Appendix H:

Technical Analyses to Support Stream Flow Estimation and TMDL Loading Capacity Calculations

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H.1 Overview

Total maximum daily loads (TMDLs) are required to address impairments on the 303(d) list. TMDLs for temperature impairments in the Lost and Upper Klamath subbasins were developed (Figure H- 1 and Figure H- 2, respectively). Waters included in this analysis are identified in Figure H- 1.

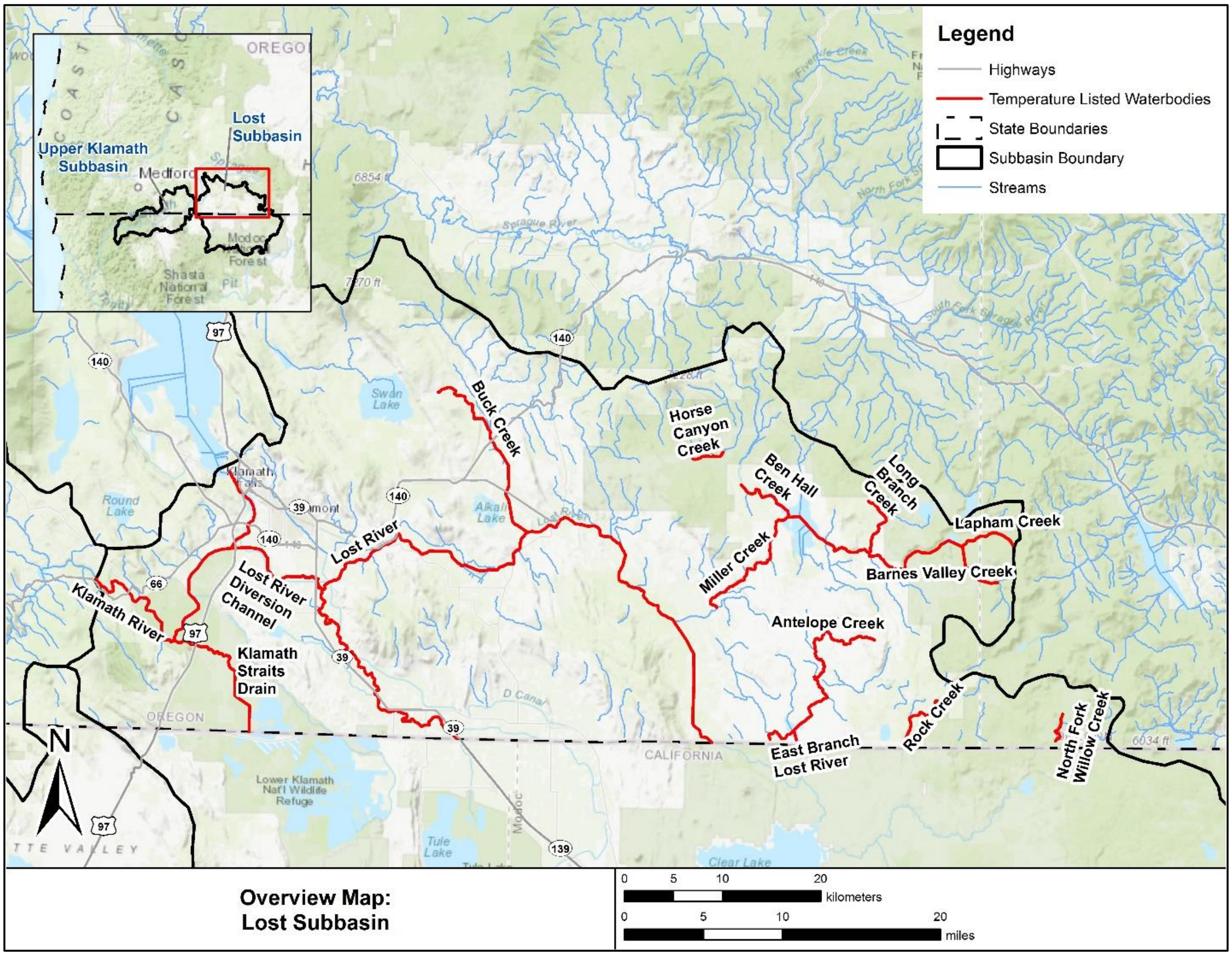

Figure H- 1. Lost River Subbasin 303(d) listings addressed by these TMDLs

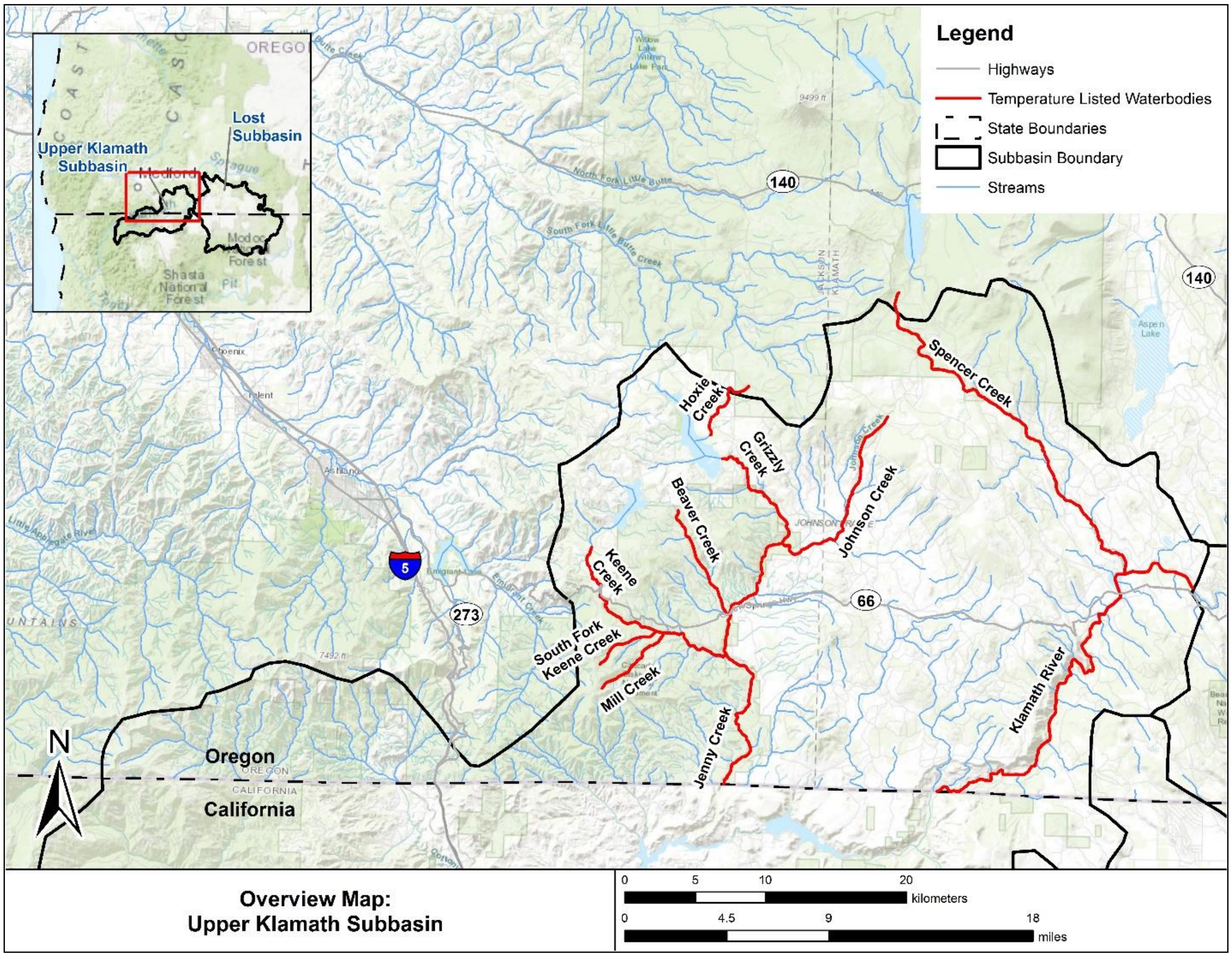

Figure H- 2. Upper Klamath River Subbasin 303(d) listings addressed by these TMDLs

Table H- 1. Water quality limited segments for temperature in this TMDL analysis

Subbasin	Waterbody Name
Lost	Antelope Creek
Lost	Antelope Creek
Lost	Barnes Valley Creek
Lost	Ben Hall Creek
Lost	Buck Creek
Lost	East Branch Lost River
Lost	Horse Canyon Creek*
Lost	Klamath Straits Drain
Lost	Lapham Creek
Lost	Long Branch Creek
Lost	Lost River*
Lost	Lost River Diversion Channel
Lost	Miller Creek
Lost	North Fork Willow Creek

Subbasin	Waterbody Name
Lost	Rock Creek
Upper Klamath	Beaver Creek
Upper Klamath	Grizzly Creek
Upper Klamath	Hoxie Creek
Upper Klamath	Jenny Creek
Upper Klamath	Johnson Creek
Upper Klamath	Keene Creek
Upper Klamath	Keene Creek
Upper Klamath	Klamath River
Upper Klamath	Mill Creek
Upper Klamath	South Fork Keene Creek
Upper Klamath	Spencer Creek
Upper Klamath	Jenny Creek
*Listed as Unnamed Latitude Longitude Identification (LLID) #1212355422566; identified as Horse Canyon Creek	

This appendix documents the technical information used to calculate TMDL loading capacity for the waterbodies listed in Table H- 1. Details associated with water quality standards, source analysis, and other TMDL components are documented in the TMDL report itself.

The technical approach for these TMDLs varies by waterbody. In some cases, the approach uses a water quality model, while in other cases no modeling is conducted to calculate the loading capacity and available data or other tools are used to estimate flow. Table H- 2 identifies the approach used to calculate the loading capacities.

For many of the tributaries to the Klamath and Lost rivers that are included in this analysis, the technical approach does not involve modeling (Table H- 2). To obtain flow statistics and calculate the thermal loading capacity for these ungaged streams, the United States Geological Survey (USGS) StreamStats program was applied to estimate river flow (Section H.1.1). The technical approaches for Spencer Creek, Klamath Straits Drain, Lost River Diversion Channel (to the Klamath River), and the Lost River involve use of observed data and previous modeling efforts. Whenever possible, observed data or modeling estimates were used for verification of or comparison with temperature or flow estimates. Station locations with observed data are also identified in Table H- 2.

Additional details associated with loading capacity calculations, allocation of the thermal loading capacity, and calculation of excess thermal loads and evaluation of temperature exceedance are described below. Waterbody-specific nuances are described in Section H.2.

Table H- 2. Flow Estimation approach and data availability

303(d) ID	Waterbody Name	Flow Estimation Method	Station ID
Lost River Subbasin			
24458	Antelope Creek	StreamStats	None
2182	Antelope Creek	StreamStats	None
12738	Barnes Valley Creek	StreamStats	None
12737	Ben Hall Creek	StreamStats	None

303(d) ID	Waterbody Name	Flow Estimation Method	Station ID
12766	Buck Creek	StreamStats	None
24459	East Branch Lost River	StreamStats	None
2166	Horse Canyon Creek**	StreamStats	None
21952	Klamath Straits Drain	Flow Measurements	USGS 11509340
12726	Lapham Creek	StreamStats	None
12732	Long Branch Creek	StreamStats	None
24463	Lost River	CE-QUAL-W2 model output for flow	USGS (420025121132800, 421010121271200, 11488495)
NA	Lost River Diversion Channel	Calculated using Flow Measurements	Net flow derived from measurements at Wilson Dam, minus diversions at Station 48 and Miller Hill
1993	Miller Creek	StreamStats	None
1994	North Fork Willow Creek	StreamStats	None
12729	Rock Creek	StreamStats	None
Upper Klamath River Subbasin			
12872	Beaver Creek	StreamStats	None
2158	Grizzly Creek	StreamStats	None
2180	Hoxie Creek	StreamStats	None
2159	Johnson Creek	StreamStats	None
2163	Keene Creek	StreamStats	OWRD (11514500)***
2178	Keene Creek	StreamStats	None
2168	Mill Creek	StreamStats	None
2181	South Fork Keene Creek	StreamStats	None
12815	Spencer Creek	Flow measurements; Heat Source modeling	OWRD (11510000)
1984	Jenny Creek	StreamStats	None

*See Appendix A for details on all shading analyses and Heat Source modeling.
**Listed as Unnamed Latitude Longitude Identification (LLID) #1212355422566; identified as Horse Canyon Creek
***Available data were collected 1984-1996, so may not be representative of more recent conditions. OWRD = Oregon Water Resources Department; USGS = United States Geological Survey

H.1.1 StreamStats

StreamStats v4.2.1 is a web-based geographic information system (GIS) application developed by the USGS (https://streamstats.usgs.gov/ss/). StreamStats has a map-based interface that allows the user to determine drainage area delineations, basin characteristics, and estimates of streamflow statistics for user-selected locations along available streams. The program also provides users with access to stream monitoring data by selecting USGS data-collection stations in the map application and providing access to flow statistics and other information for the stations.

StreamStats provides estimates of various streamflow statistics for user-selected sites by solving site-specific regression equations. The regression equations were developed through a process, known as regionalization, which involves use of regression analysis to relate streamflow statistics computed for a group of selected stream gages (usually within a state) to basin characteristics measured for the stream gages. Basin characteristics are used to obtain estimates of the streamflow statistics for ungaged sites.

StreamStats regression equations for Oregon were developed by Cooper (2005) and Risley et al. (2008). The equations are based on basin characteristics and flow statistics, such as the historical flow (5^{th}, 10^{th}, 25^{th}, 50^{th} and 95^{th} percent exceedances) and annual and monthly 7-day, 10-year (7Q10) and 7-day, 2-year (7Q2) low flows. Flow statistics were computed at 466 streamflow-gaging stations throughout Oregon and adjacent areas of neighboring states. The study area was divided into 10 regions based on ecological, topographic, geologic, hydrologic, and climatic criteria. The program includes a total of 910 annual and monthly regression equations created to estimate the seven flow statistics for ungaged stream sites in the 10 regions of Oregon.

When applying the tool, the user selects a location along a stream and StreamStats estimates the associated drainage area. Basin characteristics are then estimated for the selected drainage, including drainage area, mean annual precipitation, mean slope, and climactic characteristics. Drainage areas are calculated from a polygon area with data from Global Watershed. Mean annual precipitation and other climate characteristics are calculated using an area-weighted mean with 800-m resolution Parameter-elevation Regressions on Independent Slopes Model (PRISM) data from 1971-2000 (Risley et al 2008; Cooper 2005). Slope is determined using ArcInfo Grid with National Hydrography Dataset Plus (NHDPlus V1) 30-m resolution elevation data.

Flow-duration regression equations primarily use drainage area and mean annual precipitation to generate 5-, 10-, 25-, 50-, and 95-percent duration flows. When the data are available, StreamStats will use the following parameters to calculate monthly flow-duration statistics: average soil permeability, mean basin slope, mean annual maximum air temperature over the basin, minimum basin slope, mean maximum January temperature, maximum elevation minus minimum elevation, and available water capacity, calculated from the U.S. Natural Resources Conservation Service (NRCS) State Soil Geographic (STATSGO) dataset. Ultimately, StreamStats was applied to each water quality limited segment to estimate the expected range of flows in the drainage. Details are described for each water quality limited segment in Section H.2, while the overall approach is described in Section H.1.3 below.

H.1.2 TMDL Development

The temperature TMDL and loading capacity are presented in terms of a thermal load. Details associated with the water quality standards used in the TMDL are provided in the main TMDL document. The applicable criteria for the TMDL waterbodies are provided in

Table H- 3. The water quality standards for temperature (OAR 340-041-0028[1]) are presented as the seven-day-average daily maximum (7DADM) temperature in degrees Celsius (°C). The water quality standards also include a human use allowance (HUA) equivalent to 0.3°C.

Details associated with TMDL development varies by waterbody. General information is provided below that is applicable to all waterbodies, while waterbody-specific nuances are presented in Section H.2 below.

[1] https://secure.sos.state.or.us/oard/viewSingleRule.action?ruleVrsnRsn=68734

Table H- 3. Water quality limited segments for temperature in this TMDL and their water quality criteria

303(d) ID	Waterbody Name	River Mile	Use: Applicable Criterion (°C as 7DADM)
Upper Klamath Subbasin			
12872	Beaver Creek	0 to 5.5	Redband trout: 20.0
2158	Grizzly Creek	0 to 3	Redband trout: 20.0
2180	Hoxie Creek	0.8 to 4.4	Redband trout: 20.0
2159	Johnson Creek	0 to 9.4	Redband trout: 20.0
2163	Keene Creek	0 to 7.2	Redband trout: 20.0
2178	Keene Creek	7.5 to 9.7	Redband trout: 20.0
2168	Mill Creek	0 to 3.9	Redband trout: 20.0
2181	South Fork Keene Creek	0 to 3.1	Redband trout: 20.0
12815	Spencer Creek	0 to 18.9	Redband trout: 20.0
21952	Klamath Straits Drain	0 to 9.8	Cool Water Species: Narrative
1984	Jenny Creek	0 to 17.8	Redband trout: 20.0
Lost Subbasin			
24458	Antelope Creek	0 to 14.1	Redband trout: 20.0
2182	Antelope Creek	2 to 3	Redband trout: 20.0
12738	Barnes Valley Creek	0 to 14	Redband trout: 20.0
12737	Ben Hall Creek	0 to 8.7	Redband trout: 20.0
12766	Buck Creek	0 to 11.8	Redband trout: 20.0
24459	East Branch Lost River	0 to 2.4	Redband trout: 20.0
12726	Lapham Creek	0 to 4	Redband trout: 20.0
12732	Long Branch Creek	0 to 4.6	Redband trout: 20.0
24463	Lost River	4.8 to 65.4	Cool Water Species: Narrative
1994	North Fork Willow Creek	0 to 2.3	Redband trout: 20.0
12729	Rock Creek	0 to 4.3	Redband trout: 20.0
2166	Unnamed (Horse Canyon Creek)	0 to 2.2	Redband trout: 20.0
NA	Lost River Diversion Channel to Klamath River	0 to 7.9	Cool Water Species: Narrative
1993	Miller Creek	0 to 9.6	Redband trout: 20.0

H.1.3 Loading Capacity Equation

For all waterbodies, the thermal loading capacity was calculated using Equation H- 1 below. The loading capacity values for each water quality limited segment are provided as examples in Section H.2 below, while specific loading capacities can be calculated for any given flow measurement using Equation H- 1.

Loading capacities were calculated for each of the 18 ungaged tributaries to the Klamath and Lost rivers using flow estimates from StreamStats (note: Antelope Creek includes two segments on the 303(d) list). Specifically, a range of expected flows was obtained for each tributary from StreamStats based on the drainage area, mean annual precipitation, and other basin characteristics. The approach used to estimate flow for Spencer Creek and the Lost River are presented in the waterbody-specific discussions below.

A load capacity curve was developed using different flow conditions for each water quality limited segment, which characterizes the allowable thermal load capacity for a range of expected flows throughout the year.

Loading Capacity Equation

$$\boldsymbol{LC} = (\boldsymbol{T_C} + \boldsymbol{HUA}) \times \boldsymbol{Q_R} \times \boldsymbol{C_F}$$

Equation H- 1

where,

LC = Loading Capacity (kilocalories per day).

T_C = The applicable temperature criteria (°C).

HUA = The 0.3°C human use allowance allocated to point sources, nonpoint sources, margin of safety, or reserve capacity. The HUA provision does not apply for waters designated for cool water species criterion. On these waters this portion of the equation can removed.

Q_R = The daily average river flow rate, upstream (cubic feet per second [cfs]).

C_F= Conversion factor using cubic feet per second: (2,446,622 kcal-s/°C-ft^3-day)

$$\frac{1\,m^3}{35.314\,ft^3} \times \frac{1000\,kg}{1\,m^3} \times \frac{86{,}400\,sec}{1\,day} \times \frac{1\,kcal}{1\,kg \times 1°C} = 2{,}446{,}622$$

H.2 Loading Capacity Calculations

TMDL loading capacity calculations are presented below for the Lost River and Upper Klamath River subbasin waterbodies listed inTable H- 2. Details associated with each waterbody are included in the waterbody-specific sections.

H.2.1 Lost Subbasin

Waters in the Lost River subbasin are identified in Table H- 1 and illustrated in Figure H- 1. As described below, all waters in this subbasin include a StreamStats approach to calculate the thermal loading capacity except for the Lost River.

H.2.1.1 Antelope Creek

There are two 303(d) listed segments for Antelope Creek: a 1-mile segment that was listed in 1998 (303(d) ID 2182) and a 14.1-mile segment listed in 2010 (303(d) ID 24458) (Table H- 1). The 1-mile segment is included in the 2010 listing and are both addressed by this TMDL. The 14.1-mile listed segment of Antelope Creek begins in the Rocky Plateau, flows south through Antelope Flat, and ends with a 0.6-mile segment inside the Willow Valley Reservoir (Figure H-3). Antelope Creek drains an area approximately 57.6 square miles (sq mi) and experiences a mean annual precipitation of 17.5 inches (Table H- 4). A subset of basin characteristics produced and used by StreamStats to determine flow rates in Antelope Creek are presented in Table H- 4.

Expected flows in Antelope Creek range from 0.4 cfs, representative of low flow conditions, to 103 cfs for very high flow conditions (

Table H- 5). These flows were used in Equation H- 1 to calculate loading capacities for Antelope Creek during the various flow conditions. The thermal loading capacity, which was calculated using the lowest flow estimate for the condition, applies to the full range of flows until the next flow condition is reached (

Table H- 5). For example, if the flow rate in Antelope Creek is 5 cfs, the thermal loading capacity is considered to be 5.71E+07 kcal/day, as this falls within the dry flow condition.

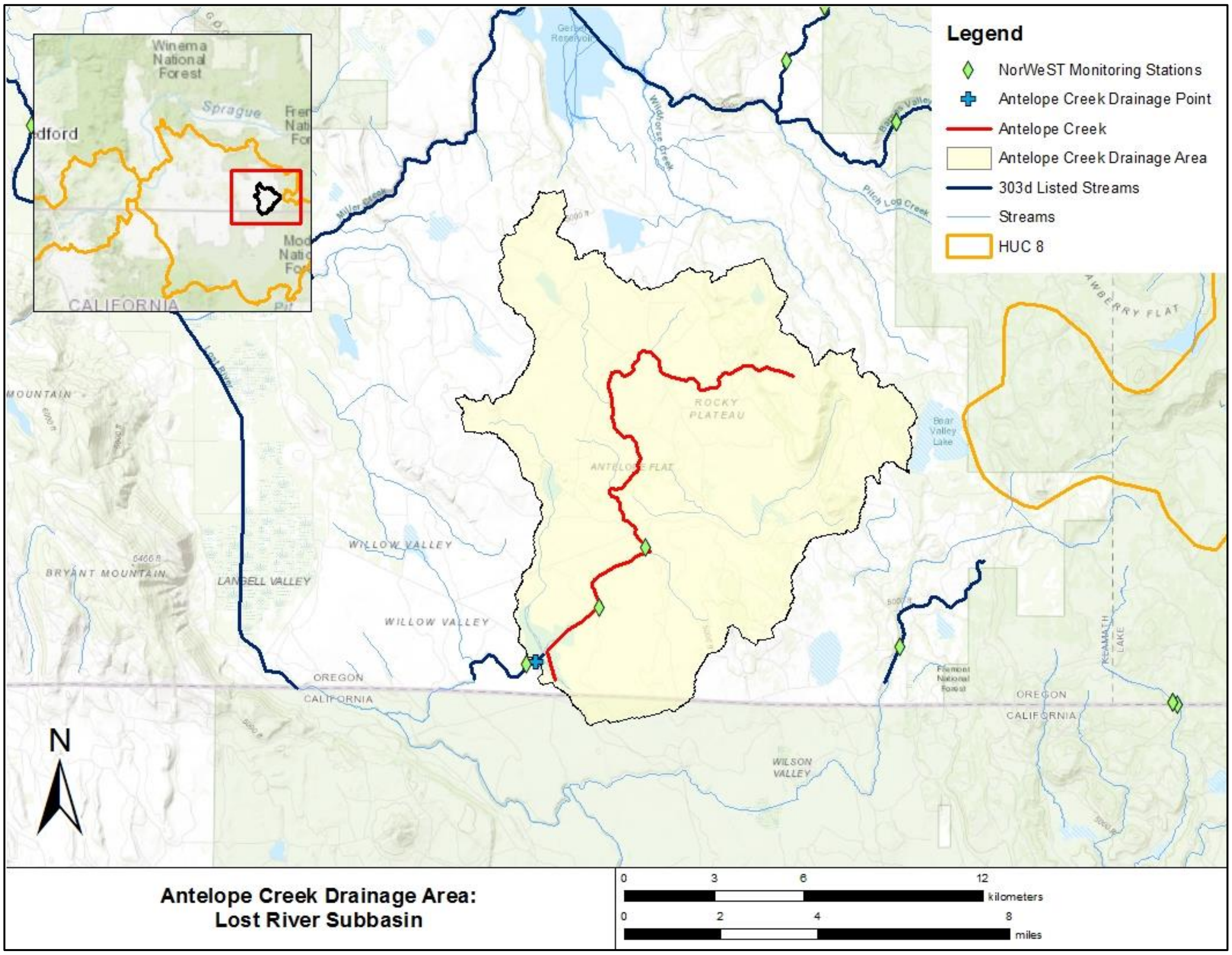

Figure H- 3. Antelope Creek drainage area.

Table H- 4. Antelope Creek basin characteristics used in StreamStats.

Parameter	Value	Units
Drainage Area	57.6	sq mi
Mean Annual Precipitation	17.5	in
Mean Annual Maximum Air Temperature	15.2	°C
Mean Basin Slope	2.32	degrees
Relief	952	ft
Average Soil Permeability	0.97	in/hr
Source: U.S. Geological Survey, 2012, The StreamStats program for Oregon, online at http://water.usgs.gov/osw/streamstats/oregon.html.		

Figure H- 4 presents the relationship between flow conditions and total loading capacity, which ranges from 2.16E+07 kcal/day to 5.12E+09 kcal/day for low and very high flow conditions, respectively (

Table H- 5). This curve characterizes the thermal loading capacity of Antelope Creek for the range of expected flows throughout the year and serves as a reference to estimate the loading capacity for different flow rates using Equation H- 1.

Table H- 5. Antelope Creek thermal loading capacity by flow condition.

Flow Condition	Representative Flow Estimate (cfs)[1]	Applicable Flow Range	Thermal Loading Capacity (kcal/day)[2]
Low	0.4	<1 cfs	2.16E+07
Dry	1	1 cfs to <7 cfs	5.71E+07
Mild	7	7 cfs to <23 cfs	3.23E+08
Moderate	23	23 cfs to <59 cfs	1.12E+09
High	59	59 cfs to <103 cfs	2.95E+09
Very High	103	≥103 cfs	5.12E+09

[1] Estimated from StreamStats analysis.
[2] Loading capacity calculated using Equation H- 1, the representative flow estimate from the second column, and the applicable criterion plus HUA (20.0°C plus 0.3°C). This loading capacity applies to the flow range in the third column of the table.

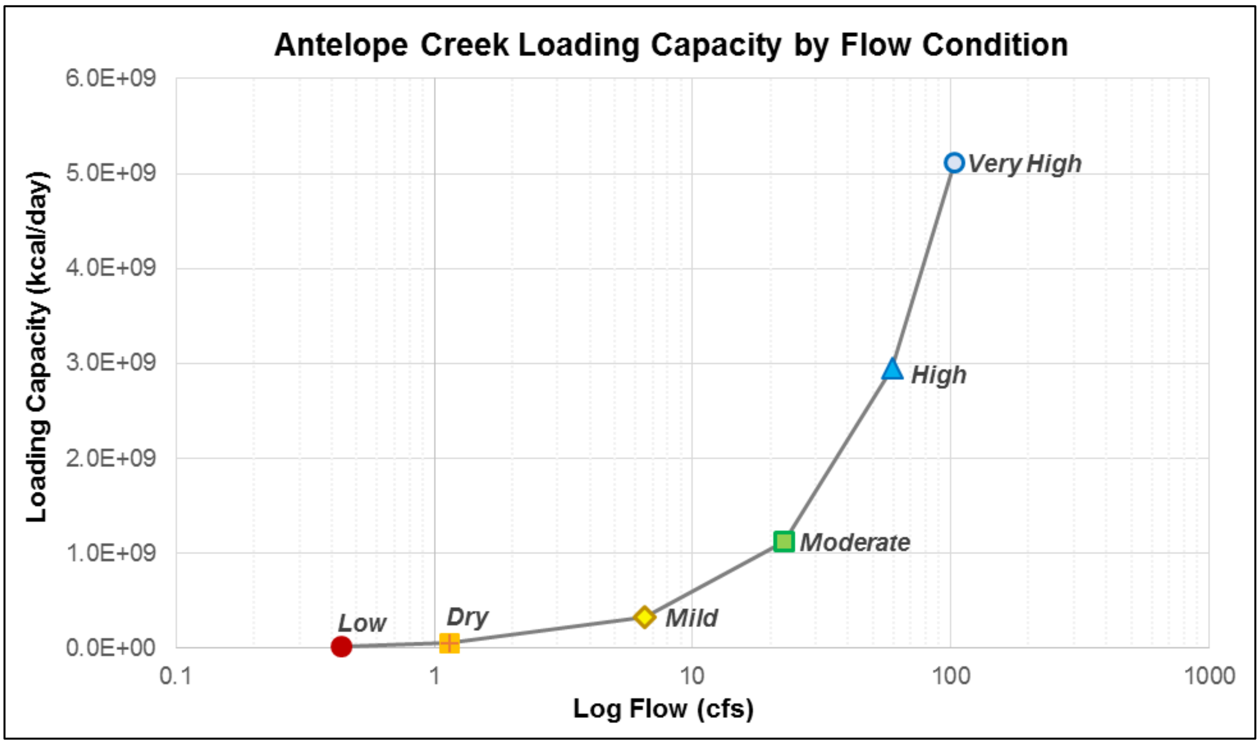

Figure H- 4. Antelope Creek loading capacity curve by flow condition.

H.2.1.2 Barnes Valley Creek

The water quality limited segment of Barnes Valley Creek is 14 miles long (Table H- 1) and begins south of Juniper Mountain, flows through Barney Valley and ends before Geber Reservoir (Figure H- 5). The Barnes Valley Creek drainage area is 94.3 square miles and includes Long Branch and Lapham creeks. Also included in the drainage area are Pitch Log, Strawberry and Wilson creeks. A subset of basin characteristics that are produced by

StreamStats and used to determine flow statistics for Barnes Valley Creek are presented in Table H- 6.

Table H- 6. Barnes Valley Creek basin characteristics used in StreamStats.

Parameter	Value	Units
Drainage Area	94.3	sq mi
Mean Annual Precipitation	21.2	in
Mean Annual Maximum Air Temperature	13.9	°C
Mean Basin Slope	4.02	degrees
Relief	1590	ft
Average Soil Permeability	1.53	in/hr
Source: U.S. Geological Survey, 2012, The StreamStats program for Oregon, online at http://water.usgs.gov/osw/streamstats/oregon.html.		

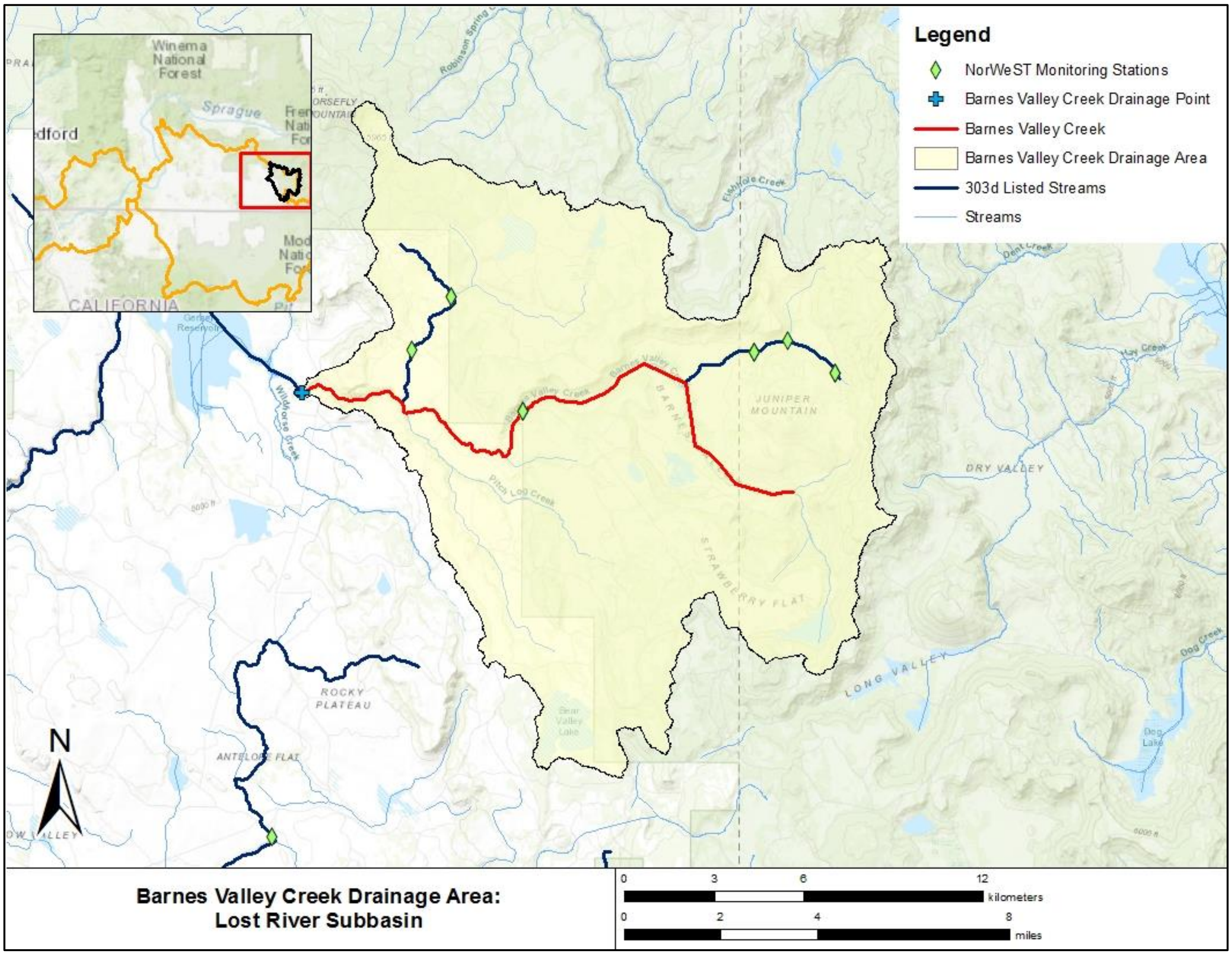

Figure H- 5. Barnes Valley Creek drainage area.

Estimated flow rates for Barnes Valley Creek range from 4 cfs during low flow conditions to 186 cfs for very high flow conditions (). These flows were used in Equation H- 1 to calculate the loading capacity of Barnes Valley Creek for a range of expected flow conditions (Table H- 7). The thermal loading capacity, which was calculated using the lowest flow estimate for the condition, is applied for the full range of flows until the next flow condition is reached (Table H-7).

The relationship between flow condition and thermal loading capacity is represented in Figure H- 6 and, as expected, load capacity increases with increasing flow rates. During the lowest flow condition, Barnes Valley Creek has a thermal loading capacity of 2.07E+08 kcal/day; when the creek is experiencing very high flow conditions, the thermal loading capacity reaches 9.24E+09 kcal/day (Table H- 7). This curve characterizes the thermal loading capacity of Barnes Valley Creek for the range of expected flows throughout the year and can be used as a reference to estimate the loading capacity for different flow rates (Figure H- 6).

Table H- 7. Barnes Valley Creek thermal loading capacity by flow condition.

Flow Condition	Representative Flow Estimate (cfs)[1]	Applicable Flow Range	Thermal Loading Capacity (kcal/day)[2]
Low	4	<6 cfs	2.07E+08
Dry	6	6 cfs to <16 cfs	2.85E+08
Mild	16	16 cfs to <48 cfs	8.10E+08
Moderate	48	48 cfs to <115 cfs	2.38E+09
High	115	115 cfs to <186 cfs	5.71E+09
Very High	186	≥186 cfs	9.24E+09

[1] Estimated from StreamStats analysis.

[2] Loading capacity calculated using Equation H- 1, the representative flow estimate from the second column, and the applicable criterion plus HUA (20.0°C plus 0.3°C). This loading capacity applies to the flow range in the third column of the table.

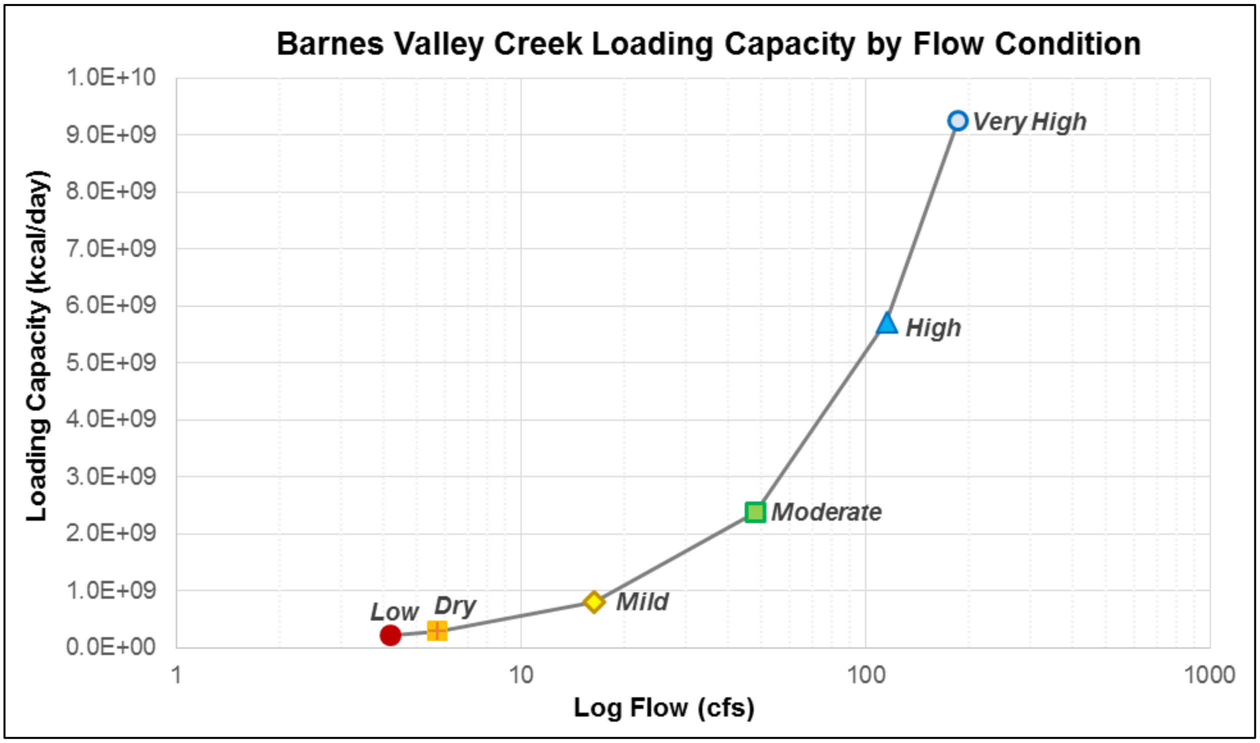

Figure H- 6. Barnes Valley Creek loading capacity curve by flow condition.

H.2.1.3 Ben Hall Creek

Ben Hall Creek is listed for an 8.7-mile long segment (Table H- 1) that begins at the south boundary of Dry Prairie, flows through Geber Reservoir, and terminates at the outlet of the reservoir that flows into Barnes Valley Creek (Figure H- 7). Due to the location of the stream through Geber Reservoir, the drainage area was delineated as far downstream on the water quality limited segment in StreamStats as possible, representing flows coming from the northwest. The drainage area covers an area of approximately 87 square miles. This drainage area extends from Bly Ridge and Yanax Butte in the north to Paddock Butte in the east and Goodlow Mountain in the west. A subset of basin characteristics that are produced by StreamStats and used to determine flow statistics for Ben Hall Creek are presented in Table H-8.

Table H- 8. Ben Hall Creek basin characteristics used in StreamStats.

Parameter	Value	Units
Drainage Area	86.7	sq mi
Mean Annual Precipitation	19.6	in
Mean Annual Maximum Air Temperature	14.8	°C
Mean Basin Slope	4.32	degrees
Relief	2380	ft
Average Soil Permeability	1.56	in/hr
Source: U.S. Geological Survey, 2012, The StreamStats program for Oregon, online at http://water.usgs.gov/osw/streamstats/oregon.html		

Representative flow estimates for Ben Hall Creek range from 2.7 cfs during low flow conditions to 160 cfs for very high flow conditions (Table H- 9). These expected flows were used in Equation H- 1 to determine the range of loading capacities of Ben Hall Creek. The thermal loading capacity, which was calculated using the lowest flow estimate for the condition, applies to the full range of flows until the next flow condition is reached (Table H- 9). As expected, the loading capacity increases with increasing flow conditions, from 1.33E+08 to 1.95E+09 to 7.95E+09 kcal/day for low, moderate, and very high flow conditions, respectively. The relationship between total loading capacity and flow conditions is illustrated in Figure H- 8. This curve characterizes the thermal loading capacity of Ben Hall Creek for the range of expected flows throughout the year and can be used as a reference to estimate the loading capacity for different flow rates (Figure H- 8).

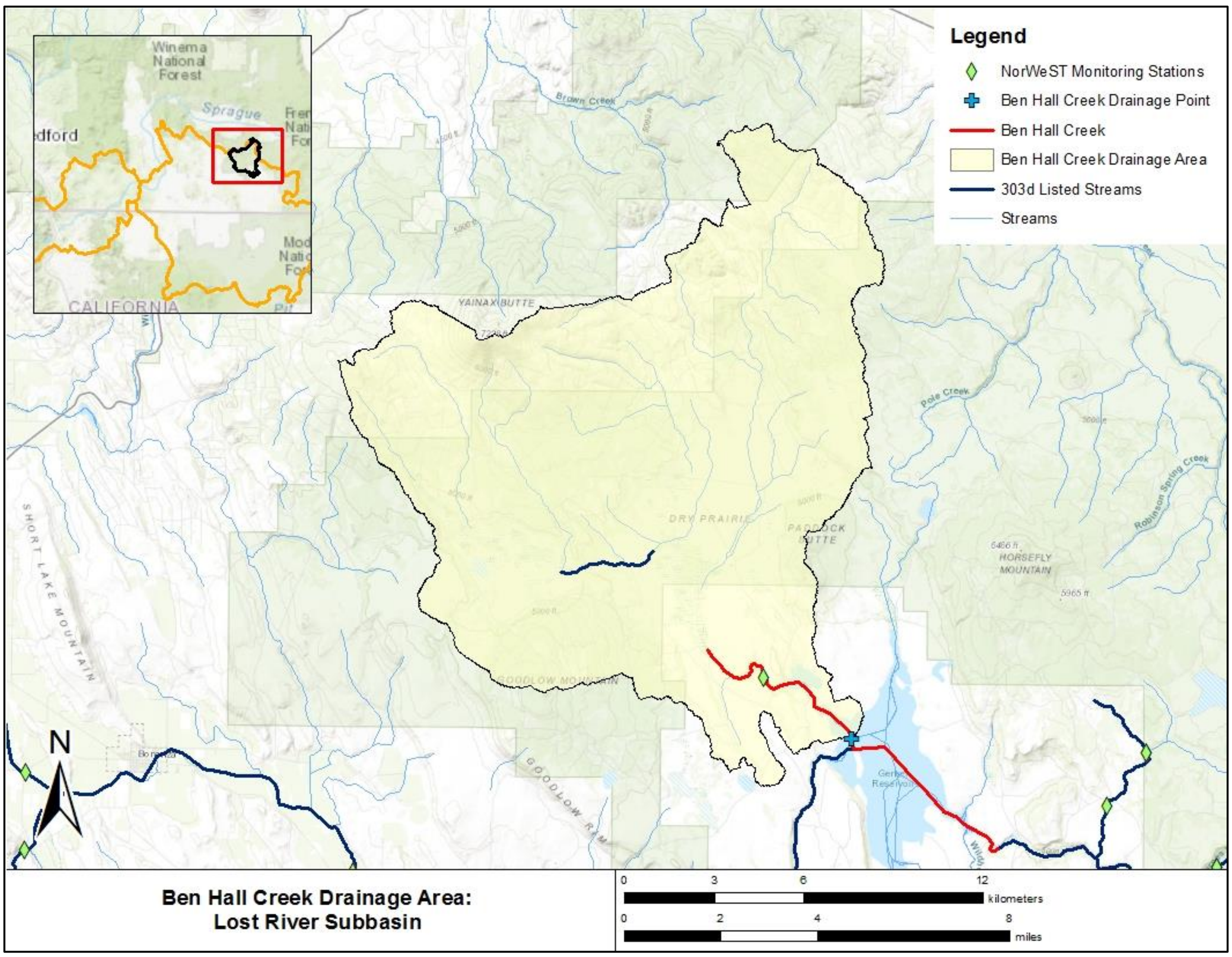

Figure H- 7. Ben Hall Creek drainage area.

Table H- 9. Ben Hall Creek thermal loading capacity by flow condition.

Flow Condition	Representative Flow Estimate (cfs)[1]	Applicable Flow Range	Thermal Loading Capacity (kcal/day)[2]
Low	2.7	<3.9 cfs	1.33E+08
Dry	3.9	3.9 cfs to <13 cfs	1.95E+08

Flow Condition	Representative Flow Estimate (cfs)[1]	Applicable Flow Range	Thermal Loading Capacity (kcal/day)[2]
Mild	13	13 cfs to <39 cfs	6.31E+08
Moderate	39	39 cfs to <97 cfs	1.95E+09
High	97	97 cfs to <160 cfs	4.81E+09
Very High	160	≥160 cfs	7.95E+09

[1] Estimated from StreamStats analysis.

[2] Loading capacity calculated using Equation H- 1, the representative flow estimate from the second column, and the applicable criterion plus HUA (20.0°C plus 0.3°C). This loading capacity applies to the flow range in the third column of the table.

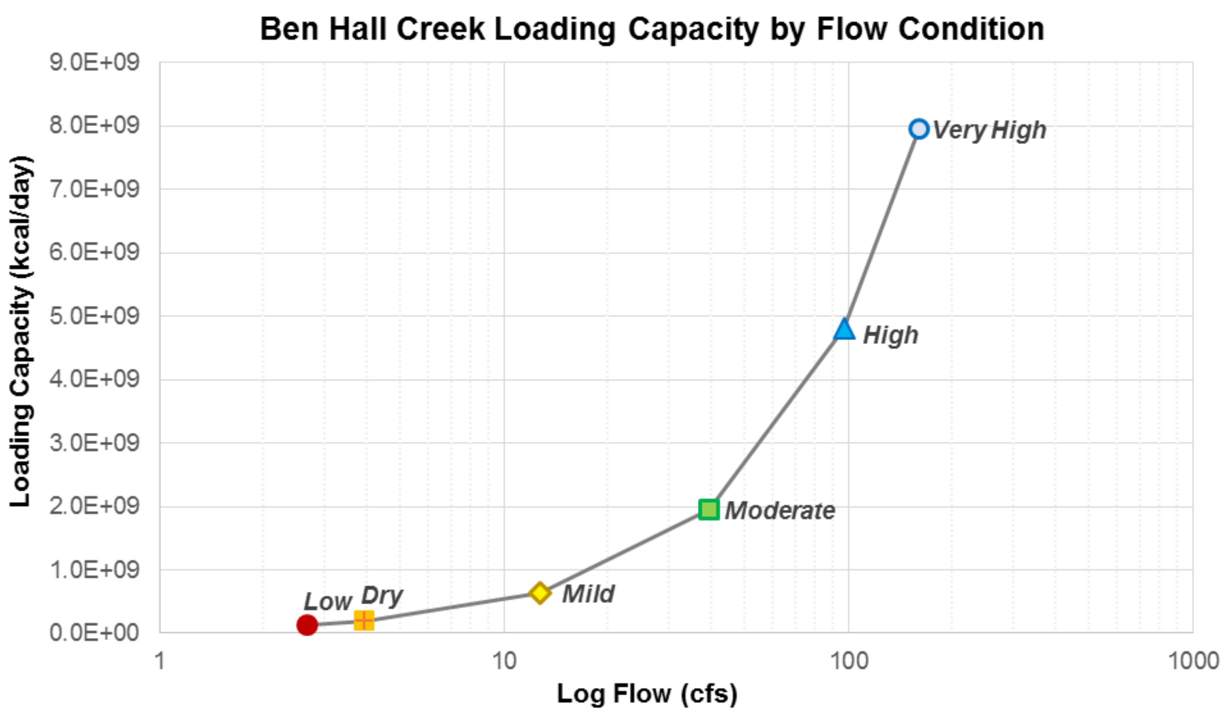

Figure H- 8. Ben Hall Creek loading capacity curve by flow condition

H.2.1.4 Buck Creek

Buck Creek is a tributary to the Lost River and is listed as a water quality limited segment for 12.8 miles (Table H- 1). The segment begins east of Swan Lake Rim, flows south through Yonna Valley under Highway 140 E, and ends at its confluence with the Lost River (Figure H-9). This segment of Buck Creek drains an area of approximately 177 square miles and includes Wildhorse Creek to the east. A subset of the basin characteristics produced by StreamStats and used in the site-specific regression equations to determine flow statistics are presented in

Table H- 10.

Flow conditions for Buck Creek were estimated to range from 3 cfs for low flow conditions, to 44 cfs for moderate conditions, to 181 cfs for very high flow conditions (Table H- 11). These estimated flow conditions were used in Equation H- 1 to determine the thermal loading capacity of Buck Creek for the range of expected flows (Table H- 11). Calculated thermal loading capacity of Buck Creek ranges from 1.39E+08 kcal/day to 2.18E+09 kcal/day to 8.99E+09 kcal/day for low, moderate and very high flow conditions, respectively. The thermal loading capacity was calculated using the lowest flow estimate for the flow condition, however the loading capacity applies to the full range of flows until the next flow condition is reached (Table H- 11). Figure H- 10 demonstrates the relationship between flow rate and thermal loading capacity. This curve characterizes the thermal loading capacity of Buck Creek for the range of expected flows throughout the year and can be used as a reference to estimate the loading capacity for different flow rates using Equation H- 1 (Figure H- 10).

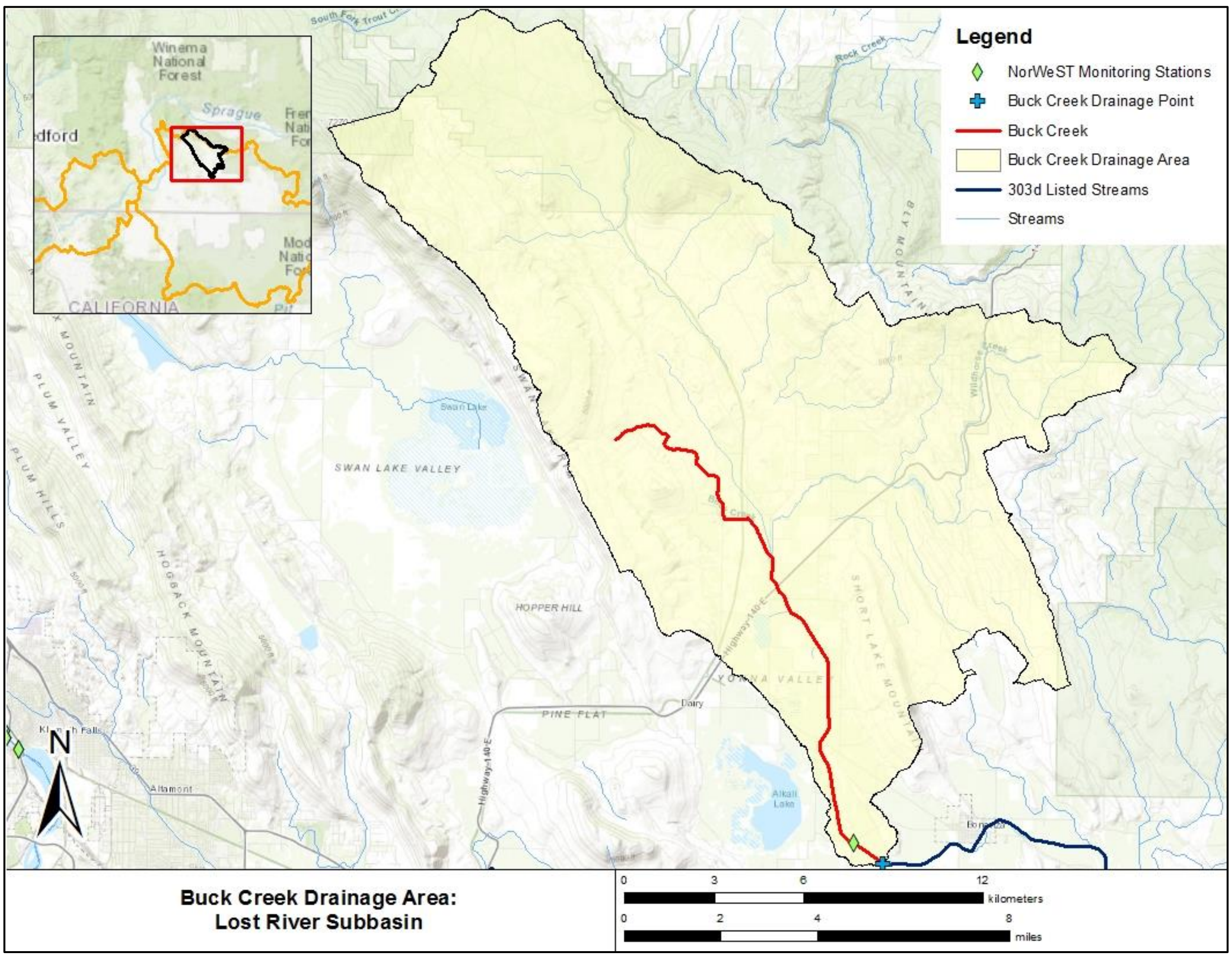

Figure H- 9. Buck Creek drainage area.

Table H- 10. Buck Creek basin characteristics used in StreamStats.

Parameter	Value	Units
Drainage Area	117	sq mi
Mean Annual Precipitation	17.6	in
Mean Annual Maximum Air Temperature	15.5	°C
Mean Basin Slope	4.87	degrees
Relief	3150	ft
Average Soil Permeability	2.09	in/hr
Source: U.S. Geological Survey, 2012, The StreamStats program for Oregon, online at http://water.usgs.gov/osw/streamstats/oregon.html.		

Table H- 11. Buck Creek thermal loading capacity by flow condition.

Flow Condition	Representative Flow Estimate (cfs)[1]	Applicable Flow Range	Thermal Loading Capacity (kcal/day)[2]
Low	3	<4 cfs	1.39E+08
Dry	4	4 cfs to <14 cfs	2.15E+08
Mild	14	14 cfs to <44 cfs	6.95E+08
Moderate	44	44 cfs to <108 cfs	2.18E+09
High	108	108 cfs to <181 cfs	5.36E+09
Very High	181	≥181 cfs	8.99E+09
[1] Estimated from StreamStats analysis. [2] Loading capacity calculated using Equation H- 1, the representative flow estimate from the second column, and the applicable criterion plus HUA (20.0°C plus 0.3°C). This loading capacity applies to the flow range in the third column of the table.			

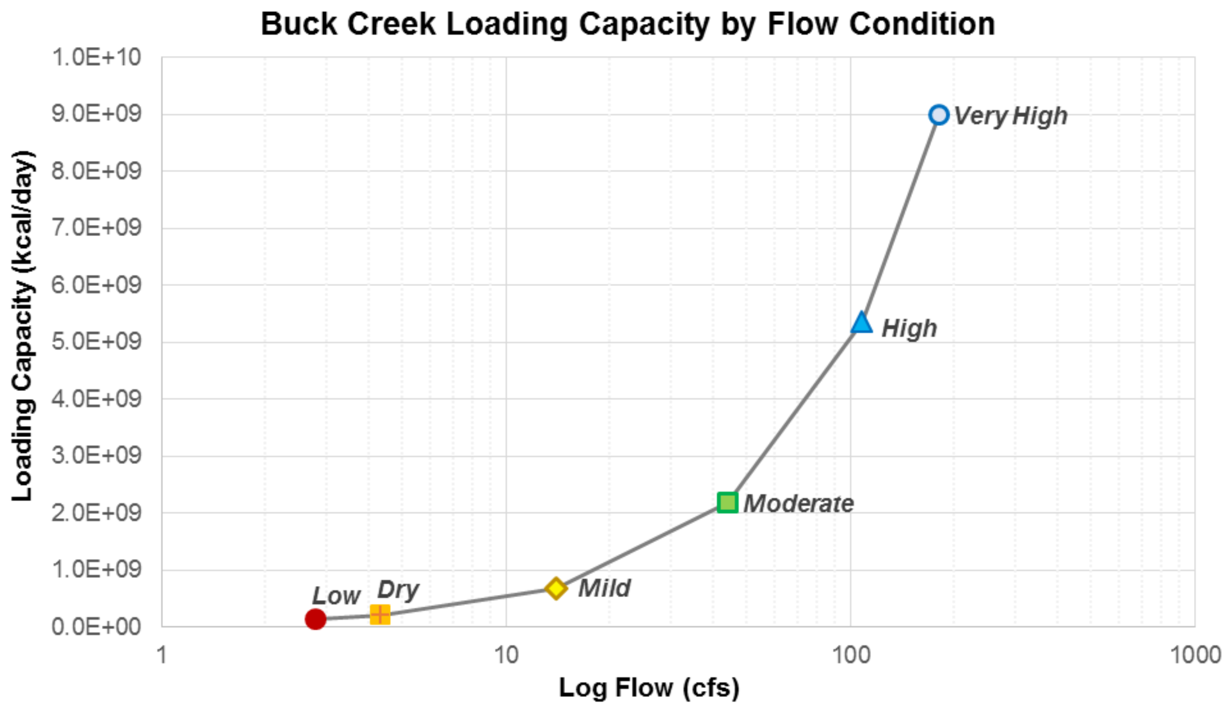

Figure H- 10. Buck Creek loading capacity curve by flow condition

H.2.1.5 East Branch Lost River

The water quality limited segment of the East Branch Lost River is a 2.4 mile segment (Table H-1) that is located south of and includes the Antelope Creek drainage as well as the Willow Valley Reservoir (Figure H- 11). The segment passes below Willow Valley Road and ends just before the California/Oregon border. Because the water quality limited segment of East Branch Lost River has approximately 0.2 miles of the segment located inside the reservoir and is immediately downstream of Antelope Creek, its drainage area includes the reservoir as well as Antelope Creek. In total, the drainage area is about 59 square miles and extends partly into California (Figure H- 11). A subset of basin characteristics produced by StreamStats and used to determine flow rate statistics for the East Branch Lost River is presented in Figure H- 11.

Table H- 12. East Branch Lost River basin characteristics used in StreamStats.

Parameter	Value	Units
Drainage Area	59	sq mi
Mean Annual Precipitation	17.5	in
Mean Annual Maximum Air Temperature	15.2	°C
Mean Basin Slope	2.31	degrees
Relief	1080	ft
Average Soil Permeability	0.97	in/hr
Source: U.S. Geological Survey, 2012, The StreamStats program for Oregon, online at http://water.usgs.gov/osw/streamstats/oregon.html		

Representative flow estimates for various flow conditions in East Branch Lost River range from 0.5 cfs for low and dry flow conditions to 105 cfs during very high flow conditions (Table H- 13). These estimated flows were used in Equation H- 1 to calculate the thermal loading capacity for the flow conditions experienced throughout the year. Thermal loading capacity in the creek ranges from 2.42E+07 kcal/day for low flow conditions to 5.21E+09 kcal/day for very high flow conditions. The thermal loading capacity, which was calculated using the lowest flow estimate for the condition, applies to the full range of flows until the next flow condition is reached (Table H- 13). The relationship between loading capacity and streamflow in East Branch Lost River is presented in Figure H- 12. This curve characterizes the thermal loading capacity for the various flow regimes expected in the creek.

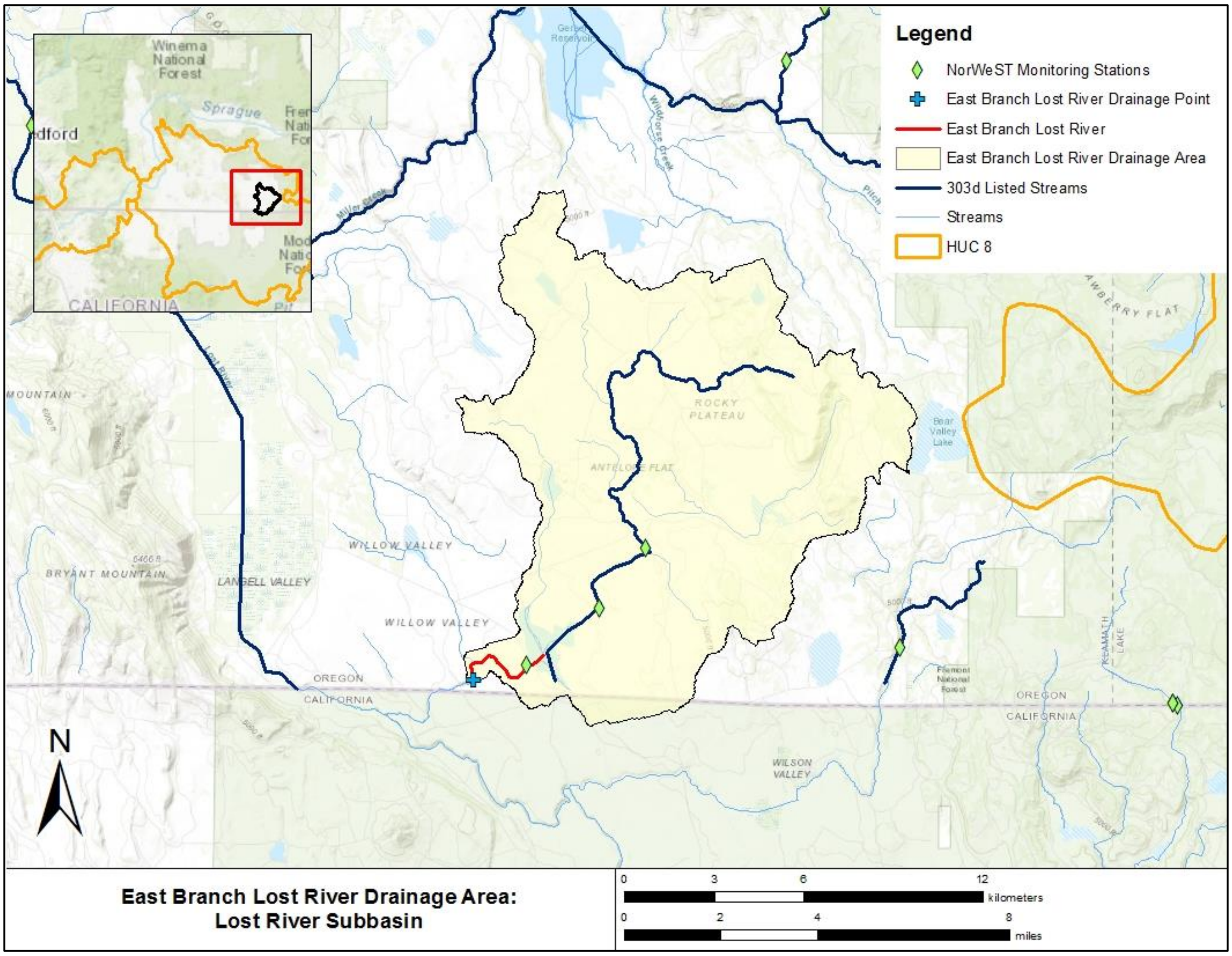

Figure H- 11. East Branch Lost River drainage area.

Table H- 13. East Branch Lost River thermal loading capacity by flow condition.

Flow Condition	Representative Flow Estimate (cfs)[1]	Applicable Flow Range	Thermal Loading Capacity (kcal/day)[2]
Low	0.5	<1 cfs	2.42E+07
Dry	1	1 cfs to <7 cfs	6.06E+07
Mild	7	7 cfs to <23 cfs	3.32E+08
Moderate	23	23 cfs to <61 cfs	1.15E+09
High	61	61 cfs to <105 cfs	3.00E+09
Very High	105	≥105 cfs	5.21E+09

[1] Estimated from StreamStats analysis.

[2] Loading capacity calculated using Equation H- 1, the representative flow estimate from the second column, and the applicable criterion plus HUA (20.0°C plus 0.3°C). This loading capacity applies to the flow range in the third column of the table.

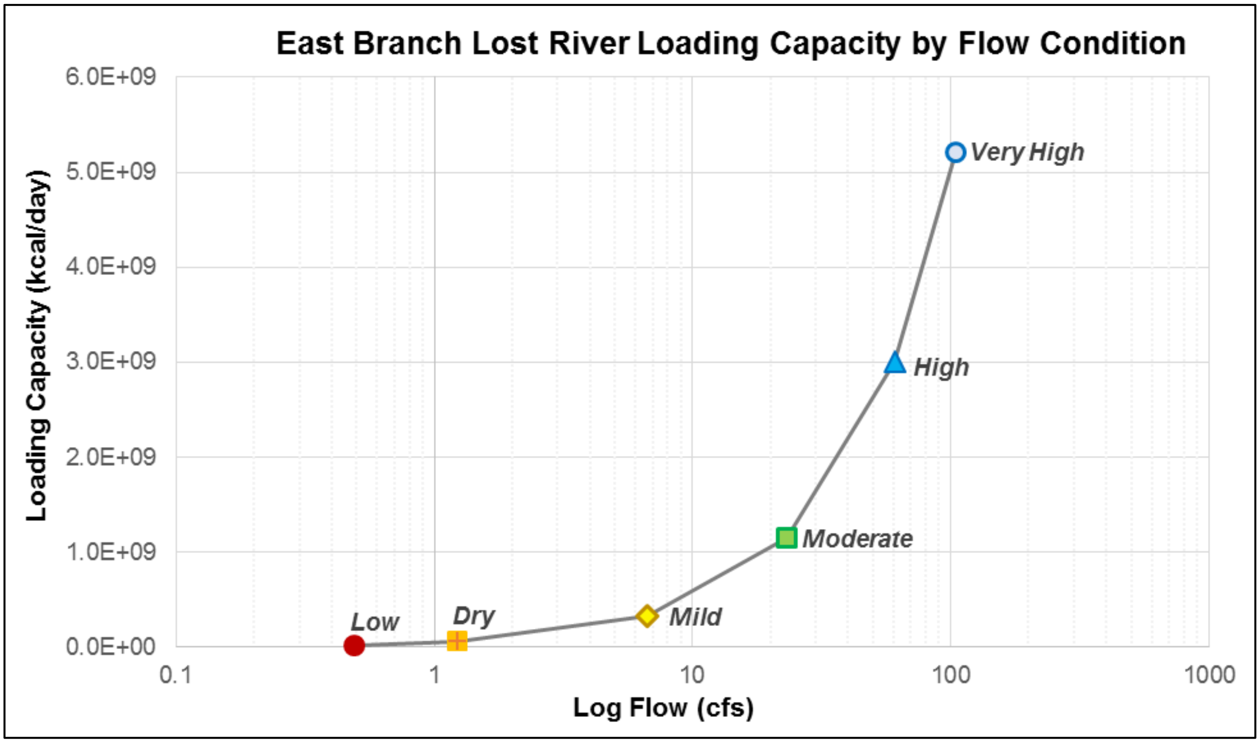

Figure H- 12. East Branch Lost River loading capacity curve by flow condition.

H.2.1.6 Unnamed (Horse Canyon Creek)

Horse Canyon Creek has been referred to as Unnamed Segment: LLID #1212355422566 in previous TMDLs but has since been identified. The water quality limited segment of Horse Canyon Creek is 2.2 miles long (Table H- 1) and runs from west to east in the Fremont National Forest south of Keno Springs Road and ends just north of Dry Prairie Reservoir (Figure H- 13). This segment of Horse Canyon Creek drains a 28 square mile area that extends north to Yainax Butte and south to Goodlow Mountain. A subset of the basin characteristics produced by

StreamStats and used in their regression equations to determine flow rate statistics are presented in Table H- 14.

Table H- 14. Horse Canyon Creek basin characteristics used in StreamStats.

Parameter	Value	Units
Drainage Area	28.4	sq mi
Mean Annual Precipitation	20	in
Mean Annual Maximum Air Temperature	14.4	°C
Mean Basin Slope	5.01	degrees
Relief	n/a	ft
Average Soil Permeability	1.41	in/hr
Source: U.S. Geological Survey, 2012, The StreamStats program for Oregon, online at http://water.usgs.gov/osw/streamstats/oregon.html		

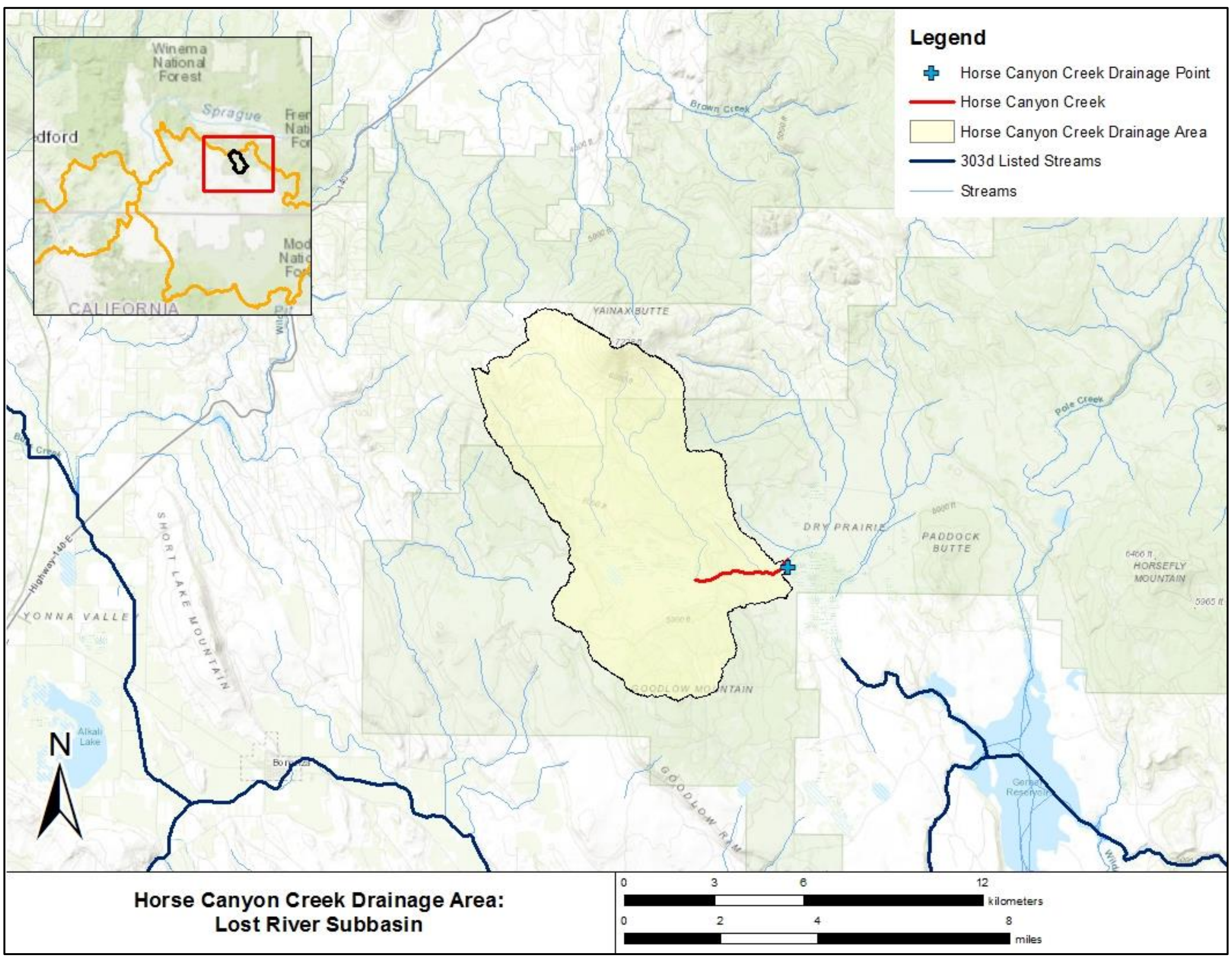

Figure H- 13. Horse Canyon Creek drainage area.

Expected flow rates for various conditions in Horse Canyon Creek are presented in Table H- 15 and range from 0 cfs for low flow conditions to 68 cfs for very high flow conditions. These flow rates were used in Equation H- 1 to determine the thermal loading capacity of Horse Canyon Creek for the array of expected flow conditions. The thermal loading capacity ranges from 0.00E+00 kcal/day for low flow conditions to 1.16E+07 kcal/day for dry conditions to 3.36E+09 kcal/day for very high flow conditions (Table H- 15). The thermal loading capacity, which was calculated using the lowest flow estimate for the condition, applies to the full range of flows until the next flow condition is reached (Table H- 15). However, Equation H- 1 can be used to calculate the thermal loading capacity for flow rates below 0.2 cfs in the low flow condition.

The relationship between streamflow and thermal loading capacity in Horse Canyon Creek is presented in Figure H- 14. This curve characterizes the thermal loading capacity for the various flow regimes expected in the creek throughout the year. As thermal loading capacity is dependent on flow, it is expected that during a low flow condition with a streamflow of 0 cfs the thermal loading capacity is 0 kcal/day. The low flow condition thermal loading capacity is represented at the origin, or the lowest part of the load capacity graph, in Figure H- 14 since a 0 cfs flow cannot be readily illustrated on a log scale.

Table H- 15. Horse Canyon Creek thermal loading capacity by flow condition.

Flow Condition	Representative Flow Estimate (cfs)[1]	Applicable Flow Range	Thermal Loading Capacity (kcal/day)[2]
Low	0	<0.2 cfs	0.00E+00
Dry	0.2	0.2 cfs to <4 cfs	1.16E+07
Mild	4	4 cfs to <14 cfs	2.00E+08
Moderate	14	14 cfs to <39 cfs	7.15E+08
High	39	39 cfs to <68 cfs	1.95E+09
Very High	68	≥68 cfs	3.36E+09

[1] Estimated from StreamStats analysis.

[2] Loading capacity calculated using Equation H- 1, the representative flow estimate from the second column, and the applicable criterion plus HUA (20.0°C plus 0.3°C). This loading capacity applies to the flow range in the third column of the table.

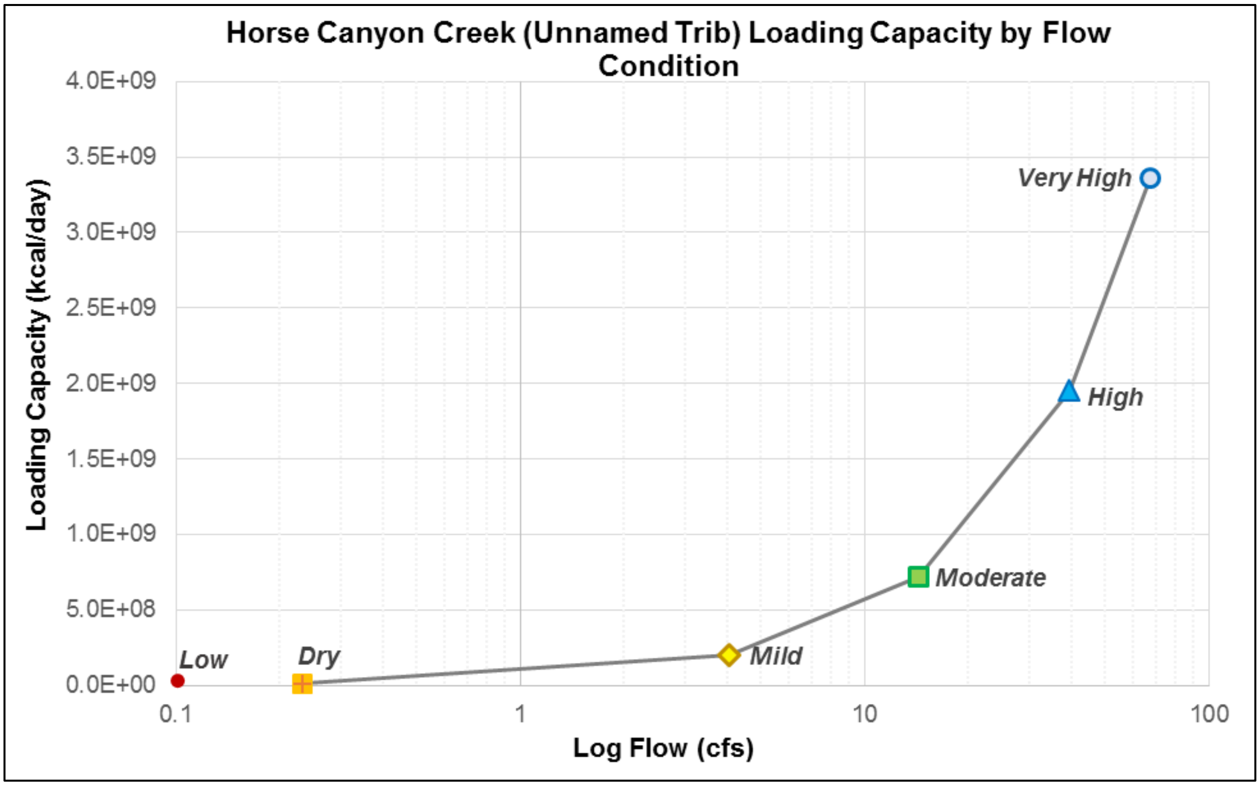

Figure H- 14. Horse Canyon Creek loading capacity curve by flow condition.

H.2.1.7 Klamath Straits Drain

The water quality listed segment for Klamath Straits Drain is approximately a 10-mile segment. The drain/canal conveys water from the Lower Klamath National Wildlife Refuge (LKLNWR) and irrigated land which has been reclaimed from Lower Klamath Lake to the Klamath River. The drain begins at Stateline after the LKLNWR and extends up to the Klamath River.

Representative flow estimates for Klamath Straits Drain were obtained from observed measurements at USGS 11509340 - Klamath Straits Drain Near Worden, OR (Figure H- 15). This station has historical data from 10/31/2011 to present (at the time of analysis the flow data up to 3/18/2019 was used). Flows were typically lowest during the summer months with high flows observed during the winter/early spring period.

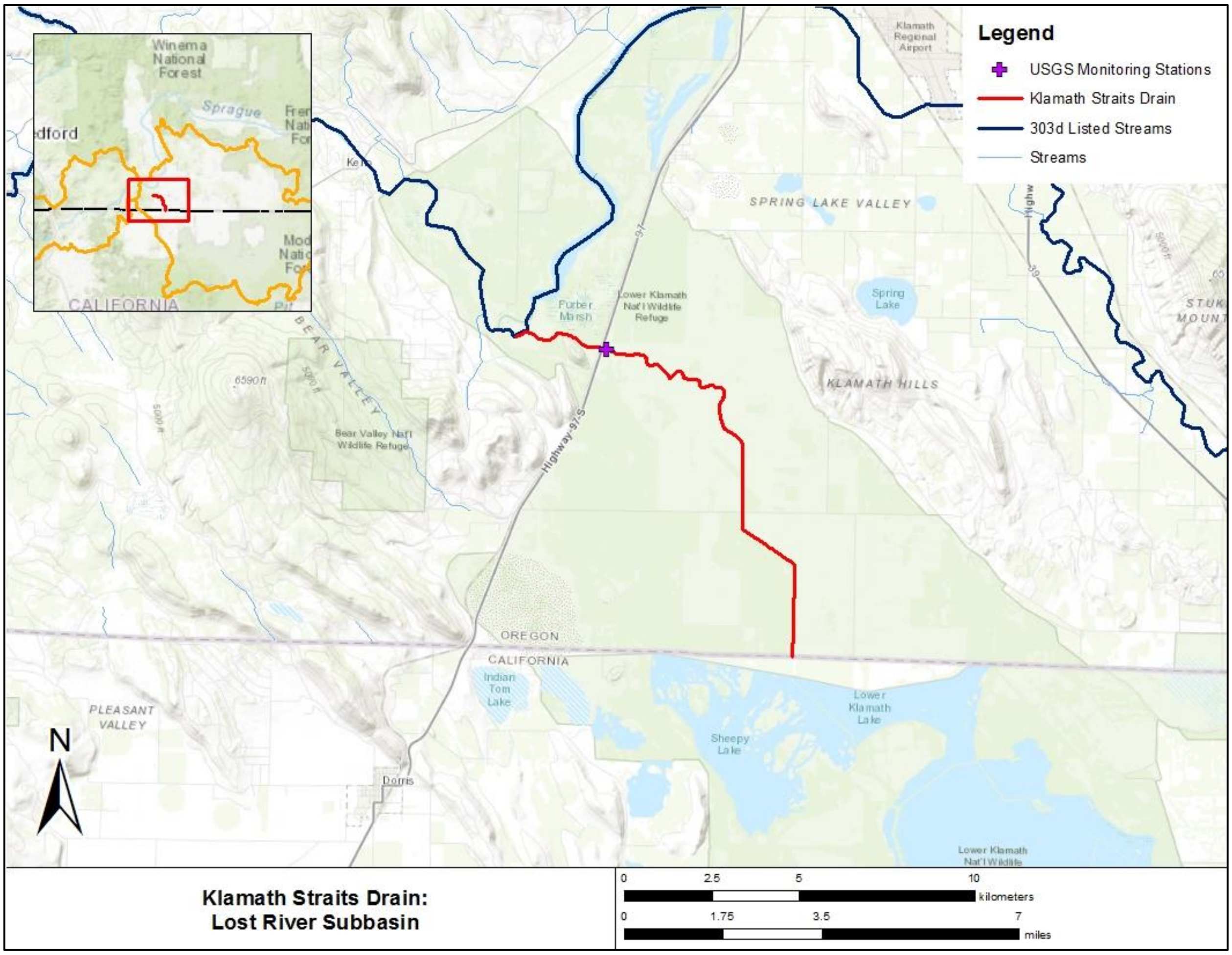

Figure H- 15. Klamath Straits Drain location: Lost River Subbasin.

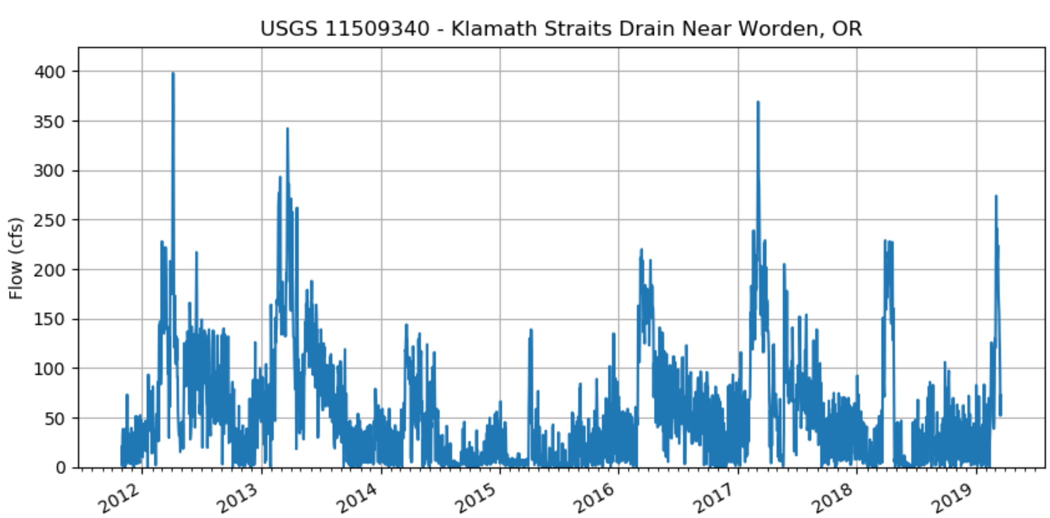

Figure H- 16. Daily flow data at Klamath Straits Drain.

A flow frequency analysis was constructed on the 2011 to 2019 data using the Weibull plotting positions method. Figure H- 17 illustrates the flow percentile distribution and Table H- 16 below summarizes the flow statistics that were used in the thermal loading capacity calculations. The top one perecent of flows had some very extrememe high flow values ranging from 247 to 398 cfs.

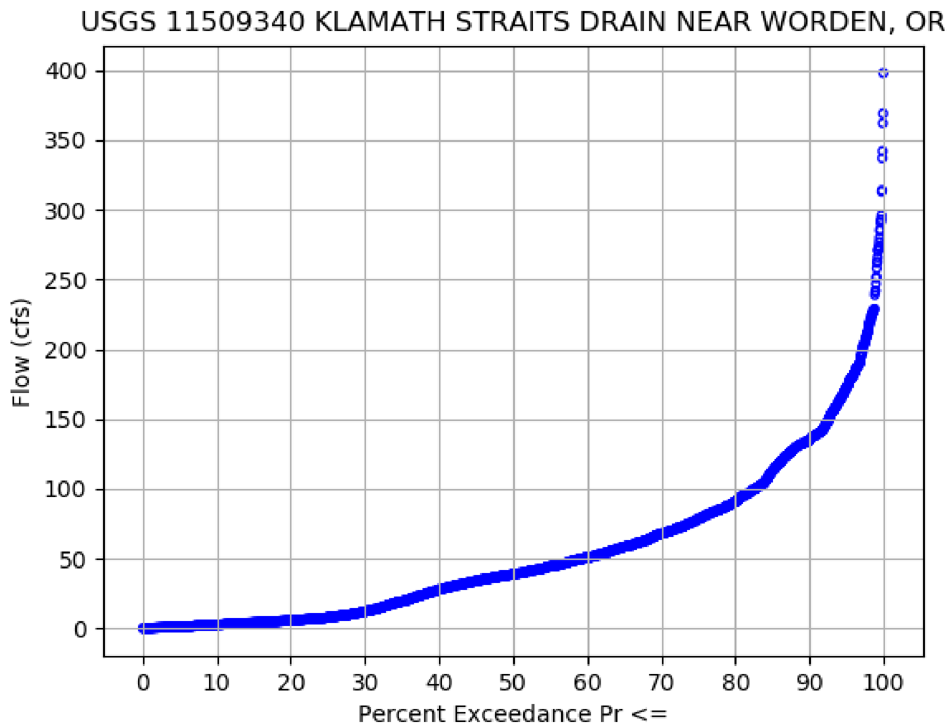

Figure H- 17. Flow duration curve for Klamath Straits Drain (10/31/2011 to 3/18/2019).

Table H- 16. Klamath Straits Drain thermal loading capacity by flow condition.

Flow Condition	Representative Flow Estimate (cfs)[1]	Applicable Flow Range	Thermal Loading Capacity (kcal/day)[2]
Low	0.24	<1 cfs	1.64E+07
Dry	1	1 cfs to <39cfs	6.85E+07
Mild	39	39 cfs to <78 cfs	2.67E+09
Moderate	78	78 cfs to <135 cfs	5.34E+09
High	135	135 cfs to <173 cfs	9.25E+09
Very High	173	≥173 cfs	1.19E+10

[1] Estimated from analysis of 2011-2019 observed flows at USGS Station 11509340.

[2] Loading capacity calculated using Equation H- 1, the representative flow estimate from the second column, and the applicable criterion plus HUA (27.9°C plus 0.1°C). This loading capacity applies to the flow range in the third column of the table.

The flow estimates resulted in a range from 0.24 cfs during low flow conditions to 173 cfs for very high flow conditions (Table H- 16). These expected flows were used in Equation H- 1 to determine the range of loading capacities for the Klamath Straits Drain. The thermal loading capacity, which was calculated using the lowest flow estimate for the condition, applies to the full range of flows until the next flow condition is reached (Table H- 16). The loading capacity increases with increasing flow, from 1.64E+07 to 1.19E+10 kcal/day for low and very high flow conditions, respectively. The relationship between total loading capacity and flow conditions is illustrated in Figure H- 18. This curve characterizes the thermal loading capacity of Klamath Straits Drain for the range of expected flows throughout the year and can be used as a reference to estimate the loading capacity for different flow rates (Figure H- 18).

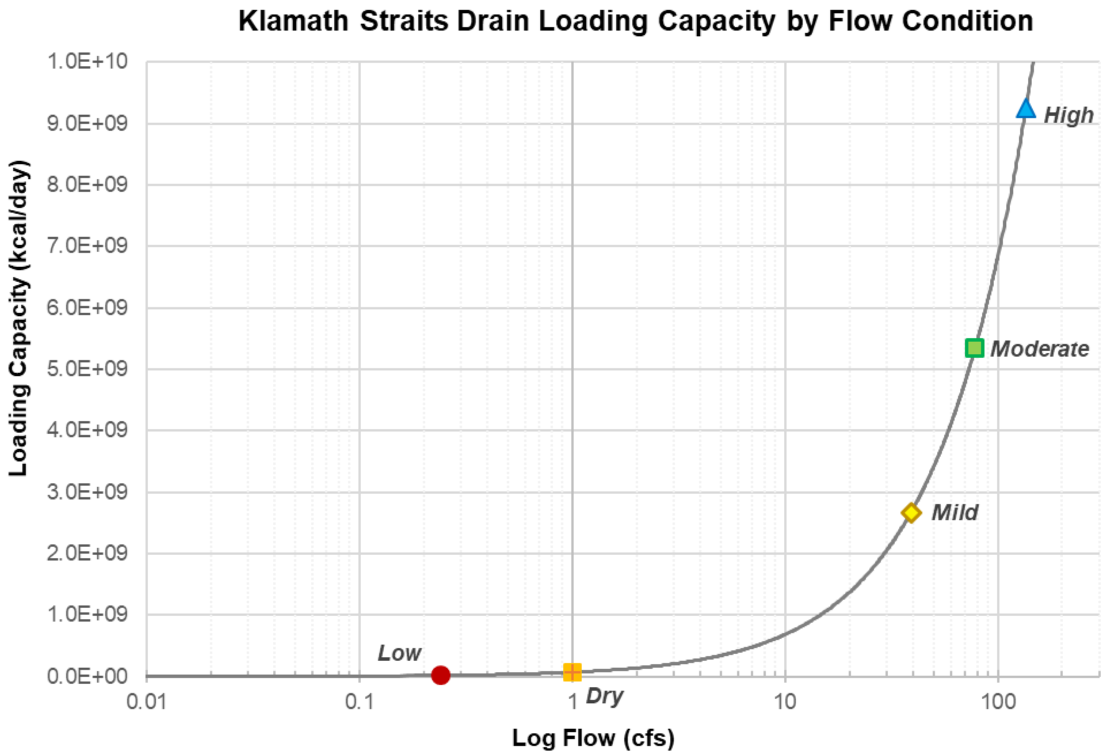

Figure H- 18. Klamath Straits Drain loading capacity curve by flow condition.

H.2.1.8 Jenny Creek

Jenny Creek is a tributary to the Klamath River. Jenny Creek is listed for a 17.8-mile segment (out of which approximately 14.7-miles is in Oregon) that begins at the confluence with Johnson Creek to the Oregon/California border (ultimately feeding into the Klamath River). Jenny Creek drains an area of approximately 200 square miles (Figure H- 19). A subset of the basin characteristics produced by StreamStats and used to determine streamflow statistics for Jenny Creek from the Oregon/California border is presented in Table H- 17.

Table H- 17. Jenny Creek basin characteristics used in StreamStats.

Parameter	Value	Units
Drainage Area	200	sq mi
Mean Annual Precipitation	29.1	in
Mean Annual Maximum Air Temperature	14.22	°C
Mean Basin Slope	7.77	degrees
Relief	3560	ft
Average Soil Permeability	1.48	in/hr
Source: U.S. Geological Survey, 2012, The StreamStats program for Oregon, online at http://water.usgs.gov/osw/streamstats/oregon.html.		

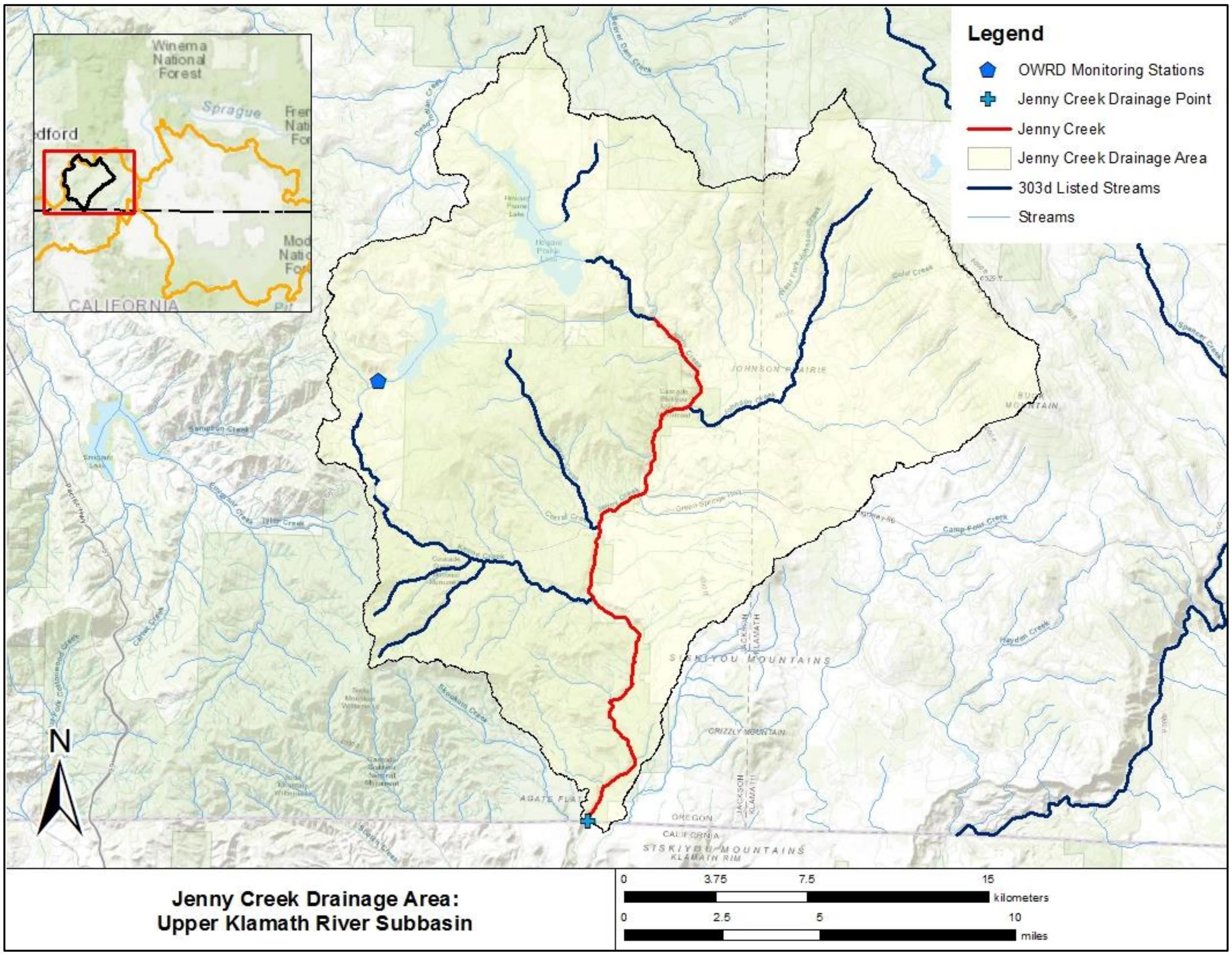

Figure H- 19. Jenny Creek drainage area.

Representative flow estimates for Jenny Creek are 29 cfs during low flow conditions and range from 37 cfs for dry flow conditions to 471 cfs for very high flow conditions (Table H- 18). These representative flows were used in Equation H- 1 to calculate the thermal loading capacity of Jenny Creek for the range of expected flow conditions. The thermal loading capacity for Jenny Creek ranges from 0.43E+09 kcal/day during low flow conditions to 2.34E+10 kcal/day during very high flow conditions (Table H- 18). The thermal loading capacity, which was calculated using the lowest flow estimate for each condition, applies to the full range of flows until the next flow condition is reached (Table H- 18).

The relationship between streamflow and thermal loading capacity in Jenny Creek at the Oregon/California border is presented in Figure H- 20. This curve characterizes the thermal loading capacity for the various flow regimes expected in the creek throughout the year. Note that the loading capacity is presented based on StreamStats at the downstream and the compliance was evaluated using the Heat Source Model developed for Jenny Creek.

Table H- 18. Long Branch Creek thermal loading capacity by flow condition.

Flow Condition	Representative Flow Estimate (cfs)[1]	Applicable Flow Range	Thermal Loading Capacity (kcal/day)[2]
Low	29	<37 cfs	1.43E+09
Dry	37	37 cfs to <70cfs	1.83E+09
Mild	70	70 cfs to <156 cfs	3.48E+09
Moderate	156	156 cfs to <327 cfs	7.75E+09
High	327	327 cfs to <471 cfs	1.62E+10
Very High	471	≥471 cfs	2.34E+10

[1] Estimated from StreamStats analysis.

[2] Loading capacity calculated using Equation H- 1, the representative flow estimate from the second column, and the applicable criterion plus HUA (20.0°C plus 0.3°C). This loading capacity applies to the flow range in the third column of the table

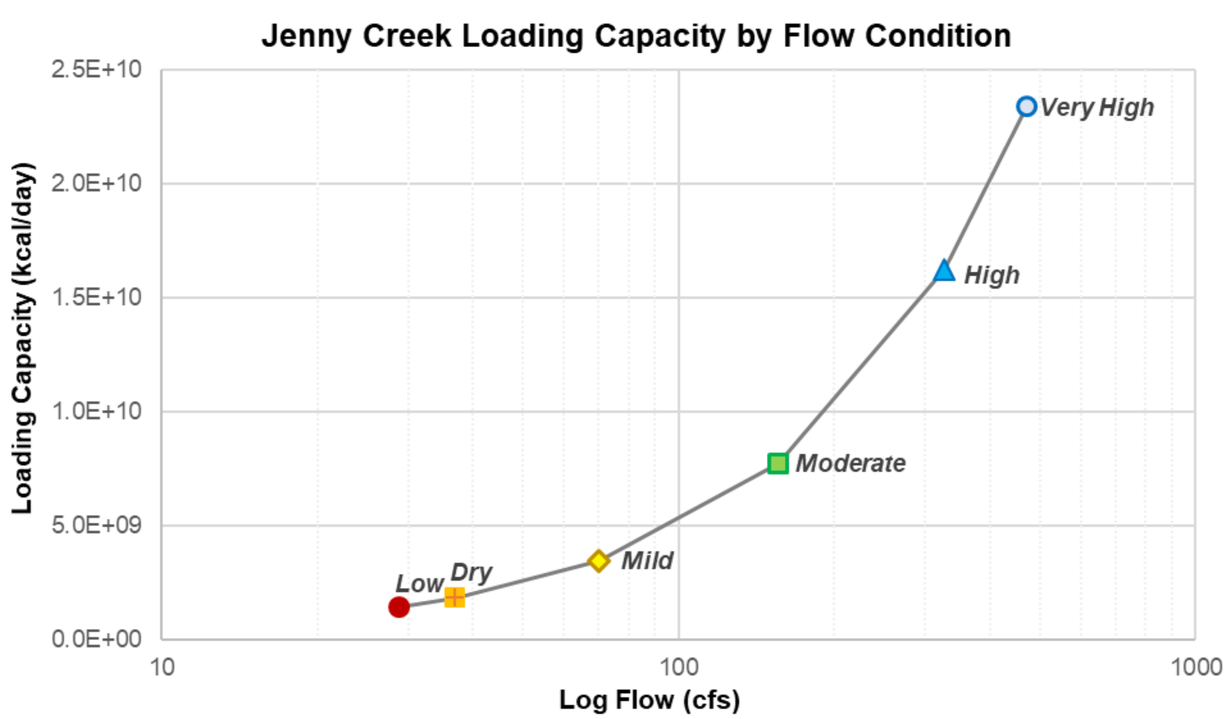

Figure H- 20. Jenny Creek loading capacity curve by flow condition.

H.2.1.9 Lapham Creek

The water quality limited segment of Lapham Creek has its headwaters in Holmes Meadow and flows west for 4 miles to its confluence with Barnes Valley Creek (Table H- 1 and Figure H- 15). An approximate area of 11.6 miles drains to Lapham Creek, which includes Wilson Creek to the north that flows through Arkansas Flat and Arkansas Reservoir (Figure H- 15). As a tributary to Barnes Valley Creek, the drainage area of Lapham Creek, which extends north to Pill Lake and south to Juniper Mountain, comprises the north east part of the Barnes Valley Creek drainage area (Figure H- 5). Table H- 17 presents a subset of the basin characteristics produced by StreamStats and that are used in the site-specific regression equations to determine the representative flow estimates.

Estimated flow rates for various flow conditions in Lapham Creek are presented in Table H- 18 and range from 0 cfs for low and dry flow conditions to 2 cfs for mild flow conditions and 38 cfs for very high flow conditions. These flows were used in Equation H- 1 to determine the thermal loading capacity of Lapham Creek for the range of expected streamflows. The thermal loading capacity, which was calculated using the lowest flow estimate for the condition, is applicable to the full range of flows until the next flow condition is reached (Table H- 18). Equation H- 1 can be used to calculate the thermal loading capacity for flow rates below 2 cfs.

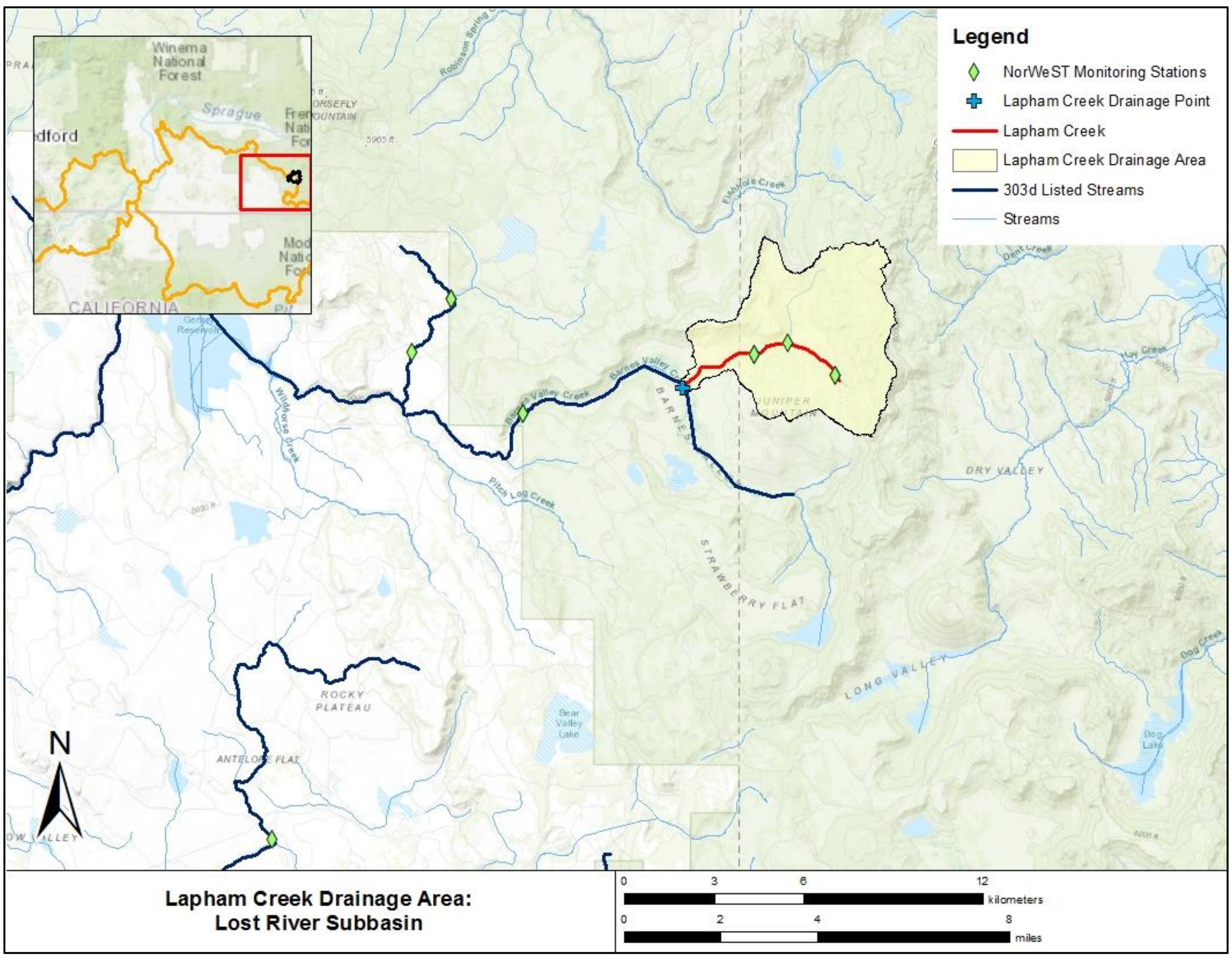

Figure H- 21. Lapham Creek drainage area.

Table H- 19. Lapham Creek basin characteristics used in StreamStats.

Parameter	Value	Units
Drainage Area	11.6	sq mi
Mean Annual Precipitation	22.5	in
Mean Annual Maximum Air Temperature	13.2	°C
Mean Basin Slope	7.39	degrees
Relief	1270	ft
Average Soil Permeability	1.64	in/hr
Source: U.S. Geological Survey, 2012, The StreamStats program for Oregon, online at http://water.usgs.gov/osw/streamstats/oregon.html.		

Figure H- 22 demonstrates the relationship between thermal loading capacity and streamflow in Lapham Creek and characterizes the thermal loading capacity for the flow regimes expected throughout the year. Similar to Horse Canyon Creek, streamflow for low and dry flow conditions were estimated to have a flow rate of 0 cfs and thus a thermal loading capacity of 0 kcal/day for each condition. The low and dry flow condition thermal loading capacities are represented at the origin of the load capacity curve in Figure H- 22 since streamflow is presented on a log scale and cannot display a 0 cfs flow.

Table H- 20. Lapham Creek thermal loading capacity by flow condition.

Flow Condition	Representative Flow Estimate (cfs)[1]	Applicable Flow Range	Thermal Loading Capacity (kcal/day)[2]
Low	0	0	0.00E+00
Dry	0	0 cfs to <2 cfs	0.00E+00
Mild	2	2 cfs to <8 cfs	9.78E+07
Moderate	8	8 cfs to <22 cfs	3.75E+08
High	22	22 cfs to <38 cfs	1.08E+09
Very High	38	≥38 cfs	1.88E+09

[1] Estimated from StreamStats analysis.

[2] Loading capacity calculated using Equation H- 1, the representative flow estimate from the second column, and the applicable criterion plus HUA (20.0°C plus 0.3°C). This loading capacity applies to the flow range in the third column of the table.

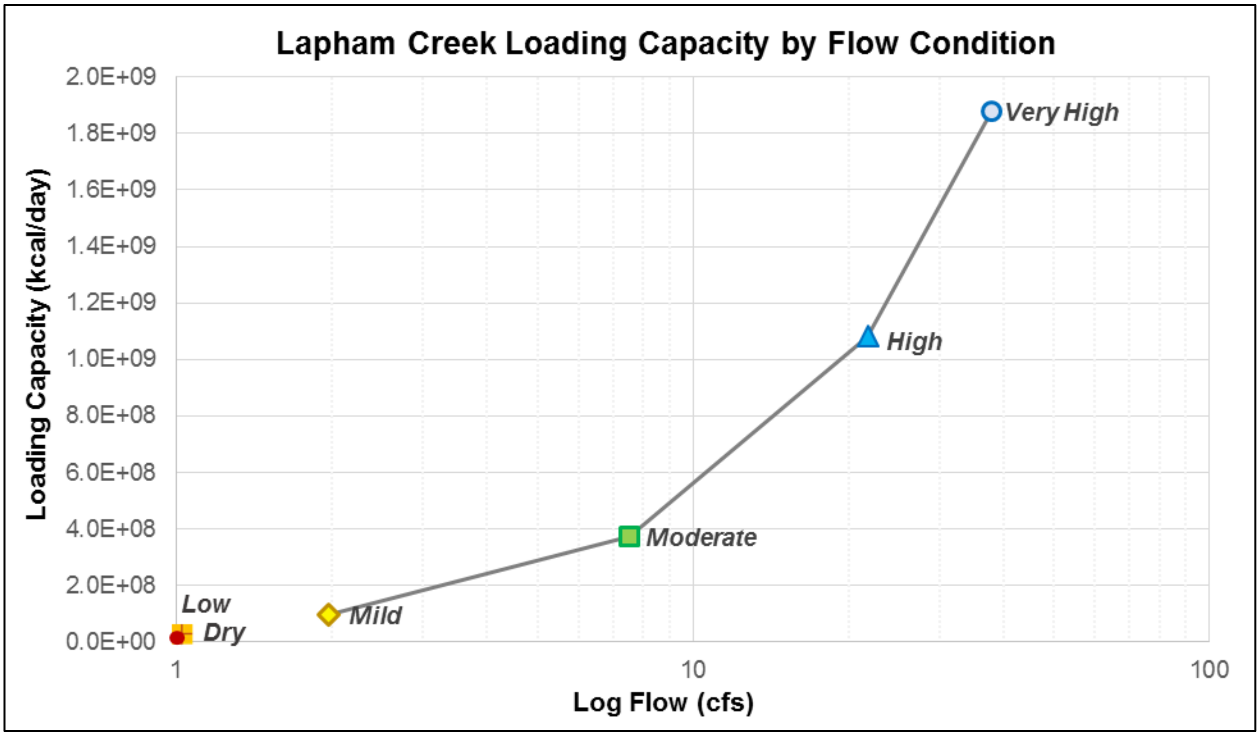

Figure H- 22. Lapham Creek loading capacity curve by flow condition.

H.2.1.10 Long Branch Creek

Long Branch Creek is a tributary to Barnes Valley Creek and is listed for a 4.6 mile segment that begins at Long Branch Spring, flows south to the east of Barnes Valley Road, and ends at its confluence with Barnes Valley Creek (Table H- 1 and Figure H- 23). Long Branch Creek drains an area of approximately 23 square miles and similar to Lapham Creek, which is also a tributary to Barnes Valley Creek, comprises a part of the Barnes Valley Creek drainage area (Figure H- 5). A subset of the basin characteristics produced by StreamStats and used to determine streamflow statistics for Long Branch Creek is presented in Table H- 21.

Table H- 21. Long Branch Creek basin characteristics used in StreamStats.

Parameter	Value	Units
Drainage Area	23.2	sq mi
Mean Annual Precipitation	21.1	in
Mean Annual Maximum Air Temperature	14.1	°C
Mean Basin Slope	2.68	degrees
Relief	1380	ft
Average Soil Permeability	1.16	in/hr
Source: U.S. Geological Survey, 2012, The StreamStats program for Oregon, online at http://water.usgs.gov/osw/streamstats/oregon.html		

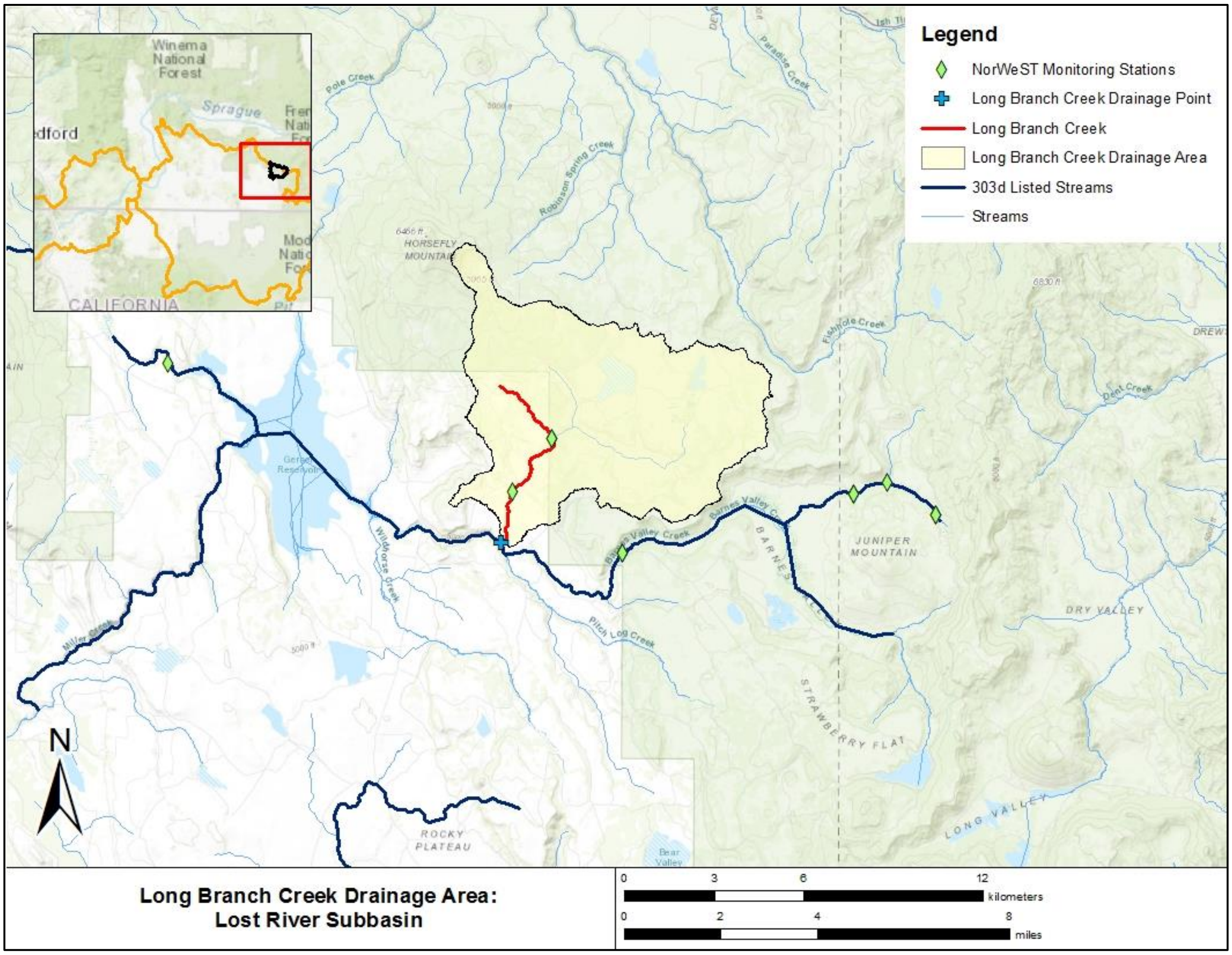

Figure H- 23. Long Branch Creek drainage area.

Representative flow estimates for Long Branch Creek are 0 cfs during low flow conditions and range from 0.1 cfs for dry flow conditions to 61 cfs for very high flow conditions (

Table H- 22). These representative flows were used in Equation H- 1 to calculate the thermal loading capacity of Long Branch Creek for the range of expected flow conditions. The thermal loading capacity for Long Branch Creek ranges from 0.00E+00 kcal/day during low flow conditions to 3.03E+09 kcal/day during very high flow conditions (

Table H- 22). The thermal loading capacity, which was calculated using the lowest flow estimate for each condition, applies to the full range of flows until the next flow condition is reached (

Table H- 22). Equation H- 1 can be used to calculate the thermal loading capacity for low flow rates below 0.1 cfs.

The relationship between streamflow and thermal loading capacity in Long Branch Creek is presented in Figure H- 24. This curve characterizes the thermal loading capacity for the various flow regimes expected in the creek throughout the year. As thermal loading capacity is dependent on flow, a low flow condition with a streamflow of 0 cfs results in a thermal loading capacity of 0 kcal/day. The low flow condition thermal loading capacity is represented at the origin, or the lowest part of the load capacity graph, in Figure H- 24 since streamflow is displayed on a log scale that cannot easily illustrate a 0 cfs flow.

Table H- 22. Long Branch Creek thermal loading capacity by flow condition.

Flow Condition	Representative Flow Estimate (cfs)[1]	Applicable Flow Range	Thermal Loading Capacity (kcal/day)[2]
Low	0	<0.1 cfs	0.00E+00
Dry	0.1	0.1 cfs to <4 cfs	4.68E+06
Mild	4	4 cfs to <13 cfs	1.80E+08
Moderate	13	13 cfs to <36 cfs	6.46E+08
High	36	36 cfs to <61 cfs	1.77E+09
Very High	61	≥61 cfs	3.03E+09

[1] Estimated from StreamStats analysis.

[2] Loading capacity calculated using Equation H- 1, the representative flow estimate from the second column, and the applicable criterion plus HUA (20.0°C plus 0.3°C). This loading capacity applies to the flow range in the third column of the table.

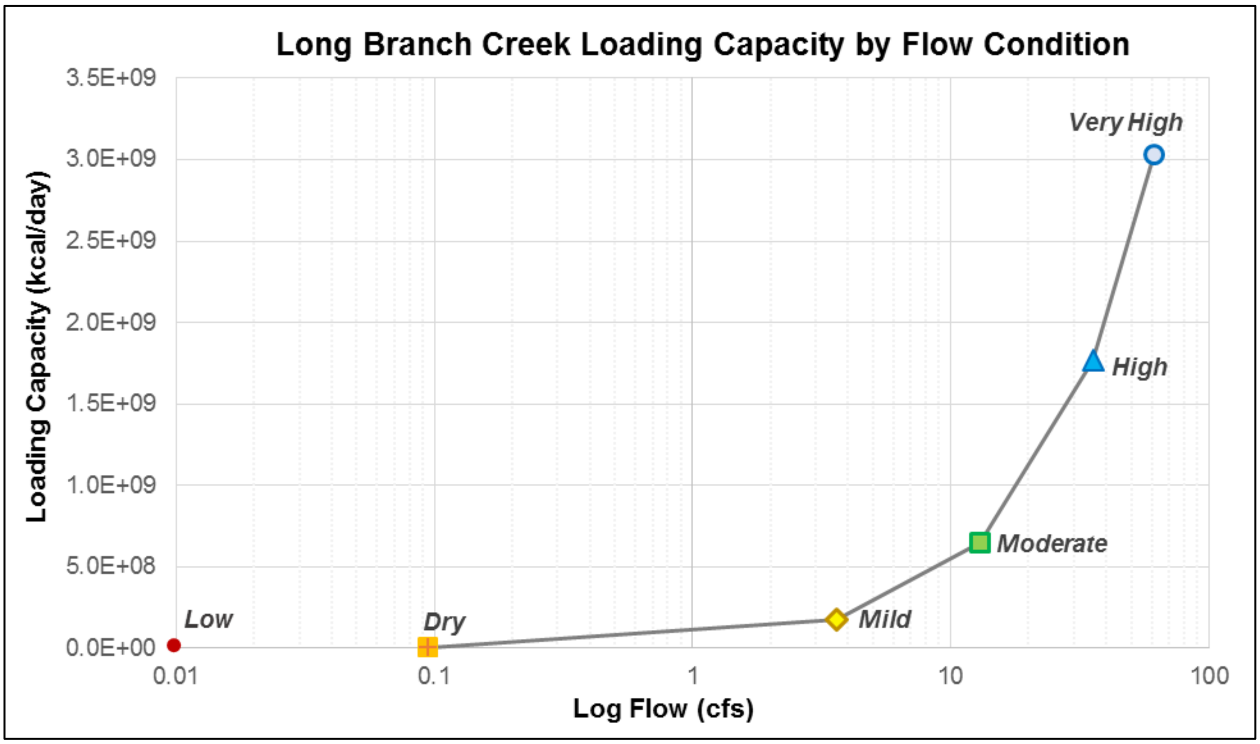

Figure H- 24. Long Branch Creek loading capacity curve by flow condition.

H.2.1.11 Lost River

The Lost River is listed for a 60.6-mile long segment (Table H- 1). It originates in California near Clear Lake and runs north into Oregon before looping back south, terminating in California at Tule Lake (Figure H- 25). The drainage area, which is largely within Oregon, covers an area of approximately 1,080 square miles. It includes the Klamath Falls Lakeview Forest State Park and parts of the Fremont and Winema national forests. Most of the drainage is privately held; the Bureau of Land Management and the U.S. Forest Service own the majority of public land. There are many tributaries to the Lost River and the river is channelized, including several impoundments (Malone Dam, Harpold Dam, Wilson Diversion Dam, and Anderson Rose Dam) to facilitate water storage and support diversion canals and return flow drains. Water from the Lost River drainage can be discharged to Keno Reservoir through the Lost River Diversion Channel as part of irrigation water delivery and flood control operations (Figure H- 26).

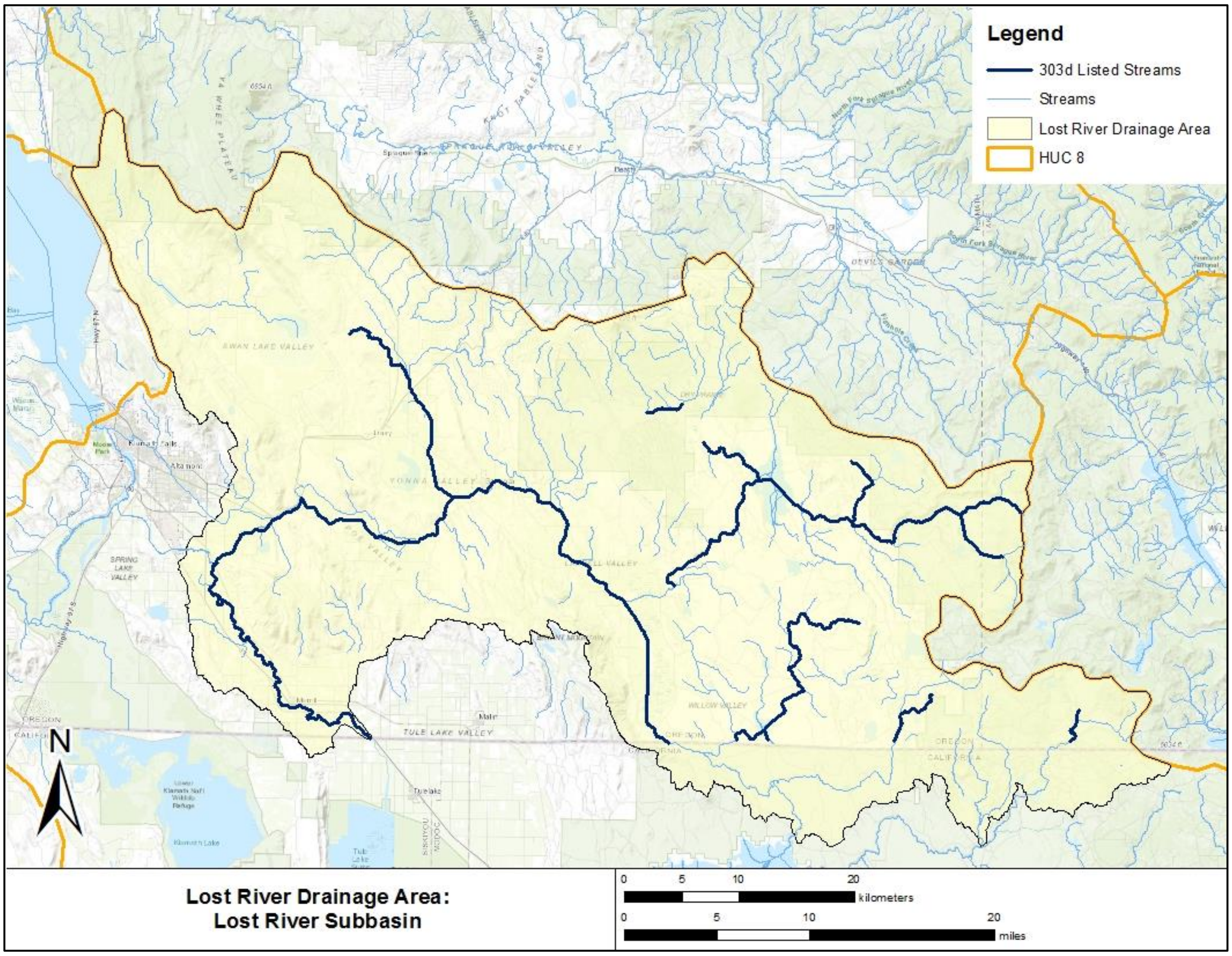

Figure H- 25. Lost River drainage area.

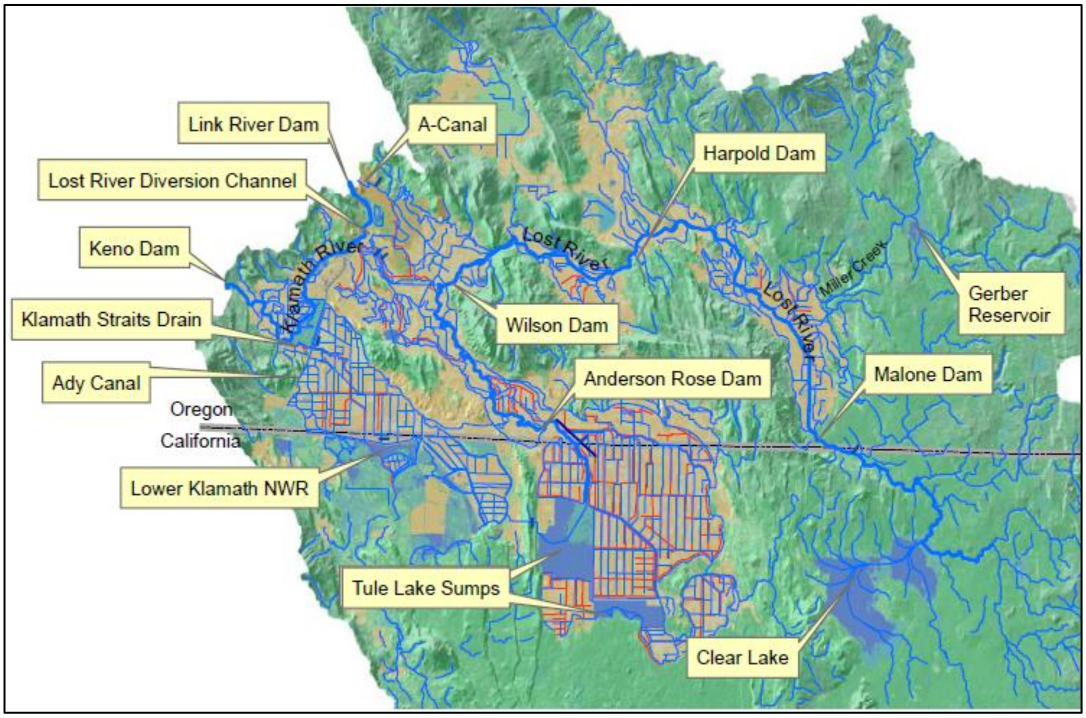

Figure H- 26. Lost River and major hydrologic features.

Representative flow estimates for the Lost River were obtained from the modeling performed to support the 2010 TMDLs (Appendix F of DEQ 2018). This effort incorporated upstream dams and flow alternations and is therefore useful to estimate flows at the Stateline, where there is no monitoring station. Flow from the currently available model, without any modifications, was used to calculate the loading capacity for the Lost River. The model included a dozen linked CE-QUAL-W2 segments for 1999 (2004 was also modeled, but not for a full year). These modeled flows were summarized to compare seasonal trends (Figure H- 27). Average daily flows were lowest during June and August (11.5 and 13.3 cfs, respectively). The minimum daily flows were below 10 cfs for March through November, likely due to withdrawals during this period. The lows flows, along with the corresponding high air temperatures during the summer period results in higher stream temperatures, making this the critical period for TMDL development.

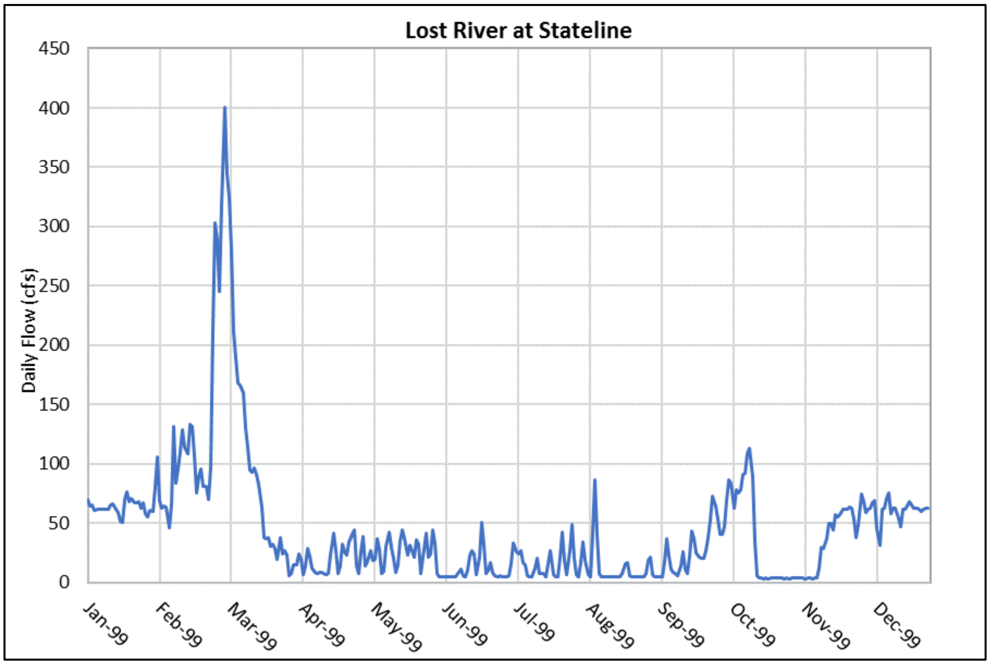

Figure H- 27. Modeled Lost River flows at the Stateline (1999).

A flow frequency analysis was constructed on the 1999 modeled flows using the Weibull plotting positions method. Figure H- 28 illustrates the flow percentile distribution and Table H- 23 below summarizes the flow statistics that were used in the thermal loading capacity calculations. The top one perecent of flows had some very extrememe high flow values ranging from 308 to 400 cfs.

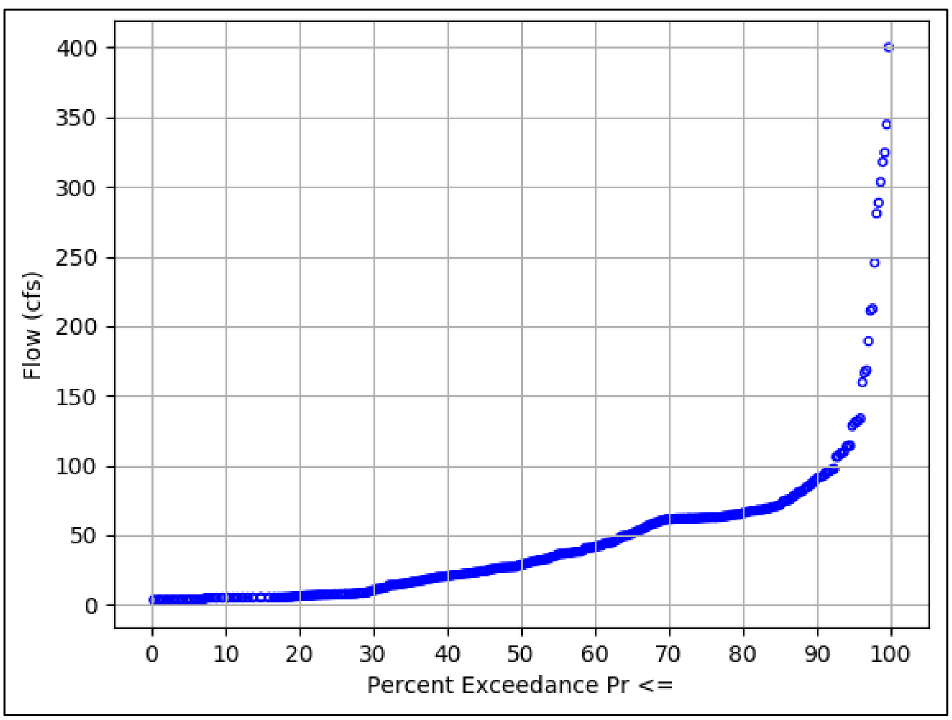

Figure H- 28. Flow duration curve for Lost River at the Stateline (1999).

Conditions represented by the 1999 simulation were analyzed to determine how they compared to more recent flow records in the basin. This analysis was used to confirm that the modeled time period is representative of recent hydrological conditions. Flow comparisons were made to three USGS stations along the Lost River with measured flow for 2012 to 2015 (Table H- 23). The observed flow at these stations were instantaneous measurements taken approximately twice a month.

Table H- 23. Description and location of flow monitoring stations on the Lost River.

Site name	Site name abbreviation	USGS Station Number	Latitude	Longitude
Lost River below Malone Reservoir	LRBM	420025121132800	42° 00' 25.2"	-121° 13' 27.6"
Lost River below Harpold Reservoir	LRBH	421010121271200	42° 10' 10"	-121° 27' 12"
Lost River at East-West Road*	LREW	11488495	41° 57' 14"	-121° 30' 12"
*Note: station is located in California, approximately 2.5 miles below the Stateline				

Model output was extracted from the model outlet closest to each monitoring station and are presented as flow duration curves, which were developed using the Weibull plotting position method. The observed flow data were overlaid on top of the flow duration curves to evaluate how historical flow measurements compared to the distribution of the 1999 modeled flow at LRBM, LRBH, and LREW (Figure H- 29, Figure H- 30, and Figure H- 31, respectively). As illustrated by the plots, the year 1999 includes the range of flow conditions that were observed over the more recent period of record and the critical low flow period were well represented in the 1999 model output. These analyses indicate that 1999 is representative of more recent flow conditions throughout the river.

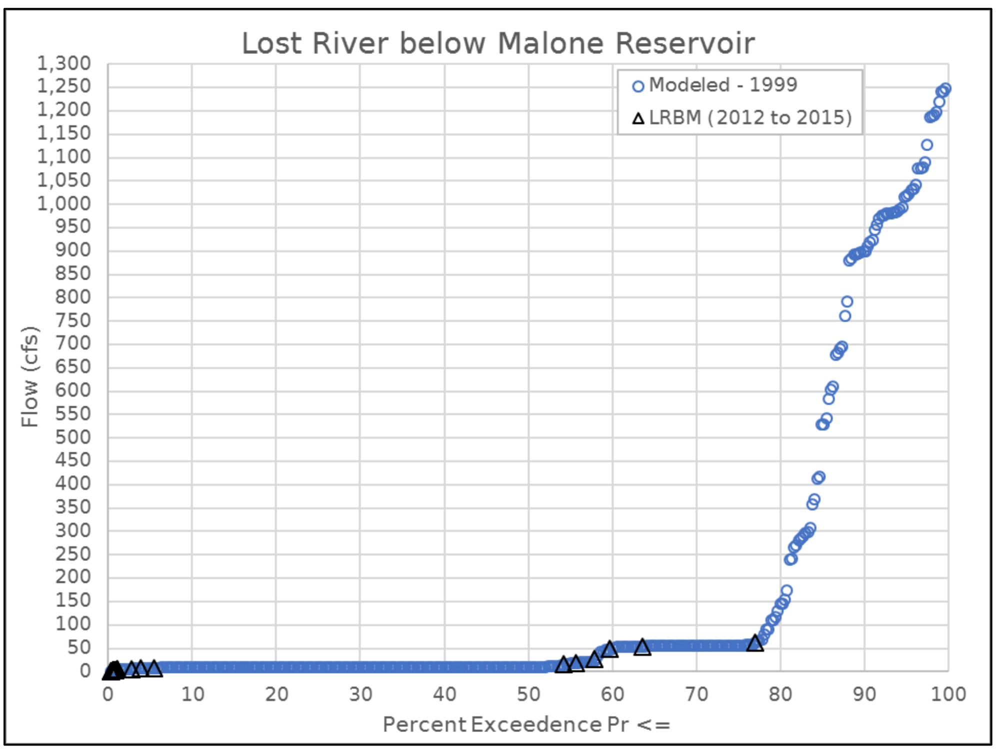

Figure H- 29. Flow duration curve at Lost River below Malone Reservoir (1999) compared to LRBM observations.

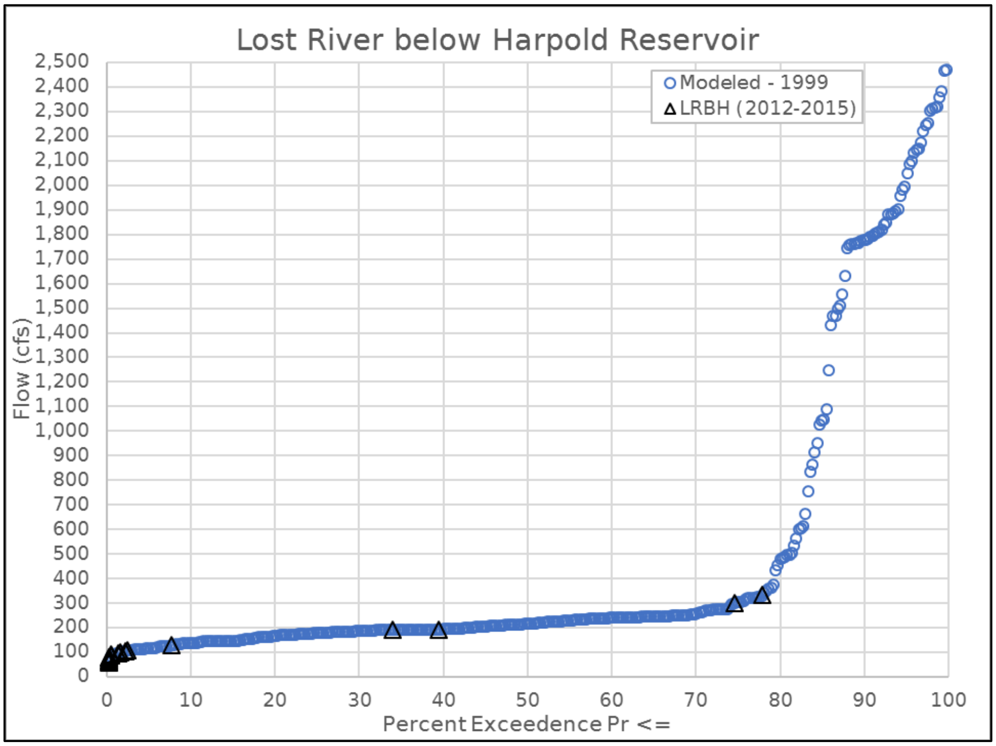

Figure H- 30. Flow duration curve at Lost River below Harpold Dam (1999) compared to LRBH observations.

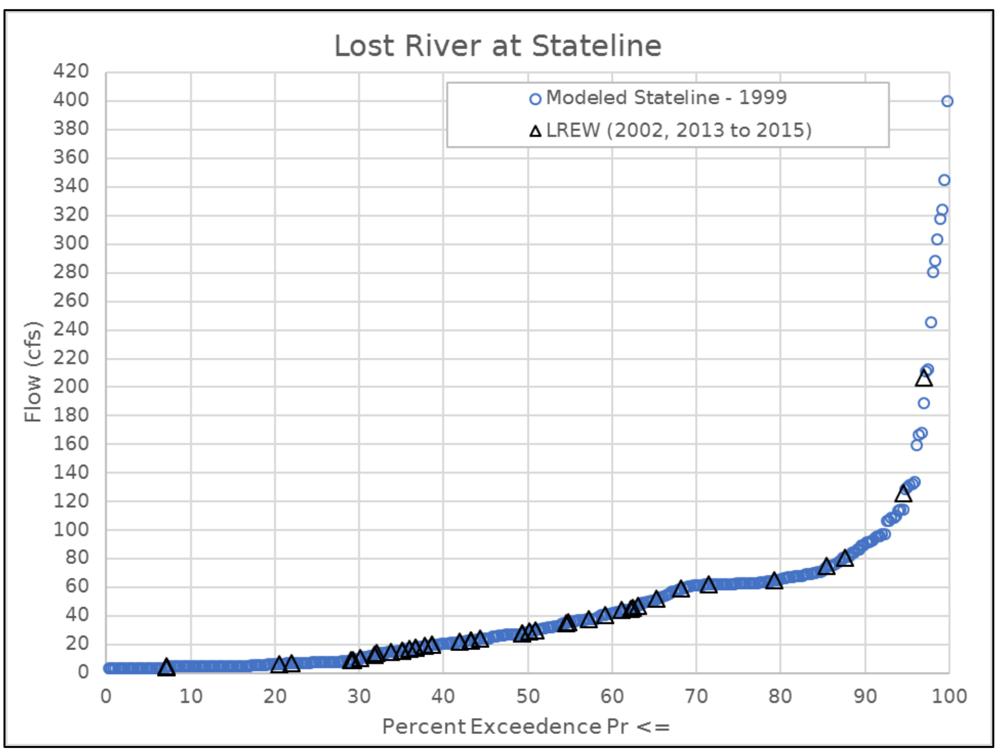

Figure H- 31. Flow duration curve at Lost River at Stateline (1999) compared to LREW observations.

In addition to the flow comparisons, air temperature comparisons were also performed to evaluate whether the modeled period is representative of more recent conditions. Hourly and monthly air temperature data from the past eighteen years available at the Klamath Falls station were compared to conditions during 1999 (Figure H- 32 and Figure H- 33, respectively). Monthly comparisons show that the air temperature during July and August 1999 are at the lower end of the range of observations over the years (Figure H- 33); however, the model does include hourly short-term variations shown in the hourly time series (Figure H- 32). Hourly air temperatures during July and August of 1999 reach 98.96°F and 95°F, respectively, which is comparable to the other years evaluated.

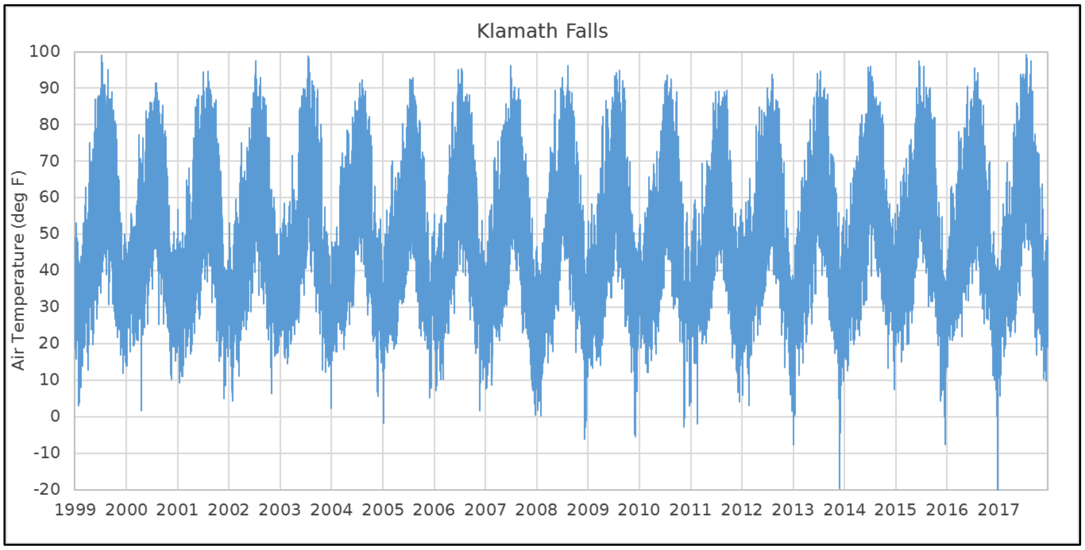

Figure H- 32. Hourly air temperature at Klamath Falls from 1999 to 2017.

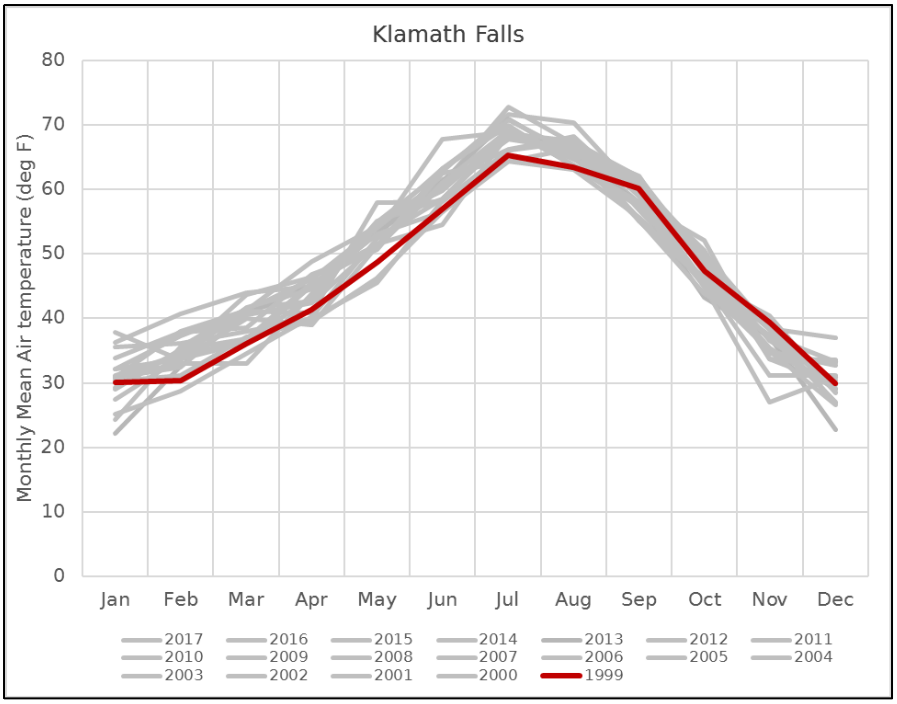

Figure H- 33. Monthly average air temperatures (1999 to 2017).

Ultimately, the 1999 modeled flows at the Stateline (Figure H- 28) were used to calculate the thermal loading capacity. The comparison with the observed flow data was useful to ensure the modeling resulted in flow ranges observed more recently. Similarly, the temperature comparisons were important to confirm that 1999 is reasonably representative of more recent meteorological conditions.

The flow estimates at Stateline resulted in a range from 3 cfs during low flow conditions to 126 cfs for very high flow conditions (Table H- 24). These expected flows were used in Equation H-1 to determine the range of loading capacities for the Lost River. The thermal loading capacity, which was calculated using the lowest flow estimate for the condition, applies to the full range of flows until the next flow condition is reached (Table H- 24). The loading capacity increases with increasing flow, from 1.45E+08 to 5.25E+09 kcal/day for low and very high flow conditions, respectively. The relationship between total loading capacity and flow conditions is illustrated in Figure H- 34. This curve characterizes the thermal loading capacity of the Lost River for the range of expected flows throughout the year and can be used as a reference to estimate the loading capacity for different flow rates (Figure H- 34).

Table H- 24. Lost River thermal loading capacity by flow condition.

Flow Condition	Representative Flow Estimate (cfs)[1]	Applicable Flow Range	Thermal Loading Capacity (kcal/day)[2]
Low	3	<4 cfs	1.45E+08
Dry	4	4 cfs to <29cfs	1.53E+08
Mild	29	29 cfs to <63 cfs	1.20E+09
Moderate	63	63 cfs to <90 cfs	2.61E+09
High	90	90 cfs to <126 cfs	3.72E+09
Very High	126	≥126 cfs	5.25E+09

[1] Estimated from analysis of 1999 modeled flows at the Stateline (Appendix F in DEQ 2018).

[2] Loading capacity calculated using Equation H- 1, the representative flow estimate from the second column, and the applicable criterion plus HUA (16.7°C plus 0.3°C). This loading capacity applies to the flow range in the third column of the table.

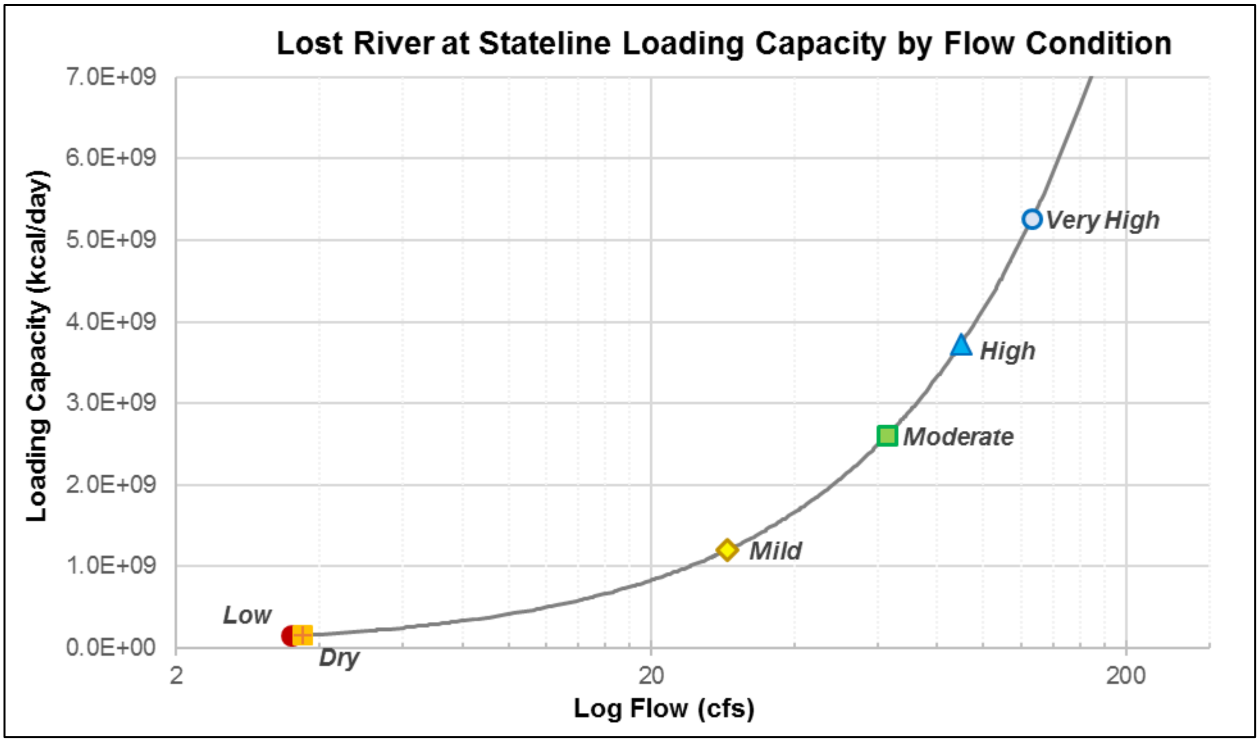

Figure H- 34. Lost River loading capacity curve by flow condition

H.2.1.12 Lost River Diversion Channel

The water quality listed segment for Lost River Diversion Channel (LRDC) is approximately an 8-mile segment. The LRDC conveys excess water from the Lost River to the Klamath River. The channel begins below Wilson Reservoir Dam and extends west through the Lost River and Klamath Valleys up to the Klamath River for approximately 8 miles (Figure H- 35)

The LRDC flow into the Klamath River was calculated using the net flow derived from measurements at Wilson Dam, minus diversions at Station 48 and Miller Hill. The following USBR Hydromet stations were used to calculate the daily flows in the LRDC:

i) Wilson Dam: Average canal discharge from the Lost River Diversion Channel at C-G crossing (LRD) were downloaded from the USBR website. Daily flow data were available from 2013 to 2019.

ii) Miller Hill: Average pump discharge at Miller Hill Pump Plant (MHPO) were downloaded from the USBR website. Daily pump discharge data were available from 1999 to 2019.

iii) Station 48. Average pump discharge data were provided by USBR. Daily flow data were available from 2012 to 2019.

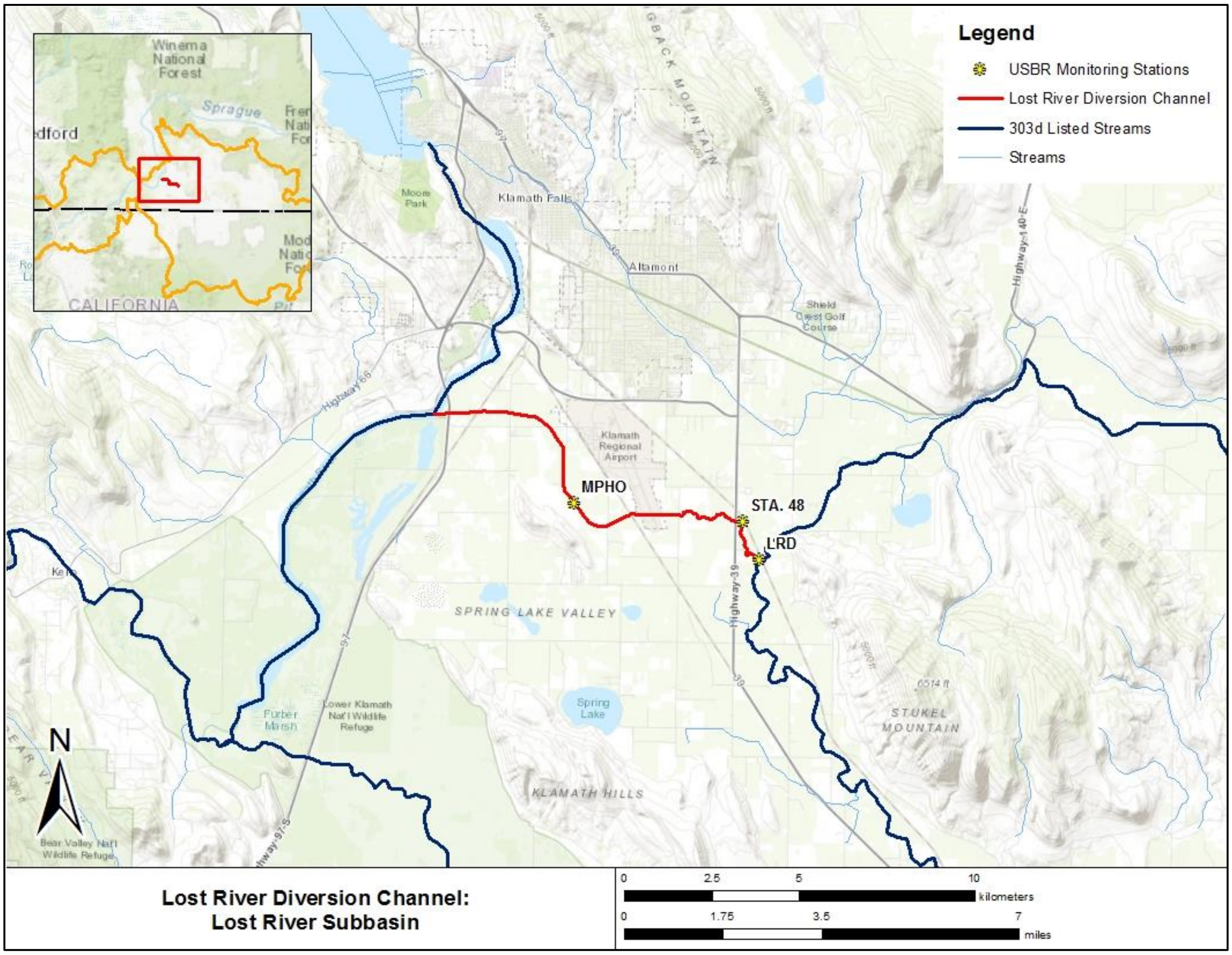

Figure H- 35. Lost River Diversion Channel location: Lost Subbasin.

The available flow data were used to calculate the daily flow in LRDC. The calculated flows in the channel are quite variable and were positive and negative depending on the direction of flow in the channel. Figure H- 36 shows the calculated flows for LRDC to the Klamath River. The positive flows indicated flows going to the Klamath River and were used in the analysis. In general flows to the Klamath River from LRDC were minimal or non-existent (mostly negative or zero) from mid-April through mid-September based on the operation of flows.

Figure H- 36. Daily flow time series for LRDC.

A flow frequency analysis was constructed on the 2013 to 2019 data using the Weibull plotting positions method. Figure H- 37 illustrates the flow percentile distribution and Table H- 25 below summarizes the flow statistics that were used in the thermal loading capacity calculations. The top one perecent of flows had some very extrememe high flow values ranging from 875 to 1689 cfs.

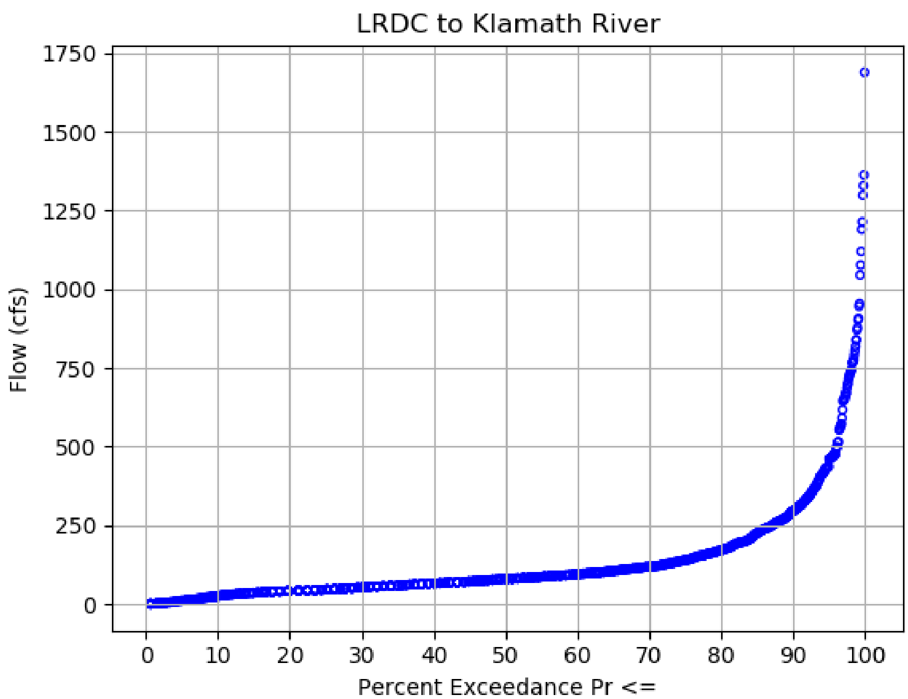

Figure H- 37. Flow duration curve for Lost River Diversion Channel to Klamath River (8/5/2013 to 6/9/2019).

Table H- 25. Lost River Diversion Channel to Klamath River thermal loading capacity by flow condition.

Flow Condition	Representative Flow Estimate (cfs)[1]	Applicable Flow Range	Thermal Loading Capacity (kcal/day)[2]
Low	1	<1 cfs	6.85E+07
Dry	11	1 cfs to <11cfs	7.54E+08
Mild	80	80 cfs to <140 cfs	5.48E+09
Moderate	140	140 cfs to <295 cfs	9.59E+09
High	295	295 cfs to <437 cfs	2.02E+10
Very High	437	≥437 cfs	2.99E+10

[1] Estimated from analysis of 2013-2019 daily flow data where the net flow is derived from measurements at Wilson Dam, minus diversions at Station 48 and Miller Hill.

[2] Loading capacity calculated using Equation H- 1, the representative flow estimate from the second column, and the applicable criterion plus HUA (27.9°C plus 0.1°C). This loading capacity applies to the flow range in the third column of the table.

The flow estimates resulted in a range from 1 cfs during low flow conditions to 437 cfs for very high flow conditions (Table H- 25). These expected flows were used in Equation H- 1 to determine the range of loading capacities for the LRDC. The thermal loading capacity, which was calculated using the lowest flow estimate for the condition, applies to the full range of flows until the next flow condition is reached (Table H- 25). The loading capacity increases with increasing flow, from 6.85E+07 to 2.99E+10 kcal/day for low and very high flow conditions, respectively. The relationship between total loading capacity and flow conditions is illustrated in Figure H- 38. This curve characterizes the thermal loading capacity of LRDC for the range of expected flows throughout the year and can be used as a reference to estimate the loading capacity for different flow rates (Figure H- 38).

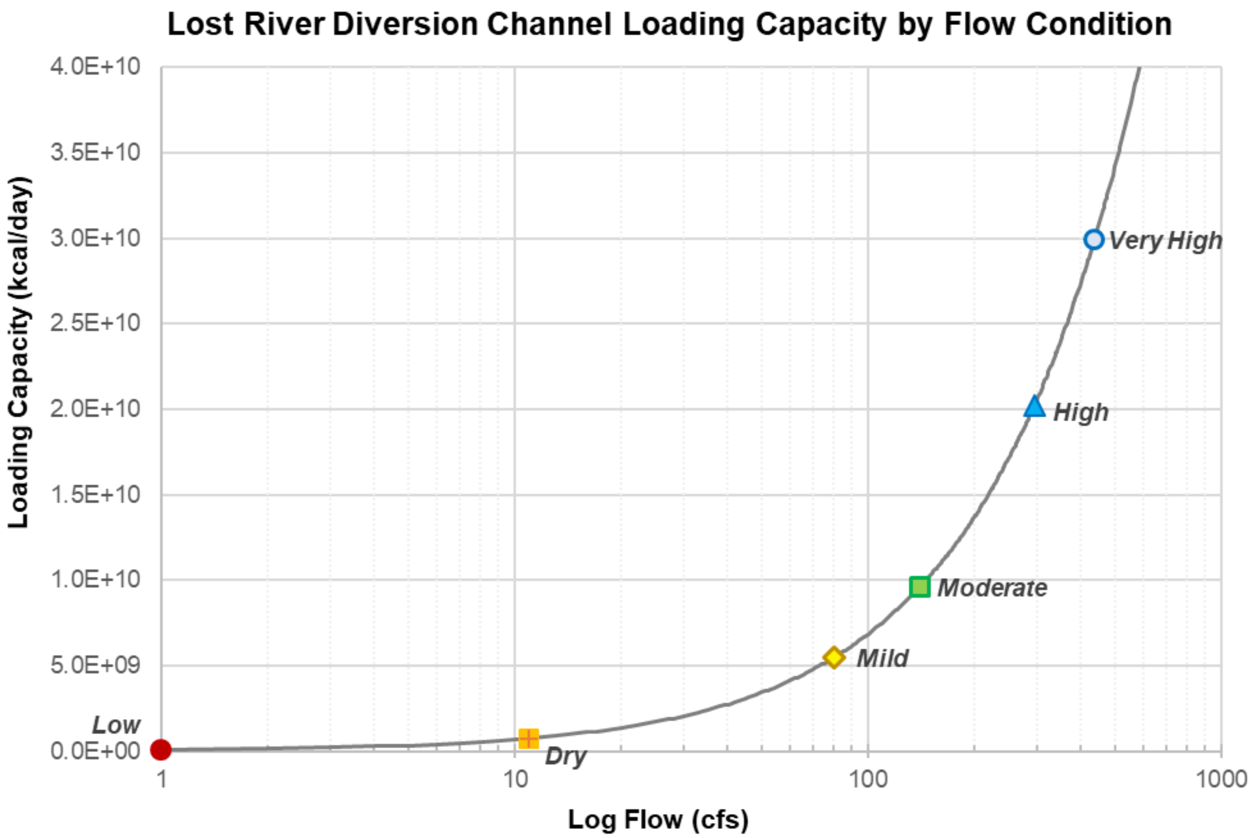

Figure H- 38. Lost River Diversion Channel to Klamath River loading capacity curve by flow condition.

H.2.1.13 North Fork Willow Creek

North Fork Willow Creek is listed for a 2.3-mile segment and is located in Yocum Valley in the Fremont National Forest just north of the Oregon/California border (Table H- 1 and Figure H- 39). The segment begins just east of Center Peak and flows south to an area called The Potholes near the intersection of NF-11 and NF-419. The drainage area for this segment is approximately 26 square miles and includes East Willow Creek in the east, which is a tributary to North Fork Willow Creek, and Albertson Reservoir in the north. It extends to Brushy Mountain in the west. Table H- 26 includes a subset of basin characteristics produced by StreamStats including mean annual precipitation and mean annual maximum air temperature, which were used in determining flow statistics for North Fork Willow Creek.

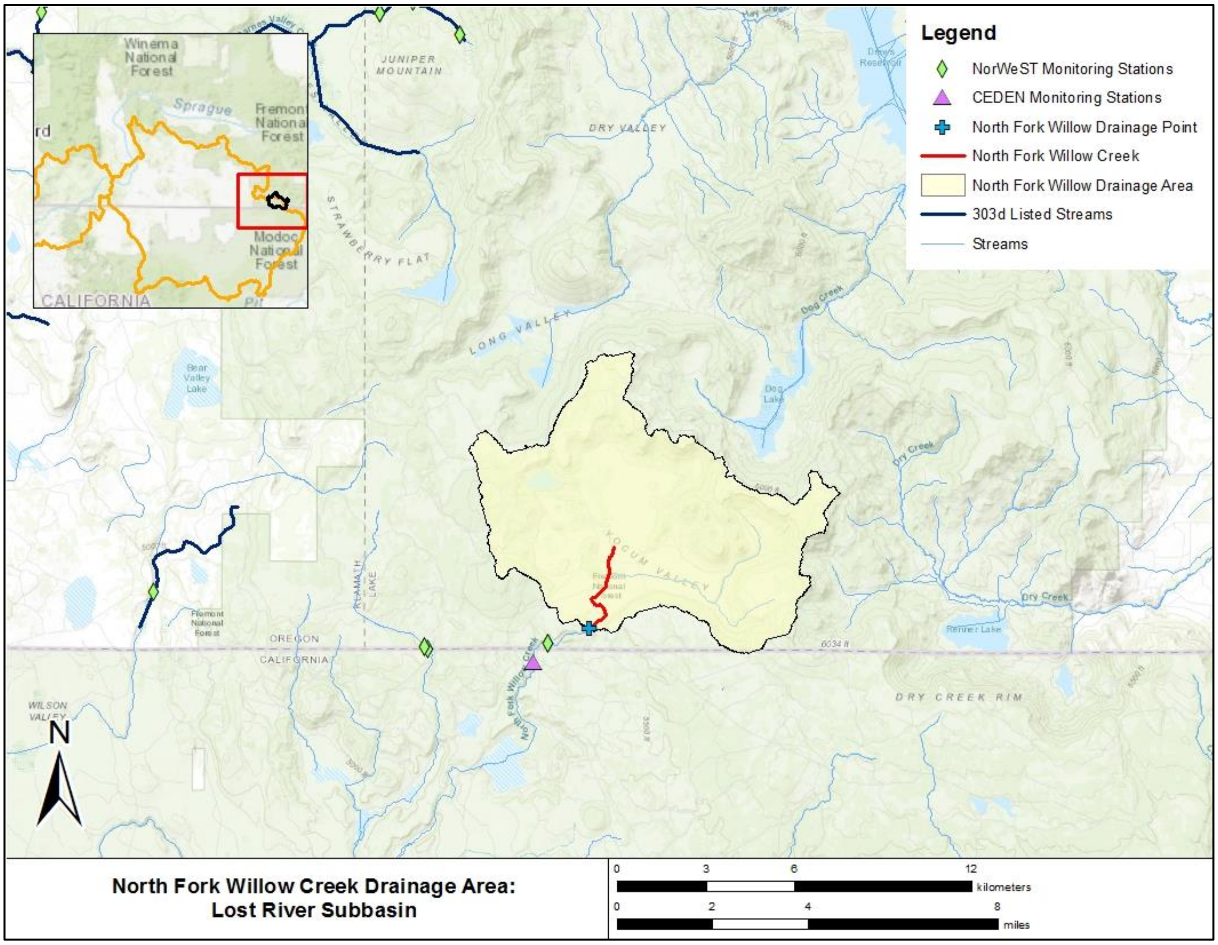

Figure H- 39. North Fork Willow Creek drainage area.

Table H- 26. North Fork Willow Creek basin characteristics used in StreamStats.

Parameter	Value	Units
Drainage Area	26	sq mi
Mean Annual Precipitation	22	in
Mean Annual Maximum Air Temperature	13.3	°C
Mean Basin Slope	5.26	degrees
Relief	995	ft
Average Soil Permeability	1.87	in/hr
Source: U.S. Geological Survey, 2012, The StreamStats program for Oregon, online at http://water.usgs.gov/osw/streamstats/oregon.html.		

Expected flow rates in North Willow Creek range from 0.02 cfs for low conditions to 70 cfs for very high flow conditions (Table H- 27). These flow estimates were used in Equation H- 1 to determine the thermal loading capacity for the listed segment during the various expected flow conditions. The thermal loading capacity of North Fork Willow Creek is presented in Table H- 27 and ranges from 8.10E+05 kcal/day to 3.47E+09 kcal/day for low and very high flow conditions, respectively. Thermal loading capacity, which was calculated using the lowest flow estimate for the condition, applies to the full range of flows until the next flow condition is reached (Table H-

27). For example, for a flow rate below 4 cfs, the thermal loading capacity is 2.28E+07 kcal/day, associated with the dry flow condition. The relationship between flow rate and thermal loading capacity is displayed in Figure H- 40, which characterizes the thermal loading capacity for the various flow regimes expected in the creek throughout the year.

Table H- 27. North Fork Willow Creek thermal loading capacity by flow condition.

Flow Condition	Representative Flow Estimate (cfs)[1]	Applicable Flow Range	Thermal Loading Capacity (kcal/day)[2]
Low	0.02	<0.5 cfs	8.10E+05
Dry	0.5	0.5 cfs to <4 cfs	2.28E+07
Mild	4	4 cfs to <15 cfs	2.22E+08
Moderate	15	15 cfs to <41 cfs	7.65E+08
High	41	41 cfs to <70 cfs	2.06E+09
Very High	70	≥70 cfs	3.47E+09

[1] Estimated from StreamStats analysis.

[2] Loading capacity calculated using Equation H- 1, the representative flow estimate from the second column, and the applicable criterion plus HUA (20.0°C plus 0.3°C). This loading capacity applies to the flow range in the third column of the table.

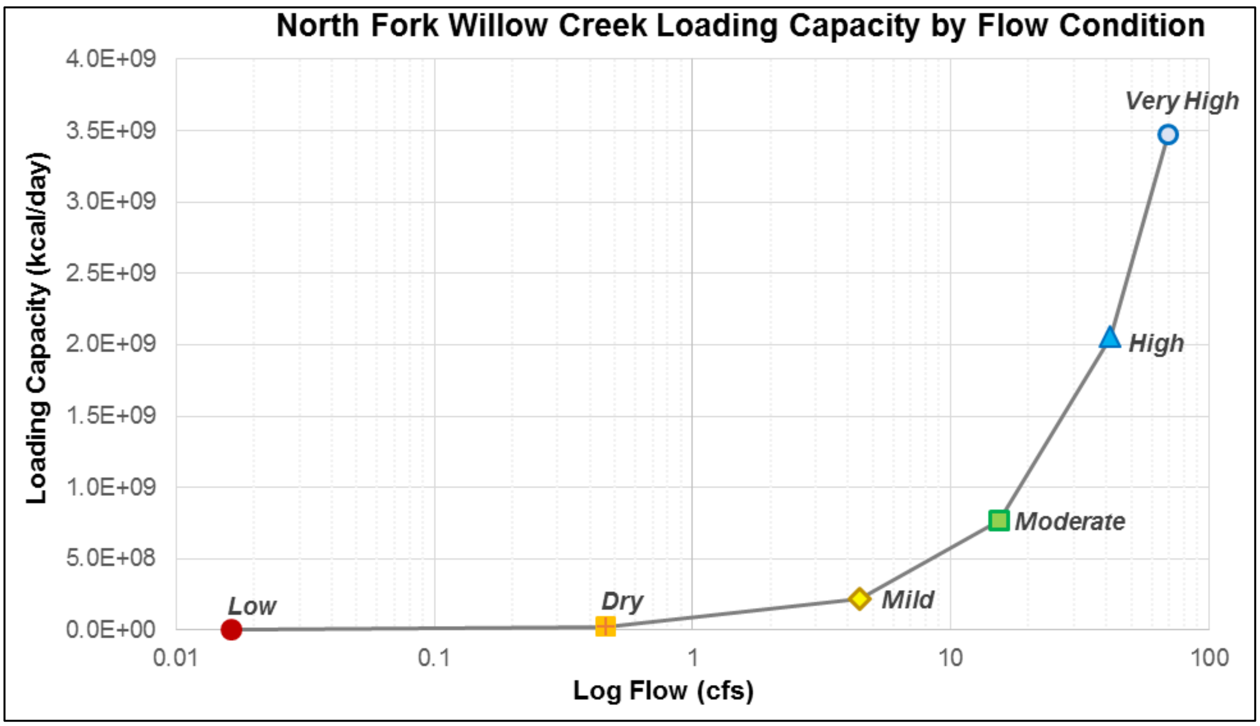

Figure H- 40. North Fork Willow Creek loading capacity curve by flow condition.

H.2.1.14 Rock Creek

Rock Creek is listed for a 4.3-mile segment (Table H- 1) and is located between Antelope Creek and North Fork Willow Creek just north of the Oregon/California border on the western border of Fremont National Forest. The area that drains to this segment of Rock Creek extends north to just below Bear Valley Lake and east into Fremont National Forest to Brushy Mountain (Figure H- 41). The drainage area covers an area of about 15 square miles and receives a mean annual precipitation of 20.4 in. A subset of basin characteristics produced by StreamStats and used to determine stream flow statistics for Rock Creek is included in Table H- 28.

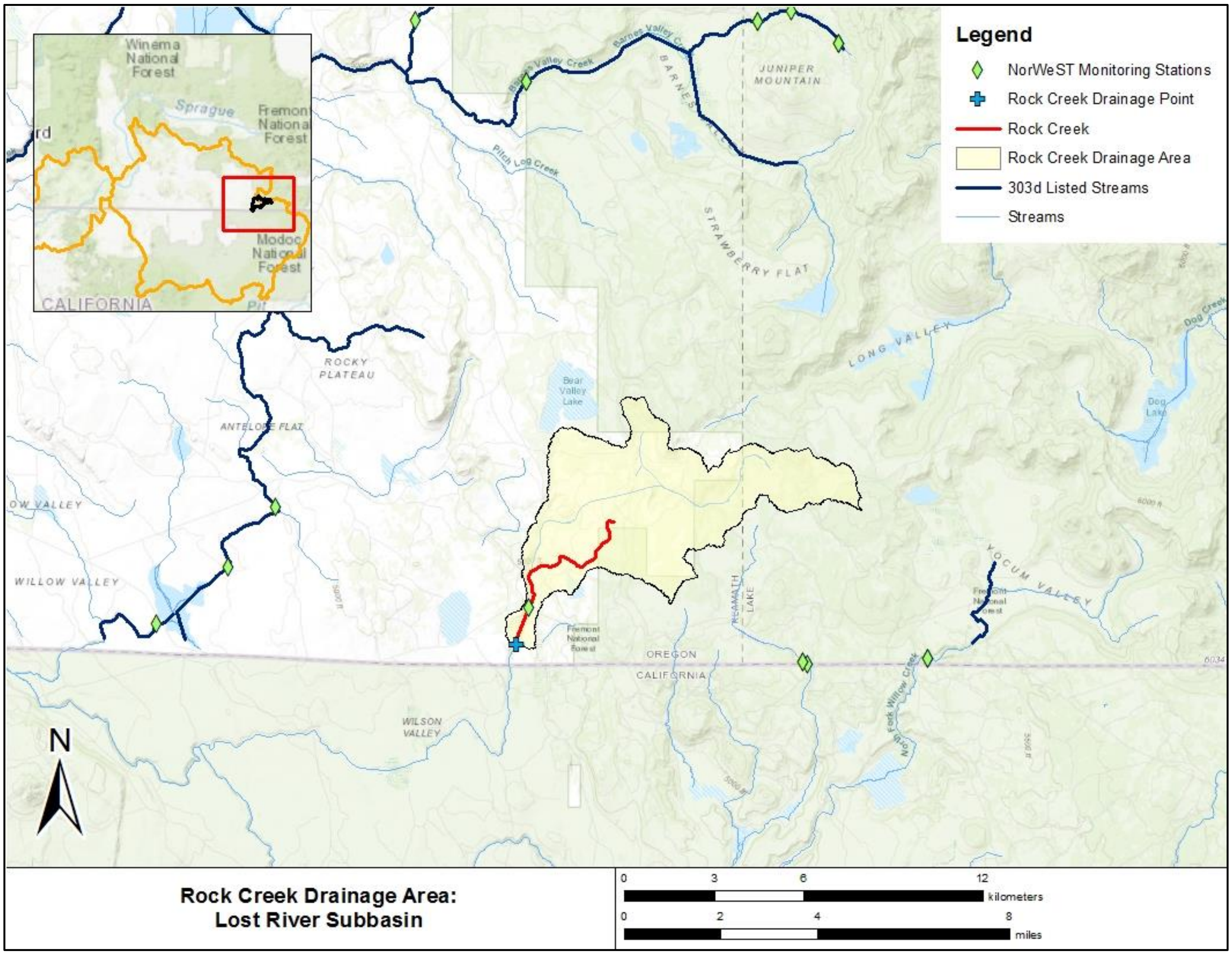

Figure H- 41. Rock Creek drainage area.

Table H- 28. Rock Creek basin characteristics used in StreamStats.

Parameter	Value	Units
Drainage Area	15.1	sq mi
Mean Annual Precipitation	20.4	in
Mean Annual Maximum Air Temperature	14.1	°C
Mean Basin Slope	3.65	degrees

Parameter	Value	Units
Relief	1010	ft
Average Soil Permeability	1.53	in/hr
Source: U.S. Geological Survey, 2012, The StreamStats program for Oregon, online at http://water.usgs.gov/osw/streamstats/oregon.html.		

Representative flow estimates for various flow conditions in Rock Creek range from 0 cfs for low and dry flow conditions to 42 cfs during very high flow conditions (Table H- 29). These expected flows were used in Equation H- 1 to calculate the thermal loading capacity for flows throughout the year in Rock Creek. Thermal loading capacity in Rock Creek ranges from 0.00E+00 kcal/day to 2.09E+09 kcal/day for low and very high flow conditions, respectively. As thermal loading capacity is dependent on flow, it is expected that a flow rate of 0 cfs will result in a thermal loading capacity of 0 kcal/day. The thermal loading capacity, which was calculated using the lowest flow estimate for the condition, applies to the full range of flows until the next flow condition is reached (Table H- 29). Equation H- 1 can be used to calculate the thermal loading capacity for low and dry flow conditions with rates below 2 cfs.

The relationship between loading capacity and streamflow in Rock Creek is demonstrated in Figure H- 42. This curve characterizes the thermal loading capacity for the various flow regimes expected in the creek. The thermal loading capacities for low and dry flow conditions are represented at the origin, or the lowest part of the load capacity graph, in Figure H- 42 since streamflow is displayed on a log scale that cannot be used to illustrate a 0 cfs flow.

Table H- 29. Rock Creek thermal loading capacity by flow condition.

Flow Condition	Representative Flow Estimate (cfs)[1]	Applicable Flow Range	Thermal Loading Capacity (kcal/day)[2]
Low	0	0	0.00E+00
Dry	0	0 cfs to <2 cfs	0.00E+00
Mild	2	2 cfs to <8 cfs	1.06E+08
Moderate	8	8 cfs to <24 cfs	4.12E+08
High	24	24 cfs to <42 cfs	1.18E+09
Very High	42	≥42 cfs	2.09E+09

[1] Estimated from StreamStats analysis.

[2] Loading capacity calculated using Equation H- 1, the representative flow estimate from the second column, and the applicable criterion plus HUA (20.0°C plus 0.3°C). This loading capacity applies to the flow range in the third column of the table.

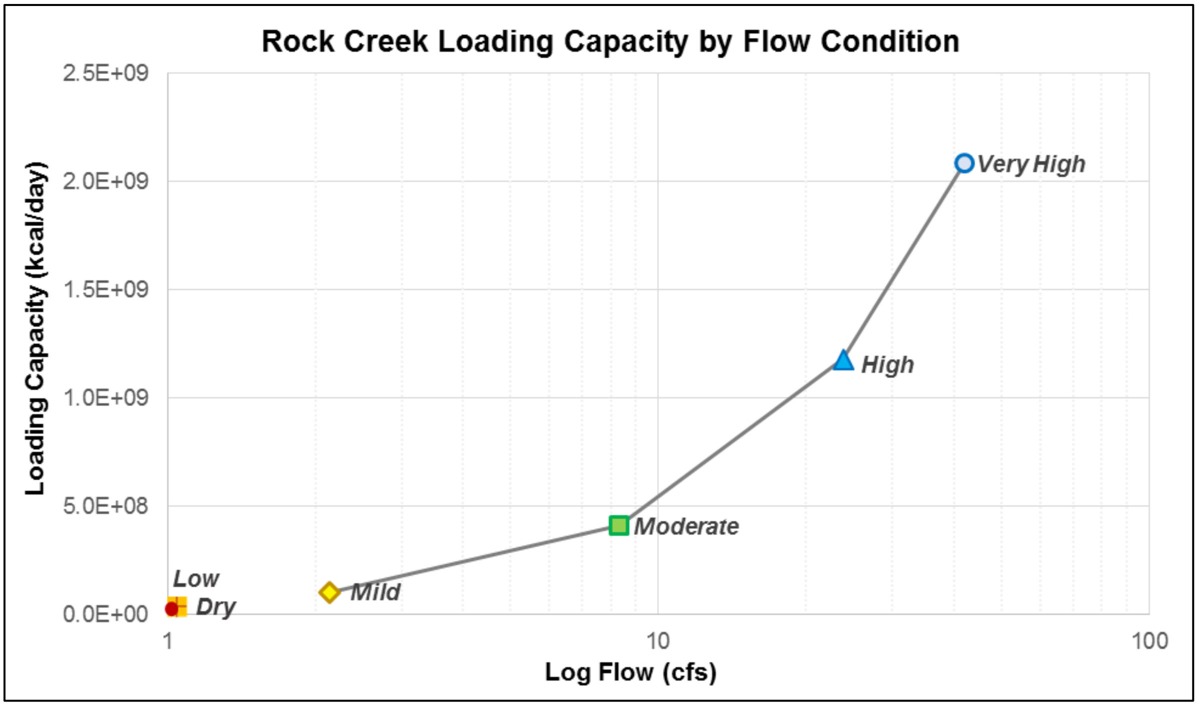

Figure H- 42. Rock Creek loading capacity curve by flow condition.

H.2.2 Upper Klamath Subbasin

Waters in the Upper Klamath River subbasin are identified inTable H- 1 and illustrated in Figure H- 2. As described below, all of the waters in this subbasin include a StreamStats approach to calculate the thermal loading capacity except for Spencer Creek.

H.2.2.1 Beaver Creek

Beaver Creek is a tributary to Jenny Creek and is located in Cascade Siskiyou National Monument south of Hyatt Reservoir and Howard Prairie Lake (Figure H- 43). The listed segment is 5.5 miles long (Table H- 1) and stretches from Crane Prairie to its confluence with Jenny Creek. It has a contributing drainage area that includes tributaries such as South Fork Beaver Creek and Corral Creek. The drainage area covers approximately 13.6 square miles between Chinquapin Mountain and Little Chinquapin Mountain and extends north toward the Wildcat Glades. A subset of the drainage basin characteristics produced by StreamStats and used to determine stream flow statistics in Beaver Creek is presented in Table H- 30.

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Table H- 30. Beaver Creek basin characteristics used in StreamStats.

Parameter	Value	Units
Drainage Area	13.6	sq mi
Mean Annual Precipitation	29.9	in
Mean Annual Maximum Air Temperature	14.2	°C
Mean Basin Slope	9.87	degrees
Relief	2710	ft
Average Soil Permeability	2.05	in/hr
Source: U.S. Geological Survey, 2012, The StreamStats program for Oregon, online at http://water.usgs.gov/osw/streamstats/oregon.html.		

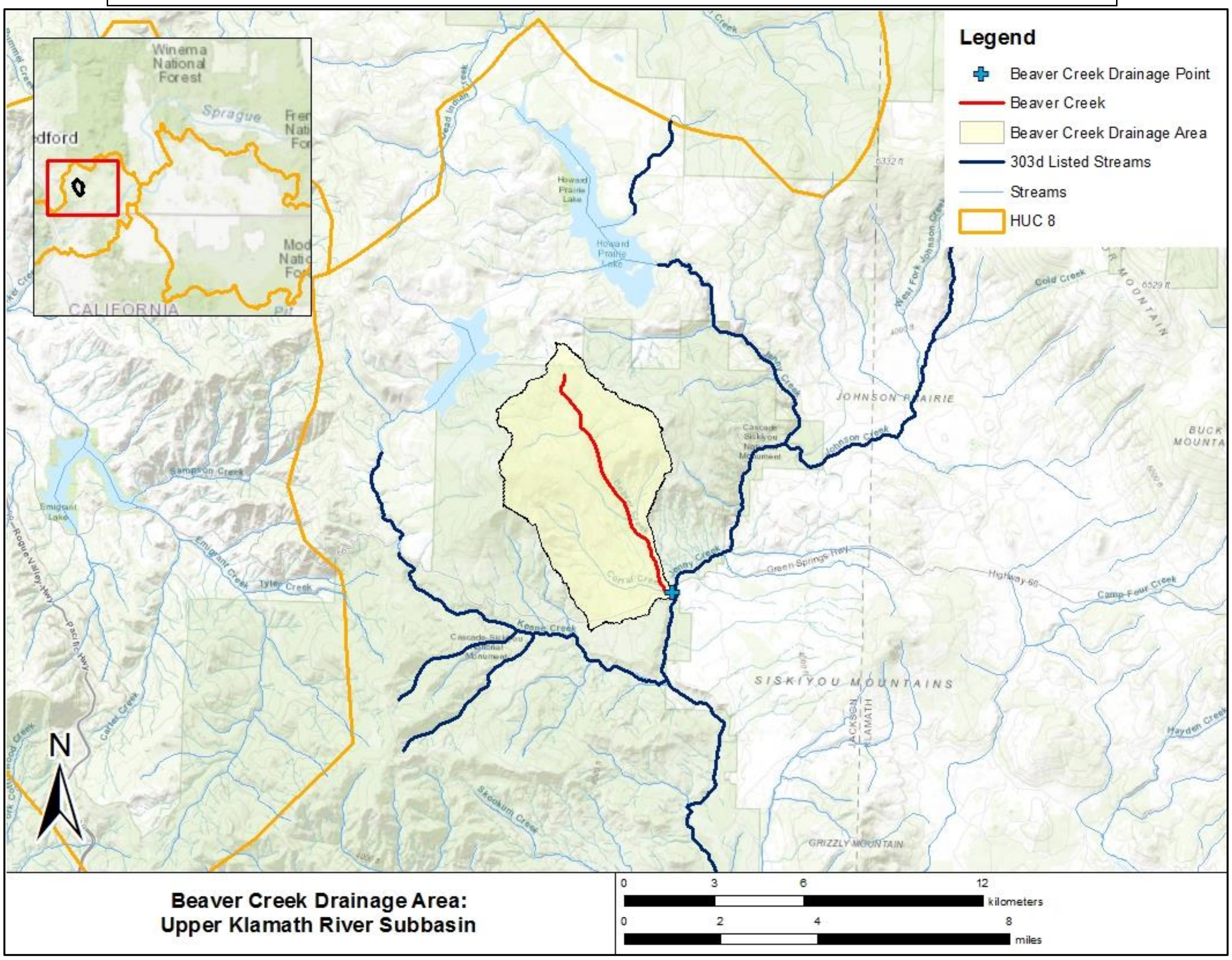

Figure H- 43. Beaver Creek drainage area.

Flow conditions for Beaver Creek were estimated to range from 0.3 cfs during low flow conditions to 58 cfs for very high flow conditions (Table H- 31). These flow rates were used in Equation H- 1 to calculate loading capacities for the range of expected flow conditions in Beaver Creek (Table H- 31). The thermal loading capacity, which was calculated using the lowest flow estimate for each condition, should be considered for the full range of flows until the minimum flow of the next flow condition (Table H- 31). The relationship between flow condition and thermal loading capacity is illustrated in Figure H- 44, and as expected, load capacity increases with increasing flow rates. During the lowest flow condition, Beaver Creek has a thermal loading capacity of 1.25E+07 kcal/day; when the creek is experiencing very high flow conditions, the thermal loading capacity reaches 2.87E+09 kcal/day. This curve characterizes the thermal loading capacity of Beaver Creek for the range of expected flows throughout the year and can be used as a reference to estimate the loading capacity for different flow rates (Figure H- 44).

Table H- 31. Beaver Creek thermal loading capacity by flow condition.

Flow Condition	Representative Flow Estimate (cfs)[1]	Applicable Flow Range	Thermal Loading Capacity (kcal/day)[2]
Low	0.3	<1 cfs	1.25E+07
Dry	1	1 cfs to <4 cfs	2.56E+07
Mild	4	4 cfs to <14 cfs	2.09E+08
Moderate	14	14 cfs to <36 cfs	6.75E+08
High	36	36 cfs to <58 cfs	1.79E+09
Very High	58	≥58 cfs	2.87E+09

[1] Estimated from StreamStats analysis.

[2] Loading capacity calculated using Equation H- 1, the representative flow estimate from the second column, and the applicable criterion plus HUA (20.0°C plus 0.3°C). This loading capacity applies to the flow range in the third column of the table

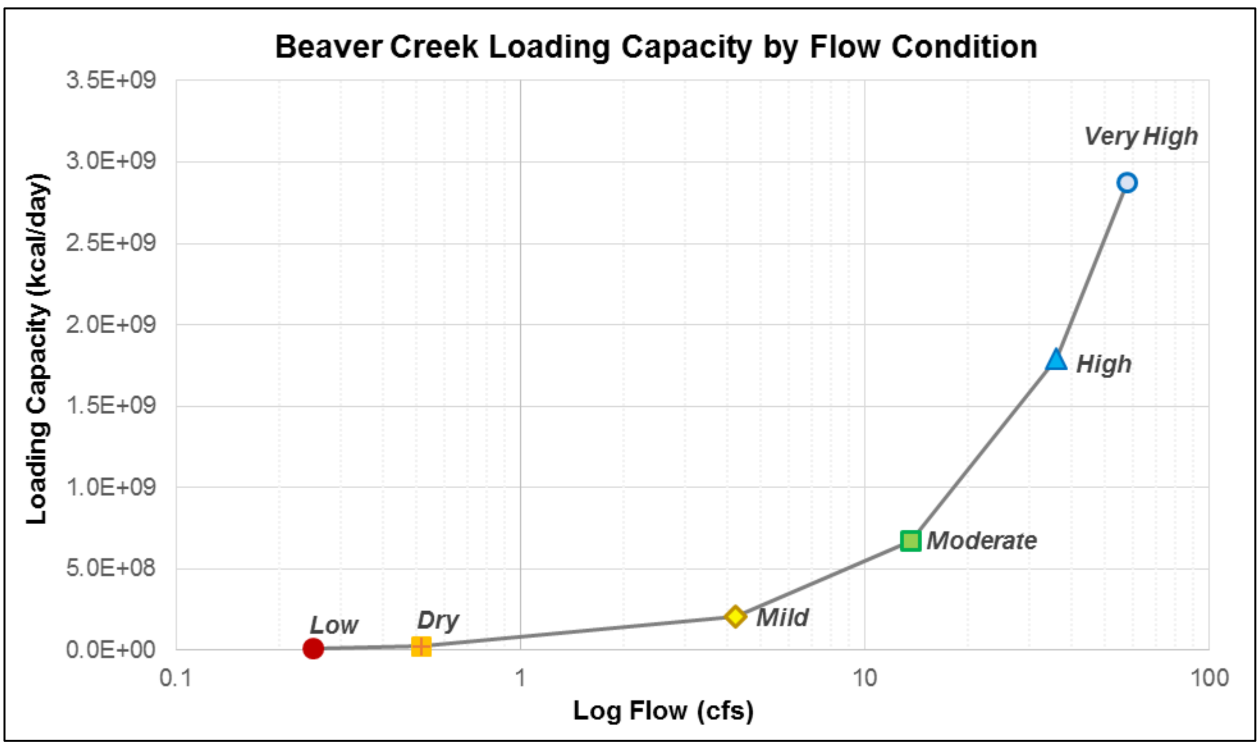

Figure H- 44. Beaver Creek loading capacity curve by flow condition.

H.2.2.2 Grizzly Creek

The water quality limited segment of Grizzly Creek is a 3-mile segment that stretches from its headwaters in Howard Prairie Lake to its confluence with Jenny Creek (Table H- 1 and Figure H- 45). The segment is located on the northern boundary of Cascade Siskiyou National Monument north of Beaver Creek. An area of about 35.4 square miles drains to Grizzly Creek and includes Howard Prairie Lake as well as its contributing creeks including water quality limited segment Hoxie Creek in the north. Table H- 32 includes a subset of drainage basin characteristics produced by StreamStats and used to determine the stream flow statistics for Grizzly Creek.

Table H- 32. Grizzly Creek basin characteristics used in StreamStats.

Parameter	Value	Units
Drainage Area	35.4	sq mi
Mean Annual Precipitation	34.6	in
Mean Annual Maximum Air Temperature	13.4	°C
Mean Basin Slope	5.72	degrees
Relief	2110	ft
Average Soil Permeability	1.82	in/hr
Source: U.S. Geological Survey, 2012, The StreamStats program for Oregon, online at http://water.usgs.gov/osw/streamstats/oregon.html		

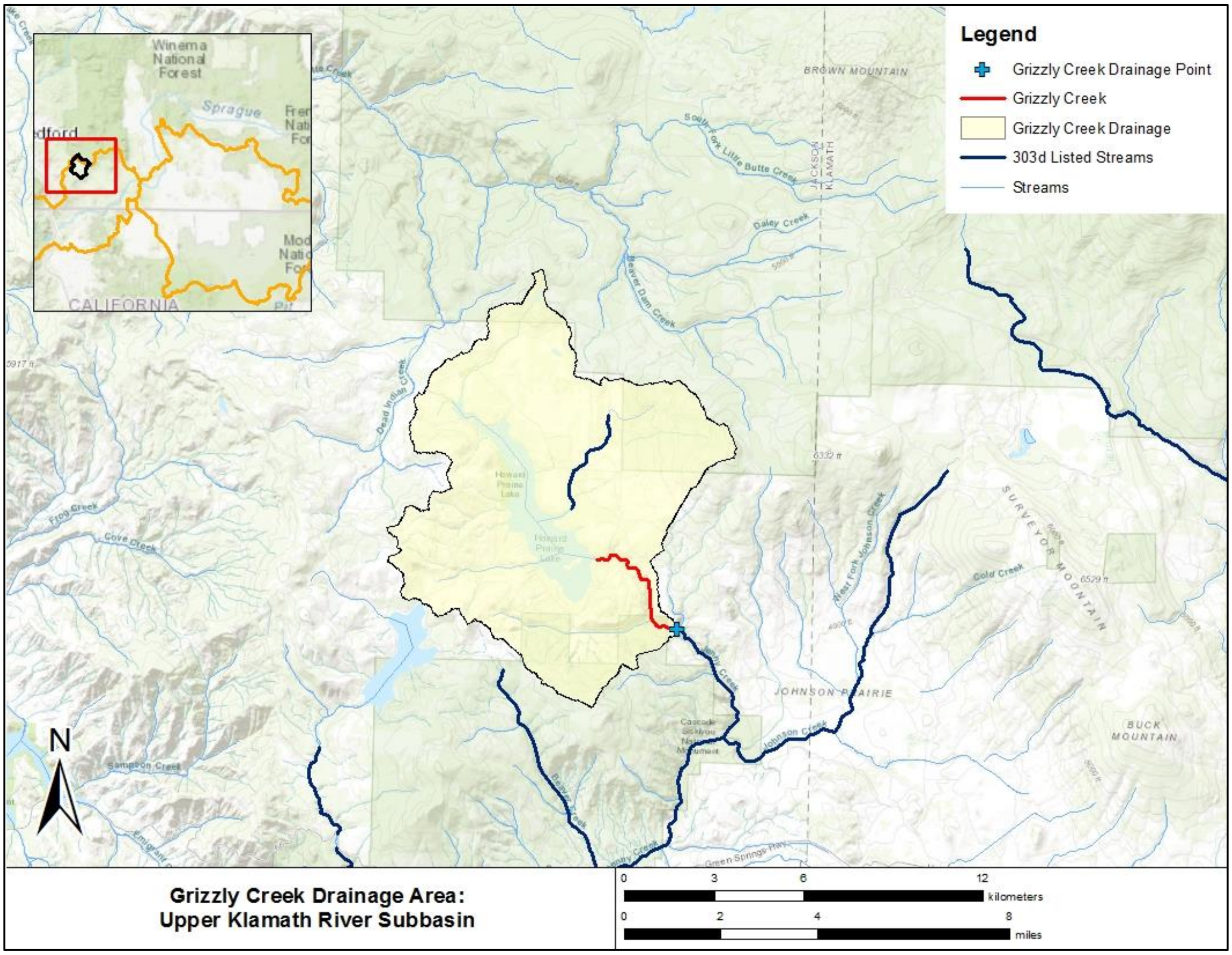

Figure H- 45. Grizzly Creek drainage area.

Representative flow estimates for Grizzly Creek range from 6 cfs during low flow conditions to 144 cfs for very high flow conditions (Table H- 33). These flows were incorporated into Equation H- 1 to calculate the thermal loading capacity of Grizzly Creek across the range of flow conditions expected throughout the year. The loading capacity increases with increasing flow conditions, from 2.98E+08 kcal/day to 7.15E+09 kcal/day for low to very high flow conditions (Table H- 33). The thermal loading capacity, which was calculated using the lowest flow estimate for each condition, applies to the full range of flows within that flow condition (Table H- 33). The relationship between loading capacity and streamflow is presented in Figure H- 46.

Table H- 33. Grizzly Creek thermal loading capacity by flow condition.

Flow Condition	Representative Flow Estimate (cfs)[1]	Applicable Flow Range	Thermal Loading Capacity (kcal/day)[2]
Low	6	<7 cfs	2.98E+08
Dry	7	7 cfs to <16 cfs	3.28E+08

Flow Condition	Representative Flow Estimate (cfs)[1]	Applicable Flow Range	Thermal Loading Capacity (kcal/day)[2]
Mild	16	16 cfs to <41 cfs	7.80E+08
Moderate	41	41 cfs to <97 cfs	2.04E+09
High	97	97 cfs to <144 cfs	4.82E+09
Very High	144	≥144 cfs	7.15E+09

[1] Estimated from StreamStats analysis.

[2] Loading capacity calculated using Equation H- 1, the representative flow estimate from the second column, and the applicable criterion plus HUA (20.0°C plus 0.3°C). This loading capacity applies to the flow range in the third column of the table.

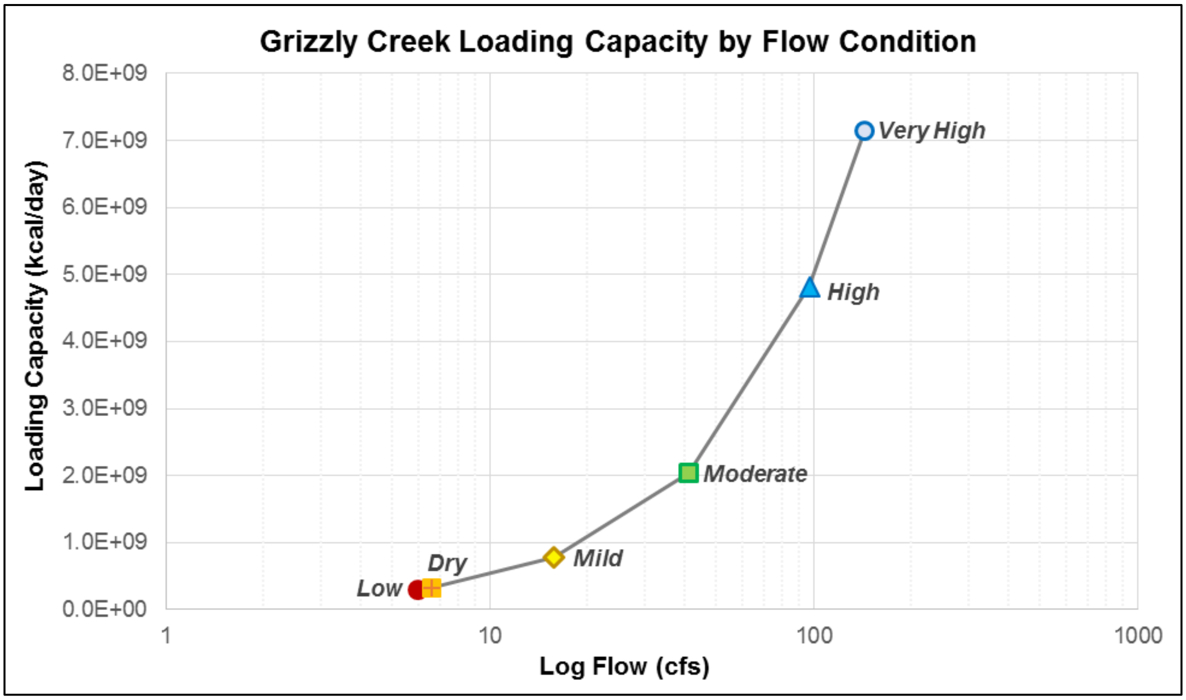

Figure H- 46. Grizzly Creek loading capacity curve by flow condition.

H.2.2.3 Hoxie Creek

The listed segment of Hoxie Creek is 3.6 miles long (Table H- 1), begins near the southern border of Rogue River National Forest and drains into Howard Prairie Lake (Figure H- 47). The drainage area of this segment is 8.9 square miles and, as mentioned above, comprises a part of the drainage area of Grizzly Creek, which is located at the south end of Howard Prairie Lake. In addition to the drainage area,

Table H- 34 presents a subset of basin characteristics produced by StreamStats and used to estimate streamflow statistics for Hoxie Creek.

Table H- 34. Hoxie Creek basin characteristics used in StreamStats.

Parameter	Value	Units
Drainage Area	8.9	sq mi
Mean Annual Precipitation	35.3	in
Mean Annual Maximum Air Temperature	13.2	°C
Mean Basin Slope	4.39	degrees
Relief	1620	ft
Average Soil Permeability	1.81	in/hr
Source: U.S. Geological Survey, 2012, The StreamStats program for Oregon, online at http://water.usgs.gov/osw/streamstats/oregon.html.		

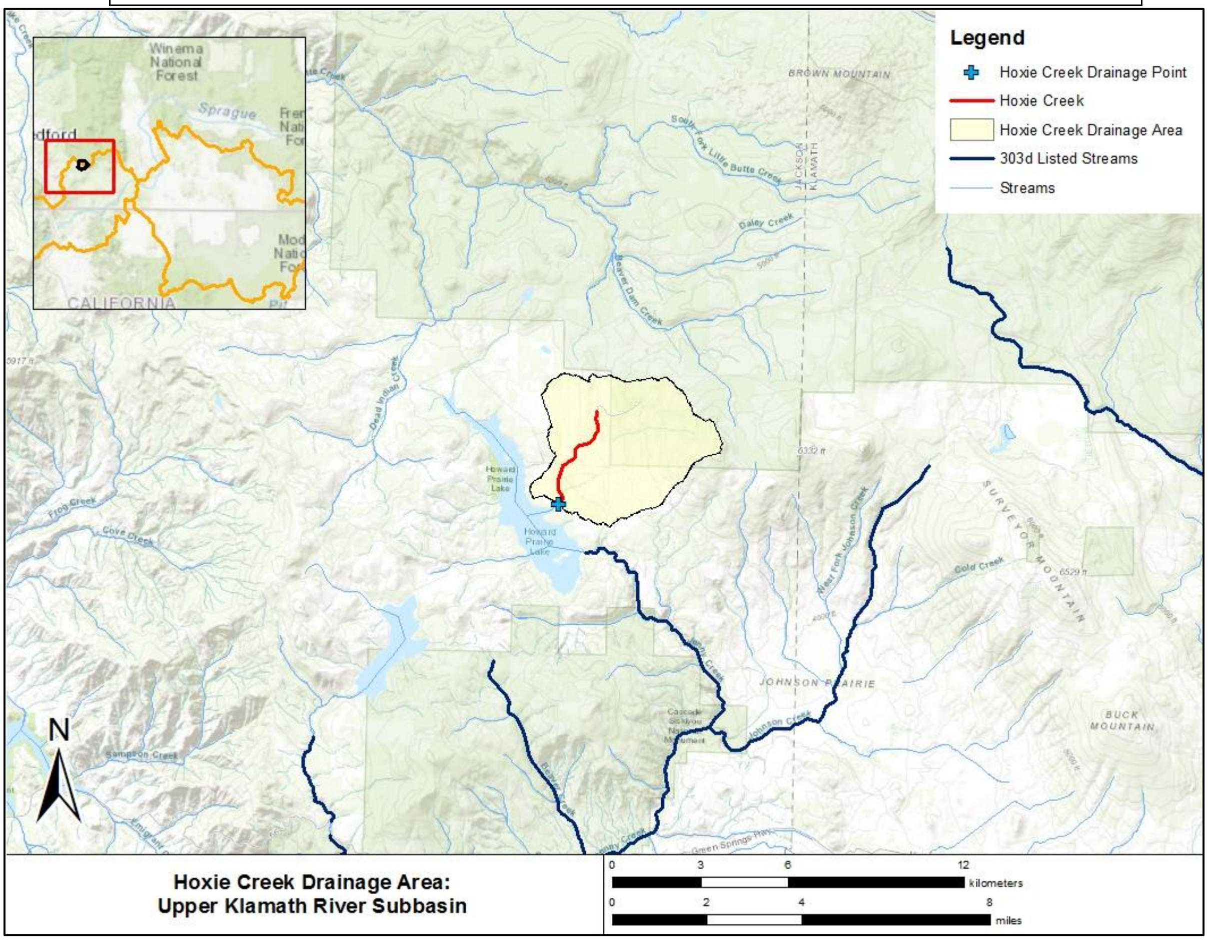

Figure H- 47. Hoxie Creek drainage area.

Expected flow conditions in Hoxie Creek were estimated to range from 0.2 cfs during low flow conditions to 49 cfs during very high flow conditions (

Table H- 34). These representative flows were used in Equation H- 1 to calculate the thermal loading capacity of Hoxie Creek for the range of typical flow conditions. The thermal loading capacity for Hoxie Creek ranged from 1.21E+07 kcal/day for low flows and 2.45E+09 kcal/day for very high flows (

Table H- 34). The thermal loading capacity, which was calculated using the lowest flow estimate for the condition, applies to the full range of flows until the next flow condition is reached (

Table H- 34). For example, a flow rate of 0.5 cfs would be considered to have a thermal loading capacity of 1.99E+07 kcal/day (dry flow condition). The relationship between loading capacity and streamflow in Hoxie Creek is presented in Figure H- 48. This curve characterizes the thermal loading capacity for the various flow regimes expected in the creek throughout the year.

Table H- 35. Hoxie Creek thermal loading capacity by flow condition.

Flow Condition	Representative Flow Estimate (cfs)[1]	Applicable Flow Range	Thermal Loading Capacity (kcal/day)[2]
Low	0.2	<0.4 cfs	1.21E+07
Dry	0.4	0.4 cfs to <4 cfs	1.99E+07
Mild	4	4 cfs to <12 cfs	1.87E+08
Moderate	12	12 cfs to <32 cfs	5.86E+08
High	32	32 cfs to <49 cfs	1.57E+09
Very High	49	≥49 cfs	2.45E+09

[1] Estimated from StreamStats analysis.

[2] Loading capacity calculated using Equation H- 1, the representative flow estimate from the second column, and the applicable criterion plus HUA (20.0°C plus 0.3°C). This loading capacity applies to the flow range in the third column of the table.

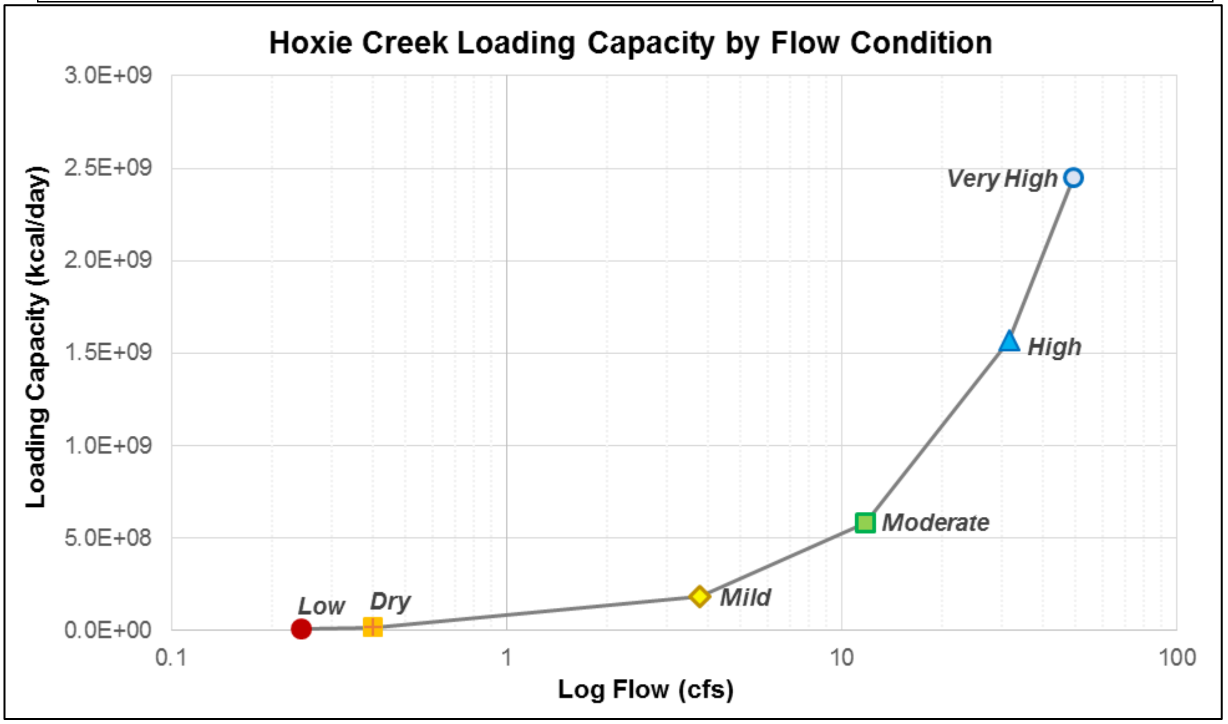

Figure H- 48. Hoxie Creek loading capacity curve by flow condition.

H.2.2.4 Johnson Creek

Johnson Creek is a tributary to Jenny Creek and is listed for a 9.4-mile long segment (Table H- 1). The listed segment of the creek is located in Johnson Prairie between Howard Prairie Lake and Klamath Falls and drains about 60 square miles, including West Fork Johnson Creek and Cold Creek (Figure H- 49). Table H- 36 includes a subset of the basin characteristics produced by StreamStats and used to determine streamflow statistics for the Johnson Creek drainage area.

Table H- 36. Johnson Creek basin characteristics used in StreamStats.

Parameter	Value	Units
Drainage Area	60	sq mi
Mean Annual Precipitation	29	in
Mean Annual Maximum Air Temperature	14	°C
Mean Basin Slope	6.73	degrees
Relief	2,900	ft
Average Soil Permeability	1.18	in/hr
Source: U.S. Geological Survey, 2012, The StreamStats program for Oregon, online at http://water.usgs.gov/osw/streamstats/oregon.html.		

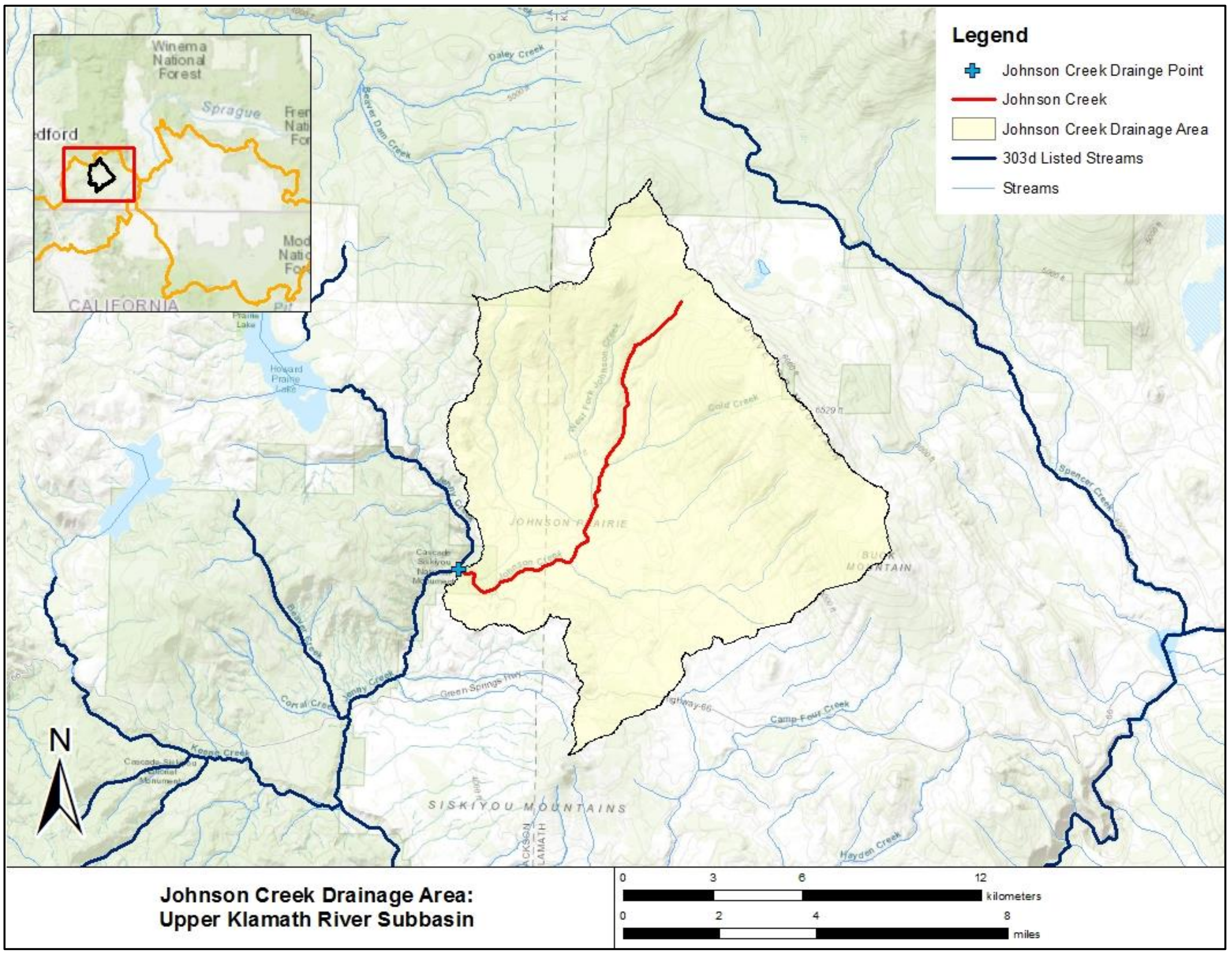

Figure H- 49. Johnson Creek drainage area.

Expected flows for Johnson Creek range from 7 cfs for low flow conditions to 181 cfs during very high flow conditions (Table H- 37). These representative flow values were used in Equation H- 1 to calculate loading capacities across a range of flow conditions in Johnson Creek (Table H- 37). The thermal loading capacity, which was calculated using the lowest flow estimate for the condition, applies to the full range of flows until the next flow condition is reached (Table H- 37). The loading capacity increases with increasing flows, from 3.33E+08 to 2.54E+09 to 8.99E+09 kcal/day for low, moderate, and very high flow conditions, respectively. The relationship between total loading capacity and flow conditions is illustrated in Figure H- 50. This curve characterizes the thermal loading capacity of Johnson Creek for the range of expected flows throughout the year and can be used as a reference to estimate the loading capacity for different flow rates (Figure H- 50).

Table H- 37. Johnson Creek thermal loading capacity by flow condition.

Flow Condition	Representative Flow Estimate (cfs)[1]	Applicable Flow Range	Thermal Loading Capacity (kcal/day)[2]
Low	7	<8 cfs	3.33E+08
Dry	8	8 cfs to <19 cfs	3.97E+08
Mild	19	19 cfs to <51 cfs	9.54E+08
Moderate	51	51 cfs to <119 cfs	2.54E+09
High	119	119 cfs to <181 cfs	5.91E+09
Very High	181	≥181 cfs	8.99E+09

[1] Estimated from StreamStats analysis.

[2] Loading capacity calculated using Equation H- 1, the representative flow estimate from the second column, and the applicable criterion plus HUA (20.0°C plus 0.3°C). This loading capacity applies to the flow range in the third column of the table.

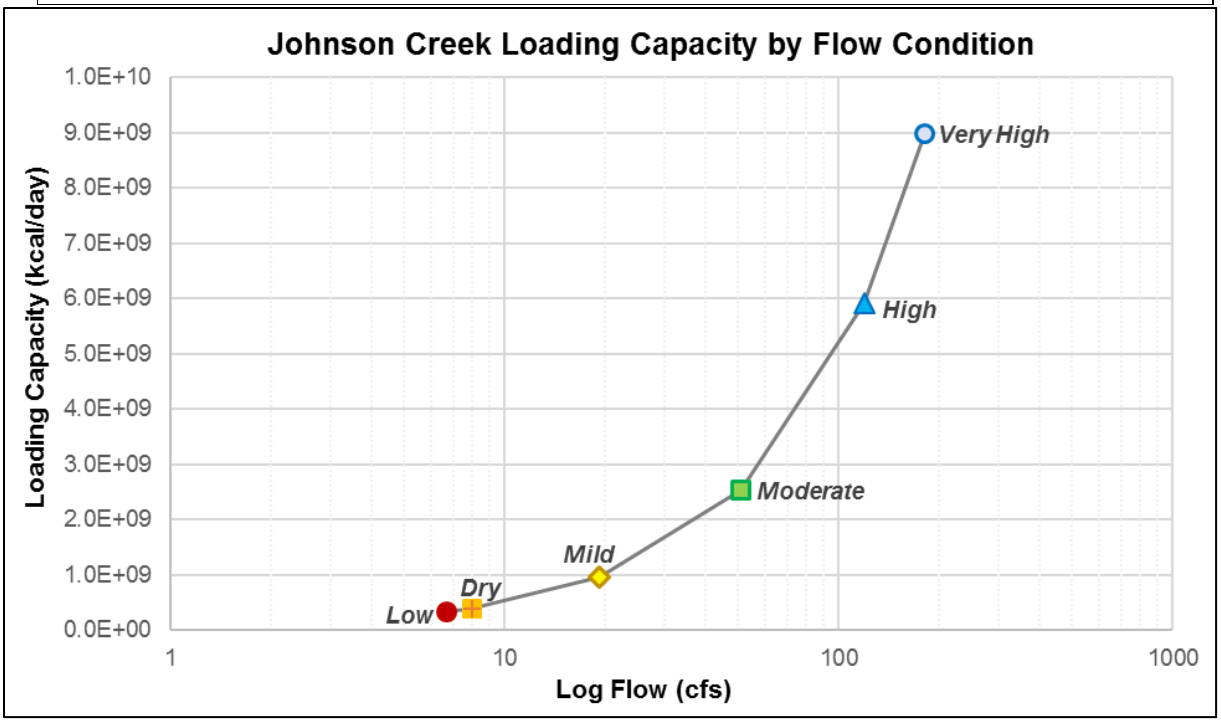

Figure H- 50. Johnson Creek loading capacity curve by flow condition

H.2.2.5 Keene Creek (Listing ID 2163)

Keene Creek 2163 is a tributary to Jenny Creek located in Cascade Siskiyou National Monument just south of Beaver Creek. It is listed for a 7.2-mile segment (Table H- 1) that has its headwaters in Keene Creek Reservoir by Green Springs Summit (Figure H- 51). The segment runs to the south of Green Springs Highway through Tubs Spring State Park until its confluence with Jenny Creek (Figure H- 51). The drainage area for Keene Creek 2163 covers 41 square miles and includes water quality limited segments Keene Creek 2178 (Section H.2.2.6), as well as, South Fork Keene Creek and Mill Creek, which are both tributaries to Keene Creek 2163. The drainage area also includes Hyatt Reservoir in the north and is adjacent to the Beaver Creek drainage area to the east. Table H- 38 includes a subset of basin characteristics produced by StreamStats and used to determine stream flow statistics for Keene Creek 2163.

Flow conditions for Keene Creek 2163 were estimated to range from 5 cfs for low flow conditions to 147 cfs for very high flow conditions (Table H- 39). These estimated flow conditions were used in Equation H- 1 to determine the thermal loading capacity of Keene Creek 2163 for the range of expected flows (Table H- 39). The thermal loading capacity of Keene Creek 2163 ranges from 2.70E+08 kcal/day to 7.30E+09 kcal/day for low and very high flow conditions, respectively. The thermal loading capacity was calculated using the lowest flow estimate for the condition, but applies to the full range of flows until the next flow condition is reached (Table H- 39). Figure H- 52 presents the relationship between flow rate and thermal loading capacity. This curve characterizes the thermal loading capacity of Keene Creek 2163 for the range of expected flows throughout the year and can be used as a reference to estimate the loading capacity for different flow rates (Figure H- 52).

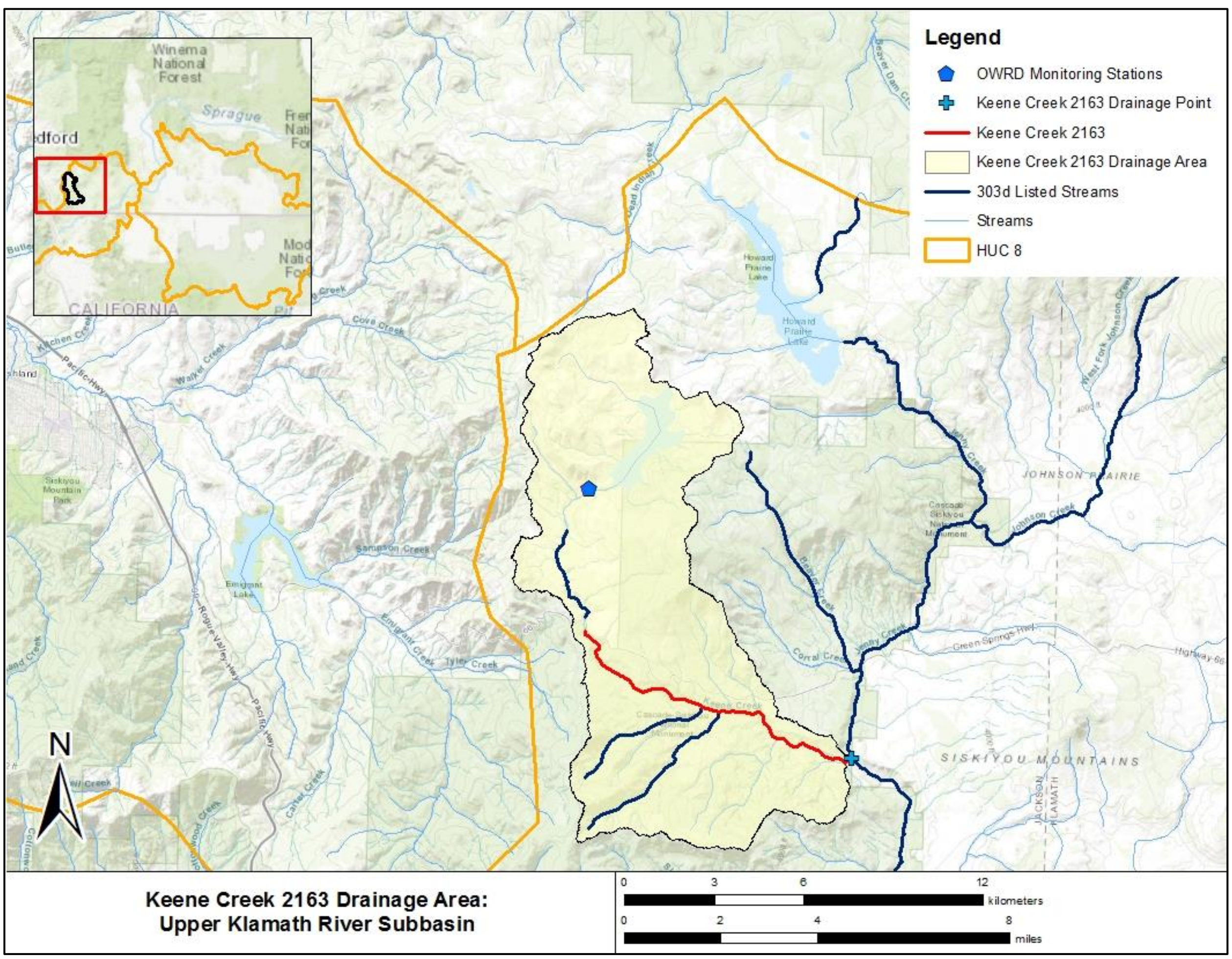

Figure H- 51. Keene Creek 2163 drainage area

Table H- 38. Keene Creek 2163 basin characteristics used in StreamStats

Parameter	Value	Units
Drainage Area	41	sq mi
Mean Annual Precipitation	31.7	in
Mean Annual Maximum Air Temperature	13.7	°C
Mean Basin Slope	9.69	degrees
Relief	2890	ft
Average Soil Permeability	1.88	in/hr
Source: U.S. Geological Survey, 2012, The StreamStats program for Oregon, online at http://water.usgs.gov/osw/streamstats/oregon.html.		

OWRD station 11514500 is located downstream of Hyatt Reservoir and upstream of the Keene Creek 2163 drainage area (Figure H- 51). During the time period of available data at this station (1984-1996), observed flows were lower than estimated StreamStats flows in the impaired segment, though within the same magnitude. Lower observed flows are expected at this location since the station drains a smaller area and is influenced by the upstream reservoir.

Table H- 39. Keene Creek 2163 thermal loading capacity by flow condition

Flow Condition	Representative Flow Estimate (cfs)[1]	Applicable Flow Range	Thermal Loading Capacity (kcal/day)[2]
Low	5	<6 cfs	2.70E+08
Dry	6	6 cfs to <15 cfs	3.08E+08
Mild	15	15 cfs to <41 cfs	7.65E+08
Moderate	41	41 cfs to <98 cfs	2.05E+09
High	98	98 cfs to <147 cfs	4.86E+09
Very High	147	≥147 cfs	7.30E+09

[1] Estimated from StreamStats analysis.

[2] Loading capacity calculated using Equation H- 1, the representative flow estimate from the second column, and the applicable criterion plus HUA (20.0°C plus 0.3°C). This loading capacity applies to the flow range in the third column of the table

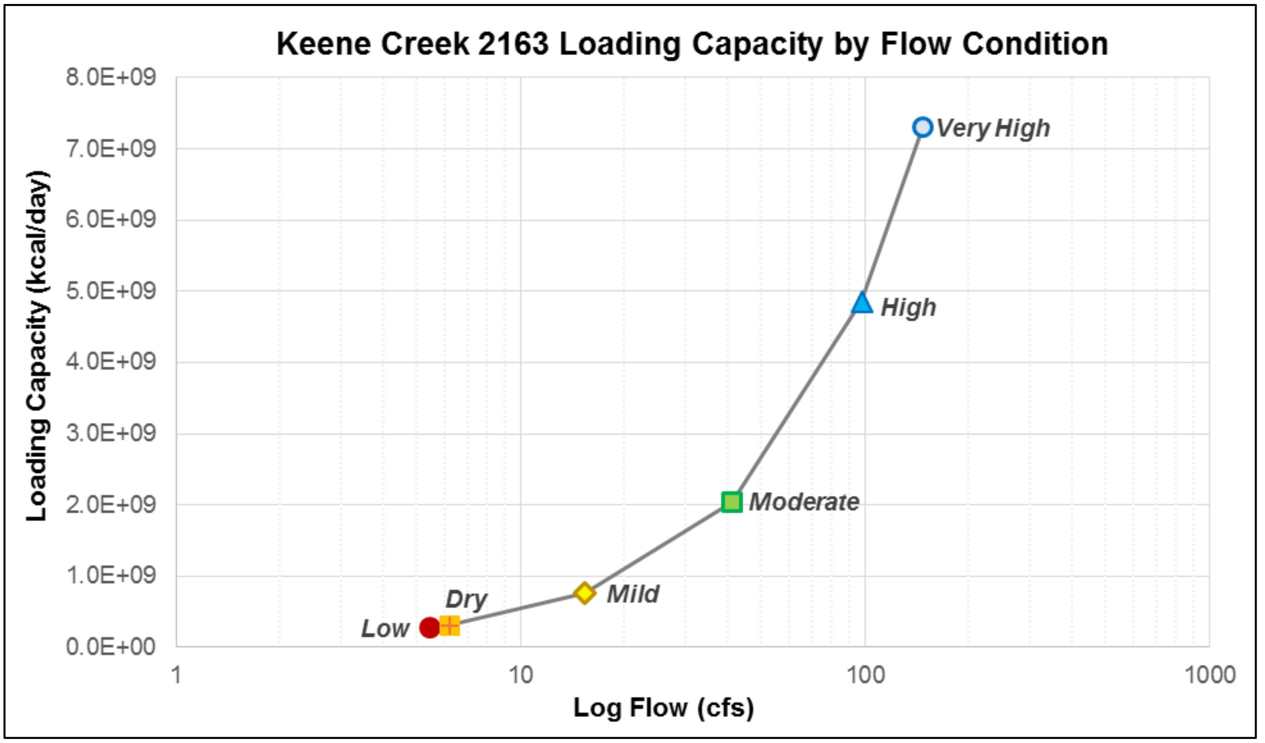

Figure H- 52. Keene Creek 2163 loading capacity curve by flow condition

H.2.2.6 Keene Creek (Listing ID 2178)

The water quality limited segment of Keene Creek 2178 is located upstream of Keene Creek 2163, north of Keene Creek Reservoir (Figure H- 53). The listed segment is 2.2 miles long (Table H- 1) and has its headwaters in Little Hyatt Reservoir near Hyatt Meadows and runs south, parallel to Old Hyatt Prairie Road, before ending in Keene Creek Reservoir. The drainage area for Keene Creek 2178 is approximately 20 square miles and comprises the most northern part of the drainage area for Keene Creek 2163, including tributaries such as Cottonwood Creek and Burnt Creek (Table H- 40 and Figure H- 53). The eastern boundary of the drainage area is adjacent to part of the western boundary of Beaver Creek extending from the Wildcat Glades to

Chinquapin Mountain. A subset of basin characteristics produced and used by StreamStats to determine stream flow statistics are listed in Table H- 40.

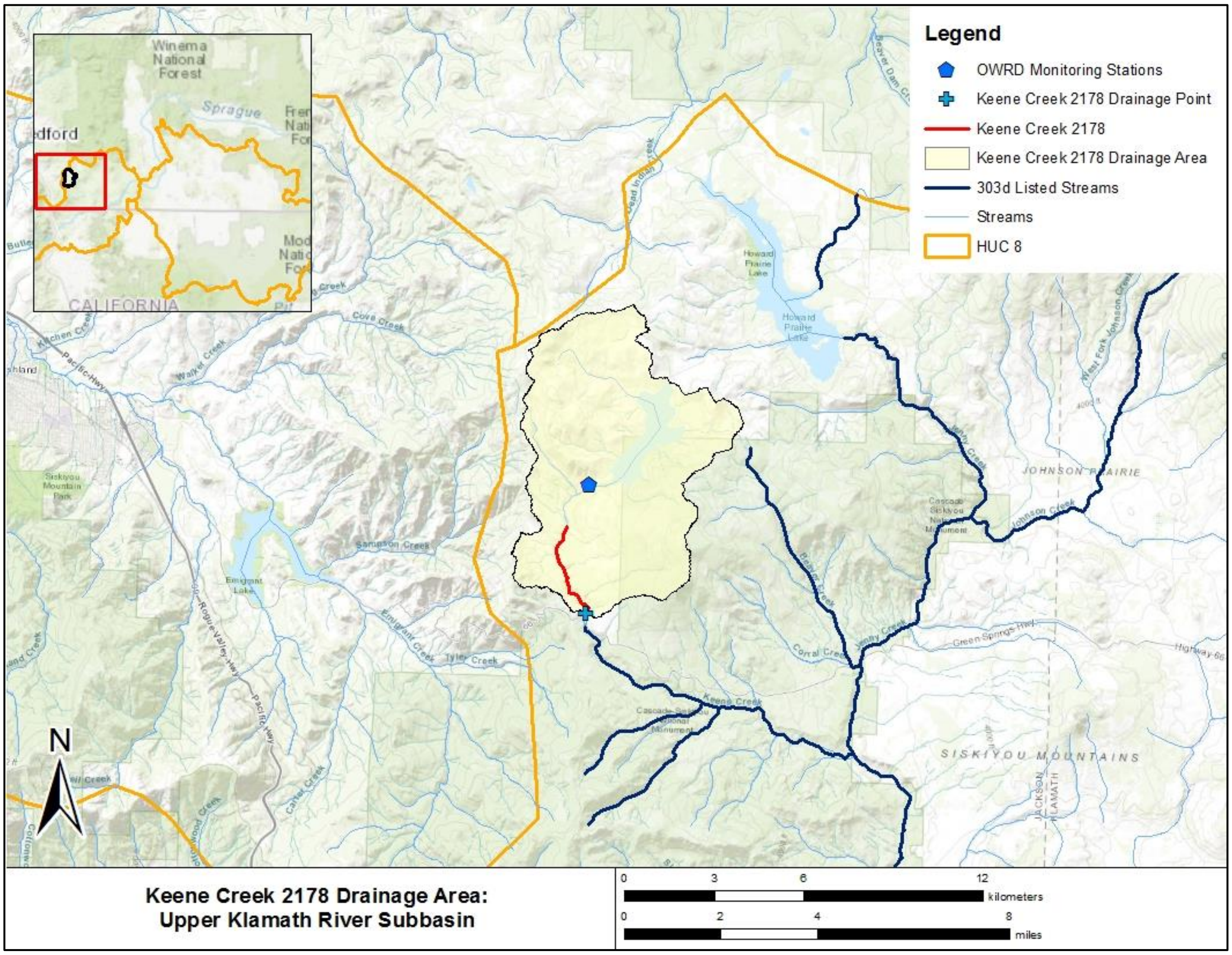

Figure H- 53. Keene Creek 2178 drainage area.

Table H- 40. Keene Creek 2178 basin characteristics used in StreamStats.

Parameter	Value	Units
Drainage Area	19.9	sq mi
Mean Annual Precipitation	35.7	in
Mean Annual Maximum Air Temperature	12.9	°C
Mean Basin Slope	7.46	degrees
Relief	1720	ft
Average Soil Permeability	2.08	in/hr
Source: U.S. Geological Survey, 2012, The StreamStats program for Oregon, online at http://water.usgs.gov/osw/streamstats/oregon.html		

Representative flow estimates for various flow conditions in Keene Creek 2178 range from 2.9 cfs for low flow conditions to 94 cfs during very high flow conditions (Table H- 41). These representative flows were used in Equation H- 1 to calculate the thermal loading capacity for the expected flows throughout the year in Keene Creek 2178. Thermal loading capacity for the creek ranges from 1.43E+08 kcal/day to 4.68E+09 kcal/day for low and very high flow conditions, respectively. The thermal loading capacity, which was calculated using the lowest flow estimate for the condition, applies to the full range of flows until the next flow condition is reached (Table H- 41). For example, when streamflow in Keene Creek 2178 is 5 cfs, the thermal loading capacity is 1.53E+08 kcal/day (part of the dry flow condition). The relationship between loading capacity and streamflow in Keene Creek 2178 is represented in Figure H- 54. This curve characterizes the thermal loading capacity for the various flow regimes expected in the creek.

Table H- 41. Keene Creek 2178 thermal loading capacity by flow condition.

Flow Condition	Representative Flow Estimate (cfs)[1]	Applicable Flow Range	Thermal Loading Capacity (kcal/day)[2]
Low	2.9	<3.1 cfs	1.43E+08
Dry	3.1	3.1 cfs to <9 cfs	1.53E+08
Mild	9	9 cfs to <25 cfs	4.51E+08
Moderate	25	25 cfs to <63 cfs	1.26E+09
High	63	63 cfs to <94 cfs	3.11E+09
Very High	94	≥94 cfs	4.68E+09

[1] Estimated from StreamStats analysis.

[2] Loading capacity calculated using Equation H- 1, the representative flow estimate from the second column, and the applicable criterion plus HUA (20.0°C plus 0.3°C). This loading capacity applies to the flow range in the third column of the table

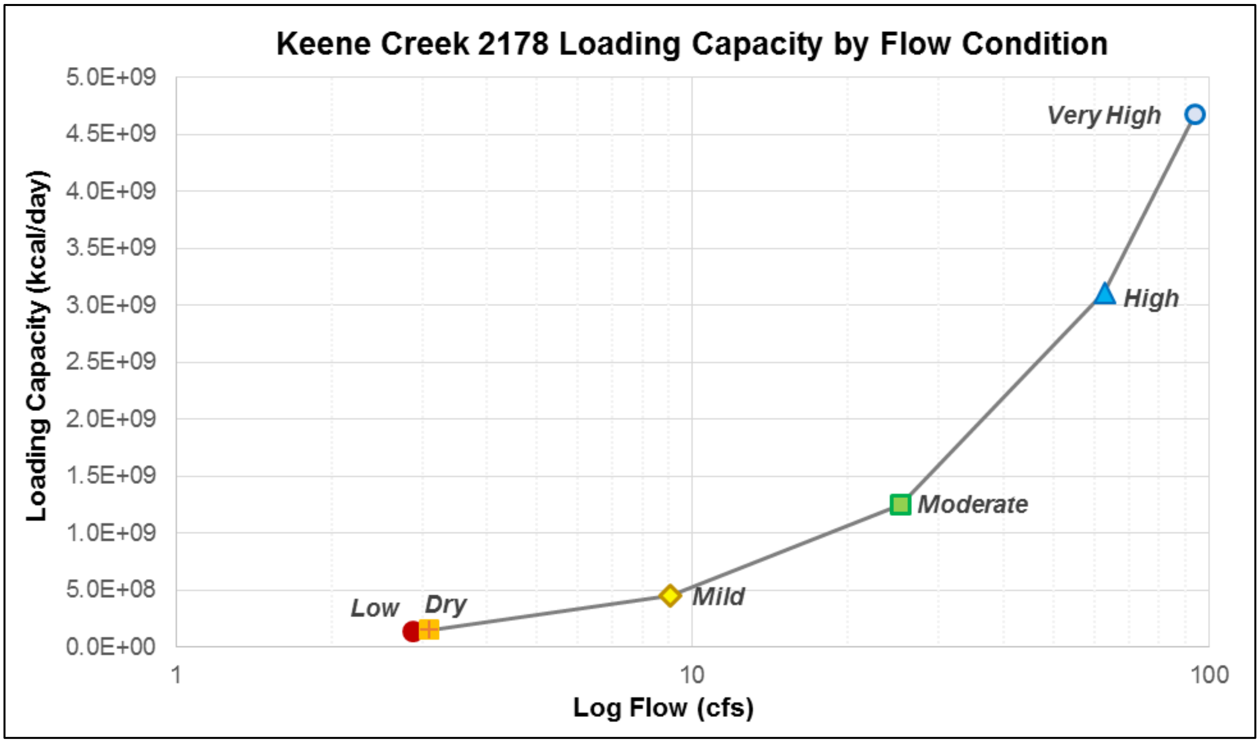

Figure H- 54. Keene Creek 2178 loading capacity curve by flow condition.

H.2.2.7 Mill Creek

Mill Creek is a tributary to Keene Creek 2163 and is located south of South Fork Keene Creek in Cascade Siskiyou National Monument. The creek is listed for a 3.9 mile segment (Table H- 1) that drains an area of approximately 2.9 square miles (Table H- 42) and comprises a part of the south west portion of the Keene Creek 2163 drainage area. The segment begins near Soda Mountain and flows from southwest to northeast to its confluence with Keene Creek 2163 (Figure H- 55). Table H- 42 includes a subset of basin characteristics produced and used by StreamStats to determine representative streamflow statistics of Mill Creek.

Table H- 42. Mill Creek basin characteristics used in StreamStats.

Parameter	Value	Units
Drainage Area	2.87	sq mi
Mean Annual Precipitation	31.4	in
Mean Annual Maximum Air Temperature	13.8	°C
Mean Basin Slope	16.1	degrees
Relief	2400	ft
Average Soil Permeability	2.09	in/hr
Source: U.S. Geological Survey, 2012, The StreamStats program for Oregon, online at http://water.usgs.gov/osw/streamstats/oregon.html		

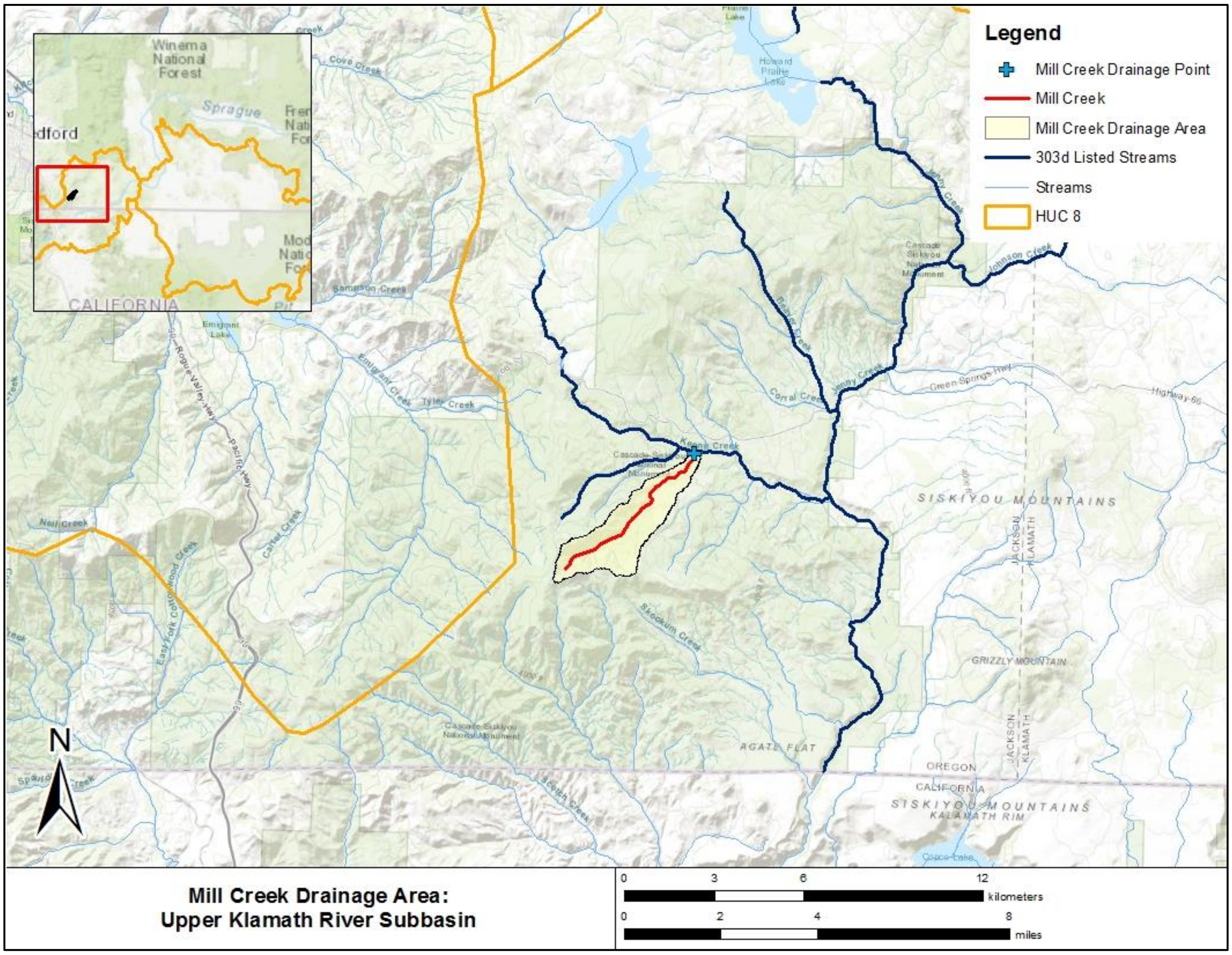

Figure H- 55. Mill Creek drainage area.

Representative flow rates for various flow conditions in Mill Creek are presented in Table H- 43

and range from 0 cfs for low and dry flow conditions to 18 cfs for very high flow conditions. These flows were used in Equation H- 1 to determine the thermal loading capacity of Mill Creek for the array of expected flow rates. The thermal loading capacity ranges from 0.00E+00 kcal/day for low and dry flow conditions to 4.38E+07 kcal/day for mild flow conditions and 8.84E+08 kcal/day for very high flow conditions (Table H- 43). The thermal loading capacity, which was calculated using the lowest flow estimate for the condition, applies to the full range of flows until the next flow condition is reached (Table H- 43). Equation H- 1 can be used to calculate thermal loading capacity for low and dry flows below 1 cfs. The relationship between loading capacity and streamflow in Mill Creek is presented in Figure H- 56. As thermal loading capacity is dependent on flow, it is expected that during a low flow condition with a flow rate of 0 cfs the thermal loading capacity is 0 kcal/day. The low and dry flow condition thermal loading capacities are represented at the origin, or the lowest part of the load capacity graph, in Figure H- 56 since streamflow is displayed on a log scale and cannot easily be illustrated as a 0 cfs flow.

Table H- 43. Mill Creek thermal loading capacity by flow condition.

Flow Condition	Representative Flow Estimate (cfs)[1]	Applicable Flow Range	Thermal Loading Capacity (kcal/day)[2]
Low	0	0	0.00E+00
Dry	0	0 cfs to <1 cfs	0.00E+00
Mild	1	1 cfs to <3 cfs	4.38E+07
Moderate	3	3cfs to <11 cfs	1.72E+08
High	11	11 cfs to <18 cfs	5.26E+08
Very High	18	≥18 cfs	8.84E+08

[1] Estimated from StreamStats analysis.

[2] Loading capacity calculated using Equation H- 1, the representative flow estimate from the second column, and the applicable criterion plus HUA (20.0°C plus 0.3°C). This loading capacity applies to the flow range in the third column of the table

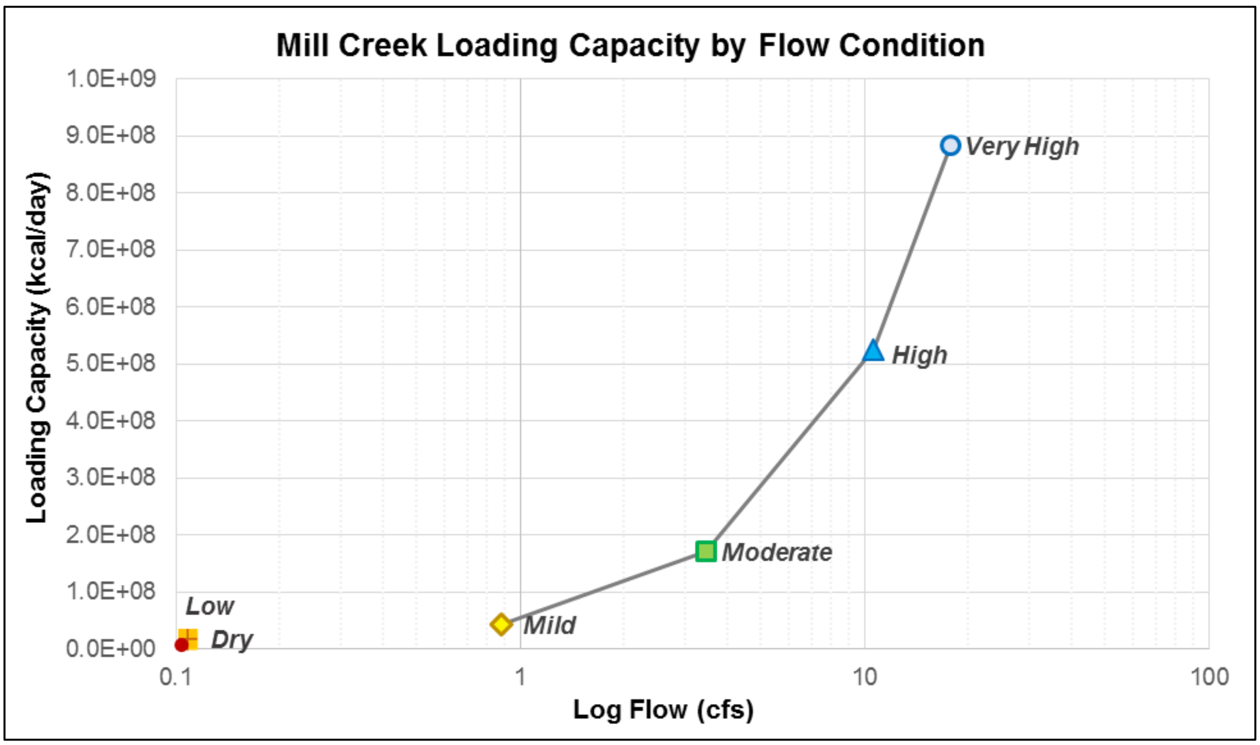

Figure H- 56. Mill Creek loading capacity curve by flow condition.

H.2.2.8 South Fork Keene Creek

South Fork Keene Creek is a tributary to Keene Creek 2163 located north of Mill Creek in Cascade Siskiyou National Monument. The water quality limited segment is 3.1 miles long (Table H- 1) and flows east from Soda Mountain Road to its confluence with Keene Creek 2163 (Figure H- 57). The creek drains an area of approximately 2.8 square miles and together with the drainage area of Mill Creek comprises the southwestern section of the Keene Creek 2163 drainage area. A subset of basin characteristics produced and used by StreamStats to determine streamflow statistics for South Fork Keene Creek are presented in Table H- 44.

Table H- 44. South Fork Keene Creek basin characteristics used in StreamStats.

Parameter	Value	Units
Drainage Area	2.77	sq mi
Mean Annual Precipitation	30.9	in
Mean Annual Maximum Air Temperature	13.8	°C
Mean Basin Slope	13.5	degrees
Relief	1970	ft
Average Soil Permeability	2.08	in/hr
Source: U.S. Geological Survey, 2012, The StreamStats program for Oregon, online at http://water.usgs.gov/osw/streamstats/oregon.html		

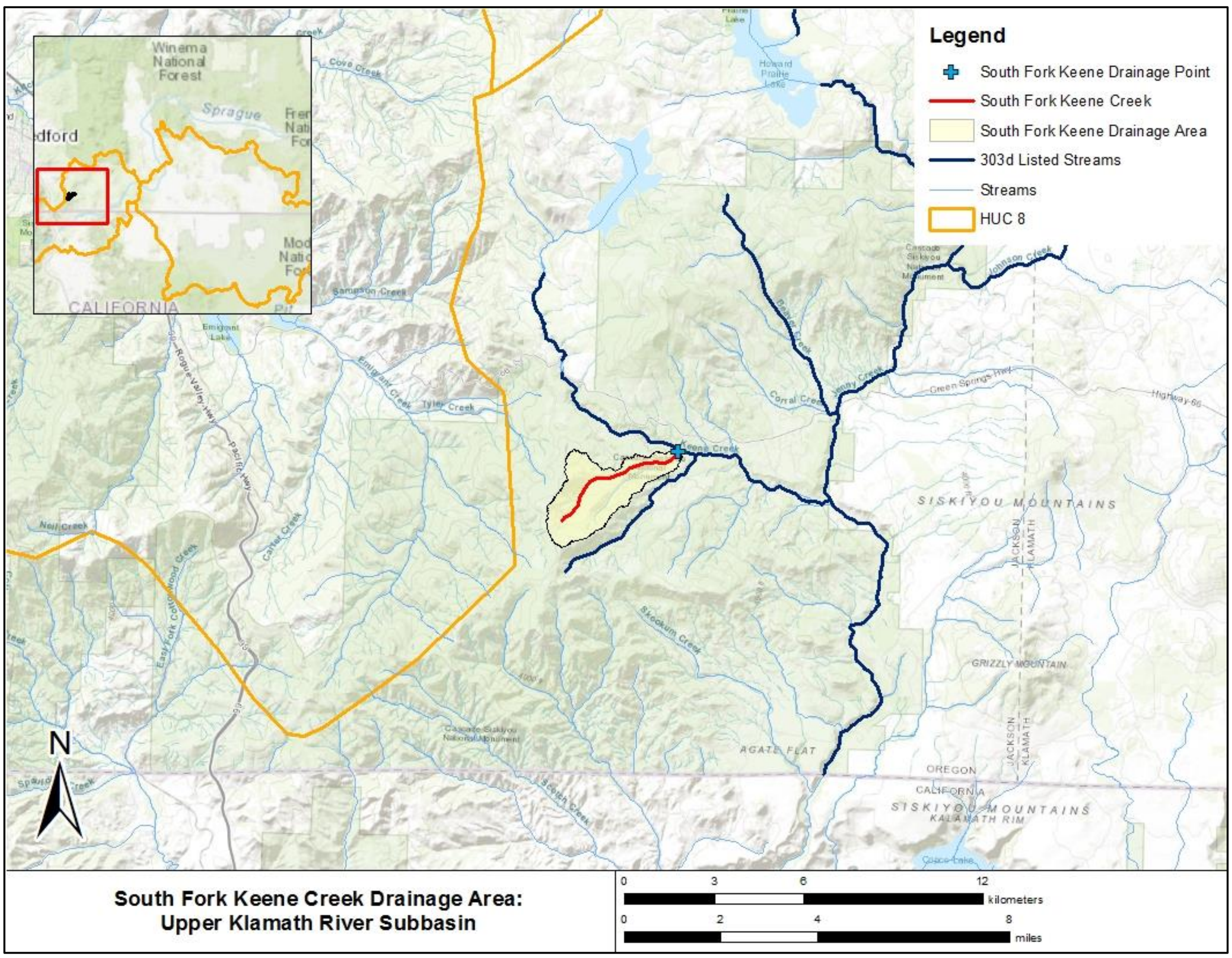

Figure H- 57. South Fork Keene Creek drainage area.

Representative flow estimates for various flow conditions in South Fork Keene Creek range from 0 cfs for low and dry flow conditions to 42 cfs during very high flow conditions (Table H- 45). These expected flows were used in Equation H- 1 to calculate the thermal loading capacity for the flow rates experienced throughout the year in South Fork Keene Creek. Thermal loading capacity in the creek ranges from 0.00E+00 kcal/day for low and dry flow conditions to 2.09E+09 kcal/day for very high flow conditions. The thermal loading capacity, which was calculated using the lowest flow estimate for the condition, applies to the full range of flows until the next flow condition is reached (Table H- 45). As expected based on Equation H- 1, a flow rate of 0 cfs results in a thermal loading capacity of 0 kcal/day. Equation H- 1 can be used to calculate thermal loading capacity for low and dry flows less than 2 cfs.

The relationship between loading capacity and streamflow in South Fork Keene Creek is presented in Figure H- 58. This curve characterizes the thermal loading capacity for the various flow regimes expected in the creek. The thermal loading capacities for low and dry flow conditions are represented at the origin, or the lowest part of the load capacity graph, in Figure H- 58 since streamflow is displayed on a log scale and a 0 cfs flow cannot be readily illustrated.

Table H- 45. South Fork Keene Creek thermal loading capacity by flow condition.

Flow Condition	Representative Flow Estimate (cfs)[1]	Applicable Flow Range	Thermal Loading Capacity (kcal/day)[2]
Low	0	0	0.00E+00
Dry	0	0 cfs to <2 cfs	0.00E+00
Mild	2	2 cfs to <8 cfs	1.06E+08
Moderate	8	8 cfs to <24 cfs	4.12E+08
High	24	24 cfs to <42 cfs	1.18E+09
Very High	42	≥42 cfs	2.09E+09

[1] Estimated from StreamStats analysis.

[2] Loading capacity calculated using Equation H- 1, the representative flow estimate from the second column, and the applicable criterion plus HUA (20.0°C plus 0.3°C). This loading capacity applies to the flow range in the third column of the table.

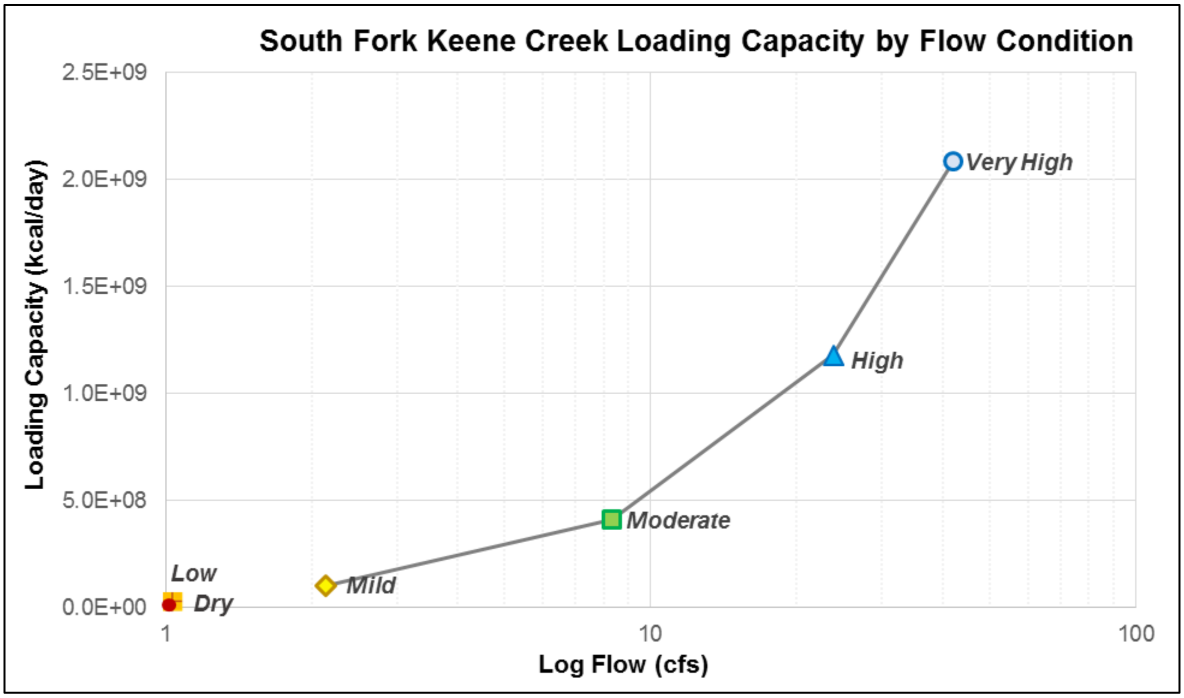

Figure H- 58. South Fork Keene Creek loading capacity curve by flow condition.

H.2.2.9 Spencer Creek

Spencer Creek is listed for an 18.9-mile long tributary to the Klamath River (Table H- 1). It terminates in the Klamath River at the JC Boyle Reservoir and is the northern-most drainage in the Upper Klamath River subbasin (Figure H- 59). The drainage area covers an area of approximately 84.8 square miles. Clover Creek is its largest tributary, joining Spencer Creek from the north. The Rogue River Siskiyou National Forest is in the headwaters and Surveyor Mountain forms the western boundary of the drainage area.

Representative flow estimates for Spencer Creek were obtained from observed measurements at Oregon Water Resources Department (OWRD) gage 11510000, which is located near the mouth of the creek (Figure H- 59). This station has historical data (1929-1932) as well as more recent monitoring beginning in 2002. The summer flows in the 1930s data were similar in magnitude to the more recent measurements. Monthly average temperatures were calculated for the 2002-2018 data. These data were then summarized to compare seasonal trends (Figure H- 60). Flows were typically lowest during July, August, and September. The lows flows, along with the corresponding high air temperatures during the summer period results in higher stream temperatures, making this the critical period for TMDL development. The minimum monthly average flow during the observed period was approximately 5 cfs, observed during July and August (Figure H- 60); however, monthly average flows were observed as high as 40.5 and 31.1 cfs during the months of July and August, respectively, with monthly mean values below 20 cfs.

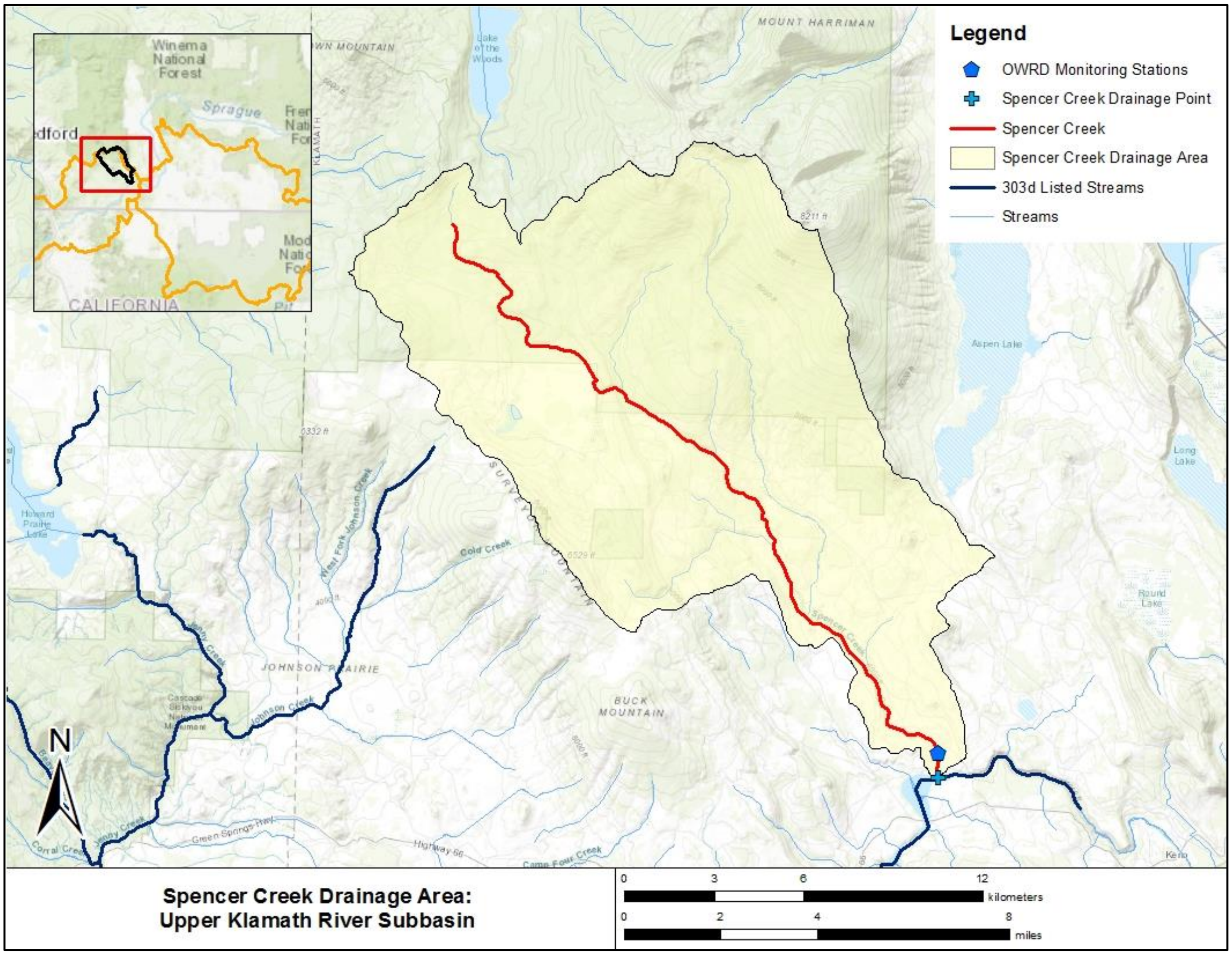

Figure H- 59. Spencer Creek drainage area.

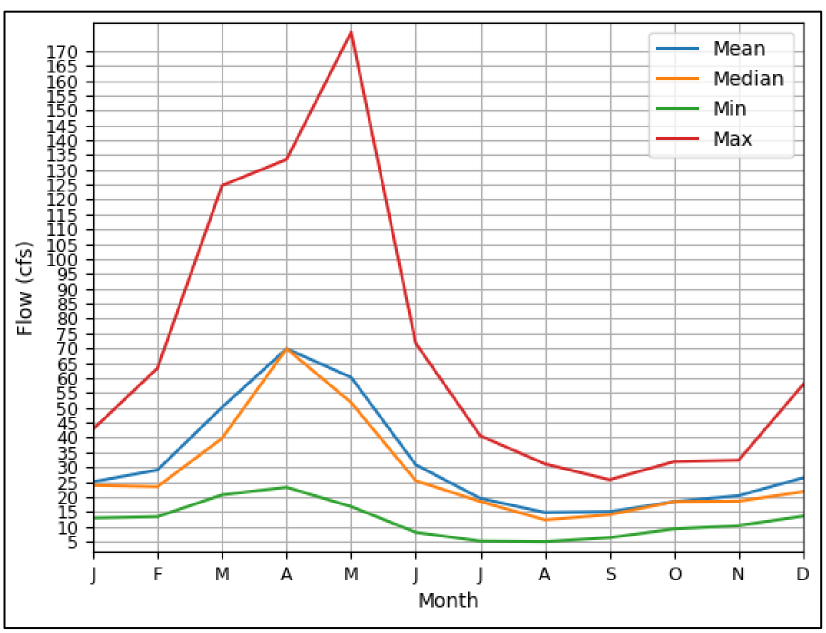

Figure H- 60. Summary of average monthly flow statistics for Spencer Creek.

A flow frequency analysis was constructed on the 2002 to 2018 data using the Weibull plotting positions method. Figure H- 61 illustrates the flow percentile distribution and Table H- 46 below summarizes the flow statistics that were used in the thermal loading capacity calculations. The top one perecent of flows had some very extrememe high flow values ranging from 175 to 358 cfs. In addition, Appendix A compares the Heat Source model flow with the available data. This comparison illustrates that both analyses resulted in similar flow ranges and ensures that the restored flows included in the Heat Source model were reflected in the observed data.

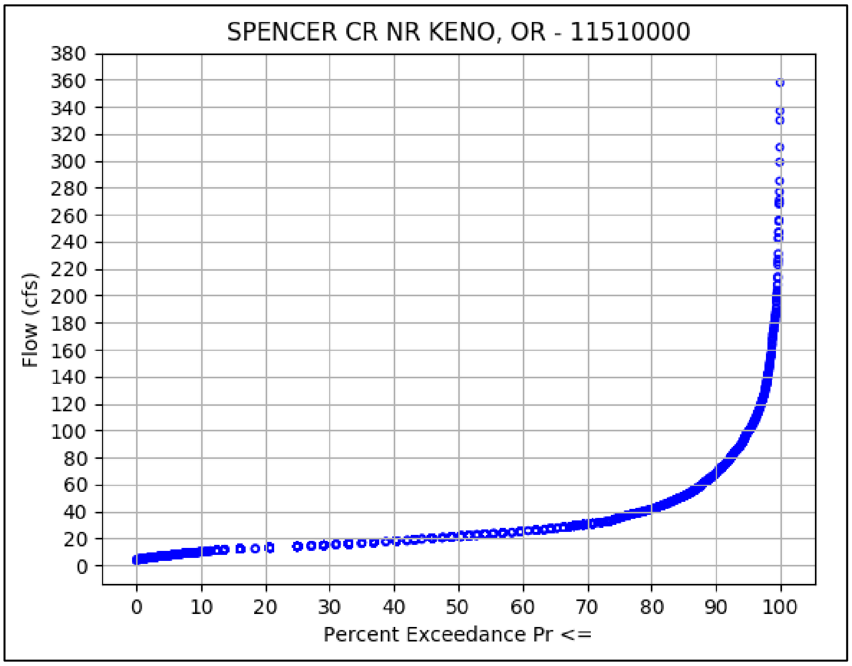

Figure H- 61. Flow duration curve for Spencer Creek.

Table H- 46. Spencer Creek thermal loading capacity by flow condition.

Flow Condition	Representative Flow Estimate (cfs)[1]	Applicable Flow Range	Thermal Loading Capacity (kcal/day)[2]
Low	4.2	<7 cfs	2.08E+08
Dry	7	7 cfs to <21cfs	3.68E+08
Mild	21	21 cfs to <35 cfs	1.04E+09
Moderate	35	35 cfs to <68 cfs	1.74E+09
High	68	68 cfs to <98 cfs	3.38E+09
Very High	98	≥98 cfs	4.87E+09

[1] Estimated from analysis of 2002-2018 observed flows at OWRD Station 11510000.

[2] Loading capacity calculated using Equation H- 1, the representative flow estimate from the second column, and the applicable criterion plus HUA (20.0°C plus 0.3°C). This loading capacity applies to the flow range in the third column of the table.

The flow estimates resulted in a range from 4.2 cfs during low flow conditions to 98 cfs for very high flow conditions (Table H- 46). These expected flows were used in Equation H- 1 to determine the range of loading capacities for Spencer Creek. The thermal loading capacity, which was calculated using the lowest flow estimate for the condition, applies to the full range of flows until the next flow condition is reached (Table H- 46). The loading capacity increases with increasing flow, from 2.08E+08 to 4.87E+09 kcal/day for low and very high flow conditions, respectively. The relationship between total loading capacity and flow conditions is illustrated in Figure H- 62. This curve characterizes the thermal loading capacity of Spencer Creek for the range of expected flows throughout the year and can be used as a reference to estimate the loading capacity for different flow rates (Figure H- 62).

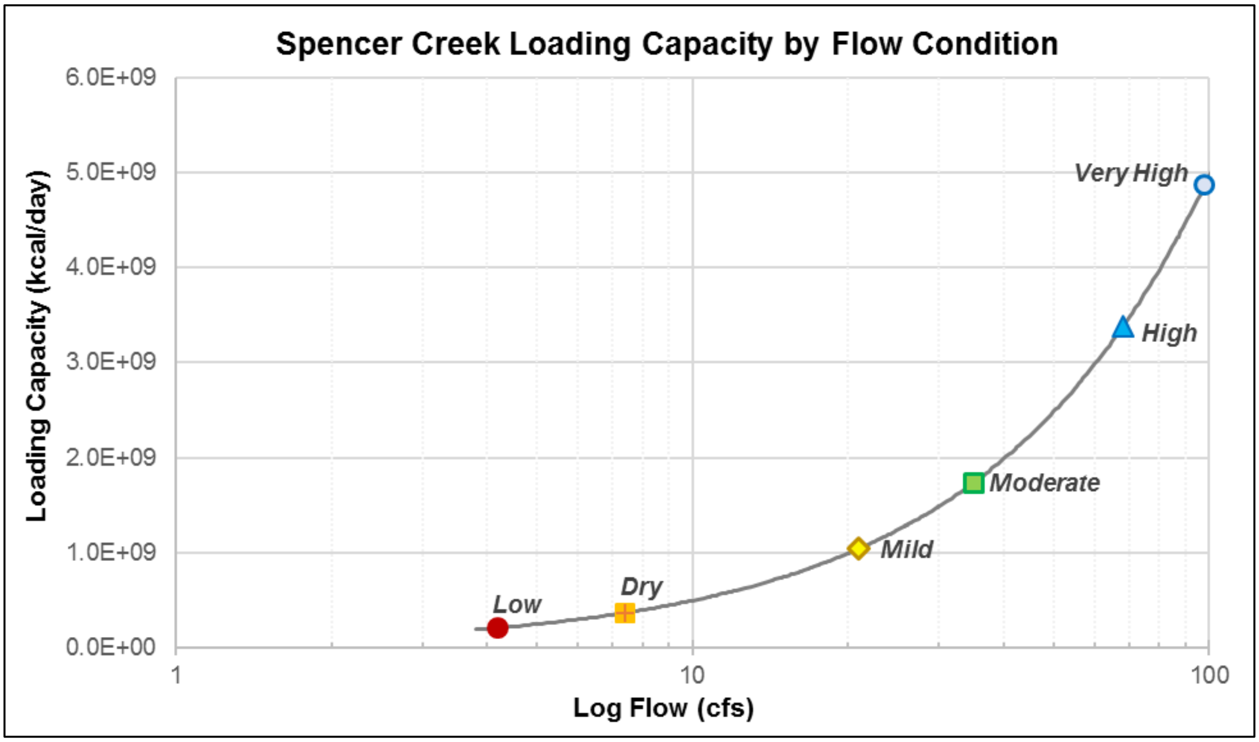

Figure H- 62. Spencer Creek loading capacity curve by flow condition.

H.2.2.10 Miller Creek

Miller Creek is a tributary to the Lost River and is listed for a 9.6-mile long segment. Miller Creek originates downstream of Gerber Reservoir and flows into irrigation canals within Langell Valley southeast of Bonanza and finally into the Lost River. The extent of the listing is from Gerber Reservoir to its confluence with Pine Creek. Miller Creek drains an area of approximately 275 square miles (Figure H- 63). A subset of the basin characteristics produced by StreamStats and used to determine streamflow statistics for Miller Creek are presented in Table H- 47.

Table H- 47. Miller Creek basin characteristics used in StreamStats.

Parameter	Value	Units
Drainage Area	275	sq mi
Mean Annual Precipitation	19.7	in

Parameter	Value	Units
Mean Annual Maximum Air Temperature	14.67	°C
Mean Basin Slope	3.89	degrees
Relief	3090	ft
Average Soil Permeability	1.38	in/hr
Source: U.S. Geological Survey, 2012, The StreamStats program for Oregon, online at http://water.usgs.gov/osw/streamstats/oregon.html.		

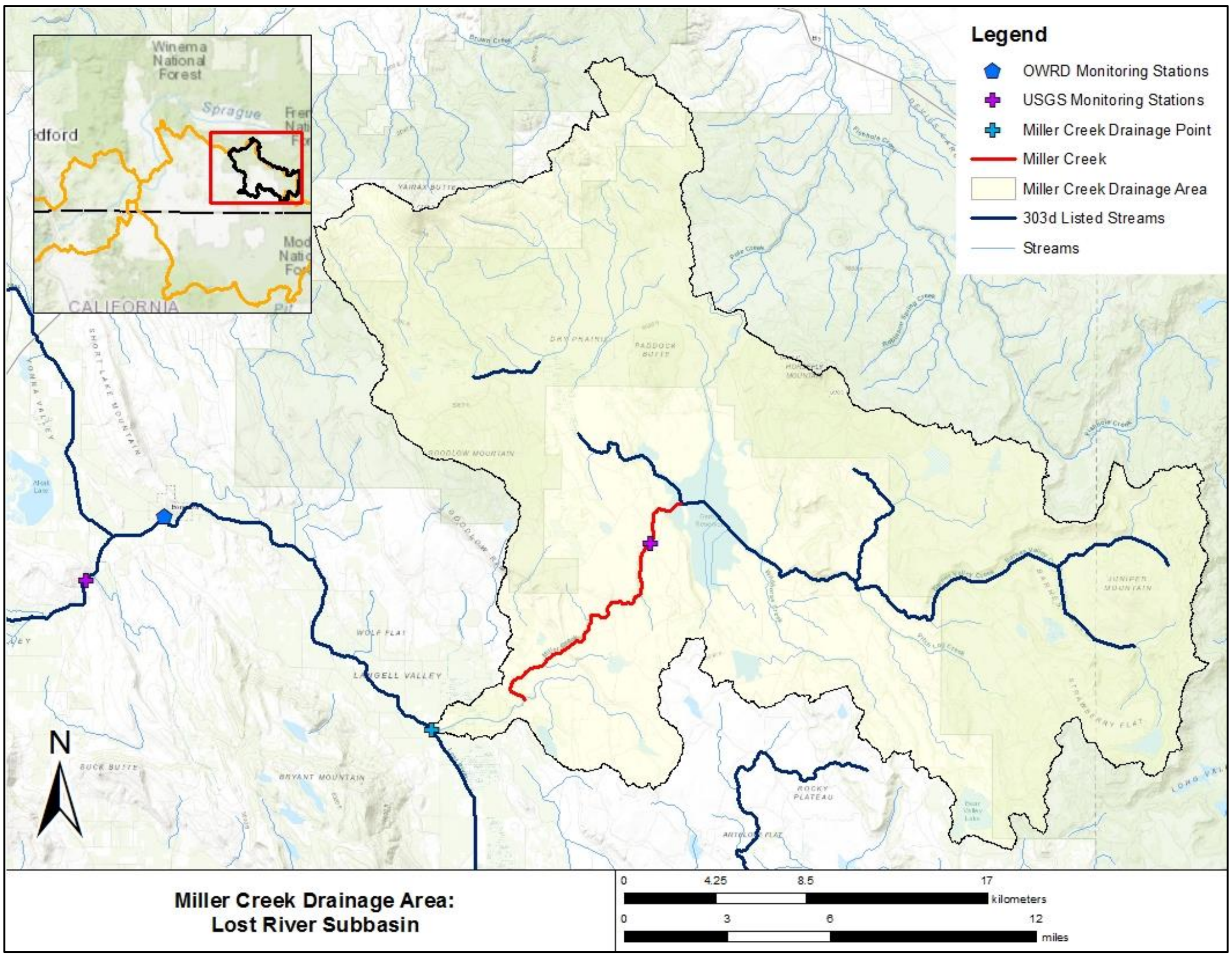

Figure H- 63. Miller Creek drainage area.

Representative flow estimates for Miller Creek are 13 cfs during low flow conditions and range from 19 cfs for dry flow conditions to 401 cfs for very high flow conditions (Table H- 48). These representative flows were used in Equation H- 1 to calculate the thermal loading capacity of Miller Creek for the range of expected flow conditions. The thermal loading capacity for Miller Creek ranges from 6.61E+08 kcal/day during low flow conditions to 1.99E+10 kcal/day during very high flow conditions (Table H- 48). The thermal loading capacity, which was calculated using the lowest flow estimate for each condition, applies to the full range of flows until the next flow condition is reached (Table H- 48).

The relationship between streamflow and thermal loading capacity in Miller Creek is presented in Figure H- 64. This curve characterizes the thermal loading capacity for the various flow regimes expected in the creek throughout the year. Note that the loading capacity is presented based on StreamStats at the downstream and the compliance was evaluated using the Heat Source Model developed for Jenny Creek.

Table H- 48. Miller Creek thermal loading capacity by flow condition.

Flow Condition	Representative Flow Estimate (cfs)[1]	Applicable Flow Range	Thermal Loading Capacity (kcal/day)[2]
Low	13	<19 cfs	6.61E+08
Dry	19	19 cfs to <44cfs	9.44E+08
Mild	44	44 cfs to <115 cfs	2.19E+09
Moderate	115	115 cfs to <255 cfs	5.71E+09
High	255	255 cfs to <401 cfs	1.27E+10
Very High	401	≥401 cfs	1.99E+10

[1] Estimated from StreamStats analysis.

[2] Loading capacity calculated using Equation H- 1, the representative flow estimate from the second column, and the applicable criterion plus HUA (20.0°C plus 0.3°C). This loading capacity applies to the flow range in the third column of the table.

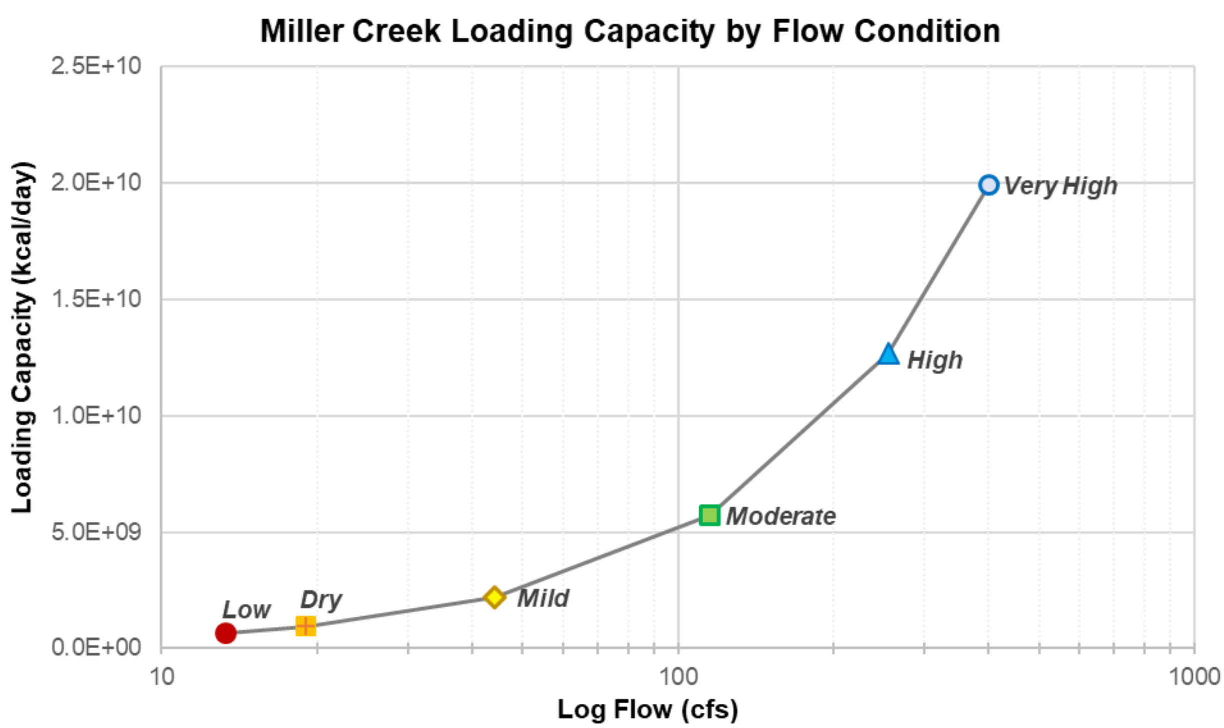

Figure H- 64. Miller Creek loading capacity curve by flow condition.

H.3 Assumptions

Assumptions were made during implementation of this technical approach. These assumptions include:

- The thermal loading capacities were calculated using the lowest flow estimate for each flow condition; however, the loading capacity applies to the entire range of flows within that condition. This approach captures the expected range of flows for each impaired segment. It results in a conservative application of the loading capacity when the observed flow in a specific condition is higher than the lowest flow estimate used in the TMDL calculations.
- StreamStats flow estimates are representative of flow conditions in the various waterbodies. Actual flow within a waterbody may vary from the StreamStats estimates, especially in the case of drainages with reservoirs. However, this approach was considered reasonable to address waterbodies with no other flow data because the equation to calculate the thermal loading capacity is provided, so more precise loading capacity values can be calculated for specific measured flow values.
- Modeled flows from 1999 were used to represent the Lost River. This assumption was verified through comparison to more recent flow and temperature data to ensure that the modeling period was still representative of recent conditions (Section H.2.1.11).

H.4 References

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Cooper, R.M. 2005. Estimation of peak discharges for rural, unregulated streams in western Oregon: U.S. Geological Survey Scientific Investigations Report 2005-5116, 134 p.

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Risley, J., Stonewall, A., and T. Haluska. 2008. Estimating flow-duration and low-flow frequency statistics for unregulated streams in Oregon: U.S. Geological Survey Scientific Investigations Report 2008-5126, 22 p.