Defining basin water quality: Land use, tributary input, and downstream dynamics

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ABSTRACT

During a 1-year period, we sampled surface water in a Chesapeake Bay tributary stream located in the Valley and Ridge and Blue Ridge provinces. Median nitrate and chloride concentrations for 7 sites along the mainstem and 5 tributary streams show that water quality tracks land use patterns and other sub-watershed characteristics. Our findings corroborate the well-known relationship between land use and solute load. We can well predict nitrate and chloride concentration with agricultural and urban development. However, our results show that nitrate loads at downstream sampling stations are not as high as predicted based on land use. This finding is contrary to predictability of chloride concentration. Moreover, all of the major predictors of water quality are inter-correlated, so we unable to separate the effect of land use, topography, and geology. The data largely confirm the control of water quality by land use practices; however, the results further indicate that spatial changes of water quality depend on stream path opportunities for remediation or the geological control of preferential flow paths

INTRODUCTION

Many previous studies have demonstrated the effects of land use on stream water quality on the basin scale (e.g., Omernik, 1977; Herlihy et al., 1998). These expected relationships often drive the basis for watershed monitoring design. Much of the monitoring work has been done by government agencies targeting impaired streams. Less frequently have citizens initiated sampling programs focused on determining baseline water quality for their community.

Water quality in the mid-Atlantic, particularly non-point source pollution, increasingly focused on tributary inputs into the Chesapeake Bay. One of the world's largest estuaries, the Bay is threatened by eutrophication from anthropogenic inputs of nutrients. Most of the water quality analyses has been done in Coastal and Piedmont systems (Lowrance et al., 1995), but characterization of the inputs from watersheds in the Valley and Ridge and Blue Ridge provinces becomes increasingly important as legislation is proposed to impose land use restrictions on these headwater streams influencing the Bay. The Maury River watershed that we study is part of the upper James River basin, which itself is implicated as a major exporter of nutrients and sediment to the Chesapeake Bay (Sprague et al., 2000; VADCR, 2000).

Targeting the sources of non-point source pollution requires understanding the relationships between water quality and watershed characteristics including land use patterns. Much work has been done to relate the amounts of anthropogenic nutrient input (including nitrate and phosphate) to agriculture, with greater proportions of agricultural land discharging greater amounts of nutrients (e.g. Hill, 1978; Dillon and Kirchner, 1975; and others). This relationship has become an important factor in many empirical model of nutrient discharge. Virginia uses land cover data plus animal census numbers in determining priority watersheds for nonpoint source pollution (Hession et al., 2000) Spatial modeling suggests that although agricultural land remains a primary source of N for the James River, urban sources account for more than a third of the load (Sprague et al., 2000).

Other water constituents have been used to indicate stream impairment. The conservative (non-reactive) anion chloride has often been shown to have strong relationship to the amount of urban land or development within a watershed and has been used to indicate human disturbance in a watershed including roads, industry and fertilizer use (Herlihy et al., 1998).

For nutrients, riverine inputs occur in two flow systems: baseflow and surface runoff. Different constituents dominate each of the flow types. For nutrients, the groundwater source of baseflow enhances the flow of nitrate whereas phosphorous is found primarily in rapid surface flows or storm flows because it is generally bound to sediments (Jordan et al., 1997; and references therein).

Given the importance of nutrient loads and the fact that they can be well predicted in source areas by land use, the objective in this paper is to explain the downstream dynamics of baseflow water quality and to predict changes for varying land use across variable tributary scales in the Valley and Ridge and Blue Ridge. We use differences in behavior of conservative and non-conservative constituents to understand the delivery mechanisms or transport and behavior of pollutant loads in basins of differing size.

METHODS AND STUDY AREA

The data for this study come from a citizen-volunteer sampling program initiated with a Chesapeake Bay Program grant. Field data describing pH, temperature, dissolved oxygen, and conductivity combined with samples analyzed for major ion chemistry and bacteria were collected biweekly at 11 sites in the Maury River watershed in the upper James River basin of Virginia. Here we examine the spatial trends in the median nitrate and chloride concentrations to analyze the effect of spatially concentrated land use patterns on water quality. Sampling commenced in August 2000 on the Maury River sites, and in January 2001 on the tributary sites and continued biweekly through July of 2001. Air-free, 250 ml samples were collected from below the water surface by volunteers and analyzed within 24 hours of collection. Nitrate and chloride levels were measured using ion chromatography. The bulk of the samples are taken at nearly the same time during each 24-hour long, biweekly period, but individual sampling locations vary in time of day, from approximately 9 am to 5 pm.

The Maury River rises in Paleozoic sedimentary rocks of the Valley and Ridge province in the headwaters and reaches the igneous and metamorphic rocks of the Blue Ridge near the confluence with the James River. The steep terrain found in the Blue Ridge and sandstone ridges of the western part of the basin limits most agricultural practices to valley floors, which are underlain by shale in the headwaters and limestone in the southern end of the Great Valley (Figure 1). Land cover in the headwaters and the extremities of individual subwatersheds is primarily deciduous forest. Agriculture is primarily pasture and hay, with approximately ten percent under tillage. Unlike the Shenandoah Valley of northern Virginia, the Maury River watershed has few concentrated animal feeding operations, particularly few poultry facilities.

Flow in the Maury River (Figure 2) is described by gauges near the headwaters (above sampling station MR02, Figure 1) and the mouth of the basin (above MR05, Figure 1). Discharge follows a winter increase and summer decline in baseflow with overprinted storms that occur during any season. Stormflow is more important in the headwaters, leaving a higher baseflow at the downstream gauge. The peak in baseflow occurs in March for both gauges. Sampling occurred during the 4th year of a 5-year “drought” in which baseflow has declined. Sampling coincided with only 3 higher flows during November, March, and May, and only two of those occurred very near the peak of flow. We use the median value to represent base flow water quality for each station, largely because we only have one year of data, and this year was particularly dry. These conditions limit our ability to determine a stage-dependent load curve that accounts for seasonal and temporal variability.

Spatial data were investigated using GIS analyses of several data sets. Land use was examined using 30-meter resolution National Land Cover Data (NLCD, Vogelmann et al., 2001) for Virginia. The NLCD data reflect land use interpreted from 1992 satellite images. Although the region is developing through low-density rural housing growth, land use at the subwatershed scale is stable enough to be predictive. NLCD categories were merged into a generalized land use map consisting of forest and wetlands (NLCD codes 41-43, 91, 92), developed (21-23, 85) and agriculture (81, 82). Also at a 30-m resolution, elevation data were obtained in 7.5 minute quadrangles and mosaiced into a single layer. Slope was derived from unsmoothed elevations using the standard slope calculation in ArcView. Road data are U. S. Census Bureau TIGER layers for Rockbridge, Augusta and Bath Counties, and the cities of Lexington and Buena Vista. These data are not discriminated by pavement type or size. Road density was approximated by calculating the average distance to roads for all 30 m grid cells in each subwatershed. The landscape metrics were calculated for the subwatershed above each sampling point and cumulated for sampling stations continuing downstream.

To assess the impact of the riparian zone on water quality, we use a 100 m buffer along each side of the streams in the EPA RF3 stream network for the Maury River watershed. The characteristics of the land use, road density and slope were determined for the buffered area for each subwatershed. The RF3 file represents a digital compilation of the hydrography of USGS 1:100,000 scale maps. This differs from the NLCD dataset, which was georeferenced to the 3 arc second topographic information (1:250,000 scale), and the digital topography, which was at a finer resolution. Therefore, the stream network is not entirely coincident on the three data sets, leading to some inconsistency, commonly up to 30 m but never more than 50 m.

RESULTS

Our findings confirm the well-known relationship between land use and solute load. As summarized by chloride and nitrate (Figure 3), water with high quality enters the southern end of the Great Valley or Shenandoah Valley (below MR02) and thereafter degrades to maximum concentration after passing through Lexington at station MR04. One can readily see the influence of tributary additions to the general low concentration flow entering from the headwaters. Hays, Kerrs, and Woods Creek all have significantly higher chloride and nitrate concentrations than the Maury River. These watersheds are intensively grazed and are experiencing increasing low-density residential development. Woods Creek flows through the city of Lexington (population 5500) and is otherwise pasture.

Quantitative investigation of the watershed properties related to the water quality values indicate relationships with specific land use patterns and aquifer characteristics (Table 1). The concentrations of nitrate are most strongly correlated with the percent agriculture in the watershed (R= 0.954; Figure 4). Other significantly correlated variables at the 0.05 level were the % of agriculture in the 100m buffer (R=0.845), % of carbonate (R=0.953), % of carbonate in the 100m buffer (R=0.910), % of forest (R= -0.937), % of forest in the buffer (R= -0.906), % urban (R= .664), % urban in the 100m buffer (R = 0.649), and the mean slope (R=0.807).

At all sites, the relationship of chloride concentration at all of the sites is strongest to the percent development in the watershed (Figure 5A). The value for Woods Creek skews the regression because it is an outlier in both the amount of chloride and the amount of urban land in the watershed. For our investigation, we chose to remove that point from the dataset and to treat the Woods Creek watershed separately. Without the data point, chloride and urban land are still highly correlated with a slightly different slope (Figure 5B). The most significant correlation for all sites (with the Woods Creek outlier removed) is the % of urban in the watershed (R= 0.918). Other significant correlations (at the 0.05 level) are the % of urban in the 100m buffer (R= 0.911), area (R=0.624), and the area in the buffer (R=0.670). The strongest relationship for the Woods Creek watershed sites is the average distance to roads within the watershed, which is another indicator of the amount of development in the watershed (R= -0.944; Figure 6A). For nitrate in Woods Creek, there is a strong relationship for distance to roads and nitrate with two points lying much higher than the line (Figure 6B). WC09 is the headwater site for Woods Creek and SR01 is above the confluence of Sarahs run and Woods Creek. For nitrate and % development there are three data points that are off the main trend; WC09 and SR02 are headwater sites and SR01 is in a highly developed stream reach (Figure 6C).

Stepwise multiple regression analysis was applied separately to median nitrate and chloride values for all of the land use and watershed characteristic values in order to build an optimal linear model from the sets of regressors. Regressions were performed for all the sites, the tributaries, and Woods Creek separately.

For nitrate (in the Maury and tributaries) using all variables, regression analysis predicted 2 models; one included only agriculture (R^2=0.910), and the second included agriculture and area (R^2=0.962). If coefficients of the first model (agriculture only; NO_3= 0.0933(%Agriculture)+ 0.363) are used to predict nitrate values, the values are all over-predicted for the Maury river mainstem sites (Figure 7A). If the area is included in the model (NO_3=0.848(%Agriculture) - 4.09e-10(Area)+0.926), the nitrate is better predicted for these Maury sites (Figure 7B).

In order to investigate the influence of contributing watershed area to the water quality, the regression values for the tributaries were used to predict the values for the mainstem Maury. For the tributaries, 2 regression models were predicted; one with agriculture (R^2=0.977) and one with agriculture and the average distance to roads in the 100m buffer (R^2=0.995). The coefficients form these models were used to predict values for nitrate in the mainstem Maury. For model 1: (NO_3=0.0817(%Agriculture)+ 0.976) the model overpredicted all of the Maury River sites (Figure 8A) and for model 2: (NO_3 = 0.0702(%Agriculture) – 0.00253(Average distance to Roads in the 100m buffer) + 1.952) had higher residuals for the Maury River sites (Figure 8B).

Similar regressions for median chloride concentrations were performed for all of the sites (excluding the Woods Creek tributary value as an outlier). For chloride, 2 models were predicted; one included the % of urban land use (R^2=0.843) and the other included %urban and the slope in the 100m buffer (R^2= 0.942). The models were used to predict chloride in the watershed (model 1: Cl =2.575(%urban)+2.069); Figure 9A) and (model 2: Cl = 3.193(%urban) – 0.453(slope in the 100 m buffer) +5.862; Figure 9B). The distribution of the residuals for chloride are distinctly different than for nitrate indicating a different relationship to land use for these two constituents or a difference in loading or transfer processes.

DISCUSSION

Our data clearly confirms the control of water quality by land use practices. The major changes of water quality as represented by median nitrate correlated clearly with the major land use characteristics of the watershed. Baseflow water quality in the mid-Atlanic region of the U.S. is well correlated to land use (Herlihy et al., 1998), with chloride indicating any human activity while nitrate concentration is strongly correlated with agriculture. In this study, the best predictor of nitrate concentration from the multiple regression models is % agriculture, but the addition of road density improves the model measurably (Figure 8) for the tributary model. Road density is a surrogate for development and more completely characterizes the low-density development characteristic of former pasture areas than does the NLCD cell data. Moreover, nitrate concentration has a strong relationship to urban development on land use maps (Figure 6B and 6C). Because we focus on a small, relatively densely developed watershed, we can infer that development will be an increasingly important contributor of nitrate to the overall load, even in a headwater area. Sprague et al. (2000) partition more than one third of the overall nitrogen load in the James River to developed sources including septic tanks. Their modeling of the upper James River shows the most concentrated load in the Maury River watershed comes from urbanized areas. Thus, agriculture is the dominant control on nitrate concentration in the Maury River, but development may be an important contribution where low density development follows agricultural patterns. In fact, the Woods Creek data show that urban loading, given a high impervious cover, can be as high as agriculture (Figure 6C).

The attribution of nitrate source to agriculture is in some ways confounded by the nearly total correlation of multiple landscape characteristics. The median nitrate value is also highly correlated to carbonate bedrock, percent forest, and slope. Agricultural activity occurs primarily in the Great Valley carbonate sections of the watershed, with some pasture/hay in the shale valleys of the headwaters (Figure 1). Likewise, the inverse correlation of high slope and agriculture is logical. This covariation of predictor variables is unfortunate because Lowrance et al. (1995) suggest that both geology and slope should change the behavior of shallow groundwater flow paths, and hence the delivery of nitrate to streams. In shale and steep sandstone areas, water flow is concentrated in the rhizosphere and removes nitrate. In carbonates, deep water flow paths and seepage to the river at discrete discharge points limits the ability of vegetation, particularly riparian buffers to interact with water to remove nitrogen. In steep forested areas, high permeability soils transmit water as throughflow which has an opportunity to interact with saturated zones at the base of the slope. We cannot eliminate the effect of slope and rock type from our data because of the covarying landscape metrics, but we suspect it may be a combination of several effects. In a national dataset, Omernik (1977) found no relationship of water quality measures to geology when considering land use.

Lowrance et al. (1995) also predict that riparian buffers will be of little affect in treating nitrogen pollution in the Valley and Ridge due to limited floodplain area and complex flow paths. In our models, road density is the only riparian buffer variable that appears as a predictor of water quality. The forest in riparian buffer areas is either ineffective, as suggested by Lowrance et al. (1995), or the forest buffer area is simply mirroring the conditions in the watershed uplands. The latter is borne out by the high correlation of the two variables (FOREST, FORBUF; Table 1). At the synoptic level of our data, we cannot determine the effect of forest buffers, because they apparently do not exist in great enough quantity in the agricultural areas to separate them out as a variable.

The behavior of chloride, which is the conservative tracer that is a “good surrogate indicator for general human disturbance in the watershed” when including agriculture (Herlihy et al., 1998), is more strongly predicted by developed sources (URBAN). However, when excluding the Woods Creek outlier, chloride concentration is not correlated with agricultural activity. The negative correlation for SLOPE in the multiple regression model is likely a reflection of the fact that steep slopes that don’t support agriculture or urban land uses, rather than a true relationship between slope and the transport or production of chloride.

Differences in loading or transport of chloride and nitrate concentration becomes evident by looking at the data from upstream to downstream (Figure 3). After leaving the headwaters region, the water quality deteriorates with increasing inputs from agricultural and urban sources. For just the Maury River mainstem sites, the peak of chloride coincides with the peak of urbanized land use percentage at MR06 (Figure 3) below the two towns and development paralleling two interstates (Figure 1). The large drop in chloride near the mouth of the stream shows the influx of Bufffalo Creek, which has little urbanization. On the other hand, nitrate concentration increases upon entering the agricultural and developed valley, but it does not continue to rise. The percentage of forest decreases across the valley reaching its lowest value at the MR07. Thus the spatial trend of nitrate concentration does not follow the increasing percentage of roads, urban, and agricultural land use across the valley. The downstream Maury River sites (MR02-MR07) have less nitrate than is predicted by the trend of land use and by the expected trend from tributary loads (Figure 8). Even though the tributaries continue to supply high nitrate concentrations to the Maury, the concentration does not increase below Lexington (MR04). This under-prediction occurs despite steadily increasing values for both urban and agricultural land use within the lower reaches of the watershed. This change with increasing distance along the stream is further identified by the improvement of the multiple regression model with the addition of area (Figure 7).

The clear result that nitrate concentration in baseflow discharge for the downstream segment of the Maury River mainstem (Figure 3) signals either a change in the rate of delivery of nutrients to the stream or their uptake by biological processes. As the Maury River leaves the headwaters underlain by sandstone and shale in the Allegheny Mountains and enters the Great Valley underlain by carbonates, karst processes dominate the flow paths for groundwater. Baseflow per unit area is greater the downstream gauge (Figure 1), particularly in the summer and during the lowest discharge periods. The karst surficial characteristics and lower relief of the valley promote the increased baseflow and reduced stormflow per unit area of the watershed. Increased water retention will have the effect of diluting the nutrient concentration in groundwater, as suggested by Hill (1996) for riparian buffers. However, concentration of the conservative tracer chloride does not have the same decrease for the valley section of the river compared with the tributaries and upstream segment of the mainstem (Figures 3 and 9). The mainstem Maury River sites are not different from the tributary sites when predicting chloride concentration with land use characteristics; thus, the conservative and non-conservative ions have different basin scaling behaviors.

If dilution is not reducing nitrate concentrations, then organic or inorganic processes are responsible for the uptake of nutrients along the flow path. Uptake by organic matter and denitrificaiton by bacteria remove nitrogen as waters move along the flow path. In larger watersheds, more time allows a greater amount of nutrient spiraling (Allan, 1995). In a smaller watershed in upstate New York, Wall et al. (1998) observed nitrogen utilization by phytoplankton uptake in the low-slope segments of the main stream. This mechanism likely represents only a temporary removal of the nitrogen and storage in stream flora, because greater nutrient export generally occurs during flood flows (Allan, 1995) that is not represented in our sampling. More permanent uptake and denitrification also occurs in the hyporheic zone and in stagnant or dead zones associated with low water velocity (Duff and Triska, 2000). The opportunities for riparian buffer uptake and nitrate reduction increase in larger order streams with more stagnant stream-side channels. Hinkle et al. (2001) observed significant vegetative nitrate uptake and/or nitrate reduction by river water transport into the sediments adjacent to the channel. The main stem of the Maury River downstream of sampling point MR02 has nearly 100 percent riparian forest buffer due to topographic constraints on agriculture. Moreover, the lower reaches of the Maury have a wider floodplain with an alluvial fill that supports the biotic uptake and subsurface transformation of nutrients. Thus the sidestream and instream biota have the potential to lower the nitrate concentration relative to tributary predictions.

This transformation and/or storage of nitrate is clear for the Maury River mainstem, but the absolute size of the basin does not appear to be the sole factor for nitrate scaling. In Woods Creek (Figure 1 and 6C), nitrate concentration is high but decreases in the downstream direction through the edges of Lexington. Woods Creek and its major tributary, Sarahs Run - which is adjacent to a major US highway and flows Department of Transportation and agricultural chemical storage facility (sources of chlorides and nutrients) - enter with lower water quality associated with agricultural land use and generally improve flowing through the low and high density sewered residential sections of Lexington. Water quality in Woods Creek again degrades passing through the commercial center of Lexington down to the confluence with the Maury River. The opportunity for storage or uptake improve the water even though the road and urban contributions should be increasing. This water quality improvement occurs below a golf course where water storage in a pond may provide the opportunity for nutrient uptake, much like in the higher-order Maury River

SUMMARY

In summary, our findings confirm the well-known relationship between land use and solute load. We can well predict nitrate and chloride concentration with agricultural and urban development. However, our results show that nitrate loads at downstream sampling stations are not as high as predicted based on land use. This finding is contrary to predictability of chloride concentration. Moreover, all of the major predictors of water quality are inter-correlated, so we unable to separate the effect of land use, topography, and geology. While the data do largely confirm the control of water quality by land use practices, they further indicate that spatial changes of water quality depend on stream path opportunities for remediation or the geological control of preferential flow paths. These results for a spatially varied Valley and Ridge watershed in the Chesapeake Bay drainage basin both confirm previous findings and suggest additional research avenues.

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Figure 1
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Defining basin water quality: Land use, tributary input, and downstream dynamics

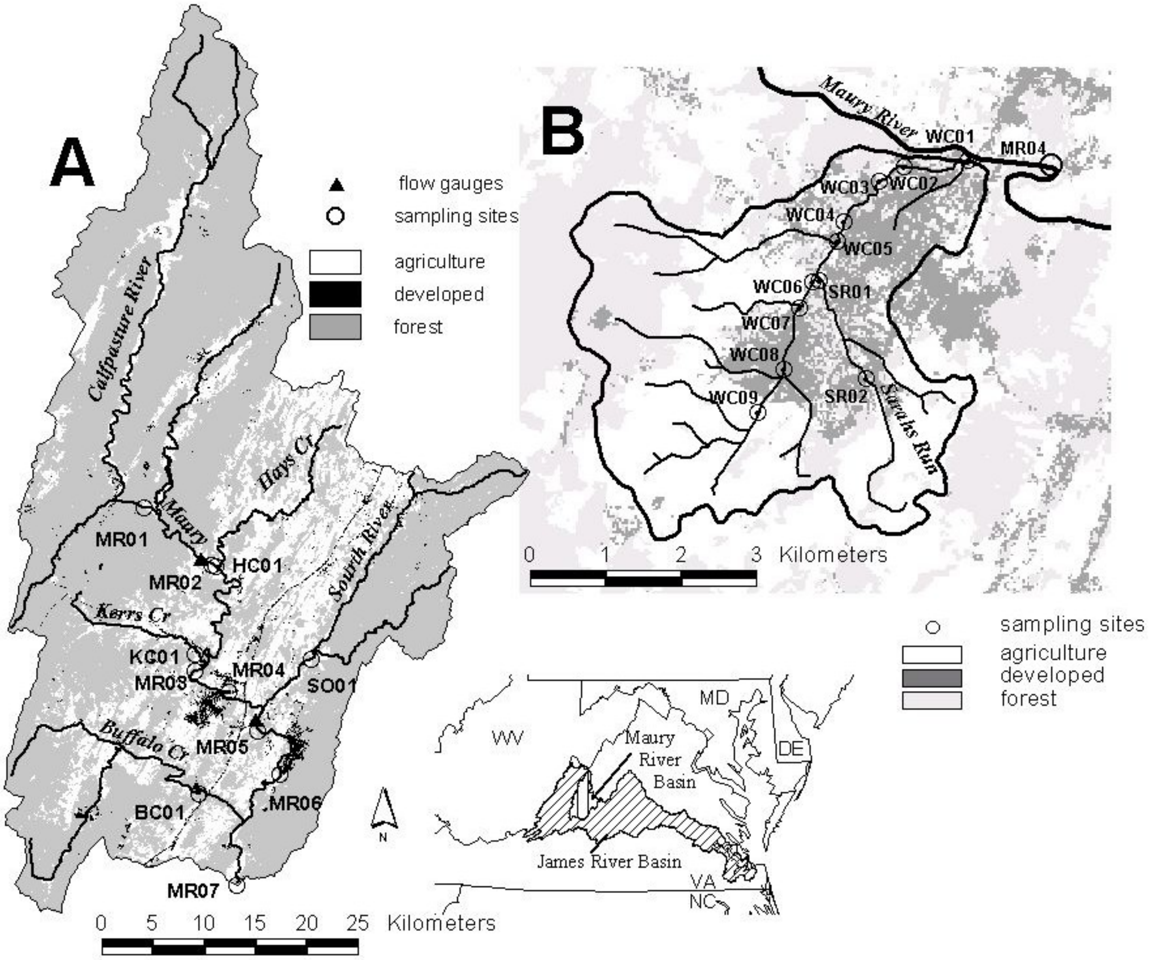

Figure 2
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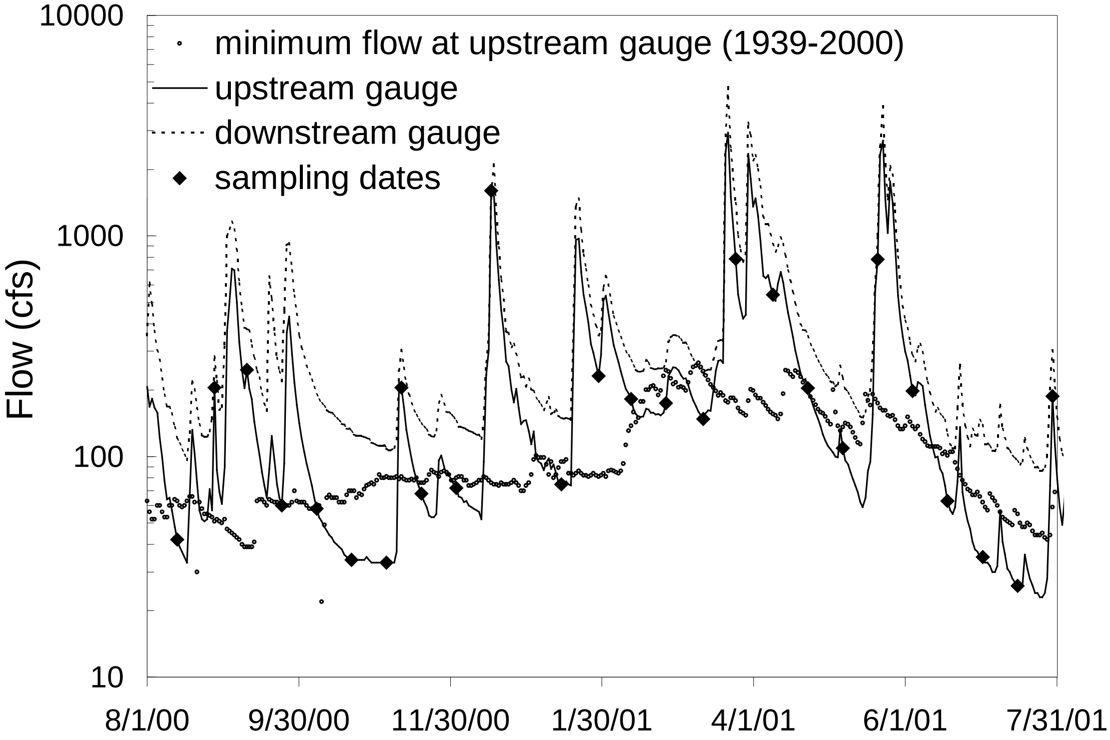

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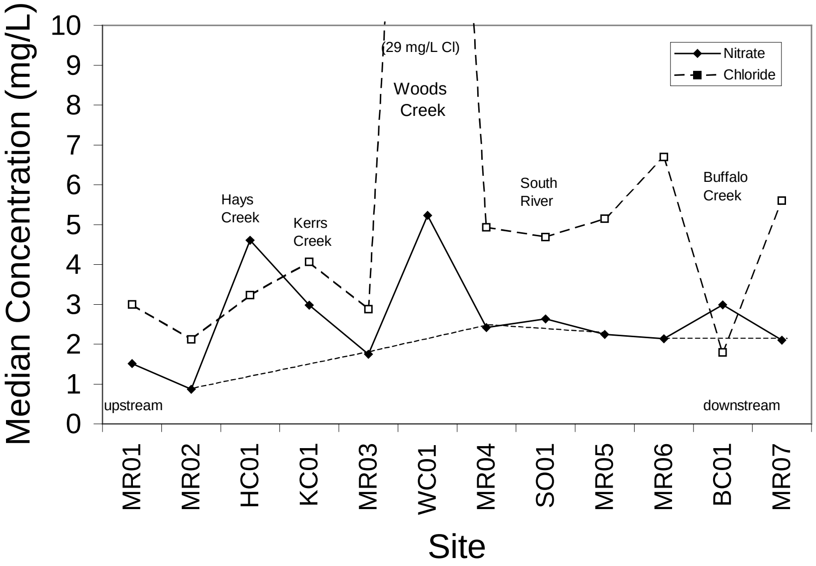

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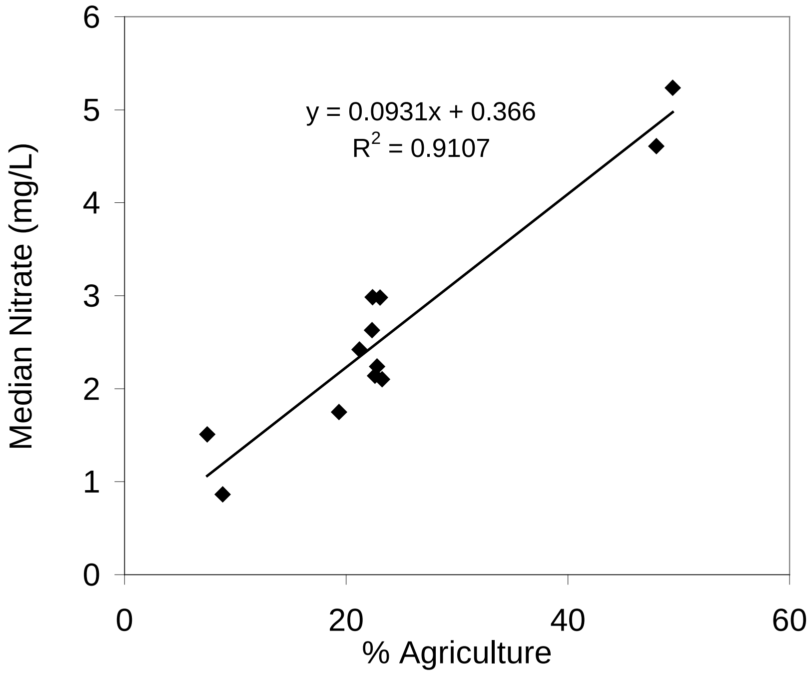

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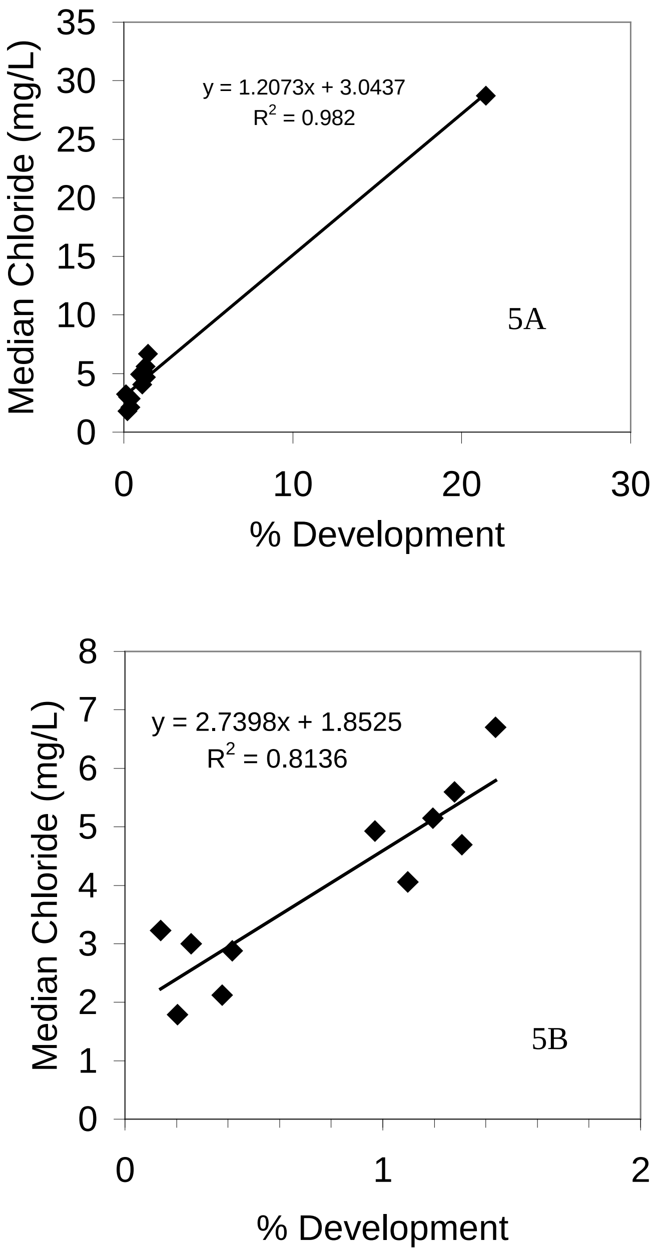

Figure 6

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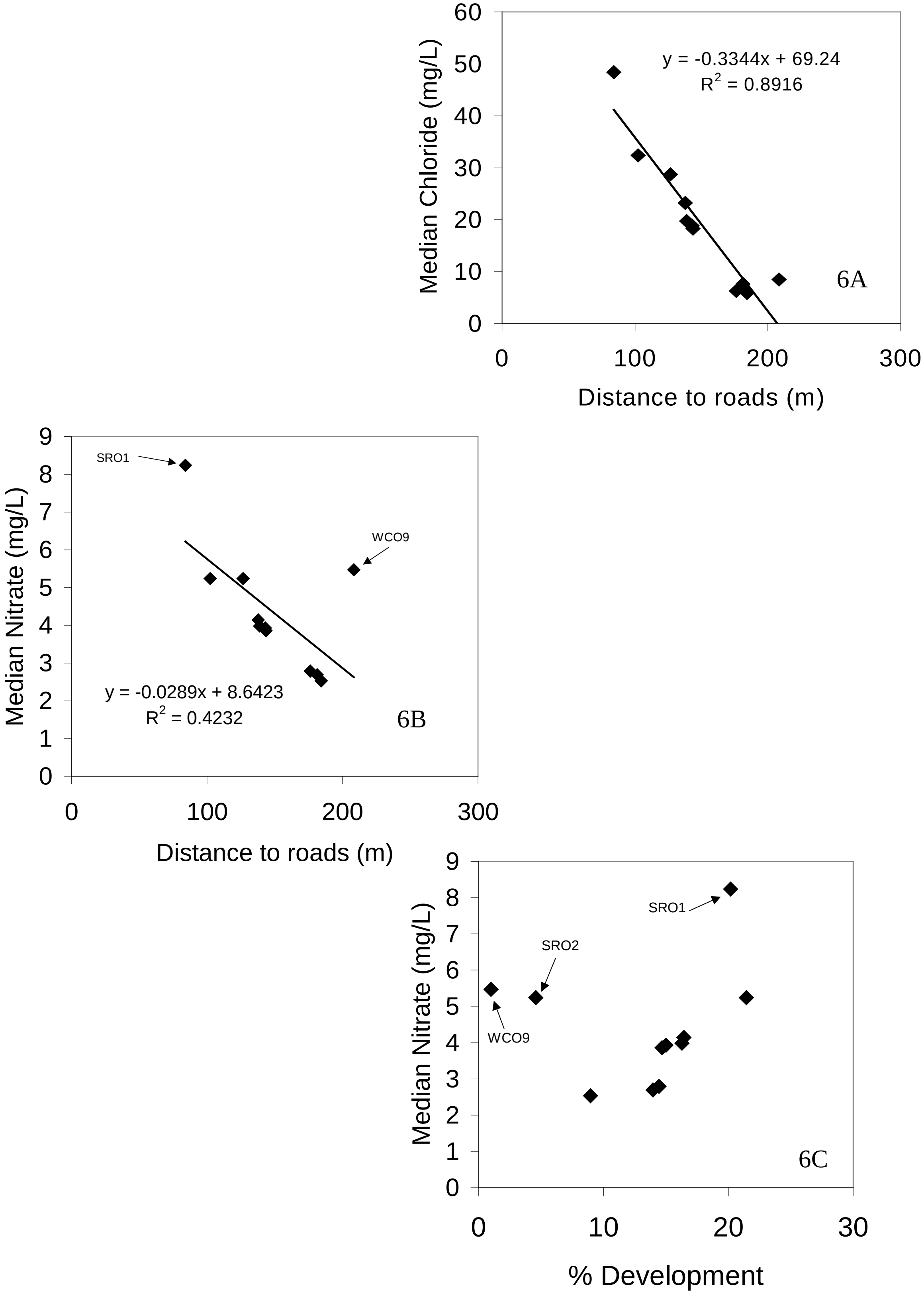

Figure 7
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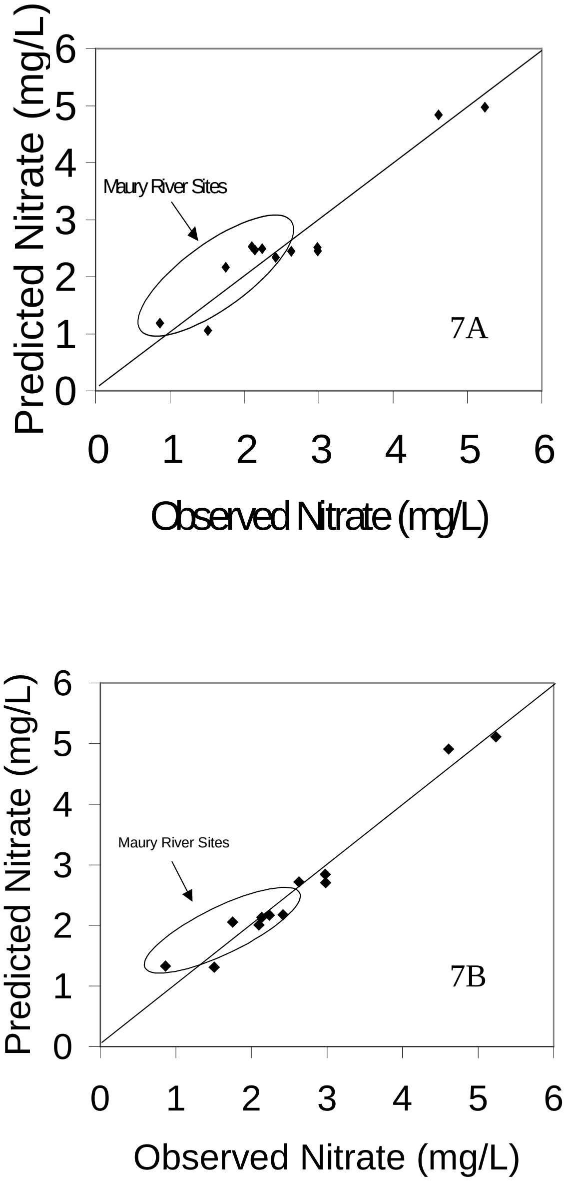

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Figure 8
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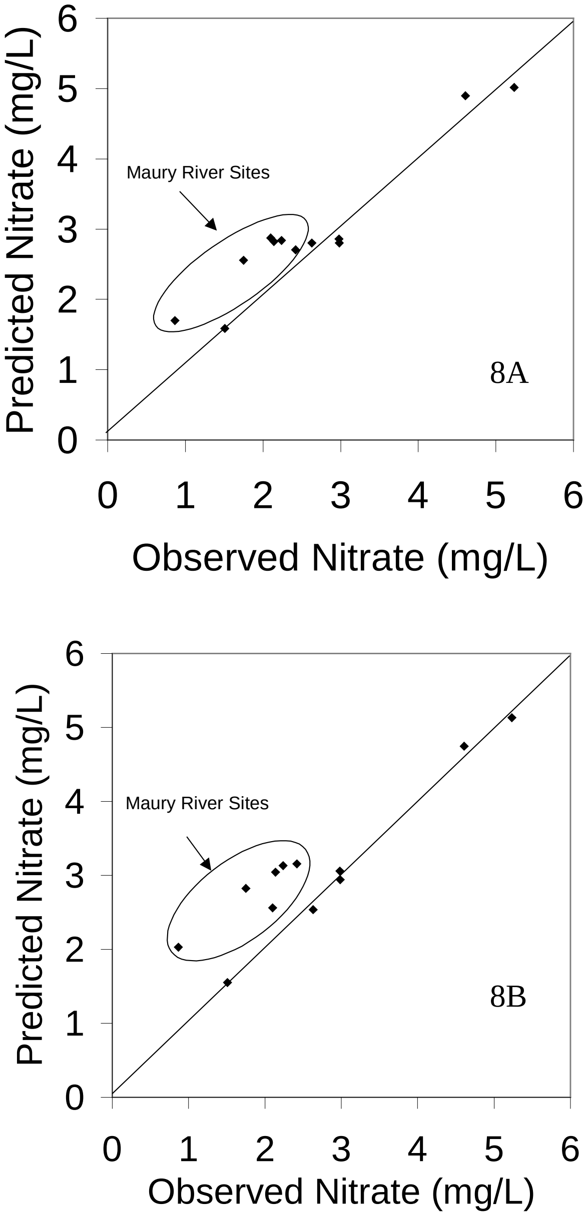

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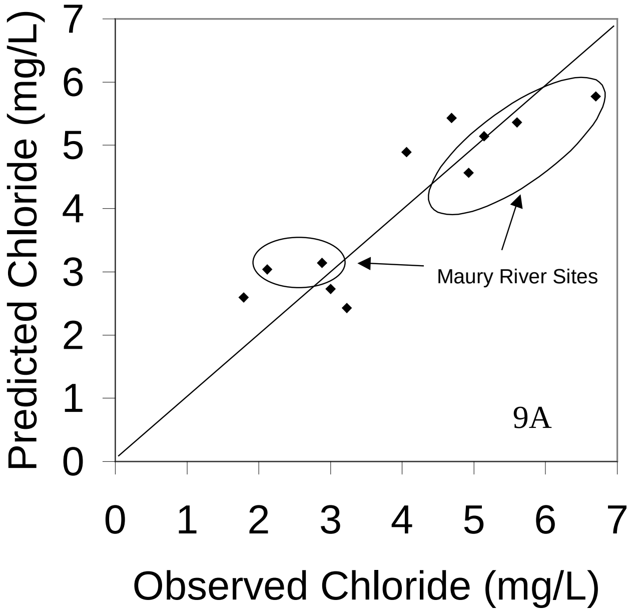

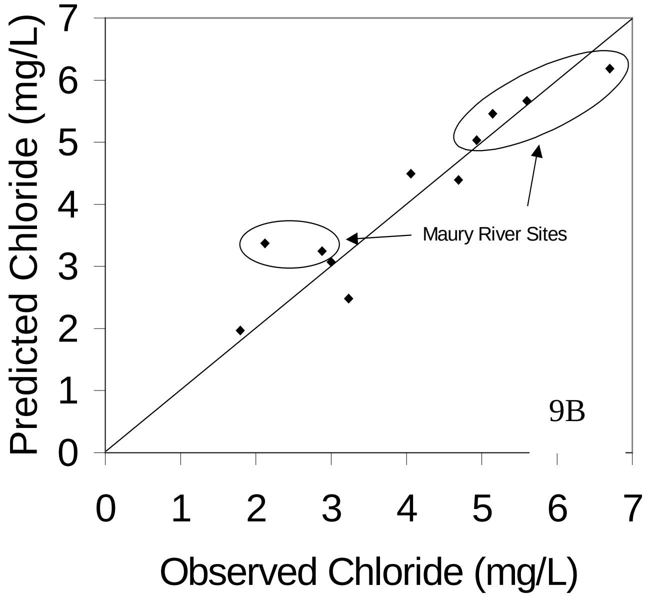

Figure 1. Study sites and sampling locations. A. The Maury River watershed showing the locations of the flow gauges, and sampling sites overlying the land use map. B. The Woods Creek sub-basin with the locations of the sampling sites overlying the land use map.

Figure 2. Flow data for the year sampling period for both the upstream and downstream gauges (labeled on Figure 1). The minimum flow for a 41 year period and the dates of sampling in the Maury River are shown.

Figure 3. Median concentrations for both nitrate and chloride for each of the Maury River sites and tributaries. MRO1 –MRO7 are the upstream to downstream sampling sites for the Maury (as shown in Figure 1). HC01 is the Hays Creek tributary stream; KC01 is the Kerrs Creek tributary; WC01 is the Woods Creek tributary; SO01 is the South River tributary; and BC01 is the Buffalo Creek tributary.

Figure 4. % Agriculture versus median nitrate concentration for the Maury River and tributaries.

Figure 5. % Development versus median chloride concentration A., All sites including the Woods Creek tributary; and B., all sites excluding the Woods Creek outlier.

Figure 6. Relationships for the sites along the Woods Creek urban corridor. A., Distance to roads versus median chloride concentration; B., Distance to roads versus median nitrate concentration. WC09 and SR01 are the headwaters of the Woods Creek and its tributary, respectively; C., % Development versus median nitrate concentration. WC09 and SR02 are both headwater sites in predominantly agricultural land.

Figure 7. Observed versus predicted nitrate for two models: A., including agriculture as a the single predictor; and B., including agriculture and area as predictors.

Figure 8. Observed versus predicted nitrate using the tributaries to predict the Maury sites: A., including agriculture as the single predictor; and B., including agriculture and distance to roads as predictors.

Figure 9. Observed versus predicted chloride for two models: A., using %urban as the single predictor; and B., using % urban and the slope and predictors.

Table 1: Correlation matrix for the Maury River sites and tributaries. AREA = contributing area (m) of land; AREABUF = area (m) in the 100m buffer; CO3= % of carbonate; CO3BUF = % of carbonate in the 100m buffer; AGR = % agriculture; FOREST = % of forested land cover; URBAN = % of developed land; AGRBUF = % agriculture in the 100m buffer; FORBUF= the % forest in the 100m buffer; URBBUF = % developed in the 100m buffer; SLOPE = the average slope of the land; SLOPE = the average slope in the 100m buffer; ROAD = the average distance to roads (m); ROADBUF = the average distance to roads (m) in the 100m buffer; MEDCL = the median chloride values (mg/L); MEDNO3 = median nitrate values (mg/L).

	AREA	AREABUF	CO3	CO3BUF	AGR	FOREST	URBAN	AGRBUF	FORBUF	URBBUF	SLOPE	SLOPEBU	ROAD	ROADBUF	*MEDCL*	MEDNO3
AREA	1.000	**0.992**	-0.461	-0.352	-0.355	0.375	-0.325	-0.250	0.314	-0.313	0.210	-0.044	-0.065	0.083	***0.624***	-0.552
AREABUF	**0.992**	1.000	-0.381	-0.271	-0.297	0.326	-0.309	-0.193	0.274	-0.299	0.192	0.022	-0.049	0.115	***0.670***	-0.489
CO3	-0.461	-0.381	1.000	**0.988**	**0.924**	**-0.883**	0.570	**0.891**	**-0.878**	0.556	**-0.776**	-0.119	-0.391	-0.340	*-0.020*	**0.953**
CO3BUF	-0.352	-0.271	**0.988**	1.000	**0.899**	**-0.845**	0.514	**0.909**	**-0.860**	0.501	**-0.768**	-0.121	-0.440	-0.387	*0.022*	**0.910**
AGR	-0.355	-0.297	**0.924**	**0.899**	1.000	**-0.960**	**0.630**	**0.907**	**-0.935**	**0.618**	**-0.864**	-0.253	-0.480	-0.346	*0.158*	**0.954**
FOREST	0.375	0.326	**-0.883**	**-0.845**	**-0.960**	1.000	**-0.822**	**-0.783**	**0.980**	**-0.814**	**0.919**	0.364	0.505	0.389	*-0.205*	**-0.937**
URBAN	-0.325	-0.309	0.570	0.514	**0.630**	**-0.822**	1.000	0.327	**-0.815**	**1.000**	**-0.788**	-0.490	-0.416	-0.369	***0.918***	**0.664**
AGRBUF	-0.250	-0.193	**0.891**	**0.909**	**0.907**	**-0.783**	0.327	1.000	**-0.811**	0.316	**-0.752**	-0.221	-0.505	-0.417	*0.047*	**0.845**
FORBUF	0.314	0.274	**-0.878**	**-0.860**	**-0.935**	**0.980**	**-0.815**	**-0.811**	1.000	**-0.810**	**0.961**	0.479	**0.590**	0.506	*-0.140*	**-0.906**
URBBUF	-0.313	-0.299	0.556	0.501	**0.618**	**-0.814**	**1.000**	0.316	**-0.810**	1.000	**-0.789**	-0.506	-0.424	-0.378	***0.911***	**0.649**
SLOPE	0.210	0.192	**-0.776**	**-0.768**	**-0.864**	**0.919**	**-0.788**	**-0.752**	**0.961**	**-0.789**	1.000	**0.667**	0.568	0.511	*0.006*	**-0.807**
SLOPEBUF	-0.044	0.022	-0.119	-0.121	-0.253	0.364	-0.490	-0.221	0.479	-0.506	**0.667**	1.000	0.365	0.450	*0.268*	-0.190
ROAD	-0.065	-0.049	-0.391	-0.440	-0.480	0.505	-0.416	-0.505	**0.590**	-0.424	0.568	0.365	1.000	**0.928**	*-0.218*	-0.375
ROADBUF	0.083	0.115	-0.340	-0.387	-0.346	0.389	-0.369	-0.417	0.506	-0.378	0.511	0.450	0.928	1.000	*0.034*	-0.322
MEDCL	-0.240	-0.221	0.556	0.506	**0.640**	**-0.826**	**0.992**	0.335	**-0.817**	**0.991**	**-0.787**	-0.478	-0.439	-0.364	*1.000*	**0.656**
MEDNO3	-0.552	-0.489	**0.953**	**0.910**	**0.954**	**-0.937**	**0.664**	**0.845**	**-0.906**	**0.649**	**-0.807**	-0.190	-0.375	-0.322	*0.023*	1.000

Bold and underlined values correlation is significant at the 0.01 level (2-tailed).
Bold values correlation is significant at the 0.05 level (2-tailed).
Italicized column with *MEDCL (* Median Chloride) is for the values excluding Woods Creek