Appendix E

Deschutes River Mainstem Dissolved Oxygen TMDLs Technical Analysis

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ACRONYMS/ABBREVIATIONS

Acronym/Abbreviation	Definition
°C	Degrees Celsius
µg/L	Micrograms per Liter
7Q10	Seven-day average low flow with a ten-year recurrence interval
AKART	All known, available, and reasonable methods of prevention, control, and treatment
BMP	Best Management Practices
BOD	Biochemical Oxygen Demand
CBOD	Carbonaceous Biochemical Oxygen Demand
cfs	Cubic Feet per Second
CWA	Clean Water Act
DEM	Digital Elevation Model
DIN	Dissolved Inorganic Nitrogen
DMR	Discharge Monitoring Report
DO	Dissolved Oxygen
Ecology	Washington Department of Ecology
EIM	Environmental Information Management System
EMC	Event Mean Concentration
EPA	United States Environmental Protection Agency
FLIR	Forward Looking Infrared Radiometer
ft	Feet
GIS	Geographic Information System
kg/day	Kilograms per Day
kg-DIN/day	Kilograms of Dissolved Inorganic Nitrogen/Day
kg/ha/yr	Kilograms per Hectare per Year
kg-TN/day	Kilograms of Total Nitrogen per Day
km	Kilometers
LiDAR	Light Detection And Ranging
mg/L	Milligrams per Liter
mg-N/L	Milligrams Nitrogen per Liter

Acronym/Abbreviation	Definition
mg-P/L	Milligrams Phosphorus per Liter
MS4	Municipal Separate Storm Sewer System
N/A	Not Applicable
NH_3	Ammonia
NHD	National Hydrography Dataset
NLCD	National Land Cover Database
NO_X	Nitrogen Oxides
NPDES	National Pollutant Discharge Elimination System
NSDZ	Near-Stream Disturbance Zone
N-STEPS	Nutrient Scientific Technical Exchange Partnership and Support
PA	Pollution Abatement
PARIS	Water Quality Permitting and Reporting Information System
QAPP	Quality Assurance Project Plan
RM	River Mile
RMSE	Root Mean Square Mile
SWMP	Stormwater Management Program
TKN	Total Kjeldahl Nitrogen
TMDL	Total Maximum Daily Load
TN	Total Nitrogen
TP	Total Phosphorus
TSS	Total Suspended Solids
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
WDFW	Washington Department of Fish and Wildlife
WLA	Wasteload Allocation
WQ	Water Quality
WQA	Water Quality Assessment
WQS	Water Quality Standard
WSDOT	Washington State Department of Transportation

1.0 INTRODUCTION

This appendix is based a report prepared by Tetra Tech under contract with the Environmental Protection Agency, Region 10. All work was conducted in accordance with an approved Quality Assurance Project Plan (QAPP; Tetra Tech, 2019). The objectives of the technical analyses presented in this report include identifying and quantifying key stressors that influence dissolved oxygen (DO) levels in the mainstem of the Deschutes River (Figure 1), ensuring protection of downstream water quality standards, establishing a Total Maximum Daily Load (TMDL), and determining the required load reductions. The segments addressed, in order from upstream to downstream, include parts of the river between the Lake Lawrence Tributary and Reichel Creek (Listing ID 47756), from Tempo Lake Tributary to Spurgeon Creek (Listing ID 47754), from Spurgeon Creek to Chambers Creek (Listing ID 47753), and from Chambers Creek to the outlet into Capitol Lake (Listing ID 10894). The most upstream DO-impaired segment of the Deschutes River is situated above Offutt Lake. The latter three DO-impaired segments are in series downstream of Offutt Lake, which marks the breakpoint along the mainstem where the designated aquatic life use and associated water quality criteria shift.

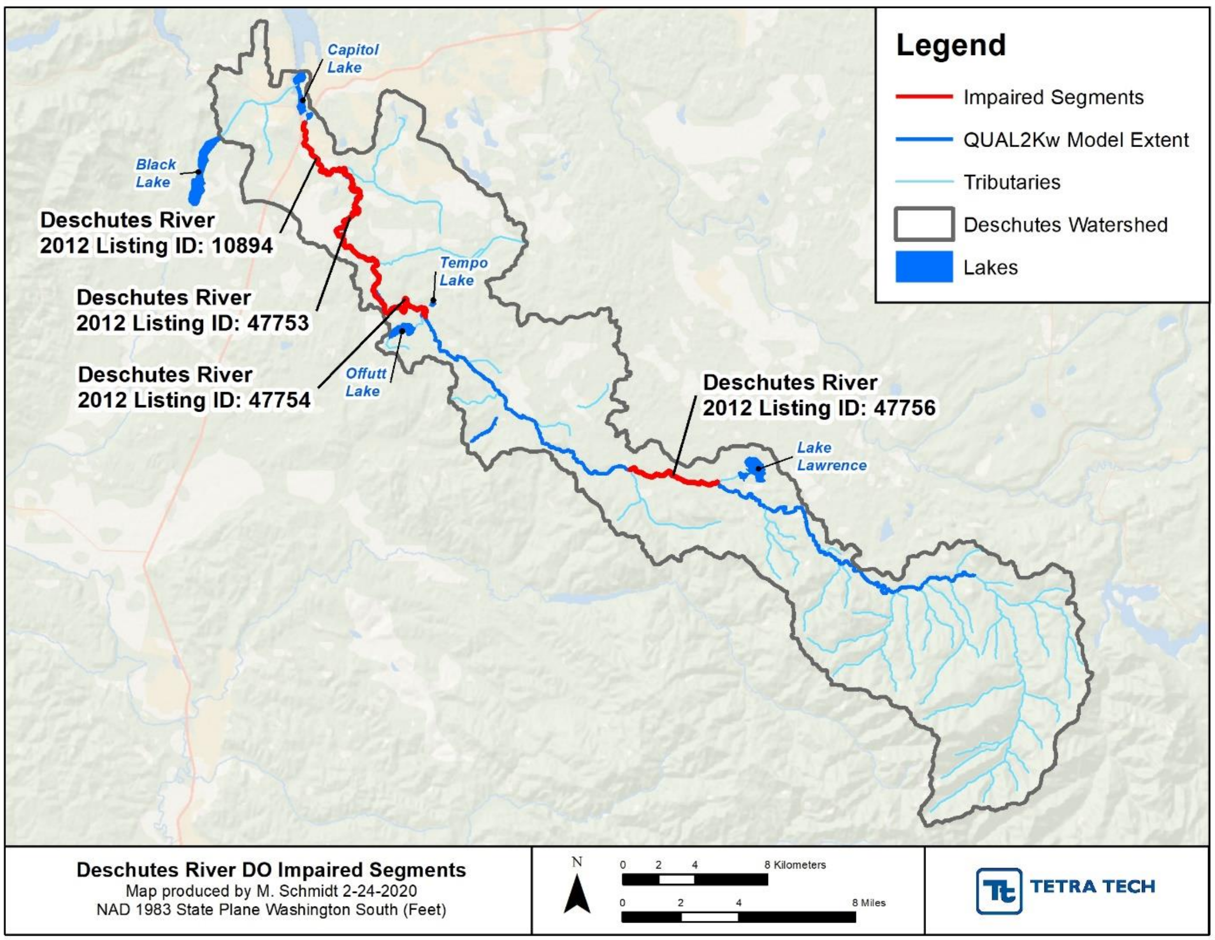

Figure 1. 2012 303(d) segments impaired for dissolved oxygen along the Deschutes River mainstem.

1.1 BACKGROUND

In the *2015 Deschutes TMDLs*, Ecology developed a calibrated QUAL2kw model (QUAL2Kw; Pelletier and Chapra, 2006) to understand the watershed dynamics for the mainstem of the Deschutes River, and quantify system potential conditions for temperature and DO. In these TMDLs, the Environmental Protection Agency (EPA) used Ecology's existing QUAL2kw to determine appropriate TMDL targets. The objectives of the technical analyses were two-fold: (1) evaluating assimilative capacities for DO in the impaired reaches of the Deschutes River based on water quality criteria; and (2) determining the nutrient load reductions needed to achieve the criteria. A riparian shade model (Shade.xls), with inputs derived from TTools (an ArcGIS extension) were used as inputs into the QUAL2Kw model. The Shade.xls model was also developed by Ecology for the *2015 Deschutes TMDLs* and is also used in these TMDLs. EPA also evaluated downstream water quality standards to ensure the most stringent criterion was applied in order to protect downstream designated uses.

2.0 AVAILABLE DATA

Data used in the technical analyses for the DO TMDL include geographic information system (GIS) spatial datasets for drainage areas, land use/cover, permitted urban stormwater boundaries, and Washington State Department of Transportation (WSDOT) operated roadways. In addition, the assessments described in this report apply instream water chemistry and flow monitoring data as well as operational procedures and effluent data from point sources. The assessment also incorporates data from several literature sources (e.g., regional groundwater studies).

2.1 GIS

GIS data were used to develop catchment boundaries for the impaired waterbodies and to differentiate between Municipal Separate Storm Sewer Systems (MS4s) and non-MS4 areas. Sources of GIS data are shown in Table 1. Both point and nonpoint sources can contribute pollution to the waterbodies, the latter of which can be summarized by land use/cover The National Land Cover Dataset (NLCD 2011 at a 30-meter resolution) was used to classify land use/cover in each tributary's drainage area (Figure 2). The land use across the watershed as illustrated by the National Land Cover Database (NLCD) is shown in Figure 3.

Table 1. Geospatial data sources for Deschutes River DO TMDL.

Purpose	GIS Datasets
Develop watershed boundaries and catchment areas	Catchment boundaries shapefile from NHDPlus V2[1]
Definition of MS4 and non-regulated areas	MS4 boundaries from Ecology
	Land use/cover from National Land Cover Dataset 2011
	National highways from WSDOT

[1]http://www.horizon-systems.com/nhdplus/nhdplusv2_home.php

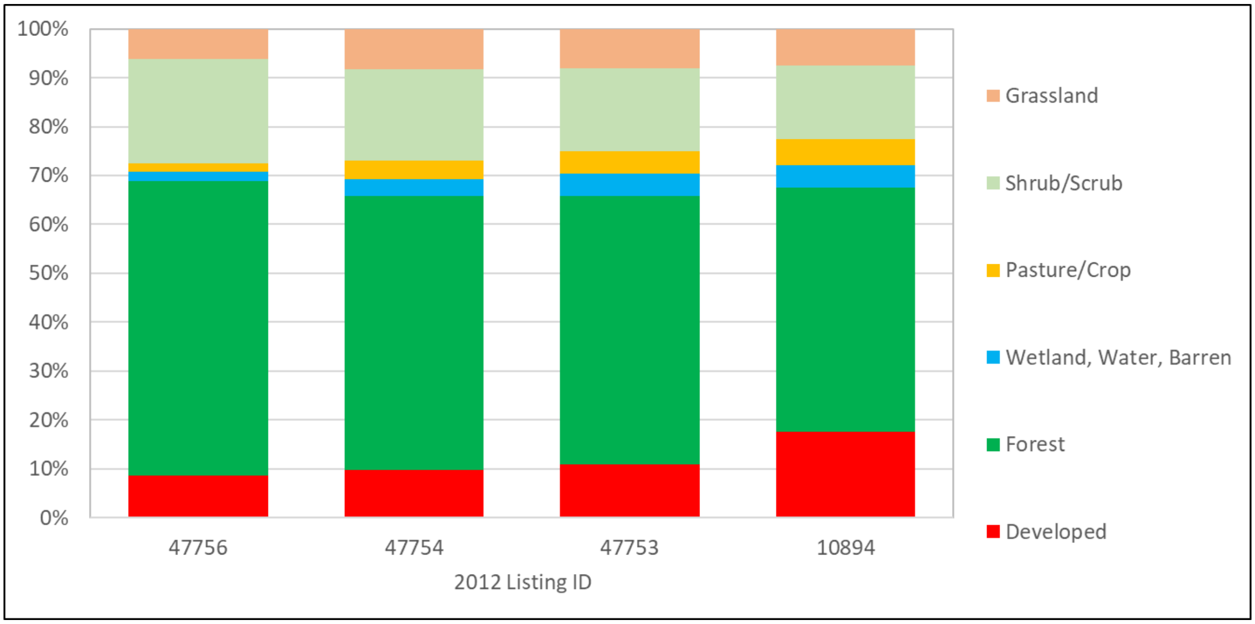

Figure 2. Aggregated land use/cover for the cumulative drainage areas of the reaches impaired for DO.

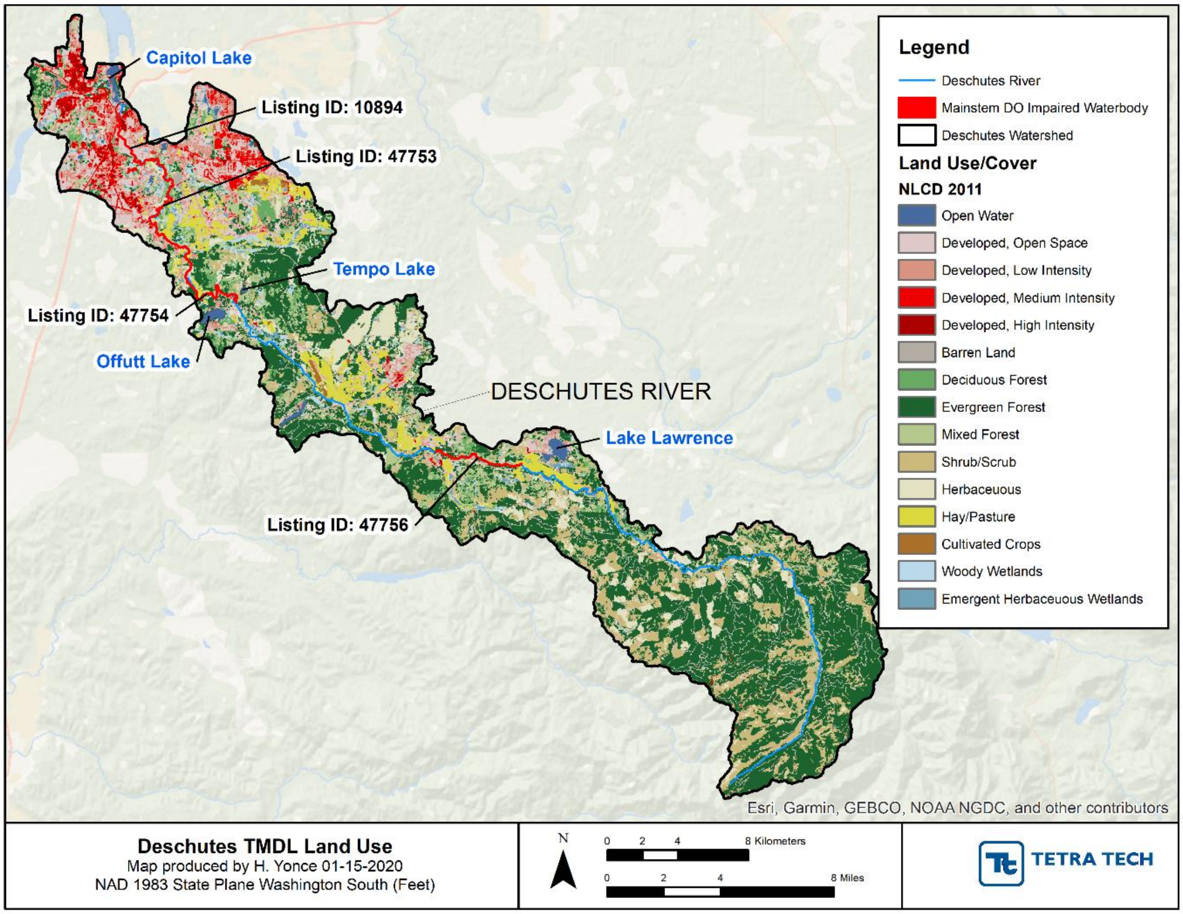

Figure 3. NLCD 2011 land use/cover in the Deschutes River watershed.

2.2 FLOW AND WATER CHEMISTRY DATA

All data which the Washington Department of Ecology (Ecology) used in the development of the QUAL2Kw model were collected in 2003 and 2004. For additional information on instream monitoring, refer to Ecology's technical report for the project (*Water Quality Study Findings*, Roberts et al., 2012).

The most robust, continuous flow monitoring data were obtained from United States Geological Survey (USGS) sites 12080010 (Deschutes River at E. Street Bridge at Tumwater, WA) and 12079000 (Deschutes River near Rainier, WA). Additionally, flow was measured intermittently throughout the watershed between 2003 and 2004 at approximately 30 water quality sampling locations.

Groundwater and surface water temperature data were recorded periodically across the watershed from 2003 – 2004. Data were collected using 23 groundwater piezometers, around 20 water column monitoring locations along the Deschutes River mainstem, and around 10 water column monitoring locations along tributaries. Ecology applied these data as model boundary conditions (e.g., representative tributary flows and loads), and they were previously used by Ecology to calibrate and verify the QUAL2Kw simulation for the Deschutes River as discussed in the technical report (Roberts et al., 2012).

Groundwater DO concentration data was measured using piezometer locations across the watershed. These were used by Ecology to parameterize springs and diffuse groundwater conditions in the QUAL2Kw model. DO was monitored at seven locations between 2003 and 2004 using piezometers (Figure 4). In general, these observations suggest that resurfacing groundwater is anoxic in most of the watershed (Table 2).

Table 2. Deschutes River watershed observed groundwater DO data (groundwater DO data was only collected in 2004, not 2003).

Piezometer	Location Description	Count of Observations	Mean of DO Observations (mg/L)	Well Sampling Depth (ft)
AGJ754	Percival Creek at Mouth	4	0.45	3.4 - 3.9
AGJ759	Deschutes River near WEYCO 860 Rd	2	5.91	4.2 - 4.7
AHT006	Deschutes River at Vail Rd SE	4	0.17	4.1 - 4.6
AHT007	Deschutes River at Vail Loop Rd	4	4.09	4.3 - 4.8
AHT009	Deschutes River at Military Rd	1	0.10	2.9 - 3.4
AHT011	Deschutes River at Cowlitz Dr	1	0.10	3.3 - 3.8
AHT014	Deschutes River at Henderson Blvd SE	4	0.14	3.9 - 4.4

Instream DO concentration data were measured at 18 locations throughout the Deschutes River watershed (Table 3 and Figure 4). This includes the Thurston County site DESD0000 (Deschutes River at Tumwater), seven other mainstem Deschutes sites with data from the Environmental Information Management System (EIM), and 10 tributary locations. Instream DO sampling across the watershed reveals that there are several locations that do not meet DO criteria (red highlight in Table 3).

Table 3. Deschutes River watershed observed instream DO data (2003 - 2004).

Site[1]	Name	Applicable DO Criteria (1-Day Minimum, (mg/L)	DO Observation Statistics (mg/L)			
			Count	Mean	Min[2]	Max
Deschutes River Monitoring Sites						
13-DES-37.4	Deschutes River at RM 37.4	9.5	305	9.11	7.84	12.76
13-DES-28.6	Deschutes River at RM 28.6	9.5	368	8.28	6.96	12.45
13-DES-20.5	Deschutes River at RM 20.5	9.5	26	10.92	8.75	12.55
13-DES-09.2	Deschutes River at RM 09.2	8.0	379	8.52	7.49	12.32
13-DES-05.5	Deschutes River at RM 05.5	8.0	311	8.89	7.51	12.21
13-DES-02.7	Deschutes River at RM 02.7	8.0	35	10.16	8.92	11.75
13-DES-00.5	Deschutes River at RM 00.5	8.0	396	8.72	7.26	12
DESDE0000	Deschutes River at Tumwater	8.0	18	11.21	9.3	12.76
Tributary Monitoring Sites						
13-THU-00.1	Thurston Creek at 3000 Rd	9.5	1	10.2	-	-
13-HUC-00.3	Huckleberry Creek at 3000 Rd	9.5	31	10.21	8.7	12.02
13-LAK-00.0	Lake Lawrence Tributary	9.5	3	2.55	2.39	2.76
13-REI-00.9	Reichel Creek at Vail Loop Rd	9.5	35	7.73	4.3	11.65
13-SPU-00.0	Spurgeon Creek nr Rich Rd	8.0	24	10.3	8.15	12.38
13-AYE-00.0	Ayer Creek	8.0	36	3.64	1.05	8.62
13-CHA-00.1	Chambers Creek	8.0	23	9.82	8.34	11.25

[1]Mainstem and tributary monitoring sites are ordered from upstream to downstream.

[2]Minimum DO concentrations that are below the lowest 1-day minimum DO concentration standard are highlighted in red.

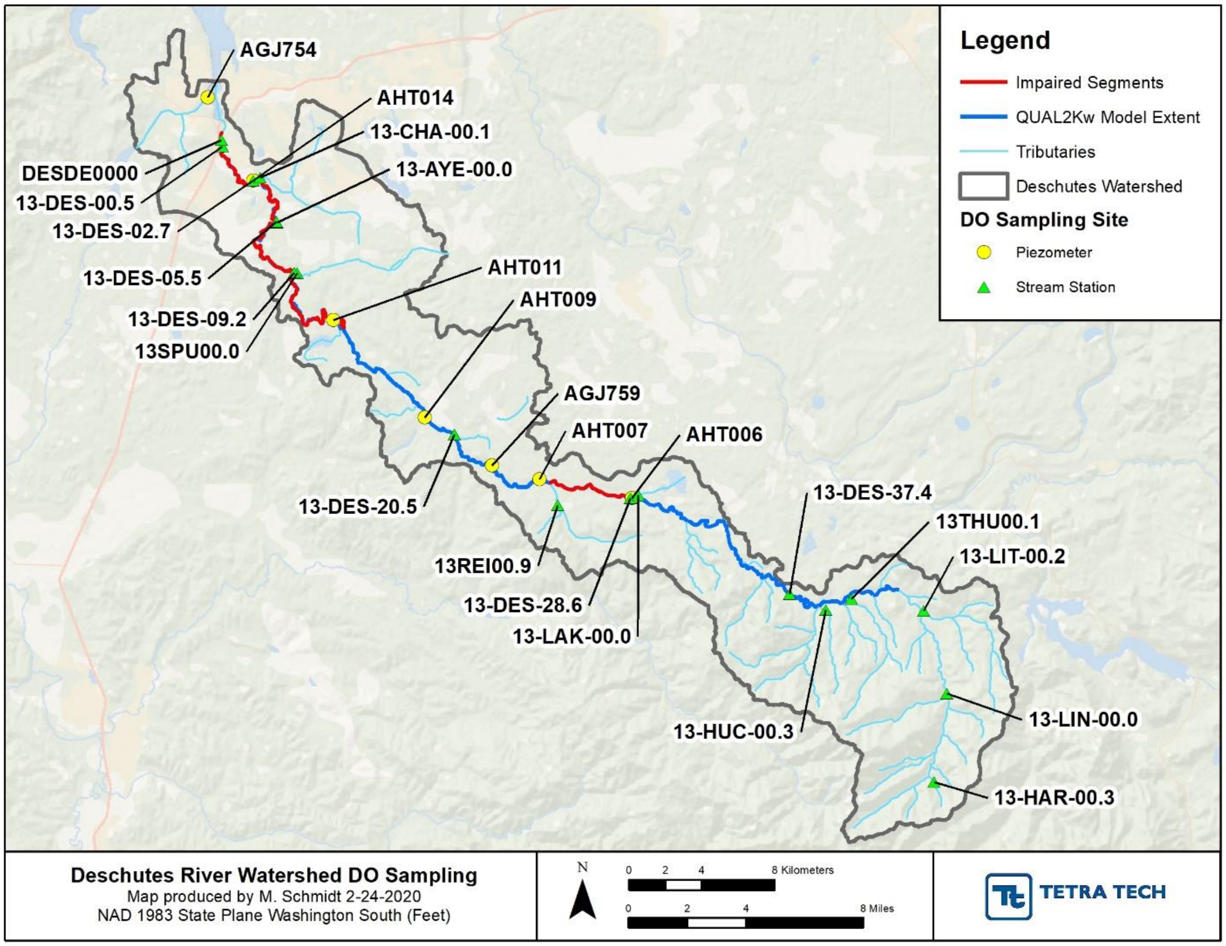

Figure 4. DO sampling locations across the Deschutes River watershed.

Nutrient-related water chemistry parameters such as nitrogen and phosphorus species were measured across the watershed. Seven piezometers measured groundwater water chemistry in 2003 and 2004 (Figure 4). Instream water chemistry sampling was conducted at 12 mainstem and tributary sites between 2003 and 2004. Water chemistry parameters measured at both piezometer and instream locations included ammonia, nitrate and nitrite, ortho-phosphate, total phosphorus, and total persulfate nitrogen. Limited instream sampling of biochemical oxygen demand (BOD) was also conducted. The largest sample set of water chemistry records were collected at the seven mainstem Deschutes River monitoring sites (which were used for model calibration), as well as monthly monitoring along Ayer Creek, Chambers Creek, Reichel Creek, and Spurgeon Creek. Data counts and averages by constituent and site are included in Table 4 and Table 5. Note that there were only five measurements of BOD[1] across the watershed project area from 2003-2004 along three tributaries (Ayer Creek, Spurgeon Creek, and Lake Lawrence Tributary). Those results ranged from 2.0 – 4.0 mg/L. For reference, unpolluted rivers generally have BOD concentrations less than 2 mg/L, whereas untreated sewage often has BOD concentrations exceeding 200 mg/L (Chapra, 2014).

[1] These measurements from the Washington EIM database for BOD are listed as “Biochemical Oxygen Demand (BOD), 5 day at 20 deg C” using result method SM5210B.

Table 4. Deschutes River watershed observed instream nitrogen species data (2003 - 2004).

Site[1]	Name	Ammonia		Nitrate + Nitrite		Total Persulfate Nitrogen[2]	
		Count	Mean (mg/L)	Count	Mean (mg/L)	Count	Mean (mg/L)
Deschutes River Monitoring Sites							
13-DES-37.4	Deschutes River at RM 37.4	14	0.01	14	0.17	21	0.22
13-DES-28.6	Deschutes River at RM 28.6	16	0.01	16	0.29	24	0.35
13-DES-20.5	Deschutes River at RM 20.5	30	0.01	30	0.55	41	0.61
13-DES-09.2	Deschutes River at RM 09.2	14	0.01	14	0.65	21	0.72
13-DES-05.5	Deschutes River at RM 05.5	14	0.01	14	0.62	21	0.71
13-DES-02.7	Deschutes River at RM 02.7	26	0.01	26	0.72	34	0.8
13-DES-00.5	Deschutes River at RM 00.5	38	0.01	38	0.68	48	0.77
DESDE0000	Deschutes River at Tumwater	0	No Data	18	0.64	0	No Data
Tributary Monitoring Sites							
13-LAK-00.0	Lake Lawrence Tributary	1	0.1	1	1.66	2	1.74
13-REI-00.9	Reichel Creek at Vail Loop Rd	16	0.02	16	0.37	23	0.68
13-SPU-00.0	Spurgeon Creek nr Rich Rd	20	0.01	20	0.25	31	0.4
13-AYE-00.0	Ayer Creek	18	0.04	18	0.35	29	0.61
13-CHA-00.1	Chambers Creek	19	0.01	19	1.61	27	1.78

[1]Mainstem and tributary monitoring sites are ordered from upstream to downstream.

[2]As discussed in the technical analyses, reference total nitrogen conditions for the Cascades and Lower Puget Level II Ecoregions are 0.055 and 0.340 mg/L, respectively. For comparison purposes, all the Deschutes River monitoring sites and the outlets of all the tributary monitoring sites listed are in the Lower Puget ecoregion. (Note that a majority of the Reichel Creek drainage area is in the Cascades ecoregion, but the outlet is in the Lower Puget ecoregion.)

Table 5. Deschutes River watershed observed instream phosphorus species data (2003 - 2004).

Site[1]	Name	Ortho-Phosphate		Total Phosphorus[2]	
		Count	Mean (mg/L)	Count	Mean (mg/L)
Deschutes River Monitoring Sites					
13-DES-37.4	Deschutes River at RM 37.4	14	0.01	14	0.01
13-DES-28.6	Deschutes River at RM 28.6	16	0.01	16	0.01
13-DES-20.5	Deschutes River at RM 20.5	30	0.01	31	0.58
13-DES-09.2	Deschutes River at RM 09.2	14	0.01	14	0.02
13-DES-05.5	Deschutes River at RM 05.5	14	0.01	14	0.02
13-DES-02.7	Deschutes River at RM 02.7	26	0.02	25	0.84
13-DES-00.5	Deschutes River at RM 00.5	38	0.02	38	0.61
DESDE0000	Deschutes River at Tumwater	0	No Data	18	0.03
Tributary Monitoring Sites					
13-LAK-00.0	Lake Lawrence Tributary	1	0.01	1	0.05
13-REI-00.9	Reichel Creek at Vail Loop Rd	16	0.02	16	0.05
13-SPU-00.0	Spurgeon Creek nr Rich Rd	20	0.02	20	0.03
13-AYE-00.0	Ayer Creek	18	0.03	18	0.07
13-CHA-00.1	Chambers Creek	19	0.02	19	0.02

[1]Mainstem and tributary monitoring sites are ordered from upstream to downstream.

[2]As discussed in the technical analyses, reference total phosphorus conditions for the Cascades and Lower Puget Level II Ecoregions are 0.00906 and 0.0195 mg/L, respectively, for comparison purposes. For comparison purposes, all the Deschutes River monitoring sites and the outlets of all the tributary monitoring sites listed are in the Lower Puget ecoregion. (Note that a majority of the Reichel Creek drainage area is in the Cascades ecoregion, but the outlet is in the Lower Puget ecoregion.)

2.3 KEY LITERATURE RESOURCES

EPA evaluated the following literature resources for the purpose of deriving natural reference conditions for surface water and groundwater resources in the Deschutes River watershed.

2.3.1 EPA's Nutrient Ecoregion Recommendations

Ambient Water Quality Criteria Recommendations: Information Supporting the Development of State and Tribal Nutrient Criteria for Rivers and Streams in Nutrient Ecoregion II (USEPA, 2000)

EPA issued this report to support states, tribes, and other agencies in the development of localized ambient nutrient criteria for freshwater rivers and streams. The ambient nutrient criteria are also recommended for other applications, including defining discharge permit limits and for establishing targets for TMDLs. The report presents EPA's current recommended criteria for total nitrogen (TN) and total phosphorus (TP) for the Western Forested Mountains Nutrient Ecoregion II, which includes the Puget Lowlands and Cascades sub-ecoregions (Level III).

The ambient water quality criteria recommendations comprise a suitable reference condition derived from the 25th percentile of the distribution of historical data within an ecoregion.

Natural conditions were characterized based on the Level III ecoregion (Figure 5 and Section 5.3) and used as inputs to the QUAL2kw model. The following tributaries were classified as the Puget Lowland ecoregion: Huckleberry Creek, Mitchell Creek, Fall Creek, Hull/Pipeline Creek, Lake Lawrence Tributary, Reichel Creek, Tempo Lake Tributary, Spurgeon Creek, Ayer/Elwanger Creek, Chambers Creek, and multiple unnamed creeks. These tributaries and waterbodies were classified as the Cascades Ecoregion: Deschutes River headwaters, Thurston Creek and Johnson Creek.

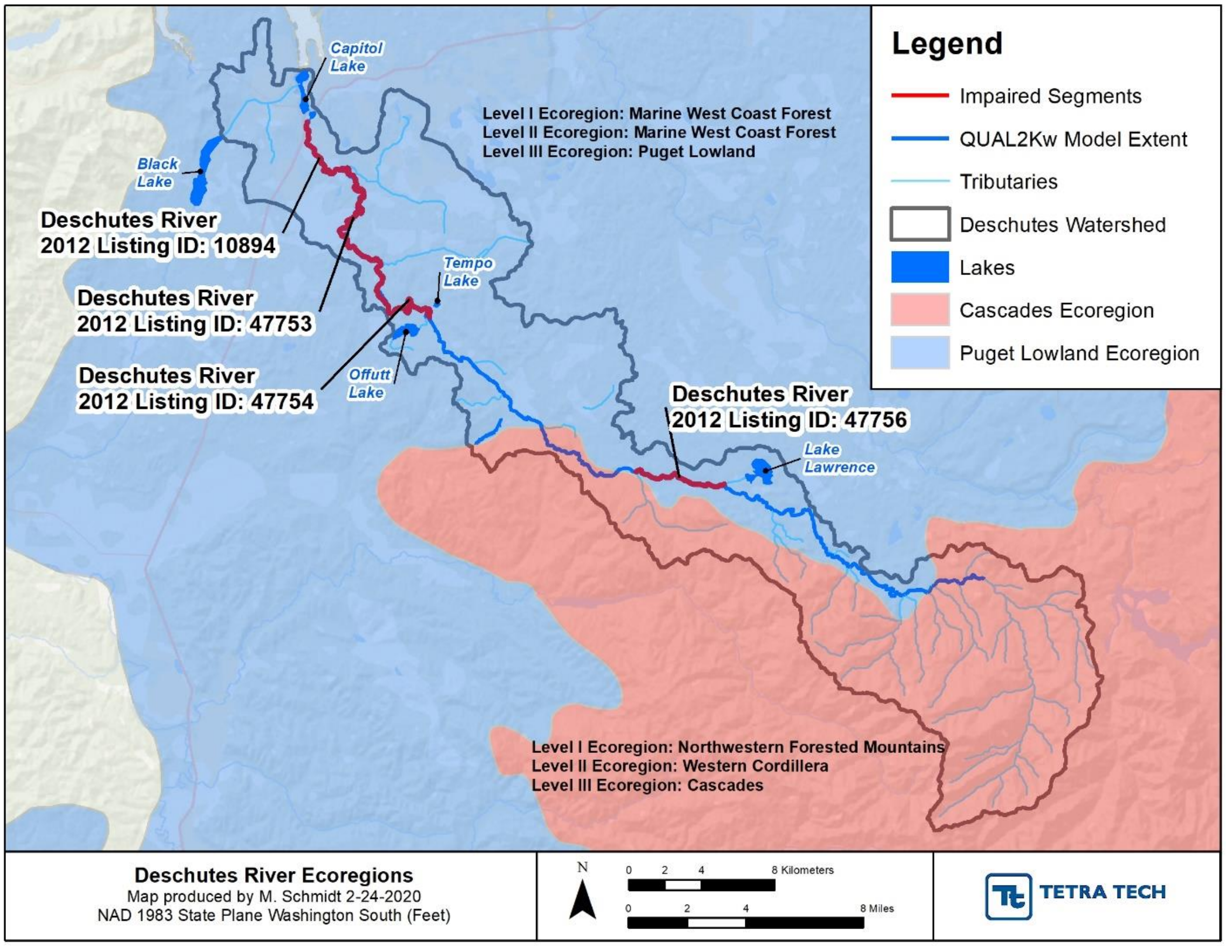

Figure 5. Ecoregions in the Deschutes River watershed.

2.3.2 Washington's N-STEPS Analysis

Analysis of Washington Nutrient and Biological Data (Periphyton) for the Nutrient Scientific Technical Exchange Partnership Support (N-STEPS) (USEPA, 2018b)

This report summarizes water chemistry analyses completed using monitoring data from across the State of Washington. The research effort focused on identifying nutrient conditions in Washington streams and evaluated thresholds for periphyton responses. The least disturbed sites were assigned reference site designations based on screening criteria. The reference sites served as benchmarks for non-reference sites. Difficulties finding reference-quality streams in the Puget Lowlands, however, is discussed in the report. As a result, the reference site concentrations tend to be higher than those from EPA's ambient nutrient criteria report (above) and for other ecoregions in Washington. For example, the 75th percentile TN concentration for reference sites in the Puget Lowlands is about 0.66 mg/L whereas it is 0.12 mg/L for reference sites across the other ecoregions in Washington. Due to the limitations regarding the reference sites in the Puget Lowlands, the NSTEPS values were not used to represent natural conditions in the Deschutes River watershed.

2.3.3 USGS Hydrology and Groundwater Report

Hydrology and Quality of Ground Water in Northern Thurston County, Washington (USGS, 1998)

This groundwater conditions report was prepared by USGS in cooperation with the Thurston County Department of Health. Groundwater quality concentrations of common constituents are summarized (minimum, median, maximum concentrations) for the entire Lower Puget region in Northern Thurston County as well as by specific geohydrologic unit (medians only). Information from this groundwater study was used to inform the natural conditions scenarios for DO.

3.0 NUMERIC TARGET SELECTION

The Deschutes River DO TMDLs must be protective of water quality in the river as well as water quality in downstream Capitol Lake. The portion of the river upstream of Offutt Lake has a DO criterion of 9.5 mg/L, while the downstream of Offutt Lake criteria is less stringent, at 8.0 mg/L. Thus, the upstream part of the river inherently protects the downstream part. The applicable criterion for Capitol Lake is equally stringent at 8.0 mg/L. Therefore, the TMDLs for the Deschutes River are also protective of downstream water quality in Capitol Lake.

Using QUAL2kw, EPA chose numeric nutrient targets that would achieve in-stream DO water quality criteria for both the impaired segments and the downstream waterbodies. The QUAL2kw temperature model scenario 5 from the *2015 Deschutes TMDLs* was used as the baseline for setting up the DO scenario for these TMDLs. Thus, the shading targets that were previously approved by EPA, also form surrogate targets for these DO TMDLs. The full method for deriving the nutrient targets is explained in Section 5.0. Nutrients and shade are the targets and may aid with implementation, but the success of the TMDLs will be measured via attainment of the DO water quality standard.

Targets were established for two locations, the downstream end of the impaired segment (Listing ID 47756) near Reichel Creek (upstream of Offutt Lake) and the downstream end of the impaired segment (Listing ID 10894) near the Deschutes River mouth (downstream of Offutt Lake). The targets for the river downstream of Offutt Lake are comprehensively protective of the other two upstream impaired segments (Listing IDs 47753 and 47754). Downstream of Offutt Lake, existing nutrient loads are applied as the targets because the shading targets from the approved temperature TMDLs (*2015 Deschutes TMDLs*) result in achievement of the applicable DO criteria for those segments.

Targets associated with the fine sediment TMDL for the Deschutes River are implicitly incorporated. The QUAL2Kw model was not originally set-up and calibrated for sediment, thus, a direct representation (i.e., apply lower total suspended solids [TSS] concentrations) of the fine sediment TMDL was not feasible. Ultimately, reductions in sediment will correspond to reductions in the delivery of particulate nutrients and organic matter to the river. Implementation measures to control sediment loads will support the needed reductions in nutrient loads.

4.0 EXISTING DISSOLVED OXYGEN SOURCE ASSESSMENT

Existing nutrient source loads were evaluated for nonpoint upland sources as well as the following point sources: aquaculture facilities, permittees covered by the General Permits for Industrial Stormwater, Sand and Gravel, Construction Stormwater, permitted urban stormwater entities (MS4s).

Point sources are direct inflows into a waterway that are subject to individual permit limits and effluent requirements (unless illicit or in cases where a facility doesn't meet the requirements for needing a discharge permit). Because point sources flow directly into waterways, their effluent discharges are more strictly regulated than nonpoint sources, which do not have discrete concentrated inflow points to waterbodies.

4.1 AQUACULTURE FACILITIES

There is an existing fish hatchery located immediately upstream of Tumwater Falls that has been in operation since 2004, and a second fish hatchery is proposed upstream at Pioneer Park (Figure 6). While not an existing source, the Pioneer Park hatchery is incorporated into this TMDL to ensure that future effluent loads will be protective of the TMDL of the river. Both hatcheries are located along the lower Deschutes River aligning with the segment listed as impaired for DO (Listing ID 10894).

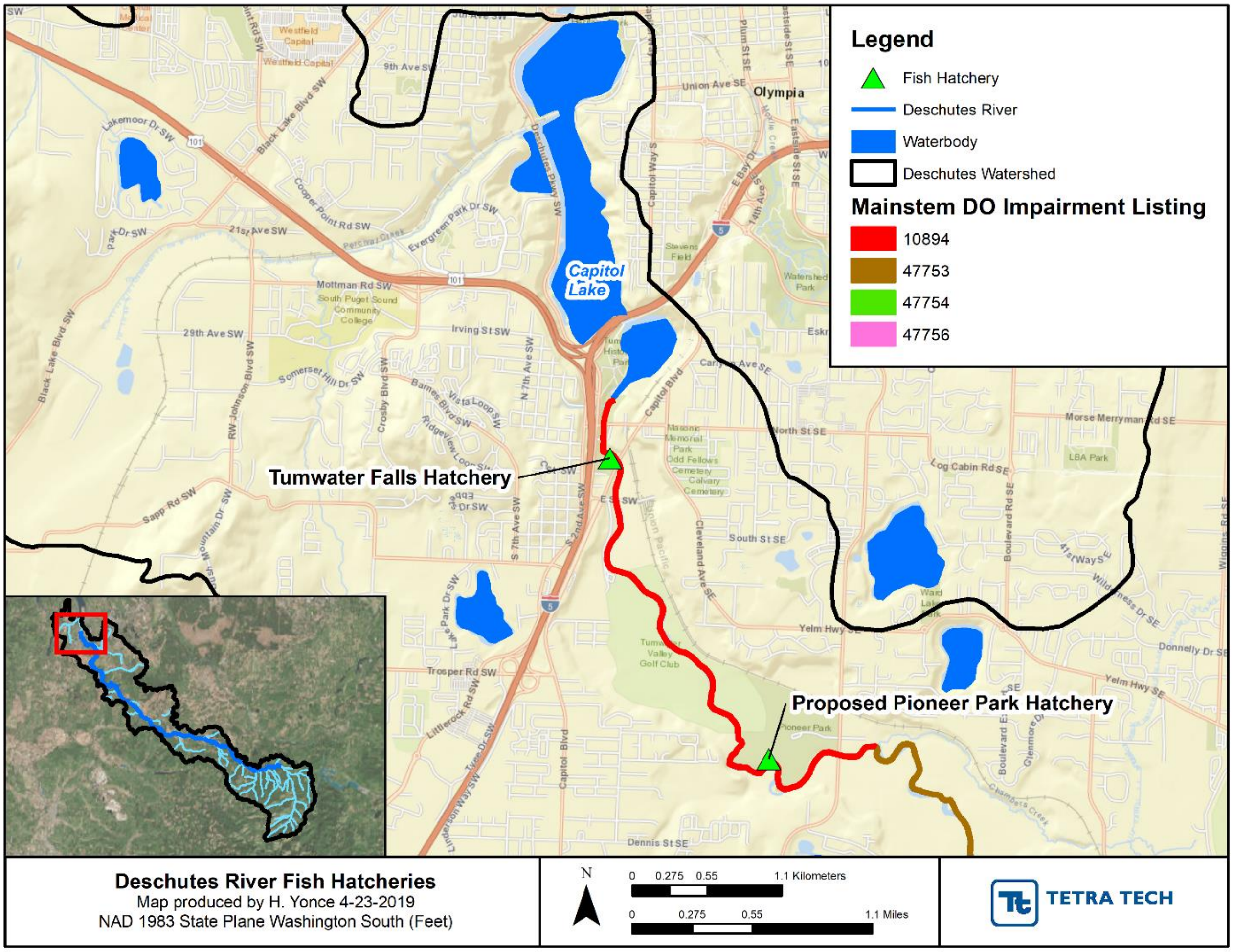

Figure 6. Existing and proposed fish hatcheries in the Deschutes River watershed.

4.1.1 Tumwater Falls Hatchery

The Tumwater Falls Hatchery is the only active hatchery along the Deschutes River according to the Washington Department of Fish and Wildlife (WDFW). The hatchery does not have a National Pollutant Discharge Elimination System (NPDES) permit because its production levels do not currently meet Ecology's criteria for needing permit coverage for its discharges. It is included in these TMDLs in case production increases in the future or Ecology's criteria for permit coverage change. The hatchery is located within Tumwater Falls Park near the Senator P.H. Carlyon Bridge at Deschutes River RM (River Mile) 0.2. The hatchery population is sub-yearling Chinook salmon and the annual production goal is 18,493 adults. There is a maximum of 24,000 pounds of fish present at any given time, although this peak is not sustained for more than a couple of days at a time. According to the Washington State Government "Hatchery Environmental Compliance" website, this hatchery is compliant for fish passage and water quality. The facility is subject to meet AKART (all known, available, and reasonable methods of prevention, control, and treatment) requirements.

A memorandum about the Tumwater Falls Hatchery was generated to approximate monthly nutrient and BOD loading from the facility (HDR, 2019). According to this memo, the Tumwater Falls Hatchery facility feeds and rears sub-yearling Chinook salmon from February – June before releasing the fish. There is no facility discharge July – August, and then adults return September – October. Adults are not fed in the fall, and there is minimal discharge from September to December, with no discharge in January. Monthly nutrient and BOD loads from the facility were approximated based on typical fish poundage and feed information. Solids, nutrient, and BOD loadings were estimated using published ratios of pollutant produced per pound of feed. Ratios associated with phosphorus were modified to account for the low-phosphorus feed that is used at this facility. About 80 percent of solids and organic nutrients are assumed to be vacuumed and treated at a nutrient abatement pond, while the remaining 20 percent are assumed to be discharged to the Deschutes River. All dissolved nutrient waste generated from feeding and rearing are assumed to be discharged into the Deschutes River. During November and December, the facility routes pass-through Coho salmon upstream, but these adults are not fed.

The facility currently holds a temporary NPDES construction permit (WAR307310) effective 2/25/2019 for the "Tumwater Falls Hatchery Redevelopment". This redevelopment does not appear to involve an expansion of capacity, but rather improved infrastructure for both general operation and enhanced tourism experience. The Tumwater Falls Hatchery did not discharge during the simulation period of the QUAL2kw model (August 2004); therefore, the Tumwater Falls Hatchery point source is not explicitly included in the calibration model or the critical conditions TMDL model scenario. The hatchery does discharge during other seasons and, thus, contributes to the long-term DO demand (e.g., accumulation of nutrients). Thus, existing loads by month for the Tumwater Falls Hatchery are tabulated to support the assignment of a reserve Wasteload Allocation (WLA), should the facility need permit coverage in the future.

4.1.2 Proposed Pioneer Park Hatchery

The Washington Department of Fish and Wildlife is leasing land in Pioneer Park for a state-run hatchery to raise and release Chinook salmon in tandem with the Tumwater Falls Hatchery. The Pioneer Park Hatchery has not been built yet, but planned operations indicate the facility would meet the production threshold for requiring a NPDES permit.

A memorandum about the proposed Pioneer Park Hatchery was generated to approximate anticipated monthly nutrient loading from the facility (WDFW and HDR, 2018). According to the memorandum, there are two stages of planned operations for the facility. For the purpose of these TMDLs, they are referred to as the "near-term proposed" and "long-term proposed" operations. The near-term proposed operations include hatching, rearing, and feeding sub-yearling Chinook salmon juveniles January – June 15, not operating (zero-discharge) June 15 – August 30, and then housing adults September – December with limited discharge. Waste generated from feed and fish waste is routed through a pollution abatement (PA) pond which is expected to remove 80 percent of organic nutrients. The source water during egg incubation is groundwater. Long-term proposed operations for the hatchery (timeline unknown) include year-round activity in support of sub-yearling and yearling Chinook salmon, Coho salmon, and steelhead. Year-round feeding planned for future potential operations would peak around May – June 15, and the highest nutrient loads are estimated for April and May when fish poundage and feed applied peaks. For this operation, most of the feed is associated with the sub-yearling Chinook salmon, which are expected to exit the facility prior to mid-June, leaving the yearling Chinook salmon, Coho salmon, and steelhead over the summer. The Chinook salmon are expected to return to the facility as adults in August and September and egg incubation will follow in September to December.

The Pioneer Park Hatchery was not in operation during the simulation period (August 2004); therefore, this hatchery is not explicitly represented in the QUAL2Kw model. However, anticipated monthly loads for the Pioneer Park Hatchery were tabulated to support the assignment of a WLA. The facility is in the planning phases for construction and an NPDES application has been submitted to Ecology (L. Niewolny, personal communication, 5/28/2020).

4.1.3 Hatchery Nutrient Loads

Daily average nutrient loads by month for both hatcheries are presented in Table 6. WDFW provided estimated loads by nutrient species for both facilities (HDR, 2019; WDFW and HDR, 2018). These were aggregated to evaluate the anticipated TN and TP loads.

Table 6. Average daily nutrient loads by month and aquaculture facility (HDR, 2019; WDFW and HDR, 2018).

Month	Tumwater Falls Hatchery (existing conditions)		Pioneer Park Hatchery (near-term proposed)		Pioneer Park Hatchery (long-term proposed)	
	TP (kg/day)	TN (kg/day)	TP (kg/day)	TN (kg/day)	TP (kg/day)	TN (kg/day)
January	No discharge		0.10	1.76	0.29	2.81
February	0.10	1.71	0.21	3.77	0.83	7.20
March	0.24	4.26	0.30	5.32	0.96	9.69
April	0.29	5.12	0.43	7.60	1.16	13.23
May	0.31	5.43	0.86	15.19	0.59	10.41
June	0.15	2.56	0.43[1]	7.60[1]	0.05	0.97
July	No discharge		No discharge		0.68	4.65
August	No discharge		No discharge		0.67	4.46
September	0.05	0.07	0.59	3.11	0.70	4.98
October	0.05	0.07	0.59	3.11	0.68	4.62
November	0.05	0.07	0.59	3.11	0.70	5.04
December	0.05	0.07	0.59	3.11	0.78	6.35

[1]Currently proposed loads for the Pioneer Park Hatchery include discharge until June 15, so this load represents an average for the entire month, although discharge occurs until June 15 (i.e., mass loading to the river is comprehensively accounted for in the June estimate).

4.2 GENERAL PERMITS

EPA estimated existing nutrient loads for facilities covered under the General Permits for Sand and Gravel, Industrial Stormwater, and Construction Stormwater. The loads for the facilities were calculated as the product of estimated annual runoff and representative Event Mean Concentrations (EMCs) for industrial urban stormwater. The Simple Method (Schueler, 1987) was applied to estimate annual runoff. It is an empirical formulation based on data from several dozen sites spanning the range of possible percent imperviousness. It was originally developed as an efficient, yet reasonably accurate, method to estimate stormwater runoff for the purpose of quantifying nutrient loads for urban lands. It has been adopted and adapted by numerous municipalities and agencies since its publication for various purposes, chiefly in relation to compliance with stormwater management criteria. The required information for the Simple Method was readily available in this watershed. Since a mechanistic watershed model was not available to predict annual runoff, the Simple Method was a feasible and appropriate option for approximating runoff-associated loads for these facilities. The form of the equation is:

$$R = 0.9 * P * (0.05 + 0.9\ I_a)$$

where *R* is the runoff depth (inches), *P* is the annual precipitation depth (inches), and I_a is the impervious area fraction (0 to 1).

The average annual precipitation depth, *P*, between 2000 – 2018 at the Olympia Airport (GHCND: USW00024227) was about 50.14 inches. Site footprints were assumed to be fully impervious because most developed soils have lost some infiltration potential following site disturbance and compaction, so I_a is equivalent to 1. solving for *R*, the estimated annual average runoff depth was about 42.9 inches per year, or 3.58 feet per year, for all three categories of General Stormwater permittees.

To obtain the annual runoff volume, the runoff depth, *R,* is multiplied by the contributing area. The contributing area for each permit holder was based on facility site footprints provided by Ecology in acres, and they are shown in Table 7, Table 8, and Table 10 (L. Weiss, personal communication, 9/27/2019).

Site-specific discharge monitoring records were unavailable for all the permit holders for relevant parameters (i.e., nitrogen and phosphorus) because the facilities are not required to conduct stormwater nutrient monitoring. Therefore, EPA used the representative median concentrations for industrial land reported for NPDES Phase I Stormwater permittees in Western Washington (Hobbs et al., 2015):

- TN: 1,095 µg/L; and
- TP: 171 µg/L.

The median concentration was applied because it is less affected by outliers and small sample sizes compared to the average concentration. Site conditions and activities, such as lack of or reduced vegetation on pervious portions of the property, will inherently influence loading dynamics from these facilities. Nevertheless, nutrient loads from these property-owners are anticipated to be a minor component of the overall loading to the segments impaired for low levels of DO. All active General Permit holders discussed in the following sections are located downstream of Offutt Lake.

4.2.1 Sand and Gravel

Sand and gravel process, dewatering, and stormwater discharges covered by NPDES permits are subject to regulations specified in Ecology's *Sand and Gravel General Permit* (effective April 1, 2018). Depending on the type of sand and gravel activity, water quality sampling to be reported regularly as Discharge Monitoring Reports (DMRs) may be required. Monitoring constituents for the facilities include pH, turbidity, TSS and oil sheen; however, the current General Permit does not specify requirements for monitoring nutrients. Water temperature is considered for sampling if the receiving waterbody is impaired for elevated water temperature. Sampling frequency requirements vary by constituent from twice monthly (turbidity), quarterly (pH and TSS), or daily when runoff occurs (oil sheen). In addition, permittees are required to implement Best Management Practices (BMPs) to prevent, control, and treat discharges as necessary to comply with state water quality standards.

Although the three facilities permitted under the Sand and Gravel General Permit are only authorized to discharge stormwater, other allowable discharges that could be authorized under the General Permit are not considered a source of nutrient loading. As a result, the source assessment focused on loading associated with stormwater. To obtain the existing daily average stormwater loads for the sand and gravel facilities, average annual runoff depth (*R,* Section 4.2), the site area, and the representative event mean concentration (EMC, Section 4.2) are multiplied, along with the appropriate conversion factor to correct the units. The resulting approximated existing daily average stormwater loads for sand and gravel facilities are presented in Table 7.

Table 7. Approximated average daily existing stormwater TN and TP loads for sand and gravel facilities.

Permittee	Permit Number	Deschutes River Segment Listing ID	Site Area (acres)[1]	TN Load (kg/day)	TP Load (kg/day)
Lakeside Industries (Olympia Airport)	WAG501042	47753	13	0.17	0.03
Alpine Sand and Gravel (Rixie Rd)	WAG501037	10894	145	1.92	0.30
Lakeside Industries (Waldrick Rd)	WAG501231	47754	50	0.66	0.10

[1]Site areas were provided by Ecology (L. Weiss, personal communication, 9/27/2019).

4.2.2 Industrial Stormwater

Industrial stormwater discharges covered by NPDES permits are subject to regulations defined in Ecology's *Industrial Stormwater General Permit* (as modified, effective January 1, 2020). Depending on the type of industrial activity, stormwater discharges have the potential to contain nutrients or other biostimulatory constituents that contribute to low oxygen levels in receiving waters. All industrial stormwater facilities covered under the General Permit are required to monitor pH annually but sampling of BOD5, nitrate and nitrite, and total phosphorus is only required if activities include "chemical and allied products," "air transportation," or "food and kindred products." None of these are applicable to the single relevant facility, which is categorized as "motor freight transportation." All permittees covered by the General Permit for Industrial Stormwater must implement a Stormwater Pollution Prevention Plan that specifies the BMPs used to prevent, control, and treat discharges to comply with water quality standards.

To obtain the existing daily average stormwater loads for the industrial facilities, average annual runoff depth (*R,* Section 4.2), the site area, and the representative event mean concentration (EMC, Section 4.2) are multiplied, along with the appropriate conversion factor to correct the units. The resulting approximated existing daily average stormwater loads for industrial facilities are presented in Table 8.

Table 8. Approximated existing stormwater TN and TP loads for industrial facilities.

Permittee	Permit Number	Deschutes River Segment Listing ID	Site Area (acres)[1]	TN Load (kg/day)	TP Load (kg/day)
ONeill and Sons Trucking Inc	WAR001404	47753	28	0.37	0.06

[1]Site area was provided by Ecology (L. Weiss, personal communication, 9/27/2019).

4.2.3 Construction Stormwater

Construction stormwater discharges covered by NPDES permits are subject to regulations defined in Ecology's *Construction Stormwater General Permit* (as modified, effective January 1, 2016). The General Permit for Construction Stormwater specifies that permit holders are required to not contribute to the violation of surface water and groundwater quality standards and sediment management standards. Facilities covered by the permit must implement all known, available, and reasonable methods of prevention, control, and treatment, develop and implement a Stormwater Pollution Prevention Plan, and apply stormwater BMPs. Active construction stormwater permittees within the tributary catchments are listed in Table 9.

All active construction stormwater permittees in the Deschutes River watershed are downstream of Offutt Lake. In addition, all sites are in the catchments of the Deschutes River segments on the 303(d) list for low levels of DO. The sites are all within MS4 boundaries, excluding Keanland Park. This means that pollutant loading from active construction sites is inexplicitly aggregated with MS4 existing loads (except for Keanland Park that is aggregated with nonpoint sources). It is still important to understand the current contributions to the overall existing nutrient load coming from construction stormwater sites. Thus, EPA estimated the aggregate construction stormwater nutrient loads using the site footprints for the active permittees. Construction activities are temporary and related stormwater discharges are not expected to significantly elevate loading to waterbodies, as the permit conditions primarily focus on limiting discharges off-site.

To obtain the existing daily average stormwater loads for the construction facilities, average annual runoff depth (*R,* Section 4.2), the site area, and the representative event mean concentration (EMC, Section 4.2) are multiplied, along with the appropriate conversion factor to correct the units. The resulting approximated existing daily average stormwater loads for construction facilities are presented in Table 10.

Table 9. Active NPDES permitted construction stormwater permits.

Permittee	Permit Number	Deschutes River Segment Listing ID
Briggs Nursery Work Area 3	WAR009218	10894
Wilderness East Townhomes	WAR011023	
Chestnut Village	WAR126151	
Briggs Townhomes	WAR302181	
Elm Street Plat	WAR303339	
Stonewell Lodge and Cottages	WAR303583	
Briggs Town Center	WAR304815	
Log Cabin Road Reservoir	WAR304957	
Ridge at Ward Lake	WAR305013	
Craft District	WAR305245	
Lacey Learning Center	WAR306221	
Tumwater Boulevard Plat	WAR306543	
Tumwater Falls Hatchery Redevelopment	WAR307310	
College St and 22nd Ave Roundbout	WAR307346	
Tumwater Alternative Learning Center	WAR307607	
College and Yelm Pavement Rehabilitation	WAR307679	
Lakeview Meadows Lacey	WAR307787	
Briggs West Residential - Phase 1	WAR308303	
Woodbrook Townhomes	WAR308378	
19th Ave. Duplexes	WAR308487	
Rumac St Wastewater Improvements	WAR308775	
Polo Apartments Phase-2	WAR308864	

Permittee	Permit Number	Deschutes River Segment Listing ID
Deschutes Heights	WAR012341	47753 and 10894
Deschutes River Highlands Division 2	WAR125827	
Keanland Park	WAR301629	
Deschutes River Highlands Division 2B	WAR305141	
Deschutes Heights - Lot 35	WAR305364	
Kaufman Headquarters	WAR305843	
Bradbury Estates and Bradbury North	WAR306480	
Shinn Estates	WAR306508	
Henderson Park Plat	WAR306593	
The Preserve Century	WAR306884	
Deschutes Heights Capital Development	WAR308645	
Deschutes Heights Dermanoski	WAR308646	
Deschutes Heights Lots 82 88 and 89	WAR308847	
Deschutes Heights Lots 72 and 90	WAR308848	

Table 10. Approximated existing stormwater TN and TP loads for all active permitted construction sites (aggregated downstream of Offutt Lake).

Permittee	Permit Number	Location	Site Area (acres)[1]	TN Load (kg/day)	TP Load (kg/day)
Construction Stormwater	Multiple	Downstream of Offutt Lake	342	4.52	0.71

[1]Site areas were provided by Ecology (L. Weiss, personal communication, 2/19/2019).

4.3 MUNICIPAL SEPARATE STORM SEWER SYSTEMS (MS4s) AND NON-POINT SOURCES

Urban areas that collect stormwater runoff in MS4s and discharge it to surface waters are required to have an NPDES permit under the Clean Water Act (CWA). Incorporated cities with populations over 100,000 and unincorporated counties with populations over 250,000 are regulated under Phase I MS4 permits, and smaller jurisdictions are regulated under Phase II MS4 permits. Four entities in the study area hold active Western Washington Phase II MS4 Permits and one entity holds a Phase I MS4 permit (Table 11 and Figure 7). The City of Lacey does not intersect any of the bacteria impaired catchments. Interstate 5 bisects the Deschutes River watershed within the drainage area of the most downstream segment impaired for low DO (Listing ID 10894) (Wagner and Bilhimer, 2015). MS4 permittees are required to use available methods of prevention, control, and treatment to prevent and manage pollution to waters of the state to meet the goals of the CWA.

All entities associated with these types of MS4 permit must develop and implement a Stormwater Management Program (SWMP), and have two options relative to stormwater discharge:

1. The city or county permittee may make annual payments into a collective fund to implement effectiveness and source identification studies; or
2. Conduct stormwater discharge monitoring.

MS4s were required to provide written notification to Ecology by December 1, 2019 regarding their selected option for monitoring. No discharge monitoring data were available for the MS4s in Ecology's PARIS database.

Table 11. Permitted municipal separate storm sewer systems (MS4s) in the Deschutes River watershed.

Jurisdiction	Permit Type	Permit Number
City of Lacey	Western Washington Phase II Municipal Stormwater Permit	WAR045011
City of Olympia	Western Washington Phase II Municipal Stormwater Permit	WAR045015
City of Tumwater	Western Washington Phase II Municipal Stormwater Permit	WAR045020
Thurston County	Western Washington Phase II Municipal Stormwater Permit	WAR045025
WSDOT	WSDOT Phase 1 Municipal Stormwater Permit	WAR043000A

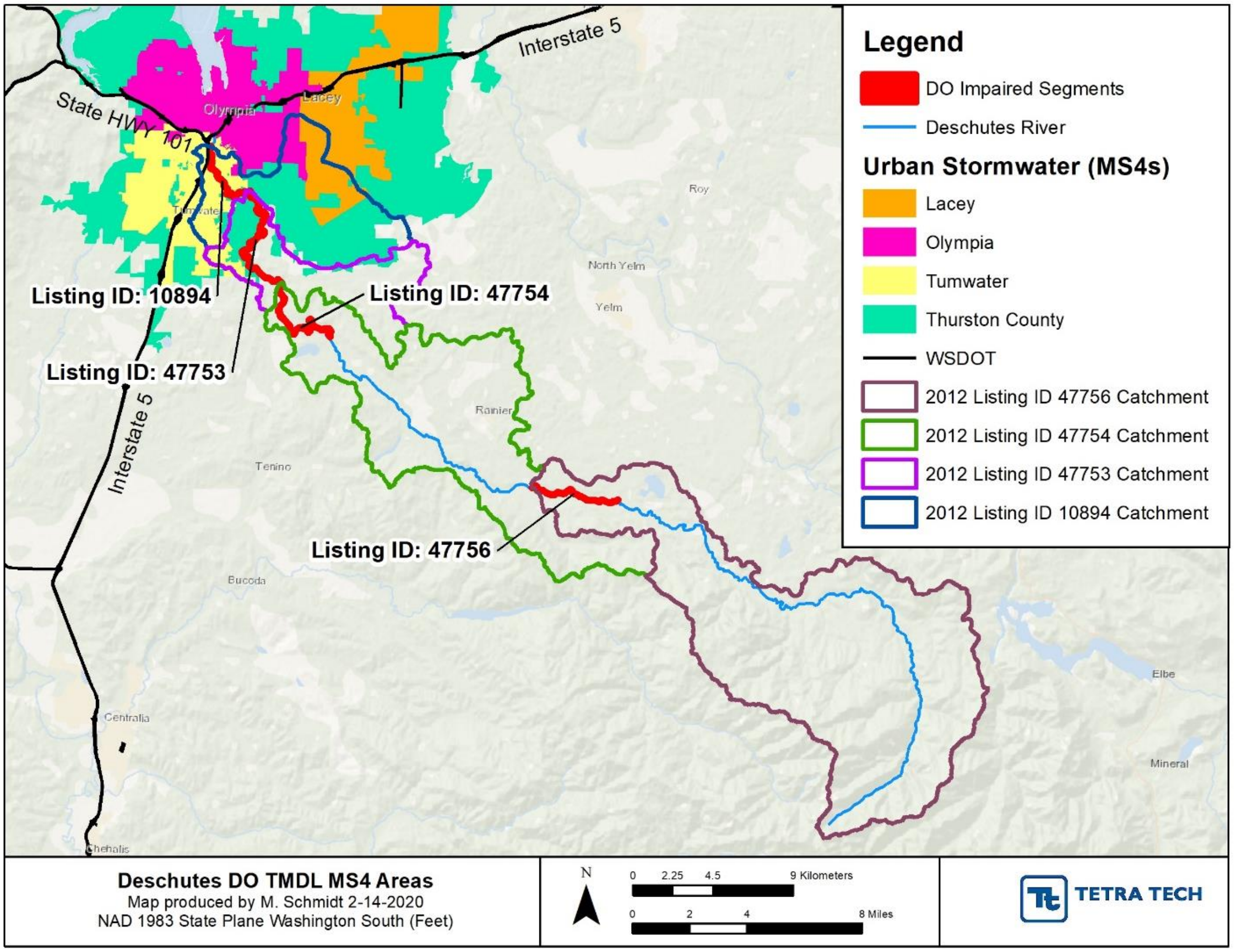

Figure 7. Municipal separate storm sewer systems in the Deschutes River watershed.

The dynamics of nutrient loading in urban streams poses a challenge for quantifying MS4 stormwater flows and loads. Factors such as unknown or highly variable event mean concentrations at stormwater outfalls, uncertain stormwater flow pathways and runoff volumes, and subsurface conveyances contribute to general uncertainty that makes quantifying urban stormwater flows and loads particularly difficult. Therefore, existing loads for each MS4 jurisdiction are determined based on representative land-use based export coefficients and existing instream flows and nutrient concentrations. The area that falls under MS4 regulation draining to each DO-impaired segment was approximated for this purpose (Table 12).

WSDOT responsible land (Interstate 5 corridor) had to be estimated separately from the MS4s. Since it is fully contained within the city and county MS4 boundaries, it was differentiated and removed from the underlying city and/or county MS4. A linear coverage from WSDOT[2] was used to approximate WSDOT responsible land. Right-of-way widths were not listed as attributes in the coverage so the linear coverage was buffered and dissolved based on review of aerial imagery to approximate WSDOT responsible land (Figure 8). To span the lanes and shoulders, Interstate on and off ramps were buffered by 15 feet (30 feet total width across the lane and shoulder

[2] NatHwySysState.shp; https://www.wsdot.wa.gov/mapsdata/geodatacatalog/default.htm

based on imagery review) and the four-lane, single direction interstate roads were buffered by 60 feet (about 175 feet total width across the eight lanes, shoulder, and median based on imagery review).

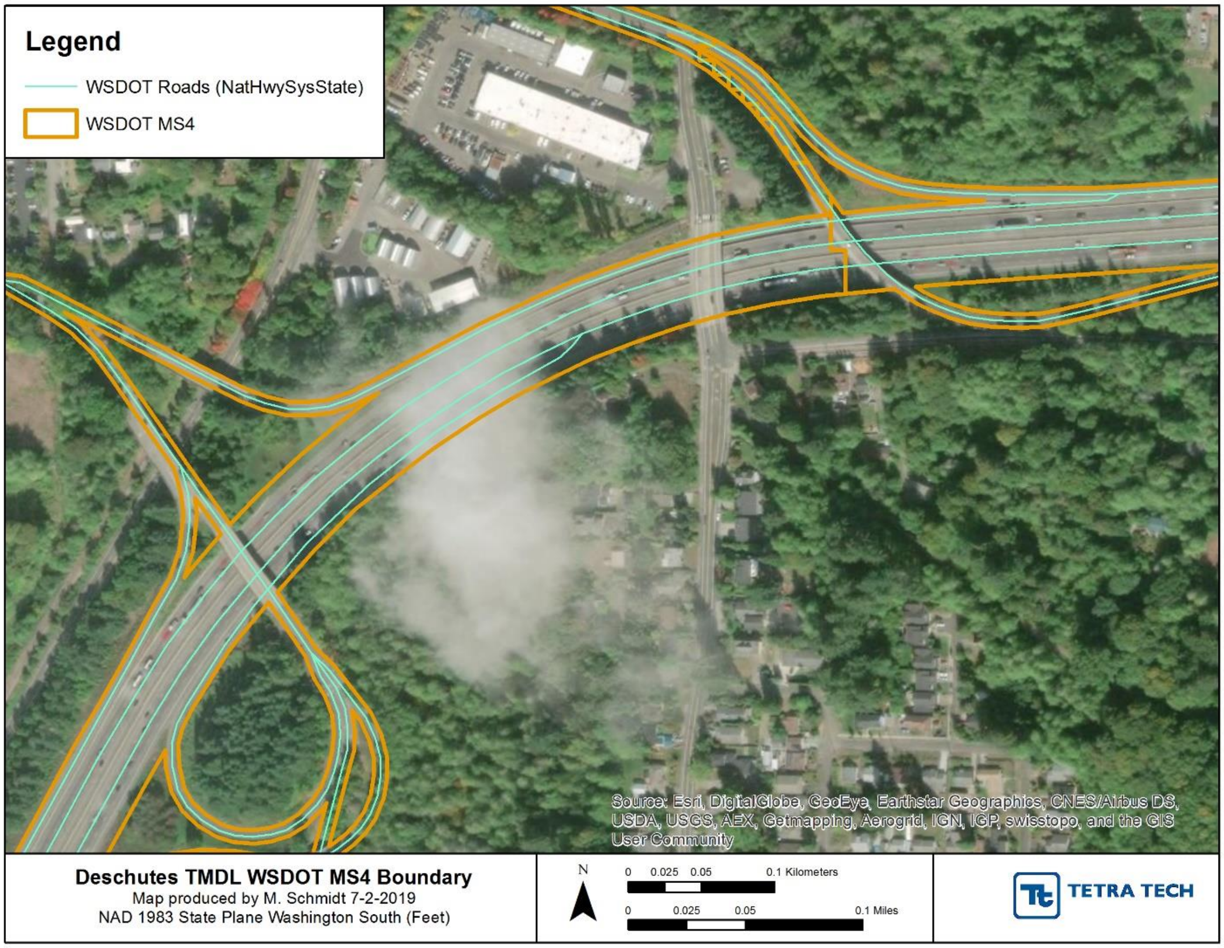

Figure 8. Washington State Department of Transportation MS4 Boundary.

Table 12. Total area (acres) for river segments listed as DO impaired with MS4 sources.

Land Use/ Land Cover	Non-MS4	MS4: Thurston County	MS4: City of Lacey	MS4: City of Olympia	MS4: City of Tumwater	MS4: WSDOT
Listing ID 10894 - Chambers Creek to Outlet to Capitol Lake						
Pasture, Cropland	4,207	986	30	61	1	-
Developed	8,403	4,373	2,125	462	2,395	22
Forest	48,118	1,728	117	248	183	-
Grassland	6,862	428	6	44	146	-
Shrub, Scrub	14,967	311	9	24	7	-
Water, Wetland, Barren	3,667	685	104	69	69	-
Total	86,224	8,511	2,391	908	2,801	22
Listing ID 47753 - Spurgeon Creek to Chambers Creek						
Pasture, Cropland	3,955	102	-	-	-	-
Developed	8,204	1,095	-	-	322	-
Forest	47,949	398	-	-	48	-
Grassland	6,815	174	-	-	121	-
Shrub, Scrub	14,932	69	-	-	4	-
Water, Wetland, Barren	3,608	300	-	-	1	-
Total	85,463	2,138	0	0	496	0

* No MS4 regulated entities are within the drainage areas of 2012 Listing IDs 47754 and 47756.

** “-“ indicates no area present

Existing nutrient loads from upland sources were estimated for the cumulative drainage area to each reach impaired for low levels of DO (Figure 7), and the steps, summarized in Figure 9, are outlined in the following paragraphs.

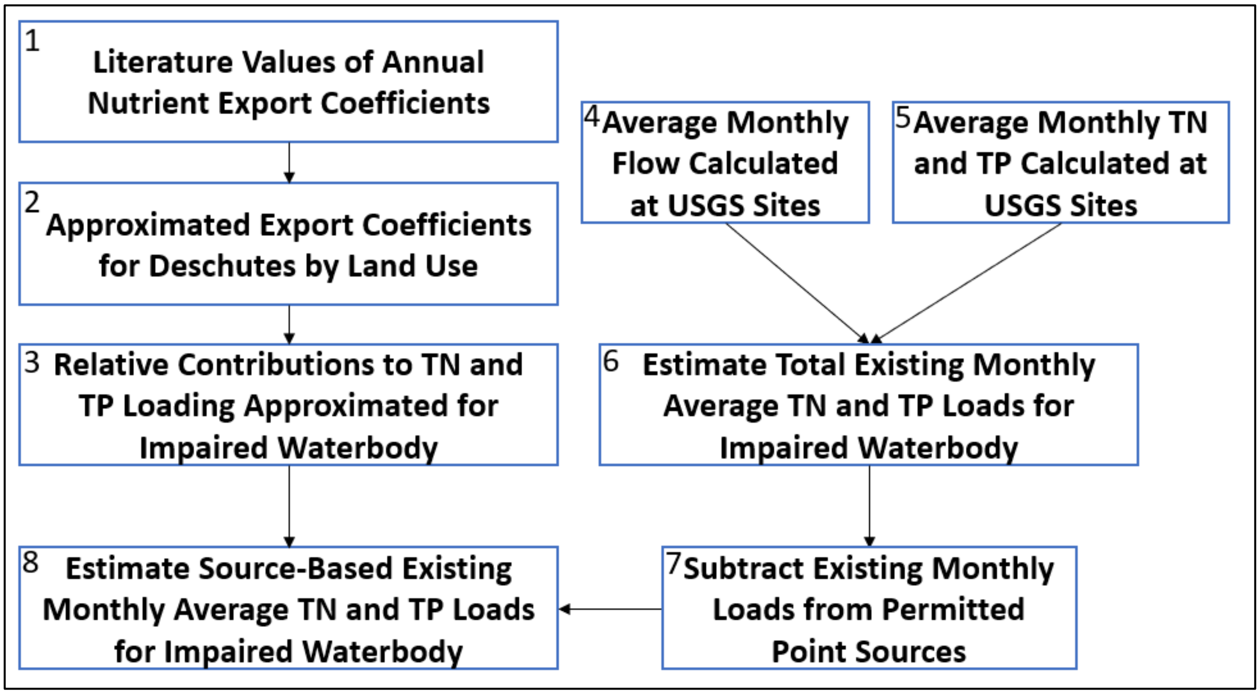

Figure 9. Approach for estimating existing upland nutrient loads.

1. Literature Values of Annual Nutrient Export Coefficients

The Green-Duwamish River watershed is located approximately 40 miles north of the Deschutes River watershed, and most of the watershed is within the Puget Lowlands ecoregion with the headwaters located in the Cascades ecoregion, similar to the Deschutes River watershed. *The Water Quality Statistical and Pollutant Loadings Analysis of the Green-Duwamish Watershed Water Quality Assessment* prepared for King County was written to provide analytical tools to evaluate current and potential water quality issues within this Washington watershed (Herrera, 2007). The report assesses and analyzes water quality data from the Green-Duwamish watershed from 2002 – 2003 and is applicable for comparison with the Deschutes River watershed both for reasons of physical proximity and shared ecoregion makeup. Export coefficients for the Green-Duwamish watershed were developed based on water quality monitoring data from sites with dominant single land-use types (low and medium density developed, high density developed, agriculture, and forest). Annual average loading rates by land use were used as the basis for developing representative export coefficients for the Deschutes River watershed (Herrera, 2007). Annual export coefficients were available for TP, NH_3, and NO_x, as shown on the left-hand side of Table 13. An export coefficient for TN was not available. Instream data indicate that inorganic nitrogen (NH_3+NO_X) constitutes about 63 percent of TN in the tributaries discharging to the Deschutes River. This information is applied to approximate representative TN export coefficient rates.

2. Approximated Export Coefficients for Deschutes by Land Use

Annual export coefficients from Herrera (2007) were applied to the aggregated land use classes (derived from NLCD 2011). Land use/cover data from King County and the Puget Sound Regional Council were used in Herrera (2007), which includes multiple urban categories such as commercial/industrial, low-density residential, and high-density residential. In the Herrera (2007) study, these were aggregated into combined urban categories of low/medium density developed and high density developed, although the land use aggregation scheme is not specified. In addition, NLCD 2011 includes land use types not covered, such as open space developed. Therefore, the export coefficient for all developed lands was calculated as the average of the low/medium and high density developed classes presented in Herrera (2007). The export coefficients for agriculture were applied to the crop/pasture aggregated land use class, and the export coefficients for forest were applied directly to forests. Herrera (2007) did not include export coefficients for wetland, open water, or barren land uses. Instead, those rates were approximated from the wetland and barren land uses as presented in detailed nitrogen and phosphorus source loading documents generated as part of TMDL efforts across the state of Minnesota (MPCA 2004; 2013). For shrub/scrub and grassland land uses, estimates were based on the relative relationship between export coefficients presented in White et al. (2015) as summarized by ecoregion. In White et al. (2015), forests, grasslands, and croplands were listed as exhibiting far higher export coefficients for the Puget Lowlands ecoregion than are presented in Herrera (2007), therefore, the relative difference of the grassland coefficient, being higher than forest, but far less than cropland, was applied to estimate these rates as approximately 25 percent higher than the Herrera (2007) forest rate.

Table 13. Annual export coefficients for nutrients by land use.

Land Use Type	Annual Export Coefficient (kg/ha/yr) from Herrera (2007)				Deschutes Land Use	Deschutes Annual Export Coefficients (kg/ha/yr)	
	TP	NH_3	NO_X	TN[1]		TP	TN
Low and Medium Density Developed	0.33	0.1	5.9	9.5	Developed Lands	0.50	11.5
High Density Developed	0.67	1.0	7.6	13.6			
Agriculture	0.97	0.2	13.0	20.9	Crop/Pasture	0.97	20.9
Forest	0.31	0.1	7.7	12.3	Forest	0.31	12.3
-					Shrub/Scrub and Grassland[2]	0.39	15.4
-					Water/Wetland/Barren[3]	0.00	3.1

[1]TN was estimated based on the assumption that inorganic nitrogen is representative of 63 percent of TN based on boundary condition inputs from the calibrated Deschutes River QUAL2Kw model.

[2]Export coefficients for Shrub/Scrub and Grassland were estimated as 25 percent higher than forests based on the relationship exhibited in White et al. (2015) for grasslands relative to both cultivated cropland and forests.

[3]Export coefficients for Water/Wetland/Barren were estimated based on evaluations of wetland and barren land use types as presented in MPCA (2004; 2013)

3. Relative TN and TP Load Contributions

The relative TN and TP load contributions were computed from the estimated source loads. The source loads were established for each land use by multiplying the export coefficients (Table 13) by the corresponding land use area within the catchment. MS4s were separated in this analysis and tend to be dominated by developed land, although include a mixture of land uses based on NLCD classifications. Relative source contributions were calculated by dividing the source load for the land use by the total load from all land uses in the catchment. Relative source contributions are shown in Figure 10 to Figure 13. Forests, the largest land use category, were estimated to contribute 48 – 57 percent of upland TN loading at the river outlet and near Reichel Creek, respectively. Similarly, forests constitute 21 – 53 percent of upland TP loading at the same locations. Nutrient loading contributions from MS4s account for 8 percent and 12 percent of TN and TP upland loads at the river outlet. There are no MS4s draining to the section of the river impaired for DO that spans from Lake Lawrence Creek to Reichel Creek (2012 Listing ID 47756).

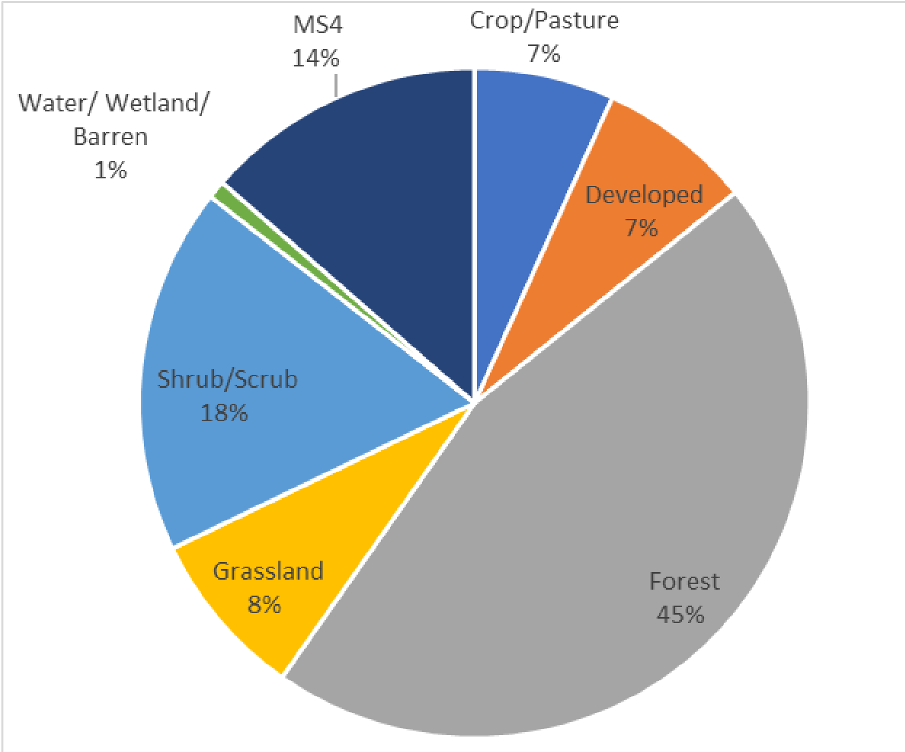

Figure 10. Relative TN upland loading contributions at the Deschutes River outlet.

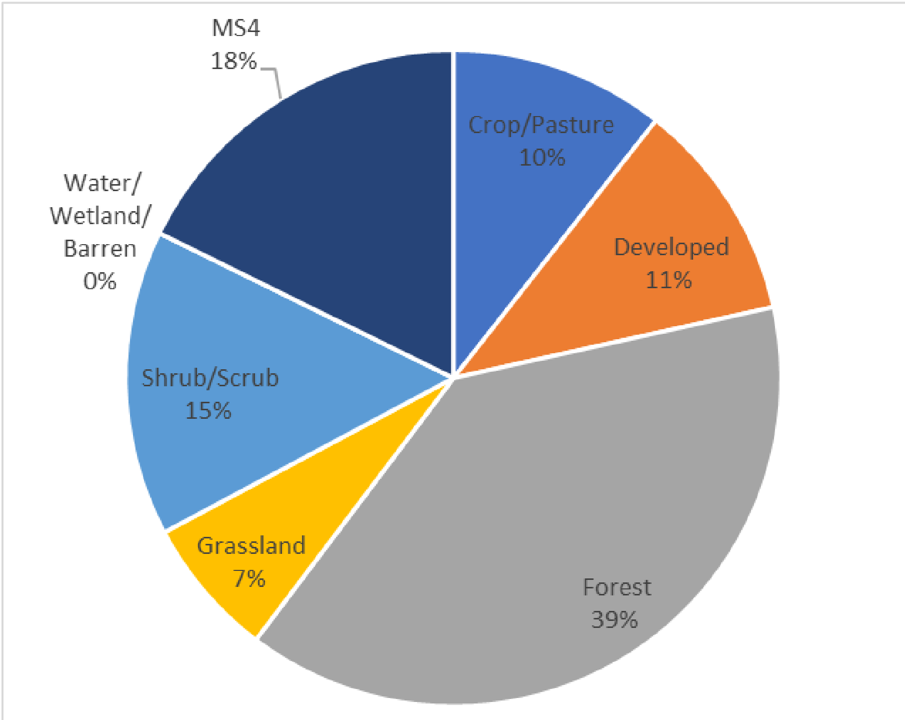

Figure 11. Relative TP upland loading contributions at the Deschutes River outlet.

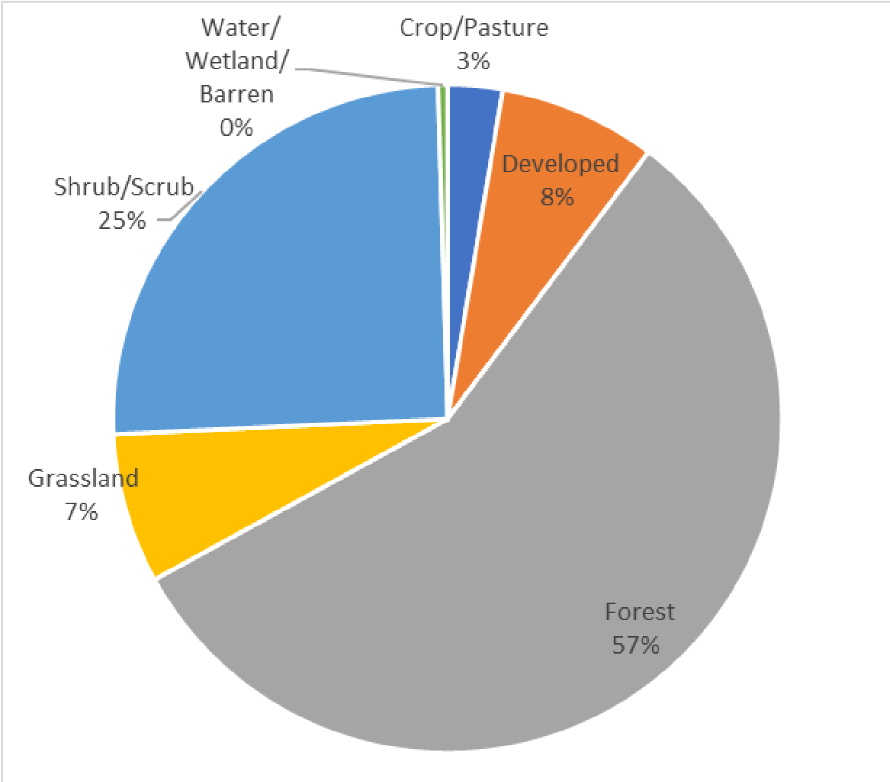

Figure 12. Relative TN upland loading contributions near Reichel Creek (2012 Listing ID 47756).

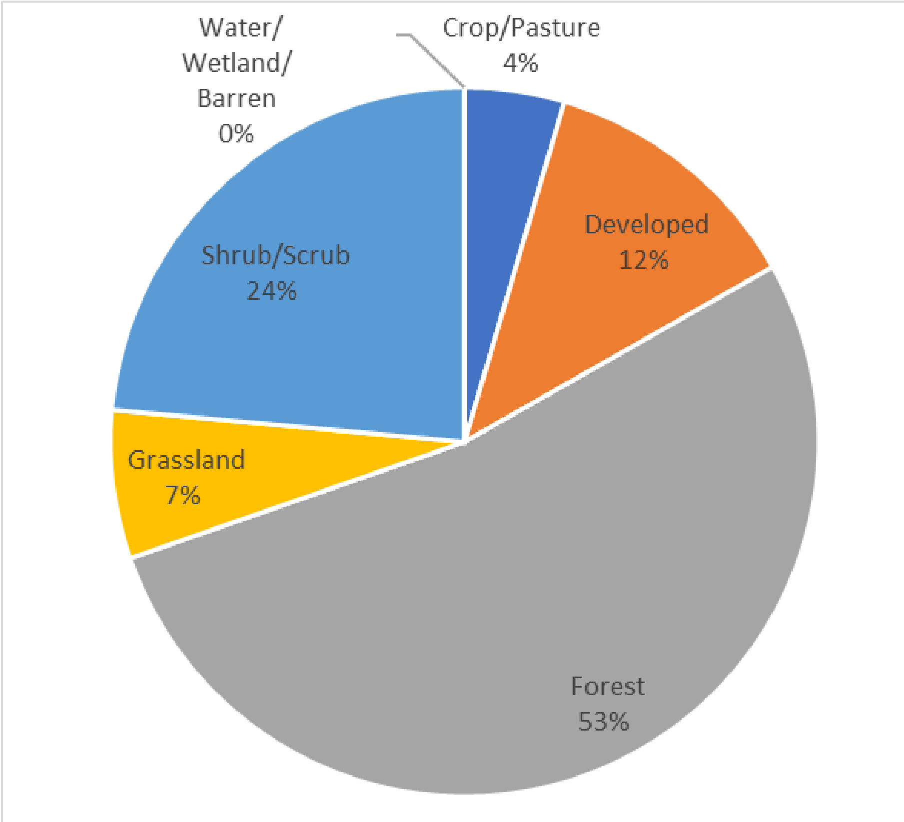

Figure 13. Relative TP upland loading contributions near Reichel Creek (2012 Listing ID 47756).

As described next in Steps 4 through 6, existing TN and TP loads were estimated from flow monitoring records and observed nutrient concentrations. The existing loads were then attributed to the various source categories based on the relative contributions presented above, as discussed in Step 8.

4. Average Monthly Flow Calculated at USGS Sites

For the portion of the river upstream of Offutt Lake listed as impaired (Listing ID 47756), which extends from Lake Lawrence Creek to Reichel Creek, there is a USGS gage located near the downstream extent of that segment (USGS 12079000: Deschutes River near Rainier, WA; drainage area 89.8 square miles). The average flow rates by month at USGS 12079000 from 2000-2019 range from 35 – 479 cfs (Table 14), and the lowest flow rates have historically occurred between July to September. Another long-term USGS gage is located near the Deschutes River outlet. This gage (USGS 12080010: Deschutes River at E St Bridge at Tumwater, WA; drainage area 162 square miles) has average flow rates by month that have historically ranged from 260 – 645 cfs (Table 14; 2000-2019).

5. Average Monthly TN and TP Calculated at USGS Sites

The average flows by month (Step 4) were paired with average monthly TN and TP concentrations for the Deschutes River to approximate existing loading conditions. Using instream water chemistry grab sample results (Table 4 and Table 5) from locations upstream of Offutt Lake (13-ES-20.5, 13-DES-28.6, and 13-DES-37.4) and downstream of Offutt Lake (13-DES-00.5, 13-DES-02.7, 13-DES-05.5, and 13-DES-09.2), average nutrient concentrations were summarized by month and river section (marked by Offutt Lake) using available results from 2003 and 2004. Average TP observed upstream and downstream of Offutt Lake was 13.8 and 19.4 µg/L, respectively. Average TN ranged from 301 - 891 µg/L, with lower concentrations observed upstream of Offutt Lake. Rather than only applying data from the monitoring site nearest the USGS flow gage, available data from multiple monitoring sites were aggregated upstream and downstream of Offutt Lake to increase the robustness of the dataset. Nevertheless, site-specific conditions and processes do alter nutrient observations across the watershed. For example, downstream of Offutt Lake, the observed TP concentration is about 10 percent higher using only the single site, but about 20 percent lower for TN. The TMDL analysis includes information about the percent reductions needed by monitoring site to inform implementation planning.

Table 14. Average flows and nutrient concentrations by month (2000-present).

Month	Average Monthly Conditions Downstream of Offutt Lake			Average Monthly Conditions Upstream of Offutt Lake		
	Flow (cfs) at USGS 12080010	Observed TN (µg/L)	Observed TP (µg/L)	Flow (cfs) at USGS 12079000	Observed TN (µg/L)	Observed TP (µg/L)
January	645	686	17.7	479	390	13.7
February	484	770	17.9	353	405	12.5
March	276	793	16.3	403	366	13.3
April	260	700	13.5	295	274	9.0
May	303	891	19.8	168	392	15.5
June	381	763	22.5	101	301	12.5
July	418	855	22.8	50	654	15.2

Month	Average Monthly Conditions Downstream of Offutt Lake			Average Monthly Conditions Upstream of Offutt Lake		
	Flow (cfs) at USGS 12080010	Observed TN (µg/L)	Observed TP (µg/L)	Flow (cfs) at USGS 12079000	Observed TN (µg/L)	Observed TP (µg/L)
August	469	765	22.2	35	759	23.3
September	500	771	18.1	44	506	10.4
October	566	723	21.0	97	409	12.4
November	600	775	16.1	346	388	8.2
December	589	745	18.6	452	440	12.3

6. Estimate Existing TN and TP Loads

Existing TN and TP loads were calculated by month and location by multiplying flow by observed concentration (Table 14) and a conversion factor (2.45), to convert to units of kilograms per day. The results are shown in Table 15.

Table 15. Existing nutrient loads by month based on monitoring data.

Month	River Outlet (Relative to 2012 Listing IDs 10894, 47753, 47754)				Near Reichel Creek (Relative to 2012 Listing ID 47756)	
	TN (kg/day)	TP (kg/day)	TN minus Permitted Point Sources (kg/day)	TP minus Permitted Point Sources (kg/day)	TN (kg/day)	TP (kg/day)
Jan	1,081	27.9	1,078	27.4	45	16.0
Feb	911	21.2	905	20.6	350	10.8
Mar	535	11.0	527	10.2	361	13.1
Apr	445	8.6	437	7.8	198	6.5
May	661	14.7	652	13.9	162	6.4
Jun	711	20.9	705	20.3	74.4	3.1
Jul	873	23.3	870	22.8	79.7	1.9
Aug	877	25.5	874	25.0	64.4	2.0
Sep	943	22.2	939	21.6	54.2	1.1
Oct	1,000	29.1	997	28.5	96.9	2.9
Nov	1,137	23.7	1,133	23.2	329	6.9
Dec	1,074	26.8	1,070	26.3	487	13.6

7. Subtract Existing Loads from Non-MS4 Point Sources

The existing loads associated with non-MS4 point sources (Tumwater Falls Hatchery and General Permit holders for Industrial Stormwater and Sand and Gravel Stormwater) were previously tabulated (Sections 4.1 and 4.2). Monthly loads for Tumwater Falls Hatchery were estimated based on the facility's daily loading rate (varied by month; Section 4.1.1) and the number of days in the month. Monthly loads for Industrial Stormwater and Sand and Gravel Stormwater facilities were approximated based on site-specific daily loading rates (not varied by month; Section 4.2) and the number of days in the month. The monthly loads were then subtracted from the total existing TN and TP loads. There are no aquaculture facilities or MS4 permittees located upstream of Reichel Creek (Listing ID 47756). The Pioneer Park Hatchery is not yet constructed, but it is anticipated to be located along the lower Deschutes River. The resulting nutrient loads are attributed to upland loading sources (Table 16).

Table 16. Existing upland nutrient loads by month and source at the river outlet (2012 Listing IDs 10894, 47753, 47754).

Month	MS4 (all land uses)					Non-MS4					
	Thurston Co.	Lacey	Olympia	Tumwater	WSDOT	Developed	Forest	Water/ Wetland/ Barren	Crop/ Pasture	Shrub/ Scrub	Grassland
Existing Upland TN Load (kg/day)											
Jan	87.6	22.5	9.0	26.9	0.2	80.3	491	9.4	72.7	191	87.5
Feb	73.5	18.9	7.6	22.6	0.2	67.4	412	7.9	61.0	160	73.5
Mar	42.8	1.0	4.4	13.1	0.1	39.2	240	4.6	35.5	93.3	42.8
Apr	35.5	9.1	3.7	10.9	0.1	32.5	199	3.8	29.5	77.4	35.5
May	53.0	13.6	5.5	16.3	0.1	48.5	297	5.7	43.9	116	52.9
Jun	57.3	14.7	5.9	17.6	0.1	52.5	321	6.1	47.5	125	57.2
Jul	70.7	18.1	7.3	21.7	0.2	64.8	396	7.6	58.6	154	70.6
Aug	71.0	18.2	7.3	21.8	0.2	65.1	398	7.6	58.9	155	71.0
Sep	76.3	19.6	7.9	23.4	0.2	69.9	428	8.1	63.3	166	76.2
Oct	81.0	20.8	8.4	24.9	0.2	74.2	454	8.7	67.2	177	81.0
Nov	92.1	23.6	9.5	28.3	0.2	84.4	516	9.8	76.4	201	92.0
Dec	87.0	22.3	9.0	26.7	0.2	79.7	487	9.3	72.1	190	86.9
Existing Upland TP Load (kg/day)											
Jan	2.8	0.8	0.3	0.9	<0.1	2.9	10.5	0.0	2.9	4.1	1.9
Feb	2.2	0.6	0.2	0.7	<0.1	2.3	8.1	0.0	2.2	3.2	1.5
Mar	1.0	0.3	0.1	0.3	<0.1	1.1	3.9	0.0	1.1	1.5	0.7
Apr	0.8	0.2	0.1	0.3	<0.1	0.9	3.1	0.0	0.8	1.2	0.6
May	1.4	0.4	0.1	0.5	<0.1	1.5	5.4	0.0	1.5	2.1	1.0
Jun	2.1	0.6	0.2	0.7	<0.1	2.2	7.8	0.0	2.1	3.0	1.4
Jul	2.4	0.7	0.2	0.8	<0.1	2.5	8.9	0.0	2.4	3.5	1.6
Aug	2.6	0.7	0.3	0.9	<0.1	2.7	9.7	0.0	2.7	3.8	1.7

Month	MS4 (all land uses)					Non-MS4					
	Thurston Co.	Lacey	Olympia	Tumwater	WSDOT	Developed	Forest	Water/ Wetland/ Barren	Crop/ Pasture	Shrub/ Scrub	Grassland
Existing Upland TN Load (kg/day)											
Sep	2.3	0.6	0.2	0.8	<0.1	2.4	8.5	0.0	2.3	3.3	1.5
Oct	3.0	0.9	0.3	1.0	<0.1	3.2	11.2	0.0	3.1	4.4	2.0
Nov	2.4	0.7	0.2	0.8	<0.1	2.5	8.9	0.0	2.4	3.5	1.6
Dec	2.7	0.8	0.3	0.9	<0.1	2.8	10.1	0.0	2.8	3.9	1.8

8. Estimate Existing TN and TP Loads for Upland Sources

The observed nutrient loads by month and location were attributed to upland sources based on the relative contributions depicted in Figure 10 to Figure 13, which are detailed in Table 17 and Table 18.

Table 17. Existing upland nutrient loads by month and source near Reichel Creek (2012 Listing ID 47756; no MS4s).

Month	Developed	Forest	Water/ Wetland/ Barren	Crop/ Pasture	Shrub/ Scrub	Grassland
Existing Upland TN Load (kg/day)						
Jan	34.8	259	2.1	12.1	116	33.2
Feb	26.7	199	1.6	9.3	88.5	25.4
Mar	27.5	205	1.6	9.5	91.3	26.2
Apr	15.1	112	0.9	5.2	50.1	14.4
May	12.3	91.9	0.7	4.3	41.0	11.8
Jun	5.6	42.0	0.3	2.0	18.7	5.4
Jul	6.1	45.4	0.4	2.1	20.2	5.8
Aug	4.9	36.3	0.3	1.7	16.2	4.6
Sep	4.1	30.6	0.2	1.4	13.7	3.9
Oct	7.4	55.0	0.4	2.6	24.5	7.0
Nov	25.1	187	1.5	8.7	83.2	23.9
Dec	37.1	276	2.2	12.9	123	35.3
Existing Upland TP Load (kg/day)						
Jan	2.0	8.5	0.0	0.7	3.8	1.1
Feb	1.3	5.8	0.0	0.5	2.6	0.7

Month	Developed	Forest	Water/ Wetland/ Barren	Crop/ Pasture	Shrub/ Scrub	Grassland
Mar	1.6	6.9	0.0	0.6	3.1	0.9
Apr	0.9	3.7	0.0	0.3	1.6	0.5
May	0.7	3.2	0.0	0.3	1.4	0.4
Jun	0.4	1.6	0.0	0.1	0.7	0.2
Jul	0.2	1.1	0.0	0.1	0.5	0.1
Aug	0.2	1.1	0.0	0.1	0.5	0.1
Sep	0.1	0.5	0.0	<0.1	0.2	0.1
Oct	0.4	1.6	0.0	0.1	0.7	0.2
Nov	0.9	3.7	0.0	0.3	1.6	0.5
Dec	1.7	7.4	0.0	0.6	3.3	0.9

Table 18. Average upland nutrient loads aggregated by source at the river outlet (2012 Listing IDs 10894, 47753, 47754) and upstream of Offutt Lake (2012 Listing ID 47756; no MS4s).

Jurisdiction	Upstream of Offutt Lake		Downstream of Offutt Lake at River Outlet	
	TN Load (kg/day)	TP Load (kg/day)	TN Load (kg/day)	TP Load (kg/day)
Thurston County	-	-	62	1.9
Lacey	-	-	15	0.5
Olympia	-	-	6.4	0.2
Tumwater	-	-	19	0.6
WSDOT	-	-	0.1	<0.1
Non-MS4	255	8	643	14

5.0 QUAL2KW MODEL RESULTS AND TMDL

For their work on the *2015 Deschutes TMDLs*, Ecology selected QUAL2Kw as the receiving water model. In addition to QUAL2Kw, Ecology used other tools, such as TTools and the Shade.xls model, to support the QUAL2Kw application. These models and tools are widely used for developing TMDLs and remain appropriate for developing the revised TMDLs.

5.1 QUAL2KW MODEL DEVELOPMENT AND CALIBRATION

Using data collected to support the *2015 Deschutes TMDLs*, Ecology developed Shade.xls and QUAL2Kw models for the Deschutes River. The Deschutes River mainstem was segmented into 69 one-kilometer reaches in the QUAL2Kw model - originating near the Deschutes River headwaters and extending downstream of Tumwater Falls near the outlet to Capitol Lake. Reach hydraulics were based on stream survey and gage records, while meteorological inputs were based on a series of local gage sites and monitoring at the Olympia Airport. Inputs for headwater, diffuse, and tributary inflows and water quality conditions were based on water balances between gaged locations, and the available data from the 2003-2004 extensive watershed monitoring period.

To support the development of the receiving water model, Ecology developed a Shade.xls model to predict existing effective shade conditions and solar heat loads for the various model periods. Effective shade is the fraction of shortwave solar radiation that does not reach the stream surface because vegetative cover and topography intercept it. Effective shade is influenced by latitude/longitude, time of year, stream geometry, topography, and vegetative buffer characteristics, such as height, width, overhang, and density. Data inputs for the Shade.xls model are readily available (e.g., aerial imagery; digital elevation models [DEMs], and additional data (e.g., vegetation height from first and last returns, overhang) can be estimated from Light Detection And Ranging (LiDAR) and other data sources like TTools.

TTools is an ArcGIS extension which uses input coverages and grids to develop vegetation and topography data perpendicular to the stream channel, and samples longitudinal stream channel characteristics, such as the near-stream disturbance zone (NSDZ) and elevation. TTools can sample spatial data within the riparian zone including vegetation height and land use classification depending on available remote sensing data. Typically, these include LiDAR outputs, DEMs, riparian vegetation digitized from aerial imagery (digital orthophoto quadrangles and rectified aerial photos), and FLIR (forward looking infrared radiometer) thermal imaging temperature data.

Data sources that Ecology used in developing the Shade.xls model included the following (more detailed information can be found in the *2015 Deschutes TMDLs* and supporting technical documentation):

- LiDAR data of vegetation and bare earth elevation from the Puget Sound LiDAR Consortium;
- Field observations of vegetation species type, height, and density from August 11-15, 2003;
- Hemispherical digital photography at nine locations (to use for comparison with Shade.xls model results); and
- Bankfull and wetted widths which were digitized from color orthophotos and supplemented with field observations.

The Shade.xls model was run for the date July 24, 2004 and simulated results of topographic and vegetative shade were determined to accurately represent existing shading conditions. The resulting reach-averaged integrated hourly effective shade (i.e., the fraction of potential solar radiation blocked by topography and vegetation) from the Shade.xls model served as an input to the QUAL2Kw receiving water quality model.

The Excel-based QUAL2K model was originally developed at Tufts University as a one-dimensional river water quality model capable of simulating steady-state hydraulics, a diel heat budget, and water quality kinetics. Ecology updated the original QUAL2K model to QUAL2Kw, which can simulate dynamic hydraulics with continuous and variable boundary conditions (Pelletier and Chapra, 2006). QUAL2Kw is a one-dimensional model that simulates temperature, nutrients, dissolved oxygen, pH, phytoplankton, and bottom algae. The QUAL2Kw model is also designed to simulate sediment diagenesis and hyporheic flow through the riverbed. Both features were used in Ecology's TMDL simulations. The QUAL2Kw model allows for user-defined inputs of heat and constituent mass inputs for point and nonpoint sources, including resurfacing of diffuse groundwater. The calibrated Deschutes River QUAL2Kw model that was developed and calibrated by Ecology to support the *2015*

Deschutes TMDLs was applied without modifications for these TMDLs. As discussed in this report, the calibrated QUAL2Kw model was adapted to run multiple scenarios to determine the oxygen-demanding loads needed to meet the DO Water Quality Standard (WQS) at critical conditions.

Ecology's QUAL2Kw model applied inputs from the existing conditions Shade.xls model, meteorological data (e.g., air temperature, wind), flow, and water chemistry observations across the watershed. Ecology developed a QUAL2Kw model scenario for their temperature TMDL that was calibrated for the date of July 24, 2004, representative of the period July 21-27, 2004 (the hottest 7-day average temperature in 2004). The model was verified using the same parametrization, but boundary condition inputs were modified with available observation data for the following periods: July 30, 2003 (representative of the hottest 7-day average temperature in 2003), August 20, 2003 (thermal infrared survey data available), and August 8, 2003 (cool, non-storm conditions). Ecology created TMDL scenarios using the calibrated QUAL2Kw model to evaluate the impacts of restoration activities on water temperature. The model scenario for the *2015 Deschutes TMDLs* included restoration of riparian vegetation along the channel corridor and corresponding impacts (e.g., cooled microclimate and channel improvements) along with improved tributary temperatures and restored baseflows. These were applied as the baseline for the scenarios developed for the revised DO TMDL.

Ecology also developed a QUAL2Kw model scenario to represent system potential DO using the best available water chemistry data (water temperature, DO, pH, and nutrients). The calibration model scenario was run for August 11, 2004, representative of August 10-12, 2004 because continuous DO observations were recorded during this period. A verification scenario was developed for August 13, 2003 (longitudinal DO data was sampled August 11-15, 2003).

Ecology calibrated the QUAL2Kw model by minimizing the root mean square error (RMSE) between the measured and predicted minimum and maximum values for a variety of parameters including DO. In addition, graphical comparisons of predicted and observed concentrations were used to evaluate model goodness-of-fit. The rates governing chemical and biological processes were auto-calibrated to optimize model performance within a reasonable range of constrained rate constant inputs (Pelletier, et al., 2006). Ecology's calibration process consisted of conducting about 1,500 runs with altered parameter sets, and the simulations were performance-ranked based on RMSE to determine the final calibration model. The RMSE for the final calibrated DO model was 0.64 mg/L for the daily minimum DO, and 0.53 mg/L for the combined daily minimum and maximum values. Diel swings in DO were under-predicted in general, with an observed average daily fluctuation of 2.3 mg/L and a simulated average daily fluctuation of 1.7 mg/L. In general, the model tended to over-predict minimum DO concentrations. Nevertheless, the thorough calibration process (e.g., application of visual comparisons and performance based-metrics) was considered acceptable for direct application of Ecology's model for the development of these TMDLs.

Calibration results are presented below for DO (Figure 14) and nutrients (Figure 15). Model simulation of nitrogen and phosphorus species show a good representation of observed instream concentrations along the Deschutes River based on data collected on 7/20/2004 and 7/21/2004. DO results for the verification model (August 11-15, 2003) show a good fit to the longitudinal stream walk survey (Figure 16).

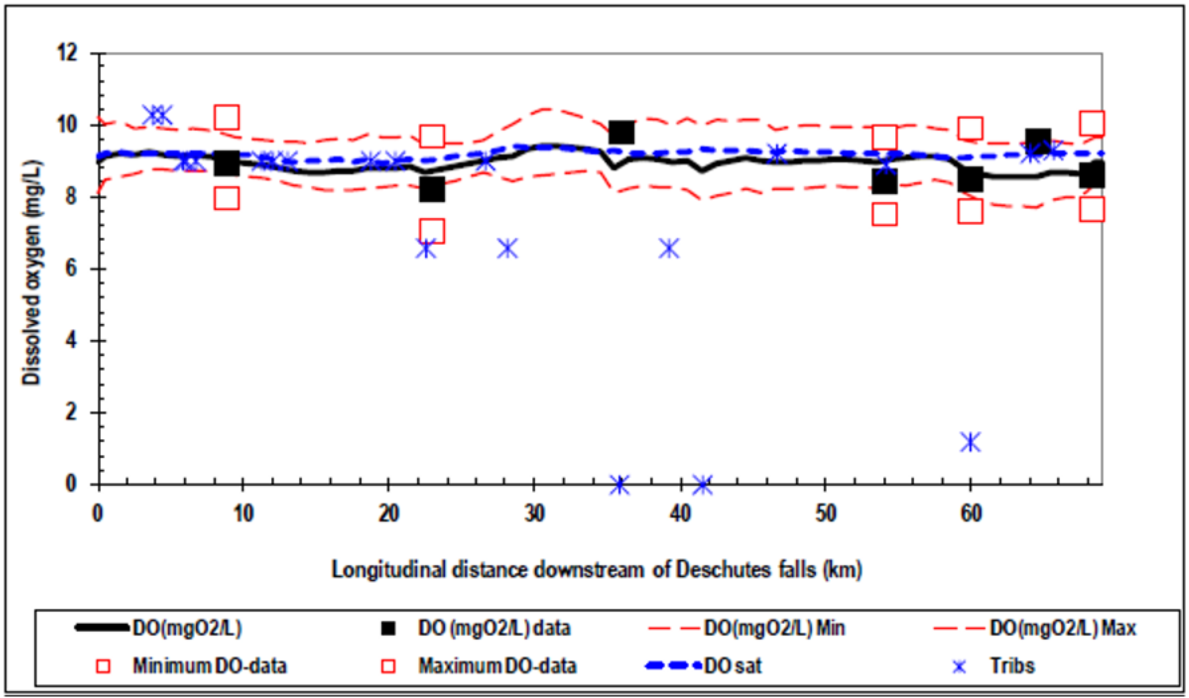

Figure 14. Ecology QUAL2Kw calibration model results: DO (Roberts et al., 2012).

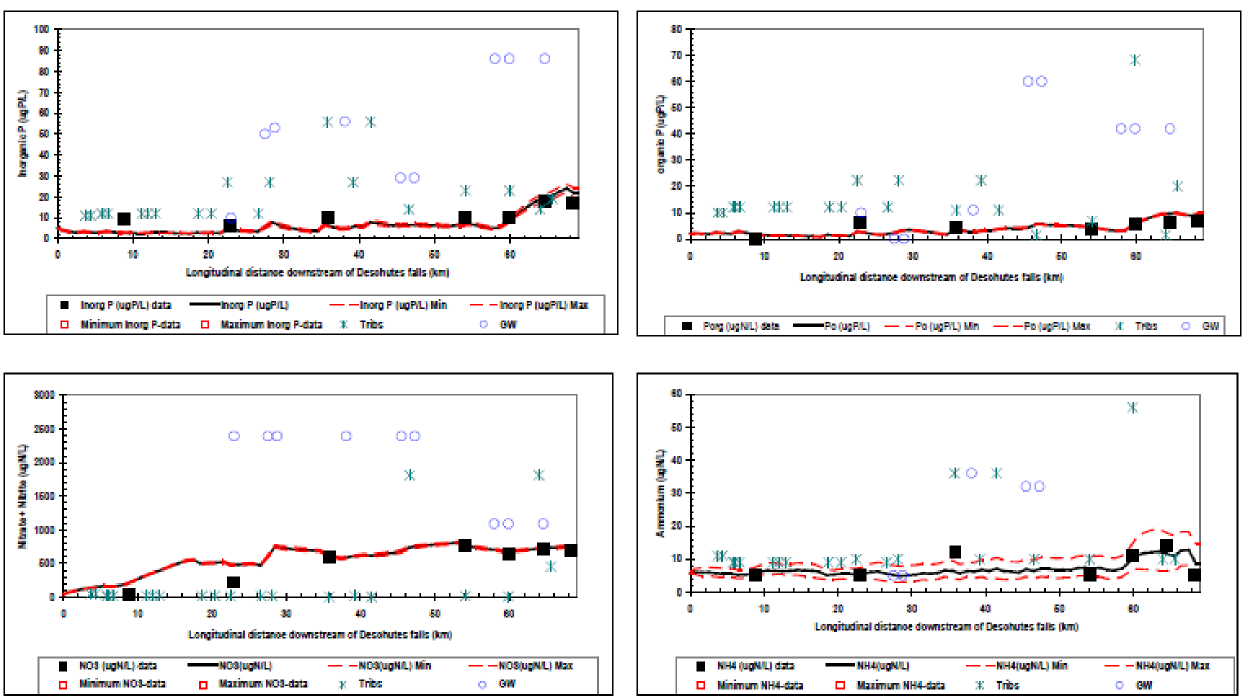

Figure 15. Ecology QUAL2Kw calibration model results: inorganic phosphorus, organic phosphorus, nitrate, and ammonia (Roberts et al., 2012).

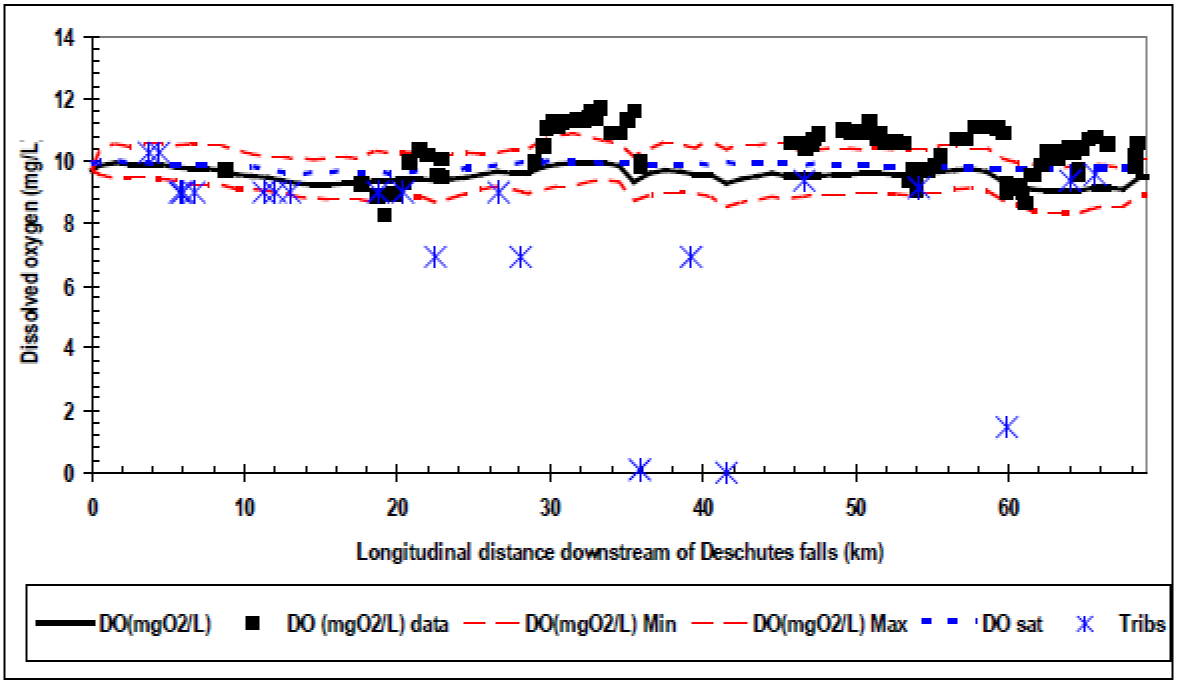

Figure 16. Ecology QUAL2Kw confirmation/verification model results: DO (Roberts et al., 2012).

5.2 SIMULATION OF EXISTING CRITICAL CONDITIONS

Ecology defined critical conditions in *2015 Deschutes TMDLs* as a period for which flows are critically low and air temperatures are critically high. This was done to approximate the worst-case scenario for water temperature in the Deschutes River. Ecology applied the 7-day average low flow with a 10-year recurrence interval (7Q10) as the critical low flow condition to use in the QUAL2Kw model for the temperature TMDL. 7Q10 statistics were developed by USGS at the Rainer and E. Street bridge stations based on historical gaging records. Critically high air temperatures were developed as the 90th percentile observed air temperature based on long-term data from the Olympia Airport.

The temperature calibration model for July 24, 2004 was used to evaluate the critical condition scenario for temperature that applied 7Q10 flows and 90th percentile air temperatures. The DO calibration model was developed for August 11, 2004, so input parameters were updated to reflect the alternative date (e.g., dew point temperature) and the model was calibrated for DO evaluation purposes. The DO critical conditions scenario also applied the 7Q10 flows and 90th percentile air temperatures, which EPA maintained for these TMDLs. The likelihood of both 7Q10 flows and 90th percentile air temperatures coinciding is lower than either condition occurring individually, so this serves as a conservative assumption for these TMDLs.

Using Ecology's calibrated model, EPA ran the same DO critical conditions simulation (7Q10 flow and 90th percentile air temperature). All other model inputs, including shade from topography and riparian vegetation, are based on current conditions in the watershed. Under this critical state, minimum DO does not achieve the numeric DO criteria for most of the mainstem, although it is achieved from approximately the Tempo Lake tributary to halfway between Spurgeon and Chambers Creeks. Under critical conditions, DO saturation is below the criterion upstream of Offutt Lake. This is due to elevated water temperatures.

The QUAL2Kw model simulates a critical conditions period when stormwater contributions (including MS4s) are anticipated to be zero. However, during other periods of the year stormwater contributes biostimulatory substances and nutrients to the river. Nutrient loading from the watershed, uptake by algae, and settling and decomposition of detrital matter in the riverbed sediment are long-term processes that impact DO throughout the year, including during critical summer low flow conditions (e.g., through algal respiration and photosynthesis, sediment oxygen demand). The QUAL2Kw model is used to establish the assimilative capacity of the river and the long-term loading protective of DO conditions during critical periods. The ambient nutrient concentrations needed to achieve the DO standard are assessed with the QUAL2Kw model and are defined for the TMDLs. The ambient nutrient concentration targets are then used to define flow-based TMDLs for nitrogen and phosphorus, which extrapolate the TMDL for conditions across the full flow regime observed at key gage locations along the Deschutes River (i.e., from dry periods when baseflow dominates streamflow and stormwater contributions are negligible to wet conditions when stormwater is the largest contributor of flow and nutrients to the river).

5.3 SIMULATION OF NATURAL CONDITIONS

Two scenarios were simulated to evaluate natural conditions in the watershed and river, using Ecology's QUAL2kw model. The first was the natural conditions scenario for water temperature (Scenario 5 as presented in the approved temperature TDMLs from the *2015 Deschutes TMDLs*) (Section 5.3.1). The second was natural conditions for DO (Section 5.3.2). A summary of the parameters for each of the natural conditions scenarios is provided in Table 23.

5.3.1 Natural Conditions for Temperature

EPA applied Ecology's QUAL2Kw scenario that approximates natural conditions for water temperature in the Deschutes River (more detail can be found in the *2015 Deschutes TMDLs* and supporting technical documents). In the natural conditions for temperature scenario, water temperatures that are lethal for salmon (≥ 22 ºC) are not predicted to occur under critical conditions. Along the length of the river, the maximum water temperature is predicted to be 18.34 ºC, and the mean water temperature is 16.93 ºC. However, as shown with red shading in Figure 17, there are areas in which the natural conditions for temperature do not achieve the applicable numeric temperature WQS.

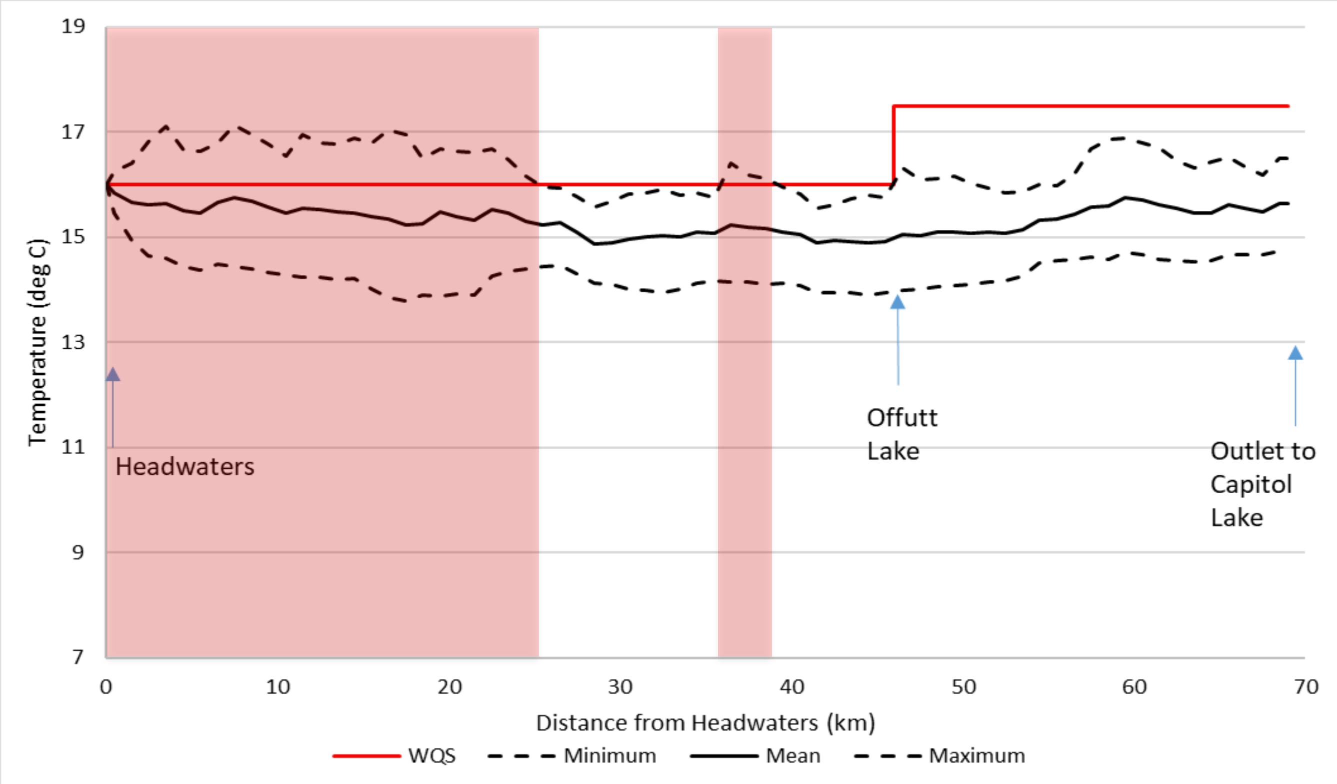

Figure 17. Natural conditions for temperature restored: water temperature (red shaded areas highlight numeric WQS exceedances).

The natural conditions for temperature are crucial to the simulation of DO because the saturated DO concentration is a function of water temperature. DO saturation is lower when water temperatures are warmer and represents the maximum concentration of mean DO that can be achieved instream due to physical processes. The QUAL2Kw DO results when the model is set to natural conditions for temperature (four elements described above) under critical conditions are shown in Figure 18. The numeric DO criterion downstream of Offutt Lake is attained (DO minimum concentration exceeds 8.0 mg/L). However, the numeric DO criterion upstream of Offutt Lake is not attained in any location (DO minimum concentration is less than 9.5 mg/L everywhere). The DO saturation is between 9.5 and 10.0 mg/L under natural conditions for temperature, which is nearly equivalent to the numeric WQS for DO applicable to this portion of the river.

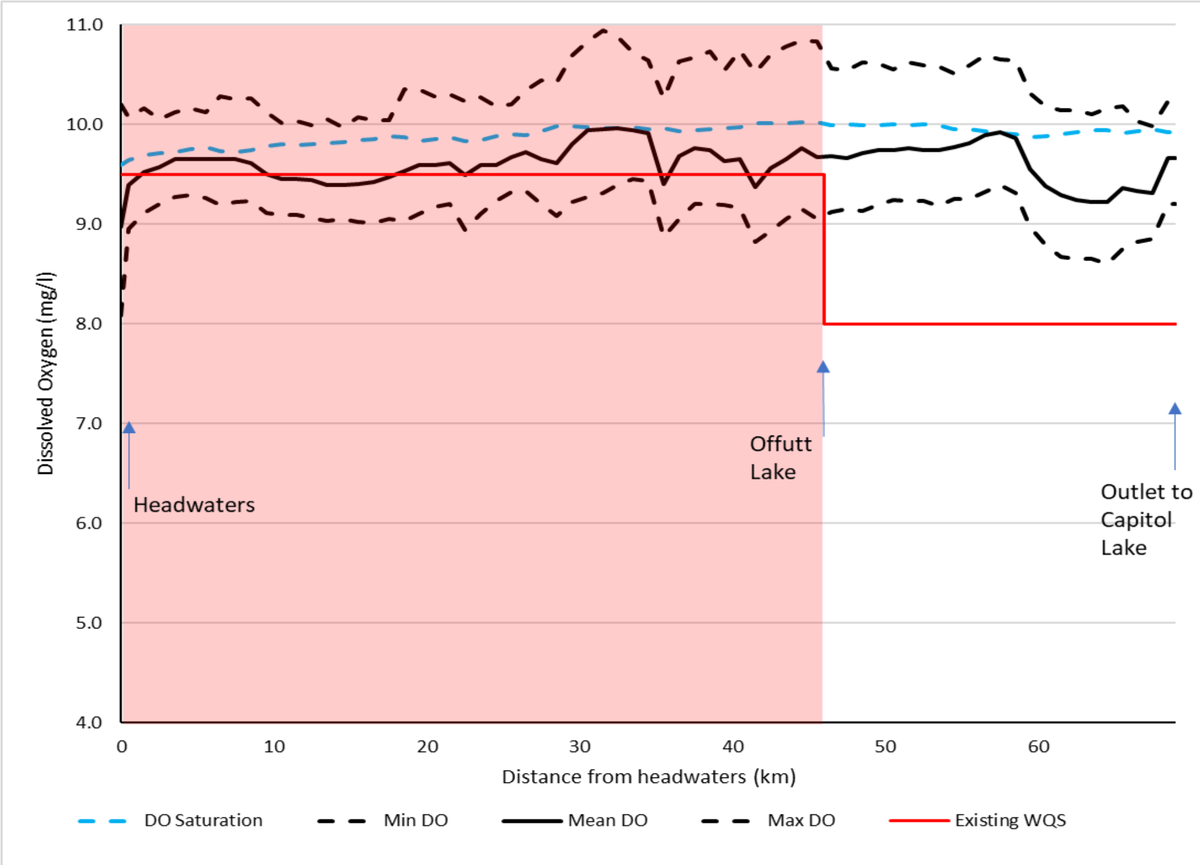

Figure 18. Natural conditions for temperature restored: dissolved oxygen under critical conditions (red shaded areas highlight where the numeric DO WQS is not met).

5.3.2 Natural Conditions for Dissolved Oxygen

Ecology applied the natural conditions for temperature as the baseline for the DO natural conditions QUAL2Kw model scenario. Water temperature is only one driver of DO levels, so Ecology also considered additional DO and nutrient reduction scenarios (more detail can be found in the *2015 Deschutes TMDLs* and supporting technical documents). This TMDL applies the same overall approach but uses different assumptions about the natural condition values for some of the model inputs, further described below.

Natural conditions prior to human development were estimated for model inputs using historical records, long-term monitoring, geological data, reference watersheds, and literature reviews (described in Section 2.0). Like the temperature scenario, natural conditions were represented for the watershed; therefore, natural condition water quality inputs for the headwaters, tributaries, diffuse groundwater inflows, and spring inflows were applied.

In their model scenario, Ecology applied the 10th percentile concentration from available (2003-2004) monitoring records as the natural condition for each nutrient species and BOD. However, these data were collected under the influence of human activities (e.g., historic logging, agricultural crop cultivation, urban development). It is likely that even the 10th percentile concentrations may be elevated compared to natural conditions. Therefore, for this TMDL, available literature-based information for characterizing natural conditions in the watershed was applied by source type (e.g., groundwater) and Level III ecoregion, as shown in Table 19,Table 20, and Table 21. As compared to the values in Table 21, the 10th percentile concentrations applied by Ecology for the tributaries ranged from 10 to 113 µg/L for organic N, 9 to 10 µg/L for ammonia, 10 to 117 µg/L for nitrite+nitrate, 1 to 4 µg/L for organic P, and 7 to 10 µg/L for inorganic P. Nearly all model inputs for the river headwaters can vary hourly, although the numeric temperature and DO criteria were applied statically throughout the day to conservatively approximate the worst-case state (highest heat load and lowest oxygen load). Note the QUAL2Kw model represents CBOD ultimate (CBODu).

Table 19. Approximated natural conditions for DO for the Deschutes River headwaters.

Parameter	Units	Input	Data Source and Rationale
Temperature	ºC	16.00	Established from Ecology's temperature QUAL2Kw model scenario (Roberts et al., 2012).
DO	mg/L	9.50	DO criterion for the Deschutes River at its headwaters.
CBODu slow	mg/L	0.49	In the absence of available data, calculated using the QUAL2Kw model stoichiometric ratios to estimate Carbonaceous Biochemical Oxygen Demand (CBOD) as a function of natural condition TP (see below): TP µg-P/L * 40 µg-C/1 ug-P * 2.69 µg-O_2/1 µg-C * 0.001 mg/µg = BOD mg-O_2/L. The total calculated BOD was split equally between CBOD slow and CBOD fast.
CBODu fast	mg/L	0.49	
TN	µg/L	55	25th percentile data from Cascades ecoregion (USEPA, 2000). Ammonia and organic nitrogen modified using observed speciation ratios. Nitrate: 5 µg/L; Ammonia: 9.72 µg/L (9 percent of total Kjeldahl nitrogen [TKN]); Organic N: 40.28 µg/L (91 percent of TKN).
TP	µg/L	9.06	25th percentile data from Cascades ecoregion (USEPA, 2000). Modified using observed speciation ratios. Organic P: 2.59 µg/L (29 percent of TP); Inorganic P: 6.47 µg/L (71 percent of TP).
Detritus	mg/L	0.25	Calibration model held constant.

Table 20. Approximated natural conditions for DO for diffuse groundwater and spring sources.

Parameter	Units	Input[1]	Data Source and Rationale
Temperature	ºC	13.00	Established from Ecology's temperature QUAL2Kw model scenario (Roberts et al., 2012).
DO	mg/L	3.90	Modified using median reference concentration for the Lower Puget region (USGS, 1998).
CBODu slow	mg/L	2.15	In the absence of available data, calculated using the QUAL2Kw model stoichiometric ratios to estimate CBOD as a function of natural condition TP (see below): TP µg-P/L * 40 µg-C/1 ug-P * 2.69 µg-O_2/1 µg-C * 0.001 mg/µg = BOD mg-O_2/L. The total calculated BOD was split equally between CBOD slow and CBOD fast.
CBODu fast	mg/L	2.15	
TN	µg/L	331 - 395	Modified using median reference concentration for the Lower Puget region (USGS, 1998). Ammonia and organic nitrogen based on observed speciation ratios and percent decrease in nitrate relative to natural conditions because other N species were not reported. Nitrate: 330 µg/L; Ammonia: 0.69 – 58.41 µg/L; Organic N: 0.00 – 6.66 µg/L.
TP	µg/L	40	Modified using median reference concentration for the Lower Puget region (USGS, 1998). Based on observed speciation ratios. Organic P: 0.00 – 26.97 µg/L; Inorganic P: 13.03 – 40.00 µg/L.
Detritus	mg/L	0.00	Calibration model setup held constant.

[1]There are multiple groundwater inflows (diffuse sources) and springs (point sources) represented in the QUAL2Kw model. Monitoring data reveal different groundwater concentrations and speciation ratios across the watershed, therefore, the range across the different input locations is shown, where applicable.

[2]Calibration model concentrations of organic and inorganic phosphorus range from 0.0 – 60.0 and 10.0 – 86.0 µg/L respectively, across the multiple diffuse groundwater inflows and springs represented in the model. As a fraction of TP, speciation of organic and inorganic phosphorus ranges from 0 – 67 percent and 33 – 100 percent, respectively along the mainstem from diffuse sources. Organic and inorganic phosphorus concentrations for the two springs are 11.0 and 56.0 µg/L respectively, which reflect speciation of 16 percent and 84 percent, respectively.

Table 21. Approximated natural conditions for DO for tributaries.

Parameter	Units	Input[1]	Data Source and Rationale
Temperature	ºC	16.00 or 17.50	Established from Ecology's temperature QUAL2Kw model scenario (Roberts et al., 2012).
DO	mg/L	8.0 or 9.5	DO criterion applicable to each tributary.
CBODu slow	mg/L	0.5 – 1.0	In the absence of available data, calculated using the QUAL2Kw model stoichiometric ratios to estimate CBOD as a function of natural condition TP (25th percentile see below): TP µg-P/L * 40 µg-C/1 ug-P * 2.69 µg-O_2/1 µg-C * 0.001 mg/µg = BOD mg-O_2/L. The total calculated BOD was split equally between CBOD slow and CBOD fast.
CBODu fast	mg/L	0.5 – 1.0	
TN	µg/L	55 (Cascades) and 340 (Lower Puget)	25th percentile data from Cascades and Lower Puget ecoregions (USEPA, 2000). Ammonia and organic nitrogen modified using observed speciation ratios. Nitrate: 5.00 – 260.00 µg/L; Ammonia: 4.31 – 37.89 µg/L; Organic N: 23.81 – 74.52 µg/L.
TP	µg/L	9.06 (Cascades) and 19.5 (Lower Puget)	25th percentile data from Cascades ecoregion (USEPA, 2000). Modified using observed speciation ratios. Organic P: 0.82 – 9.75 µg/L; Inorganic P: 2.28 – 10.66 µg/L.
Detritus	mg/L	0.25	Calibration model setup held constant.

[1]There are multiple tributaries represented in the QUAL2Kw model. Monitoring data reveal different concentrations and speciation ratios across the watershed, therefore, the range across the different input locations is shown, where applicable.

The QUAL2Kw simulated results for natural conditions for DO are shown below (Figure 19). The numeric criterion is not attained for the section of the Deschutes River upstream of Offutt Lake because the minimum concentration is below the allowable 1-day minimum DO concentration of 9.5 mg/L. The daily mean and daily maximum concentrations are also plotted to show the predicted diurnal variation due to algae productivity and other temporal fluctuations in stressors and processes (e.g., air temperature impacts on chemical reactions). The diel swing in DO from the calibration model was approximately 1.7 mg/L, and restoration of natural conditions was predicted to reduce the difference to approximately 1.2 mg/L (both critical conditions scenarios). In part, lower ambient nutrient concentrations limit algae, reducing daytime oxygen production and nighttime oxygen consumption activities, narrowing the diurnal variation.

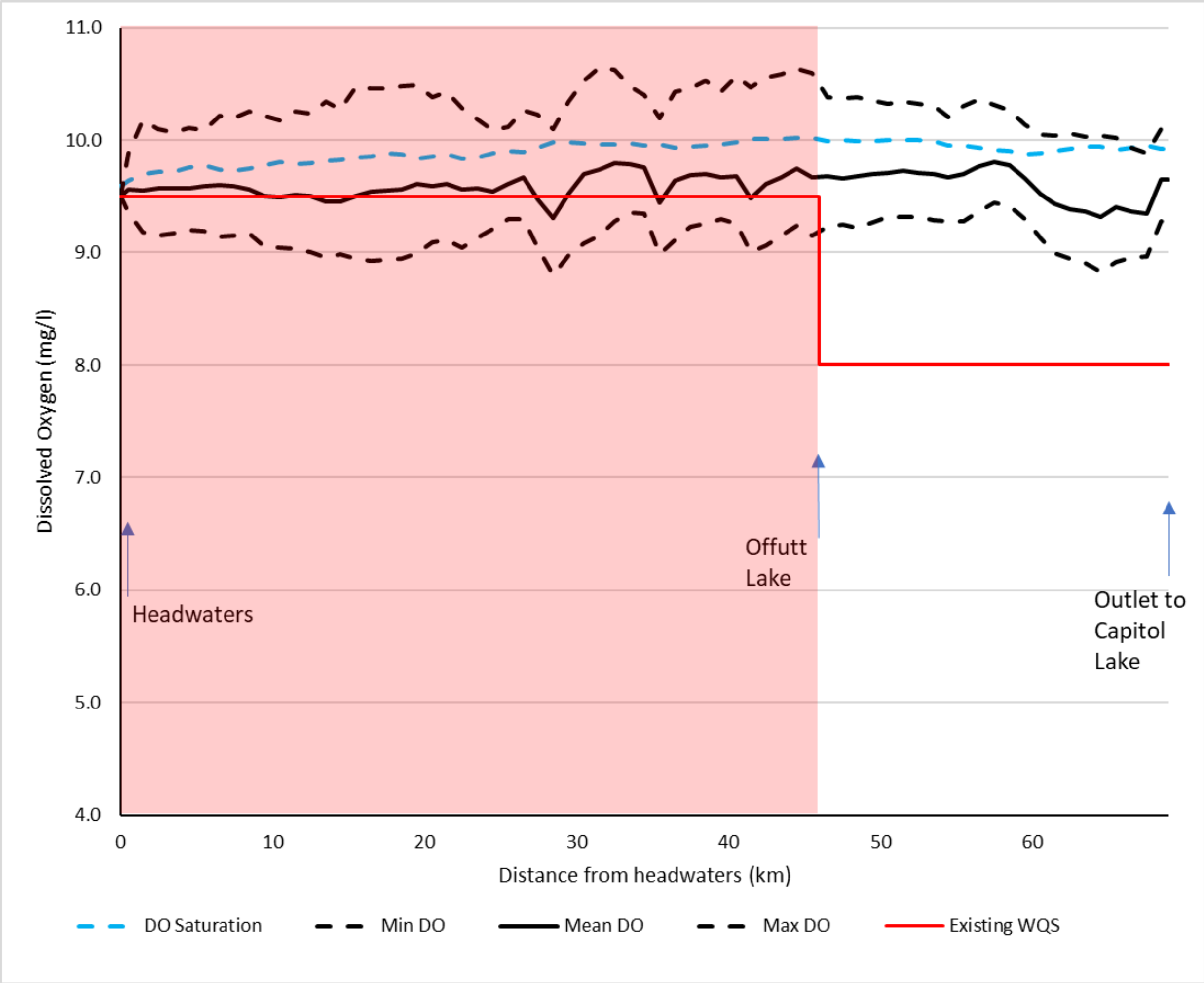

Figure 19. Natural conditions for DO under critical conditions (red shading indicates DO lower than existing WQS under critical conditions).

The same graphic presented in Figure 19 is shown in Figure 20 highlighting the reaches which are identified as impaired for low levels of DO. Based on the QUAL2Kw simulation of natural conditions for DO, under critically low flow and high air temperatures, the downstream DO impaired segments (2012 Listing IDs 10894, 47754, and 47753) would be able to attain the applicable numeric criterion for minimum DO of 8.0 mg/L. Conversely, the upstream DO impaired segment (2012 Listing ID 47756) and the entire mainstem upstream of Offutt Lake would be unable to attain the applicable numeric criterion for daily minimum DO of 9.5 mg/L. Average daily DO concentrations are predicted to be over 9.5 mg/L in most locations, although biological reactions and other fluctuating processes cause oxygen levels to fall below the criterion for minimum daily DO for the entire upper river. Thus, the water quality target for the TMDL upstream of Offutt Lake is the natural condition DO concentration minus a 0.2 mg/L allowed comprehensive decrease due to human actions. The water quality target for the TMDL downstream of Offutt Lake is the numeric criterion of 8.0 mg/L.

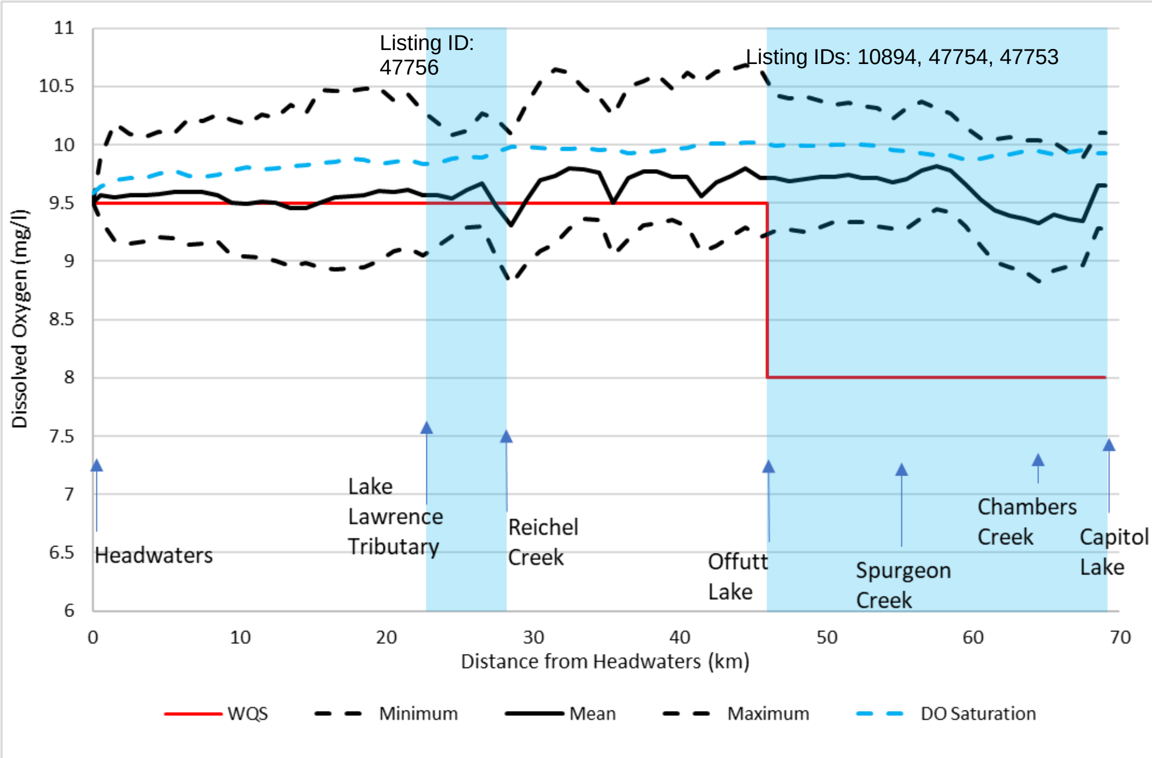

Figure 20. Approximated natural conditions for DO (blue shading shows segments identified as impaired for DO on the 2012 303(d) list).

Tabular results of the DO natural conditions simulation depicted in Figure 19 and Figure 20 are summarized below for sections of the Deschutes River between major tributaries (Table 22). Results are provided for each of the four impaired reaches as well as for non-impaired segments represented in the receiving water model. The mean DO ranges from approximately 9.5 – 9.7 mg/L, with maximum DO ranging from 10.1 – 10.7 mg/L, and minimum DO ranging from 8.8 – 9.2 mg/L.

Table 22. Natural conditions for DO along the Deschutes River (red shading indicates where the minimum DO concentration is below the numeric lowest 1-day minimum DO WQS).

Deschutes Mainstem Segment	Impaired Reach	Distance from Model Headwaters (km)	Dissolved Oxygen (mg/L)				
			Existing Numeric WQS	Mean	Min	Max	Saturation
Headwaters to Thurston Creek	-	0.0 - 3.6	9.5	9.6	9.2	10.2	9.7
Thurston Creek to Mitchell Creek	-	3.7 - 5.9	9.5	9.6	9.2	10.1	9.8
Mitchell Creek to Fall Creek	-	6.0 - 11.1	9.5	9.5	9.0	10.3	9.8
Fall Creek to Hull/Pipeline Creek	-	11.2 - 18.6	9.5	9.5	8.9	10.5	9.8
Hull/Pipeline Creek to Lake Lawrence	-	18.7 - 22.4	9.5	9.6	9.0	10.5	9.9
Lake Lawrence to Reichel Creek	47756	22.5 - 28.0	9.5	9.6	9.0	10.3	9.9
Reichel Creek to Spring at Rte 507	-	28.1 - 35.7	9.5	9.6	8.8	10.6	10.0
Spring at Rte 507 to Silver Spring	-	35.8 - 41.4	9.5	9.7	9.2	10.6	10.0
Silver Spring to Tempo Lake	-	41.5 - 46.5	9.5	9.7	9.1	10.7	10.0
Tempo Lake to Spurgeon Creek	47754	46.6 - 54.0	8.0	9.7	9.3	10.4	10.0
Spurgeon Creek to Chambers Creek	47753	54.1 – 63.9	8.0	9.6	8.9	10.4	9.9
Chambers Creek to Capitol Lake	10894	64.0 - 69.0	8.0	9.5	8.8	10.1	9.9

5.4 STRESSOR RESPONSE

Ambient nutrient concentrations impact instream chemical and biological reactions and DO concentrations in the river. EPA completed sensitivity tests with the QUAL2Kw model to evaluate nutrient stressor – DO response relationships. The DO response resulting from changes in ambient TP concentrations are shown in Figure 21 and Figure 22 for the lower river and upper river, respectively. Monitoring records indicate about 43 percent of TP is organic phosphorus and 64 percent is inorganic phosphorus. The DO response resulting from changes in ambient TN concentrations are provided in Figure 23 and Figure 24. Monitoring records indicate that TN is comprised of about 12 percent organic nitrogen, 1 percent ammonia, and 87 percent nitrate and nitrite – therefore, most of the response can be attributed to reductions in inorganic forms of nitrogen.

Based on the fitted stressor-response curves, lower ambient nutrient concentrations are shown to improve the minimum DO concentration. Therefore, the nutrient concentrations needed to meet the water quality criteria upstream of Offutt lake were evaluated with the QUAL2kw model (Section 5.5). Based on those results, corresponding nutrient TMDLs were established (Section 6.0).

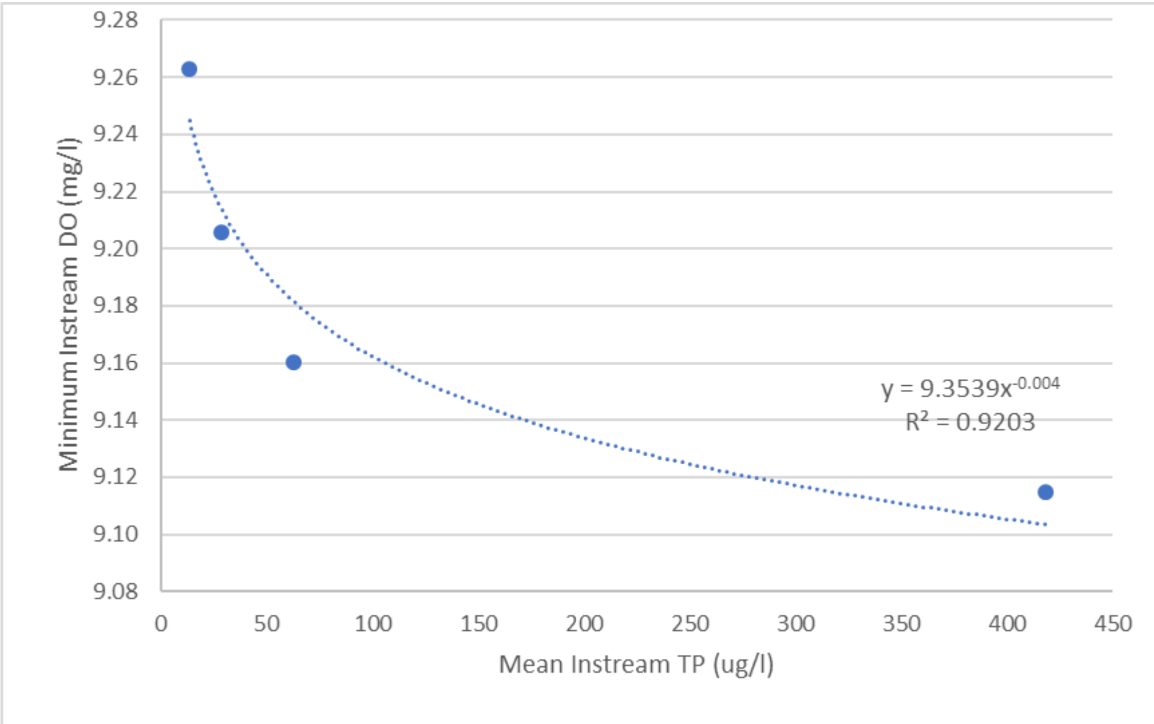

Figure 21. Stressor response: impact of changes on instream DO due to changes in ambient total phosphorus (TP) at the downstream end of the model (2012 Listing ID: 10894).

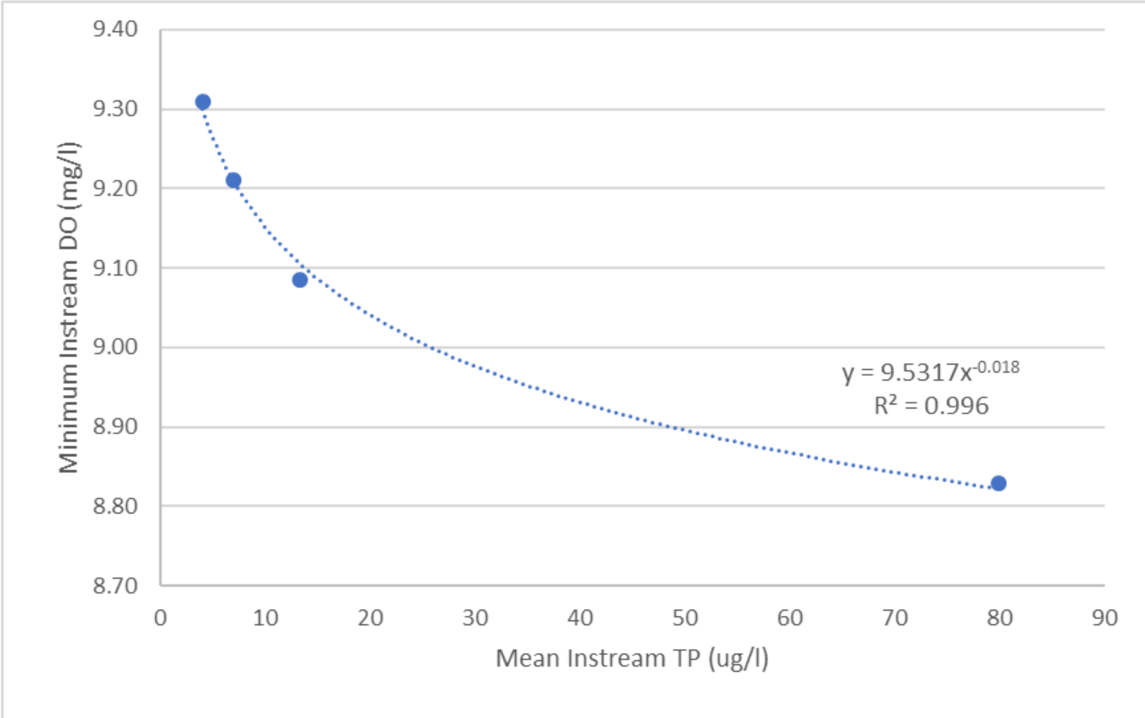

Figure 22. Stressor response: impact of changes on instream DO due to changes in ambient total phosphorus (TP) near Reichel Creek (2012 Listing ID: 47756).

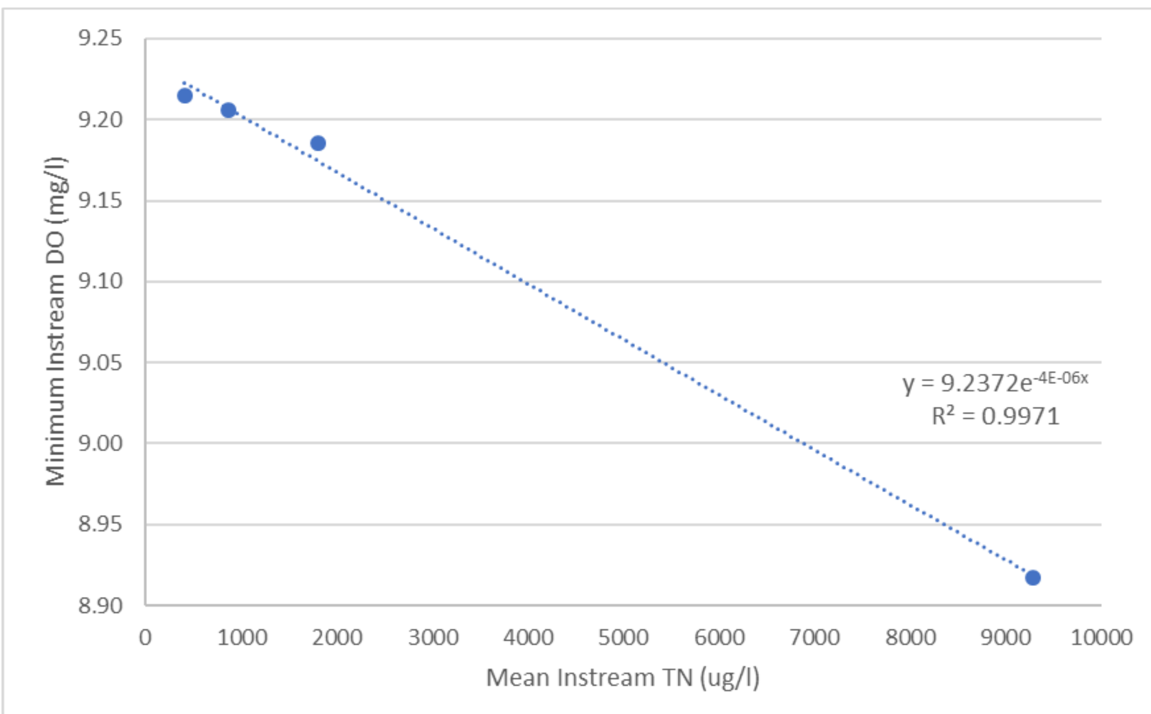

Figure 23. Stressor response: impact of changes on instream DO due to changes in ambient total nitrogen (TN) at the downstream end of the model (2012 Listing ID: 10894).

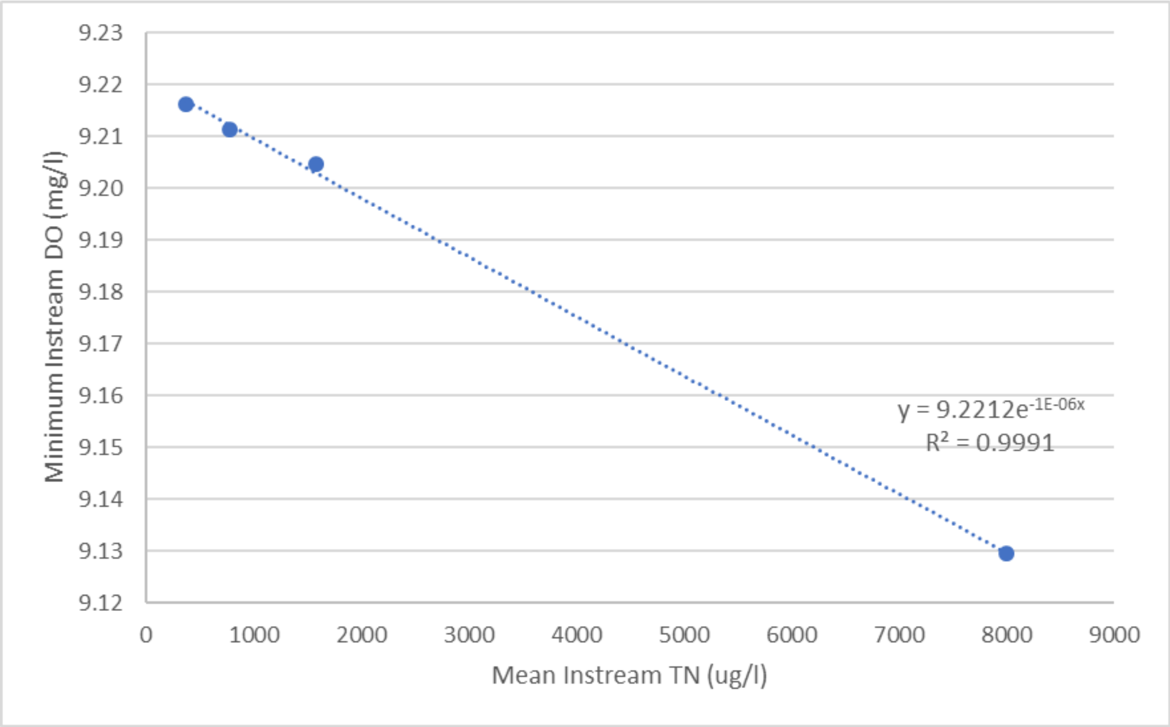

Figure 24. Stressor response: impact of changes on instream DO due to changes in ambient total nitrogen (TN) near Reichel Creek (2012 Listing ID: 47756).

5.5 TMDL SCENARIO

The results of the natural conditions simulation for DO show that the 8.0 mg/L minimum DO criterion is attained downstream of Offutt Lake (Figure 20). In fact, with natural conditions for temperature restored downstream of Offutt Lake (without natural conditions for other oxygen-depleting stressors), the 8.0 mg/L criterion is met. Therefore, nutrient targets downstream of Offutt Lake TMDL are defined based on existing levels. There is no need to require nutrient load reductions downstream of Offutt Lake because the numeric Water Quality (WQ) criterion is met with a wide margin of error under existing nutrient levels (minimum DO concentrations are approximately 0.4 – 1.0 mg/L above the numeric WQ criterion).

The numeric water quality criterion of a minimum of 9.5 mg/L DO is violated under natural conditions for DO upstream of Offutt Lake. Therefore, nutrient targets upstream of Offutt Lake are set at a level that attains the minimum DO concentration predicted under natural, critical conditions minus an allowable depletion of 0.2 mg/L due to human actions. Allowing for the 0.2 mg/L depletion from natural conditions, the DO water quality criteria upstream of Offutt Lake range from 8.6 – 9.0 mg/L (Table 24).

A TMDL scenario was developed to evaluate nutrient loading targets needed to meet the DO criteria upstream of Offutt Lake (i.e., natural condition with allowable deviation). This scenario was built upon the natural conditions for temperature scenario, and also included the following:

1. Headwaters, tributaries, springs, and groundwater boundary inflows were set to natural nutrient conditions (nitrogen and phosphorus species as shown in Table 19 to Table 21) upstream of Offutt Lake.
2. Headwaters and all tributaries were set to the applicable lowest 1-day minimum DO criterion (8.0 or 9.5 mg/L), or the established TMDL targets.

3. EPA is developing TMDLs for tributaries impaired for low levels of DO, temperature, and/or pH. The shade and nutrient targets assigned in those TMDLs were incorporated as inputs to the model.

Aside from these boundary condition changes, all other model inputs from the natural conditions for water temperature were held constant. The explicit differences between the three QUAL2Kw scenarios are summarized in Table 23. The results of the TMDL scenario are presented in Figure 25 and Table 24. In Figure 25, there is small section of the river about five kilometers upstream of Offutt Lake that is slightly below the target, by <0.05 m/L. For the TMDL evaluation, results are aggregated to sections of the river spanning a few kilometers in length. Overall, this segment (Silver Spring to Tempo Lake Outlet) achieves the target concentration for the TMDL.

Table 23. Summary of QUAL2Kw Scenarios for the Deschutes River.

Condition	Scenario		
	Natural Conditions for Temperature	**Natural Conditions for DO[1]**	**DO TMDL**
Critical conditions for flow (7Q10) and air temperature (90th percentile)	X	X	X
System potential vegetation shade for mainstem and tributaries, cooled riparian microclimate, and stream stabilization characterized as a narrowed width (Section 4.3.1)	X	X	X
Natural nutrient conditions for headwaters, tributaries, springs and groundwater (nitrogen and phosphorus species and CBOD)		X	X (Upstream of Offutt Lake only)
Natural DO concentrations for headwaters and tributaries		X	X (Upstream of Offutt Lake only)
Natural conductivity, pH, alkalinity, and DO concentrations in groundwater and springs		X	

[1]Natural DO concentrations for headwaters and tributaries were approximated conservatively as the DO WQS from the TMDL because either 1) the waterbodies are not identified as impaired for DO or 2) TMDLs are being developed to restore DO conditions to the WQS, or better. Targets established for tributary TMDLs were applied in the TMDL scenario. The remaining parameters were based on the calibrated QUAL2Kw model.

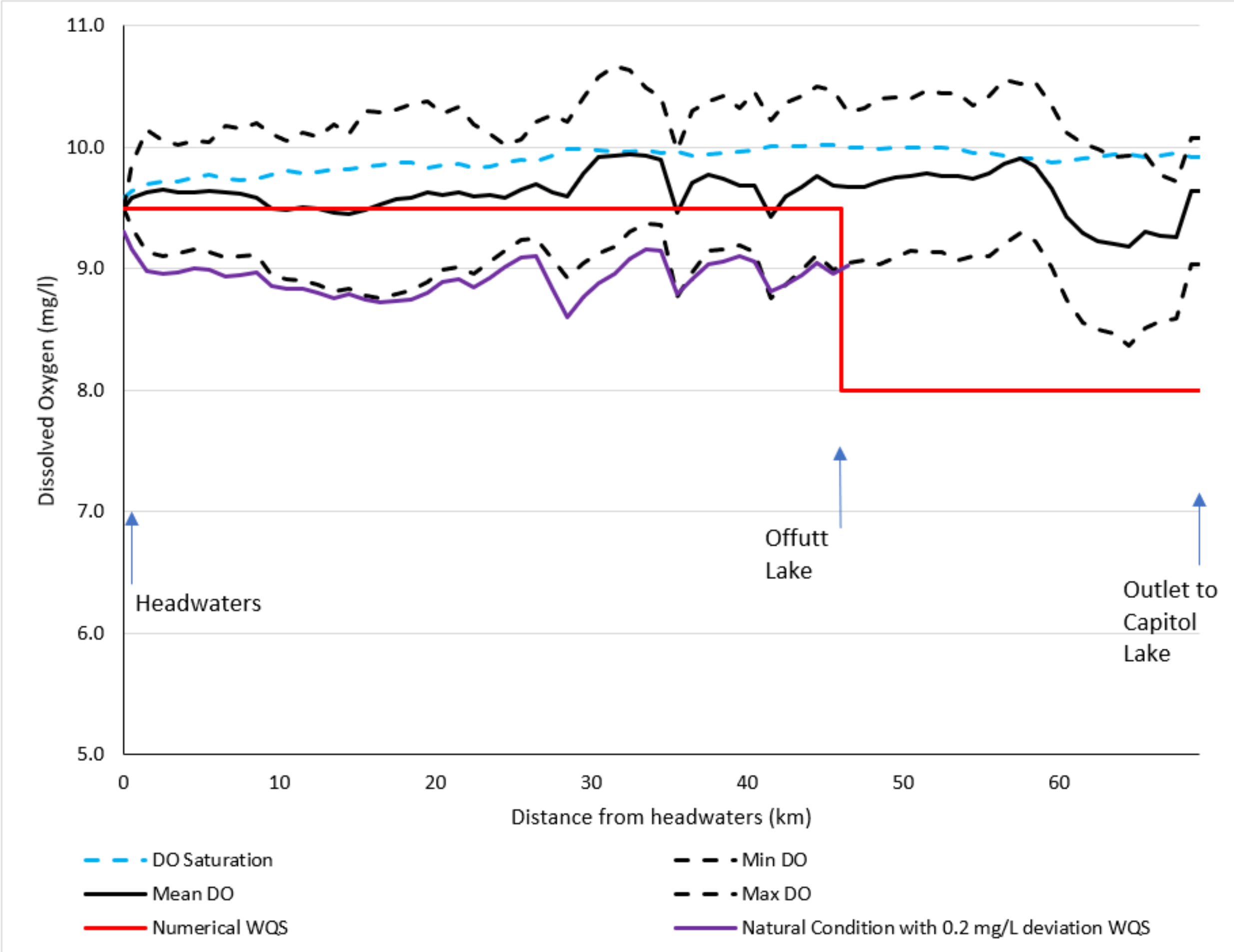

Figure 25. TMDL scenario results: DO relative to both numeric WQS and natural conditions with allowable deviation of 0.2 mg/L WQS.

Table 24. Minimum DO concentrations for the TMDL scenario.

Deschutes River Segment	2012 Listing ID for DO	Distance from Model Headwaters (km)	Minimum Dissolved Oxygen (mg/L)			
			DO Natural Critical Conditions	Water Quality Criterion[1]	TMDL Scenario	TMDL Deviation from Natural Condition
Headwaters to Thurston Creek	-	0.0 - 3.6	9.2	9.0	9.1	0.1
Thurston Creek to Mitchell Creek	-	3.7 - 5.9	9.2	9.0	9.1	0.1
Mitchell Creek to Fall Creek	-	6.0 - 11.1	9.0	8.8	8.9	0.1
Fall Creek to Hull/Pipeline Creek	-	11.2 - 18.6	8.9	8.7	8.8	0.1
Hull/Pipeline Creek to Lake Lawrence	-	18.7 - 22.4	9.0	8.8	8.9	0.1
Lake Lawrence to Reichel Creek	47756	22.5 - 28.0	9.0	8.8	9.0	0.0
Reichel Creek to Spring at Rte 507	-	28.1 - 35.7	8.8	8.6	8.8	0.0
Spring at Rte 507 to Silver Spring	-	35.8 - 41.4	9.1	8.9	9.0	0.1
Silver Spring to Tempo Lake (near Offutt Lake)	-	41.5 - 46.5	9.0	8.8	8.8	0.2
Tempo Lake to Spurgeon Creek	47754	46.6 - 54.0	9.2	8.0	9.0	N/A[1]
Spurgeon Creek to Chambers Creek	47753	54.1 – 63.9	8.9	8.0	8.5	N/A[1]
Chambers Creek to Capitol Lake	10894	64.0 - 69.0	8.8	8.0	8.4	N/A[1]

[1]The existing DO criterion downstream of Offutt Lake is maintained at 8.0 mg/L. Upstream of Offutt Lake, the natural condition with the allowable deviation (0.2 mg/L) standard is applied.

6.0 TMDL AND REQUIRED REDUCTIONS

TMDLs are expressed as flow-varied loads based on the TN and TP concentration targets established through QUAL2Kw modeling. These TMDLs also assume that Ecology's assigned temperature TMDLs in the *2015 Deschutes TMDLs* will be implemented. As described in Section 3.0, TMDL targets and the derived loads are established for two locations: (1) the downstream end of the river upstream of Offutt Lake and (2) the downstream end of the river near the Deschutes mouth (before it enters Capitol Lake).

Ambient TN and TP concentrations from the TMDL model scenario upstream of Offutt Lake are 0.175 mg-N/L and 0.006 mg-P/L. The corresponding percent reductions are approximately 55 percent for TN and 57 percent for TP. Downstream of Offutt Lake, there are no reductions in existing nutrient loads required because the thermal loads assigned in Ecology's Deschutes River temperature TMDL are shown to result in the achievement of the applicable DO criteria. Thus, the nutrient loads downstream of Offutt Lake are established based on existing average ambient concentrations at the outlet of 0.763 mg-N/L and 0.019 mg-P/L.

The flow-varied TMDLs are defined as follows:

$$TN\ TMDL = Q \times TN \times 2.45$$

where $TN\ TMDL$ is the total maximum daily TN load in units of kilograms per day, Q is the average daily streamflow in units of cubic feet per second, TN is the TN concentration target in units of milligrams per liter (0.175 mg/L upstream of Offutt Lake and 0.763 mg/L downstream of Offutt lake), and 2.45 is a multiplicative factor to convert the load to units of kilograms per day.

$$TP\ TMDL = Q \times TP \times 2.45$$

where $TP\ TMDL$ is the total maximum daily TP load in units of kilograms per day, Q is the average daily streamflow in units of cubic feet per second, TP is the TP concentration target in units of milligrams per liter (0.006 mg/L upstream of Offutt Lake and 0.019 mg/L downstream of Offutt Lake), and 2.45 is a multiplicative factor to convert the load to units of kilograms per day.

To support implementation (e.g. if permitted sources receive a limit for dissolved inorganic nitrogen, or DIN), the relationship between TN and DIN was analyzed. Based on the critical conditions QUAL2Kw modeling for the Deschutes River TMDL, approximately 85 percent of TN is DIN at the river outlet to Capitol Lake. Although instream and upland dynamics will influence nutrient stoichiometry in the river, the ratio can be used for comparison purposes. An approximate DIN target based on the median flow for the lower river is about 397 kg-DIN/day (467 kg-TN/day * 0.85 DIN/TN = 397 kg-DIN/day).

The TN and TP reductions required for monitoring locations upstream of Offutt Lake are shown in Figure 26 and Figure 27.

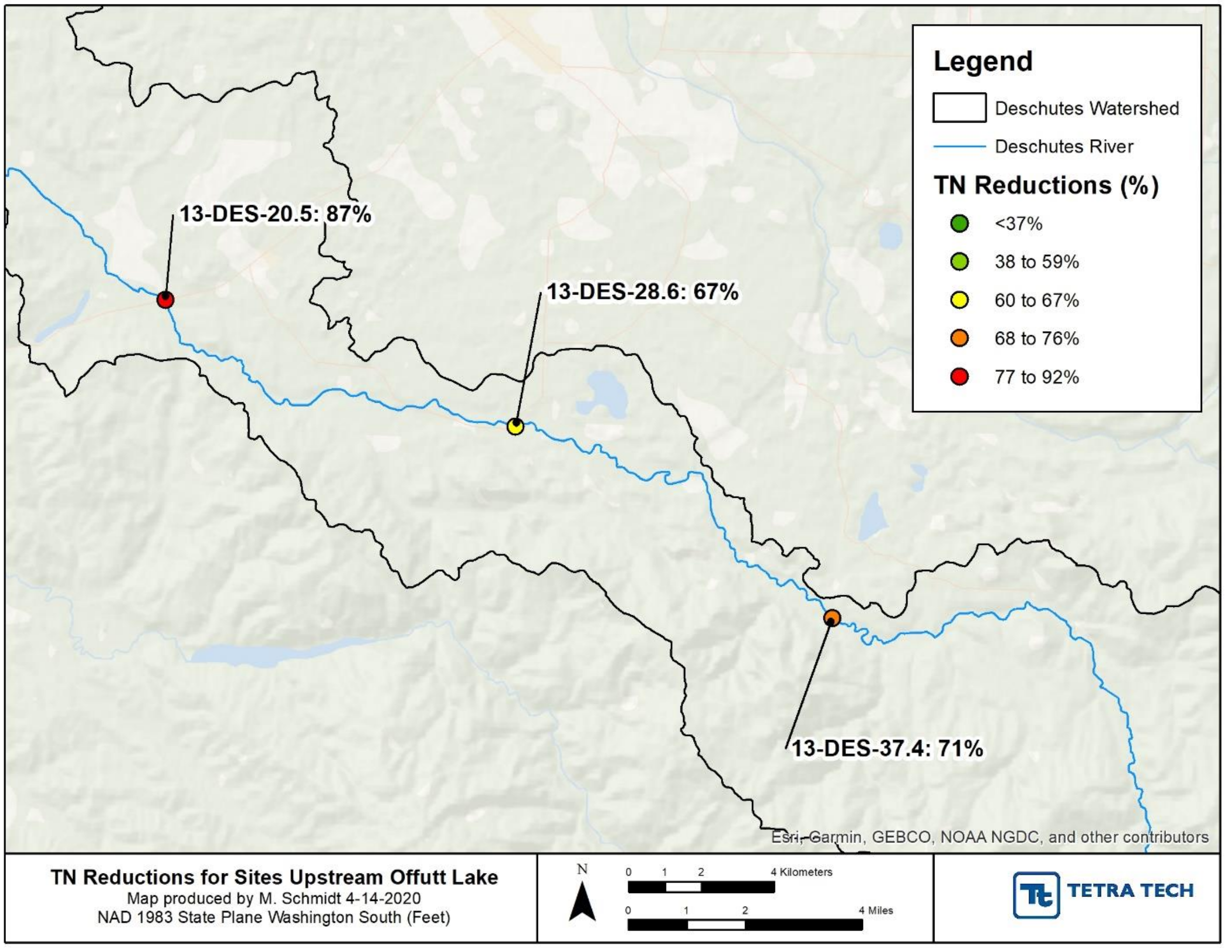

Figure 26. Required nitrogen reductions for Deschutes River monitoring sites upstream of Offutt Lake (based on maximum observed concentration and target concentration).

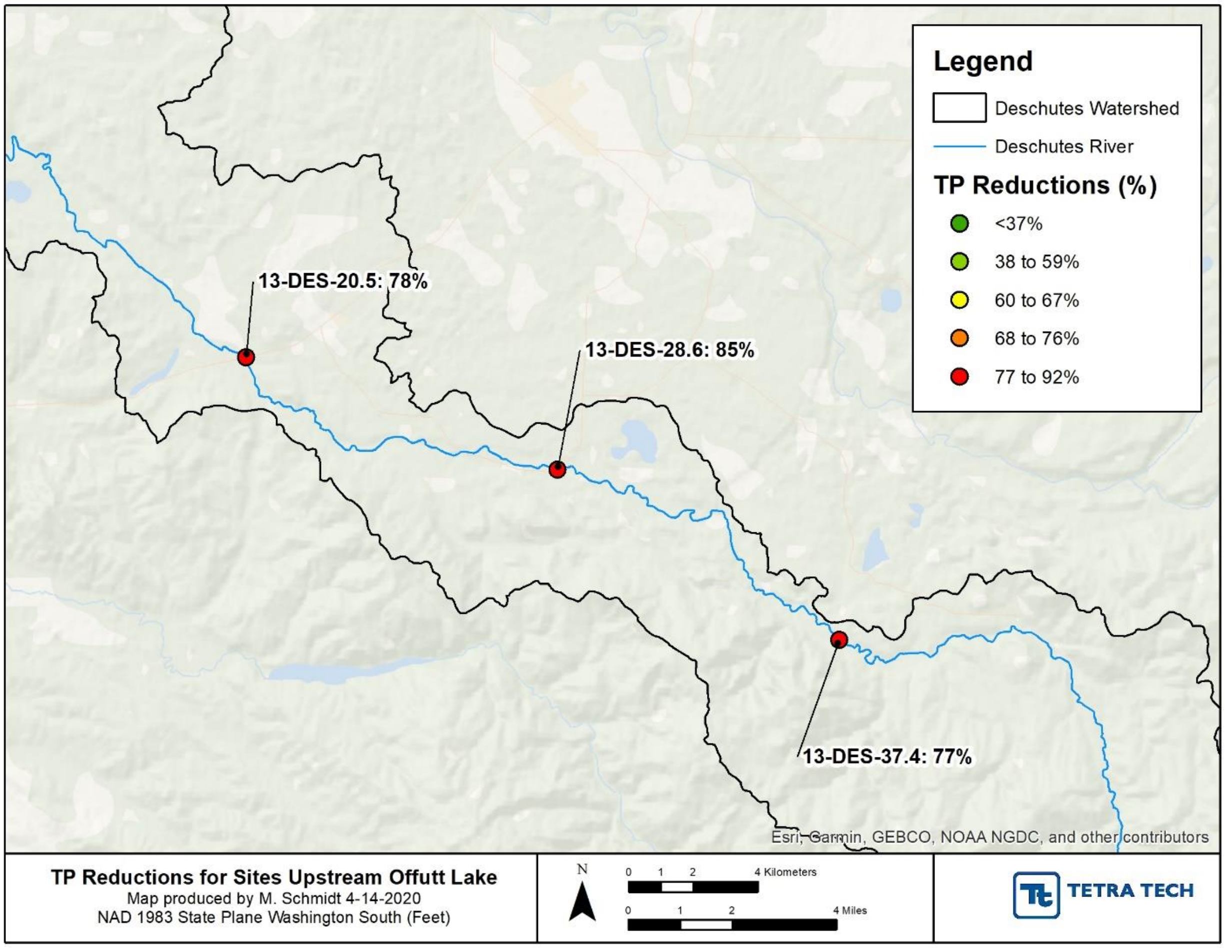

Figure 27. Required phosphorus reductions for Deschutes River monitoring sites upstream of Offutt Lake (based on maximum observed concentration and target concentration).

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