Relationships Between Physical and Chemical Water Quality Across Land Uses of Southern Ohio

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ABSTRACT

Impairment of physical and chemical water quality due to land-use change is a growing concern. We assessed these impacts by surveying 38 stream reaches across three study catchments with contrasting land uses in southern and central Ohio. Sampling occurred seasonally in 2016-2017 for nutrient concentrations, in-stream habitat quality, and stream geomorphic parameters. Nutrient concentrations were found to vary seasonally and by catchment: total phosphorus and orthophosphate were highest in the mixed-use watershed and total nitrogen and nitrate were lowest in the forested watershed. As expected, stream habitat quality was higher in forested and mixed-use watersheds than in the agricultural watershed. Accounting for catchment land use, habitat quality increased with increasing substrate grain size and width:depth ratio. Total phosphorus and orthophosphate decreased with increasing grain size, while orthophosphate concentrations were positively associated with glide habitat. Nutrient concentrations were not related to siltation, width-depth ratio, or amount of instream cover. Our results suggest that some fluvial geomorphic features may aid in regulating nutrient dynamics in streams, and highlight the potential role of stream restoration in improving stream habitat quality and reducing stream phosphorus loading.

BACKGROUND

Changes in land use and land cover has been of increasing concern due to associated impairment n of aquatic ecosystems. Agricultural, urban, and industrial development can alter not only the chemical condition of stream and river ecosystems, but also fluvial geomorphic conditions. Geomorphic alterations impact nutrient spiraling, specifically spiraling length and rates of nutrient recycling, through residence time of water and exposure to biochemically reactive substrates (Ensign and Doyle 2006). An important step in reducing eutrophication and impairment of freshwater ecosystems is to understand not only the amount of nutrients entering waterways, but also how the geomorphology of stream and rivers influences nutrient availability in these ecosystems. **The objective of this study was to explore associations between physical and chemical water-quality responses to land use.**

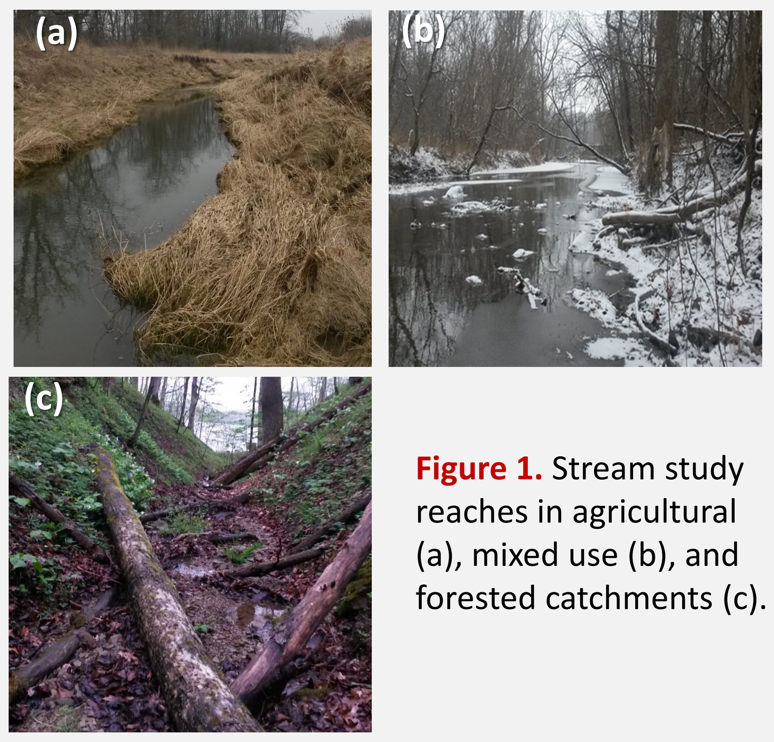


Figure 1. Stream study reaches in agricultural (a), mixed use (b), and forested catchments (c).

STUDY SYSTEM

This study was conducted in 38 stream reaches across 3 study catchments in the Ohio River Basin. Land use varied by catchment, with dominant uses including agriculture, mixed-use, and forest. Chemical water-quality samples were collected seasonally, while habitat quality and geomorphic parameters were measured during summer in 2016-2017.

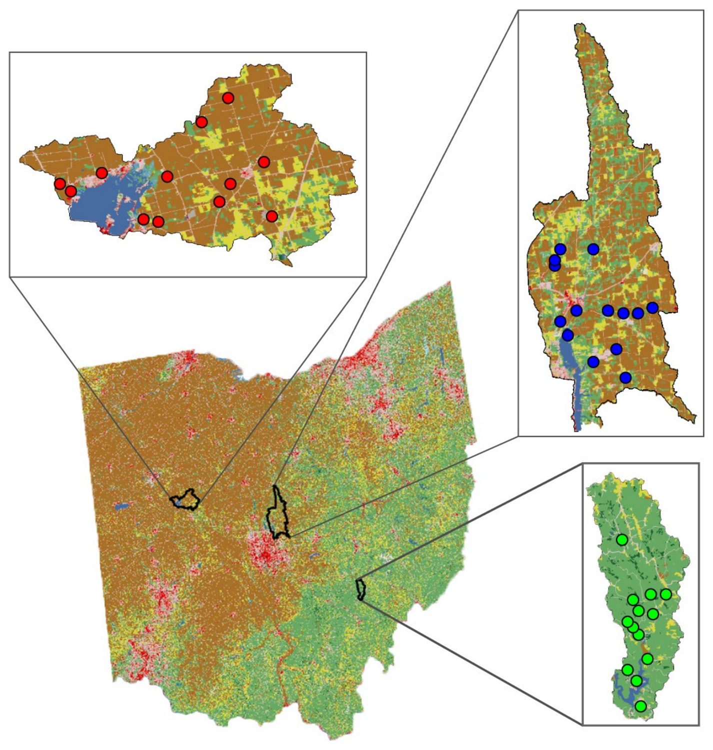


Figure 2. Study areas in central and southern Ohio. Land cover includes agriculture (brown and yellow), developed (red), and forest (green). Circles indicate sample locations. Land cover GIS layer from Homer et al. (2015).

METHODS

- Bulk water samples were analyzed for total N, total P, NO_3, and PO_4 at the Ohio Agricultural Research and Development Center's STAR Lab.
- Stream channel geomorphic surveys were conducted using a Gowin Total Station & Topcon Tesla Data Collector laser theodolite and prism rod.
- Stream geomorphic parameters were calculated using the Ohio Department of Natural Resources STREAM Module (Mecklenburg, 2004)
- Streambed particle size was determined using a gravelometer and Wolman pebble count (Wolman, 1954)
- In-stream habitat quality was determined using the Ohio Qualitative Habitat Evaluation Index (QHEI).

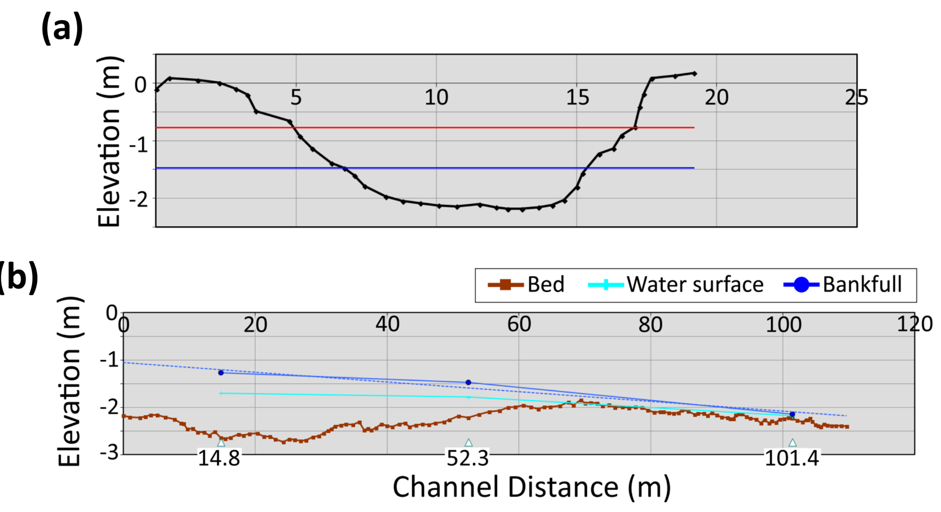


Figure 3. Example of stream lateral transect (a) and longitudinal profile (b) from the STREAM Module (Mecklenburg,2004).

- ANOVA and Tukey HSD were used to examine differences in nutrient concentrations and habitat quality by catchment.
- Linear mixed-effects models were used to explore relationships of habitat quality and nutrient concentrations with geomorphic parameters.
- The statistical program R was used for data analysis (R Core Team, 2014).
  - R packages used for data analysis were lme4 (Bates et al., 2015), lmerTest (Kuznetsova et al., 2017), MuMIn (Barton 2018), and ggplot2 (Wickham 2009).

RESULTS

- Variability among catchments was observed for Log TP (ANOVA: F = 5.03 , p = 0.007), Log PO_4 (ANOVA: F = 24.69, p < 0.001), Log TN (ANOVA: F = 52.71, p < 0.001), Log NO_3 (ANOVA: F = 57.96, p < 0.001), and QHEI (ANOVA: F = 7.27, p = 0.002).

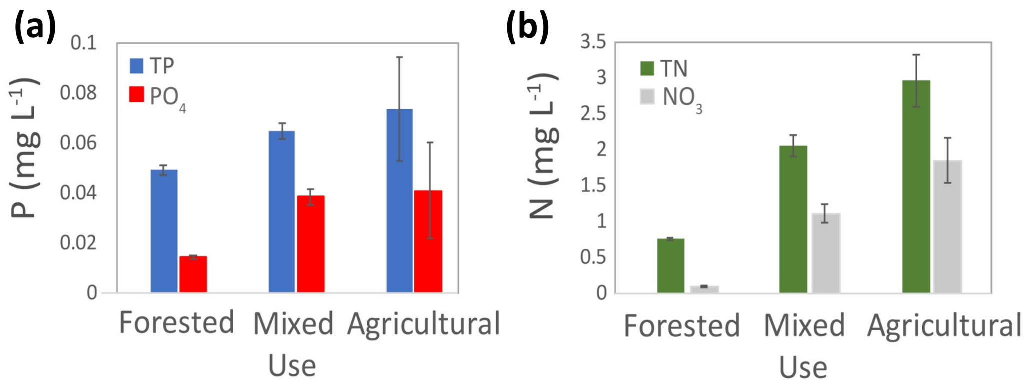


Figure 4. Variation in phosphorus (a) and nitrogen (b) species by land use type. Error bars indicate +/- 1 SE.

Figure 5. Variation in QHEI by land use type. Error bars indicate +/- 1 SE.

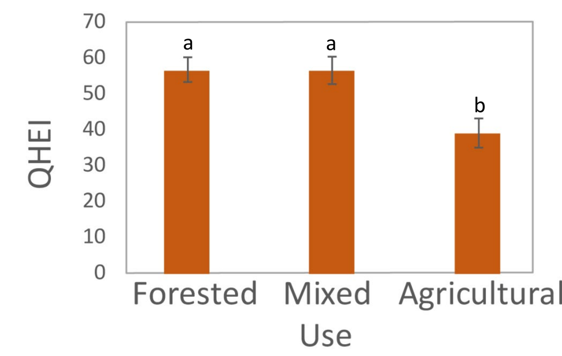


Table 1. Mixed-effects models with random effect of catchment and fixed effect of D_{50}. R^2m = marginal R^2. R^2c = conditional R^2. Significant p values are in bold.

	D_{50}				
Response	R^2m	R^2c	F	df	p
QHEI	0.09	0.39	9.58	1, 61.33	**0.003**
Log (TP)	0.05	0.27	4.54	1, 61.52	**0.04**
Log (TN)	0.03	0.46	3.57	1, 61.21	0.07
Log (PO_4)	0.03	0.53	3.85	1, 61.17	**0.05**
Log (NO_3)	0.01	0.47	0.64	1, 61.19	0.42

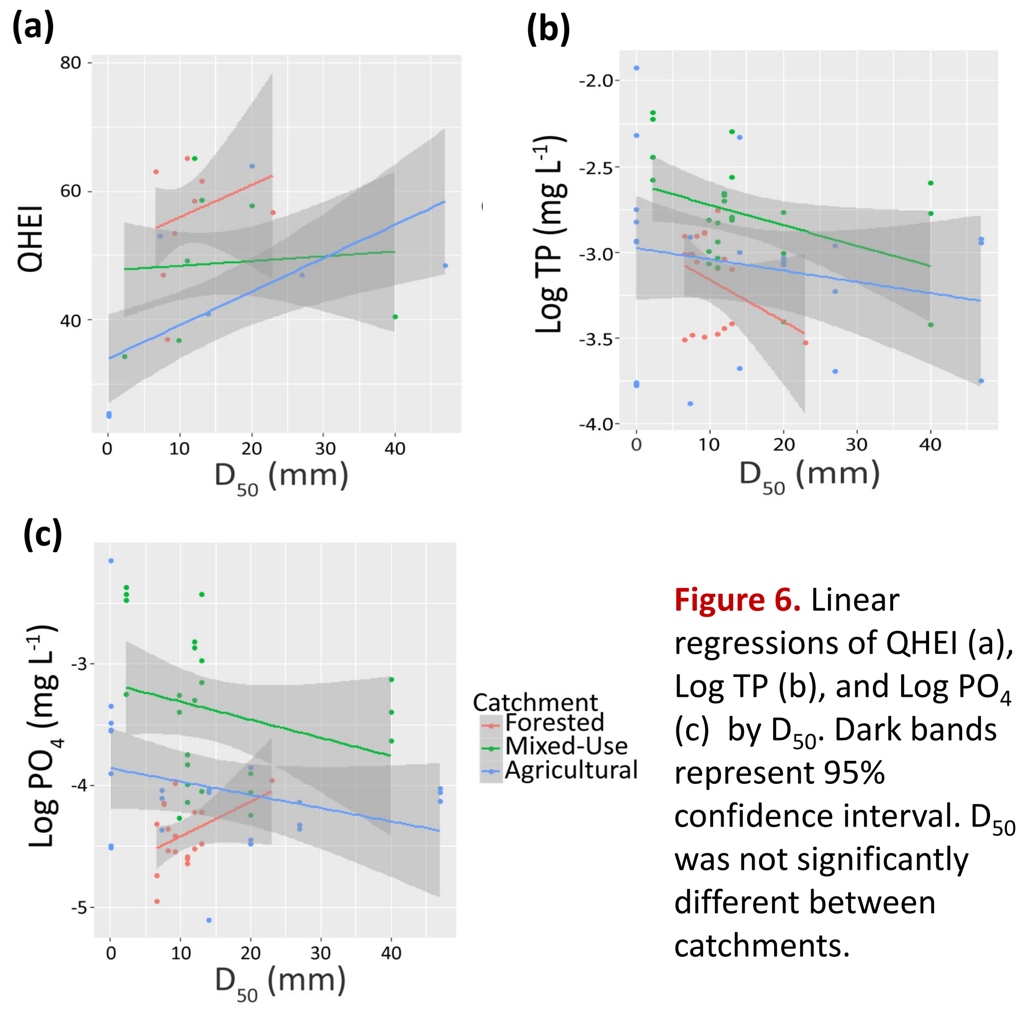


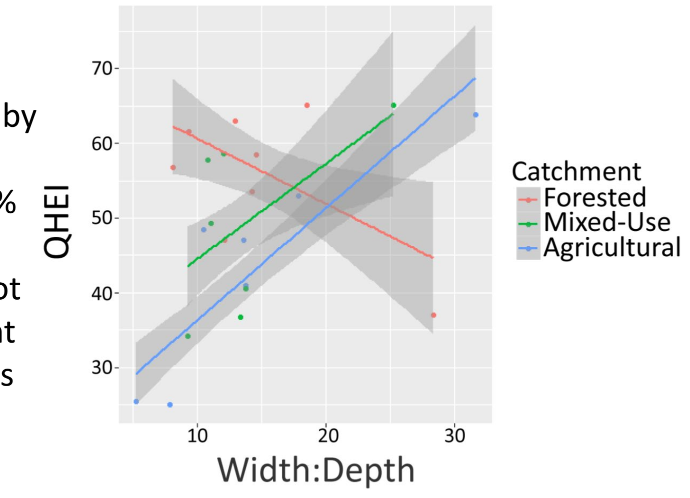
Figure 6. Linear regressions of QHEI (a), Log TP (b), and Log PO_4 (c) by D_{50}. Dark bands represent 95% confidence interval. D_{50} was not significantly different between catchments.

Table 2. Mixed-effects models with random effect of catchment and fixed effect of Width:Depth. R^2m = marginal R^2. R^2c = conditional R^2. Significant p values are in bold.

	Width:Depth				
Response	R^2m	R^2c	F	df	p
QHEI	0.21	0.42	23.24	1, 61.23	**<0.001**
Log (TP)	<0.01	0.19	< 0.01	1, 61.35	0.93
Log (TN)	0.02	0.40	1.81	1, 61.12	0.18
Log (PO_4)	0.01	0.48	1.51	1, 61.12	0.22
Log (NO_3)	<0.01	0.45	0.69	1, 61.10	0.41

RESULTS

Figure 7. Linear regressions of QHEI by Width:Depth. Dark bands represent 95% confidence interval. Width:Depth was not significantly different between catchments



- No significant relationships were seen for nutrient concentrations or habitat quality with siltation, amount of instream cover, or relative proportion of pool/riffle/run habitat.

CONCLUSIONS

- Overall, positive relationships were observed between habitat quality and D_{50}, as well as width:depth ratio after accounting for variation among catchments. Increased sediment size and width:depth ratio may result in increased habitat heterogeneity of stream reaches, thereby increasing stream habitat quality.
- Primarily, negative relationships were found for TP and PO_4 with D_{50} after accounting for variation among catchments. Increased D_{50} may result in increased habitat availability for basal resources, such as periphyton, that can uptake nutrients, as well as less sediment bound TP or PO_4, typically associated with smaller grain sizes, that could be exported to the water column.
- Our results highlight the potential role of stream restoration in improving stream habitat quality and reducing stream phosphorus loading.

NEXT STEPS

- Incorporate additional geomorphic parameters - such as sinuosity, entrenchment ratio, and width of floodprone area - into the analysis of nutrient concentration and habitat quality.
- Examine geomorphic impacts on nutrient loading, streamflow regime, and discharge rates.

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