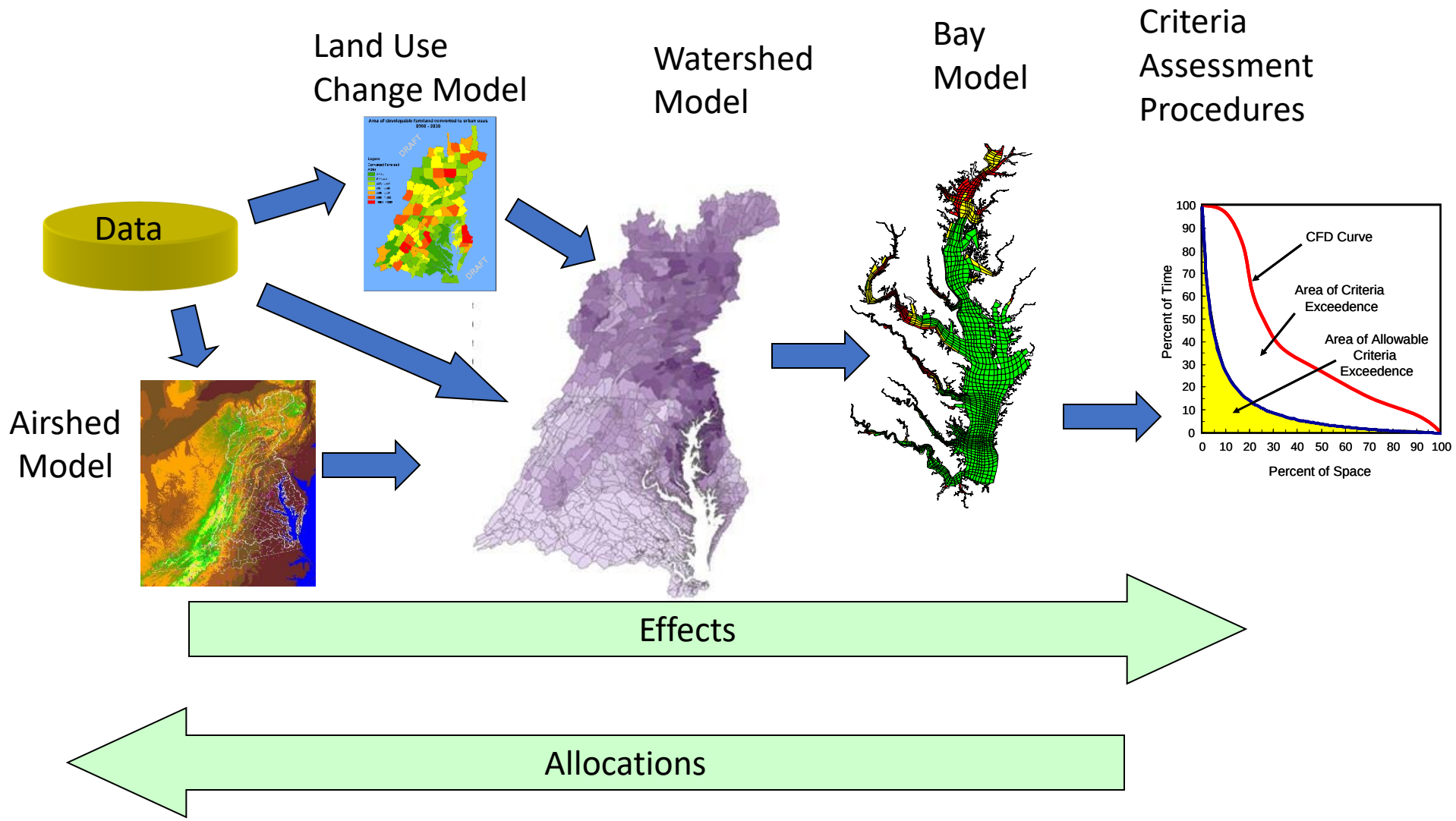
Uncertainty Quantification and Use in TMDL models

WQGIT 1/22/2024

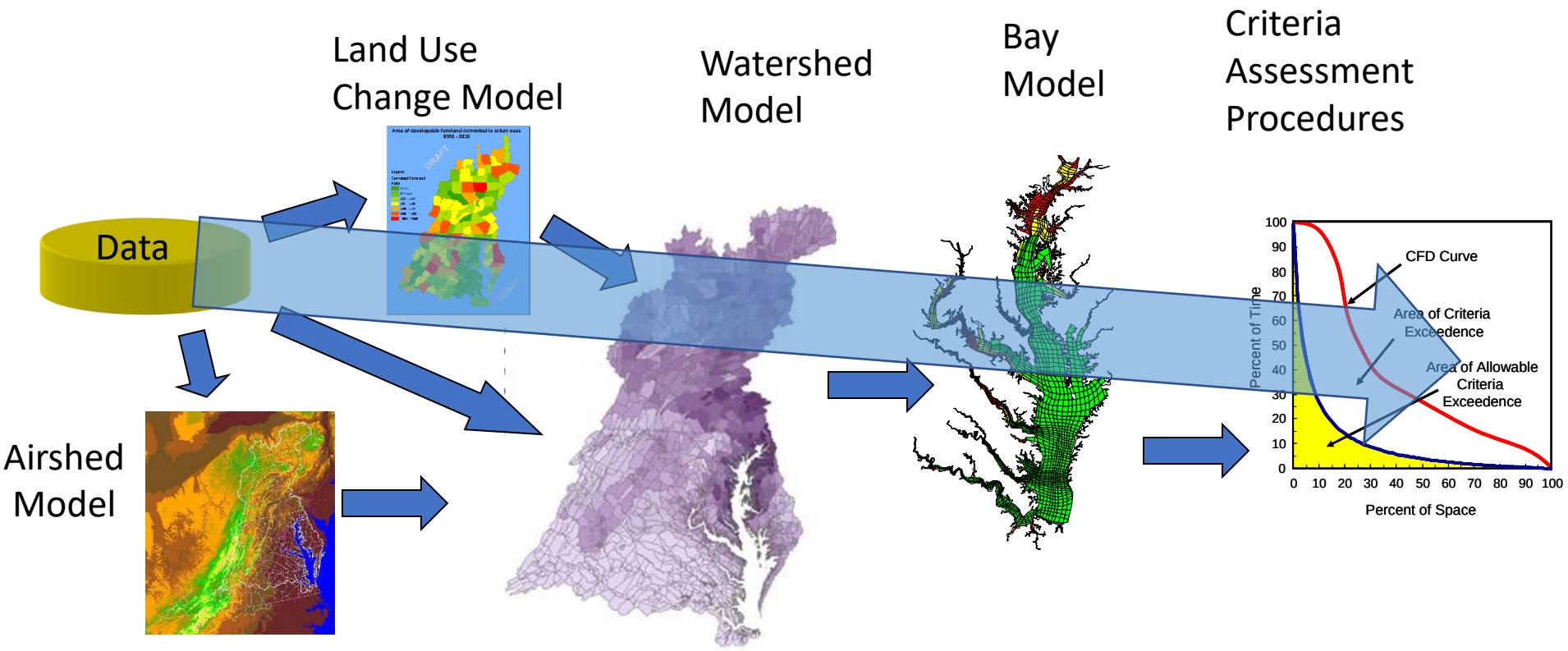
STAC Requests for Uncertainty Analysis

- 2017 BMP uncertainty workshop
- 2017 optimization workshop
- 2017 Watershed model Review
- 2008 Watershed model Review
- 2008 Modeling in the Chesapeake Bay Program: 2010 and Beyond
- 2005 Watershed model Review
- 2016 Climate Workshop
- 2014 Phosphorus dynamics Review
- 2014 Conowingo Workshop
- 2013 multiple models workshop
- 2012 multiple models workshop
- …
- **2016 model uncertainty workshop**

Uncertainty Estimation – CBP Decision Support System

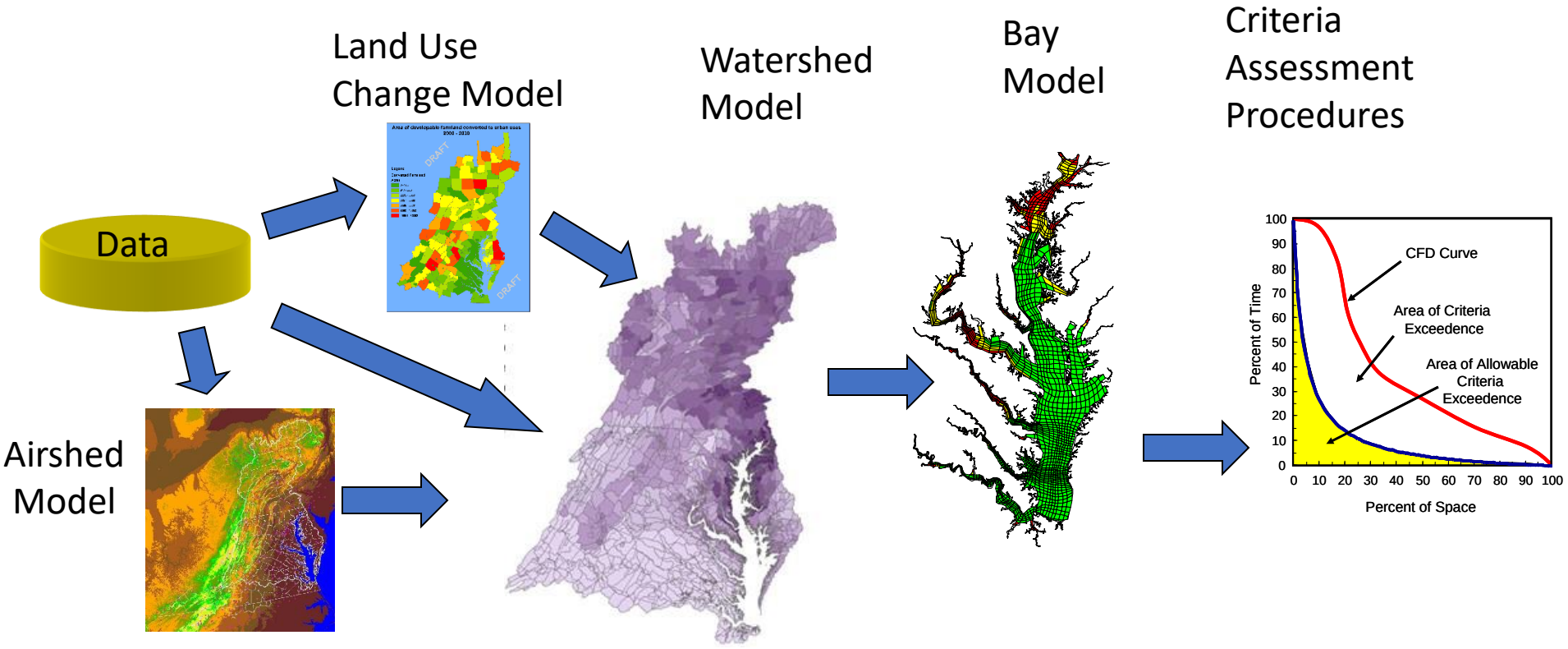


Uncertainty Estimation – CBP Decision Support System



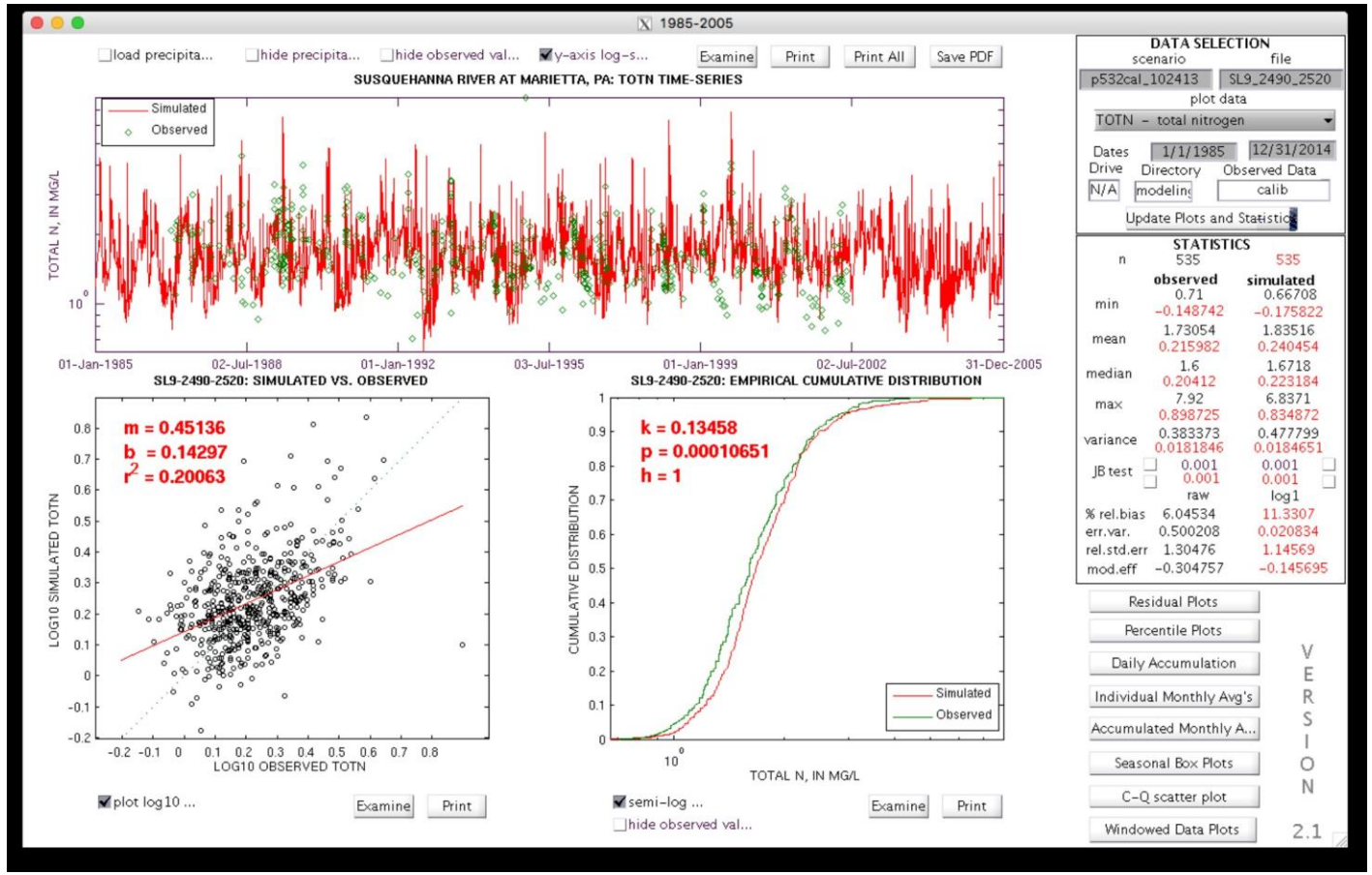
What is the confidence that a certain set of management actions will result in a particular amount of standards attainment?

Uncertainty Estimation – CBP Decision Support System



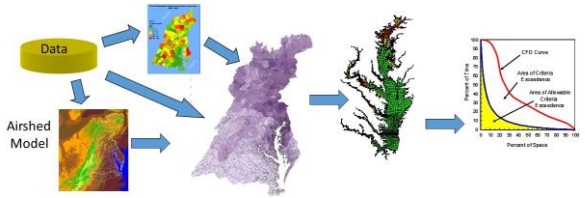
What is the confidence that a certain set of management actions will result in a particular amount of standards attainment?
Where should the CBP spend resources to increase that confidence.

Methods – Skill Assessment



✓Relatively simple to perform

X Doesn't answer the right question



Methods – Integrated

X + Y

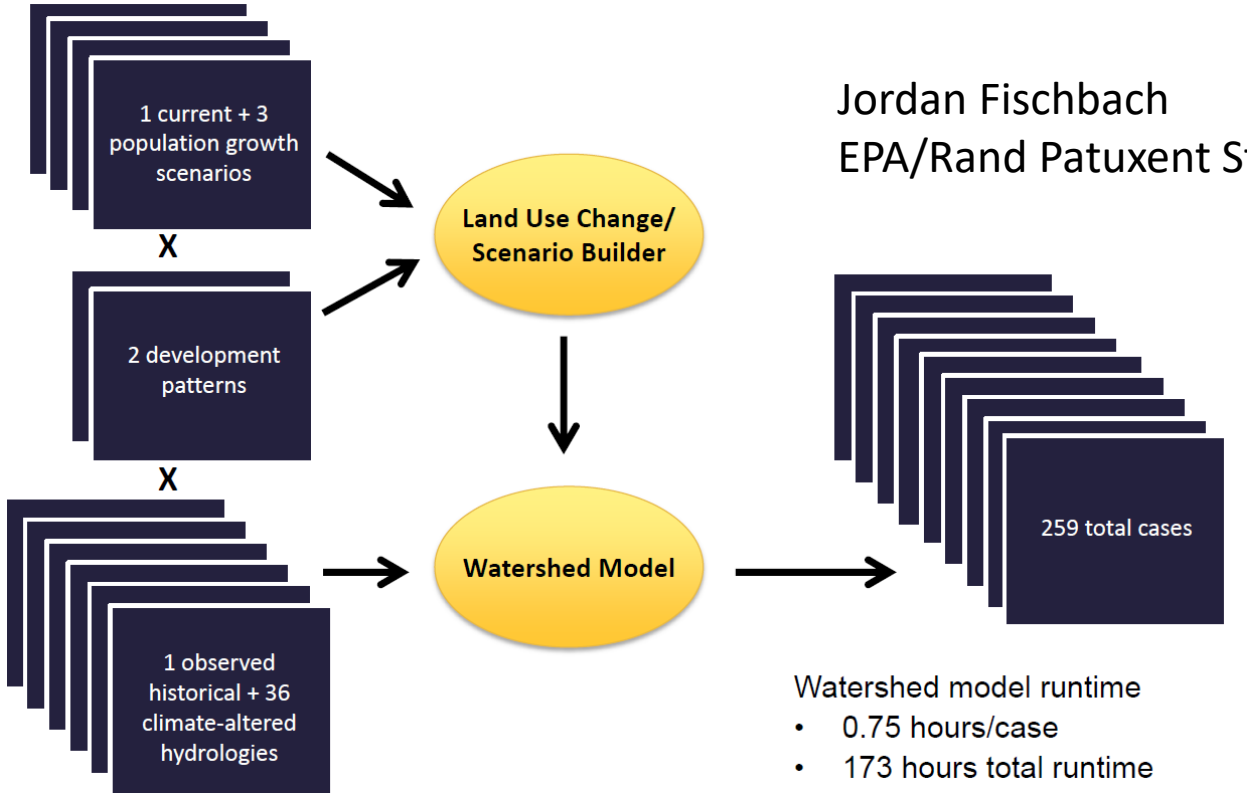
$$\sigma^2_{X\pm Y} = \sigma^2_X + \sigma^2_Y$$

✓Mathematically correct

☹ Practically impossible to insert into all models

X Requires information that we don't have

Methods – Wrapper



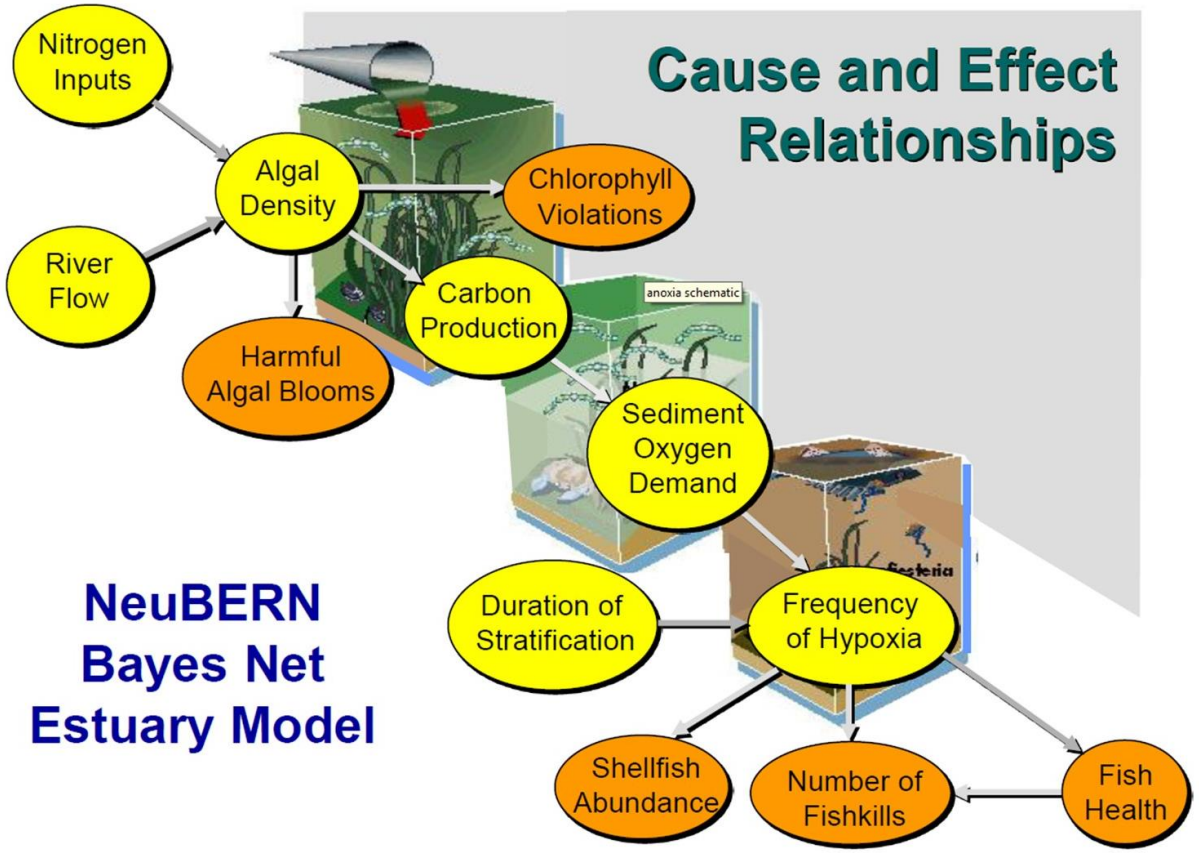
Jordan Fischbach
EPA/Rand Patuxent Study

Watershed model runtime
- 0.75 hours/case
- 173 hours total runtime

✓Can answer the correct question

☹ Very significant effort

Methods – Framework



Ken Reckhow
Neuse River

✓Answers the correct question

☹ May not have the information needed to build it

STAC 2016 Uncertainty Workshop Draft Recommendations

- Get Started Now
  - Management Track – What to do with uncertainty
  - Technical Track – start by identifying sources
- Develop Long Term Plan
  - Management Track
    - Incorporate into decision making
    - Allocate additional resources
  - Technical Track
    - Make it part of the modeling processes
    - Determine a method or combination of methods

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- **CalCAST**
- Statistical version of CAST
- Estimates uncertainty of loads and parameters
- Unsure if it can estimate uncertainty of change in load

Inform

CalCAST

Average Load
+
Δ Inputs * Sensitivity
*
BMPs
*
Acres
*
Land to Water
*
River Delivery

Load by land-river segment and land use

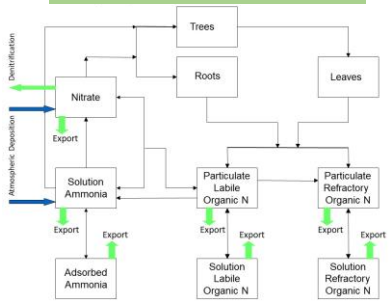
Phase 7 CAST Structure

Average Load
+
Δ Inputs * Sensitivity
*
BMPs
*
Acres
*
Land to Water
*
River Delivery

Load by land-river segment and land use

Constrain

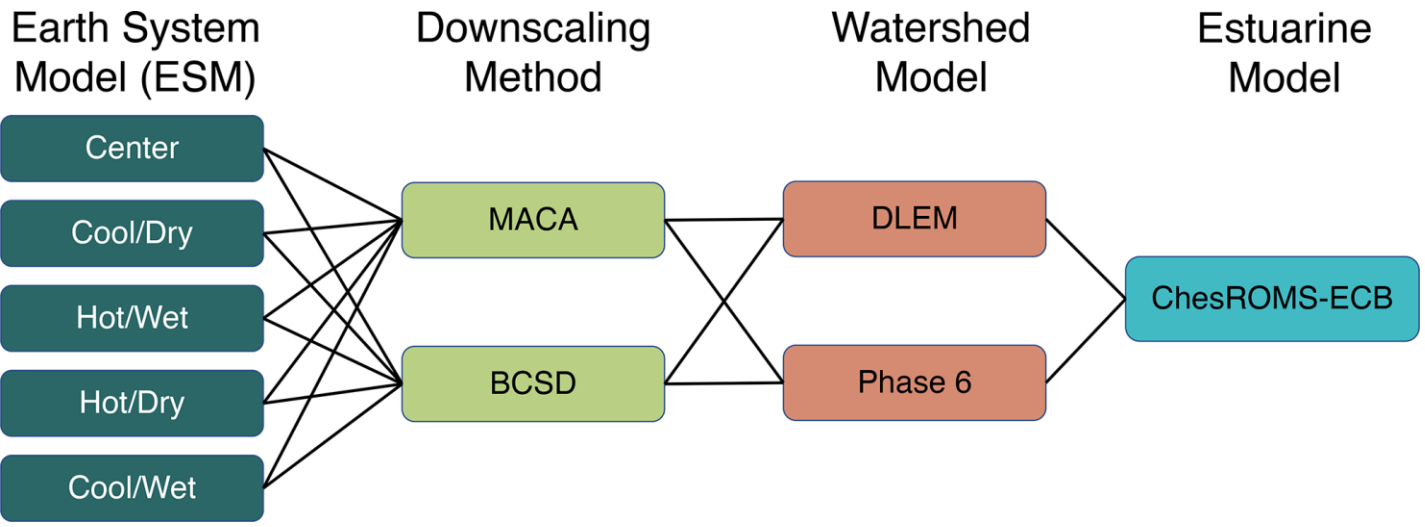
Temporal downscaling model

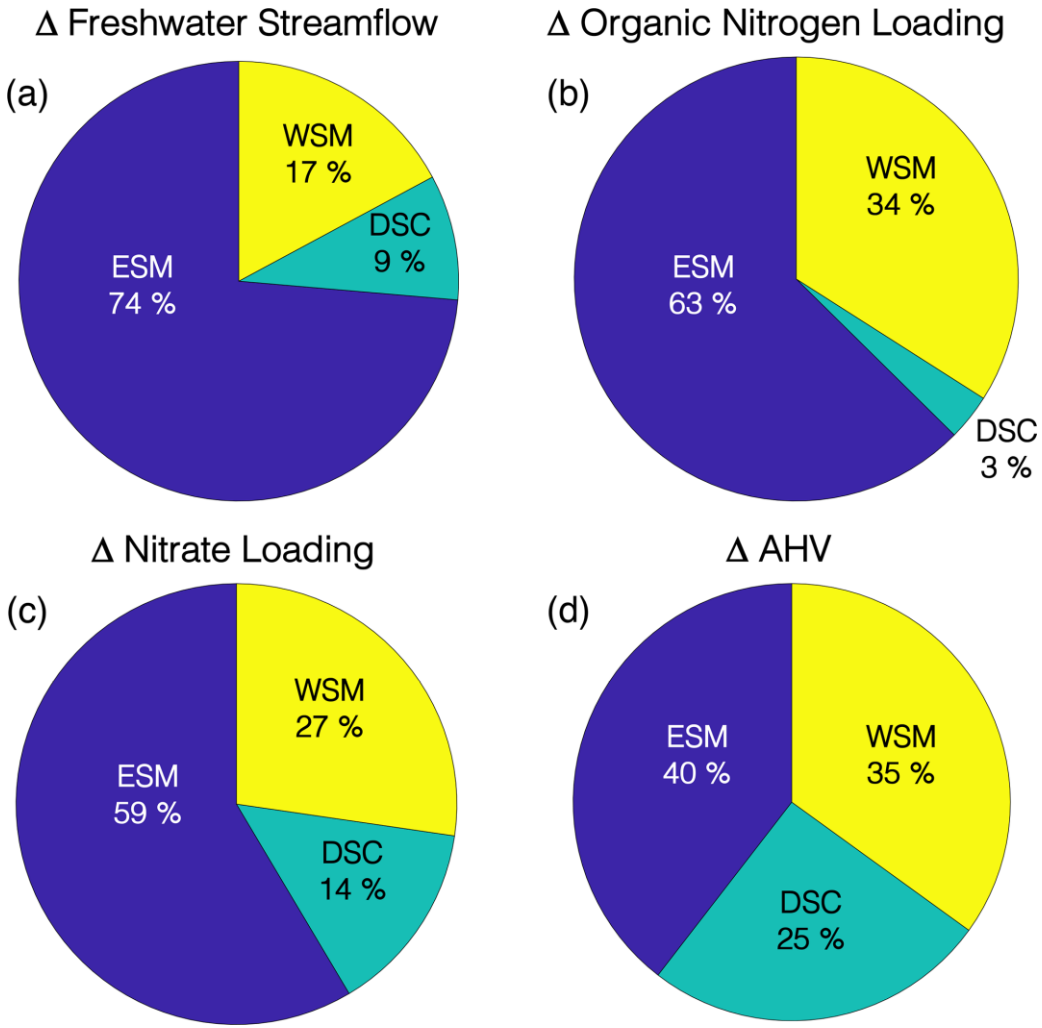


CAST model documentation; section 1
https://cast.chesapeakebay.net/Documentation/ModelDocumentation

Method – Wrapper/Framework

Multiple Models





Hinson, K.E., Friedrichs, M.A., Najjar, R.G., Herrmann, M., Bian, Z., Bhatt, G., St-Laurent, P., Tian, H. and Shenk, G., 2023. Impacts and uncertainties of climate-induced changes in watershed inputs on estuarine hypoxia. Biogeosciences, 20(10), pp.1937-1961.

Method – Wrapper/Framework

Collaborations

- NSF grant
- Collaboration headed by UMCES
- Linking models of physical and social systems together
- Raleigh Hood, Victoria Coles, DG Webster, Patrick Bitterman, Peter Claggett, Fred Ducca, Sevgi Erdogan, Marshall Grossman, Gary Shenk, Jason Yoo

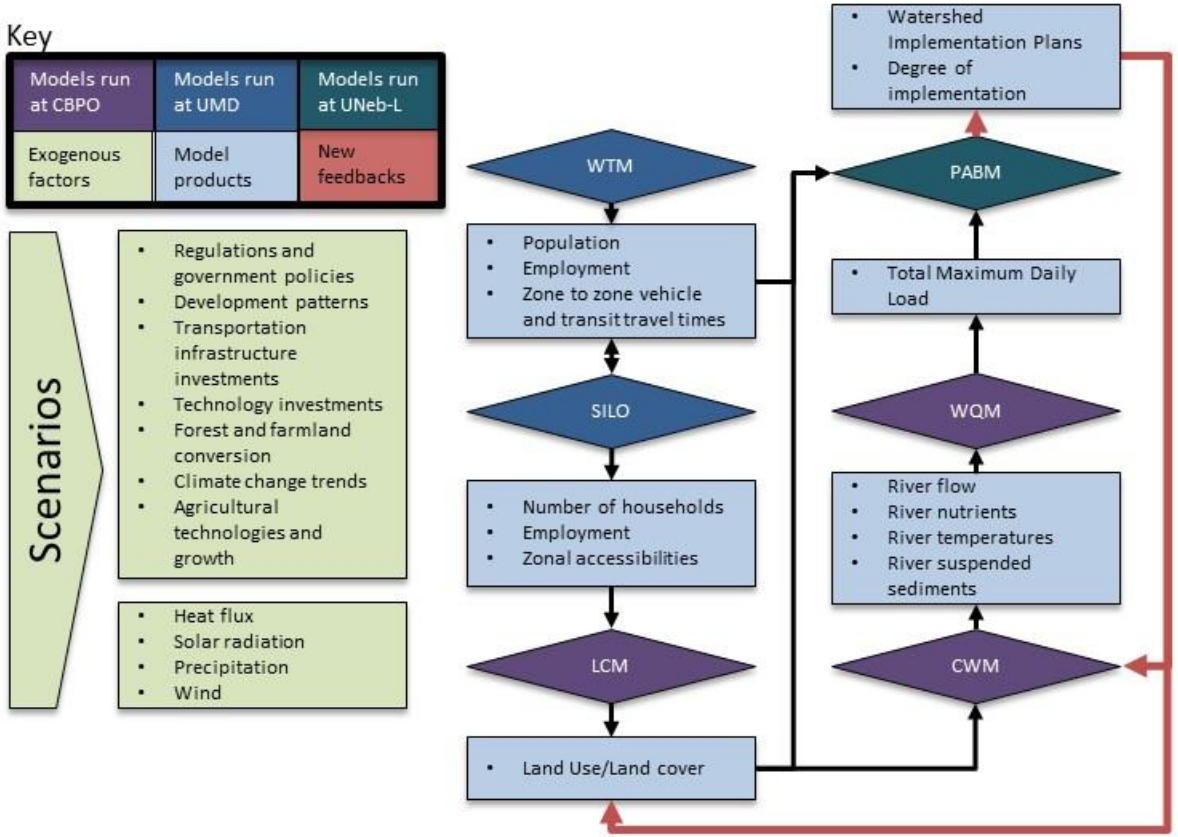


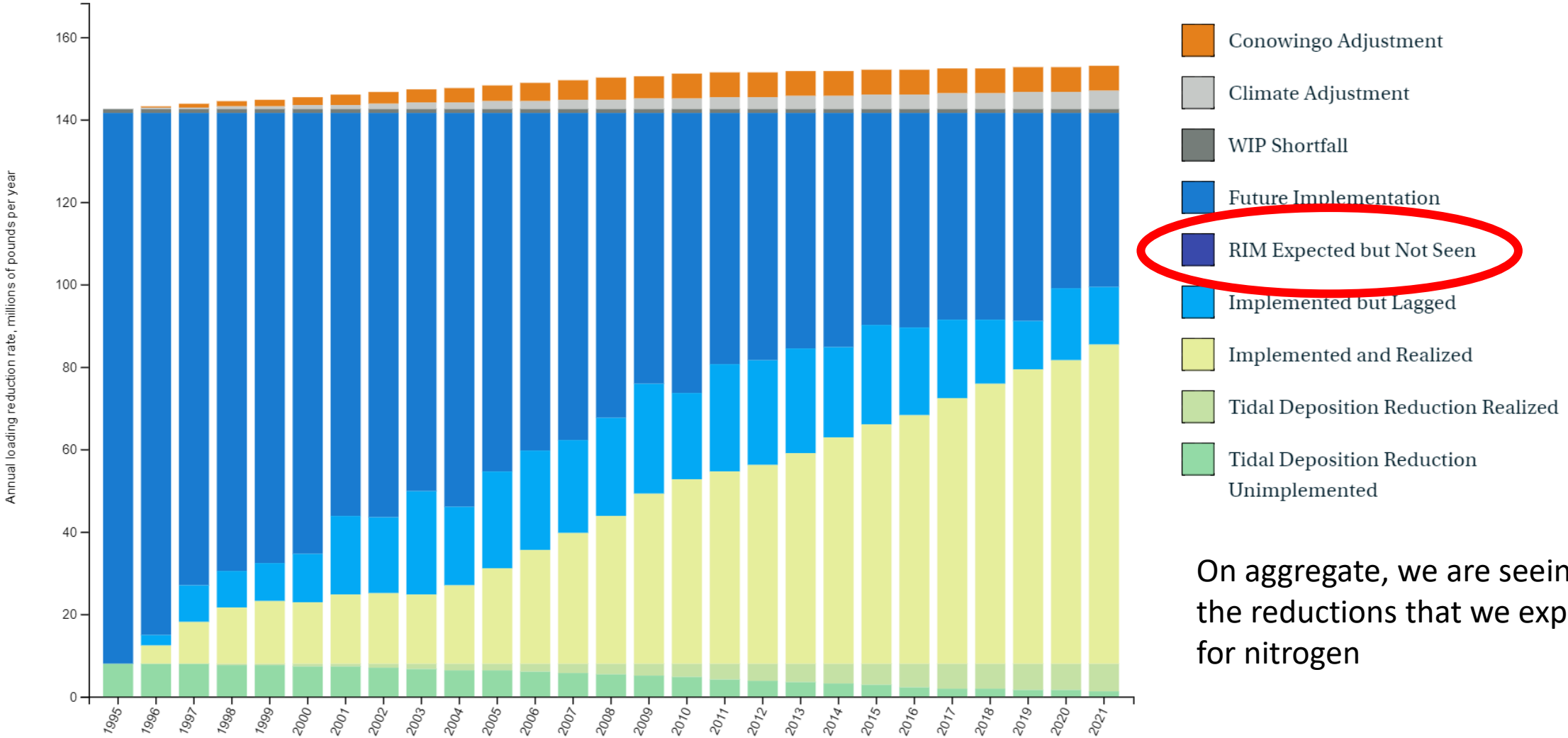
Figure 2: Schematic of model coupling and linkages. WTM = Chesapeake Bay Watershed Transportation Model, SILO = Simple Integrated Land use Orchestrator, LCM = Chesapeake Bay Land Cover Model, CWM = Chesapeake Bay Community Watershed Model, WQM = Chesapeake bay CH3D physical model implementation with ICM biogeochemistry, PABM=Policy Agent Based Model Ensemble. Red arrows are the novel proposed linkages.

Chesapeake Bay TMDL Indicator: Total Nitrogen

The Conowingo and Climate Adjustments were added after 2018.

VIEW CHART VIEW TABLE

Method – Skill Assessment



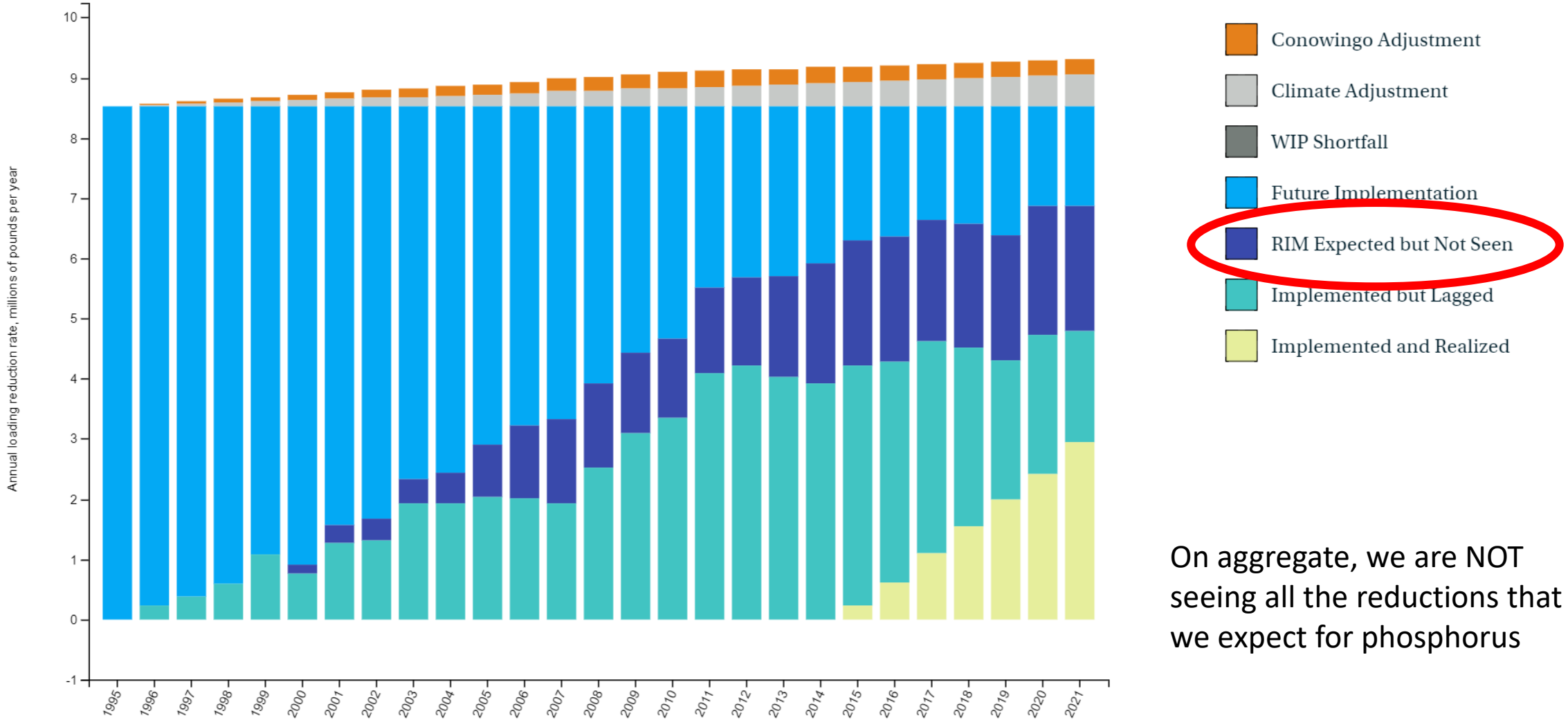
On aggregate, we are seeing the reductions that we expect for nitrogen

TMDL Total Phosphorus experiment

[Footnote about how Conowingo and Climate Adjustments are new after 2018.]

VIEW CHART VIEW TABLE

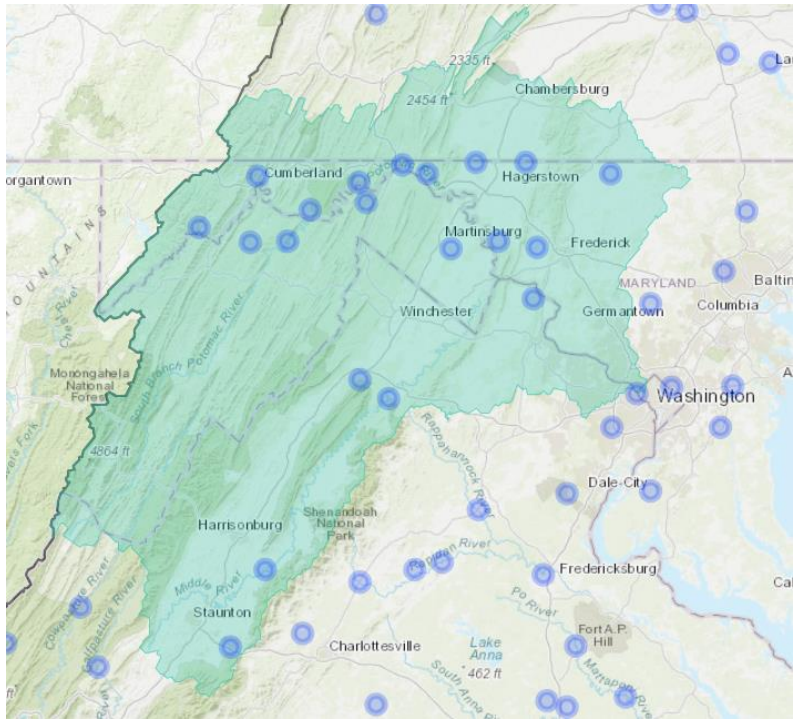
Method – Skill Assessment

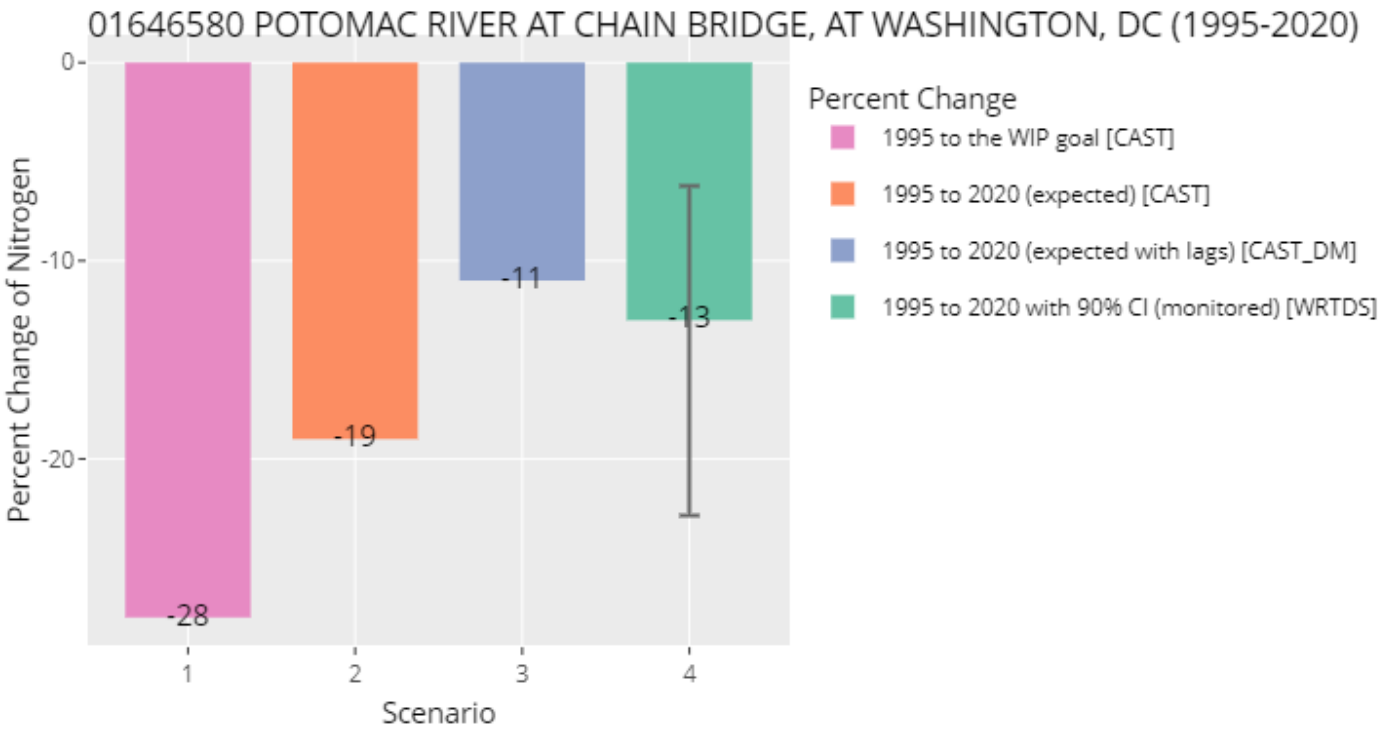


On aggregate, we are NOT seeing all the reductions that we expect for phosphorus

Example 1: 01646580 Potomac River Total Nitrogen

Method – Skill Assessment





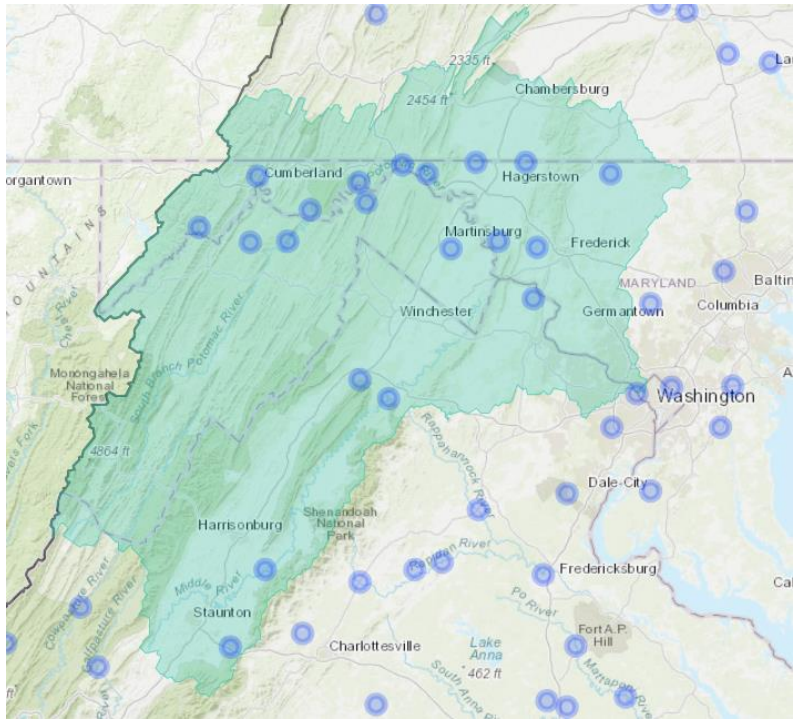
Interpretive Text

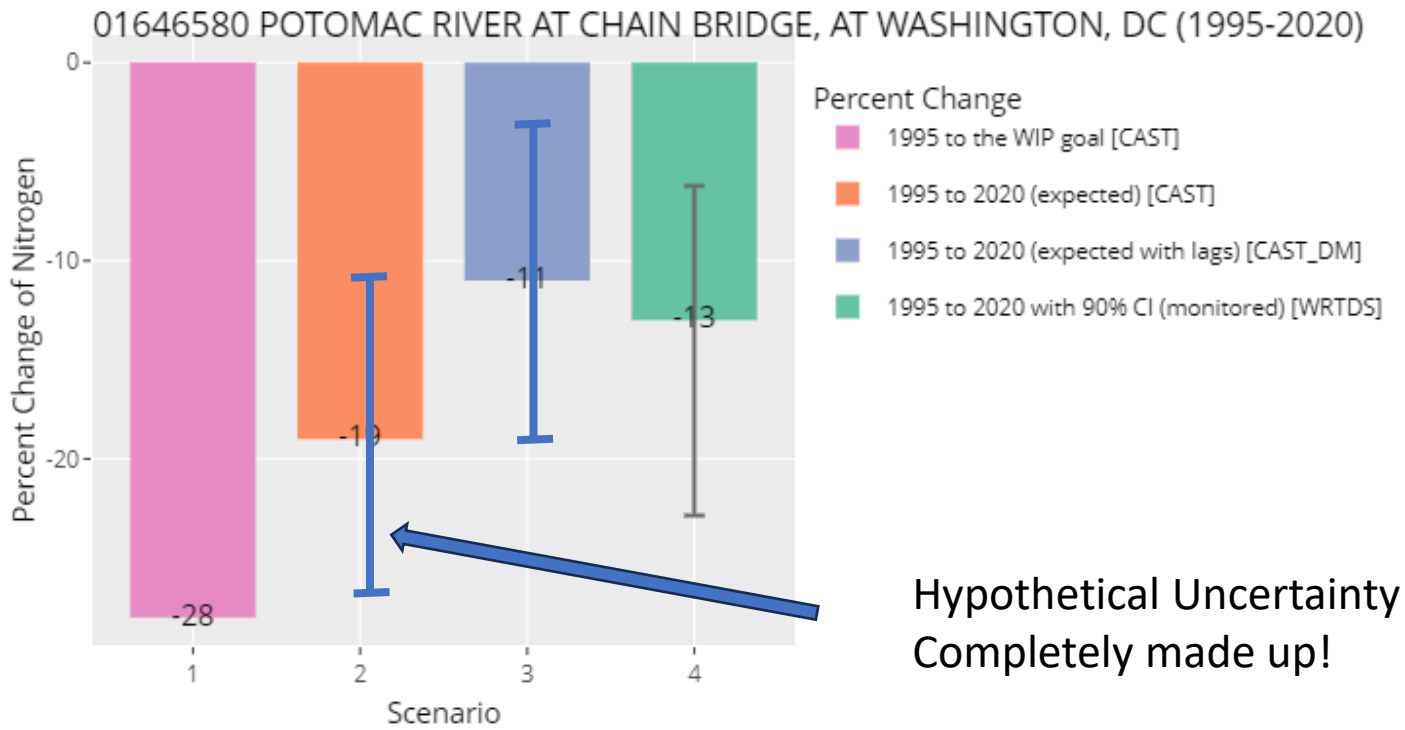
1. CAST estimates a 28 percent reduction in the long term from **implementation of the WIP** using 2025 land use and inputs.
2. CAST estimates a 19 percent reduction in the long term from **2020** land use, inputs, and management practices.
3. The Dynamic Watershed Model estimates that only a 11 percent reduction would have been seen by 2020, accounting for lags, sampling frequency, and other factors.
4. The river monitoring data show a 13 percent reduction with a 90% uncertainty range between 6 and 23 percent reduction.

Implication: The observed response is as expected over the period of 1995-2020.

Example 1: 01646580 Potomac River Total Nitrogen

What would we gain if we could add uncertainty to watershed model estimates





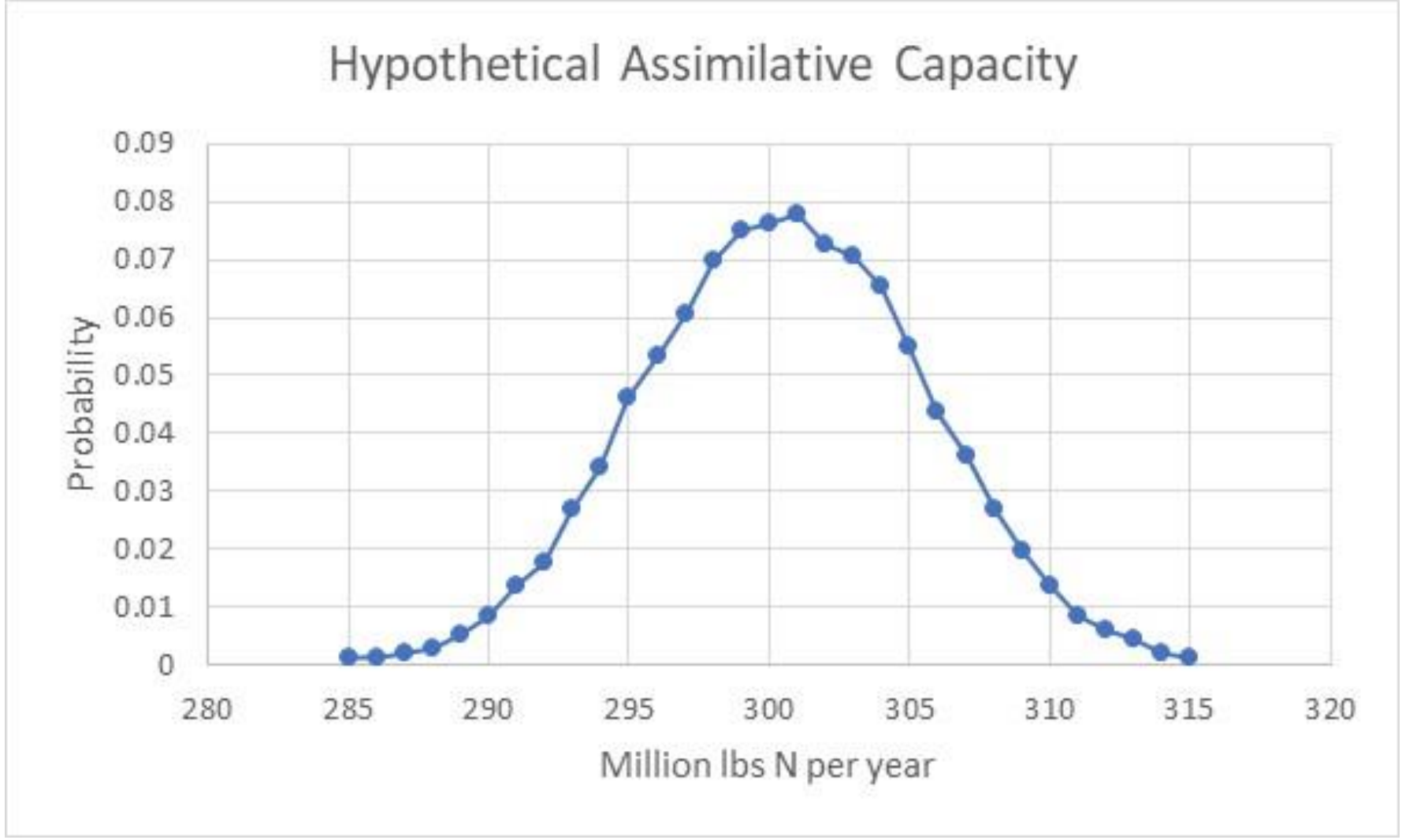
Hypothetical Uncertainty
Completely made up!

<u>What is the probability that:</u>

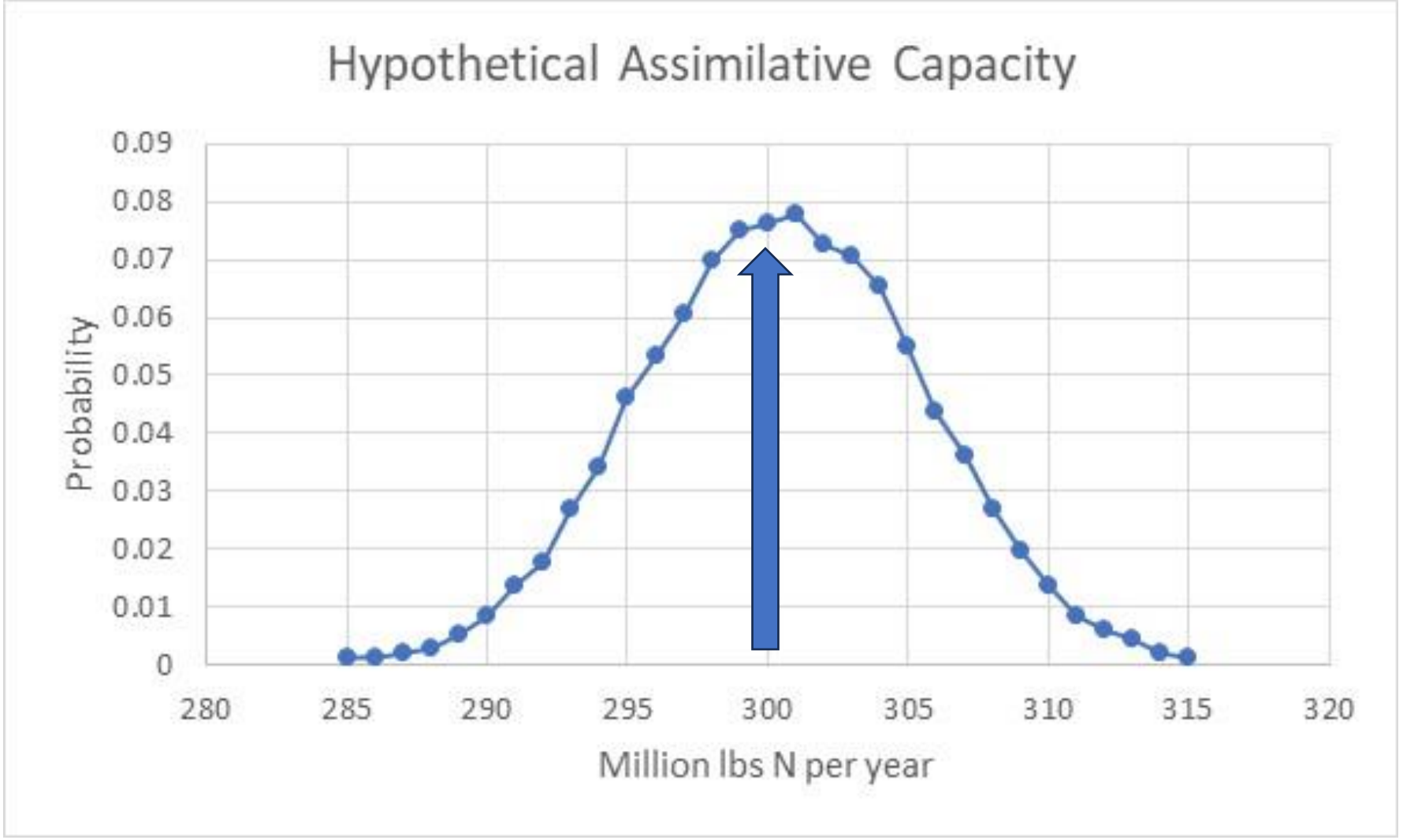
- We have achieved the WIP goal in this watershed? (no more UQ needed) (Green vs Pink)
- We have implemented enough to achieve the WIP goal? (Orange vs Pink)
- The reported actions are having the expected effect? (Blue vs Green)
-

Overall Management Question: Purpose

- Understand the weak links
- Protect against over-implementation
- Protect against under-implementation

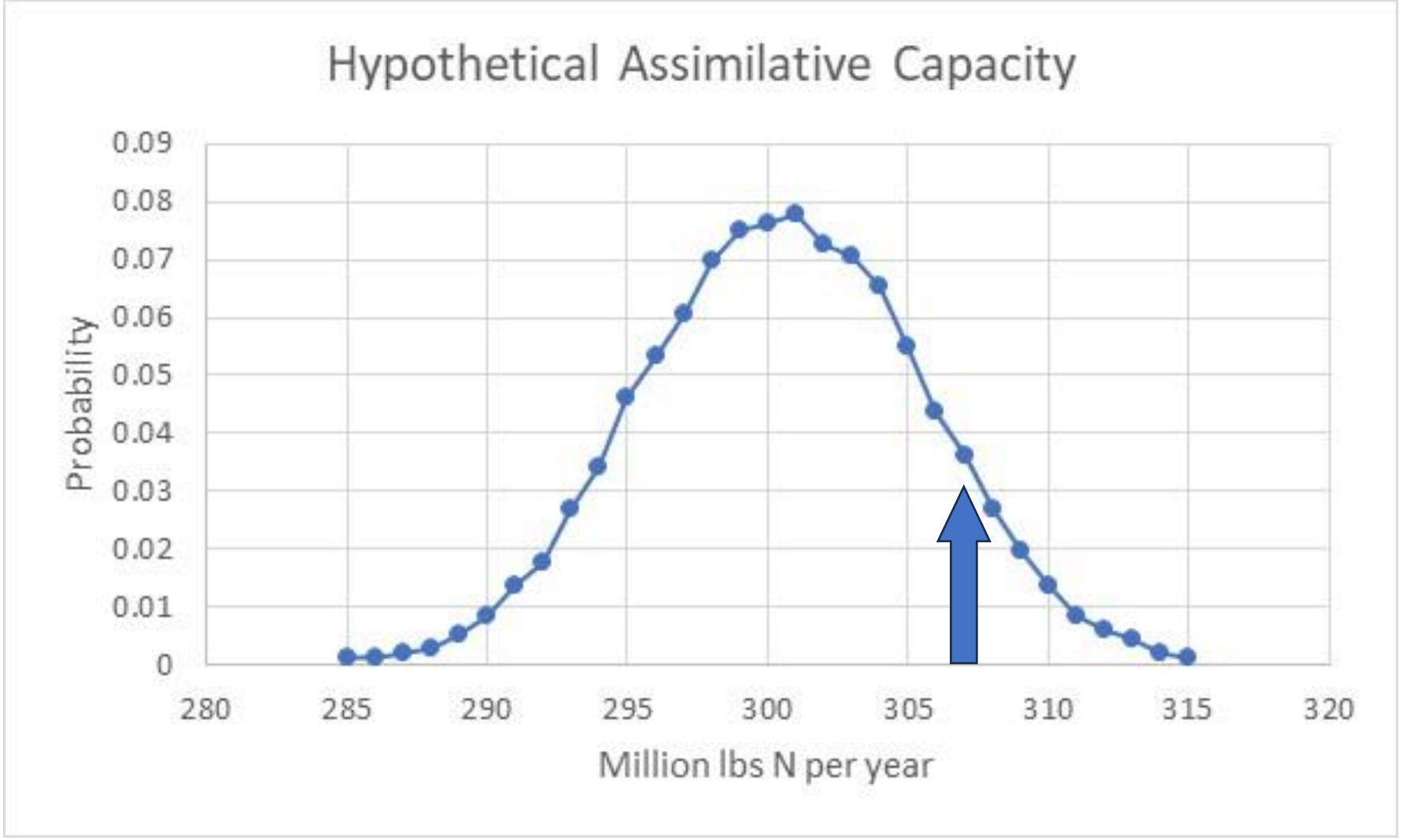


- **These numbers are completely made up!!!**



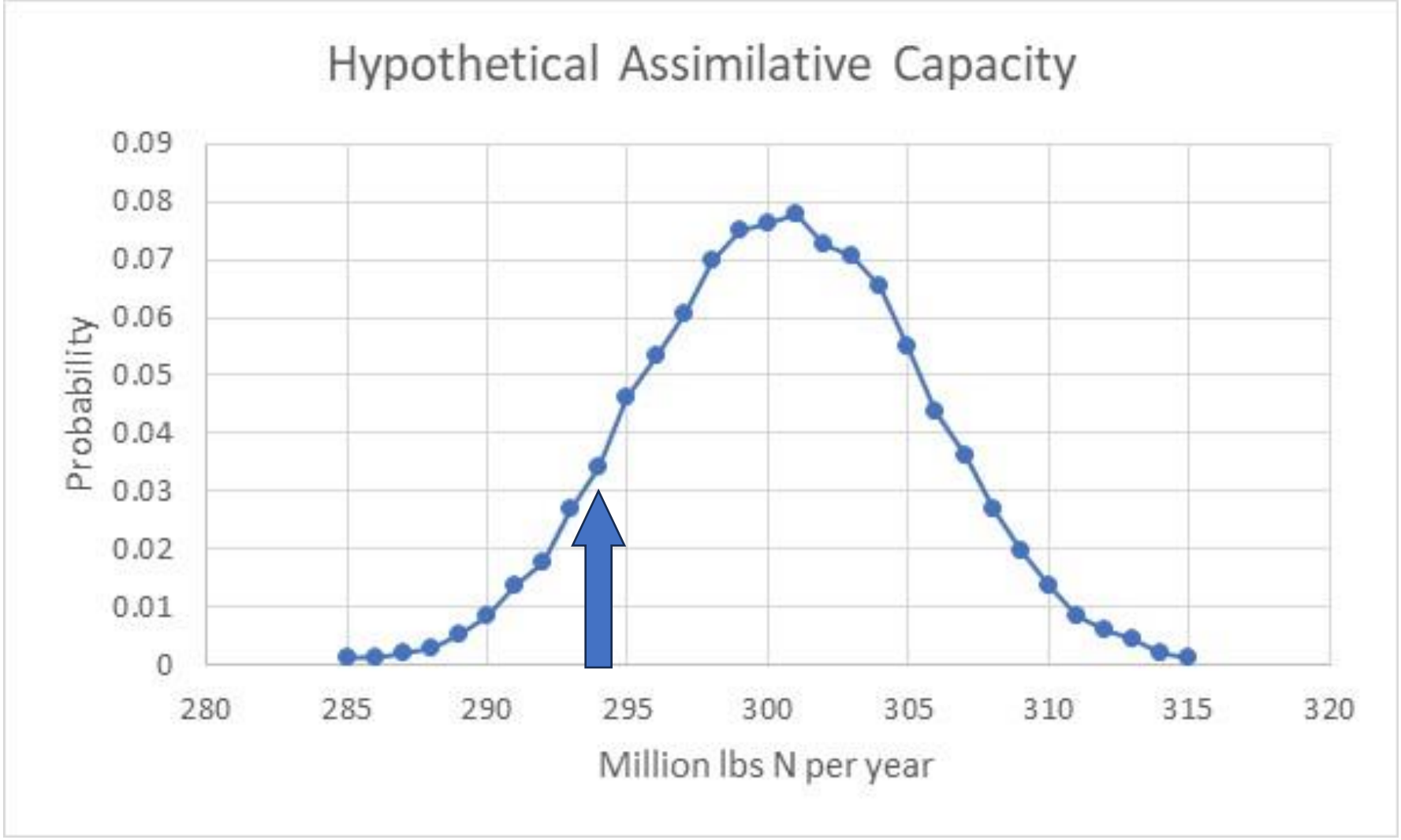
Credit to
Elgin Perry

- **These numbers are completely made up!!!**
- Balanced Approach – Goal is set at the center of the distribution



Credit to Elgin Perry

- **These numbers are completely made up!!!**
- Cautious approach – 90% sure that we will not make unnecessary reductions



Credit to
Elgin Perry

- **These numbers are completely made up!!!**
- Protective approach – 90% sure that we will reach water quality goals

TMDL specifies the protective approach

- **TMDL = ΣWLA + ΣLA + MOS**
- Where **WLA** is the sum of wasteload allocations (point sources), **LA** is the sum of load allocations (nonpoint sources and background) and **MOS** is the margin of safety.

- TMDL is a constant
- Increases in MOS necessarily decrease allocations

https://www.epa.gov/tmdl/overview-total-maximum-daily-loads-tmdls

Summary

- Modelers are making headway in quantification
- Need to know what WQGIT wants to do with uncertainty