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Bayesian hierarchical modeling characterizes spatio-temporal variability in phosphorus export across the contiguous United States

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Phosphorus (P) inputs from anthropogenic activities are subject to riverine (hydrologic) P export, causing water quality problems in lakes and coastal systems. Nutrient budgets have been used as a quantitative means of assessing the amount of nutrients imported to and exported from a system. However, at large spatial scales, estimates of hydrologic P losses are usually not available or assumed as a fixed fraction of the budget terms. In addition, fluxes in nutrient budgets are generally not quantified at regular intervals. In this study, we estimate P losses across 150 US watersheds at an approximately 4-digit Hydrologic Unit Code (HUC 4) watershed scale from 1997-2017. To explain the spatio-temporal variability in these estimates, we develop a Bayesian model based on various anthropogenic P inputs (e.g., fertilizer, animal manure, point sources, and atmospheric deposition) and outputs (crop removal) from national inventories, climatic factors, background soil P content, and watershed characteristics. In addition, a hierarchical approach accounts for additional sources of variability across different regions. Model results help us identify hot spots of P loss, along with the primary factors contributing to these losses. Results indicate that the greatest P losses (per unit area) occur in the Mid-Atlantic and Great Lakes regions, mainly due to high anthropogenic inputs. Additionally, the Upper Colorado region is found to have the highest temporal variability in P loss, whereas the Lower Mississippi region has the lowest.