Assessing the Effects of Nutrients on Agricultural Streams: Implications for Nutrient Criteria

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Background

The U.S. Geological Survey's National Water-Quality Assessment Program (NAWQA) studied nutrient-biota interactions in eight agricultural areas across the United States (fig. 1). Samples were collected from 232 wadeable streams that captured the range of nutrient enrichment within each study area. Nutrient (nitrogen and phosphorus), algal biomass (benthic and sestonic chlorophyll *a*), habitat, and algal and invertebrate community data were collected at each stream site during the growing season. Stream metabolism and denitrification were assessed at a subset of sites.

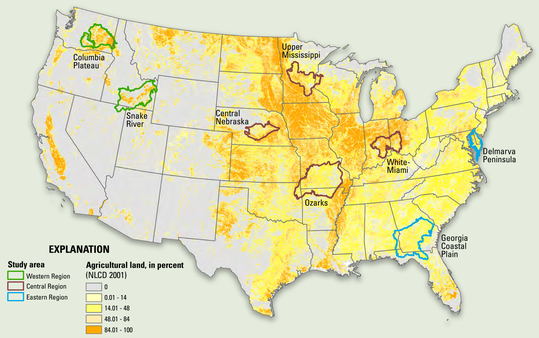

Figure 1. Locations and percentage of agricultural land use in, the eight study areas included in the assessment of the effects of nutrients in agricultural streams.

The study areas are grouped into three naturally distinct regions based on general patterns in elevation, climate, hydrology, land use, and stream-water properties. Western Region sites were drier, cooler, are at higher elevations, with less overland runoff, and were heavily influenced by irrigated agriculture (fig. 1), compared to the characteristically wetter, warmer, and lower elevations, with substantial riparian wetland systems, at the Eastern Region sites. Central Region sites were topographic and climatic intermediates, with a wide range in agricultural practices, water use, and riparian systems, but with the greatest nutrient input of the three regions.

Nutrient Enrichment in Agricultural Streams

In most study areas, the concentrations of total nitrogen (TN) and total phosphorus (TP) were substantially higher than modeled background concentrations, which reflects the increased nutrient inputs associated with agricultural practices. The exceptions were the low concentrations of TN measured in the Ozarks, and of TP measured in the Ozarks and Georgia Coastal Plain (fig. 2).

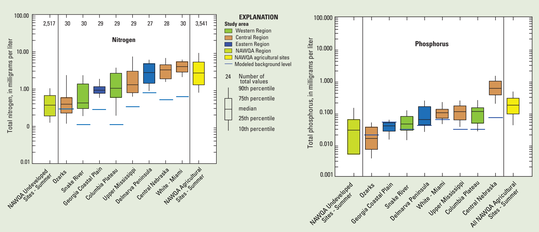

Figure 2. Study areas listed in order of increasing median concentration for total nitrogen and phosphorus. The NAWQA undeveloped and agricultural boxplots are based on data collected between 1992 and 2001 in summer months.

RESULTS

Nutrient concentrations and algal biomass are rarely correlated because of a lack of a sufficient nutrient gradient and complex interactions

Dosing studies have shown as nutrient (nitrogen and phosphorus) concentrations increase, plant biomass increases; however, the relation in streams is complicated by biological processes and habitat (fig. 3). Instream production can be dominated by benthic or sestonic algae, or by mats of aquatic macrophytes. Algae can be limited by physical (scouring, riparian cover, or turbidity) or biological (grazing) properties. In some streams, high aquatic plant biomass can reduce nutrient concentrations through uptake, although in other streams, canopy cover or turbidity suppress plant production regardless of nutrient concentrations.

The complex relation between nutrients and biomass is reflected in data from our study. For example, the Georgia Coastal Plain sites contained low TP and benthic algal biomass due to extensive wetland riparian systems, which filter nutrients and reduce light penetration (fig. 4). Sites in the White Miami tended to be saturated with nutrients, and therefore have little additional influence on algal biomass. Sites in the Delmarva Peninsula contained a range of conditions from low to high nutrients which correlate with algal biomass.

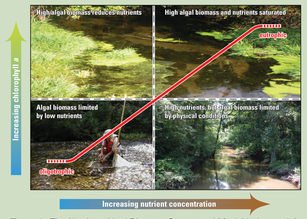

Figure 3. The Nutrient-Algal Biomass Conceptual Model helps explain weak relations between nutrients and algal biomass, suggesting other factors will be necessary to determine stream trophic level (Munn and others, 2010).

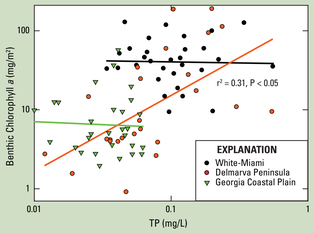

Figure 4. Comparison of total phosphorus and benthic algal biomass relations in three study areas.

Some agricultural streams are not effective at removing nitrogen from the water column and therefore transport large quantities of nitrogen downstream

Once nitrogen enters a stream it can be biochemically transformed into a different form—nitrate to N_2 gas through denitrification, taken up by algae or aquatic plants, or be transported downstream. In many agricultural streams, the presence of tile drains, or channel clearing and straightening, has reduced the amount of time surface water is in contact with the microbial community (transient water storage), typically resulting in low nitrate uptake and retention, and large nitrate transport (Duff and others, 2008).

Investigations of nutrient transport and uptake within selected study sites indicated that most surface-water nitrate transported in a reach was carried out of the reach and nutrient input from groundwater within the reach was relatively minor (fig. 5). In some cases, this was due to uptake or denitrification as shallow groundwater flowed through the streambed (fig. 6).

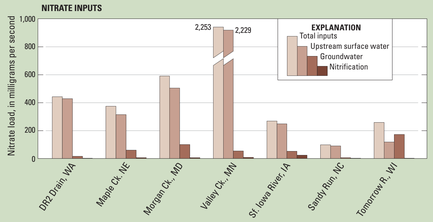

Figure 5. Just 4 to 17 percent of nutrients entering the reach were derived from groundwater; most nutrients originated upstream. Differences in upstream and downstream nitrate loads in selected agricultural streams were minimal.

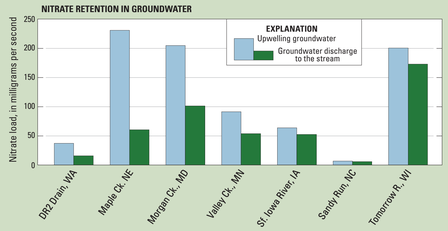

Figure 6. Differences in shallow groundwater nutrient loads and stream outputs are due to uptake or denitrification during transport through the streambed.

Groundwater inflow to streams can continue to be a nitrogen source for an extended period regardless of changes in management practices

Nutrient transport pathways depend on the hydrology and geochemistry of a watershed. The following coverages were used to determine the dominant type of hydrologic transport (fig. 7):

- *Tile drain locations from the National Resources Inventory (Wieczorek, 2004)*
- *Groundwater locations from the Base Flow Index (BFI) Assessment (Wolock, 2003a), and*
- *Overland flow locations from the surface-water model TOPMODEL (Wolock, 2003b and 2003c)*

The fraction of the stream nitrate load derived from base flow increased as BFI increased, but orthophosphate (OP) did not (fig. 8; Tesoriero and others, 2009). This suggests that hydrology controls nitrate transport, but does not control OP. In moderate to high BFI watersheds, lag times between nitrogen applications to the land surface and discharge to streams may be high (Puckett and others, 2010).

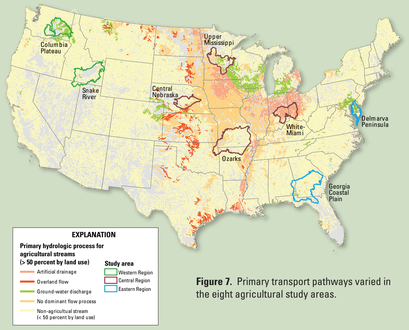

Figure 7. Primary transport pathways varied in the eight agricultural study areas.

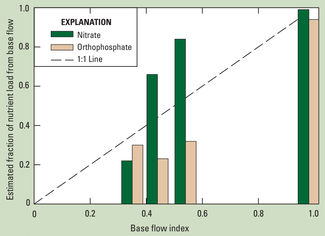

Figure 8. If hydrology is the major influence on transport pathways, the fraction of the total nutrient load derived from base flow should increase as the Base Flow Index increases (Tesoriero and others, 2009).

Biological condition of aquatic communities declined with increasing nutrient enrichment

The biological condition of a stream can be expressed as observed taxa over expected (O/E) taxa from regional reference sites. The closer the observed taxa are to the expected taxa (i.e., approaching a measure of 100 percent) is indicative of good conditions, in this case, good water quality (Van Sickle and others, 2005).

The biological condition for algae and macroinvertebrate communities decreased with increasing concentrations of TN and TP in agricultural streams in this study. Nutrient categories were based on the 33rd and 66th percentiles of NAWQA summer data collected from 1992 to 2001 (fig. 9).

The agricultural intensity index combines percentage of agricultural land use in the watershed; percentage of agricultural land use in the riparian zone; and predicted TN and TP loadings to the watershed to assess the overall effect of agriculture within the watershed (fig. 10*A*). Biological condition varied among regions with Midwest streams having the lowest overall mean O/E score for both algae and macroinvertebrates (fig. 10*B*) and the highest agricultural intensity score.

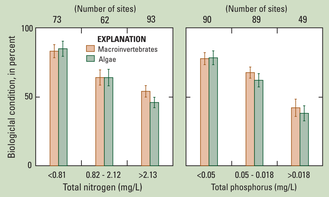

Figure 9. Mean biological condition of NAWQA aquatic communities by nutrient category as defined using one-third percentiles of summer NAWQA nutrient data (1991-2001).

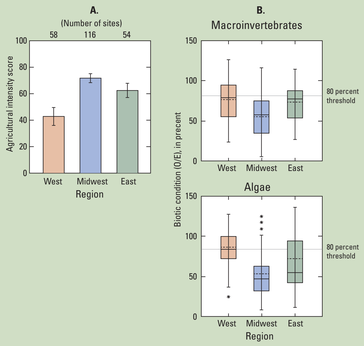

Figure 10. Agricultural intensity (*A*) and biotic conditions (*B*) of NAWQA sites by region.

Implications

Agricultural landscapes provide unique challenges to the development of nutrient criteria, primarily because of non-point nutrient inputs across different environmental settings. An understanding of nutrient sources, transport pathway, habitat condition, and biological response is needed to improve efforts to manage nutrients.

- *An assessment needs to incorporate nutrient concentrations and biological response to understand the condition in a stream.*
- *In areas with elevated nitrate concentrations in groundwater and a significant groundwater inflow component, reductions of instream nitrate concentrations may not be seen immediately despite the implementation of Agricultural Best Management Practices.*
- *Stream habitat alterations and ecosystem losses have reduced the natural ability of streams to remove nitrate and led to increased nitrate concentrations in the streams. This underscores the need for management strategies that promote conservation of natural structure and function in streams to maintain hydrologic attributes and biodiversity that help manage nutrients.*
- *Regional differences in biological attributes and metrics are important considerations in developing monitoring programs to evaluate ecological benefits resulting from best management practices.*

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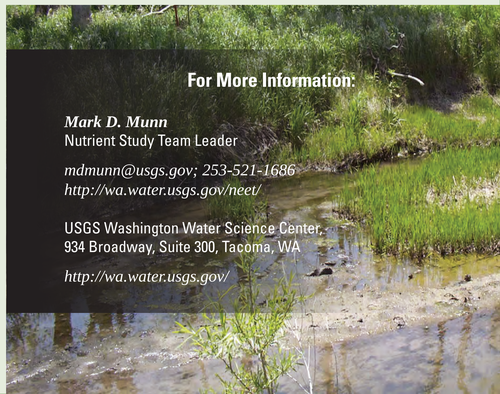

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