# Spatial variation in water chemistry in the last free-flowing river draining the Sierra Nevada, CA: Are the uplands important?

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## Introduction

Initiative for fluvial restoration in California has grown rapidly in the past decade, creating impetus to search the Sacramento-San Joaquin watershed for source areas of sediment, nutrients and other potential pollutants. Out of this effort has arisen the need to determine (1) where restoration efforts should be concentrated (2) how water quality dynamics function in minimally impacted vs impaired systems and (3) what role upland drainages play in the water quality dynamics of the Delta.

The Sacramento-San Joaquin Delta is the terminus of a massive watershed ($1.63 \times 10^7$ ha) occupying 40% of the land mass of California draining 20 major tributaries (Jassby and Cloern, 2000). The Delta is a diverse, tidally-influenced, fresh water estuary that plays a dual role as the hub for the California water transfer business, and as the sole conduit for migratory aquatic species between the ocean and the Sierra Nevada Mountains. Due to the economic and ecological importance of this area the Delta has become the focus of ecosystem rehabilitation efforts (CALFED, 1998) with the goals of providing good water quality for all beneficial uses and improving and increasing aquatic and terrestrial habitat. In the present condition fish populations using the Delta as passage and home have declined (Jassby et al., 1995; Moyle et al., 1992), with some endemic species having already gone extinct and others threatened (Kohlhorst, 1997; Meng and Moyle, 1995). This trend continues down the food chain with invertebrate populations showing significant decline (Orsi, 1999; Orsi and Mecum, 1996), and may ultimately be traced to impaired water quality.

Of the 20 watersheds draining into the Delta only one has no major dam on its course. The Cosumnes River's 2100 km of undammed waterways serve as a valuable scientific resource for the study of watershed dynamics in California. It has been clearly shown that the presence of major dams on the course of a waterway acts to thermally and chemically buffer the river. Thermal buffering on the diurnal and seasonal scale was reported by Webb and Walling (1996) in Wimbleball Lake, England. In Kelly's (Kelly, 2001) analysis of inputs and outputs from five major dams in the Western United States the wide range in seasonal dissolved solids seen upstream of the reservoirs was essentially reduced to a constant downstream. Kelly also observed that flux dynamics were altered by reservoirs with some impoundments retaining solutes and others producing. Clearly lake dynamics, including stratification, retention, and mixing alter the chemical fluxes moving through them. Subsequently, what we find in the Cosumnes River is the last resource for the study of free-flowing watersheds in California. It is hoped that the water chemistry data which have been collected on the Cosumnes will serve as a criterion for watershed hydrochemical function and aid in the future research of the other 19 watersheds draining into the Central Valley of California.

It is with this impetus that we have set out to define the spatial distribution of chemical fluxes in the Cosumnes watershed and to address the question of whether rehabilitation efforts should be focused on the lowlands or uplands. The senescing of algal blooms in the Stockton ship canal and the subsequent creation of a dissolved oxygen barrier to fish migration (Foe et al., 2002) has brought focus to the problem of excess nutrient loading in Sierran Rivers. Research over the past 10 years has shown that nutrient export from watersheds is the result of several interacting processes including release from fertilization, mineralization, fixation, atmospheric deposition, and sewage effluent. Regulating this export are hydrologic processes (residence time, flow path, hysterisis) and transformation and immobilization dynamics (denitrification, uptake, sedimentation, adsorption). The influences of these processes on nutrient export can vary across the basin depending upon variable catchment characteristics (Arheimer and Liden, 2000), thus linking streamwater quality to these characteristics has become an effective source-search tool used by a number of researchers (Arheimer et al., 1996; Clow et al., 1995; Creed and Band, 1998; Johnes and Heathwaite, 1997; Walling and Webb, 1975; Walling and Webb, 1980). Yet, research on spatial variation in watershed chemistry has generally gone on in either minimally impacted remote watersheds (Cameron, 1996; Creed and Band, 1998; Jain, 2002) or in small sub-watersheds (Driscoll et al., 1987; Lawrence and Driscoll, 1990; Sidle et al., 1995; Williams et al., 2001; Williams et al., 1993), thus there exists a need for studies on large watersheds in mixed-use areas.

The object of this study is to delineate the watershed characteristics which drive water quality dynamics in the last free-flowing watershed in the Central Valley of California. The resultant data will be addressed in terms of the potential impact on water quality in the Sacramento-San Joaquin Delta.

**The Study Area**

The Cosumnes River Watershed, located southeast of Sacramento, CA encompasses 1989 $km^2$ of terrain and 2101 km of waterways (Fig. 1). The headwaters emerge at an elevation of 2200 m in a subalpine ecosystem underlain by granitic bedrock. The human population is sparse in the uplands and some logging of the coniferous forest is the only significant land use. The middle reaches of the Cosumnes River wind their way through oak woodland habitat developed on metamorphic bedrock dominated by schists and shales. These intermediate elevations are less rural with the dominant land uses being cattle grazing and viticulture. Valley sediments and annual grasslands dominate the lower Cosumnes Watershed as the river descends to its confluence with the Mokelumne River and the important aquatic habitat of the Bay-Delta ecosystem. Land use in the lower reaches is dominated by production agriculture (*e.g.,* row crops and viticulture) with some suburbanization (Fig 2a, b).

In the Mediterranean climate of central California there is a strong seasonal cycle with virtually all of the annual precipitation occurring between December and March. Average precipitation in the upper watershed is 804 mm $y^{-1}$ while approximately 445 mm $y^{-1}$ accumulates in the lowlands. The Cosumnes River, as gauged at Michigan Bar (Fig. 1), has a long-term (1907-2002) mean daily discharge of 510 cfs (http://cdec.water.ca.gov/cgi-progs/queryLonger?989).

Water sampling stations were located at 28 sites throughout the Cosumnes River Watershed (Fig. 1). The sites were selected across a range of land uses, geology types, and stream orders.

## Methods

Grab samples were collected from 28 sites every 2 weeks from October 1998 to September 2002. In California, the water year is defined as October 1 through September 30 to coincide with the onset of the rainy season in late-October to early-November. During the 2000 and 2001 water years, additional storm samples were collected whenever flows exceeded 1000 cfs at the Michigan Bar Gauging station (Fig. 1). The sampling design resulted in approximately 37 samples/site/year.

Electrical conductivity (EC), pH, and turbidity were measured on unfiltered subsamples. Total suspended solids (TSS) was measured from a 500 ml sample collected from the thalweg of the river and at approximately the mid-depth of the water column. The 500 ml subsample was filtered through a pre-weighed glass fiber filter, the filter was dried at 60 $^{o}$C for 24 hours and weighed again, the difference being the mass of sediment in the water sample. A separate 125 ml sample was filtered through a 0.2 μm polycarbonate membrane (Nuclepore) and stored at 4 $^{0}$C through completion of analysis. Major cations ($Ca^{2+}$, $Mg^{2+}$, $K^{+}$, $Na^{+}$) and anions ($Cl^{-}$, $NO_3^{-}$, $PO_4^{3-}$, $SO_4^{2-}$) were measured using ion chromatography (Dionex 500x; CS12 cations; AS4A anions). A Dohrmann UV enhanced-persulfate TOC analyzer (Phoenix 8000) was used in the analysis of dissolved organic carbon (DOC). Total phosphorous (TP) was analyzed from a persulfate-digested split of unfiltered sample (Yu et al., 1994), the digested sample was measured with the ammonium molybdate method using a Hitachi U-2000 spectrophotometer (Clesceri et al., 1998). Total nitrogen (TN) was measured on a persulfate-digested split of unfiltered sample on a Carlson autoanalyzer (Carlson, 1978; Carlson, 1986). Finally, chlorophyll-a (Chl-a) was measured from a separate 2000 ml sample using standard fluorometry techniques (Clesceri et al., 1998).

Water quality data were grouped by site and median values assigned to each subwatershed for each water quality parameter measured. Geographic data for each subwatershed was obtained from the Information Center for the Environment (UCDavis) and multiple linear regressions were conducted. In order to simplify the geography/water quality regression model 10 of the 23 constituents measured where used in the regression analysis, they included $Cl^{-}$, EC, $K^{+}$, $Mg^{2+}$, $NO_3^{-}$, Si, TN, TP, TSS, and Chl-a. These constituents were regressed against each other and eight geographical parameters (% sedimentary, % igneous, % metamorphic, % forest, % grassland, % agriculture, % urban, elevation). The water quality and geographical data were not normally distributed across the subwatersheds so a non-parametric test (Kendall's tau) was used to determine significance of relations (Helsel and Hirsch, 1992).

**Results**

Though chemistry varied across each of the 28 subwatersheds, upland drainages tended to deliver dilute, cold, and clear waters to the lowlands, while lower elevation subwatersheds produced more turbid warm waters with elevated levels of constituents (Fig. 3). In the upper watershed median TN for the 16 subwatersheds was 0.15 mg $l^{-1}$ while median EC was 62.9 $\mu S\ cm^{-1}$. This contrasted sharply with the lower watershed where median concentrations of TN and EC over the four year course of this study were 0.83 mg $l^{-1}$ and 192.5 $\mu S\ cm^{-1}$ respectively (Figs. 5a and 4b). Another major constituent of concern, suspended sediment, had median concentrations of 1.6 mg $l^{-1}$ in the upper watershed and 8.7 mg $l^{-1}$ in the lower watershed, indicating that the lower watershed has a greater number of sediment sources (Fig. 4a). TP and $NO_3^-$ both were more concentrated in the lowlands especially in the Deer Creek subwatershed (Figs. 5b, 6a), while Si and $K^+$ were more evenly distributed throughout the watershed (Figs. 6b, 7a). Magnesium seemed to be concentrated in the mid to lower watershed (Fig. 7b), while the biologically important constituents Chl-a and DOC were most concentrated in the lower watershed, especially the Deer Creek subwatershed (Figs. 8a, 8b). The geography of the upper watershed is quite different from the lower watershed (Fig. 3) and this difference must have an impact on the water quality. In order to quantify the relation between geography and water quality, multiple linear regression analysis between water quality parameters and landscape characteristics was preformed.

*Geography and water chemistry*

During the first regression run EC had a strong negative correlation with %forest (-0.78) and elevation (-0.57) and a strong relation with the dominate anions, cations, and nutrients measured (Fig. 9, Table 1). Following a different trend was Si, with a negative relation to % grassland (-0.75) and a positive relation to % igneous (0.41). Chl-a was negatively correlated to % forest (-0.54) and positively correlated with the amount of sedimentary rock in each sub-basin (0.55). TSS had the strongest relation with % agriculture (0.72) as well as strong relations with % sedimentary (0.70) and % igneous (-0.58). This analysis was heavily influenced by the high concentrations of all constituents that were exported from the Deer Creek subwatershed. Because the aquatic chemistry of this subwatershed is controlled by multiple waste water treatment plants the six subwatersheds which constitute Deer Creek were removed and the analysis was run again.

Without the effects of the waste water treatment plants multiple colinearity between many of the constituents decreased and the impact that the landscape itself has on water quality became more clear (Table 2, Fig. 9). The impact agriculture has on water quality was enumerated with positive relations to TSS, TP, TN, and Chl-a (0.90, 0.97, 0.52, 0.49); while % urban had weak positive relations with EC and TP (0.32, 0.29). The negative relations between most water quality parameters and % forest, % igneous, and elevation where made stronger with the omission of Deer Creek, while the positive relation between TSS and % agriculture and % sedimentary bedrock also increased (0.90 and 0.88, respectively). Next to TN, % metamorphic had the strongest relationship with $NO_3^-$ (0.63) after Deer Creek was omitted. TN and TP were uncorrelated to % agriculture in the first run because of the heavy nutrient loading occurring in Deer Creek, after Deer Creek was omitted the correlation became significantly strong (0.52 and 0.97 respectively).

*Fluxes in the Upper and Lower Basin*

During w.y. 1999 and w.y. 2000 (two wet years) the upper watershed produced an average water flux of $6.99 \times 10^{11}$ L $yr^{-1}$. Because the lower watershed is not gauged a generous flow estimate was calculated for Cosumnes at Twin Cities based on 150% of the flow at Michigan Bar. Even with this overestimate of flow it was clear that the upper watershed contributes significantly to the overall flux from the entire watershed (Fig. 11). The lower watershed delivered approximately 150% more flux of the ions $Na^+$, $Mg^{2+}$, $Cl^-$, $SO_4^{2-}$, but actually delivered less $K^+$, $Ca_2^+$, and Si than the upper watershed. While the upper basin proved to be an important source for some major ions, far more TSS was delivered by the lower basin, if the fluxes from w.y. 1999 and w.y. 2000 are averaged the lower basin delivered 800% more TSS than the upper basin. Nitrate fluxes were nearly as disparate with approximately 500% more $NO_3^-$ being generated in the lower watershed.

In w.y. 2001 a similar analysis was conducted, except for this dry year we included DOC, TP, and TN data (Fig. 12). With the lower reaches in the Cosumnes being ephemeral and the majority of the precipitation occurring in the upper basin, it was expected that our flow estimates for Twin Cities would be too generous for a dry year, but many of the same flux relationships between the basins held, so the flow estimates were kept. Fluxes of $Na^{+}$, $K^{+}$, $Mg^{2+}$, $Ca^{2+}$, $Cl^{-}$, $SO_4^{2-}$, Si, and TSS were, of course reduced during this low flow year but the relative contributions from the two sub-basins remained the same. The nitrate response was very different with the lower watershed apparently acting as an annual nitrate sink while the upper watershed continued to export this vital nutrient. Conversely, the lower watershed produce 528% more TP and 299% more TN than the upper watershed during the dry year of 2001. From figure 8b it was expected that the upper watershed would contribute relatively little DOC when compared with the lower watershed but the flux analysis indicates that the lower watershed delivers only 1.5 times as much DOC as the upper watershed, indicating that the uplands are a non-trivial source of DOC for the Delta.

**Discussion**

When gaining streams switch to losing streams during dry spells it becomes difficult to calculate chemical export rates. This is due to the fact that the export point which is measured in the river (i.e. the most downstream station) is not the only export point, water and the constituents carried along with it are being lost along miles of river bed. The result is an open ended mass balance. The mass balance conducted in this research assumes that the chemical flux input from the upper basin moves conservatively through the lower basin, this is a good assumption during the winter when stormflows move quickly through the system and the lower reaches are gaining ground water, but during the summer this assumption is invalid. This apparent difficulty in calculating mass balances for ephemeral stream is not an issue in the Cosumnes Watershed for two related reasons: (1) water flow during the summer (when the river is losing to ground water) is so low that it does not have a great effect on the annual flux budget; (2) The Mediterranean climate of the region acts to concentrate all the annual precipitation into the few winter months so summer storms rarely, if ever, occur.

Flux analysis between the upper and lower watersheds revealed the importance of the upper watershed for the delivery of major non-nutrient anions and cations. This was especially evident for $K^+$, and Si, (Figs. 7a and 6b) which are known to be largely derived from the dissolution of igneous rocks. During wet years the upper watershed delivers a relatively insignificant amount of nutrients and sediment to the lowlands, but during dry years when there are no large storms to effectively flush agricultural fields and annual grasslands, the upper watershed contributes a relatively significant amount of TN and $NO_3^-$ to the lowlands. During w.y. 2001 the lower watershed actually acted as a $NO_3^-$ sink, most likely because higher hydraulic residence times promoted nutrient uptake and/or denitrification. Research in the Mokelumne has indicated that large impoundments can act to sever the chemical continuity between the upland and the lowlands. Like many reservoirs (Hannan, 1979), the Pardee – Camanche reservoir system on the Mokelumne acts as a substantial chemical sink. This sink reduces the flux of constituents coming from the upper watershed, and by doing so reduces the importance of the upper watershed to downstream chemistries. In the Cosumnes we have seen how important the upper watershed is in determining downstream chemistries. It is concluded from our studies that the emplacement of dams on 19 of the 20 tributaries draining into the Delta has shifted the primary source of many dissolved constituents in the water from the upland to the lowlands.

Because many of the tributaries in the lower Cosumnes are ephemeral and the tributaries in the upper basin run year-round it was decided that flux calculations should not be used in intrabasin comparisons when running a regression analysis. For this reason median concentrations were used when conducting multiple linear regressions with geographical characteristics. This technique has been successfully used to identify chemical drivers in previous studies (Arheimer and Liden, 2000; Tippett et al., 1993) and proved very useful in this analysis.

Agricultural lands in the Cosumnes Basin apparently have a large impact on stream water quality as TSS and TP are strongly correlated to % agricultural land. Strangely, $NO_3^-$ had no significant correlation with % agriculture which may indicate that either nutrient uptake is rapid in this system or that fertilizer application is not very heavy. In future studies winter medians, instead of annual medians, could be used in order to isolate the season when the terrestrial environment is most directly connected with the aquatic, such analysis would exclude the influence of summertime nutrient uptake, a process which creates annual median values of zero at a number of sites in the basin. These numerous zero values may be the cause for such poor relationships between $NO_3^-$ and geography. Conversely, there were no zero values for TN and TP and after the removal of Deer Creek from the analysis strong correlations between these constituents and % agriculture developed. Apparently the anthropogenic point source inputs from Deer Creek were masking the other "diffuse" driving forces behind nutrient export in the basin. This technique of isolating and eliminating point source inputs when conducting a geographic analysis of water quality drivers proved useful and is recommended for future studies.

The urban influence in the watershed did not come to light in our regression model largely because the urban areas are so few and patchy across the basin, this meant that many zeroes where included in the regression reducing the significance of any relation between % urban and water quality. Conversely, % forest was a workable number in 24 of the 28 basins used in the regression so many significant relations developed. The most interesting include the negative correlations with Chl-a and TSS. Trees shading the river and holding in place entrainable sediment can explain these relations.

Finally bedrock type seemed to have a control on a number of water quality parameters. Sedimentary rocks were strongly related to high stream water TSS concentrations while igneous rocks were negatively correlate to just about everything we measured, the latter relations may be a relic of the fact that all the igneous rocks reside in the upper watershed, but it can be seen how unconsolidated sediments in lowland stream beds could contribute to stream water TSS. Most interestingly, % metamorphic rock was most strongly related to water TN and $NO_3^-$ levels. In fact % metamorphic rock was the greatest geographic determinant of stream water $NO_3^-$ a fact which may attest to the presence of geologic nitrogen sources in the basin. Geologic nitrogen sources have been documented in nearby tributaries of the Mokelumne (Holloway and Dahlgren, 1999; Holloway et al., 1998) so the probability that there are similar sources in the Cosumnes is high.

## Conclusions

This study has shown which geographic variables have the greatest control on water quality in the Cosumnes Watershed. Stream water suspended sediment and total nutrients are closely related to agricultural land use and the major flux of these constituents come from the lower basin, where cultivation is intensive. The upper basin is an important source of non-nutrient dissolved species, assuming this holds true for the other rivers draining the Sierra Nevada, and seeing as impoundments act as sinks for dissolved species, it is concluded that the emplacement of dams on 19 of the 20 tributaries draining into the Delta has shifted the primary source of many dissolved constituents in the water from the upland to the lowlands. These results indicate that the lowlands are the primary source of TSS, TN, TP, $NO_3^-$, and $PO_4^{3-}$, because these are major constituents of concern restoration efforts should be focused in this area.

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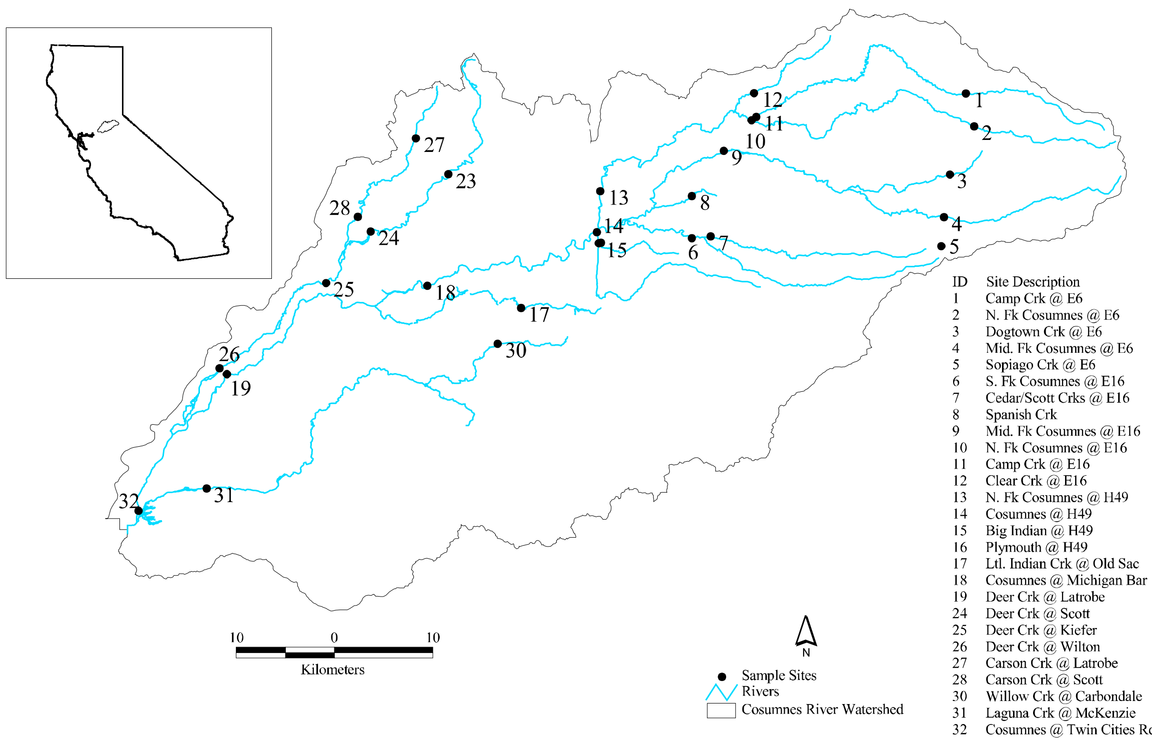
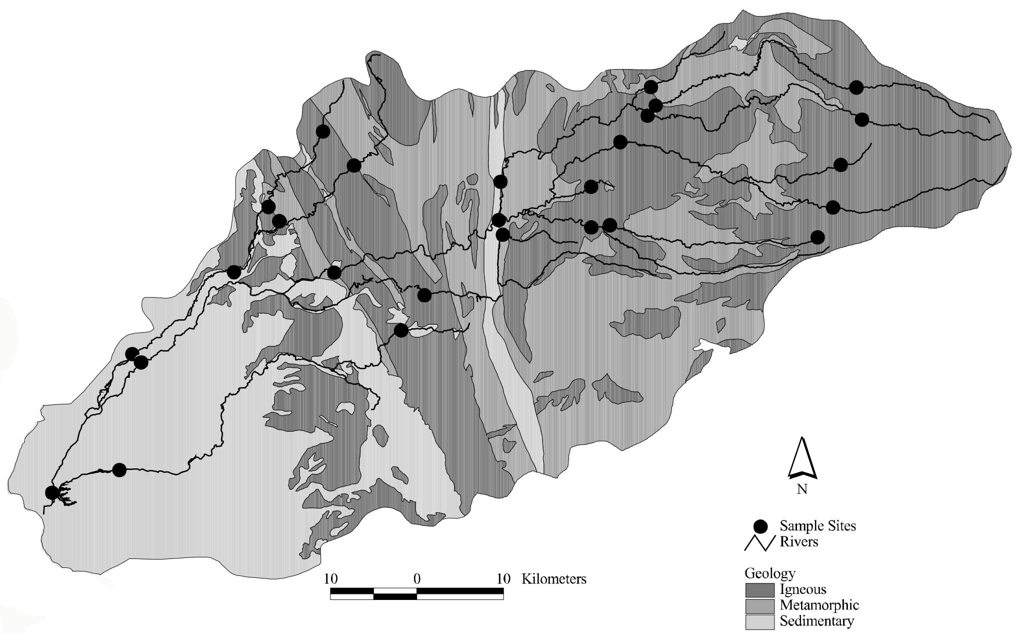



Figure 1. Map of the Cosumnes Watershed with water quality sampling sites. Each sampling site marked the downstream end of a subwatershed.

a.




b.

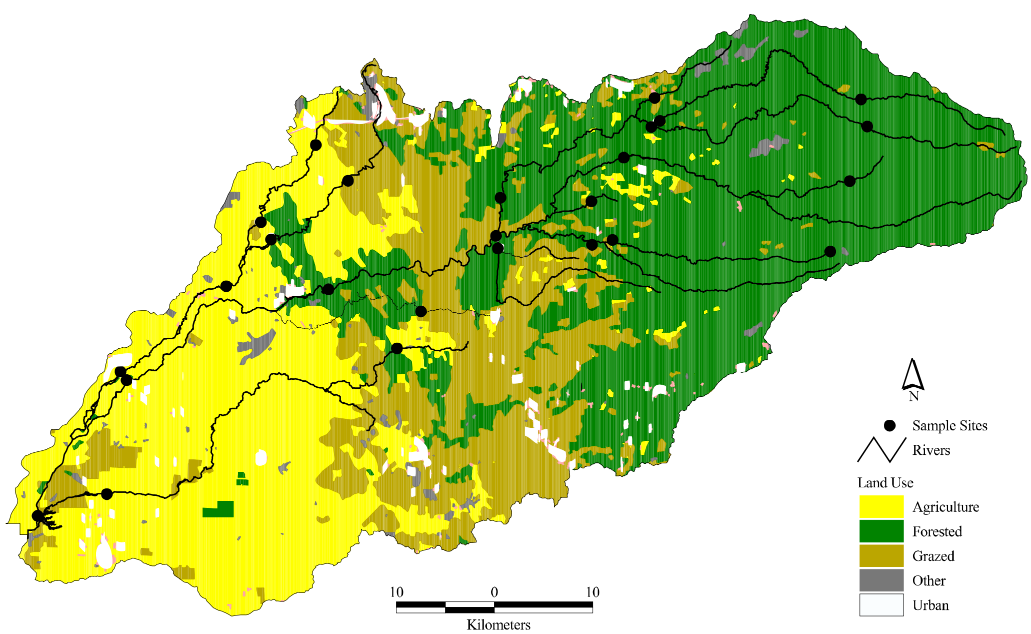



Figure 2. Maps of the Cosumnes Watershed showing geology (a) and land use (b)

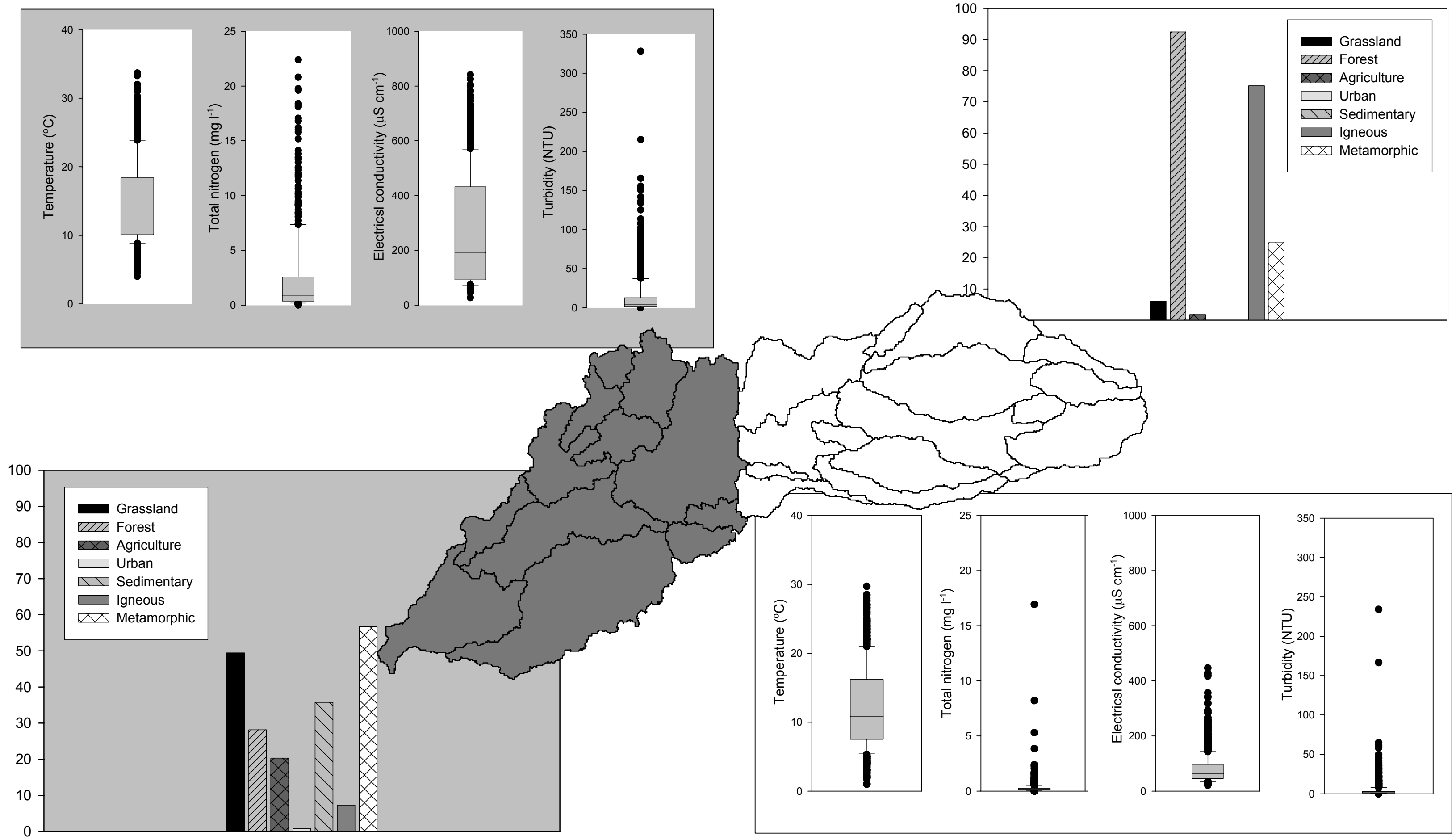
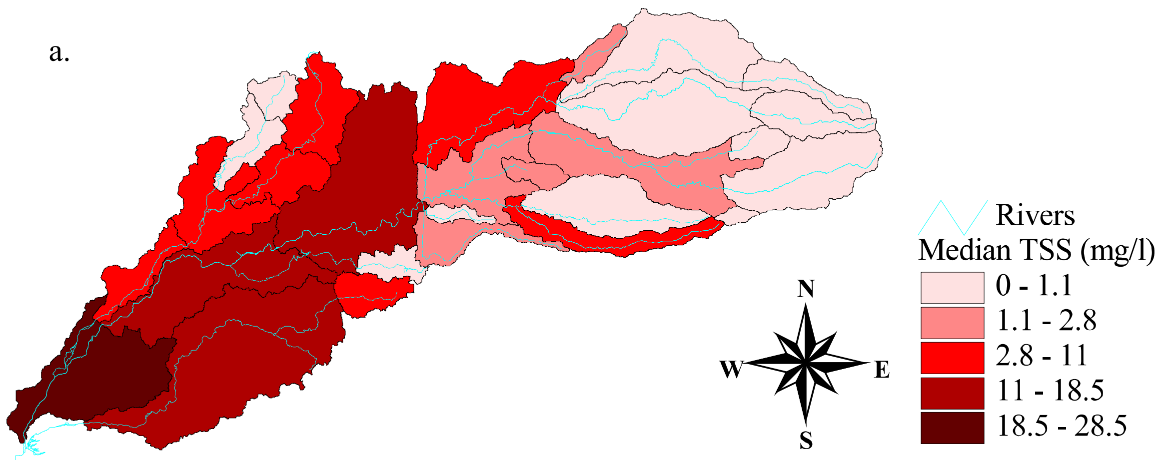



Figure 3. Landscape characteristics and chemistry varies substantially between the upper watershed (in white) and the lower watershed (in grey).

a.




b.

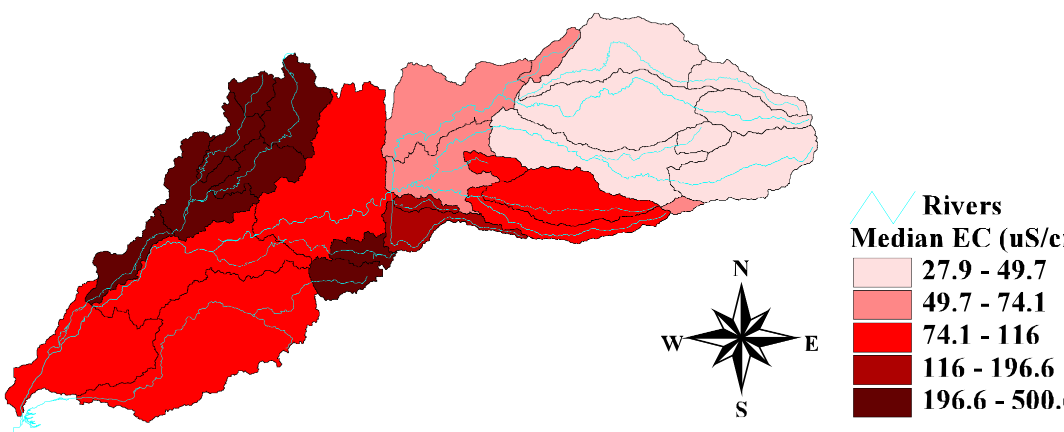
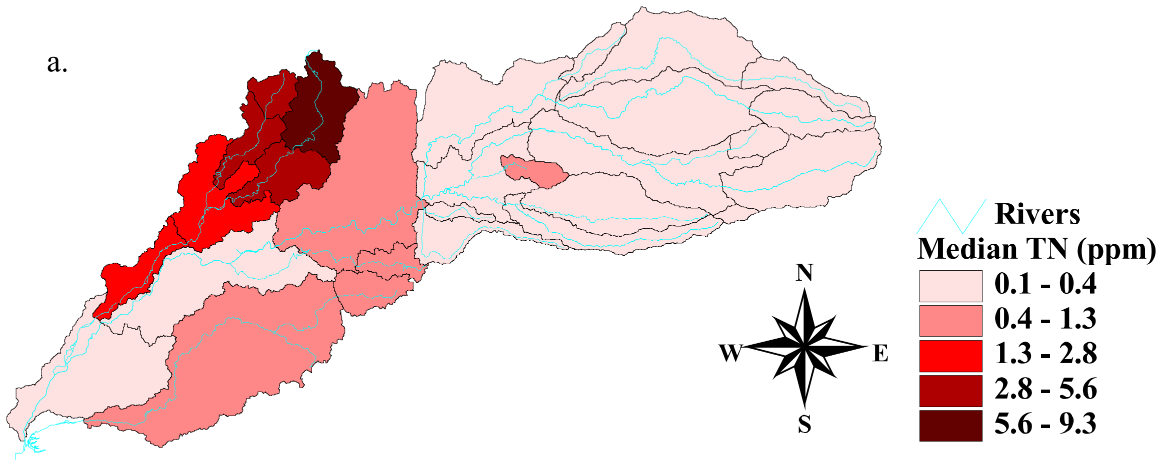



Figure 4. Median concentrations of TSS (a) and EC (b) for samples collected between Oct. 1998 and Oct. 2001.

a.




b.

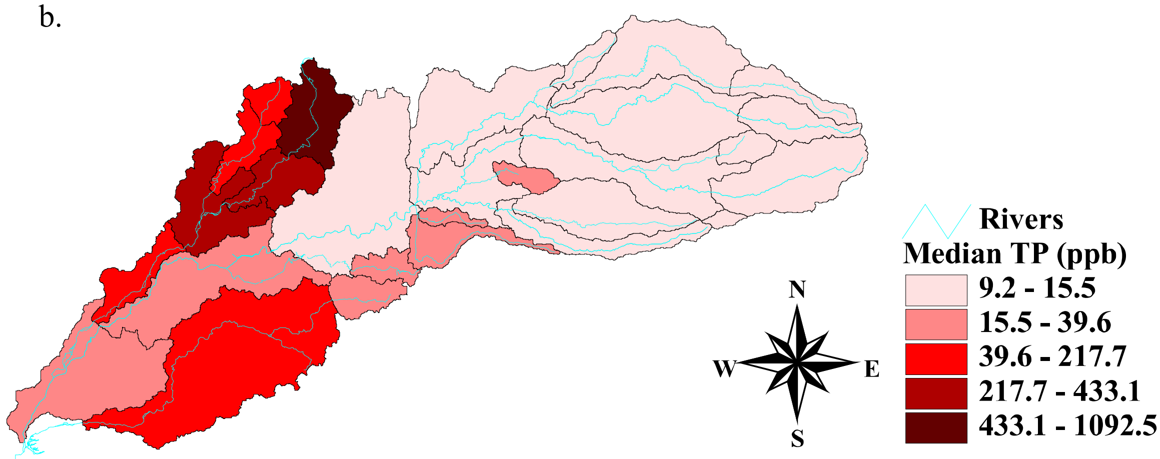
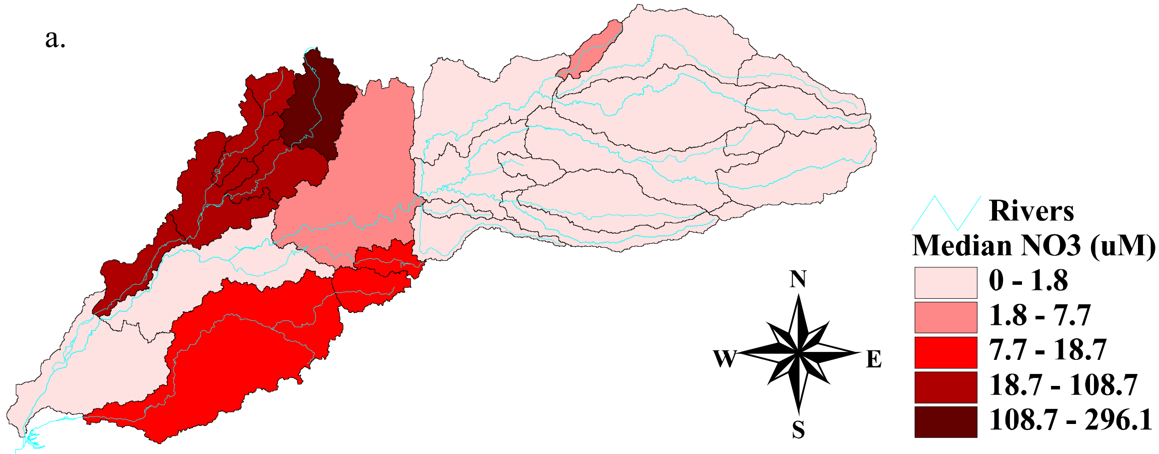



Figure 5. Median concentrations of TN (a) and TP (b) for samples collected between Oct. 1999 and Oct. 2001.

a.




b.

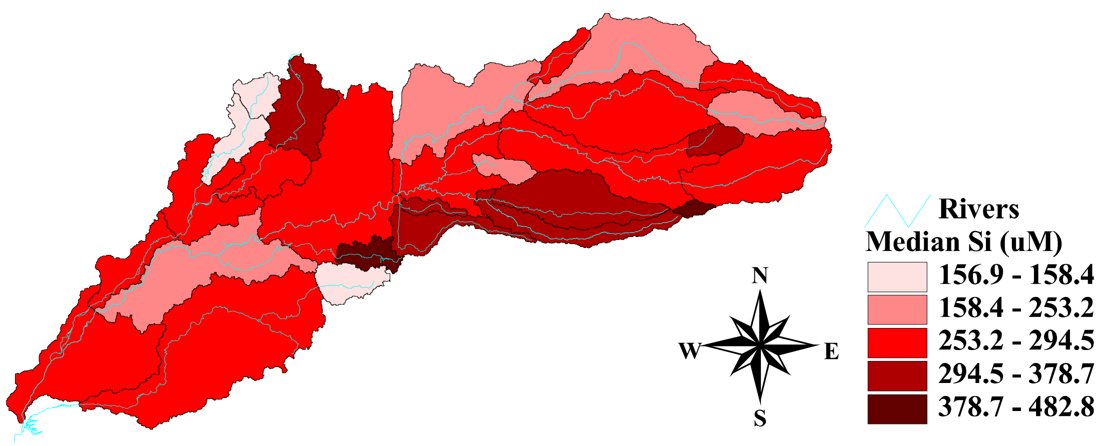
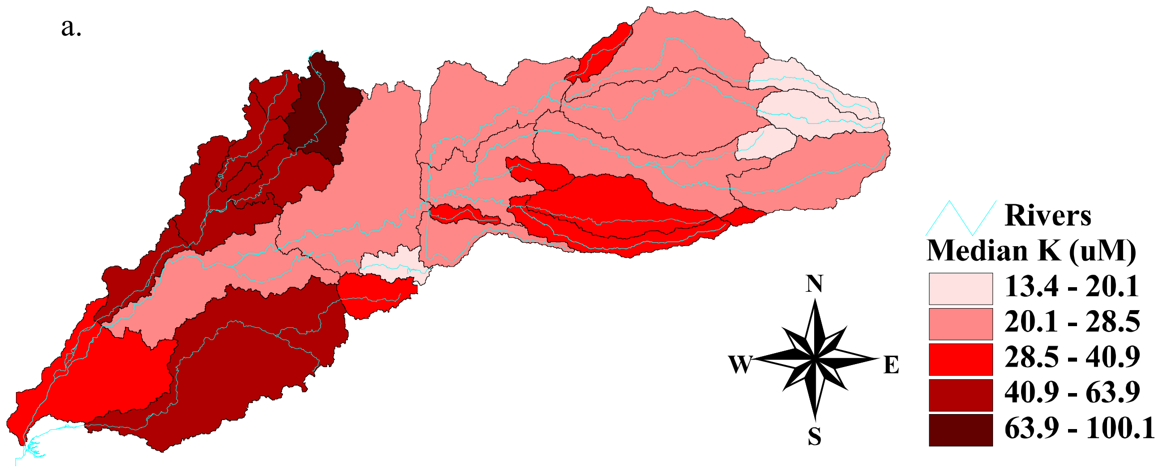



Figure 6. Median concentrations of $NO_3^-$ (a) and Si (b) for samples collected between Oct. 1998 and Oct. 2001. While high $NO_3^-$ concentrations were primarily found in the Deer Creek subwatershed, Si concentrations were more evenly disbursed across the watershed.

a.




b.

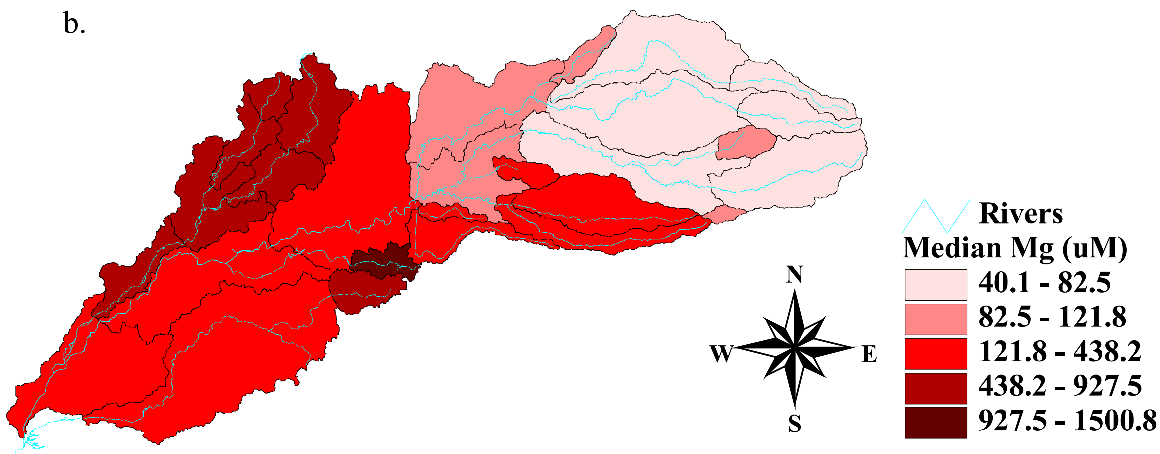
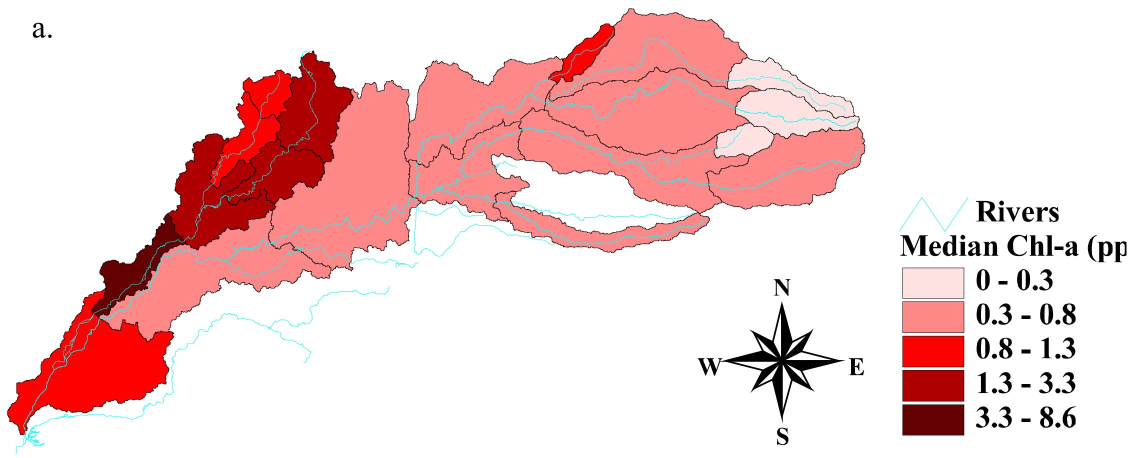



Figure 7. Median concentrations of $K^+$ (a) and $Mg^{2+}$ (b) for samples collected between Oct. 1998 and Oct. 2001. $K^+$, unlike many of the other ions, was fairly evenly distributed across the basin.



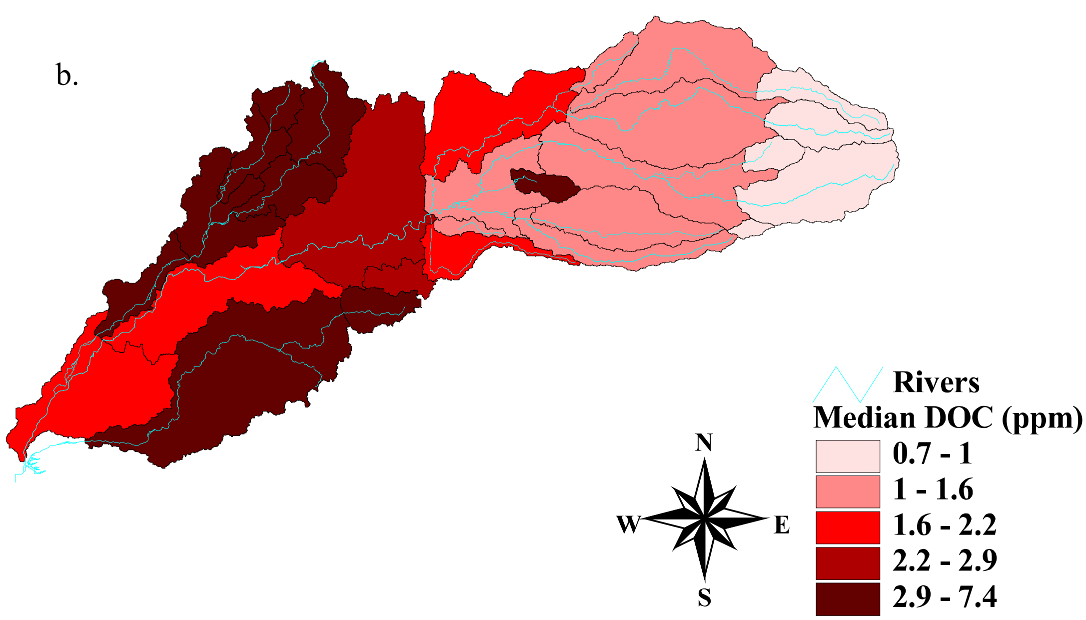




Figure 8. Median concentration map for Chl-a (a) and DOC (b) samples collected between Oct. 1998 and Oct. 2001. Chl-a was not collected at all of the sample sites so there are data gaps on the map.

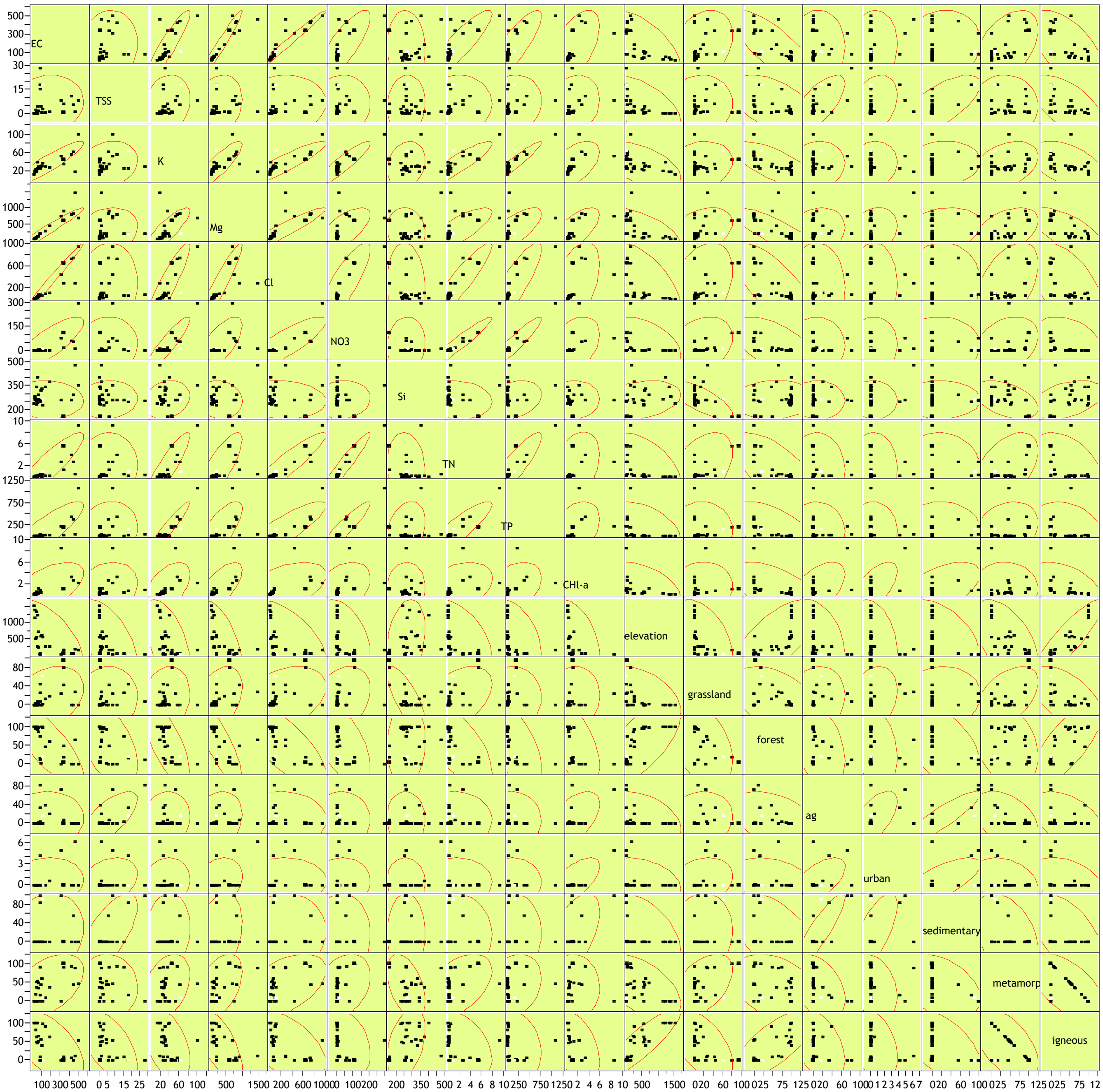



Figure 9. Scatterplot matrix showing regressions between ten water quality parameters and eight landscape characteristics. This initial run included the Deer Creek subwatershed.

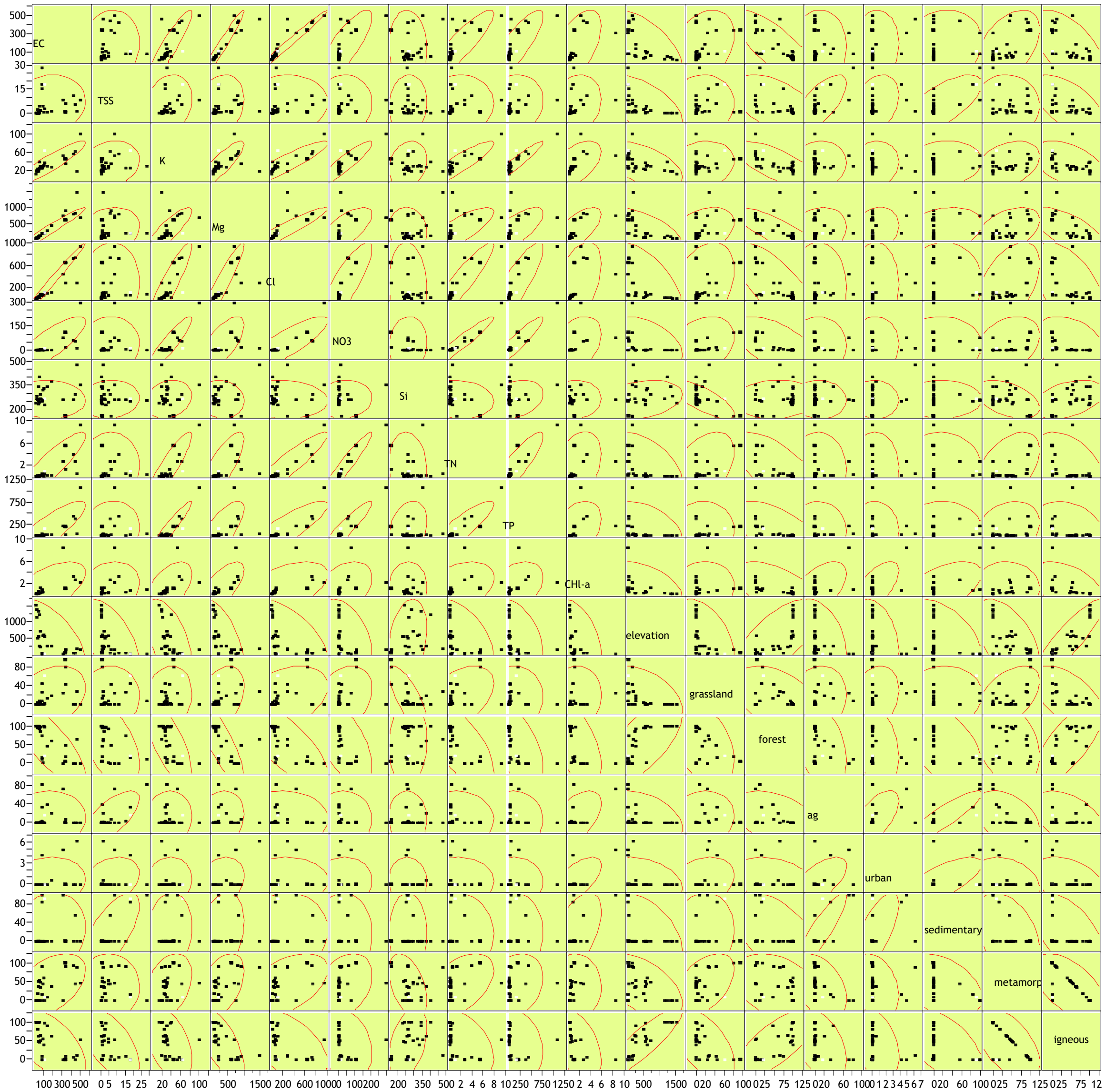



Figure 10. Scatterplot matrix for ten water quality parameters and eight landscape characteristics. The second regression run excluded the Deer Creek subwatershed.

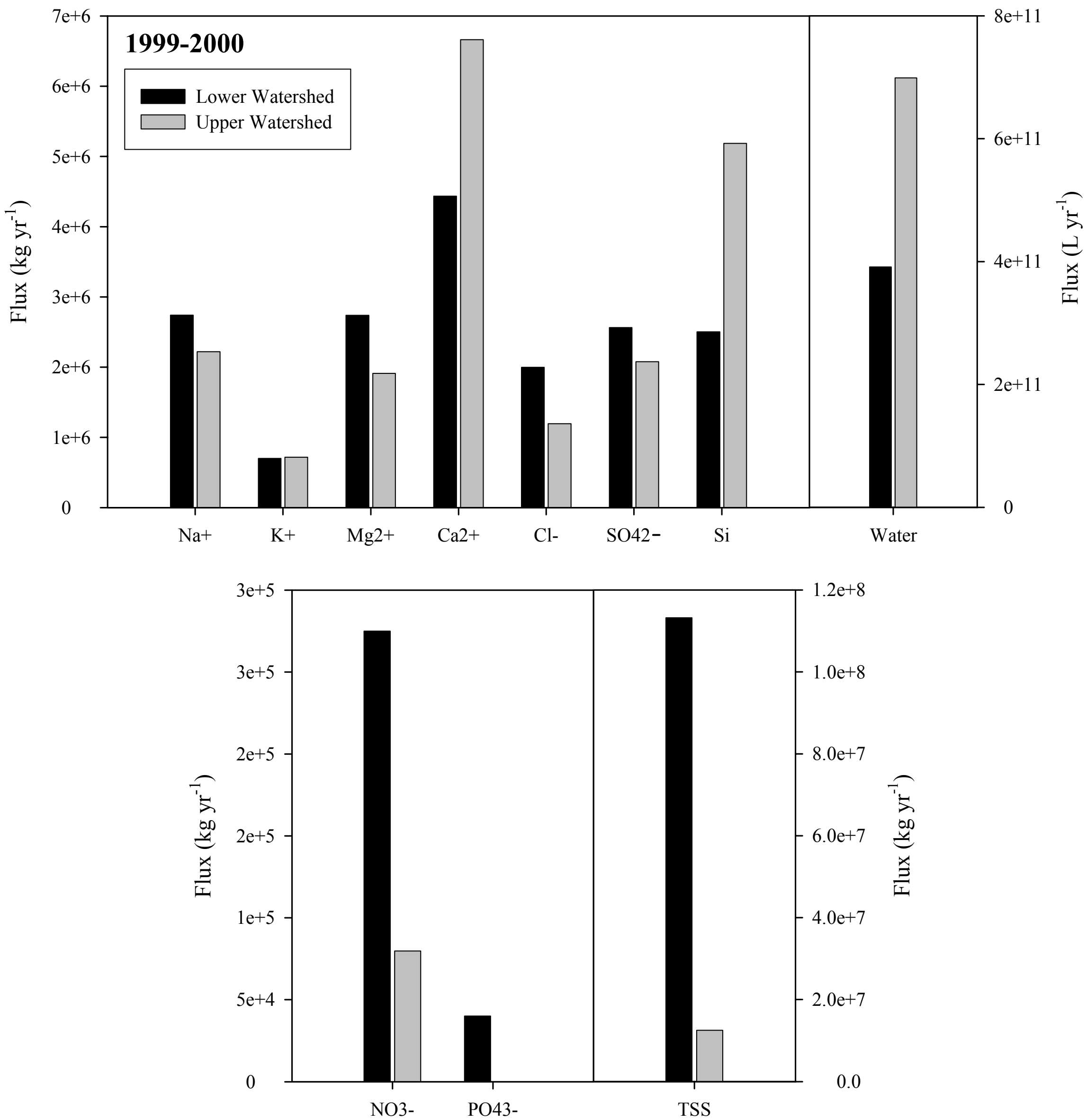



Figure 11. Dissolved and suspended average annual fluxes from the upper and lower watersheds for the wet water years of 1999-2000. The upper watershed contributes substantially to all constituents except nutrients and TSS. Note: lower watershed fluxes are calculated by subtracting the upper watershed input from the flux export from the entire watershed.

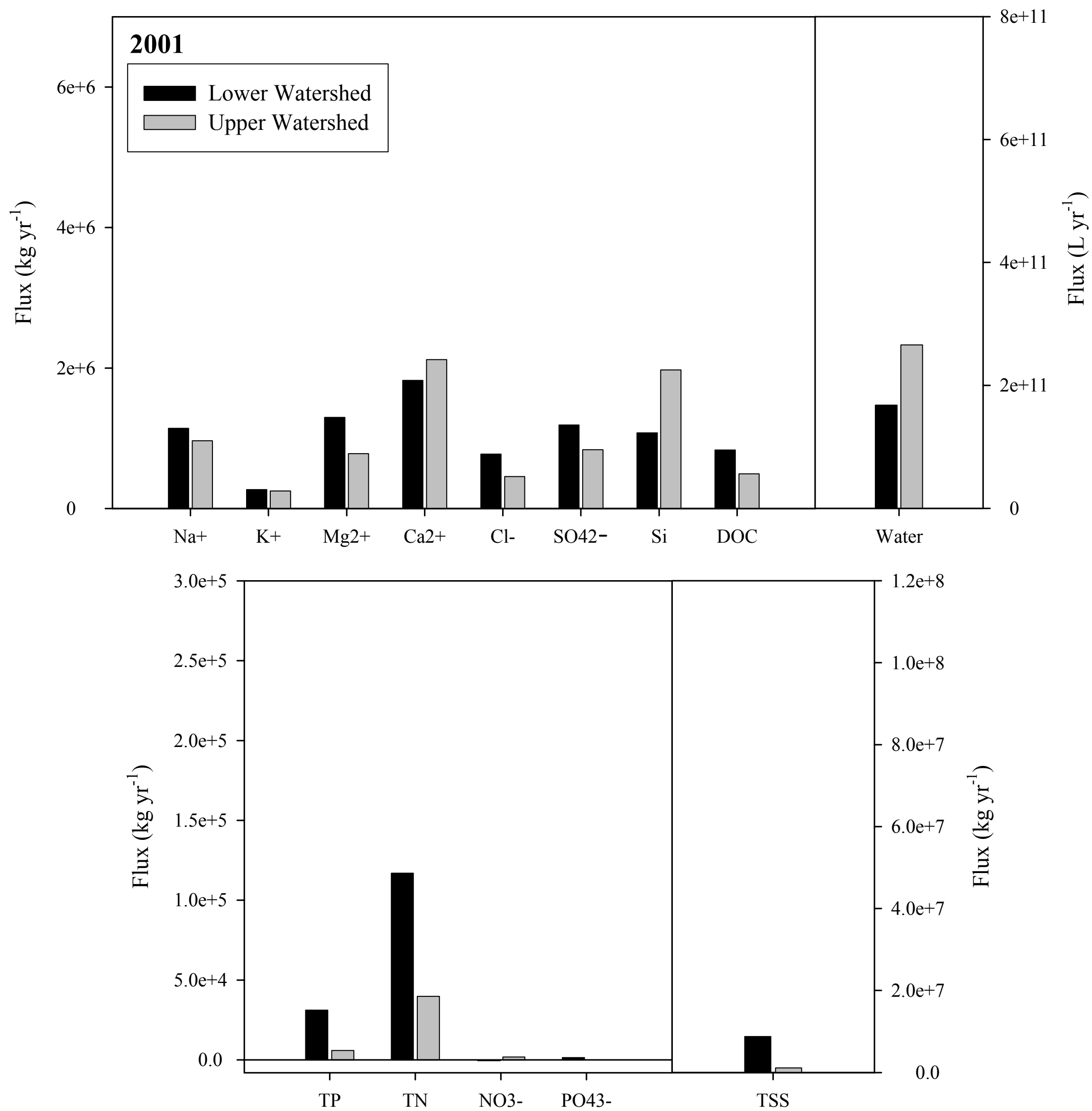



Figure 12. Dissolved and suspended annual fluxes from the upper and lower watersheds for the dry water year of 2001. The upper watershed plays a more important during dry years, especially in terms of $NO_3^-$ export.

Table 1. Multiple linear regression analysis for constituents of interest and geographic data. Regressions are run with the inclusion of Deer Creek. Significance of regressions was determined by Kendall's tau (*correlation is significant between the 0.05 and 0.1 level).

| | EC | TSS | K | Mg | Cl | NO3 | Si | TN | TP | CHl-a | elevation | grassland | forest | agriculture | urban | sedimentary | metamorphic | igneous |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| EC | 1.00 | 0.12 | 0.93 | 0.98 | 0.99 | 0.82 | -- | 0.90 | 0.85 | 0.58 | -0.57 | 0.33 | -0.78 | -- | -- | -- | 0.49 | -0.58 |
| TSS | 0.12 | 1.00 | 0.20 | 0.18 | 0.07 | 0.04 | -- | 0.03 | 0.13 | 0.18 | -0.57 | 0.04 | -0.50 | 0.72 | -- | 0.70 | -- | -0.60 |
| K | 0.93 | 0.20 | 1.00 | 0.86 | 0.92 | 0.92 | -- | 0.90 | 0.96 | 0.53 | -0.55 | -- | -0.72 | -- | -- | 0.15 | -- | -0.45 |
| Mg | 0.98 | 0.18 | 0.86 | 1.00 | 0.95 | 0.71 | -- | 0.81 | 0.74 | 0.70 | -0.62 | 0.35 | -0.82 | 0.15 | 0.23* | 0.29* | 0.45 | -0.67 |
| Cl | 0.99 | 0.07 | 0.92 | 0.95 | 1.00 | 0.86 | -- | 0.93 | 0.86 | 0.51 | -0.53 | 0.36 | -0.74 | -0.04* | -- | 0.08* | 0.51 | -0.54 |
| NO3 | 0.82 | 0.04 | 0.92 | 0.71 | 0.86 | 1.00 | 0.08* | 0.96 | 0.94 | 0.37 | -0.38 | 0.28 | -0.57 | -- | -- | -0.02* | 0.33 | -0.28 |
| Si | -- | -- | -- | -- | -- | 0.08* | 1.00 | -- | -- | -- | -- | -0.75* | -- | -- | -- | -- | -- | 0.41* |
| TN | 0.90 | 0.03 | 0.90 | 0.81 | 0.93 | 0.96 | -- | 1.00 | 0.89 | 0.38 | -0.45 | 0.44 | -0.65 | -- | -- | -0.03 | 0.50 | -0.42 |
| TP | 0.85 | 0.13 | 0.96 | 0.74 | 0.86 | 0.94 | -- | 0.89 | 1.00 | 0.39 | -0.37 | -- | -0.58 | -- | -- | 0.02 | -- | -0.25 |
| CHl-a | 0.58 | 0.18 | 0.53 | 0.70 | 0.51 | 0.37 | -- | 0.38 | 0.39 | 1.00 | -0.41 | -- | -0.54 | -- | -- | 0.55 | -0.04* | -0.47 |
| elevation | -0.57 | -0.57 | -0.55 | -0.62 | -0.53 | -0.38 | -- | -0.45 | -0.37 | -0.41 | 1.00 | -0.41 | 0.69 | -0.37 | -- | -0.44 | -0.54* | 0.89 |
| grassland | 0.33 | 0.04 | -- | 0.35 | 0.36 | 0.28 | -0.75* | 0.44 | -- | -- | -0.41 | 1.00 | -0.41 | 0.09 | 0.24 | -- | 0.52* | -0.57 |
| forest | -0.78 | -0.50 | -0.72 | -0.82 | -0.74 | -0.57 | -- | -0.65 | -0.58 | -0.54 | 0.69 | -0.41 | 1.00 | -0.41 | -- | -0.51 | -0.32* | 0.76 |
| ag | -- | 0.72 | -- | 0.15 | -0.04* | -- | -- | -- | -- | -- | -0.37 | 0.09 | -0.41 | 1.00 | 0.63 | 0.90 | -- | -0.46 |
| urban | -- | -- | -- | 0.23* | -- | -- | -- | -- | -- | -- | -- | 0.24 | -- | 0.63 | 1.00 | -- | -- | -- |
| sedimentary | -- | 0.70 | 0.15 | 0.29* | 0.08* | -0.02* | -- | -0.03 | 0.02 | 0.55 | -0.44 | -- | -0.51 | 0.90 | -- | 1.00 | -- | -0.56 |
| metamorphic | 0.49 | -- | -- | 0.45 | 0.51 | 0.33 | -- | 0.50 | -- | -0.04* | -0.54* | 0.52* | -0.32* | -- | -- | -- | 1.00 | -0.54 |
| igneous | -0.58 | -0.60 | -0.45 | -0.67 | -0.54 | -0.28 | 0.41* | -0.42 | -0.25 | -0.47 | 0.89 | -0.57 | 0.76 | -0.46 | -- | -0.56 | -0.54 | 1.00 |

Table 2. Multiple linear regression analysis for constituents of interest and geographic data. Regressions are run without the inclusion of Deer Creek in order to eliminate the effect of the waste water treatment plants located in the Deer Creek subwatersheds. Significance of regressions was determined by Kendall's tau (*correlation is significant between the 0.05 and 0.1 level).

| | EC | TSS | K | Mg | Cl | NO3 | Si | TN | TP | CHl-a | elevation | grassland | forest | agriculture | urban | sedimentary | metamorphic | igneous |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| EC | 1.00 | 0.69 | 0.88 | 0.97 | 0.91 | 0.42 | -- | 0.71 | 0.49 | 0.57 | -0.78 | 0.51 | -0.79 | 0.48 | 0.32 | -- | 0.48 | -0.82 |
| TSS | 0.69 | 1.00 | 0.55 | 0.79 | 0.63 | 0.33 | -- | 0.78 | 0.86 | 0.47 | -0.69 | 0.65 | -0.74 | 0.90 | -- | 0.88 | -- | -0.85 |
| K | 0.88 | 0.55 | 1.00 | 0.78 | 0.89 | -- | -- | 0.57 | 0.50 | 0.68 | -- | -- | -0.60 | -- | -- | -- | -- | -- |
| Mg | 0.97 | 0.79 | 0.78 | 1.00 | 0.83 | 0.42 | -- | 0.75 | 0.55 | 0.48 | -0.75 | 0.61 | -0.84 | 0.56 | 0.39 | -- | 0.39* | -0.85 |
| Cl | 0.91 | 0.63 | 0.89 | 0.83 | 1.00 | 0.59 | -- | 0.73 | 0.50 | 0.81 | -0.74 | 0.41 | -0.60 | 0.47 | 0.23 | -- | 0.52 | -0.82 |
| NO3 | 0.42 | 0.33 | -- | 0.42 | 0.59 | 1.00 | -- | 0.80 | 0.03 | 0.49 | -0.30 | 0.33 | -- | -- | -0.08 | -- | 0.63* | -0.48 |
| Si | -- | -- | -- | -- | -- | -- | 1.00 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| TN | 0.71 | 0.78 | 0.57 | 0.75 | 0.73 | 0.80 | -- | 1.00 | 0.49 | 0.49 | -0.67 | 0.52 | -0.41 | 0.52 | -- | 0.44* | 0.50 | -0.79 |
| TP | 0.49 | 0.86 | 0.50 | 0.55 | 0.50 | 0.03 | -- | 0.49 | 1.00 | 0.55 | -0.48 | 0.33 | -0.66 | 0.97 | 0.29* | 0.92 | -- | -0.63 |
| CHl-a | 0.57 | 0.47 | 0.68 | 0.48 | 0.81 | 0.49 | -- | 0.49 | 0.55 | 1.00 | -0.47 | 0.24 | -0.37 | 0.49* | -- | 0.49 | -- | -0.63 |
| elevation | -0.78 | -0.69 | -- | -0.75 | -0.74 | -0.30 | -- | -0.67 | -0.48 | -0.47 | 1.00 | -0.56 | 0.53 | -0.48 | -- | -0.50 | -0.55* | 0.89 |
| grassland | 0.51 | 0.65 | -- | 0.61 | 0.41 | 0.33 | -- | 0.52 | 0.33 | 0.24 | -0.56 | 1.00 | -0.48 | 0.37 | 0.85 | 0.58 | 0.21* | -0.70 |
| forest | -0.79 | -0.74 | -0.60 | -0.84 | -0.60 | -- | -- | -0.41 | -0.66 | -0.37 | 0.53 | -0.48 | 1.00 | -0.67 | -- | -0.72 | -- | 0.66 |
| ag | 0.48 | 0.90 | -- | 0.56 | 0.47 | -- | -- | 0.52 | 0.97 | 0.49* | -0.48 | 0.37 | -0.67 | 1.00 | -- | 0.95 | -- | -0.64 |
| urban | 0.32 | -- | -- | 0.39 | 0.23* | -0.08* | -- | -- | 0.29* | -- | -- | 0.85 | -- | -- | 1.00 | -- | -- | -- |
| sedimentary | -- | 0.88 | -- | -- | -- | -- | -- | 0.44* | 0.92 | 0.49 | -0.50 | 0.58 | -0.72 | 0.95 | -- | 1.00 | -- | -0.68 |
| metamorphic | 0.48 | -- | -- | 0.39 | 0.52 | 0.63* | -- | 0.50 | -- | -- | -0.55* | 0.21* | -- | -- | -- | -- | 1.00 | -0.48 |
| igneous | -0.82 | -0.85 | -- | -0.85 | -0.82 | -0.48 | -- | -0.79 | -0.63 | -0.63 | 0.89 | -0.70 | 0.66 | -0.64 | -- | -0.68 | -0.48 | 1.00 |