James River Water Quality Model

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VIMS William & Mary Virginia Institute of Marine Science

DEQ Virginia Department of Environmental Quality

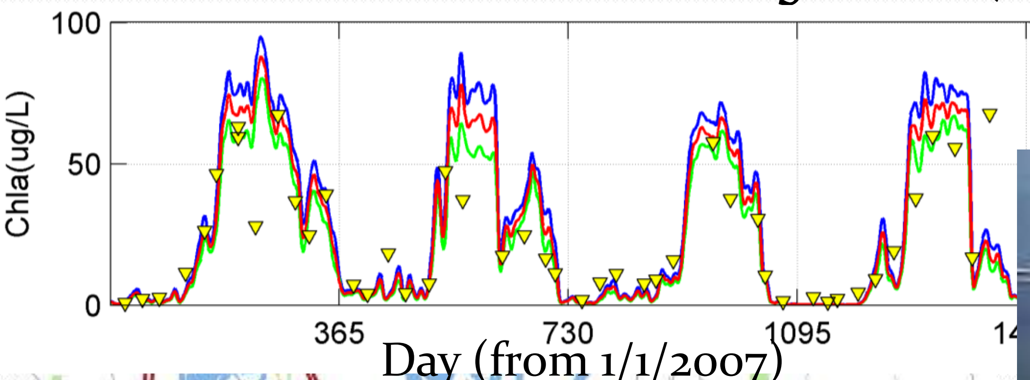
TETRA TECH

CEC

HDR HydroQual

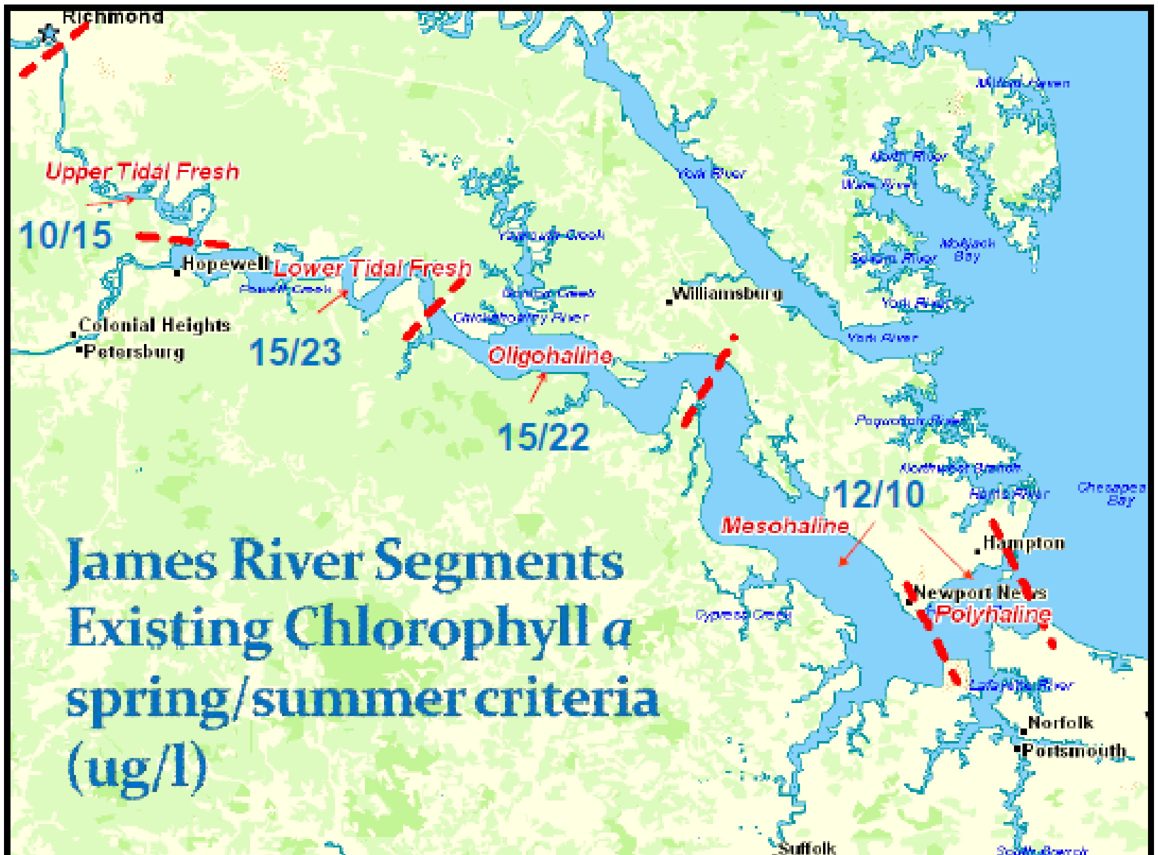
Background

- James River is eutrophic and is experiencing increasing levels of undesirable phytoplankton or Harmful Algal Blooms (HABs)
- Freshwater – *Microcystis aueroginosa* (cyanobacteria)
- Marine Waters – *Cochlodinium polykrikoides, Scippsiella trochoidea, Akashiwo sanguinea* (dinoflagellates)



Background

- In 2005, Virginia adapted new DO, water clarity and chl-a criteria for Chesapeake Bay and its tidal tributaries



Background

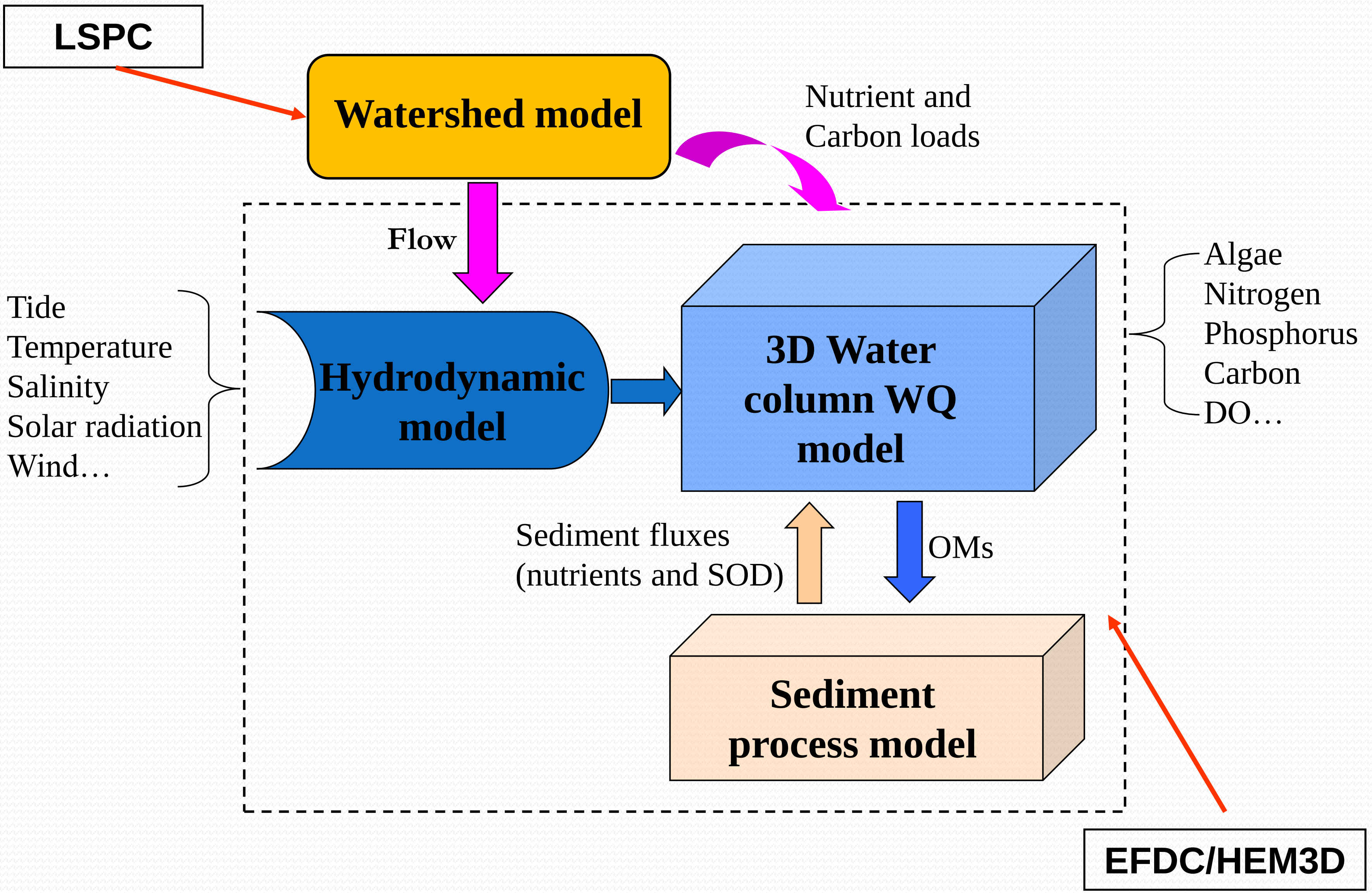
VADEQ has provided funding to support a James River Chlorophyll Study

- Science Advisory Board (SAP) - conduct scientific study to review basis for setting chlorophyll standards
- Funding for specials field/laboratory monitoring and studies
- Funding for development of site-specific water quality model

Modeling Team and Focus

- Chesapeake Environmental Communications – Prime
- Tetra Tech – Watershed Modeling
  - Modelling period: 1990-2013
- VIMS – Hydrodynamic and Eutrophication Modeling
  - Modeling period: 1991-2000, 2007-2013
- HDR – HAB Modeling
  - Modeling period: 2007-2013
- Academic Technical Support for HAB Modeling
  - Dr. Paul Bukaveckas (VCU)
  - Dr. Margie Mulholland (ODU)
  - Dr. Hans Paerl (UNC)

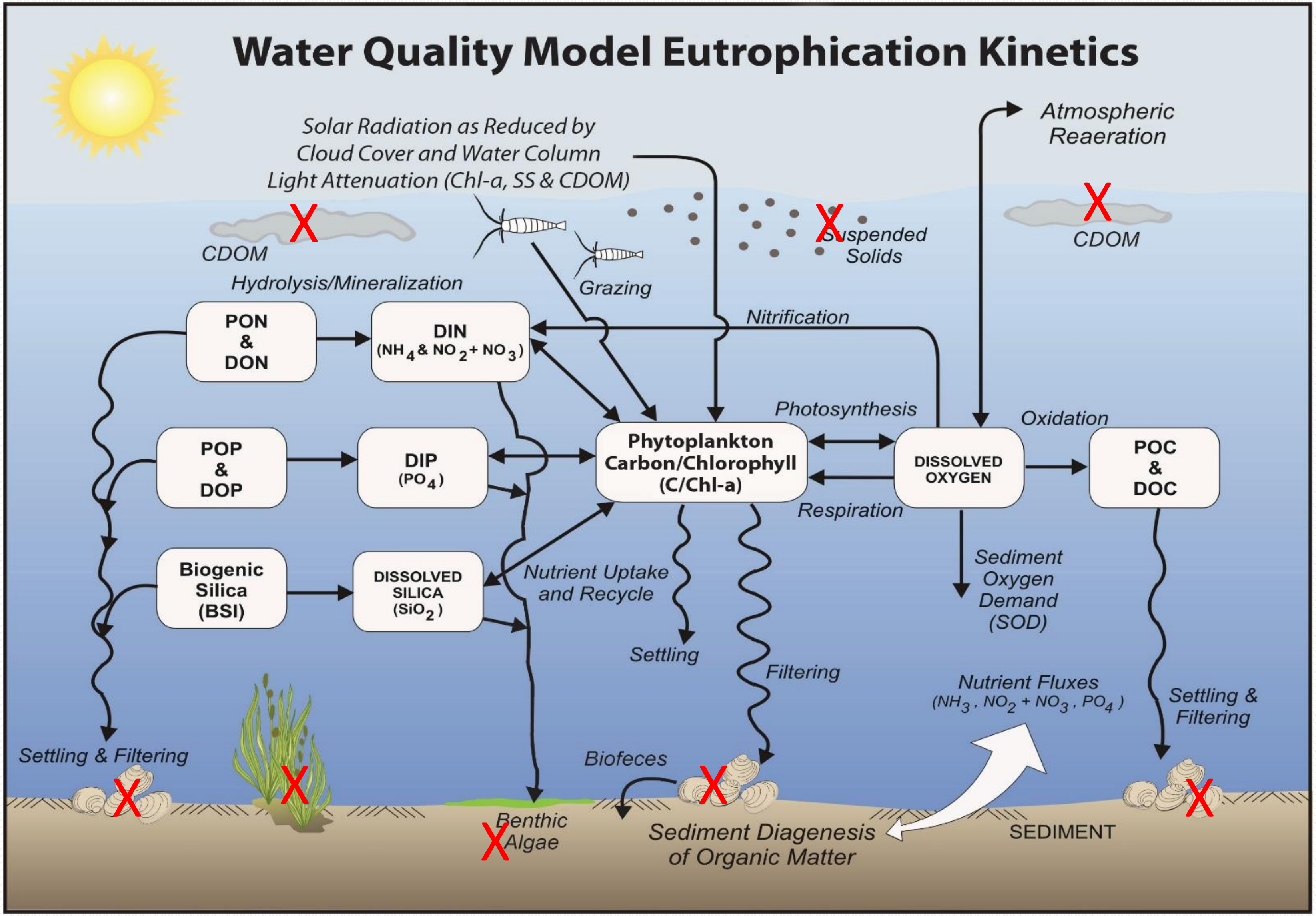
James River Modeling Framework



Model Description

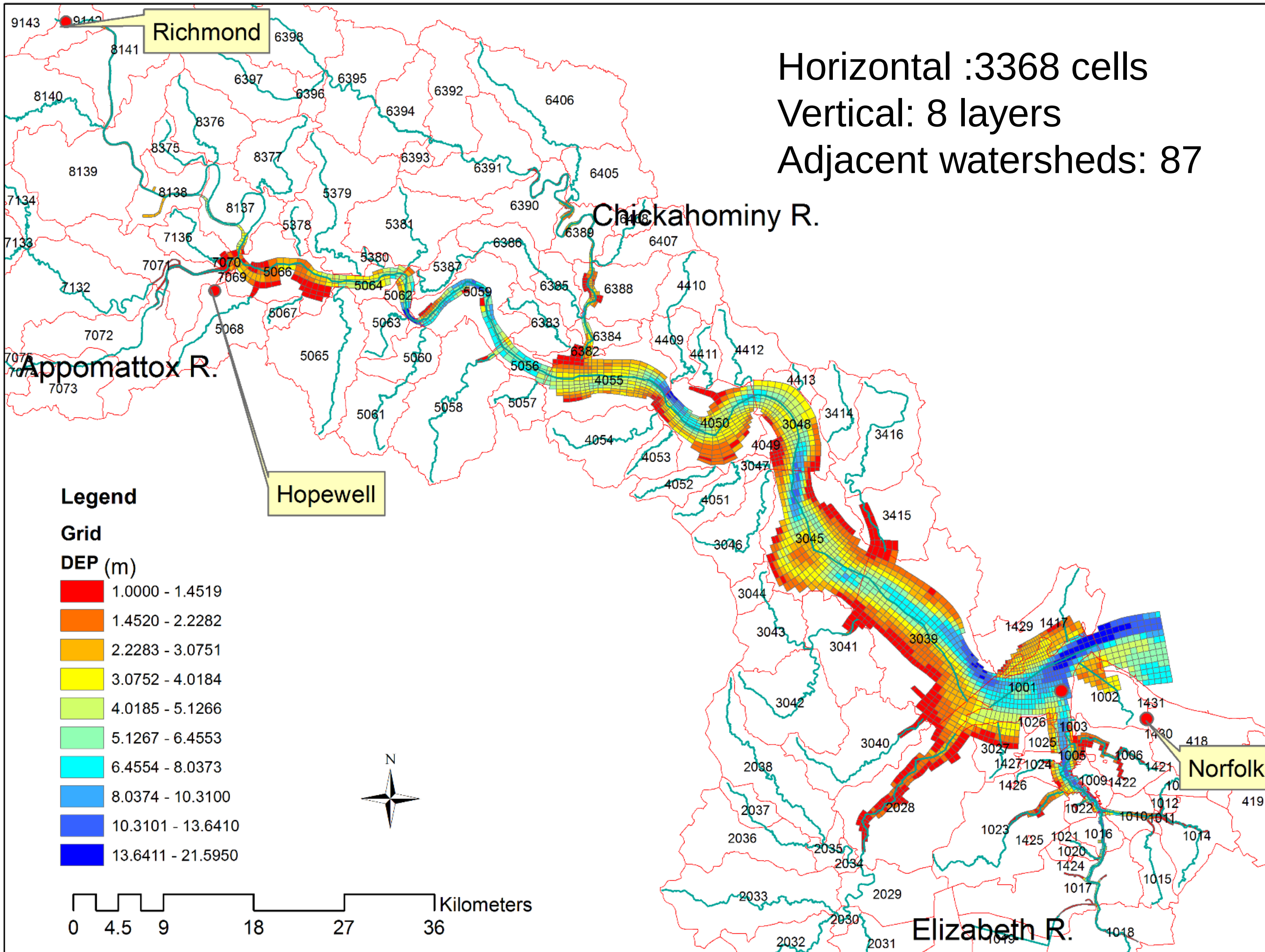
- Hydrodynamic Model: Environmental Fluid Dynamic Code (EFDC)
  - Boundary Fitted Curvilinear Grid
  - Sigma coordinates in vertical
- Water quality model (HEM3D)(referred as Conventional Eutrophication Model)
  - Similar to the early version of the Bay water quality model
  - Without zooplankton, SAV, and benthic algae
  - Bottom sediment diagenesis model is similar to DiToro and Fitzpatrick's model built inside the Chesapeake Bay water quality model

Model Kinetic Processes



Model Grid

Horizontal :3368 cells
Vertical: 8 layers
Adjacent watersheds: 87



Model Configuration

- Flow and loadings use LSPC daily model outputs
  - POC, DOC, PON, DON, NH4, NO23, POP, DOP, PO4, and DO
  - POC, DOC, PON, DON, POP, and DOP are based on ratio to total organics. Model does not simulate silica.
- Open boundary condition
  - 1991-2000 uses Chesapeake Bay model outputs (tide, salinity, temperature, and water quality state variables
  - 2007-2013 uses observations and VIMS Bay model of salinity. Water quality state variables use interpolation of observations near the James Rive mouth.
- Solar radiation uses hourly observations at Norfolk and Richmond stations
- Hourly observed wind data are used for computing aeration
- Suspended solids use spatially and temporally interpolated results based on observations
- Initial condition for bottom sediment diagensis model
  - Repeat simulations until it reach dynamic equilibrium

Atmospheric deposition

- Wet-deposition
  - NO_3: 0.133 mg/L
  - NH_4: 0.078 mg/L
  - ON : 0.026 mg/L
  - OP : 0.023 mg/L
  - PO_4 : 0.0077 mg/L
- Dry-deposition
  - NO_3: 0.018 lb/ac/d
  - NH_4: 0.044 lb/ac/d.

Algal group input at upstream

Month	Fraction Winter-spring	Fraction Summer
January	1.00	0.00
February	1.00	0.00
March	0.90	0.10
April	0.80	0.20
May	0.50	0.50
June	0.20	0.80
July	0.10	0.90
August	0.10	0.90
September	0.10	0.90
October	0.50	0.50
November	0.90	0.10
December	1.00	0.00

Parameter Considerations

- Phytoplankton species (2 algal assemblages)
  - Winter assemblage : diatoms
  - Summer assemblage: diatom and green algae
  - Motility is applied in the mesohaline zone based on salinity
- Temperature dependent growth function
- Light dependent growth function
- Carbon to Chl-a ratio
- Other parameters (used published reference values with model calibration)

Effects of light on growth

$$P^B = P^Bm \frac{I}{\sqrt{I^2 + IK^2}}$$

P^B = photosynthetic rate (g C g^{-1} Chl d^{-1})
P^Bm = maximum photosynthetic rate (g C g^{-1} Chl d^{-1})
I = irradiance (E m^{-2} d^{-1})

Parameter Ik is defined as the irradiance at which the initial slope of the production vs. irradiance relationship intersects the value of P^Bm:

$$IK = \frac{P^Bm}{\alpha}$$

The chlorophyll-specific production rate

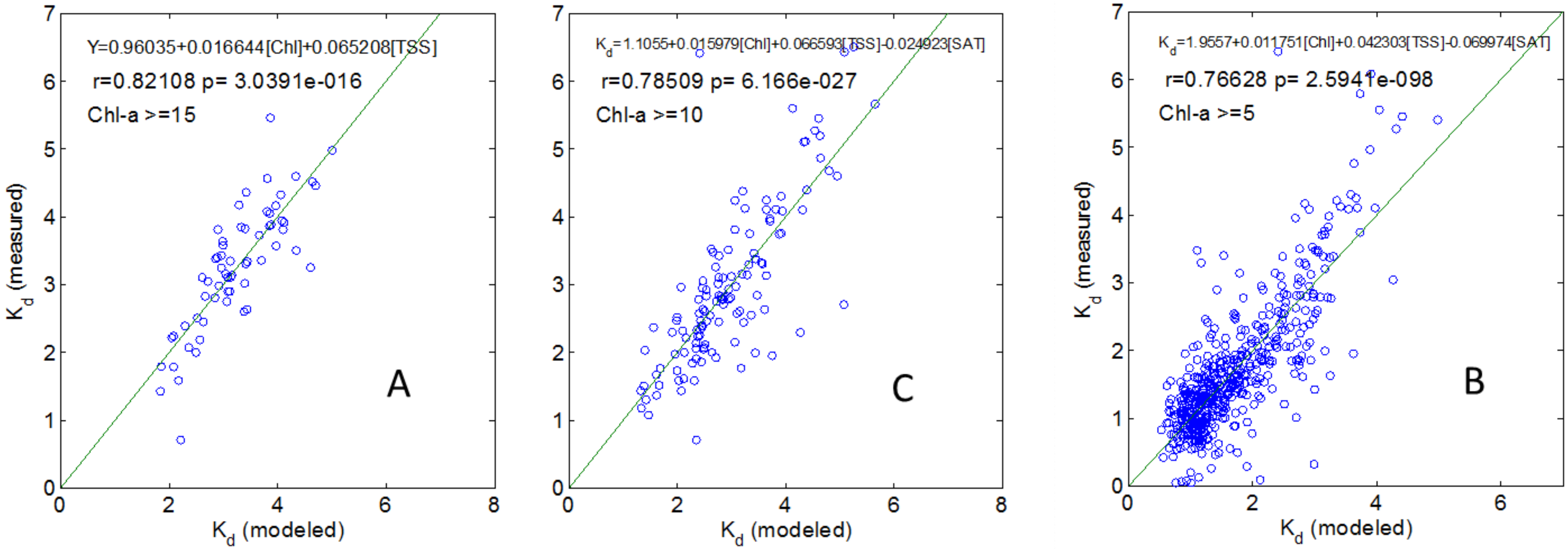
$$G = \frac{P^B}{CChl}$$

CChl = carbon-to-chlorophyll ratio (g C g^{-1} chlorophyll-a)

Light function

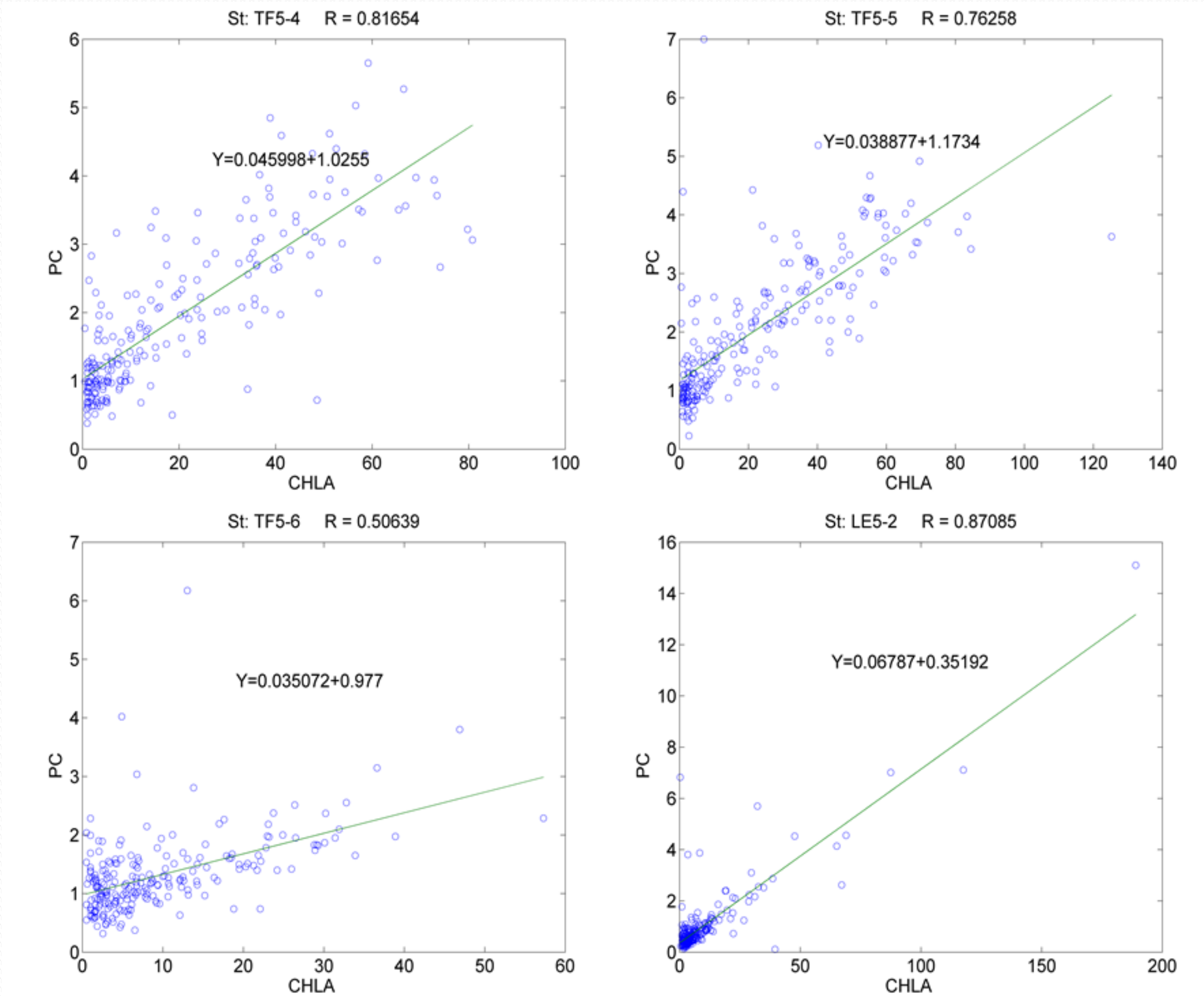
- Function of TSS, algae, suspended solid, and salinity

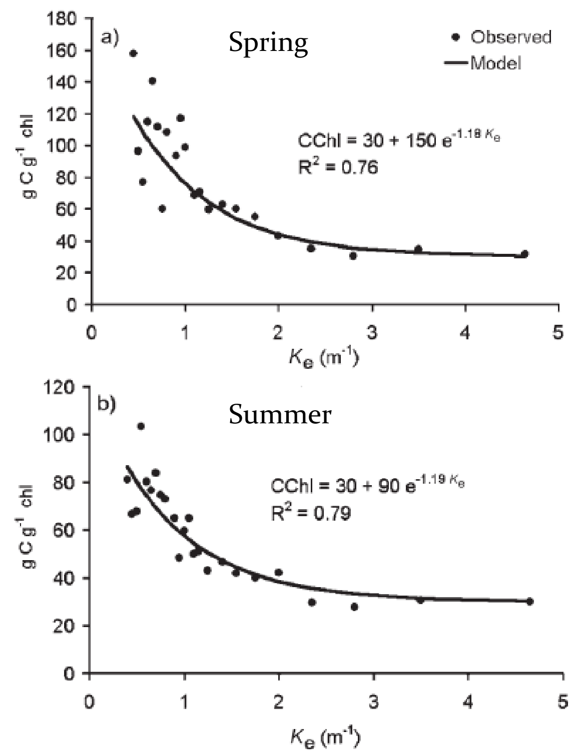
$$K_d = K_w + K_c[Chl] + K_t[TSS] + K_s[Sal]$$



C:Chl a ratio

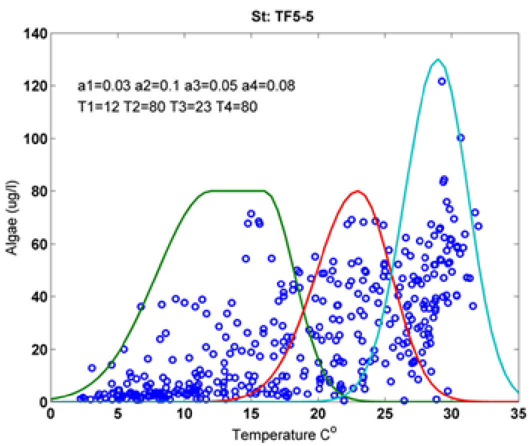
Estimate from observation data and adjusted during model calibration

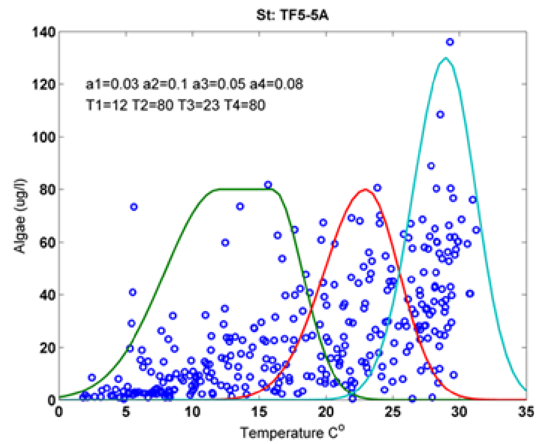


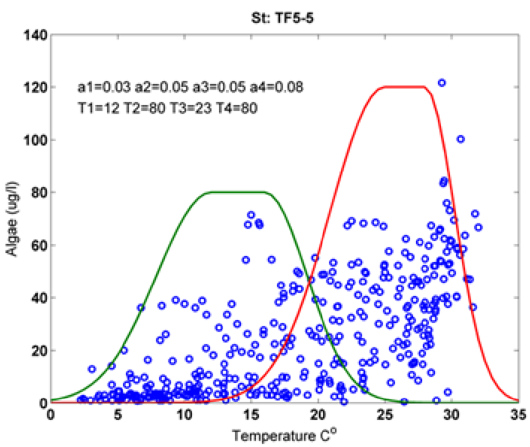


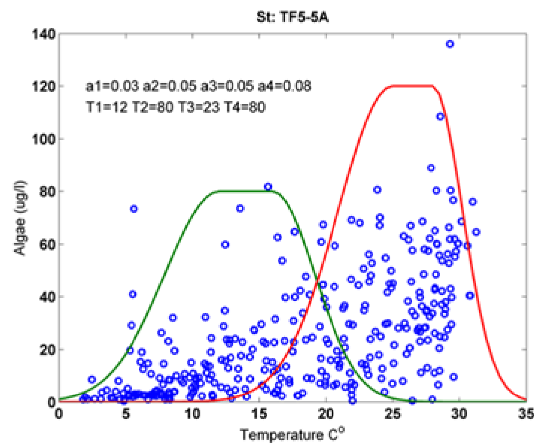
(Cerco & Noel, 2006)

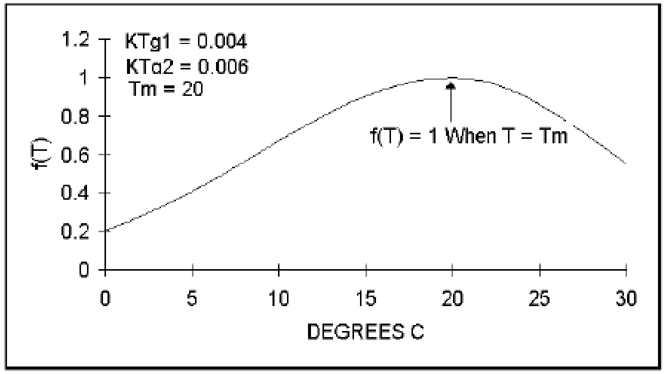
Temperature Dependent Algal Growth



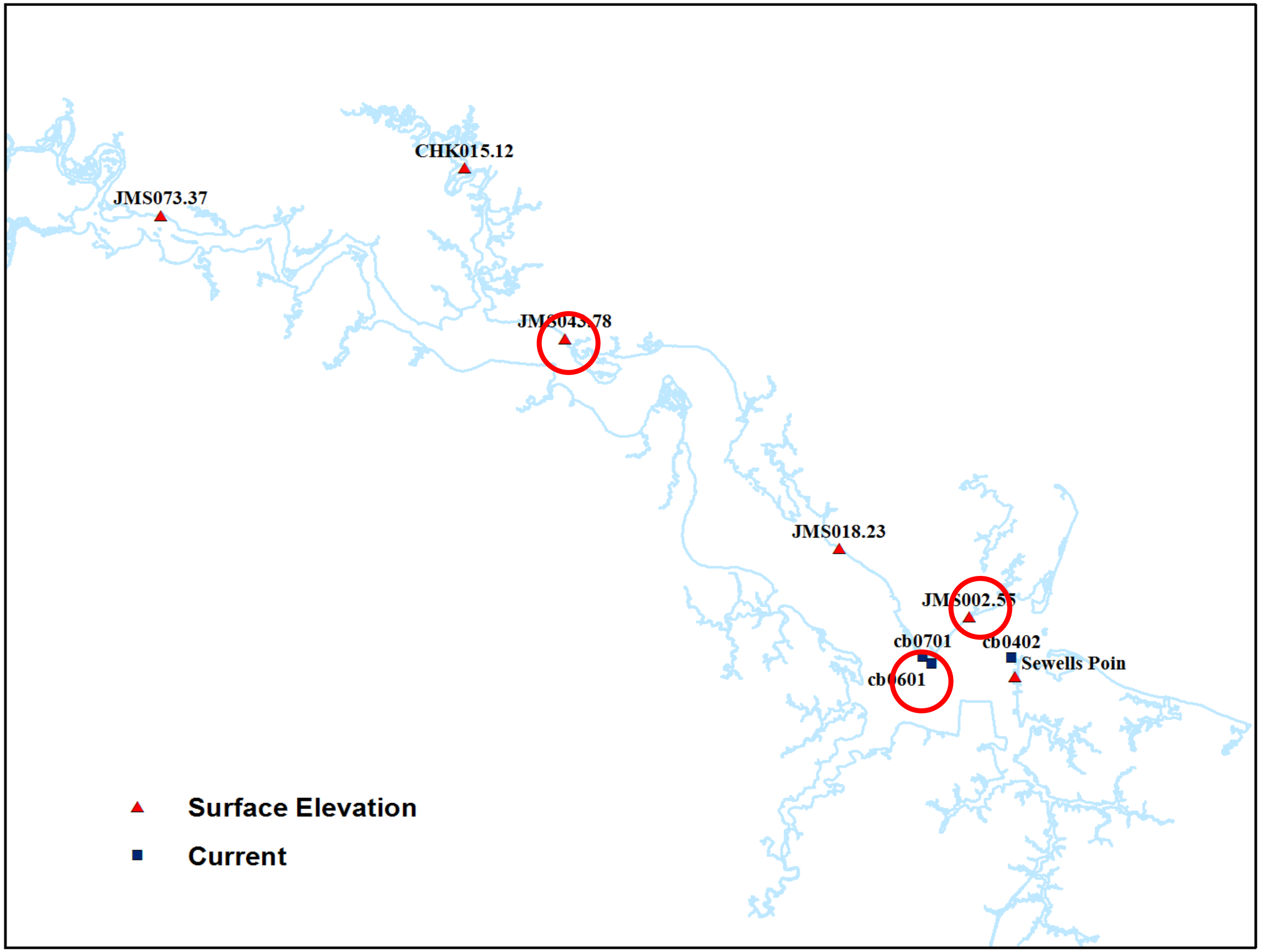




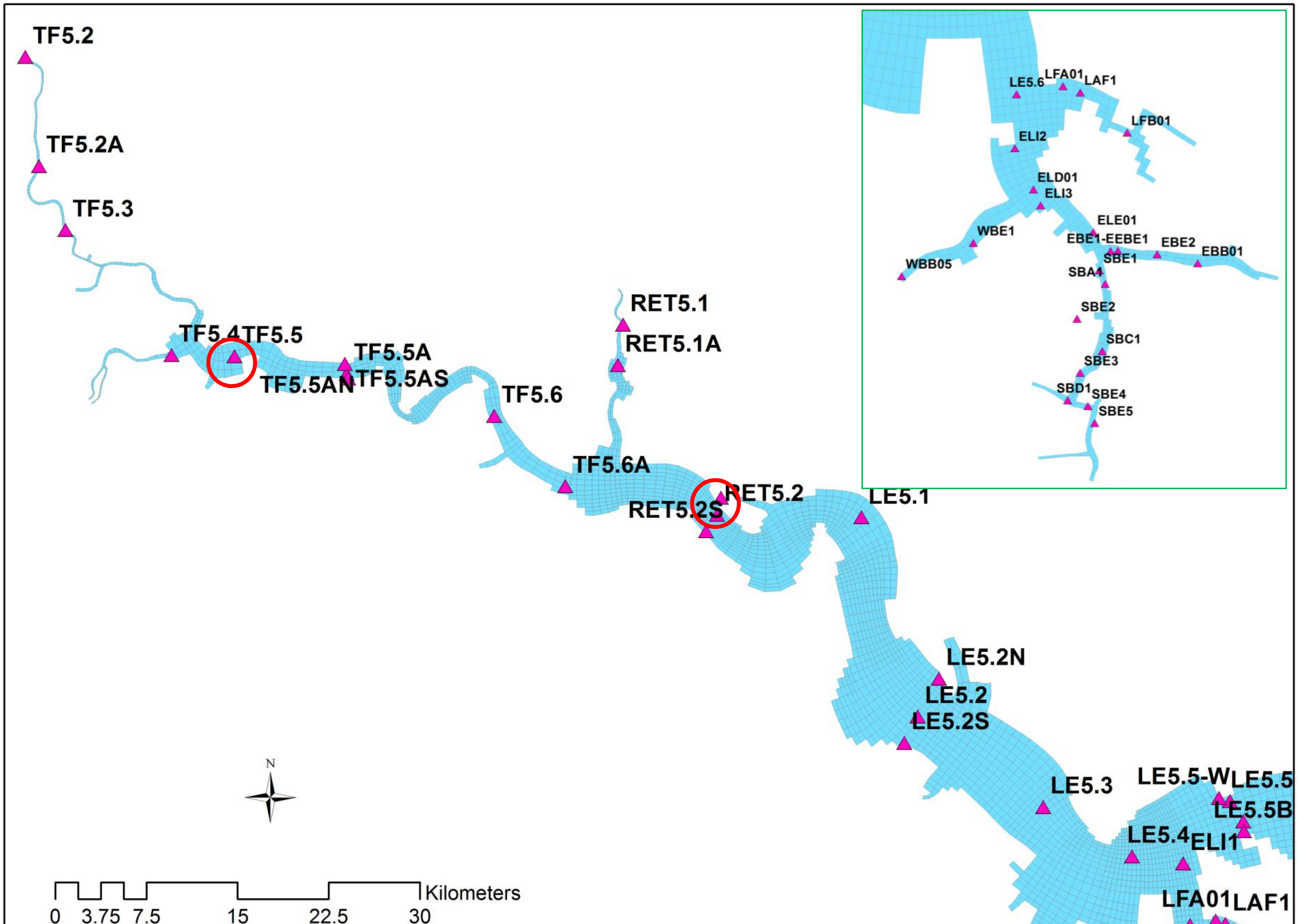




Tide and Current Observation Stations



Long-term Monitoring Station



Model Skill Assessment Criteria

- Model-data graphic comparison
  - Direct comparison
  - Scatter plots
  - Accumulative distribution
  - Error distribution
- Statistics
  - Correlation (R)
  - Root-mean-square error (ER)
  - Model Skill (SS, WS)
  - Mean error (ME)
  - Absolut mean error (AME)
  - Relative error (RE)
- Processes
  - Primary production
  - Respiration
  - Net ecosystem metabolism

$$ER = \sqrt{\frac{\sum_{k=1}^{n}(P_k - O_k)^2}{n}}$$

$$SS = 1 - \frac{\sum_{k=1}^{n}(P_k - O_k)^2}{\sum_{k=1}^{n}(O_k - \bar{O})^2}$$

$$WS = 1 - \frac{\sum_{k=1}^{n}(P_k - O_k)^2}{\sum_{k=1}^{n}(P_k - \bar{P})^2}$$

$$\mathrm{ME} = \sum_{k=1}^{n}(P_k - \mathrm{O}_k)/\mathrm{N}$$

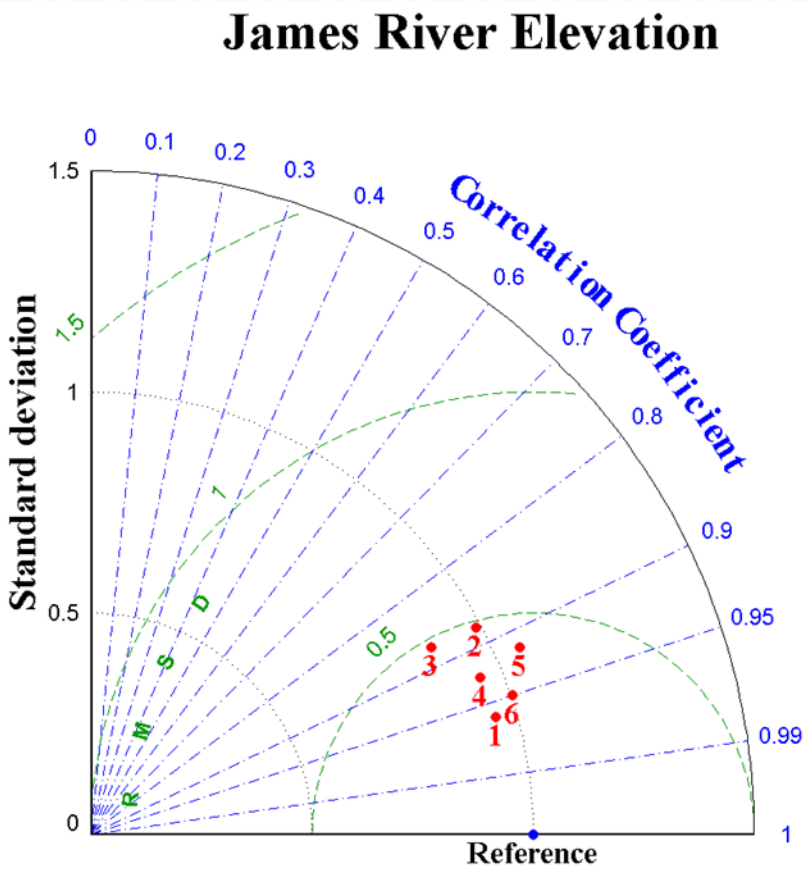
$$\mathrm{AME} = \sum_{k=1}^{n}|P_k - \mathrm{O}_k|/\mathrm{N}$$

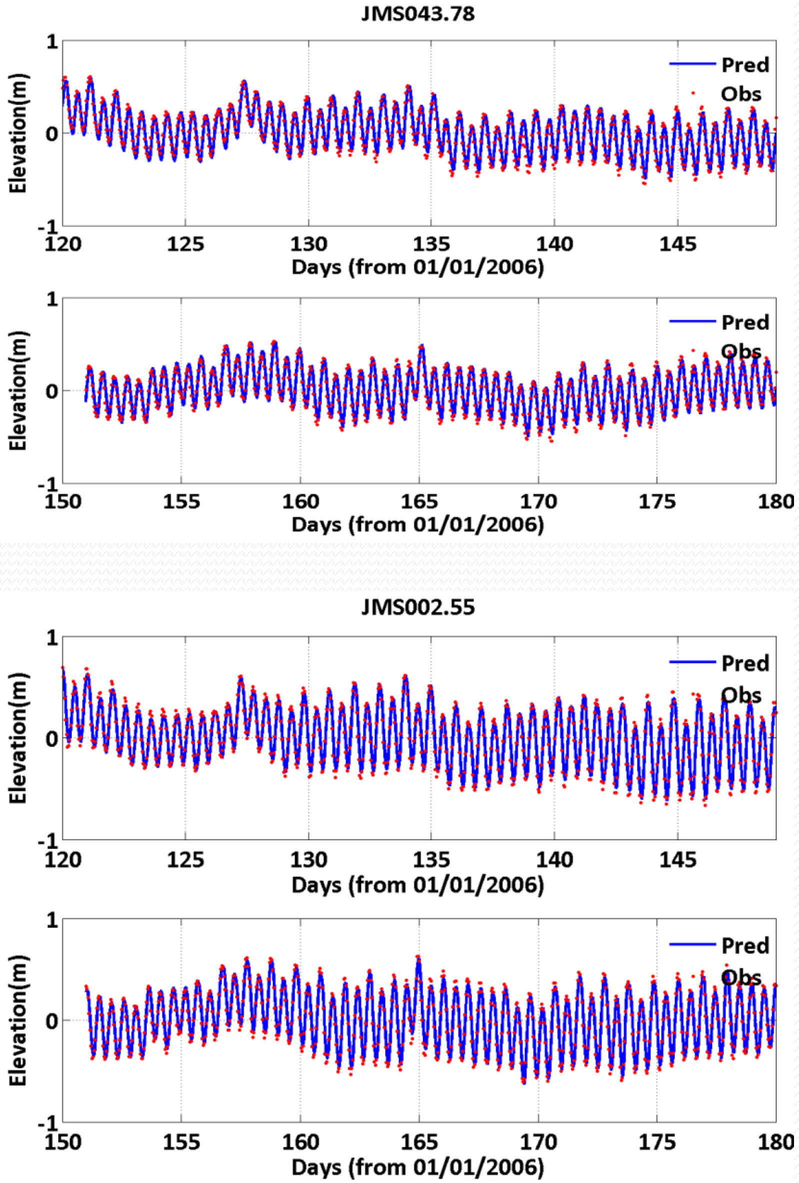
$$RE = \frac{\sum_{k=1}^{n}|P_k - O_k|}{\sum_{k=1}^{n} O_k}$$

Brief Summary of Hydrodynamic Model Calibration

- Surface elevation
- Current
- Salinity
- Temperature

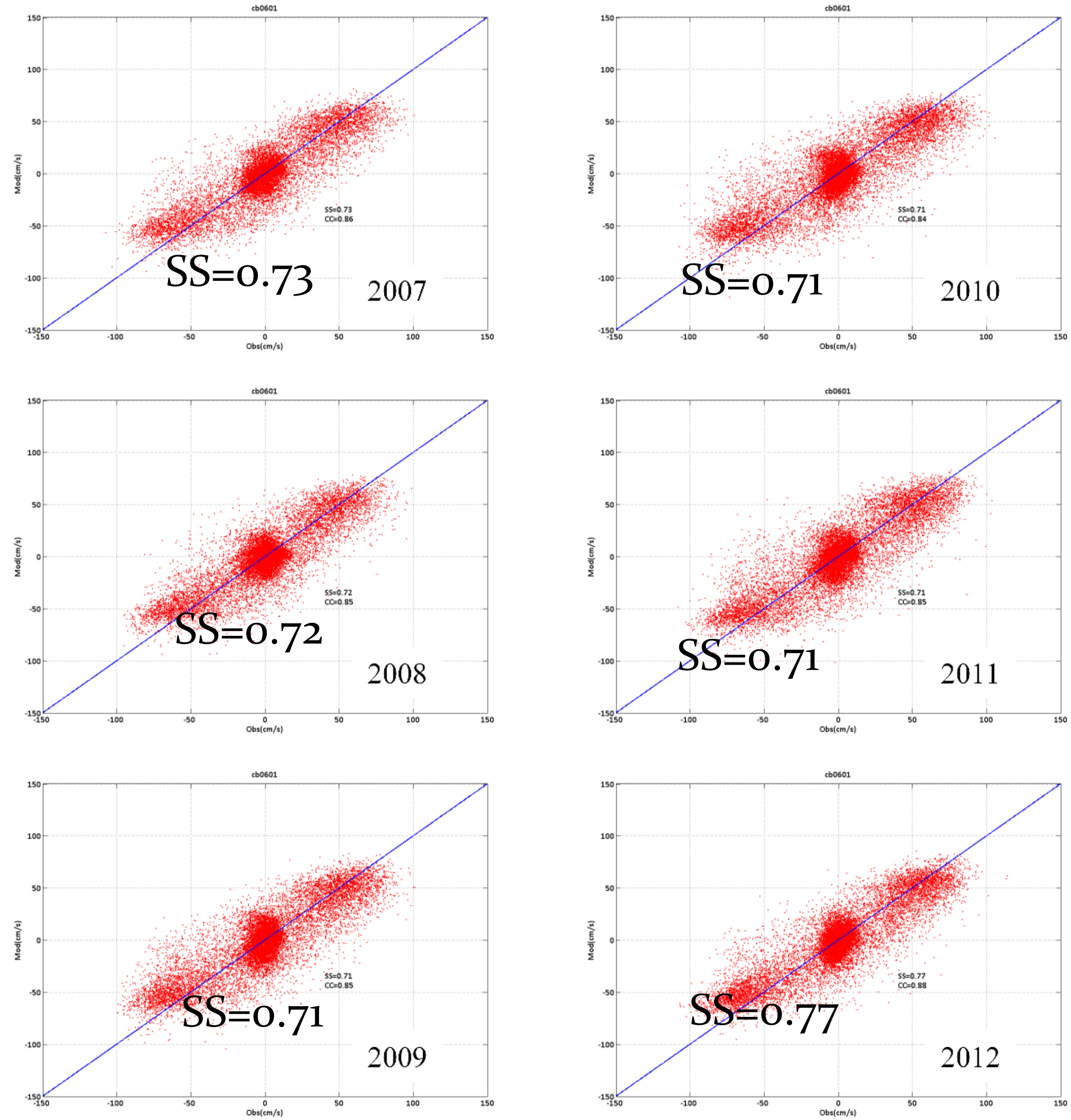
Dynamic Model Calibration



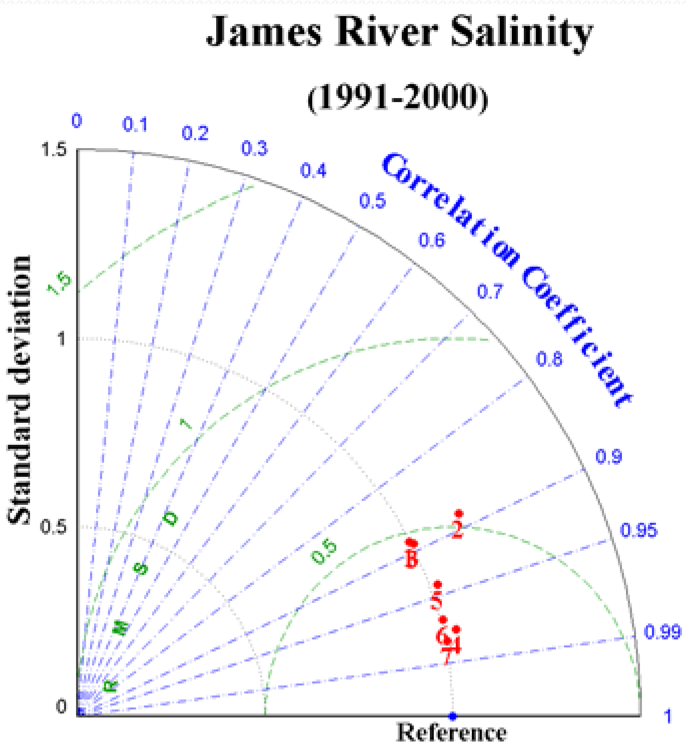


Current

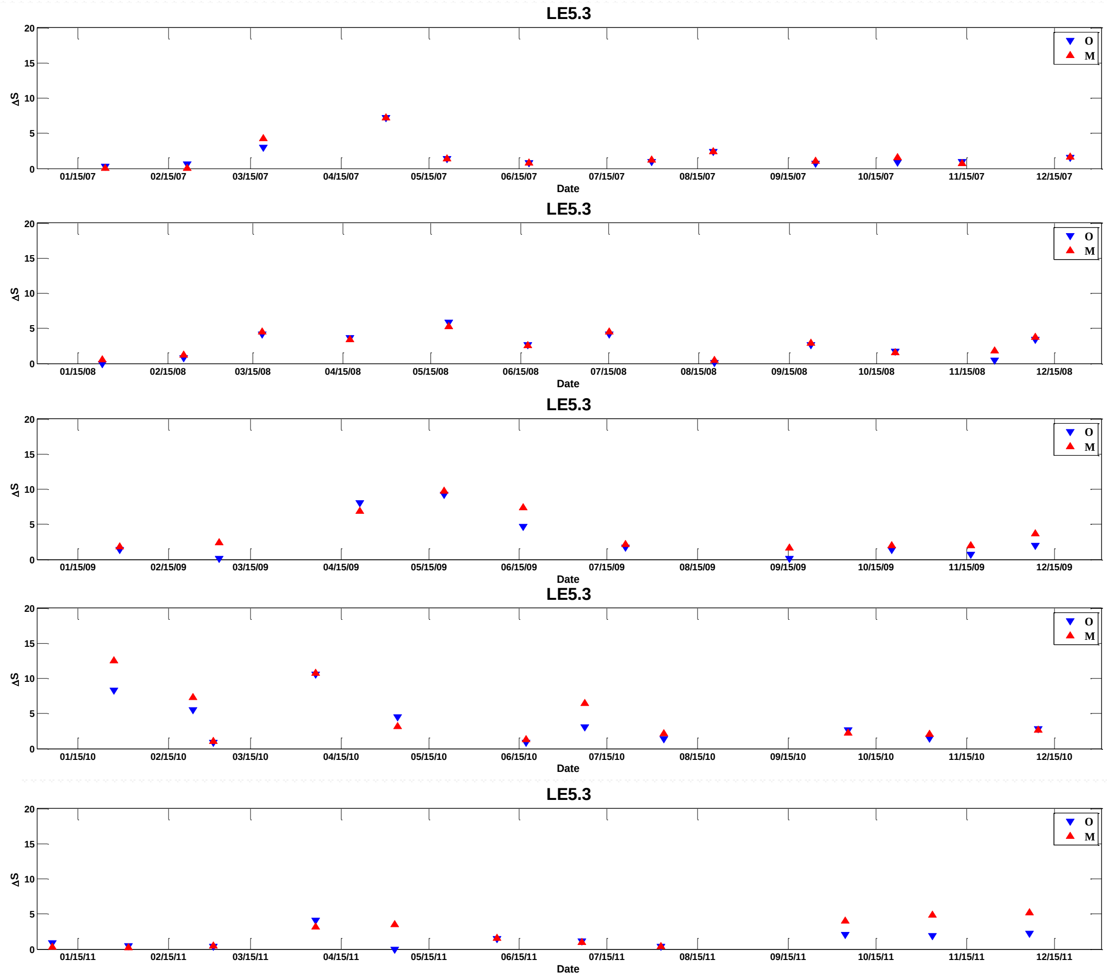
CB601 (Surface)



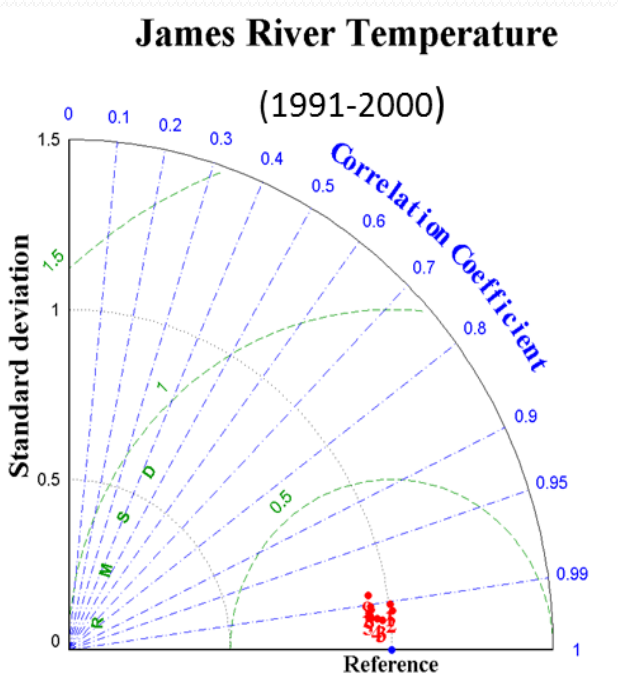
Salinity

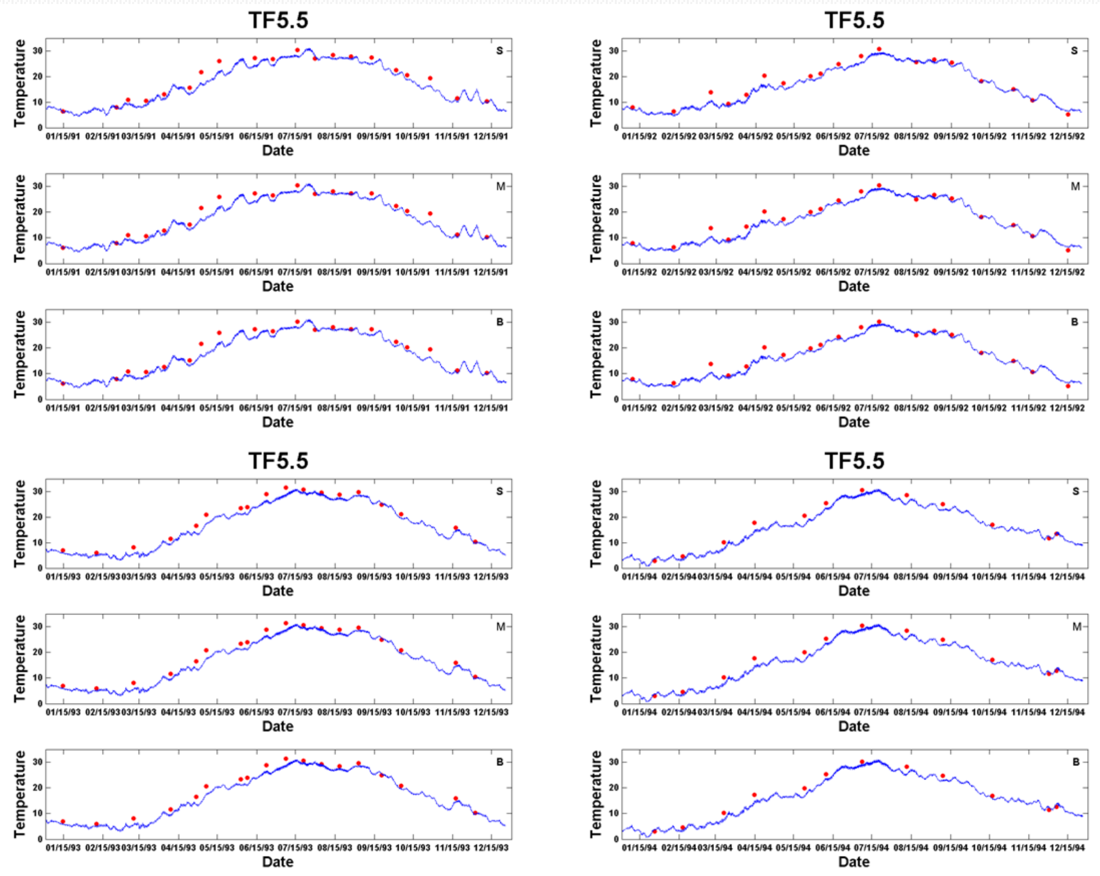


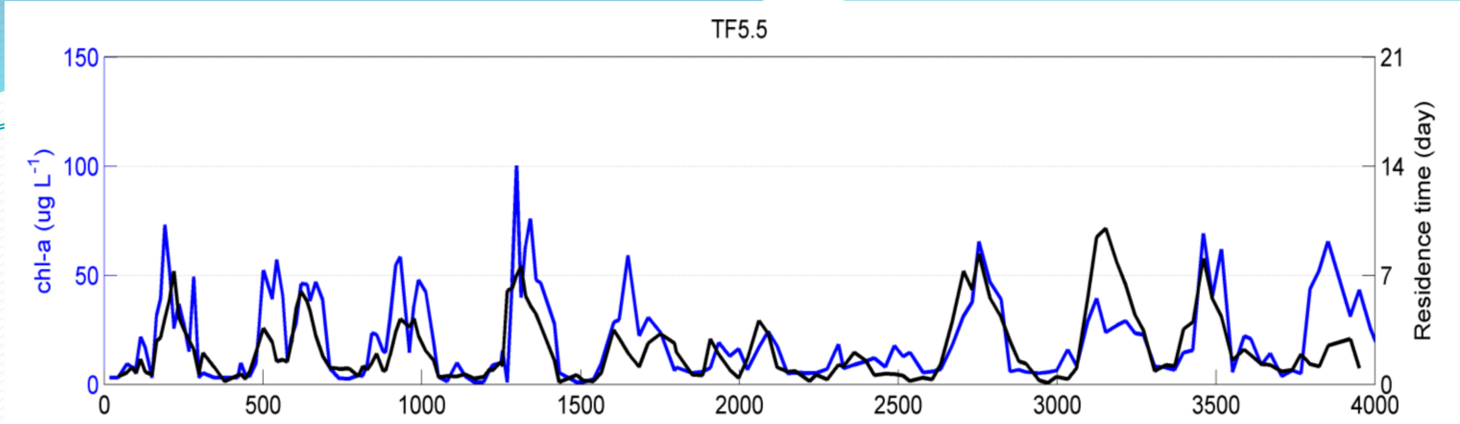
Stratification (difference between bottom and surface)



Temperature

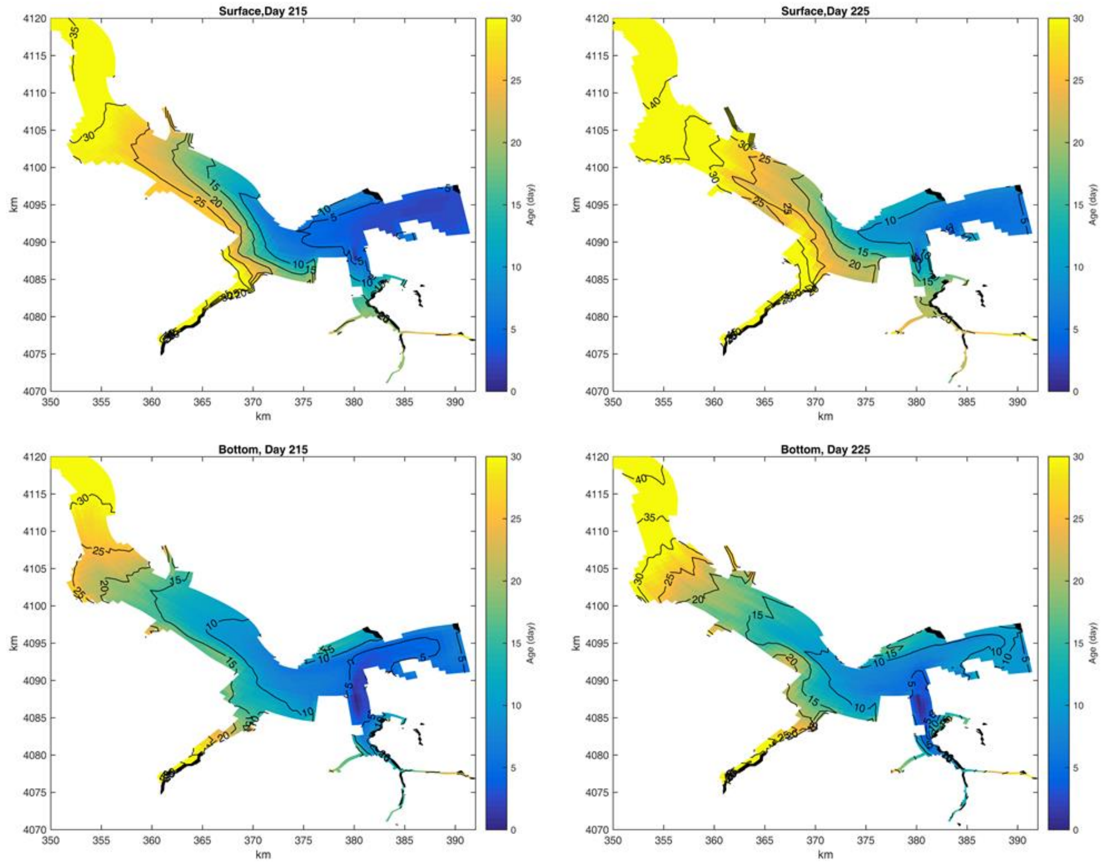






From 1/1/1990

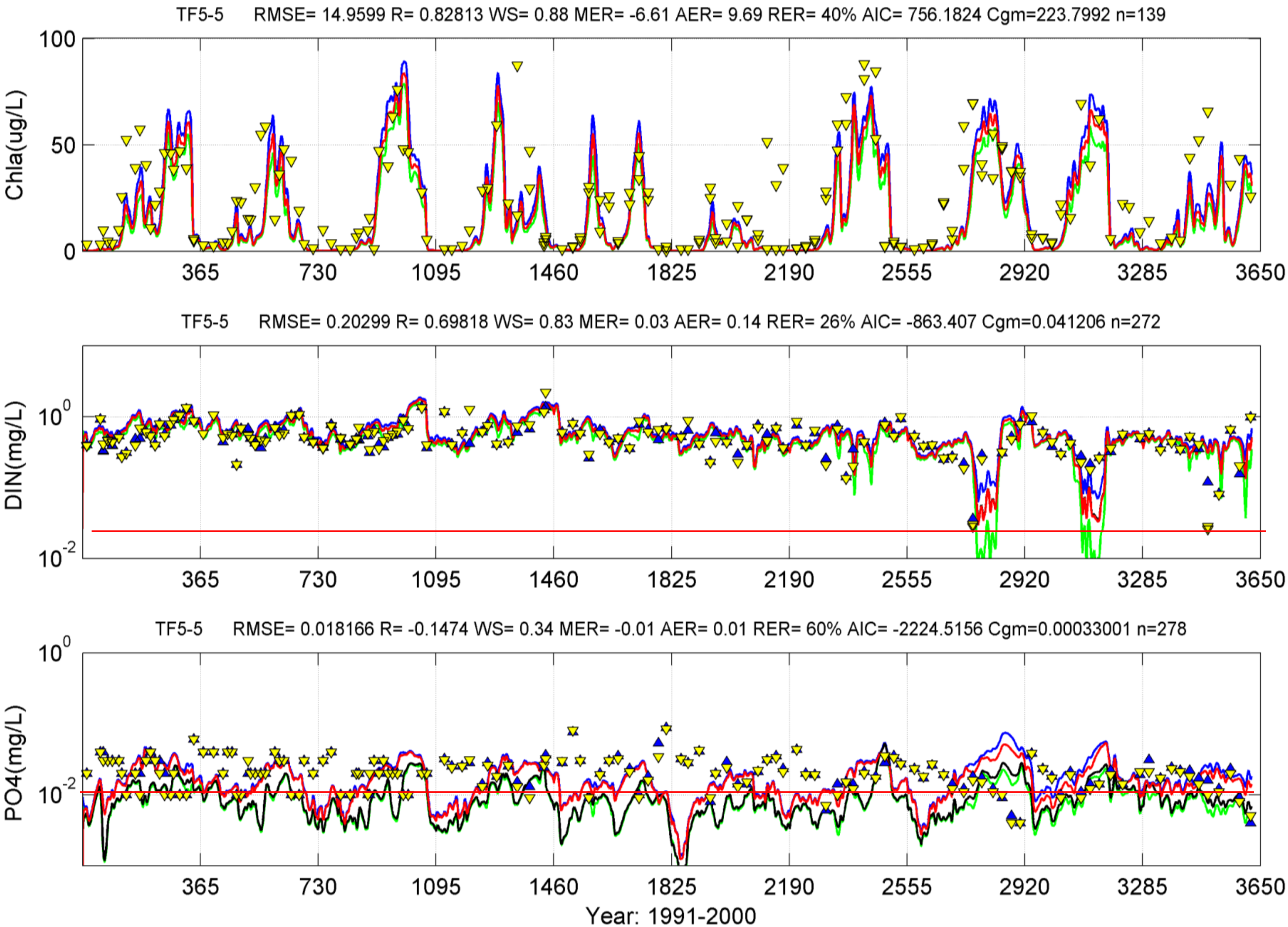
spring tide



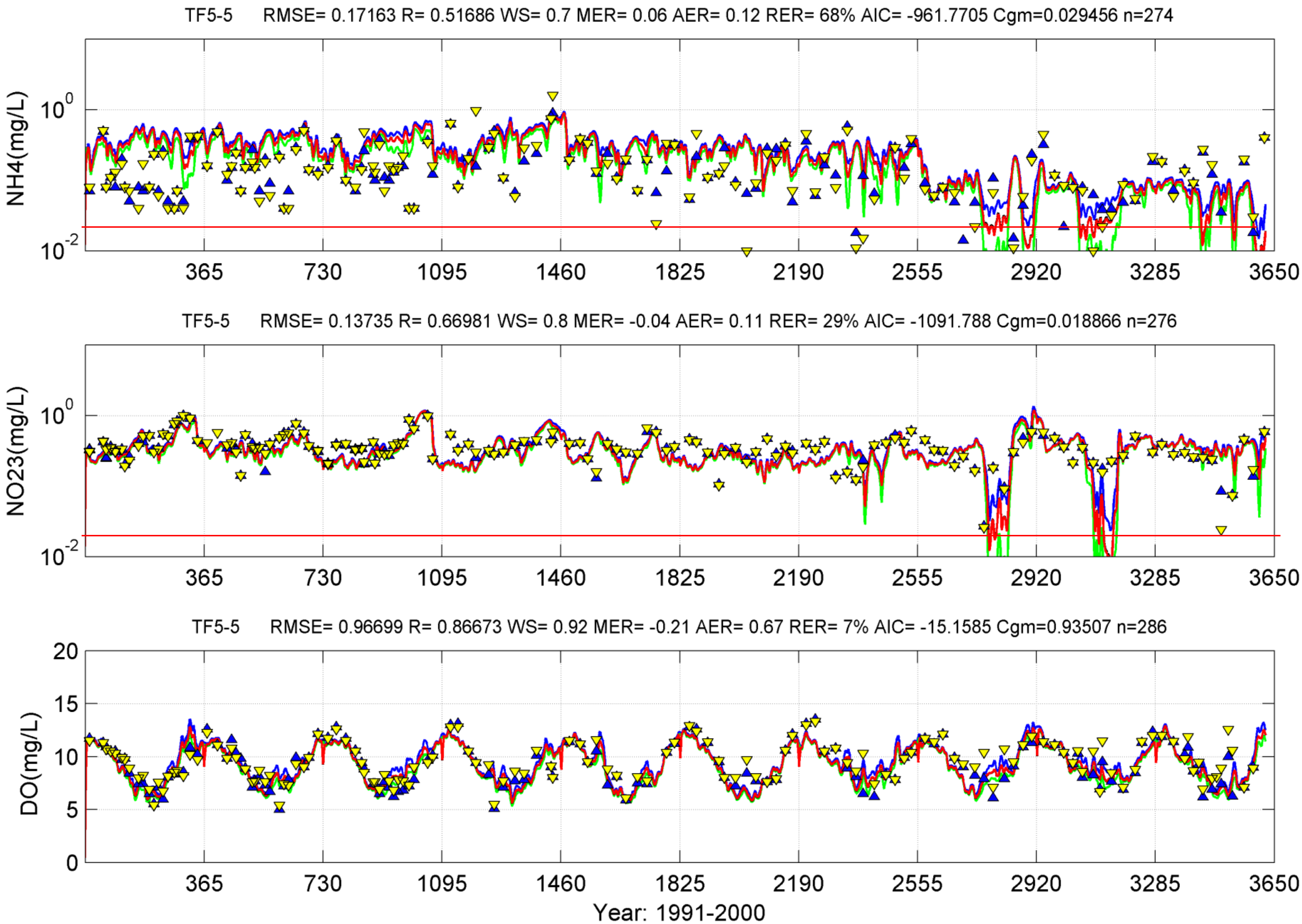
neap tide

Water Quality Model Calibration

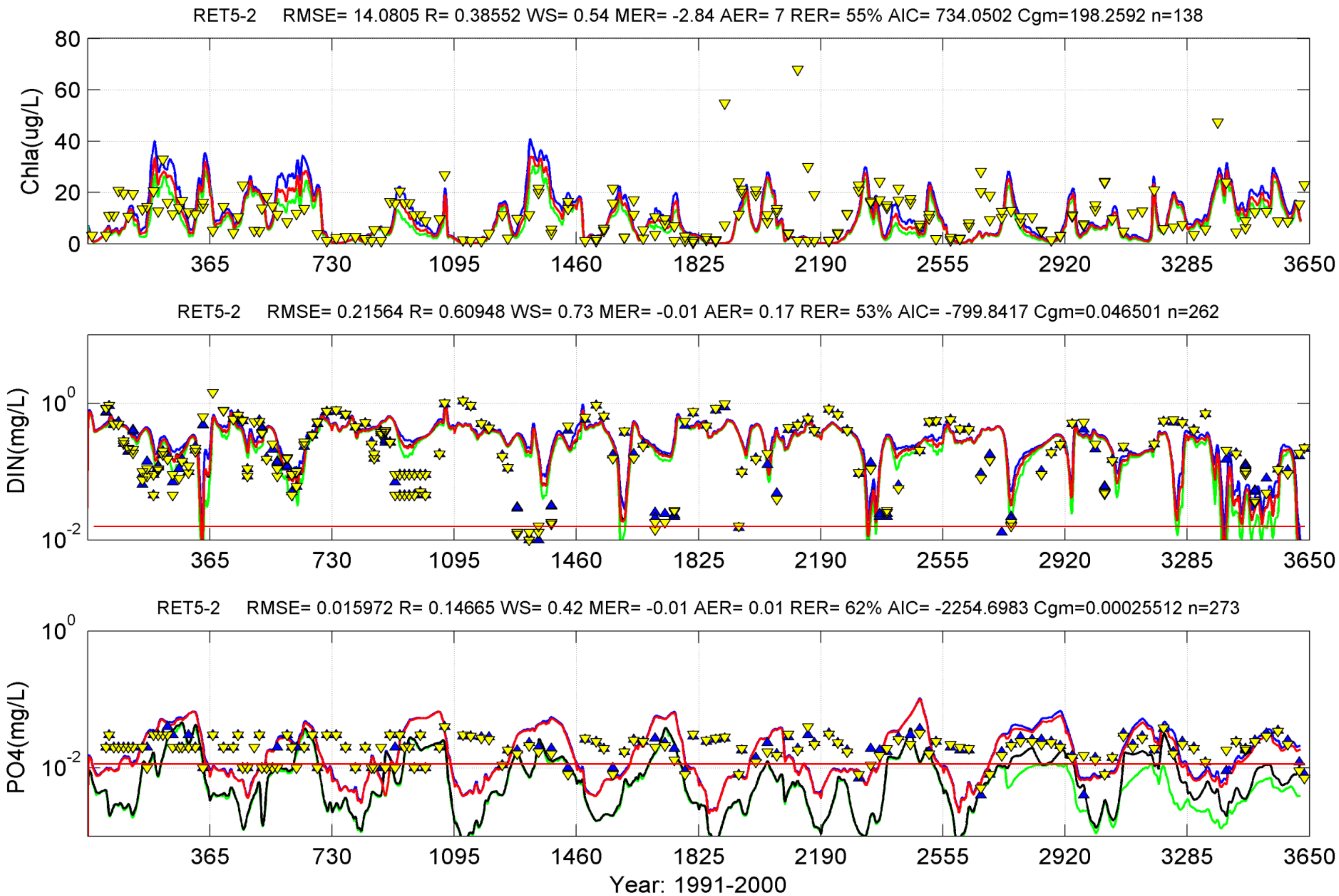
- Calibration period is from 1991-2000

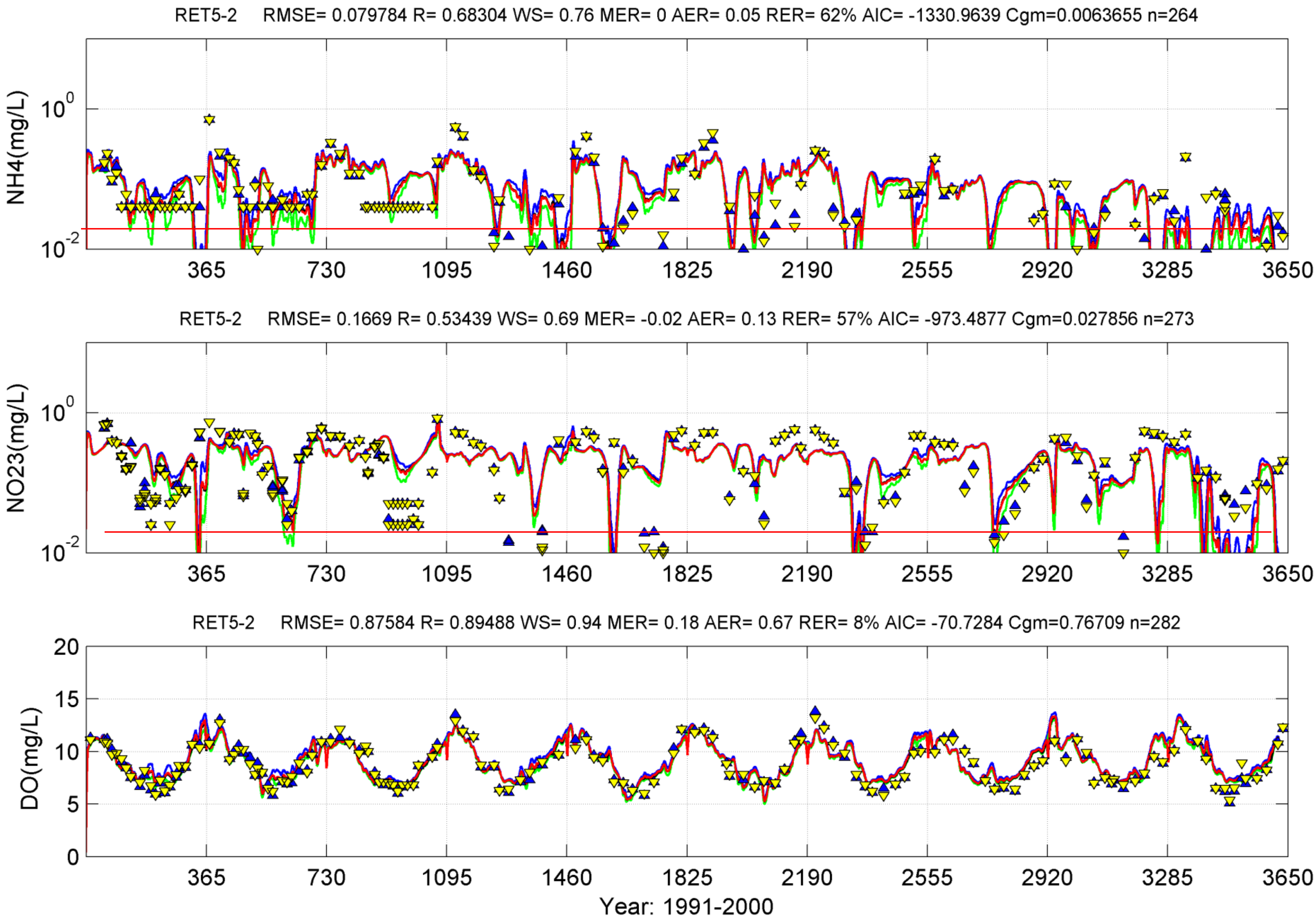


Red and black lines are daily averaged model results at surface and the bottom, respectively. Blue and green lines are daily maximum and minimum concentrations in the water column, respectively.



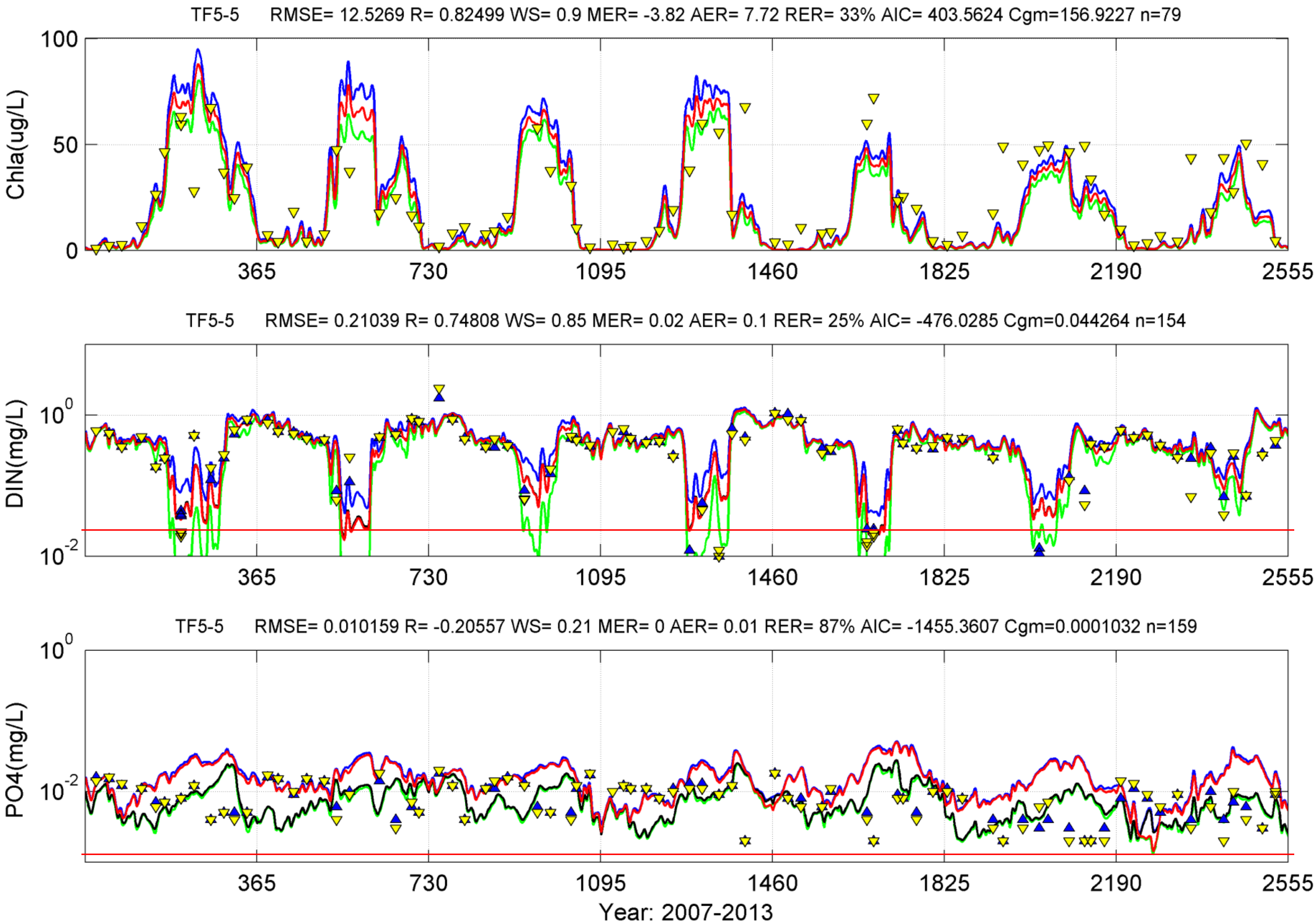
TF5-5 RMSE= 0.17163 R= 0.51686 WS= 0.7 MER= 0.06 AER= 0.12 RER= 68% AIC= -961.7705 Cgm=0.029456 n=274
NH4(mg/L)
TF5-5 RMSE= 0.13735 R= 0.66981 WS= 0.8 MER= -0.04 AER= 0.11 RER= 29% AIC= -1091.788 Cgm=0.018866 n=276
NO23(mg/L)
TF5-5 RMSE= 0.96699 R= 0.86673 WS= 0.92 MER= -0.21 AER= 0.67 RER= 7% AIC= -15.1585 Cgm=0.93507 n=286
DO(mg/L)
Year: 1991-2000

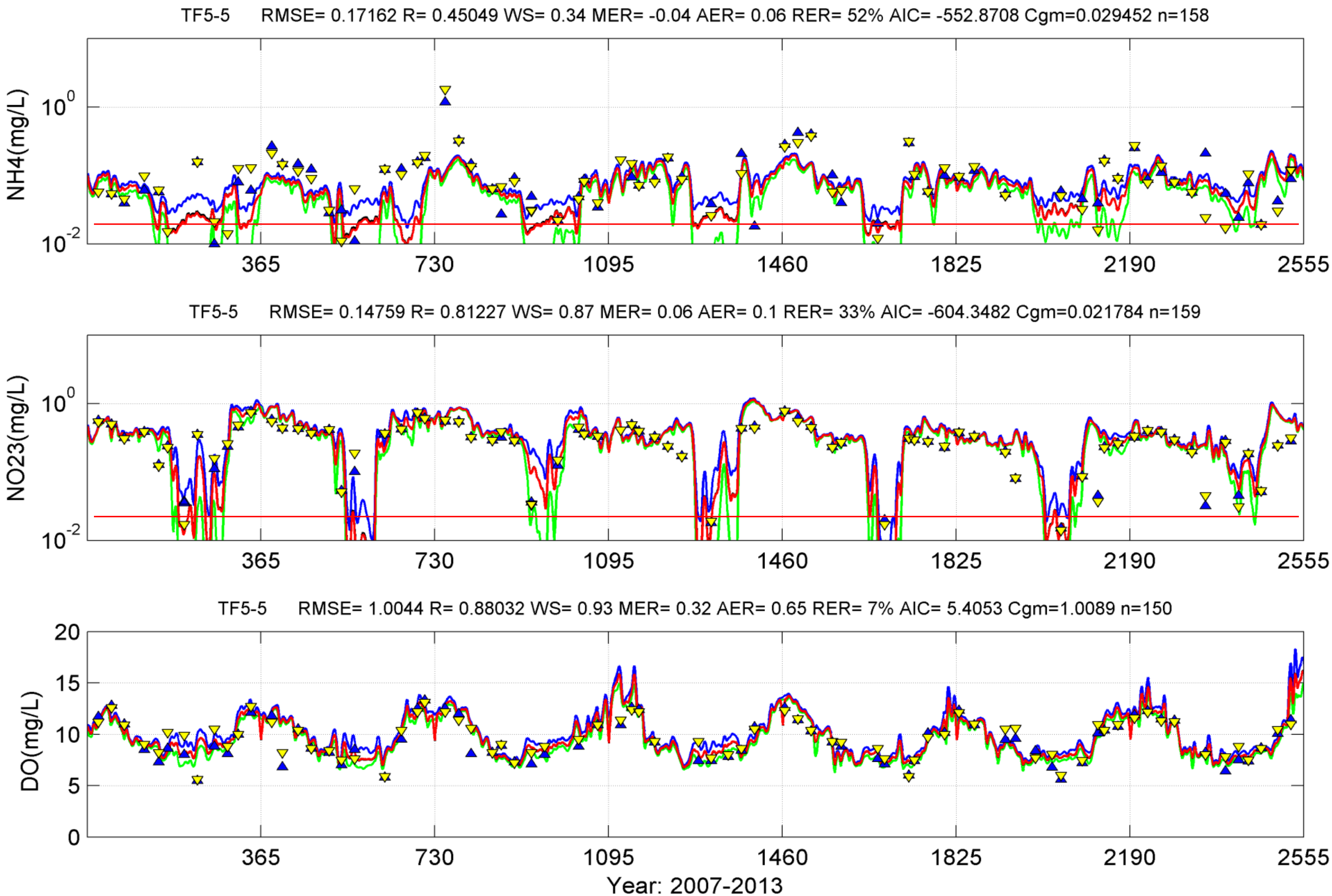

RET5-2 RMSE= 14.0805 R= 0.38552 WS= 0.54 MER= -2.84 AER= 7 RER= 55% AIC= 734.0502 Cgm=198.2592 n=138
Chla(ug/L)
0
20
40
60
80
365
730
1095
1460
1825
2190
2555
2920
3285
3650
RET5-2 RMSE= 0.21564 R= 0.60948 WS= 0.73 MER= -0.01 AER= 0.17 RER= 53% AIC= -799.8417 Cgm=0.046501 n=262
DIN(mg/L)
10^0
10^{-2}
365
730
1095
1460
1825
2190
2555
2920
3285
3650
RET5-2 RMSE= 0.015972 R= 0.14665 WS= 0.42 MER= -0.01 AER= 0.01 RER= 62% AIC= -2254.6983 Cgm=0.00025512 n=273
PO4(mg/L)
10^0
10^{-2}
365
730
1095
1460
1825
2190
2555
2920
3285
3650
Year: 1991-2000

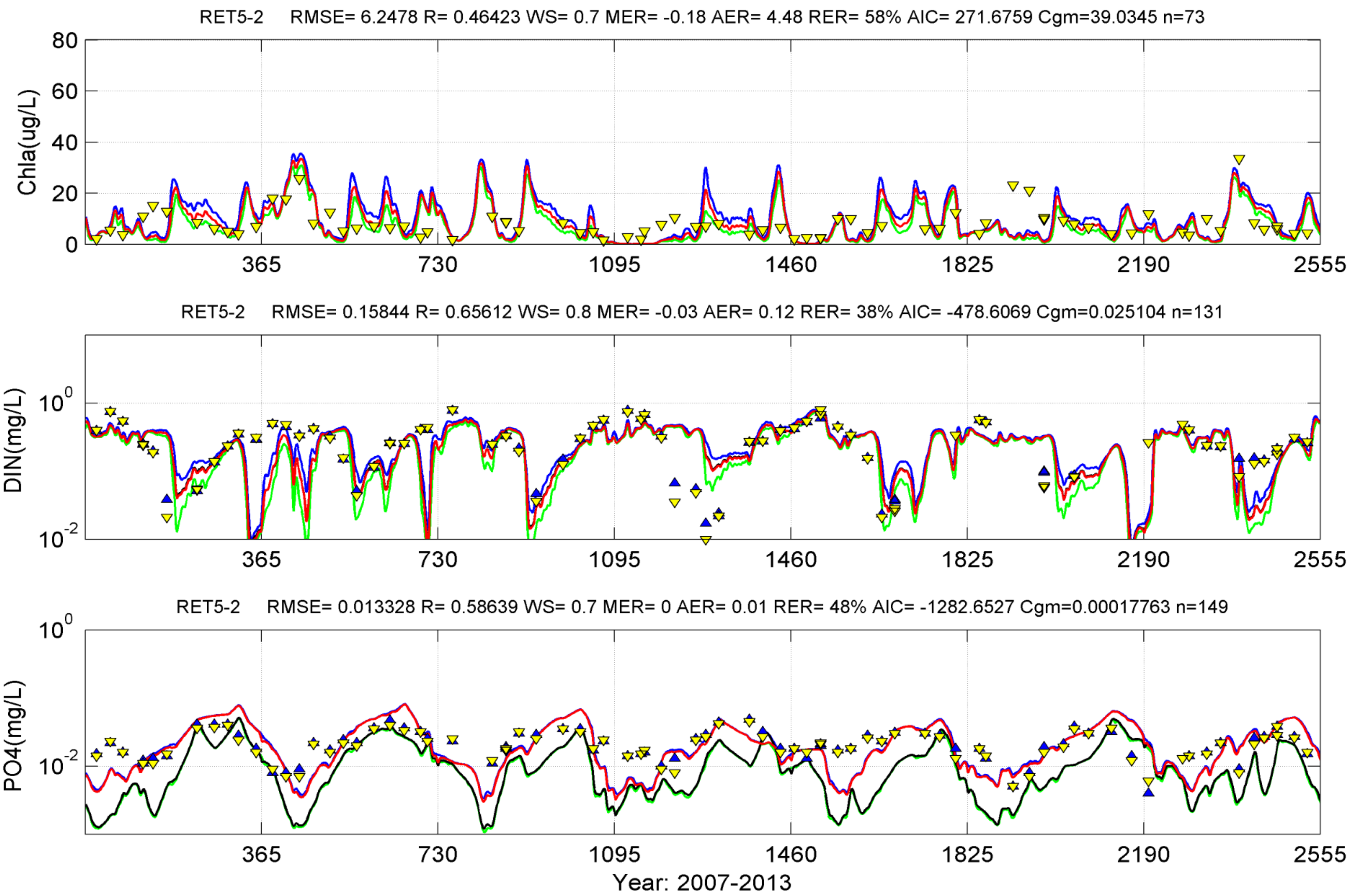

RET5-2 RMSE= 0.079784 R= 0.68304 WS= 0.76 MER= 0 AER= 0.05 RER= 62% AIC= -1330.9639 Cgm=0.0063655 n=264
NH4(mg/L)
10^0
10^{-2}
365 730 1095 1460 1825 2190 2555 2920 3285 3650
RET5-2 RMSE= 0.1669 R= 0.53439 WS= 0.69 MER= -0.02 AER= 0.13 RER= 57% AIC= -973.4877 Cgm=0.027856 n=273
NO23(mg/L)
10^0
10^{-2}
365 730 1095 1460 1825 2190 2555 2920 3285 3650
RET5-2 RMSE= 0.87584 R= 0.89488 WS= 0.94 MER= 0.18 AER= 0.67 RER= 8% AIC= -70.7284 Cgm=0.76709 n=282
DO(mg/L)
20
15
10
5
0
365 730 1095 1460 1825 2190 2555 2920 3285 3650
Year: 1991-2000

Water Quality Model Verification

- Verification period is from 2007-2013


TF5-5 RMSE= 12.5269 R= 0.82499 WS= 0.9 MER= -3.82 AER= 7.72 RER= 33% AIC= 403.5624 Cgm=156.9227 n=79
Chla(ug/L)
100
50
0
365
730
1095
1460
1825
2190
2555
TF5-5 RMSE= 0.21039 R= 0.74808 WS= 0.85 MER= 0.02 AER= 0.1 RER= 25% AIC= -476.0285 Cgm=0.044264 n=154
DIN(mg/L)
10^0
10^-2
TF5-5 RMSE= 0.010159 R= -0.20557 WS= 0.21 MER= 0 AER= 0.01 RER= 87% AIC= -1455.3607 Cgm=0.0001032 n=159
PO4(mg/L)
Year: 2007-2013


TF5-5 RMSE= 0.17162 R= 0.45049 WS= 0.34 MER= -0.04 AER= 0.06 RER= 52% AIC= -552.8708 Cgm=0.029452 n=158
NH4(mg/L)
TF5-5 RMSE= 0.14759 R= 0.81227 WS= 0.87 MER= 0.06 AER= 0.1 RER= 33% AIC= -604.3482 Cgm=0.021784 n=159
NO23(mg/L)
TF5-5 RMSE= 1.0044 R= 0.88032 WS= 0.93 MER= 0.32 AER= 0.65 RER= 7% AIC= 5.4053 Cgm=1.0089 n=150
DO(mg/L)
365
730
1095
1460
1825
2190
2555
Year: 2007-2013



RET5-2 RMSE= 6.2478 R= 0.46423 WS= 0.7 MER= -0.18 AER= 4.48 RER= 58% AIC= 271.6759 Cgm=39.0345 n=73
Chla(ug/L)
80
60
40
20
0
365
730
1095
1460
1825
2190
2555
RET5-2 RMSE= 0.15844 R= 0.65612 WS= 0.8 MER= -0.03 AER= 0.12 RER= 38% AIC= -478.6069 Cgm=0.025104 n=131
DIN(mg/L)
10^0
10^-2
RET5-2 RMSE= 0.013328 R= 0.58639 WS= 0.7 MER= 0 AER= 0.01 RER= 48% AIC= -1282.6527 Cgm=0.00017763 n=149
PO4(mg/L)
10^0
10^-2
Year: 2007-2013

Summary of

Variable Name	Mean Difference		Absolut Mean Difference		RMS		Relative Difference (%)	
	Bay	James	Bay	James	Bay	James	Bay	James
Chlorophyll	-0.72	-1.32	7.13	6.03	12.16	10.82	60.80	43.85
Dissolved Oxygen	0.91	0.01	1.14	0.61	1.76	0.93	13.29	6.95
Dissolved Inorganic Nitrogen	0.05	-0.01	0.12	0.09	0.21	0.16	52.04	40.57
Ammonium	0.03	0.00	0.06	0.04	0.12	0.10	73.48	77.90
Nitrate	0.03	-0.02	0.10	0.09	0.18	0.13	62.25	44.82
Dissolved Organic Nitrogen	0.04	0.02	0.09	0.06	0.15	0.10	39.62	23.63
Total Nitrogen	0.10	-0.10	0.23	0.17	0.38	0.28	31.16	23.24
Dissolved Inorganic Phosphorus	0.01	0.001	0.02	0.01	0.03	0.01	81.79	49.91
Total Phosphorus	-0.01	0.02	0.05	0.05	0.09	0.08	44.33	62.61
Particulate Organic Carbon	-0.23	-0.90	0.83	0.94	1.32	1.68	47.67	57.26
Light Extinction	0.30	-0.80	1.45	0.91	2.25	1.48	47.80	29.45

Summary

- Both hydrodynamic and water quality models are calibrated with good predictive skill.
- Both Conventional Eutrophication Model and Bay model do not show significant difference statistically

Scenario Simulation

Scenario (1991-2000)	Carbon		Nitrogen		Phosphorus	
	10^6 lbs/year	% Reduction	10^6 lbs/year	% Reduction	10^6 lbs/year	% Reduction
Baseline	85.9		26.4		3.5	
2010 TMDL	85.0	0.0	16.2	40	2.3	40
DO Attainment	85.1	0.0	19.1	30	2.2	40
2009 Progress	85.2	0.0	18.8	30	2.5	30
HRSD	85.7	0.0	25.1	10	3.4	0

Scenario (2007-2013)	Carbon		Nitrogen		Phosphorus	
	10^6 lbs/year	% Reduction	10^6 lbs/year	% Reduction	10^6 lbs/year	% Reduction
Baseline	78.4	-	21.2	-	2.49	-
2010 TMDL	78.5	0.1(1)	13.0	38.7	1.61	35.3
DO Attainment	78.5	0.1(1)	15.4	27.4	1.51	39.4
2009 Progress	78.5	0.1(1)	15.1	28.8	1.75	29.7
HRSD	78.7	0.4(1)	20.6	2.8	2.53	1.6(1)

(1) % increase from baseline

Spring

Segment	Year1	Year2	Calibration	2010 TMDL	DO Attainment	2009 Progress	HRSD WTP
JMSTFU	1991	1993	13.99%	0.00%	0.00%	0.00%	12.77%
JMSTFU	1992	1994	27.38%	8.42%	11.00%	17.41%	26.56%
JMSTFU	1993	1995	20.55%	8.42%	11.00%	17.41%	20.55%
JMSTFU	1994	1996	40.90%	8.42%	14.28%	20.83%	40.90%
JMSTFU	1995	1997	27.52%	0.47%	5.40%	6.35%	27.52%
JMSTFU	1996	1998	27.52%	0.47%	5.40%	6.35%	27.52%
JMSTFU	1997	1999	7.19%	0.47%	2.22%	3.01%	7.19%
JMSTFU	1998	2000	6.51%	0.00%	1.57%	2.09%	6.51%
JMSTFL	1991	1993	5.14%	0.00%	0.00%	0.00%	4.38%
JMSTFL	1992	1994	0.00%	0.00%	0.00%	0.00%	0.00%
JMSTFL	1993	1995	3.95%	0.00%	0.00%	0.00%	3.79%
JMSTFL	1994	1996	3.95%	0.00%	0.00%	0.00%	3.79%
JMSTFL	1995	1997	17.29%	4.35%	5.07%	5.87%	17.03%
JMSTFL	1996	1998	10.88%	4.35%	5.07%	5.87%	10.78%
JMSTFL	1997	1999	25.80%	4.35%	5.07%	5.87%	24.60%
JMSTFL	1998	2000	21.56%	0.00%	0.00%	0.00%	20.23%
JMSOH	1991	1993	12.58%	0.00%	0.00%	0.00%	9.22%
JMSOH	1992	1994	10.42%	0.00%	0.00%	0.00%	9.22%
JMSOH	1993	1995	0.00%	0.00%	0.00%	0.00%	0.00%
JMSOH	1994	1996	9.38%	0.00%	0.00%	0.00%	7.04%
JMSOH	1995	1997	14.15%	0.00%	0.00%	0.00%	11.75%
JMSOH	1996	1998	14.68%	0.00%	0.00%	0.00%	11.75%
JMSOH	1997	1999	14.52%	0.00%	0.00%	0.00%	8.85%
JMSOH	1998	2000	24.59%	0.00%	1.47%	2.30%	19.07%
JMSMH	1991	1993	40.71%	26.84%	31.31%	33.87%	39.43%
JMSMH	1992	1994	16.40%	9.03%	9.57%	9.57%	15.12%
JMSMH	1993	1995	6.94%	0.00%	0.00%	0.00%	6.03%
JMSMH	1994	1996	23.19%	0.00%	0.00%	6.76%	20.64%
JMSMH	1995	1997	46.74%	1.75%	2.66%	16.90%	43.82%
JMSMH	1996	1998	36.79%	1.75%	2.66%	16.90%	34.78%
JMSMH	1997	1999	36.88%	13.26%	14.81%	20.09%	35.87%
JMSMH	1998	2000	13.85%	9.12%	9.94%	9.94%	13.21%
JMSPH	1991	1993	65.62%	0.00%	0.00%	4.04%	54.25%
JMSPH	1992	1994	40.79%	0.00%	0.00%	4.04%	29.43%
JMSPH	1993	1995	16.48%	0.00%	0.00%	4.04%	15.72%
JMSPH	1994	1996	21.77%	14.97%	18.37%	21.77%	21.77%
JMSPH	1995	1997	21.77%	14.97%	18.37%	21.77%	21.77%
JMSPH	1996	1998	21.77%	14.97%	18.37%	21.77%	21.77%
JMSPH	1997	1999	0.00%	0.00%	0.00%	0.00%	0.00%
JMSPH	1998	2000	0.00%	0.00%	0.00%	0.00%	0.00%

Summer

Segment	Year1	Year2	Calibration	2010 TMDL	DO Attainment	2009 Progress	HRSD WTP
JMSTFU	1991	1993	44.69%	24.20%	28.16%	29.25%	44.55%
JMSTFU	1992	1994	42.50%	20.10%	25.56%	26.52%	42.50%
JMSTFU	1993	1995	28.47%	13.86%	17.14%	17.68%	28.47%
JMSTFU	1994	1996	7.06%	1.70%	3.68%	3.82%	7.06%
JMSTFU	1995	1997	19.73%	18.91%	19.18%	19.45%	19.73%
JMSTFU	1996	1998	44.04%	31.75%	32.98%	33.66%	44.04%
JMSTFU	1997	1999	68.87%	55.07%	56.58%	57.26%	68.87%
JMSTFU	1998	2000	64.64%	42.91%	45.65%	46.88%	64.64%
JMSTFL	1991	1993	48.79%	24.07%	34.94%	36.91%	47.39%
JMSTFL	1992	1994	51.13%	34.40%	40.81%	41.88%	50.63%
JMSTFL	1993	1995	36.65%	27.07%	32.88%	33.08%	36.51%
JMSTFL	1994	1996	12.34%	7.32%	8.58%	8.78%	12.21%
JMSTFL	1995	1997	21.77%	21.77%	21.77%	21.77%	21.77%
JMSTFL	1996	1998	36.45%	30.51%	32.24%	32.11%	36.45%
JMSTFL	1997	1999	46.75%	30.51%	38.81%	38.38%	46.75%
JMSTFL	1998	2000	36.21%	12.72%	22.96%	22.92%	36.21%
JMSOH	1991	1993	11.98%	0.00%	0.00%	0.00%	10.23%
JMSOH	1992	1994	11.98%	0.00%	0.00%	0.00%	10.23%
JMSOH	1993	1995	0.32%	0.00%	0.00%	0.00%	0.12%
JMSOH	1994	1996	0.00%	0.00%	0.00%	0.00%	0.00%
JMSOH	1995	1997	1.68%	0.00%	0.00%	0.00%	1.68%
JMSOH	1996	1998	1.68%	0.00%	0.00%	0.00%	1.68%
JMSOH	1997	1999	1.68%	0.00%	0.00%	0.00%	1.68%
JMSOH	1998	2000	0.00%	0.00%	0.00%	0.00%	0.00%
JMSMH	1991	1993	10.84%	8.57%	8.85%	9.30%	9.75%
JMSMH	1992	1994	10.84%	8.57%	8.85%	9.30%	9.75%
JMSMH	1993	1995	9.94%	8.57%	8.85%	9.30%	9.75%
JMSMH	1994	1996	0.00%	0.00%	0.00%	0.00%	0.00%
JMSMH	1995	1997	3.87%	0.00%	0.00%	0.00%	2.45%
JMSMH	1996	1998	3.87%	0.00%	0.00%	0.00%	2.45%
JMSMH	1997	1999	28.12%	0.00%	0.00%	2.27%	26.67%
JMSMH	1998	2000	21.77%	0.00%	0.00%	2.27%	21.77%

Loading Comparison

Scenario (1991-2000)	Carbon		Nitrogen		Phosphorus	
	10^6 lbs/year	% Reduction	10^6 lbs/year	% Reduction	10^6 lbs/year	% Reduction
Baseline	85.9		26.4		3.5	
2010 TMDL	85.0	0.0	16.2	38.5	2.3	35.7
DO Attainment	85.1	0.0	19.1	27.6	2.2	38.0
2009 Progress	85.2	0.0	18.8	28.8	2.5	29.5
HRSD	85.7	0.0	25.1	5.0	3.4	4.8

Scenario (2007-2013)	Carbon		Nitrogen		Phosphorus	
	10^6 lbs/year	% Reduction	10^6 lbs/year	% Reduction	10^6 lbs/year	% Reduction
Baseline	78.4	-	21.2	-	2.49	-
2010 TMDL	78.5	0.1(1)	13.0	38.7	1.61	35.3
DO Attainment	78.5	0.1(1)	15.4	27.4	1.51	39.4
2009 Progress	78.5	0.1(1)	15.1	28.8	1.75	29.7
HRSD	78.7	0.4(1)	20.6	2.8	2.53	1.6(1)

Segment	Year1	Year2	Calibration	2010 TMDL	DO Attainment	2009 Progress	HRSD WTP
JMSTFU	1991	1993	14.0%	0.0%	0.0%	0.0%	12.8%
JMSTFU	1992	1994	27.4%	8.4%	11.0%	17.4%	26.6%
JMSTFU	1993	1995	20.5%	8.4%	11.0%	17.4%	20.5%
JMSTFU	1994	1996	40.9%	8.4%	14.3%	20.8%	40.9%
JMSTFU	1995	1997	27.5%	0.5%	5.4%	6.4%	27.5%
JMSTFU	1996	1998	27.5%	0.5%	5.4%	6.4%	27.5%
JMSTFU	1997	1999	7.2%	0.5%	2.2%	3.0%	7.2%
JMSTFU	1998	2000	6.5%	0.0%	1.6%	2.1%	6.5%
JMSTFL	1991	1993	5.1%	0.0%	0.0%	0.0%	4.4%
JMSTFL	1992	1994	0.0%	0.0%	0.0%	0.0%	0.0%
JMSTFL	1993	1995	4.0%	0.0%	0.0%	0.0%	3.8%
JMSTFL	1994	1996	4.0%	0.0%	0.0%	0.0%	3.8%
JMSTFL	1995	1997	17.3%	4.3%	5.1%	5.9%	17.0%
JMSTFL	1996	1998	10.9%	4.3%	5.1%	5.9%	10.8%
JMSTFL	1997	1999	25.8%	4.3%	5.1%	5.9%	24.6%
JMSTFL	1998	2000	21.6%	0.0%	0.0%	0.0%	20.2%
JMSOH	1991	1993	12.6%	0.0%	0.0%	0.0%	9.2%
JMSOH	1992	1994	10.4%	0.0%	0.0%	0.0%	9.2%
JMSOH	1993	1995	0.0%	0.0%	0.0%	0.0%	0.0%
JMSOH	1994	1996	9.4%	0.0%	0.0%	0.0%	7.0%
JMSOH	1995	1997	14.2%	0.0%	0.0%	0.0%	11.7%
JMSOH	1996	1998	14.7%	0.0%	0.0%	0.0%	11.7%
JMSOH	1997	1999	14.5%	0.0%	0.0%	0.0%	8.8%
JMSOH	1998	2000	24.6%	0.0%	1.5%	2.3%	19.1%
JMSMH	1991	1993	40.7%	26.8%	31.3%	33.9%	39.4%
JMSMH	1992	1994	16.4%	9.0%	9.6%	9.6%	15.1%
JMSMH	1993	1995	6.9%	0.0%	0.0%	0.0%	6.0%
JMSMH	1994	1996	23.2%	0.0%	0.0%	6.8%	20.6%
JMSMH	1995	1997	46.7%	1.7%	2.7%	16.9%	43.8%
JMSMH	1996	1998	36.8%	1.7%	2.7%	16.9%	34.8%
JMSMH	1997	1999	36.9%	13.3%	14.8%	20.1%	35.9%
JMSMH	1998	2000	13.8%	9.1%	9.9%	9.9%	13.2%
JMSPH	1991	1993	65.6%	0.0%	0.0%	4.0%	54.3%
JMSPH	1992	1994	40.8%	0.0%	0.0%	4.0%	29.4%
JMSPH	1993	1995	16.5%	0.0%	0.0%	4.0%	15.7%
JMSPH	1994	1996	21.8%	15.0%	18.4%	21.8%	21.8%
JMSPH	1995	1997	21.8%	15.0%	18.4%	21.8%	21.8%
JMSPH	1996	1998	21.8%	15.0%	18.4%	21.8%	21.8%
JMSPH	1997	1999	0.0%	0.0%	0.0%	0.0%	0.0%
JMSPH	1998	2000	0.0%	0.0%	0.0%	0.0%	0.0%

← Spring

Summer →

Segment	Year1	Year2	Calibration	2010 TMDL	DO Attainment	2009 Progress	HRSD WTP
JMSTFU	1991	1993	44.69%	24.20%	28.16%	29.25%	44.55%
JMSTFU	1992	1994	42.50%	20.10%	25.56%	26.52%	42.50%
JMSTFU	1993	1995	28.47%	13.86%	17.14%	17.68%	28.47%
JMSTFU	1994	1996	7.06%	1.70%	3.68%	3.82%	7.06%
JMSTFU	1995	1997	19.73%	18.91%	19.18%	19.45%	19.73%
JMSTFU	1996	1998	44.04%	31.75%	32.98%	33.66%	44.04%
JMSTFU	1997	1999	68.87%	55.07%	56.58%	57.26%	68.87%
JMSTFU	1998	2000	64.64%	42.91%	45.65%	46.88%	64.64%
JMSTFL	1991	1993	48.79%	24.07%	34.94%	36.91%	47.39%
JMSTFL	1992	1994	51.13%	34.40%	40.81%	41.88%	50.63%
JMSTFL	1993	1995	36.65%	27.07%	32.88%	33.08%	36.51%
JMSTFL	1994	1996	12.34%	7.32%	8.58%	8.78%	12.21%
JMSTFL	1995	1997	21.77%	21.77%	21.77%	21.77%	21.77%
JMSTFL	1996	1998	36.45%	30.51%	32.24%	32.11%	36.45%
JMSTFL	1997	1999	46.75%	30.51%	38.81%	38.38%	46.75%
JMSTFL	1998	2000	36.21%	12.72%	22.96%	22.92%	36.21%
JMSOH	1991	1993	11.98%	0.00%	0.00%	0.00%	10.23%
JMSOH	1992	1994	11.98%	0.00%	0.00%	0.00%	10.23%
JMSOH	1993	1995	0.32%	0.00%	0.00%	0.00%	0.12%
JMSOH	1994	1996	0.00%	0.00%	0.00%	0.00%	0.00%
JMSOH	1995	1997	1.68%	0.00%	0.00%	0.00%	1.68%
JMSOH	1996	1998	1.68%	0.00%	0.00%	0.00%	1.68%
JMSOH	1997	1999	1.68%	0.00%	0.00%	0.00%	1.68%
JMSOH	1998	2000	0.00%	0.00%	0.00%	0.00%	0.00%
JMSMH	1991	1993	10.84%	8.57%	8.85%	9.30%	9.75%
JMSMH	1992	1994	10.84%	8.57%	8.85%	9.30%	9.75%
JMSMH	1993	1995	9.94%	8.57%	8.85%	9.30%	9.75%
JMSMH	1994	1996	0.00%	0.00%	0.00%	0.00%	0.00%
JMSMH	1995	1997	3.87%	0.00%	0.00%	0.00%	2.45%
JMSMH	1996	1998	3.87%	0.00%	0.00%	0.00%	2.45%
JMSMH	1997	1999	28.12%	0.00%	0.00%	2.27%	26.67%
JMSMH	1998	2000	21.77%	0.00%	0.00%	2.27%	21.77%
JMSPH	1991	1993	0.00%	0.00%	0.00%	0.00%	0.00%
JMSPH	1992	1994	0.00%	0.00%	0.00%	0.00%	0.00%
JMSPH	1993	1995	13.83%	0.00%	0.00%	0.00%	13.45%
JMSPH	1994	1996	38.14%	0.00%	0.00%	21.77%	37.76%
JMSPH	1995	1997	38.14%	0.00%	0.00%	21.77%	37.76%
JMSPH	1996	1998	21.77%	0.00%	0.00%	21.77%	21.77%
JMSPH	1997	1999	21.77%	11.56%	11.56%	18.75%	21.77%
JMSPH	1998	2000	38.52%	16.18%	17.31%	31.70%	38.14%

What needs to be improved/updated for James River Model?

- Current model used LSPC flow, which may not same as Bay Phase 6 WSM. We will use Bay WSM to run hydrodynamic model to be consistent with loadings
- Loading
  - Currently LSPC nonpoint source loadings are slightly lower than previous SWM loading
  - There are some discrepancies in point source loadings, especially in scenario loadings
- Boundary condition
  - Will use updated Bay model results as open boundary condition
- Atmospheric deposition
  - Using Bay atmospheric deposition

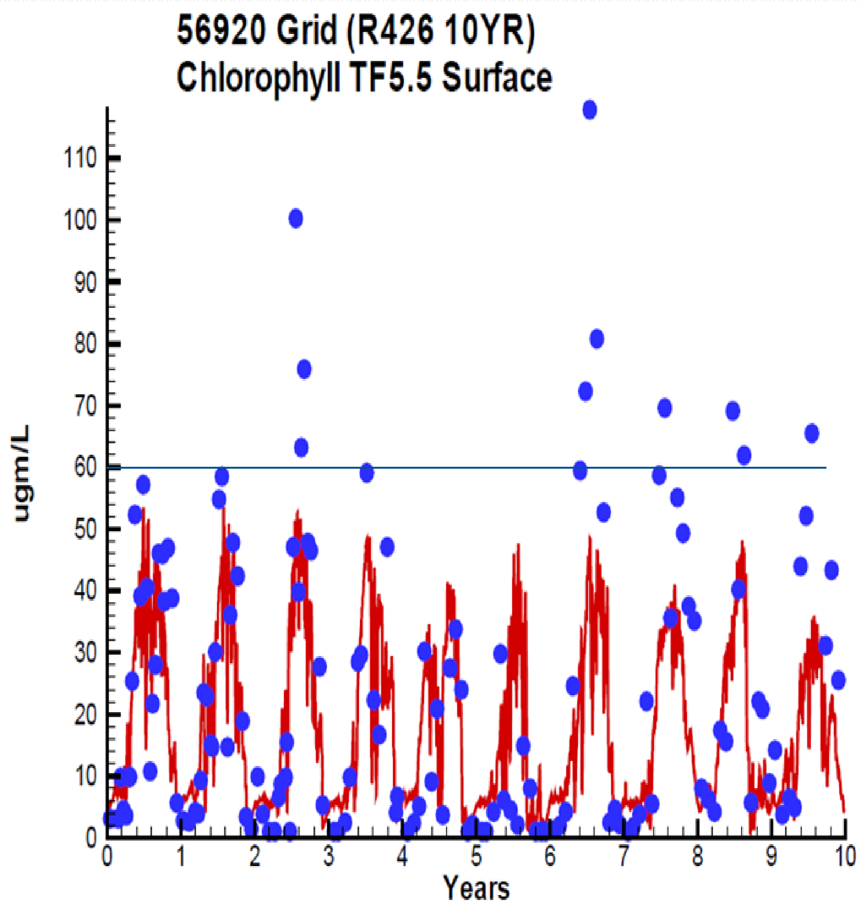
Major tasks:

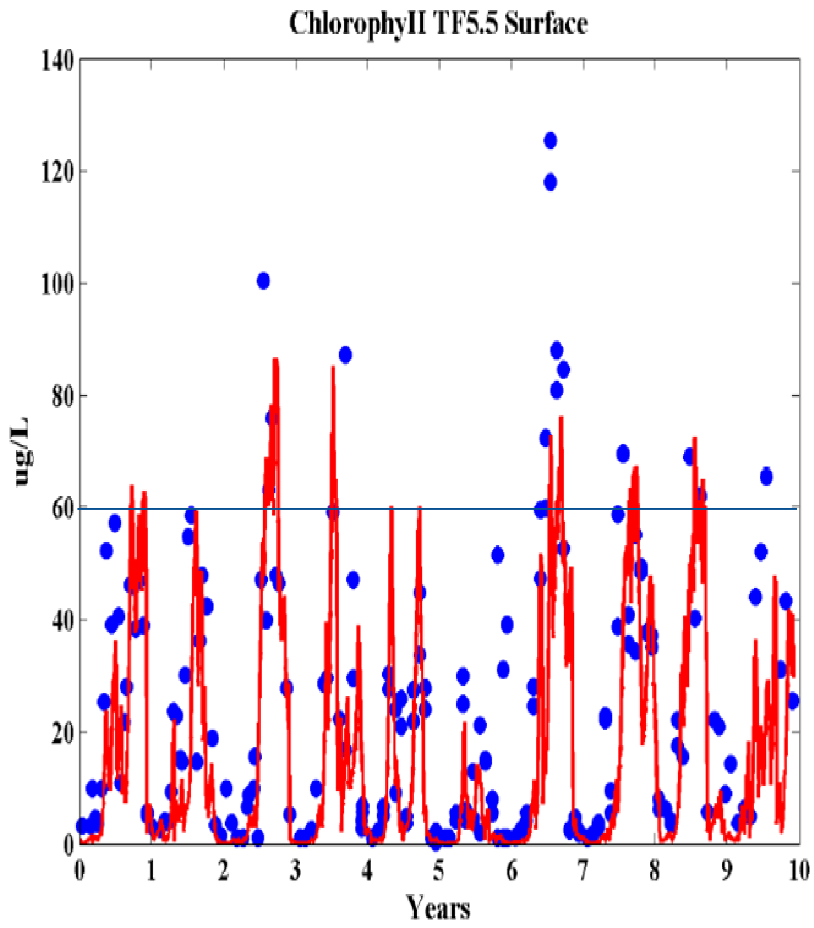
1. **Conduct model verification using Bay WSM and revise model parameters if it is needed**
2. **Conduct scenario runs**

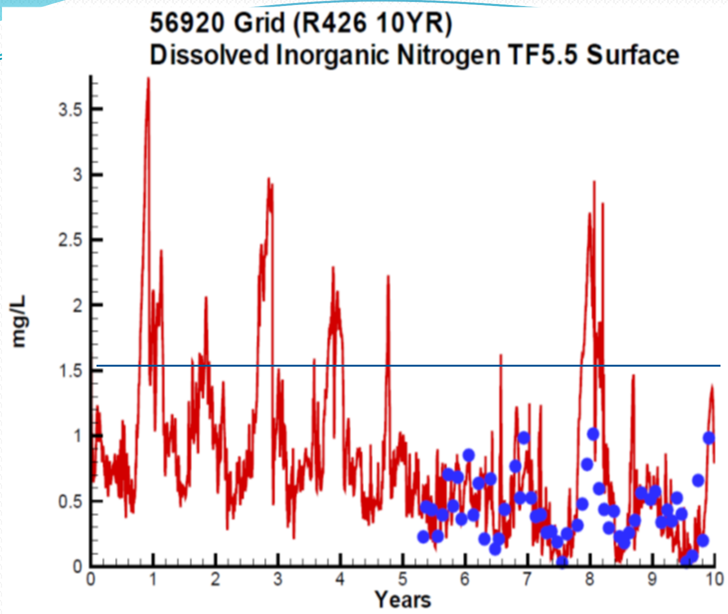
Tasks for 2017

- Work with CBP Modeling Workgroup to link James River water quality to Phase 6 WSM, watershed, airshed, and Bay/James boundary conditions.
  - Need both existing condition and scenarios
  - Schedule: April: preliminary loading, June: final loading
- Conduct model verification
  - Schedule: Complete by June 30.
- Scenario runs
  - Schedule: Complete by August 31.
- Analysis of model results
  - Work with DEQ and Bay Program to analyze results
  - Conduct model run when it is needed
  - Schedule: August-September 30
- Final model results
  - End of 2017

Comparison with Bay Model



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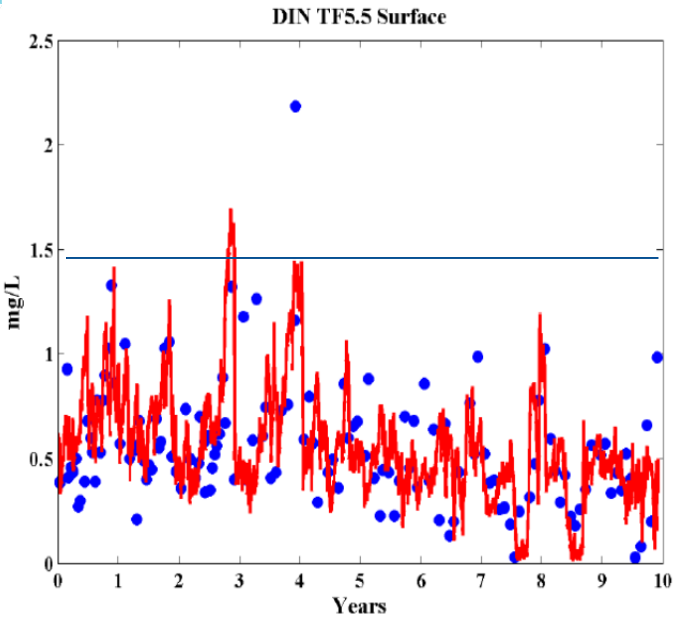
Years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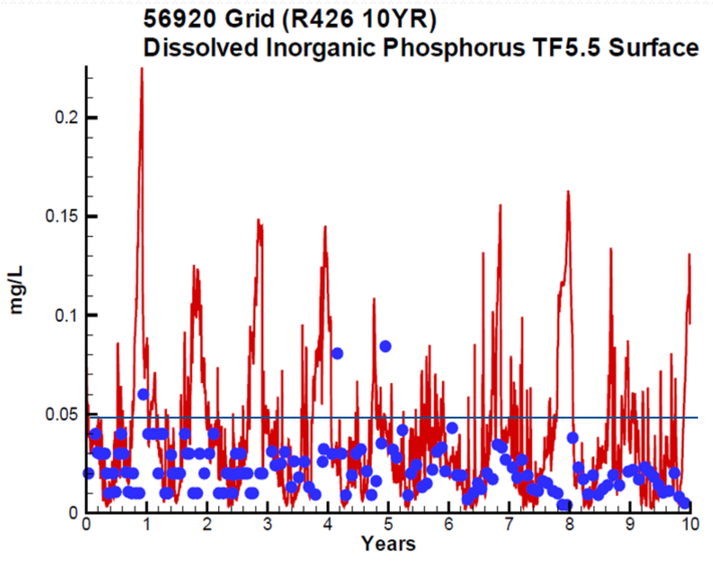
mg/L
Years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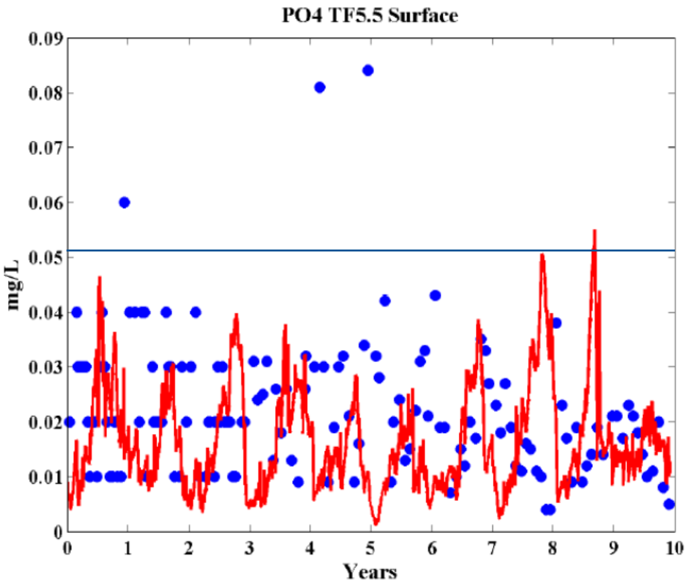
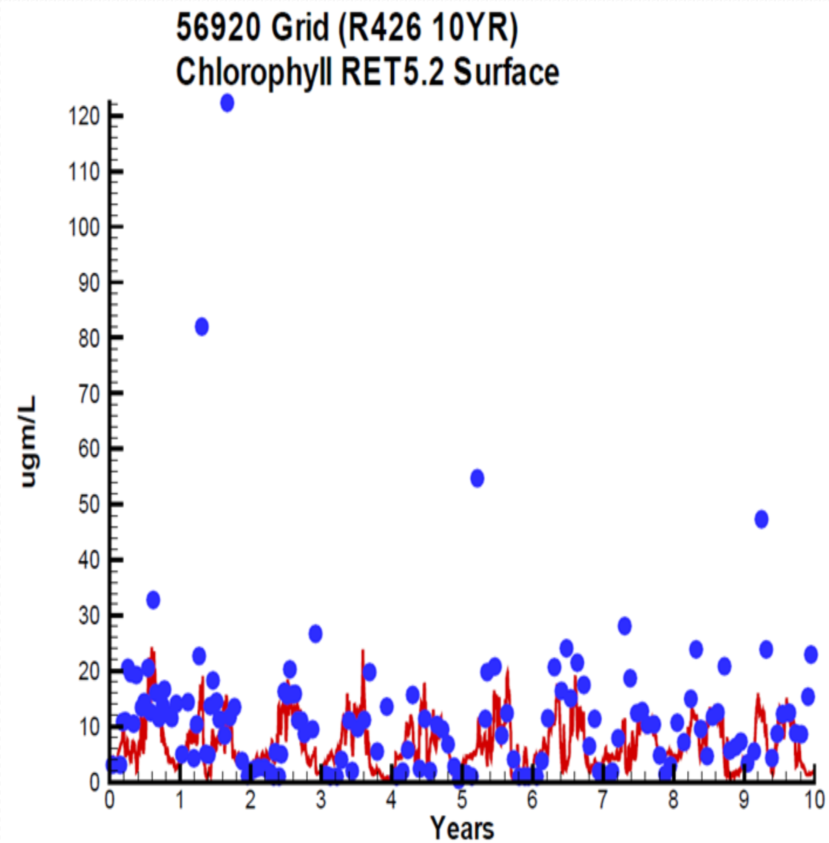
Dissolved Inorganic Phosphorus TF5.5 Surface
mg/L
Years


PO4 TF5.5 Surface
mg/L
Years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Chlorophyll RET5.2 Surface
ugm/L
Years
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10
20
30
40
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110
120
1
2
3
4
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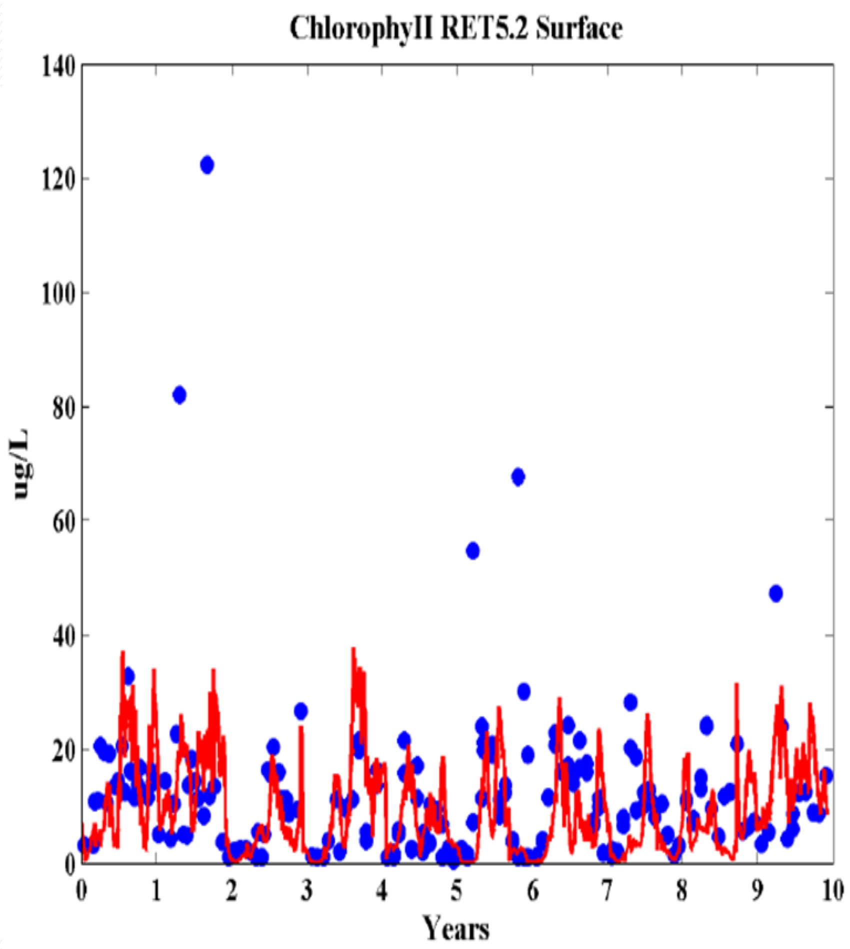
6
7
8
9
10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ug/L
Years
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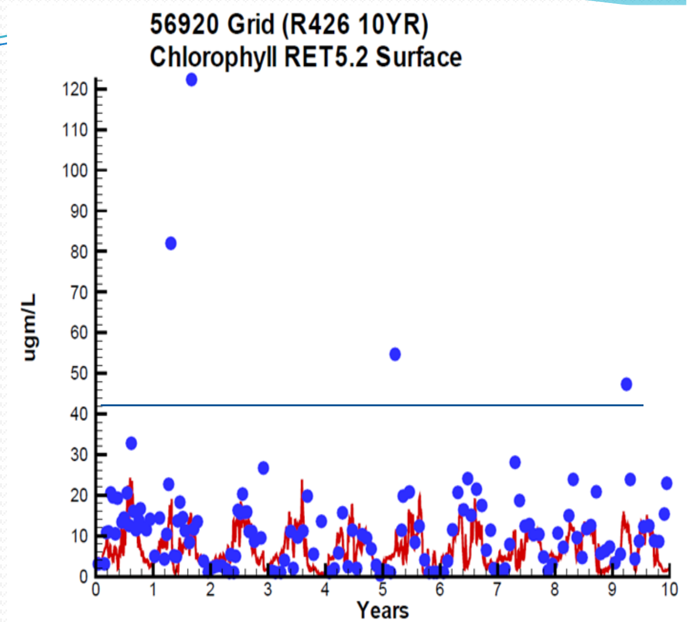
6
7
8
9
10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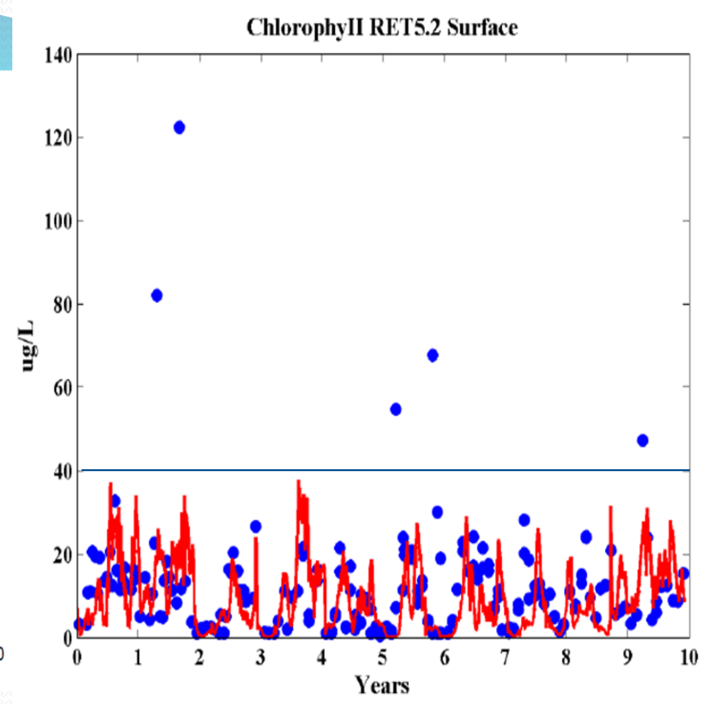
Chlorophyll RET5.2 Surface
ugm/L
Years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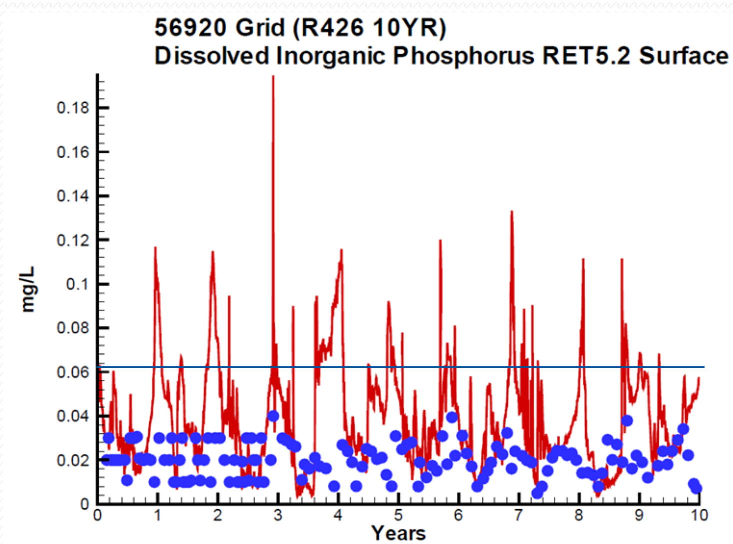
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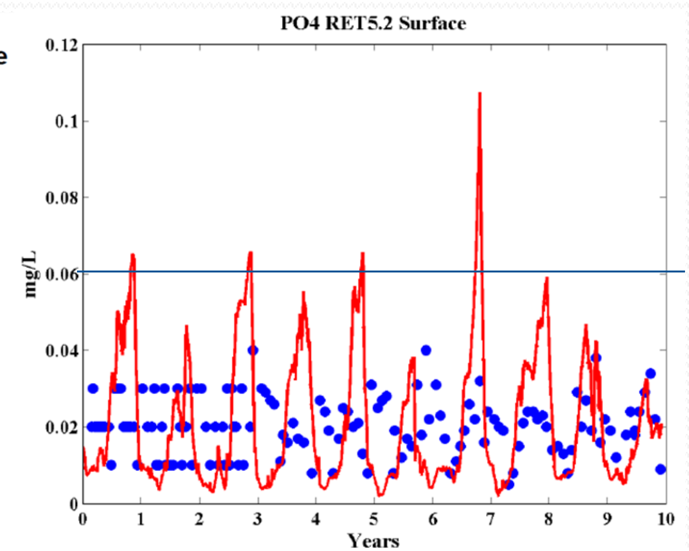
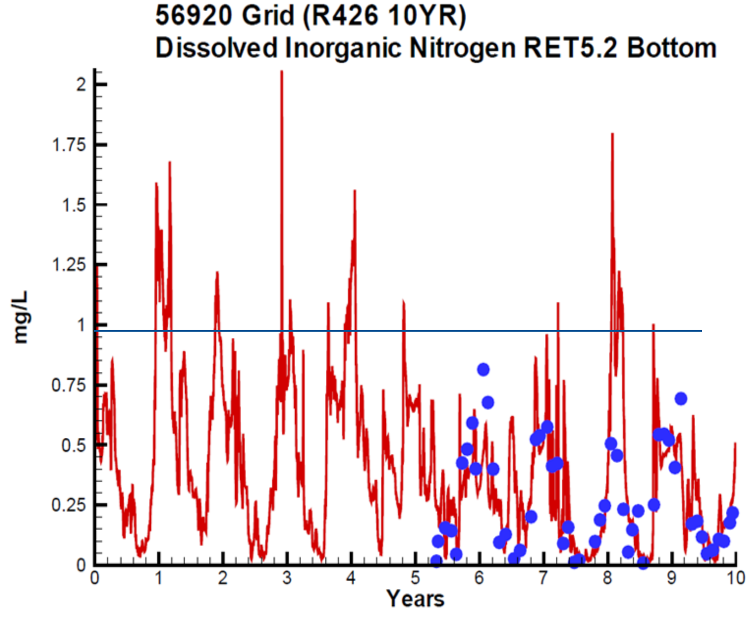
Dissolved Inorganic Phosphorus RET5.2 Surface
mg/L
Years


PO4 RET5.2 Surface
mg/L
Years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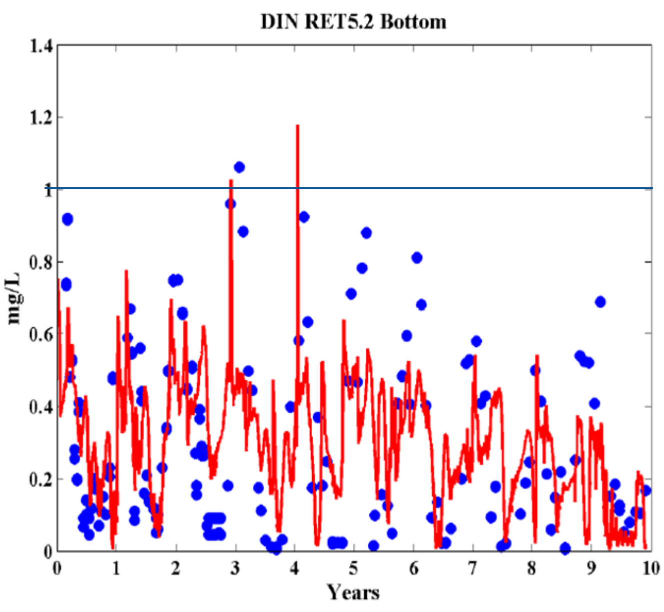
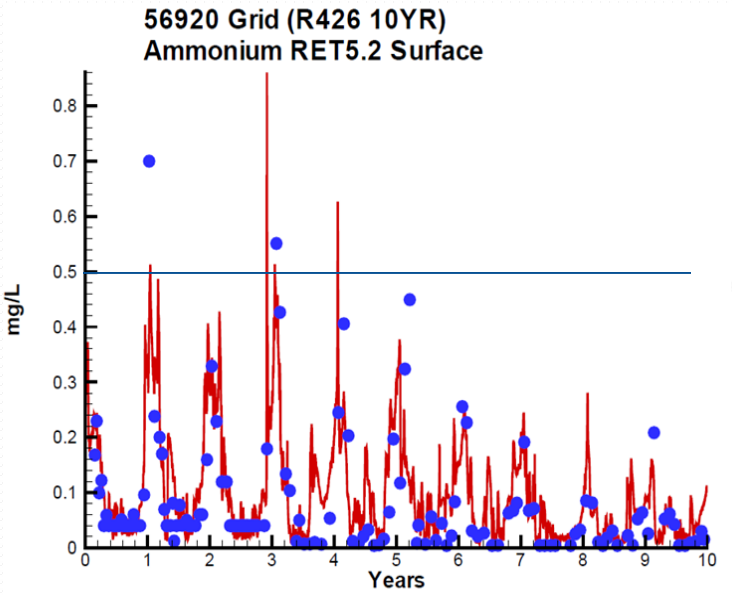
Dissolved Inorganic Nitrogen RET5.2 Bottom
mg/L
Years


DIN RET5.2 Bottom
mg/L
Years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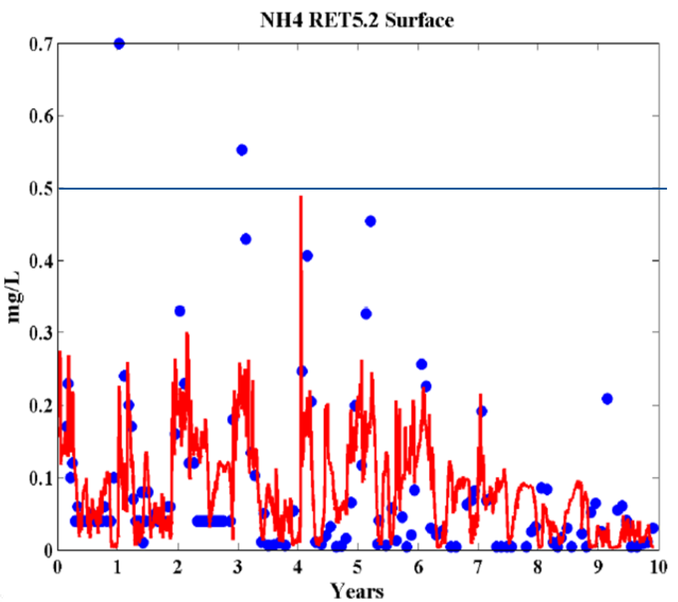
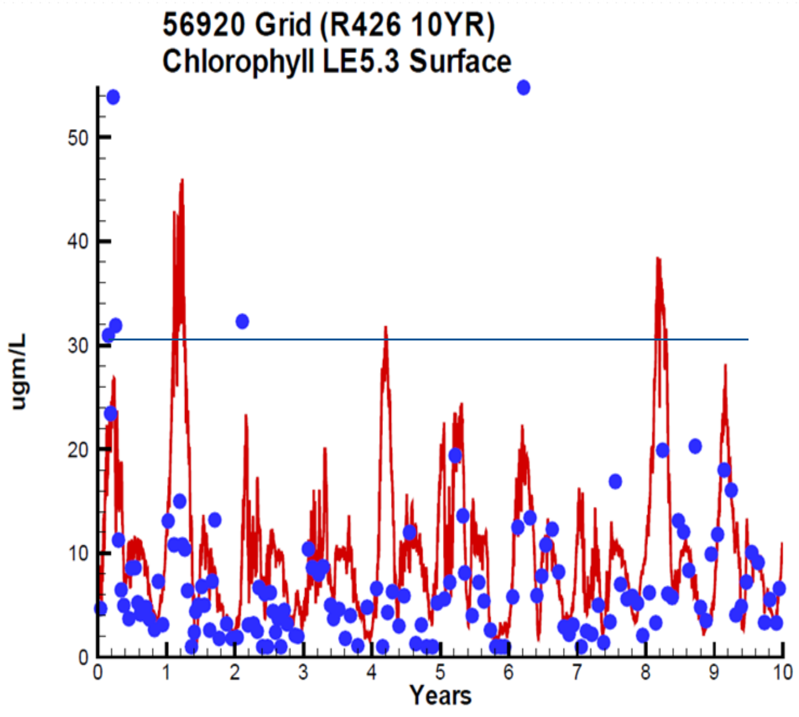
Ammonium RET5.2 Surface
mg/L
Years


NH4 RET5.2 Surface
mg/L
Years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ugm/L
Years
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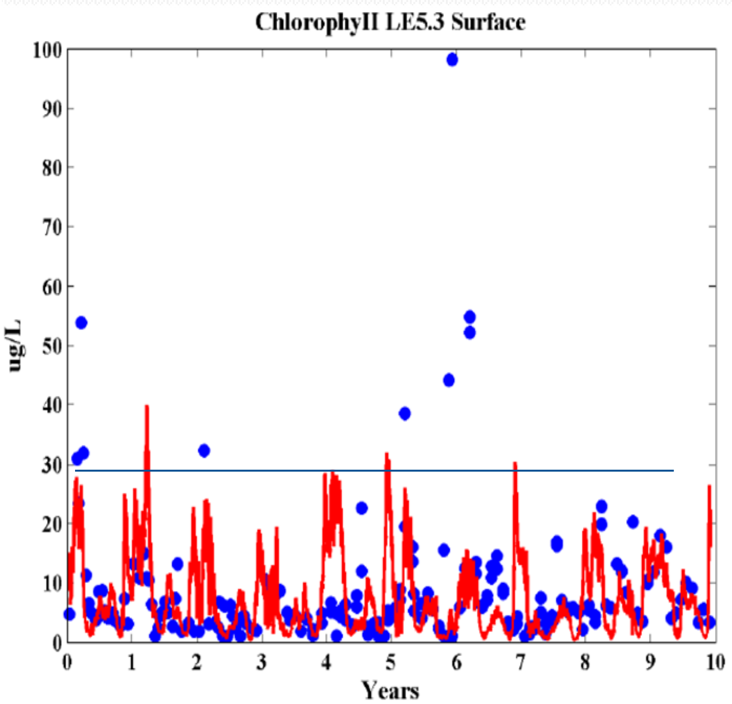
9
10


Chlorophyll LE5.3 Surface
ug/L
Years
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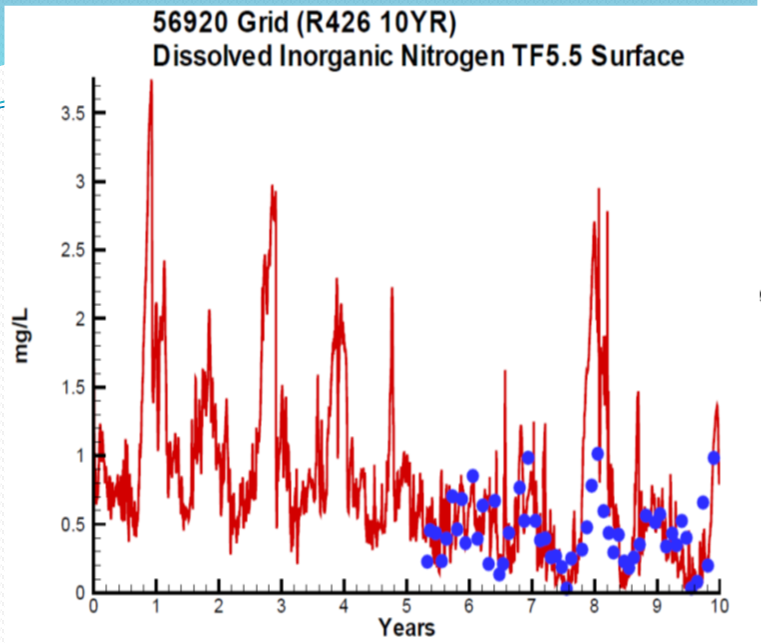
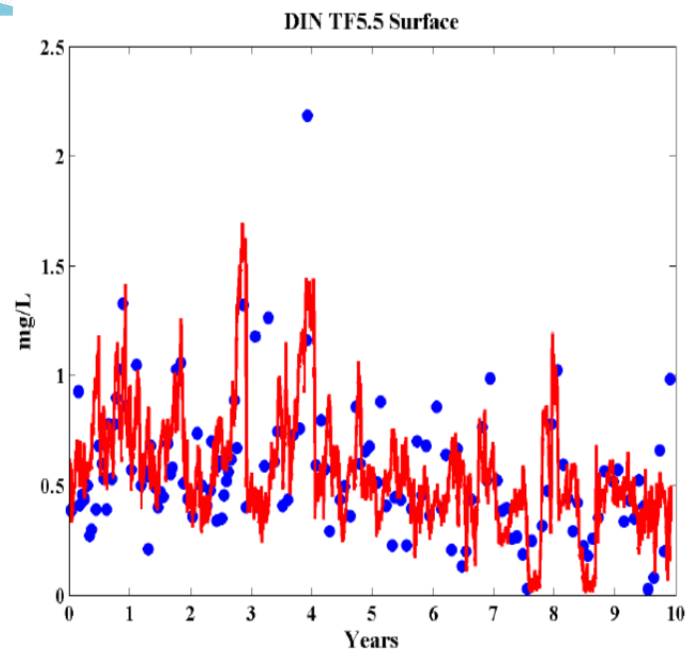
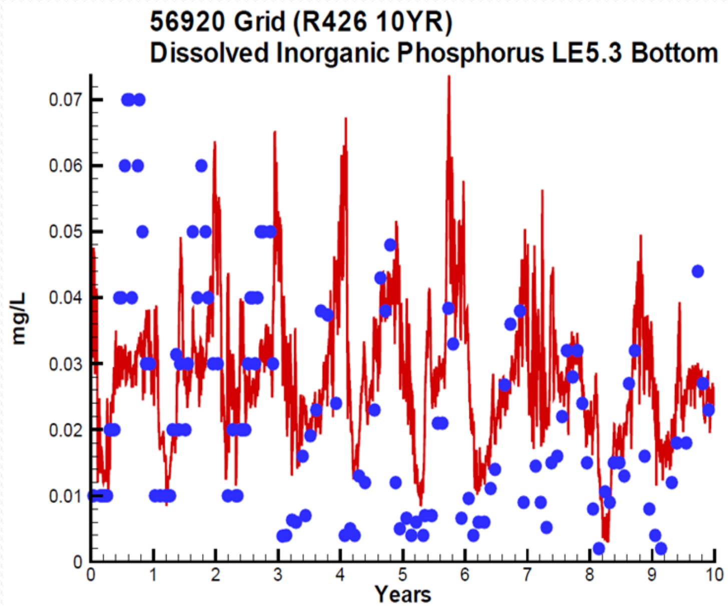


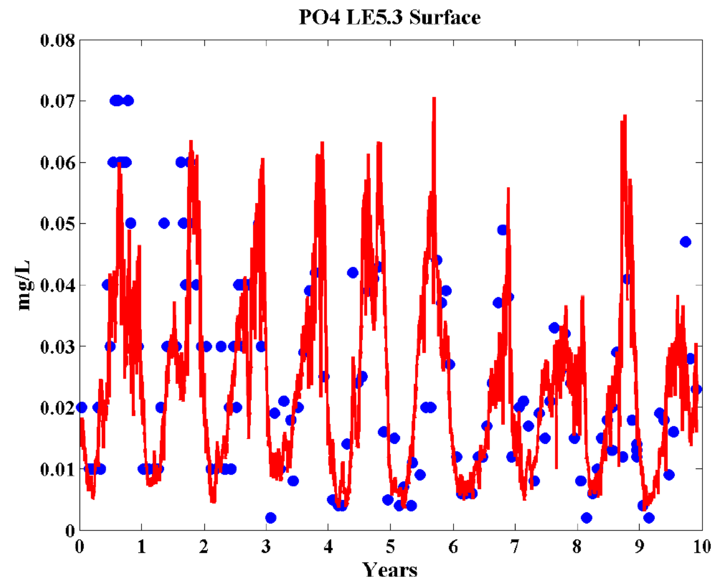
56920 Grid (R426 10YR)
Dissolved Inorganic Nitrogen TF5.5 Surface
mg/L
Years



DIN TF5.5 Surface
mg/L
Years



56920 Grid (R426 10YR)
Dissolved Inorganic Phosphorus LE5.3 Bottom
mg/L
Years



PO4 LE5.3 Surface
mg/L
Years