Relations of Hydrologic and Physical Characteristics to Aquatic Assemblages in Low-Gradient Streams in Agricultural Settings in the North-Central and Northeastern U.S.

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ABSTRACT

A multidisciplinary study was conducted to evaluate the effects of hydrology, landscape, and land use on aquatic assemblages in low-gradient, agricultural areas across the northeastern and north-central United States. Hydrologic variables representing five components of streamflow (timing, magnitude, duration, frequency, rate of change) were calculated for 86 sites from The Nature Conservancy's Indicators of Hydrologic Alteration software program. Using a non-redundant subset of 75 hydrologic variables generated from daily mean streamflow values, cluster analysis produced five major hydrologic classes that varied in landscape, land use, water quality, and algal- and macroinvertebrate-assemblage structure. Sites within the same hydrologic class often were close spatially and had similar land use and geology. In addition, location (east to west) and land use were shown to be highly predictive of streamflow. Differences among the five classes were explained by high- and low-flow predictability, evapotranspiration rates, percent of clay or silt substrates, and road density. Sites in agricultural classes differed greatly, for example, Midwestern agricultural streams were more flashy and had less variable flow than other agricultural classes. Sites within urban classes generally had unpredictable but frequent flooding, short duration of high-flow pulses, and sustained periods of low-flow.

Macroinvertebrate-assemblage structure varied among hydrologic classes. The richness of Ephemeroptera, Plecoptera, and Trichoptera (EPT) taxa was lowest for classes within urban settings. Attributes such as flow predictability, flood predictability, frequency of low-flow pulses, duration of high-flow pulses, and flow per unit area were highly predictive of the structure of aquatic assemblages. A combination of natural (location, geology) and anthropogenic (land use) factors that contribute to these hydrologic processes will be considered in improving the management of agricultural and urban streams in the northeastern and north-central United States.

METHODS

- Eighty-six stream sites with co-located U.S. Geological Survey continuous streamflow-monitoring stations in the North-Central and Northeastern United States were selected for this study. The sites are in areas where agriculture is the traditional land use (although some sites are now largely urbanized) and have drainage areas of < 5,000 km2.
- Using a non-redundant subset of 75 hydrologic variables, a hierarchical cluster analysis (Clarke and Gorley, 2006) was used to group the 86 sites into five hydrologic classes. The variables that best characterized sites within classes were identified using correlation, principal components analysis, and SIMPER (a procedure in PRIMER-E that allows the user to evaluate individual species contributions to the separation of groups or clusters).
- Biological data collected during 1993 to 2002 at a subset of 60 sites were aggregated with basin-scale land-use, physical features, and water-quality variables. Linear regression was used to identify relations between assemblage structure and the various attributes.
- Assemblage metrics were computed and ANOSIM (a non-parametric analysis of community similarity) was used to test for differences in invertebrate assemblage structure among hydrologic classes.
- The BEST procedure (an analytical technique to link species and environmental patterns; Clarke and Warwick, 2001) was used to identify the hydrologic, physical, or water-chemistry variables that best explained the variation in the composition of aquatic assemblages.

REFERENCES

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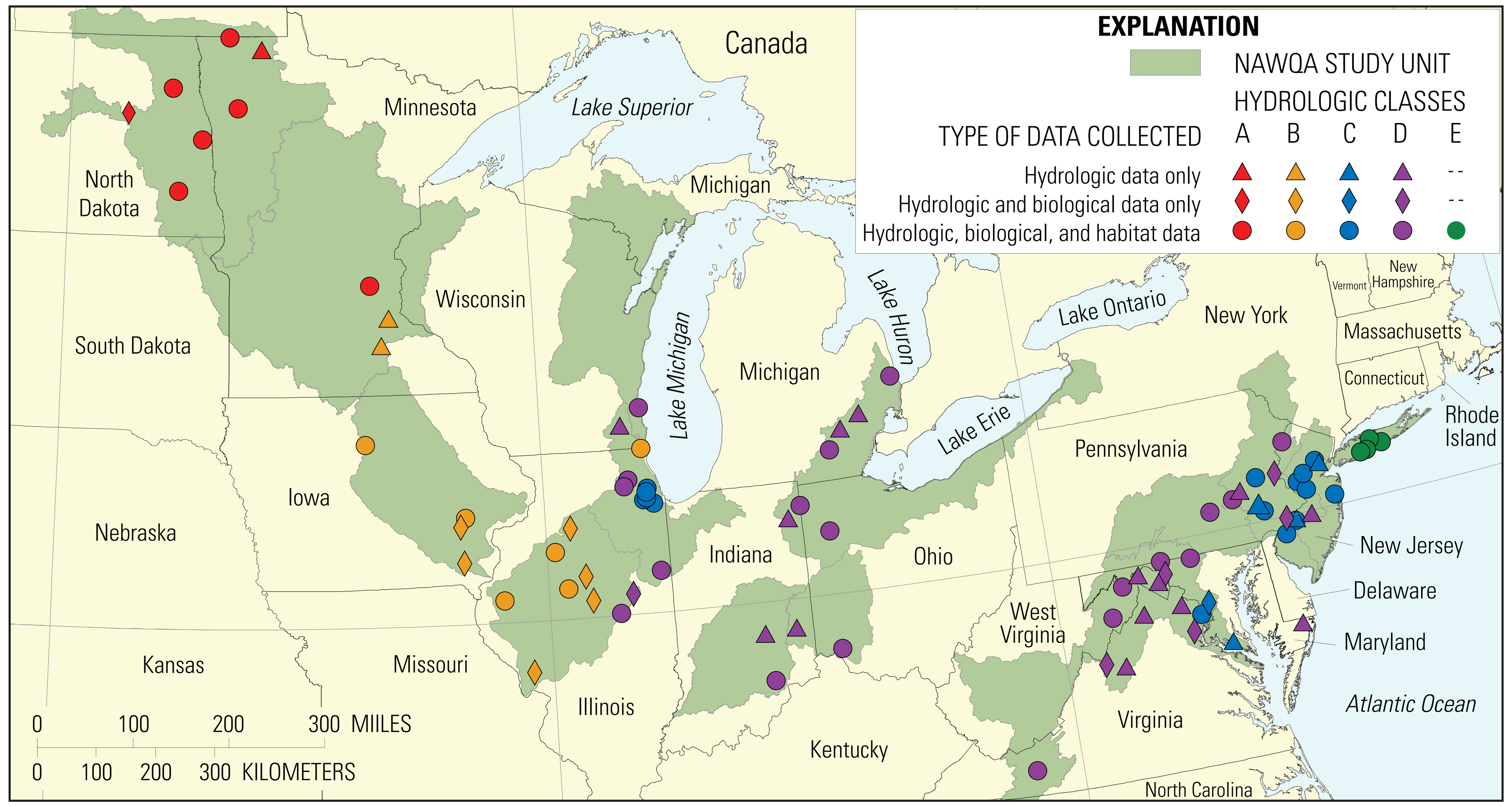


Data from 86 stream sites with a combination of (1) hydrologic data only, (2) hydrologic and biological data, or (3) hydrologic, biological, and habitat data were analyzed in this study.

CLASS A

- Agricultural land use
- Slow, steady flow
- High flood predictability
- Low flood frequency
- Slowest rise rate
- Longest high-flow duration
- Highest organic matter content
- High water capacity
- Low % EPT, High % Tolerant Benthic Invertebrates

CLASS B

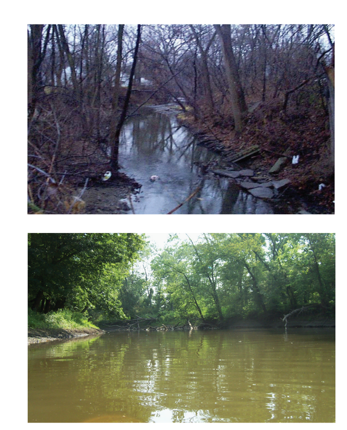
- Agricultural land use
- Tile drainage
- Slow, steady flow
- Least flood predictability
- Average flood freuqnecy
- Most variable rise rate
- Highest water capacity soils
- Least amount of large substrate
- High % EPT Invertebrates

CLASS C

- Urbanizing agricultural streams
- Small watersheds
- Fast, unpredictable flow
- Highest flow per unit area
- Unpredictable flooding
- High flood freuqnecy
- Quickest rise rate
- Least variable high-flow duration
- Low % EPT

CLASS D

- Mainly agricultural land use
- Wide range of basin slope, drainage area, and percent agri-culture among sites
- Very predictable flow
- Low variability
- High % EPT

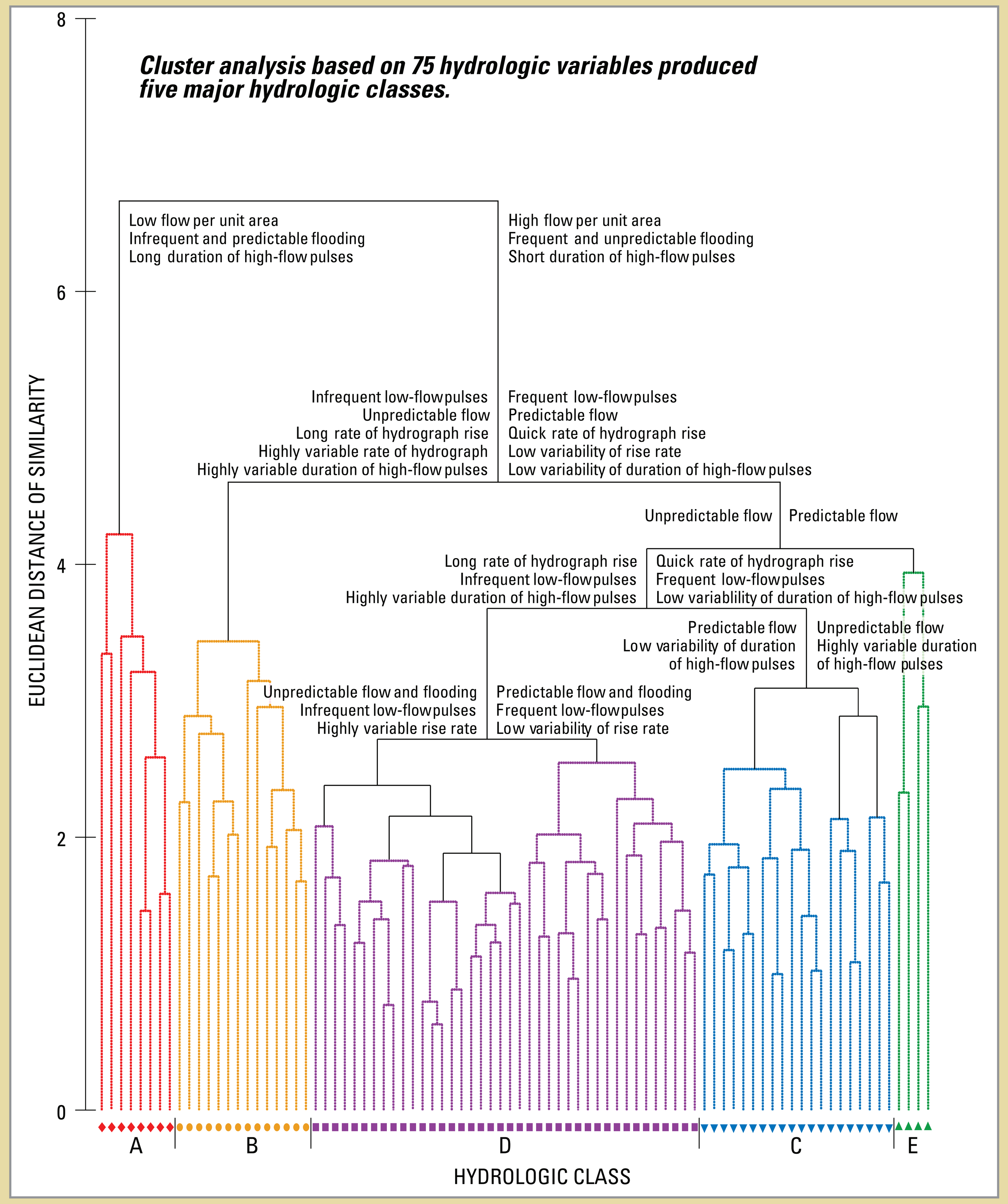


CLASS E

- Urbanized streams in Long Island, NY
- Ground-water dominated flow
- Flashy and variable flow regime
- Frequent flooding
- Short high-flow duration
- Least variable rise rate
- Least organic matter content
- Least soil water capacity
- Low % EPT Invertebrates

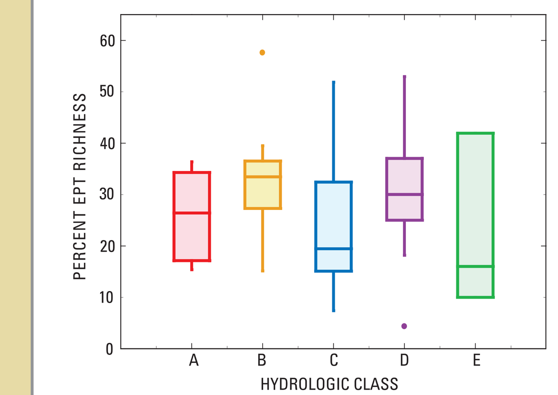
Characteristics of hydrologic classes important to aquatic assemblages

	CLASS A	CLASS B	CLASS C	CLASS D	CLASS E
Benthic Invertebrates	Variability of the rise rate Flood infrequency Evapotranspiration Latitude	Variability of the rise rate Flow per unit area	Frequency of low flow pulses pH Basin slope	Flood infrequency Flood predictability Latitude Soil organic matter content	Drainage area Latitude
Algae	Duration of high-flow pulses Basin slope Average soil water capacity	Flood predictability Variability of the rise rate Phosphrus concentrations	Flood predictablity Road density Soil permeability pH	Frequency of low-flow pulses Basin slope Average soil water capacity	Drainage area Latitude

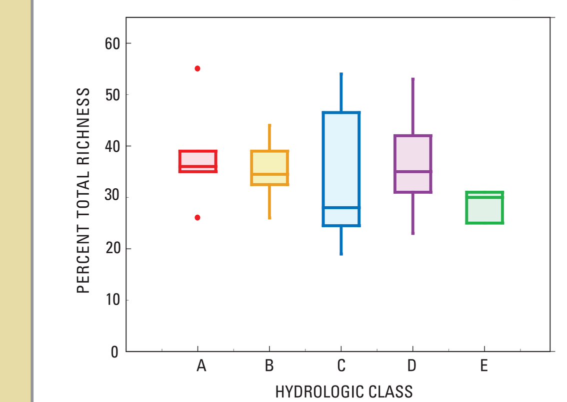


Assemblage metrics by hydrologic class.

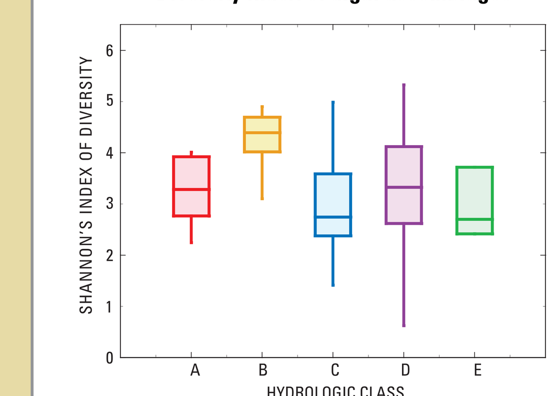
Percent of total richness composed of EPT taxa



Total richness of invertebrate assemblages



Diversity index of algal assemblages



ANOSIM (a non-parametric analysis of similiarity) indicated significant differences among communities between hydrologic classes with the exception of B & D; C & D, and C & E.

DISCUSSION

Class-specific hydrologic, landscape, and land-use variables appeared to explain the variability in structure of aquatic assemblages. Although streams with similar physical and land-use settings had similar flow regimes, different factors accounted for the majority of that variability, even among areas with similar land use.

For example, the variability in invertebrate assemblages in Class B streams was best explained by differences in the rate of hydrograph rise and flow per unit area, whereas the variability of invertebrate assemblages in Class C streams was best explained by the frequency of low-flow pulses. Some aspects of the flow regime were directly related to the biotic integrity of streams within classes. For Class B streams, percent EPT richness appeared to be negatively related to predictable flow processes and positively related to a highly variable frequency of low-flow pulses. Conversely, Class C streams had the lowest percent EPT richness of all classes that were directly related to predictable flooding, infrequent low-flow pulses, and a slow rise rate.

Poff and Ward (1989) theorized that as the flow of streams becomes more predictable, invertebrate assemblages become more trophically complex; conversely, streams with frequent flooding are trophically simple and should have low invertebrate species richness. Some results of this study appear to support this hypothesis, specifically for urban Class C, where as flooding became more predictable, the richness of EPT taxa increased and assemblages were comprised of a higher proportion of intolerant invertebrate taxa. Findings for Class B, however, did not fully support this hypothesis. For example, as flooding became more predictable, the invertebrate communities consisted of fewer sensitive taxa and algal assemblages had lower overall diversity scores for diatoms.

It is probable, however, that this discrepancy is more likely a function of differences in the substrate used to sample the aquatic assemblages (woody debris was sampled for Class B streams) as opposed to predicted response to hydrologic alteration.