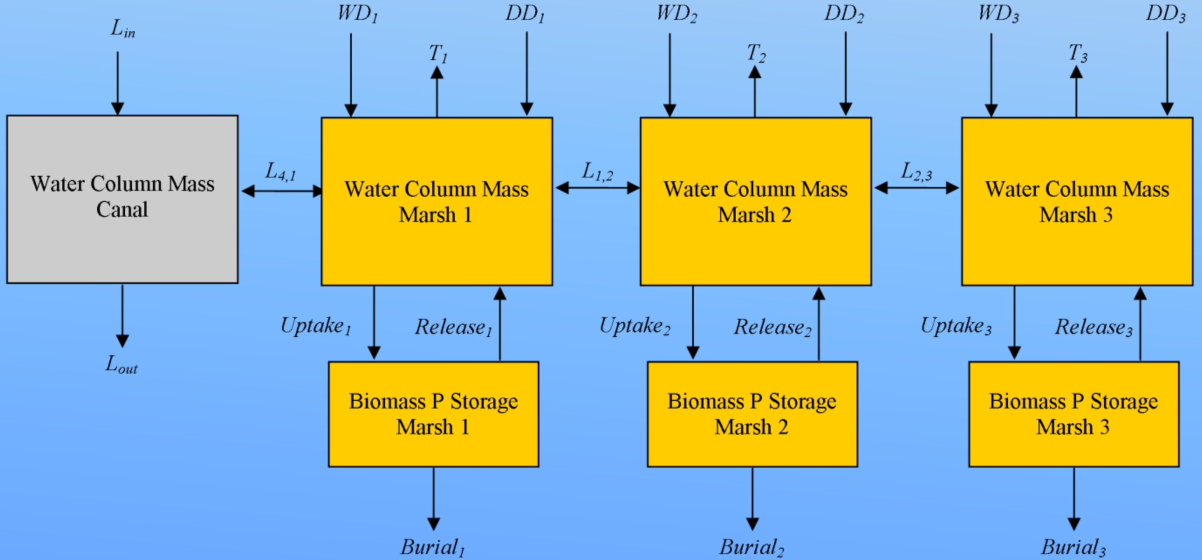
$$\frac{dS}{dt} = F_C F_z k_1 SC - k_2 S^2 - k_3 S$$

S = temporary storage in biomass (mg/m^2)
C = concentration of surface water (mg/m^3)
F_c = concentration multiplier
F_z = depth multiplier
k_1 = maximum uptake rate (m^3/mg-yr)
k_2 = recycle rate (m^2/mg-yr)
k_3 = burial rate (1/yr)

Water Column Concentration

$$\frac{dhC}{dt} = L - QC - F_C F_z k_1 SC + k_2 S^2$$

h = water depth (m)
L = loading rate in the cell (mg/m^2-yr)
 * Includes transpiration (T) and deposition (WD and DD)
Q = outflow (m/yr)



Total phosphorus water quality model schematic. Adapted from Walker and Kadlec (2006)

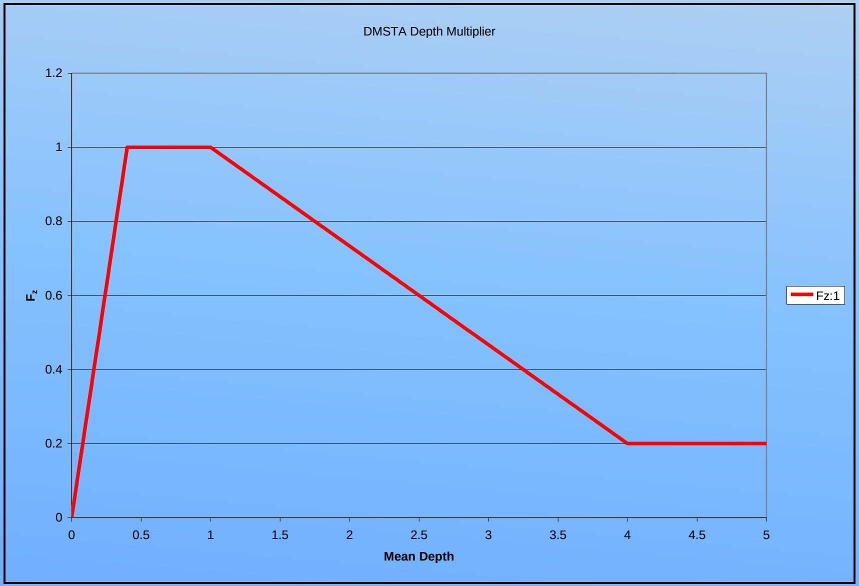
Phosphorus Equations

- Concentration Multiplier

$$F_c = \frac{0.3}{C + 0.3}$$

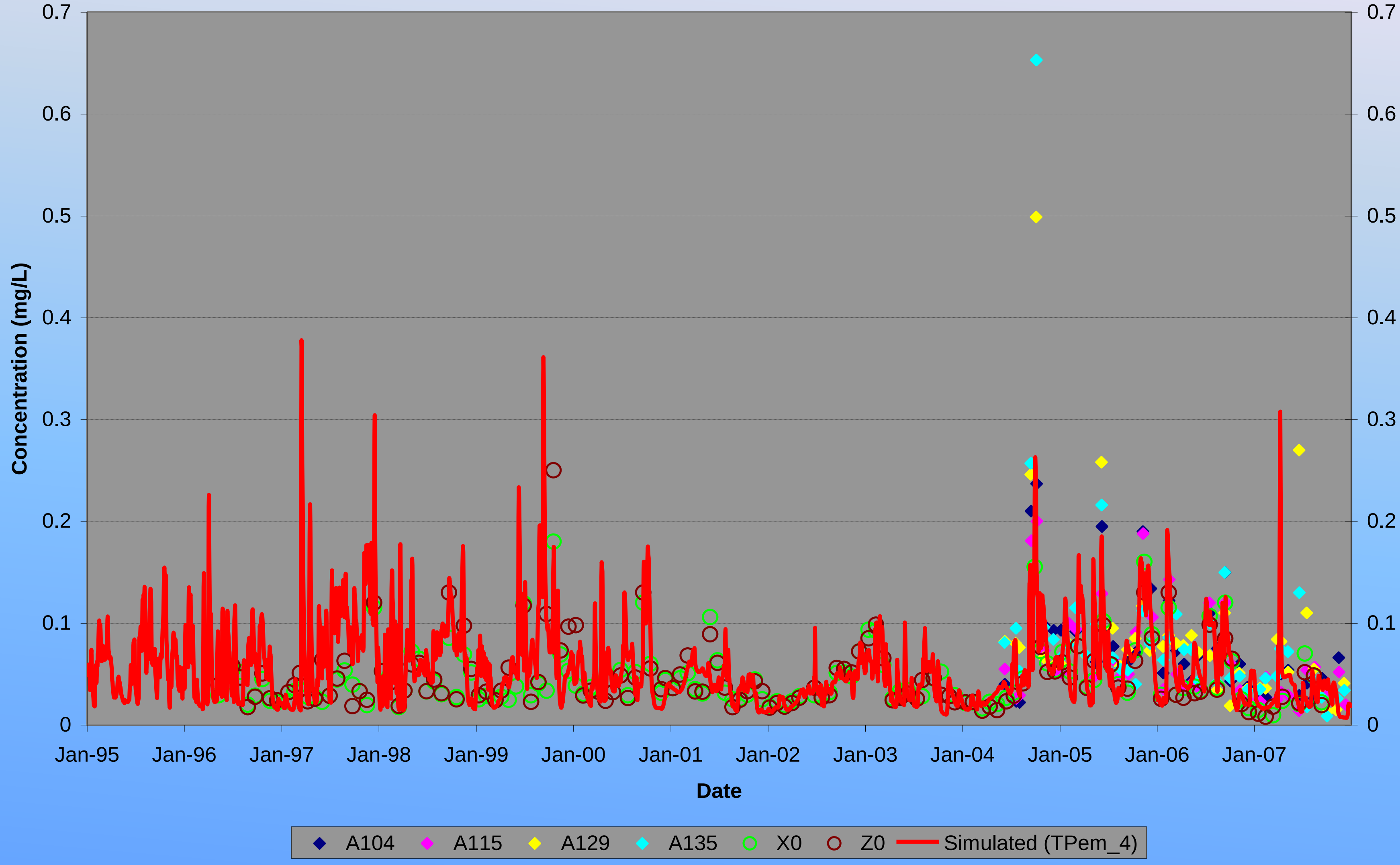
F_c = concentration multiplier (dimensionless)
C = TP concentration

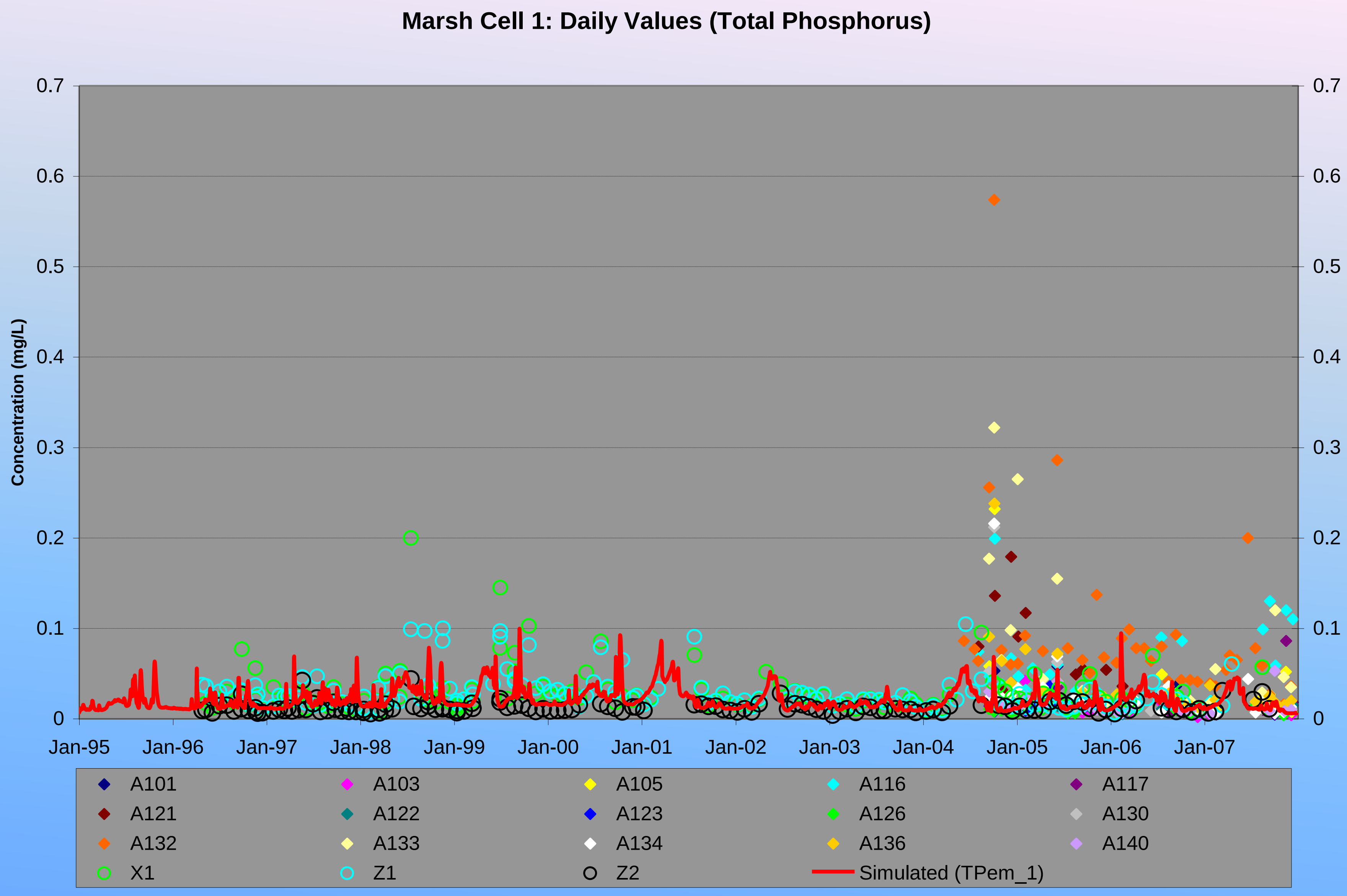
- Depth Multiplier
  - Defined by the provided graph
  - dimensionless

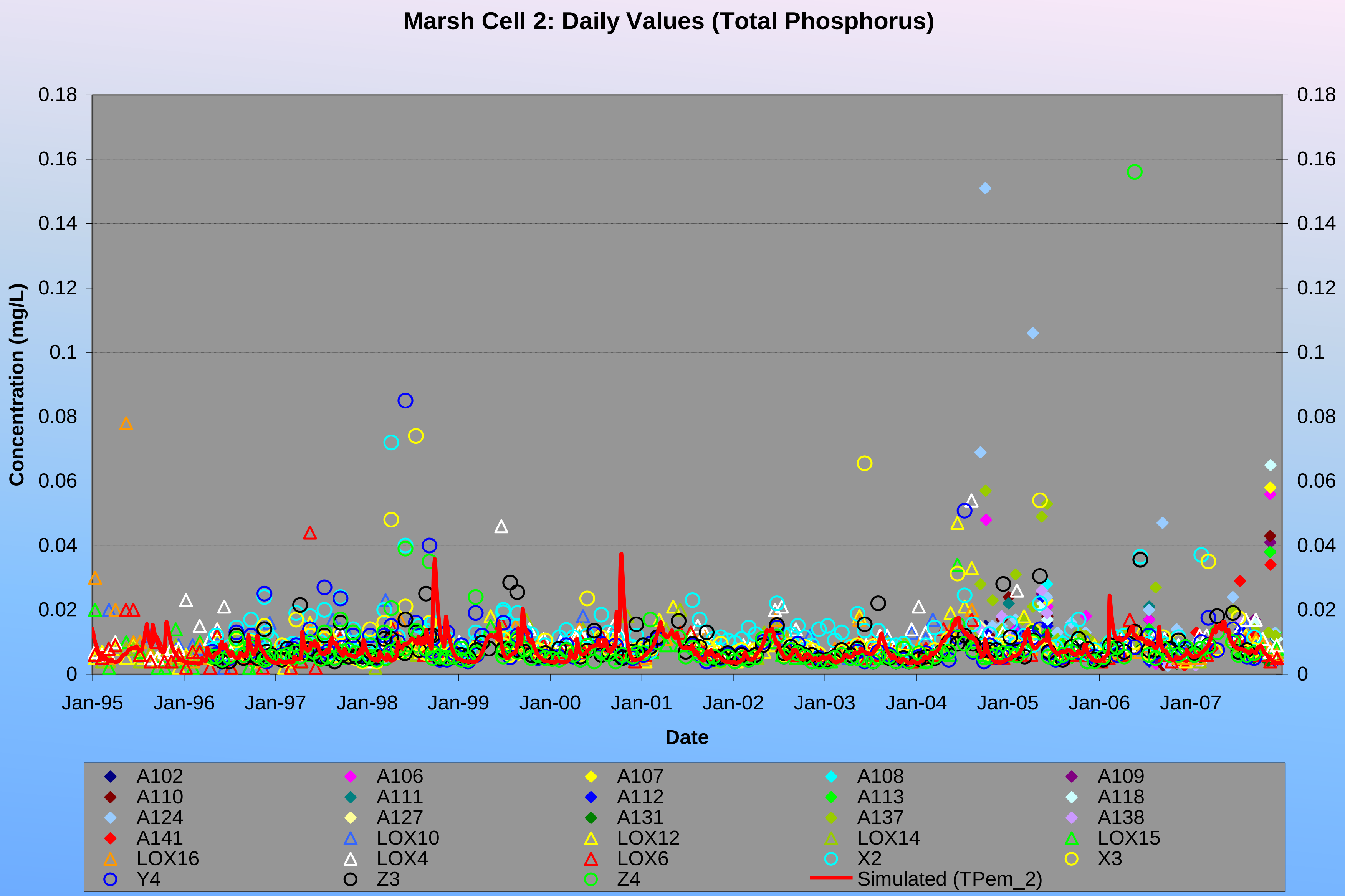


Graph of the Depth Multiplier function for the Emergent and PEW data sets. Adapted from Walker and Kadlec (2006)

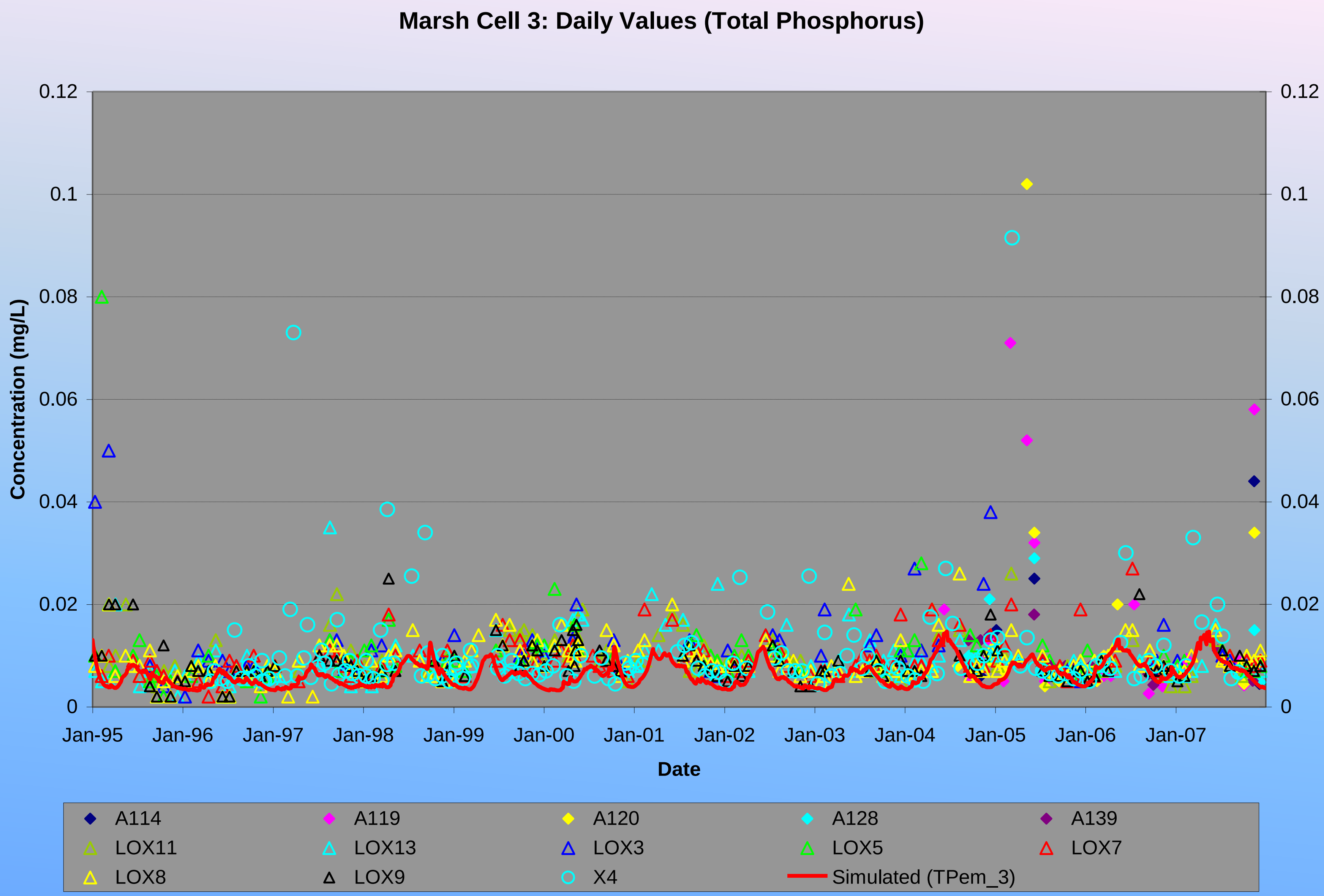
Canal Cell 4: Daily Values (Total Phosphorus)



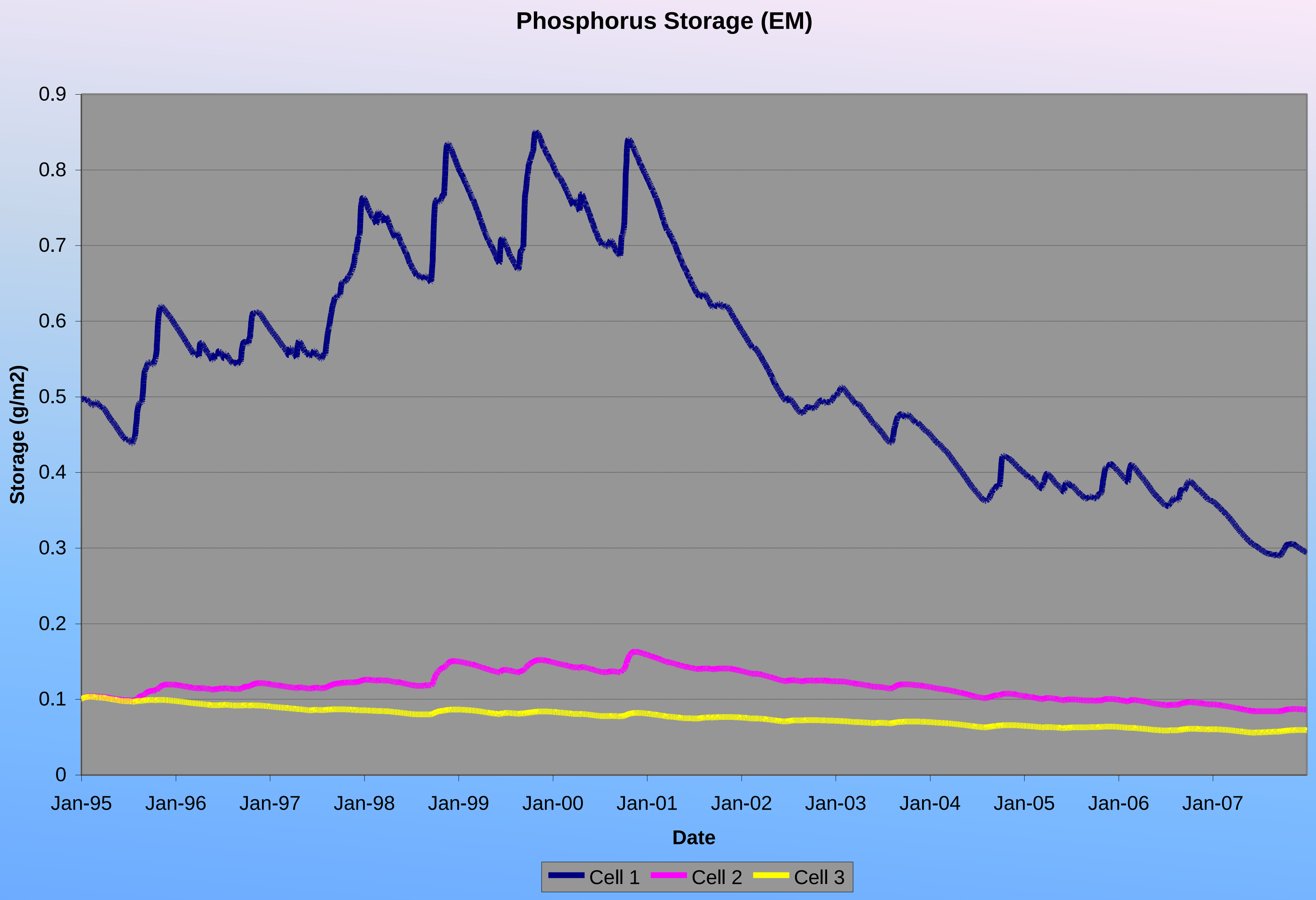

Marsh Cell 1: Daily Values (Total Phosphorus)
Concentration (mg/L)
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Jan-95
Jan-96
Jan-97
Jan-98
Jan-99
Jan-00
Jan-01
Jan-02
Jan-03
Jan-04
Jan-05
Jan-06
Jan-07
A101
A103
A105
A116
A117
A121
A122
A123
A126
A130
A132
A133
A134
A136
A140
X1
Z1
Z2
Simulated (TPem_1)



Marsh Cell 2: Daily Values (Total Phosphorus)
Concentration (mg/L)
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
Jan-95
Jan-96
Jan-97
Jan-98
Jan-99
Jan-00
Jan-01
Jan-02
Jan-03
Jan-04
Jan-05
Jan-06
Jan-07
Date
A102
A106
A107
A108
A109
A110
A111
A112
A113
A118
A124
A127
A131
A137
A138
A141
LOX10
LOX12
LOX14
LOX15
LOX16
LOX4
LOX6
X2
X3
Y4
Z3
Z4
Simulated (TPem_2)



Marsh Cell 3: Daily Values (Total Phosphorus)
Concentration (mg/L)
0.12
0.1
0.08
0.06
0.04
0.02
0
Jan-95
Jan-96
Jan-97
Jan-98
Jan-99
Jan-00
Jan-01
Jan-02
Jan-03
Jan-04
Jan-05
Jan-06
Jan-07
Date
A114
A119
A120
A128
A139
LOX11
LOX13
LOX3
LOX5
LOX7
LOX8
LOX9
X4
Simulated (TPem_3)

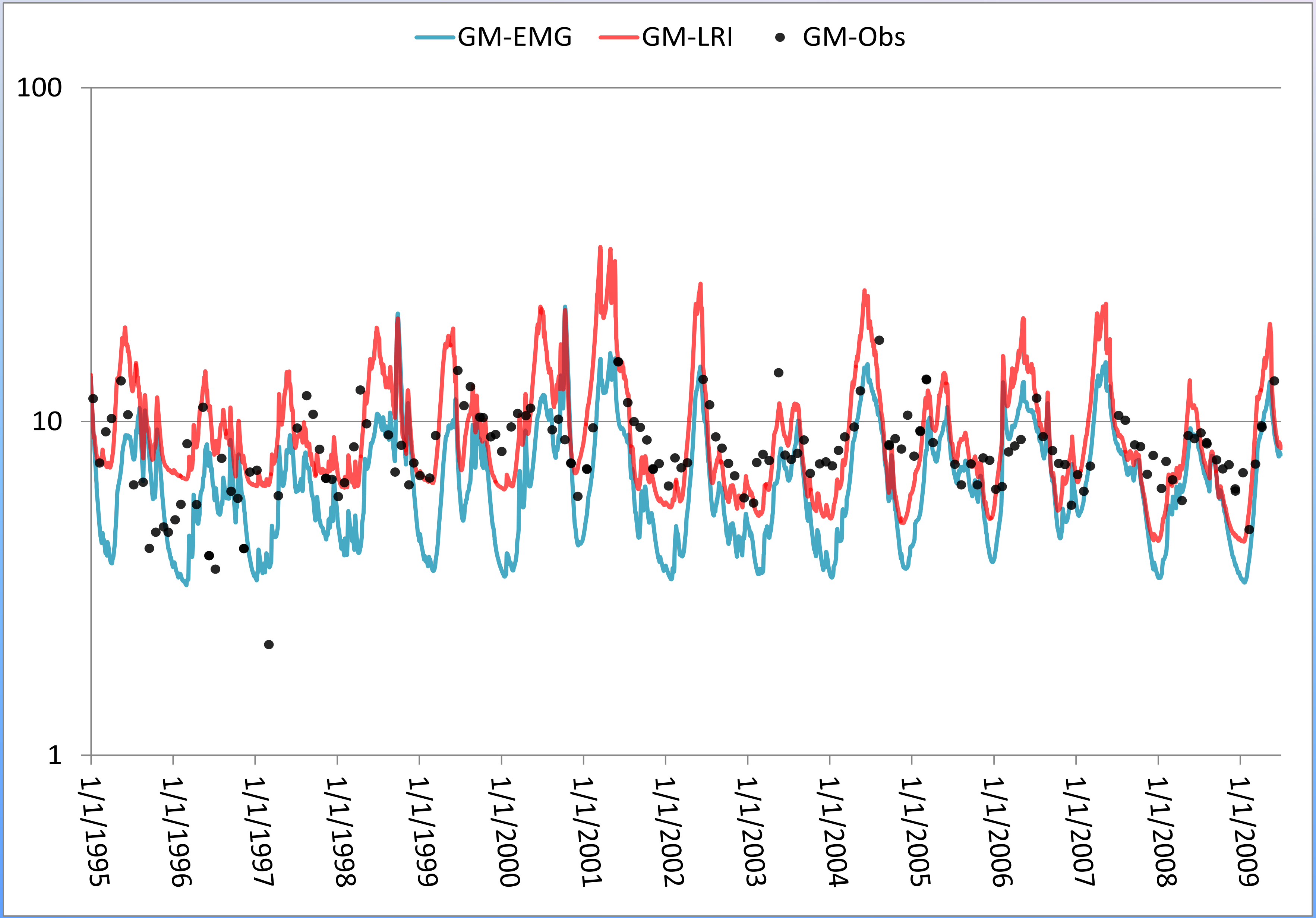


Phosphorus Storage (EM)
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Storage (g/m2)
Jan-95
Jan-96
Jan-97
Jan-98
Jan-99
Jan-00
Jan-01
Jan-02
Jan-03
Jan-04
Jan-05
Jan-06
Jan-07
Date
Cell 1
Cell 2
Cell 3

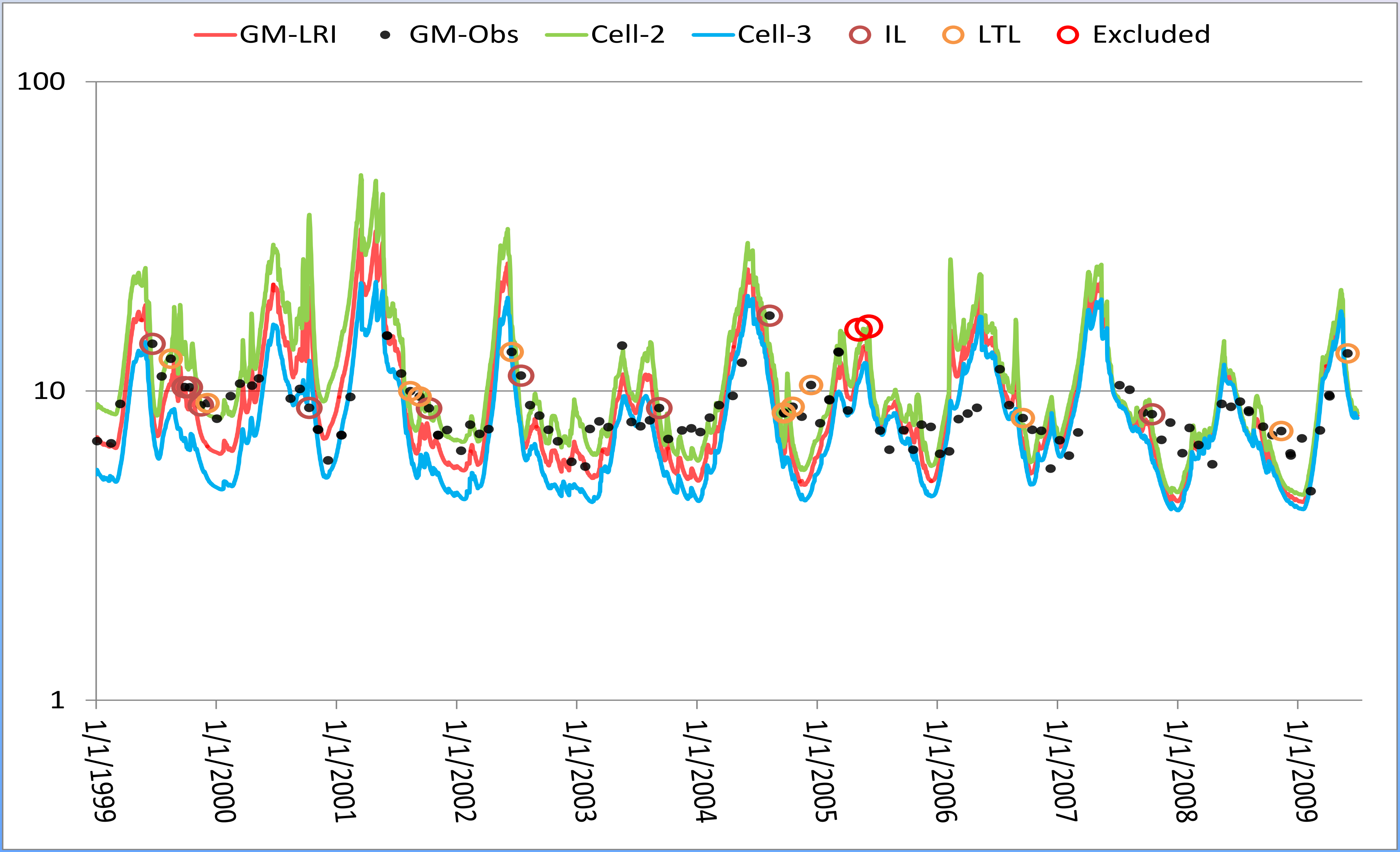
Recalibration

- DMSTA EM parameters work surprisingly well
- However, projected geometric mean corresponding to EVPA sampling is too low
- Used integral absolute error (IAE) in Berkeley-Madonna automated parameter optimization
- Identified new parameter set that gives lower mean error (bias) got geometric mean

Comparison of Calibrations with Observations



Consent Decree Level Excursions

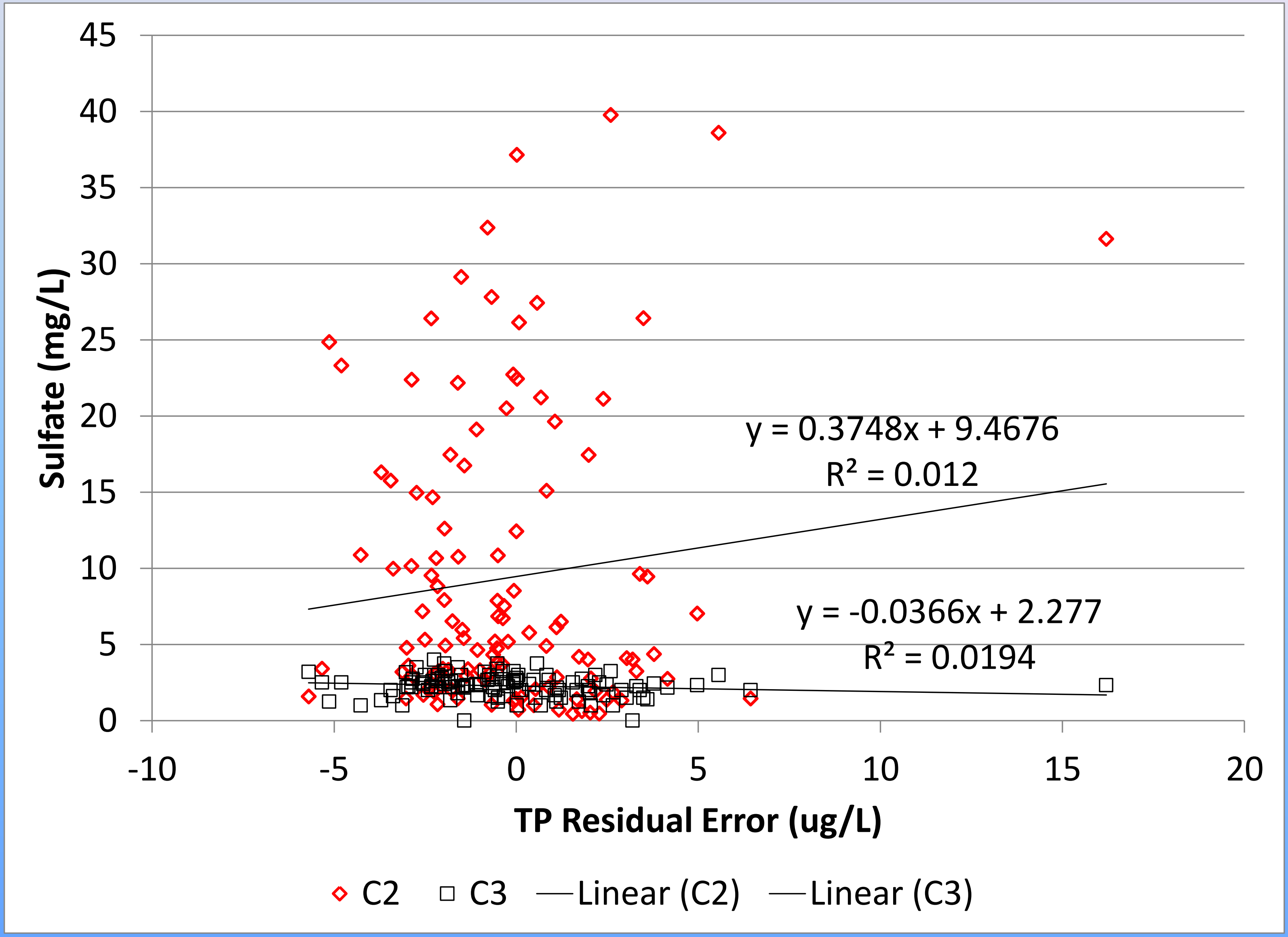


Examination of Residual Error

What did we leave out of the model that is important in affecting TP concentration?

- Sulfate?
- Temperature dependence?

Observed Sulfate vs TP Residual (Modeled TP – Obs TP)



Temperature Dependence

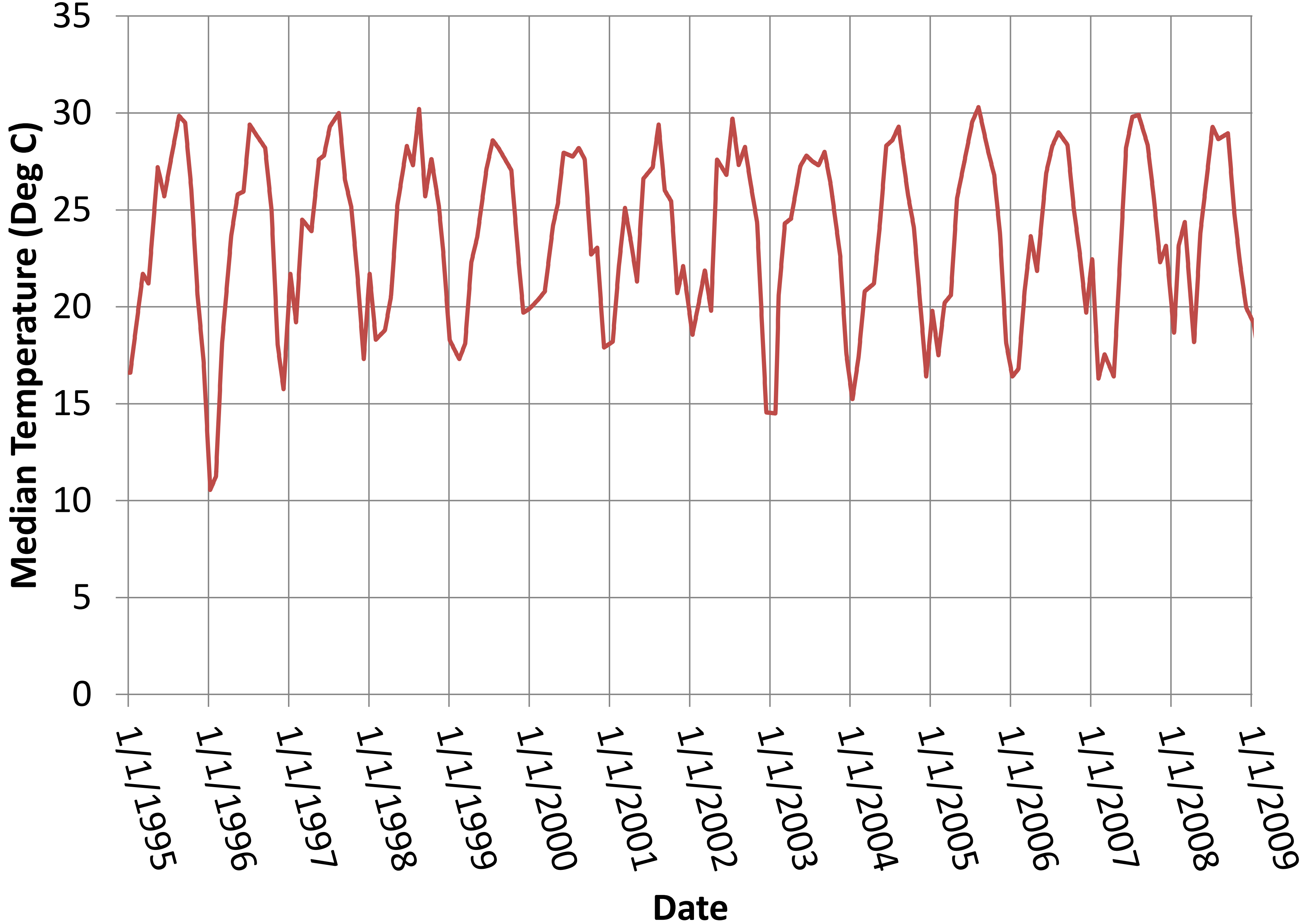
- Biological/Chemical
  - carbonaceous degradation
  - nitrogenous degradation
  - sediment oxygen demand
  - nitrification
  - Denitrification
  - Photosynthesis
  - Algal growth
  - Respiration
  - OP-DIP
  - ON-NH3
- Physical
  - reaeration
  - dispersion

Temperature Correction Factor

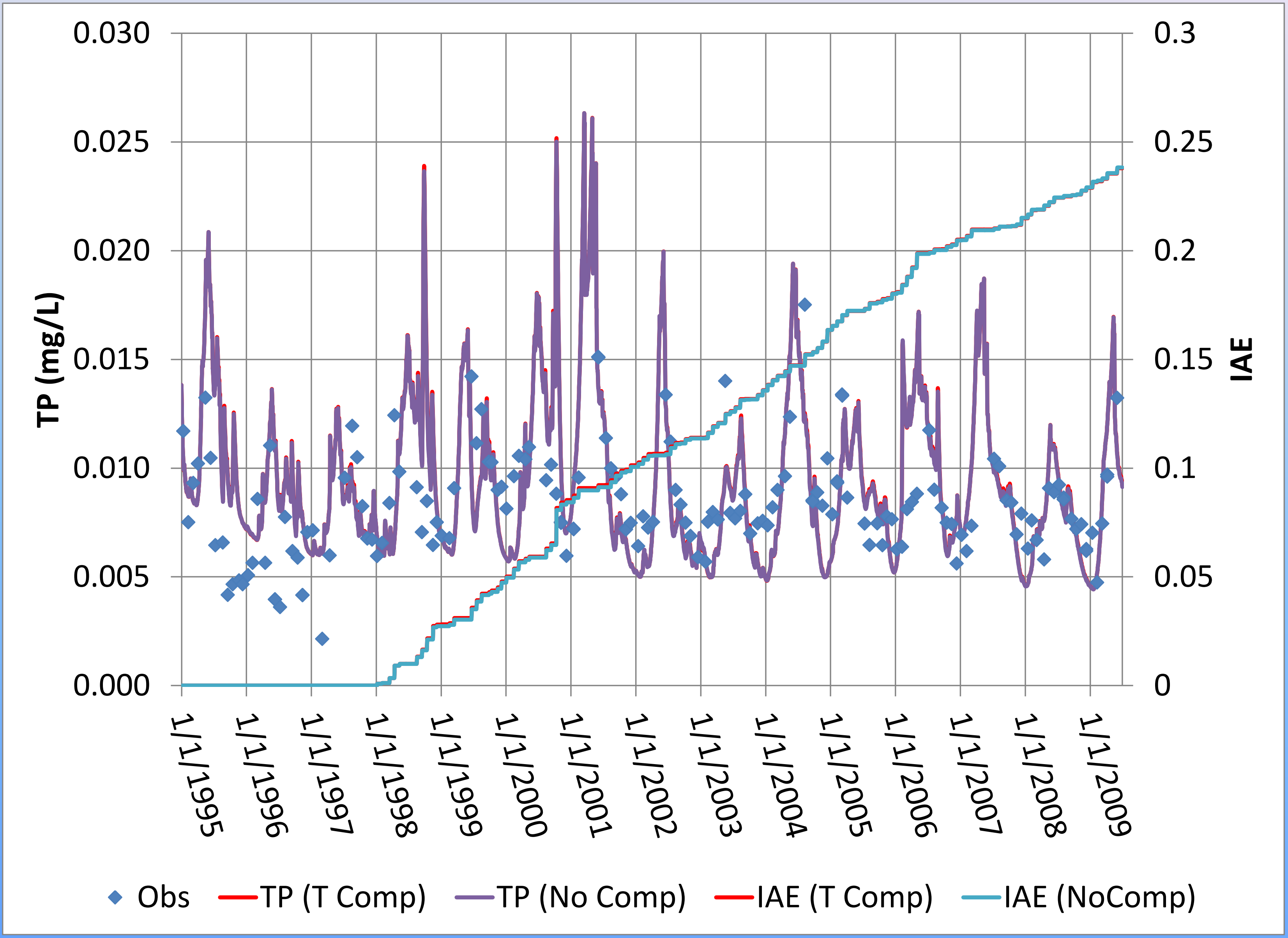
Modified Arrhenius Relationship:

$$Rate_T = Rate_{20}\Theta^{(T-20)}$$

$$\Theta\ is\ temperature\ coefficient$$


35
30
25
20
15
10
5
0
Median Temperature (Deg C)
1/1/1995
1/1/1996
1/1/1997
1/1/1998
1/1/1999
1/1/2000
1/1/2001
1/1/2002
1/1/2003
1/1/2004
1/1/2005
1/1/2006
1/1/2007
1/1/2008
1/1/2009
Date

TP With/Without Temperature Compensation



Conclusions

- SRSM is comparatively easy to use and provides rapid results
- SRSM predicts temporal trends in TP, and response to loading alterations
- The model is useful for screening some management alternatives or structural changes
- Prediction of geometric mean of EVPA (interior) sampling sites was improved by recalibration
- No apparent temperature effects on TP kinetic rates
- Sulfate was not related to model residual error, suggesting no significant relationship between sulfate concentration and TP kinetics

For more information:

- Email: mike@mwaldon.com
- Visit:
  - http://loxmodel.mwaldon.com
  - http://sofia.usgs.gov/lox_monitor_model