Seasonal forecasts of Chesapeake Bay hypoxia: update on model refinements

Modeling Workgroup Quarterly Review
8 April 2020

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Seasonal forecasts of Chesapeake Bay hypoxia

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Lucas Gonzalez, Salisbury Daily Times Published 6:00 a.m. ET June 20, 2019 | Updated 4:57 p.m. ET June 20, 2019

University of Michigan Chesapeake Bay hypoxia forecasting model

Driver:

Jan-May average Susquehanna TN load

Calibration target:

Mean July hypoxic volume (HV) ([DO] < 2 mg/L)

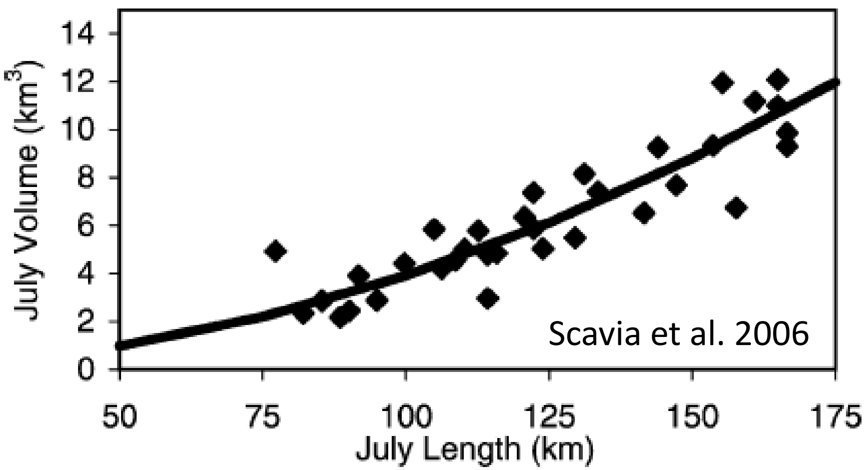
Model output:

Average subpycnocline [DO] as a function of distance from TN source

Hypoxic length = sum of all segments with [DO] < 2 mg/L

Hypoxic length → **hypoxic volume** through empirical V-L relationship

V-L relationship



Revisions to the UM Chesapeake Bay hypoxia forecasting model

At the January MWG Quarterly Review we proposed the following short-term revisions:

Re-calibrate model to different sets of HV estimates, HV metrics, loading periods and load sources

1. **HV metrics:** average summer, total annual, average monthly
2. **Load sources**: consider major load sources other than Susquehanna (e.g., other RIM loads, point sources)
3. **Load time frames**: e.g., Jan-May, Dec-May, etc.
4. **HV estimates**:
    - HV estimated through interpolation of cruise data
    - Simulated HV from 3D models (e.g., ChesROMS-ECB, ROMS-RCA)

Summary of calibration exercises so far

1. HV metrics:
Avg Jun, Avg Jul, Avg Aug, Avg Sep, Avg Summer, Tot Annual

2. Load sources:
Sus, Pot, Sus+Pot, Sus+Pot+PS, All 9 RIM rivers, All 9 RIM rivers + Point Sources

3. Load time frames:
Oct-May (all possible combinations)
Oct-Jun (all possible combinations)

4. HV estimates
Interpolated estimates from Murphy et al. 2011
3 sets of interpolated estimates: Murphy et al. 2011, Bever et al. 2013 and Zhou et al. 2014

Best 10 models for each HV metric

Total Annual HV

Lsource	Lperiod	NSE	r2	RMSE	MAE	RSTDE
All_withPS	Jan_Jun	0.52	0.52	1.23	0.96	1.30
All_noPS	Jan_Jun	0.51	0.52	1.24	0.98	1.29
Sus_Pot	Jan_Jun	0.48	0.50	1.27	1.00	1.34
All_noPS	Jan_May	0.48	0.50	1.28	1.00	1.34
All_withPS	Feb_Jun	0.48	0.48	1.28	1.06	1.33
Sus_Pot_PS	Jan_Jun	0.48	0.48	1.28	1.00	1.32
All_withPS	Jan_May	0.47	0.48	1.29	0.98	1.35
All_withPS	Mar_Jun	0.47	0.48	1.29	1.10	1.35
Sus_Pot	Jan_May	0.47	0.48	1.30	0.98	1.36
All_noPS	Feb_Jun	0.46	0.49	1.30	1.07	1.37

NSE: Nash-Sutcliffe Efficiency; r2: R^2 of observed vs. predicted regression; RMSE: Root Mean Square Error; MAE: Mean Absolute Error; RSTDE: Residual Standard Error

Best 10 models for each HV metric

Summer Average HV

Lsource	Lperiod	NSE	r2	RMSE	MAE	RSTDE
All_withPS	Jan_Jun	0.40	0.43	1.01	0.81	1.04
Sus_Pot_PS	Jan_Jun	0.37	0.41	1.03	0.82	1.06
All_withPS	Dec_Jun	0.36	0.40	1.03	0.86	1.08
Sus_Pot_PS	Dec_Jun	0.36	0.40	1.04	0.83	1.08
All_withPS	Jan_May	0.36	0.41	1.04	0.86	1.09
Sus_Pot_PS	Jan_May	0.35	0.40	1.04	0.83	1.09
All_withPS	Dec_May	0.33	0.38	1.06	0.90	1.11
Sus_Pot_PS	Dec_May	0.32	0.37	1.07	0.87	1.12
All_withPS	Feb_Jun	0.29	0.37	1.09	0.89	1.14
All_noPS	Jan_Jun	0.29	0.42	1.09	0.90	1.13

NSE: Nash-Sutcliffe Efficiency; r2: R^2 of observed vs. predicted regression; RMSE: Root Mean Square Error; MAE: Mean Absolute Error; RSTDE: Residual Standard Error

Best 10 models for each HV metric

June Average HV

Lsource	Lperiod	NSE	r2	RMSE	MAE	RSTDE
All_noPS	Mar_Jun	0.25	0.30	1.75	1.45	1.81
All_withPS	Apr_Jun	0.24	0.28	1.77	1.42	1.83
All_withPS	Mar_Jun	0.24	0.26	1.77	1.46	1.81
All_withPS	Apr_May	0.22	0.27	1.79	1.46	1.83
Sus_Pot	Mar_Jun	0.22	0.25	1.79	1.5	1.85
All_noPS	Apr_May	0.21	0.31	1.80	1.45	1.90
Sus_Pot	Jan_Jun	0.21	0.25	1.80	1.51	1.85
All_noPS	Mar_May	0.21	0.27	1.80	1.49	1.91
All_noPS	Jan_Jun	0.21	0.24	1.81	1.52	1.86
Sus_Pot_PS	Apr_May	0.20	0.26	1.81	1.49	1.86

July Average HV

Lsource	Lperiod	NSE	r2	RMSE	MAE	RSTDE
Sus_Pot_PS	Oct_May	0.29	0.30	2.38	1.82	2.46
Sus_Pot_PS	Nov_Jun	0.29	0.29	2.39	1.82	2.47
All_withPS	Nov_May	0.29	0.29	2.39	1.78	2.52
Sus_Pot_PS	Oct_Jun	0.28	0.28	2.40	1.86	2.44
Sus_Pot_PS	Dec_May	0.28	0.28	2.40	1.87	2.45
All_withPS	Dec_Jun	0.28	0.28	2.40	1.85	2.50
All_withPS	Oct_Jun	0.28	0.28	2.40	1.84	2.50
Sus_Pot_PS	Nov_May	0.28	0.28	2.41	1.83	2.47
Sus_Pot_PS	Dec_Jun	0.28	0.28	2.41	1.88	2.48
All_withPS	Nov_Jun	0.27	0.27	2.42	1.83	2.49

Best 10 models for each HV metric

August Average HV

Lsource	Lperiod	NSE	r2	RMSE	MAE	RSTDE
All_withPS	Jan_Jun	0.22	0.24	1.63	1.30	1.69
All_withPS	Jan_May	0.20	0.22	1.65	1.32	1.69
Sus_Pot_PS	Jan_May	0.18	0.21	1.67	1.35	1.74
All_withPS	Feb_Jun	0.16	0.20	1.69	1.32	1.76
Sus_Pot_PS	Jan_Jun	0.16	0.19	1.69	1.36	1.72
All_withPS	Dec_Jun	0.15	0.18	1.70	1.43	1.77
All_noPS	Jan_Jun	0.15	0.21	1.71	1.34	1.76
All_noPS	Jan_May	0.13	0.20	1.72	1.37	1.76
All_withPS	Dec_May	0.12	0.16	1.73	1.42	1.78
All_withPS	Feb_May	0.12	0.18	1.74	1.36	1.78

September Average HV

Lsource	Lperiod	NSE	r2	RMSE	MAE	RSTDE
Pot	Jun	-0.11	0.00	1.31	1.03	2.42
All_withPS	Dec_May	-0.20	0.01	1.36	1.11	1.33
All_withPS	Dec_Jun	-0.20	0.01	1.36	1.10	1.31
Sus_Pot_PS	Dec_May	-0.20	0.01	1.36	1.11	1.32
Sus_Pot_PS	Dec_Jun	-0.21	0.01	1.37	1.12	1.32
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Preliminary Considerations

Load sources:

- Best performing models often based on “**All rivers + PS**”, with “**All rivers without PS**” and “**Sus + Pot + PS**” showing similar performance. “**Sus**”, “**Pot**” and “**Sus + Pot**” perform consistently worse than when combined with other sources

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HV metrics:

- Highest model performances obtained for **Summer Average HV (NSE = 0.40)** and **Total Annual HV (NSE = 0.52),** both using Jan-Jun load and "All rivers + PS"

- Model performance progressively deteriorates for metrics later in the season (best NSE is **0.25** for Avg Jun, **0.29** for Avg Jul**, 0.22** for Avg Aug and **-0.11** for Avg Sep)

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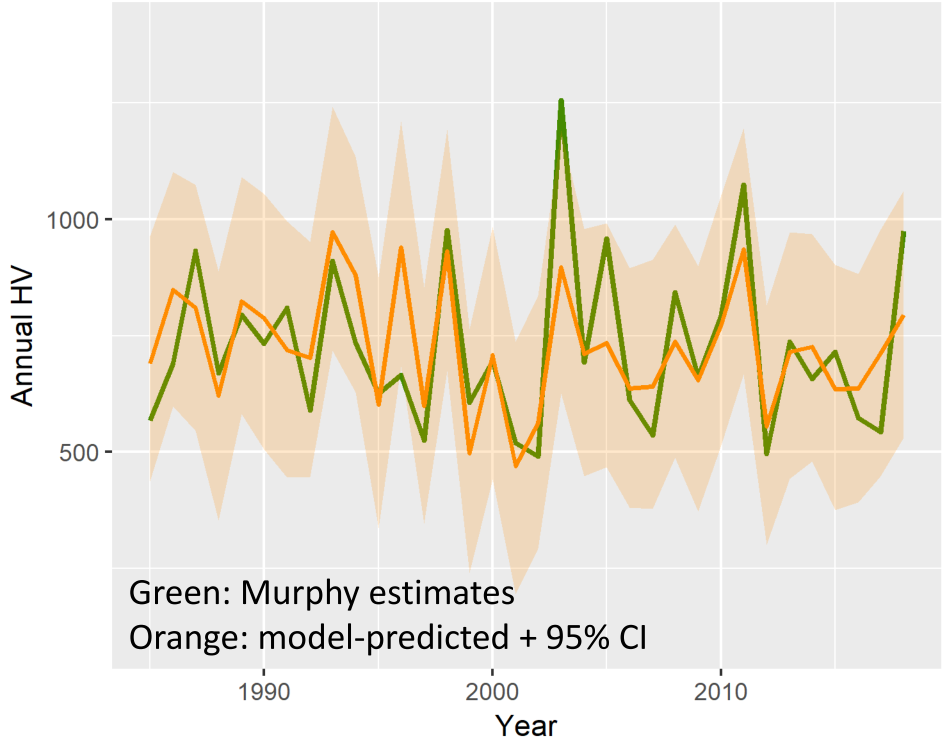
Load time frames:

- While adding the June load often improves model performance compared to using loads until May only, the improvement is often relatively small

- Different HV metrics best explained by different load time frames: June HV appears best correlated to loads later in spring (Mar-Jun), while other HV metrics show best correlations when also including earlier loads (Oct-May for July HV and Jan-Jun for August)

Performance of **best model OVERALL** (calibrated to 1985-2018 Murphy **Tot Annual HV** estimates and **Jan-Jun** loads from **All 9 Rivers + Point Sources)**

NSE	r2	RMSE	MAE	RSTDE
0.52	0.52	1.23	0.96	1.30



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Next steps

- Finalize results including multiple sets of interpolated HV estimates (Murphy et al. 2011, Bever et al. 2013 and Zhou et al. 2014) and maybe 3D model-based HV estimates

- Get ready for 2020 seasonal forecast:

  - Develop a strategy to best communicate updated model results in a way that minimizes confusion while ensuring continuity with respect to past forecasts

Any questions or feedback?

Extra slides

University of Michigan Chesapeake Bay hypoxia forecasting model

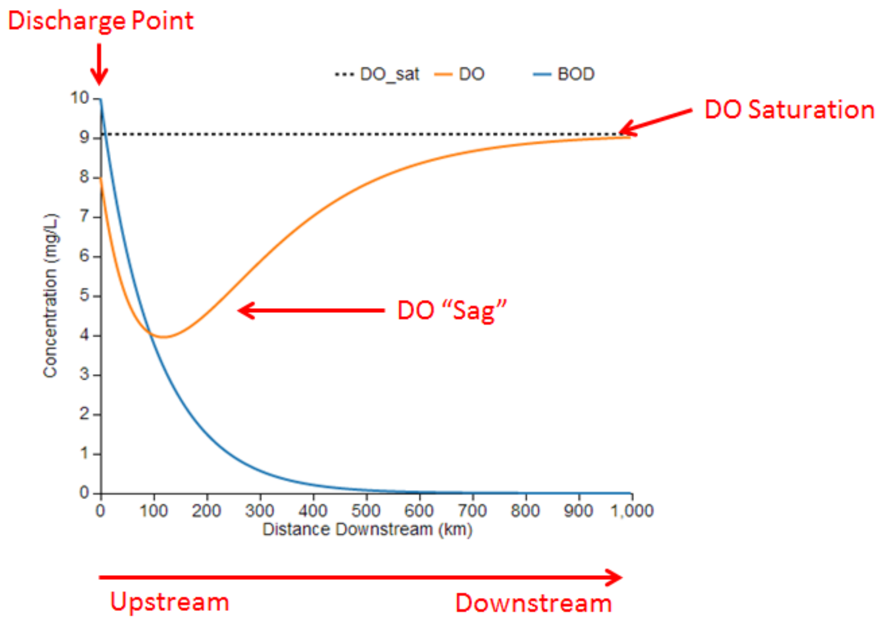
Streeter-Phelps Model

Biological Oxygen (BOD): Demand

$$\frac{dBOD}{dt} = -v * \frac{dBOD}{dx} - a * BOD$$

Dissolved Oxygen (*DO*):

$$\frac{dDO}{dt} = -v * \frac{dDO}{dx} + a * BOD - b * DO$$



t: time (d)

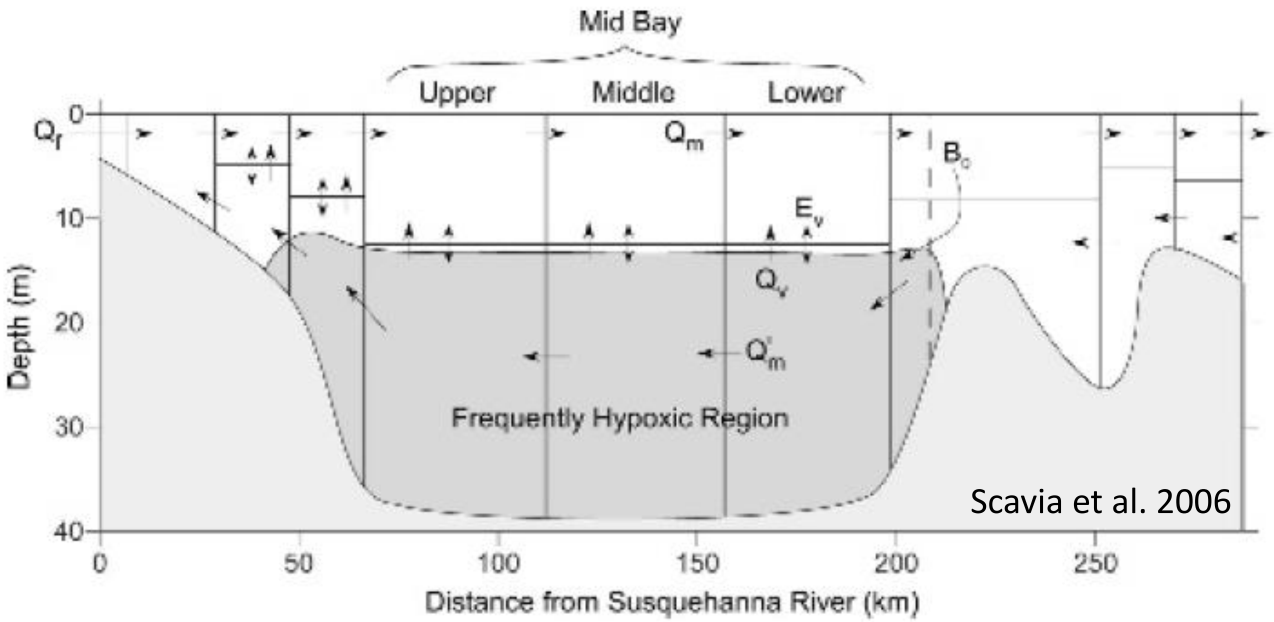
x: distance from source of *BOD* (km)

a: *BOD* decomposition rate (d^{-1})

b: *DO* re-aeration rate (d^{-1})

v: downstream advection (km d^{-1})

University of Michigan Chesapeake Bay hypoxia forecasting model



Scavia et al. 2006

Model driver: Jan-May average **TN load from Susquehanna** at Conowingo

⬇

TN → C through Redfield Ratio (5.67 gC/gN)

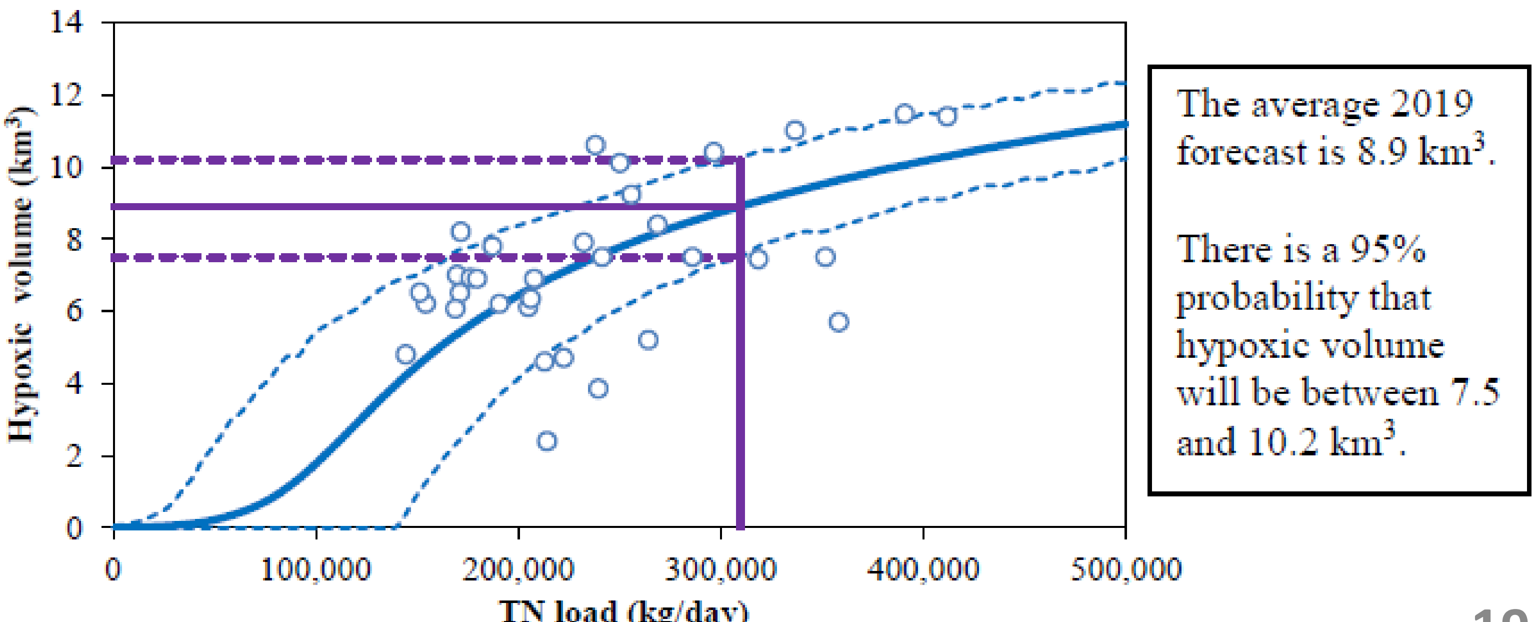
F: fraction of C assumed to settle below the pycnocline

C → BOD through respiration ratio (2.4 gO_2/gC)

University of Michigan Chesapeake Bay hypoxia forecasting model

Seasonal forecast

The 2019 Forecast **- Given the average January-May 2019 total nitrogen load of 309,403 kg/day, this summer's hypoxia volume forecast is 8.9 km^3, the 4th largest in the past 20 years.**



http://scavia.seas.umich.edu

Total annual loads by river (kg/year)

Note: Point source data are missing for Jul-Dec 2018

River combinations tested so far: **Sus alone, Pot alone, Sus+Pot, Sus+Pot+PS, All 9 rivers, All 9 rivers + PS**

PS = Point Sources discharging below non-tidal river monitoring stations