The Effects of River Discharge on Seasonal Phytoplankton Blooming Pattern in Upper James

Wang, Harry V., Joseph Zhang, and Zhengui Wang

Virginia Institute of Marine Sciences,
Gloucester Point, VA 23062
hvwang@vims.edu

James River SAP meeting, 2014, November 20, 2014

Outline:

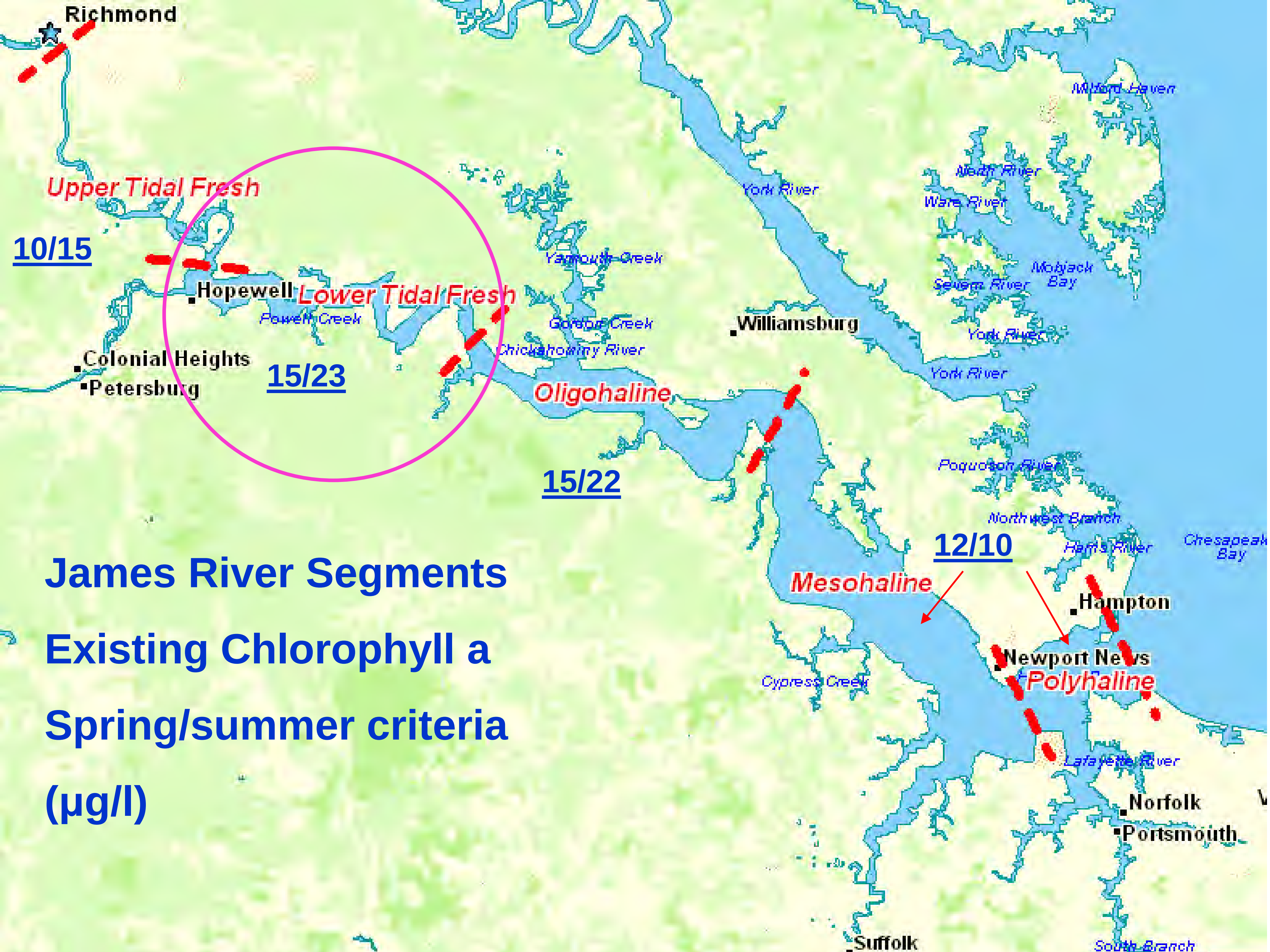
- The Seasonal Phytoplankton Distribution in the Upper James
- The Results of Long-term Statistical Data Analysis
- The Hypothesis for the Mechanism of Flow flushing versus Nutrient Delivery
- Chlorophyll modeling results using Coupled SELFE-ICM

James River Segments

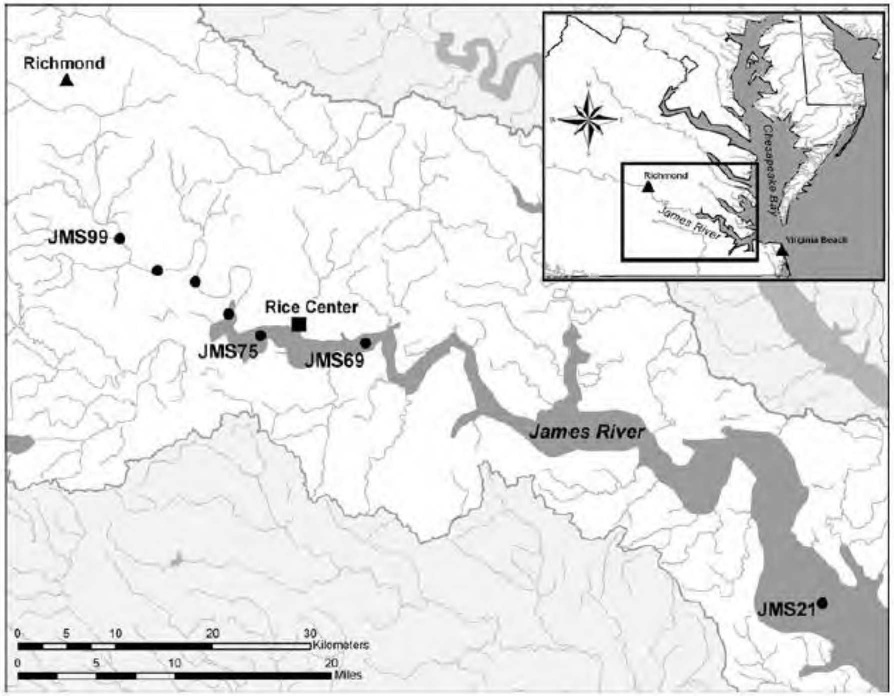
Existing Chlorophyll a

Spring/summer criteria

(µg/l)



The Observed Chl-a Distribution in Upper James



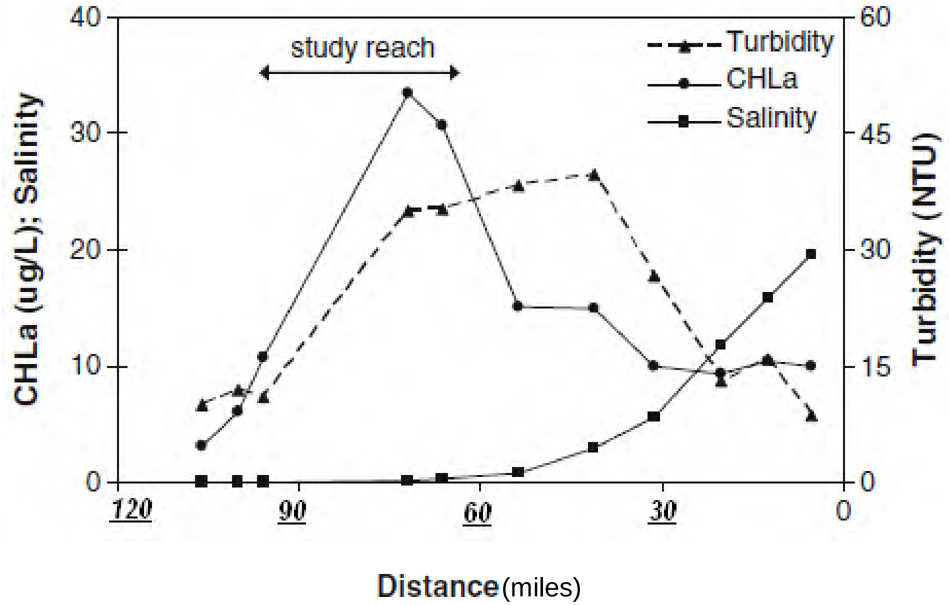


Fig. 1 Longitudinal patterns in turbidity, salinity and CHL*a* in the James River Estuary (distance is from the confluence with Chesapeake Bay). Data are average values for 1999–2004 based on monthly sampling for the Chesapeake Bay Program by the Virginia Department of Environmental Quality (http://www.deq.state.va.us/bay/cbpmon.html)

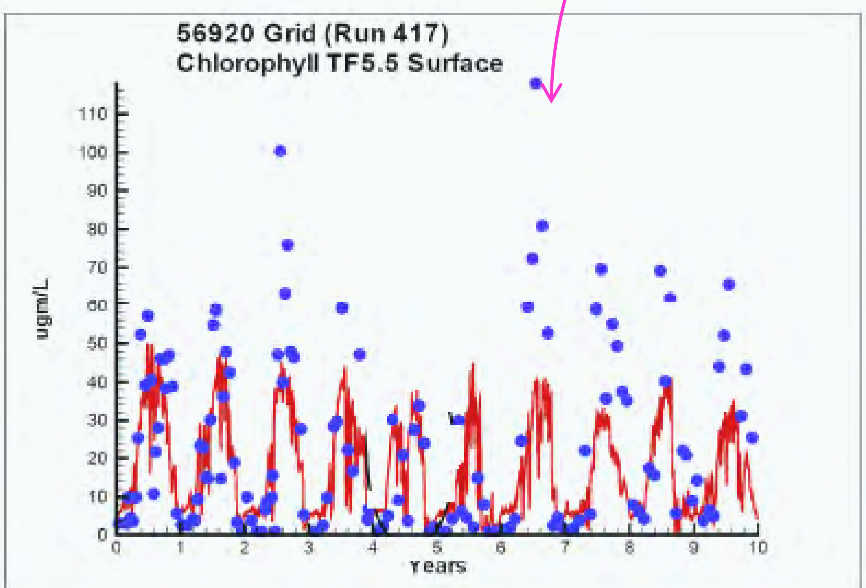
Bukaveckas, P., and Laura Barry (2011), Estuaries and Coasts, 34:569-582

The Current Bay Model results (Miss the localized condition !)

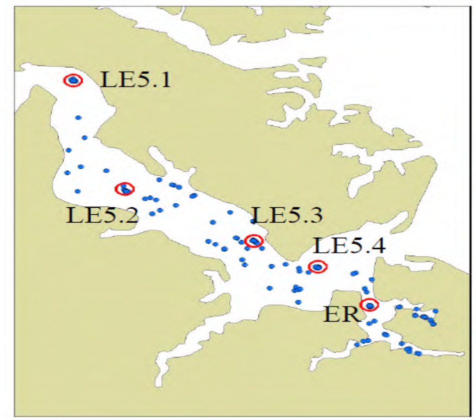
How do we improve water quality model prediction?

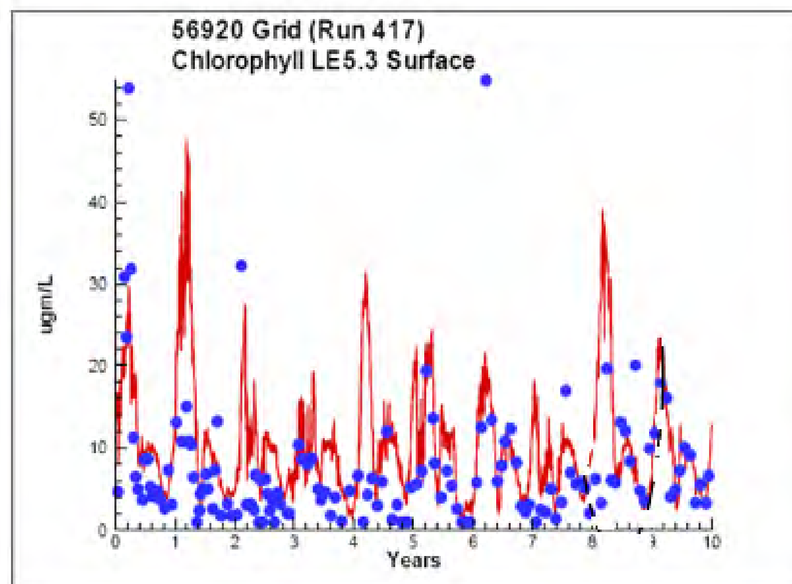
Upper James

Stations TF5.5 and TF5.5A are marked with black dots and circled in red.



Lower James





Station group (mid-stream, location of summer peak: TF5.4 TF5.5 TF5.5A)

Summary of regression analysis between Chl-a and each parameter

Statistical Model:

$$\log(CHLA) = a + bx + \varepsilon$$

(Linear regression, log transform on Chl-a)

Raw Data

Parameters	R^2	samples
WTEMP	0.52	178
SALINITY	<0.05	167
SECCHI	<0.05	174
TSS	0.06	179
TP	0.15	177
TN	0.18	175
FLOW	0.31	180
FLOW5	0.41	180
FLOW10	0.42	180
FLOW20	0.39	180
FLOW30	0.35	180
FLOW40	0.3	180

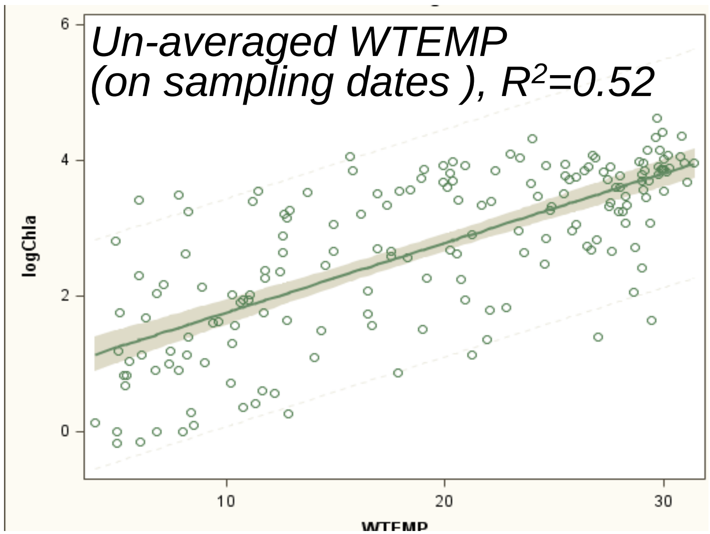
Monthly (ensemble average, 1995~2010)

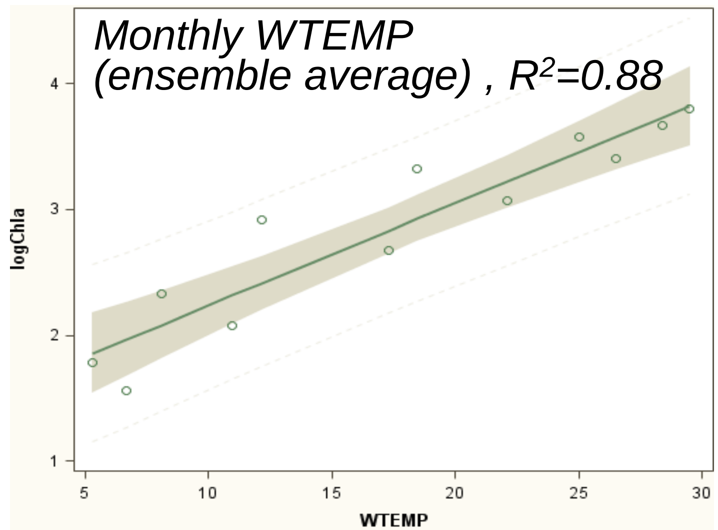
Parameters	R^2
WTEMP	0.88
SALINITY	<0.05
SECCHI	<0.05
TSS	<0.05
TP	0.62
TN	0.12
FLOW	0.83

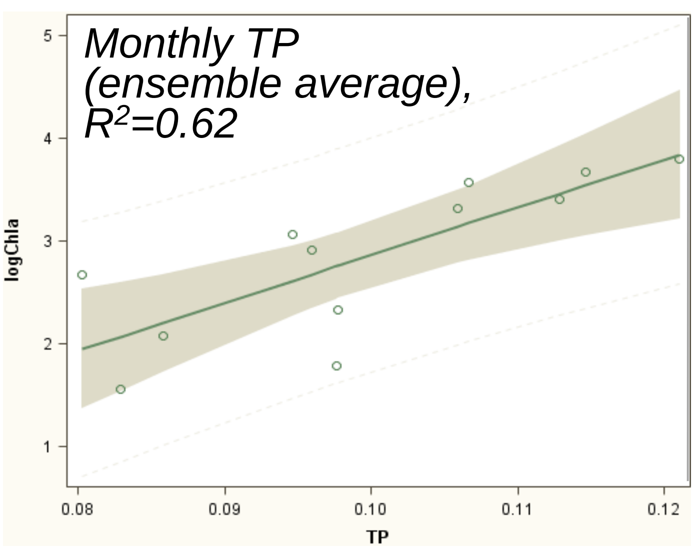
12 samples per parameter

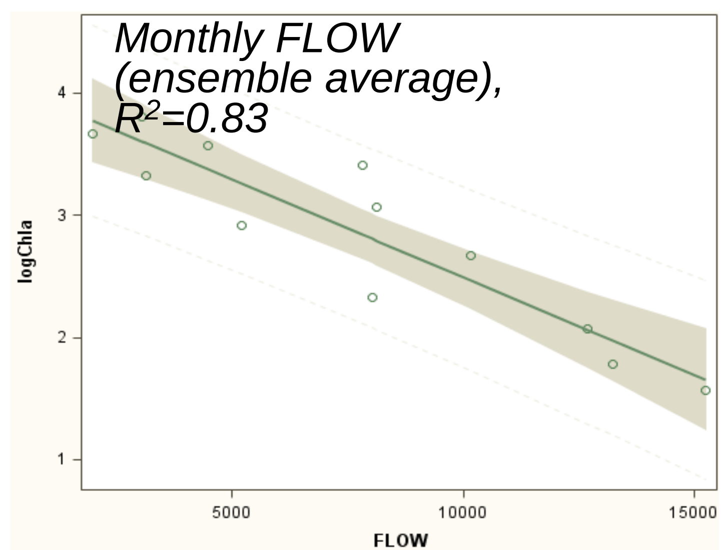
Station group (mid-stream, location of summer peak: TF5.4 TF5.5 TF5.5A)

Selective regression plots between Chl-a and each water quality parameter 1995~2010 , (only those with high correlation)









Local Residence Modeling using SELFE

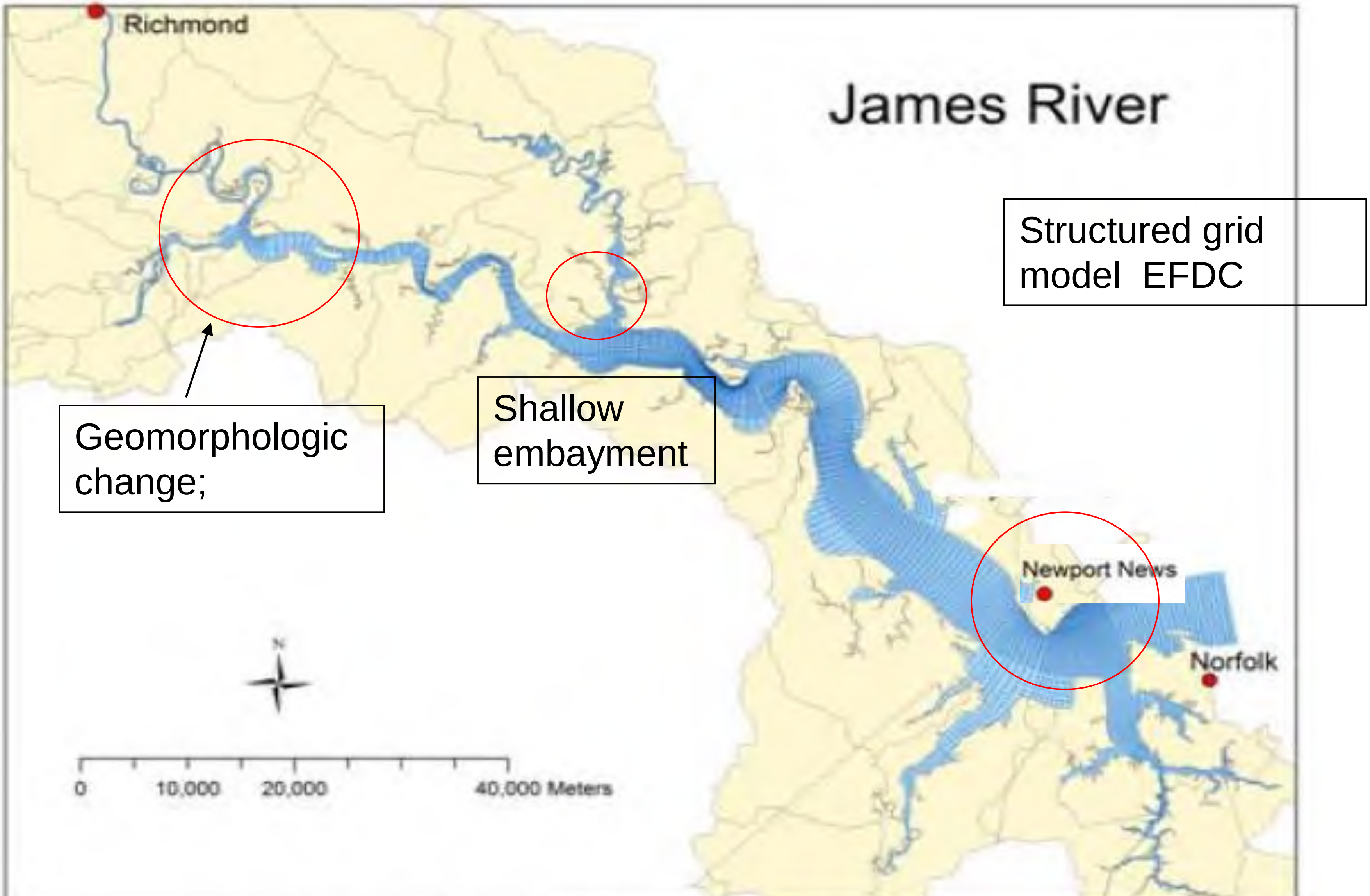
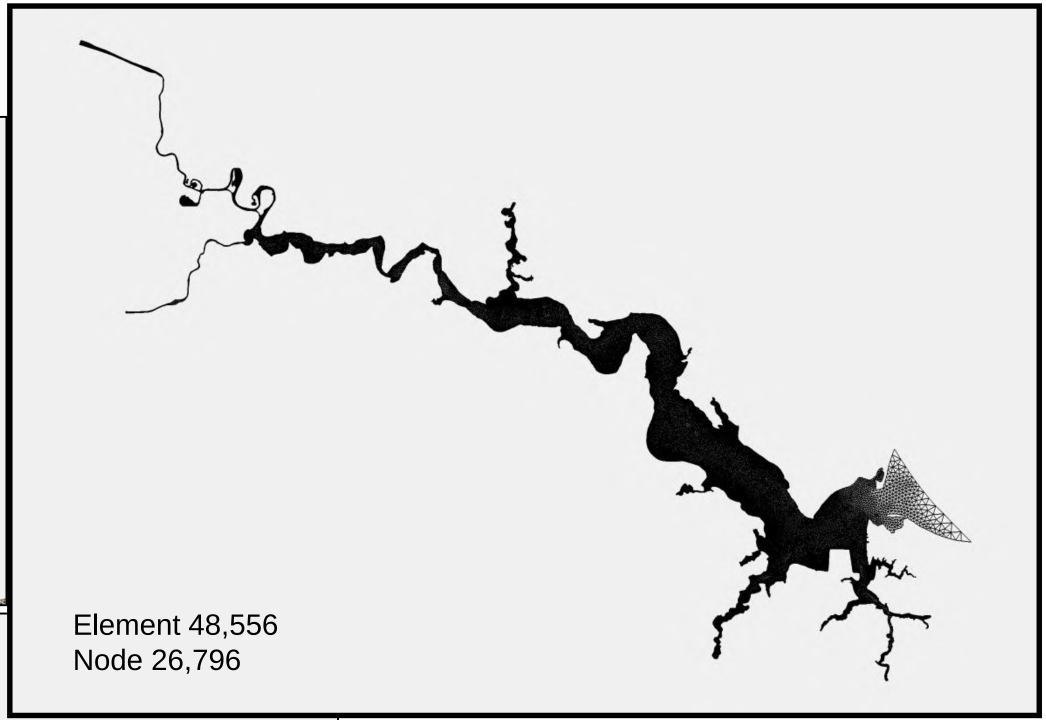
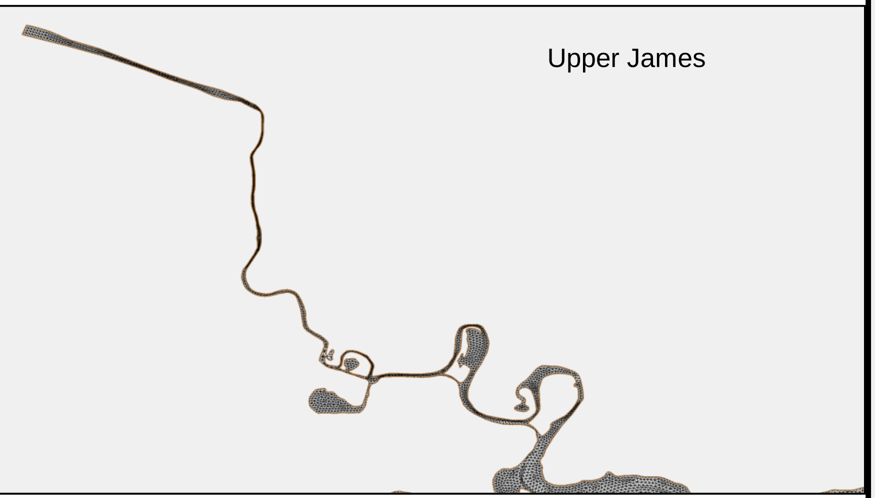


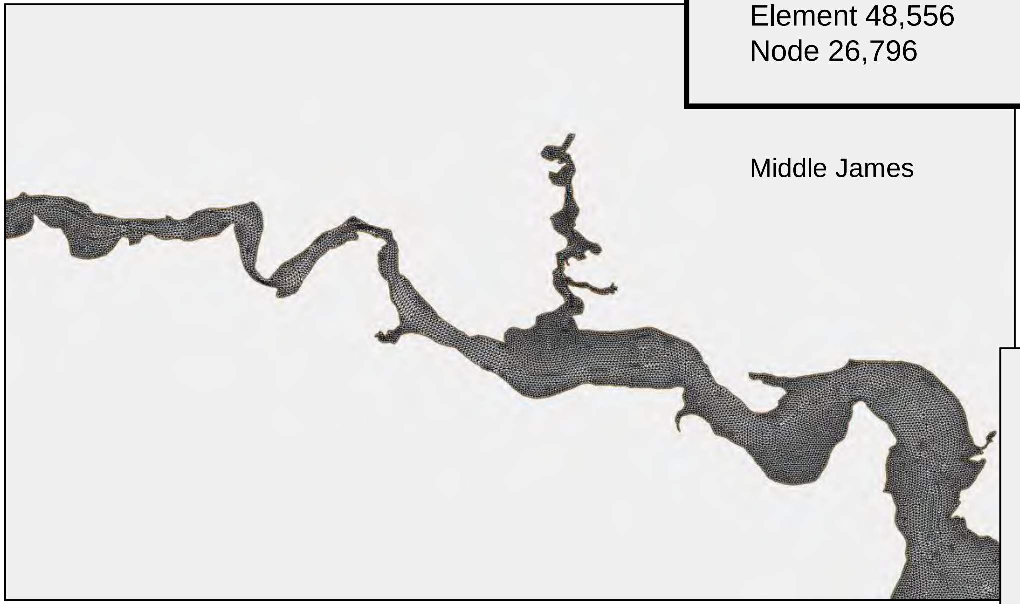
Figure 13. Existing EFDC hydrodynamic grid

Jian Shen (2011)

Highly Resolved 3D Unstructured Grid Model SELFE







The 3D unstructured grid SELFE model

The model SELFE (Semi-implicit, Eulerian-Lagrangian, Finite Element) http://www.ccalmr.ogi.edu/CORIE/modeling/SELFE/)

Key Features:

- **Unstructured triangular grid in the horizontal dimension & hybrid SZ coordinates in the vertical dimension.**

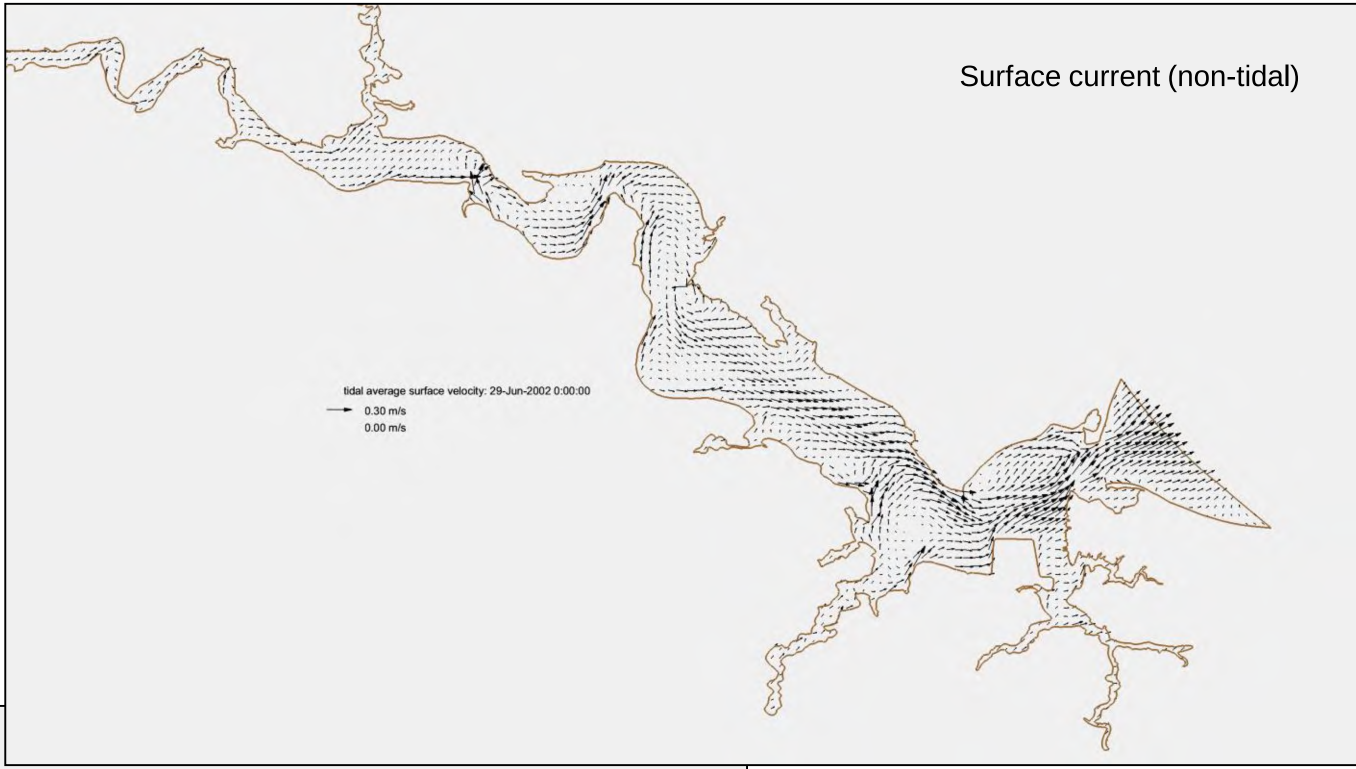
- **Semi-implicit finite-element Eulerian-Lagrangian algorithm to solve the Navier-Stokes equations not constrained by CFL stability -> numerical efficiency.**

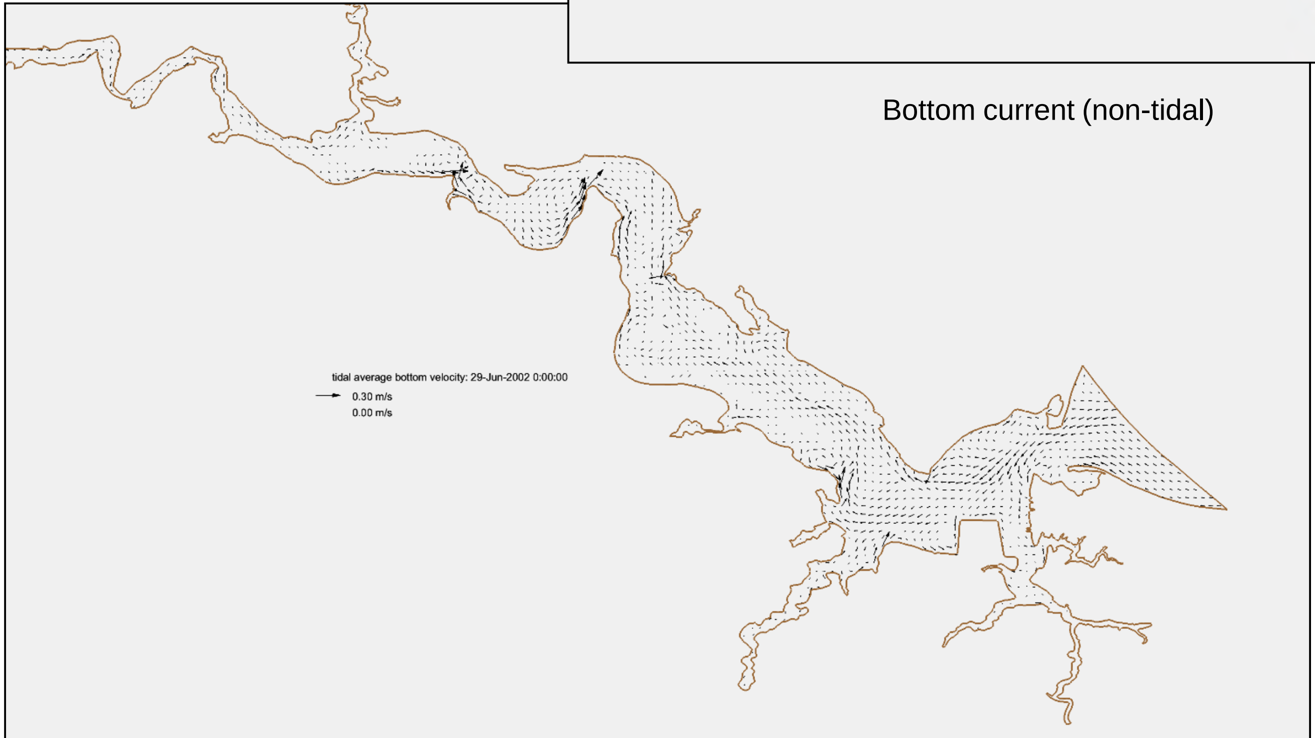
- **It is naturally incorporate simulation of wetting-and-drying process.**

- **The model was fully parallelized with domain decomposition and MPI protocol.**

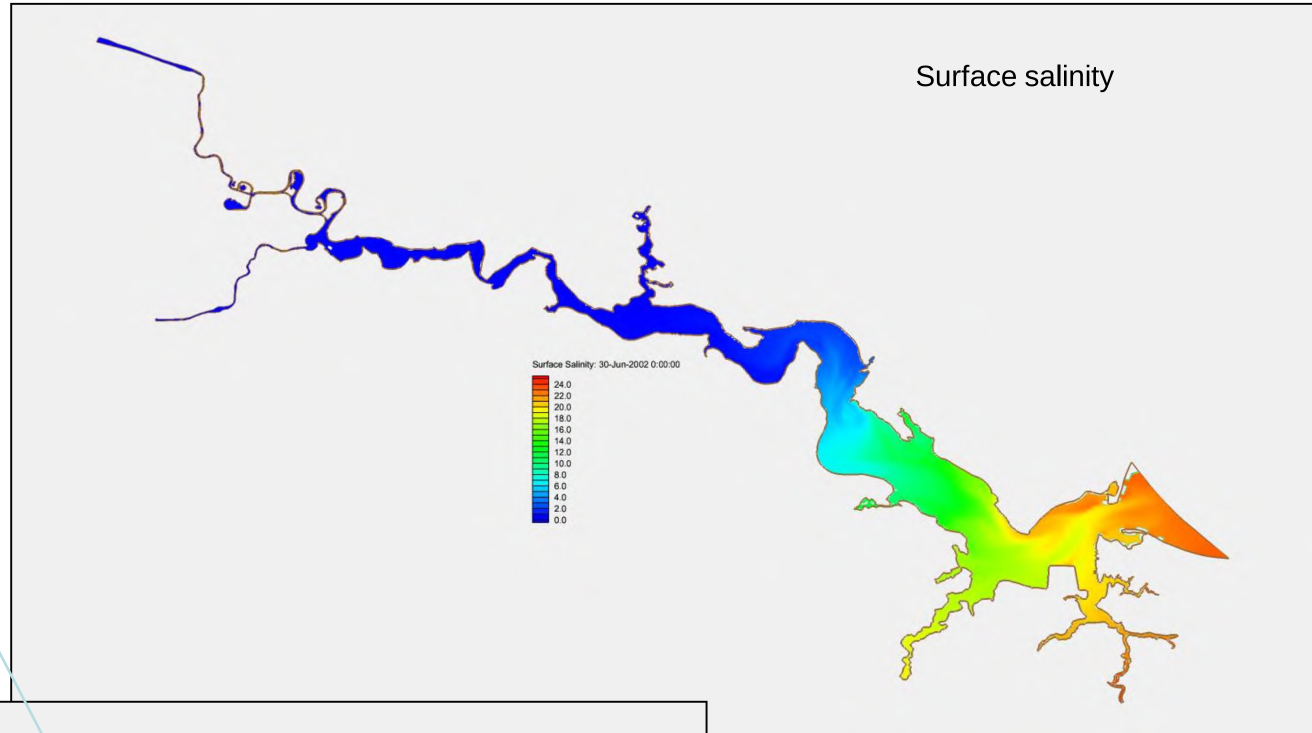
Typical of gravitational circulation

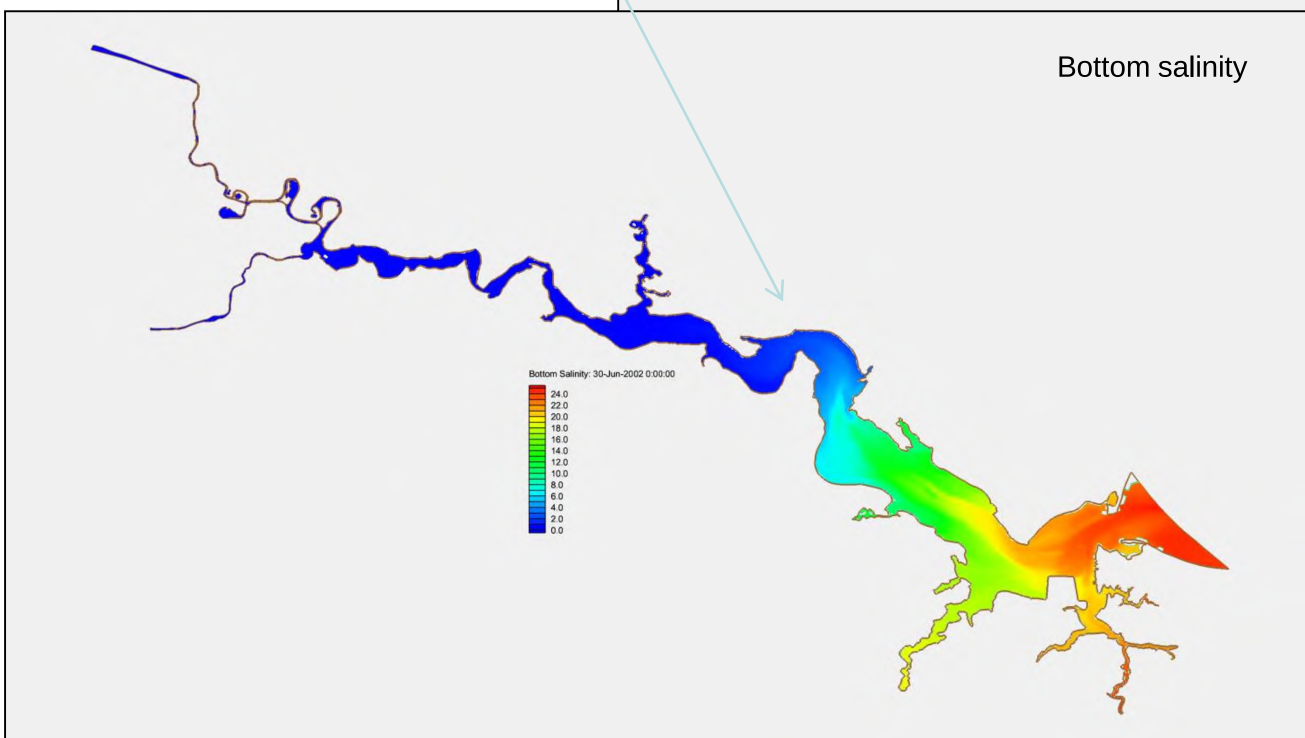
(under mean discharge 200m**3/sec)





The salt intrusion up to Williamsburg, VA





Calculation of the Mean Age

$$\frac{\partial c(t,\vec{\mathrm{x}})}{\partial t} + \nabla(uc(t,\vec{\mathrm{x}}) - K\nabla c(t,\vec{\mathrm{x}})) = 0$$

$$\frac{\partial \alpha(t,\vec{\mathrm{x}})}{\partial t} + \nabla(u\alpha(t,\vec{\mathrm{x}}) - K\nabla \alpha(t,\vec{\mathrm{x}})) = c(t,\vec{\mathrm{x}})$$

$$a(t,\vec{\mathrm{x}}) = \frac{\alpha(t,\vec{\mathrm{x}})}{c(t,\vec{\mathrm{x}})}$$

C = tracer concentration

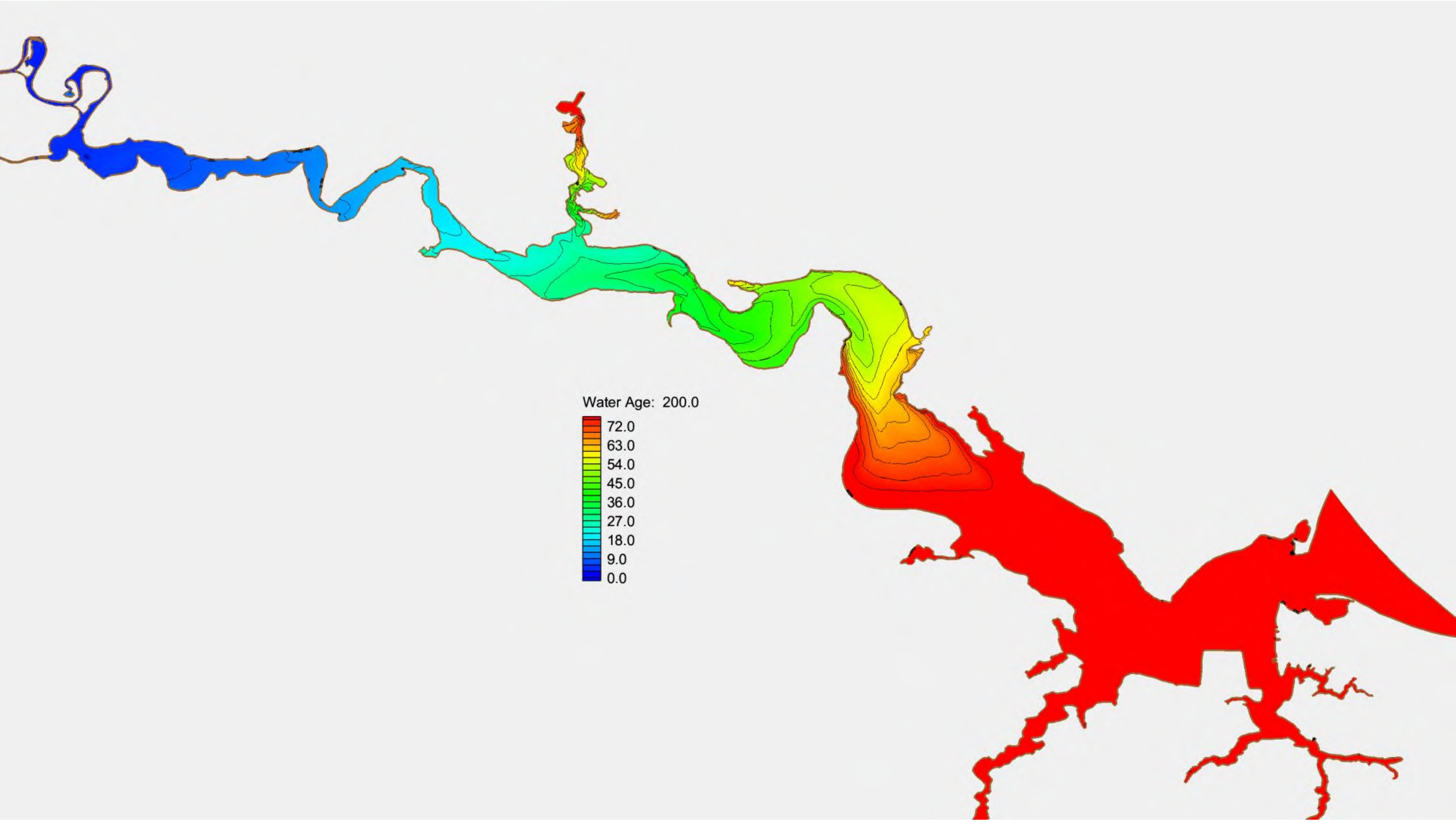
α = the age concentration

a = the mean age

(Deleersnijder et al., 2001; Beckers et al., 2001): Shen and Haas (2004); Shen and Wang (2007)

The mean, age of water in the James River

Under average river discharge condition 200 m**3/sec



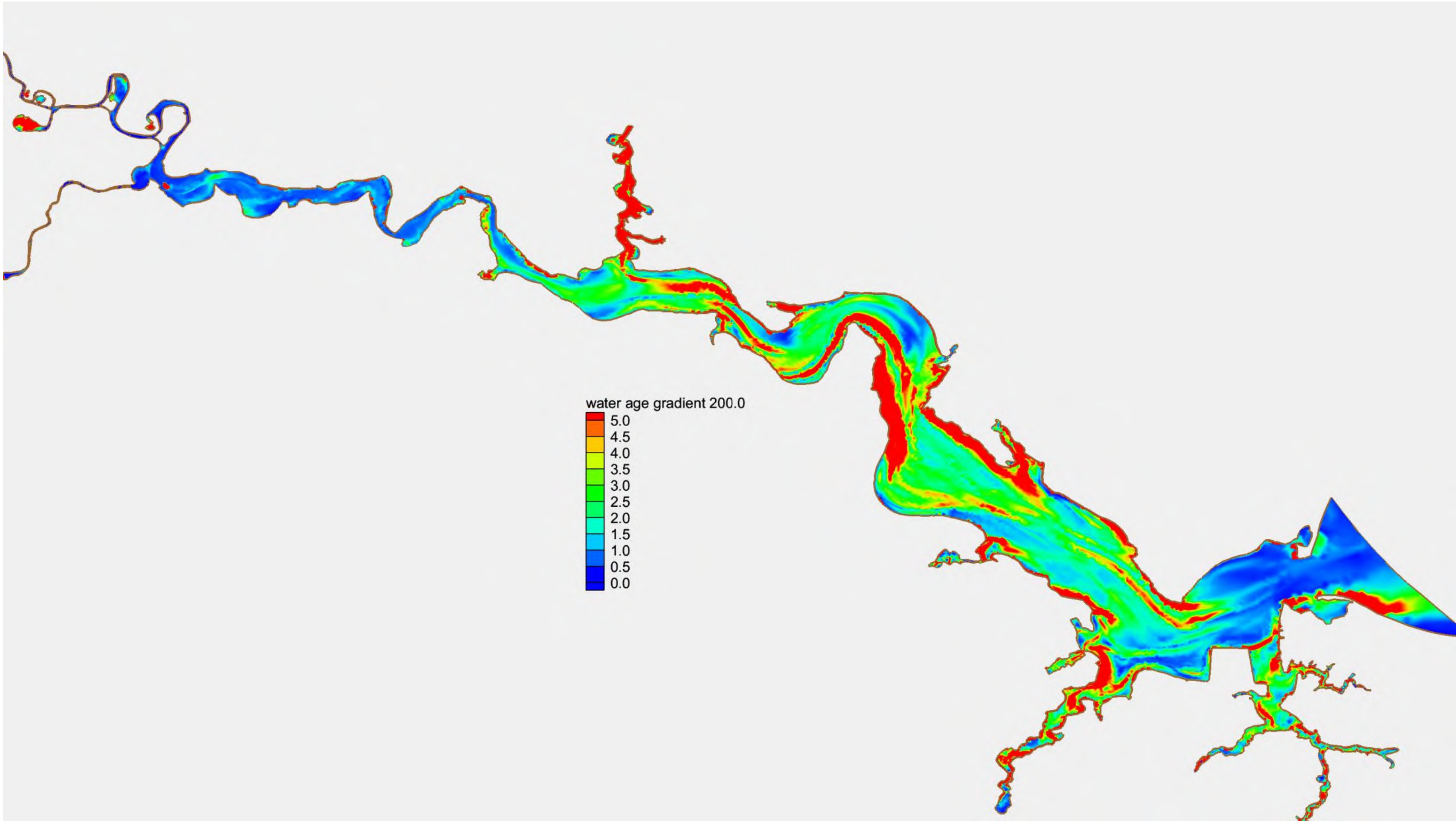
Define Age Gradient by taking gradient of mean age

- Think of age as cumulative distribution time for a fluid parcel to travel downstream. We can define a probability density function of the of age.

- It is a quantity which has the dimension of inverse of Lagragian velocity;

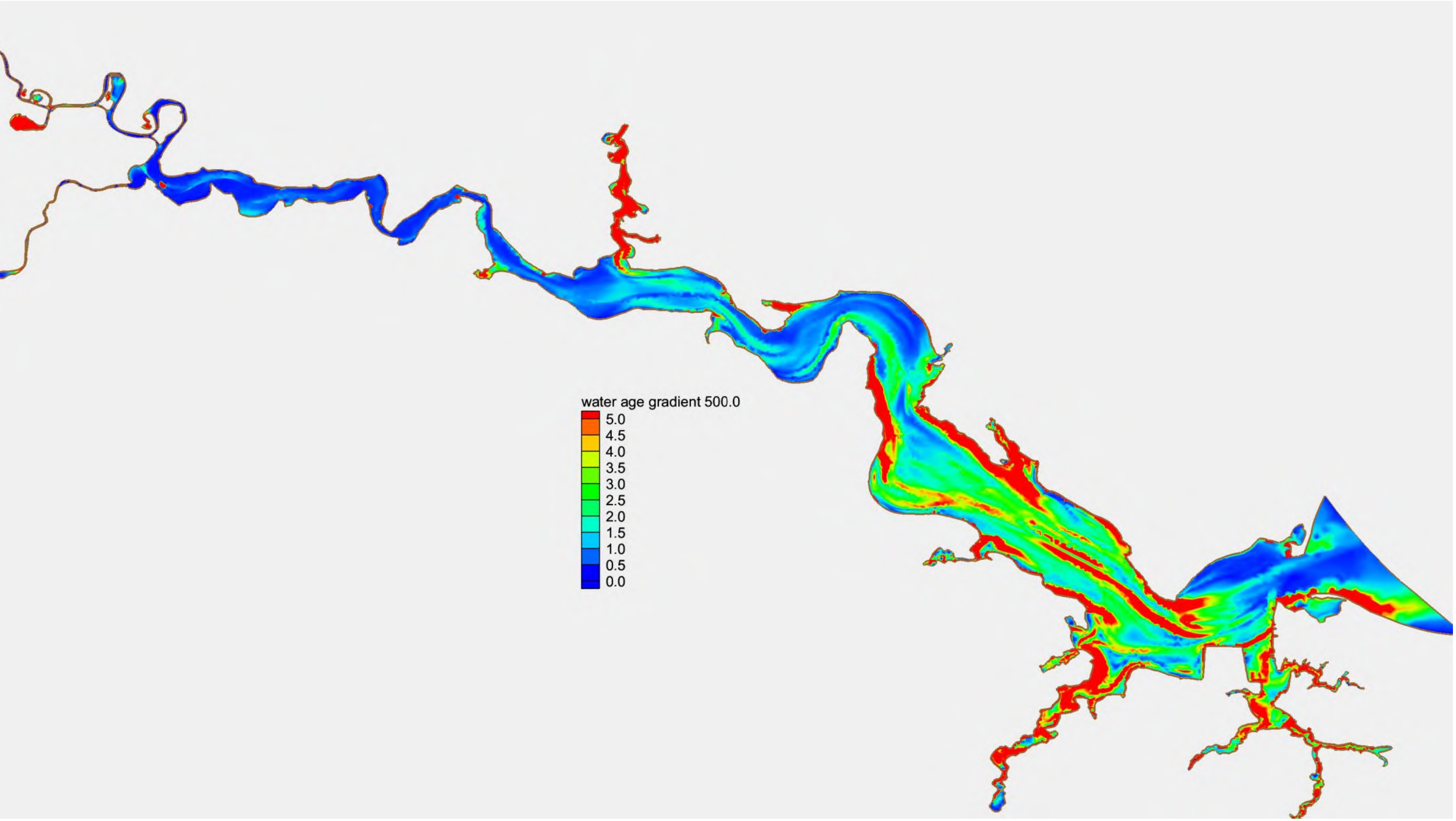
- Physically, the age gradient related to local residence time.

Under average river discharge condition 200 m**3/sec

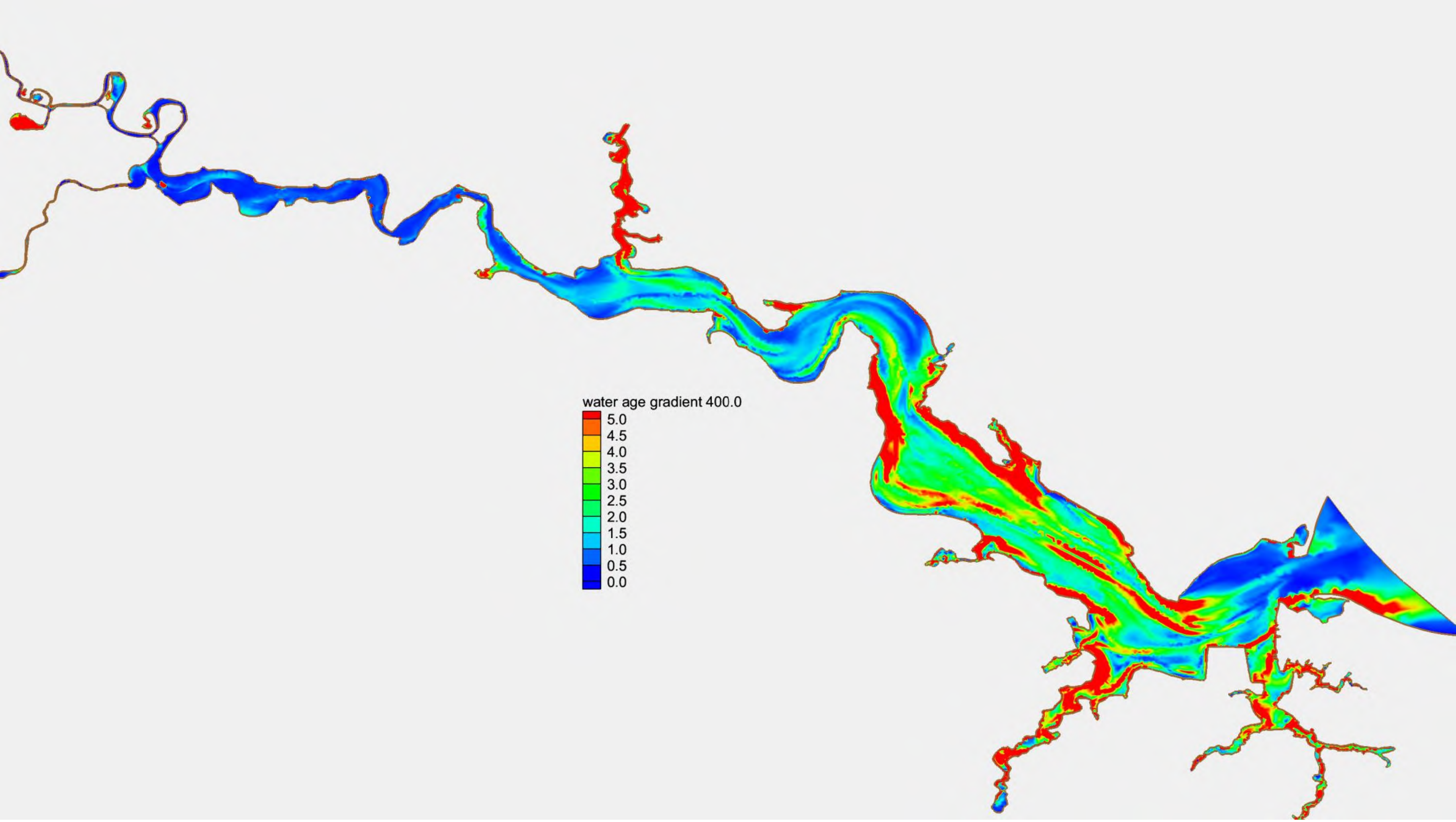


Local residence time (days/km) - varying with river discharge

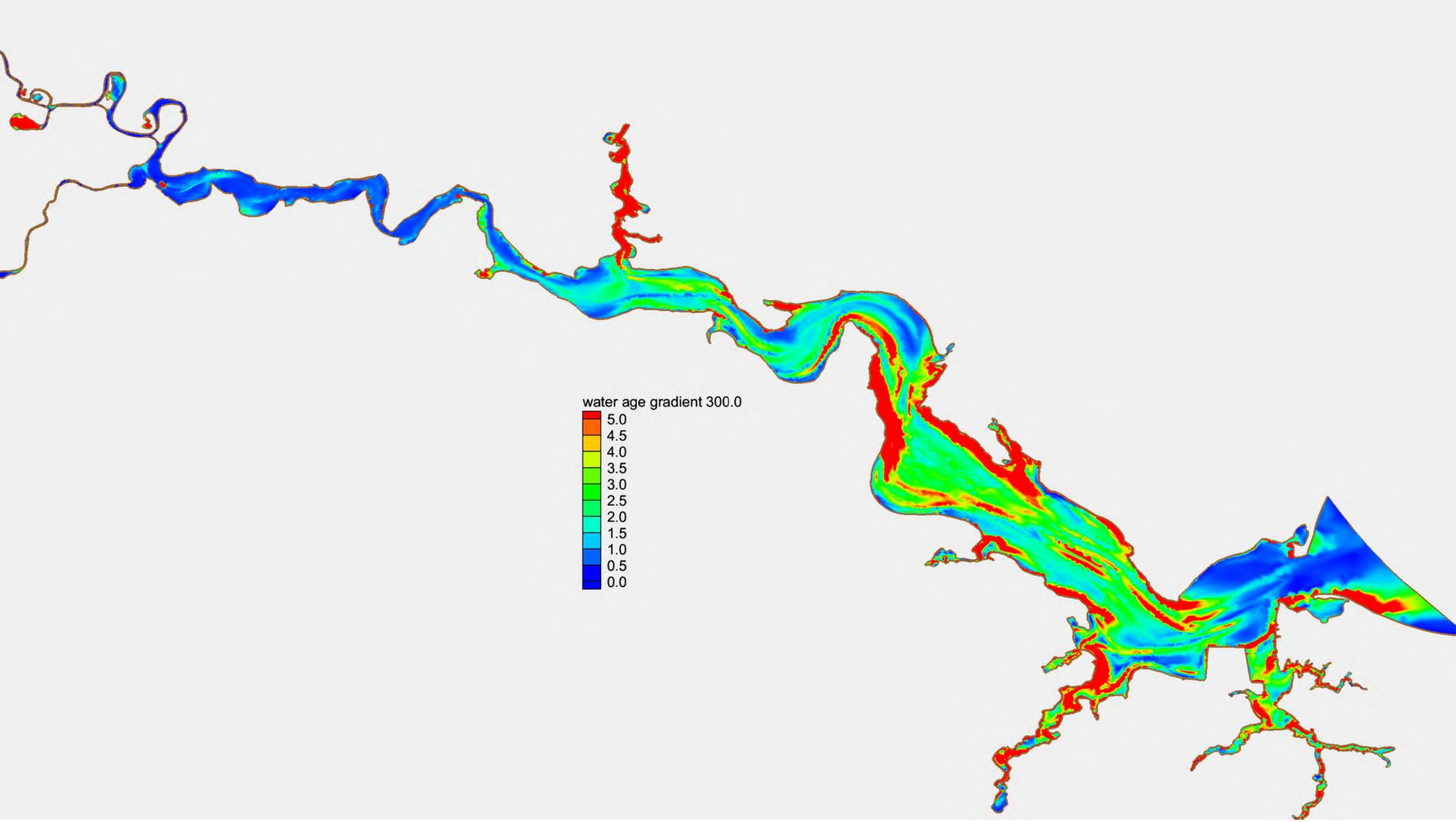
500 m**3/sec



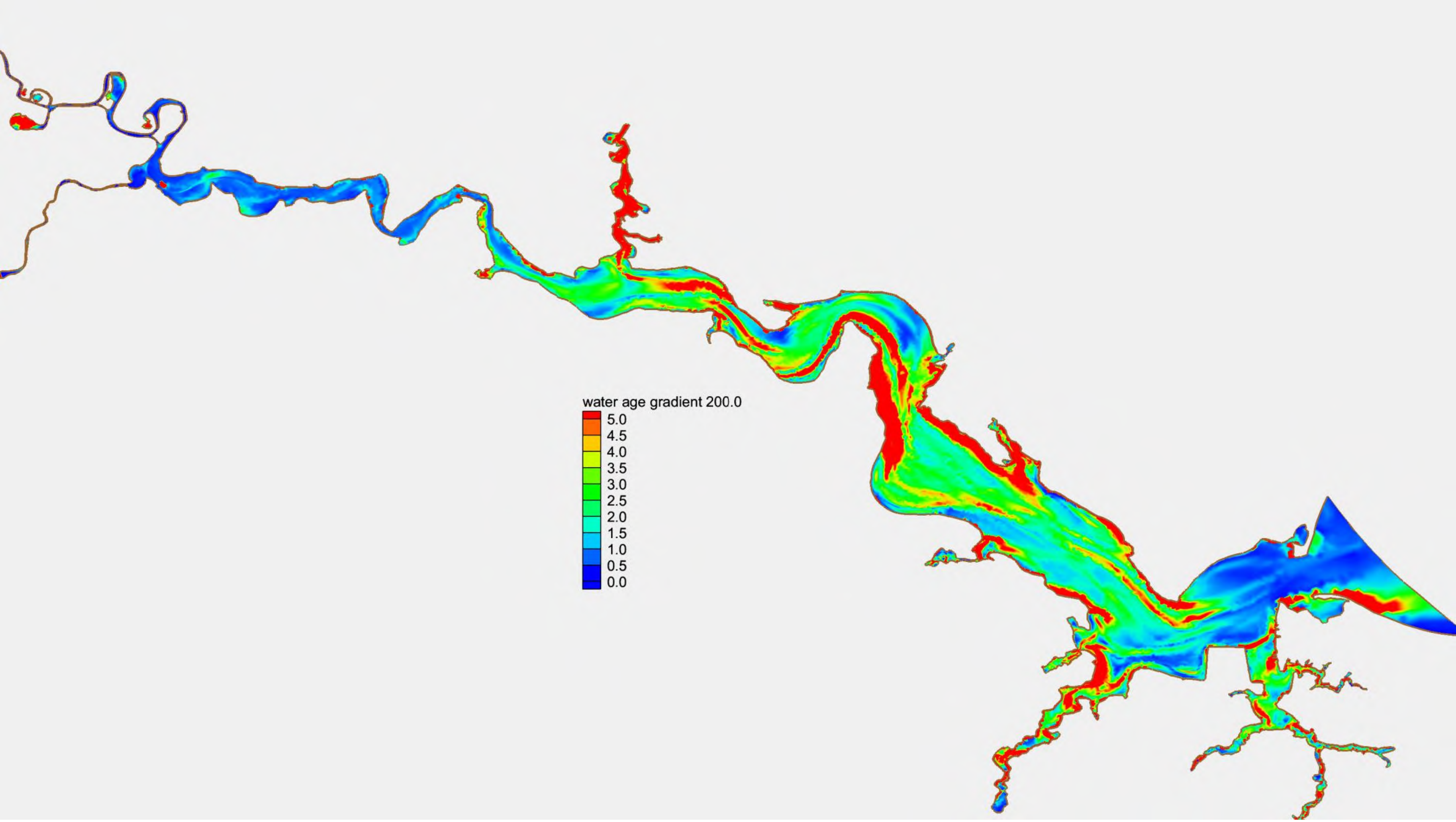
400 m**3/sec



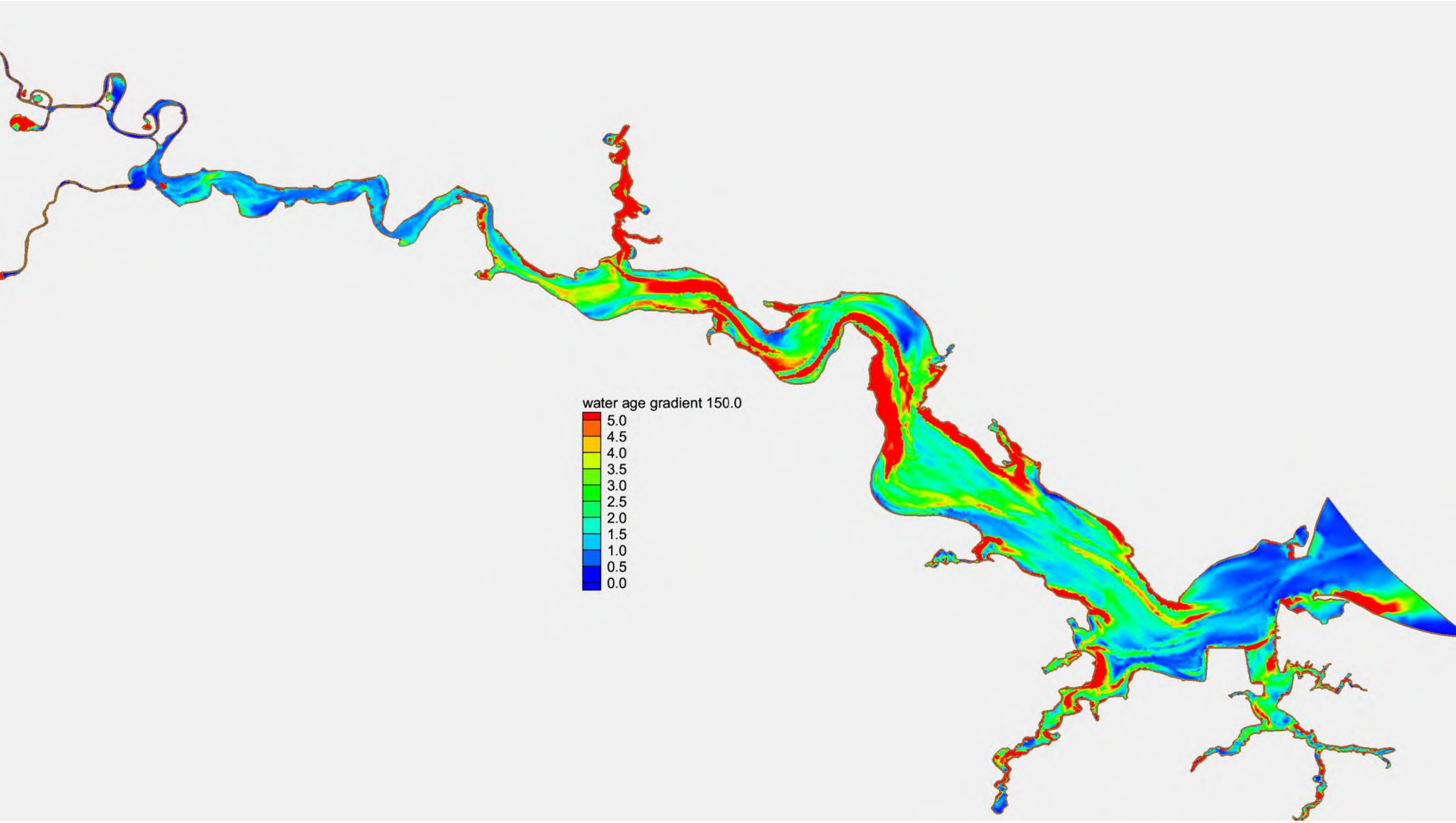
300 m**3/sec



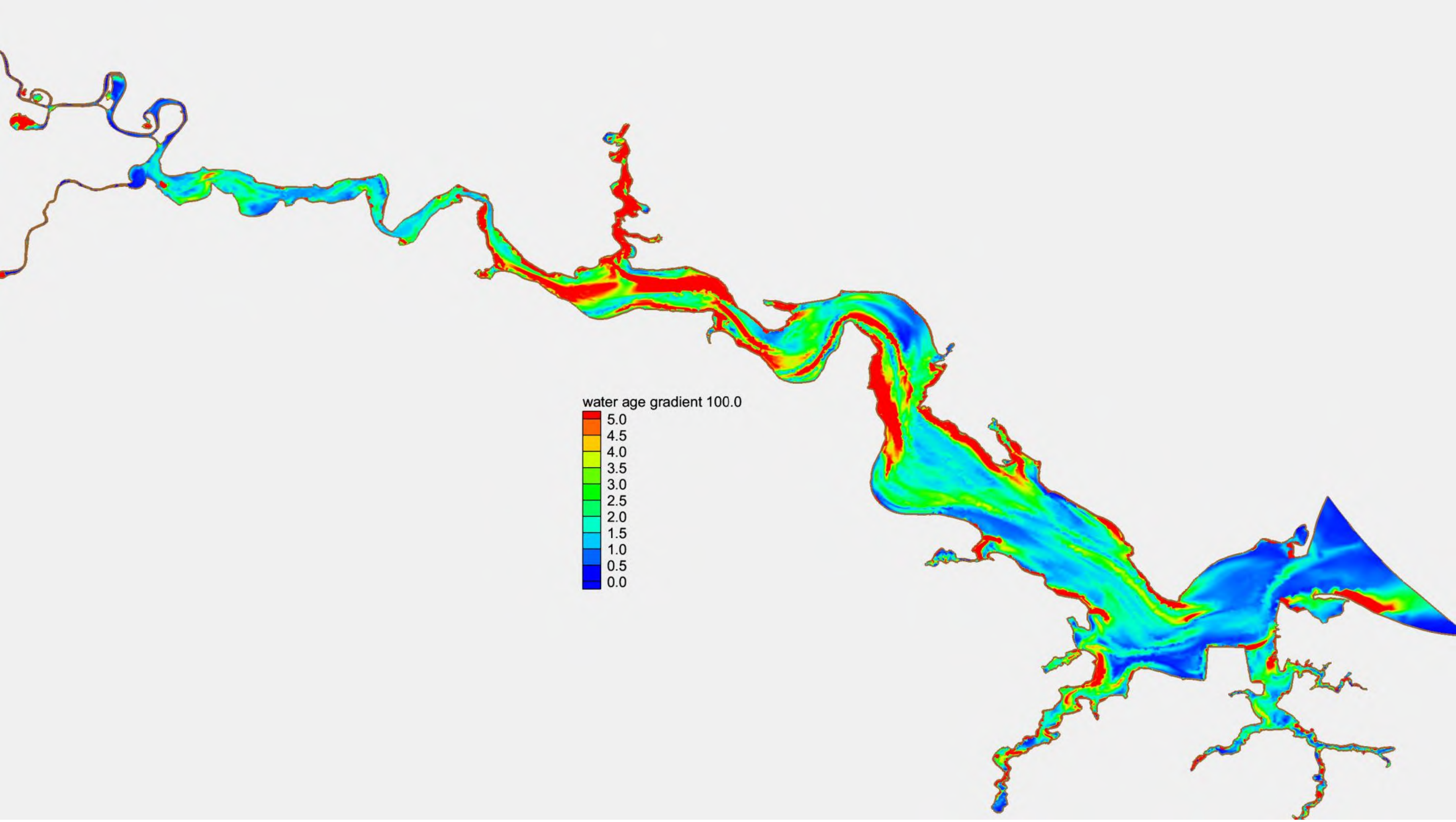
200 m**3/sec



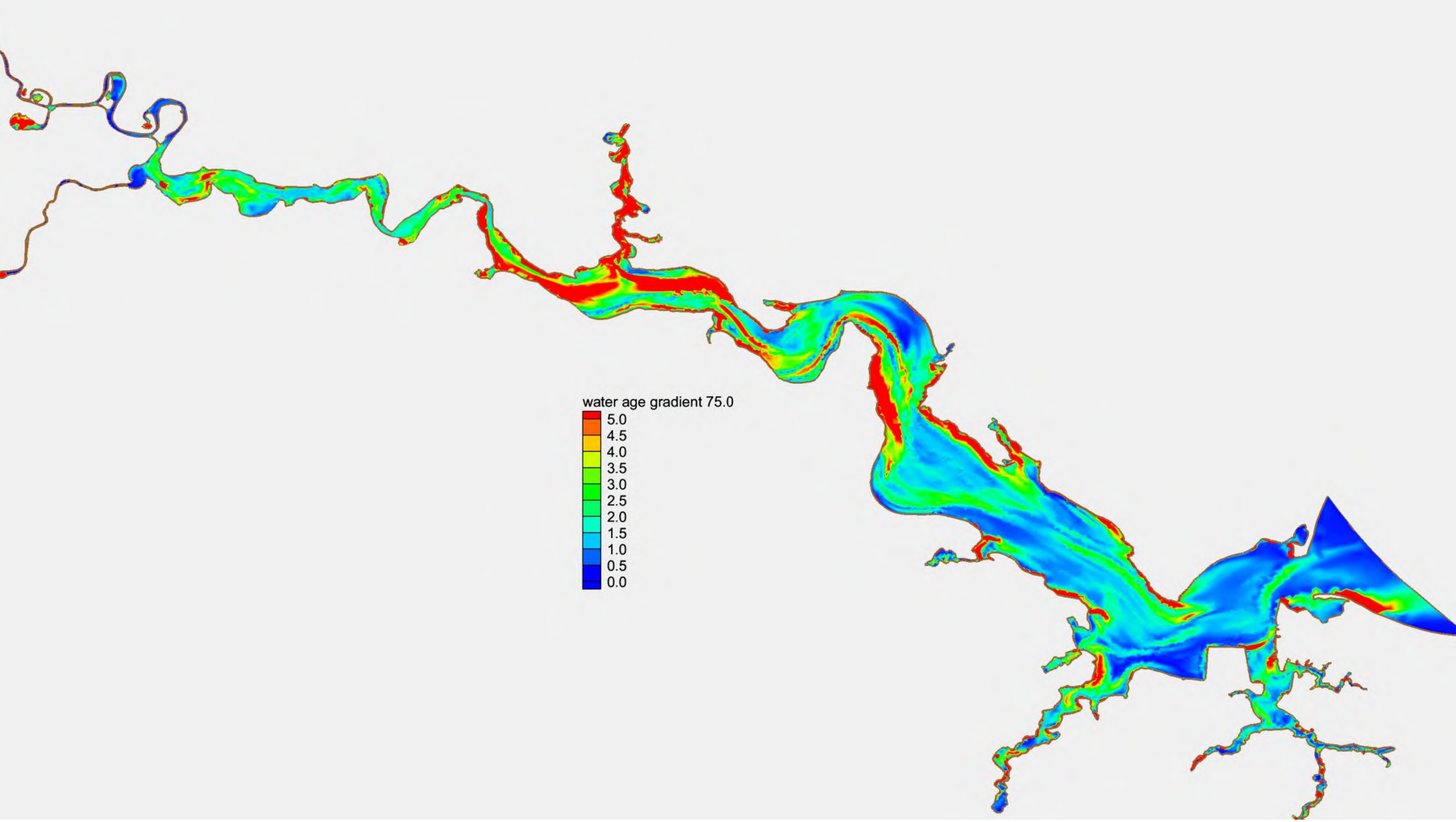
150 m**3/sec



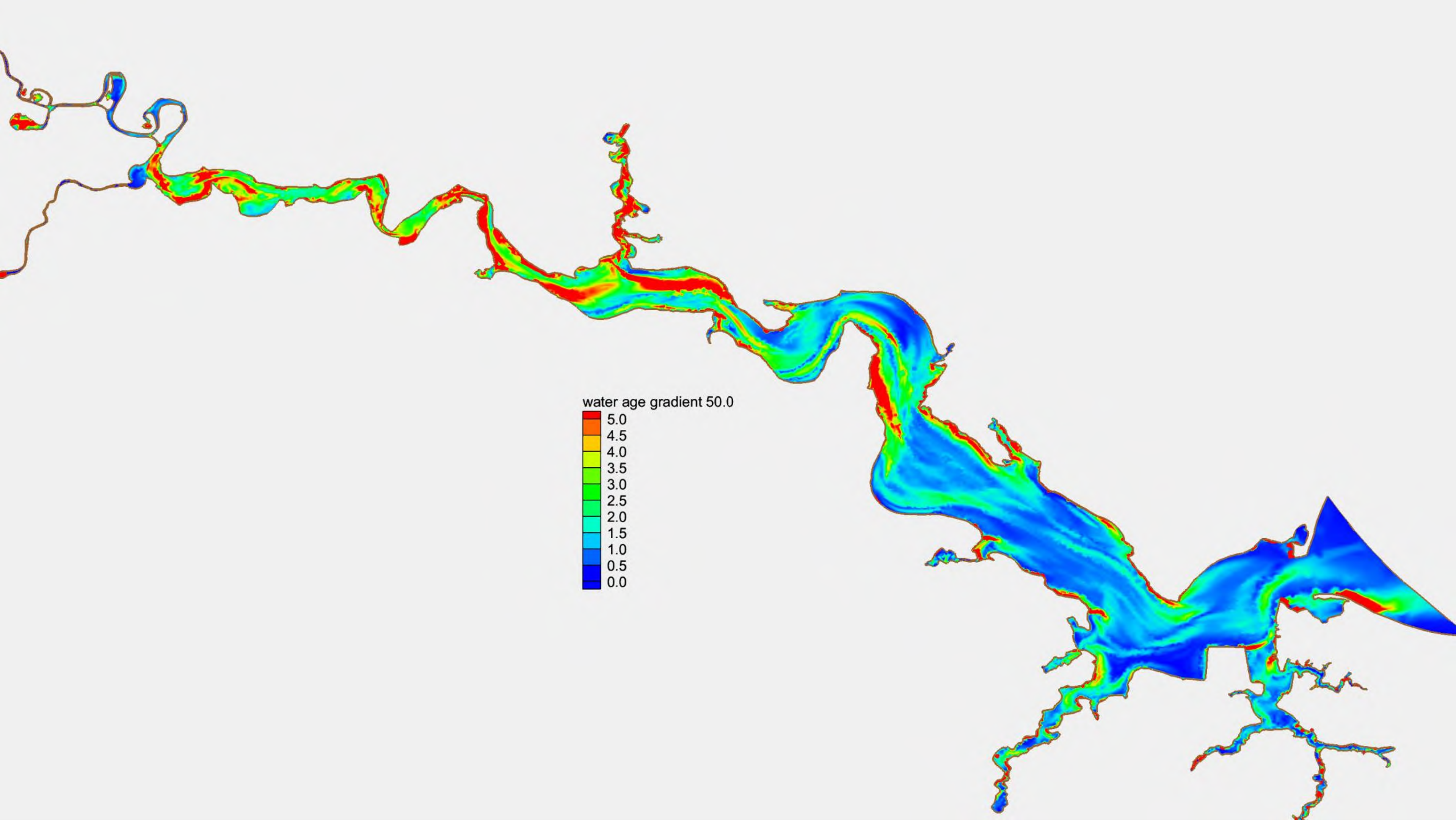
100 m**3/sec



75 m**3/sec



50 m**3/sec



The high resident time zone coincide with the location of seasonal phytoplankton blooming peak

30 m**3/sec

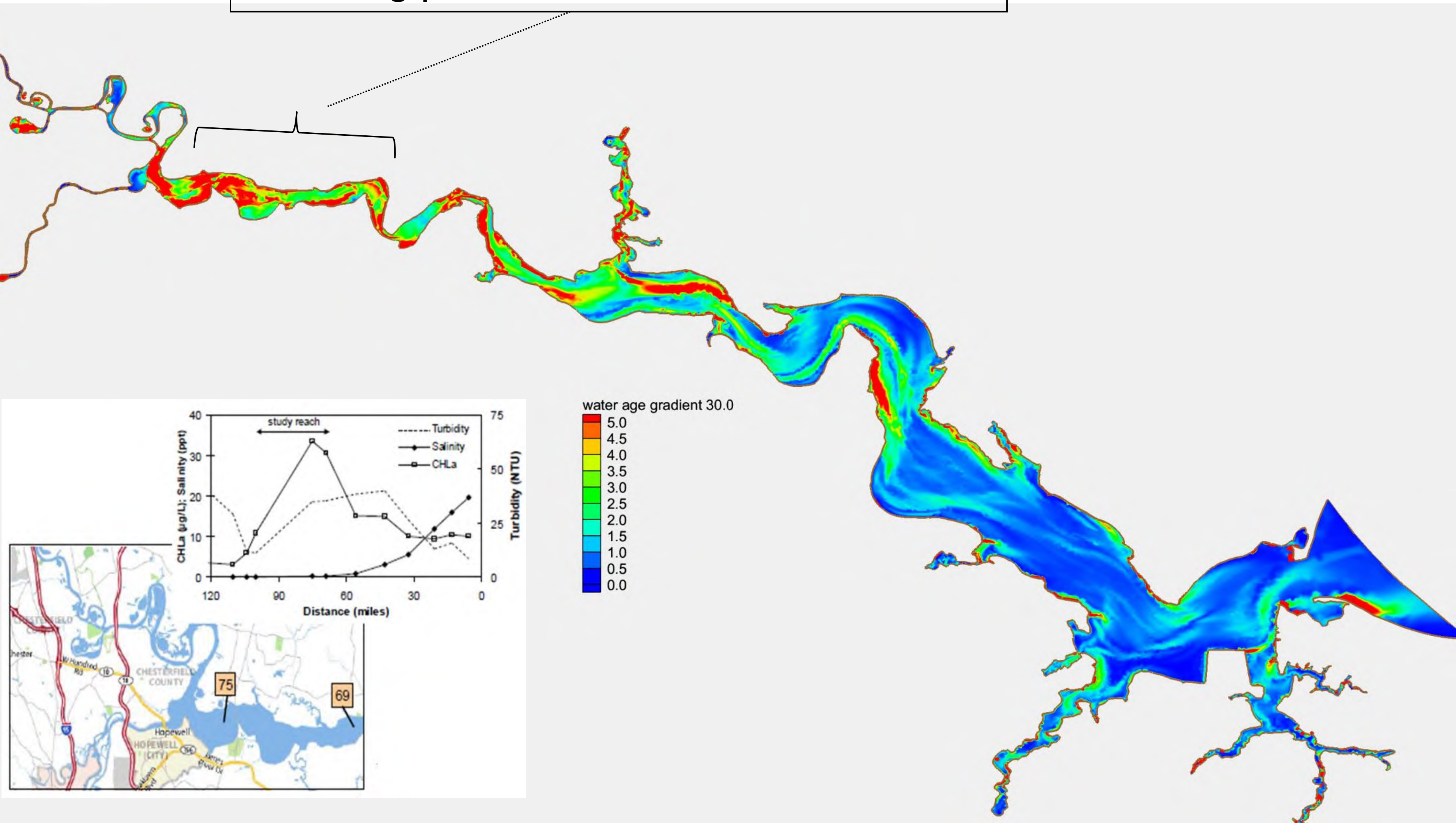
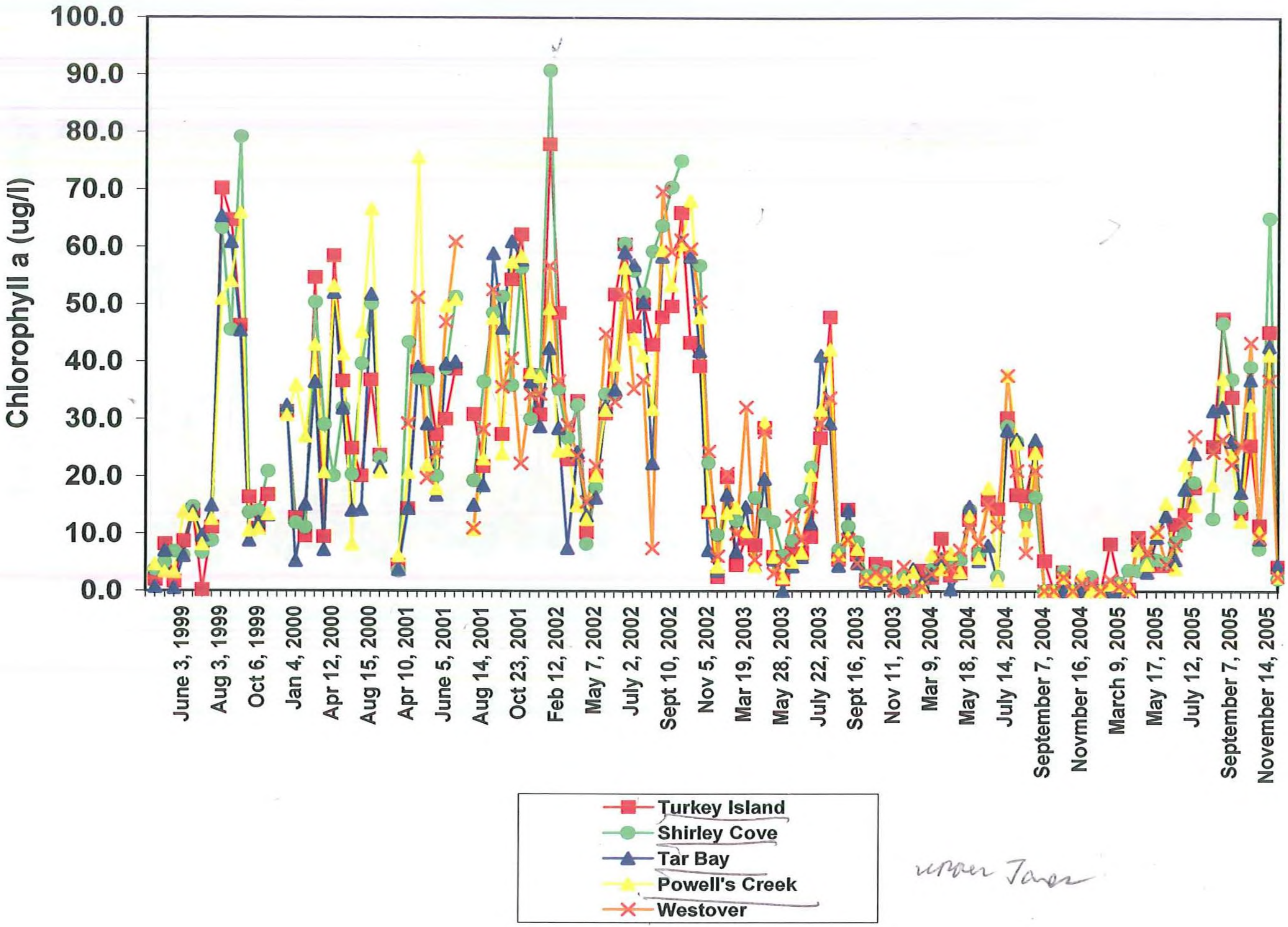
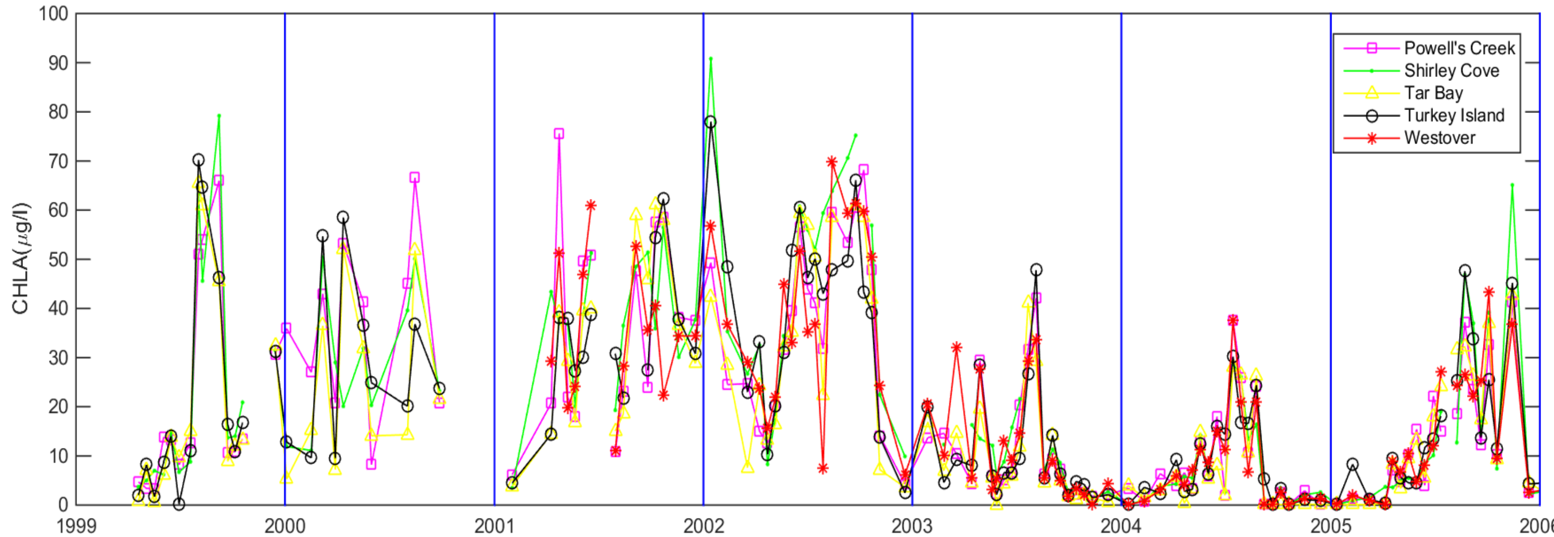
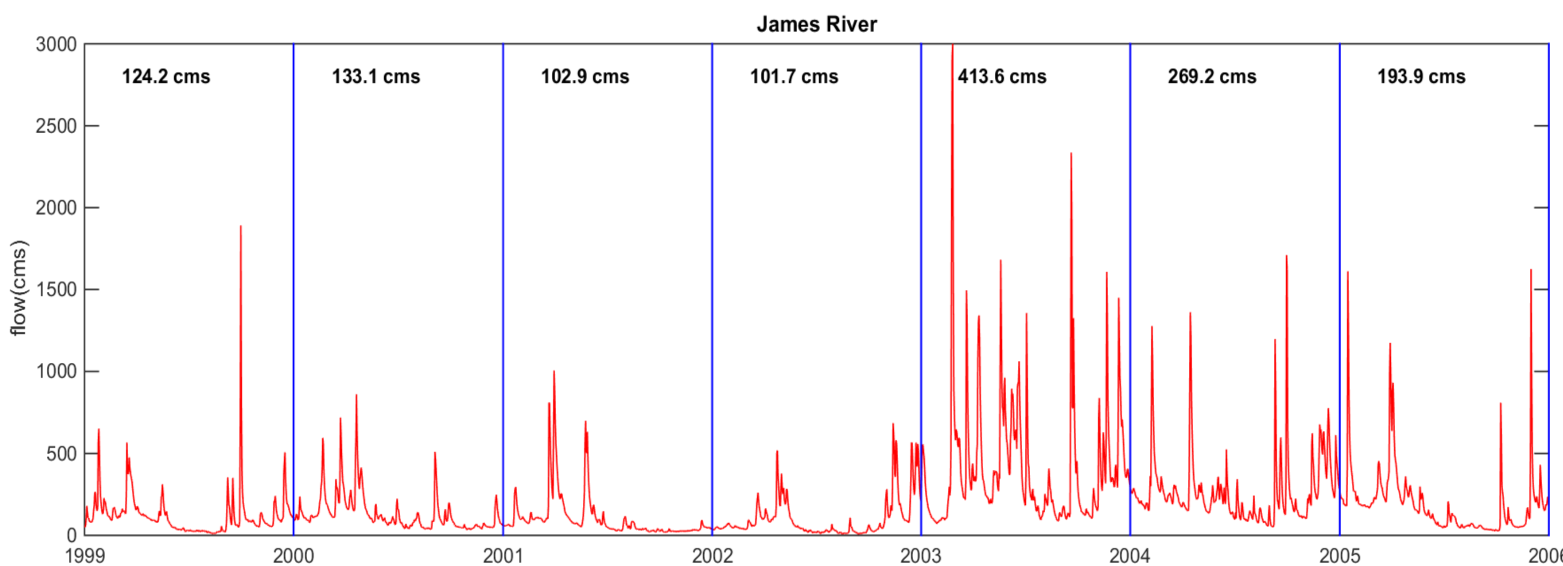
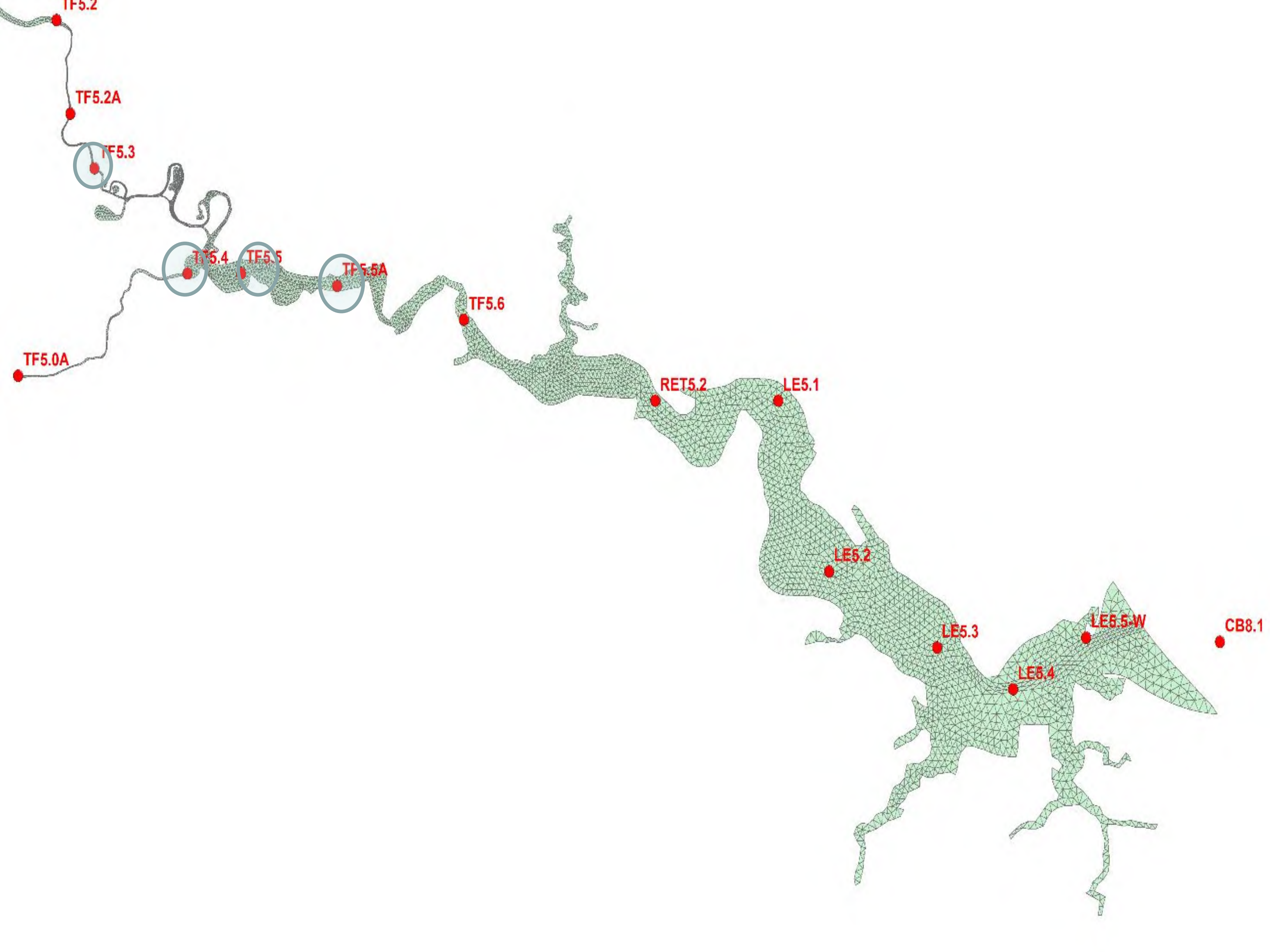


Figure 3-6. Phytoplankton as Chlorophyll a

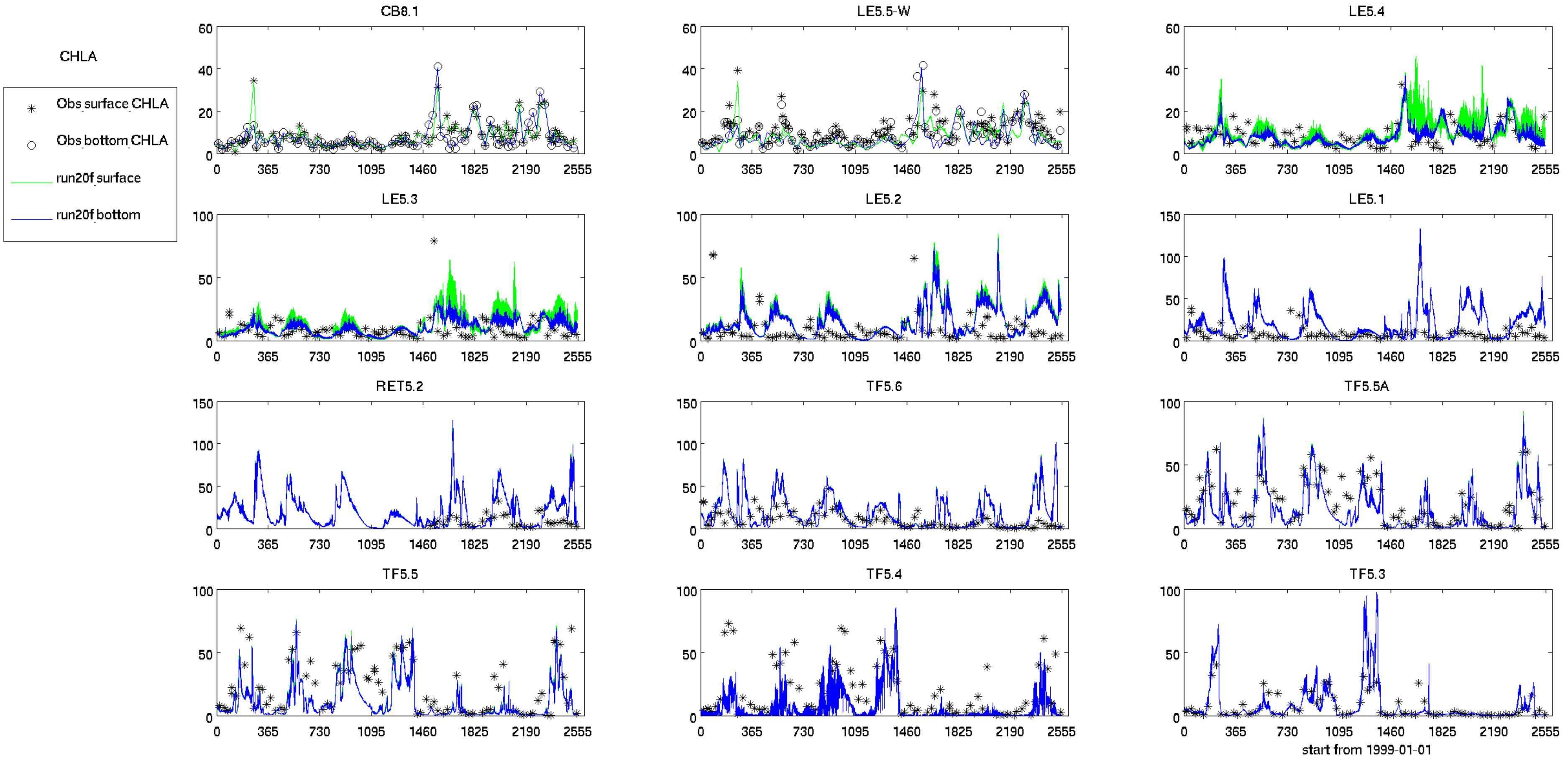


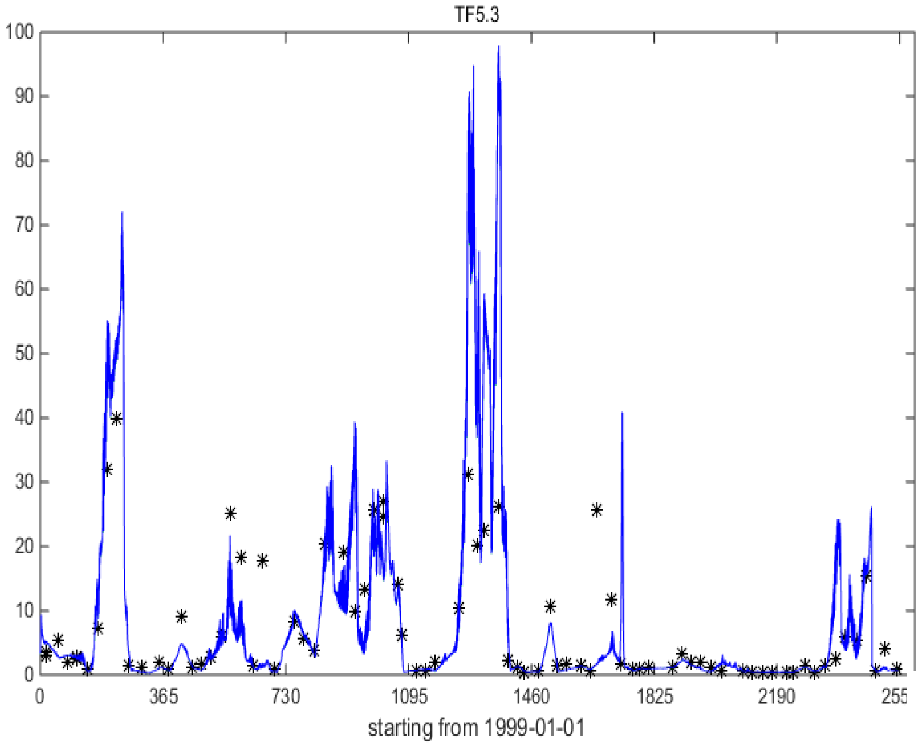

CHLA(μg/l)
Powell's Creek
Shirley Cove
Tar Bay
Turkey Island
Westover
1999
2000
2001
2002
2003
2004
2005
2006

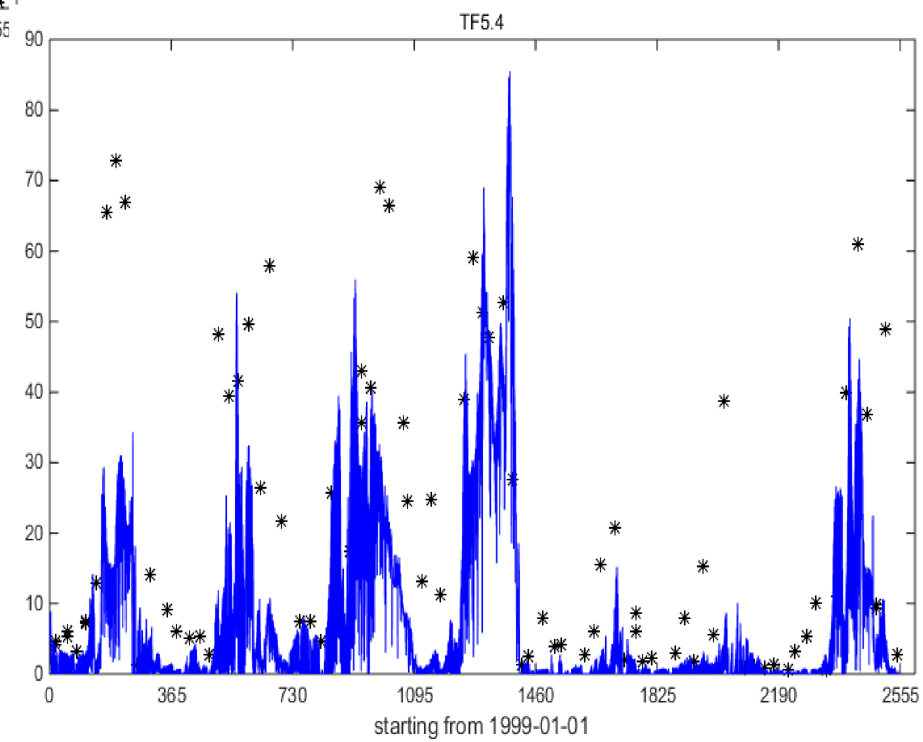

James River
flow(cms)
124.2 cms
133.1 cms
102.9 cms
101.7 cms
413.6 cms
269.2 cms
193.9 cms
1999
2000
2001
2002
2003
2004
2005
2006

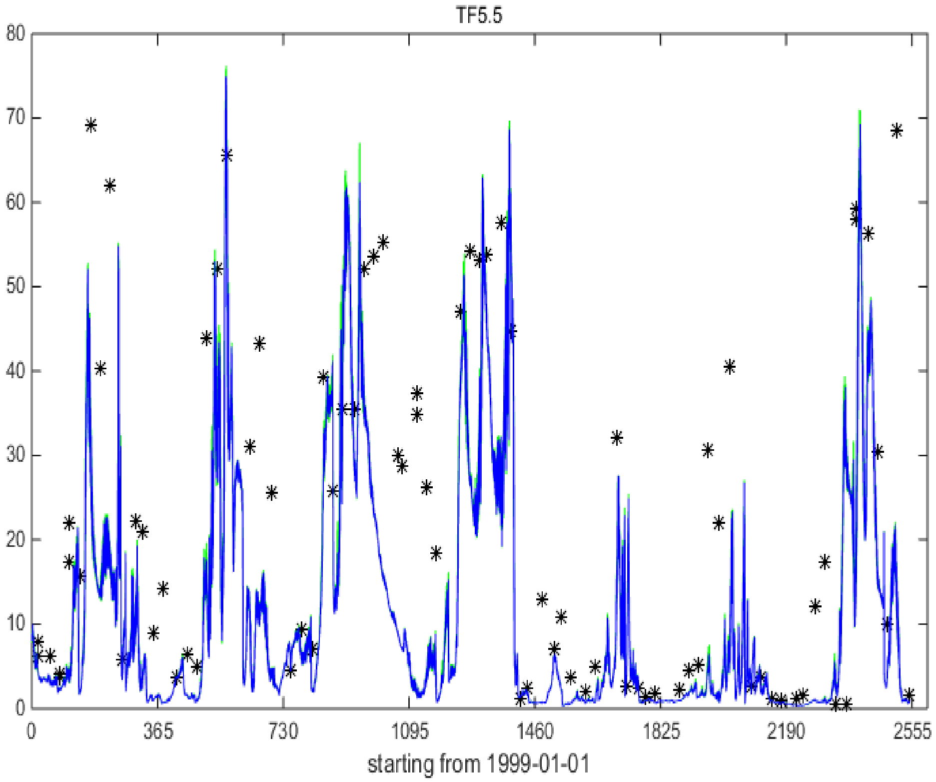

TF5.2
TF5.2A
TF5.3
TF5.4
TF5.5
TF5.5A
TF5.6
TF5.0A
RET5.2
LE5.1
LE5.2
LE5.3
LE5.5-W
CB8.1
LE5.4

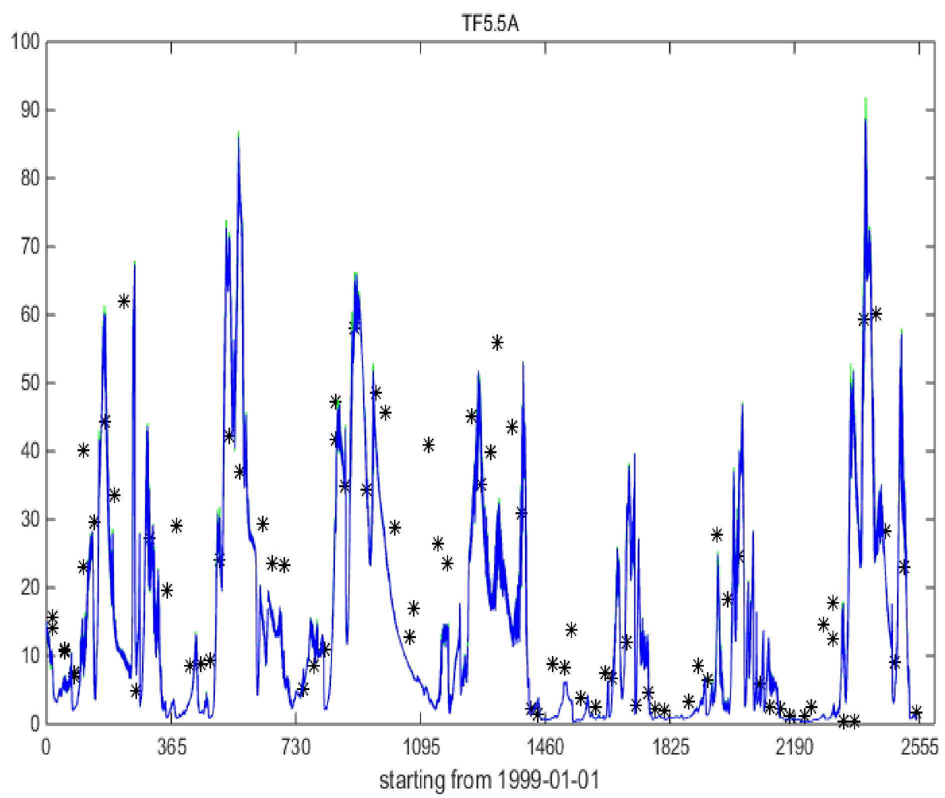
1. Chlorophyll-a Results:

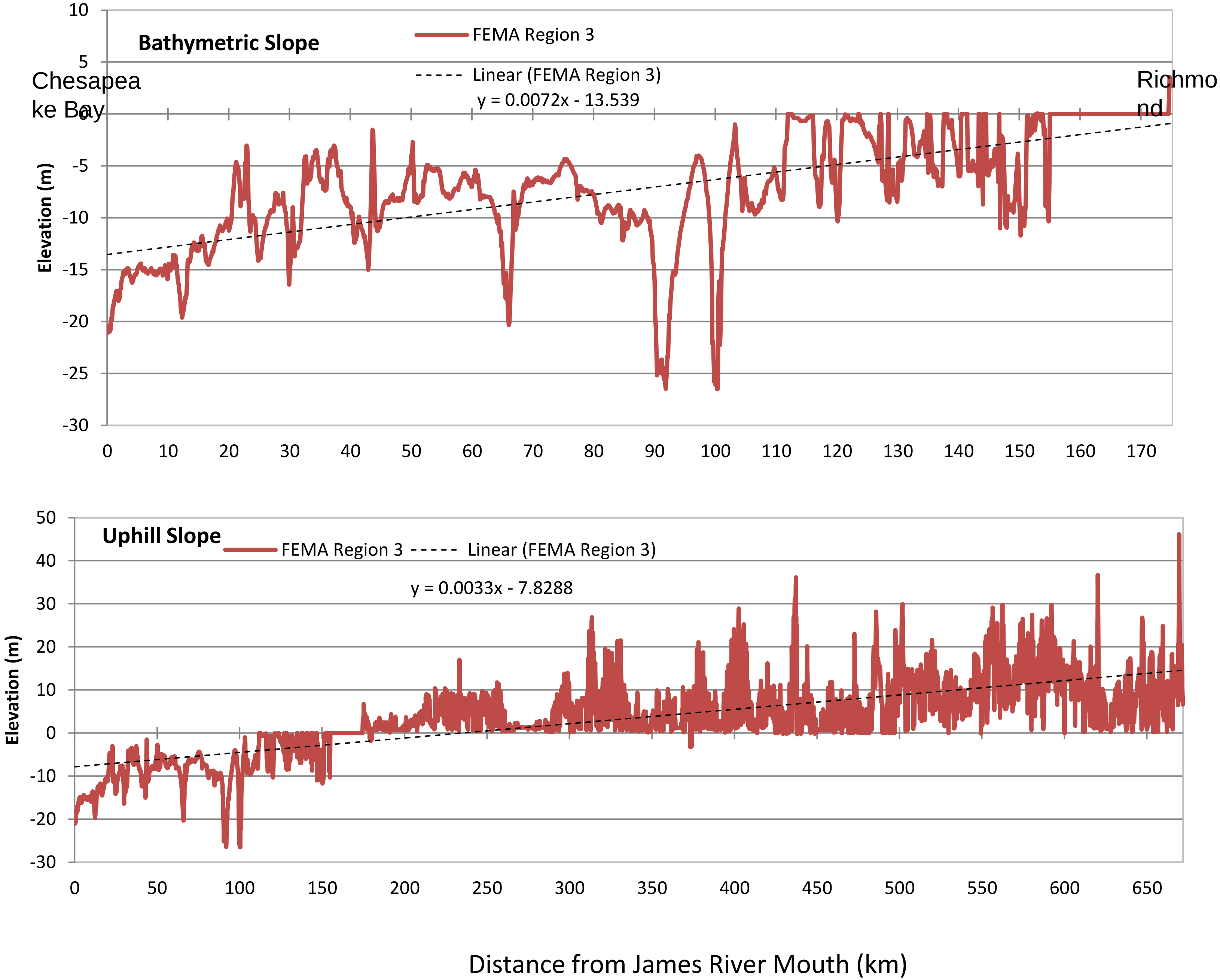


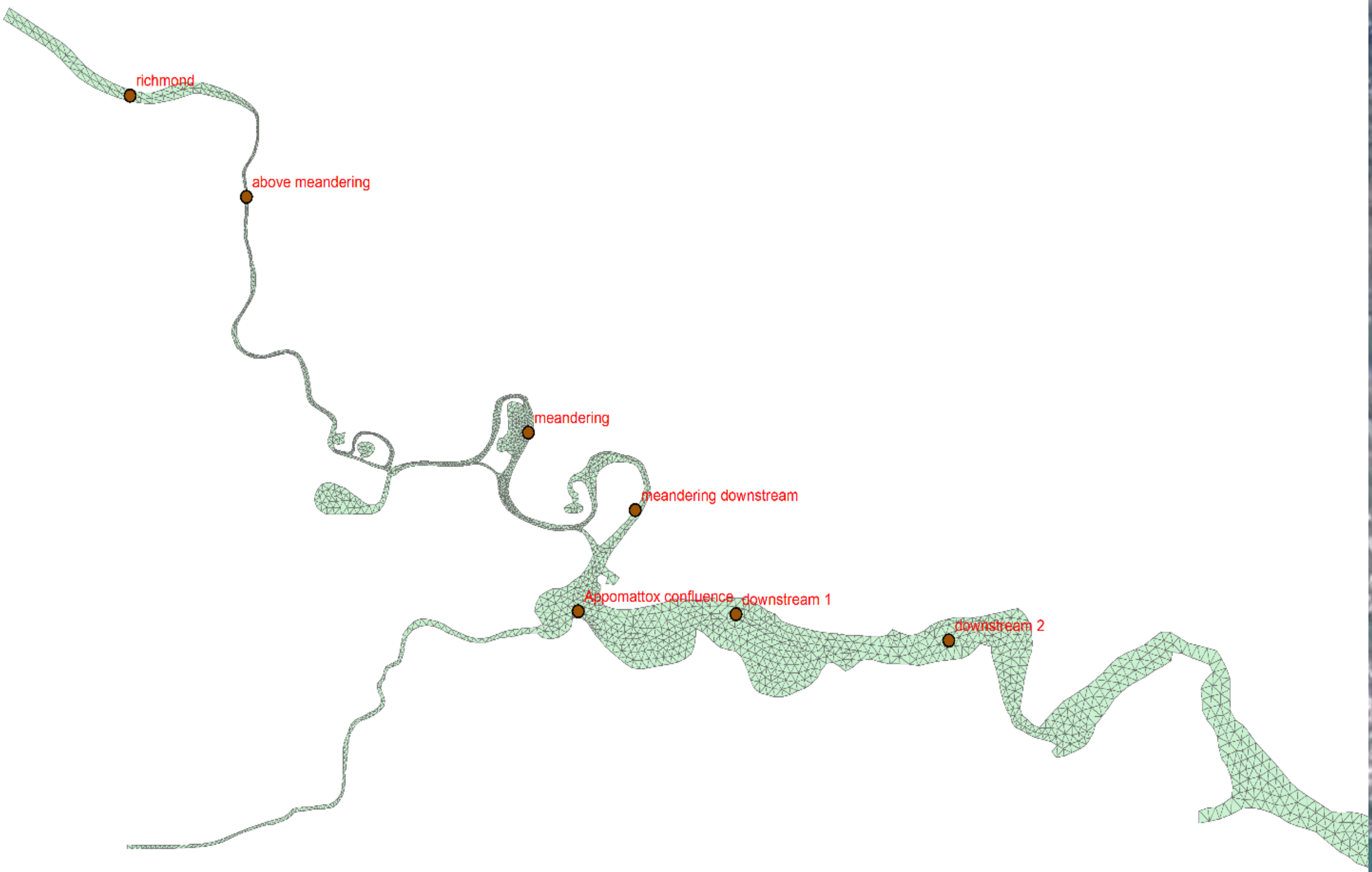

TF5.3
100
90
80
70
60
50
40
30
20
10
0
0
365
730
1095
1460
1825
2190
255
starting from 1999-01-01


TF5.4
90
80
70
60
50
40
30
20
10
0
0
365
730
1095
1460
1825
2190
2555
starting from 1999-01-01

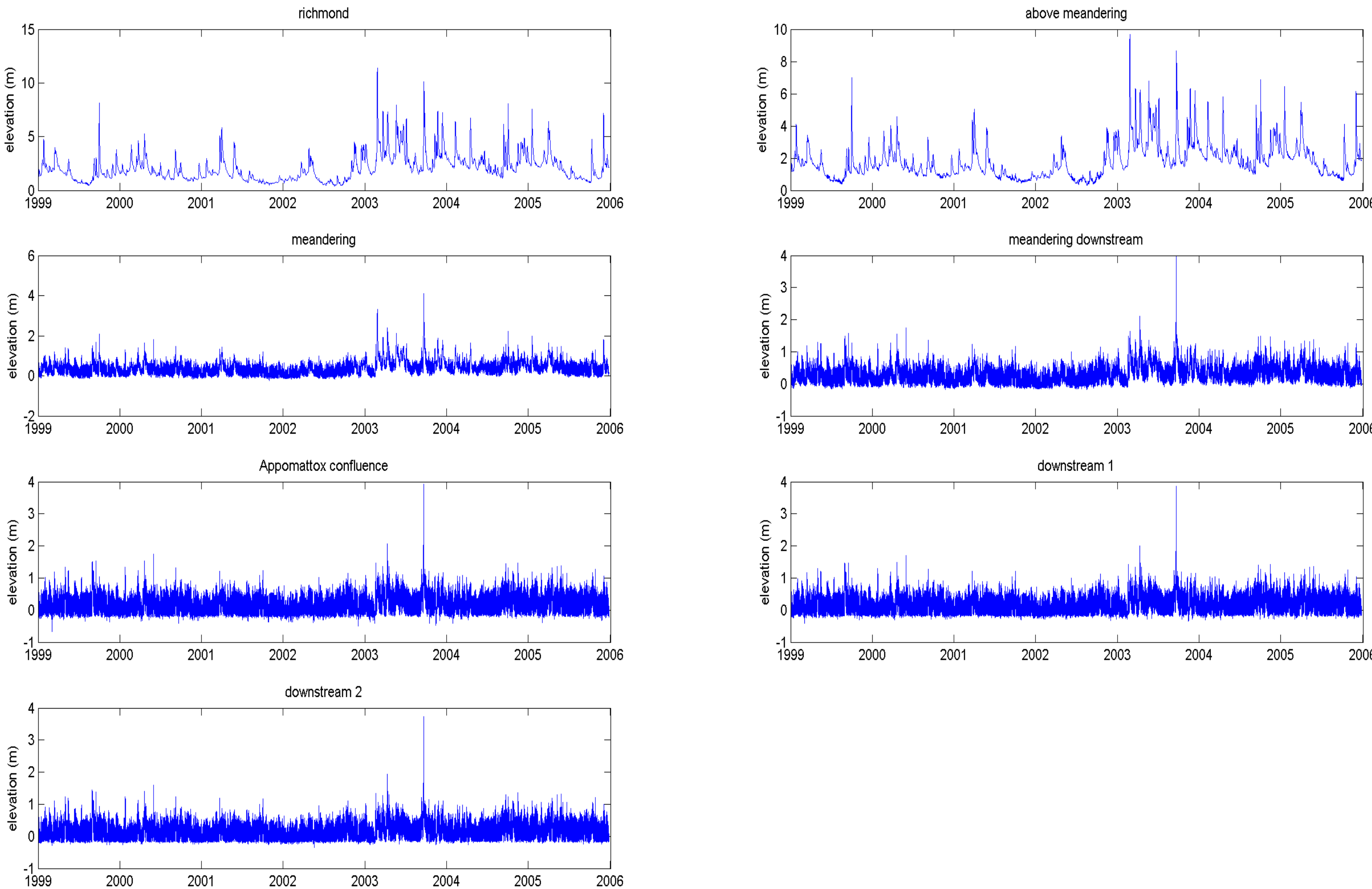

TF5.5
80
70
60
50
40
30
20
10
0
0
365
730
1095
1460
1825
2190
2555
starting from 1999-01-01


TF5.5A
100
90
80
70
60
50
40
30
20
10
0
0
365
730
1095
1460
1825
2190
2555
starting from 1999-01-01

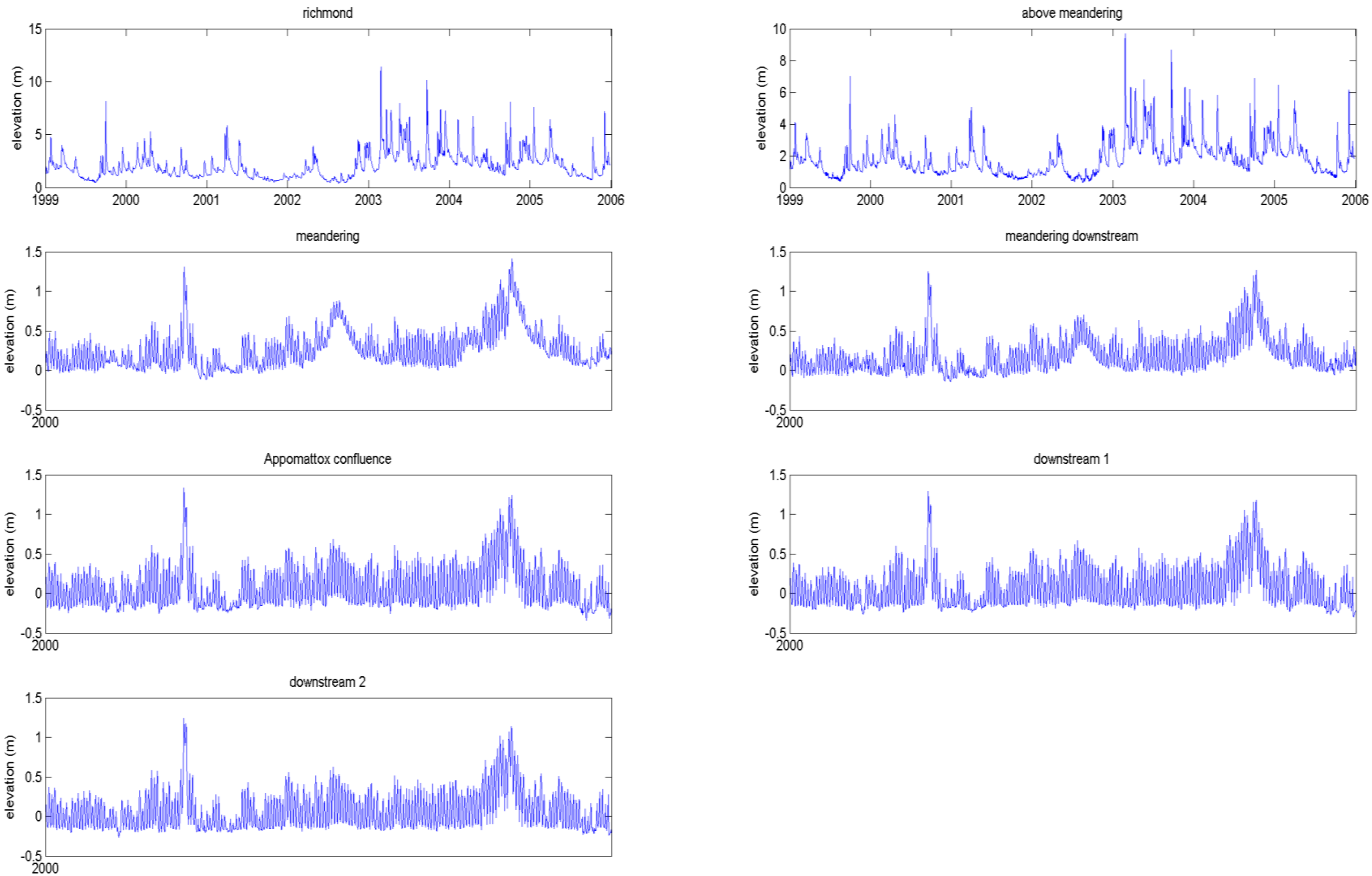

Bathymetric Slope
FEMA Region 3
Linear (FEMA Region 3)
y = 0.0072x - 13.539
Chesapeake Bay
Richmond
Elevation (m)
10
5
0
-5
-10
-15
-20
-25
-30
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
Uphill Slope
FEMA Region 3
Linear (FEMA Region 3)
y = 0.0033x - 7.8288
Elevation (m)
50
40
30
20
10
0
-10
-20
-30
0
50
100
150
200
250
300
350
400
450
500
550
600
650
Distance from James River Mouth (km)


richmond
above meandering
meandering
meandering downstream
Appomattox confluence
downstream 1
downstream 2

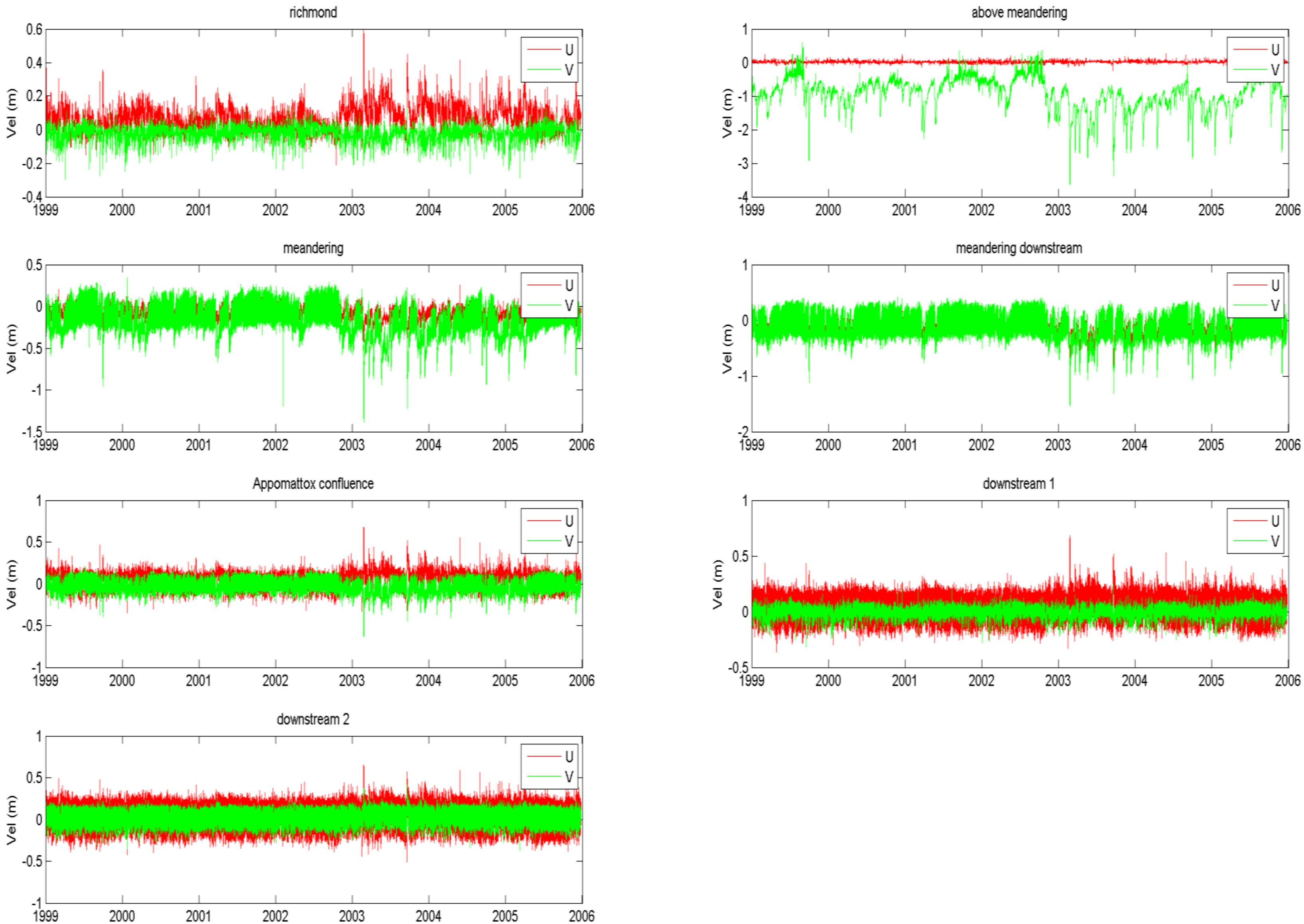
2. Water elevation



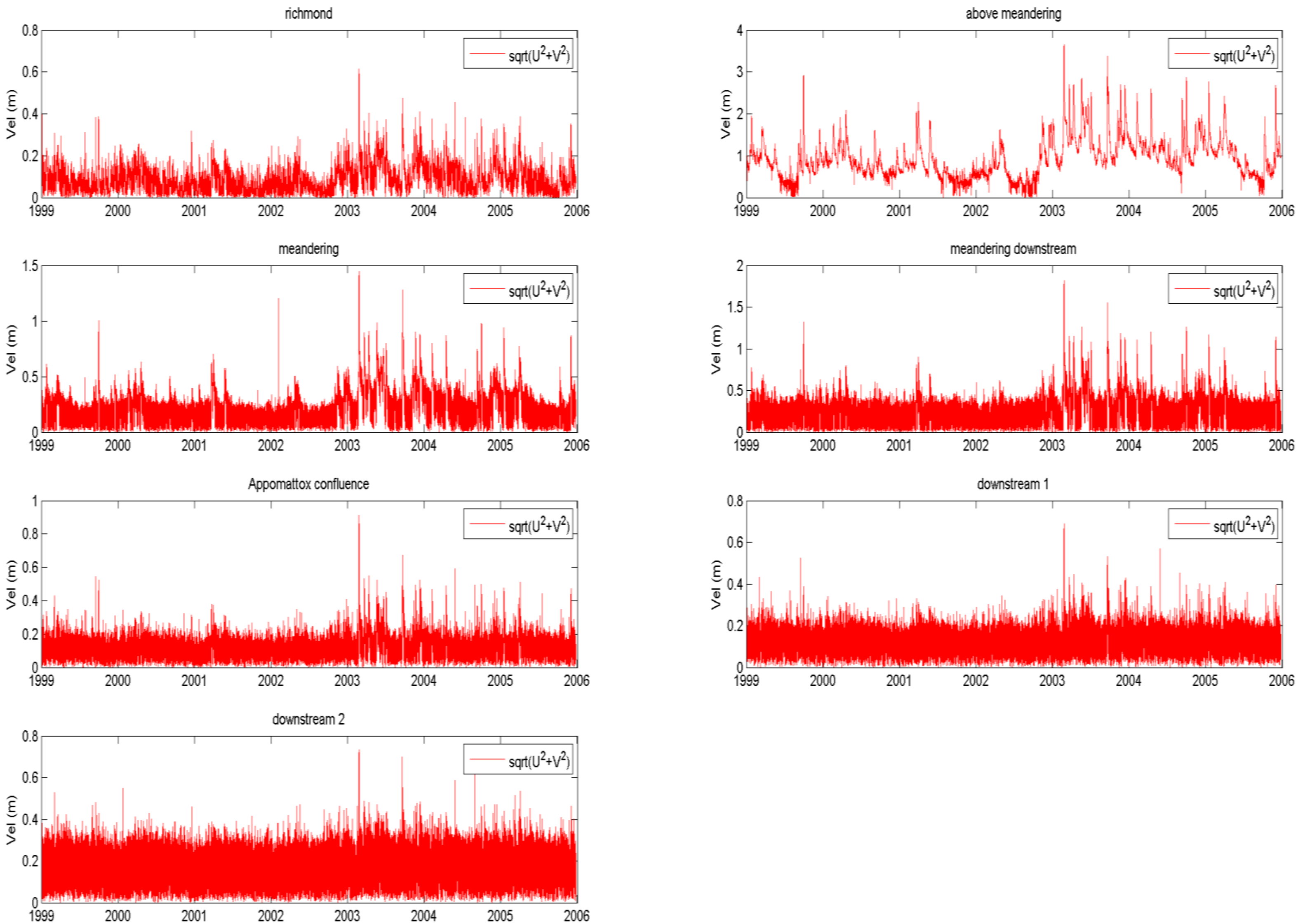
Water elevation (cont') - tidal variation



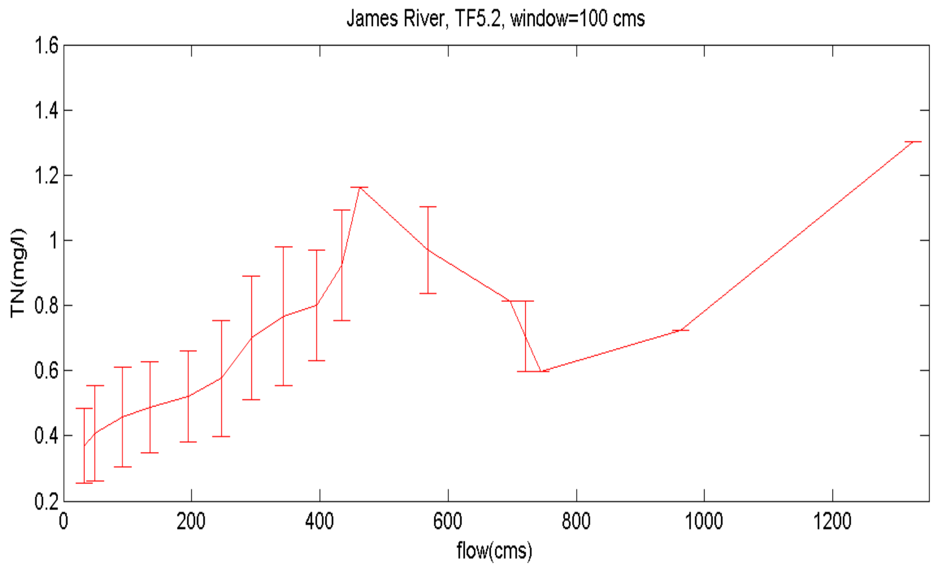
3. Velocity – u and v component

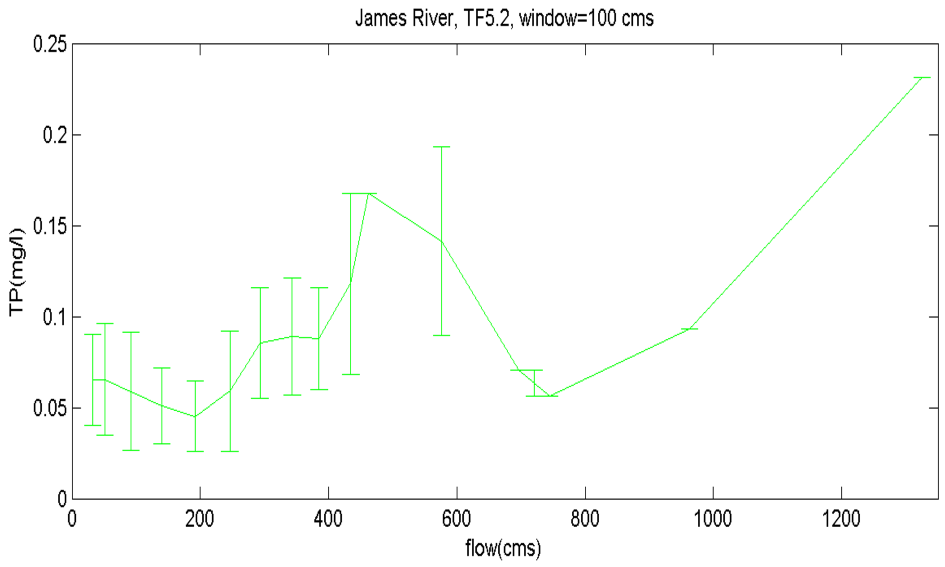


Velocity magnitude (cont')



4. Relationship between TN and TP to River discharge





Summary:

1. The Phytoplankton was found to bloomed in the Upper James in the summer season near Hopewell (tidal fresh zone) with a localized maximum feature.
2. The long-term statistical data analysis found that the pattern is correlated inversely with the monthly river discharge.
3. The highly resolved unstructured grid model SELFE-ICM was used for a diagnostic study and it was found:

(a)the local mean residence time (age gradient) migrated from downstream up to Hopewell region during summer season, which is coincided with the local high chlorophyll zone.

(b) The chlorophyll prediction consistent with inter-annual year results and strongly depending on the fall-line discharge