Landscape Patterns and Water-quality Relationships in New Jersey Pinelands Streams

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Cover: Skit Branch at Carranza Road, Wharton State Forest, Tabernacle, NJ. Photograph taken by Robert A. Zampella.

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Abstract

We evaluated how landscape patterns might influence land-use-proximity and water-quality relationships in New Jersey Pinelands streams by relating pH and specific conductance to the percentage of altered land (developed land and upland agriculture) in a series of cumulative stream buffers (ranging in width from 0-100 m to 0-700 m) and associated watersheds. Specific conductance and pH were positively correlated. The percentage of altered land in all seven buffers and associated watersheds provided a proportional measure of watershed disturbance. R-square values produced by the pH regression models increased upgradient (near stream to basin divide), ranging from 0.69 to 0.77. In contrast, the R-square values for the specific conductance models decreased upgradient, ranging from 0.81 to 0.71. These contrasting patterns are most likely attributable to subtle variations in the distribution of the water-quality variables in relation to altered land in each of the cumulative buffers rather than to a proximity effect. Although we cannot conclude that proximity has a direct effect on water quality, our results strongly support a conclusion that variations in land use are associated with changes in water quality and that both near and far land uses provide a relatively good measure of water quality in the Pinelands watersheds that we studied.

Introduction

Urban land and agriculture are associated with the degradation of stream-water quality throughout the United States (Johnson et al. 1997, Carpenter et al. 1998, Herlihy et al. 1998, Rhodes et al. 2001). In the New Jersey Pinelands (Figure 1), where all watersheds share a similar underlying geology characterized by the unconsolidated sands and gravels of the Kirkwood-Cohansey aquifer (Rhodehamel 1979a, Zapecza 1989, Newell et al. 2000), water-quality degradation in streams is related primarily to non-point source pollution associated with basin-wide developed (urban) and upland-agricultural land (Morgan and Good 1988, Zampella 1994, Dow and Zampella 2000, Hunchak-Kariouk and Nicholson 2001, Baker and Hunchak-Kariouk 2006, Zampella et al. 2007, Conway 2007). Contamination of the Kirkwood-Cohansey aquifer, which is the dominant source of flow to Pinelands streams (Rhodehamel 1979b), is linked to both urban and agricultural land uses (Watt and Johnson 1992, Vowinkel and Tapper 1995, Johnson and Watt 1996, Stackelberg et al. 1997, Szabo et al. 1997, Bunnell et al. 1999).

The results of several North American studies have indicated that accounting for the proximity of land use to streams does not improve the relationship between land use and water quality beyond that attributed to the proportion of different land uses in the entire watershed (Omernik et al. 1981, Osborne and Wiley 1988, Hunsaker et al. 1992, Sliva and Williams 2001). In contrast, Tufford et al. (1998), Basnyat et al. (1999), and Tran et al. (2010) found that near-stream land uses were better predictors of water quality than more distant land uses. Other studies have produced mixed results (Hunsaker and Levine 1995, King et al. 2005, Johnson et al. 1997).

In a previous study of Pinelands stream-water quality, Zampella et al. (2007) found that including the proximity of developed and upland-agricultural land to a monitoring site, using inverse-distance-weighted land-use values, did not improve the relationship between land use and water quality beyond that obtained using watershed-wide land-use data. In this paper, we evaluated how landscape patterns might influence land-use-proximity and water-quality relationships in Pinelands streams by relating pH and specific conductance to the percentage of altered land (developed land and upland agriculture) in a succession of cumulative stream buffers and describing land-use relationships among the buffers.

Methods

Study-site Selection

We selected 47 stream-monitoring sites located throughout the Pinelands (Figure 1) that displayed a range of watershed conditions characterized by the percentage of developed land and upland-agricultural land. All of the streams are associated with the unconfined Kirkwood-Cohansey aquifer system (Rhodehamel 1979a, 1979b, Zapecza 1989).

Watershed Characteristics

Watersheds were created using stream data obtained from the New Jersey Department of Environmental Protection (NJDEP 1996), a digital-elevation model (NJDEP 2002), and Arc Hydro (Environmental Systems Research Institute Inc.,

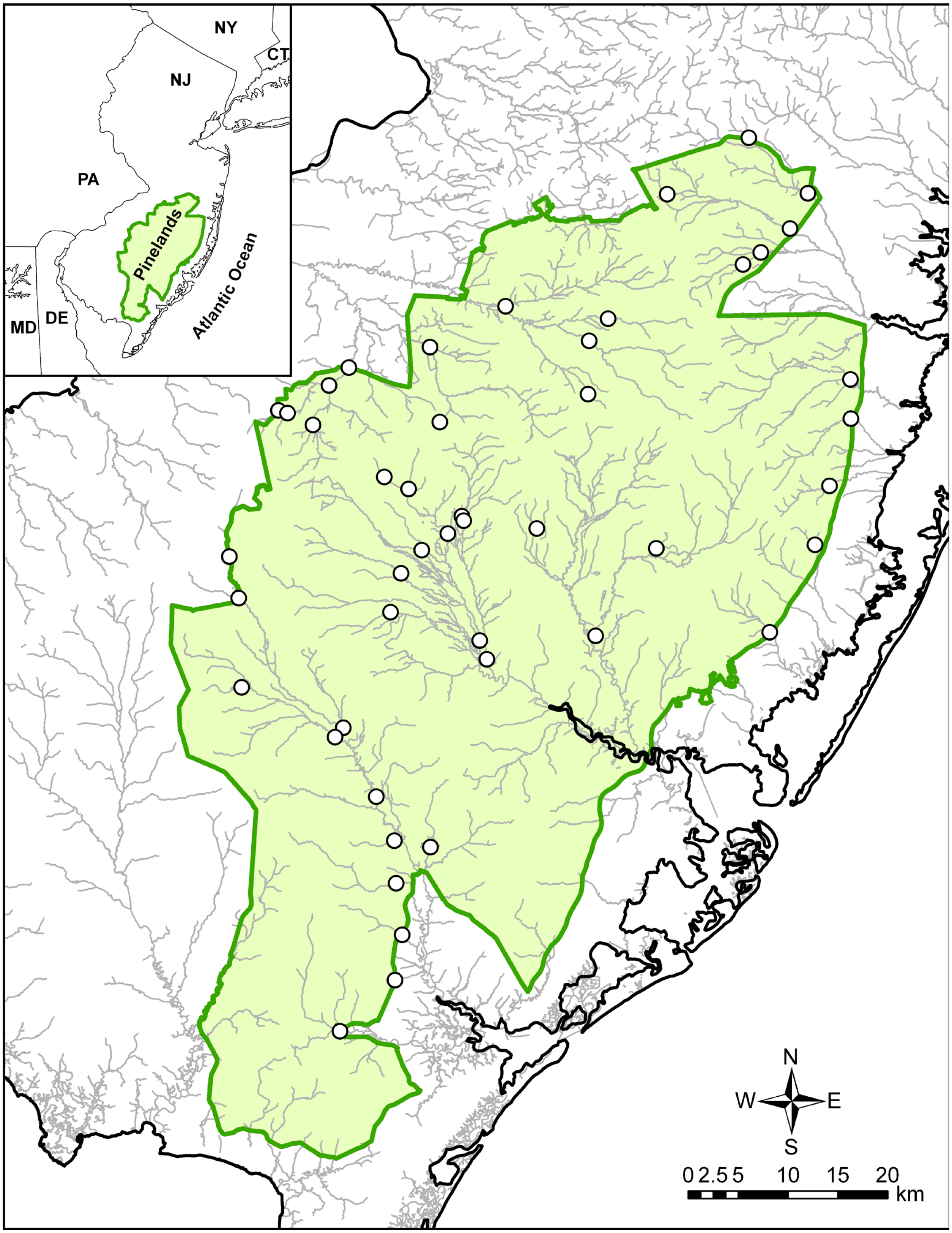

Figure 1. The location of 47 water-quality sampling sites in the New Jersey Pinelands.

Redlands, CA 2007). The watershed area associated with the monitoring sites ranged from 4.4 to 397 km^2, with a mean (± 1 SD) of 56.2 ± 68.9 km^2. Using ArcView software (Environmental Systems Research Institute Inc., Redlands, CA, 1999-2006) and digital land-use/land-cover data (NJDEP 2007), which classifies land uses using a modified Anderson et al. (1976) system, we determined the percentage of developed land, upland agriculture, wetlands (water, palustrine wetlands, and wetland agriculture), and upland forest in the watersheds associated with each water-quality monitoring site and within seven cumulative stream buffers (0-100 m through 0-700 m, which was the maximum buffer found in several basins) surrounding each stream. We refer to the Anderson-type land-use classes of urban land and agriculture as developed land and upland agriculture, respectively. The term "altered land" refers to the combined percentage of developed land and upland agriculture in a watershed.

Water-quality Sampling

Specific conductance and pH are good indicators of watershed disturbance in the Pinelands (Dow and Zampella 2000, Conway 2007) and both are positively correlated with other water-quality variables such as calcium, magnesium, chloride, and nitrate-nitrogen (Zampella 1994). Streams draining forested Pinelands watersheds are usually acidic with low concentrations of dissolved solids. Both specific conductance and pH increase as the percentage of altered land in a watershed increases. Specific conductance and pH were measured monthly from June through September in 2005, March through October in 2006 and 2007, and April through June in 2008 for a total of 23 sampling dates. Specific conductance was measured with an Orion model-122 meter and pH was measured using an Orion model-250A meter. All sampling runs were completed under baseflow conditions over a two- to three-day period.

Data Analysis

Landscape patterns. Using mean values for the 47 basins, we summarized the percentage of basin area represented by each cumulative buffer and the percentage of each cumulative buffer composed of altered land and wetlands. To determine if the percentage of altered land in each of the cumulative stream buffers provided similar, relative measures of watershed disturbance, we used Pearson correlation analysis to evaluate land-use relationships among the cumulative buffers and associated watersheds. Arcsine-transformed altered-land-use percentages, expressed as a proportion (arcsine ($\sqrt{p}$)), were used in the correlation analyses.

Land-use/water-quality relationships. We used Spearman rank correlation to evaluate the association between pH and specific conductance. Simple linear regression was used to relate both pH and specific conductance to the percentage of altered land in each of the seven cumulative buffers and associated watersheds. Arcsine-transformed altered land-use percentages and log transformed specific conductance values were used in all regression analyses. Scatterplots indicated that all water-quality/land-use relationships were linear. For each regression, we visually inspected a plot of residuals versus predicted values to evaluate whether the assumptions of homoescedasticity (constant variance among residuals) and independence of error terms were met. We also inspected normal probability plots and histograms and used the Shapiro-Wilks test statistic to determine if the residuals were normally distributed.

Statistical significance. Because of a lack of independence among the cumulative buffers, we did not evaluate the statistical significance of the land-use relationships among the buffers and associated watersheds. Instead, we used the correlation coefficients as descriptive statistics and applied an alpha level of 0.05 as the criterion to determine which coefficients were meaningful. An alpha level of 0.05 was also used to assess the statistical significance of each regression model and the single Spearman rank correlation. Significance levels for related regression models were adjusted using the sequential Bonferroni method (Rice 1989). The statistical analyses were completed using Statistica 7.1 (StatSoft, Inc., Tulsa, OK).

Results

Landscape patterns. The mean percentage of each cumulative buffer represented by altered land increased and the percentage represented by wetlands decreased in an upgradient (i.e., near-stream to basin divide) direction (Figure 2). On average, upland forest made up nearly all of the remaining basin area in each buffer and other land uses represented less than one-percent of each buffer. A comparison of coefficients of variability (Zar 1999) indicated that the relative variability of altered land was highest in the 0-100-m buffer (64.5) and decreased in an upgradient direction (61.5 to 57.5). Wetlands were the dominant land cover in the 0-100-m buffer. On average, nearly one-half of the basin-wide wetlands were associated with the 0-100-m stream buffer. More than one-half of basin area and basin-wide altered land was found within 300 m and 400 m of the stream, respectively.

Altered land in all seven buffers and associated watersheds provided a proportional measure of watershed disturbance. Pearson correlation coefficients relating the percentage of altered land among the seven cumulative buffers ranged from 0.95 to > 0.99 (Table 1). Coefficients describing the relationship between the basin-wide altered-land values and altered land-use values in the seven cumulative-buffers ranged from 0.93 to > 0.99 and increased with increasing cumulative-buffer width. The p-value for all correlations was < 0.001.

Land-use/water-quality relationships. Basin-wide altered land ranged from < 1% to 63%. Specific conductance and pH values ranged from 31.5 to 265.3 μS cm^{-1} and 4.0 to 6.8, respectively. Spearman rank correlation revealed a positive relationship between the two variables (Spearman r = 0.73, p < 0.001). Based on the Shapiro-Wilk test, pH values approached normality (p = 0.03). Both raw (p < 0.001) and log-transformed (p = 0.003) specific conductance values were skewed to the left and clearly deviated from normality.

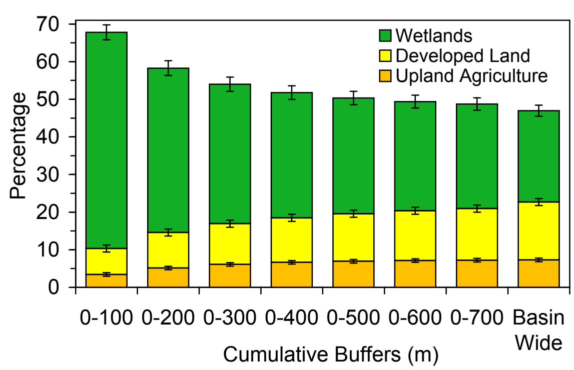

Figure 2. Mean (± 1 SE) altered land and wetland values as a percentage of cumulative buffer area and basin-wide values. On average, forest land made up nearly all of the remaining basin area in each buffer and basin. Other land uses represented less than one-percent of each buffer.

A total of 16 regression models, including eight pH models and eight specific conductance models, were produced. All regression models met the required assumptions of linearity, homoescedasticity, independence of error terms, and normality. The initial p-values for all regression models were < 0.001 and all related models were significant following the Bonferroni adjustment.

Although very similar, the slopes of the regression lines for the eight pH-based models decreased slightly in an upgradient direction (Figure 3). The R-square values produced by the pH models increased upgradient, ranging from 0.69 to 0.77 (Figure 4). The intercepts displayed a similar pattern. The patterns displayed by the regression lines produced by the specific conductance models were similar to those produced by the pH models (Figure 3). However, unlike the pH models, the R-square values for the specific conductance models decreased upgradient, ranging from a high of 0.81 to a low of 0.71 (Figure 4).

Discussion

Hydrologic processes suggest that proximate land uses should have a greater effect on stream-

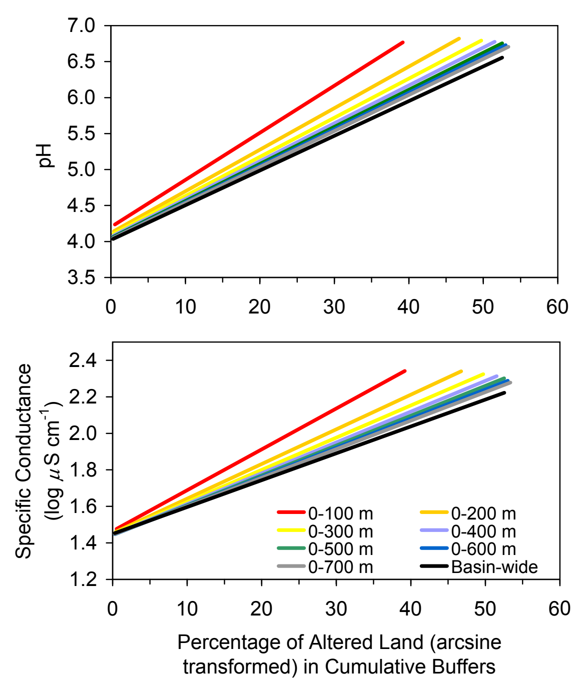

Figure 3. Regression lines relating pH (top) and specific conductance (bottom) to the percentage of altered land in seven cumulative buffers.

Table 1. Pearson correlation coefficients relating the percentage of altered land among seven cumulative stream buffers and associated drainage basins for 47 stream sites. Values shown as > 0.99 are < 1.00. The p-value for all correlations was < 0.001.

	Cumulative Buffers (m)							
Cumulative Buffers (m)	0-100	0-200	0-300	0-400	0-500	0-600	0-700	Basin-wide
0-100	-							
0-200	0.99	-						
0-300	0.98	> 0.99	-					
0-400	0.97	0.99	> 0.99	-				
0-500	0.96	0.99	> 0.99	> 0.99	-			
0-600	0.96	0.98	0.99	> 0.99	> 0.99	-		
0-700	0.95	0.98	0.99	> 0.99	> 0.99	> 0.99	-	
Basin-wide	0.93	0.97	0.98	0.99	0.99	0.99	> 0.99	-

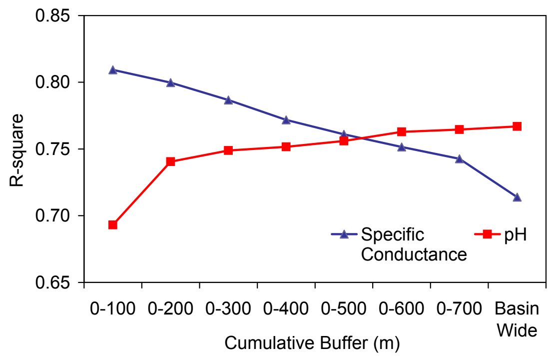

Figure 4. Comparison of R-square values produced by regression models relating pH and specific conductance and the percentage of altered land within watersheds and seven cumulative-stream buffers ranging from 0-100 m to 0-700 m.

water quality than distant land uses. Groundwater discharging from the Kirkwood-Cohansey aquifer is the dominant source of flow to Pinelands streams (Rhodehamel 1979b), with discharge to a point in a stream originating from sources that are near and far (Modica et al. 1997, 1998). Modeling studies have indicated that groundwater travel times from recharge areas to a stream increase with distance to the stream (Modica 1996, 1997, Kauffman et al. 2001). Proximity may also influence the relationship between land use and contaminants that are transported by surface runoff. In developed areas, stormwater runoff may be an important source of some constituents such as sodium and chloride (Robinson et al. 1996), which have a significant effect on specific conductance and nitrate-nitrogen (Baker and Hunchak-Kariouk 2006).

Although it is tempting to associate the variations in land-use/water-quality relationships that we observed to the proximity of altered land to streams, the patterns that we described are most likely attributable to subtle variations in the distribution of the water-quality data in relation to altered land in each of the cumulative buffers. Allan (2004) suggested that the relationship between land use and stream conditions is influenced by how closely near-stream land-use resembles basin-wide land-use patterns and that the greater influence attributed to riparian land use in some studies is probably due to greater variation in land use in these near-stream areas. In our study, the relative variability of altered land was highest in the 100-m cumulative buffer, but the relationship between land-use proximity and water quality displayed by pH was the opposite of that for specific conductance even though the two variables were positively correlated.

The strong correlation in the percentage of altered land found among the cumulative buffers indicates that all provide a similar relative measure of land-use intensity. The regression analyses demonstrated that both near and far land uses provide a relatively good measure of water quality in the watersheds that we studied. This is especially true for pH as indicated by the similarity of R-square values based on the different cumulative buffers. Although we cannot conclude that proximity has a direct effect on water quality, our results strongly support a conclusion that variations in land-use intensity are associated with changes in water quality. For both pH and specific conductance, altered land accounted for a majority of the variation in water quality regardless of which buffer was analyzed. The R-square values for pH and conductance equate to correlation coefficients ranging from 0.83 to 0.88 and 0.84 to 0.90, respectively.

Most studies addressing the issue of proximity have evaluated the relationship between water-quality and land use in individual buffers (Omernik et al. 1981, Osborne and Wiley 1988, Hunsaker et al. 1992, Johnson et al. 1997). In our study we evaluated cumulative buffers. Whether individual or cumulative buffers are used, it would be difficult to separate the relative influence of near and far land uses on stream water quality. Although comparison of R-square values may provide an indication of which water-quality/land-use relationship may provide the best predictive model, conclusions concerning the direct effect of land-use proximity should be made with some caution. Perhaps the best way to address the effect of proximity is to compare watersheds with disproportionate land use patterns, an approach described by Omernik et al. (1981). However, Omernik et al. (1981) also indicated that such patterns seldom exist, an observation supported by the land use patterns found in the watersheds that we studied.

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