Appendix B

Whipple Creek Watershed-Scale Stormwater Plan Report

Assessment of Existing Water Quality Conditions

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Contents

Figures

Tables

Appendices

Summary

This addresses Clark County's 2013-2018 NPDES Phase I Municipal Stormwater Permit (hereafter referred to as "Permit" but specifically Permit Section S5.C.5.c.ii.1.a) watershed-scale stormwater planning requirement to assess existing water quality conditions as applied to the Whipple Creek watershed. Under Washington's latest state-wide water quality assessment from 2014, 1.4 miles of Whipple Creek's lower main stem have been identified in the state's 303(d) list or category 5 as polluted waters with impaired beneficial uses due to water temperatures, bacteria, and bioassessment results. This report and its appendices summarize Whipple Creek watershed water quality conditions and likely general pollutant sources based on county water quality monitoring from August 2001 through October 2015 and recent land cover mapping. Exploratory data analysis was systematically applied to enhance perspectives and gain insights on potential stormwater impacts to inform watershed planning.

This watershed planning report's assessment of existing water quality conditions is based on three Clark County sources of monitoring results that used subsets of the same nine monitoring locations (Figure 1). The first is a relatively long-term (starting as early as August 2001 and running through June 2014) monthly data set from a central Whipple Creek watershed main stem monitoring station. The second source utilized spans one year of monthly data (October 2011-September 2012) from one tributary and two main stem sites. The third set includes up to sixteen months (July 2014-Oct 2015) of watershed-wide base and storm flow stream monitoring results from all nine monitoring locations. All water quality monitoring was performed by trained county staff following standard operating procedures and project quality assurance project plans (QAPPs). The assessment relies on data derived from field trip meter readings, water quality samples' laboratory analyses (except continuous water temperature data from summertime deployed sensors / loggers for this important and uniquely monitored parameter that is addressed in detail in this report's appendices), and geographic information system (GIS) analyses.

The overall approach used for this Whipple Creek watershed planning water quality assessment starts with comparing monitoring results to state water quality standards, followed by equally important exploratory data analyses of the full range of water quality results and land cover relationships for subtle water quality patterns or anomalies suggestive of pollutant sources. For streams, such as those in the Whipple Creek watershed, not specifically listed in Washington's revised 2012 surface water quality standards (Washington Department of Ecology, 2012) the highest and most relevant state designated beneficial uses to be protected are: 1) aquatic life use of salmonid spawning, rearing, and migration and 2) human use of primary contact recreation such as swimming. While this assessment's dissolved metals data may not meet the standard's monitoring frequencies typically intended for industrial outfalls, the state standard's criteria are conservatively applied in an effort to leverage limited data to assess if metals pollution even appears as a possible stormwater issue in the Whipple Creek watershed.

This assessment concludes that the Whipple Creek watershed's existing water quality is substantially degraded. Existing water quality conditions for the Whipple Creek watershed are summarized in Table 1 based on applicable state water quality standards. The latest watershed-wide data indicate four of the seven evaluated standards' parameters were often exceeded throughout much of the watershed; including water temperature, fecal coliform, turbidity, and dissolved oxygen. Only the state standards' criteria for dissolved copper, dissolved zinc, and pH were mostly met throughout much of the monitored watershed.

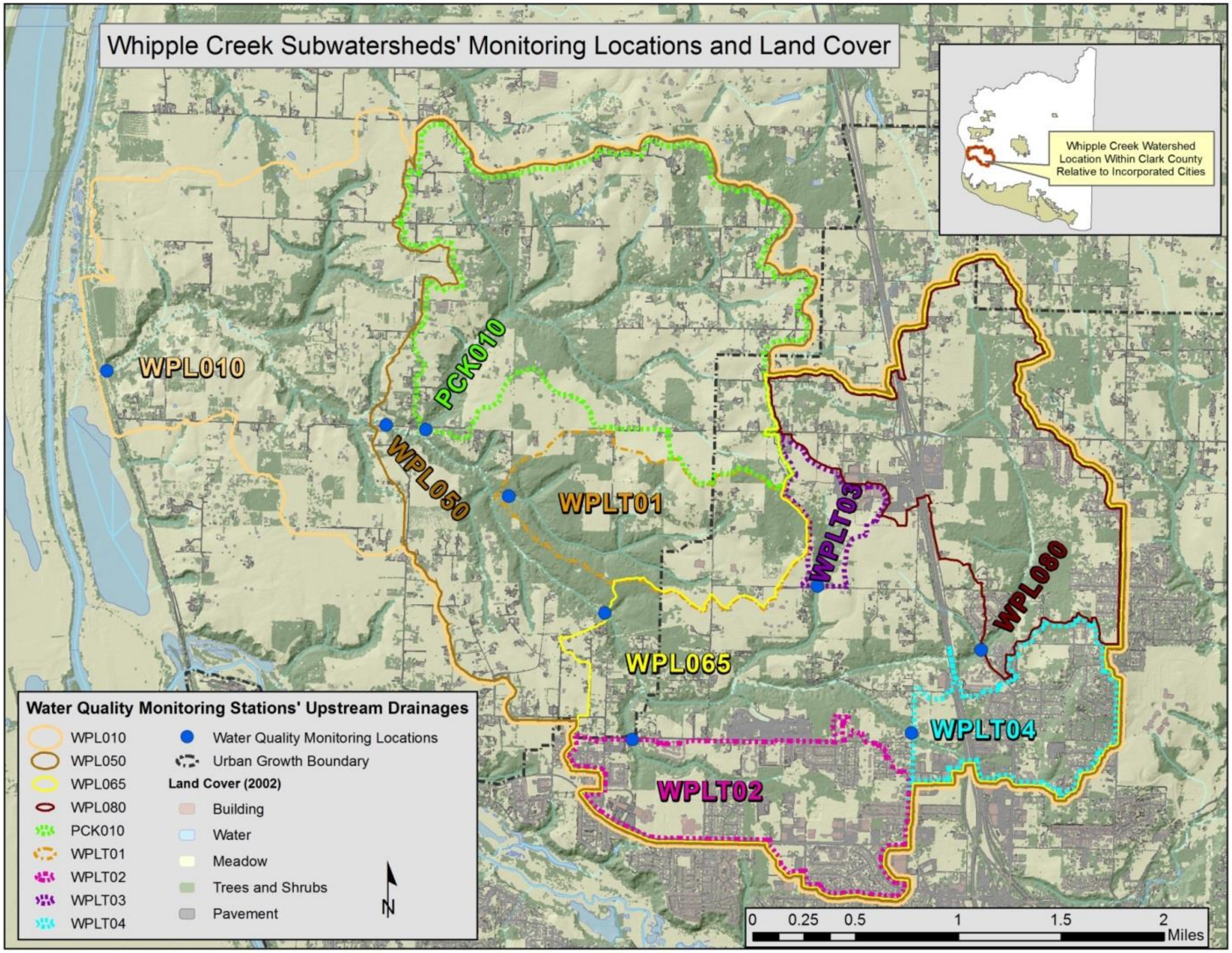

Figure 1 Whipple Creek watershed water quality monitoring locations and general land cover

Table 1 Summary of Whipple Creek watershed water quality per state water quality standards

Water Quality Parameter	State Designated Use Protection: Water Quality Standard Criteria & As Applicable Exceedance Frequency Limit	Met Water Quality Standard	Comments on 2014-2015 Watershed-wide Monitoring Results Exceedance of State Water Quality Standards Criteria
Temperature	Aquatic Life Use: 7-Day Average Daily Maximum (7-DADMax) of 17.5°C once every 10 years on average	No	Most lower main stem and some tributary subwatersheds commonly exceeded criteria especially during July & August, up to 87 and 77 times / year, respectively
Fecal Coliform	Primary Contact Recreation Use: < geom. mean of 100 cols./100 mL & < 10% of samples: 200 cols./100 mL Preferable to average by season of < 12 months	No	Except for WPL065 and WPL080 wet season, all of the other subwatersheds exceeded the state's geometric mean criterion during both seasons. All the stations also exceeded the 10% criterion during both the wet and dry seasons.
Dissolved Copper	Aquatic Life Use: Criteria formula using water hardness Acute: 1 hr. avg. < once every 3 yrs. Chronic: 4 day avg.<once every 3 yrs. Apply both acute & chronic on average over 3 years	Mostly Yes	Only WPLT03 & WPLT04 exceed chronic and acute criteria and for both stations' criteria in only 6% of their respective samples. PCK010 exceeds chronic in 11% and acute in 6% of samples
Dissolved Zinc	Aquatic Life Use: Criteria formula using water hardness Acute: 1 hr. avg. < once every 3 yrs. Chronic: 4 day avg.<once every 3 yrs. Apply both acute & chronic on average over 3 years	Mostly Yes	Only WPLT03 exceeded either criterion but did so for both in only 6% of its samples
pH	Aquatic Life Use: 6.5 – 8.5 pH units	Mostly Yes	Across all monitoring stations, only a very few were slightly below (lowest value of 5.86) lower 6.5 criteria boundary. WPL050 – 2.8%, WPL080- 4.7%, and WPLT02 3.2% of all their measured values.
Turbidity	Aquatic Life Use: 5 NTU over background or 10% increase when background is >50 NTU	No	High turbidity is a watershed-wide issue: 55-95% of main stem station values exceeded criterion, 55-98% of tributary station values exceeded criterion.
Dissolved Oxygen	Aquatic Life Use: 1-day minimum of 8.0 mg/L once every 10 years on average	No	Low dissolved oxygen values likely occur over much of the watershed based on the high frequency of mid-day measurements approaching minimum criterion.

Additionally, most parameters' discrete sample or field measurement data are assessed through statistical exploratory data analysis graphs including scatterplots of values over time and, as applicable, in boxplots and probability plots of results grouped by location, wet or dry season, and base or storm flow. The different nature of stream temperature's in situ logged data, consisting of one-hour interval large data sets, allows a more detailed assessment using different graphical tools that include bar charts, time series plots, empirical cumulative distribution function plots, and scatterplots (included in this report's appendices). Monitoring was performed at locations chosen using professional judgement to target likely representative subwatersheds at their most downstream sites and reflect results from a wide range of flows. Patterns and especially anomalies in the graphed results were evaluated in light of subwatersheds' predominant land covers to gain insights on likely pollution sources and delivery mechanisms.

From a watershed planning perspective, the following are the most important exploratory analyses observations:

Water Temperature

- Given consistent recent stream temperature patterns between many watershed- wide stations and the long running mid-watershed WPL050 station, frequent high summer stream temperatures have likely been an ongoing and widespread issue where riparian shading is limited. This is especially true for the exposed lower half of the main stem of Whipple Creek, on Packard Creek, and the more developed WPLT04 tributary.
- Much of the watershed's tributary and headwater (i.e. WPL080) summer flows likely comes directly from relatively cool shaded groundwater whereas lower main stem waters are heated by direct sunlight for longer periods. Benefits from cooler streams also need to consider their relative flow contributions in reducing downstream heat loading.
- Other positive feedback heating factors beyond warm air temperatures such as decreased streamflow and upstream cumulative heat loading contribute to disproportionate upswings in stream heating during the very hottest summer periods for the lower main stem, Packard Creek, and WPLT04.

Fecal Coliform

- Similar to the overall patterns seen for stream temperatures, high fecal coliform levels are likely an ongoing watershed-wide issue since most locations exceeded both of the state standard's dual fecal coliform criteria.
- Fecal coliform overall patterns in location medians showed lower calculated median fecal coliform levels for the main stem group than for the tributary groups (but most not significantly different) except for WPLT04 and a tendency for increasing medians from upstream to downstream within each of these groups.
- Among the tributaries, the highly developed WPLT04 subwatershed has the lowest calculated median and has the least variable fecal coliform values whereas the less developed Packard Creek's fecal coliform median is almost significantly higher and its fecal coliform is much more variable. These contrasting patterns suggest non-stormwater sources of fecal coliform for these subwatersheds.
- Resident beaver and less dilution likely play a role in relatively more significantly higher main stem dry season fecal coliform medians than corresponding medians for tributaries.
- The consistent pattern of higher calculated storm flow than base flow fecal coliform medians (though not often statistically significant) across all monitoring stations strongly suggests surface runoff factors play an important role in bacterial levels.
- Consistent patterns of high dry season storm flow medians versus very low wet season base flow medians are likely driven by a combination of storm runoff of accumulated nonpoint source

bacteria between dry season storms versus more dilution of constant bacteria sources such as failing septic systems during wet season base flows.
- Relatively high dry season base flow fecal coliform medians for WPLT01 and WPLT03 suggest ongoing contribution of bacteria from wildlife, livestock, or failing septic systems.
- The relative impact on fecal coliform concentrations from flow type is much greater than from season based on patterns found in nested location-season-flow type boxplots.

Dissolved Copper

- The relatively few dissolved copper state standards' criteria exceedances occurred during storm flows in just three mixed to more developed tributary subwatersheds.
- There tends to be slight increases in calculated dissolved copper medians from down to upstream within groups of main stem and tributary stations.
- Significantly higher storm flow dissolved copper medians for the most developed WPLT02 and WPLTO4 subwatershed stations supports idea of storm first flush impact from developed areas.

Dissolved Zinc

- The single WPLT03 sample that exceeded both chronic and acute criteria suggests isolated high dissolved zinc issues.
- However, the tendency of increasing calculated dissolved zinc medians from downstream to upstream and associated Water Quality and Land Cover Relationships findings of significant direct relationships between development and dissolved zinc suggest consistent widespread development related zinc pollutant impacts.
- Significantly higher storm flow dissolved zinc medians for the most developed WPLT02 & WPLTO4 subwatershed stations supports the idea of first flush impacts from developed areas.
- Relatively low storm flow dissolved zinc levels in the lower main stem suggest dilution, travel time factors, or instream pollutant reduction mechanisms taking place.

pH

- Excessively low or high pH is not a substantial issue anywhere in the Whipple Creek watershed.

Turbidity

- High turbidity is a widespread issue throughout the Whipple Creek watershed with more than three-quarters of all monitored values substantially elevated above background levels.
- Turbidity is almost always elevated with storm flows, often more than two orders greater than base flow for middle to high range values, likely due to soil erosion during surface runoff and instream channel erosion.

Dissolved Oxygen

- Low dissolved oxygen values likely occur over much of the watershed based on the high frequency of mid-day measurements approaching state standard's minimum criterion.

More detailed descriptions of patterns found in the monitored water quality parameter results and observations on likely pollutant sources from the exploratory data analyses graphs are summarized in

Table 2. This report's Appendix 1 contains the full more detailed analyses of Whipple Creek watershed stream temperatures.

Whipple Creek Watershed Water Quality and Land Cover Relationship Evaluation Conclusions

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 can be used to generally explore the extent to which water quality (dependent variable) is influenced by hydrological or land use factors (independent variables). This watershed study's basic statistical analyses (see Appendix 2) of relationships are between nine subwatershed's median water quality parameter values and their percentages of land covers with additional evaluations focused on specific flow types for relationships initially found to be significant under all flow types. The six water quality parameters evaluated included temperature, turbidity, pH, dissolved copper, dissolved zinc, and fecal coliform bacteria. The associated five land covers evaluated included forest, pasture, grass, impervious surfaces, and water. The water quality data analyzed for the relationship evaluations spanned most of water year 2002 through 2015 for one main stem monitoring location, water year 2012 for two main stem and one tributary locations, and from July 2014 through May 2015 for nine monitoring locations spread watershed-wide. The end point of May 2015 for the watershed-wide data period is sooner than that used for the water quality assessment because that was the latest data available when this water quality versus land cover analyses occurred. The following summarizes the more relevant findings from the relationship analyses that are directly applicable to watershed stormwater planning:

- No substantial anomalies from what would be typically expected were found in the type and direction of the monitored water quality versus forest, pasture, grass, or impervious land cover relationships that would otherwise suggest unusual sources of pollution.
- Of the six water quality parameters evaluated under overall (base, storm, and unclassified) flow conditions, only dissolved zinc had multiple statistically significant linear relationships with relative amounts of four 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 grassland covers.
- Under overall flow conditions, linear regression correlation (r^2) showed that at least 69% of the variance in dissolved zinc is explained by each of the four 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.

- 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.
- 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.
- Preliminary linear regression 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.
- The consistent and substantial contrast between patterns in storm and base flow dissolved zinc median concentrations strongly suggest the important role stormwater plays for this pollutant in the more developed subwatersheds.

Table 2 Summary of Whipple Creek watershed water quality per exploratory data analyses

Water Quality Parameter	Unusual Patterns Over Time and Exceedances of State Standards Criteria	Most Parameters Boxplots	Temperature Scatter / CDF Plots and Other Parameters Probability Plots	Overall Observations (*most important italicized*)
Water Temperature	• WPL050 exceeded criteria 13-70 times annually from 2002-2013 • Watershed-wide monitoring during the summers of 2014 & 2015 showed many exceedances during both summers (sites / frequency): WPL010 / 42 & 61, WPL050 / 63 & 85, WPL065 / 64 & 87, Packard / 61 & 75, and WPLT04 / 77 (just 2015) • WPL080's water temperatures tended to decline slightly during the warmest months of 2014 & 2015	• NA	• Cumulative distribution function (CDF) plots of 7-day average daily (7-DAD) maximum stream temperatures during the summers of 2014 and 2015 show only a small percentage of some of the watershed tributaries and headwater reaches exceeded state standards • Summer 2014 and 2015 CDFs show from 40 to 60 percent of lower mains stem sites' 7-DAD maximum stream temperatures exceeded state standards. • During 2015 periods that include the hottest 10% of 7-DAD maximum stream temperatures, the intensity of their stream water heating increases compared to the rest of the temperature range • Over both the 2014 and 2015 summers, scatterplots showed relationships where almost all of the monitored streams 7-DAD maximum temperatures increased at fairly constant rates of about 1 degree Celsius water temperature for every 2.5 to 3 degree rise in 7-DAD maximum air temperatures. • During the summer of 2015, WPLT04 exhibited a steeper slope in its scatterplot of 7-DAD maximum stream versus air temperature relationship above 30 degrees Celsius suggesting this stream site may be the most susceptible to direct heating with air temperature.	• *The lower main stem WPL050 has commonly exceeded applicable water temperature criteria 13-70 times per year from 2002-2013, with most occurring during July and August.* • *Watershed-wide monitoring during the summers of 2014 & 2015 showed many exceedances each summer (especially during the record warm summer of 2015) for the three lower main stem sites (42 – 87 times per summer), Packard Creek (61 & 71,) and WPLT04 (77 during summer 2015).* • *The above sites with many exceedances tended to be for stream reaches having little shading from riparian forests based on digital land cover maps.* • *WPL080 appears to have an unusually high proportion cool groundwater flow since its temperatures tended to decline during the warmest summer months of both 2014 & 2015.* • *Much of the watershed's tributary and headwater summer flows likely comes directly from relatively cool shaded groundwater whereas lower main stem waters are heated by direct sunlight for longer periods and impacted by warm flows from upstream.* • Lower main stem, Packard Creek and especially WPLT04 tributaries appear to be susceptible to a greater rate of stream heating during very hottest summer days and nights (possibly due to less stream cooling at night) compared to other sites. • The relatively stable relationships for monitored streams versus air temperatures suggests that these streams react similarly over a range of energy inputs but *the duration and magnitude of heat impact how warm they get on the hottest days of summer.* • The contrasting patterns for some the of warmest stream temperatures in CDF plots versus stable water / air temperature relationships in scatter plots implies *other positive feedback heating factors such as decreased streamflow and upstream cumulative heat loading contribute to upswings in stream heating during the very hottest summer*

Water Quality Parameter	Unusual Patterns Over Time and Exceedances of State Standards Criteria	Most Parameters Boxplots	Temperature Scatter / CDF Plots and Other Parameters Probability Plots	Overall Observations (*most important italicized*)
				periods for the lower main stem, Packard Creek, and WPLT04. • *Potential downstream benefits of some cool stream reaches should also take into account their respective inflows' thermal loading for watershed planning implementation*, such as riparian plantings.
Fecal Coliform	• As expected, results varied widely, by up to five orders of magnitude. • On a wet and dry seasonal basis, across almost all monitoring locations both criteria were usually exceeded, often by substantial amounts (4.5 to 97 times criteria). • Of the 36 applicable evaluations (possible combinations of wet or dry season's dual criteria for 9 stations), only two stations exceeded at most one of the unique criteria combinations while seven locations exceeded both criteria for both seasons	• Monitoring location median fecal coliform counts range from 280 (WPLT080) to 830 (WPLT02). • Except for the uppermost tributary, all calculated main stem medians were lower than the tributary medians. • While not statistically significant, the overall spatial patterns show increasing medians from upstream to downstream within the main stem and tributary groups. • Boxplots for the more urban WPLT04 and rural Packard Creek tributaries suggest non-stormwater sources of fecal coliform • Calculated medians for dry season always higher than wet season with 5 of 9 significant • Calculated medians for storm flow always higher than for base flows with only 2 of 9 significantly higher • Nesting subgrouping of boxplots by season and flow type allows an evaluation of their synergistic impact on fecal coliform • The calculated medians for dry season storm flows were always the highest whereas those of the wet season base flow were the lowest (8 of 9 differences were significant) • The significant separation between wet season bae and storm flow medians suggests a reduced continuing bacteria sources between storms	• There is less seasonal effect on fecal coliform levels at the high wet and dry season concentrations than for lower concentrations especially for the lower and middle main stem stations • Among the tributaries, WPLT02 and WPLT04 have slightly more variability across both seasons and more commingling of seasonal points at higher concentrations which may reflect similar stormwater impacts for these two more developed subwatersheds	• *High fecal coliform levels are a watershed-wide issue since most locations exceeded both of the state standard's dual fecal coliform criteria.* • While differences in location medians were mostly not statistically significant, *the overall pattern in location medians showed lower calculated median fecal coliform levels on the main stem than on the tributaries except for WPLT04*. • Compared to other locations, the boxplot *analyses for the more urban WPLT04 and rural Packard Creek tributaries suggest non-stormwater sources of fecal coliform for these subwatersheds.* • *There are fairly consistent seasonality and flow influences on fecal coliform.* • More common significantly *higher main stem dry season medians than for tributaries may result from resident beaver and less dilution.* • *The consistent pattern of higher calculated storm flow than base flow fecal coliform medians (though not often statistically significant) across all monitoring stations strongly suggests surface runoff factors play an important role in bacterial levels.* • *Consistent patterns of high dry season storm flow medians versus very low wet season base flow medians likely are driven by a combination of storm runoff of accumulated nonpoint source bacteria between dry season storms versus more dilution of constant bacteria sources such as failing septic systems during wet season base flows.* • Unusually high wet season base flow fecal coliform variability at WPLT02 and *relatively high dry season base flow fecal coliform medians for WPLT01 and WPLT03 suggest ongoing contribution of bacteria from wildlife, livestock, or failing septic systems*.

Water Quality Parameter	Unusual Patterns Over Time and Exceedances of State Standards Criteria	Most Parameters Boxplots	Temperature Scatter / CDF Plots and Other Parameters Probability Plots	Overall Observations (*most important italicized*)
Dissolved Copper	• WPLT03 & WPLT04 both exceed chronic and acute criteria in 6% of samples. • PCK010 exceeds chronic in 11% and acute in 6% of samples	• Tends to be slight increases in calc. medians from down to upstream main stem and tributary stations. • Almost none of the stations have clearly significant differences in their median copper levels. • No seasonality. • Within stations' base flow calculated median copper was always lower than that for storm flow though often not statistically different.	• Consistently across watershed, base flow dissolved copper is usually less than that for storm flow but for some sites lower base and storm flow dissolved copper values do overlap • Generally is less difference between base and storm flow concentrations throughout their ranges for the main stem stations than for the tributary stations • Tributary stations storm flow's divergence from base flows at higher concentrations suggests tributaries are more susceptible to the effects of stormwater runoff	• *All dissolved copper state standards' criteria exceedances occurred during storm flows in just three mixed to more developed tributary subwatersheds.* • *There tends to be slight increases in calculated dissolved copper medians from down to upstream within groups of main stem and tributary stations.* • *Significantly higher storm flow dissolved copper medians for the most developed WPLT02 and WPLTO4 subwatershed stations supports storm first flush impact from developed areas.*
Dissolved Zinc	• Only WPLT03 exceeded either chronic or acute criteria and did so in only one sample or 6% of samples for both criteria	• Tends to be slight increases in calc. medians from down to upstream main stem and tributary stations. • Two lowest downstream stations main stem and tributary medians are significantly less than their corresponding most upstream main stem and three most upstream tributary stations. • No seasonality. • Within stations' base flow calc. median zinc was usually lower (except WPL010, WPL050, & WPLT01) than that for storm flow though often not statistically different.	• The lower main stem stations' unusually low storm flow dissolved zinc levels relative to base flow suggest impacts from pollutant travel time, downstream dilution, or instream pollutant reduction mechanisms • Generally is less difference between base and storm flow concentrations throughout their ranges for the main stem stations than for the tributary stations • Tributary stations storm flow's divergence from base flows at higher concentrations suggests tributaries are more susceptible to the effects of stormwater runoff	• *The single WPLT03 sample that exceeded both chronic and acute criteria suggests isolated occurrences of high dissolved zinc.* • *However, the tendency of increasing calculated dissolved zinc medians from downstream to upstream and associated Water Quality and Land Cover Relationships Report's findings of significant direct relationships between development and dissolved zinc suggest consistent widespread development related zinc pollutant impacts.* • *Significantly higher storm flow dissolved zinc medians for the most developed WPLT02 & WPLTO4 subwatershed stations supports the idea of first flush impacts from developed areas.* • *Relatively low storm flow dissolved zinc levels in the lower main stem suggest dilution, travel time factors, or instream pollutant reduction mechanisms taking place.*
pH	• Across all monitoring stations, only a very few (9 or 2% of all measurements) were slightly below (lowest value of 5.86) lower 6.5 criteria boundary. • WPL050 – 2.8%, WPL080- 4.7%, and WPLT02 3.2% of all their measured values were below 6.5 lower criterion.	• Only WPL010's and WPLT04's medians are significantly less than any of the other respective main stem or tributary medians. • Very little seasonality or flow type influences	• NA	• *Excessively low or high pH is not a substantial issue anywhere in the Whipple Creek watershed.*
Turbidity	• High turbidity is a widespread	• No significant difference in	• Strong flow type influences on turbidity	• *High turbidity is a widespread issue throughout the*

Water Quality Parameter	Unusual Patterns Over Time and Exceedances of State Standards Criteria	Most Parameters Boxplots	Temperature Scatter / CDF Plots and Other Parameters Probability Plots	Overall Observations (*most important italicized*)
	issue throughout the Whipple Creek watershed • 76% of watershed wide turbidity values exceeded criterion of 5 NTU above an estimated background level of 2 NTU • 55-95% of main stem station values exceeded criterion • 55-98% of tributary station values exceeded criterion	medians across stations. • No seasonality. • Storm flow median turbidity significantly higher than base flow median turbidity across all nine stations. • WPLT03 base flow turbidity most variable. • Packard Creek storm flow median turbidity highest calculated value and clearly significantly higher than WPL065 & WPL080 storm flow median turbidity	are consistently shown across watershed. • Storm flow low turbidity values overlap with base flow low turbidity values but separation increases dramatically with higher values	*Whipple Creek watershed with more than three-quarters of all monitored values substantially elevated above background levels.* • *Turbidity is almost always elevated with storm flows, often more than two orders greater than base flow for middle to high range values, likely due to soil erosion during surface runoff and instream channel erosion.* • Packard Creek storm flow turbidity tends to be highest.
Dissolved Oxygen	• Likely low dissolved oxygen levels frequently drop below the 8 mg/L minimum criterion given the pattern of mid-day monitored values across the watershed.	• NA	• NA	• *Low dissolved oxygen values likely occur over much of the watershed based on the high frequency of mid-day measurements approaching state standard's minimum criterion.*

Recommendations

The following are overall recommendations to protect or improve stream water quality during implementation of the Whipple Creek watershed plan:

- Perform stream temperature confirming follow-up field reconnaissance on stream reaches identified as having potentially beneficial cooler temperatures (i.e., WPL080) or excessive heating (i.e., WPLT04 and PCK010) as suggested by watershed wide baseline monitoring.
- After confirming the stream length extent of beneficial cooling or excessive heating, follow up with more detailed field measurements of stream / air temperatures and flow for thermal loadings.
- Based on the detailed thermal loading analyses consider reach specific combinations of management options such as: targeted stream side tree planting, property conservation easements along naturally cool stream reach refugees, and using hot weather forecasts to alter the timed release of cool stormwater stored in existing or future flexibly designed stormwater detention facilities to reduce peak stream temperatures. Perform downstream continuous stream temperature monitoring to confirm / calibrate possible temperature mitigation.
- Evaluate potential stream heating impacts from open water, beaver ponds, and low shading above WPL010, WPL050, WPL065, WPLT04, and PCK010.
- Fecal coliforms generally greater sensitivity to flow type than seasonality suggests surface runoff factors play an important role in bacteria levels so both stormwater and rural/agricultural fecal coliform Best Management Practices (BMPs) should be pursued.
- Consistent fecal coliform patterns of high dry season storm flow medians versus very low wet season base flow medians are likely driven by a combination of storm runoff of accumulated nonpoint source bacteria between dry season storms versus more dilution of constant bacteria sources such as failing septic systems during wet season base flows. These patterns are especially pronounced for Packard Creek, WPLT01, and WPLT03 so pursuing both stormwater and rural/agricultural fecal coliform BMPS should be a priority for them.
- Relatively high dry season base flow fecal coliform medians for WPLT01 and WPLT03 suggest ongoing contribution of bacteria from wildlife, livestock, or failing septic systems so these potential sources would need further investigation.
- While the relatively few isolated state standards exceedances during storm flows for dissolved zinc and especially dissolved copper may suggest these metals are currently not substantial problems, their tendencies of increasing concentrations for storm flows over base flows (though usually not significant) and from downstream to more developed upstream subwatersheds suggest the need to address stormwater impacts.
- The Water Quality versus Land Cover Relationships findings of significant direct relationships between development and dissolved metals medians (dissolved zinc appears more sensitive than dissolved copper to development impacts) for the most developed subwatersheds supports likely stormwater impacts and the need to continue addressing especially zinc with stormwater BMPs.

- Given the predominant and consistent relationship 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.
- The consistent and substantial contrast between patterns in storm and base flow dissolved zinc median concentrations versus land cover strongly suggest the important role stormwater plays and the need to address this pollutant in the more developed subwatersheds.
- Preliminary linear regression analyses suggest with 95% confidence, 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. These local thresholds could serve to help inform and prioritize stormwater management efforts.
- Currently pH is not an issue that needs to be addressed in the Whipple Creek watershed.
- Wide spread high turbidity issues should be addressed by reducing soil and channel erosion.
- Apparent wide spread low dissolved oxygen issues can be addressed using the same management tools used for temperature.

Introduction

As required in the Permit's Section S5.C.5.c (Ecology, 2012), existing water quality conditions within the Whipple Creek watershed planning study area were assessed using available and sufficient stream water quality data. An additional important application of the assessment monitoring results is to help calibrate the water quality components of a continuous runoff model used to evaluate stormwater management strategies to support existing and designated stream beneficial uses. The Whipple Creek watershed plan water quality assessment includes this report and more detailed analyses summaries in its appendices "Whipple Creek Watershed Stream Temperatures" and "Water Quality and Land Cover Relationships".

Under sections 305 (b) and 303(d) of the federal Clean Water Act, Washington State is required to perform regular water quality assessments and list the status of waterbodies in the state (Washington Department of Ecology 303d web page). The state's 303 (d) list includes those waters that are in the polluted water category for which beneficial uses are impaired. Under this category, polluted waters require a Total Maximum Daily Load (TMDL) or other water quality improvement project. This category means Ecology has data showing that water quality standards have been violated for one or more pollutants, and there is no TMDL or pollution control plan. Based on a query using the Washington State Department of Ecology's 303d web page, approximately 1.4 stream miles of the main stem of Whipple Creek (Figure 2) downstream from Clark County's WPL050 site are identified within the latest 303(d) list from 2014 as falling under category 5 for bacteria, bioassessment, and water temperature. The state's listings are based on Clark County monitoring at WPL050 for bacteria from 2002 through 2010, for temperature from 2002 and 2006 through 2010, and for the bioassessment from 2001 through 2009.

This watershed planning assessment utilized more comprehensive and current water quality data sources. Requiring sources of known reliability, accuracy, and timeliness limited applicable monitoring results to three Clark County projects. The projects and their monitoring frequencies are: Long-term Index Site Program (LISP) – monthly for water quality starting in 2001 and for continuous temperature starting in 2002, Stormwater Needs Assessment Project (SNAP) – monthly during water year 2012 from October 2011 through September 2012, and the Whipple Creek Watershed Plan (WSPLAN) – monitoring targeted storm or base flows with up to three monitoring runs within a day from July 2014 through October 2015.

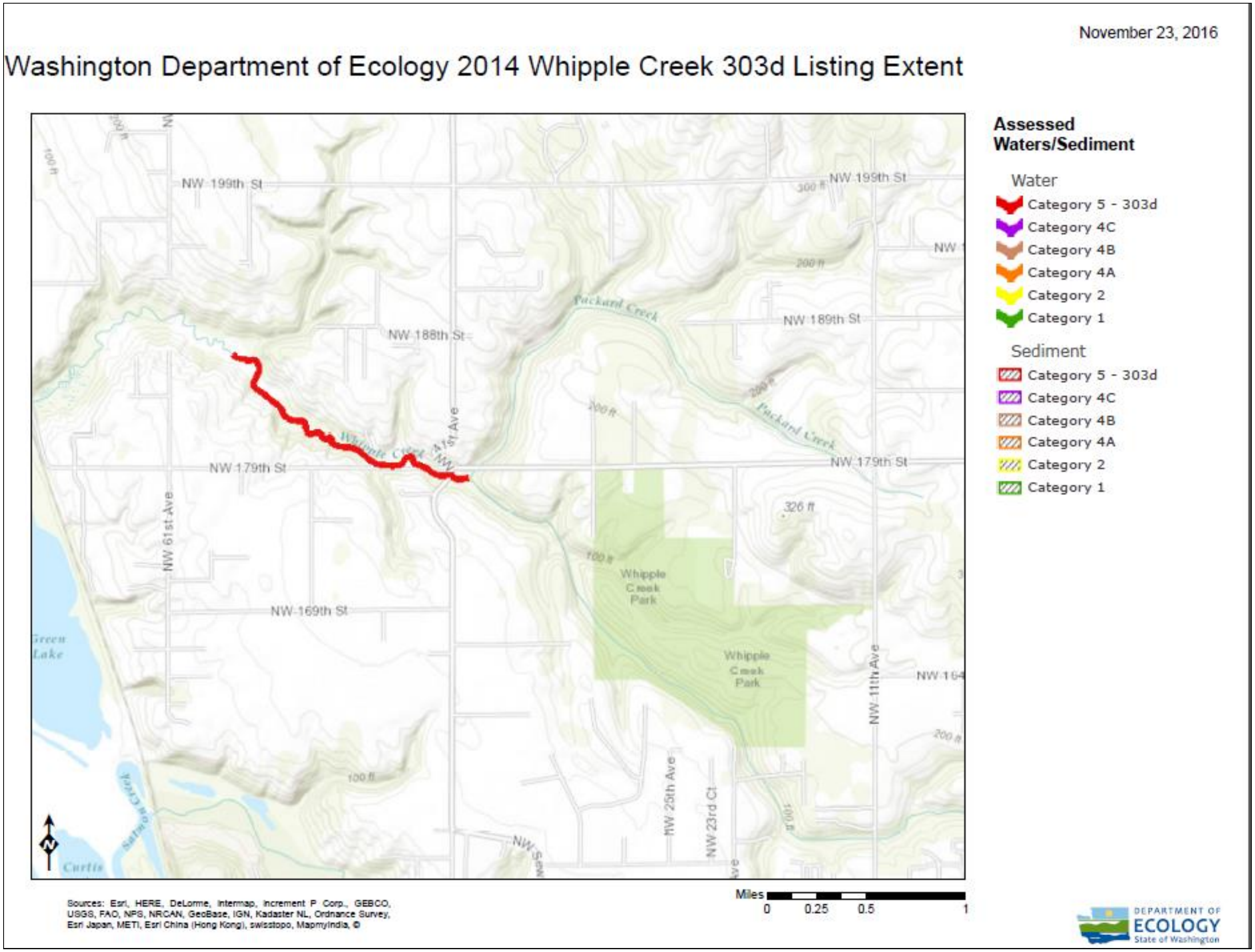

Figure 2 Washington State Department of Ecology web page map of 303d listed stream reaches within the Whipple Creek watershed

Methods

Monitoring Methods

The monitoring utilized specific quality assurance project plans (QAPPs), standard operating procedures (SOPs), and Washington State accredited laboratories for analyses of water samples. Monitoring locations were selected using best professional judgement (non-random) for targeting the farthest downstream location within selected areas of the Whipple Creek watershed to capture representative measurements and samples of upstream subwatershed water quality. Monitoring station names are based on the stream name and percent upstream from the stream's mouth (except plots' Packard Creek's WPLT00PCK010).

This report's assessment of existing water quality conditions used three Clark County project sources of monitoring results that utilized subsets of the same nine monitoring locations (Figure 3). The first is a relatively long-term (starting as early as August 2001 and running through June 2014) monthly data set from the central Whipple Creek watershed WPL050 main stem monitoring station. The second source utilized spans one year of monthly data (October 2011-September 2012) for the two main stem stations of WPL010 and WPL080 as well as the one Packard Creek (PCK010) tributary site. The third set includes up to sixteen months (July 2014-Oct 2015) of watershed-wide base and storm flow stream monitoring results from all nine monitoring locations including four main stem (WPL010, WPL050, WPL065, and WPL080) and five tributary (PCK010, WPLT01, WPLT02, WPLT03, and WPLT04) sites.

Figure 3 Whipple Creek watershed main stem and tributary water quality monitoring locations

All data is from county project monitoring performed by qualified and trained county staff using SOPs with prepared field and sampling equipment. Procedures were followed as described in applicable project quality assurance project plans (Clark County NPDES Long-term Index Site Project QAPP, 2004; Benthic Macroinvertebrate and Water Temperature Monitoring for Watershed Characterization in Clark County QAPP, 2004; Clark County Stormwater Needs Assessment Program Characterization Projects QAPP, 2011; and Clark County NPDES Whipple Creek Water Quality and Biological Assessment Project QAPP, 2014). Procedures included: calibration or pre- / post- checking of hand-held field meters, following SOPs for sampling and meters, utilizing lab prepared sample bottles for grab samples, transport of samples in ice filled insulated chests, timely sample delivery to a state accredited analytical laboratory, appropriate labelling and documentation for field trips and sample chain-of-custodies, etc.

Table 3 summarizes the monitoring methods used to collect this assessment's existing water quality data. At each monitoring location standard operating procedures were followed to minimize potential negative impacts on monitoring results. Monthly field meter measurements or samples were taken in approximately the same stream locations and sequence of locations during field trips. Handheld field meters' cable-end probes were placed in or grab samples were collected from the well-mixed center portions of the streams. WPL050's continuous temperature sensor / logger was also deployed to the same shaded stream reach annually for a period that included at least the warmest portion of each summer.

Data Evaluation Methods

This assessment first utilizes state water quality standards followed by statistical exploratory data analyses to evaluate existing stream water quality conditions in the Whipple Creek watershed. Table 4 presents the most applicable State water quality standards' designated uses and criteria (Ecology, 2011, pp. 55-58). Since Whipple Creek is not specifically listed otherwise in Washington State Water Quality Standard's Table 602, defaults apply for protecting an aquatic life designated use of salmonid spawning, rearing, and migration and human primary contact recreation. In addition to salmonid rearing and migration use, the most stringent key characteristic for spawning/rearing use is salmon or trout spawning and emergence that only occur outside of the summer season. Primary contact recreation use is intended to protect swimmers from waterborne disease. In order to consistently interpret results from a watershed-wide perspective, comparisons to state standard criteria mostly focused on the July 2014 through October 2015 period during which monitoring occurred at nine stations across the Whipple Creek watershed.

In addition to comparisons with state water quality standards, this assessment utilizes statistical exploratory data analyses through a range of graphs to help characterize water quality and gain further insights on watershed streams' potential pollutant sources. The watershed's stream water quality is systematically assessed and characterized through graphs primarily created using MINITAB® Release 14.1 statistical software (MiniTab, 2003) to compare and summarize watershed-wide results. Graphed results are presented and interpreted in the context of important factors that often influence water quality; including subwatersheds' relative location and general land covers, wet (October - April) or dry (May – September) seasonality, and base or storm flows. Where appropriate, the graphs show exceedances of applicable state water quality standards criteria. Given this assessment's relatively small sample sizes and resulting limited power to detect statistically significant differences in monitoring location or their subgroup parameter medians, noteworthy overall consistent patterns in calculated medians (without regard to significance of differences) were often emphasized since these may be of practical significance.

Table 3 Summary of water quality monitoring methods used for Whipple Creek watershed data assessment

Water Quality Parameter	Monitoring Frequency / Location Duration	Field Meter or Lab Sample	Method Reporting Limit	Accuracy	Lab Method Reference
Temperature	Summer Hourly Continuous / WPL050 - 12 yrs.	HOBO® Water Temp Pro Sensor /Logger	0.02°C	±0.21°C @ 25°C	NA
	Monthly / Others - WY2012	In-Situ Troll® 9500, YSI™ 6920, YSI™ 85	0.01°C	±0.1°C	NA
Fecal Coliform Bacteria	Monthly / WPL050 – 10 yrs., Others - WY2012	Lab Sample	2 CFU/ 100 mL	NA	Membrane filter SM 9222D
Dissolved Copper	Monthly / Start WY2013 (only WPL050)	Lab Sample	0.1 ug/L	25 % Error	EPA 200.8
Dissolved Zinc	Monthly / Start WY2013 (only WPL050)	Lab Sample	0.5 ug/L	25 % Error	EPA 200.8
pH	Monthly / WPL050 – 12 yrs., Others - WY2012	In-Situ Troll® 9500, YSI® 6920, YSI® 60	0.01 units	±0.1 pH units	NA
Turbidity	Monthly / WPL050 – 12 yrs., Others - WY2012	Hach® 2100P	0.01 NTU	±5% of reading	NA
Dissolved Oxygen	Monthly / WPL050 – 12 yrs., Others - WY2012	In-Situ Troll® 9500, YSI™ 6920, YSI™ 85	0.01 mg/L	±0.2 mg/L	NA

Table 4 Whipple Creek watershed streams' Washington State designated uses and water quality standards criteria

Parameter	Applicable Designated Use	State WQ Standard Criteria
Temperature	Aquatic Life: salmonid spawning, rearing, and migration	7-Day Average Daily Maximum (7-DADMax) of 17.5°C
Fecal Coliform	Primary contact recreation	< geometric mean of 100 colonies / 100 mL and <10% of samples: 200 colonies / 100 mL
Dissolved Copper	Aquatic Life – most sensitive biota : Toxic substances	Acute and chronic criteria math formulas incorporating water hardness
Dissolved Zinc	Aquatic Life – most sensitive biota : Toxic substances	Acute and chronic criteria math formulas incorporating water hardness
pH	Aquatic Life: salmonid spawning, rearing, and migration	6.5 – 8.5 pH units
Turbidity	Aquatic Life: salmonid spawning, rearing, and migration	5 NTU over background
Dissolved Oxygen	Aquatic Life: salmonid spawning, rearing, and migration	1-day minimum of 8.0 mg/L once every 10 years on average

Water quality parameters were systematically evaluated using a series of plots contrasting subwatershed monitoring location and subgroup results. Depending on available data, graphs include water quality plots over time, boxplots often grouped by potential influencing factors, and sometimes probability plots. To help consistently interpret results from the most widespread and recent data available, all of the detailed boxplots and probability plots focused on the July 2014 through October 2015 period having watershed-wide water quality data. In order to further evaluate seasonality or flow type influences, probability plots provide a different perspective and more information across the full range of results beyond what is available through boxplots' limited summary statistics. Comparison plots used similar sample sizes. Log-normal probability plots and fitted distributions are used because most of the water quality variables have positively skewed distributions and their variabilities often increase with medians. In general, water quality observations often form a straight line (at least from about the 10 to 90 percentile points) on log-normal probability paper (Burton and Pitt, p. 585). Grouping of results in boxplots (Helsel and Hirsch, pp. 343-344, 423-424) and probability plots by location, wet or dry season, and sampled flow type helps visualize potential confounding or exogenous factors, evaluate their influence on water quality, and tease out likely contributing pollution sources. Where applicable, the analyses present up to four levels of factor subgroups based on monitoring location, season, relative flow, and nested combinations of these groups.

Plots are presented in a consistent order and appearance. Monitoring station names consist of a three-letter abbreviation of the monitored stream's name followed by a three number combination indicating its relative location as a percentage upstream from the stream month. Whenever possible, similar plot types use identical scale ranges to support their direct comparisons. Monitoring location values plotted over time and boxplot coloring use the same monitoring location specific colors as those in the Figure 1.

Each water quality parameter's exploratory data analyses starts with monitoring location values plotted over time to both provide historical context and show relative frequencies of state water quality standards exceedances. Next, descriptive statistics for each monitoring location or subgroup are depicted by boxplots': colored interquartile ranges (IQR or 25^{th} - 75^{th} percentiles), whiskers (vertical lines from the IQR to values falling within 1.5 times the IQR), outliers (colored asterisks of values beyond the whiskers), median values (numerically labeled horizontal lines), and 95% confidence intervals around the medians (grey shaded internal boxes). If the internal grey boxes' ranges overlap then their median values are not statistically different at the 95% confidence level and vice versa. Boxplots are not used to summarize water temperature and dissolved oxygen because differences for each of these two parameters may be substantially driven by the time of day at which they were measured.

If boxplots suggest widespread seasonal or flow type water quality influences then probability plots are used to explore these factors impact. Probability plots show monitoring location values plotted on log-normal axes with a straight-line log-normal distributions fitted to the data, curved lines of the distribution's 95% confidence intervals, and sometimes criteria reference lines. Probability plots can indicate possible range of the values expected, data variation, and their likely probability distribution type (Burton and Pitt, 2002, pp. 584-585). If plotted points form a straight line on a log-normal probability plot it suggests the data are log-normally distributed. Steeper probability plot slopes for the plotted points or their fitted distribution indicates less variability in the values and vice versa. Multiple data sets can also be plotted on the same plot (such as for different sites, different seasons, different habitats, etc.) to indicate obvious similarities or differences in the data sets. In comparing different data sets, similar variances are indicated by generally parallel plots of the data on the probability plots.

Results and Discussion

Background

Water quality monitoring from March 2002 through October 2015occurred across a wide range of flows as reflected by WPL050's water quality monitored flows spanning from less than1 to 213 cfs capturing both base and storm flows (Figure 4).

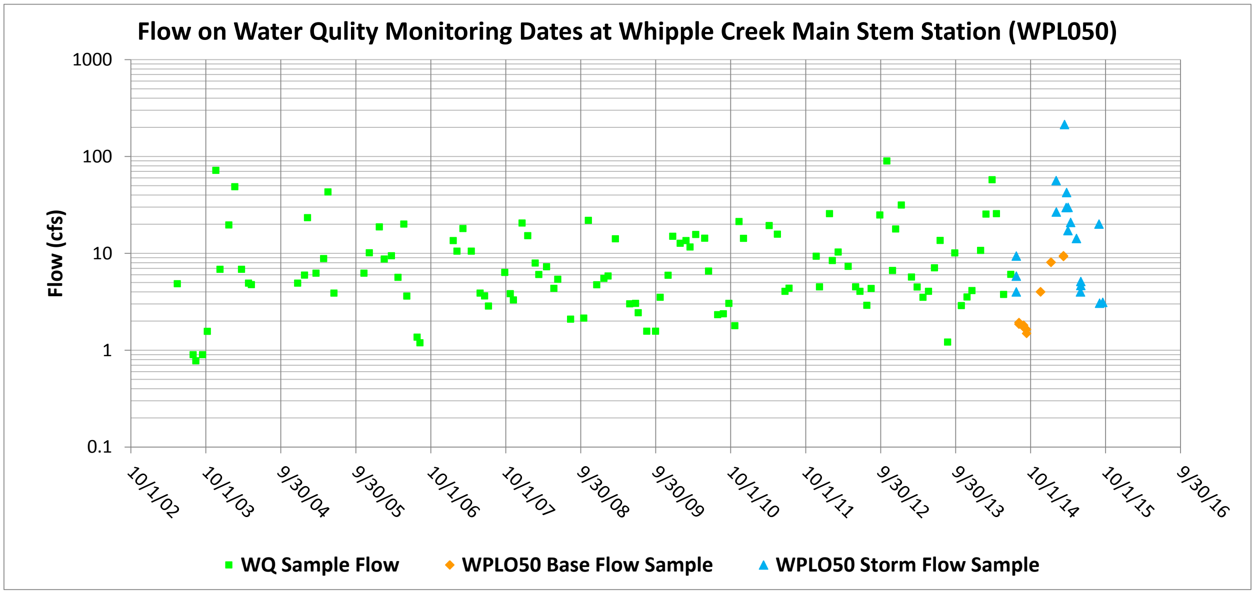

Figure 4 Flows at times of water quality monitoring for the mid-lower Whipple Creek watershed WPL050 monitoring station

The mid-lower watershed main stem monitoring location of WPL050 has by far the longest period of monthly data with some physical parameters' monitoring starting as early as 2002. Two additional main stem (WPL010 and WPL065) and Packard Creek locations' monthly data for water year 2012 (October 2011 – September 2012) is also included in the non-metal parameter plots of values over time. The farthest right portion of the time plots includes up to twelve base and eighteen storm flow monitoring results from July 2014 through October 2015 from nine watershed-wide locations. Often, the storm events include up to three samples per storm.

Stream Water Temperature

Appendix 1 presents the full assessment of the Whipple Creek watershed's stream temperatures.

Fecal Coliform

The scatterplot of Whipple Creek watershed fecal coliform (Figure 5) values over time includes all available County monitored fecal coliform results to provide historical context. As expected, the scatterplot shows that fecal coliform values varied widely (by up to five orders of magnitude) both over time and across monitoring stations. Generally, the long-term fecal coliform results for the mid-watershed WPL050 main stem monitoring location show that this station's monthly, random sampling date results prior to July 2014 were less variable and had comparatively fewer very high values than the subsequent watershed plan's targeted storm and base flow monitoring results across multiple main stem and tributary watershed locations.

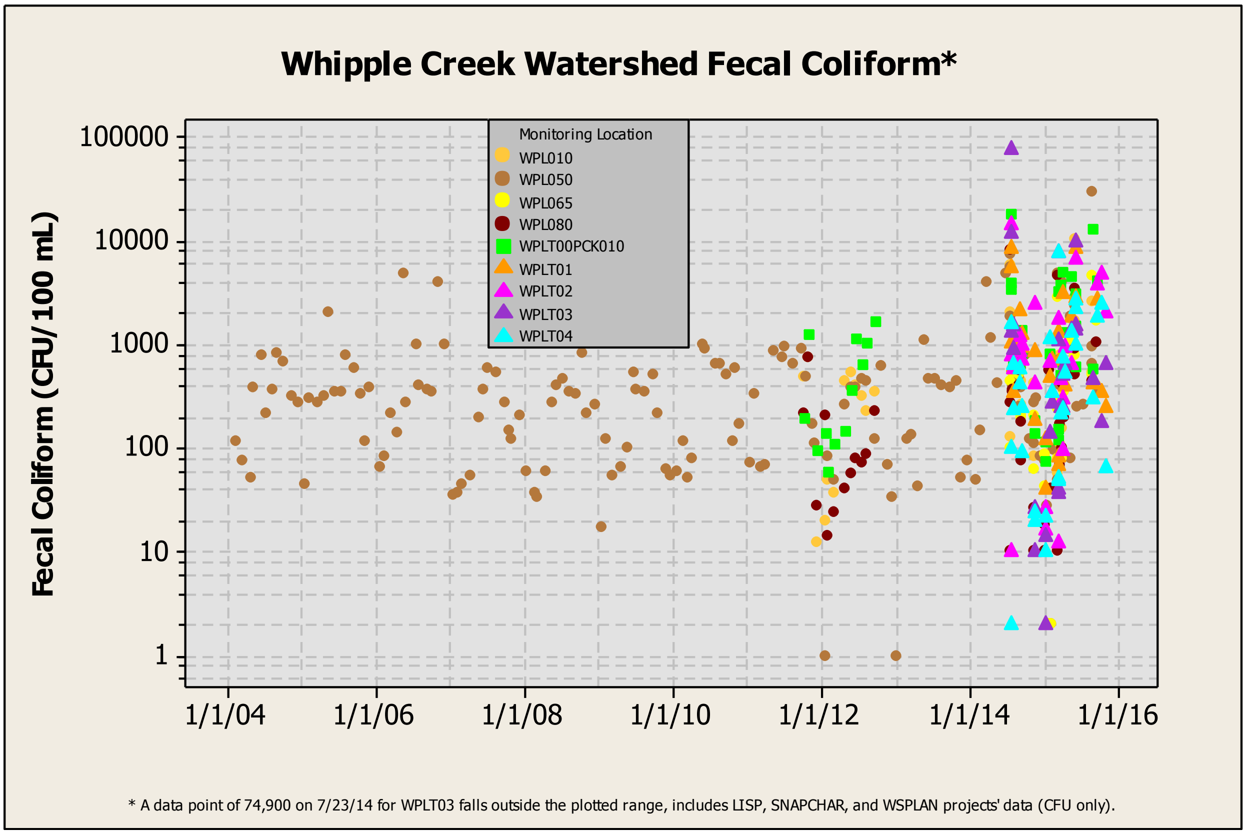

Figure 5 Scatter plot of Whipple Creek watershed monitoring stations long-term and recent fecal coliform levels

Following the state's preference for averaging fecal coliform values on a seasonal basis in applying state standards' fecal coliform criteria (Washington Department of Ecology, revised January 2012, p. 17), these analyses specifically used wet (October 1 – April 30) and dry (May 1 – September 30) seasons for evaluations. Figure 6 summarizes how each monitoring location's fecal coliform results for the July 2014 through October 2015 period compare to applicable Washington State standards' dual criteria. Overall, across almost all Whipple Creek watershed monitoring locations, both of the state's fecal coliform criteria were usually exceeded, often by substantial amounts. Based on the 36 assessments of nine monitoring locations compared across the four criteria of wet (October-April) or dry (May-September) season geometric mean or 10% criteria combinations, just two stations exceeded only one of the seasonal criteria while seven locations exceeded both criteria for the two seasons. Only seasonal values for the main stem monitoring stations of WPL065 (93) and WPL080 (75) were below the seasonal geometric mean criterion of 100 colonies / 100 mL and this only occurred for the wet season. All nine stations' 10% of samples (90th percentile of their respective station's log-normal distributions) seasonal criterion of 200 colonies / 100 mL were exceeded during both the wet and dry seasons. The level of exceedances were often quite substantial, ranging up to 4.5 times the wet season and 27 times the dry season geometric mean criterion as well as 27 times the wet season and 97 times the dry season 10% criterion.

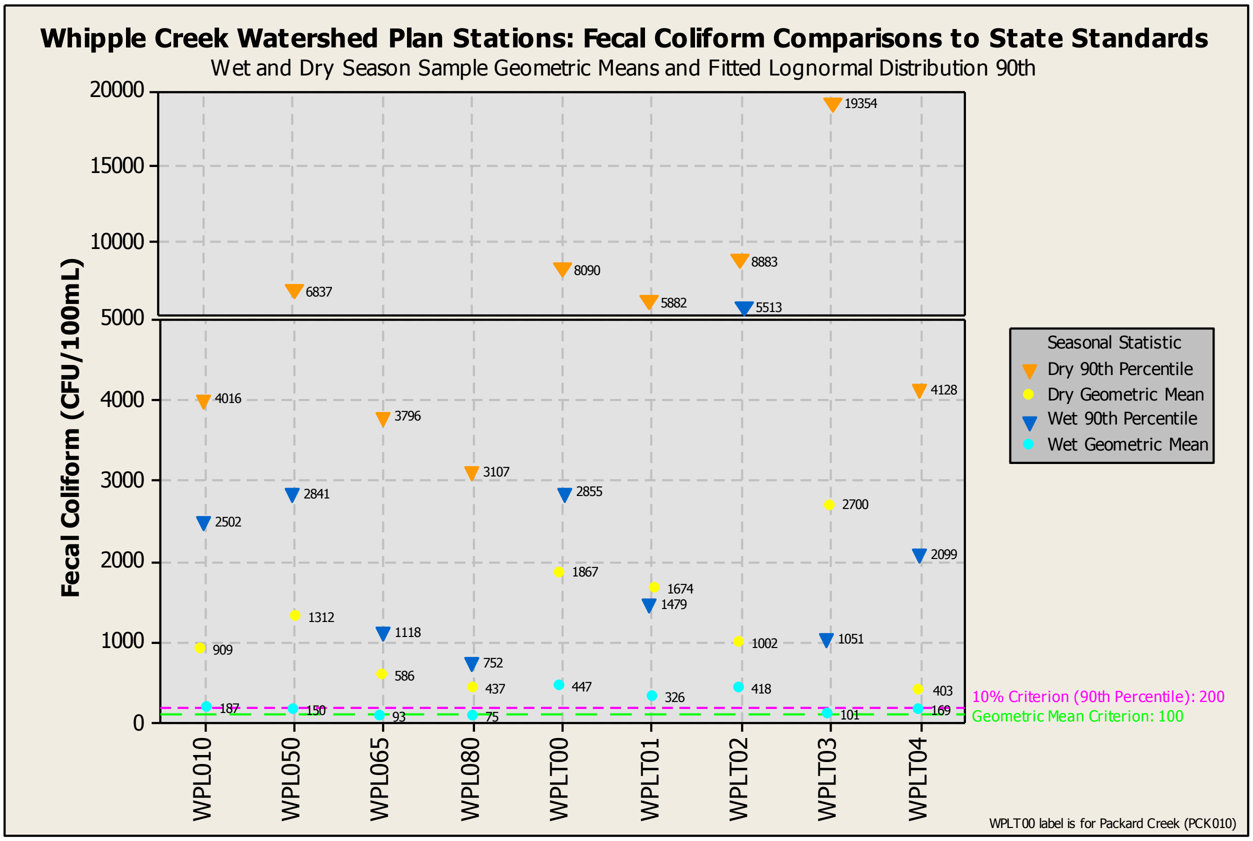

Figure 6 Whipple Creek watershed plan monitoring results comparison to state standards for fecal coliform

The following series of fecal coliform boxplots and probability plots present increasingly detailed perspectives by partitioning potentially important factors that could substantially impact stream fecal coliform levels. At the most general level comparing bacteria counts across the Whipple Creek watershed, the boxplots in Figure 7 display the central tendency (median) and variability (interquartile range or IQR) for each monitoring station and suggest potential differences. Median fecal coliform counts (i.e., colony forming units or CFUs) range from 280 for WPL080 to 830 for WPLT02. Overall, except for the uppermost WPLT040 tributary, all of the calculated main stem medians were lower than the tributary medians. All other factors held constant, this may be partly attributed to bacteria die off over time as fecal coliform are carried downstream. However, with the exception of low medians for WPL080 and WPL065, there appears to be no statistically significant difference in the median fecal coliform values for most of the monitoring stations as demonstrated by their boxplots' internal grey shaded boxes overlapping ranges (i.e., medians' 95% confidence intervals). The few non-overlapping internal boxes show Packard Creek's median (750) is significantly higher than that of both WPL080 (280) and WPL065 (315) while WPLT02's median (830) is only higher than that of WPL080.

Figure 7 boxplots' colored inter-quartile-ranges (IQR or 25th through 75th percentiles depicting one perspective on variation), also show the spread for the middle 50% of stations' fecal coliform values generally expands with increasing values of location medians. The smallest IQRs are associated with WPL080 and WPL065 stations that have the lowest value medians while wider IQRs are found for higher median valued stations and especially for the more variable Packard Creek. While not statistically significant, the overall spatial pattern depicted in the monitoring location boxplots suggests fecal coliform levels generally increase from upper to lower main stem reaches and from upper to lower watershed tributaries (even though these tributaries do not drain into each other). Interestingly, the tributary with the lowest median and smallest IQR for fecal coliform is for the small tributary WPLT04, which has one of the most densely developed subwatersheds (Figure 1). Conversely, the large, mostly rural Packard Creek tributary subwatershed has a one of the higher medians and a greater portion of relatively higher fecal coliform values (as shown by the higher upper extent of its IQR). These patterns suggest possible non-stormwater conveyance sources of fecal coliform for these two subwatersheds.

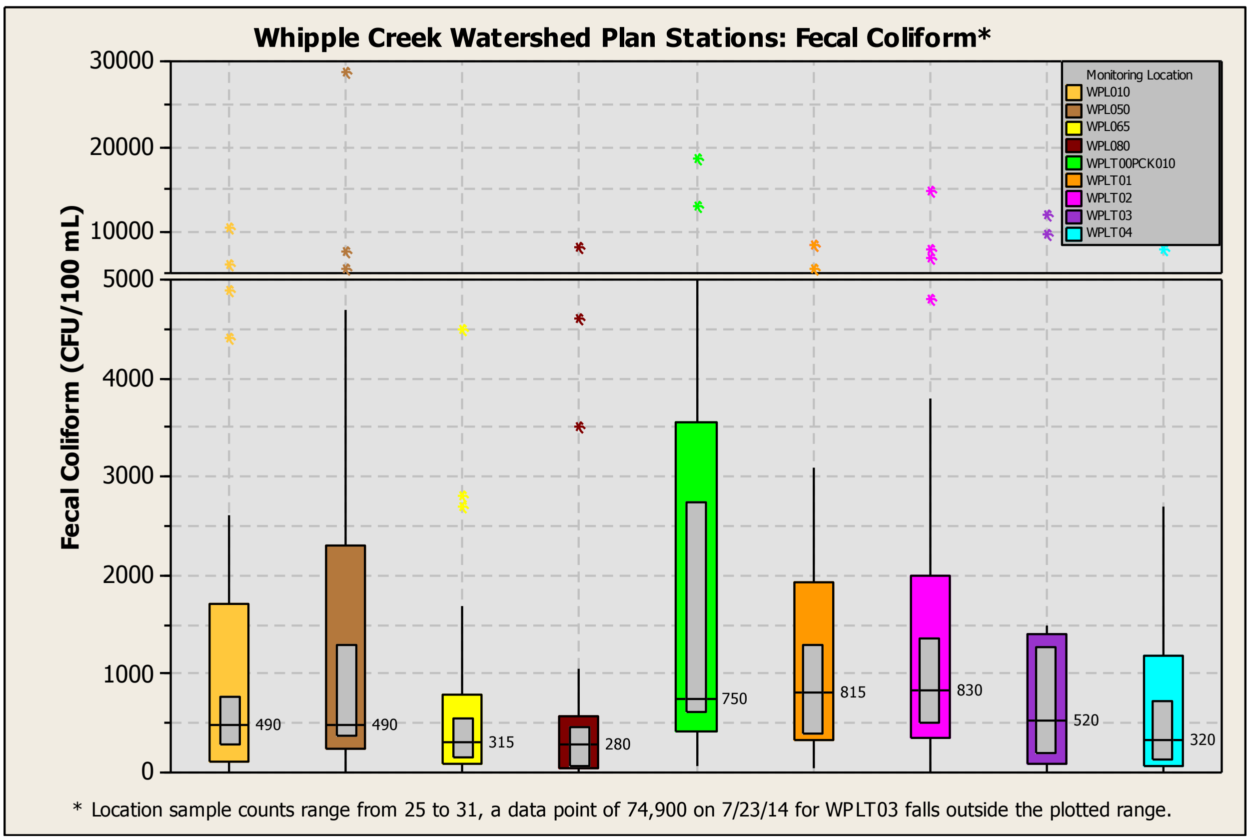

Figure 7 Boxplots of Whipple Creek watershed plan stations' fecal coliform results

There appears to be fairly consistent seasonality and flow components to the fecal coliform results across the watershed (Figure 8 and Figure 9). Dry season fecal coliform medians and IQRs are often substantially higher than wet season values. All monitoring locations' dry season fecal coliform calculated medians were higher than their respective wet season medians (average dry season median 4.3 times that of wet season) with five of the nine locations being significantly higher statistically (on average 6 times as much). Similarly, these same five locations' dry season IQRs were higher such that there was no overlap with their respective wet season IQRs. As shown by narrower wet season IQRs for all locations except for WPLT02, there also was less variability in wet season fecal coliform levels than for the dry season results. For main stem versus tributary seasonal medians, three of the four main stem (75%) and only two of five tributary (40%) stations' dry season medians were significantly higher than their corresponding wet season medians. The more common significantly higher main stem dry season medians may result from resident beaver and lower dry season flows resulting in less dilution of bacteria levels.

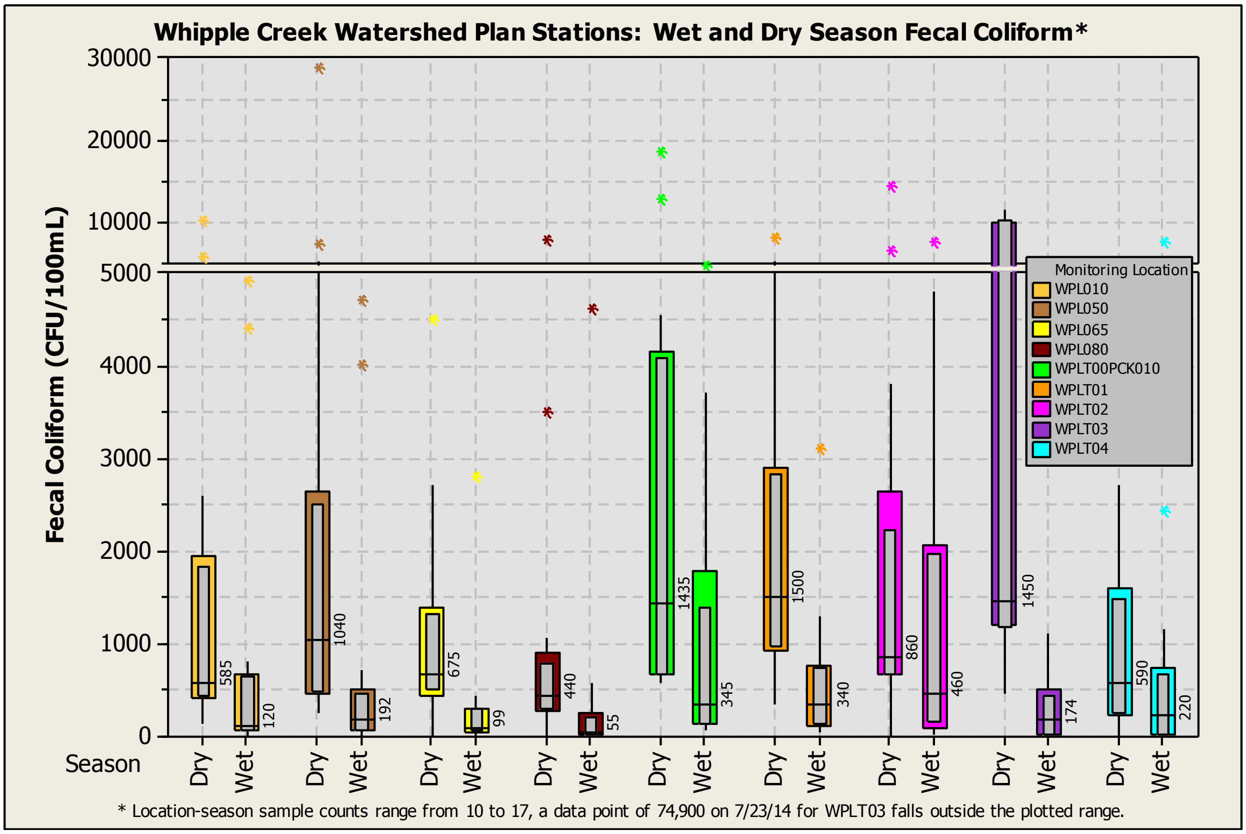

Figure 8 Boxplots of Whipple Creek watershed plan stations' fecal coliform results grouped by season

Like the overall dry season median pattern, storm flow fecal coliform calculated medians were always higher than those for their respective base flows (on average four times as much). However, statistically only two of the nine locations' (WPL050 and WPLT00PCK010 / Packard Creek) storm flow medians were significantly higher (on average 7.5 times as much) than their respective base flow medians with no overlap in both their median confidence intervals and IQRs (Figure 9). The generally lower base flow fecal coliform results also showed less variability (having narrower IQRs) than those for storm flows. The overall consistent pattern of higher calculated medians and IQRs for storm versus corresponding base flows across all monitoring stations strongly suggest surface runoff factors play an important role in bacteria levels in the monitored streams.

The most detailed boxplot partitioning of fecal coliform monitoring results utilizes sequentially nested grouping by flow type within season within monitoring location (Figure 10). This figure zooms in on the narrower range of results from zero to 10,000 to highlight some of the differences at the lower portion of concentrations where most of the values fall. By nesting these groups by factors that have already been shown to likely influence median fecal coliform concentrations their synergistic influences can be evaluated.

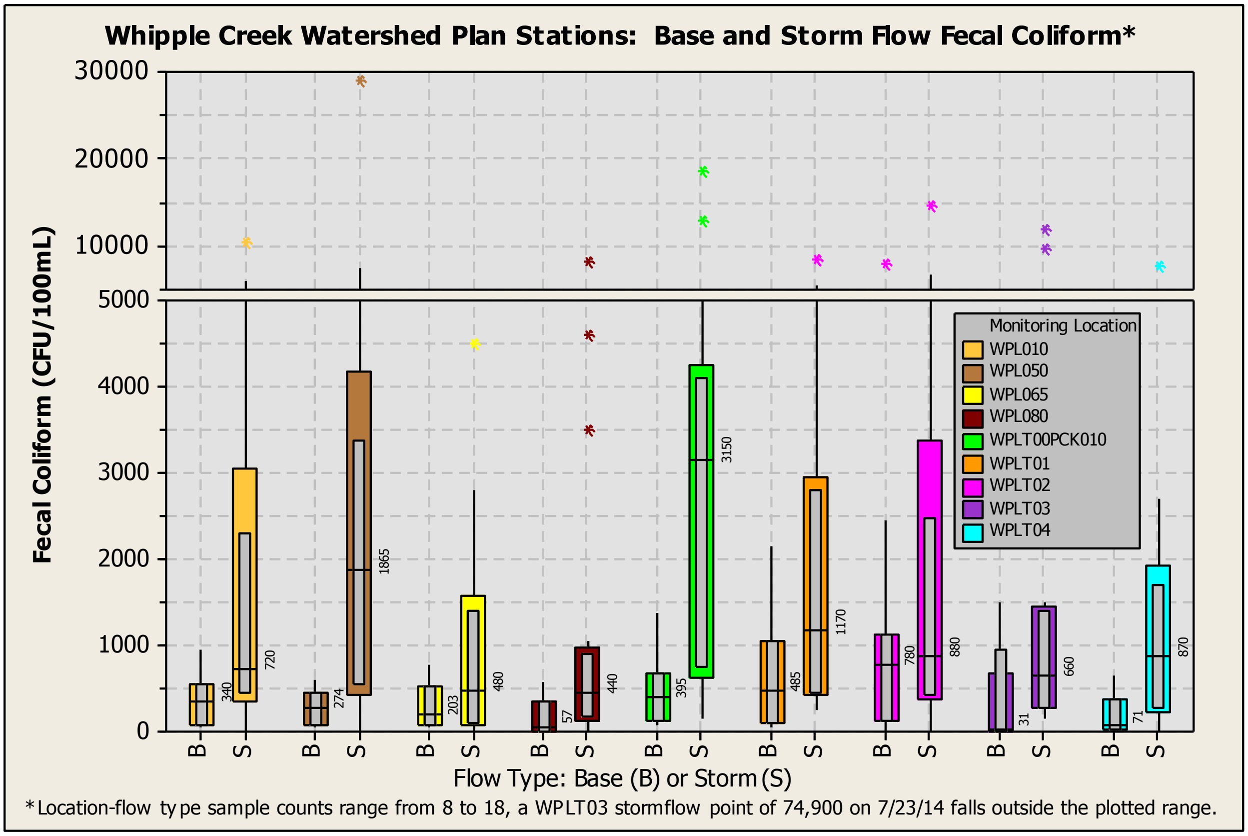

Figure 9 Boxplots of Whipple Creek watershed plan stations' fecal coliform results grouped by flow type

Several consistent patterns and unique features emerge in the detailed fecal coliform boxplots of Figure 10. Across all the monitoring locations, the calculated fecal coliform medians (red circles in the figure) for dry season storm flow were the highest whereas their medians for the wet season base flow were the lowest. Within monitoring locations, the dry season storm flow medians were always significantly higher than their wet seas base flow medians except for station WPLT02. Additionally, dry season base flow calculated medians were always greater than their corresponding within monitoring location wet season base flow medians. Within any monitoring location, the smallest difference between the relatively high dry season storm flow medians and the next closest subgroup medians was 250 CFU at WPLT03 while that for the relatively low wet season base flow was 116 CFU for WPL065. The relative impact on fecal coliform concentrations from flow type is much greater than from season as depicted by within monitoring locations' much larger differences between base and storm flow boxplots compared to corresponding pairs of base or storm flow boxplots for a location's dry and wet seasons.

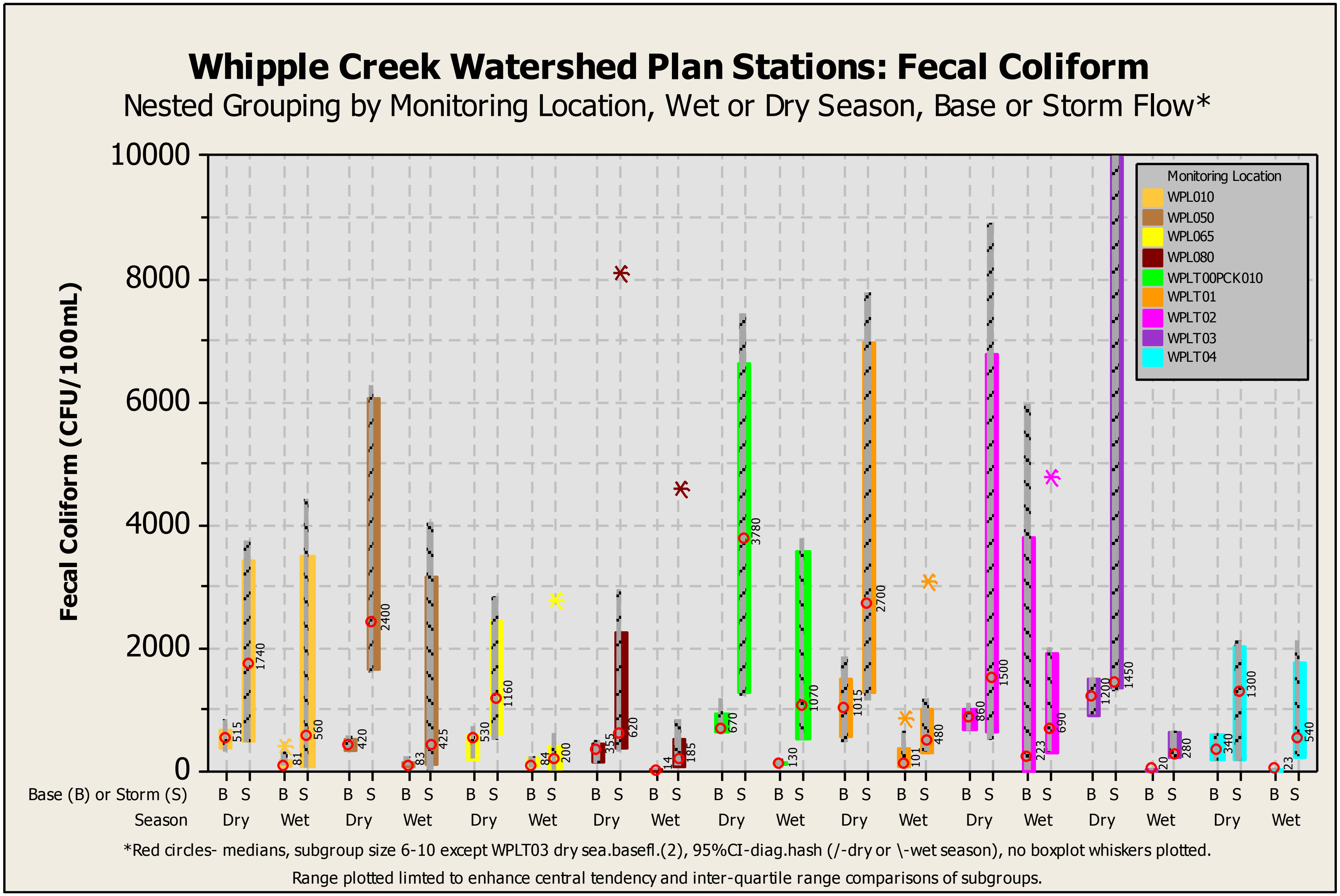

Figure 10 Boxplots of Whipple Creek watershed plan stations' fecal coliform results grouped by flow type nested within season

From a statistically significant perspective of within station subgroup medians, none of the high dry season storm flow medians was different from at least one other same station subgroup median but there were four low wet season base flow subgroup medians that were different (Figure 10). The statistically significant separation (based on separation between their median's applicable 95% confidence boundaries) for the four wet season base flow medians from the nearest other within location subgroup medians always occurred with its corresponding wet season storm flow subgroup. However, the magnitude of the four differences is sequentially wider from the upper main stem (WPL080) to the upper tributaries (WPLT03 and WPLT04) to the Packard Creek tributary. This spatial pattern and magnitude of the significantly lower medians for these wet season base flow subgroups suggests a lack of continuing bacteria sources between wet season storm flow events for these headwater tributaries and especially for Packard Creek. Not only are the wet season base flow fecal coliform group medians the lowest for within station subgroups but their 95% confidence intervals and IQR's are also generally the narrowest by far (except for WPLT02) which suggest very little variability in most of their values. Given that the within monitoring location subgroup sizes consist of at most ten samples, it is not surprising that many of these subgroups' median 95% confidence intervals overlap. Larger sample sizes could provide more power to statistically test the significance of meaningful differences between the subgroup medians especially for highly variable parameters such as fecal coliform.

These detailed nested boxplot patterns (especially for the consistent patterns in calculated high and low group medians) may be due to a combination of storm runoff of accumulated nonpoint source bacteria from hard surfaces during dry season storms and dilution due to larger wet season base flows with shorter pollutant accumulation periods between storms. The Washington Department of Ecology notes in their "White Salmon River Watershed Fecal Coliform Bacteria Attainment Monitoring Study" (Ecology, 2011, p. 20) that "The critical conditions for nonpoint sources generally occur during high-rainfall periods, particularly during the start of a rainfall event when bacteria are 'flushed' from surface soils into the streams" (cited reference not listed in the report's reference list). The low wet season base flow medians could also be partly attributed to dilution of any relatively constant fecal coliform sources (e.g., failing septic systems, beavers, etc.) during the wet season. WPLT02's generally higher medians and wider ranging IQR suggest unusual fecal coliform sources impacting it over a wide range of seasonal and flow conditions. The very unusual WPLT02 fecal coliform wet season base flow subgroup results (whose median is 93 higher and IQR is bar far wider than that of the next highest similarly grouped median) would need further investigation as to the potential pollutant sources. The unique pattern in the WPLT02 boxplots, especially for the unusually high variability wet season base flows, suggests potential ongoing impacts from nearby resident beavers and waterfowl living in a large upstream pond / wetland or a relatively large continuous manmade source of fecal contamination. Additionally, the relatively high median fecal coliform values (>1,000 CFU / 100 mL) during dry season base flow conditions for the tributary monitoring locations of WPLT01 (mostly rural land cover subwatershed) and WPLT03 (mixed land cover subwatershed but median based on just two samples) also suggests possible wildlife, livestock, or human sources such as failing septic systems contributing bacteria.

The common general patterns of fecal coliform asymmetric distributions, increasing variability (as shown by the boxplot IQRs) with increasing fecal coliform median values, seasonality, and the interpretation of a state water quality standards 10% criterion on a seasonal basis suggest the need to evaluate fecal coliform results using log-normal probability distributions for further insights. The Washington State Department of Ecology Environmental Assessment Program uses a stream's 90th percentile of its log-normal distribution of sampled fecal coliform results to calculate and assess a stream's attainment of the state fresh water standard's 10 percent criterion of 200 fecal coliform colonies / 100 mL (Ecology, 2011, p.17).

Figure 11 presents a series of identically scaled fecal coliform log-normal probability plots fitted with wet (green) and dry (orange) season straight-line log-normal distributions and their corresponding 95% confidence intervals for each of the nine Whipple Creek watershed monitoring locations. Also superimposed on each plot are the 90th percentile values along each season's fitted log-normal distribution which match their equivalent calculated 90th percentile values presented in Figure 6. That most of each plot's seasonal values fall within their corresponding fitted log-normal distribution's 95% confidence intervals suggest that the log-normal distribution is a reasonable overall statistical model to use on the data across all the monitoring locations. The greatest difference in an individual monitoring location's 90th percentile seasonal values is, by far, for WPLT03 (depicted on Figure 11 by blue labels and vertical dashed lines dropping to the horizontal log scale) similar to that in Figure 6 (depicted parallel to the broken non-log vertical scale).

Most of the monitoring locations' probability plot seasonal subgroups (Figure 11) contain similar sample sizes (all within three of each other except for five more for WPLT03's wet season) allowing direct evaluations of differences in the spread of their seasonal values. Similar to the observations made for the seasonal boxplots, almost all of the equivalent percentile wet season values tend to be lower than (to the left of) their corresponding percentile dry season values. Five stations (four of which are for the wet season) have at least one very low result likely at the laboratory reporting limit for fecal coliform. The generally steeper slopes of the fitted dry season log-normal lines relative to their wet season lines implies slightly less variability for the dry season. However, at many locations' higher values their fitted lines and confidence intervals either approach or cross over each other and conversely there is greater separation at lower values. This high value overlap is especially true for the main stem locations and Packard Creek. However, there is considerable seasonal overlap throughout the full range of values for WPLT02 and WPLT04 which reinforces the lack of seasonal effects seen in the boxplots for the two locations. The greatest separation in fitted log-normal lines and their confidence intervals throughout the full range of seasonal values is for the WPLT03 monitoring location. These probability plot patterns suggest that there is less seasonal effect (less separation and more comingling of points) at the higher wet and dry season concentrations especially for the lower main stem of Whipple Creek and WPLT02 and WPLT04 tributaries. Much of the main stem locations' probability plots clearer seasonal separation at lower concentrations may be due to their consistent lower base flow and higher storm flow concentrations during the both seasons also shown in the nested seasonal-flow boxplots of Figure 10. Compared to the other subwatersheds, the slightly flatter slopes of WPLT02's and WPLT04's fitted log-normal distributions for both the wet and dry seasons suggest more variable fecal coliform across both seasons for these more developed subwatersheds.

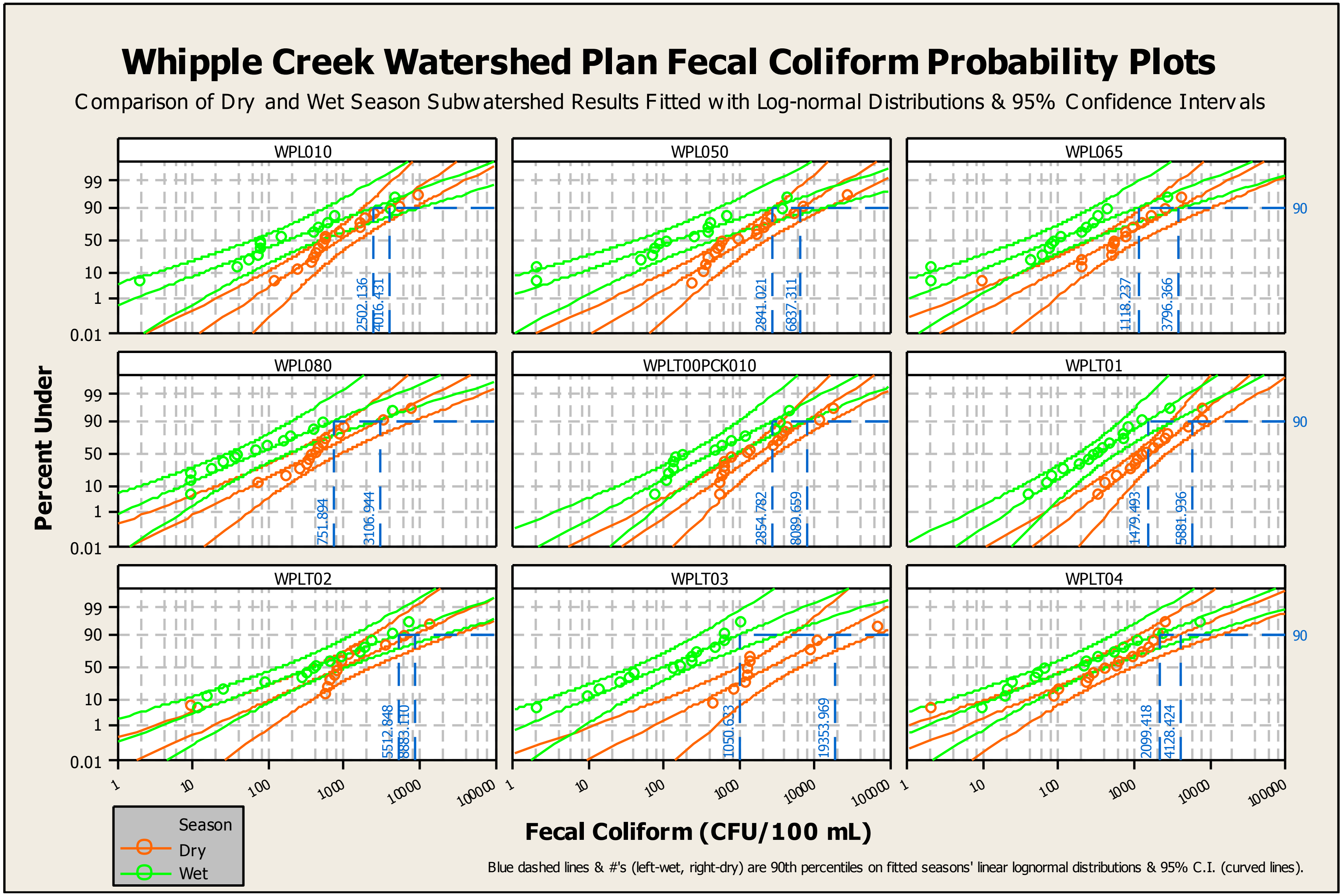

Figure 11 Log-normal probability plots of Whipple Creek watershed plan stations' fecal coliform results grouped by season

Dissolved Copper and Dissolved Zinc

This summary of Whipple Creek watershed dissolved copper and dissolved zinc monitoring results compares and contrasts levels of these two metal pollutants across multiple main stem and tributary watershed locations and suggests factors likely influencing them. The scatterplots of Whipple Creek watershed dissolved copper (Figure 12) and dissolved zinc (Figure 13) present historical context by showing the range of their values over time. The scatterplots show that the mid-watershed main stem WPL050 long-term monitoring location's monthly, (randomly selected sampling dates) dissolved copper and zinc values were comparable (both mostly below 2 ug/L) prior to the start of watershed-wide monitoring in July of 2014. The subsequent watershed plan's higher frequency, targeted storm and base flow monitoring showed both dissolved metals varied much more widely throughout the watershed than they did during the prior monthly WPL050 monitoring. Generally, watershed-wide dissolved zinc values were both higher and varied more than dissolved copper levels.

Possible exceedances of applicable state freshwater quality standard's acute and chronic criteria were evaluated for both dissolved copper and dissolved zinc where simultaneous water hardness values were available during the watershed plan's targeted base and storm flow monitoring period of July 2014 through October 2015. Both dissolved copper and dissolved zinc each had 266 applicable pairs of dissolved metal and corresponding hardness values for evaluation. The applicable state water quality standards (Ecology, revised 2012, p.26-30) include language for the acute and chronic criteria that suggest the need for more frequent monitoring than performed for the watershed plan. For dissolved copper and zinc, the state's criteria language specifically state for acute "A 1-hour average concentration not to be exceeded more than once every three years on the average" and for chronic "A 4-day average concentration not to be exceeded more than once every three years on the average". Therefore, the application of the water hardness specific numeric criteria is only to provide relative context even though exceedance terms are used in these analyses.

As shown in Figure 12, Whipple Creek watershed plan (WSP) monitoring locations exceeded dissolved copper acute criterion three times (across three stations, 1.1% of all WSP samples, and 6% of these individual stations' samples) and chronic criterion four times (across three stations, 1.5% of all WSP samples, and from 6 to 11% of these individual stations' samples). Figure 13 shows only one exceedance each for dissolved zinc acute and chronic criterion (both for WPLT03, 0.4% of all WSP samples, and 6% of this station's samples for each criterion). The dissolved copper exceedances ranged from 117% to 449% for acute and 126% to 634% for chronic criteria. The dissolved zinc exceedances were 303% of acute and 332% of chronic criteria. All of the exceedances for both dissolved metals occurred during storm flow events across a combination of wet and dry seasons.

Whipple Creek watershed plan monitoring location boxplots for dissolved copper (Figure 14) and dissolved zinc (Figure 15) show central tendencies, distributions, and contrasting patterns for the concurrently collected and equivalent sample sizes for these two metals across the watershed. All the distributions for both metals are asymmetrical and skewed toward high values with most monitoring locations having at least one high outlier above the plotted whiskers. An extreme dissolved copper outlier of 39.8 ug/L for Packard Creek is four times higher than the uppermost plotted range of all the other dissolved copper values. Falling above the plotted range of most dissolved zinc values are the three extreme outliers of 17.3 ug/L for WPLT02 as well as two for WPLT03 of 27.7 ug/L and 202 ug/L (more than thirteen times higher than the top of the plotted range).

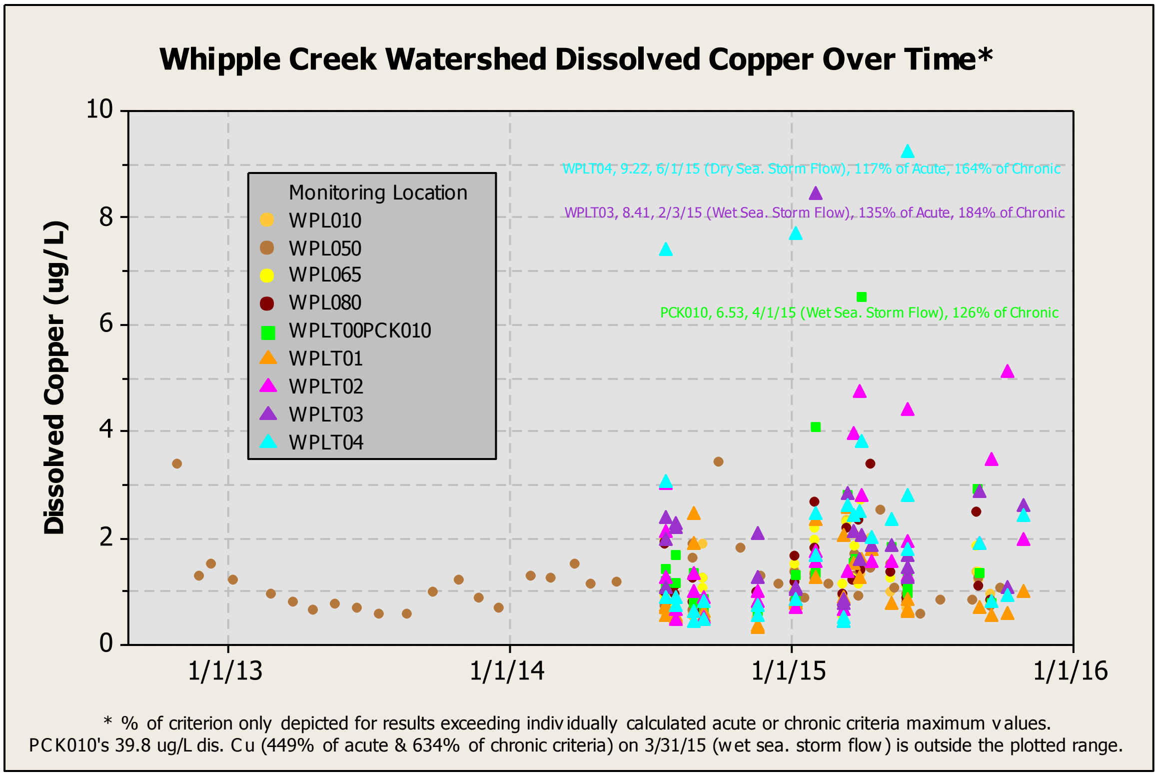

Figure 12 Whipple Creek watershed dissolved copper levels over time and exceedances of state standards

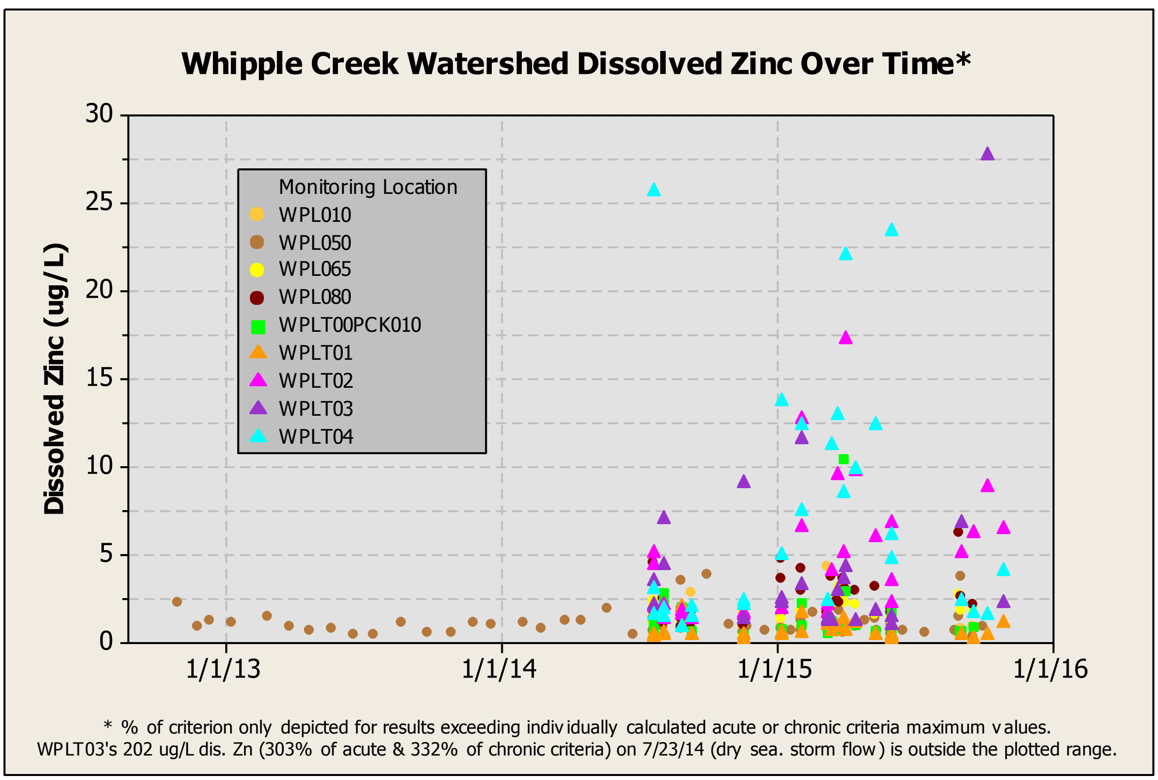

Figure 13 Whipple Creek watershed dissolved zinc levels over time and exceedances of state standards

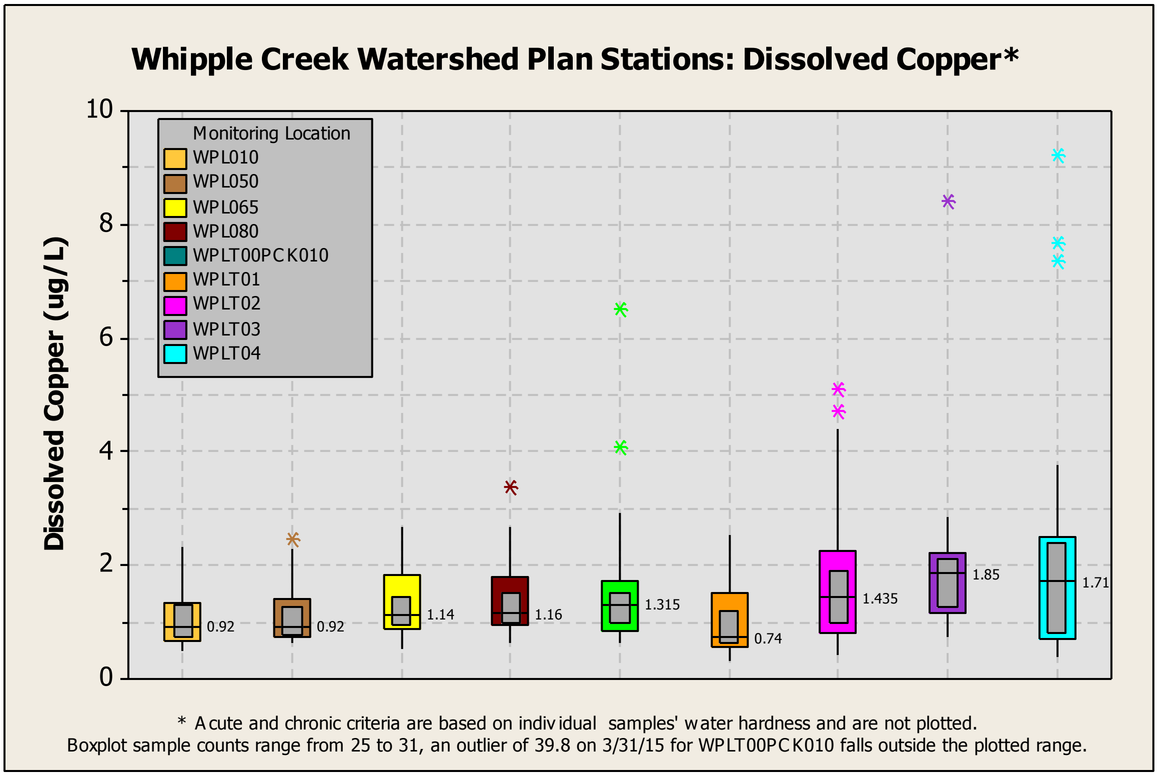

Figure 14 Boxplots of Whipple Creek watershed plan stations' dissolved copper results

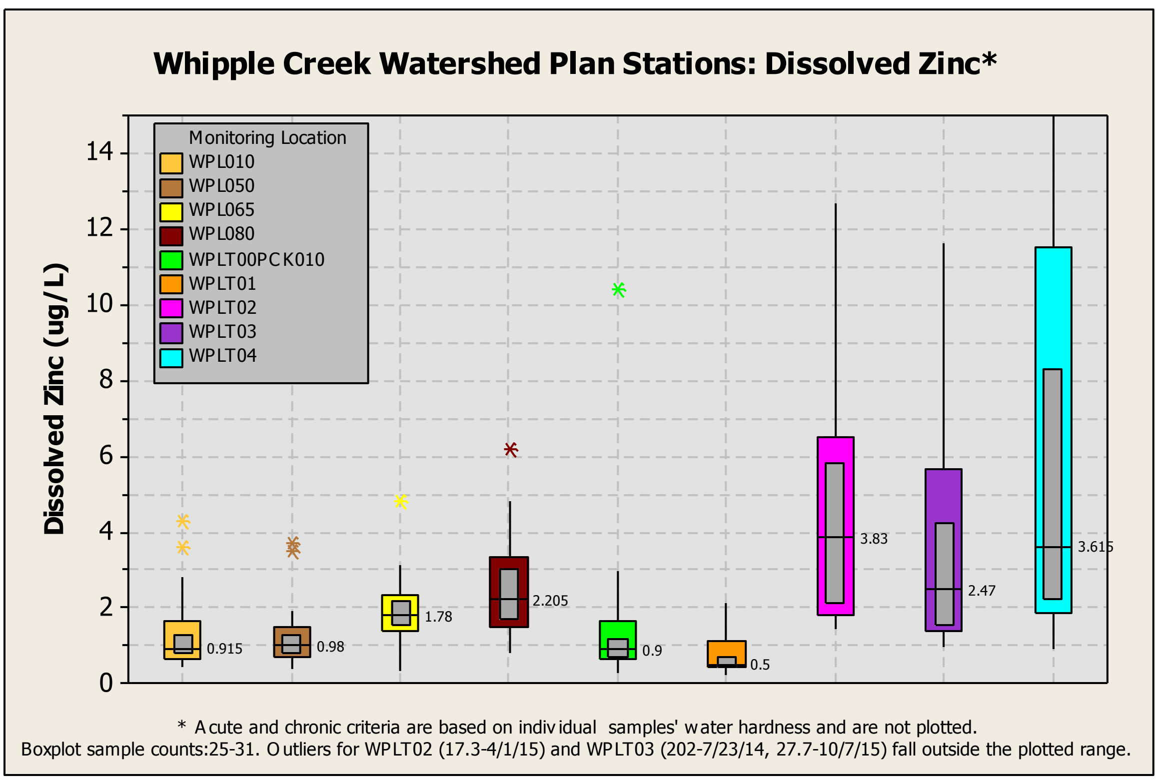

Figure 15 Boxplots of Whipple Creek watershed plan stations' dissolved zinc results

From a watershed wide perspective, there tends to be slight increases in the calculated medians and interquartile ranges from downstream to upstream for the main stem and tributary monitoring locations (as shown from left to right within these subgroups in Figure 14 and Figure 15 except slight decreases for WPLT01) but most of these increases are not statistically significant. In fact, for dissolved copper, the only statistically significant difference in monitoring location medians is that the WPLT01 median of 0.74 ug/L is significantly less than the WPLT03 median of 1.85 ug/L (all the other dissolved copper boxplots' internal grey 95% confidence interval boxes overlap). For dissolved zinc, both of the two most downstream main stem and tributary monitoring stations' medians were significantly less than those for the most upstream main stem and three most upstream tributaries. The overall watershed wide pattern of decreasing dissolved metals from upstream to downstream (especially for dissolved zinc) suggests that higher concentrations are driven by increased development impacts in the upper tributaries and main stem headwater subwatersheds with dilution of concentrations likely occurring further downstream.

The potential impact of seasonality on dissolved metal concentrations was evaluated by the grouping of results in seasonal boxplots. The evaluation utilized two seasons, consisting of a wet season running from October through April and a dry season running from May through September. As depicted in both Figure 16 for dissolved copper and Figure 17 for dissolved zinc, the nearly consistent overlap between the pairs of dry and wet season internal grey boxes for each monitoring location indicates no significant difference between the within monitoring location seasonal medians. The only exception to this pattern is for dissolved copper at WPLT01, but even this site's confidence intervals around their medians almost overlap so the significance of their differences in medians is likely marginal. Therefore, it is concluded that seasonality is not an important factor in the concentrations of these two dissolved metals and is not incorporated in further analyses of dissolved copper and zinc.

The influence of base and storm flow factors on Whipple Creek watershed dissolved metals was also evaluated. Paired base and storm flow boxplots of dissolved metals concentrations for each monitoring location are presented in Figure 18 for dissolved copper and in Figure 19 for dissolved zinc. Within each monitoring location, the base flow calculated dissolved copper median (labeled values on boxplots) was always lower (though often not statistically different) than the median for its storm flow. Similarly, within location base flow calculated dissolved zinc medians were always lower than their corresponding storm flow medians except for the two most downstream main stem (WPL010 and WPL050) and the WPLT01 tributary site.

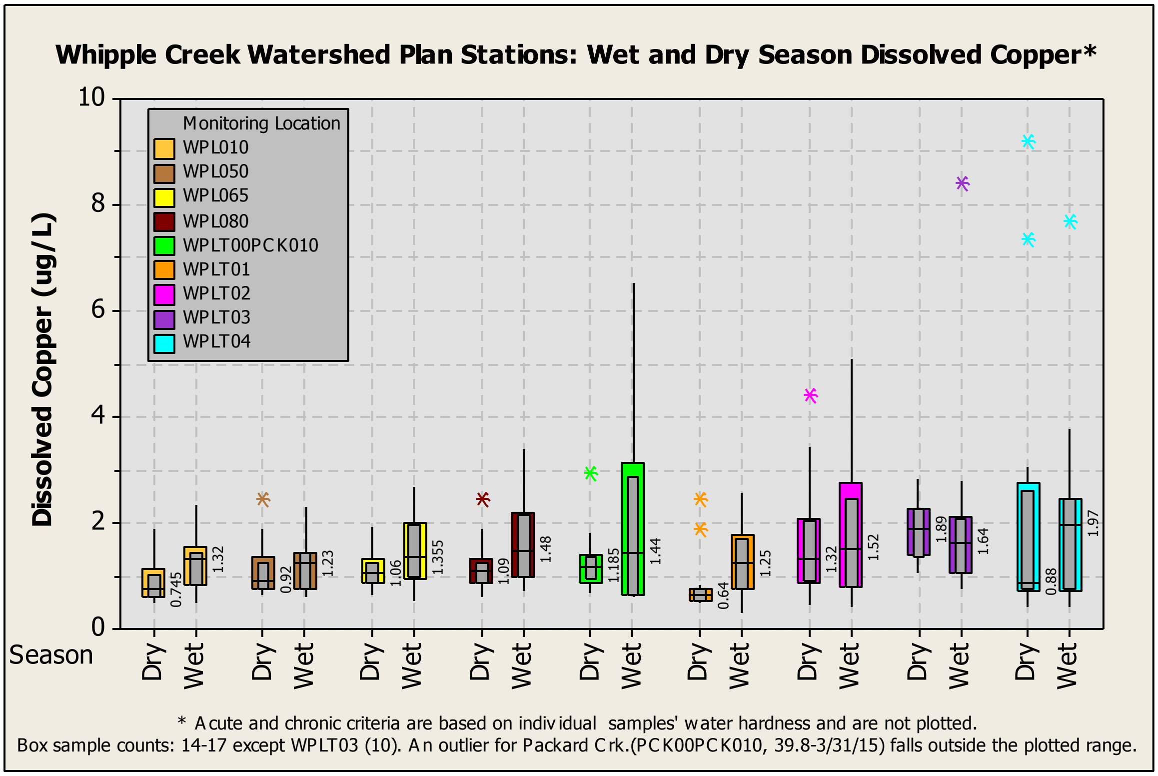

Figure 16 Boxplots of Whipple Creek watershed plan stations' dissolved copper results grouped by season

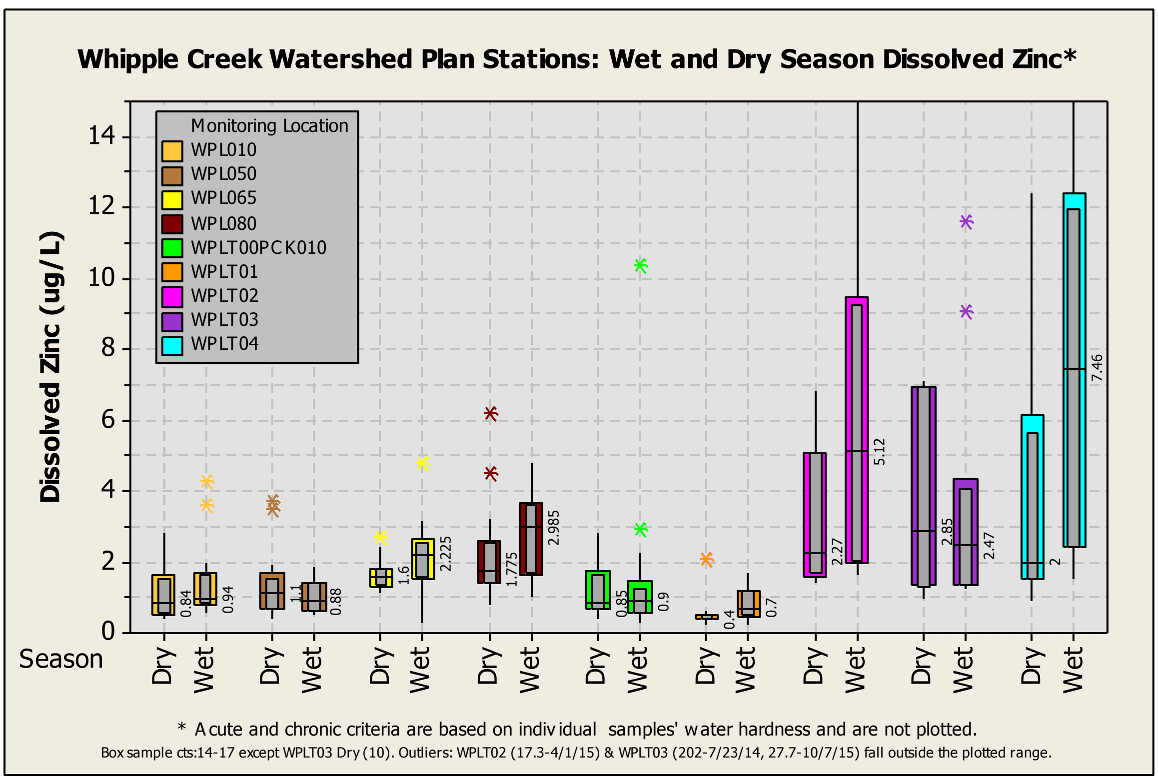

Figure 17 Boxplots of Whipple Creek watershed plan stations' dissolved zinc results grouped by season

Significant differences in median dissolved metal concentrations between base and storm flow for individual monitoring locations is much more common for flow type than it was for wet and dry seasons. Of the nine locations monitored, base and storm flow median dissolved copper levels (Figure 18) were not significantly different for five sites (three main stem and two tributaries) but were significantly different for four sites (two each for main stem and tributary sites). However, of the four significant differences in median dissolved copper levels, only two tributary sites' medians were clearly different (as depicted by clear separation of the base and storm flows' internal grey boxes for WPLT02 and WPLT04) in which both had significantly higher storm flow medians compared to base flow medians. There is a very similar overall pattern across monitoring locations for significant differences between base and storm flow median dissolved zinc levels (Figure 19). Across the same nine monitoring locations, base and storm flow median dissolved zinc levels were not significantly different for six sites (three main stem and three tributaries) but were significantly different for three sites (one main stem and two tributary sites). Again, there were only clear significant differences in the dissolved zinc medians for the same two tributary sites of WPLT02 and WPLT04, which both had significantly higher storm flow medians compared to base flow medians.

Compared to WPL050's relatively constant monthly dissolved metals levels, the more variable and higher watershed-wide dissolved metals concentrations (Figure 12 and Figure 13) after July 2014 are likely largely due to the more frequent targeted storm and base flow monitoring. Specifically, the preferential targeting of storm flows likely captures the higher concentration of metals often associated with the first flush of pollutants from impervious surfaces during the beginning of a storm. Some of the lower values are likely during base flow conditions when dissolved pollutants have already passed downstream and concentrations become diluted. The common pattern of higher storm than base flow calculated dissolved metals medians, especially significantly higher storm flow medians for the most developed subwatersheds of WPLT02 and WPLT04, strongly supports that there are first flush dissolved metal impacts from the more developed areas.

Whether dissolved metal concentrations were generally increasing or decreasing between the first and second samples (averaged five hours apart) within a base or storm sampling event were briefly evaluated. Patterns would provide insights on departures from expectations and mechanisms operating within the watershed. One surprising pattern for both metals during base flow monitoring events was that increases occurred over time much more often on the lower main stem (except WPL050) while more decreases usually occurred for the tributaries. This within sampling event pattern suggest pollutant travel time downstream may play a more important role by increasing downstream concentrations even during base flows when decreasing concentrations over time would typically be expected throughout the watershed. Storm flow concentrations would be highly dependent on when sampling occurred within an event.

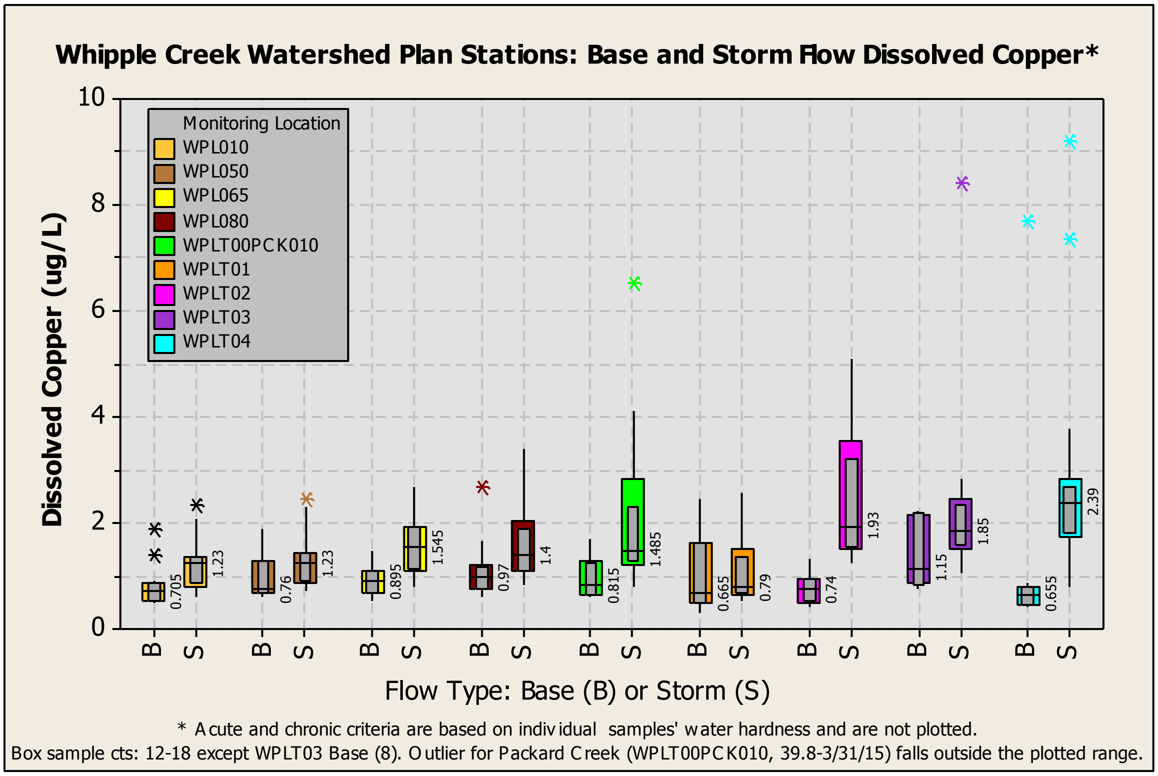

Figure 18 Boxplots of Whipple Creek watershed plan stations' dissolved copper results grouped by flow type

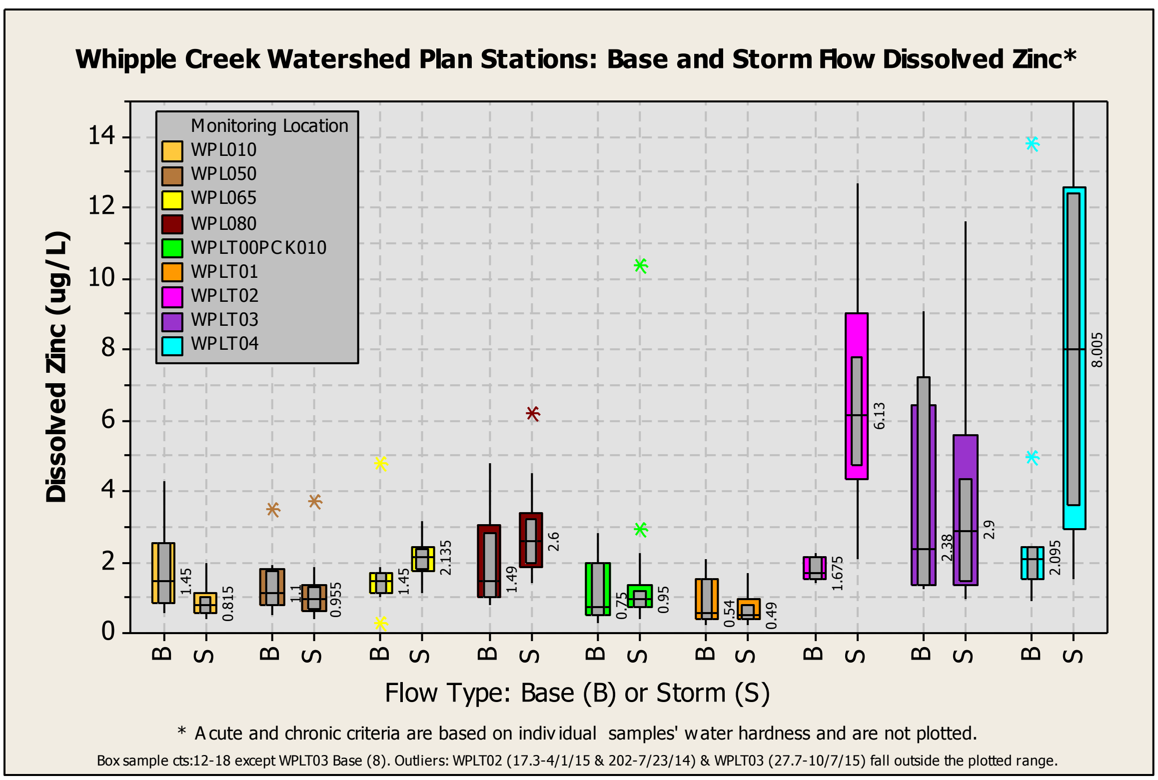

Figure 19 Boxplots of Whipple Creek watershed plan stations' dissolved zinc results grouped by flow type

Figure 20 and Figure 21 present Whipple Creek watershed plan monitoring locations' paired base flow and storm flow probability plots fitted with straight-line log-normal distributions and 95% confidence intervals. These plots show that most of the monitoring stations dissolved metals concentrations fit log-normal distributions fairly well, storm flow concentrations are usually higher (to the right) but often overlap with those of base flow at their lower levels, and the variability (shown by the slope of the straight line distributions) differs considerably for some of the sites.

Overall, for both dissolved metals, there generally is less difference between base and storm flow concentrations throughout their ranges for the main stem locations than for the tributaries (as depicted by the relatively wider separation between base and storm flow distributions for individual tributaries in Figure 20 and Figure 21). The general pattern in both dissolved metals' tributary storm flow probability plots of usually having both flatter slopes and more divergence at higher concentrations (except for WPLTPCK010 – Packard Creek's dissolved zinc) from their base flows suggests that the tributaries are more susceptible to the effects of stormwater runoff especially during the short term periods of stormwater runoff.

Interestingly, while the main stem dissolved zinc probability plots' slopes (variability) remain relatively constant, the horizontal position of their storm flow distributions (and their plotted blue points) appears to gradually shift to the right from downstream to upstream main stem locations (Figure 21). This gradual shift suggest a general increase in storm flow dissolved zinc values from downstream to upstream along the main stem of Whipple Creek. WPL050 and especially WPL010 have unusual horizontal positions in their storm flow dissolved zinc probability plots in that they are mostly less than (to the left of) their corresponding base flow distributions. This switch from the usual pattern of higher storm flow values suggests these lower main stem sites' zinc levels are affected by pollutant travel time (also see above interpretation of within sampling event increasing or decreasing patterns), overall dilution, or some instream mechanism that reduces dissolved zinc levels as they travel downstream.

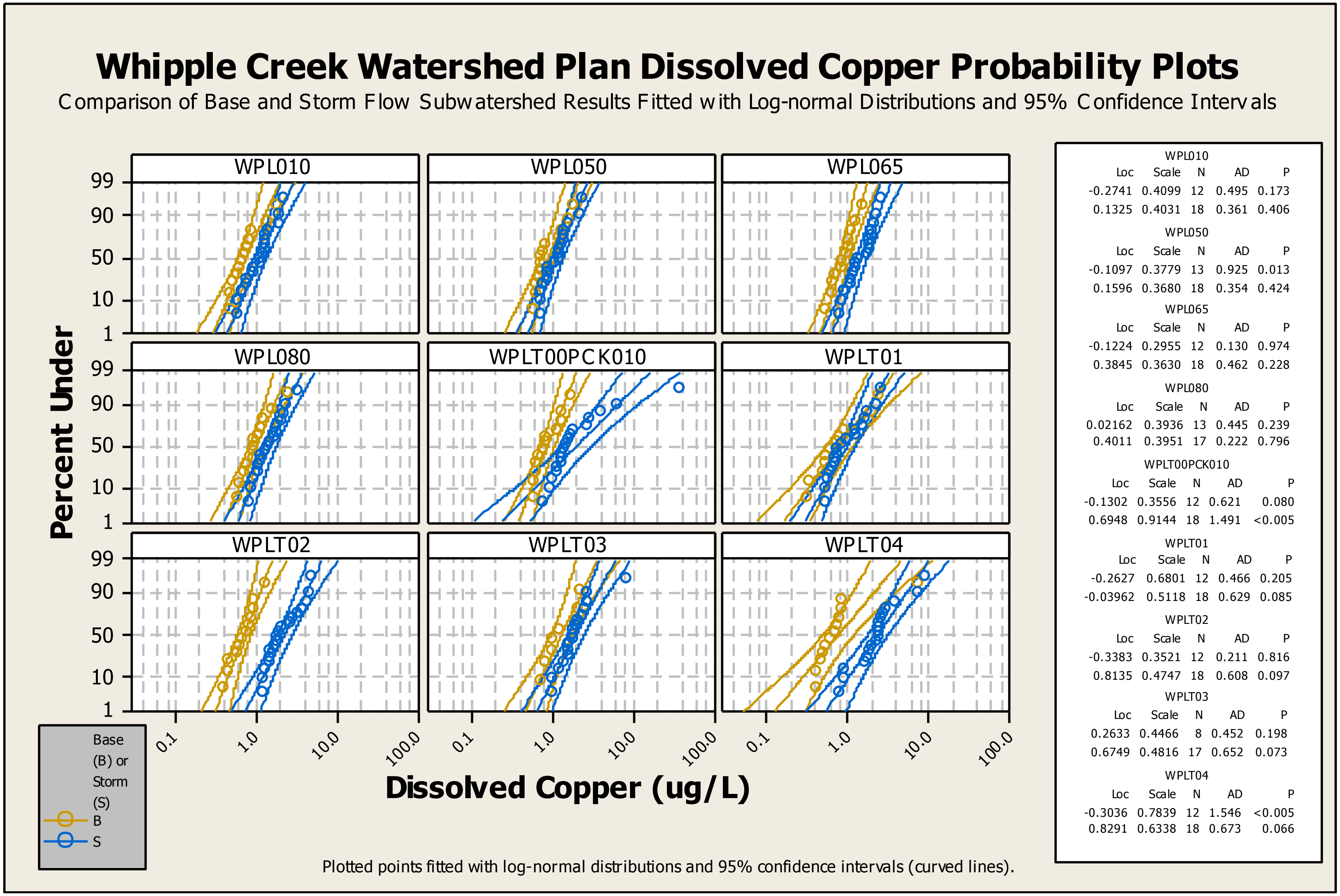

Figure 20 Log-normal probability plots of Whipple Creek watershed plan stations' dissolved copper results grouped by flow type

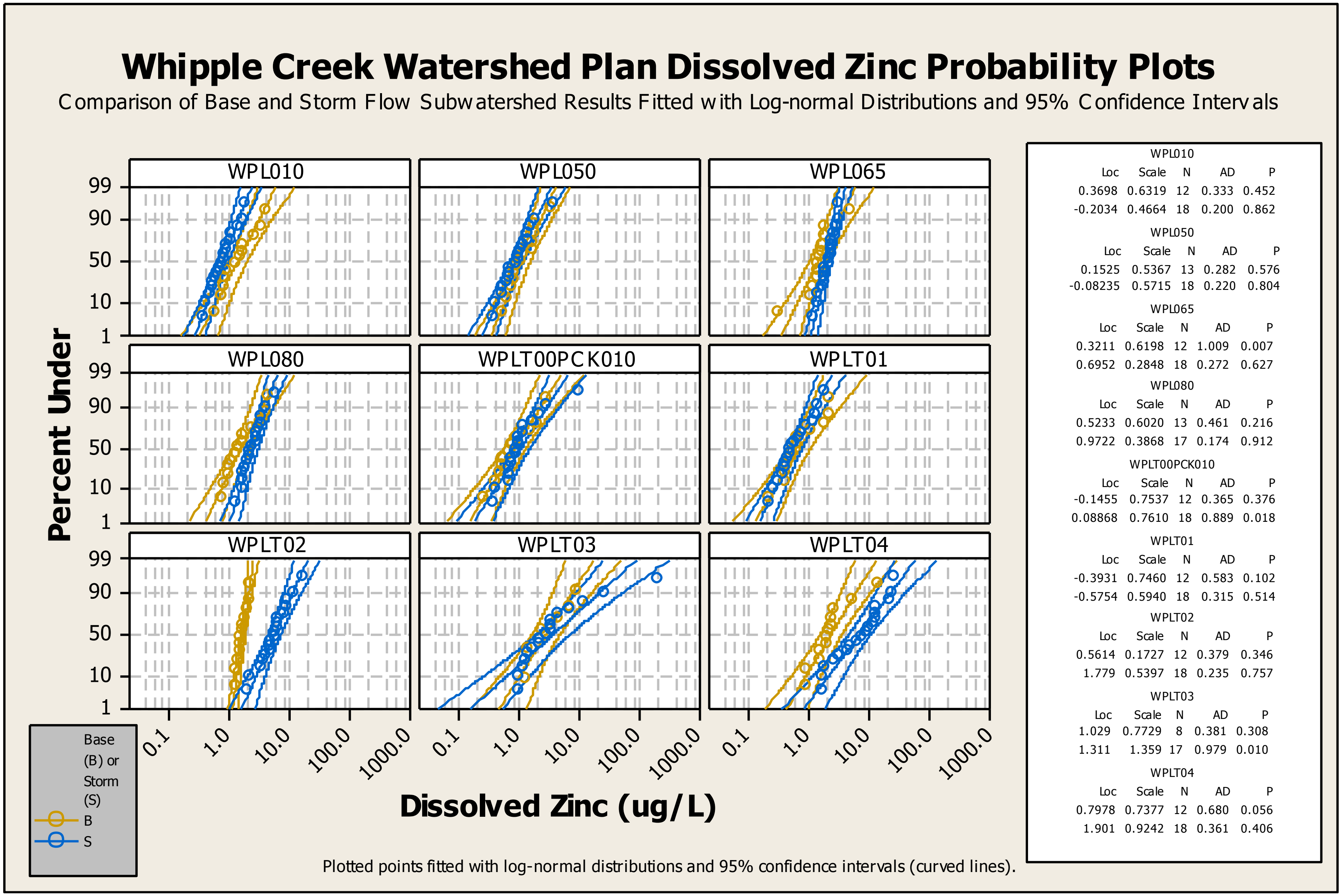

Figure 21 Log-normal probability plots of Whipple Creek watershed plan stations' dissolved zinc results grouped by flow type

pH

The Whipple Creek watershed scatterplot (Figure 22) shows that the vast majority of monitored pH values across all monitoring stations fell within the applicable state standard's pH criteria range of 6.5 to 8.5. Only nine pH values (or 2%) of all measurements fell slightly below the lower criteria value of 6.5. On a station basis, the counts and percentages of all monitored pH values less than 6.5 were: WPL050 – five (2.8%), WPL080 – two (4.7%), and WPLT02 – one (3.2%). The lowest pH value of 5.86 (for WPL050 on 11/25/13) may be of questionable accuracy but could not be eliminated outright based on review of other applicable information.

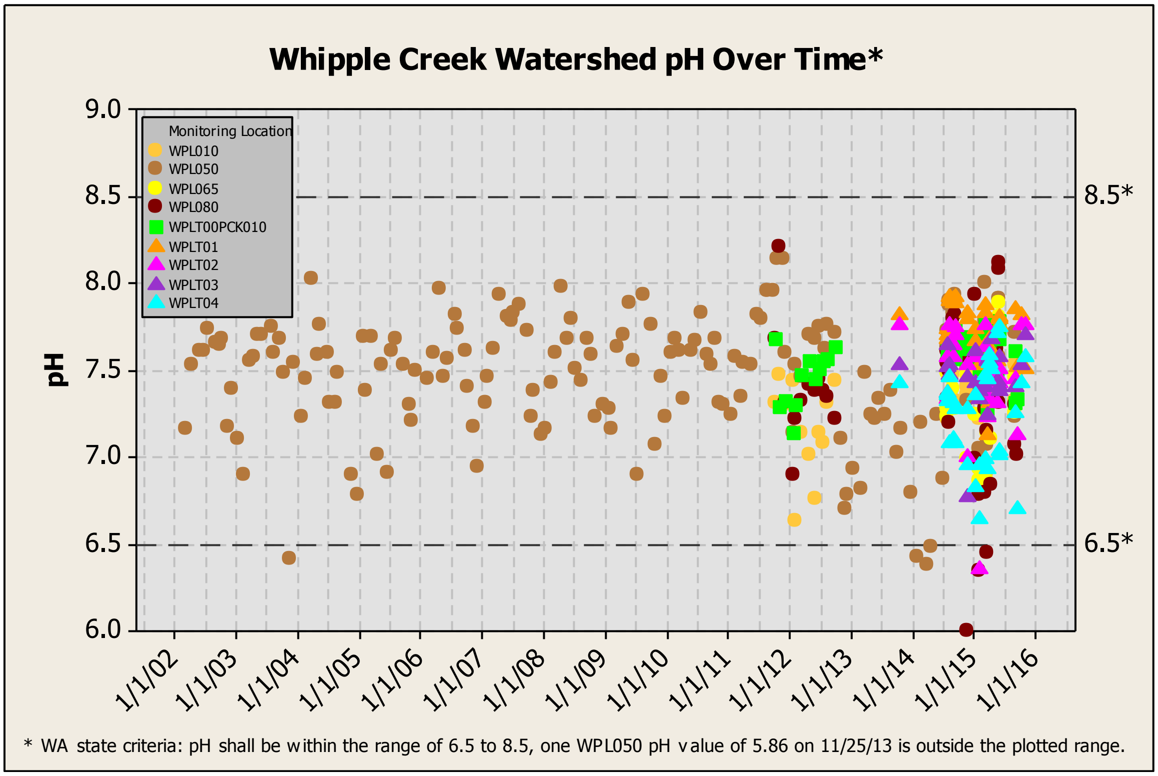

Figure 22 Whipple Creek watershed pH over time and exceedances of state standards

Each of the main stem and tributary group monitoring locations' respective calculated median pH values gradually decrease with distance upstream except for the relatively lower medians for the most downstream main stem (WPL010) and tributary (Packard) stations (Figure 23). However, the only statistical difference in any of the main stem stations' pH medians is that WPL010's is significantly less than WPL050's. Among the tributaries, only WPLT04's median is significantly less than any of the other tributary medians.

There is very little seasonal and flow type influence on median pH values across the Whipple Creek watershed. This is shown by the overlap within the monitoring locations' pairs of internal grey shaded boxes for eight of the nine monitoring locations' paired wet and dry season pH boxplots (Figure 24) and seven of the nine base and storm flow pH boxplots (Figure 25).

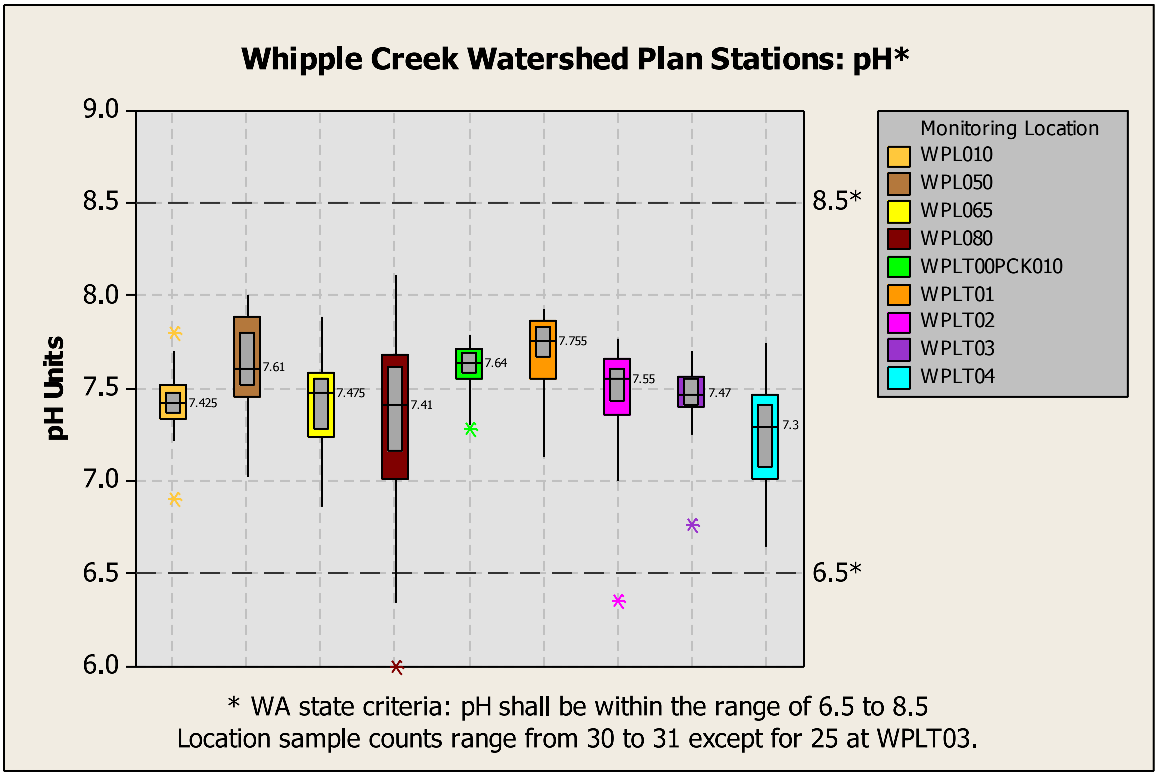

Figure 23 Boxplots of Whipple Creek watershed plan stations' pH results

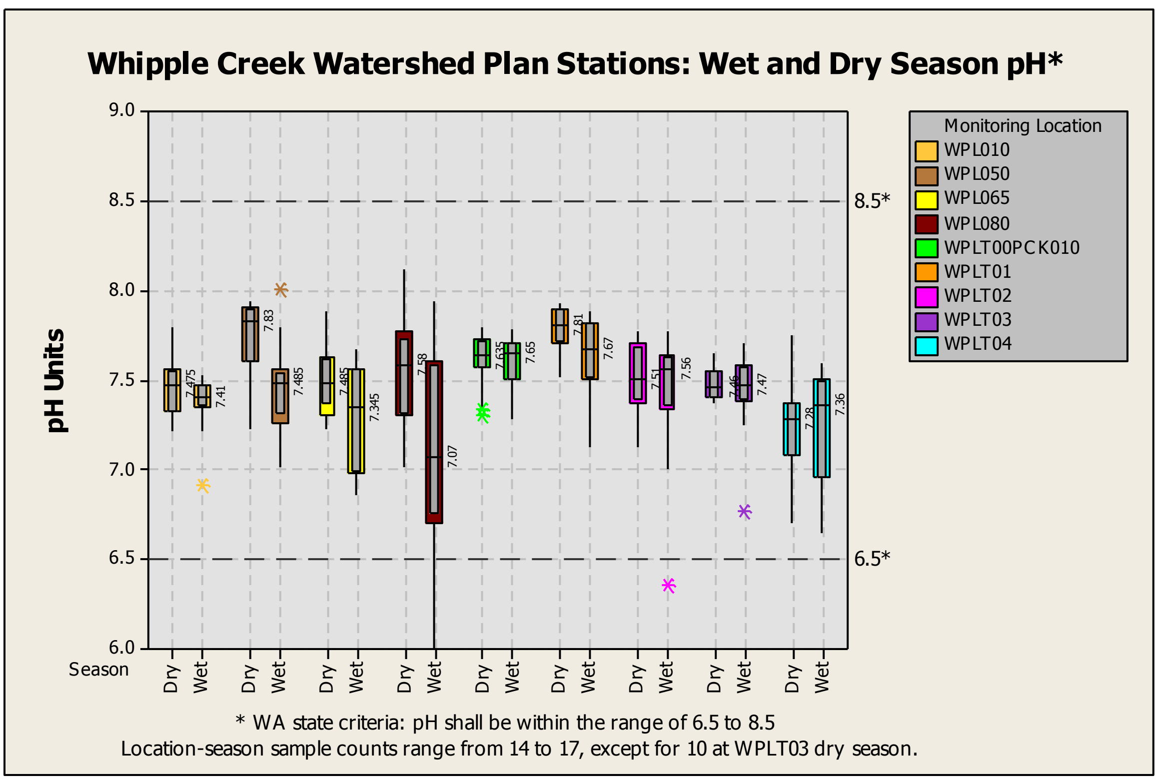

Figure 24 Boxplots of Whipple Creek watershed plan stations' pH results grouped by season

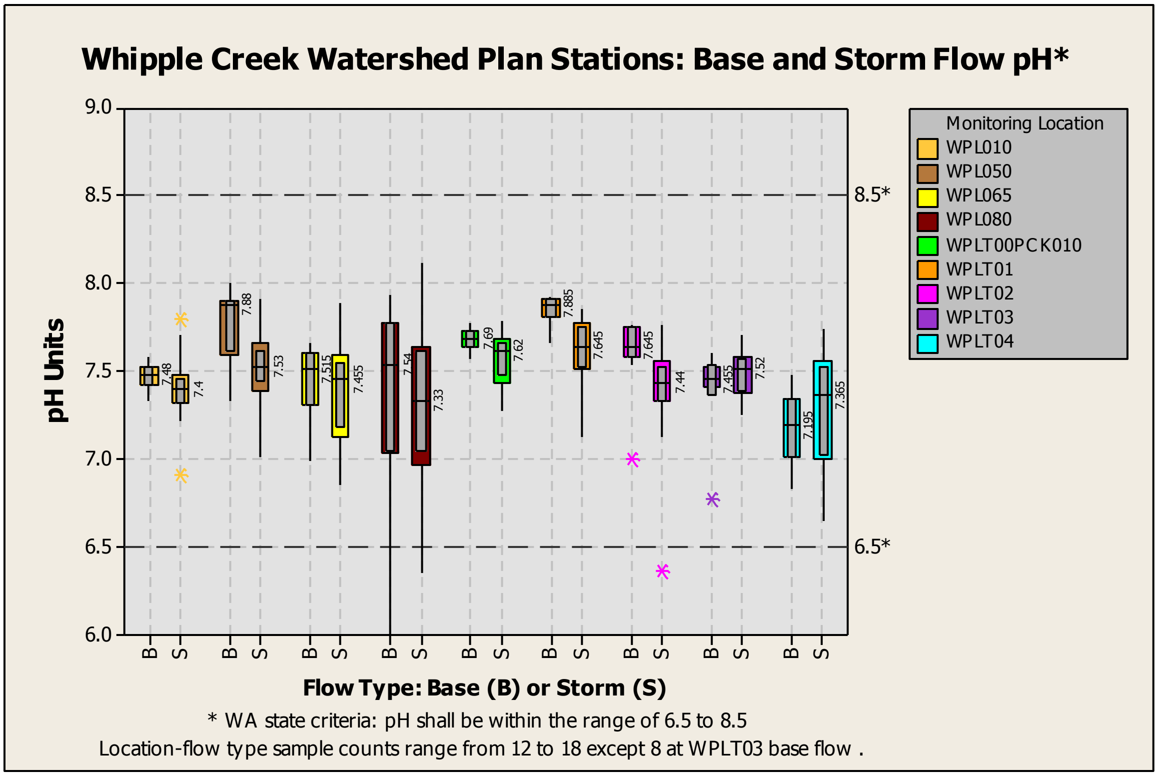

Figure 25 Boxplots of Whipple Creek watershed plan stations' pH results grouped by flow type

Turbidity

High turbidity is a widespread issue throughout the Whipple Creek watershed based on the applicable state criterion of "Turbidity shall not exceed 5 NTU over background when the background is 50 NTU or less" (Ecology, revised 2012, p.13). Figure 26 shows, in fact, the majority (76%) of all Whipple Creek watershed monitoring location turbidity values exceed 7 NTU when an estimated background turbidity level of 2 NTU is used. On an individual monitoring location basis, the percentages of turbidity values greater than 7 NTU range for the main stem stations from 55% (WPL080) to 95% (WPL010) and for tributary stations from 55% (WPLT02) to 98% (Packard Creek). Even the state's alternative criterion of "10% increase in turbidity when the background turbidity is more than 50 NTU" is commonly exceeded.

There are no statistically significant differences in median turbidities across all the Whipple Creek monitoring stations (Figure 27). Similar to pH, there is little seasonal influence on median turbidity values across the Whipple Creek watershed since all of the within monitoring locations' pairs of dry and wet season internal grey boxes overlap (Figure 28). However, just the opposite pattern exists for monitoring location base and storm flow median turbidity values where strong flow type influences are shown by no overlap for all within monitoring location flow type pairs' internal grey boxes (Figure 29). This is likely due to soil erosion during surface runoff and instream channel erosion. WPLT03's base flow turbidity is the most variable across the base flow boxplots. Packard Creek has the highest calculated storm flow median turbidity value but is only significantly higher than the two most upstream main stem storm flow medians for WPL065 and WPL080. The strong influence of flow type on turbidity values is also evident in all the monitoring locations' probability plots where there is an expanding separation with increasing turbidities between the base and storm flow fitted log-normal distributions and plotted points (Figure 30).

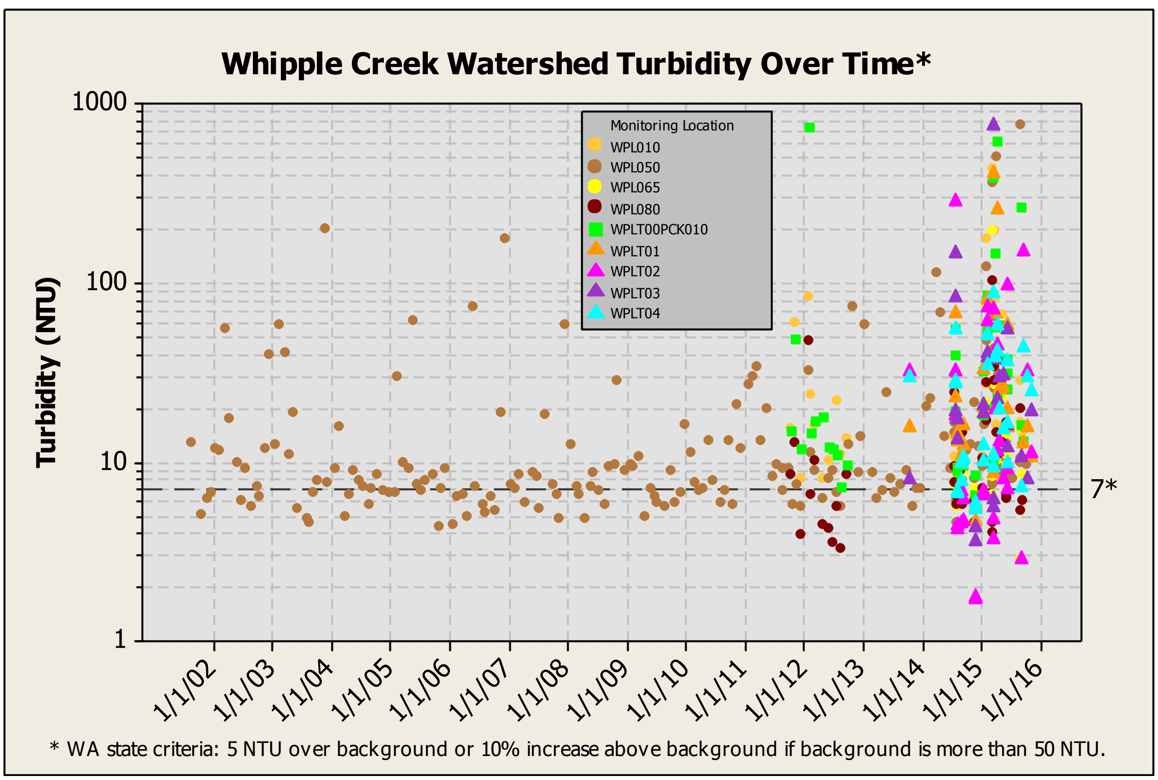

Figure 26 Whipple Creek watershed turbidity over time and exceedances of state standards

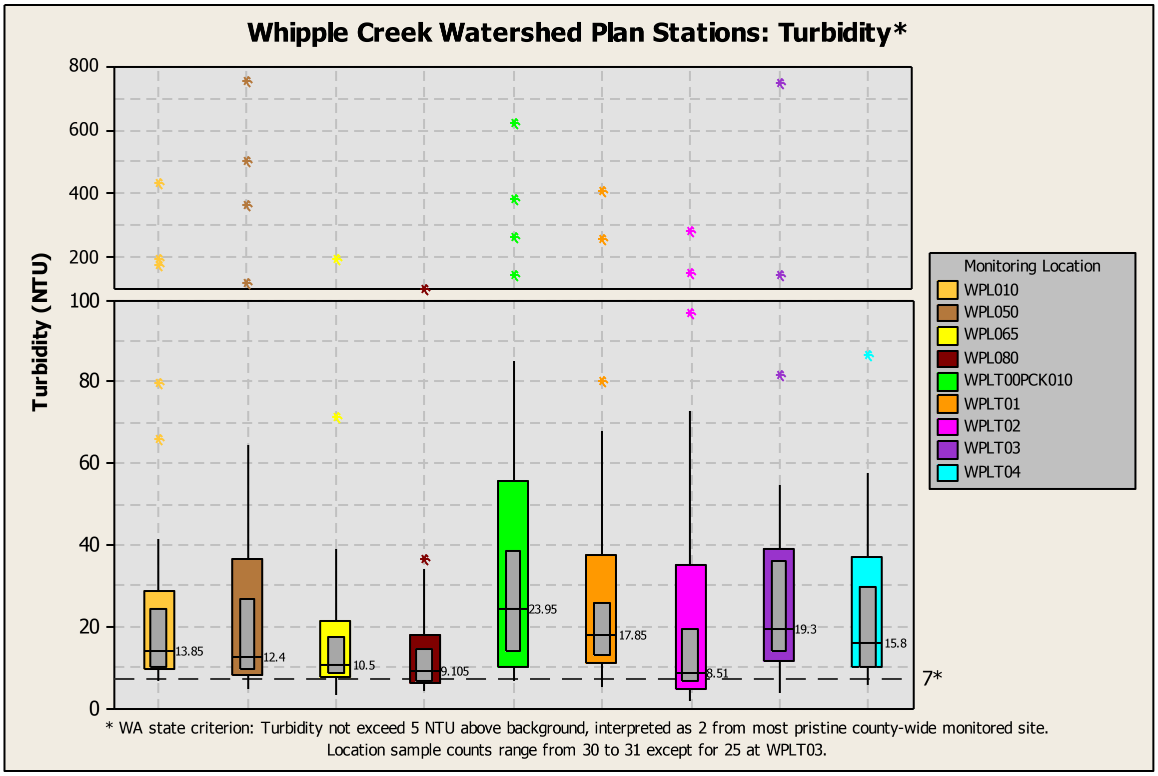

Figure 27 Boxplots of Whipple Creek watershed plan stations' turbidity results

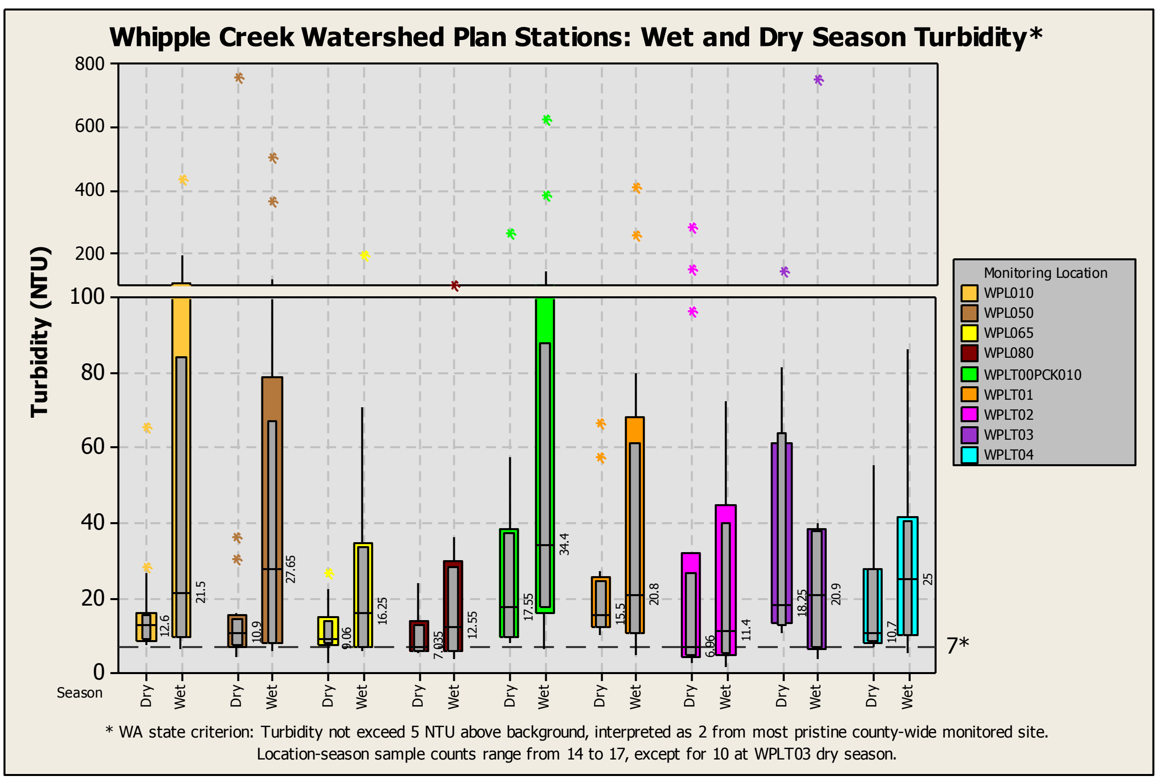

Figure 28 Boxplots of Whipple Creek watershed plan stations' turbidity results grouped by season

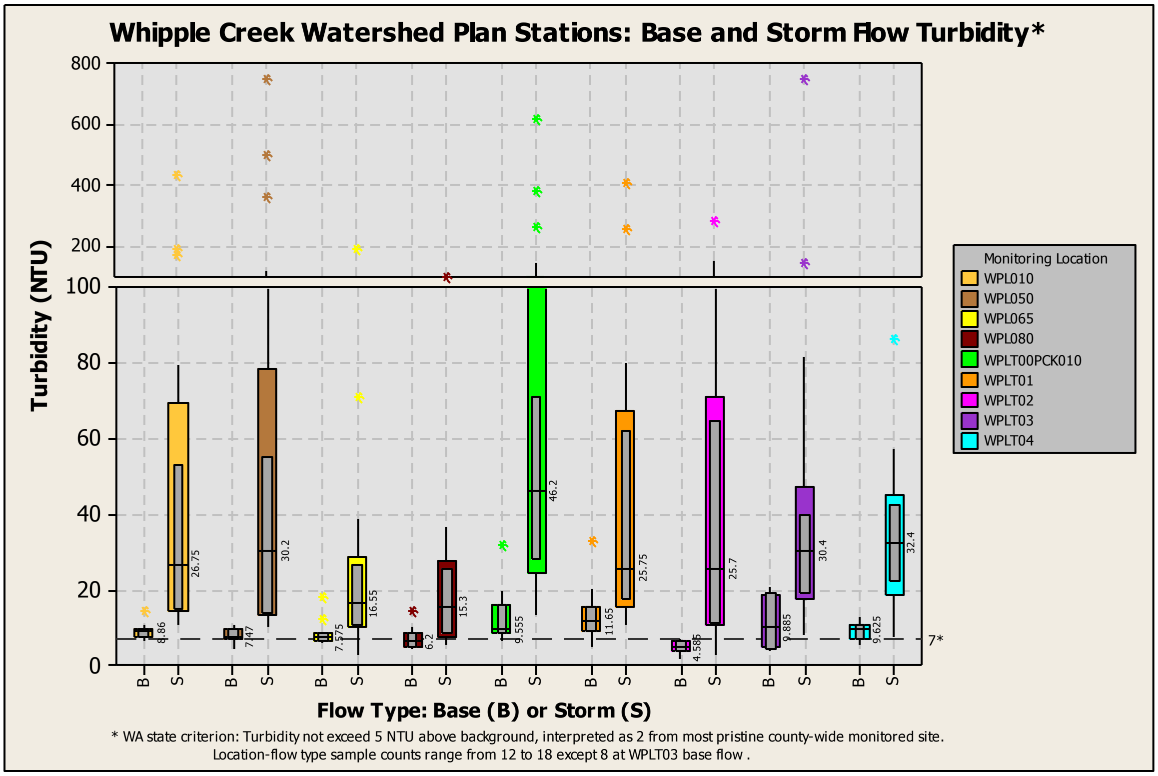

Figure 29 Boxplots of Whipple Creek watershed plan stations' turbidity results grouped by flow type

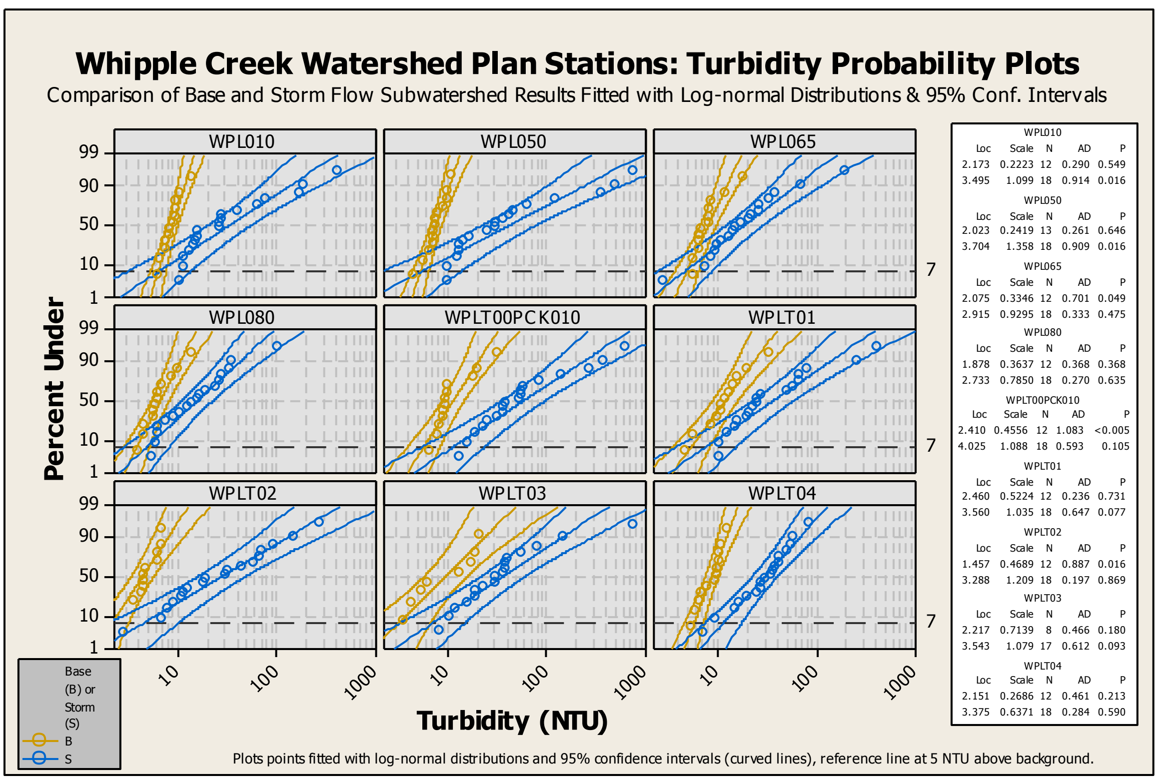

Figure 30 Log-normal probability plots of Whipple Creek watershed plan stations' turbidity results grouped by flow type

Dissolved Oxygen

Based on very limited available data, only a general overview is presented here on the dissolved oxygen conditions for streams in the Whipple Creek watershed. Figure 31 shows existing mid-day dissolved oxygen readings on random dates each month at up to four Whipple Creek watershed stream monitoring locations. Washington State's applicable criterion is included in the plot only for context.

Importantly, Figure 31 does not reflect daily dissolved oxygen minimums since the plotted points represent levels measured close to the middle of the daylight period. Daily dissolved oxygen minimums typically occur near sunrise after over-night respiration depletes oxygen levels and prior to the start of daylight driven photosynthesis potentially increasing dissolved oxygen. Many factors impact dissolved oxygen levels including, among others, biochemical oxygen demand, water temperature impacts on oxygen solubility, localized light intensity, and sunlight duration. The values for many of plotted dissolved oxygen points may be closer to daily peak oxygen levels given the mid-day timing of their measurements. Even with these values likely being closer to daily maximums, six (3%) of all the values (all for WPL050) are below the state 1 day minimum criterion. Given the pattern of many values being within 1 mg/L of the 8 mg/L minimum criterion, it is highly likely that exceedances of the applicable criterion occur especially for the lower main stem watershed locations of WPL010 and WPL050. No further exploratory analyses is performed due to the lack of available diurnal stream dissolved oxygen values and the above noted limitations for interpretation.

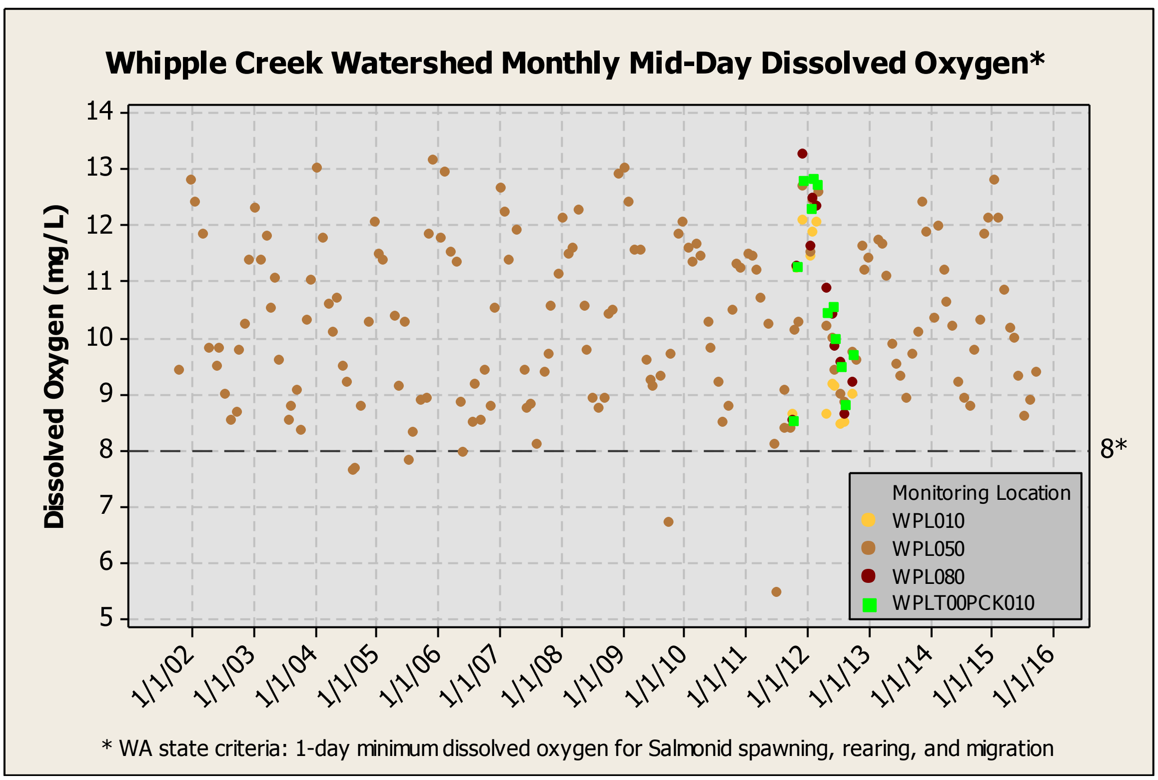

Figure 31 Whipple Creek watershed monthly mid-day dissolved oxygen levels over time relative to state standards criteria

Conclusions

This report and its appendices partially address Clark County's 2013-2018 NPDES Phase I Municipal Stormwater Permit watershed-scale stormwater planning requirement to assess existing water quality conditions within the county selected Whipple Creek watershed. It summarizes conditions and likely general pollutant sources in the watershed based on recent, reliable Clark County water quality monitoring project data and land cover data. Exploratory data analysis was systematically applied to enhance perspectives and gain insights on potential stormwater impacts to inform watershed planning.

This assessment evaluated the Whipple Creek watershed's water quality condition based on state standards for surface waters, general pollutant sources suggested by data patterns revealed through exploratory data analyses, and water quality versus land cover relationships. The most applicable state designated uses to be protected for the watershed's surface waters are: 1) aquatic life use of salmonid spawning, rearing, and migration and 2) human use of primary contact recreation such as swimming.

This assessment concludes that the Whipple Creek watershed's existing water quality is substantially degraded. The latest watershed-wide data indicate four of the seven evaluated standards' parameters were often exceeded throughout much of the watershed; including water temperature, fecal coliform, turbidity, and dissolved oxygen. Only the state standards' criteria for dissolved copper, dissolved zinc, and pH were mostly met throughout much of the monitored watershed. The highest frequency and severity of state standards exceedances generally occurred for warm temperatures on Whipple Creek's middle to lower main stem and developed WPLT04 subwatershed whereas high fecal coliform bacteria and turbidity occurred throughout most of the watershed. Fairly consistent patterns between water quality results for the long-term, lower-mid watershed WPL050 station and more recent results from most watershed- wide stations suggest that some water quality parameters (especially stream temperature, fecal coliform bacteria, turbidity and likely dissolved oxygen) have probably been an ongoing watershed-wide issue for at least several years.

Recommendations

The following are overall recommendations to protect or improve stream water quality during implementation of the Whipple Creek watershed plan:

- Perform stream temperature confirming follow-up field reconnaissance on stream reaches identified as having potentially beneficial cooler temperatures (i.e., WPL080) or excessive heating (i.e., WPLT04 and PCK010) as suggested by watershed wide baseline monitoring.
- After confirming the stream length extent of beneficial cooling or excessive heating, follow up with more detailed field measurements of stream / air temperatures and flow for thermal loadings.
- Based on the detailed thermal loading analyses consider reach specific combinations of management options such as: targeted stream side tree planting, property conservation easements along naturally cool stream reach refugees, and using hot weather forecasts to alter the timed release of cool stormwater stored in existing or future flexibly designed stormwater detention facilities to reduce peak stream temperatures. Perform downstream continuous stream temperature monitoring to confirm / calibrate possible temperature mitigation.
- Evaluate potential stream heating impacts from open water, beaver ponds, and low shading above WPL010, WPL050, WPL065, WPLT04, and PCK010.

- Fecal coliforms generally greater sensitivity to flow type than seasonality suggests surface runoff factors play an important role in bacteria levels so both stormwater and rural/agricultural fecal coliform Best Management Practices (BMPs) should be pursued.
- Consistent fecal coliform patterns of high dry season storm flow medians versus very low wet season base flow medians are likely driven by a combination of storm runoff of accumulated nonpoint source bacteria between dry season storms versus more dilution of constant bacteria sources such as failing septic systems during wet season base flows. These patterns are especially pronounced for Packard Creek, WPLT01, and WPLT03 so pursuing both stormwater and rural/agricultural fecal coliform BMPS should be a priority for them.
- Relatively high dry season base flow fecal coliform medians for WPLT01 and WPLT03 suggest ongoing contribution of bacteria from wildlife, livestock, or failing septic systems so these potential sources would need further investigation.
- While the relatively few isolated state standards exceedances during storm flows for dissolved zinc and especially dissolved copper may suggest these metals are currently not substantial problems, their tendencies of increasing concentrations for storm flows over base flows (though usually not significant) and from downstream to more developed upstream subwatersheds suggest the need to address stormwater impacts.
- The Water Quality versus Land Cover Relationships findings of significant direct relationships between development and dissolved metals medians (dissolved zinc appears more sensitive than dissolved copper to development impacts) for the most developed subwatersheds supports likely stormwater impacts and the need to continue addressing especially zinc with stormwater BMPs.
- Given the predominant and consistent relationship 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.
- The consistent and substantial contrast between patterns in storm and base flow dissolved zinc median concentrations versus land cover strongly suggest the important role stormwater plays and the need to address this pollutant in the more developed subwatersheds.
- Preliminary linear regression analyses suggest with 95% confidence, 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. These local thresholds could serve to help inform and prioritize stormwater management efforts.
- Currently pH is not an issue that needs to be addressed in the Whipple Creek watershed.
- Wide spread high turbidity issues should be addressed by reducing soil and channel erosion.
- Apparent wide spread low dissolved oxygen issues can be addressed using the same management tools used for temperature.

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Appendices

Appendix 1 Whipple Creek Watershed Stream Temperatures

Whipple Creek Watershed Stream Temperatures

Introduction

This document addresses the important stream temperature component of Clark County's Whipple Creek watershed assessment of existing water quality conditions. The assessment is required for watershed-scale stormwater planning by the NPDES Phase I Municipal Stormwater Permit (WA Dept. of Ecology, 2012).

Under sections 305 (b) and 303(d) of the federal Clean Water Act, Washington State is required to perform regular water quality assessments and list the status of waterbodies in the state (Washington Department of Ecology 303d web page). The state's 303 (d) list includes those waters that are in the polluted water category for which beneficial uses are impaired. Under the state's latest 303 (d) listing from 2014, approximately 1.4 stream miles of the main stem of Whipple Creek downstream from the WPL050 site is listed for high water temperatures under category 5. Under this category, polluted waters require a Total Maximum Daily Load (TMDL) or other water quality improvement project. This impaired water body's category means Ecology has data showing that water quality standards have been violated for one or more pollutants, and there is no TMDL or pollution control plan. The state's listing is based on unpublished 2002 and 2006 through 2010 Clark County stream temperature data from station WPL050.

Recent county watershed-wide monitoring during the summers of 2014 and 2015 demonstrate individual streams' relative susceptibility to heating. Susceptibility is suggested by patterns in the spatial distribution, duration, and magnitude of concurrent average peak summer stream temperatures. Stream locations showing anomalies from the general pattern, such as sites with extended periods of unusually warm or cold average values, often are of the most interest for watershed management activities.

Differences across streams' concurrent average peak summer stream temperatures take into account the net effect of multiple heating factors on individual stream reaches while muting confounding seasonal variability. Important summer heating or cooling factors on stream reaches include: the amount of solar radiation versus shading; heat transfer between stream water and the air or exposed streambed rocks; the combined thermal loading effects from previous warm days / nights and varying flows and temperatures of upstream reaches; and the relative contributions from fairly constant temperature cooler groundwater. Typically, the highest Whipple Creek watershed stream temperatures occur during consecutive very warm summer days that have a cumulative heating impact on streams during very low flows.

The patterns in concurrent maximum stream temperature can help spatially and temporally target permanent long-term through temporary short-term specific watershed management activities to both protect relatively cool thermal refuges and mitigate warmer stream reaches. Future long-term actions could include permanent conservation easements along existing beneficial cooler stream reaches or warmer stream reaches targeted for streamside tree planting. Promoting low impact development and continued implementation of stormwater best management practices improves wet season stormwater infiltration and cooler groundwater contribution to summer base flows. Summer heatwaves could trigger short-term water releases from relatively cooler depths of specifically designed stormwater detention facilities to reduce peak temperatures on targeted heat stressed stream reaches. Recent cellular communication and control technology allows for offsite monitoring and remotely controlled releases from targeted facilities based on weather forecasts. Maximum stream temperature patterns should be taken into account in targeting flexible designs of future stormwater facilities and management actions.

Methods

There are several background items common across all monitoring results presented. Each monitoring station name consists of a three-letter abbreviation of the monitored stream's name followed by three numbers indicating its approximate location as a percentage upstream from the stream mouth. Most of the stream temperature analyses use 7-Day Average Daily Maximum (7-DAD Maximum) water or air temperatures. The 7-DAD Maximum represents a moving average of seven daily maximum temperatures centered on day four. The 7-DAD Maximum water temperatures are compared to Washington's criterion of 17.5 degrees Celsius that is applicable to the Whipple Creek watershed's streams.

Monitoring locations were chosen to provide representative temperature measurements along targeted areas of the Whipple Creek main stem or tributary stream mouths. Stream temperatures were monitored continuously during the summers of 2014 and 2015 at up to ten Whipple Creek watershed sites (Figure 32). These sites included five along the main stem (i.e., WPL010, WPL050, WPL065, WPL080, and WPL090) and five on tributaries (i.e., PCK010, WPLT01, WPLT02, WPLT03, and WPLT04). The tributary site WPLT04 was monitored only during the summer of 2015.

Clark County staff monitored stream temperatures following standard operating procedures (Clark County, 2003, pp. 19-22). In situ stream temperature measurements were automatically logged every hour using programmed Onset HOBO® Water Temp Pro v2 combination temperature sensors / loggers. Within each targeted stream reach, field staff found locations primarily with adequate water depth and secondarily with representative shading. Steel rebars hammered into the streambed secured PVC pipe-protected / shaded Water Temp Pros at a submerged depth near the streambed. Specific locations were flagged using color tape and photographed to make them easier to find later (Figure 33). At least annually, stream temperature data were downloaded in the field from the loggers to an Onset HOBO® Optic USB Base Station data shuttle.

After two summers of data collection, Clark County staff compiled, manipulated, and analyzed temperature data. Following field trips, stream temperature data were uploaded from the data shuttle into Microsoft Excel 2010 ® spreadsheets to store and initially review the data. Air temperature data were compiled from National Weather Service web sites. Stream and air temperature 7-DAD Maximums were also calculated using the spreadsheets. Maps were created using ESRI ARC MAP 10.2.2®. All graphs were created using MINITAB® Release 14 Statistical Software.

The Whipple Creek watershed's large summer stream temperature data set is summarized in a series of graphs and figures that include bar charts, a map, time series plots, cumulative distribution function plots, and scatter plots fitted with Lowess smoother lines. The bar charts show counts of the monitored streams' exceedances of applicable state stream temperature criterion. The map depicts the watershed wide spatial distribution of exceedances grouped by count categories overlaid, for context, on an aerial image of land cover. The time series plots compare two summers of concurrent daily values for multiple sites' average maximum stream temperatures (i.e. 7-DAD Maximums), the lower Whipple Creek's flows at WPL050, and air temperature ranges. The cumulative distribution function plots show how each site's 7-DAD Maximum results change over different percentages of the sorted results. The scatterplots depict the relationship between concurrent 7-DAD Maximum stream versus air temperatures.

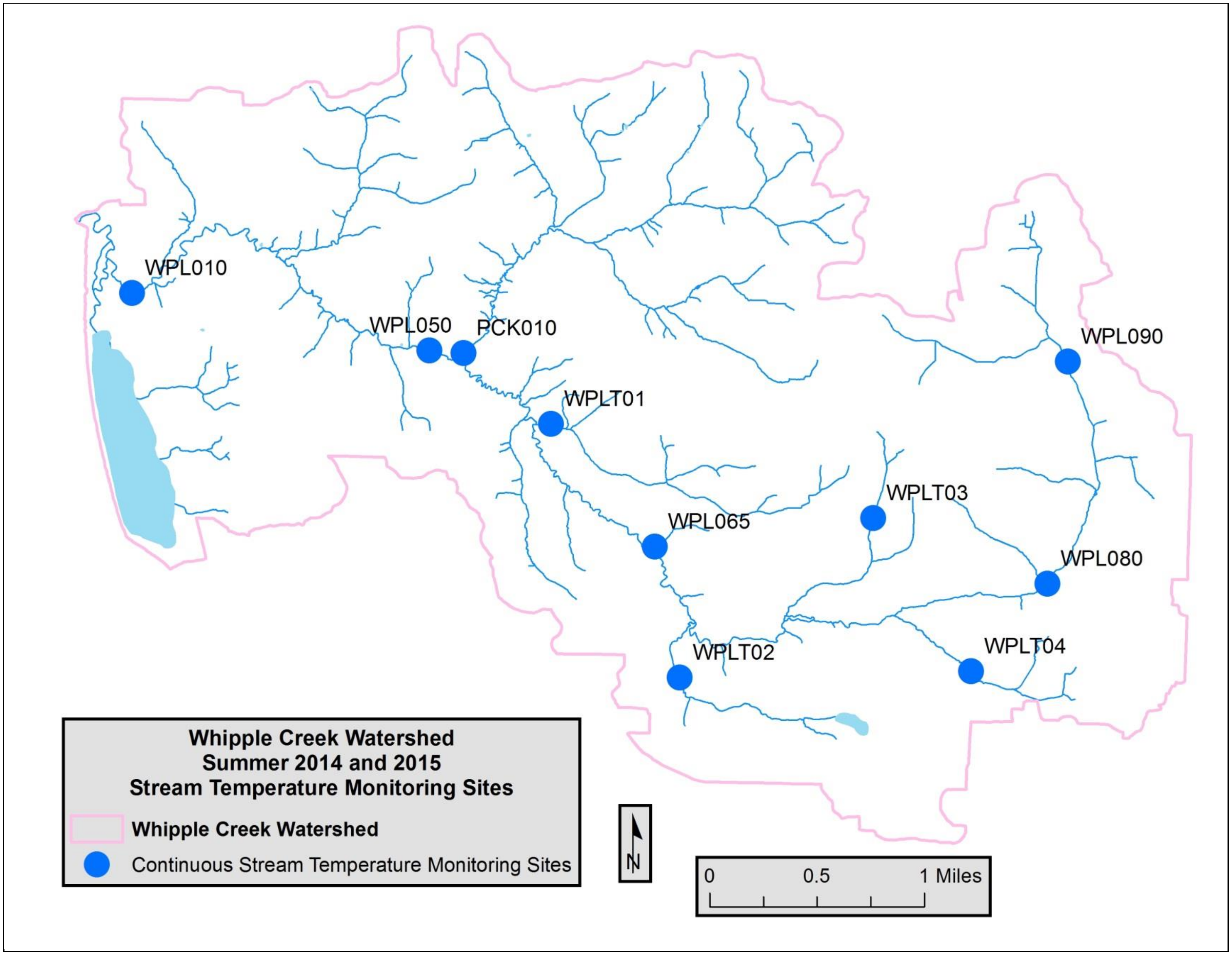

Figure 32 Whipple Creek Watershed stream temperature monitoring sites

Figure 33 Example of temperature logger location with flagging tape as shown for Packard Creek (PCK010)

Results and Discussion

Weather During Watershed Monitoring

Since weather can be a major driver of stream temperatures, the following presents a summary of 2014 and 2015 summer daily temperature and precipitation data from nearby long-term weather stations concurrent with most of the presented stream temperature results. Overall, the summer of 2014 was somewhat warmer over most of the summer months with fairly typical precipitation but the summer of 2015 was unusually hot and dry (National Weather Service Annual Climate Reports for Portland, Oregon, 2016, online at WEATHER.GOV/PORTLAND).

Table 5 summarizes the amount of departure from normal (derived from weather station daily mean temperature or total precipitation values for the 1980-2010 normal comparison period) for the primarily targeted 2014 and 2015 summer months' daily mean air temperature or total precipitation values. The five-month total departures from normal reflect the cumulative impact over each year's entire summer from unusual air temperatures or precipitation. The five-month average departure represents the typical monthly departure over the five summer months. The five-month total departures show that 2015's cumulative temperature departure of +16.6 ° F was 70% more than 2014's already above normal cumulative departure of +9.7 ° F. Conversely, the very dry 2015 five-month cumulative precipitation departure was more than 17 times lower than that of 2014.

More specifically, the National Weather Service Portland Oregon office reports both downtown Portland (monitored since 1874) and the nearby Portland International Airport weather station (i.e., PDX monitored since 1940, with normals based on the latest three decade period 1980-2010) broke several heat and no rainfall period records during the summer of 2015. In 2015, downtown Portland had the most June days having at least 80° F. (18 days) and the second most days in June with no rain (27 days). For the 2015 warm season, PDX set records of 88 days with high temperatures of at least 80 ° F (normal is 54 days) and 29 days with high temperatures of at least 90 ° F (normal is 12 days) while also having two days in July over 100° F. On a monthly basis during 2015 for PDX: June had the warmest daily average highs, lows, and means; most days above 90 ° F (9 days); and most consecutive days with no rain (24 days); July was the second warmest July; August was on the warmer side but was more normal; and September had near normal temperatures and rainfall.

Table 5 PDX weather station mean monthly values departures from normal

	PDX Weather Station Monthly Values Departures From Normal			
	Mean Temperature (° F)		Total Rainfall (inches)	
Month	2014	2015	2014	2015
May	+2.4	+2.8	-0.08	-1.88
June	-0.4	+6.7	+0.63	-1.30
July	+2.1	+4.7	+0.40	-0.08
August	+3.0	+2.9	-0.66	-0.01
September	+2.6	-0.5	-0.49	-0.21
5 Month Total	+9.7	+16.6	-0.20	-3.48
5 Month Avg.	+1.9	+3.3	-0.04	-0.70

2014 and 2015 Summer Stream Temperature Monitoring Results

The two summers of simultaneous continuous stream temperature monitoring across multiple Whipple Creek watershed sites allows more in-depth comparisons of how this important water quality parameter varies throughout the watershed over biologically stressful warm periods. These detailed monitoring results support: analyses at a higher temporal and spatial resolution, greater confidence in capturing a representative range of temperatures, interpretation across a broader context of weather conditions, and accounting for location factors in addressing subwatershed or stream reach susceptibility to heating.

Comparisons of the two consecutive summer stream temperature data sets enhances an evaluation of the relative cumulative impact from or resistance to heating at each site assuming that other location factors have not dramatically changed over this timeframe. Many subwatershed scale and site-specific factors, such as degree of shading and relative groundwater contributions to base flow, can substantially affect an individual stream site's summer temperature regime or pattern. However, usually the cumulative impact of these site-specific location factors on summer stream temperature regimes is relatively consistent year over year unless there is a dramatic landscape change at the monitoring site or upstream of it. Even if landscape changes occurred at one site, it is unlikely to occur similarly across all monitoring sites. Therefore, the magnitude of stream temperature differences at corresponding portions of consecutive summers and the cumulative differences in their summer regimes is more likely the net result of each site's relative resistance to the two summers' heating.

For 2014 and 2015 watershed wide stream temperature context, Figure 34 shows that the lower Whipple Creek main stem (monitored at WPL050) has a long history from at least 2002 through 2015 of exceeding the state's applicable stream temperature criterion multiple times per year during the summer. Historically, most WPL050 exceedances occurred during the months of July and August.

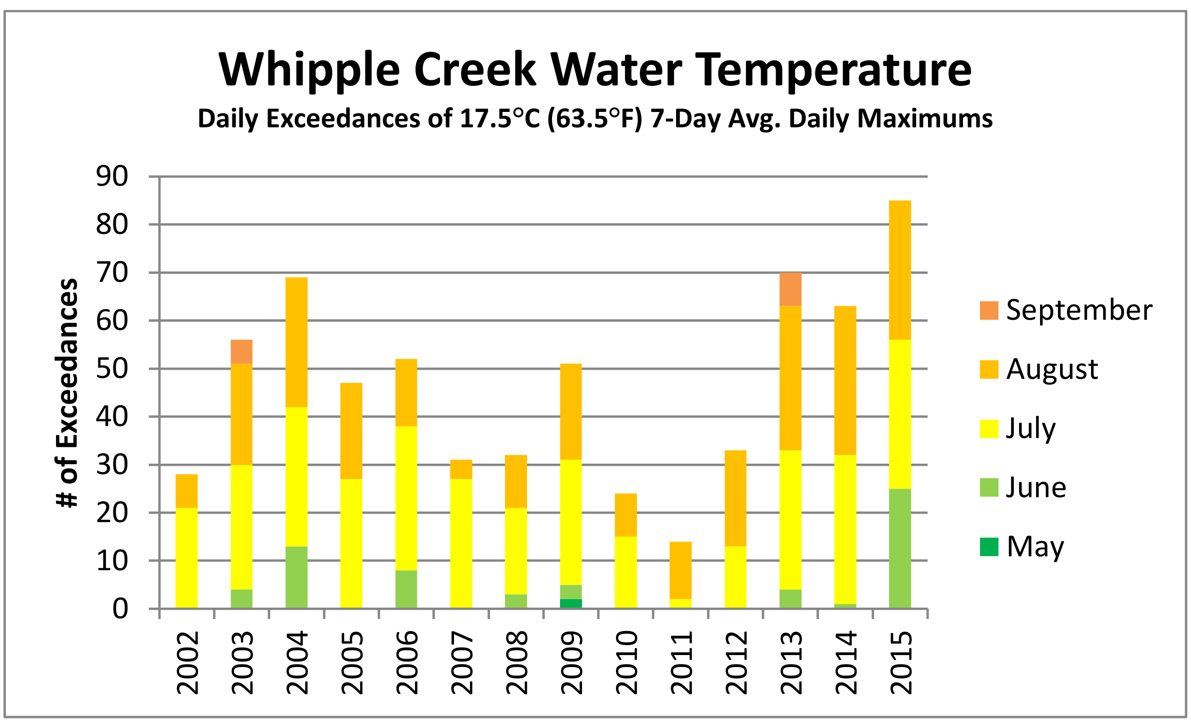

Figure 34 Lower Whipple Creek WPL050 main stem sites long-term exceedances of state temperature criterion

Figure 35 summarizes more recent information from the summers of 2014 and 2015 on the frequency of state criterion temperature exceedances across the Whipple Creek watershed. Similar to the earlier pattern shown for WPL050, most exceedances also occurred during the warmest months of July and August on the lower main stem sites, more urbanized WPLT04 tributary, and the large mid-watershed Packard Creek (PCK010) tributary. The lower main stem's and Packard Creek's relatively low riparian shading and cumulative upstream heat loading impacts probably contribute to their common exceedances. WPL050's summer 2015 count of 85 exceedances was the most recorded (an increase of about 21% over the previous 2013 high count of 70) for this location, likely reflecting the very warm heating early in the summer of 2015.

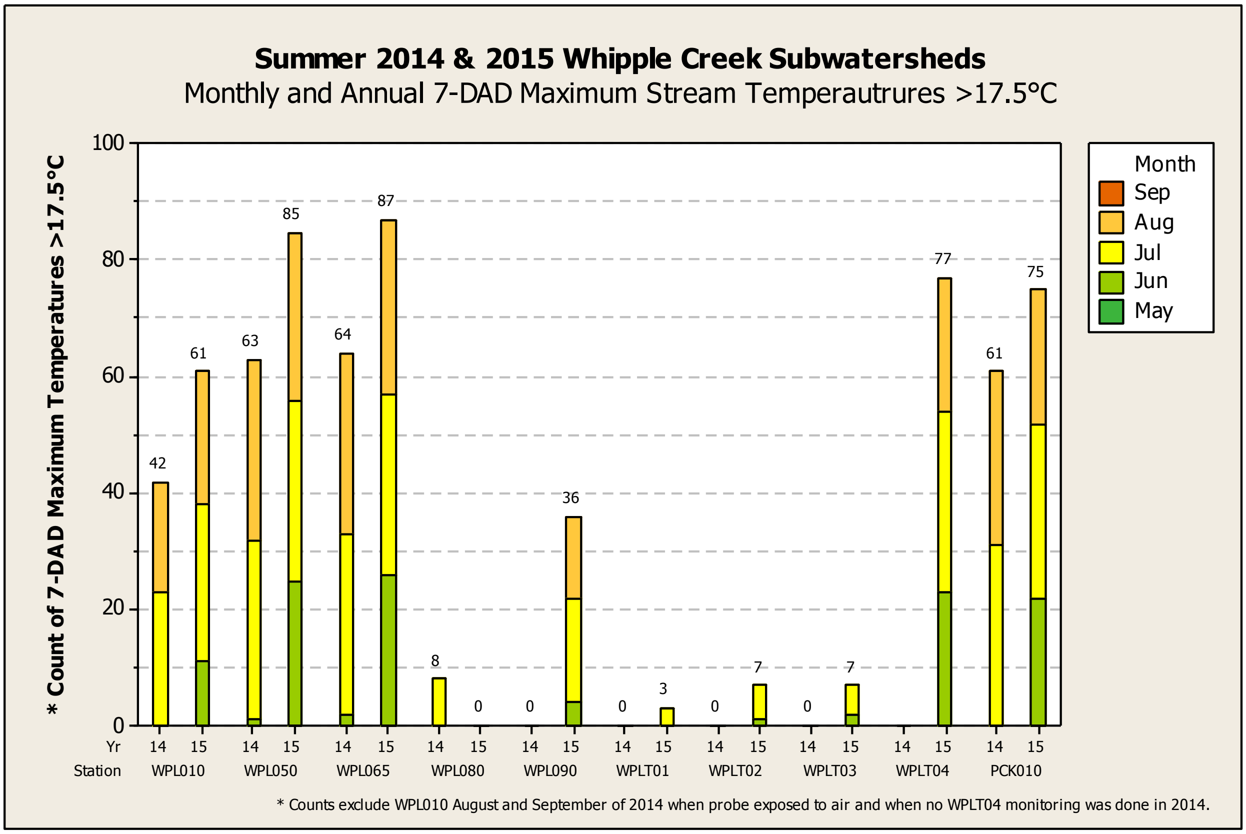

Figure 35 Whipple Creek subwatershed monthly/annual counts of 7-DAD maximum stream temperatures greater than 17.5 °C

Figure 36 shows, for the exceptionally warm summer of 2015, the distribution across the watershed of stream temperature exceedances (grouped into categories of counts) in the context of land cover depicted by an aerial image from 2013. Relatively little riparian shading (as suggested by the lack of or very narrow bands of dark green vegetation areas adjacent to stream reaches) is more pronounced especially along Whipple Creek's lower main stem and above WPLT04. These reaches with reduced riparian cover are consistent with their higher number of exceedances. Conversely, most of monitored tributary stream sites with more forested riparian areas and less urbanized watersheds (i.e., WPLT01 and WPLT03) tend to have fewer exceedances.

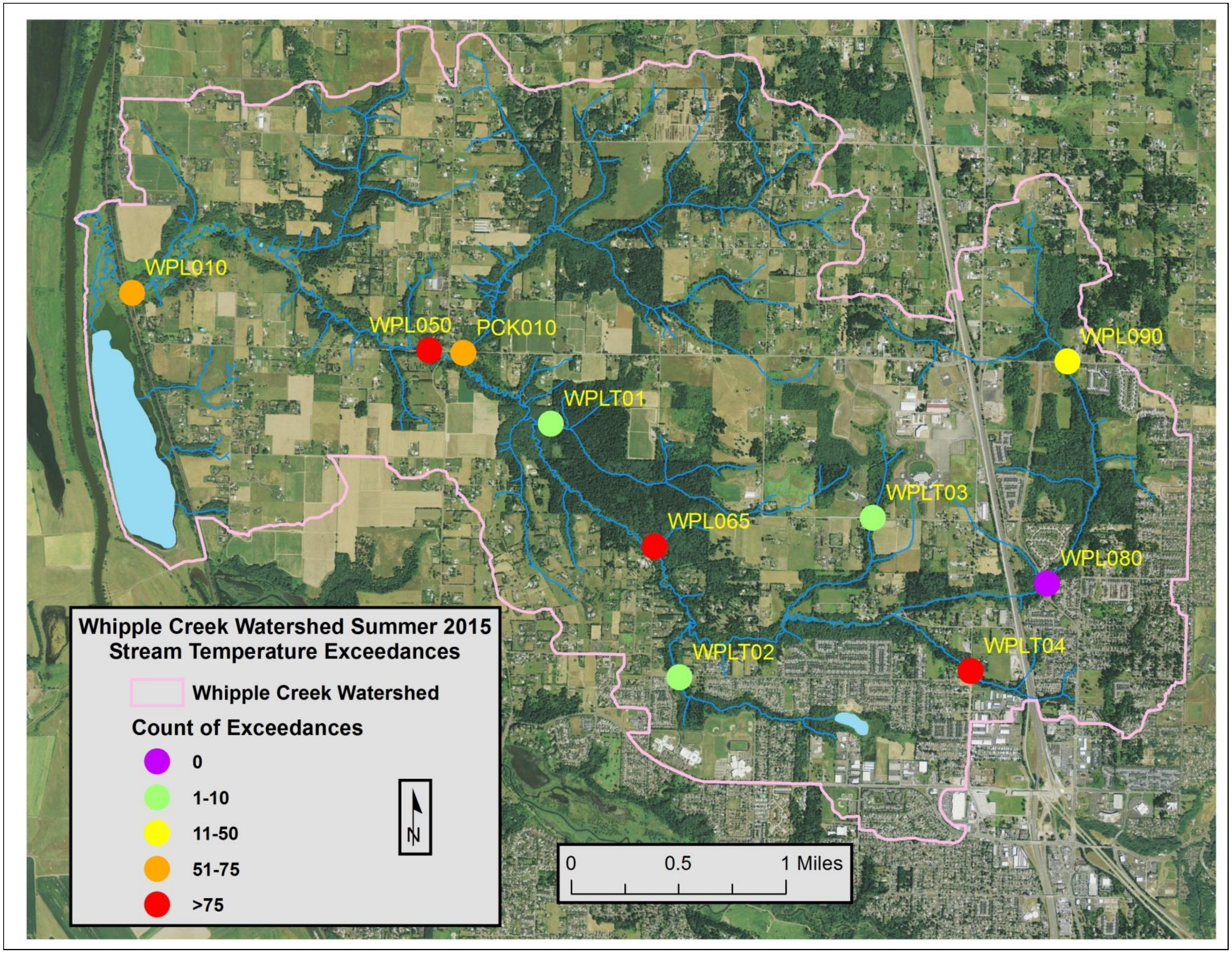

Figure 36 Whipple Creek watershed stream temperature exceedances of state temperature criteria

While recognizing the caveat that relatively small differences in stream temperatures can be driven by site-specific conditions, several general patterns did emerge in the Whipple Creek watershed data. Figure 37 and Figure 38 present, respectively, summer 2014 and 2015 daily time series of: each Whipple Creek monitoring sites' 7-DAD Maximums, the lower main stem Whipple Creek (WPL050) mean daily flows, and a nearby National Weather Service station's (Portland, Oregon Airport – PDX) daily air temperature maximums, minimums, and departures from normal.

Compared to 2014, the summer of 2015's unusually warm air temperatures are shown by the much more common and longer duration of above normal daily mean air temperatures (dashed green lines) shown in the lower graphs of Figure 37 and Figure 38. However, if warming climate trends continue, the 2015 air temperatures may be more typical of future biologically stressful summer conditions.

As would be expected, many of the summer WPL050 flow peaks shown in Figure 37 and Figure 38 approximately coincide with dips in the 7-DAD Maximums. This overall pattern likely reflects the cooling effect on stream temperatures from relatively colder summer storm rainfall, overcast periods' reduced direct solar heating, and possibly more cool groundwater remaining in the streams due to less evapotranspiration. Given the multiple day moving average calculation of the 7-DAD Maximums, corresponding dips in daily mean stream temperatures would have been more substantial. Contrasting with the other monitoring stations, WPL080's unusual stream temperature increases (medium dark blue solid line) immediately around and after the first late summer storms (with large antecedent dry periods) suggest that this site's likely groundwater dominated, previously consistently cool base flow becomes overwhelmed and heated by warmer stormflow.

Interestingly, most of the main stem 7-DAD Maximums (solid color lines) track together fairly tightly until they start to exceed the state criterion of 17.5 degrees Celsius in early July of 2014 and early June 2015. The lower main stem (i.e., WPL010, WPL050, and WPL065) temperatures still generally parallel each other after the start of July 2014 while after early June 2015 they tend to diverge further apart, especially during the warmest months of July and August. Summer 2015's one-month earlier rise above the criterion and larger divergence of temperatures likely are due to the unusually warm and dry summer of 2015 and varying stream heating susceptibility. Reflecting its headwater character similar to tributaries, the uppermost main stem site WPL090 temperatures stay well below those of all the other main stem sites.

During both summers, the upper main stem site WPL080 temperatures track tightly with the other main stem sites until they rise above the criterion, after which WPL080 substantially diverges from them staying mostly below the criterion during both summers. WPL080 temperatures tended to actually decline slightly during the warmest months as the other main stem stations' temperatures tended to increase and bounce around at much warmer temperatures.WPL080's cooler temperatures could reflect an increasing proportion of its flow coming from typically consistent cooler groundwater. Ground water temperatures, as measured from a nearby (Latitude 45 44 06 N, Longitude 122 40 50 W, approximately 1.25 miles west of WPL080) 196 foot deep well on May 16, 1988 suggest ground water temperatures of about 13 degrees Celsius (USGS, Turney, 1990, pp. 54-55). WPL080's decreasing temperatures are unlikely due solely to slight increases in riparian plant cover because shading would likely be fairly constant during the summer.

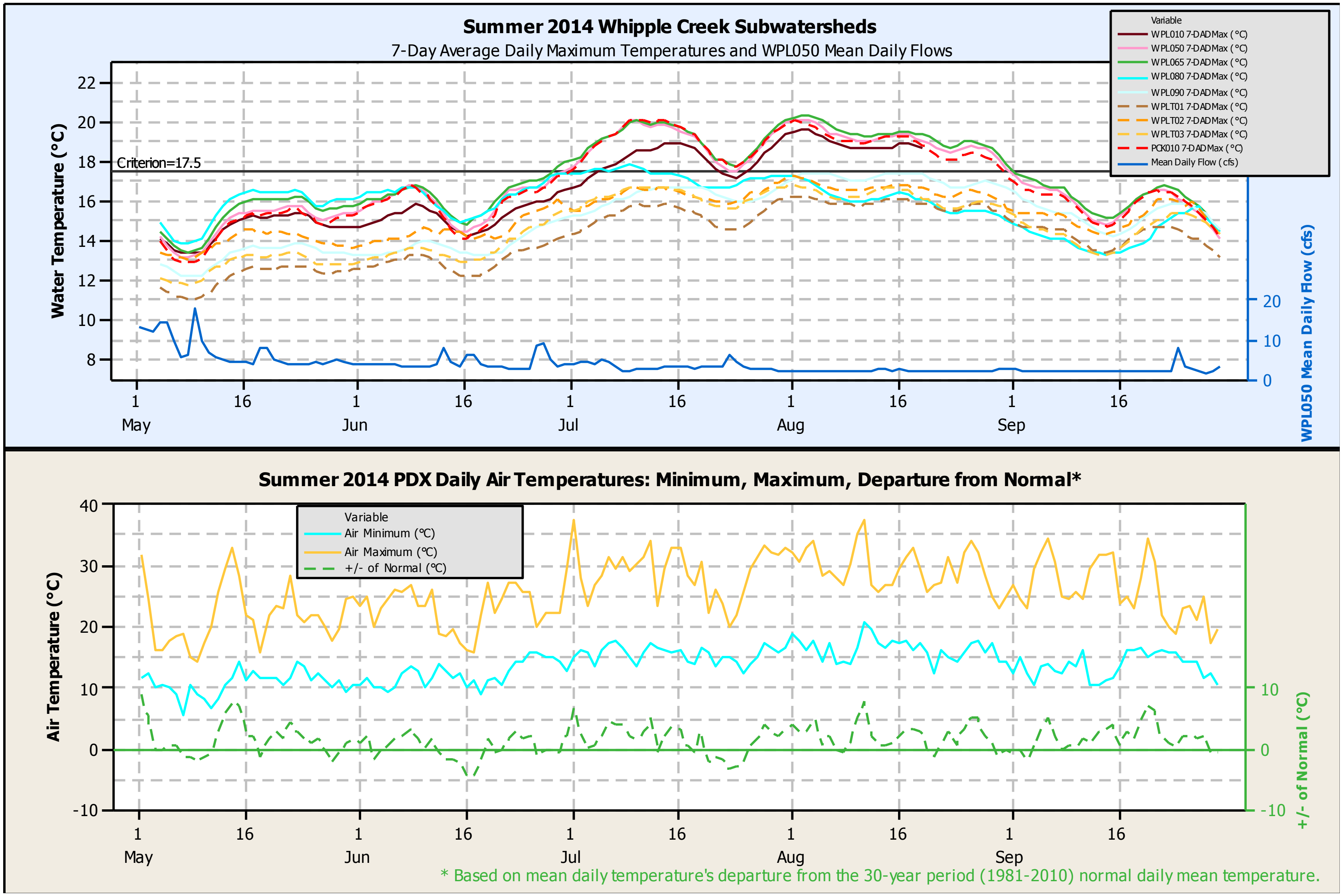

Figure 37 Summer 2014 Whipple Creek Subwatersheds 7-DAD Maximum Water Temperatures and PDX Daily Air Temperatures

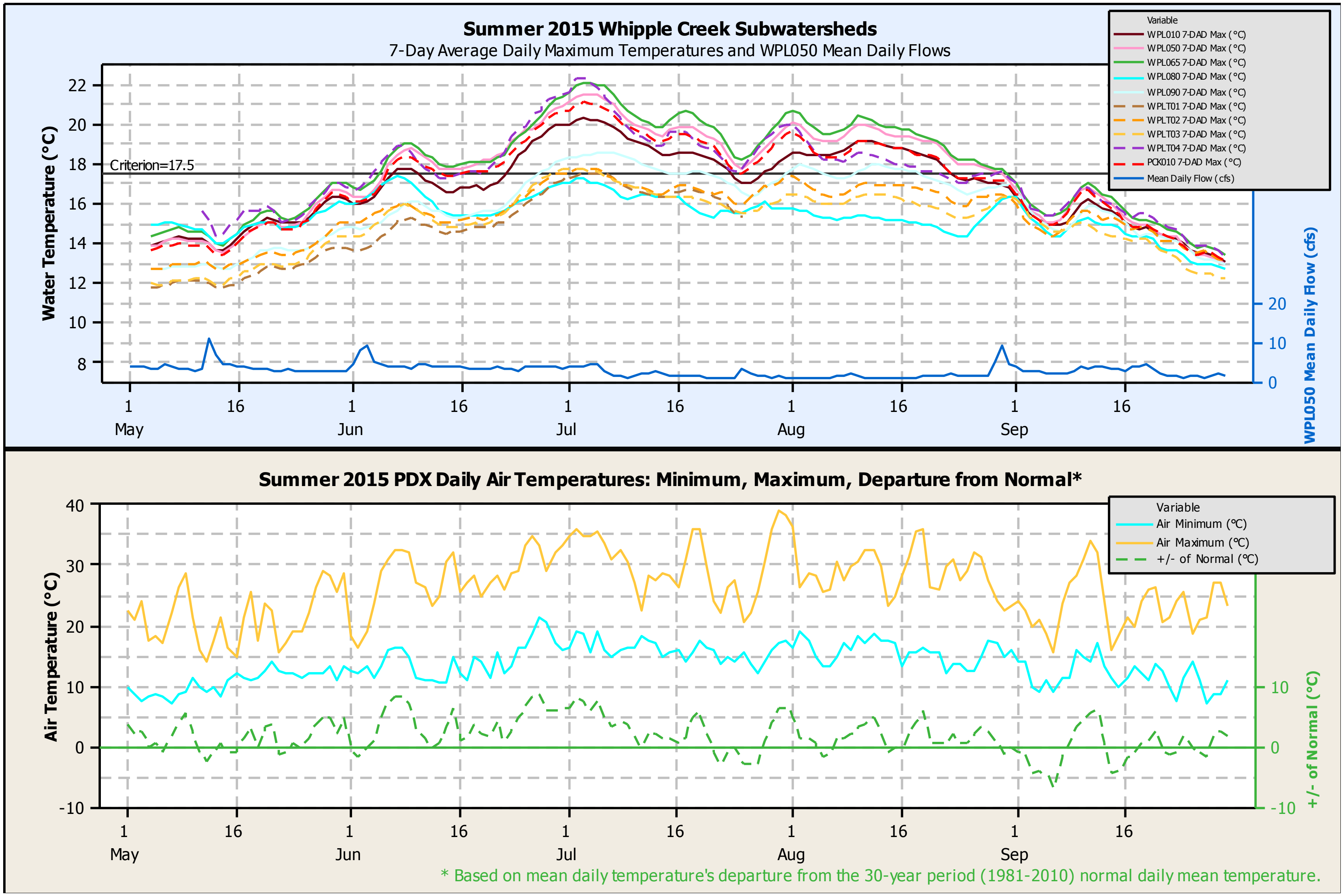

Figure 38 Summer 2015 Whipple Creek Subwatersheds 7-DAD Maximum Water Temperatures and PDX Daily Air Temperatures

Given the likely very similar daily weather influences across the relatively small distances between the monitoring stations (less than five miles), the spatial order and the relative timing pattern for these streams' temperatures hints at their susceptibility to summer heating. Many of the tributary and upper main stem streams represent headwater areas where the majority of summer stream water is probably recently derived from relatively cool groundwater sources. Whereas, the lower main stem waters are more likely to have been exposed to either indirect or direct sunlight for extended periods of time during which heating could be occurring and as well as impacted by already heated flows from upstream. As shown in Figure 37 and Figure 38, many of the higher and larger peaks in the 7-DAD Maximums coincide with the highest air temperature peaks especially those air temperature peaks of longer duration.

Cumulative Distribution Function (CDF) plots of Figure 39 and Figure 40 present a different perspective on the 2014 and 2015 May through September summer maximum stream temperatures. Both figures show increasing separation of the lower main stem 7-DAD maximum temperatures from those of the watershed tributaries and main stem headwater reaches. During both summers, only a very small percentage of some of these tributaries and headwater reaches 7-DAD maximums consistently exceeded the criterion except for WPL090's 25 percent during 2015. However, during both summers, from 40 to 60 percent of the lower main stem sites' 7-DAD maximums exceeded it. Importantly, the summer 2015 CDF slopes of most lower Whipple Creek main stem and WPLT04 and PCK010 tributaries drop consistently for the warmest 7-DAD Maximums above the 90^{th} percentile in Figure 40. This suggests, during very hot summer days and nights (less stream cooling at night), a greater rate of heating susceptibility for these monitored stream reaches. Specifically, during 2015 periods that include the hottest ten percent of 7-DAD Maximum stream temperatures, the intensity of their stream water heating increases compared to the rest of the temperature range.

WPL080's CDF plotted lines in Figure 39 and Figure 40 are very different from all the other monitoring locations, especially during 2015, in that they cross over many of the other stations' plotted lines. These unusual WPL080 temperature patterns appear to be valid based on a review of field notes and similar temperature readings from a secondary thermistor located in a nearby flow gaging station. The pattern of WPL080's relatively large percentage of sustained cooler temperatures (as indicated by similar steeper slopes in both of its summer CDF plots) supports that a substantial part of its summer flows come from relatively cold year-round groundwater associated sources in this stream reach.

The general relationships between concurrent 7-Day Average Daily Maximum Whipple Creek watershed stream and nearby weather station air temperatures are shown in the scatterplots with Lowess smoothing lines in Figure 41, Figure 42, and Figure 43. The 7-DAD maximum air temperatures started about one degree Celsius warmer at the low end and ended about three degrees warmer at the high end during the summer of 2015 compared to the summer of 2014. Over both summers, almost all the monitored streams' 7-DAD maximum temperatures increased at fairly constant rates of about 1 degree Celsius water temperature for every 2.5 to 3 degree rise in 7-DAD maximum air temperature. Importantly, this relatively stable relationship during very different air temperature regime summers, suggest that these streams react similarly over a range of energy inputs but the duration and magnitude of heat impact how warm they get on the hottest days of summer. The previously described unusual WPL080 stream temperatures patterns are very pronounced in these figures.

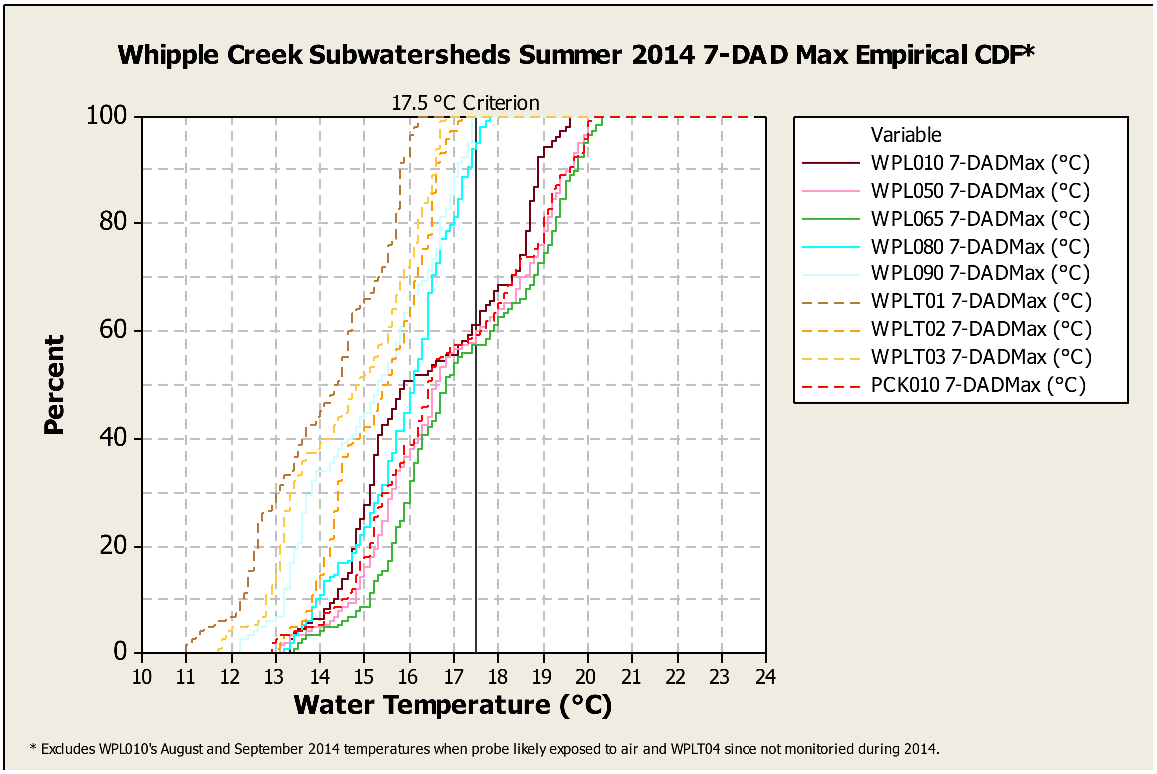

Figure 39 May–Sept. 2014 Whipple Creek subwatersheds 7-DAD Max. water temperatures cumulative distribution function (CDF)

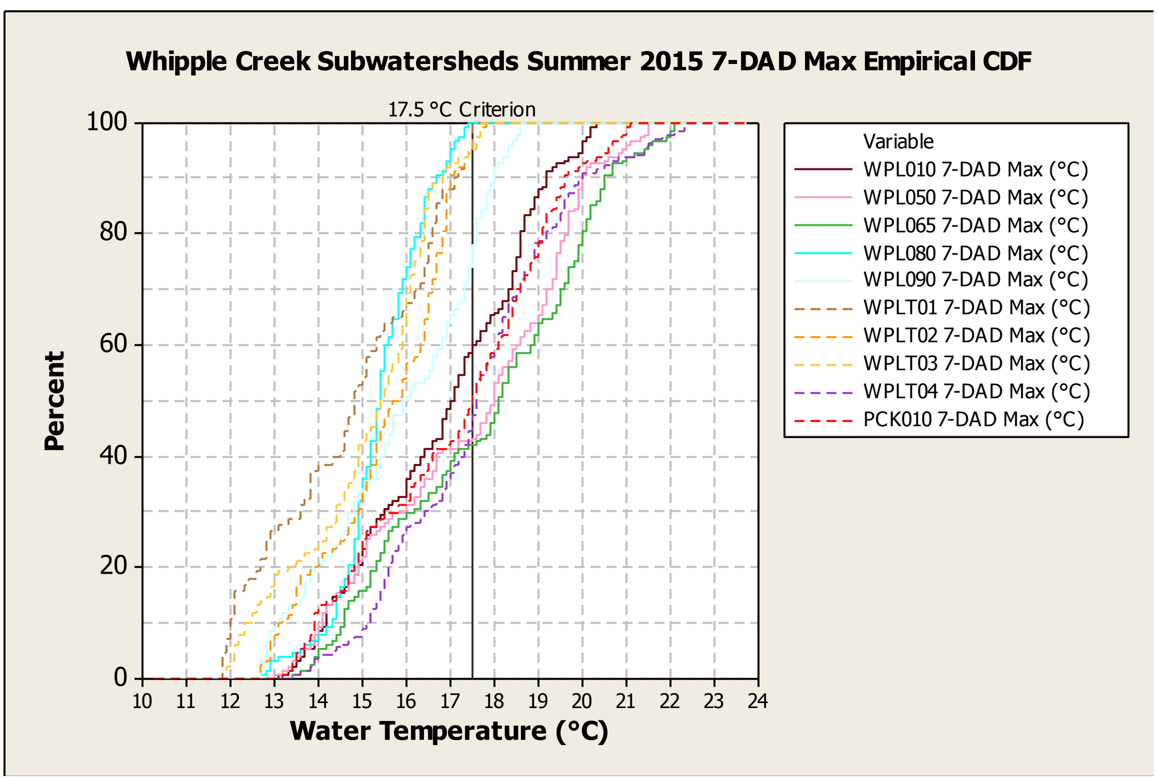

Figure 40 May–Sept. 2015 Whipple Creek subwatersheds 7-DAD Max. water temperatures cumulative distribution function

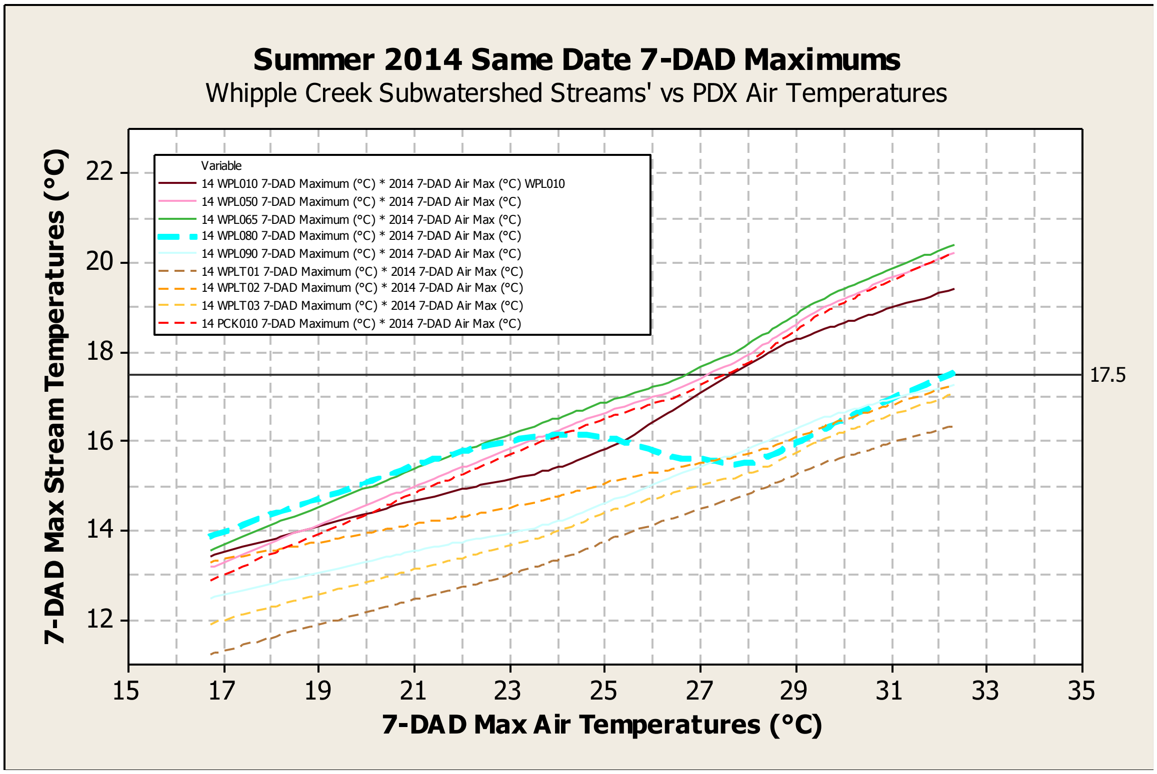

Figure 41 Whipple Creek subwatershed summer 2014 7-DAD maximum stream versus air temperatures

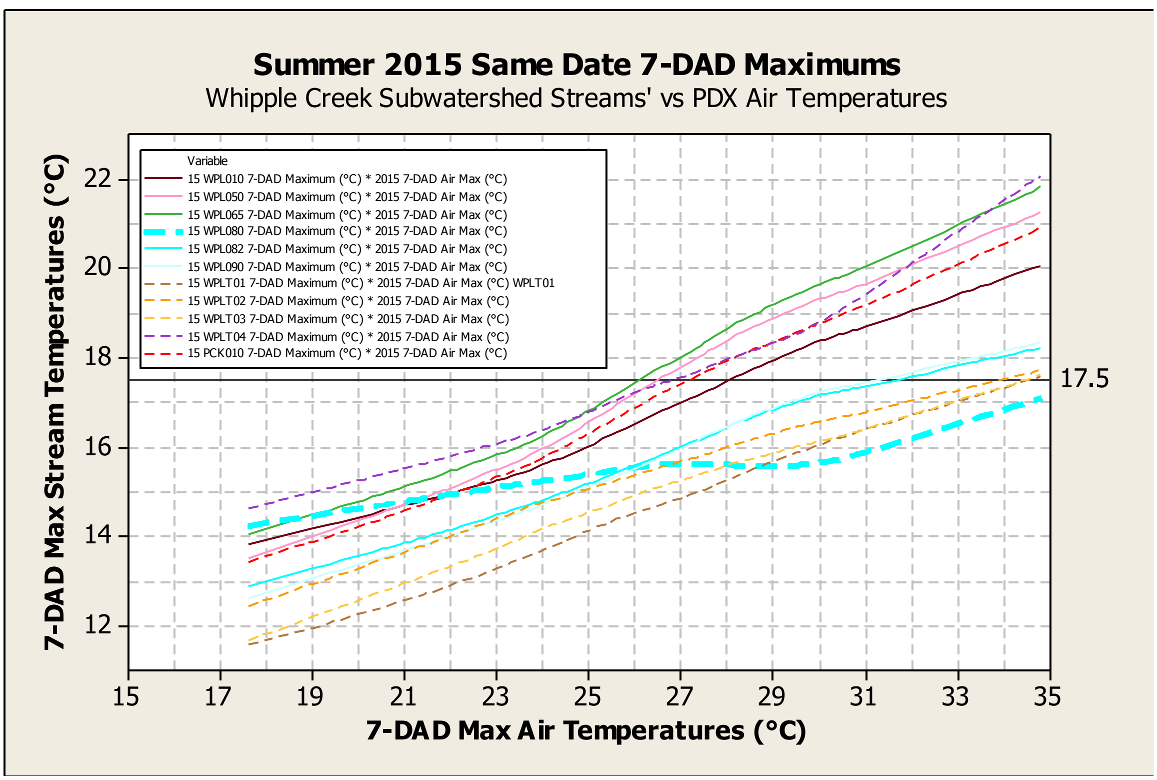

Figure 42 Whipple Creek subwatershed summer 2015 7-DAD maximum stream versus air temperatures

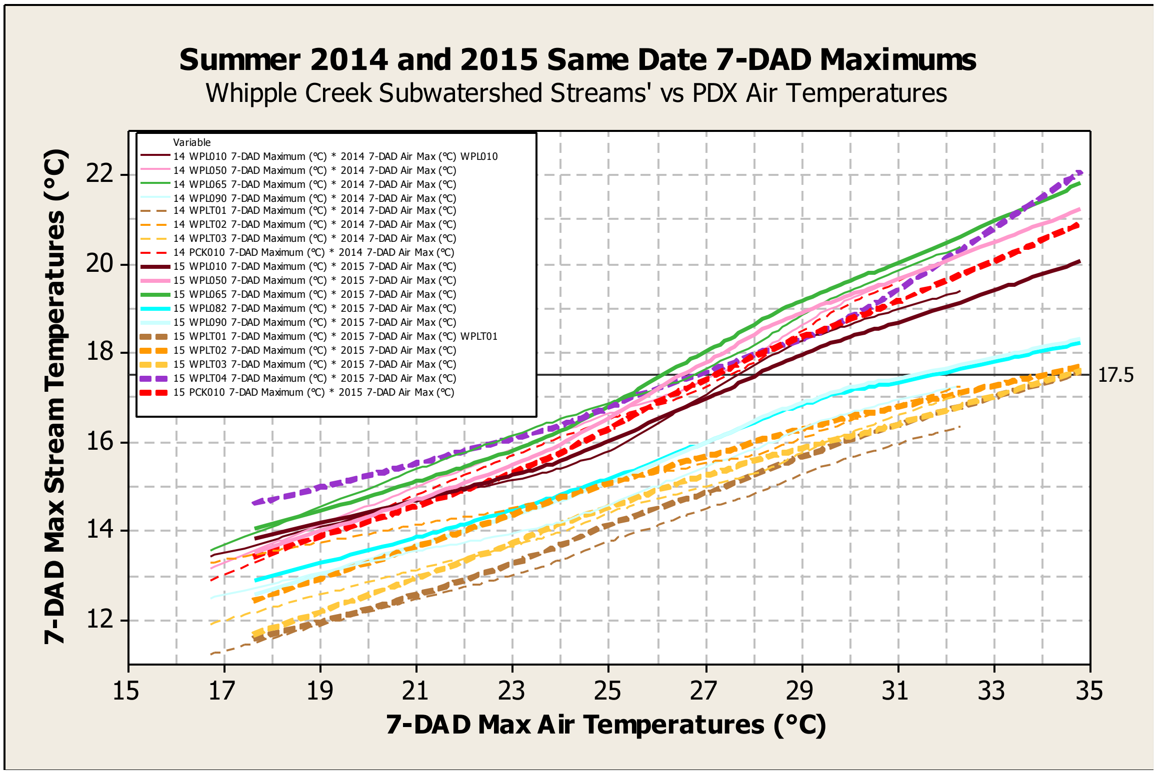

Figure 43 Overlay of Whipple Creek subwatershed summer 2014 and 2015 7-DAD maximum stream versus air temperatures

During the single summer of 2015 for which stream temperature was monitored for WPLT04, it exhibited a steeper slope for 7-DAD maximum stream temperatures above 30 degrees Celsius air temperature. This change in slope suggests that this stream site may heat up even more rapidly than others with increasing maximum air temperatures and may need more temperature mitigation actions implemented.

The 7-DAD Maximum CDF plots and scatterplots of Figure 39 through Figure 43 suggest that other factors beyond just air temperature related factors are contributing to the intensity of stream heating for the hottest 10 percent 7-DAD Maximum stream temperatures of the lower main stem and WPLT04 and PCK010 tributaries in Figure 40. Given only WPLT04 shows a substantial upswing in its 2015 scatter plot slope (above 30 Celsius air temperature in Figure 42 suggesting it may be the most susceptible to direct heating), implies other positive feedback heating factors such as decreased stream flow and upstream cumulative heat loading contribute to non-linear stream heating during the very hottest summer periods.

Relative Flow Context

Flow was continuously monitored during 2015 at three stations within the Whipple Creek watershed: WPL048 – the long-term flow monitoring station (just downstream from water quality monitoring station WPL050) near the intersection of NW179th Street and 41st Avenue; WPL082 – just east of Interstate 5 and adjacent to Union Road; and PCK012 - near the mouth of tributary Packard Creek just upstream from WPL048. The minimum, median, and maximum of mean daily flows (in cubic feet per second) across the five dry season summer months of 2015 (from May 1 through September 30) were, respectively: WPL048 = 0.92, 3.1, 10.9; WPL082 = 0.30, 0.43, 1.21; and PCK012 = 0.05,0.33, 1.62. The median summer measured flows for WPL082 and PCK012 represent approximately 14% and 11%, respectively, of that for WPL048.

Table 6 shows HSPF continuous flow modeled estimated median summer flows for most of the Whipple Creek watershed streams' temperature monitoring stations or nearby flow monitoring stations (excludes WPL090) and calculated summer medians flows for sites with flow monitoring. The averages of the 2014 and 2015 summer HSPF modeled medians (dark shaded table cells) match relatively well with the summer 2015 medians of actual monitored flows (dark shaded table cells) for WPL048, WPL082, and PCK012. The HSPF 2015 summer WPL050 and WPL080 medians were about a third lower and PCK010 was half again higher (light shaded in the table) than those based on actual monitoring. It is understandable that summer low flow estimated and monitored flows show some degree of differences given the inherent uncertainty, low precision, and error in both estimating and measuring very low flows.

From a heat loading perspective, the estimated percent of total Whipple Creek watershed flow (second from last row) of Table 6 gives some idea of the potential beneficial impact from cooler Whipple Creek watershed stream reaches. Combining the relative differences of concurrent peak summer 7-DAD maximum temperatures for the various stream reaches (depicted in Figure 37 and Figure 38) with their estimated percentage of the total watershed flow (Table 6) can give an idea of how much each cooler stream reach is benefiting downstream warmer reaches. More detailed analyses would be needed to calculate individual stream reach heat or cooling impacts. For example, the five degree Celsius difference in the warmest summer 2015 7-DAD maximum temperatures (during early July 2015, WPL065's 22°C versus WPL080's 17°C) needs to be put in the relative dilution context of each reaches' percentage (respectively, 37% and 13%) of the entire watershed's flow. The relative cooling benefits of stream reaches could then be weighted, prioritized, and utilized for watershed planning. Conversely, Packard Creek's (PCK010) generally very warm, large flow contribution (22%) combined with the similarly warm WPL065 and WPL050 waters appear to be somewhat temperature mitigated by the time their waters reach WPL010. An example application of this prioritization approach could be to promote riparian plantings along Packard Creek given its very warm temperatures, relatively large flow contribution, and potentially shade benefited narrow width.

Table 6 Whipple Creek subwatershed summer flow medians: 2014 and 2015 medians of HSPF estimated flows and 2015 monitored flows

Median Summer Values: Monitoring Station's HSPF Estimated and 2015 Monitored Flows – cfs (based on mean daily flow estimates)										
Flow	**Period**	**WPL010**	**WPL050**	**WPL065**	**WPL080**	**WPLT01**	**WPLT02**	**WPLT03**	**WPLT04**	**PCK010**
HSPF	**Summer 2014**	3.5	3.0	1.3	0.46	0.27	0.24	0.05	0.16	0.79
	Summer 2015	2.3	1.9	0.8	0.29	0.17	0.15	0.03	0.11	0.49
	Summer Averages	2.9	2.5	1.1	0.37	0.22	0.20	0.04	0.13	0.64
	% of Total Watershed Flows	100%	86%	37%	13%	8%	7%	1%	5%	22%
Actual	**2015 Monitored Flows**	NA	3.1 (WPL048)	NA	0.43 (WPL082)	NA	NA	NA	NA	0.33 (PCK012)

Future Stream Temperature Monitoring Recommendations

At a minimum for future temperature monitoring, consistently record continuous stream temperatures from May 1 through October 1 across the full range of targeted representative stream monitoring sites. It is important that the timing and magnitude of daily maximums be captured not only during the hottest summer periods but also in the transition period from spring to summer to identify year-to-year differences in both the timing and rate of changes in daily maximums.

By the following spring after the first summer of continuous stream temperature monitoring at baseline stations, perform exploratory data analyses on the 7-DAD Maximum stream temperature data similar to the graphical analyses presented above. These analyses should include: time series plots, cumulative distribution plots, scatter plots of 7-DAD maximum stream temperatures versus 7-DAD maximum air temperatures based on a nearby National Weather Service station, approximate thermal loading summaries, etc. Anomalies in average temperature patterns could suggest sites having either net beneficial cooling factors or excessive heating impacts that may need further investigation.

Early exploratory data analyses will provide adequate time to plan targeted, follow-up field reconnaissance monitoring of peak summer stream temperatures and related factors. This planning should utilize a prioritization process based on continuous temperature patterns, scope specific targeted stream reaches using GIS aerial images to review riparian land cover, and schedule follow-up fieldwork. Schedule fieldwork for monitoring teams based on forecasted windows of extended hot weather during July or August to measure near simultaneously peak stream temperatures across multiple targeted stream reaches.

Both upstream and downstream reaches from continuous baseline stations with excessive or cooler peak summer water temperatures should be targeted for reconnaissance monitoring to approximately identify the spatial extent of heating factors or verify potential beneficial base flow groundwater influences. The follow-up monitoring should be limited to relatively simple, quick spot measurements and direct observations of reach specific factors during short duration fieldwork. The fieldwork duration should last at most a couple of hours at a single stream reach during late afternoon peak temperatures to minimize confounding additional heating during the fieldwork. Preference should be given to monitoring over the full length of a targeted stream reach rather than overly detailed measurements or observations. Splitting the monitoring effort into concurrent work by staff teams would facilitate timely capture of data. Fieldwork monitoring should use handheld meters for spot stream temperature and conductivity measurements (if severe lack of mixing is obvious then measure across applicable stream cross-sections at various depths), visually estimate flow rates, measure air temperatures above the stream, record GPS locations, as well as visually approximate shading and streambed exposure. All data should be recorded on standardized field sheets / field computer input forms.

Whipple Creek Watershed Plan Implementation Recommendations: Stream Temperature

The following are overall recommendations specific to protecting or improving stream temperatures during implementation of the Whipple Creek watershed plan:

- Perform stream temperature confirming follow-up field reconnaissance on stream reaches identified as having potentially beneficial cooler temperatures or excessive heating as suggested by patterns in the 7-DAD maximum temperature analyses of the two-year screening period of watershed-wide baseline continuous stream temperatures.
- For more detailed stream temperature field reconnaissance, target those reaches draining to the WPL080 site for cool waters and the WPLT04 and PCK010 for excessive heating.
- Follow the recommended stream temperature field reconnaissance procedures in the "Future Stream Temperature Monitoring Recommendations" section above during the hottest extended periods of summer.
- After confirming the stream length extent of beneficial cooler waters or excessive heating, as needed, follow up with more detailed field measurements of stream / air temperatures and flow for thermal loading analyses and energy inputs.
- Based on the detailed thermal loading analyses consider reach specific combinations of management options such as: targeted stream side tree planting, property conservation easements along naturally cool stream reach refugees, and using hot weather forecasts to alter the timed release of cool stormwater stored in existing or future flexibly designed stormwater detention facilities to reduce peak stream temperatures. Perform downstream continuous stream temperature monitoring to confirm / calibrate possible temperature mitigation.
- Evaluate potential stream heating impacts from open water, beaver ponds, and low shading above WPL010, WPL050, WPL065, WPLT04, and PCK010.

Whipple Creek Stream Temperature Analyses References

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Washington State Department of Ecology. August 1, 2012. *Phase I Municipal Stormwater Permit National Pollutant Discharge Elimination System (NPDES) and State Waste Discharge General Permit for discharges from Large and Medium Municipal Separate Storm Sewer Systems*. Olympia, WA 74 p.

Appendix 2 Whipple Creek Watershed Water Quality and Land Cover Relationships

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, base flows, 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 44) 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 7). 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.

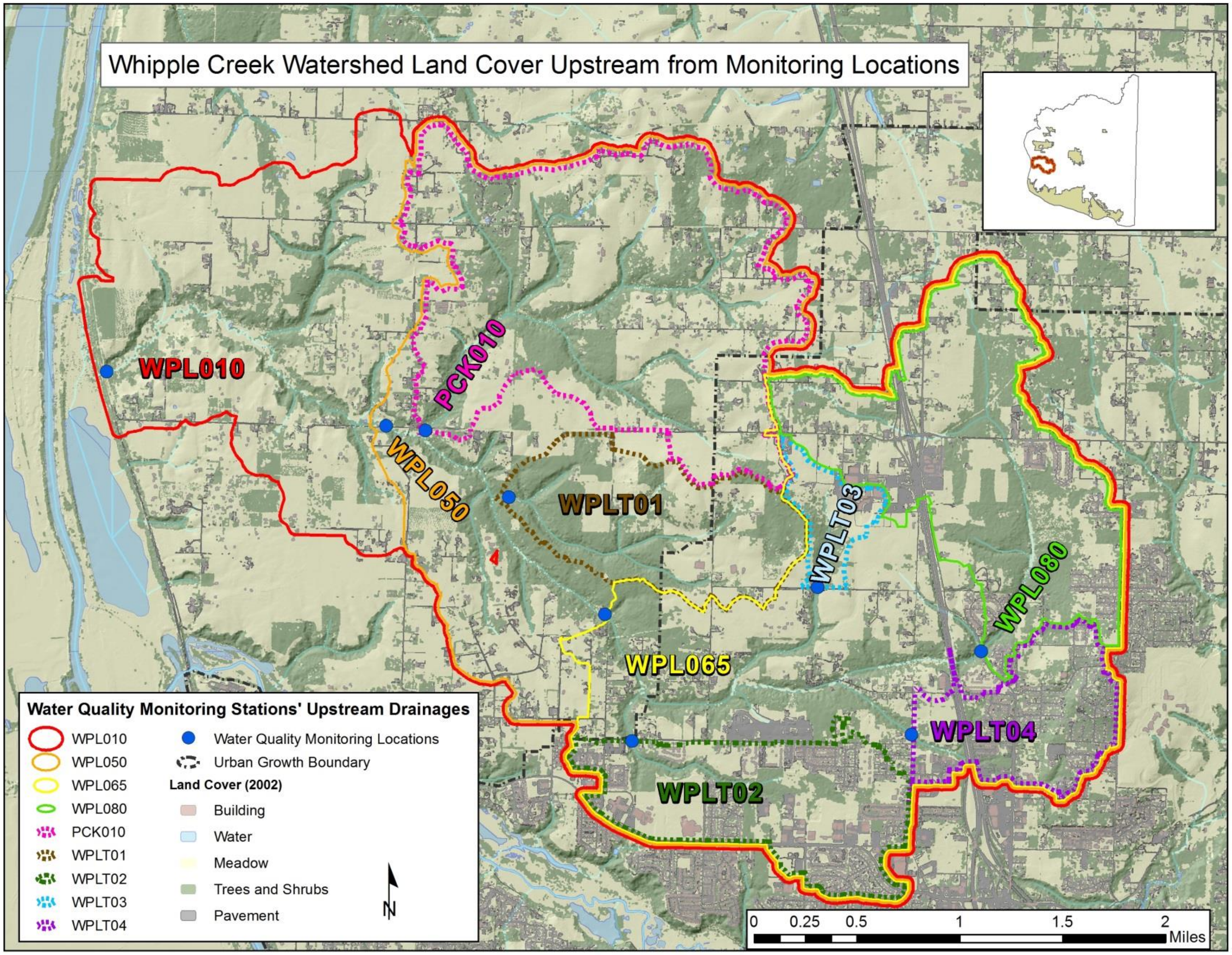

Figure 44 Whipple Creek Subwatersheds Water Quality Monitoring Stations and General Land Covers

Table 7 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 8). Forest, pasture, and grass dominate the main stem subwatersheds' land cover which, combined, total at least 80 %t of each drainage (Figure 45). 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 8 and Figure 46).

Table 8 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 47 allows a visual assessment of water quality versus land cover variable pairs and the relationship shapes for the overall flow type data. The scatterplots' dashed-red lowess ("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 47, 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 9 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).

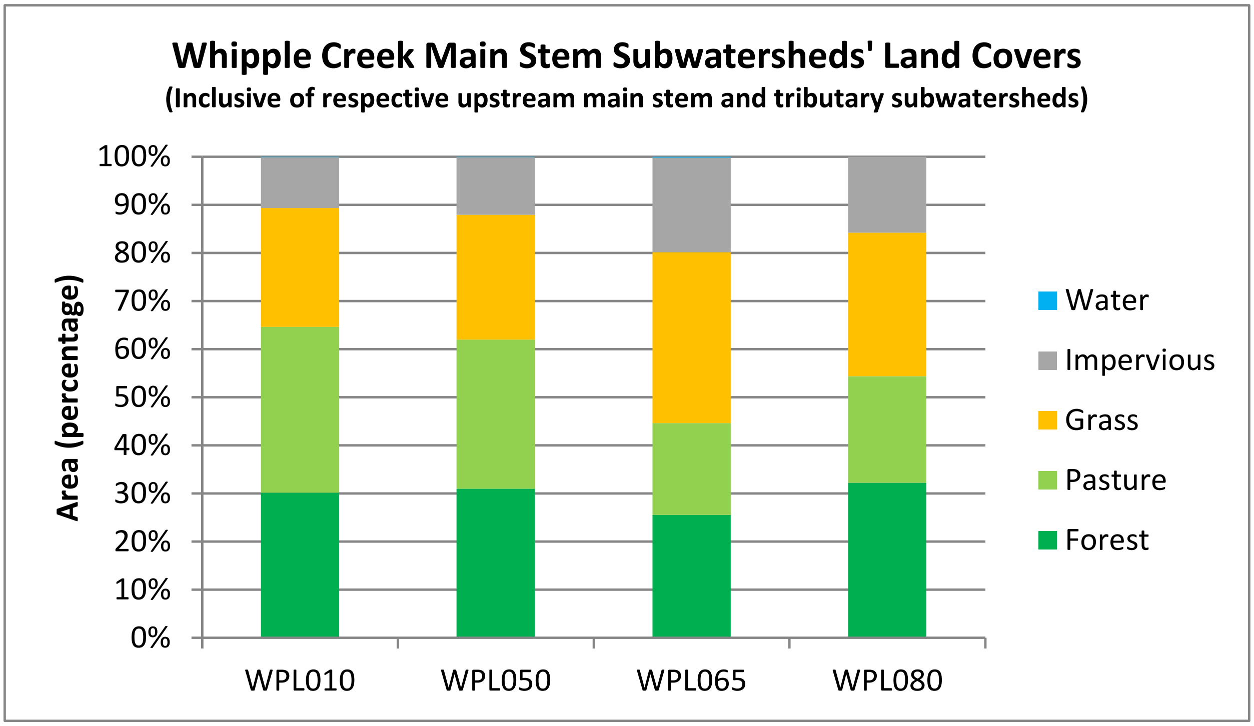

Figure 45 Whipple Creek main stem subwatersheds upstream land cover percentages

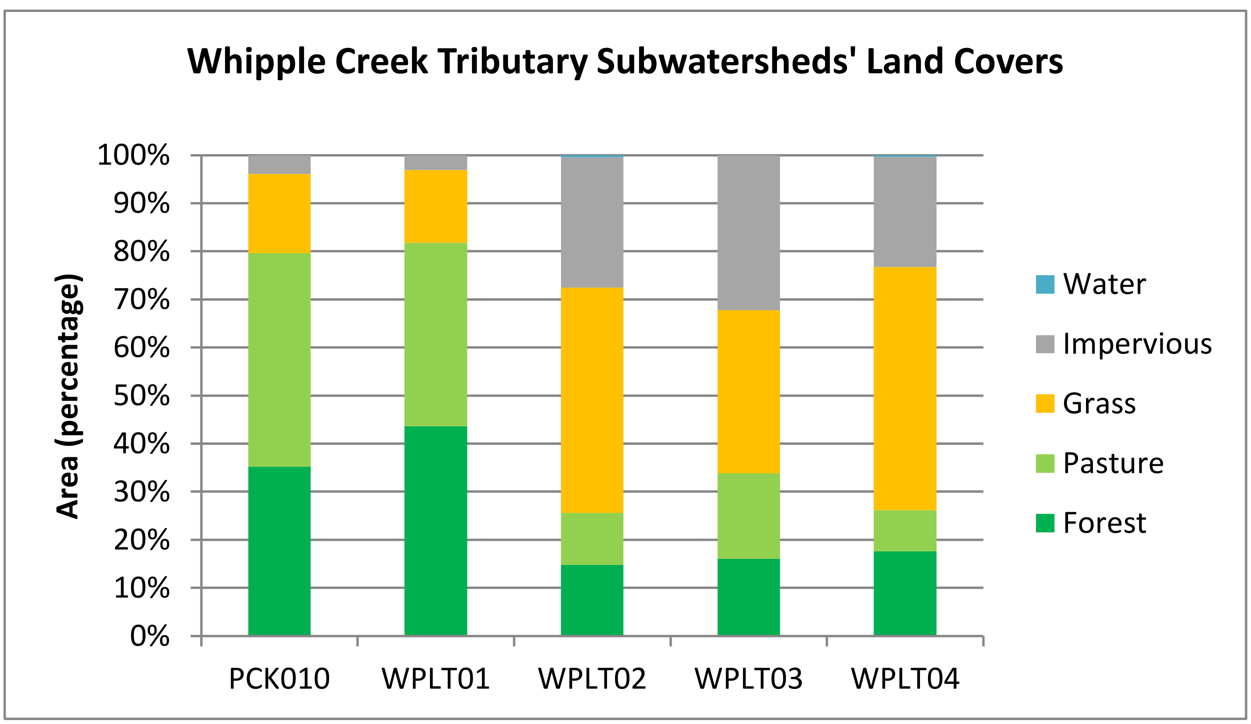

Figure 46 Whipple Creek tributary subwatersheds upstream land cover percentages

Significant linear relationships are high-lighted by two hues of green borders around their respective scatterplots in Figure 47 and two shades of grey cells in Table 9.

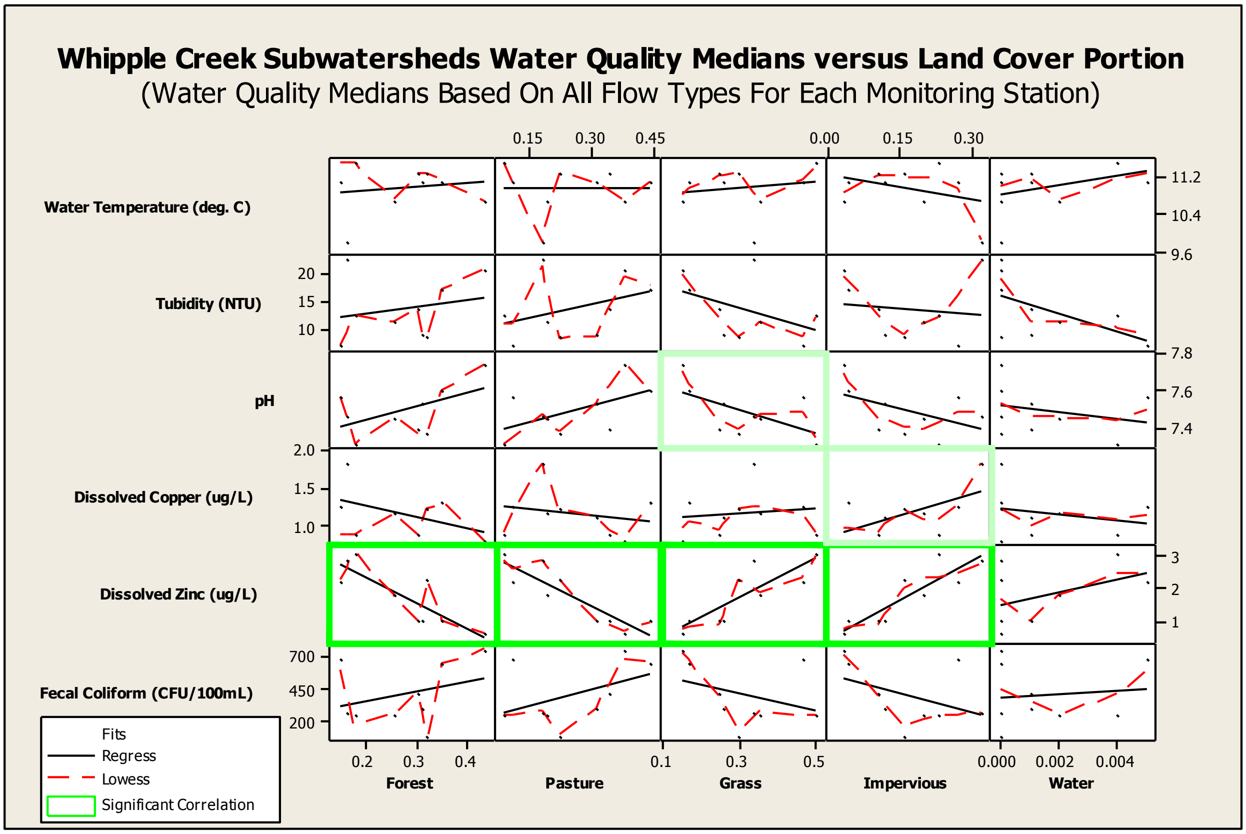

Figure 47 Scatterplot matrix of Whipple Creek subwatersheds' water quality medians versus portion of general land covers fit with linear regression and lowess smoother lines (borders depict significance at 0.05 – bright green and ~ 0.10 - light green)

Table 9 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 47 and dark grey shaded p-value cells in Table 9). 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 9 and scatterplot slopes in Figure 47) 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 9). 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 48 and Figure 49 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 44. The identical vertical and horizontal scales of the individual land cover panels in Figure 49 facilitate comparisons of its fitted regression and lowess lines' slopes and directions. Figure 48 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 49 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 inter-correlations 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 inter-correlations 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.

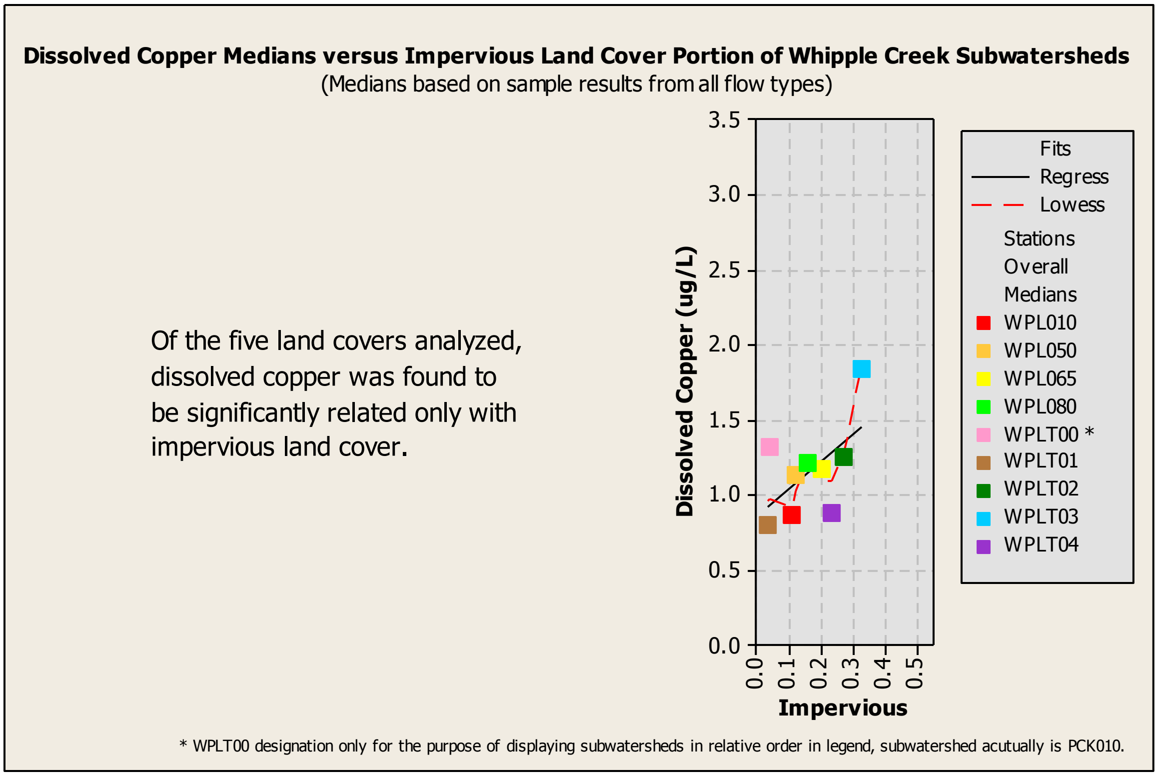

Figure 48 Scatterplot of dissolved copper median concentrations versus impervious surface land cover within subwatersheds

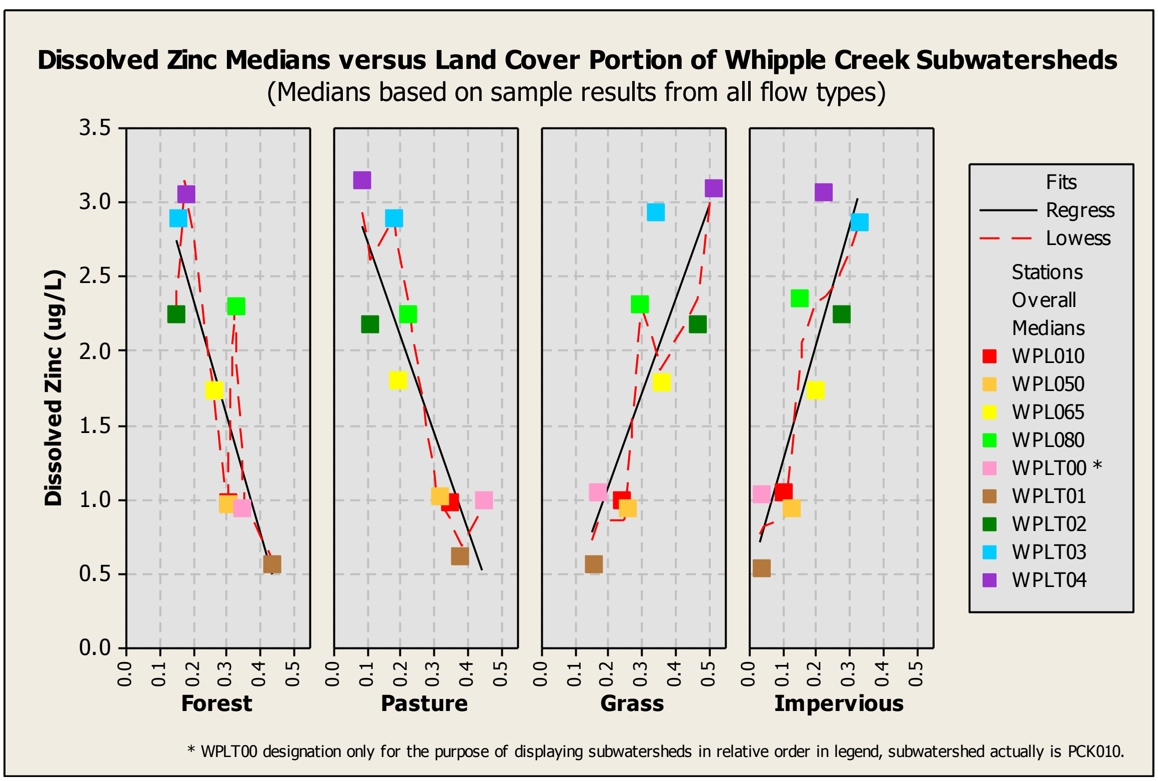

Figure 49 Scatterplot panels of dissolved zinc median concentrations versus general land cover within subwatersheds

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 50 and Figure 51 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 7) equivalent weight can be given to their interpretation for flow type boxplots and regressions.

Figure 50 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 45 and Figure 46). 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 land cover stormwater runoff contribute to those significant relationships.

Figure 51 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.

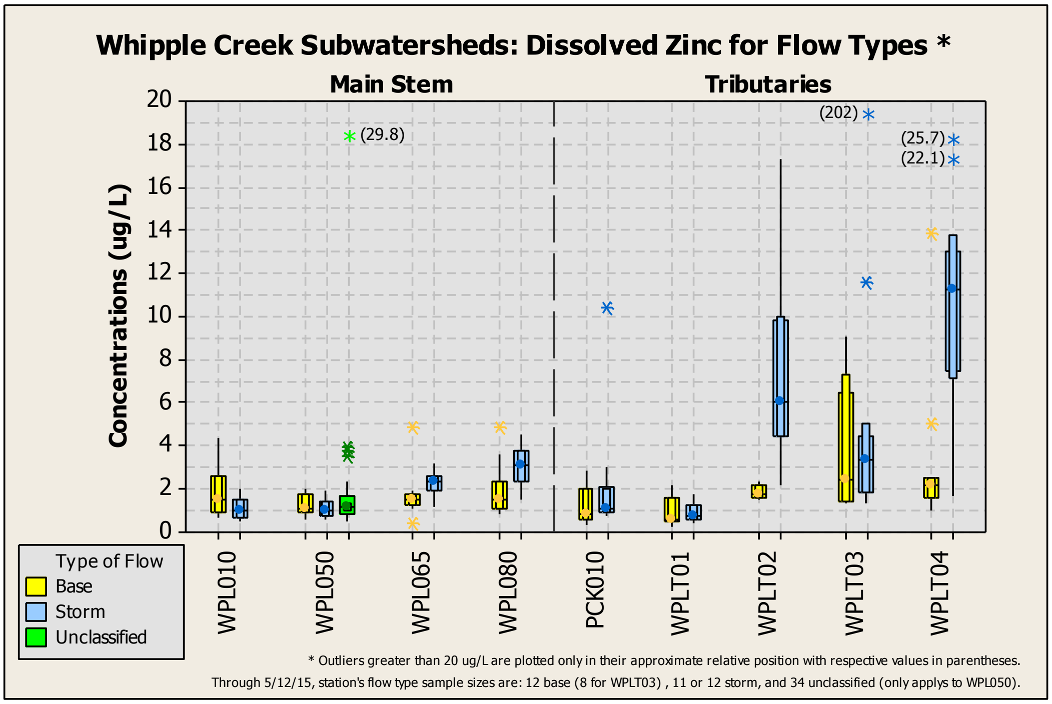

Figure 50 Boxplots of Whipple Creek subwatersheds' dissolved zinc by flow type

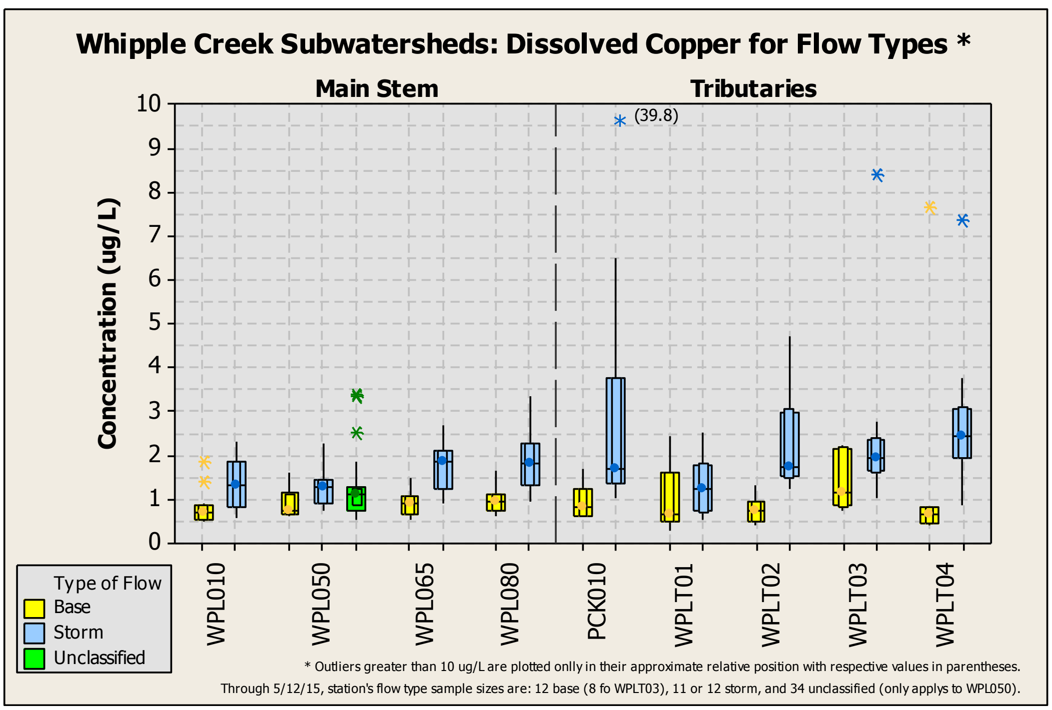

Figure 51 Boxplots of Whipple Creek subwatersheds' dissolved copper by flow type

Flow Type Dissolved Zinc and Dissolved Copper Relationships

Figure 52 through Figure 56 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 48 and Figure 49 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 50 and 3 outliers of 31 dissolved copper values in Figure 51. 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 52 through Figure 55) 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 55 compared to those of dissolved copper in equivalently scaled Figure 56. 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 57 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.

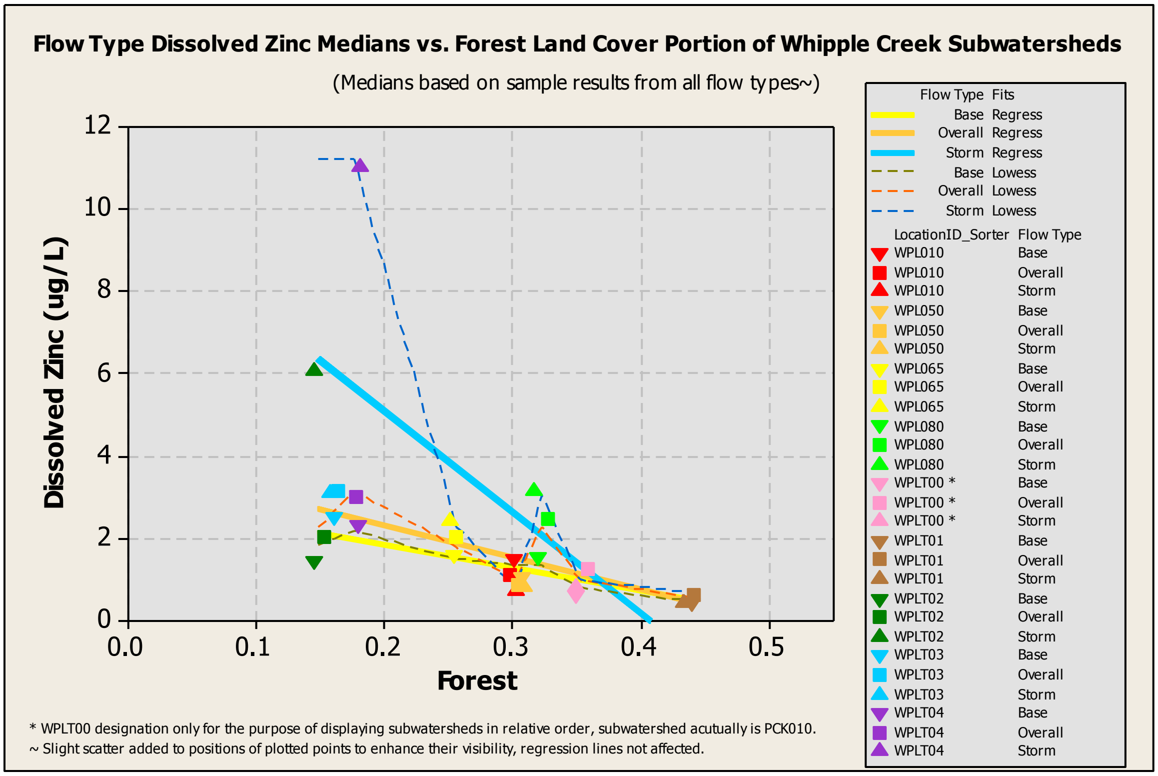

Figure 52 Flow type dissolved zinc medians versus proportion of forest land cover

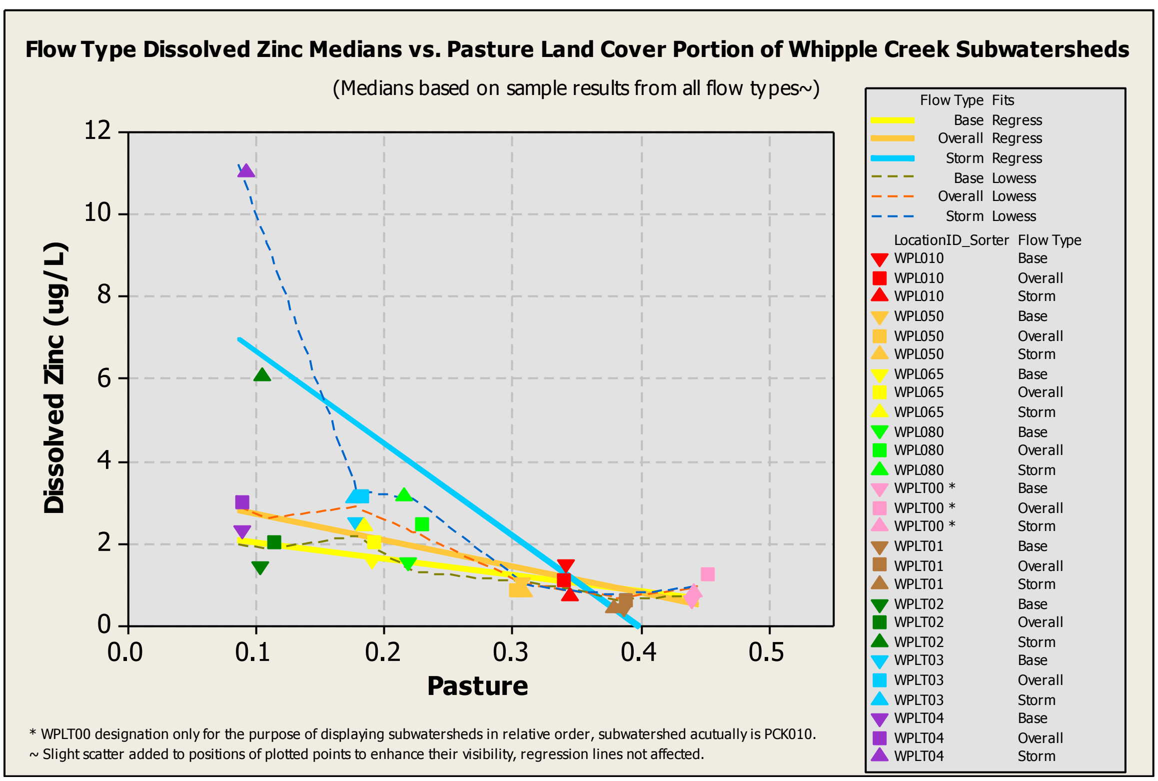

Figure 53 Flow type dissolved zinc medians versus proportion of pasture land cover

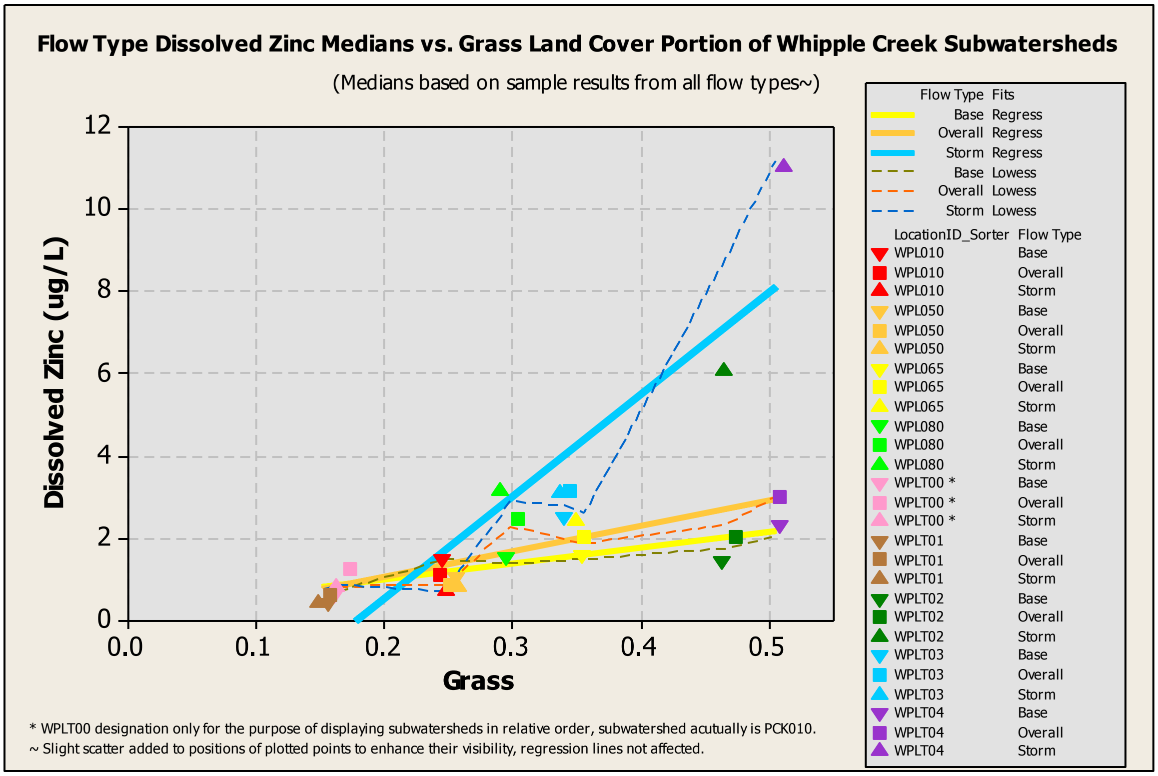

Figure 54 Flow type dissolved zinc medians versus proportion of grass land cover

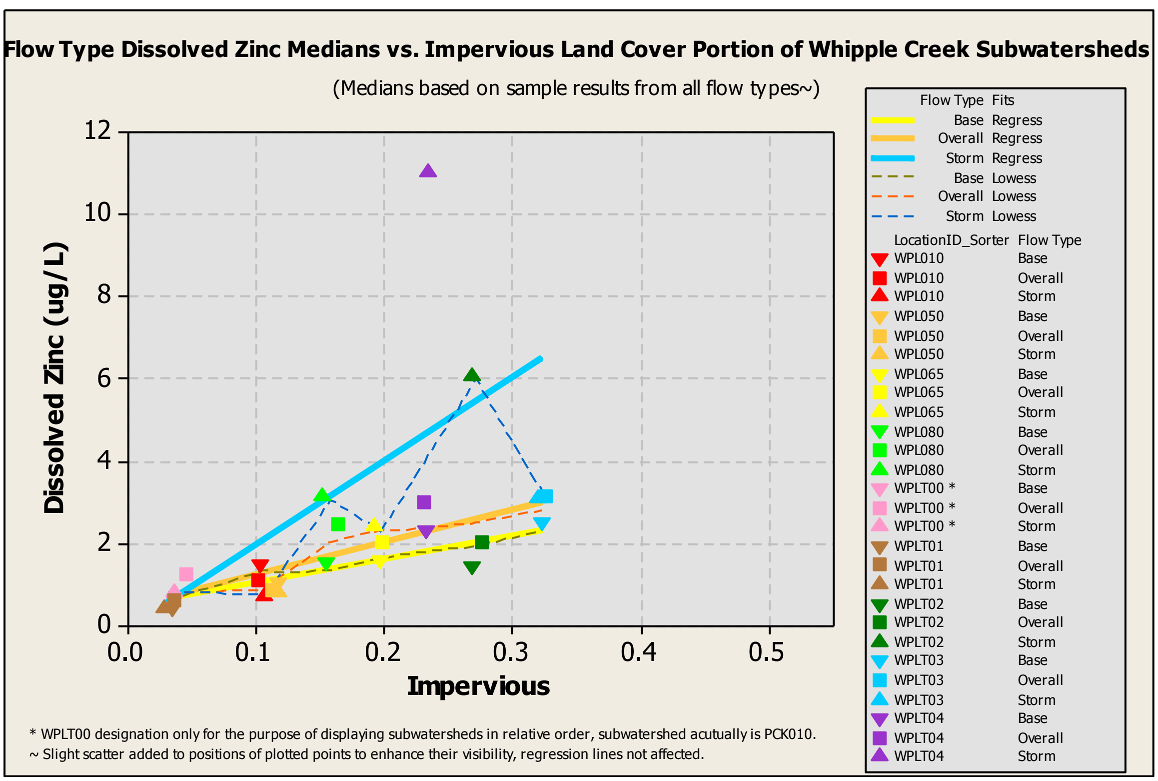

Figure 55 Flow type dissolved zinc medians versus proportion of impervious land cover

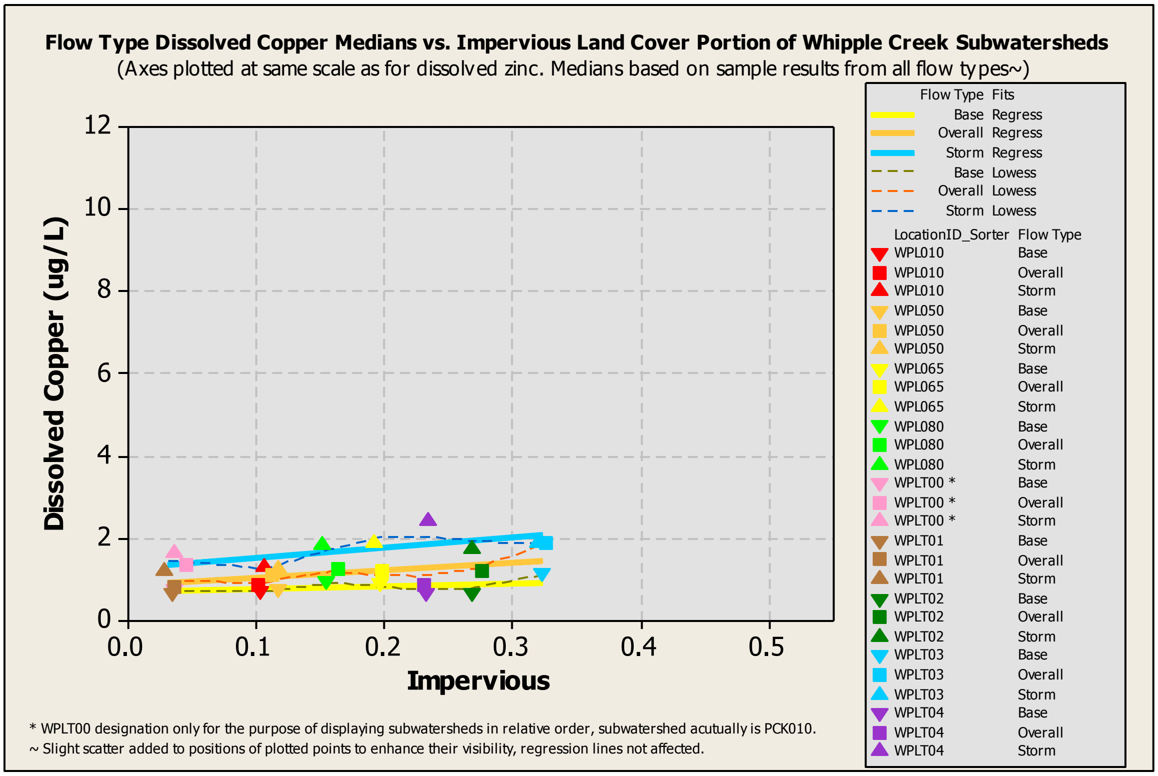

Figure 56 Flow type dissolved copper medians versus proportion of impervious land cover (same scales as dissolved zinc)

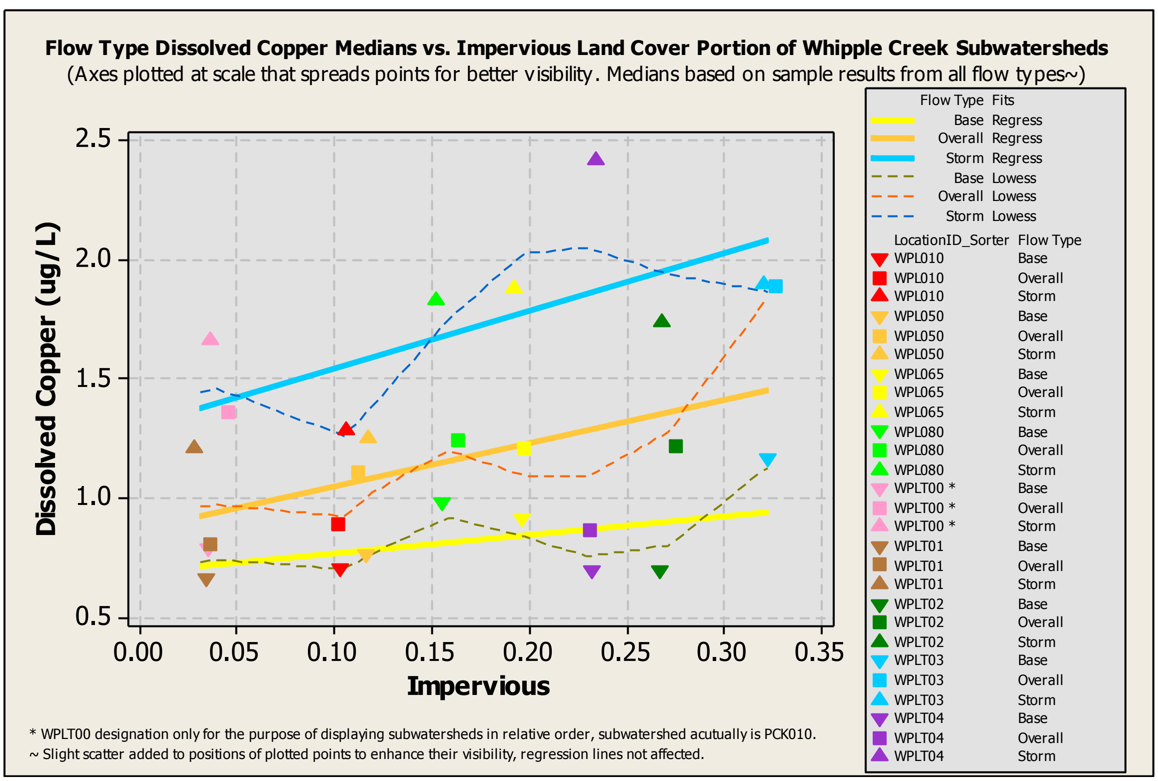

Figure 57 Flow type dissolved copper medians versus proportion of impervious land cover (scales expanded to range of data)

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 10 for those relationships found to have significant overall flow type relationships. The overall flow type correlations are identical to those presented in Table 9 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 10 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 47). 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 47 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 58) 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. In addition, 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.

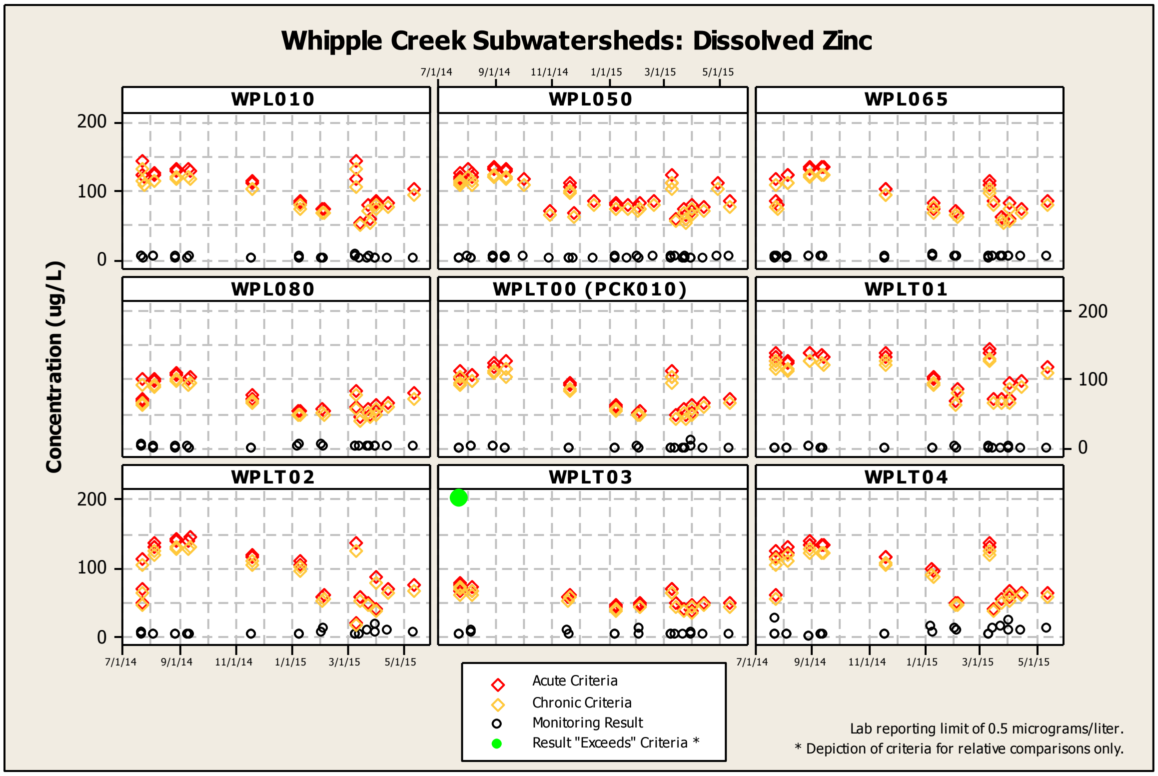

Figure 58 Plot of Whipple Creek subwatersheds' dissolved zinc values over time and applicable state criteria values

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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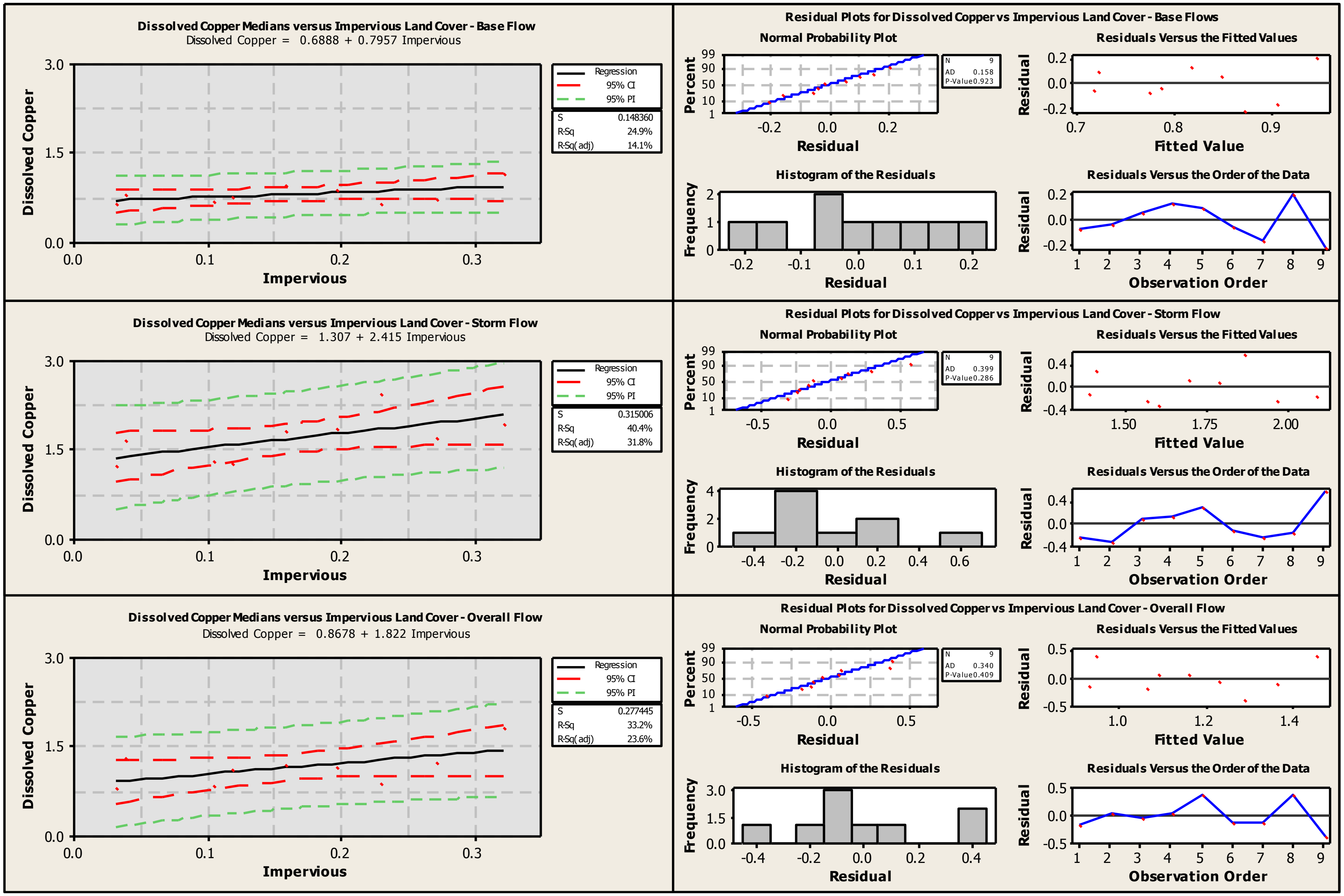
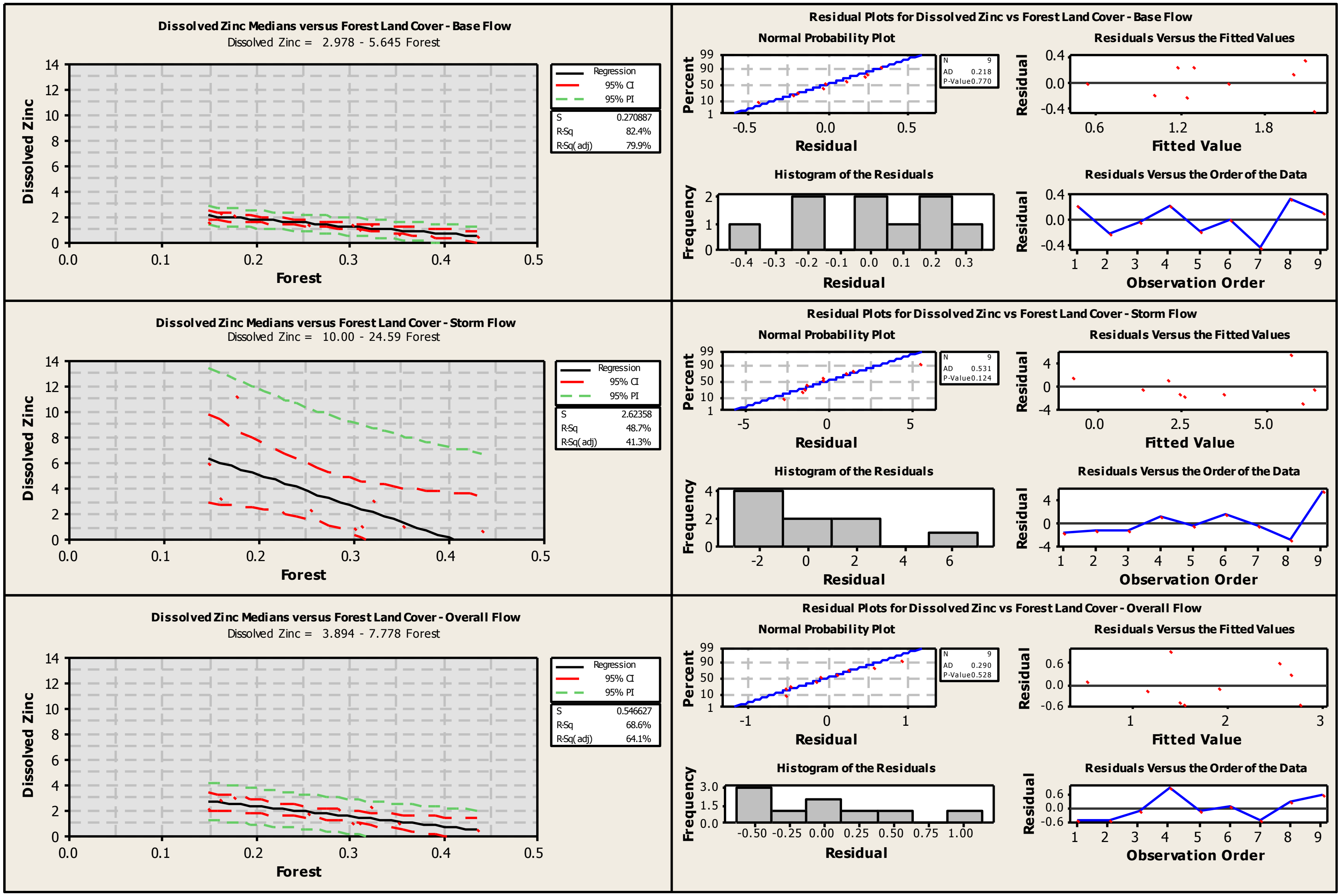
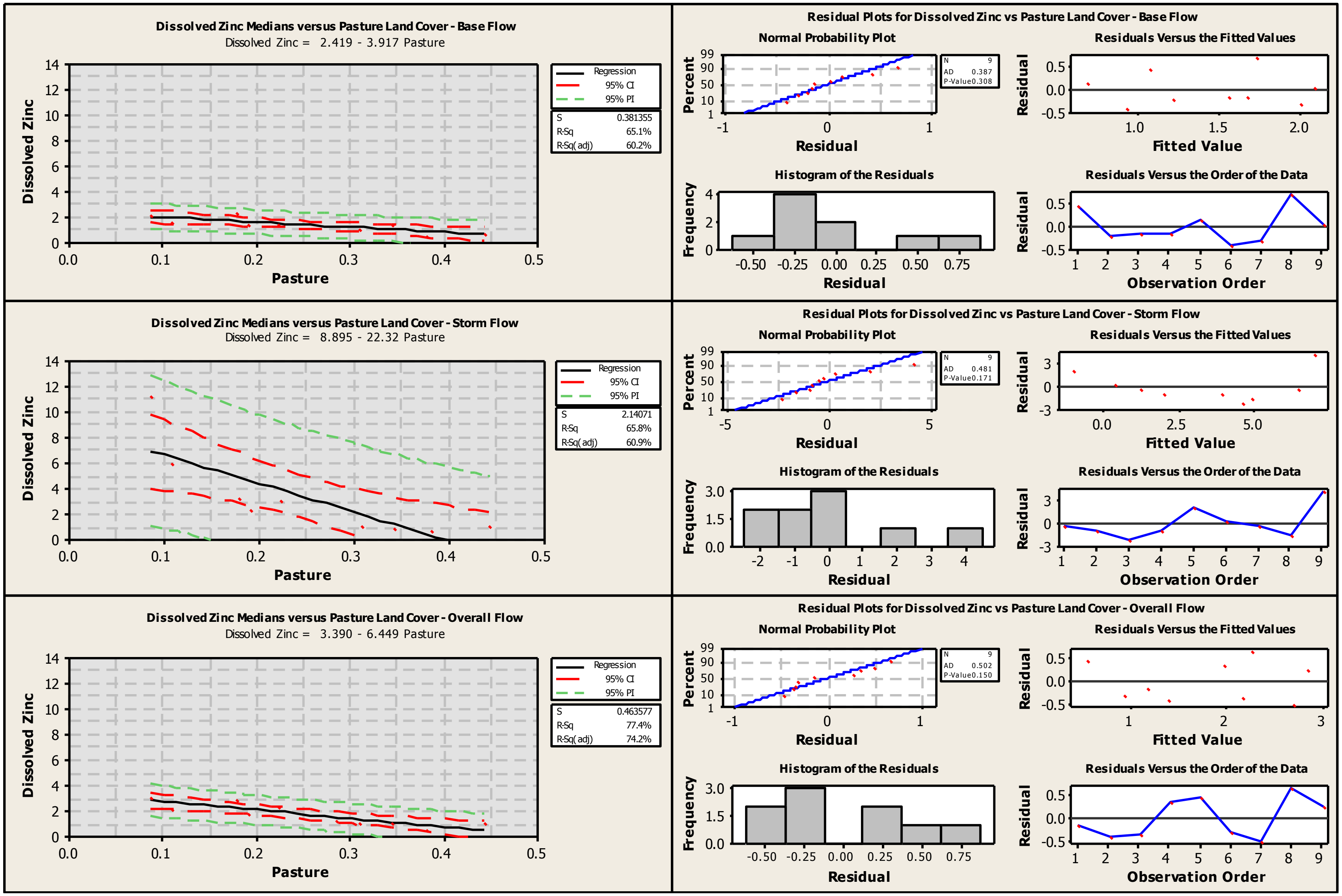
Appendix 3 Detailed graphs summarizing flow-type dissolved metals versus land cover regressions' confidence / prediction intervals and assumption evaluations



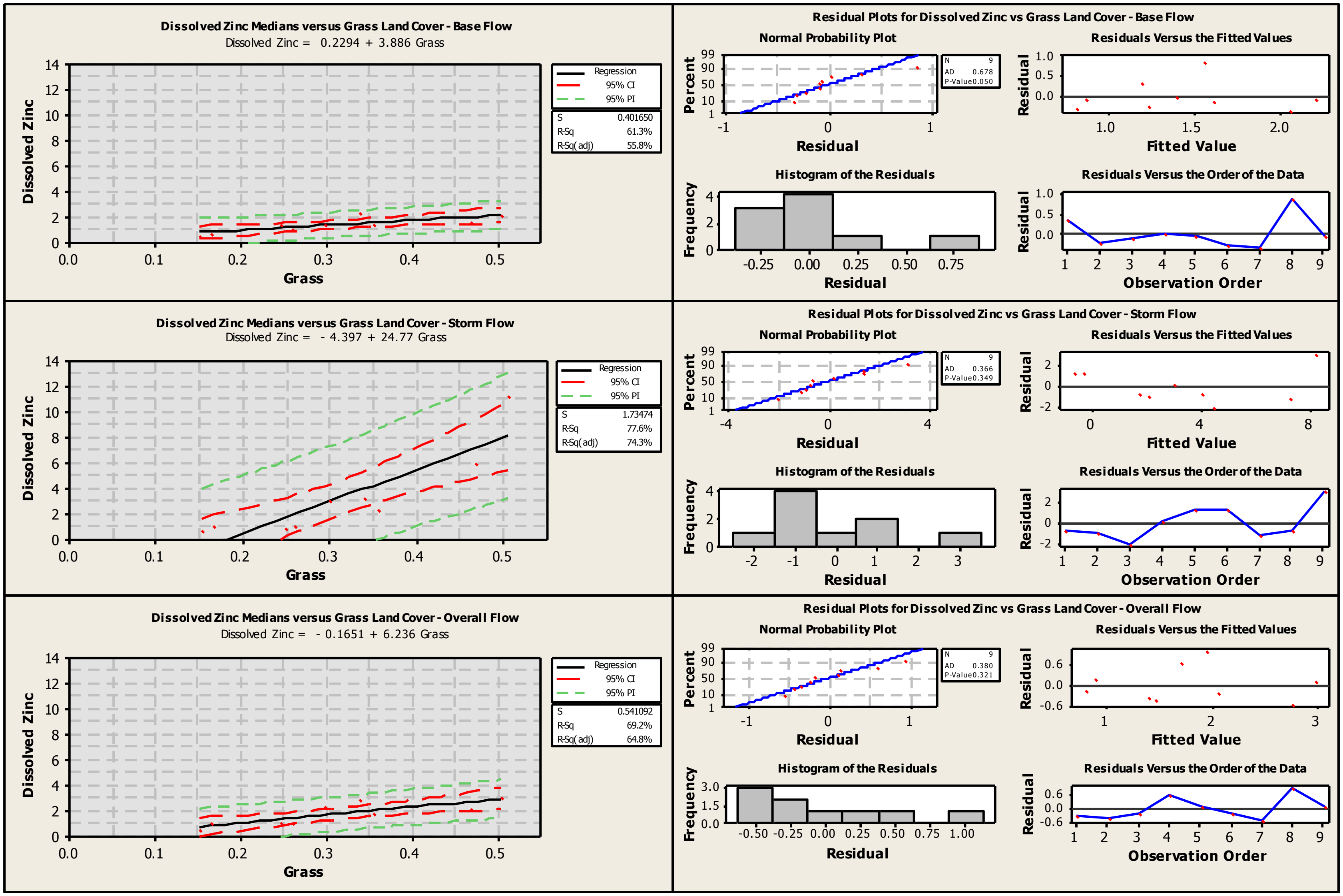
Flow Type Dissolved Copper versus Impervious Land Cover Regression Confidence / Prediction Intervals and Assumption Evaluations



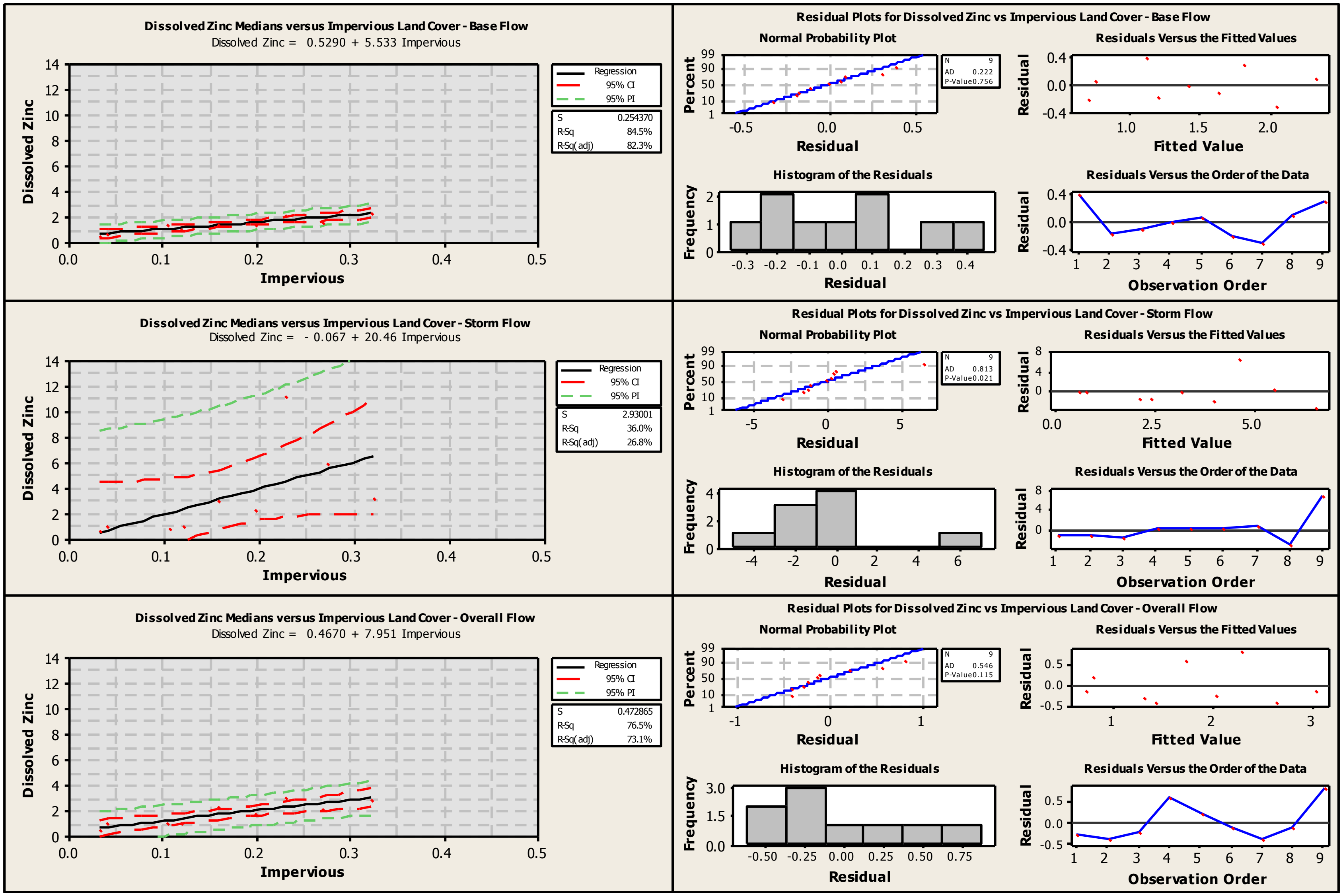
Flow Type Dissolved Zinc versus Forest Land Cover Regression Confidence / Prediction Intervals and Assumption Evaluations



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