01/07/2025

Phase 7 WSM Development – Linkage of the Dynamic Watershed Model (DWSM) and Main Bay Model (MBM)

Modeling Workgroup Quarterly Meeting – January 2025

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[1] Penn State, [2] UMCES, [3] US EPA, [4] VA DEQ – Chesapeake Bay Program Office

Presentation Outline

Phase 7 Dynamic Watershed Model (DWSM)

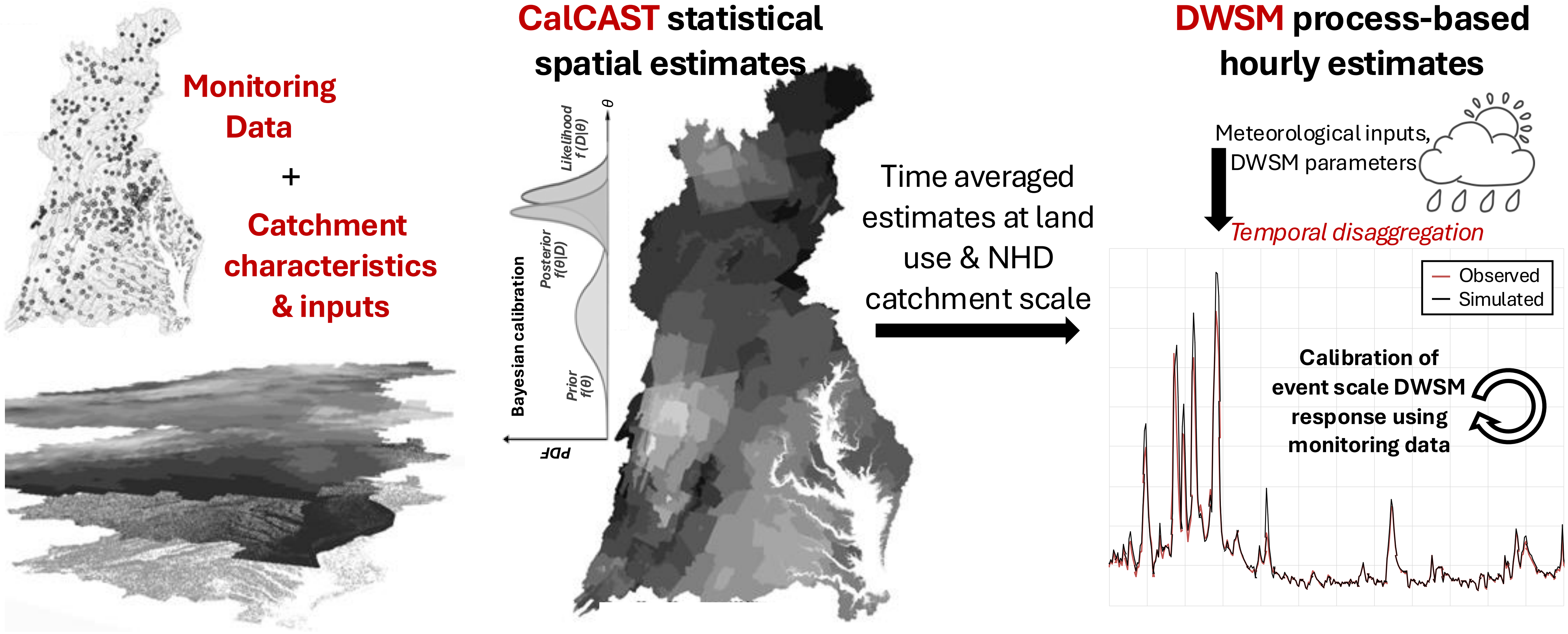
1. **Dynamic Watershed Model Overview**
2. **Review of prior model development progress**
3. **Linkage of the DWSM and Main Bay Model (MBM)**
   - Summary of 3 beta versions of the watershed loads
   - QA QC between CBPO and VIMS practitioners
   - Needs and plans for future linkage refinements
   - CMAQ data for improving Phase 7 CBP airshed N loads
   - Other Phase 7 activities
4. **Summary and next steps**

Purpose

NHD Scale Dynamic Watershed Model (DWSM)

- Inputs for the estuarine models (MBM/MTMs)
- Watershed model calibration and scenario applications
- Support research and collaboration activities

Framework: Statistical Model (CalCAST) → Dynamic Watershed Model (DWSM)



- Data-driven CalCAST informs DWSM parameters and responses.
- NHD-scale DWSM prototype is now using CalCAST *average annual* (a) total flow, (b) stormflow, (c) sediment erosion and delivery factors, and (d) total nitrogen and total phosphorus loads and delivery factors.

Dynamic Watershed Model (DWSM) Development

- Year 2022: NHD-scale model structure and prototypes for hydrology, sediment, and nutrients.
  - Operational prototypes with reasonable runtime and on the graph paper model results.
- Year 2023: Incremental refinements of model prototypes in terms of model segmentation, CalCAST→DWSM linkage, and simulation of the small streams.
- **Year 2024: [Q1] stream water quality routing based on β parameters; [Q2] mechanics of water quality calibrations (step 1 of 2); [Q3] refinements of streamflow, water temperature, mechanics of water quality calibrations (step 2 of 2);**

Development Milestones (2022)

100K NHD	NHD-scale model structure; Hydrology prototype; Expanded simulation period 1985 to 2020; [1][2]
HYDROLOGY	Hydrology calibration (CalCAST→DWM) method updates; initial testing of numerical simplifications for flow routing; [3]
SEDIMENT	Sediment model; Hydrology model calibration updates with respect to stormflow; [4]
NUTRIENTS	Nutrient (Nitrogen and Phosphorus) model; Updated sediment model; [5]

[1] https://d18lev1ok5leia.cloudfront.net/chesapeakebay/documents/progress-in-phase-7-wsm-development-1.4.2022-gopal_bhatt_penn_state.pdf
[2] https://d18lev1ok5leia.cloudfront.net/chesapeakebay/documents/progress_in_phase_7_wsm_development_4.5.2022_-_gopal_bhatt_penn_state.pdf
[3] https://d18lev1ok5leia.cloudfront.net/chesapeakebay/documents/progress_in_phase_7_wsm_development_-_gopal_bhatt_penn_state_7.12.22.pdf
[4] https://d18lev1ok5leia.cloudfront.net/chesapeakebay/documents/Progress-in-Phase-7-WSM-Development-Gopal-Bhatt-Penn-State-10.4.22-v2.pdf
[5] https://d18lev1ok5leia.cloudfront.net/chesapeakebay/documents/Progress-in-Phase-7-WSM-Development-Gopal-Bhatt-Penn-State-1.10.2023.pdf

… incremental improvements during 2023

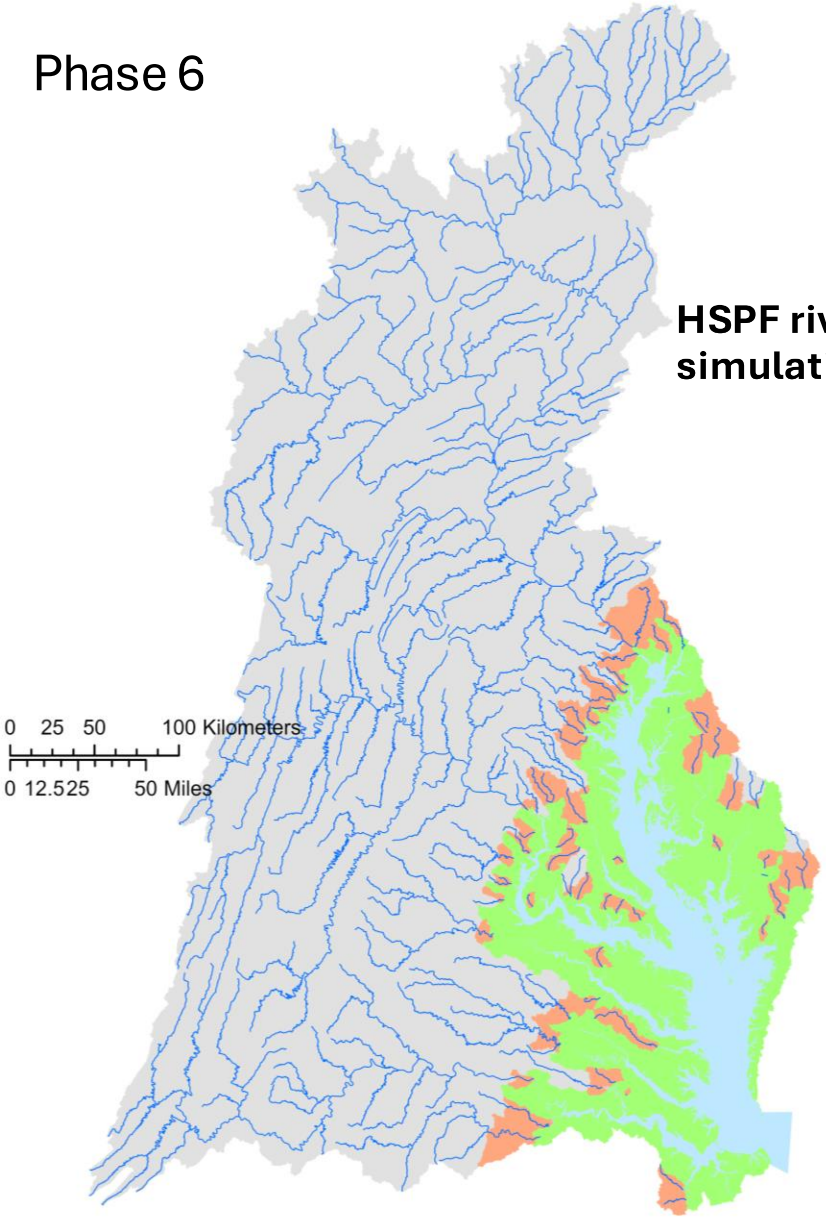
Segmentation	We performed re-segmentation and tested the revised model. ▪ tidal percent attribute was updated using new shoreline layer ▪ all databases (river mainstem, topology, etc.) were updated ▪ segmentations in the tidal watershed were improved
Model	Improvements on overcoming the 'aggregation effect' in the simulation of river mainstems (CalCAST → DWM) ➢ Non-iterative hydraulic routing for small 100K NHDplus streams ➢ WQ routing (TN) for small 100K NHDplus streams
Simulation	Testing on Amazon AWS and MS Azure cloud HPC environments with various node type and size configurations

[1] https://d18lev1ok5leia.cloudfront.net/chesapeakebay/documents/20230404-BHATT-Phase-7-WSM-Development-Dynamic-Model-Development-2023Q1.pdf
[2] https://d18lev1ok5leia.cloudfront.net/chesapeakebay/documents/Progress-in-Phase-7-WSM-Development-Gopal-Bhatt-Penn-State-6.20.2023.pdf
[3] https://d18lev1ok5leia.cloudfront.net/chesapeakebay/documents/Progress-in-Phase-7-WSM-Development-Gopal-Bhatt-Penn-State-10.17.2023.pdf
[4] https://d18lev1ok5leia.cloudfront.net/chesapeakebay/documents/20240109-BHATT-Phase-7-WSM-Development-Dynamic-Model-Development-2023Q4.pdf

[1] https://d18lev1ok5leia.cloudfront.net/chesapeakebay/documents/Progress-in-Phase-7-WSM-Development-Gopal-Bhatt-Penn-State-CBPO-4.2.2024.pdf
[2] https://d18lev1ok5leia.cloudfront.net/chesapeakebay/documents/Phase-7-WSM-Development-Modeling-WG-July-2024.pdf
[3] https://d18lev1ok5leia.cloudfront.net/chesapeakebay/documents/3_1000_20241008-BHATT-Phase-7-WSM-Development-Dynamic-Model-Development-2024Q3.pdf

<u>Terminal</u> and <u>Tidal</u> loadings

Phase 6



HSPF river simulation

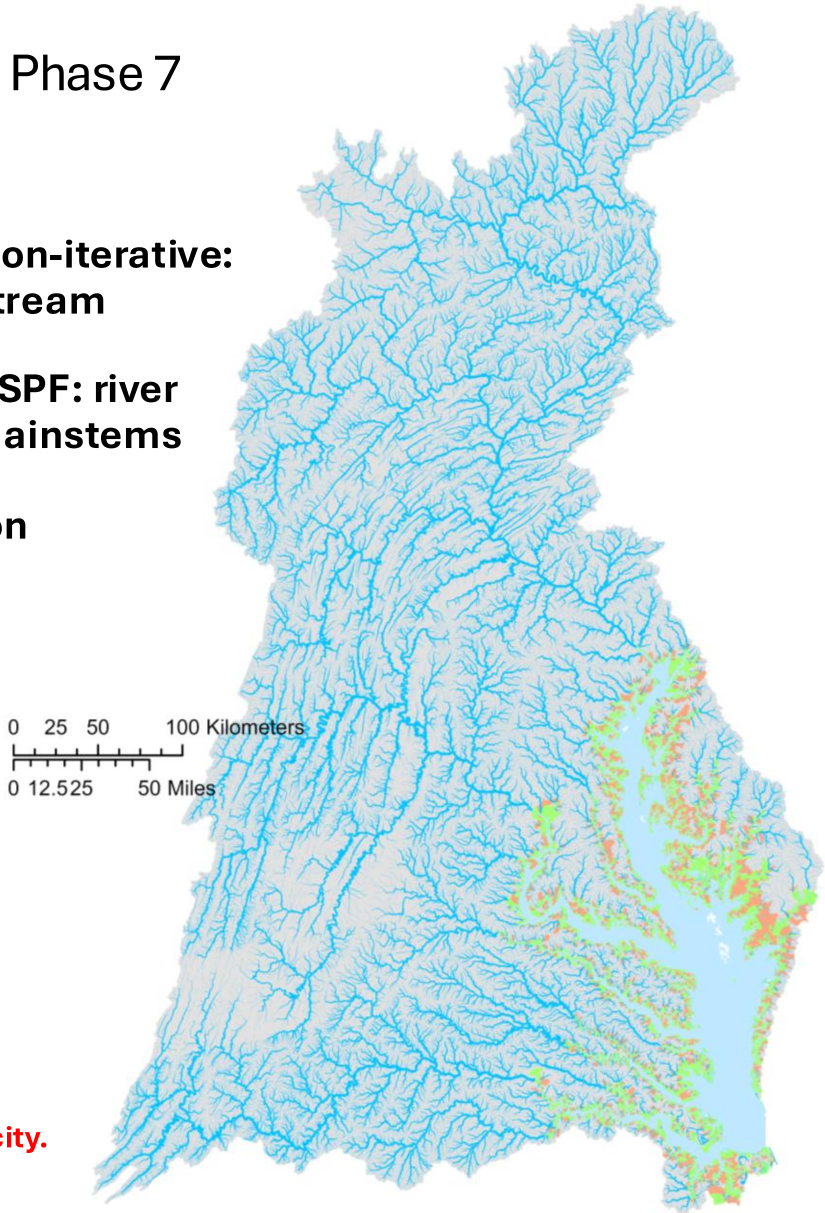
- Non Tidal
- Terminal
- Tidal

no river simulation

Non-iterative: stream

HSPF: river mainstems

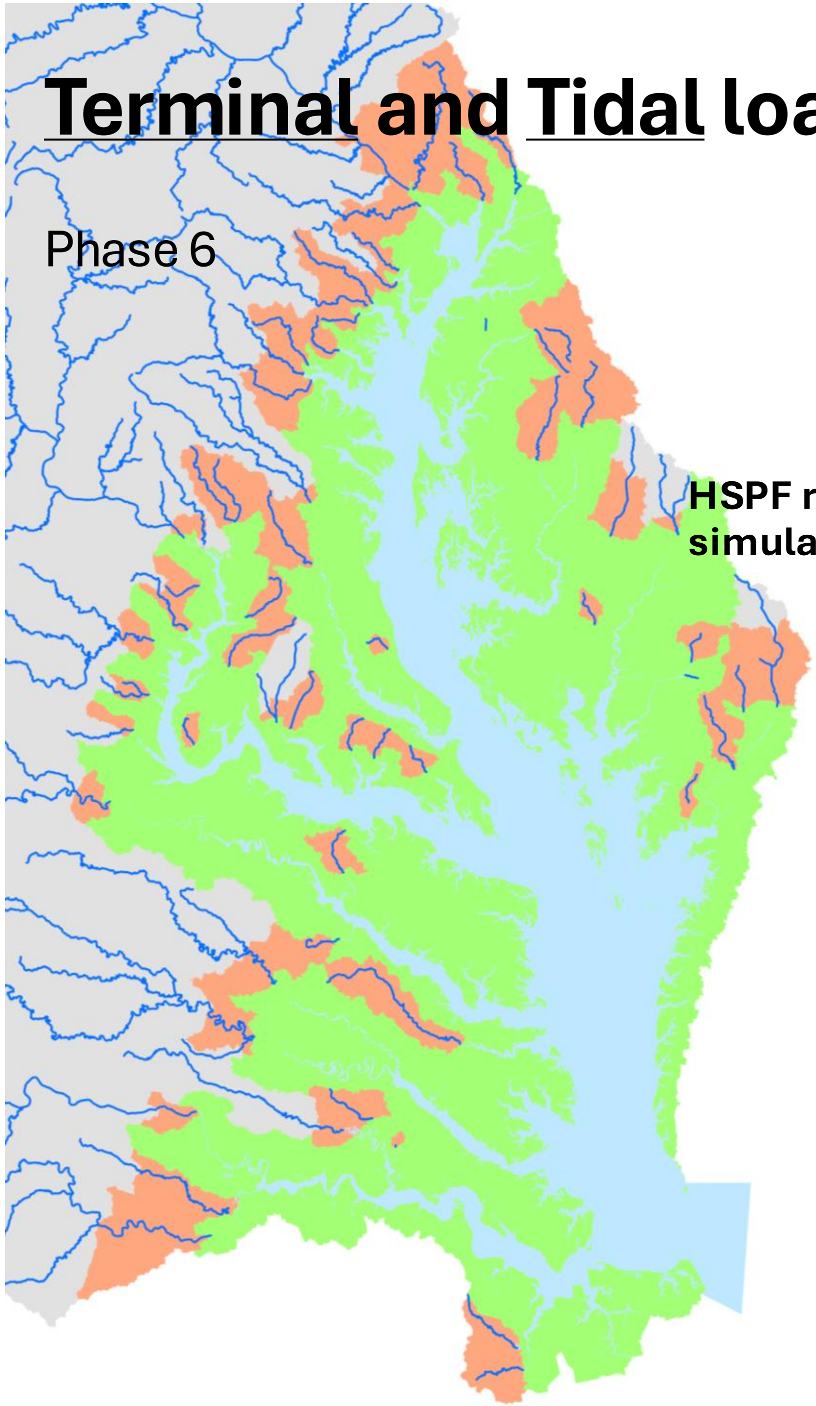
Phase 7



Notice change in the coverage of tidal areas with direct discharge to the Bay.

It translates to greater spatial specificity.

Terminal and Tidal loadings



HSPF river simulation

- Non Tidal
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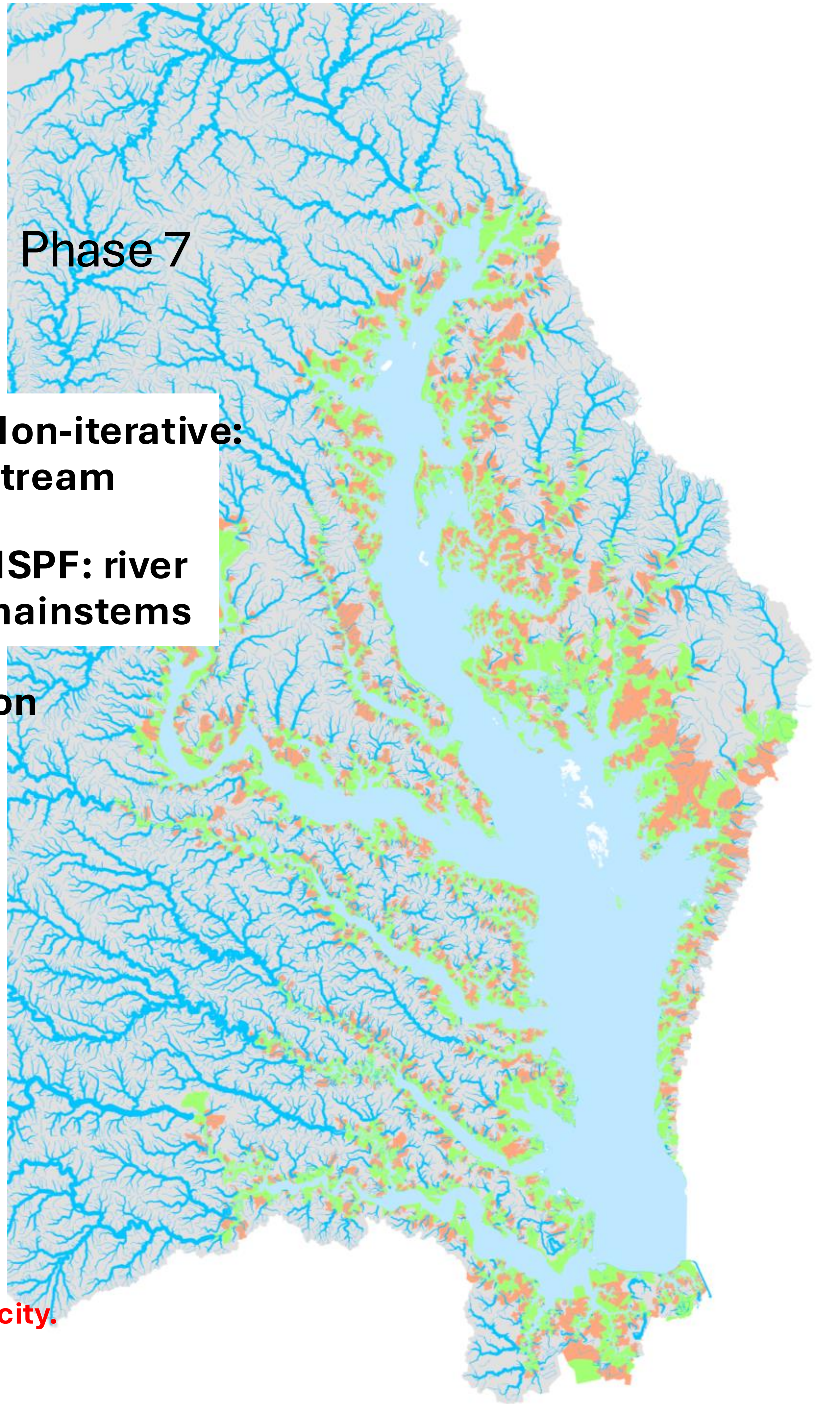
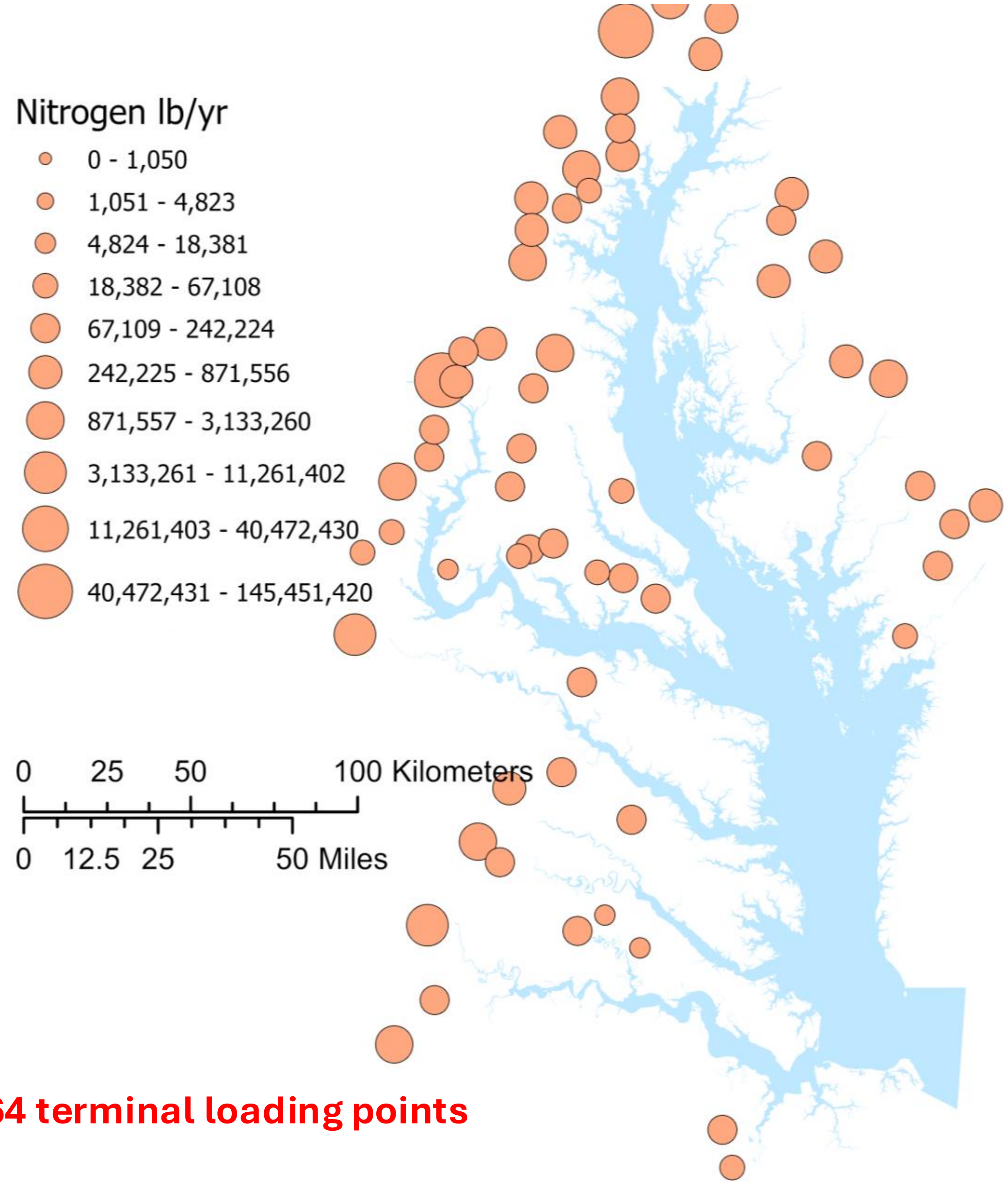


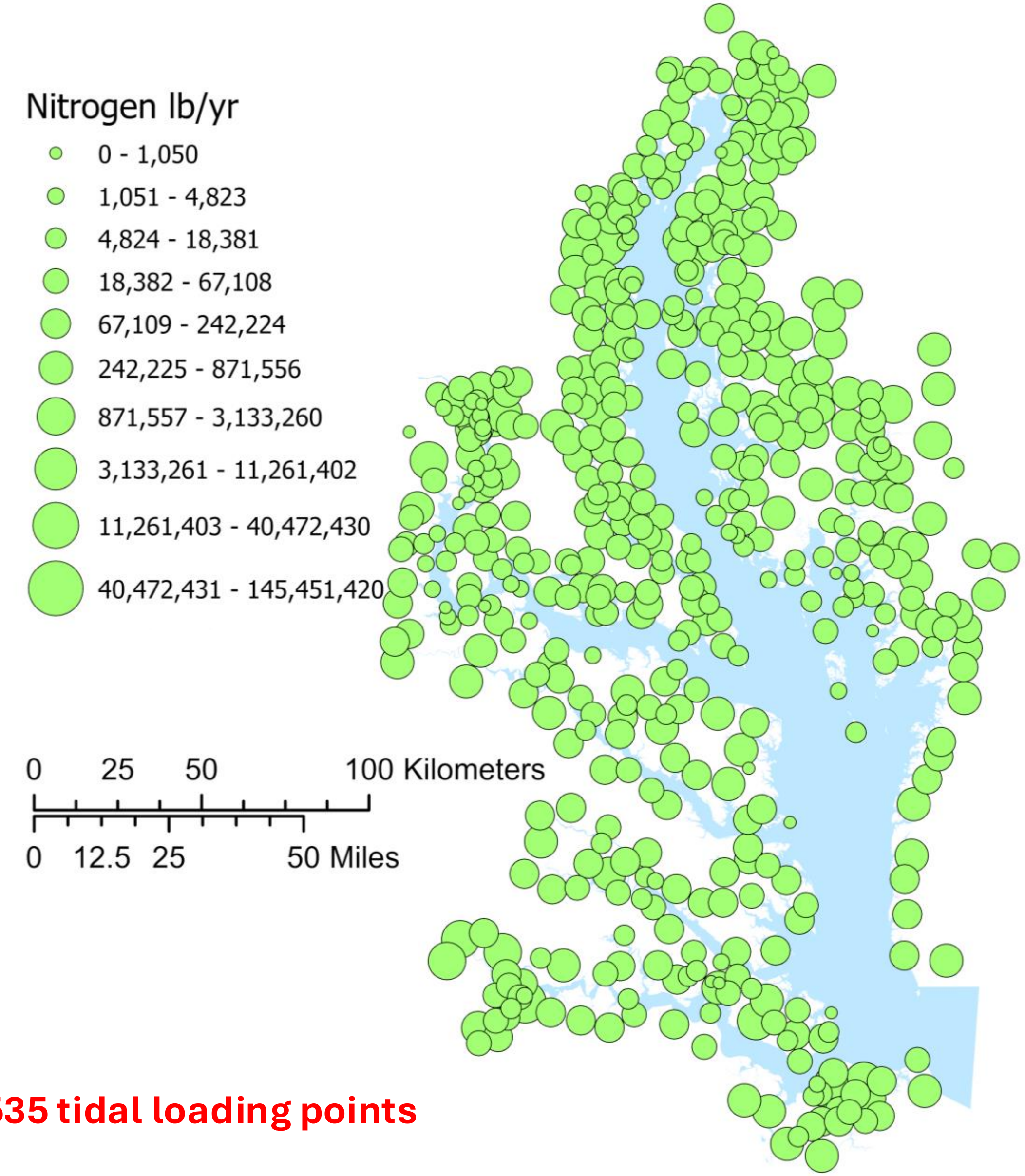
Notice change in the coverage of tidal areas with direct discharge to the Bay.

It translates to greater spatial specificity.

Phase 6: Terminal and Tidal loadings

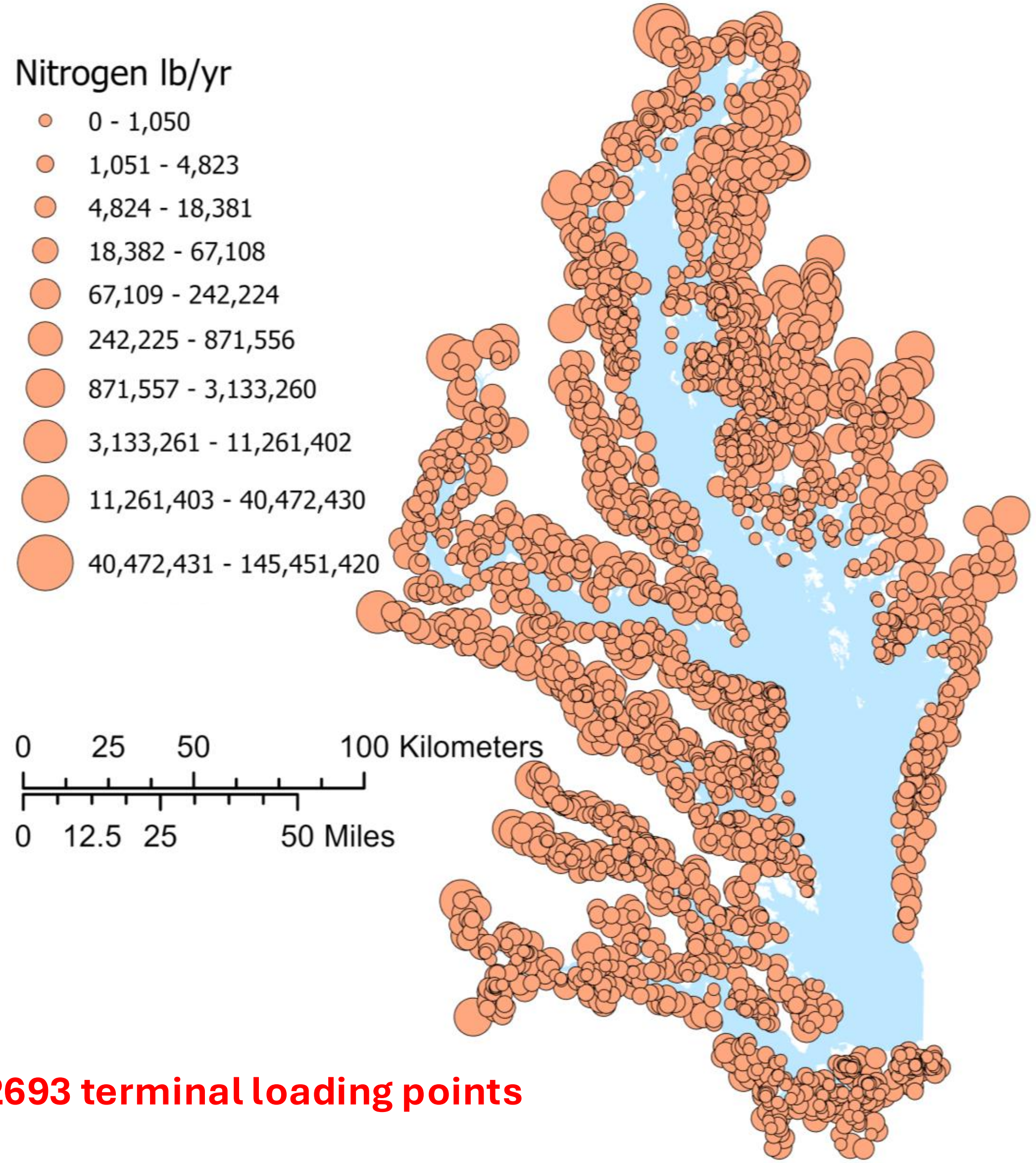


64 terminal loading points

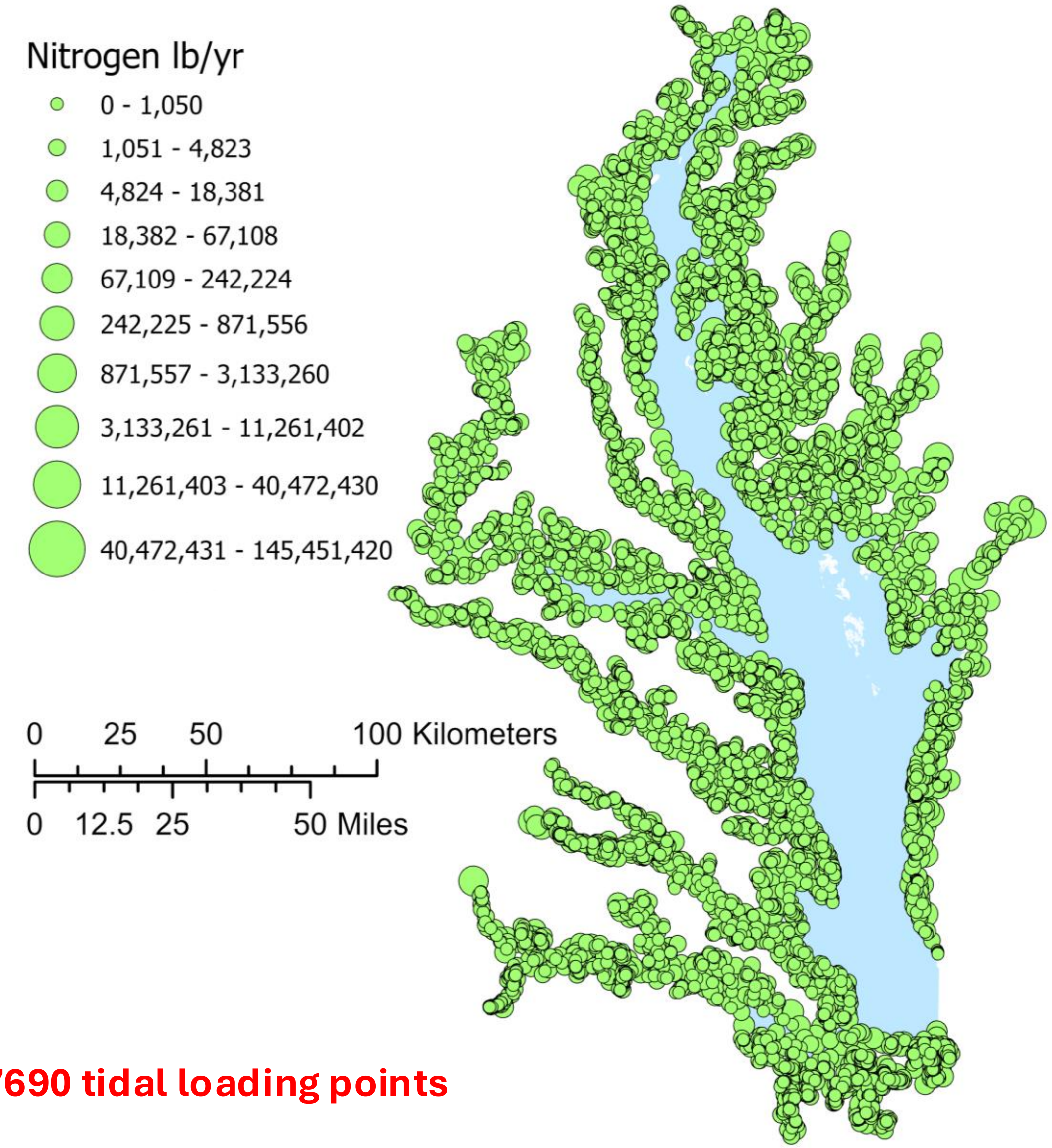


535 tidal loading points

Phase 7: Terminal and Tidal loadings



2693 terminal loading points



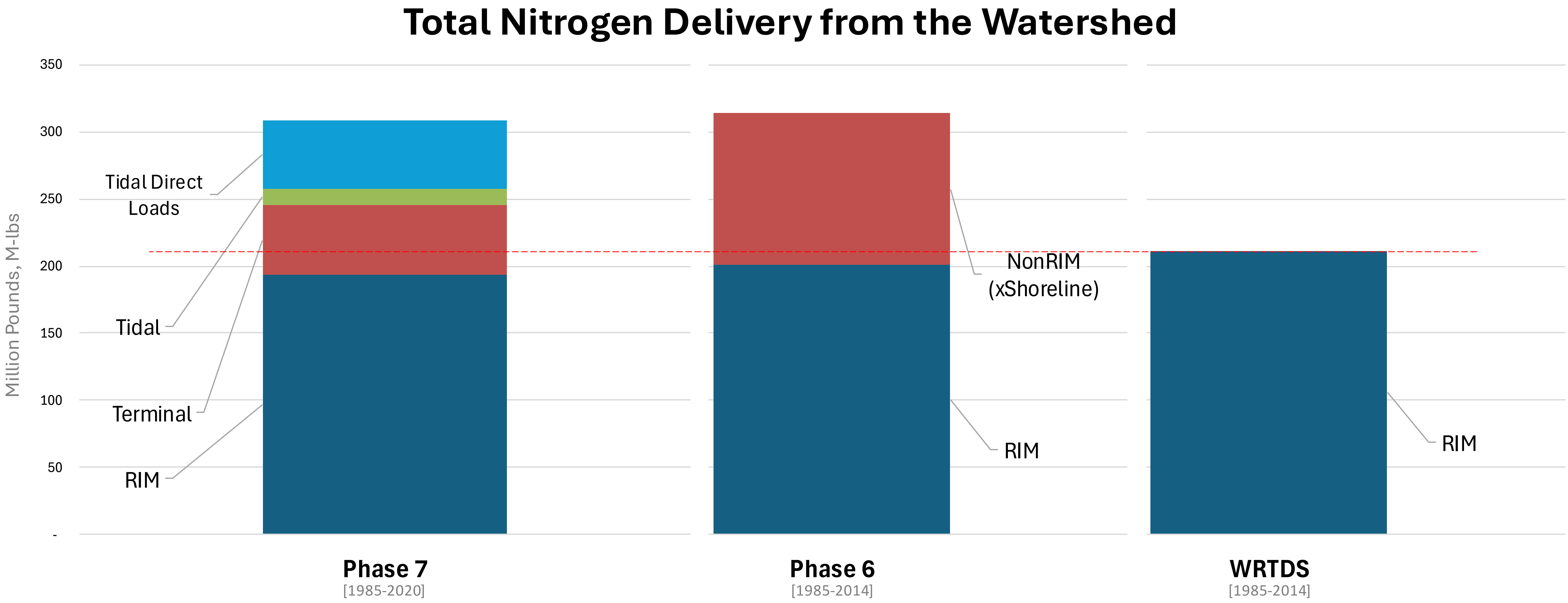
7690 tidal loading points

We developed 3 incrementally refined beta versions

[1] October 2024	The model version that we presented to the Modeling Workgroup
[2] November 2024	NHD scale point source inputs and a few minor model refinements
[3] December 2024	Updated CalCAST parameters (v20241031) + DWSM recalibration

[1] October 2024

The model version that we presented to the Modeling Workgroup



"Tidal Direct Loads" is currently not included in Phase 7 DWSM

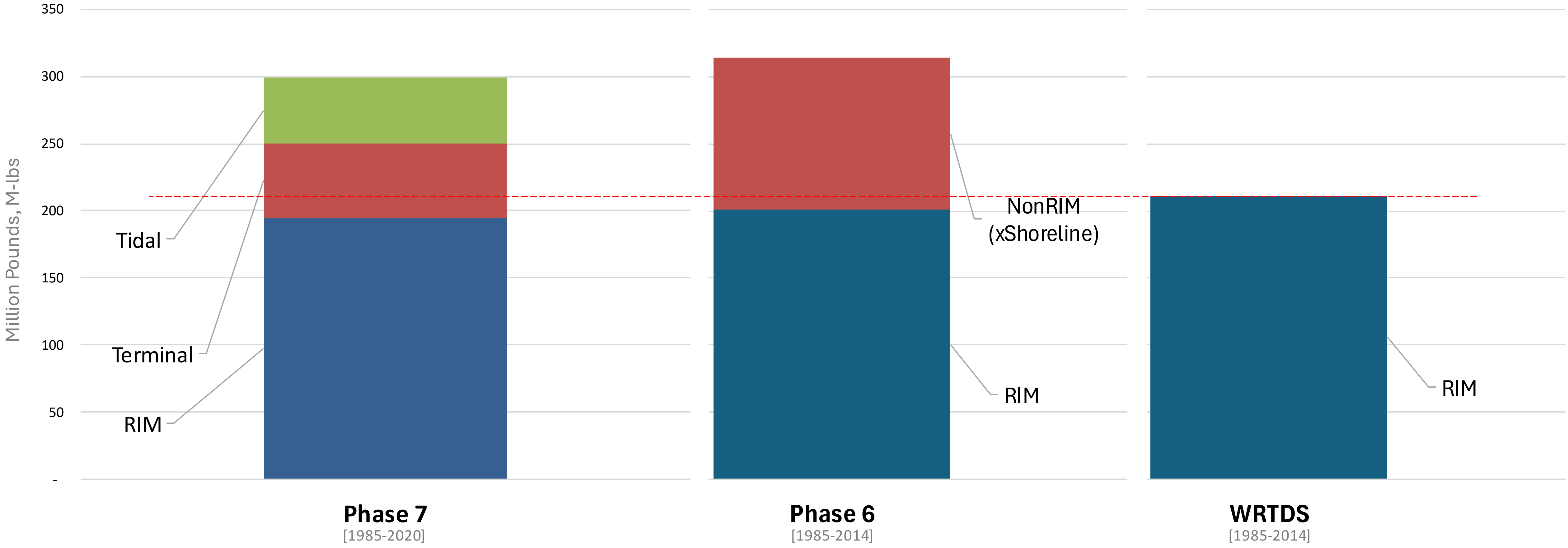
1985-2020 P7 beta version; 1985-2014 for Phase 6; 1985-2014 for WRTDS

Δ total $P7_{\beta}$ vs. P6 = -18%
Δ total $P7_{\beta}$ + P6 Tidal Direct Loads vs. P6 = -2%

[2] November 2024

NHD scale point source inputs and a few minor model refinements

Total Nitrogen Delivery from the Watershed

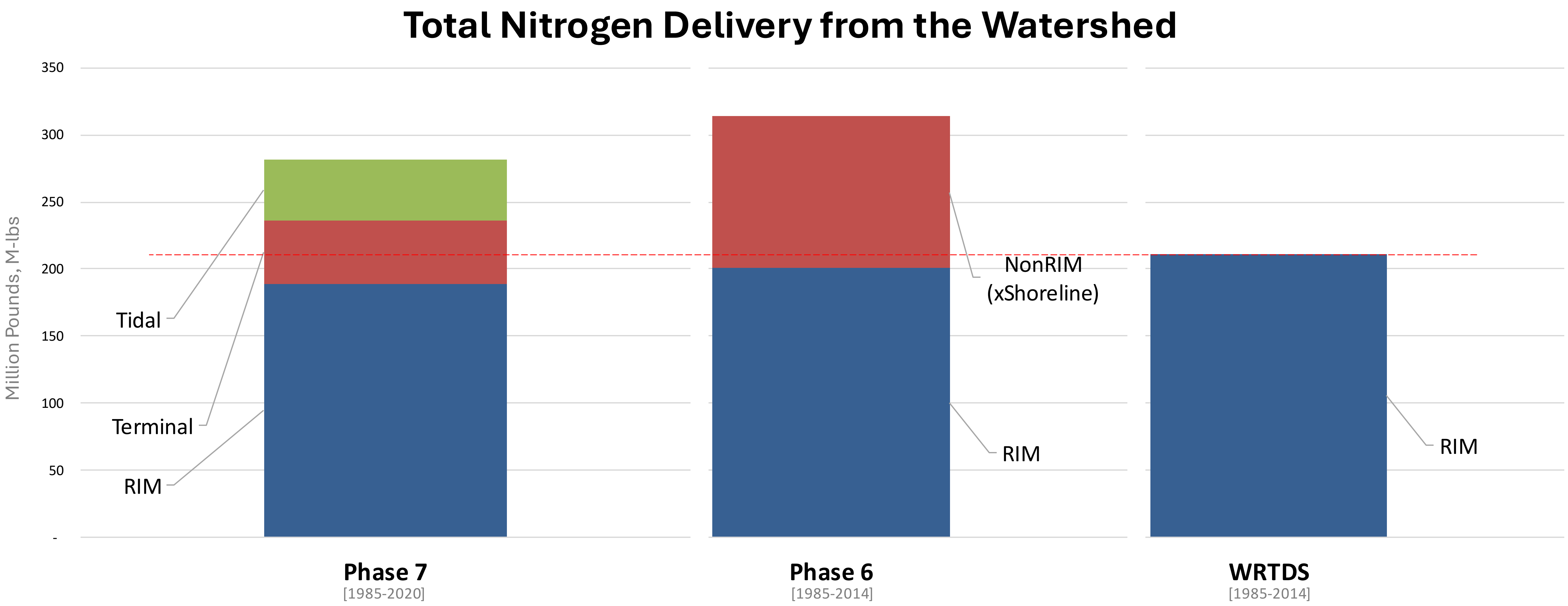


"Tidal Direct Loads" are now included in Phase 7 DWSM

Δ total $P7_{\beta}$ *vs. P6 = -5%*

[3] December 2024

Updated CalCAST parameters (v20241031) + DWSM recalibration

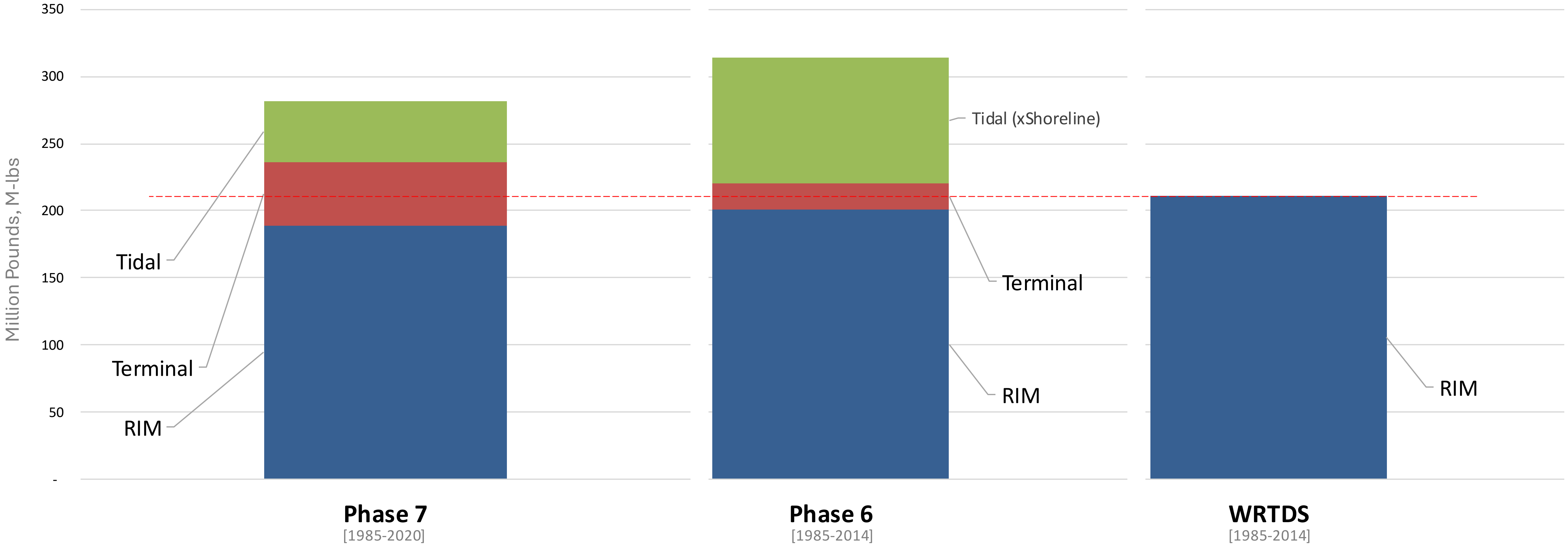


Δ total $P7_{\beta}$ vs. P6 = -10%

[3] December 2024

Updated CalCAST parameters (v20241031) + DWSM recalibration

Total Nitrogen Delivery from the Watershed



Δ total $P7_{\beta}$ vs. P6 = -10%

[1] October 2024

The model version that we presented to the Modeling Workgroup

Phase 7 RIM stations loads vs. WRTDS

(a) biases in 1985-2014 average loads as compared to WRTDS; (b) NSE of annual loads in parentheses;

Rivers	Flow	Nitrogen	Phosphorus	Sediment
Susquehanna Conowingo MD	+00.0% (+0.946)	+05.1% (+0.773)	+68.1% (-0.954)	+18.1% (+0.452)
Susquehanna Marietta PA	-01.2% (+0.938)	+04.2% (+0.641)	+26.3% (-0.529)	+02.8% (-0.129)
Potomac Washington, DC	+00.3% (+0.885)	-35.2% (+0.228)	+24.3% (+0.262)	-08.5% (-0.461)
James Cartersville, VA	+03.7% (+0.891)	-39.1% (+0.219)	-06.2% (+0.800)	-36.0% (+0.625)
Rappa. Fredericksburg, VA	-01.3% (+0.903)	-19.0% (+0.673)	-13.8% (-2.679)	-41.9% (-0.737)
Appomattox Matoaca, VA	00.0% (+0.903)	-18.2% (+0.743)	-01.1% (+0.555)	-32.9% (+0.526)
Pamunkey Hanover, VA	+03.6% (+0.815)	-14.1% (+0.684)	-09.4% (+0.020)	-44.2% (+0.229)
Mattaponi Beulahville, VA	+11.0% (+0.714)	+61.6% (-2.501)	+01.8% (+0.272)	+101.7% (-10.449)
Patuxent Bowie, MD	+03.8% (+0.857)	+06.8% (+0.821)	-04.8% (+0.641)	+26.9% (+0.496)
Choptank Greensboro, MD	-05.4% (+0.730)	+103.2% (-6.738)	+11.0% (+0.562)	-19.3% (+0.106)

(a) some differences can be attributed to WRTDS method and DWSM loads for the 1985-2014 averaging period

[3] December 2024

Updated CalCAST parameters (v20241031) + DWSM recalibration

Phase 7 RIM stations loads vs. WRTDS

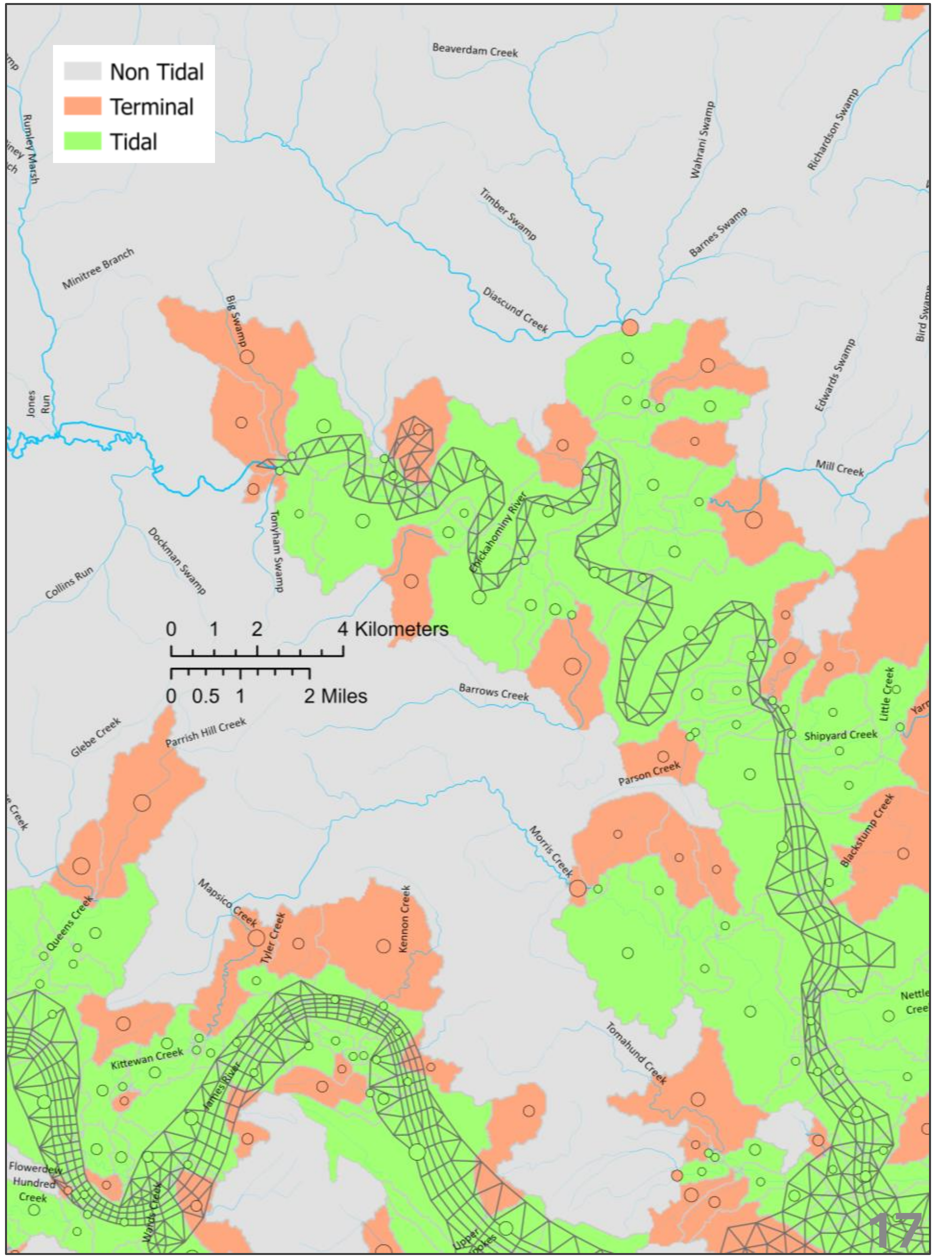
(a) biases in 1985-2014 average loads as compared to WRTDS; (b) NSE of annual loads in parentheses;

Rivers	Flow	Nitrogen	Phosphorus	Sediment
Susquehanna Conowingo MD	+00.0% (+0.946)	-07.7% (+0.774)	+18.1% (+0.213)	+18.0% (+0.433)
Susquehanna Marietta PA	-01.2% (+0.938)	-08.3% (+0.496)	-14.0% (+0.132)	+02.6% (-0.115)
Potomac Washington, DC	+00.3% (+0.885)	-19.3% (+0.666)	-10.1% (+0.724)	-08.4% (-0.503)
James Cartersville, VA	+03.7% (+0.891)	-19.6% (+0.663)	-27.8% (+0.513)	-36.0% (+0.627)
Rappa. Fredericksburg, VA	-01.3% (+0.903)	-00.5% (+0.830)	-14.9% (-2.454)	-41.9% (-0.750)
Appomattox Matoaca, VA	00.0% (+0.903)	+12.9% (+0.416)	+24.5% (+0.216)	-32.7% (+0.534)
Pamunkey Hanover, VA	+03.6% (+0.815)	+04.3% (+0.750)	+13.6% (-0.388)	-44.2% (+0.229)
Mattaponi Beulahville, VA	+11.0% (+0.714)	+23.2% (+0.100)	+63.3% (-3.073)	+101.3% (-10.342)
Patuxent Bowie, MD	+03.8% (+0.857)	+01.3% (+0.494)	+01.3% (+0.693)	+28.7% (+0.501)
Choptank Greensboro, MD	-05.4% (+0.730)	+01.6% (+0.807)	+45.5% (+0.125)	-19.4% (+0.116)

(a) some differences can be attributed to WRTDS method and DWSM loads for the 1985-2014 averaging period

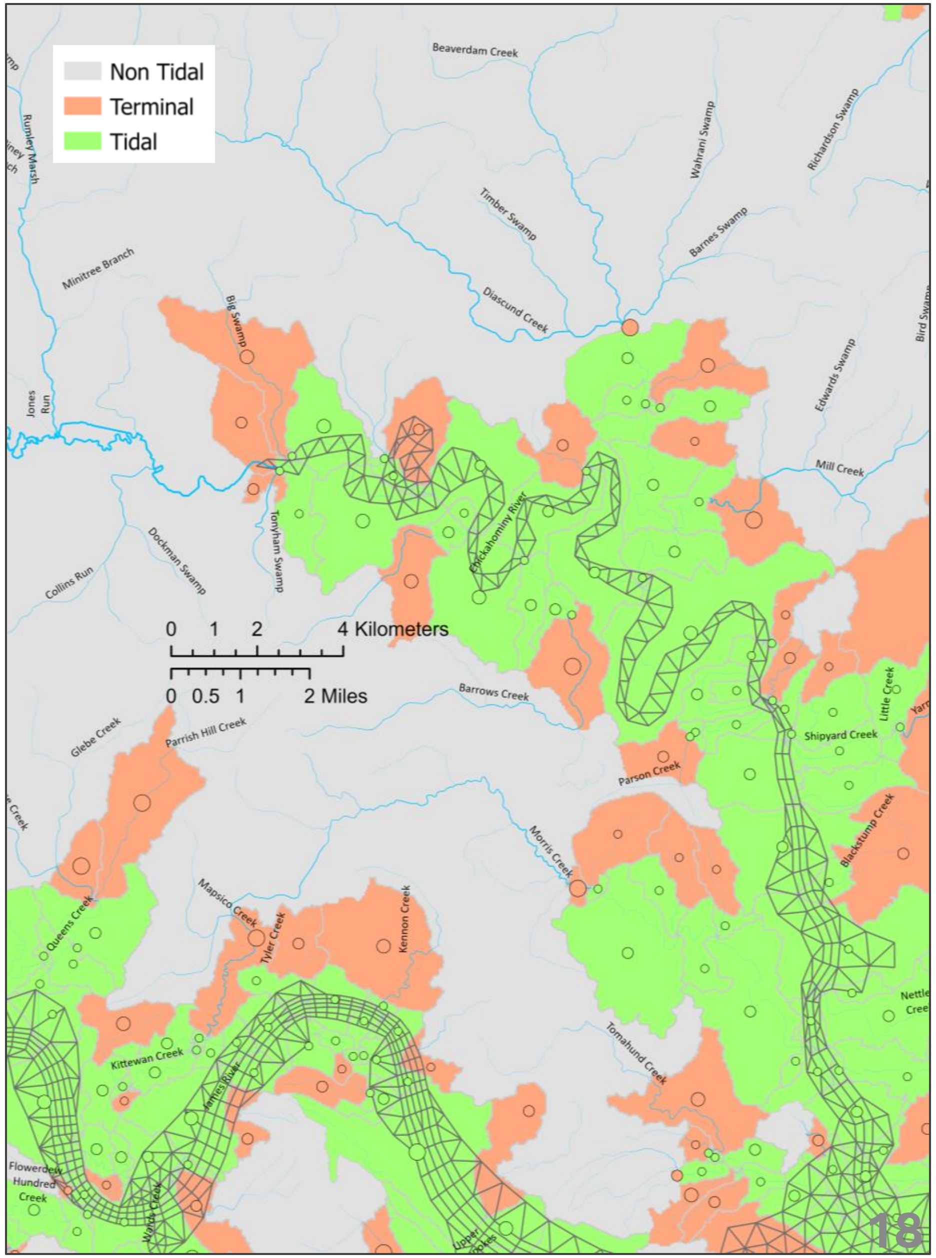
QA QC between CBPO and VIMS practitioners

- **Review and verification of data files, formats, units, and model variables**
  - We found some redundancies (e.g., some catchments are entirely tidal waters or wetlands)
  - We found need for some constraints (e.g., T > 50°C but Q < 0.00005 m^3/s)
  - We found an issue in the version of P6 WSM loads used in MBM
- **Spatial linkages [Zhengui Wang, VIMS]: making use of P7 NHD catchments geospatial layer specifying *terminal* and *tidal* attributes**
  - A couple of terminal streams does not have corresponding NHD catchments
- **Variable linkages [Zhengui Wang, VIMS; Richard Tian, CBPO]: DWSM and MBM model variables aren't the same and so they require data processor subroutines.**
  - E.g., Organic N is one variable in DWSM, but in MBM it is divided into G1, G2, and G3



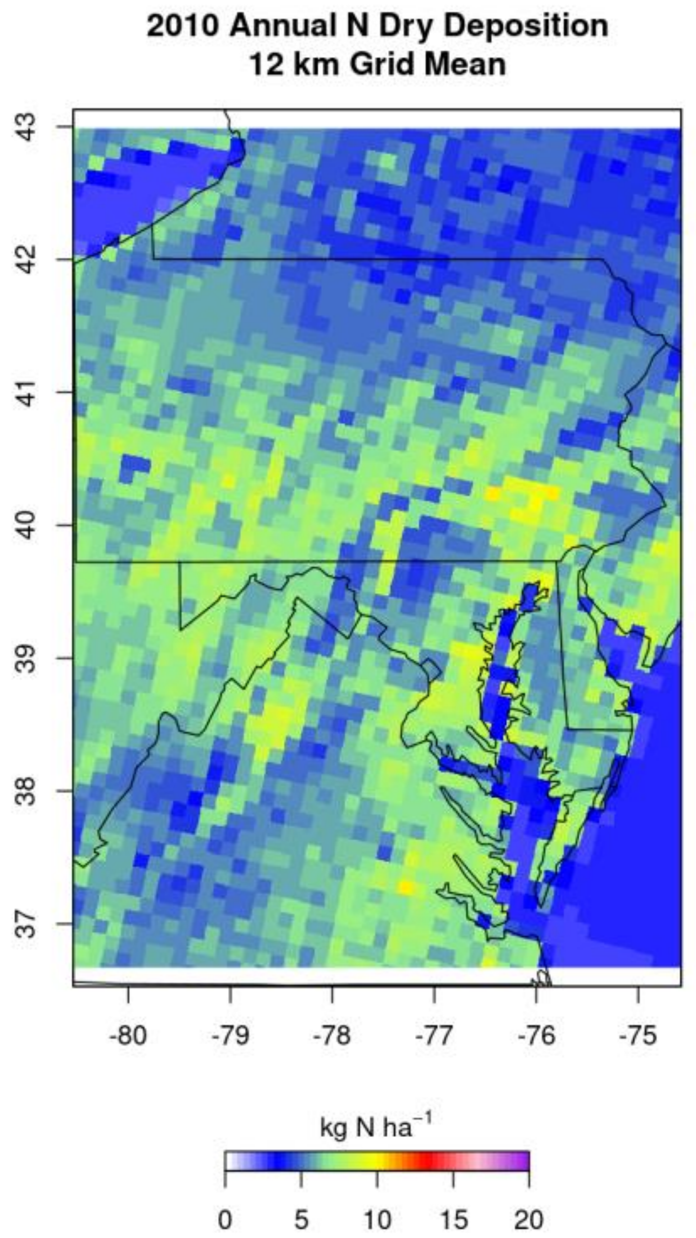
Needs and plans for linkage refinements

- **MBM for SCHISM and Chesapeake Global Collaboratory (CBC) for habitat and living resource models are using NetCDF.**
- **A new subroutine at CBPO for processing daily time series of watershed flows and loads into NetCDF should replace current practice of sharing text files.**
- **DWSM and SCHISM-ICM variable conversion will be addressed [Richard Tian, CBPO].**
- **So, 234,306 files [{2,858 + 10,159} x 18] will be replaced by one NetCDF file.**
- **The 9 RIM tributaries will be differentiated.**
- **The development and testing, which will occur in 2025 Q1, will reduce errors, improve transfer efficiency of model outputs, and eliminate learning curves in model linkage among MBM and MTM teams.**



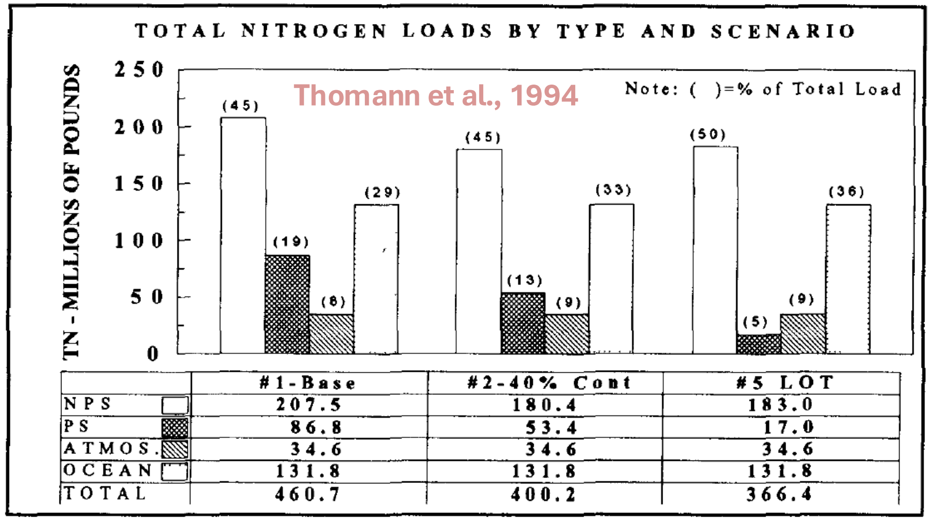
New CMAQ data in Phase 7 CBP Airshed N loads

- We received wet and dry, oxidized and reduced N deposition data at 12 km spatial resolution from CMAQ model version 5.3.2 [Jesse Bash, EPA].
- Spatial coverage includes both watershed and estuarine model domain for the 2002 to 2019 period.
- We developed scripts for the processing of loads and performed initial analysis.



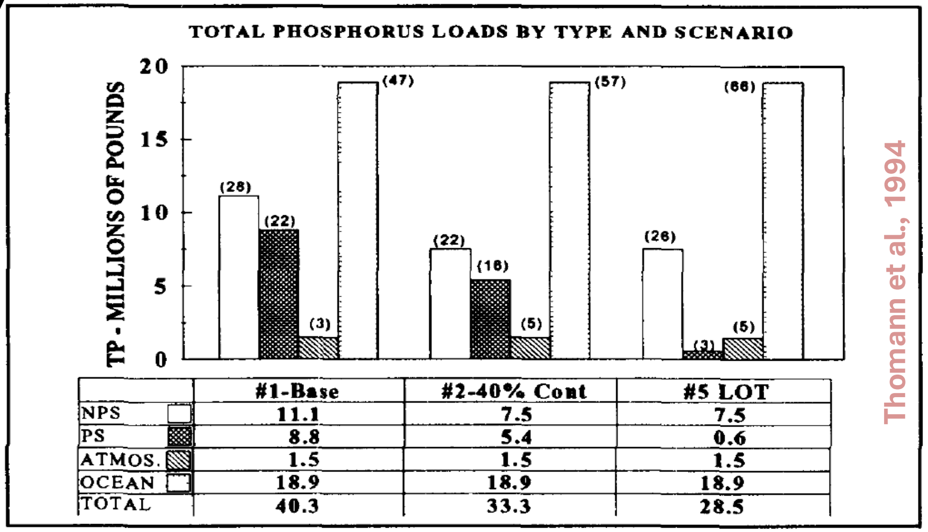
New CMAQ data in Phase 7 CBP Airshed N loads

- **Some of the issues that we are trying to tackle here include:**
  - **preparing atmospheric N inputs for the 1991 to 2000 short-term and 1985 to 2024 long-term model calibration periods.**
  - **leverage both existing CBP airshed model (1985-2014) and new CMAQ model (2002-2019) data.**
  - **expand the spatial coverage to generate inputs for the SCHISM domain that now extend beyond Chesapeake Bay into the Coastal Ocean.**
    - ***Calculated ocean nutrient input load is estimated to contribute about 30-35% of the total input nitrogen load and about 45-65% of the total input phosphorus load*** **(Thomann et al., CBP/TRS 101/94, April 1994)**
  - **We are proposing a spatial and trend analysis of CMAQ (2002-2019) data to produce simple relationships for expanding CBP airshed (1985-2014) data of Chesapeake Bay to the Coastal Ocean.**



	#1-Base	#2-40% Cont	#5 LOT
NPS	207.5	180.4	183.0
PS	86.8	53.4	17.0
ATMOS.	34.6	34.6	34.6
OCEAN	131.8	131.8	131.8
TOTAL	460.7	400.2	366.4

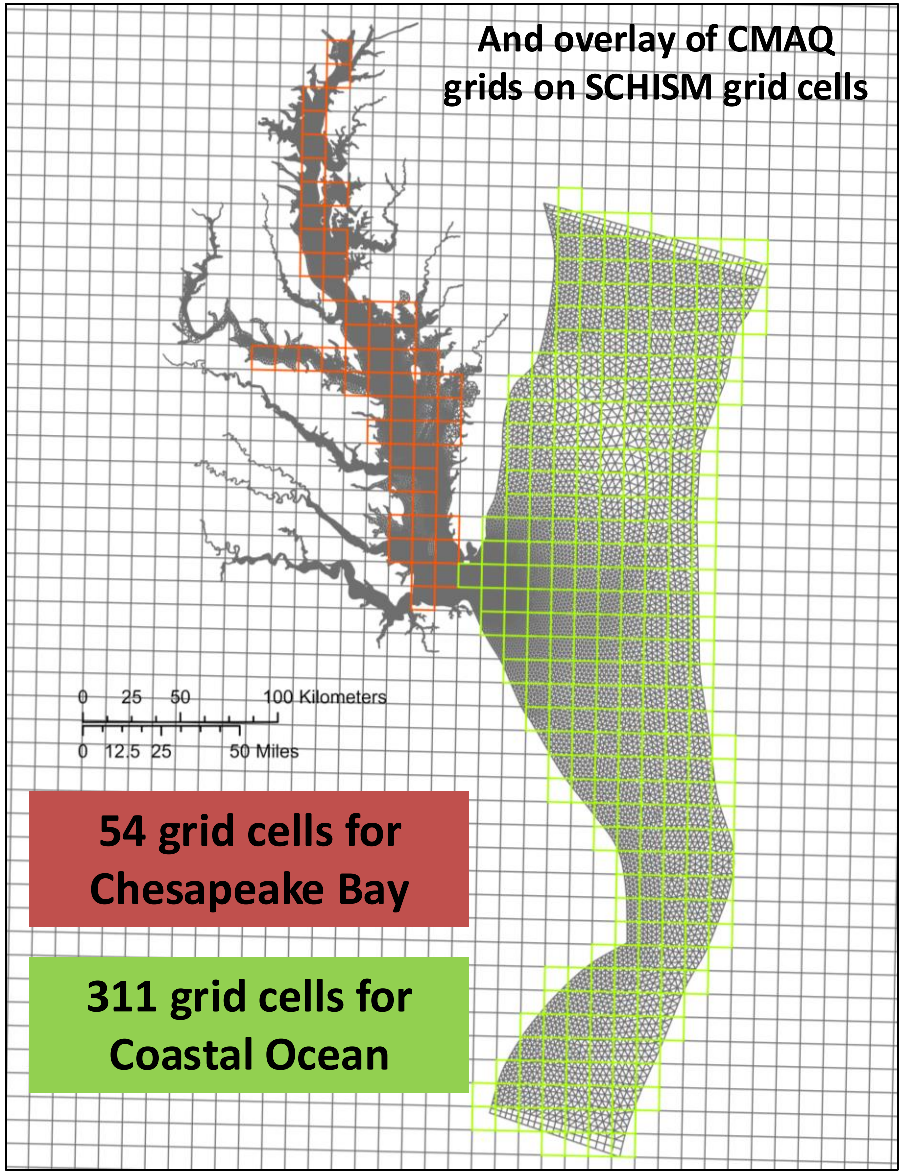
Ocean loading of TN is a significant component of the total load to the Bay and is estimated to range from 29% to 36% of the TN loading for Base to LOT.

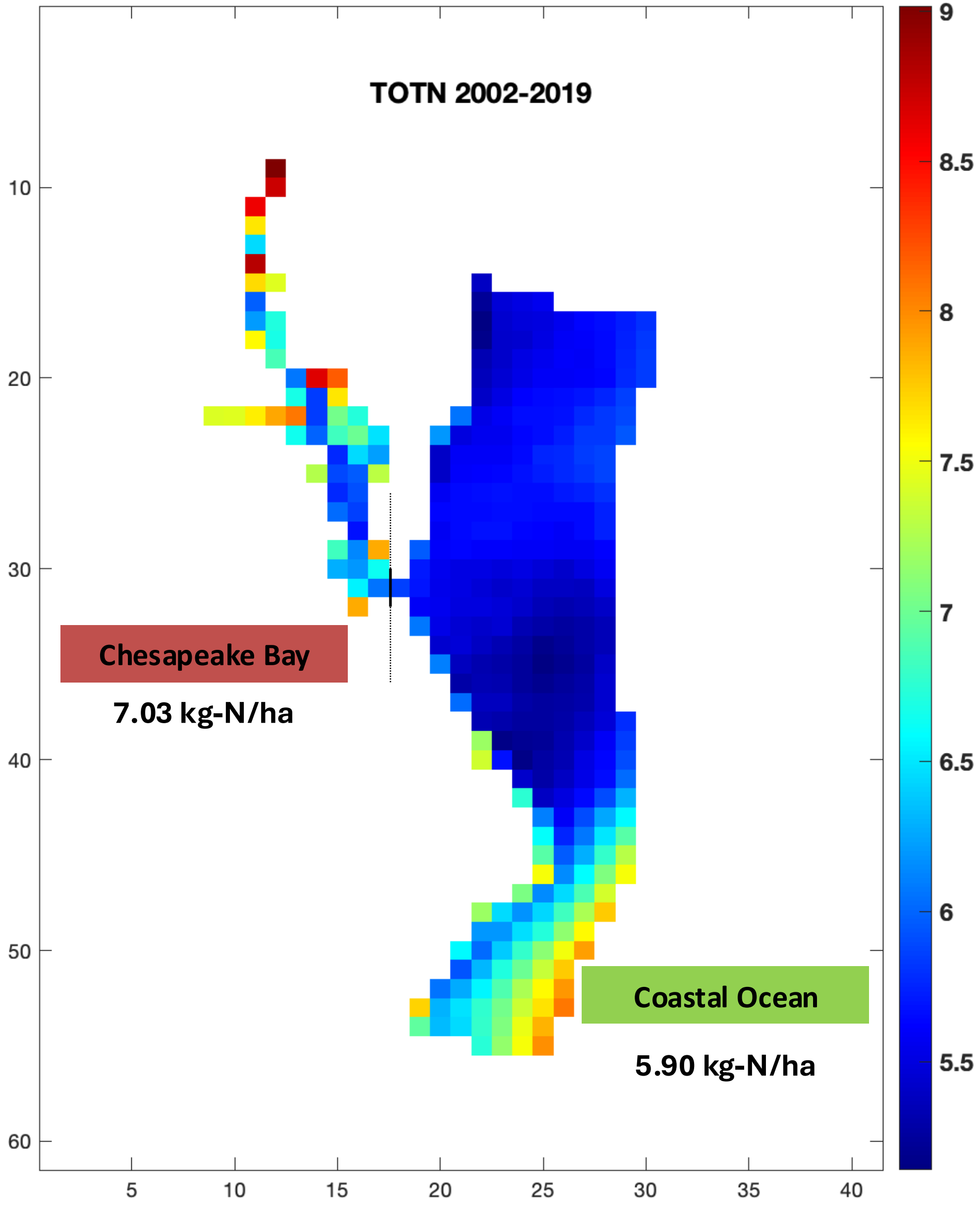


	#1-Base	#2-40% Cont	#5 LOT
NPS	11.1	7.5	7.5
PS	8.8	5.4	0.6
ATMOS.	1.5	1.5	1.5
OCEAN	18.9	18.9	18.9
TOTAL	40.3	33.3	28.5

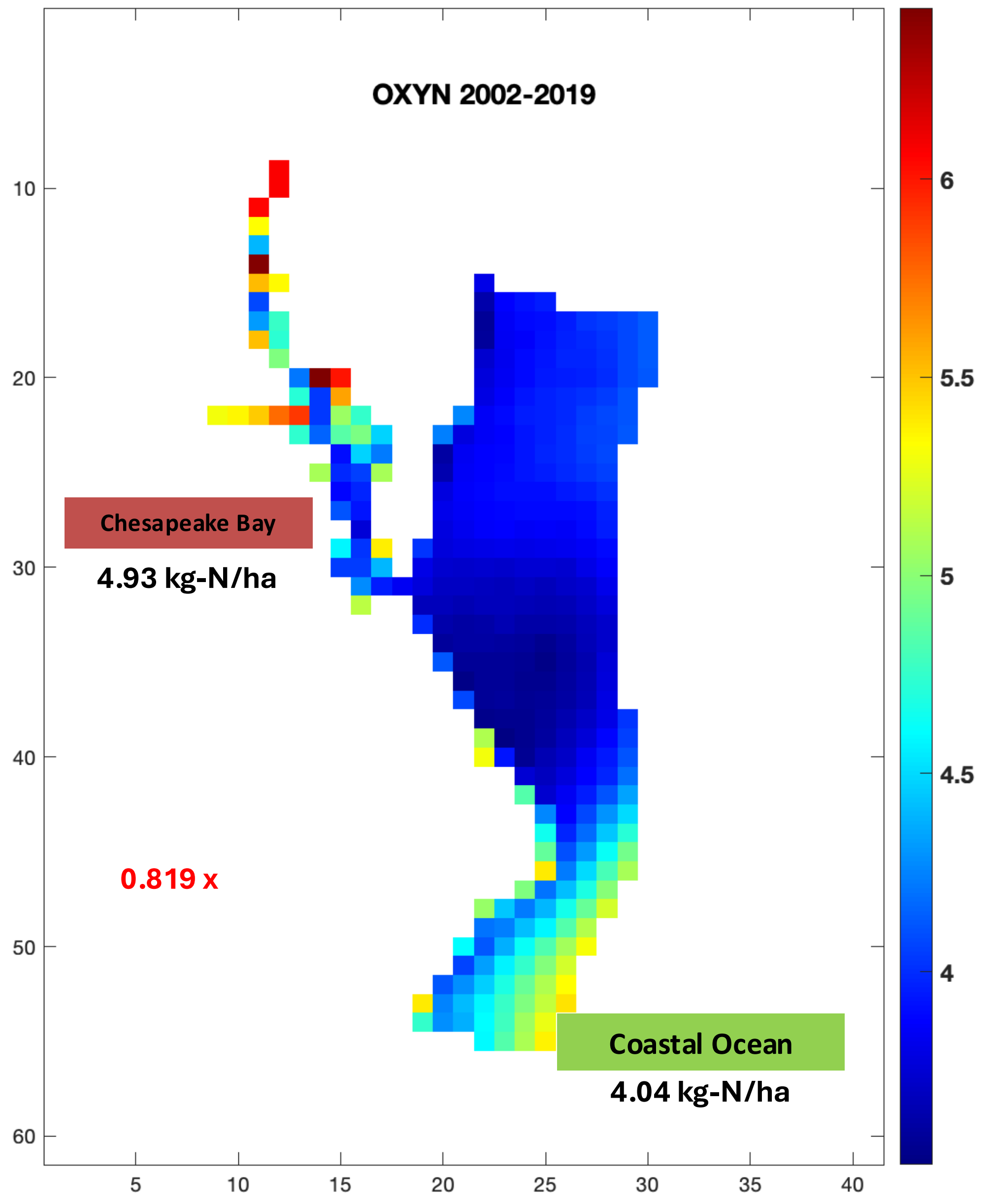
The ocean loading of TP dominates the loading inputs accounting for as much as 66% of the TP load at the LOT scenario.

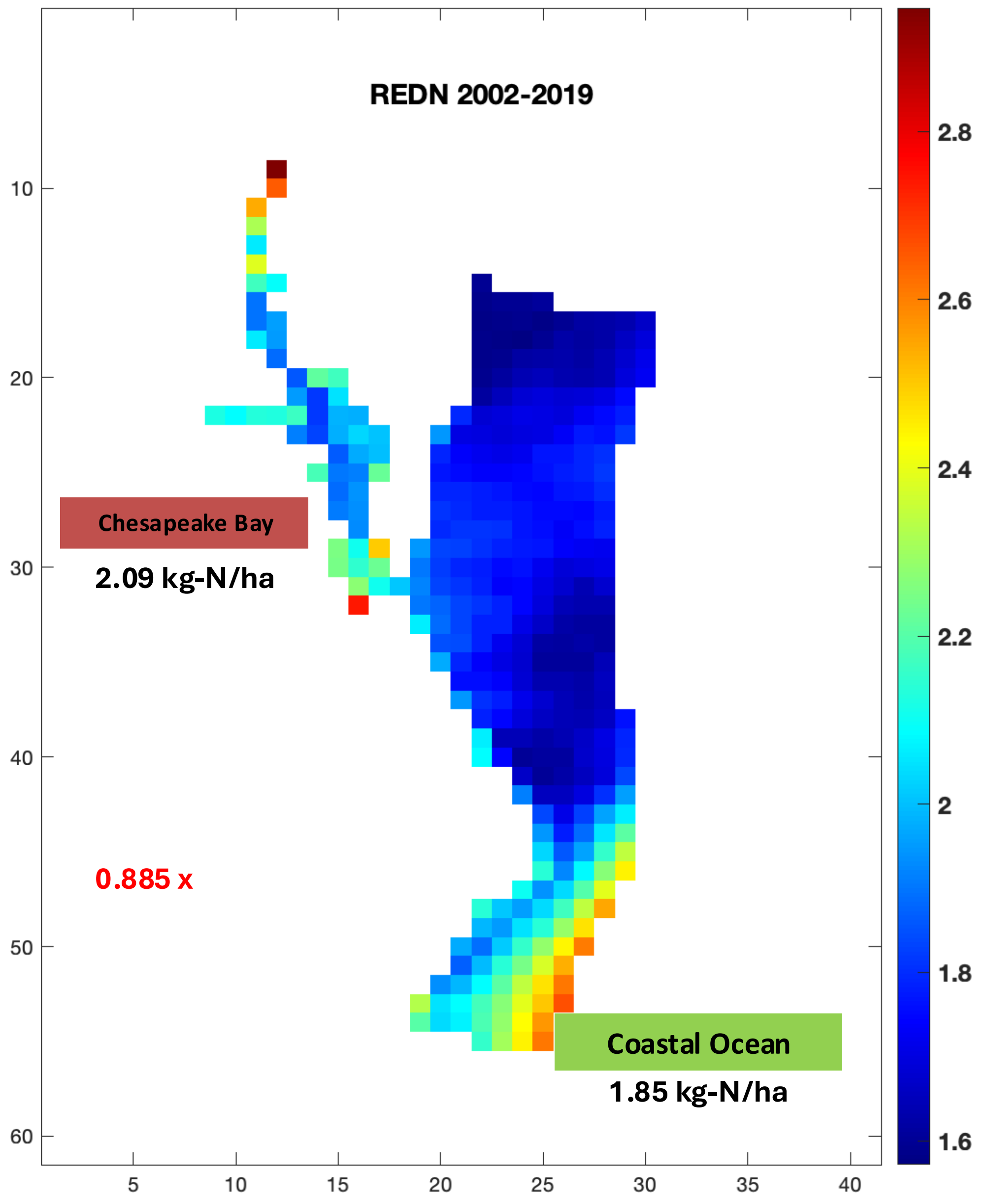
New CMAQ data in Phase 7 CBP Airshed N loads

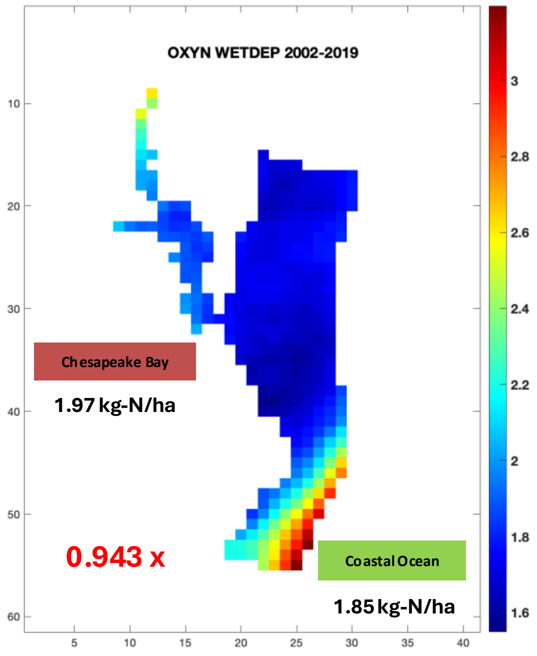


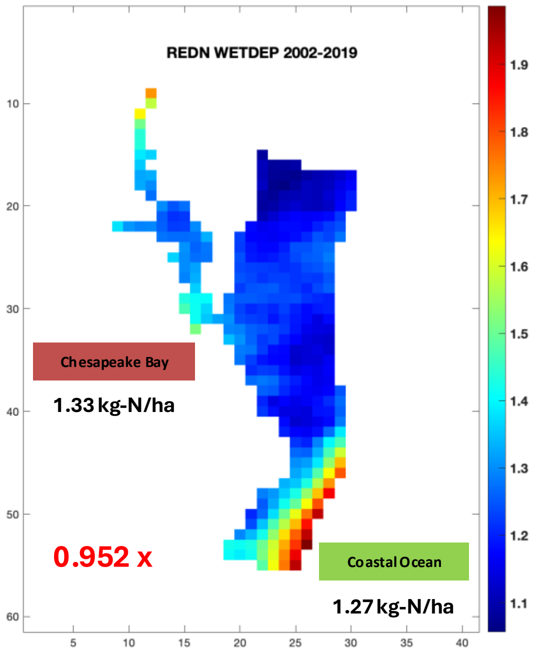


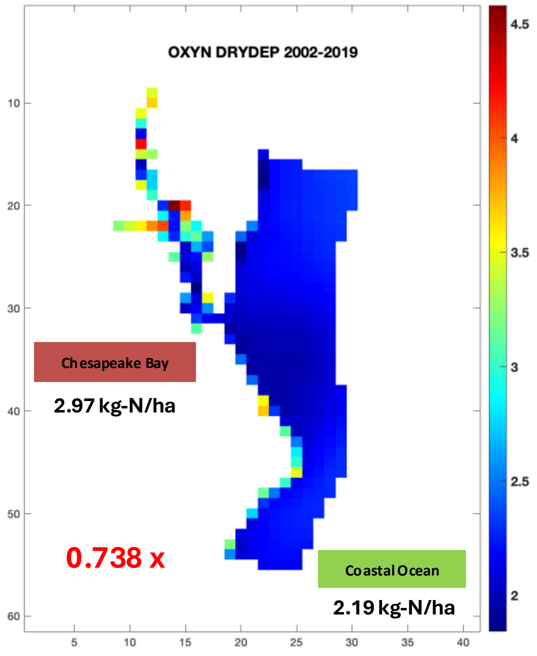
Coastal Ocean = 0.839 x Chesapeake Bay

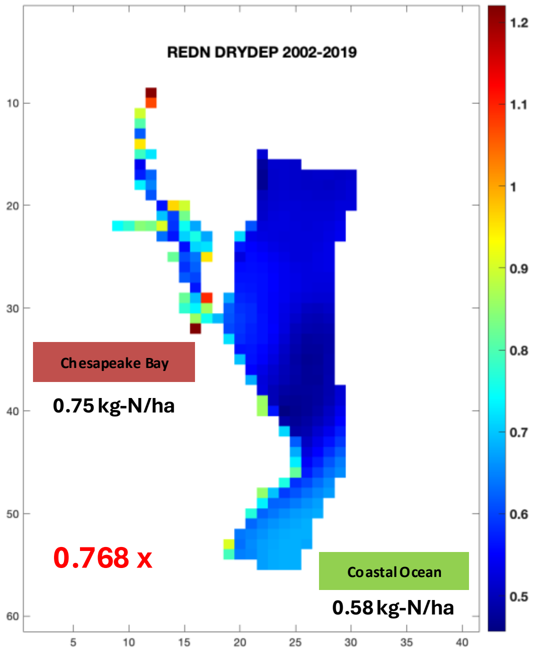

OXYN 2002-2019
Chesapeake Bay
4.93 kg-N/ha
0.819 x
Coastal Ocean
4.04 kg-N/ha


REDN 2002-2019
Chesapeake Bay
2.09 kg-N/ha
0.885 x
Coastal Ocean
1.85 kg-N/ha



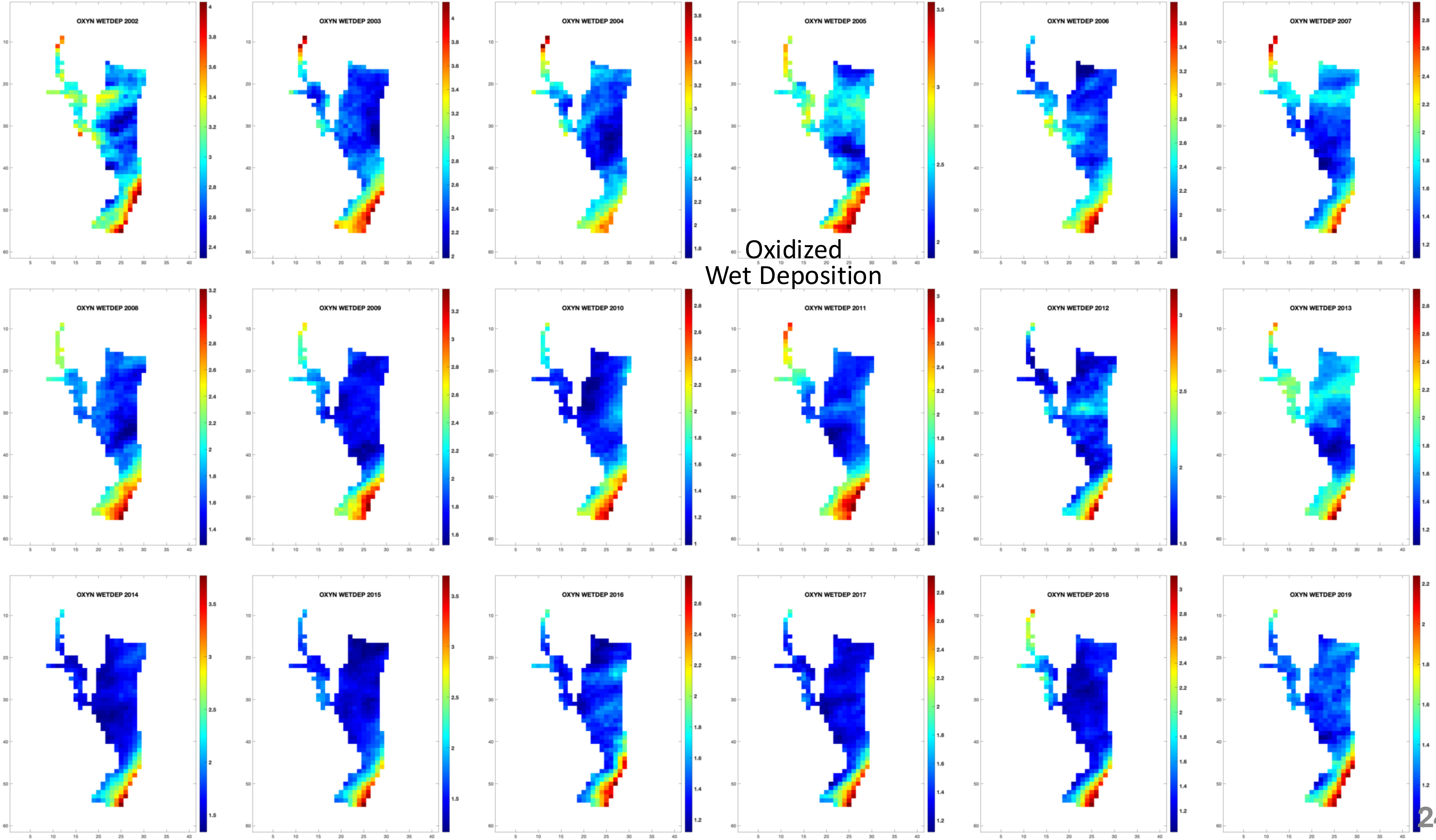




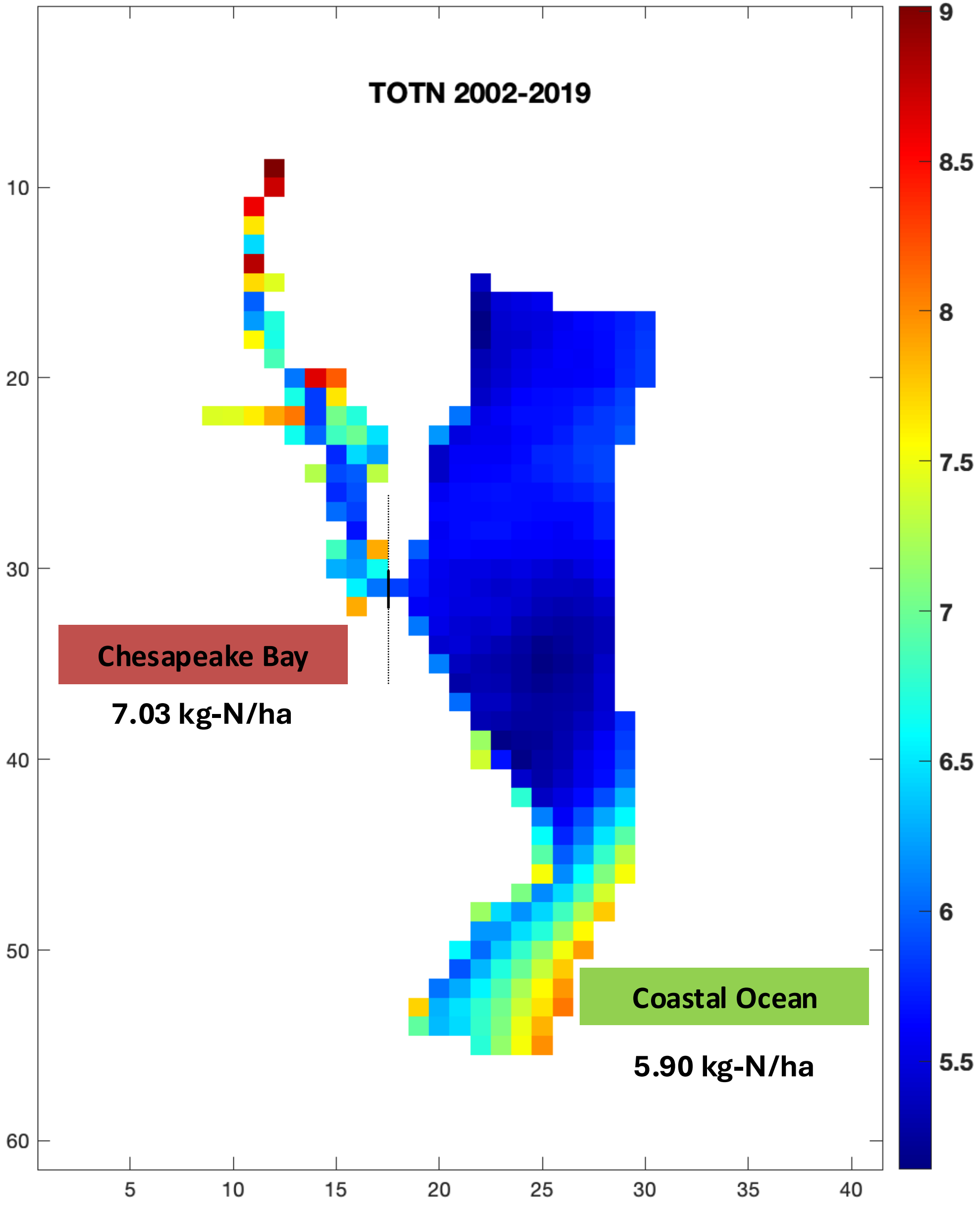


Spatial variability appears to be mainly due to that of wet depositions

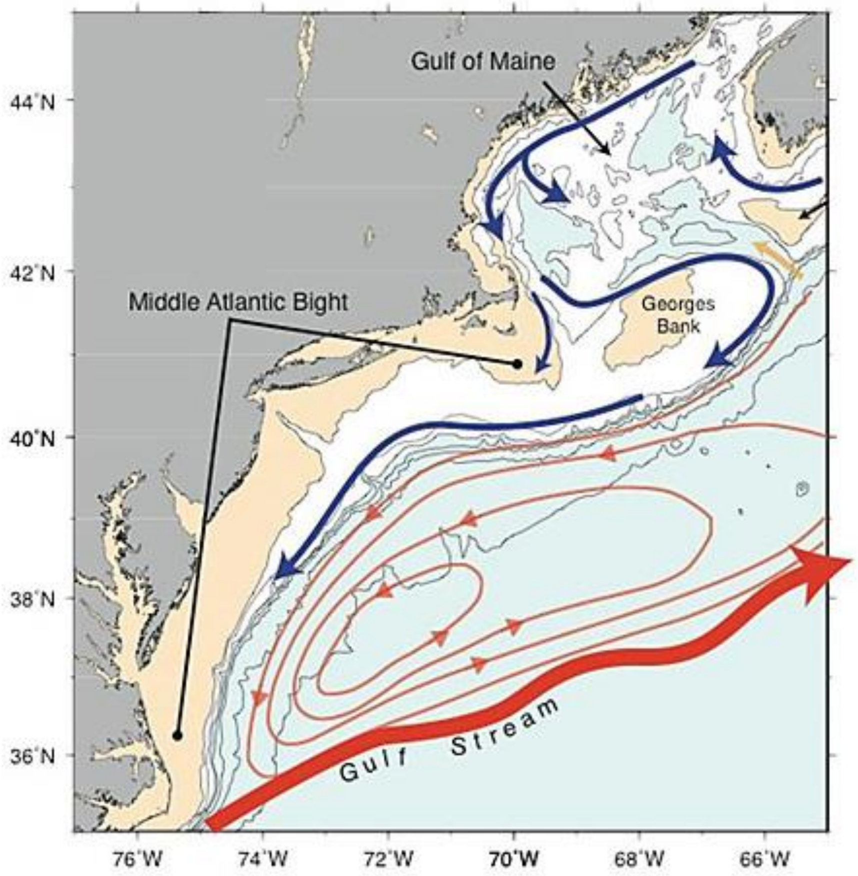
Oxidized Wet Deposition



New CMAQ data in Phase 7 CBP Airshed N loads



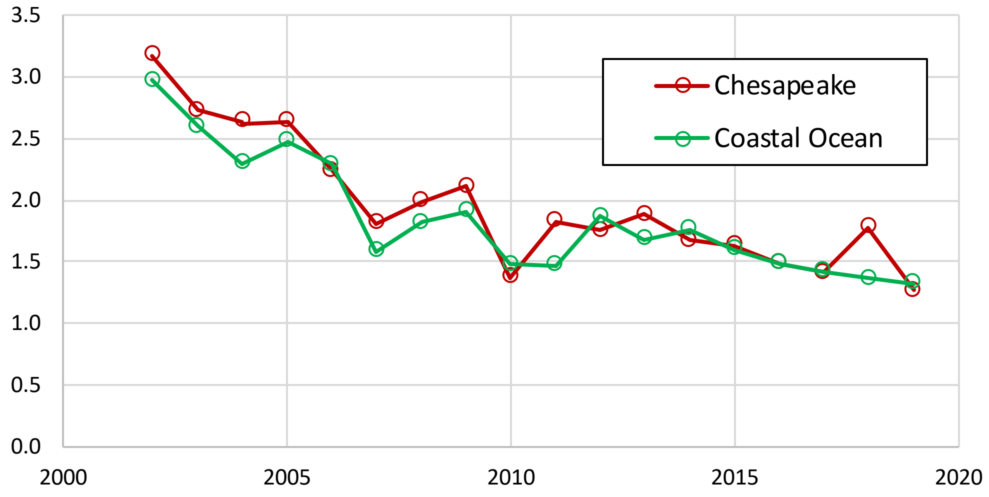
There is spatial variability in the TN deposition in the Coastal Ocean.



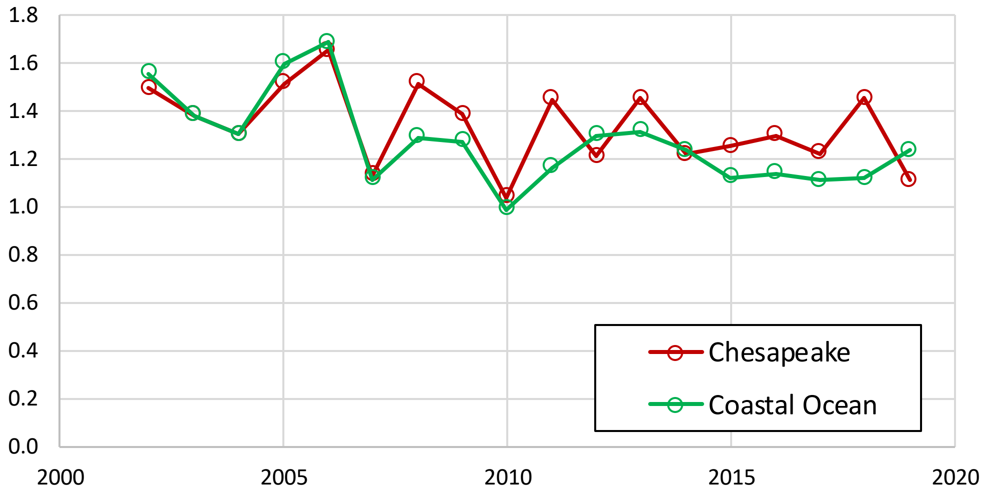
But due to prevalence of southward-flowing cool currents (blue) and warmer currents (red) associated with the Gulf Stream, higher deposition in the southern portion of Coastal Ocean may not have an impact on the Chesapeake Bay water quality.

Trend in CMAQ data (Chesapeake vs. Coastal Ocean)

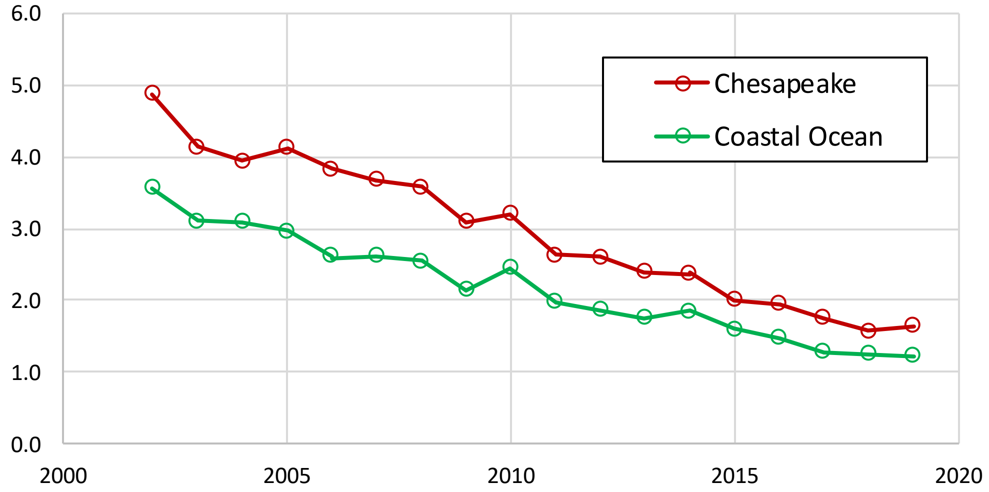
Oxidized Wet Deposition



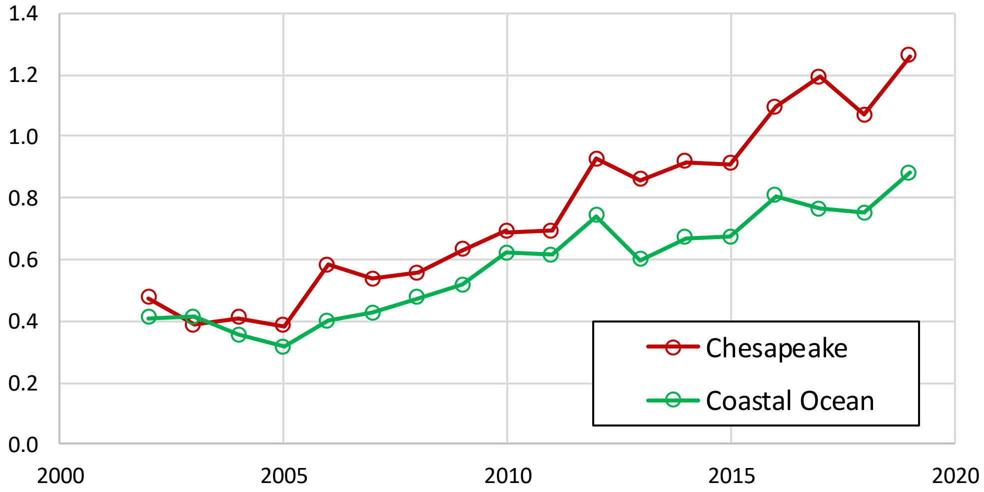
Reduced Wet Deposition



Oxidized Dry Deposition

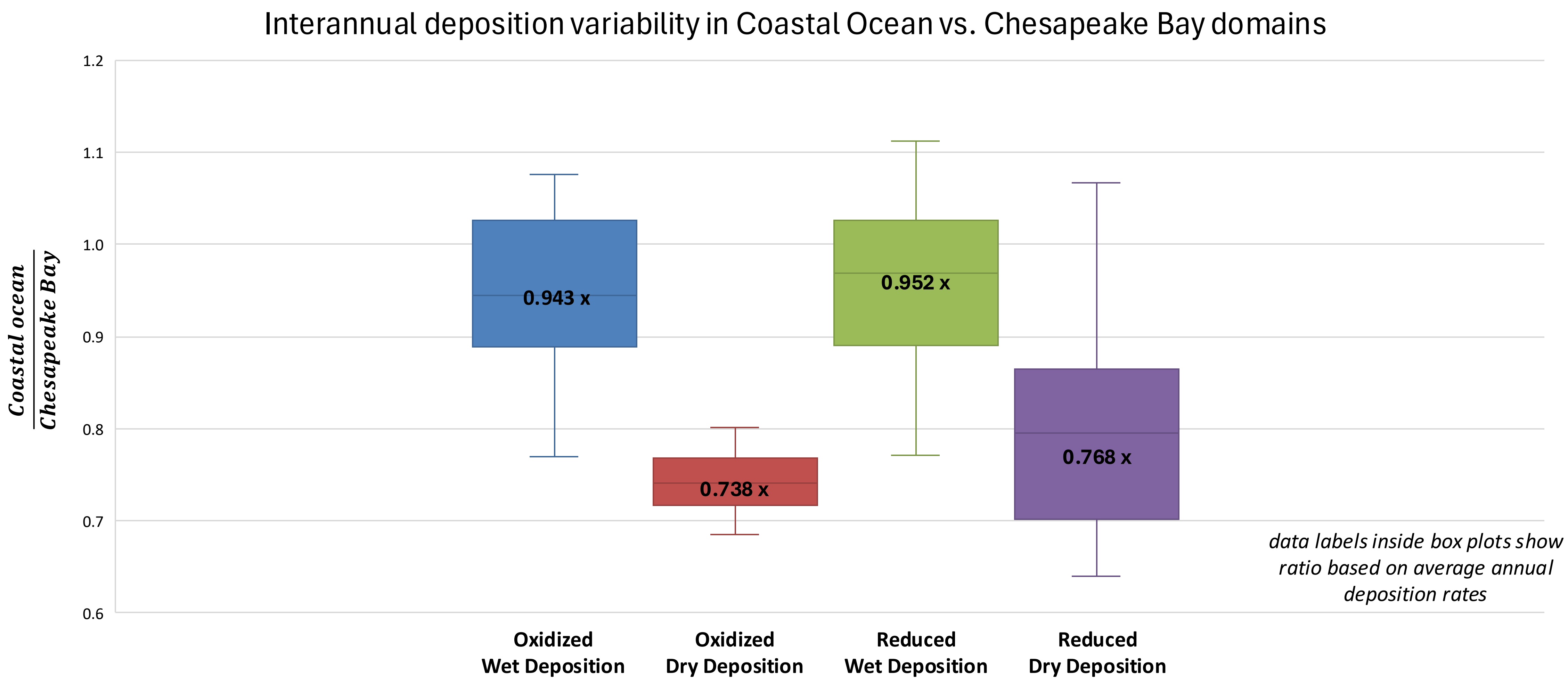


Reduced Dry Deposition



Trends in depositions over time are similar between Chesapeake and Coastal Ocean domains suggesting we may be able to use Chesapeake Bay trends for the Coastal Ocean.

Interannual variability (Coastal Ocean vs. Chesapeake Bay)



Other Phase 7 activities

- **We revised our beta model to include point source and septic loads at NHD scale.**
- **We made source code refinements as well.**
- **We also incorporated new CalCAST parameters.**
- **We are looking into improving the simulation of the November 1985 streamflow event in Potomac.**
  - It appears that rainfall adjustment that was applied in Phase 5 and Phase 6 is resulting in over estimation of simulated streamflow.
  - We generated a rainfall dataset without such adjustment but that resulted in substantial under simulation of streamflow.
- **We are working on refining our estimates of beta parameters.**

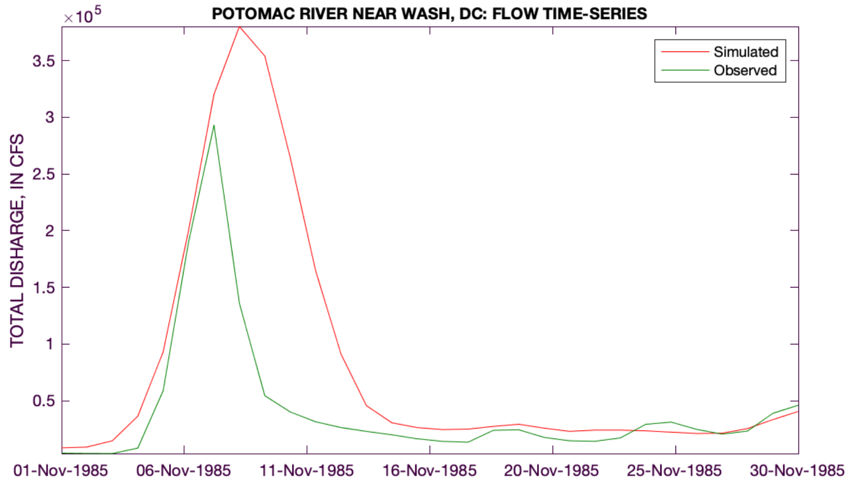


Figure: With November 1985 rainfall adjustment as applied in Phase 5 and Phase 6 DWSM resulted in over estimation of streamflow.

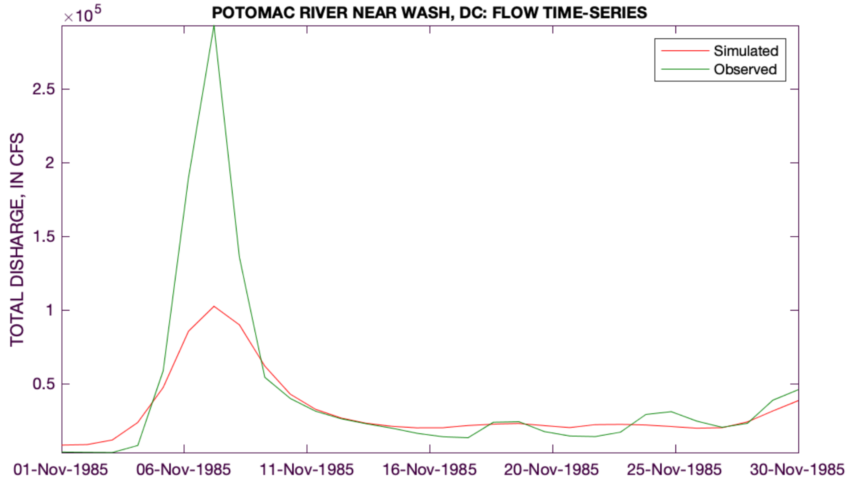


Figure: Without any November 1985 rainfall adjustment resulted in substantial underestimation of streamflow.

Summary

1. We developed 3 versions of incrementally refined loads data for linking watershed model flows and loads with the estuarine model given the stage of our models and inputs.

- we will continue making progress on multiple fronts (DWSM refinements, new CalCAST data, CMAQ inputs, etc.)
- and on our collaborations with the MBM team on model linkages

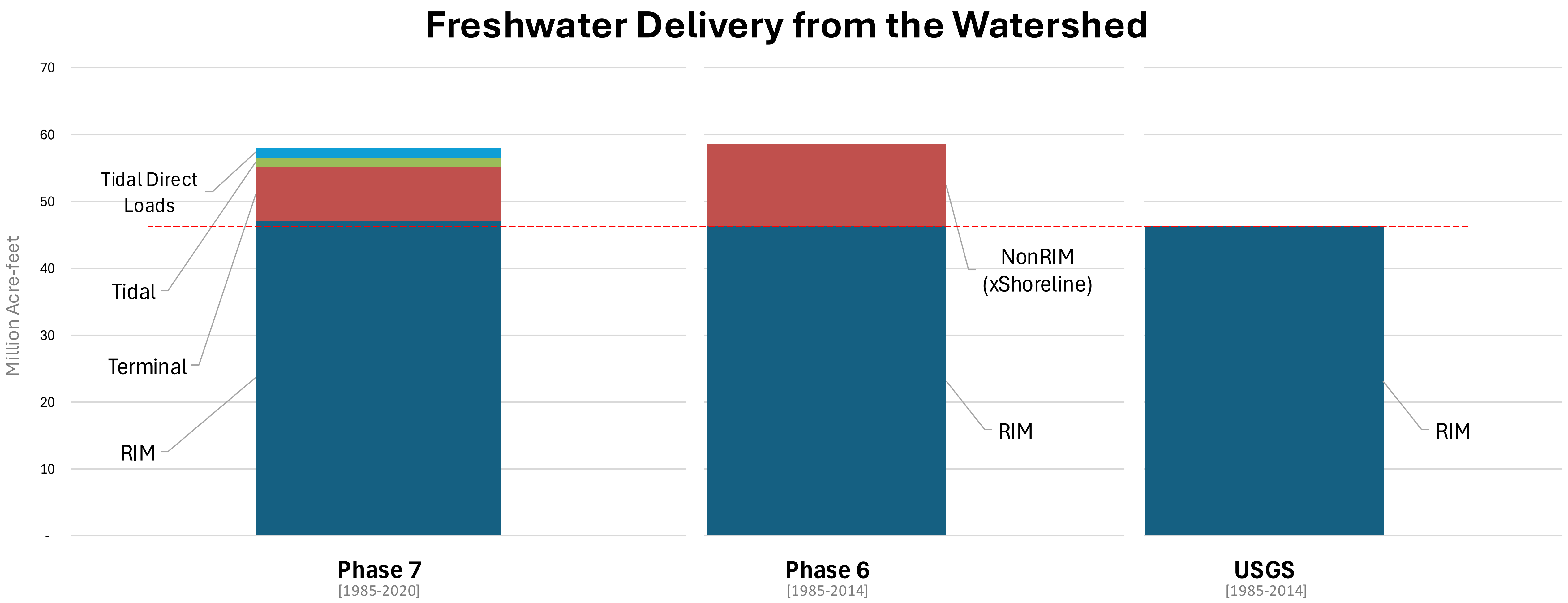
>> Next Steps for the Phase 7 Dynamic Watershed Model (DWSM)

2. We need to continue to incrementally improve the model on multiple fronts: (a) incorporation of new inputs where appropriate; (b) model parameters; (c) calibration methods and processes; (d) linkage with the MBM and MTMs.

Appendices

Freshwater Delivery from the Watershed

[1] October 2024 | The model version that we presented to the Modeling Workgroup



Showing "Tidal Direct Loads" from Phase 6 were not included in this P7 beta version

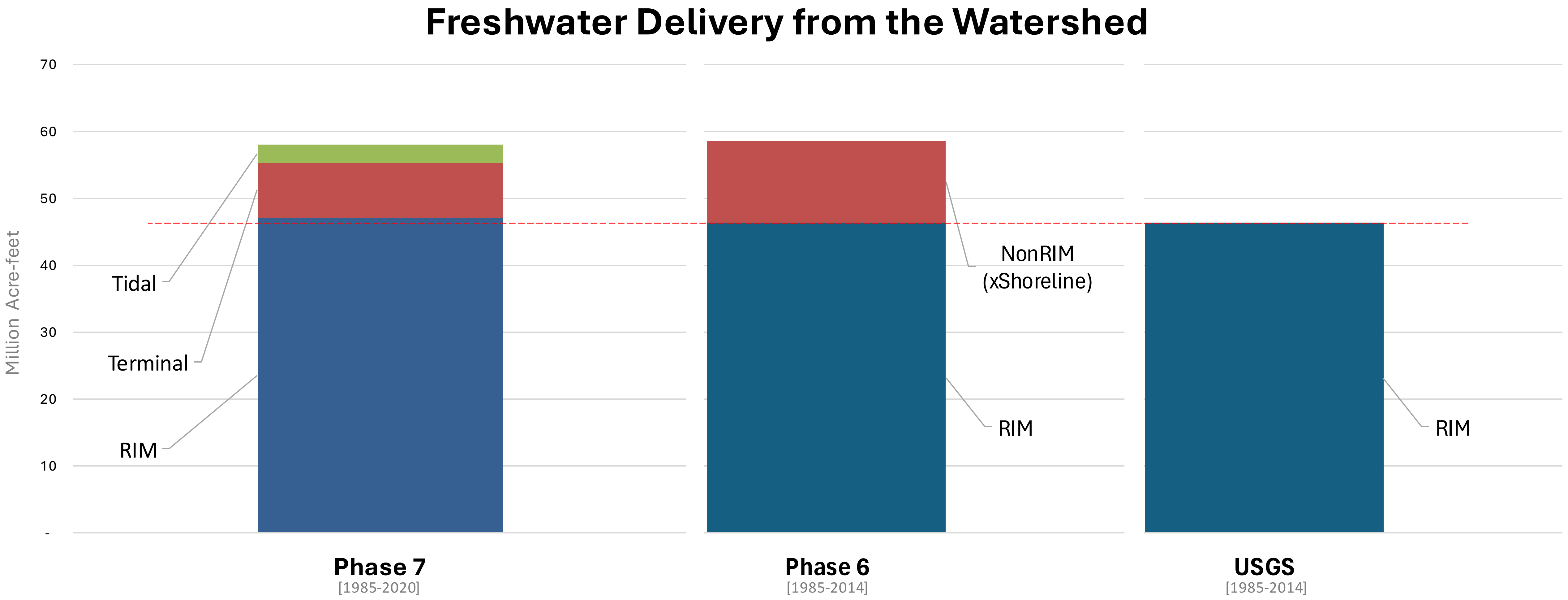
1985-2020 P7 beta version; 1985-2014 for Phase 6; 1985-2014 for WRTDS

Δ total $P7_\beta$ vs. P6 = -3%

Δ total $P7_\beta$ + P6 Tidal Direct Loads vs. P6 = -1%

[2] November 2024

NHD scale point source inputs and a few minor model refinements

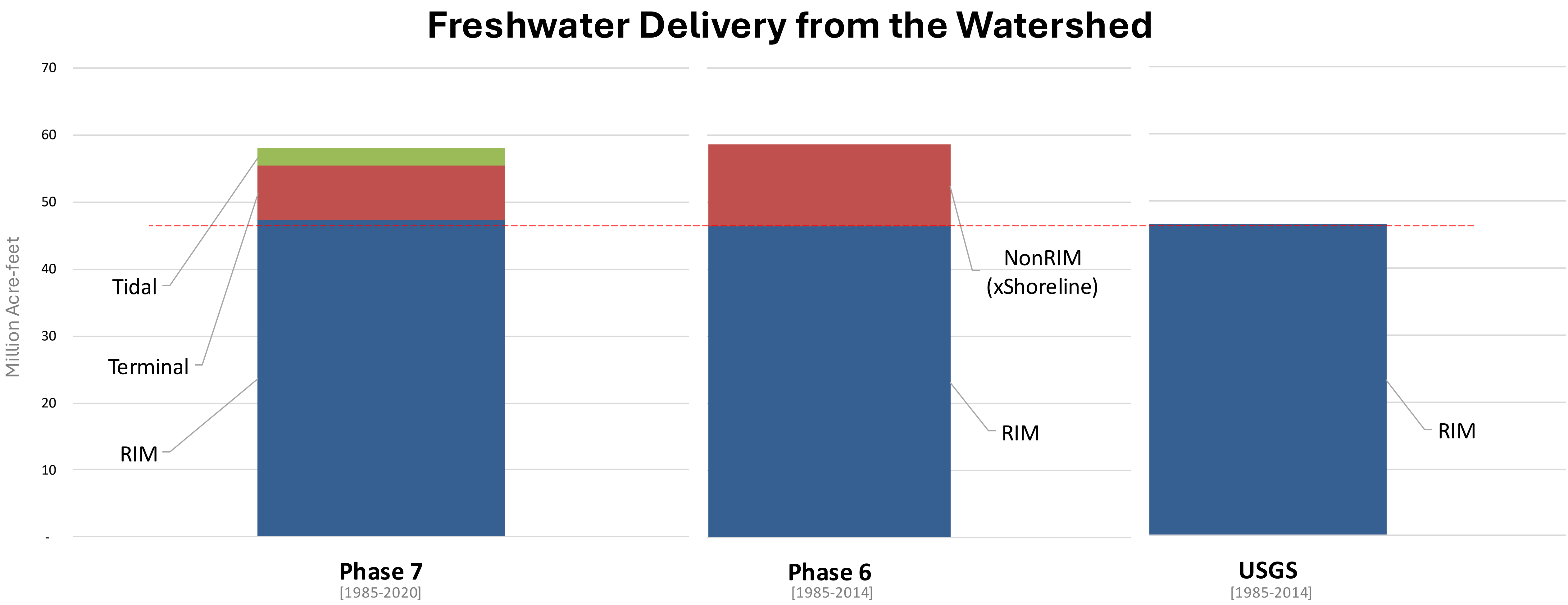


"Tidal Direct Loads" are now included in Phase 7 DWSM

Δ total $P7_{\beta}$ vs. P6 = -1%

[3] December 2024

Updated CalCAST parameters (v20241031) + DWSM recalibration

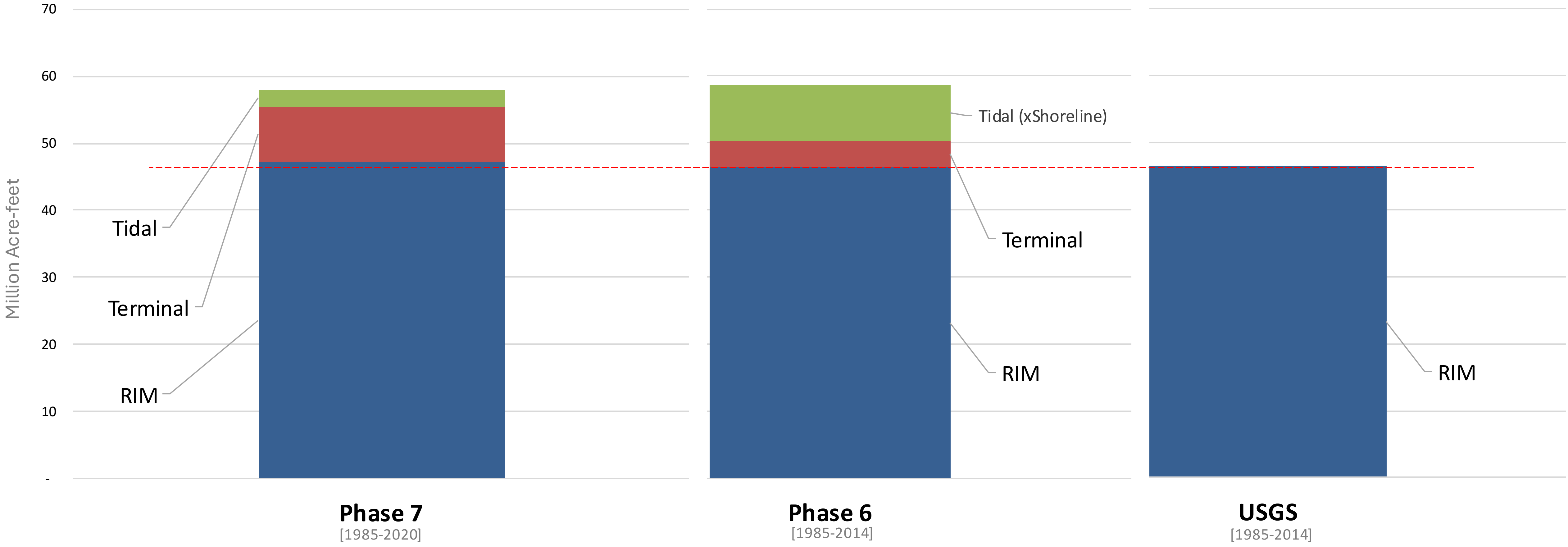


Δ total $P7_{\beta}$ vs. P6 = -1%

[3] December 2024

Updated CalCAST parameters (v20241031) + DWSM recalibration

Freshwater Delivery from the Watershed



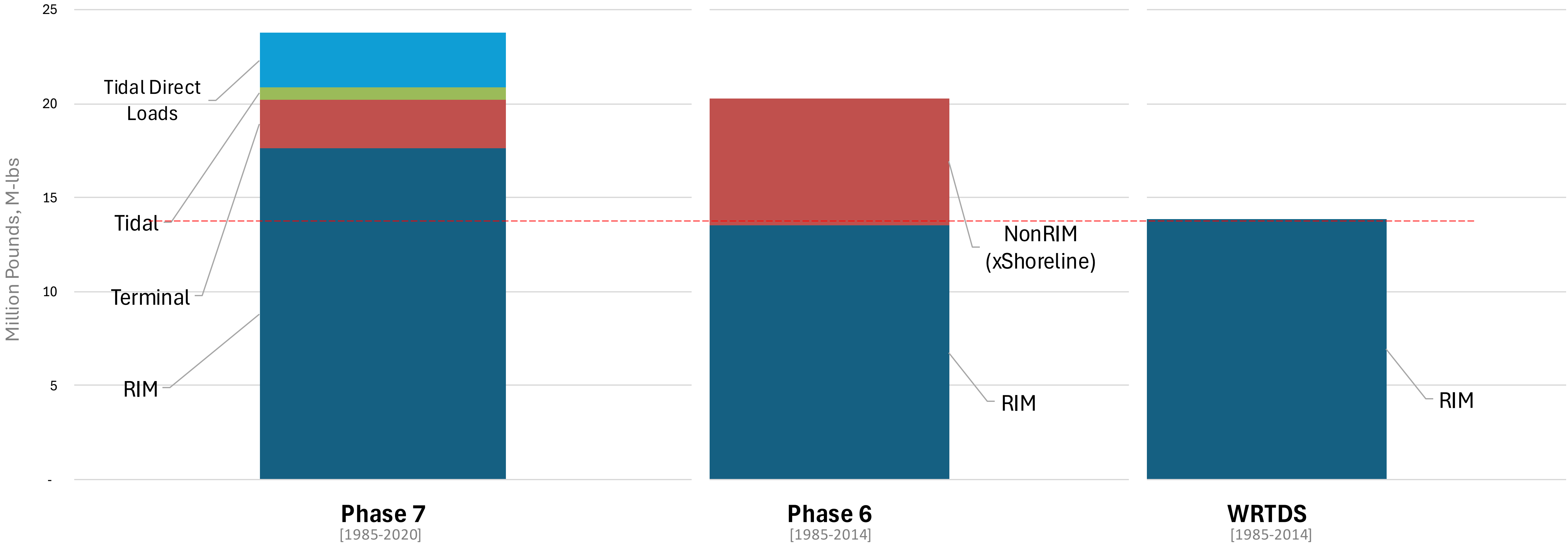
Δ total $P7_{\beta}$ *vs. P6 = -1%*

Total Phosphorus Delivery from the Watershed

[1] October 2024

The model version that we presented to the Modeling Workgroup

Total Phosphorus Delivery from the Watershed



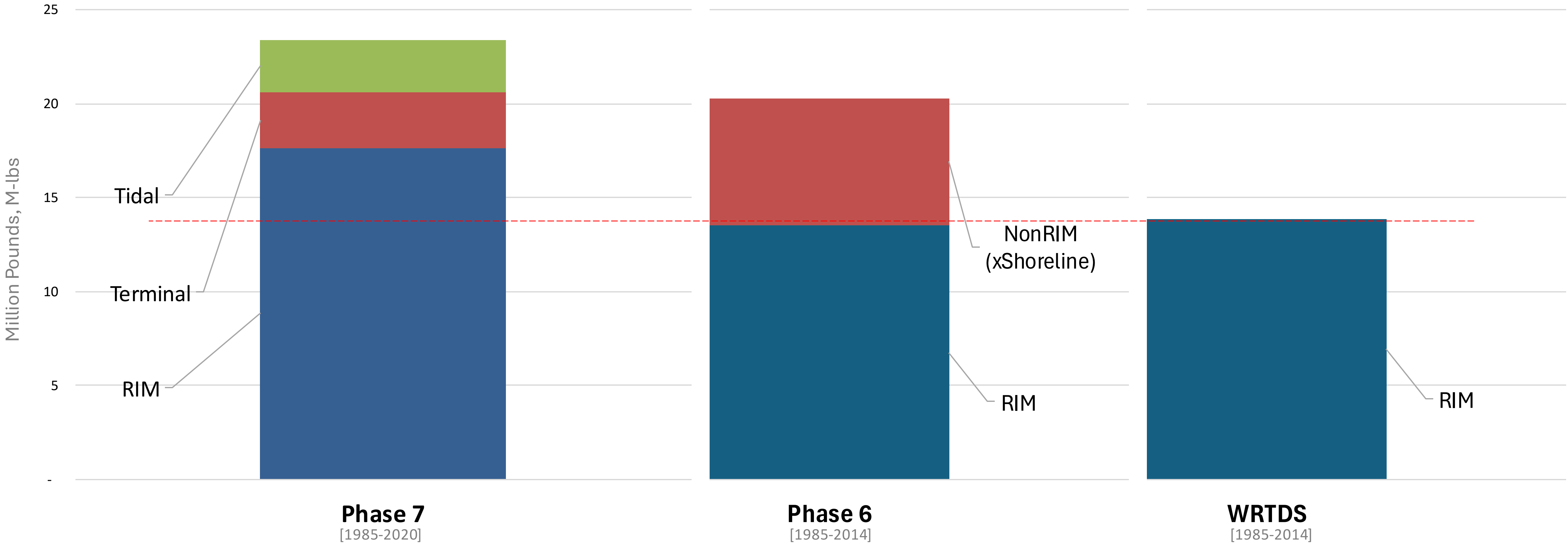
"Tidal Direct Loads" is currently not included in Phase 7 DWSM

Δ total $P7_{\beta}$ vs. P6 = +3%

Δ total $P7_{\beta}$ + P6 Tidal Direct Loads vs. P6 = +17%

[2] November 2024 NHD scale point source inputs and a few minor model refinements

Total Phosphorus Delivery from the Watershed



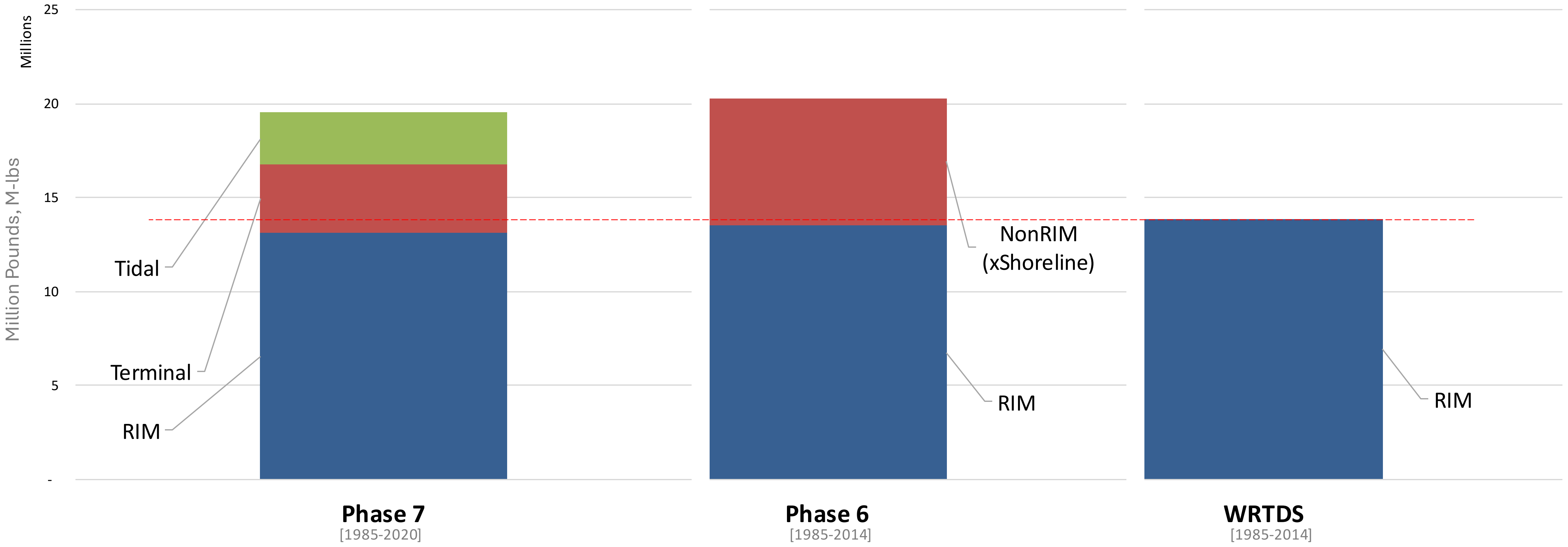
"Tidal Direct Loads" are now included in Phase 7 DWSM

Δ total $P7_{\beta}$ vs. P6 = +15%

[3] December 2024

Updated CalCAST parameters (v20241031) + DWSM recalibration

Total Phosphorus Delivery from the Watershed

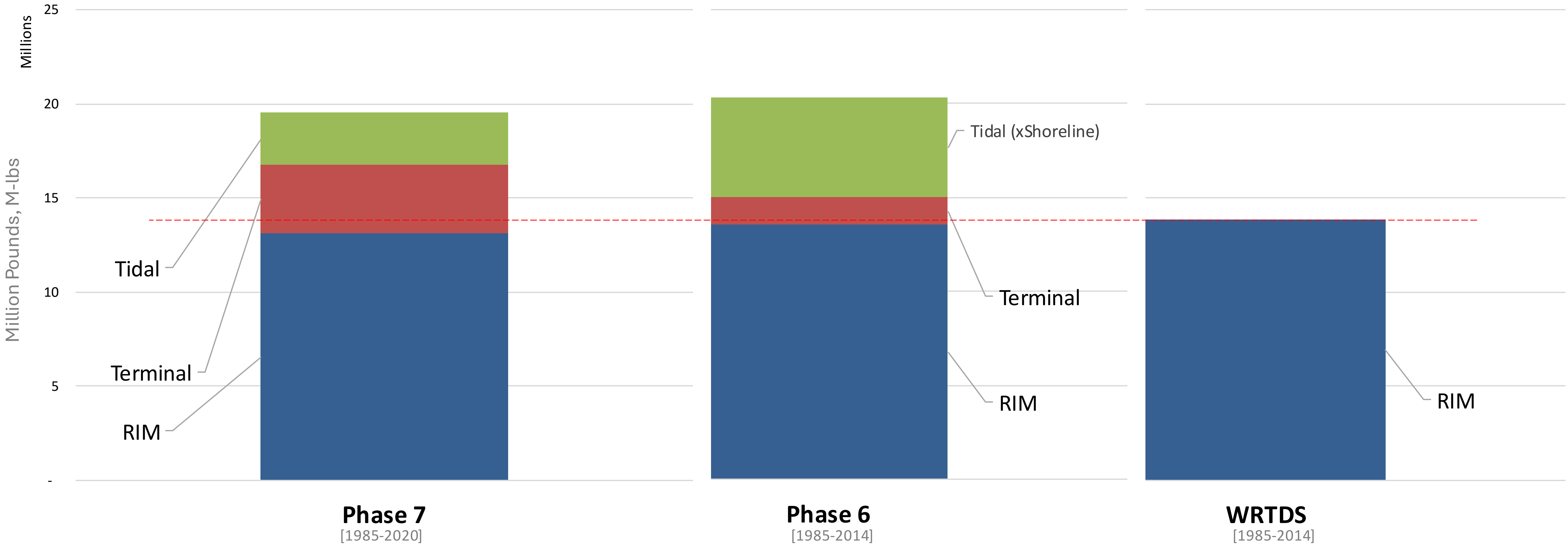


Δ total P7$_\beta$ *vs. P6 = -4%*

[3] December 2024

Updated CalCAST parameters (v20241031) + DWSM recalibration

Total Phosphorus Delivery from the Watershed

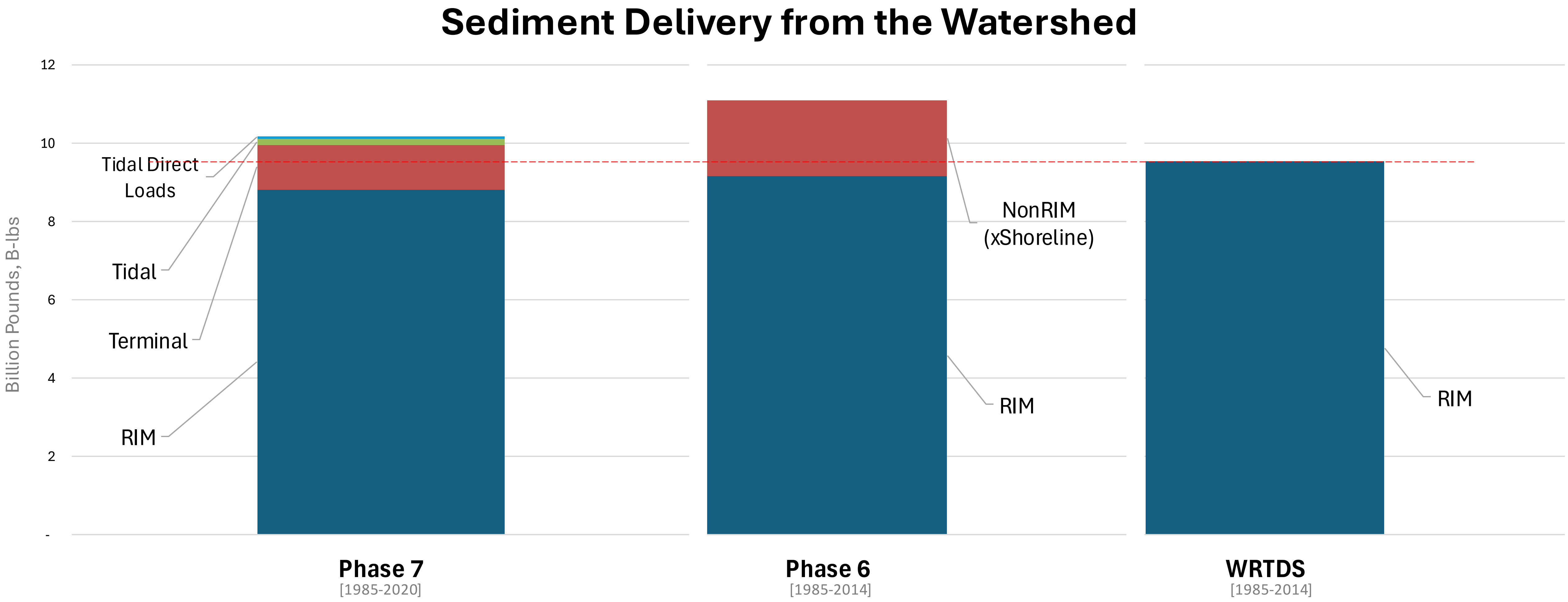


Δ total $P7_{\beta}$ vs. P6 = -4%

Sediment Delivery from the Watershed

[1] October 2024

The model version that we presented to the Modeling Workgroup



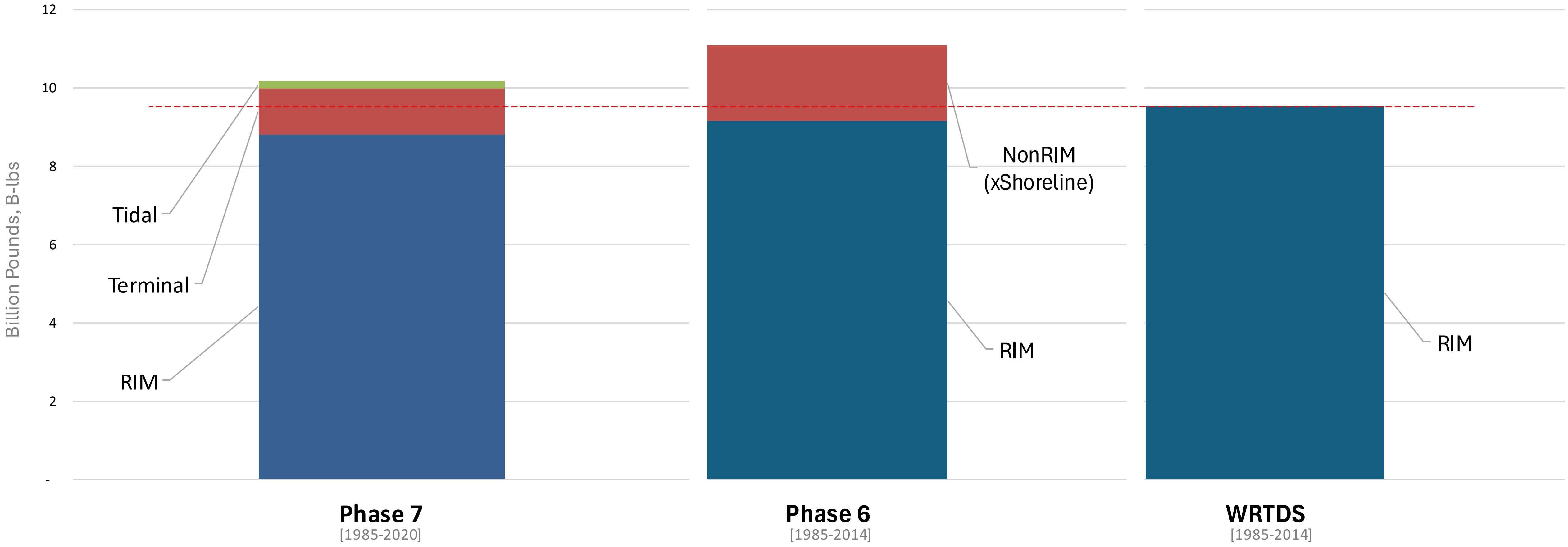
"Tidal Direct Loads" is currently not included in Phase 7 DWSM

Δ total $P7_\beta$ vs. P6 = -9%

Δ total $P7_\beta$ + P6 Tidal Direct Loads vs. P6 = -8%

[2] November 2024 NHD scale point source inputs and a few minor model refinements

Sediment Delivery from the Watershed

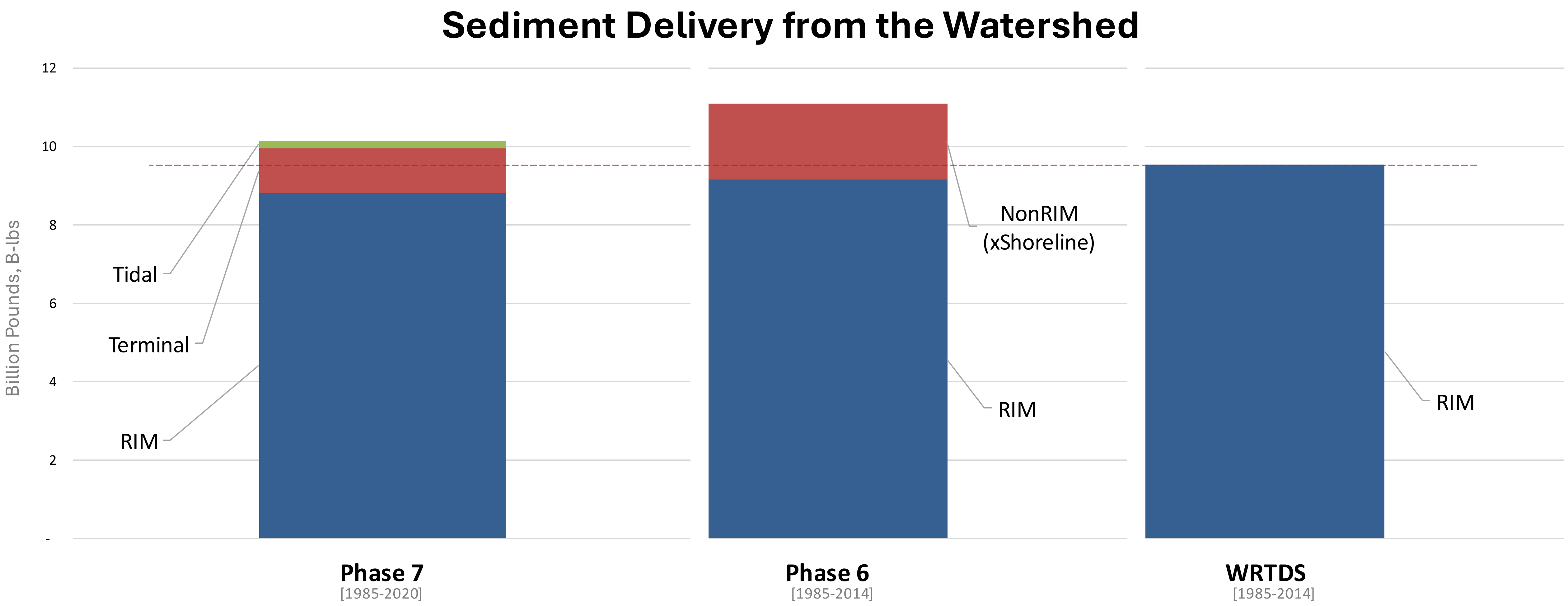


"Tidal Direct Loads" are now included in Phase 7 DWSM

Δ total $P7_{\beta}$ vs. P6 = -8%

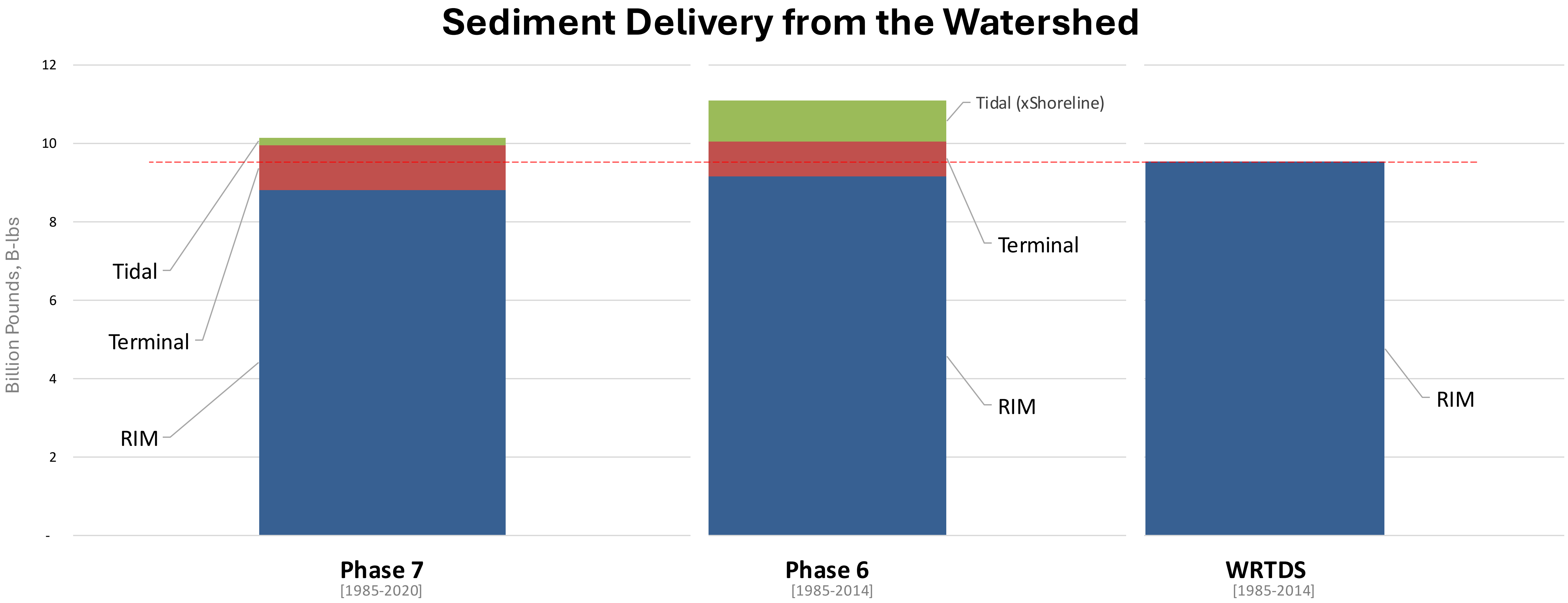
[3] December 2024

Updated CalCAST parameters (v20241031) + DWSM recalibration



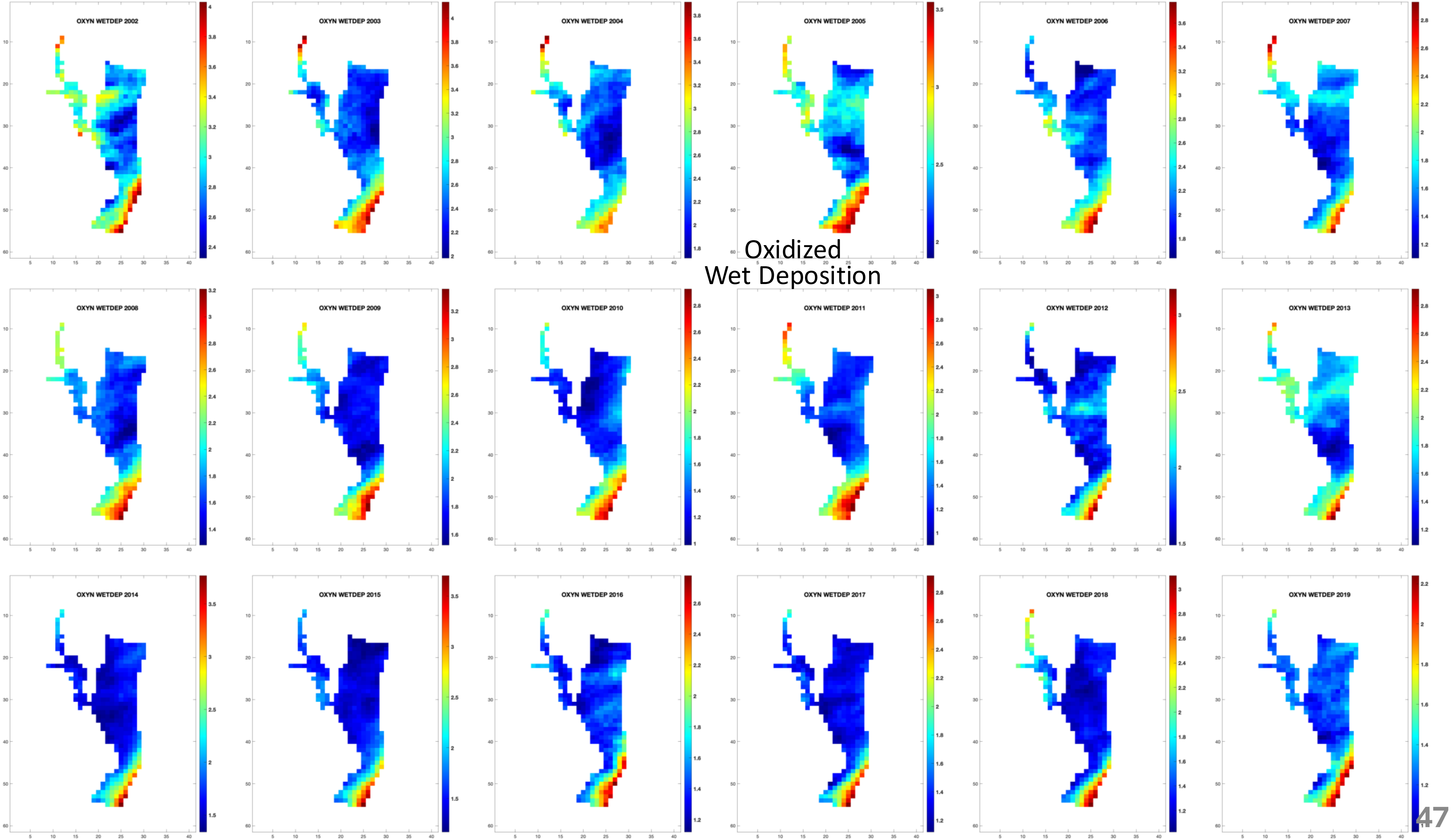
Δ total $P7_{\beta}$ vs. P6 = -8%

[3] December 2024 | Updated CalCAST parameters (v20241031) + DWSM recalibration

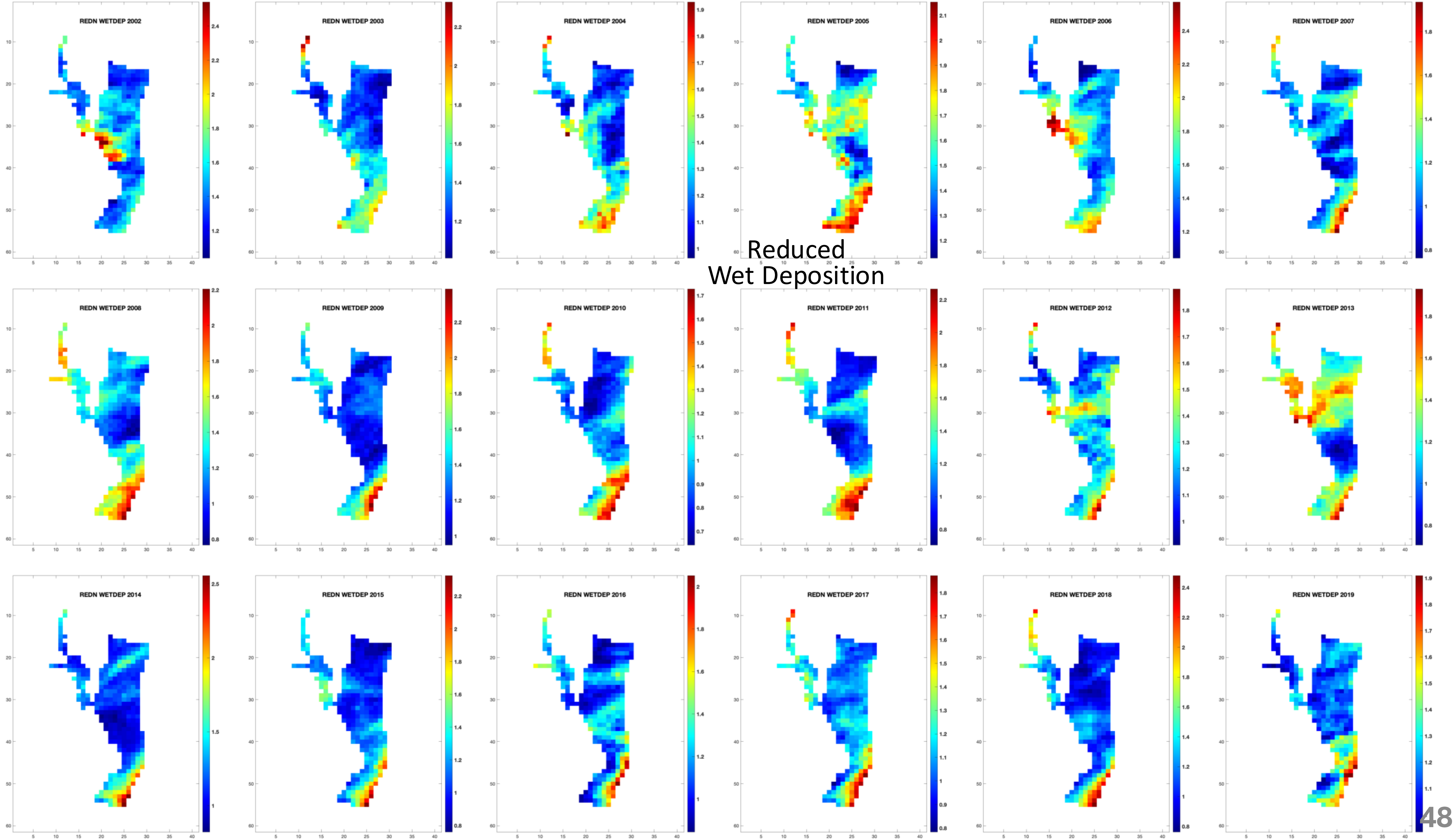


Δ total P7$_\beta$ vs. P6 = -8%

Oxidized
Wet Deposition



Reduced Wet Deposition



>> Next Steps for the Phase 7 Dynamic Watershed Model (DWSM)

1. Inputs:

▪ Direct loads – change ~~point sources~~, diversions/withdrawals, and ~~septic from P6 river segment scale to NHD (missing tidal direct loads)~~; ~~add flow with septic~~ (load sensitivity to future climate); treatment of withdrawals in small stream modules and tidal areas with direct discharge to the Bay;▪ Effect of best management practices; ▪ Replace use of 12 landcover classes fixed in time (inputs do change over time); ▪ Water quality monitoring data and WRTDS (WRTDS-K);

2. Model parameters:

- Beta parameters for flow and seasonal variability; transfer of loading trends from land to stream routing modules; ~~CalCAST parameters~~;

3. Calibration:

- Calibration methods and watershed processes (e.g., hydrologic simulation anomalies; Conowingo infill; module for source of organic nutrients);