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Quantifying watershed sensitivity to spatially variable N loading from mountain resort development

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Effectively managing watershed nitrogen (N) requires understanding of the sources and fate of anthropogenic N in terrestrial and aquatic ecosystems and their variation across space and time. Headwater streams in mountain environments may be particularly susceptible to N enrichment from residential and resort development. We examined watershed sensitivity to spatially variable N loading from mountain resort development in the 220 km2 West Fork of the Gallatin River, Big Sky, Montana, USA. We combined analyses of spatial and seasonal streamwater N and carbon (C) concentration data, watershed N mass balance calculations, three-component mixing models of N sources using nitrate (NO_3-) isotopes, spatial and multiple regression approaches, and numerical modeling to examine the effects of anthropogenic N loading on the timing, magnitude, and speciation of watershed N retention and export. Our analyses indicate that biological uptake of N during the growing season masked N enrichment in the summer months. However, other results indicate considerable anthropogenic impacts to streamwater N export and speciation throughout the year and on an annual basis. Our new Big Sky nutrient export model (BiSN) incorporated spatial stream water chemistry, data from instream tracer additions and geologic weathering experiments, and terrain and land use analysis to quantify the spatial variability of watershed sensitivity to N loading and the relative importance of upland, riparian, and instream N retention (storage, removal, or transformation) across land use/land cover (LULC) and landscape positions. Modeling results revealed that small amounts of wastewater loading occurring in watershed areas with short travel times to the stream had disproportionately large impacts on watershed nitrate export compared to spatially distributed N loading or localized N loading in watershed areas with longer travel times. During summer base flow conditions, 98%–99% of watershed N retention occurred in the uplands, most likely from biological assimilation or lack of hydrologic transport. The relative role of instream N retention increased with N loading downstream through the stream network. This work demonstrates the importance of characterizing the spatial variability of watershed N loading, export and retention mechanisms, and considering landscape position of N sources to effectively manage watershed N.