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Friends of the Metolius

Water Quality Analysis

Final Report

Prepared for

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1. EXECUTIVE SUMMARY

This report presents statistical findings from the analysis of available monitoring data collected within the Metolius River Basin with the objective to characterize the current state of water quality conditions of the basin and river and to assess any potential trends that may be observed. Data analyzed were collected by Friends of the Metolius (FOM) and combined with the ODEQ LASAR database and range in time from 1969 to 2013. Where statistical methods do not allow for quantitative characterization, qualitative assessments have been provided.

In additional to selected queries, statistical analyses presented herein include the Mann-Whitney Rank Sum Test to evaluate spatial variability between locations, temporal changes in the central tendency of the data and differences between ambient vs. storm event water quality, and the Seasonal Kendall's Tau to more explicitly assess temporal trends.

The analysis found no criticality concerning trends for the Metolius River. Both quantitative and qualitative findings suggest the stream water quality in the Metolius Watershed is in excellent condition, particularly with respect to ODEQ and EPA Ecoregional criteria and water-contact recreation standards. Relatively high nutrient concentrations, which appear to occur as far upstream as the head waters, are likely due primarily to natural geologic conditions. Given the available data and sampling nature, significant quantitative findings that would suggest campgrounds or wildfire have some impact on the water quality are not able to be made currently although the potential and some qualitative assessments are generally supported by literature and case studies.

Following statistical analyses in conjunction with qualitative spatial considerations, initial recommendations with respect to future sampling within the Metolius Watershed include reduction of the number of sampling locations to strategic monitoring points on the main stem of the river and increased sampling at these locations during and after specific events such as fires, storms, and landslides. Additionally, significant increases to sampling documentation and further spatial characterization have also been recommended.

2. INTRODUCTION & BACKGROUND

Although the Metolius River is generally regarded as relatively pristine, water quality data collected over recent decades can be useful to assess whether or not this "condition" has recently changed or is likely to change in the future. The analyses conducted by Geosyntec Consultants (Geosyntec) and presented herein include hypothesis tests and trend analysis that both quantitatively and qualitatively evaluate in-stream water quality, how it is changing over time and space, and what factors potentially drive these changes. For example, the trends and relationships between the water quality constituents of the Metolius River and watershed geology, wildfires, and anthropogenic use (e.g., development and recreational use) are explored to the extent warranted by available data and information.

2.1 Watershed Background

The Metolius River ranks between first and second for water quality in Oregon after sections of the Grande Ronde River (ODEQ, 2013). The Metolius River is a tributary to the Deschutes River, connecting via Lake Billy Chinook (Map A-1). Much of the watershed is protected forest and as a result, the stream's health is pristine. Several studies have investigated water quality in the Metolius River and the surrounding area due to the relatively pristine nature of the stream system and the unique geology of the area (Peterson & Groh, 1972; Sisters Ranger District, 2004). Of note are significant historical volcanic events/activity and a river system fed predominantly by springs rather than surface runoff. Because of these primarily volcanic geological features, the river's water quality characteristics display unusually high levels of phosphorus and nitrogen nutrients (Peterson & Groh, 1972). In addition, the watershed frequently experiences intense wildfires (increasing in intensity over the last century). These wildfires can potentially cause sediment and nutrient rich overland flow (due to mobilization following vegetation loss or the chemical suppressants used in fire operations, which are often nitrate or phosphate based). Several areas around the watershed are used for seasonal recreation and include several campgrounds, summer cabins, and day use facilities.

The geology of the Metolius watershed has been previously studied (Peterson & Groh, 1972; Sisters Ranger District, 2004). Here we present a summary of those findings. The Metolius Springs are in the transition zone between the High Cascades geomorphic province on the west and the High Lava Plains on the east. The oldest rocks consist of alternating layers of basaltic-andesite and breccia and agglomerate typical of these types of volcanic centers. These eruptive rocks cover sandstone, diatomite, and pumice typical of the High Lava Plains to the east. The younger rocks in the region are from the High Cascade province made of variable volcanic and glacial-fluvial material.

Black Butte is in the historical path and generally represents the headwaters of the Metolius River. The rocks that make up Black Butte are basaltic andesite typical of the High Cascades.

Water that once flowed overland now percolates downward though the permeable sands and gravels beneath Black Butte and then surfaces again at the lowest point north of Black Butte at the current day Metolius Springs (Peterson & Groh, 1972). Given the river is predominantly spring fed and not characterized with significant "flushing", high flow events, it is vulnerable to sedimentation, particularly in the upper watershed because of the lack of flood events with enough hydraulic force needed to flush gravel and finer sediments downstream. The Metolius Springs have been identified as a possible source of both high phosphorus and high nitrogen concentrations in the river downstream (Sisters Ranger District, 2004). The high phosphorus concentrations are attributed to the geology, whereas the nitrogen source is unknown at the time of writing (Sisters Ranger District, 2004).

The Metolius watershed experiences frequent burning in the form of wildfires with increasing intensity over the last century. Although Geosyntec make no explicit conclusions on the reasons for this trend, potential explanations could include changes to watershed vegetation cover (generally characterized by loss of lodge pole forests and conversion to dense shrub-like cover), changes to the hydrologic/meteorological regime and anthropogenic sources. In the past 20 years the watershed has experienced 17 wildfires larger than a Class D (100 acres or more burned) based on US Forest Service fire data. Several studies have shown that wildfires can raise in-stream phosphorus and nitrogen concentrations by considerable amounts for periods up to several years (Smith, Sheridan, Lane, Nyman, & Haydon, 2011). FOM has also expressed concern that phosphorus based fire suppressants could influence in-stream water quality. The influence of wildfires on water quality has become an important concern given the extent and intensity of the more recent wildfires, such as the 2003 the Bear Butte Fire and the Booth Fires (BB).

The relatively small number of campgrounds, recreational sites, and limited residential areas in the basin are likely the sole dischargers of pathogens and other pollutants from anthropogenic sources. Important to note is that for pathogens in particular (typically measured as fecal coliform or E. coli as an indicator) any warm-blooded animal can release pathogens to the environment. For this reason, true sources of pathogens are difficult to identify without bacterial source tracking (a form of DNA fingerprinting). Anthropogenic sources could include, but are not limited to, leaking septic systems, dispersed camp latrines, pet waste, trash, and roadway pollution. Given that there are no other major anthropogenic sources of pathogens identified in the basin (e.g., wastewater plant discharges), these sources, though limited in number and size, are of interest for this pristine river system.

2.2 Document Organization

Six sections make up the majority of this document as follows.

- Section 2, Introduction & Background, summarizes the current understanding of the watershed and the scope of this analysis.
- Section 3, Data Analyzed and Preprocessing, documents the data from FOM, other sources used, and any modifications made to the data before the analysis.
- Section 4, Methods, describes what analyses were used and their relevance to the project.
- Section 5, Analysis and Discussion, presents the results and Geosyntec's interpretation of those results.
- Section 6, Current and Future Water Quality Conditions, compares the current trends in the watershed to local standards and requirements.
- Section 7, Conclusions and Recommendations, section provides brief recommendations to change monitoring to provide better a characterization of some of the more complex water quality phenomenon in the watershed.

3. DATA ANALYZED AND PREPROCESSING

The following analyses considered several data sources to help provide a better understanding of the baseline water quality and potential changes in quality of the Metolius watershed. Water quality data sources included the FOM database (the data sources are described below) and the Oregon Department of Environmental Quality (ODEQ) Laboratory Analytical Storage and Retrieval (LASAR) database. Stream flow and precipitation data were obtained from the United States Geological Survey (USGS) and United States Department of Agriculture (USDA), respectively. Here we describe how the data were processed (if any) and any special considerations made, such as removal of data points.

3.1 Water Quality Data

The sections below briefly describe each independent data set and how these were combined when appropriate to produce a comprehensive dataset used in subsequent analyses.

3.1.1 FOM Data

Data acquired from the FOM (on 9 April 2014) ranged from 1995 to 2013. These data are a compilation of data from FOM, the United States Forest Service, ODEQ, Portland General Electric Company, and The Confederated Tribes of Warm Springs. The data were standardized where appropriate to remove duplicate constituent names or units (e.g., "Phosphorus – Total" and "Total Phosphorus") based on conversations with Umpqua Research, the primary lab used for sample analysis. Datasets were grouped for analysis based on location ID, constituent name, and measurement unit. A complete list of constituents at each location, number of non-detects (ND), total sample size, and temporal extent of data in the FOM database are found in Appendix A: Data Summary.

The periods of record where data are suspected as being erroneous were removed from the dataset entirely. These include data points reported to be below the detection limit and those not flagged as a lab estimate (Figure 1). Only Nitrate as N and Orthophosphate as P sampled collected prior to the year 2000 at Locations 1, 3, 4, 7, 9, 11, 12, and 18 were affected. In total, 195 data points of 14,509 data points were removed.

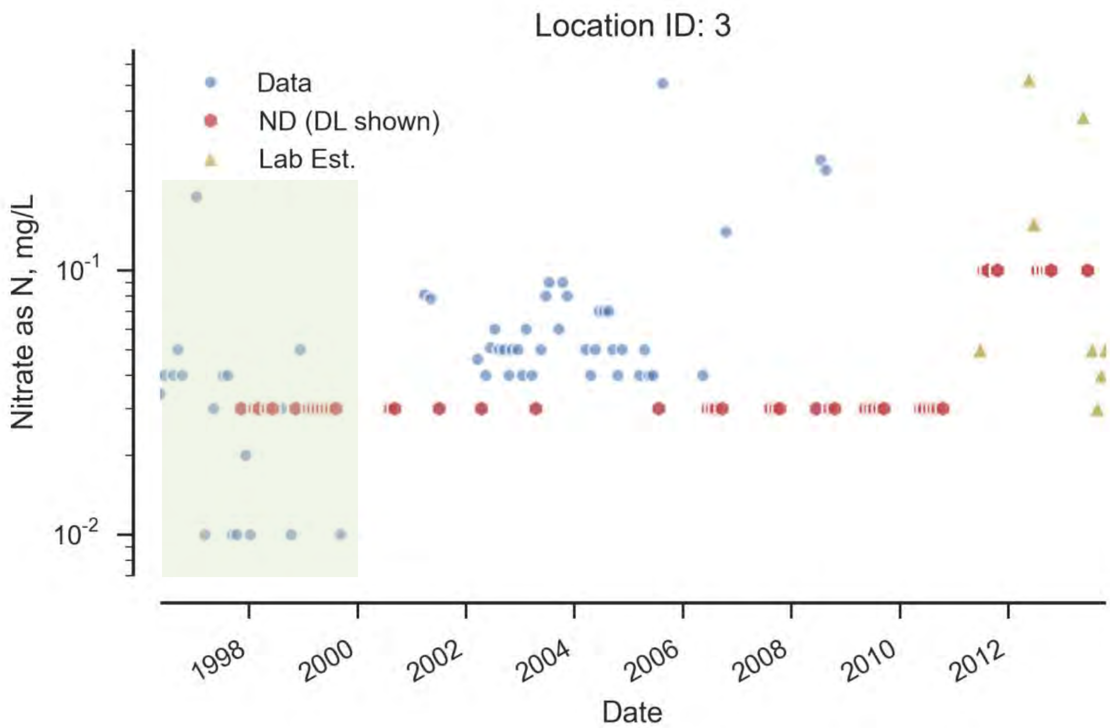

Figure 1: A sample plot of FOM Nitrate as N data at Monitoring Location 3. Data points in the shaded region were removed because the non-detect (ND) points under the detection limit (DL) could not be verified as lab estimates such as those found later in the record.

3.1.2 LASAR Data

ODEQ LASAR data were retrieved 28 May 2014 from station 10690 Metolius River north of Camp Sherman (Bridge 99, Lat: 44.5565, Long:-121.6195) (ODEQ, n.d.). The dataset contained 71 water quality constituents, with samples ranging from 1969 to 2012, containing greater than 7,000 data points. Data were filtered and edited to combine duplicate locations, constituents, and standardize the units as described below. A complete list of constituents at each location, total sample size, and temporal extent of data in the LASAR database are found in Appendix A: Data Summary.

3.1.3 Combined Dataset

Following review and analyses of the independent datasets, a combined water quality dataset containing data received from FOM and ODEQ LASAR database was produced for subsequent analyses. Data were filtered and edited to combine duplicate locations, constituents, and standardize the units between the FOM and DEQ data, as some of these data were already included in the FOM dataset. ODEQ LASAR data were added to Monitoring

Location 13. In addition, Locations 12, 13, and 18 where combined into a single location (Location ID 13), as the locations other than the original Location 13 had few data points and were reasonably close to Location 13 to combine the datasets. Table 1 shows a list of the constituents from both the FOM and LASAR database after translation to common terms. However, due to limited data at some locations not all of these constituents were used in each analysis.

Table 1: Constituent list for the combined FOM and LASAR database.

Total List of Constituents Analyzed			
E. coli	Calculated Dissolved Hardness as $CaCO_3$	Ammonia	Total Recoverable Calcium
Nitrate	Total Coliform	Ammonia as N	Total Recoverable Hardness as $CaCO_3$
Total Phosphorus	Fecal coliform	Total Organic Carbon	Total Recoverable Antimony
Ortho Phosphorus	Calculated Un-ionized Ammonia as N	Field Alkalinity as $CaCO_3$	Total Recoverable Arsenic
pH	Dissolved Sodium	Field pH	Total Recoverable Barium
Dissolved Oxygen	Dissolved Potassium	Field Temperature	Total Recoverable Beryllium
Nitrate as N	Color	Field Turbidity	Total Recoverable Cadmium
Orthophosphate as P	Field Alkalinity as $CaCO_3$	Nitrate/Nitrite as N	Total Recoverable Chromium
Biochemical Oxygen Demand 5 Day Un-Diluted	Total Phosphate as PO_4	Percent Saturation Field Dissolved Oxygen	Total Recoverable Copper
Biochemical Oxygen Demand Stream	Nitrite as N	Pheophytin a	Total Recoverable Iron
Chlorophyll-a	Total Calcium	Total Kjeldahl Nitrogen	Total Recoverable Lead
Dissolved Orthophosphate as P	Dissolved Calcium	Total Solids	Total Recoverable Manganese
Chemical Oxygen Demand	Dissolved Magnesium	Total Suspended Solids	Total Recoverable Nickel
Conductivity	Enterococcus	Turbidity	Total Recoverable Selenium
Field Conductivity	Stream Field Stage Instantaneous	Orthophosphate as PO_4	Total Recoverable Silver
Field Dissolved Oxygen	Temperature	Chloride	Total Recoverable Zinc
Alkalinity as $CaCO_3$	Total Recoverable Magnesium	Sulfate	Total Recoverable Thallium

3.1.3.1 Significance of Water Quality Constituents Analyzed

Below is a brief description of each of the major water quality constituents analyzed in this report. Several additional water quality constituents were analyzed, but are excluded from this descriptive list.

3.1.3.1.1 pH

pH is a measurement of the amount of basicity or acidity in water. Several chemical and biological processes are significantly influenced by pH and require specific ranges. Natural changes to pH are caused by atmospheric deposition and weathering of rocks (US EPA, n.d.-c).

3.1.3.1.2 Alkalinity as $CaCO_3$

Alkalinity is a measurement of a waterbody's capacity to neutralize acid (and thus affect pH). This constituent is one of the best measurements to assess the sensitivity of acidic inputs and how quickly a waterbody's pH might respond to that input (US EPA, n.d.-i).

3.1.3.1.3 Dissolved Oxygen

Dissolved oxygen is a critical water quality constituent for aquatic life. With too little dissolved oxygen sensitive species will relocate or die (US EPA, n.d.-a).

3.1.3.1.4 Biochemical Oxygen Demand

Biological oxygen demand is the amount of dissolved oxygen used by microorganisms while decomposing organic matter in water. This constituent is also a measurement of the chemical oxidization of the inorganic matter in water. The greater the biological oxygen demand the more rapidly dissolved oxygen can be depleted (US EPA, n.d.-a).

3.1.3.1.5 Conductivity

Conductivity measures the ability of water to pass an electrical current. Generally, conductivity is influenced by the amount of inorganic dissolved solids, such as chloride and sodium. The primary natural cause of changes to conductivity is geology. Areas composed of inert materials, such as granite, tend to have low conductivity, whereas areas with clay soils tend to have high conductivity (US EPA, n.d.-h).

3.1.3.1.6 Total Phosphorus

A measurement of all phosphorus (orthophosphate, condensed phosphate, and organic phosphate) in-stream, including dissolved and suspended fractions (US EPA, n.d.-e).

3.1.3.1.7 (Dissolved) Orthophosphate as P

Orthophosphate is a term that refers to the phosphate molecule on its own (opposed to being attached to a suspended particle). Dissolved Orthophosphate measures only the dissolved fraction of total orthophosphate (US EPA, n.d.-e).

3.1.3.1.8 Nitrate and nitrites as N

Nitrates are found in several forms in the environment. These nutrients are essential for plant life, but can be harmful in excess amounts. High levels of nitrates, in addition to phosphorous, can accelerate eutrophication (US EPA, n.d.-f). Nitrates are generally metabolized into nitrites by animals.

3.1.3.1.9 Chlorophyll a

Chlorophyll a is an indirect measurement of the amount of photosynthesizing plant matter at the time of collection. In streams, this generally represents algae or phytoplankton. The amount of these organisms can greatly affect the dissolved oxygen, biological oxygen demand, pH, and water chemistry (Department of Ecology, 2014).

3.1.3.1.10 Pheophytin a

Pheophytin is a natural degradation product of chlorophyll. This constituent is often used to correct chlorophyll results.

3.1.3.1.11 E. coli

E. coli is typically used as an indicator organism of fecal contamination and pathogens. While the presence of the organism is natural, a high number of organisms in a sample can cause concern. E. coli is a species of fecal coliform bacteria that is specific in origin to fecal material from warm blooded animals (US EPA, n.d.-j).

3.1.3.1.12 Total Solids

A measurement of dissolved, suspended, and settleable solids in water. Dissolved solids often contain several nutrients and minerals, whereas suspended and settleable solids are often clay minerals, plankton, algae, and other organic matter (US EPA, n.d.-g). Total suspended solids (TSS) include the suspended fraction of total solids that pass through a fine filter (typically 0.45 micron).

3.1.3.1.13 Turbidity

A measurement of water clarity. High turbidity is often correlated with higher water temperature, reduced dissolved oxygen, and reduced photosynthesis (US EPA, n.d.-d).

3.1.3.1.14 Temperature

Different organisms often require different temperature ranges for optimal health. In addition, different chemical and biological processes or reactions also require different temperature ranges (US EPA, n.d.-b).

3.2 Stream Flow Data

Stream flow data of the Metolius river were retrieved from the USGS Gauge 14091500 Metolius River near Grandview, OR (USGS, n.d.). Daily data were retrieved for the period of record from 1954 to present, and 15 minute instantaneous data were retrieved from 2007 to present.

3.3 Precipitation Data

Precipitation data were retrieved from the Snow Telemetry (SNOTEL) station at Hogg Pass, OR from 1984 to present (USDA, n.d.). Hogg Pass was the closest available station to the basin and is located to the east of Hoodoo Mountain Resort along the Pacific Crest Trail. SNOTEL precipitation data is reported as consecutive accumulation. Thus, daily precipitation values were calculated by taking the difference of two consecutive days. Hourly data is available beginning in 1993 at the same gauge; however, after inspecting the data we determined that the hourly record contained too many erroneous data points, such as extremely high values that did not match the daily record, for use in this analysis. Consequently, only the daily data were used in the analysis.

The hydrology of the Metolius Basin is complex due to a steep rain gradient that increases to the west (Sisters Ranger District, 2004). Visually, this can be seen by the stark contrast in vegetation cover as you move east off the Cascade Range (Figure 2).

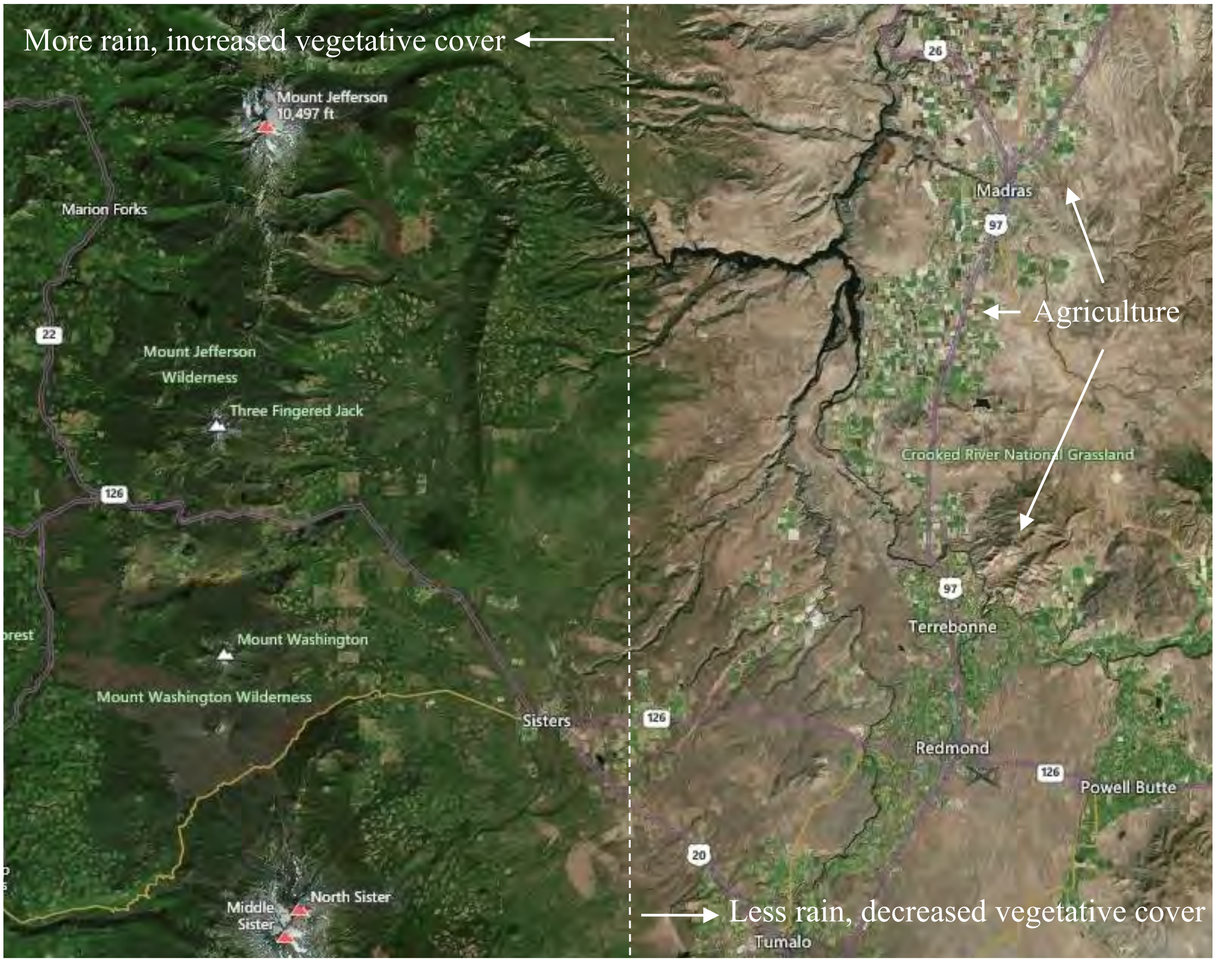

Figure 2: Screenshot from Bing maps showing significant change in vegetative cover moving east off the Cascade Range. Also note significant agriculture (green geometric or circular fields) east of Deschutes River in the vicinity of Hwy 97.

Thus, a single rain gauge does not adequately represent the timing of peaks caused by over land flow. However, because flow at the Metolius is primarily from groundwater, we still found a reasonably good correlation between precipitation at Hogg Pass and USGS Gauge 14091500. Figure 3 shows a comparison of stream flow data and precipitation data for the 2006 water year.

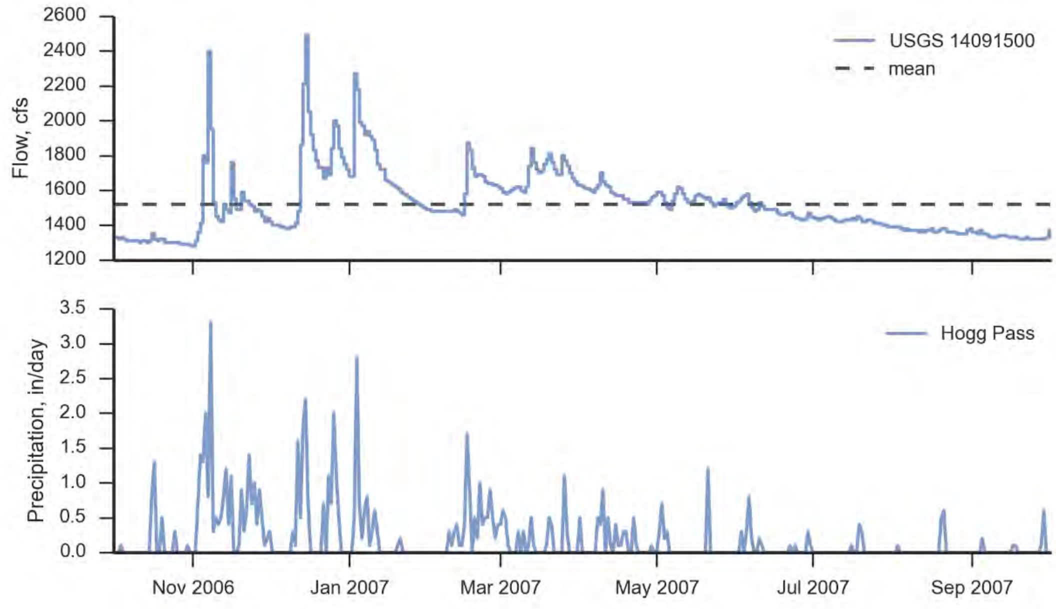

Figure 3: Comparison of stream flow at USGS gauge 14091500 and precipitation at SNOTEL station at Hogg Pass for the 2006 water year.

4. METHODS

The bulk of this analysis is composed of two parts 1) a quantitative based analysis focused on the statistical characterization of the data, and 2) a more qualitative comparison of selected water quality standards or reference criteria to water quality summary statistics and graphical methods. The combined quantitative and qualitative results were used to identify potential temporal and spatial trends in the data. Specifically, the Mann-Whitney Rank Sum test was used to identify differences between the central tendency of the data at a fixed point while looking at temporal events, such as ambient and storm conditions (i.e., does a respective water quality constituent change, or not, at a given location under different ambient conditions). We used the Seasonal Kendall test to evaluate temporal trends. Spatial trends were also evaluated using the Mann-Whitney Rank Sum test to identify difference between monitoring locations. General time series analyses, graphical interpretation and qualitative geospatial analyses were also used in conjunction with statistical procedures to identify changes in the data due to both temporal and spatial relationships.

4.1 Statistical Characterization of the Data

The sections below briefly describe each statistical analysis and how these were applied to Metolius watershed data. All data and results are attached as Supporting Data.

4.1.1 General Summary Statistics

Included with this document are general summary statistics such as the number of samples, the number of non-detects, mean, median, and standard deviation. All non-detects were estimated using a Regression on Order Statistics (ROS) method (Helsel & Cohn, 1997).

4.1.2 Mann-Whitney Rank Sum Test

The Mann-Whitney Rank Sum test is a nonparametric test of the null hypothesis that two groups arise from the same population. Rejection of the null hypothesis ($p < 0.05$) confirms that the two groups are statistically different in their medians (Helsel & Hirsch, 1993).

The Mann-Whitney Rank Sum was used in the analysis of Metolius watershed data to examine spatial trends between monitoring locations, temporal changes in the central tendency of the data at a fixed location before and/or after a known event, and to compare ambient water quality and storm event water quality. All non-detects were estimated with ROS. In addition to the Mann-Whitney Rank Sum test, we compared the overlap of the median confidence intervals as a secondary metric for (dis)similarity.

For the spatial trend analysis, the combined dataset was used without further modification. Select constituents were compared between every possible paired location combination.

Data for temporal trend analysis were prepared in one of two ways. First, when looking at specific events, such as a wildfire, the data were group based on pre and post event dates and limited in their temporal extent (before and after the event) based on proximity to other events likely to influence the data and assumptions made from the literature (such as the typical residence time of nutrients created during a burn event).

Second, the data were grouped based on storm events to identify if a difference exists between ambient and storm conditions. Using precipitation data from Hogg Pass (USDA, n.d.), discrete storms in the basin were identified when the precipitation for a single day exceeded 0.1 inch with a minimum inter-event period of 48 hours.

4.1.3 Seasonal Kendall Test

The Seasonal Kendall's tau method was used to identify temporal trends at a fixed location while accounting for seasonal variability. Accounting for seasonality is required because most surface waters show strong seasonal patterns in water quality. The Seasonal Kendal's tau test is a fully nonparametric test that accounts for seasonality by computing the Mann-Kendall test on each season separately across all years in the record, and then combining the results. If the seasons are defined monthly then January data is only compared to January data, etc., and no data is compared across seasonal boundaries. The results from each season are combined to form an overall test statistic, which is evaluated against a standard normal distribution to test the null hypothesis that no trend is present.

Because of irregular sampling frequency of the FOM and LASAR combined dataset, we resampled the dataset to a monthly frequency by taking the median value of all observations for each month, as described by Helsel & Hirsch (1993). The dataset was further aggregated based on monitoring locations and constituent. If multiple detection limits were present over the extent of the data, all data below the highest detection limit were treated as non-detects of that limit to prevent bias. Datasets with less than two complete seasonal cycles or less than 25 data points were discarded. We defined statistical significance as $p < 0.05$.

4.1.4 Quantile-Quantile Plots

Quantile-quantile (QQ) plots compare the percentile values of two datasets. Constituent concentration percentiles (one pair at a time) were compared at each monitoring location separately. Data were preprocessed using ROS to estimate non-detect values and, thus, providing more accurate estimates of the lower percentiles. Quantile-quantile plots show whether two samples arise from similar distributions and the relationship of their distributions. No cause-effect relationship between parameters is necessarily implied when using QQ plots since the data points are not paired in time.

4.2 Box Plots

Box plots provide a visual and graphical representation of the data set in question. These plots display not only means and range, but give a more comprehensive view of the spread of an entire data set for a given constituent. A general description of box plot representation is shown below in Figure 4.

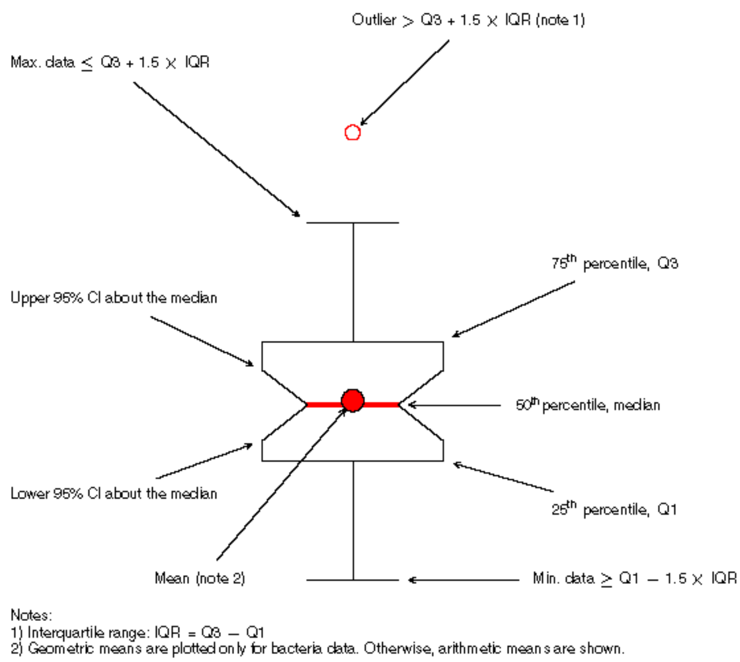

Figure 4: Visual description of a box plot.

4.3 Semi-Quantitative Comparisons

In addition to hypothesis testing and statistical comparisons, data were compared to current in-stream water quality standards and criteria for the state of Oregon. Data series and graphical output from statistical analyses were also assessed visually to identify potential trends and relationships when hypothesis testing was inappropriate. Ultimately, these assessments will support any hypothesis testing to identify the current and future health of the Metolius.

4.3.1 Oregon Water Quality Standards & EPA Recommended Ecoregional Nutrient Criteria

The Oregon Water Quality Standards are used to assess if the quality of a river or lake is adequate for aquatic life, recreational use, drinking, and other uses (ODEQ, 2014). ODEQ also uses the standard as a regulatory tool to prevent pollution as much as possible and to provide a public metric of the "quality" of receiving waters. The Environmental Protection Agency (EPA) must approve all state water quality criteria.

The EPA recommended ecoregional nutrient criteria are recommended criteria to help reduce excess nutrients in waterbodies throughout the United States (U.S. EPA, 2000). The EPA works with states to develop locally appropriate water quality criteria for nutrients in lakes, reservoirs, rives, and other waterbodies. The recommended ecoregional nutrient criteria were developed by taking the seasonal median concentrations from rivers and streams within the same ecoregion, computing the 25th percentiles of those seasonal medians, and then computing the median of the 25th percentile seasonal medians. States and Tribes are recommended to determine their own reference sites for rivers and streams within the ecoregion at different geographic scales and to compare them to EPA's reference conditions. The Metolius River is located in Ecoregion II, subregion 11n (U.S. EPA, 2000). Ecoregional criteria values are provided and compared with relevant summary statistics in Section 6.1.

4.3.2 Time Series Comparisons

Time series plots comparing flow, precipitation, fire dates and fire class size, and a constituent of interest at a specific location were used to visually identify trends and qualitative relationships between these three variables. When identifying periods before and after a fire, we found the size of the data did not support hypothesis testing, thus a visual approach was used.

4.3.3 Qualitative GIS Analyses

GIS analyses utilized the spatial distribution of Metolius water quality data in combination with watershed topography, wildfire occurrence and spread, vegetative cover, tributary stream networks and data on development/recreational sites to qualitatively assess the likelihood of influence from anthropogenic sources and wildfires as well as to support full and queried statistical analyses. Although limited data were obtained for development sites (generally campground locations), data from the 2013 recreation year along with information on specific locations were used to assess annual use and the rate of site turnover as symbolized in Map A-3 (i.e., annual use as a fraction of site capacity). Wildfire occurrence was symbolized by fire class (size of the affected area) and clipped to the Metolius watershed boundary; fire class was not re-evaluated following spatial clipping.

Additional spatial information not currently available that could assist with this type of analysis in the future may include the type, location, and extent of fire-suppressants applied during fire management operations, observed landslides, high-resolution LiDAR, georeferenced aerial photography, and distance between developed sites (campgrounds, septic systems, parking lots, etc.) and downstream monitoring locations. This type of proximity data can be useful to qualitatively assess the likelihood of potential impacts to receiving waters.

5. ANALYSIS AND DISCUSSION

5.1 Relationships of Constituents

5.1.1 Quantile-Quantile Plots

Geosyntec compared the quantiles of select constituents at all locations to gauge potential relationships (based only on the data itself) between constituents, and if these relationships changed at different sampling locations. Table 2 shows the constituents used in the analysis. Additional figures are found in Appendix B: Quantile-Quantile Plots. All unique pairs of independent parameters were analyzed. Again, QQ plots do not necessarily indicate causal relationships between respective parameters.

Table 2: List of Constituents used for Quantile-Quantile Plots

Constituents used for Quantile-Quantile Plots	
Alkalinity as $CaCO_3$	Field Temperature
Ammonia as N	Nitrate/Nitrite as N
Biochemical Oxygen Demand 5 Day Un-Diluted	Nitrite
Biochemical Oxygen Demand Stream	Nitrite as N
Calculated Un-ionized Ammonia as N	Ortho Phosphorus
Chemical Oxygen Demand	Orthophosphate as P
Chlorophyll-a	Percent Saturation Field Dissolved Oxygen
Dissolved Orthophosphate as P	pH
Dissolved Oxygen	Pheophytin a
E. Coli	Total Kjeldahl Nitrogen
Enterococcus	Total Organic Carbon
Fecal coliform	Total Phosphorus
Field Alkalinity as $CaCO_3$	Total Solids
Field Conductivity	Total Suspended Solids
Field Dissolved Oxygen	Turbidity
Field pH	

Figure 5 shows that total phosphorus and E. coli concentrations have similarly shaped probability distributions and are potentially monotonically related (i.e., increase in total phosphorus corresponds with, but does not necessarily result in an increase in E. coli). This figure only indicates a potential correlation between these two variables, not that any significant causation exists between them. Similar results were found by the USGS between E. coli and total phosphorus (USGS, 2003).

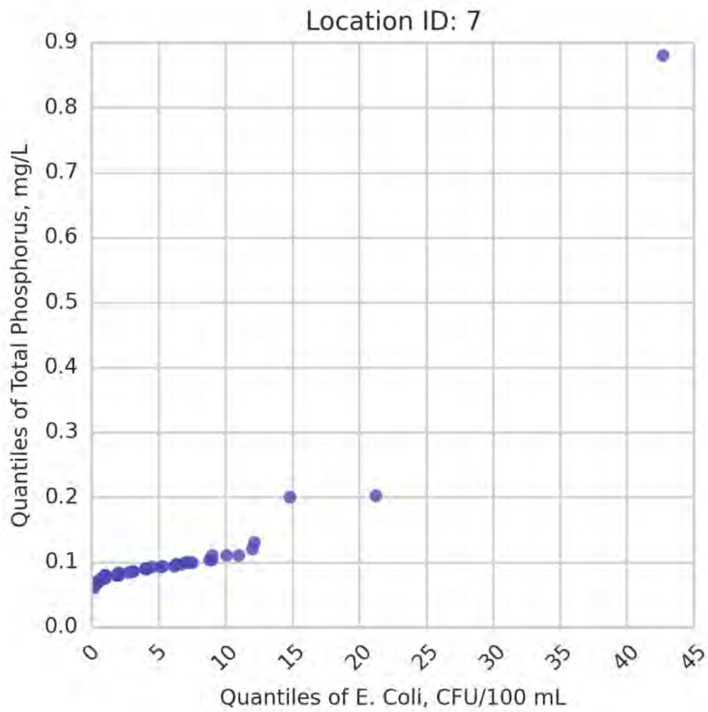

Figure 5: QQ plot of Total Phosphorus and E. coli indicating a monotonic relationship between the percentile concentrations.

5.2 Temporal Trends

5.2.1 Comparison of Water Quality during Ambient and Storm Conditions

Water quality data taken during ambient (dry weather) and storm events (as determined from the analysis described in Section 4.1.2) were compared using the Mann-Whitney Rank Sum test at both a basin-wide scale and at individual monitoring locations. Table 3 shows the constituents analyzed for this analysis. E. coli, nitrate as N, dissolved oxygen, and orthophosphate as P were the only constituents that showed significant results ($p < 0.05$), as shown in Table 4. The median confidence intervals, which show if the distributions of each dataset are near each other, vary at each sample location. If the intervals do not overlap, the difference between the two groups is more significant.

Table 3: List of constituents analyzed for ambient and storm conditions.

Constituent Name
Dissolved Oxygen
E. Coli
Nitrate as N
pH
Orthophosphate as P
Total Phosphorus
Turbidity

Table 4: Test statistics of the Mann-Whitney Rank Sum (where $p < 0.05$) for ambient vs. storm water.

Results of Mann-Whitney Rank Sum: Ambient vs. Storm					
Location	**Constituent**	**Units**	***p***	***U***	**Median Confidence Levels Overlap?**
1	E. Coli	CFU/100 mL	0.008	314.00	True
2	E. Coli	CFU/100 mL	0.006	34.00	False
3	E. Coli	CFU/100 mL	0.001	562.00	True
3	Nitrate as N	mg/L	0.000	16.00	False
4	Dissolved Oxygen	mg/L	0.015	28.00	False
4	Nitrate as N	mg/L	0.044	68.00	True
5	E. Coli	CFU/100 mL	0.010	125.50	True
6	E. Coli	CFU/100 mL	0.000	159.50	False
7	E. Coli	CFU/100 mL	0.027	664.00	True
7	Orthophosphate as P	mg/L	0.002	0.00	False
8	Orthophosphate as P	mg/L	0.021	0.00	False
9	E. Coli	CFU/100 mL	0.049	693.00	True
9	Nitrate as N	mg/L	0.000	16.00	False
17	Turbidity	NTU	0.029	329.00	True
Basin Wide	E. Coli	CFU/100 mL	0.000	43111.50	True
Basin Wide	E. Coli	MPN/100 mL	0.003	7267.00	True
Basin Wide	Orthophosphate as P	mg/L	0.020	6179.00	True

Box plots along with discussion of the differences between ambient and storm event concentrations for each constituent listed in Table 4 are provided below.

5.2.1.1 *E. coli*

All monitoring locations showed decreased concentrations of E. coli during storm events, except for Location ID 6 where the inverse was true. Location ID 6 is unique and located outside of the main stem or tributaries. At a basin-wide scale, this decreasing trend during storm events is also true. However, because the median confidence intervals overlap the difference between the concentrations, while significant, are not exceedingly large basin-wide as shown in Figure 6. The decreased concentrations during storm events are most likely due to dilution from the additional inflows from upland tributaries receiving overland runoff and shallow interflow. Due to data limitations, first flush phenomena (i.e., higher concentrations at the beginning of a storm) were not able to be assessed at any of the sample locations. The concept of first flush effects on E. coli would generally apply more to overland flow originating from developed or unvegetated areas and would require intra-event storm data to assess.

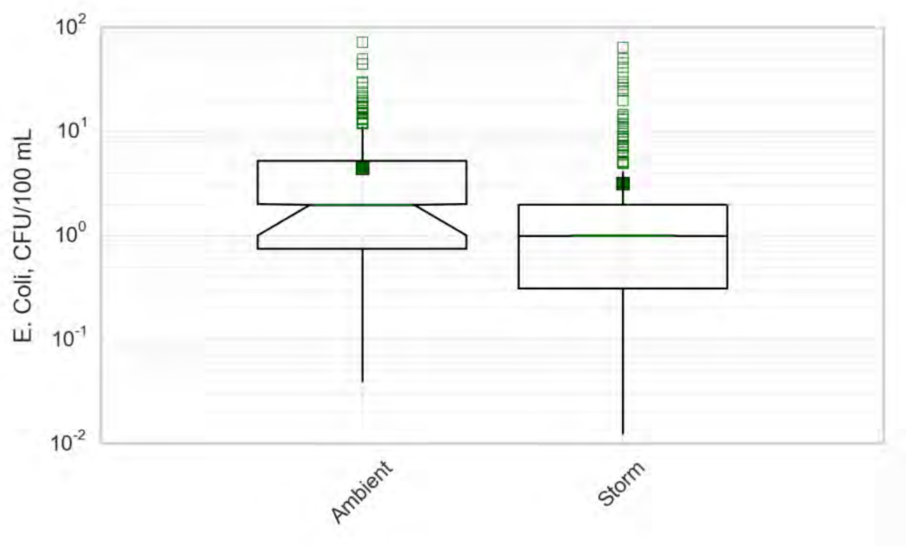

Figure 6: Comparison of basinwide E. coli concentrations (CFU per 100 mL) during ambient and storm conditions.

Because of the relatively low amount of development and recreation sites within the Metolius watershed, observed temporal results showing a statistical decrease in E. coli concentrations during and following storm events is generally expected and more indicative of natural sources of bacteria rather than anthropogenic sources.

5.2.1.2 Nitrate as N

Nitrate as N was only significantly different during ambient and storm conditions at Locations 3, 4, and 9. At all three locations, the concentrations were higher during storm conditions than ambient conditions. The median confidence intervals did not overlap, except for at Location 4. While not statistically significant, concentrations are also higher basin wide, as shown in Figure 7.

Monitoring points 3, 4, and 9 are all located in the upper section of the watershed, indicating that the elevated Nitrate as N concentrations is possibly caused by a localized event or source. Mast & Clow (2008) observed, in a subalpine coniferous forest in Glacier National Park that the first-year, post-fire nitrate concentrations were 10 times higher than an unburned control forest. These authors also found that concentrations decreased fourfold over the four year study period following the burn. Thus, it is possible that the difference in concentrations seen in this dataset are due to sampling events around the 2002 Cache Mountain and 2007 GW fire. Concentrations are low and these findings are consistent with the literature, stating that the stream is nitrogen limited (Sisters Ranger District, 2004).

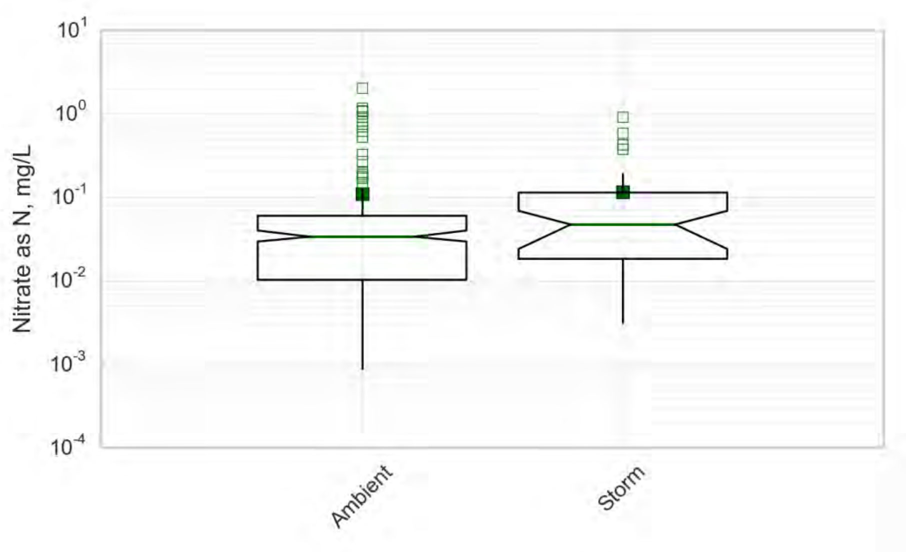

Figure 7: Comparison of Nitrate as N concentrations during ambient and storm conditions in the basin.

5.2.1.3 Dissolved Oxygen

Concentration of dissolved oxygen were only significantly different during ambient and storm conditions at Location 4, where the ambient condition showed higher concentrations. This trend is possibly caused by the confluence of the Lake Creek tributary just upstream of the monitoring location. The historical depth of release from Suttle Lake could have significant effect on instream DO concentrations. These results indicate that oxygen rich water, possibly from the upper mixed layer of the Lake, was more likely to be released during ambient condition. Changes to the operating condition of the dam in the last few years could affect this result. The median confidence intervals of the two datasets at this location do not overlap, indicating that the difference is large.

Storm and ambient dissolved oxygen concentrations are similar basin wide, however, as shown in Figure 8. As expected, with higher flows resulting from storm events within the watershed and subsequent increases in stream turbulence (tending to increase the amount of air entrainment), the upper quartile and median values were slightly higher in the storm dataset. Overall, it appears that storm events do not significantly influence dissolved oxygen concentrations in this watershed.

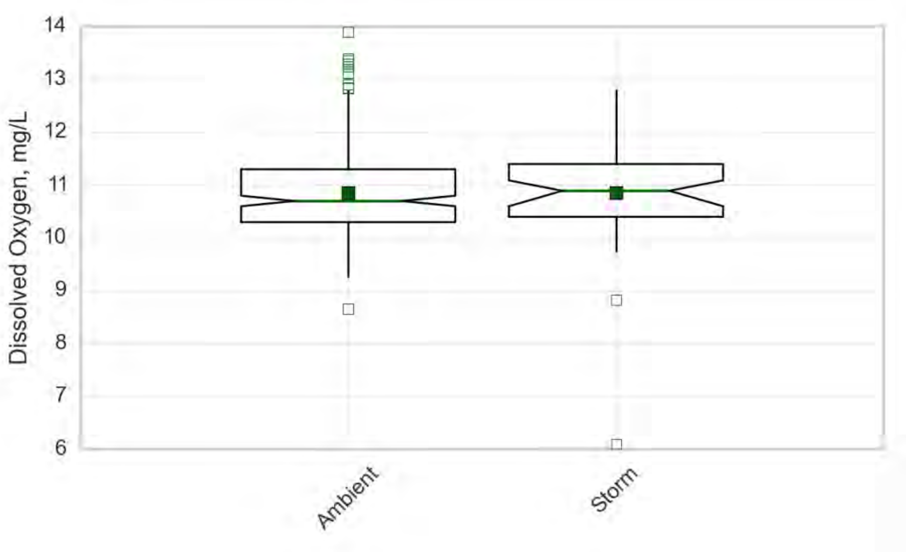

Figure 8: Comparison of Dissolved Oxygen concentrations during ambient and storm conditions in the basin.

5.2.1.4 Orthophosphate as P

Orthophosphate as P concentrations were significantly different for ambient and storm events at Locations 7 and 8, and over the entire watershed. At all locations, the ambient condition showed higher concentrations than the storm condition. At Locations 7 and 8, the median confidence intervals do not overlap whereas overlap exists when the data are considered over the whole basin (Figure 9). Orthophosphate can be associated with weathering of minerals in the watershed particularly volcanic rock. Thus, dilution is expected during storm events. It is unlikely that these results are due to wildfires in the region. A study of 20 streams in Yellowstone National Park over a five year period following extensive wildfires in 1988 shows the orthophosphate concentrations are typically unaffected by wildfires (Minshall, Robinson, & Lawrence, 1997).

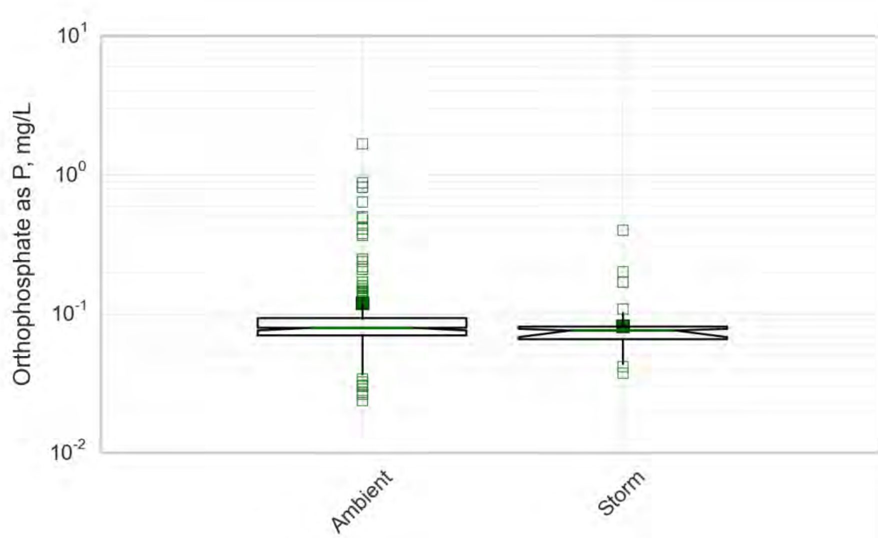

Figure 9: Comparison of Orthophosphate as P concentrations during ambient and storm conditions in the basin.

Although not statistically significant, potential reduction in the mean value during storm events could result from dilution resulting from rainfall and runoff into the Metolius River.

5.2.1.5 Turbidity

Concentrations of turbidity were only significantly different at Location 17 between ambient and storm conditions. The number of available studies that report turbidity, and also have the appropriate collection methods and sampling regimes is very limited (Smith et al., 2011). Based on the research conducted in an alpine region in Australia, elevated turbidity levels may persist during stormflow events where there are large post fire inputs of sediment (Lyon & O'Connor, 2008). Given the extensive fire history in the basin increases in turbidity during storm events may be expected. However, given the grab-sample frequency and the high contribution of groundwater to the river, the result is not completely surprising. With more turbidity data following a burn and additional information on the pre and post fire vegetation cover and, potentially, the soil characteristics, which can become hydrophobic under high heat conditions, more of a relationship between turbidity and storm events may be found.

While differences between ambient and storm conditions over the basin (Figure 10) were not statistically significant, we observed a general increase in turbidity with storm events. The upper quartile, mean, and median of the storm data was higher, as expected with greater flows that can generally mobilize sediment. Whether increases to in-stream turbidity result from overland runoff concentrations and/or mobilized channel or upland tributary sediment was not possible to assess given the current data.

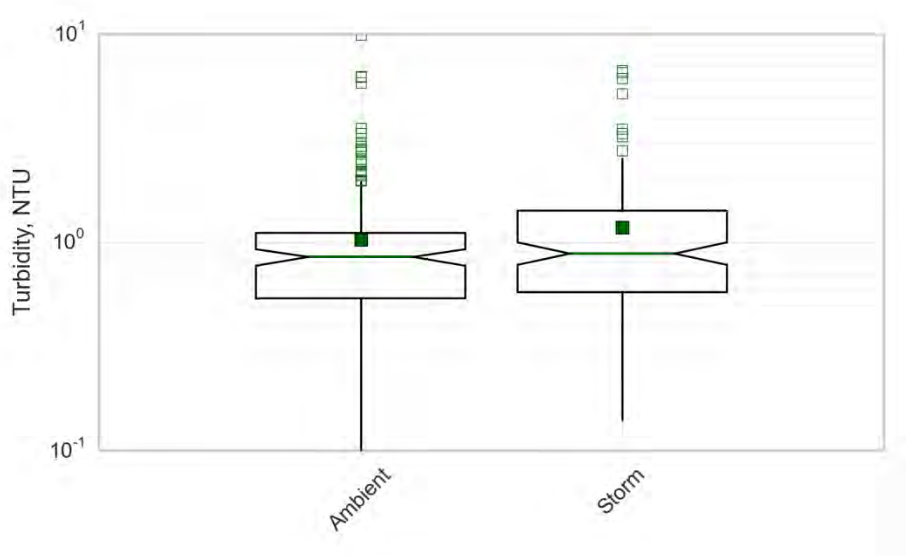

Figure 10: Comparison of Turbidity concentrations during ambient and storm conditions in the basin.

5.2.2 Long Term Trend Analysis

We found several temporal trends; some unique to specific locations or side channels. Table 5 shows the constituents analyzed for temporal trends. Select time series plots for some of these constituents are provided below. Time series plots for all of the constituents are included in Appendix C. No conflicting results were found, although some tributaries show trends dissimilar to other monitoring locations on the main stem of the river. Table 6 shows a summary of the result statistics of the Seasonal Kendall's tau test, only significant trends shown.

Table 5: List of constituents used for trend analysis using the Seasonal Kendall's tau test.

Constituents evaluated using Seasonal Kendall's tau test	
Alkalinity as $CaCO_3$	Field Temperature
Ammonia as N	Nitrate/Nitrite as N
Biochemical Oxygen Demand 5 Day Un-Diluted	Nitrite
Biochemical Oxygen Demand Stream	Nitrite as N
Calculated Un-ionized Ammonia as N	Ortho Phosphorus
Chemical Oxygen Demand	Orthophosphate as P
Chlorophyll-a	Percent Saturation Field Dissolved Oxygen
Dissolved Orthophosphate as P	pH
Dissolved Oxygen'	Pheophytin a
E. Coli	Total Kjeldahl Nitrogen
Enterococcus	Total Organic Carbon
Fecal coliform	Total Phosphorus
Field Alkalinity as $CaCO_3$	Total Solids
Field Conductivity	Total Suspended Solids
Field Dissolved Oxygen	Turbidity
Field pH	-

Table 6: Significant results of the Seasonal Kendall's tau test.

Seasonal Kendall's tau test ($p < 0.05$) (n > 25)						
Location ID	**Date Range**	**Constituent**	**Unit**	***p***	***n***	***Trend***
1	1997-2005	Orthophosphorus	mg/L	0.006	64	Decreasing
3	1996-2009	Orthophosphorus	mg/L	0.002	88	Increasing
3	1996-2009	E. Coli	CFU/100 mL	0.001	88	Increasing
7	1996-2009	E. Coli	CFU/100 mL	0	89	Increasing
9	1996-2009	E. Coli	CFU/100 mL	0.002	89	Increasing
13	1969-2012	Ammonia as N	mg/L	0	151	Decreasing
13	2002-2012	Dissolved Orthophosphate as P	mg/L	0.001	58	Decreasing
13	1969-2012	Total Suspended Solids	mg/L	0.002	162	Decreasing
13	1977-2009	Total Kjeldahl Nitrogen	mg/L	0.034	122	Decreasing
13	1974-2012	Field Conductivity	umhos/cm @ 25 C	0.026	152	Increasing
13	1977-2009	Turbidity	NTU	0	146	Increasing
13	1969-2012	Field pH	pH Units	0	160	Increasing
15	2002-2008	pH	pH Units	0.045	29	Increasing
15	2002-2008	Dissolved Oxygen	mg/L	0.008	29	Increasing
17	2000-2008	Dissolved Oxygen	mg/L	0.014	52	Increasing
17	2000-2008	Turbidity	NTU	0	52	Increasing

5.2.2.1 Orthophosphorus

Significant temporal trends of orthophosphorus were different throughout the basin. Results were only significant at two different locations, a monitoring point along Lake Creek and at the head waters of the Metolius.

At Monitoring Location 1 (Mouth/Lake Creek), orthophosphorus shows a decreasing trend, as shown by Figure 11. Concentrations at this location are most likely affected by multiple factors including hydrologic and geologic interactions, biological uptake, and possible dam operations (pre-2013 before dam removal at Suttle Lake).

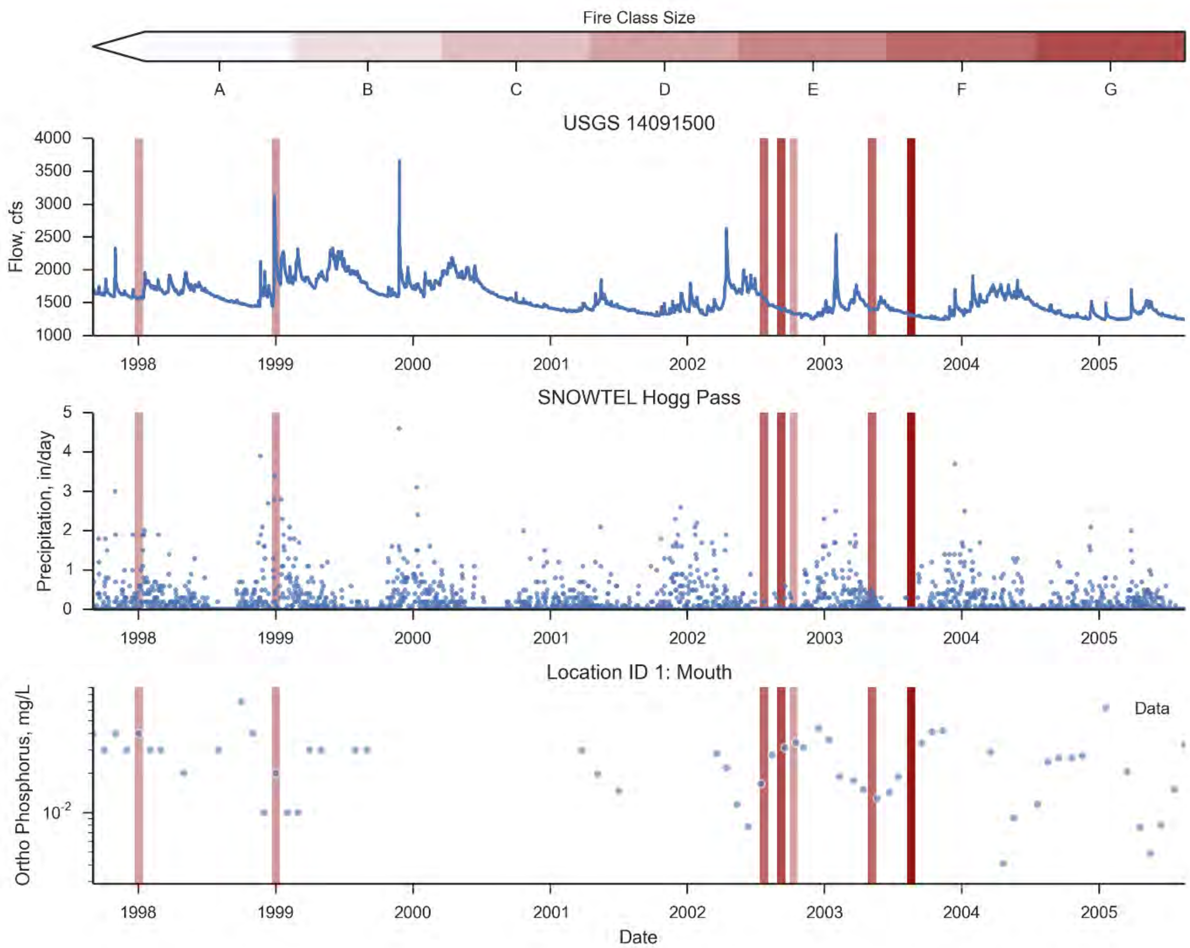

Figure 11: Orthophosphorus concentrations at Monitoring Location 1 compared to flow and precipitation. This location shows a significant decreasing trend. Note the width of lines for fire events are not intended to imply any time duration.

Orthophosphorus concentrations at Location 3 (Mouth) near the confluence of the Metolius River and Lake Creek tributary are increasing as shown by Figure 12. These concentrations are several times higher than Location 1. The mixing of Lake Creek with the Metolius River, which is phosphorus rich, probably causes these higher concentrations at this monitoring location. However, the apparent trend may also be caused by differences in analytical methods and/or laboratories used during earlier years compared to the later years of the available record.

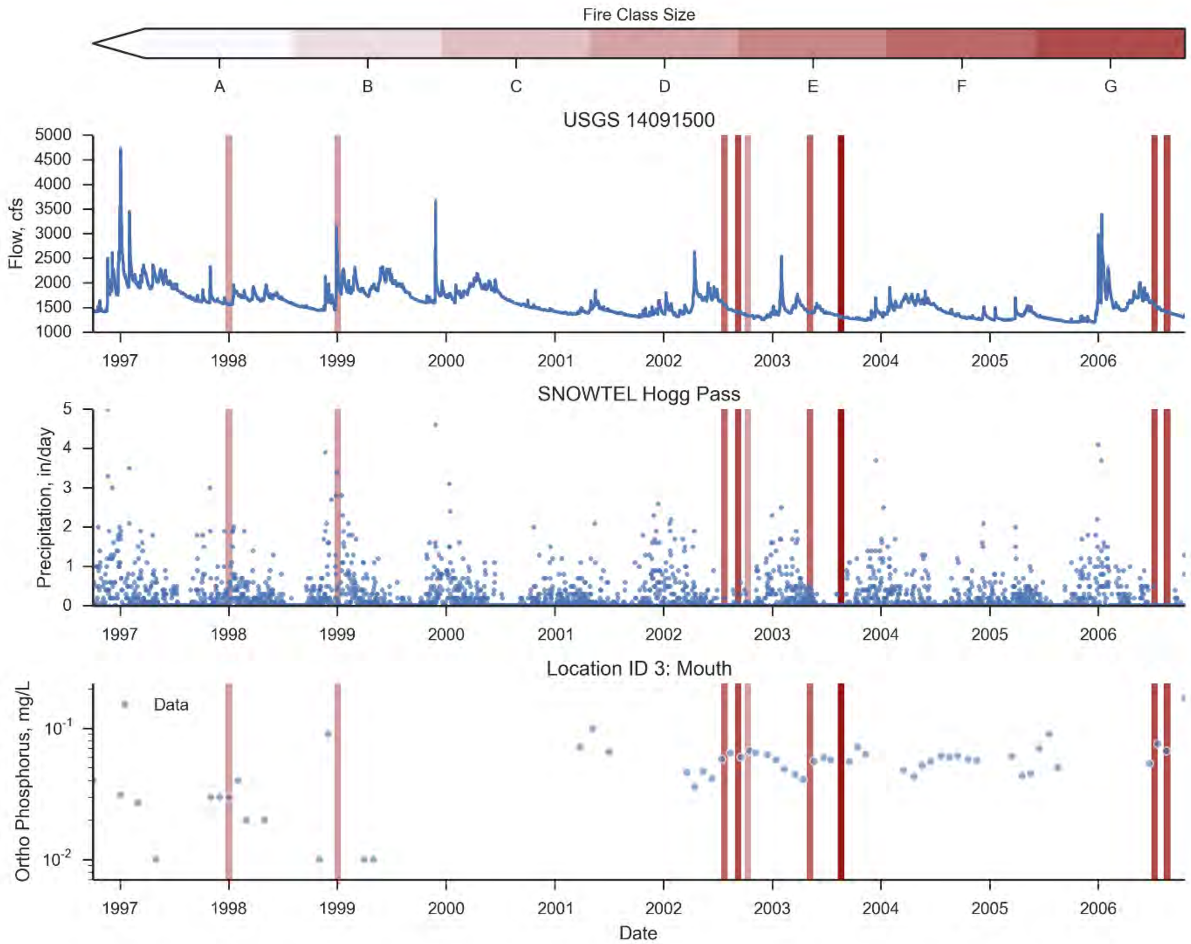

Figure 12: Orthophosphorus concentrations at Monitoring Location 3 compared to flow and precipitation. This location shows a significant increasing trend.

Both locations show seasonal peaks in concentrations. The peaks of these concentrations seem visually correlated with the onset of the high flow and the rainy season. This trend is most likely geology or land use driven, as the literature does not indicate correlations between post-wildfire conditions and elevated orthophosphorus concentrations.

5.2.2.2 Dissolved Orthophosphate as P

Monitoring Location 13 showed a significant decreasing trend for dissolved orthophosphate as P as shown by Figure 13. The seasonal peaks in the data appear inversely correlated with peaks in flow and rainfall, suggesting that storm flow events are potentially diluting the concentrations. Thus, the source of this orthophosphate is most likely geological and/or predominantly stored in groundwater. Because this constituent is sampled only at Monitoring Location 13, it is unclear if this trend is basin wide or limited to this location.

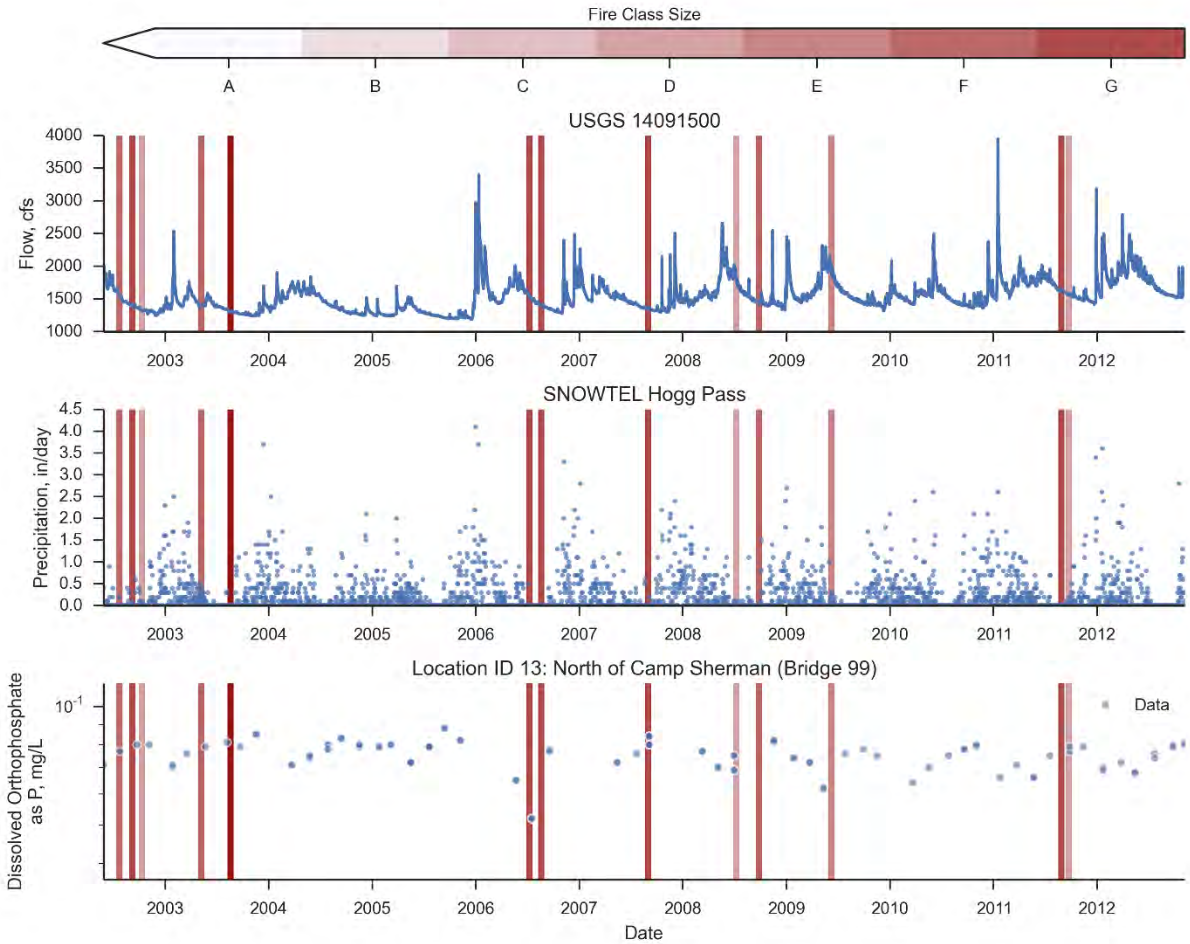

Figure 13: Dissolved Orthophosphate concentrations at Monitoring Location 13 compared to flow and precipitation. This location shows a significant decreasing trend.

5.2.2.3 Ammonia as N

Monitoring Location 13 showed a significant decreasing trend for ammonia as N, as shown in Figure 14. However, the high values before 1984 appear to be using a different method of detection based on the detection limit for that time period. While this was accounted for in the analysis by using the highest non-detect limit as the lowest value, data are questionable given the high number of non-detect values later in the record. These concentrations do not appear to show seasonality. Monitoring Location 13 is the only location were ammonia as N is sampled (potentially due to its proximity to the Wizard Falls Fish Hatchery), so it is unclear if this trend is present at other monitoring locations in the watershed.

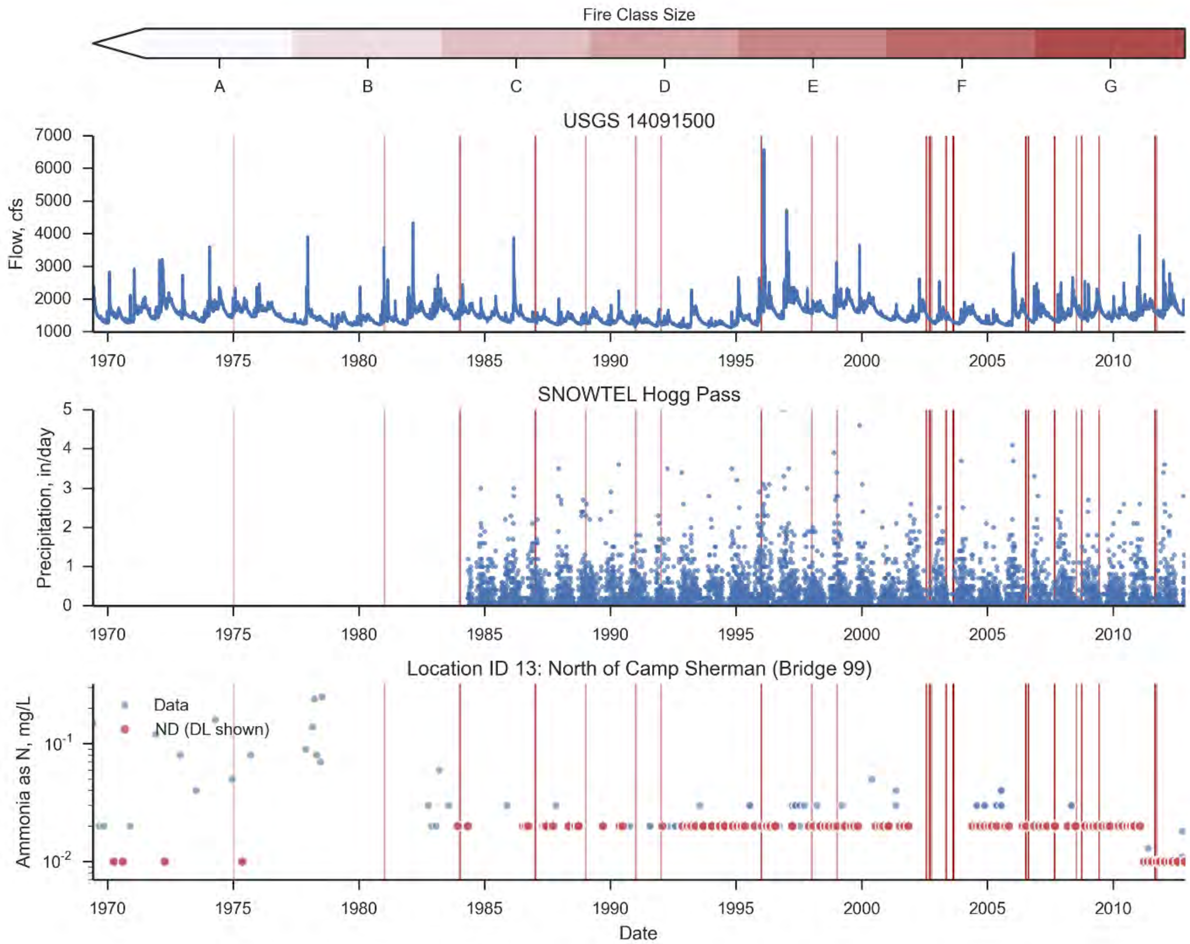

Figure 14: Ammonia as N concentrations at Monitoring Location 13 compared to flow and precipitation. This location shows a significant decreasing trend.

5.2.2.4 Total Kjeldahl Nitrogen

Based on the Seasonal Kendall tau results (Table 6), there is no statistically significant trend of concentrations for total Kjeldahl nitrogen. However, these results are biased by the single detect value in 1993. The data show that only non-detects have been reported since July 1995, thus no statement about the trend can be made. Total Kjeldahl nitrogen is only monitored at Location 13.

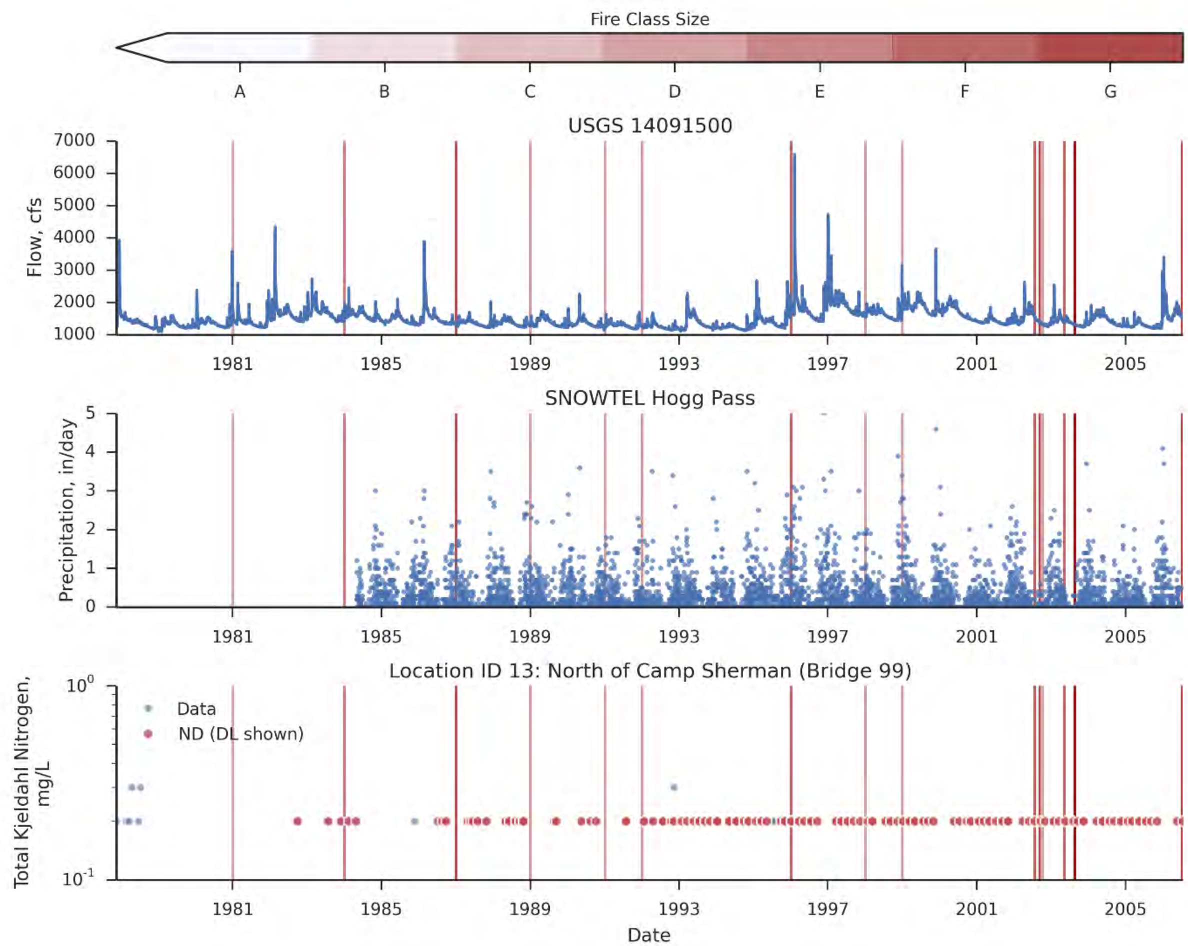

Figure 15: Total Kjeldahl nitrogen concentrations at Monitoring Location 13 compared to flow and precipitation. This location shows no significant trend.

5.2.2.5 E. coli

Based on the Seasonal Kendall tau results (Table 6), there is a statistically significant increasing trend at Monitoring Locations 3, 7, and 9 for E. coli concentrations. These three locations are in the upstream section of the watershed indicating that this trend might be due to land usage. As shown in Map A-3, Monitoring Locations 7 and 9 are located in the most densely used campground areas and Location 3 is located just upstream of these campgrounds and downstream of the next most used clusters of campgrounds at Suttle Lake.

Monitoring Location 3 shows a clear increasing trend as shown by Figure 16. Concentration values previous to 2001 were all below 10 CFU/100mL. However, values after this year show data points several times above this concentration and fewer non-detect values. This trend also corresponds with an increase in the number of fire events in the watershed. It is likely that any effect from fires on E. coli would have more to do with subsequent increases to overland flow and mobilization of sediment following burn events as the fire itself and high temperatures should lead to bacterial die-offs. For many of these events, Monitoring Location 3 is the nearest sampling point in the watershed before dilution can occur as shown in Map A-2

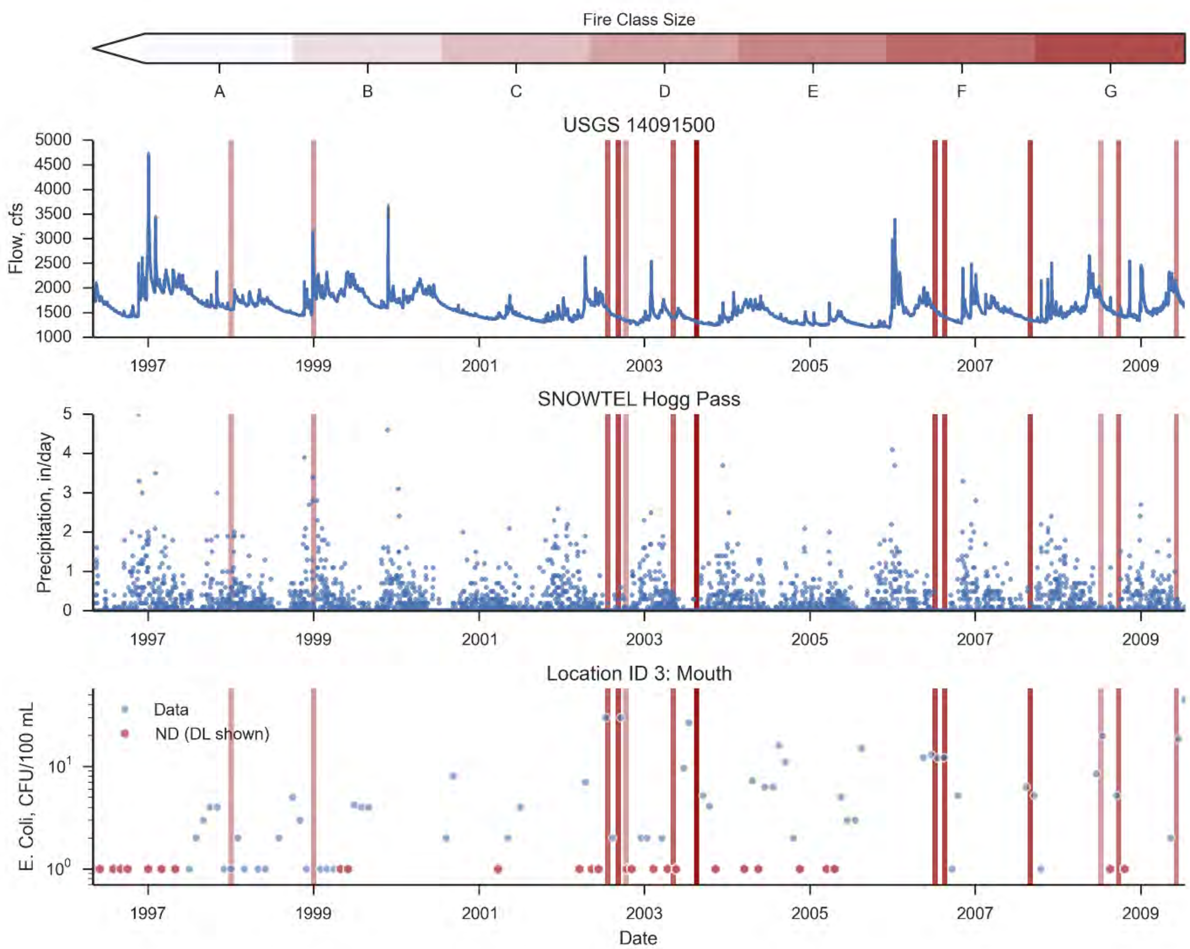

Figure 16: E. coli concentrations at Monitoring Location 3 compared to flow and precipitation. This location shows a significant increasing trend.

Monitoring Location 7 shows a similar increasing trend as Monitoring Location 3, although the increase in concentration is not as high, as shown by Figure 17. In addition, the increasing trend does not appear correlated with the increased fire frequency starting in 2002, as the trend appears to start after 1999. Thus, this trend is most likely related to land use around the sampling site as mentioned above.

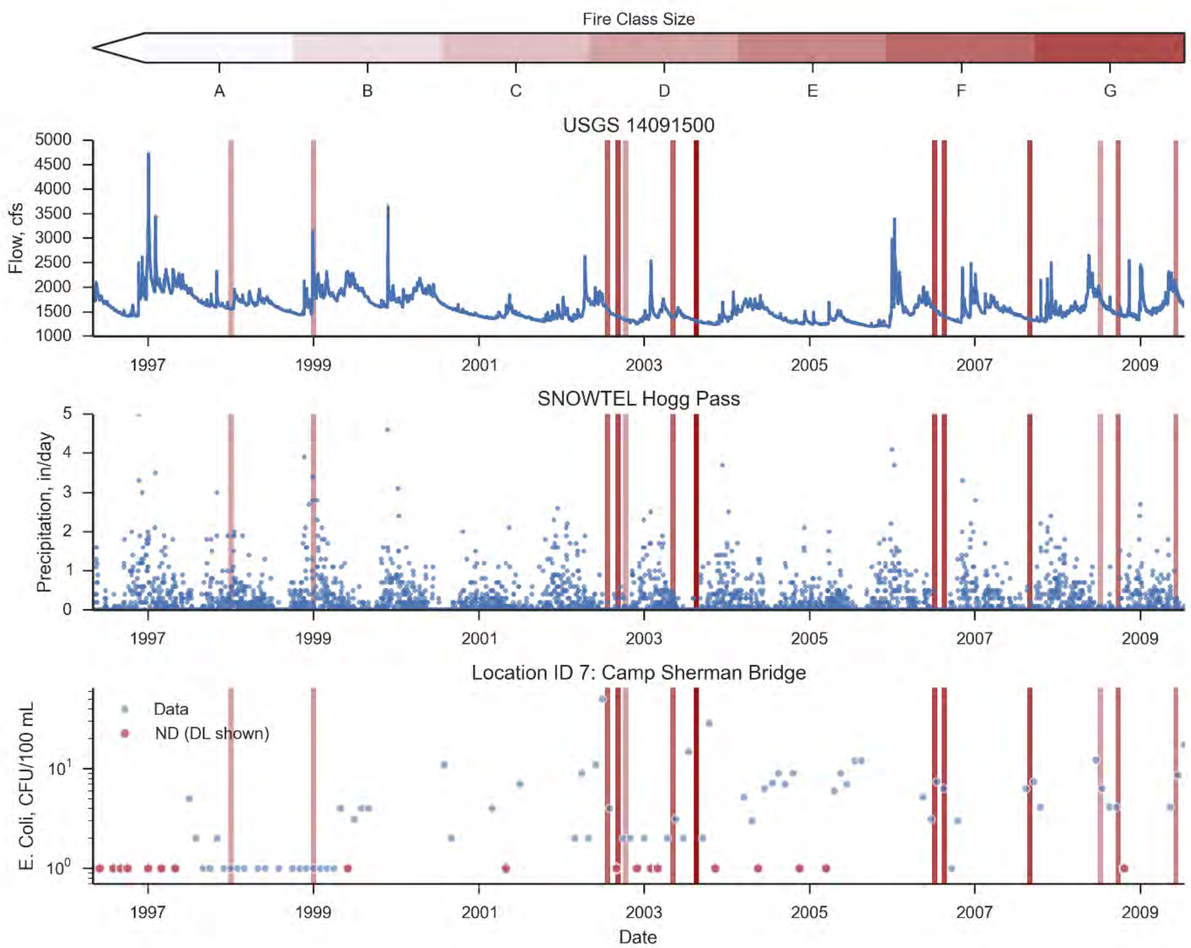

Figure 17: E. coli concentrations at Monitoring Location 7 compared to flow and precipitation. This location shows a significant increasing trend.

As shown by Figure 18, Monitoring Location 9 displays a similar increasing trend as Monitoring Location 7 with the same characteristics of increased concentrations appearing after 1999. Geographically, Monitoring Location 9 is just downstream of Monitoring Location 7 (see Map A-1), thus this outcome would be expected due to proximity and no significant input sources between locations.

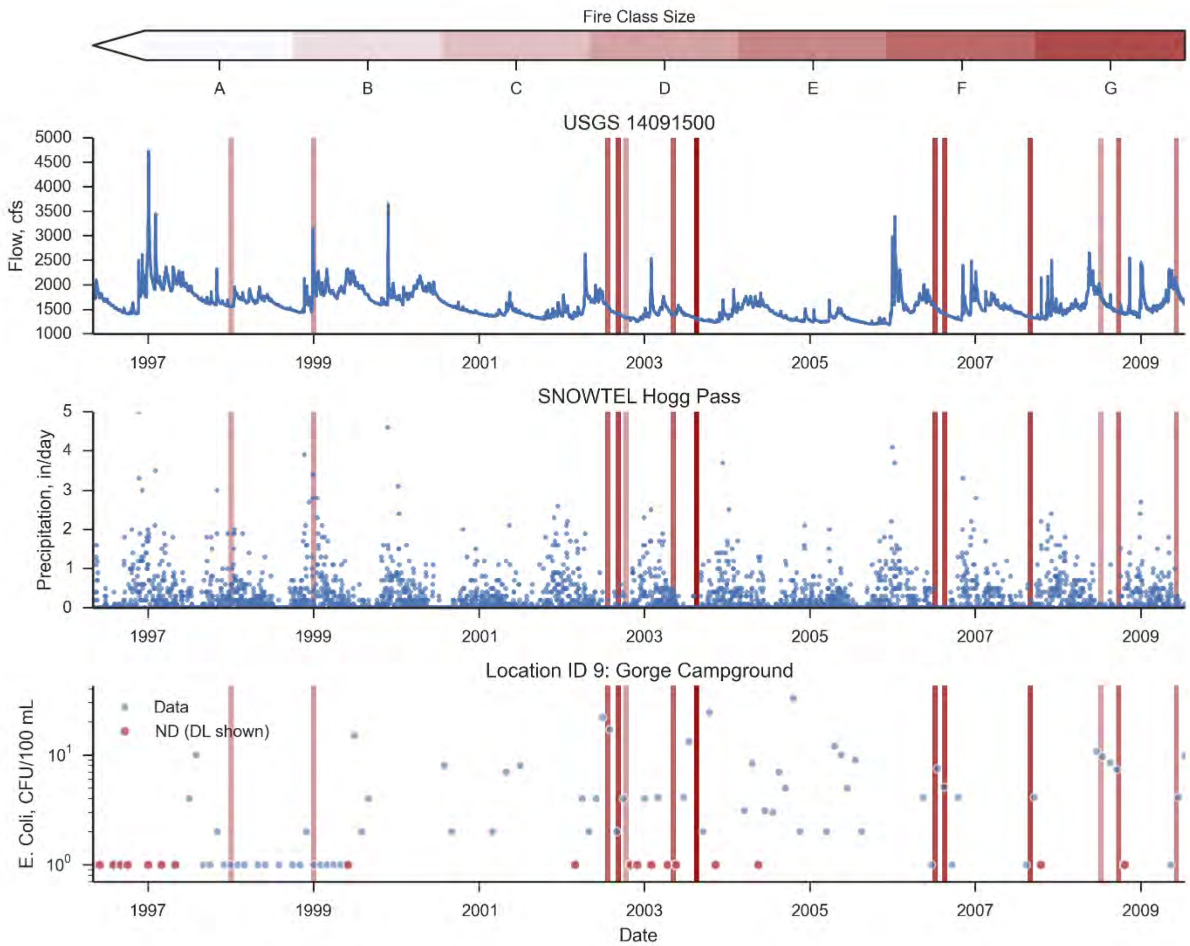

Figure 18: E. coli concentrations at Monitoring Location 9 compared to flow and precipitation. This location shows a significant increasing trend.

Even though these three monitoring locations show increasing trends the concentrations of E. coli are far below the in-stream water quality standards in this area of Oregon, as discussed in Section 6.1. In other words, although some increasing trends for bacteria can be observed within the data, in-stream concentrations indicate the overall condition of the Metolius River is exceptional and acceptable for human water-contact and recreation. No exceedance of the single sample criterion (406 MPN/100ml) was observed within the available data. Given the available data, it is unclear if these data have any seasonality or if the trends observed are simply due to changes in sampling or analysis methods over the years.

5.2.2.6 Total Suspended Solids

Monitoring Location 13 showed a significant decreasing trend for total suspended solids base on the Seasonal Kendall's Tau as shown by Figure 19. Previous to 1980, concentrations were generally above the detection limit, whereas concentrations afterwards are often flagged as non-detect values. Total Suspended Solids are only monitored at Location 13, thus we cannot determine if the high values before 1980 are due to an event upstream or basin wide. Because Total Suspended Solids is an important water quality parameter and often correlated to additional parameters, it is recommended that Total Suspended Solids be analyzed along with all water quality samples in future events. This would allow more robust correlation analyses and improved understanding of in-stream and runoff characteristics within the Metolius watershed.

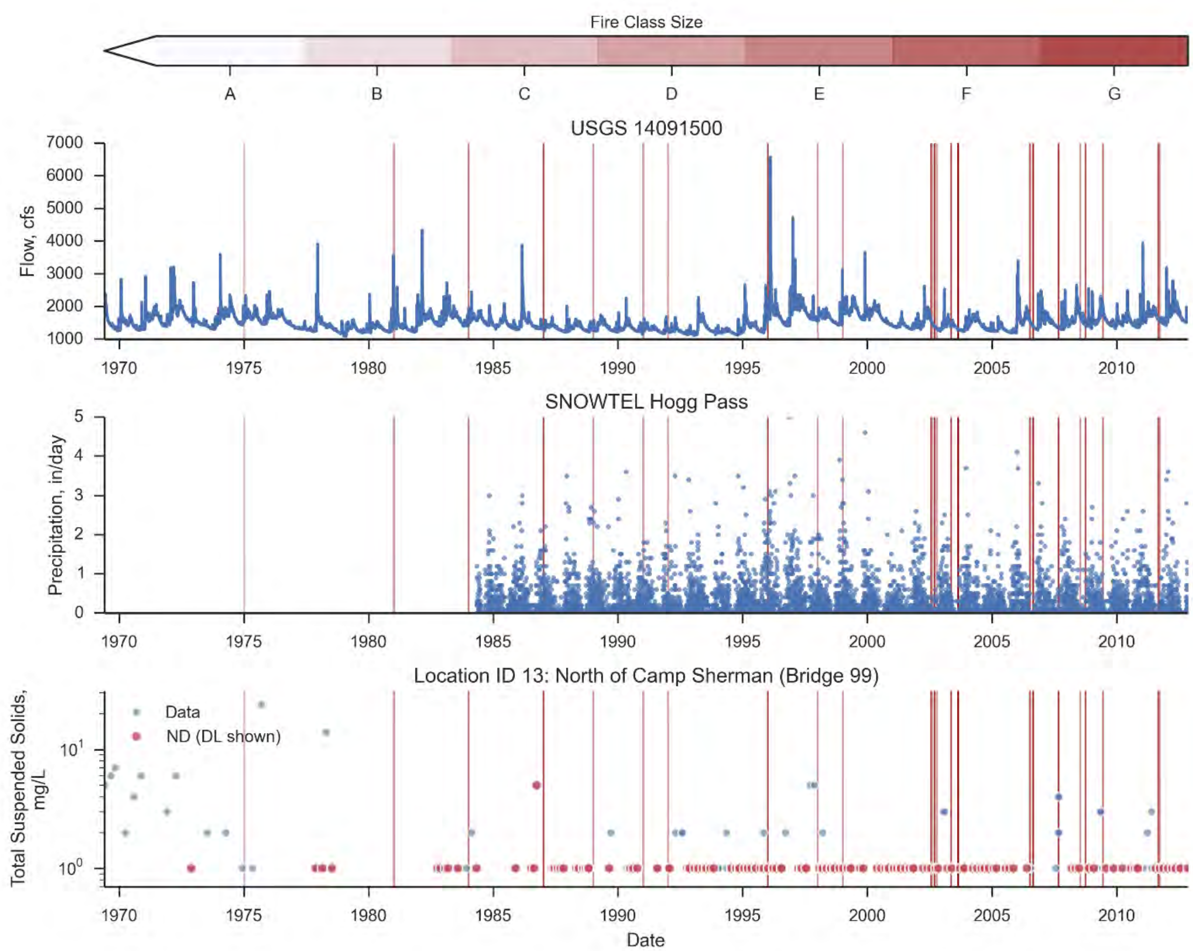

Figure 19: Total suspended solids concentrations at Monitoring Location 13 compared to flow and precipitation. This location shows a significant decreasing trend.

5.2.2.7 Turbidity

Concentrations of turbidity showed a significant increasing trend at Monitoring Locations 13 and 17 based on the Seasonal Kendall's Tau. Turbidity did not show a significant trend at the other monitoring locations. Increases in turbidity are generally seen after wildfires due to the creation of hydrophobic soils under high heat conditions which can result in the effective reduction of infiltration causing more overland flow and increased erosion (Mast & Clow, 2008).

Parts of the dataset at Monitoring Location 13 after 1994 show suspect data where data points are below the detection limit, as seen in Figure 20. During this time period both FOM and ODEQ were sampling. All of these values were considered as non-detects for the Seasonal Kendall's tau test. Very few detects are present before 1994 with several appearing after 2006. Increased turbidity could be correlated with the increase in the number of acres burned by fire in the watershed. Total Suspended Solids analyses are recommended to be conducted on samples used for turbidity to improve correlation analyses and system understanding.

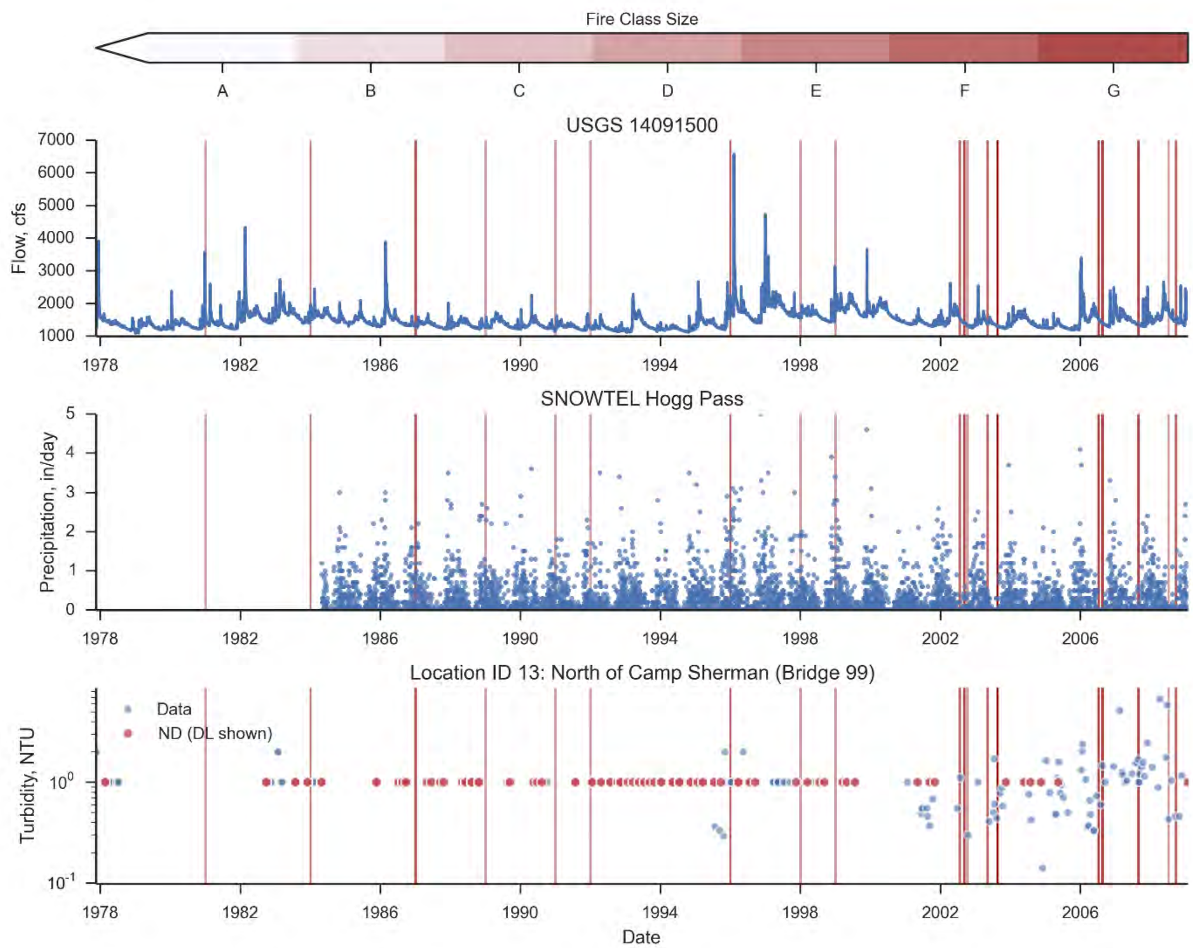

Figure 20: Turbidity concentrations at Monitoring Location 13 compared to flow and precipitation. This location shows a significant increasing trend. All data points below the DL were treated as though they were at the DL.

Increases in concentrations of turbidity at Monitoring Location 17 are much greater in magnitude than the trends seen at Monitoring Location 13, as shown by Figure 21. These data do not show any non-detect values. Monitoring Location 17 is downstream of Monitoring Location 13 and as a result, the volumetric flow at this monitoring location is most likely greater, which could account for the increased turbidity concentrations with less deposition of solids due to increased turbulence.

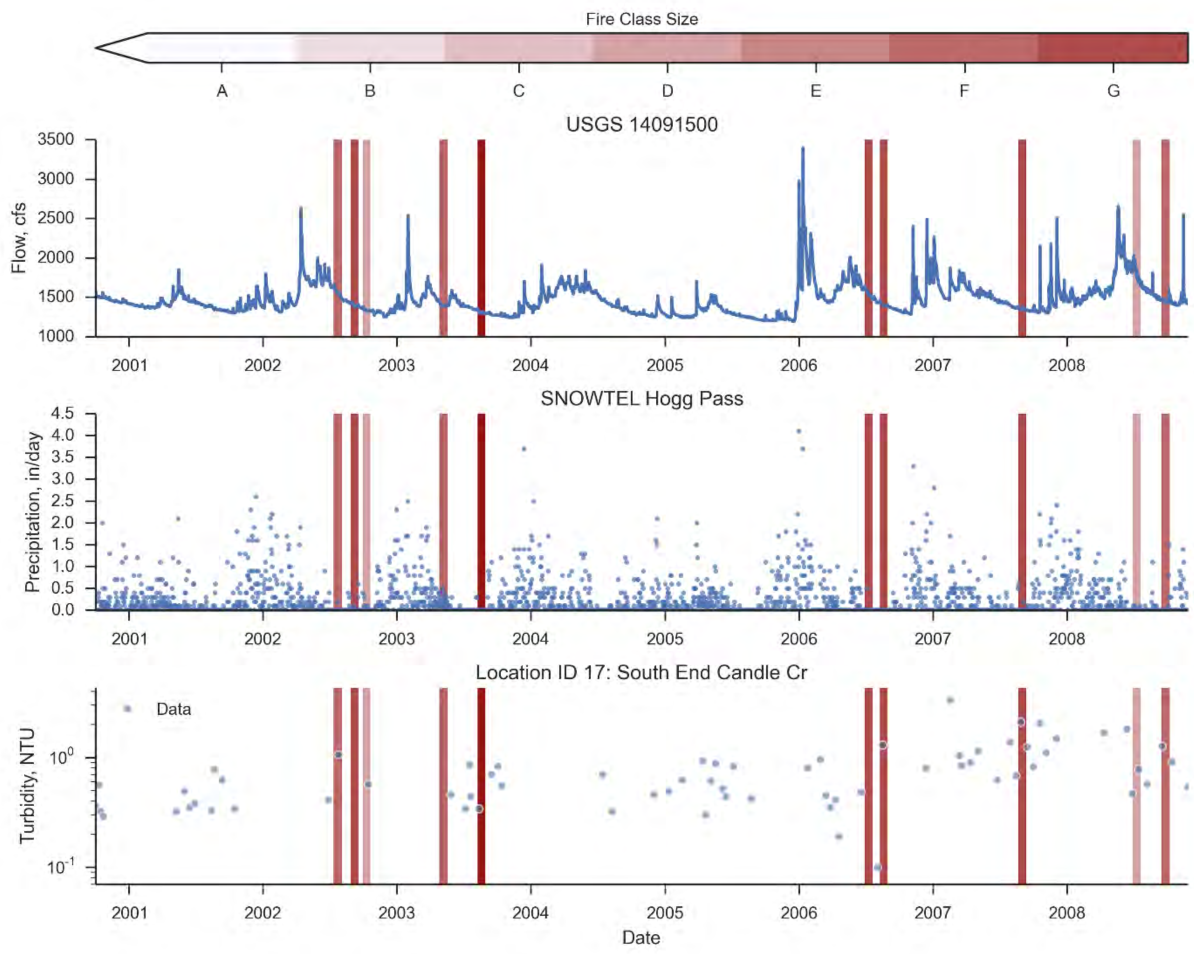

Figure 21: Turbidity concentrations at Monitoring Location 17 compared to flow and precipitation. This location shows a significant increasing trend.

5.2.2.8 Field Conductivity

Based on the Seasonal Kendall tau results (Table 6), there is a statistically significant trend of concentrations of field conductivity at Monitoring Location 13, as shown by Figure 22. The data appear to show a seasonal pattern correlated to precipitation and flow events. Field conductivity is only monitored at Location 13 and thus any assumptions as to whether this trend affects the entire watershed cannot be made at this time. Due to increased fire frequency and the number of acres burned by fire we expect this increase in conductivity due to higher particulates. Individual fire events do not appear to influence the data; however this may be a factor of sampling frequency, as discussed in Section 5.4.

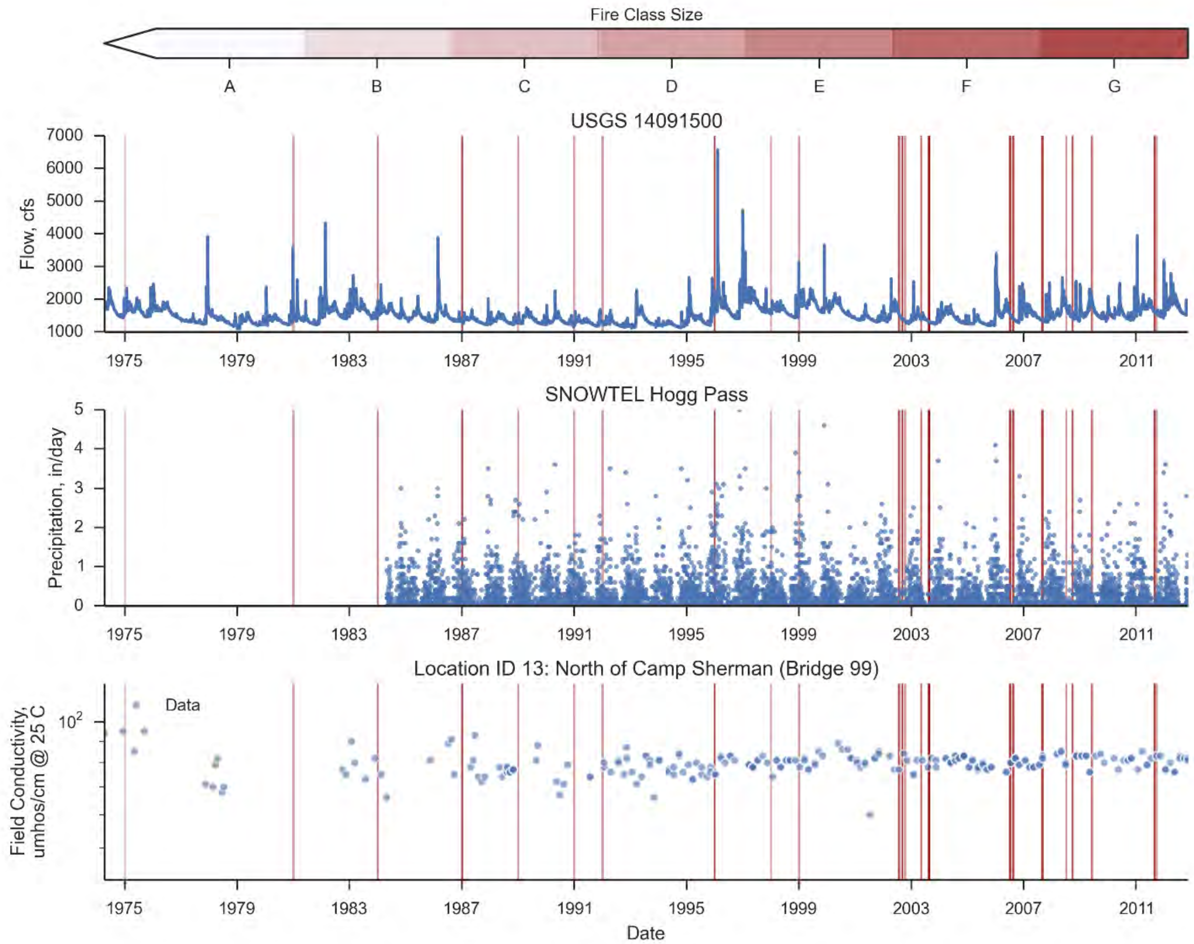

Figure 22: Field conductivity concentrations at Monitoring Location 13 compared to flow and precipitation. This location shows a significant increasing trend.

5.2.2.9 pH

pH showed a significant increasing trend at Monitoring Locations 13 and 15 based on the Seasonal Kendall's tau. Wildfires typically raise the pH of soil after a burn by removing organic acids and adding base cations from the ashes of the fire (Smith et al., 2011). The most immediate impact of fire is to the top layer of soil, potentially being released over some time period following burn events. Although sample locations do not indicate all the necessary details, potential releases and/or stormwater runoff from the Wizard Falls Fish Hatchery could contain ammonia and high pH flows.

pH at Monitoring Location 13 shows a steadily increasing trend, as seen in Figure 23. The data shows some seasonality loosely occurring with rainfall and flow events. No single increase to pH values were a result of a single forest fire, even though increased pH is generally an observed result of forest fires. This lack of sudden increases could be a result of sampling frequency, as discussed in Section 5.4.

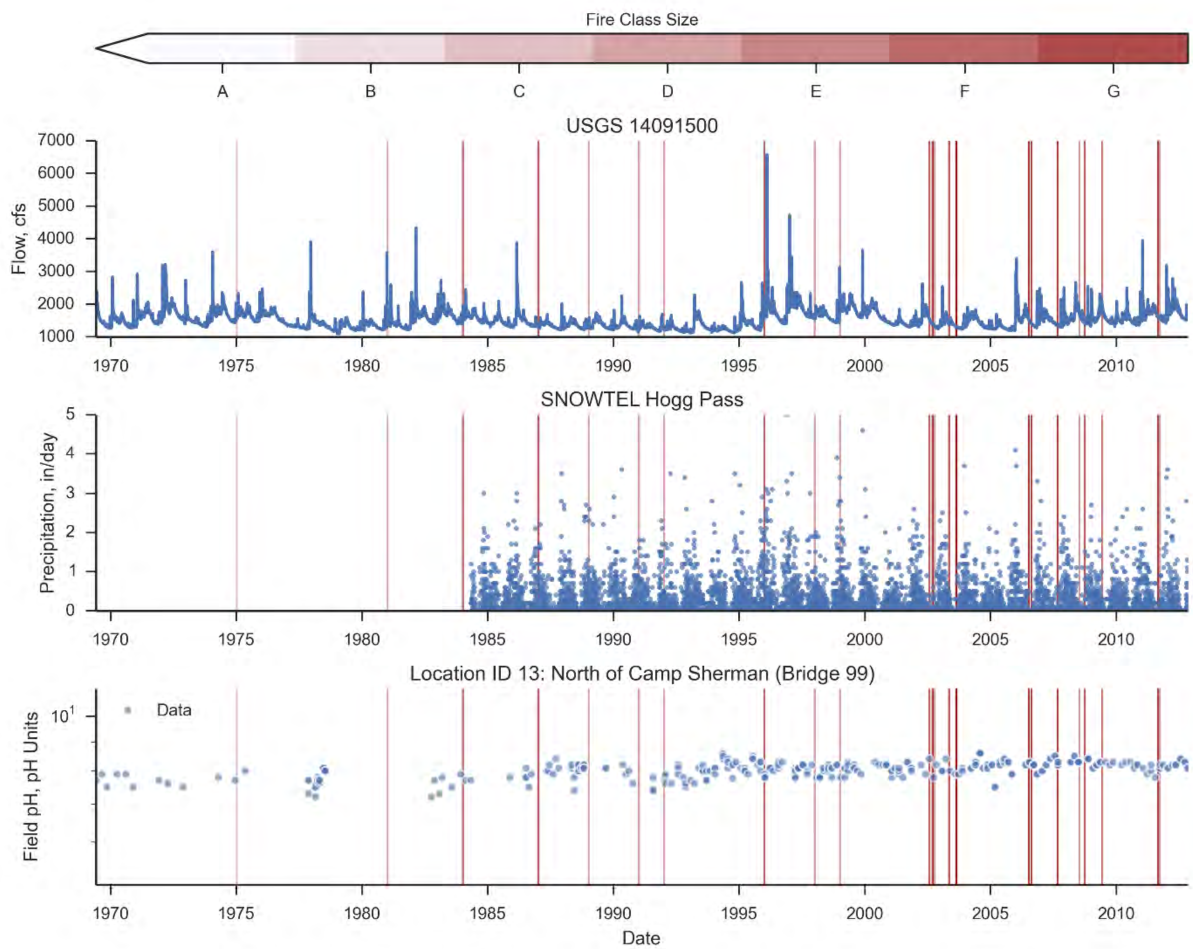

Figure 23: Field pH concentrations at Monitoring Location 13 compared to flow and precipitation. This location shows a significant increasing trend.

pH values at Monitoring Location 15 also show a statistically significant increasing trend based on the Seasonal Kendall's Tau, as seen in Figure 24. However, the trend is only barely significant and the long term validity of this trend is unknown given the more limited period of record for this monitoring location and few data points for the years 2004 and 2006.

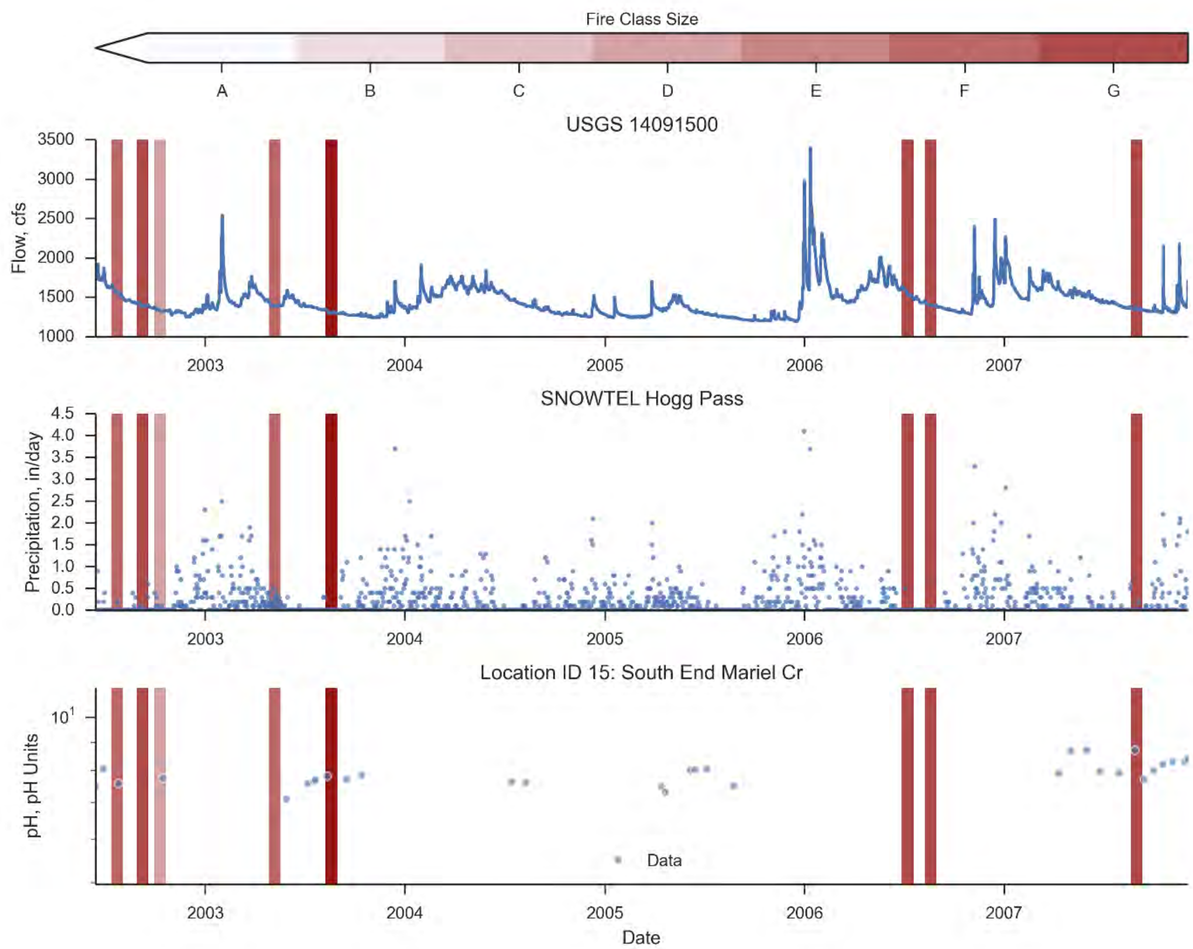

Figure 24: pH concentrations at Monitoring Location 15 compared to flow and precipitation. This location shows a significant increasing trend.

5.2.2.10 Dissolved Oxygen

Concentrations of dissolved oxygen showed significant increasing trends at Monitoring Locations 15 and 17 based on the Seasonal Kendall's Tau. Data for this water quality constituent only date back to 2001, thus long term trends are unknown. It is possible that the trend seen during the period of record is due to increased volumetric flow and turbulence from greater volumes of stormwater runoff.

Monitoring Location 15 shows an increasing trend from 2002 to 2009, as seen in Figure 25. However, the data in this figure is sampled seasonally and data are missing for the year 2006. Thus, the value of this statistic is questionable and only supported by data at the downstream Monitoring Location 17.

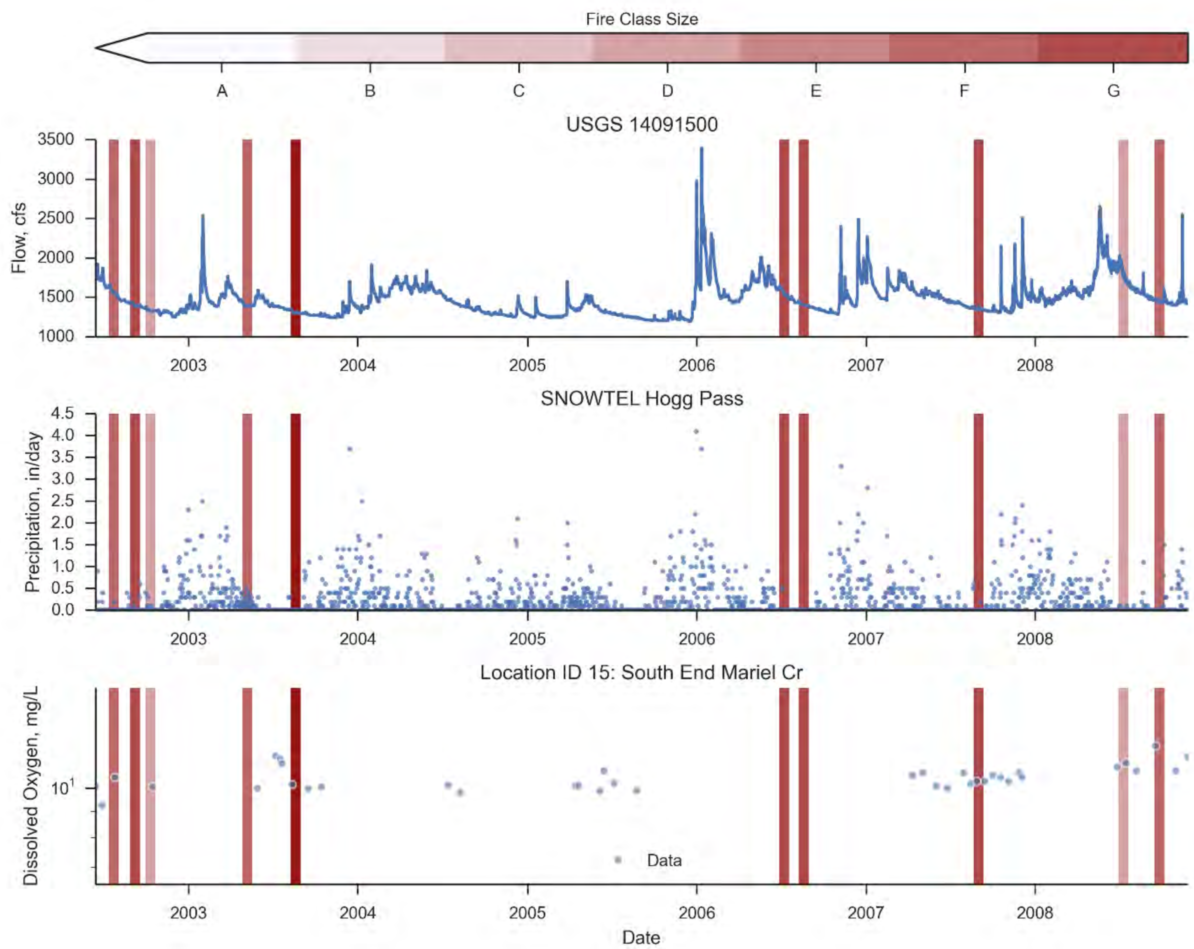

Figure 25: Dissolved oxygen concentrations at Monitoring Location 15 compared to flow and precipitation. This location shows a significant increasing trend.

The data at Monitoring Location 17 (Figure 26) are more reliable for a long term trend analysis as the data spans more years with fewer seasonal data gaps.

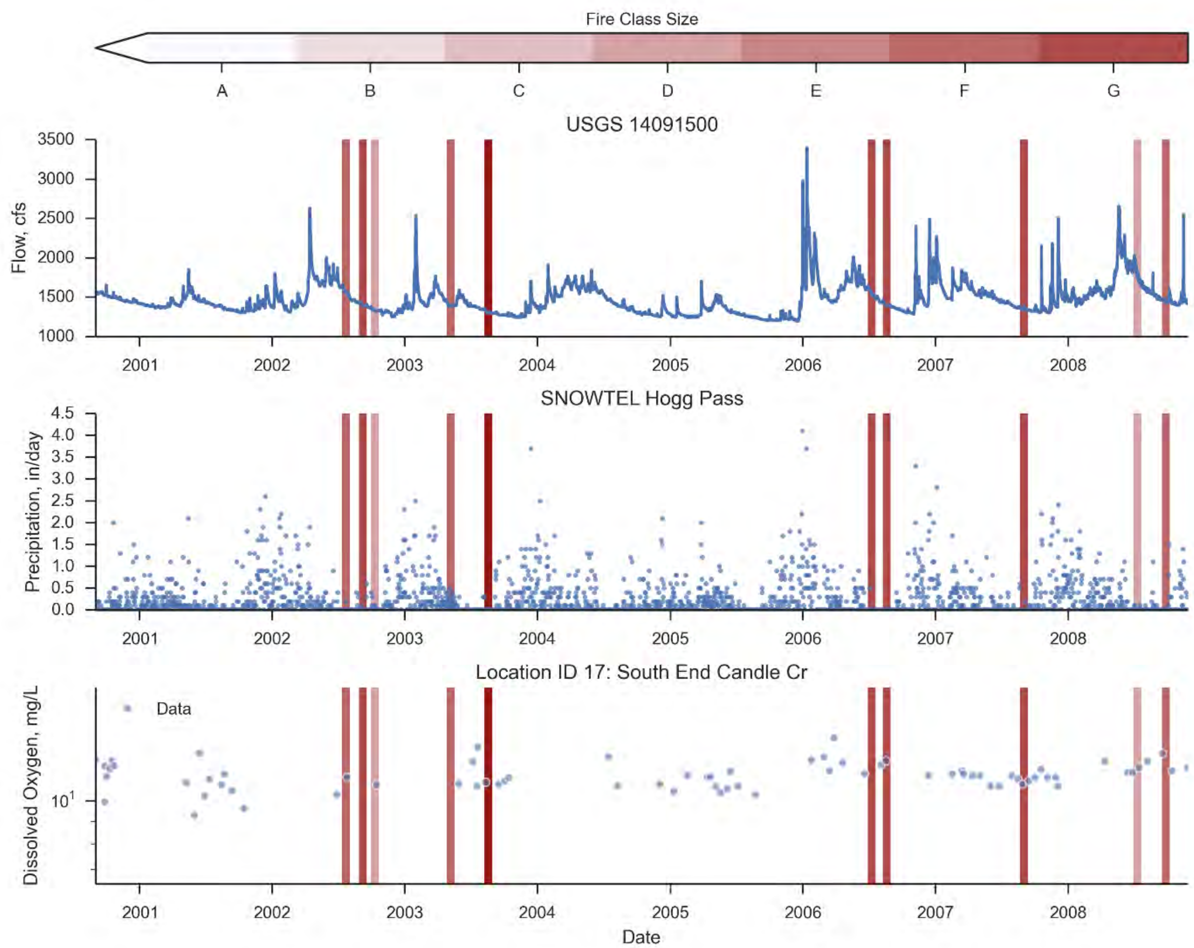

Figure 26: Dissolved oxygen concentrations at Monitoring Location 17 compared to flow and precipitation. This location shows a significant increasing trend.

5.3 Spatial Trends

The analyses and results in the following sections were analyzed with respect to spatial location relative to the overall watershed and do not consider temporal aspects other than data collection.

5.3.1 Comparison of Upstream and Downstream Water Quality

The Mann-Whitney Rank Sum test was used to identify statistical difference trends between different monitoring locations. Table 7 shows the constituents analyzed for spatial trends. These constituents were chosen because they are collected at most of the monitoring locations (see Task Memo 1 for details). The results of the Mann-Whitney Rank Sum test identify locations with unique water quality characteristics and show the locations that are similar, which can be used to inform future monitoring plans.

Table 7: List of constituents analyzed for spatial trends.

Constituent Name
Dissolved Oxygen
E. Coli
Nitrate as N
pH
Orthophosphate as P
Total Phosphorus
Turbidity

Table 8 shows the number of dissimilar constituents between monitoring locations. Two monitoring stations that include data for several constituents and show a large number of dissimilar constituents indicate notable differences in water quality between those two stations. Monitoring Locations 3 and 13 have the largest number of dissimilar constituents when compared to other locations, whereas Location 10 and 11 have the least. However, this would generally be expected as Locations 10 and 11 only monitor for E. coli and nitrate. Given that Locations 10 and 11 are both on tributary streams to the main stem of the Metolius River with relatively similar up-gradient (i.e., tributary) land use and vegetation cover, a low number of dissimilar constituents would be expected. In contrast, Locations 3 and 13 reflect points on the Metolius River with different tributary areas and land use types. The tributary area of Location 13 includes Camp Sherman, the Wizard Falls Fish Hatchery and seven additional recreational sites. The tributary area of Location 3 includes the area surrounding the headwaters, area from Black Butte, and Lake Creek (these areas are less associated with human use and are smaller in total tributary area than Location 13). The number of dissimilar constituents between these respective locations is a reflection of some of these differences in tributary area characteristics. With limited data, there is greater potential for incorrectly identifying similar locations than there is for incorrectly identifying dissimilar locations.

Table 8: Comparison of FOM sampling locations. This table shows the number of statistically dissimilar constituents at each location pair. Overall, the watershed is relatively consistent. The locations with the largest numbers of dissimilar constituent concentrations are Locations 3 and 13.

Number of statistically dissimilar (p<=0.05) constituents per location-location pair															
Location	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**13**	**14**	**15**	**16**	**17**
1	1		1		2	1	1	1			2				
2		1	1	1		1	1	1		1					
3			4		5	4	1	4			6	1	2	1	1
4					2	2	3	3			5			1	1
5					1		1				1				
6						2	2	2		1	4			1	1
7							2	1	1		5	1		1	1
8								1	1		2				
9									1		4			1	1
10										1					
11											1				
13												3	2	3	1
14														1	3
15														1	2
16															1

Table 9 shows the statistically different constituents that also have non-overlapping median confidence intervals. Monitoring Location 3 shows several differences both up and downstream for all constituents except for nitrate and turbidity (which is not monitored at this location). Locations 4, 6, 7, 9, and 13 show at least three constituents with statistical differences. These results indicate that the samples from these locations come from a significantly different distribution either because the sampling location is geographically isolated from the rest of the stations (such as a tributary stream), or because other factors have affected the water quality such as tributary geology, vegetative cover, or land use. Overall, the differences indicate spatial variability of water quality throughout the watershed.

Table 9: List of statistically dissimilar (p<=0.05, median confidence intervals do not overlap) locations per location-constituent pair. **Bold** indicates locations with 3 or more different constituents.

Location	Dissolved Oxygen, mg/L	E. Coli, CFU/100 mL	E. Coli, MPN/100 mL	Nitrate as N, mg/L	Orthophosphate as P, mg/L	Total Phosphorus, mg/L	Turbidity, NTU	pH, pH Units
1		6, 8				4, 6, 7, 9, 13		
2		3, 4, 7, 8, 9						
3	**4, 6, 7, 9, 13**, 14, 15, 16, 17	2, **6**, 8	**4, 6, 7, 9, 13**		**7, 13**	**4, 6, 7, 9, 13**		**13**
4	**3**, **13**, 16, 17	2, 6, **8**, **13**	**3**, 7, **8**, 9	7, **8**, 9, **13**		1, **3**, 9, **13**		**13**
6	**3**, **13**, 16, 17	1, **3**, 4, 7, 8, 9	**3**, **13**			1, **3**, **13**		
7	**3, 13**, 16, 17	2, 6, **13**	**3**, 4, **13**	4, 8	**3**	1, **3**		
8		1, 2, 3, **4**, 6, 10, 13	**4**, 13	**4**, 7				
9	**3, 13**, 16, 17	2, 6, **13**	**3**, 4, **13**	4		1, **3**, 4		
13	**3, 4, 6, 7, 9**, 14, 15, 17	**4**, **7**, 8, **9**	**3**, **6**, **7**, 8, **9**	**4**	**3**	1, **3**, **4**, **6**	14, 15, 16	**3, 4**
14	3, 13, 16, 17						13, 17	
15	3, 13, 16, 17						13, 17	
16	3, 4, 6, 7, 9, 14, 15						13, 17	

5.3.1.1 E. coli

Figure 27 shows that concentrations of E. coli throughout the river are low and consistently below the water-contact recreational standard of 126 MPN/100 ml (30-day average).

Monitoring Location 8 shows the highest values and also corresponds spatially to proximate recreational sites with the greatest amount of use. Concentrations then decrease downstream, which would indicate that these elevated concentrations are related to more frequent recreational use rather than general terrestrial inputs.

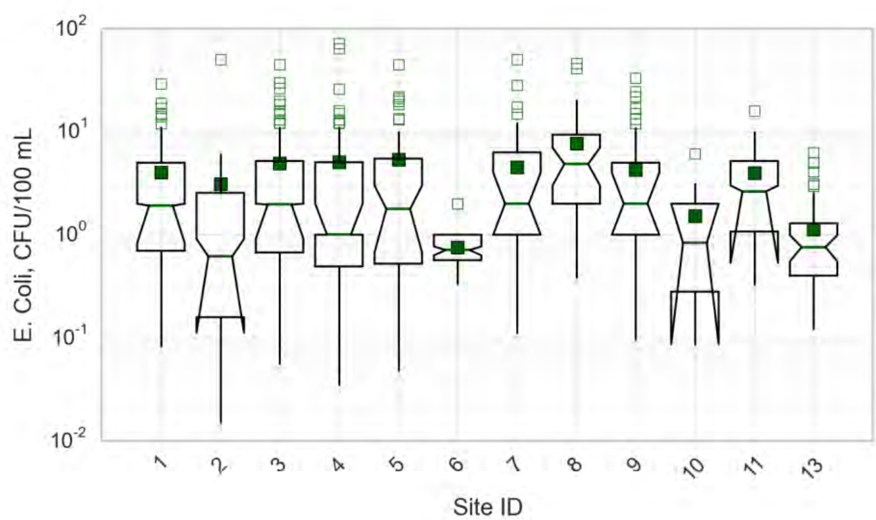

Figure 27: Concentrations of E. coli arranged from upstream to downstream.

5.3.1.2 Dissolved Oxygen

Spatial trends of dissolved oxygen are typical of the spring fed river. As shown in Figure 28, concentrations show a generally increasing trend with each downstream monitoring location. This result is expected with increasing volumetric flow from overland runoff, additional spring inputs, tributary confluence and associated main channel turbulence. Concentrations decrease at Monitoring Location 14 when the Metolius River enters Lake Billy Chinook where flow velocities decrease (generally reducing mixing, turbulence and air entrainment) and temperatures increase (reducing the ability of the water to "hold" oxygen in the dissolved form).

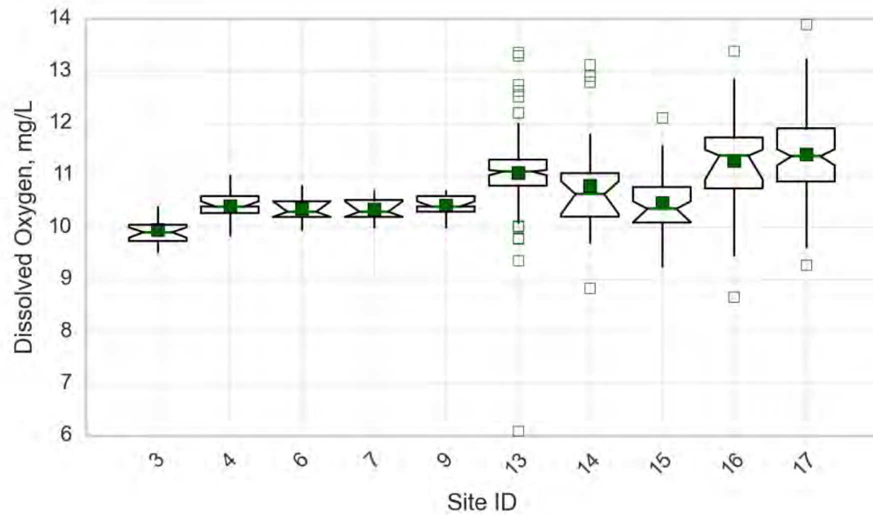

Figure 28: Concentrations of dissolved oxygen arranged from upstream to downstream. Side channel tributaries listed last after Monitoring Location 14.

5.3.1.3 Nitrate as N

The headwaters of the Metolius River appear to be the source of the nitrates, as concentrations tend to decrease downstream until monitoring Location 9, as shown by Figure 29. The trend of decreasing Nitrates with increasing distance from the headwaters is previously speculated as being related to algae and bacterial uptake (Sisters Ranger District, 2004), but could likely indicate dilution of the groundwater rich flows from upland tributaries. There are too few data points at Location 8 to say that concentrations decrease before Locations 9 and 13. However, both of these monitoring locations are downstream of high use campground and recreational areas, as shown by Map A-3 and Map A-4. The difference between concentrations at monitoring Location 4 and 9 is statistically significant.

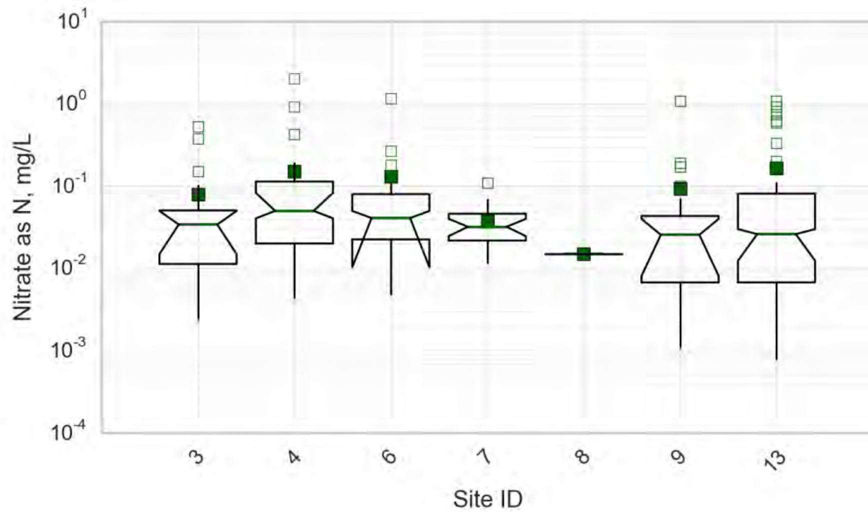

Figure 29: Concentrations of nitrate as N arranged from upstream to downstream.

5.3.1.4 Orthophosphate as P

We observed a wide range of values for orthophosphate as P concentrations, as shown by Figure 30. Unfortunately, the headwaters did not meet the criteria for hypothesis testing. In general, concentrations were high at all monitoring locations. We did not observe a decreasing trend similar to nitrate and previously noted by the Sisters Ranger District (2004). This is possibly due to more strict testing criteria, ROS statistics, and a different subset of the FOM dataset.

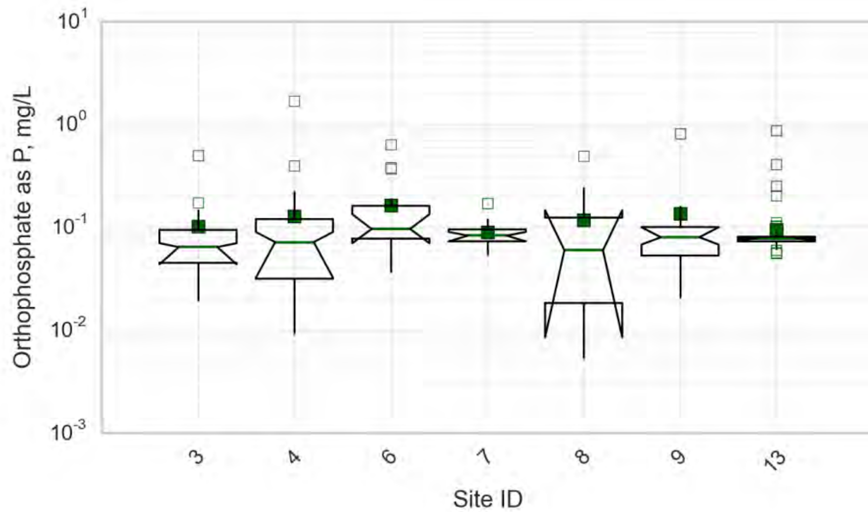

Figure 30: Concentrations of orthophosphate as P arranged from upstream to downstream.

5.3.1.5 Total Phosphorus

Results for total phosphorus were highly variable, even at monitoring locations along the main stem of the river, as shown by Figure 31. Several factors could contribute to this result including sampling time, number of samples, geology, and localized events or development. Two of the monitoring locations were limited in data (Locations 5, 8). Excluding these sampling locations, all of the significant results (provided in the supporting data) are between upstream monitoring locations not near recreational areas or campgrounds and those downstream (not necessarily near recreational areas of campgrounds).

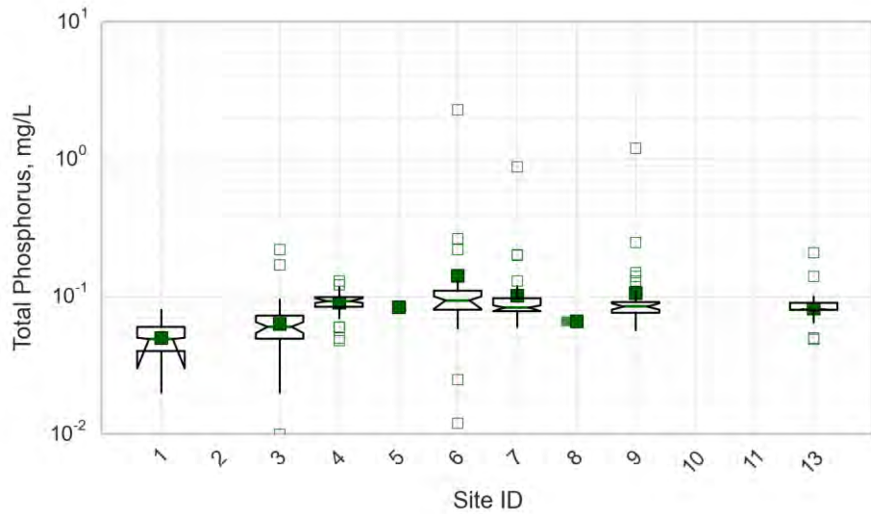

Figure 31: Concentrations of total phosphorus arranged from upstream to downstream.

5.3.1.6 Turbidity

Of the monitoring locations that monitored for turbidity, Locations 13 and 17 showed statistically significant differences from the rest of the data, as shown by Figure 32. The former result is expected, given that Location 13 is on the main stem of the river. Differences in geology, or possibly fire history, may explain why Location 17 shows less turbidity than the other creeks, but this was not verified in this analysis.

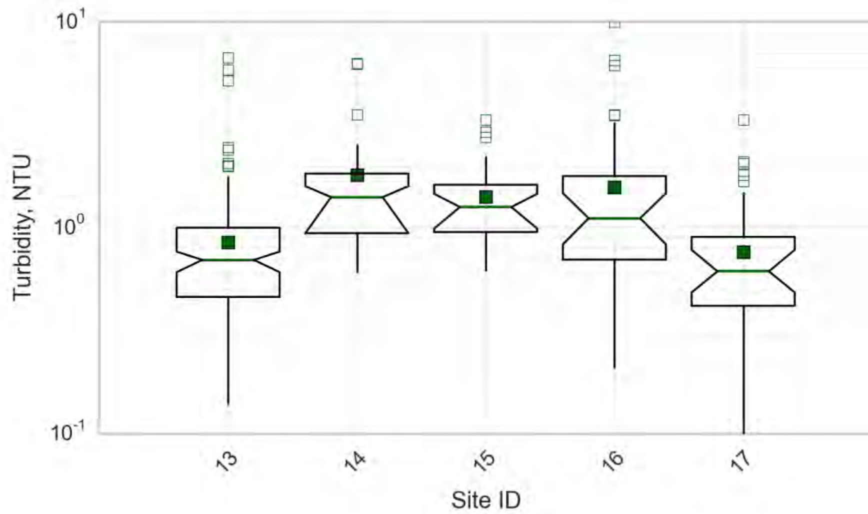

Figure 32: Concentrations of total turbidity arranged from upstream to downstream. Side channel tributaries listed last after Monitoring Location 14.

5.3.1.7 pH

The only statistically significant differences of pH between monitoring locations was between Location 13 and Locations 3, 4, and 7. Monitoring Location 13 showed a higher median value than the other upstream locations. Figure 33 shows that there is an increasing trend in pH from the head waters to the downstream section of the river. This indicates that Metolius Springs cause lower pH compared to the rest of the geology and land use factors in the watershed.

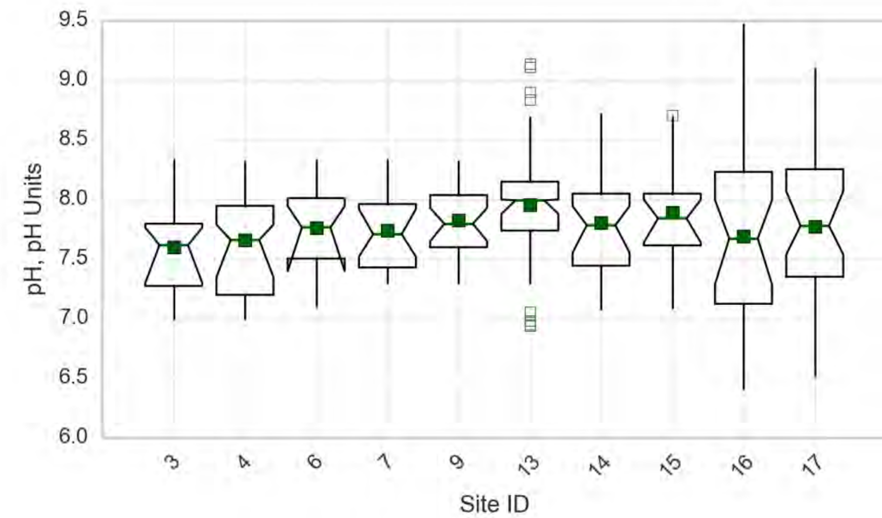

Figure 33: Concentrations of total pH arranged from upstream to downstream. Side channel tributaries listed last after Monitoring Location 14.

5.4 Caveats

Several caveats limited the quality and extent of these analyses. These include limitations on the type of predictions possible with grab sample data, limitations due to the timing and frequency of data collection, and a highly variable rain gradient across the basin causing climate variability and uncertainty for areas not characterized by appropriate rain gauge distribution. Additionally, the lack of explicit information associated with each individual grab sample (detailed spatial location and surrounding context, supporting duplicates, photos/visual observations, distance and depth of sample, stream flow during sampling, who took the sample, QA/QC procedures, laboratory methods, field notes and anything else related to documentation) make qualitative correlations and assessment of potential cause-effect relationships extremely difficult and quantitative and quantitatively inappropriate for many parameters and/or locations.

Grab sample data typically show high levels of variability within sample populations. This is caused by the varying techniques used by different technicians when collecting the data, location, depth and timing of the sample given environmental variability, random error from technician to technician, handling and storage from the field to the lab, and varying lab practices. Samples from FOM showed less variability than what would typically be expected from grab samples (as shown by the summary statistics in Appendix A), which although still subject to grab sample limitations, did improve confidence in this analysis.

As described in Section 2.1, the Metolius River watershed lies on a steep rain gradient that significantly influences the vegetation, fire regimes, and tributary flow patterns (Sisters Ranger District, 2004). The average annual rainfall in the watershed varies from 11 inches (near the eastern edge of the watershed) to 165 inches near South Sisters. This steep gradient affects any correlations between flow and rainfall, as the high variability in rainfall throughout the basin cannot be estimated easily from a single rain gauge.

The timing and frequency of data collection have the greatest effect on the results of this analysis, particularly with respect to qualitative correlations between wildfires, anthropogenic impacts and in-stream water quality. It is likely that several trends that were expected, such as short term suspended solids and nutrient increases following rain events after a fire, were not observed in the data because of the timing and/or location of sample collection. In addition, several assumptions were made due to a lack of metadata, such as the precipitation conditions during sampling.

6. CURRENT AND FUTURE WATER QUALITY CONDITIONS

6.1 Oregon Water Quality Standards & EPA Recommended Ecoregional Nutrient Criteria

To assess the current and future health of the Metolius River we compared the data to both the EPA Recommended Ecoregional Nutrient Criteria (USEPA, 2000) and Oregon Water Quality Standards (ODEQ, 2014) for the region. The Metolius watershed is part of Ecoregion II and subregion 11. Ecoregion II has general conditions for water quality and each subregion has specific criteria. Table 10 and Table 11 show the EPA and ODEQ requirements.

Table 10: Applicable Ecoregional Criteria (USEPA, 2000a).

Constituent	Aggregate Nutrient Ecoregion II Reference Conditions	Subregion 11 Reference Conditions
Chlorophyll-a, ug/L	1.08	1.35
Nitrate/Nitrite – N, mg/L	0.014	0.010
Total Phosphorus, mg/L	0.01	0.0325
Turbidity, NTU	1.30	0.80

Table 11: Applicable Oregon Water Quality Standards (ODEQ, 2014).

Constituent	Water Quality Standard
Dissolved Oxygen, mg/L	Min 11.0** or 8.0***
E. Coli, counts/100ml	Max 406 counts/100mL per sample, or 126 counts/100mL for 30 day log mean (shown in Figure 34)

**11.0 mg/L minimum for streams that contain spawning/rearing Bull Trout.
***8.0 mg/L minimum for cold water streams.

We compared these requirements to the quartiles, mean, minimum, maximum, and outliers (shown using box plots) in each dataset, as shown by Figure 34. The requirement for total phosphorus was exceeded at all monitoring locations, potentially indicating significant geological and “natural” sources. As previously stated, these elevated concentrations are likely due to the phosphorus rich geology at the headwaters (Peterson & Groh, 1972; Sisters Ranger District, 2004). While total phosphorus did not show any significant temporal trends, inorganic phosphorus shows a decreasing trend in the upstream section of the basin, but not anywhere else. Thus, concentrations of phosphorus nutrients are expected to remain above these water quality requirements in the future. Although temperatures and main channel flows of the Metolius River likely prevent algae blooms within the upper watershed, upon entering Lake Billy Chinook, velocities slow, temperature rises, the Deschutes River joins and significant algae blooms are observed as shown by Figure 35. Given the significant amount of agriculture along the Deschutes and relative volumetric flow, it is highly unlikely that the Metolius is solely responsible for these algae blooms.

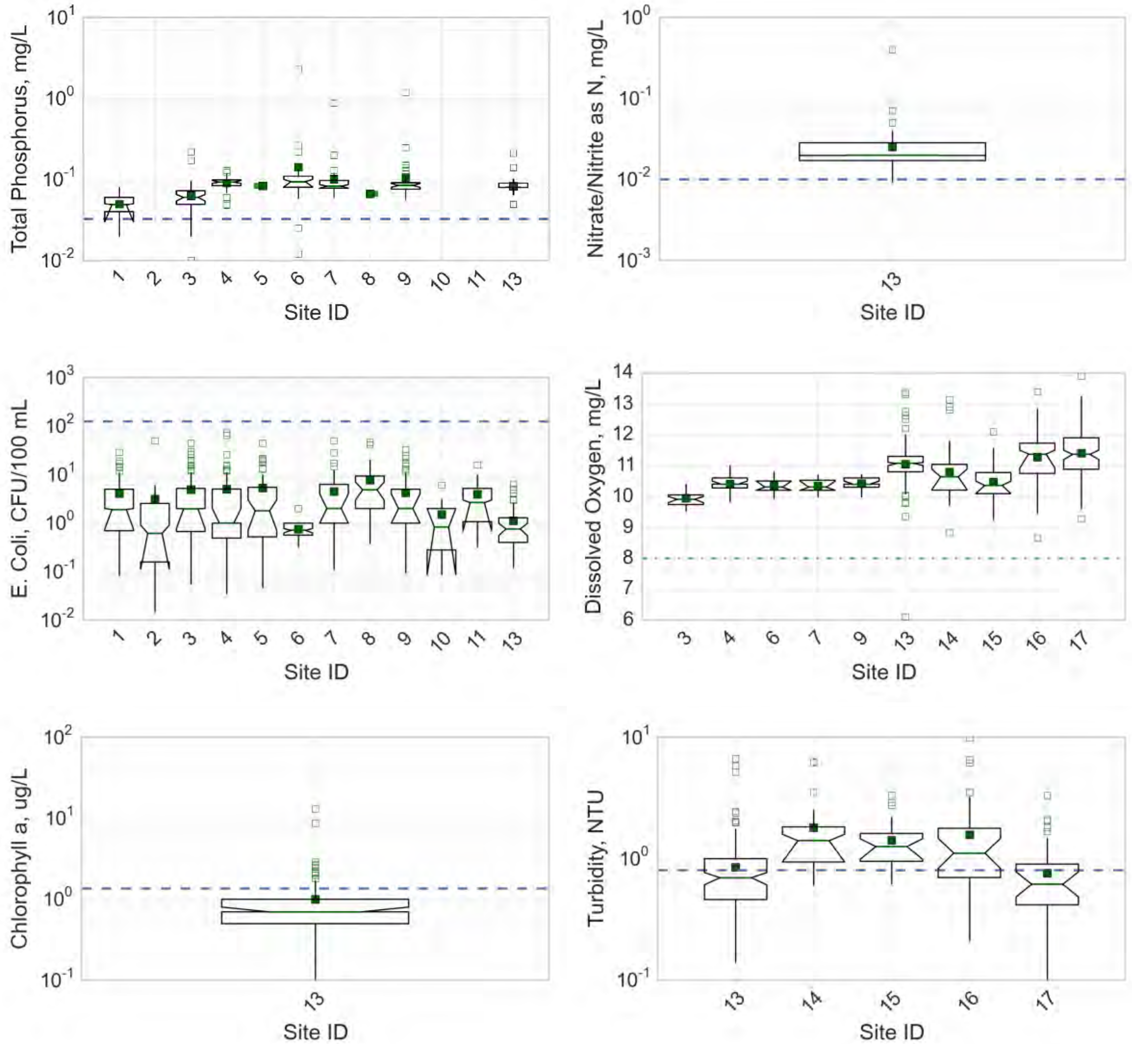

Figure 34: Applicable water quality standards of the entire dataset for (left to right starting at top) total phosphorus, nitrate/nitrite, E. coli, dissolved oxygen, chlorophyll-a, and turbidity. Concentrations of total phosphorus and nitrate/nitrite exceeded the standards at all locations they were sampled. Blue dashed lines indicate a maximum criterion, whereas green dash-dot lines indicate a minimum standard.

Figure 35: Bing maps aerial showing the Metolius and Deschutes Rivers entering Lake Billy Chinook and significant algae coverage within the lake. Note clear mixing break-points on both rivers and significant agriculture east of the Deschutes River.

Concentrations of nitrate/nitrite also exceeded the requirements, but were only sampled at Monitoring Location 13. The median concentrations of nitrate/nitrite are approximately double the requirement of 0.01 mg/L. Without more samples throughout the watershed it is unclear if these higher concentrations are localized to Monitoring Location 13. High concentrations at this location are expected to remain constant, as this constituent did not show a significant temporal trend.

Mean and median concentrations of E. coli were below 30-day log mean requirement of 126 counts/100mL at all locations, as shown by Figure 34. All of the maximums and outliers in the data were also below the requirements. As such, concentrations of E. coli are not considered an issue in the watershed at this time with respect to water-contact recreation. However, given the increasing trend to in-stream concentrations in the areas with increased use and populations (Monitoring Locations 3, 7, and 9) there is potential for individual samples to start exceeding the requirements. The ODEQ water quality standards specifically state that concentrations cannot exceed a 30-day log mean of 126 E. coli organisms per 100 mL, based on a minimum of five samples and that no single sample may exceed 406 E. coli organisms per 100 mL.

Concentrations of dissolved oxygen comply with the minimum standard, with only a single outlier at Location 13 below 8 mg/L. The more strict criteria of 11 mg/L apply only when the stream contains spawning or rearing Bull Trout. Historically, these fish have used the Metolius for this purpose from late July through December (Ratliff, 1996). A subset of the data was taken for these months (specifically, the beginning of August to the end of December) to compare to the 11 mg/L standard, as shown by Figure 36. The upstream sections of the watershed do not meet this standard. However, given that the Metolius does not have any point source dischargers to the river (that were known at the time of writing), these concentrations are most likely natural and thus cannot be improved easily without in-stream modification to channel hydraulics.

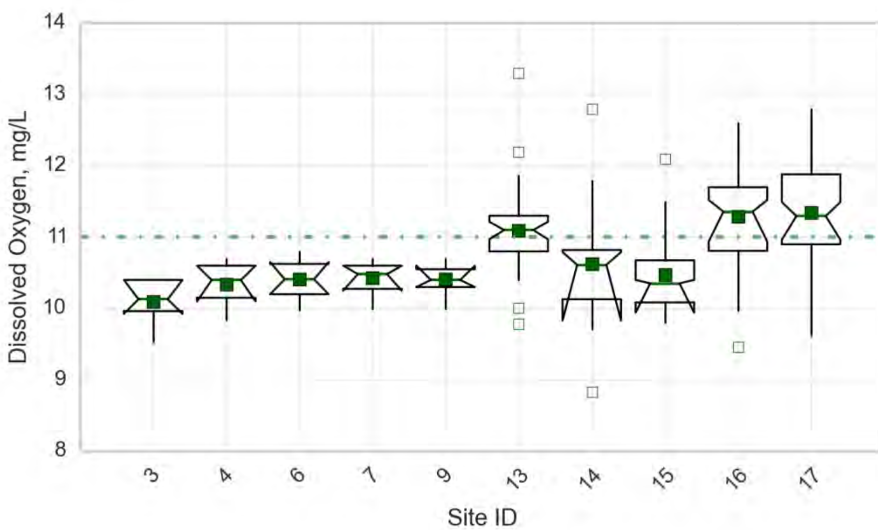

Figure 36: Subset of dissolved oxygen data from the beginning of August to the end of December compared to the ODEQ water quality standard for streams containing spawning or rearing Bull Trout. Green dash-dot line indicates a minimum standard.

Concentrations of chlorophyll-a generally comply with the maximum requirement. All quartiles are below this requirement, with the maximum and outliers of the data exceeding the requirement. Chlorophyll-a did not show a significant temporal trend during hypothesis testing and given that phosphorus and nitrogen nutrients also show no increasing trend we expect this to remain relatively consistent. Thus, chlorophyll-a is not a concern within the main channel of the Metolius River given no evidence of an increasing trend in the data and only the upper range of the data exceeding the requirement.

The mean and median values of turbidity generally exceeded the requirements of 0.8 NTU. Most of the rivers in this ecoregion show relatively low turbidity which is why the standard is low (USEPA, 2000). The occasionally high turbidity values in the Metolius are most likely influenced by the frequent wildfires in the area, as turbidity tends to increase after a fire (Harrison, Dyer, Wright, & Levings, 2014). Given the more frequent occurrence of wildfires in the watershed over the last 10 years, the increase in turbidity values at Monitoring Locations 13 and 17 are not unexpected. However, the turbidity levels in the Metolius are still well below harmful levels to aquatic life, which typically begin past 10 NTU (Jeff Bash, Cara Berman, & Susan Bolton, 2001).

6.2 Impacts of Wild Fires

Given the available data, only qualitative speculations on the long term and short term impacts of wild fires could be made. Several studies have investigated the changes to water chemistry caused by either wildfires or prescribed burns in coniferous and mixed-conifer forests (Bêche, Stephens, & Resh, 2005; Minshall et al., 1997; Smith et al., 2011) along with changes to overland flow, erosion, and soil characteristics (Shakesby & Doerr, 2006). Based on this research, we believe that these trends are likely present in the Metolius Basin, even if they are not directly highlighted by the current data, as explained in Section 5.4. A more robust and strategic sampling plan to collect data following a fire would help to address this uncertainty.

Generally, phosphorus and nitrogen nutrients are the primary water quality parameters affected by fires in addition to increased stormwater runoff, potential erosion, and associated total suspended solids mobilization. The export of total phosphorus and total nitrogen have varied considerably (from a multiple of 0.3-2 times unburned export) for small fires to large increases (a multiple of 20-431 times unburned export) for large fires (Smith et al., 2011). This export typically persists for one year, with higher values observed at the plot scale than the catchment scale. Several factors influence both the temporal and magnitude export components of these nutrients including the type and extent of vegetation lost to fire, erosion processes, the extent of delivery to streams (e.g. duration and intensity of precipitation, hill-slope, terrain roughness, impoundments and flow path), soil types, as well as rates of pre-fire atmospheric deposition (Smith et al., 2011) and sampling time. In-stream concentrations of these nutrients have varied widely in the literature. At Monitoring Location 13, the range of total phosphorus data are within the same order of magnitude throughout the entire record (approximately 1982 through 2013), as shown by Figure 37.

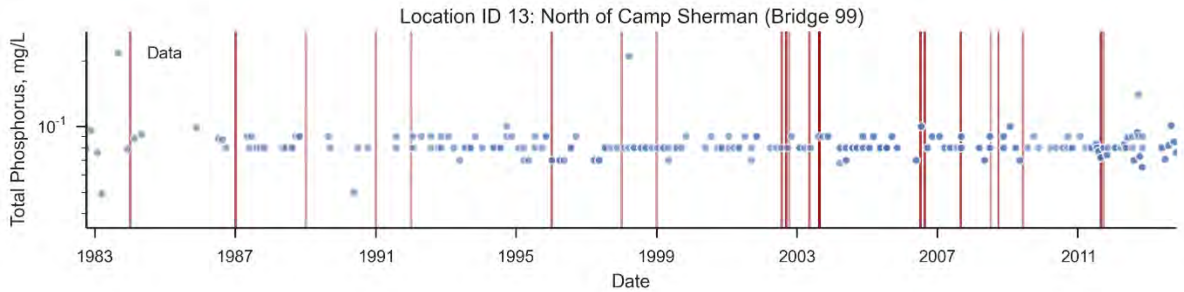

Figure 37: Time series of total phosphorus at Monitoring Location 13. Horizontal lines indicate dates of fires.

A four year subalpine forest study in a Montana river found that in-stream total phosphorus concentrations were unaffected by fire (Mast & Clow, 2008). In contrast, other studies focused on mix deciduous and coniferous and subalpine forests found significant increases in total phosphorus concentrations in tributaries and downstream lakes (McEachern, Prepas, Gibson, & Dinsmore, 2000; Wright, 1976). Trends in in-stream nitrogen nutrients found in the Metolius were more consistent with the literature. The increase in nitrate concentrations during storm events is expected to continue given the frequency of fires in the area (Mast & Clow, 2008). As mentioned, the hydrological and constituent variability and the ability to adequately monitor and capture the full range of post-fire constituent concentrations is challenging and presents the greatest source of variability in study results (Smith et al., 2011).

6.3 Impacts of Development

Map A-3 shows a use-based weighting of each campground or recreation facility for which data were available (i.e., the number of annual visitors as a fraction of capacity) estimating the turnover rate of each site. The most used areas of the basin are around Suttle Lake and Camp Sherman. The rest of the watershed is characterized by relatively lower usage, with the exception of one site upstream of Monitoring Location 13.

As shown in Section 5.3.1, the primary differences between monitoring locations near heavily used campgrounds and those in less used areas are E. coli concentrations. Other constituents did not show any clear relationship with campground proximity. Although E. coli concentration are far below the applicable standards, continued monitoring and potentially further investigation of specific locations with respect to on-site pit-toilets/septic systems or evidence of dispersed latrines. Although campground facilities are generally implemented in the Metolius watershed using pit-toilets with sealed and ABS-lined waste reservoirs below ground surface, these “chambers” are susceptible to long-term degradation, cracking of the ABS and/or concrete resulting in potential leakage that may be mobilized by groundwater and/or interflow that would generally flow down-gradient towards the river. Potential other terrestrial sources include animal waste not removed by pet-owners and the improper disposal and storage of trash which may include both human and animal waste.

These usage patterns generally agree with the trend analysis preformed in Section 5.2, as the monitoring locations that showed increasing trends in E. coli are located near these high use areas. While these trends were significant, the water quality at these locations does not appear to be adversely affected by the recreational sites (with respect to water quality standards for water-contact recreation) and the slope of the trend lines is low-moderate. Thus, given the current usage of these facilities the watershed should remain healthy in the near future assuming there are not significant increases in usage.

7. CONCLUSIONS AND RECOMMENDATIONS

Following all statistical analyses performed in space and time, the Metolius watershed and River appear to be in good standing with respect to those water quality constituents analyzed and regional in-stream standards. The primary exception to this conclusion would be the nutrient parameters, phosphorus and to a lesser extent, nitrate which do exceed regional standards. However, given the available data and literature findings, it's likely these parameters are predominantly naturally occurring and therefore not likely concerns for the Metolius River itself (not considering potential effects from wildfires). Although the relative load contributions from the Deschutes River are substantially greater than those for the Metolius River, Lake Billy Chinook clearly experiences seasonal algae blooms to which both rivers contribute (phosphorus typically being the limiting parameter for algae).

This analysis found no critically concerning trends for the Metolius River. Fires, based on the limited data, may have affected the overall water quality of the basin over the time range of the data. It is likely that fires affect water quality greater in the short term and during storm events; however, this study could not verify those trends based on the available data. In terms of overall water quality, there were minimal difference between different monitoring locations except for monitoring locations near developed areas and monitoring locations not near developed sites, and the most upstream monitoring locations and most other downstream monitoring locations (which showed statistical difference for several constituents). Developed areas, such as recreational areas and campgrounds, minimally influenced water quality with the exception of E. coli. This constituent showed increasing trends at most monitoring locations near developed areas, but was still considerably under all of the comparison criteria and requirements at all locations. Other trends were limited to specific constituents primarily at Monitoring Location 13. Increasing trends included: orthophosphorus (Location 3), pH (Location 13), turbidity (Locations 13 & 17), and conductivity (Location 13). Decreasing trends included: orthophosphorus (Location 1), ammonia (Location 13), dissolved orthophosphorus (Location 13), TSS (Location 13), and total Kjehldahl nitrogen (Location 13).

The summary statistics provided in the supporting information, the above trends and relationships, and comparisons of the data to current water quality criteria and standards should adequately provide a baseline to compare future water quality data in the Metolius River. In addition to these analyses, below are a brief set of recommendations to improve the current understanding of the water quality in the Metolius Basin.

7.1 Recommendations

All of the above findings could be considerably influenced by sampling times, sampling protocols, systematic and random error from various personnel, techniques and instrumentation, and the inherent variability of grab samples in a natural system. While the analyses attempted to characterize the effects of storm events by correlating flow with a nearby rain gauge, the steep rain gradient in the basin likely causes significant variability in the mobilization of constituents between certain individual monitoring locations (specifically after fire events). Based on these limitations and the results comparing the statistical similarity of monitoring locations, the following recommendations for monitoring conducted within the Metolius watershed to assess in-stream water quality include:

1. Substantially increase the sampling documentation to include factors that could affect the quality of the grab sample, such as:
    a. Personnel, time, ambient conditions, depth, notes on specific location, photos, calibration of instruments, methods, storage, handling, changes to protocols, etc.
2. Decrease the current number of sampling locations to include only the current locations along the main stem of the river.
    a. Unless able to capture some local effects from fires, particularly in the western upper watershed.
3. Reduce the monitored constituents to the following:
    a. Lab parameters:
        i. Total Suspended Solids,
        ii. Total Kjehldahl nitrogen,
        iii. Nitrate + nitrite,
        iv. Total Phosphorus,
        v. Soluble Reactive Phosphorus (SRP) instead of Orthophosphorus,
        vi. E. coli,
        vii. Biological oxygen demand
        viii. Dissolved organic carbon
    b. Field parameters:

   i. Dissolved oxygen,
   ii. pH,
   iii. Turbidity,
   iv. Temperature
4. Modify the sampling routine to include both wet weather and dry weather sampling conditions at the head waters and one or more sampling locations downstream.
   a. Wet weather sampling should occur at least 1 hour after the start of a storm and target storms greater than 0.25 inches in total depth.
   b. Intra-event monitoring should also be considered (not considering budgetary restraints).
5. Increase the sampling frequency of nitrogen and phosphorus directly after a burn event for a period of approximately three weeks (or enough to capture the first storm event) at one or more sampling locations downstream of the burn in addition to collecting reference samples upstream of the burn.
   a. If possible these sampling events should occur during the first precipitation events that cause overland flow, as the primary nutrient flux (not from ash) will likely occur at this time. Thus, the same wet weather sampling procedures as above should be followed.
6. Work with the United States Forest Service and Sisters Ranger District to document fire management operations, fire location, fire extent and type of fire- suppressants used.

In addition to the above recommendations efforts to better characterize the highly variable rain gradient such as local and spatially explicit hydrologic monitoring, and better understand stormwater and groundwater interactions are recommended. Such efforts for the characterization of the highly variable rain gradient could include a localized network of low-cost rain gauges and/or interpolation from other datasets (such as those available from http://www.prism.oregonstate.edu/). Given the geology of the Metolius watershed, significant groundwater contributions to the river and generally isolated anthropogenic use, it is likely that ground and surface water interactions and pathways could influence how anthropogenic impacts are assessed. Although significant characterization of this interaction would likely incur substantial costs (monitoring wells, surface water/groundwater model, etc.) time-correlated samples of surface flow and interflow could be a useful metric.

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ATTACHMENTS