Appendix H

Whipple Creek Watershed-Scale Stormwater Plan Report

Clark County Stream B-IBI Versus Hydrologic Metrics Relationships

Prepared by

Bob Hutton, Natural Resource Specialist

Clark County Department of Public Works

Clean Water Division

May 2015

Table of Contents

Figures

Tables

Introduction / Summary

The relationships between local streams' biological health and regionally appropriate hydrologic metrics are examined in this study to help address Clark County's 2013-2018 NPDES Phase I Municipal Stormwater Permit (permit) section S5.C.5.c. watershed-scale stormwater planning requirements (WA Dept. of Ecology, 2012). The applicability of several hydrologic metrics with documented Pacific Northwest use in scientific literature is evaluated primarily using local monitoring data. As referenced in the permit, evaluations emphasized metrics from research done on Puget Sound Lowland Streams (DeGasperi *et al*. 2009) calculated mostly from daily average flows and that have the greatest potential for ecological relevance as resource management tools.

This study recommends using the statistically significant linear relationship found between the Benthic Index of Biotic Integrity and the T_{Qmean} hydrologic metric based on local data. This will allow estimating future biological conditions under full build-out scenarios for Clark County's Whipple Creek watershed planning area. Estimates would apply the relationship's linear regression to metric values derived from predicted hydrology based on simulations from a continuous runoff / water quality model calibrated to Whipple Creek. Finding acceptable values for hydrologic metrics, reflecting hydrologic change between pre-disturbance and post-disturbance watershed conditions, would ideally become a focus for watershed management rather than a one-size-fits-all approach or infeasible requirements to completely restore the pre-disturbance flow regime (DeGasperi *et al*., 2009 p. 514).

Methods

The statistical evaluation of relationships used five years (2005-2009) of data from systematically collected annual aquatic macroinvertebrate samples and monitored continuous flow for multiple Clark County streams. Stream health was evaluated using Pacific Northwest Benthic Index of Biotic Integrity (B-IBI) scores. Stream macroinvertebrate samples were collected and preserved using standardized methods (Clark County, 2004) primarily by trained county staff with periodic assistance from volunteers (Figure 3). The samples were then processed, enumerated, and summarized into B-IBI scores using standardized protocols by an independent, qualified professional laboratory (Aquatic Biology Associates, Inc.). Flows were derived from recorded 15-minute interval continuous stream stages (example hydrology station setups are shown in Figure 1 and Figure 2). The finalized continuous stage records were converted to flows using maintained ratings for each flow gage site (Clark County, 2003; Clark County, 2014) with data management via time series software (Aquarius, 2013). Statistical relationships between stream health B-IBI scores (response variable) and hydrologic metrics (predictor variable) were analyzed by county staff using MINITAB (Minitab, 2003) statistical software and widely accepted regression statistical procedures.

Relationship evaluations used respective pairs of multi-year average B-IBI scores and hydrologic metric values from a watershed's monitoring stations usually located within a couple hundred feet of each other. Stream station name codes (e.g. WPL048) are based on the relative percent upstream from the mouth of the watershed's main stem or subwatershed tributary stream, as applicable.

Figure 1 Whipple Creek hydrology monitoring station (WPL048) staff gages, transducer pipe, and accessible equipment shelter

Figure 2 Cougar Creek hydrology monitoring station (CGR018) staff gage, diagonal pipe housing pressure transducer, and secure equipment shelter

Figure 3 B-IBI stream macroinvertebrate field sampling in Gee Creek

Several issues needed addressing prior to statistical evaluations to select the most locally appropriate B-IBI stream health versus hydrologic metric regression relationship. Issues examined included addressing limitations of local data and choosing regionally applicable hydrologic metrics that are ecologically relevant flow management tools (DeGasperi *et al*., 2009, p. 514). The hydrologic metrics evaluated in this current study were narrowed down to three: 1) T_{Qmean} - previously used by Clark County and in the Puget Sound area (Booth *et al.*, 2001); 2) High Pulse Count; and 3) High Pulse Range. All three metrics also have documented use in the permit referenced and more recent Puget Sound Lowland study (DeGasperi, *et al.*, 2009). Table 1 provides definitions for each of these three hydrologic metrics evaluated along with that for high flow pulse.

Table 1 Hydrologic metric definitions

Hydrologic Metric	Definition
T_{Qmean} *	Fraction of a year that the daily mean discharge rate exceeds the annual mean discharge rate
High Flow Pulse ~	Occurrence of daily average flows that are equal to or greater than a threshold set at twice (two times) the long-term daily average flow rate
High Pulse Count (HPC) ~	The number of days each water year that discrete *high flow pulses* occur
High Pulse Range (HPR) ~	The range in days between the start of the first *high flow pulse* and the end of the last *high flow pulse* during a water year

Sources: Booth *et al*. (2001, pp. 19-20) * and DeGasperi *et al*. (2009, pp. 512 and 518) ~

Additionally, the number of local monitoring station data sets fully analyzed was reduced to help minimize potential confounding effects on the relationships between any of the hydrologic metrics and B-IBI subwatershed scores as well as help meet hydrologic metric assumptions (DeGasperi *et al*., 2009, p. 527 and Booth *et al*., 2001, pp. 37-38). Watershed physiographic factors such as basin size, relative topographic relief, broad floodplains, geologic settings (Booth, 2001, pp. 20-21) could contribute to potential confounding effects on relationships. All Clark County monitoring locations with available B-IBI scores and multiple years of continuous hydrology data were screened based on their upstream watershed's relative size and physiographic / climate factors using previous subwatershed characterization and classification analyses by Clark County (Clark County / Wierenga, 2005, p. 8). With no human impact, subwatershed main stem streams classified in the same subwatershed group likely would have comparable water quantity, water quality, and biological structure.

In this previous classification work, Clark County subwatersheds were classified into 14 groups to help evaluate the effects of the stormwater management program on receiving waters (Clark County, 2005, pp. 8-9). The classification thresholds applied to the subwatershed attribute values were derived from literature and staff knowledge related to watershed management for stormwater and fisheries conservation. Each subwatershed was assigned to a category for each of the classifying characteristic factors. A nested sort of category values, by characteristic, was performed on the subwatershed dataset (based on results from statistical cluster analysis) in the following order: stream size, hydrogeology, soil hydrology, topography, and annual precipitation. Subwatersheds were assigned to a common subwatershed group (SWG) if they had the same relative classifications' category results across stream size, hydrogeology, soil hydrology, topography, and precipitation. Table 2 shows the themes, classifying characteristics, attributes for categories, and threshold values used to classify county subwatersheds. The three possible dominant hydrogeologic categories are unconsolidated sedimentary material (PctUSR), Troutdale gravels (PctTroutdale), and older rock (PctRock). Dominant soil hydrology subwatershed classifications were consolidated by combining soil units' associated hydrologic groups into either "A/B Soil" or "C/D Soil" categories representing mostly moderately to well-drained soils or poorly drained soils, respectively.

Table 2 Clark County subwatershed classification characteristics, thresholds, and categories (from Clark County, 2005, p.9)

Theme	Classifying Characteristic	Attribute	Threshold Values
Hydrology	Stream size	Maximum observed stream order	Small: $1^{st} – 4^{th}$ order, Large: > 4^{th} order
Soils and Geology	Dominant hydrogeologic category	Percent hydrogeologic category	NA
Soils and Geology	Dominant hydrologic soil group	Percent A/B soil, Percent C/D soil	>50% subwatershed area
Physical Properties	Topography	Average subwatershed slope	Low: <5%, Medium: 5-30%, High: > 30%
Climate	Annual precipitation	Average annual precipitation	Low: <65", Medium: 65-90", High: > 90"

Results and Discussion

Among Clark County subwatersheds having both annual B-IBI and continuous flow monitoring data, Table 3 highlights by color those screened for similarity to the Whipple Creek watershed (assumed represented by the upper Whipple Creek subwatershed) for use in statistical evaluations of relationships. The subwatersheds in Table 3 are presented mostly in relative order of similarity (with those subwatershed letter designated groups closer alphabetically being most similar) to Upper Whipple Creek subwatershed. Green-shading indicates subwatersheds most similar to Upper Whipple Creek's based on having very similar small stream order size, the same dominant hydrogeology of unconsolidated sedimentary material (PctUSR), the same dominant C/D soil hydrology, and low annual precipitation. The yellow-shaded subwatersheds were also deemed similar enough overall to the Whipple Creek subwatershed for further evaluation. The adequately similar designation of the yellow-coded subwatersheds is supported by their consistent small stream order size, their individual group's mainly physiographically driven classifications being within 4 out of a possible 14 alphabetically labeled subwatershed groups of Whipple Creek's "M" classification, and professional judgment based on knowledge about each of them.

The purple shaded subwatersheds in Table 3 are interpreted as most dissimilar to Whipple Creek's subwatershed. The Upper, Middle, and Lower Lacamas Creek and the Lower Little Washougal River subwatersheds (along with their much smaller nested non-flow monitored subwatersheds) are not considered similar enough because their B-IBI monitored upstream drainages have much larger combined flows and areas than Whipple Creek's. Curtin and Yacolt Creeks are also dissimilar to Whipple Creek due to both their predominantly sandy bottom substrates impacting B-IBI scores and relatively large year-round groundwater contribution to their flow (hydrological outliers compared to most county streams) which is likely not reflected in their respective "L" and "I" classifications. Jones Creek subwatershed is quite unlike Whipple Creek across multiple characteristics due to is 100% older rock hydrogeology, substantial 99% A/B soil hydrology, relatively steep 29% average subwatershed slope, and very high average annual precipitation of 105".

Table 4 provides an overall assessment of similarity for the twelve B-IBI subwatersheds considered for further evaluation of their B-IBI score versus hydrologic metric relationships. It presents each subwatershed's upstream drainage area, subwatershed group classification, overall similarity to the Whipple Creek watershed, and inclusion or rationale for exclusion. Three high (green), three moderate (yellow), and six very low (purple) color-coded subwatersheds designate their overall similarity compared to the Whipple Creek watershed. Importantly, the Whipple Creek subwatershed is assumed representative of the entire Whipple Creek watershed.

Moderate similarity subwatersheds were retained for further evaluation because limiting more involved statistical relationship evaluations to just the three most similar subwatersheds to Whipple Creek's would not allow enough data points to develop representative relationships across a broader geographic area. Whereas, including the very low similarity subwatersheds could overly confound relationships (DeGasperi, *et al*., 2009, p. 527). Therefore, it was determined that a compromise of including the three moderately similar subwatersheds with the three high similarity subwatersheds would allow for a reasonable evaluation of the B-IBI score versus hydrologic metric relationships.

Table 3 Clark County B-IBI and discharge monitored subwatersheds' characteristic categories (values) and group classifications*

Subwatershed	Stream Order Size	Dominant Hydrogeology	Dominant Soil Hydrology	Topography	Annual Precipitation	Subwatershed Group (SWG)
Matney Creek	Small (3)	PctRock (66%)	A/B Soil (62%)	Medium (13%)	Medium (70")	I
Brezee Creek	Small (3)	PctTroutdale (96%)	C/D Soil (80%)	Medium (14%)	Low (53")	J
Cougar Creek	Small (1)	PctUSR (~100%)	A/B Soil (87%)	Medium (6%)	Low (42")	K
Whipple Creek - upper	***Small (3)***	***PctUSR (87%)***	***C/D Soil (54%)***	***Medium (8%)***	***Low (42")***	***M***
Gee Creek - upper	Small (4)	PctUSR (91%)	C/D Soil (94%)	Medium (6%)	Low (46")	M
Mill Creek	Small (3)	PctUSR (89%)	C/D Soil (88%)	Low (4%)	Low (48")	N
Non-comparable T_{Qmean} Subwatersheds due to Too Large of an Upstream Watershed or Dissimilar Hydrology						
Lacamas Creek - lower	Small (4)	PctUSR (88%)	C/D Soil (61%)	Medium (5%)	Low (46")	M
Lacamas Creek - middle	Small (4)	PctUSR (61%)	C/D Soil (98%)	Low (4%)	Low (49")	N
Curtin Creek	Small (2)	PctUSR (100%)	A/B Soil (88%)	Low (4%)	Low (44")	L
Yacolt Creek	Small (3)	PctRock (60%)	A/B Soil (90%)	Medium (13%)	Medium (80")	I
Lacamas Creek - upper	Small (4)	PctRock (89%)	A/B Soil (91%)	Medium (19%)	Medium (88")	I
Jones Creek (Little Washougal River - upper)	Small (4)	PctRock (100%)	A/B Soil (99%)	Medium (29%)	High (105")	H
Little Washougal River -lower	Large (5)	PctRock (60%)	A/B Soil (NA) (68%)	Medium (15%)	Medium (NA)(66")	B

* Based on previous Clark County classification work (Wierenga, 2005)

Table 4 Monitored subwatersheds drainage area, classification group, Whipple Creek similarity, and evaluation rationale

Subwatershed B-IBI Station (Identifier)	Upstream Drainage Area (sq. km^2)	Sub-watershed Group	Overall Similarity to Whipple Creek Watershed	Inclusion / Exclusion Rationale for Further Evaluation
Whipple Creek (WPL050)	***17***	***M***	***High (Assumed Same)***	Included
Gee Creek -upper (GEE050)	23	M	High	Included
Mill Creek (MIL010)	30	N	High	Included
Cougar Creek (CGR020)	8	K	Moderate	Included
Brezee Creek (BRZ010)	9	J	Moderate	Included
Matney Creek (MAT010)	17	I	Moderate	Included
Lacamas Creek-lower (LAC050)	148	M	Very Low	Excluded - Large Upstream Drainage
Curtin Creek (CUR020)	28	L	Very Low	Excluded - Groundwater Contribution / Substrate
Yacolt Creek (YAC005)	20	I	Very Low	Excluded - Groundwater Contribution/ Substrate
Lacamas Creek-upper, (LAC090)	35	I	Very Low	Excluded -Large Upstream Drainage
Jones Creek (JNS060) [Little Washougal River – upper]	18	H	Very Low	Excluded – Hydrogeology, Soil, Slope, Precipitation
Little Washougal River – lower (LWG015)	63	B	Very Low	Excluded - Large Upstream Drainage

Figure 4 shows the location within Clark County of subwatersheds screened, their relative similarity, and the monitoring station locations for high and moderate similarity subwatersheds. The relative position of monitoring stations within subwatersheds or their larger watersheds reflect the portion of upstream drainage basin represented by both the B-IBI scores and hydrologic metrics. All of the B-IBI and flow monitoring stations are located near the outlet of their respective subwatersheds except for Gee Creek. Gee Creek's B-IBI station is at the outlet of the upper Gee Creek subwatershed while its flow monitoring station is located further downstream. However, use of this downstream Gee Creek flow gage is justified because it has relatively little additional contributing drainage area compared to the Upper Gee Creek subwatershed and Gee Creek's upper and lower subwatersheds are similar physiographically.

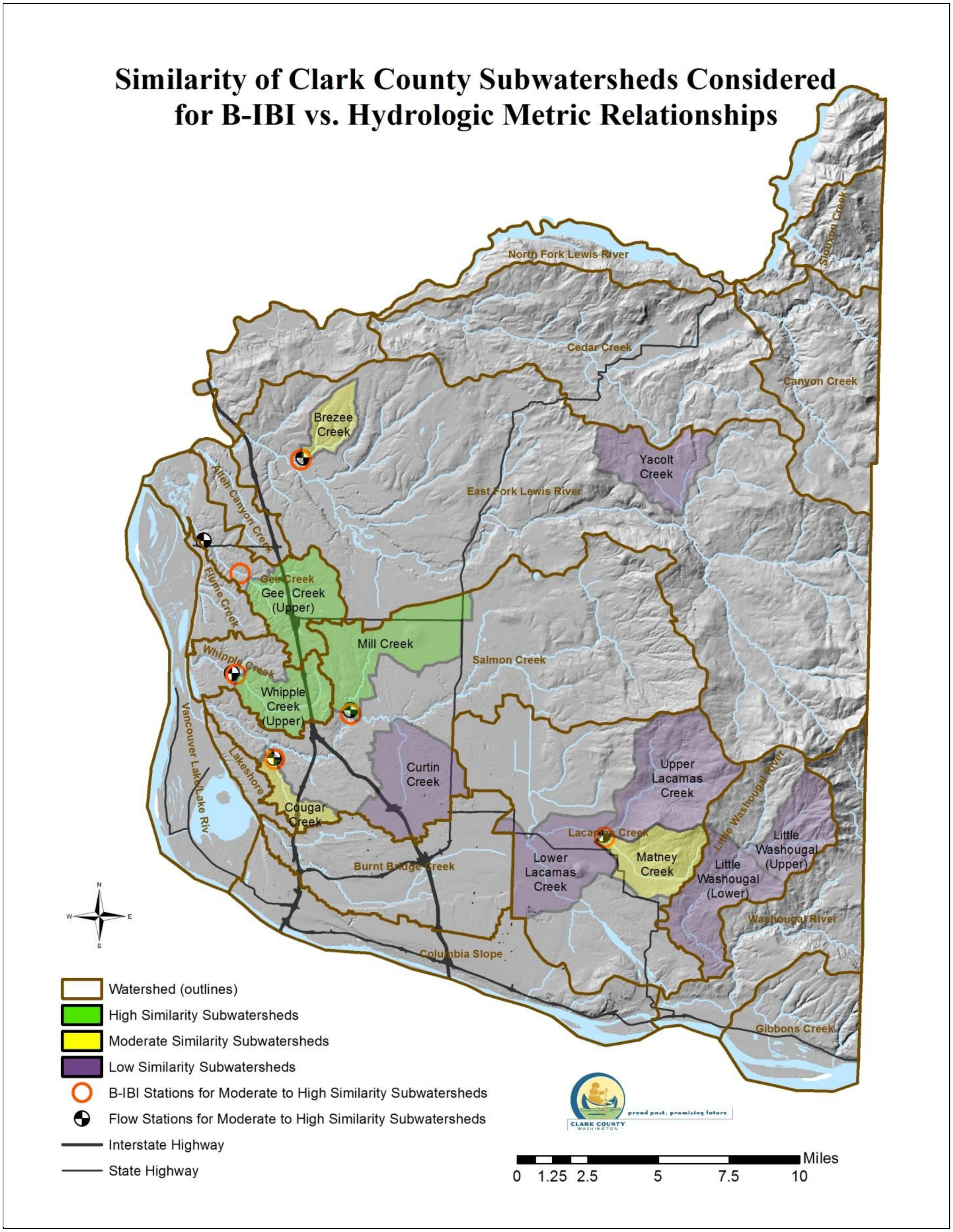


Figure 4 Clark County subwatersheds considered for B-IBI versus hydrologic metric relationships and monitoring station locations for high and moderate similarity subwatersheds

Booth *et al*. developed several hydrologic measures for an EPA study based in the Puget Sound area "that identify both hydrologic changes in streams and differences between streams that result from urban development and are likely to have ecological effects" (Booth *et al*., 2001, pp.19-20). One of the metrics they developed was T_{Qmean}. Individual stream T_{Qmean} statistics were based on each stream's overall average of annual fractions of a year that daily mean flow rate exceeded respective annual mean flow rate. Mean annual discharge was exceeded approximately 30% of the time across the Puget Lowland streams.

At a more detailed analysis level of the Puget Sound Lowland stream data (Booth *et al*., 2001, pp. 37-38), significantly lower mean T_{Qmean} values were found for urban than suburban drainage areas of less than 20 km^2. Additionally, T_{Qmean} varied little from year to year for streams with stable land use (coefficient of variation of 17% during 1989-1998) and can be estimated reliably from a relatively short (e.g., ~10 years) stream flow record. Generally, T_{Qmean} for urban streams was less than 30% (n=11, mean 0.29) and statistically less than that for suburban streams for which it was greater than 30% (n=12, mean 0.34). Additionally, independent of the level of urban development, larger streams (drainage area > 30 km^2) typically have more attenuated stream flow patterns and thus higher T_{Qmeans} than smaller streams (< 30 km^2). The mean T_{Qmean} for larger streams (0.35) was significantly greater than that for smaller streams (0.28).

DeGasperi *et al*. (2009) analyzed daily average flow values and stream biological responses (B-IBI scores) from 16 monitored streams in King County, Washington to evaluate relationships between fifteen hydrologic metrics and B-IBI scores across a gradient of urbanization (DeGasperi, et. al., 2009, pp. 512 and 518). Of the fifteen metrics evaluated for ecological relevance, HPC and HPR were found to best meet the four criteria of: "(1) sensitive to urbanization consistent with expected hydrologic response, (2) demonstrate statistically significant trends in urbanizing basins, (3) be correlated with measures of biological response to urbanization, and (4) be relatively insensitive to potentially confounding variables like basin area."

Based on the literature and to address issues noted earlier, the hydrologic metrics evaluated in this current Clark County study for their relationships to B-IBI scores are limited to: T_{Qmean}, High Pulse Count (HPC), and High Pulse Range (HPR). B-IBI was shown to have a statistically significant linear relationship with T_{Qmean} in the Puget Lowland region (Booth *et al*., 2001, DeGasperi *et al*., 2009, p. 528). HPC and HPR were found to have best met criteria for ecological relevance in the stormwater permit referenced 2009 DeGasperi paper. Table 5 presents the calculated multi-year averages for B-IBI scores (reflecting stream biological health) as well as $T_{Qmean,}$, HPC (and log base 10 equivalents), and HPR hydrologic metrics for all Clark County subwatersheds considered for further evaluation.

While T_{Qmean} is a reliable indicator of hydrologic change over time in a stream basin, it varies with drainage area and other physiographic conditions. Thus, T_{Qmean} should only be used to compare similar stream basins (Booth *et al*., 2001, p.41). This report's appendix presents exploratory data analyses results from regressing B-IBI on T_{Qmean} based on various combinations of data from all available Clark County and other referenced Puget Sound Lowland (DeGasperi *et al*., 2009) monitored watersheds. However, to improve consistency and reduce potential confounding for further evaluations in this current Clark County study, the subwatersheds focused on for more involved statistical analyses of relationships are limited to those considered moderate to high in overall similarity to the Whipple Creek subwatershed (color coded yellow and green in Table 5).

Table 5 Clark County subwatersheds' average B-IBI and hydrologic metrics (T_{Qmean}, High Pulse Count and Logs, and High Pulse Range)

Clark County B-IBI Station (Identifier)	Water Years	Average B-IBI	Average T_{Qmean}	Average High Pulse Count	Average High Pulse Count (log 10)	Average High Pulse Range
Whipple Creek (WPL050)	***2005 - 2009***	***22***	***0.27***	***12***	***1.079***	***160***
Gee Creek –upper (GEE050)	2005 - 2009	24	0.25	11	1.041	137
Mill Creek (MIL010)	2005 - 2009	27	0.27	9	0.954	140
Cougar Creek (CGR020)	2005 - 2009	20	0.26	19	1.279	261
Brezee Creek (BRZ010)	2005 - 2009	28	0.29	6	0.778	138
Matney Creek (MAT010)	2005 - 2008	34	0.33	10	1.000	151
Lacamas Creek-lower (LAC050)	2003 - 2009	22	0.27	8	0.903	144
Curtin Creek (CUR020)	2004 - 2009	22	0.33	6	0.778	138
Lacamas Creek-upper (LAC090)	2004 - 2009	30	0.26	9	0.954	168
Yacolt Creek (YAC005)	2004 - 2009	42	0.31	5	0.699	93
Jones Creek (JNS060) [Little Washougal River – upper]	2004 - 2009	46	0.35	8	0.903	200
Little Washougal River – lower (LWG015)	2004 - 2009	32	0.23	8	0.903	162

Table 6 summarizes and Figure 5, Figure 6, and Figure 7 depict the statistical relationships between the more similar Clark County subwatersheds' individual average B-IBI scores (response variable) and each of the three Pacific Northwest hydrologic metrics (predictor variable) evaluated more fully in this study. The ranges of these and many appendix figures' x and y axes are comparable to those in DeGasperi *et al*. (2009) paper's figure 6 to facilitate comparisons with those found for the Puget Sound urbanizing basins.

The analyses results are important for Clark County because T_{Qmean} was the only evaluated hydrologic metric found to have a statistically significant (R^2 of 82.2%, p-value of 0.013 versus as an acceptable Type I error rate of 0.05) and reasonable linear relationship when B-IBI was regressed on it. Given the small sample size of six subwatersheds, evaluations of the best-fit linear regression relied primarily on visual interpretation of graphics with some statistical testing of regression assumptions. For example, scatterplots and residual plots (in the appendix) were evaluated for outliers and non-constant variance in the residuals versus the predictor (Ott, pp. 365-366) hydrologic metrics.

Table 6 Summary of B-IBI linear regressions on hydrologic metrics for moderate and high similarity Clark County subwatersheds

Hydrologic Metric	Linear Regression Equation	Pearson Correlation R^2 (% of B-IBI Variation Explained by Regression Equation)	Significance of Association between B-IBI and Hydrologic Metric (Ho: slope = 0): p-value	Predictor Hydrologic Metric Significantly Explains B-IBI Variation ($\alpha = 0.05$)	Assessment of Linear Regression: Fit Reasonable / Generally Meets Regression Assumptions (Violations)
T_{Qmean}	Avg BIBI = - 16.7 + 154 Avg TQmean	82.2%	0.013	Yes	Yes /Mostly
High Pulse Count (Log10)	Avg BIBI = 45.2 – 18.9 Log10 Avg HPC	38.5%	0.189	No	Marginal Fit (Outlier - Matney) / No (Residuals Non-normal & Non-constant Variance)
High Pulse Range	Avg BIBI = 35.7 – 0.06 Avg HPR	33.1%	0.232	No	Marginal Fit (Outlier - Matney) / Marginally Meets (Residuals Non-constant Variance)

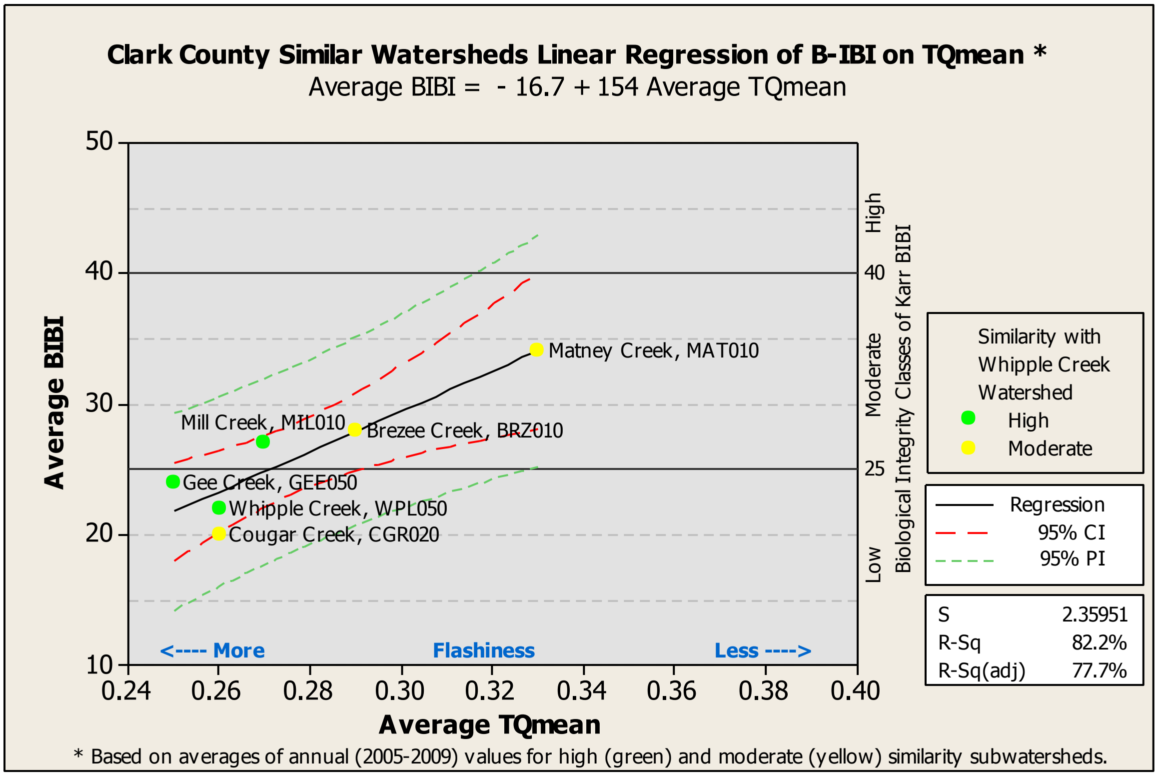


Figure 5 Linear regression of average B-IBI on average TQmean across similar subwatersheds

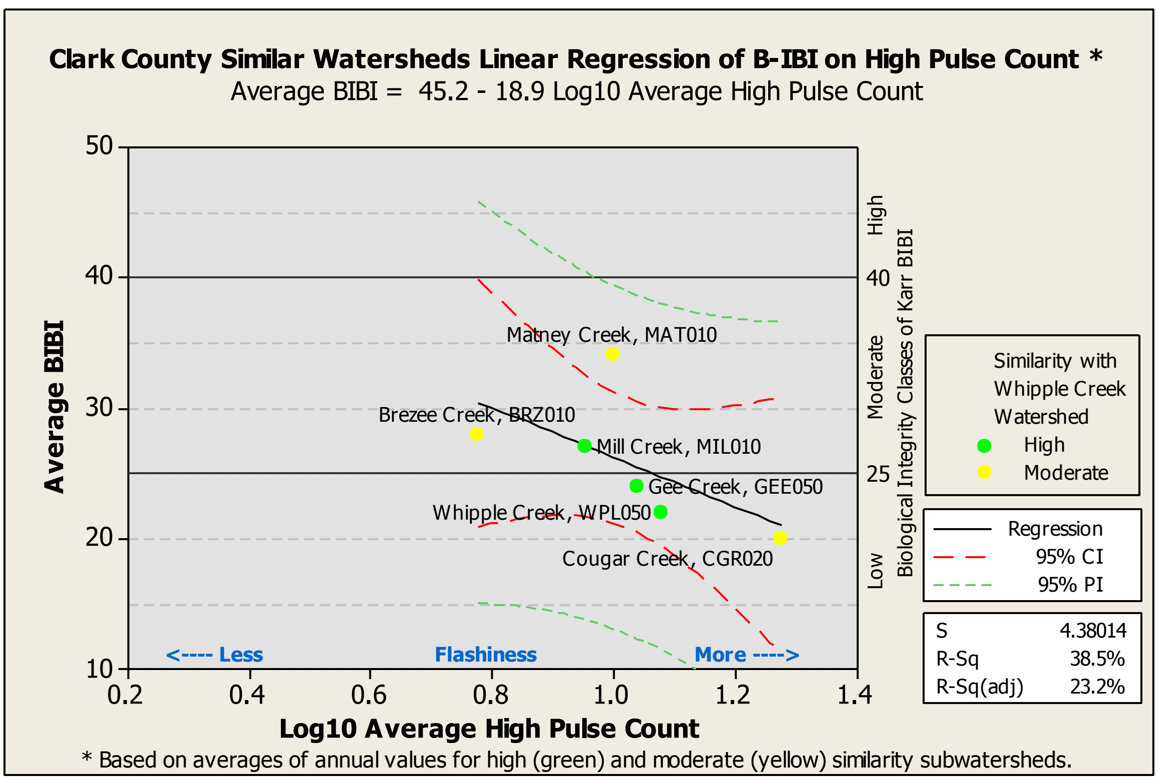


Figure 6 Linear regression of average B-IBI on average High Pulse Count (Log10) across similar subwatersheds

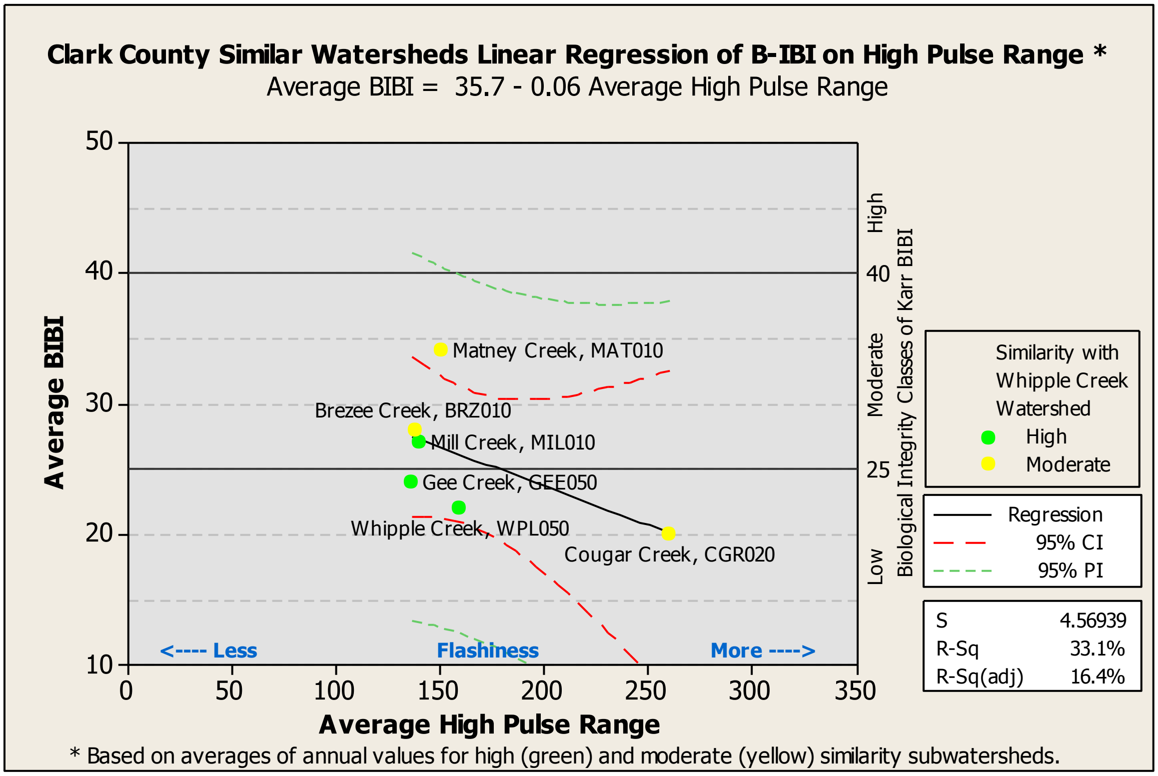


Figure 7 Linear regression of average B-IBI on average High Pulse Range across similar subwatersheds

Charts in the appendix of this document summarize exploratory data analyses and general evaluations of the goodness of linear regression model fit and assumptions. The exploratory data analyses scatterplots of Clark County B-IBI or hydrologic metrics versus water year depict how subwatershed average yearly values varied over time. There does not appear to be any obvious trends for these values over the 5-year (2005 - 2009) timeframe evaluated. The scatterplot of Clark County subwatershed B-IBI versus T_{Qmean} fitted with both Lowess smoothing and least squares regressions shows that the linear model order appears to adequately fit the observed data. The distributions of differences (residuals or errors) between response variable observed values and their respective predicted or fitted values (MiniTab Release 14.1 software Help) are depicted in the plots showing B-IBI residuals across the individual subwatersheds. The variation of Clark County stream residuals appears to be fairly constant and random across the range of average T_{Qmean} predictors and fitted values from the regression model thus likely does not violate the assumptions of homogeneous error variances and independence (Ott, pp. 365-366). The "Residual Versus the Order of the Data" plot is not applicable since there is no meaning to the order of the subwatershed B-IBI values. The other linear regression assumption of normally distributed errors was also evaluated for the similar Clark County watersheds. Both the T_{Qmean} residuals' near linear plotted values on the normal probability plot and Anderson-Darling normality test statistic's relatively large p-value of 0.55 suggest that the null hypothesis of normality can not be rejected (MiniTab Release 14.1 software Help). Overall, the linear regression assumptions are generally assumed to have been satisfied at an acceptable level given the sample size of six moderate to high similarity Clark County subwatersheds whose relationships were evaluated in more depth.

Also presented in the appendix are brief exploratory analyses on the linear relationships between B-IBI (response) and T_{Qmean} (predictor) for mostly combined data from Clark and King Counties' streams (based on additional data downloaded from the 2009 DeGasperi research from the American Water Resources Association journal web page). These analyses showed poorer correlation coefficients (usually much lower R^2) than the similar Clark County watersheds for several combinations of Clark and / or King County stream data, even when only smaller watersheds (drainage areas of < 30 km^2) were evaluated.

Conclusions

Amongst the twelve Clark County subwatersheds having both adequate amounts of annual B-IBI and continuous flow monitoring data, six were found to be either moderately or highly similar to the Whipple Creek watershed that is the subject of watershed planning. Further analyses was performed on the linear regression relationships between these six watersheds' average B-IBI scores and three Pacific Northwest hydrologic metrics: T_{Qmean}, High Pulse Count, and High Pulse Range. The analyses of the Clark County data showed that only T_{Qmean} had a significant linear relationship (significantly explained B-IBI variation, R^2 of 82%, p-value of 0.013). It is recommended that this linear regression of B-IBI on T_{Qmean} be used in Clark County's Whipple Creek watershed planning effort for estimating future biological conditions in conjunction with model simulations of predicted hydrology.

References

Aquarius Informatics Inc., Aquarius Time-Series Software Version 3.3, 2013. Vancouver, BC.

Aquatic Biology Associates Inc., Pacific Northwest Level 2 Identification Protocol, Corvallis, OR

Booth, B.B., J.R. Karr, S. Schauman, C.P. Konrad, S.A. Morley, M.G. Larson, P.C. Henshaw, E.J. Nelson, and S.J. Burges, (EPA Grant # R82-5284-010) 2001. *Urban Stream Rehabilitation in the Pacific Northwest*. University of Washington, Seattle, WA. 78p.

Clark County, June 2014. *Clark County NPDES Watershed Planning Hydrology Monitoring Project - Quality Assurance Project Plan*. Vancouver, WA. 37 p.

Clark County, November 2004. *Clark County NPDES Long-term Index Site Project - Quality Assurance Project Plan*. Vancouver, WA. 17 p.

Clark County, September 2003. *Clark County Hydrology Monitoring Project Quality Assurance Project Plan*. Vancouver, WA. 40 p.

Clark County / Wierenga R., January 2005. *Technical Report: Subwatershed Characterization and Classification Clark County Washington*. Vancouver, WA. 17 p.

DeGasperi, C.L., H.B. Berge, K.R. Whiting, J.J. Burkey, J.L. Cassin, and R.R. Fuerstenberg, 2009. Linking hydrologic alteration to biological impairment in urbanizing streams of the Puget Lowland, Washington, USA. *Journal of the American Water Resources Association* 45: 512-533.

Minitab Inc., MINITAB Statistical Software Release 14.1, 2003. State College, PA.

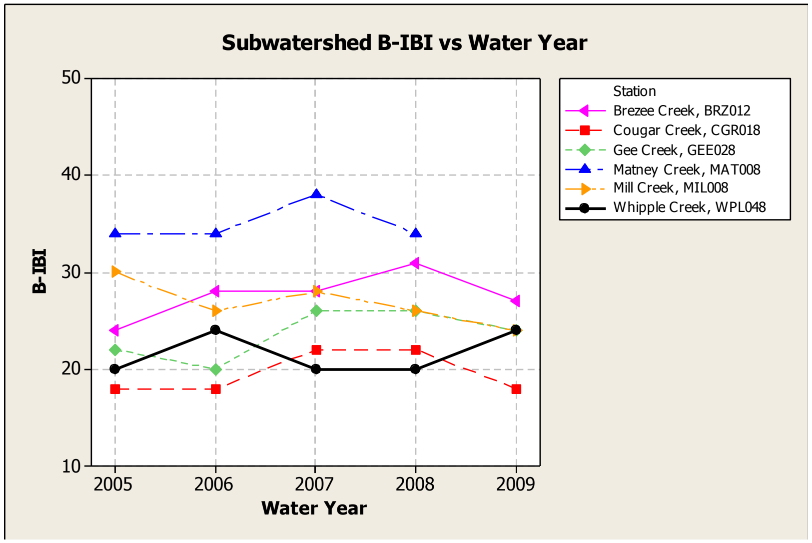
Ott, L., 1988, *An Introduction to Statistical Methods and Data Analysis*. PWS-Kent Publishing Company, Boston, MA. 835 p.

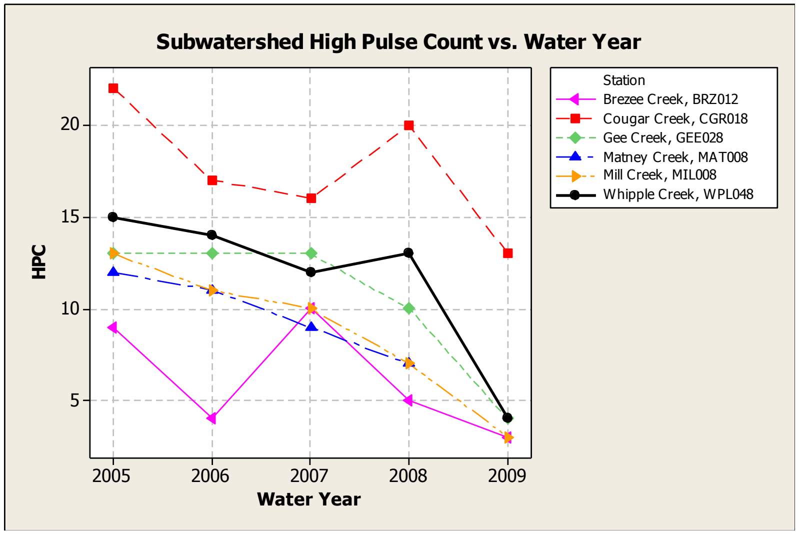
Washington State Department of Ecology. August 1, 2012. *Phase I Municipal Stormwater Permit National Pollutant Discharge Elimination System (NPDES) and State Waste Discharge General Permit for discharges from Large and Medium Municipal Separate Storm Sewer Systems*. Olympia, WA 74 p.

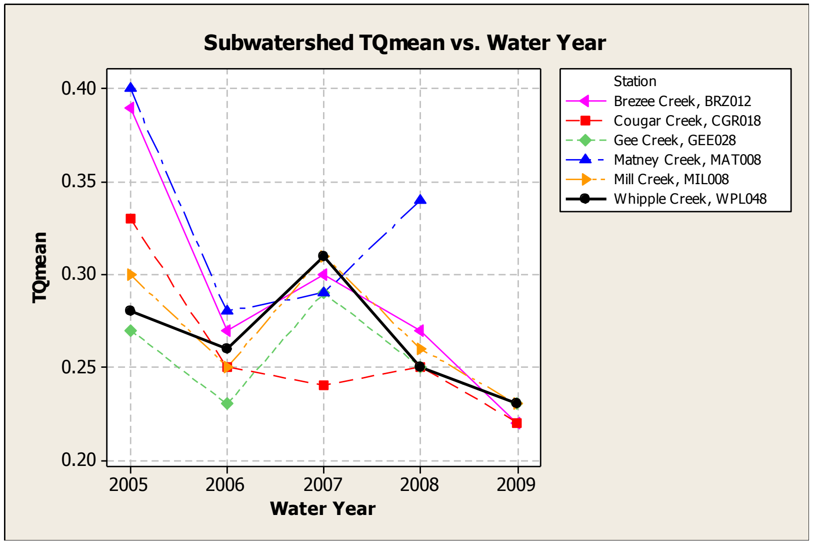
Appendices

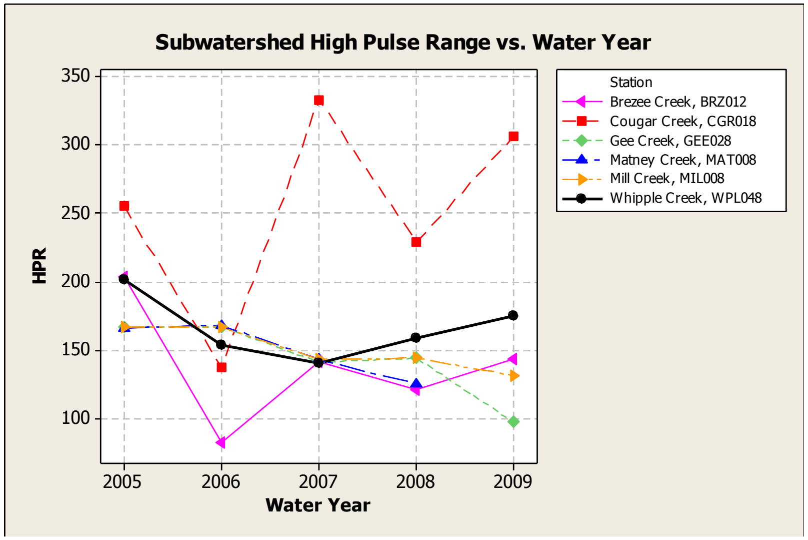
Exploratory Data Analyses:

Clark County Subwatershed B-IBI, T_{Qmean}, High Pulse Count, and High Pulse Range values across water years



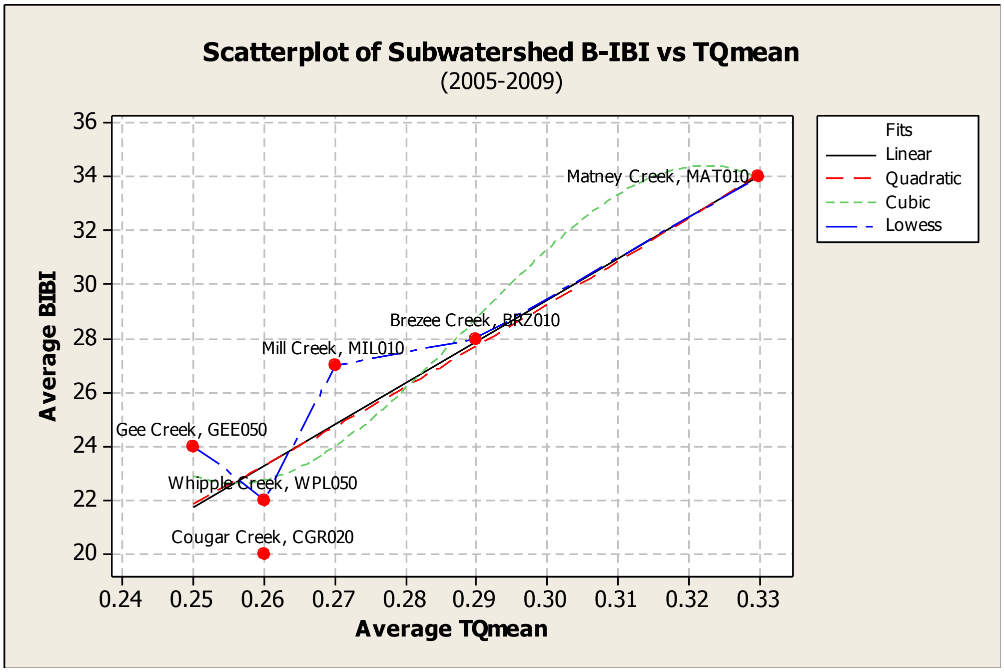




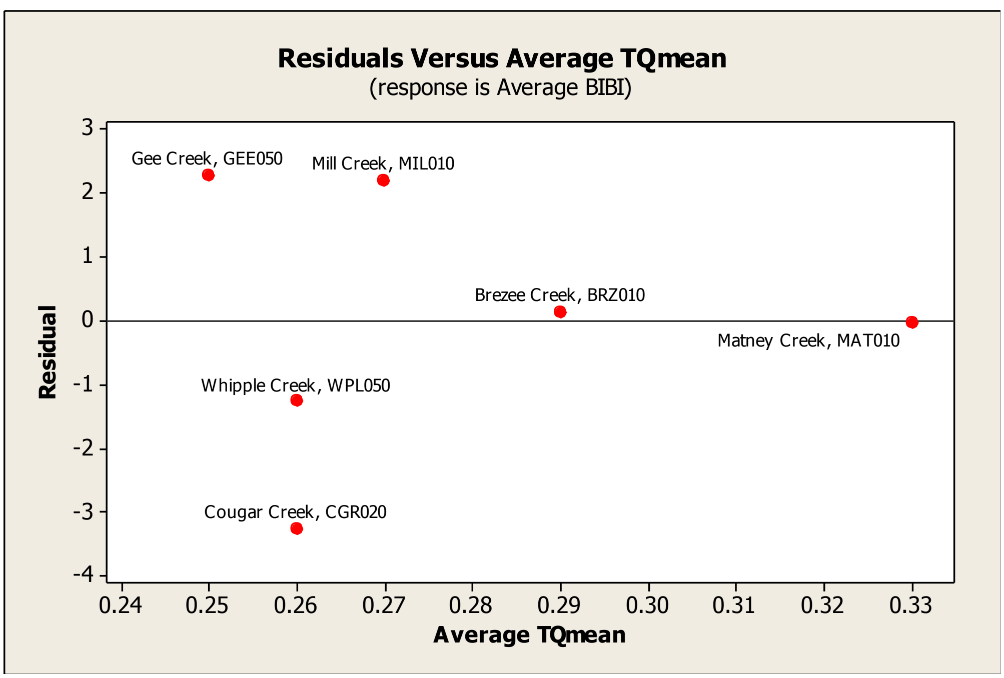


Clark County Similar Watersheds Assumption Evaluations:

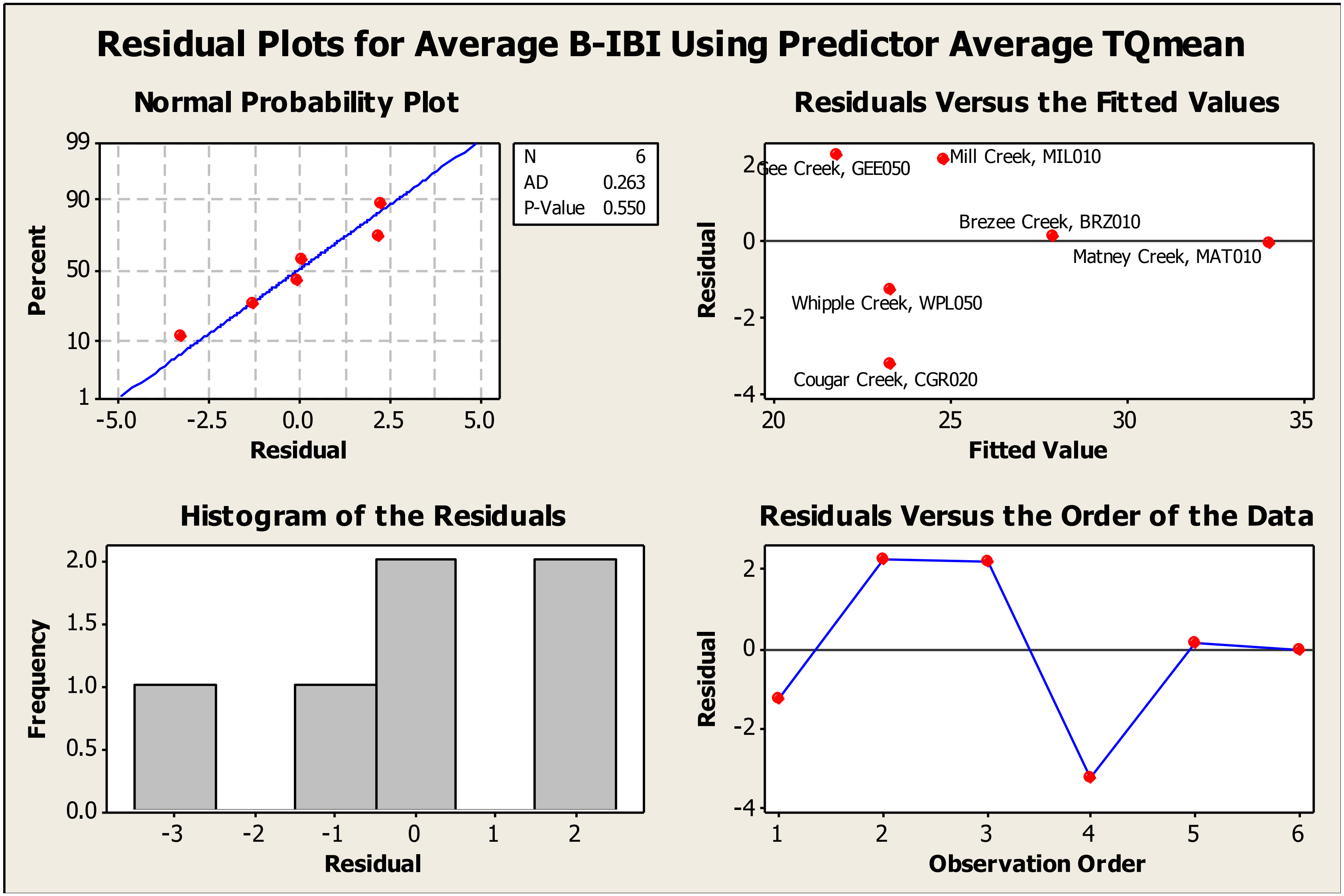
Regression models' appropriateness: average B-IBI regressed on average T_{Qmean}
(scatterplot with Lowess smoothing connector line and linear, quadratic, and cubic models fit)



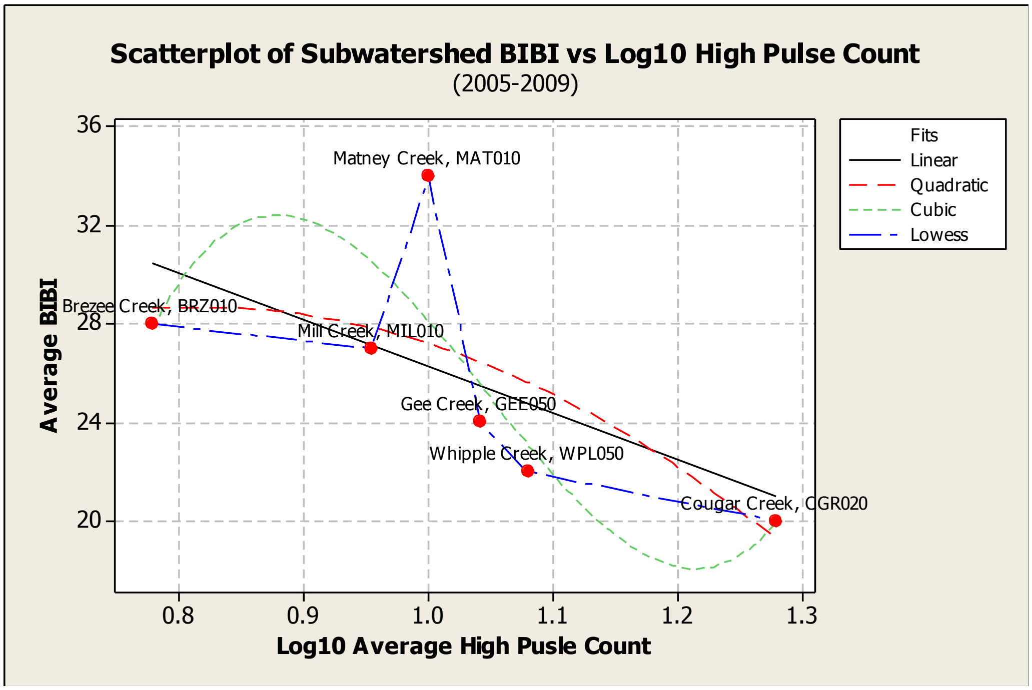
B-IBI residuals (differences between subwatersheds' observed B-IBI and their fitted values on linear regression) across range of Average T_{Qmean} predictors



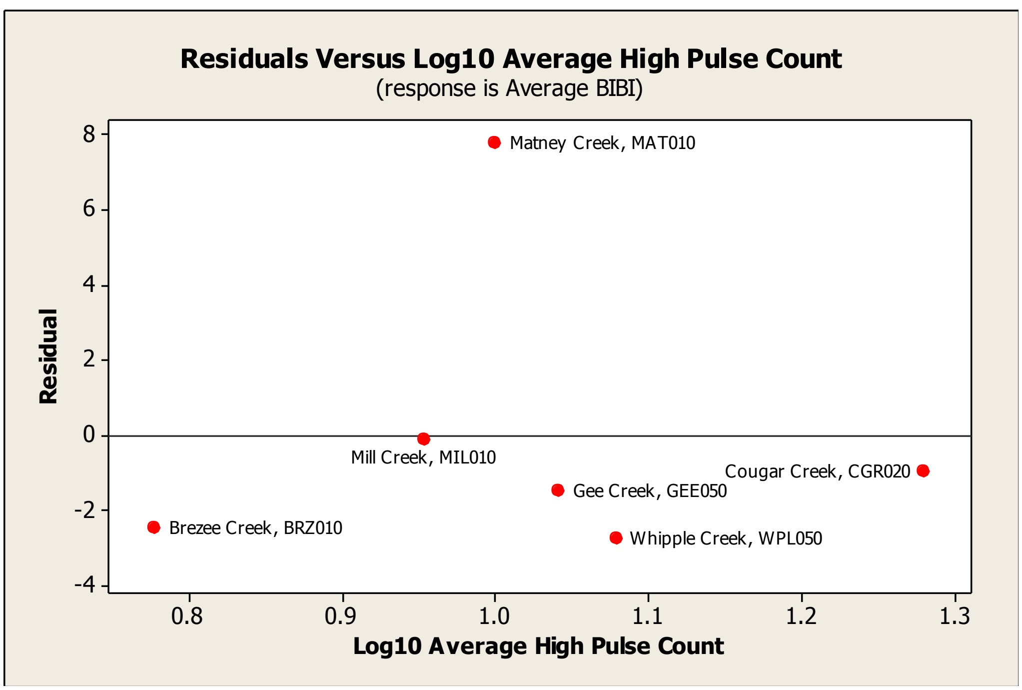
B-IBI residuals (differences between subwatersheds' observed B-IBI and their fitted linear regression on predictor T_{Qmean})



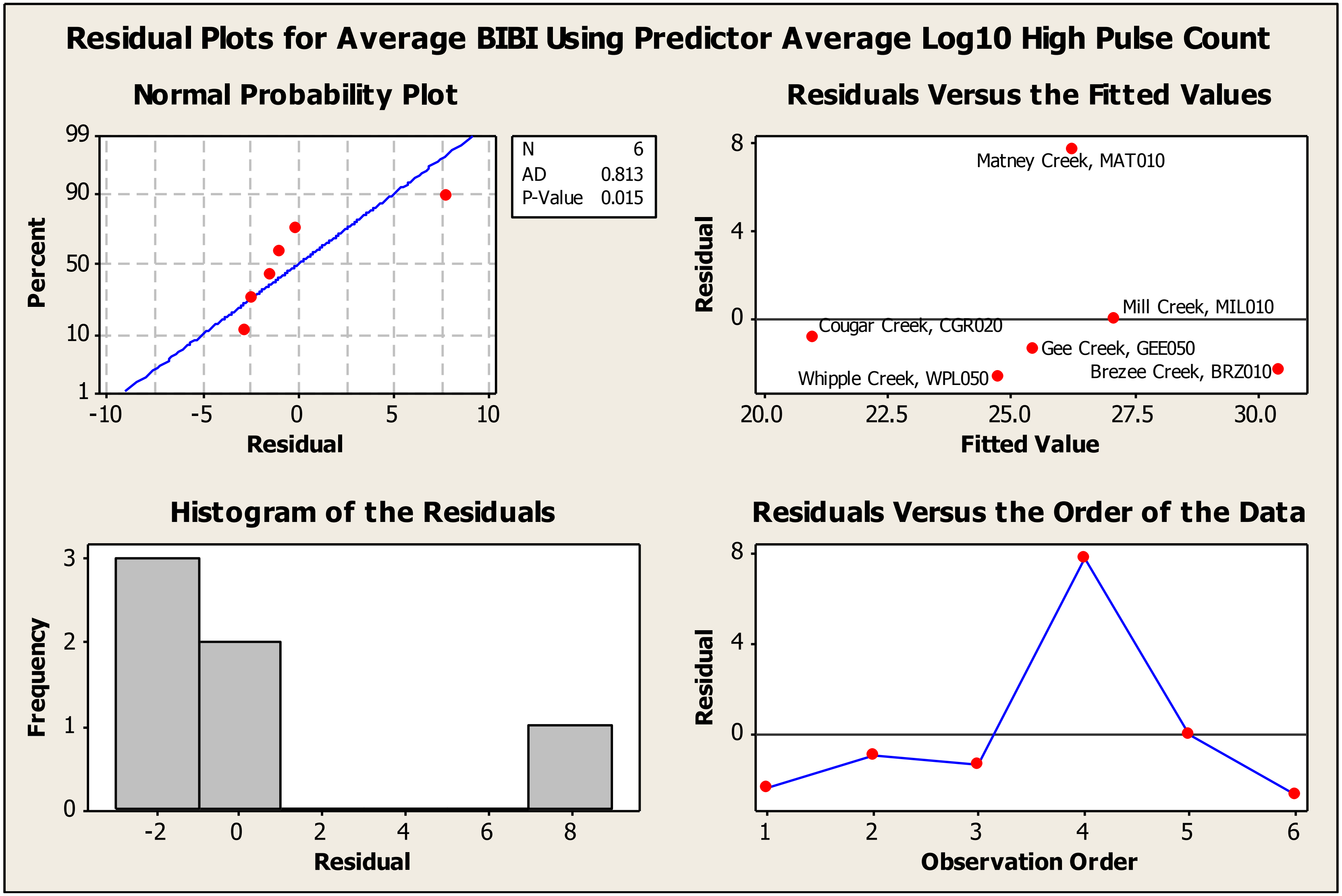
Regression models' appropriateness: average B-IBI regressed on average Log10 High Pulse Count (scatterplot with Lowess smoothing connector line and linear, quadratic, and cubic models fit)



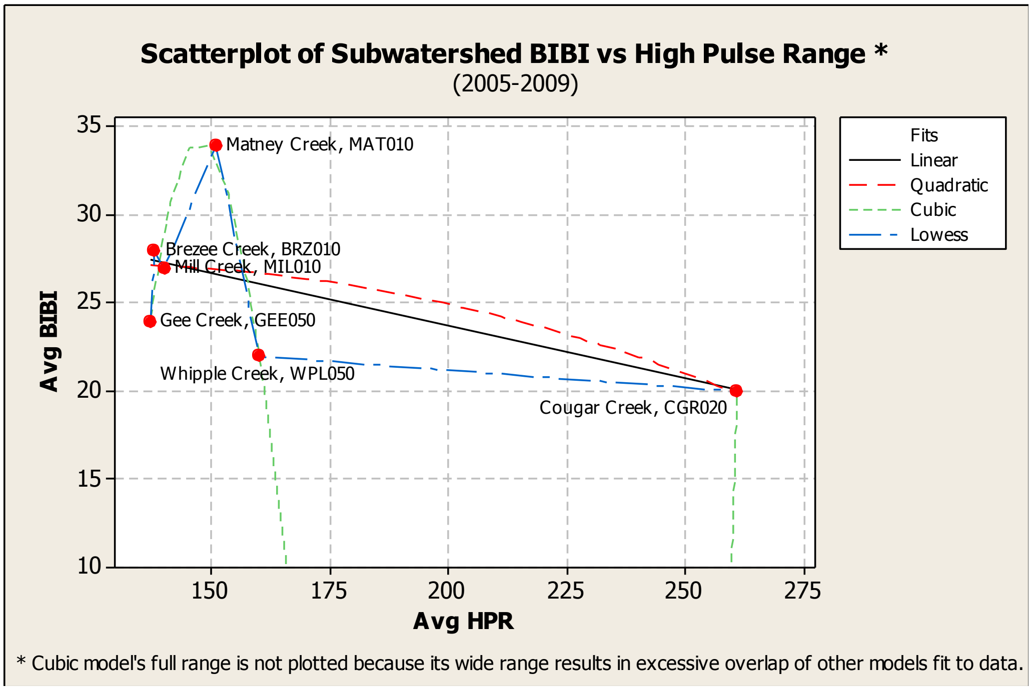
B-IBI residuals (differences between subwatersheds' observed B-IBI and their fitted values on linear regression) across range of Average High Pulse Count predictors



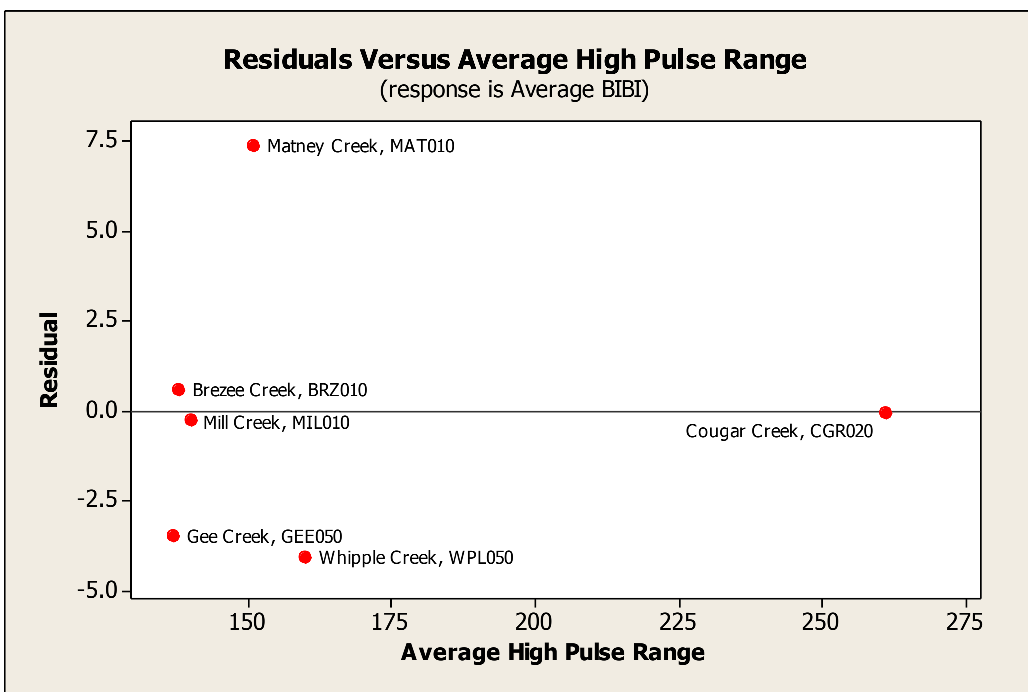
B-IBI residuals (differences between subwatersheds' observed B-IBI and their fitted linear regression on predictor Log10 High Pulse Count)



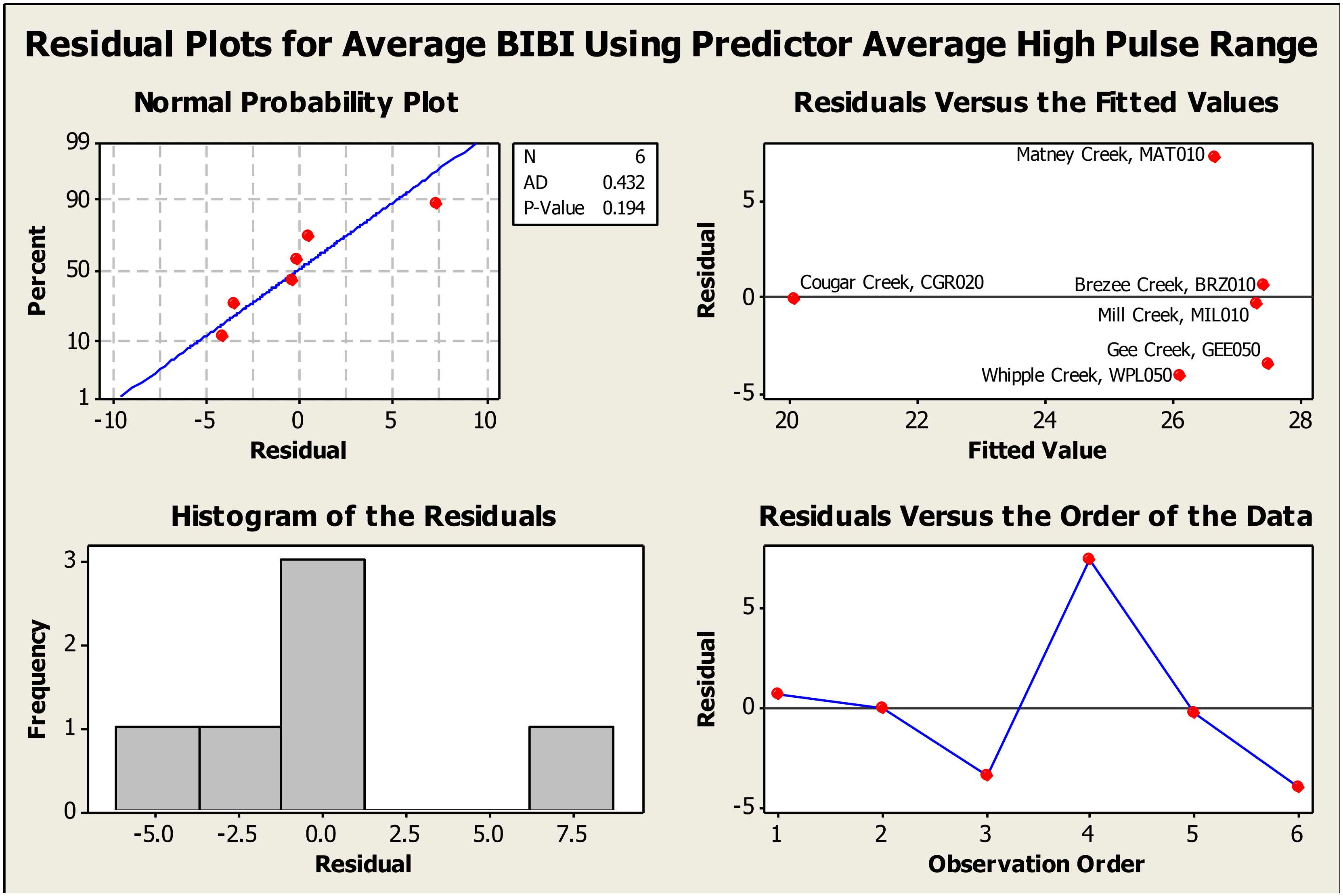
Regression models' appropriateness: average B-IBI regressed on average High Pulse Range (scatterplot with Lowess smoothing connector line and linear, quadratic, and cubic models fit)



B-IBI residuals (differences between subwatersheds' observed B-IBI and their fitted values on linear regression) across range of Average High Pulse Range predictors

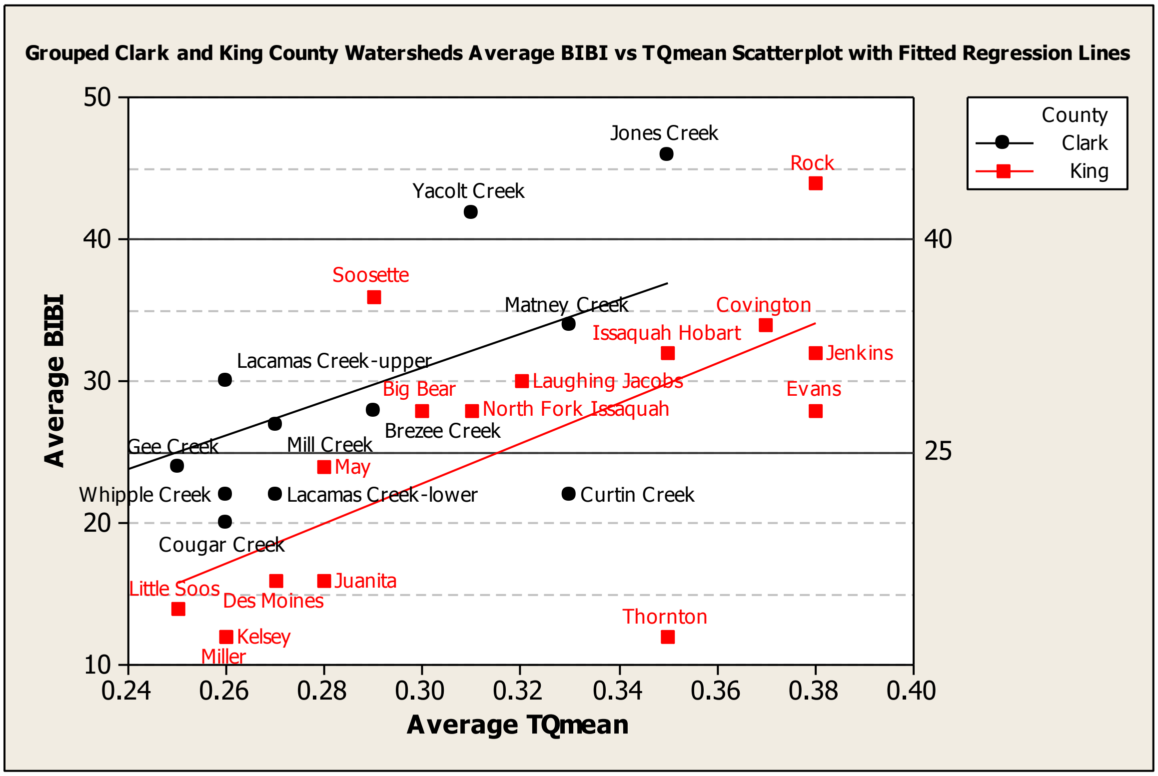


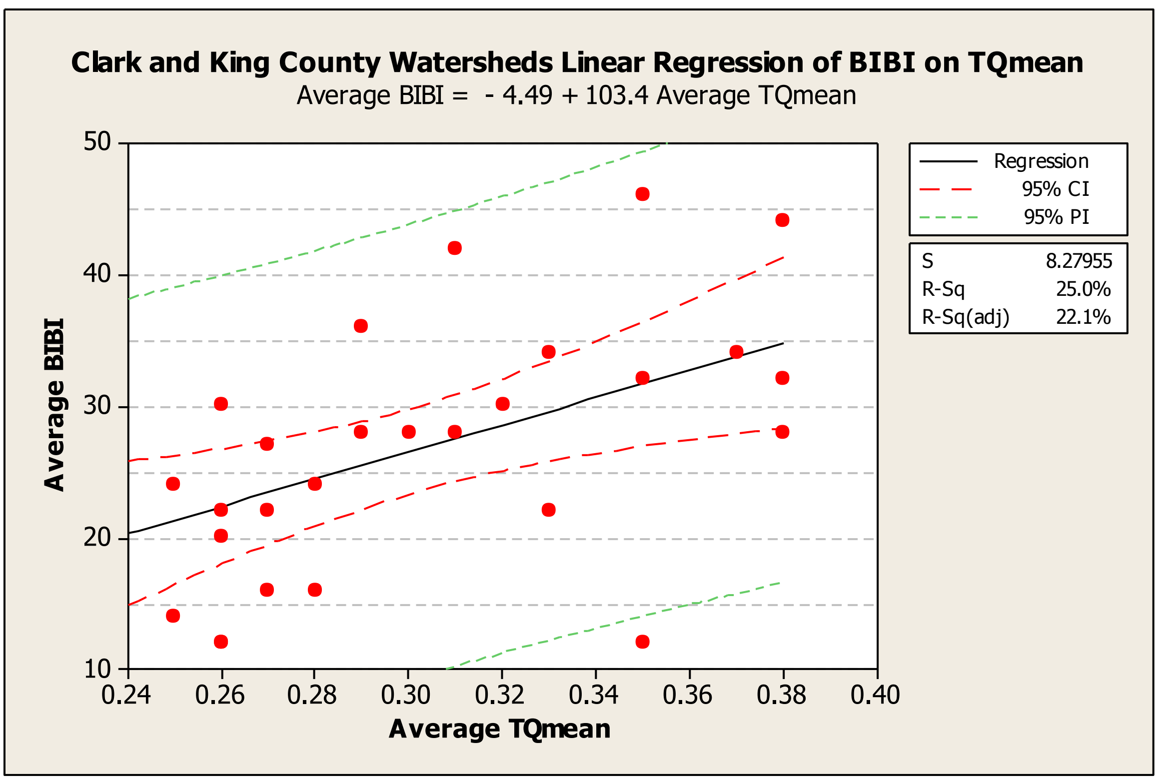
B-IBI residuals (differences between subwatersheds' observed B-IBI and their fitted linear regression on predictor High Pulse Range)

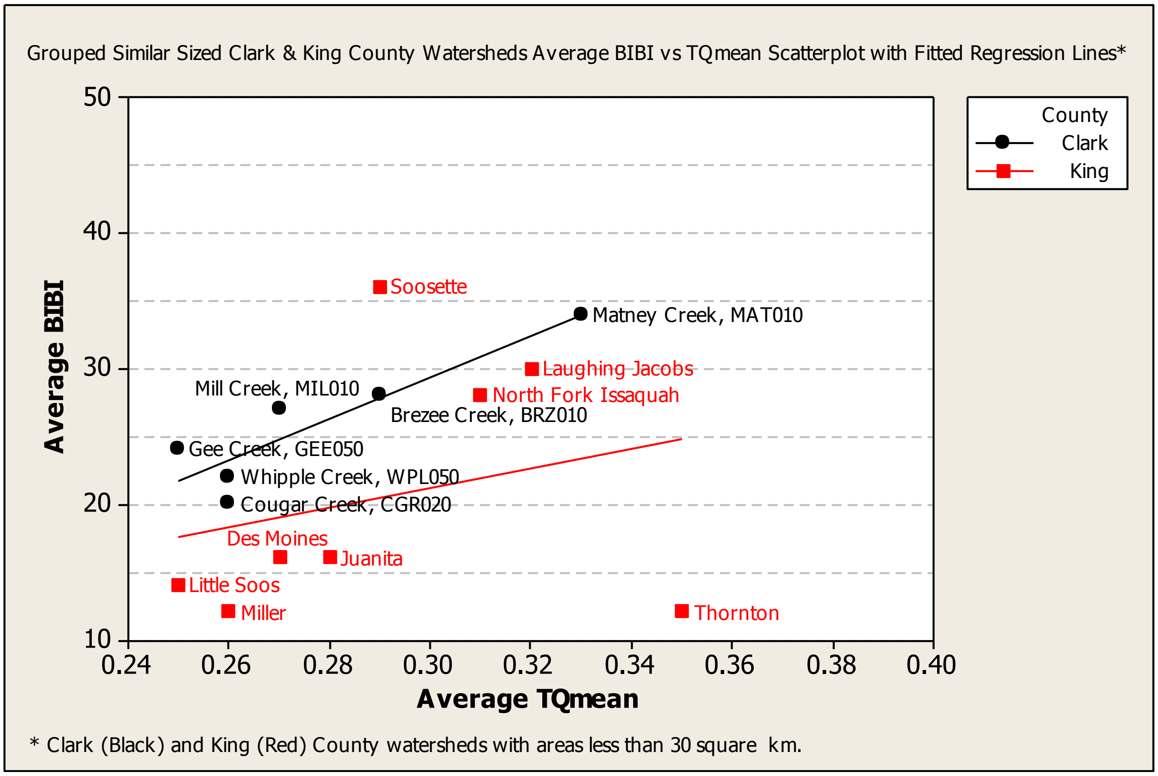


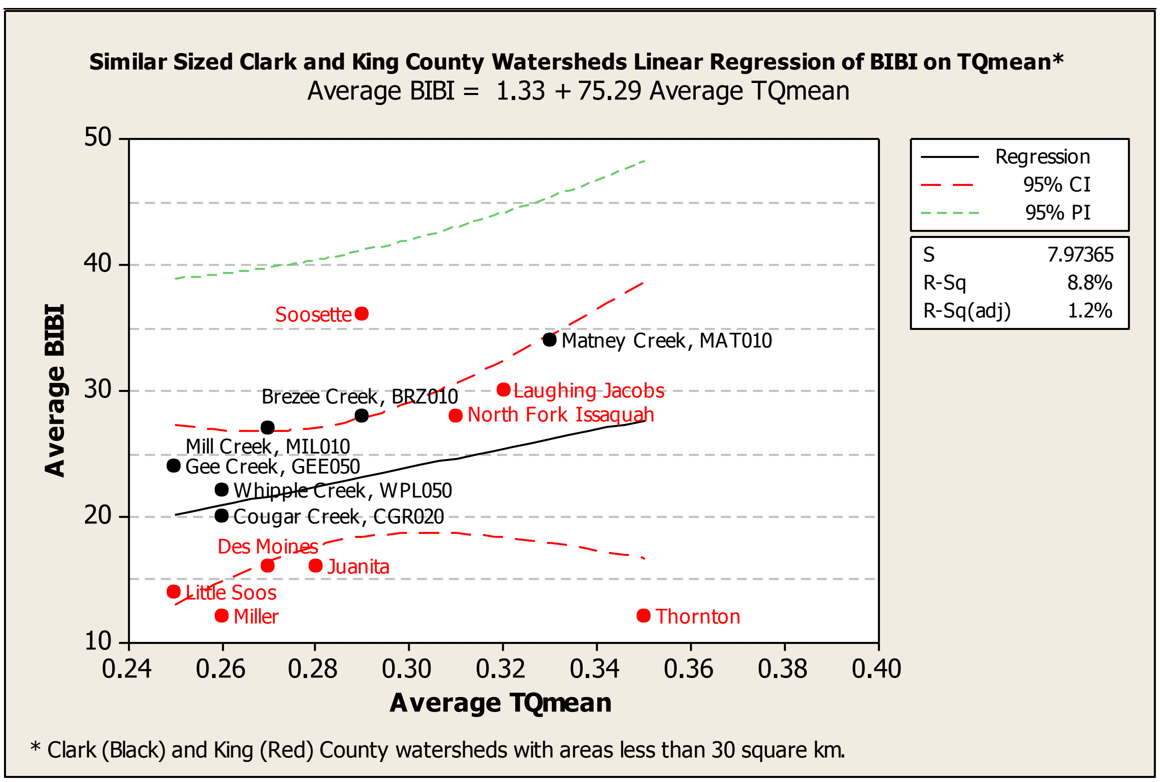
Exploratory Data Analyses:

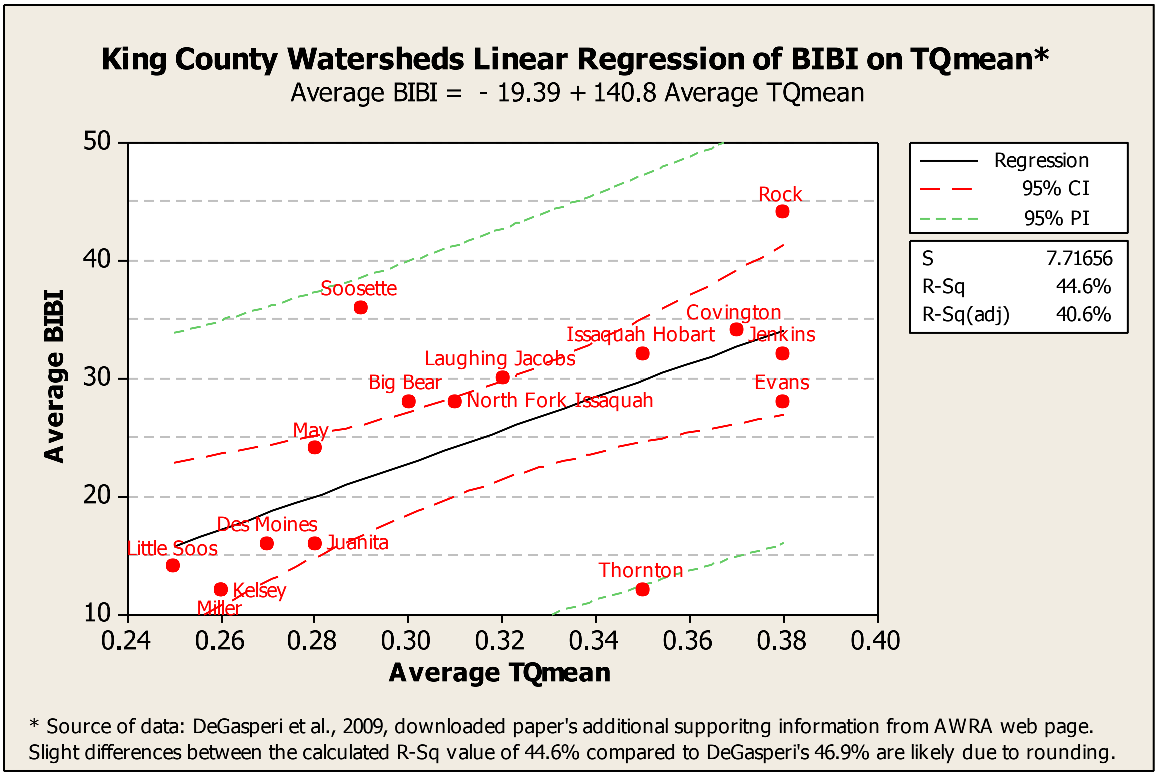
Clark and King County Subwatersheds B-IBI versus T_{Qmean} Scatterplots and Linear Relationships

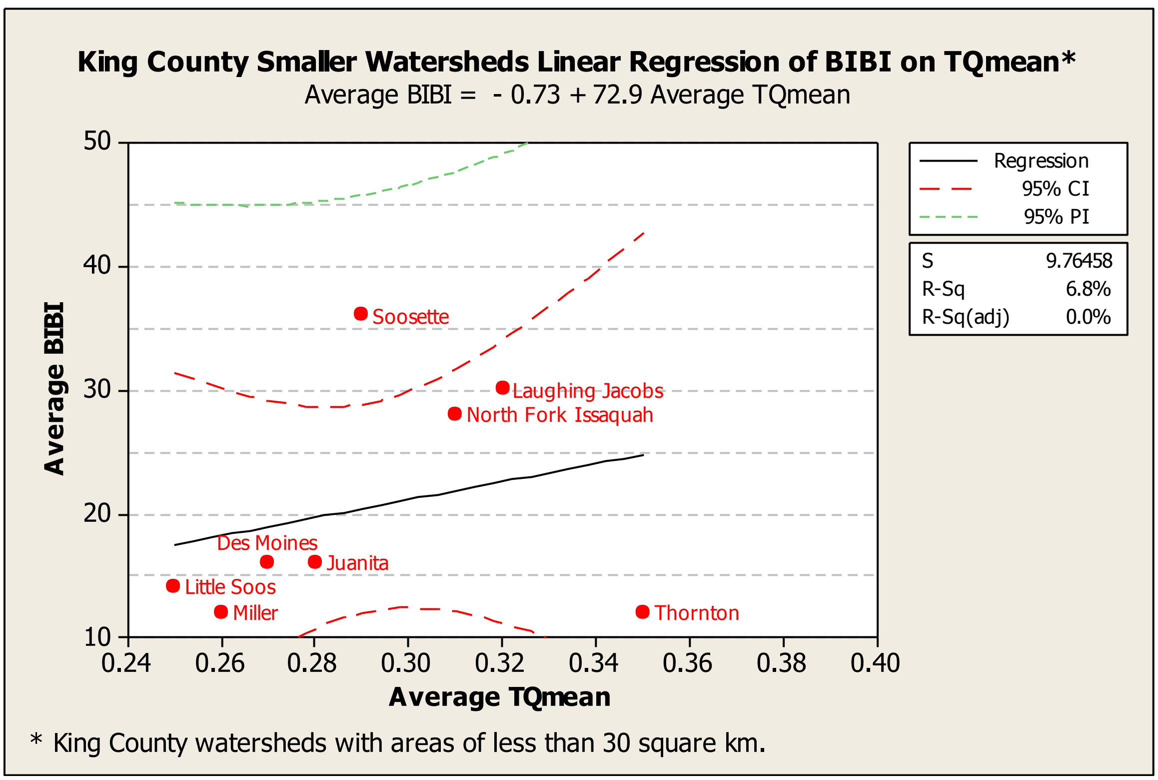





Grouped Similar Sized Clark & King County Watersheds Average BIBI vs TQmean Scatterplot with Fitted Regression Lines*
County
Clark
King
Average BIBI
Average TQmean
Soosette
Matney Creek, MAT010
Laughing Jacobs
North Fork Issaquah
Mill Creek, MIL010
Brezee Creek, BRZ010
Gee Creek, GEE050
Whipple Creek, WPL050
Cougar Creek, CGR020
Des Moines
Juanita
Little Soos
Miller
Thornton
* Clark (Black) and King (Red) County watersheds with areas less than 30 square km.


Similar Sized Clark and King County Watersheds Linear Regression of BIBI on TQmean*
Average BIBI = 1.33 + 75.29 Average TQmean
Regression
95% CI
95% PI
S 7.97365
R-Sq 8.8%
R-Sq(adj) 1.2%
Average BIBI
Average TQmean
Soosette
Matney Creek, MAT010
Laughing Jacobs
North Fork Issaquah
Brezee Creek, BRZ010
Mill Creek, MIL010
Gee Creek, GEE050
Whipple Creek, WPL050
Cougar Creek, CGR020
Des Moines
Juanita
Little Soos
Miller
Thornton
* Clark (Black) and King (Red) County watersheds with areas less than 30 square km.


King County Watersheds Linear Regression of BIBI on TQmean*
Average BIBI = - 19.39 + 140.8 Average TQmean
Regression
95% CI
95% PI
S 7.71656
R-Sq 44.6%
R-Sq(adj) 40.6%
Average BIBI
Average TQmean
Rock
Soosette
Covington
Issaquah Hobart
Jenkins
Laughing Jacobs
Big Bear
North Fork Issaquah
Evans
May
Des Moines
Juanita
Little Soos
Thornton
Kelsey
Miller
* Source of data: DeGasperi et al., 2009, downloaded paper's additional supporitng information from AWRA web page.
Slight differences between the calculated R-Sq value of 44.6% compared to DeGasperi's 46.9% are likely due to rounding.


King County Smaller Watersheds Linear Regression of BIBI on TQmean*
Average BIBI = - 0.73 + 72.9 Average TQmean
Regression
95% CI
95% PI
S 9.76458
R-Sq 6.8%
R-Sq(adj) 0.0%
Average BIBI
Average TQmean
Soosette
Laughing Jacobs
North Fork Issaquah
Des Moines
Juanita
Little Soos
Miller
Thornton
* King County watersheds with areas of less than 30 square km.