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James River Basin Watershed Inputs and Critical Conditions

Andrew Parker, Tetra Tech

Science Advisory Panel Meeting

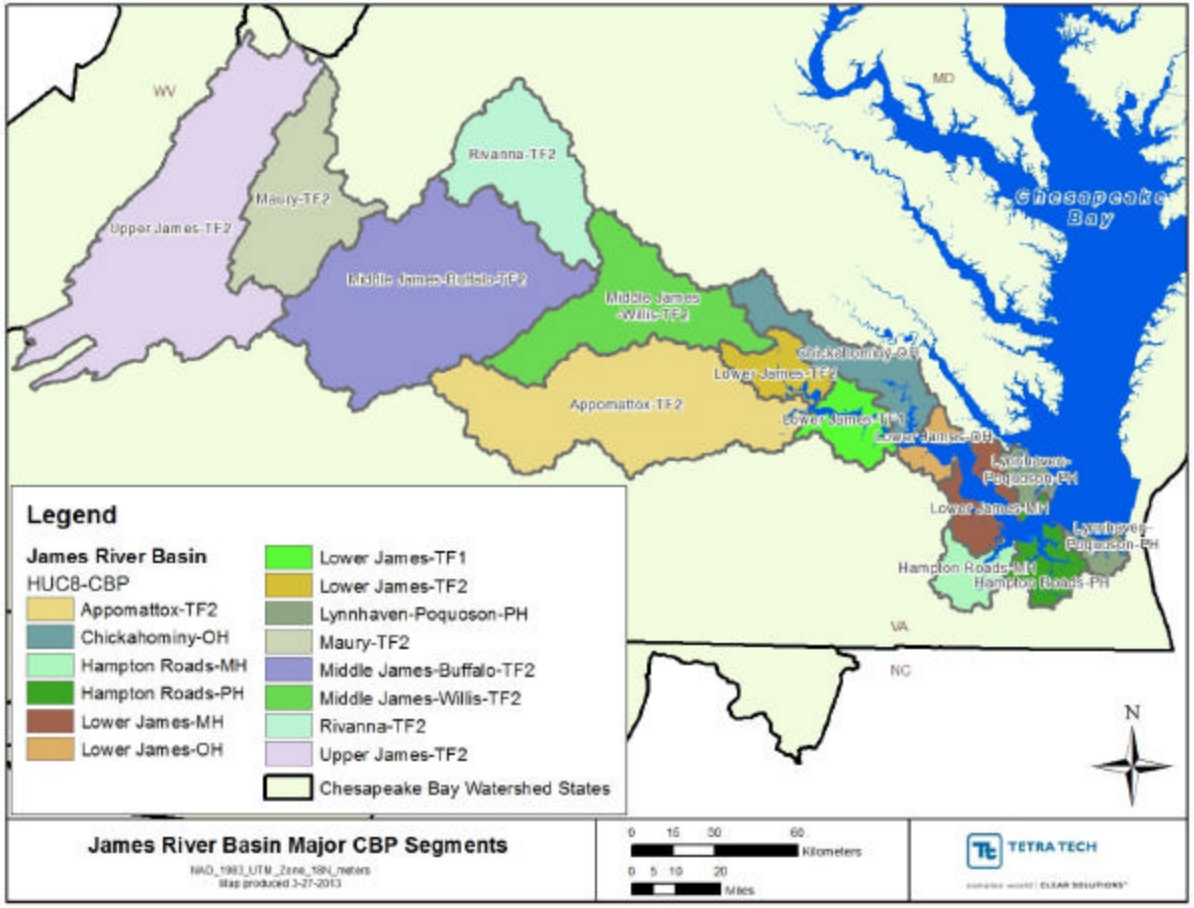
April 26, 2013

VCU Rice Center

CEC | HDR | HydroQual | VIMS William & Mary Virginia Institute of Marine Science | TETRA TECH | ODU | VCU | UNC

Analysis Objectives

- Assess watershed flow and pollutant load inputs to tidal James
  - Temporal and spatial trends
- Evaluate critical conditions
  - Occurrence of WQ exceedances
  - Temporal and spatial trends



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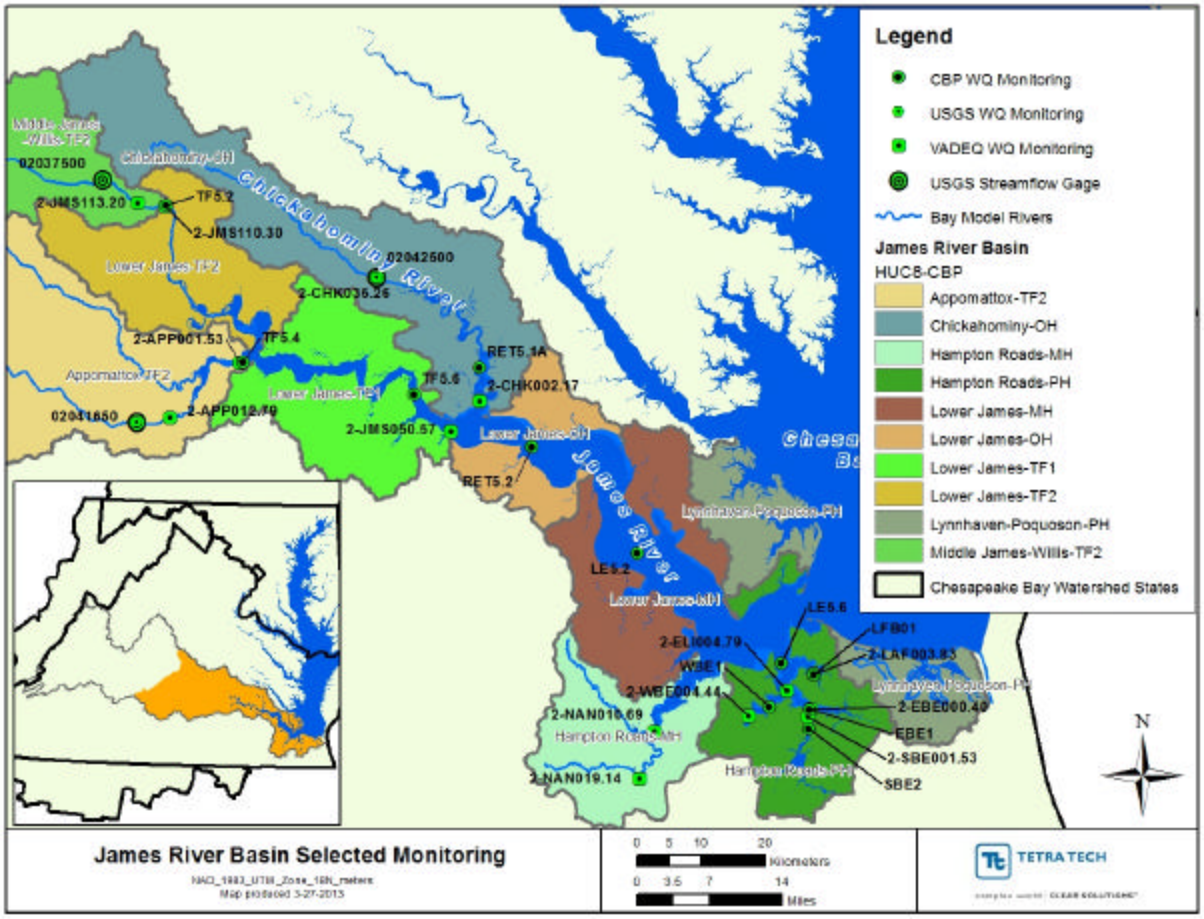
Source Data

- Lower James Focus
- Stream Flow Data
  - USGS
- WQ Data
  - USGS
  - EPA-CBPO
  - DEQ
- Bay Model Output
  - Flows
  - Pollutant Loads



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Source Data

HUC8-CBP Segment	Station ID	Sample Dates	Sample Count												
			Chl a	S. Solid	TSS	TP	PO_4	PO_4 F.	TN	NH_3	NO_2	NO_3	NO_X	NO_X F.	Org. N
Appom.-TF2	TF5.4	7/12/84-9/20/12	440	663	0	782	0	804	900	0	0	0	0	926	882
	2-APP001.53	1/14/80-12/4/12	168	788	0	469	0	913	0	154	154	154	0	413	0
	2-APP012.79	1/14/80-12/17/12	1	322	0	313	130	130	59	258	258	258	2	0	0
	02041650	1/17/80-2/5/13	172	761	381	540	14	819	536	73	14	14	29	833	391
Chick.-OH	RET5.1A	4/18/88-9/20/12	387	677	0	634	0	677	815	0	0	0	0	856	878
	2-CHK002.17	1/29/80-12/10/12	30	315	0	308	96	160	57	265	256	256	9	0	0
	2-CHK035.26	4/26/84-12/5/12	0	156	0	158	0	12	146	158	12	12	146	0	0
	02042500	1/18/80-2/5/13	10	117	143	170	23	200	170	35	1	1	35	200	52
Middle James-Willis-TF2	TF5.2	7/12/84-9/20/12	433	337	0	390	0	409	595	0	0	0	0	564	574
	2-JMS110.30	1/23/80-12/4/12	172	487	0	315	15	541	0	167	167	166	2	218	0
	2-JMS113.20	5/17/06-12/4/12	124	154	0	154	0	125	149	27	0	0	27	127	0

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Source Data

HUC8-CBP Segment	Station ID	Sample Dates	Sample Count												
			Chl a	S. Solid	TSS	TP	PO_4	PO_4 F.	TN	NH_3	NO_2	NO_3	NO_X	NO_X F.	Org. N
Lower James-TF1	TF5.6	7/12/84-9/20/12	443	677	0	786	0	818	883	0	0	0	0	913	881
	2-JMS050.57	5/19/80-12/4/12	0	186	0	219	145	35	65	164	157	157	7	0	0
Lower James-OH	RET5.2	7/12/84-9/6/12	438	658	0	785	0	805	980	0	0	0	0	989	1001
Lower James-MH	LE5.2	9/25/84-9/6/12	439	668	0	765	0	800	917	0	0	0	0	949	891
Hampton Roads-MH	2-NAN010.69	6/14/83-6/5/02	6	130	0	119	41	89	0	121	132	132	0	0	0
	2-NAN019.14	1/29/80-12/27/12	68	320	0	297	126	133	59	256	261	262	0	0	0
Hampton Roads-PH	EBE1	2/27/89-9/26/12	522	555	0	559	0	556	526	0	0	0	0	561	524
	LE5.6	9/25/84-9/25/12	451	669	0	770	0	795	905	0	0	0	0	922	778
	LFB01	1/22/98-9/25/12	184	375	0	333	0	371	358	0	0	0	0	371	448
	SBE2	2/28/89-9/26/12	522	556	0	559	0	571	540	0	0	0	0	572	543
	WBE1	2/27/89-9/25/12	521	556	0	545	0	563	526	0	0	0	0	566	567
	2-EBE000.40	1/7/80-12/13/12	41	246	0	124	39	208	0	158	168	169	0	78	0
	2-ELI004.79	1/22/98-12/18/12	197	389	0	18	0	382	0	2	0	0	0	382	0
	2-LAF003.83	1/22/98-12/18/12	203	399	0	18	0	390	0	0	0	0	0	390	0
	2-SBE001.53	1/7/80-5/19/10	1	190	0	130	39	136	0	163	175	175	0	1	0
	2-WBE004.44	1/22/98-12/18/12	195	386	0	33	14	374	0	13	14	14	0	375	0

Watershed Inputs

Watershed Inputs Background

- What is the nutrient contribution to the tidal James?
  - Coincident flow and water quality data used to estimate loads
  - CBPO watershed model output used where flow data were unavailable or water quality data were tidally influenced
- 5 segments (90% of watershed):
  - Middle James-Willis-TF1
  - Appomattox-TF2
  - Chickahominy-OH
  - Hampton Roads-MH (Nansemond R.)
  - Hampton Roads-PH (Elizabeth R.)
- 5 pollutants
  - Total nitrogen (TN)
  - Total phosphorus (TP)
  - Nitrate (NO_3)
  - Organic nitrogen (Org N)
  - Dissolved ortho-phosphorus (PO_4)

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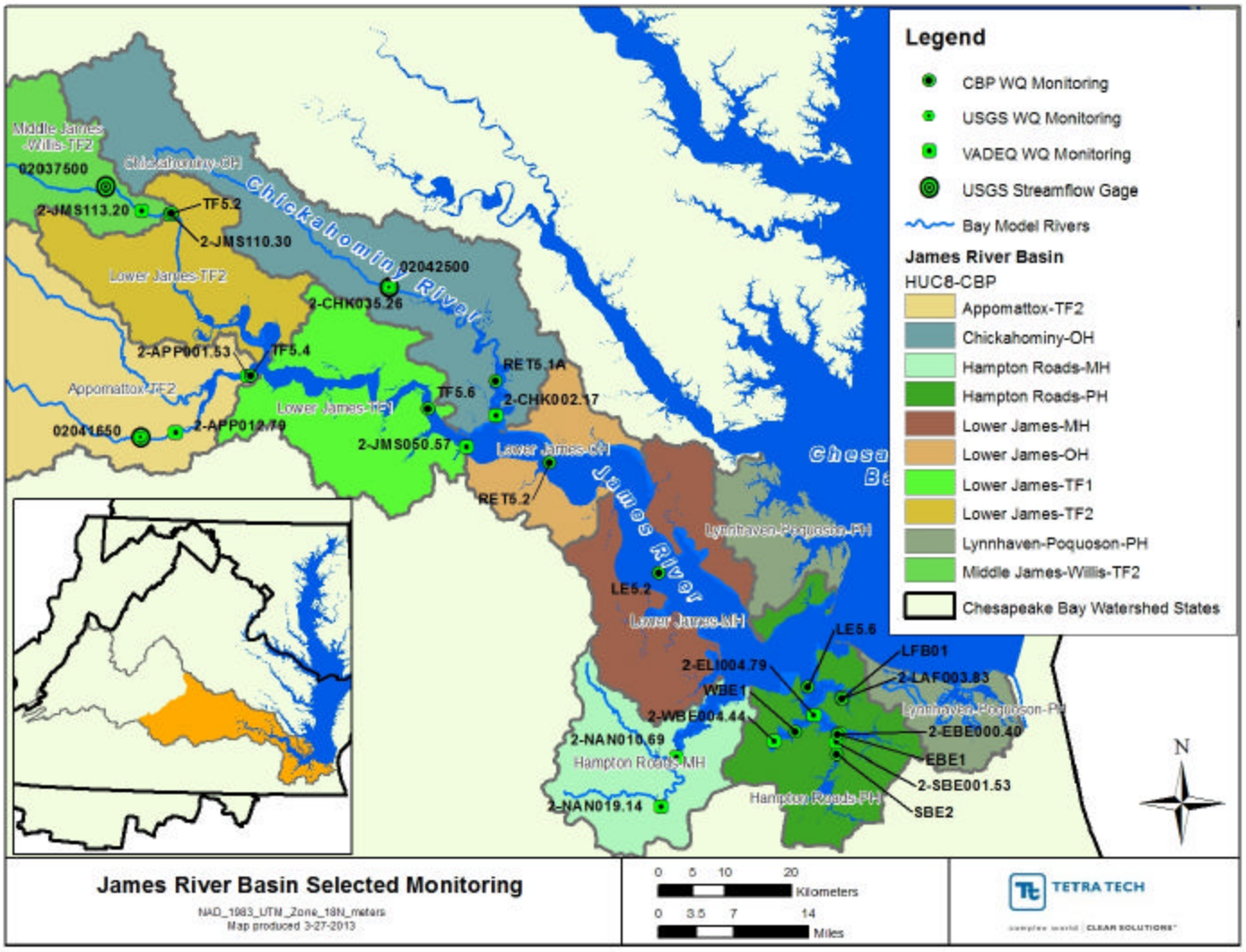
Watershed Inputs Background



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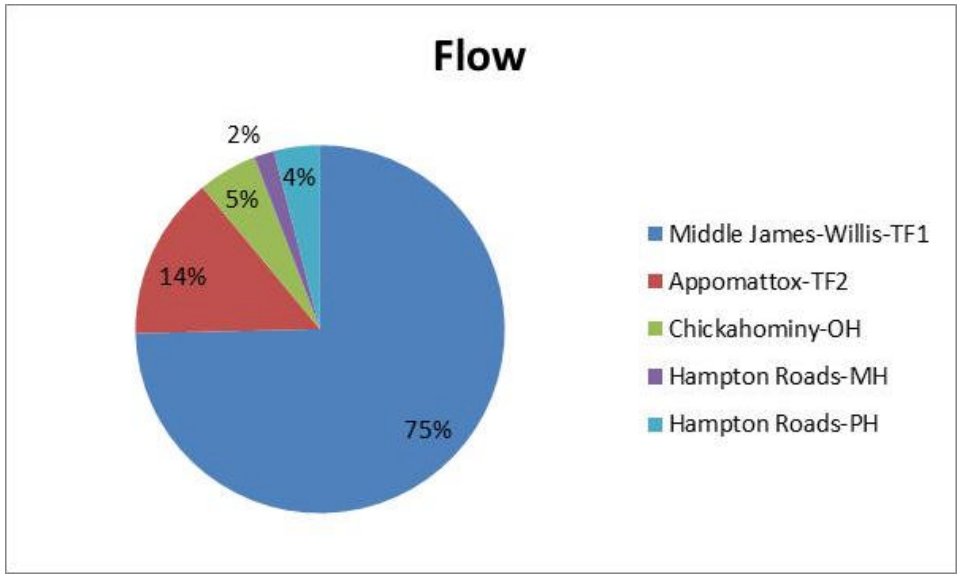
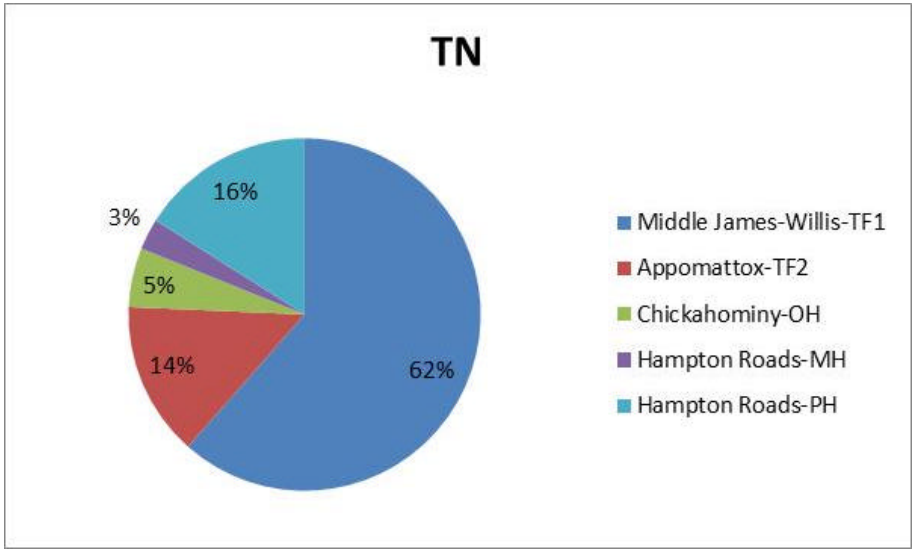
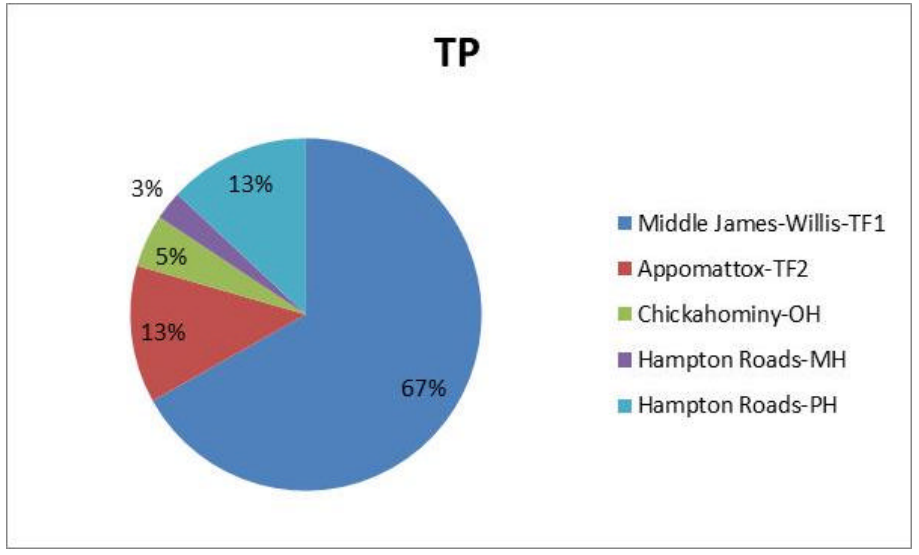
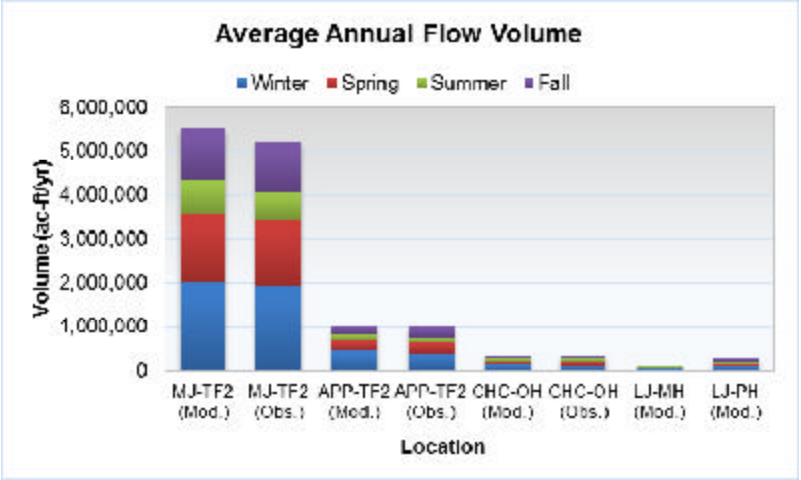
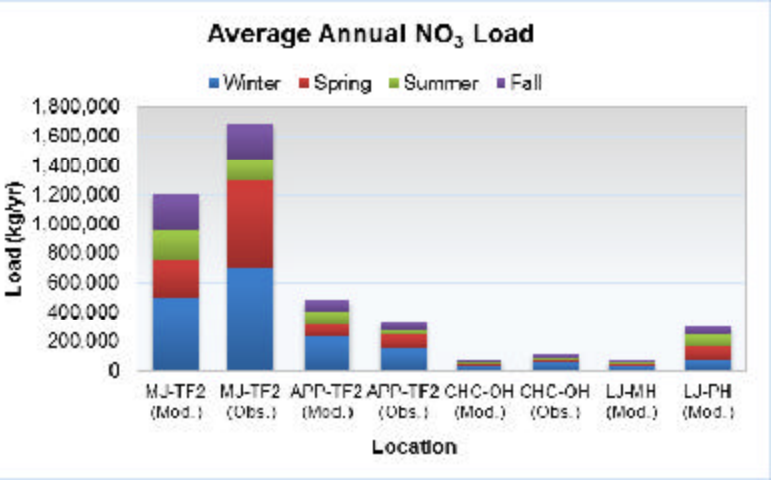
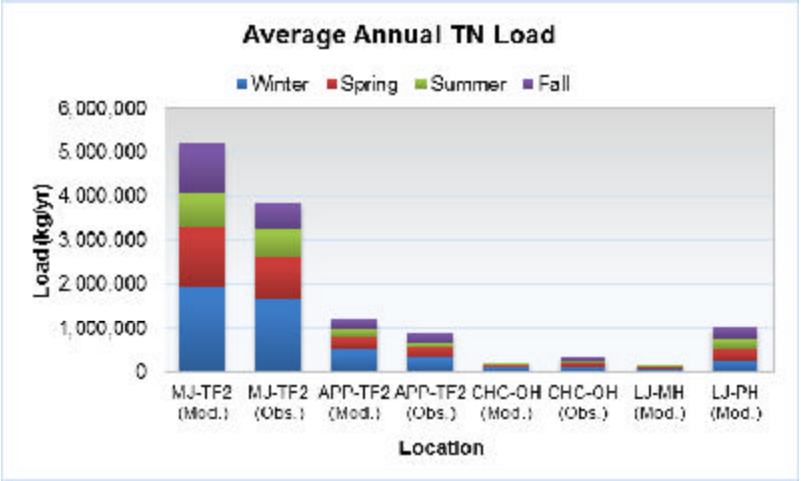

Flow
2%
4%
5%
14%
75%
Middle James-Willis-TF1
Appomattox-TF2
Chickahominy-OH
Hampton Roads-MH
Hampton Roads-PH

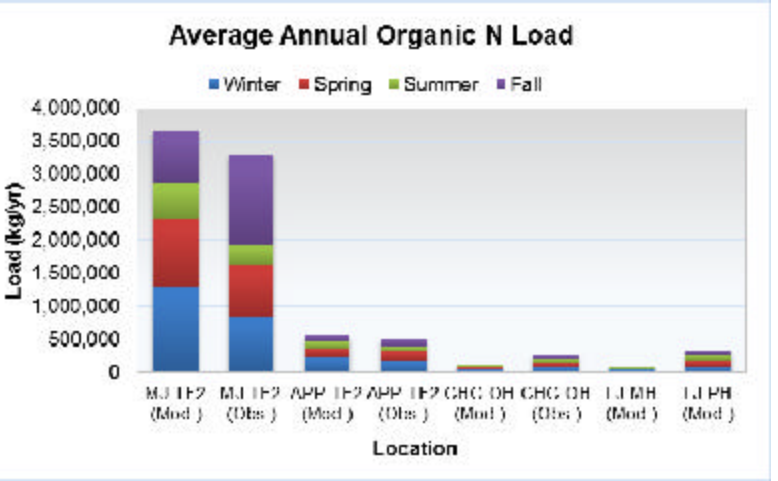

TN
16%
3%
5%
14%
62%
Middle James-Willis-TF1
Appomattox-TF2
Chickahominy-OH
Hampton Roads-MH
Hampton Roads-PH

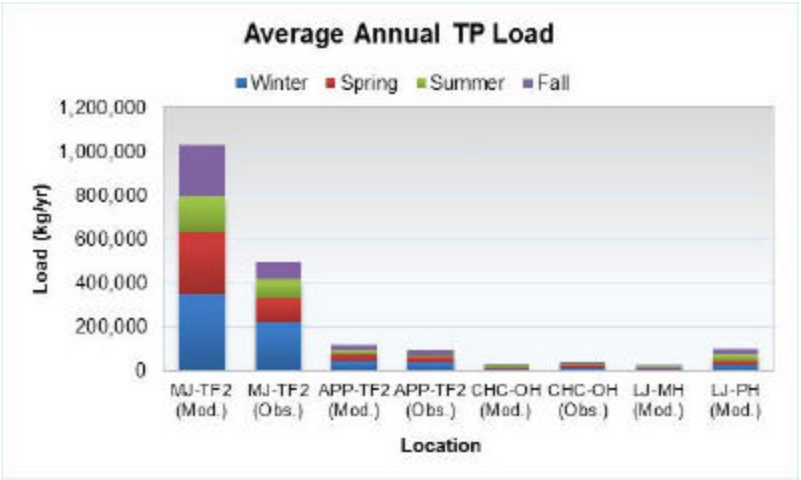

TP
3%
13%
5%
13%
67%
Middle James-Willis-TF1
Appomattox-TF2
Chickahominy-OH
Hampton Roads-MH
Hampton Roads-PH

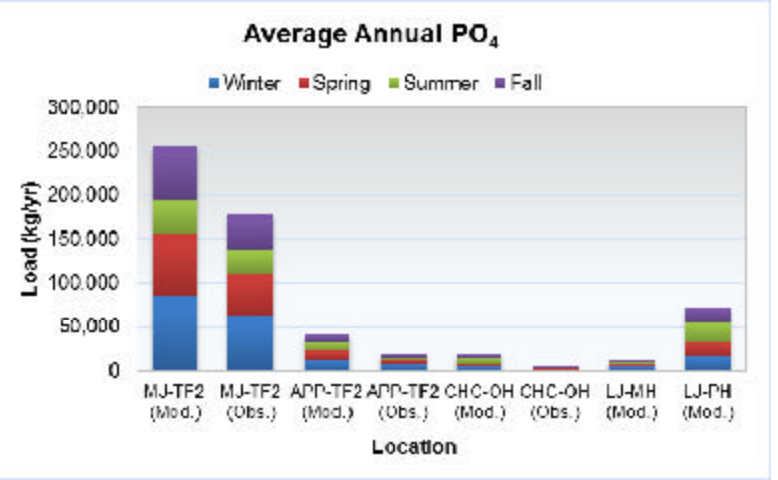

Average Annual Flow Volume
Winter
Spring
Summer
Fall
Volume (ac-ft/yr)
8,000,000
5,000,000
4,000,000
3,000,000
2,000,000
1,000,000
0
MJ-TF2 (Mod.)
MJ-TF2 (Obs.)
APP-TF2 (Mod.)
APP-TF2 (Obs.)
CHC-OH (Mod.)
CHC-OH (Obs.)
LJ-MH (Mod.)
LJ-PH (Mod.)
Location

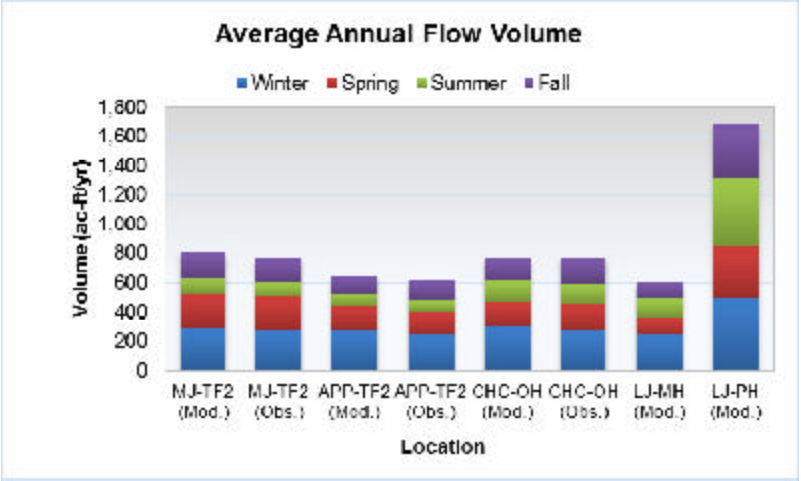

Average Annual NO3 Load
Winter
Spring
Summer
Fall
Load (kg/yr)
1,800,000
1,600,000
1,400,000
1,200,000
1,000,000
800,000
600,000
400,000
200,000
0
MJ-TF2 (Mod.)
MJ-TF2 (Obs.)
APP-TF2 (Mod.)
APP-TF2 (Obs.)
CHC-OH (Mod.)
CHC-OH (Obs.)
LJ-MH (Mod.)
LJ-PH (Mod.)
Location

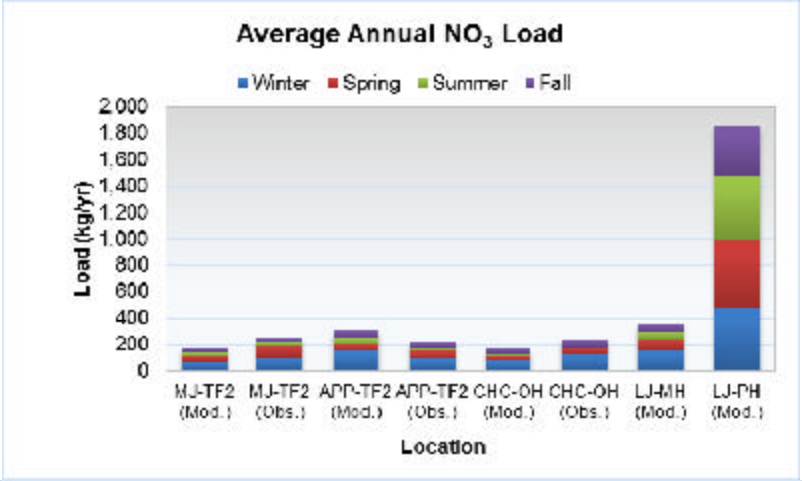

Average Annual TN Load
Winter
Spring
Summer
Fall
Load (kg/yr)
6,000,000
5,000,000
4,000,000
3,000,000
2,000,000
1,000,000
0
MJ-TF2 (Mod.)
MJ-TF2 (Obs.)
APP-TF2 (Mod.)
APP-TF2 (Obs.)
CHC-OH (Mod.)
CHC-OH (Obs.)
LJ-MH (Mod.)
LJ-PH (Mod.)
Location

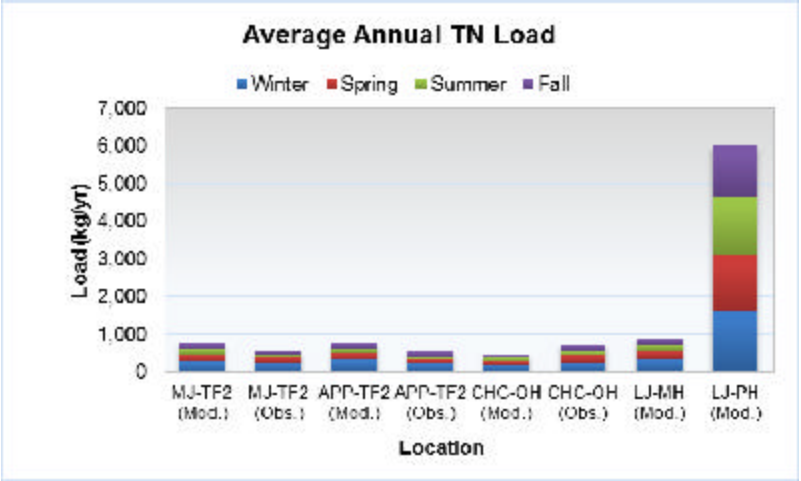

Average Annual Organic N Load
Winter
Spring
Summer
Fall
Load (kg/yr)
4,000,000
3,500,000
3,000,000
2,500,000
2,000,000
1,500,000
1,000,000
500,000
0
MJ-TF2 (Mod.)
MJ-TF2 (Obs.)
APP-TF2 (Mod.)
APP-TF2 (Obs.)
CHC-OH (Mod.)
CHC-OH (Obs.)
LJ-MH (Mod.)
LJ-PH (Mod.)
Location


Average Annual TP Load
Winter
Spring
Summer
Fall
Load (kg/yr)
1,200,000
1,000,000
800,000
600,000
400,000
200,000
0
MJ-TF2 (Mod.)
MJ-TF2 (Obs.)
APP-TF2 (Mod.)
APP-TF2 (Obs.)
CHC-OH (Mod.)
CHC-OH (Obs.)
LJ-MH (Mod.)
LJ-PH (Mod.)
Location

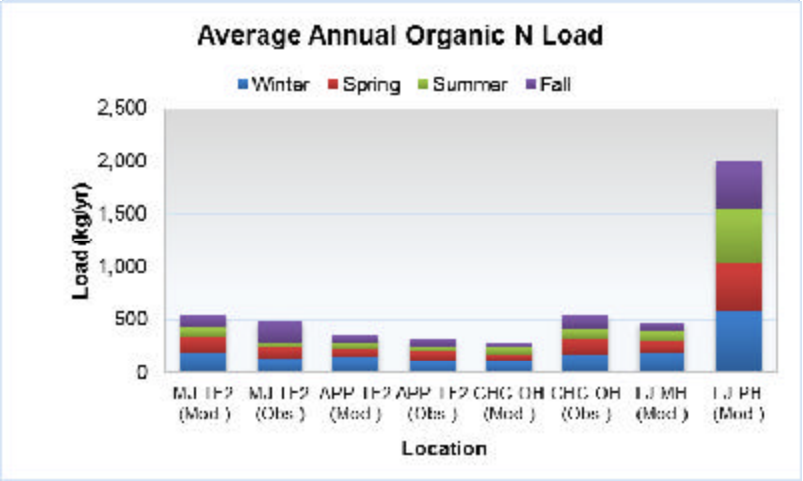

Average Annual PO4
Winter
Spring
Summer
Fall
Load (kg/yr)
300,000
250,000
200,000
150,000
100,000
50,000
0
MJ-TF2 (Mod.)
MJ-TF2 (Obs.)
APP-TF2 (Mod.)
APP-TF2 (Obs.)
CHC-OH (Mod.)
CHC-OH (Obs.)
LJ-MH (Mod.)
LJ-PH (Mod.)
Location

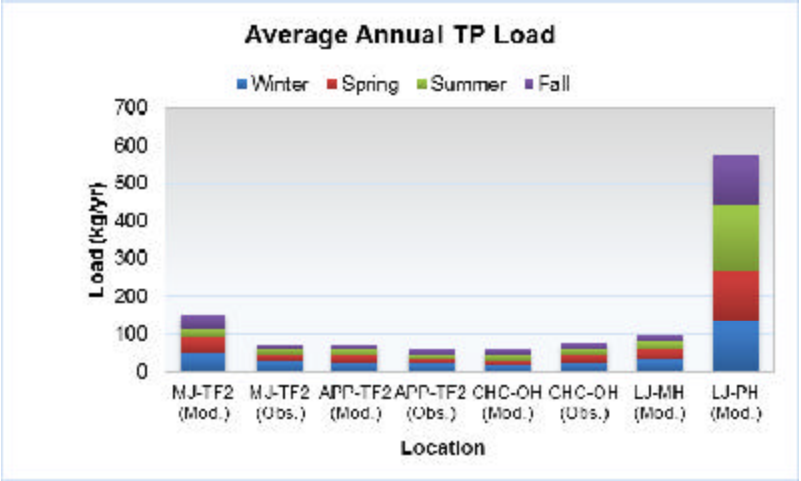

Average Annual Flow Volume
Winter
Spring
Summer
Fall
Volume (ac-ft/yr)
1,800
1,600
1,400
1,200
1,000
800
600
400
200
0
MJ-TF2 (Mod.)
MJ-TF2 (Obs.)
APP-TF2 (Mod.)
APP-TF2 (Obs.)
CHC-OH (Mod.)
CHC-OH (Obs.)
LJ-MH (Mod.)
LJ-PH (Mod.)
Location

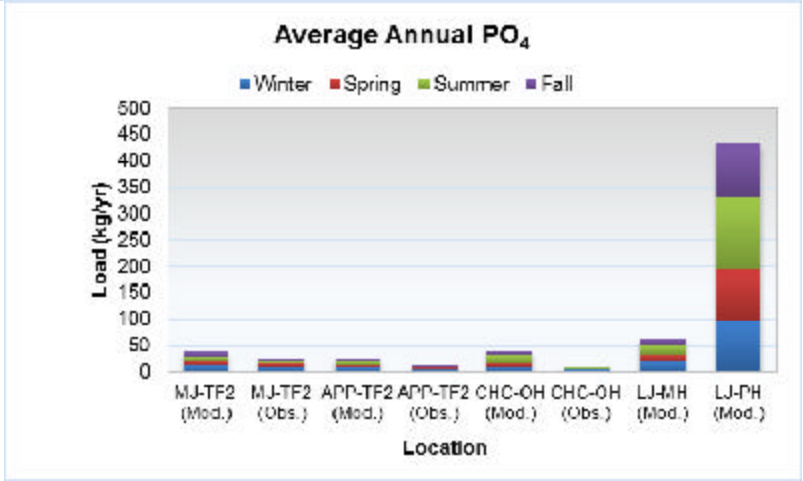

Average Annual NO3 Load
Winter
Spring
Summer
Fall
Load (kg/yr)
2,000
1,800
1,600
1,400
1,200
1,000
800
600
400
200
0
MJ-TF2 (Mod.)
MJ-TF2 (Obs.)
APP-TF2 (Mod.)
APP-TF2 (Obs.)
CHC-OH (Mod.)
CHC-OH (Obs.)
LJ-MH (Mod.)
LJ-PH (Mod.)
Location


Average Annual TN Load
Winter
Spring
Summer
Fall
Load (kg/yr)
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
MJ-TF2 (Mod.)
MJ-TF2 (Obs.)
APP-TF2 (Mod.)
APP-TF2 (Obs.)
CHC-OH (Mod.)
CHC-OH (Obs.)
LJ-MH (Mod.)
LJ-PH (Mod.)
Location

Per acre


Average Annual Organic N Load
Winter
Spring
Summer
Fall
Load (kg/yr)
2,500
2,000
1,500
1,000
500
0
MJ-TF2 (Mod.)
MJ-TF2 (Obs.)
APP-TF2 (Mod.)
APP-TF2 (Obs.)
CHC-OH (Mod.)
CHC-OH (Obs.)
LJ-MH (Mod.)
LJ-PH (Mod.)
Location


Average Annual TP Load
Winter
Spring
Summer
Fall
Load (kg/yr)
700
600
500
400
300
200
100
0
MJ-TF2 (Mod.)
MJ-TF2 (Obs.)
APP-TF2 (Mod.)
APP-TF2 (Obs.)
CHC-OH (Mod.)
CHC-OH (Obs.)
LJ-MH (Mod.)
LJ-PH (Mod.)
Location


Average Annual PO4
Winter
Spring
Summer
Fall
Load (kg/yr)
500
450
400
350
300
250
200
150
100
50
0
MJ-TF2 (Mod.)
MJ-TF2 (Obs.)
APP-TF2 (Mod.)
APP-TF2 (Obs.)
CHC-OH (Mod.)
CHC-OH (Obs.)
LJ-MH (Mod.)
LJ-PH (Mod.)
Location

Watershed Inputs Summary

HUC8-CBP Seg	Drainage Description	Drainage Area (mi^2)	Flow (ac-ft/yr)	Average Annual Load (kg/yr)				
				TN	TP	NO_3*	Organic N	PO_4*
Middle James-Willis-TF1	James River above Richmond, VA	6,803	5,220,046 (5,498,103)	3,862,264 (5,200,729)	497,462 (1,029,412)	1,684,411 (1,210,077)	3,306,826 (3,668,970)	178,599 (256,273)
Appomattox-TF2	Appomattox River	1,612	1,004,705 (1,041,983)	889,927 (1,214,049)	93,908 (116,339)	342,016 (483,926)	515,389 (559,754)	20,012 (42,620)
Chickahominy-OH	Chickahominy River	470	363,779 (359,017)	341,327 (216,167)	36,092 (27,363)	113,556 (76,945)	255,122 (128,392)	4,798 (18,742)
Hampton Roads-MH**	Nansemond River	201	(122,613)	(178,566)	(19,595)	(71,870)	(94,948)	(12,441)
Hampton Roads-PH**	Elizabeth River	168	(282,399)	(1,007,514)	(97,125)	(311,000)	(336,028)	(72,701)
Total		9,254	6,993,543 (7,304,115)	6,279,599 (7,817,025)	744,181 (1,289,834)	2,522,853 (2,153,818)	4,508,312 (4,788,092)	288,551 (402,777)

*Bay Model simulated values in (parentheses)

Watershed Inputs Summary

- Higher flows (winter>spring/fall>summer) result in higher nutrient loads
- Generally consistent nutrient contribution across watershed
  - Exception is Hampton Roads-PH drainage (Elizabeth R.)
    - Urban watershed (Norfolk and Portsmouth)
    - Permitted discharges
- Applicability of analysis
  - Similar analysis during calibration
  - Accurate representation of facilities
  - Improve model nutrient prediction

Critical Condition Analysis

Critical Conditions and TMDLs

$$TMDL = \sum_{i=1}^{n} WLA_i + \sum_{i=1}^{n} LA_i + MOS$$

- WLAs (40 C.F.R. §130.2(h))
- LAs (40 CFR 130.2(g))
  - Range from reasonably accurate estimates to gross allotments
- MOS (CWA 303(d)(1)(C), 40 CFR 130.7(c)(1))
  - Implicit or explicit (USEPA 1991)
- Critical conditions (40 CFR 130.7(c)(1))
  - "Determinations of TMDLs shall take into account critical conditions for stream flow, loading, and water quality parameters."
- Seasonal variation (CWA 303(d)(1)(C), 40 CFR 130.7(c)(1))

Previous Analysis for the James River

- Analysis during Bay TMDL development
  - Tested for correlation between flow and chlorophyll *a* exceedances of criteria
  - Flow magnitude assessed as return period
  - Average annual flows summarized for 3-yr period
  - Return period compared to Chlorophyll *a* violations over the Bay Model simulation time period (1984–2004)
  - Similar approach to bay-wide analysis for DO, which targeted 10-yr return period (1993-1995)
  - No strong correlation found
- Previous analysis limitations
  - One flow gage (02037500) used for analysis at all locations
  - Water quality data only though 2004

Updated Analysis

- Reconstructed previous analysis using updated water quality and flow data (1984–2012)
- Data summarized for spring and summer
- Correlation was assessed for five locations

HUC8-CBP Segment	USGS Stream-flow Station	Water Quality Station
Appomattox-TF2	02041650	TF5.4
Middle James-Willis-TF2	02037500	TF5.2
Lower James-TF1	Sum of 02037500; 02041650	TF5.6
Lower James-MH	Sum of 02037500; 02041650; 02042500	LE5.2
Lower James-OH	Sum of 02037500; 02041650; 02042500	RET5.2

Analysis Results

- Strength of correlation determined using:
  - Non-parametric Kendall Tau
    - Score range -1 to 1
    - Score of 1 indicates perfect association, negative sign indicates inverse relationship

Kendall Tau Score (abs.)	Correlation
0.0–0.33	Weak
0.33–0.67	Moderate
0.67–1.0	Strong

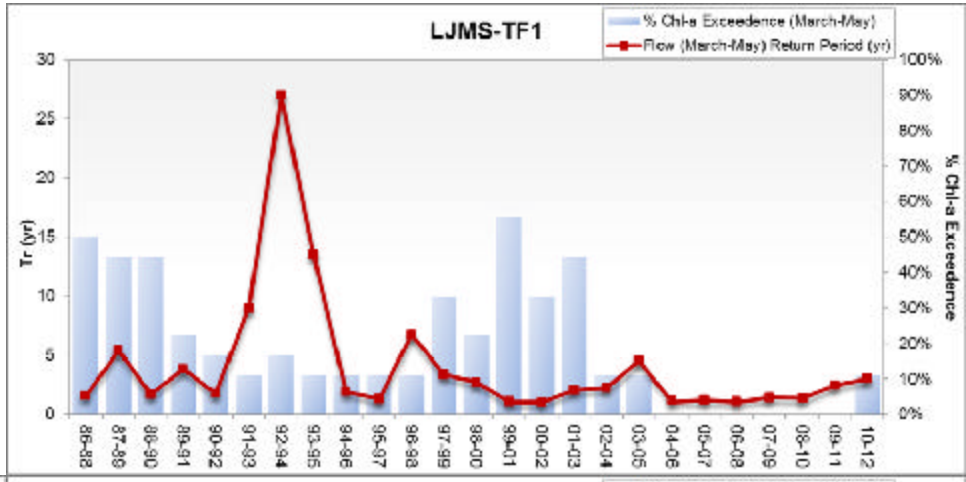
  - Single-variable linear regression with hypothesis test to determine significance

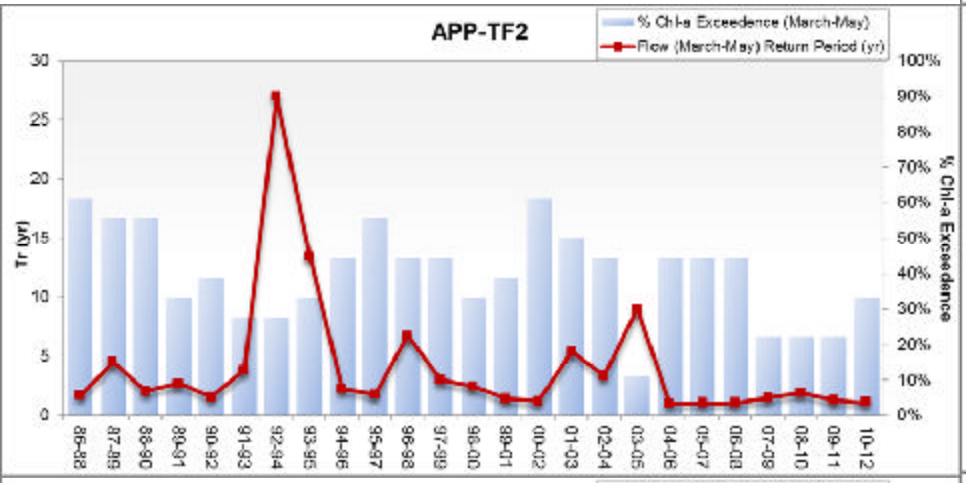
Analysis Results-Spring

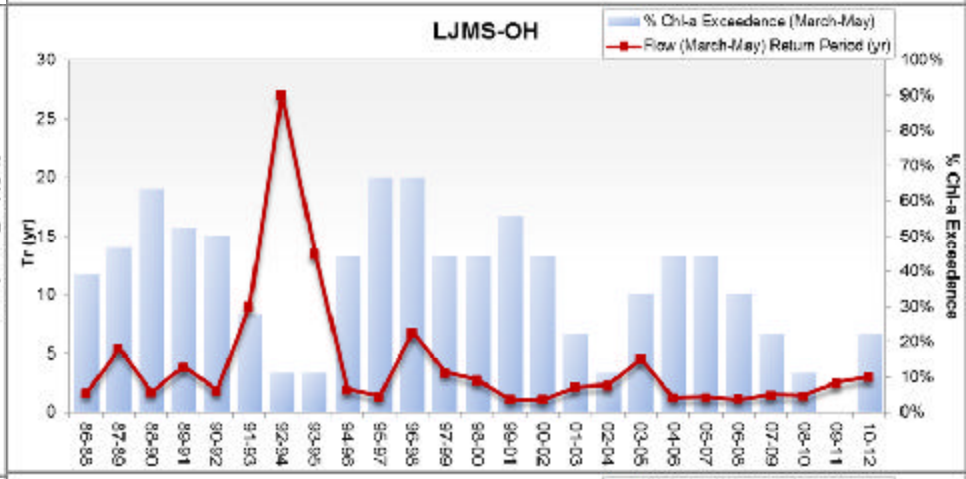
HUC8-CBP Segment	Kendall Tau Score	r^2	p-value
Appomattox-TF2	-0.13	0.08	0.36
Middle James-Willis-TF2	0.07	0.00	0.82
Lower James-TF1	0.08	0.00	0.58
Lower James-OH	-0.16	0.12	0.27
Lower James-MH	0.10	0.00	0.51

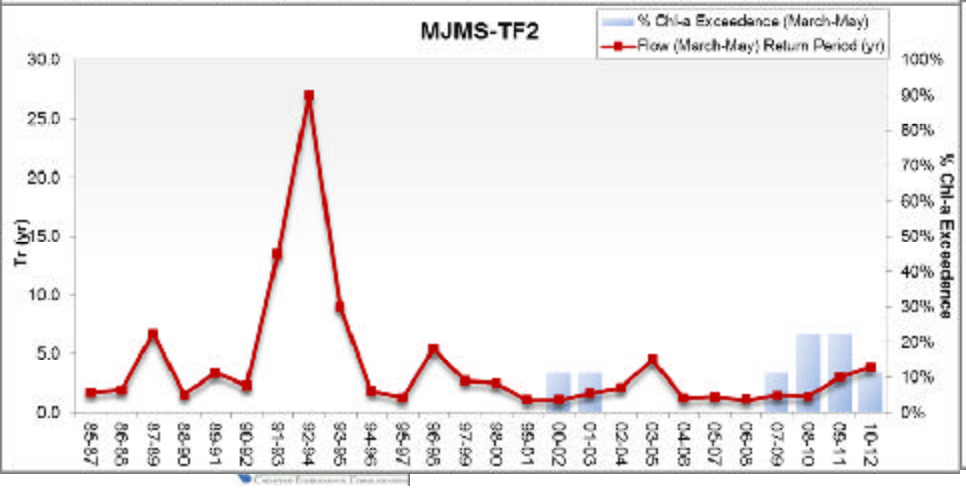
- Tau scores indicate weak correlations during spring
- Appomattox-TF2 and Lower James-OH show the highest scores (inverse relationship)
- Appomattox-TF2 and Lower James-OH only segments with $r^2>0$
- No segment meets hypothesis test (low p-value)

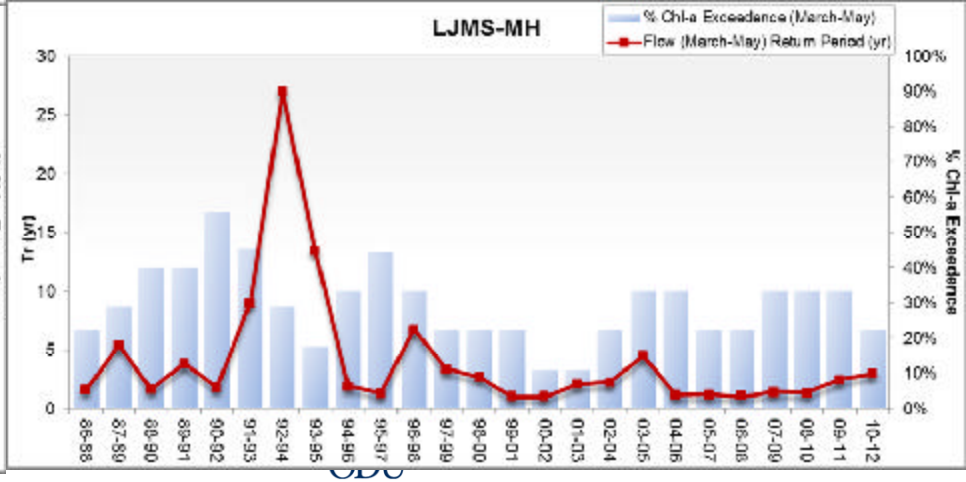
Analysis Results-Spring









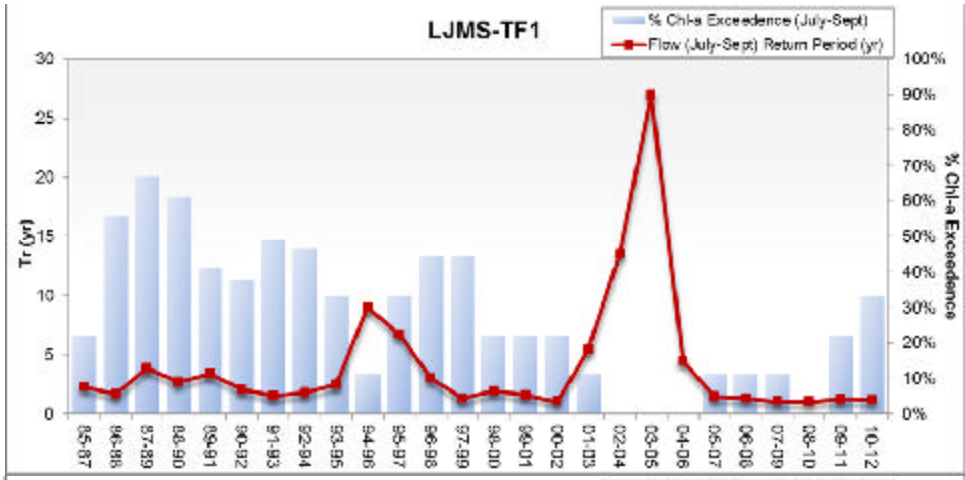


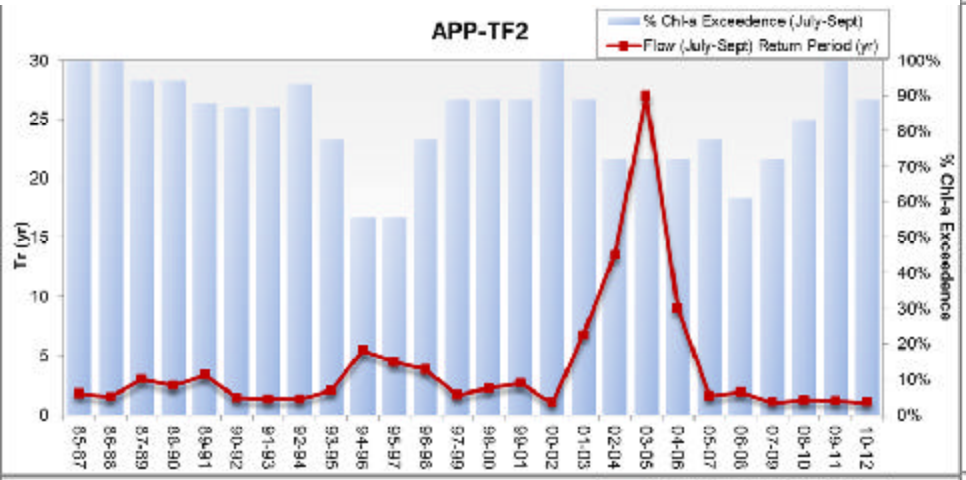
Analysis Results-Summer

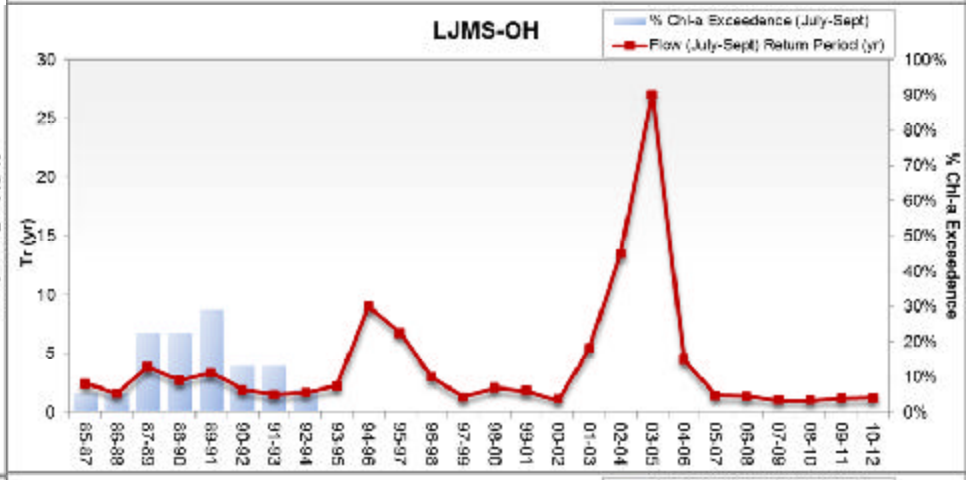
HUC8-CBP Segment	Kendall Tau Score	r^2	p-value
Appomattox-TF2	-0.31	0.13	**0.03**
Middle James-Willis-TF2	0.36	0.61	0.08
Lower James-TF1	0.00	0.15	1.00
Lower James-OH	0.08	**0.02**	0.57
Lower James-MH	-0.19	0.1	0.17

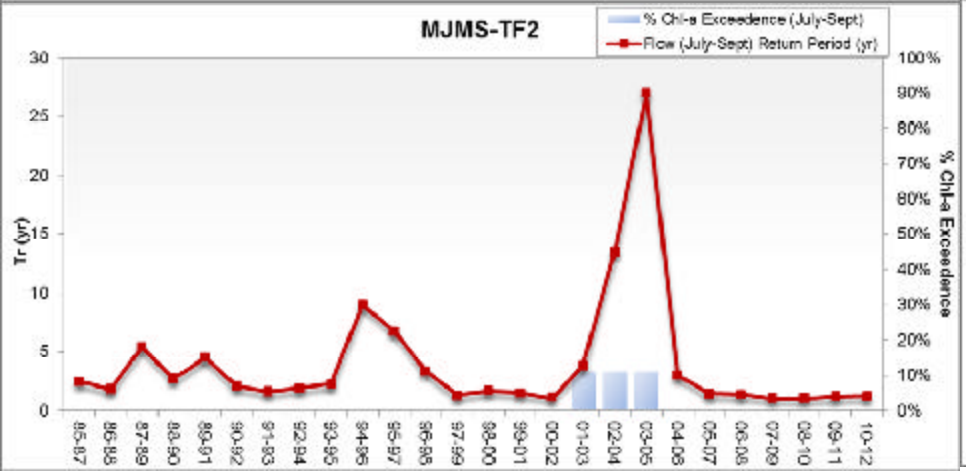
- Tau scores indicate weak correlations during summer but stronger than for spring
- ~Moderate scores are seen at Appomattox-TF2 (inverse) and Middle James-Willis-TF2 (direct)
- Appomattox-TF2 meets hypothesis test ($p<0.05$)

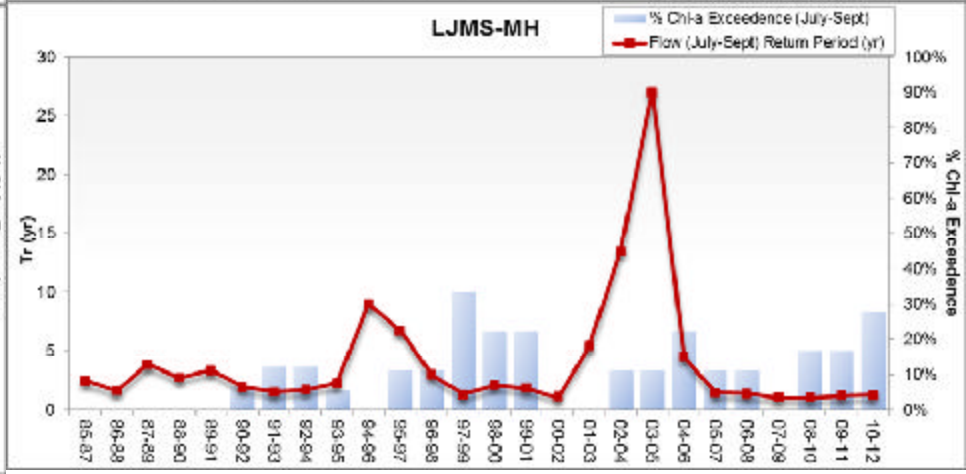
Analysis Results-Summer









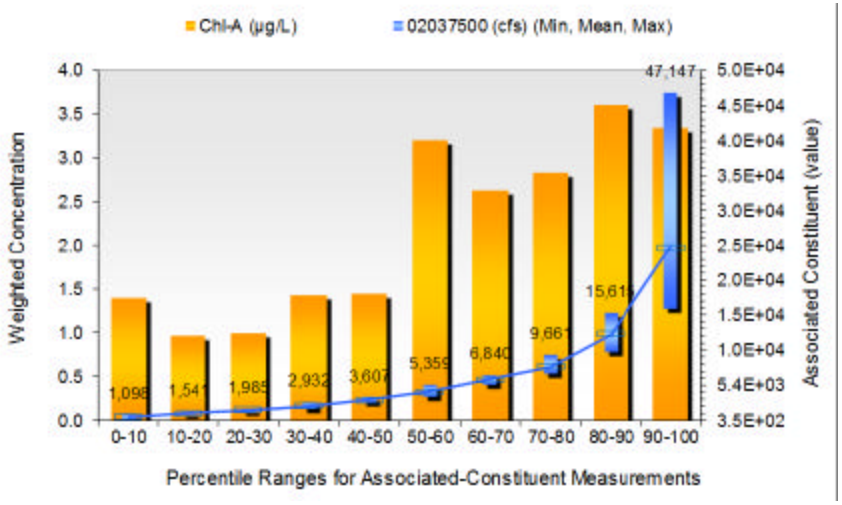


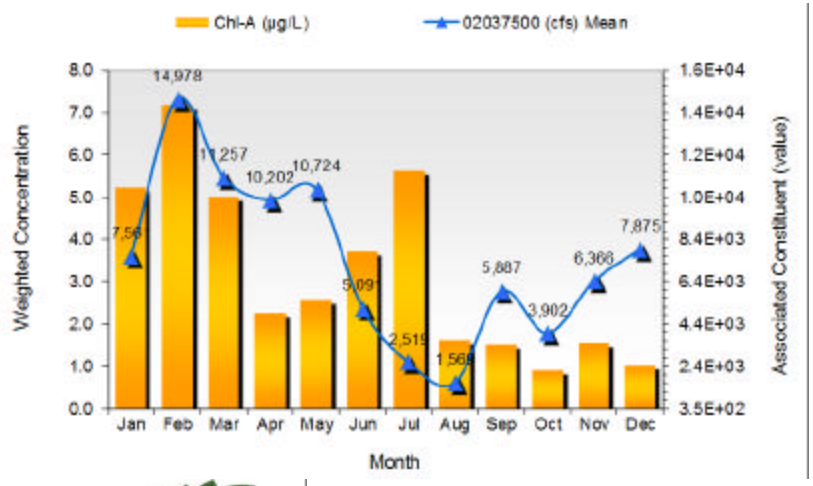
Paired Data Analysis

- Water quality and flow data paired with coincident chlorophyll *a* sampling
- Supplements statistical analysis
- Same five locations plus Hampton Roads-PH and Chickahominy-OH
- Paired data compared in 2 ways:
  1. Grouped into percentile ranges with weighted chlorophyll *a* concentrations compared to min, max, and mean of the paired flow or pollutant concentration
  2. Grouped by month with weighted chlorophyll *a* concentrations compared to mean flow or pollutant concentration

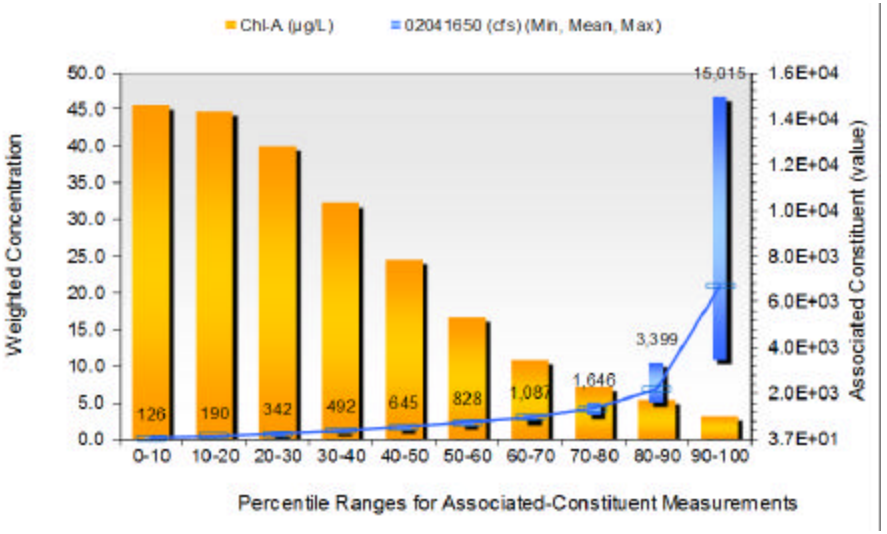
Paired Data Analysis

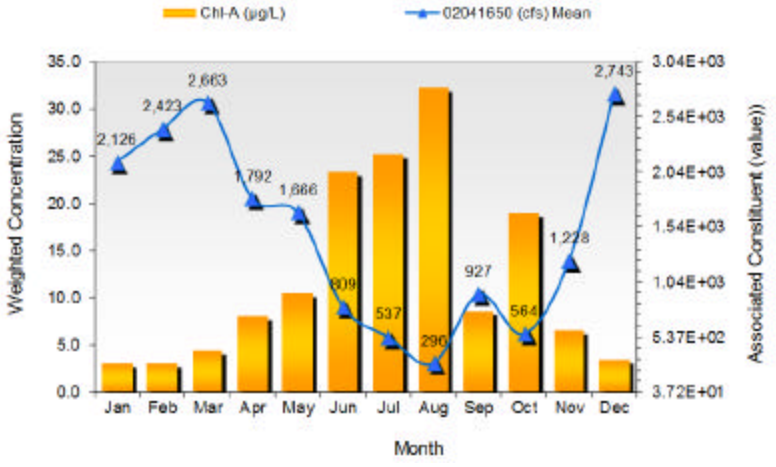
Middle James Willis-TF2





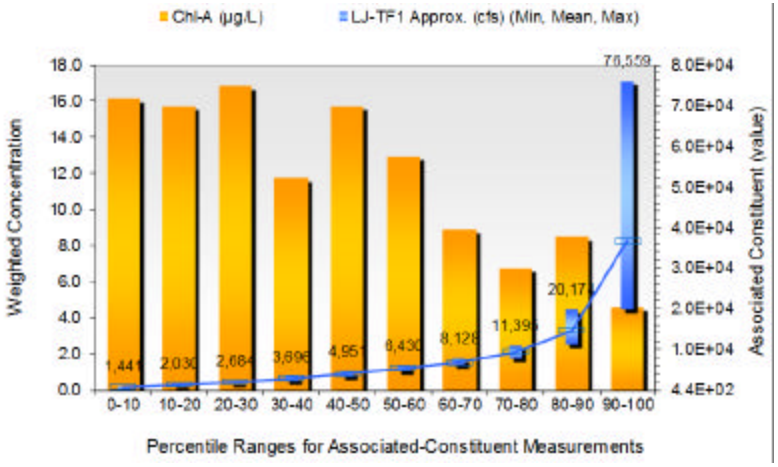
Appomattox-TF2

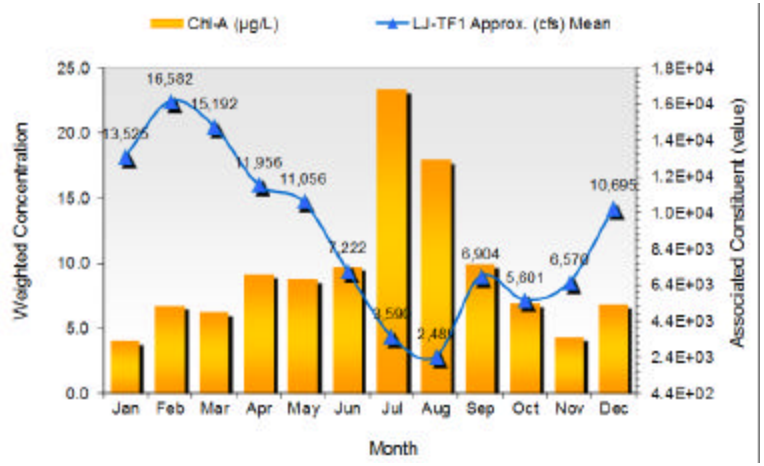




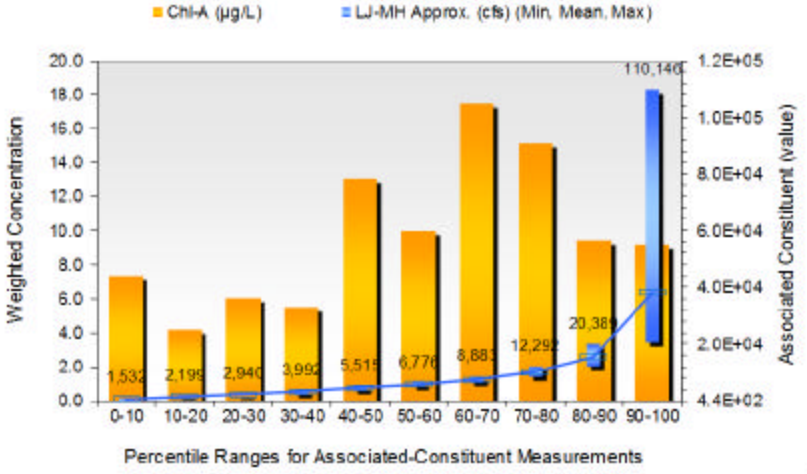
Paired Data Analysis

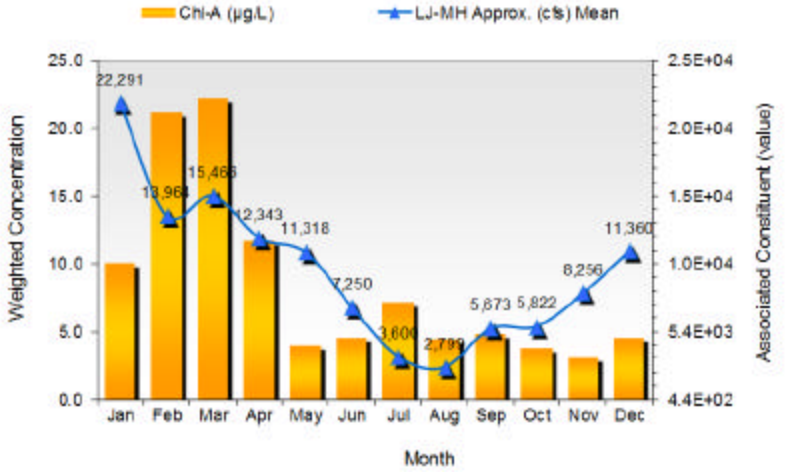
Lower James-TF1





Lower James-MH





Analysis Summary

- Statistical analysis
  - Generally weak relationship between flow and chlorophyll *a* exceedances
  - Justifies deterministic model development
- Paired data analysis
  - Variable relationship by location
  - Justifies deterministic model development
  - Useful for supporting watershed model calibration

Potential Next Steps

- Use chlorophyll *a* concentrations rather than exceedances
- Vary flow averaging periods (months and multi-year averaging period)
- Focus solely on algae data analysis and not flow