Spatial and temporal controls on nutrient fluxes across a mixed-use watershed in north-central Ohio, USA

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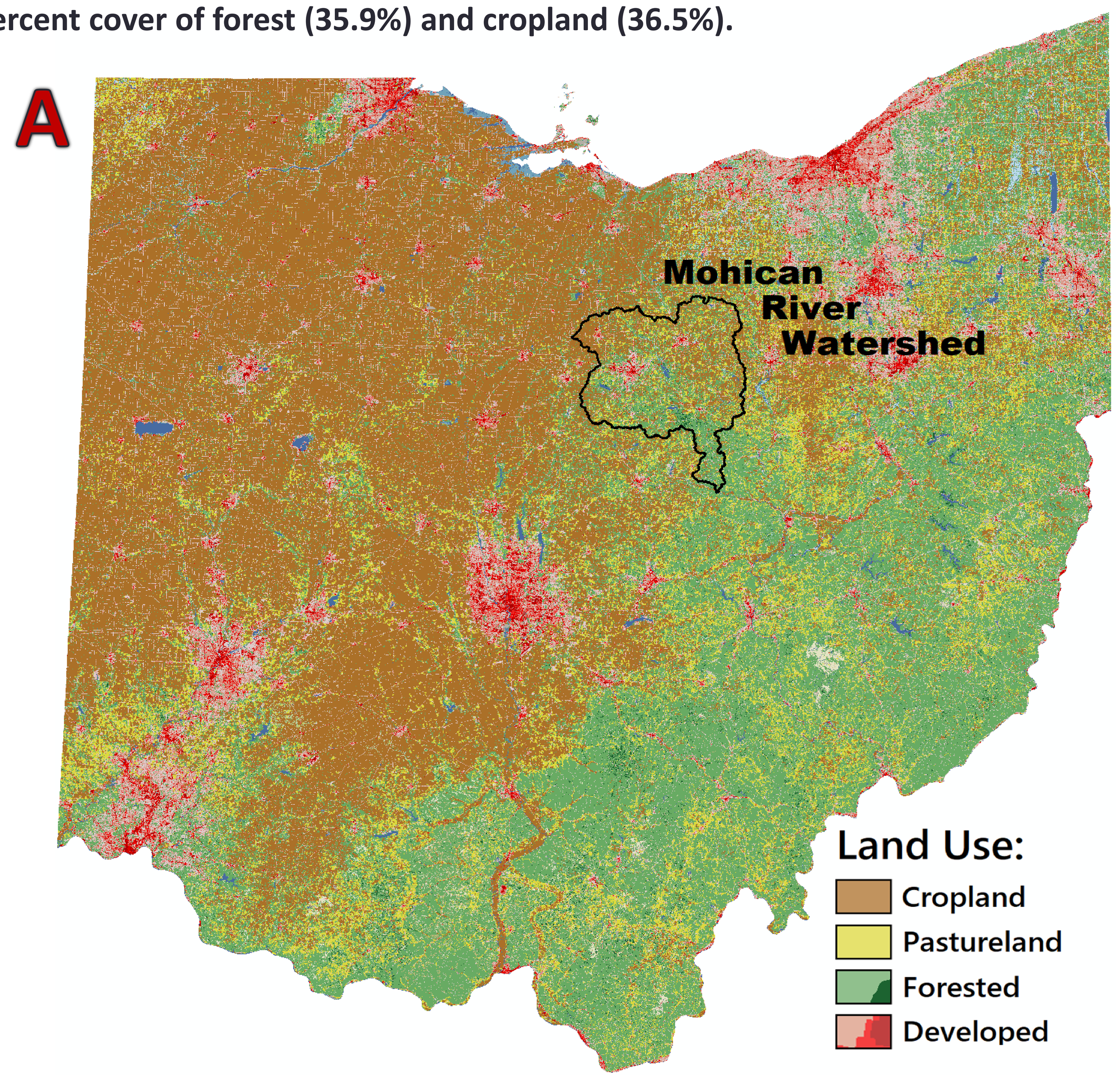
INTRODUCTION

Over the last century, runoff from farms and cities, along with land cover and land use changes, have drastically altered the mass balance of nutrients in aquatic systems, affecting both their ecological functioning and the living communities they support. Here we present the results of a multi-year, long-term study designed to assess the control of land-use and hydrology on nutrient fate and transport within a mixed land-use watershed in north-central Ohio. A total of 64 streams (with a mix of urban, cropland, pasture, and forest catchments) have been sampled periodically since the summer of 2008.

LAND USE / LAND COVER

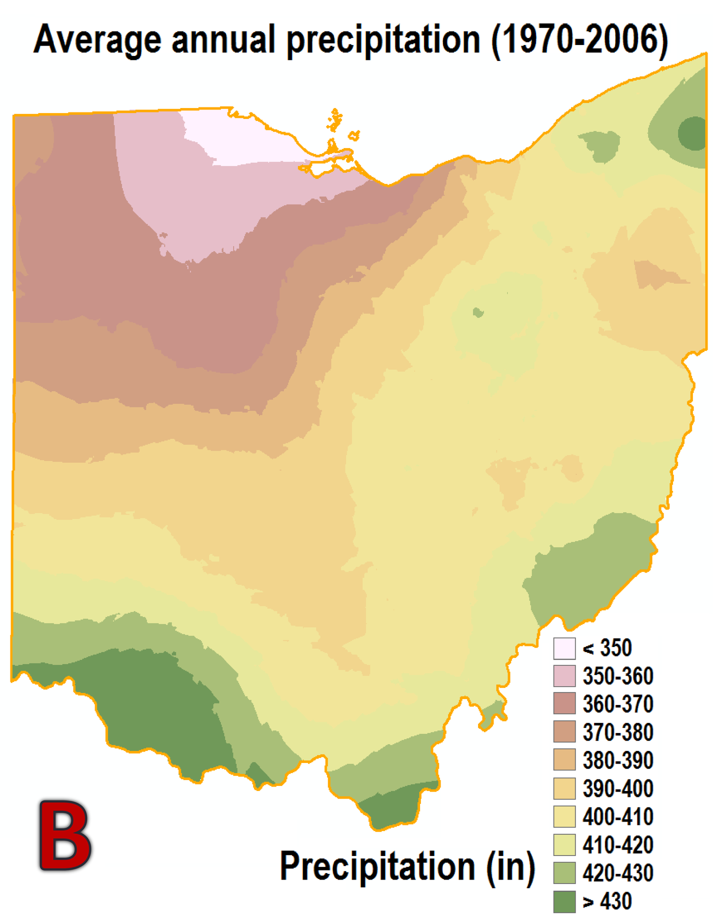
Since its inception, Ohio has experienced significant shifts in its land use. At the time of the settlement of Marietta (in 1788), forests and woodlands covered about 95% of the State's land area. By 1940, the forest cover had been reduced to only about 12% of the State's land area (Diller, 1944). Since then, forest cover has steadily increased, until reaching the current level of 31% (NLCD, 1992-2011; NRI, 1945-2012; USDA Census of Agriculture, 1840-2012). But the distribution of forests and farmlands in Ohio is far from uniform. Most of the forest cover is concentrated on the Hill Country (SE portion of the state), while the Glaciated Region contains most of the croplands and pasturelands (Fig. A). The Mohican River watershed sits on a transitional zone between the Hill Country and the Glaciated Region, and it contains almost the same percent cover of forest (35.9%) and cropland (36.5%).

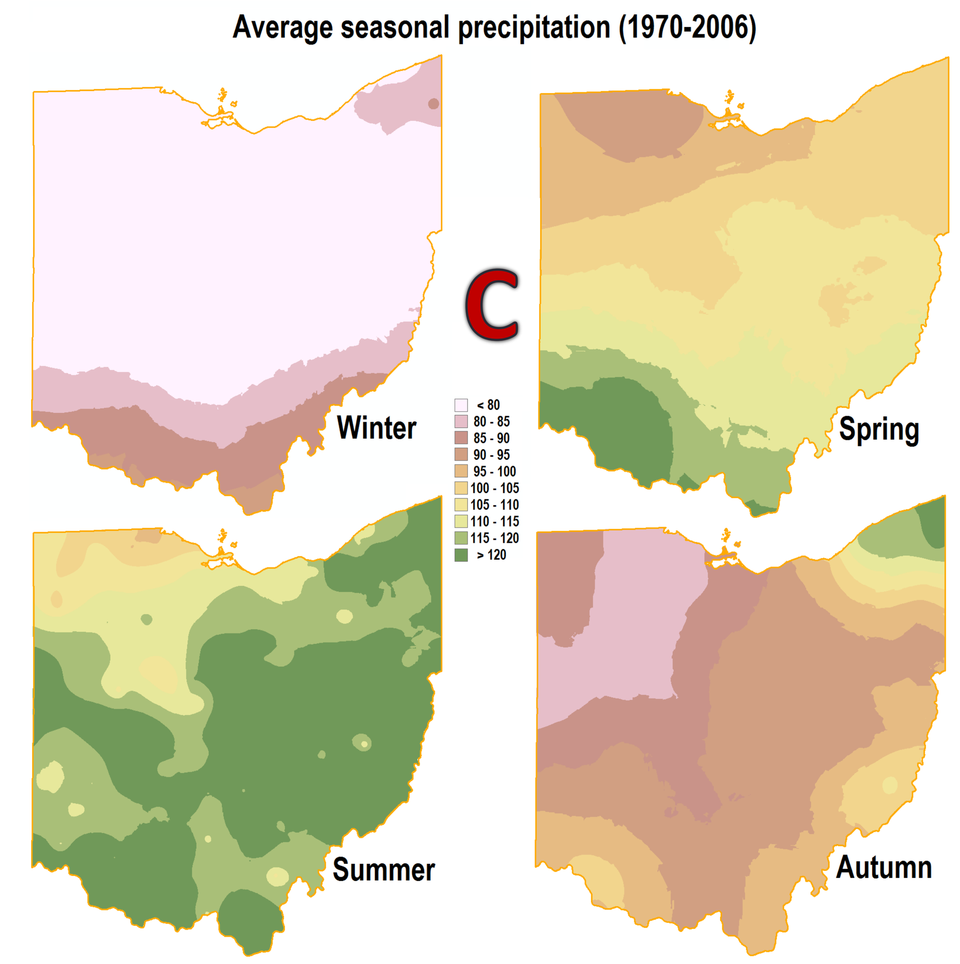


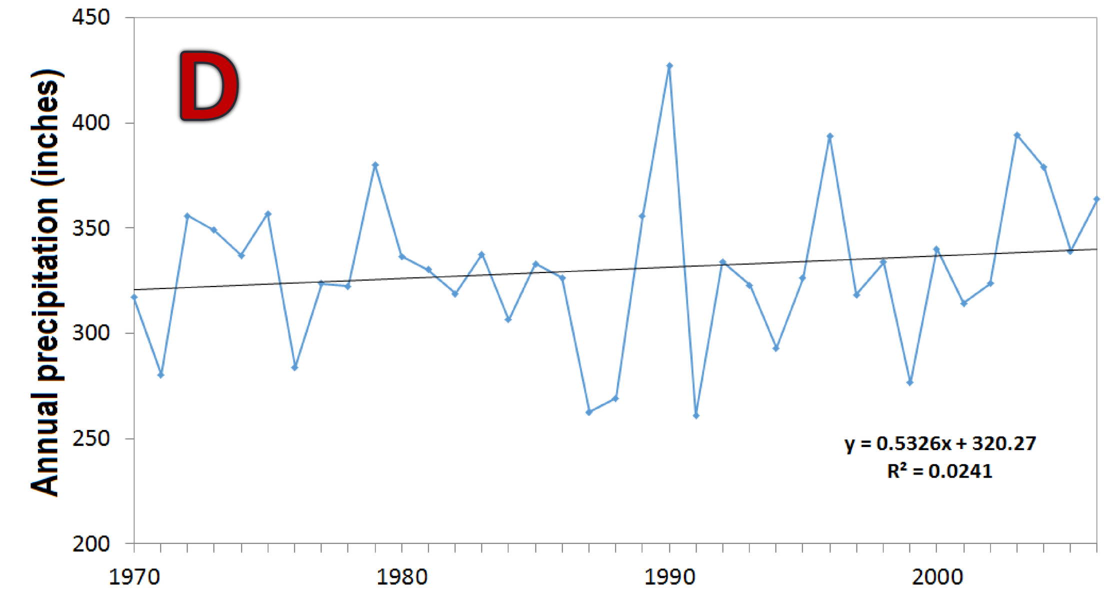
HYDROLOGY

Monthly precipitation data for 205 stations in all 88 counties of Ohio between 1970 and 2006 were collected from the NOAA National Climatic Data Center (NCDC) database. Figure B shows the typical precipitation amounts throughout the state during this period. There is a marked latitudinal variation throughout the state with average annual precipitation increasing from NW to SE, ranging from about 300 in/year in Lucas County (the driest) to over 340 in/year in Clermont County (the wettest). Figure C shows the average precipitation by seasons. Precipitation occurs in all months and seasons but is generally greatest during the summer (total precipitation is usually above 100 inches) and least during the winter months (total precipitation amounts below 90 inches). Summer precipitation accounts for 30% of the annual total.

HYDROLOGY

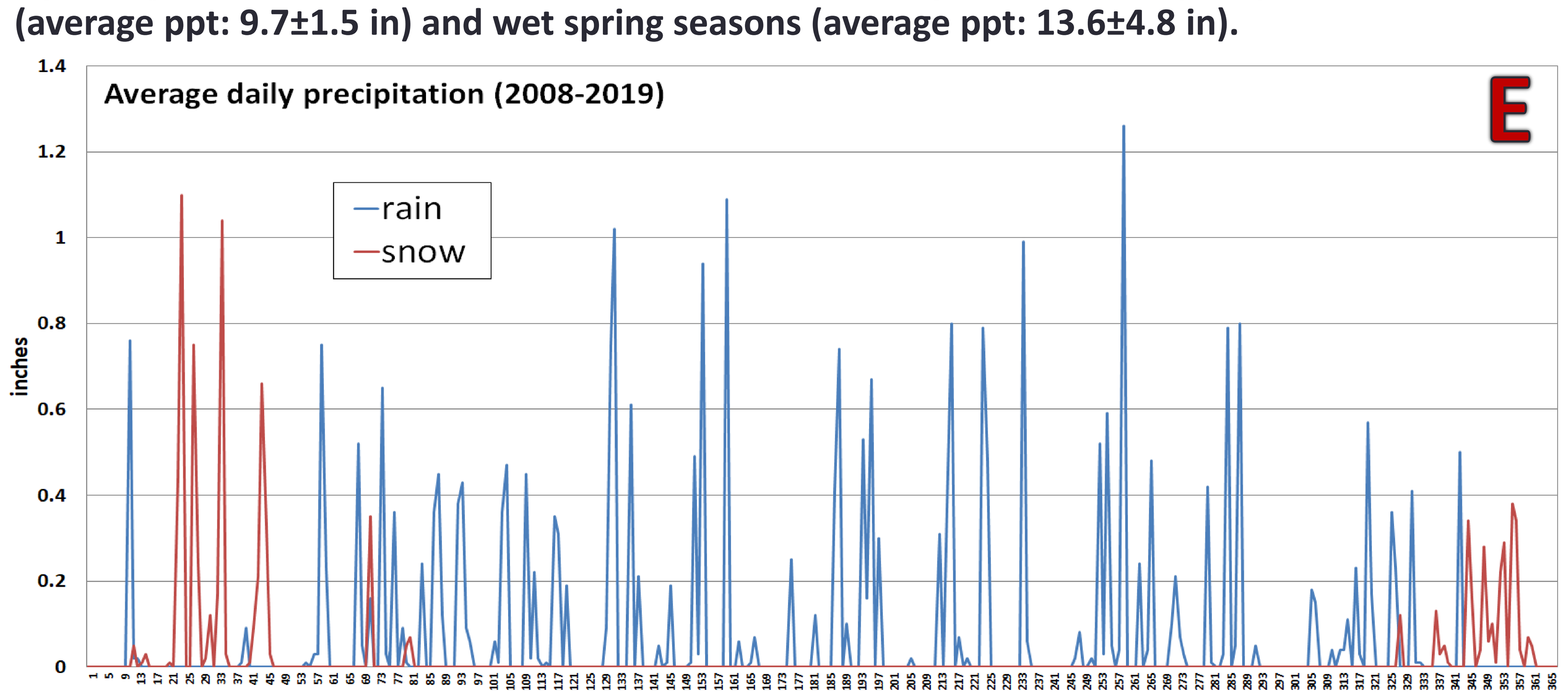


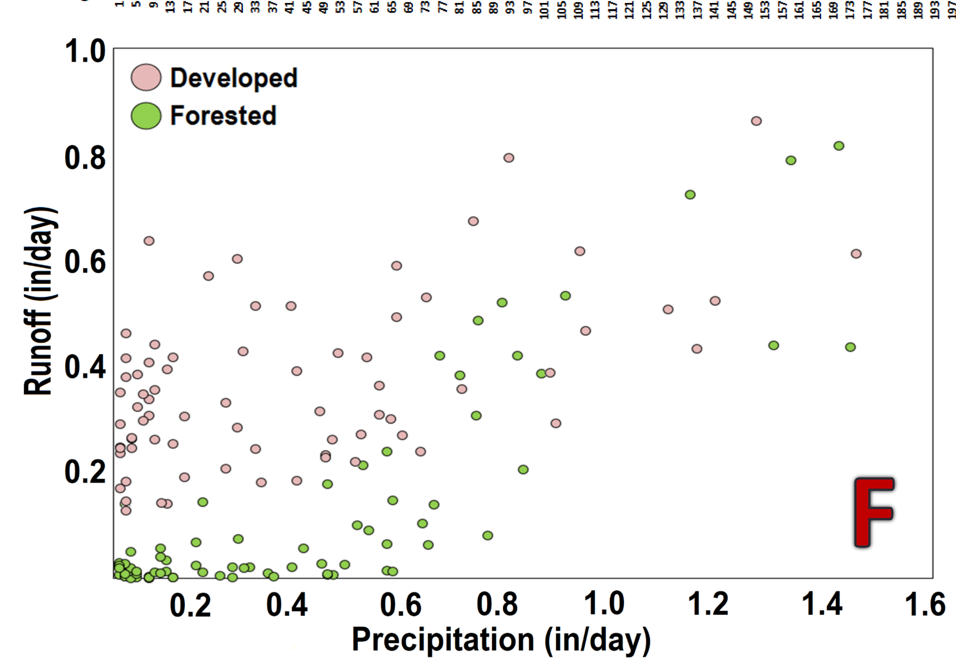




Although there is significant inter-annual variability (Fig. D), there has been a slight increase in precipitation during the period of study (about +144 inches per decade). The last ten years has seen the sharpest increase (+54 inches per year).

Figure E shows daily precipitation in the Mohican watershed during the study period. Hydrological conditions exhibited marked seasonality, with usually dry winter seasons (average ppt: 9.7±1.5 in) and wet spring seasons (average ppt: 13.6±4.8 in).

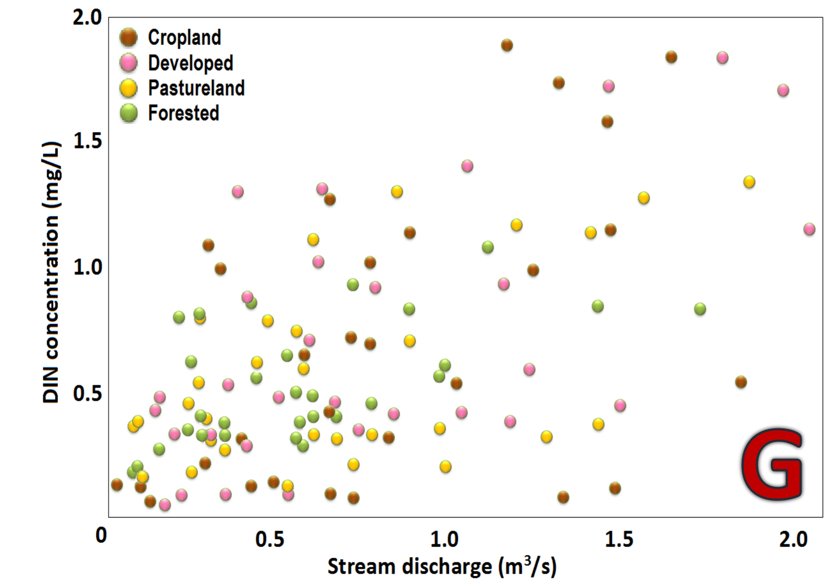


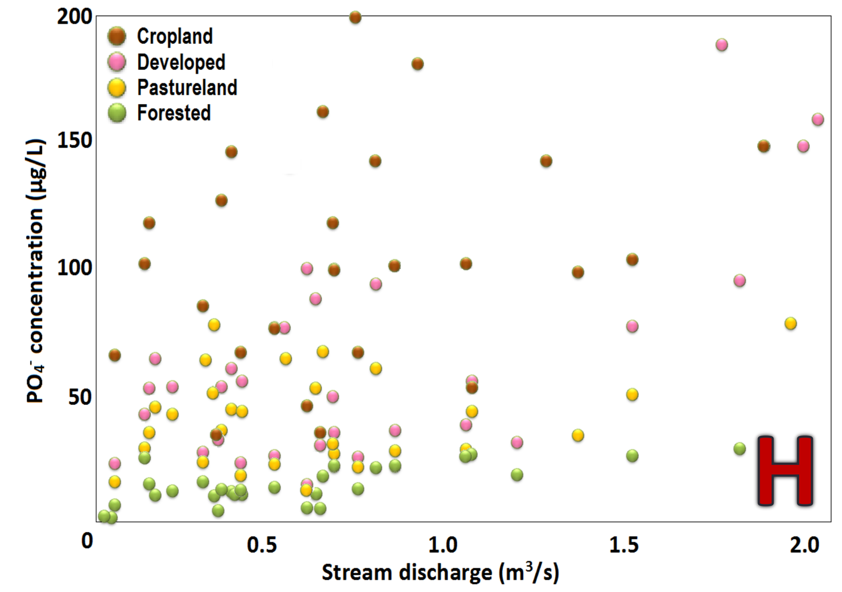


Runoff generation in response to precipitation events is faster in streams draining developed catchments and slowest in forested streams, where runoff is generated only by events >0.04 in/day (figure F). Hydrologic connectivity in the watershed appear to be limited, since only about 25% of precipitation inputs were translated into quick flow.

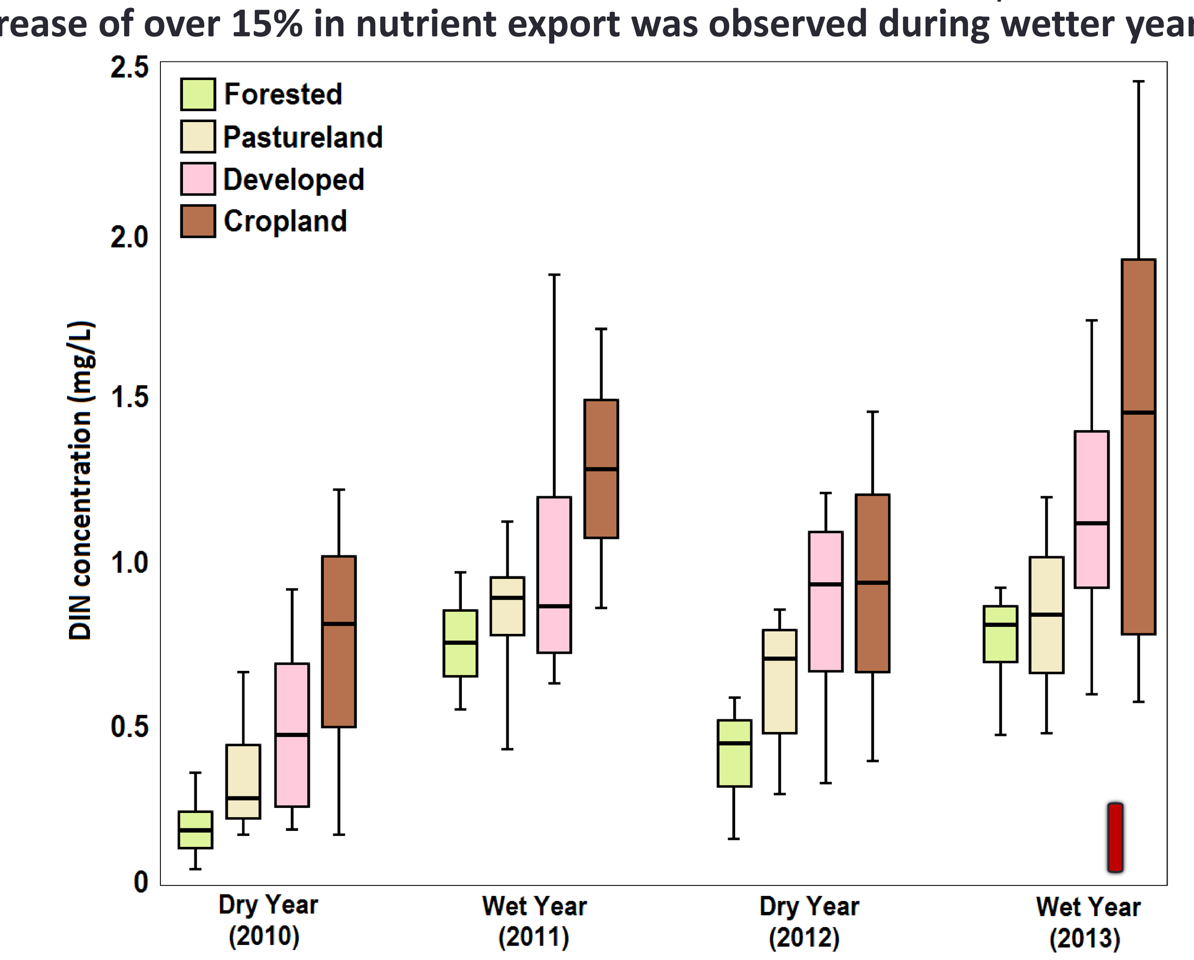
NUTRIENT CONCENTRATIONS

Hydrological factors, along with land use of the reach-catchment area, have strong influence on nutrient fluxes, as indicated in figures G and H). There is a significant, positive correlation between runoff and nutrient concentrations (R^2 values are: 0.40 for streams draining developed landscapes, 0.34 for forested streams, 0.30 for cropland, and 0.28 for pastureland).





This short-term hydrological variability is compounded by the effects of long-term geomorphic and climatic changes. Although our long-term dataset showed no significant increasing or decreasing trends in nutrient concentrations at the studied streams, there were significant inter-annual and seasonal variations on both DIN (p = 0.02) and PO_4 concentrations (p < 0.01), and an increase of over 15% in nutrient export was observed during wetter years (Fig. I).



Compared to dry years, nutrient fluxes during wetter years are, on average, 16% higher in urban catchments and 47% higher in forested catchments, but 32% lower in pasture-dominated catchments. Baseflow is responsible for only between 20-30% of the annual nutrient export from the watershed. In addition, there is a marked shift between local and external controls on biogeochemical processes under baseflow and stormflow conditions. During stormflow, nutrient input is primarily hydrologically controlled (Fig. J). During baseflow (Fig. K), biological processes dominate both the production and removal of nutrient ions from the stream.