Draft Technical Support Document Upper Yaquina Watershed TMDLs

Bacteria and Dissolved Oxygen

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1. Introduction

1.1 Document purpose and organization

This document provides comprehensive supporting information on technical analyses and decisions for the Total Maximum Daily Loads Report and Water Quality Management Plan for addressing bacteria and dissolved oxygen impairments in the waters of the Upper Yaquina River Watershed. Information presented in this document is non-regulatory and does not impose any legal requirements. Rather, this document provides explanation of TMDL concepts and analysis and support for conclusions and requirements presented in the Upper Yaquina River Watershed TMDLs Report and WQMP, which are proposed for adoption by Oregon's Environmental Quality Commission, by reference, into rule [add OAR 340-042-0090(xx) post adoption].

This document is organized into sections with titles reflective of the TMDL elements required by OAR 340-042-0040(4) in the Upper Yaquina River Watershed TMDLs Report for bacteria and dissolved oxygen. This organization is intended to assist readers to readily access the information relied on for TMDL element-specific determinations.

1.2 Overview of TMDL elements

According to OAR 340-042-0030 Definitions (15): Total Maximum Daily Load means a written quantitative plan and analysis for attaining and maintaining water quality standards and includes the elements described in OAR 340-042-0040. Determinations on each element are presented in the Upper Yaquina River Watershed TMDLs Report for bacteria and dissolved oxygen. Technical information supporting those determinations are presented in this report at the section headings that correspond to the TMDL elements for which complex analysis was undertaken, as well as in appendices.

In plain language, a TMDL is a water quality budget plan to ensure that the receiving waterbody can attain water quality standards that protect beneficial uses of the waterbody. This budget calculates and assigns pollutant loads for discharges of point (end of pipe) and non-point (landscape) sources, in consideration of natural background levels, along with determination of a margin of safety and reserve capacity.

A margin of safety considers the uncertainty in predicting how accurately pollutant reductions will result in meeting water quality standards and can be expressed either explicitly, as a portion of the allocations, or implicitly, by incorporating conservative assumptions in the analyses. Reserve capacity sets aside some portion of the loading capacity for use for pollutant discharges that may result from future growth and new or expanded sources.

A key element of analysis is the amount of pollutant that a waterbody can receive and still meet the applicable water quality standard. This element is referred to as the "loading capacity" of a waterbody. Because the loading capacity must not be exceeded by pollutant loads from all existing sources plus the margin of safety and reserve capacity, it can be considered the maximum load. Hence, the loading capacity is often referred to as the TMDL.

Another key element of analysis is allocating portions of the loading capacity or TMDL to known sources. Allocations are quantified measures that assure water quality standards will be met and may distribute the pollutant loads between nonpoint and point sources. “Load allocations” are portions of the loading capacity that are attributed to: 1) non-point sources such as urban, agriculture, rural residential or forestry activities; and 2) natural background sources such as soils or wildlife. “Wasteload allocations” are portions of the total load that are allotted to point sources of pollution, such as permitted discharges from sewage treatment plants, industrial wastewater or stormwater. As noted above, allocations can also be reserved for future uses, termed “reserve capacity.”

This general TMDL concept is represented by the following equation:

$$TMDL = \sum \text{Wasteload Allocations} + \sum \text{Load Allocations} + \text{Reserve Capacity} + \text{Margin of Safety}$$

Together, these elements establish the pollutant loads necessary to meet the applicable water quality standards for impaired pollutants and protect beneficial uses.

2. Location

2.1 Geographic

The Upper Yaquina River watershed constitutes the headwaters of the Yaquina River, which empties directly into the Pacific Ocean through Yaquina Bay at Newport, OR. The watershed is immediately upstream from the confluence of Big Elk Creek and the Yaquina River. The analyses presented in this document will exclude a small portion of the Upper Yaquina watershed that drains the most downstream part of the Yaquina River (approximately starting 2.5 miles (4 km) from upstream from the confluence of Big Elk Creek). This section of the Yaquina River is considered estuarine and thus subject to estuarine and shellfish harvest criteria rather than freshwater criteria (Oregon State University Libraries & Press and Institute for Natural Resources, 2021). The major roads in the Upper Yaquina River watershed include US-20 and OR-180, along with many secondary private and county roads located throughout the watershed. The outlet of the watershed is immediately upstream of Elk City Road Bridge over the Yaquina River near the intersection of Elk City Road and Jacobson Road. One long-term flow monitoring station and one ambient water quality monitoring station are co-located near the mouth of the watershed (OWRD gage 14306030/11476-ORDEQ) near Chitwood, OR, as shown on Figure 2.1.

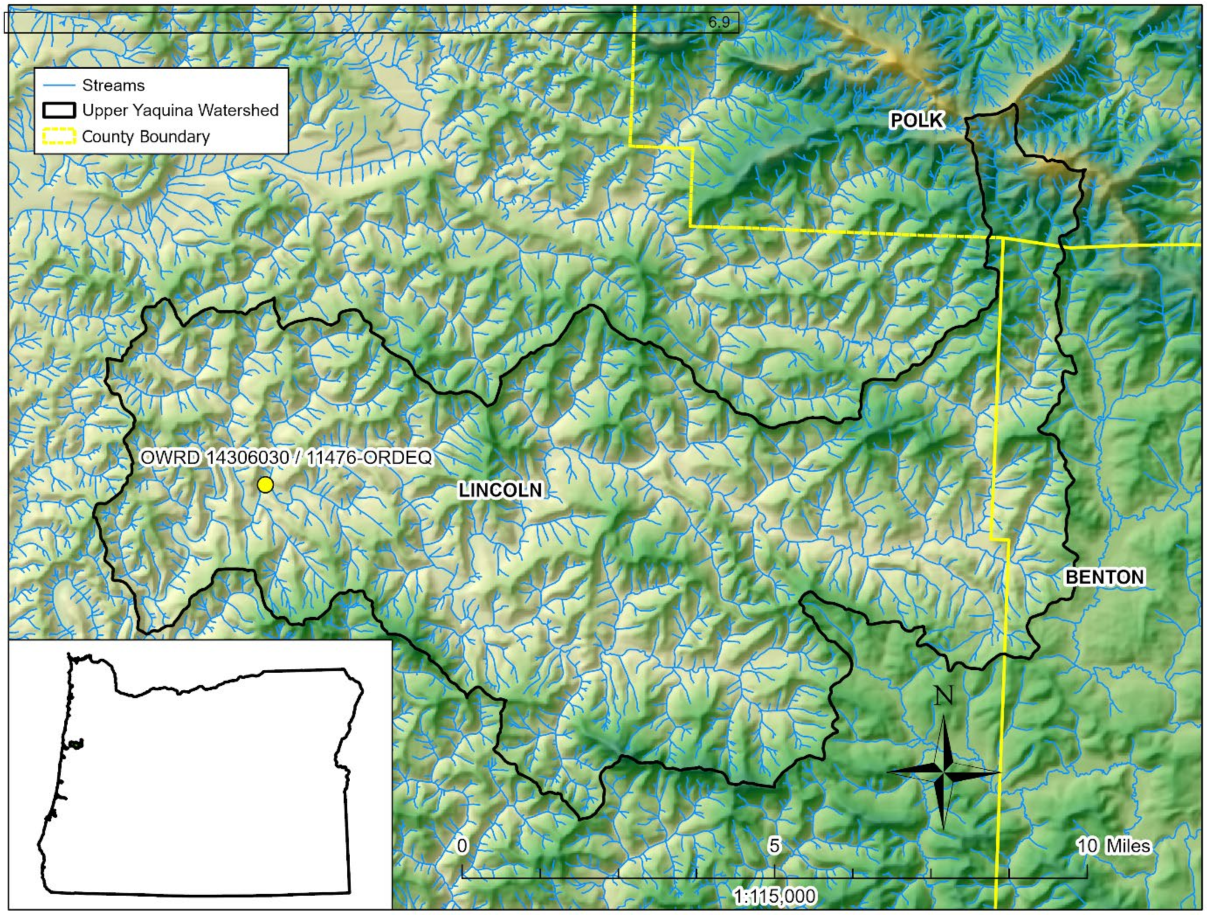


Figure 2.1: Upper Yaquina River Watershed boundaries with long-term flow monitoring station

2.1.1 Ecoregions

The Upper Yaquina watershed is located in the Coast Range Level III Ecoregion. Vegetation in the Coast Range Ecoregion is buffered from heat stress by cool air masses above the Pacific Ocean moving inland. Fog also is common in the area during summer and fall months. A sitka spruce (*Picea sitchensis* (Bong.) Carr.) forest once dominated the area before Euro-American settlement; the area has been logged multiple times since the 1800s. Dominant tree species now include sitka spruce, Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), western hemlock (*Tsuga heterophylla* (Raf.) Sarg.), bigleaf maple (*Acer macrophyllum* Pursh), and red alder (*Alnus rubra* (Bong.) Regel) (Franklin & Dyrness, 1988). Level III ecoregions are further divided into Level IV ecoregions (Figure 2.1.1). Most of the watershed is part of the Level IV Mid-Coastal Sedimentary ecoregion (Christensen, et al., 2016) (Thorson, et al., 2003). This ecoregion is mountainous and is underlain by a mix of sand and siltstone (Roering, 2005). Intensive management for timber production of Douglas-fir occurs throughout the ecoregion (Kennedy & Spies, 2004). Landslides are common and play a strong role in soil formation, sediment transport, and sediment retention (May & Gresswell, 2003). Two small portions of the watershed lie within the Level IV Coastal Uplands ecoregion (Figure 2.1.1). However, for the purposes of this TMDL, the watershed is best characterized as mid-coast sedimentary.

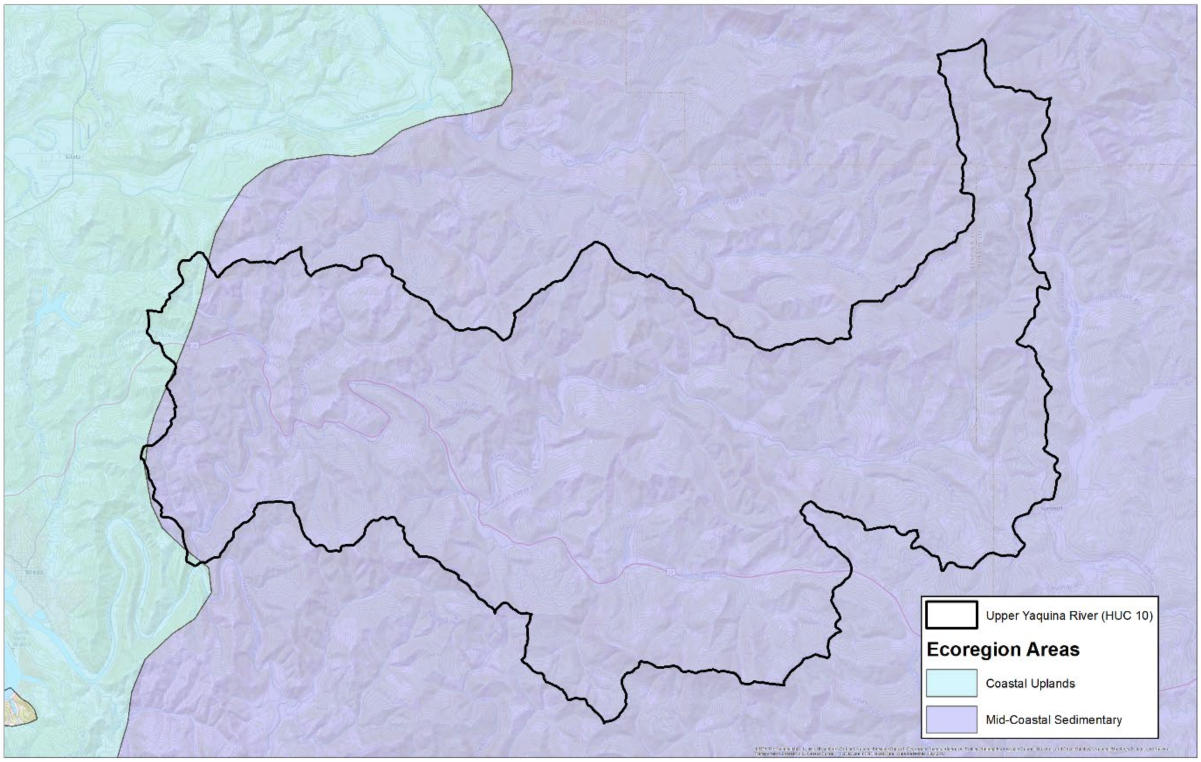


Figure 2.1.1: Level IV Ecoregions - Upper Yaquina River Watershed

2.1.2 Soils and geology

The soils and geology of the Upper Yaquina Watershed are typical for upland areas in the Coast Range of Oregon. Soils are well drained and derive from sedimentary, volcanic and igneous rock (Soil Survey Staff, 2021). Underlying geology is composed almost exclusively of sedimentary turbidite sandstones and siltstones of the Tyee formation. Siletzia basalts (volcanic in origin) are found only at the highest elevations in the northeastern portion of the watershed (see Figure 2.1.2a).

The soils in the Upper Yaquina Watershed align with the topography. Although there are many soil series identified in the watershed (Figure 2.1.2b), four-Preacher, Bohannon, Apt, and Eilertsen-compose 95% of the watershed area (Table 2.1.2). The soils of these series tend to be well drained and deep with high levels of organic matter in the surface horizon. These traits combine to result in soils with moderately low runoff potential as represented in Soil Hydrologic Group (Soil Survey Staff, 2021) of B covering much of the watershed (Figure 2.1.2c). Soil with moderately high runoff potential are located higher up in the eastern part of the watershed.

Overland and subsurface water flows drive bacteria transport and nutrient loading in many watersheds. Overland flow occurs when the precipitation rate exceeds infiltration rate of the underlying soil or when the entire soil profile becomes saturated (a common occurrence near streams or other lowland areas of the drainage network). Bacterial survival in soil is affected primarily by moisture and particle size, although factors like temperature, pH, nutrients, and competition with other bacteria also play a role (Jamieson, Gordon,, Sharples, Stratton, & Madani, 2002). Nutrient retention and transport in soils are influenced by similar physicochemical factors as well as competition for nutrients between vegetation and microbes. As shown in Table 2.1.2, the cool, wet soils in the Upper Yaquina watershed are optimal for bacterial survival and nutrient transport.

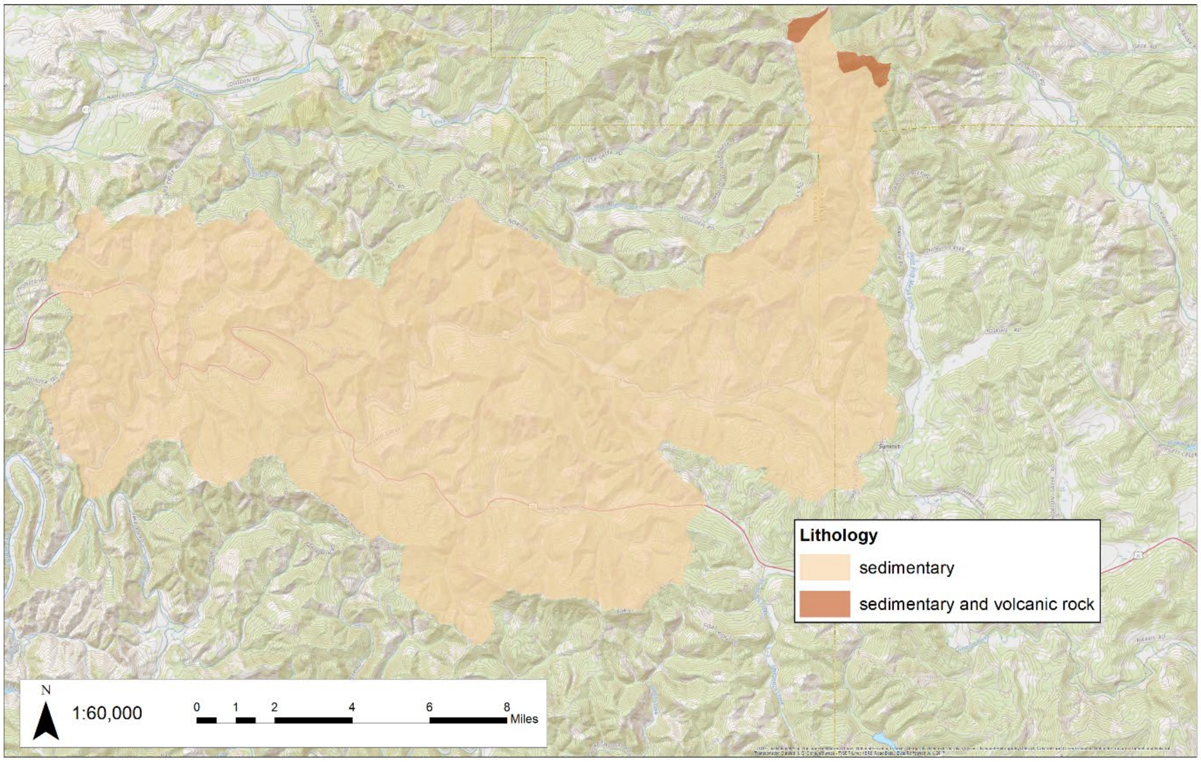


Figure 2.1.2a: Lithology - Upper Yaquina River Watershed

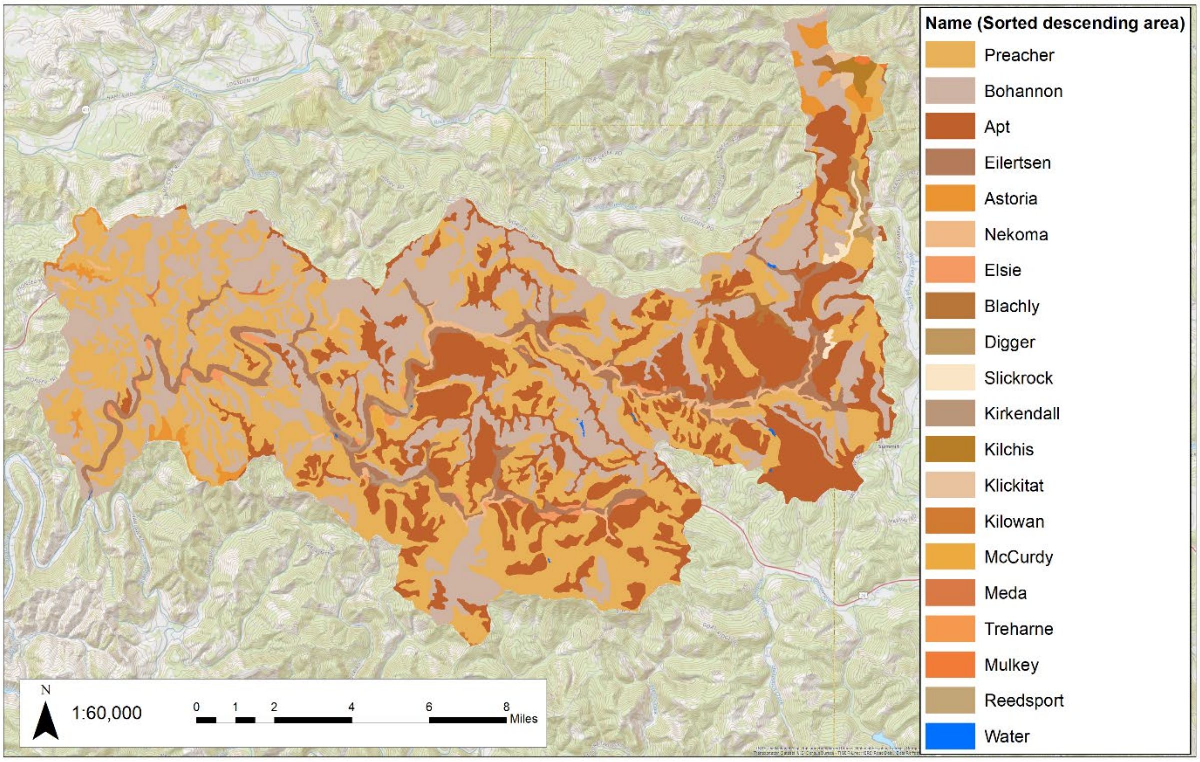


Figure 2.1.2b: Soils - Upper Yaquina River Watershed

Table 2.1.2: Soils occurring in the Upper Yaquina River Watershed

Name	General Description	Occurrence	Slope Range	Area in watershed
Preacher	Moderately deep well drained with parent material consists of colluvium and residuum derived from sedimentary rock and high organic matter content in the surface horizon.	mountain slopes, mountains	5 to 35	36.6%
Bohannon	Moderately deep well drained with parent material consists of colluvium and residuum derived from sedimentary rock and high organic matter content in the surface horizon.	mountain slopes, mountains	5 to 35	30.5%
Apt	Very deep well drained soil with parent material of colluvium and residuum derived from sedimentary rock and high organic matter content in the surface horizon.	mountain slopes, mountains	5 to 30	22.4%
Eilertsen	Deep well drained with parent material consists of mixed silty alluvium derived from volcanic and sedimentary rock and high organic matter content in the surface horizon.	stream terraces	0 to 3	5.1%
Astoria	Deep well drained soil with parent material of colluvium and residuum derived from sedimentary rock and high organic matter content in the surface horizon.	mountain slopes, mountains	5 to 30	1.3%

Name	General Description	Occurrence	Slope Range	Area in watershed
Nekoma	Deep well drained with parent material consists of silty and loamy recent alluvium over stratified loamy and sandy alluvium and low organic matter content in the surface horizon.	flood plains	0 to 3	1.3%
Elsie	Deep well drained with parent material consists of mixed silty alluvium derived from volcanic and sedimentary rock high organic matter content in the surface horizon.	terraces	7 to 15	0.5%
Blachly	Very deep well drained soil with parent material consists of residuum and colluvium derived from basic igneous and sedimentary rock and low organic matter content in the surface horizon.	mountains	3 to 30	0.4%
Digger	Deep well drained with parent material consists of loamy colluvium and residuum derived from sandstone and siltstone and high organic matter content in the surface horizon.	mountain slopes, mountains	60 to 90	0.3%
Kilchis	Shallow well drained with parent material consists of colluvium derived from igneous rock and high organic matter content in the surface horizon.	mountain slopes, mountains	60 to 90	0.3%
Kirkendall	Deep well drained with parent material consists of mixed alluvium derived from sedimentary rock and low organic matter content in the surface horizon.	flood plains	0 to 3	0.3%
Slickrock	Deep well drained with parent material consists of residuum and colluvium derived from sedimentary rock and high organic matter content in the surface horizon.	mountains	25 to 50	0.3%
Klickitat	Moderately deep well drained with parent material consists of colluvium and residuum derived from basalt and high organic matter content in the surface horizon.	mountains	3 to 30	0.2%
Kilowan	Moderately deep well drained with parent material consists of fine textured residuum and colluvium derived from sedimentary rock and high organic matter content in the surface horizon.	mountains	50 to 75	0.1%
McCurdy	Deep moderately well drained with parent material consists of clayey alluvium derived from mixed sources derived from sedimentary rock and low organic matter content in the surface horizon.	terraces	3 to 12	0.1%
Meda	Deep well drained with parent material consists of loamy and gravelly alluvium derived from diabase and low organic matter content in the surface horizon.	hills, alluvial fans	2 to 5	0.1%
Mulkey	Moderately deep well drained with parent material consists of loamy colluvium and residuum derived from basalt or other coarse-grained intrusive igneous rock and low organic matter content in the surface horizon.	mountain slopes, mountains	5 to 30	0.1%

Name	General Description	Occurrence	Slope Range	Area in watershed
Treharne	Deep moderately well drained with parent material consists of residuum and colluvium derived from sedimentary rock and low organic matter content in the surface horizon.	stream terraces	0 to 3	0.1%
Reedsport	Moderately deep well drained with parent material consists of colluvium and residuum derived from sedimentary rock and high organic matter content in the surface horizon.	mountain slopes, mountains	60 to 85	0.0%

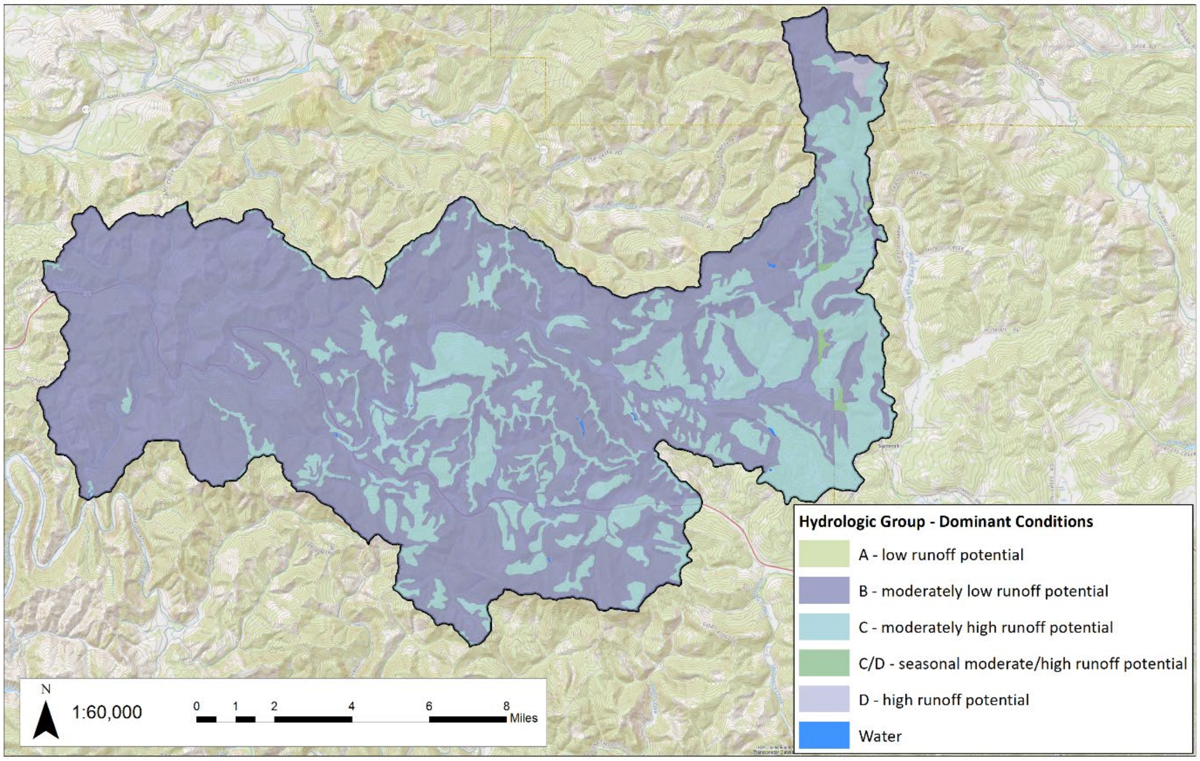


Figure 2.1.2c: Hydrologic groups of soils - Upper Yaquina River Watershed

2.1.3 Land use

DEQ used information reported in the 2011 National Land Cover Database, as reported in Table 2.2 and Figure 2.2 of the Upper Yaquina River Watershed TMDLs Rule, to conduct modeling and analysis. Although more recent versions of this database exist, DEQ used the National Oceanic and Atmospheric Administration C-CAP Land Cover Atlas data and tools (https://coast.noaa.gov/digitalcoast/tools/lca.html) to determine if watershed scale land cover change is significant since 2011.

The scale of the tool is the Siletz-Yaquina subbasin, which is adequate for assessing land cover changes in the Upper Yaquina River Watershed. Because 90% of the land use (zoning) in the watershed is private or state forestland, land use in the watershed has not changed measurably in the past decade at the scale of the watershed. A few properties changed land use from prime forest to other (agriculture or rural residential). While these changes can be tracked, they are insignificant.

The percent of land cover does appear to shift between forest and scrub/shrub and/or grassland cover categories due to clear-cut timber harvesting and associated changes in stand seral stage. Since the overall forested acreage is slightly higher, and scrub/shrub slightly lower, in 2016 than 2011, DEQ is confident that both the EPA HSPF model and DEQ's linked water quality modeling and analyses do not underestimate runoff and nutrient loads from the watershed to the Yaquina River. Therefore, updating the analyses from the 2011 land cover data and information would not result in different outcomes.

2.2 Climate

2.2.1 Current climate characteristics

A Mediterranean climate characterizes the Upper Yaquina River Watershed, with a warm dry season (summer/early fall) and a cool wet season (fall/winter/spring) (Figure 2.2). Based on PRISM data from 1980 – 2010 (Daly, et al., 2008), the long-term average annual temperature (±1 standard deviation) in the watershed is 51.6±0.2°F (10.9±0.1°C) and the long-term average annual precipitation is 71±6 inches (181±16 cm) of total precipitation falls in Upper Yaquina watershed annually. Spatially, annual average temperatures and precipitation range from 62.8°F (17.1°C) and 67 inches (170 cm), respectively, at low elevations to 41.1°F (5.1°C) and 171 inches (434 cm), respectively, near the eastern crest of the watershed.

The close proximity to the Pacific Ocean buffers the range of both seasonal and diurnal temperature fluctuations in the Upper Yaquina watershed. During the wet season, precipitation moves inland from west to east, with the strongest storms originating from the southwest or northwest from the Gulf of Alaska. As storms move inland, orographic lift (air pushed upwards from topography) forces moisture from warmer to cooler air masses, resulting in precipitation increasing with elevation. In the Upper Yaquina watershed, nearly all precipitation falls as rain. Snowfall can occur at the highest elevations; but a seasonal snowpack does not develop.

2.2.2 Climate change

Section under development

DEQ considered published information on regional climate change in developing these TMDLs. DEQ recognizes that longer-term climate patterns as well as inter-annual variability affect multiple watershed processes and in-stream conditions. The analysis and modeling that was performed to develop the dissolved oxygen and bacteria TMDLs used existing data and does not include "future" climate scenarios or climate projections derived from established models such as the Global Change Assessment Model (USDOE, 2023). The Climate Toolbox (UC et al, 2023) provides a wide range of tools to examine regional climate projections, including temperature, precipitation and changes in streamflow. Based on these projections, summer and fall in the region that includes the upper Yaquina watershed are predicted to be warmer and drier in the next 20 to 70 years compared to the base period of 1970 – 2000.
DEQ concluded that the Oregon Climate Assessments (OCCRI, 2023a) and published County-specific reports/projections (OCCRI, 2023b) are a useful reference for this important topic.

DEQ concluded that there is high variability in climate projections and even greater uncertainty in the potential associated outcomes affecting conditions on the ground in a given watershed (landslide risk, hydrology, flood, drought, wildfire, etc). Incorporating these factors is beyond the scope of the TMDL analysis, or other documents including the WQMP or this TSD.

As described in the specific sections, stream flow statistics represents a key element of the TMDLs analysis. The dissolved oxygen analysis used streamflow as a variable, so accounts for variability and uncertainty in that parameter.

DEQ agrees that elected officials, scientists, natural resource and land managers, property owners and the public at large should be advised of the relevant reports referenced above. However, DEQ concluded that (a) summarizing these reports and potential impacts could result in a considerable amount of speculation about future conditions not directly relevant to the development of the TMDLs and (b) that the impacts of climate change need to be addressed by all parties. These TMDLs are not the most appropriate or effective mechanism to articulate climate projections and impacts.

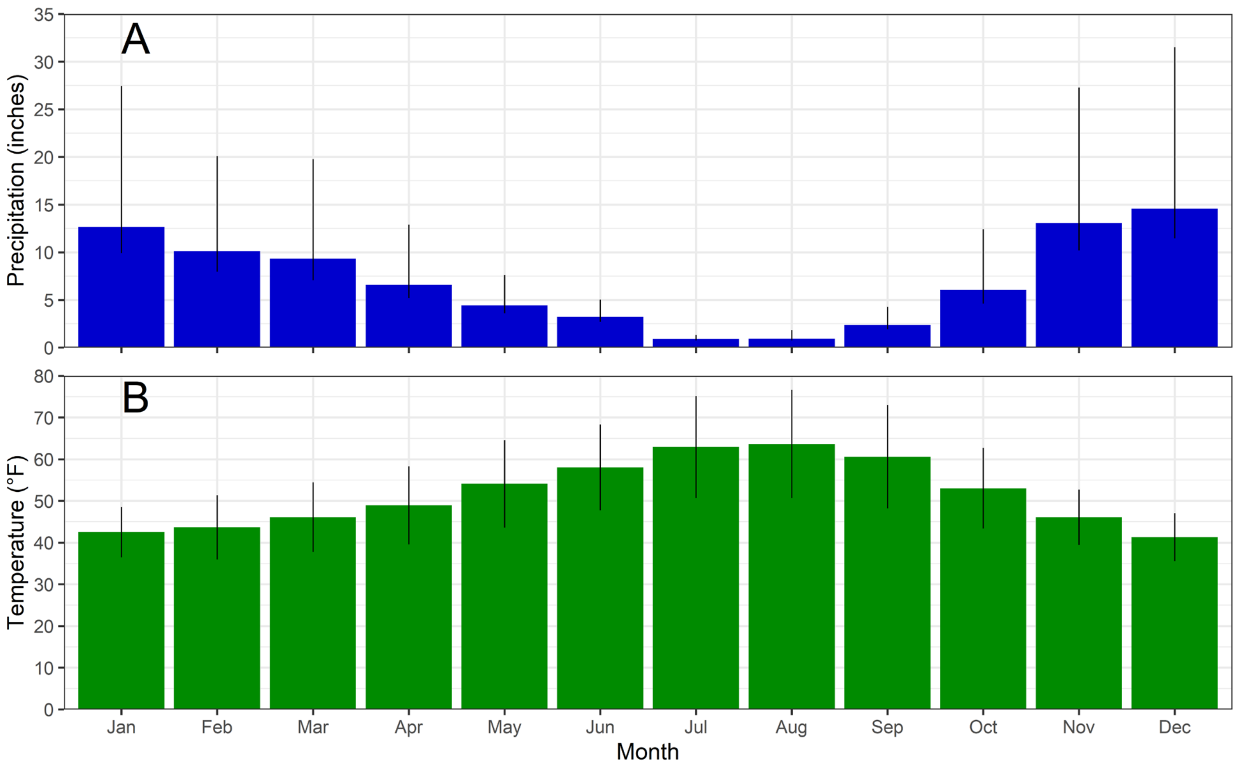


Figure 2.2: Mean, minimum and maximum monthly precipitation and temperature - Upper Yaquina River Watershed, 1980-2010

2.3 Hydrology

Streamflow in the Upper Yaquina River follows a seasonal pattern, with high flows coinciding with the winter months and low flows occurring during late summer/early fall. An Oregon Water Resources Division stream flow gage (14306030) near the watershed outlet has been recording daily stream flows since water year (October 1st – September 30th) (Oregon Water Resources Department, 2018).

As shown in Figure 2.3a, in a typical year, 2% of annual discharge occurs during the months of July, August, and September. Conversely, over 56% of a year's discharge occurs across the winter months of December, January and February.

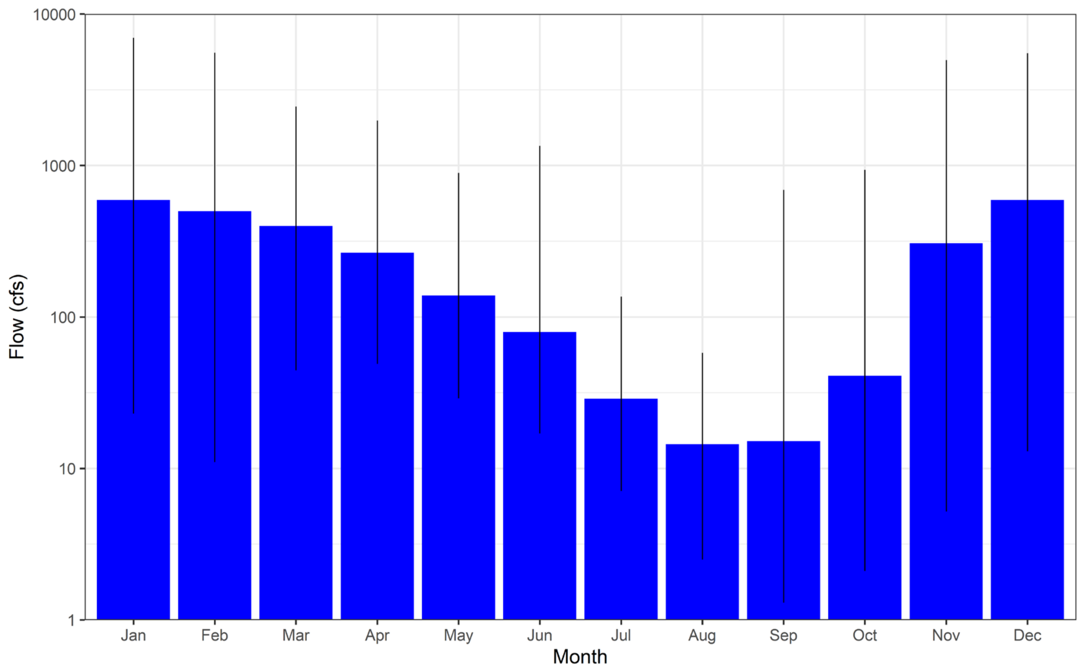


Figure 2.3a: Average, minimum and maximum monthly flows - OWRD gage station 14306030 - Upper Yaquina River, 1972-2015

DEQ uses the flow category names represented in Table 2.3 to be consistent in all TMDLs beginning in 2022 and for clarity in communicating with the TMDL implementers and the public. The exceedance probability ranges describe flow duration intervals and are consistent with groupings in EPA's Load Duration Curve Guidance referred to respectively as: Low Flows; Dry Conditions; Mid-Range Flows; Moist Conditions; and, High Flows (USEPA, 2007). DEQ's flow categories were also informed by flow regimes described in the US Geological Survey report on a regression-based method for predicting flow-duration curves, and roughly coincide with USGS' nonexceedance probability ranges: Low Flow (0.02%-10%); Medium Flow (20%-90%); and High Flow (95%-99.98%) (USGS 2018).

Table 2.3: Flow categories

Flow Category	Exceedance Probability	Hydrologic Description
Low	90%-100%	Watershed soils dry, may be drought conditions, storage empty, channel levels near or below lowest (7Q10) flow, long dry and warm periods between weather events, entirely groundwater return flow as source to stream flow
Medium-Low	60%-90%	Watershed soils much below saturated, storage empty, channels much less than bank-full, extended periods between weather events, some shallow subsurface, but mainly groundwater return flow as source to stream flow
Medium	40%-60%	watershed soils partially saturated, storage almost empty, channels less than bank-full, typical size storms or snow melt events, surface, shallow subsurface and groundwater return flow as source to stream flow
Medium-High	10%-40%	watershed soils partially saturated, storage partially full, channels near bank-full, moderate size storms or snow melt events, mainly surface or shallow subsurface flow as source to stream flow
High	0%-10%	watershed soils completely saturated, storage near capacity, channels at or near flood stages, large storms or snow melt events, mainly surface or shallow subsurface flow as source to stream flow

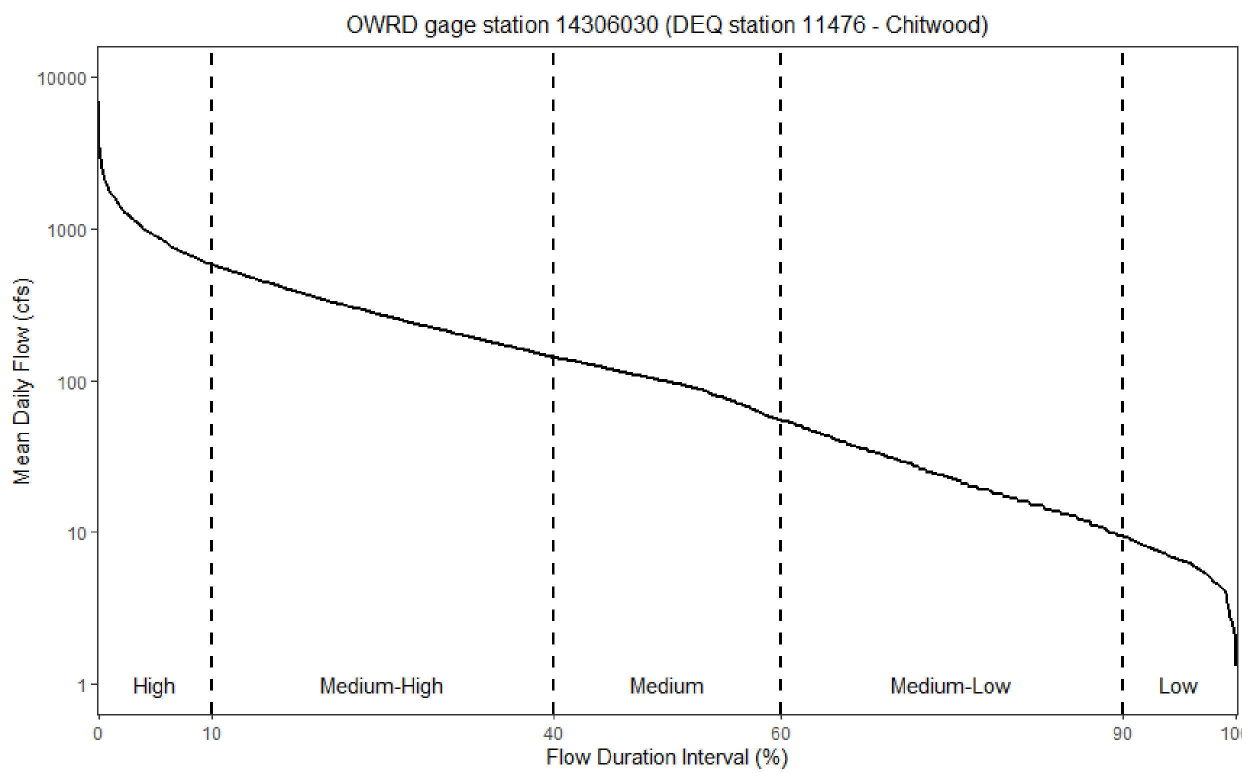


Figure 2.3b: Flow duration interval for mean daily flows – Upper Yaquina River, 1/1/2000 to 12/31/2015

Flow durational intervals for water years 2000-2015 show flows typical of a rain-dominated, Medditerranean climate, as shown in Figure 2.3b. Based on DEQ flow categories, Low flows in the Upper Yaquina River ranged from 1.3 to 9.3 cfs, Medium-Low flows ranged from 9.4 to 54.0

cfs, Medium flows ranged from 54.7 to 141 cfs, Medium-High flows ranged from 142 to 577 cfs, and High flows ranged rom 578 to 6960 cfs from 2007-2017.

According to OWRD records (Oregon Water Resources Division, 2022), 231 surface water withdrawal rights, 21 water storage rights, and one groundwater withdrawal exist within the Upper Yaquina River watershed. Given the inconsistent nature of records documenting withdrawal, storage, and release of water for industrial, agricultural, domestic and other purposes, DEQ did not explicitly consider the effects in modeling the watershed hydrology and assumed these anthropogenic hydrologic modifications are embedded in the calibrated hydrological model.

3. Pollutants and water quality status

3.1 Dissolved oxygen pollutants and impacts

The most common pollutants that affect DO include excess heat and light resulting from the reduction or removal of riparian vegetation, excess nutrient loading (nitrogen and phosphorus) and excess loading of oxygen demanding substances (organic matter and ammonia) (Kemp and Dodds 2002). Additionally, human-mediated influences on flows and channel morphology can affect DO (Abdul-Aziz and Ishtiaq 2014). This section will describe specific factors that influence DO in streams and rivers.

3.1.1 Air-water exchange

The capacity for oxygen to be dissolved in stream or river water (solubility) is directly proportional to temperature, atmospheric pressure and salinity. Oxygen solubility increases with increasing atmospheric pressure and decreases with increasing temperature and salinity. The direction by which oxygen exchanges between water and air depends on DO saturation level in water. Below 100% saturation, atmospheric oxygen dissolves into water. Above 100% saturation, dissolved oxygen degasses back to atmospheric oxygen.

Air-water exchange rate (K_{O2}; gas transfer velocity) describes the physical exchange (reaeration) of oxygen between the atmosphere and water (Figure 4.2.1). Reaeration increases with increasing temperature, the ratio of surface area to volume of water in channel, stream velocity, and the degree of friction between air and the water surface (Aristegi, Izagirre, and Elosegi 2009). The form and complexity of stream or river channels can influence these factors.

3.1.2 Gross primary production

Photosynthesis by aquatic plants (macrophyptes) and algae (attached to substrates on stream beds and suspended in the water column), converts carbon dioxide to organic carbon in the presence of light and produces oxygen as a byproduct. Gross primary production refers the total amount photosynthesis, in terms of carbon fixed or oxygen produced, within a defined ecosystem. Environmental factors that limit gross primary production include temperature, light input (required for photosynthesis and influencing temperature) and nutrients, notably nitrogen and phosphorus (Fellows et al. 2006). These factors can be managed through changes to riparian vegetation structure and composition, channel morphology and nutrient inputs from point and nonpoint sources. Increasing gross primary production can increase DO concentrations above 100% saturation during the day but may decrease DO concentrations substantially at night through an interrelated increase in oxygen demand by ecosystem respiration.

3.1.3 Ecosystem respiration

Ecosystem respiration, which includes aerobic respiration by autotrophic (plants and algae) and heterotrophic (bacteria, fungi, and animals) organisms, consumes DO to oxidize organic carbon. Autotrophic respiration is closely linked with factors that influence gross primary production. Heterotrophic organisms rely on organic matter for carbon, including organic matter originating from autochthonous (aquatic plants and algae) and allochthonous (terrestrial organic matter transported into the stream or river in particulate or dissolved (<0.7 μm diameter) form) sources.

The largest fraction of heterotrophic respiration in streams and rivers typically occurs in bed sediments and the underlying hyporheic zone (where surface water and groundwater mix below or lateral to the channel) and is referred in this TMDL as sediment oxygen demand. Factors that influence rates of heterotrophic respiration include the quantity and quality of organic matter available for decomposition, nutrient availability (nitrogen and phosphorus) and temperature. The heterotrophic component of ecosystem respiration increases with increasing quality and quantity of organic matter, nutrient availability and temperature.

3.1.4 Other factors

Other chemical and biological processes can lower DO concentrations in rivers and streams under specific conditions. In the two-step biological process of nitrification, aerobic bacteria consume DO to harvest energy from ammonium (NH_4^+) and nitrite (NO_2^-) ions, producing nitrate (NO_3^-) as the end product. Nitrification can consume measurable amounts of DO in systems with high loading rates of NH_4^+ or labile organic N, such as downstream of wastewater treatment plants and areas with applications of commercial fertilizers or livestock cultivation (Glibert, Maranger, Sobota, & Bouman, 2014). Nitrification responds to changes in temperature, pH and organic carbon availability (aerobic heterotrophic organisms typically outcompete nitrifying organisms for NH_4^+).

Collectively, the capacity of water or sediments to consume oxygen for the oxidation of organics and ammonium is referred to as biochemical oxygen demand (water column) or sediment oxygen demand (sediment). Biochemical and sediment oxygen demand are influenced by the factors that influence gross primary production, ecosystem respiration and nitrification, as well as the quantity and quality of organic matter loaded from nonpoint and point sources in and upstream.

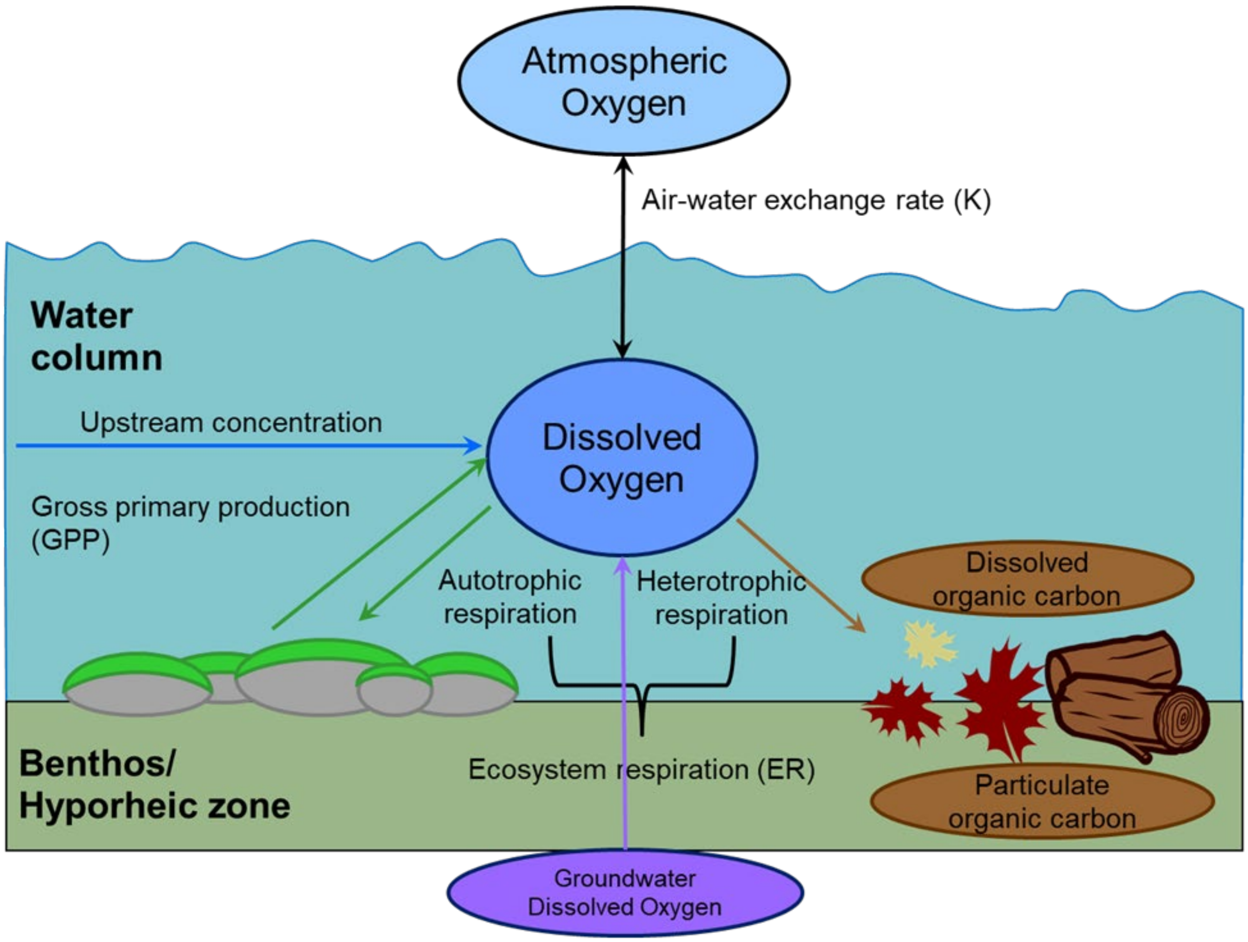


Figure 3.1: Conceptual diagram of major factors influencing DO concentrations and saturations in streams

3.1.5 Nutrients

Nonpoint sources of nutrients considered for the development of the Upper Yaquina DO TMDL included inorganic and organic fractions of nitrogen and phosphorus. These nutrients can limit biological activity and biochemical oxygen demand in stream and river ecosystems, which in turn can influence DO levels. DEQ compiled information on nitrogen and phosphorus sources from forestlands, rural residential areas and agricultural lands. DEQ also used the results for the South Yamhill Pesticide Stewardship Partnership (ODEQ 2021) as a source of information for commonly used and detected pesticides in industrial silviculture in western Oregon that contain nitrogen and phosphorous in various formulations. The forest chemical application category will be tracked through Oregon Department of Forestry's FERNS notification system. See Appendix 1 for links to data sources used in the HSPF watershed model.

3.1.5.1 Nitrogen

Nonpoint source nitrogen input data and estimates compiled for the Upper Yaquina River Subbasin included atmospheric deposition of nitrogen, nitrogen fixation by red alder, background inputs from weathering and organic matter input from forestlands, input from wildlife, input from agriculture (livestock), silvicultural fertilizer applications and input from septic systems. Prevailing winds combined with minimal upwind industrial and agricultural activity suggests that most deposition to the Upper Yaquina originates from over the Pacific Ocean.

Atmospheric deposition rates for nitrogen (2.9 kg N/ha/yr and 0.138 mg N/L in rainwater) are among the lowest rates in the continental US (National Atmospheric Deposition Program, 2020). Based discussions with the Oregon Department of Agriculture (December 2019) and the Technical Workgroup (April 2019), agricultural input from inorganic fertilizer is negligible in the subbasin and is not included as a nitrogen nonpoint source in the source assessment. Although one site was approved in the past, there currently are no active municipal biosolids application sites in the watershed.

3.1.5.2 Phosphorus

Nonpoint source phosphorus inputs to the Upper Yaquina River watershed included weathering from geologic source material, input of organic matter from forestlands, input from wildlife, input from livestock management, silvicultural chemical applications and input from septic systems. Atmospheric phosphorus deposition rates are extremely low along the Pacific Northwest coast (Vet et al. 2014); thus, this input was not considered in the source assessment. As with nitrogen, phosphorus input from inorganic fertilizer is negligible in the watershed and is not included as a phosphorus nonpoint source. Silvicultural pesticide application is one source of phosphorus added to the watershed that was evaluated using information from the Oregon Department of Forestry FERNS database, but insufficient data were available to estimate nonpoint source inputs to water through runoff or direct deposition. Therefore, silvicultural pesticide application cannot currently be distinguished from background and general nonpoint sources.

3.1.6 Effective shade and view to sky

Effective shade refers to the amount of solar flux blocked from reaching the surface of waterbody by vegetation and topography. The fraction of the channel surface area exposed to the sky (view to sky) is used to calculate exchange of heat between the water column and atmosphere via longwave radiation. Effective shade along the Upper Yaquina River and the fraction of the channel exposed to the sky was calculated using LiDAR data collected in the Mid-Coast region in 2011-2012. To calculate these parameters, the TTools package and Heat Source model developed by ODEQ was used (Michie, TTools, 2019; Michie, Heat Source 9, 2019; Boyd and Kasper 2007). These tools use LiDAR-derived bare earth elevation and surface elevation (which includes vegetation and structures) along with estimated canopy density to calculate topographic and vegetation shading to a designated stream reach.

3.2 Bacteria pollutants and impacts

Contact or ingestion of water with elevated levels of fecal contamination increases pathogen exposure risk to people. Because of the technical difficulty, time expense, and costliness of testing directly for the presence of multiple pathogens, fecal indicator bacteria are usually sampled and analyzed instead of many specific bacterial strains. Two bacteria groups, coliform and fecal streptococci, indicate possible fecal contamination in surface waters. Both groups of fecal indicator bacteria live in the intestinal tracts of mammals and birds and, thus, commonly occur in human and animal feces. Therefore, monitoring these indicator levels determines presence or absence of pathogenic microorganisms in surface waters. The State of Oregon uses *Escherichia coli* (E. coli) to indicate fecal contamination and elevated pathogen risks in freshwater systems.

Fecal pollution from both point and nonpoint sources can lead to fecal contamination of waterbodies as indicated by high levels of E. coli. Examples of nonpoint sources of fecal indicator bacteria are failing on-site septic systems, pastures (livestock and wildlife) and resident waterfowl in parks. These nonpoint sources can travel via surface runoff or could be directly deposited in a waterbody.

Recreational use of fecal contaminated waters could lead to mild to severe illnesses in humans. Recreational use not only includes swimming but any activity that could result in ingestion of water, such as fishing through contact of hands with water, any water sports or children playing along the banks or shores. Water with high levels of fecal indicator bacteria can pose a disease risk to livestock. Infections like Johne's disease are caused by the ingestion of *Mycobacterium avium spp*. Paratuberculosis in manure of infected animals that reduce weight gain in cattle and could be fatal in a minority of cases (Harris & Barletta, 2001). Deer could also contract Johne's disease, which leads to wasting like symptoms, and may serve as an environmental reservoir for the bacterium (Edge, et al., 2012). Fecal contamination of irrigation water can also raise the risk of *Listeria monocytogenese* in fresh produce (Weller, Wiedmann, & Strawn, 2015).

3.3 Water quality status

Initial development of TMDLs for dissolved oxygen and bacteria were based on the Category 5 impairments documented in DEQ's 2012 Integrated Report for the freshwater portion of the Upper Yaquina River Watershed. However, DEQ must develop TMDLs based on the current water quality status and the effective Section 303d list at the time of TMDL issuance and can consider other factors to ensure water quality is protected or restored, including overwhelming evidence. In this case, DEQ's 2022 Integrated Report, which was approved by EPA on September 1, 2022, is now in effect.

DEQ revised its water quality assessment methodology for the 2018-2020 Integrated Report cycle. One of the primary changes involves segmentation of streams and rivers into Assessment Units or AUs, which was applied to the 2022 cycle. This approach is intended to assist DEQ and stakeholders to better understand status and address impairments. Use of the AU approach can revise how the water quality status of a smaller segment is categorized. This revised methodology resulted in the current water quality status for dissolved oxygen and bacteria in the Upper Yaquina River watershed, discussed and shown in the tables that follow.

These Upper Yaquina River Watershed bacteria and dissolved oxygen TMDLs do not address Category 5 assessment units in the estuarine portions of the watershed, including the most downstream 4.4 miles of the Yaquina River within the watershed, which is tidally influenced. The revised assessment methodology for Oregon's 2018-2020 Integrated Report re-classified this segment as estuarine, based on the update of estuarine habitats in Oregon using the Coastal and Marine Ecological Classification Standard (CMECS) and associated geospatial data. The freshwater dissolved oxygen TMDL is not needed to address the tidal segment because monitoring data show that estuarine criterion of 6.5 mg/L was achieved (OAR-041-0016(5)). For bacteria, the freshwater assessment unit (OR_SR_1710020401_02_105953) adjacent to the estuarine assessment unit (OR_EB_1710020403_01_107231) was moved to Category 2 (attaining) for E. coli in the 2022 Integrated Report. Hence, there is limited evidence linking upstream (freshwater) bacteria conditions to the estuarine assessment unit, that was listed in the 2010 Integrated Report.

These estuarine and tidally influenced assessment units will be addressed in future TMDLs, as needed. However, implementation of the load allocations in freshwater portions of the watershed is anticipated to reduce loads of bacteria and pollutants affecting dissolved oxygen reaching the upper estuary.

3.3.1 Dissolved oxygen water quality status

Table 3.3.1a: Upper Yaquina River Watershed Assessment Units - dissolved oxygen status on Oregon's 2022 Integrated Report

Assessment Unit Name, Description and Identification Number	Approximate Assessment Unit Length (Miles)	2022 Assessment Category	Parameter -Period	Addressed in TMDL?
Yaquina River Little Yaquina River to Little Elk Creek OR_SR_1710020401_02_105951	16.03	Category 5	Dissolved Oxygen-Spawning	yes
Yaquina River Little Yaquina River to Little Elk Creek OR_SR_1710020401_02_105951	16.03	Category 2	Dissolved Oxygen-year- round	yes
Yaquina River Little Elk Creek to Sloop Creek OR_SR_1710020401_02_105953	9.50	Category 5	Dissolved Oxygen-Spawning	yes
Yaquina River Little Elk Creek to Sloop Creek OR_SR_1710020401_02_105953	9.50	Category 3	Dissolved Oxygen-year- round	yes
Little Elk Creek Headwaters Watershed Assessment Unit to confluence with Yaquina River OR_SR_1710020401_02_105950	3.39	Category 5	Dissolved Oxygen-Spawning	yes
Little Elk Creek Headwaters Watershed Assessment Unit to confluence with Yaquina River OR_SR_1710020401_02_105950	3.39	Category 3	Dissolved Oxygen-year- round	yes
Young Creek-Yaquina River HUC12 Watershed Unit (1st through 4th order streams) OR_WS_171002040101_02_106126	83.7	Unassessed	Dissolved Oxygen – year-Round	yes*
*Effective shade allocations not applied to 1-4 order streams, but phosphorus load allocations applied watershed wide				

In addition to spatial changes in shifting from stream segments to AUs, the 2018-2020 assessment methodology also significantly restructured the decision matrix for assessing excursions of the dissolved oxygen criteria, along with other changes.

The Upper Yaquina River at river miles 0 to 56.8 was included on the 2012 303d list due to excursions from the cold water aquatic life for DO concentration and percent saturation criteria. The cold water aquatic life listing was based on three excursions out of 20 samples taken at station 11476 between 06/21/1994 and 07/16/2003 and two excursions out of two samples taken at station 12301 between 08/30/1994 and 08/14/1996. The Upper Yaquina River at river miles 26.9 to 53.9 was assigned to Category 5 in 2012 for excursions of the salmonid spawning criteria for DO concentration and percent saturation. This 303d listing results from five excursions out of 28 samples collected between 03/22/1994 and 11/04/2003 at station 11476. All these reaches were retained on the 2018-2020 and 2022 303d lists for salmonid spawning criteria for DO concentration and saturation.

The Little Elk Creek AU, previously unassessed, was assigned to Category 5 in 2018-2020 cycle for excursions of the salmonid spawning dissolved oxygen criteria but assigned to Category 3 (insufficient data) for year-round criterion due to monitoring equipment failure. The spawning period Category 5 status and year-round Category 3 status was retained on the 2022 Integrated Report.

During the 2018/2020 assessment, the Young Creek-Yaquina River HUC12 Watershed Assessment Unit (OR_WS_171002040101_02_106126) was placed in Category 5 for dissolved oxygen (year-round). During the 2022 assessment, DEQ determined that this decision was erroneous and revised the status to “unassessed” based on lack of supporting data. Although effective shade allocations will not be applied to the 1st-4th order streams in this watershed AU, phosphorus allocations will be applied. As described in the margin of safety section and affirmed in Section 9.1.2 of the TMDL, applying the phosphorus reductions in this AU will meet the dissolved oxygen criteria for cold water and spawning.

The 303d listing for the lower 2.5 miles of the Upper Yaquina River was based on two excursions of the criteria out of five days of sampling between 01/16/2008 and 05/05/2008 at station 34456 located at Elk City Road Bridge near Pioneer. However, continuous monitoring data collected by DEQ in 2016 confirms that tidal influence extends upstream beyond the station.

As noted in Table 3.3.1a, for the 2018-2020 Integrated Report, the freshwater segment of the Upper Yaquina River was divided into two AUs: OR_SR_1710020401_02_105951 and AU OR_SR_1710020401_02_105953 and reclassified from category 5 to category 2 for dissolved oxygen year-round based on the updated assessment methodology and a restrictive data window. Thus, the assessment methodology reached a different conclusion for the status of these AUs than provided through the in-depth TMDL data analysis and modeling documented herein.

The 2012 Integrated Report was in effect during design of monitoring projects to support TMDL data analysis and model development, such that monitoring in the listed segments were conducted in July and October 2016. The data for each period/impairment combination was evaluated in the TMDL analysis. Although the spatial extent of the QUAL2Kw model used for the DO TMDL (explained in Section 4 of this report) is 34 km and does not completely overlap the two reclassified AUs (41.08 km), the more detailed TMDL analysis was based on modeling scenarios that affect instream dissolved oxygen levels, including low flow, excess solar radiation and nutrient loads. Using the QUAL2Kw model, DEQ generated load allocations necessary to meet criteria for both AUs during non-spawning and spawning periods. The TMDL analyses concluded that achieving the nonpoint source load allocations (through excess load reductions) would result in attainment of the dissolved oxygen criteria in freshwater, during both the year-round cold-water and spawning period for the impaired assessment units.

3.3.2 Bacteria water quality status

Table 3.3.2 contains the assessment units impairment listings for bacteria from the 2022 Integrated Report.

Table 3.3.2: Water quality assessment unit status for bacteria in the Upper Yaquina River Watershed from Oregon's 2022 Integrated Report

Assessment Unit Name, Description and Identification Number	Parameter	Beneficial uses	Assessment Category	Addressed in TMDL?
Yaquina River Little Yaquina River to Little Elk Creek OR_SR_1710020401_02_105951	E. coli	Water Contact Recreation	Category 5	Yes
Little Elk Creek to Sloop Creek OR_SR_1710020401_02_105953	E. coli	Water Contact Recreation	Category 2	Yes
Yaquina River Little Yaquina River to Little Elk Creek OR_SR_1710020401_02_105951	Fecal Coliform	Fishing - Shellfish Harvesting	Category 5	Not directly*
Yaquina River Little Elk Creek to Sloop Creek OR_SR_1710020401_02_105953			Category 5	Not directly*
Yaquina River Estuary: Mainstem upper OR_EB_1710020403_01_107231			Category 5	No
*Fecal coliform is not the applicable criterion for the designated freshwater beneficial use and these listing will be removed in the 2024 Integrated Report submittal.				

For freshwater AUs identified as impaired for fecal coliform (OR_SR_1710020401_02_105951 and OR_SR_1710020401_02_105953): DEQ reviewed the applicability of the Section 303d status for fecal coliform for these two freshwater AUs shown in Table 3.2(a). Based on the 2018/2020 Integrated Report methodology and the 2016 revisions to Oregon's Bacteria Standards – OAR 340-041-0009, DEQ concluded that identifying these two AUs as impaired for fecal coliform is a legacy of the prior bacteria standard combined with EPA's additions to Oregon's Section 303d list in 2010.

DEQ's Standards and Assessment Program confirmed that E. coli rather than fecal coliform is the applicable criterion for the designated freshwater beneficial use (A. Borok, pers comm, May 17, 2022) and since sufficient E. coli data is available for assessment in these freshwater AUs, that information supersedes the legacy fecal coliform Section 303d listings for fecal coliform and these will be removed in the 2024 Integrated Report cycle (L. Merrick, pers comm, May 17, 2022).

Since E. coli data was used in the 2018-2020 and 2022 assessments and Integrated Reports to determine water quality status for bacteria in both freshwater AUs, the Section 303d listings for fecal coliform (Table 3.2.2) are not addressed in the Upper Yaquina River Watershed bacteria TMDL.

For the upper estuarine AU (OR_EB_1710020403_01_107231): The fecal coliform assessment status (Category 5) is not addressed in this TMDL. As noted in Section 3.3, because the freshwater assessment unit adjacent to this estuarine unit is now attaining, there is limited evidence linking upstream (freshwater) bacteria conditions to the estuarine assessment unit. In addition, since E. coli is a subset of fecal coliform bacteria, implementation of this bacteria TMDL will also decrease fecal coliform bacteria loads throughout the freshwater units of the watershed. Thus, fecal coliform loads to the upper estuarine unit will also be reduced, though the TMDL did not quantify the reduction. It should also be noted that the shellfish harvesting beneficial use occurs in the lower estuary. As needed, the estuarine AU will be addressed as part of a future estuarine TMDL that will incorporate the allocations of this TMDL.

The freshwater bacteria TMDL was developed using E. coli grab sample data collected over approximately 20 years (primarily 2007-2013) at multiple stations in the freshwater segment. The bacteria criteria are not linked to specific date ranges, so pollutant loading and allocations are dependent on concentration and flow for the single sample maximum or utilize a 90-day averaging time for the geometric mean. The TMDL technical analysis concluded that achieving the nonpoint source load allocations (through excess load reductions) would result in attainment of the water contact recreation criteria under the full range of flow conditions, as defined by flow duration curves and detailed in Section 5 of this report.

4. Dissolved oxygen data evaluation and analyses

4.1 Dissolved oxygen evaluation overview

To evaluate and analyze dissolved oxygen in the Upper Yaquina Watershed, DEQ compiled and evaluated historical monitoring data, conducted focused monitoring studies during critical periods of the year and developed watershed and water quality models (Figure 4.1). Historical monitoring data (collected from 2000-2015 calendar years) were used to identify critical periods and flow conditions for the focused studies (2016) used for TMDL model development. In addition to water quality data collected historically or as part of the focused studies, DEQ also accessed flow data from OWRD, compiled relevant remote sensing data for climate and landscape characterization, and developed a spatially and temporally explicit watershed model to characterize watershed hydrology and sources of relevant nutrients (nitrogen and phosphorus). Figure 4.1 provides a conceptual framework for dissolved oxygen analytical approach in the Upper Yaquina Watershed. Details on the components of the approach are provided in the subsequent sections and referenced appendices.

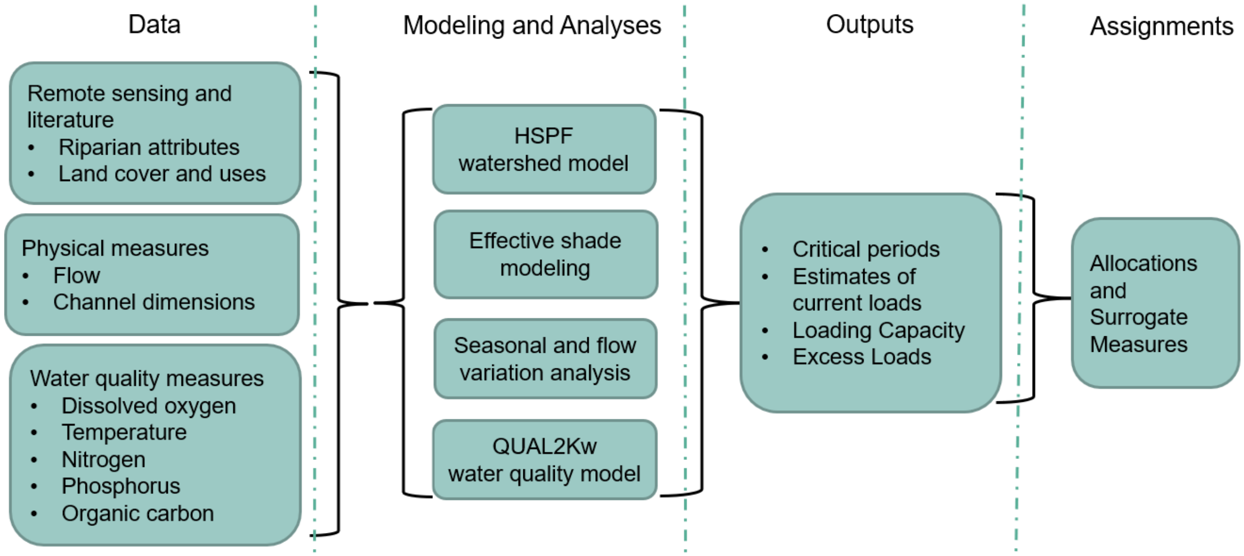


Figure 4.1: Schematic of dissolved oxygen analytical approach

4.2 Dissolved oxygen data and analysis results

4.2.1 Seasonal and flow variation analysis

The TMDL evaluated excursions of the salmonid spawning criteria from October 15 and May 15 and excursions of the cold-water aquatic life from May 16th to October 14th. Salmonid spawning uses in the Upper Yaquina apply from October 15th to May 15th, while cold water aquatic life uses apply year-round (OAR-340-041-0016). However, because the salmonid spawning criterion supersedes the cold-water aquatic life criterion, DEQ only evaluated excursions of the cold-water aquatic life criterion during non-spawning periods (May 16th to October 14th in the Upper Yaquina Watershed) when insufficient data are available to evaluate time-based statistical summary criteria. DEQ examined historical data to evaluate excursions from the applicable water quality standard for DO (OAR 340-041-0016) and provide the basis for defining the critical period for TMDL load allocations.

DEQ constrained the analysis to the period of 2000 through 2015 (calendar years) to capture the period when dissolved oxygen listings for the Upper Yaquina were first added to the 303(d) list. DEQ also relied on data collected and analyzed as part of the assessment and reporting process for the biennial Integrated Report to EPA, as required by Sections 303(d) and 305(b) of the federal Clean Water Act in 2018. Dissolved oxygen concentration and saturation data (“A” and “B” grade only; Table 4.2.1a) from January 1, 2000 to December 31, 2015 were queried from ORDEQ stations 11476-ORDEQ, 12301-ORDEQ, 33112-ORDEQ, 34455-ORDEQ, and 34454-ORDEQ from the DEQ Ambient Water Quality Management System (AWQMS) database (Table 4.2.1b). Grab sample data were considered individually while continuous data were summarized as a daily minimum value according to methods from the 2018-2020 Integrated Report (Anthony, 2020).

Table 4.2.1a: Data quality indicators for continuous data collected - Upper Yaquina River, July 2016

Water Quality Parameter Continuous (15-min interval):	**"A" grade** Accuracy	Precision	**"B" grade** Accuracy	Precision
Dissolved oxygen (DO; mg/L)	≥ -0.3; ≤ 0.4	≤ ±0.3	≤ 1	≤ 1
pH (standard units)	≤ ±0.2	≤ ±0.3	≤ ±0.5	≤ ±0.5
Water temperature (°C)	≤ ±0.5	≤ ±0.5	≤ ±1.0	≤ ±2.0
Specific Conductivity (SpC; µS)	≤ ±7%	≤ ±10%	≤ ±10%	≤ ±15%

Table 4.2.1b: Monitoring stations in the Upper Yaquina Watershed where dissolved oxygen data was collected between 2000 and 2015

Monitoring Location	Station Description	Assessment Unit Identification Number
11476-ORDEQ	Yaquina River at Trapp Road (Chitwood)	OR_SR_1710020401_02_105953
12301-ORDEQ	Yaquina River at Eddyville	OR_SR_1710020401_02_105951
36912-ORDEQ	Little Elk Cr near mouth	OR_SR_1710020401_02_105950
33112-ORDEQ	Yaquina Mainstem at Nashville Road Hwy 180 DS of confluence with Trout Creek	OR_SR_1710020401_02_105951
34455-ORDEQ	Yaquina River at Hwy 180 Bridge blw Buttermilk Creek	OR_SR_1710020401_02_105951
34454-ORDEQ	Yaquina River at Clem Road bridge	OR_SR_1710020401_02_105951

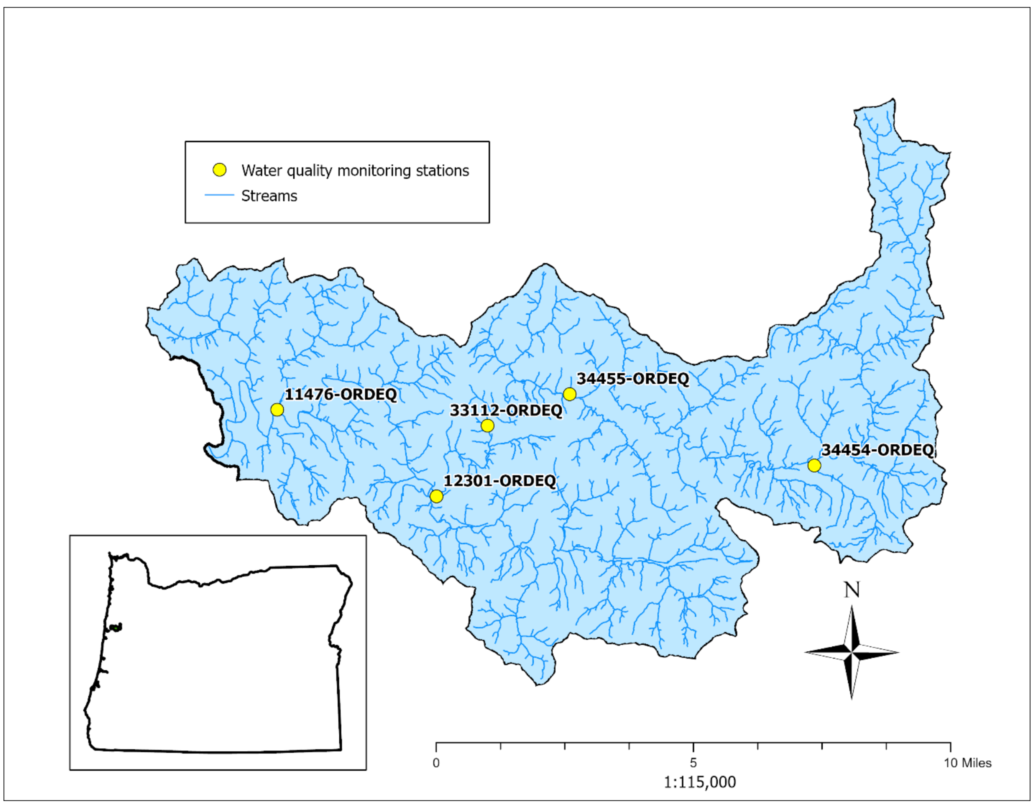


Figure 4.2.1a: Water quality monitoring stations in the Upper Yaquina Watershed where dissolved oxygen data was collected between 2000-2015

Within the Upper Yaquina Watershed, dissolved oxygen data were collected at five stations on the mainstem Yaquina River (Table 4.2.1a; Figure 4.2.1a). All sites had at least four grab samples for either Salmonid Spawning or the Cold Water aquatic life periods (Tables 4.1.2c and 4.2.1d). None had continuous data summaries available in the DEQ water quality database.

Table 4.2.1c: Monitoring stations in the Upper Yaquina Watershed where dissolved oxygen data was collected from 2000 to 2015 during the Salmonid Spawning period (Oct 15th to May 15th

Monitoring Location ID	Grab data (samples)
11476-ORDEQ	125
12301-ORDEQ	15
33112-ORDEQ	62
34455-ORDEQ	15
34454-ORDEQ	57

Table 4.2.1d: Monitoring stations in the Upper Yaquina Watershed where dissolved oxygen data was collected from 2000 to 2015 during the Cold Water period (May 16th to Oct 14th)

Monitoring Location ID	Grab data (samples)
11476-ORDEQ	84
12301-ORDEQ	4
33112-ORDEQ	45
34455-ORDEQ	5
34454-ORDEQ	43

Based on available data collected between 2000 and 2015, excursions (of both concentration and saturation) from the cold-water and salmonid spawning periods criteria occurred almost exclusively from mid-summer (mid-July) through early fall (mid-November; Figures 4.2.1b and 4.2.1c). Because of the concentration of excursions occurred during the period of the water year in which low flows are most common, DEQ also examined the relationships between dissolved oxygen concentration and saturation with flow duration intervals in Upper Yaquina River. Continuous flow monitoring is only available at station 11476-ORDEQ; thus dissolved oxygen data at other stations are compared against flow duration intervals at this station with the assumption that flow duration intervals are similar watershed-wide.

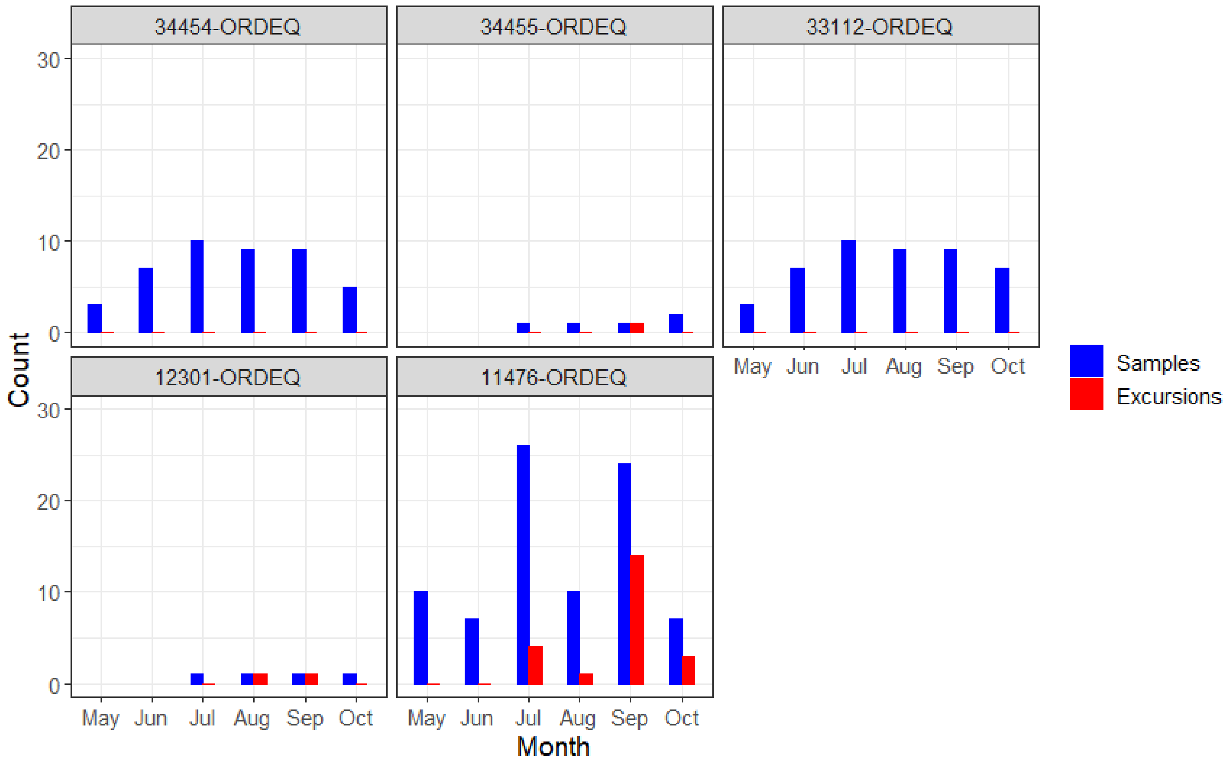


Figure 4.2.1b: Number of samples and dissolved oxygen excursions from Cold Water aquatic life criteria

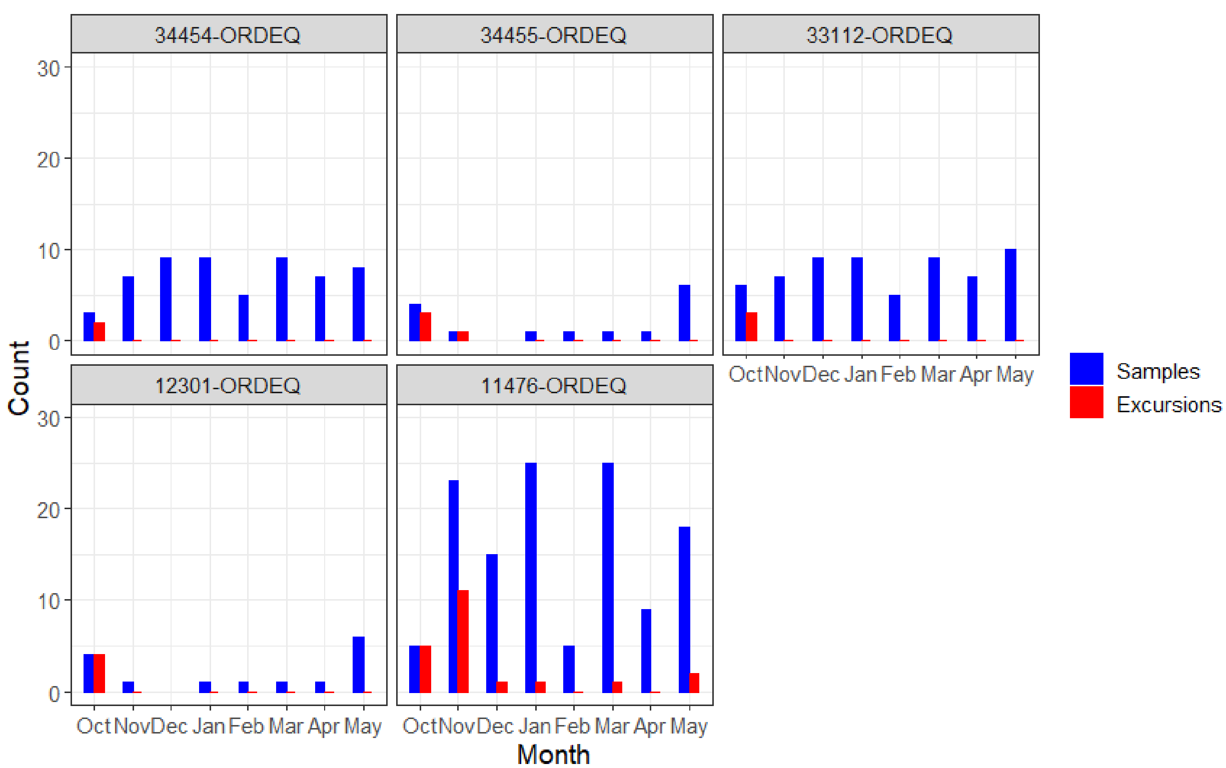


Figure 4.2.1c: Number of samples and dissolved oxygen excursions from Salmonid Spawning criteria

Comparison of dissolved oxygen concentration and saturation measurements from 2000 through 2015 with flow duration intervals show that excursions from the cold-water aquatic life criteria occurred exclusively during medium-low and low flow categories (Figure 4.2.1d). Excursions reflect comparisons to single sample concentration (8.0 mg/L) and percent saturation (90%) criteria for dissolved oxygen. Refer to Figure 2.3b for DEQ flow categories. A similar comparison for the salmonid spawning period suggests that, while excursions also occur mostly at Medium-Low and Low flow categories across all sites, several excursions at 11476-ORDEQ also were observed in higher flow categories during the fall months (Figure 4.2.1e). Subsequent data collection during the summer and fall months of 2016 further investigated potential causes of dissolved oxygen excursions across all flow categories.

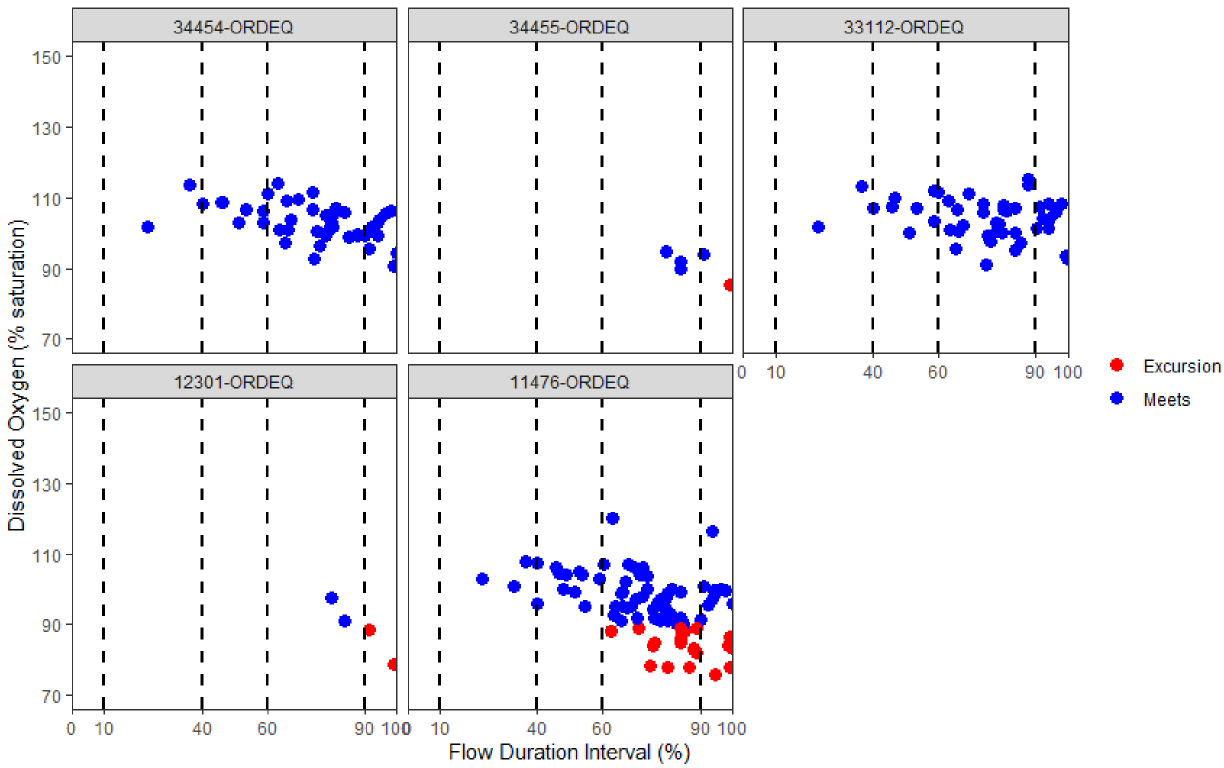


Figure 4.2.1d: Dissolved oxygen saturation versus flow duration intervals calculated from continuous flow monitoring for Cold Water aquatic life period

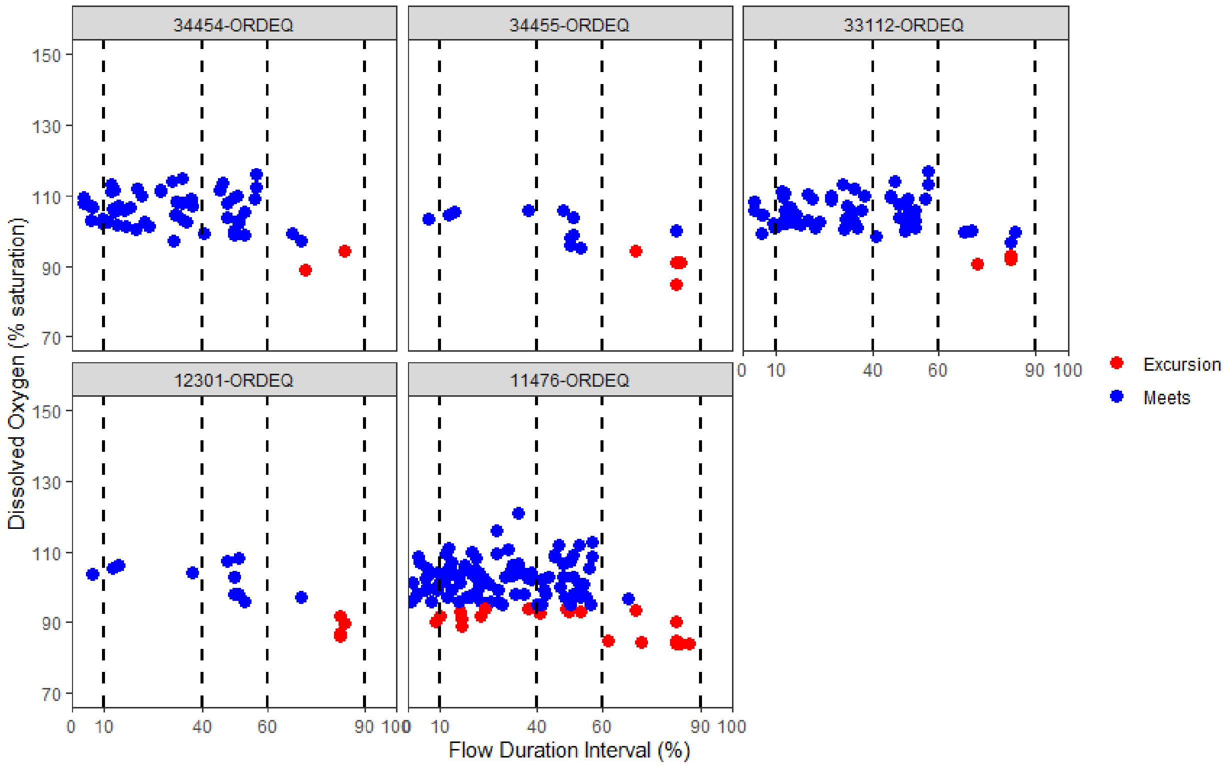


Figure 4.2.1e: Dissolved oxygen saturation versus flow duration intervals calculated from continuous flow monitoring for salmonid spawning period

4.2.2 Dissolved oxygen data and analysis: 2016 TMDL Study

In the summer and fall of 2016, DEQ conducted sampling to evaluate dissolved oxygen status during suspected critical periods and to collect data for calibrating a water quality model (QUAL2Kw) for identifying factors contributing to dissolved oxygen excursions from the cold-water aquatic life and salmonid spawning criteria. During both study time periods, continuous and grab sample data were collected from stations on the mainstem Yaquina River listed in Table 4.2.1b. The 2016 studies spanned a wide range of flow conditions from 2000 through 2015 during the times of year when dissolved oxygen excursions from the cold-water aquatic life and salmonid spawning criteria were observed, as shown on Figure 4.2.2a. On the figure, thick blue lines with dates above indicate the range of flows during specific TMDL studies in 2016.

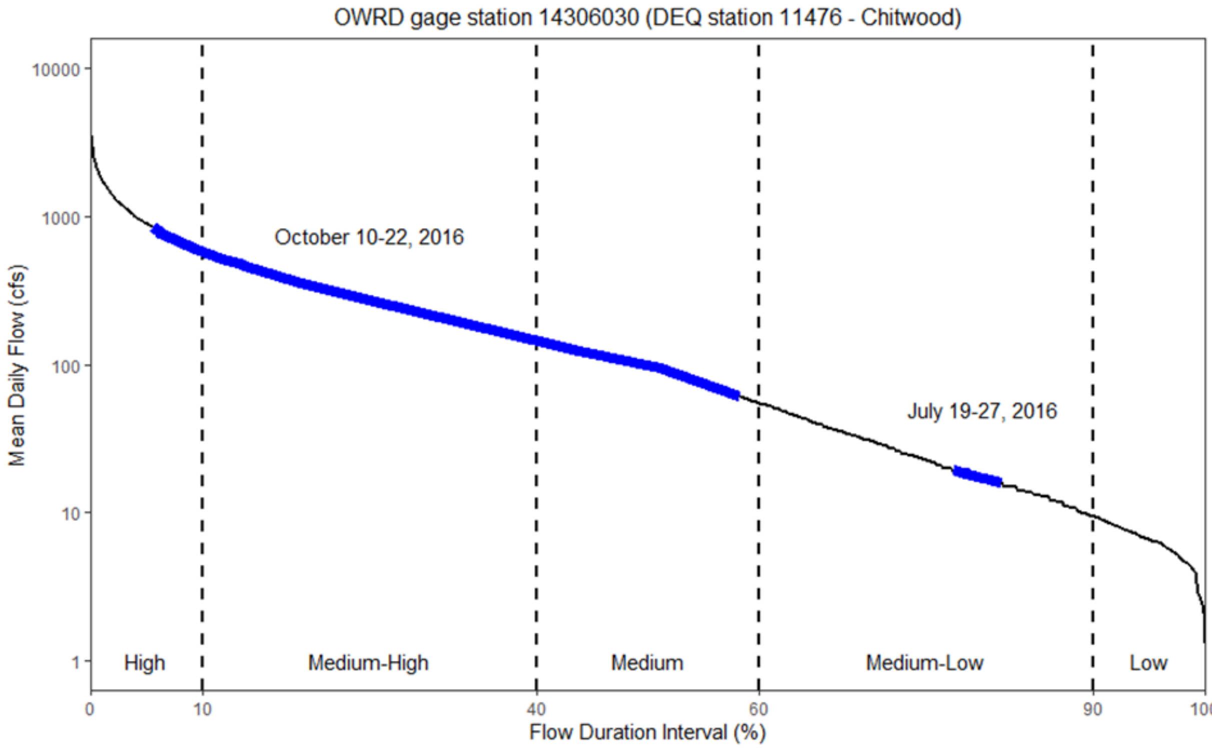


Figure 4.2.2a: Flow duration intervals based on mean daily flows

Flow conditions remained stable during the July study period (Figure 4.2.2b). These flow conditions allowed DEQ to evaluate factors influencing dissolved oxygen in the Upper Yaquina by developing and calibrating a linked watershed-water quality model (described in Section 4.3).

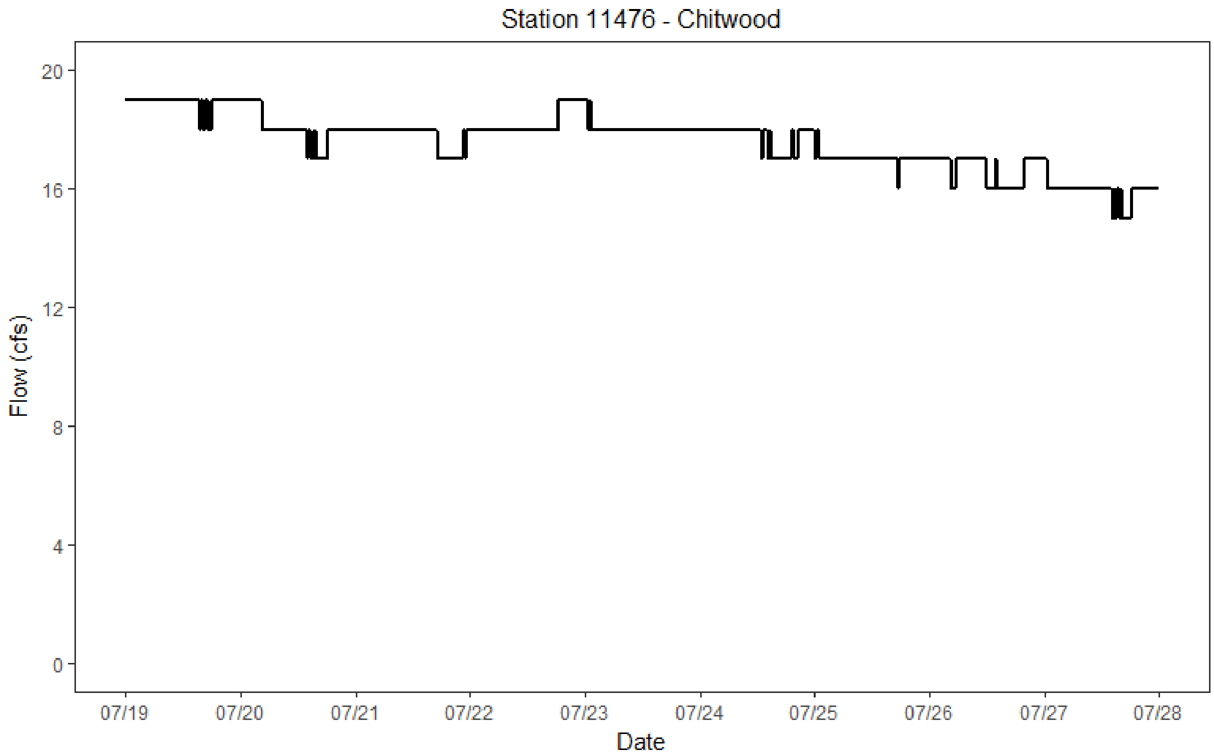


Figure 4.2.2b: Hourly flow measurements from 19-28 July 2016 - Upper Yaquina River

Flow conditions during the October study period were more variable than the July study period due to a large storm originating from the Pacific Ocean on October 13th (Figure 4.2.2b). Because of the flow variability, DEQ could not develop and calibrate the watershed-water quality model. Instead, DEQ compared continuous DO data with corresponding continuous flow, temperature, specific conductivity, pH, and turbidity (two locations) data collected at the four locations with sondes. DEQ explored correspondence among variables graphically, rather than statistically, because of expected hysteresis in relationships of water quality parameters with flow. Describing the nature of hysteresis allowed DEQ to understand watershed and in-stream controls on DO levels. Subsequently, the linked HSPF-QUAL2Kw model calibrated for the July period was applied using stable flow conditions for the October period.

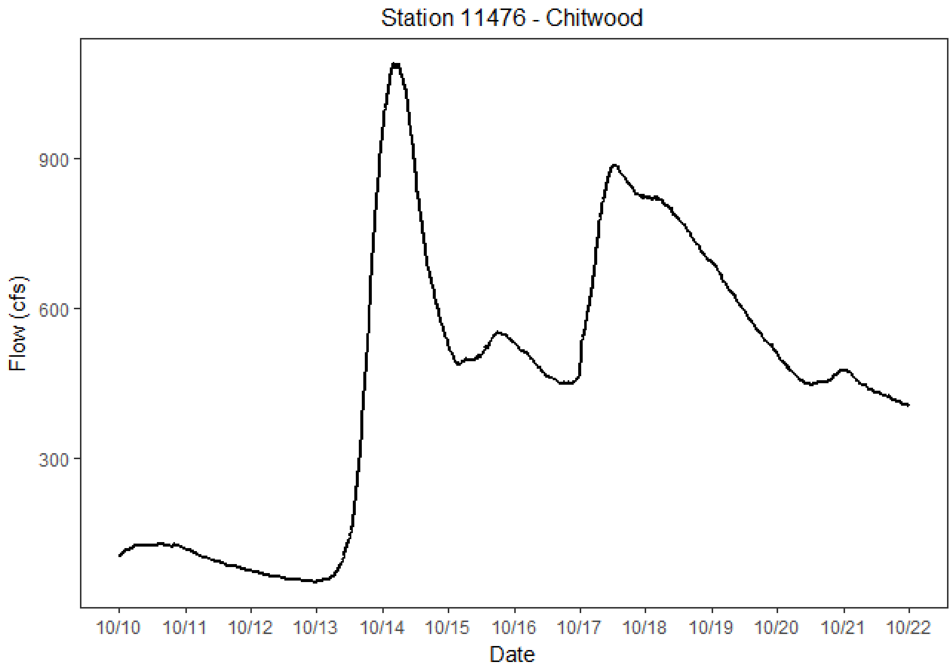


Figure 4.2.2c: Hourly flow measurements from 10-22 October 2016 - Upper Yaquina River

4.2.3 Continuous data methods and analysis

Continuous (time-series) data were collected at 15-minute intervals at each station with YSI multiparameter sondes (Yellow Springs Instruments Inc., Yellow Springs, OH) during both study periods. Continuously monitored data included DO, pH, water temperature and specific conductivity (Table 4.2.3). All sonde data analyzed adhered to the “A” or “B” data quality criteria described in DEQ’s quality assurance plan for data analysis (DEQ04-LAB-0003-QAG, Version: 5.0; DEQ 2016). Sondes were audited before, during and after each deployment period to assess data quality criteria.

For the July study period, continuous DO data were compared against Cold Water aquatic life water quality criteria (8.0 mg/L or 90% saturation; OAR-041-0016). The study period was intended to capture seasonal and flow conditions when excursions from the Cold-Water Aquatic Life criteria were most likely based on previous analyses (Sobota, Analysis of continuous dissolved oxygen data from Oregon's Mid Coast in 2008 and implications for TMDL development, 2014).

For the October study period, continuous DO data were compared against the Salmonid Spawning water quality standard (11.0 mg/L or 95% saturation; OAR-041-0016). Although a portion of the monitoring period fell several days before the onset of the designated spawning season (October 15 – May 15), monitoring was designed to capture early fall season conditions where most excursions of DO occur (Sobota, Analysis of continuous dissolved oxygen data from Oregon's Mid Coast in 2008 and implications for TMDL development, 2014).

Table 4.2.3: Continuous and grab sample water chemistry sampling stations - Upper Yaquina River

Station	Description	Latitude (°)	Longitude (°)	QUAL2Kw Model reach mile (km)
34454	Yaquina River at Clem Road Bridge	44.6478	-123.6263	21.10 (33.95)
33112	Yaquina River at Nashville Rd Hwy 180	44.6559	-123.7545	10.06 (16.20)
12301	Yaquina River at Eddyville	44.6352	-123.7748	7.24 (11.65)
11476	Yaquina River at Trapp Road (Chitwood)	44.6577	-123.8348	0 (0)

4.2.4 Grab sampling and analysis

Grab samples for supporting chemistry data were collected twice daily (morning and afternoon) on five separate days over the period. The objective was to characterize diel variation in water quality parameters that can influence processes that control DO concentrations. Grab sample data included: ammonium (NH_4-N), nitrate/nitrite (NO_3-N), total Kjeldahl nitrogen (TKN), total phosphorus (TP), soluble reactive phosphorus (SRP), 5-day Carbonaceous Biological Oxygen Demand (CBOD), total suspended solids (TSS), total organic carbon (TOC) and chlorophyll a. All sampling procedures and chemical analyses were conducted in accordance with DEQ's quality assurance plan (DEQ14-LAB-0020-QAPP). Only data with "A" and "B" grades, which indicate appropriate sampling, storage, processing, and analysis techniques, were used for analysis and QUAL2Kw model development, calibration, and validation (DEQ09-LAB-0006-QAG; DEQ, 2016).

Grab samples for nutrients and organic carbon showed no specific diel or weekly trend over the monitoring period for each site during the July study. Thus, descriptive statistics (average and standard deviation) were used to describe characteristics during the monitoring period and boundary conditions for the QUAL2Kw model. Additional water quality data collected during this period were also described with this approach

Because flow varied widely during the October study, DEQ also examined correlations of DO and flow with these parameters by pairing grab sample data to the nearest 15-minute interval of continuous DO and flow data. Similarly, DEQ explored these correlations graphically due to expected pronounced hysteresis in correlations among parameters.

4.2.5 July 2016 Study

From 19 July to 27 July 2016, daily minimum DO concentrations and saturations generally decreased from the most upstream station (34454-ORDEQ) to below the confluence of the Yaquina with Little Elk Creek (12301-ORDEQ); but increased downstream at station 11476-ORDEQ. This is shown on Figure 4.2.5a and Figure 4.2.5b, where blue lines indicate the cold water dissolved oxygen criteria of 8 mg/L and 90% saturation (OAR-041-0016). The lowest DO concentration observed was 7.2 mg/L at 0630 on 27 July 2016 at station 12301-ORDEQ. The highest DO concentration observed was 11.3 mg/L at 1615 on 19 July 2016 at station 11476-ORDEQ.

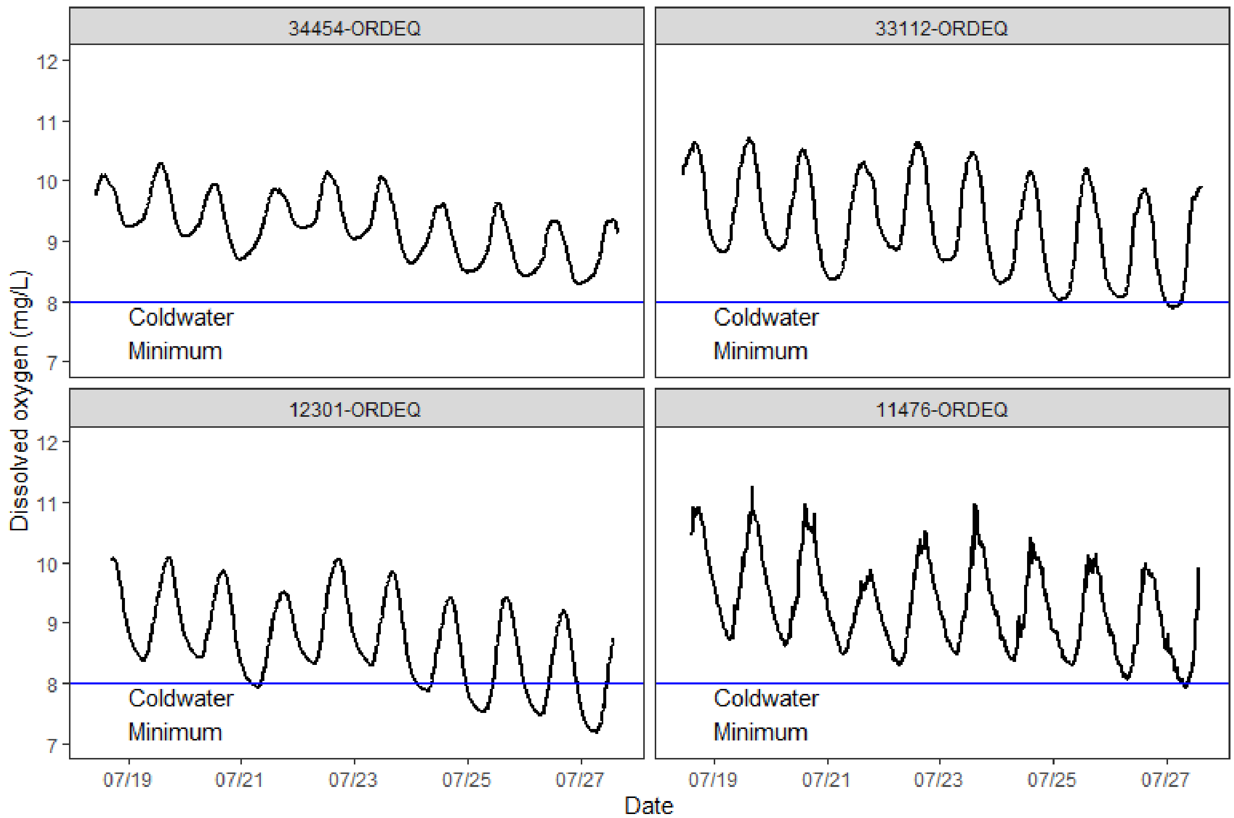


Figure 4.2.5a: Continuous 15-minute interval dissolved oxygen concentrations - Upper Yaquina River during July 2016

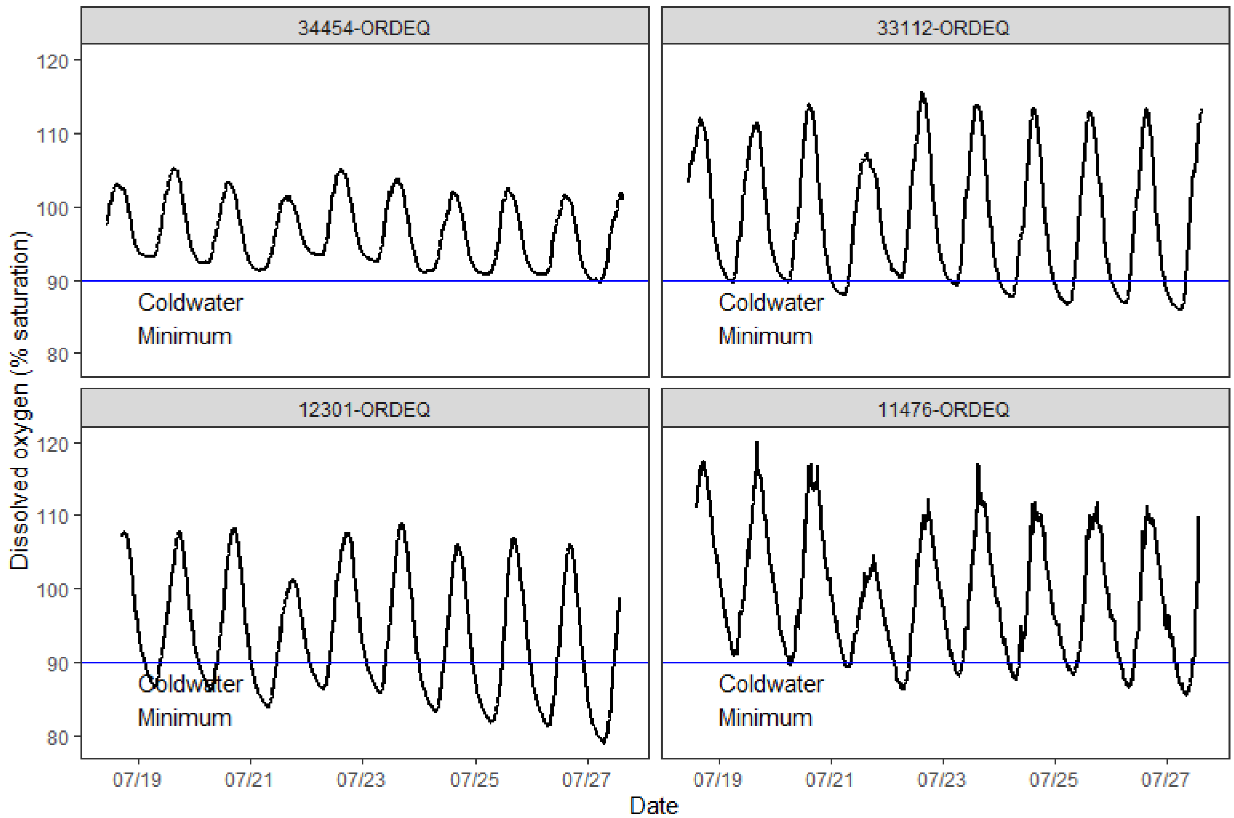


Figure 4.2.5b: Continuous 15-minute interval dissolved oxygen saturations - Upper Yaquina River during July 2016

Temperature patterns did not follow a consistent upstream to downstream pattern across sites during the monitoring period (Figure 4.2.5c). Stations 33112-ORDEQ and 12301-ORDEQ tended to be the warmer than both the upstream (34454-ORDEQ) and downstream (11476-ORDEQ) stations. The warmest temperature measured was 22.4 °C at 1545 on 26 July 2016 at station 33112-ORDEQ. The coldest temperature measured was 15.0°C at 0815 on 19 July 2016 at station 34454-ORDEQ.

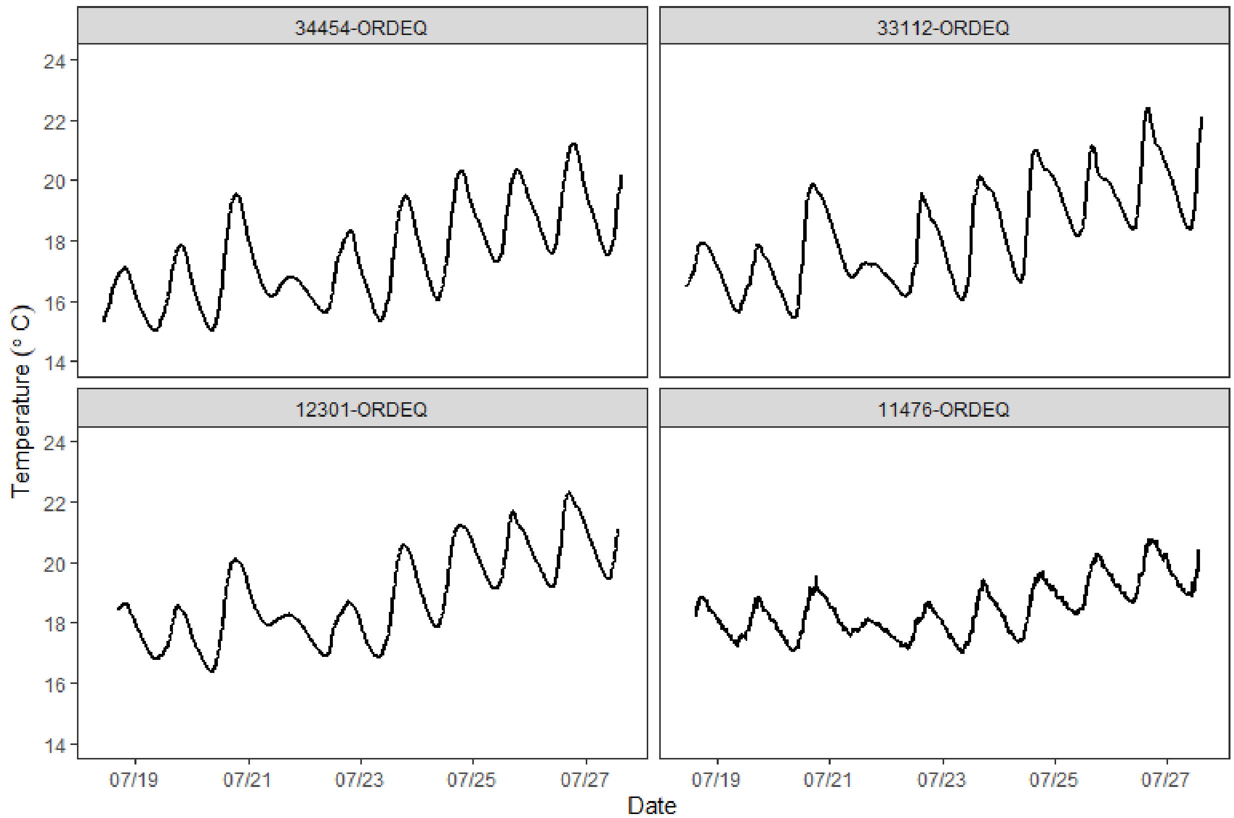


Figure 4.2.5c: Continuous 15-minute interval water temperature - Upper Yaquina River during July 2016

In addition, pH exhibited slight variations (<0.6 su) within the range of the water quality standard of 6.5 - 8.5 (OAR 340-041-0225). Specific conductivity did not exhibit consistent diel patterns across the sites and was within the normal range for freshwater (<200 uS/cm).

Across all sites, 26 July 2016 had the lowest DO concentration for one complete 24 hr cycle (Figure 4.2.5a; Figure 4.2.5b) and warmest water temperature (Figure 4.2.5c). This date captured the worst-case scenario for DO during the monitoring period and was thus used as the basis for HSPF model outputs and QUAL2Kw model calibration.

Table 4.2.5 presents the mean plus or minus (±) one standard deviation for key grab sample water quality measurements taken at each sampling station (moving from upstream to downstream) during the monitoring period. TOC, CBOD, organic N, and organic P concentrations all increased from the upstream to downstream. Inorganic forms of N and P tended to peak in at the middle stations (33112-ORDEQ and 12301-ORDEQ) and decrease at the most downstream station (11476-ORDEQ). Chlorophyll a and total suspended solid (TSS) concentrations were both low (<2 μg/L and <2 mg/L, respectively) across all sites.

Table 4.2.5: Grab sample average and standard deviations - Upper Yaquina River in July 2016

Station	TOC	CBOD	NO_3-N	NH_4-N	Organic N	PO_4-P	Organic P
34454	1.2±0.7	0.5±0.2	0.224±0.017	0.011±0.003	0.127±0.055	0.018±0.002	0.011±0.004
33112	1.3±0.1	0.5±0.1	0.338±0.014	0.017±0.004	0.159±0.071	0.019±0.002	0.012±0.003
12301	1.5±0.1	0.6±0.2	0.295±0.014	0.023±0.004	0.180±0.033	0.017±0.001	0.013±0.001
11476	1.7±0.1	0.8±0.3	0.291±0.016	0.010±0.005	0.208±0.055	0.010±0.002	0.022±0.007

Notes: All units are mg/L. n=10 for each parameter. TOC = Total Organic Carbon; CBOD = Carbonaceous Biochemical Oxygen Demand; NO_3-N = Nitrate/Nitrite as Nitrogen; NH_4-N = Ammonium as Nitrogen; PO_4-P = phosphate as phosphorus.

4.2.6 October 2016 Study

From 10 to 19 October 2016, daily minimum DO concentrations and saturations were consistent from the most upstream station (34454-ORDEQ) to station 11476-ORDEQ (Figures 4.2.6a and 4.2.6b). The blue line indicates the cold water dissolved oxygen criterion of 11 mg/L (OAR-041-0016). The lowest DO concentration and saturation observed was 9.7 mg/L and 90.8% saturation at 17:45 on 10 October 2016 at station 11476-ORDEQ. The highest DO concentration observed was 11.2 mg/L at 14:00 on 12 October 2016 at station 33112-ORDEQ. The highest DO saturation value observed was 102.9% at 15:45 on 12 October 2016 at station 33112-ORDEQ. Storm events on 13 October and 17 October disrupted the diel cycle of DO at all stations (except station 33112-ORDEQ, where the sonde was pulled on 13 October to avoid loss during high flows). Following the storm event on 13 October, only small diel fluctuations in DO concentration and saturation occurred for the rest of the monitoring period, with DO concentrations 0.5 – 1.0 mg/L below the standard of 11.0 mg/L (Figure 4.2.6a) and DO saturation fluctuating around the 95% standard except at Station 12301-ORDEQ (Figure 4.2.6b).

Temperature patterns did not follow a consistent upstream to downstream pattern across sites during the monitoring period (Figure 4.2.6c). Station 11476 tended to be the warmer than the upstream stations. The warmest temperature measured was 14.0 °C at 1515 on 10 October 2016 at station 11476-ORDEQ. The coldest temperature measured was 9.1 °C at 0815 on 12 October 2016 at station 34454-ORDEQ.

pH dropped 0.2 – 0.4 su across with increased flows on 13 October 2016, disrupting diel cycles pre-storm at the three upstream stations and remaining consisting lower than pre-storm for the remainder of the monitoring period (Figure 4.2.6d). Specific conductance spiked across all sites during the storm event on 13 October; but then quickly dropped to and below pre-storm levels (Figure 4.2.6e). Continuous turbidity data for the entire period were only collected at the most downstream station (11476-ORDEQ) and showed large spikes during the storm event on 13 October (Figure 4.2.6f).

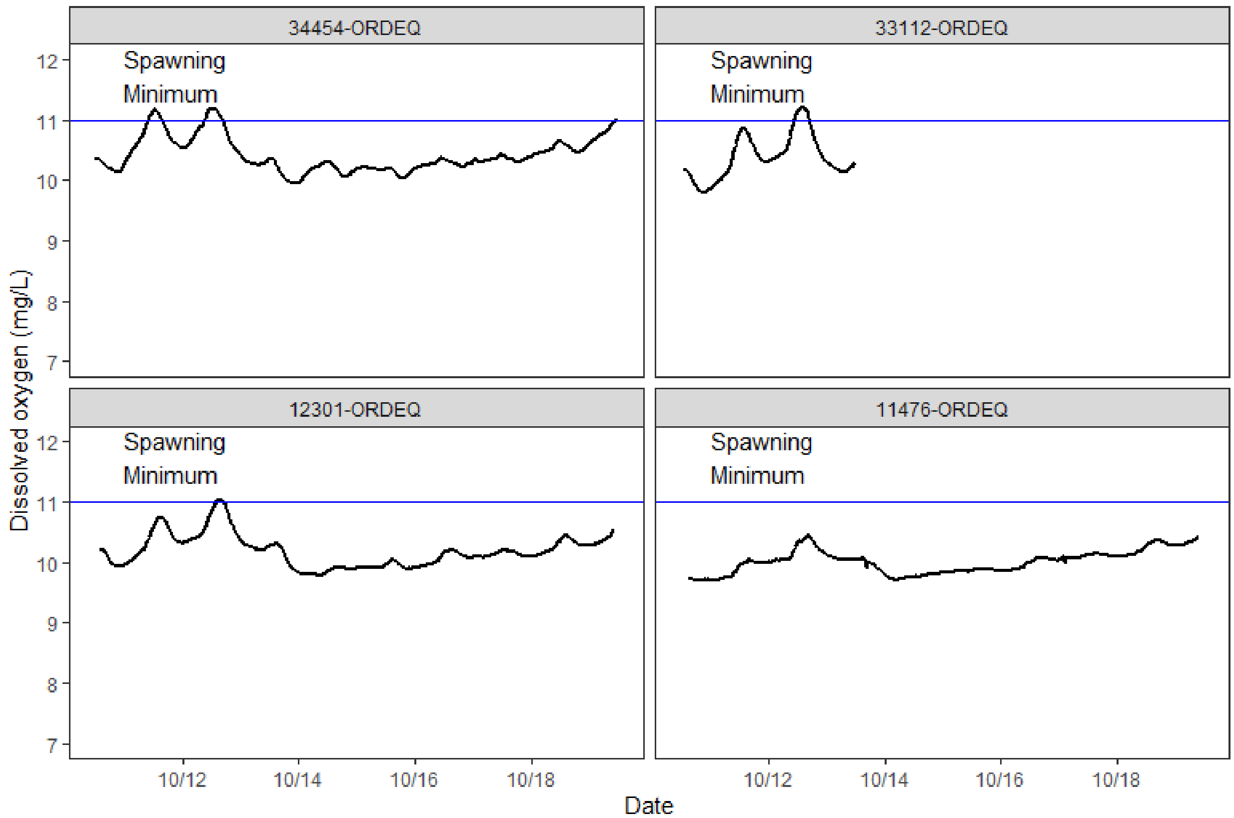


Figure 4.2.6a: Continuous 15-minute interval dissolved oxygen concentrations - Upper Yaquina River

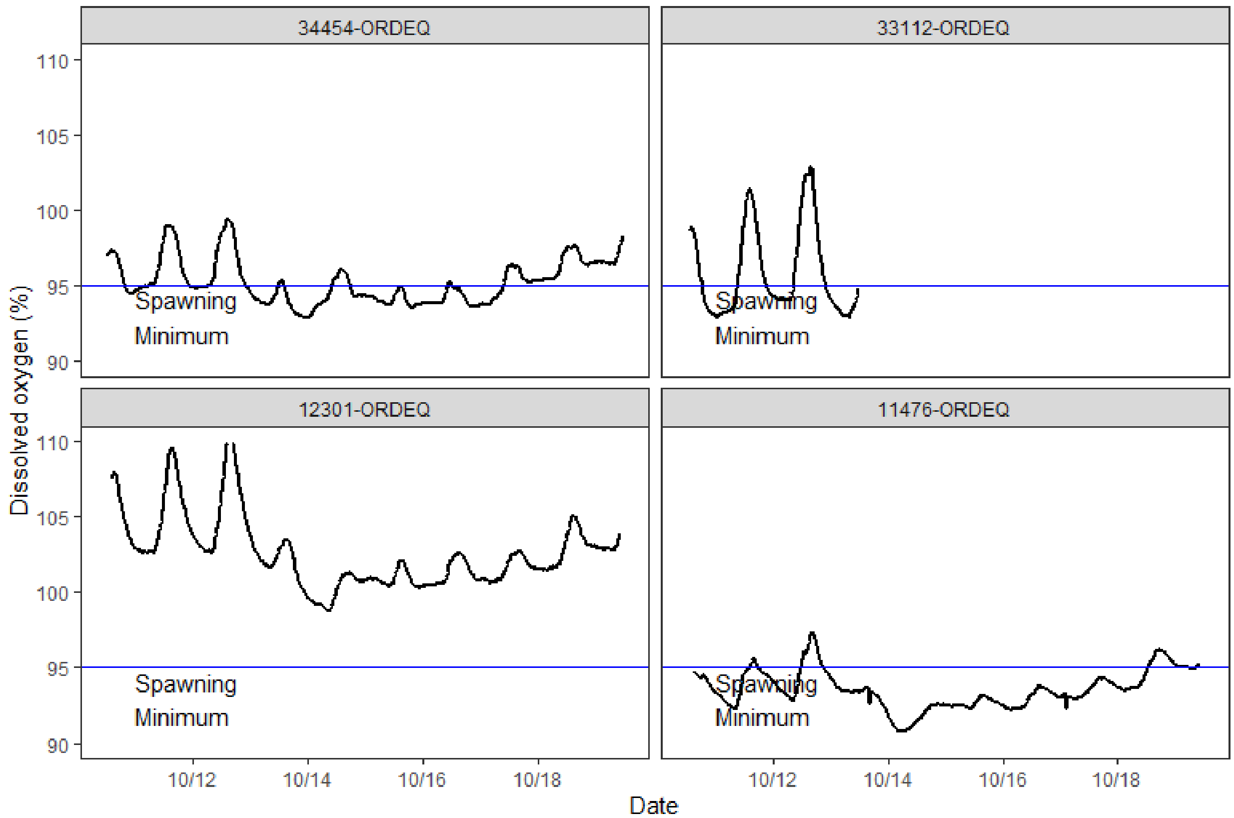


Figure 4.2.6b: Continuous 15-minute interval dissolved oxygen saturations - Upper Yaquina River

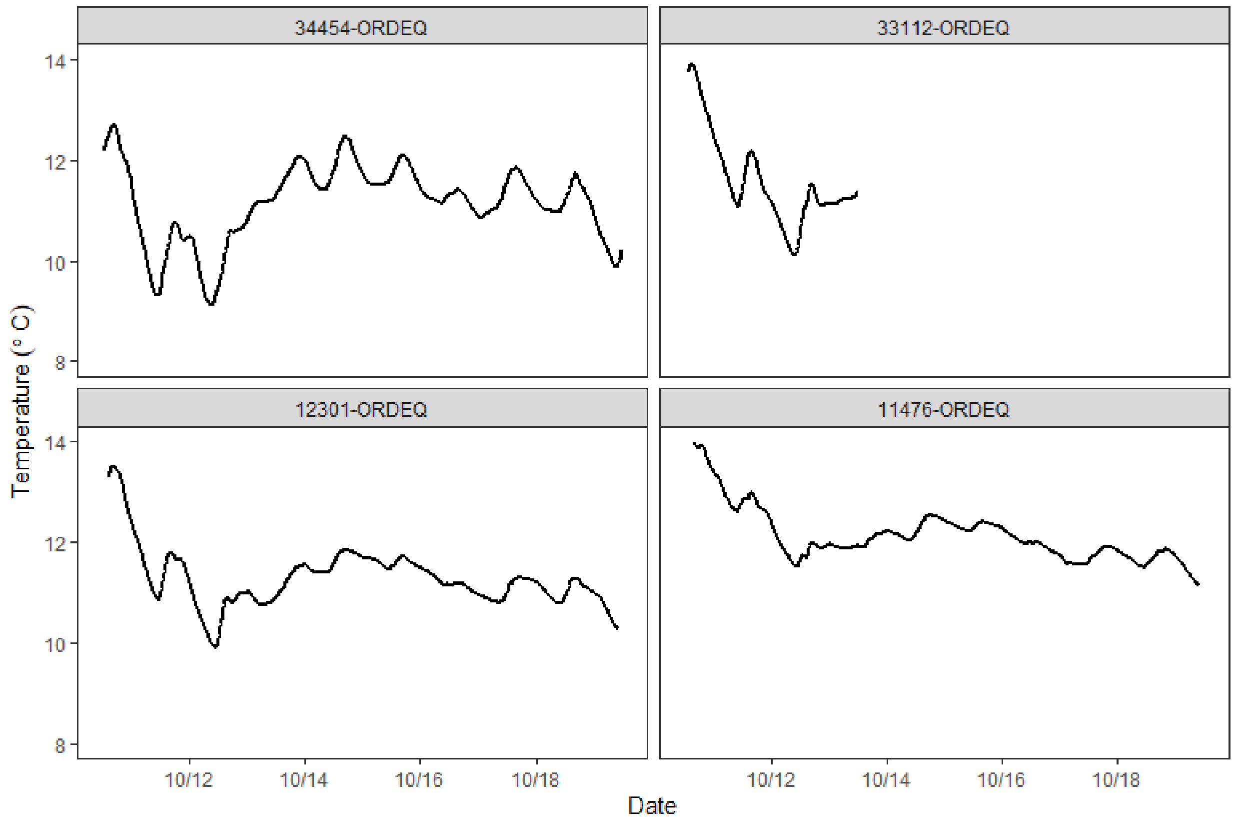


Figure 4.2.6c: Continuous 15-minute interval temperature - Upper Yaquina River

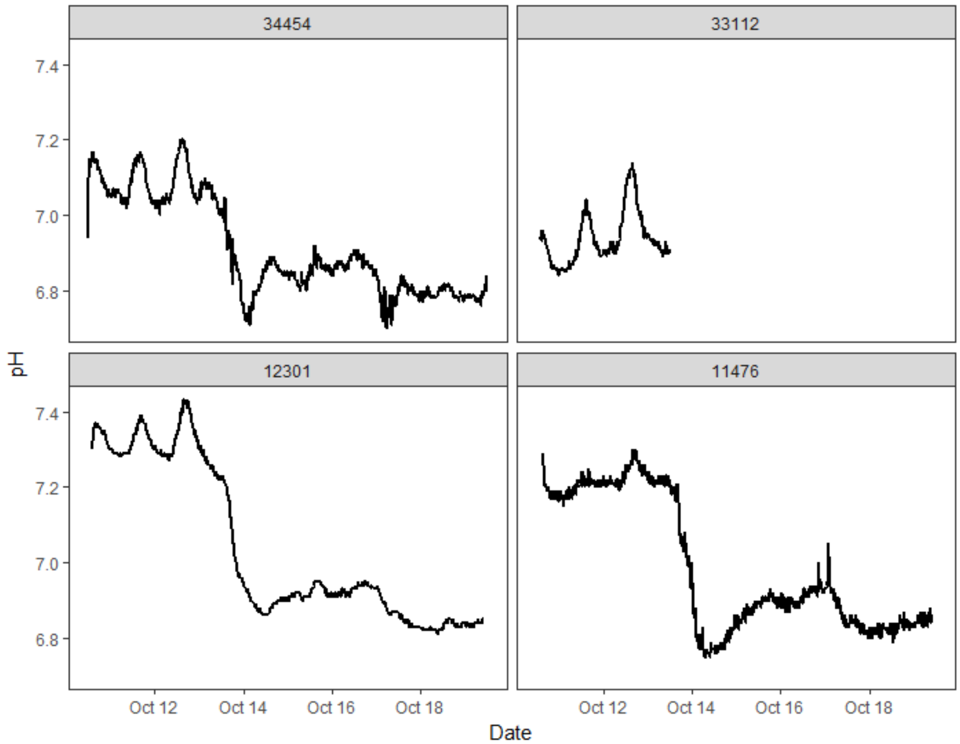


Figure 4.2.6d: Continuous 15-minute interval pH - Upper Yaquina River

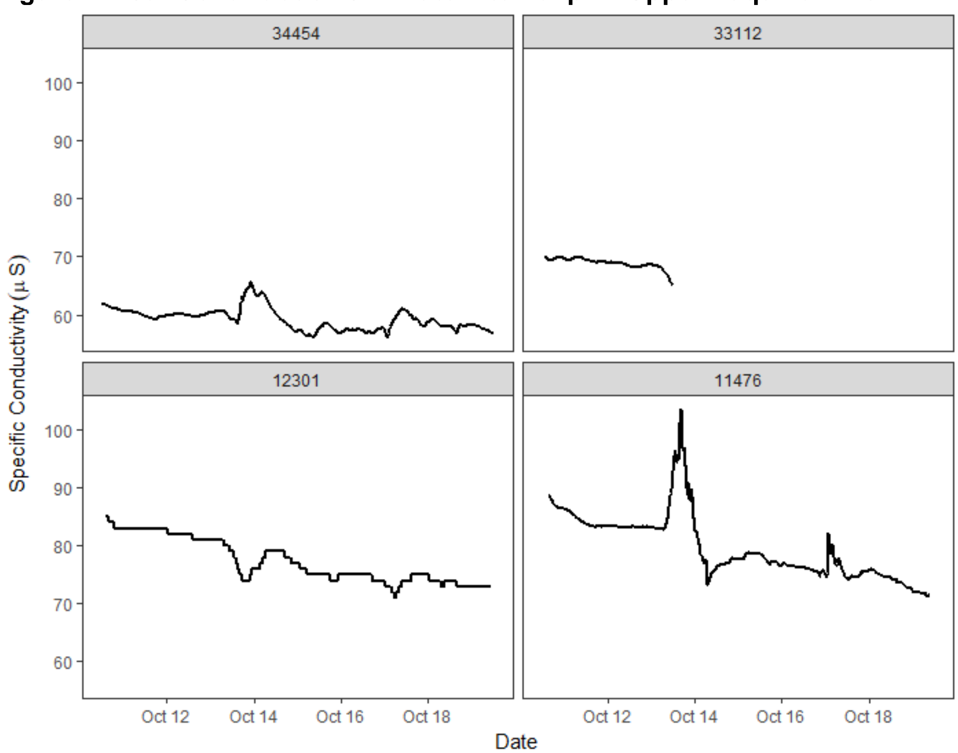


Figure 4.2.6e: Continuous 15-minute interval specific conductance - Upper Yaquina River

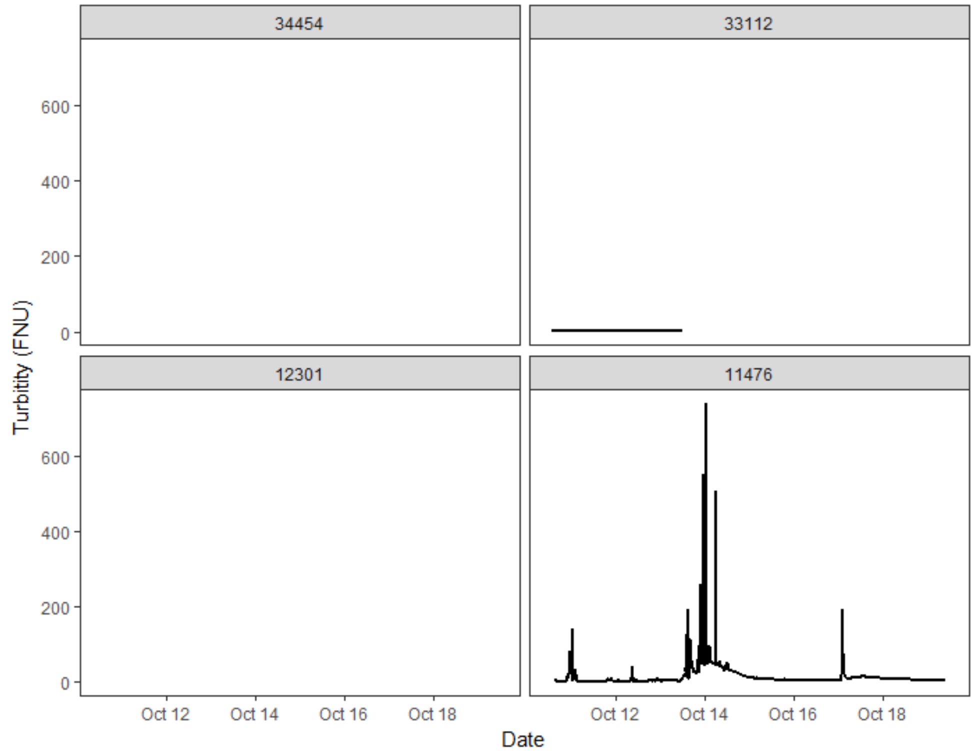


Figure 4.2.6f: Continuous 15-minute interval turbidity - Upper Yaquina River

Distinguishing temporal patterns of grab samples for nutrients and organic carbon over the course of the monitoring period proved difficult. Of the parameters examined, only nitrate/nitrite-nitrogen showed identifiable temporal patterns over the course of the monitoring period (Figure 4.2.6g). Other parameters diurnal variation and variation across days; but no clear response to flow events could be seen (for example see total organic carbon; Figure 4.2.6h).

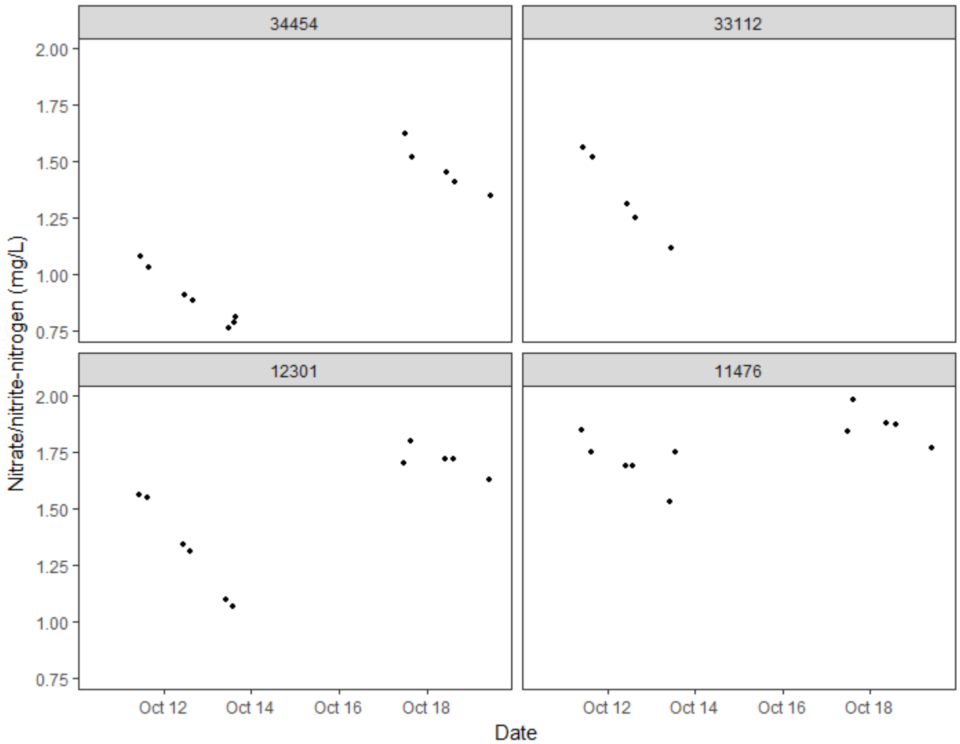


Figure 4.2.6g: Grab samples for nitrate/nitrite-nitrogen from - Upper Yaquina River

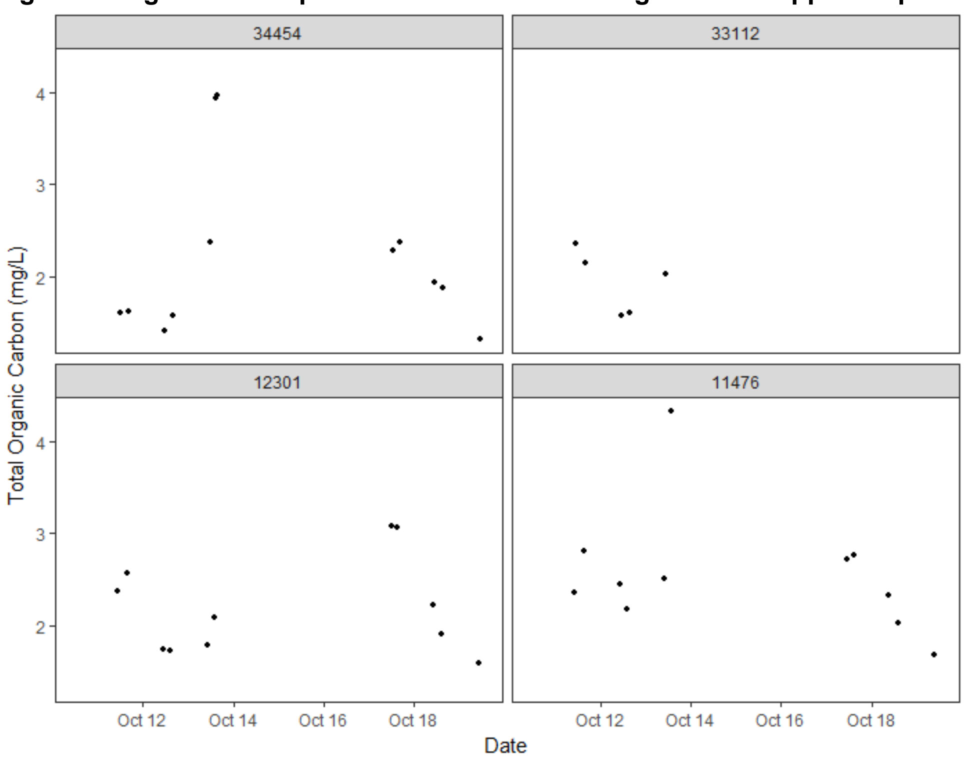


Figure 4.2.6h: Grab samples for Total Organic Carbon - Upper Yaquina River

Because of hysteresis present in the relationships between water quality parameters and flow, DEQ did not examine statistical correlations among parameters. Instead, DEQ examined graphical patterns among DO and other parameters to give insight on important hydrological, chemical, and biological processes that may be producing observed temporal patterns.

Comparison of DO concentration and saturation with flow data show that diel cycles of DO controlled by biological activity (characterized by peaks in DO concentration during midday) were disrupted by storm flows and became synched with fluctuations in temperature after 13 October (Figures 4.2.6i, 4.2.6j, 4.2.6k). Diel cycles began to align with a signal characteristic of biological activity in the last two days of the monitoring period as flows continued to recede following the storm events (Figures 4.2.6c and 4.2.6d).

Comparison of grab sample data, although collected at a comparatively high frequency, with flow data did not reveal any distinct patterns of constituents with flow beyond which could be seen from time series of grab samples. However, comparison of other continuously collected parameters with flow data provided insight on transition of water sources in the main channel. Most prominent of the shift in continuously collected parameters (beyond DO and temperature) with flow was pH, which declined by 0.2 to 0.4 su with increasing flows following the storm on 13 October Figure 4.2.6d). Comparison of DO concentration data with pH during the monitoring period shows that DO and pH cycles were coupled prior to the storm on 13 October and became desynchronized after the storm events (Figure 4.2.6l).

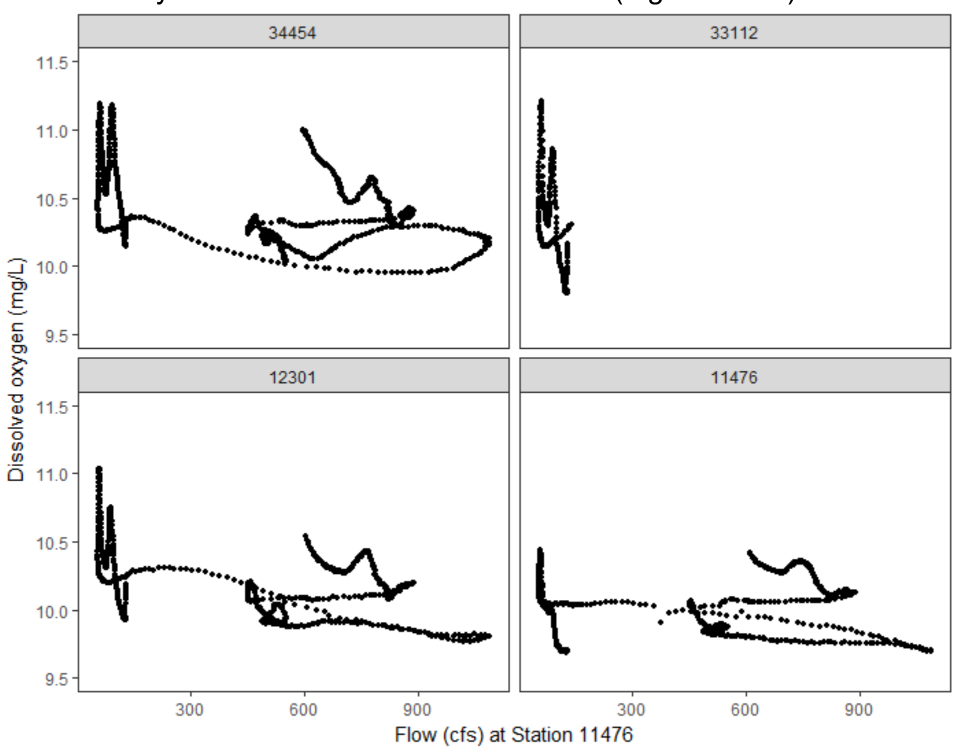


Figure 4.2.6i: Comparison of dissolved oxygen concentration with flow 10 - 19 October 2016 - Upper Yaquina River (note data from 33112 does not extend past 13 October 2016)

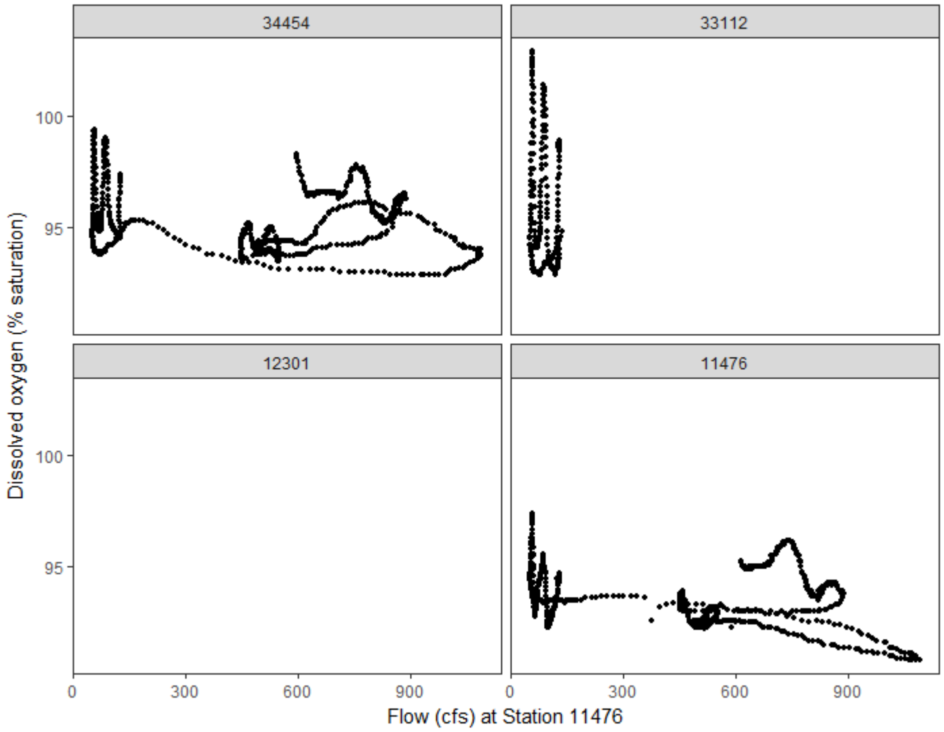


Figure 4.2.6j: Comparison of dissolved oxygen saturation with flow 10 - 19 October 2016 - Upper Yaquina River (note data from 33112 does not extend past 13 October 2016)

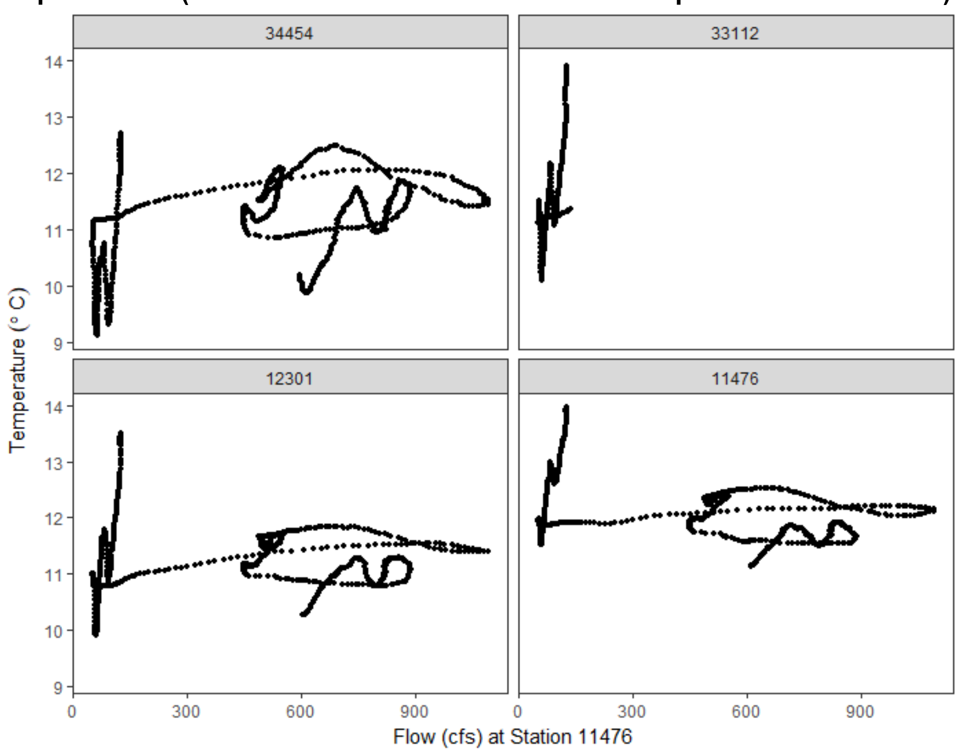


Figure 4.2.6k: Comparison of stream temperature with flow 10 - 19 October 2016 - Upper Yaquina River (note data from 33112 does not extend past 13 October 2016)

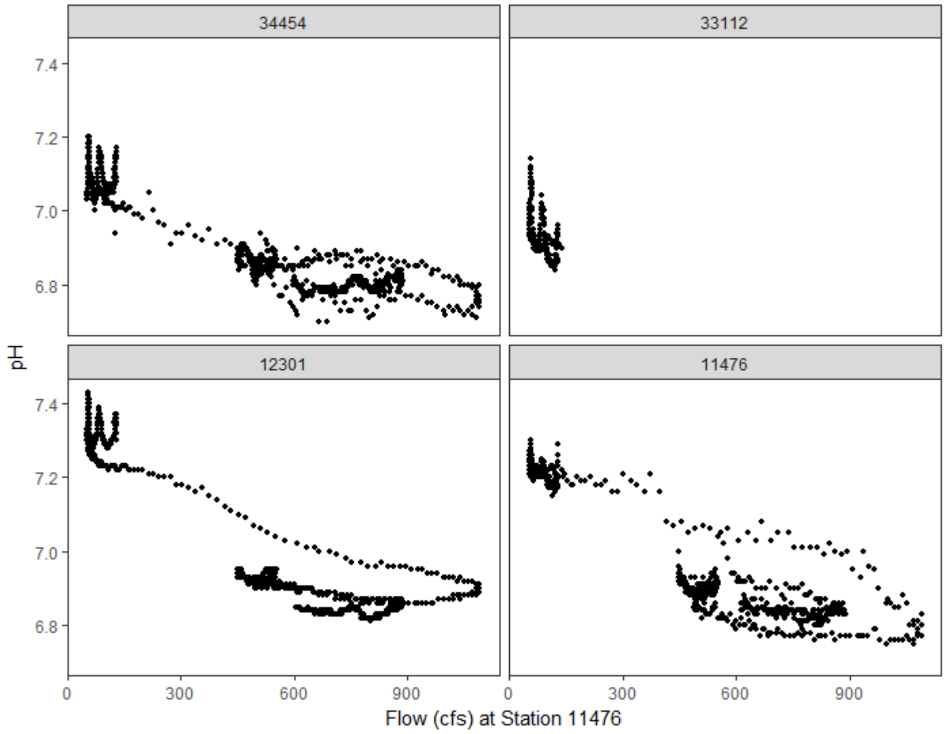


Figure 4.2.6l: Comparison of pH with flow 10 - 19 October 2016 - Upper Yaquina River (note data from 33112 does not extend past 13 October 2016)

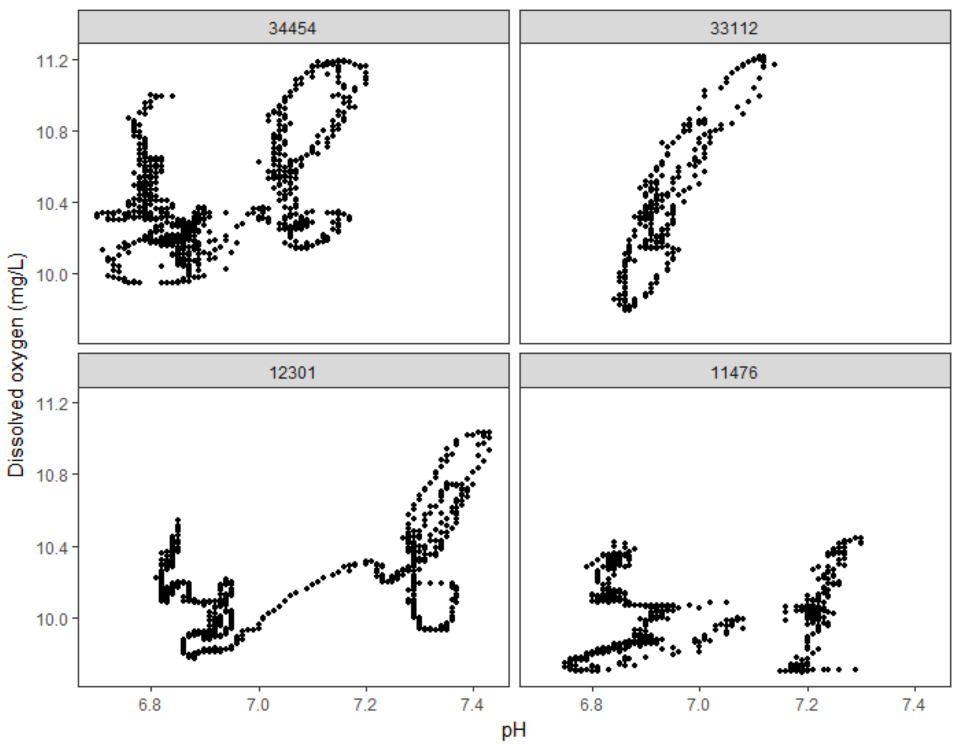


Figure 4.2.6m: Comparison of dissolved oxygen with pH 10 - 19 October 2016 on the Upper Yaquina River.

The analysis of data collected in October 2016 supports the concept that the storm events disrupt diel cycles of DO controlled by biological activity and become more reflective of diel temperature cycles in the period following storm events. Prior to the storm event in the evening of 13 October 2016, diel cycles in DO reflected gross primary production during the day, which raise DO levels, and ecosystem respiration during the night, which lower DO levels (Bernot, et al., 2010). Following the storm events on 13 and 17 October 2016, DO concentrations and saturations became synched with temperature cycles, with DO levels peaking at night with cooler temperatures and falling during the day as temperatures warmed. Diel patterns became more reflective of biological cycles during the falling limb of the hydrograph after the 17 October 2016 high flow event, as seen by more pronounced peaks in DO concentrations shifting toward the late afternoon.

Partial support exists for the concept that groundwater flushing suppresses DO levels in the Upper Yaquina River after storm events. Although DO concentrations and saturation dropped following storm events, they only dropped to levels near or slightly below the surface water standard (11.0 mg/L or 95% saturation; OAR 340-41-0016). This suggests that water entering the channel contained relatively high oxygen levels.

In predominantly forested watersheds such as the Upper Yaquina, most flow from storm events enters stream networks through subsurface flow paths, with limited overland flow (Tetra Tech, 2017). The drop in pH associated with the storm event suggests that dissolved organic matter (DOM), which is acidic, was flushed to the Upper Yaquina during and following the storm events in the monitoring period. Although TOC sampling did not show a clear relationship with flow, several samples from the station 34454 (the uppermost station) in the afternoon of 13 October suggest elevated TOC concentration entered the system with the onset of high flows (Figure 4.2.6h).

The examination of DO and other water quality data reveal a complex response to storm events and the receding limb of storm flows. DEQ believes that well-oxygenated, shallow groundwater flushed from hillslopes and riparian areas into the stream network during storm events in the monitoring period. The drop in pH agrees with the concept that DOM in soil solution (shallow subsurface) flushed into the system rather than from a deep groundwater source or via overland flow, which typically does not have the levels of TOC observed at the upper most station (34454) during the onset of the storm on 13 October 2016. With rising flows and flushing of well-oxygenated water into the system, DEQ believes that DO levels in river sediments remained above the intergravel DO standard of 8.0 mg/L (OAR 340-41-0016), meaning that the surface water standard of 9.0 mg/L applied to the system during the monitoring period.

Based on this analysis, DEQ decided that TMDL development efforts for meeting spawning criteria use the calibrated QUAL2Kw model developed for rearing and migration criteria in July 2016. Flows captured during July 2016 monitoring are closer to the low flows that are of most concern during the onset of the fall spawning period (Figure 4.2.2a).

4.3 Modeling analysis

DEQ used linked watershed-water quality models to identify factors that influenced dissolved oxygen in the Upper Yaquina River Watershed and to determine the total loads, where applicable, of these factors and the contribution by source categories. The linked models were structured to evaluate the spatial effects of loads and factors that influence dissolved oxygen in the Upper Yaquina River. However, DEQ focused on watershed wide reductions in overall loads to make TMDL implementation tractable with the local community and ensure that dissolved oxygen standards are met throughout the watershed. Based on the TMDL model analysis, DEQ determined that solar radiation and total phosphorus loading were the two pollutants contributing to violations of the cold water and salmonid spawning criteria for dissolved oxygen during the critical periods in the Upper Yaquina River Watershed. The modeling and conclusions are based on data collected during the July 2016 TMDL study; data collected during the October 2016 encompassed non-steady flows and were subject to statistical analysis presented in Section 4.2.

As detailed in Figure 4.1 and sections that follow, outputs from the HSPF watershed model, spatial data describing riparian shade and meteorological data were used as inputs for the QUAL2Kw model, which simulated dissolved oxygen concentrations in the 303(d) listed reach of the Upper Yaquina River. The two models allowed DEQ to link existing or potential watershed sources of nonpoint source pollution with changes in water quality and violations of the applicable dissolved oxygen criteria.

4.3.1 Watershed model: Hydrologic Simulation Program-Fortran

A Hydrologic Simulation Program-Fortran or HSPF model was developed by EPA's consultant, Tetra Tech, to characterize hydrologic patterns and nutrient inputs for water years 1996 – 2014. HSPF uses topographic, geologic, soil, land use/land cover, meteorological and other relevant environmental and land management information to estimate hydrologic patterns and the sources and transport of materials in a spatially and temporally explicit manner. The Upper Yaquina Watershed was divided into 22 distinct catchments to simulate flow and nutrient loads, as shown in Figure 4.1.1, with single digit numbers designating model segments and five-digit numbers marking monitoring stations.

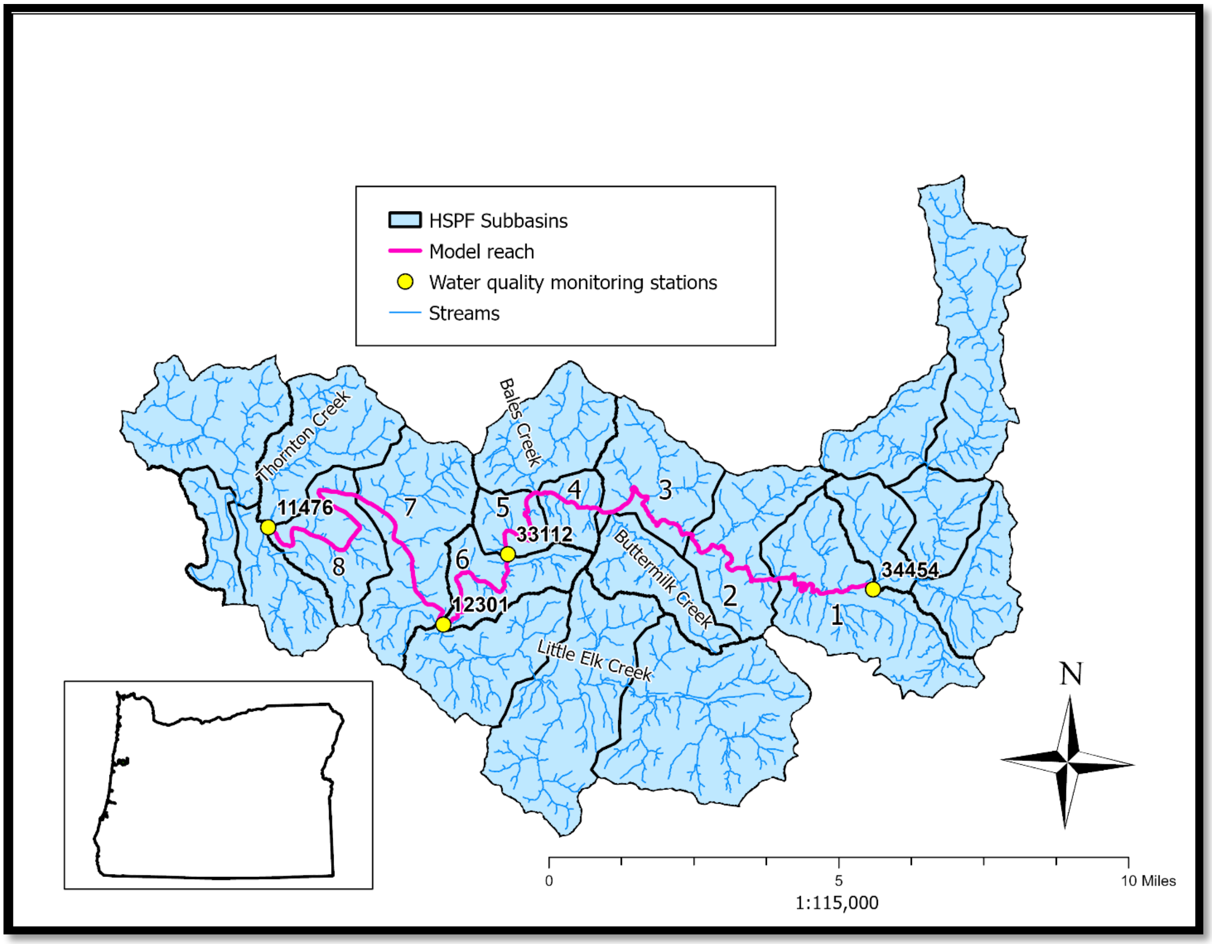


Figure 4.3.1: HSPF subbasins and modeled reach - Upper Yaquina Watershed

Although many small tributaries contribute flow to the QUAL2Kw model reach, only four tributaries were simulated using HSPF as direct tributary inputs to the model reach, because of the way that subwatersheds in the HSPF model were configured. Of these, Little Elk Creek contributes that largest single flow and nutrient input from a tributary to the Upper Yaquina River. HSPF simulates the remaining tributary inputs to the reach combined with diffuse inflows through groundwater. Thus, inputs for these reach segments cannot be distinguished between groundwater and tributaries.

Tetra Tech provides details on the development, calibration, and validation of the model as described in their report, attached as Appendix 1. Estimates of flow, nutrient and organic matter sources and transport in the Upper Yaquina watershed were used as boundary conditions for the reach-scale QUAL2Kw model, discussed below.

4.3.2 Water quality model: QUAL2Kw

QUAL2Kw (v.6.0) is a reach-scale, process-based, mass-balance water quality model that simulates diel DO cycles at steady-state or dynamic flow conditions. QUAL2Kw has been used for DO TMDL development in Oregon, Washington and other states (Turner, Pelletier, & Kasper, 2009; Pelletier, Chapra, & Tao, 2006; Washington Department of Ecology, 2022). The model is both temporally and spatially explicit in that water quality processes are simulated on an hourly basis in discrete reach segments specified by the user.

The mathematical framework for the model for the change in a constituent concentration (*C*; in this instance DO) over time in the water column of reach *i* is given by:

Equation 4.3.2: $$\frac{dc_i}{dt} = \frac{Q_{i-1}}{V_i}c_{i-1} - \frac{Q_i}{V_i}c_i - \frac{Q_{a,i}}{V_i}c_i + \frac{E'_{i-1}}{V_i}(c_{i-1} - c_i) + \frac{E'_i}{V_i}(c_{i+1} - c_i) + \frac{W_i}{V_i} + S_i$$

Where *Q* is flow (volume per time), *V* is volume, *a* is abstraction (indicating flow loss in reach *i*), E′ is the bulk dispersion coefficient between upstream and downstream reaches (volume per time), W_i is external loading of the constituent of interest to the reach (mass per time), and S_i is sources and sinks of the constituent of interest due to physical, chemical, and biological mass transfer mechanisms (Pelletier, Chapra, & Tao, 2006).

4.3.2.1 QUAL2Kw spatial and temporal extents

Tributary inflows, groundwater inflow, outflows (flow abstractions) and point source discharges must all be delineated (and aggregated) within individual reach segments. DEQ acquired data on flows in the Yaquina River mainstem from the HSPF model and field measurements summarized in Figure 4.2.2.3. The HSPF model segments provided groundwater inflows and abstractions. DEQ used the repeating diel simulation option in QUAL2Kw v.6.0 to simulate dissolved oxygen dynamics for a 21.10 mile (33.95 km) reach of the Upper Yaquina River between the upper and lower continuous data monitoring stations in 2016 (Model mile 21.10 = 34454-ORDEQ (upstream) to mile 0 = 11476-ORDEQ (downstream), as shown in Figure 4.1.1). The repeating diel simulation option uses steady-state flow data and meteorological data over a designated period. For this simulation, DEQ chose to model the 24-hour period that represented the lowest minimum DO concentrations observed in the monitoring period.

DEQ used 11.25-minute simulation steps with a fourth-order Runge-Kutta numerical simulation method. Based on the recommendations from the model's authors, DEQ used the Brent pH solution method. Data describing aspects of hyporheic or surface transient storage zone exchange were not available, so these components were not simulated. By not including these components, scenarios that manipulate hyporheic zones or transient storage cannot be evaluated directly. However, these components maybe added in future iterations of the model if or when data become available. DEQ used the lumped method to compute heat conduction to deep sediments based on methods described by the model's authors in the model guidance ((Washington Department of Ecology, 2022). DEQ used the Di Toro (2001) model for sediment oxygen demand and nutrient fluxes to simulate sediment diagenesis because field data describing sediment oxygen demand or nutrient fluxes was not available. Lastly, DEQ chose not to simulate alkalinity changes due to nutrient fluxes because of the absence of alkalinity data.

4.3.2.2 QUAL2Kw reach description

The simulation reach was broken into eight distinct segments based both on (1) the locations of monitoring stations with continuous and grab sample data and (2) the HSPF model segmentation (Figure 4.3.1). DEQ originally set up monitoring to capture four specific segments. However, because continuous data suggested that flows were tidally affected at the most downstream monitoring site during July (34456-ORDEQ), DEQ set the next upstream site (11476-ORDEQ) as the most downstream site in the model reach. An advantage to setting 11476-ORDEQ as the downstream reach boundary is that OWRD monitors flow continuously at this station (OWRD station 14306030). This monitoring site also is a water quality sampling station for DEQ's ambient monitoring network.

Although many tributaries contribute flow to the model reach, DEQ only considered the four tributaries simulated using HSPF as direct tributary inputs to the model reach because of the way that subwatersheds in the HSPF model were configured (Figure 4.3.1). Of these, Little Elk Creek contributes that largest single flow and nutrient input to the modeled reach. HSPF simulates the remaining tributary inputs to the reach combined with diffuse inflows through groundwater. Thus, inputs for these reach segments cannot be distinguished between groundwater and tributaries.

HSPF simulations supplied estimates of flow and nutrient load inputs to the QUAL2Kw model reach. For other parameters not simulated by HSPF (DO, pH and CBOD), DEQ set parameter values to values from the nearest upstream monitoring station in the model reach. This conservative approach allowed the maintenance of a mass balance in the QUAL2Kw model.

4.3.2.3 QUAL2Kw reach physical dimensions

River channel dimensions were derived from field measurements, GIS analysis and empirical scaling equations (Turner, Pelletier, & Kasper, 2009). DEQ measured wetted width, depth and flow velocity at three of the continuous monitoring sites as part of flow measurements collected during the monitoring periods. For widths at the margins of each of the eight segments, DEQ fit an exponential model of width versus river mile (km) with the wetted width measurements collected in the model reach. DEQ derived slope estimates for each segment from 3 ft (~1 m) LiDAR elevation data at each monitoring site and the linear stream distance between the monitoring sites. DEQ used the Manning formula to calculate flow for each QUAL2Kw model segment (Washington Department of Ecology, 2022):

Equation 4.3.2.3a: $\boldsymbol{Q = \frac{S_0^{1/2}}{n}\frac{A_c^{5/3}}{P^{2/3}}}$

Where Q is discharge (from HSPF model outputs), S_0 is bottom slope, n is the Manning roughness coefficient, A_c is cross-sectional area of the stream channel, and P is wetted perimeter of the stream channel. DEQ assumed a trapezoidal cross-sectional channel shape and calculated A_c as:

Equation 4.3.2.3b: $\boldsymbol{A_c = [B_0 + 0.5(s_{s1} + s_{s2})H]H}$

Where B is stream bottom width, s_{s1} and s_{s2} are the two side slopes for the channel margins, and H is stream channel depth.
P was calculated as:

Equation 4.3.2.3c: $\boldsymbol{P = B_0 + H\sqrt{s_{s1}^2 + 1} + H\sqrt{s_{s2}^2 + 1}}$

H can then be solved iteratively by substituting Equations 4.3.2.3b and 4.3.2.3c into Equation 4.3.2.3a and terminating the iterations when estimated error falls below 0.001% between successive iterations (Washington Department of Ecology, 2022). Following determination of H, A_c and B can be determined from the continuity equation (Washington Department of Ecology, 2022).

4.3.2.4 QUAL2Kw calibration

DEQ used the PIKAIA genetic algorithm to calibrate water quality parameters and processes not directly measured during the monitoring period (Pelletier, Chapra, & Tao, 2006). The algorithm in QUAL2Kw employs several steps, starting with selection of a random set of parameter values from uniform distributions that DEQ initially defined from the literature. This random selection procedure is run independently to produce an initial set of models. The model is optimized over a specified number of generations in which new models are generated by combining models from successive generations based on a fitness score that reflects model fit to observed data. Details of the algorithm can be found in Pelletier, Chapra and Tao (2006). For the algorithm, DEQ set the following:

- initial models = 100
- Generations = 50
- Digits to encode genotype = 5
- Crossover mode = equal probability of one or two point crossover
- Crossover probability = 0.85
- Mutation mode = one point, adjustable based on fitness
- Initial mutation rate = 0.005
- Minimum mutation rate = 0.0005
- Maximum mutation rate = 0.25
- Relative fitness differential = 1
- Reproduction plan = full generational replacement
- Elitism = 1
- Shuffle probability = 0
- Restart from previous evolution = initial population selected from uniform distribution
- Skip high Courant conditions = Yes

Model fitness for use in the algorithm was calculated as the inverse of the pooled Root Mean Squared Coefficient of Variation or RMSCV; where Root Mean Square Error (RMSE) was divided by the average of the measured and modeled values of dissolved oxygen, temperature, fast CBOD, organic N, ammonium-N, nitrate/nitrite-N, organic P and inorganic P (soluble reactive P). For temperature and dissolved oxygen, DEQ calculated RSMCV every 3 hours for the simulation period. For the remaining parameters, RMSCV was calculated from average values in the monitoring and simulation periods.

DEQ also weighted several parameters, times and monitoring stations more importantly than others in the calibration process to reflect the importance of fitting DO and temperature at stations with DO violations. These weights were assigned based on best professional judgment after consultation with the QUAL2Kw model authors. Because DEQ was most interested in accurately representing diel cycles in DO concentrations, the RMSCV of DO at 6 AM, 9 AM, 12 PM, 3 PM and 6 PM were given a weighing factor of 10. Additionally, DEQ weighted the RMSCV of DO at 12301-ORDEQ, which had the most frequent and severe violations of DO, by an additional factor of 10 at the times listed above. RMSCV of hourly temperature was given a weight of 5, average values of ammonium, nitrate/nitrite and inorganic P were given a weight of 2, and fast CBOD, organic N and organic P were given a weight of 1.

DEQ used the algorithm in the QUAL2Kw model to calibrate model parameters controlling channel roughness (Manning's n), reaeration of DO, nutrient processes, decomposition of organic matter and growth of primary producers (Table 4.3.2.4). DEQ set the limits of the values for these parameters according to values recommended by QUAL2Kw model authors (Pelletier, Chapra, & Tao, 2006). All other model parameters were set to the default values initially set in the model distribution and held constant (Washington Department of Ecology, 2022). Additionally, DEQ used the QUAL2Kw algorithm to determine the relative contribution of nitrate/nitrite-N to ammonium-N loading of inorganic N from diffuse and tributary sources supplied from the HSPF model by using the algorithm to determine the amount of nitrate-N within the range of total inorganic N concentration estimated by HSPF. The remaining portion was assumed to be ammonium-N.

Table 4.3.2.4: Parameters calibrated using the genetic algorithm for QUAL2Kw

Parameter	Minimum value	Maximum value
Carbon (g)	30	60
Nitrogen (g)	5	9
Phosphorus (g)	0.5	2
Settling velocity (m/d)	0	2
User reaeration model parameter A (unitless)	3	6
User reaeration model parameter B (unitless)	0.5	1
User reaeration model parameter C (unitless)	-1.85	-1.5
Slow CBOD hydrolysis rate (1/d)	0.05	0.25
Slow CBOD temperature correction (unitless)	1	1.07
Slow CBOD oxidation rate (1/d)	0	5
Slow CBOD temperature correction (unitless)	1	1.07
Fast CBOD oxidation rate (1/d)	0	5
Fast CBOD temperature correction (unitless)	1	1.07
Organic N hydrolysis (1/d)	0.05	0.3
Organic N hydrolysis temperature correction (unitless)	1	1.07
Organic N settling velocity (m/d)	0.05	2
Nitrification (1/d)	0.05	3
Nitrification temperature correction (unitless)	1	1.07
Denitrification (1/d)	0	2
Denitrification temperature correction (unitless)	1	1.07
Sediment denitrification transfer coefficient (m/d)	0	1
Sediment denitrification temperature correction (unitless)	1	1.07
Organic P hydrolysis (1/d)	0.05	0.3
Organic P hydrolysis temperature correction (unitless)	1	1.07
Organic P settling velocity (m/d)	0.05	2
Phytoplankton maximum growth rate (1/d)	1.5	3
Phytoplankton growth rate temperature correction (unitless)	1	1.07
Phytoplankton respiration rate (1/d)	0.05	0.5
Phytoplankton respiration rate temperature correction (unitless)	1	1.07
Phytoplankton death rate (1/d)	0	1
Phytoplankton death rate temperature correction (unitless)	1	1.07
Phytoplankton nitrogen half saturation constant (µg N/L)	10	25
Phytoplankton phosphorus half saturation constant (µg P/L)	1	5
Phytoplankton inorganic carbon half saturation constant (moles/L)	1.30E-06	1.30E-04
Phytoplankton light constant (langleys/d)	40	110
Phytoplankton ammonia preference (µg N/L)	15	30
Phytoplankton settling velocity (m/d)	0.05	2
Bottom plants maximum growth rate ($g/m^2/d$)	50	200
Bottom plants growth rate temperature correction (unitless)	1	1.07
Bottom plants first-order model carrying capacity ($g/m^2/d$)	50	200
Bottom plants basal respiration rate (1/d)	0.02	0.2
Bottom plants photo-respiration rate parameter (unitless)	0	0.6
Bottom plants photo-respiration temperature correction (unitless)	1	1.07
Bottom plants excretion rate (1/d)	0	0.5

Parameter	Minimum value	Maximum value
Bottom plants excretion rate temperature correction (unitless)	1	1.07
Bottom plants death rate (1/d)	0	0.5
Bottom plants death rate temperature correction (unitless)	1	1.07
Bottom plants coefficient of scour function (1/d/m^3/s)	0	0.1
Bottom plants exponent of scour function (unitless)	0	2
Bottom plants minimal biomass after scour event (g/m^2)	0	10
Catastrophic scour rate during flood event (1/d)	0	100
Critical flow or velocity for catastrophic scour (m^3/s)	0	50
Bottom plants nitrogen half saturation constant (µg N/L)	100	500
Bottom plants phosphorus half saturation constant (µg P/L)	25	100
Bottom plants inorganic carbon half saturation constant (moles/L)	1.30E-06	1.30E-04
Bottom plants light constant (langleys/d)	40	110
Bottom plants ammonia preference (µg N/L)	15	30
Bottom plants subsistence quota for nitrogen (mg N/g)	7.2	36
Bottom plants subsistence quota for phosphorus (mg P/g)	1	5
Bottom plants maximum uptake rate for nitrogen (mg N/g/d)	350	1500
Bottom plants maximum uptake rate for phosphorus (mg P/g/d)	50	200
Bottom plants internal nitrogen half sat ratio (unitless)	1.05	5
Bottom plants internal phosphorus half sat ratio (unitless)	1.05	5
Bottom plants nitrogen uptake water column fraction (unitless)	0	1
Bottom plants phosphorus uptake water column fraction (unitless)	0	1
Detritus dissolution rate (1/d)	0.05	0.5
Detritus dissolution rate temperature correction (unitless)	1.07	1.07
Detritus settling velocity (m/d)	0.05	2
Manning's n HW (unitless)	0.02	0.8
Manning's n Segment 1 (unitless)	0.02	0.8
Manning's n Segment 2 (unitless)	0.02	0.8
Manning's n Segment 3 (unitless)	0.02	0.8
Manning's n Segment 4 (unitless)	0.02	0.8
Manning's n Segment 5 (unitless)	0.02	0.8
Manning's n Segment 6 (unitless)	0.02	0.8
Manning's n Segment 7 (unitless)	0.02	0.8
Manning's n Segment 8 (unitless)	0.02	0.8
Bottom Algal cover Segment 1 (%)	0	100
Bottom Algal cover Segment 2 (%)	0	100
Bottom Algal cover Segment 3 (%)	0	100
Bottom Algal cover Segment 4 (%)	0	100
Bottom Algal cover Segment 5 (%)	0	100
Bottom Algal cover Segment 6 (%)	0	100
Bottom Algal cover Segment 7 (%)	0	100
Bottom Algal cover Segment 8 (%)	0	100
SOD cover Segment 1 (%)	0	100
SOD cover Segment 2 (%)	0	100
SOD cover Segment 3 (%)	0	100
SOD cover Segment 4 (%)	0	100
SOD cover Segment 5 (%)	0	100
SOD cover Segment 6 (%)	0	100
SOD cover Segment 7(%)	0	100
SOD cover Segment 8 (%)	0	100
Nitrate loading Segment 1 (µg N/L)	0	428
Nitrate loading Segment 2 (µg N/L)	0	448

Parameter	Minimum value	Maximum value
Nitrate loading Segment 3 (μg N/L)	0	472
Nitrate loading Segment 4 (μg N/L)	0	363
Nitrate loading Segment 5 (μg N/L)	0	442
Nitrate loading Segment 6 (μg N/L)	0	339
Nitrate loading Segment 7 (μg N/L)	0	299
Nitrate loading Segment 8 (μg N/L)	0	333
Buttermilk Creek - Nitrate (μg N/L)	0	371
Bales Creek - Nitrate (μg N/L)	0	313
Little Elk Creek - Nitrate (μg N/L)	0	370
Thorton Creek - Nitrate (μg N/L)	0	388
Bottom Plant AFDM Segment 1 (g/m^2)	1	50
Bottom Plant AFDM Segment 2 (g/m^2)	1	50
Bottom Plant AFDM Segment 3 (g/m^2)	1	50
Bottom Plant AFDM Segment 4 (g/m^2)	1	50
Bottom Plant AFDM Segment 5 (g/m^2)	1	50
Bottom Plant AFDM Segment 6 (g/m^2)	1	50
Bottom Plant AFDM Segment 7 (g/m^2)	1	50
Bottom Plant AFDM Segment 8 (g/m^2)	1	50
Bottom Plant C/N ratio Segment 1 (mol/mol)	20	40
Bottom Plant C/N ratio Segment 2 (mol/mol)	20	40
Bottom Plant C/N ratio Segment 3 (mol/mol)	20	40
Bottom Plant C/N ratio Segment 4 (mol/mol)	20	40
Bottom Plant C/N ratio Segment 5 (mol/mol)	20	40
Bottom Plant C/N ratio Segment 6 (mol/mol)	20	40
Bottom Plant C/N ratio Segment 7 (mol/mol)	20	40
Bottom Plant C/N ratio Segment 8 (mol/mol)	20	40

4.3.2.5 QUAL2Kw sensitivity analysis

DEQ examined the final model sensitivity to slight changes in calibrated parameters. DEQ used the companion add-on (called YASAIw), that was supplied with the QUAL2Kw Microsoft Excel workbook, to vary the selected auto-calibrated parameters ±5%. The procedure works by setting upper and lower bounds on each auto-calibrated parameter (±5%) and running the QUAL2Kw model 1,000 iterations. During each of the 1,000 model runs, a value for each auto-calibrated model parameter is picked randomly from a uniform distribution, defined by the upper and lower bounds, for each parameter.

The resulting effect of varying each parameter during each model run was averaged across all model iterations to estimate change in DO. DEQ specifically targeted the change in DO at 6 AM (daily minimum) and at 3 PM (daily maximum) on 26 July 2016 at the three downstream monitoring stations (stations 33112-ORDEQ, 12301-ORDEQ, and 11476-ORDEQ) as the comparisons.

4.3.3 Nutrient inputs from HPSF to QUAL2Kw

For the Upper Yaquina Watershed, QUAL2Kw was linked to the HSPF model outputs of flow accumulation and nutrient loading to estimate the degree to which in-stream physical, chemical and biological processes influenced DO concentration and saturation in the Upper Yaquina River. Outputs from the calibrated HSPF model, which covered 1996 through 2014, provided land-based sources of nutrient loading to the Upper Yaquina River QUAL2Kw model. To use

HSPF model outputs, DEQ queried the 18 years of daily simulations by narrowing the dataset to within ±2 weeks of the Julian day used for QUAL2Kw model simulation (26 July) and ±2 cfs of the observed flow at the OWRD gauging station at Chitwood (14306030 Yaquina R near Chitwood, OR; ODEQ station ID 11476). Applying these criteria returned 46 individual days of nutrient loading outputs for flows similar to 26 July 2016. DEQ averaged flow and loads of inorganic and organic N and P to use as inputs to the QUAL2Kw model reach. Coefficients of variation for flow and nutrient loads from these subsets were <10%. Figure 4.3.3a, Figure 4.3.3b and Figure 4.3.3c present the results and model segments and major tributary inputs are marked on the figures.

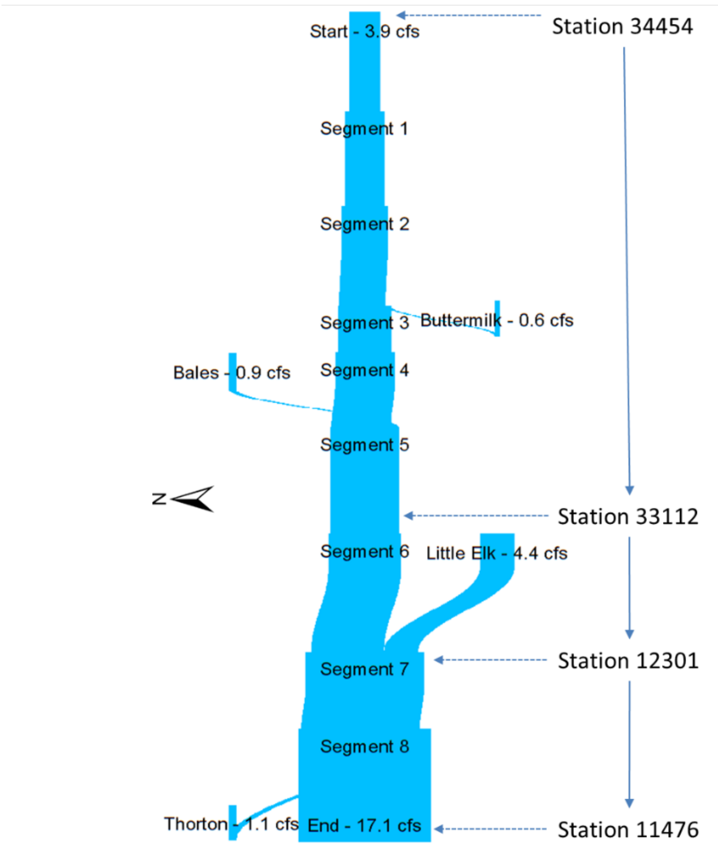


Figure 4.3.3a: Flow accumulation and abstraction along the model reach - Upper Yaquina River

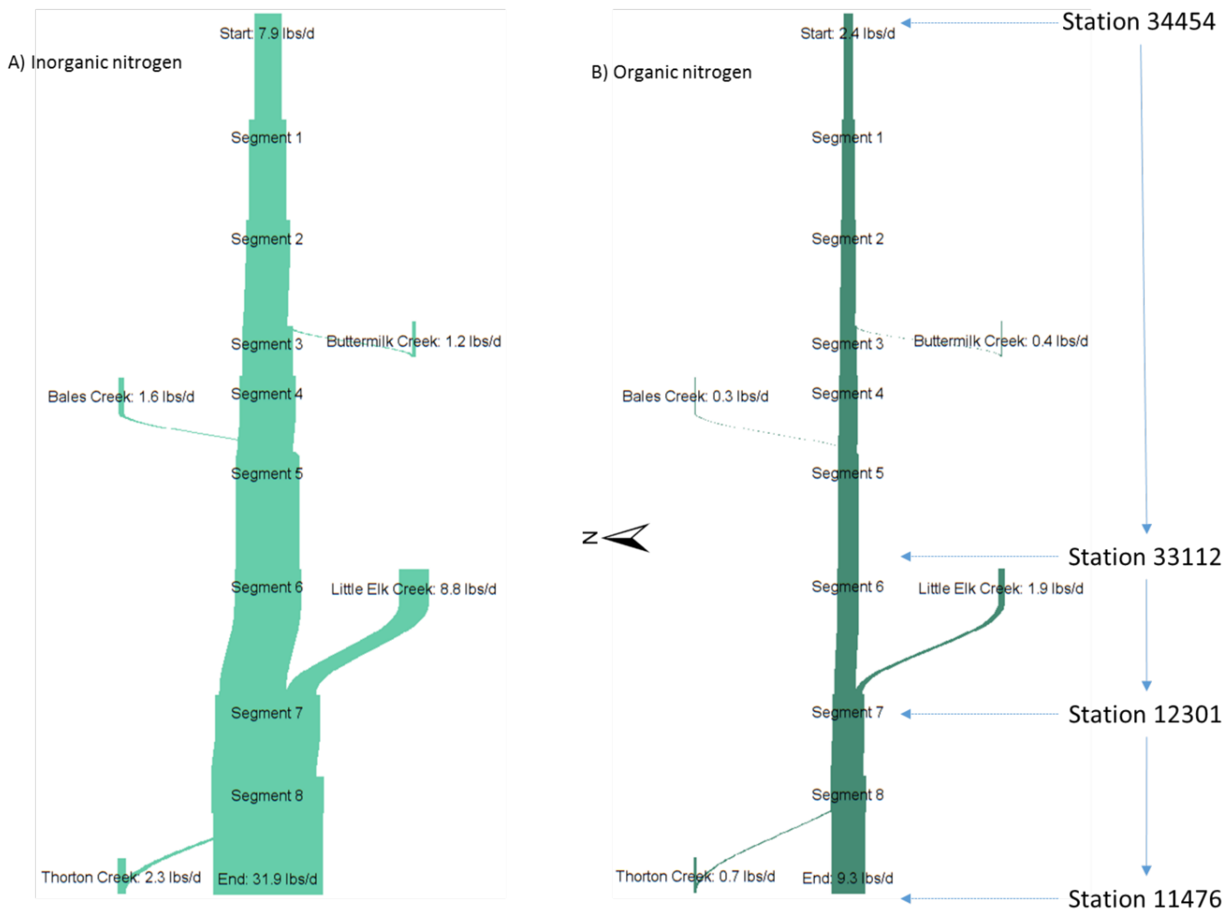


Figure 4.3.3b: Inorganic and organic nitrogen loading along the model reach - Upper Yaquina River

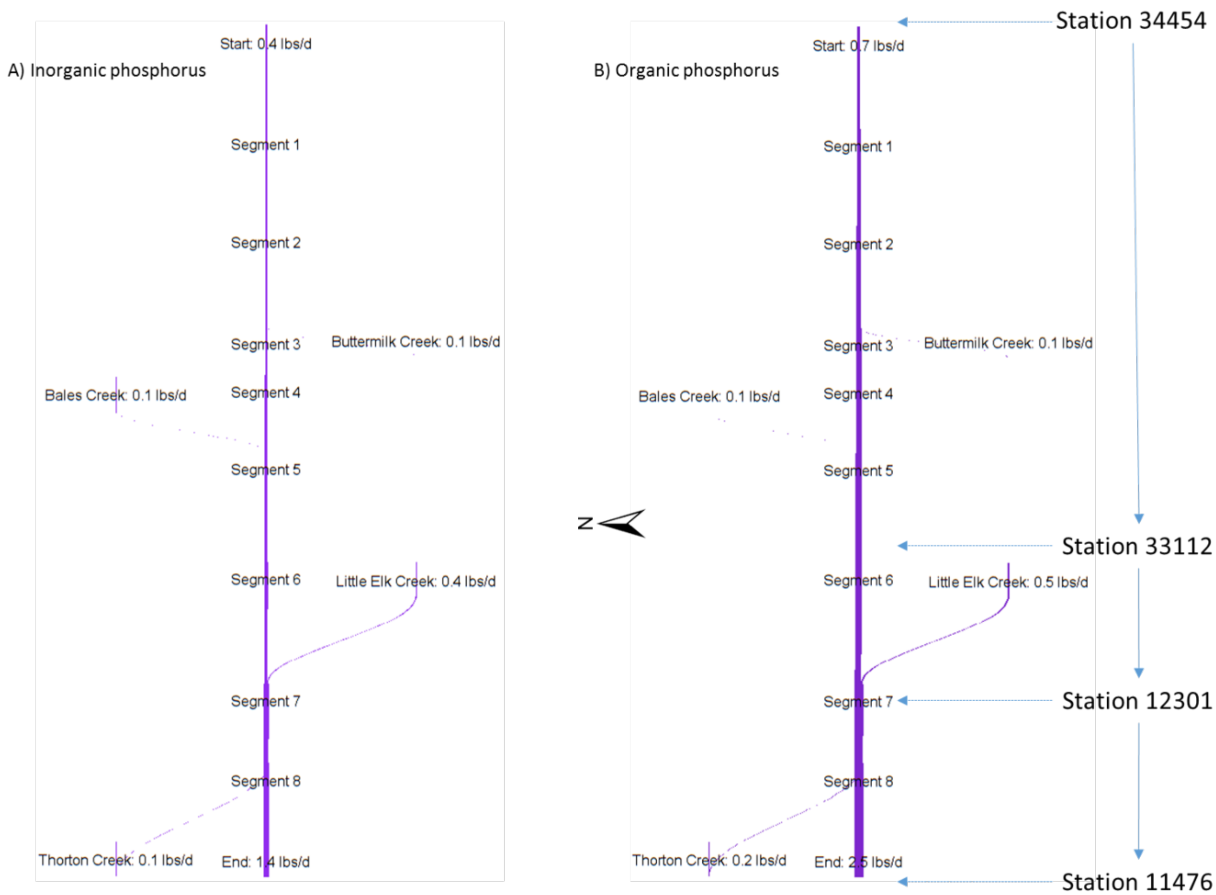


Figure 4.3.3c: Inorganic and organic phosphorus loading along the model reach - Upper Yaquina River

4.3.4 Effective shade modeling and heat flux

DEQ calculated effective shade and the fraction of the channel exposed to the sky using LiDAR data collected in the Mid-Coast region in 2011-2012. Effective shade refers to the amount of solar energy blocked by vegetation and topography. The fraction of the channel surface area exposed to the sky (view to sky) is used to calculate exchange of heat between the water column and atmosphere via longwave radiation. To calculate these parameters, DEQ used the TTools package and Heat Source model developed by DEQ (Michie, Heat Source 9, 2019; Michie, TTools, 2019). These tools use LiDAR-derived bare earth elevation and surface elevation (which includes vegetation and structures) along with estimated canopy density to calculate topographic and vegetation shading to a designated stream reach.

Outputs describing topographic and vegetation elevation generated by TTools are used as inputs to the Shade-a-lator submodel in the Heat Source model. This submodel calculates the potential amount of solar radiation reaching the surface of the stream segement ($SR_{Potential}$), the actual amount of solar radiation reaching the surface (SR_{Actual}), and the fractional area of the stream channel open to the sky on an hourly basis for a specified Julian day. Effective shade (*ES*) can be calculated for each hour of the simulation day in the reach with the following equation:

Equation 4.3.4: $$ES = \left(1 - \frac{SR_{Actual}}{SR_{Potential}}\right) * 100$$

For each model segment, DEQ calculated effective shade and the fraction of sky opening at 164-ft (50-m) increments and averaged these incremental values for every hour of the simulation period to arrive at an average effective shade value for the entire reach segment.

Other important parameters for determining heat flux within the QUAL2Kw model reach include sediment thermal characteristics, parameters describing light input and coefficients describing transfer of heat on the surface of the stream (Pelletier, Chapra, & Tao, 2006). DEQ used default values recommended by the model authors (set in the input worksheet) except for sediment thermal characteristics. For sediment thermal characteristics, DEQ set sediment thermal conductance to 4.18 W/m/°C to reflect sandstone geology and sediment thermal diffusivity to 0.0064 cm^2/s to reflect sedimentary material (Pelletier, Chapra, & Tao, 2006).

To characterize the temperature of deep sediments in the model reach, DEQ calculated the average annual air temperature for the Upper Yaquina Watershed in the year 2015 from PRISM data (Daly, et al., 2008). DEQ used 2015 rather than take the average of the previous 30 years (30-year normal; commonly used in analysis of regional climate), because the year 2015 was nearly 1 °C warmer than the 30-year normal (1980 – 2010) for the basin. This is consistent with climate projections of warmer summers in the coming century (IPCC, 2014).

Simulation of the transfer of heat from the atmosphere to the stream relies on meteorological data. The nearest weather station with hourly temperature, dew point, wind speed and cloud cover data are located in Newport, Oregon. Because coastal weather often differs significantly from weather in the interior Coast Range, DEQ used daily data downloaded from PRISM (Daly, et al., 2008) to calculate temperature, dew point and cloud cover for the Upper Yaquina Watershed. DEQ set wind to zero, assuming that the topography and riparian vegetation would limit wind compared to the coast (Newport), where substantial wind was recorded for the day of simulation.

Temperature of groundwater and tributary inputs to the model reach were set to the in-stream temperature measured at the upstream monitoring station because data for these inputs were not available.

4.3.5 Flow and channel dimension data and analysis

DEQ measured width, depth and slope at each of the DEQ monitoring locations to build power law models that related each of these variables to model reach kilometer. These models were used to estimate width, depth and slope at locations within the model reach.

In addition, daily mean flows were recorded at Oregon Water Resources Division gaging station 14306030, which is the same location as DEQ continuous monitoring station 11476. All monitoring locations are shown on (Figure 4.2.1a).

Table 4.3.5: Width, average depth and slope measurements at monitoring stations - Upper Yaquina River

Station	River model mile (km)	Width (ft)	Average depth (ft)	Slope (%)
34454-ORDEQ	21.10 (33.95)	20.80	0.50	0.480
33112-ORDEQ	10.06 (16.20)	31.00	0.96	0.175
12301-ORDEQ	7.24 (11.65)	NA	NA	0.196
11476-ORDEQ	0 (0)	74.01	1.46	0.125

The equations for scaling width across the model reaches was:

Equation 4.3.5: $\boldsymbol{ln(W) = 3.02384 - 0.03714x}$

Where *W* is stream wetted width (meters) and *x* is River kilometer. Units were converted from metric to English units using standard conversions.

Figure 4.3.5a presents simulated discharge (represented by a line) and discharge measured 26 July 2016 (represented as points) moving from upstream to downstream from left to right. This figure demonstrates that simulated discharge increased fivefold from upstream to downstream along the study reach and compared well with measured values.

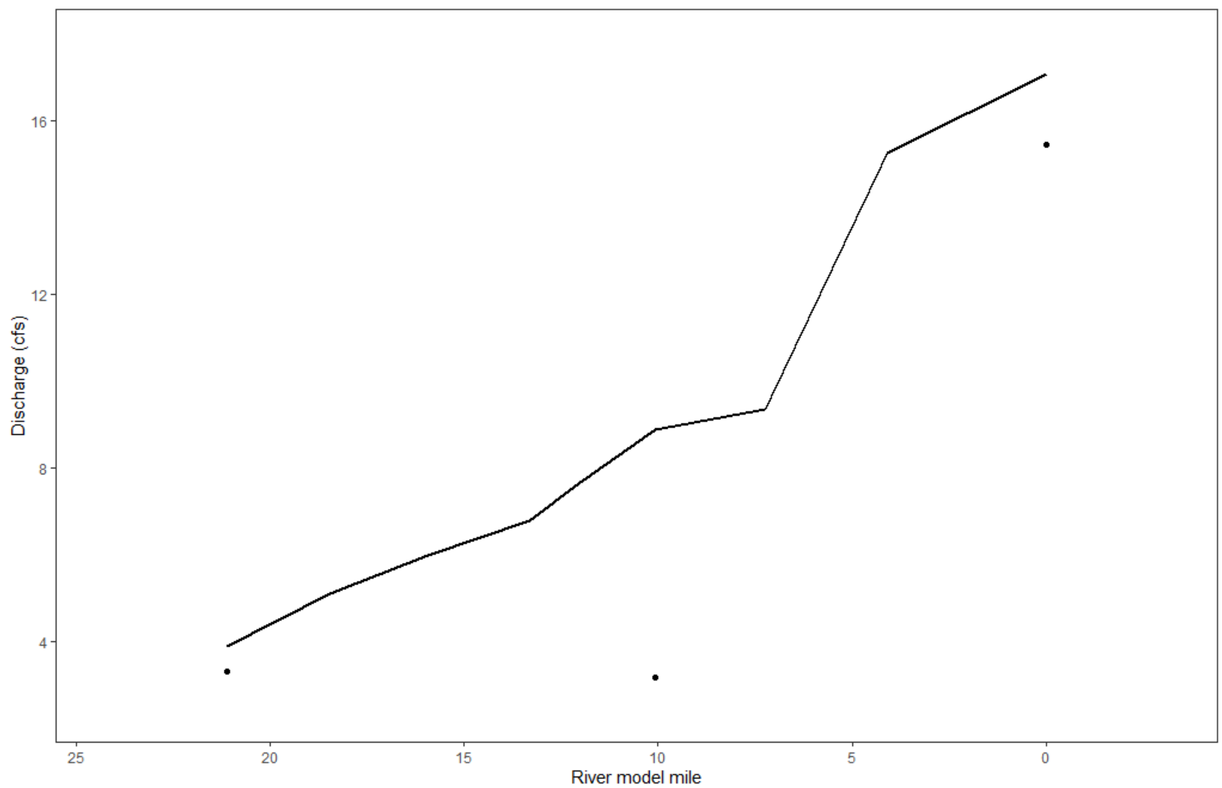


Figure 4.3.5a: Simulated and measured discharge along the model reach - Upper Yaquina River

Manning's n was simulated to generally increase from upstream to downstream, with peak values at model mile 7.24, as shown in Figure 4.3.5b, moving from upstream to downstream from left to right.

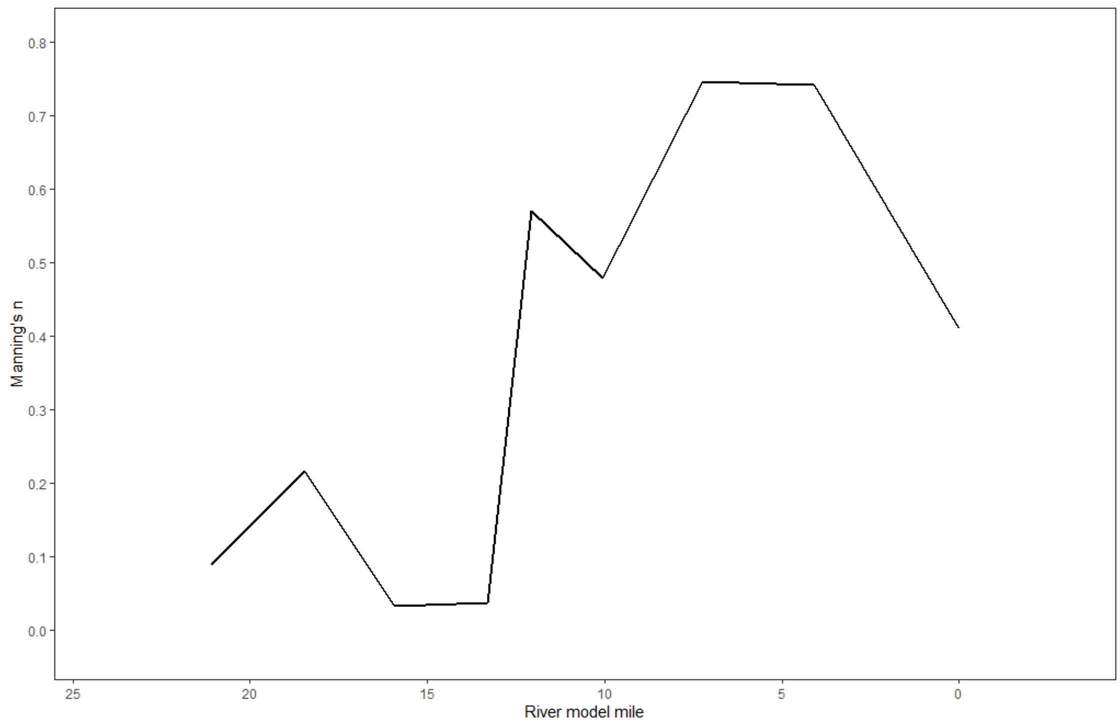


Figure 4.3.5b: Manning's n values from calibration in model reach - Upper Yaquina River

Reaeration of dissolved oxygen, in contrast, strongly peaked in the upper segments of the simulation reach and decreased markedly downstream of model mile 12.4, as shown in Figure 4.3.5c, moving from upstream to downstream from left to right.

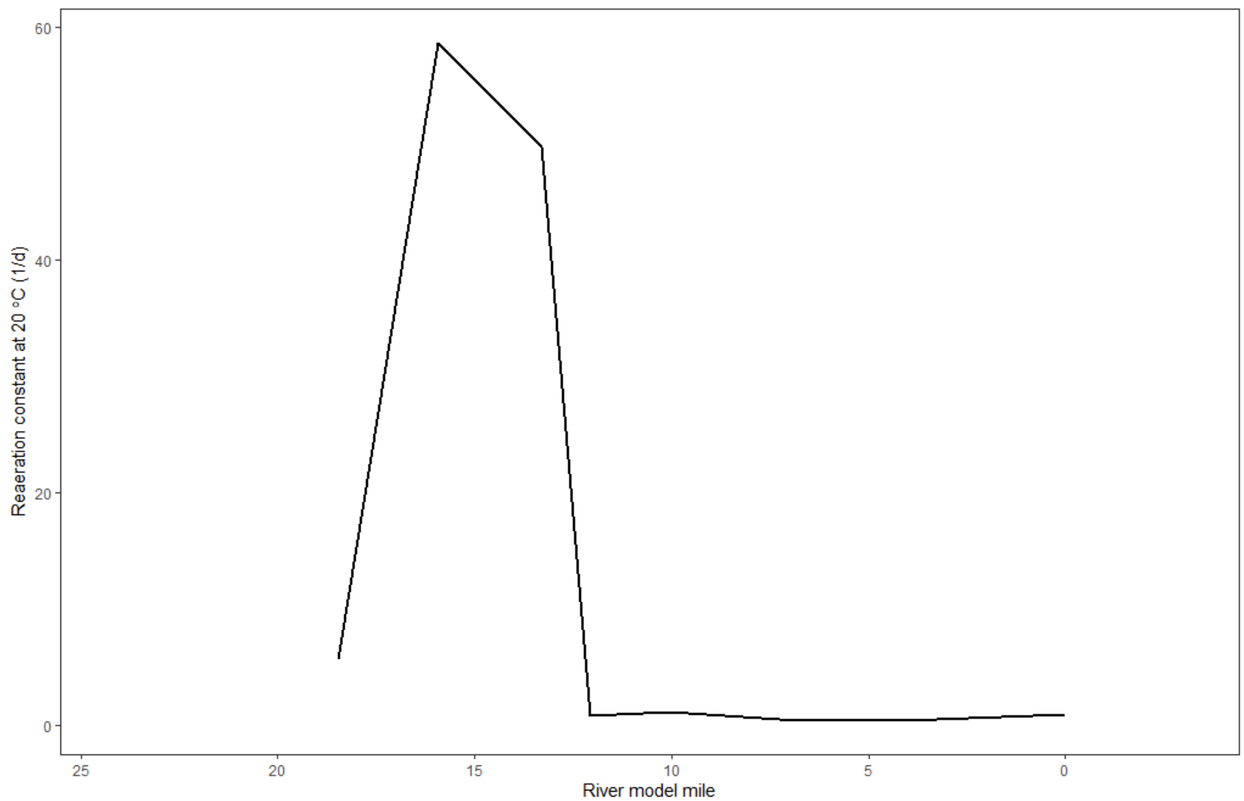


Figure 4.3.5c: Reaeration coefficient for dissolved oxygen from calibration in model reach -Upper Yaquina River

4.3.6 Effective shade results

Figure 4.3.6a, moving from upstream to downstream from left to right, shows hourly effective shade from riparian vegetation and topographic features along the model reach, as the mean for individual model segments. Hourly effective shade estimates generally showed that upper portions of the model reach experienced higher levels of effective shade for most of the day (until 20:00), as shown in Figure 4.3.6a. The lowest levels of effective shade occurred between 11:00 and 14:00 in the middle portions of the reach. Before 09:00 and after 17:00, effective shade was consistently above 80% across the entire reach.

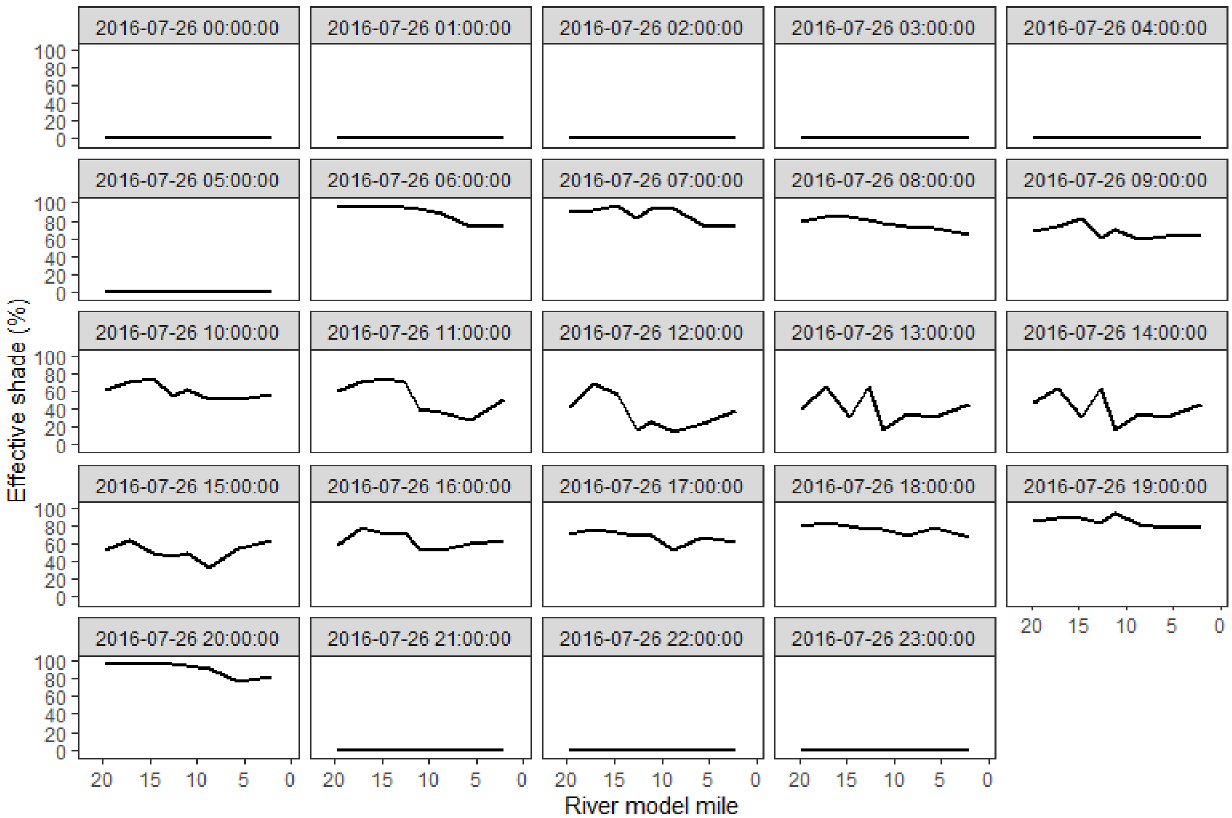


Figure 4.3.6a: Hourly effective shade from riparian vegetation and topographic features along the model reach - Upper Yaquina River

As shown in Figure 4.3.6b, moving upstream to downstream from left to right, the unshaded view to sky along the reach for 26 July 2016 fluctuated slightly around 60%, with the lowest percent of view to sky in the most upstream reaches.

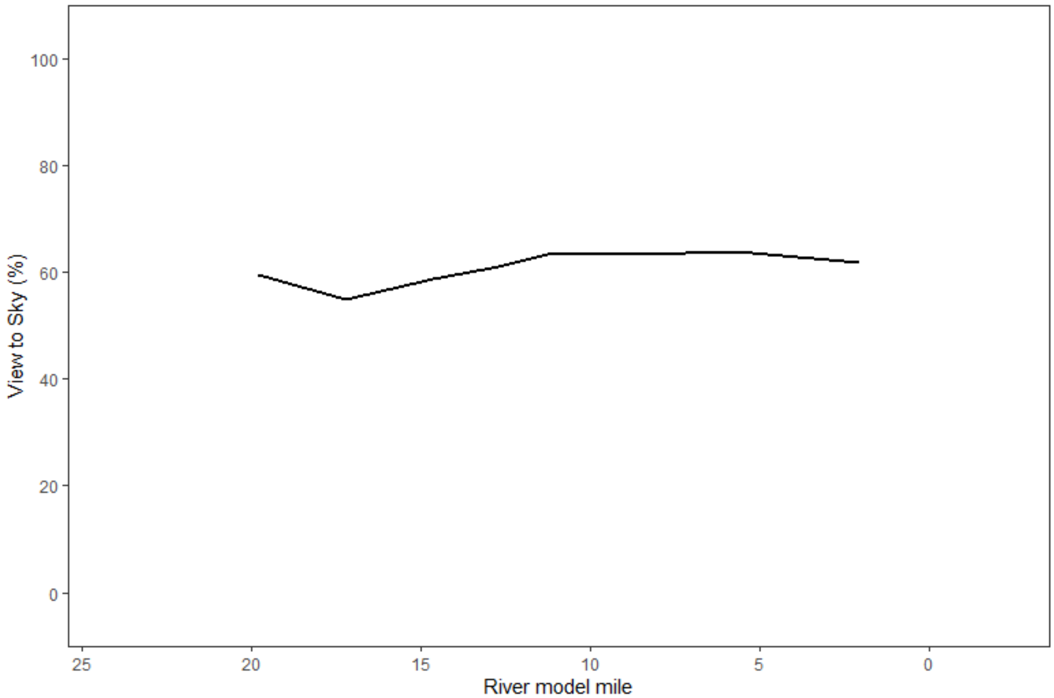


Figure 4.3.6b: Unshaded view to sky along the model reach - Upper Yaquina River

4.3.7 Diel simulations

The final calibrated QUAL2Kw model included an overall RMSCV for DO at three hour increments in the model day (26 July 2016) of 5.3% across the three downstream monitoring stations, as presented in Table 4.3.7a. At station 12301-ORDEQ, which had the most frequent and severe DO excursions from the applicable criteria, RMSCV was 6.3%, although RMSCV was 0.8 to 2.2% during the time (12 AM – 6 AM) with the lowest DO concentrations. At 6 AM, which corresponded to the minimum DO concentrations across monitoring stations, the mean RMSCV across stations was 3.2%.

Table 4.3.7a: Root Mean Square Coefficient of Variation for simulated dissolved oxygen - Upper Yaquina River

	Root Mean Square Coefficient of Variation (%)								
Station	**12 AM**	**3 AM**	**6 AM**	**9 AM**	**12 PM**	**3 PM**	**6 PM**	**9 PM**	**Overall**
33112-ORDEQ	7.2	3.5	0.4	5.2	0.4	0.3	5.4	11.2	5.5
12301-ORDEQ	2.2	2.5	0.8	6.8	10.1	8.1	7.7	2.7	6.3
11476-ORDEQ	2.5	4.2	5.2	6.3	1.8	5.5	3.7	0.6	4.1
Overall:	4.6	3.5	3.2	6.1	5.6	5.4	5.7	6.7	5.3

The final model adequately simulated diel cycles in both DO and temperature across all monitoring sites, as presented in Figure 4.3.7a, where the blue line indicates the cold water dissolved oxygen criterion of 8 mg/L (OAR-041-0016), and Figure 4.3.7b. Both figures present measured diel values with black dots and simulated diel values with black lines. In general, cyclical patterns at Station 12301-ORDEQ (Eddyville) were simulated most accurately with respect to measured data. At station 33112-ORDEQ (Nashville Road), minimum and maximum DO concentrations were simulated accurately; but the timing of the minimum and maximum values were shifted approximately one hour later than what was observed. Simulations of diel cycles in DO were dampened compared to measured data at the most downstream sampling station (11476-ORDEQ, Chitwood), indicating that the model underestimated the DO range in the diel cycle.

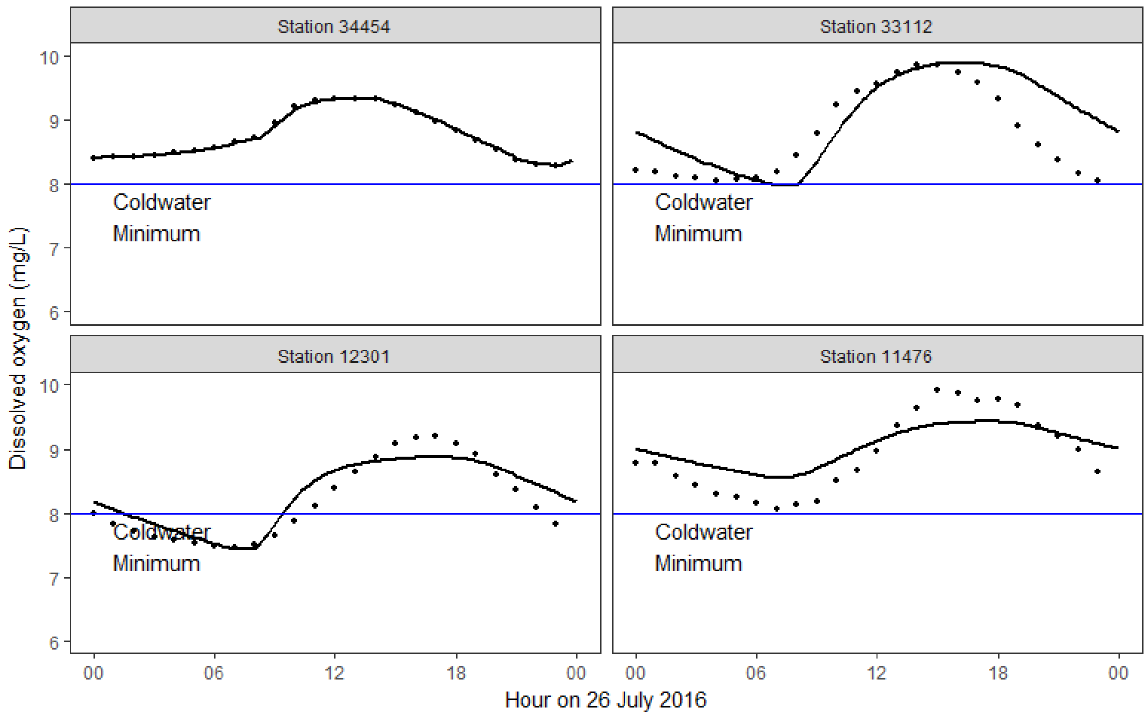


Figure 4.3.7a: Diel patterns in measured and modeled DO values - Upper Yaquina River

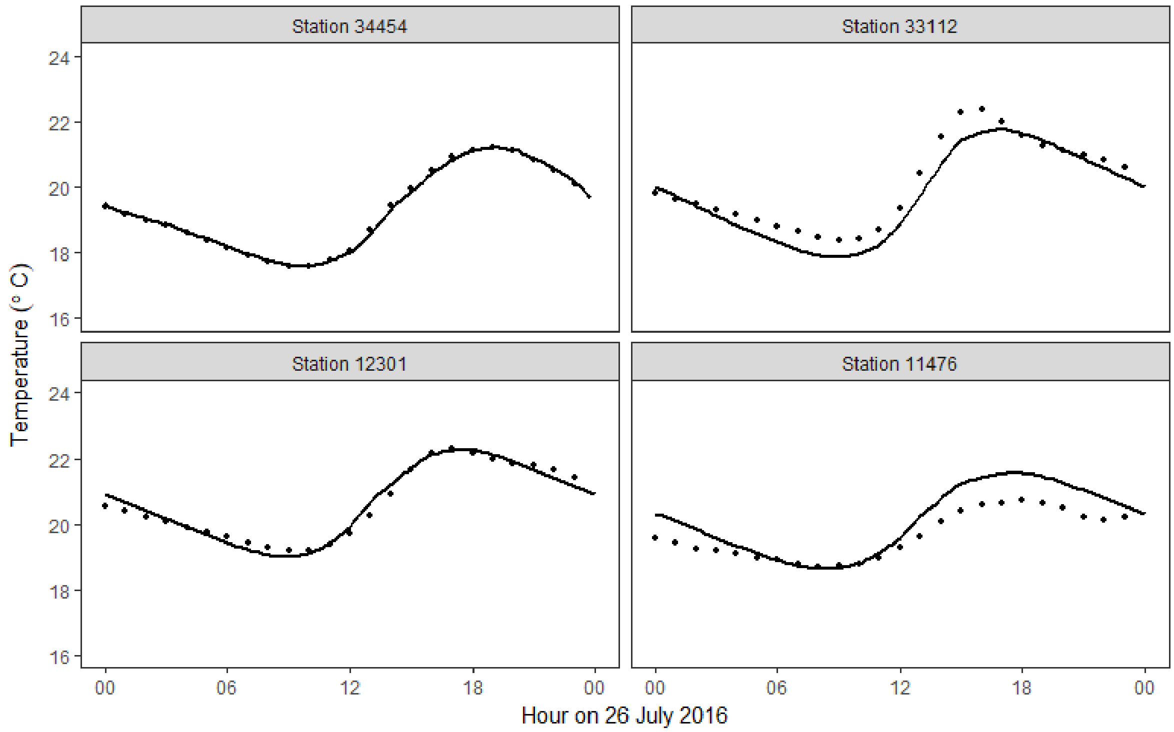


Figure 4.3.7b: Diel patterns in measured and modeled temperature values - Upper Yaquina River

4.3.8 Longitudinal simulations

Longitudinal patterns of dissolved oxygen, temperature and nutrients simulated by the QUAL2Kw model fit the calibration dataset well. Simulations of DO suggest a spike in maximum DO immediately downstream of the most upstream monitoring station due to modeled high aquatic productivity, as presented in Figure 4.3.8a. The figure presents DO means measured on 26 July 2016 as black dots with bars indicating maximum and minimum values and modeled means as the solid back line with dashed lines representing maximum and minimum values. The minimum simulated DO increased for the first few kilometers downstream of the start of the reach and then steadily decline to station 12301 (Eddyville). Downstream of 12301, minimum simulated DO increased to the end of the model reach (station 11476). Minimum DO levels fell below the standard of 8.0 mg/L just upstream of station 33112 and remained below the standard to station 12301.

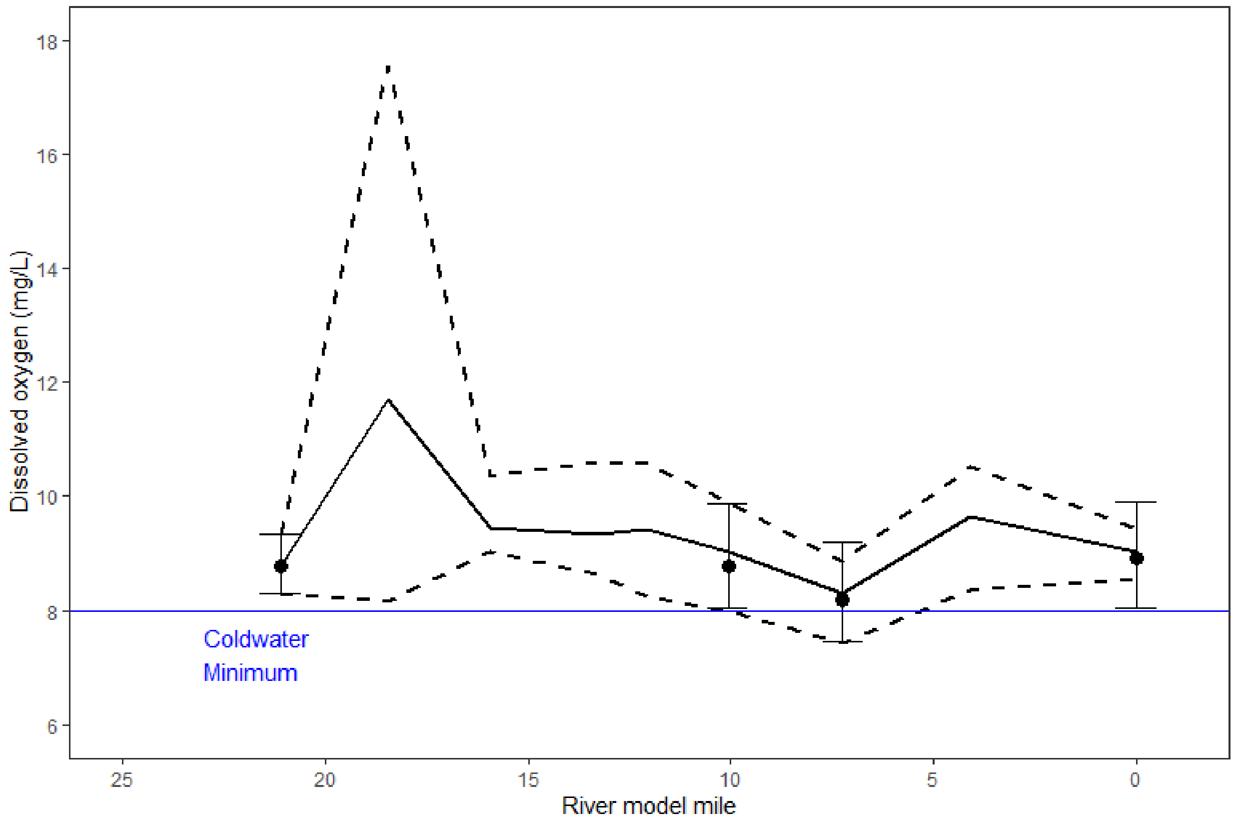


Figure 4.3.8a: Longitudinal patterns in measured and modeled dissolved oxygen - Upper Yaquina River

Longitudinal temperature patterns in the model reach suggest that diel temperature fluctuations were largest in the reaches between the most upstream station (34454) and station 33112 (Nashville Road). Minimum simulated temperatures were lowest here; but maximum temperatures were also simulated to be warmest, as shown in Figure 4.3.8b. The figure presents DO means measured on 26 July 2016 as black dots with bars indicating maximum and minimum values and modeled means as the solid back line with dashed lines representing maximum and minimum values. Downstream of station 33112, diel fluctuations in temperature stabilized downstream to the end of the model reach according to the simulations.

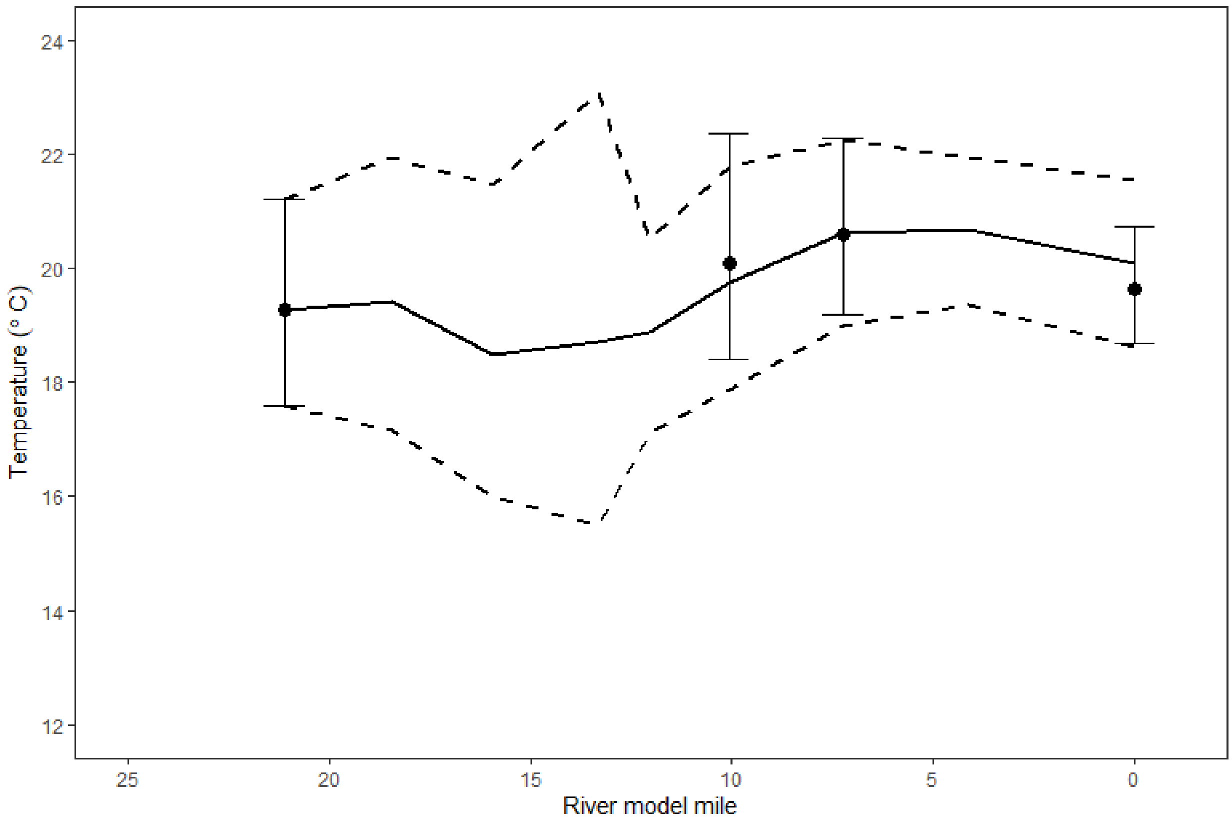


Figure 4.3.8b: Longitudinal patterns in measured and modeled dissolved oxygen - Upper Yaquina River

Simulations of nutrient dynamics are presented in Figures 4.3.8c through 4.3.8g, which depict measured nutrient values as black dots and modeled values as a solid black line. Measured data were collected twice daily from 19 – 26 July 2016; the model was run for 26 July 2016. For nitrate, concentrations dropped slightly downstream of the most upstream station (34454-ORDEQ) and then increased to peak at station 33112-ORDEQ, as presented in Figure 4.3.8c.

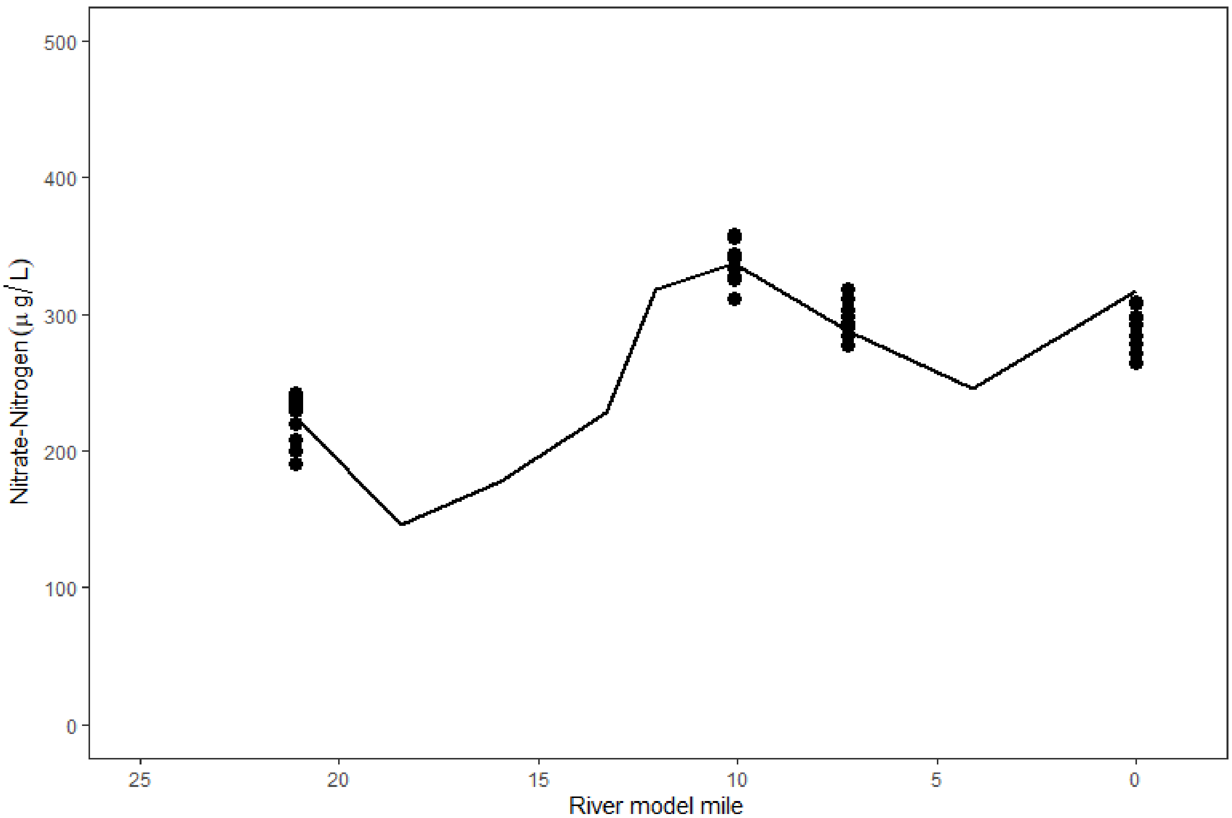


Figure 4.3.8c: Longitudinal patterns in measured and modeled values of nitrate-nitrogen - Upper Yaquina River

Downstream of 33112-ORDEQ, simulated nitrate declines for several kilometers and then stabilize to the end of the model reach. Simulations of ammonium showed a much more dynamic change. Downstream of station 34454-ORDEQ, ammonium concentrations were simulated to spike over 200 μg NH_4-N/L and then rapidly decline to slightly above the measured concentrations of ~ 10-20 μg NH_4-N/L, as shown in Figure 4.3.8d.

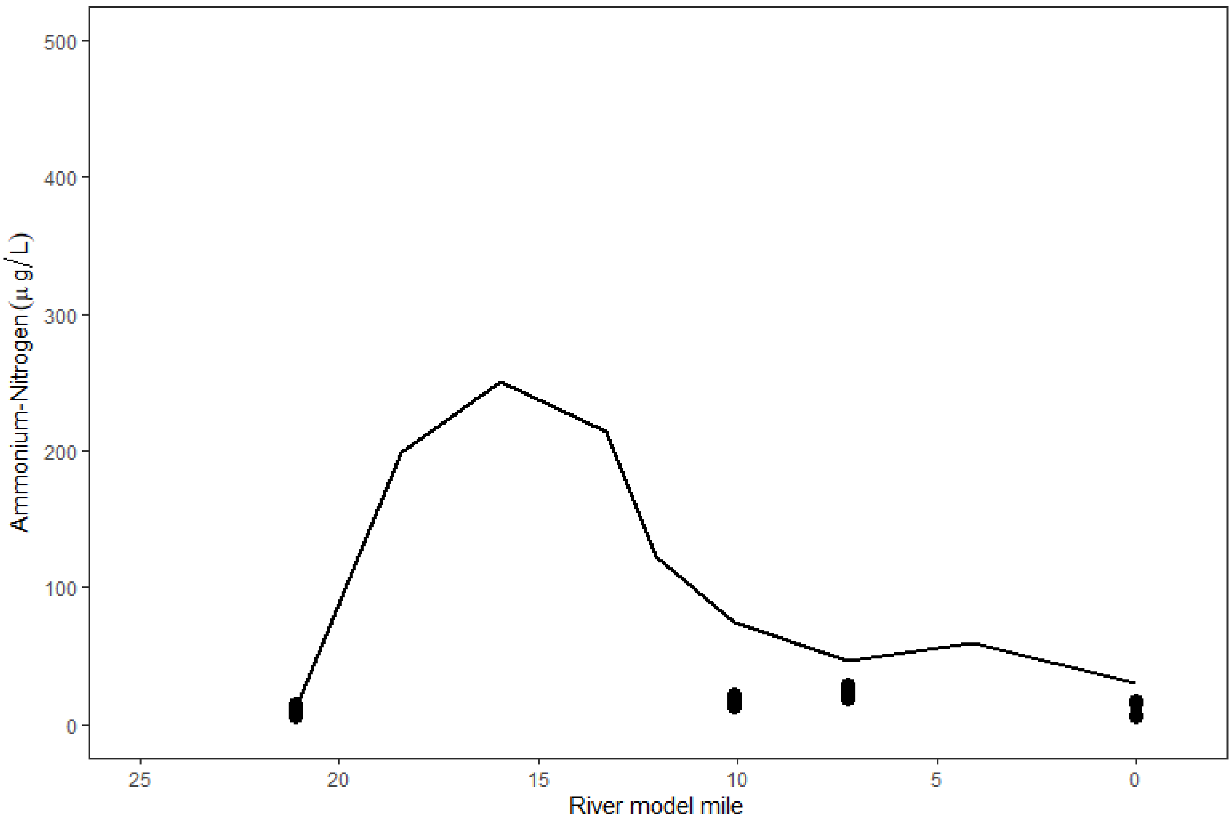


Figure 4.3.8d: Longitudinal patterns in measured and modeled values of ammonium-nitrogen - Upper Yaquina River

Simulated organic N also spiked above 400 µg N/L downstream of station 34454 and then fall to the measured levels of 100 – 300 µg N/L downstream, as shown in Figure 4.3.8e.

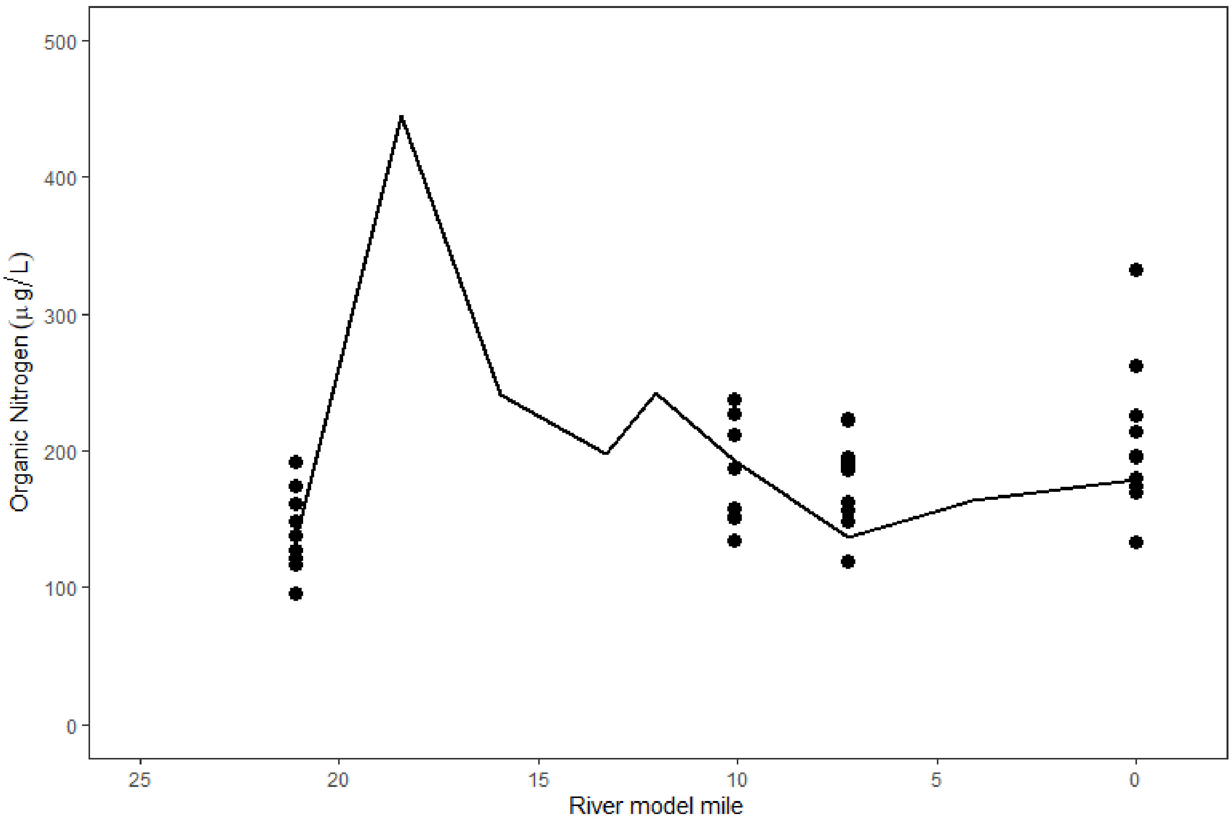


Figure 4.3.8e: Longitudinal patterns in measured and modeled values of organic nitrogen - Upper Yaquina River

Simulations of inorganic P were less consistent with measured data and showed a sharp drop downstream of the model reach start, as shown in Figure 4.3.8f. However, measured inorganic P levels were quite low, and the absolute difference between simulated and measured inorganic P was nearly the same as for N species.

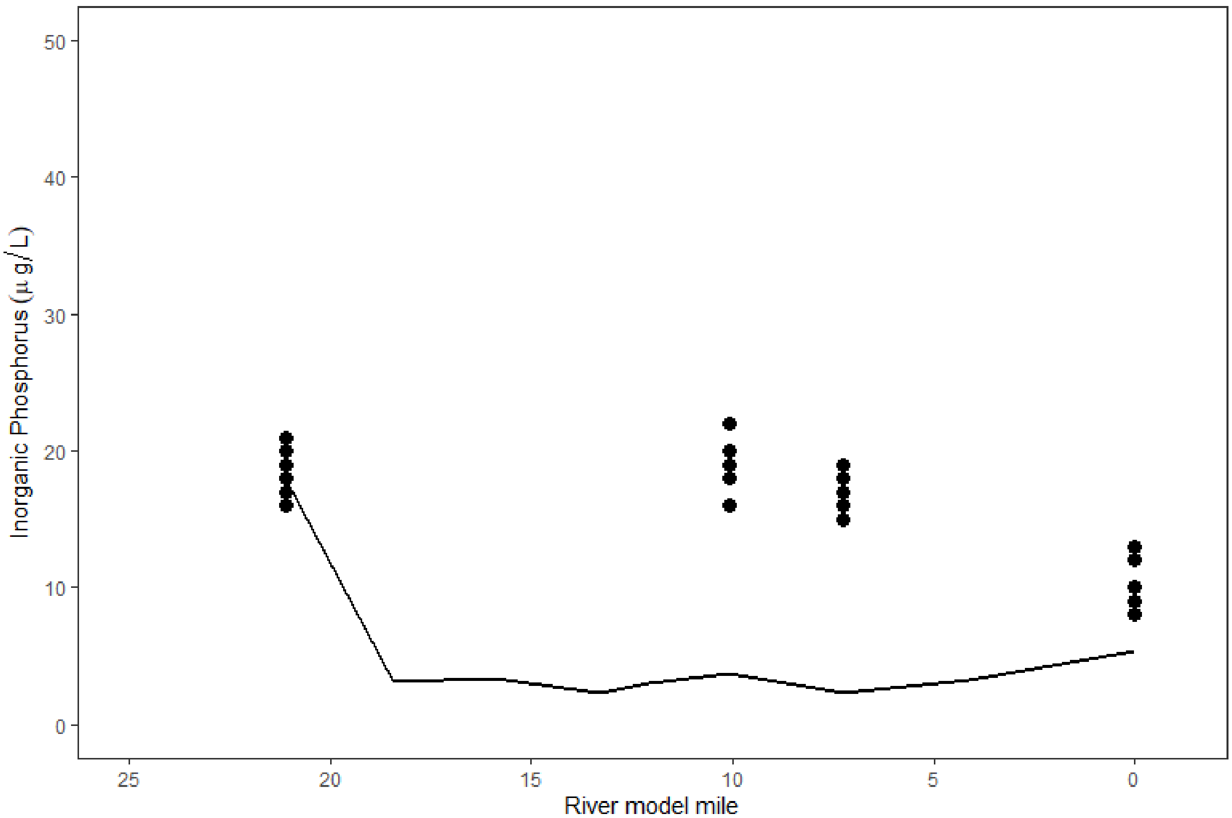


Figure 4.3.8f: Longitudinal patterns in measured and modeled values of inorganic phosphorus - Upper Yaquina River

The longitudinal pattern in organic P simulations showed a similar pattern to that of organic N, albeit smaller in magnitude, as presented in Figure 4.3.8g.

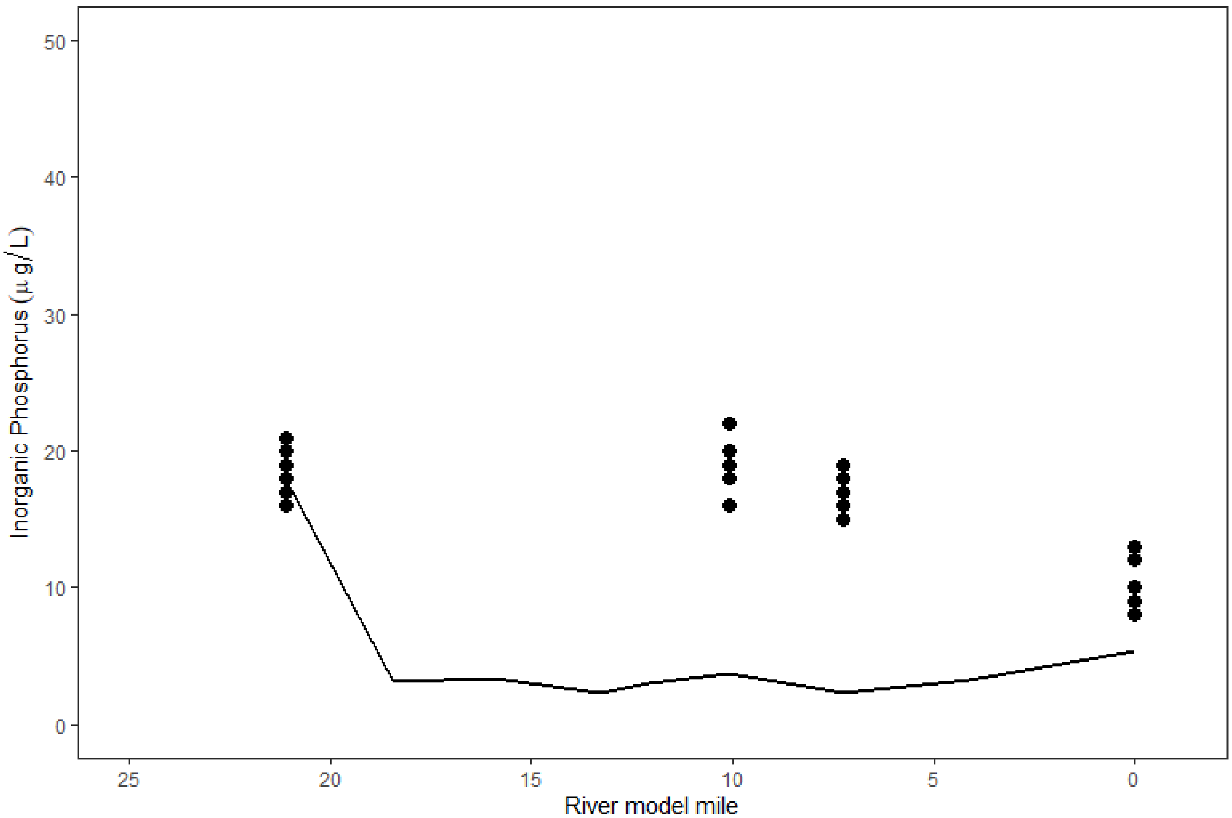


Figure 4.3.8g: Longitudinal patterns in measured and modeled values of organic phosphorus - Upper Yaquina River

4.3.9 Flux of dissolved oxygen and limiting factors at Station 12301

Because exceedances of the applicable DO criterion occurred most frequently and severely at station 12301 (Eddyville), DEQ provides a more detailed description of the DO fluxes modeled by QUAL2Kw in the calibrated model, as shown in Figure 4.3.9a. Periphyton photosynthesis was the largest influx of DO over the course of the simulation day. Advection/dispersion was a constant loss over the course of the simulation day while periphyton peaked as the largest outflux of DO at the same time as peak periphyton photosynthesis. Simulated DO fluxes, whether in- or out-fluxes, were insignificant from oxidation of fast and slow CBOD, nitrification, reaeration, sediment oxygen demand and tributary/groundwater inputs.

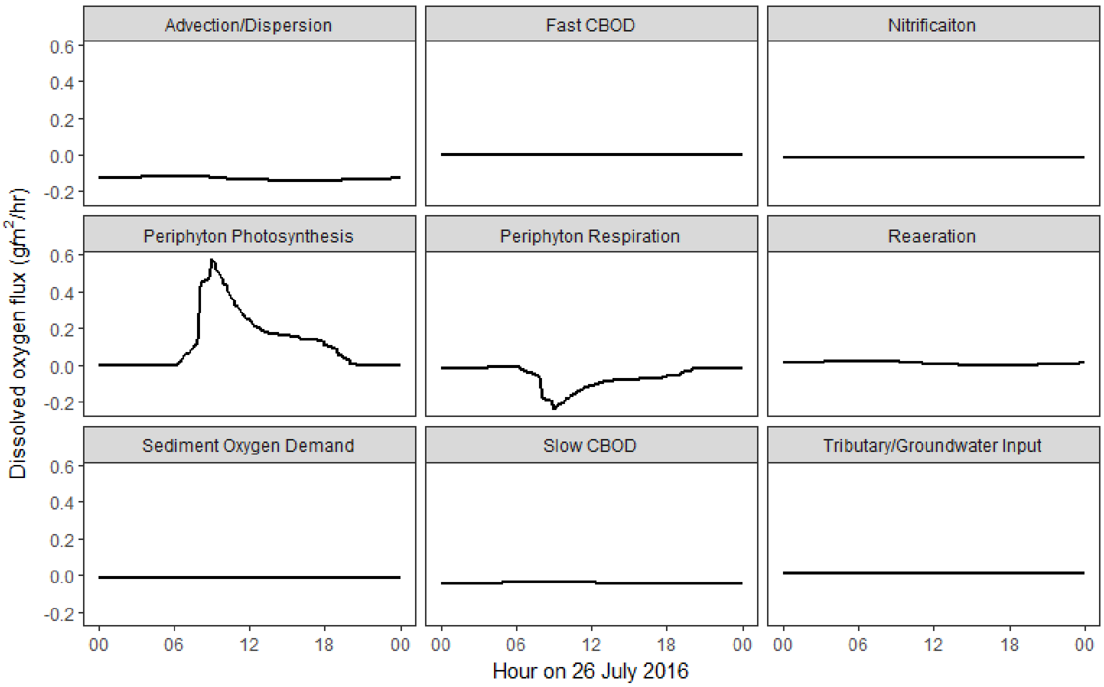


Figure 4.3.9a: Dissolved oxygen fluxes in model Reach 6 immediately upstream of station 12301 (Eddyville)

Because dynamics of periphyton productivity (gross primary production and respiration) provided the largest fluxes of DO in the model segment upstream of station 12301-ORDEQ, DEQ examined which factors limited periphyton growth in this reach. Two factors, light and P availability, most strongly limited periphyton productivity over the course of the simulation day in the reach upstream of station 12301-ORDEQ, as shown in Figure 4.3.9b, where values are the percent of potential productivity with the factor designated in the panel. Over the full 24-hour period of the simulation, P availability was the most limiting factor to periphyton productivity. Light limited periphyton productivity in the morning and afternoon hours. N availability also limited periphyton productivity, but not to the degree of P availability or light based on current conditions. Carbon availability and temperature had no substantial effects on periphyton productivity.

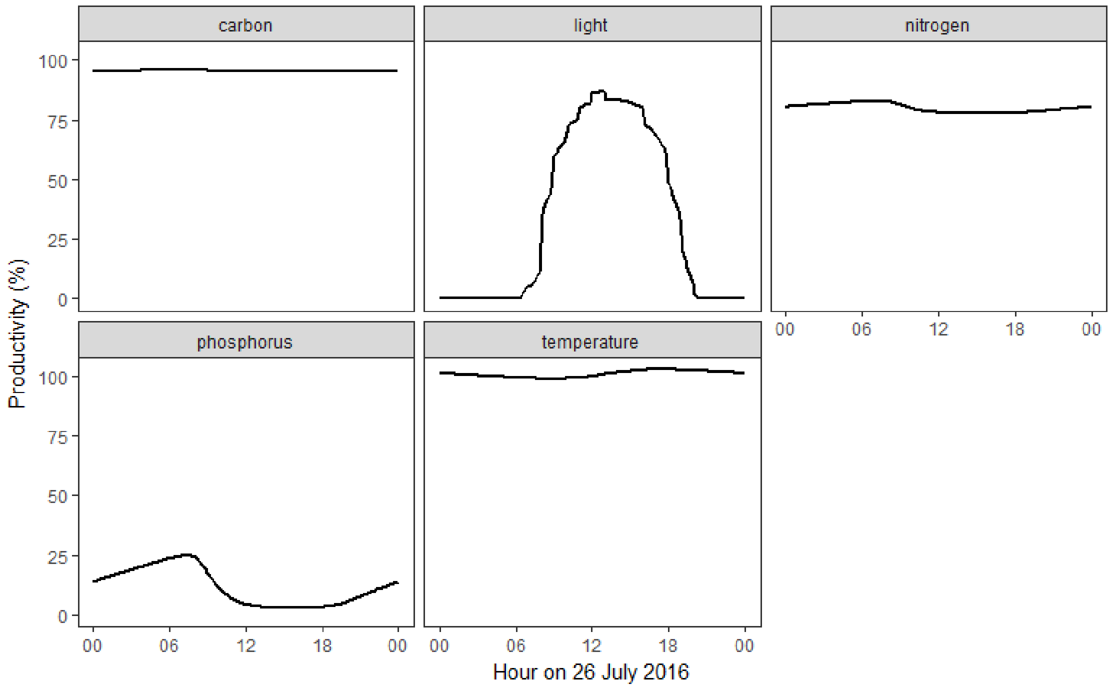


Figure 4.3.9b: Limiting factors for periphyton productivity in model Reach 6 upstream of station 12301 (Eddyville)

4.3.10 QUAL2Kw model sensitivity analysis

Comparisons between measured and modeled DO at all sampling stations suggests that the model accurately represented physical, chemical and biological processes influencing DO in the Upper Yaquina River Watershed. The fit between modeled and measured DO and temperature data at 12301-ORDEQ (Eddyville) suggests that strategies can be devised to alter processes responsible for violations of the DO water quality standard observed in the reach upstream of this station.

Based on examination of individual DO fluxes in model segments, altering processes involved with periphyton photosynthesis and respiration should have the largest influence on DO concentrations in the Upper Yaquina River Watershed. Factors that generally control periphyton growth include nutrients, light input, available substrate, temperature and stream flow (Bernot, et al., 2010). Examination of factors influencing periphyton productivity in critical model segments (i.e., Reach 6 upstream of station 12301-ORDEQ) suggests that, in current conditions, P availability and light input most strongly limit periphyton productivity in the Upper Yaquina River. Light limitation is supported by previous studies that document limiting factors for primary productivity in stream and rivers throughout the Pacific Northwest (Gregory, 1980). P limitation is supported by the high N to P ratios (average±standard deviation of the molar ratio of TN to TP= 34.9±5.7) measured in the water column during the monitoring period, which was much higher than the Redfield ratio of 16:1 N to P molar ratio optimal for aquatic plant growth (Redfield, 1958).

4.3.11 Channel and riparian characteristics sensitivity analysis

The monitoring and modeling for the Upper Yaquina occurred during a period when flows were approximately two- to three-times greater that than critical low flow conditions. The 7Q10, which describes the lowest seven-day average flow every 10 years and is used throughout the United

States to set water pollution discharge permit limits (US Environmental Protection Agency, 2018), was 6.9 cfs (Distribution-Free Method) from July 15th through August 15th at station 11476 based on the period of record from 1972 through 2015 (Oregon Water Resources Department, 2018). This suggests that although flow conditions were well above critical low flow conditions, DO levels still exhibited excursions from the applicable water quality standard.

The increase in Manning's n downstream in the model reach reflects the transition from a higher gradient, faster flowing stream to a lower gradient channel with a high width to depth ratio at approximately river km 19.4. Re-aeration rates undergo a rapid decrease and reflect a rapid shift at this point in the reach. Re-aeration rate theoretically increases with both channel roughness, which Manning's n reflects, and stream velocity (Bernot, et al., 2010). While re-aeration rates should increase with Manning's n, which reflects channel roughness, the rapid decline in stream velocity downstream in the Upper Yaquina, also at around river km 19.4, caused re-aeration rates to decrease downstream. Although Manning's n was high, the combination with low stream velocities a wide channel, relatively shallow channel (width to depth ratio > 20:1) likely constrained atmospheric exchange. Thus, efforts to increase atmospheric exchange through manipulations of channel complexity in this reach should not rely only on Manning's n as a measure for tracking restoration progress.

The longitudinal change in effective shade along the model reach reflects shifts in stream azimuth, stream width and the extent of riparian forest buffers along the Upper Yaquina River. In the upper reaches (between 34454-ORDEQ and 33112-ORDEQ), riparian forest buffers have been retained along a mostly east-to-west flowing river. This results in relatively high shading during the midday on this reach. In the middle segments of the model reach (stations 33112-ORDEQ to 12301-ORDEQ), the Yaquina River turns to a southwest orientation and enters into broader valleys with narrow riparian buffers. The combination of landscape position and riparian characteristics, thus greatly reduces effective shade in this reach. Downstream of station 12301-ORDEQ, the Yaquina re-enters a more constrained topography and reorients (mostly) to east to west. Thus, effective shade generally increases downstream from Eddyville to end of the model reach at Station 11476-ORDEQ. Because light is a primary limiting factor for primary production in stream ecosystems (Bernot, et al., 2010), DEQ expected that primary productivity would have a greater influence on diel patterns in dissolved oxygen in segments between stations 33112-ORDEQ and 12301-ORDEQ.

4.3.12 DO Modeling and analyses conclusions and recommendations

DEQ's analyses and modeling demonstrate that biological processes strongly influence DO concentrations in the Upper Yaquina River Watershed during summer conditions (high water temperatures, low flows). DEQ recommends increasing riparian shade and reducing nutrient loading, particularly P, to reduce periphyton activity and raise minimum DO levels to achieve the Oregon water quality criteria. Specific scenarios evaluating the effects of plausible restoration and management strategies to achieve these goals will be identified in cooperation with local stakeholders to develop water quality management plans.

4.4 DO Loading Capacity and Excess Loads

Bases on the analysis and modeling in Section 4.2, DEQ determined that loading capacity and excess loads related to DO excursions apply during Medium- to Low-flows from July to October/early November (Figure 4.4a). Dissolved oxygen excursions from the Cold-Water

Aquatic Life and Salmonid Spawning periods are most frequent during these times and flows in the Upper Yaquina River.

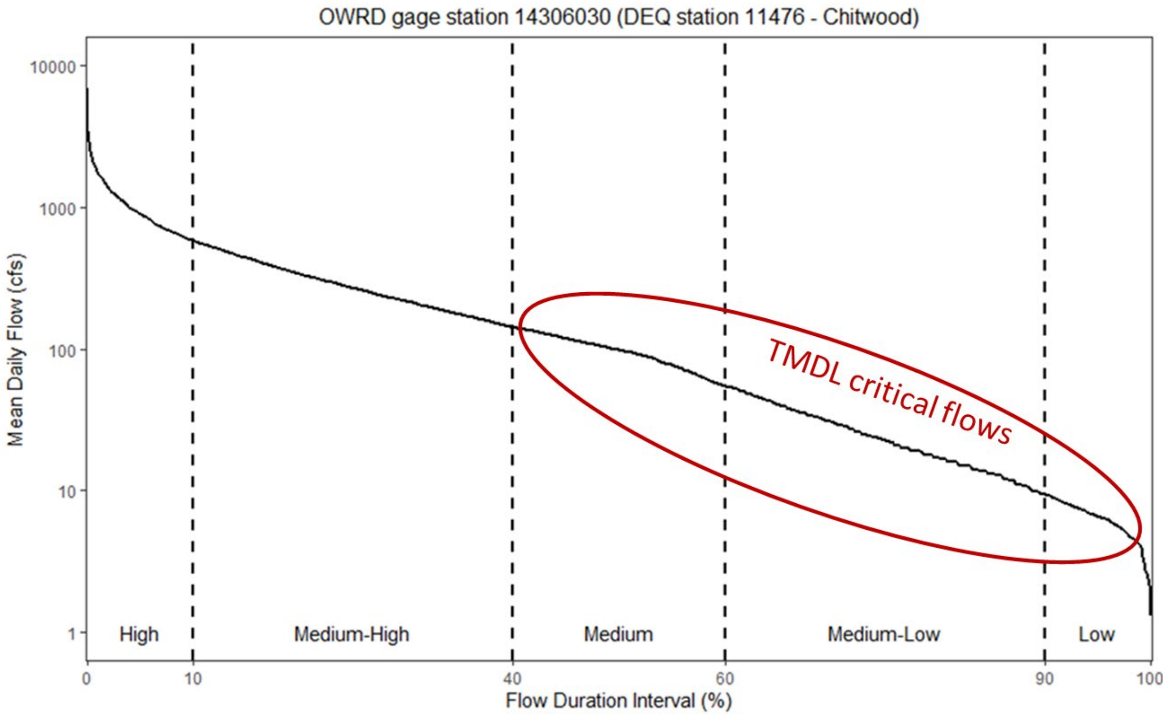


Figure 4.4a. Critical flow periods for the dissolved oxygen TMDL – Upper Yaquina River

DEQ calculated DO excess loads by determining the pollutants affecting DO and the levels of the pollutant loads needed to meet the DO criteria. The required pollutant levels were calculated using the target dissolved oxygen concentration for cold water aquatic life in the Upper Yaquina River Watershed. Excess loads for the Upper Yaquina River are, therefore, the difference between the existing loads of total phosphorus or solar flux and the loading capacities of total phosphorus or solar flux. Required reduction can be inferred from existing total phosphorus water column concentration or solar input:

Equation 4.4a:

$$R = 1 - \frac{TL}{EL} \times 100$$

where R is the required percent reduction, TL is the target surface water total phosphorus concentration (μg/L) or solar input (W/m^2), and EL is the existing surface water total phosphorus concentration or solar load calculated from observed data collected during the period of 2016 (total phosphorus) or 2012 (solar load).

Plots demonstrating that minimum dissolved oxygen concentrations (and by proxy saturation) will be met at the critical sampling station (12301-ORDEQ) by reducing total solar radiation load to the modeled reach or mean total phosphorus concentration at 11476-ORDEQ are displayed in Figure 4.4b and Figure 4.4c.

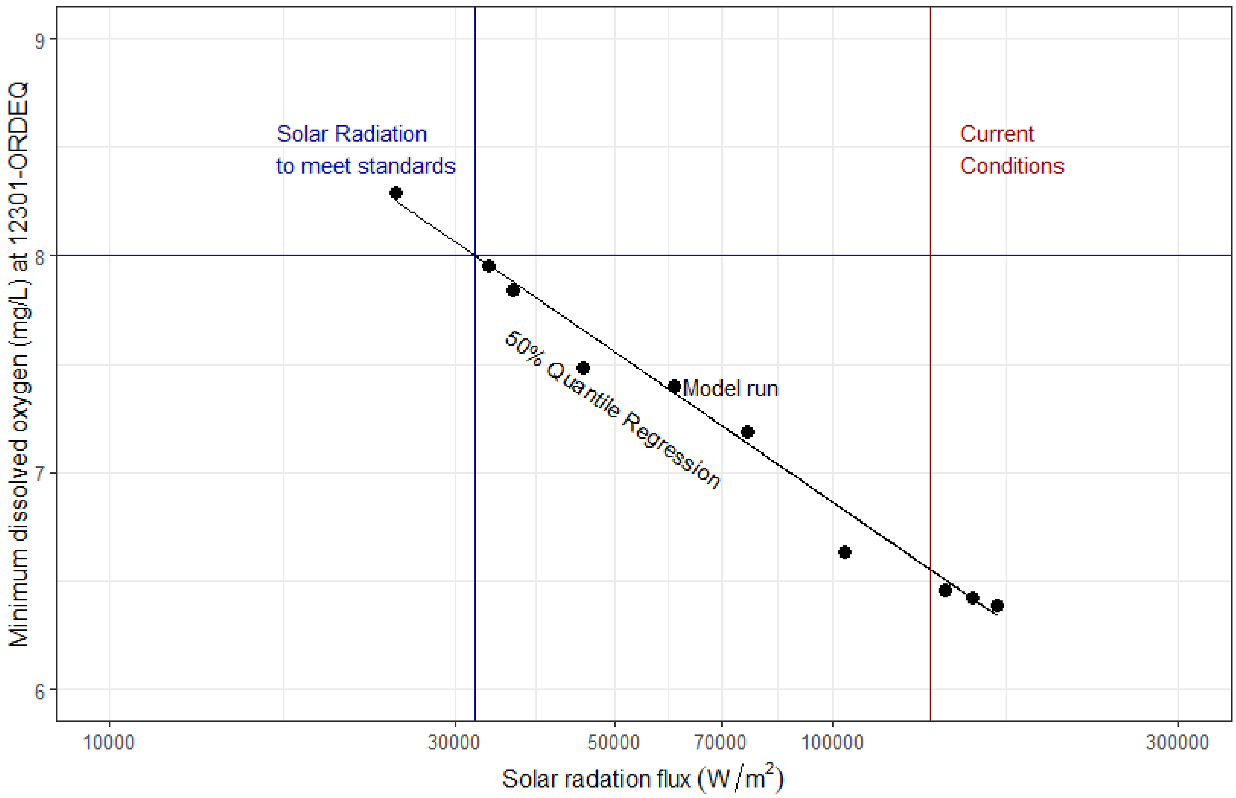


Figure 4.4b: Quantile regression of systematic variation in solar radiation of the calibrated QUAL2Kw model - Upper Yaquina River

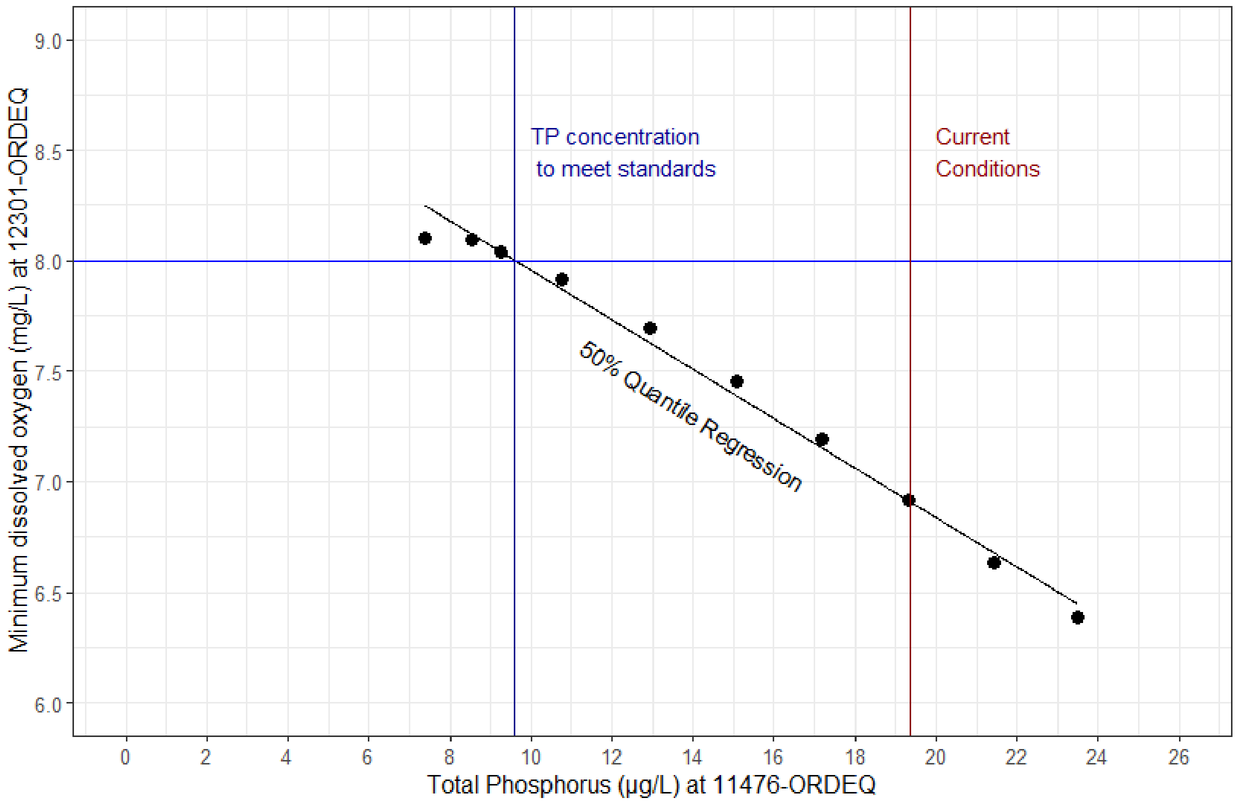


Figure 4.4c: Quantile regression of systematic variation in total phosphorus concentrations in the calibrated QUAL2Kw model - Upper Yaquina River

The existing solar input (EL) was calculated using LiDAR imagery of bare earth and vegetation height collected by DOGAMI in 2012 and processed using the Shade-a-lator component of the Heat Source model v.9 (Michie, Heat Source 9, 2019). Existing total phosphorus loads and concentrations (EL) were calculated using the inputs from upstream into the modeled reach, inputs to the modeled reach from major tributaries, and inputs from groundwater in the modeled reach from the calibrated HSPF model for period and flow conditions of interest (Appendix 1). Solar flux was converted to solar load for consistency with other dissolved oxygen and temperature TMDLs using the following equations:

Equation 4.4a:

$$Solar\ Power\ (W) = \ Daily\ Solar\ Flux\ \left(\frac{W}{m^2}\right) \times model\ length\ (m) \times model\ reach\ average\ width(m)$$

$$Solar\ Load\ \left(\frac{kcal}{day}\right) = Solar\ Power\ \left(W\ or\ \frac{J}{s}\right) \times \frac{86400\ s}{1\ day} \times \frac{1\ cal}{4.1868\ J} \times \frac{1\ kcal}{1000\ cal}$$

Based on this conversion the current load (Margin of Safety scenario) is $34{,}155{,}033{,}534$ kcal/day and equivalent to 45% effective shade (total amount of solar radiation blocked from reaching the river surface by topographic features and riparian vegetation).

The excess loads from solar and total phosphorus input were calculated by using the required reductions and the estimated daily loads for the Upper Yaquina River, which were calculated using the linked HSPF-QUAL2Kw model. The required percent reductions were applied directly to the current load to estimate the excess load:

Equation 4.4b:

$$L_{Excess} = R \times L_{Current}$$

where $L_{Excess}$is is the excess flux in kcal/day (solar) or lbs/day (total phosphorus), R is the required reduction in load (expressed as a fraction), and $L_{Current}$ is the current flux or load in kcal/day (solar) or lbs/day (total phosphorus) estimated using the linked HSPF-QUAL2Kw model, which were estimated to be 34,155,033,534 kcal/day and 4.28 lbs/day.

The total solar excess load for the Upper Yaquina is expressed as Equation 4.4c.
Equation 4.4c:

$$L_{Excess} = 0.76 \times 34{,}155{,}033{,}534\ \frac{kcal}{day} = 25{,}957{,}846{,}948\ \frac{kcal}{day}$$

The load capacity for solar load can then be calculated as the remaining load, using Equation 4.4d.
Equation 4.4d:

$$Load\ Capacity = L_{Current} - L_{Excess} = 34{,}155{,}033{,}534\frac{kcal}{day} - 25{,}957{,}846{,}948\frac{kcal}{day}$$
$$= 8{,}197{,}207{,}223\ \frac{kcal}{day}$$

$$Load\ Capacity = 8{,}197{,}207{,}223\frac{kcal\ of\ solar\ input}{day}$$

This capacity of 8,197,207,223 kcal/day corresponds to the 76 percent reduction and was used to calculate allocations and remaining parts of the TMDL equation. This solar load capacity is equal to 87% effective shade for the model reach. Applying this percent reduction to similar flow conditions after October 15th also meets the Salmonid Spawning criteria for dissolved oxygen for the critical period and flow.

The total phosphorus excess load for the Upper Yaquina is calculated using Equation 4.4e.
Equation 4.4e:

$$L_{Excess} = 0.503 \times 4.29\frac{lbs}{day} = 2.16\frac{lbs}{day}$$

The load capacity for total phosphorus can then be calculated as the remaining load, using Equation 4.4f.
Equation 4.4f:

$$Load\ Capacity = L_{Current} - L_{Excess} = 4.29\frac{lbs}{day} - 2.16\frac{lbs}{day} = 2.13\frac{lbs}{day}$$

$$Load\ Capacity = 2.13\frac{lbs\ of\ total\ phosphorus}{day}$$

This load capacity of 2.13 lbs/day corresponds to the 50 percent reduction and was used to calculate allocations and remaining parts of the TMDL equation. Applying this percent reduction to similar flow conditions after October 15th also meets the Salmonid Spawning criteria for dissolved oxygen. Note that presented results are based on expressing percentages to single digits and pounds to 1/100th significant figures.

4.5 DO Source Assessment and Load Contribution

Permitted point source discharges of wastewater do not exist within the Upper Yaquina River Watershed. DEQ reviewed its publicly accessible database of Water Quality Permitted Facilities for existing permitted (NPDES and WPCF) activities located within the Upper Yaquina watershed. As of May 12, 2022, there are no facilities that hold either class of permit.

At any time, an entity may propose an activity that requires a construction stormwater permit (NPDES 1200-C). However, these permits are temporary and specifically require an erosion and sediment control plan, so represent an insignificant source of phosphorus when the conditions of the permit are met. Other NPDES permits are reviewed on a case-by-case basis and incorporate an evaluation of current water quality status, including whether or not a receiving water body is impaired and if so, the pollutants. Therefore, this TMDL contains no additional waste load allocations for registered entities of this general stormwater permit.

The only permitted discharge in the watershed is the Oregon Department of Transportation NPDES Municipal Separate Storm Sewer System (MS4) permit, which is more closely aligned with nonpoint source evaluation (see allocation approach sections for phosphorus (4.6) and bacteria (5.6)).

DEQ considered and evaluated several factors in assessing the nonpoint sources of pollution impacting dissolved oxygen in watershed streams and estimates of contribution significance. Light, organic matter and nutrient inputs in unmanaged portions of the watershed contribute to fueling biological productivity – both gross primary production and ecosystem respiration – in the waterways through several different pathways. Additionally, physical factors and processes in unmanaged areas affect channel morphology in ways that can influence air-water exchange rates.

4.5.1 Solar load

In unmanaged portions of forested watersheds, such as the Upper Yaquina Watershed, light inputs to streams typically are low (Stanley Vincent Gregory 1980). Through natural disturbance regime processes such as forest fires, wind storms, debris flows, and other landscape processes, patches of the Upper Yaquina River and tributaries periodically receive increased light inputs, creating localized conditions with higher biological activity and depressed DO levels in the riverine network (Wimberly and Spies 2001; S. V. Gregory et al. 1991). However, disturbance return intervals, particularly fire and debris flows, in the Oregon Coast Range historically varied from 200 to 1000 years (Wimberly and Spies 2001), making these potential periodic depressions in DO highly infrequent and patchy.

To estimate site potential shade (least amount of light input from natural vegetation shading) along the reach of the Upper Yaquina prior to European settlement, DEQ estimated site potential tree heights based on modeled vegetation data for western Oregon. DEQ acquired modeled vegetation data (2011) from Oregon State University (Oregon State University, 2022) which is depicted in Figure 4.5.1a. Within a ~100-foot buffer along the TMDL model reach, DEQ linked the Ecological Systems Code in the modeled vegetation dataset with forest type and site potential tree heights described for the Nestucca River basin temperature TMDL (Oregon DEQ, 2003), as presented in Table 4.5.1a. Using the DEQ Ttools package (Michie, TTools, 2019) and the Shade-a-lator module of Heat Source v.9.0 (Michie, Heat Source 9, 2019), site potential effective shade was estimated assuming an understory vegetation density of 0.9 and a value of 0 for emergent vegetation.

Based differences throughout the day for the TMDL model (26 July 2016), the current effective shade along the TMDL model reach is 45%, whereas the calculated site potential effective shade is 91% (assuming minimal natural disturbances) for the QUAL2Kw model reach, as shown in Figure 4.4.1b. Therefore, the TMDL target for the model reach of 87% falls within the realm of achievable goals. Additionally, the percent of the channel exposed to the sky, which controls the flux of longwave radiation to and from the stream channel is approximately 38% less in the TMDL model reach than pre-European settlement, as shown in Figure 4.5.1c.

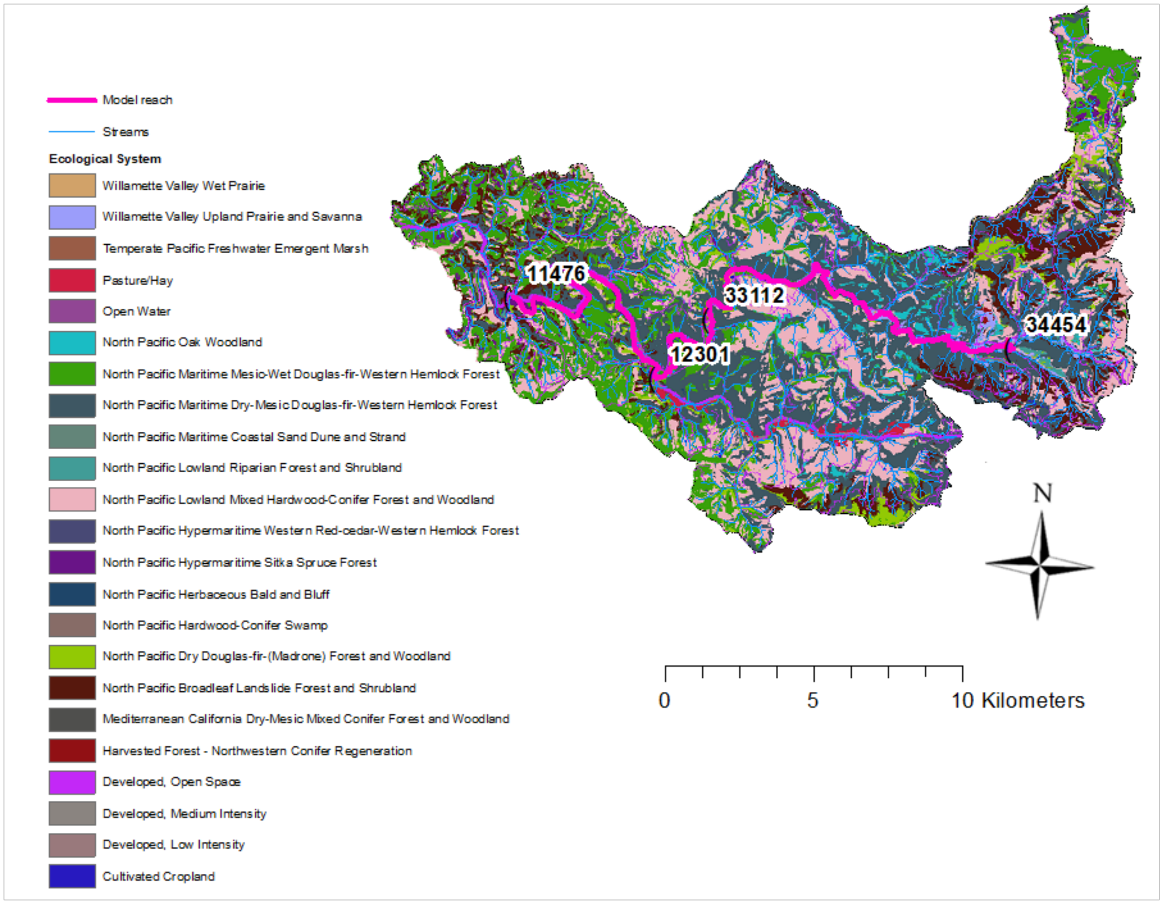


Figure 4.5.1a. Ecological Systems of the Upper Yaquina River in 2011

Table 4.5.1a: Ecological systems linked with site potential vegetation and height within a ~100-foot buffer of the model reach - Upper Yaquina River

Ecological Systems Name	Site Potential Vegetation	Site Potential Height (ft)
Developed, Open Space	Mixed deciduous and conifer	142
North Pacific Maritime Mesic-Wet Douglas-fir-Western Hemlock Forest	Conifer	185
North Pacific Lowland Riparian Forest and Shrubland	Mixed deciduous and conifer	142
Cultivated Cropland	Mixed deciduous and conifer	142
North Pacific Hypermaritime Sitka Spruce Forest	Conifer	185
North Pacific Dry Douglas-fir-(Madrone) Forest and Woodland	Mixed deciduous and conifer	142
North Pacific Maritime Dry-Mesic Douglas-fir-Western Hemlock Forest	Conifer	185
Willamette Valley Wet Prairie	Deciduous	105
North Pacific Broadleaf Landslide Forest and Shrubland	Deciduous	105
Willamette Valley Upland Prairie and Savanna	Deciduous	105
North Pacific Lowland Mixed Hardwood-Conifer Forest and Woodland	Mixed deciduous and conifer	142
North Pacific Oak Woodland	Deciduous	105
Developed, Low Intensity	Mixed deciduous and conifer	142

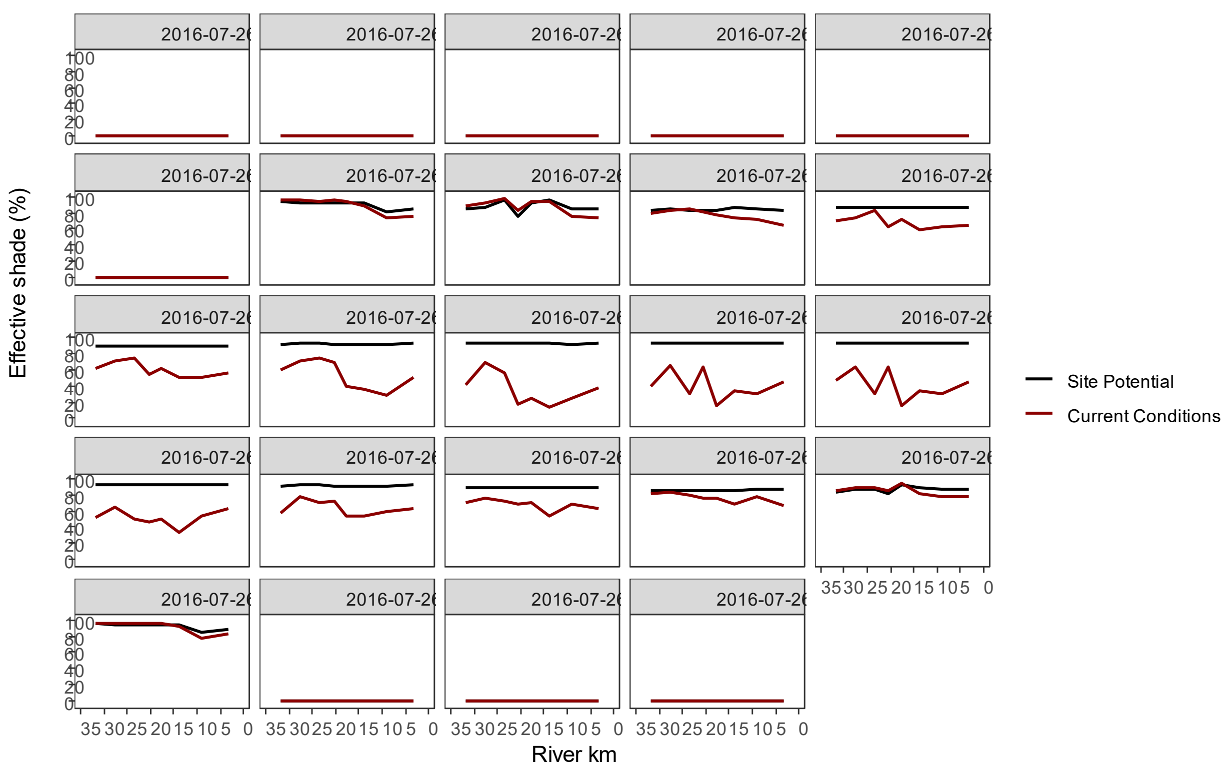


Figure 4.5.1b: Comparison of site potential and current conditions of effective shade by hour along the model reach - Upper Yaquina River

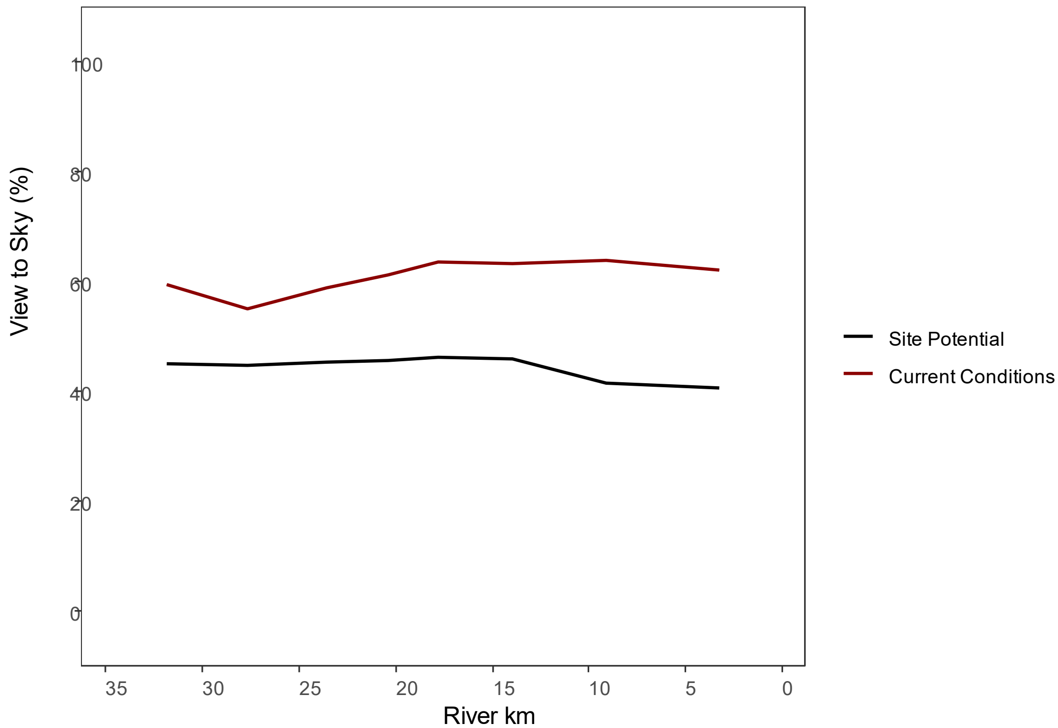


Figure 4.5.1c: Comparison of site potential and current conditions of view to sky along the model reach - Upper Yaquina River

4.5.2. Effective Shade Curves

Effective shade curves represent the applicable surrogate measure for solar radiation for streams not specifically modeled for shade (or dissolved oxygen). The solar radiation load and effective shade surrogates are identified by ecoregions or other relevant ecological units for a range of types of restored vegetation (i.e., grasses and herbs, shrubs, simple or complex overstory). Effective shade curves represent the maximum possible effective shade for a given vegetation type or plant association during the designated critical period for the TMDL. Natural disturbance rates are not included in the effective shade curve calculations because these are generally unpredictable stochastic processes. The values presented within the effective shade curves represent the effective shade that would be attained if the vegetation class were at its stated restored height and density. The vegetation heights and densities were determined for the Upper Yaquina watershed consistent with the methods used for the mainstem Upper Yaquina River (above) and summarized in Table 4.5.1. The range of vegetation densities represents potential variation based on local factors (see Tables 5.4.2 a and b and Figures 5.4.2a-h below). DEQ evaluated both the 50% and 90% densities. The lower range of 50% density provides users with potential variations in effective shade based on site specific factors. For the TMDL, DEQ used the 90% density as site potential vegetation targets, to incorporate a margin of safety. This 90% density is consistent with other EPA-approved TMDLs for coastal Oregon, including the Nestucca Bay Watershed and Tillamook Bay Watershed temperature TMDLs (DEQ 2001; DEQ 2002)

Table 4.5.2a: Site Potential Vegetation types and characteristics used in developing shade curves for the Upper Yaquina watershed

Code	Ecoregion	Site Potential Vegetation type	Height (ft)	Canopy density	Overhang (ft)
100	Western Hemlock Zone	Deciduous	105	50%	6.9
101	Western Hemlock Zone	Mixed Deciduous and Conifer	142	50%	6.9
102	Western Hemlock Zone	Conifer	185	50%	6.6
200	Western Hemlock Zone	Deciduous	105	90%	6.9
201	Western Hemlock Zone	Mixed Deciduous and Conifer	142	90%	6.9
202	Western Hemlock Zone	Conifer	185	90%	6.6

Table 4.5.2b: Potential Upper Yaquina River Watershed effective shade targets, as percent

	Stream Width (ft)	50% Density			90% Density		
		Stream Aspect			Stream Aspect		
		North-South	NW-SE or NE-SW	East-West	North-South	NW-SE or NE-SW	East-West
Deciduous	10	78%	80%	82%	95%	95%	97%
	20	71%	72%	74%	90%	88%	92%
	30	66%	65%	67%	85%	82%	88%
	40	62%	59%	59%	81%	76%	81%
	50	58%	55%	51%	78%	72%	73%
	60	54%	51%	44%	75%	68%	65%
	70	51%	47%	39%	72%	65%	58%
	80	48%	45%	35%	69%	62%	53%
	90	46%	42%	32%	66%	60%	49%
	100	43%	40%	30%	64%	57%	45%
Coniferous	10	87%	90%	92%	97%	97%	98%
	20	84%	86%	89%	94%	94%	96%
	30	80%	82%	86%	92%	91%	95%
	40	77%	78%	82%	90%	88%	93%
	50	75%	74%	78%	88%	85%	91%
	60	72%	70%	74%	86%	82%	89%
	70	70%	67%	70%	84%	80%	86%
	80	67%	65%	65%	83%	78%	83%
	90	65%	62%	60%	81%	76%	80%
	100	63%	60%	56%	80%	74%	76%
Mixed	10	84%	86%	88%	96%	96%	98%
	20	79%	80%	83%	93%	92%	95%
	30	75%	75%	78%	90%	88%	92%
	40	71%	70%	73%	87%	83%	89%
	50	67%	65%	67%	84%	79%	86%
	60	64%	62%	61%	82%	76%	81%
	70	62%	58%	55%	79%	74%	75%
	80	59%	56%	50%	77%	71%	70%
	90	57%	53%	46%	75%	69%	66%
	100	54%	51%	42%	74%	67%	62%

These shade curves (Figures 4.5.2a-h), and the underlying tables (Tables 4.5.2a-b) from which the curves were developed, are not location-specific. Therefore, the curves do not factor in topographic shading that may be present at specific locations on the landscape. DEQ expects DMAs and responsible persons to evaluate location-specific conditions within their jurisdictions or ownership to determine the amount of topographic shading and any additional shading needed from vegetation to reach full site potential shade targets.

The effective shade curves incorporate latitude, critical summertime period (July 24), elevation, stream width and stream aspect. Site-specific effective shade simulations for the modeled portion of the Yaquina River (Section 4.5.1 above) supersede the effective shade curves for that reach. Reaches and tributaries that were not modeled are represented by the ecoregions and vegetation types summarized in Table 4.5.2.

Figure 4.5.2a. Effective shade curves for deciduous forest restored conditions with 50% density (105 ft tall; 6.9 ft overhang of vegetation above the stream channel).

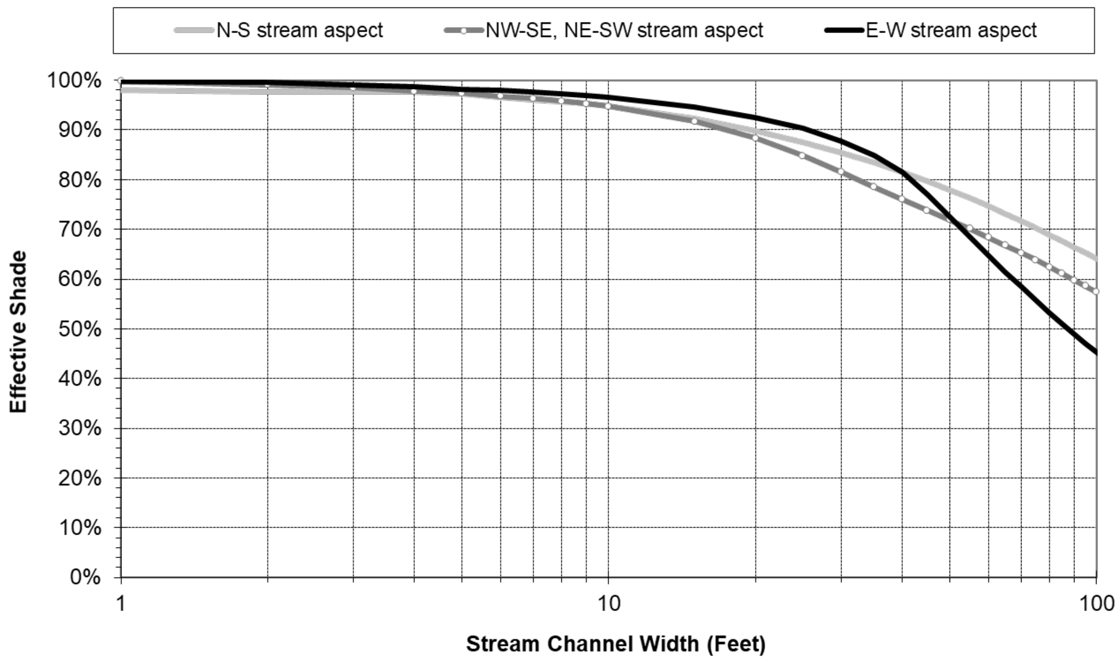


Figure 4.5.2b. Effective shade curves for deciduous forest restored conditions with 90% density (105 ft tall; 6.9 ft overhang of vegetation above the stream channel).

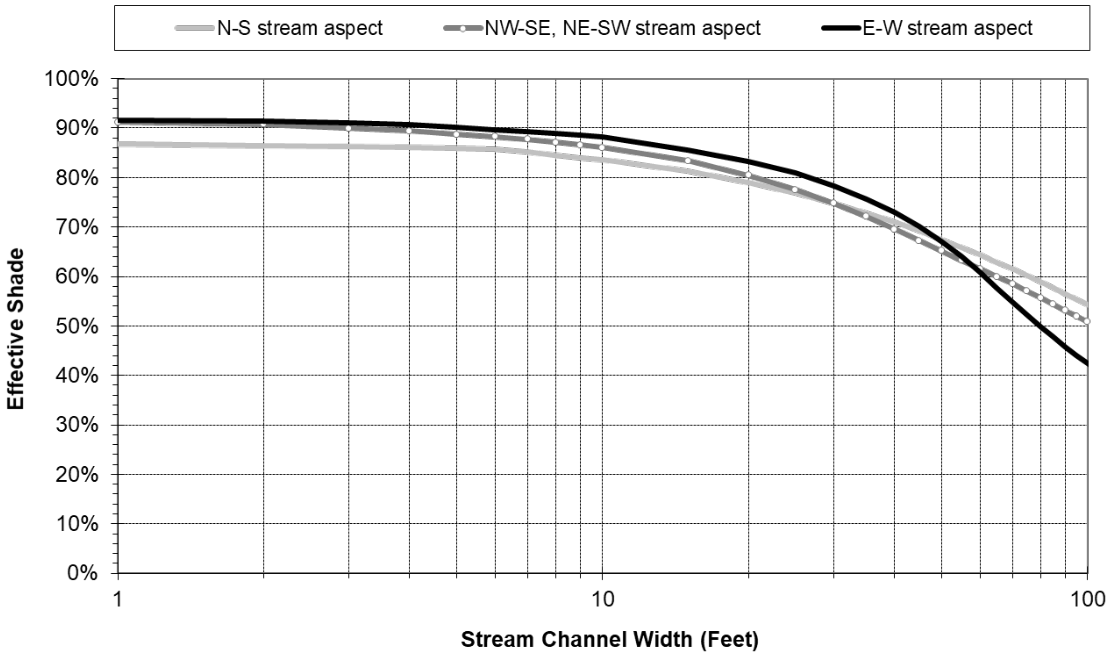


Figure 4.5.2c. Effective shade curves for mixed coniferous-deciduous forest restored conditions with 50% density (142 ft tall; 6.9 ft overhang of vegetation above the stream channel).

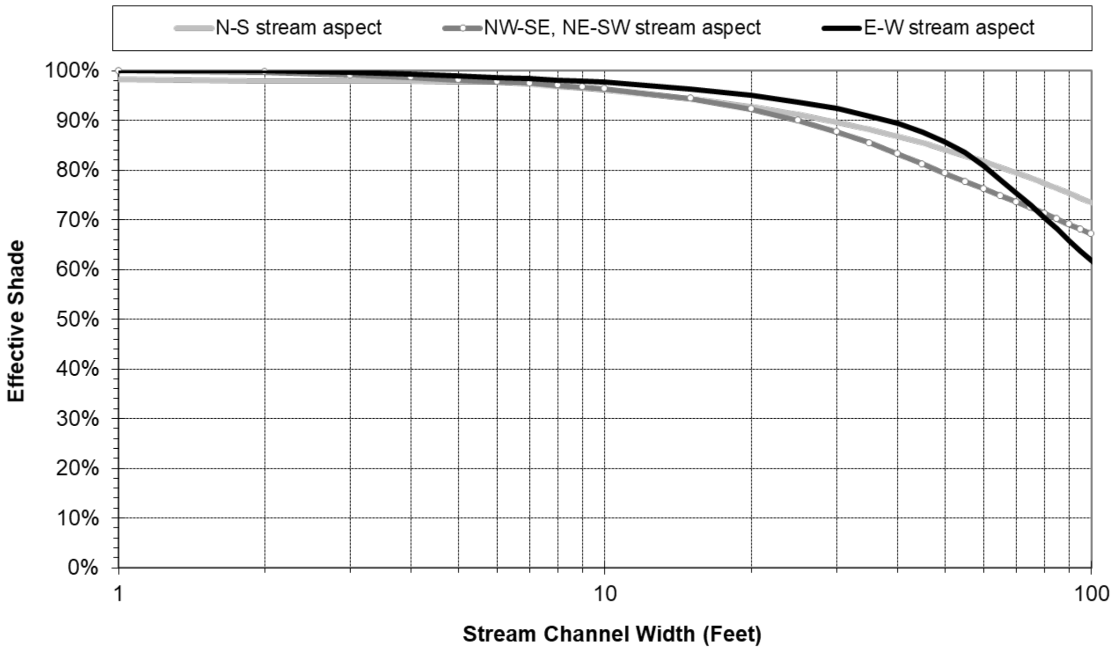


Figure 4.5.2d. Effective shade curves for mixed coniferous-deciduous restored conditions with 90% density (142 ft tall; 6.9 ft overhang of vegetation above the stream channel).

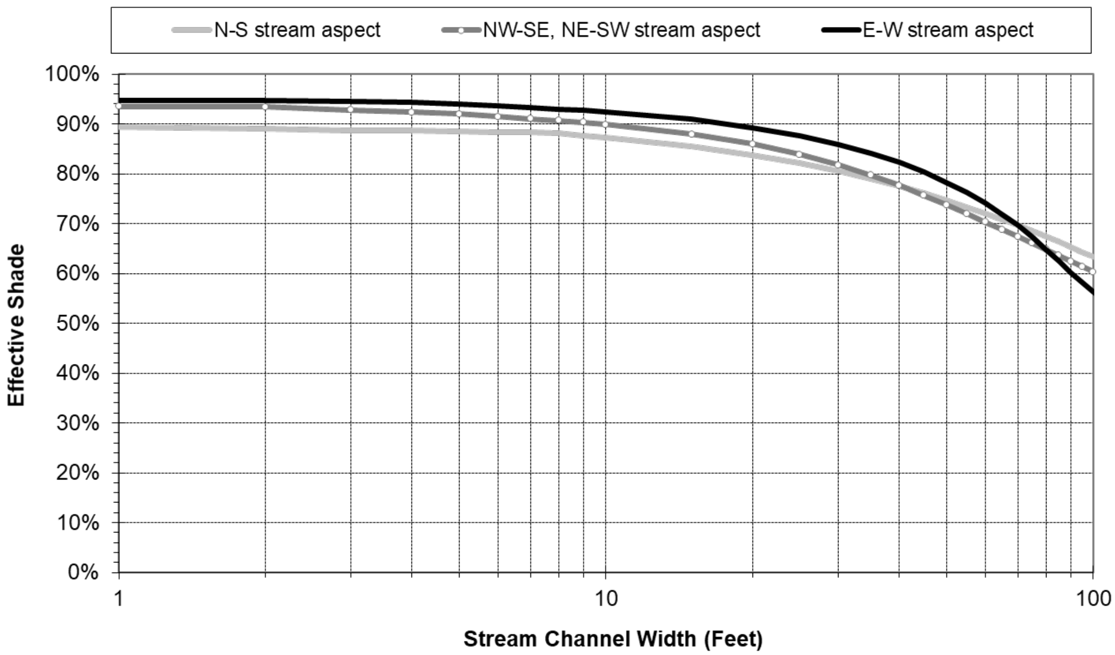


Figure 4.5.2e. Effective shade curves for coniferous forest restored conditions with 50% density (185 ft tall; 6.6 ft overhang of vegetation above the stream channel).

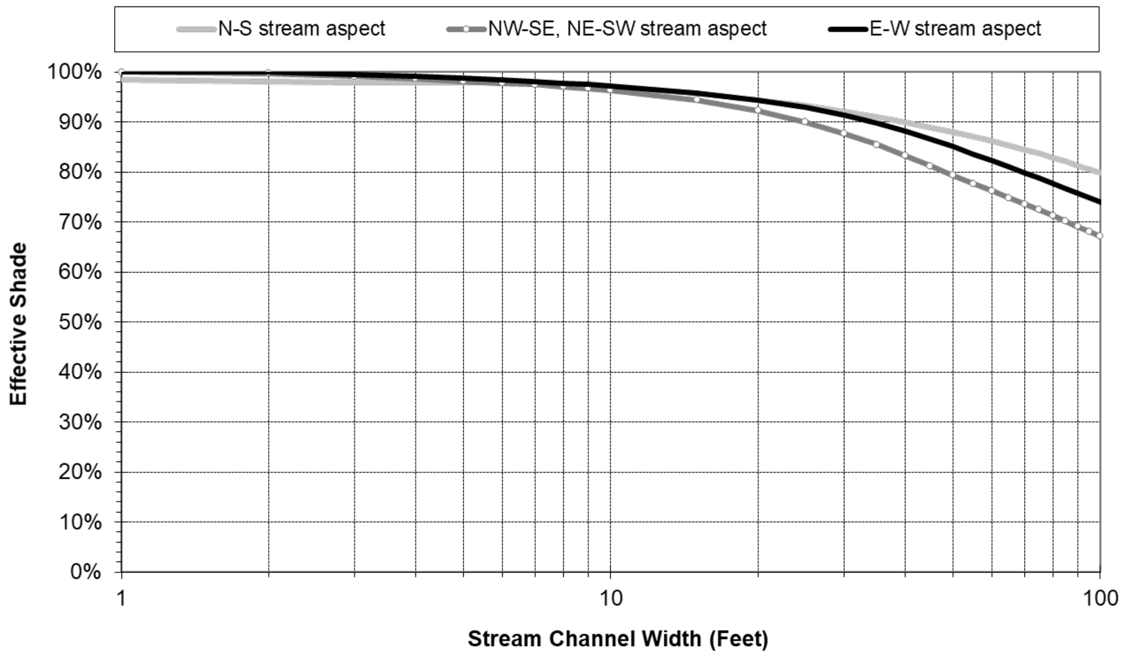


Figure 4.5.2f. Effective shade curves for coniferous forest restored conditions with 90% density (185 ft tall; 6.6 ft overhang of vegetation above the stream channel).

Local geology, geography, soils, climate, legacy impacts, natural disturbance rates, and other factors determine the specific mix and characteristics (i.e., age, height, canopy density) of plant species that establish and grow at a specific location and may also prevent effective shade from reaching the values presented in the effective shade curves. The goal of the TMDL is to achieve water quality standards. Minimizing anthropogenic impacts on effective shade is an important implementation strategy. DEQ recognizes that natural disturbances may affect whether effective shade reaches the levels presented in the effective shade curves.

4.5.4 Organic matter

Inputs of organic matter in the Upper Yaquina River watershed largely derived from forest ecosystems. Prior to European settlement, forests in the Upper Yaquina were dominated by a mosaic of old-growth conifers, such as Sitka spruce (*Picea sitchensis* (Bong.) Carr.), western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) and Douglas-fir (*Pseudotsuga menziesii* (Mirbel) Franco), interspersed with early-successional hardwood, such as red alder *(Alnus rubra* Bong.) (Franklin and Dyrness 1973). Thus, organic matter entering the Yaquina River likely consisted of a mix of labile and recalcitrant organic matter (dissolved and particulate) and these inputs are considered background. Microbial decomposition of this material consumes oxygen in the Upper Yaquina stream network. This decomposition also releases nutrients that can be used both by downstream primary producers and heterotrophs for biological activity.

4.5.5 Nutrients

4.5.5.1 Background sources of nutrients

Background sources of nutrients – nitrogen and phosphorus – in the Upper Yaquina watershed include atmospheric deposition, geologic weathering/erosion, biological nitrogen fixation and wildlife.

Phosphorus returned from the ocean through anadromous salmonid biomass was historically important in many coastal Oregon streams; but is now an insignificant source (Compton, et al., 2006).

Atmospheric deposition of nitrogen and phosphorus from human-based sources represents a small component of total human moderated input of nutrients to the Yaquina River due to the proximity to the Pacific Ocean. Prevailing winds combined with minimal upwind industrial and agricultural activity suggests that most deposition to the Upper Yaquina originates from over the Pacific Ocean. Atmospheric deposition rates for nitrogen (2.9 kg N/ha/yr and 0.138 mg N/L in rainwater) are among the lowest rates in the continental US and likely represent background inputs (National Atmospheric Deposition Program, 2020). Likewise, phosphorus deposition rates are low (0.001-0.005 kg P/ha/yr) along the Pacific Northwest coast (Vet et al. 2014).

Nutrient inputs through weathering and erosion vary according to underlying geology and can be episodic via mass wasting (landslide) events. The Tyee sandstone underlying most of the Upper Yaquina tends to be low in both nitrogen and phosphorus. In areas underlain by more recent volcanic rocks - which constitutes only a small area of the Upper Yaquina – inputs of phosphorus from weathering can be elevated (Vanderbilt, Lajtha, and Swanson 2003).

Biological nitrogen-fixation (N-fixation) typically comprises a substantial input of biologically available nitrogen to undisturbed watersheds (Cleveland et al. 1999). In the Upper Yaquina watershed, red alder, an early-successional tree with a symbiotic relationship with N-fixing bacteria in root nodules, constitutes the largest source of N-fixation (Brown and Ozretich 2009). Historically, inputs of N from red alder fixation in the Upper Yaquina watershed were likely episodic and tied to disturbances that reset forest succession in portions of the watershed. Currently, however, red alder covers more forested area throughout the Oregon Coast Range than historically because of a combination of human-induced disturbances such as fire, land clearing, and silvicultural practices (Kennedy and Spies 2004).

Background nutrient inputs from wildlife sources generally represents a recycling of nutrient inputs listed above. While there may be some interbasin transfer, in the absence of specific information DEQ assumed inputs and exports of nutrients via wildlife vectors balance out. Wildlife that seasonally accesses pasture along the main stem river include elk and deer (Jason Kirchner, ODFW, personal communication). Based on input from the bacteria technical working group and information from the regional ODFW wildlife manager (J. Kirchner, pers comm), elk behavior and movement patterns around the mainstem Yaquina River can be summarized as follows:

- Roosevelt Elk do not tend to migrate extensively
- Elk follow the pasture/grass
- Elk congregate lower in winter, move higher in summer
- Some landowners discourage elk from congregating on their property and others do not

Based on HSPF model calculations of current land use/land cover conditions, background inputs of nitrogen and phosphorus to the model reach during low flows when cold water and spawning DO excursions occur make up ~75% and ~42%, respectively, of nutrient loads delivered to the Yaquina River. Some of these background inputs are affected by anthropogenic activities including land cover and stream channel alteration. Thus, background inputs are not easily distinguished from anthropogenic sources and are also likely to be partially addressed by the actions DEQ identifies in the Upper Yaquina Watershed TMDL Water Quality Management Plan. The phosphorus biogeochemical cycle in the environment and aquatic systems is complex (Wetzel, 2001) and characterization of background sources and pathways will require additional evaluation by DEQ and entities responsible for implementing the TMDL.

4.5.5.2 Agricultural activities

The primary agricultural activities that may contribute diffuse inputs of nutrients to the streams in the Upper Yaquina River Watershed includes: hay cultivation, Christmas tree farming, and livestock grazing and rearing ((USDA, 2022); Technical Working Group). Livestock grazing and pasture management comprise the most important agricultural activities in the watershed. Livestock present in the Upper Yaquina watershed may include beef cattle, dairy cows, horses, and sheep (JA Shipman, Soil Survey of Lincoln County). Cattle are significant sources of organic matter and nutrients to the watershed, although horses may be locally significant at different times of the year. Based on stakeholder input, an average of 266 cow-calf pairs are, on average, typically are present in the watershed. Because of topographic constraints, most livestock grazing occurs near the mainstem river and several primary tributaries, and often includes access to the channel (observations from Technical Working Group members and USDA Natural Resource Conservation Service and Oregon Department of Agriculture's Strategic Implementation Area Evaluation (ODA, 2021)).

Nitrogen and phosphorus may be applied directly as inorganic fertilizers or via livestock manure that is deposited during grazing or spread following collection from confined facilities. However, based on information from previous watershed assessments ("USGS Scientific Investigations Report 2006-5012" n.d.) and discussions with the Technical Workgroup, manure deposition associated with domestic livestock is the agricultural activity with the highest potential for nutrient inputs in the watershed. Based on HSPF model simulations (Appendix xx), livestock manure was estimated to contribute 24% and 57% of the total N and P, respectively, loads to the study reach during the flow conditions associated with exceedances of the DO criteria.

4.5.5.3 Rural residential land use

Rural residential areas may contribute organic matter and nutrients through several different mechanisms. Maintenance of lawns or gardening activities can lead to increased surface and subsurface runoff of nutrients and organic matter to adjacent streams or rivers. However, available data suggest these inputs are minor in the Upper Yaquina ("USGS Scientific Investigations Report 2006-5012" n.d.). Unique to rural residential areas is the presence of onsite wastewater treatment (septic) systems. With the lack of centralized sewage lines in the Upper Yaquina Watershed and aging infrastructure in older homes close to the stream network, leaching of organic matter and nutrients from failing or improperly installed septic systems potentially contributes to DO depletion in the stream network. However, based on HSPF simulations, on-site septic systems are estimated to currently contribute only 0.4 and 0.7% of total N and P, respectively, to nutrient loading in the Upper Yaquina during low flows when cold water and spawning DO excursions occur (Appendix 1). Based on 2020 census figures, the population and housing density in the watershed is very low. Even so, older septic systems have higher failure rates and a single illicit discharge could contribute excess nutrients and organic matter to the stream network.

4.5.5.4 Silvicultural activities

DEQ reviewed information on potential nonpoint nutrient sources and pathways from the silvicultural sector for this TMDL. These sources and pathways include soil from erosion and runoff from harvest units or roads, organic matter inputs (e.g., dead vegetation and slash) and forestry chemical applications.

Shallow landslides or roads not constructed and maintained to current standards have been shown to deliver a significant amount of fine sediment to stream networks. There are miles of unsurfaced roads that are hydrologically connected to the stream network at multiple locations. The road system requires periodic maintenance and repairs to prevent sediment from reaching waters of the state.

Commercial forestry chemical applications are also a potential source of nitrogen and phosphorus to streams. Many of the common herbicides used in forestry contain nitrogen compounds and at least one contains phosphorus (glyphosate). The levels of these chemicals (or their degradates) reaching waters of the state are expected to be very low when strictly following FPA regulations and label requirements. However, data from NCASI (2013) and Oregon's Pesticide Stewardship Partnership Program demonstrate that detectable levels of herbicides and their degradates, including aminomethylphosphonic acid (AMPA) (Grandcoin et al 2017), reach the stream network from chemical applications. The pathway, fate and transport of those chemicals is of interest for both protection of aquatic life and minimizing cultural eutrophication of waterbodies. Phosphorus sorbed to soil is the most likely pathway for inorganic phosphorus to reach waters of the state from chemical application (Hebert et al 2019, Holtan 1988).

DEQ obtained the Notification of Operations/Application for Permit (NOAP) data files available through the Oregon Department of Forestry's FERNS database as of June 11, 2020 (Nov 2014 to May 2020). These units are shown in Figure 4.5.5.4 as orange polygons and with reported fertilizer applications as green polygons. Based on the acreage information in Notification of Operation or Permit in ODF's FERNS database DEQ assumed one application per year per unit (typically, there are several applications per unit each year).

Using areal herbicide application rate values reported in the literature (NCASI 2013), DEQ estimated that chemical applications on commercial forest land contribute at least 1500 kg/year (about 31 kg/km^2) load of phosphorus to the Upper Yaquina River watershed on an annual basis consistent with the higher range of P-glyphosate inputs reported for research in agricultural systems (Hebert et al, 2019). DEQ intends to coordinate a detailed evaluation of P-glyphosate inputs with the Oregon Department of Forestry as part of TMDLs implementation.

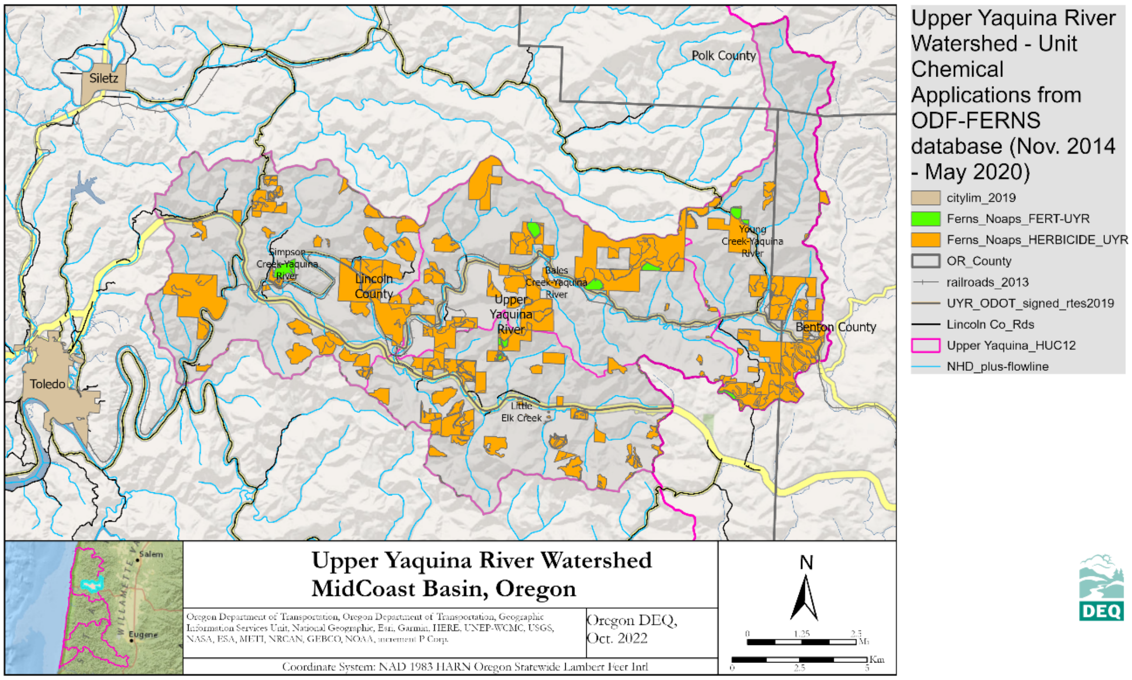


Figure 4.5.5.4: Unit chemical applications of herbicide in the Upper Yaquina River Watershed

Prior to The Oregon Forest Practices Act of 1971 and the FPA administrative rules, there were few restrictions on harvest location, type, size or proximity to waterbodies or requirements to control runoff of organic matter or sediment from forest operations, including roads. Therefore, DEQ assumed that silvicultural activities may have been a significant historical source of organic matter and nutrients reaching the Yaquina River and tributaries, but the effects on dissolved oxygen levels were not evaluated in depth.

The current FPA rules contain best management practices developed to provide for protection of water resources and other values. Primary sources of information on the FPA and implementing rules include: Oregon Department of Forestry, OSU College of Forestry - Forestry & Natural Resources Extension Program and Oregon Forest Resources Institute. The current regulations require landowners to leave specific configurations of vegetated buffers along certain streams (except Type N), wetlands, and lakes to protect water quality and fish and wildlife habitat. The Oregon Department of Forestry and Oregon Forest Resources Institute provides guidance for timber harvest and visual descriptions of buffers in its Publications.

Expanded FPA riparian protections for various stream classifications in Oregon adopted by the Oregon Board of Forestry in October 2022. The riparian rules in effect for small and medium sized fish bearing streams during the period preceding and including the data collection and model period for this TMDL were determined to be inadequate to prevent excess solar thermal gain in streams and have since been revised. The revised rules further expand protection for small and medium streams, including non-fish (Type N) streams.

Private Forest Landowners and the Oregon Plan (ODF 2012) was developed under the Oregon Plan for Salmon and Watersheds to identify high priority voluntary measures for forest landowners to expand water and aquatic resource protection. A recent state agency Report (Abraham, et al, 2017) summarizes the available information on these activities. This Report confirms that voluntary projects are not consistently reported to the Oregon Watershed Restoration Inventory database. DEQ has not identified an effective tracking mechanism to determine where and when voluntary expanded protections are being implemented and translate those into watershed “functional” response and water quality improvements at a watershed scale. In contrast, incentive-based improvements using OWEB and certain other funding sources are required to be reported to OWRI.

Nutrient export from minimally disturbed forestland has been measured to be significantly lower than that from agricultural or residential land uses (Poor and McDonnell 2007). These results are consistent with the estimates from the Upper Yaquina HSPF landscape scale watershed model used in this TMDL. Because forest operations result in varying degrees of disturbance and most private operations include periodic chemical applications (herbicide and/or fertilizer), DEQ considered that any specific operation may increase nutrient export for short periods. However, both field data and modeling suggest these levels are comparatively low at a watershed scale.

Forest operations conducted in strict compliance with the current FPA rules are unlikely to result in significant fine sediment export to streams, except in the event of a shallow landslide or road system failure. Therefore, absent geographic-specific information to the contrary, direct soil erosion and runoff from silviculture as a significant nutrient source is not explicitly considered in this TMDL. The estimates of nutrient export from the NLCD 2011 land cover data in the HSPF model (Appendix 1) were used in developing the nonpoint source load allocations. During the TMDL implementation phase, DEQ will coordinate with DMAs to assess and reduce primary sources of erosion and fine sediment, nutrients and organic matter reaching the stream network, including those potentially from silviculture.

The types of information needed to fill data gaps and reduce uncertainty in nutrient inputs to the Upper Yaquina Watershed from primary source Sectors are summarized in Table 4.5.5.4

Table 4.5.5.4: Data gaps and sources of information to address uncertainty in nutrient inputs to the Upper Yaquina River Watershed

Source Sector	Pollutant	Source Activity	Source of information	Data gaps / needs
Silvicultural practices (state & private)	Nitrogen	Fertilizer application	FERNS / NOAP	Annual summary report from ODF (estimated lbs. / year)
Silvicultural practices (state & private)	Nitrogen containing compounds (including: Imazapyr, Diuron, triazine chemical class and degradates; Hexazinone; triclopyr; Fluridone; metsulfuron-methyl; sulfometuron methyl, others)	Chemical application	FERNS / NOAP	Annual summary report from ODF (estimated lbs. / year)
Silvicultural practices (state & private)	Phosphorus (including: Glyphosate and degradates)	Chemical application	FERNS / NOAP	Annual summary report from ODF (estimated lbs. / year)
Agricultural practices	Nitrogen	Fertilizer application	ODA – SIA; NRCS;	Summarize information

Source Sector	Pollutant	Source Activity	Source of information	Data gaps / needs
			Incorporate nutrient loading and nutrient management plans into Ag Area Plan	on exogenous (non-local) nutrient applications (total lbs. / year)
Agricultural practices	Phosphorus (including Glyphosate and degradates)	Fertilizer and Chemical application	ODA – SIA; NRCS; Incorporate nutrient loading and nutrient management plans into Ag Area Plan	Summarize information on chemical application (total lbs. / year)
Agricultural practices, rural residential land use, road-side weed control, other anthropogenic activities	Atrazine, DEET, hexazinone, fluridone, Imazapyr, metsulfuron-methyl, sulfometuron methyl, aminomethylphosphonic acid (AMPA- degradate of glyphosate), desethylatrazine (degradate of atrazine), triclopyr	Chemical application	South Yamhill PSP monitoring	Summarize information on chemical application (total lbs. / year)

4.5.6 Riparian and channel degradation

Degradation of stream channels and removal of riparian forests as a result of land use practices represents a potentially important process influencing DO in the Yaquina River. Historical agricultural and forestry practices in the watershed, including riparian logging, log drives and potentially splash dams ("Oregon Coast Splash Dams and Log Drives - ScienceBase-Catalog" n.d.), have simplified much of the stream network in the Upper Yaquina River Watershed by scouring large wood and coarse sediment and incising stream banks. Historical clearing of riparian forest areas by agricultural and forestry activities removed most of the large conifers from riparian areas in the watershed; a large portion of these areas have been reforested by deciduous species such as red alder (Kennedy and Spies 2004) or colonized by invasive species in lower gradient reaches. Moreover, both historical and contemporary activities associated with agriculture, rural development, transportation infrastructure (i.e., roads and railroads) and forestry have narrowed the extent that riparian forests extend upslope from stream and river channels. This landscape-scale conversion results in significantly increased light inputs and reduced the inputs of large wood to the stream network, thereby affecting the functions provided by an intact riparian zone.

Quantitative information on the magnitude and extent of mainstem Yaquina River channel degradation caused by historical land use activities in the Upper Yaquina River Watershed cannot be determined without significant analytical effort. The upland and riparian areas have undergone significant anthropogenic alterations that have affected riparian function, channel form and sediment processes over the past century. Without active intervention via voluntary or incentive-based projects, natural riparian processes and function in many areas in the Upper Yaquina Watershed will not recover in the next several decades. Many of these issues, challenges and recommended actions are documented in the Limiting Factors Assessment and

Restoration Plan, Buttermilk, Spilde, and Yaquina Headwaters Sixth fields (Bio-Surveys, LLC 2007) prepared for the Midcoast Watersheds Council to guide salmon habitat restoration. The Oregon Coast Coho Conservation Plan (ODFW, 2007) identified significant deficiency in instream habitat in the Yaquina and set overall targets for high quality habitat for the Yaquina population.

4.6 DO Allocation Approach

The approach to setting the solar radiation allocations is based on the surrogate effective shade target of 87% for the QUAL2Kw model reach determined from the analysis in Section 4.4. The total phosphorus allocation approach is based on the surrogate target of 10 μg/L of total phosphorus measured at station 11476-ORDEQ (Section 4.4) and basing the allocations on the total phosphorus loads calculated for the upstream watershed from the calibrated HSPF model. Solar load and total phosphorus allocations for unmodeled portions of the watershed are based on effective shade curves for site potential (Section 4.5.2) and setting the target concentration for tributaries and upstream portions of the watershed equal to the target of 10 μg/L of total phosphorus measured at station 11476-ORDEQ.

4.6.1 Solar radiation and total phosphorus allocations calculation

The components of the TMDL equation and its relationship to the load capacity for solar radiation loading are given below:

$$TMDL = \Sigma WLAs + \Sigma LAs + MOS + RC \ \leq LC$$

$\Sigma WLAs$ is the sum of the waste load allocations, ΣLAs is the sum of the load allocations, MOS is the margin of safety, RC is the reserve capacity, and LC is the load capacity.

The TMDL equation was reorganized for clarity to incorporate the model reach reserve capacity of 0%. Reserve capacity is set aside for future growth and is not available for the waste load allocations or load allocations. To demonstrate this, DEQ subtracted reserve capacity from both sides of the inequality of the TMDL equation, which resulted in the following form:

$$TMDL = \Sigma WLAs + \Sigma LAs + MOS + RC - RC \leq LC - RC$$

$$TMDL = \Sigma WLAs + \Sigma LAs + MOS \leq LC - RC$$

The reserve capacity is subtracted from the load capacity and the remaining load capacity is allocated among the waste load allocations and the load allocations. DEQ reserved zero percent of loading capacity for solar radiation because the expectation for future development in the watershed will not include exemptions for deviations from riparian vegetation restoration.

The remaining components of the TMDL equation for solar load are:

$$\Sigma WLAs = 0\% \times 8{,}197{,}207{,}223 \frac{kcal}{day} = 0 \frac{kcal}{day}$$

$$\Sigma LAs = 100.0\% \times 8{,}197{,}207{,}223 \frac{kcal}{day} = 8{,}197{,}207{,}223 \frac{kcal}{day}$$

$$TMDL = \Sigma WLAs + \Sigma LAs + MOS + RC$$

$$TMDL = 0 \frac{kcal}{\text{day}} + 8{,}197{,}207{,}223 \frac{kcal}{day} + implicit + 0 \ \frac{kcal}{day} = 8{,}197{,}207{,}223 \frac{kcal}{day}$$

Note the expressing percentages and kilocalories to the nearest digit may result in apparent deviations from 100% accounting.

As for solar load, DEQ designated 0% reserve capacity for total phosphorus because the expectation for future development in the watershed will not include exemptions for deviations from best management practices designed to prevent total phosphorus runoff to surface waters.

The remaining components of the TMDL equation for total phosphorus are:

$$\Sigma WLAs = 1\% \times 2.13 \frac{lbs}{day} = 0.01 \frac{lbs}{day}$$

$$\Sigma LAs = 42\% \times 2.13 \frac{lbs}{day} + 57\% \times 2.13 \frac{lbs}{day} + 1\% \times 2.13 \frac{lbs}{day} = 2.13 \frac{lbs}{day}$$

$$TMDL = \Sigma WLAs + \Sigma LAs + MOS + RC$$

$$TMDL = 0 \frac{\text{lbs}}{\text{day}} + 2.13 \frac{lbs}{day} + implicit + 0 \frac{lbs}{day} = 2.13 \frac{lbs}{day}$$

Note the expressing percentages to the nearest digit and pounds to the nearest 1/100th may result in apparent deviations from 100% accounting.

4.6.2 Dissolved Oxygen Nonpoint Source and Background Load Allocation Methodology

Solar load allocations apply to all nonpoint source categories in the Upper Yaquina River Watershed. For the model reach solar load allocations will be met through reducing solar input by 76% to the main river channel of the model reach through riparian vegetation restoration irrespective of land use/land cover in the areas adjacent (≤ 100 m on both banks) to the channel. Because the target effective shade for the model reach (87%) is similar to effective shade expected from site potential vegetation (91%), applying effective shade curves (see Section 4.5.2) for site potential vegetation in unmodeled portions of the watershed will be sufficient to attain water quality standards for dissolved oxygen.

Achievement of the solar load allocations will rely on riparian vegetation restoration and associated channel restoration to provide areas for riparian restoration. A number of programs and organizations, including the EPA Section 319 grant program, the Oregon Watershed Enhancement Board, the ODA Strategic Implementation Area program, Watershed Councils, and Soil and Water Conservation Districts, can fund and/or facilitate riparian restoration in the Upper Yaquina Watershed (some of which is already underway). Riparian and channel restoration are common environmental management activities throughout Oregon; thus, implementation of restoration activities should meet reasonable assurance guidelines.

Timeline for attainment of the solar allocation for the modeled and unmodeled portions of the watershed will depend on the starting condition of the riparian vegetation for specific river and stream segments. Reasonable expectations to achieve the majority of solar load reductions based on growth curves for site potential vegetation are 20-45 years. The environmental impact of meeting the riparian restoration activities is expected to be entirely beneficial without unintended consequences. In addition to meeting the water quality standard for dissolved oxygen, riparian restoration has numerous water quality and environmental benefits including (but not limited to): limiting heating of surface waters, providing large wood for channel habitat improvements, and supplying food resources for aquatic and terrestrial organisms.

Load allocations for Nonpoint Source Sectors specifically related to solar loading include:

- General Nonpoint Sector: 76% reduction of kilocalories per day in the modeled reach and achievement of site potential vegetation in unmodeled portions of the watershed:
    - Forestry
    - Agriculture
    - Water Conveyance Entities
    - Transportation Networks

The load allocation for total phosphorus in the entire Upper Yaquina Watershed include background loads and anthropogenic nonpoint sources. For the modeled reach, the 50% percent reduction allocation was applied to General Nonpoint, Agricultural and Rural Residential Sectors. For the General Nonpoint Source Sector, DEQ could not separate background and anthropogenic sources based on the modeling analysis; thus the 50% reduction applies to all components of the sector. The 50% reduction for the Agricultural Sector applies specifically to total phosphorus originating from livestock (cow-calf pairs) waste and loaded to the river. The 50% reduction for the Rural Residential Sector applies to total phosphorus originating from septic system leaching to the river system.

Achievement of the total phosphorus load allocations will rely on implementation of best management practices for reducing runoff of total phosphorus from all Nonpoint Source Sectors. Best management practices may include (but are not limited to): reducing sediment runoff from roadways, reducing or improving the timing of fertilizer/chemical applications to forested areas to minimize surface water runoff, livestock exclusion and providing livestock watering sources away from river and stream channels, and upgrading septic systems to modern technology. Additionally, riparian restoration will also reduce total phosphorus runoff to streams and rivers in the watershed. Similar to the ways to achieve riparian restoration, a number of programs and organizations, including the EPA Section 319 grant program, the Oregon Watershed Enhancement Board, the ODA Strategic Implementation Area program, Watershed Councils, Soil and Water Conservation Districts, and the USDA National Resources Conservation Service, can fund and/or facilitate best management practice implementation in the Upper Yaquina Watershed (some of which is already underway). Many of the suggested best management practices are standards in forestry, agriculture, and rural residential environmental management in Oregon and elsewhere; thus, implementation of restoration activities should meet reasonable assurance guidelines. Practices that reduce total phosphorus loading will also reduce the runoff of sediments and nitrogen, both of which can impact aquatic life in freshwater ecosystems and downstream estuarine systems.

As with solar load attainment, the timeline for meeting the total phosphorus allocation for the modeled and unmodeled portions of the watershed will depend on the current best management practices already implemented in specific river and stream segments. In the Agricultural Sector, reducing livestock waste runoff to targets should be achievable within 10 years based on relatively quick timeline to implement practices and the reduction in phosphorus runoff. Similarly, identifying and upgrading malfunctioning septic systems based on community outreach and available funding should be achievable within a 10-year timeframe. The timeline for achieving the target total phosphorus allocation in the General Nonpoint Sector may extend beyond 10 years based on the diversity of sources and best management practices. Some practices, such as reducing sediment runoff or improving the efficiency of forestry chemical applications, could be implemented and have an effect within a 10-year timeframe. However, other practices, such as riparian vegetation restoration, may not be fully implemented and effective for 20-40 years.

Load allocations for Nonpoint Source Sectors related to total phosphorus include:

- General Nonpoint Sector: 50% reduction of pounds of total phosphorus per day:
  - Atmospheric deposition
  - Natural weathering and erosion
  - Forestry
  - Water impoundments
  - Water Conveyance Entities
  - Transportation Networks
- Agriculture: 50% reduction of pounds of total phosphorus per day:
  - Livestock (cow-calf pairs)
- Rural residential: 50% reduction of pounds of total phosphorus per day:
  - Leaky septic systems

DEQ's expectation is that all relevant management strategies will be applied to the controllable portions of each source toward achieving each responsible entity's portion of the aggregated Nonpoint Source General Sector reductions needed.

4.6.3 Dissolved Oxygen Point Source Waste Load Allocation Methodology

There is one entity assigned an NPDES permit in the Upper Yaquina Watershed. The Oregon Department of Transportation is assigned a statewide MS4 Phase I permit for stormwater discharge from its transportation network. The permit authorizes ODOT owned and/or operated roads, water quality facilities, maintenance yards, rest areas and other facilities located in ODOT highway right-of-way to discharge stormwater to surface waters. The highways managed by ODOT in the Upper Yaquina are paved, so ODOT does not have unsurfaced roads.

The ODOT MS4 permit requires that ODOT implement a Stormwater Management Program (SMP) designed to reduce pollutants from its MS4. The SMP must include control measures that include public education and outreach; a program to detect and eliminate illicit discharges into the MS4; a program to minimize impacts from construction site runoff; implementation of a post-construction site runoff program to reduce discharges of pollutants and control runoff; and other control measures. If ODOT complies with all the terms and conditions of the permit, it is presumed that ODOT is not causing or contributing to an excursion of applicable water quality standards. If ODOT or DEQ determines that a pollutant in ODOT's MS4 discharge is causing or contributing to an excursion of an applicable water quality standard, the permit specifies that ODOT must take corrective actions.

The elimination of excess total phosphorus entering the stormwater covered by the ODOT MS4 is addressed under Schedule A (Stormwater Management Program Control Measures) of the permit. The seven control measures designed to eliminate excess total phosphorus entering the stormwater are: Public Education and Outreach, Public Involvement and Participation, Illicit Discharge Detection and Elimination (Schedule A.3.c), Construction Site Runoff Control (Schedule A.3.d), Post-Construction Site Runoff Control (Schedule A.3.e), and Pollution Prevention and Good Housekeeping (Schedule A.3.f) and Stormwater Retrofit Strategy (Schedule A.3.h). ODOT is required to conduct an ongoing education and outreach program to inform the public about the impacts of stormwater discharges on waterbodies and steps to reduce pollutants in stormwater runoff. Total phosphorus should be addressed as a target topic as a stormwater education activity or message. The Public Involvement and Participation measure requires that ODOT implement a program that provides opportunities for the public to effectively participate in ODOT activities and processes, where applicable and/or appropriate. Part of this measure involves the facilitation of an ODOT website which should include total phosphorus educational material as well as a place to report illicit discharges. Prevention of illicit dumping of wastes into the stormwater system is of specific concern, and the entire Illicit Discharge Detection and Elimination measure needs to be implemented to ensure excess total phosphorus loads are not introduced to the stormwater system under the MS4. The procedures outlined in the Illicit Discharge Detection and Elimination control measure map out how the potential of illicit dumping of wastes would be addressed. The construction site runoff control measure requires ODOT to use and maintain erosion controls, sediment controls, and waste materials management controls at all ground-disturbing projects from initial clearing through final stabilization to reduce pollutants in stormwater discharges to the MS4 from construction sites. This measure will reduce the amount of construction sediment and waste material from entering stormwater. In addition, the post-construction site runoff control measure requires ODOT to implement its post-construction site runoff program to reduce discharges of pollutants and control stormwater runoff from project sites in its coverage area. As part of this post-construction requirement, ODOT must continue to maintain an inventory and implement a strategy to ensure that all water quality facilities (WQFs) are operated and maintained. These water quality facilities provide treatment for stormwater containing total phosphorus and help with stormwater volume reduction which correlates with a total phosphorus load reduction. For the Pollution Prevention and Good Housekeeping control measure, requirements in the permit for (1) inspecting and cleaning catch basins on an as-needed basis; and (2) litter control would reduce the potential for excess total phosphorus loads entering stormwater. Implementation of these control measures are expected to keep total phosphorus loads in MS4 stormwater <1% of the WLA. The stormwater retrofit strategy permit measure also has the potential to help address phosphorus in stormwater. As stated in the permit, ODOT must develop a Stormwater Quality Retrofit Strategy that addresses areas identified by ODOT as having an impact on water quality, and that are underserved, difficult to maintain in its current design, or lacking stormwater quality controls. This measure will provide ODOT the opportunity to improve stormwater quality controls where they are insufficient or absent and has the potential to assist with the removal of total phosphorus from stormwater. This measure could also help ODOT maximize stormwater volume reduction which correlates with total phosphorus load reduction.

Given these requirements in the permit, ODOT facilities in the Upper Yaquina watershed are not expected to discharge materials likely to influence DO, including significant quantities of total phosphorus. A non-zero waste load allocation up to 1% of the loading capacity is reasonable. If in the future it is determined that facilities covered by the ODOT MS4 permit discharge materials that may adversely affect DO, WLAs may be revised.

4.6.4 Dissolved oxygen reserve capacity

DEQ did not identify any projected needs for reserve capacity of solar radiation or total phosphorus due to future growth and new or expanded sources. DEQ reserved zero percent of loading capacity for solar radiation because the expectation for future development in the watershed will not include exemptions from riparian vegetation restoration practices. DEQ designated one percent of the total phosphorus loading capacity as reserve capacity, with the expectation that future development and discharges within the watershed will adhere to management practices designed to prevent excess total phosphorus runoff loading to surface waters.

4.6.5 Dissolved oxygen margin of safety

A margin of safety may be implicit through the use of conservative assumptions that result in more protective loading capacity, wasteload allocations, or load allocations. The margin of safety may also be explicitly stated as an added, separate quantity in the TMDL calculation. In any case, assumptions should be stated and the basis behind the margin of safety documented. The margin of safety is not meant to compensate for a failure to consider known sources. Due to the complexity of the TMDL analysis, DEQ determined that an implicit margin of safety was appropriate. This approach incorporates conservative assumptions about input data and model processes rather than explicitly varying loads by a fixed percentage ("Guidelines for Reviewing TMDLs under Existing Regulations Issued in 1992" 1992). Within QUAL2Kw, DEQ decreased effective shade and Manning's n by 20% and increase all N and P concentrations by 20% of the calibrated model values to calculate an implicit MOS scenario.

As shown in Figure 4.6.5a, DO concentrations and saturations simulated in the margin of safety or MOS scenario fall below the Year-round Cold Water Minimum criteria for some period of time at the three most downstream stations during the summer low flow period (33112, 12301, and 11476). At Station 12301, DO concentrations under the MOS never reach the Cold Water criterion of 8 mg/L DO or 90% saturation or the Salmonid Spawning Criteria of 11 mg/L DO or 95% saturation. This suggests that load allocations based on the MOS scenario will be protective of the DO criteria for Year-round and Salmonid-spawning critical periods.

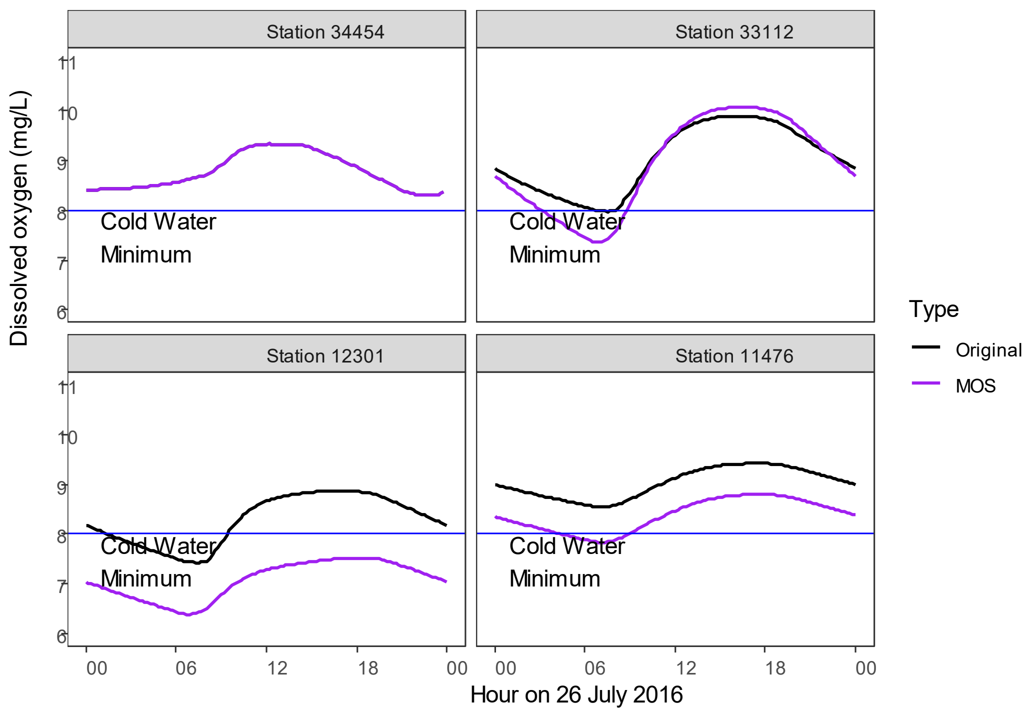


Figure 4.6.5a: Original calibrated model and margin of safety scenario for dissolved oxygen during the summer when cold water minimum criteria are in effect - Upper Yaquina Watershed

An additional MOS that DEQ requires for the DO TMDL will be to meet reduction for both solar radiation and total phosphorus loads. Although the calibrated model suggested meeting either the required solar radiation or total phosphorus load reductions would meet DO criteria, meeting both reduction requirements adds an additional layer to account for uncertainty in model outputs. Figures 4.6.5b-c demonstrate that meeting both reduction requirements ensures DO criteria for Coldwater and Salmonid Spawning will be achieved in the model reach of the Upper

Yaquina River. The figures use 95% DO saturation, the solid black line represents the mean value, dashed black lines represent minimum and maximum values and the blue solid line represents the applicable criteria.

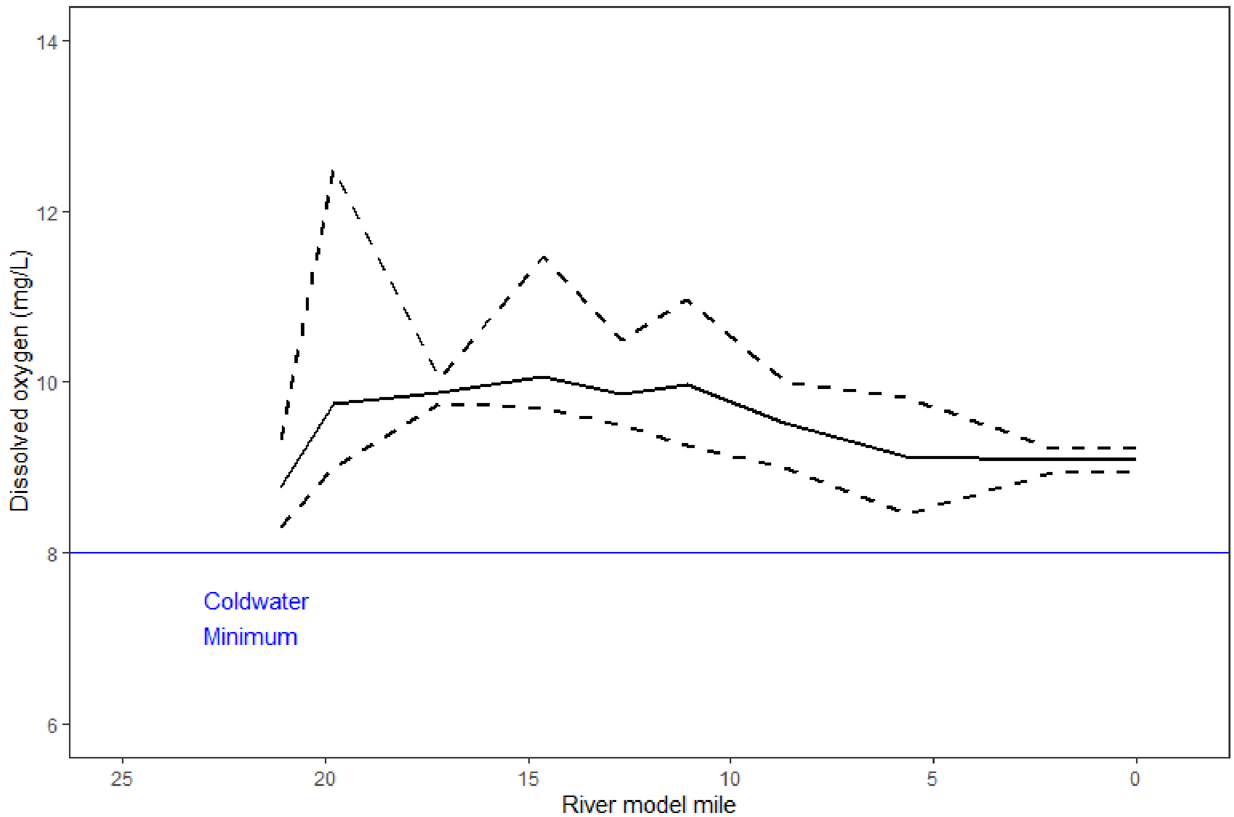


Figure 4.6.5b: Longitudinal plot of modeled dissolved oxygen with TMDL for solar radiation and total phosphorus critical period for cold water criteria.

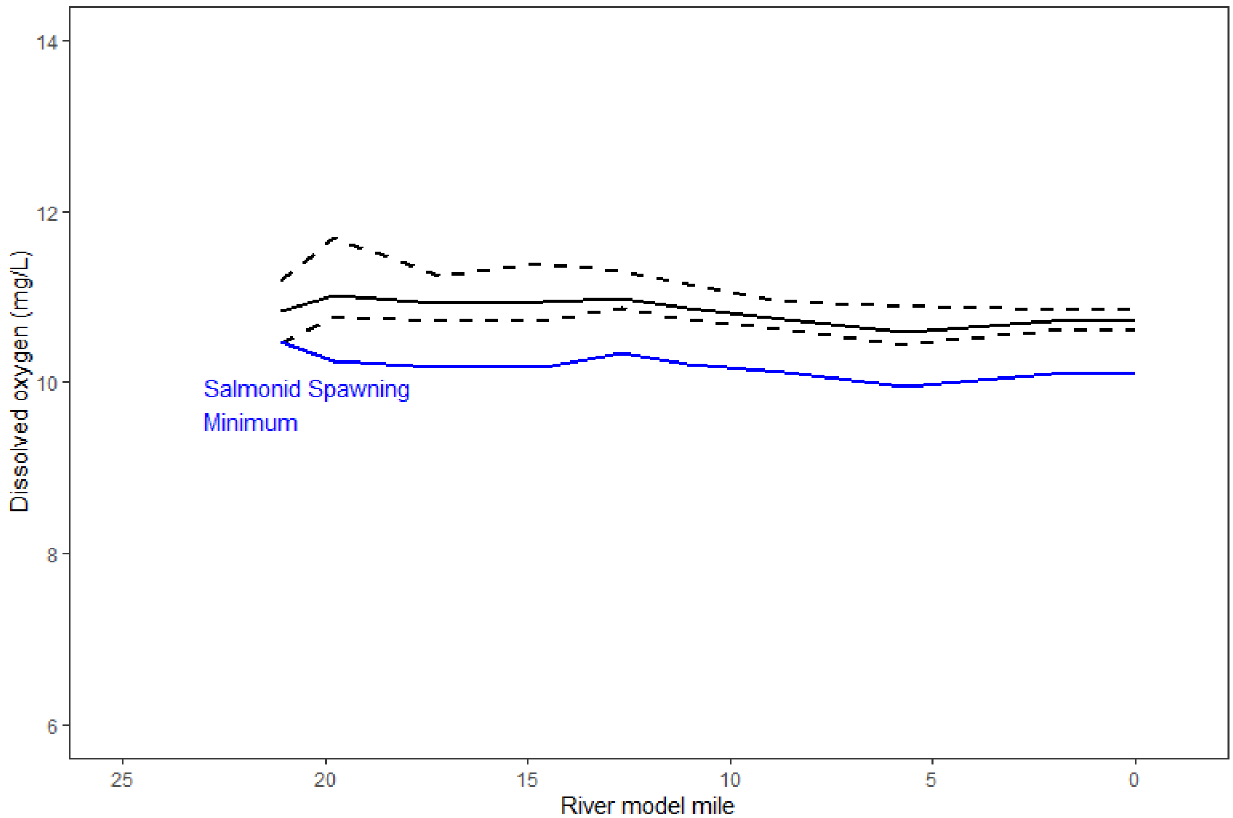


Figure 4.6.5c. Longitudinal plot of modeled dissolved oxygen with TMDL for solar radiation and total phosphorus critical period for Salmonid Spawning

5. Bacteria data evaluation and analyses

5.1 Bacteria evaluation general information

Fecal indicator bacteria are bacteria measured in water to assess the potential for fecal contamination of a waterbody. Fecal contamination of waterbodies is indicated by high levels of fecal indicator bacteria, in this case, *Escherichia coli* (abbreviated as *E. coli*). Potential sources of *E. coli* and other fecal bacteria and pathogens include fecal waste from humans, domestic animals and wildlife, which are transported to waterbodies via both point and nonpoint sources. Examples of point sources include: wastewater treatment plants and combined sewer overflows. Nonpoint sources can include direct deposition of livestock or wildlife fecal matter or surface runoff in contact with failing on-site septic systems or pastures with livestock and wildlife. Recreational use of fecal contaminated waters could lead to mild to severe illnesses in humans. Recreational use includes swimming, but also any activity that could result in ingestion of water, such as fishing through contact of hands with water, any water sports or children playing along the banks or shores. Water with high levels of fecal bacteria can pose a disease risk to livestock. Infections like Johne's disease are caused by the ingestion of *Mycobacterium avium spp*. Paratuberculosis in manure of infected animals that reduce weight gain in cattle and could be fatal in a minority of cases (Harris & Barletta, 2001) . Deer could also contract Johne's disease, which leads to wasting like symptoms, and may serve as an environmental reservoir for the bacterium (Edge, et al., 2012). Fecal contamination of irrigation water can also raise the risk of *Listeria monocytogenese* in fresh produce crops (Weller, Wiedmann, & Strawn, 2015). Irrigation and livestock watering sources are beneficial uses but are not the main ones addressed in this TMDL. The most sensitive beneficial use addressed directly in this TMDL is water contact recreation with respect to potential pathogenic exposure by fecal material.

5.2 Bacteria analysis methods overview

DEQ used load duration curves to assess current conditions, determine flow-based pollutant loading capacities and calculate necessary pollutant reductions to comply with Oregon's water quality criteria. Load duration curves are commonly used in the development of TMDLs (USEPA, 2007)and allow association of water quality concentration data with in-stream flow conditions. This association allows relation of E. coli levels to potential sources, determination of E. coli loading under various flow and seasonal conditions, and can be used to help target appropriate water quality restoration efforts (Cleland, 2007). DEQ used load duration curves to calculate observed E.coli loads and then compare the observed loads to the water quality criteria.

Throughout the process, DEQ sought input from the Technical Working Group established to work on bacteria TMDLs for the Mid-Coast region, which met regularly between 2012-2016. To improve the transparency and reproducibility of the technical work, DEQ attempted to perform each step of the process through the development of code in the R programming language (R Core Team, 2021). Copies of the code are provided in Appendix 2. A separate repository is provided for accessing the code and some of the data at: DEQ-Github Repo URL.

DEQ calculated the loading capacity at each location where bacteria samples were collected by multiplying the concentration of the bacteria criterion by the estimated flow for each sampling location. The same flow data was used to calculate the observed loads using the observed concentrations, so the relative differences between the criteria and the estimated loads are the same. Comparing observed loads to the loading capacities indicates reductions needed.

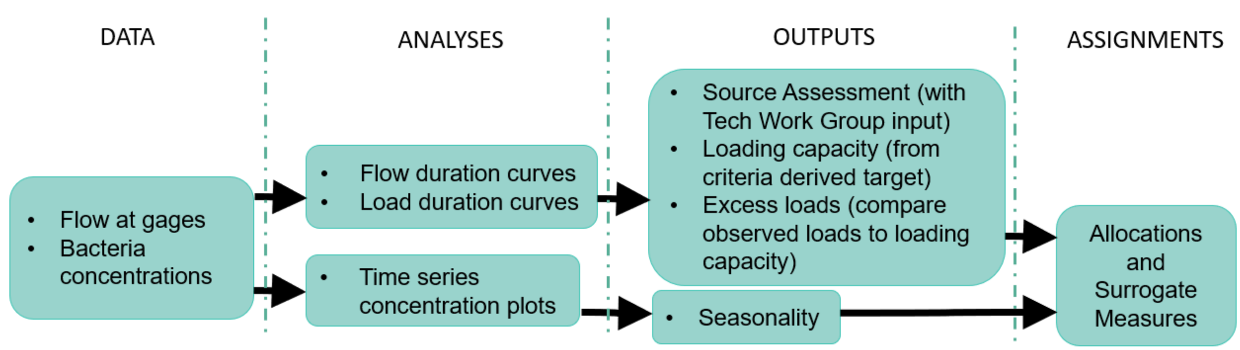


Figure 5.2: Overview of bacteria analytical approach

5.3 Bacteria data and stream flow estimates

Observed E. coli concentrations were available from six monitoring locations in the Upper Yaquina Watershed. The sampling locations are shown within the watershed boundaries on

Figure 5.3a and schematically on Figure 5.3b, along with local roads and streams, with stream flow moving from top of schematic to bottom.

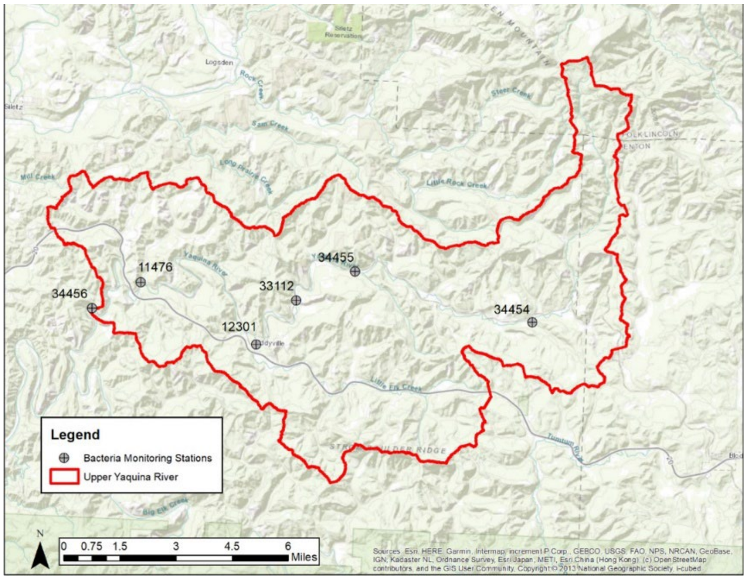


Figure 5.3a: Watershed boundaries and locations of bacteria monitoring stations - Upper Yaquina River

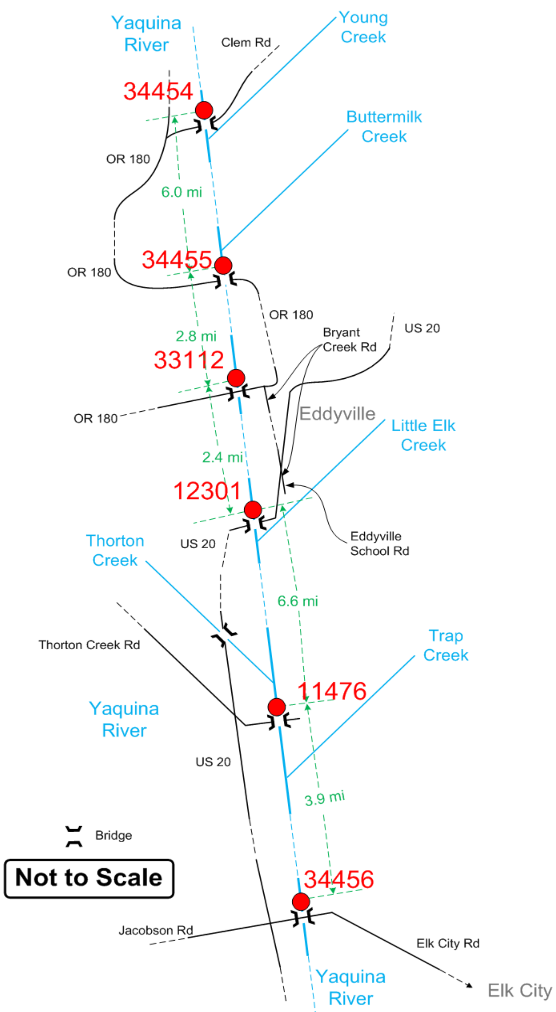


Figure 5.3b: Location of bacteria monitoring stations relative to road crossings and other landmarks - Upper Yaquina River Watershed

General information about bacteria data collected at these stations is provided in Table 5.3a. The relevance of the bacteria load to the TMDL depends on how much the observed bacteria concentration is greater than the bacteria concentration criteria.

Table 5.3a: General Information on Yaquina River bacteria monitoring stations

Station Identifier	Data Collection Agency	Location Description	Time Period	Number of Samples	> Max Criterion (406 orgs/100 ml)
11476	Oregon Department of Environmental Quality, Lincoln County Soil and Water Conservation District, US Environmental Protection Agency	Yaquina River at Trapp Road (Chitwood)	1993-03-09 to 2013-02-25	233	10
12301	Lincoln County Soil and Water Conservation District	Yaquina River at Eddyville	2007-06-20 to 2008-05-05	12	0

Station Identifier	Data Collection Agency	Location Description	Time Period	Number of Samples	> Max Criterion (406 orgs/100 ml)
33112	Lincoln County Soil and Water Conservation District	Yaquina Mainstem at Nashville Road Hwy 180 downstream of confluence with Trout Creek	2007-06-20 to 2013-02-25	65	6
34454	Lincoln County Soil and Water Conservation District	Yaquina River at Clem Road bridge	2007-06-20 to 2013-02-25	64	14
34455	Lincoln County Soil and Water Conservation District	Yaquina River at Hwy 180 Bridge below Buttermilk Creek	2007-06-20 to 2008-05-05	11	0
34456	Lincoln County Soil and Water Conservation District	Yaquina River at Elk City Road bridge near Pioneer	2007-06-20 to 2008-05-05	11	0

DEQ used several methods to explore the bacteria and flow data to better understand the conditions influencing bacteria concentrations. These methods included both tabular and visual descriptive statistics. The list of descriptive statistics and other ancillary information compiled for data from each location where bacteria data was collected is provided in Table 5.3b.

Table 5.3b: Statistics summary for each bacteria monitoring station

Parameter
Station Identifier
Flow Gage Used
Number of Samples
Time Period of Data
Number of concentrations greater than or equal to the max criterion of 406 orgs/100 ml
Maximum Load Reduction
Geometric Means for Flow Categories
Number Calculated (5 Flow-Zones)
Number of estimated geometric means greater than or equal to criterion of 126 orgs/100 ml
Minimum
Maximum
Statistics Using All Data
Arithmetic Mean
Median
Geometric Mean
Standard Deviation
Minimum
Maximum

Inter-Quartile Range (3rd minus 1st quartile)

To provide a temporal and seasonal perspective on the bacteria data, DEQ created time-series plots for each monitoring location. Bacteria data was plotted versus time and estimated flow data for the monitoring location was used to add information about the potential flow conditions when the bacteria concentration was measured. Figures 5.3c through 5.h present the time-series plots for each monitoring station, where flow conditions are added using colored shading. The point size and color in the time-series plots highlight whether a bacteria concentration is greater than or equal to the single sample maximum criterion of 406 org/100 ml. This contrast of the point allows for a qualitative visual assessment of the bacteria levels at the sampling location.

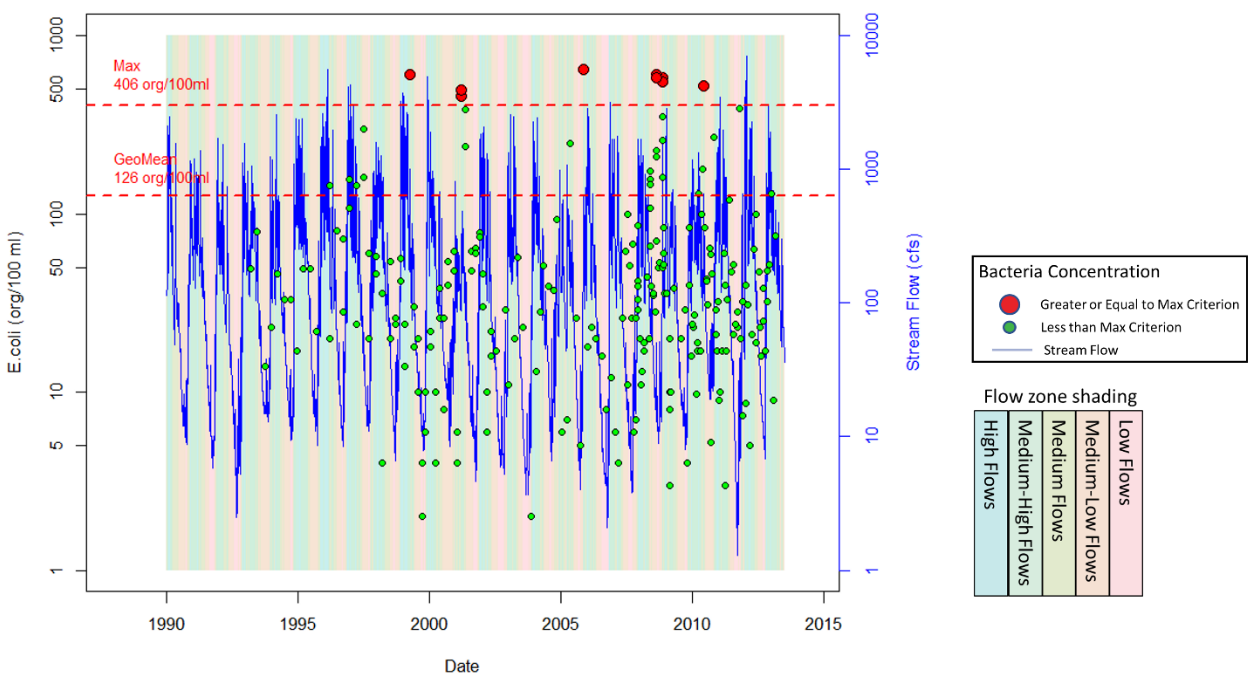


Figure 5.3c: Station 11476 time-series plot of bacteria concentrations and stream flow information

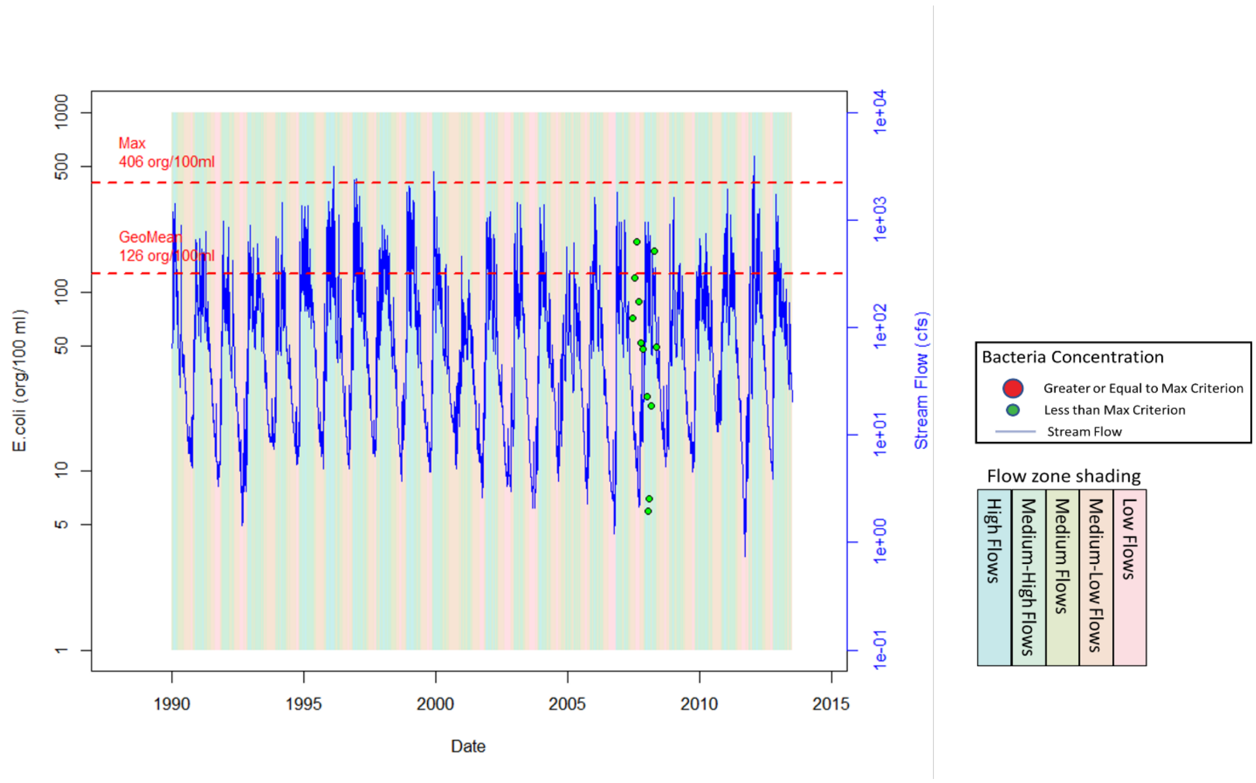


Figure 5.3d: Station 12301 time-series plot of bacteria concentrations and stream flow information

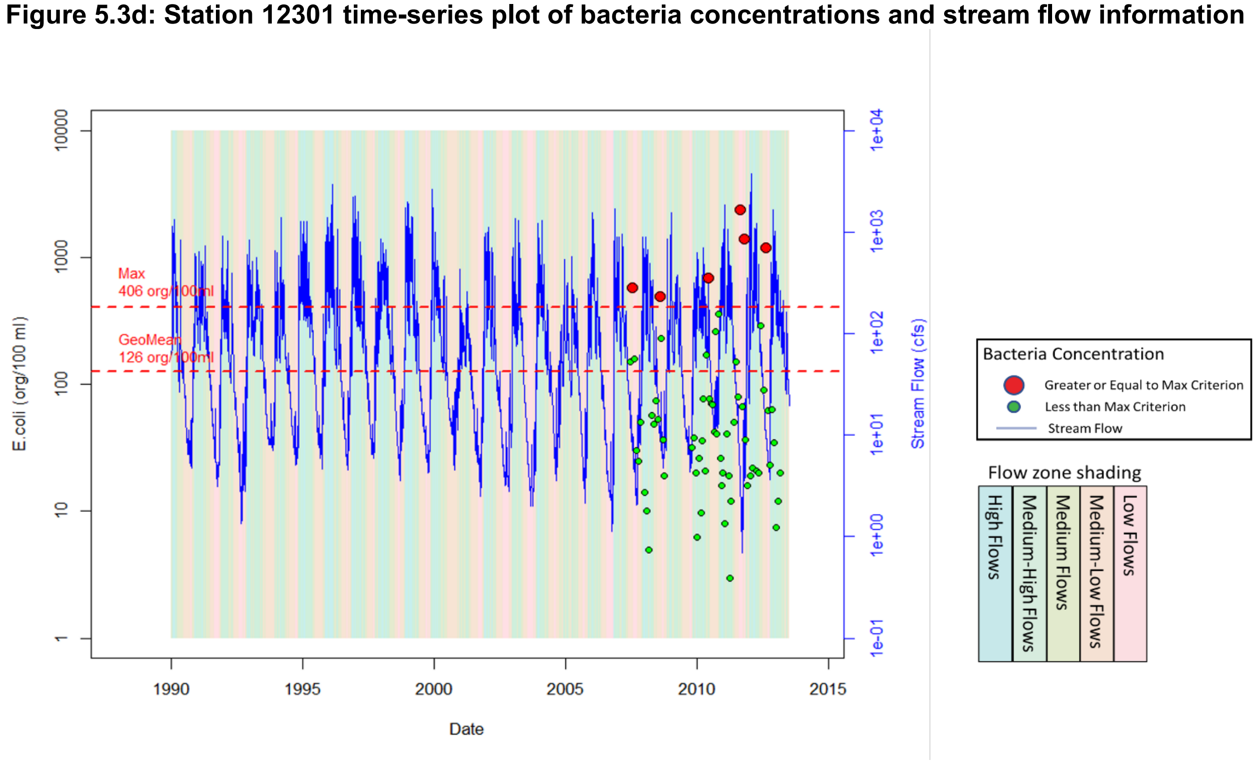


Figure 5.3e: Station 33112 time-series plot of bacteria concentrations and stream flow information

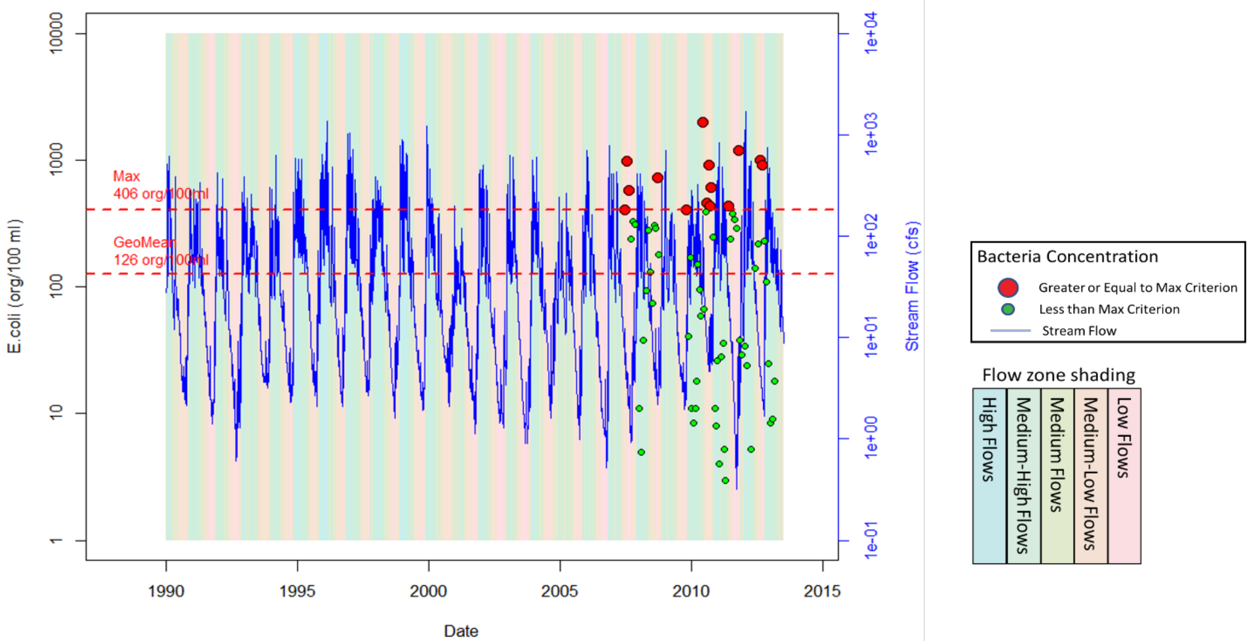


Figure 5.3f: Station 34454 time-series plot of bacteria concentrations and stream flow information

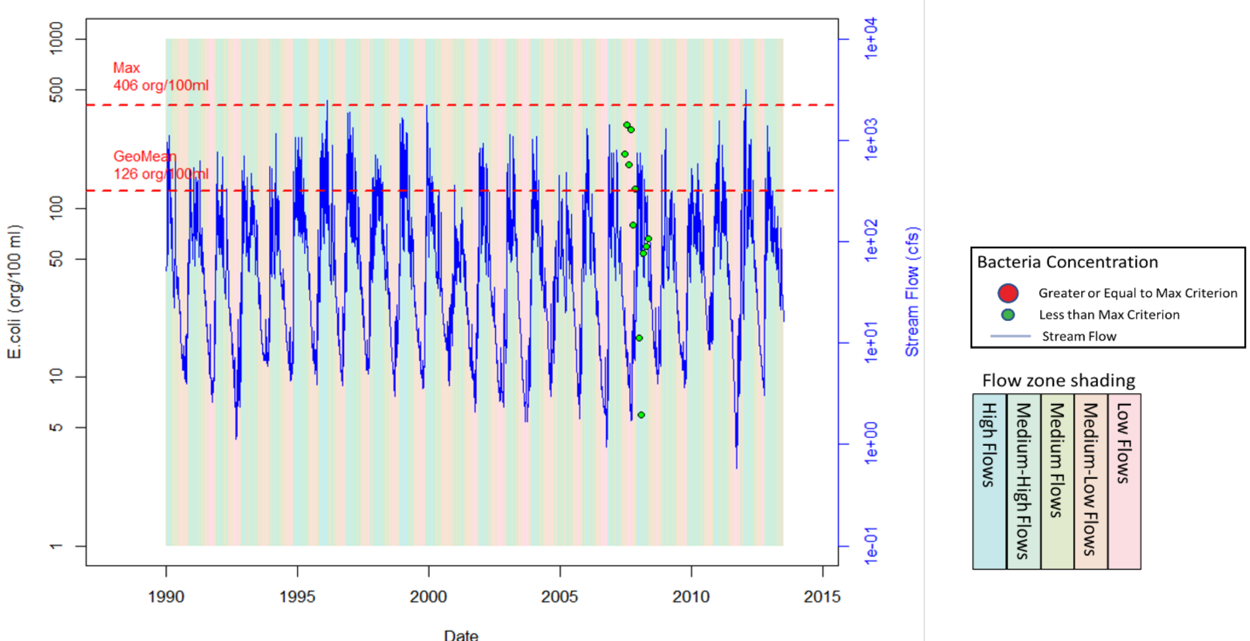


Figure 5.3g: Station 34455 time-series plot of bacteria concentrations and stream flow information

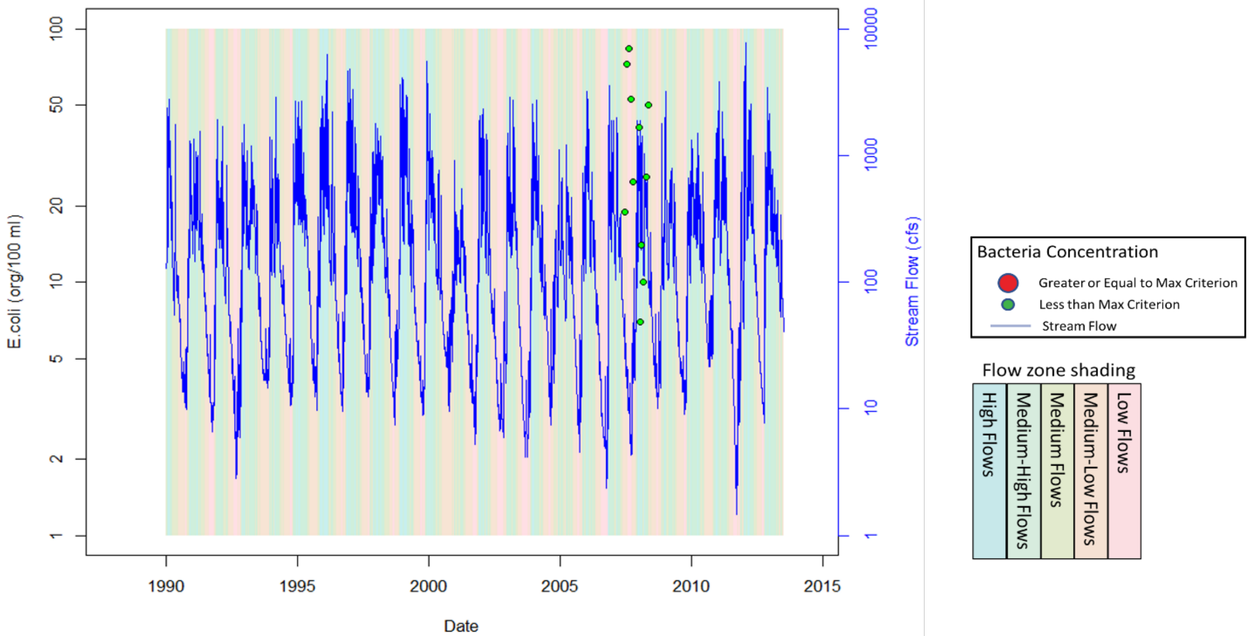


Figure 5.3h: Station 34456 time-series plot of bacteria concentrations and stream flow information

The time-series plots allowed evaluation of the time-periods covered by the observed data sets and seasonality of the processes influencing the observed bacteria concentrations above the water quality criteria. The distribution of the observed data over time varies: almost two decades for sampling location 11476 (Figure 5.3c); several years at locations 33112 and 34454 (Figures 5.3d and 5.3e); and, for short periods at locations 12301, 34455, and 34456 (Figures 5.3d, 5.3g, and 5.3h respectively). DEQ considered the temporal coverage of the data from each sampling location sufficient for use in the TMDL analysis.

The observed data was collected during all seasons, as shown in Figures 5.3c through 5.3h. Changes in stream flow exhibit a clear seasonal pattern, with lowest flows occurring in late-summer/fall and higher flows during winter/spring. Observed E. coli concentrations also occur in a pattern, with lower concentrations during higher stream flows and higher concentrations during the summer/fall seasons lower flows. DEQ considered the seasonality of the data from each sampling location sufficient for use in the TMDL analysis and the patterns were used to focus effort on identifying sources for control, particularly those with potential to contribute high concentrations at dry times of the year.

Both observed and estimated flow data were used for calculating the load duration curves in the Upper Yaquina River. Observed flow data was collected from two Oregon Water Resources Department flow gages and used to stream flow at the bacteria station locations and calculate load duration curves. The locations of the gages are shown on Figure 5.3f, data characteristics are listed in Table 5.3c. Data from gage 14306030 is located on the Upper Yaquina River, near Chitwood, OR, and was the primary source flow data. Three observations were missing from the primary gage and data from gage 14306500, located outside of the watershed boundaries, was used to fill in missing data by multiplying the observed flow on the day of the missing from the observed data at the neighboring gage.

Table 5.3c: Characteristics of data and watershed for flow gages used for load duration curve calculation

Stream Flow Gage	Period of Record Used	Number of Observations	Number of Missing Observations	Drainage Area (sqr mi)	Mean Annual Precipitation (in.)
14306030	1990 to 2013	8591	3	70.8	74
14306500	1990 to 2013	8591	2	331.0	84

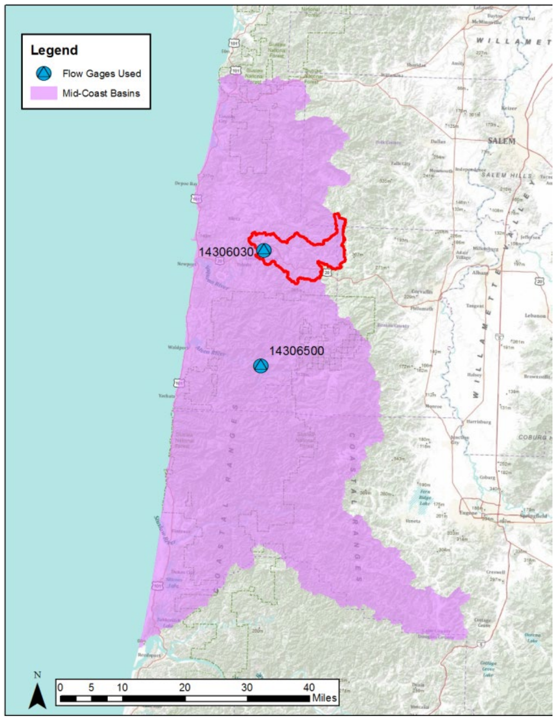


Figure 5.3f: Flow gage locations used for Upper Yaquina River load duration curve calculations

Estmated flow data was used at bacteria sampling locations where observed flow data was not available. Two methods were applied to estimate daily flow and flow characteristics:

1) the modified Drainage Area Ratio method was used to estimate daily mean streamflow; and,
2) 2) USGS StreamStats flow duration regression equations to generate annual flow duration prediction intervals.

The Drainage Area Ratio method is commonly applied to estimate streamflow in ungaged watersheds (Hirsch 1979). The method assumes that area-normalized streamflow in the ungaged watershed is equal to that observed in a gaged reference watershed. Ungaged streamflow is therefore calculated as shown in Equation 5.3a.

Equation 5.3a: Ungaged Streamflow Calculated by the Drainage Area Ratio Method

$$Q_u = Q_r \frac{A_u}{A_r}$$

Where,
Q_u is daily mean streamflow in the ungaged watershed,
Q_r is daily mean streamflow in the reference watershed,
A_u is the drainage area of the ungaged watershed, and A_r is the drainage area of the reference watershed.

Much of the precipitation results from orographic effects in the Coast-Range of Oregon, causing significant differences in flow due to large difference in the elevations. To account for possible orographic related differences, the standard Drainage Area Ratio equation was modified as in Equation 5.3b to include the ratio of average annual precipitation.

Equation 5.3b: Modified Drainage Area Ration Method Equation

$$Q_u = Q_r \frac{A_u}{A_r}\frac{P_u}{P_r}$$

Where,
P_u is average annual precipitation in the ungaged watershed and
P_r is average annual precipitation in the reference watershed.

DEQ prepared flow duration curves using the follow steps from EPA's guidance (USEPA 2007):

1. Sort data in descending order of flow rate magnitude
2. Assign ranks to the sorted flow data with the highest flow rank 1 and lowest flow rank equal to the number of observations (the average of the ranks was used to address ties)
3. Calculate the exceedance as
   100 * (1 – rank of flow observation / total number of flow observations)
4. Plot the data with exceedance on the x-axis and flow rate on the y-axis.

Figures 5.3i through 5.3n present flow duration curves for estimated daily flow at all monitoring stations, with regression equation estimates and corresponding error bars. The blue line demonstrates the typical shape of the curve with a negative slope indicating lower flows occur more often than higher flows. The y-axis is a $\log_{10}$ scale to accommodate the large range in the magnitude of flows. The use of the curve to estimate percent of the time that a flow will be equal to or greater than the specified value is exemplified in red on the figure, where the flow rate for an exceedance of 49% is estimated to be 100 cfs. This allows categorization of flows into ranges.

DEQ used the flow category names represented in Table 5.3d to be consistent in all TMDLs beginning in 2022 and for clarity in communicating with the TMDL implementers and the public. The exceedance probability ranges describe flow duration intervals and are consistent with groupings in EPA's Load Duration Curve Guidance referred to respectively as: Low Flows; Dry Conditions; Mid-Range Flows; Moist Conditions; and, High Flows (EPA 2007). DEQ's flow categories were also informed by flow regimes described in the US Geological Survey report on a regression-based method for predicting flow-duration curves, and roughly coincide with USGS' nonexceedance probability ranges: Low Flow (0.02%-10%); Medium Flow (20%-90%); and High Flow (95%-99.98%) (USGS 2018).

Table 5.3d: Flow categories

Flow Category	Exceedance Probability	Hydrologic Description
Low	90%-100%	Watershed soils dry, may be drought conditions, storage empty, channel levels near or below the lowest 7-day average flow that occurs (on average) once every 10 years (7Q10), long dry and warm periods between weather events, entirely groundwater return flow as source to stream flow
Medium-Low	60%-90%	Watershed soils much below saturated, storage empty, channels much less than bank-full, extended periods between weather events, some shallow subsurface, but mainly groundwater return flow as source to stream flow
Medium	40%-60%	Watershed soils partially saturated, storage almost empty, channels less than bank-full, typical size storms or snow melt events, surface, shallow subsurface and groundwater return flow as source to stream flow
Medium-High	10%-40%	Watershed soils partially saturated, storage partially full, channels near bank-full, moderate size storms or snow melt events, mainly surface or shallow subsurface flow as source to stream flow
High	0%-10%	Watershed soils completely saturated, storage near capacity, channels at or near flood stages, large storms or snow melt events, mainly surface or shallow subsurface flow as source to stream flow

Next, DEQ used an independent method to assess the quality of estimated flow data. DEQ compared the USGS StreamStats flow duration interval estimates to flow duration curves of the estimated flow data from the Drainage Area Ratio method. The USGS StreamStats program includes development of regression equations to estimate stream flow statistics for gaged and ungaged watersheds throughout the US. For the state of Oregon, regional regression equations were derived to predict daily mean streamflow magnitudes corresponding to 5, 10, 25, 50, and 95% exceedance probabilities on annual and monthly basis (Risley, Stonewall and Haluska 2008). The Upper Yaquina Watershed is in Region 1 for the Regression equations and the coefficients and exponents were taken from Table 7 of the StreamStats Report and Tables for Oregon are at: http://pubs.usgs.gov/sir/2008/5126/. Several watershed characteristics are included as predictor variables for the Mid-Coast Region regressions (e.g., drainage area, mean annual precipitation, soil storage capacity). The definitions of the parameters used in the StreamStats equations are listed in Table 5.3e and values for the exponents used in the equation are given in Table 5.3f. The values used to calculate the error statistics are given in Table 5.3g. The error statistics (standard error of the estimate) included with regression equations allowed for the calculation of prediction intervals for each flow duration statistic.

The equations for the annual statistics were calculated for each location using the Equations 5.3c, d and e, with coefficients and exponents defined in Tables 5.3e and f.

Equation 5.3c:

$$FDC = BCF \times 10^{a} \times DRNAREA^{b} \times PRECIP^{c}$$

Where,
FDC is the flow duration curve statistic for percentiles of 5%, 10%, 25%,and 50%,
BCF is the bias correction factor, and
The remaining coefficients are defined in Table 5.3d and the exponents are listed in Table 5.3e

Equation 5.3d:

$$FDC = BCF \times 10^{a} \times DRNAREA^{b} \times PRECIP^{c} \times SC^{d}$$

Where,
FDC is the flow duration curve statistic for percentiles of 95%,
BCF is the bias correction factor, and
The remaining coefficients are defined in Table 5.3d and the exponents are listed in Table 5.3e

Equation 5.3e:

$$CI_{Lower} = 10^{-SEE} \times \frac{FDC}{BCF} \text{ and } CI_{Upper} = 10^{SEE} \times \frac{FDC}{BCF}$$

Where,
CI is the 95% confidence lower or upper interval,
SEE is the standard error of the estimate listed in Table 5.3e,
FDC is the flow duration curve statistic for the percentile,
BCF is the bias correction factor listed in Table 5.3e, and
The remaining coefficients are defined in Table 5.3d and the exponents are listed in Table 5.3e

Table 5.3e: Parameter definitions for calculation of error bars - USGS StreamStats equations for Oregon

Parameter	Definition
DRNAREA	Drainage area in square miles of watershed to gage or station
PRECIP	Average annual precipitation for the drainage area of the gage or station
SC	Available water capacity in inches of the top 60 inches of soil in the drainage area of the gage or station

Table 5.3f: Exponent values for USGS StreamStats equations for Oregon

Flow Duration Percentiles (FDC)	Bias Correction Factor (BCF)	Exponents				log_{10} of Standard Error of Estimate (log_{10}(SEE))
		a	b	c	d	
5%	1.01508	-0.3834	1.0067	0.8470	0	0.078
10%	1.01384	-0.6488	1.0114	0.8927	0	0.074
25%	1.01555	-1.3592	1.0116	1.0911	0	0.079
50%	1.02287	-2.4906	1.0132	1.4513	0	0.097
95%	1.08456	-2.7120	1.0559	1.6250	1.3421	0.190

Table 5.3g: Parameter values for calculation of error bars - USGS regression equation for flow duration curves at bacteria sampling stations

Station or Gage	DRNA REA[1]	PRE CIP[2]	FOR EST[3]	WAT CAP[4]	elev. gage[5]	ELEV [6]	ELEV MAX[7]	DRN DENSITY[8]	JANMIN TMP[9]
14306030	70.8	71.7	72.6	0.13	40	612	2680	0.86	33.6
11476	70.8	71.7	72.6	0.13	43	612	2680	0.86	33.6
12301	39.8	72.7	75.1	0.13	75	676	2680	0.89	33.4
33112	37.4	73.1	75.6	0.13	102	695	2680	0.91	33.4
34454	15.3	81.4	79.3	0.13	230	870	2680	0.86	33.4
34455	31.4	73	76	0.13	138	715	2680	0.91	33.4
34456	79.4	72.3	71.4	0.13	16	589	2680	0.88	33.7

Notes:
[1] DRNAREA is Drainage area in square miles of watershed to gage or station
[2] PRECIP is the average annual precipitation for the drainage area of the gage or station
[3] FOREST is the percent of land area covered by forest in the drainage area of the gage or station
[4] WATCAP is the available water capacity in inches of the top 60 inches of soil in the drainage area of the gage or station
[5] elev gage is elevation of gage or station in feet
[6] ELEV is mean elevation of the drainage area of the gage or station in feet
[7] ELEVMAX is the maximum elevation in the drainage area of the gage or station in feet
[8] DRNDENSITY is the density of stream network in drainage are calculated as ratio of total stream miles divided by drainage area of the gage or station in square miles
[9] JANMINTMP is the mean of minimum temperatures in degrees F for the month of January for the gage or station

Based on this comparison, the estimated flow from the Drainage Area Ratio method represented the hydrologic conditions of the bacteria station watershed well, if the flow duration curve for the estimated flow was within the 95% confidence bands of each of the exceedance probabilities from the USGS regression equations. DEQ plotted the prediction intervals for annual flow duration statistics with the flow duration curve for the estimated flow at each monitoring station, as shown on Figures 5.3i through 5.3n.

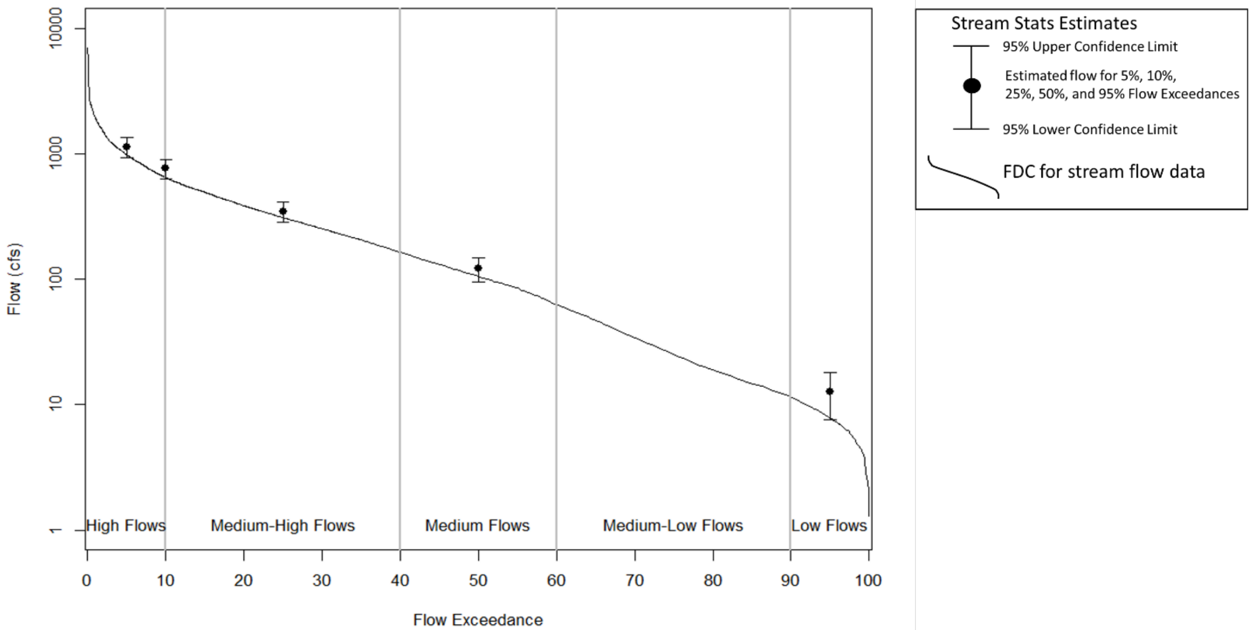


Figure 5.3i: Station 11476 flow duration curve

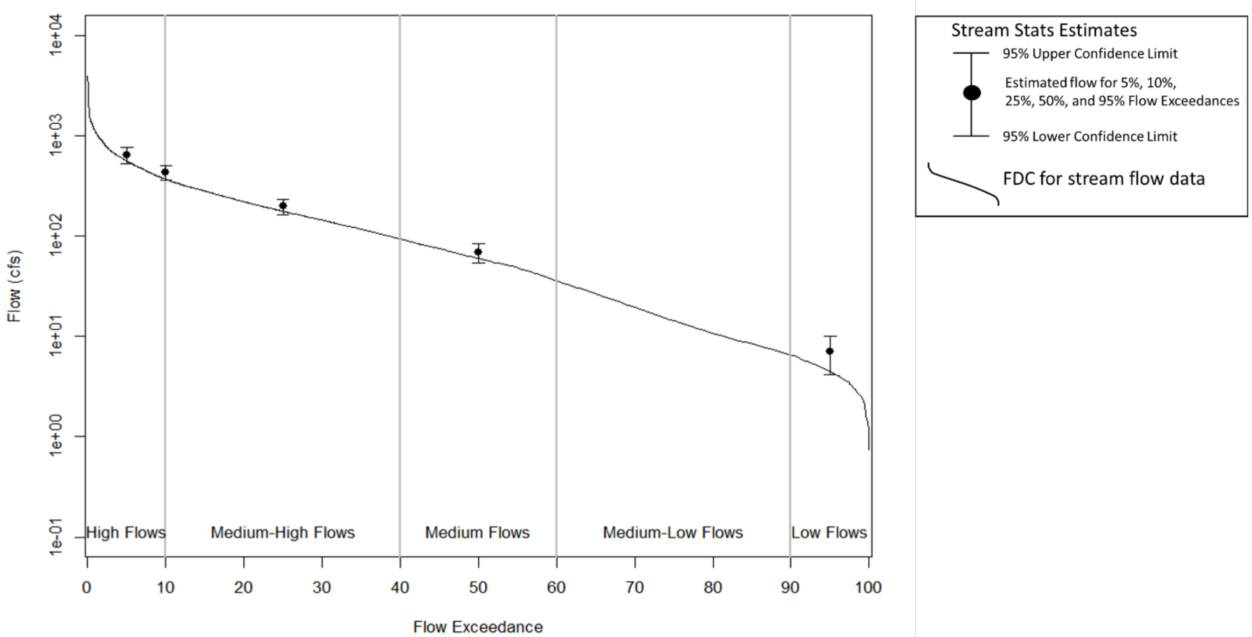


Figure 5.3j: Station 12301 flow duration curve

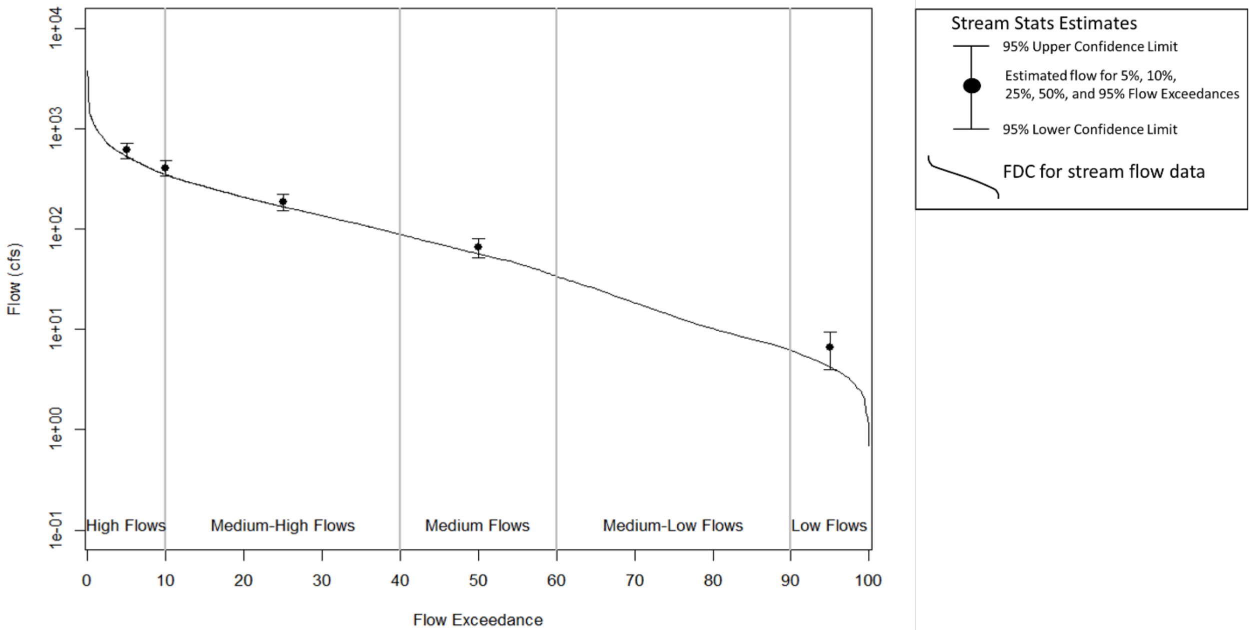


Figure 5.3k: Station 33112 flow duration curve

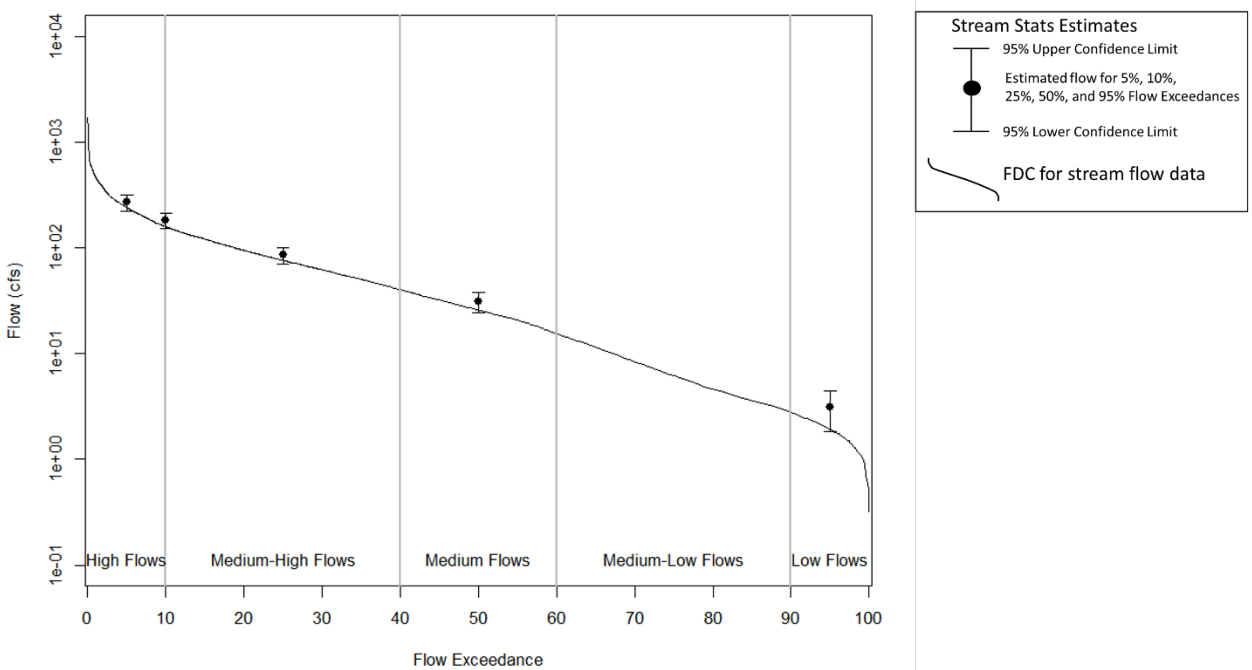


Figure 5.3l: Station 34454 flow duration curve

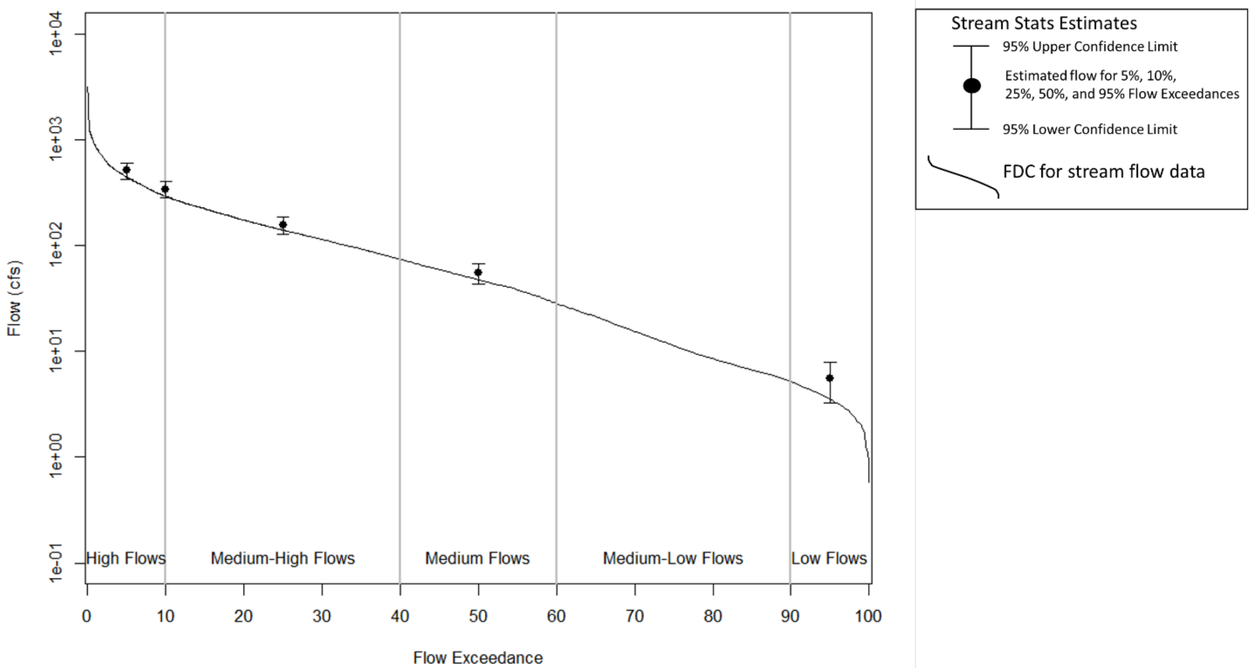


Figure 5.3m: Station 34455 flow duration curve

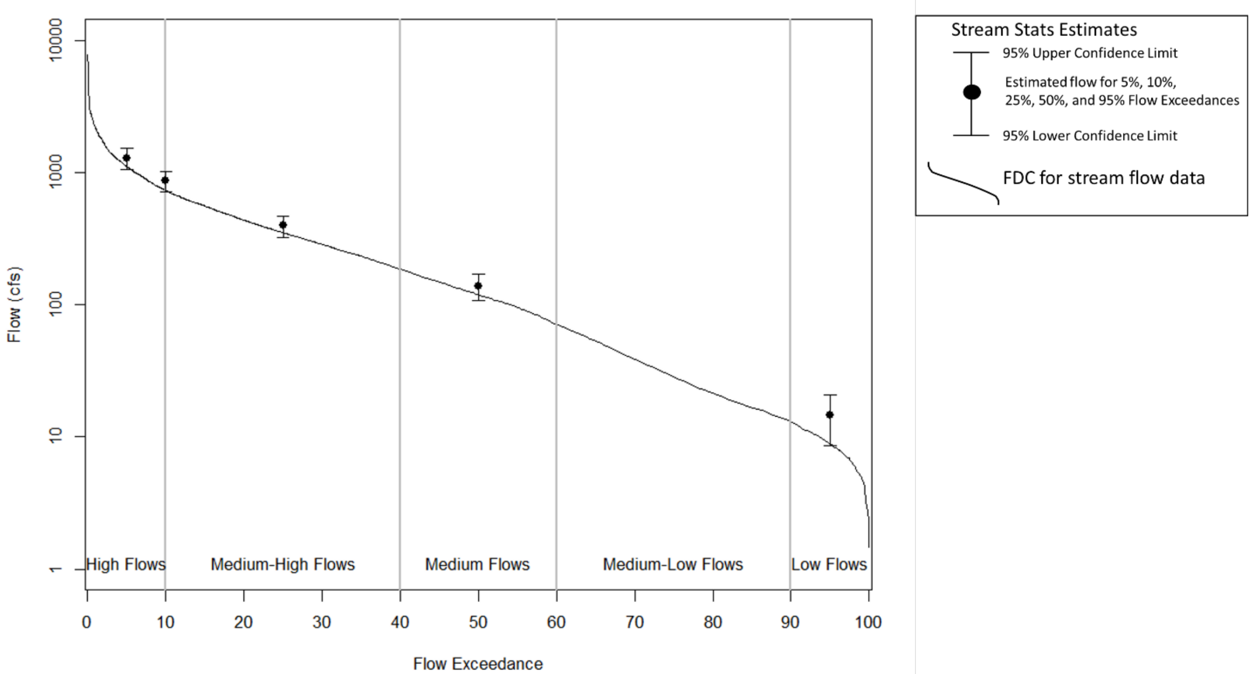


Figure 5.3n: Station 34456 flow duration curve

The estimated flow shown in the flow duration curve figures above was acceptable for use in subsequent load duration curve calculations because the estimated flow duration curve is between the prediction intervals of the StreamStats equation estimates. However, if the flow duration curve for the estimated flow was not within the prediction intervals, the estimated flow was still used, but the assignment of the flow categories in the load duration curves was considered less reliable for evaluating potential sources of the bacteria. Such error introduced when estimating flow does not affect whether the observed bacteria load meets the water quality criterion load. Since the observed and water quality criterion bacterial loads calculation use the same flow data, the relative position on the load duration curve of the loads will remain the same as the concentrations from which they are derived.

Next, DEQ estimated load duration curves for each location bacteria samples were collected, to determine flow-based pollutant loading capacity, assess current conditions and calculate the necessary pollutant reductions to comply with Oregon's water quality criteria. The load duration curve combines information from the flow duration curve with observed bacteria concentrations, which enhances understanding of sources and transport mechanisms in the watershed. In alignment with EPA's recommended methods (USEPA 2007), the load for the load duration curve is the product of a volume of flow and the measured bacteria concentration. The daily average flow is used for the flow volume, which results in bacteria load, expressed as organisms per day. Values of predictor variables specific to the watersheds draining to the bacteria sampling stations were obtained from the Oregon StreamStats online tool and reported for each monitoring location that flow was estimated in Table 5.3h.

Table 5.3h: Statistical summary for bacteria monitoring stations

Parameter	Value	Value	Value	Value	Value	Value
Station Identifier	11476	12301	33112	34454	34455	34456
Flow Gage Used	14306030	14306030	14306030	14306030	14306030	14306030
Number of Samples	233	12	65	64	11	11
Time Period of Data	1993 to 2013	2007 to 2008	2007 to 2013	2007 to 2013	2007 to 2008	2007 to 2008
Number of concentrations greater than or equal to the max criterion of 406 orgs/100 ml	10	0	6	14	0	0
Maximum Load Reduction %	37	NA	83	80	NA	NA
Geometric Means for Flow Categories						
Number Calculated (5 Flow-Zones)	5	5	5	5	4	5
Number of estimated geometric means greater than or equal to criterion of 126 orgs/100 ml	0	1	0	2	2	0
Minimum	24	13	21	20	10	13
Maximum	67	129	116	381	228	67
Statistics using all data						
Arithmetic Mean	74	71	159	264	127	37
Median	33	50	38	135	79	26
Geometric Mean	35	45	48	91	79	28
Standard Deviation	122	61	377	361	106	26
Minimum	2	6	3	3	6	7
Maximum	649	190	2400	2000	310	84
Inter-Quartile Range (3rd minus 1st quartile)	45	71	57	325	138	35
Notes: NA is not applicable for this parameter because it could not be calculated						

Figures 5.3o through 5.3t present load duration curves from each monitoring station. Red dots indicate concentrations at or above the criterion, gray circles are below the criterion and maximum percent reduction amounts are noted in red, when needed. Percent reductions were calculated as the difference between the observed load and the load for the single sample maximum criterion, divided by the observed load.

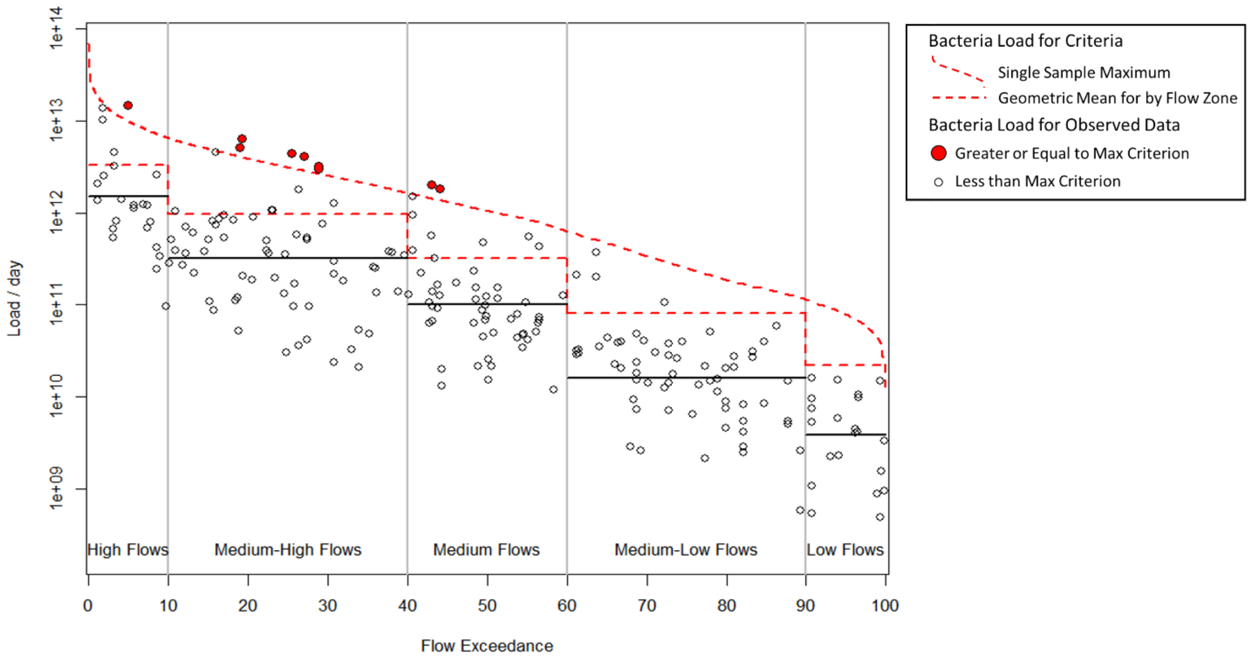


Figure 5.3o: Station 11476 load duration curve

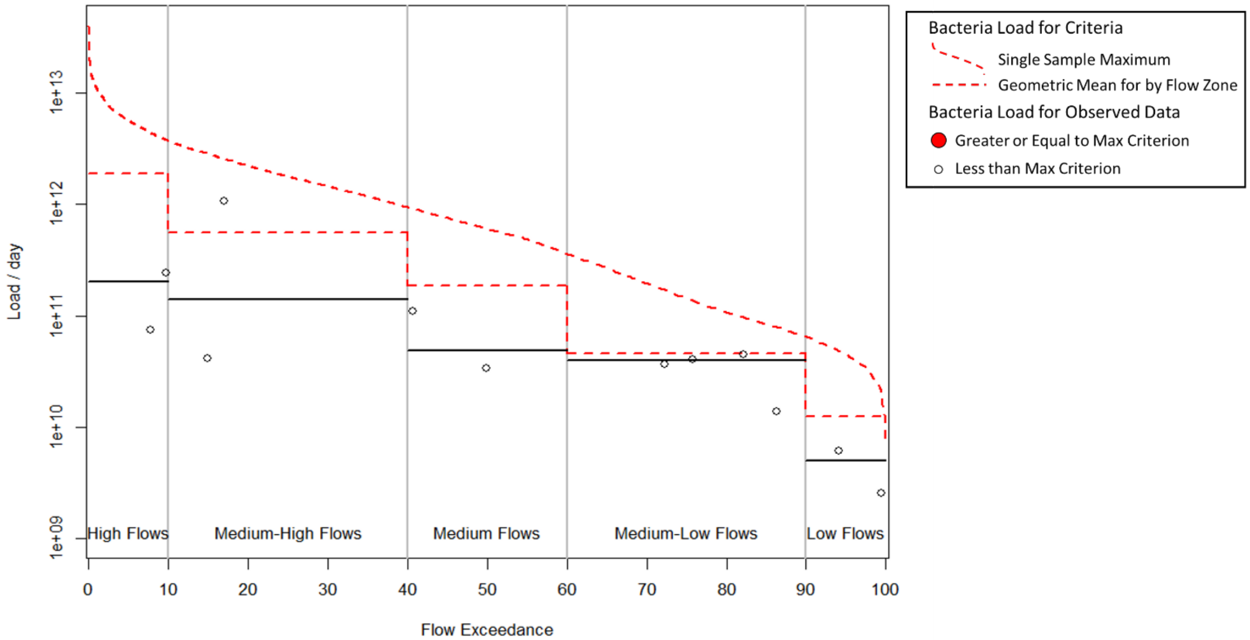


Figure 5.3p: Station 12301 load duration curve

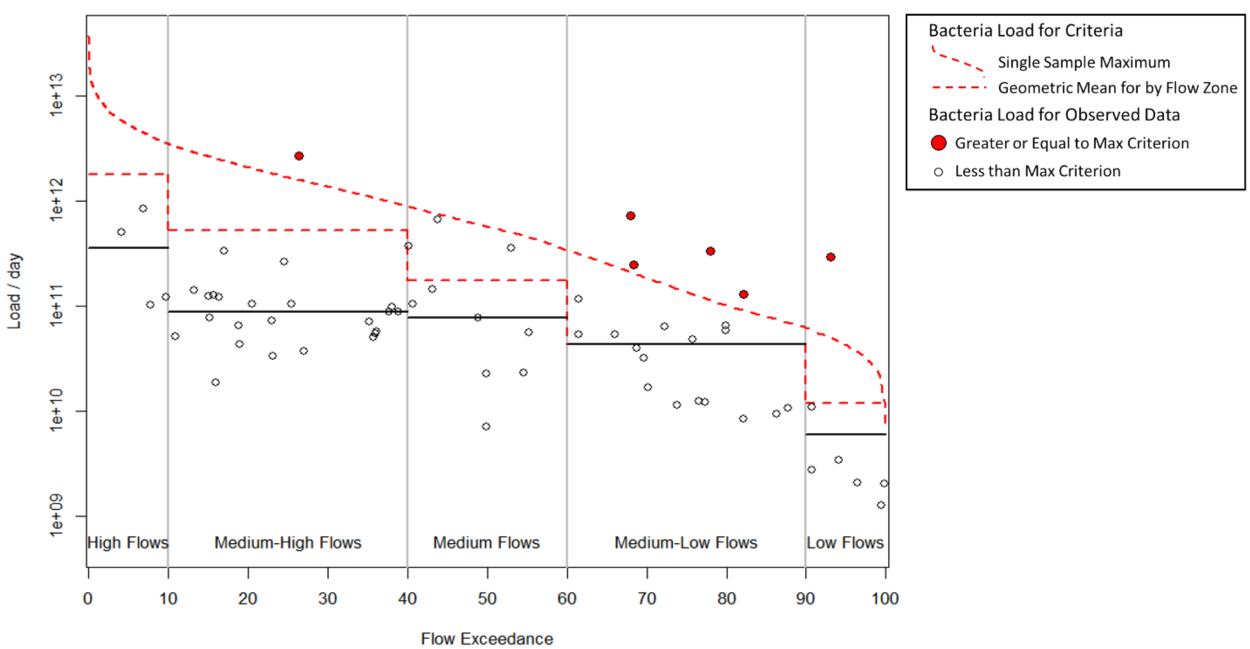


Figure 5.3q: Station 33112 load duration curve

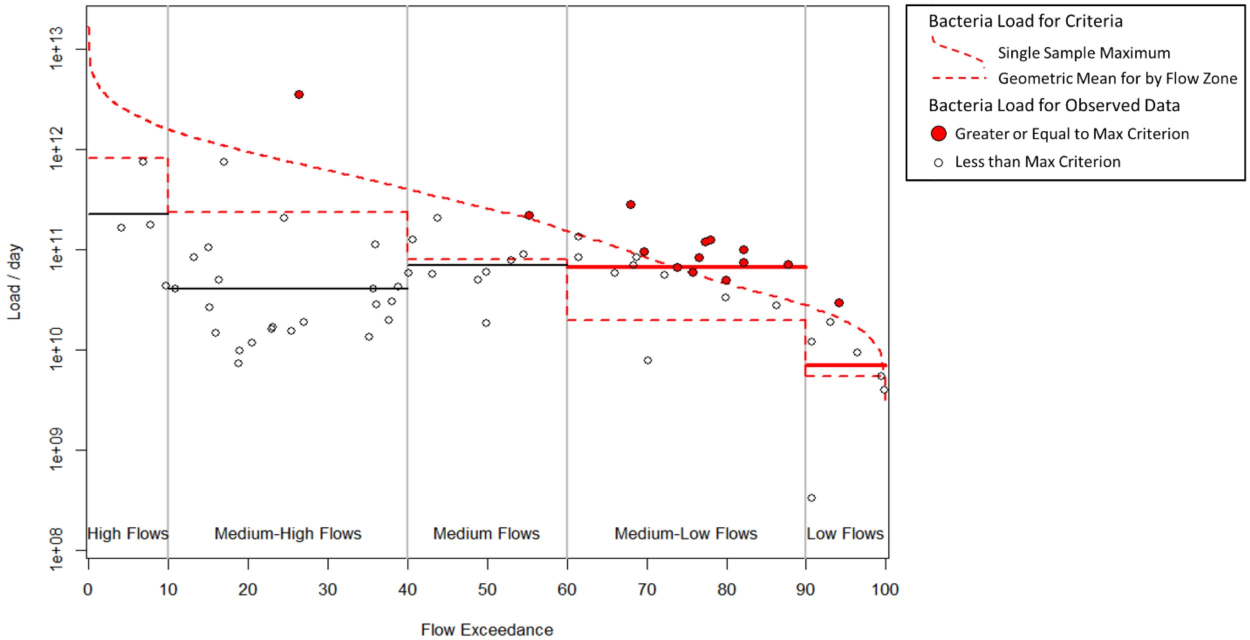


Figure 5.3r: Station 34454 load duration curve

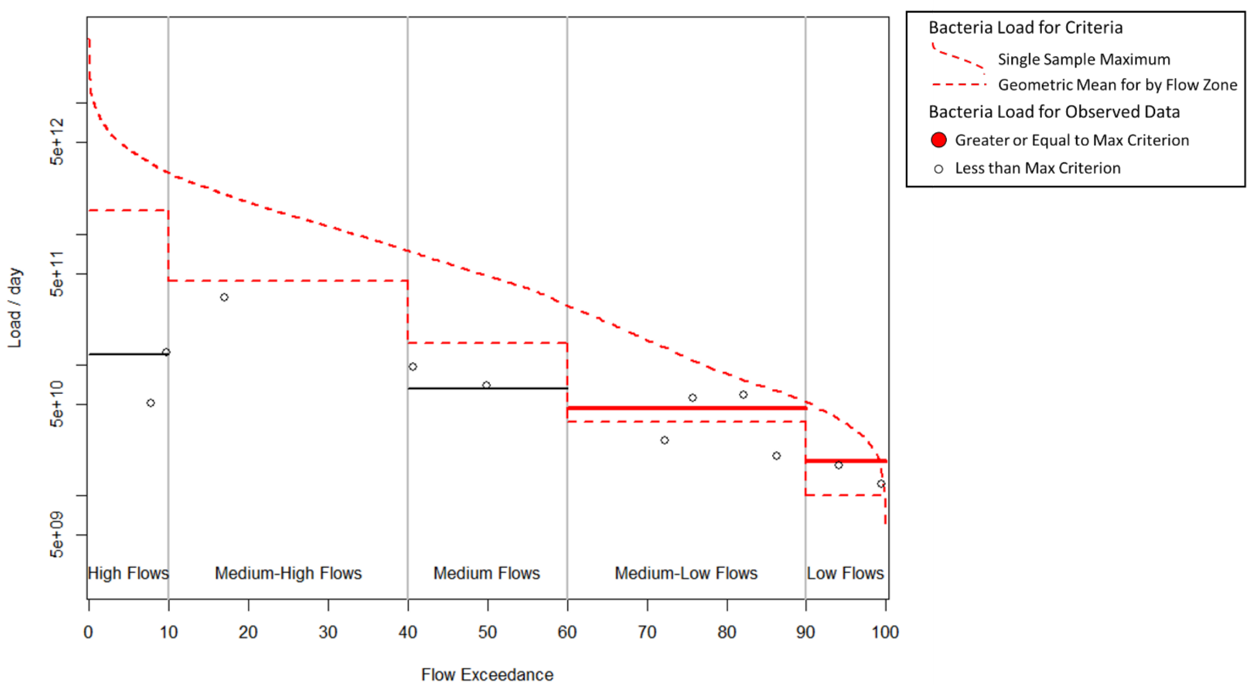


Figure 5.3s: Station 34455 load duration curve

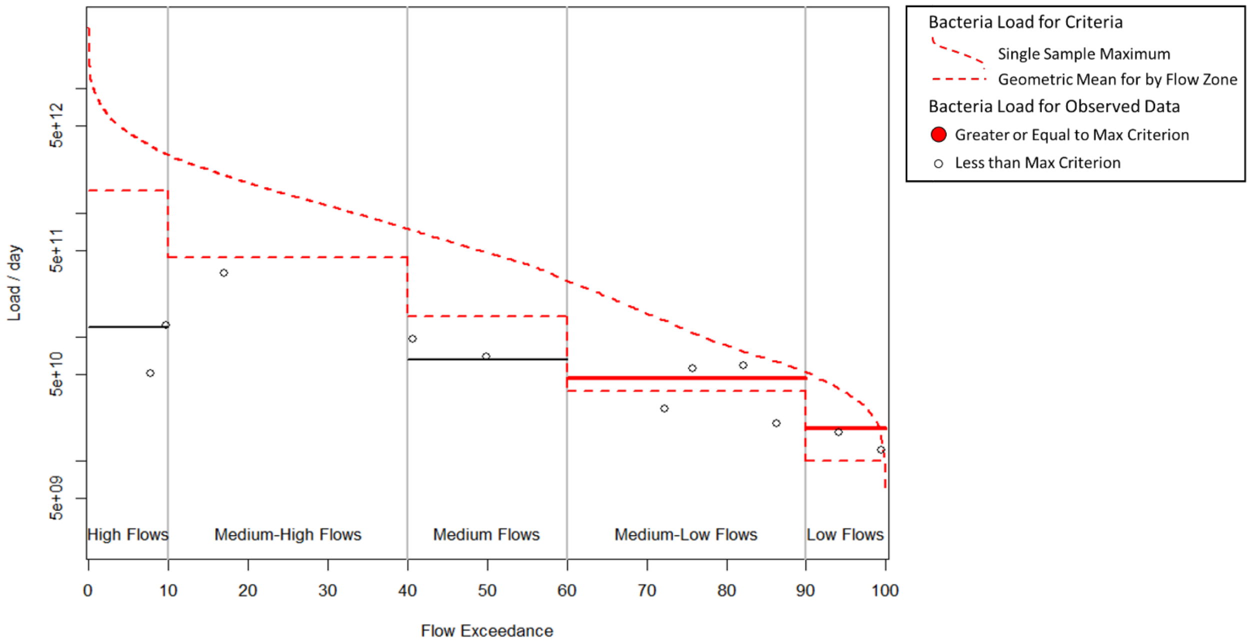


Figure 5.3t: Station 34456 load duration curve

Of the six locations where load duration curves were estimated, three require reductions in to meet the single sample maximum criterion. Data sets were sparse at the three locations where a reduction was not indicated, meaning a small number of total samples that cover a shorter time period that at the other locations. These sparse data sets may be one reason why reductions were not indicated at these locations. Another contributing factor could be that the conditions in the watersheds for these locations could be in a state where bacteria loads are easily assimilated into the streams, keeping concentrations stay below the single sample maximum criterion. These possibilities will be discussed for each station with or without reductions indicated.

5.4 Bacteria targets and loading capacity

This section provides an analytical basis for the selection of the concentration used to calculate the loading capacity for bacteria TMDLs in Oregon. The freshwater recreation water quality criteria for E. coli, per 340-041-0009(1)(a), has two parts:

(A) A 90-day geometric mean of 126 E. coli organisms per 100 mL;
(B) No single sample may exceed 406 E. coli organisms per 100 mL

In alignment with the theoretical basis for EPA's bacteria criteria guidance, upon which the Oregon bacteria water quality standard relies, DEQ pursued two objectives. First is demonstration of the relationship between the two parts of the bacteria criteria. The second objective is use of this relationship, in combination with the duration of the geometric mean, to show that calculating the loading capacity using the single sample maximum concentration as the TMDL target will also meet the geometric mean criterion.

5.4.1 Relationship between bacteria criteria components

The foundation of the linkage between the two criteria is that the single sample maximum density is calculated from a probability distribution using the geometric mean density. EPA's guidance for developing the bacteria criteria used a lognormal probability distribution to describe the bacteria densities observed at bathing areas using base 10 logarithms and a log-standard deviation of 0.4 (USEPA 1986). DEQ used the same log-standard deviation value to revise the bacteria standard (ODEQ 1995). Working with lognormal probability distributions can be simplified by using the logarithms of the bacteria densities, which allows use of a standard normal probability distribution. A simplified form of the cumulative probability function using logarithms base 10 and a standard normal distribution is given in Equation 5.4a.

Equation 5.4a: Simplification of a log-normal distribution using logarithms and standard normal distribution

$$log_{10}(E.coli) = log_{10}(geometric\ mean\ E.coli\ criterion) + N(p,0{,}1) \times \log \text{standard deviation}$$
$$log_{10}(E.coli) = log_{10}(126) + N(p,0{,}1) \times 0.4$$

Where $N(p,0{,}1)$ is the result from a standard-normal distribution (mean = 0, standard deviation = 1) for probability of p (ranges from 0 to 1).

The result from Equation 5.4a is shown in Figure 5.4a: E. coli criteria for geometric mean of 126 cfu/100 ml (50% frequency Interval) and a log standard deviation of 0.4. The frequency Interval is the probability of Equation 5.4a multiplied by 100. This cumulative probability distribution was then used to calculate a single sample maximum density for a given risk of illness level (ODEQ 1995).

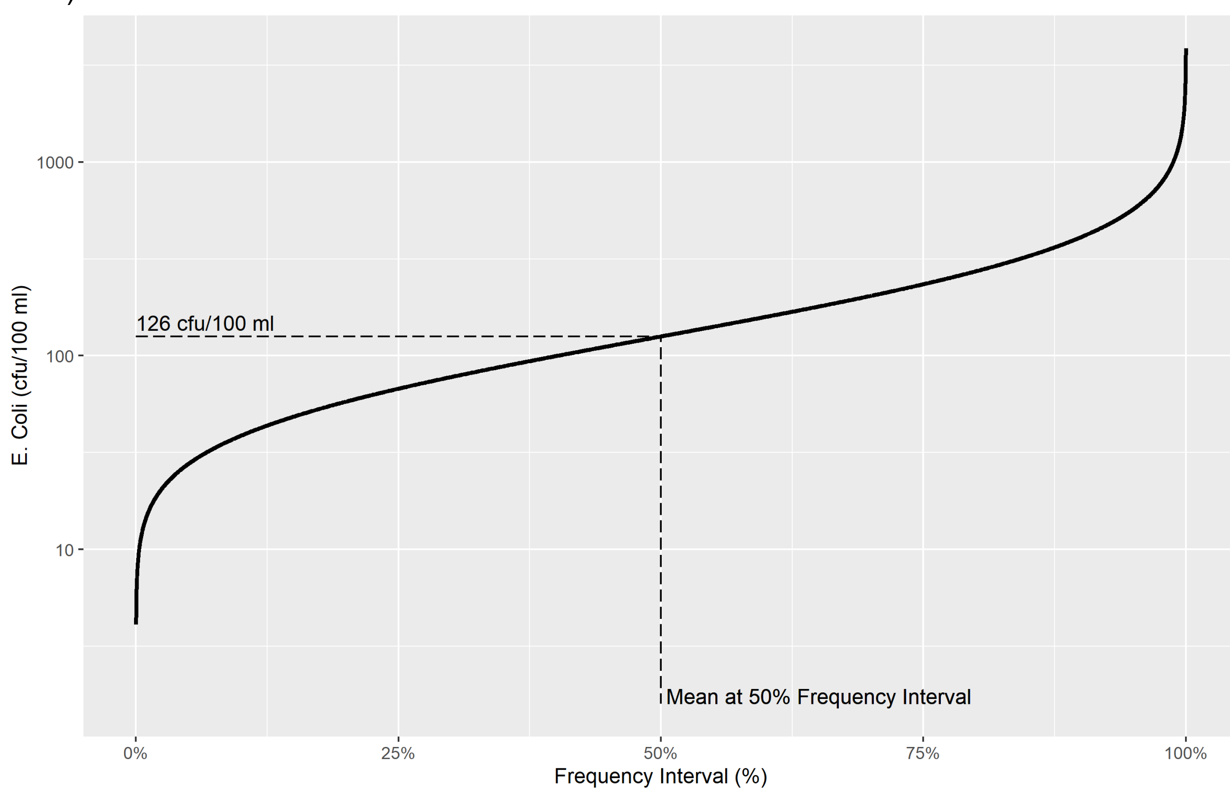


Figure 5.4a: Cumulative probability distribution using Equation 5.4a

EPA provided several different illness risk levels based on bathing use intensity ranging from Designated Beach Area having the highest intensity with lowest allowable illness risk to Infrequently Used Full Body Contact Recreation having the lowest bathing use intensity with highest allowable illness risk (USEPA 1986). The bathing intensity used for the revision of Oregon's freshwater bacteria criteria in 1995 was Lightly Used Full Body Contact Recreation that corresponded to an illness risk 90% (ODEQ 1995). The illness risk level of 90% (or p = 0.9) was used as the frequency interval in Equation 5.4a to calculate an E. coli density for the single sample maximum criterion of the bacteria standard for freshwater (ODEQ 1995).

A sample calculation for single sample maximum density for an illness risk level of 90% (or p = 0.9) is given in 5.4b, below. The single sample maximum density values provided in the EPA bacteria guidance used three significant figures in the calculations (USEPA 1986) and this is what was used in Equation 5.4b, which resulted in a value of 407. The value given in the guidance by USEPA and used in Oregon's bacteria water quality standard is 406. The approximate value of the logarithm base 10 of 406 is approximately 2.6085.

Equation 5.4b: Calculation of single sample maximum density at an illness risk level of 90% (p = 0.9) using Equation 5.4a

$$log_{10}(E.coli) = log_{10}(126) + N(0.9,0,1) \times 0.40$$
$$log_{10}(E.coli) = 2.10 + 1.28 \times 0.40 = 2.10 + 0.512 = 2.61$$
$$E.coli = 10^{2.61} \approx 407.4 \approx 407 > 406\,\text{cfu}/100\,\text{ml}$$

Both of the E. coli criteria are shown in Figure 5.4b with the underlying probability distribution function connecting the values: geometric mean of 126 cfu/100 ml (50% frequency interval) and single sample maximum of 406 cfu/100 ml (90% frequency interval). Oregon's latest revision of the bacteria water quality standard still uses this method to calculate the single sample maximum although some of the terminology has changed (ODEQ 2016).

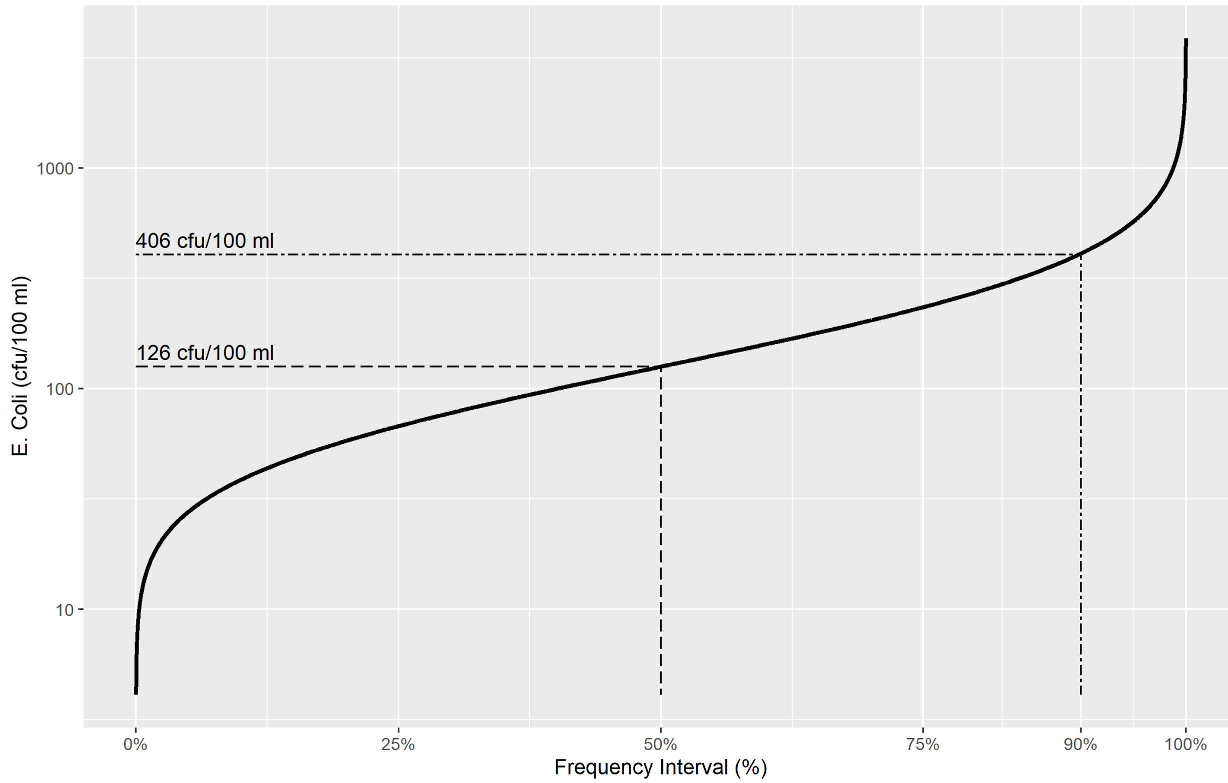


Figure 5.4b: Cumulative probability distribution using Equation 5.4a with both criterion values indicated

5.4.2 Target using single sample criterion also meets geomean criterion

The EPA guidance for setting targets for bacteria TMDLs uses the duration of the calculation of the geometric mean to demonstrate how using the single sample maximum as the target is protective of the geometric mean (USEPA 2007). Similarly, the 90-day duration to calculate a new illness risk level (frequency interval) can be used, based on the fact that in a 90-day period the daily maximum concertation will not exceed the single sample maximum when this concentration of 406 cfu/100 ml is selected as the target for the TMDL. The duration can be used to calculate a frequency interval using the following formula is given in Equation 5.4c.

Equation 5.4c: Formula to calculate frequency interval from duration used to calculate geometric mean (USEPA, 2007).

$$Frequency\ Interval = \frac{Duration}{(Duration + 1)}$$

The frequency interval calculation for the 90-day duration is shown in Equation 5.4d below.

Equation 5.4d: Calculation using Equation 5.4c of frequency interval for the 90-day duration of the geometric mean criterion.

$$Frequency\ Interval = \frac{90}{(90 + 1)} = \frac{90}{91} = 0.989 = 98.9\%$$

The frequency interval (98.9%) of the 90-day duration can then be used with the density of the single sample maximum (406 cfu/100 ml) to calculate the new geometric mean of a lognormal (log base 10) with a log standard deviation of 0.4 by rearranging Equation 5.4a and solving for the geometric mean. This calculation is done to three significant figures as was done in the bacteria criteria guidance (USEPA 1986). The steps in the calculation of the new geometric mean are shown in Equation 5.4e below.

Equation 5.4e: Calculation of new geometric mean with the single sample maximum of 406 cfu/100 ml at a frequency inverval of 98.9% that corrsponds to the 90-day duration

$$log_{10}(geometric\ mean\ E.coli\ ) = log_{10}(single\ sample\ maximum\ E.coli\ criterion) - N(p, 0{,}1) \times 0.4$$
$$log_{10}(geometric\ mean\ E.coli\ ) = log_{10}(406) - N(0.989{,}0{,}1) \times 0.4$$
$$log_{10}(geometric\ mean\ E.coli\ ) = 2.61 - 2.29 \times 0.4$$
$$log_{10}(geometric\ mean\ E.coli\ ) = 2.61 - 0.916$$
$$log_{10}(geometric\ mean\ E.coli\ ) = 1.69$$
$$geometric\ mean\ E.coli\ = 49.0 \frac{cfu}{100\ ml} < 126 \frac{cfu}{100\ ml}$$

The cumulative probability distributions are compared in Figure 5.4c, with the two geometric means indicated on the y-axis and two frequency intervals indicated on the x-axis. The geometric mean of 126 cfu/100 ml with the single sample maximum of 406 cfu/100 ml at a frequency inverval (illness risk) of 90% is indicated by a solid line. The cumulative probability function for the new geometric mean of 49 cfu/100 ml with the single sample maximum of 406 cfu/100 ml at a frequency inverval of 98.9% that corrsponds to the 90-day duration is indicated by a dashed line.

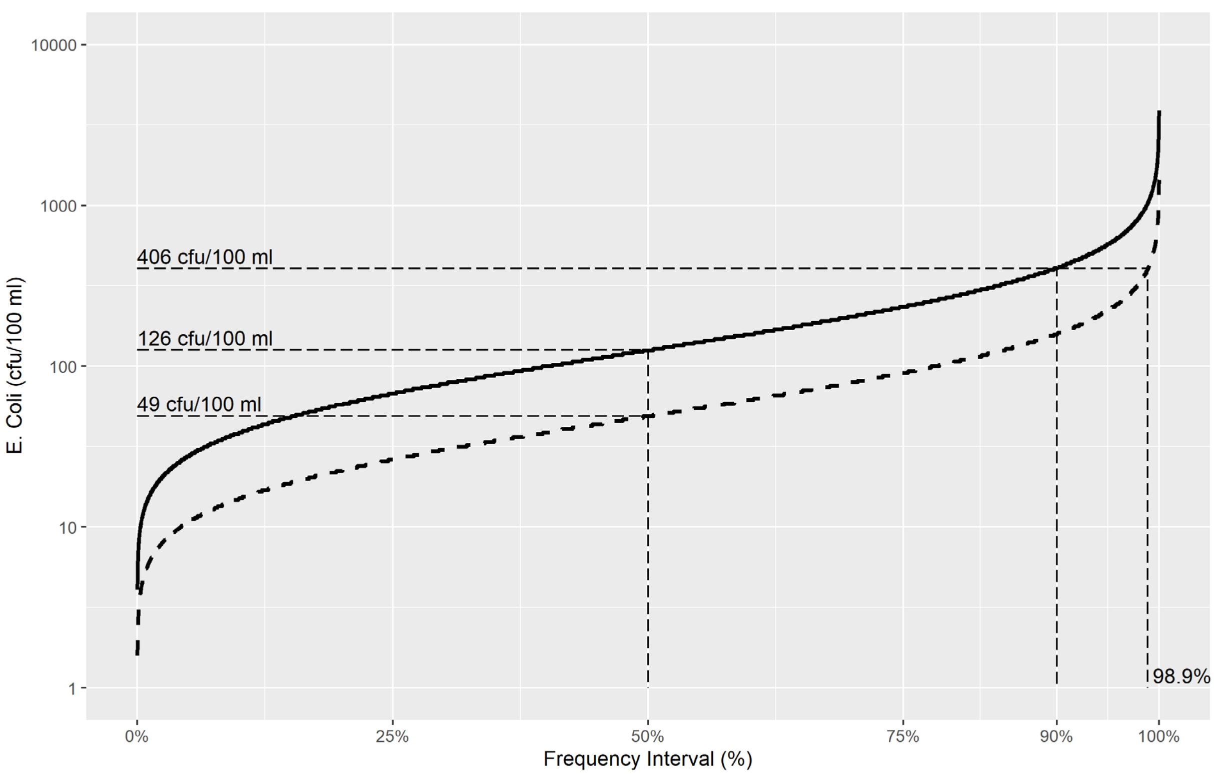


Figure 5.4c: Comparison of the cumulative probability functions

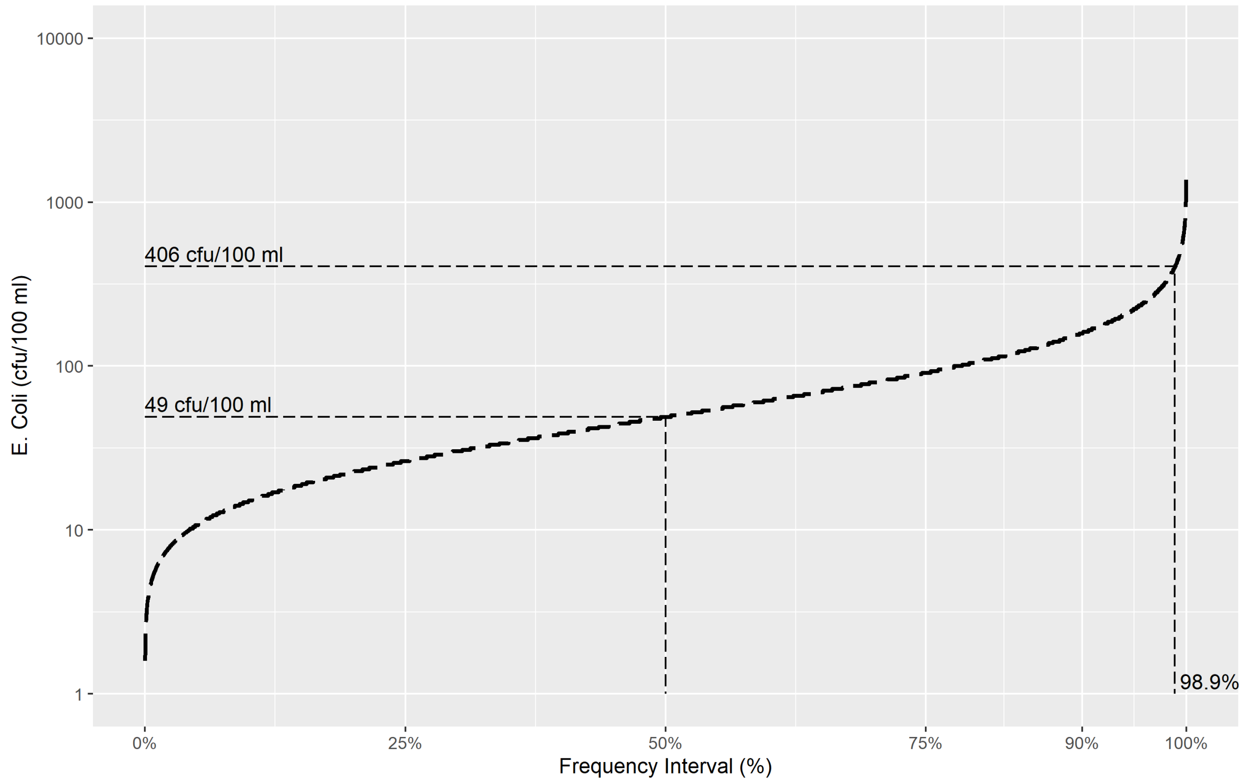


Figure 5.4d: Cumulative probability function for the new geometric mean

The cumulative distribution function for the new geometric mean will result in lower bacteria concentrations across the entire frequency interval range compared to the distribution for the geometric mean for the criterion. The cumulative probability function for the new geometric mean of 49 cfu/100 ml and frequency interval corresponding to the 90-day duration for the single sample maximum concentration of 406 cfu/100 ml is shown by itself in Figure 5.4d. Selection of the single sample maximum criterion as the maximum daily concentration for the TMDL and specifying that this concentration will not be exceeded over the 90-day period will meet the geometric mean criterion as shown in Equation 5.4e because the new geometric mean (49 cfu/100 ml) is less than the geometric mean for the criterion (126 cfu/100 ml).

5.4.3 Loading capacity and excess load

As noted above, the maximum single sample daily concentration of E. coli was set as the TMDL target. Comparison of observed concentrations to this target concentration across the range of flow categories were presented in the load duration curves from each monitoring station in Section 5.3. The noted reductions from those evaluations are summarized in Table 5.4.3. From these, DEQ selected the highest percent reduction to apply across the watershed. Thus an 83% reduction represents the excess load. DEQ then applied this reduction to determine loading capacities at each flow category, as shown in Figures 5.4.3a-f, which visually represent loading capacities. From these plots, DEQ quantified maximum daily loads at each flow category, as presented in Table 8.2 of the Upper Yaquina Watershed TMDLs Rule.

Table 5.4.3: Percent reductions for each monitoring location

Station	Number of observations above target	Maximum Reduction	Flow Category	Additional Reduction to meet TMDL Target
11476	10	37%	Medium-High	46%
12301	0	0%	NA	83%
33112	6	83%	Low	0%
34454	14	80%	Medium-High	3%
34455	0	0%	NA	83%
34456	0	0%	NA	83%
Note: NA is not applicable due to no reduction need identified				

The additional reductions to be made for each of the location to meet the TMDL target listed in Table 5.4.3 provide an additional indication of how the implicit margin of safety is being used. Even though a reduction of 37% was calculated for the sampling location 11476, and additional 46% reduction will be assigned here to meet the TMDL target. The same is true for location 34454, but to a lesser extent (only 3% additional reduction). The additional reduction of 83% for sampling locations 12301, 34455 and 34456 are more conservative because no reductions were identified using for these sites. This conservative approach helps address the uncertainty when considering if the sources and transport processes are represented with the small number of samples collected for a short time period at these locations. Figures 5.4.3a-f show observed bacteria levels reduced by 83% and these plots help to visually emphasize protection against not meeting the target criterion the additional reductions provide.

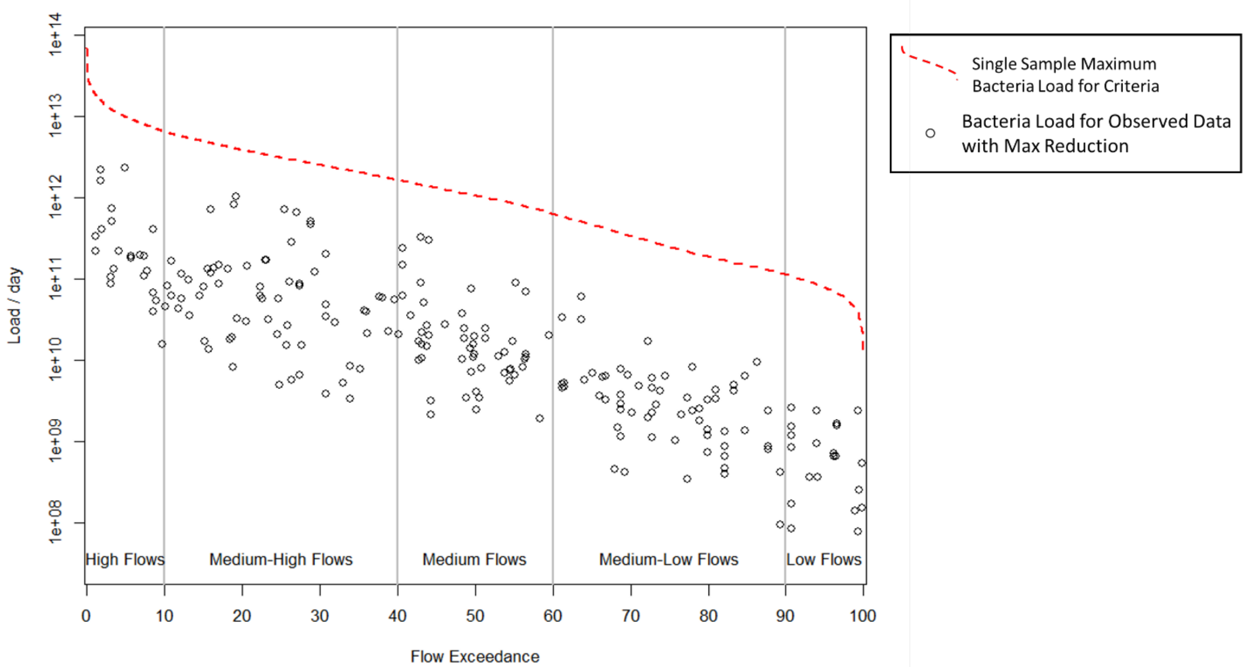


Figure 5.4.3a: Load duration curve at Station 11476 with TMDL target reductions applied

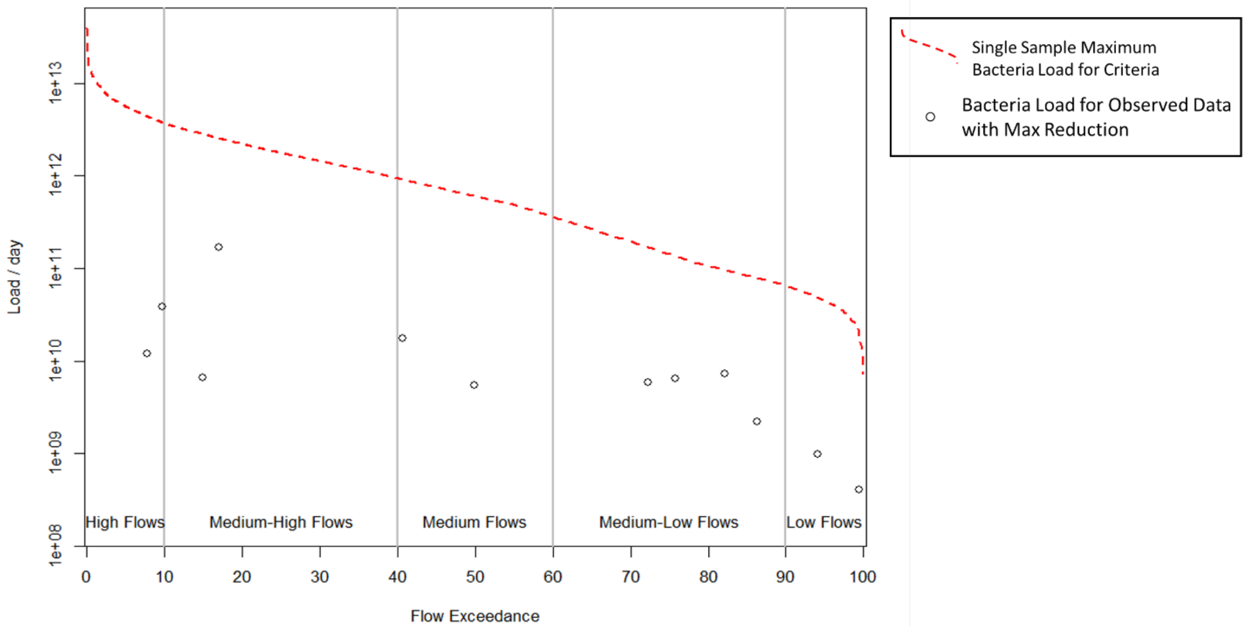


Figure 5.4.3b: Load duration curve at Station 12301 with TMDL target reductions applied

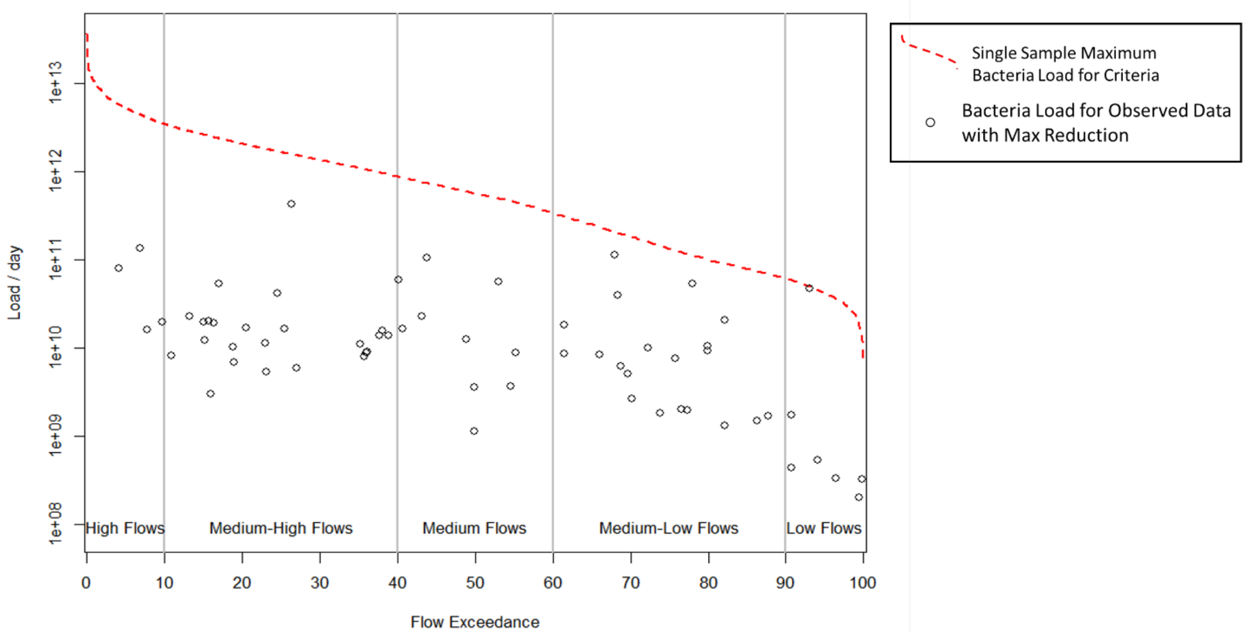


Figure 5.4.3c: Load duration curve at Station 33112 with TMDL target reductions applied

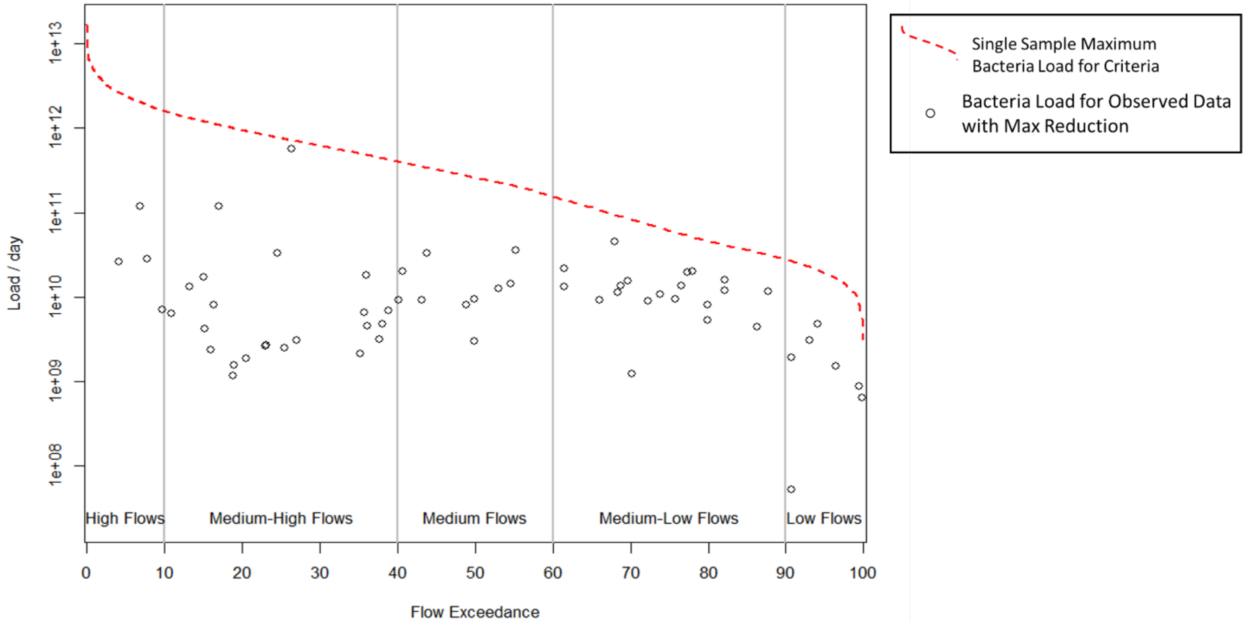


Figure 5.4.3d: Load duration curve at Station 34454 with TMDL target reductions applied

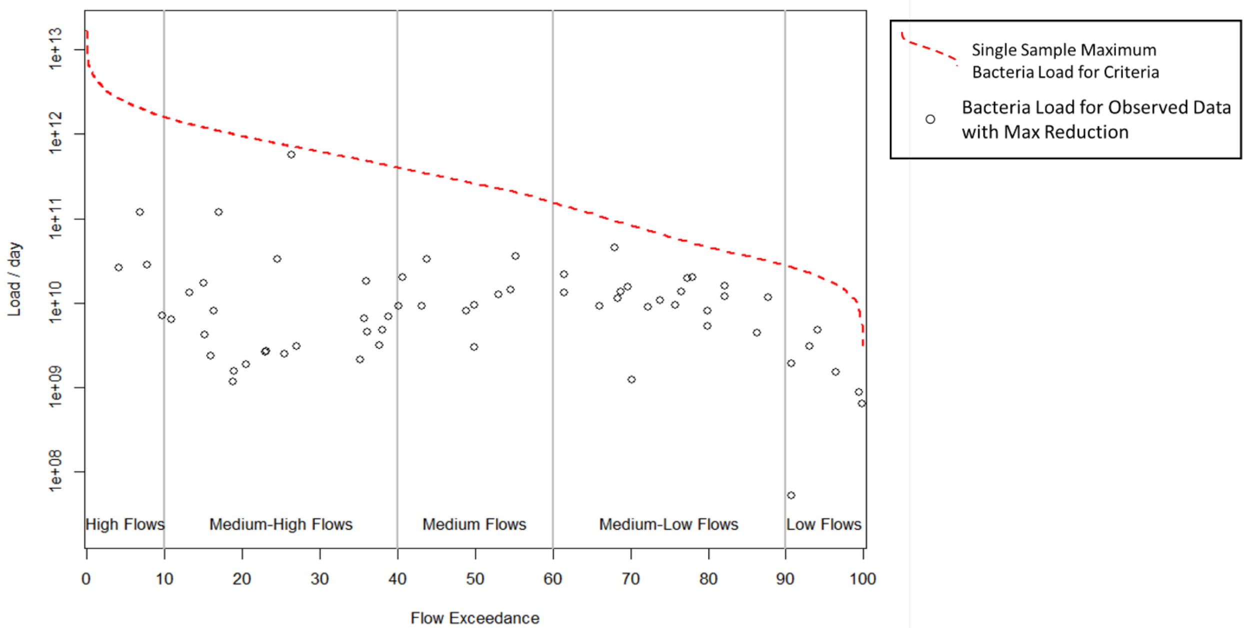


Figure 5.4.3e: Load duration curve at Station 34455 with TMDL target reductions applied

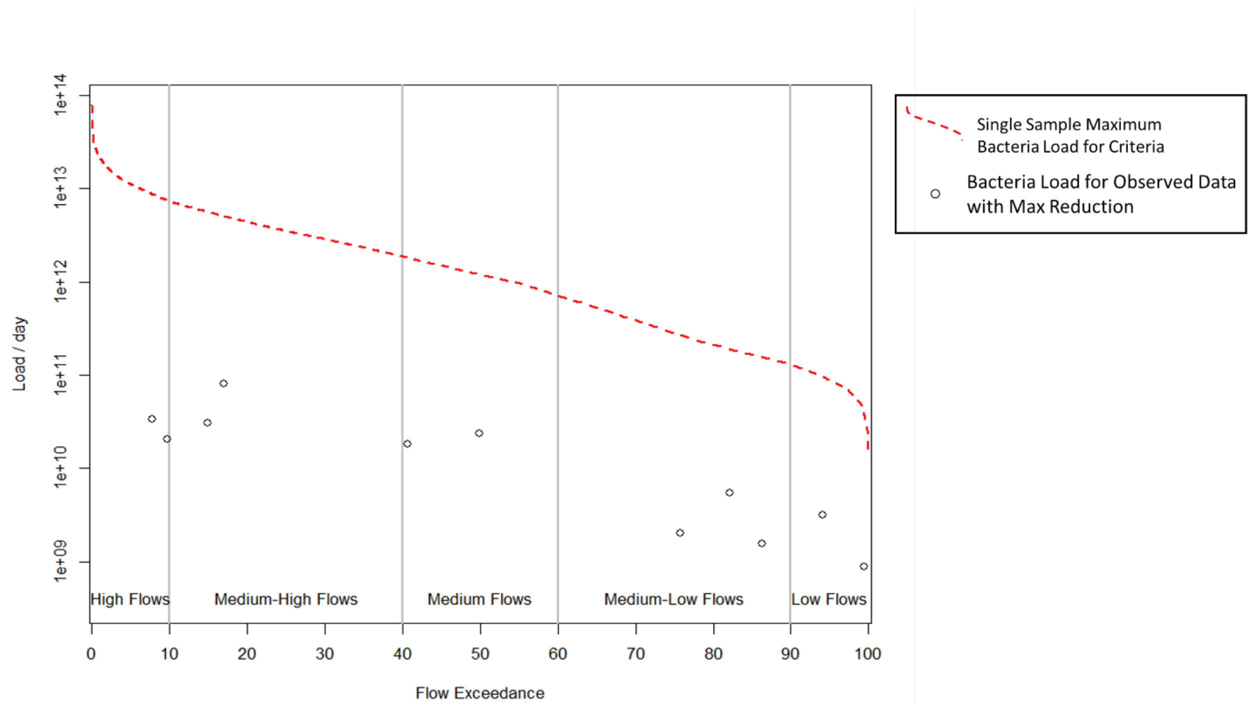


Figure 5.4.3f: Load duration curve at Station 34456 with TMDL target reductions applied

5.5 Bacteria source assessment and load contributions

5.5.1 Bacteria source identification

DEQ used EPA guidance documents and input from the local technical working group, also called TWG, to identify bacteria sources that could be present for different hydrologic conditions. This information was tabulated to create a detailed set of pollution sources that may influence bacteria concentrations in the freshwater portion of the Yaquina River. The initial source identification matrix shown in Table 5.5a was based on the USEPA's "Example Source Area/Hydrologic Condition Consideration Matrix" (USEPA, 2007). The relative importance of each potential source was classified as High or Medium within each flow zone (Cleland, 2007) and blank cells indicate that sources are insignificant in those ranges. The potential sources of bacteria loading fit into six general categories, but each of these categories can be subdivided when watershed-specific pollution sources are identified.

Table 5.5a: Initial source identification matrix adapted from EPA guidance

Potential Source	High flows	Medium-High Flows	Medium Flows	Medium-Low Flows	Low Flows
Point Sources				Medium	High
Combined sewer overflows	High	High	High		
On-site wastewater systems			High	Medium	
Riparian areas		High	High	High	
Stormwater: Impervious Areas		High	High	High	
Stormwater: Pervious Areas	High	High	Medium		

DEQ asked the technical working group to apply their local knowledge and experience to evaluate watershed-specific sources in the context of how the hydrologic conditions within each flow zone move bacterial pollution through the environment (Cleland, 2007). The technical working group members were asked to consider all potential sources in the Mid-Coast Basin and revise the initial identification matrix accordingly. DEQ analysts and work group members jointly performed this exercise and DEQ compiled the results into an expanded potential source identification matrix shown in Table 5.5b. It is important to note that some potential sources listed in Table 5.5b are not present in the Upper Yaquina River watershed because the matrix was developed for multiple watersheds within the Mid-Coast basin.

Table 5.5b: Mid-Coast basin expanded potential bacteria source identification matrix

Potential Sources	High Flows	Medium-High Flows	Medium Flows	Medium-Low Flows	Low Flows
Point Sources				M	H
On-site systems					
Failure-Direct Discharge			M	H	H
Malfunction-Surface Loading	L	M	H		
Domestic Wading Animals				M	H
Wildlife					
Aquatic Mammals			M	H	H
Waterfowl			M	H	H
Terrestrial Mammals			M	H	H
Riparian Areas					
Within Bankfull Area			M	H	H
Floodplain in Close Proximity to Stream	M	H	H	M	
Stormwater: Impervious Land					
Transportation	M	H	H		
Rural Residential	M	H	H		
Urban Residential/Commercial	M	H	H		
Stormwater: Pervious Land					
Rural Residential	M	H	H		
Urban Residential/Commercial	M	H	H		
Agricultural Lands	M	H	H		
Camping/Recreation/ Park Land	L	M	H		
Combined Sewer Overflow	H	H	L		
Relative importance of source = H-High, M-Medium, L-Low and blank-insignificant					

DEQ analysts provided the load duration curves, expanded potential source identification matrix and summary information to the technical working group members and asked them to identify other potential sources of bacteria specific to the Upper Yaquina River watershed. They evaluated each of the watersheds contributing to each of the stations where bacteria data were collected in the watershed.

5.5.2 Bacteria load contributions

DEQ estimated loads from potential sources for the watershed using simple models developed for Big Elk Creek, which is adjacent to the Upper Yaquina River. The bacteria sources modeled are listed in Table 5.5c. DEQ obtained initial input values and then refined the models using literature resources (Zeckoski, et al. 2005; ASAE 1998; Geldreich, 1978; USDA 2009). The models were developed to represent the main processes, storages and transport pathways that affect bacteria from various sources (Zeckoski, et al., 2005). The technical working group provided feedback about the models and assisted in determining watershed specific input data. DEQ acquired information about dominant sources of bacteria from analysis of spatial data, habitat information from literature sources and from the technical working group. DEQ calculated several scenarios of potential source magnitudes by varying characteristics of the sources to investigate the change in relative contributions. This helped in understanding the upper limits of each source, such as all pasture having access to streams, large populations of wildlife, or high failure rates of on-site systems. Flow charts describing the main components and operations of the bacteria source models are provided in Appendix 2.

Table 5.5c: Bacteria source models developed for Big Elk Creek

Source	Description
Cow-calf operation	Agricultural operation where calves are reared with cows for approximately a year. Then calves leave the watershed. Cow and calves are treated as pairs. Bacteria production increases from the pairs as the calves increase in size over the year. The locations of cow-calf pairs vary throughout the year. Pairs spend most of the winter confined, then are moved to pasture (or forest if available) during the rest of the year. The endpoints for the bacteria are: die-off, storage (confinement only), deposition on land (pasture or forest), and direct deposition in streams (from pairs in or immediately around streams). Bacteria generated from confinement goes to storage and then all this bacteria goes to die-off (storage time and methods were considered long enough for most of bacteria to die off). Die-off also occurs on land, but this model did not consider that.
On-site wastewater treatment and pets	On-site systems used to treat residential wastewater. On-site systems have both a tank to separate solids and a drain field to treat liquid. Possibility of direct discharge to streams is modeled for older residences. Untreated wastewater seeps to the surface or directly enters streams (for systems near streams) when systems fail. Untreated wastewater seeping to surface is loaded to residential areas. Pets per household is used to calculate number of pets. Bacteria from pets is loaded to surface of residential areas.
Beavers	Beavers contributed bacteria to either forest land surface or directly to streams. Habitat was buffered area streams within forests with animal density of beavers per acre of habitat.
Coyotes	Coyotes contributed bacteria to all land surfaces or directly to streams. Habitat was considered entire watershed area with animal density of coyotes per acre.
Deer	Deer contributed bacteria to all land surfaces or directly to streams. Habitat was considered entire watershed area with animal density of deer per acre.
Ducks	Ducks contributed bacteria to all land surfaces or directly to stream. Habitat was buffered area streams or ponded water bodies with animal density of ducks per acre of habitat. Animal density varied for two seasons to account for migration.
Elk	Elk contributed bacteria to forest, pasture land surfaces or directly to stream. Habitat area and animal densities varied for two seasons. Habitat area was based on elevation with winter habitat only at lower elevations and all pasture and forest areas as habitat for rest of year.
Geese	Geese contributed bacteria to all land surfaces or directly to streams. Habitat was buffered area streams or ponded water bodies with animal density of ducks per acre of habitat. Animal density varied for two seasons to account for migration.
Gulls	Gulls contributed bacteria to all land surfaces or directly to streams. Habitat was considered entire watershed area with animal density of gulls per acre.
Herons and Egrets	Herons and Egrets contributed bacteria to all land surfaces or directly to streams, with higher numbers in and around streams. Habitat was considered entire watershed area with animal density of birds per acre.
Otters	Otters contributed bacteria to either forest or pasture land surface or directly to streams. Habitat was streams within forests or pasture areas and animal density was otter per mile of stream.

Source	Description
Raccoons	Raccoons contributed bacteria to all land surfaces or directly to streams. Habitat was considered entire watershed area with animal density of raccoons per acre.

5.6 Bacteria allocation approach

As indicated in the modeling and collection of local information to identify and assess bacteria sources, point source contributions are extremely limited and nonpoint sources are the drivers of bacteria loads in streams within the watershed. In line with these proportional contributions, point source waste load allocations make up the smallest fraction of the allocation distribution, followed by a generous margin of safety and substantial load allocations for nonpoint sources, inclusive of background sources. The allocation distribution structure reflects proportional contributions, as well as allowing for uncertainty and any subsequent change to permitted discharges. Proportionality and conservative margin of safety support reasonable assurance of implementation.

5.6.1 Bacteria point source waste load allocation methodology

Point source discharges with the most potential for containing bacteria include wastewater from municipal sewage treatment and stormwater in contact with fecal material. Within the Upper Yaquina Watershed, there are no permitted discharges of municipal wastewater or stormwater in contact with fecal matter. Therefore, the potential for bacteria in point source discharges within the watershed is very low. Permitted discharges within the basin are limited to intermittent seasonal discharges from short term projects registered under the statewide construction stormwater general permit (NPDES 1200C) and highway stormwater from Oregon Department of Transportation NPDES Municipal Separate Storm Sewer System (or MS4) permit. Due to the small volume, temporary duration, low potential for bacteria presence at measurable loads and lack of currently assigned coverage in the watershed, DEQ did not assign wasteload allocations for 1200C stormwater discharges. DEQ notes that construction stormwater provisions are captured in ODOT's MS4 permit and the associated wasteload allocation approach described below, covering any ODOT construction projects in the basin.

Although ODOT's MS4 permit does not specify an effluent limit for fecal indicator bacteria and highway stormwater runoff is not anticipated to be a significant source of bacteria, background sources of bacteria may be present in highway stormwater conveyances. Therefore, DEQ opted to assign a non-zero wasteload allocation of at least 1% of the loading capacity for ODOT's MS4 permit. EPA's draft TMDLs to Stormwater Permits Handbook (EPA 2008) offers several methods for calculating wasteload allocations for NPDES stormwater permits, including MS4 permits. DEQ chose the ratio of jurisdictional boundary method, which calculates the ratio of ODOT jurisdictional area to the total watershed area to determine a percentage of the bacteria loading capacity to be given as the wasteload allocation for ODOT's MS4 permit discharges within the watershed.

Because there is not a readily available source of the extents of the ODOT jurisdictional boundary within the watershed, DEQ estimated right-of-way area using road centerlines from 2019 Oregon Transportation Network spatial data. The following steps and accompanying figures describe the Geographic Information Systems analysis DEQ performed to get the polygon feature of the ODOT MS4 permit jurisdictional boundary within the Upper Yaquina Watershed:

1. Clipped or_trans_network_public2019.gdb with Upper Yaquina watershed boundary using feature WatershedBoundary to create uyr_or_trans_network_public2019 feature in uyr_or_trans_network_public2019.gdb
2. Use file uyr_or_trans_network_public2019 in uyr_or_trans_network_public2019.gdb to get:
    a. Select roads that are owned by ODOT using field “ROADOWNER” equal to “Oregon Department of Transportation” to create ODOT_uyr_or_trans_network_public2019
    b. Buffer the roads in ODOT_uyr_or_trans_network_public2019 with 30 feet each side on centerline to get approximate right of way area
    c. Dissolve Buffer to get the total area of right of way
    d. Add field to dissolve attribute named “Area_ac” then calculated area in acres to get estimate of jurisdictional boundary
    e. Rename polygon feature from previous step to “JurisdictionalBoundary”
3. Manually calculate the percent of the watershed that is in jurisdictional boundary of ODOT MS4 (0.4%), using the area of the watershed (53,212 acres) from “ACRES” field in the Watershed feature and the ODOT MS4 jurisdictional boundary area estimate (217 acres) from the “Area_ac” field in the JurisdictionalBoundary feature.

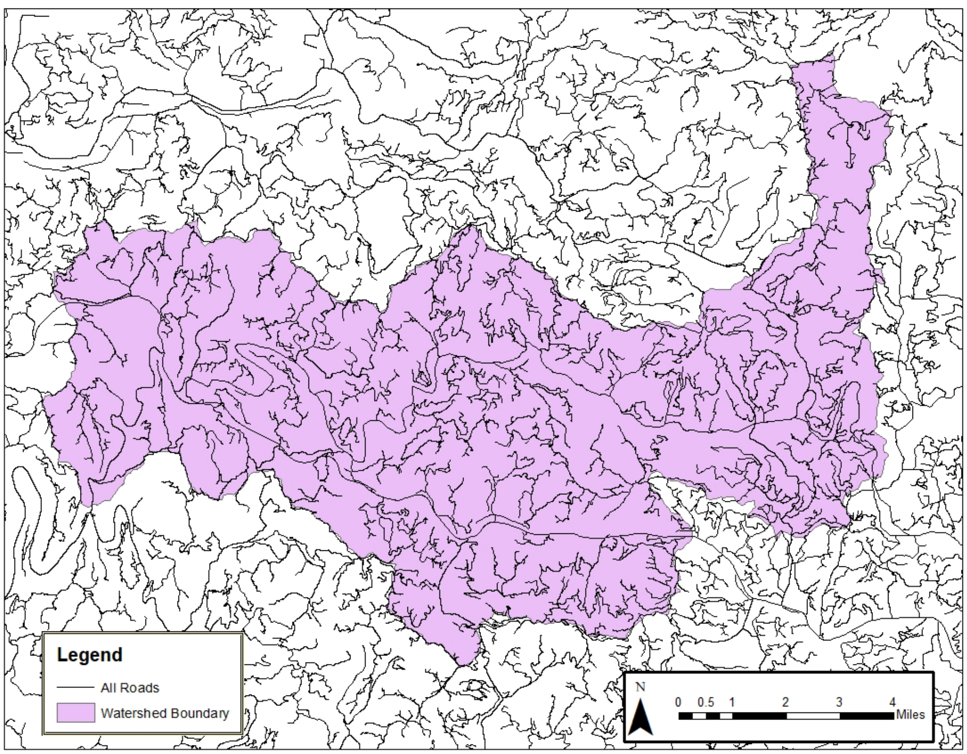


Figure 5.6.1a: Watershed boundary with all roads in ODOT’s dataset

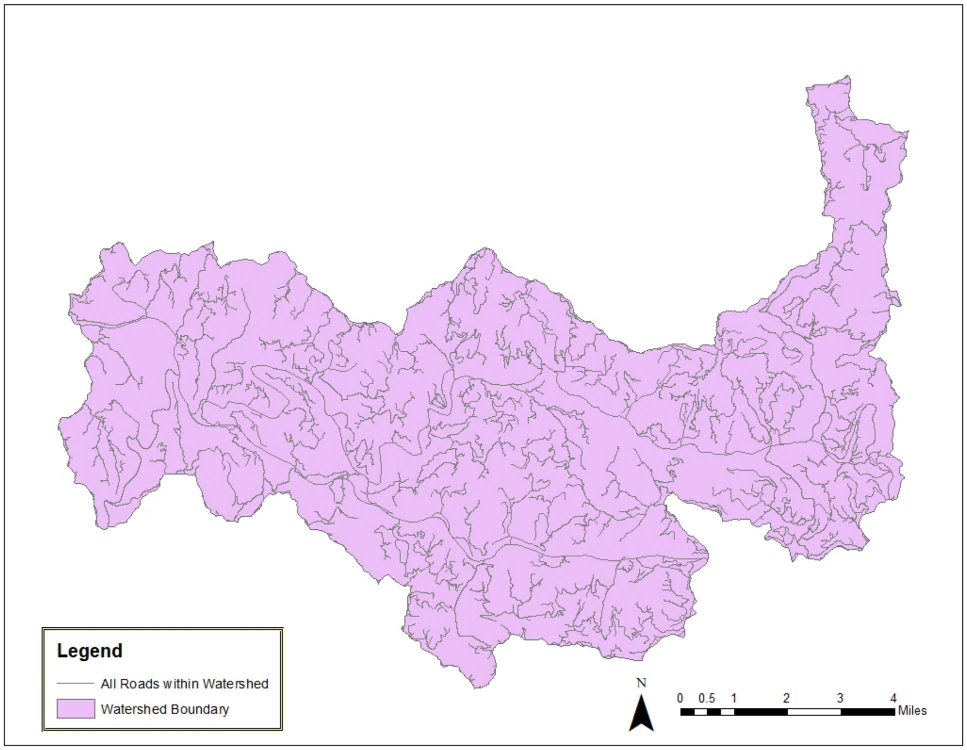


Figure 5.6.1b: ODOT's dataset clipped to watershed boundary

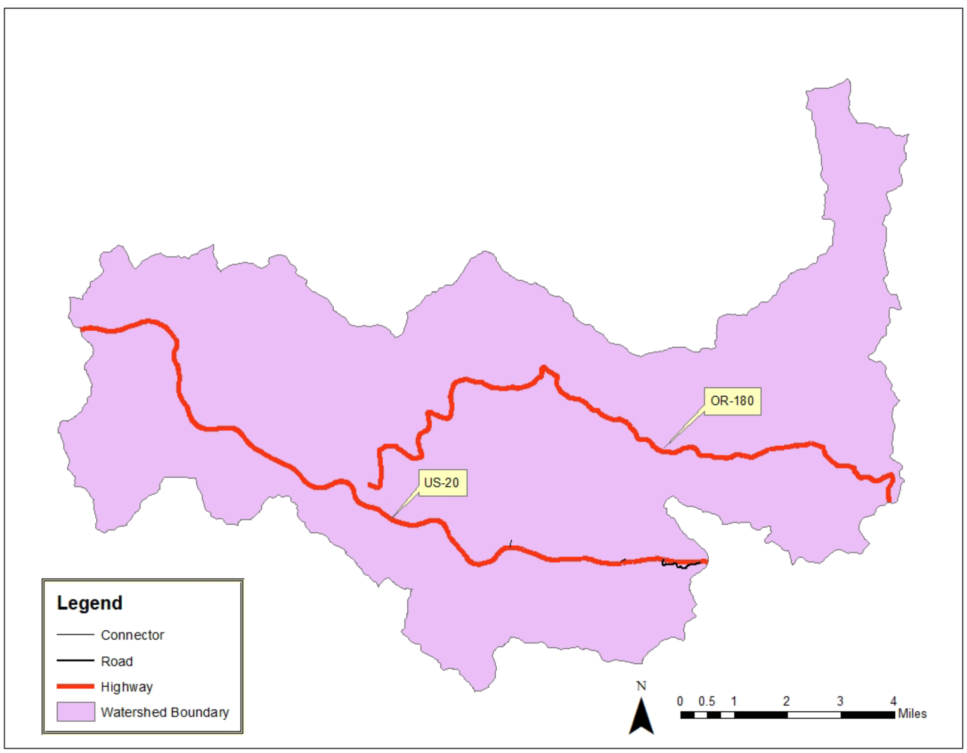


Figure 5.6.1c: Watershed boundary with ODOT-owned roads extracted

Figure 5.6.1d: Zoom to portion of US-20 centerline with 30 foot buffer

Figure 5.6.1e: Zoom to portion of OR-180 centerline with 30 foot buffer

There is uncertainty in the estimation of jurisdictional area and resultant potential bacteria loads due to the following factors: 1) roads tend to be near the valley bottoms and adjacent to streams; 2) the episodic nature of pollutant loads from roads makes it difficult to capture only using jurisdictional boundary area to watershed area ratio; and, 3) the mixture of impervious and pervious contributing areas results in variations in loads from different locations within the estimated jurisdictional boundaries, even for the same events. Therefore, although the calculated ratio of jurisdiction area to watershed area was 0.4%, DEQ assigned 1% of the loading capacity as the ODOT MS4 wasteload allocation.

In addition to the estimated ratio of MS4 jurisdictional area to watershed area being less than 1%, implementation of the following permit conditions and control measures is anticipated to keep bacteria loads in highway stormwater discharges within the watershed below the wasteload allocation of 1% of the loading capacity:

- Public education and outreach – including information specifically on bacteria
- Public involvement and participation – including facilitation of a public website with bacteria information and illicit discharge reporting
- Illicit discharge detection and elimination – including procedures for addressing potential illicit dumping of wastes
- Construction site runoff control – requiring use and maintenance of controls for erosion, sediment and waste materials management at all ground disturbing projects, from initial clearing through final stabilization, to reduce all potential pollutants in stormwater
- Post-construction site runoff control – including inventorying and maintaining all water quality facilities, which reduce loads of bacteria and other pollutants
- Pollution prevention and good housekeeping – including inspection and cleanout of catch basins and litter control, both of which contribute to reducing loads of bacteria and other pollutants

5.6.2 Bacteria nonpoint source and background load allocation methodology

DEQ used relative contributions of identified sources to calculate the load allocations for the sources. DEQ calculated relative contributions as the ratio of the source load to the total load of all the sources. DEQ then calculated reduction scenarios for each station. The reductions were applied to sources only in the contributing land area to the station sub-watershed. If there was another station upstream, only the loads from the area of the sub-watershed downstream of the upstream station were calculated. The steps in the process for each source were as follows:

1. Sum loads from sources for total current load for sub-watershed
2. Calculate the relative contribution of each source to total load
3. Apply percent reduction to a source
4. Calculate reduced load for each source
5. Sum reduced loads from sources for total reduced load for sub-watershed
6. Subtract the ratio of the total reduced load over the total current load from one and multiply by one-hundred to get source load reduction
7. Compare source load reduction to TMDL target reduction
    a. Source load reduction less than or equal to TMDL target reduction, accept scenario
    b. Source load reduction greater than TMDL target reduction, reject scenario.

The scenarios were presented in a tabular format. The columns of the table were the percent reduction of each source in order to obtain the TMDL target reduction. As noted in the steps above, the scenarios that met the TMDL target reduction were retained and presented for feedback to the technical working group and Designated Management Agencies responsible for these sources. The feedback was included in the assessment of which scenario to select for the load allocations. The load allocations were provided to the Technical Working Group to get their input.

No reductions in wildlife sources were made. The wildlife source load was estimated to be relatively minor compared to anthropogenic sources during the critical period. These sources were considered to be part of the background sources of bacteria (OAR 340-042-0030(1)).

5.6.3 Bacteria critical period considerations

Seasonal variations are observed in the hydrologic conditions of the Upper Yaquina River Watershed as wet conditions and high flows during the late fall through spring and drier conditions with low flows in the summer through early fall. DEQ captured these variations in the load duration curves and time-series plots analyses and identified critical conditions for bacteria as the summer through early fall period, during which higher bacteria concentrations and lower flows are observed.

DEQ identified the maximum percent reduction in bacterial loading is needed to meet criterion during these critical conditions. DEQ applied the maximum percent reduction throughout the year at all sampling locations. This includes conditions and the locations when bacteria concentrations were greater than or equal to the single sample maximum criterion (406 cfu/100 ml) but resulted in a percent reduction less than the maximum to meet the criterion. During implementation, DEQ will require management actions year round to achieve the maximum percent reduction for the critical conditions and other conditions that bacteria concentrations were greater than or equal to the single sample maximum criterion.

6. Water quality management plan support

6.1 Streamside vegetation management strategies

Based on the excess solar radiation and shade deficit calculated along the mainstem Yaquina River and review of aerial imagery for riparian vegetation on major tributaries, DEQ identified the general streamside vegetation management strategies listed below to increase site effective shade. These primary strategies are classified as follows:

1. Vegetation planting or establishment: Estimated linear stream miles or number of acres within 30 meters from the stream bank that need native woody vegetation established or planted to achieve TMDL effective shade targets. This strategy recognizes that certain locations have little or no existing overstory vegetation producing shade and are therefore prime locations for riparian restoration projects. Sites may currently be dominated by invasive species.

2. Vegetation enhancement, maintenance and growth: Estimated linear stream miles or number of acres within 30 meters from the stream bank that have existing vegetation

that needs to grow and mature, recognizing that full site potential shade can only be achieved by ensuring that these activities are routinely conducted to maintain vegetation success and survival and provide for optimal growth (maintenance, growth and protection strategies).

3. Vegetation thinning and management: Estimated linear stream miles or number of acres within 30 meters from the stream bank that might need vegetation density reduction. Current site conditions are over-dense dense trees that need thinning to promote development of a healthy mature riparian forest or dominated by invasive species. This strategy recognizes that healthy plant communities may require that these activities be routinely conducted to ensure survival, health and optimal growth of the desired vegetation.

6.1.1 Documentation of recommend riparian buffer dimensions

[This section is still being developed]

Effective shade is the percent of potential daily solar radiation flux that is blocked by vegetation and topography (Boyd and Kasper. 2007, McIntyre et al., 2018). Effective shade is negatively correlated with riparian vegetation removal (McIntyre et al., 2018).

Physical and ecological factors effecting effective shade include, vegetation height, vegetation buffer width, vegetation density, stream aspect, stream width, cloudiness, and latitude. Vegetation and vegetation removal has strong relationship to shade and solar radiation loading. The response of shade to vegetation removal will depend on the interaction of vegetation height, density, and buffer width. Vegetation height has influence on shade because it affects shadow length (DeWalle 2010; DeWalle 2008, Cristea and Janish 2007, Li et al 2012). Vegetation density and vegetation buffer affects the attenuation of solar radiation through the canopy (DeWalle 2010; DeWalle 2008, Garner et al 2014, Groom et al 2018). Allen and Dent 2001 found combinations of basal area, stand density (trees/acre), species composition, average stand diameter, and live crown ratios and the interaction between stand structure and aspect are important variables in predicting shade.

Shade was best predicted by riparian basal area and tree height. Sites with higher stocking levels, wider uncut buffers, or fewer stream banks harvested had greater basal area and higher shade. (Groom et al 2011).

Srihdar et al 2004 conducted a sensitivity analysis altering factors that influence solar radiation on net heat fluxes and found that canopy density (measured through LAI) had the greatest effect on the study stream temperatures in Washington State. Solar radiation is almost completely attenuated by canopies with LAI between 7 and 10. Average tree height appeared to be the second most sensitive parameter followed by buffer width. Tree heights above 30 meters resulted in minimal change to the radiation penetration. Buffers widths greater than 30 meters only had minimal effect on stream temperature.

Gomi et al 2006 also found 30 meter buffers minimized harvest effects. 10 meter buffers on north south oriented streams were found to be effective because they were shaded from late morning to early afternoon by the overhead canopy, although the authors provided a caveat that anomalous warming occurred both preharvest and postharvest during low-flow periods, confounding interpretation.

Li et al 2012 found that tree height, canopy overhang from the bank, channel width, and latitude for east to west streams all had strong effects on the daily time series of shade. Latitude did not have a strong influence on shade for north south streams. Latitude determines the sun's altitude which has a direct impact on the amount of direct solar radiation (Dewalle, 2010; DeWalle, 2008). Maximum altitudes occur at solar noon and have higher altitudes at latitudes closest to the equator (NOAA 2002, Meeus 1998).

On streams with little or no vegetation, overcast days exert a first order control on net energy flux (Garner et al 2014, Rutherford et al 2004,).
Height and density of plants varies by vegetation species and thus influence shading potential (Allen and Dent 2001; Brown and Brazier, 1972, Steinblums et al 1984).

DEQ developed specific streamside vegetation management recommendations for forestry operations to address stream temperature impairments. DEQ based these recommendations on results presented in (Groom_2018) and modeling. On July 23, 2015, DEQ presented these recommendations to the Board of Forestry.

DEQ's modeling and analysis concluded that the following riparian management strategies would be likely to result in clear-cut harvests on perennial small and medium sized streams having no more than a 0.3 degrees Celsius temperature increase after the first harvest entry almost or more than 50% of the time:

- 90 foot no-cut buffers;
- a 170 foot wide Riparian Management Area and 275 square feet of basal area target retained per 1,000 foot of stream; and
- The State Forest Management Plan and management strategies implementing the plan in 2015.

Instead, for no measurable temperature increase to occur on perennial small and medium sized streams after the first harvest entry almost, or more than 50% of the time, DEQ recommended:

- 120 foot no-cut buffers; or
- No reduction in effective shade from pre- to post- harvest

DEQ determined in this TMDL that the generally applicable Forest Practices Act rules in effect prior to 2022 were not adequate to implement the TMDL load allocations for excess solar radiation loading on small and medium fish-bearing streams to meet the dissolved oxygen criteria. Specifically, DEQ found that the ODF vegetation retention requirements along salmon steelhead and bull trout streams (prescription option 2 in Oregon Administrative Rules 629-642-0105(11)) are inadequate to protect cold water (DEQ 2018).

For this TMDL, DEQ's analyses to address dissolved oxygen impairments in the Upper Yaquina Watershed identified necessary solar radiation reductions, which are expressed by achieving effective shade percentages tabulated by stream size, orientation and vegetation types. DEQ applied the previous conclusions regarding buffer widths for forestry operations, because these results address levels of shading due to riparian vegetation, which is not dependent on the land use or activities that may impact the vegetation.

DEQ's shade assessment for the modeled portion of the Yaquina River used a distance of 131 feet from the stream centerline, which results in a riparian zone width of approximately 100 to 120 feet based on the varying width of the stream over the 21 miles segment. The TMDL shade allocations and WQMP implementation strategies do not require a specific buffer width, rather the surrogate allocation is effective shade. Multiple site-specific factors determine the overstory vegetation characteristics necessary to meet the shade allocation, including stream width, orientation, vegetation height, overhang, canopy density and topographic shading.

Specific riparian buffer widths apply to forest land under the Oregon Forest Practices Act, so DEQ will not consider or approve more narrow buffers on land under ODF's jurisdiction. Lincoln County's code identifies a specific riparian buffer width (based on comprehensive land use planning) that may not meet the shade allocations under certain circumstances.

Based on RipStream study results (Groom et al. 2011) and Oregon Department of Forest documentation for the Board of Forestry (ODF, 2015) and other analyses and modeling (Groom et al, 2018), an approximately 100- to 120- foot buffer width comprised of mid-seral to mature native overstory vegetation (conifer or mixed conifer-deciduous) in this area of the coast range provides the effective shade needed to meet the shade allocation in this TMDL. That is, the 100- to 120- foot buffer is a default "meets shade allocation" buffer without further measurement or analysis. Therefore, a DMA/RP (other than ODF/private forestry) could select this fixed buffer width as one option to meet the shade allocation, provided the buffer were established and maintained.

6.1.2 Measuring effective shade

The effective shade measurement methods and quality control procedures for use of a solar pathfinder instrument are outlined in the Water Quality Monitoring Technical Guide Book (OWEB, 1999) and the solar pathfinder manual (Solar Pathfinder, 2016).

Methods for use of hemispherical imagery and analysis software are described in Ringwald et al 2003, WADOE 2019a, and WADOE 2019b.

6.1.3 Methods to identify areas along the modeled reach in need of riparian restoration

Areas in need of restoration in the riparian zone along the model reach for the Upper Yaquina River were identified as areas with ≤3 ft tall vegetation based on LiDAR imagery (3 ft spatial resolution) from 2011 (DOGAMI, 2021). The modeled reach was divided into three segments between the water quality monitoring stations on the Upper Yaquina:

- Segment 1 (reaches 1to5): between 34454-ORDEQ and 33112-ORDEQ; 11.0 river miles
- Segment 2 (reaches 5to7): between 33112-ORDEQ and 12301-ORDEQ; 2.8 river miles
- Segment 3 (reaches 7to8): between 12301-ORDEQ and 11476-ORDEQ; 7.2 river miles

For each Segment, DEQ created an approximately 100 ft horizontal zone around the center streamline using the channel widths from the calibrated QUAL2Kw model. To do this, DEQ created 131 ft zone on each side of the stream line using the ArcGIS Pro 3.0.2 Pairwise Buffer Analysis Tool and removed that channel area that corresponded to following channel widths used in the QUAL2Kw water quality model:

- Segment 1 (Model subsegment 1 to 5): 26.1 ft; resulting buffer zone of 118 ft
- Segment2 (Model subsegment 5 to 7): 37.9 ft; resulting buffer zone of 112 ft
- Segment3 (Model subsegment 7 to 8): 54.7 ft; resulting buffer zone of 103 ft

These zones correspond to approximate100-foot distance “buffers” on each side of the river. The term buffer is also commonly used to describe a setback zone or area along a stream designated for certain levels of protection, and a wide range of distances are used in different applications, including agriculture, forestry and local planning and development codes. Within the calculated riparian zones for each segment, DEQ extracted jurisdictional areas of responsible persons, including Designated Management Agencies, based on taxlot and zoning information. The area of the channel corresponding to the segment channel widths above was excluded from subsequent analysis. These jurisdictional areas were overlain on the LiDAR vegetation height raster from 2011 (DOGAMI, 2021). Vegetation heights were classified as ≤ 3 ft or > 3 ft. The total area of land with ≤ 3 ft tall vegetation by jurisdictional area within the riparian zone were calculated using Zonal Statistics from the Spatial Analyst toolbox in ArcGIS Pro 3.0.1. Linear stream miles with vegetation height ≤ 3 ft within the buffer zone by jurisdictional area were calculated using the maximum number of sampling points per stream node (spaced every 164 ft on the stream line) used by the Heat Source v.8.0 Shade-a-lator submodel (5 spaced evenly over 120 ft per cardinal and intercardinal directions; excluding the stream node) that had ≤ 3 ft vegetation height.

Based on this approach, maps were developed to depict DMA distribution within the buffer zone along the modeled reach of the Upper Yaquina River and assign shade gaps by jurisdictional areas. Static representations of these maps are provided as Figures 2.1a-c in the Upper Yaquina River Watershed Water Quality Management Plan and interactive versions are planned for posting to DEQ’s website to assist responsible persons with implementation planning and tracking.

6.2 Timelines for attainment of water quality standards

DEQ developed projected timelines for attainment of interim and final pollutant load reduction targets by estimating the time to reduce the excess load to a de minimis level. Once the excess pollutant load is negligible or zero, the applicable water quality criterion is calculated to be met. This approach provides a realistic range of outcomes based on the assumptions described below. Periodic water column monitoring is needed to quantitatively assess progress towards meeting TMDL targets and numeric criteria.

Excess pollutant loads are identified for solar radiation, phosphorus and bacteria (see TMDL Report Table 8.1 and Section 8.2) and represents the computational basis for the load reductions to attain loading capacities. Along with water column conditions, excess pollutant load reduction is a key measure of progress towards attaining the TMDLs.

DEQ used two primary approaches to estimate timelines to reduce excess pollutant loads: one is based on a consistent (linear) annual reduction in excess load amount and the other is based on a consistent annual percent reduction, based on the starting excess load. The response variable in each scenario is “cumulative excess load reduced” which is a proportion between zero and 1.0 (which is 100%). Therefore, 1.0 cumulative reduction corresponds to zero excess load. The specific scenarios used to estimate timelines for reducing excess load solar radiation, total phosphorus and bacteria are described in more detail below.

An annual linear reduction (by mass or percent) in excess load is possible but unlikely due to environmental variability and human activities. However, since measurable improvements can either occur in multiple small steps or several larger ones, averaging the projected reductions in excess load over 5-year periods (10-years for effective shade) allows periodic comparison and re-evaluation of current load and excess load using water column monitoring data or surrogate measures and aligns with DEQ's five-year review approach to determine implementation progress (see Section 6 of the WQMP).

6.2.1 Timelines for achieving effective shade targets

For solar radiation, excess pollutant load is identified in radiation units (e.g., langleys/day), whereas effective shade (%) is the primary surrogate measure used in this TMDL. The estimated timelines for achieving excess solar radiation load reductions for the Yaquina River for the QUAL2Kw model reach identified in above in Figure 4.3.1 (Clem Road to Trapp Creek) were developed in the following scenarios using estimated effective shade produced by a dominant overstory stand type in the Western Hemlock Wet environment that is a mix of TSHE/PSME/ALRU and the target stand stage is mid-seral (50-79 years) (McCain & Diaz, 2002). Tree heights and other characteristics are consistent with published growth curves for the dominant mid-seral stage species in the wet hemlock series on sites with average site index for the coast range ecoregion in Lincoln County (ODF, 2020). These vegetation characteristics are consistent with that used in DEQ's site potential shade modeling (see Section 4.5.2. above).

DEQ considered three scenarios, based on the assumptions that DMAs and other entities will conduct extensive riparian improvement and planting on segments of the Yaquina River with the highest effective shade deficiency, in the first five years following TMDL issuance, and that the three primary riparian vegetation strategies are consistently implemented until the riparian vegetation class reaches a mid-seral stage conifer-deciduous mix or equivalent characteristics. In addition, these scenarios assume that no measurable existing overstory vegetation is intentionally removed thereby reducing the current conditions shade (identified above in Section 4.5.1) through implementation of management strategies to enhance, maintain and protect growth of vegetation in riparian areas.

Scenario A: DEQ assumed that overstory vegetation grows steadily, consistent with average conifer and red alder growth curves for this portion of the coastal range and associated effective shade is produced at a rate commensurate with tree growth without significant disturbance. Assumes excess load is reduced by 5% annually.

Scenario B: Same as Scenario A, except that DEQ assumed stochastic events (drought, wind, fire, disease, etc.) affect the stand, so that a small portion of the vegetation fails to establish or is lost. This disturbance results in the effective shade being produced at an inconsistent rate and hence provides lower overall excess solar radiation reduction (randomly varies from 0.0-0.05).

Scenario C: Same as Scenario B except that a slightly different stochastic variation in solar radiation reduction was used (0.01-0.05). Comparing this scenario to A and B suggests that resulting effective shade may be highly sensitive to minor variations in disturbance that produces more uncertainty in estimating time to fully reduce excess solar load.

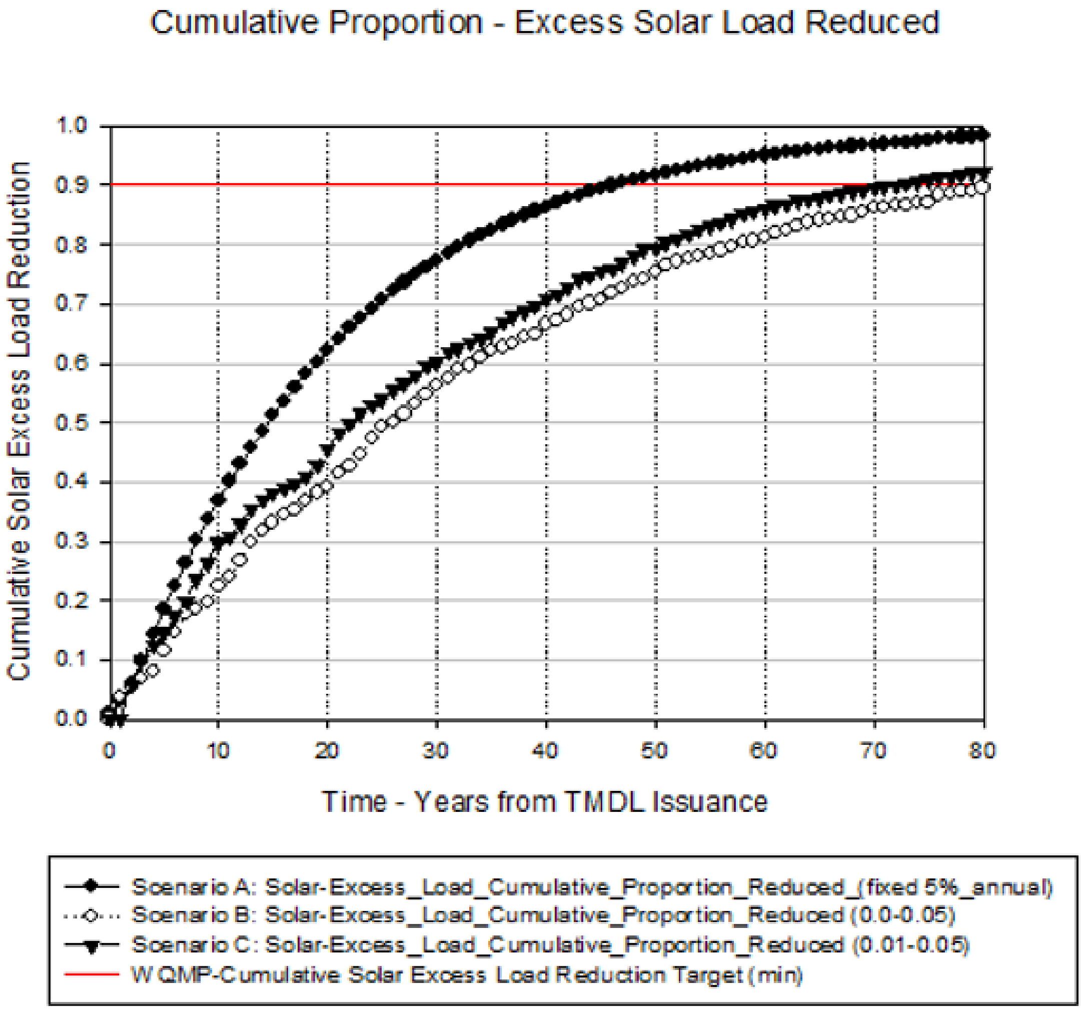


Figure 6.2.1a: Scenarios to estimate time to achieve solar radiation load reduction in the Yaquina River

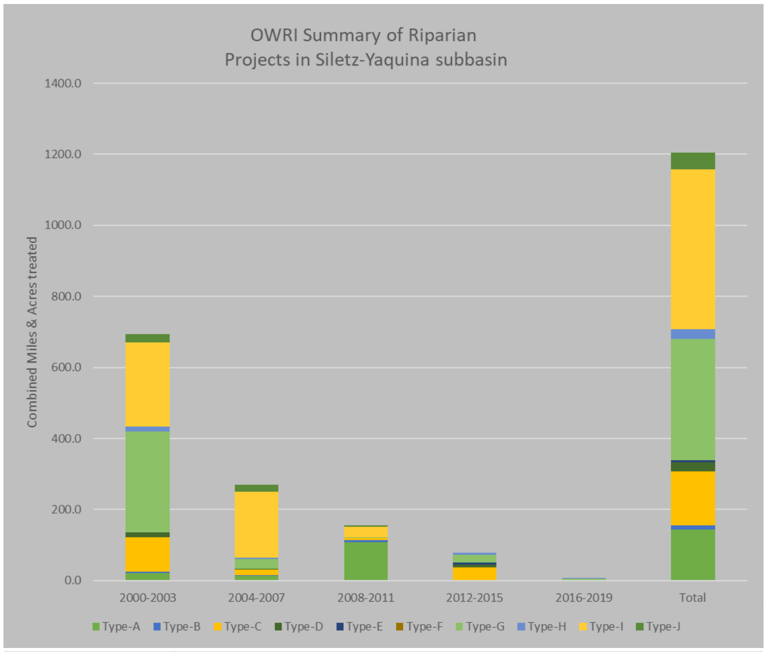
These are relatively simple scenarios and reasonable assumptions. Numerous future scenarios can be developed using a range of assumptions about rates of riparian planting and plant success combined with disturbance rates. However, these scenarios indicate that a concerted effort to (a) re-plant and establish riparian areas to a functioning buffer width using a site compatible mix of native tree species and (b) maintain and ensure success of these projects will significantly reduce solar radiation loading consistent with achieving the TMDL targets. These scenarios also indicate that (c) progress is measurable in approximately 10-year increments using LiDAR, aerial imagery and other remote sensing to assess riparian vegetation characteristics, combined with field validation.

These scenarios suggest that cumulative solar load reduction approaches 1.0 asymptotically and may plateau short of the TMDL target. However, the target includes a margin of safety of approximately 20% in current effective shade, intended to address uncertainty in the estimated time period to attain the effective shade targets. Therefore, DEQ concluded that a 90% reduction in excess load is a target that can realistically be achieved within 50-75 years from the vegetation management strategies identified herein, absent catastrophic loss of riparian trees, such as a stand-replacing fire.

Shade curves (Figures 4.5.2a-h above) identify the effective shade targets for the streams that were not explicitly modeled for excess radiation load and shade deficit. Shade curves are based on the same overstory vegetation associations and characteristics used in developing these estimates, but there is not sufficient information on current shade conditions to develop timelines to increase effective shade (and thereby reduce excess solar load) to site potential values throughout the watershed. DEQ assumed that timelines to reduce excess solar load throughout the watershed have a similar trajectory as that for the Yaquina River, recognizing that effective shade can increase more quickly on smaller width streams. As specific information about effective shade conditions is obtained in other areas, timelines can be estimated using an approach consistent with that for the modeled segment.

Significant uncertainty exists in meeting timelines for establishing shade. DEQ reviewed the riparian improvement projects reported in the OWRI database in the Siletz-Yaquina subbasin from 2000 to 2019. Progress towards achieving functioning riparian areas under the Oregon Plan for Salmon and Watersheds has slowed substantially in the past 10 -15 years, based on these data. DEQ recognizes that this summary does not include all plant establishment projects, but this result is consistent with ODA's evaluation for the SIA (ODA, 2021) and DEQ's evaluation of recent near-stream aerial imagery.

For lands under ODF jurisdiction, riparian areas harvested to the minimum distance allowed on small and medium fish bearing streams prior to 2015 were demonstrated to often be deficit in providing adequate effective shade to meet the state's water temperature criterion, whereas those units harvested under rules in effect from 2015-2022 have an elevated risk of not providing adequate shade for certain streams to attain applicable temperature criterion. However, the temperature impacts and shade deficit for these streams can be estimated using published methods.



Treatment Abbreviation:	Treatment
Type-A	Riparian trees planted: conifer (acres treated)
Type-B	Riparian trees planted: conifer (miles of treatment)
Type-C	Riparian trees planted: conifer and hardwood (acres treated)
Type-D	Riparian trees planted: conifer and hardwood (miles of treatment)
Type-E	Riparian trees planted: hardwood (acres treated)
Type-F	Riparian trees planted: hardwood (miles of treatment)
Type-G	Riparian fencing (acres treated)
Type-H	Riparian fencing (miles of treatment)
Type-I	Voluntary riparian tree retention (acres treated)
Type-J	Voluntary riparian tree retention (miles of treatment)

Figure 6.2.1b: OWRI database riparian improvement projects in the Siletz-Yaquina subbasin 2000-2019

6.2.2 Timelines for achieving phosphorus load reductions

The estimated timelines for achieving excess total phosphorus load reductions were developed using the following scenarios:

Scenario A: This scenario assumes immediate and sustained application of additional erosion and sediment control measures combined with steady reduction of livestock manure contribution to the river through implementation of best management practices. DEQ assumed a fixed total phosphorus mass load reduction of 5% of the starting excess daily total phosphorus during the critical period, which results in approximately 30% excess load reduction (lb/day) in five years and 100% reduction in about 12 years.

Scenario B: This scenario assumes consistent application of erosion and sediment control measures for all land uses combined with steady reduction of livestock manure contribution to the river through implementation of best management practices. DEQ assumed a fixed 10% excess total phosphorus load reduction (on an annual basis) is achieved and results in reduction of excess total phosphorus load by 50% in 6.5 years and 90% in approximately 22 years. This scenario produces a cumulative excess load reduction that approaches 1.0 asymptotically and may plateau short of the TMDL target of zero excess load (and the mass-based load allocation). However, the TMDL target includes a 20% margin of safety in excess total phosphorus load, intended to address the uncertainty in the estimated time period to attain the TMDL targets.

Scenarios C and D: These scenarios each assume that the annual rate of reduction varies randomly variation between 0 and 10% due to stochastic environmental factors or human activity. For instance, variability in background (wildlife) bacteria sources can occur and progress towards reducing fine sediment source loads may rise and fall in any given year over the projected time-period. These assumptions provide estimates for the rate of excess load reduction that are lower than Scenario A.

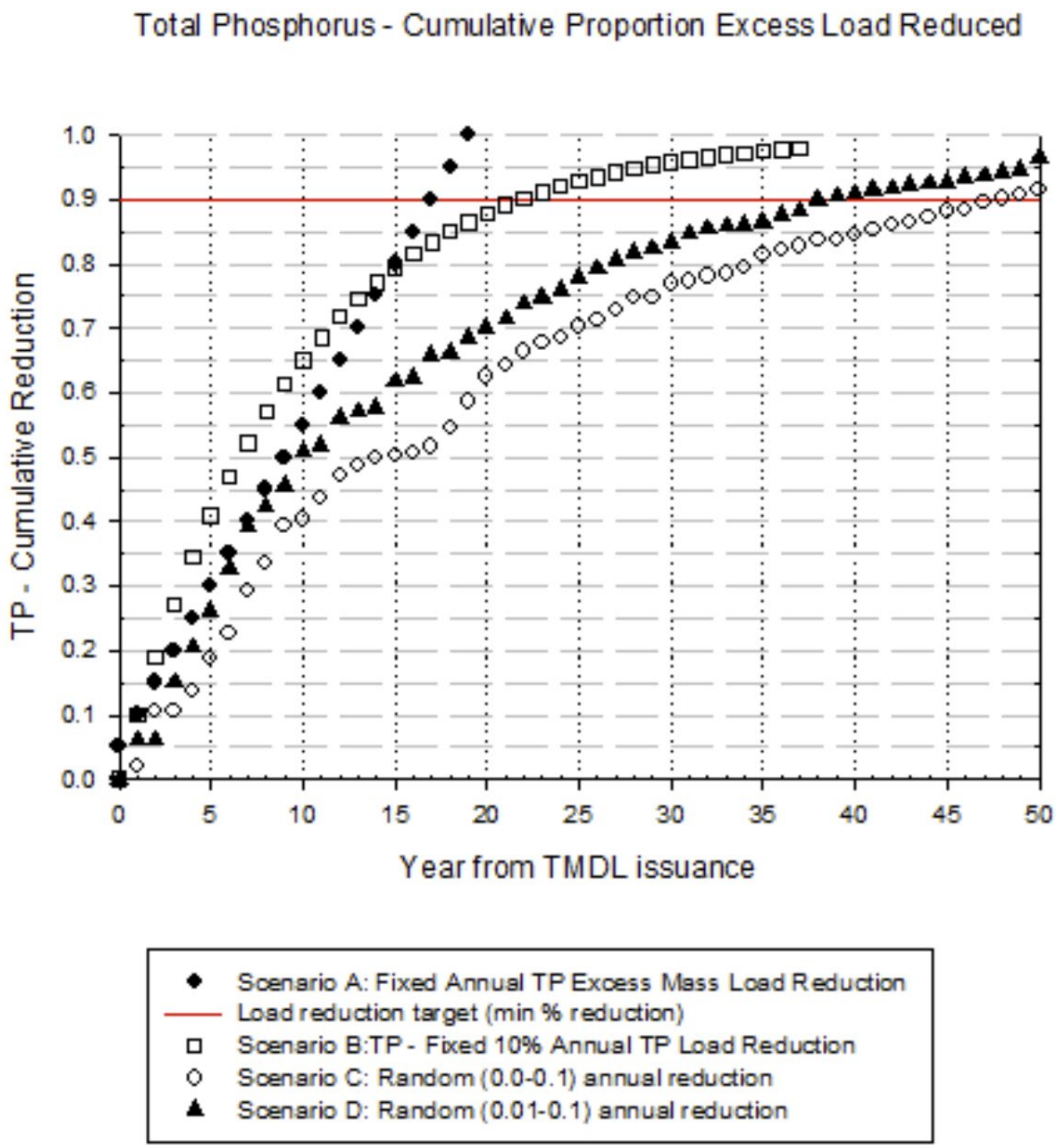


Figure 6.2.2: Scenarios to estimate time to achieve phosphorus reductions in the Yaquina River

DEQ estimated that the excess phosphorus load from the agricultural sector could be reduced to the load allocation within 5-7 years of initiating the Strategic Implementation Area process by Oregon Department of Agriculture's Agricultural Water Quality Management Program. The SIA process uses site-specific evaluation of land condition and practices to identify potential sources of water pollution then address those issues through a combination of regulatory and voluntary measures.

DEQ concluded that the other primary sources assigned a phosphorus load allocation (runoff from roadways, silviculture and background and failing septic systems) are generally more variable or episodic (e.g., weather-related, or mobile) and often more difficult to identify and control than livestock management that includes stream access. The estimated timeframes above consider that those sources require additional assessment or monitoring to identify the specific locations for implementing management strategies and specific practices or control measures. Primary assessment activities are identified as strategies in the WQMP that are expected to be incorporated into DMA's implementation plans to guide activities for the initial five-year cycle.

6.2.3 Timelines for achieving bacteria load reductions

The estimated timelines for achieving excess bacteria (E. coli) load reductions were developed using the following scenarios:

Scenario A: In this scenario, the annual projected excess bacteria load reduction (orgs/day) is based on 10% of the starting excess load, beginning year one, and then 10% of the excess load balance each year thereafter. Therefore, the cumulative reduction in excess load increases annually. The cumulative reduction reaches 90% in about 22 years and asymptomatically approaches 1.0 between 25 - 30 years.

Scenarios B – D: These scenarios each assume that the annual rate of reduction is subject to slight variation between 0 and 10% due to stochastic environmental factors or human activity. For instance, variability in background (wildlife) bacteria sources can occur and existing source loads may rise and fall in any given year over the projected time-period. These assumptions provide a range of estimates for the rate of excess load reduction that are lower than Scenario A.

Scenarios E and F: These scenarios assume that the annual rate of reduction is randomly increased a small amount between 10% and 20% (Scenario E) and between 10% and 20% (Scenario F). These assumptions result in estimates for the rate of excess load reduction that are higher than Scenario A.

The average rate of excess load reduction can be estimated using this approach and provides a measurable instream target. These scenarios also indicate that cumulative excess load reduction approaches 1.0 asymptotically and may plateau short of the TMDL target of zero excess load. However, the TMDL target includes a 10% margin of safety in excess bacteria load, intended to address uncertainty in the estimated time period to attain the TMDL targets.

Comparing these additional scenarios to Scenario A indicates that excess load reductions may be sensitive to slight variations in either disturbance or increased assumed load reduction rate. The resulting estimates for time to reduce excess load by 90% range from 10 to 40+ years. These scenarios also show that actions taken to reduce anthropogenic nonpoint bacteria loading in the initial 5 years following TMDL issuance are critical to attaining the TMDL targets in a reasonable timeframe, despite stochastic factors and other sources of uncertainty.

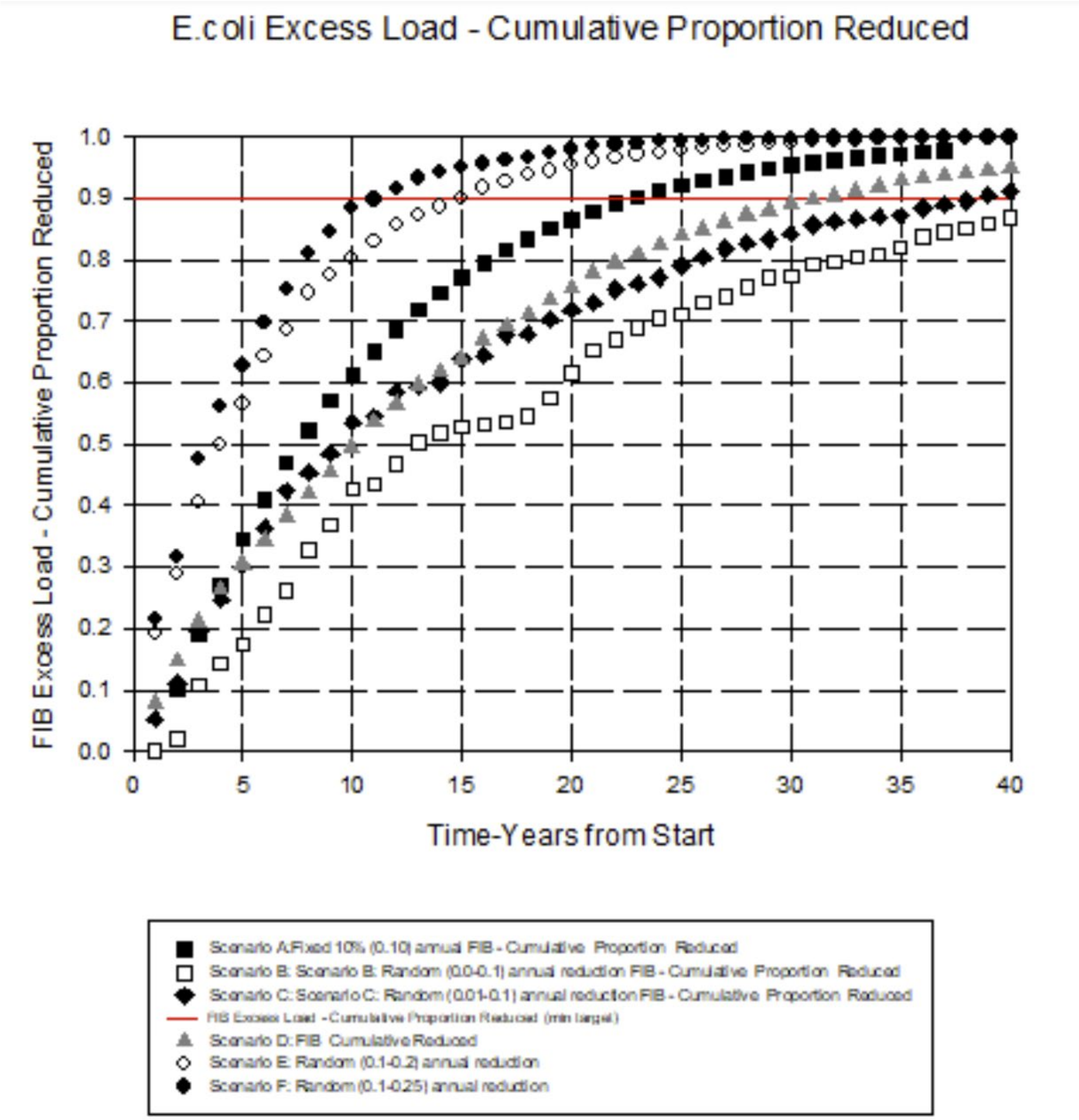


Figure 6.2.3: Scenarios to estimate time to achieve bacteria reductions in the Yaquina River

DEQ estimated that the excess bacteria load from the agricultural sector could be reduced to the load allocation within 5-7 years of initiating the Strategic Implementation Area process by Oregon Department of Agriculture's Agricultural Water Quality Management Program. The SIA process uses site-specific evaluation of land condition and practices to identify potential sources of water pollution then address those issues through a combination of regulatory and voluntary measures. Based on the source assessment and information provided by the technical working group, background (wildlife) and on-site septic sources are generally less predictable and more difficult to identify and control than livestock management and represent a relatively small proportion of overall excess load during the critical low flow period, considering the low residential density in the upper portion of the watershed. The estimated timeframes above consider that those sources may therefore require additional assessment or monitoring to identify the specific locations for implementing management strategies and specific practices or control measures.

6.3 Estimating costs of OC Coho habitat restoration

In response to Rule Advisory Committee input, DEQ identified information specific to coastal coho recovery for the Yaquina population, based on review of Oregon Coast Coho Conservation Plan (ODFW 2007) documentation the Oregon Coast Coho Conservation Plan for the State of Oregon: 12-year Assessment (ODFW 2019) and discussions with ODFW. This information (described below) can be used to estimate the costs of habitat restoration and the status of progress towards achieving the targets, as well as providing a basis for inferences to the relations between progress towards OCCCP targets and the TMDLs rule and associated implementation strategies.

ODFW's OCCCP established high-quality habitat targets for each population within the Oregon Coast Coho Evolutionary Significant. The amount of high-quality habitat (defined as capable of producing 2,800 coho smolts per mile) across all fresh water and estuarine life stages is one of the principal measurable criteria used to evaluate progress and achievement of the desired status for the Oregon Coast Coho ESU. A significant reduction of high-quality, complex stream habitat is the primary factor limiting recovery for most of the OC Coho populations, including the Yaquina population, and the secondary factor for this population is water quality (ODFW, 2007 and ODFW, 2019). ODFW identified linkages among primary and secondary limiting factors, acknowledging that improvements in certain habitat metrics (including riparian condition) will help improve water quality. ODFW estimated costs of restoration for 44 miles of high-quality habitat for the Yaquina population, which is about 23% of the OCCCP goal of 191 miles, the status of which indicates a substantial amount of the goal is yet to be realized. Improved aquatic habitat depends on, among other things, a source of large wood to improve channel complexity. Riparian forests are one primary source of large wood. The riparian conditions in much of the Yaquina River and primary tributaries within the scope of the TMDLs are severely deficient in overstory vegetation that provide functions of shade and source of large wood to streams. The dissolved oxygen TMDL identifies deficiencies in streamside shade, which is one riparian function, and sets targets for meeting water quality criteria.

DEQ concluded that the improvements in riparian vegetation condition necessary to provide the shade required to meet TMDLs load allocations and attain Oregon's water quality standards (and thereby Clean Water Act requirements) directly serve the specific OCCCP habitat targets for the Yaquina population as well as supporting the broader Oregon Plan habitat strategy. Although the TMDL shade targets are consistent with improving aquatic habitat these cannot alone achieve the OCCCP targets.

DEQ concluded that further analysis should be conducted by a multi-disciplinary team in an Oregon Plan for Salmon and Watersheds context.

7. Acknowledgements

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[Add relevant LSAC and TWG members]

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8. References

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Appendix 1: Watershed modeling by Tetra Tech, 2017

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Appendix 2: Load Duration Curves Results Package for

review by bacteria technical working group

[pdf ready to include]

Appendix 3: TMDL and WQMP comments and responses

[To be completed following public comment period]