

Draft

TECHNICAL MEMORANDUM

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To: Chelsea Morris and Raghu Namburi, Washington State Department of Ecology
Jessica Atlakson, City of Redmond

Copy to: Redmond Paired Watershed Study Technical Advisory Committee

From: Timothy Clark, John Lenth, and Meghan Mullen, Herrera Environmental Consultants

Subject: Addendum 2 to the Quality Assurance Project Plan for the Redmond Paired Watershed Study: Update to Section 13.2 Data Analysis Procedures

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Introduction

This addendum provides updated trend analysis procedures for the Redmond Paired Watershed Study (RPWS) Trend Analysis Report for Water Years 2016 to 2025. Specifically, this addendum replaces Section 13.2 (Data Analysis Procedures) of the RPWS Quality Assurance Project Plan (QAPP). Section 13.2 describes the procedures used to evaluate whether receiving-water conditions are changing over time and whether observed changes are consistent with the study's watershed-scale rehabilitation objectives.

Monitoring for the RPWS initiated in 2016 and has continued through water year 2025. As a result, the 2016–2025 Trend Analysis Report will provide the first opportunity to evaluate a decade of monitoring data across the RPWS study watersheds. This addendum was prepared to document refinements to the statistical and supporting analytical procedures that will be used for the 2016–2025 Trend Analysis Report.

The updates described in this addendum were informed by input from the RPWS Technical Advisory Committee (TAC) during a meeting on June 23, 2026, and in responses to a follow-up web survey. TAC members reviewed proposed revisions to the trend analysis approach, identified preferred supplemental analyses, and provided recommendations regarding spatial datasets and riparian buffer widths. In addition to comments received verbally during the June 23 meeting, written responses were received from representatives of the City of Redmond, Seattle Public Utilities, City of Kirkland, and King County.

This amendment to the QAPP for the RPWS was prepared to document the following updates:

- Inclusion of specific physical habitat indicators for conducting trend analyses.
- Use of Kendall's Tau as the primary statistic for trend evaluation (replacing use of both Kendall's Tau and Pearson's r).
- Use of p-value adjustments when interpreting statistical significance across repeated tests
- Inclusion of mixed effects model to efficiently evaluate trends based on watershed classification (Application, Control, Reference) for indicators. This provides a holistic and efficient result for the study question.
- Inclusion of supplemental climate and temperature analyses.
- Evaluation of selected spatial datasets for watershed and riparian qualitative trend analysis

Unless explicitly described in this addendum, all other data collection, processing, management, quality assurance, and reporting procedures will be consistent with those identified in the RPWS QAPP.

13.2 – Data Analysis Procedures

For the purposes of the Trend Analysis Report for Water Years 2016 to 2025, this section wholly replaces section 13.2 in the QAPP (Herrera 2015). All trend analyses conducted for the Water Years 2016–2025 evaluation shall follow the procedures described herein.

The RPWS is being implemented to evaluate the effectiveness of watershed rehabilitation efforts for improving receiving-water conditions at the watershed scale. To answer this question, the Status and Trends Monitoring component of the RPWS utilizes a paired-watershed experimental design involving the collection of hydrologic, chemical, physical habitat, biological, and watershed-condition indicators in Application, Reference, and Control watersheds. Statistical analyses will be performed to evaluate temporal trends in these watersheds, with the pattern of interest being evidence that receiving-water conditions are improving in Application watersheds while conditions in Reference and Control watersheds remain relatively stable. Additional analyses will also be conducted to evaluate potential relationships between observed trends and watershed characteristics, climate conditions, and other explanatory variables. The specific data analysis procedures that will be used to evaluate trends during Water Years 2016–2025 are summarized in Table 1.

Table 1. Data Analysis Procedures for the Redmond Paired Watershed Study (Water Years 2016–2025)

Indicator	Data Analysis Procedure
Hydrology Monitoring	
• High pulse count • High pulse frequency • High pulse count duration • High pulse count range • Low pulse count • Low pulse count frequency • Low pulse count duration • Low pulse count range • Richards-Baker (RB) flashiness index • TQ Mean • Storm volume • Base volume • Total flow volume	• Mixed effects models may be used to evaluate temporal trends and potential explanatory variables while accounting for repeated observations and hierarchical structure within the RPWS dataset. Fixed effects may include time, watershed classification, climate indices, and interactions between time and watershed classification. Random effects may include monitoring station, as appropriate for the indicator being evaluated. Model selection procedures and final model structures may vary among indicators based on data availability and distributional characteristics. • Trends over time at each monitoring station will be evaluated using two-tailed nonparametric Kendall's Tau tests of correlation between each indicator and time. Statistical significance will be evaluated using an α-level of 0.05. To control the false discovery rate associated with multiple comparisons, p-values will be adjusted using the Benjamini-Hochberg procedure as described in Note a. • For a subset of indicators, binned comparisons between Water Years 2016–2020 and Water Years 2021–2025 may be used to evaluate differences between the first and second halves of the monitoring period. • Monitoring data was not available for a subset of stations for October through December 2025. To calculate low flow metrics for these stations, daily average flows for October through December 2025 were imputed based on fall daily average flow data from WY 2016 - WY2024 from the nearest station with data available. Low flow metrics were calculated using complete available measured data (CY2016 – CY2024) and imputed data (CY2016 – CY2025).
Water Quality Monitoring	

• Total suspended solids • Turbidity • Conductivity • Hardness • Dissolved organic carbon • Fecal coliform bacteria • Total phosphorus • Total nitrogen • Copper, total and dissolved • Zinc, total and dissolved	• Mixed effects models may be used to evaluate temporal trends and potential explanatory variables while accounting for repeated observations and hierarchical structure within the RPWS dataset. Fixed effects may include time, watershed classification, climate indices, and interactions between time and watershed classification. Random effects may include monitoring station and storm event, as appropriate for the indicator being evaluated. Model selection procedures and final model structures may vary among indicators based on data availability and distributional characteristics. • Trends over time at each monitoring station will be evaluated using two-tailed nonparametric Kendall's Tau tests of correlation between each indicator and time. Statistical significance will be evaluated using an α-level of 0.05. To control the false discovery rate associated with multiple comparisons, p-values will be adjusted using the Benjamini-Hochberg procedure as described in Note a.^b • Annual mass load estimates will also be derived for the following subset of indicators using the nonparametric "smearing" approach described in Helsel and Hirsch (2002): total suspended solids, total phosphorus, total nitrogen, total copper, and total zinc. Trends over time at each monitoring station will be evaluated using two-tailed nonparametric (Kendall's tau) tests of correlation between these mass load estimates and time. Statistical significance will be evaluated using an α-level of 0.05. To control the false discovery rate associated with multiple comparisons, p-values will be adjusted using the Benjamini-Hochberg procedure as described in Note a.
• Temperature	• Continuous data for temperature and conductivity will be post-processed to compute monthly average and peak values from the time series. Trends over time at each monitoring station will be evaluated using a seasonal Kendall test (Helsel and Hirsch 2002) of correlation between these values and time. Statistical significance will be evaluated using an α-level of 0.05. To control the false discovery rate associated with multiple comparisons, p-values will be adjusted using the Benjamini-Hochberg procedure as described in Note a. • Temperature analyses will include evaluation of maximum 7-day average daily maximum (7-DADMax) temperatures and trends in temperature exceedance frequency where sufficient data exist.

Sediment Quality Monitoring

• Total organic carbon • Copper • Zinc • Polycyclic aromatic hydrocarbons • Phthalates	• Mixed effects models may be used to evaluate temporal trends and potential explanatory variables while accounting for repeated observations and hierarchical structure within the RPWS dataset. Fixed effects may include time, watershed classification (Application, Control, and Reference), and interactions between time and watershed classification. Random effects may include monitoring station, as appropriate for the indicator being evaluated. Model selection procedures and final model structures may vary among indicators based on data availability and distributional characteristics. • Trends over time at each monitoring station will be evaluated using two-tailed nonparametric Kendall's Tau tests of correlation between each indicator and time. Statistical significance will be evaluated using an α-level of 0.05. To control the false discovery rate associated with multiple comparisons, p-values will be adjusted using the Benjamini-Hochberg procedure as described in Note a.
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Physical Habitat Monitoring

• Riparian canopy closure • Wood volume • Residual pool area • Substrate – median particle diameter • Bed stability	• Trends over time at each monitoring station will be evaluated using two-tailed nonparametric (Kendall's tau) tests of correlation between these indicators and time. Statistical significance will be evaluated using an α-level of 0.05. To control the false discovery rate associated with multiple comparisons, p-values will be adjusted using the Benjamini-Hochberg procedure as described in Note a.
Biological Monitoring	
• Benthic Index of Biotic Integrity • Taxa Richness • Ephemeroptera Richness • Plecoptera Richness • Trichoptera Richness • Clinger Percent • Long-Lived Richness • Intolerant Richness • Percent Dominant • Predator Percent • Tolerant Percent	• Mixed effects models may be used to evaluate temporal trends and potential explanatory variables while accounting for repeated observations and hierarchical structure within the RPWS dataset. Fixed effects may include time, watershed classification, climate indices, and interactions between time and watershed classification. Random effects may include monitoring station, as appropriate for the indicator being evaluated. Model selection procedures and final model structures may vary among indicators based on data availability and distributional characteristics. • Trends over time at each monitoring station will be evaluated using two-tailed nonparametric (Kendall's tau) tests of correlation between these indicators and time. Statistical significance will be evaluated using an α-level of 0.05. To control the false discovery rate associated with multiple comparisons, p-values will be adjusted using the Benjamini-Hochberg procedure as described in Note a.
Watershed and Riparian Buffer Land Cover Change	
• Impervious Percent Cover • Canopy Cover	• Supplemental analyses of riparian conditions may be conducted using GIS datasets describing tree canopy and impervious surface coverage. Riparian analyses will generally utilize a 100-foot buffer on each side of the stream channel. • No statistical analyses are planned. Changes in the watershed and riparian buffer will be used to provide context to observed (or non-observed) trends in physical, biological, and water quality conditions.

- a. To control the false discovery rate associated with multiple comparisons, p-values will be adjusted using the Benjamini-Hochberg procedure. Adjustments will be applied separately within each indicator across all stations included in the analysis. Both unadjusted and adjusted p-values may be reported; however, statistical significance will be based on the adjusted p-values.
- b. Where appropriate, variation associated with streamflow conditions may be reduced using methods similar to those described by Helsel and Hirsch (2002) prior to trend analysis.

The analyses identified in Table 1 will be performed as part of the Water Years 2016–2025 Trend Analysis Report. In addition to evaluating trends in monitored receiving-water indicators, supplemental analyses of watershed condition and land-cover change may be conducted to improve interpretation of observed trends and to provide additional lines of evidence regarding watershed rehabilitation effectiveness. The interpretation of results will utilize a weight-of-evidence approach that considers statistical significance, trend magnitude and direction, consistency among indicators, graphical patterns, and watershed context when drawing conclusions regarding changes in receiving-water conditions.

Check/Review Record

Revision	Date	Description	By (Author)	Review (Technical)	Review (PM)	Approved (CSR)	Publications