Planetary Boundaries for Phosphorus perspective and suggestion

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Anthropogenic Excretion Surplus Indicator (AESI) — Conceptual Formulation

Total metabolic phosphorus production in region *r* over time *t* (kg P yr^{-1}):

$$E\_P(r,t) = E\_H(r,t) + E\_L(r,t)$$

Human phosphorus excretion:

$$E\_H = Pop(r,t) \times e\_H(r,t)$$

Where:
Pop = human population (persons)
e_H = per-capita phosphorus excretion rate (kg P $person^{-1}$ yr^{-1})

Livestock phosphorus excretion:

$$E\_L = \Sigma\_i [N\_i(r,t) \times e\_i]$$

Where:
N_i = number of animals of species i (head)
e_i = species-specific phosphorus excretion coefficient (kg P $head^{-1}$ yr^{-1})

Anthropogenic Excretion Surplus Indicator:

$$AESI(r,t) = \max [0, E\_P - R\_WW - R\_M - A\_safe]$$

Where:
R_WW = phosphorus removed or recovered in wastewater treatment systems (kg P yr^{-1})
R_M = phosphorus captured via manure management and recovery technologies (kg P yr^{-1})
A_safe = safe agronomic phosphorus assimilation capacity without increasing runoff or erosion risk (kg P yr^{-1})

Normalized indicators:

$$AESI\_area = AESI / A\_region \text{ (kg P } km^{-2} yr^{-1})$$
$$AESI\_cap = AESI / Pop \text{ (kg P } person^{-1} yr^{-1})$$

AESI provides a boundary-relevant estimate of the minimum metabolic phosphorus surplus that must be captured, redistributed, or prevented from entering aquatic systems.