Developing spatially-explicit midpoint characterization factors for eutrophication potential

Briana Niblick[1], Andrew Henderson[2], Heather Golden[3], Jane Bare[1]

[1]U.S. EPA, Center for Environmental Solutions and Emergency Response, Cincinnati, Ohio
[2]University of Texas School of Public Health; Noblis, Inc., San Antonio, Texas
[3]U.S. EPA, Center for Environmental Measurement and Modeling, Cincinnati, Ohio

American Center for Life Cycle Assessment 2020

Disclaimer

The opinions expressed in this presentation are those of the authors and do not necessarily represent the views of policies of the U.S. Environmental Protection Agency. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

Outline

- Introduction to eutrophication
- Brief review of previous research
- New research based on recommendations
- Modeling spatial characterization factors
- Characterization factor results
- Conclusions and future research

Previous Recommendations

↓

New Data & Spatialization

↓

Site-Specific Characterization Factors

Eutrophication

- Increase in the rate of supply of organic matter to an ecosystem (Nixon 1995).
- Nutrients: forms of nitrogen (N) and phosphorus (P)
- Sources: agriculture, atmospheric deposition, sewage
- Results: hypoxia, harmful algal blooms (HABs)

Algae blooms on Assateague Island, Maryland. US EPA (2013) by Eric Vance.

Brief review of previous research

Critical Review:

1. Nutrient fate and transport models
2. LCIA eutrophication methods
3. Recommendations for future methods

Environmental Science & Technology

Critical Review

Cite This: *Environ. Sci. Technol.* 2018, 52, 9562–9578

pubs.acs.org/est

Critical Review of Eutrophication Models for Life Cycle Assessment

Ben Morelli,[†] Troy R. Hawkins,[†,√] Briana Niblick,[*,‡] Andrew D. Henderson,[‡,#] Heather E. Golden,[§] Jana E. Compton,[∥] Ellen J. Cooter,[⊥] and Jane C. Bare[‡]

[†]Franklin Associates, Eastern Research Group, 110 Hartwell Avenue, Lexington, Massachusetts 02421, United States

[‡]U.S. Environmental Protection Agency, National Risk Management Research Laboratory, 26 West Martin Luther King Drive, Cincinnati, Ohio 45268, United States

[§]U.S. Environmental Protection Agency, National Exposure Research Laboratory, 26 West Martin Luther King Drive, Cincinnati, Ohio 45268, United States

[∥]U.S. Environmental Protection Agency, National Health and Environmental Effects Research Laboratory, 200 SW 35th Street, Corvallis, Oregon 97333, United States

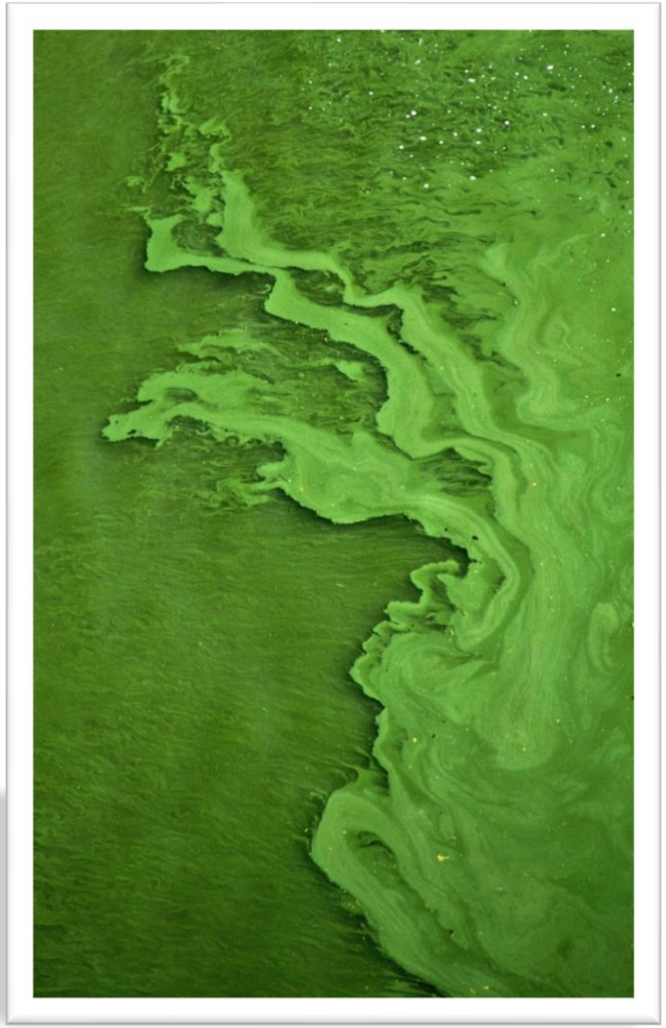
[⊥]U.S. Environmental Protection Agency, National Exposure Research Laboratory, 109 T.W. Alexander Drive, Research Triangle Park. North Carolina 27709. United States

Morelli B, Hawkins TR, Niblick B, Henderson AD, Golden HE, Compton JE, Cooter E, Bare JC, 2018. Critical review of eutrophication models for life cycle assessment. *Environ Sci Tech* 52, 9562–9578.

Previous work: LCIA nutrient model status

- N fate & transport in freshwater
  - Modeled in less detail than P
  - Lacks sub-watershed spatial differentiation
- Freshwater eutrophication
  - Global spatial differentiation - Helmes et al. (2012)
- Marine eutrophication
  - Global spatial differentiation - Cosme et al. (2015, 2016)
- Gaps in inventory characterization
  - Releases to land (N, P)

Data Gaps



Previous work: LCIA Eutrophication Methods

- Recent work (2012-2017) has moved the eutrophication impact category towards the goal of **spatial differentiation**.
- Some fate factors still missing:
  - Full **terrestrial releases**
  - Full **sub-watershed N emissions**
- Existing models could improve LCIA fate factors.
  - Varying levels of effort would be required to implement models.

Excerpted list of recommendations adapted from Morelli et al. (2018).

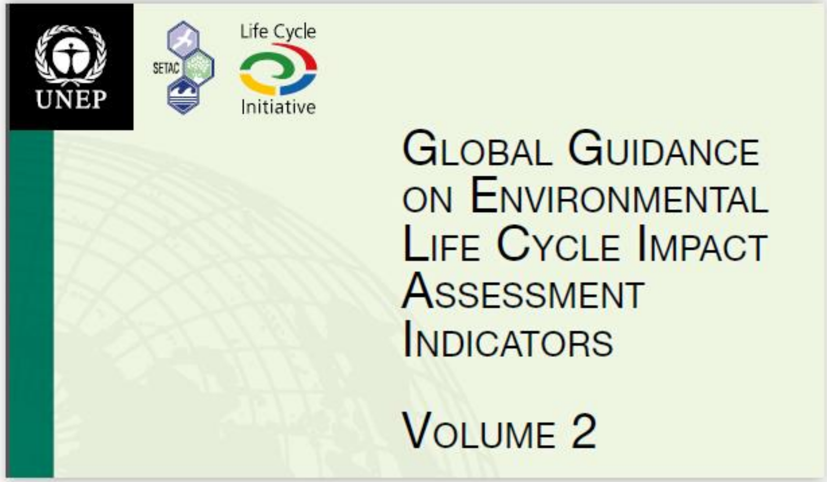
LCIA Method	Environmental Compartment	Priority	Effort
Freshwater and Marine	All Compartments	1	E
	Soil & Freshwater	2	D
Freshwater Eutrophication	Freshwater	1	E
		2	M
		2	M
	Soil	1	E
		1	M
Marine Eutrophication	Freshwater & Marine	1	E
	Marine	2	D
		3	D
	Air	2	M
		3	D

Previous work: Method recommendations

1. Separate freshwater and marine eutrophication categories.
2. For marine eutrophication:
   - Use methods outlined in Cosme et al. (2017) as state-of-the-science.
3. Integrate atmospheric fate factors, especially for N.
   - Use Roy et al. (2012) source receptor matrices as state-of-the-science.

Recommendations consistent with 2019 UNEP/SETAC guidance for eutrophication.

lifecycleinitiative.org/training-resources/global-guidance-for-life-cycle-impact-assessment-indicators-volume-2/



Calculating fate factors

Fate factor for midpoint characterization factor (CF):

$$\boldsymbol{FF_{e-r}}, \text{ where } ff_{e-r,ij} = \frac{\text{mass substance in compartment } r, \text{location } j}{\left(\text{mass emitted to compartment } e, \frac{\text{location } i}{\text{time}}\right)}$$

FF: fate factor
e: emission compartment
r: receiving compartment
i: emission location
j: resulting steady-state mass in other location(s)

fate factor units = time

Fate factors that can be used directly for midpoint CFs:

- Freshwater eutrophication: P emission → freshwater
- Marine eutrophication: N emission → LME, inland freshwater, or inland soil

Fate Factors: Spatial Manipulation

For marine eutrophication, [air emissions] need to be coupled to [N in LMEs].

$\boldsymbol{FF_{air\text{-}LME}}$ represents steady-state mass of N in the LMEs due to an emission to air.

$$\boldsymbol{FF_{air-LME}} = FF_{air-ground,ij} \times \boxed{\frac{moles\ N}{moles\ subst.}} \times ST_{air-NEWS2\_comp} \times FF_{NEWS2\_comp-LME}$$

FF: fate factor
ST: spatial transform
air: emission to air
LME: large marine ecosystem
ground: deposition
NEWS2_comp: NEWS2 basin
i: emission location
j: resulting steady-state mass in other location(s)

stoichiometric conversion

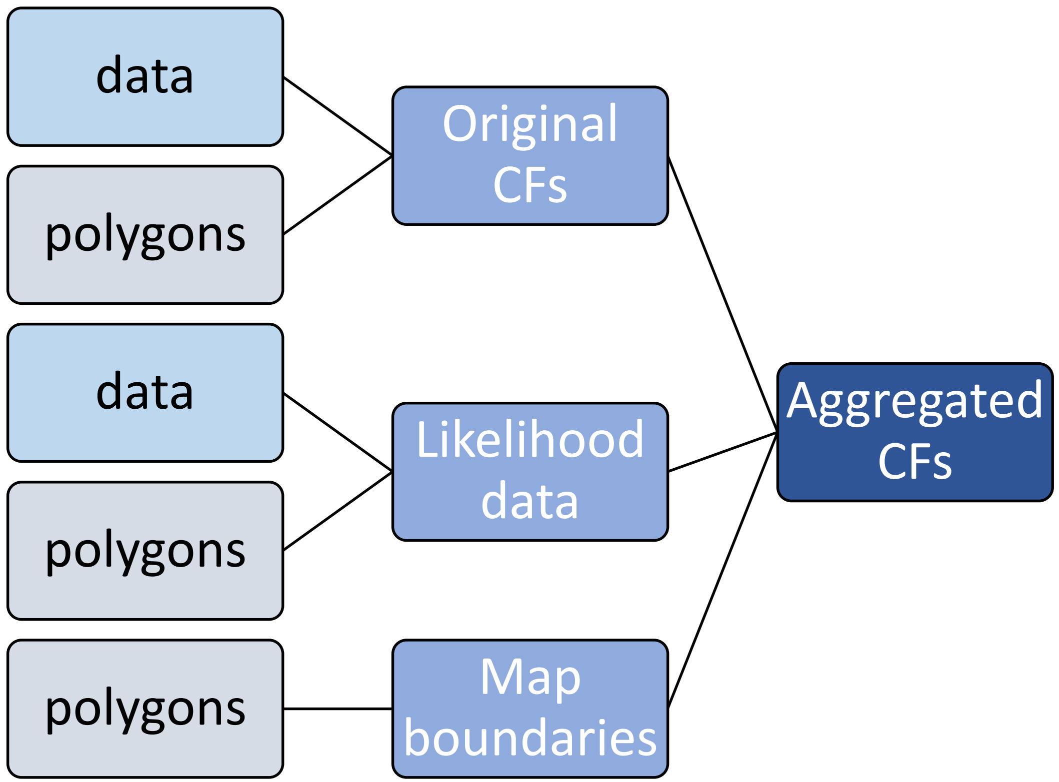
Fate factors requiring spatial manipulation for midpoint CFs:

- Freshwater eutrophication: emissions → soil (10% runoff rule)
- NHx and NOx: air emissions → deposition to land

Aggregation of characterization factors

Each set of spatial CFs is specified by:

- Substance flow
- Compartments
  - emission compartment
  - intermediate transfer compartment
  - receiving compartment
- Aggregation resolution
- Likelihood data – land use type
  - Agricultural
  - Non-agricultural – industry, transport, human waste
  - General – unknown/background data



Components of Spatial CFs

Eutrophication Category	Substance Flow	Emission Compartment	Emission Resolution	Transfer Compartment	Receiving Compartment	Receiving Resolution
FRESHWATER	P	FW	$0.5° \times 0.5°$ cells	-	FW	$0.5° \times 0.5°$ cells
MARINE	N	LME	NEWS2 basins	-	LME	LME
MARINE	N	FW, Soil	NEWS2 basins	-	LME	LME
MARINE	NH_x, NO_x	Air	$2° \times 2.5°$ cells	-	LME	LME
MARINE	NH_x, NO_x	Air	$2° \times 2.5°$ cells	FW	LME	LME
MARINE	NH_x, NO_x	Air	$2° \times 2.5°$ cells	Soil	LME	LME

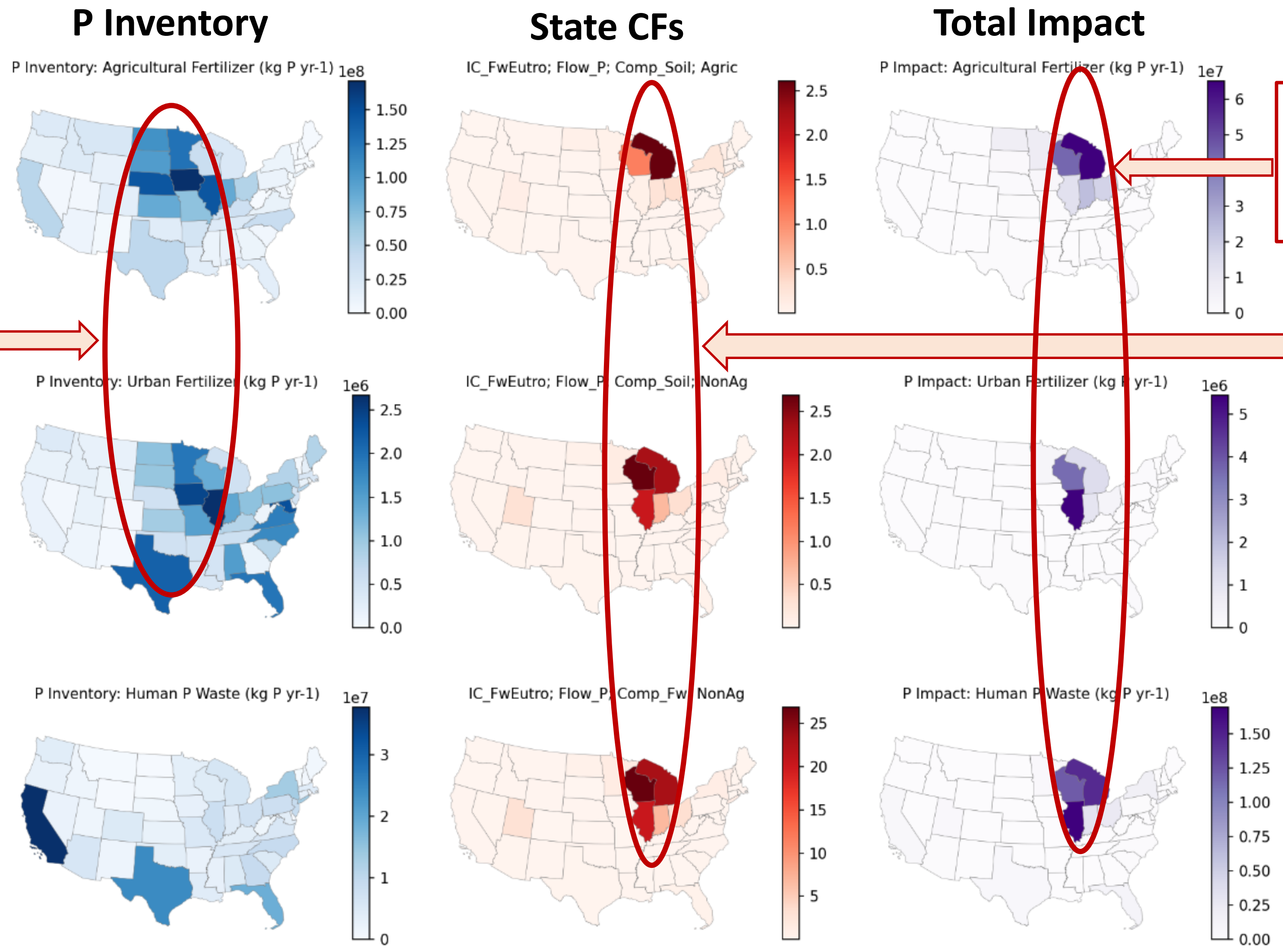
Application: Freshwater Eutrophication

U.S. agricultural regions
- Clear in rural areas
- Urban areas scaled by population

Agricultural fertilizer

Urban fertilizer

Human waste



CF dominance > variation in P inventory

Great Lakes: retention time

Henderson AD, Niblick B, Golden HE, Bare JC. Modeling spatially-resolved characterization factors for eutrophication potential in life cycle assessment. *To be submitted.*

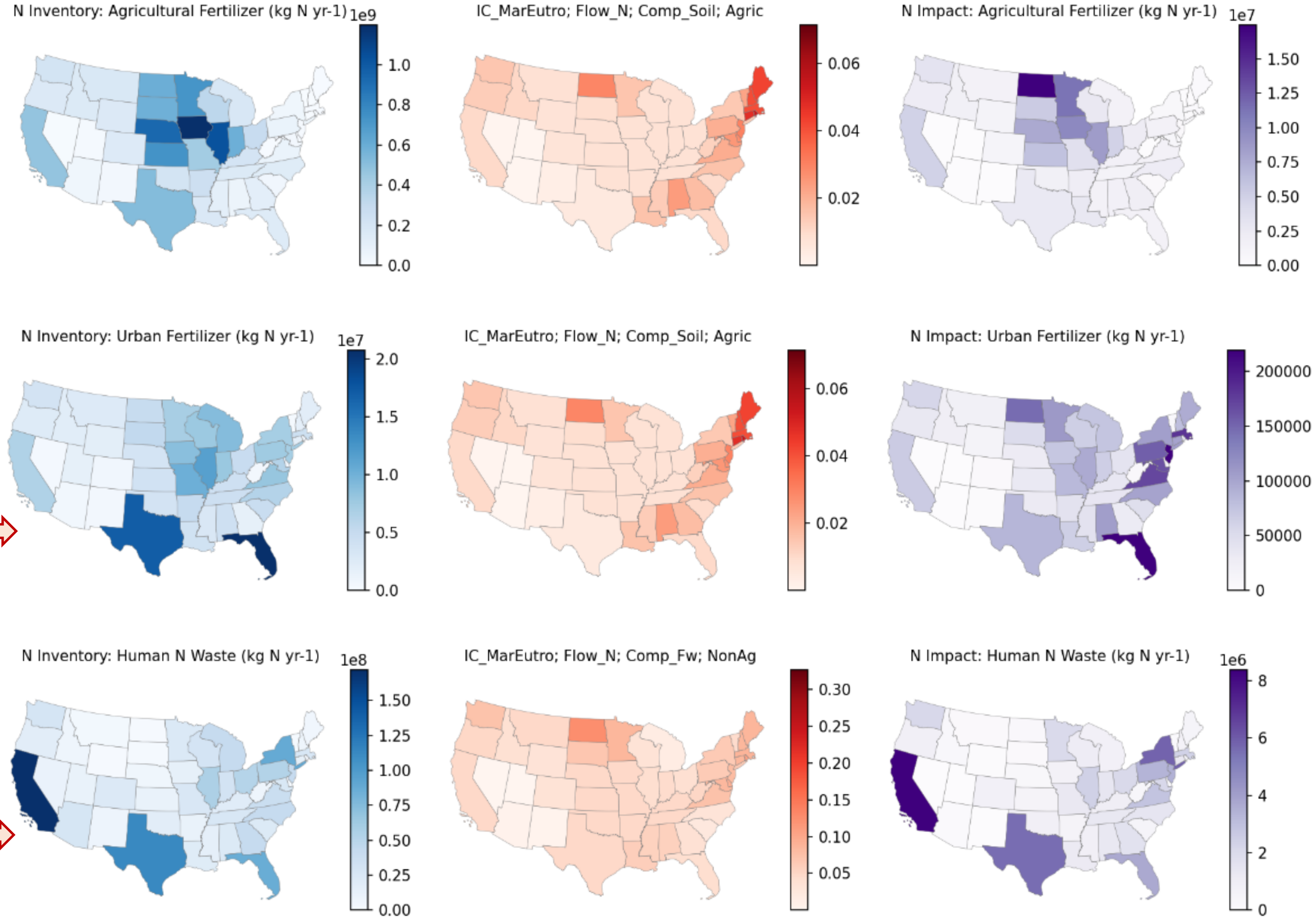
Application: Marine Eutrophication

N Inventory | **State CFs** | **Total Impact**

Agricultural fertilizer

Urban fertilizer

Human waste



Suburban values from lawn care, landscaping, golf centers.

Human waste values centered around urban density.

Variation in N inventory > influence of CF

Henderson AD, Niblick B, Golden HE, Bare JC. Modeling spatially-resolved characterization factors for eutrophication potential in life cycle assessment. *To be submitted.*

Discussion

- The research uses the common assumption that freshwater systems are P-limited and marine systems are N-limited.
- P total impacts are driven by CFs, whereas N total impacts are driven more by inventory.
  - P freshwater CFs vary by several orders of magnitude near large bodies of water.
    - Example: States bordering the Great Lakes vs. states further inland)
  - CFs for atmospheric emissions of N show modest variation.
- Sources of N and P can be difficult to identify, especially in urban and suburban regions (as compared to agricultural regions). Source uncertainty could be quantified and data improved in future research.

Conclusions & Future Research

- We have developed site-specific freshwater and marine eutrophication characterization factors for the United States at the midpoint-level.
- We applied these characterization factors to evaluate state-level nutrient inventories of agricultural fertilizer, urban fertilizer, and human waste.
- Recommendations for future research:
  - Address nutrient co-limitation across the freshwater-marine continuum.
  - Characterize N and P releases to land to move beyond the 10% runoff assumption.
  - Develop further spatial refinement, especially as global data quality improves and more data become available.
  - Add temporal refinement (e.g., seasons, crop rotation).
  - Consider modeling endpoints as the science for effect modeling improves.

References

Cosme N, Mayorga E, and MZ Hauschild (2017). Spatially explicit fate factors for waterborne nitrogen emissions at the global scale. *International Journal of Life Cycle Assessment*, 1-11.

Helmes RJK, Huijbregts MAJ, Henderson AD, and O Jolliet (2012). Spatially explicit fate factors of phosphorous emissions to freshwater at the global scale. *International Journal of Life Cycle Assessment 17* (5), ..

Morelli B, Hawkins TR, Niblick B, Henderson AD, Golden HE, Compton JE, Cooter E, and JC Bare (2018). Critical review of eutrophication models for life cycle assessment. *Environ Sci Tech 52*, 9562–9578.

Nixon SW (1995). Coastal marine eutrophication: A definition, social causes, and future concerns. *Ophelia*, 41: 199-219.

Rosenbaum RK, Margni M, and O Jolliet (2007). A flexible matrix algebra framework for the multimedia multipathway modeling of emission to impacts. *Environ. Int. 33*, 624–634.

Sabo RD, Clark CM, Bash J, Sobota D, Cooter E, Dobrowolski JP, Houlton BZ, Rea A, Schwede D, Morford SL, and JE Compton (2019). Decadal shift in nitrogen inputs and fluxes across the contiguous United States: 2002–2012. *Journal of Geophysical Research: Biogeosciences 124*(10), 3104-3124.

UNEP/SETAC Life Cycle Initiative (2019). Global Guidance on Environmental Life Cycle Impact Assessment Indicators (GLAM), Vol. 2, Available: https://www.lifecycleinitiative.org/training-resources/global-guidance-for-life-cycle-impact-assessment-indicators-volume-2/.

US EPA (2018). National Inventory of Reactive Nitrogen, Environmental Dataset Gateway, DOI: https://doi.org/10.23719/1418976.

US EPA (2019). National Inventory of Phosphorus (v1, 8.30.19), Environmental Dataset Gateway, DOI: https://doi.org/10.23719/1504278.

Thank you!

Contact: niblick.briana@epa.gov

This research was funded by the SERDP-ESTCP program under Special Project WP-2757 with principal investigators Kelly Scanlon (DOD) and Wesley Ingwersen (US EPA).

Work was conducted under U.S. EPA Contract No. EP-C-16-015 to Eastern Research Group, Inc.