Appendix A

Whipple Creek Watershed-Scale Stormwater Plan Report

Water Quality and Land Cover Relationship

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Introduction

Exploratory statistical analyses was performed on the relationships between Whipple Creek subwatersheds' water quality and general land covers to support the stormwater planning assessment of existing local water quality conditions, screen for broad potential pollution sources, and provide insights for water quality modeling. For nonpoint source pollution analysis and watershed management, linear regression is often used to determine the extent to which water quality (dependent variable) is influenced by hydrological or land use factors (independent variables) such as the percentage of land treatment (EPA, 1997, pp. 1-4). Practical applications of these regression results include the ability to predict water quality impacts due to changes in the independent variables.

Stormwater management planning encompasses a wide range of site-specific issues including understanding local problems and pollutant sources that monitoring can help identify (Burton and Pitt, 2002, p. 10). Discharge from storm drainage systems includes warm weather stormwater, snowmelt, baseflows, and inappropriate discharges to the storm drainage that all may be important to consider when evaluating alternative stormwater management options. Given that stormwater management's main purpose is to reduce adverse impacts on receiving water beneficial uses, it is important in any stormwater runoff study to assess the detrimental effects that runoff is actually having on a receiving water.

Nationally, accumulated data on stormwater quality indicate that concentrations and loads vary widely, but several important factors are involved including land use (Minton, 2002, p.13, 17-18). Minton summarizes the influence of land use factors as:

> "Researchers have differed as to the significance of different land uses. There appears to be a general agreement that loading differs between land uses, whereas there is a lack of agreement as to whether concentration differs. At a minimum, land use can be divided into two broad groups with respect to concentration differences: open space and low-density residential and all other urban land uses. The data from the most comprehensive study ever undertaken suggest no significant difference in event mean concentrations between land use types with the exception of open space. It was concluded that land use type is virtually useless as a predictor of concentration. The data indicate that variation is greater within, rather than between, residential, commercial, industrial, and mixed-use sites."

Given this limited applicability of ***event mean concentrations and land use*** data as well as sparse local continuous flow data for estimating loads, this Whipple Creek study performed only exploratory statistical analyses of ***grab sample water quality*** relationships with ***land cover*** (note not specific ***land use*** types). It is acknowledged that multiple interacting factors determine the quality of stormwater and even more so that of receiving waterbodies where additional in-stream processes occur. The underlying complex interactions of mechanistic factors impacting subwatershed stream water quality (such as the magnitude and timing of individual storm event flows, surface runoff impacts, evapotranspiration, in-stream processes, etc.) are addressed through this watershed planning project's implementation of HSPF continuous flow water quality modeling. Importantly, both this statistical analyses and the HSPF model utilize the same watershed wide land cover data while the model calibration focuses on water quality data from the long running lower-watershed monitoring station (WPL050) also included in this study.

Therefore, only Whipple Creek subwatersheds' portions of general land covers falling within open space or development categories are related to their respective stream's median water quality values using simple linear regression. This study's goals are to see if land cover helps explain variation in grab sample monitored water quality and gain insights on potential general pollution sources and possible anomalies.

Methods

Stream water quality monitoring occurred at nine monitoring stations (Figure 1) located at the mouth of four main channel or main stem (labeled from downstream to upstream as WPL010, WPL050, WPL065, and WPL080) and five tributary drainages (from most downstream to upstream depicted as PCK010 [Packard Creek], WPLT01, WPLT02, WPLT03, and WPLT04). From at least July 2014 through May 2015, Clark County staff followed standard operating procedures in taking stream field measurements and collecting grab samples (Clark County, 2014). All water samples were analyzed at a nearby Washington State Department of Ecology accredited laboratory to help meet analytical hold times.

Water quality is represented by six parameters' median values to assign dependent variable values for relationships based on flow type (Table 1). Medians are used for central tendency because they are more resistant to outliers. Each median is based on at least 11 monitoring events per station (grouped by flow type) except for one tributary station with slightly fewer events (WPLT03). Typically, monitoring events at each station included at least 12 random base flow and 11 storm events for most parameters except for 8 base flow events for WPLT03. Additionally, water quality monitoring was performed monthly during unclassified flow events at the Packard Creek tributary and most main stem stations in water year 2012 with substantially more similar monitoring occurring at WPL050 going back to water year 2002 (yielding between 31 and 165 monthly monitored parameter results as part of a long-term monitoring project).

Land cover is represented by the relative portion of five general land cover types upstream from each monitoring location (based on previously mapped catchments). The catchments and land cover types are the same used for input to the Whipple Creek Watershed Plan's HSPF model. Most land cover data was originally derived using methods developed in the Puget Sound area (Hill and Bidwell, 2003) and applied to 2000 Landsat satellite imagery. Clark County staff then aggregated some closely related land cover classes and updated acreages using a Geographic Information System (ESRI, 2014, ArcGIS 10.2.2 for Desktop) and interpretation of 2014 aerial photographs as well more recent subdivision documentation. Final land cover types included forest, pasture, grass, impervious surfaces, and water. During the update, open areas around development were interpreted as falling within the grassy (urban lawn-like) land cover.

Data management and analyses utilized standardized procedures (Clark County, 2014) and existing software systems operated by Clark County staff. Data management included data review, finalization, and upload into the County's water quality database (WQDB based on Microsoft Access) and data manipulation using spreadsheets (Microsoft Excel). Statistical analyses were performed using MiniTab Statistical Software (Minitab Inc., Version 14, 2003). Analyses focused primarily on a straightforward screening of relationships between individual pairs of variables representing available Whipple Creek subwatershed water quality data (using medians) versus proportion of each subwatershed in a particular general land cover category. Relationships were evaluated via simple linear regression (Helsel and Hirsch, 2000, pp. 221 - 222) where one explanatory or independent variable (land cover) is used in statistical models. More complex multiple explanatory variable / multivariate regression statistical models were not evaluated in this basic screening study.

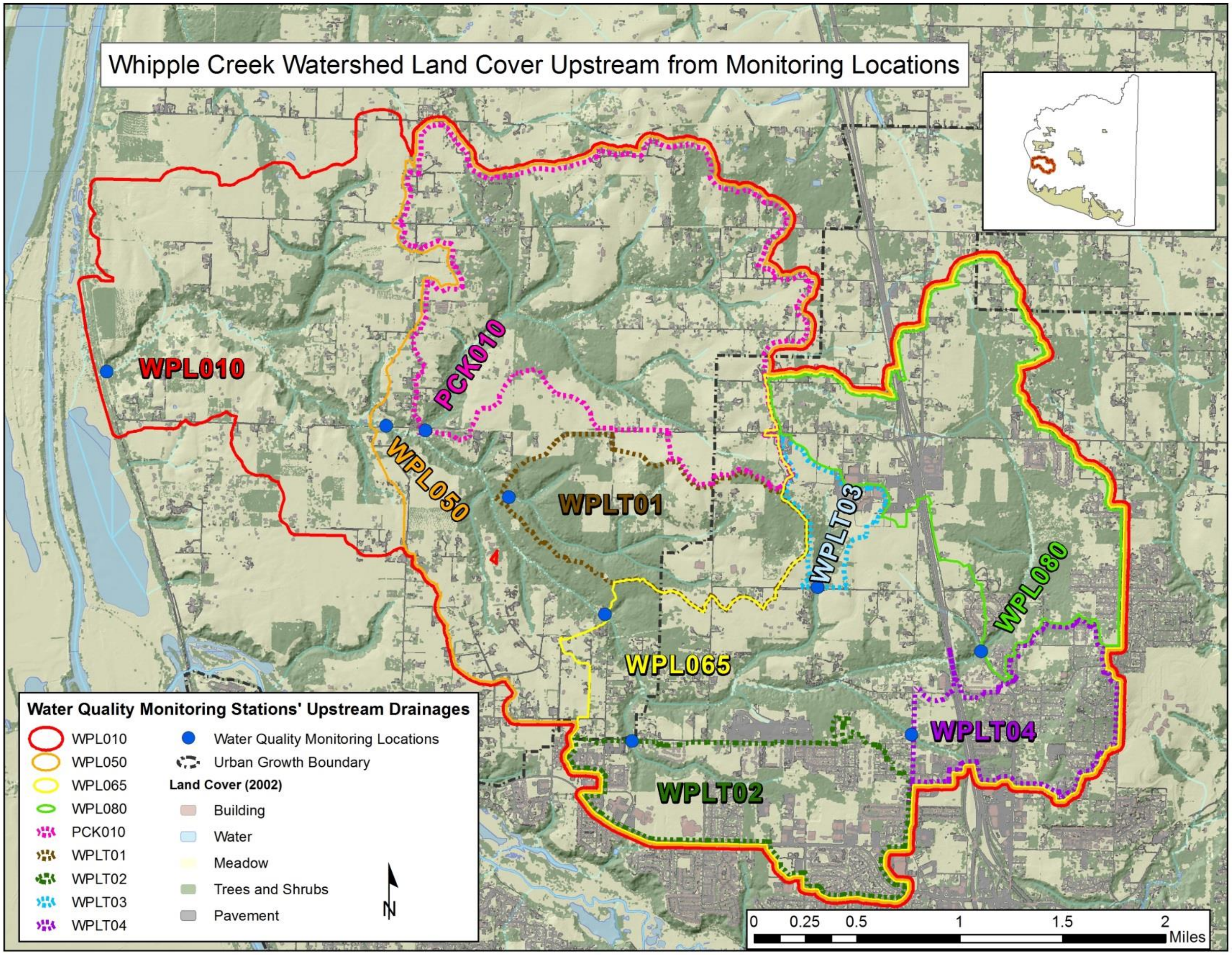


Figure 1 Whipple Creek Subwatersheds Water Quality Monitoring Stations and General Land Covers

Table 1 Whipple Creek main stem and tributary subwatershed median water quality values and sample sizes by flow type

Whipple Creek Main Stem Subwatersheds Water Quality Medians																
Station	WPL010 Medians				WPL050 Medians				WPL065 Medians			WPL080 Medians				
Monitoring Period	WY12 Monthly, July'14-May '15				WY'02-'15 Monthly, July '14 - May '15				July '14 - May '15			WY12 Monthly, July'14-May '15				
Flow Type	Base	Storm	Unclassif.	Overall	Base	Storm	Unclassif.	Overall	Base	Storm	Overall	Base	Storm	Unclassif.	Overall	
Sample Size *	12	12	12	36	12	12	*	*	12	12	24	12	12	12	36	
Parameter (units)																
Water Temperature (degrees C)	11	10.9	12.6	11.3	11	10.6	11.2 (164)	11.1 (188)	11.4	10.7	10.7	10.8	11	13.4	11.3	
Tubidity (NTU)	8.9	35.3	14.5	13.5	7.6	39.6	8.2 (165)	8.6 (189)	7.6	24.5	11.1	6.2	20.7	6	8.4	
pH	7.48	7.37	7.22	7.4	7.89	7.5	7.53 (158)	7.53 (182)	7.52	7.26	7.46	7.54	7.41	7.37	7.38	
Dissolved Copper (ug/L)	0.71	1.32	NA	0.87 (24)	0.76	1.28	1.14 (31)	1.13 (55)	0.9	1.86	1.17	0.96	1.82	NA	1.22 (24)	
Dissolved Zinc (ug/L)	1.5	0.9	NA	1.0 (24)	1	1	1.1 (34)	1.0 (58)	1.5	2.3	1.8	1.4	3.1	NA	2.3 (24)	
Fecal Coliform (CFU/100 mL)	340	800 (11)	335	420 (35)	262	1865 (10)	275 (136)	315 (158)	203	390 (8)	265 (20)	57	280 (11)	76	100 (35)	

Whipple Creek Tributary Subwatersheds Water Quality Medians																
Station	PCK010 Medians				WPLT01 Medians			WPLT02 Medians			WPLT03 Medians			WPLT04 Medians		
Monitoring Period	WY12 Monthly, July'14-May '15				July '14 - May '15			July '14 - May '15			July '14 - May '15			July '14 - May '15		
Flow Type	Base	Storm	Unclassif.	Overall	Base	Storm	Overall	Base	Storm	Overall	Base	Storm	Overall	Base	Storm	Overall
Sample Size *	12	12	12	36	12	11	23	12	11	23	8	11	19	12	11	23
Parameter (units)																
Water Temperature (degrees C)	10.8	10.5	12.3	11.1	10.5	10.7	10.7	11.1	11.1	11.1	6.1	10.5	9.8	11.5	11.5	11.5
Tubidity (NTU)	9.6	56	13.2	17.3	11.7	50.9	20.8	4.6	32	6.9	9.9	38.6	22.6	9.6	37.9	12.5
pH	7.69	7.6	7.5	7.6	7.89	7.56	7.74	7.65	7.37	7.57	7.46	7.52	7.47	7.2	7.37	7.32
Dissolved Copper (ug/L)	0.82	1.69	NA	1.32 (24)	0.67	1.25	0.8	0.74	1.73	1.25	1.15	1.93	1.85	0.66	2.44	0.88
Dissolved Zinc (ug/L)	0.8	1	NA	1.0 (24)	0.5	0.7	0.6	1.7	6	2.2	2.4	3.3	2.9	2.1	11.2	3.1
Fecal Coliform (CFU/100 mL)	395	3350	276	650	485	1040	760	780	665 (10)	695 (22)	31	660	280	71	740 (9)	250 (21)

* Common sample size across all station parameters unless noted otherwise in parentheses after median value.

Results and Discussion - Water Quality versus Land Cover Relationships

Land Covers

It is assumed that the main stem monitoring stations' water quality reflects that of nested upstream tributary and / or other main stem subwatersheds' land cover (Table 2). Forest, pasture, and grass dominate the main stem subwatersheds' land cover which, combined, total at least 80 %t of each drainage (Figure 2). WPL080 and even more so WPL065 have relatively more grass and impervious surface but less pasture and forest than WPL010 and WPL050. WPL065's higher levels of grass and impervious land covers is impacted by the higher percentages of these same land covers contributed from its nested main stem WPL080 and tributary WPLT02, WPLT03, and WPLT04 subwatersheds (Table 2 and Figure 3).

Table 2 Whipple Creek water quality monitoring stations upstream drainage areas

Whipple Creek Monitored Subwatersheds Nested Hierarchy, Land Cover Acreages and Relative Percentages												
Drainages		Forest		Pasture		Grass		Impervious		Water		Total
Nested Main Stem	Tributaries	Acres	%	Acres	%	Acres	%	Acres	%	Acres	%	Acres
	WPLT01	228	44	199	38	79	15	16	3	0	0	522
	WPLT02	83	15	61	11	263	47	152	27	3	0	561
	WPLT03	19	16	21	18	41	34	39	32	0	0	119
	WPLT04	64	18	31	9	183	51	83	23	1	0	363
	WPL080*	323	32	223	22	299	30	158	16	0	0	1003
WPL065 Total		743	26	554	19	1031	35	572	20	5	0	2906
	PCK010	535	35	674	44	250	16	59	4	0	0	1517
WPL050 Total		1747	31	1745	31	1459	26	672	12	5	0	5628
WPL010 Total		2136	30	2434	34	1749	25	746	11	7	0	7071

*WPL080 is the main stem headwater tributary

Screening of Overall Flow Type Water Quality versus Land Cover Relationships

A scatterplot matrix allows assessing many pairs of variable relationships at once (MiniTab Release 14 Statistical Software Help). Figure 4 allows a visual assessment of water quality versus land cover pairs of variables and the shape of their relationships for the overall flow type data. The scatterplots' dashed-red lowesss ("LOcally-Weighted Scatterplot Smoother") lines allow exploration of the relationship between two variables without fitting a specific model such as a regression line (MiniTab Release 14 Statistical Software Help). However, the scatterplots are also fitted with linear regressions for comparisons with this basic statistical model. Throughout Figure 4, the overall shape of many of the lowess lines suggests that linear regression often is a reasonable statistical model to use. However, of the six water quality parameters evaluated, dissolved zinc most commonly appears to have relatively little scatter around its linear regression. These simple linear regression plots suggest multiple Whipple Creek subwatershed land covers help predict dissolved zinc levels while impervious surfaces may suggest dissolved copper levels.

Significant Overall Flow Type Water Quality versus Land Cover Relationships

Table 3 summarizes formal statistical tests, using Pearson product moment correlation coefficients (r), of the strength of linear relationships (Ott, 1988, pp. 319-320) or associations between pairs of water quality (response) versus land cover (predictor) variables for overall flow types. The p-values are the likelihood for each null hypothesis of an individual correlation equaling zero versus the two-tailed alternative hypothesis of a correlation not equaling zero (MiniTab Release 14 Statistical Software Help). The r^2 values give the proportion of the total variability (Ott, 1988, p. 320) in the y-values (individual water quality parameter) that can be accounted for by the independent variable (individual land cover type).

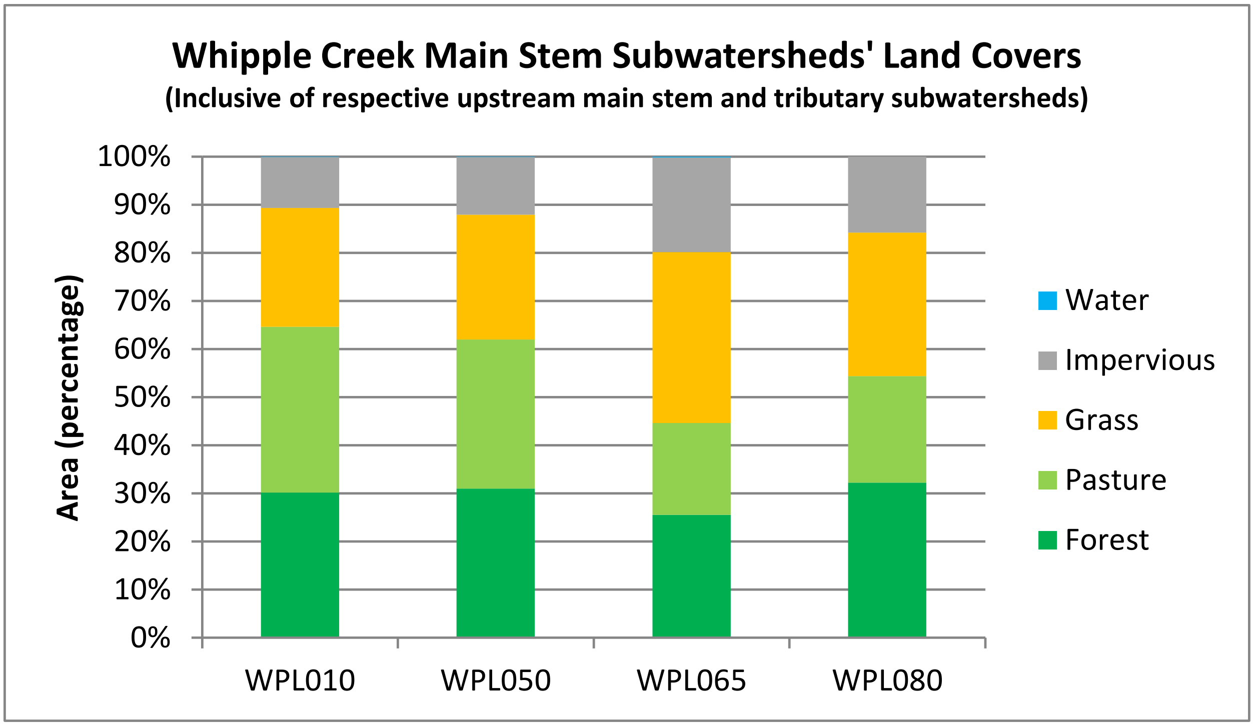


Figure 2 Whipple Creek main stem subwatersheds upstream land cover percentages

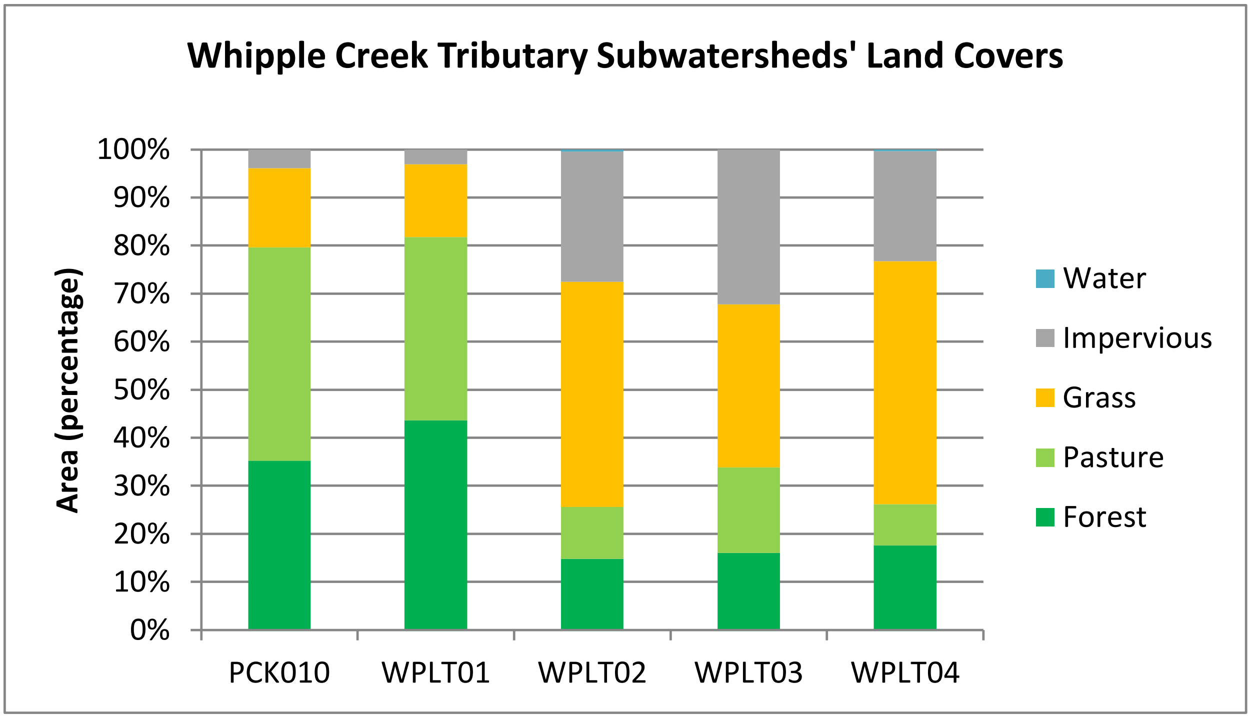


Figure 3 Whipple Creek tributary subwatersheds upstream land cover percentages

Significant linear relationships are high-lighted by two hues of green borders around their respective scatterplots in Figure 4 and two shades of grey cells in Table 3.

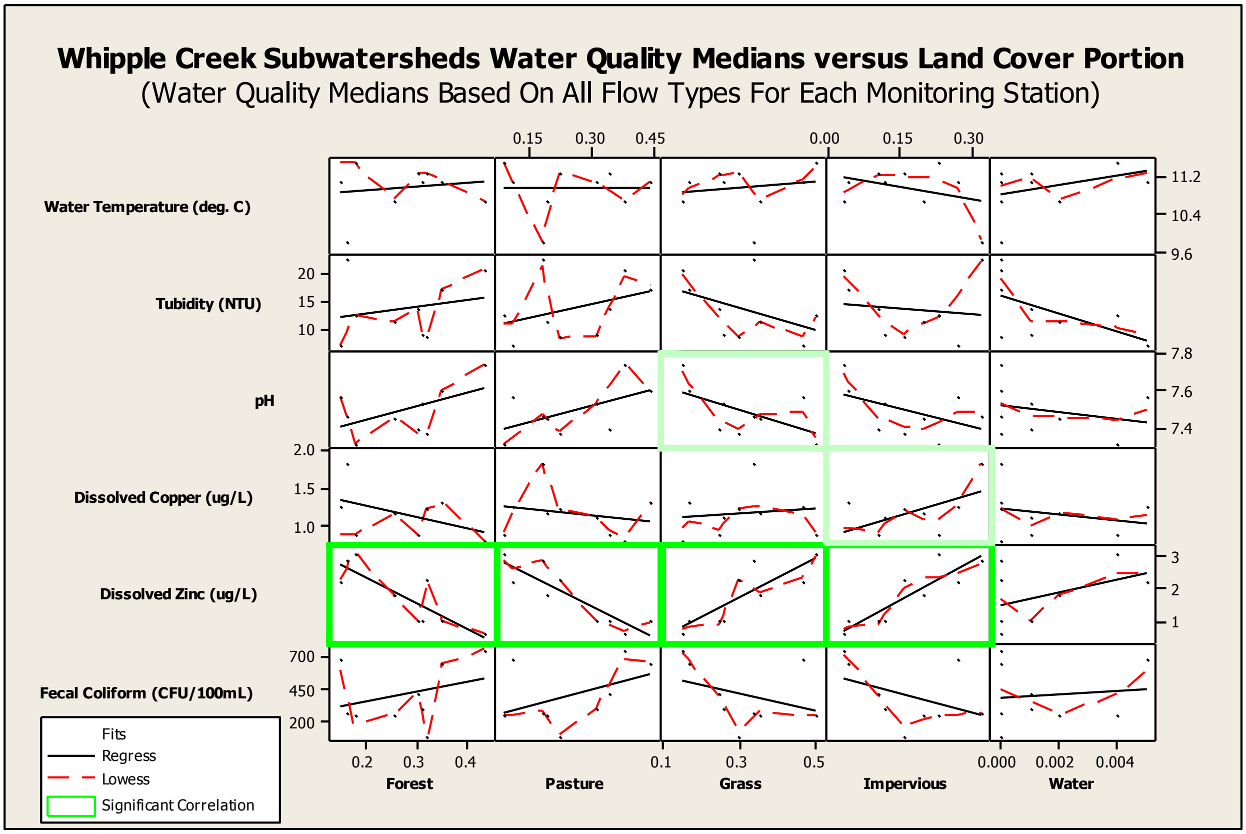


Figure 4 Scatterplot matrix of Whipple Creek subwatersheds' water quality medians versus portion of general land covers fit with linear regression and lowess smoother lines (borders depict significance at 0.05 – bright green and ~ 0.10 - light green)

Table 3 Correlation coefficient matrix for individual Whipple Creek subwatersheds' overall flow type water quality medians versus portion of general land covers relationships

Water Quality Parameter*	Forest			Pasture			Grass			Impervious			Water		
	r	p-value	r^2	r	p-value	r^2	r	p-value	r^2	r	p-value	r^2	r	p-value	r^2
Temperature	0.167	0.667	0.03	0.028	0.943	0.00	0.142	0.716	0.02	-0.376	0.319	0.14	0.377	0.317	0.14
Turbidity	0.228	0.555	0.05	0.383	0.309	0.15	-0.454	0.220	0.21	-0.135	0.729	0.02	-0.558	0.118	0.31
pH	0.521	0.150	0.27	0.554	0.122	0.31	-0.582	0.100	0.34	-0.478	0.193	0.23	-0.246	0.523	0.06
Dissolved Copper	-0.466	0.207	0.22	-0.204	0.599	0.04	0.106	0.786	0.01	0.576	0.105	0.33	-0.218	0.572	0.05
Dissolved Zinc	-0.828	0.006	0.69	-0.880	0.002	0.77	0.832	0.005	0.69	0.875	0.002	0.77	0.440	0.236	0.19
Fecal Coliform	0.303	0.428	0.09	0.434	0.243	0.19	-0.348	0.358	0.12	-0.409	0.274	0.17	0.099	0.800	0.01

* Shaded cells have correlations (r) that are not equal to zero at attained significance levels (p-values) less than this study's acceptable significance levels (α) of 0.05 (high - dark blue) or approximately 0.10 (moderate - light blue).

At a significance level (α) of 0.05 (highly significant), only overall flow's dissolved zinc medians had any significant linear relationships with or were found to be linearly dependent on (Helsel and Hirsch, 1993, p. 219) any of the land covers (bright green bordered scatterplots in Figure 4 and dark grey shaded p-value cells in Table 3). In fact, dissolved zinc's linear regressions on four of the five land cover types were significant at this level. Water was the only land cover type found to be not significantly associated with dissolved zinc. Water as a land cover is not of practical significance for further subwatershed analyses given its relatively very small total surface area of 7 acres, which represents about 1/1000 of the total Whipple Creek watershed area. The analyses show dissolved zinc has indirect significant relationships (negative r's in Table 3 and scatterplot slopes in Figure 4) with the more open space land cover categories of forest and pasture versus direct relationships (positive r and scatterplot slope) with the more development linked categories of grass and impervious surfaces.

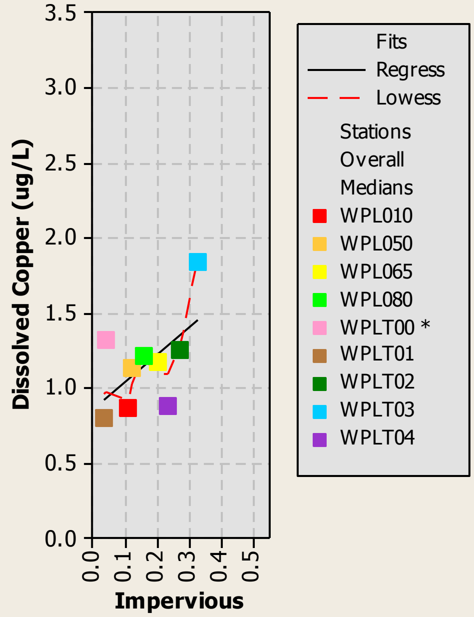
Taking the square of the coefficient of linear correlation (r^2) gives the percent of variance in the response variable that is helped explained by the predictor variable (Helsel and Hirsch, 2000, p. 231). The r^2 for the significant overall flow's dissolved zinc linear relationships, indicates that between 69 and 77 percent of the variance of dissolved zinc medians is explained by the individual effect of four of the five land covers (Table 3). In addition, dissolved copper medians had somewhat of a significant (p-value of 0.105) direct linear relationship with impervious land cover that explained 33 percent of the variation in the median values for this metal. Median pH values also had a moderately significant (p-value of 0.10) indirect linear relationship with grass land cover that explained 34 percent of pH variation. While pH's relationship is statistically significant, most of its values across all monitoring stations fell in an acceptable relatively narrow range (mostly 6.5 to 8.0) as far as possible impacts. Therefore, pH is not discussed further.

Using subwatershed symbols, Figure 5 and Figure 6 depict significant relationships between overall flow's dissolved metal medians versus land cover based on data from all flow types (their overall flow regression equations are in the appendix). In most of the remaining figures, subwatershed symbol colors match those used in the map of Figure 1. The identical vertical and horizontal scales of the individual land cover panels in Figure 6 facilitate comparisons of its fitted regression and lowess lines' slopes and directions. Figure 5 shows dissolved copper's single significant land cover relationship with impervious land cover. Compared to dissolved zinc, dissolved copper medians are lower and its linear relationship's slope appears much smaller suggesting its slower rate of increase with greater amounts of impervious surfaces.

The patterns depicted in Figure 6 reflect the similar and complimentary impacts on dissolved zinc levels from open space versus development related land covers. The direction and slopes of the regression lines are very similar for each of the pairs of open space (forest and pasture) versus development (grass and impervious) relationships. These two groups' regressions also tend to be mirror images of each other. The comparable nature of and apparent parallel regression slopes for each of the open space versus development dominated land cover regressions suggests possible intercorrelations within these pairs of independent land cover variables. This implies that using either regression from each pair may suffice for predicting dissolved zinc. However, multiple regression statistical analysis would be required to evaluate potential intercorrelations of each additional independent variable and their contribution to the prediction of the response variable (Kleinbaum et al. 1988, pp. 106 and 124) of water quality. This level of analysis is beyond the scope of this basic screening study especially given that each linear relationship is based on just nine water quality / land cover pairs of variable values.

Dissolved Copper Medians versus Impervious Land Cover Portion of Whipple Creek Subwatersheds
(Medians based on sample results from all flow types)

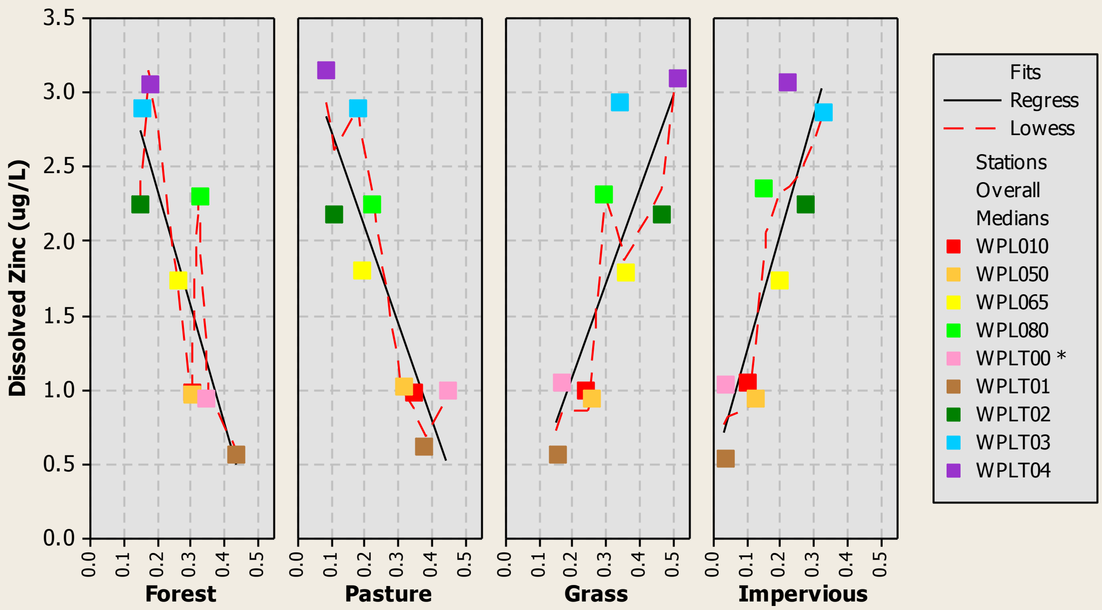
Of the five land covers analyzed, dissolved copper was found to be significantly related only with impervious land cover.



* WPLT00 designation only for the purpose of displaying subwatersheds in relative order in legend, subwatershed acutually is PCK010.

Figure 5 Scatterplot of dissolved copper median concentrations versus impervious surface land cover within subwatersheds

Dissolved Zinc Medians versus Land Cover Portion of Whipple Creek Subwatersheds
(Medians based on sample results from all flow types)



* WPLT00 designation only for the purpose of displaying subwatersheds in relative order in legend, subwatershed actually is PCK010.

Figure 6 Scatterplot panels of dissolved zinc median concentrations versus general land cover within subwatersheds

Flow Type Dissolved Zinc and Dissolved Copper Distributions

Since dissolved zinc's and to a lesser extent dissolved copper's significant overall flow type linear relationships may have practical watershed management implications, additional exploratory analyses focused primarily on their subwatershed flow-type descriptive statistics and their role in linear regression relationships. Boxplots in Figure 7 and Figure 8 compare these parameters' distribution and central tendencies for each of the monitored Whipple Creek subwatersheds (using color-coding to illustrate flow types for each monitoring station). Each subwatershed boxplot can depict values for its: median (darker color-filled circle), interquartile range or IQR (outer box), 95% confidence intervals around the median (inner boxes), whiskers (values falling within 1.5 times the IQR from the median), and outliers beyond the whiskers (asterisks). These flow type medians represent a more detailed look than the calculated overall medians (based on all of a subwatershed's flow type results) presented so far in the above graphs. Importantly, since all of the base and storm flow boxplots are based on approximately the same sample sizes (except a slightly smaller sample size for WPLT03 base flow, also see Table 1) equivalent weight can be given to their interpretation for flow type boxplots and regressions.

Figure 7 shows the important role storm flow plays in dissolved zinc concentrations for more developed subwatersheds. For the more developed subwatersheds, dissolved zinc median storm flow concentrations (depicted by the blue boxplots' inner boxes illustrating 95% confidence intervals [C.I.] around their medians) are mostly significantly higher than those for their respective subwatershed's base flows (yellow boxplots' inner boxes). The most developed subwatersheds of WPLT02, WPLT03, and WPLT04 have at least 23% impervious and 34% grass land covers (also see Figure 2 and Figure 3). Additionally, WPLT02 and WPLT04 tributary subwatersheds' storm flow dissolved zinc median confidence intervals are much higher than those for all the other subwatersheds' storm and base flows except for WPLT03 (possibly due to fairground's galvanized roofs). Conversely, the two furthest downstream main stem (WPL010 and WPL050) and tributary (PCK010 and WPLT01) stations' storm flow dissolved zinc medians are significantly lower (depicted by their inner blue coded boxes not overlapping with those for WPLT02 – WPLT04) and their respective percentages of grass/impervious surfaces both are relatively low (at most 12% impervious and 26% grass). The relatively inverse pattern of land cover proportions of open space land covers (forest/pasture) for these same subwatersheds reflects their remaining larger undeveloped areas. Importantly, there are no significant differences in the base flow dissolved zinc median concentrations across all of the subwatersheds (all of the inner yellow boxes appear to overlap). The overall contrast between patterns in storm and base flow dissolved zinc median concentrations strongly suggest the important role stormwater plays in dissolved zinc concentrations in the more developed subwatersheds. All of these patterns are consistent with the significant relationships found between the land covers and overall median dissolved zinc values but provide more specific information to support the hypothesis that stormwater runoff from these land covers contribute to those significant relationships.

Figure 8 shows a few different patterns for dissolved copper medians from those for dissolved zinc. Compared to base flows, higher storm flow median dissolved copper concentrations are more widespread across subwatersheds than for dissolved zinc. Dissolved copper has six while dissolved zinc has four subwatersheds with significantly higher storm flow versus base flow median concentrations. However, as shown by the boxplot median confidence intervals' pattern across subwatersheds as well as their ranges and magnitudes about their medians, dissolved zinc appears to be more sensitive than dissolved copper to development's impact on storm flow water quality. Similar to dissolved zinc, there are no significant differences in the base flow dissolved copper median concentrations across all of the subwatersheds.

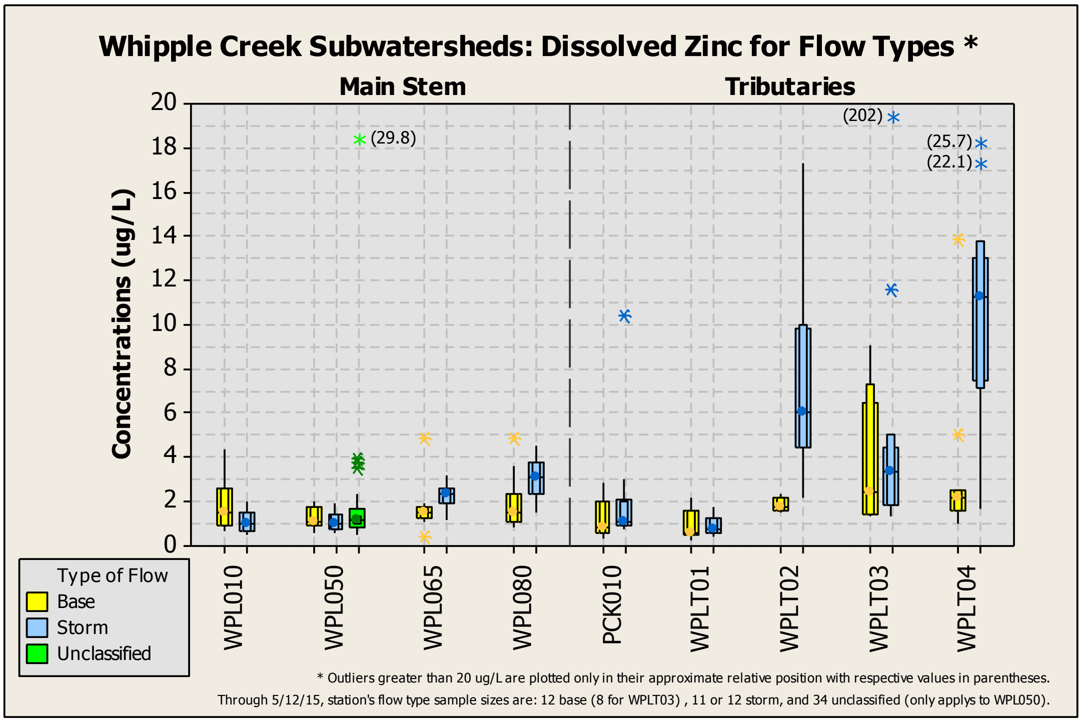


Figure 7 Boxplots of Whipple Creek subwatersheds' dissolved zinc by flow type

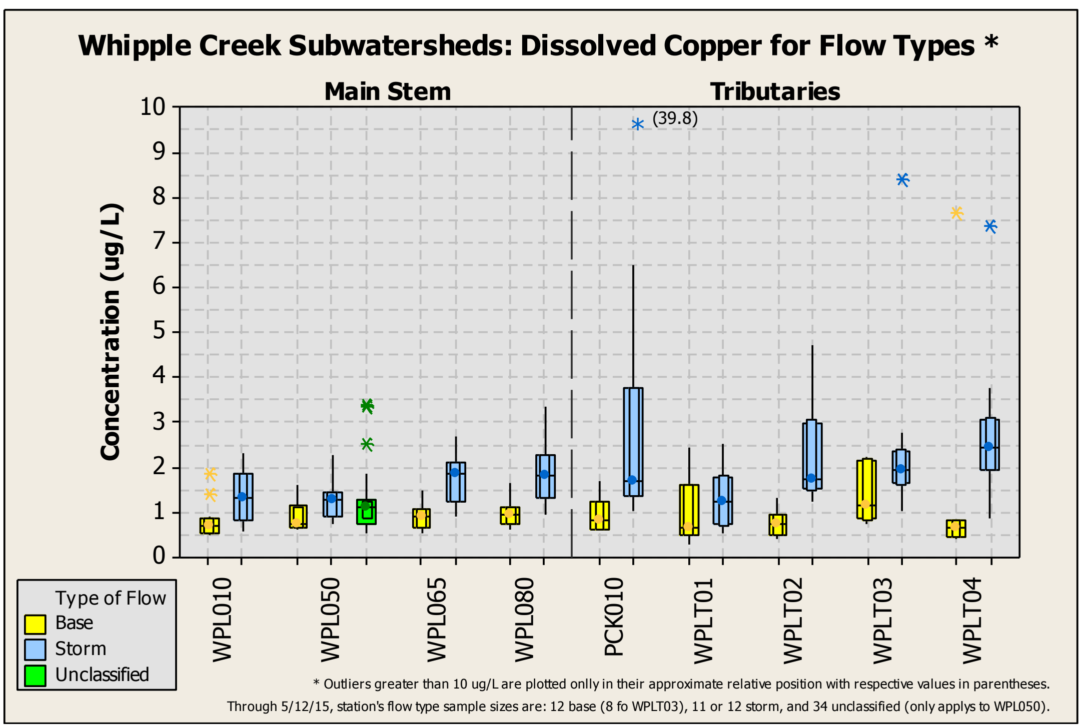


Figure 8 Boxplots of Whipple Creek subwatersheds' dissolved copper by flow type

Flow Type Dissolved Zinc and Dissolved Copper Relationships

Figure 9 through Figure 13 present more detailed analyses of the previously identified overall flow type's significant dissolved metal medians versus land cover linear relationships to help explore base and storm flow's potential impact on the relationships. These figures use the same ranges on their axes to facilitate comparisons. Within each of these figures, each monitoring station's dissolved metals medians are classified into one of the three flow types of base, storm, and overall (symbolized respectively with downward-point triangles, upward-pointing triangles, or squares). Overall is a combined data set consisting of medians calculated from base and storm flow's respective dissolved copper or zinc data values plus unclassified flows' dissolved metals values for just WPL050. The overall regressions are identical to those presented in Figure 5 and Figure 6 but are included for relative comparisons to base and storm flow regressions. In general, based on the lowess lines fitted to these flow type data sets, it appears linear regression is a reasonable model for consistent use across all variable combinations but possibly least applicable for forest and pasture storm flows.

As noted previously, most of the regressions' dissolved metal base and storm flow medians are calculated from very similar sample size data sets. The generally similar sample size exceptions are for WPL050 metals' overall medians which include a much larger sample size that is dominated by unclassified flow type values. However, most of WPL050's unclassified flow dissolved metal values are similar to their respective base and storm flow values. This similarity is shown by WPL050's unclassified data interquartile ranges and whiskers overlapping with those for its base and storm values except for 4 outliers of 34 dissolved zinc values in Figure 7 and 3 outliers of 31 dissolved copper values in Figure 8. Thus, equal weight is assumed in regressions for each base and storm flow dissolved metal median versus land cover data point and WPL050's overall regression is interpreted similarly as all others.

These flow type plots show the substantial and important role that WPLT02 and especially WPLT04 storm flow concentrations have on the slope of their dissolved metals versus land cover linear relationships. The horizontal scatterplot positons for WPLT02's and WPLT04's relatively high storm flow median dissolved zinc concentrations (up-pointing darker green and purple triangle symbols, respectively, in Figure 9 through Figure 12) are consistent with their subwatersheds' relative amounts of potentially pollutant generating land covers. Conversely, all flow types' relatively low dissolved zinc medians for the lower main stem, Packard, and WPLT010 subwatersheds tend to be clustered in the scatterplots' lower right for forest / pasture or lower left for grass / impervious surface. This is also consistent with the expected lower dissolved zinc pollutants levels across all flow types for these mostly open space dominated subwatersheds.

While the dissolved metals versus impervious land cover flow type linear regressions' slopes were not tested statistically for differences, dissolved zinc concentrations across both base and storm flow types appear to respond more than those for dissolved copper to potential impacts from development. This is depicted by the consistent appearance of steeper dissolved zinc versus impervious land cover regression slopes across flow types in Figure 12 compared to those of dissolved copper in equivalently scaled Figure 13. Even though dissolved coppers values are lower overall, this would be a valid comparison in absolute concentration terms since both graphs use the same scales on their axes. Figure 14 shows dissolved copper medians versus impervious land cover using an expanded view of axes scales to better depict differences between dissolved copper flow types across their full range of results.

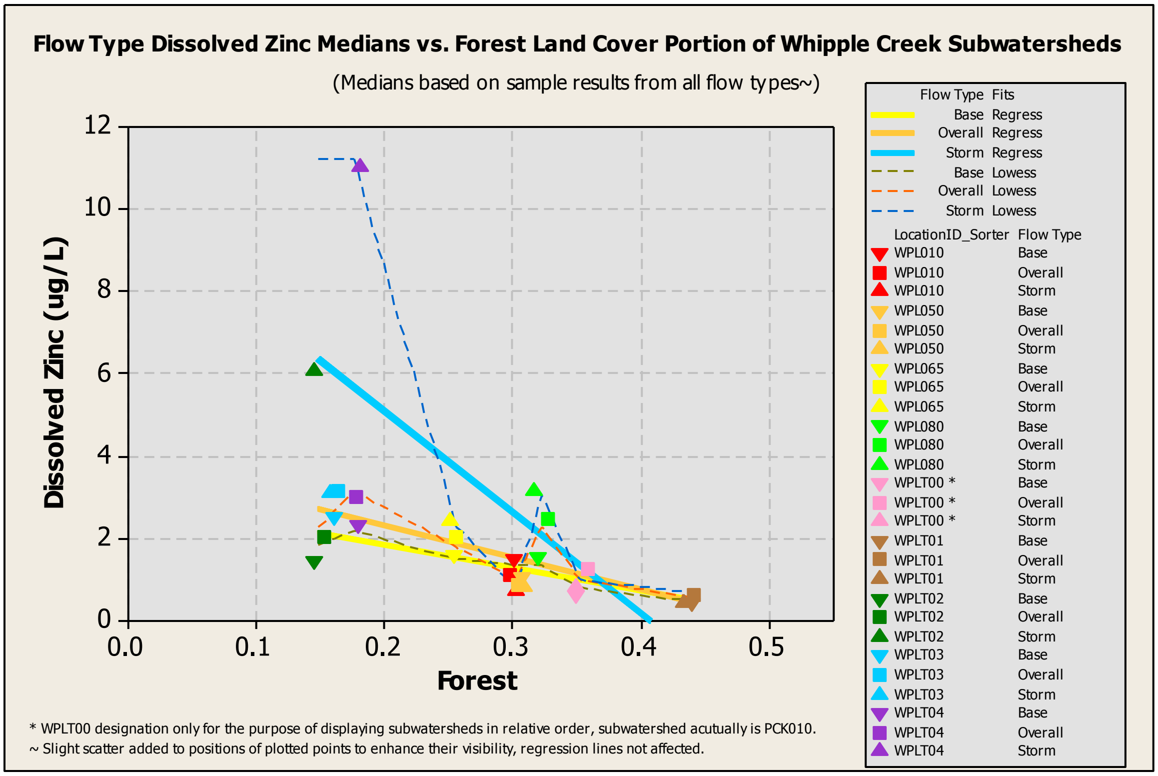


Figure 9 Flow type dissolved zinc medians versus proportion of forest land cover

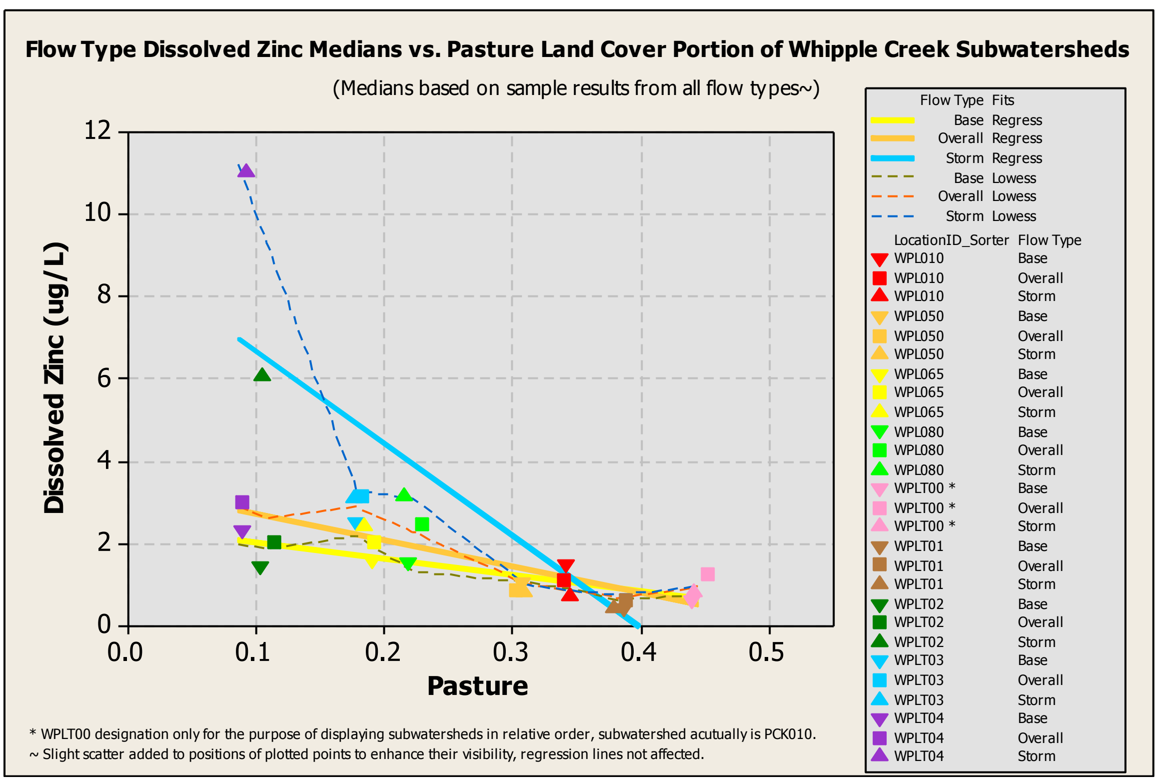


Figure 10 Flow type dissolved zinc medians versus proportion of pasture land cover

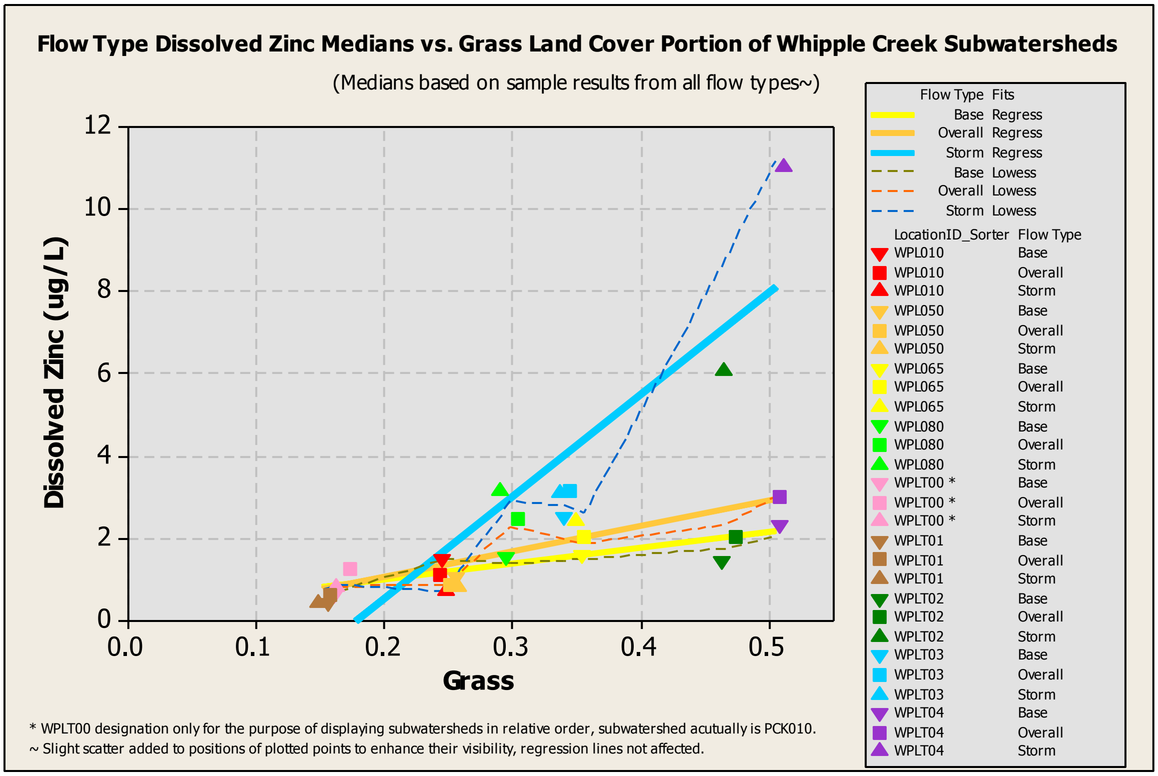


Figure 11 Flow type dissolved zinc medians versus proportion of grass land cover

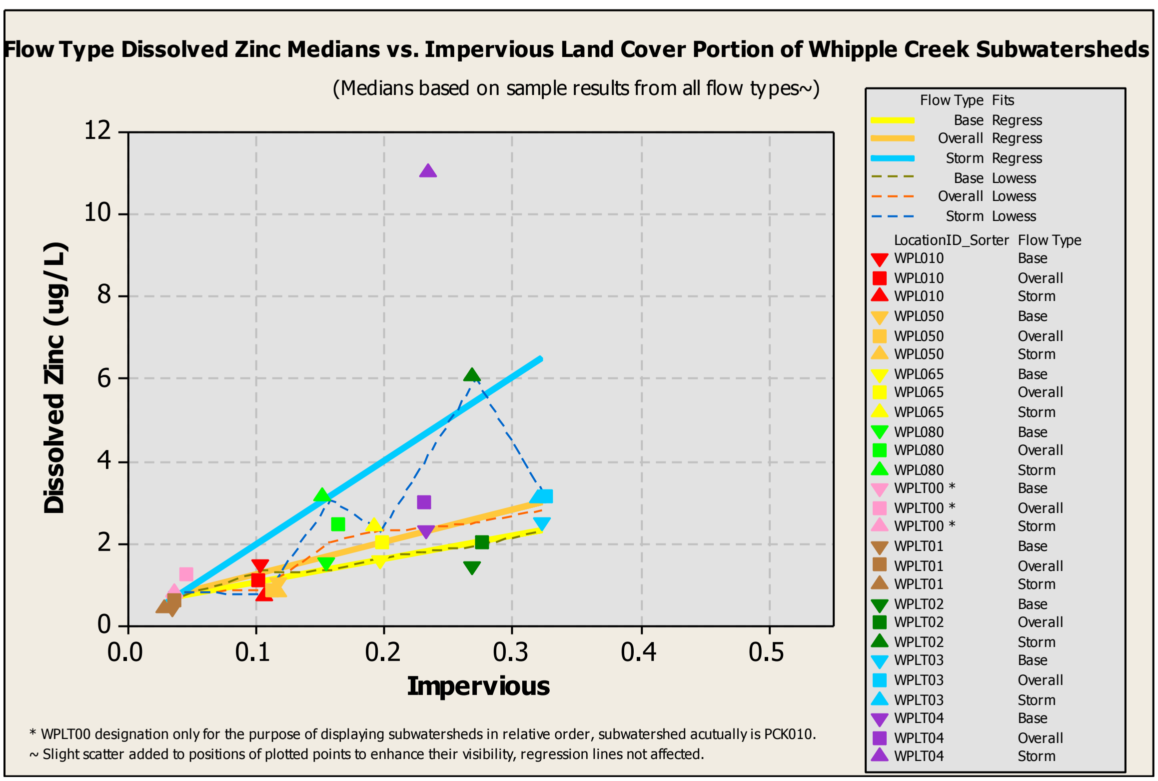


Figure 12 Flow type dissolved zinc medians versus proportion of impervious land cover

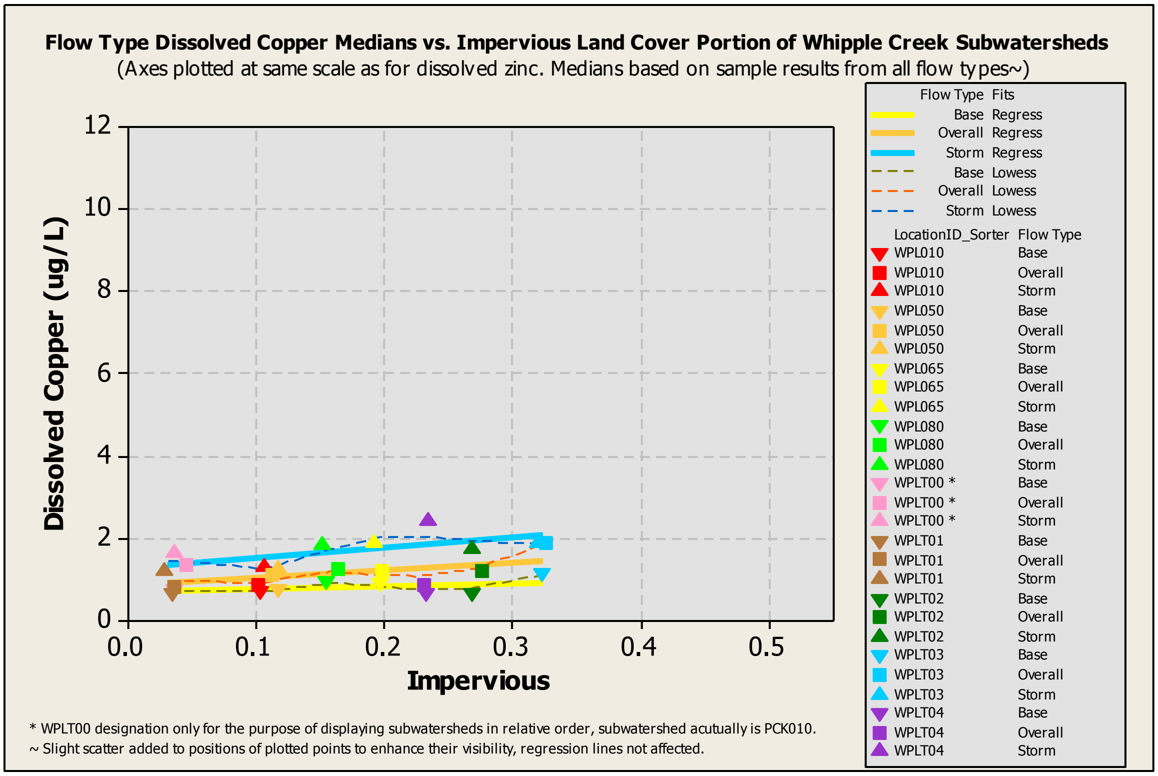


Figure 13 Flow type dissolved copper medians versus proportion of impervious land cover (same scales as dissolved zinc)

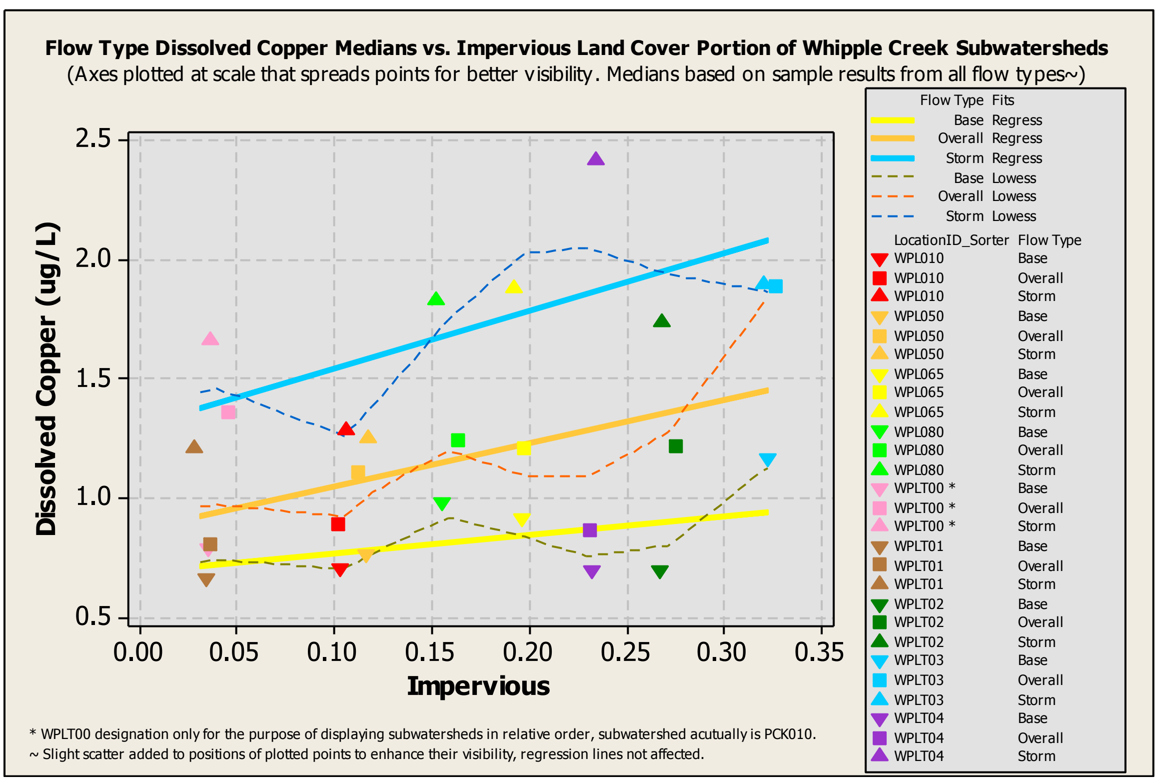


Figure 14 Flow type dissolved copper medians versus proportion of impervious land cover (scales expanded to range of data)

This study's appendix contains the calculated linear regression equations and graphs for Whipple Creek subwatersheds' dissolved zinc medians versus most land covers and dissolved copper medians versus impervious land cover depicted across all flow types. The regressions represent the modeled mean response values (MiniTab Release 14 Statistical Software Help) for a range of predictor values. The potential limited representativeness of this study's small sample size of nine subwatershed monitoring locations was somewhat offset by using water quality medians as dependent variable values for developing the regressions. Each median is based primarily on between 11 and 189 individual parameter results. Importantly, differences in dissolved metals flow type medians versus land cover regressions' slopes were not formally tested statistically given this study's limited screening purpose, the relatively small available sample sizes, and differing correlation significance levels for some base and storm flow type relationships.

Correlation values for base and storm flow dissolved copper versus impervious and dissolved zinc versus four land covers are presented in Table 4 for those relationships found to have significant overall flow type relationships. The overall flow type correlations are identical to those presented in Table 3 but are included here for relative comparisons. Only the correlation for dissolved copper medians' storm flow versus impervious land cover linear relationship was found to be even moderately significant (p-value of 0.066). In contrast, all of the correlations for dissolved zinc medians' base and storm flow types versus the four land covers' linear relationships were highly significant except for storm flow versus impervious which was moderately significant.

Table 4 Correlation coefficient matrix for individual Whipple Creek subwatersheds' with significant overall flow type water quality medians versus portion of general land covers relationships – base and storm flow type correlations

Water Quality Parameter*	Flow Type	Forest			Pasture			Grass			Impervious		
		r	p-value	r^2	r	p-value	r^2	r	p-value	r^2	r	p-value	r^2
Dissolved Copper	Base	NA	NA	NA	NA	NA	NA	NA	NA	NA	.50	0.172	.25
	Storm	NA	NA	NA	NA	NA	NA	NA	NA	NA	0.636	0.066	.40
	Overall	-0.466	0.207	0.22	-0.204	0.599	0.04	0.106	0.786	0.01	0.576	0.105	0.33
Dissolved Zinc	Base	0.908	0.001	0.82	0.807	0.009	0.65	0.783	0.013	0.61	0.919	0.000	0.85
	Storm	0.698	0.037	0.49	0.811	0.008	0.66	0.881	0.002	0.78	0.60	0.088	0.36
	Overall	-0.828	0.006	0.69	-0.880	0.002	0.77	0.832	0.005	0.69	0.875	0.002	0.77

* Shaded cells have correlations (r) that are not equal to zero at attained significance levels (p-values) less than this study's acceptable significance levels (α) of 0.05 (high - dark blue) or approximately 0.10 (moderate - light blue).

However, insights on the potential impacts of flow type on the regressions' modeled average response slope and range are possible from examining their respective confidence interval bands in the detailed regression graphs found in this study's appendix. Overall, potentially significant differences in base versus storm flow regression dissolved zinc values appear more often at the extremes of land cover percentages. This pattern is partially due to storm flow's apparent steeper slope compared to that of base flow. Storm flow's dissolved zinc values appear to become significantly larger over those of base flows when forest or pasture land cover drops below approximately 25% of the subwatershed area (no overlap between their respective storm flows' lower and base flows' upper red dashed confidence interval bands). Conversely, with increasing subwatershed portions of grass land cover over approximately 30%, storm flow dissolved zinc appears to become increasingly larger than that for base flow (increasing gap between their respective lower and upper red-dashed interval bands). Less difference between dissolved zinc's storm and base flow versus impervious land cover relationships is depicted by the slight overlap in their respective lower and upper confidence bands when impervious exceeds 20%. However, this overlap is minimal and probably impacted by dissolved zinc stormflow versus impervious land cover's moderately significant correlation. These preliminary analyses patterns suggest, at or close to the 95% confidence level, that as the portion of Whipple Creek subwatersheds' developed area exceeds 20 to 30 percent there is substantially more average dissolved zinc in storm flows compared to their respective base flows.

Additionally, the location of Clark County Fairgrounds mostly within the smallest monitored subwatershed of WPLT03 could be confounding dissolved metals relationships with land cover. This subwatershed is unique in that its only substantial impervious surface includes the large concentration of Clark County Fairground structures and their adjoining impervious surfaces in the northeast corner of the subwatershed. This group of structures likely represents the largest concentrated galvanized metal surface area (typically a large potential dissolved zinc source) within the entire Whipple Creek watershed. However, this WPLT03 subwatershed has a relatively low storm flow dissolved zinc median value compared to its linear regression model (but still within the regression's 95% confidence interval). Beneficial removal of dissolved zinc could be occurring in the several stormwater treatment facilities treating runoff from the fairgrounds. The low WPLT03 median may also be due to the infrequent seasonal usage of impervious surfaces for vehicle traffic compared to the more constant traffic patterns on impervious surfaces for other more developed subwatersheds. Additionally, the fairground's most intense use is during the month of August which is typically one of the driest months of the year but could conceivably have heavy rainfall events. Nevertheless, there were no such concurrent intense rain events during the annual fair during this monitoring period and any such potential outlier results would be mitigated by using water quality medians. Finally, comparing the respective storm and base flow dissolved zinc medians versus impervious land cover regression lines and their confidence bands after excluding WPLT03 in storm flow results in: increasing the stormflow regression slope by one half, increasing its r^2 to 55% (p-value of 0.035), and decreasing the threshold for significant difference between them to about 17% impervious land cover. This supports the unusual impact that this subwatershed has on the dissolved zinc and likely also the dissolved copper regressions.

Interestingly, while both dissolved copper base and storm flow medians versus impervious land cover regression slopes and values appear substantially less than those for dissolved zinc, there was no overlap in the confidence bands between dissolved copper's base and storm flow regressions. This implies that predicted storm flow dissolved copper values are significantly higher than those of base flow throughout the range of approximately 5% to 30% of impervious land cover.

Based on this limited monitoring data, these storm flow versus base flow dissolved metals concentration differences for various land covers reinforces the need to control stormwater dissolved metals sources especially in more urbanized subwatersheds. This finding has stormwater management implications for the Whipple Creek Plan area.

Statistical Assumption Evaluations

Statistical assumptions were briefly evaluated for the linear regressions of subwatershed median dissolved zinc versus most land covers and dissolved copper versus impervious land cover relationships (primarily by examination of diagnostic plots). The review of linear regression assumptions was limited to just these base, storm, and overall storm flow relationships because they appeared to have the best linear fit of all the parameters monitored (Figure 4). Additionally, the narrow screening purposes of this study and the relatively small subwatershed sample sizes of water quality medians, respectively, reduced the need for and ability to evaluate assumptions.

The five assumptions associated with linear regression (Helsel and Hirsch, 2000, pp. 224 – 225 and 231-238) and their interpretation for this study's limited statistical analyses are summarized below. First, as noted above and depicted by the lowess fitted lines in Figure 4 the linear model appears reasonable for all the significant dissolved metal relationships. Second, the data used to fit the regression model are generally representative of both monitored Whipple Creek subwatershed water quality and land cover. Third, as suggested by the lack of extreme changes in dissolved zinc over time (Figure 15) and displayed more clearly in this study's appendix "Residual Versus the Fitted Values" plots, the variance of the relationships' residuals appears fairly constant (homoscedastic). For each of the land covers evaluated, there appears to be one or two residuals that are slightly larger (usually for the difference between each fitted line and the median of WPLT04 storm flow and less often for WPLT03 base flow) than the remaining others. Fourth, as depicted in the appendix's "Residuals Versus the Order of the Data" plots there may be some correlation between residuals over space (residual are not totally independent) as suggested by consecutive positive or negative residuals clumping together. Given the order of subwatersheds plotted, the net potential effect of this assumption violation suggests that the regression lines somewhat under-predict storm flow dissolved zinc and copper values more often especially for the more developed WPLT04 subwatershed. Alternatively, the linear regression assumption that y-values are statistically independent of one another ((Kleinbaum et al., 1988, p. 45) is supported by the use of median water quality values. Fifth, the appendix's "Normal Probability Plots" and "Histograms of the Residuals" plots and their Anderson-Darling statistics (p-values less than significance level suggest non-normality, MiniTab Release 14 Statistical Software Help) suggest almost all of the residuals are normally distributed at a 0.05 significance level except for dissolved zinc's storm flow versus impervious land cover regression (p-value of 0.02). A lack of normality could slightly reduce the power (Helsel and Hirsch, 2000, p. 236) of this study's storm flow dissolved zinc median versus impervious land cover statistical tests of correlation, thus increasing the chances of falsely declaring the correlations were significant.

However, it is important to not read too much into plots, especially from a couple of odd points or residual variances that seem to both grow and shrink over the range of predicted values (Helsel and Hirsch, 2000, p. 232). For example in small sample sizes (n<50), the normal probability plot may display curvature (that increases as sample size decreases) in the tails even if residuals are normally distributed (MiniTab Help "Residual Plot Choices", 2003). Additionally, the likely correlation between residuals over space is not surprising given the nested hierarchy of the monitored subwatersheds where several upper subwatersheds are part of downstream main stem subwatersheds. Also, potential correlations between residuals over time have been minimized by using medians of water quality values collected over time. Therefore, likely violations of some of the linear regression assumptions are deemed acceptable trade-offs given the overall study's main purpose of limited exploratory screening of potential sources or unusual patterns for stormwater pollution.

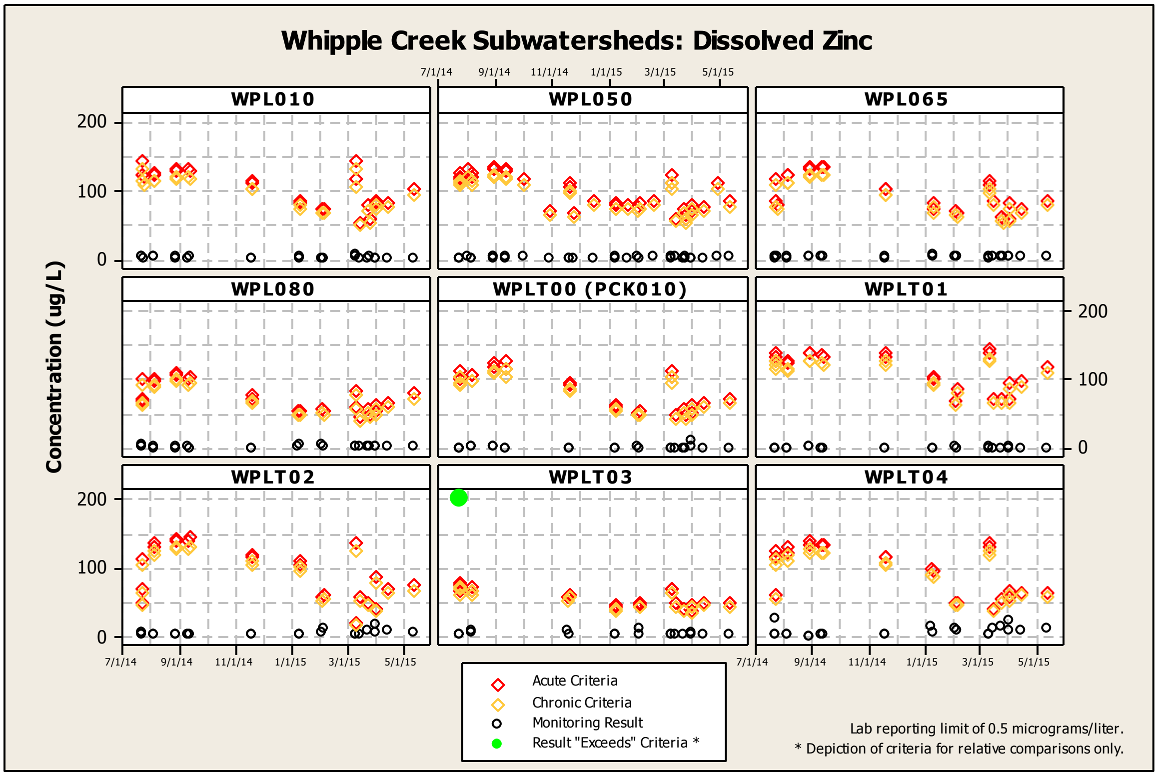


Figure 15 Plot of Whipple Creek subwatersheds' dissolved zinc values over time and applicable state criteria values

Conclusion

In support of Clark County's required stormwater planning for the Whipple Creek watershed, this report summarizes and interprets the relationships between the existing conditions of the watershed's stream water quality and general land covers. The goals of analyzing these relationships focused on screening them for practical insights and potential pollutant anomalies that could affect watershed management approaches as well as providing context for continuous water quality modeling. This report's emphasis on stream water quality versus land cover relationships precludes interpretation of state water quality standards, which is addressed in the Whipple Creek Watershed Plan's "Assessment of Existing Water Quality Conditions" section. The fundamental analyses tools in this report may serve as a template for supporting stormwater planning in other Clark County watersheds.

This Whipple Creek watershed study leveraged limited existing data to evaluate potential general sources of pollution based on broad land cover types that typically reflect relatively low to high stormwater pollutant risk. As watersheds become developed, their proportions of forest and pasture decline while impervious surfaces and residential grass areas increase. This study compared water quality median values from monitoring stations with their upstream relative portions of these general land cover types. An underlying assumption is that subwatershed streams' water quality reflects varying degrees of stormwater impacts typical of broad land cover types. Under this assumption, basic statistical relationships were developed and evaluated based on changes in water quality associated with the proportion of general land covers across nine Whipple Creek subwatersheds. Regression statistical analysis was used to screen the broad land cover types and their impacts as potential stormwater pollutant sources within the Whipple Creek watershed planning area. Specifically, using simple linear regression, the variation in six water quality parameters' medians (response variable) were related to the proportion of each subwatershed in five general land cover types (predictor variable) on a pair-wise basis sequentially for overall, base and storm flow monitored conditions.

This study's important practical findings include:

- No substantial anomalies from what would be typically expected were found in the type and direction of the monitored water quality versus land cover relationships that would otherwise suggest unusual sources of pollution.
- Most of the six monitored water quality parameters were found to be not significantly correlated with land cover under overall flow conditions. However, the uncorrelated parameters of water temperature and pH are often strongly influenced by localized site factors while turbidity and fecal coliform can be impacted by a range of land cover sources.
- Under overall flow conditions, only dissolved zinc had multiple statistically significant (at 95% significance levels) linear relationships with relative amounts of various land covers while dissolved copper had only a single less significant direct relationship with impervious land cover. Subwatershed dissolved zinc median concentrations had four significant linear relationships: inverse relationships (negative correlations) with forest and pasture as well as direct relationships (positive correlations) with impervious and grass land covers. Linear regression correlation (r^2) showed that at least 69% of the variance in dissolved zinc is explained by each of these land covers. Dissolved copper's lone significant linear relationship correlation with impervious land cover was weaker with a p-value of 0.105 and an r^2 indicating 33% of variance explained.
- The direction and slopes of the overall flow type dissolved zinc regression lines are very similar for each of the pairs of open space (forest and pasture) as well as development (grass and

impervious) relationships. The regression lines' mirror image patterns for open space versus development related land covers reflect their likely similar and complimentary impacts.

- Boxplots showed that storm flows from those subwatersheds with more development related land covers usually had significantly and substantially higher median dissolved zinc values than their respective base flows. This, in turn, impacted the slopes of their relationships' regression lines.
- Importantly, boxplots also showed there are no significant differences in the base flow dissolved zinc or dissolved copper median concentrations across all of the subwatersheds.
- Dissolved zinc appears to be more sensitive than dissolved copper to development's impact on stream water quality. While dissolved metals versus impervious land cover regressions' slopes were not tested statistically for differences, dissolved zinc's correlations with land covers were highly significant across both base and storm flows for seven of the eight relationships compared to dissolved copper storm flow versus impervious land cover's one moderate correlation.
- Overall, potentially significant differences in base versus storm flow regression modeled average dissolved metals values become clearer at thresholds of Whipple Creek subwatershed development percentages. These preliminary analyses suggest at or close to the 95% confidence level, when the portion of the subwatersheds' forest or pasture drops below 25 percent or as developed area exceeds 20 to 30 percent there is substantially more and increasing average dissolved zinc in storm flows compared to their respective base flows. Similarly, dissolved copper's threshold appears closer to only 5 percent of a subwatershed classified as the impervious land cover type but its smaller slope indicates that it increases at a slower rate.
- Given the predominant and consistent patterns found across all base, storm, and overall flow conditions between the response variable dissolved zinc and predictor variables of portions of general land cover types, any of the significantly related land covers by themselves could serve as a screening surrogate measure of likely dissolved zinc stormwater impacts on stream water quality. However, known mechanisms and pathways for transport of dissolved zinc from impervious surfaces would make this land cover a logical choice for predictions. Similarly, impervious land cover could serve as a surrogate for dissolved copper's likely impact under both storm and overall flow conditions.

Dissolved zinc and copper have a range of possible sources associated with development's impervious surfaces with many related to vehicle transportation. Among other possible sources, they include: galvanized metal products, building exteriors, public infrastructure and especially vehicle tires, brakes, and bodies (Minton, 2002, pp. 14 - 18). The significant dissolved zinc versus multiple land covers and dissolved copper versus impervious land cover relationships found in this study's analysis of the Whipple Creek watershed are consistent with the amount of development and its typical potential sources of pollution.

Based on this study's limited monitoring data, the potential implications of the overall and especially the apparent storm flow versus base flow dissolved metals relationship differences as subwatersheds become more developed reinforces the need to control stormwater dissolved metals sources. The consistent and substantial contrast between patterns in storm and base flow dissolved zinc median concentrations strongly suggest the important role stormwater plays in the more developed subwatersheds. These results are consistent with the idea that common development land covers such as impervious surfaces and development's typical associated human activities can be significant sources of some stormwater pollutants. As part of the Whipple Creek watershed planning project's existing conditions assessment, this initial and basic statistical analysis of local data is intended to provide context for and compliment more in-depth, sophisticated mechanistic water quality modelling using the continuous HSPF model. This study met its exploratory analyses goals for gaining insights on potential general pollution sources and checking for anomalies in Whipple Creek watershed pollutant versus land cover relationships.

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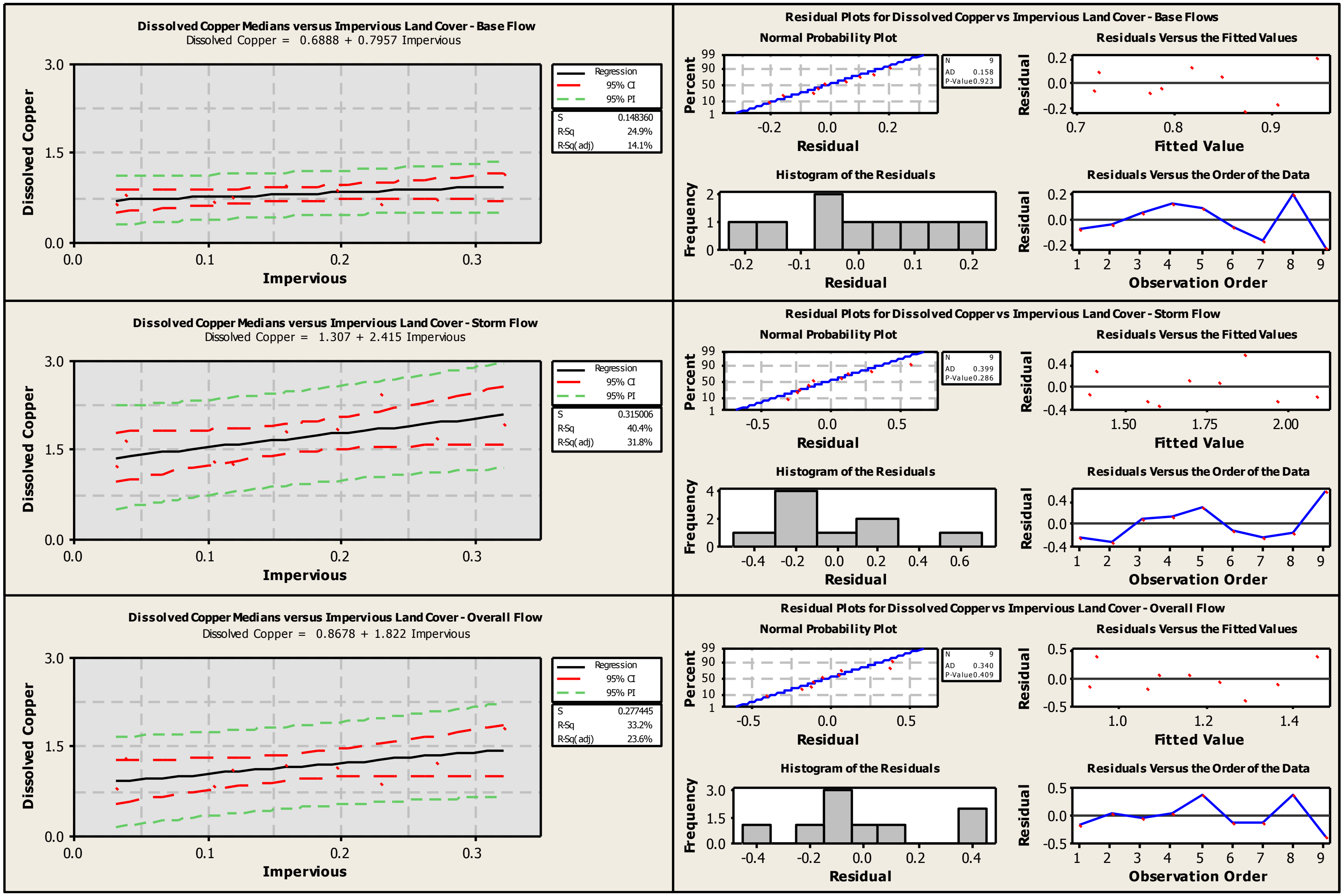
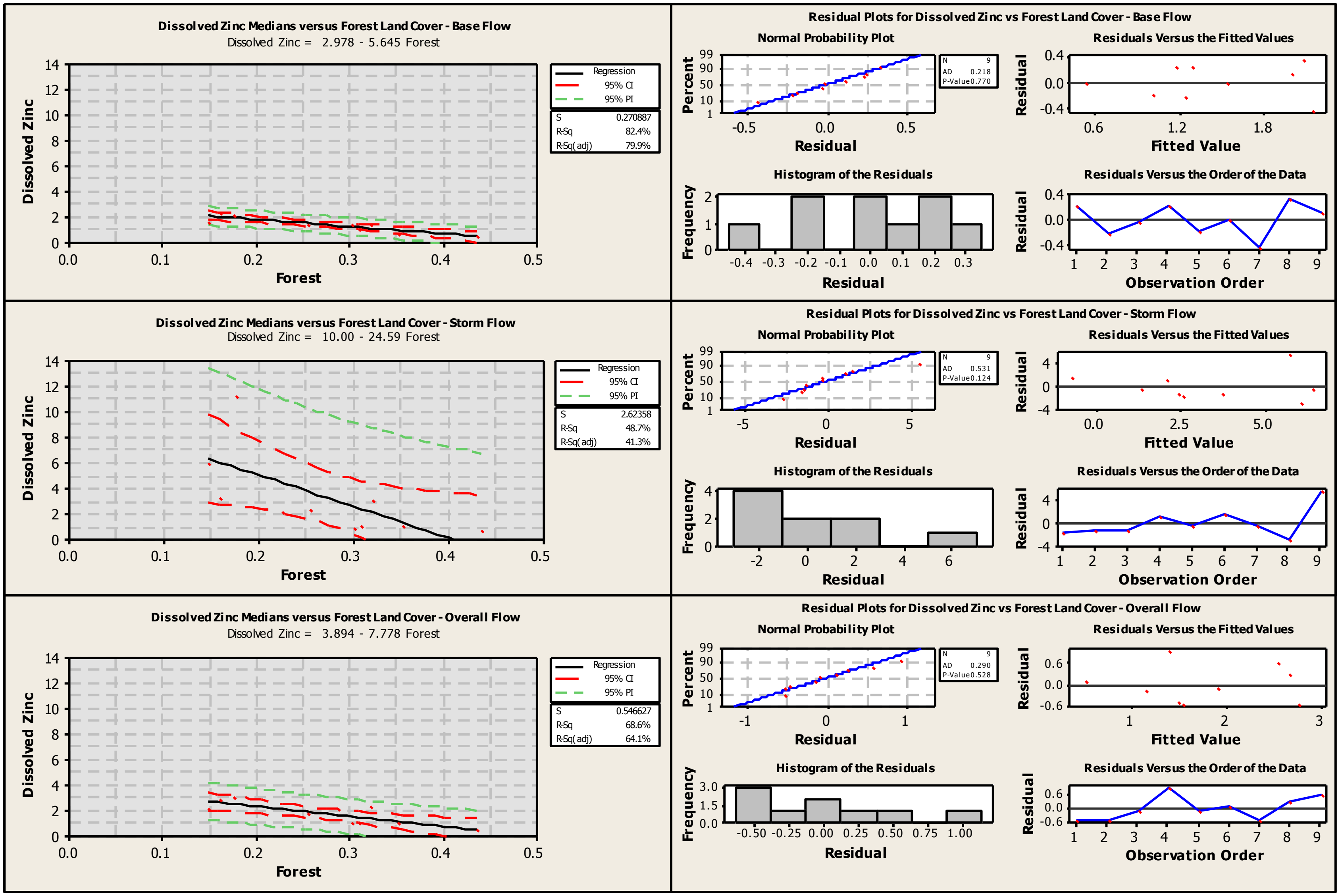
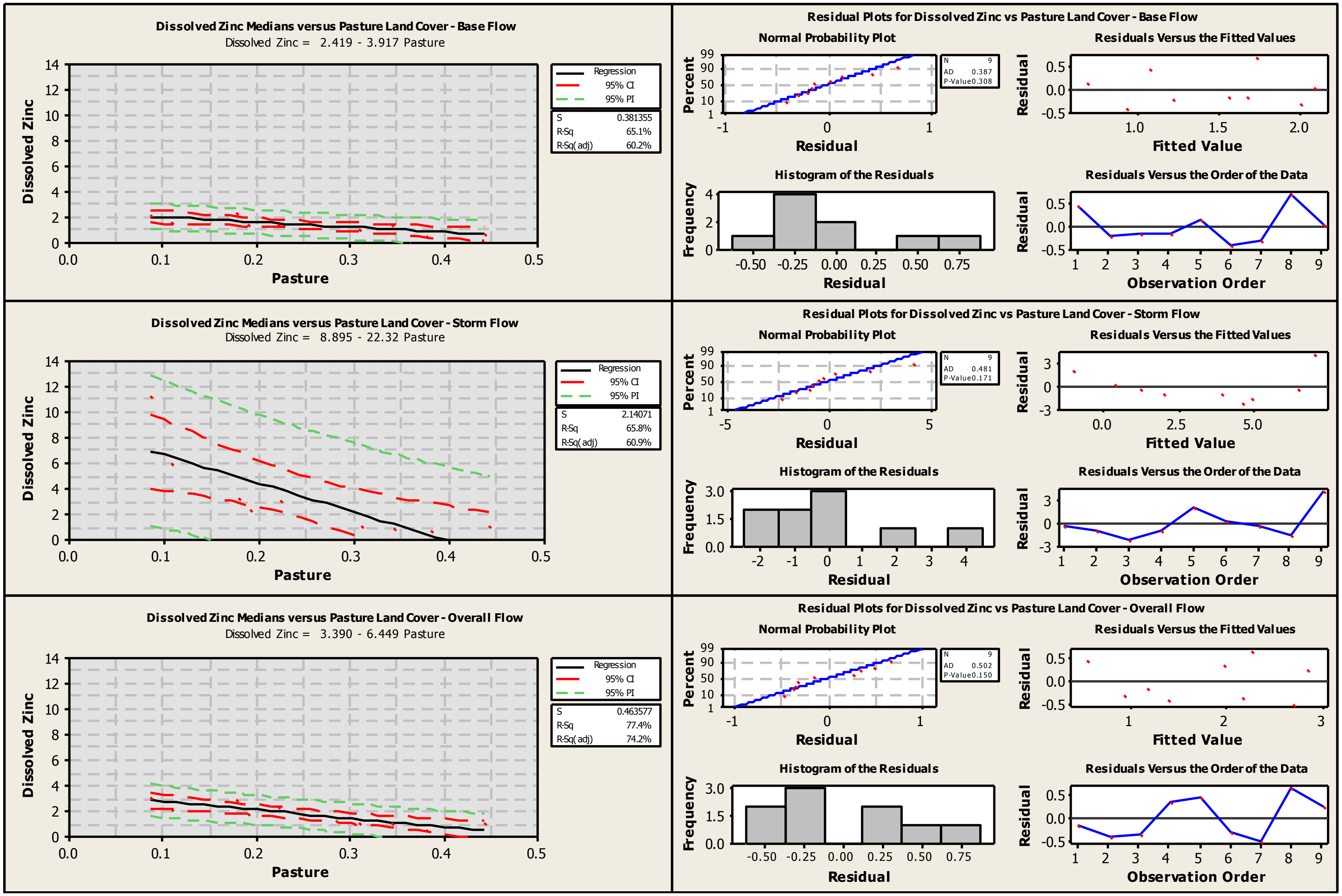
Appendix 1 Detailed Graphs Summarizing Flow Type Dissolved Metals versus Land Cover Regressions’ Confidence / Prediction Intervals and Assumption Evaluations



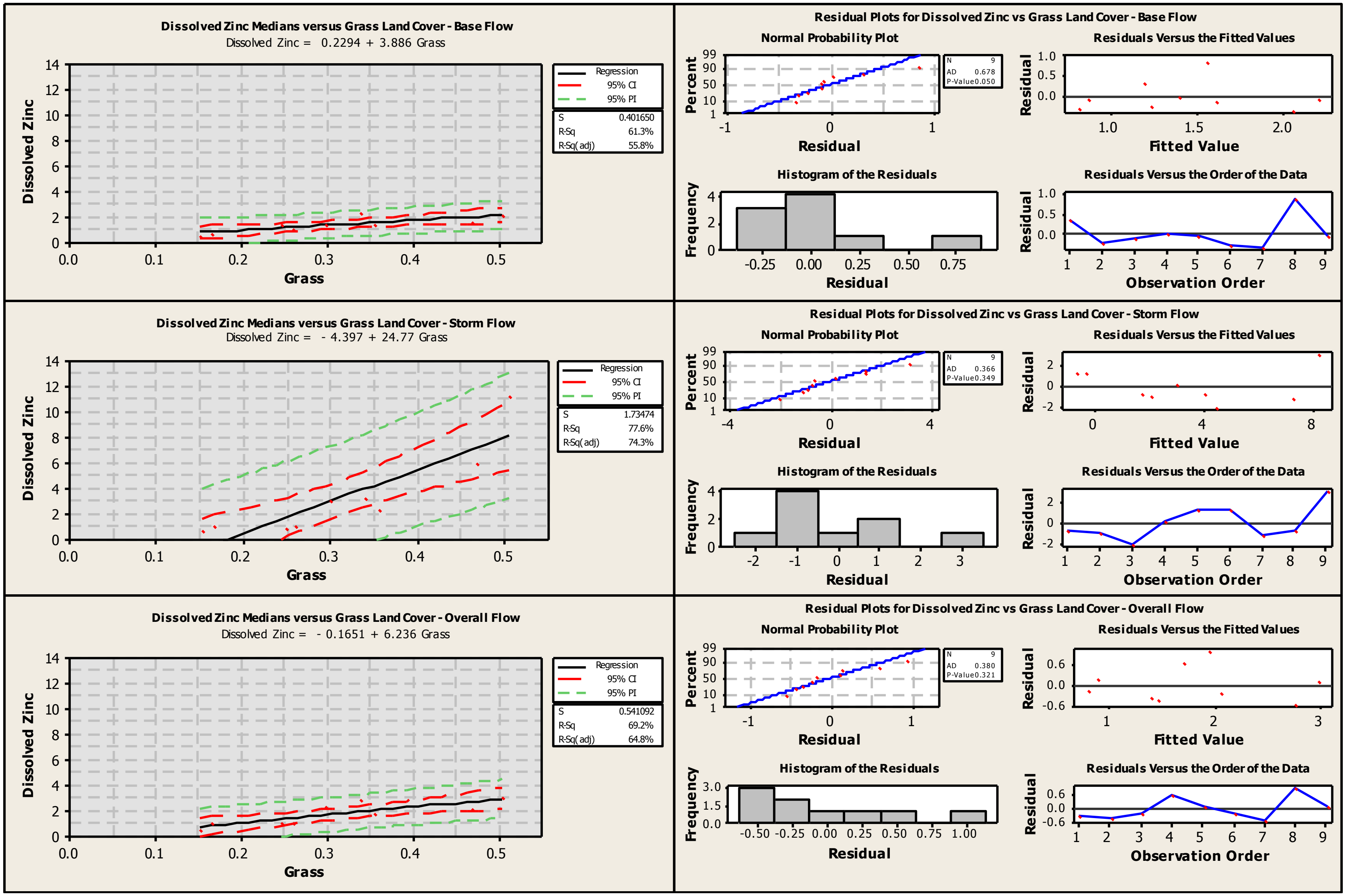
Flow Type Dissolved Copper versus Impervious Land Cover Regression Confidence / Prediction Intervals and Assumption Evaluations



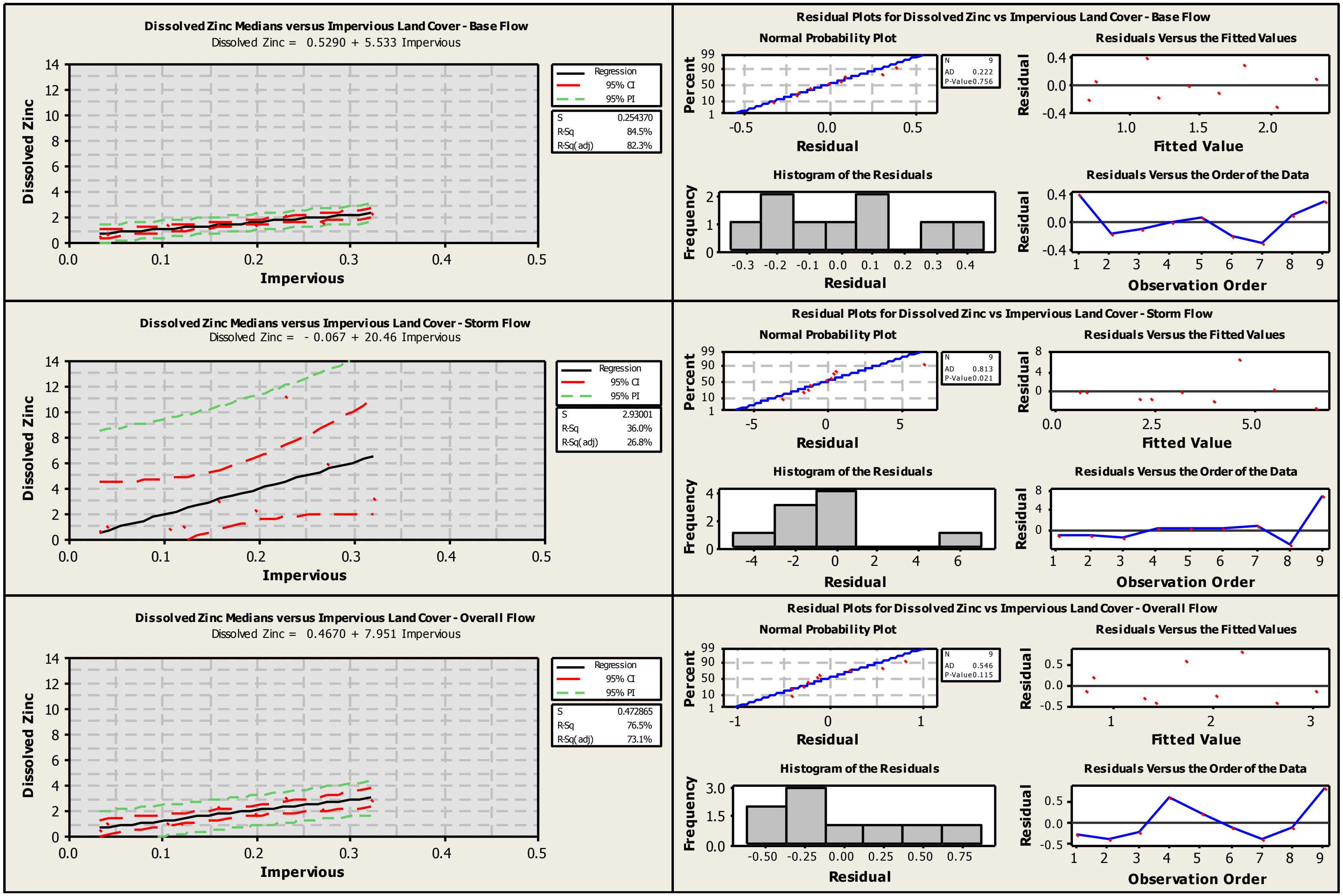
Flow Type Dissolved Zinc versus Forest Land Cover Regression Confidence / Prediction Intervals and Assumption Evaluations



Flow Type Dissolved Zinc versus Pasture Land Cover Regression Confidence / Prediction Intervals and Assumption Evaluations



Flow Type Dissolved Zinc versus Grass Land Cover Regression Confidence / Prediction Intervals and Assumption Evaluations



Flow Type Dissolved Zinc versus Impervious Land Cover Regression Confidence / Prediction Intervals and Assumption Evaluations