Total Maximum Daily Loads for the Willamette Subbasins

Technical Support Document

Appendix A: Heat Source Model Report

Amended, May 2025

State of Oregon
DEQ Department of Environmental Quality

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1. Overview

The Heat Source model was used to predict/evaluate hourly stream temperatures, solar radiation fluxes, daily effective shade, and stream temperature responses. The map in **Figure 1-1** provides an overview of where the Heat Source model was used to simulate conditions.

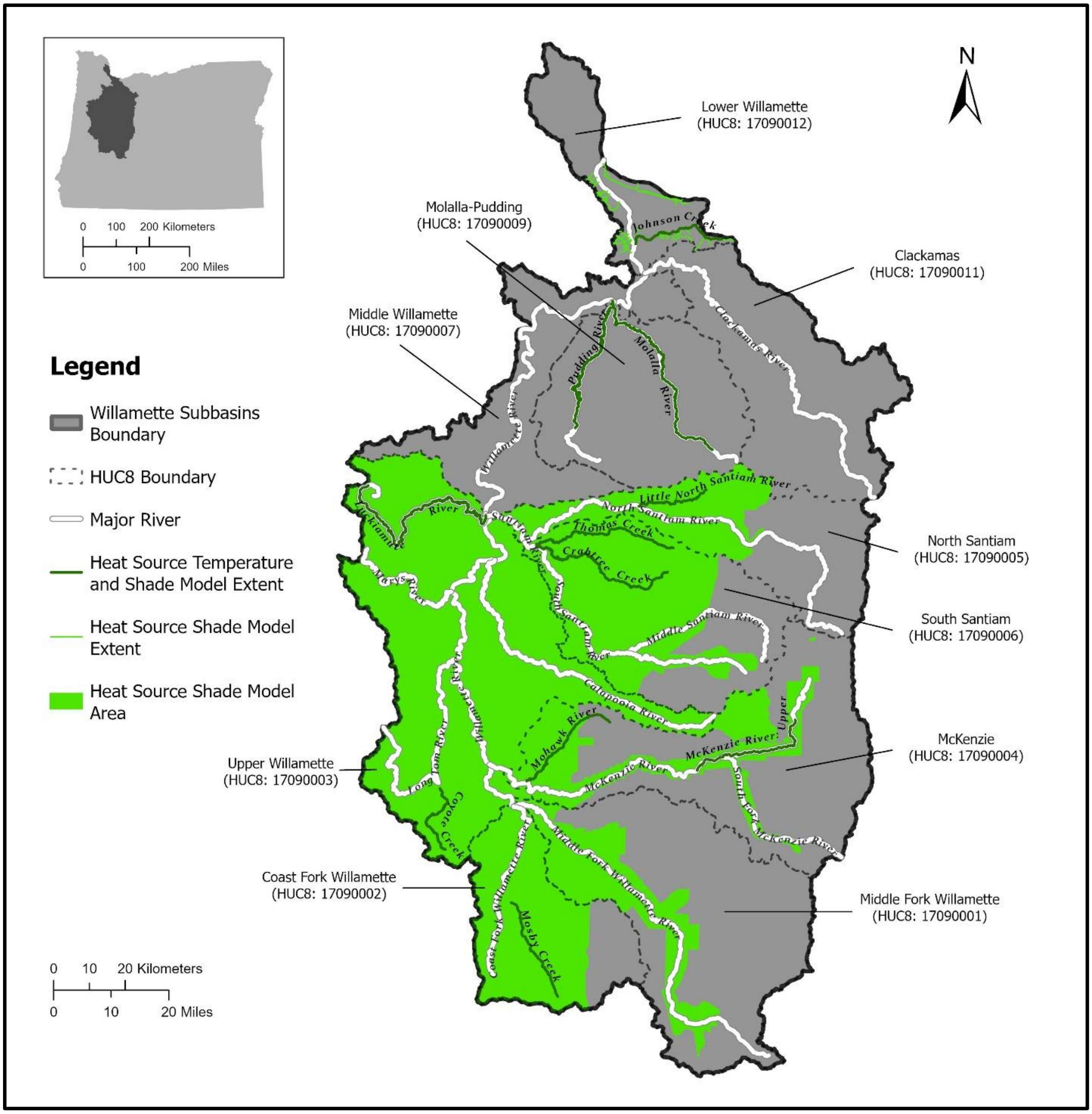


Figure 1-1: Overview of TMDL project area with model extents.

2. Available Data

2.1 Field Data

2.1.1 Stream temperature

Continuous stream temperature data were used:

- To evaluate if the waterbody achieves temperature water quality standards,
- As model input for tributary inflows or the upstream boundary condition,
- To assess model performance and goodness-of-fit by comparing to the model-predicted stream temperature data.

In some cases, instantaneous temperature data were used as model input for tributary inflows or the upstream boundary condition.

Temperature data used in this analysis were collected by the Oregon Department of Environmental Quality (DEQ) and other organizations and most of it is available in DEQ's Ambient Water Quality Monitoring System (AWQMS) database. Temperature data retrieved from DEQ's AWQMS database and used to support TMDL model development had a Data Quality Level (DQL) of A, B or E and a result status of "Final" or "Provisional". The DQL criteria are outlined in DEQ's Data Quality Matrix for Field Parameters (DEQ, 2013a). For TMDL development, only temperature results with a DQL of A, B, or E are used (DEQ, 2021). Data of unknown quality were used after careful review. Continuous stream temperature monitoring sites supporting TMDL model development are summarized in **Table 2-1** through **Table 2-11**.

Table 2-1: Stream temperature monitoring sites supporting Johnson Creek model development.

Monitoring Location ID	Monitoring Location Name	Latitude	Longitude	Source
No ID	Errol Creek	45.4638	-122.6178	City of Portland Parks & Recreation (Grab)
10853-ORDEQ	Johnson Creek at 92nd Avenue near Flavel	45.4678	-122.568	DEQ
10856-ORDEQ	Johnson Creek at SE 122nd (Portland)	45.4737	-122.536	DEQ
11321-ORDEQ	Johnson Creek at 17th Avenue	45.4467	-122.643	DEQ
11323-ORDEQ	Johnson Creek at 45th Avenue Footbridge	45.4617	-122.616	DEQ
11326-ORDEQ	Johnson Creek at Pleasant View / 190th Ave. (Gresham)	45.488	-122.468	DEQ
11327-ORDEQ	Johnson Creek at Regner Gage	45.4867	-122.421	DEQ
11329-ORDEQ	Crystal Springs Creek at mouth (Johnson Creek Park)	45.4615	-122.642	DEQ
11626-ORDEQ	Johnson Creek at Palmblad Road	45.4728	-122.403	DEQ
14211550	Johnson Creek at Milwaukie, OR	45.453	-122.643	USGS

Monitoring Location ID	Monitoring Location Name	Latitude	Longitude	Source
14211499	Kelley Creek	45.4768	-122.498	USGS
28729-ORDEQ	Johnson Creek at Revenue Road	45.4617	-122.337	DEQ
28730-ORDEQ	Johnson Creek at Short Road	45.4627	-122.358	DEQ
28731-ORDEQ	Johnson Creek at SE Circle Avenue	45.4864	-122.488	DEQ
28732-ORDEQ	Johnson Creek at SE 72nd Avenue and Bell	45.4556	-122.593	DEQ

Table 2-2: Stream temperature monitoring sites supporting Molalla River model development.

Monitoring Location ID	Monitoring Location Name	Latitude	Longitude	Source
No Station ID	Molalla at Locked Gate HW	44.9251	-122.3396	DEQ
10636-ORDEQ	Molalla at the mouth	45.2996	-122.7214	DEQ
32059-ORDEQ	Molalla at 22nd	45.2805	-122.7113	DEQ
10637-ORDEQ	Molalla River at Knights Bridge Road (Canby)	45.2675	-122.7103	DEQ
32058-ORDEQ	Molalla at Goods Br. USGS	45.2443	-122.6875	DEQ
32061-ORDEQ	Molalla abv Milk Cr	45.2377	-122.6578	DEQ
No Station ID	Molalla at Kraxberger	45.2188	-122.6055	DEQ
10881-ORDEQ	Molalla at Hwy 213 Bridge	45.1999	-122.5810	DEQ
No Station ID	Molalla abv N. Fork	45.0831	-122.4886	DEQ
32051-ORDEQ	Molalla above Pine Cr USGS	45.0121	-122.4847	DEQ
32049-ORDEQ	Molalla River upstream of Horse Creek	44.9622	-122.4325	DEQ
No Station ID	Molalla at Locked Gate HW	44.9251	-122.3396	DEQ
10362-ORDEQ	Pudding River at Arndt Road (Barlow)	45.2599	-122.738	DEQ
No Station ID	North Fork Molalla	45.0835	-122.4888	DEQ
32048-ORDEQ	Table Rock Fork Molalla River at River Mile 1	44.9681	-122.4037	DEQ
32047-ORDEQ	Copper Creek at mouth (Molalla River)	44.9242	-122.3394	DEQ

Table 2-3: Stream temperature monitoring sites supporting Pudding River model development.

Monitoring Location ID	Monitoring Location Name	Latitude	Longitude	Source
32055-ORDEQ	Pudding River at State Street	44.9144	-122.8175	DEQ
10362-ORDEQ	Pudding River at Arndt Road (Barlow)	45.2599	-122.738	DEQ
10917-ORDEQ	Pudding River at Hwy 99 (Aurora)	45.2338	-122.749	DEQ
10640-ORDEQ	Pudding River at Hwy 211 (Woodburn)	45.1504	-122.7925	DEQ
10641-ORDEQ	Pudding River at Hwy 214 (downstream of cannery outfall)	45.1264	-122.8193	DEQ
11530-ORDEQ	Pudding River at Monitor-McKee Road	45.1008	-122.83	DEQ

Monitoring Location ID	Monitoring Location Name	Latitude	Longitude	Source
31877-ORDEQ	Pudding River at Saratoga Road	45.0631	-122.8287	DEQ
PR1-5808	Pudding River at Hazel Green Rd.	45.0094	-122.8434	Marion SWCD
NPDES-98815	Woodburn WWTP	45.1509	-122.8040	DEQ
NPDES-32536	JLR, LLC	45.1261	-122.8207	DEQ
31876-ORDEQ	Mill Creek at Ehlen Road	45.2336	-122.7558	DEQ
RC1-70	Rock Creek	45.1879	-122.7446	Marion SWCD
BC1-67	Butte Creek	45.1477	-122.7804	Marion SWCD
ZC1-72	Zollner Creek	45.1004	-122.8225	Marion SWCD
LPR1-71	Little Pudding R Node 385	45.0458	-122.8948	Marion SWCD
AC1-5406	Abiqua Creek	45.0323	-122.798	Marion SWCD
10646-ORDEQ	Silver Creek at Brush Creek Road	45.0066	-122.8242	DEQ

Table 2-4: Stream temperature monitoring sites supporting Little North Santiam River model development.

Monitoring Location ID	Monitoring Location Name	Latitude	Longitude	Source
S68509	Little North Santiam at Fawn Creek	44.8314	-122.3704	Watershed Sciences (2001)
No Station ID	Little North Santiam River at Elk Horn Park	44.8028	-122.4386	BLM
S349766	Node 3 (FLIR - S349766)	44.8010	-122.4749	Watershed Sciences (2001)
S88442	Node 4 (FLIR - S88442)	44.7960	-122.5349	Watershed Sciences (2001)
No Station ID	North Fork County Park	44.7965	-122.5661	BLM
14182500	Little North Santiam River near Mehama	44.7917	-122.5778	USGS
No Station ID	Elkhorn Creek	44.8150	-122.3857	BLM
No Station ID	Sinker Creek	44.8093	-122.4168	BLM
No Station ID	Canyon Creek	44.8016	-122.4795	BLM

Table 2-5: Stream temperature monitoring sites supporting Thomas Creek model development.

Monitoring Location ID	Monitoring Location Name	Latitude	Longitude	Source
tho31a01	Upper Thomas Creek BLM Site	44.6823	-122.4827	BLM
tho25a01	Lower Thomas Creek BLM Site	44.7025	-122.5589	BLM
23779-ORDEQ	Thomas Creek at bridge at Willamette Industries gate of Thomas Creek Drive	44.7122	-122.6087	DEQ
23780-ORDEQ	Thomas Creek at Jordan Road	44.7265	-122.6995	DEQ
23781-ORDEQ	Thomas Creek at Hannah Covered Bridge (Morrison Road)	44.7123	-122.7182	DEQ
23783-ORDEQ	Thomas Creek at USGS Gage at Shindler Bridge Drive	44.7116	-122.7665	DEQ

Monitoring Location ID	Monitoring Location Name	Latitude	Longitude	Source
23784-ORDEQ	Thomas Creek at Shimanek Covered Bridge (Richardson Gap Road)	44.7162	-122.8045	DEQ
23785-ORDEQ	Thomas Creek at 0.6 miles west of Scio off NW 1st Avenue	44.7038	-122.8588	DEQ
10783-ORDEQ	Thomas Creek at Kelly Road (Riverside School)	44.6907	-122.9369	DEQ
23782-ORDEQ	Neal Creek at Lulay Road near Hannah Covered Bridge	44.7076	-122.7124	DEQ
23787-ORDEQ	Sucker Slough at Robinson Road	44.7059	-122.917	DEQ

Table 2-6: Stream temperature monitoring sites supporting McKenzie River: Upper model development.

Monitoring Location ID	Monitoring Location Name	Latitude	Longitude	Source
No Station ID	McKenzie River at Olallie (RM 75.43)	44.2572	-122.0420	DEQ
14159000	McKenzie River at McKenzie Bridge	44.1792	-122.1292	USGS
No Station ID	McKenzie River at Quartz Creek Bridge	44.1282	-122.3800	DEQ

Table 2-7: Stream temperature monitoring sites supporting Crabtree Creek model development.

Monitoring Location ID	Monitoring Location Name	Latitude	Longitude	Source
No Station ID	Crabtree Creek upstream of BLM site	44.6145	-122.5211	BLM
23742-ORDEQ	Crabtree Creek at main line bridge at F and S lines	44.5945	-122.5567	DEQ
23743-ORDEQ	Crabtree Creek at Road 311 Bridge	44.5781	-122.5816	DEQ
23766-ORDEQ	Crabtree Creek at Willamette main line road mile 11.6	44.5883	-122.6373	DEQ
23767-ORDEQ	Crabtree Creek at CR 843 swinging foot bridge	44.5983	-122.6872	DEQ
23768-ORDEQ	Crabtree Creek at Larwood Covered Bridge upstream of Roaring River	44.6294	-122.7411	DEQ
23769-ORDEQ	Crabtree Creek at Richardson Gap Road	44.6581	-122.8045	DEQ
23771-ORDEQ	Crabtree Creek at Hoffman Covered Bridge (Hungry Hill Road)	44.6534	-122.8903	DEQ
10784-ORDEQ	Crabtree Creek at Riverside School Road	44.6734	-122.9178	DEQ
No Station ID	White Rock Creek	44.5916	-122.5097	BLM
21834-ORDEQ	Roaring River at River Mile 0.10	44.6303	-122.7378	DEQ
23770-ORDEQ	Beaver Creek at Fish Hatchery Drive	44.6336	-122.8549	DEQ

Table 2-8: Stream temperature monitoring sites supporting Luckiamute River model development.

Monitoring Location ID	Monitoring Location Name	Latitude	Longitude	Source
25494-ORDEQ	Luckiamute River at Road 1430 crossing (Roadmile 3)	44.8158	-123.5667	DEQ
25493-ORDEQ	Luckiamute River at Road 1440 crossing	44.794	-123.5925	DEQ
25490-ORDEQ	Luckiamute River at Boise Roadmile 4	44.7717	-123.5795	DEQ
25488-ORDEQ	Luckiamute River at Boise Roadmile 1	44.7476	-123.5335	DEQ
25486-ORDEQ	Luckiamute River at Gaging Site	44.7189	-123.5040	DEQ
11111-ORDEQ	Luckiamute River at Hoskins	44.6753	-123.4680	DEQ
25483-ORDEQ	Luckiamute River upstream of Ritner Creek	44.7281	-123.4411	DEQ
25480-ORDEQ	Luckiamute River at Ira Hooker Road	44.7465	-123.4159	DEQ
25477-ORDEQ	Luckiamute River at Airlie Road Bridge	44.7761	-123.3432	DEQ
10659-ORDEQ	Luckiamute River at Helmick State Park	44.7828	-123.2353	DEQ
25475-ORDEQ	Luckiamute River at Corvallis Rd.	44.7567	-123.1814	DEQ
10658-ORDEQ	Luckiamute River at Lower Bridge (Buena Vista Rd.)	44.7302	-123.1623	DEQ
25492-ORDEQ	Miller Creek at mouth (Trib to Luckiamute RM 50.5)	44.7762	-123.5966	DEQ
25491-ORDEQ	Rock Pit Creek at mouth (trib to Luckiamute RM 49.8)	44.7727	-123.5850	DEQ
25489-ORDEQ	Slick Creek at mouth (Trib to Luckiamute RM 48.6)	44.7625	-123.5669	DEQ
25485-ORDEQ	Price Creek at Hwy 223 (Trib to Luckiamute RM 35.2)	44.6858	-123.4339	DEQ
25484-ORDEQ	Maxfield Creek at Hwy 223 (Trib to Luckiamute RM 34.0)	44.6948	-123.4322	DEQ
25482-ORDEQ	Ritner Creek at Ritner Wayside (Trib to Luckiamute RM 31.2)	44.7282	-123.4418	DEQ
25481-ORDEQ	Pedee Creek at Kings Highway (Trib to Luckiamute RM 30.2)	44.7445	-123.4391	DEQ
25478-ORDEQ	McTimmonds Creek at State HWY 223 (Trib to Luckiamute RM 27.7)	44.7601	-123.4101	DEQ
11114-ORDEQ	Little Luckiamute River at Elkins Rd. (Trib to Luckiamute RM 18.2)	44.7972	-123.2915	DEQ
25474-ORDEQ	Soap Creek at Buena Vista Rd. (Trib to Luckiamute RM 2.31)	44.7264	-123.1628	DEQ

Table 2-9: Stream temperature monitoring sites supporting Mohawk River model development.

Monitoring Location ID	Monitoring Location Name	Latitude	Longitude	Source
25608-ORDEQ	Mohawk River on Easy Street below Road 2201	44.2481	-122.7035	DEQ
25607-ORDEQ	Mohawk River at WEYCO shop	44.2587	-122.7319	DEQ

Monitoring Location ID	Monitoring Location Name	Latitude	Longitude	Source
22651-ORDEQ	Mohawk River at WEYCO Gate	44.2542	-122.7561	DEQ
25502-ORDEQ	Mohawk River at Paschelke Road (Earnest Bridge)	44.2014	-122.8368	DEQ
22654-ORDEQ	Mohawk River at Wendling Road	44.1729	-122.8541	DEQ
25498-ORDEQ	Mohawk River at Sunderman Road	44.1414	-122.9073	DEQ
25496-ORDEQ	Mohawk River at Old Mohawk Road	44.1042	-122.9403	DEQ
10663-ORDEQ	Mohawk River at Hill Road	44.0923	-122.9593	DEQ
25506-ORDEQ	Unnamed Creek at model meter 5821.68	44.2537	-122.7626	DEQ
25504-ORDEQ	Shotgun Creek	44.2128	-122.8293	DEQ
25503-ORDEQ	Cash Creek	44.2059	-122.8335	DEQ
25501-ORDEQ	Mill Creek	44.1884	-122.8340	DEQ
25500-ORDEQ	Cartwright Creek	44.1712	-122.8573	DEQ
25499-ORDEQ	Parsons Creek	44.1691	-122.8766	DEQ

Table 2-10: Stream temperature monitoring sites supporting Coyote Creek model development.

Monitoring Location ID	Monitoring Location Name	Latitude	Longitude	Source
25627-ORDEQ	Coyote Creek at Gillespie Corners	43.9081	-123.2505	DEQ
25626-ORDEQ	Coyote Creek at Powell Road	43.9250	-123.2713	DEQ
11148-ORDEQ	Coyote Creek at Crow	43.9872	-123.3114	DEQ
10151-ORDEQ	Coyote Creek at Petzold Road	44.0046	-123.2702	DEQ
10150-ORDEQ	Coyote Creek Centrell Rd	44.0416	-123.2677	DEQ

Table 2-11: Stream temperature monitoring sites supporting Mosby Creek model development.

Monitoring Location ID	Monitoring Location Name	Latitude	Longitude	Source
28102-ORDEQ	Mosby Creek Above West Fork Mosby Creek	43.5551	-122.8501	BLM
28101-ORDEQ	Mosby Creek Above Cedar Creek	43.6486	-122.9201	BLM
28799-ORDEQ	Mosby Creek at Blue Mountain Park (upstream Perkins Creek)	43.7278	-122.9769	DEQ
30368-ORDEQ	Mosby Creek at Layng Road	43.7779	-122.0045	DEQ
28103-ORDEQ	Mosby Creek below Row River Trail	43.7779	-123.0071	BLM
17090002_LI1380	Lilly Creek	43.5795	-122.8632	BLM
17090002_BD116	Big Dry Creek	43.6223	-122.9023	BLM
17090002_ST112	Stell Creek	43.6325	-122.9089	BLM

Monitoring Location ID	Monitoring Location Name	Latitude	Longitude	Source
17090002_CE106	Cedar Creek (Spring 1)	43.6493	-122.9196	BLM

2.1.2 Stream flow rate– continuous and instantaneous measurements

DEQ and other agencies measured instantaneous flow rate at multiple stream survey sites during the critical stream temperature period in the summers of 2000, 2001, 2002, 2004, and 2007. In addition to instantaneous flow rate, the surveys included measurements of flow velocity, wetted width, and wetted depth. DEQ also obtained continuous flow rate measurements from various United States Geological Survey (USGS) monitoring sites. These instream measurements were used to develop flow inputs into the model, support flow mass balance analysis, and calibrate the temperature models. Flow monitoring sites supporting TMDL model development are summarized in **Table 2-12** through **Table 2-29**.

Table 2-12: Continuous flow rate measurements supporting Johnson Creek model development.

Monitoring Location ID	Monitoring Location Name	Latitude	Longitude	Source
14211400	Johnson Creek at Regner Road, at Gresham, OR	45.4865	-122.4218	USGS
14211499	Kelley Creek At SE 159th Drive at Portland, OR	45.4768	-122.4984	USGS
14211500	Johnson Creek at Sycamore, OR	45.4775	-122.508	USGS
14211550	Johnson Creek at Milwaukie, OR	45.4531	-122.6434	USGS

Table 2-13: Instantaneous flow rate measurements supporting Johnson Creek model development.

Monitoring Location ID	Monitoring Location Name	Latitude	Longitude	Date	Flow (cfs/cms)
10856-ORDEQ	Johnson Creek at SE 122nd (Portland)	45.4737	-122.536	7/30/2002	2.08/0.06
11326-ORDEQ	Johnson Creek at Pleasant View / 190th Ave. (Gresham)	45.488	-122.468	7/29/2002	1.09/0.03
11329-ORDEQ	Crystal Springs Creek at mouth (Johnson Creek Park)	45.4613	-122.642	7/30/2002	8.87/0.25
28728-ORDEQ	Johnson Creek at SE 327th Avenue	45.4605	-122.326	7/29/2002	0.42/0.01
28729-ORDEQ	Johnson Creek at Revenue Road	45.4617	-122.337	7/29/2002	1.01/0.03
28732-ORDEQ	Johnson Creek at SE 72nd Avenue and Bell	45.4556	-122.593	7/30/2002	1.38/0.04

Table 2-14: Continuous flow rate measurements supporting Molalla River model development.

Monitoring Location ID	Monitoring Location Name	Latitude	Longitude	Source
14200000	Molalla River near Canby, OR	45.2443	-122.6873	USGS

Table 2-15: Instantaneous flow rate measurements supporting Molalla River model development.

Monitoring Location ID	Monitoring Location Name	Latitude	Longitude	Date	Flow (cfs/cms)
31870-ORDEQ	Molalla River at Hwy 213	45.1999	-122.5810	7/23/2004	88.6/2.51
34245-ORDEQ	Molalla River at Feyrer Park River Mile 21.0	45.1381	-122.5335	7/22/2004	50.2/1.42
31871-ORDEQ	Molalla River above North Fork LD	45.0809	-122.4859	7/21/2004	67.1/1.9
32051-ORDEQ	Molalla River upstream of Pine Creek	45.0121	-122.4847	7/20/2004	59.7/1.69
32049-ORDEQ	Molalla River upstream of Horse Creek	44.9621	-122.4325	7/20/2004	46.2/1.31
No Station ID	Molalla River at Locked Gate	44.9251	-122.3396	7/20/2004	9.6/0.27
No Station ID	North Fork Molalla River at mouth	45.0835	-122.4888	7/22/2004	44.6/1.26
32048-ORDEQ	Table Rock Fork Molalla River at River Mile 1	44.9681	-122.4037	7/20/2004	26.9/0.76

Table 2-16: Continuous flow rate measurements supporting Pudding River model development.

Monitoring Location ID	Monitoring Location Name	Latitude	Longitude	Source
14202000	Pudding River at Aurora, OR	45.2332	-122.7500	USGS
14201340	Pudding River Near Woodburn, OR	45.1512	-122.8043	USGS
14201300	Zollner Creek near Mount Angel, OR	45.1004	-122.8225	USGS

Table 2-17: Instantaneous flow rate measurements supporting Pudding River model development.

Monitoring Location ID	Monitoring Location Name	Latitude	Longitude	Date	Flow (cfs/cms)
10362-ORDEQ	Pudding River at Arndt Road (Barlow)	45.2599	-122.738	7/20/2004	69/1.95
10362-ORDEQ	Pudding River at Arndt Road (Barlow)	45.2599	-122.738	8/1/2007	50.35/1.43
32055-ORDEQ	Pudding River at State Street	44.9144	-122.8175	7/26/2004	1.09/0.03
32055-ORDEQ	Pudding River at State Street	44.9144	-122.8175	8/17/2004	0.24/0.01
32056-ORDEQ	Pudding River at Sunnyview Road	44.9563	-122.8672	7/26/2004	1.24/0.04
32056-ORDEQ	Pudding River at Sunnyview Road	44.9563	-122.8672	8/2/2007	0.19/0.01
32057-ORDEQ	Drift Creek at Hibbard Road (Pudding River)	44.9765	-122.8298	7/26/2004	1.54/0.04
14201500	Butte Creek at Monitor	45.1017	-122.745	8/3/2004	3.22/0.09
31876-ORDEQ	Mill Creek at Ehlen Road	45.2336	-122.7558	8/3/2004	3.11/0.09
31876-ORDEQ	Mill Creek at Ehlen Road	45.2336	-122.7558	8/1/2007	2.7/0.08
12210-ORDEQ	Silver Creek at James Street (Silverton)	45.0095	-122.7901	7/27/2004	8.3/0.24
34248-ORDEQ	Unnamed Trib to the Pudding at Monitor-McKee Road	45.1007	-122.8348	8/1/2007	2.1/0.06
33200-ORDEQ	Rock Creek at Meridian	45.1884	-122.7442	8/1/2007	0.27/0.01
31873-ORDEQ	Butte Creek at Hwy. 211	45.1475	-122.7802	8/1/2007	0.61/0.02

Monitoring Location ID	Monitoring Location Name	Latitude	Longitude	Date	Flow (cfs/cms)
10646-ORDEQ	Silver Creek at Brush Creek Road	45.0063	-122.8250	8/1/2007	6.91/0.2
10903-ORDEQ	Abiqua Creek at Mt. Angel / Silverton Road	45.0373	-122.8144	8/1/2007	5.23/0.15
31877-ORDEQ	Pudding R nr Mt. Angel (Saratoga Rd)	45.0630	-122.8301	8/2/2007	12.08/0.34
11536-ORDEQ	Pudding River at Nusom Road	45.0380	-122.8344	8/2/2007	11.07/0.31
11535-ORDEQ	Pudding River at Hazel Green Road	45.0096	-122.8432	8/2/2007	10.18/0.29
11530-ORDEQ	Pudding R at Monitor-McKee Rd (u/s unnamed trib and Zollner Cr)	45.1005	-122.8309	8/1/2007	21.6/0.61

Table 2-18: Continuous flow rate measurements supporting Little North Santiam model development.

Monitoring Location ID	Monitoring Location Name	Latitude	Longitud e	Source
14182500	Little North Santiam near Mehama, OR	44.7915	-122.5790	USGS

Table 2-19: Instantaneous flow rate measurements supporting Little North Santiam model development.

Monitoring Location ID	Monitoring Location Name	Latitud e	Longitud e	Date	Flow (cfs/cms)
S68509	Little North Santiam at Fawn Creek	44.8314	-122.3704	7/28/2000	33.1/0.94
No Station ID	Little North Santiam at Elkhorn	44.8028	-122.4386	7/28/2000	46.06/1.3
No Station ID	Little North Santiam at County Park	44.7965	-122.5661	7/28/2000	49.77/1.41
faw00a01	Fawn Creek	44.8323	-122.3711	8/10/2000	0.15/0
elk00a01	Elkhorn Creek	44.8150	-122.3857	8/15/2001	4.5/0.13
sin00a01	Sinker Creek	44.8093	-122.4168	6/20/2000	1.26/0.04
cas00a1	Canyon Creek	44.8016	-122.4795	6/29/2000	1.06/0.03

Table 2-20: Instantaneous flow rate measurements supporting Thomas Creek model development.

Monitoring Location ID	Monitoring Location Name	Latitude	Longitud e	Date	Flow (cfs/cms)
10783-ORDEQ	Thomas Creek at Kelly Road (Riverside School)	44.6907	-122.9369	8/7/2000	19.46/0.55
23779-ORDEQ	Thomas Creek at bridge at Willamette Industries gate of Thomas Creek Drive	44.7122	-122.6087	8/7/2000	15.37/0.44
23780-ORDEQ	Thomas Creek at Jordan Road	44.7265	-122.6995	8/7/2000	16.7/0.47
23781-ORDEQ	Thomas Creek at Hannah Covered Bridge (Morrison Road)	44.7123	-122.7182	8/8/2000	18.13/0.51
23782-ORDEQ	Neal Creek at Lulay Road near Hannah Covered Bridge	44.7076	-122.7124	8/8/2000	4.87/0.14
23783-ORDEQ	Thomas Creek at USGS Gage at Shindler Bridge Drive	44.7116	-122.7665	8/8/2000	50.03/1.42

Monitoring Location ID	Monitoring Location Name	Latitude	Longitude	Date	Flow (cfs/cms)
23784-ORDEQ	Thomas Creek at Shimanek Covered Bridge (Richardson Gap Road)	44.7162	-122.8045	8/8/2000	21.76/0.62
23785-ORDEQ	Thomas Creek at 0.6 miles west of Scio off NW 1st Avenue	44.7038	-122.8588	8/7/2000	22.07/0.62
tho31a01	Upper Thomas Creek BLM Site	44.6823	-122.4827	7/14/2000	15.96/0.45
tho25a01	Lower Thomas Creek BLM Site	44.7025	-122.5589	7/14/2000	29.48/0.83

Table 2-21: Instantaneous flow rate measurements supporting Crabtree Creek model development.

Monitoring Location ID	Monitoring Location Name	Latitude	Longitude	Date	Flow (cfs/cms)
10784-ORDEQ	Crabtree Creek at Riverside School Road	44.6734	-122.9178	7/27/2000	39.77/1.13
21834-ORDEQ	Roaring River at River Mile 0.10	44.6303	-122.7378	7/26/2000	22.89/0.65
23742-ORDEQ	Crabtree Creek at main line bridge at F and S lines	44.5945	-122.5567	7/25/2000	8.01/0.23
23743-ORDEQ	Crabtree Creek at Road 311 Bridge	44.5781	-122.5816	7/25/2000	10.75/0.3
23766-ORDEQ	Crabtree Creek at Willamette main line road mile 11.6	44.5883	-122.6373	7/25/2000	21.06/0.6
23767-ORDEQ	Crabtree Creek at CR 843 swinging foot bridge	44.5983	-122.6872	7/26/2000	25.11/0.71
23768-ORDEQ	Crabtree Creek at Larwood Covered Bridge upstream of Roaring River	44.6294	-122.7411	7/26/2000	22.46/0.64
23769-ORDEQ	Crabtree at Richardson Gap Rd	44.6581	-122.8045	7/26/2000	39.25/1.11
23770-ORDEQ	Beaver Creek at Fish Hatchery Drive	44.6336	-122.8549	7/26/2000	3.81/0.11
23771-ORDEQ	Crabtree Creek at Hoffman Covered Bridge (Hungry Hill Road)	44.6534	-122.8903	7/27/2000	46.57/1.32

Table 2-22: Continuous flow rate measurements supporting Luckiamute River model development.

Monitoring Location ID	Monitoring Location Name	Latitude	Longitude	Source
14190500	Luckiamute River Near Suver, OR	44.7833	123.2333	USGS

Table 2-23: Instantaneous flow rate measurements supporting Luckiamute River model development.

Monitoring Location ID	Monitoring Location Name	Latitude	Longitude	Date	Flow (cfs/cms)
10659-ORDEQ	Luckiamute River at Helmick State Park	44.7828	-123.2353	7/31/2001	39.31/1.11
10659-ORDEQ	Luckiamute River at Helmick State Park	44.7828	-123.2353	8/14/2001	26.1/0.74
11114-ORDEQ	Little Luckiamute River at Elkins Road	44.7972	-123.2915	7/31/2001	24.27/0.69
25477-ORDEQ	Luckiamute River at Airlie Road Bridge	44.7761	-123.3432	7/31/2001	32.89/0.93
25480-ORDEQ	Luckiamute River at Ira Hooker Road	44.7465	-123.4159	7/31/2001	22.48/0.64
25481-ORDEQ	Pedee Creek at Kings Highway	44.7445	-123.4391	7/31/2001	4.72/0.13
25482-ORDEQ	Ritner Creek at Ritner Wayside	44.7282	-123.4418	7/31/2001	4.73/0.13
25483-ORDEQ	Luckiamute River upstream of Ritner Creek	44.7281	-123.4411	7/31/2001	23.35/0.66
25484-ORDEQ	Maxfield Creek at Hwy 223	44.6948	-123.4322	7/31/2001	0.54/0.02
25485-ORDEQ	Price Creek at Hwy 223	44.6858	-123.4339	7/31/2001	1.07/0.03
11111-ORDEQ	Luckiamute River at Hoskins	44.6753	-123.4680	7/30/2001	17.24/0.49
25486-ORDEQ	Luckiamute River at Gaging Site	44.7189	-123.5040	7/30/2001	18.69/0.53
25488-ORDEQ	Luckiamute River at Boise Roadmile 1	44.7476	-123.5335	7/30/2001	21.29/0.6
25489-ORDEQ	Slick Creek at mouth	44.7625	-123.5669	7/30/2001	0.24/0.01
25490-ORDEQ	Luckiamute River at Boise Roadmile 4	44.7717	-123.5795	7/30/2001	15.03/0.43
25491-ORDEQ	Rock Pit Creek at mouth	44.7727	-123.5850	7/30/2001	0.83/0.02
25492-ORDEQ	Miller Creek at mouth	44.7762	-123.5966	7/30/2001	7.7/0.22
25493-ORDEQ	Luckiamute River at Road 1440 crossing	44.794	-123.5925	7/30/2001	4.43/0.13
25494-ORDEQ	Luckiamute River at Road 1430 crossing (Road Mile 3)	44.8158	-123.5667	7/30/2001	5.66/0.16

Table 2-24: Continuous flow rate measurements supporting Mohawk River model development.

Monitoring Location ID	Monitoring Location Name	Latitude	Longitude	Source
14165000	Mohawk River near Springfield, OR	44.0929	-122.9573	USGS

Table 2-25: Instantaneous flow rate measurements supporting Mohawk River model development.

Monitoring Location ID	Monitoring Location Name	Latitude	Longitude	Date	Flow (cfs/cms)
25608-ORDEQ	Mohawk River on Easy Street below Road 2201	44.2481	-122.7035	8/9/2001	12.5/0.35
25607-ORDEQ	Mohawk River at WEYCO shop	44.2587	-122.7319	8/9/2001	14.02/0.4
22651-ORDEQ	Mohawk River at WEYCO Gate	44.2542	-122.7561	8/9/2001	14.58/0.41
25502-ORDEQ	Mohawk River at Paschelke Road (Earnest Bridge)	44.2014	-122.8368	8/9/2001	22/0.62

Monitoring Location ID	Monitoring Location Name	Latitude	Longitude	Date	Flow (cfs/cms)
22654-ORDEQ	Mohawk River at Wendling Road	44.1729	-122.8541	8/9/2001	26.73/0.76
25498-ORDEQ	Mohawk River at Sunderman Road	44.1414	-122.9073	8/9/2001	56.61/1.6
25496-ORDEQ	Mohawk River at Old Mohawk Road	44.1042	-122.9403	8/9/2001	61.8/1.75
10663-ORDEQ	Mohawk River at Hill Road	44.0923	-122.9593	8/9/2001	55.69/1.58

Table 2-26: Continuous flow rate measurements supporting McKenzie River (Upper) model development.

Monitoring Location ID	Monitoring Location Name	Latitude	Longitude	Source
14158850	McKenzie R Blw Trail Br Dam Nr Belknap Springs, OR	44.2679	-122.0498	USGS
14159500	South Fork McKenzie River Near Rainbow, OR	44.1360	-122.2484	USGS
14162200	Blue River at Blue River, OR	44.1623	-122.3331	USGS

Table 2-27: Instantaneous flow rate measurements supporting McKenzie River (Upper) model development.

Monitoring Location ID	Monitoring Location Name	Latitude	Longitude	Date	Flow (cfs/cms)
USFS 124448	Horse Creek 200 ft west of bridge on Forest road 2638	44.1617	-122.1556	9/3/1999	423.78/12

Table 2-28: Instantaneous flow rate measurements supporting Coyote Creek model development.

Monitoring Location ID	Monitoring Location Name	Latitude	Longitude	Date	Flow (cfs/cms)
25627-ORDEQ	Coyote Creek at Gillespie Corners	43.9081	-123.2505	7/11/2001	0.39/0.01
25626-ORDEQ	Coyote Creek at Powell Road	43.9250	-123.2713	7/11/2001	0.95/0.03
11148-ORDEQ	Coyote Creek at Crow	43.9872	-123.3114	7/11/2001	2.08/0.06
10151-ORDEQ	Coyote Creek at Petzold Road	44.0046	-123.2702	7/11/2001	1.91/0.05

Table 2-29: Instantaneous flow rate measurements supporting Mosby Creek model development.

Monitoring Location ID	Monitoring Location Name	Latitude	Longitude	Date	Flow (cfs/cms)
28102-ORDEQ	Mosby Creek Above West Fork Mosby Creek	43.5551	-122.8501	7/21/2002 *	2.79/0.08
28101-ORDEQ	Mosby Creek Above Cedar Creek	43.6486	-122.9201	7/21/2002 *	3.28/0.09
30638-ORDEQ	Mosby Creek at Layng Road	43.7779	-122.0045	7/21/2002 *	3.64/0.1

*Date model was run.

2.1.3 Vegetation and habitat surveys

DEQ and partners collected ground-level habitat data to support model development. Stream survey data focused on near stream land cover classification, vegetation height and canopy measurements, channel morphology measurements, and effective shade measurements (**Section 2.1.4**).

2.1.4 Effective shade measurements

Effective shade is the percent of potential daily solar radiation flux that is blocked by vegetation and topography. A Solar Pathfinder (Solar Pathfinder, Linden, TN) instrument was used to collect effective shade measurements in the field. The effective shade measurement methods and quality control procedures used are outlined in the Water Quality Monitoring Technical Guide Book (OWEB, 1999) and the Solar Pathfinder manual (Solar Pathfinder, 2016). Effective shade measurement collection locations and results are listed in **Table** 2-30 through **Table 2-38**, with collection locations shown in **Figure 2-1**. All results represent the effective shade on a cloud free day during the model period for each stream.

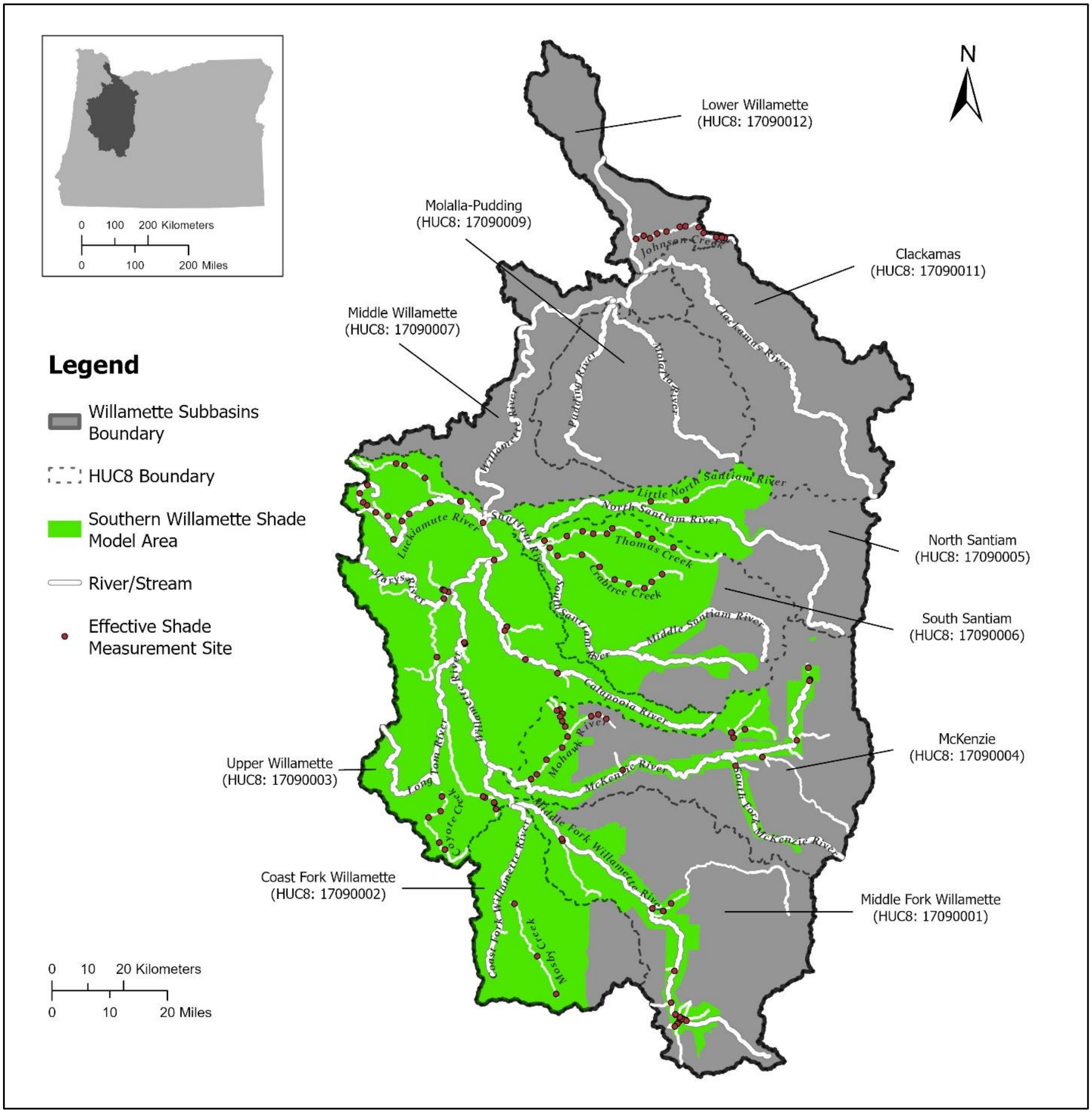


Figure 2-1: Effective shade measurement collection locations in the Willamette Subbasins project area.

Table 2-30: Effective shade measurements on Johnson Creek.

Monitoring Location Name	Latitude	Longitude	Effective Shade (%)	Source
Johnson Creek at SE 327th Avenue	45.4605	-122.3264	100	DEQ
Johnson Creek at Revenue Road	45.4617	-122.3368	100	DEQ
Johnson Creek at Short Road	45.4627	-122.3575	93	DEQ
Johnson Creek at Palmblad Road	45.4728	-122.4035	91	DEQ
Johnson Creek at Regner USGS Gage	45.4867	-122.4206	90	DEQ
Johnson Creek at Pleasant View / 190th Ave.	45.4880	-122.4676	82	DEQ
Johnson Creek at SE Circle Avenue	45.4864	-122.4880	77	DEQ
Johnson Creek at SE 122nd Avenue (Portland)	45.4737	-122.5358	79	DEQ
Johnson Creek at 92nd Avenue near Flavel	45.4678	-122.5683	20	DEQ
Johnson Creek at Bell Road and Johnson Creek Blvd	45.4557	-122.5927	67	DEQ
Johnson Creek at 45th Avenue Footbridge	45.4617	-122.6161	63	DEQ
Johnson Creek at Milwaukie Gage	45.4531	-122.6434	71	DEQ

Table 2-31: Effective shade measurements on the Little North Santiam River.

Monitoring Location Name	Latitude	Longitude	Effective Shade (%)	Source
Little North Santiam at Elk Horn Park	44.8018	-122.4428	51	BLM
Little North Santiam at North Fork County Park	44.7964	-122.5673	24	BLM

Table 2-32: Effective shade measurements on Thomas Creek.

Monitoring Location Name	Latitude	Longitude	Effective Shade (%)	Source
Thomas Creek at Kelly Road	44.6907	-122.9369	4	DEQ
Thomas Creek at 0.6 miles west of Scio off of NW 1st	44.7038	-122.8588	44	DEQ
Thomas Creek at Shimanek Covered Bridge	44.7162	-122.8045	18	DEQ
Thomas Creek at old USGS Gage at Shindler Bridge Drive	44.7116	-122.7665	37	DEQ
Thomas Creek at Hannah Covered Bridge	44.7123	-122.7182	31	DEQ
Thomas Creek downstream Jordan Creek	44.7265	-122.6995	28	DEQ
Thomas Creek at bridge at Willamette Industries Gate	44.7122	-122.6087	62	DEQ
Lower Thomas Creek BLM Site	44.7025	-122.5589	55	DEQ
Upper Thomas Creek BLM Site	44.6823	-122.4827	87	DEQ

Table 2-33: Effective shade measurements on Crabtree Creek.

Monitoring Location Name	Latitude	Longitude	Effective Shade (%)	Source
Crabtree Creek at Riverside School Road	44.6734	-122.9178	55	DEQ
Crabtree Creek at Hoffman Covered Bridge	44.6534	-122.8903	30	DEQ
Crabtree Creek at Richardson Gap Road	44.6581	-122.8045	13	DEQ
Crabtree Creek at Larwood Bridge	44.6294	-122.7411	7	DEQ
Crabtree Creek at Swinging Foot Bridge	44.5983	-122.6872	34	DEQ
Crabtree Creek at Willamette Main Line Road	44.5883	-122.6373	43	DEQ
Crabtree Creek at Road 311 Bridge	44.5781	-122.5816	55	DEQ
Crabtree Creek at Main Line Bridge	44.5945	-122.5567	41	DEQ
Crabtree Creek at BLM site	44.6145	-122.5211	56	BLM

Table 2-34: Effective shade measurements on the Luckiamute River.

Monitoring Location Name	Latitude	Longitude	Effective Shade (%)	Source
Luckiamute River at Road 1430 crossing (Roadmile 3)	44.8158	-123.5667	93	DEQ
Luckiamute River at Road 1440 crossing	44.7940	-123.5925	76	DEQ
Luckiamute River at Boise Roadmile 4	44.7717	-123.5795	84	DEQ
Luckiamute River at Boise Roadmile 1	44.7476	-123.5335	77	DEQ
Luckiamute River at Gaging Site	44.6817	-123.4678	84	DEQ
Luckiamute River at Hoskins	44.6817	-123.4678	34	DEQ
Luckiamute River just upstream Ritner Creek	44.7281	-123.4411	78	DEQ
Luckiamute River at Ira Hooker Rd.	44.7465	-123.4159	15	DEQ
Luckiamute River at Airlie Rd. Bridge	44.7761	-123.3432	31	DEQ
Luckiamute River at Helmick State Park	44.7828	-123.2353	46	DEQ

Table 2-35: Effective shade measurements on the Mohawk River.

Monitoring Location Name	Latitude	Longitude	Effective Shade (%)	Source
Mohawk River at Hill Road	44.0923	-122.9593	52	DEQ
Mohawk River at Old Mohawk Road	44.1042	-122.9403	59	DEQ
Mohawk River at Sunderman Road	44.1414	-122.9073	50	DEQ
Mohawk River at Wendling Road	44.1729	-122.8541	42	DEQ
Mohawk River at Paschelke Road	44.2014	-122.8368	71	DEQ
Mohawk River at WEYCO Gate	44.2542	-122.7561	77	DEQ
Mohawk River at WEYCO shop	44.2587	-122.7319	20	DEQ
Mohawk River on East Street	44.2481	-122.7035	96	DEQ

Table 2-36: Effective shade measurements on Coyote Creek.

Monitoring Location Name	Latitude	Longitude	Effective Shade (%)	Source
Coyote Creek at Gillespie	43.9081	-123.2505	56	DEQ
Coyote Creek at Powell Rd	43.9250	-123.2713	55	DEQ
Coyote Creek at Crow Road	43.9872	-123.3114	15	DEQ
Coyote Creek at Petzold Road	44.0046	-123.2702	64	DEQ
Coyote Creek at Centrell Road	44.0416	-123.2677	63	DEQ

Table 2-37: Effective shade measurements on Mosby Creek.

Monitoring Location Name	Latitude	Longitude	Effective Shade (%)	Source
Mosby Creek Above West Fork Mosby Creek	43.5551	-122.8501	50	DEQ
Mosby Creek Above Cedar Creek	43.6486	-122.9201	54	DEQ
Mosby Creek at Layng Road	43.7779	-123.0045	45	DEQ

Table 2-38: Effective shade measurements supporting the Southern Willamette shade model.

Monitoring Location Name	Latitude	Longitude	Effective Shade (%)	Source
Amazon Creek near East 39th Ave	44.0141	-123.0780	57	DEQ
Amazon Creek near East 27th Ave	44.0288	-123.0840	63	DEQ
Amazon Creek near East 26th Ave	44.0307	-123.0855	53	DEQ
Amazon Creek upstream of Chambers Street	44.0423	-123.1170	21	DEQ
Amazon Creek downstream of Arthur Street	44.0445	-123.1250	13	DEQ
Blue River upstream of Blue River Road (NF 15)	44.2210	-122.2634	64	DEQ
Boulder Creek upstream of OR highway 126	44.2054	-122.0375	92	DEQ
Buck Creek upstream of Railroad tracks	43.7751	-122.5255	91	DEQ
Buck Creek downstream of Road	43.7755	-122.5262	94	DEQ
Butte Creek 100 feet downstream of bridge	44.4721	-123.0599	86	DEQ
Butte Creek 300 feet downstream of bridge	44.4725	-123.0602	91	DEQ
Calapooia River at McKercher Park	44.3598	-122.8782	33	DEQ
Calapooia River 300 feet upstream of playground downstream end of side channel	44.3917	-122.9913	26	DEQ
Calapooia River near mouth	44.6375	-123.1124	26	DEQ
Coal Creek downstream NF Road 201	43.4947	-122.4230	73	DEQ
Coal Creek near mouth	43.5045	-122.4226	70	DEQ
Cogswell Creek near mouth	44.1210	-122.6409	95	DEQ
Cougar Creek near mouth	44.1388	-122.2478	90	DEQ
Deadhorse Creek upstream of road	43.5013	-122.4112	95	DEQ
Fish Lake Creek upstream of Eno Road (NF 2676)	44.3879	-122.0005	93	DEQ
Horse Creek downstream of Horse Creek Road (NF 2638)	44.1617	-122.1554	71	DEQ
Lake Creek 40 feet north of bridge	44.4261	-123.2049	68	DEQ
Lake Creek at first right turn	44.4284	-123.2058	68	DEQ
Lake Creek 100 feet upstream of Lake	44.4294	-123.2068	56	DEQ
Little Luckiamute River at George Gerlinger Park	44.8721	-123.4687	55	DEQ
Little Luckiamute River upstream Falls	44.8671	-123.4388	76	DEQ
Little Luckiamute River downstream of 223 bridge	44.8380	-123.3648	34	DEQ
Lookout Creek downstream of Forest Road 1506	44.2306	-122.2181	22	DEQ
Lookout Creek near river mile 0.3	44.2092	-122.2576	86	DEQ
Lost Creek at Elijah Bristow State Park downstream of bridge	43.9395	-122.8441	52	DEQ
Lost Creek at Elijah Bristow State Park	43.9444	-122.8468	82	DEQ
Luckiamute River at Helmick State Park	44.7824	-123.2374	21	DEQ
Luckiamute River at river mile 2.1	44.7306	-123.1550	3	DEQ
Mary's River in the Mary's River natural area	44.5375	-123.2838	7	DEQ
Mary's River upstream of railroad bridge	44.5542	-123.2695	51	DEQ
McKenzie River downstream of Clear Lake at river mile 84.3	44.3578	-121.9945	69	DEQ
McKenzie River downstream of Clear Lake at river mile 84.1	44.3550	-121.9961	63	DEQ
Middle Fork Willamette River upstream of bridge	43.4977	-122.4017	52	DEQ
Middle Fork Willamette River at Campers Flat	43.5007	-122.4131	64	DEQ
Middle Fork Willamette River upstream of Coal Creek	43.5050	-122.4226	6	DEQ
Muddy Creek 50 meters downstream of Bruce Road	44.3900	-123.3015	18	DEQ
Muddy Creek 135 meters downstream of Bruce Road	44.3906	-123.3018	8	DEQ

Monitoring Location Name	Latitude	Longitude	Effective Shade (%)	Source
North Fork Middle Fork Willamette River upstream of NF road 1910	43.7897	-122.4618	42	DEQ
North Fork Middle Fork Willamette River at river mile 2.52	43.7701	-122.4873	43	DEQ
North Fork Middle Fork Willamette River at river mile 2.43	43.7695	-122.4883	43	DEQ
Oak Creek 90 feet downstream of the 35th Street bridge	44.5602	-123.2894	76	DEQ
Oak Creek 200 feet downstream of the 30th St bridge	44.5587	-123.2837	89	DEQ
Oak Creek 100 feet upstream of Western Blvd	44.5574	-123.2821	96	DEQ
Owl Creek at gate about 0.06 miles from Shotgun Creek Road	44.2685	-122.8676	93	DEQ
Ritner Creek at Ritner Creek Park	44.7398	-123.4906	89	DEQ
Seeley Creek 50 feet downstream of Seeley Cr Road	44.2587	-122.8567	90	DEQ
Shotgun Creek 0.2 miles north of Owl Creek Road	44.2654	-122.8767	95	DEQ
Shotgun Creek 30 feet downstream of logjam	44.2508	-122.8645	96	DEQ
Shotgun Creek 120 feet upstream of bridge	44.2389	-122.8562	96	DEQ
Shotgun Creek at sewage lagoons	44.2258	-122.8451	95	DEQ
Simpson Creek downstream of Road 21	43.4962	-122.3987	88	DEQ
Slick Creek upstream of road	44.7642	-123.5656	94	DEQ
Snake Creek downstream of bridge	43.5404	-122.4535	98	DEQ
Sodom Ditch 50 feet north of Boston Mill Dr	44.4618	-123.0669	74	DEQ
Tibits Creek near mouth	44.2215	-122.2655	64	DEQ
Unnamed Tributary of Hills Creek Lake	43.6209	-122.4442	97	DEQ
Unnamed Tributary of Coal Creek upstream of FS road 2133-210	43.4881	-122.4293	96	DEQ
Unnamed Tributary of Coal Creek at the end of FS road 2133-210	43.4815	-122.4382	97	DEQ
Unknown Tributary of M.F. Willamette R near mouth (Young or What Creek)	43.5110	-122.4364	97	DEQ
Youngs Creek near mouth	43.5113	-122.4374	98	DEQ

2.2 GIS and Remotely Sensed Data

2.2.1 10-Meter Digital Elevation Model (DEM)

The Digital Elevation Model (DEM) data files are representations of cartographic information in a raster form. DEMs consist of a sampled array of elevations for a number of ground positions at regularly spaced intervals. The U.S. Geological Survey, as part of the National Mapping Program, produces these digital cartographic/geographic data files. DEM grid data are rounded to the nearest meter for ten-meter pixels. DEMs are used to determine stream elevation, stream gradient, valley gradient, valley shape/landform and topographic shade angles.

2.2.2 Light Detection and Ranging (LiDAR)

Light Detection and Ranging (LiDAR) is a remote sensing method that uses pulses of light to calculate the elevation of ground and surface features with a high degree of accuracy and resolution. LiDAR data is used to develop high resolution digital surface models (DSM) and DEMs which can then be used to derive canopy height. The Oregon Department of Geology and Mineral Industries (DOGAMI) oversees the Oregon LiDAR Consortium (OLC), which develops cooperative agreements for LiDAR collection. LiDAR collected through the OLC is made available for free and can be downloaded. LIDAR was used to characterize vegetation height and ground elevations.

2.2.3 Aerial Imagery – Digital Orthophoto Quads

Aerial imagery was used to:

- Map stream features such as stream position, channel edges and wetted channel edges,
- Map near stream vegetation,
- Map instream structures such as dams, weirs, unmapped diversions/withdrawals, etc.

A digital orthophoto quad (DOQ) is a digital image of an aerial photograph in which displacements caused by the camera angle and terrain have been removed. In addition, DOQs are projected in map coordinates combining the image characteristics of a photograph with the geometric qualities of a map.

2.2.4 Thermal Infrared Radiometry (TIR) temperature data

TIR temperature data were used to:

- Develop continuous spatial temperature data sets,
- Calculate longitudinal heating profiles/gradients,
- Visually observe complex distributions of stream temperatures at a large landscape scale,
- Map/identify significant thermal features,
- Develop flow mass balances,
- Validate simulated stream temperatures.

TIR imagery measures the surface temperature of waterbodies or objects captured in the TIR image (i.e., ground, vegetation, and stream). TIR data was gathered through a sensor mounted on a helicopter that collected digital data directly to an on-board computer at a rate that insured the imagery maintained a continuous image overlap of at least [40%]. The TIR detected emitted radiation at wavelengths from [8-12] microns (long-wave) and recorded the level of emitted radiation as a digital image across the full 12-bit dynamic range of the sensor. Each image pixel contained a measured value that was directly converted to a temperature. Each thermal image has a spatial resolution of less than one-half meter/pixel. Visible video sensor captured the same field-of-view as the TIR sensor. GPS time was encoded on the imagery.

Data collection was timed to capture maximum daily stream temperatures, which typically occur between 14:00 and 18:00 hours. The helicopter was flown longitudinally over the center of the stream channel with the sensors in a vertical (or near vertical) position. In general, the flight altitude was selected so that the stream channel occupied approximately 20-40% of the image frame. A minimum altitude of approximately 300 m was used both for maneuverability and for safety reasons. If the stream split into two channels that could not be covered in the sensor's field of view, the survey was conducted over the larger of the two channels.

In-stream temperature data loggers were distributed prior to the survey to ground truth the radiant temperatures measured by the TIR. TIR data can be viewed as GIS point coverages or TIR imagery. A TIR/video image pair is shown in **Figure 2-2**.

Direct observation of spatial temperature patterns and thermal gradients is a powerful application of TIR derived stream temperature data. Thermally significant areas can be identified in a longitudinal stream temperature profile and related directly to specific sources (i.e., water withdrawal, tributary confluence, vegetation patterns, etc.). Areas with stream water mixing with subsurface flows (i.e., hyporheic and inflows) are apparent and often dramatic in TIR data. An example of this is shown in **Figure 2-3**, which illustrates the temperature difference between the Molalla River and a spring/seep located near the confluence of the Molalla and Pudding Rivers. Thermal changes captured with TIR data can be quantified as a specific change in stream temperature or a stream temperature gradient that results in a temperature change over a specified distance.

Longitudinal river temperatures were sampled using TIR imagery in separate flights for each stream. Temperature data sampled from the TIR imagery revealed spatial patterns that are variable due to localized stream heating, tributary mixing, and groundwater influences. The TIR survey reports contain detailed flight information, results discussions, sample imagery, and longitudinal temperature profiles. **Figure 2-4** through **Figure 2-9** display plots of TIR sampled tributary and spring temperatures in the Willamette subbasins. Actual TIR data is available upon request from DEQ.

Thermal stratification was identified in TIR imagery and by comparison with the instream temperature loggers. For example, the imagery may reveal a sudden cooling at a riffle or downstream of an instream structure, where water was rather stagnant or deep just upstream. All streams and the TIR collection dates are summarized in **Table 2-39**.

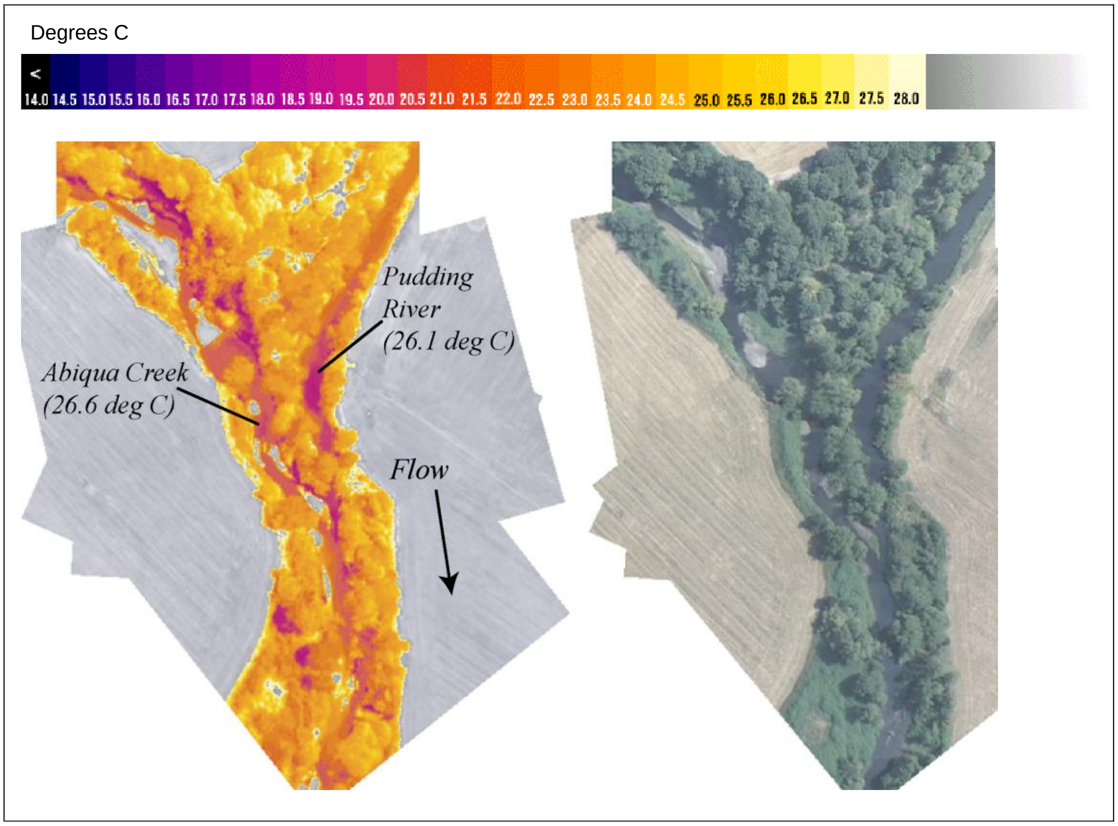


Figure 2-2: TIR/color video image pair showing Pudding River and Abiqua Creek temperatures on August 11, 2004.

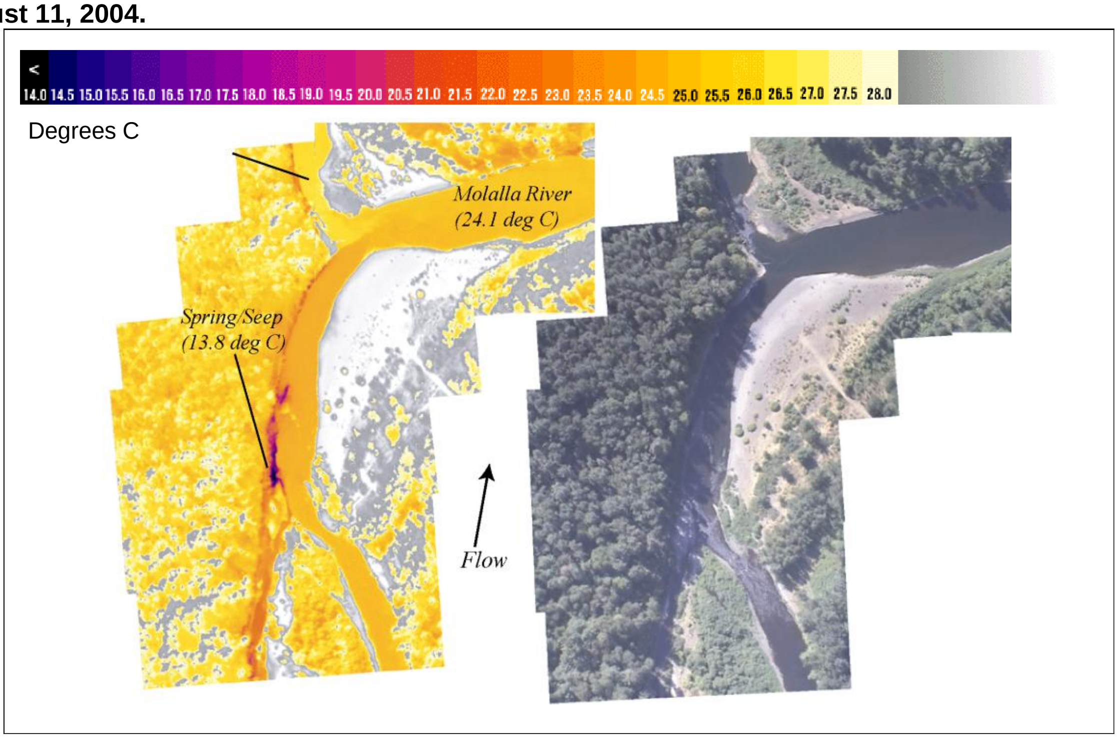


Figure 2-3: TIR/color video image pair showing the location of a spring or seep near the confluence of the Molalla and Pudding Rivers, July 26, 2004.

Table 2-39: TIR survey extents and collection dates in the Willamette Subbasins.

Stream	Survey Extent	Survey Date	Time	Survey Distance (mi)
Johnson Creek	Mouth to headwaters	7/31/2002	13:32-14:35	21.5
Beverly Creek	Mouth to headwaters	8/2/2000	15:24-15:31	2.3
Bonnie Creek	Mouth to headwaters	8/3/2000	14:38-14:41	2.0
Boulder Creek	Mouth to headwaters	8/2/2000	14:51-14:57	2.9
Canal Creek	Mouth to Elk Creek	8/2/2000	15:59-16:04	2.7
Crabtree Creek	River mile 30.6 to downstream of Crabtree Lake	8/2/2000	16:13-16:25	6.1
Elkhorn Creek	Mouth to river mile 3.3	8/1/2000	15:04-15:10	3.3
Hamilton Creek	Deer Creek to headwaters	8/3/2000	13:38-13:51	3.8
Hamilton Creek South Branch	Mouth to headwaters	8/3/2000	13:54-14:05	2.5
Little North Fork Santiam River	Mouth to Henline Creek	8/1/2000	14:33-15:00	16.8
Molalla River	Mouth to headwaters	7/26/2004	14:36-16:23	47.1
Packers Gulch	Mouth to headwaters	8/2/2000	15:05-15:14	3.0
Pat Creek	Mouth to headwaters	8/2/2000	15:34-15:37	1.4
Pudding River	Mouth to Little Pudding River	8/11/2004	16:01-17:59	36.7
Pudding River	Little Pudding River to headwaters	8/12/2004	14:07-15:48	26.8
Quartzville Creek	Green Peter Reservoir to Canal Creek	8/2/2000	15:43-15:59	8.9
Schafer Creek	Mouth to headwaters	8/2/2000	16:13-16:25	1.2
South Fork Packers Gulch	Mouth to headwaters	8/2/2000	15:01-15:05	1.8
South Fork Scott Creek	Mouth to headwaters	8/3/2000	13:22-13:33	5.3
South Santiam River	Confluence with the North Santiam River to Foster Reservoir	8/1/2000	15:32-16:16	35.9
Thomas Creek	Mouth to Neal Creek	8/3/2000	16:16-16:43	16.0
Thomas Creek	River mile 22.2 to River mile 35.8	8/3/2000	16:50-17:08	10.0
Unnamed Tributary to Crabtree Creek	Mouth to headwaters	8/3/2000	14:11-14:18	2.6
Unnamed Tributary to Quartzville Ck	Mouth to headwaters	8/2/2000	14:19-14:22	1.1
Unnamed Tributary to Unnamed Trib of Crabtree Creek	Mouth to headwaters	8/3/2000	14:20-14:24	1.1
Unnamed Tributary to Yellowstone Creek	Mouth to headwaters	8/2/2000	14:35-14:37	0.7
Unnamed Tributary to Yellowstone Creek	Mouth to headwaters	8/2/2000	14:40-14:48	1.5
West Fork Packers Gulch	Mouth to headwaters	8/2/2000	15:14-15:19	1.5
White Rock Creek	Mouth to headwaters	8/3/2000	14:26-14:35	2.7
Yellowstone Creek	Mouth to headwaters	8/2/2000	14:27-14:34	3.0
Bear Creek	Mouth to river mile 1.0	7/31/2002	16:25-16:34	1.0
Big River	Mouth to river mile 7.5	7/21/2002	16:27-16:43	7.5
Deer Creek	Mouth upstream 8.7 km	9/3/1999	16:30-16:31	5.4

Stream	Survey Extent	Survey Date	Time	Survey Distance (mi)
Eagle Creek	Mouth to Wilderness Bnd.	7/31/2002	15:14-15:54	16.5
Mosby Creek	Mouth to headwaters	7/21/2002	15:06-15:52	22.0
North Fork Eagle Creek	Mouth to river mile 5.0	7/31/2002	16:01-16:20	5.0
Sharps Creek	Mouth to Rivermile 11.0	7/21/2002	13:44-14:15	11.0
South Fork McKenzie River	Mouth to Cougar Dam	9/3/1999	16:24-16:25	4.3
McKenzie River	Quartz Creek to Trail Bridge Res.	9/3/1999	16:23-16:30	28.3

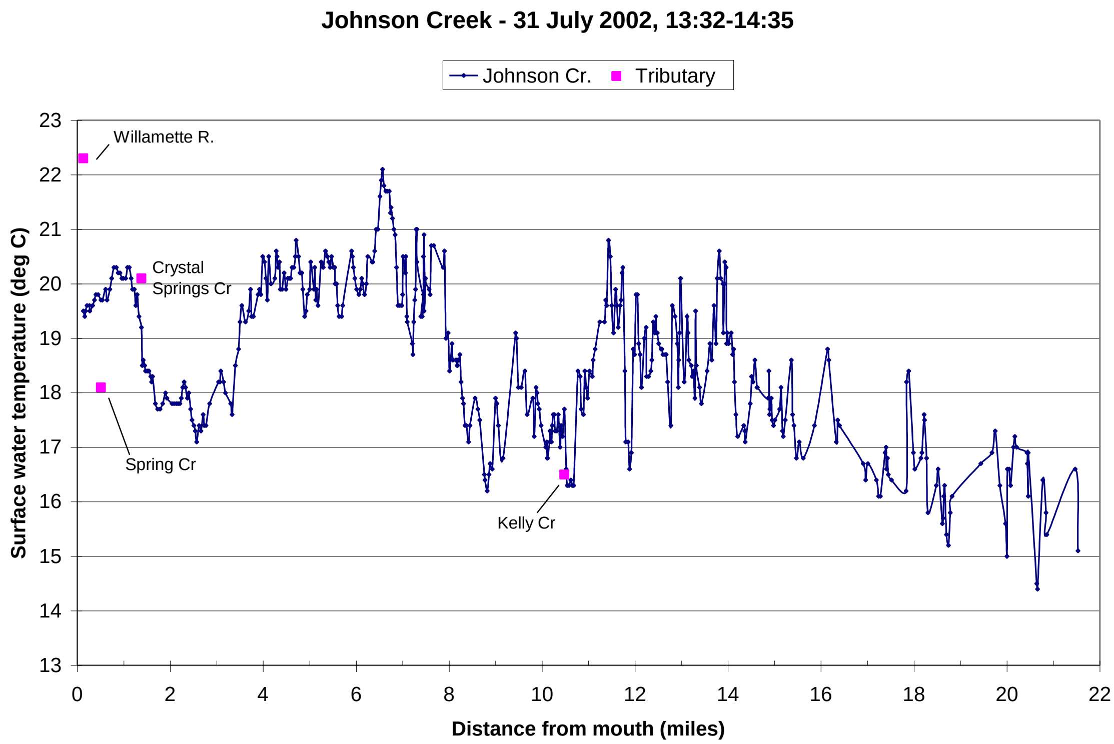


Figure 2-4: TIR temperatures for Johnson Creek in the Lower Willamette Subbasin.

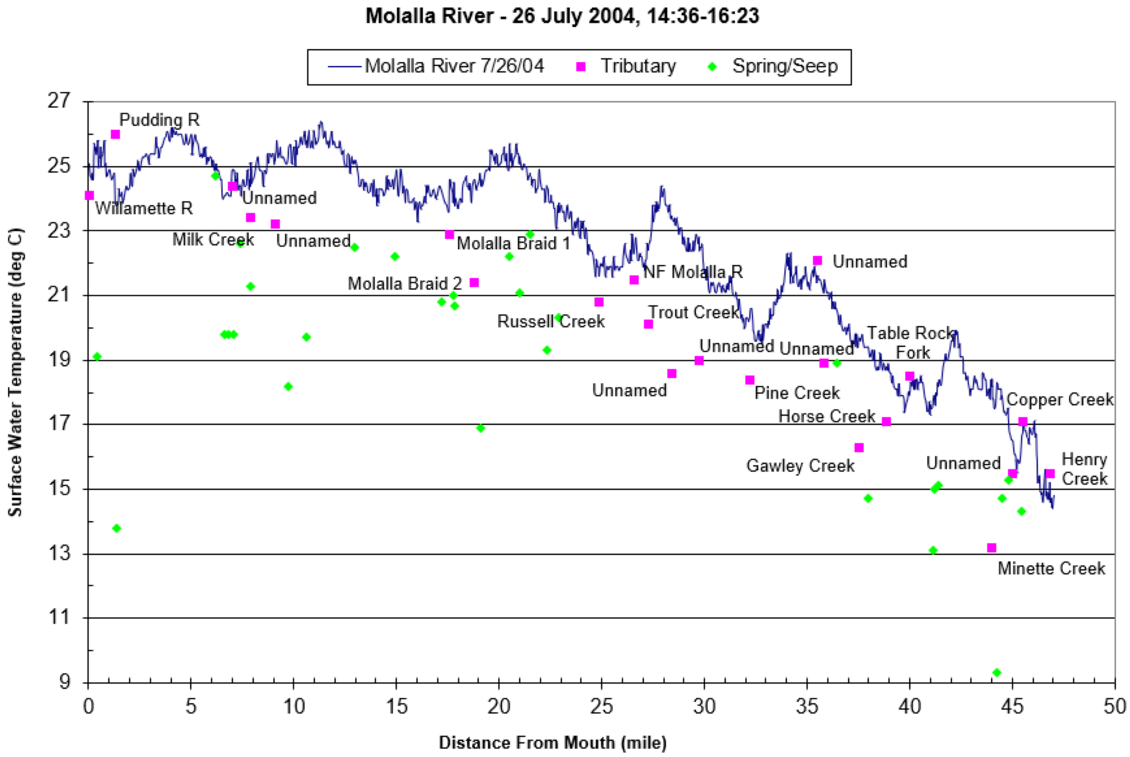


Figure 2-5: TIR temperatures for the Molalla River in the Molalla-Pudding Subbasin.

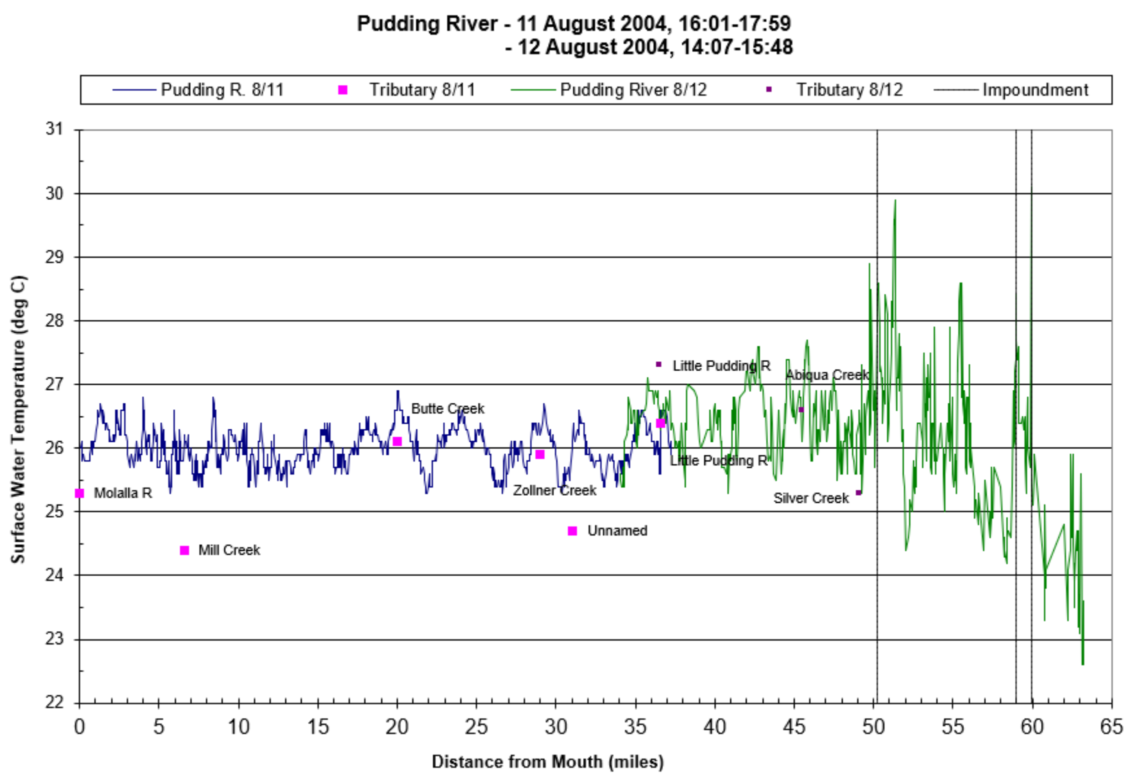


Figure 2-6: TIR temperatures for the Pudding River in the Molalla-Pudding Subbasin.

Little North Santiam - 1 August 2000, 14:33-15:00

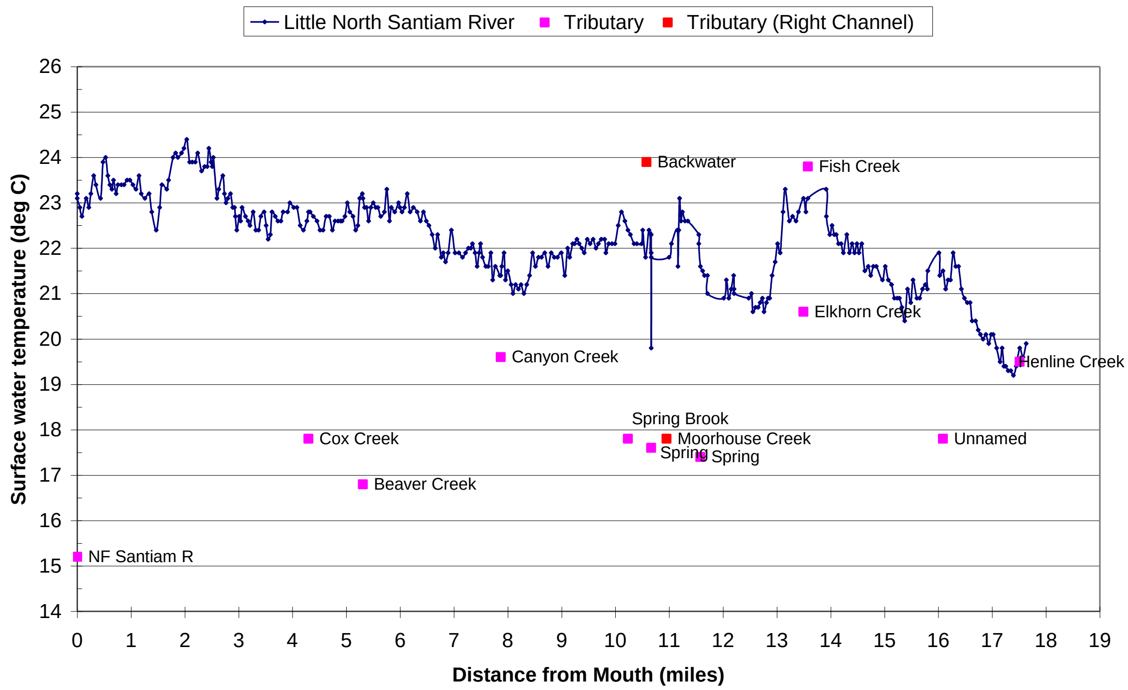


Figure 2-7: TIR temperatures for the Little North Santiam River in the North Santiam Subbasin.

Thomas Creek - 3 August 2000, 16:16-17:08

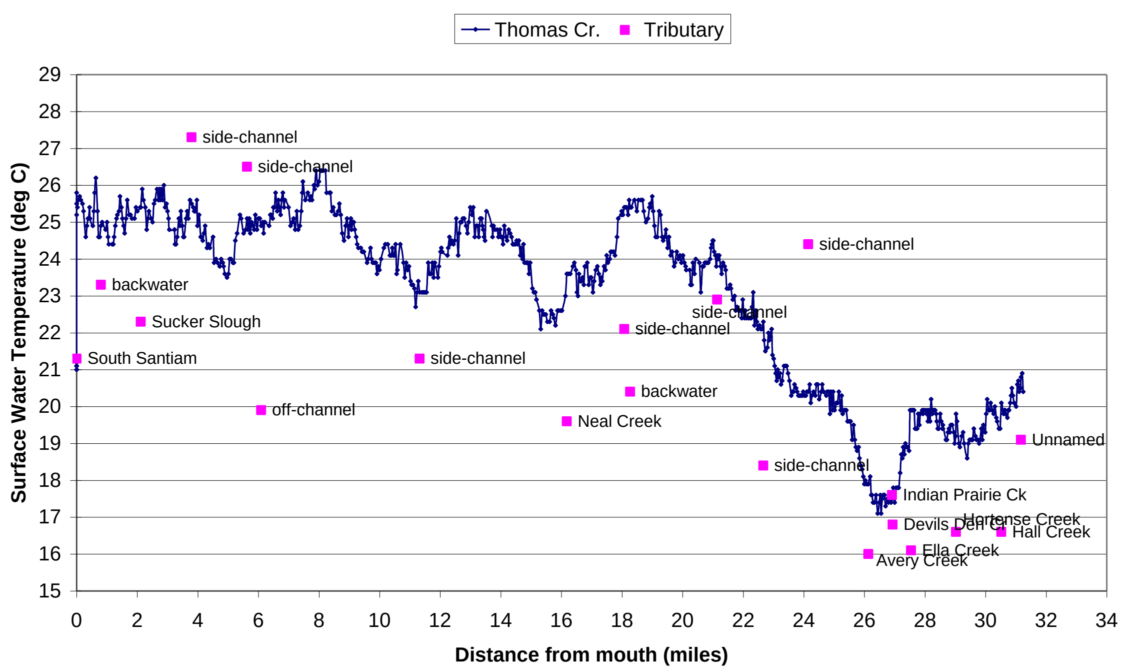


Figure 2-8: TIR Temperatures for Thomas Creek in the South Santiam Subbasin.

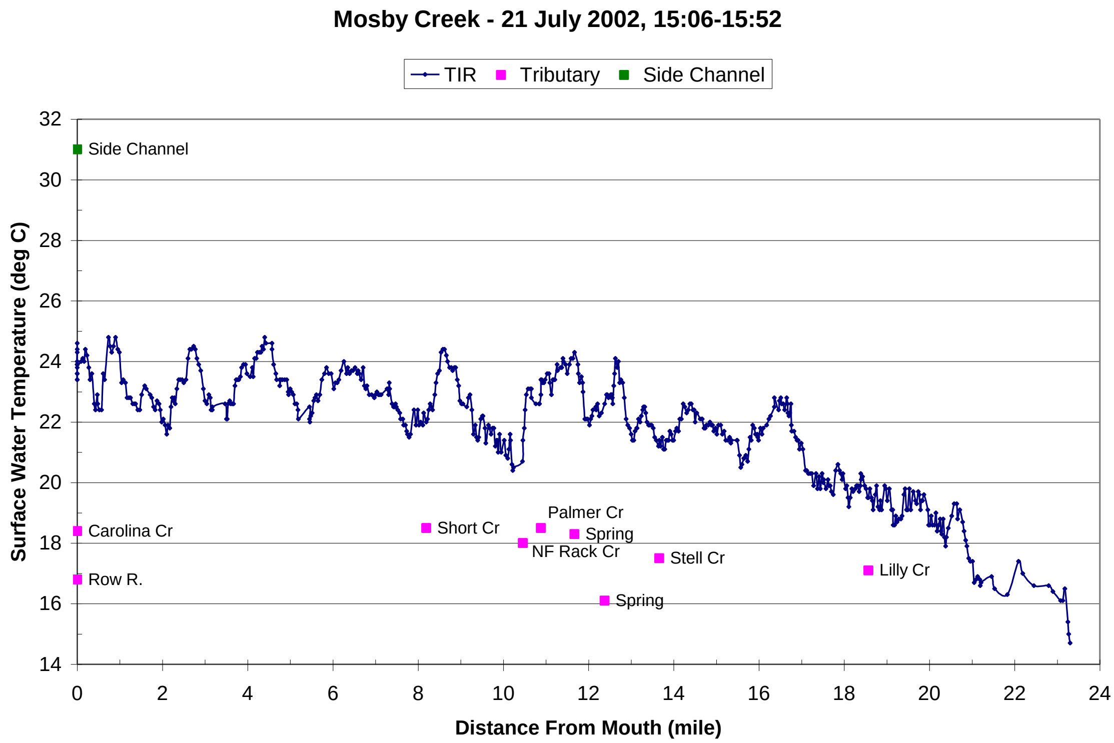


Figure 2-9: TIR temperatures for Mosby Creek in the Coast Fork Willamette Subbasin.

2.2.5 Land Ownership and Jurisdiction Mapping

Land ownership and jurisdiction was mapped in order to identify potential Designated Management Agencies (DMAs) and other responsible persons that may have vegetation management or other TMDL implementation responsibilities. A DMA is defined in OAR 340-042-0030(2) as a federal, state or local governmental agency that has legal authority over a sector or source contributing pollutants.

The land ownership and jurisdiction for any location was determined by reviewing geospatial datasets of ownership, land use, zoning, and jurisdictional boundaries, such as city limits or a county boundary. Cadastral boundaries and ownership information were acquired from county tax assessors. Ownership information provided by a county tax assessor was assumed to be the most accurate information.

The sources of the geospatial features are described in **Table 2-40**. A twelve-step decision hierarchy was used to assign a potential DMA or other responsible person to a tax lot. The decision hierarchy was implemented using an R script with all the geospatial data feeding into the decision tree.

Table 2-40: Geospatial data types and sources used to map land ownership and jurisdiction.

Geospatial data description	Feature name	Data Source
Tax Lot Ownership	Cadastral Survey	Oregon Geospatial Enterprise Office, Benton County, Clackamas County, Columbia County, Curry County, Lane County, Lincoln County, Linn County, Marion County, Multnomah County, Polk County, Washington County, Yamhill County, and Metro RLIS
County Boundaries	Boundary Counties OR (Polygons)	Bureau of Land Management
Public Land Management	Oregon Land Management – 2015, Oregon Land Management-2019	Bureau of Land Management
City Limits	Oregon City Limits - 2018	Oregon Department of Transportation
Tribal Governments	Tribal Areas	Confederated Tribes of Warm Springs, Oregon Department of Forestry, U.S. Census Bureau (2000 Census)
Roads	Oregon Transportation Network – 2017	Oregon Department of Transportation
Railroads	Oregon Railroads - 2017	Oregon Department of Transportation
Land use/Land cover	2016 NLCD	U.S. Geological Survey, Dewitz (2019)
Zoning	Oregon Zoning - 2017	Oregon Department of Land Conservation and Development

2.3 Derived Data

Several datasets used for model setup were derived or sampled from landscape scale GIS data. Sampling density was user-defined and generally matched any GIS data resolution and accuracy. The derived parameters used in the stream temperature analysis were:

- Stream position and aspect
- Stream elevation and gradient
- Maximum topographic shade angles (east, south, west)
- Channel width
- Landcover classification and mapping
- Tributary stream temperatures and flow

2.3.1 Stream position and channel width

Stream position and active channel width were estimated using the following steps:

Step 1. Stream right and left banks (looking in the downstream direction) were digitized at a 1:2,000 or smaller map scale using a combination of aerial imagery from the USDA National Agricultural Imagery Program (NAIP) (**Figure 2-10**). Channel boundaries were digitized to correspond to the active channel width, which is defined as the width between shade producing near stream vegetation, the low flow channel terrace edge, or down cut banks which were interpreted from the available datasets.

Step 2. The stream center flowline was digitized at a 1:2,000 or smaller map scale by following the center of the wetted stream area. At bifurcations the stream flowline was digitized along the largest channel.

Step 3. The stream flowline was segmented into reaches no greater than 100m, with a node separating each reach (**Figure 2-10**). These nodes determine the location and flow path for modeling. Stream segmentation was completed using a script called TTools.

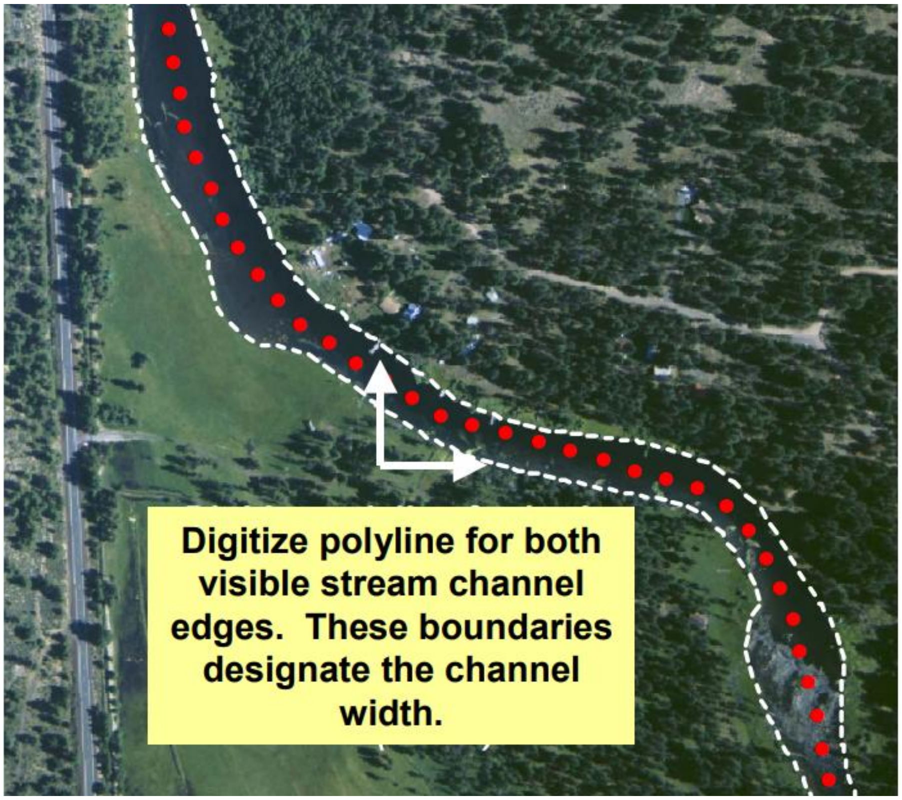


Figure 2-10: Example of digitized channel, flowline, and stream nodes.
The channel widths input into each model are plotted in the model setup Section 3.

2.3.2 Channel bottom width

The Heat Source model assumes a trapezoidal channel shape and model versions 8 and newer require input of channel bottom width depicted as b_2 in **Figure 2-11**. In the Willamette Subbasins, the Pudding River was the only stream modeled with Heat Source version 8. For the Pudding model, bottom width is estimated using **Equation 2-1**, with a conceptual diagram of the trapezoidal channel and terms used in this equation shown in **Figure 2-11**. The active channel width (b_1) is the GIS digitized channel width. Mean depth was calculated as the active channel width divided by an estimated width-to-depth ratio or the measured width-to-depth ratio at each instantaneous flow site. Channel angle z and the width-to-depth ratios are estimated model calibration parameters.

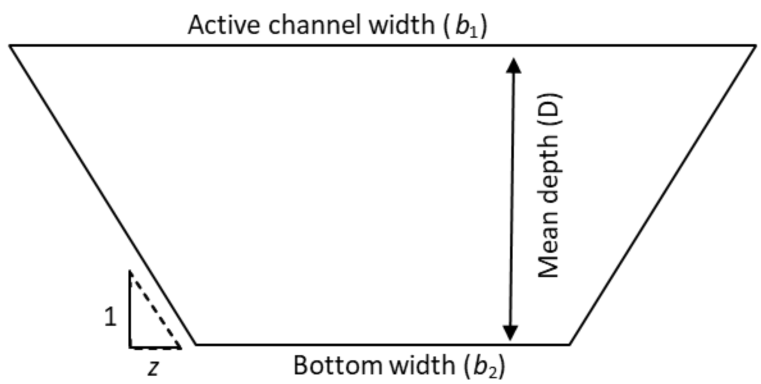


Figure 2-11: Conceptual diagram of trapezoidal channel and terms used in Equation 2-1.

$$b_2 = b_1 - 2 \cdot z \cdot D \qquad \textbf{Equation 2-1}$$

where,

$b_2 =$ Bottom width (meters)

$b_1 =$ Active channel width (meters)

$D =$ Mean active channel depth (meters). Estimated as b_1 / the width to depth ratio.

$z =$ Channel angle z defined as the change in horizontal distance (meters) for every unit rise in vertical distance (meters) of the channel side slope.

2.3.3 Stream elevation and gradient

Stream elevation and stream gradient were derived at each stream node from 10-Meter DEM data files for the Willamette River and major tributary shade models, Molalla River, Pudding River, and Johnson Creek (2002) models; and from 3-foot resolution LiDAR bare earth elevation data for the Southern Willamette shade models. Stream gradients were calculated from the elevation of the stream node using the distance between nodes. Stream elevation and gradient derivation for models completed by agencies other than DEQ are described in their respective model reports.

2.3.4 Topographic shade angles

The topographic shade angle represents the vertical angle to the highest topographic feature as measured from a flat horizon. At this angle and smaller the topographic feature will cast a shadow over the stream node as the sun moves behind it. Topographic shade angle was calculated using **Equation 2-2** as implemented in a python script called TTools. Elevations were sampled from the DEM. The maximum topographic shade angle in each direction for each stream node was found by sampling every raster cell out as far as necessary, typically 10 km in three directions (west, south, east) from each stream node.

$$\theta_T = \tan^{-1}\left(\frac{Z_T - Z_S}{d}\right) \qquad \textbf{Equation 2-2}$$

where,

$\theta_T =$ The topographic shade angle (degrees).

$Z_T =$ The elevation (meters) at the topographic feature.

$Z_S =$ The elevation (meters) at the stream node.

$d =$ Horizontal distance (meters) from the stream node to the topographic feature.

2.3.5 Land cover mapping

DEQ mapped near stream land cover using DOQs at a 1:5,000 scale, ODFW's Willamette Valley Land Use/Land Cover GIS database (ODWF, 1998), and PNWERC's Willamette River Basin Land Use and Land Cover ca. 1990 GIS dataset (PNWERC/ISE, 1999). Land cover features were mapped 300 ft in the transverse direction from each stream bank. Land cover data are developed by DEQ in successive steps.

Step 1. Land cover polygons and stream polylines are digitized from DOQs and integrated with ODFW and PNWERC datasets. All digitized polygons are drawn to capture visually like land cover features. All DEQ digitized line work is verified at 1:5,000 or less.

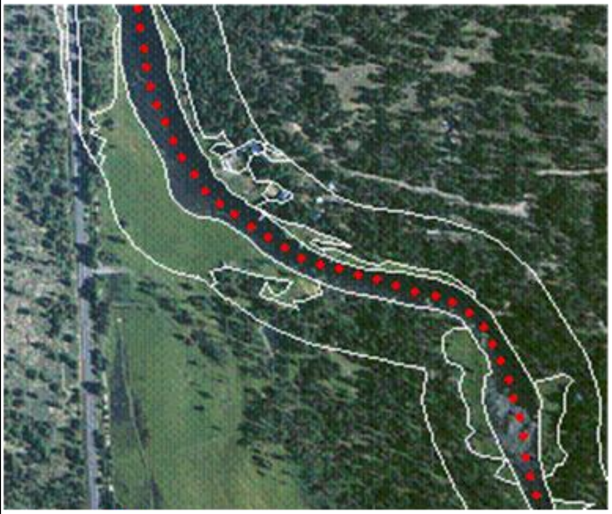
Step 2. Basic land cover types are developed and assigned to individual polygons. The land cover types used in this effort are aggregate land cover groups, such as: conifers, hardwoods, shrubs, etc., and as defined by ODFW's Willamette Valley database (ODFW, 1998) and PNWERC's Willamette River Basin Land Use and Land Cover ca 1990 dataset (PNWERC/ISE, 1999). See **Table 2-41** for landcover classifications and attributes used to describe current condition near stream landcover.

Step 3. Automated sampling is conducted on classified land cover spatial data sets in 2-dimensions. Every 100 ft along the stream (i.e., in the longitudinal direction), the near stream land cover is sampled every 15 m in a transverse direction; starting at the channel center, out to 60 m.

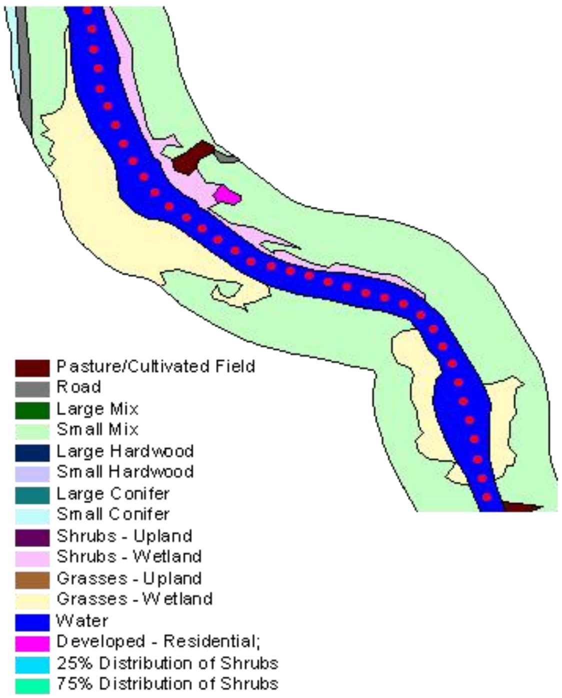
Step 4. Ground level land cover data are statistically summarized and sorted by land cover type.

Step 5. Land cover physical attributes can then be described in 2-dimensions since automated sampling occurs in both the longitudinal and transverse directions.

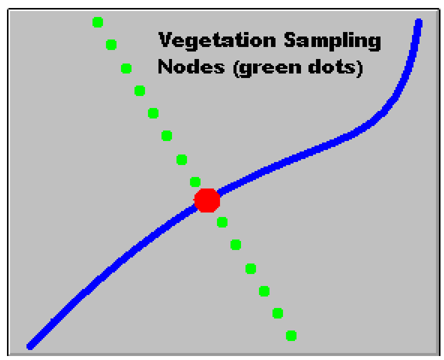
The following images in **Figure 2-12** summarize the steps followed for near stream land cover classification.



Example of Polygon Mapping of Near Stream Land Cover



Example of Classification of the Land Cover Polygons Associating a Land Cover Type to Each of the Polygons (at this point a land cover type numeric code is associated with each polygon.)



TTools longitudinal sampling pattern for near stream land cover (sampling interval is user defined). Sampling occurs for every stream data node at 9 user-defined intervals at 90 degrees from the stream centerline. A database of land cover type is created for each stream data node.

Figure 2-12: Examples of classifying near stream land cover.

Table 2-41: Current condition land cover classifications and attributes.

ODFW Landcover Code	PNWERC Landcover Code	DEQ Landcover Code	Landcover Type	Height (ft)	Density (%)
9	32, 33	**301, 3011**	Water	0	0
N/A	N/A	**304**	Barren - Rock	0	0
N/A	N/A	**308**	Barren - Clearcut	0	0
N/A	N/A	**400**	Barren - Road	0	0
N/A	N/A	**401**	Barren - Forest Road	0	0
N/A	N/A	**402**	Barren - Railroad	0	0

ODFW Landcover Code	PNWERC Landcover Code	DEQ Landcover Code	Landcover Type	Height (ft)	Density (%)
N/A	N/A	**403**	Barren - Ag. Road	0	0
N/A	N/A	**3011**	River Bottom - Floodplain	0	0
N/A	N/A	**3248**	Developed - Residential	20	100
3	N/A	**3249**	Urban Industrial	30	100
N/A	N/A	**3249**	Developed - Industrial	30	100
N/A	N/A	**3252**	Dam	0	0
N/A	N/A	**3254**	WWTP	0	0
2.1	N/A	**21**	Annual Row Crops	0	0
2.2	N/A	**22**	Annual Grass	3	75
2.3	N/A	**23**	Perennial Grass	3	75
2.4	N/A	**24**	Orchards, Vineyards, Berries, Christmas Trees, Nursery Stock	10	75
2.4	N/A	**28**	Orchards, Vineyards, Berries, Christmas Trees, Nursery Stock	40	75
2.5	N/A	**25**	Unmanaged Pasture	0	0
2.6	N/A	**26**	Parks and Cemeteries	0	0
3	N/A	**3248**	Urban Residential	20	100
20	N/A	**202**	Black Hawthorn, Hedgerows, Brushy Fields	19	25
20	N/A	**204**	Black Hawthorn, Hedgerows, Brushy Fields	26	25
20	N/A	**206**	Black Hawthorn, Hedgerows, Brushy Fields	19	75
20	N/A	**208**	Black Hawthorn, Hedgerows, Brushy Fields	26	75
21	N/A	**212**	Cottonwood	75	25
21	N/A	**214**	Cottonwood	105	25
21	N/A	**216**	Cottonwood	75	75
21	N/A	**218**	Cottonwood	105	75
22	N/A	**222**	Willow	28	25
22	N/A	**224**	Willow	43	25
22	N/A	**226**	Willow	28	75
22	N/A	**228**	Willow	43	75
30	N/A	**30**	Reed Canary Grass	6	75
30	N/A	**35**	Reed Canary Grass	6	25
31	N/A	**31**	Cattail, Bulrush	5	75
31	N/A	**315**	Cattail, Bulrush	5	25
463	N/A	**4632**	Ash, Cottonwood - Bottomland Pasture Mosaic	33	25
463	N/A	**4634**	Ash, Cottonwood - Bottomland Pasture Mosaic	93	25
463	N/A	**4636**	Ash, Cottonwood - Bottomland Pasture Mosaic	33	75
463	N/A	**4638**	Ash, Cottonwood - Bottomland Pasture Mosaic	93	75
476	N/A	**4762**	Oak, Douglas Fir - >50% Oak	53	25
476	N/A	**4764**	Oak, Douglas Fir - >50% Oak	93	25
476	N/A	**4766**	Oak, Douglas Fir - >50% Oak	53	75
476	N/A	**4768**	Oak, Douglas Fir - >50% Oak	93	75
505	N/A	**5052**	Douglas Fir, Oak - < 50% Oak	53	25

ODFW Landcover Code	PNWERC Landcover Code	DEQ Landcover Code	Landcover Type	Height (ft)	Density (%)
505	N/A	**5054**	Douglas Fir, Oak - < 50% Oak	91	25
505	N/A	**5056**	Douglas Fir, Oak - < 50% Oak	53	75
505	N/A	**5058**	Douglas Fir, Oak - < 50% Oak	91	75
506	N/A	**5062**	Oak, Madrone, Douglas Fir	50	25
506	N/A	**5064**	Oak, Madrone, Douglas Fir	87	25
506	N/A	**5066**	Oak, Madrone, Douglas Fir	50	75
506	N/A	**5068**	Oak, Madrone, Douglas Fir	87	75
510	N/A	**5102**	Maple, Alder, Fir	65	25
510	N/A	**5104**	Maple, Alder, Fir	93	25
510	N/A	**5106**	Maple, Alder, Fir	65	75
510	N/A	**5108**	Maple, Alder, Fir	93	75
512	N/A	**5122**	Douglas Fir or any Conifer	102	25
512	N/A	**5124**	Douglas Fir or any Conifer	160	25
512	N/A	**5126**	Douglas Fir or any Conifer	102	75
512	N/A	**5128**	Douglas Fir or any Conifer	160	75
999	N/A	**999**	Gravel and Sand	0	0
1000	N/A	**1002**	Unclassified Forest	56	25
1000	N/A	**1004**	Unclassified Forest	89	25
1000	N/A	**1006**	Unclassified Forest	56	75
1000	N/A	**1008**	Unclassified Forest	89	75

2.3.6 Derived data methods

Non-steady state stream models typically require a significant amount of data because of the large spatial and temporal extents the models typically encompass. As the model size or modeling period increase, the amount of information needed to parameterize it also increases. Often it is not possible to parameterize a model entirely from field data because it can be resource intensive or impractical to collect everything that is needed. In general, these data gaps may be considered and addressed in a number of ways. **Table 2-42** summarizes methods that are used to derive the data needed to parameterize the model. The most frequent approach used approach was a mass balance approach summarized below.

To the greatest extent possible, the method used to derive the model parameters for the existing TMDL models have been summarized in the boundary conditions and tributary inputs tables in the model setup and calibration section 3.

Table 2-42: Methods to derive model parameters for data gaps.

Method	Possible Parameters	Description
Direct surrogate	Tributary temperatures, meteorological inputs, sediment	Often neighboring or nearby tributary watersheds share climatological and landscape features. Model parameters that have an incomplete record or no data may be parameterized using data from a neighboring or nearby location where data is available.
Calibration adjustment	All inputs	In some instances, a significant input may be required for appropriate representation in the modeling, however little may be known about the nature of that input. An example of this is groundwater influx and temperature. Datasets for these inputs can be estimated by adjusting the necessary values within acceptable ranges during the calibration process.
Literature-based values	All inputs	Literature values are often used for model parameters or unquantified model inputs when little is known about the site-specific nature of those inputs. Examples of these types of parameters include stream bed heat transfer properties, hyporheic characteristics or substrate porosity (Bencala and Walters, 1983; Hart, 1995; Pelletier et al., 2006; Sinokrot and Stefan, 1993).
Mass balance Flow balance	Tributary temperature and flow	On modeled reaches, tributary stream flow or temperature can be estimated using a mass balance approach assuming either flow or temperature data for the tributary are known. If estimating temperature, flow is required, and if estimating flow, temperature is required. Often TIR data are used to estimate tributary flow because upstream, downstream and tributary temperatures are known, and upstream and tributary flows are known (or estimated). A flow balance can also be used (without temperature data) to estimate flow rates. The approach relies on having some flow measurements available in order estimate the flow between contributed from tributaries between the measured points.
Simple linear regression	Tributary temperature and flow	Parameters such as flow and temperature in neighboring or nearby tributaries often demonstrate similar diurnal patterns or hydrographs which allow for the development of suitable mathematical relationships (simple linear regression) in order to fill the data gaps for those inputs. This method requires at least some data exist for the incomplete dataset in order to develop the relationship.
Drainage area ratio	Tributary flow	For ungaged tributaries, flows can be estimated using the ratio between the watershed drainage areas of the ungaged location and from a nearby gaged tributary (Ries et al., 2017; Risley, 2009; Gianfagna, 2015). For example, if the watershed area upstream of a gaged tributary is 10 square kilometers, and the watershed area of an ungaged tributary is 5, the flows in the ungaged tributary are estimated to be half of those in the gaged tributary. The method is typically used to calculate low flow or flood frequency statistics. In that context a weighting factor is recommended when the drainage area ratio of the two sites is between 0.5 and 1.5. Weighting factors can be evaluated if instantaneous observed flows are available at the ungaged location.

Method	Possible Parameters	Description
Adiabatic adjustment	Air temperature	Air temperature can vary significantly throughout a watershed, particularly with large differences in elevation from headwaters to the mouth of the drainage. To account for these differences, air temperatures can be adjusted using an equation that relates air temperature measured at a meteorological station to a location of a given elevation using the dry adiabatic lapse rate of 9.8 °C/km and the differences in elevation.
GIS Data	Channel position, Channel width, Landcover, Gradient, Elevation, Topographic shade angles	Several landscape scale GIS data sets can be used to derive a number of model parameters. Digital orthophotos quads (DOQs) are used to classify landcover and estimate vegetation type, height, density, and overhang. DOQs can also be used to determine stream position, stream aspect, and channel width. A DEM consists of digital information that provides a uniform matrix of terrain elevation values. It provides basic quantitative data for deriving surface elevation, stream gradient, and maximum topographic shade angles.

TIR sampled stream temperature data can be used to develop a mass balance for stream flow using minimal ground level data collection points. Simply identifying mass transfer areas is an important step in quantifying heat transfer within a stream network. For example, using TIR temperature data, DEQ identified mass transfer areas occurring in the Willamette subbasin streams. Several of the subsurface mass transfer areas were unmapped and the relative thermal and hydrologic impact to the stream system was not previously quantified.

All stream temperature changes that result from mass transfer processes (i.e., tributary confluence, point source discharge, groundwater inflow, etc.) can be described mathematically using **Equation 2-3**.

$$T_{mix} = \frac{\left(Q_{up} \cdot T_{up}\right) + \left(Q_{in} \cdot T_{in}\right)}{\left(Q_{up} + Q_{in}\right)}$$ **Equation 2-3**

where,

$T_{mix} =$ Stream temperature from mass transfer process assuming complete mix.

$Q_{up} =$ Stream flow rate upstream from mass transfer process.

$Q_{in} =$ Inflow volume or flow rate.

$Q_{mix} =$ Resulting volume or flow rate from mass transfer process.

$T_{up} =$ Stream temperature directly upstream from mass transfer process.

$T_{in} =$ Temperature of inflow.

All water temperatures (i.e., T_{up}, T_{in} and T_{mix}) can be derived from the TIR sampled stream temperature data. Provided that at least one instream flow rate is known, the other flow rates can be calculated.

Water volume losses are sometimes visible in TIR imagery since diversions and water withdrawals usually contrast with the surrounding thermal signature of landscape features.

Highly managed stream flow regimes can become complicated where multiple diversions and return flows mix or where flow diversions and returns are unmapped and undocumented. In such cases it becomes important to establish the direction of flow (i.e., influent or effluent). With the precision afforded by TIR sampled stream temperatures, effluent flows can be determined when temperatures are the same. Temperature differences indicate that the flow is influent. This holds true even when observed temperature differences are very small. The rate of water loss from diversions or withdrawals cannot be easily calculated. DEQ estimates water withdrawal flow rates from the water right information maintained by Oregon Water Resources Department (OWRD) and with discussion with the subbasin water master.

In this fashion, a mass balance can be developed from relatively few instream measurements, TIR stream temperature data and water rights data.

3. Model setup and calibration

The setup and calibration for these models was completed by DEQ for the Willamette Basin TMDL and WQMP (DEQ, 2006) and Molalla-Pudding Subbasin TMDL (DEQ, 2008). During development, the models were adjusted iteratively until acceptable goodness-of-fit was achieved relative to the observed current conditions. DEQ did not make adjustments to the original calibrated temperature models with the exception of a minor correction to the meteorological inputs on Johnson Creek. The Heat Source shade models new to this TMDL and were not available for the 2006 TMDL. The general process for calibrating Heat Source models is described below.

The following bulleted list of Heat Source input categories and specific inputs describes the general form and function of the inputs, and why the inputs are candidates for adjustment during calibration:

- Morphology – The morphology inputs that could be used as calibration parameters include upstream and downstream channel elevations, Manning's *n*, and rating curve coefficients *a* and *b* for a power function. Channel hydraulics are important for predicting stream temperatures because they govern the surface area of water that could be exposed to solar radiation, the residence time for exposure, and the degree of light penetration into the water column. Field data for these inputs are often difficult to collect over large spatial scales, and values can vary significantly on a small scale. Heat Source is a one-dimensional model and complex channel configurations are represented as a trapezoidal pattern. Adjustments to inputs that affect channel hydraulics are often necessary to calibrate the model.
- Morphology inputs vary across Heat Source version 6, version 7 and version 8 models. In Heat Source version 7 the following morphology inputs can be adjusted during calibration in addition to the inputs used in version 6: channel gradient, channel angle z, bed particle size and percent embeddedness. In Heat Source version 8, the following morphology inputs can be adjusted during calibration in addition to the inputs used in version 6 and version 7: channel bottom width, hyporheic zone thickness, percent hyporheic exchange, and porosity.
- Meteorology – The meteorological inputs that can be modified in calibration include wind speed and cloudiness. Wind speed can vary significantly on a small geographic scale and the distance to the source of the meteorological data is often much greater than the small-scale localized weather. Hence, adjusting wind is an appropriate calibration

method to account for more site-specific weather patterns. Cloudiness is represented as a percentage of clear sky and can be adjusted to affect the amount of incoming solar radiation the stream receives.

- Meteorology inputs vary across Heat Source version 6, version 7 and version 8 models. In Heat Source version 6 cloudiness is assumed at clear sky conditions cannot be adjusted. Cloudiness can be adjusted in Heat Source version 7 and version 8.
- Mass and thermal flux – Mass and thermal inflows and outflows are inputs often adjusted during the calibration process. These inflows of heat and water consist of tributary and groundwater inflows as well as diversions (i.e., water rights withdrawals) and groundwater losses. The temporal and geographic extents of flow gaging and temperature monitoring on tributaries or groundwater are generally sparse. An effective way of improving the calibration is to complete a flow mass balance with available data, and then add, subtract, or adjust flows either globally or in specific locations within the bounds of the flow mass balance and available measurements, and the temperature response predicted by the model.
- Thermal inflow and outflow inputs vary across Heat Source version 6, version 7 and version 8 models. Heat Source version 7 and version 8 allow for variable flow rate time series on the boundary conditions and tributary inputs, as well as allow for groundwater (accretion) and diversion inputs to the model.
- Vegetation – Vegetation characteristics input into the model are often derived from aerial imagery or LiDAR. The vegetation characteristics determine the degree to which near-stream vegetation has the capacity to block incidental solar radiation on the surface of the modeled waterbody. Three vegetation inputs incorporated into the model calibration process are the vegetation density, overhang, and height. Field measurements offer a general understanding of vegetation characteristics within the watershed, however variability in these parameters can be significant on smaller geographic scales. To improve the model fit these model inputs may be modified on a global scale for different vegetation classes within the bounds of available data.

3.1 Johnson Creek

The Johnson Creek model is a water temperature model developed using Heat Source 6.5.1. The model was developed by DEQ.

3.1.1 Model extent

The extent of the model domain is Johnson Creek at Revenue Road to the mouth of Johnson Creek at the confluence with the Willamette River (**Figure 3-1**).

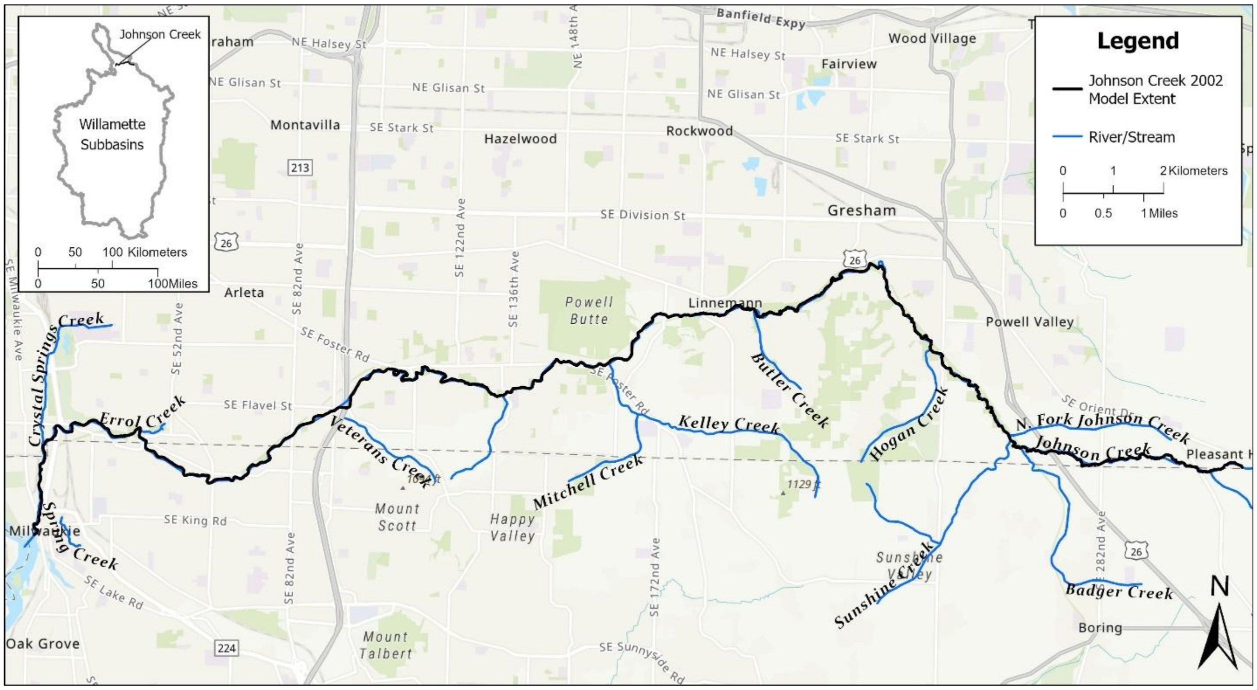


Figure 3-1: Johnson Creek temperature model extent.

3.1.2 Spatial and temporal resolution

The model input spatial resolution (*dx*) is 30 m. Outputs are generated every 100 m. The model time step (*dt*) is 1 minute and outputs are generated every hour.

3.1.3 Time frame of simulation

The model period is for a single day: July 31, 2002.

3.1.4 Meteorological inputs

The model used air temperature, relative humidity, and wind speed from various sites (**Table 3-1**). Multiplicative wind sheltering coefficients were applied to the wind speed for calibration (**Table 3-2)**. The meteorological observations are presented in **Figure 3-2**.

Table 3-1: Meteorology data sources for the Johnson Creek model.

Site ID	Site	Source	Meteorological Parameters
10009634	Portland International Airport	NCDC	Air Temperature, Relative Humidity
POBO	Powell Butte	AgriMet	Wind Speed

Table 3-2: Wind-sheltering coefficient used in the Johnson Creek model.

Model Location Name	Model Location (km)	Wind Sheltering Coefficient
Johnson Creek at Revenue Road	37.552	0.07
Johnson Creek at Short Road	35.527	0.07
Johnson Creek at Palmblad Avenue	30.312	0.07
Johnson Creek at Regner Road	27.489	0.07
Johnson Creek at Pleasant View/190th Avenue	21.752	0.07
Johnson Creek at SE Circle Avenue	20.003	0.07
Johnson Creek at SE 122nd Avenue	14.726	0.07
Johnson Creek at SE 92nd Avenue	10.339	0.07
Johnson Creek at SE 72nd Avenue and Bell Road	7.609	0.07
Johnson Creek at SE 45th Avenue	5.062	0.07
Johnson Creek at Milwaukie Gage	1.135	0.07
Johnson Creek at SE 17th Avenue	0.368	0.22

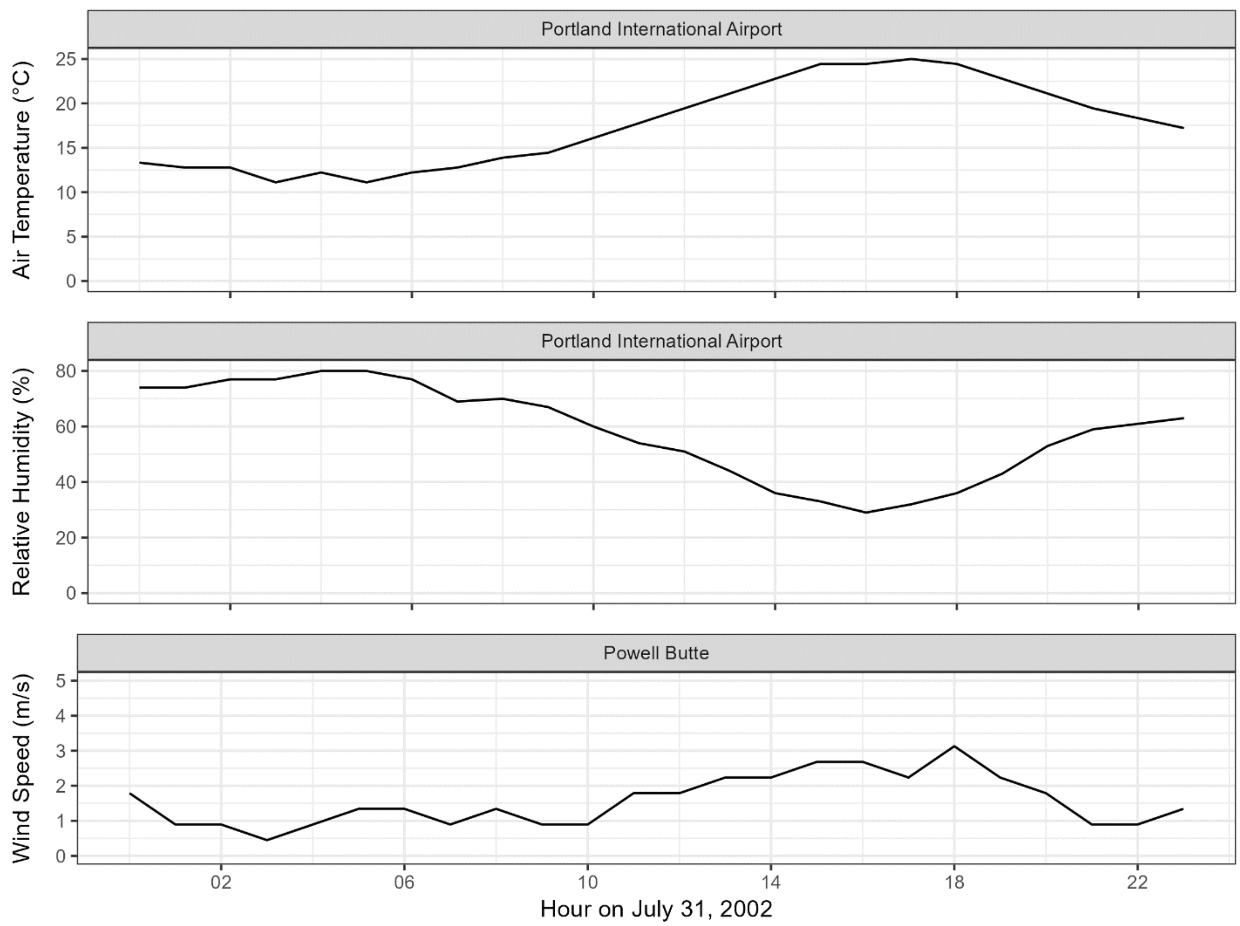


Figure 3-2: Meteorological inputs to the Johnson Creek model.

3.1.5 Temperature inputs

Hourly water temperature time series data were used to support tributary and boundary condition model setup. **Figure 3-3** shows the locations of the various stream temperature monitoring locations that were used for model setup or calibration.

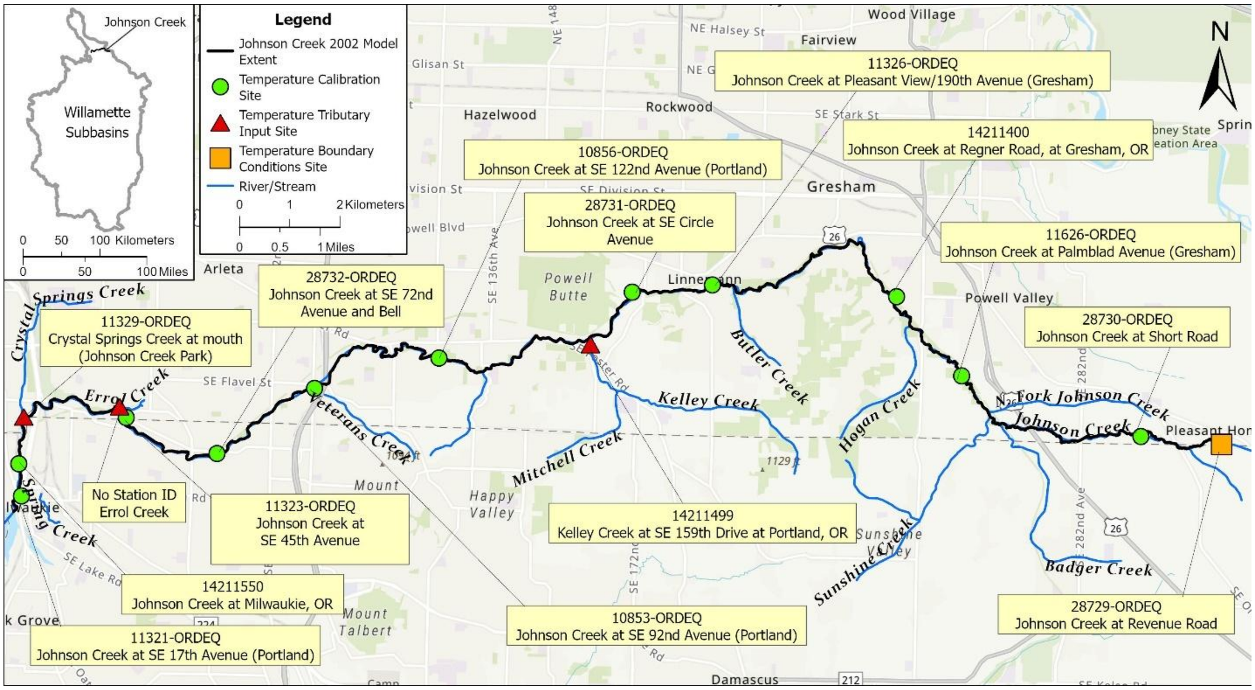


Figure 3-3: Temperature monitoring locations used for Johnson Creek model setup and calibration.

Table 3-3 and **Figure 3-4** document the water temperature inputs to the model at the boundary condition (Johnson Creek at Revenue Road) and tributaries. **Table 2-39** lists the survey extent and collection date of TIR temperature monitoring on Johnson Creek. TIR temperatures for Johnson Creek are plotted in **Figure 2-4**.

Table 3-3: Boundary condition and tributary water temperature inputs to the Johnson Creek model.

Model Location Name	Model Location (km)	Input Type	Data Source
Johnson Creek at Revenue Road	37.552	Boundary Condition	28729-ORDEQ
Sunshine Creek	31.57	Tributary	Same as Kelley Creek.
Butler Creek	22.366	Tributary	Same as Kelley Creek.
Kelley Creek	18.469	Tributary	USGS 14211499
Veterans Creek	10.646	Tributary	Same as Kelley Creek.
Errol Creek	4.817	Tributary	Grab data collected by City of Portland.
Crystal Springs Creek at mouth (Johnson Creek Park)	2.056	Tributary	11329-ORDEQ
Spring Creek	0.614	Tributary	Same as Kelley Creek.

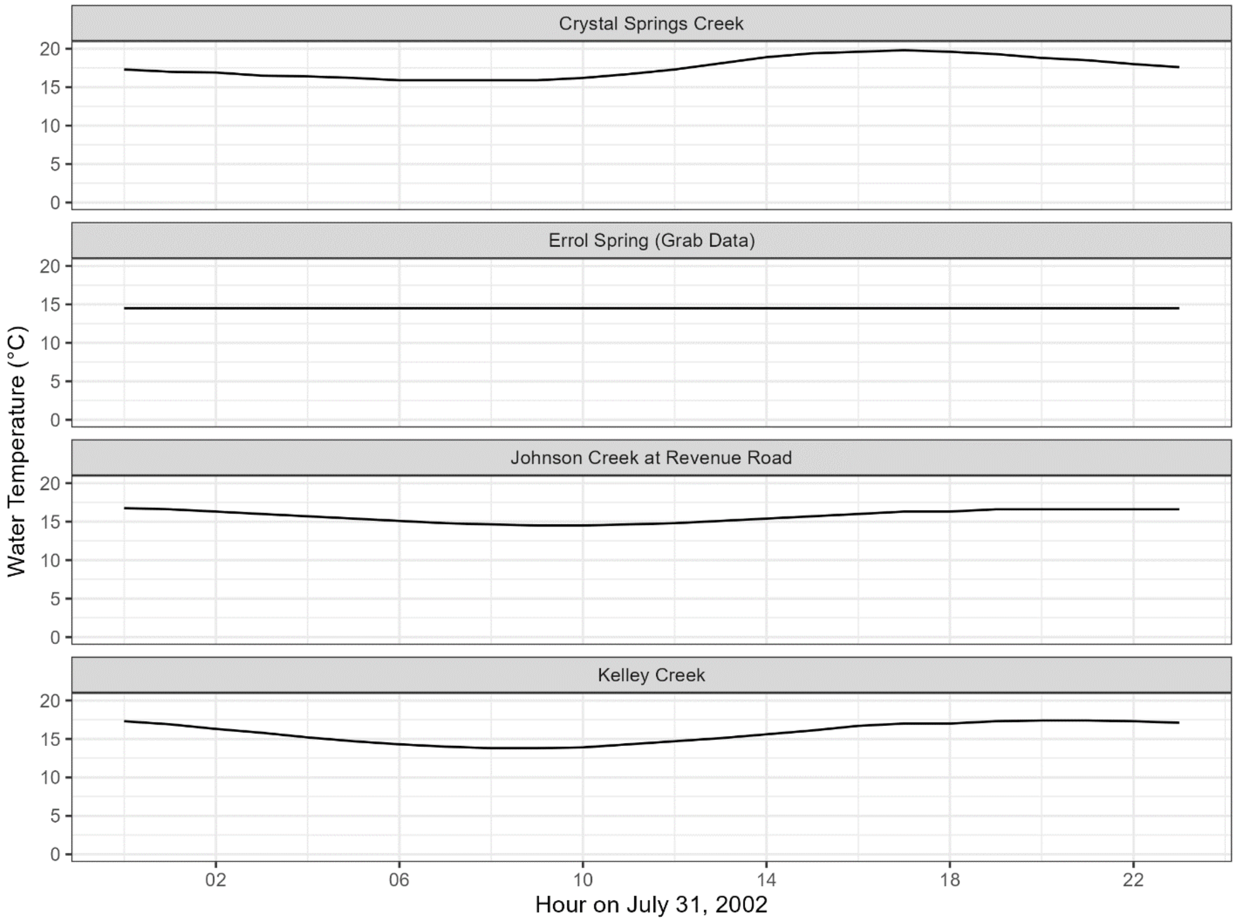


Figure 3-4: Boundary condition and tributary water temperature inputs to the Johnson Creek model.

3.1.6 Flow inputs

Hourly stream flow time series data were used to support tributary and boundary condition model setup. **Figure 3-5** shows the locations of the various stream flow monitoring locations that were used for model setup or calibration.

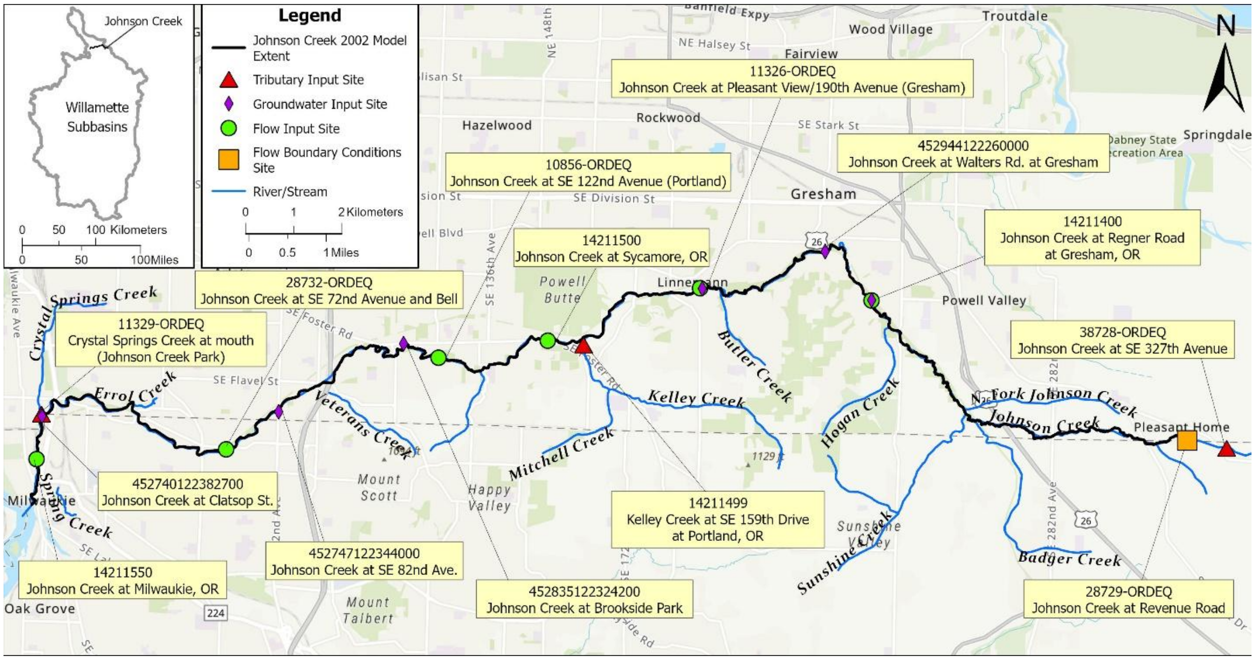


Figure 3-5: Flow monitoring locations used for the Johnson Creek model setup and calibration.
The boundary condition and tributary flow inputs to the model is summarized in Table 3-4.

Table 3-5 documents groundwater flow inputs to the model. **Figure 3-6** documents mainstem model flow setup. The model flow was estimated between measured sites using a flow mass balance, which incorporated input from tributaries and groundwater flows.

Table 3-4: Boundary condition and tributary flow inputs to the Johnson Creek model.

Model Location Name	Model Location (km)	Flow Rate (cms)	Input Type	Source
Johnson Creek at Revenue Road	37.552	0.018	Boundary Condition	Estimated using a flow mass balance based on measured flow (28729-ORDEQ).
Sunshine Creek	31.57	0.006	Tributary	80% of Kelley Creek flow
Butler Creek	22.366	0.002	Tributary	24% of Kelley Creek flow.
Kelley Creek	18.469	0.007	Tributary	USGS 14211499
Veterans Creek	10.646	0.001	Tributary	15% of Kelley Creek flow.
Errol Creek	4.817	0.0141	Tributary	Estimated using a flow mass balance based on measured flow and TIR.
Crystal Springs Creek	2.056	0.252	Tributary	Measured (11329-ORDEQ)
Spring Creek	0.614	0.001	Tributary	15% of Kelley Creek flow.

Table 3-5: Groundwater flow inputs to the Johnson Creek model.

Model Location Name	Model Location (km)	Note
Johnson Creek at Regner Gage	27.489	Estimated from USGS Seepage Investigation.
Johnson Creek at Walters Rd.	25.740	Estimated from USGS Seepage Investigation.
Johnson Creek at SE 190th Ave.	21.752	Estimated from USGS Seepage Investigation.
Johnson Creek at Brookside Park	12.64	Estimated from USGS Seepage Investigation.
Johnson Creek at SE 82nd Ave.	9.296	Estimated from USGS Seepage Investigation.
Johnson Creek at Clatsop St.	1.933	Estimated from USGS Seepage Investigation.

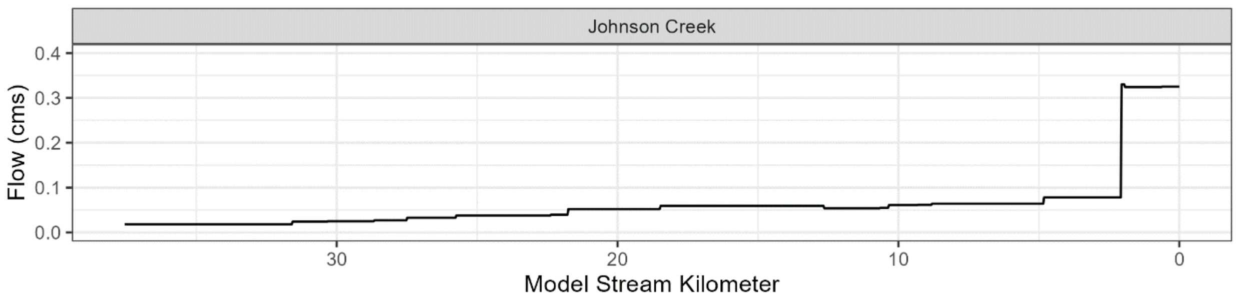


Figure 3-6: Johnson Creek longitudinal flow model setup.

3.1.7 Point source inputs

There are no point sources discharging within the model extent.

3.1.8 Landcover and topographic shade inputs

Average land cover height inputs to the Johnson Creek model are shown in **Figure 3-7**, with topographic shade angle inputs shown in **Figure 3-8**.

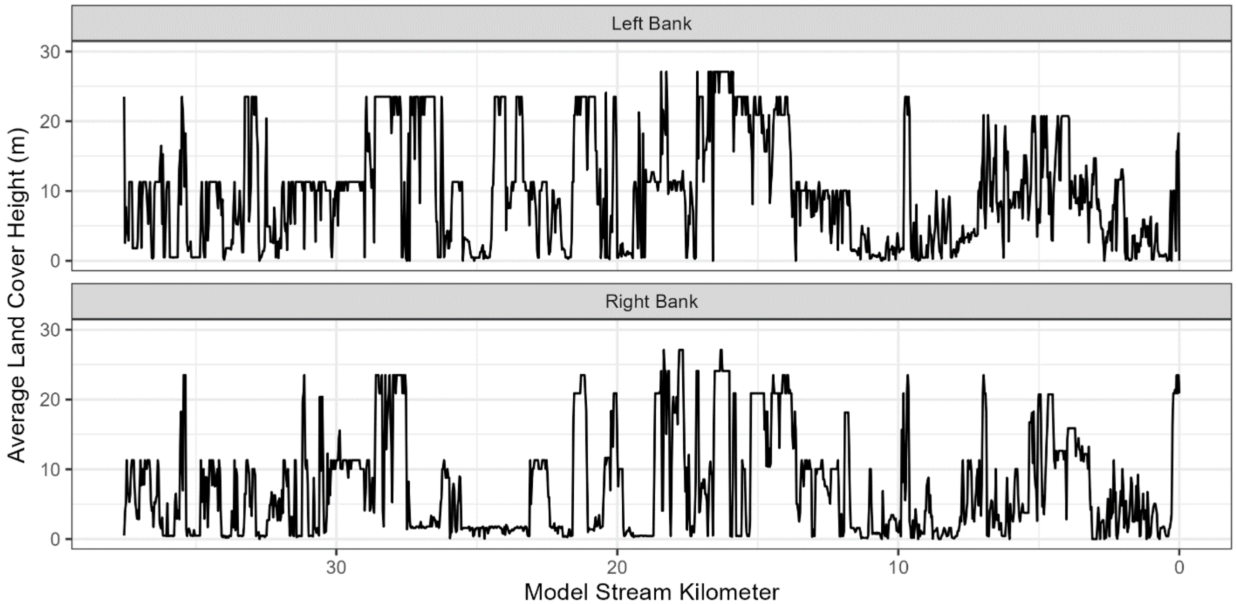


Figure 3-7: Average land cover height inputs to the Johnson Creek model.

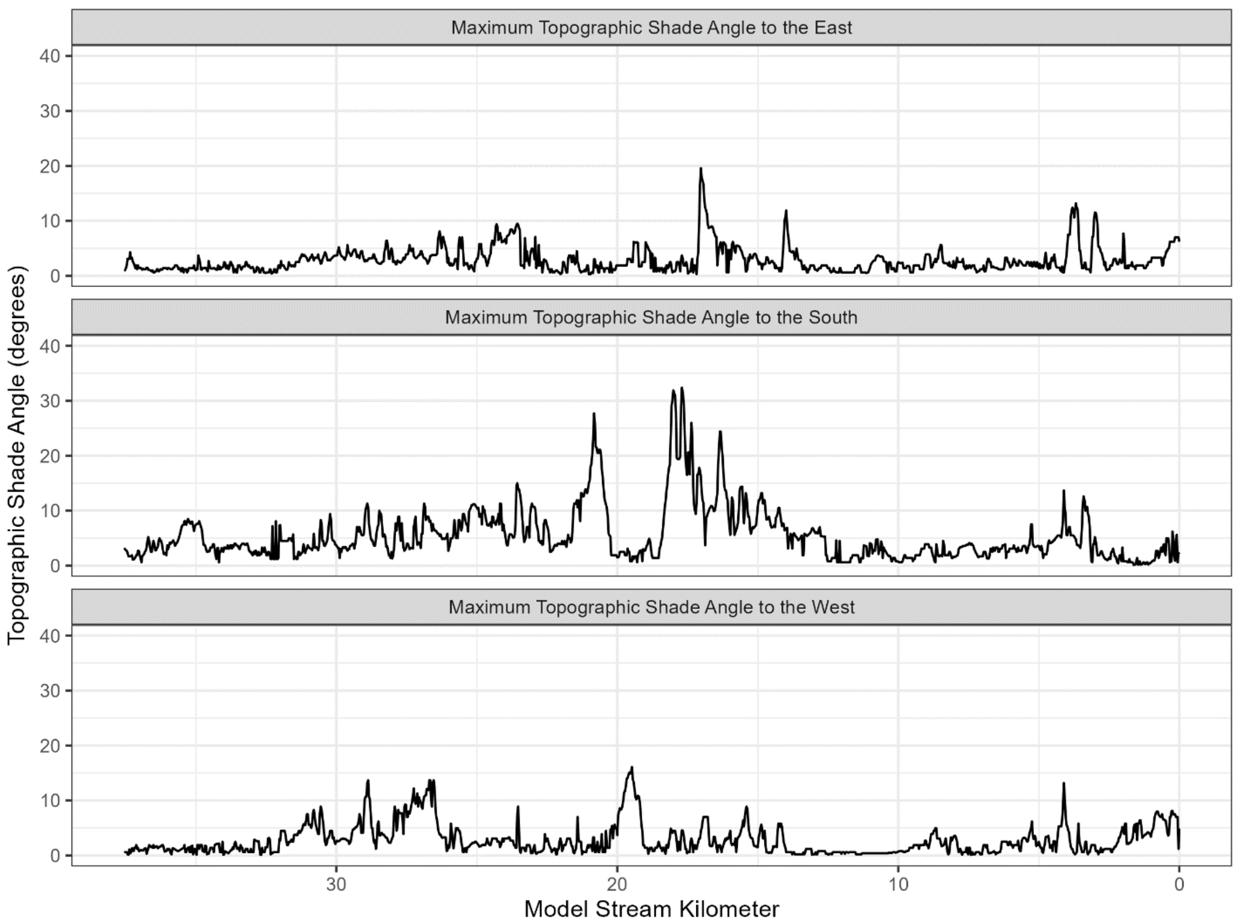


Figure 3-8: Topographic shade angle inputs to the Johnson Creek model.

3.1.9 Channel setup

Channel setup for the Johnson Creek model is presented in **Figure 3-9**. The model was setup with a constant channel incision of 0.5 m.

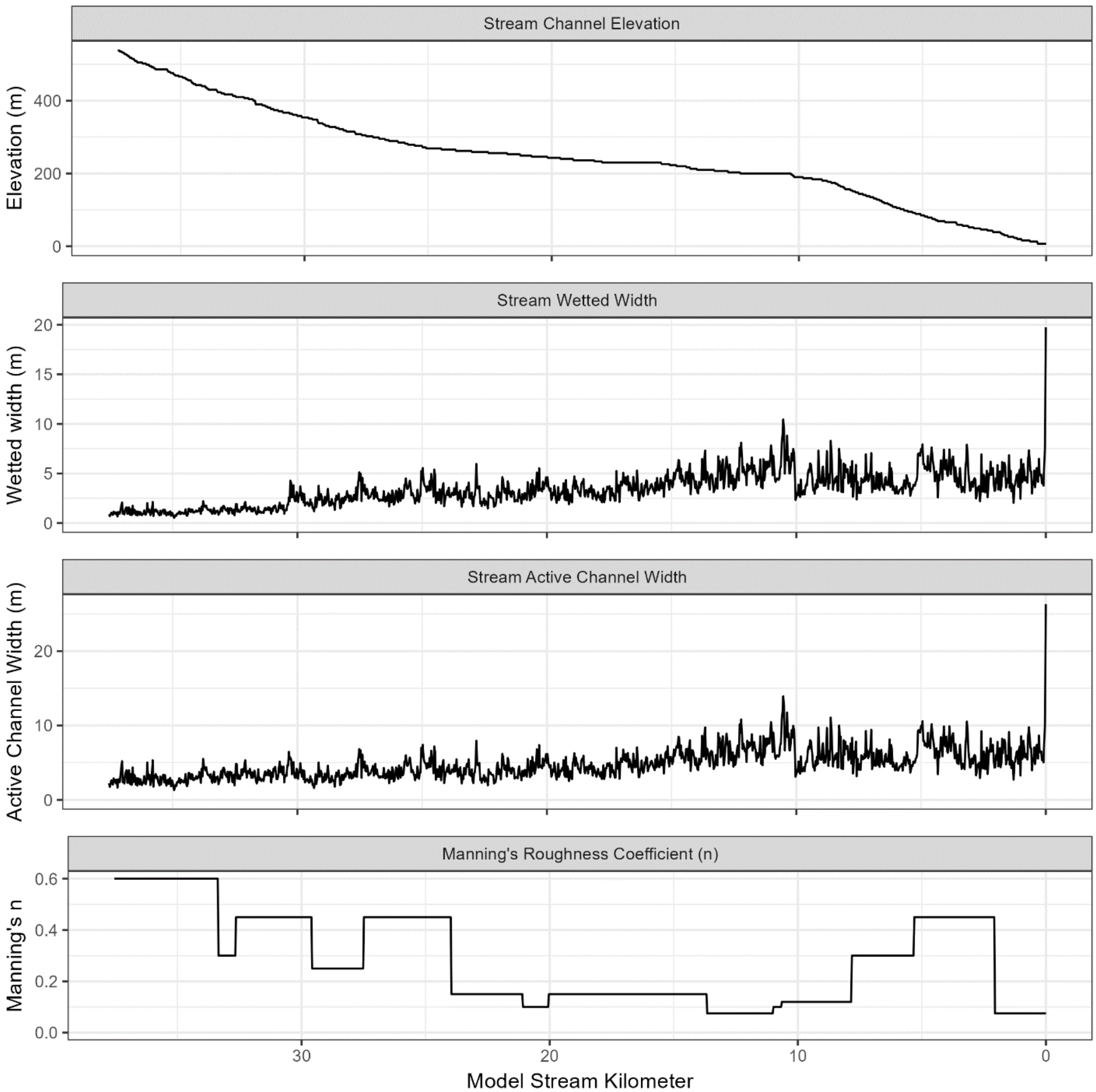


Figure 3-9: Channel setup in the Johnson Creek model.

3.1.10 Calibration results

3.1.10.1 Temperature

The model was calibrated to the continuous temperature data collected from several locations along Johnson Creek, as well as to the TIR data. Results for goodness of fit statistics comparing field observed and model-predicted temperatures are summarized in **Table 3-6**. Observed and model-predicted hourly temperatures were plotted for the monitoring stations (**Figure 3-10** through **Figure 3-20**). Modeling results comparing simulated current conditions for Johnson Creek to the TIR data are presented in **Figure 3-21**.

Table 3-6: Johnson Creek water temperature goodness of fit statistics comparing field observed and model-predicted temperatures.

Monitoring Location	Model KM	Temperature Statistics	ME	MAE	RMSE	NSE	n
All Stations		Daily Maximum	0.67	1.03	1.07	NA	11
All Stations		Hourly	-0.32	0.97	1.19	0.61	264
11321-ORDEQ: Johnson Creek at SE 17th Avenue (Portland)	0.4	Hourly	-0.4	0.52	0.62	0.89	24
14211550: Johnson Creek at Milwaukie Gage	1.1	Hourly	-0.59	0.64	0.8	0.82	24
11323-ORDEQ: Johnson Creek at SE 45th Avenue (Portland)	5.1	Hourly	1.25	1.26	1.39	-0.21	24
28732-ORDEQ: Johnson Creek at SE 72nd Avenue and Bell	7.6	Hourly	-0.55	1.02	1.23	0.61	24
10853-ORDEQ: Johnson Creek at SE 92nd Avenue (Portland)	10.3	Hourly	-1.28	1.82	2.14	-0.6	24
10856-ORDEQ: Johnson Creek at SE 122nd Avenue (Portland)	14.7	Hourly	-0.16	0.83	0.97	0.06	24
28731-ORDEQ: Johnson Creek at SE Circle Avenue	20	Hourly	-0.64	1.09	1.21	0.09	24
11326-ORDEQ: Johnson Creek at Pleasant View/190th Avenue (Gresham)	21.8	Hourly	-0.66	0.78	0.87	0.46	24
11327-ORDEQ: Johnson Creek at Regner Road (Gresham)	27.5	Hourly	-0.45	1.09	1.22	-0.01	24
11626-ORDEQ: Johnson Creek at Palmblad Avenue (Gresham)	30.3	Hourly	-0.01	0.43	0.55	0.9	24
28730-ORDEQ: Johnson Creek at Short Road	35.5	Hourly	-0.02	1.17	1.3	0.14	24
Johnson Creek TIR	Model extent		0.52	0.94	1.15	0.39	248

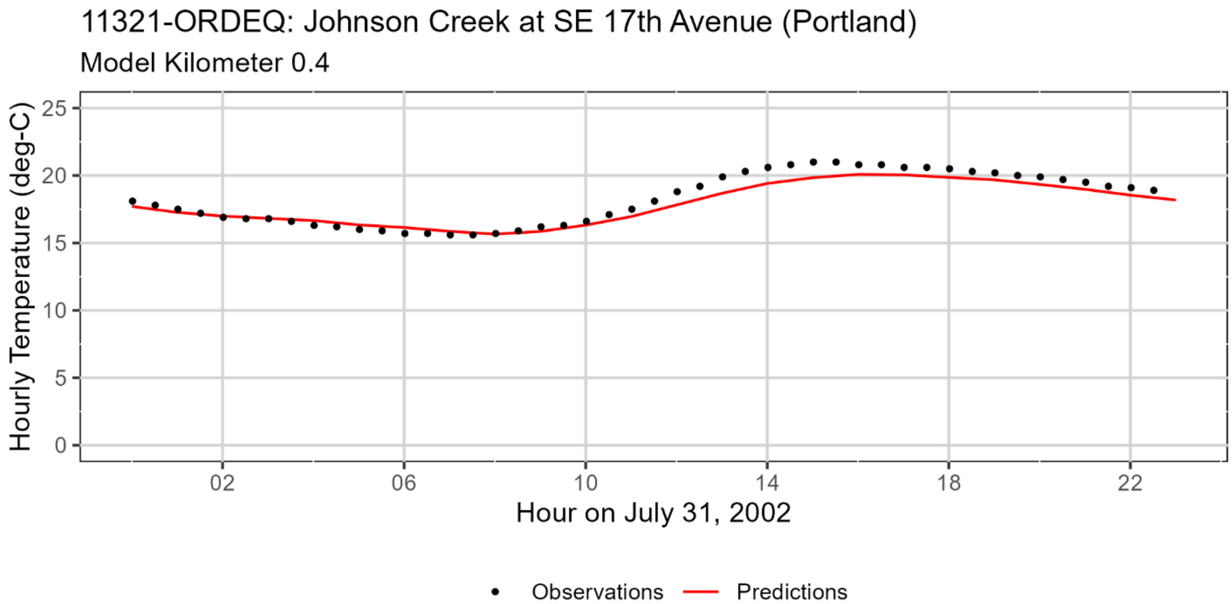


Figure 3-10: Johnson Creek measured and model-predicted hourly temperatures at monitoring station 11321-ORDEQ.

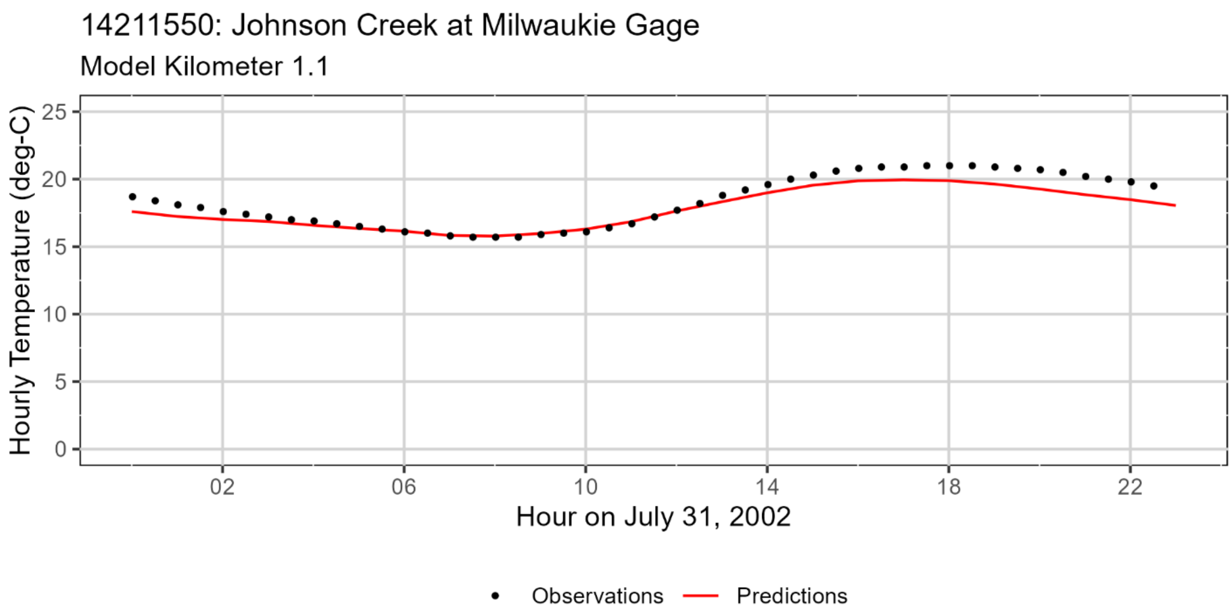


Figure 3-11: Johnson Creek measured and model-predicted hourly temperatures at monitoring station 14211550.

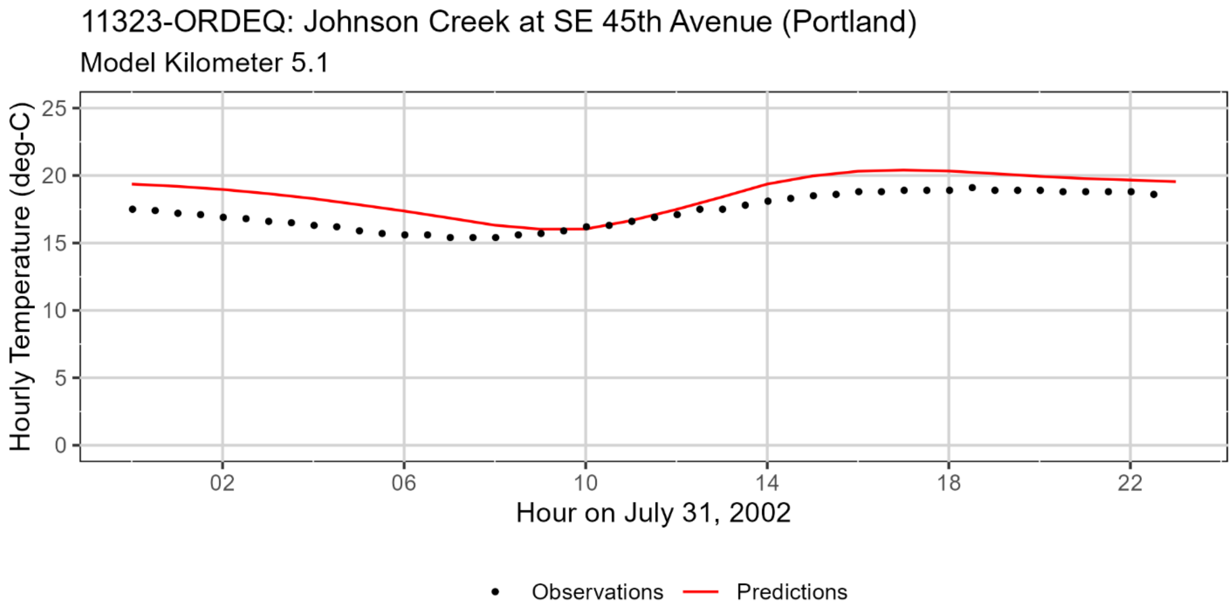


Figure 3-12: Johnson Creek measured and model-predicted hourly temperatures at monitoring station 11323-ORDEQ.

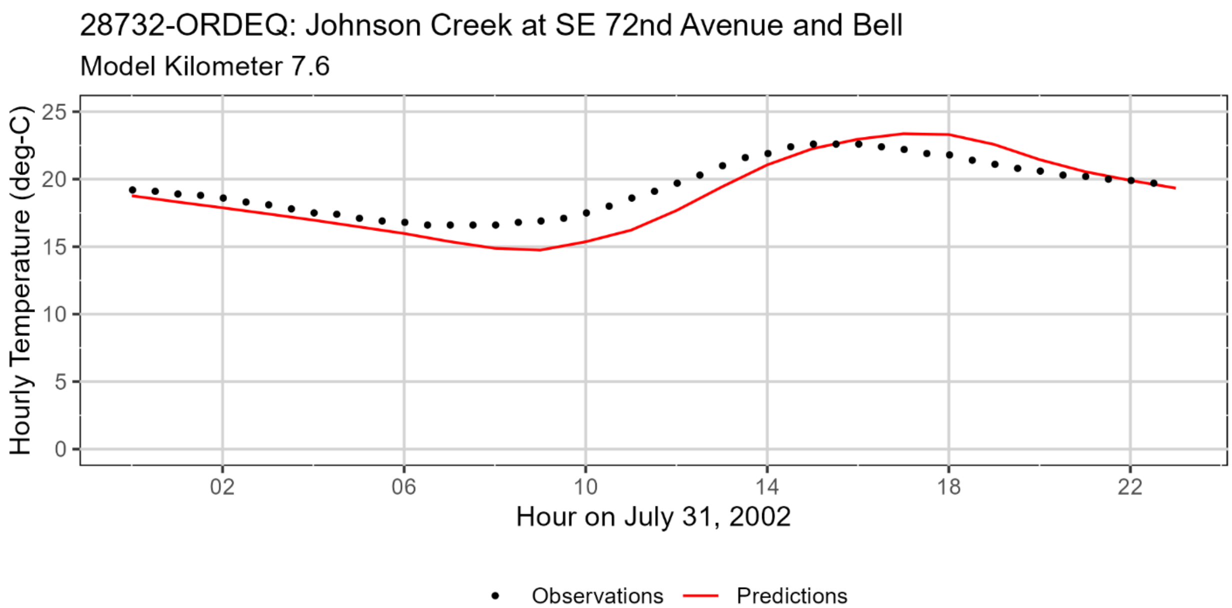


Figure 3-13: Johnson Creek measured and model-predicted hourly temperatures at monitoring station 28732-ORDEQ.

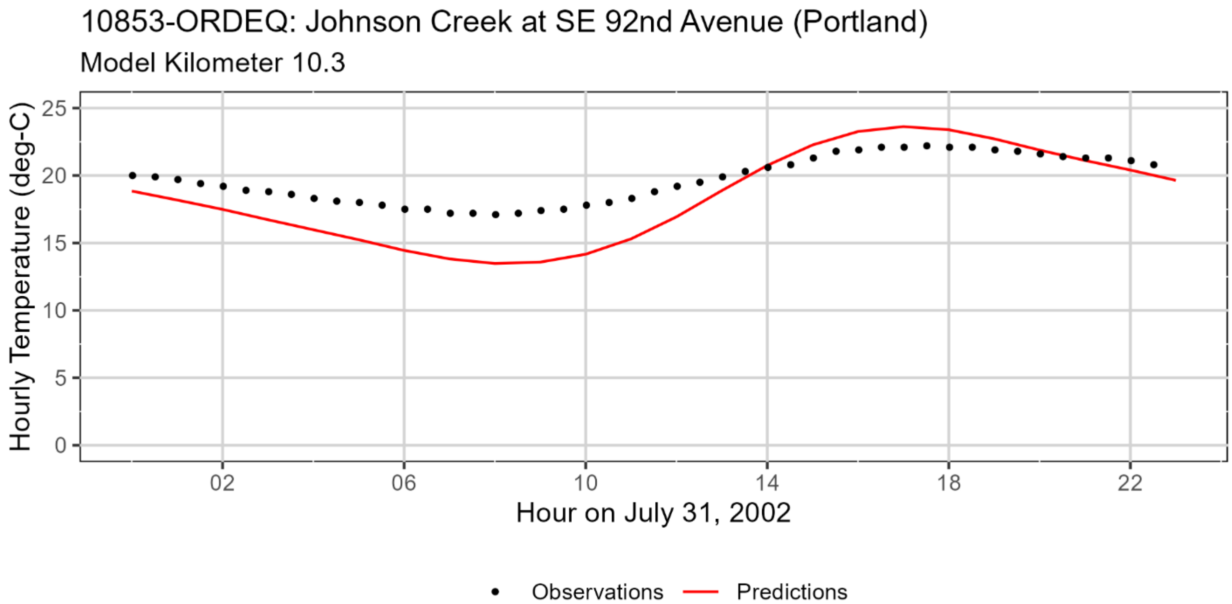


Figure 3-14: Johnson Creek measured and model-predicted hourly temperatures at monitoring station 10853-ORDEQ.

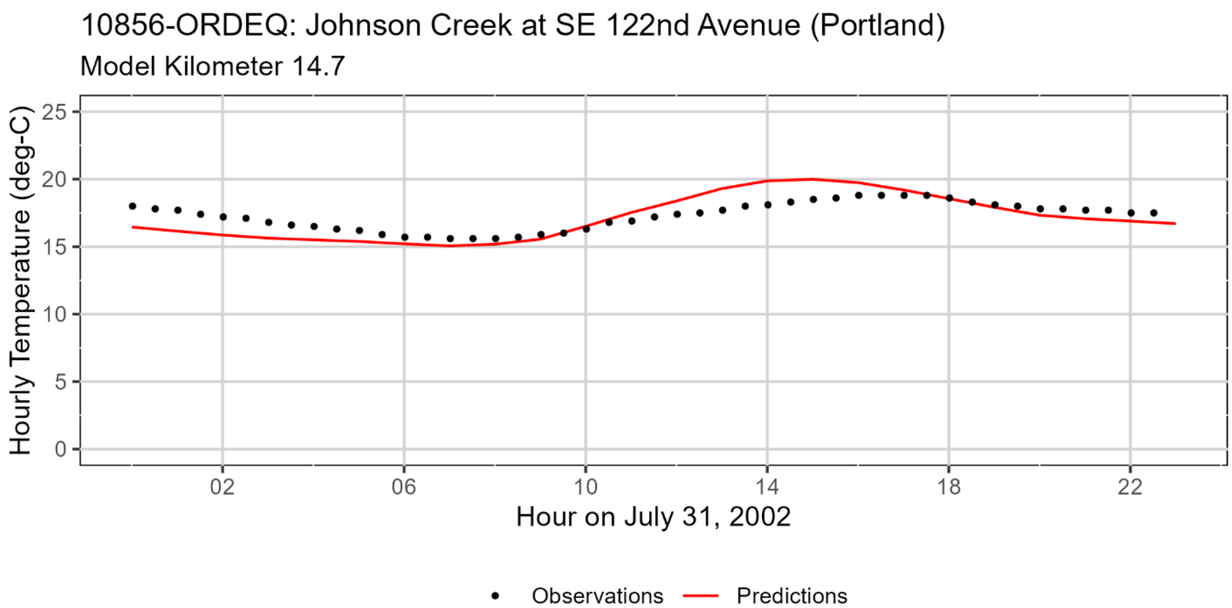


Figure 3-15: Johnson Creek measured and model-predicted hourly temperatures at monitoring station 10856-ORDEQ.

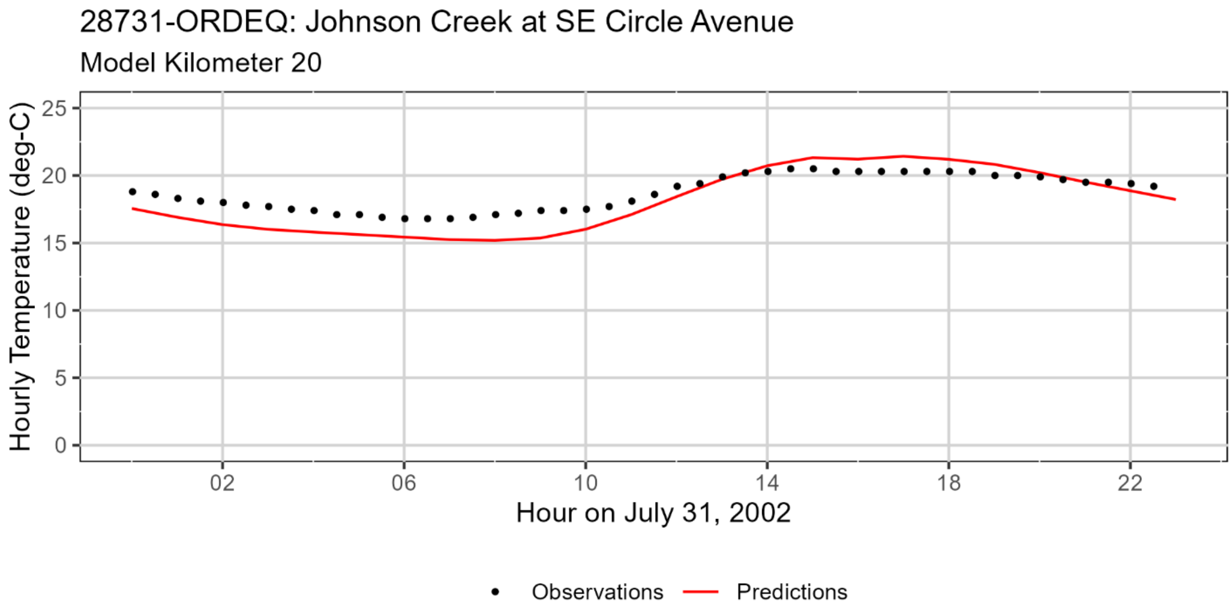


Figure 3-16: Johnson Creek measured and model-predicted hourly temperatures at monitoring station 28731-ORDEQ.

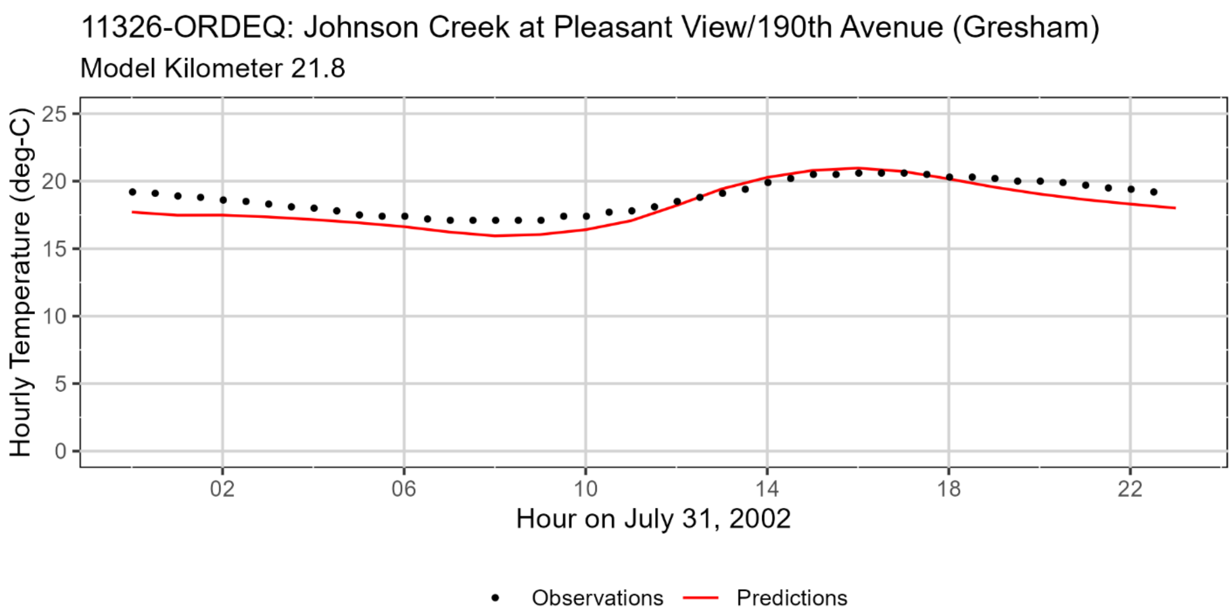


Figure 3-17: Johnson Creek measured and model-predicted hourly temperatures at monitoring station 11326-ORDEQ.

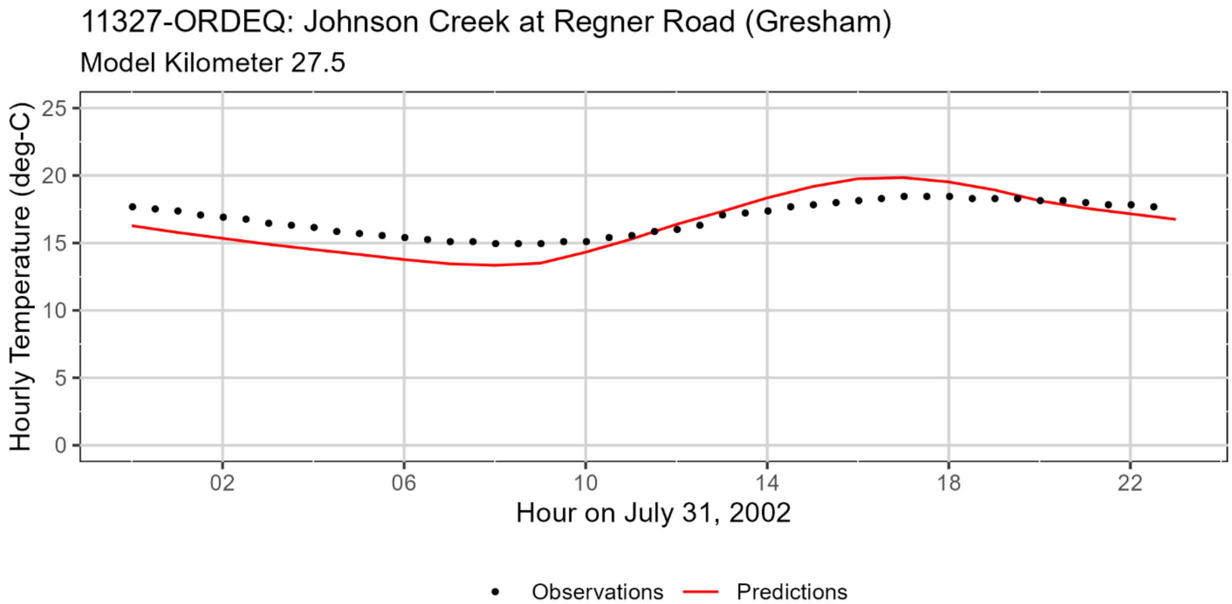


Figure 3-18: Johnson Creek measured and model-predicted hourly temperatures at monitoring station 11327-ORDEQ.

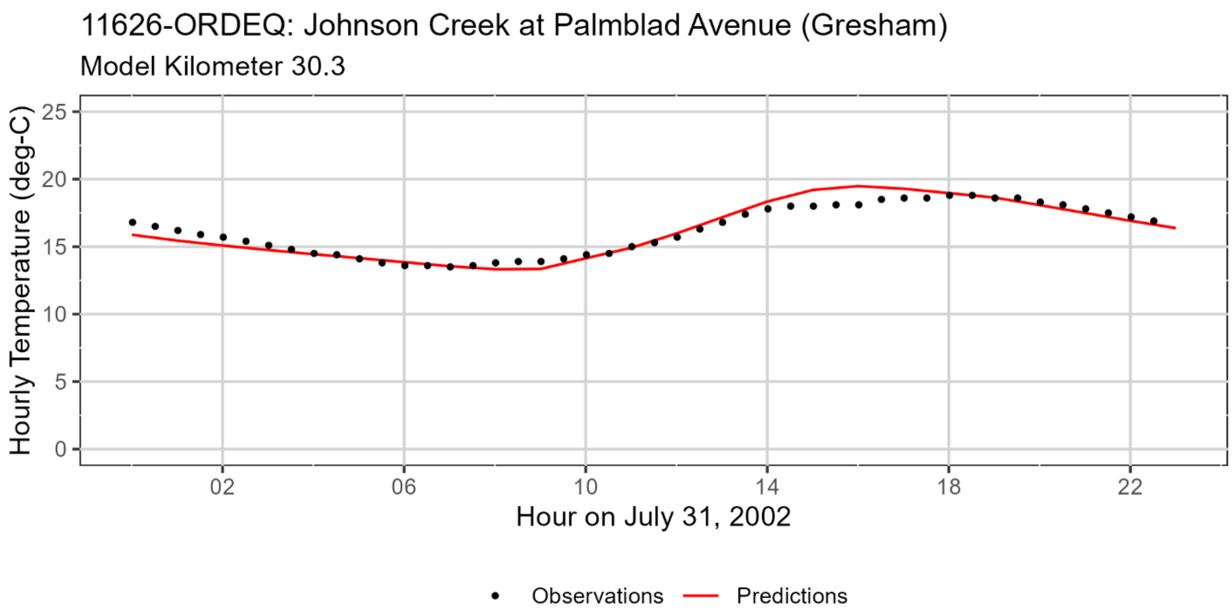


Figure 3-19: Johnson Creek measured and model-predicted hourly temperatures at monitoring station 11626-ORDEQ.

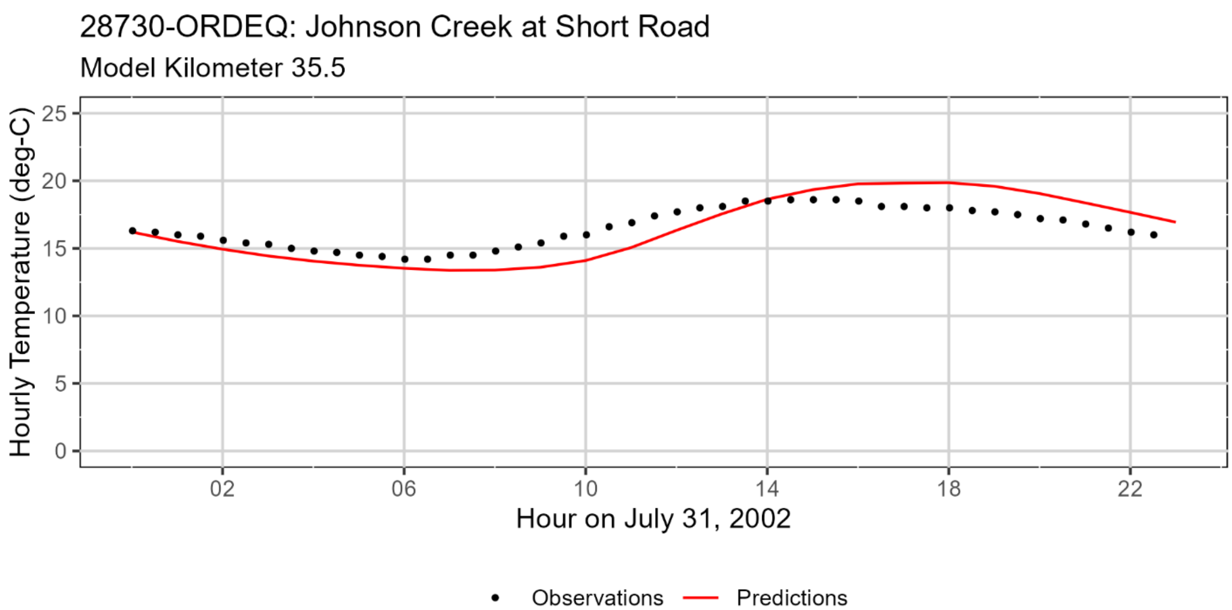


Figure 3-20: Johnson Creek measured and model-predicted hourly temperatures at monitoring station 28730-ORDEQ.

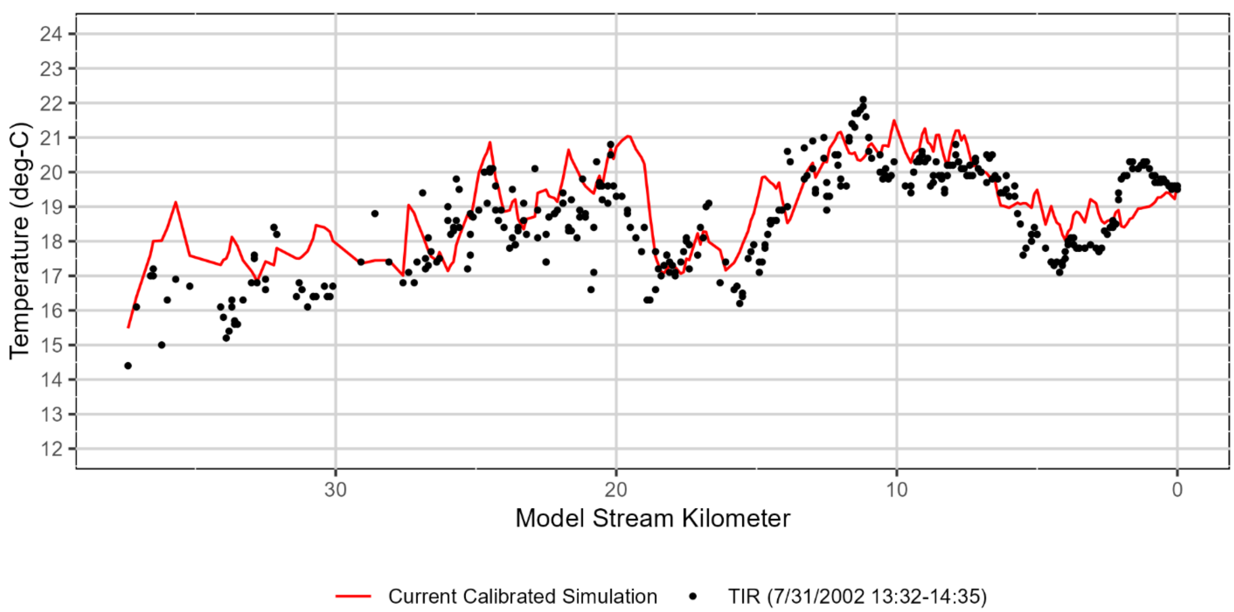


Figure 3-21: Johnson Creek TIR and simulated current stream temperatures.

3.1.10.2 Effective shade

Observed and model-predicted effective shade data were plotted along Johnson Creek (**Figure 3-22**). The observed field data used for comparison is summarized in **Table 2-30**. Results for goodness of fit statistics comparing field observed and model-predicted temperatures are summarized in **Table 3-7**.

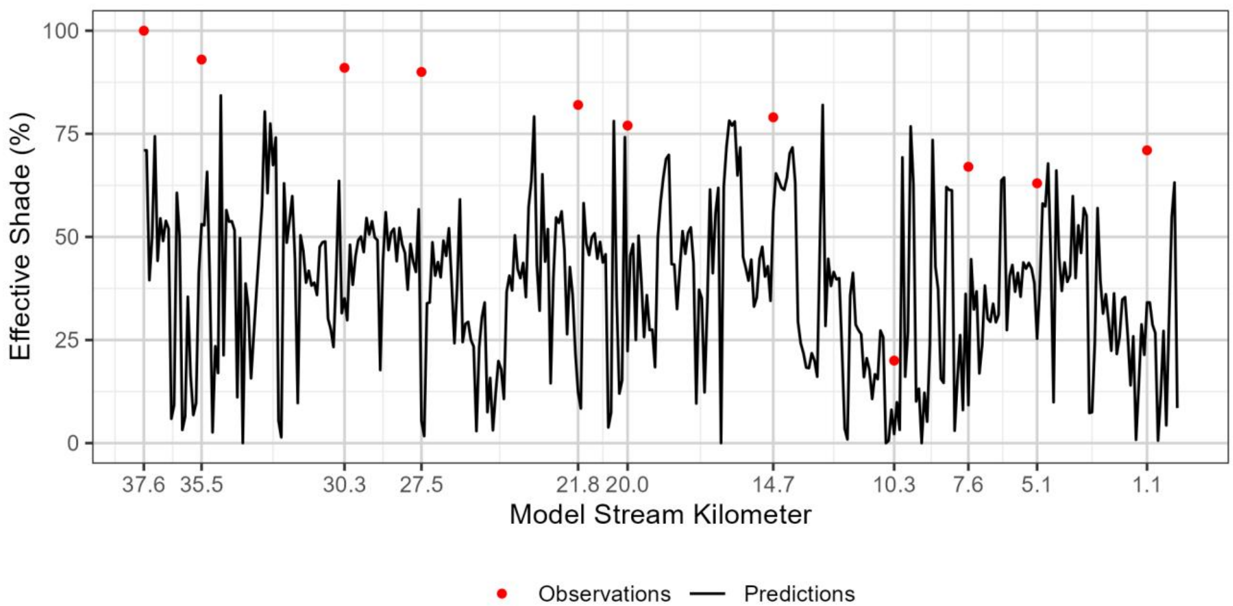


Figure 3-22: Johnson Creek field observed and predicted effective shade.

Table 3-7: Johnson Creek effective shade goodness of fit statistics comparing field observed and model values.

N	R^2	ME	MAE	RMSE
11	0.34	-46.1	46.1	50.04

3.1.10.3 Flow

A flow mass balance was completed to improve the calibration and match flows to the measured values. The observed flow used for comparison is summarized in **Table 3-8**, which is plotted with the model flow in **Figure 3-23**. Results for goodness of fit statistics comparing field observed flow and the model flow are summarized in **Table 3-9**.

Table 3-8: Johnson Creek stream flow rate measurements.

Monitoring Location	Model KM	Flow Statistics	Flow (cms)	Date
28729-ORDEQ: Johnson Creek at Revenue Road	37.6	Instantaneous	0.03	7/29/2002
14211400: Johnson Creek at Regner Road (Gresham)	27.5	Daily mean	0.03	7/31/2002
11326-ORDEQ: Johnson Creek at Pleasant View/190th Avenue (Gresham)	21.8	Instantaneous	0.03	7/29/2002
14211500: Johnson Creek at Sycamore, OR	17.7	Daily mean	0.05	7/31/2002
10856-ORDEQ: Johnson Creek at SE 122nd Avenue (Portland)	14.7	Instantaneous	0.06	7/30/2002
28732-ORDEQ: Johnson Creek at SE 72nd Avenue and Bell	7.6	Instantaneous	0.04	7/30/2002
14211550: Johnson Creek at Milwaukie, OR	1.1	Daily mean	0.4	7/31/2002

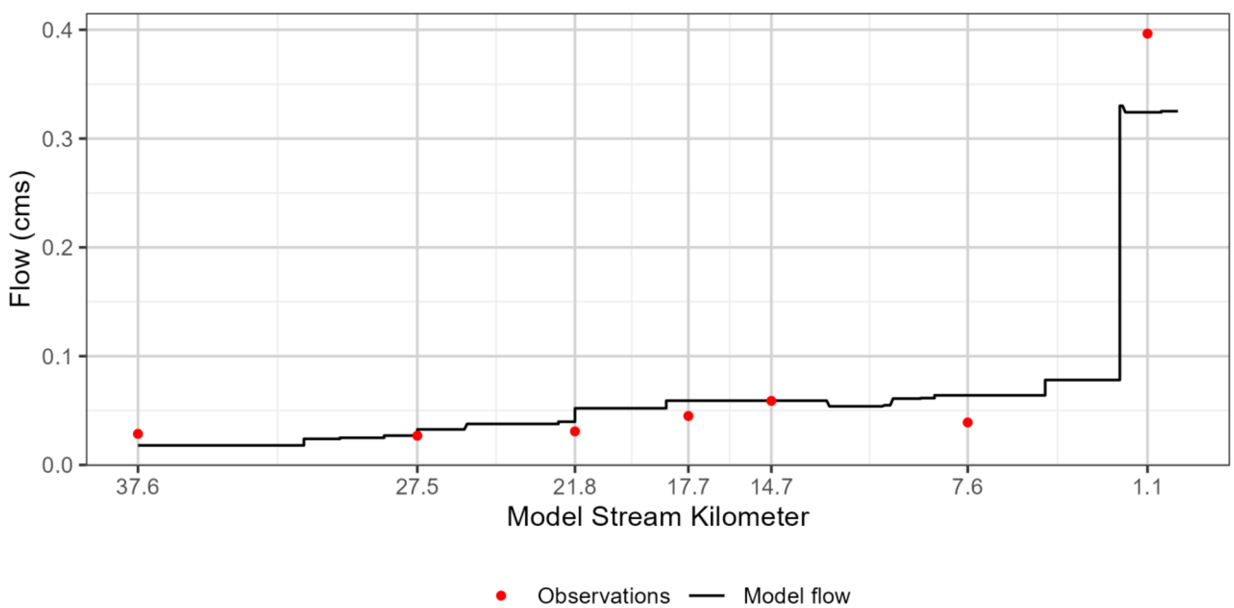


Figure 3-23: Johnson Creek field observed and model flow rates.

Table 3-9: Johnson Creek flow goodness of fit statistics comparing field observed and model flow rates.

N	R^2	ME	MAE	RMSE
7	0.99	0	0.02	0.03

3.2 Molalla River

The Molalla River model is a temperature model developed using Heat Source 7.0. The model was developed by DEQ.

3.2.1 Model extent

The extent of the model domain is the Molalla River from the mouth to river mile 44 (**Figure 3-24**).

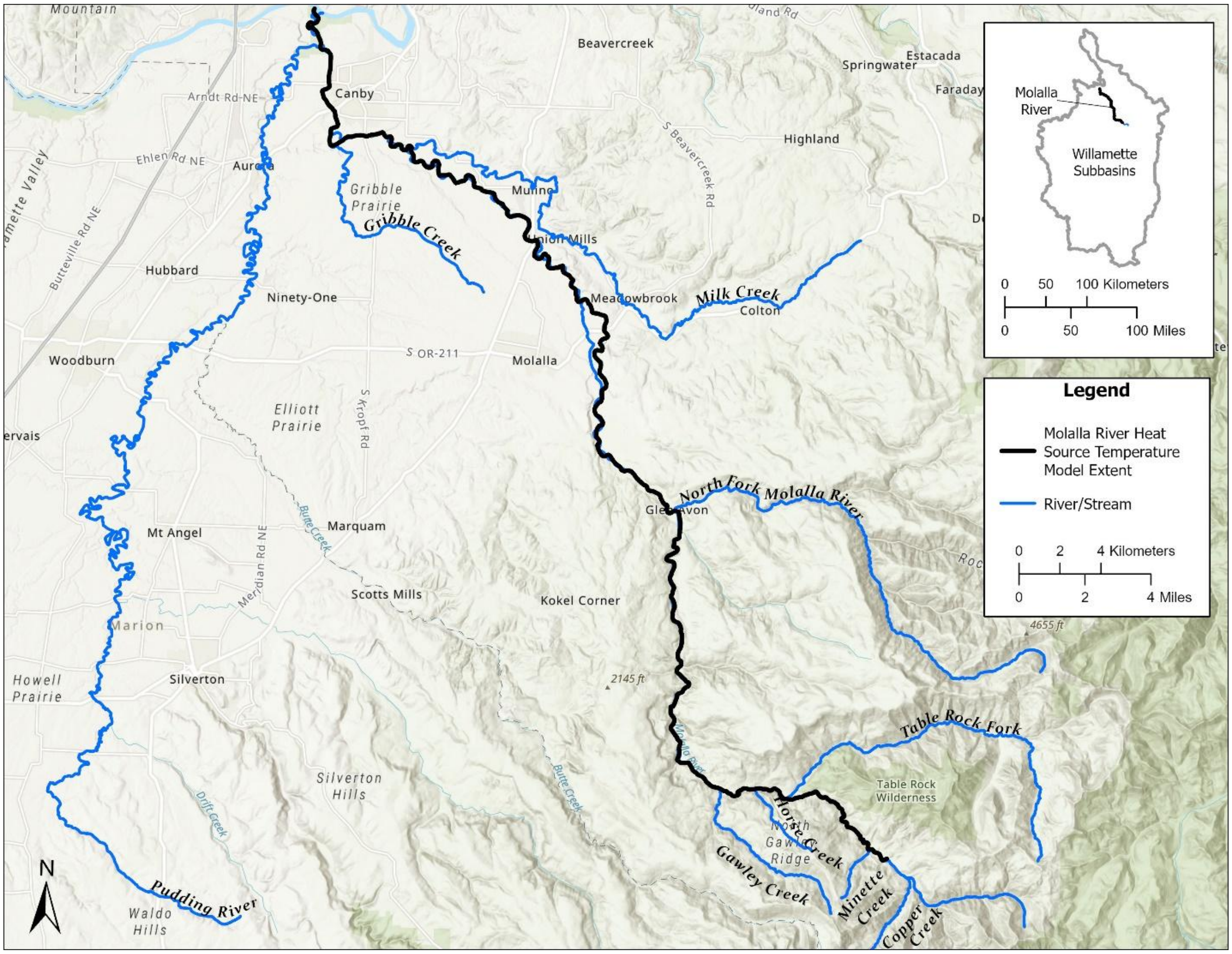


Figure 3-24: Molalla River temperature model extent.

3.2.2 Spatial and temporal resolution

The model input spatial resolution (*dx*) is 30 m. Outputs are generated every 100 m. The model time step (*dt*) is 1 minute and outputs are generated every hour.

3.2.3 Time frame of simulation

The model period is July 20, 2004 to August 02, 2004.

3.2.4 Meteorological inputs

The model was set up using hourly air temperature, relative humidity, and wind speed measurements from several meteorological monitoring sites (

Table 3-10). Air temperature data were modified using the dry adiabatic lapse rate to adjust for differences in elevation between the measurement location and the model input location. Wind speeds were adjusted to improve the calibration and to represent difference in wind speed between the measurement location and above the stream within the riparian area. Air temperature inputs, relative humidity inputs, and wind speed inputs to the Molalla River model are shown in the plots below (**Figure 3-25** through **Figure 3-27**).

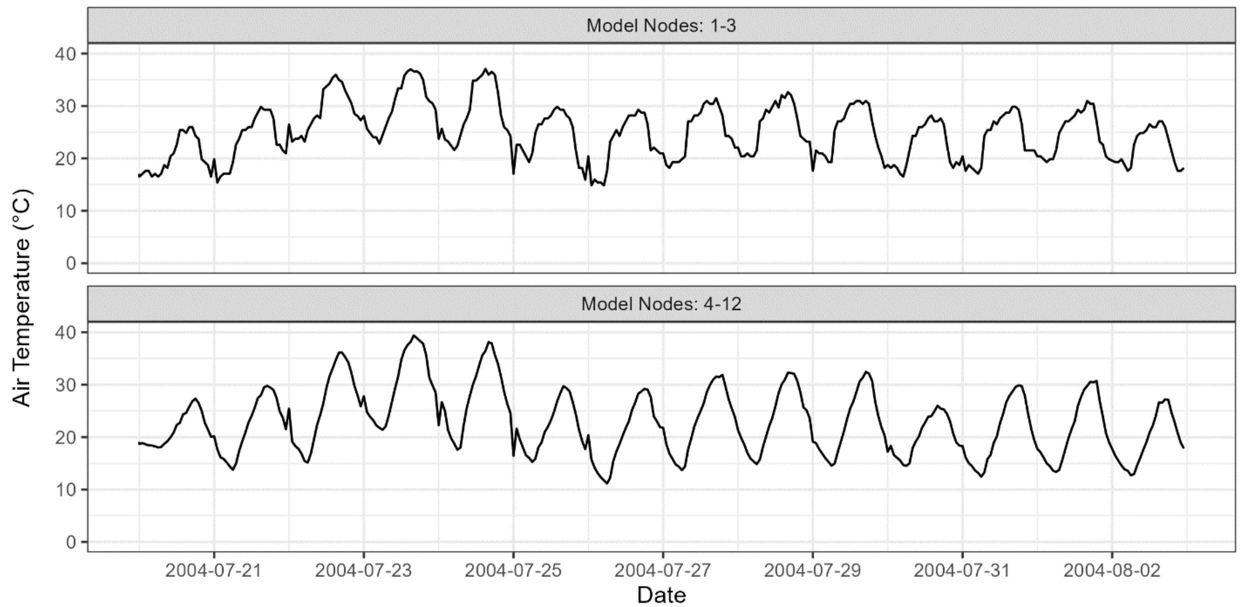


Table 3-10: Meteorology data sources for the Molalla River model.

Site	Source	Meteorological Parameters
Aurora	AgriMet	Air Temperature (Model Nodes 4-12), Relative Humidity (Model Nodes 3-12), and Wind Speed (Model Nodes 1-12)
Horse Creek	RAWS	Air Temperature (Model Nodes 1-3) and Relative Humidity (Model Nodes 1-2)

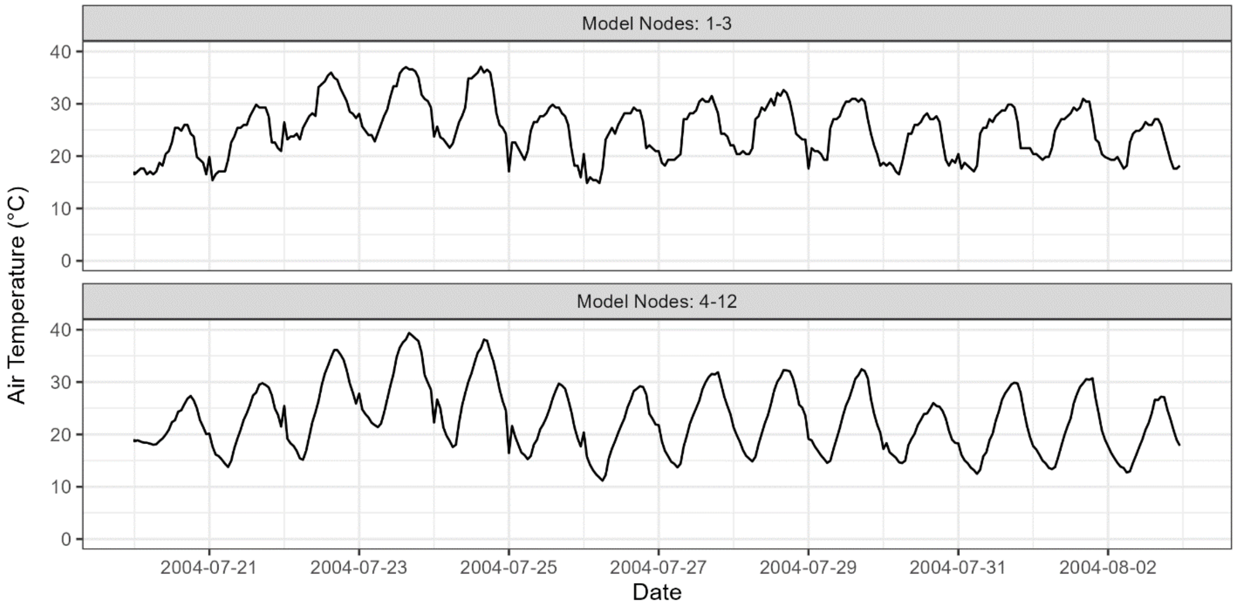


Figure 3-25: Air temperature inputs to the Molalla River model.

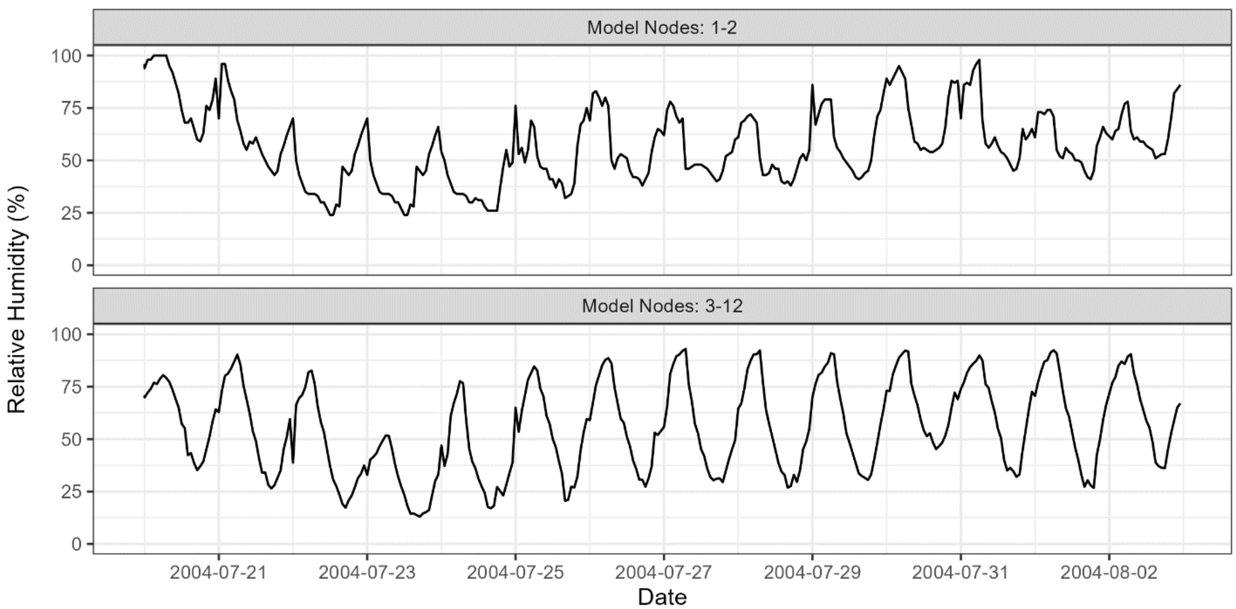


Figure 3-26: Relative humidity inputs to the Molalla River model.

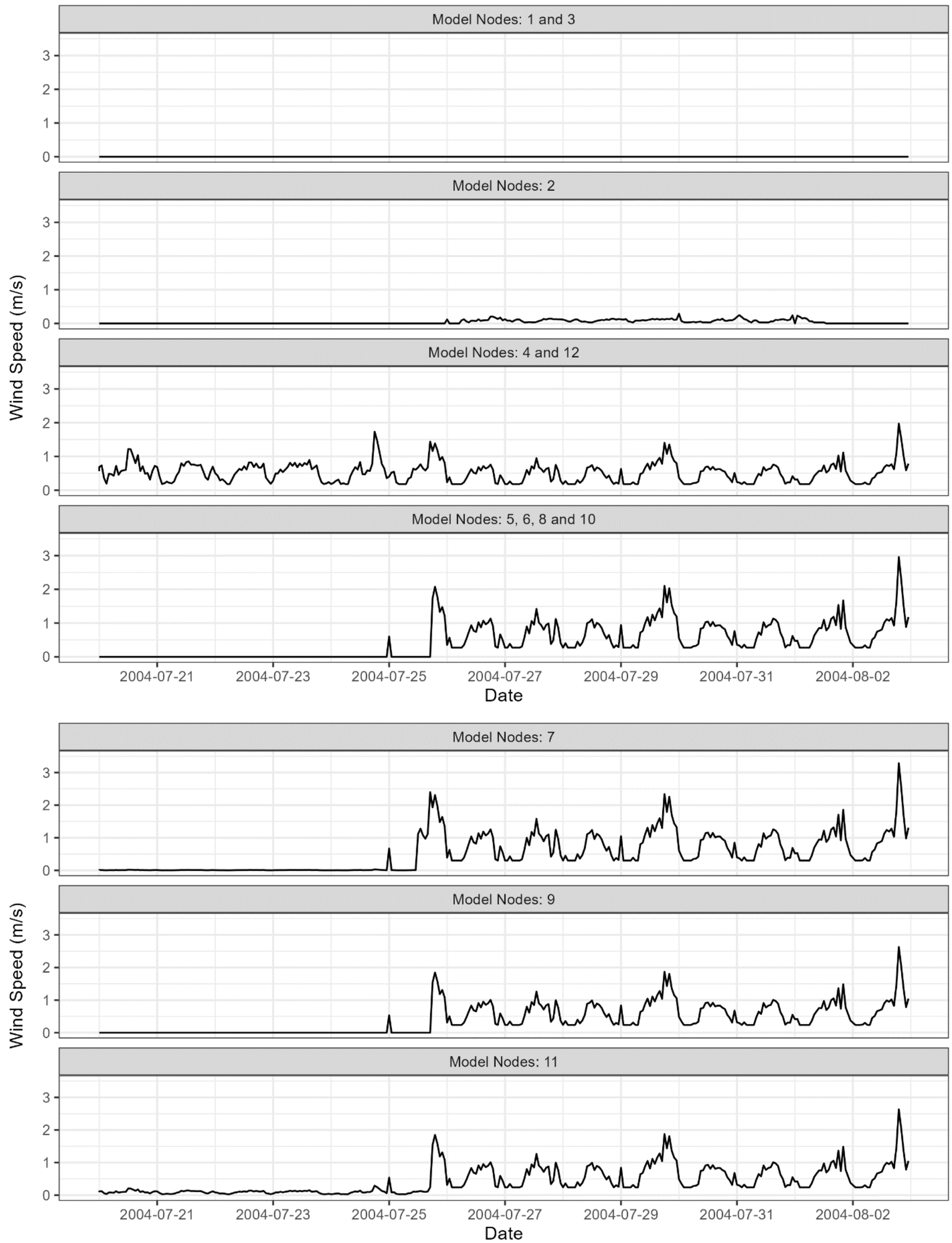


Figure 3-27: Wind speed inputs to the Molalla River model.

3.2.5 Temperature inputs

Hourly water temperature time series data were used to support tributary and boundary condition model setup. **Figure 3-28** shows the locations of the various stream temperature monitoring locations that were used for model setup or calibration.

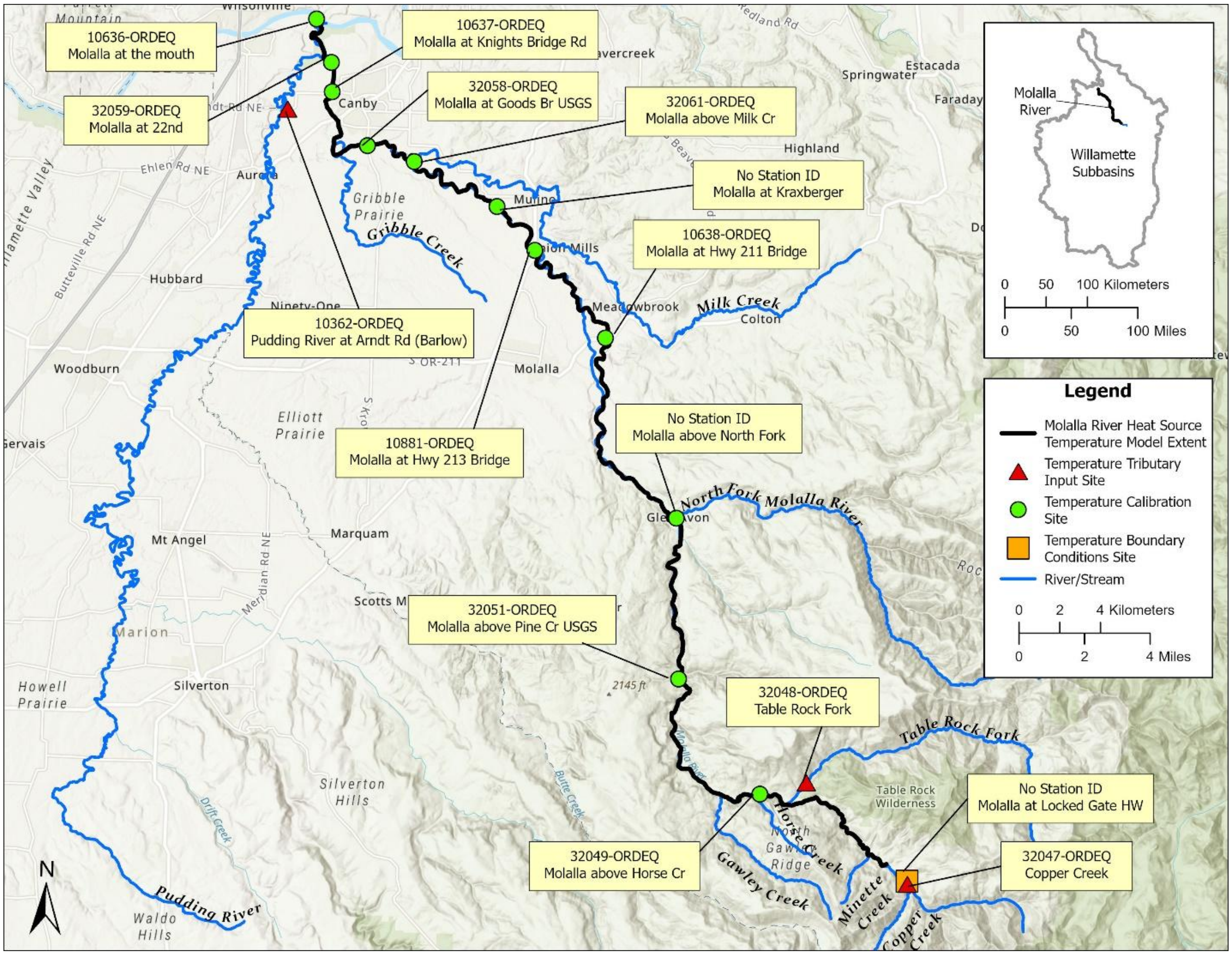


Figure 3-28: Temperature monitoring locations used for the Molalla River model setup and calibration.

Table 3-11 and **Figure 3-29** document the water temperature inputs to the model at the boundary condition (Molalla at Locked Gate HW) and tributaries where actually data were used in the model. Temperature monitors were lost from three locations (North Fork Molalla and Milk Creek at mouth, and Molalla at Feyrer Park. While continuous temperature was not available for all locations, DEQ was able to use the instantaneous temperatures measured with TIR as an estimated during the modeling period.

Table 3-11: Boundary condition and tributary water temperature inputs to the Molalla River model.

Model Location Name	Model Location (kilometers)	Input Type	Data Source
Molalla at Locked Gate HW	75.36	Boundary Condition	DEQ
Copper Creek at mouth (Molalla River)	75.33	Tributary	32047-ORDEQ
Spring at model kilometer 75.3	75.3	Tributary	Derived from TIR. Constant temperature of 14.3°C. Watershed Sciences (2005)
Unnamed tributary 6	74.6	Tributary	Derived from TIR. Constant temperature of 15.5°C. Watershed Sciences (2005)
Spring at model kilometer 74.2	74.2	Tributary	Derived from TIR. Constant temperature of 15.3°C. Watershed Sciences (2005)
Spring at model kilometer 73.77	73.77	Tributary	Derived from TIR. Constant temperature of 14.7°C. Watershed Sciences (2005)
Spring at model kilometer 73.4	73.4	Tributary	Derived from TIR. Constant temperature of 9.3°C. Watershed Sciences (2005)
Minette Creek	72.69	Tributary	Derived from TIR. Constant temperature of 13.2°C. Watershed Sciences (2005)
Table Rock Fork Molalla River at River Mile 1	66.54	Tributary	32048-ORDEQ
Horse Creek	64.65	Tributary	Derived from TIR. Constant temperature of 17.1°C. Watershed Sciences (2005)
Spring at model kilometer 63.33	63.33	Tributary	Derived from TIR. Constant temperature of 14.7°C. Watershed Sciences (2005)
Gawley Creek	62.52	Tributary	Derived from TIR. Constant temperature of 16.3°C. Watershed Sciences (2005)
Spring at model kilometer 60.84	60.84	Tributary	Derived from TIR. Constant temperature of 18.9°C. Watershed Sciences (2005)
Unnamed tributary 5	59.91	Tributary	Derived from TIR. Constant temperature of 18.9°C. Watershed Sciences (2005)
North Fork Molalla	44.94	Tributary	Derived data. DEQ.
Spring at model kilometer 39.12	39.12	Tributary	Derived from TIR. Constant temperature of 20.3°C. Watershed Sciences (2005)
Seep at model kilometer 38.16	38.16	Tributary	Derived from TIR. Constant temperature of 19.3°C. Watershed Sciences (2005)
Seep/Spring at model kilometer 35.88	35.88	Tributary	Derived from TIR. Constant temperature of 21.1°C. Watershed Sciences (2005)
Spring at model kilometer 35.07	35.07	Tributary	Derived from TIR. Constant temperature of 22.2°C. Watershed Sciences (2005)

Model Location Name	Model Location (kilometers)	Input Type	Data Source
Spring at model kilometer 32.7	32.7	Tributary	Derived from TIR. Constant temperature of 16.9°C. Watershed Sciences (2005)
Spring at model kilometer 30.63	30.63	Tributary	Derived from TIR. Constant temperature of 20.7°C. Watershed Sciences (2005)
Spring at model kilometer 30.54	30.54	Tributary	Derived from TIR. Constant temperature of 21°C. Watershed Sciences (2005)
Seep at model kilometer 29.88	29.88	Tributary	Derived from TIR. Constant temperature of 20.8°C. Watershed Sciences (2005)
Spring at model kilometer 25.59	25.59	Tributary	Derived from TIR. Constant temperature of 22.2°C. Watershed Sciences (2005)
Spring at model kilometer 22.29	22.29	Tributary	Derived from TIR. Constant temperature of 22.5°C. Watershed Sciences (2005)
Spring at model kilometer 18.33	18.33	Tributary	Derived from TIR. Constant temperature of 19.7°C. Watershed Sciences (2005)
Spring at model kilometer 16.89	16.89	Tributary	Derived from TIR. Constant temperature of 18.2°C. Watershed Sciences (2005)
Unnamed tributary 2	15.75	Tributary	Derived from TIR. Constant temperature of 23.2°C. Watershed Sciences (2005)
Spring at model kilometer 13.71	13.71	Tributary	Derived from TIR. Constant temperature of 21.3°C. Watershed Sciences (2005)
Milk Creek	12.9	Tributary	Derived from TIR. Constant temperature of 23.5°C. Watershed Sciences (2005)
Spring at model kilometer 12.69	12.69	Tributary	Derived from TIR. Constant temperature of 22.6°C. Watershed Sciences (2005)
Spring at model kilometer 12.03	12.03	Tributary	Derived from TIR. Constant temperature of 19.8°C. Watershed Sciences (2005)
Unnamed tributary 1	11.88	Tributary	Derived from TIR. Constant temperature of 24.4°C. Watershed Sciences (2005)
Spring at model kilometer 11.58	11.58	Tributary	Derived from TIR. Constant temperature of 19.8°C. Watershed Sciences (2005)
Spring at model kilometer 11.19	11.19	Tributary	Derived from TIR. Constant temperature of 19.8°C. Watershed Sciences (2005)
Spring at model kilometer 10.59	10.59	Tributary	Derived from TIR. Constant temperature of 24.7°C. Watershed Sciences (2005)

Model Location Name	Model Location (kilometers)	Input Type	Data Source
Gribble Creek	8.46	Tributary	Derived from TIR. Constant temperature of 19.1°C. Watershed Sciences (2005)
Spring at model kilometer 2.67	2.67	Tributary	Derived from TIR. Constant temperature of 13.8°C. Watershed Sciences (2005)
Pudding River at Arndt Road (Barlow)	2.55	Tributary	10362-ORDEQ
Spring at model kilometer 0.87	0.87	Tributary	Derived from TIR. Constant temperature of 19.1°C. Watershed Sciences (2005)

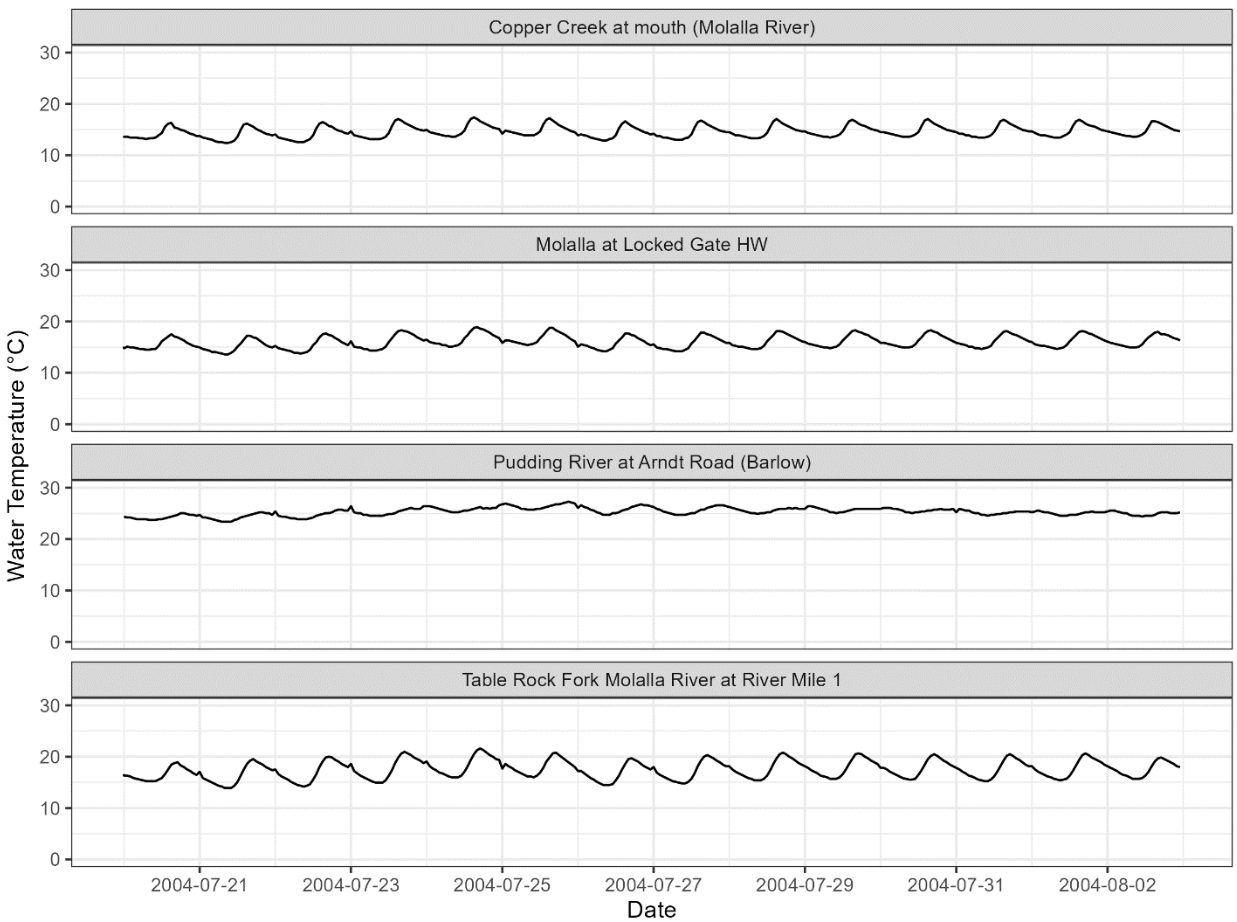


Figure 3-29: Boundary condition and tributary water temperature inputs to the Molalla River model.

3.2.6 Flow inputs

Hourly stream flow time series data were used to support tributary and boundary condition model setup. **Figure 3-30** shows the locations of the various stream temperature monitoring locations that were used for model setup or calibration.

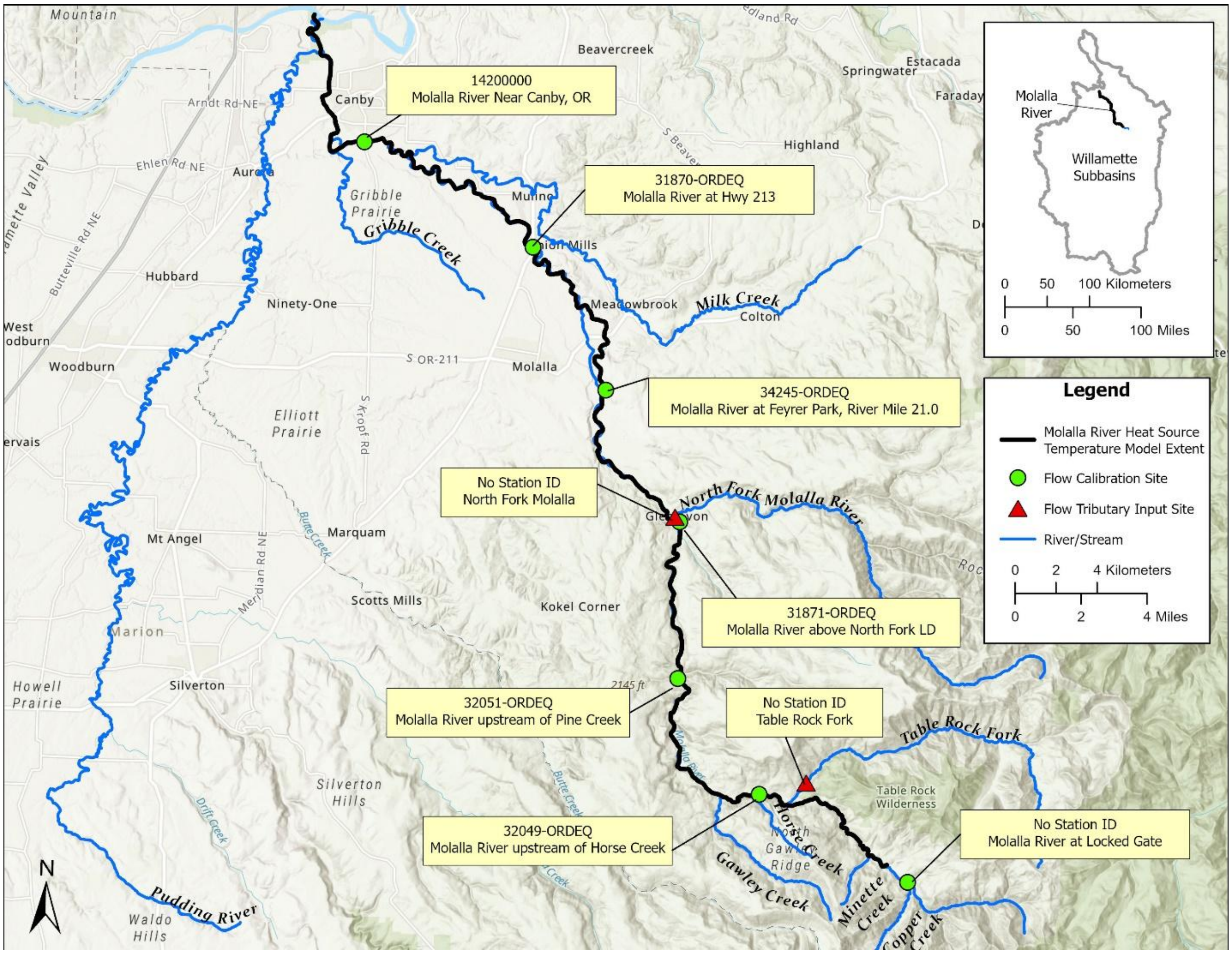


Figure 3-30: Flow monitoring locations used for the Molalla River model setup and calibration.

Table 3-12 summarizes the boundary condition and tributary flow inputs to the model. Where measured discharge was not available for model input (e.g., springs and smaller tributary streams), DEQ used a mass balance approach to estimate discharge to the mainstem Molalla River. Provided that at least one instream flow rate is known the other flow rates can be calculated using the following equation:

$$T_{mix} = \frac{(Q_{up} \times T_{up}) + (Q_{in} \times T_{in})}{Q_{mix}} = \frac{(Q_{up} \times T_{up}) + (Q_{in} \times T_{in})}{(Q_{up} + Q_{in})} \quad \textbf{Equation 3-1}$$

where,

Q_{up} = Stream flow rate upstream from mass transfer process

$Q_{in} =$ Inflow volume or flow rate

$Q_{mix} =$ Resulting volume or flow rate from mass transfer process (Q_{up} + Q_{in})

$T_{up} =$ Stream temperature directly upstream from mass transfer process

$T_{in} =$ Temperature of inflow

$T_{mix} =$ Resulting stream temperature from mass transfer process assuming complete mix

Table 3-12: Boundary condition and tributary flow inputs to the Molalla River model.

Model Location Name	Model Location (kilometers)	Flow Rate (cms)	Input Type	Data Source
Molalla at Locked Gate HW	75.36	0.27	Boundary Condition	DEQ
Copper Creek	75.33	0.13	Tributary	DEQ
Spring	75.3	0.03	Tributary	DEQ
Unnamed tributary 6	74.6	0.01	Tributary	DEQ
Spring	74.2	0.00	Tributary	DEQ
Spring	73.77	0.03	Tributary	DEQ
Spring	73.4	0.02	Tributary	DEQ
Minette Creek	72.69	0.05	Tributary	DEQ
Table Rock Fork	66.54	0.76	Tributary	DEQ
Horse Creek	64.65	0.20	Tributary	DEQ
Spring	63.33	0.00	Tributary	DEQ
Gawley Creek	62.52	0.10	Tributary	DEQ
Spring	60.84	0.08	Tributary	DEQ
Unnamed tributary 5	59.91	0.00	Tributary	DEQ
North Fork Molalla	44.94	1.26	Tributary	DEQ
Spring	39.12	0.00	Tributary	DEQ
Seep	38.16	0.00	Tributary	DEQ
Seep/Spring	35.88	0.00	Tributary	DEQ
Spring	35.07	0.00	Tributary	DEQ
Spring	32.7	0.00	Tributary	DEQ
Spring	30.63	0.27	Tributary	DEQ
Spring	30.54	0.34	Tributary	DEQ
Seep	29.88	0.00	Tributary	DEQ
Spring	25.59	0.27	Tributary	DEQ
Spring	22.29	0.13	Tributary	DEQ
Spring	18.33	0.00	Tributary	DEQ
Spring	16.89	0.04	Tributary	DEQ
Unnamed tributary 2	15.75	0.00	Tributary	DEQ
Spring	13.71	0.21	Tributary	DEQ
Milk Creek	12.9	0.74	Tributary	DEQ
Spring	12.69	0.18	Tributary	DEQ

Model Location Name	Model Location (kilometers)	Flow Rate (cms)	Input Type	Data Source
Spring	12.03	0.00	Tributary	DEQ
Unnamed tributary 1	11.88	0.00	Tributary	DEQ
Spring	11.58	0.07	Tributary	DEQ
Spring	11.19	0.07	Tributary	DEQ
Spring	10.59	0.00	Tributary	DEQ
Gribble Creek	8.46	0.00	Tributary	DEQ
Spring	2.67	0.00	Tributary	DEQ
Pudding River	2.55	1.95	Tributary	DEQ
Spring	0.87	0.00	Tributary	DEQ

3.2.7 Point source inputs

There are no point sources included in the calibrated model.

Molalla Sewage Treatment Plant (STP) discharged to Bear Creek at the time the calibrated model was developed and therefore was not included as an input. The outfall was moved to the Molalla River in 2006 and the discharge to Bear Creek was abandoned in January 2007. A current condition scenario was considered for assessment of the discharge to the Molalla River but was not developed after review of Discharge Monitoring Report (DMR) data. See section 4.3.1 for details. A waste load allocation model scenario was developed for the Molalla STP discharge. See section 4.3.4.

RSG Forest Products was also identified a potential discharge to Molalla River but was excluded because their discharge location is a settling pond that flows to a ditch, which then flows to farm ponds and terminates in a low, ponded area. There is no visible connection between the ditch and the mainstem Molalla River. DEQ NPDES Permit Program staff do not believe there is a surface water connection between the RSG Forest Products discharge location and the mainstem Molalla River.

3.2.8 Landcover and topographic shade inputs

Average land cover height inputs to the Molalla River model are shown in **Figure 3-31**, with topographic shade angle inputs shown in **Figure 3-32**.

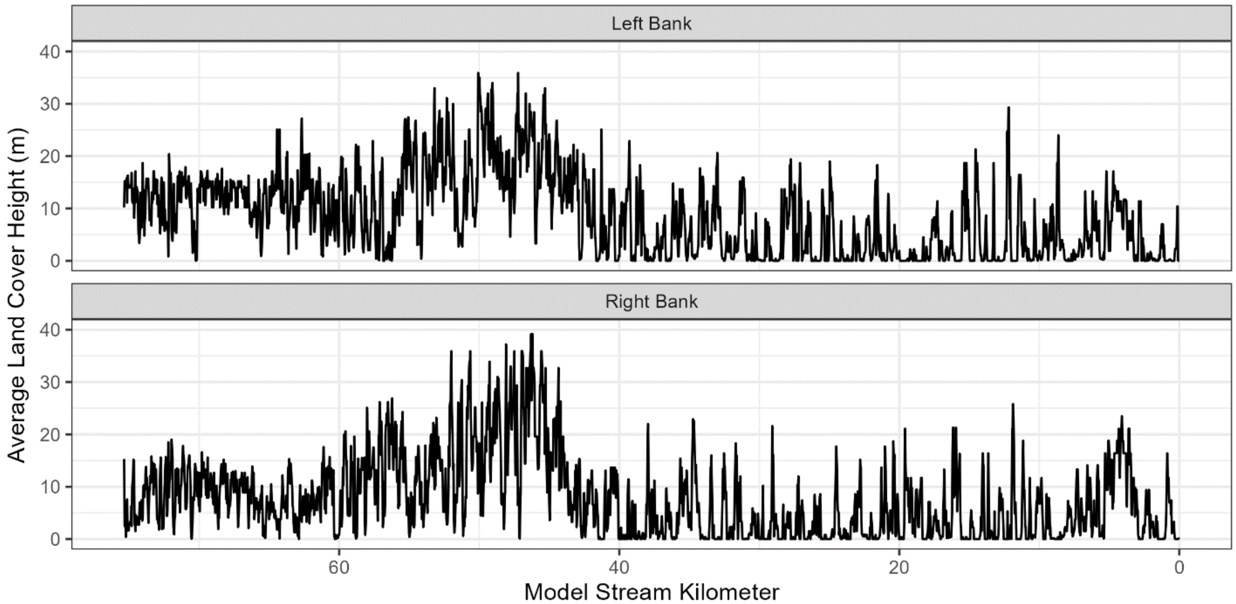


Figure 3-31: Average land cover height inputs to the Molalla River model.

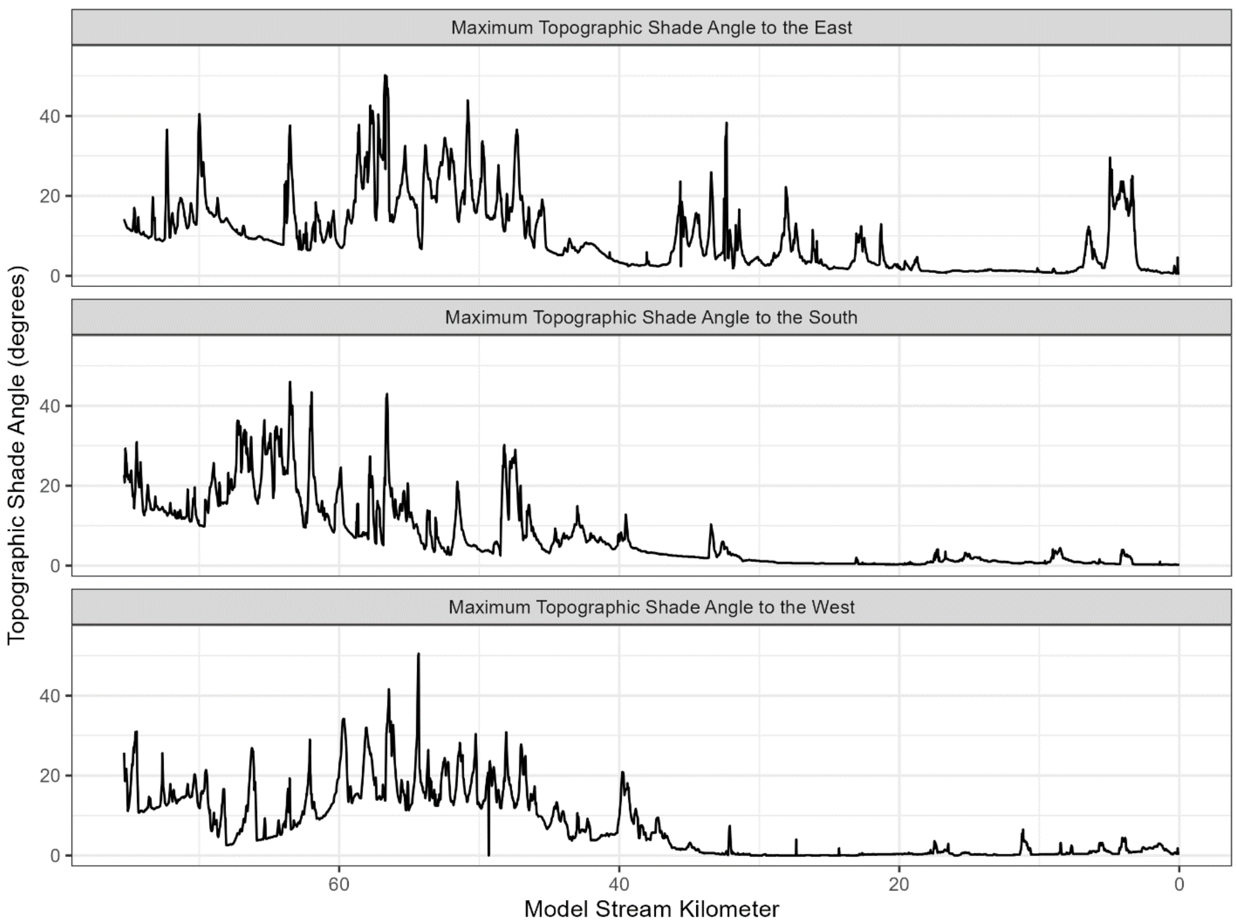
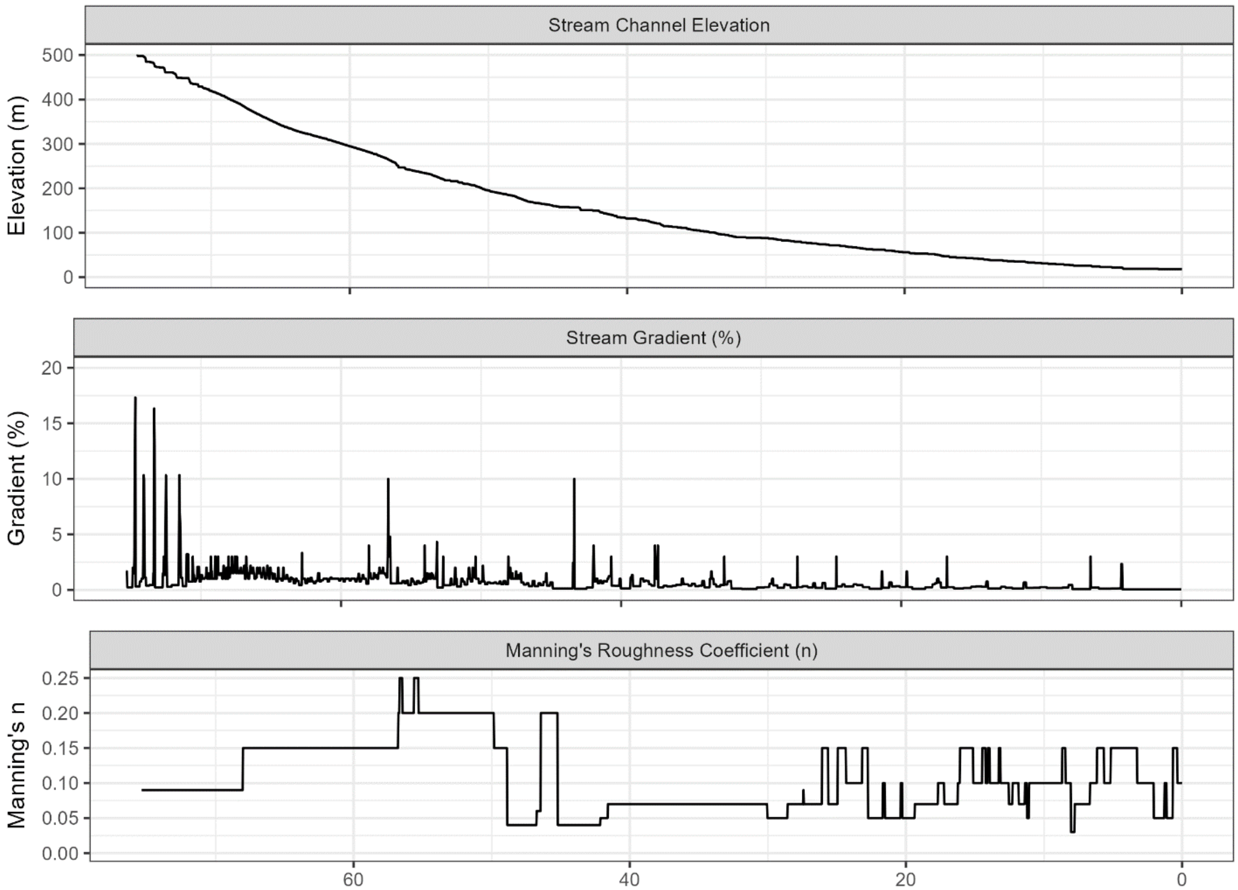


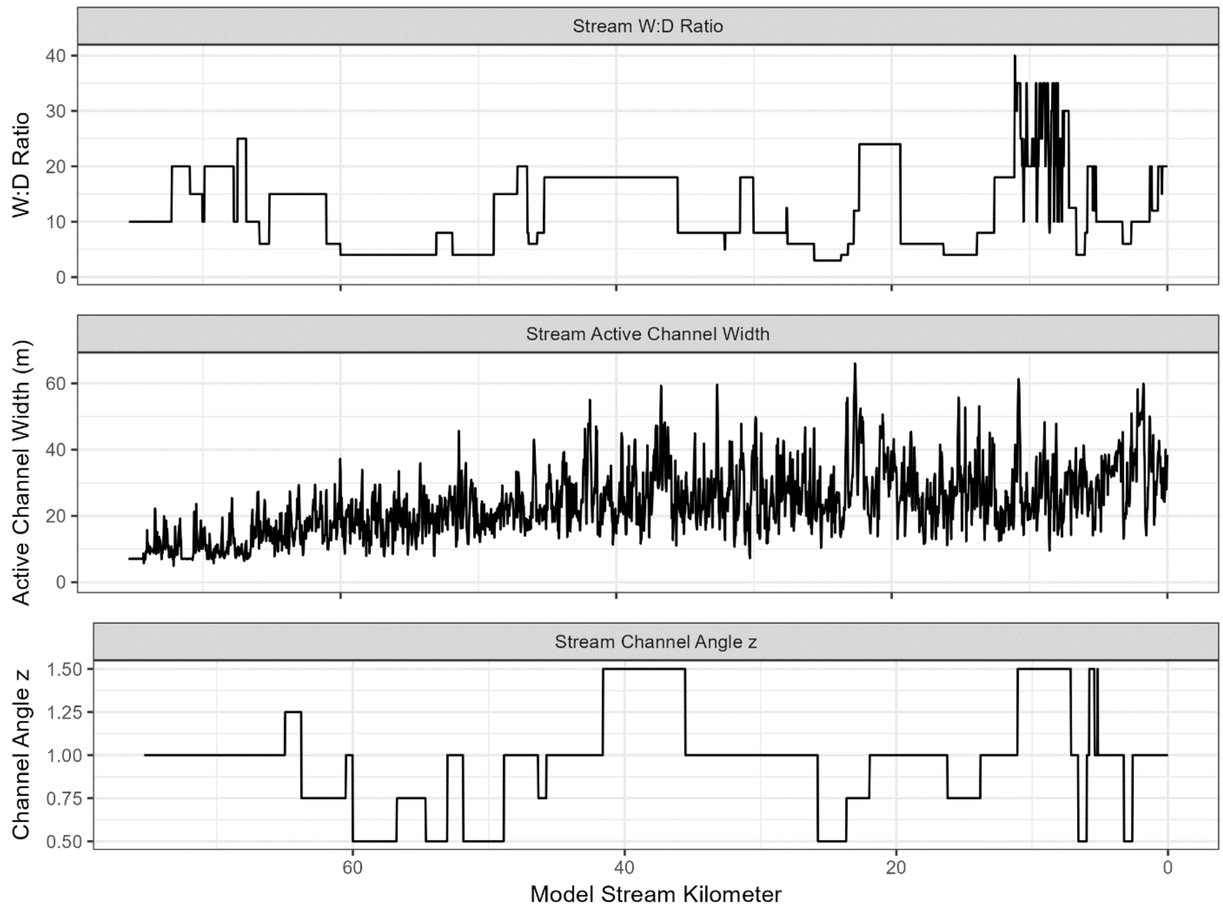
Figure 3-32: Topographic shade angle inputs to the Molalla River model.

3.2.9 Channel setup

The channel setup for the Molalla River model is shown in **Figure 3-33.**



(A)



(B)
Figure 3-33 (A) and (B): Channel setup in the Molalla River model.

3.2.10 Other model parameters

The wind function coefficients (Dunne and Leopold, 1978) for non-spatially varying parameters in the calibrated Molalla River model are presented in **Table 3-13**. Additionally, other model parameters, including horizontal bed conductivity, bed particle size, and embeddedness, are displayed in **Figure 3-34**. These values are based on literature sources. The horizontal bed conductivity values used in the model were 15, 30, 40, and 50 mm/s, while the bed particle sizes ranged from 63.5 to 254 mm. Both parameters represented gravel or cobble bed conditions (Bedient and Huber, 1992; Rosgen, 1996). Embeddedness in the model was 10% and 25%, indicating rocks that are partially surrounded by sediment and are not completely covered by fines (Simonson et al., 1994).

Table 3-13: Model coefficients for non-spatially varying parameters in the Molalla River model.

Parameter name (units)	Value
Wind Function, coefficient a	1.51×10^{-9}
Wind Function, coefficient b	1.60×10^{-9}

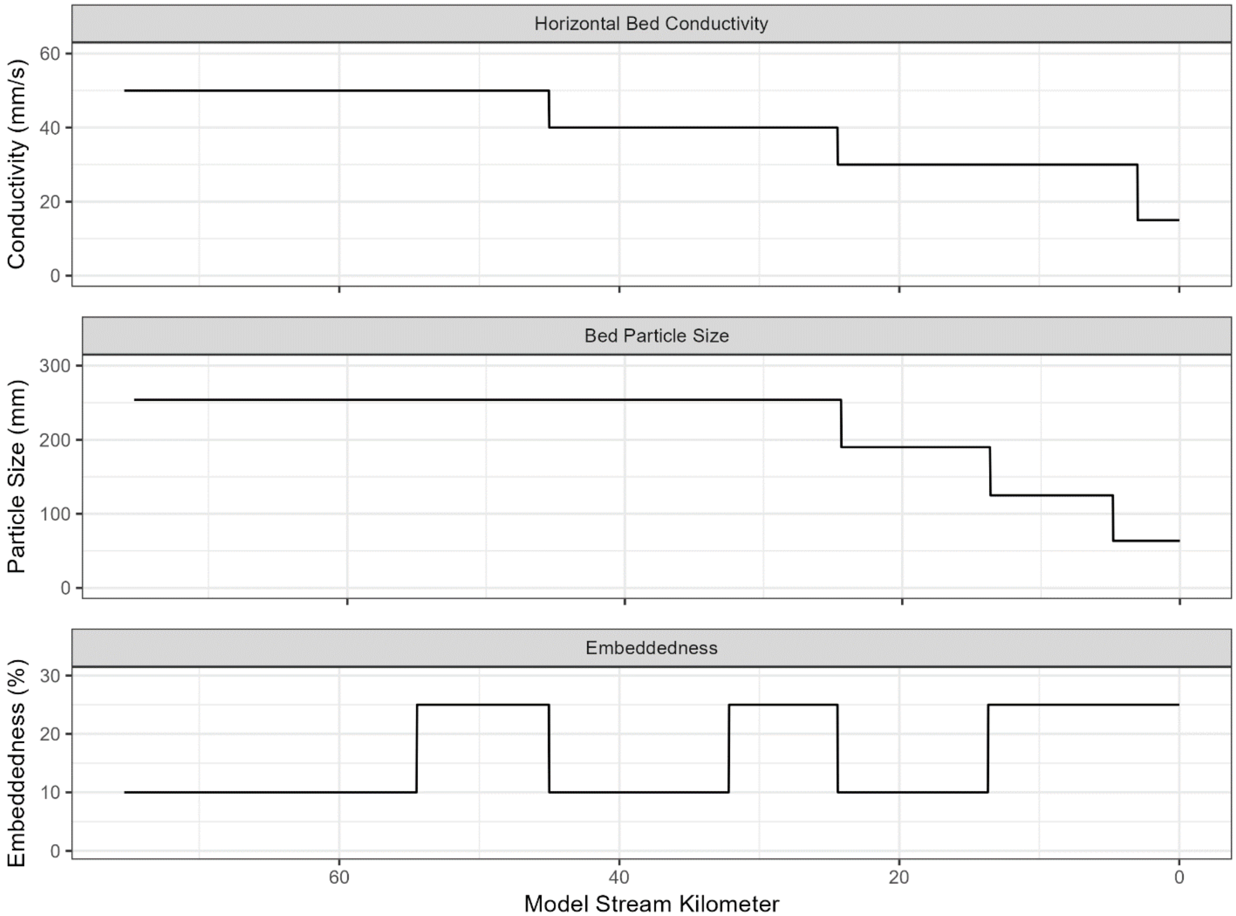


Figure 3-34: The other model parameters used for channel setup in the Molalla River model.

3.2.11 Calibration results

3.2.11.1 Temperature

The temperature model was calibrated to the TIR data collected on July 26, 2004, as well as the continuous temperature data collected at several locations along the Molalla River throughout the modeled period. Simulations were performed for a total of 44 stream miles (76 km). Results for goodness of fit statistics comparing field observed and model-predicted temperatures are summarized in

Table 3-14. Modeling results comparing simulated current condition for the Molalla River to the TIR data are presented in **Figure 3-35**. Comparison of the TIR data with the Molalla River model simulation meets the target of errors less than 1.0ºC.

Table 3-14: Molalla River model goodness of fit statistics comparing field measured and model simulated temperatures.

Monitoring Location	Model KM	Temperature Statistics	ME	MAE	RMSE	NSE	n
All Stations		7DADM	-1	1	1.14	NA	140
All Stations		Daily Maximum	-1.07	1.1	1.46	NA	140
All Stations		Hourly	-1.1	1.23	1.55	0.72	1680
10636-ORDEQ: Molalla River at mouth	0.26	7DADM	-1.45	1.45	1.46	NA	14
32059-ORDEQ: Molalla River at 22nd Avenue	3.16	7DADM	-1.42	1.42	1.49	NA	14
10637-ORDEQ: Molalla River at Knights Bridge Road (Canby)	4.76	7DADM	-1.6	1.6	1.69	NA	14
32058-ORDEQ: Molalla River at Canby-Marquam Hwy (Goods Bridge)	10.46	7DADM	-1.36	1.36	1.4	NA	14
32061-ORDEQ: Molalla River upstream of Milk Creek	13.66	7DADM	-1.04	1.04	1.05	NA	14
Model Node 7: Molalla at Kraxberger	20.46	7DADM	-1.01	1.01	1.01	NA	14
10881-ORDEQ: Molalla River at Hwy 213 Bridge (Mulino)	24.36	7DADM	-1.03	1.03	1.08	NA	14
31871-ORDEQ: Molalla River above North Fork LD	44.96	7DADM	-0.31	0.31	0.35	NA	14
32051-ORDEQ: Molalla River upstream of Pine Creek	54.46	7DADM	-0.52	0.52	0.56	NA	14
32049-ORDEQ: Molalla River upstream of Horse Creek	64.76	7DADM	-0.21	0.21	0.22	NA	14
10636-ORDEQ: Molalla River at mouth	0.26	Daily Maximum	-1.4	1.4	1.45	NA	14
32059-ORDEQ: Molalla River at 22nd Avenue	3.16	Daily Maximum	-1.67	1.67	2.06	NA	14
10637-ORDEQ: Molalla River at Knights Bridge Road (Canby)	4.76	Daily Maximum	-1.89	1.89	2.31	NA	14
32058-ORDEQ: Molalla River at Canby-Marquam Hwy (Goods Bridge)	10.46	Daily Maximum	-1.6	1.6	1.87	NA	14
32061-ORDEQ: Molalla River upstream of Milk Creek	13.66	Daily Maximum	-0.97	1	1.11	NA	14
Model Node 7: Molalla at Kraxberger	20.46	Daily Maximum Temperature	-0.94	0.99	1.06	NA	14
10881-ORDEQ: Molalla River at Hwy 213 Bridge (Mulino)	24.36	Daily Maximum	-1.31	1.31	1.76	NA	14
31871-ORDEQ: Molalla River above North Fork LD	44.96	Daily Maximum	-0.27	0.38	0.51	NA	14
32051-ORDEQ: Molalla River upstream of Pine Creek	54.46	Daily Maximum	-0.49	0.54	0.7	NA	14
32049-ORDEQ: Molalla River upstream of Horse Creek	64.76	Daily Maximum	-0.2	0.25	0.3	NA	14
10636-ORDEQ: Molalla River at mouth	0.26	Hourly	-0.7	0.75	0.94	0.58	168

Monitoring Location	Model KM	Temperature Statistics	ME	MAE	RMSE	NSE	n
32059-ORDEQ: Molalla River at 22nd Avenue	3.16	Hourly	-1.73	1.75	2.13	-0.65	168
10637-ORDEQ: Molalla River at Knights Bridge Road (Canby)	4.76	Hourly	-1.52	1.79	2.2	-0.13	168
32058-ORDEQ: Molalla River at Canby-Marquam Hwy (Goods Bridge)	10.46	Hourly	-0.99	1.04	1.34	0.41	168
32061-ORDEQ: Molalla River upstream of Milk Creek	13.66	Hourly	-1.41	1.42	1.55	0.24	168
Model Node 7: Molalla at Kraxberger	20.46	Hourly	-1.2	1.32	1.57	0.52	168
10881-ORDEQ: Molalla River at Hwy 213 Bridge (Mulino)	24.36	Hourly	-1.58	1.59	1.93	0.01	168
31871-ORDEQ: Molalla River above North Fork LD	44.96	Hourly	-0.41	0.81	1.01	0.74	168
32051-ORDEQ: Molalla River upstream of Pine Creek	54.46	Hourly	-0.67	0.98	1.24	0.24	168
32049-ORDEQ: Molalla River upstream of Horse Creek	64.76	Hourly	-0.78	0.83	0.96	0.45	168
Molalla River TIR	Model extent		0.46	0.48	0.56	NA	368

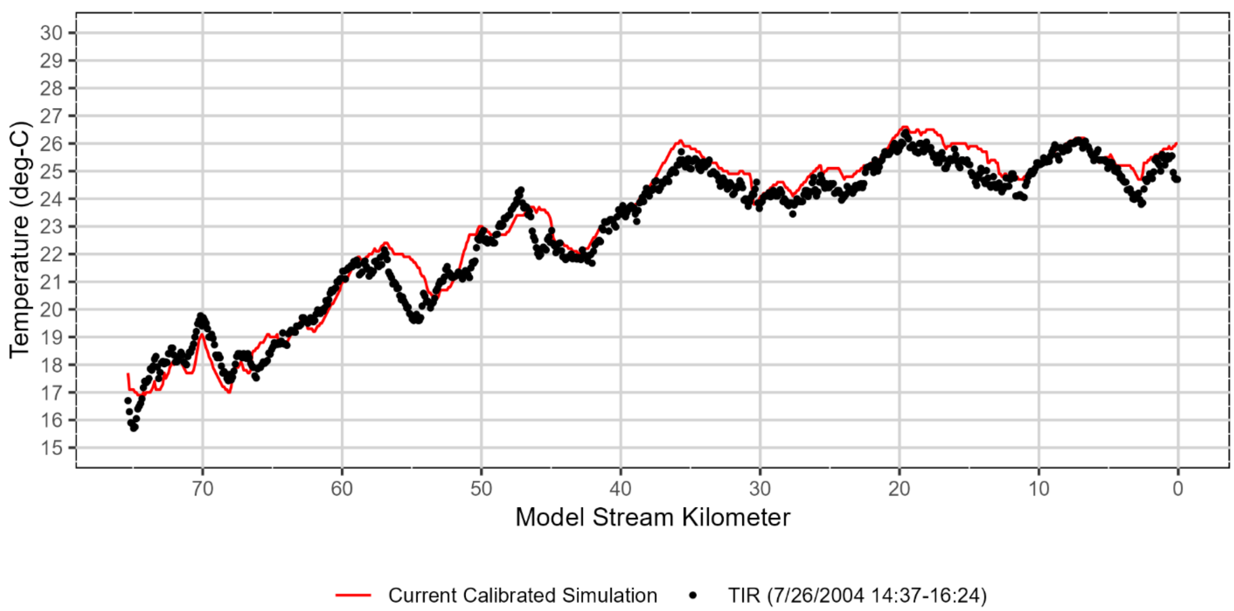


Figure 3-35: Molalla River TIR and simulated current stream temperatures. Periodic temperature decreases may indicate the influence of cooler tributaries, Springs, seeps, and groundwater interaction.

Statistics for model calibration and validation comparing simulated temperature and measured temperature at continuously monitored locations are presented in **Figure 3-36** through **Figure 3-55**. The figures show that the greatest discrepancy between simulated and measured temperatures, especially at stations at the model km 3.16 and 4.76, occurs in the first week of the model period when measured stream temperatures are higher than simulated stream temperatures. Air temperatures during this first week (July 20 - 26) were higher than the second week of the model period (July 27 - August 2). In particular, maximum measured air temperatures on July 23, 24, and 25 were near or exceeding 38ºC (100ºF). Possibly, the model is not as sensitive to spikes in air temperature as is the stream itself. The wide stream conditions in the lower river may respond more rapidly to increases in air temperature than the simulation. Temperature monitor at 10638-ORDEQ Molalla River at Hwy 211 Bridge (model km 32.16) were compromised by being exposed to air. The data at this site were not used. The goodness of fit statistics are shown in

Table 3-14.

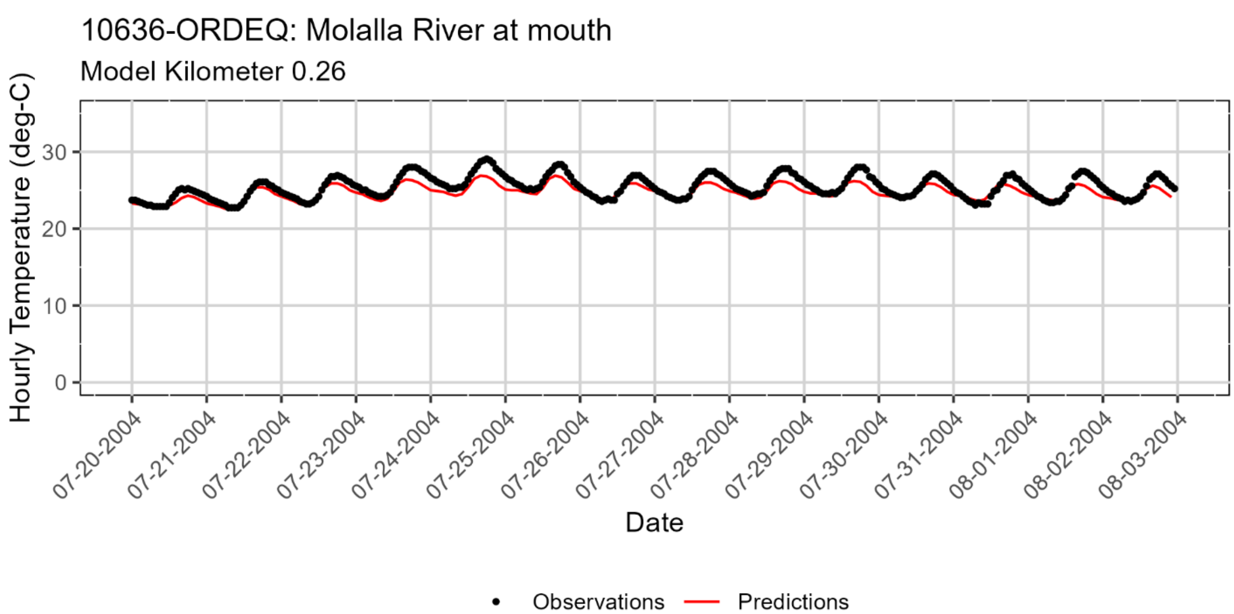


Figure 3-36: Molalla River measured and model-predicted hourly temperatures at monitoring station 10636-ORDEQ.

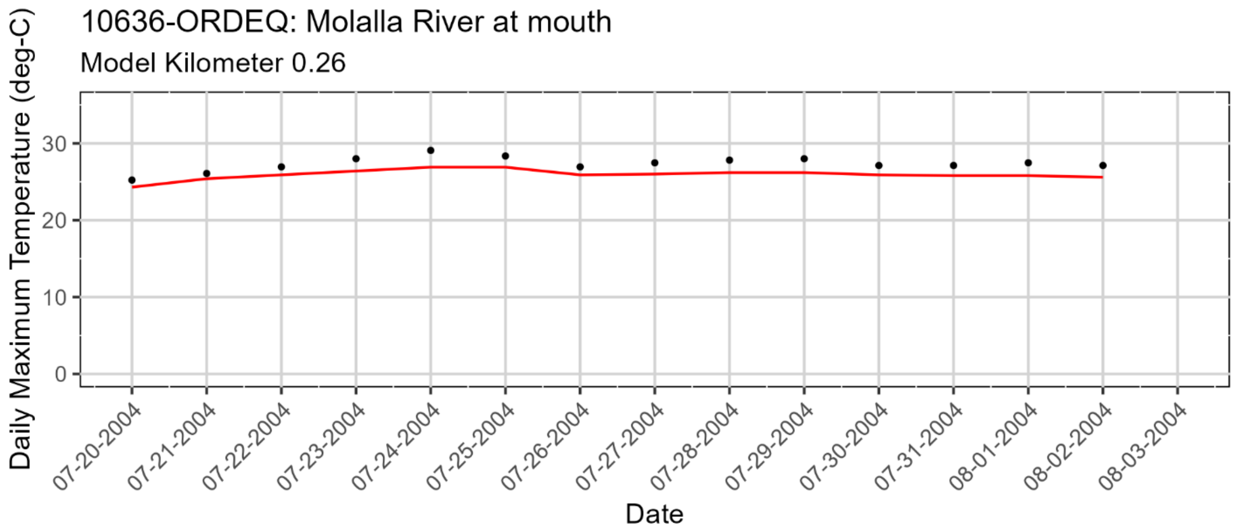


Figure 3-37: Molalla River measured and model-predicted daily maximum temperatures at monitoring station 10636-ORDEQ.

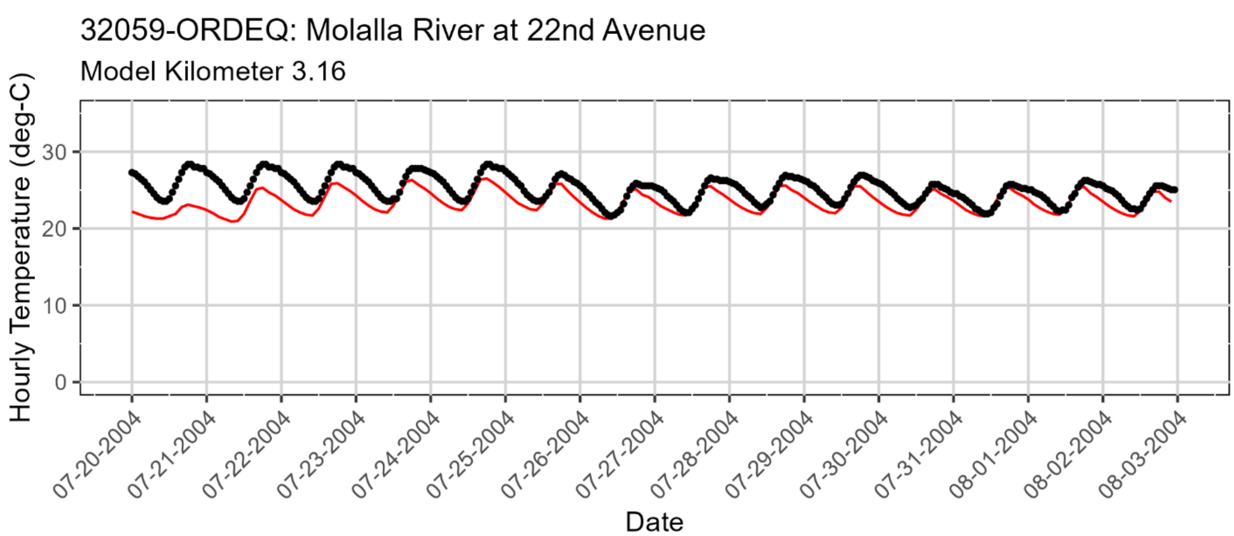


Figure 3-38: Molalla River measured and model-predicted hourly temperatures at monitoring station 32059-ORDEQ.

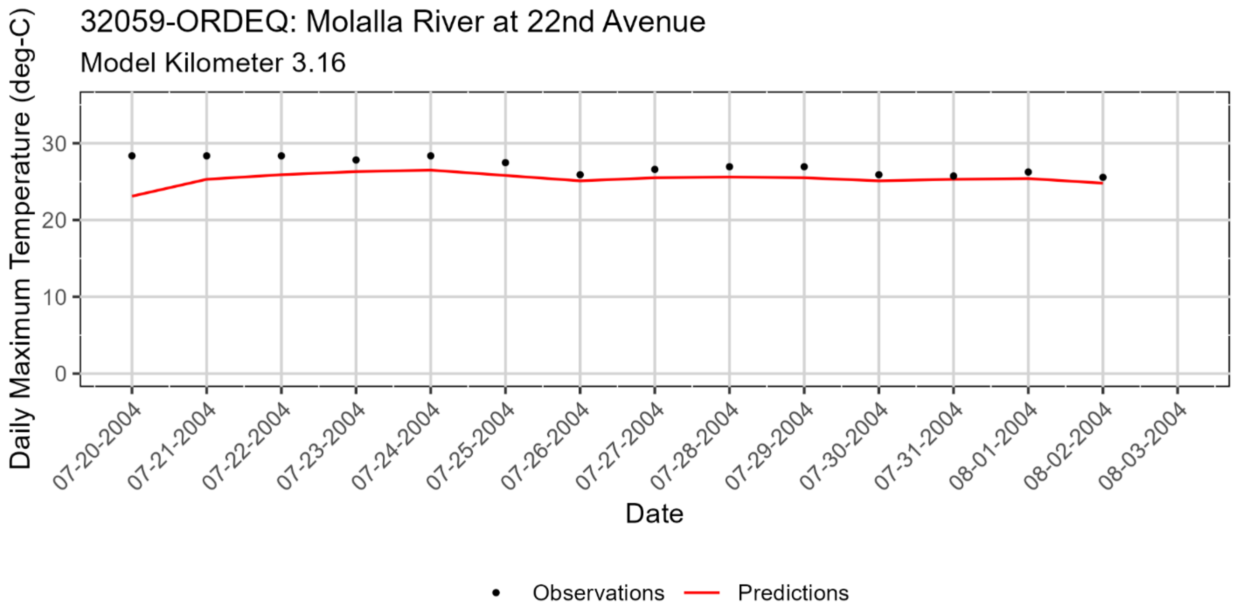


Figure 3-39: Molalla River measured and model-predicted daily maximum temperatures at monitoring station 32059-ORDEQ.

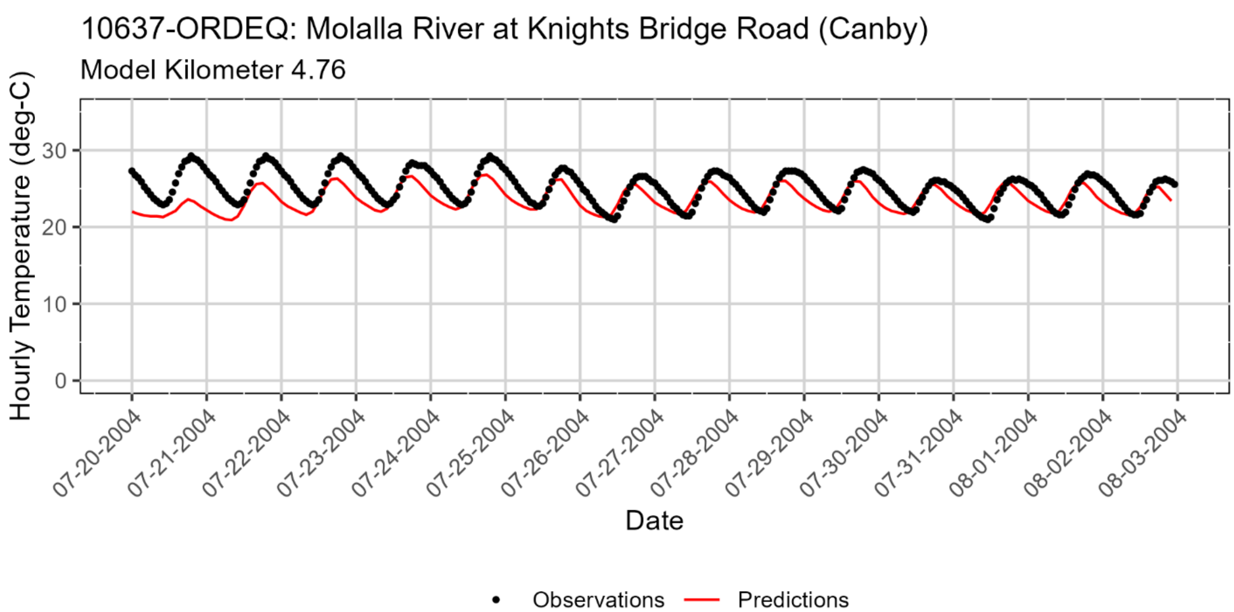


Figure 3-40: Molalla River measured and model-predicted hourly temperatures at monitoring station 10637-ORDEQ.

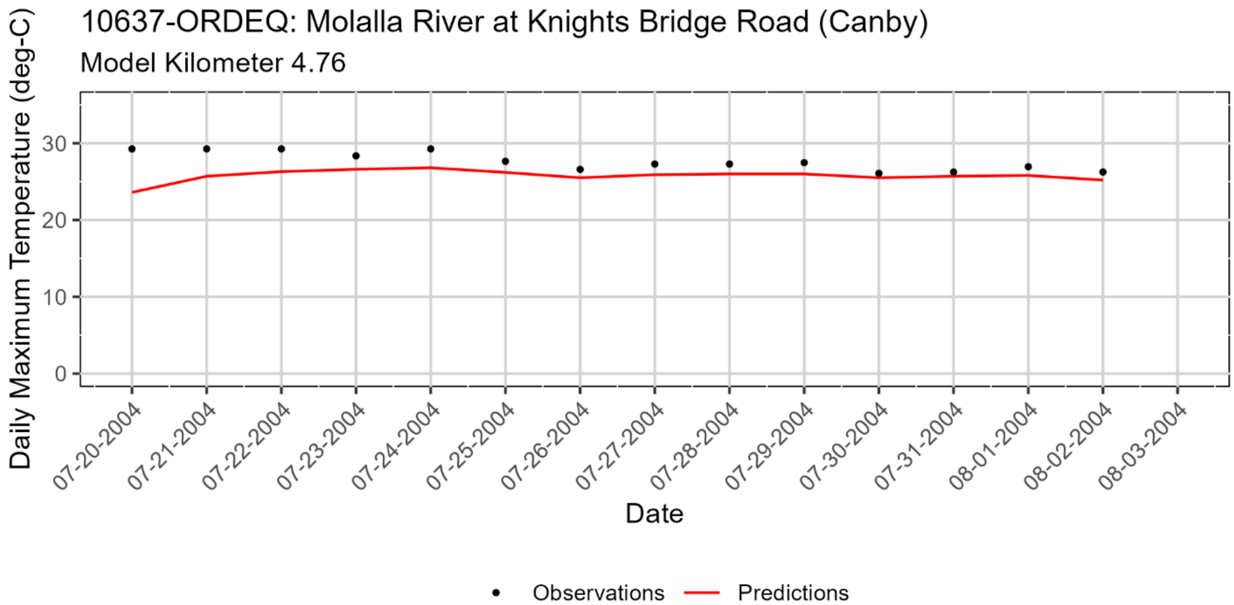


Figure 3-41: Molalla River measured and model-predicted daily maximum temperatures at monitoring station 10637-ORDEQ.

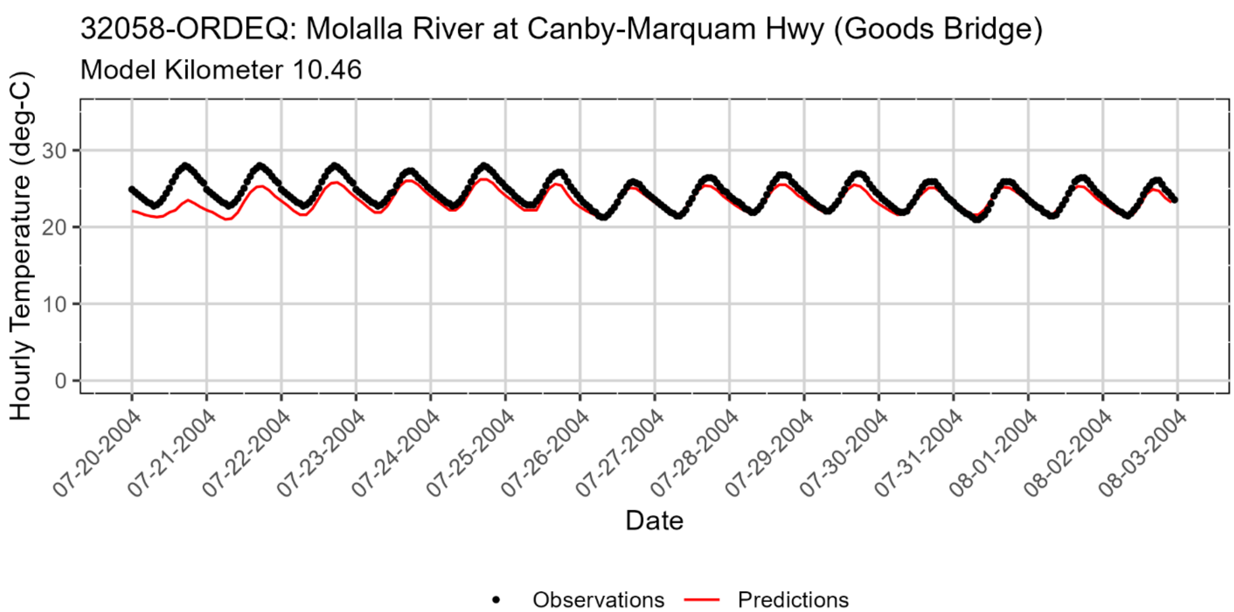


Figure 3-42: Molalla River measured and model-predicted hourly temperatures at monitoring station 32058-ORDEQ.

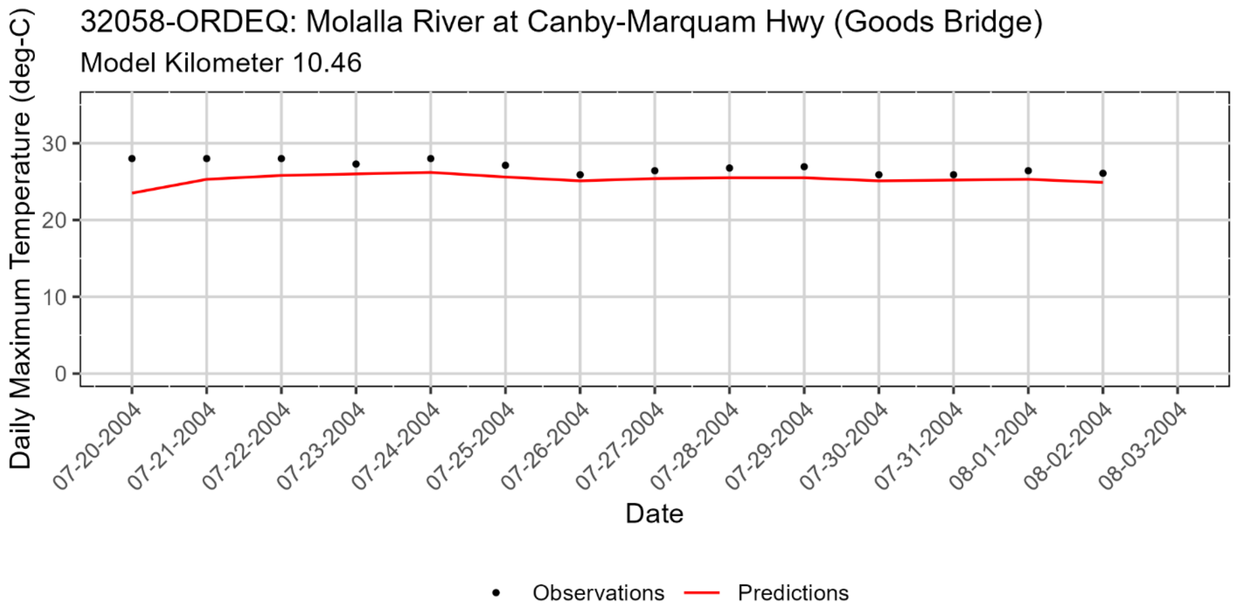


Figure 3-43: Molalla River measured and model-predicted daily maximum temperatures at monitoring station 32058-ORDEQ.

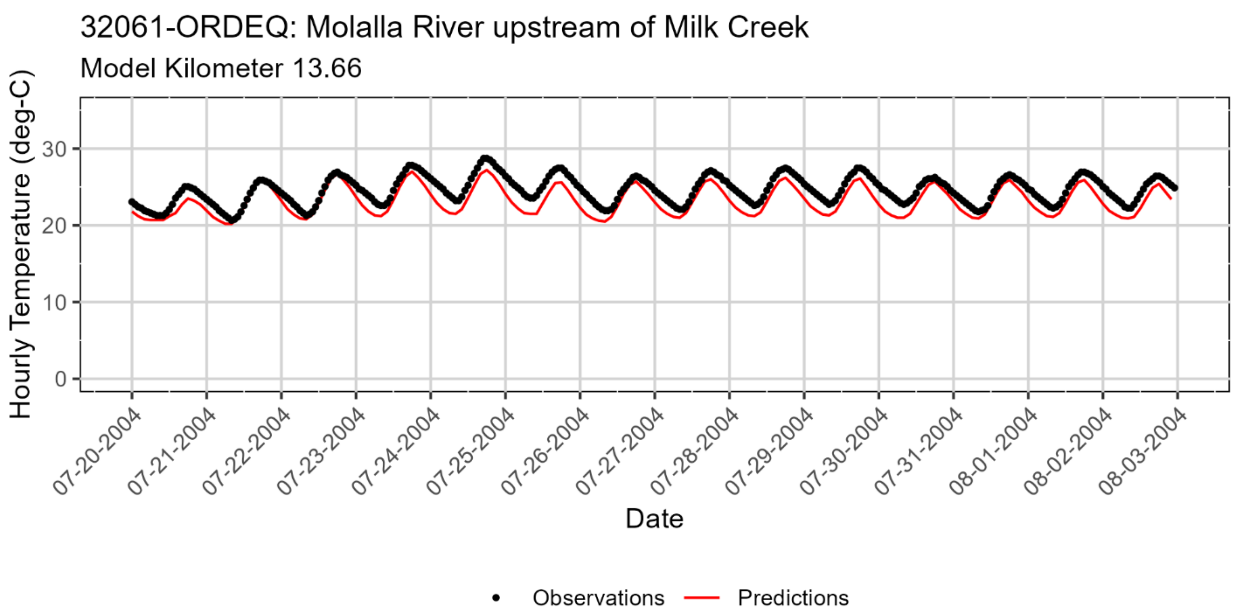


Figure 3-44: Molalla River measured and model-predicted hourly temperatures at monitoring station 32061-ORDEQ.

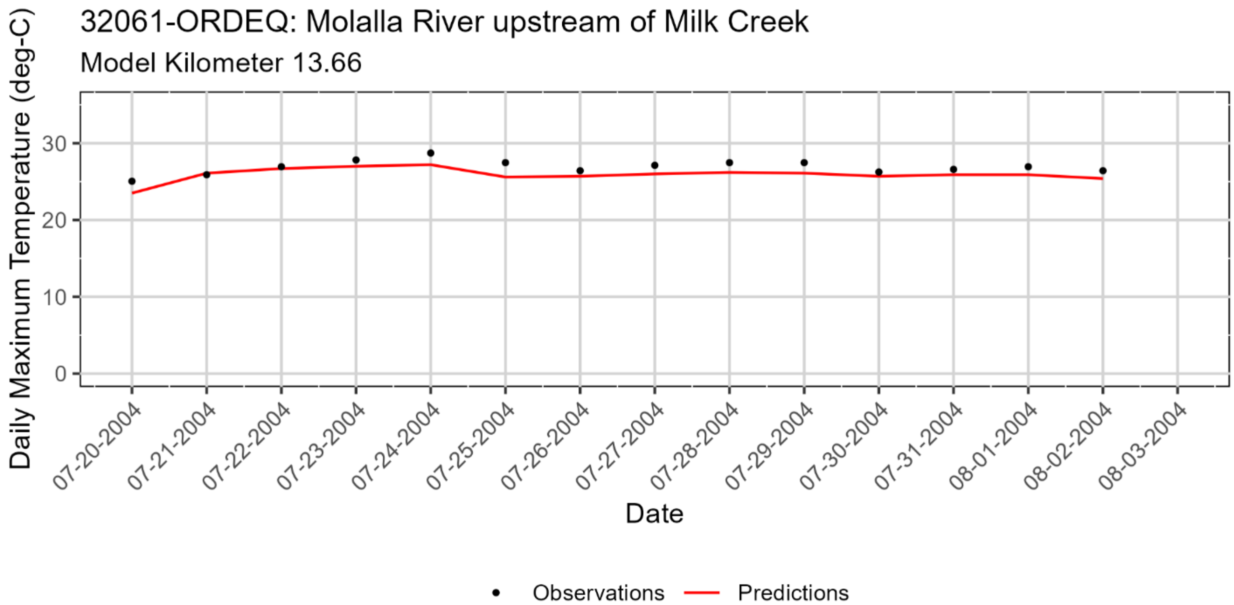


Figure 3-45: Molalla River measured and model-predicted daily maximum temperatures at monitoring station 32061-ORDEQ.

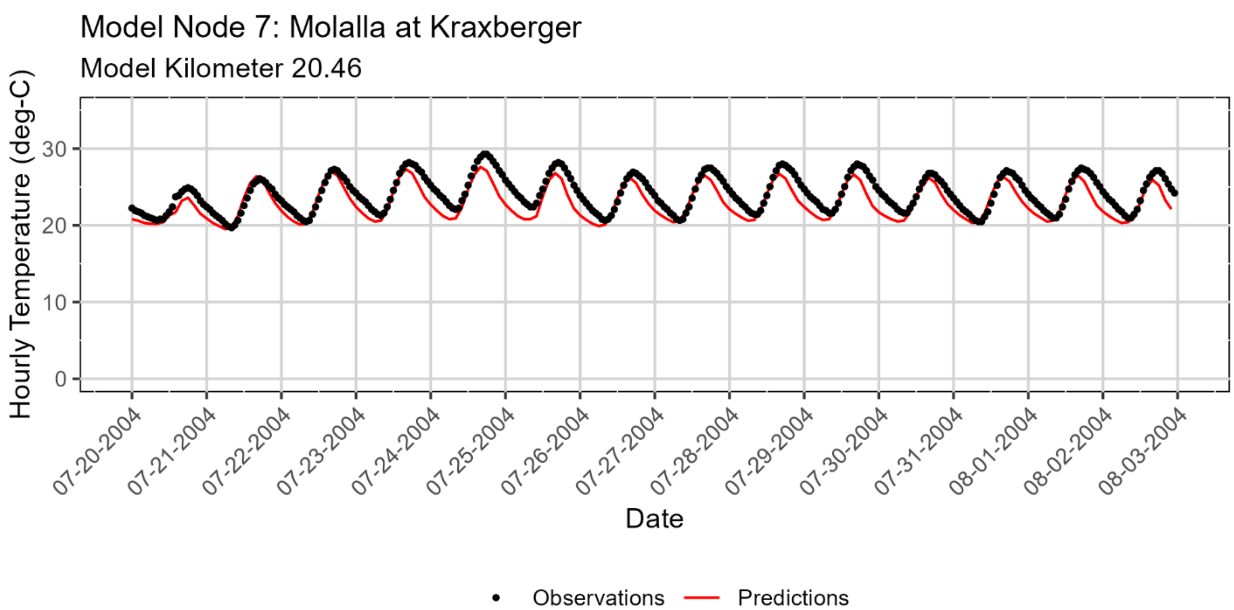


Figure 3-46: Molalla River measured and model-predicted hourly temperatures at monitoring station Model Node 7.

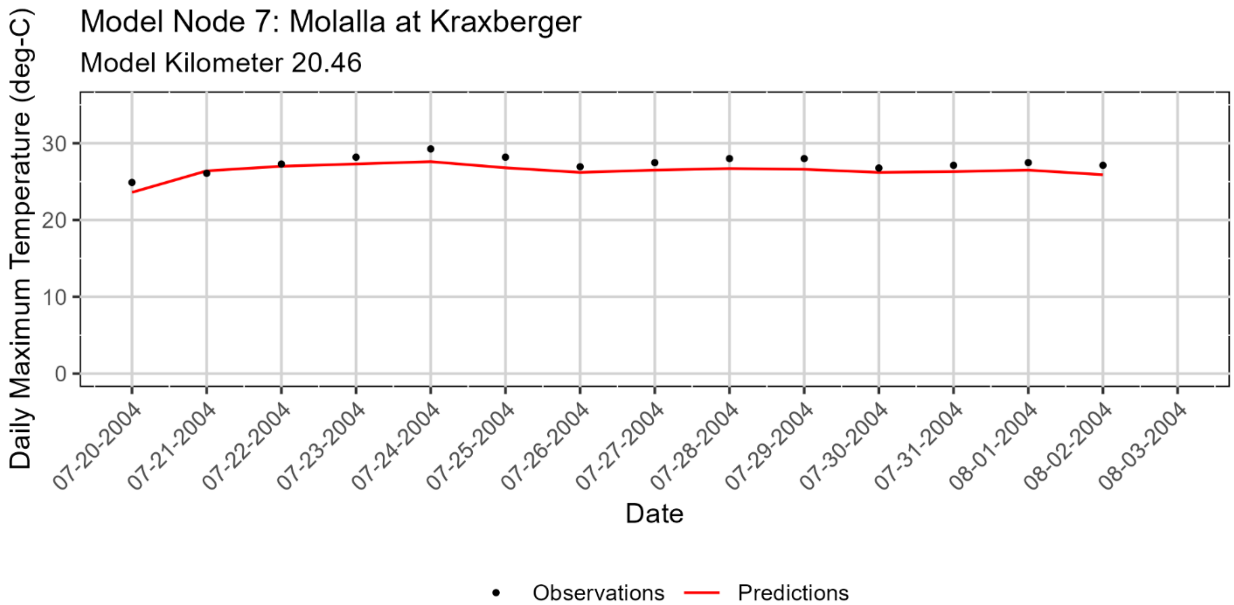


Figure 3-47: Molalla River measured and model-predicted daily maximum temperatures at monitoring station Model Node 7.

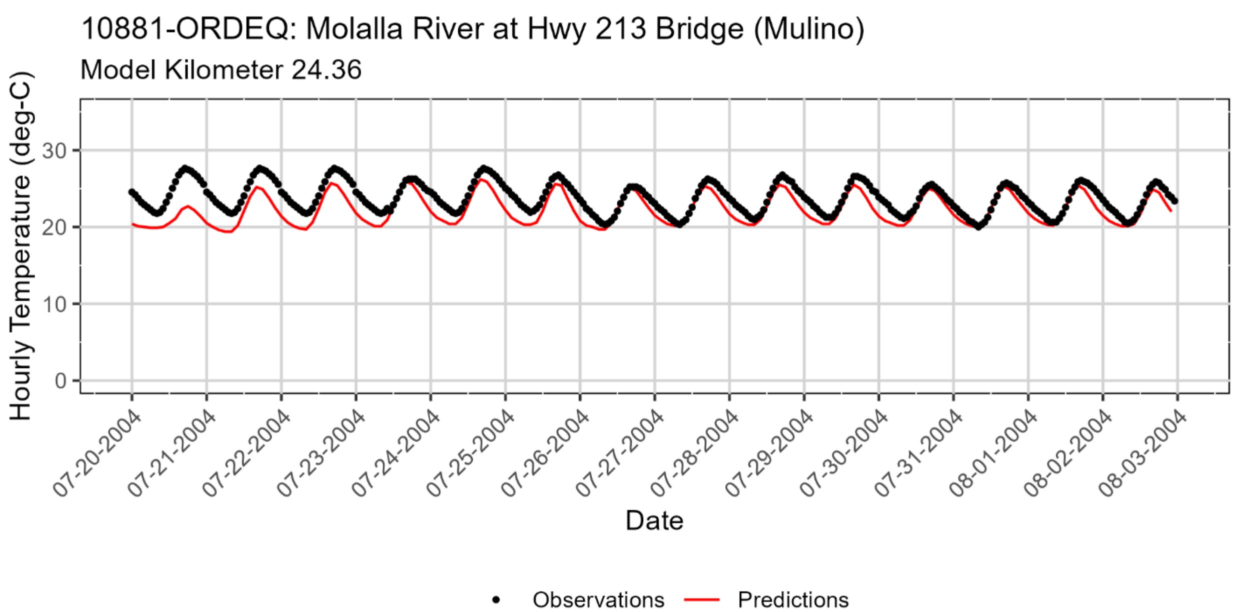


Figure 3-48: Molalla River measured and model-predicted hourly temperatures at monitoring station 10881-ORDEQ.

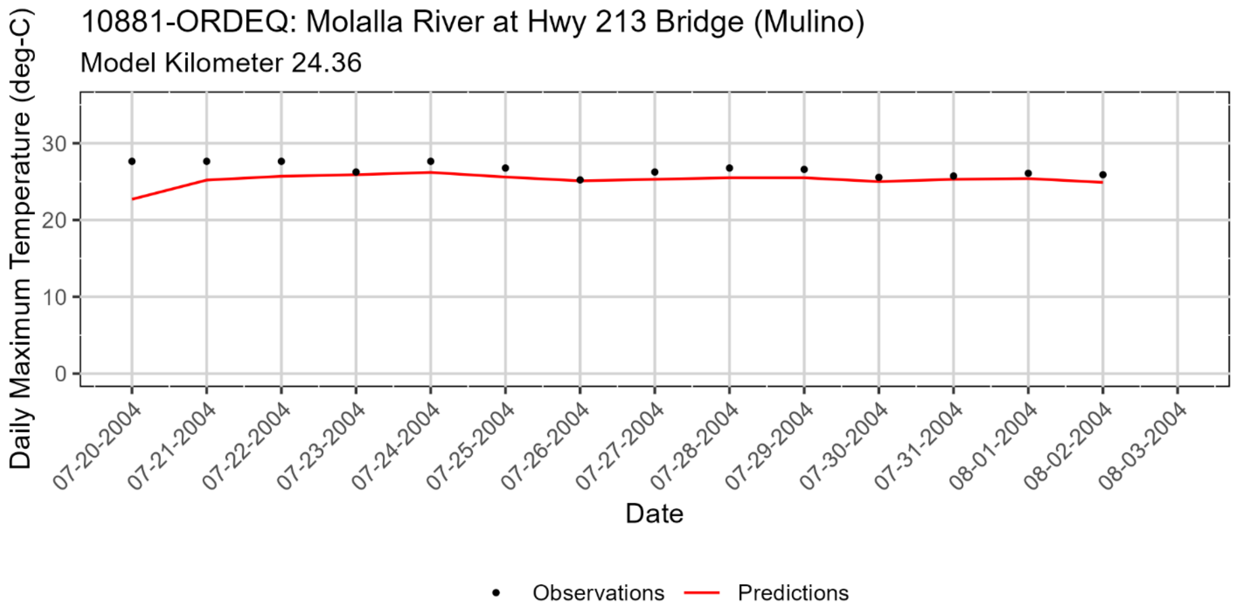


Figure 3-49: Molalla River measured and model-predicted daily maximum temperatures at monitoring station 10881-ORDEQ.

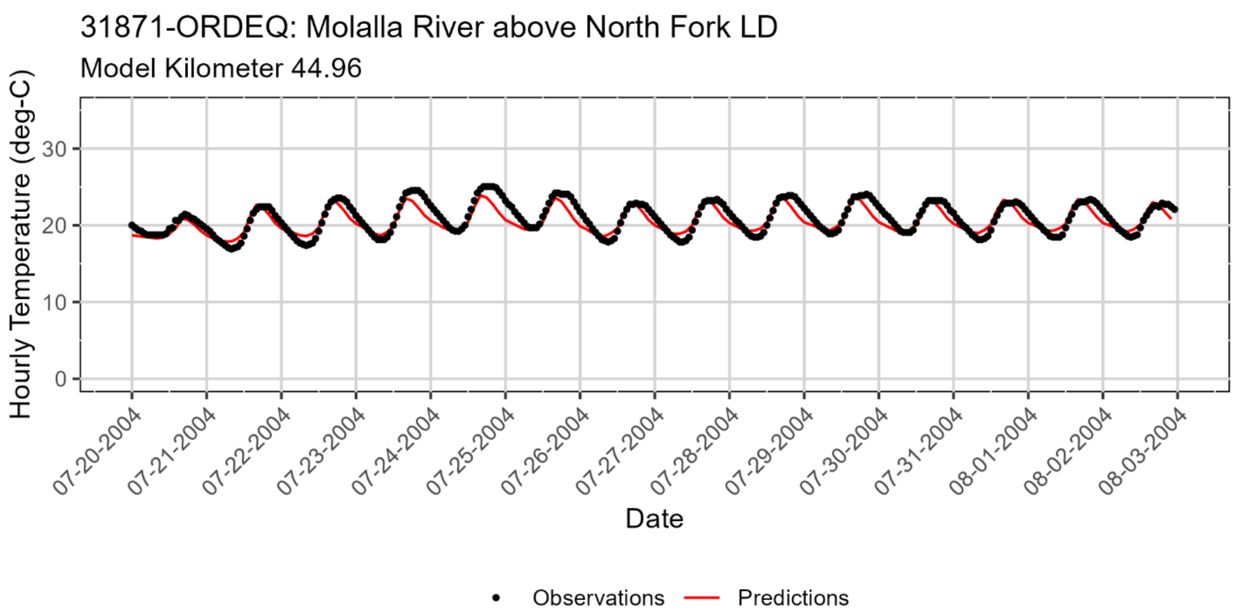


Figure 3-50: Molalla River measured and model-predicted hourly temperatures at monitoring station 31871-ORDEQ.

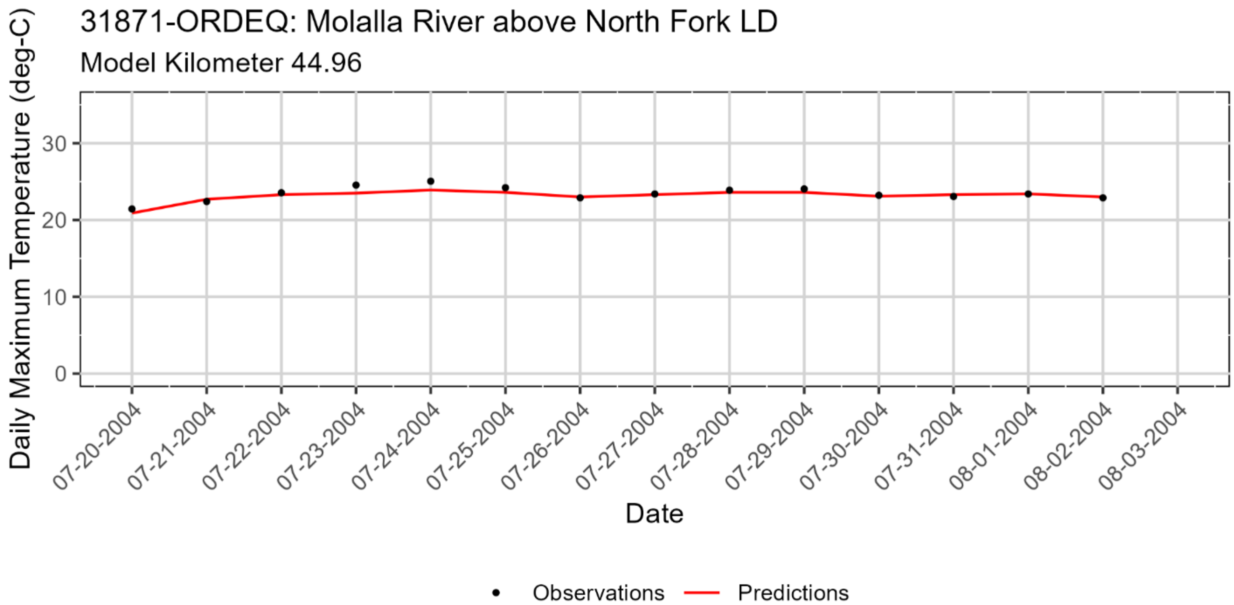


Figure 3-51: Molalla River measured and model-predicted daily maximum temperatures at monitoring station 31871-ORDEQ.

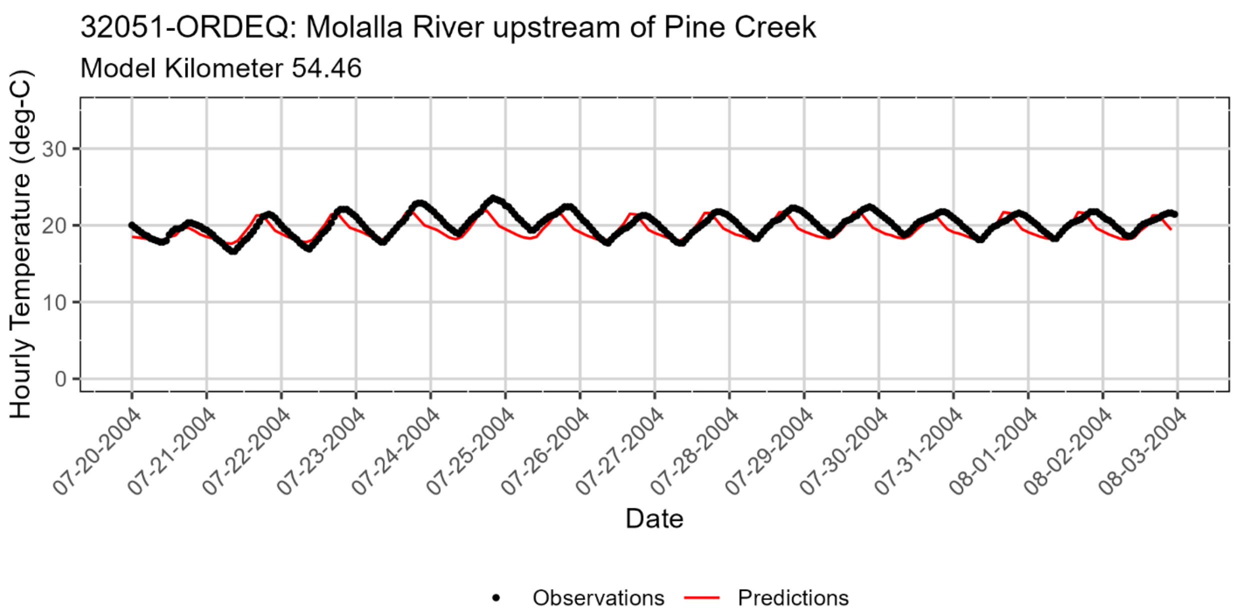


Figure 3-52: Molalla River measured and model-predicted hourly temperatures at monitoring station 32051-ORDEQ.

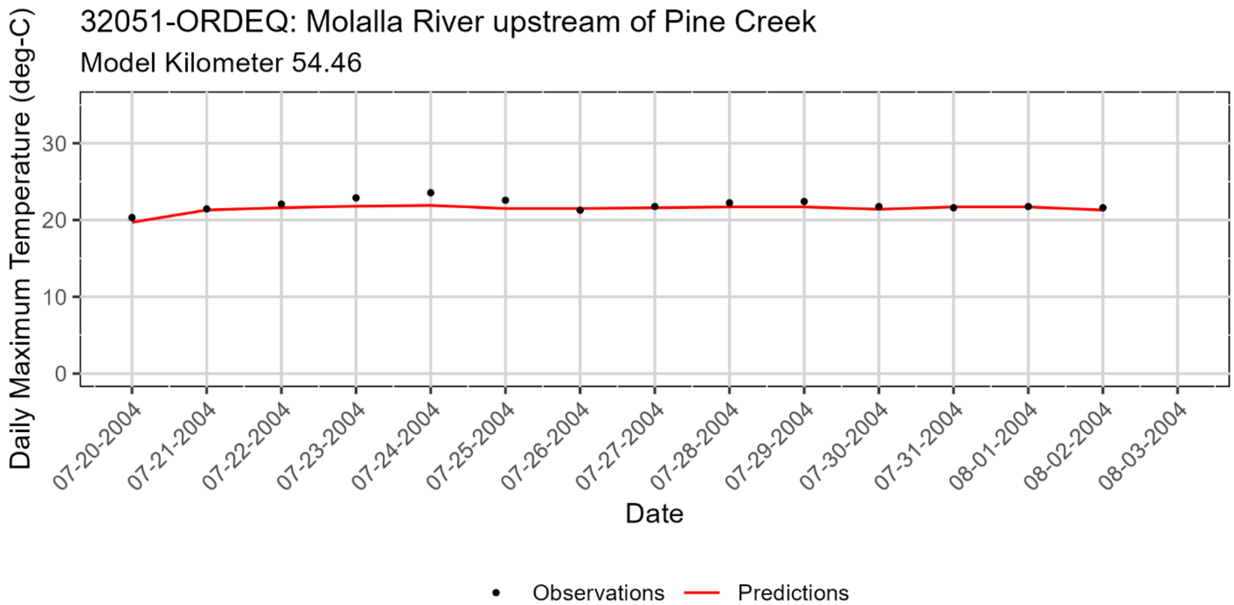


Figure 3-53: Molalla River measured and model-predicted daily maximum temperatures at monitoring station 32051-ORDEQ.

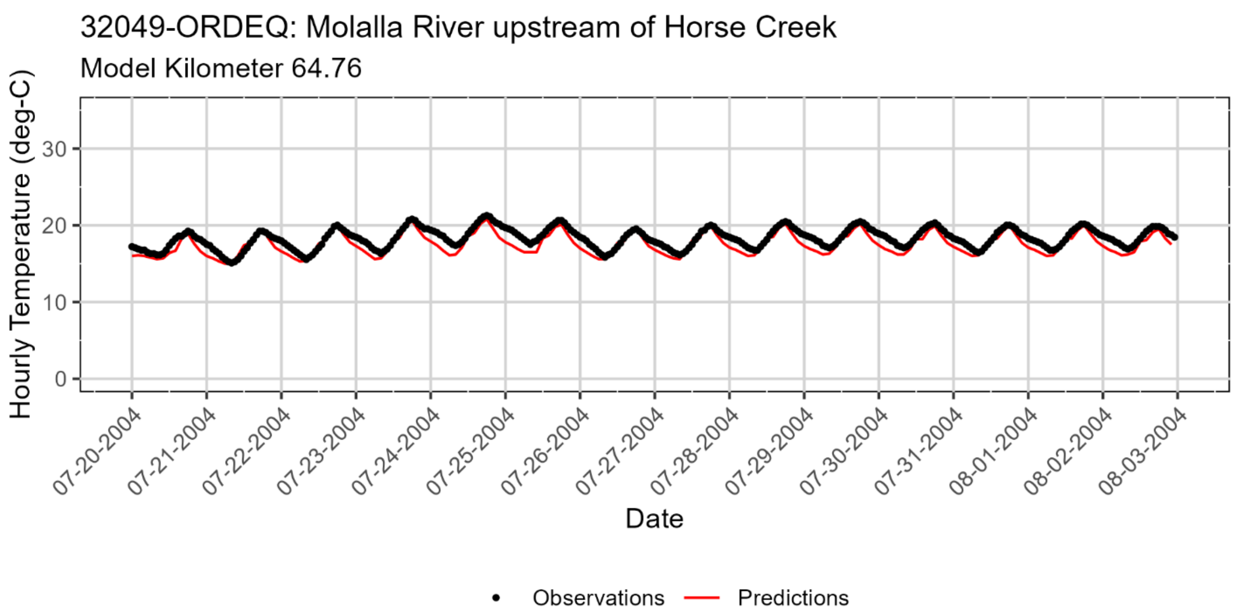


Figure 3-54: Molalla River measured and model-predicted hourly temperatures at monitoring station 32049-ORDEQ.

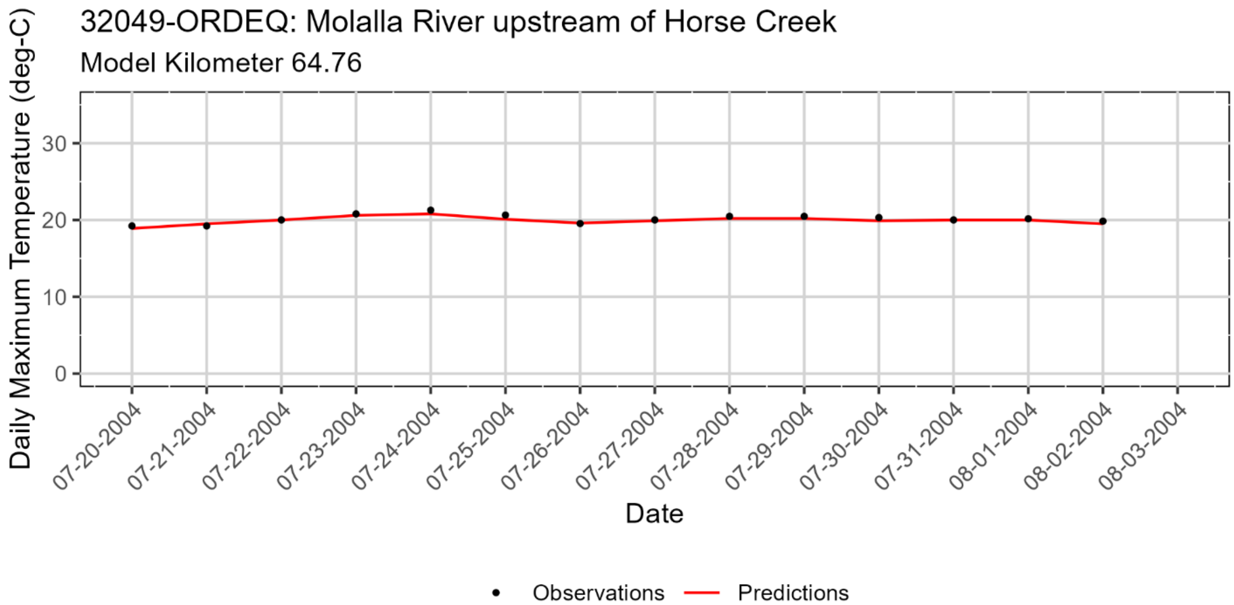


Figure 3-55: Molalla River measured and model-predicted daily maximum temperatures at monitoring station 32049-ORDEQ.

3.2.11.2 Flow

The Molalla River modeled longitudinal stream discharge based on measured flows, OWRD points of diversion (POD) data, and mass balance estimates are presented with measured discharge points in **Figure 3-56**. Stream discharge measurements were collected on July 20, 21 and 23, 2004, and these measurements were compared with the stream discharge simulated by the model on the same three days (**Table 3-15** and **Figure 3-56**). Results for goodness of fit statistics comparing field observed flow and the model flow are summarized in **Table 3-16**.

Table 3-15: Molalla River stream discharge measurements collected in July of 2004.

Monitoring Location	Model KM	Flow Statistics	Flow (cms)	Date
Model Node 0: Molalla at Locked Gate HW	75.36	Instantaneous	0.27	7/20/2004
32049-ORDEQ: Molalla River upstream of Horse Creek	64.76	Instantaneous	1.31	7/20/2004
32051-ORDEQ: Molalla River upstream of Pine Creek	54.46	Instantaneous	1.69	7/20/2004
31871-ORDEQ: Molalla River above North Fork LD	44.96	Instantaneous	1.9	7/21/2004
31870-ORDEQ: Molalla River at Hwy 213	24.36	Instantaneous	2.51	7/23/2004
14200000: Molalla River near Canby, OR	10.36	Daily mean	3.54	7/20/2004

Note: The flow rate measurement on July 22nd, 2004 at Molalla River at Feyrer Park (34245-ORDEQ, model km 35.58) recorded an unusually low value of 1.42 cms. This data point was not used for calibration in the 2008 TMDL. The 2008 TMDL reported that the temperature monitor was lost at this site and the associated temperature data was not used.

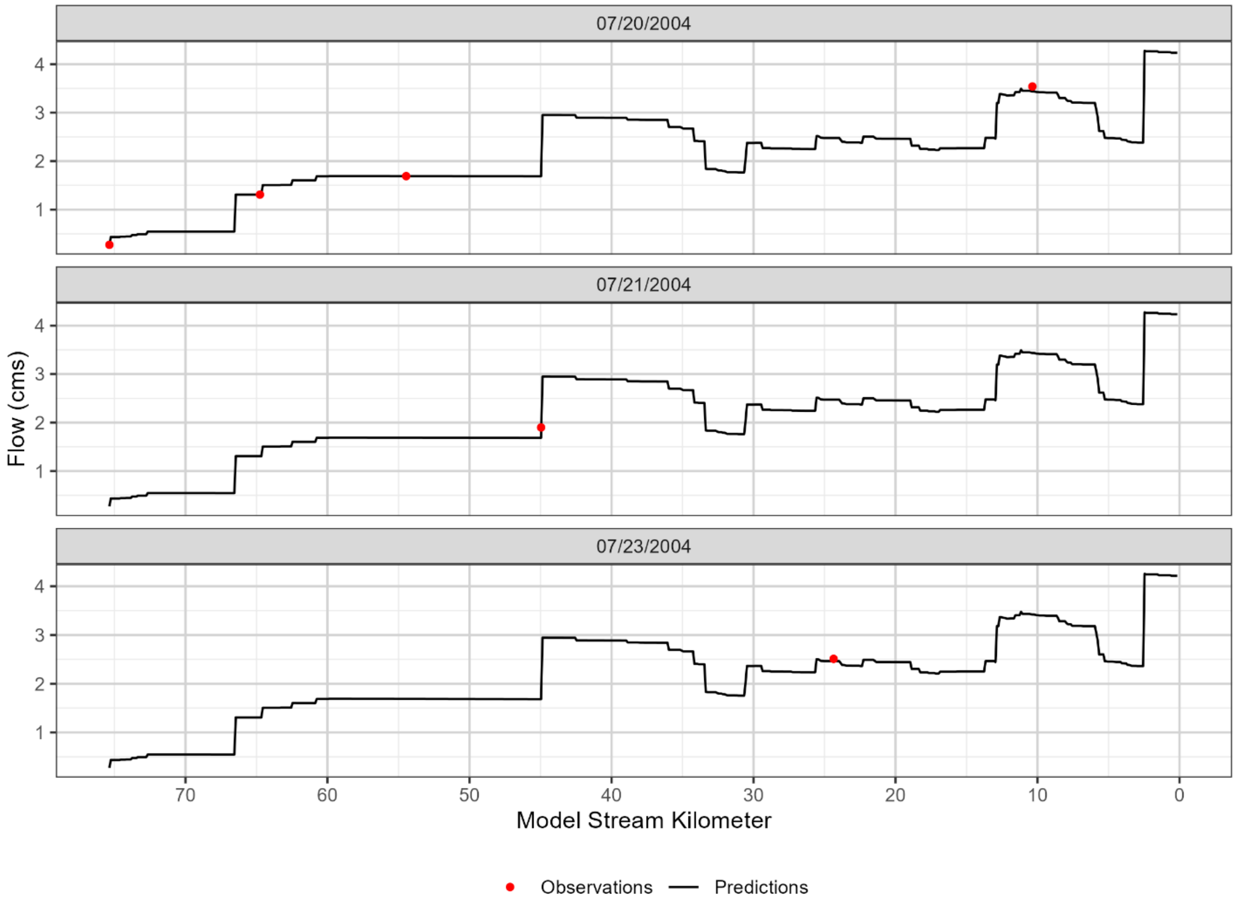


Figure 3-56: Molalla River field observed and model-predicted flow rates.

Table 3-16: Flow rate goodness of fit statistics comparing field observed and model flow rates

N	R^2	ME	MAE	RMSE
6	0.99	-0.06	0.06	0.1

3.2.11.3 Channel

DEQ verified model output by comparing model simulated characteristics with measurements of wetted depth, wetted width, and bankfull width. The average stream depth at a site is the average of each of the depth measurements (usually 10 to 20, depending on the width of the channel) recorded during the cross-sectional stream discharge measurements. The average depth measurements for the Molalla River compared with the modeled depths are shown in **Figure 3-57**. The measured depths are shown with bars that represent the range of depth measurements across the channel at that site.

Results comparing channel widths derived from GIS and modeling to those measured in the field are presented in **Figure 3-58**. The wetted width measurements agree with the simulated measurements reasonably well.

DEQ verified those remote measurements of bankfull width with four field measurements (**Figure 3-59**). The agreement is reasonable and the discrepancy between remotely measured and field measured bankfull width near the headwaters is likely because the more dense vegetation obscures the stream banks in the aerial photographs. The discrepancy may also result from the GIS measurement and the field measurement occurring at slightly different locations on the stream.

Figure 3-60 illustrates a comparison of the GIS-measured bankfull width with the simulated wetted width. The wetted width is a model-calculated characteristic based on the channel shape and the amount of stream flow. One would expect the wetted width to be less than the bankfull width, but follow a similarly varying pattern. **Figure 3-60** indicates this is generally the case and that the model's calculations of wetted width are realistic.

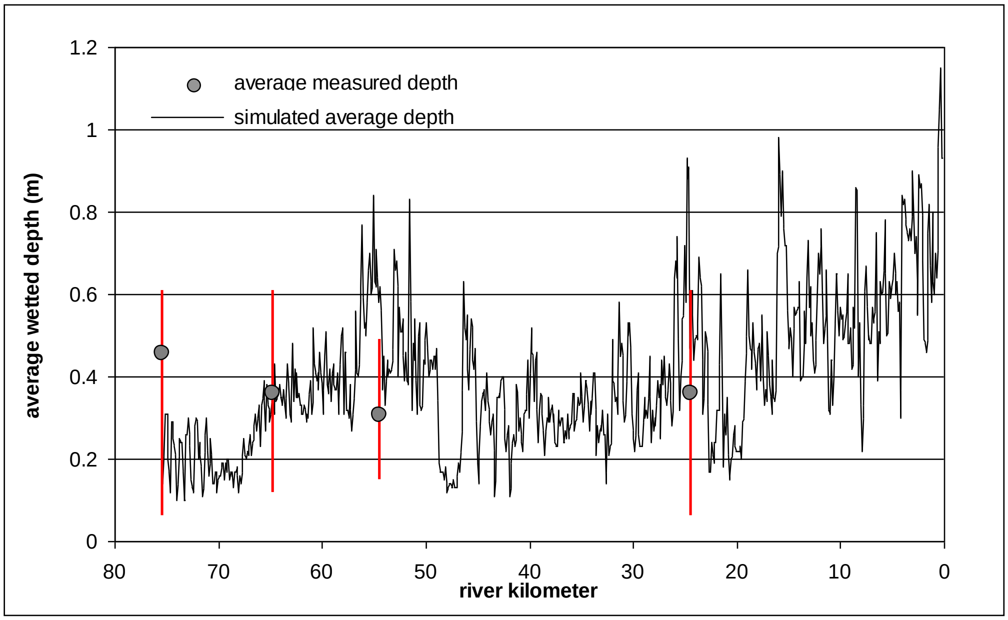


Figure 3-57: Molalla River simulated wetted depth and field measured average depth.

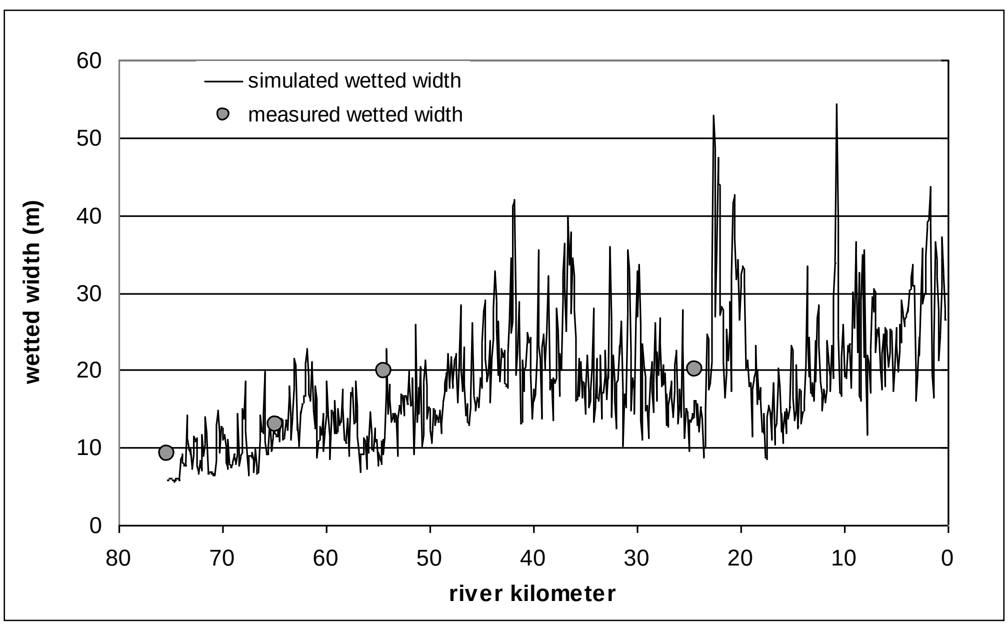


Figure 3-58: Molalla River simulated wetted width and field measured wetted width.

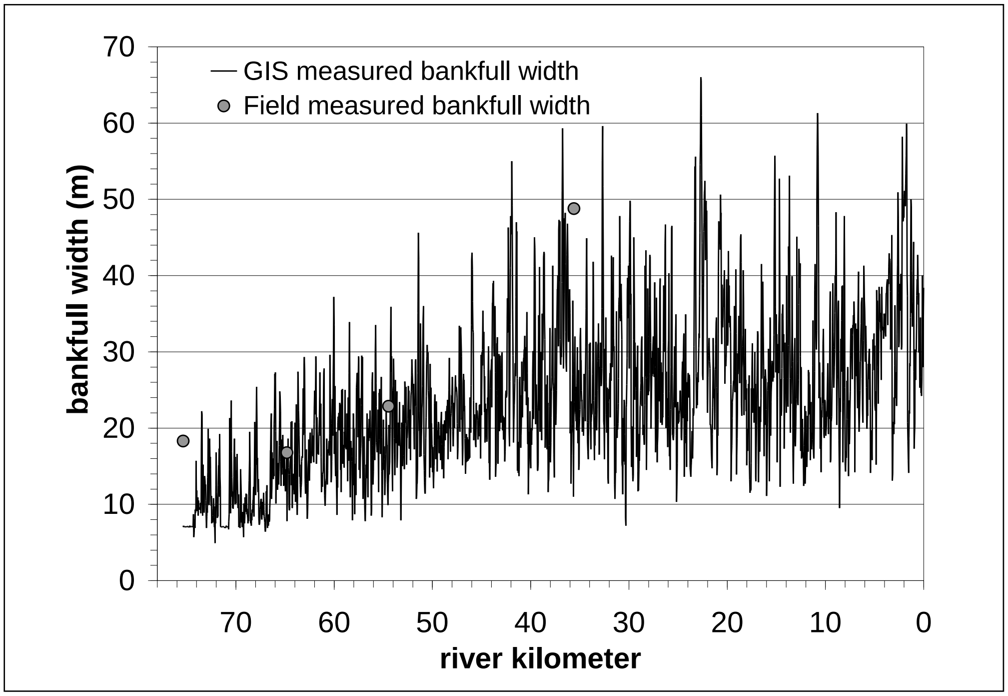


Figure 3-59: Molalla River remotely measured bankfull width and field measured bankfull width.

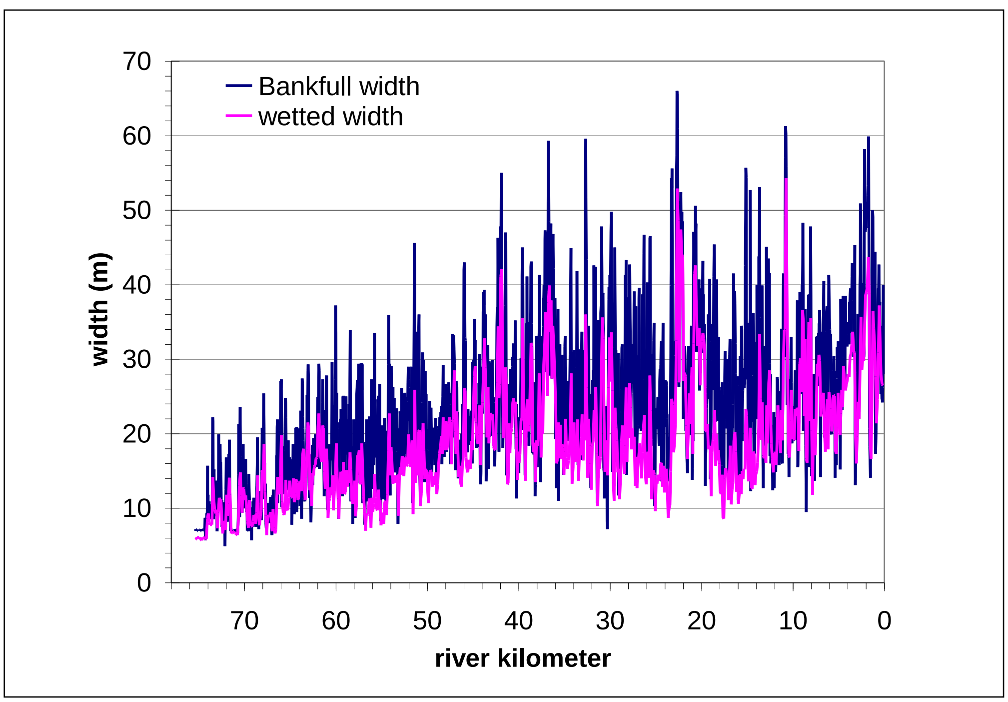


Figure 3-60: Comparison of bankfull width and simulated wetted width of the Molalla River.

3.3 Pudding River

The Pudding River model is a temperature model developed using Heat Source 8.0. The model was developed by DEQ.

3.3.1 Model extent

The extent of the model domain is the Pudding River from the mouth to upstream of the confluence with Drift Creek at river kilometer 84.5 (**Figure 3-61**).

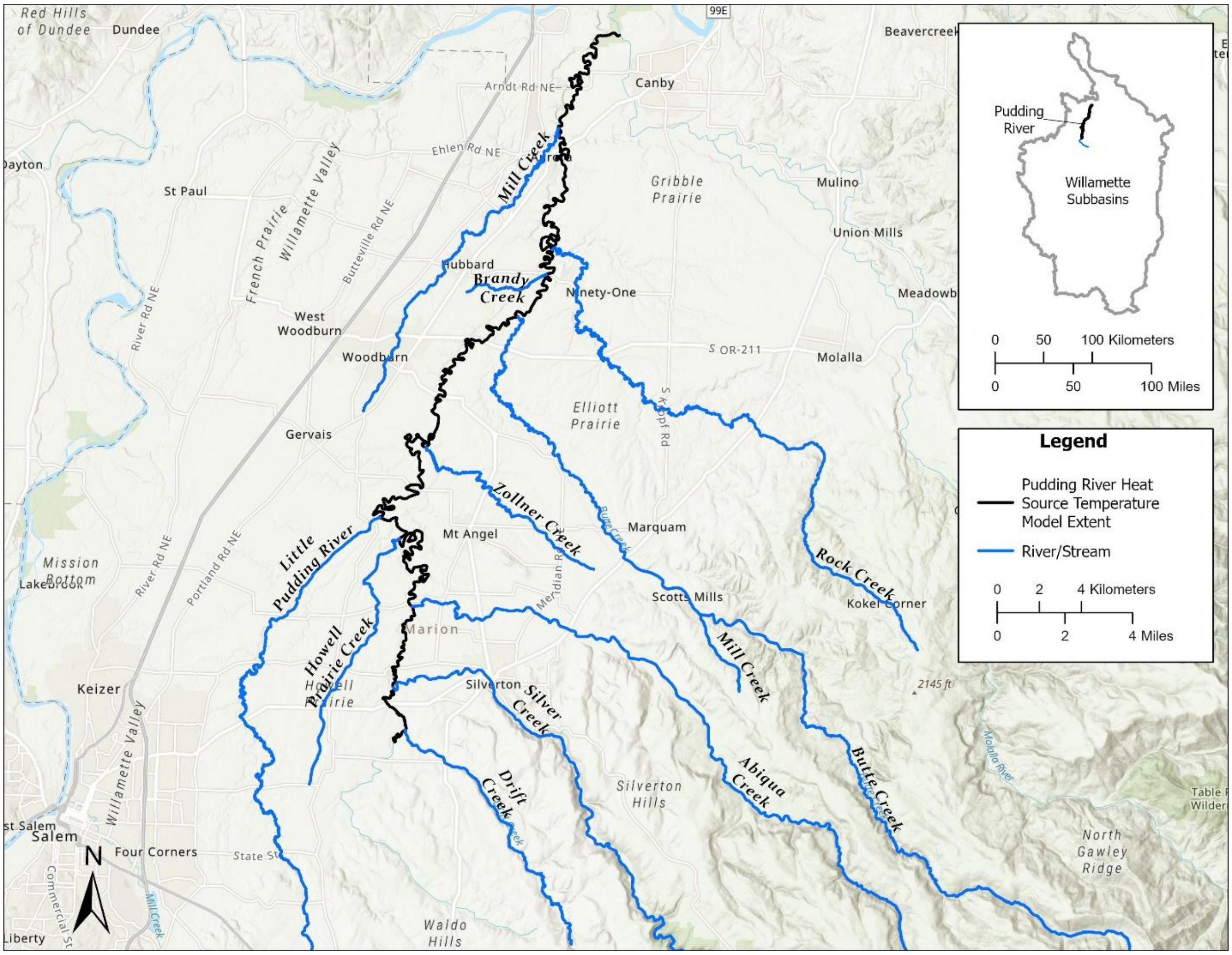


Figure 3-61: Pudding River temperature model extent.

3.3.2 Spatial and temporal resolution

The model input spatial resolution (*dx*) is 30 m. Outputs are generated every 100 m. The model time step (*dt*) is 4 minute and outputs are generated every hour.

3.3.3 Time frame of simulation

The model period is August 01, 2004, to August 14, 2004.

3.3.4 Meteorological inputs

The model was set up using hourly air temperature and relative humidity measurements and constant wind speed of zero cms (**Table 3-17** and **Figure 3-62**).

Table 3-17: Meteorology data sources for the Pudding River model.

Model Location Name	Model Location (kilometers)	Model Input	Data Source
arao - Aurora	7.7, 12.4, 36.2, 43.7, 51.7, 66.3, 79.6	Air Temperature, Relative Humidity, Wind Speed	Oregon AgriMet Weather Station
KUAO - Aurora State Airport	7.7, 12.4, 36.2, 43.7, 51.7, 66.3, 79.6	Cloudiness	NWS

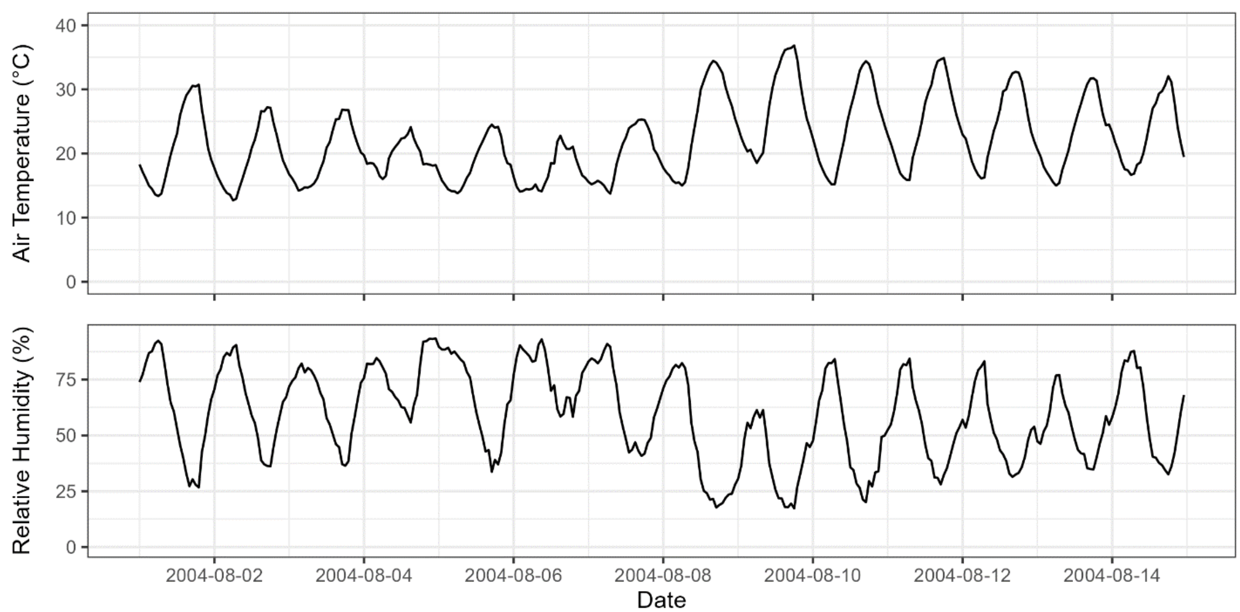


Figure 3-62: Meteorological inputs to the Pudding River model.

3.3.5 Temperature inputs

Hourly water temperature time series data were used to support tributary and boundary condition model setup. **Figure 3-63** shows the locations of the various stream temperature monitoring locations that were used for model setup or calibration.

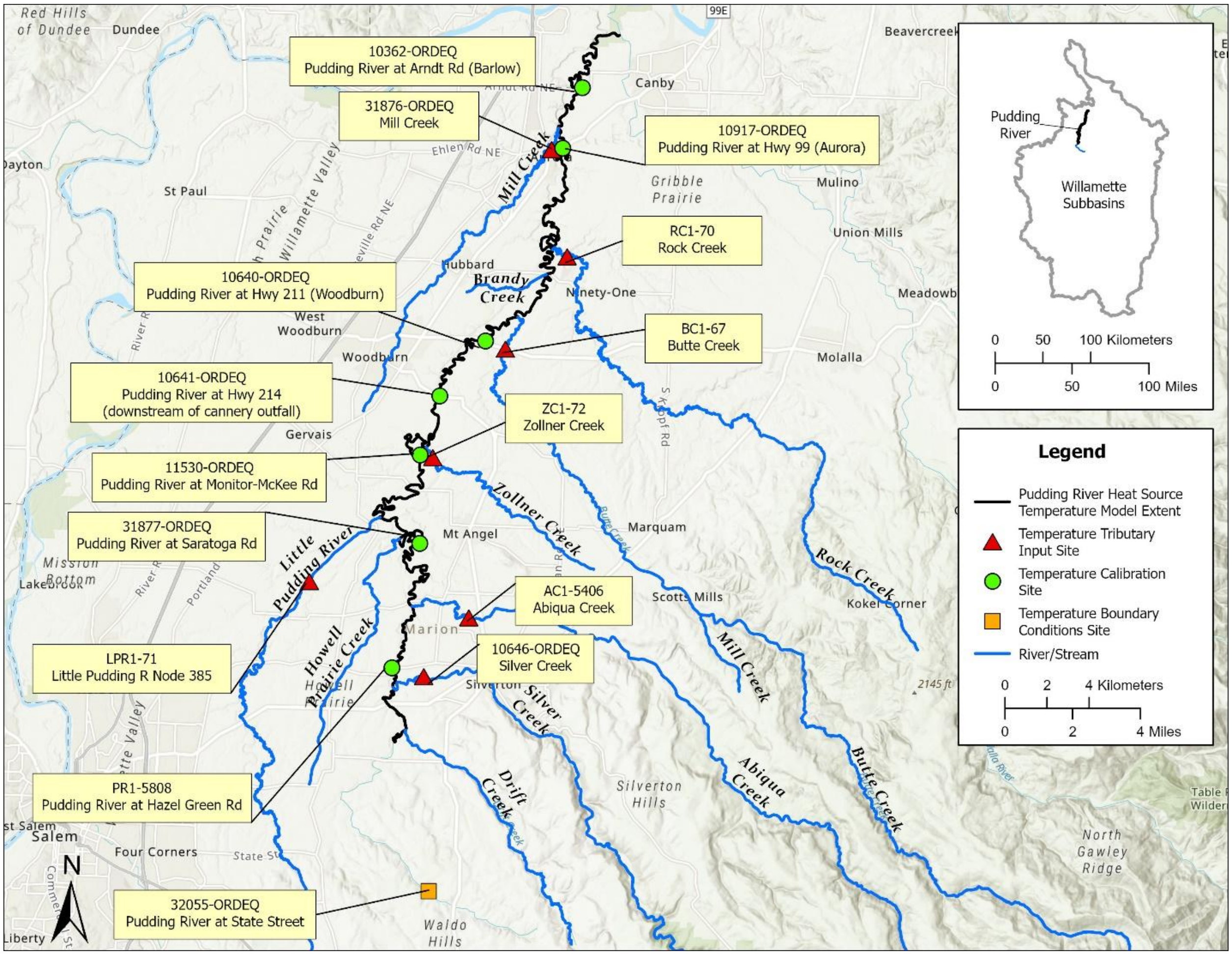


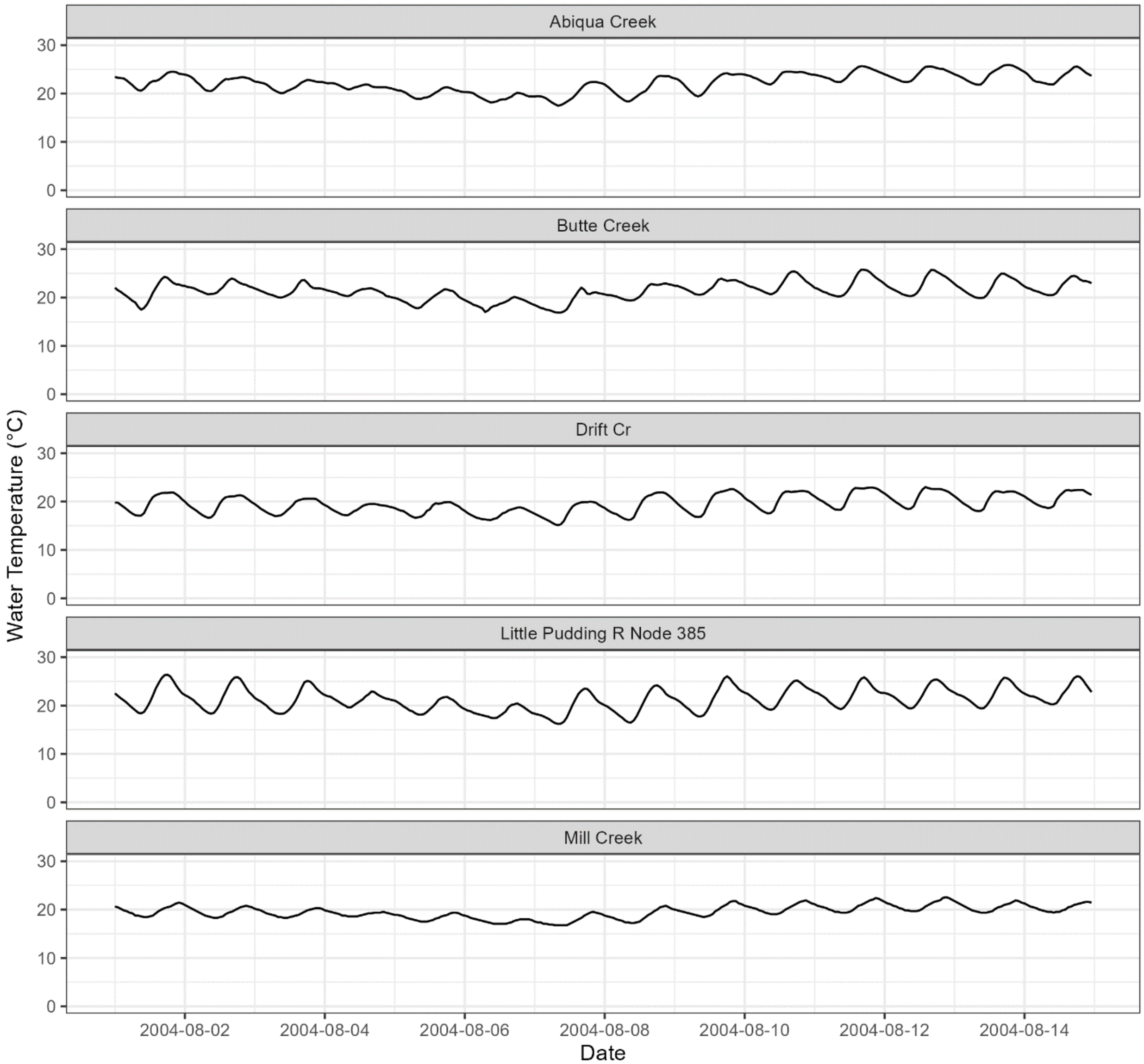
Figure 3-63: Temperature monitoring locations used for the Pudding River model setup and calibration.

Table 3-18 and **Figure 3-64** document the water temperature inputs to the model at the boundary condition (Pudding River at State Street) and tributaries.

Table 3-18: Boundary condition and tributary water temperature inputs to the Pudding River model.

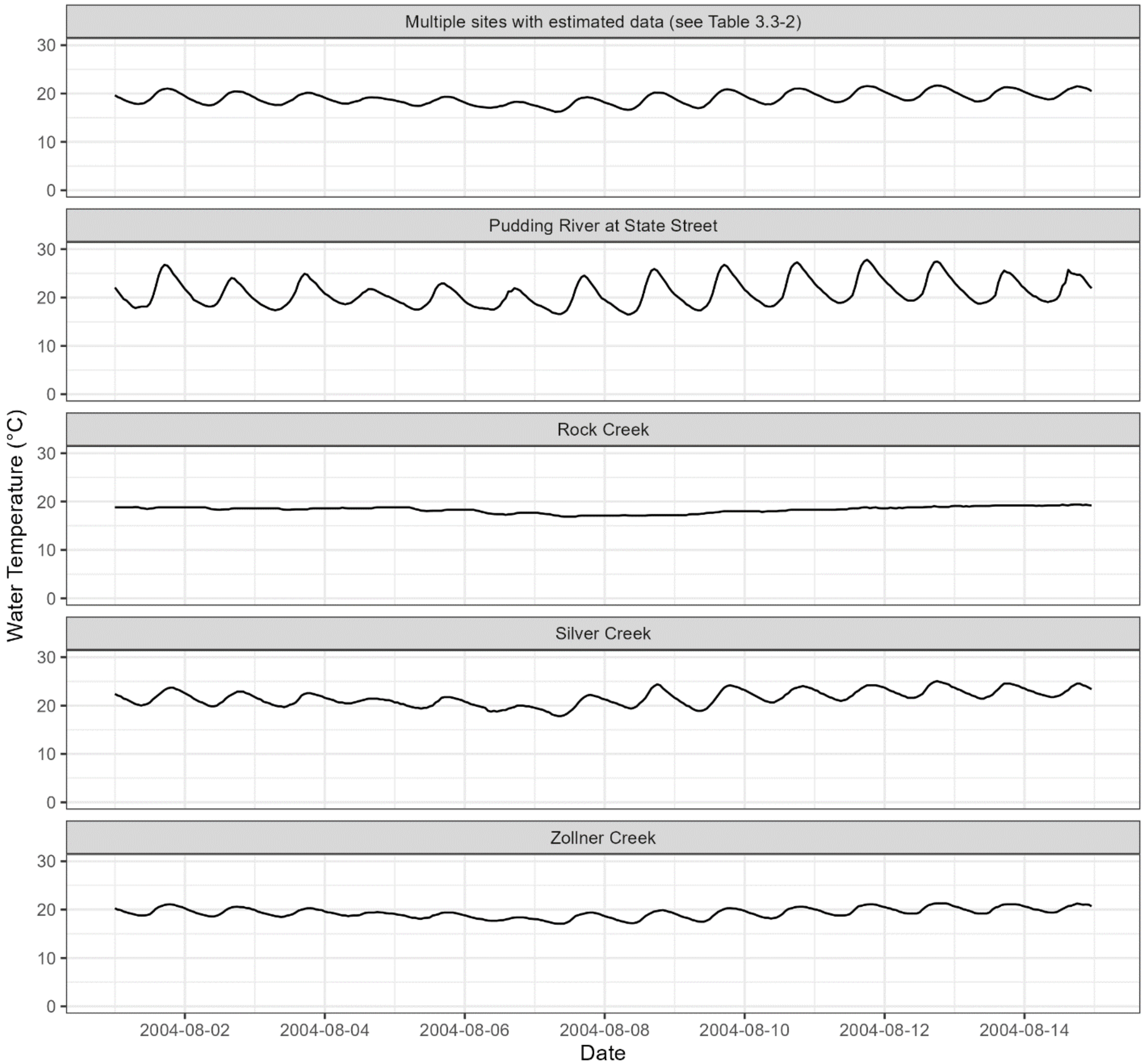
Model Location Name	Model Location (kilometers)	Input Type	Data Source
Pudding River at State Street	84.6	Boundary Condition	32055-ORDEQ
Drift Cr	84.5	Tributary	Derived from a linear interpolation between Marion County SWCD station DC2 and DEQ temperature station 32057-ODEQ.
Lower Pudding R / Howell Prairie Catchment 1 (blw Drift Cr)	82.3	Tributary	Estimated data*

Model Location Name	Model Location (kilometers)	Input Type	Data Source
Silver Creek at Brush Creek Road	81.2	Tributary	10646-ORDEQ
Lower Pudding R / Howell Prairie Catchment 2 (Silver to Abiqua) Node 180	80.9	Tributary	Estimated data*
Abiqua Creek	75.1	Tributary	Marion SWCD (AC1-5406)
Lower Pudding R / Howell Prairie Catchment 3 (upstream Mt. Angel gage) Node 278	71.1	Tributary	Estimated data*
Howell Prairie Cr Node 360	62.9	Tributary	Estimated data*
Little Pudding R Node 385	60.4	Tributary	Marion SWCD (LPR1-71)
Unnamed Trib (Sacred Heart Cr) to the Pudding at Monitor-McKee Rd Node 478	51.1	Tributary	Estimated data*
Zollner Creek	47.6	Tributary	Marion SWCD (ZC1-72)
Unnamed Trib Node 580 inflow (19% of 6th field)	40.9	Tributary	Estimated data*
Butte Creek	32.9	Tributary	Marion SWCD (BC1-67)
Brandy Creek Node 703	28.6	Tributary	Estimated data*
Rock Creek	24.9	Tributary	Marion SWCD (RC1-70)
DA between Mill Cr and Pudding R to Node 794	19.5	Tributary	Estimated data*
DA Rt side Pudding upstream Mill to Node 837	15.2	Tributary	Estimated data*
Mill Creek at Ehlen Road	10.8	Tributary	31876-ORDEQ
DA Lt side Pudding ds Mill to Arndt Rd Node 894	9.5	Tributary	Estimated data*
DA Rt side Pudding ds Mill to Arndt Rd Node 907	8.2	Tributary	Estimated data*
DA Rt side ds Arndt Rd Node 967	2.2	Tributary	Estimated data*
DA Lt side ds Arndt Rd Node 971	1.8	Tributary	Estimated data*
* Temperature data from a mix of Mill Creek (31876-ODEQ), Zollner Creek (ZC1-72-Marion SWCD), Upper Pudding Creek and groundwater data.			



Abiqua Creek
Butte Creek
Drift Cr
Little Pudding R Node 385
Mill Creek
Water Temperature (°C)
30
20
10
0
2004-08-02
2004-08-04
2004-08-06
2004-08-08
2004-08-10
2004-08-12
2004-08-14
Date

(A)



(B)
Figure 3-64 (A) and (B): Boundary condition and tributary water temperature inputs to the Pudding River model.

3.3.6 Flow inputs

Hourly stream flow time series data were used to support tributary and boundary condition model setup. **Figure 3-65** shows the locations of the various stream flow monitoring locations that were used for model setup or calibration.

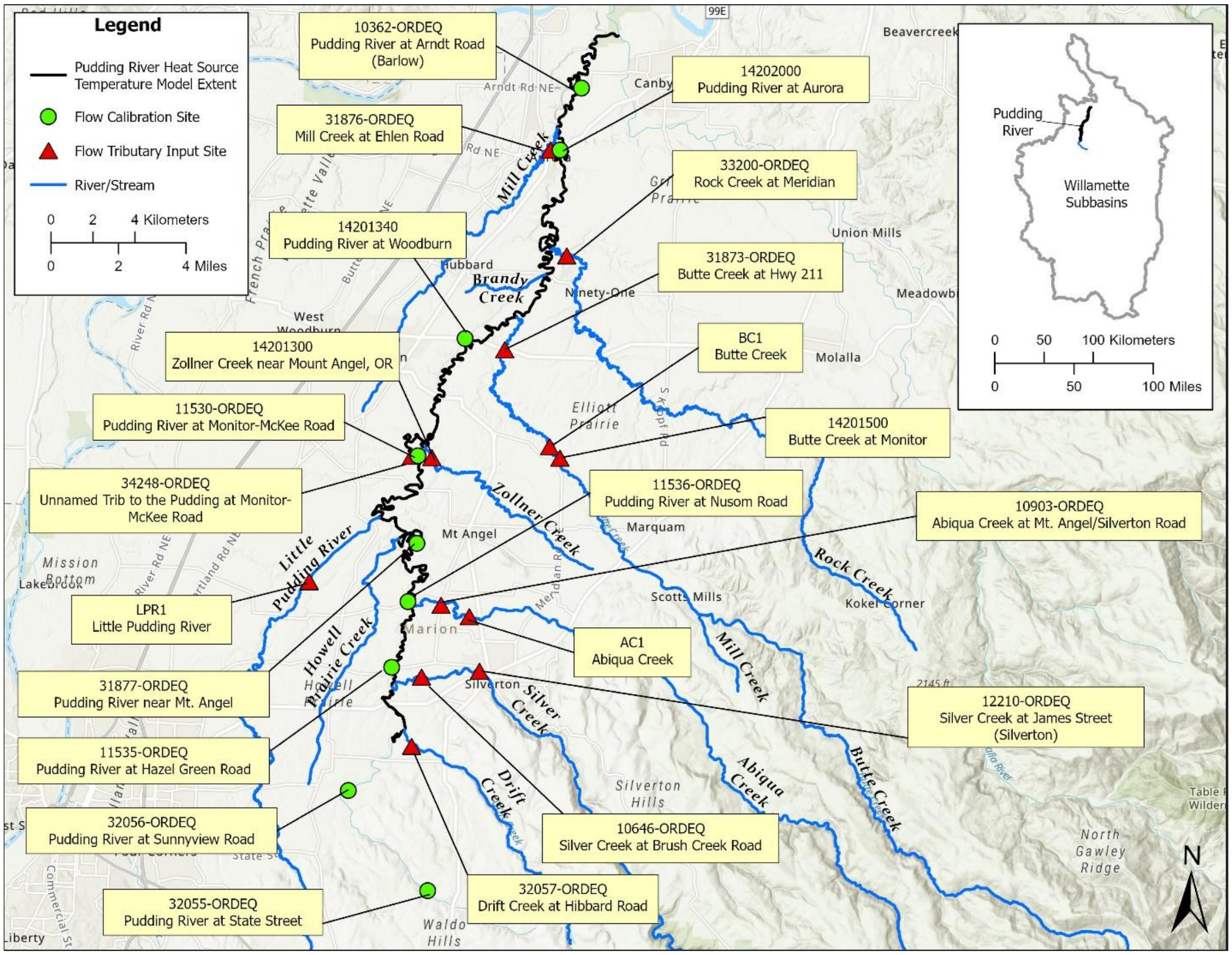


Figure 3-65: Flow monitoring locations used for the Pudding River model setup and calibration.

To provide a uniform method for estimating Pudding River tributary inflow rates, tributary inflows were based on the discharge from a reference watershed, Little Abiqua Creek. Discharge from this watershed was measured by the Little Abiqua Creek at Scotts Mills USGS gage (14200400, active from 1993 through 2004). Because little or no water is diverted from Little Abiqua Creek, it was useful for estimating natural stream flows for the subbasin. Flow statistics for the stream are shown in **Table 3-19**. As shown, the annual 7Q10 flow rate for the stream is 0.05 cms (1.7 cfs), which equals 50% of the median August flow rate.

Since natural stream flow rates were available for this gage, natural flows for all tributaries to the Pudding River were referenced to this site.

Table 3-19. Flow statistics for Little Abiqua Creek.

Time period	1st percentile (cfs)	10th percentile (cfs)	Median (cfs)	Annual 7Q10 (cfs)	August Median (cfs)
1993-2004	1.9	3.0	10.8	81.7	3.4

OWRD water availability reports (Detailed Report on the Water Availability Calculation) were used to obtain median (i.e. exceedance level: 50) August natural stream flow rates for Drift Creek, Silver Creek, Abiqua Creek, Butte Creek and Mill Creek as well as for the Pudding River at several locations (**Table 3-20**) (OWRD, 2002). As shown, the median August natural stream flow rate per unit drainage area for the Pudding River is 0.173 cfs/mi^2, based on the natural flow rate at the Pudding River mouth divided by the watershed drainage area. For tributaries, the natural flow per unit area ranges from 0.082 to 0.265 cfs/mi^2. For flow contributed by tributaries other than Drift, Silver, Abiqua, Butte and Mill Creeks, the natural flow per unit area is 0.155 cfs/mi^2.

For tributaries other than those for which natural stream flow and consumptive use estimates were explicitly provided by OWRD, natural flow was based on a natural flow per unit area of 0.155 cfs/mi^2 (**Table 3-20**). To derive this value, natural flows of Drift, Silver, Abiqua, Butte and Mill Creeks were subtracted from the natural flow of the Pudding River at mouth. The resultant flow was then divided by the Pudding River drainage area not associated with the five tributaries to derive the 0.155 cfs/mi^2 value. This value was used for the headwater area upstream from Drift Creek; several significant tributaries for which natural flows were not estimated by OWRD including Howell Prairie Creek, Little Pudding River, Zollner Creek, and Rock Creek; and a number of small drainage areas located close to the Pudding River that are not associated with named tributaries.

Table 3-20: Median August stream discharge per unit area for Pudding River and tributaries based on OWRD estimates.

Location Name	Drainage Area (sq.mi.)	Median Flow (cfs)	Median Flow / Drainage Area (cfs/sq.mi.)
Pudding River at Mouth	525	91	0.173
Pudding River above Mill Creek (Aurora gage)	480	89.6	0.187
Pudding River above Howell Prairie (Mt. Angel gage)	206	34.6	0.168
Drift Creek	17.9	2.37	0.132
Silver Creek	53.2	14.1	0.265
Abiqua Creek	78.1	15.1	0.193
Butte Creek	69.7	14.7	0.211
Mill Creek	37	3.03	0.082
Pudding River at mouth minus tributaries (Drift, Silver, Abiqua, Butte and Mill)	269.1	41.7	0.155

Natural stream flow rate for a tributary is calculated using **Equation 3-2**.

$$Q_{R,Natural} = F_{Cali}\left(\frac{Q_{R,AugMedian}}{Q_{R,LittleAbiquaCr,AugMedian}}\right)Q_{R,LittleAbiquaCr} \qquad \textbf{Equation 3-2}$$

where,

$Q_{R,Natural}$	=	Natural flow rate for tributary on given date (cfs).
F_{Cali}	=	Calibration adjustment factor.
$Q_{R,AugMedian}$	=	Median August natural stream flow rate for tributary (cfs).
$Q_{R,LittleAbiquaCr,AugMedian}$	=	Median August Little Abiqua flow rate (cfs)
$Q_{R,LittleAbiquaCr}$	=	Little Abiqua Creek flow rate for given date (cfs)

The amount of flow consumed for each day was calculated by using **Equation 3-3**. The typical percent natural flow consumed, $F_{\%Consumed,\ Normal}$, is an estimate of the percent of natural flow consumed during typical August conditions (warm, sunny days with no precipitation). It is a constant for each tributary.

The percent of typical consumptive use (CU) on a given day, $F_{\%ofNormal}$, is a value that was varied day by day in order to match observed flows. For most days, the percent of typical CU consumed ranged from 90% to 110%. On one day, August 7, which was the only day with significant precipitation, this value was reduced to 20% to allow sufficient water to remain in the system to match the large increase in flow observed at Woodburn. This is appropriate because during a rainfall event, less water is diverted for irrigation and because more of any water that is diverted is not consumed by evaporation and transpiration and, therefore, is returned to the stream.

While estimation of natural flow rates was relatively straightforward, estimation of the percent of the natural flow that was consumptively used was more complicated, particularly because very little flow data was collected during the August 2004 calibration period. Two sets of data were used to help guide derivation of the consumptive use values for each tributary: the USGS flow data at the two gages and supplemental river and tributary flow data measured by DEQ during a similar low flow period in 2007.

The consumptive use terms in **Equation 3-3**, $F_{\%Consumed,\ Normal}$ and $F_{\%ofNormal}$, were then derived through an iterative model calibration process.

$$CU = F_{\%ofNormal}\ x\ F_{\%ConsumedNormal}\ x\ Q_{R,Natural,min} \qquad \textbf{Equation 3-3}$$

where,

CU	=	Consumptive Use: quantity of stream flow rate consumed (cfs).
$F_{\%ofNormal}$	=	Percent of typical CU consumed on a given day.
$F_{\%ConsumedNormal}$	=	Typical percent of natural tributary flow rate consumed.
$Q_{R,Natural,min}$	=	10^{th} percentile low August natural tributary flow rate (cfs).

The flow input to the model for each tributary is the natural stream flow minus the consumptive use, as shown in **Equation 3-4**, with the inflows shifted by 1-day to account for time-of-travel from the tributary to the gage used in calibration. In some cases calculated CU exceeded

$Q_{R,Natural}$, in which case $Q_{R,Tributary}$ was set to zero. The values were input to the model as hourly values, with hourly values derived via linear interpolation from daily values.

$$Q_{R,Tributary} = Q_{R,Natural} - CU$$ **Equation 3-4**

where,

$Q_{R,Tributary}$	=	Tributary inflow rate to Pudding River for given date (cfs).
$Q_{R,Natural}$	=	Natural tributary flow rate for given date (cfs).
CU	=	Consumptive Use: quantity of stream flow rate consumed (cfs).

This information was used along with stream flow rates measured in August 2007 to derive natural flow and consumptive use estimates to calibrate the Heat Source model for flow. The goal was to match the measured flow at the Woodburn and Aurora gages during the period modeled.

Much of the available natural tributary flows are consumptively used, with most of the consumptive use during the summer by irrigation. **Figure 3-66** shows PODs for the Pudding River and tributaries. Thirty-seven PODs were used in calibrating the model under current conditions.

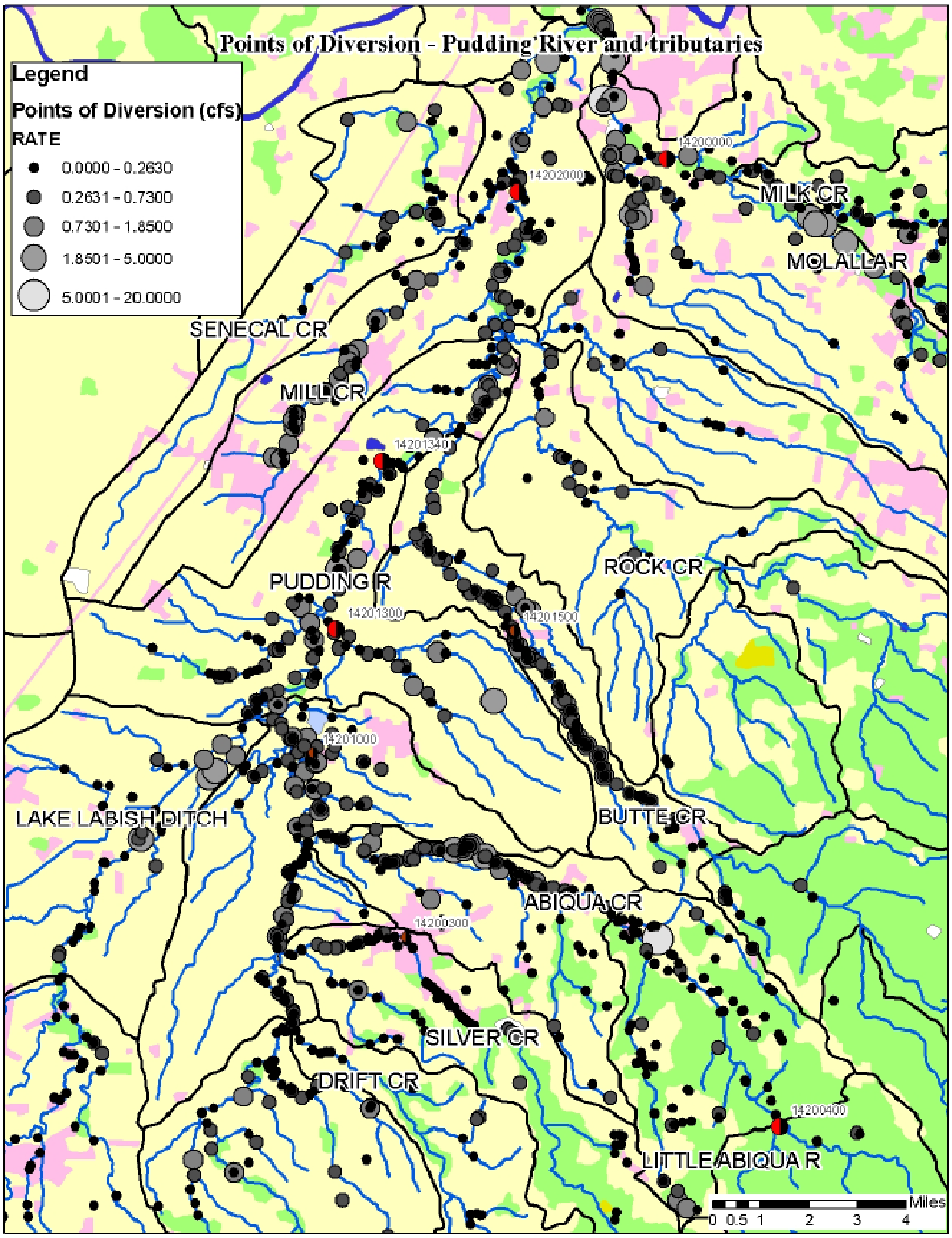


Figure 3-66: PODs from Pudding River and tributaries.

Here is an example of calculating natural stream flow rates for Silver Creek.

The Silver Creek natural stream flow rate, without consumptive use via diversions, equals 4.15 times the gauged Little Abiqua Creek flow rate, times an adjustment factor of 123% derived during the model calibration process (**Table 3-21**). Therefore, the estimated Silver Creek natural flow rate for a given day equaled 5.1 times the gauged Little Abiqua Creek flow rate for the day.

For Silver Creek, OWRD water availability reports indicate that the median August consumptive use is 6.31 cfs. Therefore, OWRD estimates that 51.5% of the estimated 14.1 cfs median August natural flow stream is consumed.

Resultant Silver Creek inflows to the Pudding River model are shown in **Table 3-21**.

Table 3-21: Tributary inflow estimates - Silver Creek Example.

Date	Tributary Consumptive use adjustment factor F%ofNormal	Little Abiqua Creek flow rate QR,LittleAbiquaCr (cfs)	Natural Flow QR,Natural (cfs)	Estimated Consumptive Use CU (cfs)	Net Flow QR,Tributary (cfs)	Net Flow Shifted 1-day QR,Tributary (cfs)
8/1/2004	70.0%	3.3	16.86	4.42	12.44	12.44
8/2/2004	100.0%	3.3	16.86	6.31	10.55	12.44
8/3/2004	110.0%	3.2	16.35	6.95	9.40	10.55
8/4/2004	110.0%	3.1	15.84	6.95	8.89	9.40
8/5/2004	100.0%	3.2	16.35	6.31	10.03	8.89
8/6/2004	80.0%	3.6	18.39	5.05	13.34	10.03
8/7/2004	20.0%	4.2	21.46	1.26	20.20	13.34
8/8/2004	110.0%	4.5	22.99	6.95	16.04	20.20
8/9/2004	100.0%	3.4	17.37	6.31	11.06	16.04
8/10/2004	90.0%	3	15.33	5.68	9.64	11.06
8/11/2004	100.0%	2.8	14.31	6.31	7.99	9.64
8/12/2004	100.0%	2.7	13.79	6.31	7.48	7.99
8/13/2004	100.0%	2.7	13.79	6.31	7.48	7.48
8/14/2004	100.0%	2.6	13.28	6.31	6.97	7.48

Table 3-22 and **Figure 3-67** document the flow inputs to the model at the boundary condition (Pudding River upstream of Drift Creek) and tributaries.

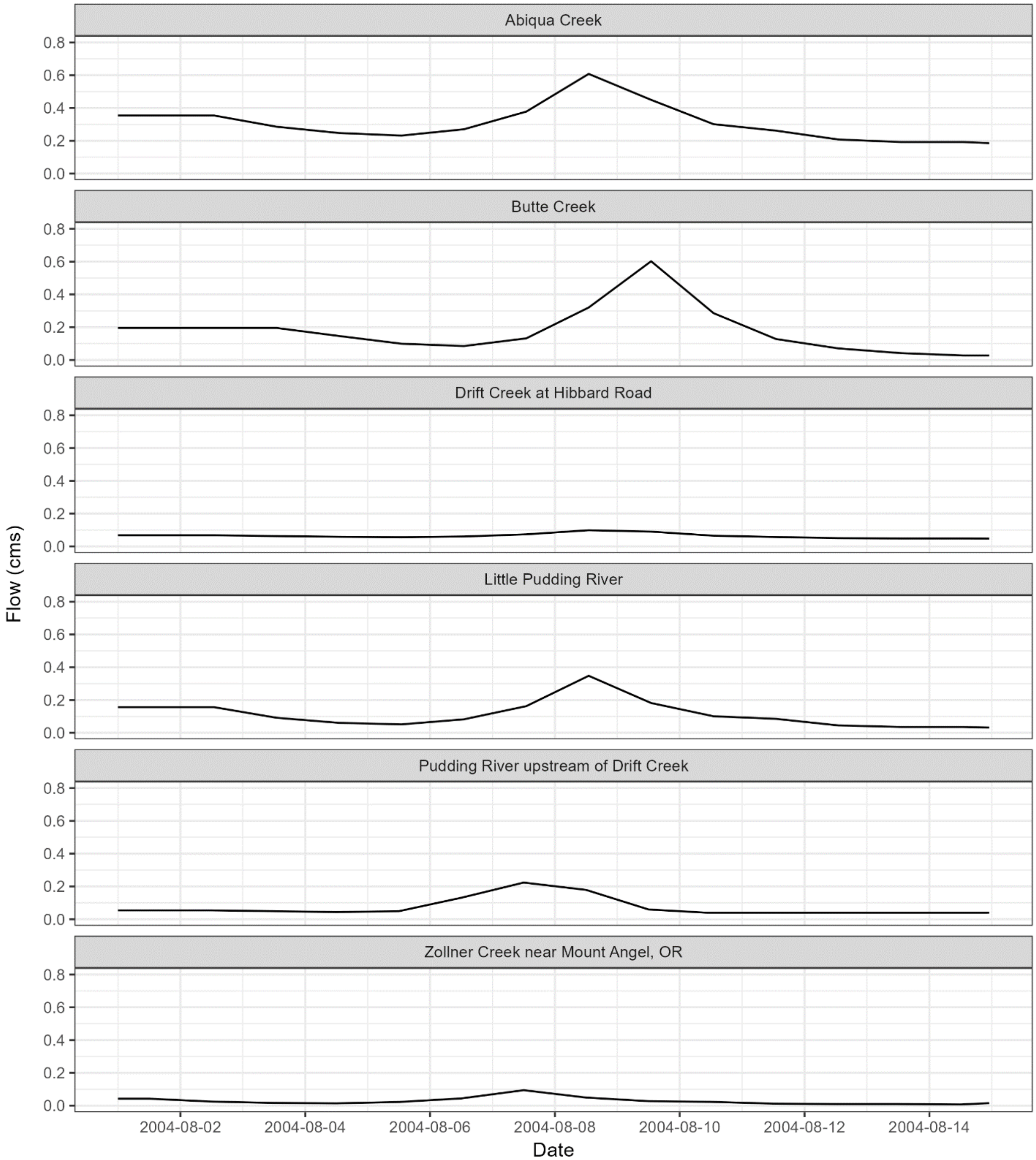


Table 3-22: Boundary condition and tributary flow inputs to the Pudding River model.

Model Location Name	Model Location (kilometers)	Input Type	Data Source
Pudding River upstream of Drift Creek	84.6	Boundary Condition	OWRD
Drift Creek	84.5	Tributary	Marion SWCD (DC1)
Lower Pudding R / Howell Prairie Catchment 1 (blw Drift Cr)	82.3	Tributary	Estimated data
Silver Creek	81.2	Tributary	Estimated data
Lower Pudding R / Howell Prairie Catchment 2 (Silver to Abiqua) Node 180	80.9	Tributary	Estimated data
Abiqua Creek	75.1	Tributary	Marion SWCD (AC1)
Lower Pudding R / Howell Prairie Catchment 3 (upstream Mt. Angel gage) Node 278	71.1	Tributary	Estimated data
Howell Prairie Cr Node 360	62.9	Tributary	Estimated data
Little Pudding River	60.4	Tributary	Marion SWCD (LPR1)
Unnamed Trib (Sacred Heart Cr) to the Pudding at Monitor-McKee Rd Node 478	51.1	Tributary	Estimated data
Zollner Creek at USGS Gage	47.6	Tributary	USGS (14201300)
Unnamed Trib Node 580 inflow (19% of 6th field)	40.9	Tributary	Estimated data
Butte Creek	32.9	Tributary	Marion SWCD (BC1)
Brandy Creek Node 703	28.6	Tributary	Estimated data
Rock Creek	24.9	Tributary	Estimated data
DA between Mill Cr and Pudding R to Node 794	19.5	Tributary	Estimated data
DA Rt side Pudding upstream Mill to Node 837	15.2	Tributary	Estimated data
Mill Creek	10.8	Tributary	Estimated data
DA Lt side Pudding ds Mill to Arndt Rd Node 894	9.5	Tributary	Estimated data
DA Rt side Pudding ds Mill to Arndt Rd Node 907	8.2	Tributary	Estimated data
DA Rt side ds Arndt Rd Node 967	2.2	Tributary	Estimated data
DA Lt side ds Arndt Rd Node 971	1.8	Tributary	Estimated data

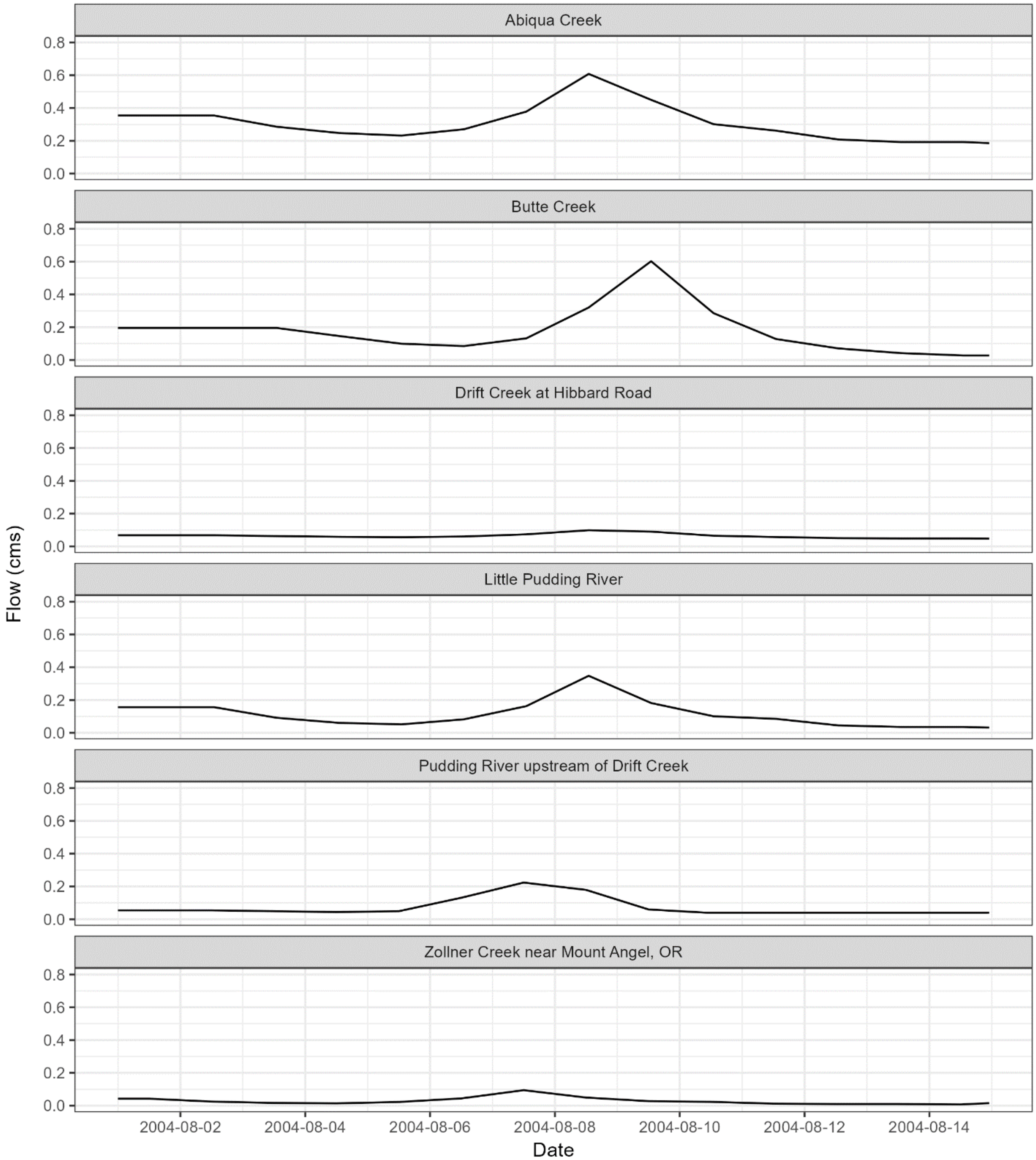


Figure 3-67: Boundary condition and tributary flow inputs to the Pudding River model.

3.3.7 Point source inputs

There are two point sources included in the calibrated model. Discharges for both were based on effluent characteristics completed at the time of model development.

Discharge from the JLR, LLC facility (formerly known as Agripac/Bruce Pac) enters the Pudding River at river mile 27. The facility currently does not discharge in the summer months, but irrigates adjacent agricultural land, separate parcels for the treated domestic wastewater and treated process water. The original calibrated model used a constant discharge rate of 0.001 cms for the JLR facility, with effluent discharging at a constant temperature of 18.0°C.

The City of Woodburn Wastewater Treatment Plant (WWTP) discharges treated and dechlorinated wastewater to the Pudding River at river mile 23.6. The original calibrated model used variable effluent temperature and flow inputs for the Woodburn WWTP. These inputs are shown in **Figure 3-68** and **Figure 3-69**, respectively.

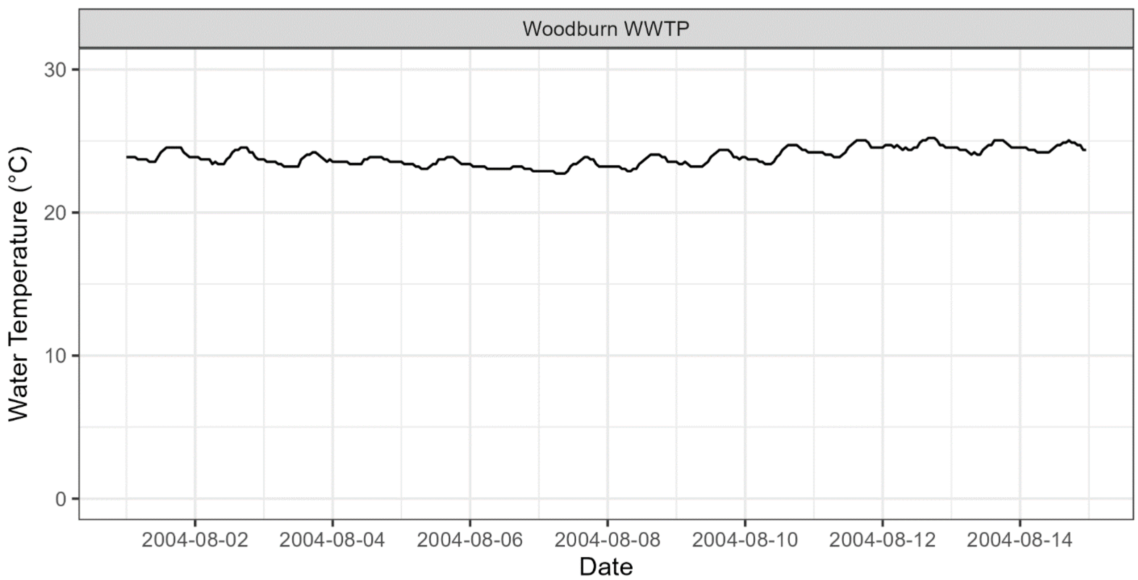


Figure 3-68: Pudding River current condition calibration model setup up for Woodburn WWTP effluent temperatures.

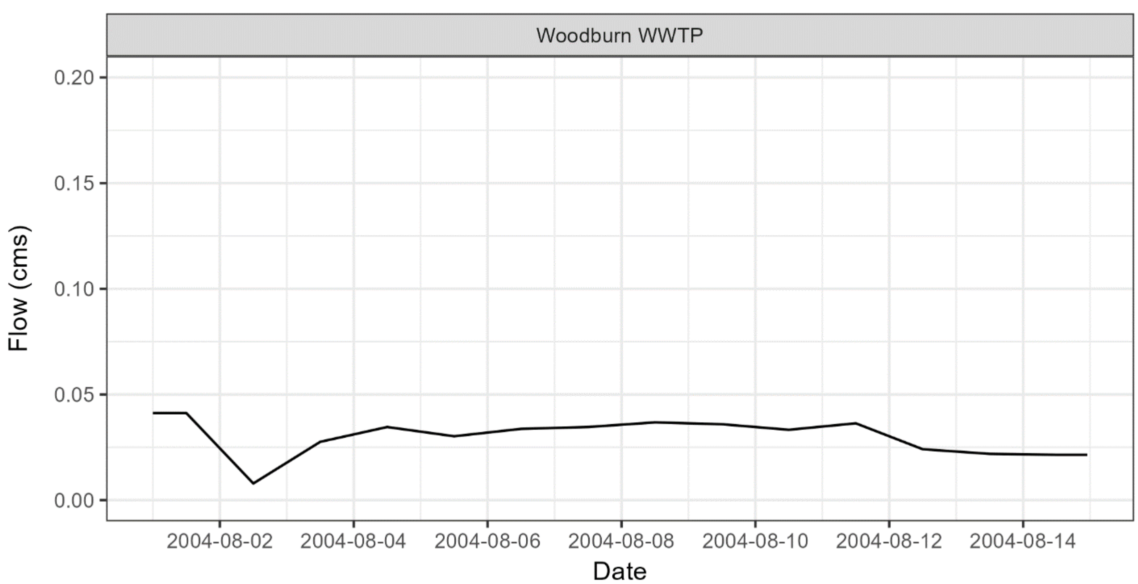


Figure 3-69: Pudding River current condition calibration model setup for Woodburn WWTP effluent flow rates.

A total of six permitted individual NPDES point sources are located along the model extent, and details about each point source are summarized in **Table 3-23**.

Gervais STP, Aurora STP and Mt. Angel STP were not included as point source inputs to the calibrated model since the facilities were not permitted to discharge during the model period.

Columbia Helicopters was not included as a point source to the calibrated model because DEQ considers wastewater from this site to have no reasonable potential to increase stream temperature in the Pudding River. The contaminants of concern for this facility are oil and grease, pH, some metals and volatile organic compounds.

Table 3-23: NPDES point sources located along the Pudding River model extent.

Facility Name (Facility Number)	Latitude/Longitude	Permit Type and Description	Stream/River Mile
Aurora STP (110020)	45.2291/-122.753	NPDES-DOM-Db: Sewage - less than 1 MGD with discharging lagoons	Pudding River RM 8.8
Columbia Helicopters (100541)	45.2776/-122.733	NPDES-IW-B16: All facilities not elsewhere classified which dispose of non-process wastewaters	Unnamed Stream (tributary to Pudding River RM 1.8) RM 2
Gervais STP (33060)	45.1079/-122.84	NPDES-DOM-Db: Sewage - less than 1 MGD with discharging lagoons	Pudding River RM 28.2
JLR, LLC (32536)	45.1261/-122.821	NPDES-IW-B05: Food/beverage processing - Large and complex. Flow greater than or equal to 1 MGD for 180 days/year or more	Pudding River RM 27
Mt. Angel STP (58707)	45.0678/-122.828	NPDES-DOM-Da: Sewage - less than 1 MGD	Pudding River RM 37.5
Woodburn WWTP (98815)	45.1509/-122.804	NPDES-DOM-C1a: Sewage - 2 MGD or more but less than 5 MGD	Pudding River RM 21.4

3.3.8 Landcover and topographic shade inputs

Average land cover height inputs and topographic shade angle inputs to the model are shown in **Figure 3-70** and **Figure 3-71**, respectively.

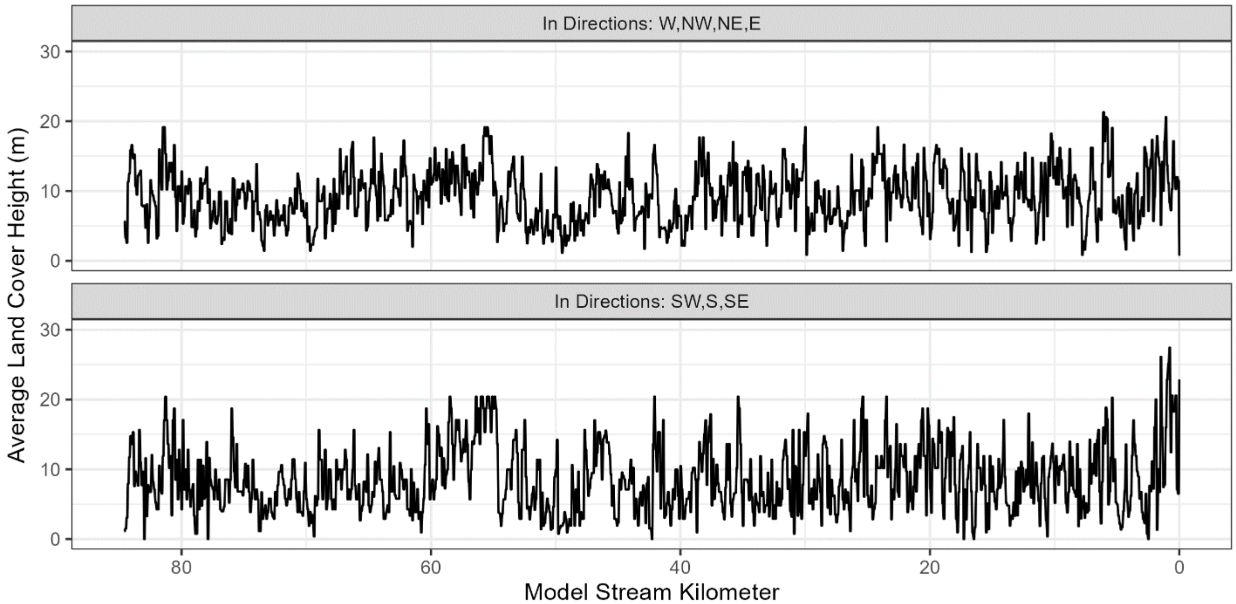


Figure 3-70: Pudding River model setup for landcover height (m).

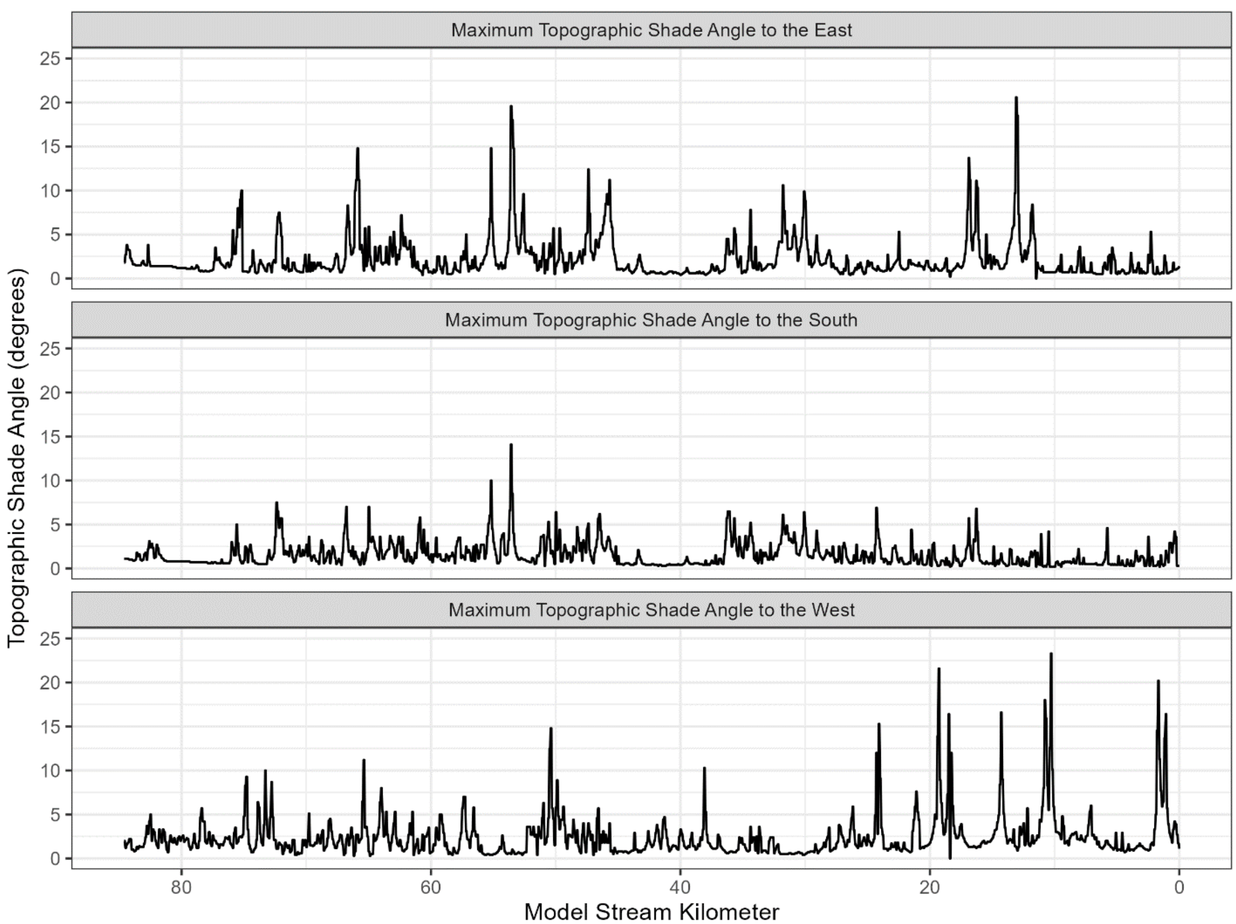


Figure 3-71: Topographic shade angle inputs to the Pudding River model.

3.3.9 Channel setup

Figure 3-72 shows channel setup for the Pudding River model.

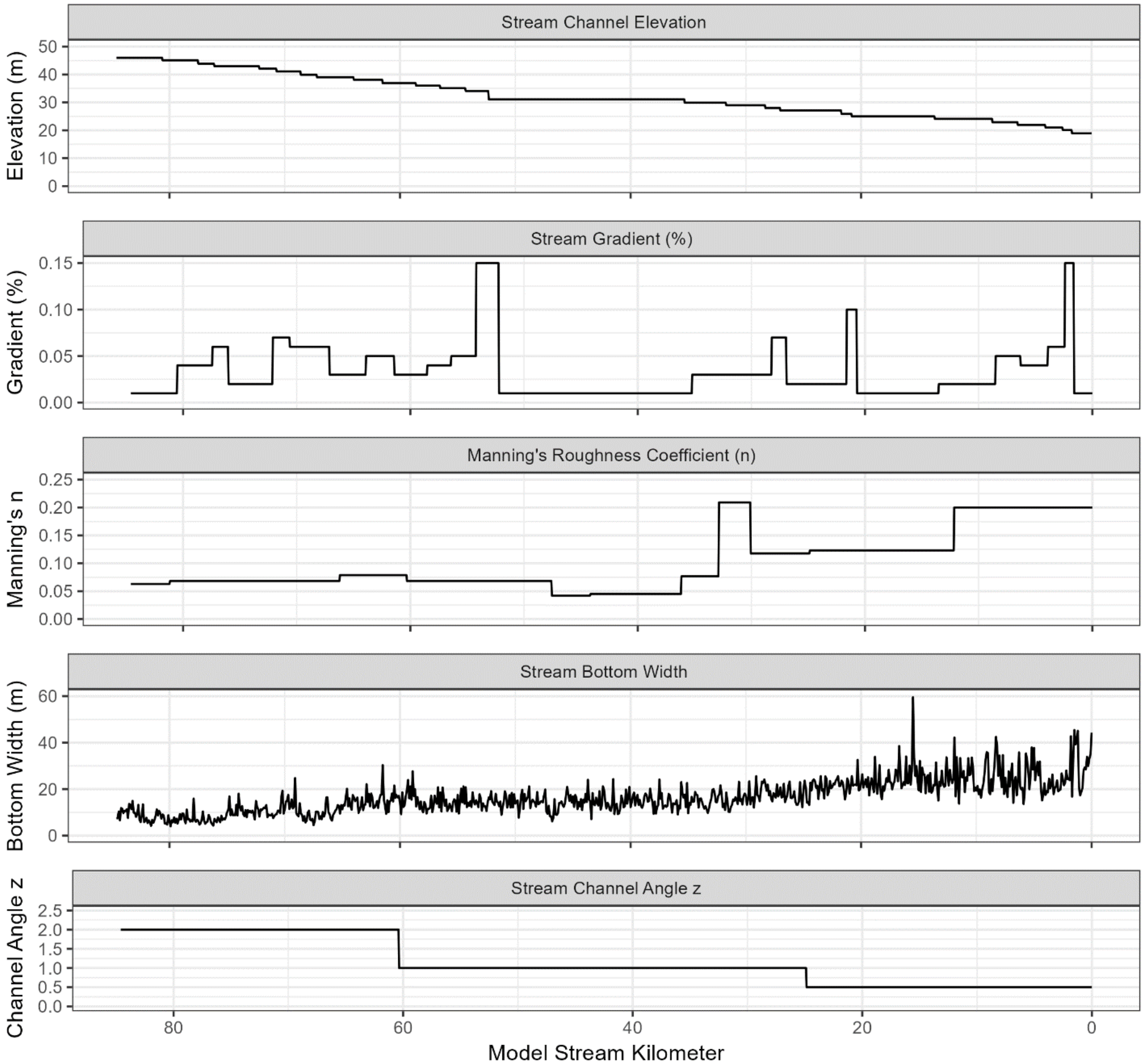


Figure 3-72: Channel setup in the Pudding River model.

3.3.10 Other model parameters

The model coefficients for non-spatially varying parameters in the calibrated Pudding River model are presented in **Table 3-24**, and sediment thermal conductivity and diffusivity are displayed in **Figure 3-73**. Many of these values were summarized by Pelletier et al. (2006).

Sinokrot and Stefan (1993) and other researchers provided a summary of typical values for thermal conductivity and thermal diffusivity across various materials. The average thermal conductivity for many sediment materials is about 1.57 W/m/°C, while the average thermal diffusivity for many different types of sediment material is about 0.0064 cm^2/sec. In the model, the sediment thermal conductivity values ranged from 1.13 to 2.36 W/m/deg-C, and the sediment thermal diffusivity ranged from 0.006 to 0.007 cm^2/sec. Both parameters represented bed conditions mostly composed of sand, with presence of shale and loam.

Typically, the hyporheic zone thickness is about 0.1 m if there is negligible hyporheic exchange and it ranges approximately from 0.2 m to 1 m if there is substantial hyporheic exchange (Bencala and Walters, 1983; Hart, 1995). The bulk hyporheic exchange flow is as a fraction of the total surface flow for each reach. Blank cells or zero indicates no hyporheic exchange. Typical porosity of cobble, gravel, sand, silt sediments ranges from about 35% to 50%.

Table 3-24: Model coefficients for non-spatially varying parameters in the Pudding River model.

Parameter name (units)	Value
Wind Function, coefficient a	1.51×10^{-9}
Wind Function, coefficient b	1.60×10^{-9}
Sediment / hyporheic zone thickness (m)	0.1
Hyporheic Exchange	0%
Porosity	41%

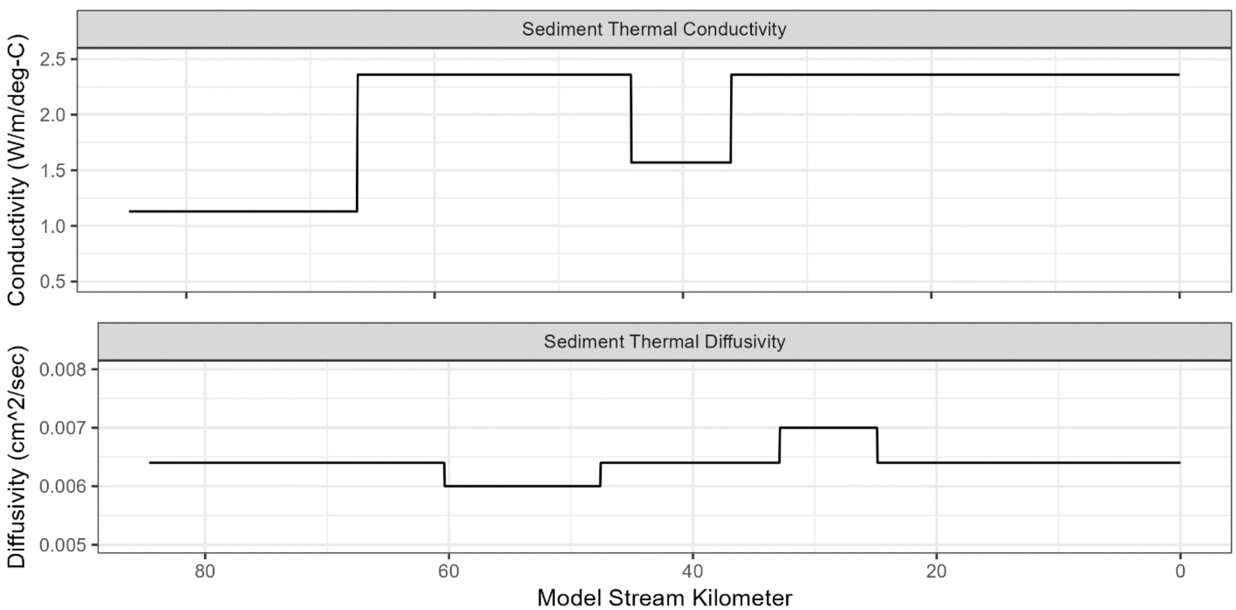


Figure 3-73: The other model parameters used for channel setup in the Pudding River model.

3.3.11 Calibration results

3.3.11.1 Temperature

The temperature model was calibrated to the TIR data collected on 8/11/2004 and 8/12/2004 as well as to the continuous temperature data collected at several locations throughout the modeled period. DEQ adjusted input variables such as channel side angle, width-to-depth ratios, roughness (which affects stream width, depth and velocity), groundwater/surface water interaction, and wind speed (which affects evaporation) in order to match both TIR and thermistor data, while still meeting velocity, depth, cross-sectional area, and width specifications. A comparison of model calculated temperature to TIR measured temperatures for the Pudding River is shown in **Figure 3-74**. Goodness of fit statistics are shown in **Table 3-25**.

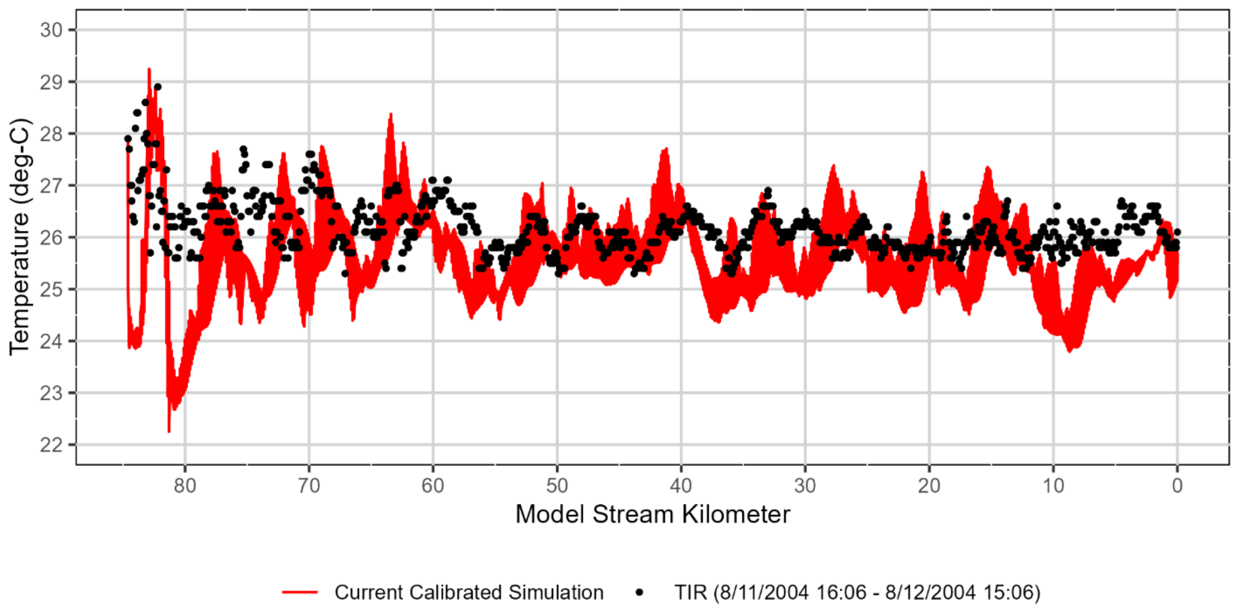


Figure 3-74: Pudding River TIR and simulated current stream temperatures.

Table 3-25: Pudding River hourly stream temperature goodness of fit statistics comparing field measured and model-predicted temperatures.

Monitoring Location	Model KM	Temperature Statistics	ME	MAE	RMSE	NSE	n
All Stations		7DADM	-1.59	1.73	2.71	NA	98
All Stations		Daily Maximum	-1.4	1.88	2.91	NA	98
All Stations		Hourly	-0.03	1.62	2.46	0.39	2352
10362-ORDEQ: Pudding River at Arndt Road (Barlow)	7.7	7DADM	0.07	0.1	0.11	NA	14
10917-ORDEQ: Pudding River at Hwy 99E (Aurora)	12.4	7DADM	0.46	0.46	0.49	NA	14
10640-ORDEQ: Pudding River at Hwy 211 (Woodburn)	36.2	7DADM	-1.13	1.13	1.13	NA	14
10641-ORDEQ: Pudding River at Hwy 214 (downstream of cannery outfall)	43.7	7DADM	-0.13	0.19	0.21	NA	14
11530-ORDEQ: Pudding River at Monitor-McKee Road	51.7	7DADM	-0.57	0.57	0.6	NA	14
31877-ORDEQ: Pudding River at Saratoga Road	66.3	7DADM	-3.76	3.76	3.89	NA	14
PR1-5808: Pudding River at Hazel Green Rd	79.6	7DADM	-5.52	5.52	5.63	NA	14
10362-ORDEQ: Pudding River at Arndt Road (Barlow)	7.7	Daily Maximum	0.03	0.53	0.63	NA	14
10917-ORDEQ: Pudding River at Hwy 99E (Aurora)	12.4	Daily Maximum	0.42	1.06	1.32	NA	14
10640-ORDEQ: Pudding River at Hwy 211 (Woodburn)	36.2	Daily Maximum	-1.08	1.08	1.17	NA	14
10641-ORDEQ: Pudding River at Hwy 214 (downstream of cannery outfall)	43.7	Daily Maximum	0.11	0.68	0.82	NA	14
11530-ORDEQ: Pudding River at Monitor-McKee Road	51.7	Daily Maximum	-0.43	0.66	0.79	NA	14
31877-ORDEQ: Pudding River at Saratoga Road	66.3	Daily Maximum	-3.33	3.72	4.5	NA	14
PR1-5808: Pudding River at Hazel Green Rd	79.6	Daily Maximum	-5.25	5.25	5.74	NA	14
10362-ORDEQ: Pudding River at Arndt Road (Barlow)	7.7	Hourly	-0.67	1.01	1.16	0.45	336
10917-ORDEQ: Pudding River at Hwy 99E (Aurora)	12.4	Hourly	-0.09	0.81	1.01	0.44	336
10640-ORDEQ: Pudding River at Hwy 211 (Woodburn)	36.2	Hourly	-0.65	0.68	0.86	0.76	336
10641-ORDEQ: Pudding River at Hwy 214 (downstream of cannery outfall)	43.7	Hourly	-0.47	0.8	1	0.6	336
11530-ORDEQ: Pudding River at Monitor-McKee Road	51.7	Hourly	-0.45	0.78	0.91	0.72	336
31877-ORDEQ: Pudding River at Saratoga Road	66.3	Hourly	1.36	2.3	2.73	0.32	336
PR1-5808: Pudding River at Hazel Green Rd	79.6	Hourly	0.68	4.73	5.34	0.16	336
Pudding River TIR	Model extent		-0.68	0.91	1.13	NA	847

The thermistors in the mainstem Pudding River, which data were used for calibrating the model, were deployed by DEQ. Tributary temperature monitoring during the calibration period was conducted by the Marion Soil and Water Conservation District and DEQ. The model closely matches DEQ's continuous monitoring data at most locations. Error statistics for hourly values and statistics for 7-Day Average Daily Maximum (7DADM) values are presented in **Table 3-25.**

Comparisons of calculated hourly values to observed data are presented in **Figure 3-75** through **Figure 3-88**. Note that no data is available for Node 7 (Bernard Road, 11528-ORDEQ) since the thermistor failed at this location during the time period modeled. Note also that the thermistor for Node 3 (Saratoga Road, 31877-ORDEQ) occasionally generated some erratic temperatures (not shown on plot) and may not be reliable.

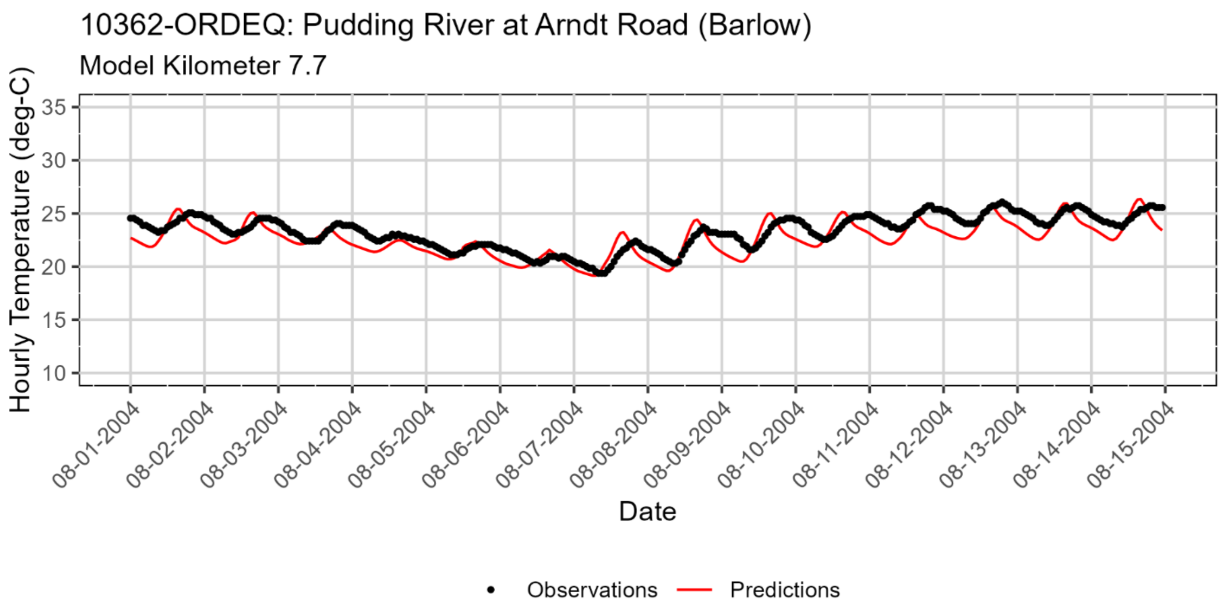


Figure 3-75: Pudding River measured and model-predicted hourly stream temperatures at monitoring station 10362-ORDEQ.

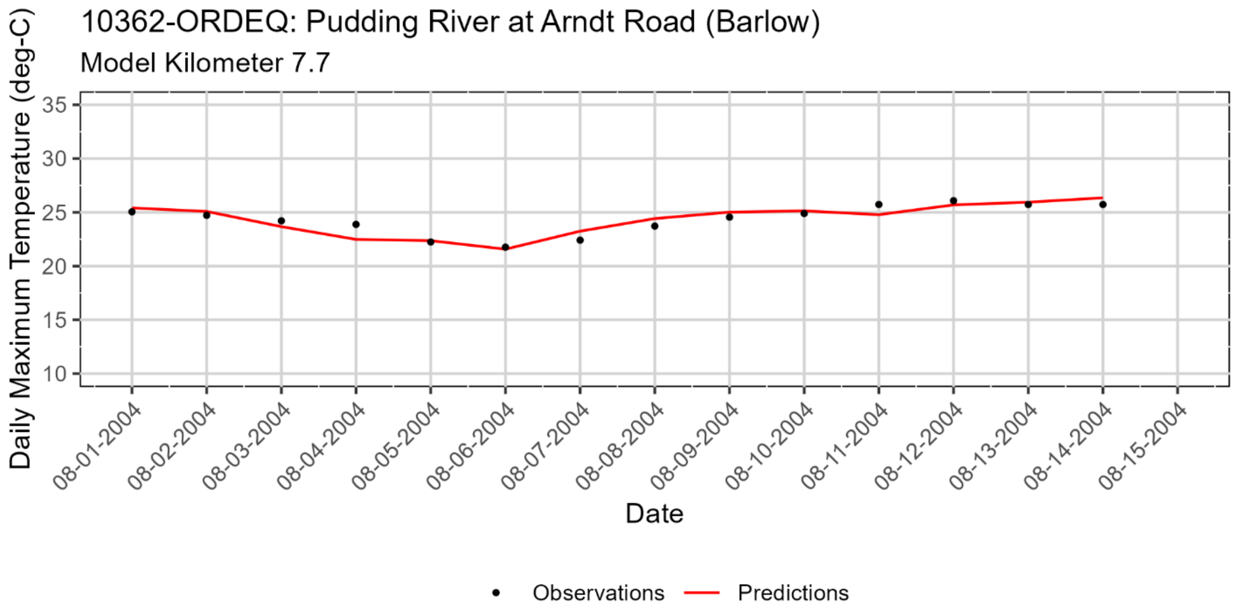


Figure 3-76: Pudding River measured and model-predicted daily maximum stream temperatures at monitoring station 10362-ORDEQ.

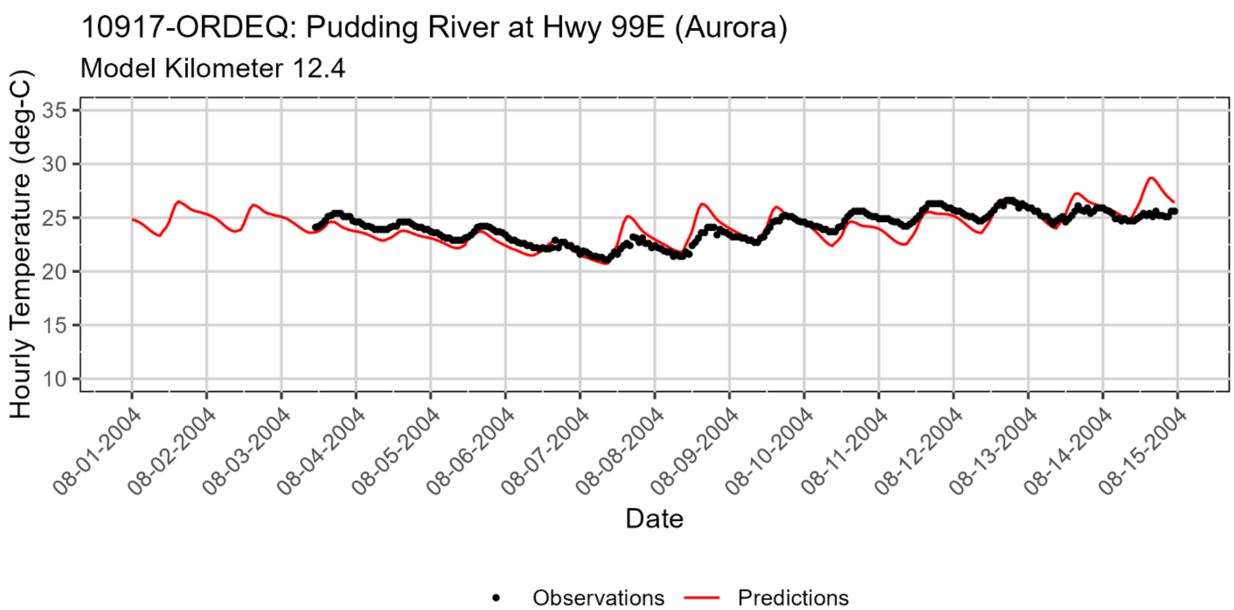


Figure 3-77: Pudding River measured and model-predicted hourly stream temperatures at monitoring station 10917-ORDEQ.

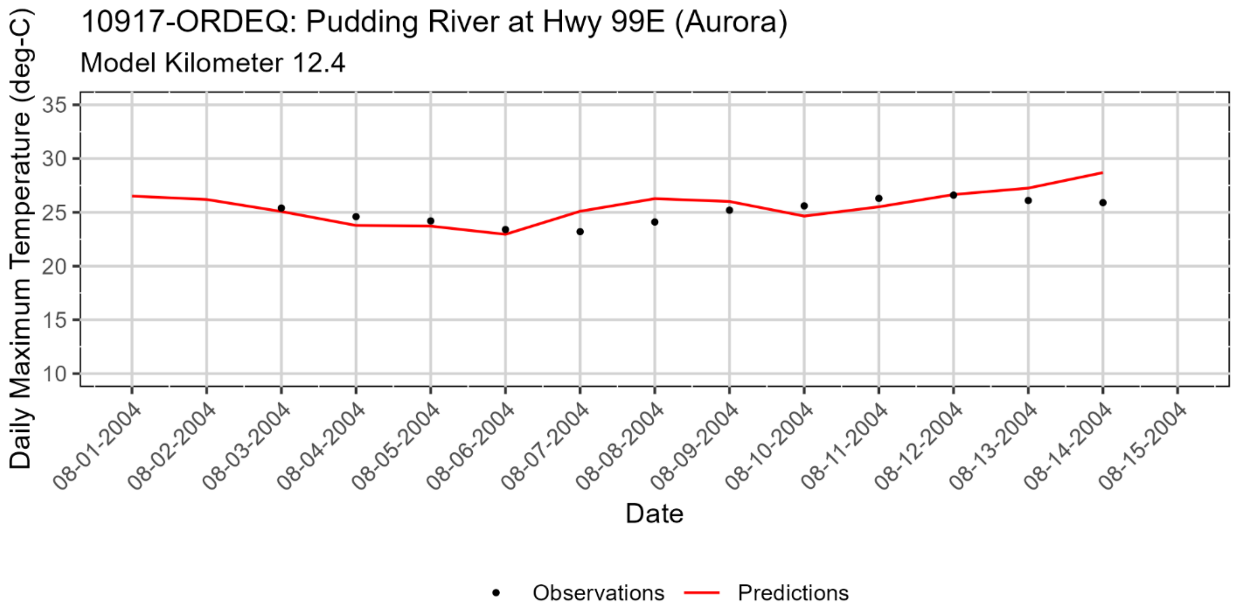


Figure 3-78: Pudding River measured and model-predicted daily maximum stream temperatures at monitoring station 10917-ORDEQ.

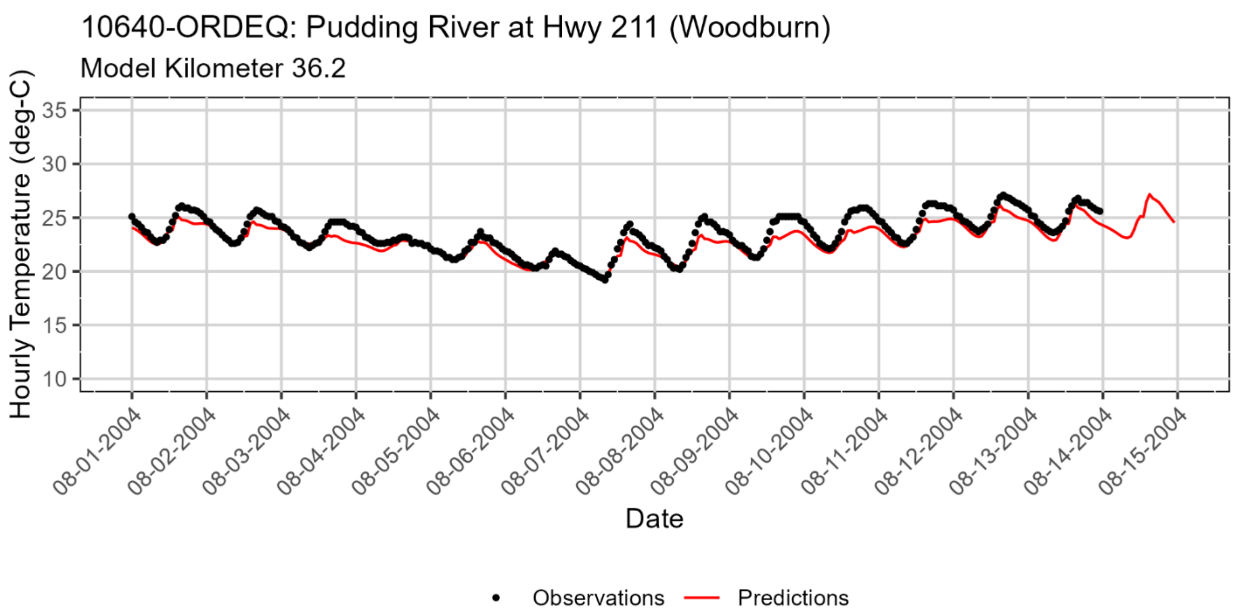


Figure 3-79: Pudding River measured and model-predicted hourly stream temperatures at monitoring station 10640-ORDEQ.

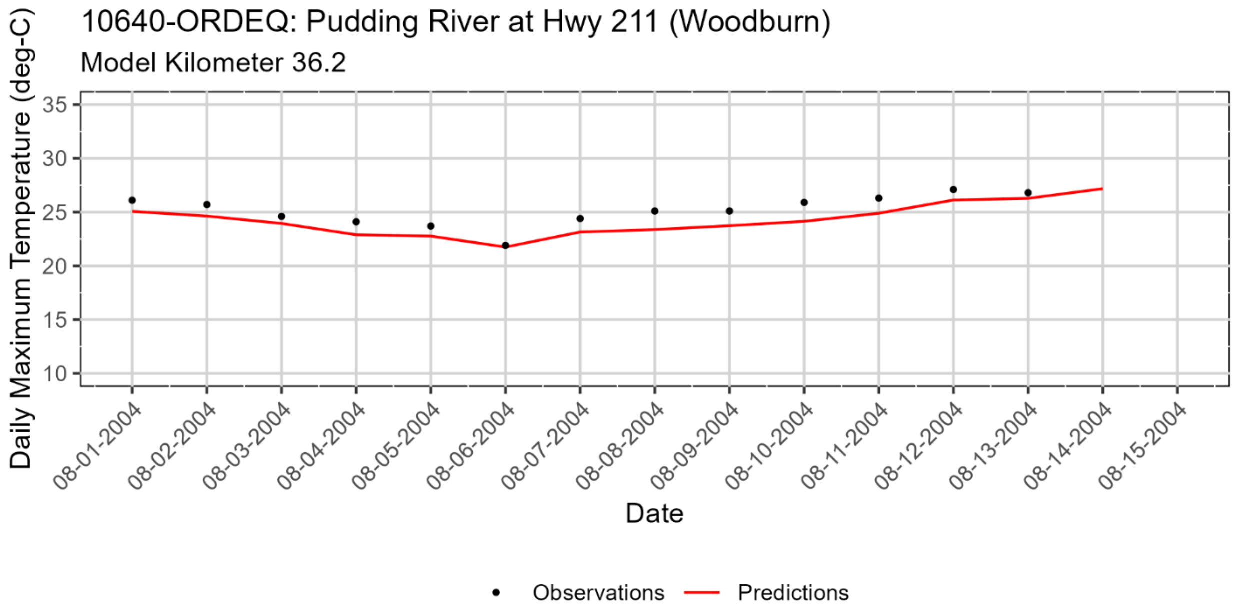


Figure 3-80: Pudding River measured and model-predicted daily maximum stream temperatures at monitoring station 10640-ORDEQ.

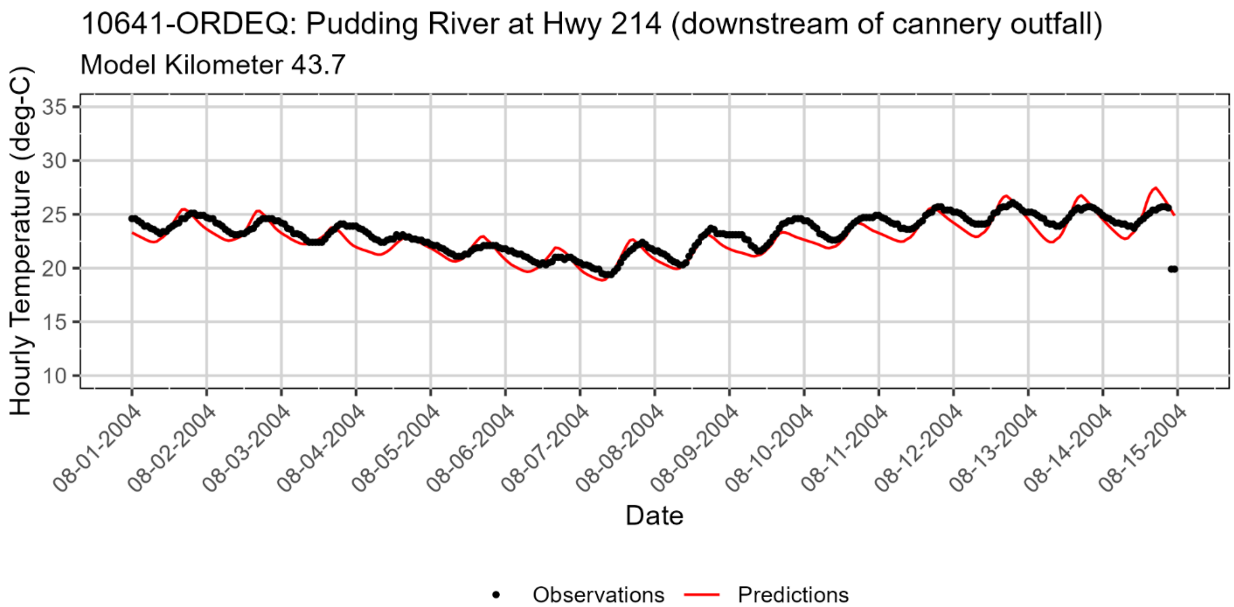


Figure 3-81: Pudding River measured and model-predicted hourly stream temperatures at monitoring station 10641-ORDEQ.

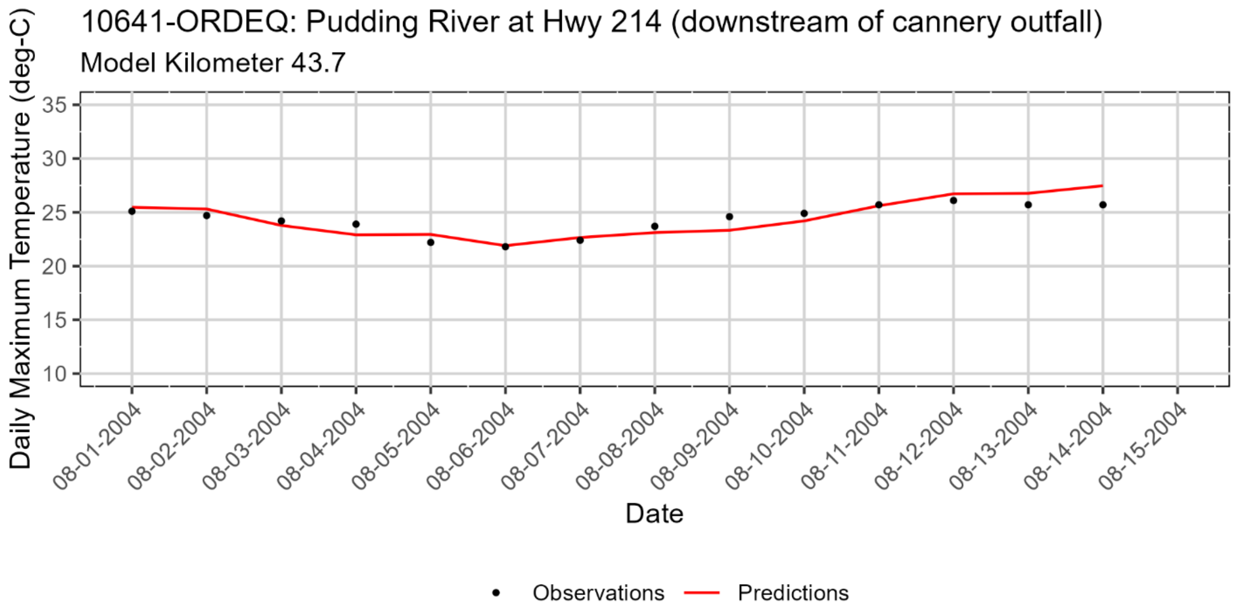


Figure 3-82: Pudding River measured and model-predicted daily maximum stream temperatures at monitoring station 10641-ORDEQ.

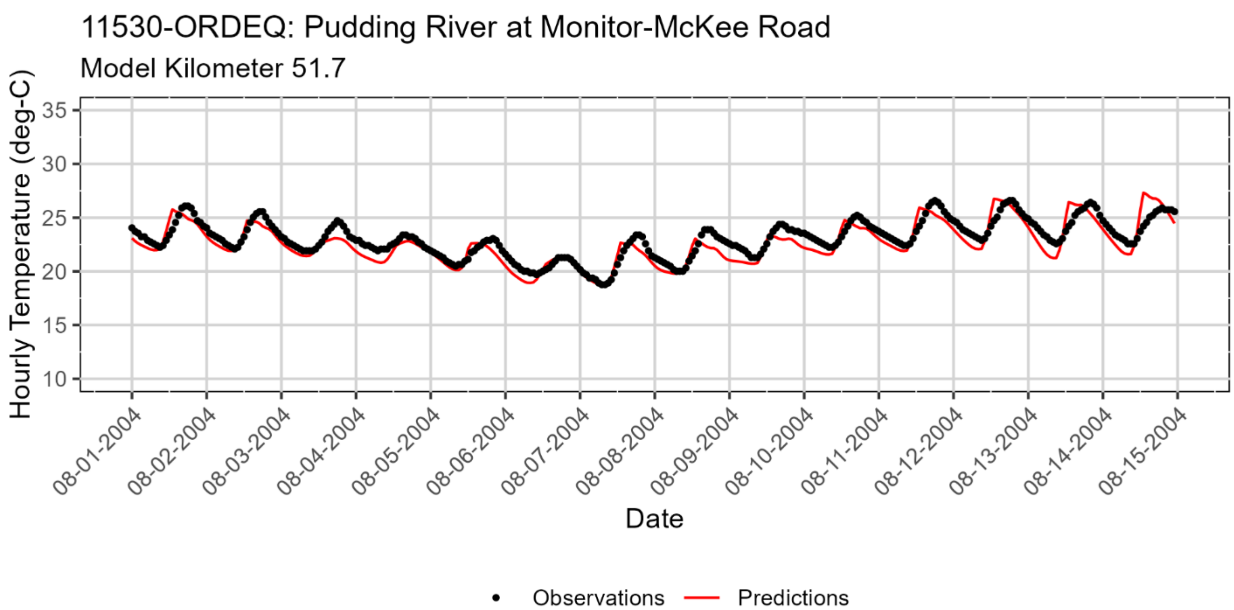


Figure 3-83: Pudding River measured and model-predicted hourly stream temperatures at monitoring station 11530-ORDEQ.

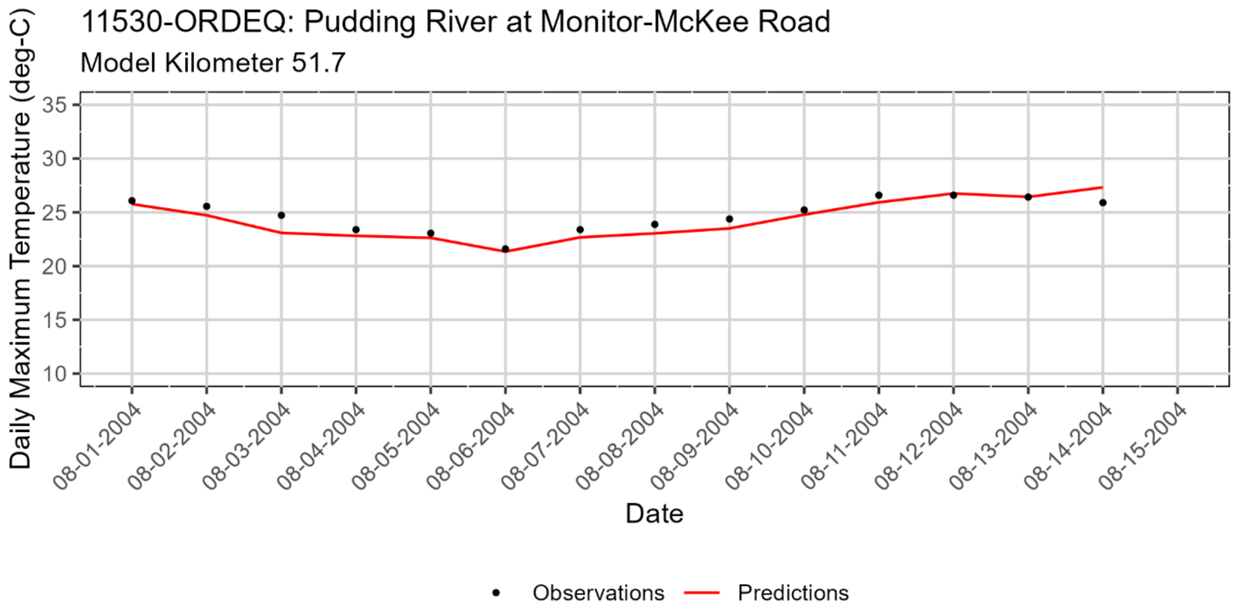


Figure 3-84: Pudding River measured and model-predicted daily maximum stream temperatures at monitoring station 11530-ORDEQ.

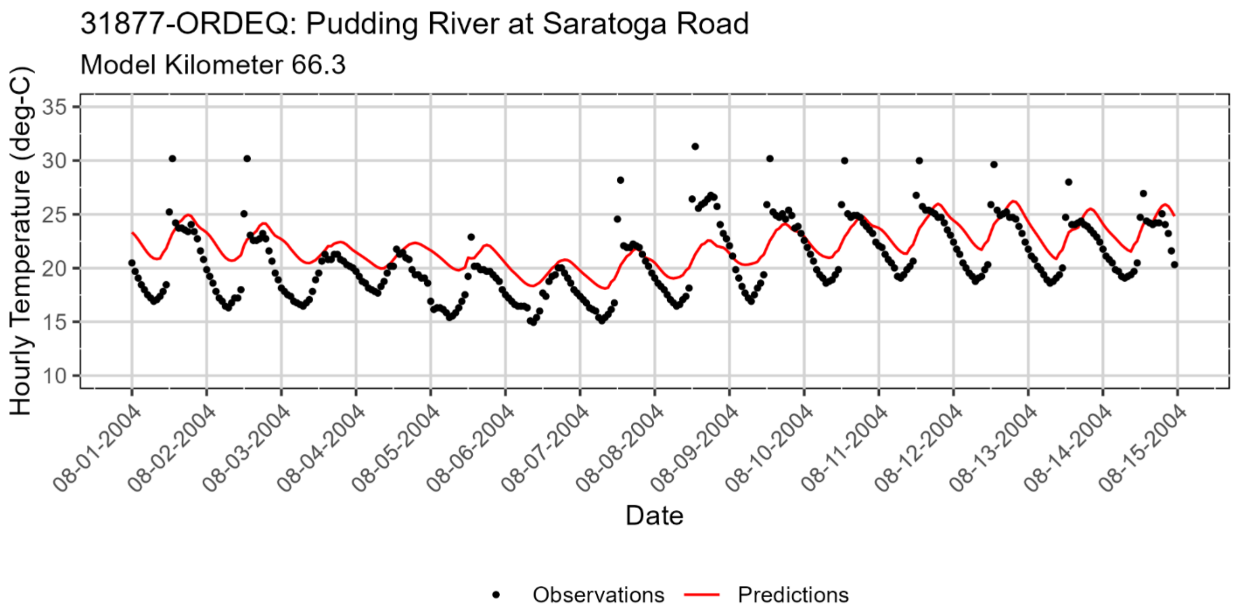


Figure 3-85: Pudding River measured and model-predicted hourly stream temperatures at monitoring station 31877-ORDEQ.

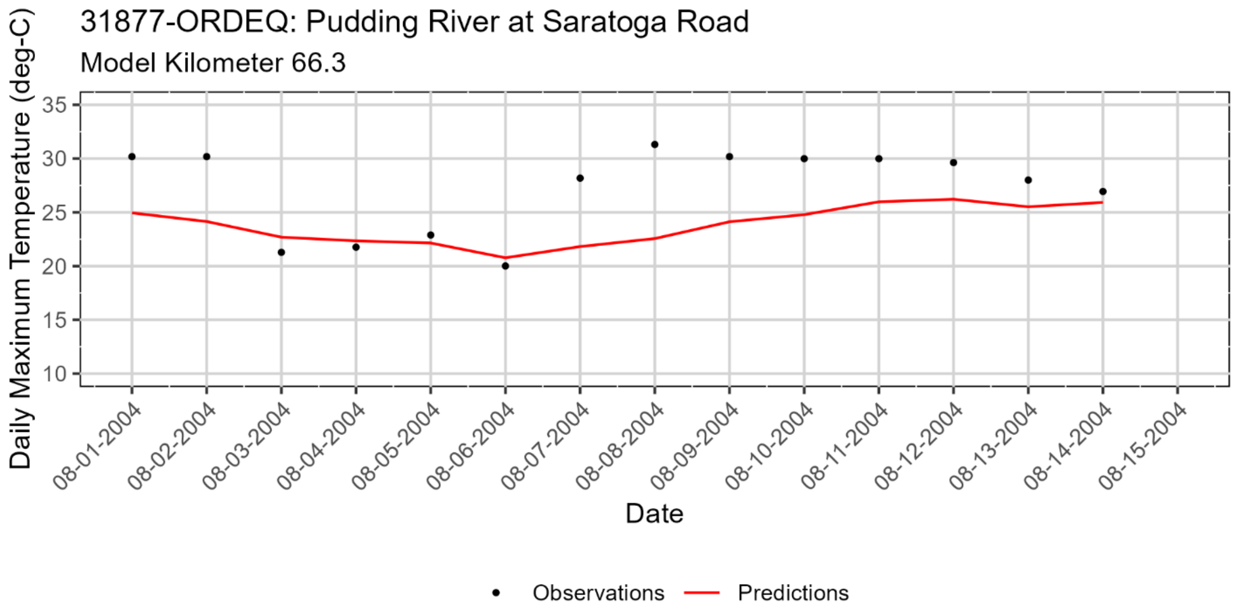


Figure 3-86: Pudding River measured and model-predicted daily maximum stream temperatures at monitoring station 31877-ORDEQ.

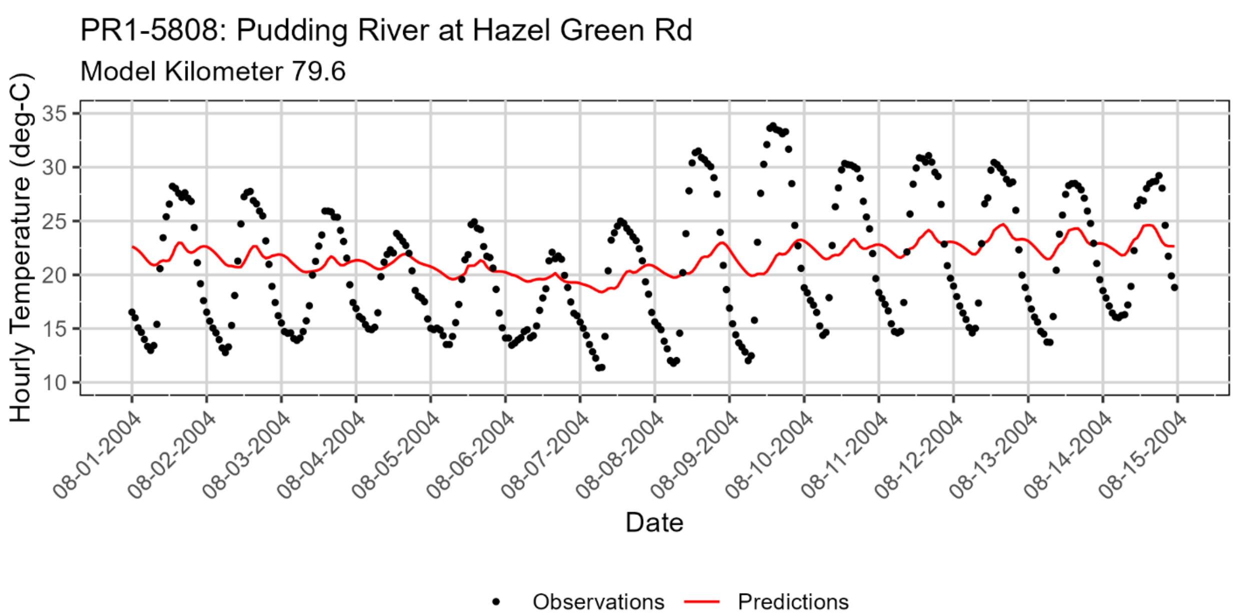


Figure 3-87: Pudding River measured and model-predicted hourly stream temperatures at monitoring station PR1-5808.

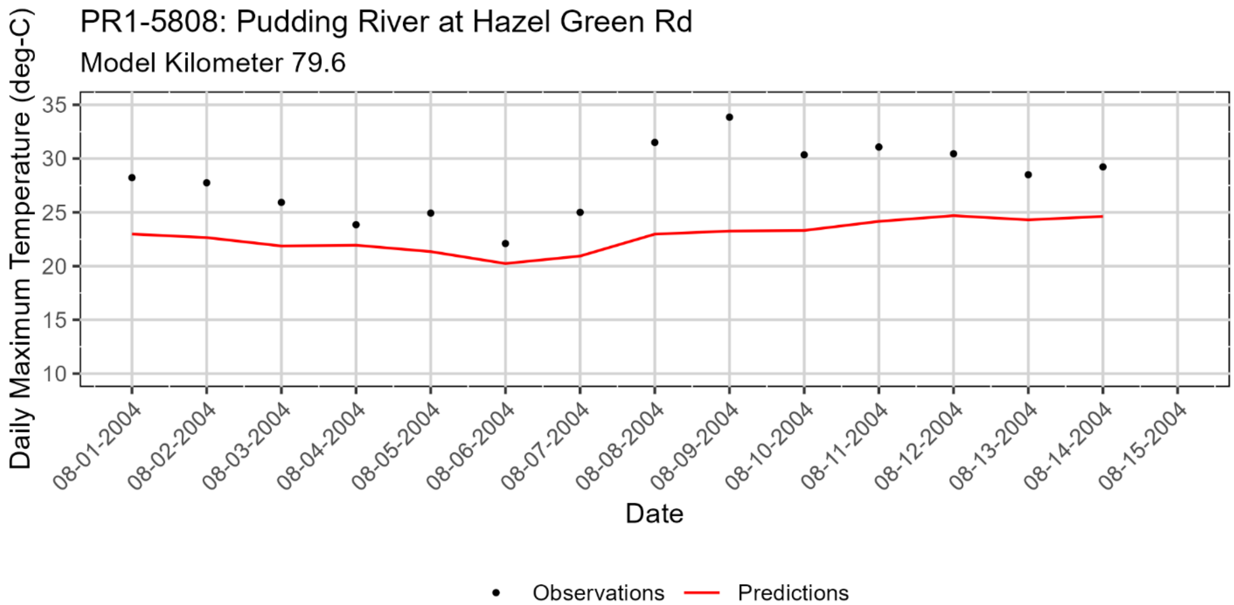


Figure 3-88: Pudding River measured and model-predicted daily maximum stream temperatures at monitoring station PR1-5808.

3.3.11.2 Flow

Comparisons of model calculated flow rates at Woodburn (model km 37.5) and at Aurora (model km 13) to values measured by the USGS gages are shown in **Figure 3-89**. As the hourly flow rates at the Aurora USGS gage were unavailable, the daily mean flow rates were used for comparison. The goodness of fit statistics are shown in **Table 3-26**. The model was well-calibrated, but it performed better at the Woodburn gage compared to the Aurora gage. The disparities in daily mean flow rates between the model's predictions and the USGS gage values were smaller at the Woodburn gage (0.09˚C) compared to the Aurora gage (0.42˚C). The model does a relatively poor job of replicating the large fluctuations in flow at the Aurora gage. As shown by **Figure 3-89**, peak flows nearly double from Woodburn to Aurora. Two major tributaries enter between these sites, Butte Creek and Rock Creek, which implies that much of the large flow increase is due to these two tributaries. Unfortunately, neither of these tributaries is currently gaged, so flow rates cannot be accurately determined. The poor performance may also be partially due to longitudinal dispersion provided by the model. The longitudinal dispersion coefficient, which is not available to users for adjustment, may be larger than is appropriate for the Pudding River.

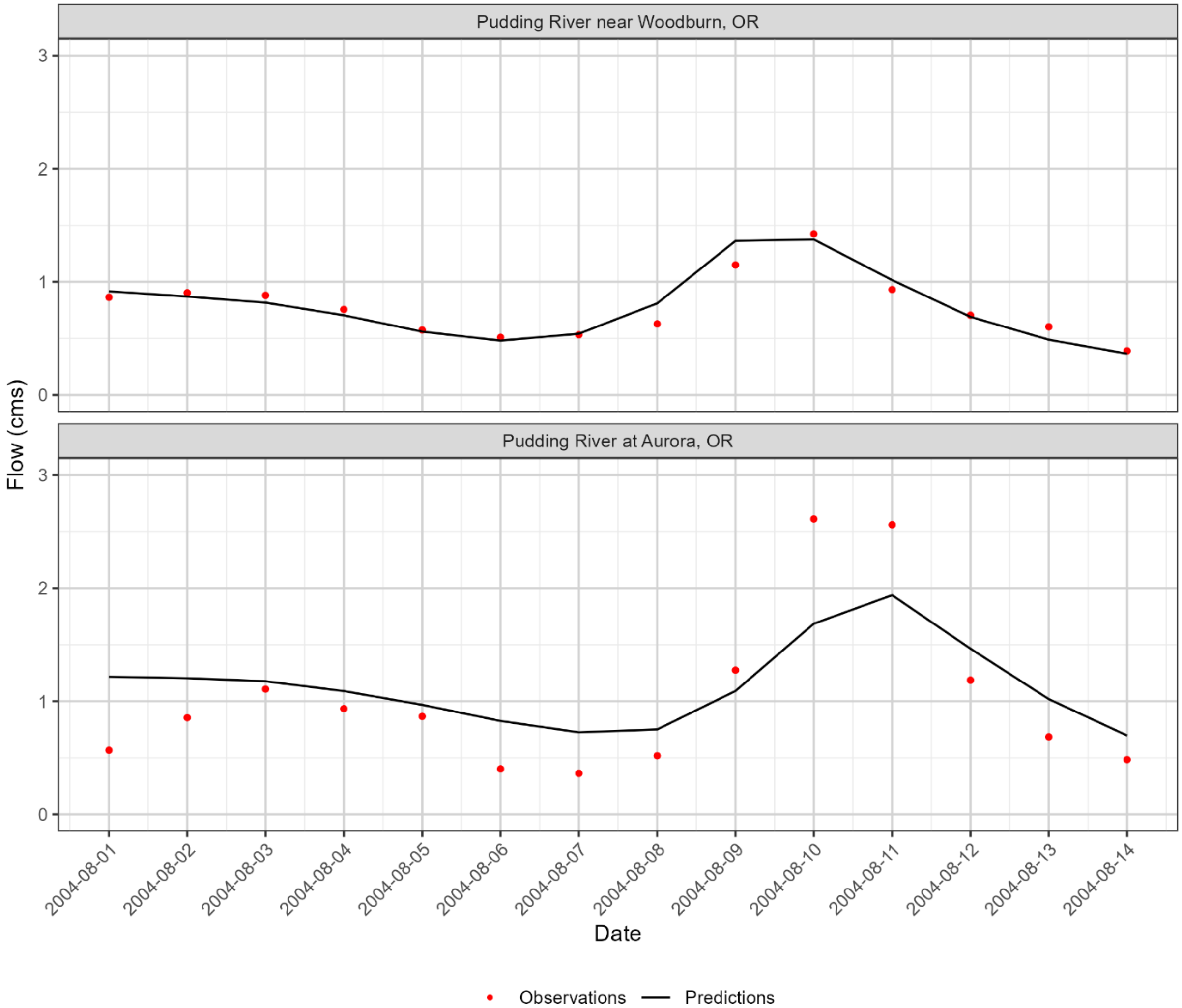


Figure 3-89. Pudding River model flow calibration at Pudding River near Woodburn (model km 37.5) and Pudding River at Aurora (model km 13).

Table 3-26: Flow rate goodness of fit statistics comparing field observed and model flow rates.

Monitoring Location	Model KM	Flow Statistics	ME	MAE	RMSE	NSE	n
All Stations		Daily Mean	0.06	0.21	0.3	0.69	28
14202000: Pudding River at Aurora, OR	13	Daily Mean	0.1	0.35	0.42	0.63	14
14201340: Pudding River near Woodburn, OR	37.5	Daily Mean	0.01	0.07	0.09	0.89	14

3.3.11.3 Bathymetry and velocity

A QUAL2E model of the Pudding River was developed by DEQ in the 1990’s using data collected in the early 1990’s (Brown and Barnwell, 1987). While the extensive dataset collected to calibrate the model could not be located, the QUAL2E model, which includes calibrated width, depth, and velocity relationships, was available. The model used relationships in which velocity, depth, and width are functions of flow, as follows:

Velocity = aQ^b
Depth = cQ^d

Width = eQ^e

Bottom widths, side angles, and Manning's roughness coefficient (*n*) were adjusted to produce surface widths which matched GIS measured widths and QUAL2E model depths, cross-sectional areas and velocities. Note that the coefficients and exponents for the QUAL2E velocity, depth and width equations were constant for each QUAL2E model reach, so the values for each QUAL2E reach are nearly constant, with variations within each reach only due to variations in flow. The ten QUAL2E reaches (reaches 1, 3, 5, 7, 9, 10, 11, 13, 14, 16 and 17) are identified in the following figures. Reaches 6, 8, 12, etc., are tributary reaches and hence do not appear in the following figures. Reaches 17 and 18 were not modeled by QUAL2E, only Heat Source.

Average flow rates for August 1 to 20, as calculated by the model, are similar to flow conditions for which the QUAL2E model was calibrated. Average flow rates for this 20-day period are shown in **Figure 3-90**. As shown, these flow rates are slightly greater than the 7Q10 rates of 15 cfs at the Woodburn gage and 25 cfs at the Aurora gage. Also shown on the plot are gage and instantaneous flow measurements from July 31 to August 3, 2007. As shown, these flows for these dates were similar to flows during the August 2004 model calibration period.

Calculated widths, depths, cross-sectional areas and velocities (based on the 20-day average flow rates) compared to QUAL2E and GIS measured values are shown in **Figure 3-91** to **Figure 3-94**. Note that the QUAL2E width, depth, and velocities are reach average values which apply for reaches that extend for large distances. Therefore, values for some Heat Source segments will be greater than QUAL2E values and for others will be less. The goal of the calibration was to reproduce the QUAL2E values on average. As shown by the plots, the Heat Source values generally reproduce the QUAL2E values quite well.

The goal of the hydraulics calibration was for reach average velocities, depths, and cross-sectional areas to be within +/- 10% of reach average values for the QUAL2E model and for reach average surface widths to not exceed reach average GIS measured channel widths by more than 10%. As shown in **Table 3-27**, the model meets these specifications.

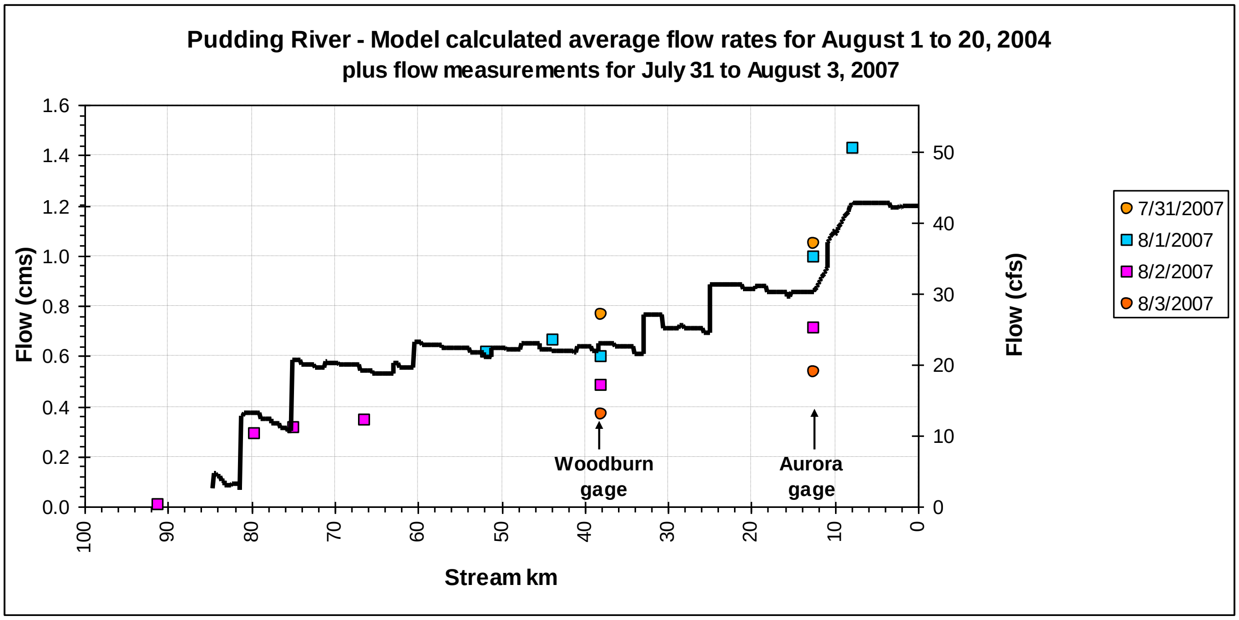


Figure 3-90: Flow rates used for hydraulics calibration and comparisons to Pudding River QUAL2E model.

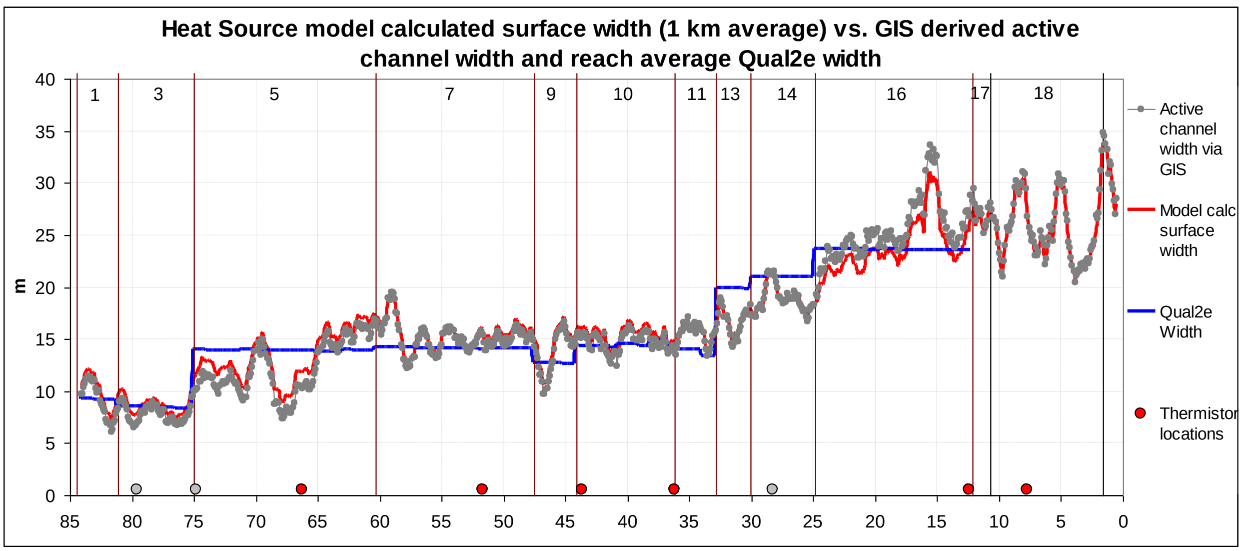


Figure 3-91: Pudding River model width calibration.

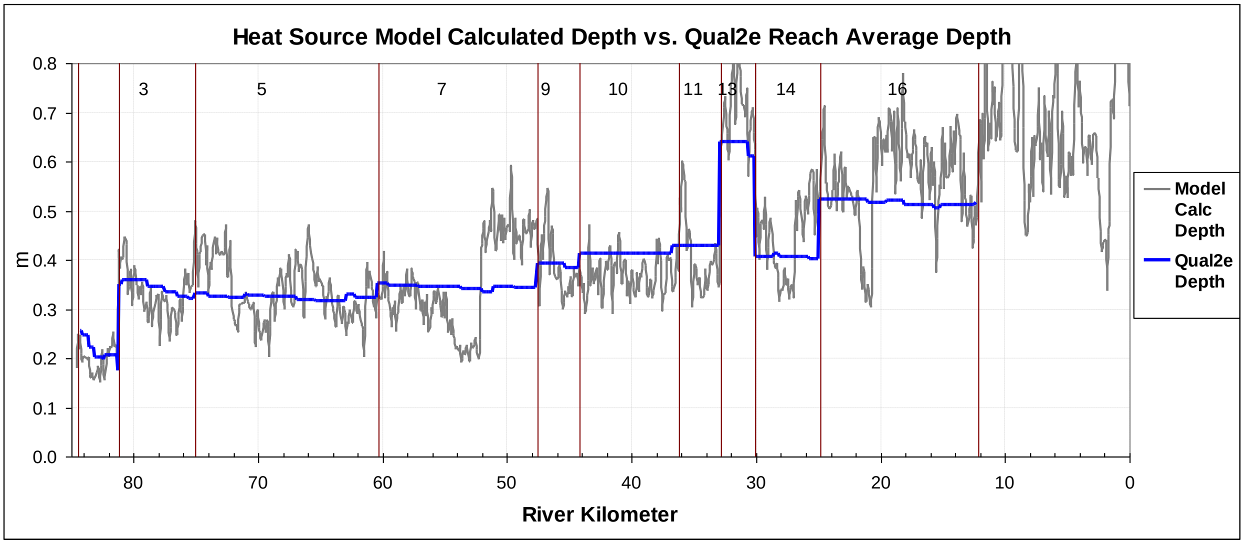


Figure 3-92: Pudding River model depth calibration.

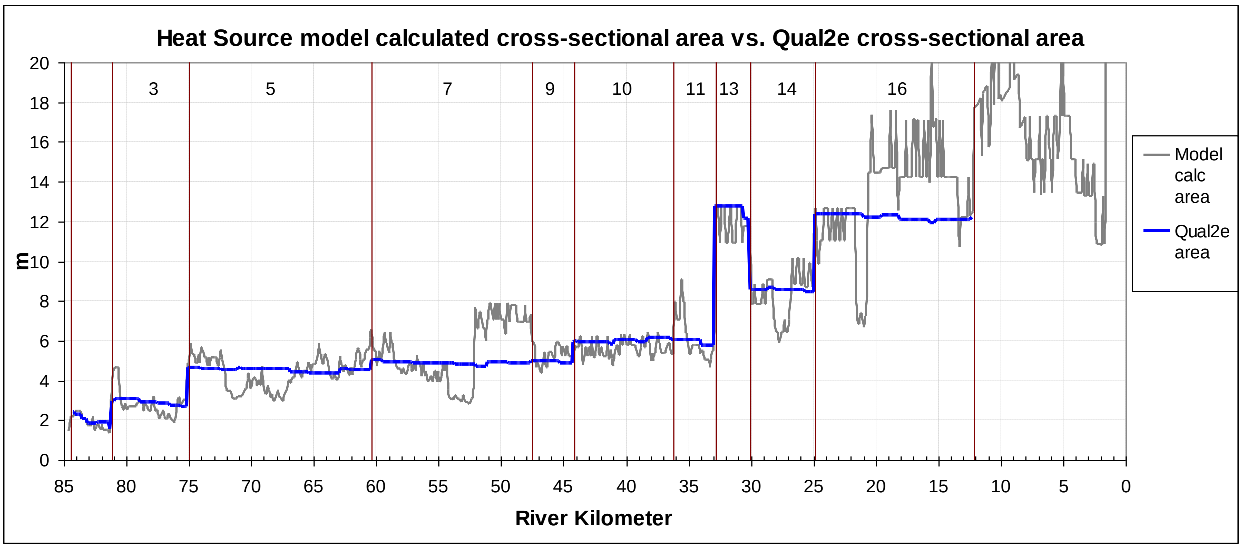


Figure 3-93: Pudding River model cross-sectional area calibration.

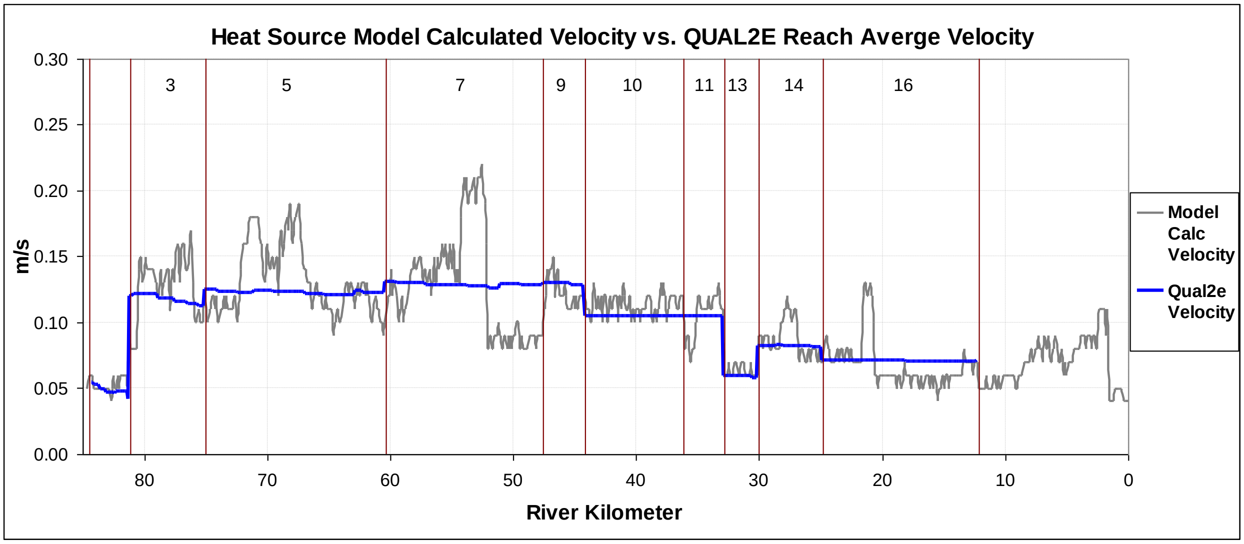


Figure 3-94: Pudding River model velocity calibration.

Table 3-27: Comparison of Pudding River Heat Source velocity, depth, area and width to target values.

Reach	Average Heat Source to QUAL2E Velocity (%)	Average Heat Source to QUAL2E Depth (%)	Average Heat Source to QUAL2E Width (%)	Average Heat Source to QUAL2E Area (%)	Ratio Model Calc Surface Width to Active Channel Width
0					1.08
1	108	90	106	93	1.09
3	108	95	101	96	1.09
5	107	104	96	97	1.09
7	99	102	109	110	1.03
9	94	99	113	108	1.05
10	107	90	106	94	1.05
11	100	94	111	104	1.01
13	109	109	87	93	1.01
14	106	110	89	97	1.00
16	96	110	101	109	0.94
17					0.98
18					0.99
19					0.99

3.4 Little North Santiam River

The Little North Santiam River model is a temperature model developed using Heat Source 6.5.1. The model was developed by DEQ.

3.4.1 Model extent

The extent of the model domain is the Little North Santiam River from the mouth to river mile 15 (**Figure 3-95**).

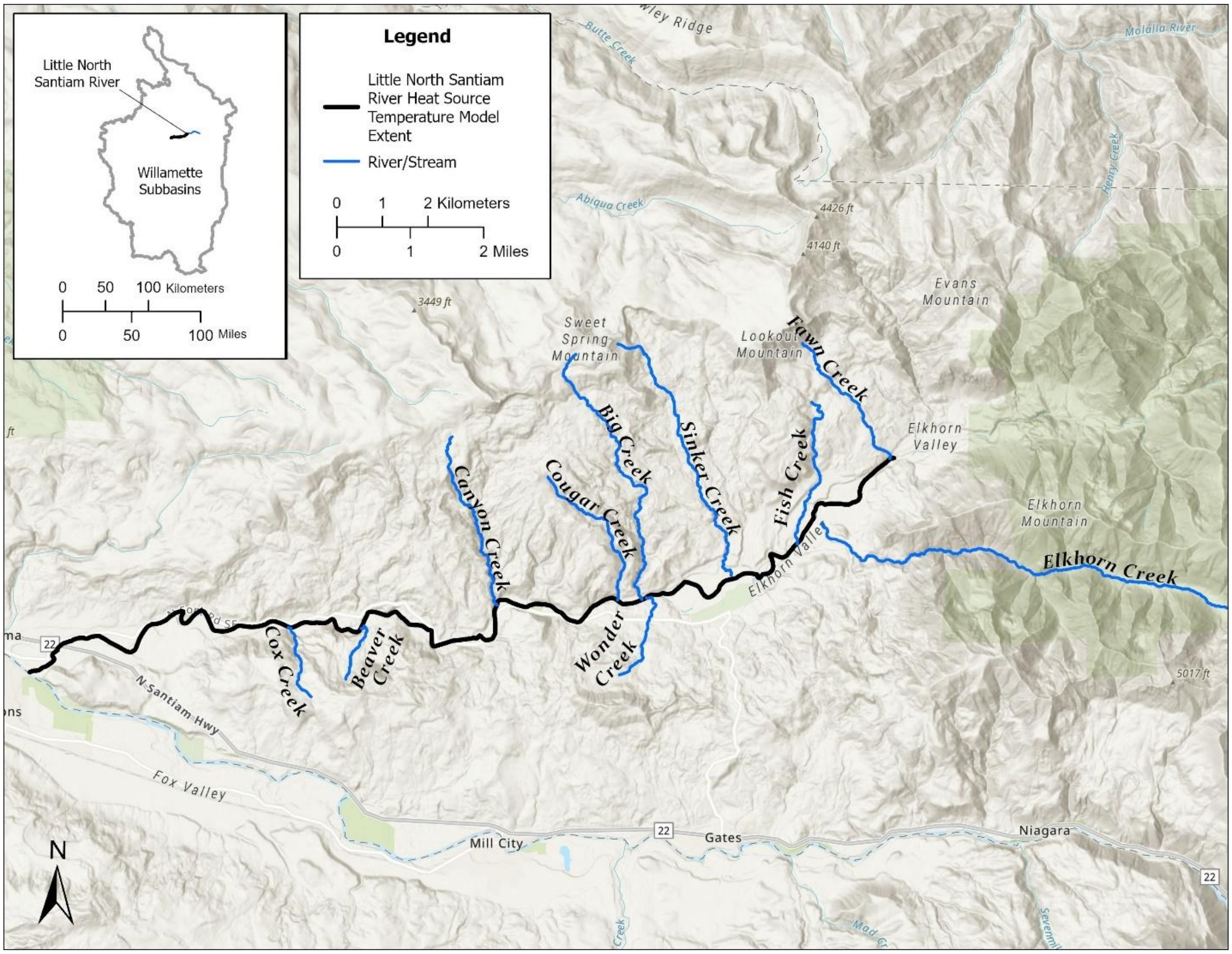


Figure 3-95: Little North Santiam temperature model extent.

3.4.2 Spatial and temporal resolution

The model input spatial resolution (*dx*) is 30 m. Outputs are generated every 100 m. The model time step (*dt*) is 1 minute and outputs are generated every hour.

3.4.3 Time frame of simulation

The model period is for a single day: August 01, 2000.

3.4.4 Meteorological inputs

The model was set up using hourly air temperature, relative humidity, and wind speed measurements from AirNav at the McNary Field Airport (KSLE) (**Figure 3-96**). Air temperature data were modified using the dry adiabatic lapse rate to adjust for differences in elevation between the measurement location and the model input location. Wind speeds were adjusted to improve the calibration using wind-sheltering coefficients listed in **Table 3-28** to represent difference in wind speeds between the measurement location and above the stream within the riparian area. Any missing data was replaced by the average of nearby time data.

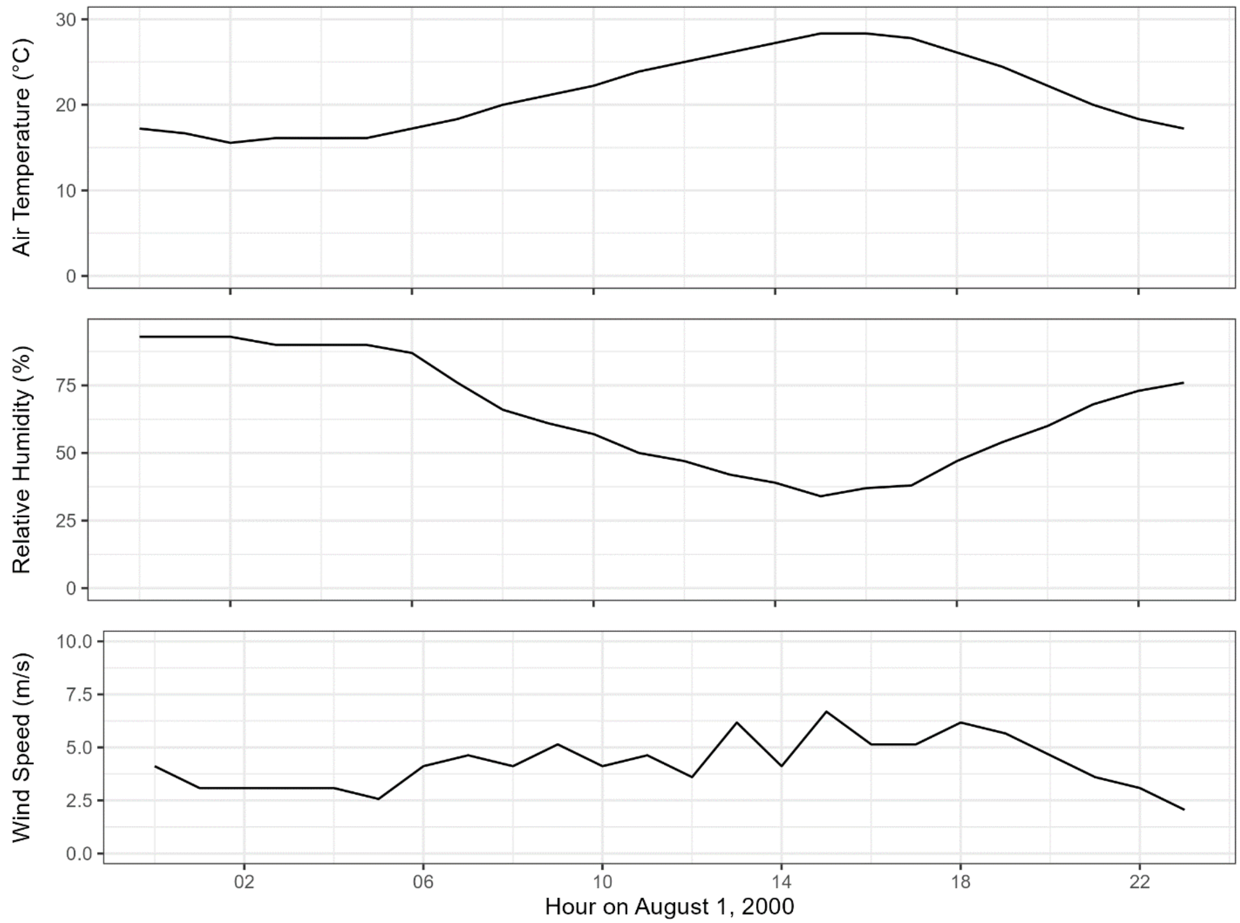


Figure 3-96: Meteorological inputs to the Little North Santiam River model.

Table 3-28: Wind-sheltering coefficient used in the Little North Santiam River model.

Model Location Name	Model Location (km)	Wind Sheltering Coefficient
Little North Santiam at Fawn Creek (FLIR - S68509)	24.811	0.125
Elk Horn Park (BLM)	17.008	0.05
Little North Fork (FLIR - S349766)	13.594	0.025
Little North Fork (FLIR - S88442)	7.559	0.025
North Fork County Park (BLM)	4.359	0.025
Little North Santiam River Near Mehama, OR (USGS - 14182500)	2.957	0.05

3.4.5 Temperature inputs

Hourly water temperature time series data were used to support tributary and boundary condition model setup. **Figure 3-97** shows the locations of the various stream temperature monitoring locations that were used for model setup or calibration.

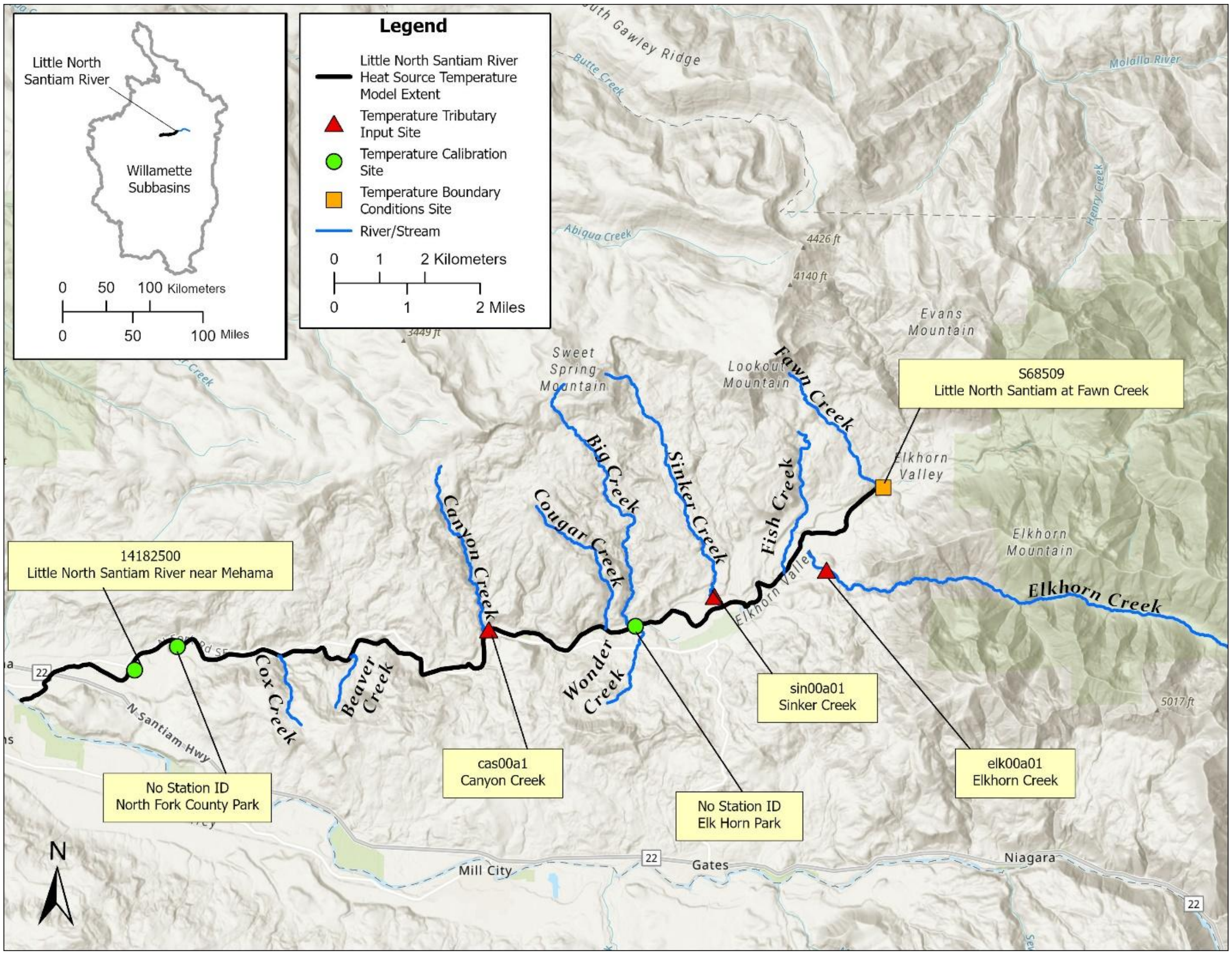
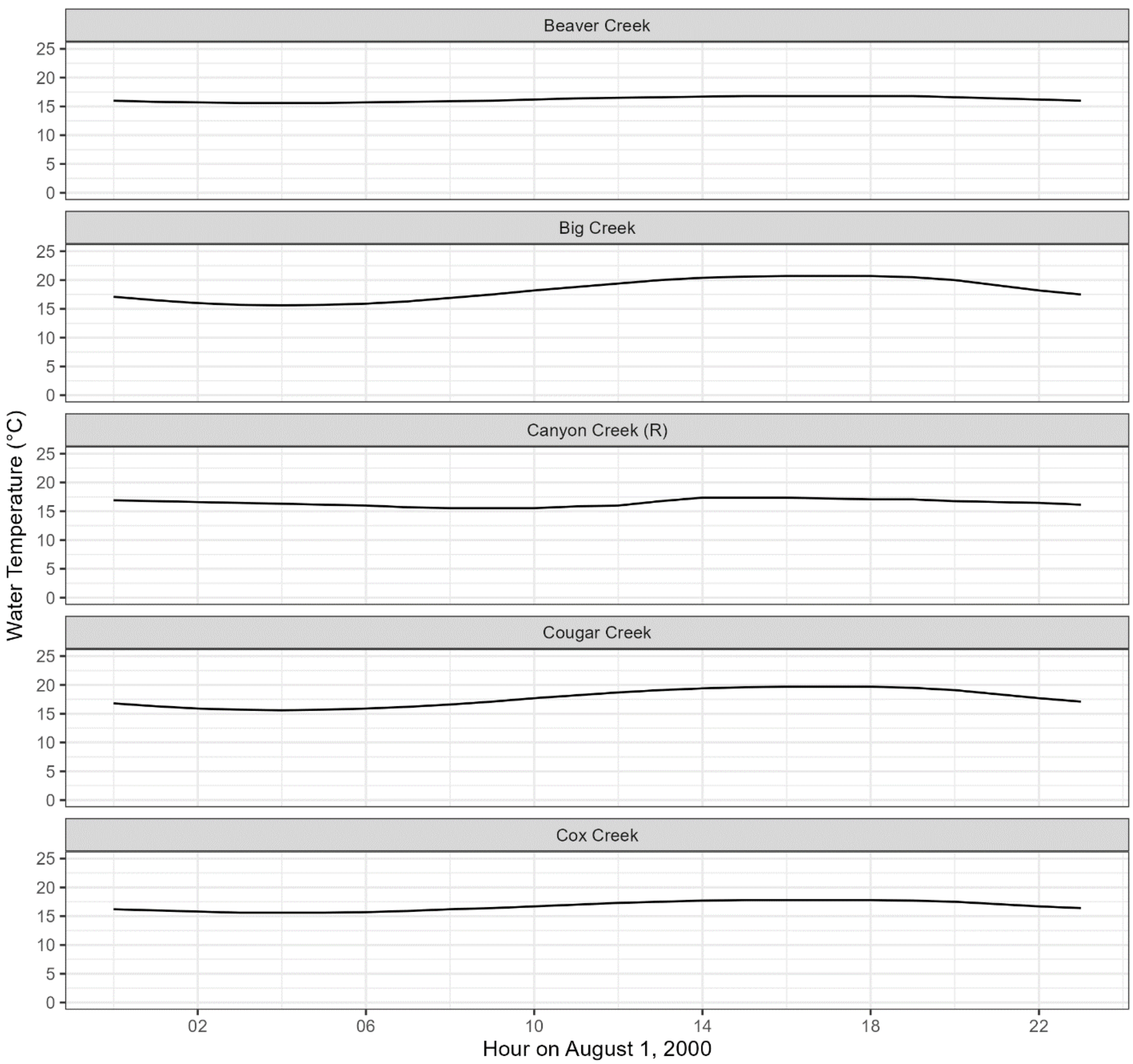


Figure 3-97: Temperature monitoring locations used for the Little North Santiam River model setup and calibration.

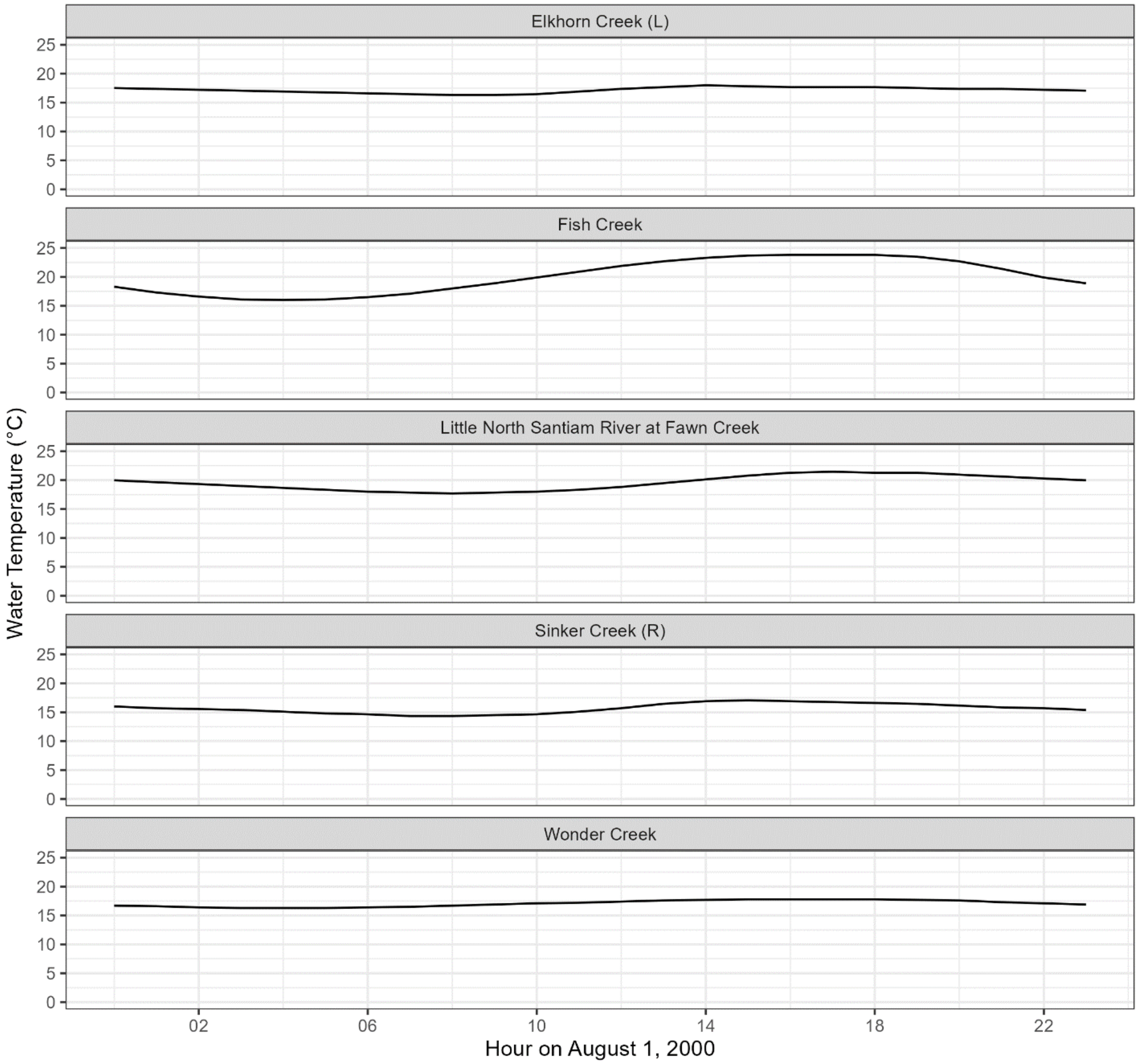
Table 3-29 and Figure 3-98 document the water temperature inputs to the model at the boundary condition (Little North Santiam River at Fawn Creek) and tributaries. Table 2-39 lists TIR Temperatures on the Little North Santiam River in the North Santiam Subbasin.

Table 3-29: Boundary condition and tributary water temperature inputs to the Little North Santiam River model.

Model Location Name	Model Location (km)	Input Type	Data Source
Little North Santiam River at Fawn Creek	24.811	Boundary Condition	Watershed Sciences (2001) (S68509)
Fish Creek	22.616	Tributary	DEQ
Elkhorn Creek	22.25	Tributary	BLM
Sinker Creek	19.507	Tributary	BLM
Wonder Creek	17.313	Tributary	DEQ
Big Creek	17.252	Tributary	DEQ
Cougar Creek	16.703	Tributary	DEQ
Canyon Creek	13.594	Tributary	BLM
Beaver Creek	9.083	Tributary	DEQ
Cox Creek	7.437	Tributary	DEQ



(A)



(B)

Figure 3-98: (A) and (B) Boundary condition and tributary water temperature inputs to the Little North Santiam River model.

3.4.6 Flow inputs

Hourly stream flow time series data were used to support tributary and boundary condition model setup. **Figure 3-99** shows the locations of the various stream flow monitoring locations that were used for model setup or calibration.

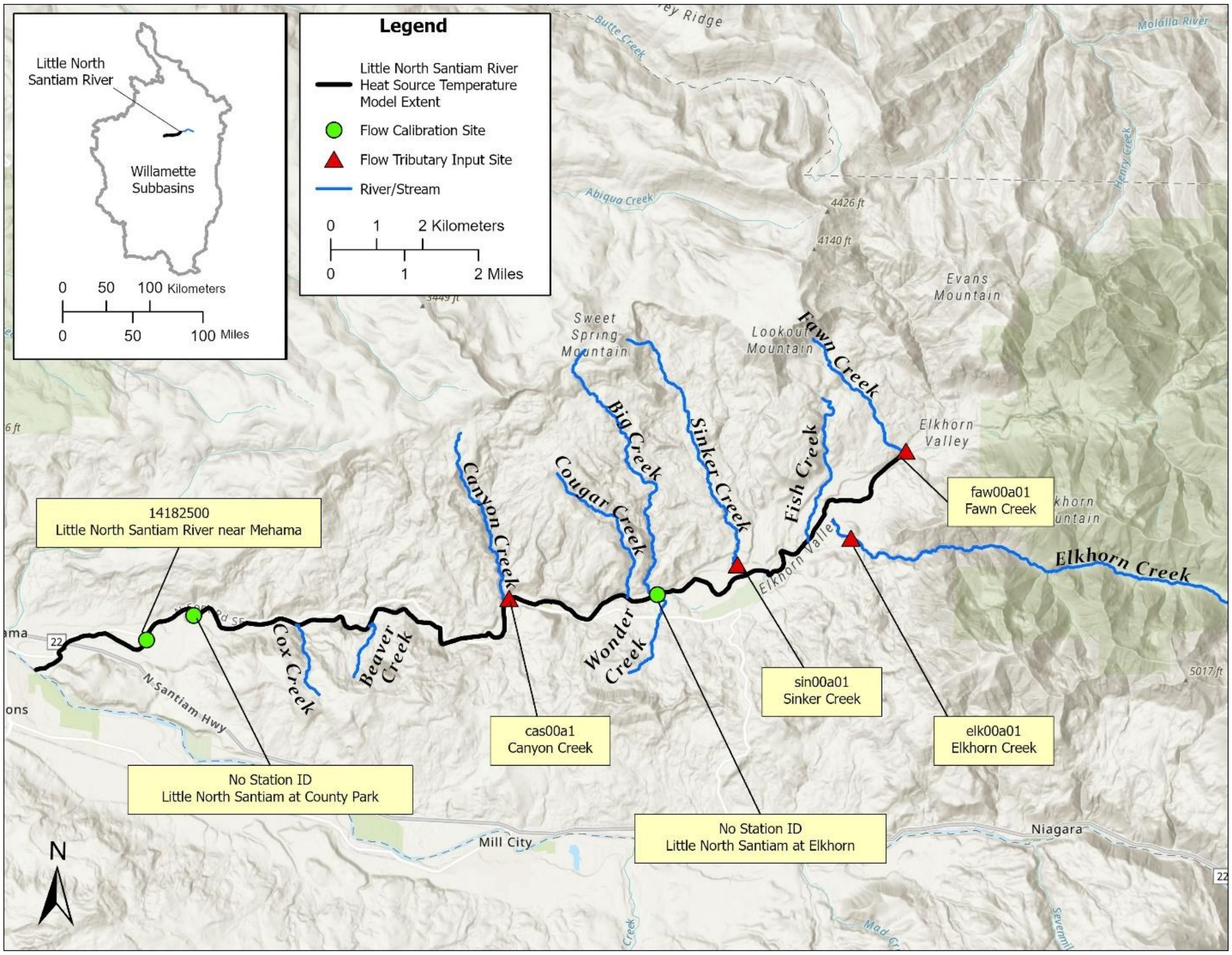


Figure 3-99: Flow monitoring locations used for the Little North Santiam River model setup and calibration.

The boundary condition and tributary flow inputs to the model is summarized in **Table 3-30**. **Figure 3-100** documents mainstem model flow setup. The model flow was estimated between measured sites using a flow mass balance, which incorporated input from tributaries and demand from PODs. The total water withdrawal volume at the PODs in the model flow amounted to 0.0623 cms.

Table 3-30: Boundary condition and tributary flow inputs to the Little North Santiam River model.

Model Location Name	Model Location (km)	Flow Rate (cms)	Input Type	Data Source
Little North Santiam at Fawn Creek	24.811	0.945	Boundary Condition	Estimated using a flow mass balance based on measured flow at Fawn Creek and TIR.
Fish Creek	22.616	0.001	Tributary	Estimated using a flow mass balance based on TIR.
Elkhorn Creek	22.25	0.1311	Tributary	BLM (elk00a01)
Sinker Creek	19.507	0.0263	Tributary	BLM (sin00a01)

Model Location Name	Model Location (km)	Flow Rate (cms)	Input Type	Data Source
Wonder Creek	17.313	0.024	Tributary	Estimated using a flow mass balance based on TIR.
Big Creek	17.252	0.080	Tributary	Estimated using a flow mass balance based on TIR.
Cougar Creek	16.703	0.080	Tributary	Estimated using a flow mass balance based on TIR.
Canyon Creek	13.594	0.0294	Tributary	BLM (cas00a1)
Beaver Creek	9.083	0.010	Tributary	Estimated using a flow mass balance based on TIR.
Cox Creek	7.437	0.01	Tributary	Estimated using a flow mass balance based on TIR.

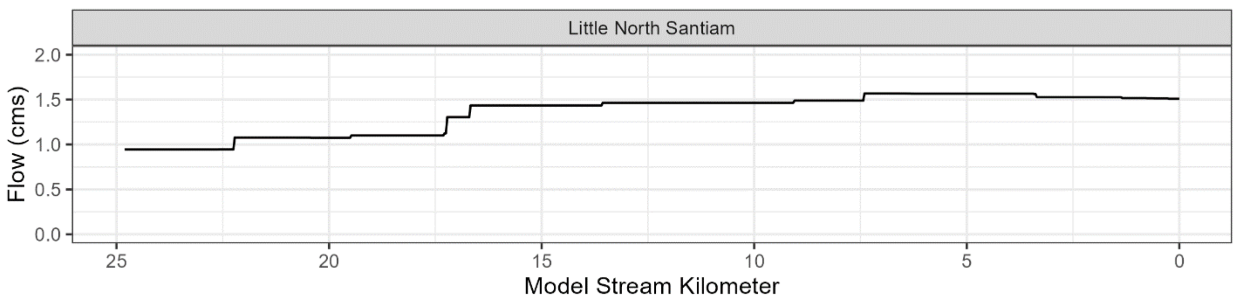


Figure 3-100: Boundary condition and mainstem flow inputs to the Little North Santiam River model.

3.4.7 Point source inputs

There are no point sources discharging within the model extent.

3.4.8 Landcover and topographic shade inputs

Average land cover height inputs and topographic shade angle inputs are shown in Figure 3-101 and Figure 3-102, respectively.

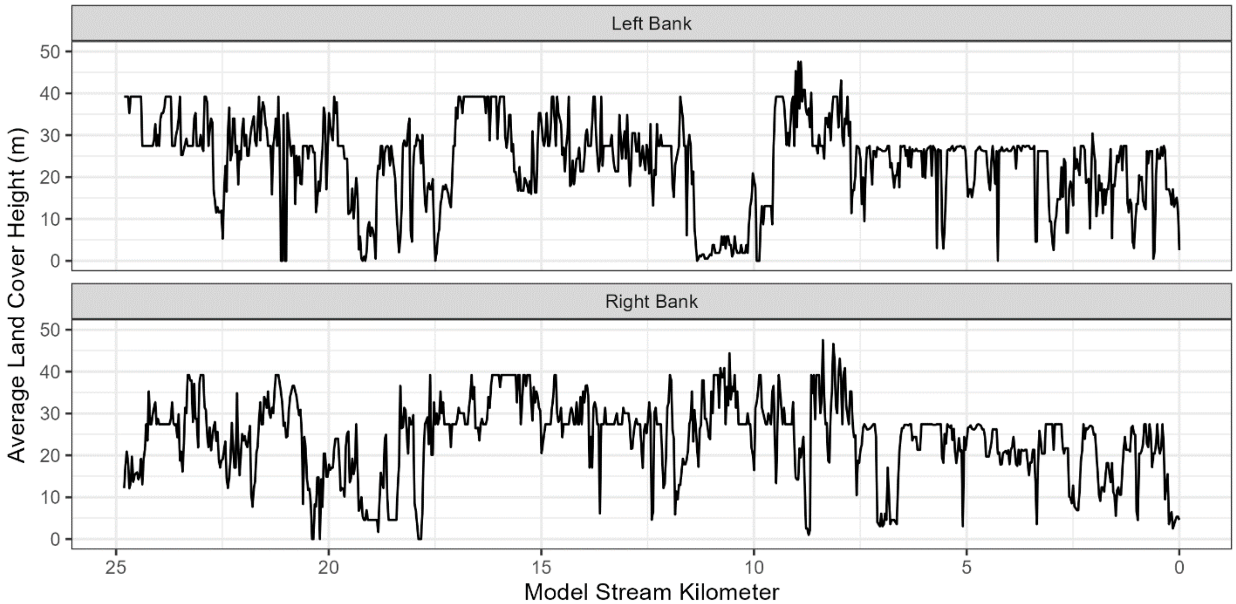


Figure 3-101: Average land cover height inputs to the Little North Santiam River model.

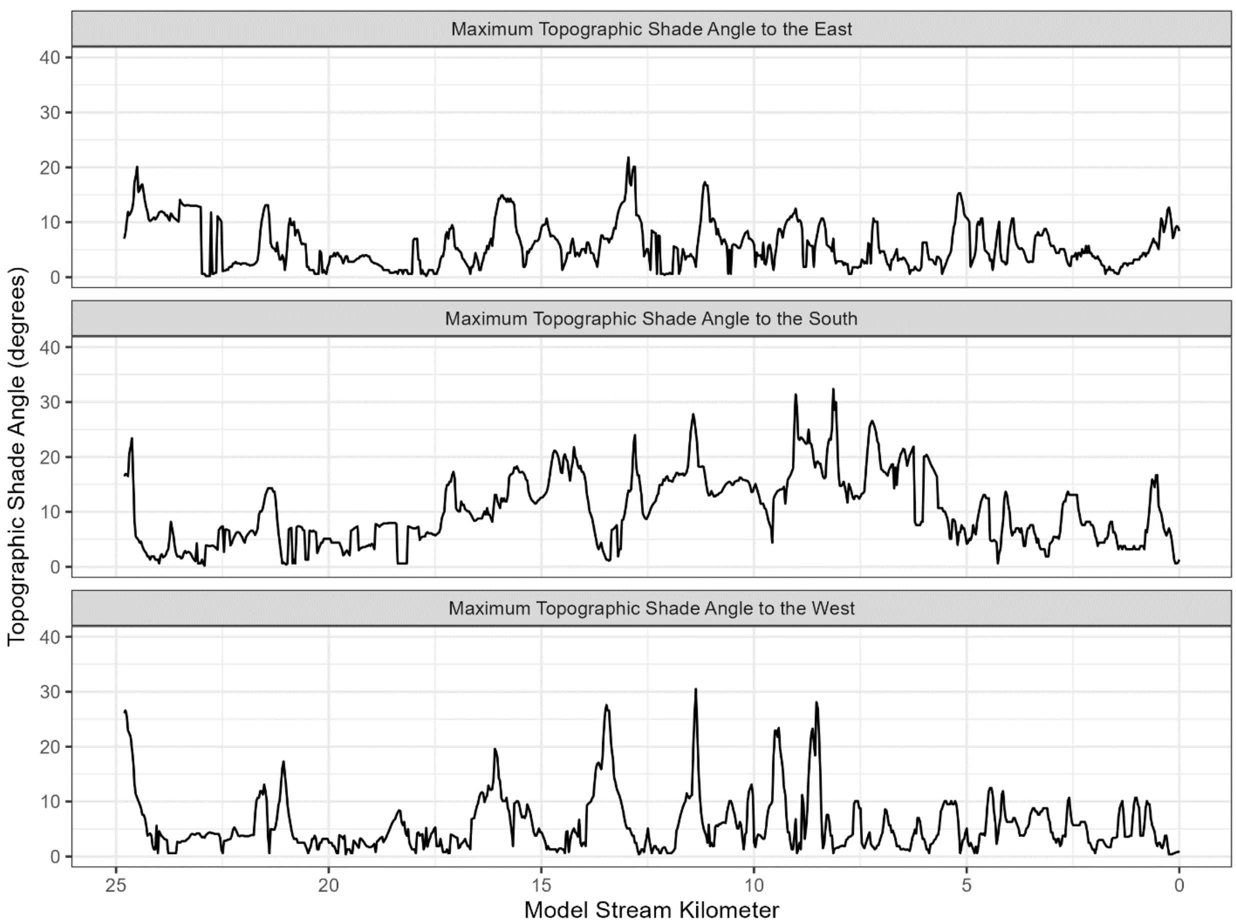


Figure 3-102: Topographic shade angle inputs to the Little North Santiam River model.

3.4.9 Channel setup

Channel setup for the Little North Santiam River model is presented in **Figure 3-103**.

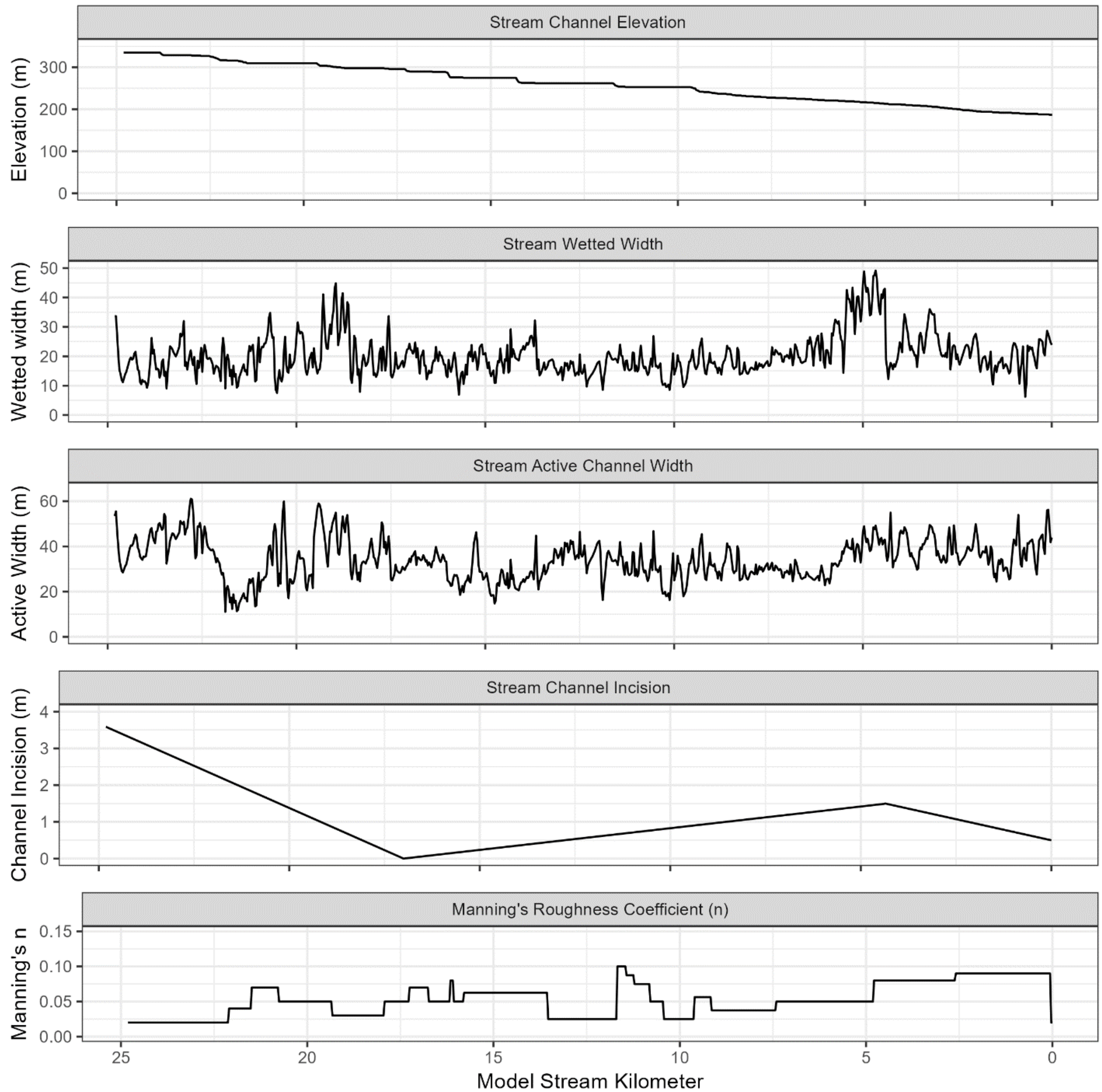


Figure 3-103: Channel setup in the Little North Santiam River model.

3.4.10 Calibration results

3.4.10.1 Temperature

The model was calibrated to the continuous temperature data collected from several locations along the Little North Santiam River, as well as to the TIR data. Results for goodness of fit statistics comparing field observed and model-predicted temperatures are summarized in **Table 3-31**. Comparisons of model-calculated temperatures to continuous temperature data collected at monitoring locations where data was successfully retrieved is presented in **Figure 3-104** through **Figure 3-108**. A comparison of model-calculated temperature to TIR measured temperatures for the Pudding River is shown in **Figure 3-109**.

Table 3-31: Little North Santiam River water temperature goodness of fit statistics comparing field observed and model-predicted temperatures.

Monitoring Location	Model KM	Temperature Statistics	ME	MAE	RMSE	NSE	n
All Stations		Daily Maximum	0.08	0.36	0.41	NA	5
All Stations		Hourly	-0.53	0.78	0.92	0.71	120
14182500: Little North Santiam River near Mehama	3	Hourly	-0.8	0.8	0.89	0.64	24
BLMNF: North Fork County Park	4.4	Hourly	-0.85	0.86	0.99	0.25	24
S88442: Model Node 4	7.6	Hourly	-1	1.03	1.17	-0.14	24
S349766: Model Node 3	13.6	Hourly	-0.21	0.81	0.92	0.53	24
BLMEH: Elk Horn Park	17	Hourly	0.23	0.39	0.46	0.92	24
Little North Santiam River TIR	Model extent		0.71	0.73	0.9	NA	249

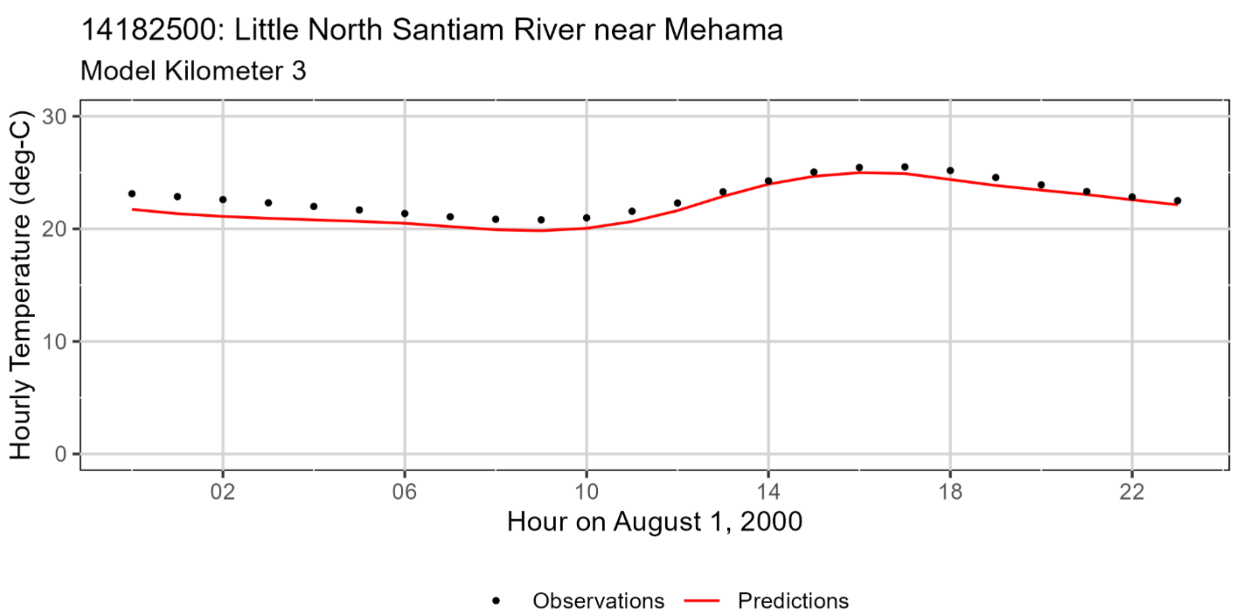


Figure 3-104: Little North Santiam River measured and model-predicted hourly temperatures at monitoring station 14182500.

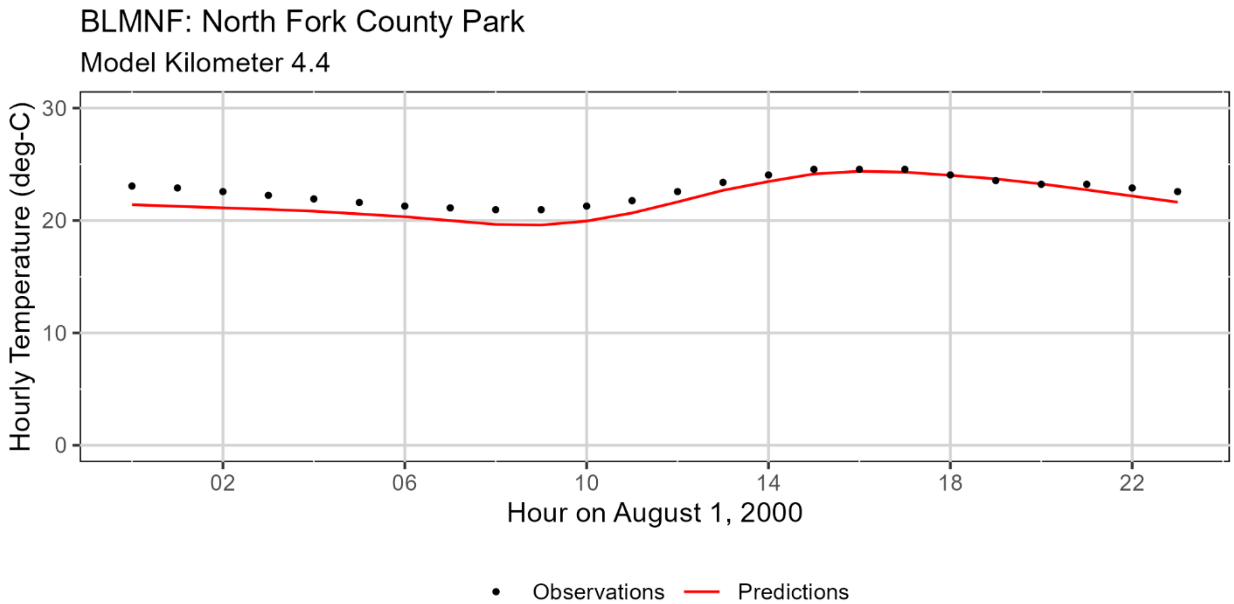


Figure 3-105: Little North Santiam River measured and model-predicted hourly temperatures at monitoring station BLMNF.

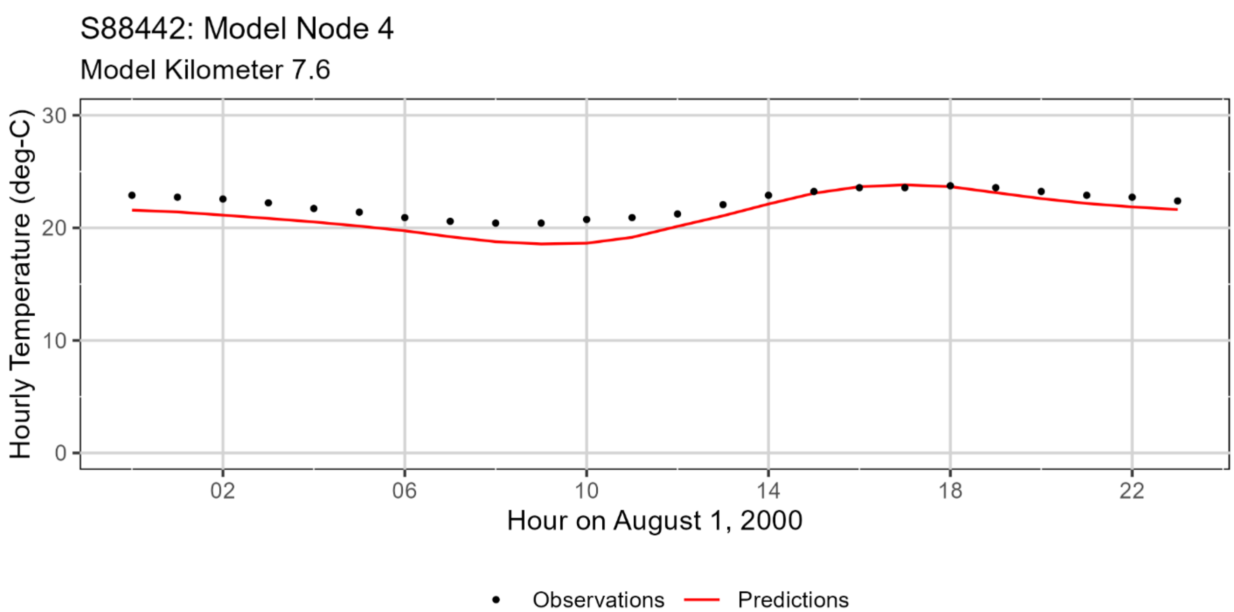


Figure 3-106: Little North Santiam River measured and model-predicted hourly temperatures at monitoring station S88442.

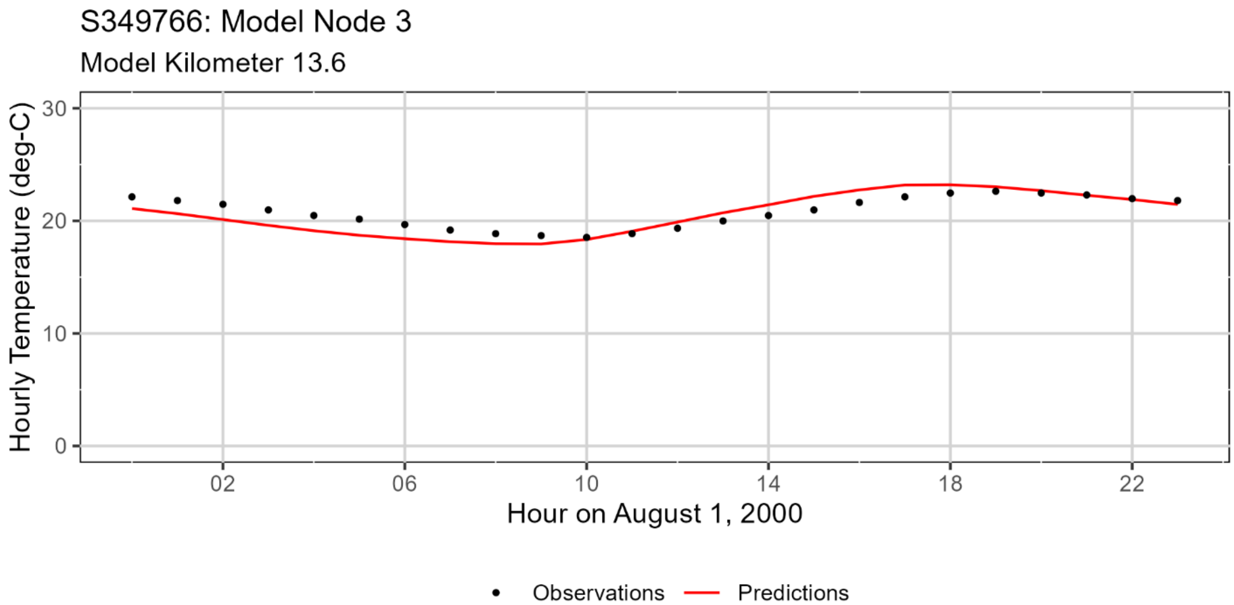


Figure 3-107: Little North Santiam River measured and model-predicted hourly temperatures at monitoring station S349766.

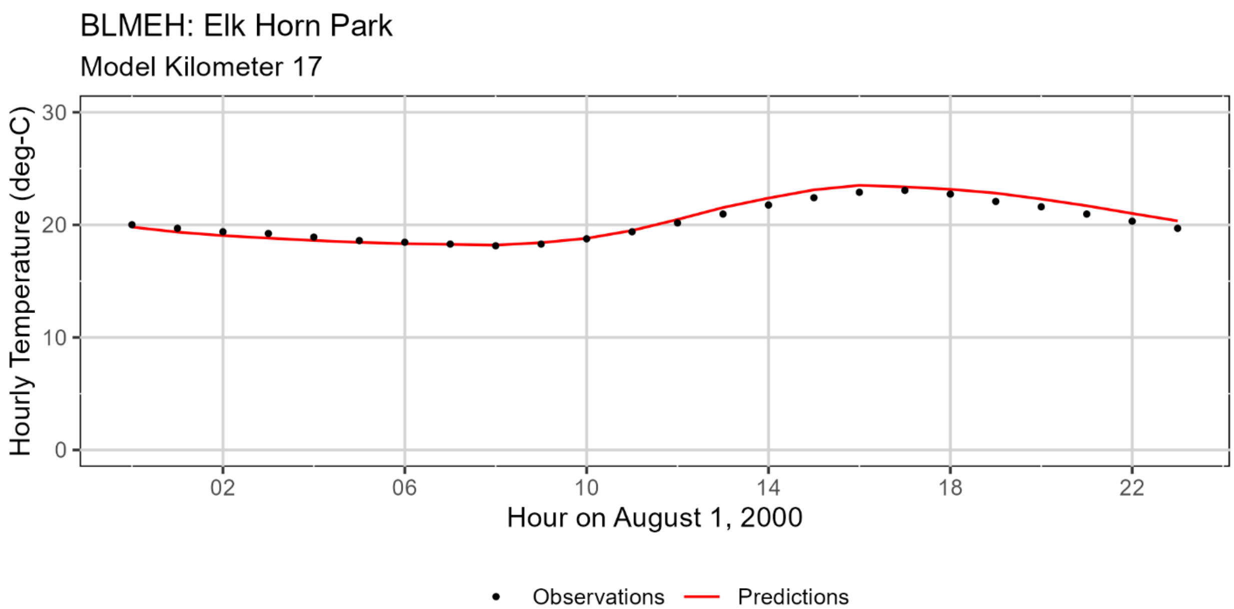


Figure 3-108: Little North Santiam River measured and model-predicted hourly temperatures at monitoring station BLMEH.

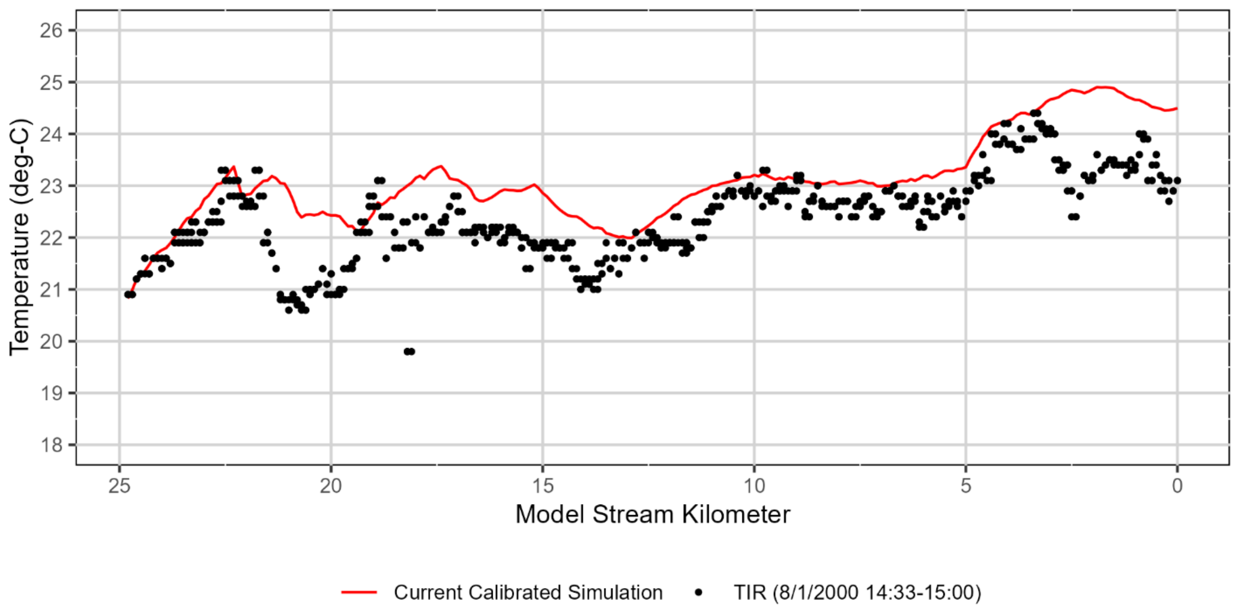


Figure 3-109: Little North Santiam River TIR and simulated current stream temperatures.

3.4.10.2 Effective Shade

Observed and model-predicted effective shade data were plotted along the Little North Santiam River (**Figure 3-110**). The observed field data used for comparison is summarized in **Table 2-31**. Results for goodness of fit statistics comparing field observed and model-predicted temperatures are summarized in

Table 3-32.

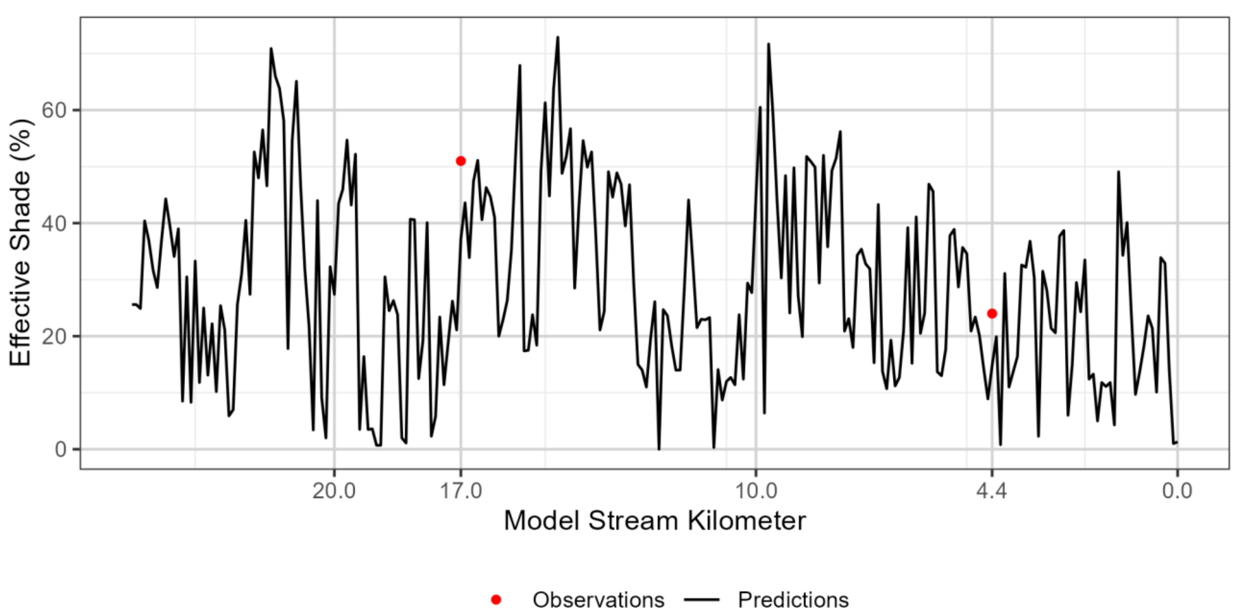


Figure 3-110: Little North Santiam River field observed and model-predicted effective shade.

Table 3-32: Little North Santiam River effective shade goodness of fit statistics comparing field observed and model values.

N	R^2	ME	MAE	RMSE
2	1.0	-11.5	11.5	11.73

3.4.10.3 Flow

A flow mass balance was completed to improve the calibration and match flows to the measured values. The observed flow used for comparison to the modeled flow is summarized in **Table 3-33**, which is plotted with the model flow in **Figure 3-111**. Results for goodness of fit statistics comparing field observed flow and the model flow are summarized in **Table 3-34**.

Table 3-33: Little North Santiam River stream flow rate measurements.

Monitoring Location	Model KM	Flow Statistics	Flow (cms)	Date
S68509: Little North Santiam at Fawn Creek	24.8	Instantaneous	0.94	8/1/2000
Model Node 2: Little North Santiam at Elkhorn	17.0	Instantaneous	1.3	7/28/2000
Model Node 5: Little North Santiam at County Park	4.4	Instantaneous	1.41	7/28/2000
14182500: Little North Santiam near Mehama, OR	3.0	Daily mean	1.59	7/28/2000

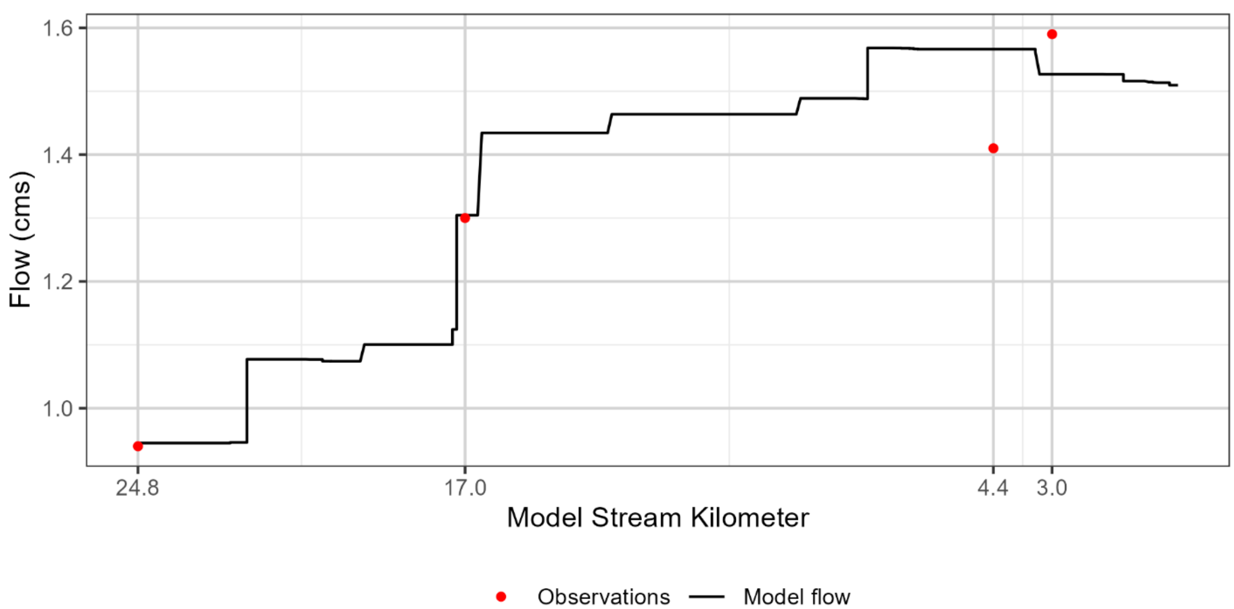


Figure 3-111: Little North Santiam River field observed and model flow rates.

Table 3-34: Little North Santiam River goodness of fit statistics comparing field observed and model flow rates.

N	R^2	ME	MAE	RMSE
4	0.89	0.03	0.06	0.08

3.4.10.4 Channel

Results comparing channels widths derived from GIS and modeling to those measured in the field are presented in **Figure 3-112**. Results shows channel widths only from streams modeled for temperature with Heat Source.

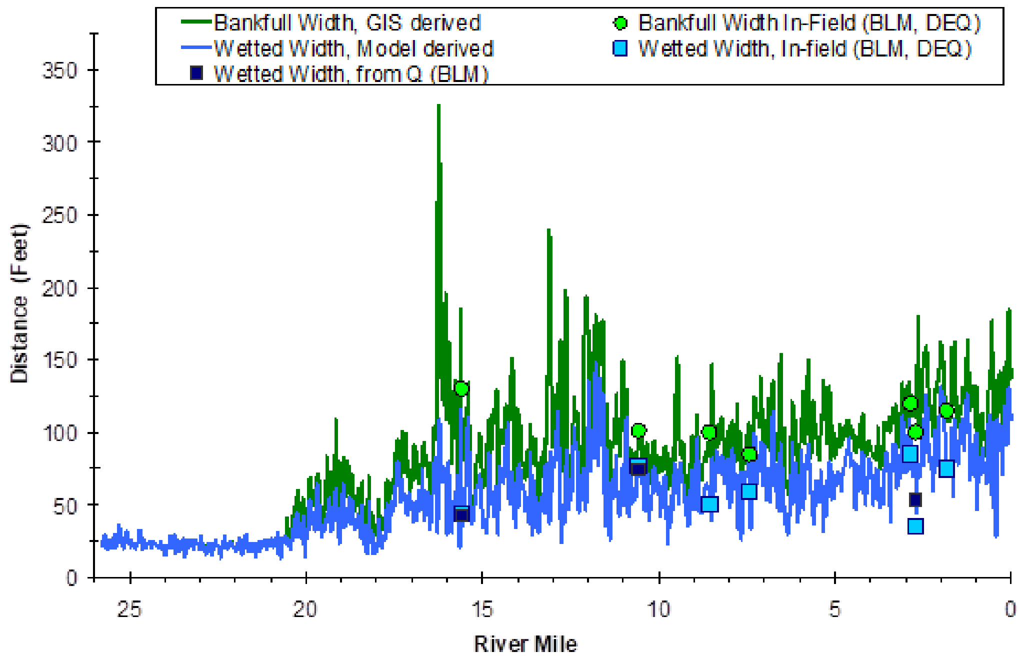


Figure 3-112: Little North Santiam River field observed and derived bankfull and wetted width.

3.5 Thomas Creek

The Thomas Creek model is a temperature model developed using Heat Source 6.5.1. The model was developed by DEQ.

3.5.1 Model extent

The extent of the model domain is Thomas Creek from the mouth to river mile 32 (**Figure 3-113**).

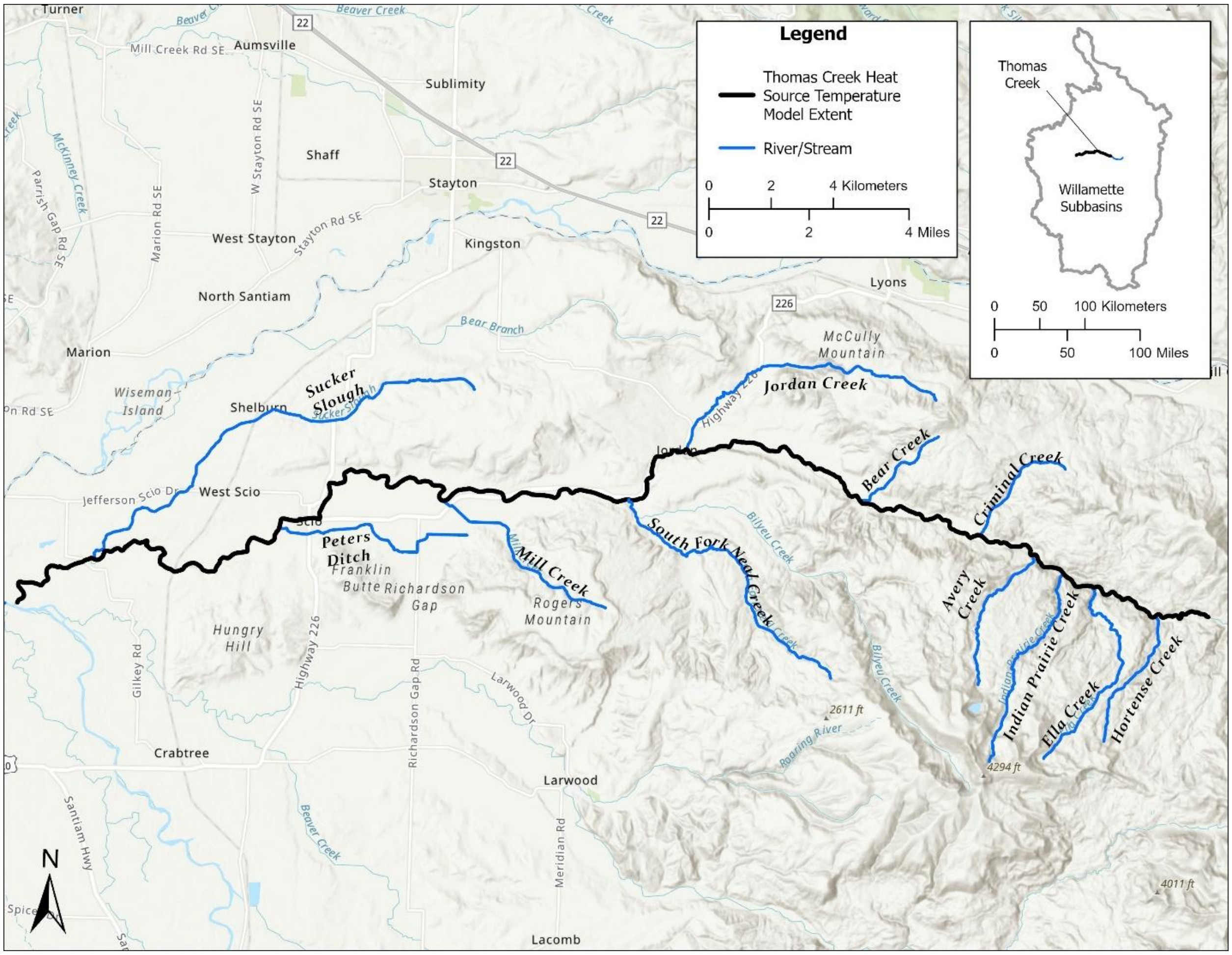


Figure 3-113: Thomas Creek temperature model extent.

3.5.2 Spatial and temporal resolution

The model input spatial resolution (*dx*) is 30 m. Outputs are generated every 100 m. The model time step (*dt*) is 1 minute and outputs are generated every hour.

3.5.3 Time frame of simulation

The model period is for a single day: August 03, 2000.

3.5.4 Meteorological inputs

The model was set up using hourly air temperature, relative humidity, and wind speed measurements (**Figure 3-114**). According to the model, the air temperature and relative humidity data can be divided into three groups (**Table 3-35**). Each group uses the same values for air temperature and relative humidity, which may correspond to three different monitoring sites. The wind speeds were measured at the Corvallis AgriMet site (crvo). Wind speeds were adjusted to improve the calibration using wind-sheltering coefficients listed in

Table 3-35 to represent difference in wind speeds between the measurement location and above the stream within the riparian area. Any missing data was replaced by the average of nearby time data.

Table 3-35: Meteorology inputs to the Thomas Creek model.

Group	Model Location (km)	Model Location Name	Wind Sheltering Coefficient
Group 1	50.871	Upper Thomas Creek BLM Site	0.04
	43.190	Lower Thomas Creek BLM Site	0.04
	38.649	Thomas Creek at bridge at Willamette Industries Gate	0.04
Group 2	29.931	Downstream Jordan Creek	0.04
	27.584	Hannah Covered Bridge	0.04
Group 3	23.165	Old USGS Gage	0.04
	19.172	Shimanek Bridge	0.04
	12.832	West of Scio	0.25
	4.084	Kelly Road	0.25

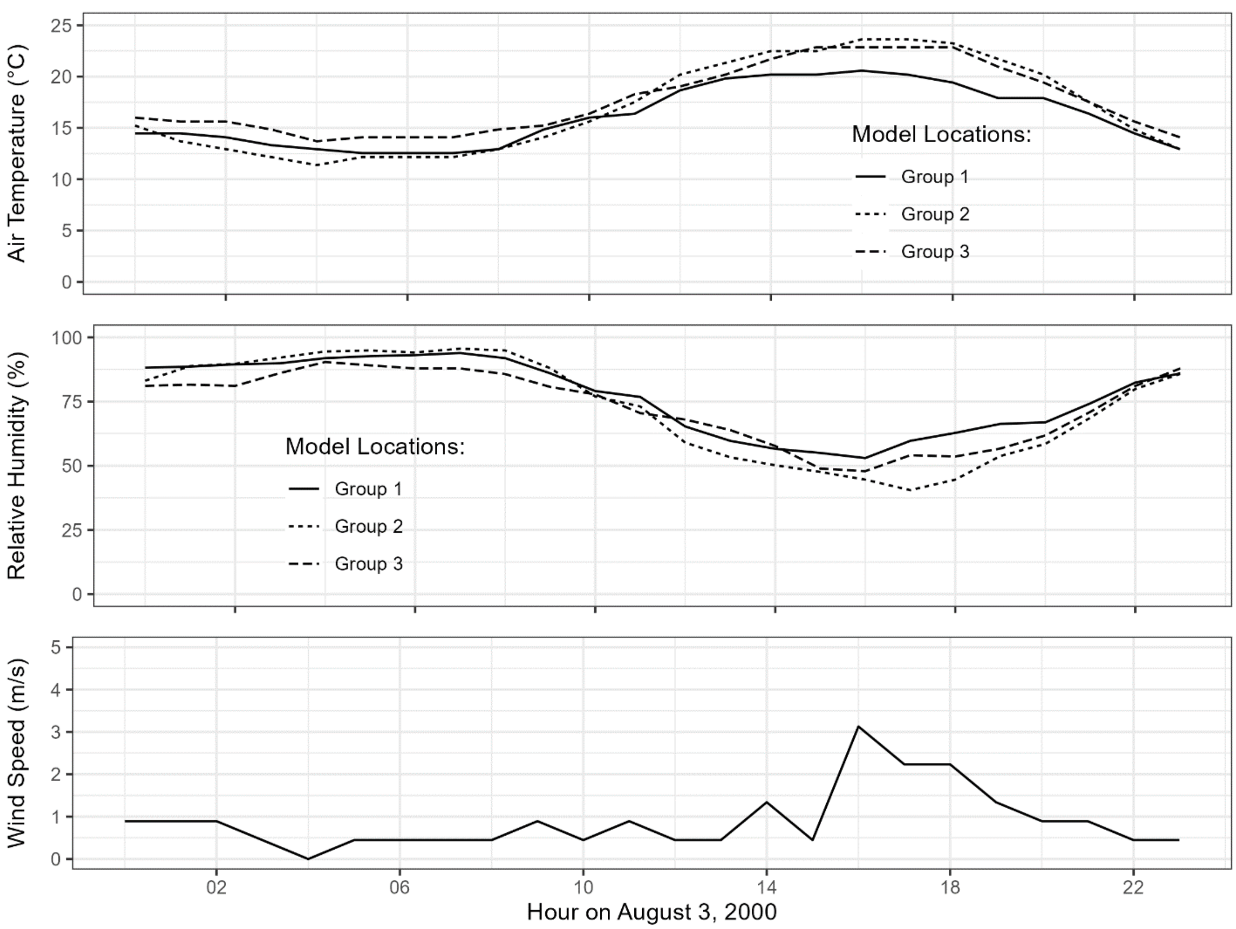


Figure 3-114: Meteorological inputs to the Thomas Creek model.

3.5.5 Temperature inputs

Hourly water temperature time series data were used to support tributary and boundary condition model setup. **Figure 3-115** shows the locations of the various stream temperature monitoring locations that were used for model setup or calibration.

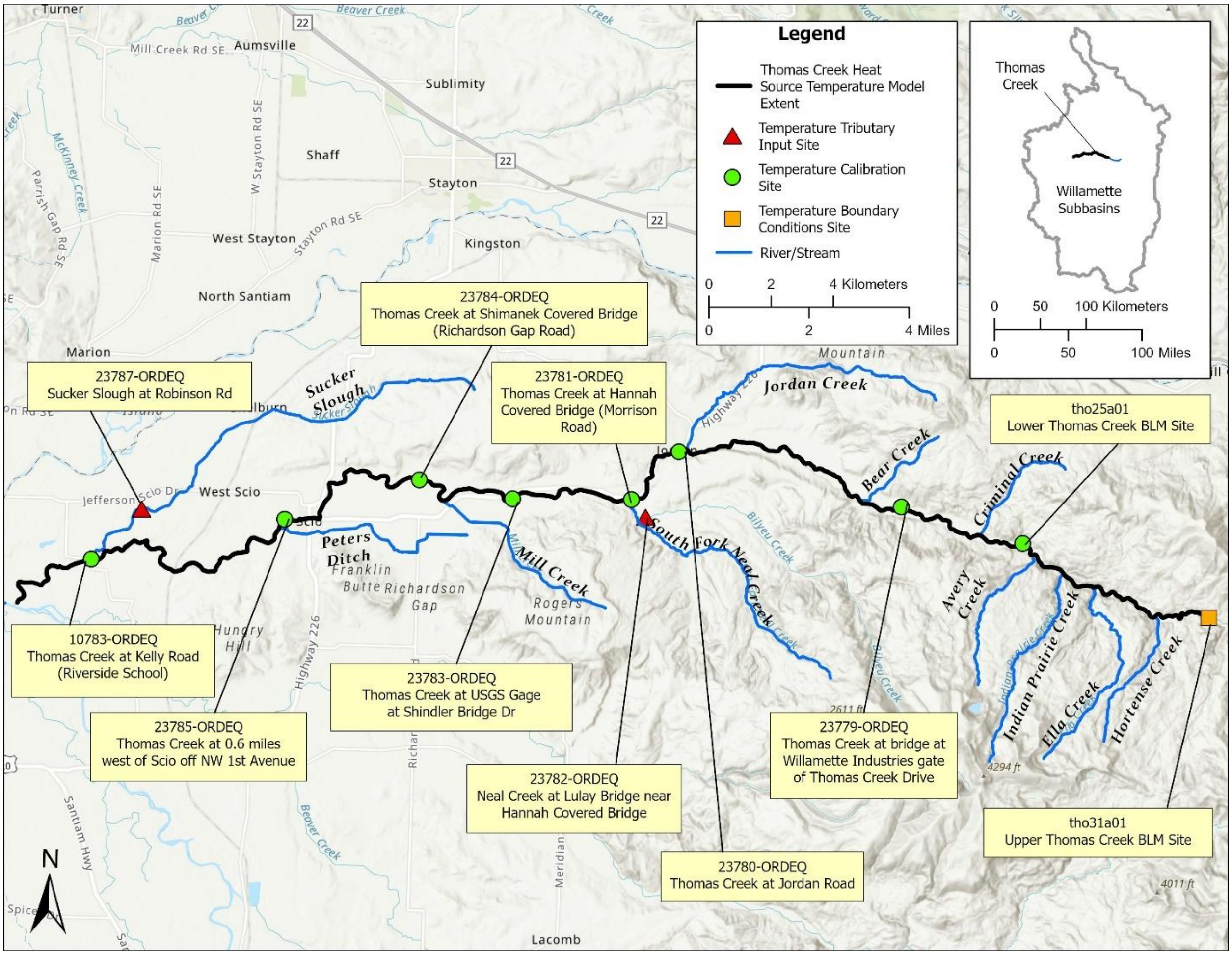
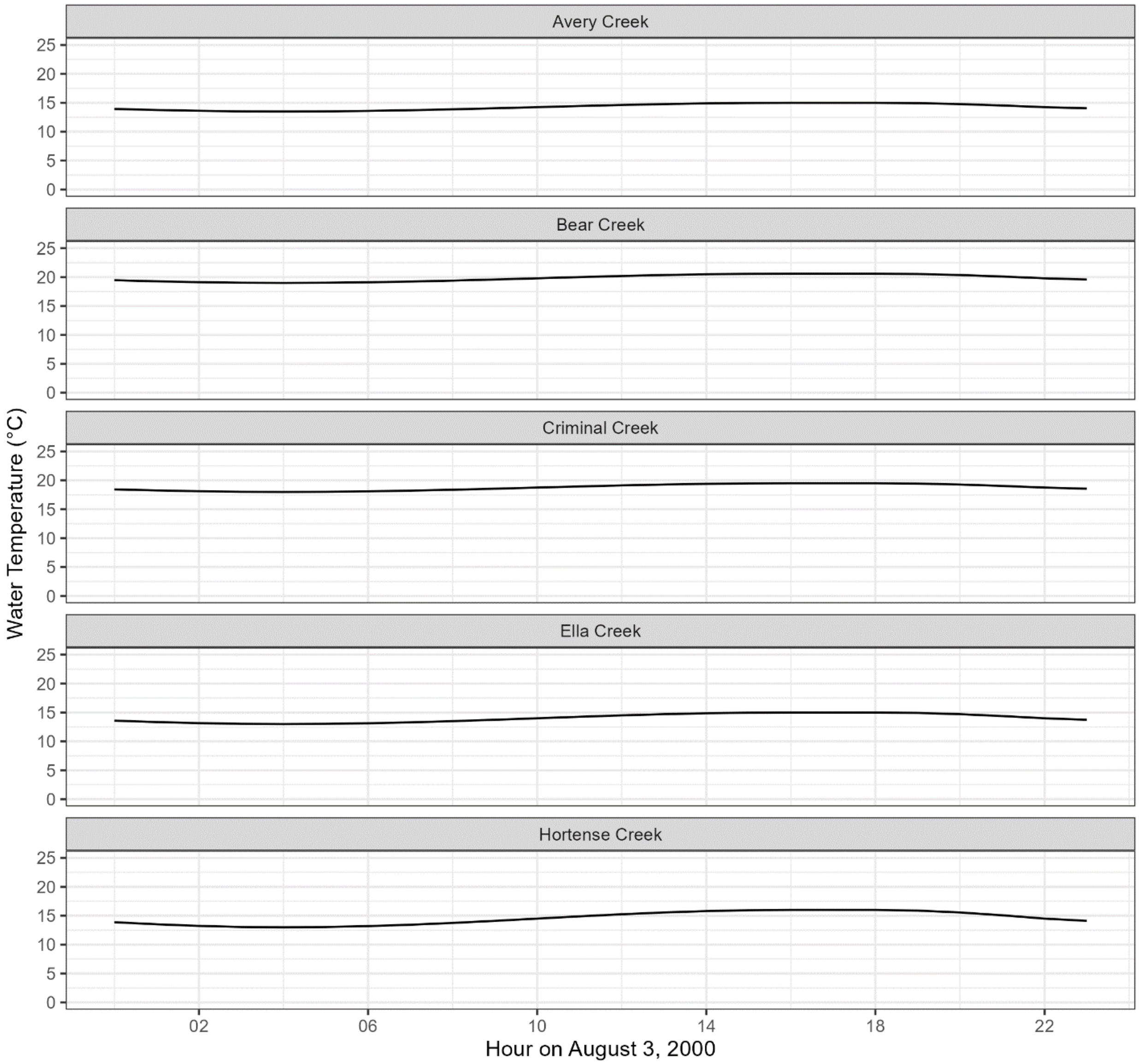


Figure 3-115: Temperature monitoring locations used for the Thomas Creek model setup and calibration.

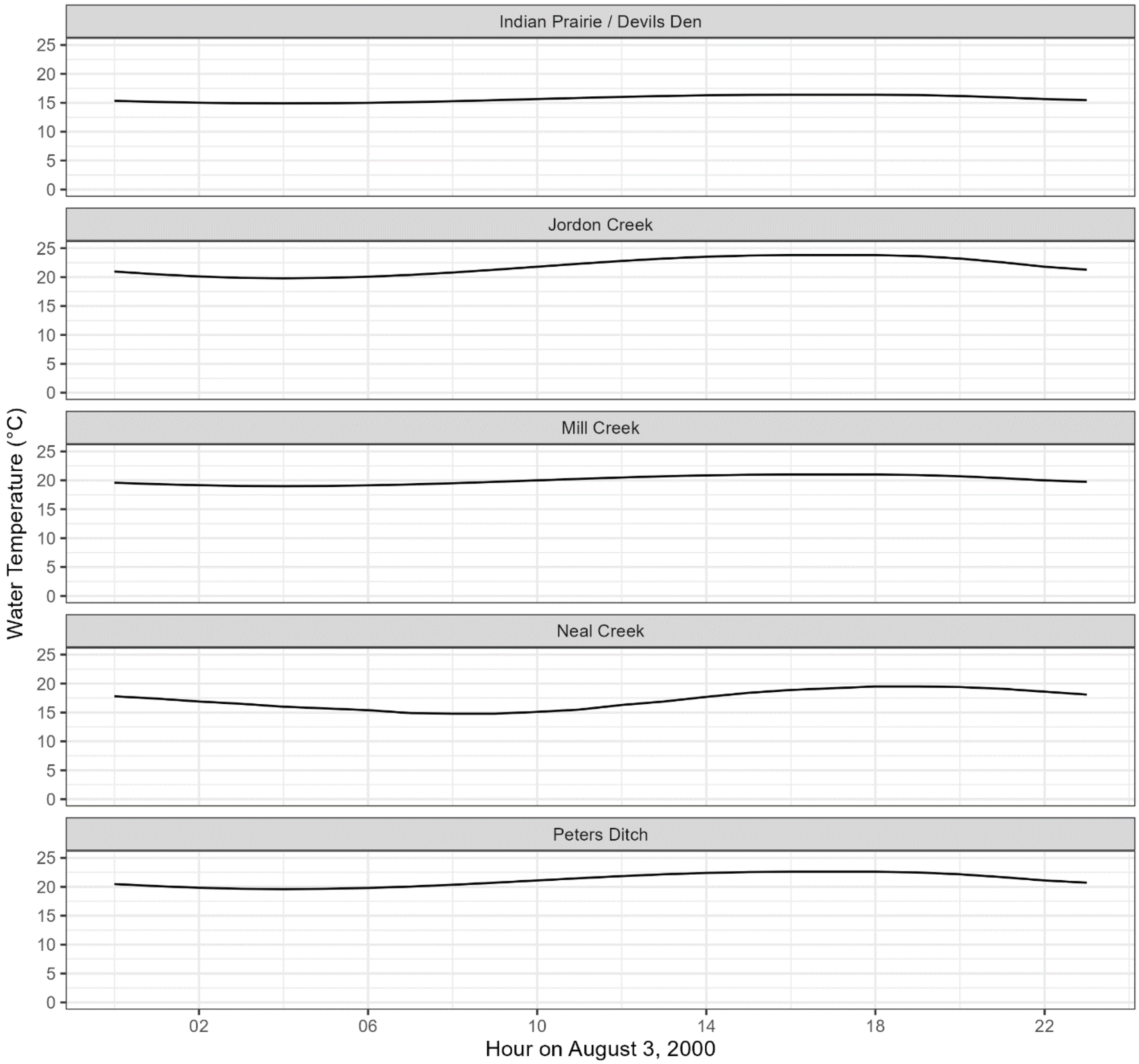
Table 3-36 and **Figure 3-116** document the water temperature inputs to the model at the boundary condition (Upper Thomas Creek BLM Site) and tributaries. **Table 2-39** lists TIR Temperatures on Thomas Creek.

Table 3-36: Boundary condition and tributary water temperature inputs to the Thomas Creek model.

Model Location Name	Model Location (km)	Input Type	Data Source
Upper Thomas Creek BLM Site	50.871	Boundary Condition	BLM (tho31a01)
Hortense Creek	48.951	Tributary	Derived from TIR. Watershed Sciences (2001)
Ella Creek	46.055	Tributary	Derived from TIR. Watershed Sciences (2001)
Indian Prairie / Devils Den	45.11	Tributary	Derived from TIR. Watershed Sciences (2001)
Avery Creek	43.83	Tributary	Derived from TIR. Watershed Sciences (2001)
Criminal Creek	41.697	Tributary	Derived from TIR. Watershed Sciences (2001)
Bear Creek	37.094	Tributary	Derived from TIR. Watershed Sciences (2001)
Spring Brook	30.541	Tributary	Derived from TIR*
Jordan Creek	30.328	Tributary	Derived from TIR. Watershed Sciences (2001)
Neal Creek at Lulay Road near Hannah Covered Bridge	27.219	Tributary	23782-ORDEQ
Small Trib	20.879	Tributary	Derived from TIR. Watershed Sciences (2001)
Mill Creek	20.574	Tributary	Derived from TIR. Watershed Sciences (2001)
Peters Ditch	12.497	Tributary	Derived from TIR. Watershed Sciences (2001)
Small Trib	11.582	Tributary	Derived from TIR. Watershed Sciences (2001)
Sucker Slough at Robinson Road	4.054	Tributary	23787-ORDEQ
* Constant temperature of 18.8°C.			

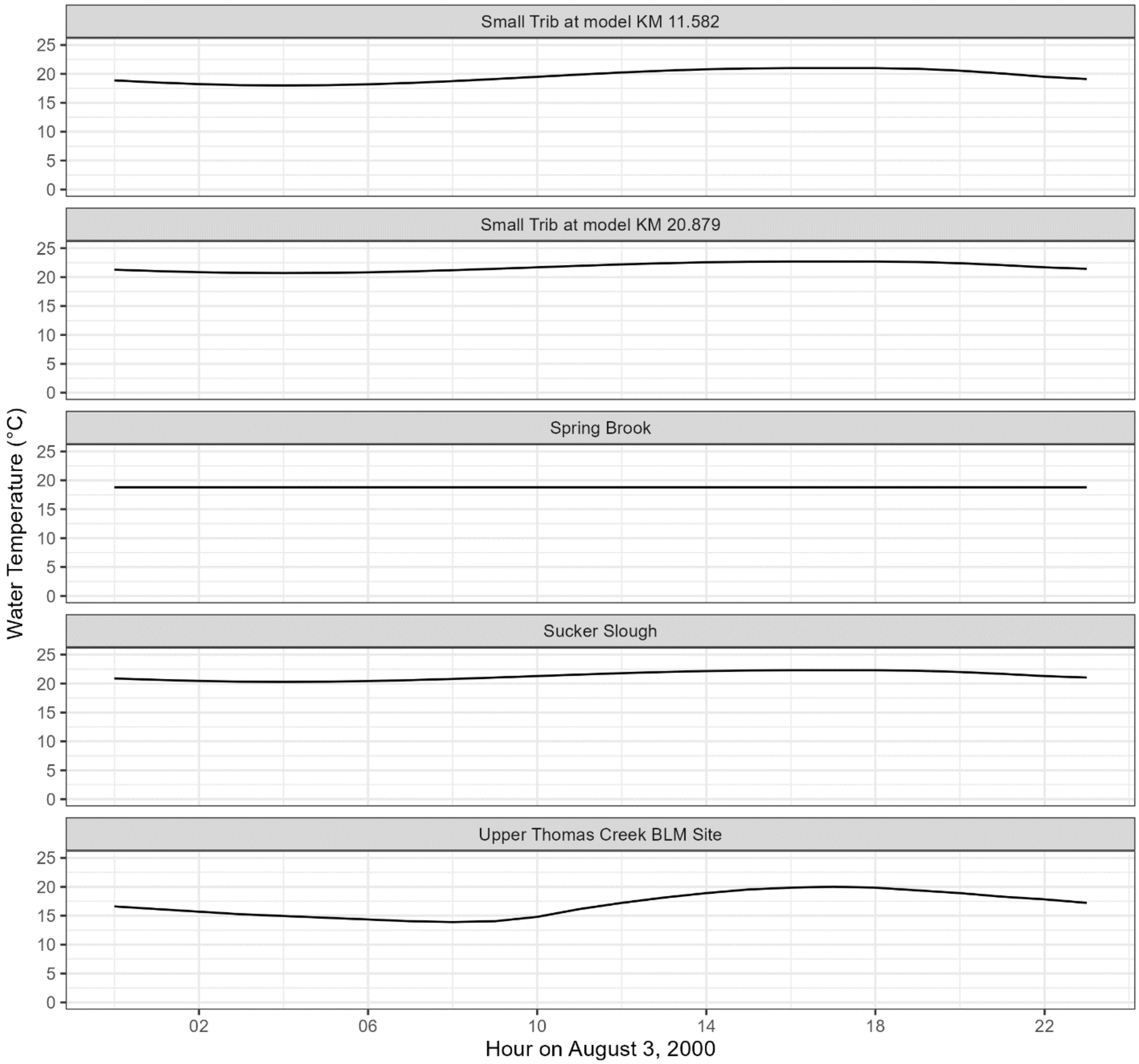

Avery Creek
Bear Creek
Criminal Creek
Ella Creek
Hortense Creek
Water Temperature (°C)
0
5
10
15
20
25
02
06
10
14
18
22
Hour on August 3, 2000

(A)



Indian Prairie / Devils Den
Jordon Creek
Mill Creek
Neal Creek
Peters Ditch
Water Temperature (°C)
0
5
10
15
20
25
02
06
10
14
18
22
Hour on August 3, 2000

(B)



(C)

Figure 3-116 (A)-(C): Boundary condition and tributary water temperature inputs to the Thomas Creek model.

3.5.6 Flow inputs

Hourly stream flow time series data were used to support tributary and boundary condition model setup. **Figure 3-117** shows the locations of the various stream flow monitoring locations that were used for model setup or calibration.

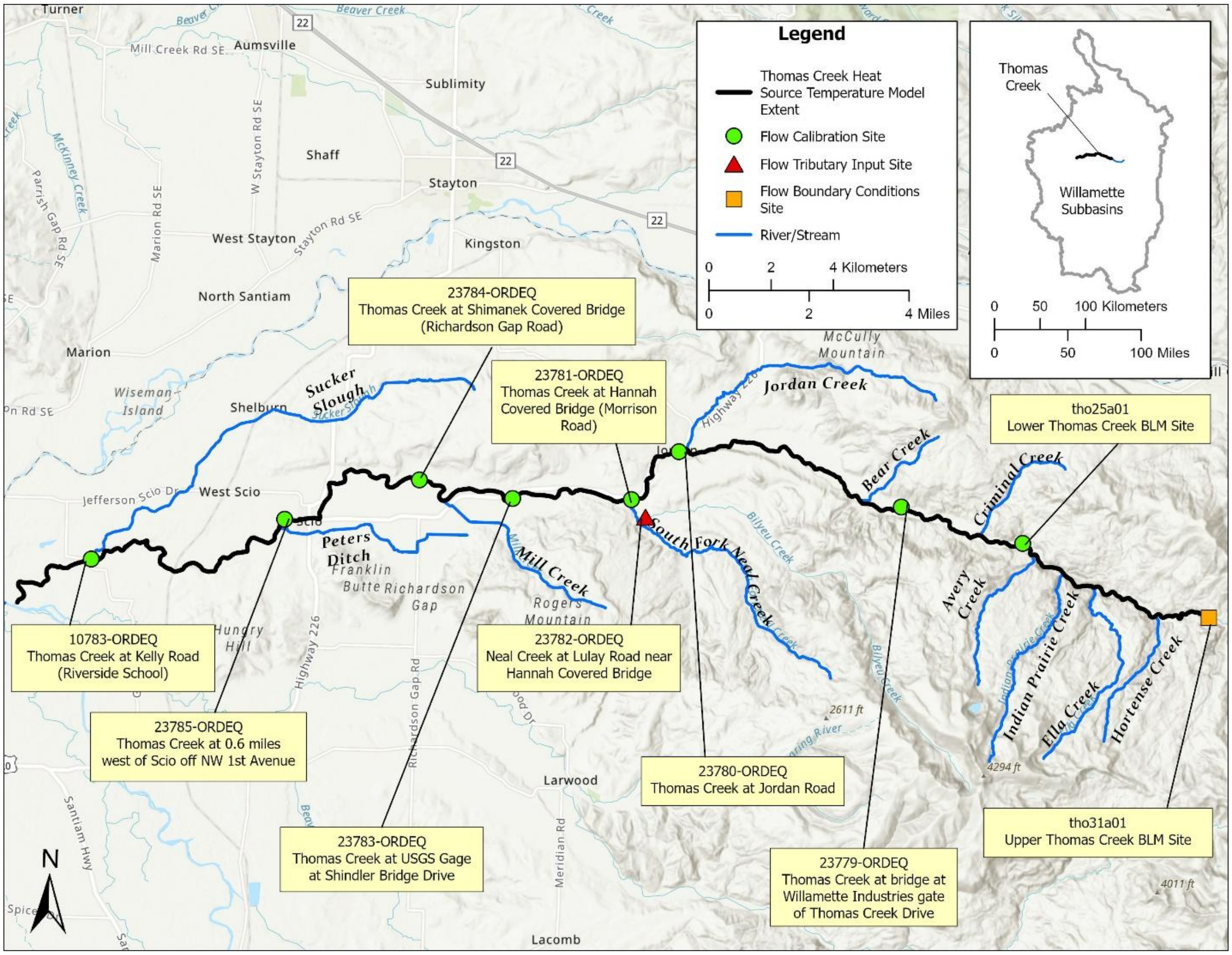


Figure 3-117: Flow monitoring locations used for the Thomas Creek model setup and calibration.

The boundary condition and tributary flow inputs to the model in summarized in **Table 3-37**. **Figure 3-118** documents mainstem model flow setup. The model flow was estimated between measured sites using a flow mass balance, which incorporated input from tributaries and demand from PODs. The model assumes that 1/3 of the permitted withdrawal rate was utilized during the model period. The total water withdrawal volume at the PODs in the model flow amounted to 0.5716 cms.

Table 3-37: Boundary condition and tributary flow inputs to the Thomas Creek model.

Model Location Name	Model Location (km)	Flow Rate (cms)	Input Type	Data Source
Upper Thomas Creek BLM Site	50.871	0.2459	Boundary Condition	BLM (tho31a01)
Hortense Creek	48.951	0.021	Tributary	Estimated using a flow mass balance based on TIR

Model Location Name	Model Location (km)	Flow Rate (cms)	Input Type	Data Source
Ella Creek	46.055	0.063	Tributary	Estimated using a flow mass balance based on TIR
Indian Prairie / Devils Den	45.11	0.060	Tributary	Estimated using a flow mass balance based on TIR
Avery Creek	43.83	0.030	Tributary	Estimated using a flow mass balance based on TIR
Criminal Creek	41.697	0.003	Tributary	BLM
Bear Creek	37.094	0.080	Tributary	Estimated using a flow mass balance based on TIR
Spring Brook	30.541	0.010	Tributary	Estimated using a flow mass balance based on TIR
Jordan Creek	30.328	0.100	Tributary	Estimated using a flow mass balance based on TIR
Neal Creek at Lulay Bridge near Hannah Covered Bridge	27.219	0.160	Tributary	DEQ (23782-ORDEQ)
Small Trib	20.879	0.050	Tributary	Estimated using a flow mass balance based on TIR
Mill Creek	20.574	0.050	Tributary	Estimated using a flow mass balance based on TIR
Peters Ditch	12.497	0.050	Tributary	Estimated using a flow mass balance based on TIR
Small Trib	11.582	0.060	Tributary	Estimated using a flow mass balance based on TIR
Sucker Slough at Robinson Road	4.054	0.050	Tributary	Estimated using a flow mass balance based on TIR

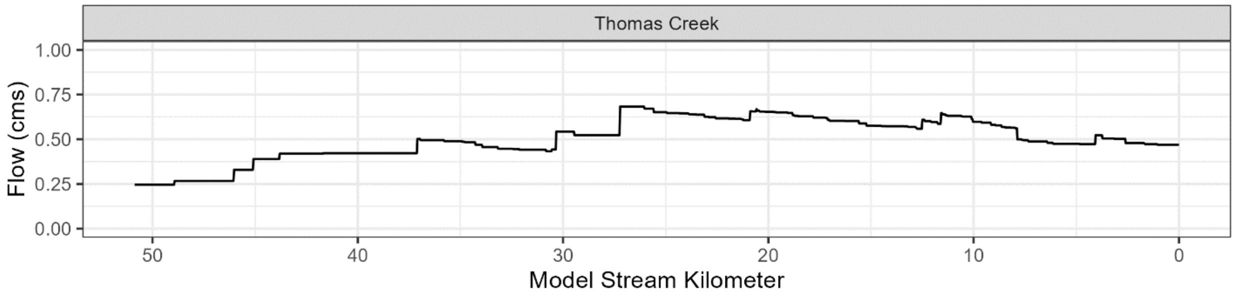


Figure 3-118: Boundary condition and mainstem flow inputs to the Thomas Creek model.

3.5.7 Point source inputs

The City of Scio STP holds an individual NPDES permit and is located near Thomas Creek river mile 7.2 (**Figure 3-119**). This location is within the extent of the model. Details about this point source are summarized in **Table 3-38.** The current NPDES permit does not authorize discharge from May 1 - Oct 31 and therefore Scio STP was not included in the model.

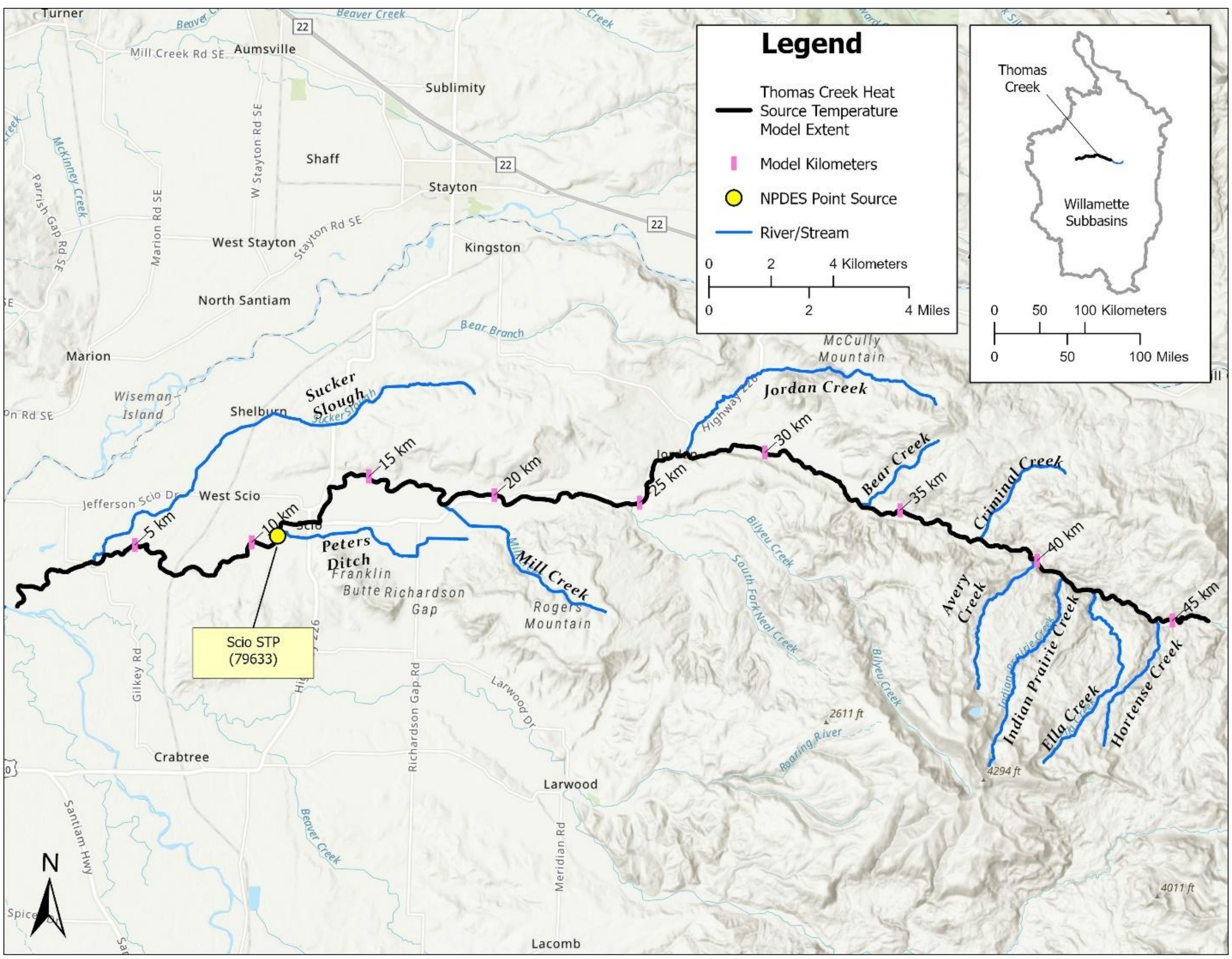


Figure 3-119: Locations of permitted individual NPDES point sources near the Thomas River.

Table 3-38: NPDES point source located along the Thomas Creek model extent.

Facility Name (Facility Number)	Latitude/Longitude	Permit Type and Description	Stream/River Mile
Scio STP (79633)	44.7001/-122.862	NPDES-DOM-Db: Sewage - less than 1 MGD with discharging lagoons	Thomas Creek RM 7.2

3.5.8 Landcover and topographic shade inputs

Average land cover height inputs and topographic shade angle inputs are shown in Figure 3-120 and Figure 3-121, respectively.

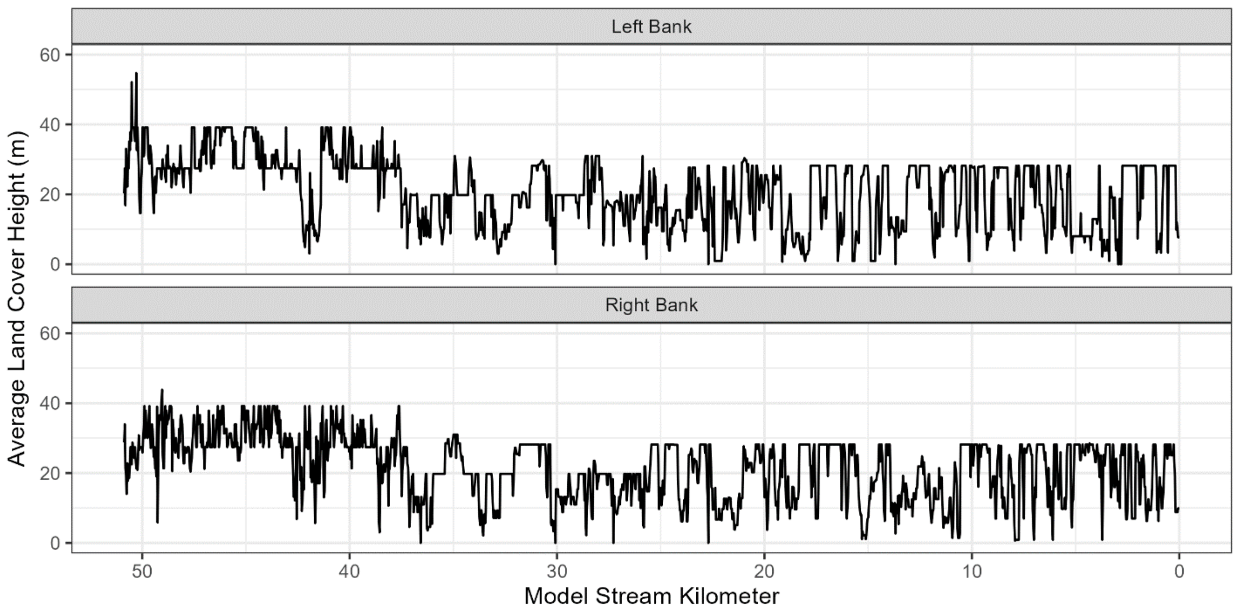


Figure 3-120: Average land cover height inputs to the Thomas Creek model.

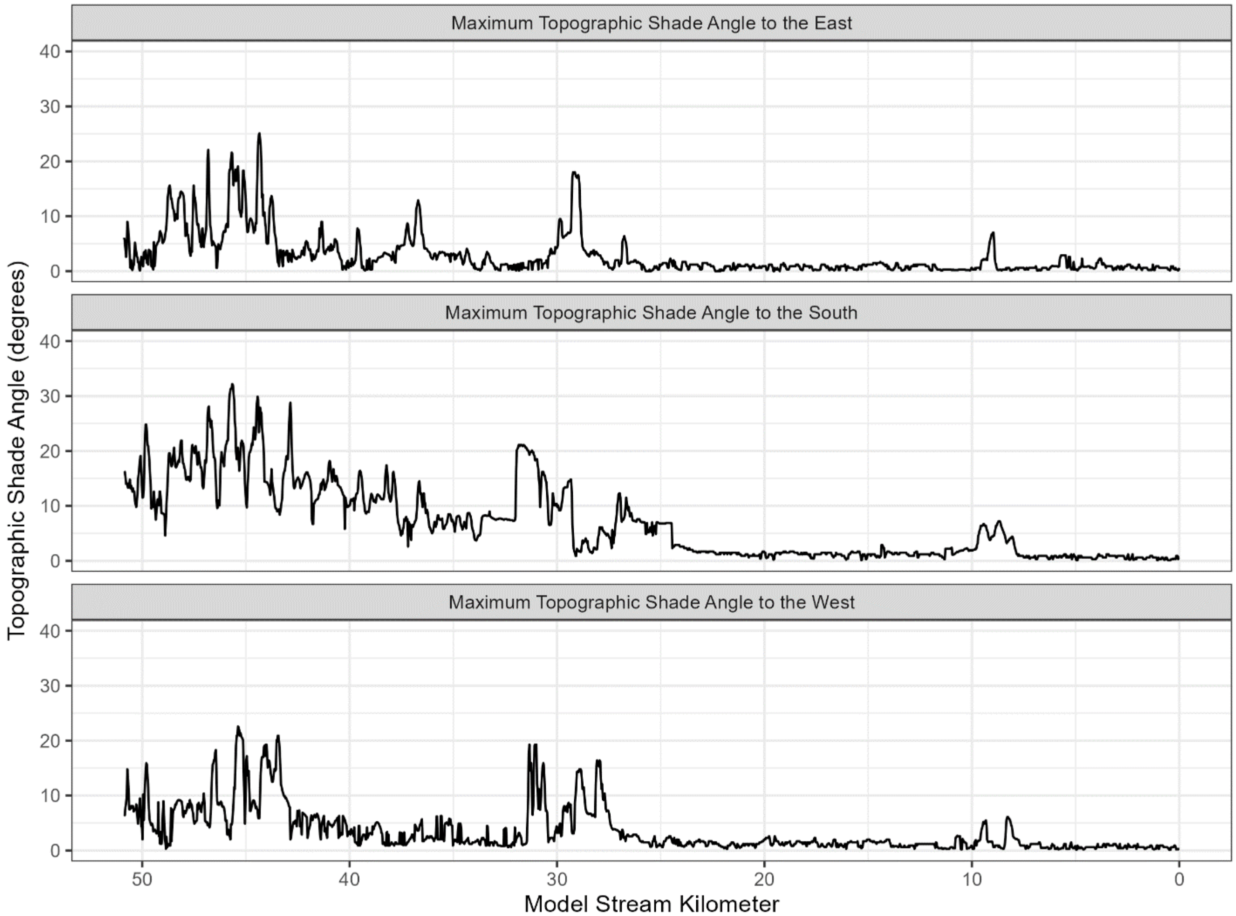


Figure 3-121: Topographic shade angle inputs to the Thomas Creek model.

3.5.9 Channel setup

Channel setup for the Little North Santiam River model is presented in **Figure 3-122**.

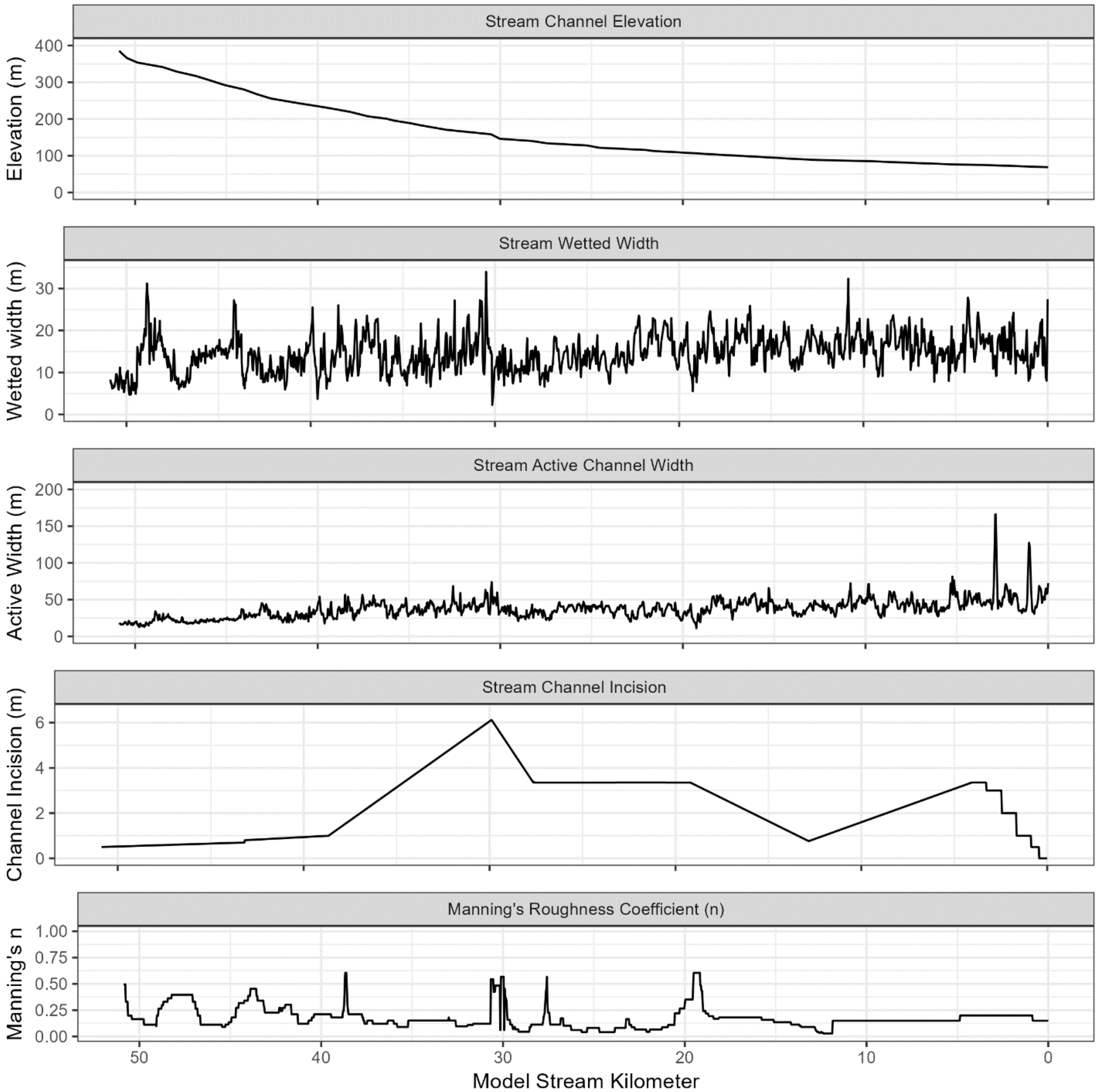


Figure 3-122: Channel setup in the Thomas Creek model.

3.5.10 Calibration results

3.5.10.1 Temperature

The model was calibrated to the continuous temperature data collected from several locations along Thomas Creek, as well as to the TIR data. Results for goodness of fit statistics comparing field observed and model-predicted temperatures are summarized in **Table 3-39**. Observed and model-predicted hourly temperatures were plotted for the monitoring stations (**Figure 3-123** through **Figure 3-130**). Modeling results comparing simulated current conditions for Johnson Creek to the TIR data are presented in **Figure 3-131**.

Table 3-39: Thomas Creek water temperature goodness of fit statistics comparing field observed and model-predicted temperatures.

Monitoring Location	Model KM	Temperature Statistics	ME	MAE	RMSE	NSE	n
All Stations		Daily Maximum	-0.32	0.66	0.89	NA	8
All Stations		Hourly	-0.73	0.97	1.16	0.84	192
10783-ORDEQ: Thomas Creek at Kelly Road	4.1	Hourly	-0.22	0.79	0.9	0.61	24
23785-ORDEQ: Thomas Creek at 0.6 miles west of Scio off of NW 1st	12.8	Hourly	-0.14	0.62	0.7	0.88	24
23784-ORDEQ: Thomas Creek at Shimanek Covered Bridge	19.2	Hourly	-1.19	1.3	1.49	-0.27	24
23783-ORDEQ: Thomas Creek at USGS Gauge at Shindler Bridge Dr	23.2	Hourly	-0.63	0.81	1.19	0.75	24
23781-ORDEQ: Thomas Creek at Hannah Covered Bridge	27.6	Hourly	-0.47	0.86	1.04	0.61	24
23780-ORDEQ: Downstream Jordon Creek	29.9	Hourly	-1.03	1.03	1.11	0.81	24
23779-ORDEQ: Thomas Creek at bridge at Willamette Industries Gate	38.6	Hourly	-1.44	1.44	1.55	0.22	24
tho25a01: Lower Thomas Creek BLM Site	43.2	Hourly	-0.74	0.88	1.02	-0.1	24
Thomas Creek TIR	Model extent		0.16	0.75	0.91	NA	510

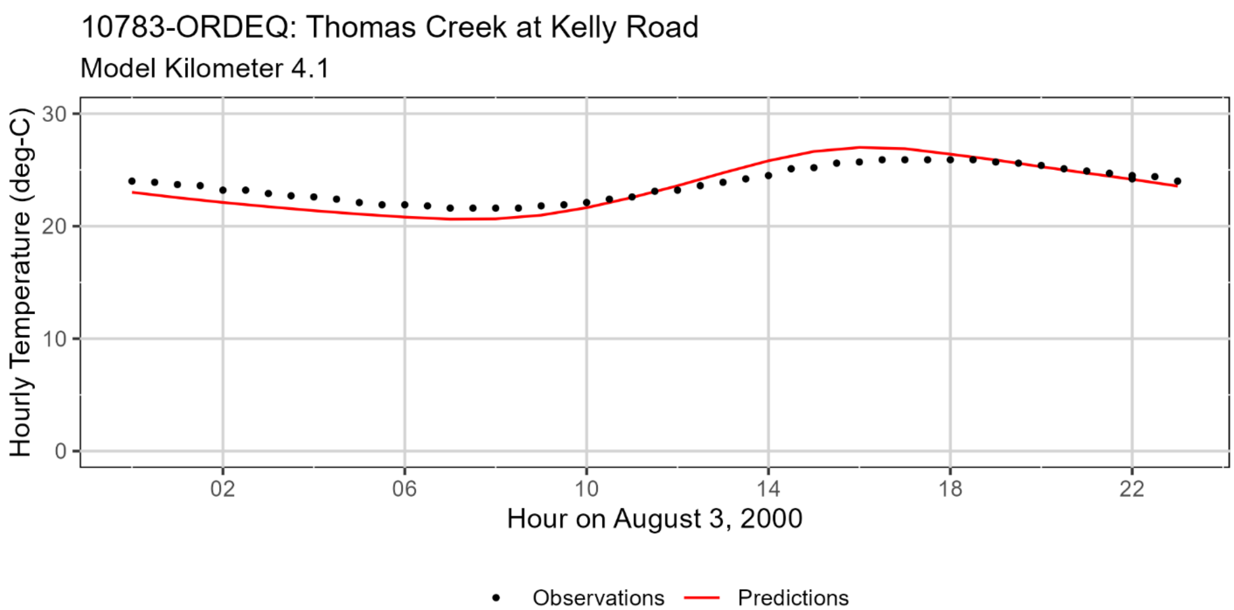


Figure 3-123: Thomas Creek measured and model-predicted hourly temperatures at monitoring station 10783-ORDEQ.

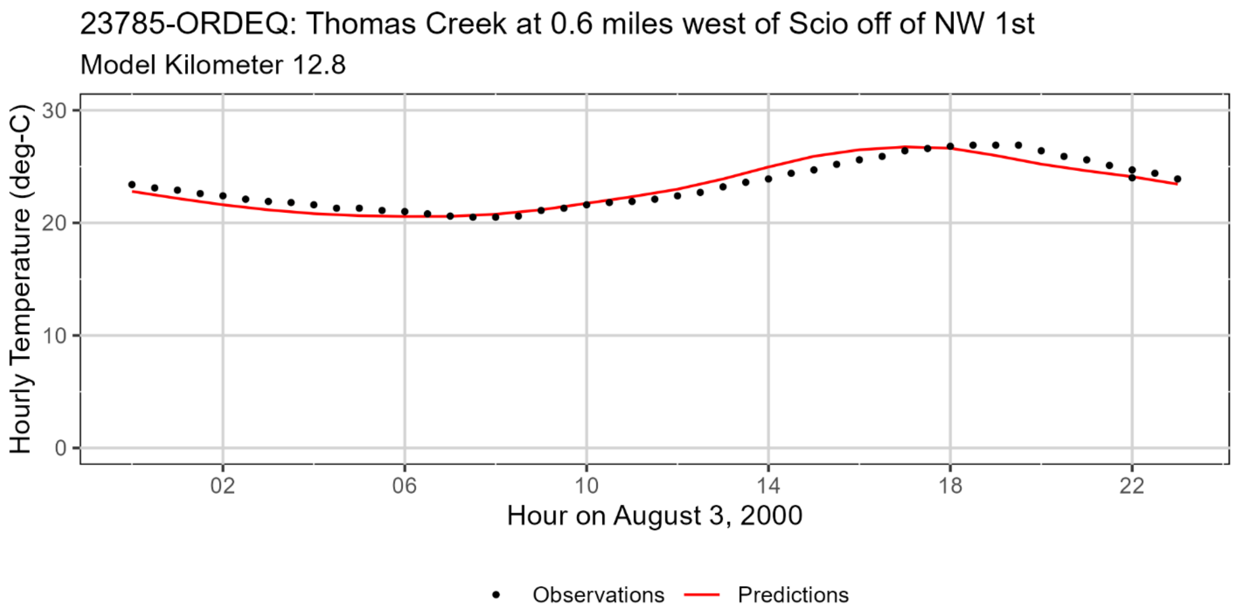


Figure 3-124: Thomas Creek measured and model-predicted hourly temperatures at monitoring station 23785-ORDEQ.

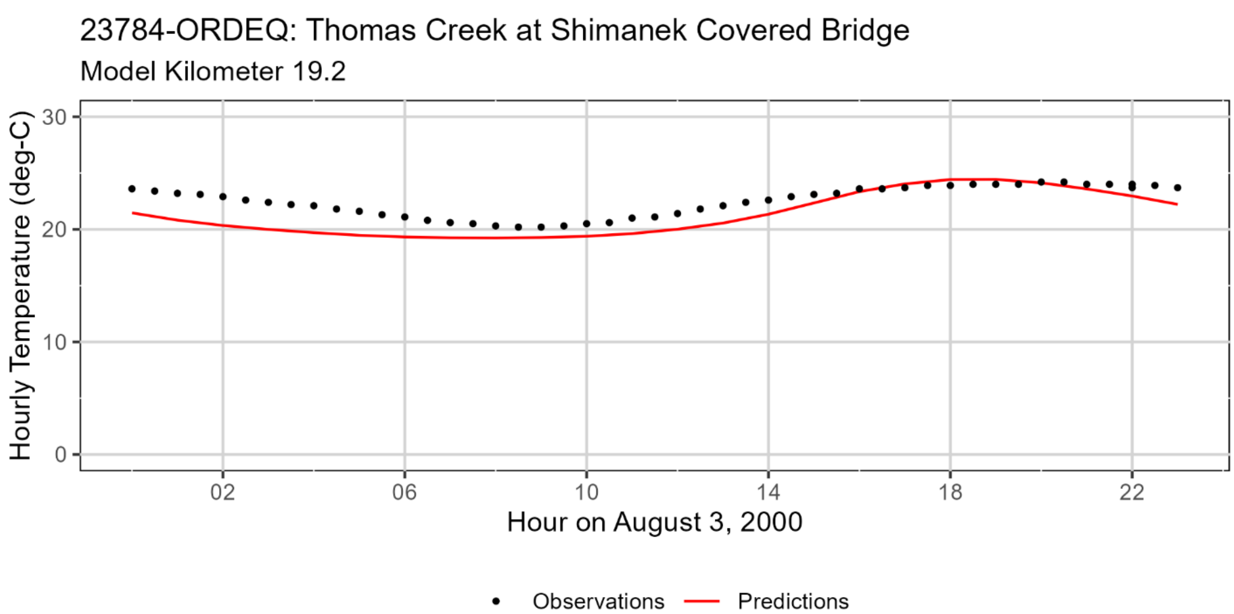


Figure 3-125: Thomas Creek measured and model-predicted hourly temperatures at monitoring station 23784-ORDEQ.

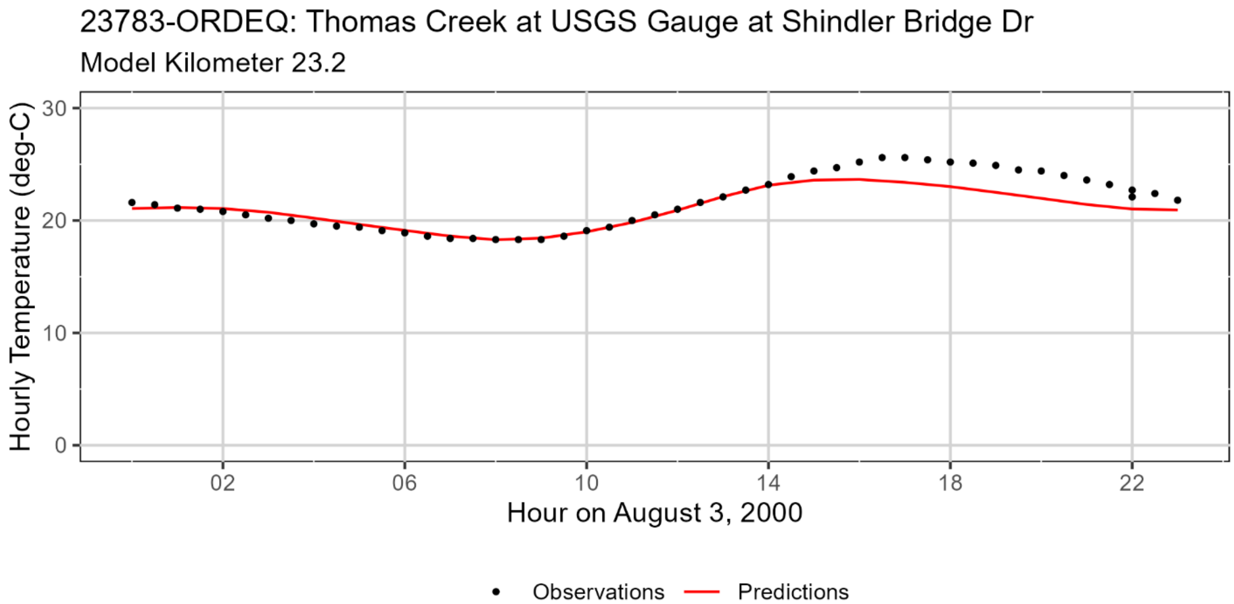


Figure 3-126: Thomas Creek measured and model-predicted hourly temperatures at monitoring station 23783-ORDEQ.

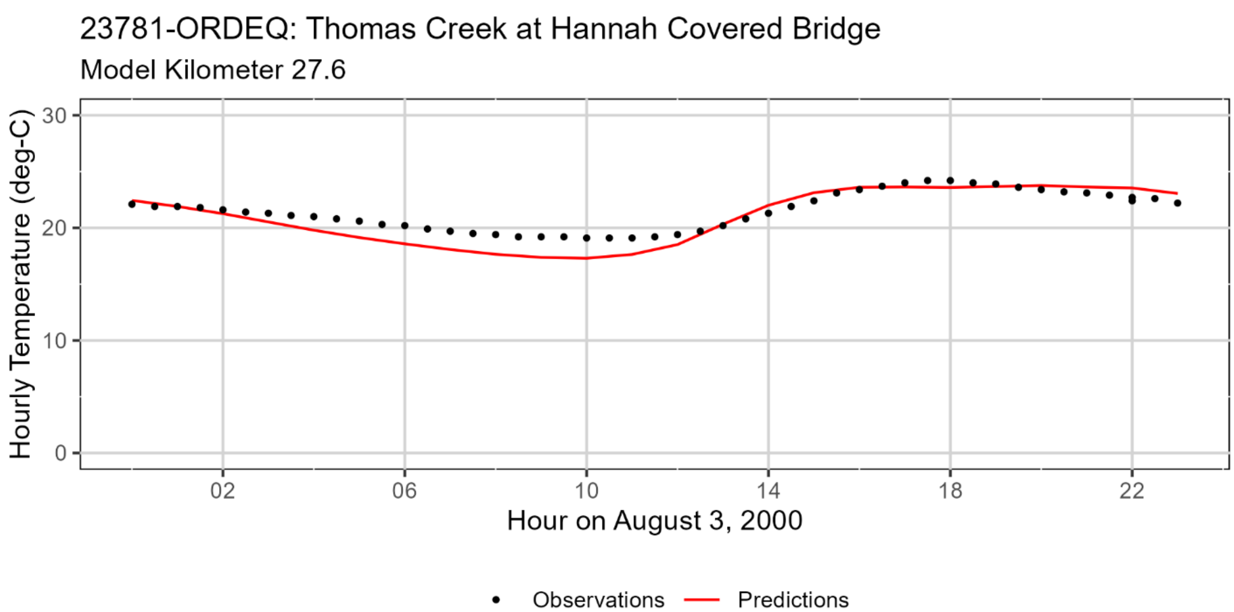


Figure 3-127: Thomas Creek measured and model-predicted hourly temperatures at monitoring station 23781-ORDEQ.

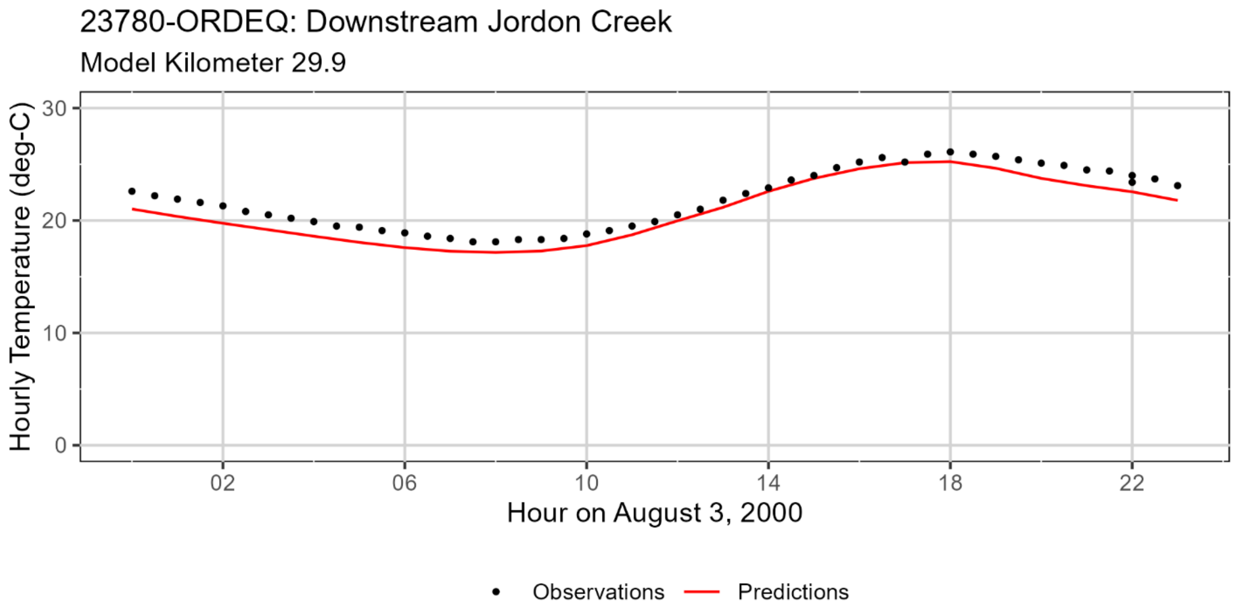


Figure 3-128: Thomas Creek measured and model-predicted hourly temperatures at monitoring station 23780-ORDEQ.

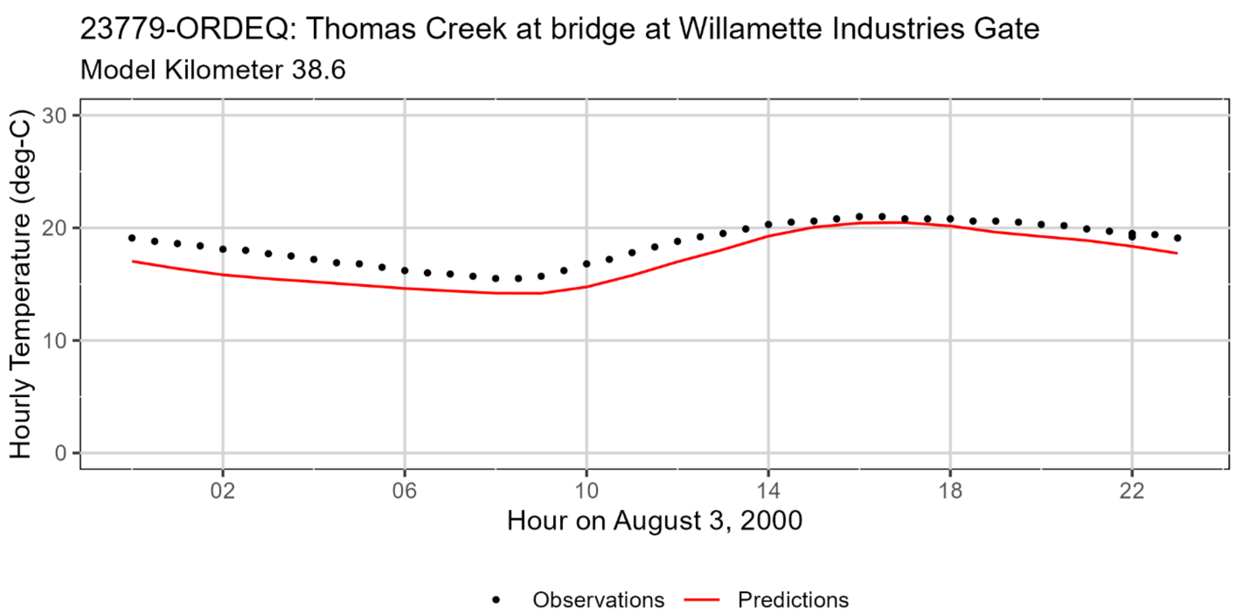


Figure 3-129: Thomas Creek measured and model-predicted hourly temperatures at monitoring station 23779-ORDEQ.

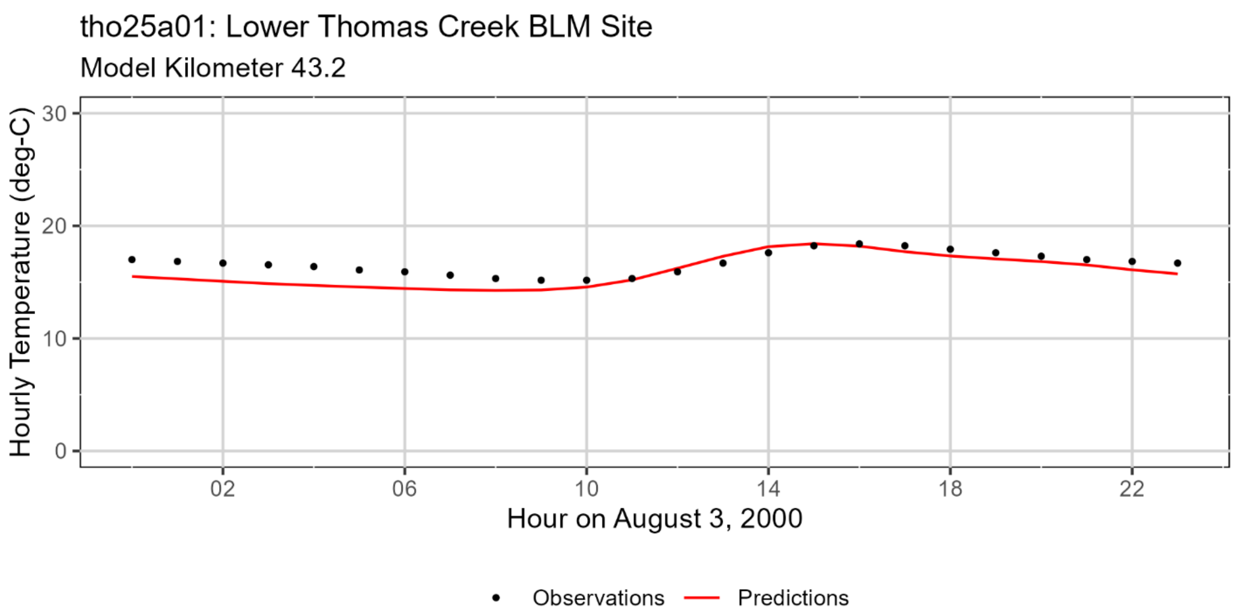


Figure 3-130: Thomas Creek measured and model-predicted hourly temperatures at monitoring station tho25a01.

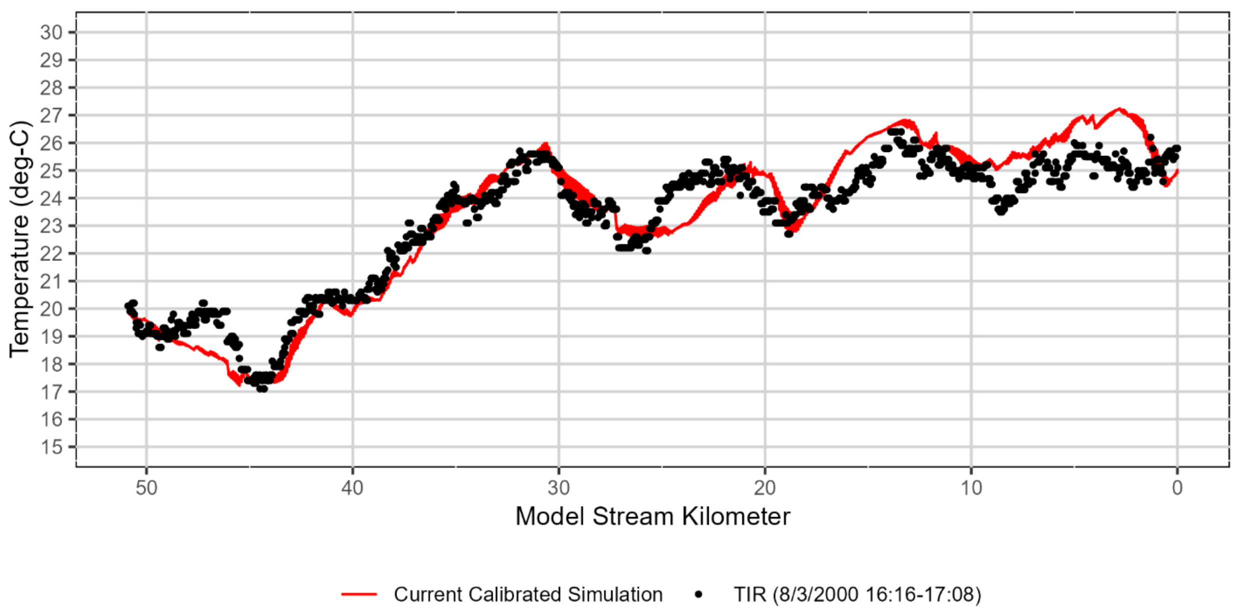


Figure 3-131: Thomas Creek TIR and simulated current stream temperatures.

3.5.10.2 Effective Shade

Observed and model-predicted effective shade data were plotted along Thomas Creek (**Figure 3-132**). The observed field data used for comparison is summarized in **Table 2-32**. Results for goodness of fit statistics comparing field observed and model-predicted temperatures are summarized in **Table 3-40**.

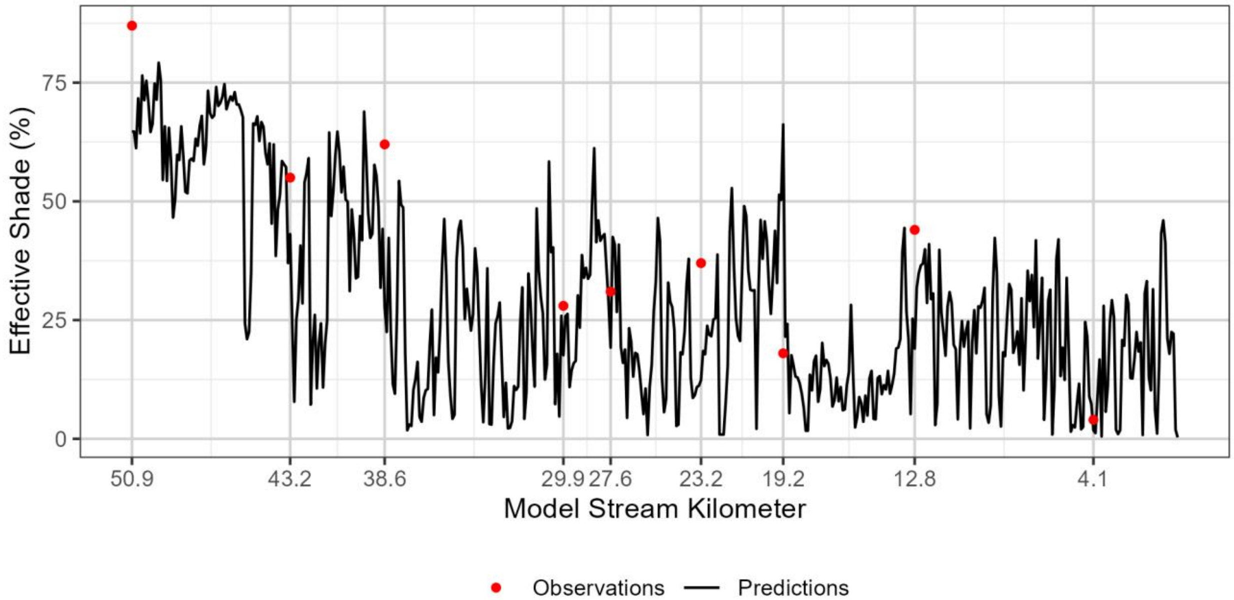


Figure 3-132: Thomas Creek field observed and model-predicted effective shade.

Table 3-40: Thomas Creek effective shade goodness of fit statistics comparing field observed and model values.

N	R^2	ME	MAE	RMSE
9	0.24	-10.48	21.19	24.99

3.5.10.3 Flow

A flow mass balance was completed to improve the calibration and match flows to the measured values. The observed flow used for comparison to the modeled flow is summarized in **Table 3-41**, which is plotted with the model flow in **Figure 3-133**. Results for goodness of fit statistics comparing field observed flow and the model flow are summarized in **Table 3-42**.

Table 3-41: Thomas Creek stream flow rate measurements.

Monitoring Location	Model KM	Flow Statistics	Flow (cms)	Date
tho31a01: Upper Thomas Creek BLM Site	50.9	Instantaneous	0.45	7/14/2000
tho25a01: Lower Thomas Creek BLM Site	43.2	Instantaneous	0.83	7/14/2000
23779-ORDEQ: Thomas Creek at bridge at Willamette Industries gate of Thomas Creek Drive	38.6	Instantaneous	0.44	8/7/2000
23780-ORDEQ: Thomas Creek at Jordan Road	29.9	Instantaneous	0.47	8/7/2000
23781-ORDEQ: Thomas Creek at Hannah Covered Bridge (Morrison Road)	27.6	Instantaneous	0.51	8/8/2000
23783-ORDEQ: Thomas Creek at USGS Gage at Shindler Bridge Drive	23.2	Instantaneous	1.42	8/8/2000
23784-ORDEQ: Thomas Creek at Shimanek Covered Bridge (Richardson Gap Road)	19.2	Instantaneous	0.62	8/8/2000
23785-ORDEQ: Thomas Creek at 0.6 miles west of Scio off NW 1st Avenue	12.8	Instantaneous	0.62	8/7/2000
10783-ORDEQ: Thomas Creek at Kelly Road (Riverside School)	4.1	Instantaneous	0.55	8/7/2000

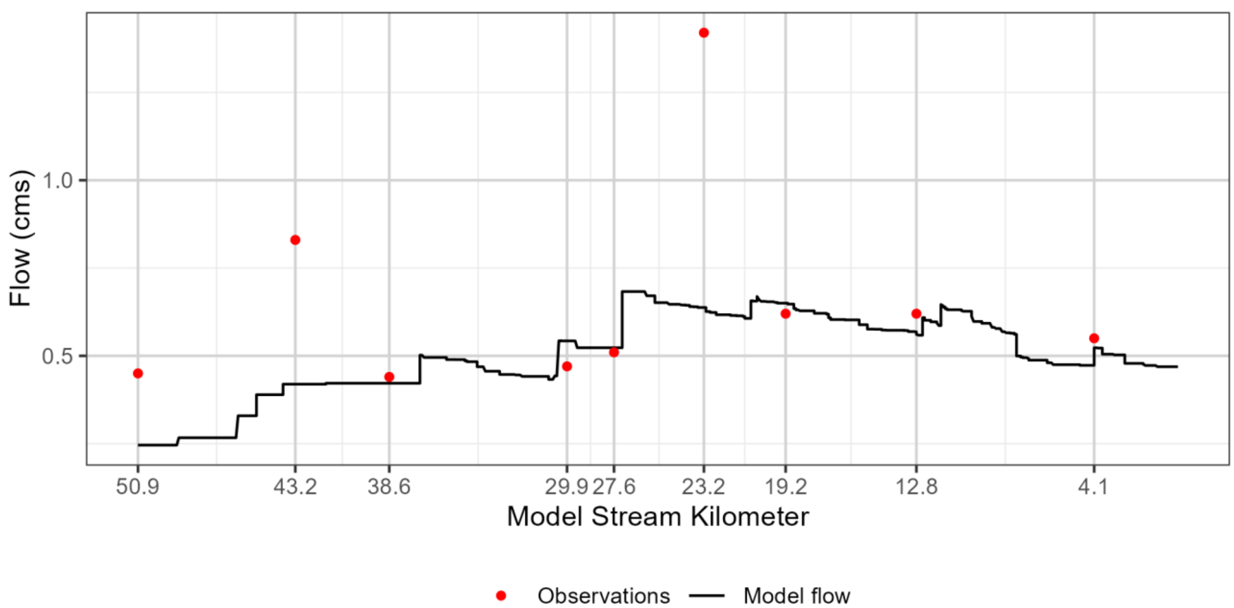


Figure 3-133: Thomas Creek field observed and model flow rates.

Table 3-42: Thomas Creek goodness of fit statistics comparing field observed and model flow rates.

N	R^2	ME	MAE	RMSE
9	0.21	-0.16	0.18	0.31

3.5.10.4 Channel

Results comparing channels widths derived from GIS and modeling to those measured in the field are presented in **Figure 3-134**. Results shows channel widths only from streams modeled for temperature with Heat Source.

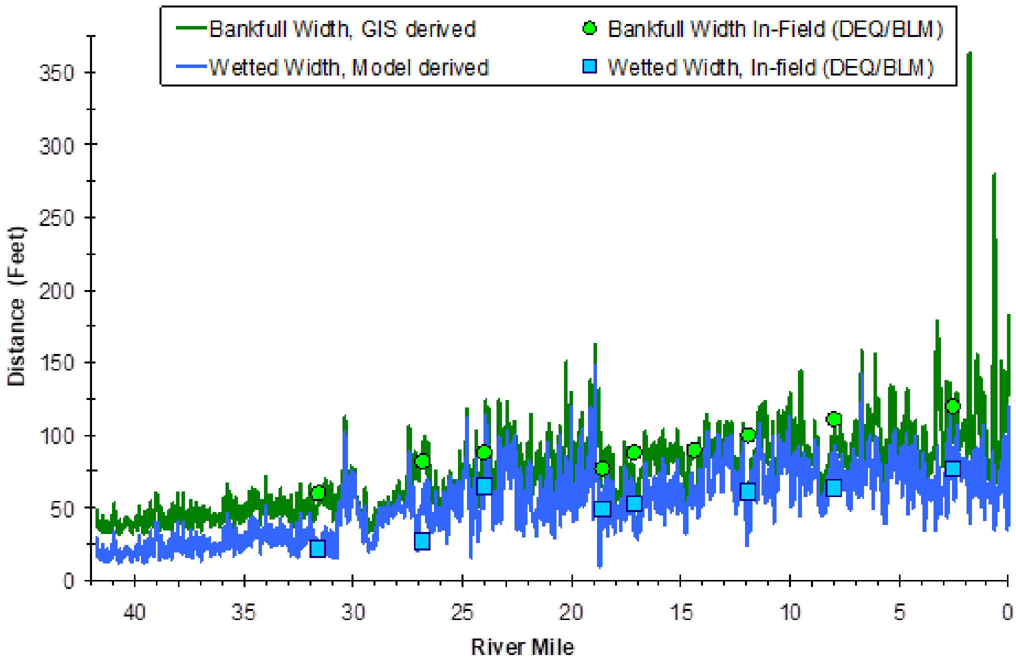


Figure 3-134: Thomas Creek field observed and derived bankfull and wetted width.

3.6 Crabtree Creek

The Crabtree Creek model is a temperature model developed using Heat Source 6.5.1. The model was developed by DEQ.

3.6.1 Model extent

The extent of the model domain is Crabtree Creek from the mouth to river mile 35 (**Figure 3-135**).

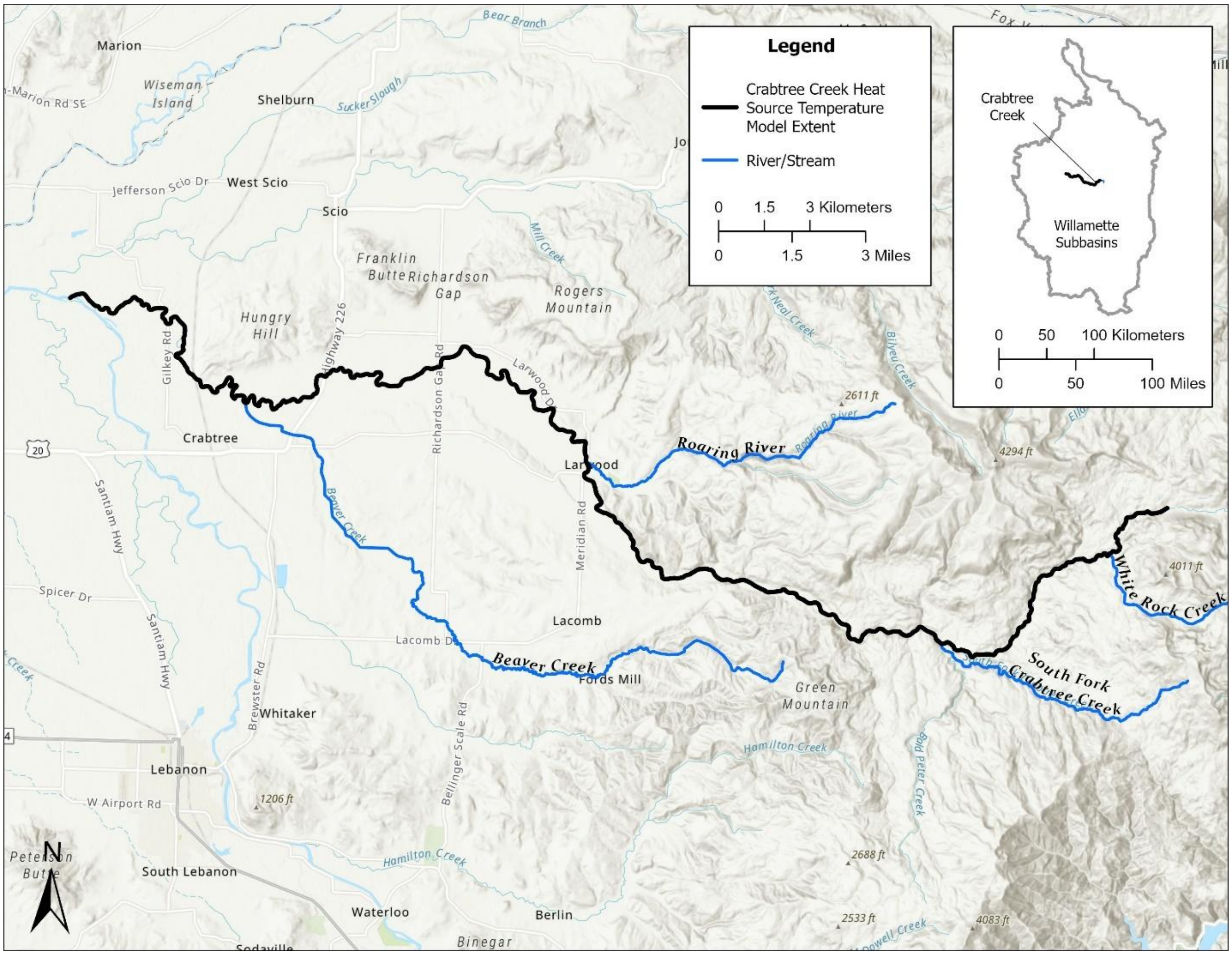


Figure 3-135: Crabtree Creek temperature model extent.

3.6.2 Spatial and temporal resolution

The model input spatial resolution (*dx*) is 30 m. Outputs are generated every 100 m. The model time step (*dt*) is 1 minute and outputs are generated every hour.

3.6.3 Time frame of simulation

The model period is for a single day: August 02, 2000.

3.6.4 Meteorological inputs

The model was set up using hourly air temperature and relative humidity measurements and constant wind speed of zero cms (**Figure 3-136**). According to the model, the air temperature and relative humidity data can be divided into three groups (**Table 3-43**). Each group uses the same values for air temperature and relative humidity, which may correspond to three different monitoring sites.

Table 3-43: Meteorology inputs to the Crabtree Creek model.

Group	Model Location
Group 1	Model KM 55.443
	Model KM 50.719
	Model KM 47.213
	Model KM 40.752
Group 2	Model KM 36.972
Group 3	Model KM 29.657
	Model KM 20.452
	Model KM 9.418
	Model KM 3.84

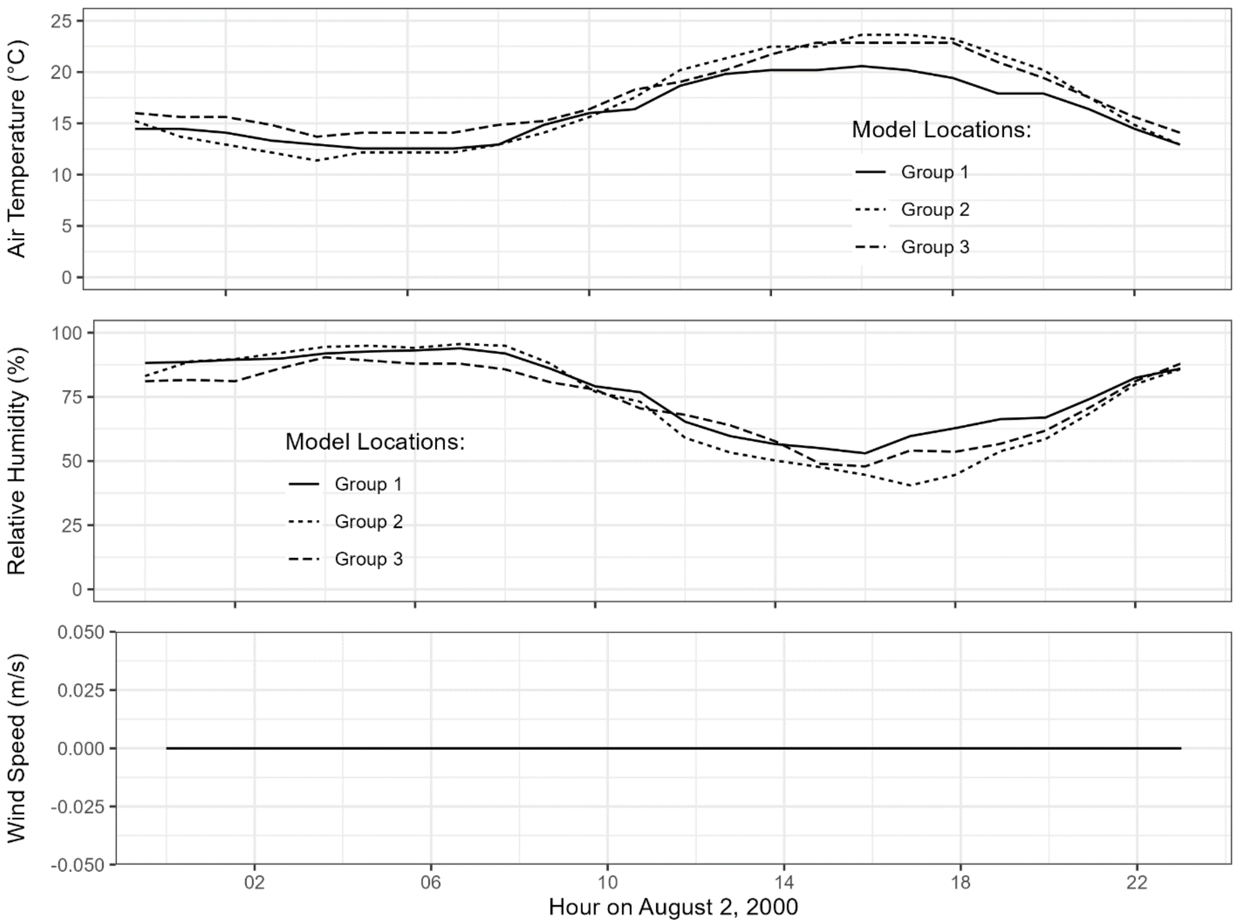


Figure 3-136: Meteorological inputs to the Crabtree Creek model.

3.6.5 Temperature inputs

Hourly water temperature time series data were used to support tributary and boundary condition model setup. **Figure 3-137** shows the locations of the various stream temperature monitoring locations that were used for model setup or calibration.

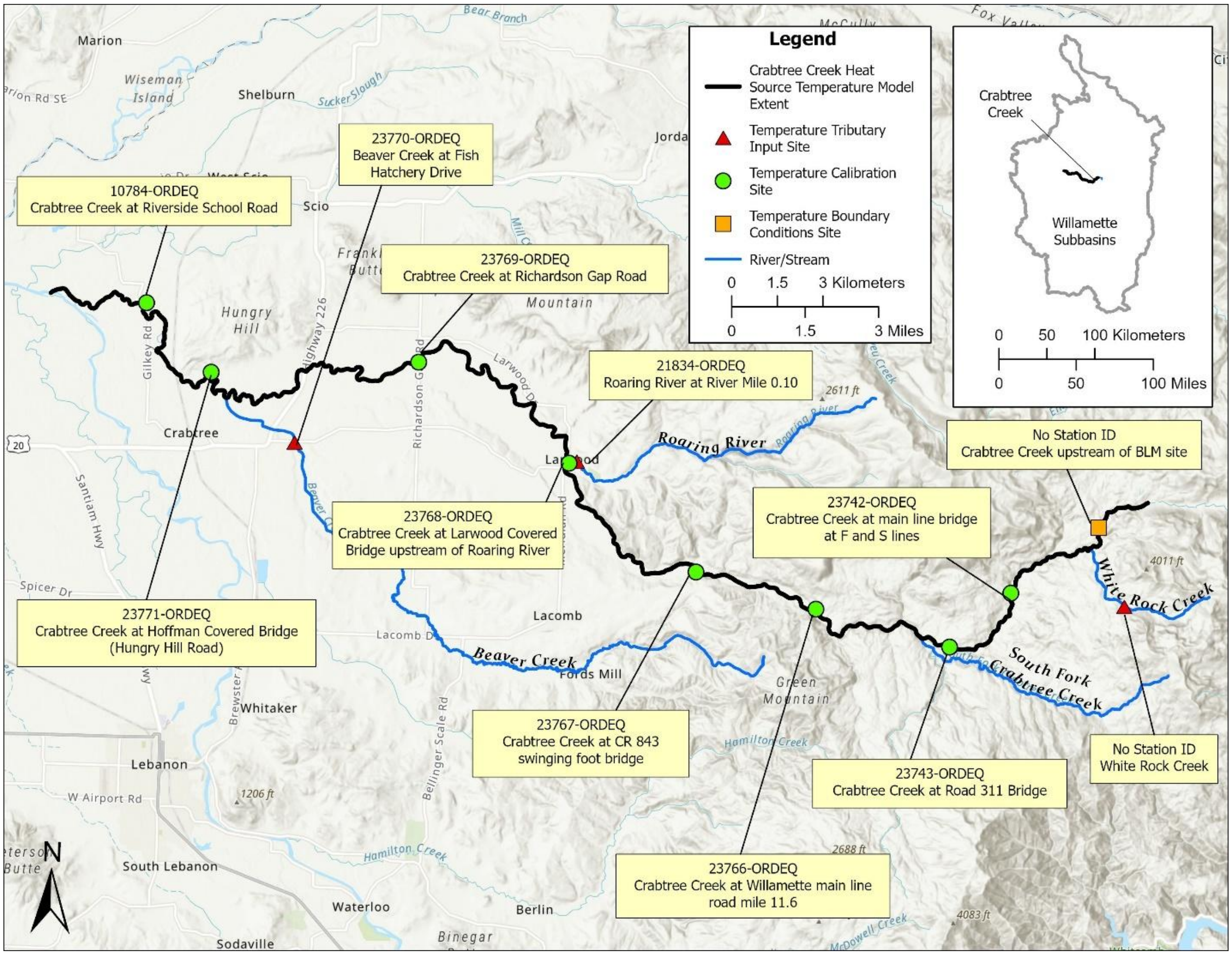


Figure 3-137: Temperature monitoring locations used for the Crabtree Creek model setup and calibration.

Table 3-44 and **Figure 3-138** document the water temperature inputs to the model at the boundary condition (Crabtree Creek upstream of BLM site) and tributaries. **Table 2-39** lists TIR Temperatures on Crabtree Creek.

Table 3-44: Boundary condition and tributary water temperature inputs to the Crabtree Creek model.

Model Location Name	Model Location (km)	Input Type	Data Source
Crabtree Creek upstream of BLM site	55.443	Boundary Condition	BLM
Beaver Creek at Fish Hatchery Drive	54.407	Tributary	23770-ORDEQ
Roaring River at River Mile 0.10	46.147	Tributary	21834-ORDEQ
SF Crabtree Creek	29.626	Tributary	DEQ
White Rock Creek	11.125	Tributary	BLM

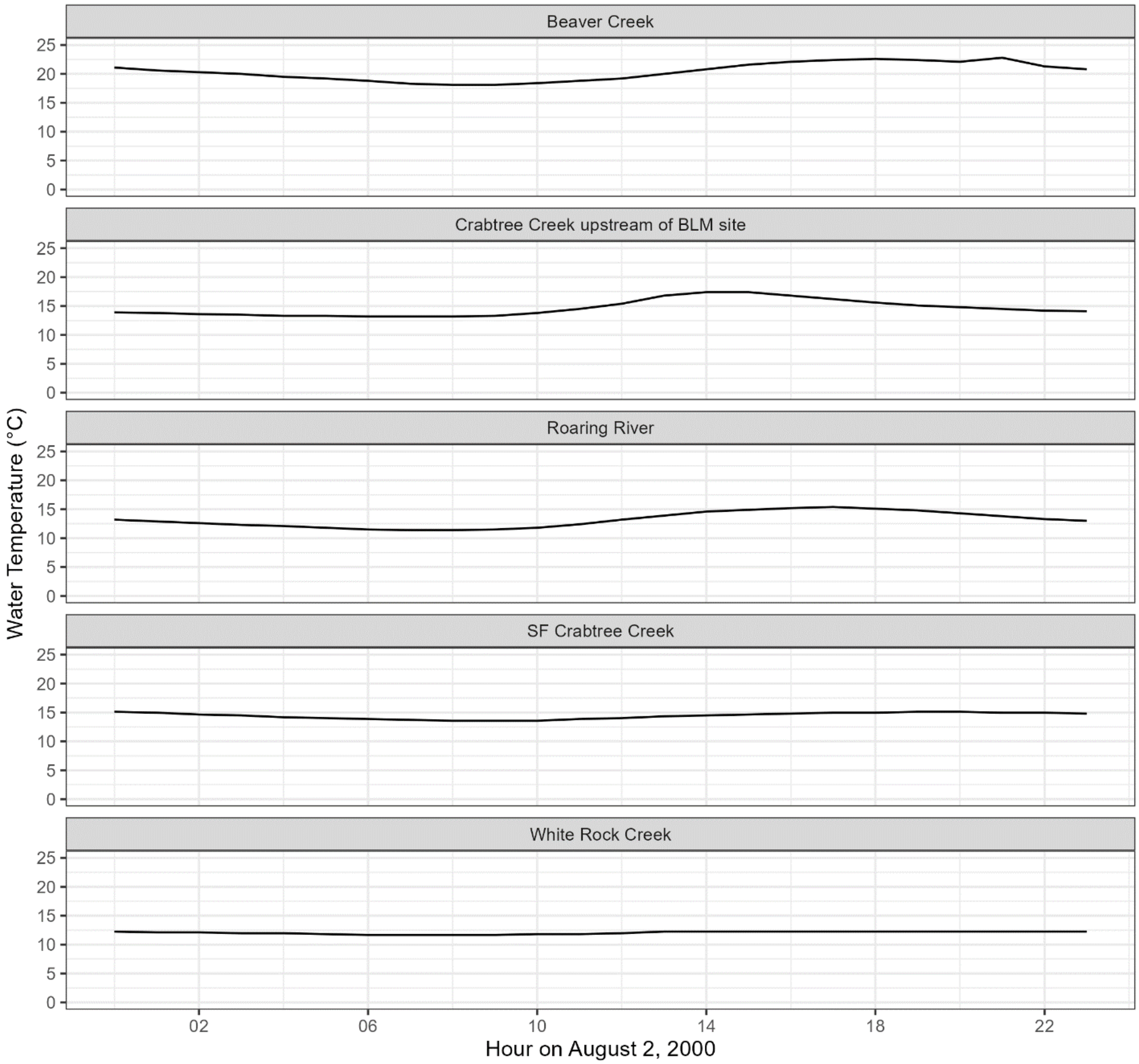


Figure 3-138: Boundary condition and tributary water temperature inputs to the Crabtree Creek model.

3.6.6 Flow inputs

Hourly stream flow time series data were used to support tributary and boundary condition model setup. **Figure 3-139** shows the locations of the various stream flow monitoring locations that were used for model setup or calibration.

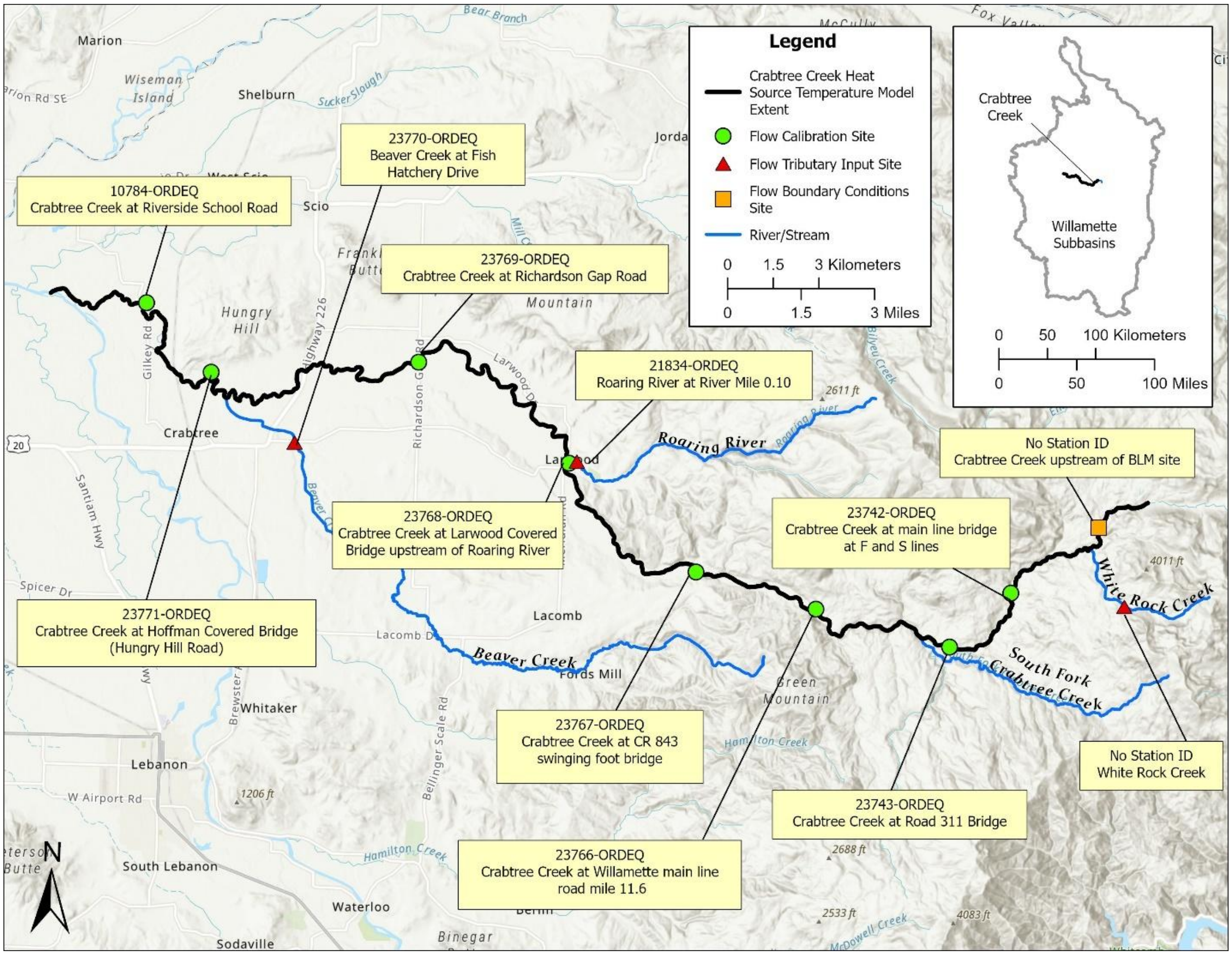


Figure 3-139: Flow monitoring locations used for the Crabtree Creek model setup and calibration.

The boundary condition and tributary flow inputs to the model is summarized in **Table 3-45**. **Figure 3-140** documents mainstem model flow setup.

Table 3-45: Boundary condition and mainstem flow inputs to the Crabtree Creek model.

Model Location Name	Model Location (km)	Flow Rate (cms)	Input Type	Data Source
Crabtree Creek upstream of BLM site	55.443	0.074	Boundary Condition	BLM
White Rock Creek	54.407	0.0023	Tributary	BLM
SF Crabtree Creek	46.147	0.292	Tributary	DEQ
Roaring River at River Mile 0.10	29.626	0.6482	Tributary	21834-ORDEQ
Beaver Creek at Fish Hatchery Drive	11.125	0.1079	Tributary	23770-ORDEQ

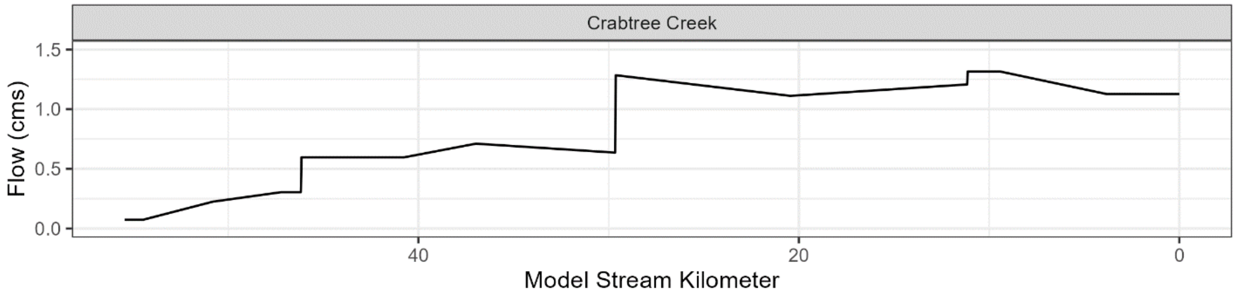


Figure 3-140: Boundary condition and mainstem flow inputs to the Crabtree Creek model.

3.6.7 Point source inputs

There are no point sources discharging within the model extent.

3.6.8 Landcover and topographic shade inputs

Average land cover height inputs and topographic shade angle inputs are shown in Figure 3-141 and Figure 3-142, respectively.

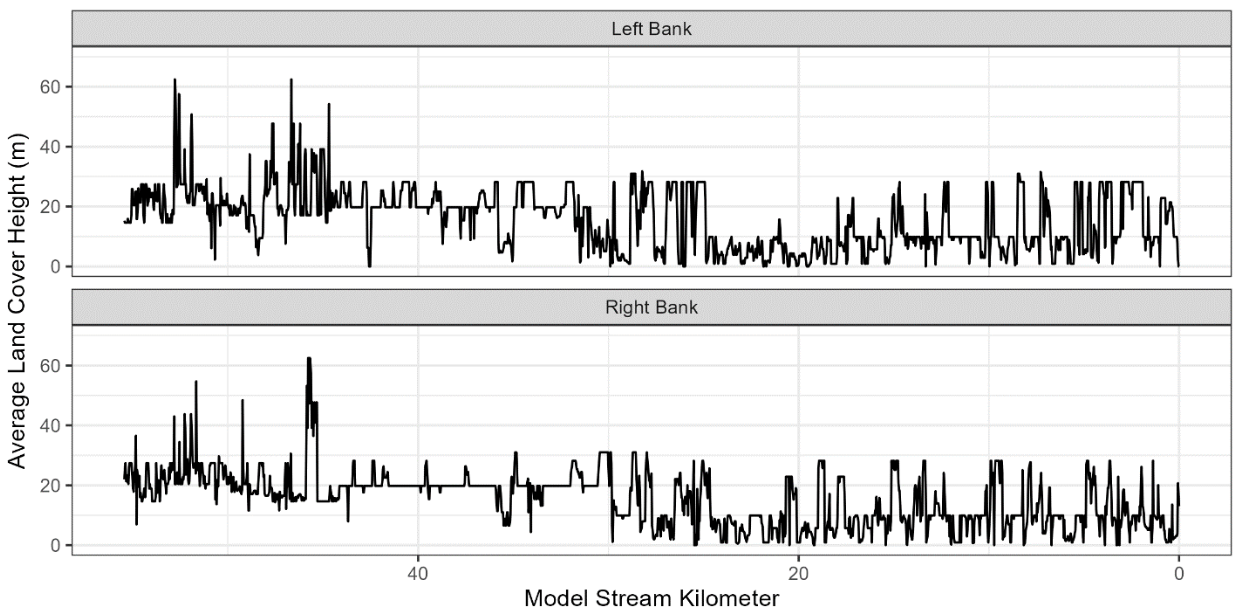


Figure 3-141: Average land cover height inputs to the Crabtree Creek model.

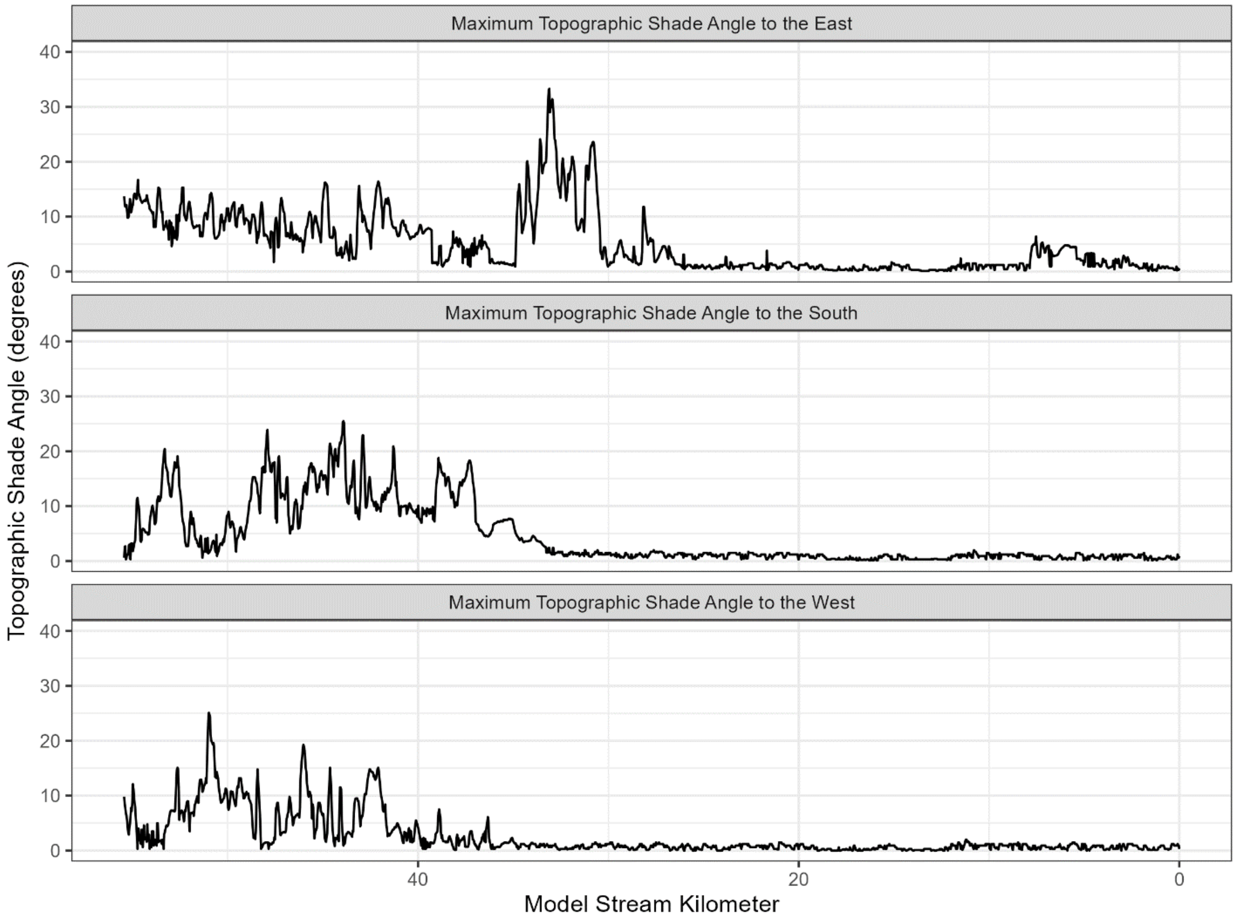


Figure 3-142: Topographic shade angle inputs to the Crabtree Creek model.

3.6.9 Channel setup

Channel setup for the Crabtree Creek model is presented in **Figure 3-143**.

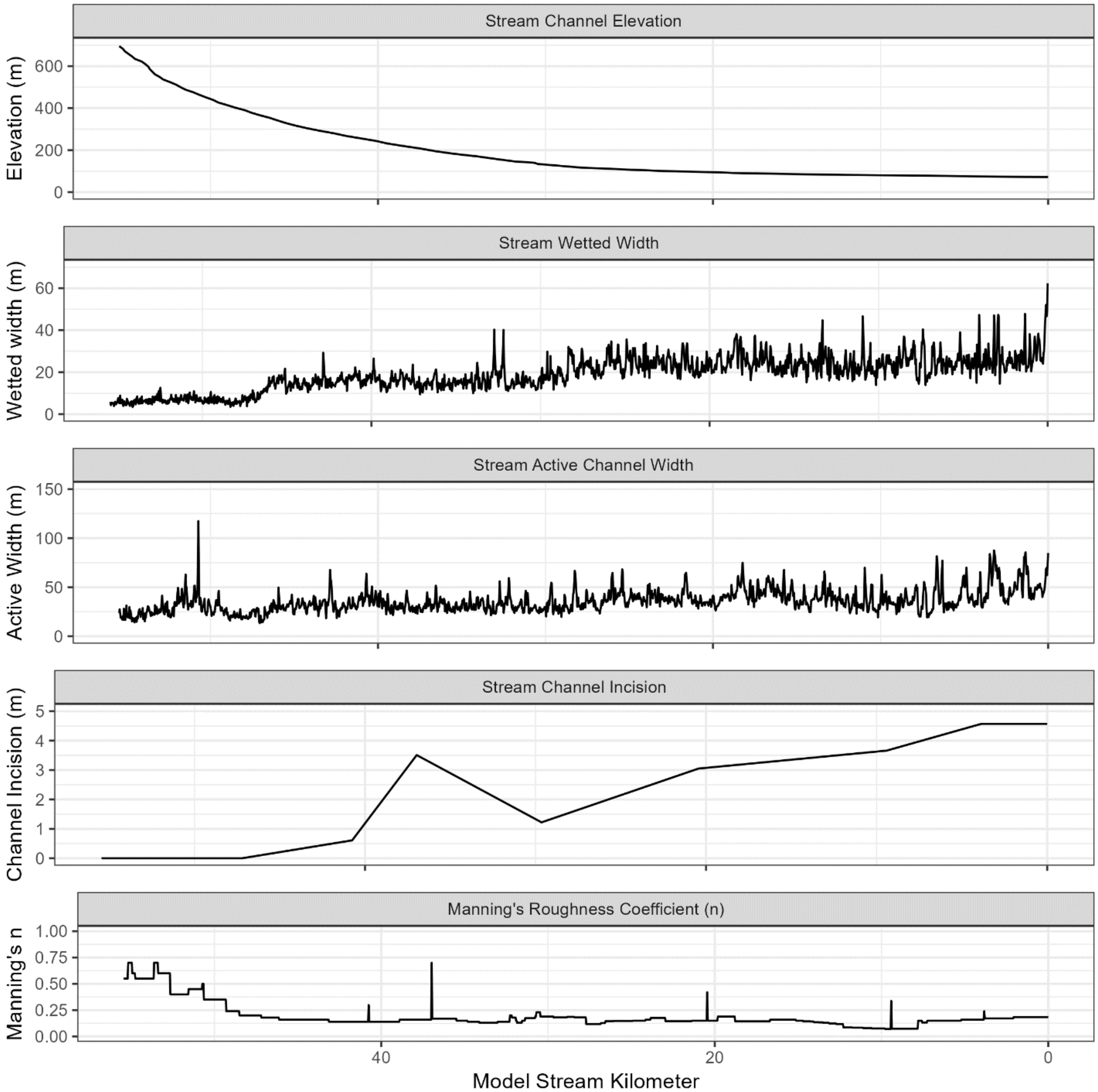


Figure 3-143: Channel setup in the Crabtree Creek model.

3.6.10 Calibration results

3.6.10.1 Temperature

The model was calibrated to the continuous temperature data collected from several locations along Crabtree Creek. Results for goodness of fit statistics comparing field observed and model-predicted temperatures are summarized in **Table 3-46**. Observed and model-predicted hourly temperatures were plotted for the monitoring stations (**Figure 3-144** through **Figure 3-151**). The TIR data was collected from the upper Crabtree Creek, where there is about a 5 km overlap on the model extent. The TIR data was not utilized for model calibration.

Table 3-46: Crabtree Creek water temperature goodness of fit statistics comparing field observed and model-predicted temperatures.

Monitoring Location	Model KM	Temperature Statistics	ME	MAE	RMSE	NSE	n
All Stations		Daily Maximum	0.73	0.75	0.88	NA	8
All Stations		Hourly	-0.26	0.97	1.26	0.86	192
10784-ORDEQ: Crabtree Creek at Riverside School	3.8	Hourly	-0.74	0.91	1.08	-0.09	24
23771-ORDEQ: Crabtree Creek at Hoffman Covered Bridge	9.4	Hourly	-0.36	0.47	0.57	0.83	24
23769-ORDEQ: Crabtree Creek at Richardson Gap Road	20.5	Hourly	0.03	0.86	1.04	0.56	24
23768-ORDEQ: Crabtree Creek at Larwood Bridge	29.7	Hourly	-0.97	1.03	1.56	0.35	24
23767-ORDEQ: Crabtree Creek at swinging foot bridge	37	Hourly	-0.41	0.8	0.89	0.88	24
23766-ORDEQ: Crabtree Creek at Willamette Main Line Road	40.8	Hourly	0.41	0.65	0.72	0.93	24
23743-ORDEQ: Crabtree Creek at Road 311 Bridge	47.2	Hourly	-0.33	1.2	1.47	0.59	24
23742-ORDEQ: Crabtree Creek at Main Line Bridge	50.7	Hourly	0.28	1.83	2.06	-0.55	24

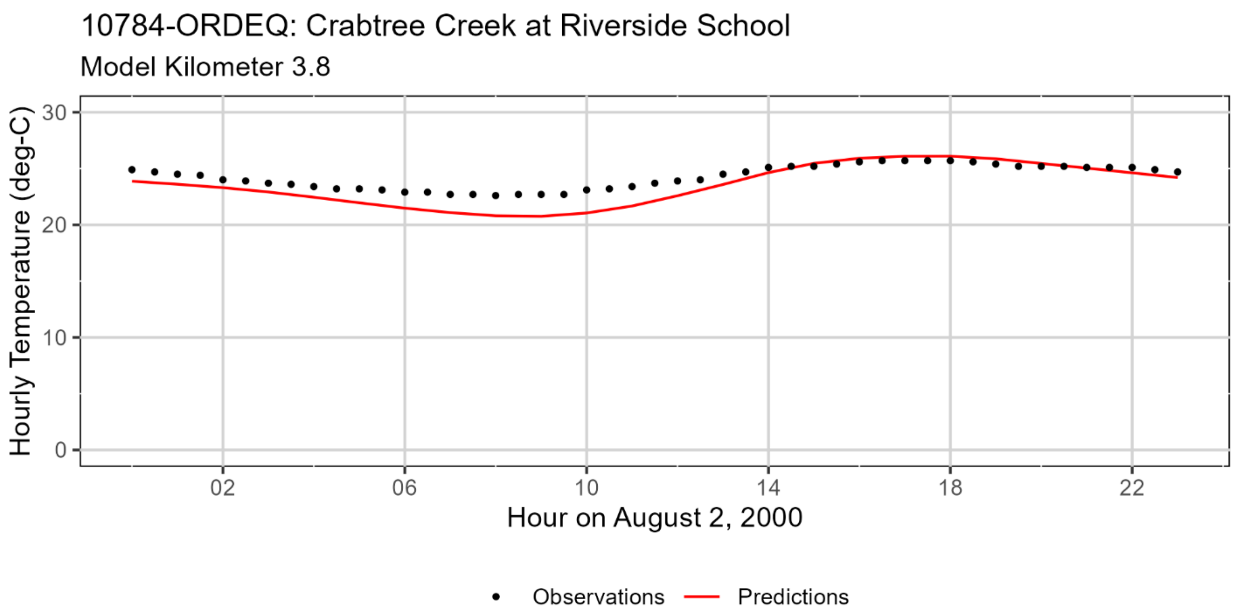


Figure 3-144: Crabtree Creek measured and model-predicted hourly temperatures at monitoring station 10784-ORDEQ.

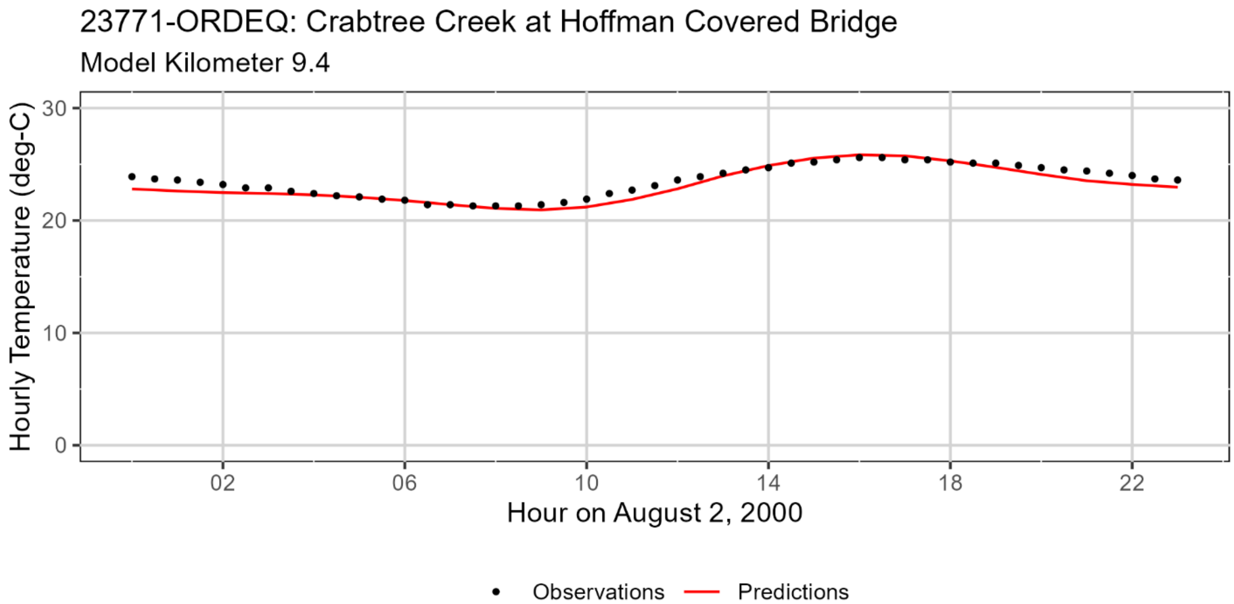


Figure 3-145: Crabtree Creek measured and model-predicted hourly temperatures at monitoring station 23771-ORDEQ.

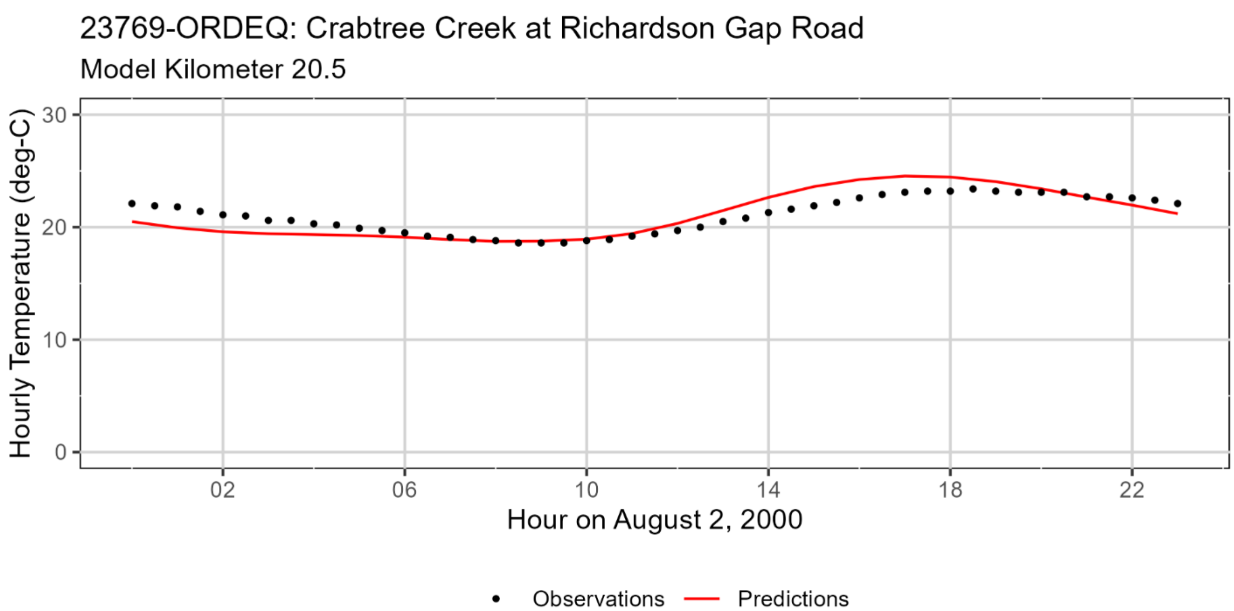


Figure 3-146: Crabtree Creek measured and model-predicted hourly temperatures at monitoring station 23769-ORDEQ.

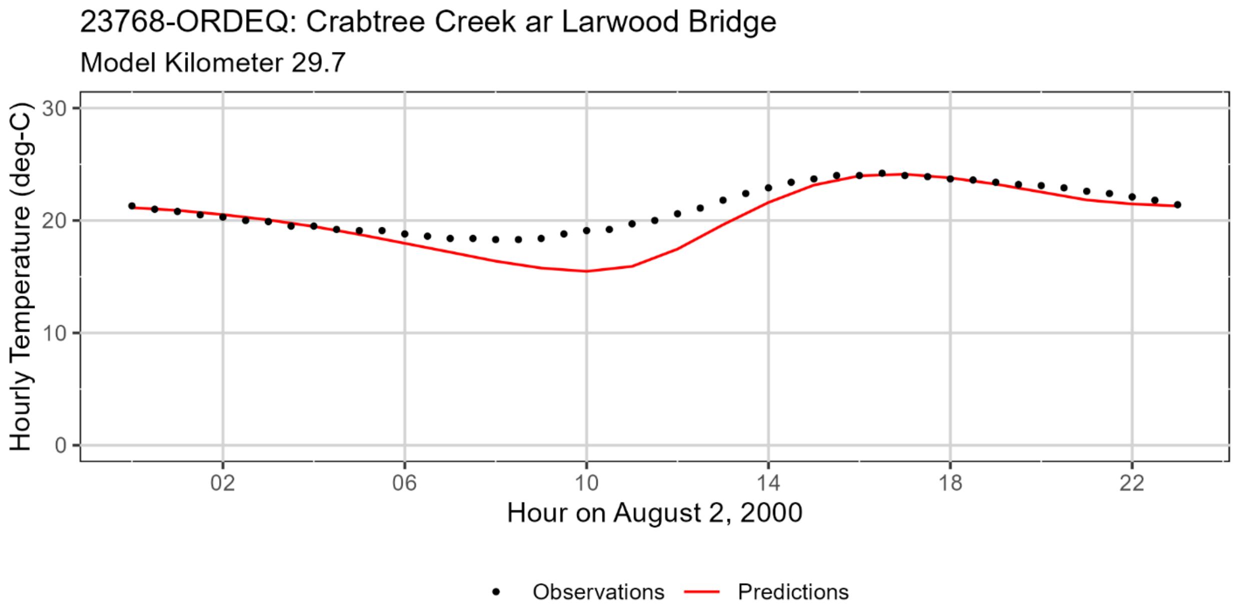


Figure 3-147: Crabtree Creek measured and model-predicted hourly temperatures at monitoring station 23768-ORDEQ.

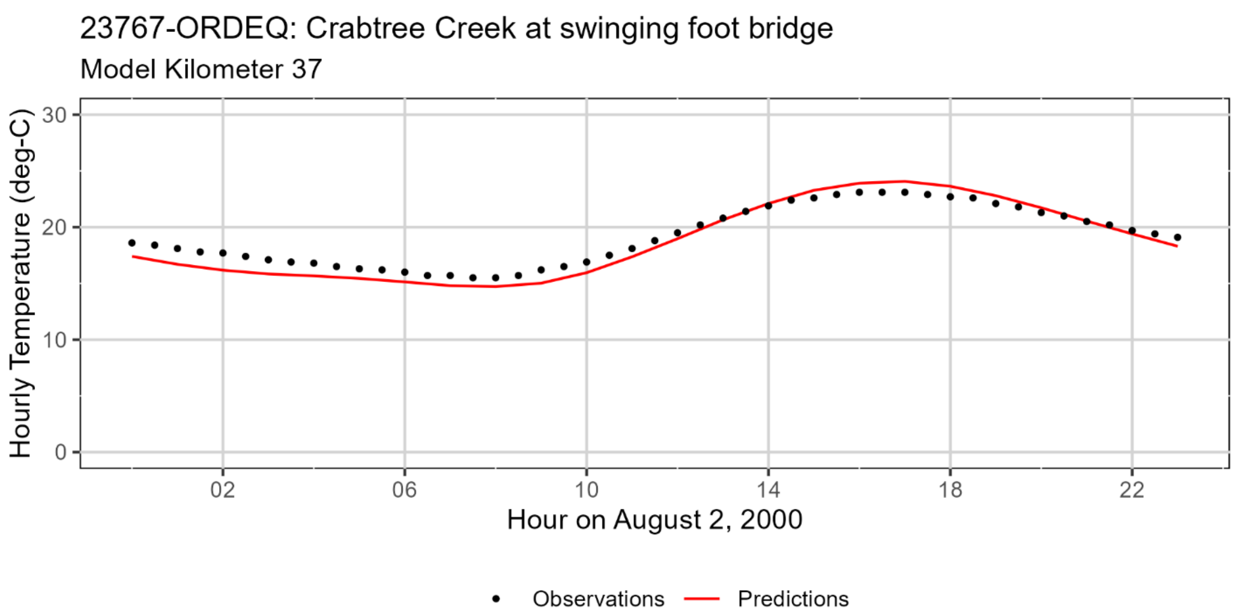


Figure 3-148: Crabtree Creek measured and model-predicted hourly temperatures at monitoring station 23767-ORDEQ.

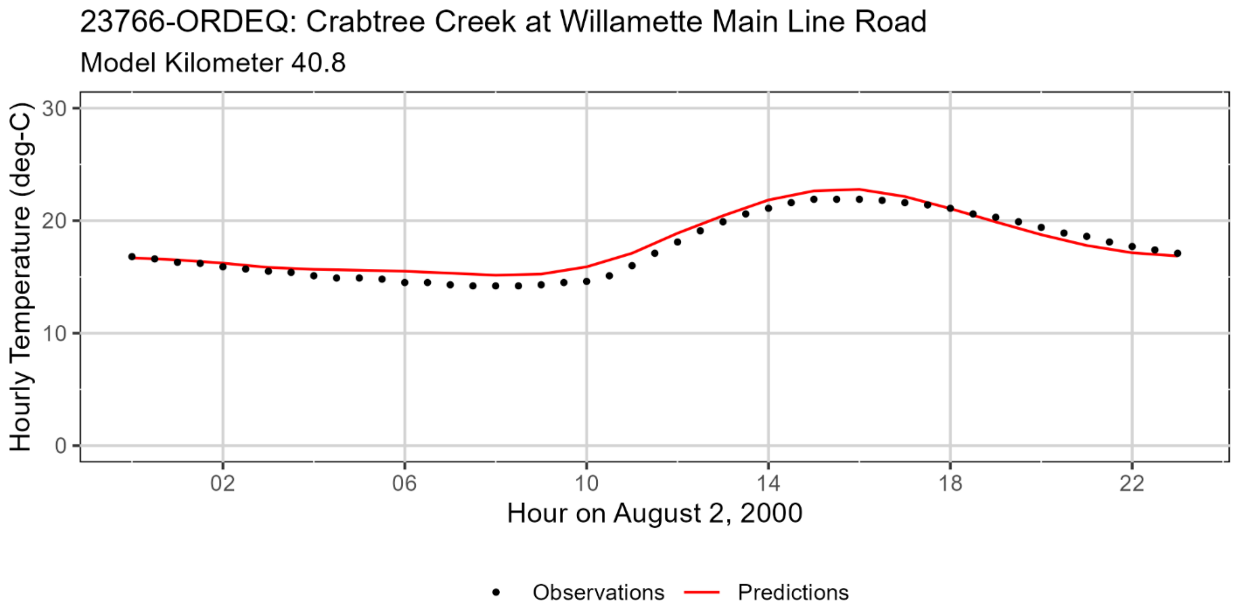


Figure 3-149: Crabtree Creek measured and model-predicted hourly temperatures at monitoring station 23766-ORDEQ.

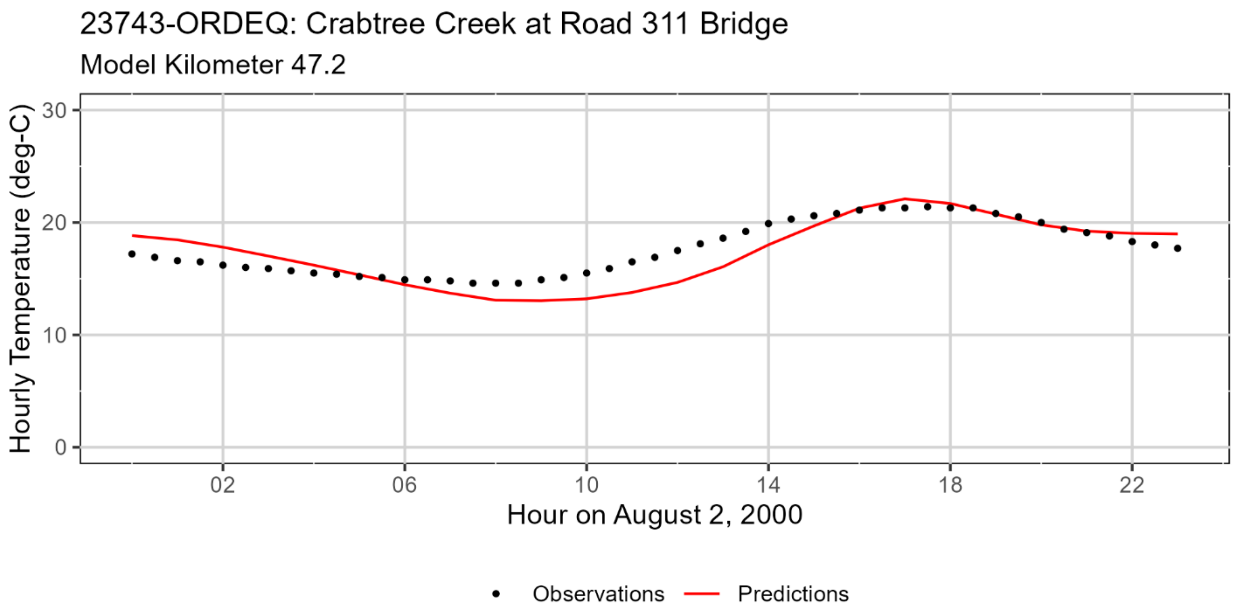


Figure 3-150: Crabtree Creek measured and model-predicted hourly temperatures at monitoring station 23743-ORDEQ.

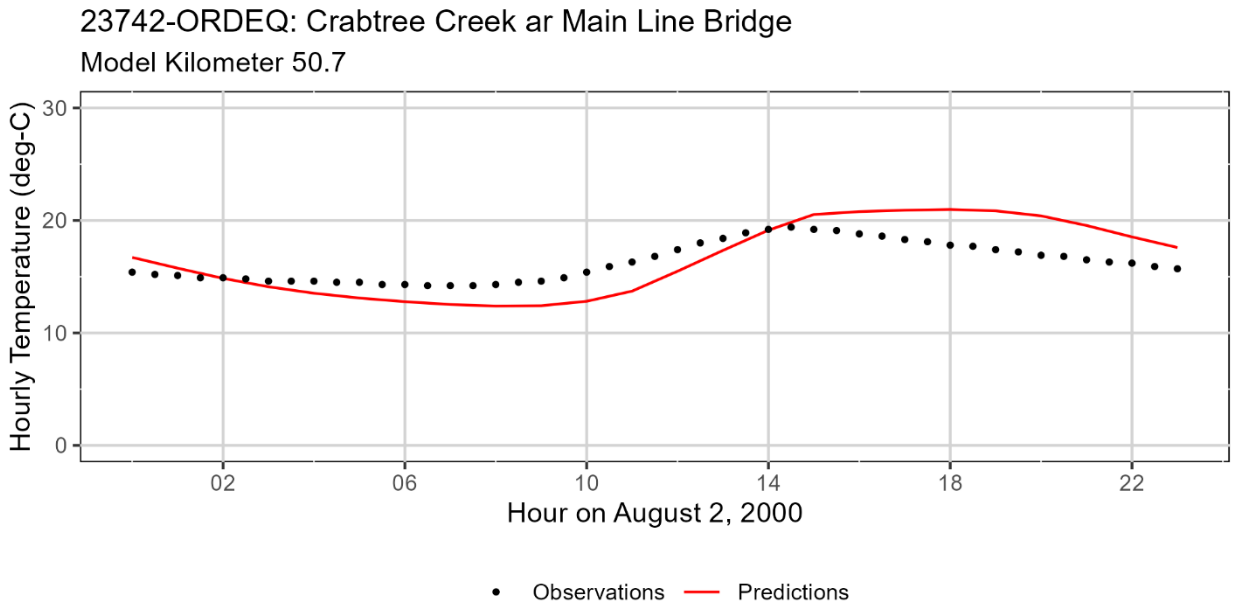


Figure 3-151: Crabtree Creek measured and model-predicted hourly temperatures at monitoring station 23742-ORDEQ.

3.6.10.2 Effective Shade

Observed and model-predicted effective shade data were plotted along Crabtree Creek (**Figure 3-152**). The observed field data used for comparison is summarized in **Table 2-33**. Results for goodness of fit statistics comparing field observed and model-predicted temperatures are summarized in **Table 3-47**.

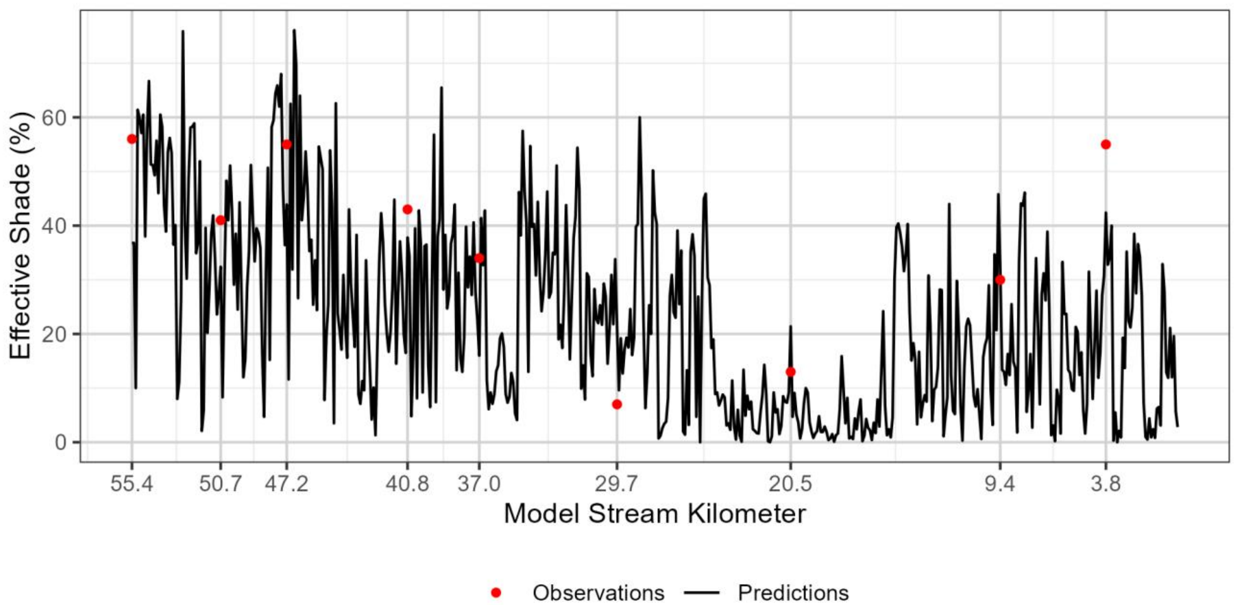


Figure 3-152: Crabtree Creek field observed and model-predicted effective shade.

Table 3-47: Crabtree Creek effective shade goodness of fit statistics comparing field observed and model values.

N	R^2	ME	MAE	RMSE
9	0.65	-5.54	11.06	12.25

3.6.10.3 Flow

A flow mass balance was completed to improve the calibration and match flows to the measured values. The observed flow used for comparison to the modeled flow is summarized in **Table 3-48**, which is plotted with the model flow in **Figure 3-153**. Results for goodness of fit statistics comparing field observed flow and the model flow are summarized in Table 3-49. Since the measured data was utilized for flow inputs, it aligns with the model's flow, therefore, resulting in a perfect goodness of fit score.

Table 3-48: Crabtree Creek stream flow rate measurements.

Monitoring Location	Model KM	Flow Statistics	Flow (cms)	Date
23742-ORDEQ: Crabtree Creek at main line bridge at F and S lines	50.7	Instantaneous	0.23	7/25/2000
23743-ORDEQ: Crabtree Creek at Road 311 Bridge	47.2	Instantaneous	0.3	7/25/2000
23766-ORDEQ: Crabtree Creek at Willamette main line road mile 11.6	40.8	Instantaneous	0.60	7/25/2000
23767-ORDEQ: Crabtree Creek at CR 843 swinging foot bridge	37.0	Instantaneous	0.71	7/26/2000
23768-ORDEQ: Crabtree Creek at Larwood Covered Bridge upstream of Roaring River	29.7	Instantaneous	0.64	7/26/2000
23769-ORDEQ: Crabtree at Richardson Gap Rd	20.5	Instantaneous	1.11	7/26/2000
23771-ORDEQ: Crabtree Creek at Hoffman Covered Bridge (Hungry Hill Road)	9.4	Instantaneous	1.32	7/27/2000
10784-ORDEQ: Crabtree Creek at Riverside School Road	3.8	Instantaneous	1.13	7/27/2000

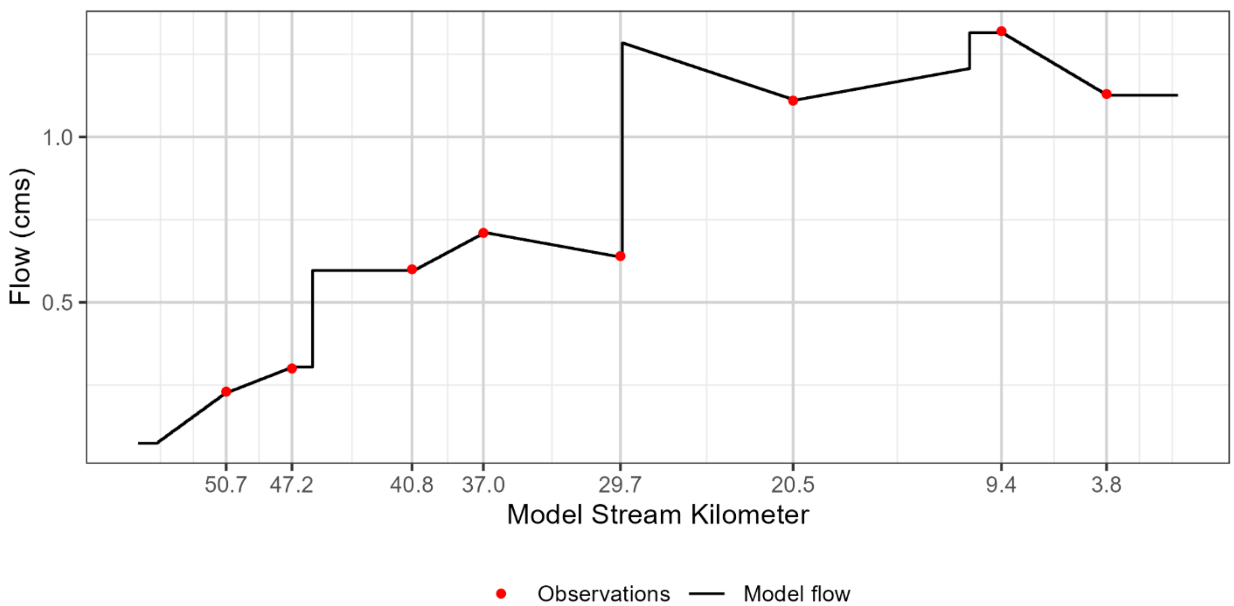


Figure 3-153: Crabtree Creek field observed and model flow rates.

Table 3-49: Crabtree Creek goodness of fit statistics comparing field observed and model flow rates.

N	R^2	ME	MAE	RMSE
8	1	0	0	0

3.6.10.4 Channel

Results comparing channels widths derived from GIS and modeling to those measured in the field are presented in **Figure 3-154**. Results shows channel widths only from streams modeled for temperature with Heat Source.

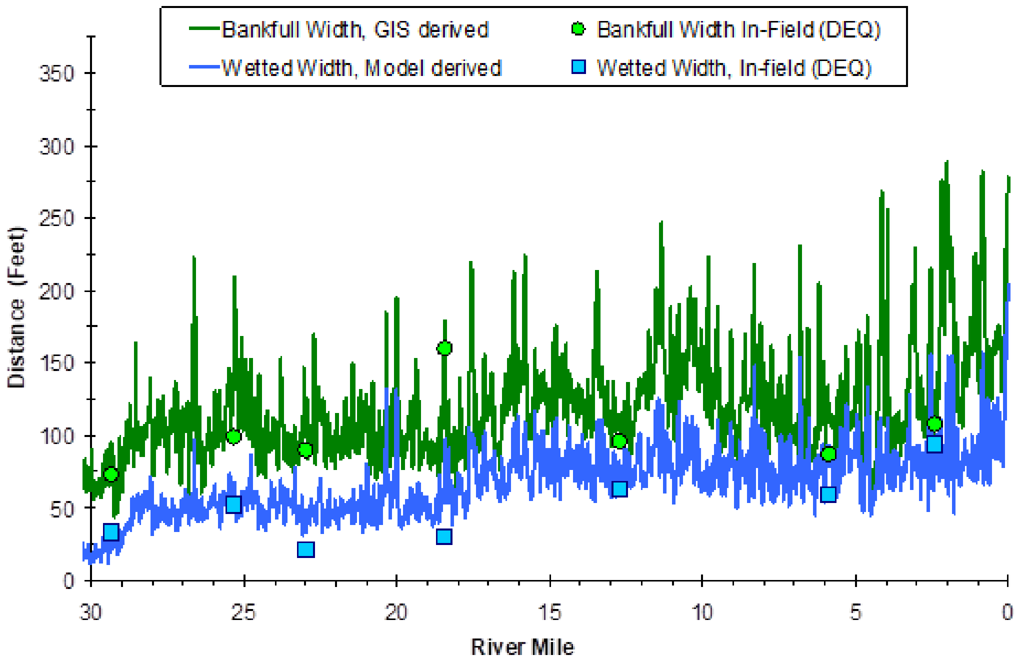


Figure 3-154: Crabtree Creek field observed and derived bankfull and wetted width.

3.7 Luckiamute River

The Luckiamute River model is a temperature model developed using Heat Source 6.5.1. The model was developed by DEQ.

3.7.1 Model extent

The extent of the model domain is the Luckiamute River from the mouth upstream to Road 1430 at river mile 57 (**Figure 3-155**).

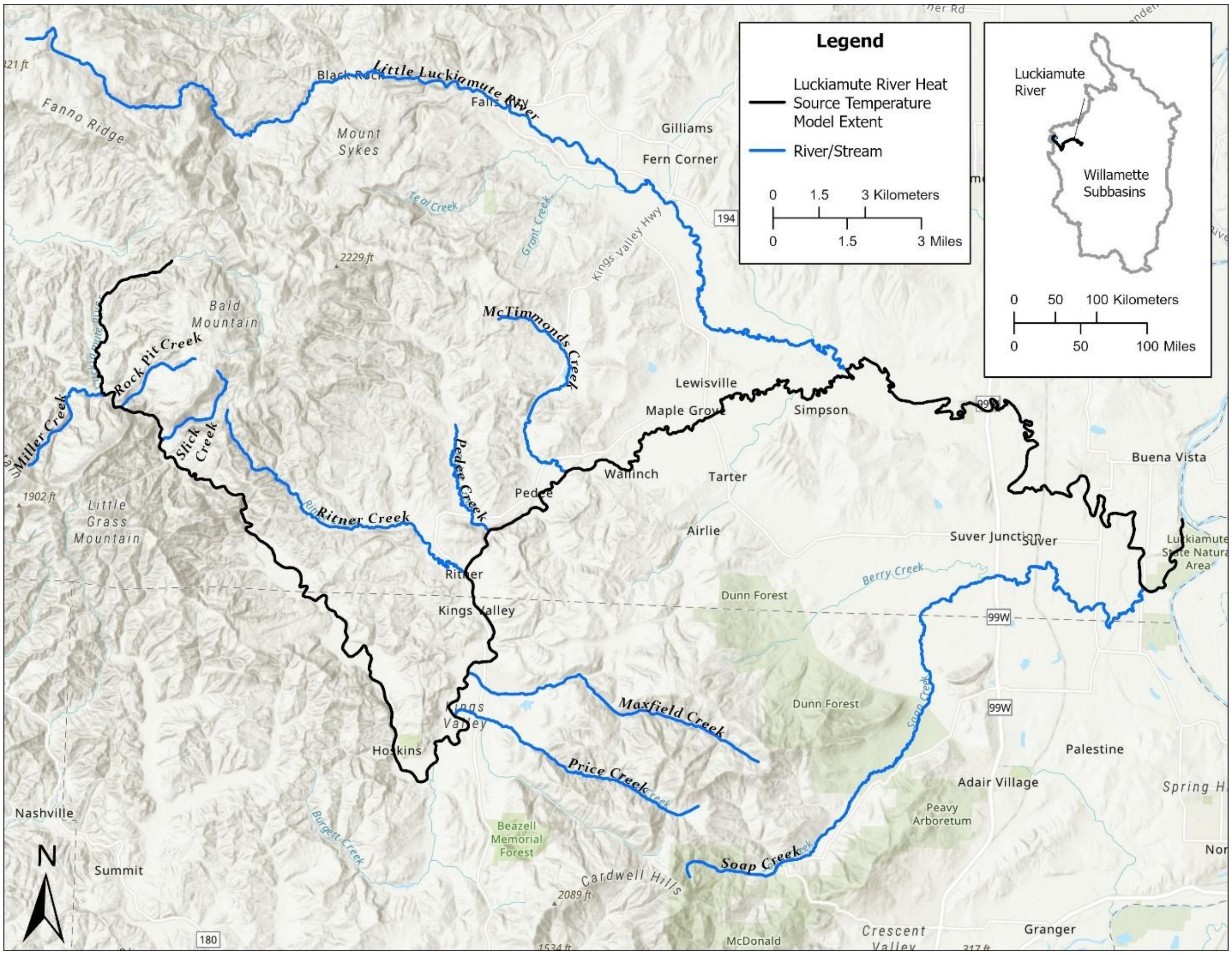


Figure 3-155: Luckiamute River temperature model extent.

3.7.2 Spatial and temporal resolution

The model input spatial resolution (dx) is 30 m. Outputs are generated every 100 m. The model time step (dt) is 1 minute and outputs were generated every hour.

3.7.3 Time frame of simulation

The model period is for a single day: August 12, 2001.

3.7.4 Meteorological inputs

The model was set up using hourly air temperature, relative humidity, and wind speed measurements from the Corvallis AgriMet site (crvo) (**Figure 3-156**). Air temperature data were modified using the dry adiabatic lapse rate to adjust for differences in elevation between the measurement location and the model input location. Wind speeds were adjusted to improve the calibration using a wind-sheltering coefficient of 0.25 to represent differences in wind speed between the measurement location and above the stream within the riparian area.

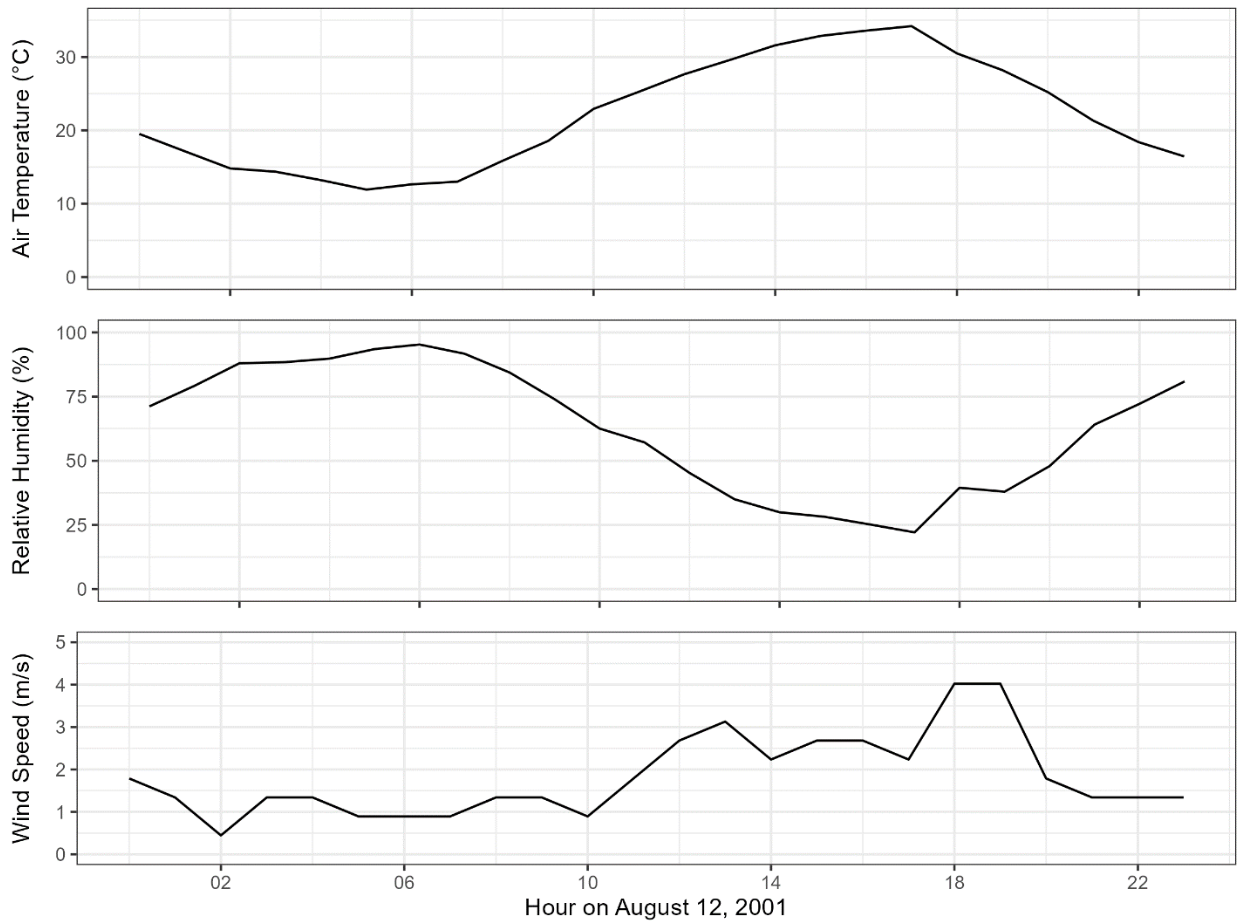


Figure 3-156: Meteorological inputs to the Luckiamute River model.

3.7.5 Temperature inputs

Hourly water temperature time series data were used to support tributary and boundary condition model setup. **Figure 3-157** shows the locations of the various stream temperature monitoring locations that were used for model setup or calibration.

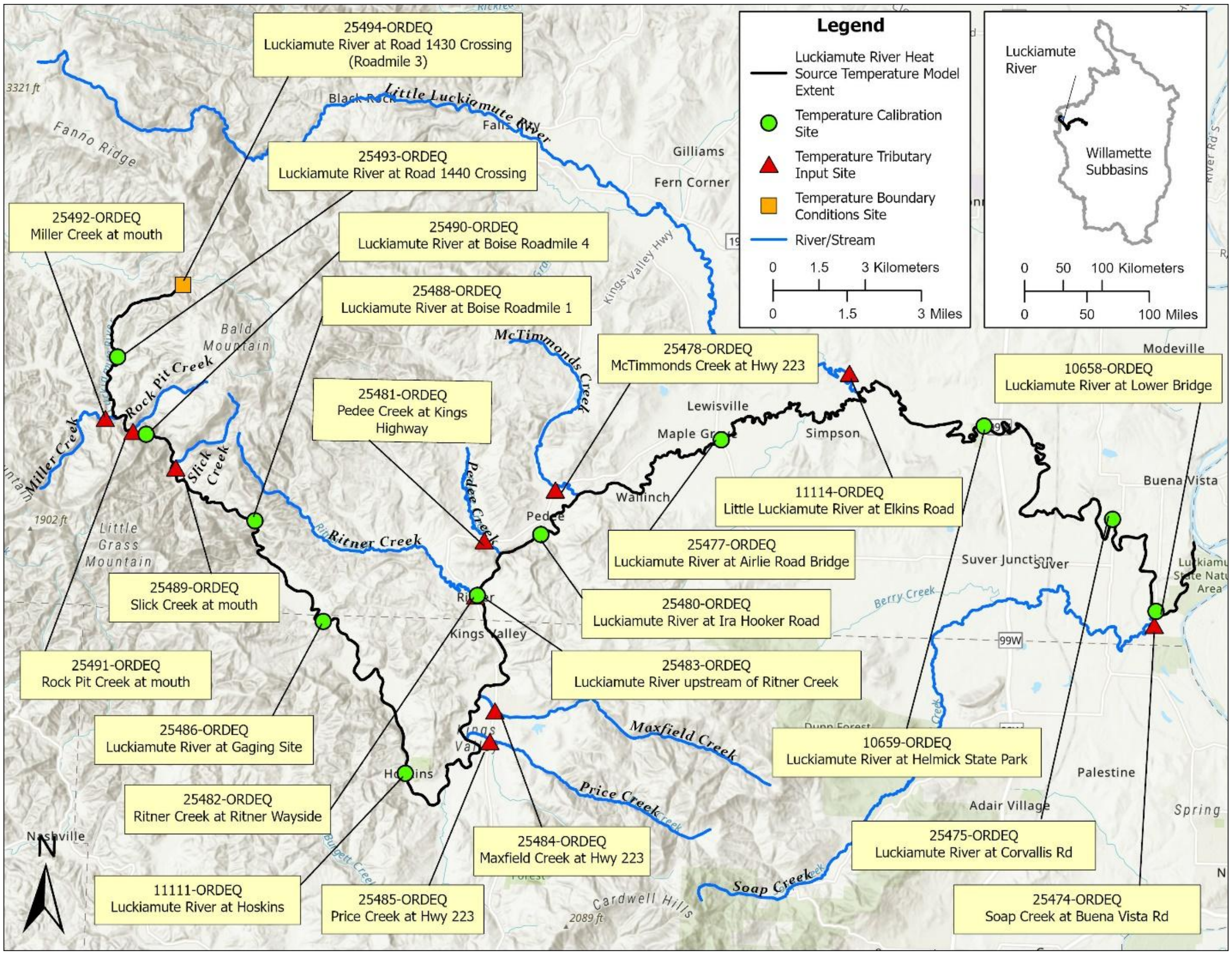
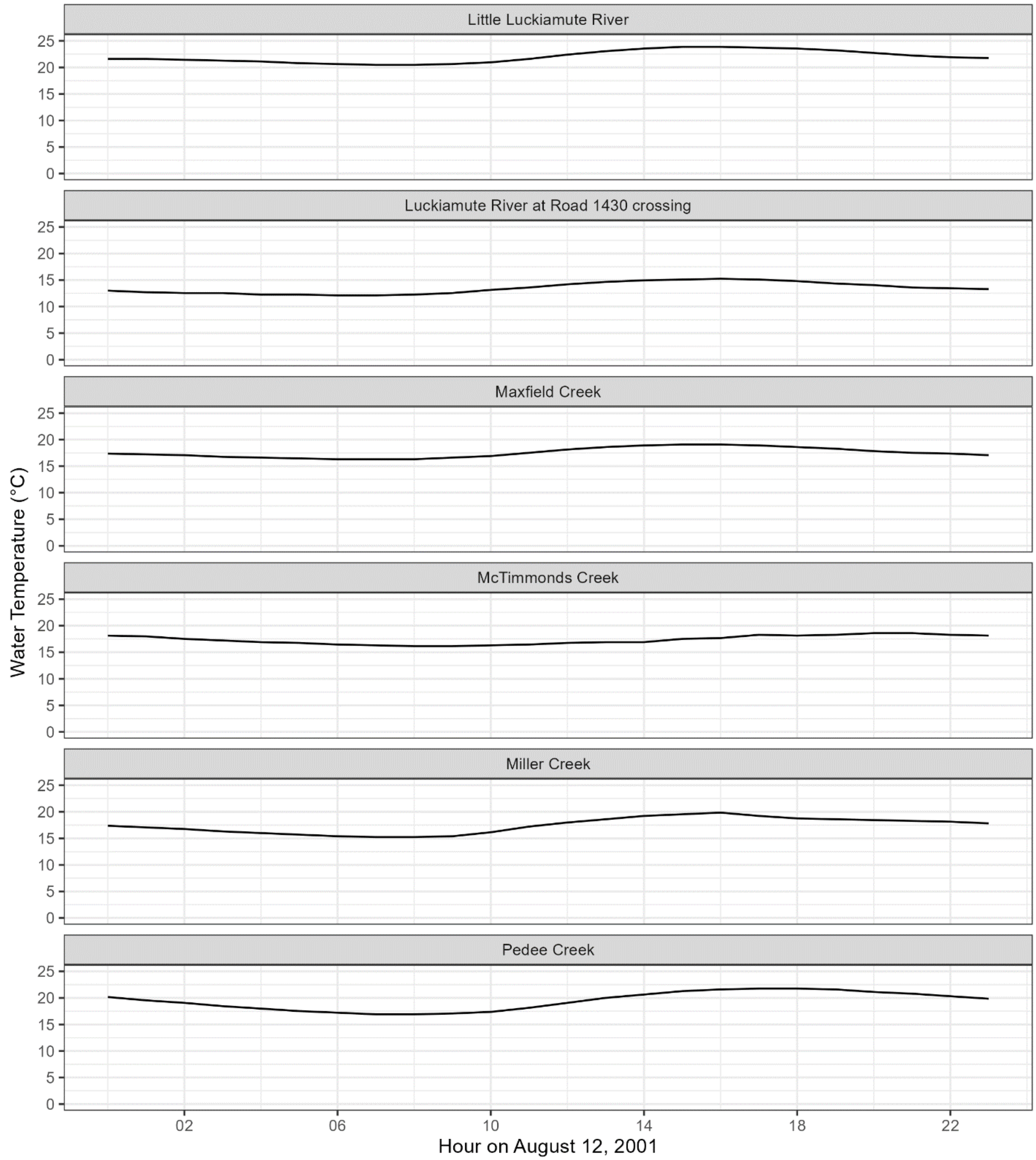


Figure 3-157: Temperature monitoring locations used for the Luckiamute River model setup and calibration.

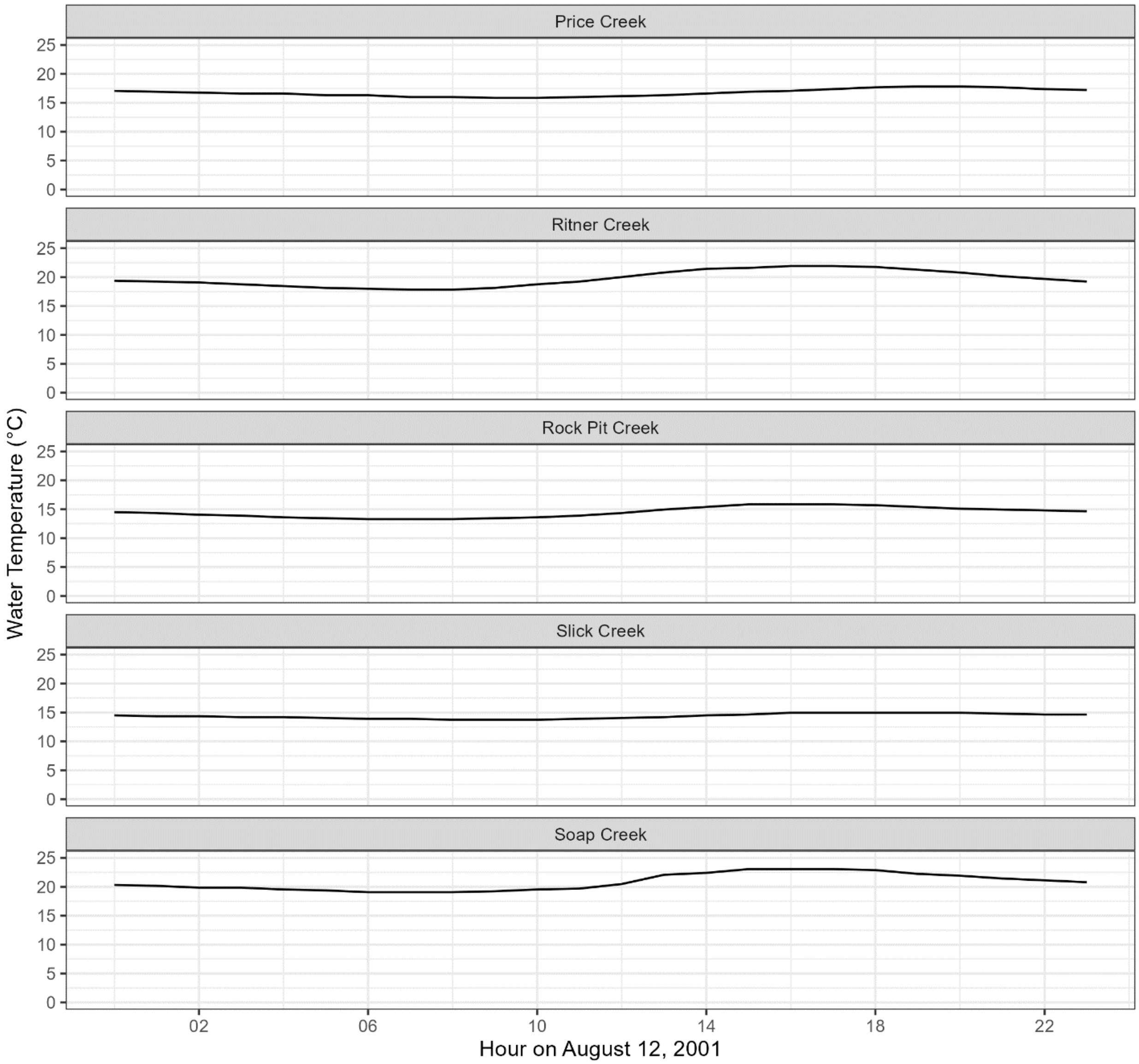
Table 3-50 and **Figure 3-158** document the water temperature inputs to the model at the boundary condition (Luckiamute River at Road 1430 crossing) and tributaries.

Table 3-50: Boundary condition and tributary water temperature inputs to the Luckiamute River model.

Model Location Name	Model Location (km)	Input Type	Data Source
Luckiamute River at Road 1430 crossing	91.470	Boundary Condition	25494-ORDEQ
Miller Creek at mouth	87.447	Tributary	25492-ORDEQ
Rock Pit Creek at mouth	83.362	Tributary	25491-ORDEQ
Slick Creek at mouth	77.663	Tributary	25489-ORDEQ
Price Creek at Hwy 223	72.603	Tributary	25485-ORDEQ
Maxfield Creek at Hwy 223	65.074	Tributary	25484-ORDEQ
Ritner Creek at Ritner Wayside	53.004	Tributary	25482-ORDEQ
Pedee Creek at Kings Highway	49.834	Tributary	25481-ORDEQ
McTimmonds Creek	40.081	Tributary	25478-ORDEQ
Little Luckiamute River at Elkins Road	22.585	Tributary	11114-ORDEQ
Soap Creek	9.174	Tributary	25474-ORDEQ


Little Luckiamute River
Luckiamute River at Road 1430 crossing
Maxfield Creek
McTimmonds Creek
Miller Creek
Pedee Creek
Water Temperature (°C)
0
5
10
15
20
25
02
06
10
14
18
22
Hour on August 12, 2001

(A)



(B)
Figure 3-158: Boundary condition and tributary water temperature inputs to the Luckiamute River model.

3.7.6 Flow inputs

Hourly stream flow time series data were used to support tributary and boundary condition model setup. **Figure 3-159** shows the locations of the various stream flow monitoring locations that were used for model setup or calibration.

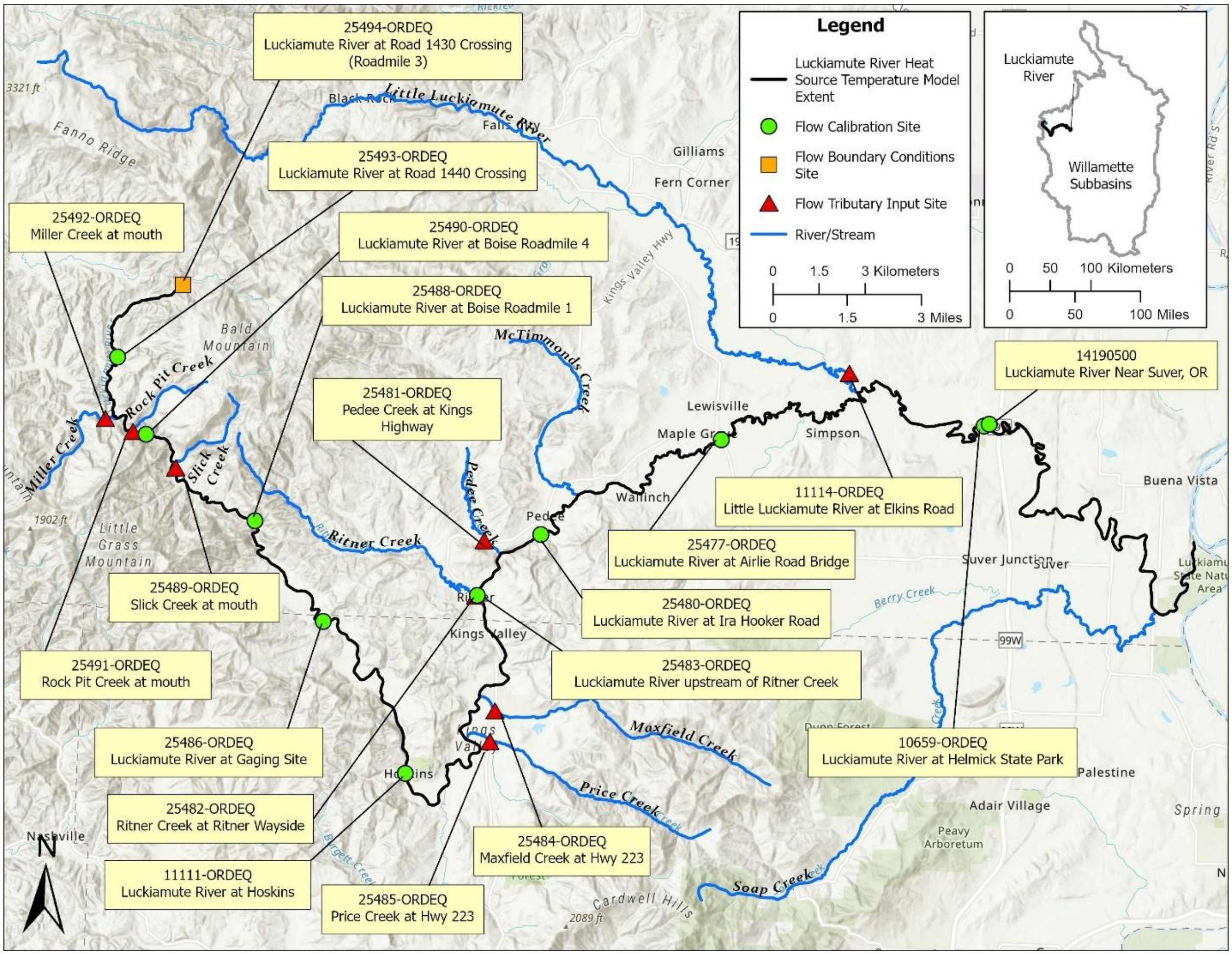


Figure 3-159: Flow monitoring locations used for the Luckiamute River model setup and calibration.

The boundary condition and tributary flow inputs to the model is summarized in

Table 3-51. **Figure 3-160** documents mainstem model flow setup. The model flow was estimated between measured sites using a flow mass balance, which incorporated input from tributaries and demand from PODs. The model assumes that 50% of the permitted withdrawal rate was utilized during the model period. The total water withdrawal volume at the PODs in the model flow amounted to 1.8227 cms.

Table 3-51: Boundary condition and tributary flow inputs to the Luckiamute River model.

Model Location Name	Model Location (km)	Flow Rate (cms)	Input Type	Data Source
Luckiamute River at Road 1430 crossing (Roadmile 3)	91.470	0.160	Boundary Condition	25494-ORDEQ
Miller Creek at mouth	87.447	0.210	Tributary	25492-ORDEQ
Rock Pit Creek at mouth	83.362	0.020	Tributary	25491-ORDEQ
Slick Creek at mouth	77.663	0.006	Tributary	25489-ORDEQ
Price Creek at Hwy 223	72.603	0.030	Tributary	25485-ORDEQ
Maxfield Creek at Hwy 223	65.074	0.015	Tributary	25484-ORDEQ
Ritner Creek at Ritner Wayside	53.004	0.130	Tributary	25482-ORDEQ
Pedee Creek at Kings Highway	49.834	0.120	Tributary	25481-ORDEQ
McTimmonds Creek	40.081	0.005	Tributary	Estimated using a flow mass balance based on TIR
Little Luckiamute River at Elkins Road	22.585	0.690	Tributary	11114-ORDEQ
Soap Creek	9.174	0.005	Tributary	Estimated using a flow mass balance based on TIR

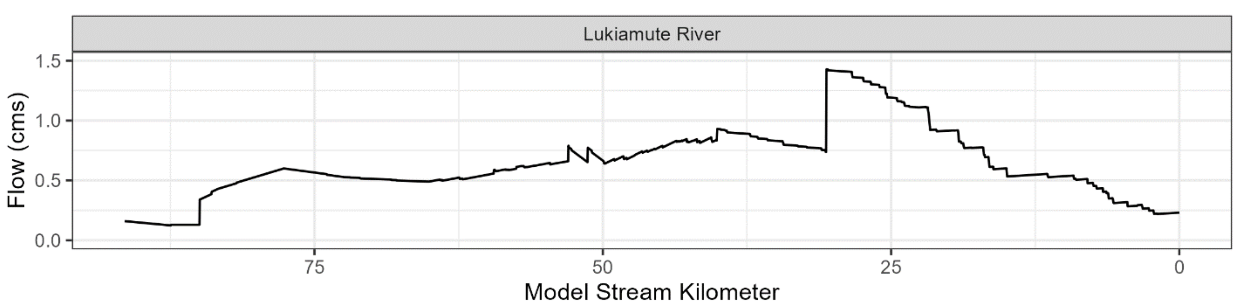


Figure 3-160: Boundary condition and mainstem flow inputs to the Luckiamute River model.

3.7.7 Point source inputs

There are no point sources discharging within the model extent.

3.7.8 Landcover and topographic shade inputs

Average land cover height inputs and topographic shade angle inputs are shown in Figure 3-161 and Figure 3-162, respectively.

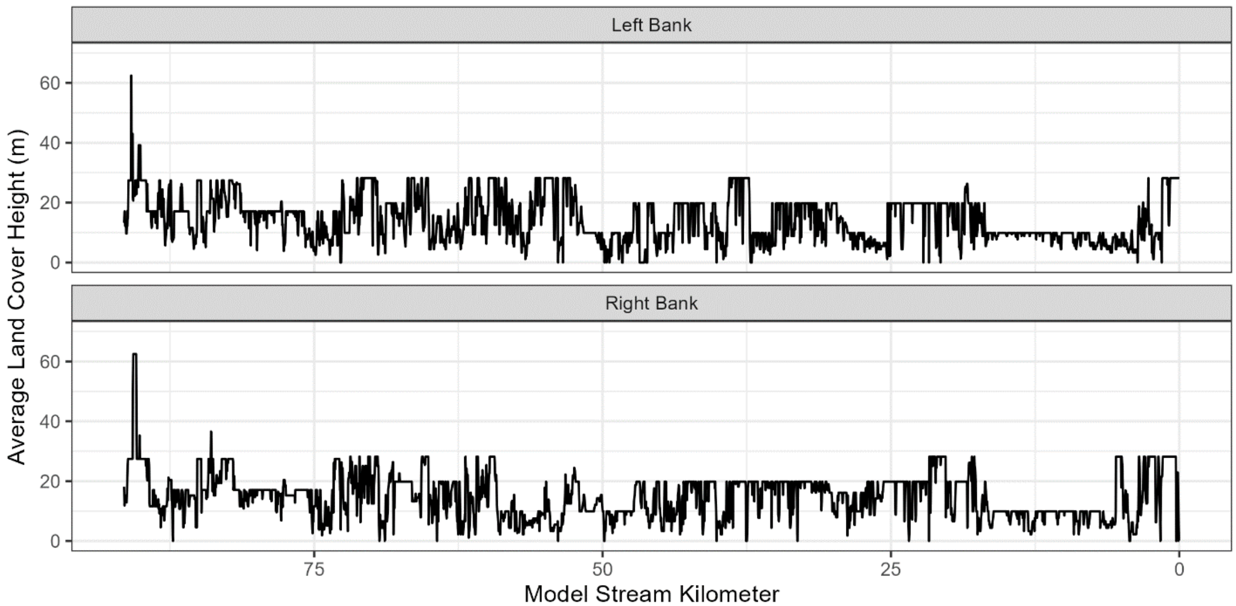


Figure 3-161: Average land cover height inputs to the Luckiamute River model.

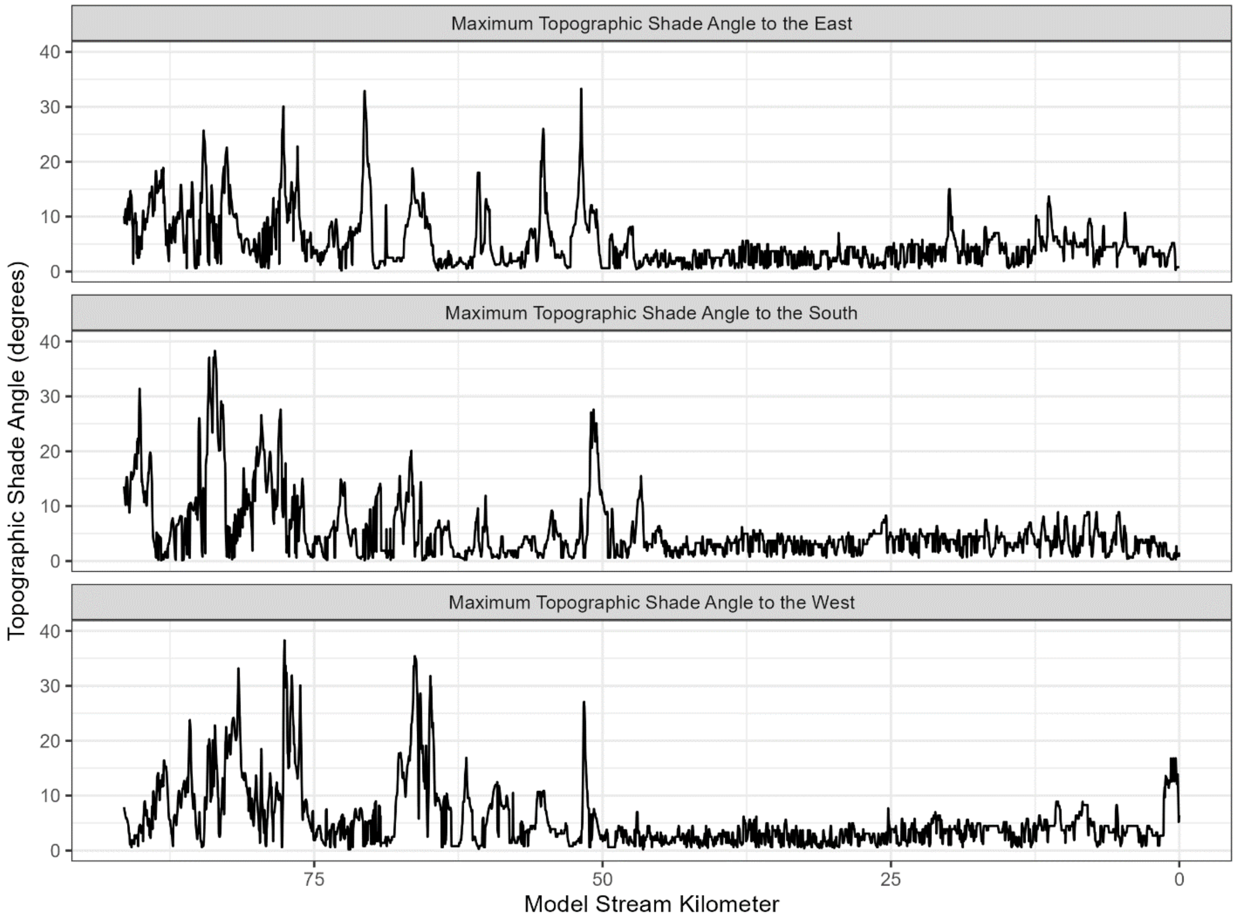


Figure 3-162: Topographic shade angle inputs to the Luckiamute River model.

3.7.9 Channel setup

Channel setup for Luckiamute River model is presented in **Figure 3-163**.

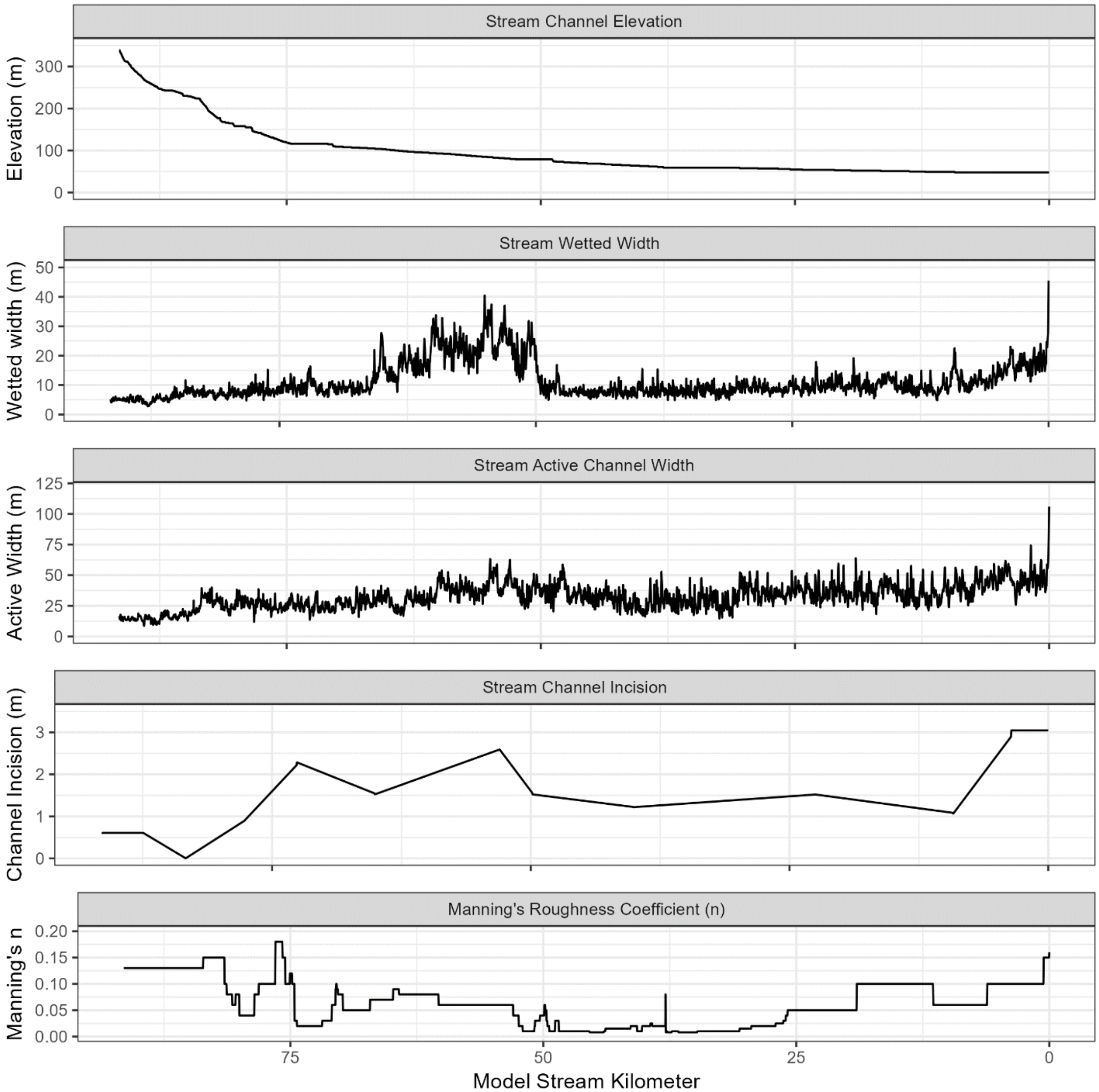


Figure 3-163: Channel setup in the Luckiamute River model.

3.7.10 Calibration results

3.7.10.1 Temperature

The model was calibrated to the continuous temperature data collected from several locations along Luckiamute Creek. Results for goodness of fit statistics comparing field observed and model-predicted temperatures are summarized in **Table 3-52**. Observed and model-predicted hourly temperatures were plotted for the monitoring stations (**Figure 3-164** through **Figure 3-175**).

Table 3-52: Luckiamute River water temperature goodness of fit statistics comparing field observed and model-predicted temperatures.

Monitoring Location	Model KM	Temperature Statistics	ME	MAE	RMSE	NSE	n
All Stations		Daily Maximum	0.43	0.74	0.81	NA	11
All Stations		Hourly	-1.09	1.32	1.68	0.66	264
10658-ORDEQ: Luckiamute River at Lower Bridge	3.6	Hourly	-0.63	1.19	1.31	-2.31	24
25475-ORDEQ: Luckiamute River at Corvallis Rd.	9.2	Hourly	-1.17	1.48	1.78	-8.47	24
10659-ORDEQ: Luckiamute River at Helmick State Park	22.6	Hourly	-1.29	1.3	1.67	-1.12	24
25477-ORDEQ: Luckiamute River at Airlie Rd. Bridge	40.1	Hourly	-2.26	2.53	2.96	-2.76	24
25480-ORDEQ: Luckiamute River at Ira Hooker Rd.	49.8	Hourly	-0.58	1.05	1.2	0.69	24
25483-ORDEQ: Luckiamute River just upstream Ritner Creek	53	Hourly	-0.95	1.43	1.65	-0.13	24
11111-ORDEQ: Luckiamute River at Hoskins	65.1	Hourly	-1.01	1.01	1.16	0.28	24
25486-ORDEQ: Luckiamute River at Gaging site	72.6	Hourly	-0.54	0.54	0.73	0.79	24
25488-ORDEQ: Luckiamute River at Boise Roadmile 1	77.7	Hourly	-0.77	0.77	0.95	0.68	24
25490-ORDEQ: Luckiamute River at Boise Roadmile 4	83.4	Hourly	-0.82	0.93	1.24	-0.03	24
25493-ORDEQ: Luckiamute River at Road 1440 Crossing	87.4	Hourly	-2.01	2.25	2.47	-2.95	24

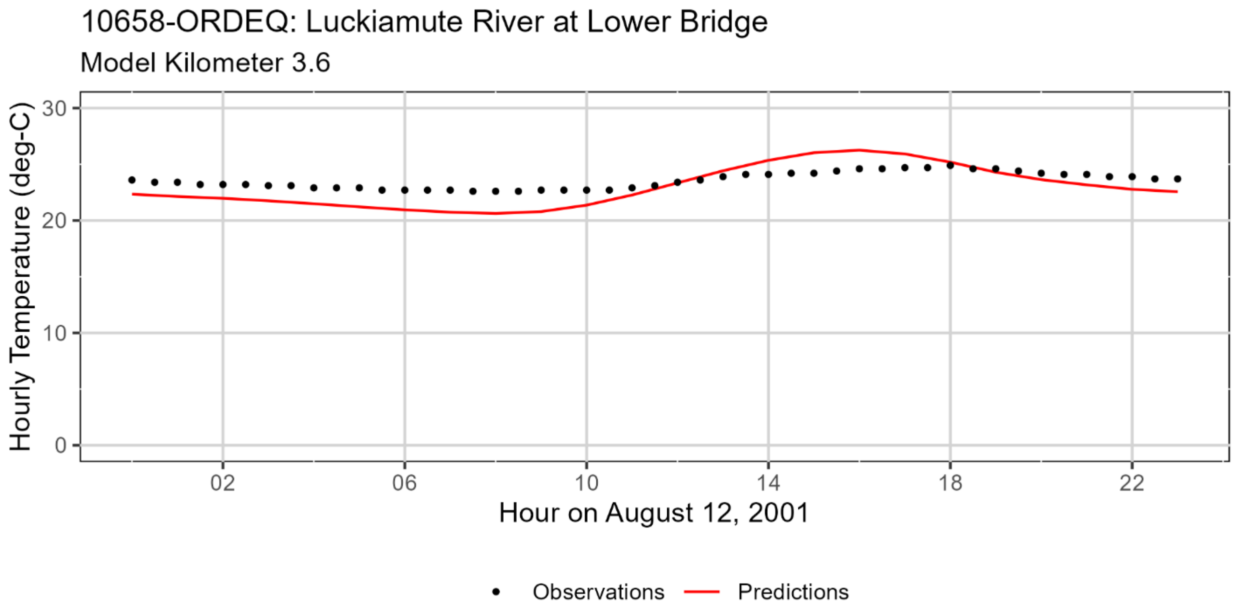


Figure 3-164: Luckiamute River measured and model-predicted hourly temperatures at monitoring station 10658-ORDEQ.

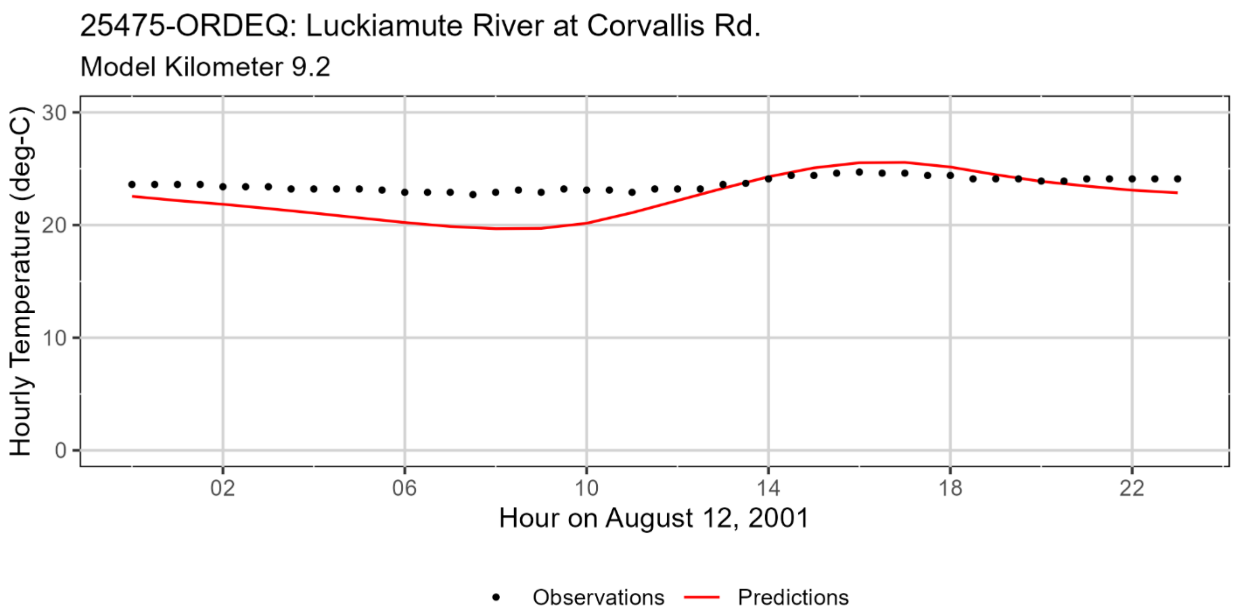


Figure 3-165: Luckiamute River measured and model-predicted hourly temperatures at monitoring station 25475-ORDEQ.

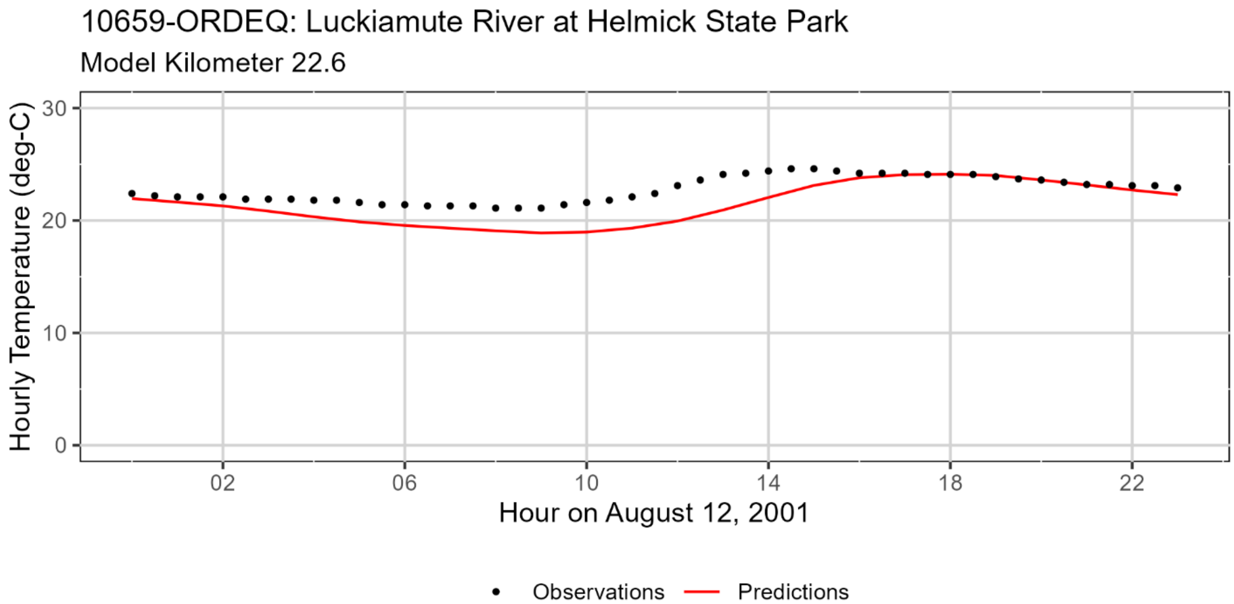


Figure 3-166: Luckiamute River measured and model-predicted hourly temperatures at monitoring station 10659-ORDEQ.

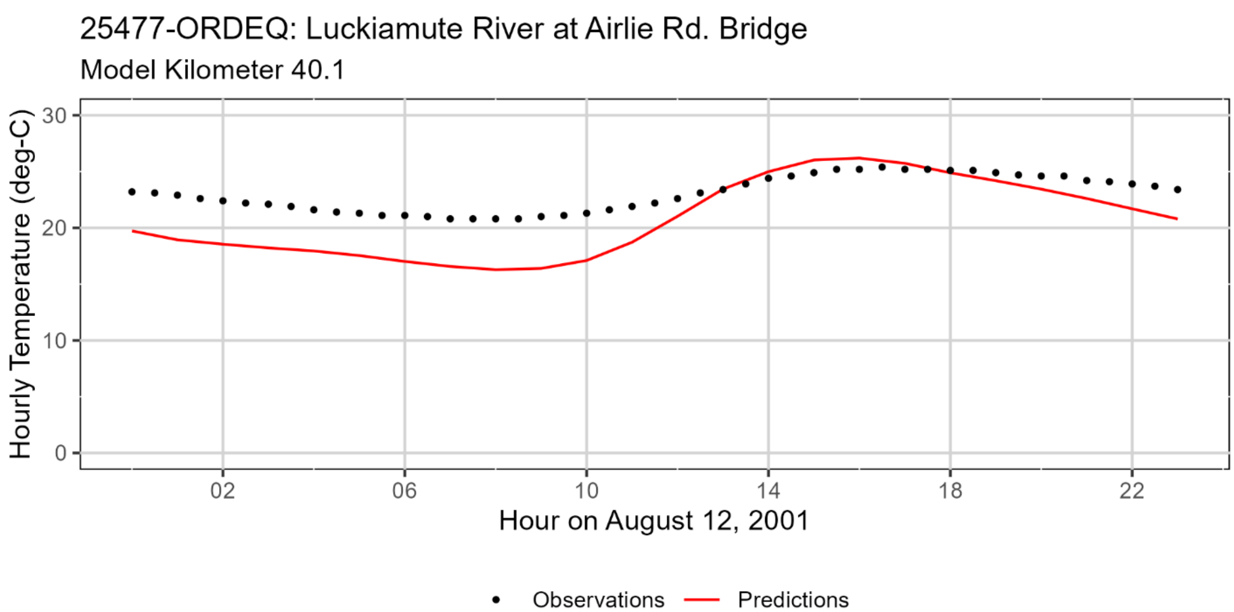


Figure 3-167: Luckiamute River measured and model-predicted hourly temperatures at monitoring station 25477-ORDEQ.

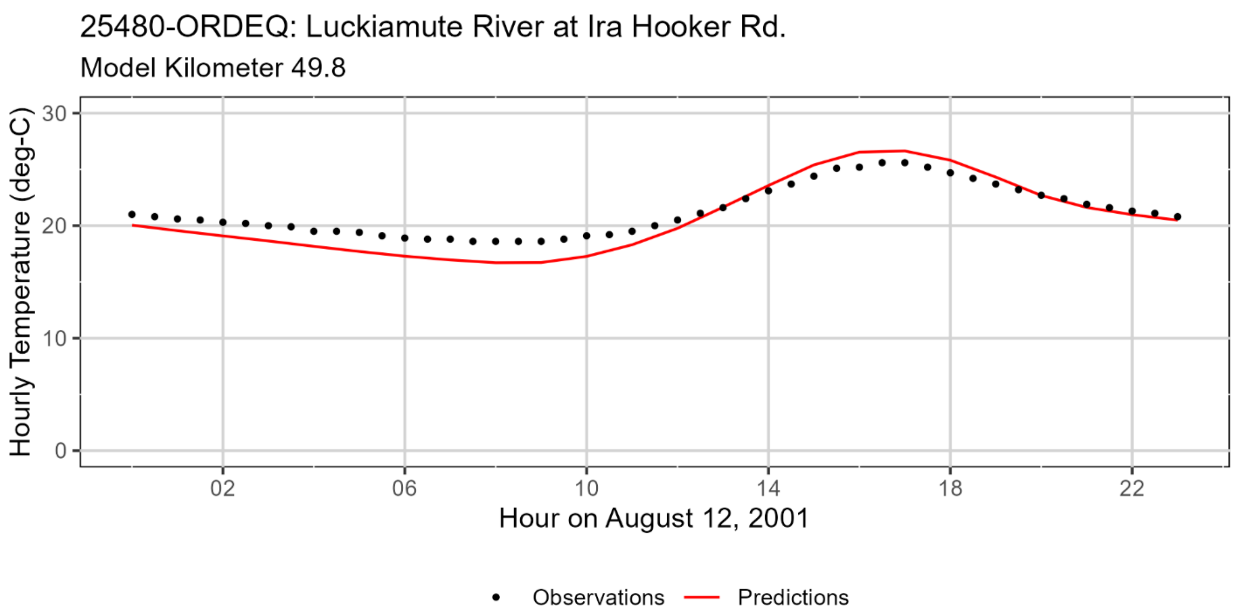


Figure 3-168: Luckiamute River measured and model-predicted hourly temperatures at monitoring station 25480-ORDEQ.

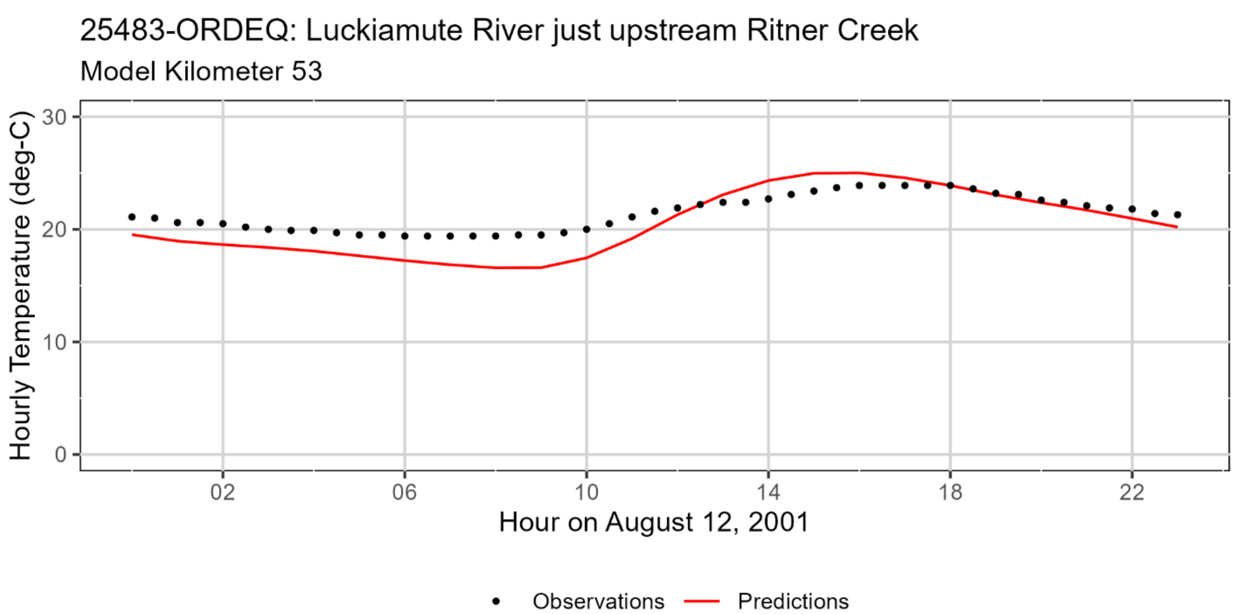


Figure 3-169: Luckiamute River measured and model-predicted hourly temperatures at monitoring station 25483-ORDEQ.

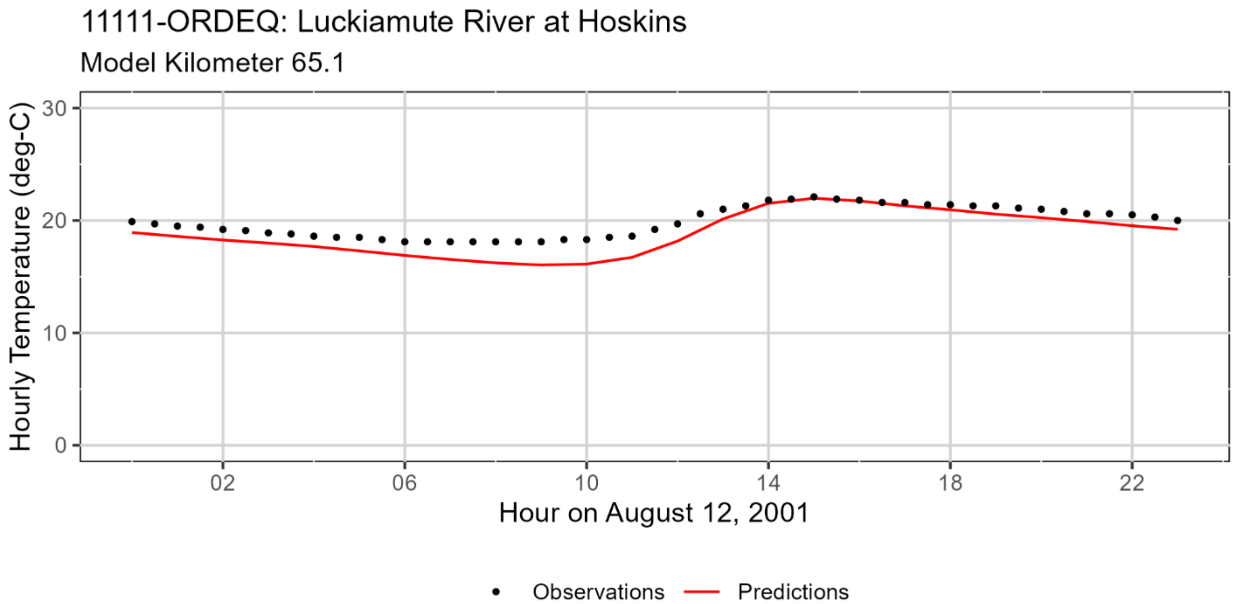


Figure 3-170: Luckiamute River measured and model-predicted hourly temperatures at monitoring station 11111-ORDEQ.

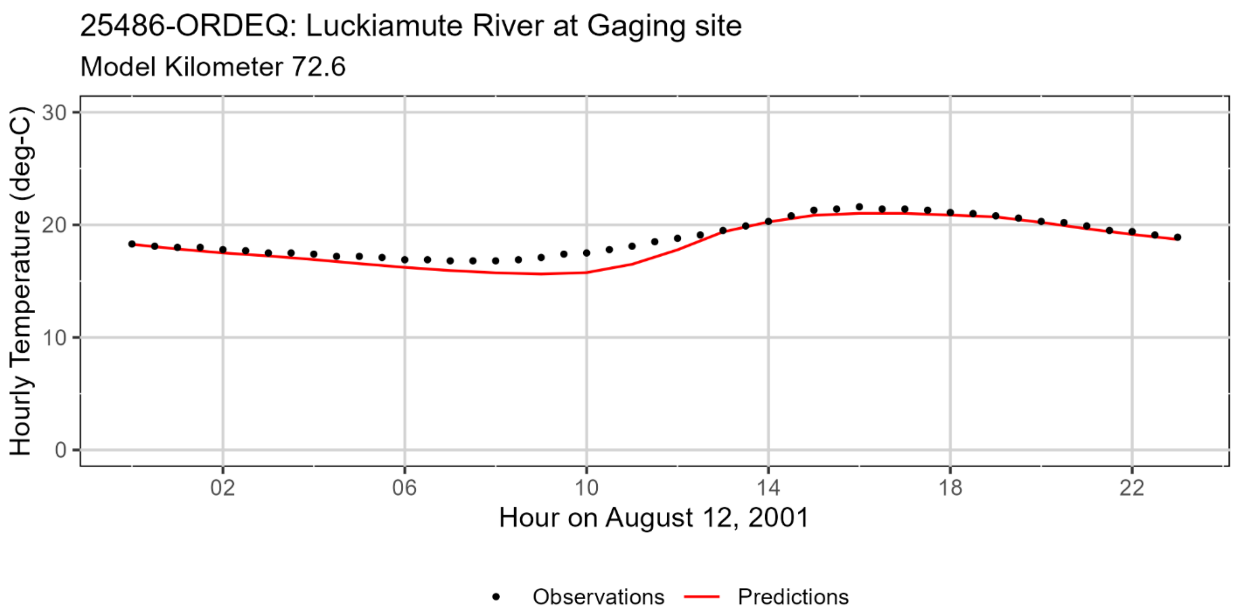


Figure 3-171: Luckiamute River measured and model-predicted hourly temperatures at monitoring station 25486-ORDEQ.

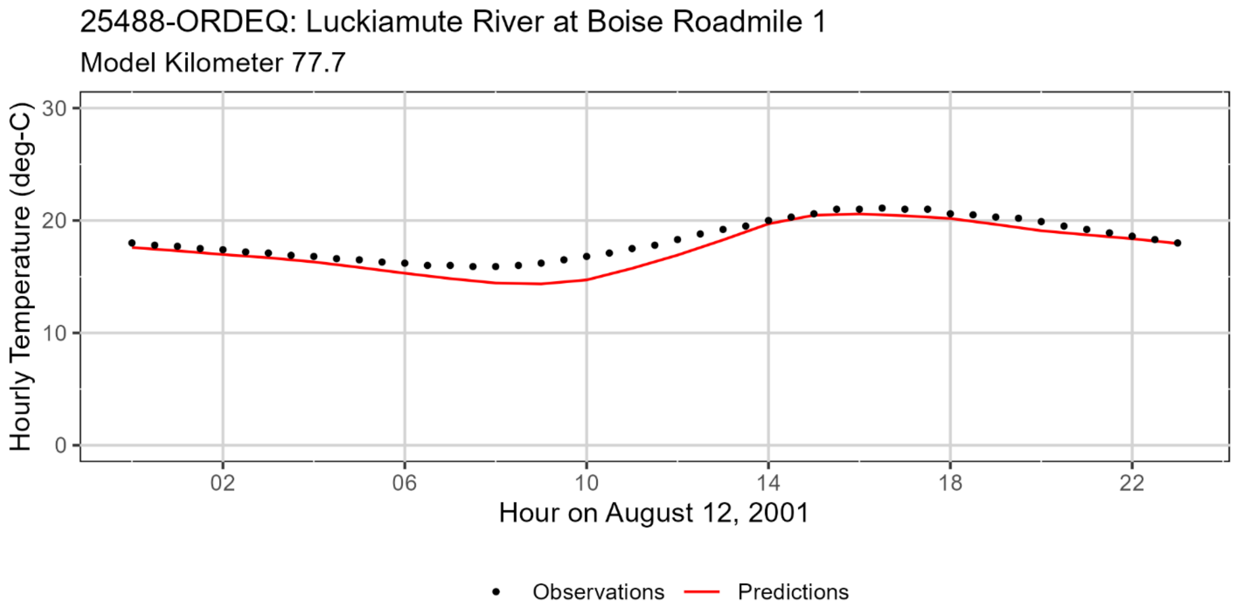


Figure 3-172: Luckiamute River measured and model-predicted hourly temperatures at monitoring station 25488-ORDEQ.

Figure 3-173: Luckiamute River measured and model-predicted hourly temperatures at monitoring station 25490-ORDEQ.

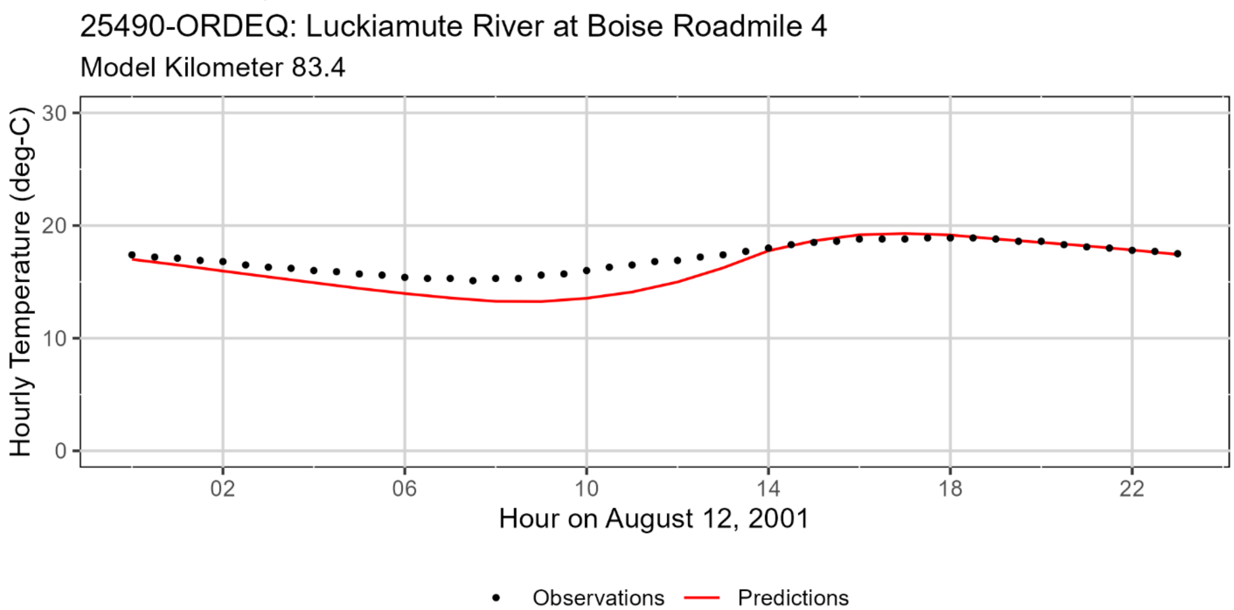


Figure 3-174: Luckiamute River measured and model-predicted hourly temperatures at monitoring station 25490-ORDEQ.

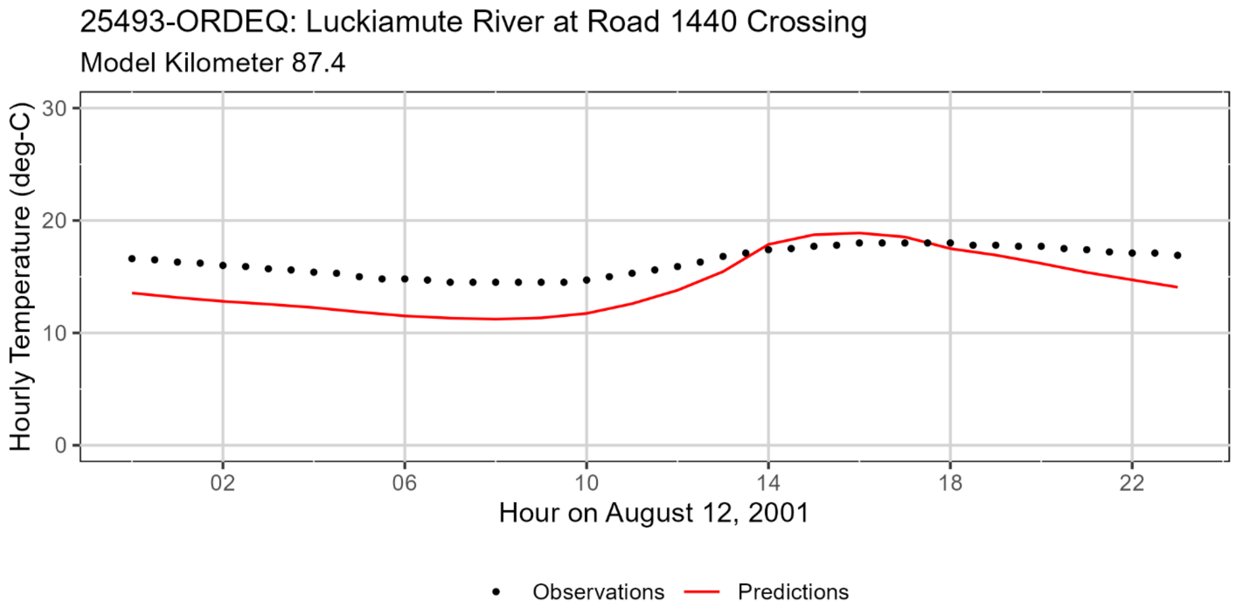


Figure 3-175: Luckiamute River measured and model-predicted hourly temperatures at monitoring station 25493-ORDEQ.

3.7.10.2 Effective Shade

Observed and model-predicted effective shade data were plotted along the Luckiamute River (**Figure 3-176**). The observed field data used for comparison is summarized in **Table 2-34**. Results for goodness of fit statistics comparing field observed and model-predicted temperatures are summarized in **Table 3-53**.

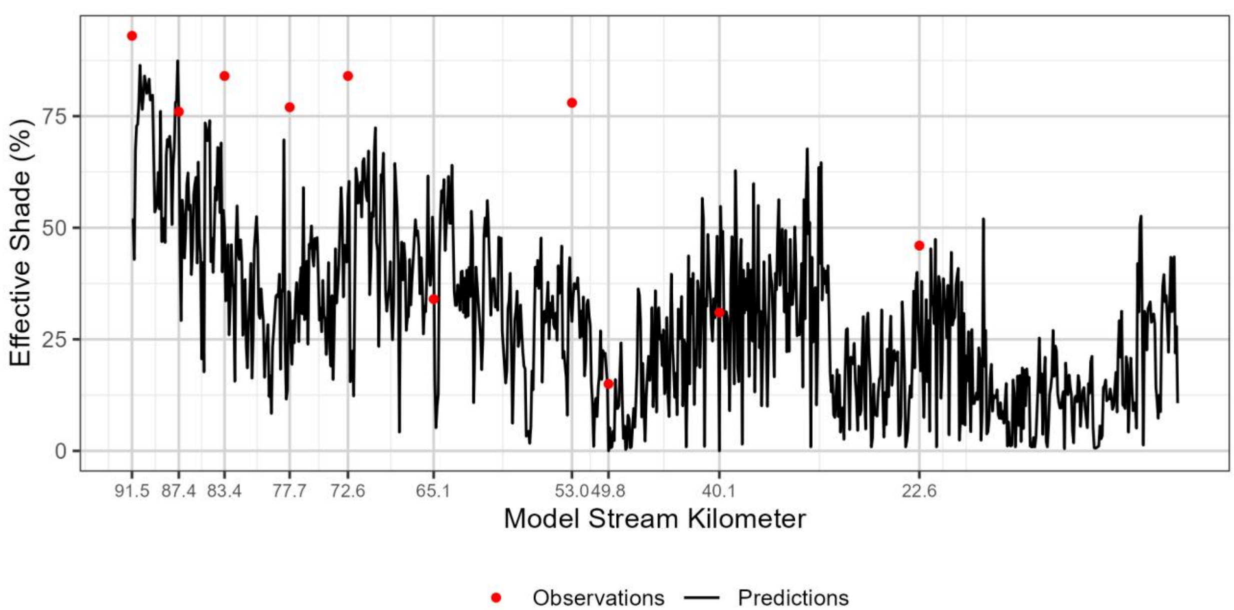


Figure 3-176: Luckiamute River field observed and model-predicted effective shade.

Table 3-53: Luckiamute River effective shade goodness of fit statistics comparing field observed and model values.

N	R^2	ME	MAE	RMSE
10	0.55	-25.08	27.32	30.84

3.7.10.3 Flow

A flow mass balance was completed to improve the calibration and match flows to the measured values. The observed flow used for comparison is summarized in **Table 3-54**, which is plotted with the model flow in **Figure 3-177**. Results for goodness of fit statistics comparing field observed flow and the model flow are summarized in **Table 3-55**.

Table 3-54: Luckiamute River stream flow rate measurements.

Monitoring Location	Model KM	Flow Statistics	Flow (cms)	Date
25494-ORDEQ: Luckiamute River at Road 1430 crossing (Road Mile 3)	91.5	Instantaneous	0.16	7/30/2001
25488-ORDEQ: Luckiamute River at Boise Roadmile 1	77.7	Instantaneous	0.6	7/30/2001
25486-ORDEQ: Luckiamute River at Gaging Site	72.6	Instantaneous	0.53	7/30/2001
11111-ORDEQ: Luckiamute River at Hoskins	65.1	Instantaneous	0.49	7/30/2001
25483-ORDEQ: Luckiamute River upstream of Ritner Creek	53.0	Instantaneous	0.66	7/31/2001
25493-ORDEQ: Luckiamute River at Road 1440 crossing	51.2	Instantaneous	0.13	7/30/2001
25480-ORDEQ: Luckiamute River at Ira Hooker Road	49.8	Instantaneous	0.64	7/31/2001
25477-ORDEQ: Luckiamute River at Airlie Road Bridge	40.1	Instantaneous	0.93	7/31/2001
10659-ORDEQ: Luckiamute River at Helmick State Park	22.6	Instantaneous	1.11	7/31/2001
10659-ORDEQ: Luckiamute River at Helmick State Park	22.6	Instantaneous	0.74	8/14/2001
14190500: Luckiamute River Near Suver, OR	22.1	Daily mean	0.88	8/12/2001
25490-ORDEQ: Luckiamute River at Boise Roadmile 4	10.4	Instantaneous	0.43	7/30/2001

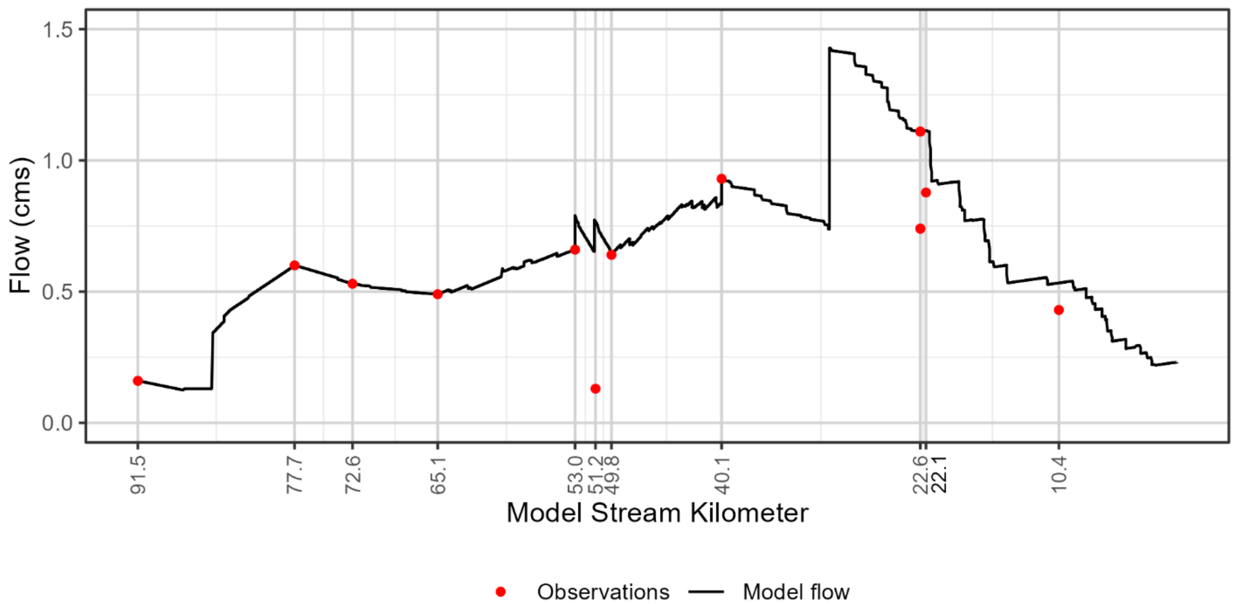


Figure 3-177: Luckiamute River field observed and model flow rates.

Table 3-55: Luckiamute River goodness of fit statistics comparing field observed and model flow rates.

N	R^2	ME	MAE	RMSE
11	0.6	0.09	0.09	0.21

3.7.10.4 Channel

Results comparing channels widths derived from GIS and modeling to those measured in the field are presented in **Figure 3-178**. Results shows channel widths only from streams modeled for temperature with Heat Source.

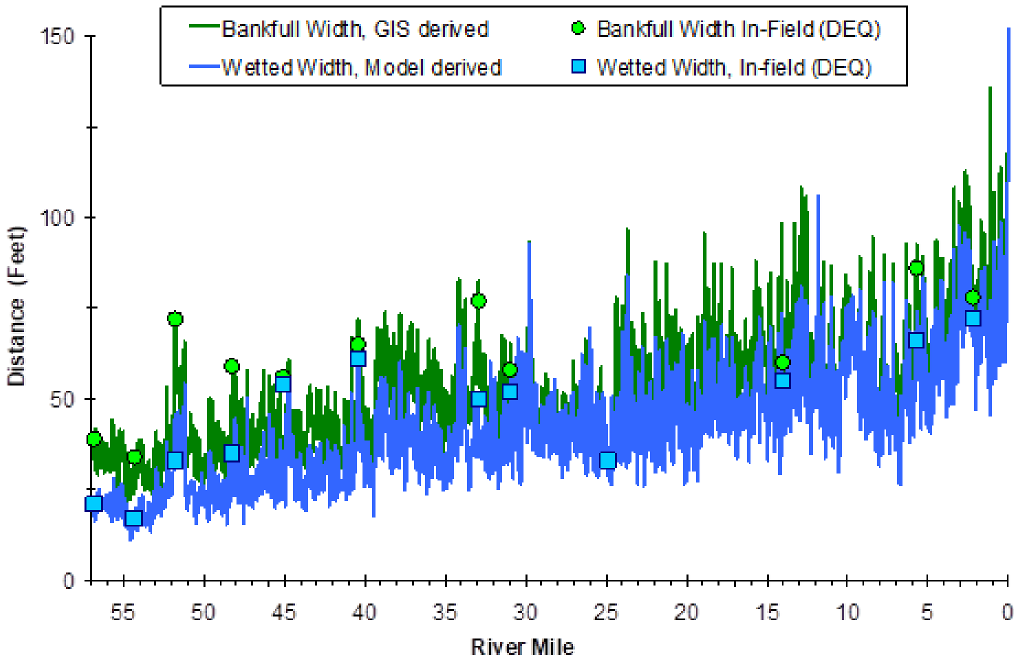


Figure 3-178: Luckiamute River field observed and derived bankfull and wetted width.

3.8 Mohawk River

The Mohawk River model is a temperature model developed using Heat Source 6.5.1. The model was developed by DEQ.

3.8.1 Model extent

The extent of the model domain is the Mohawk River from the mouth to river mile 24.7 (**Figure 3-179**).

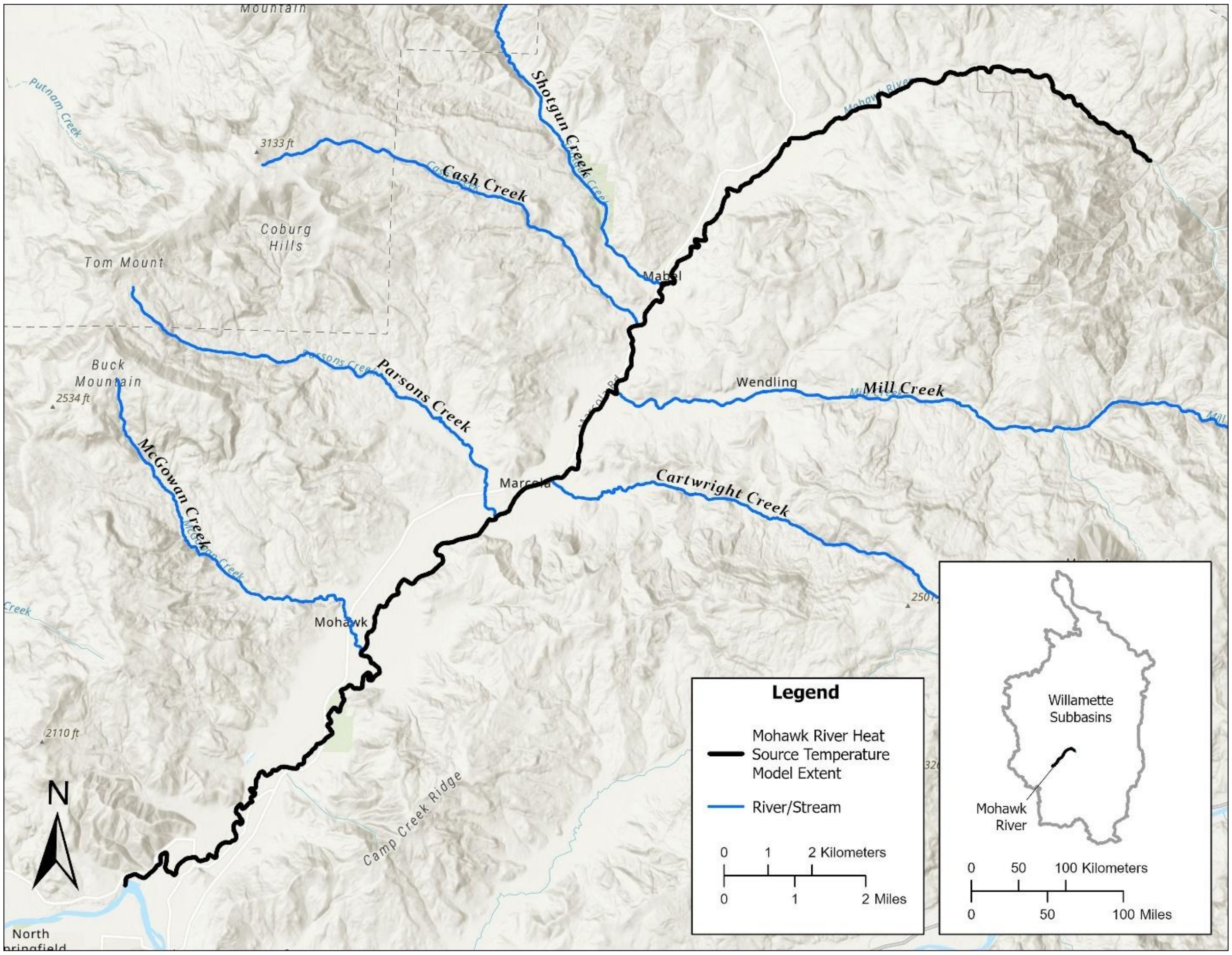


Figure 3-179: Mohawk River temperature model extent.

3.8.2 Spatial and temporal resolution

The model input spatial resolution (*dx*) is 30 m. Outputs are generated every 100 m. The model time step (*dt*) is 1 minute and outputs are generated every hour.

3.8.3 Time frame of simulation

The model period is for a single day: August 09, 2001.

3.8.4 Meteorological inputs

The model was set up using hourly air temperature, relative humidity, and wind speed measurements from the NCDC site at the Eugene Airport (KEUG) (Figure 3-180). Air temperature data were modified using the dry adiabatic lapse rate to adjust for differences in elevation between the measurement location and the model input location. Wind speeds were adjusted to improve the calibration using a wind-sheltering coefficient to represent differences in wind speed between the measurement location and above the stream within the riparian area (

Table 3-56).

Table 3-56: Wind-sheltering coefficient used in the Mohawk River model.

Model Location Name	Model Location (km)	Wind Sheltering Coefficient
Mohawk River on East Street	39.807	0.25
Mohawk River at WEYCO shop	36.85	0.25
Mohawk River at WEYCO Gate	34.564	0.05
Mohawk River at Paschelke Road	23.652	0.05
Mohawk River at Wendling Road	19.507	0.05
Mohawk River at Sunderman Road	13.076	0.05
Mohawk River at Old Mohawk Road	5.547	0.05
Mohawk River at Hill Road	2.469	0.05

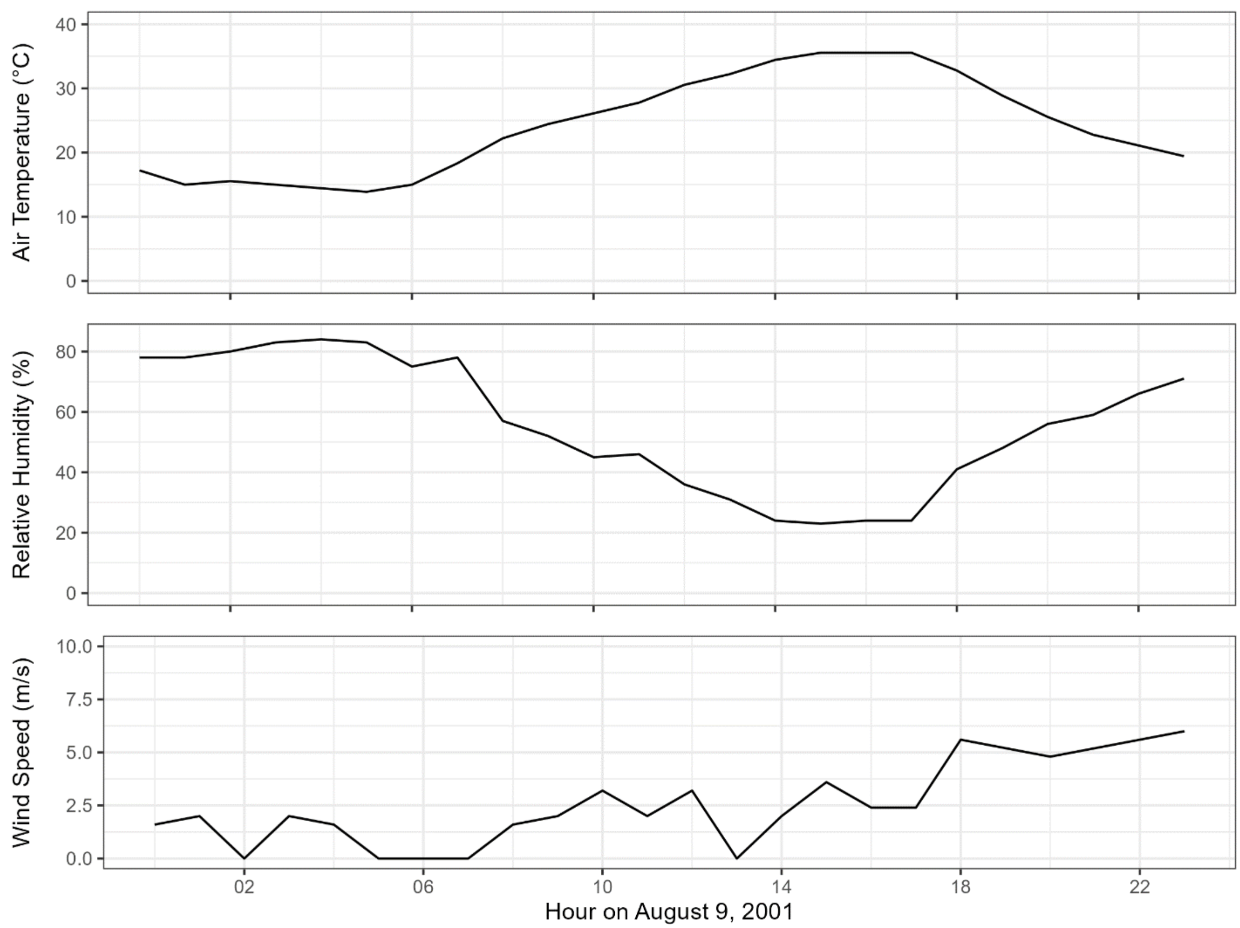


Figure 3-180: Meteorological inputs to the Mohawk River model.

3.8.5 Temperature inputs

Hourly water temperature time series data were used to support tributary and boundary condition model setup. **Figure 3-181** shows the locations of the various stream temperature monitoring locations that were used for model setup or calibration.

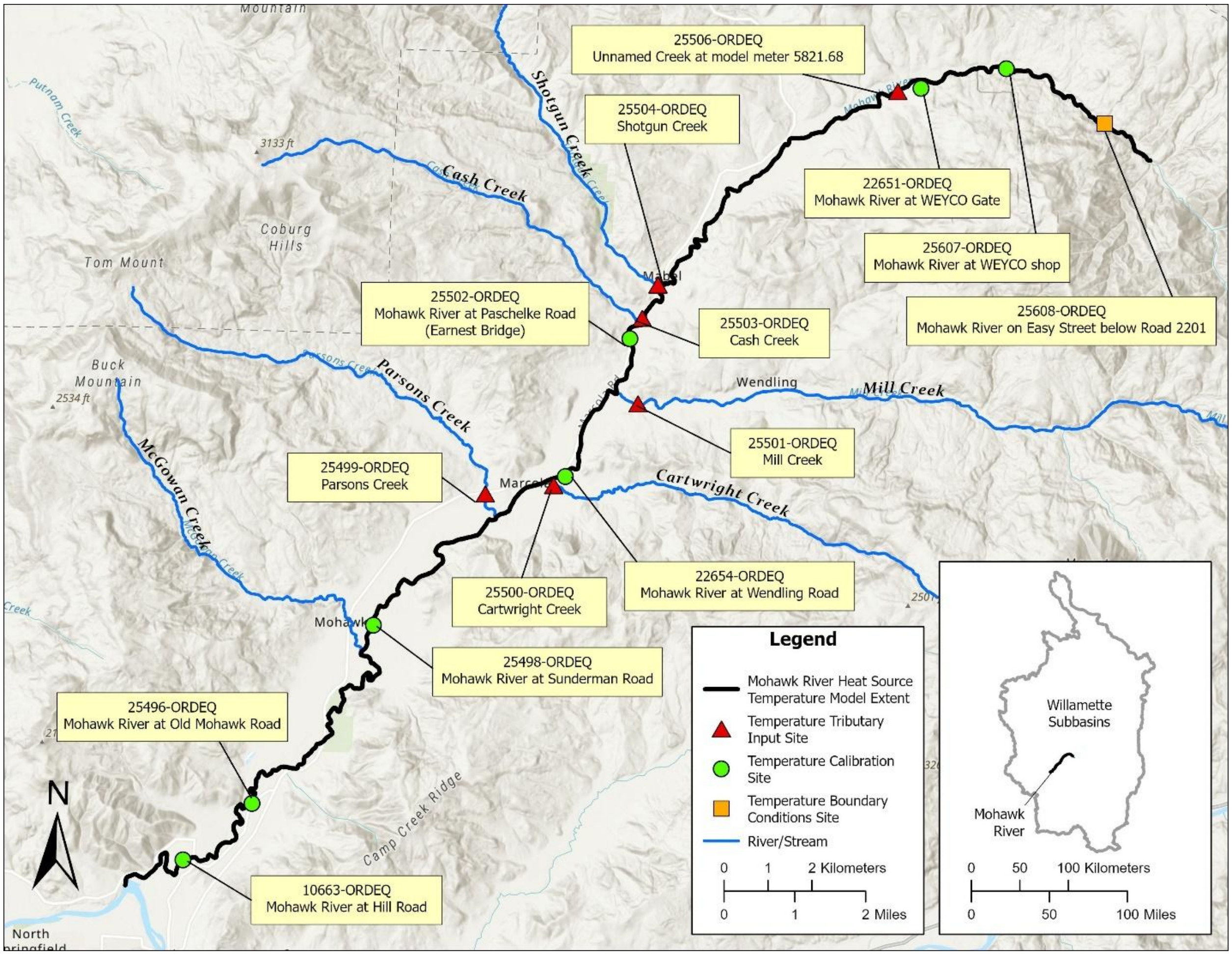
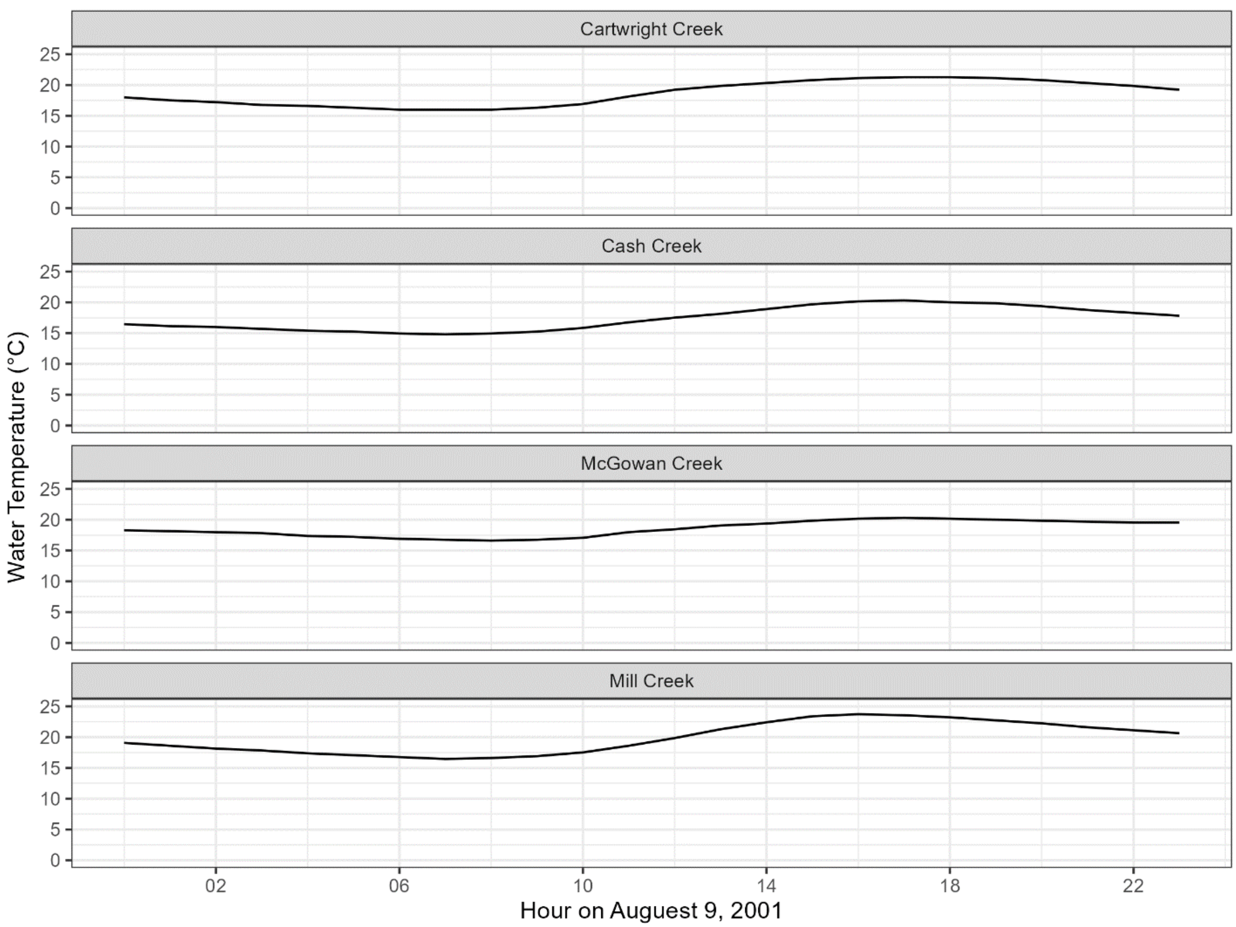


Figure 3-181: Temperature monitoring locations used for the Mohawk River model setup and calibration.

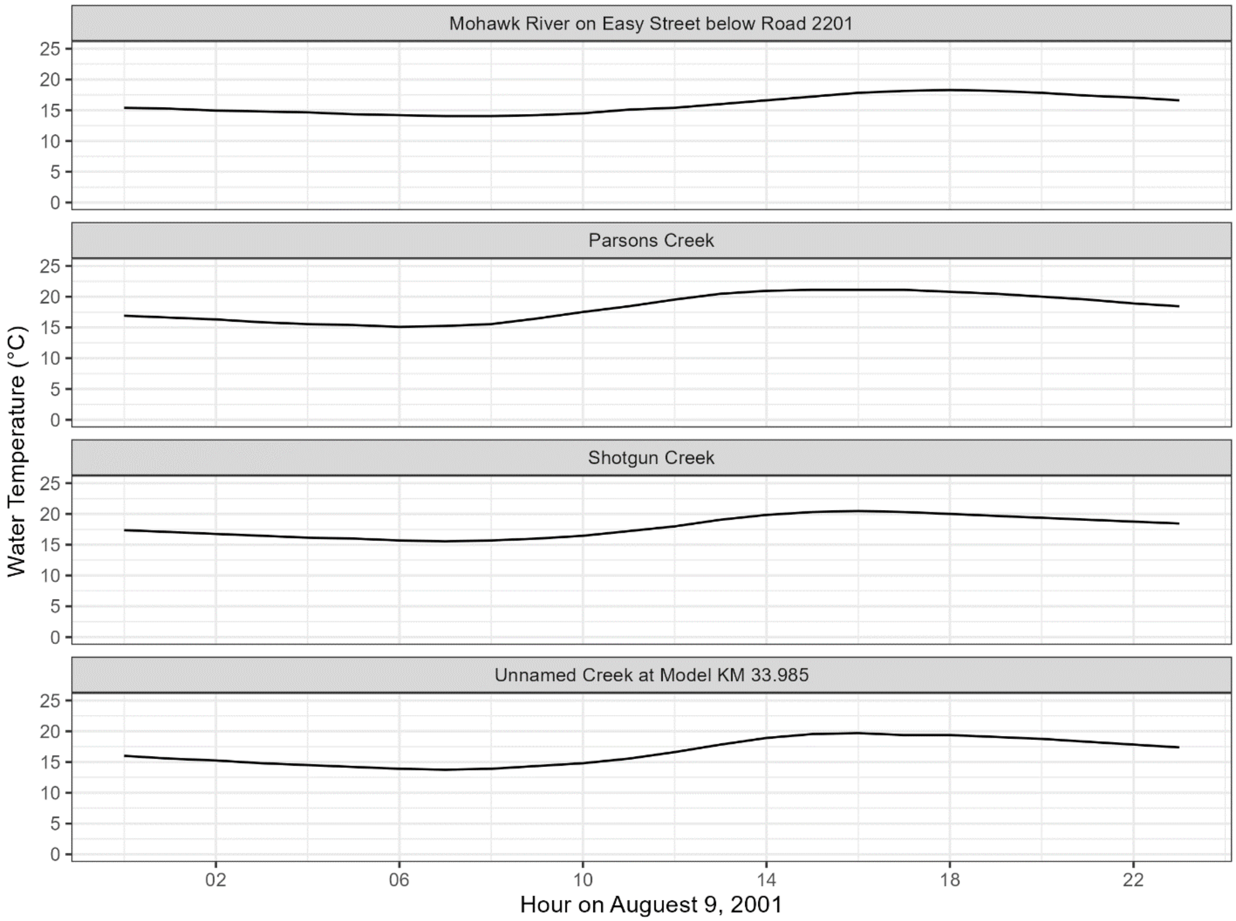
Table 3-57 and **Figure 3-182** document the water temperature inputs to the model at the boundary condition (Mohawk River on Easy Street below Road 2201) and tributaries.

Table 3-57: Boundary condition and tributary water temperature inputs to the Mohawk River model.

Model Location Name	Model Location (km)	Input Type	Data Source
Mohawk River on Easy Street below Road 2201	39.807	Boundary Condition	25608-ORDEQ
Unnamed Creek	33.985	Tributary	25506-ORDEQ
Shotgun Creek	25.420	Tributary	25504-ORDEQ
Cash Creek	24.354	Tributary	25503-ORDEQ
Mill Creek	22.159	Tributary	25501-ORDEQ
Cartwright Creek	19.202	Tributary	25500-ORDEQ
Parsons Creek	17.435	Tributary	25499-ORDEQ
McGowan Creek	12.253	Tributary	DEQ



(A)



(B)
Figure 3-182 (A) and (B): Boundary condition and tributary water temperature inputs to the Mohawk River model.

3.8.6 Flow inputs

Hourly stream flow time series data were used to support tributary and boundary condition model setup. **Figure 3-183** shows the locations of the various stream flow monitoring locations that were used for model setup or calibration.

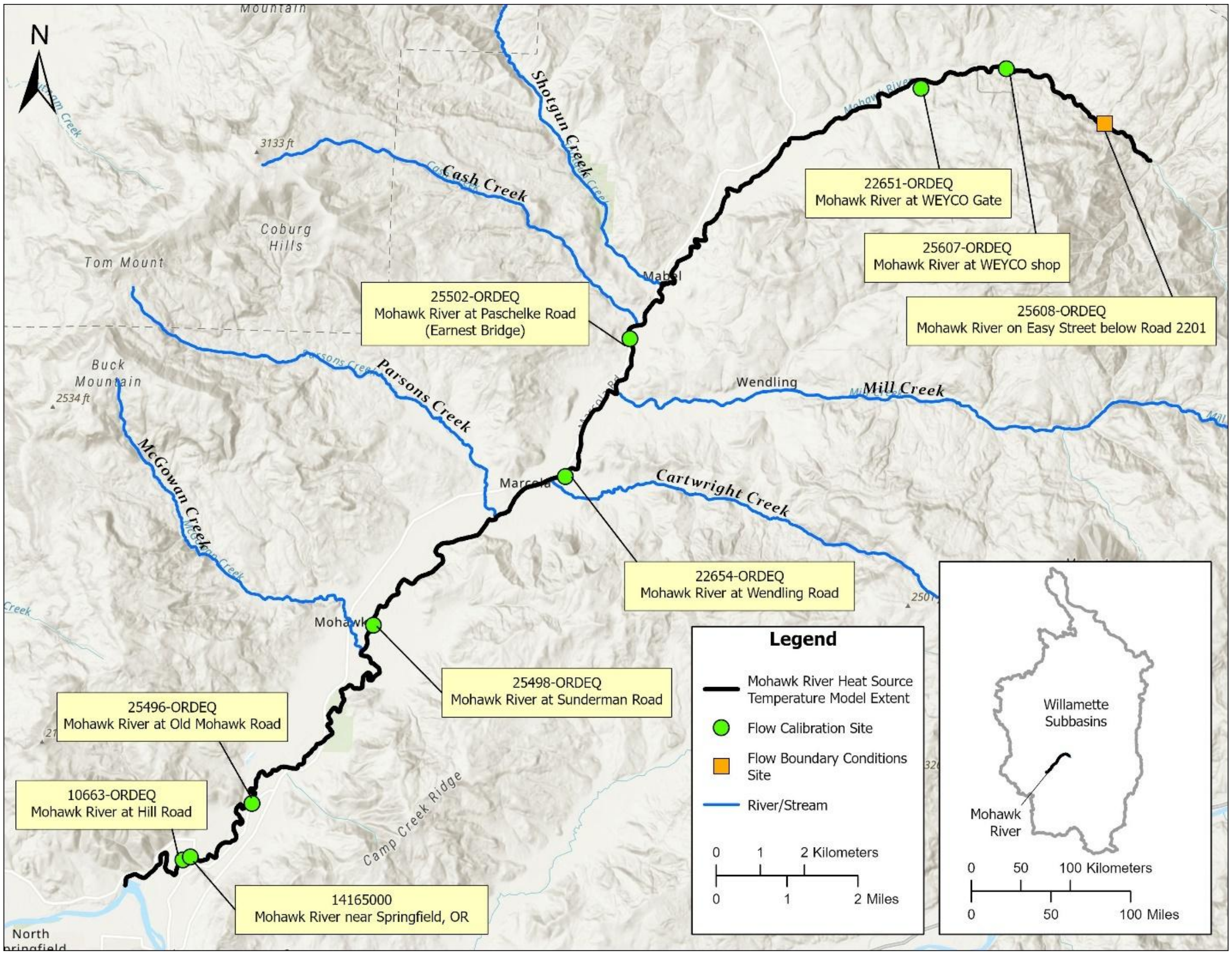


Figure 3-183: Flow monitoring locations used for the Mohawk River model setup and calibration.

The boundary condition and tributary flow inputs to the model is summarized in **Table 3-58**. **Figure 3-184** documents mainstem model flow setup.

Table 3-58: Boundary condition and tributary flow inputs to the Mohawk River model.

Model Location Name	Model Location (km)	Flow Rate (cms)	Input Type	Data Source
Mohawk River on Easy Street below Road 2201	39.807	0.3543	Boundary Condition	25608-ORDEQ
Unnamed Creek	33.985	0.0094	Tributary	DEQ
Shotgun Creek	25.420	0.1238	Tributary	DEQ
Cash Creek	24.354	0.0722	Tributary	DEQ
Mill Creek	22.159	0.1963	Tributary	DEQ
Cartwright Creek	19.202	0.0346	Tributary	DEQ
Parsons Creek	17.435	0.1434	Tributary	DEQ
McGowan Creek	12.253	0.0982	Tributary	DEQ

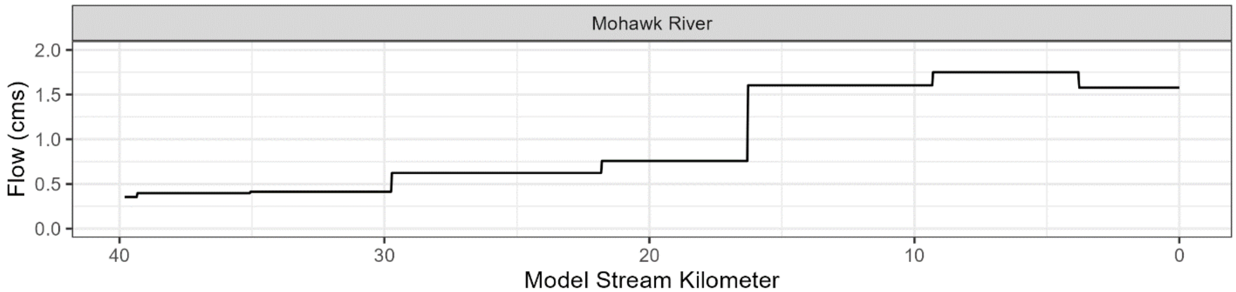


Figure 3-184: Boundary condition and mainstem flow inputs to the Mohawk River model.

3.8.7 Point source inputs

There are no point sources discharging within the model extent.

3.8.8 Landcover and topographic shade inputs

Average land cover height inputs and topographic shade angle inputs are shown in Figure 3-185 and Figure 3-186, respectively.

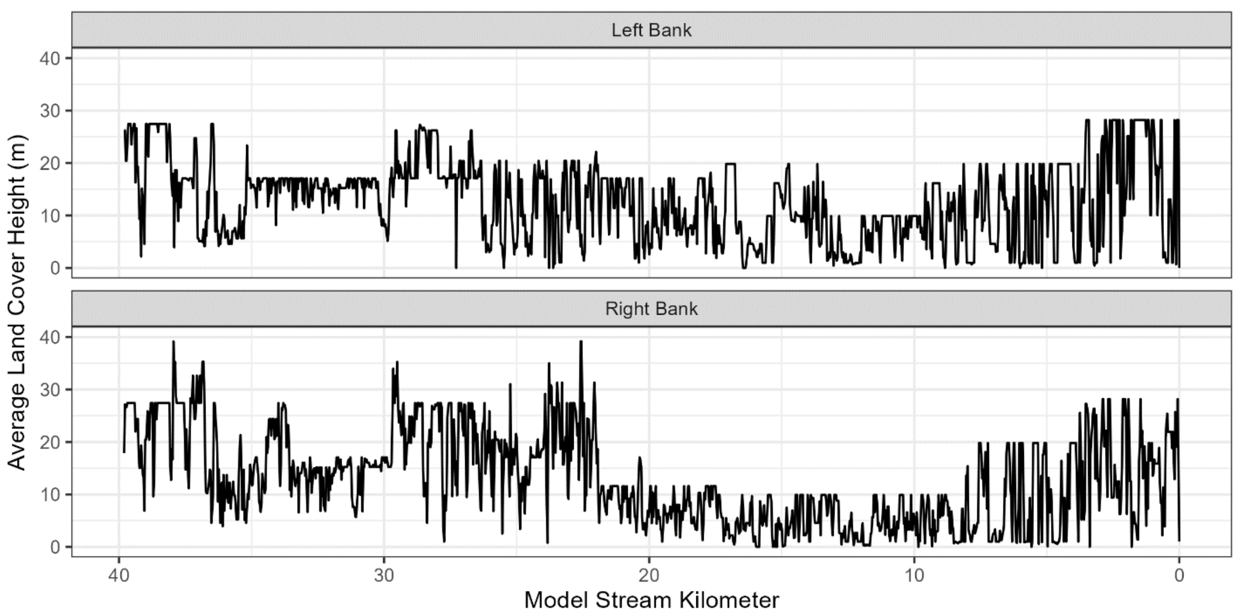


Figure 3-185: Average land cover height inputs to the Mohawk River model.

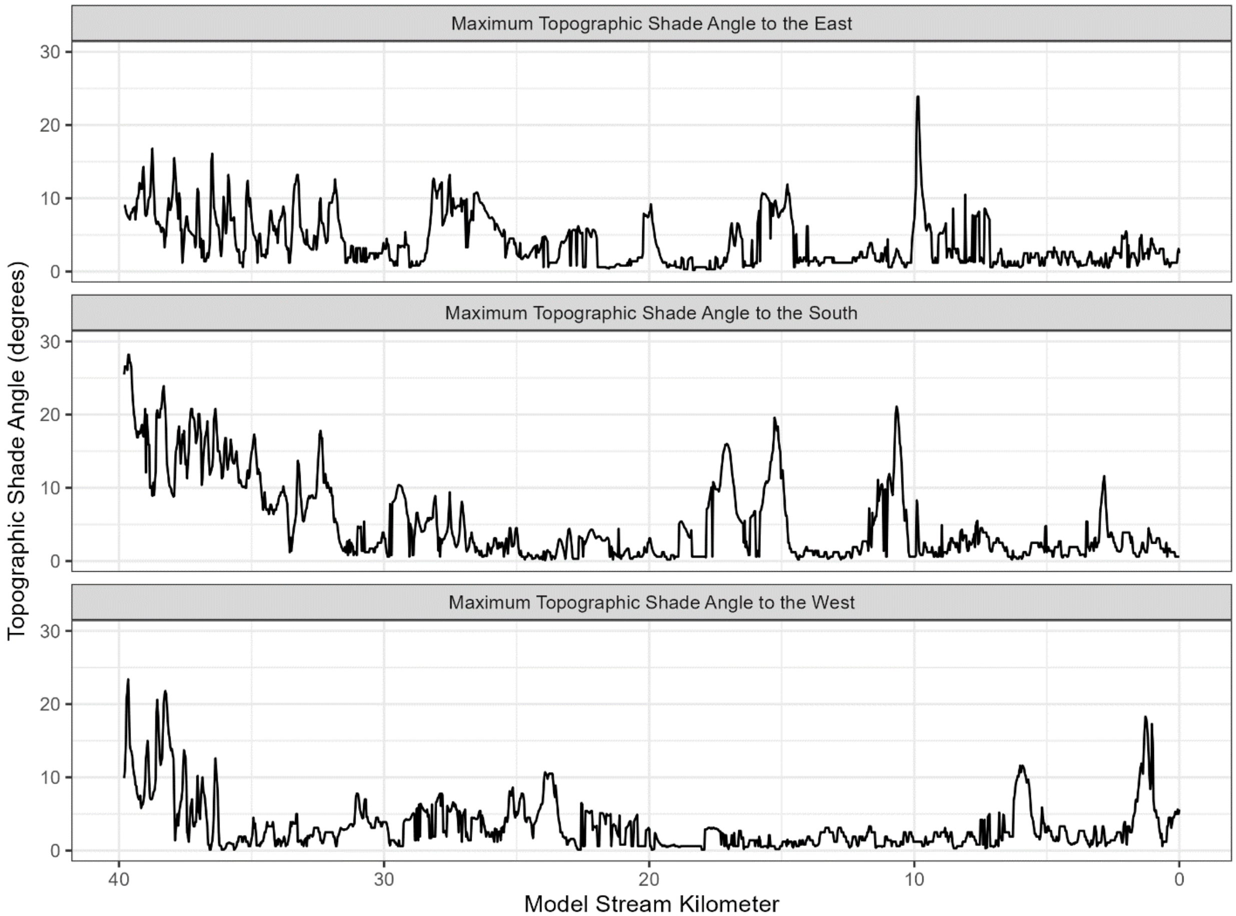


Figure 3-186: Topographic shade angle inputs to the Mohawk River model.

3.8.9 Channel setup

Channel setup for Mohawk River model is presented in **Figure 3-187**.

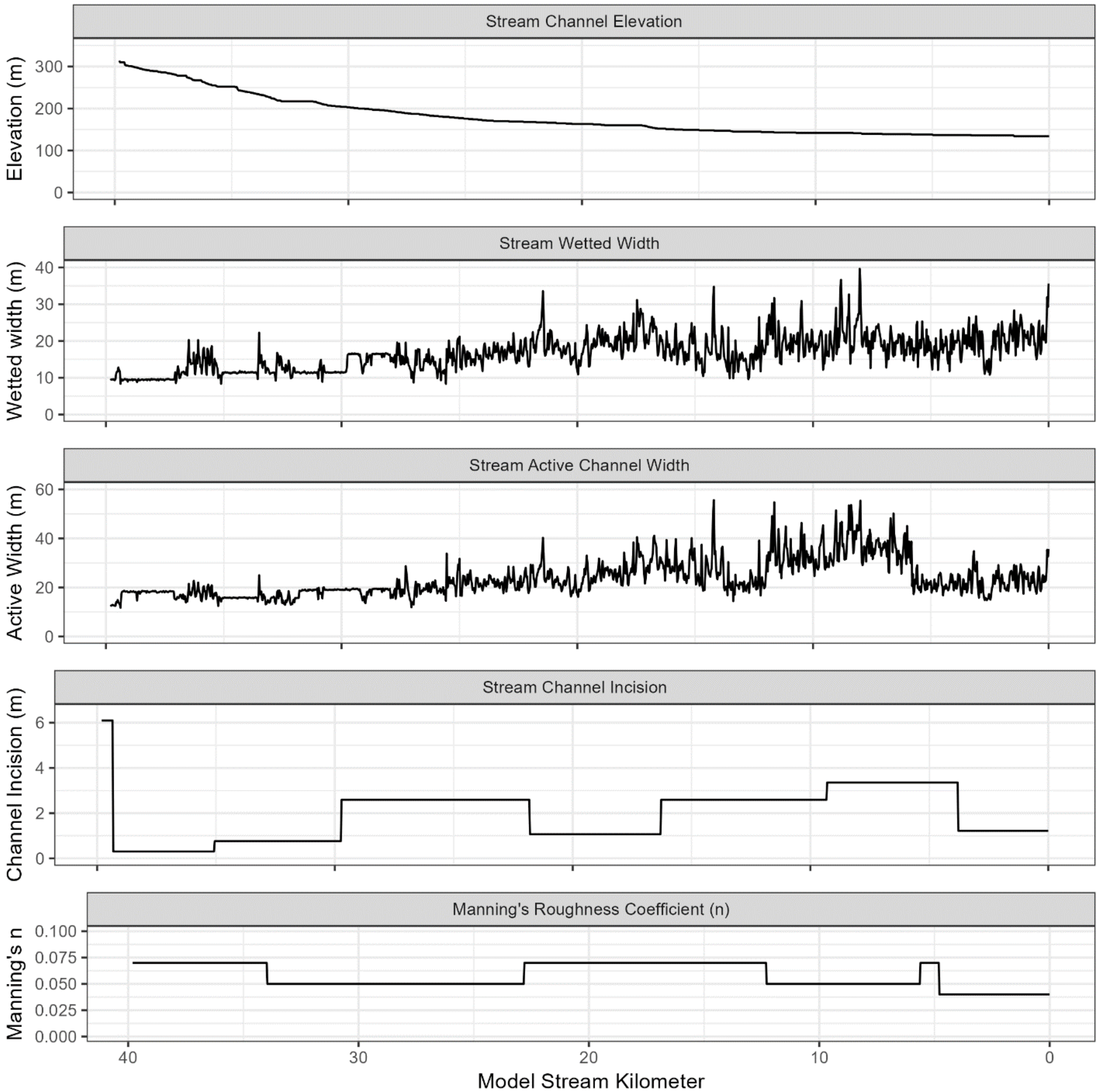


Figure 3-187: Channel setup in the Mohawk River model.

3.8.10 Calibration results

3.8.10.1 Temperature

The model was calibrated to the continuous temperature data collected from several locations along the Mohawk River. Results for goodness of fit statistics comparing field observed and model-predicted temperatures are summarized in **Table 3-59**. Observed and model-predicted hourly temperatures were plotted for the monitoring stations (**Figure 3-188** through **Figure 3-194**).

Table 3-59: Mohawk River water temperature goodness of fit statistics comparing field observed and model-predicted temperatures.

Monitoring Location	Model KM	Temperature Statistics	ME	MAE	RMSE	NSE	n
All Stations		Daily Maximum	-0.85	0.85	0.98	NA	7
All Stations		Hourly	-1.39	1.39	1.63	0.72	168
10663-ORDEQ: Mohawk River at Hill Road	2.5	Hourly	-1.84	1.84	2.07	-0.84	24
25496-ORDEQ: Mohawk River at Old Mohawk Road	5.5	Hourly	-2.15	2.15	2.31	-0.56	24
25498-ORDEQ: Mohawk River at Sunderman Road	13.1	Hourly	-1.65	1.65	1.8	-0.61	24
22654-ORDEQ: Mohawk River at Wendling Road	19.5	Hourly	-1.29	1.29	1.39	0.2	24
25502-ORDEQ: Mohawk River at Paschelke Road (Earnest Bridge)	23.7	Hourly	-1.27	1.27	1.44	0.4	24
22651-ORDEQ: Mohawk River at Weyco Gate	34.6	Hourly	-0.91	0.91	1.08	0.82	24
25607-ORDEQ: Mohawk River at WEYCO Shop	36.9	Hourly	-0.62	0.64	0.77	0.78	24

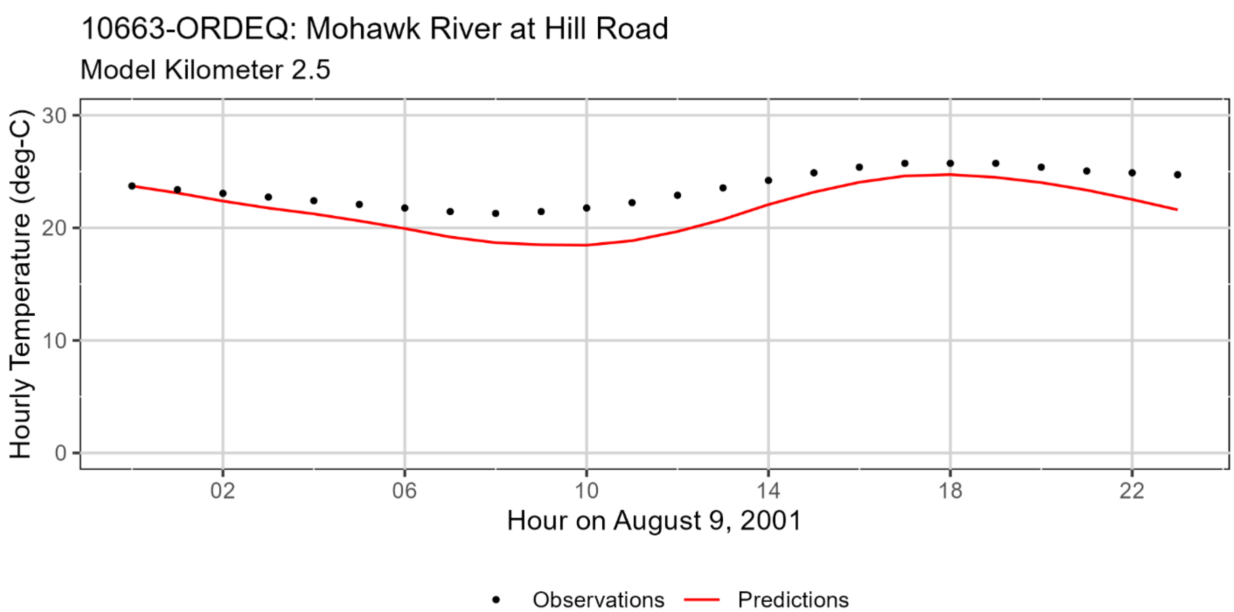


Figure 3-188: Mohawk River measured and model-predicted hourly temperatures at monitoring station 10663-ORDEQ.

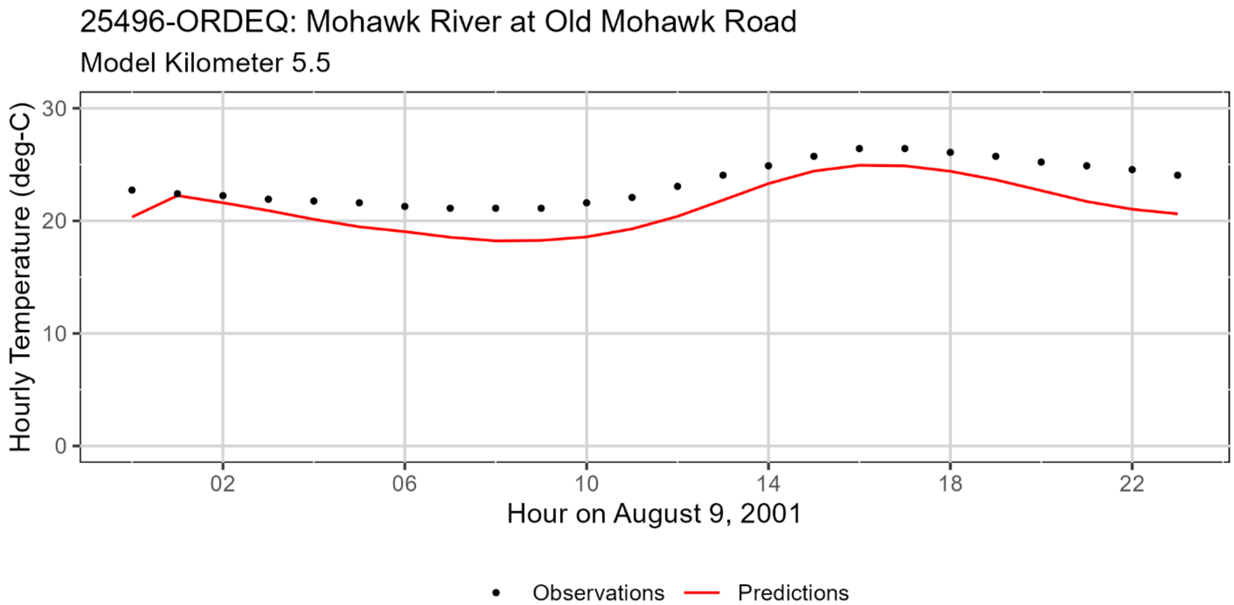


Figure 3-189: Mohawk River measured and model-predicted hourly temperatures at monitoring station 25496-ORDEQ.

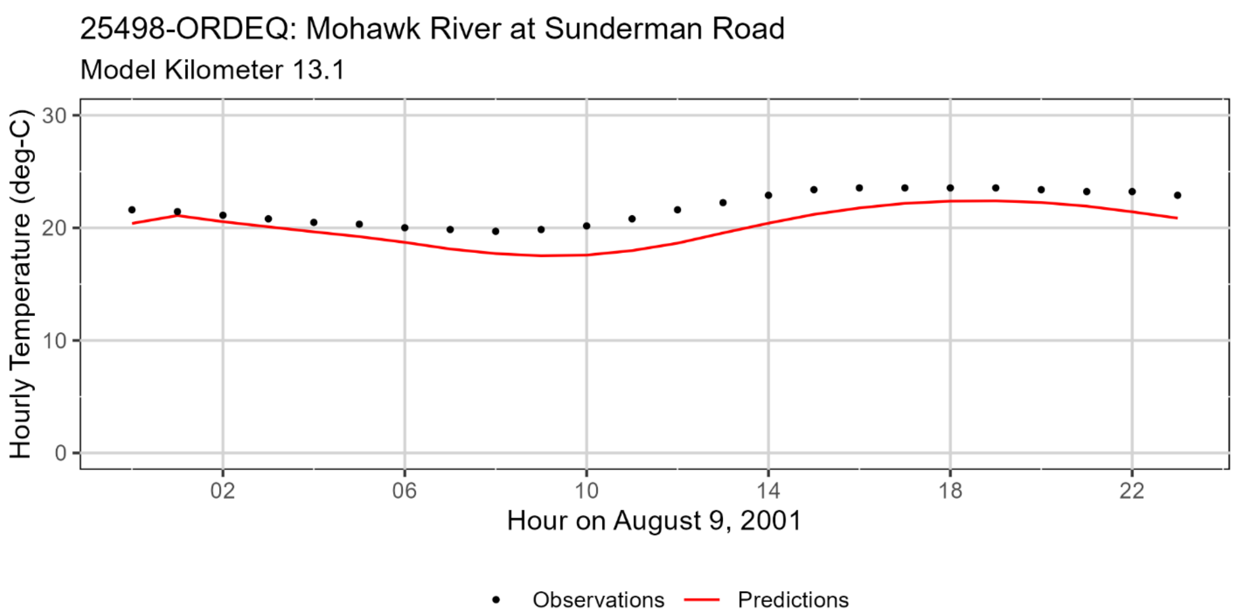


Figure 3-190: Mohawk River measured and model-predicted hourly temperatures at monitoring station 25498-ORDEQ.

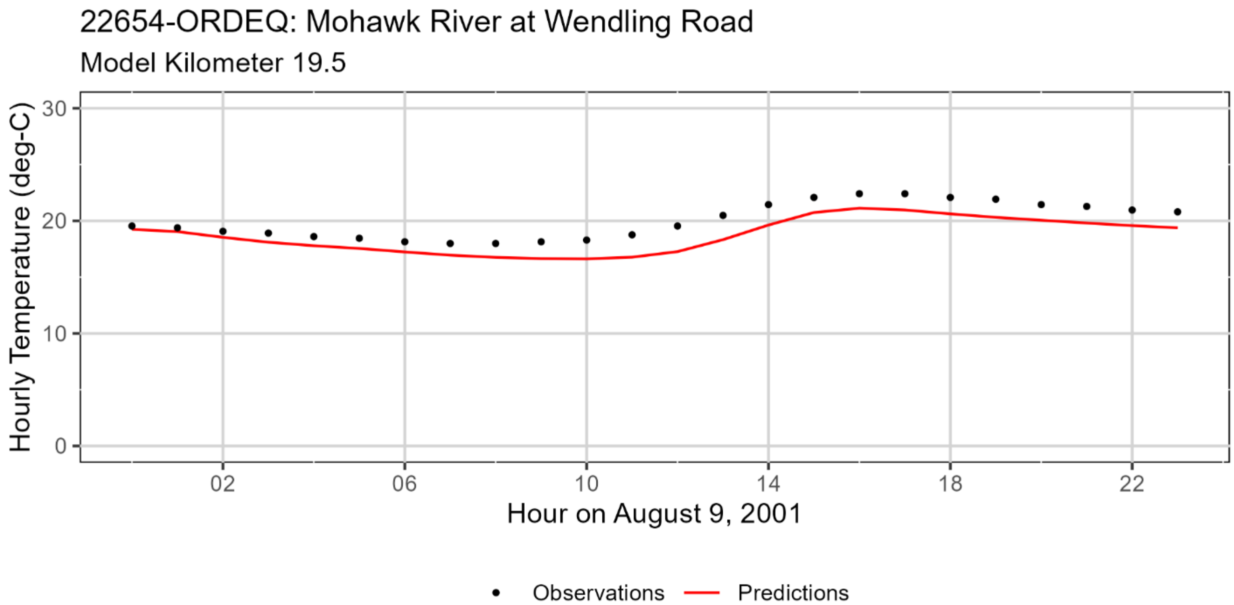


Figure 3-191: Mohawk River measured and model-predicted hourly temperatures at monitoring station 22654-ORDEQ.

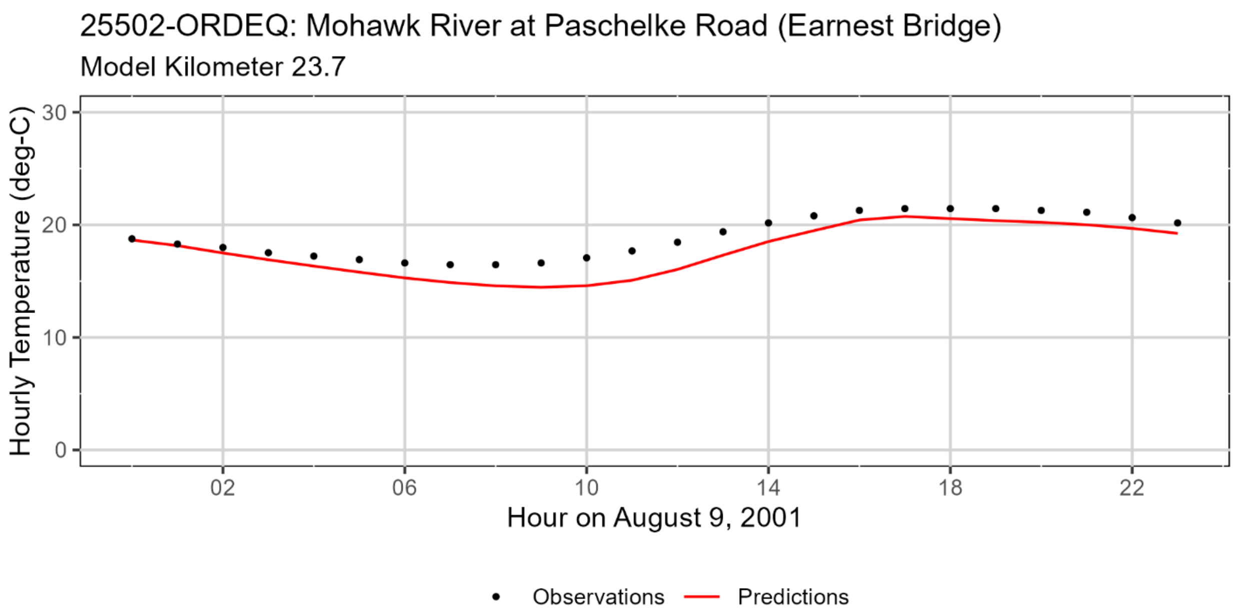


Figure 3-192: Mohawk River measured and model-predicted hourly temperatures at monitoring station 25502-ORDEQ.

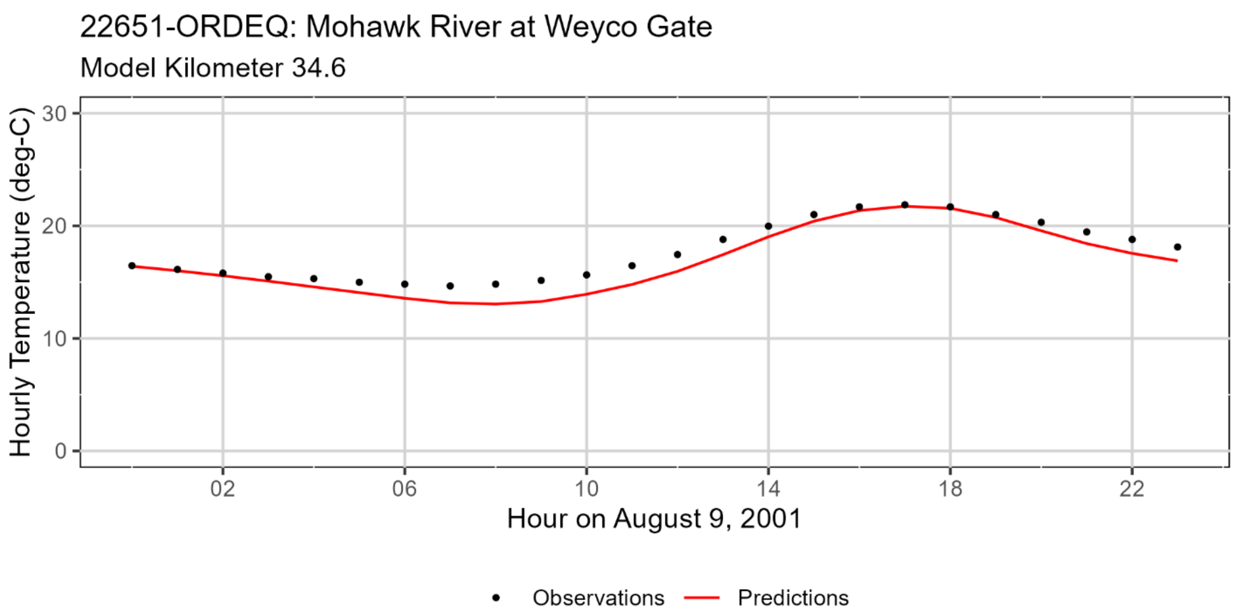


Figure 3-193: Mohawk River measured and model-predicted hourly temperatures at monitoring station 22651-ORDEQ.

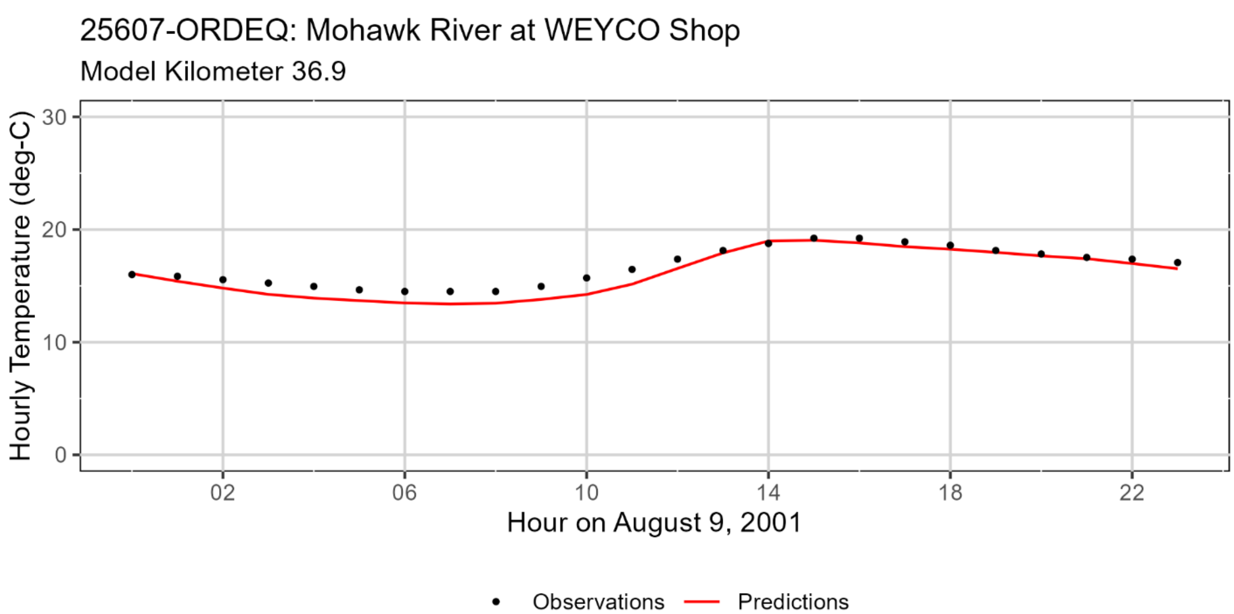


Figure 3-194: Mohawk River measured and model-predicted hourly temperatures at monitoring station 25607-ORDEQ.

3.8.10.2 Effective Shade

Observed and model-predicted effective shade data were plotted along the Mohawk River (**Figure 3-195**). The observed field data used for comparison is summarized in **Table 2-35**.

Results for goodness of fit statistics comparing field observed and model-predicted temperatures are summarized in **Table 3-60**.

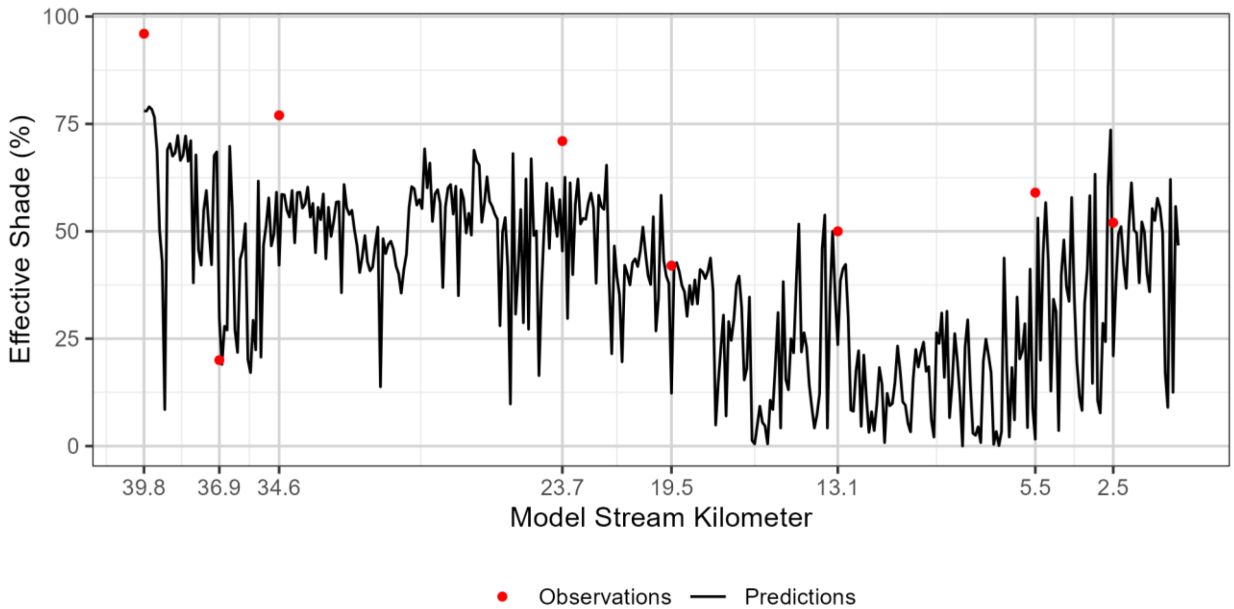


Figure 3-195: Mohawk River field observed and model-predicted effective shade.

Table 3-60: Mohawk River effective shade goodness of fit statistics comparing field observed and model values.

N	R^2	ME	MAE	RMSE
8	0.46	-26.65	29.1	31.88

3.8.10.3 Flow

A flow mass balance was completed to improve the calibration and match flows to the measured values. The observed flow used for comparison is summarized in

Table 3-61, which is plotted with the model flow in **Figure 3-196**. Results for goodness of fit statistics comparing field observed flow and the model flow are summarized in **Table 3-62**.

Table 3-61: Mohawk River stream flow rate measurements.

Monitoring Location	Model KM	Flow Statistics	Flow (cms)	Date
25608-ORDEQ: Mohawk River on Easy Street below Road 2201	39.8	Instantaneous	0.35	8/9/2001
25607-ORDEQ: Mohawk River at WEYCO shop	36.9	Instantaneous	0.40	8/9/2001
22651-ORDEQ: Mohawk River at WEYCO Gate	34.6	Instantaneous	0.41	8/9/2001
25502-ORDEQ: Mohawk River at Paschelke Road (Earnest Bridge)	23.7	Instantaneous	0.62	8/9/2001
22654-ORDEQ: Mohawk River at Wendling Road	19.5	Instantaneous	0.76	8/9/2001
25498-ORDEQ: Mohawk River at Sunderman Road	13.1	Instantaneous	1.6	8/9/2001
25496-ORDEQ: Mohawk River at Old Mohawk Road	5.5	Instantaneous	1.75	8/9/2001
14165000: Mohawk River near Springfield, OR	2.7	Daily mean	0.79	8/9/2001
10663-ORDEQ: Mohawk River at Hill Road	2.5	Instantaneous	1.58	8/9/2001

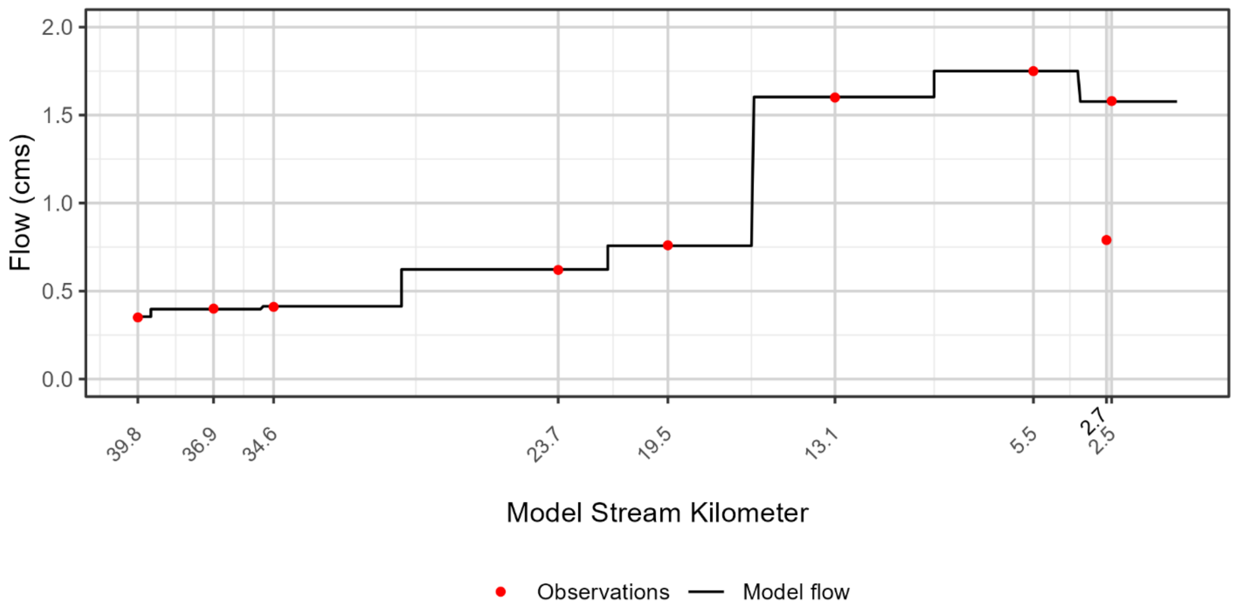


Figure 3-196: Mohawk River field observed and model flow rates.

Table 3-62: Mohawk River goodness of fit statistics comparing field observed and model flow rates.

N	R^2	ME	MAE	RMSE
9	0.81	0.09	0.09	0.26

3.8.10.4 Channel

Results comparing channels widths derived from GIS and modeling to those measured in the field are presented in **Figure 3-197**. Results shows channel widths only from streams modeled for temperature with Heat Source.

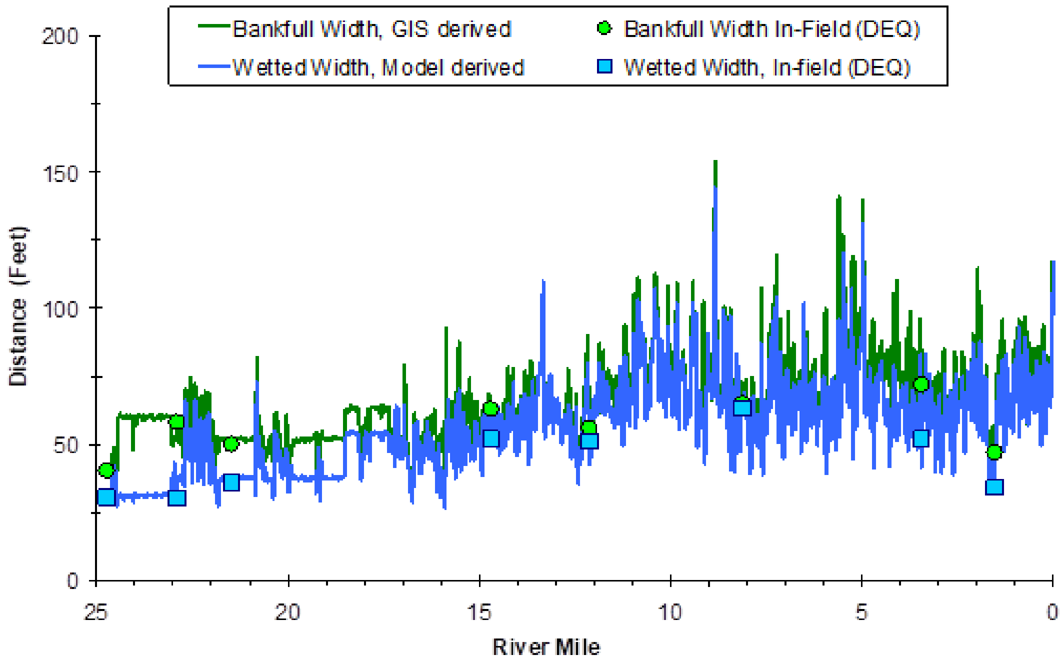


Figure 3-197: Mohawk River field observed and derived bankfull and wetted width.

3.9 McKenzie River: Upper

The McKenzie River: Upper model is a temperature model developed using Heat Source 6.0. The model was developed by DEQ.

3.9.1 Model extent

The extent of the model domain is the McKenzie River from Olallie Campground to the confluence of Quartz Creek (**Figure 3-198**).

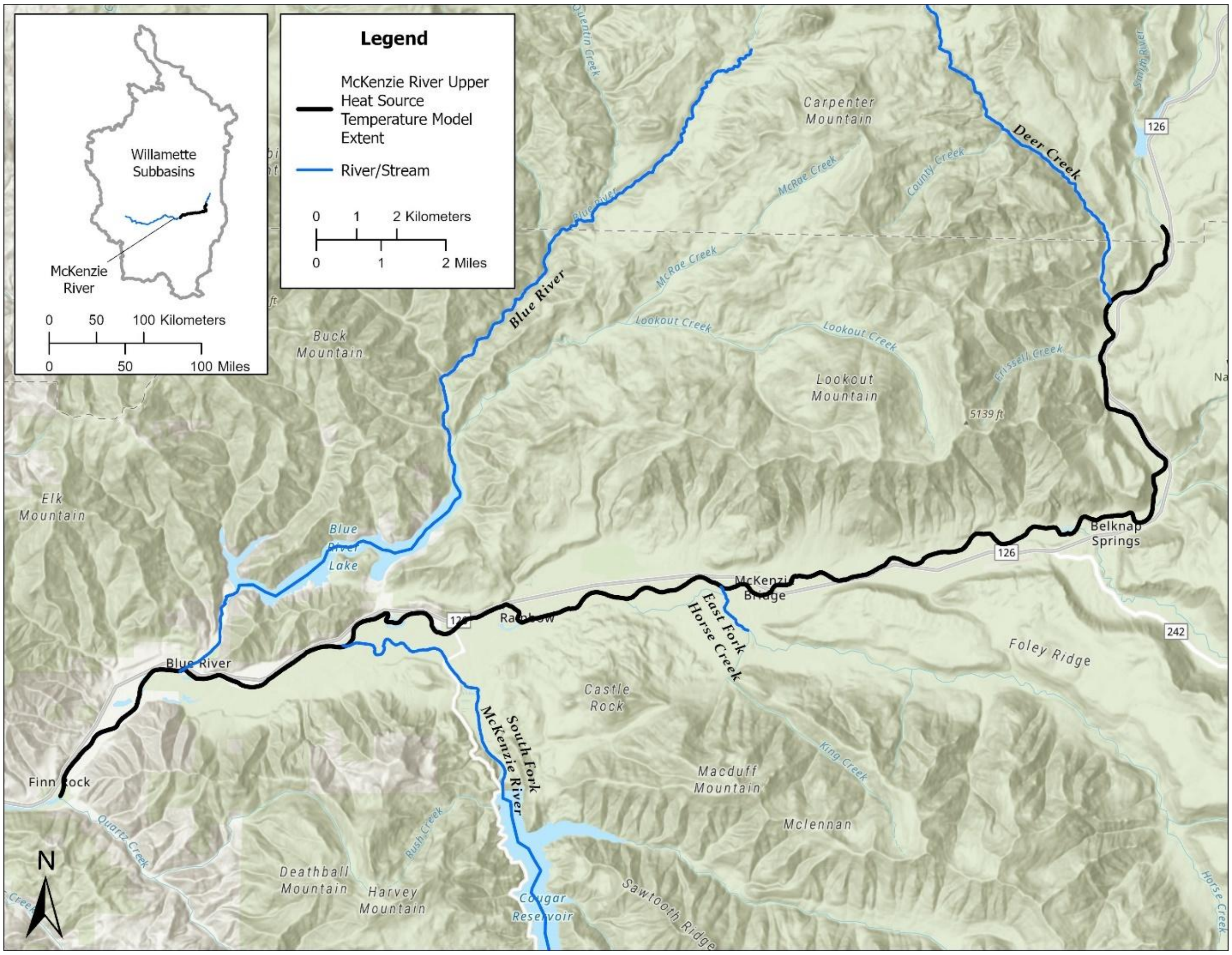


Figure 3-198: McKenzie River: Upper model extent.

3.9.2 Spatial and temporal resolution

The model input spatial resolution (*dx*) is 30 m. Outputs are generated every 100 m. The model time step (*dt*) is 1 minute and outputs are generated every hour.

3.9.3 Time frame of simulation

The model period is for a single day: September 03, 1999.

3.9.4 Meteorological inputs

The model was set up using hourly air temperature, relative humidity, and wind speed measurements from a DEQ site at the H.J. Andrews Experimental Forest Meteorological Station (Figure 3-199). Air temperature data were modified using the dry adiabatic lapse rate to adjust for differences in elevation between the measurement location and the model input location. Wind speeds were adjusted to improve the calibration by replacing zero values with 0.1 m/s.

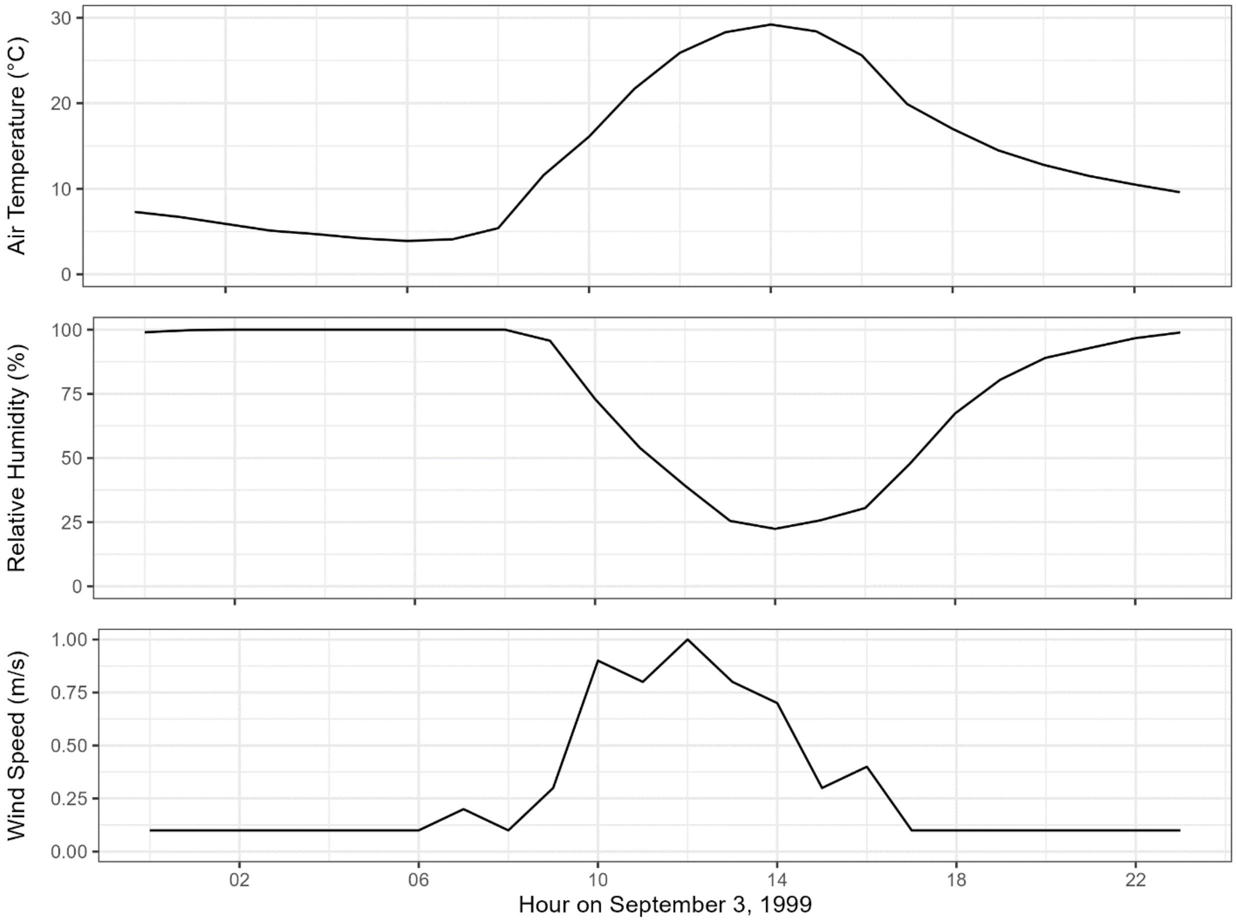


Figure 3-199: Meteorological inputs to the upper McKenzie River model.

3.9.5 Temperature inputs

Hourly water temperature time series data were used to support tributary and boundary condition model setup. **Figure 3-200** shows the locations of the various stream temperature monitoring locations that were used for model setup or calibration.

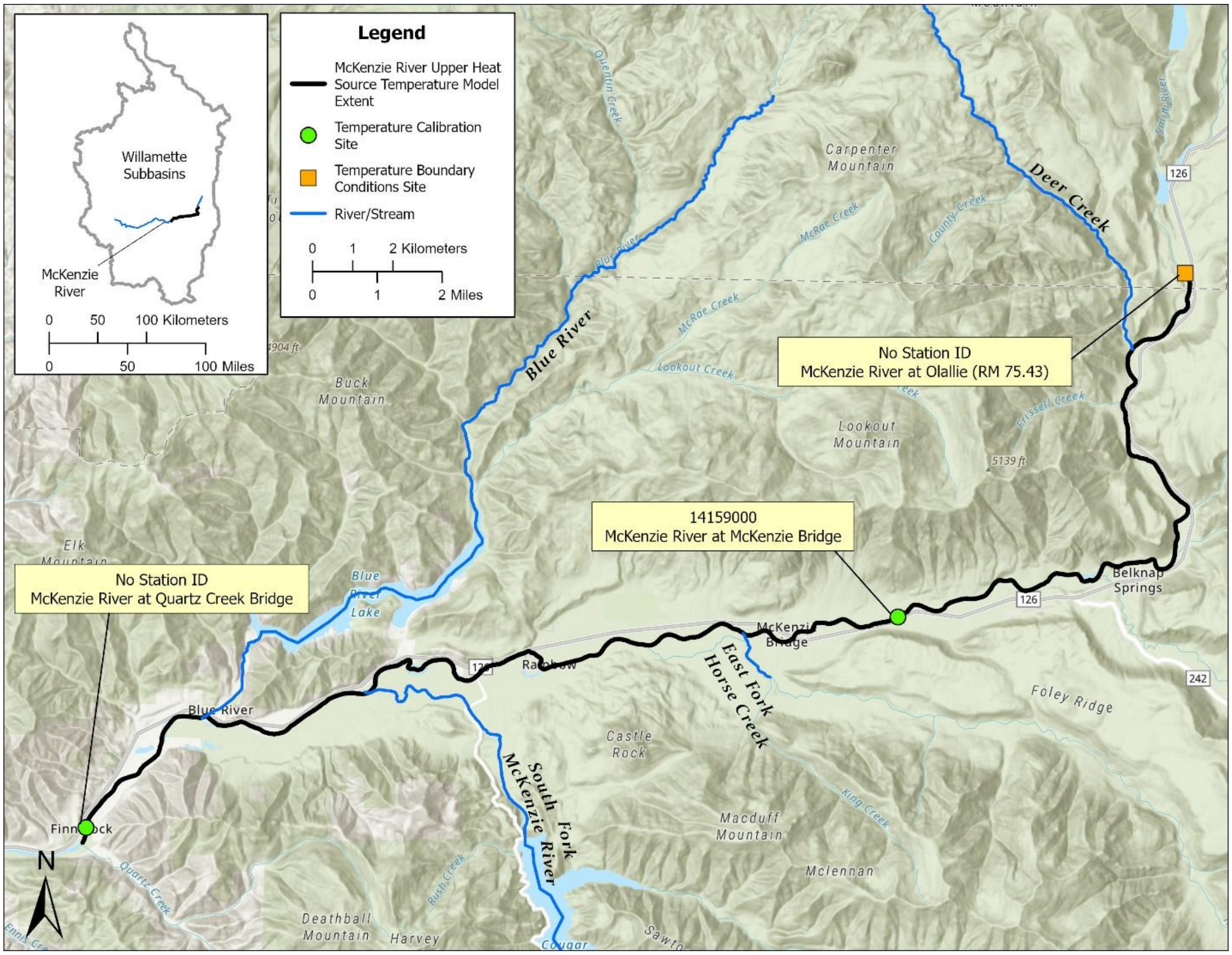


Figure 3-200: Temperature monitoring locations used for the upper McKenzie River model setup and calibration.

Table 3-63 and **Figure 3-201** document the water temperature inputs to the model at the boundary condition (McKenzie River at Olallie Campground), tributaries and groundwater accretion sites. **Table 2-39** lists TIR Temperatures on the upper McKenzie River.

Table 3-63: Boundary condition and tributary water temperature inputs to the upper McKenzie River model.

Model Location Name	Model Location (km)	Input Type	Data Source
McKenzie River at Olallie Campground	43.219	Boundary Condition	DEQ
Deer Creek	40.016	Tributary	DEQ
Groundwater (warm)	29.219	Tributary	Estimated 1 degree warmer than South Fork McKenzie temp data.
Groundwater (warm)	27.206	Tributary	Estimated 1 degree warmer than South Fork McKenzie temp data.
East Fork Horse Creek	21.106	Tributary	Estimated 1 degree warmer than South Fork McKenzie temp data.
South Fork McKenzie River	10.035	Tributary	DEQ
Blue River	4.362	Tributary	Estimated 1 degree warmer than South Fork McKenzie temp data.

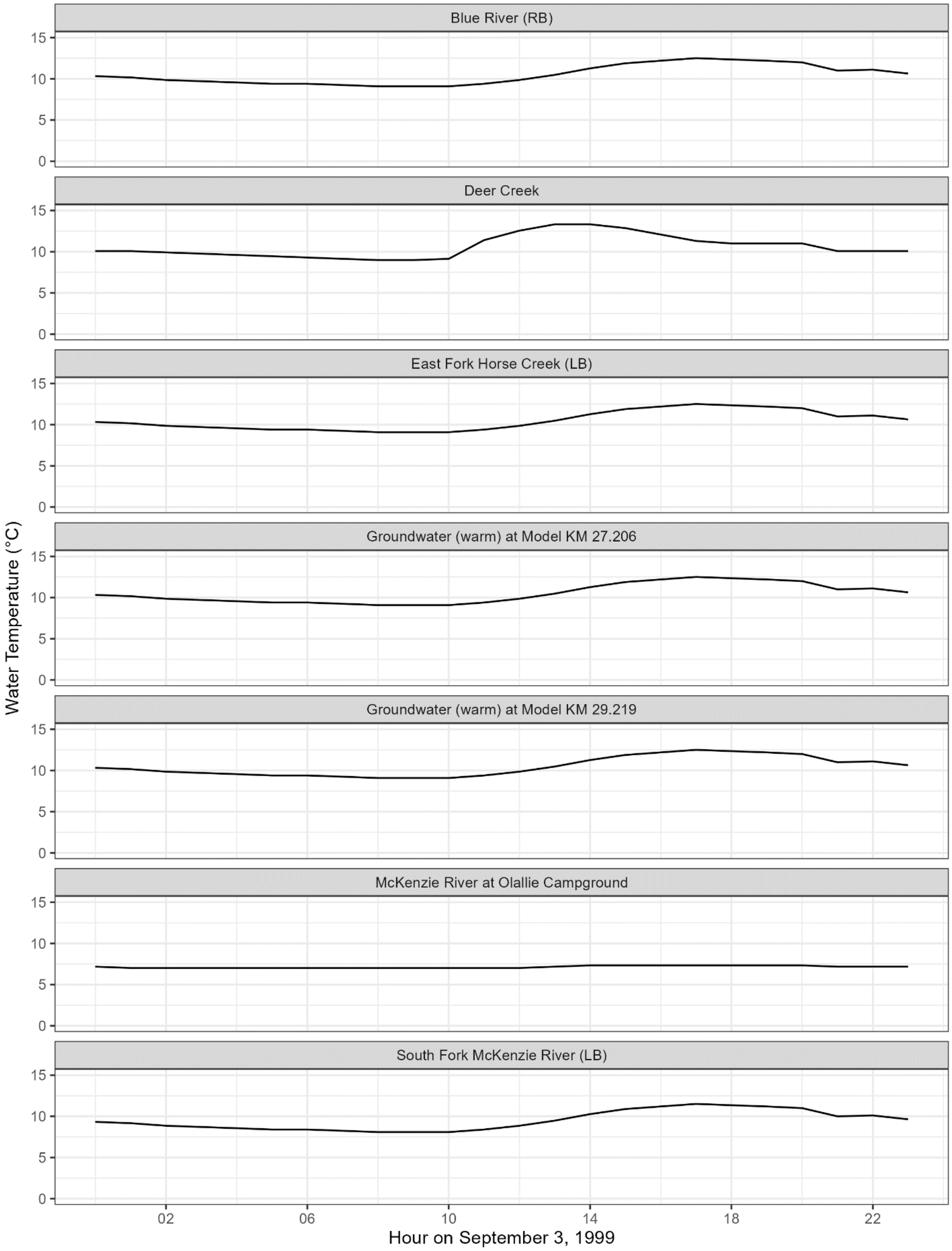


Figure 3-201: Boundary condition, ground water and tributary water temperature inputs to the upper McKenzie River model.

3.9.6 Flow inputs

Hourly stream flow time series data were used to support tributary and boundary condition model setup. **Figure 3-202** shows the locations of the various stream flow monitoring locations that were used for model setup or calibration.

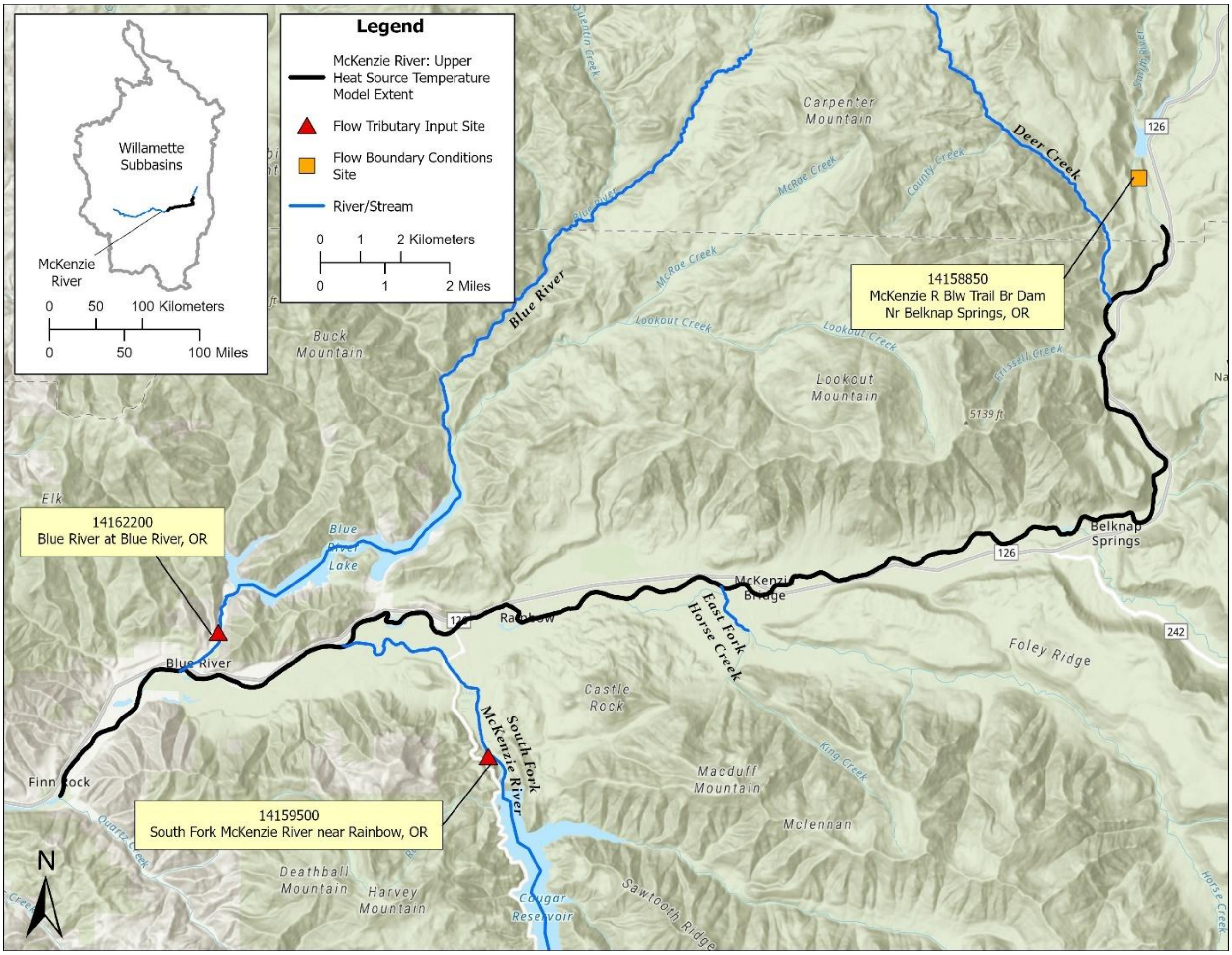


Figure 3-202: Flow monitoring locations used for the upper McKenzie River model setup and calibration.

The boundary condition and tributary flow inputs to the model is summarized in **Table 3-64**. **Figure 3-203** documents mainstem model flow setup.

Table 3-64: Boundary condition, tributary and groundwater flow inputs to the upper McKenzie River model.

Model Location Name	Model Location (km)	Flow Rate (cms)	Input Type	Data Source
McKenzie River at Olallie Campground	43.219	26.2214	Boundary Condition	USGS gage 14158850
Deer Creek	40.016	0.500	Tributary	Estimated using a flow mass balance based on TIR
Groundwater (warm)	29.219	3.500	Tributary	Estimated using a flow mass balance based on TIR
Groundwater (warm)	27.206	3.500	Tributary	Estimated using a flow mass balance based on TIR
East Fork Horse Creek	21.106	12.000	Tributary	USFS Measurement in Horse Creek
South Fork McKenzie River	10.035	20.900	Tributary	USGS gage 14159500
Blue River	4.362	1.500	Tributary	USGS gage 14162200

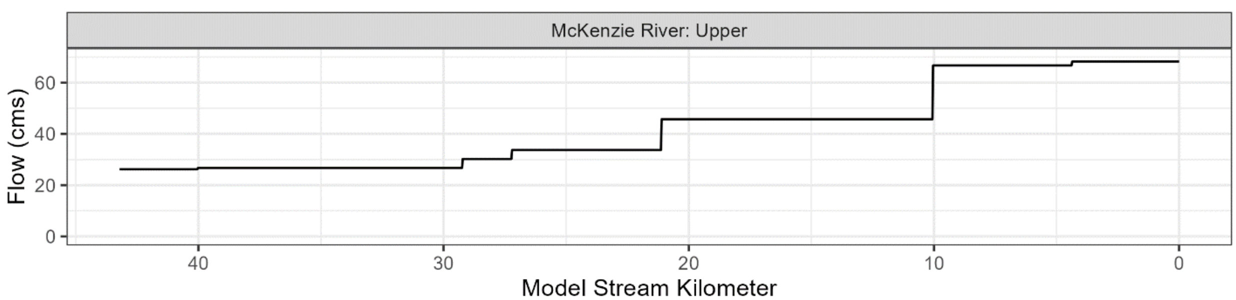


Figure 3-203: Boundary condition and mainstem flow inputs to the upper McKenzie River model.

3.9.7 Point source inputs

There is one permitted individual NPDES point source located just upstream of the model extent. The Eugene Water and Electric Board (EWEB) operates a hydroelectric project with two outfalls upstream of the model boundary condition (**Figure 3-204**). Due to the outfalls' proximity to the boundary condition location, stream temperature impacts from this point source are captured in the boundary condition input data.

While the EWEB point source was not included in the calibrated model due to its location upstream of the model boundary condition, it was added as an input to the Wasteload Allocations model scenario. For this scenario, it was assumed that the discharge was located at the boundary condition (McKenzie River at Olallie Campground).

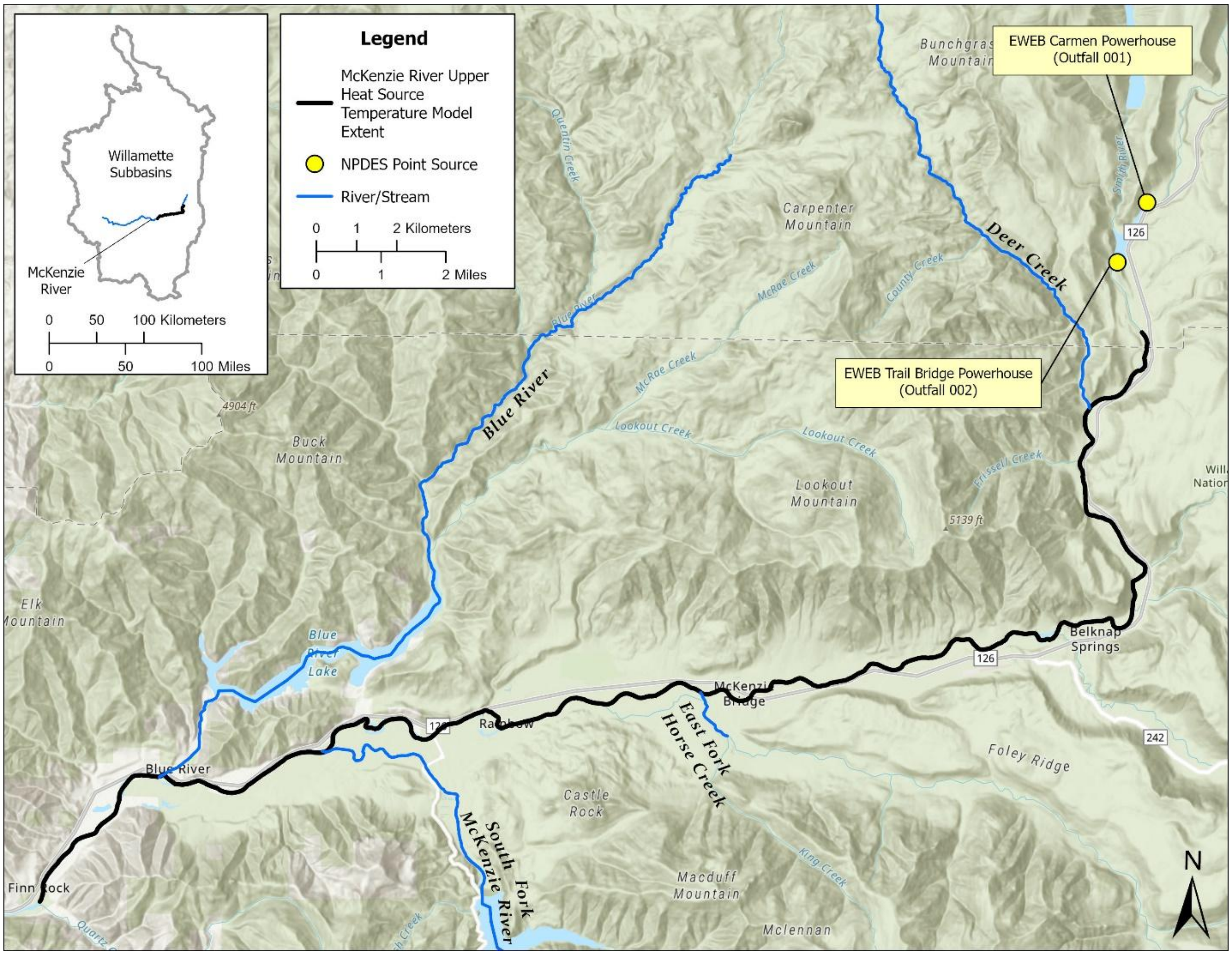


Figure 3-204: Locations of permitted individual NPDES point sources upstream of the upper McKenzie River model extent.

3.9.8 Landcover and topographic shade inputs

Average land cover height inputs and topographic shade angle inputs are shown in Figure 3-205 and Figure 3-206, respectively.

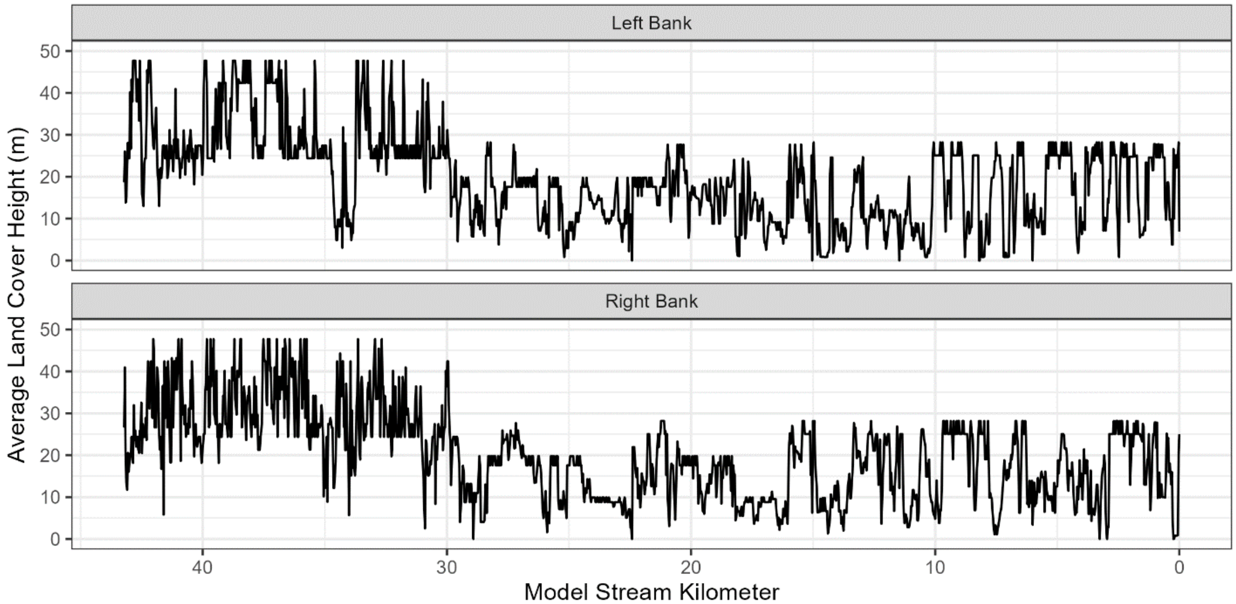


Figure 3-205: Average land cover height inputs to the upper McKenzie River model.

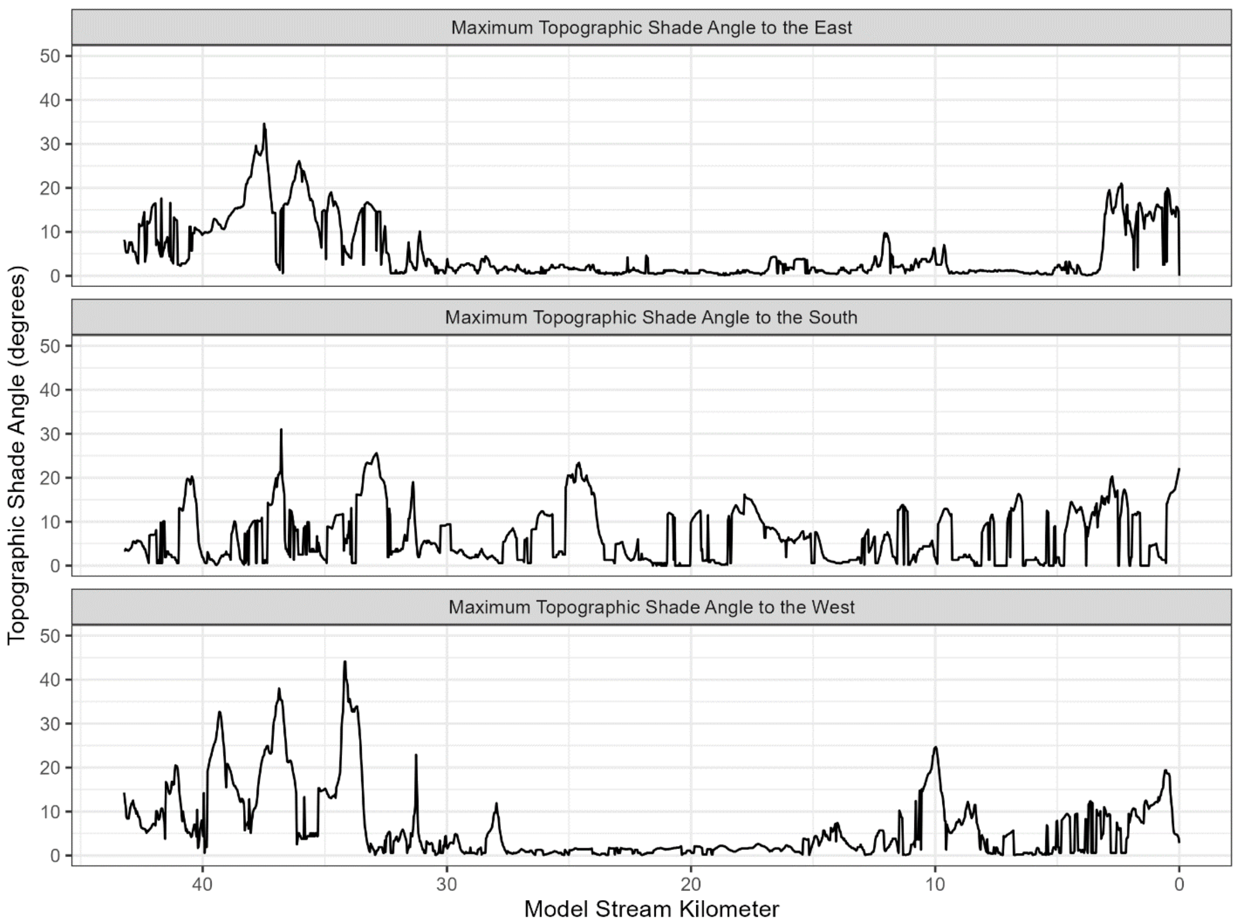


Figure 3-206: Topographic shade angle inputs to the upper McKenzie River model.

3.9.9 Channel setup

Channel setup for the Upper McKenzie River model is presented in **Figure 3-207**. For the field site at Trail Bridge Dam, one stream bank had a recorded incision of 30.5 m and the other had an incision of 0 m, and their average was used in the model. For all other sites, field-recorded incisions were used.

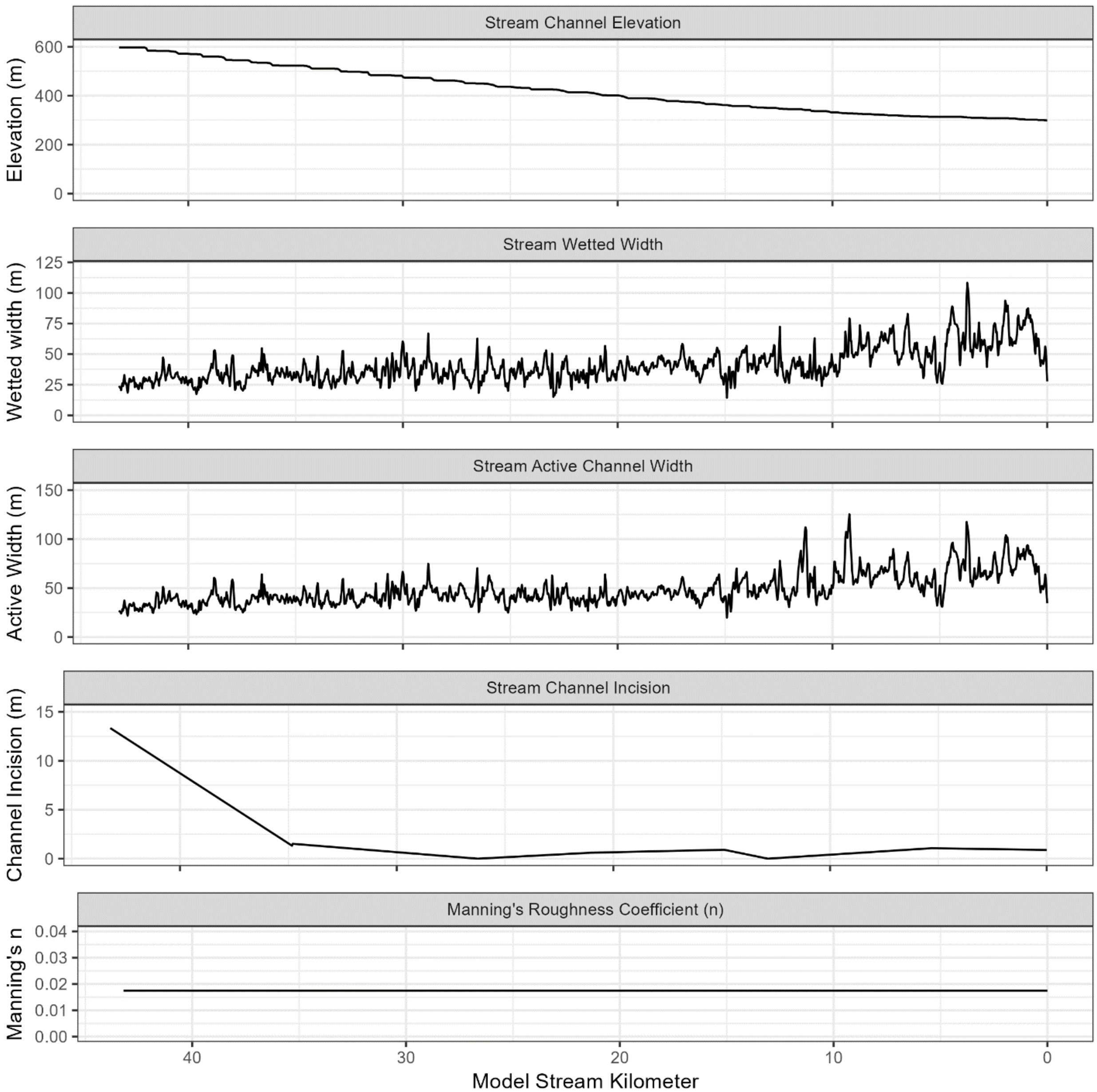


Figure 3-207: Channel setup in the upper McKenzie River model.

3.9.10 Calibration results

3.9.10.1 Temperature

The model was calibrated to the continuous temperature data collected from several locations along the Upper McKenzie River, as well as to the TIR data. Results for goodness of fit statistics comparing field observed and model-predicted temperatures are summarized in **Table 3-65**. Observed and model-predicted hourly temperatures were plotted for the monitoring stations (**Figure 3-208** through **Figure 3-210**). Modeling results comparing simulated current conditions for the upper McKenzie River to the TIR data are presented in **Figure 3-211**.

Much cooler temperatures were recorded at the Olallie Campground thermistor than along other reaches of the McKenzie River. The model stream temperature at Olallie was raised 1.5°C above the thermistor, resulting in a better match with FLIR data. FLIR data at Olallie were highly variable, ranging from 6 to 8°C, and 7°C was used in the model.

Inflows of groundwater were added to the model at two locations near Belknap Springs. These inflows are located along the boundary of two geologic regions, and fissures along this boundary have resulted in large hot springs. FLIR data indicate warmer temperatures at these locations as well.

FLIR data provided stream temperatures for four tributaries, including Deer Creek, Horse Creek, the South Fork McKenzie River, and the Blue River. The South Fork McKenzie and the Blue River have currently operating USGS gages, and the stream temperatures for Horse Creek and the Blue River were adjusted by comparing hourly temperatures to the South Fork McKenzie. Temperatures for these streams were raised by one degree at each hour (above the temperature for the corresponding hour for the South Fork McKenzie).

The majority of the flow for Horse Creek, which has three channels at the mouth, enters at the East Fork Horse River. The entire flow (from USFS flow meter measurements upstream) was input at that point in the McKenzie River.

Table 3-65: Upper McKenzie River water temperature goodness of fit statistics comparing field observed and model-predicted temperatures.

Monitoring Location	Model KM	Temperature Statistics	ME	MAE	RMSE	NSE	n
All Stations		Daily Maximum	-0.78	0.78	0.99	NA	3
All Stations		Hourly	-0.39	0.59	0.77	0.51	72
Model Node 4: McKenzie River at Quartz Creek Bridge	0.1	Hourly	0.02	0.39	0.5	0.81	24
14159000: McKenzie River at McKenzie Bridge	24.4	Hourly	-0.19	0.38	0.54	0.61	24
14158850: McKenzie River at Belknap Springs	33.5	Hourly	-0.99	0.99	1.11	-0.53	24
McKenzie River: Upper	Model extent		-0.2	0.3	0.38	0.89	433

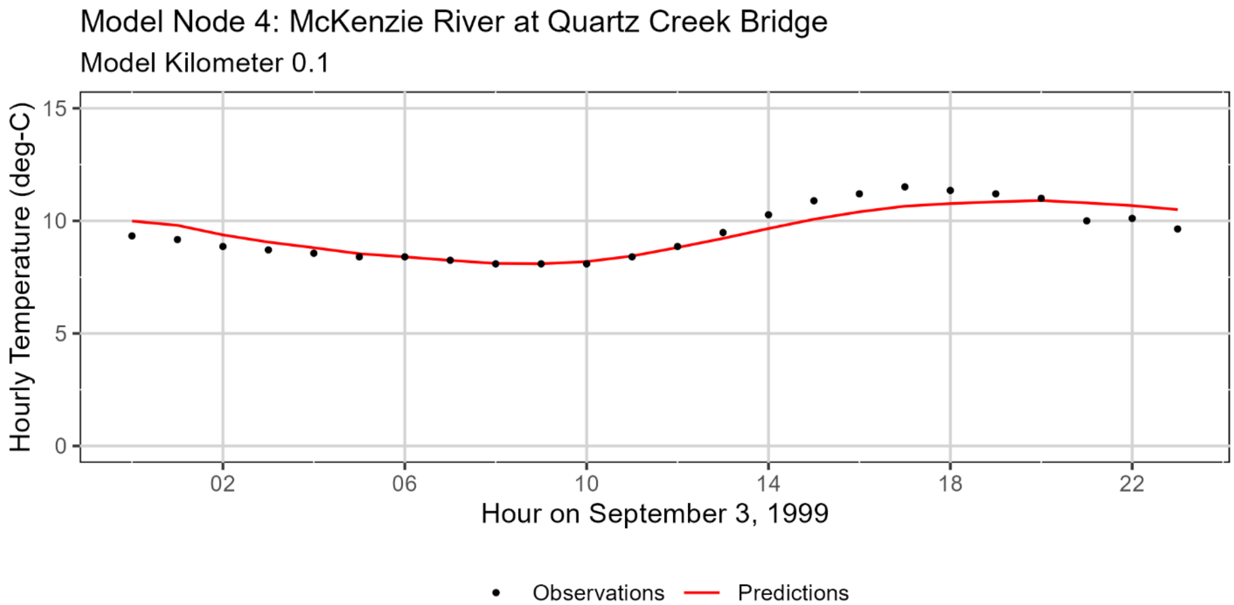


Figure 3-208: Upper McKenzie River measured and model-predicted hourly temperatures at Model Node 4.

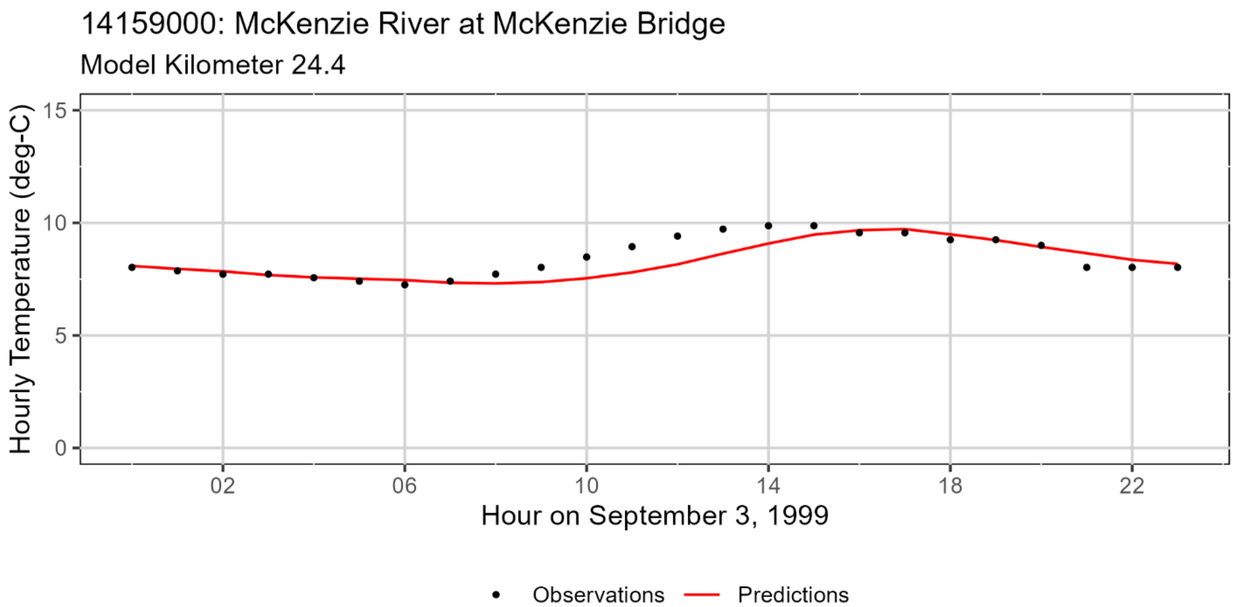


Figure 3-209: Upper McKenzie River measured and model-predicted hourly temperatures at monitoring station 14159000.

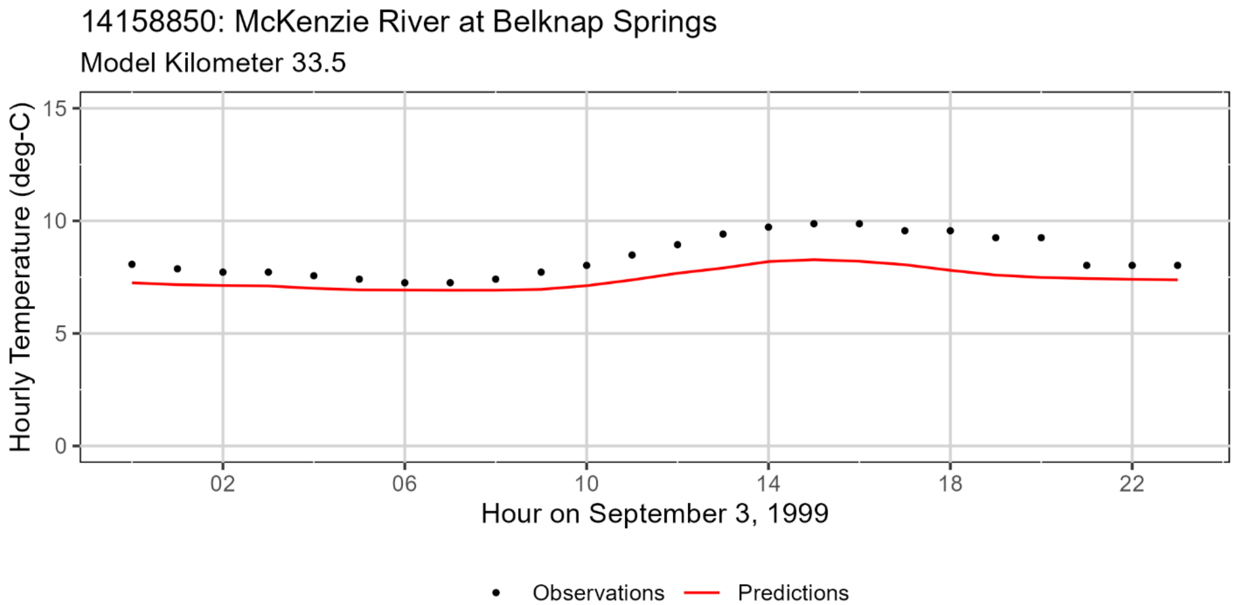


Figure 3-210: Upper McKenzie River measured and model-predicted hourly temperatures at monitoring station 14158850.

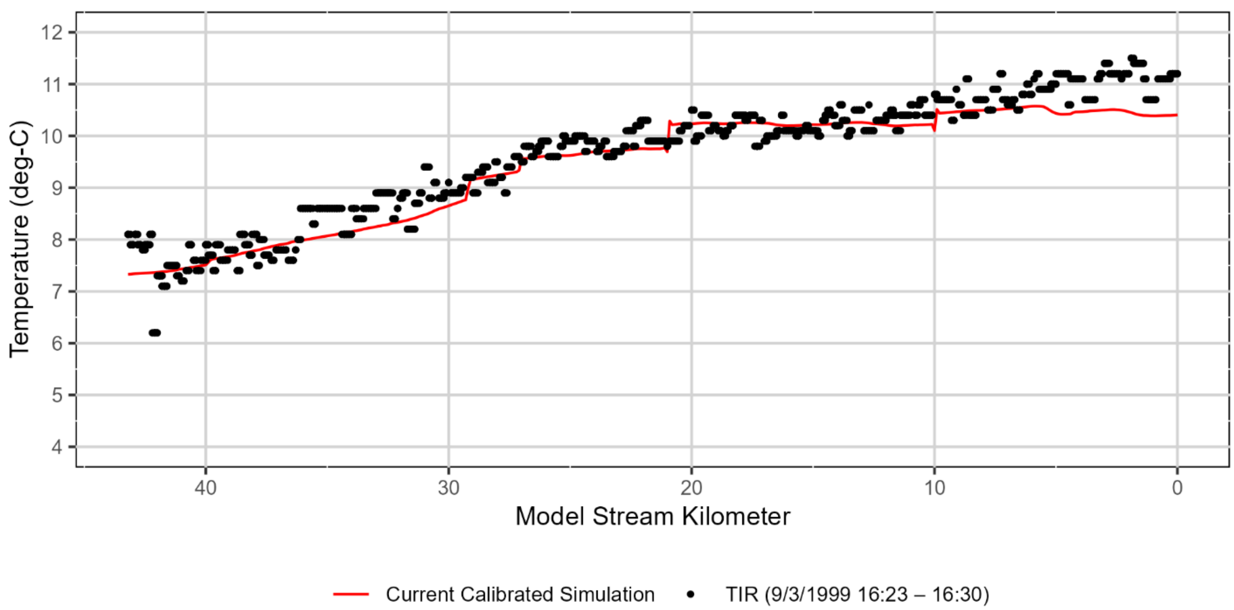


Figure 3-211: Upper McKenzie River TIR and simulated current stream temperatures.

3.9.10.2 Channel

Results comparing channel widths derived from GIS and modeling to those measured in the field are presented in **Figure 3-212**. Results shows channel widths only from streams modeled for temperature with Heat Source.

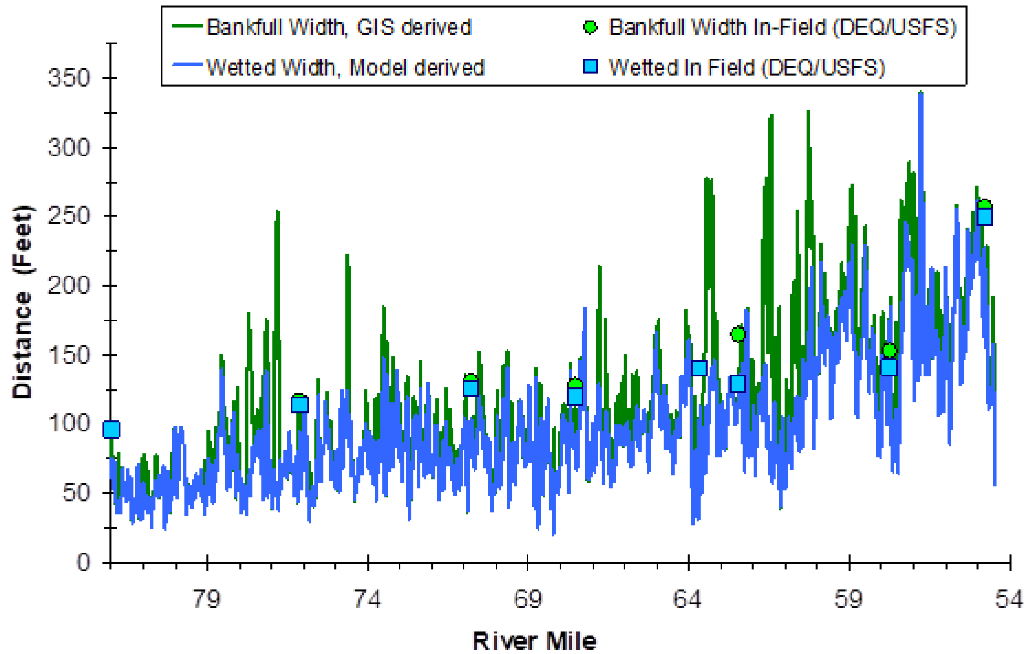


Figure 3-212: The upper McKenzie River field observed and derived bankfull and wetted width.

3.10 Coyote Creek

The Coyote Creek model is a temperature model developed using Heat Source 6.5.1. The model was developed by DEQ.

3.10.1 Model extent

The extent of the model domain is Coyote Creek from Gillespie Corners to the mouth at the Fern Ridge Reservoir (**Figure 3-213**).

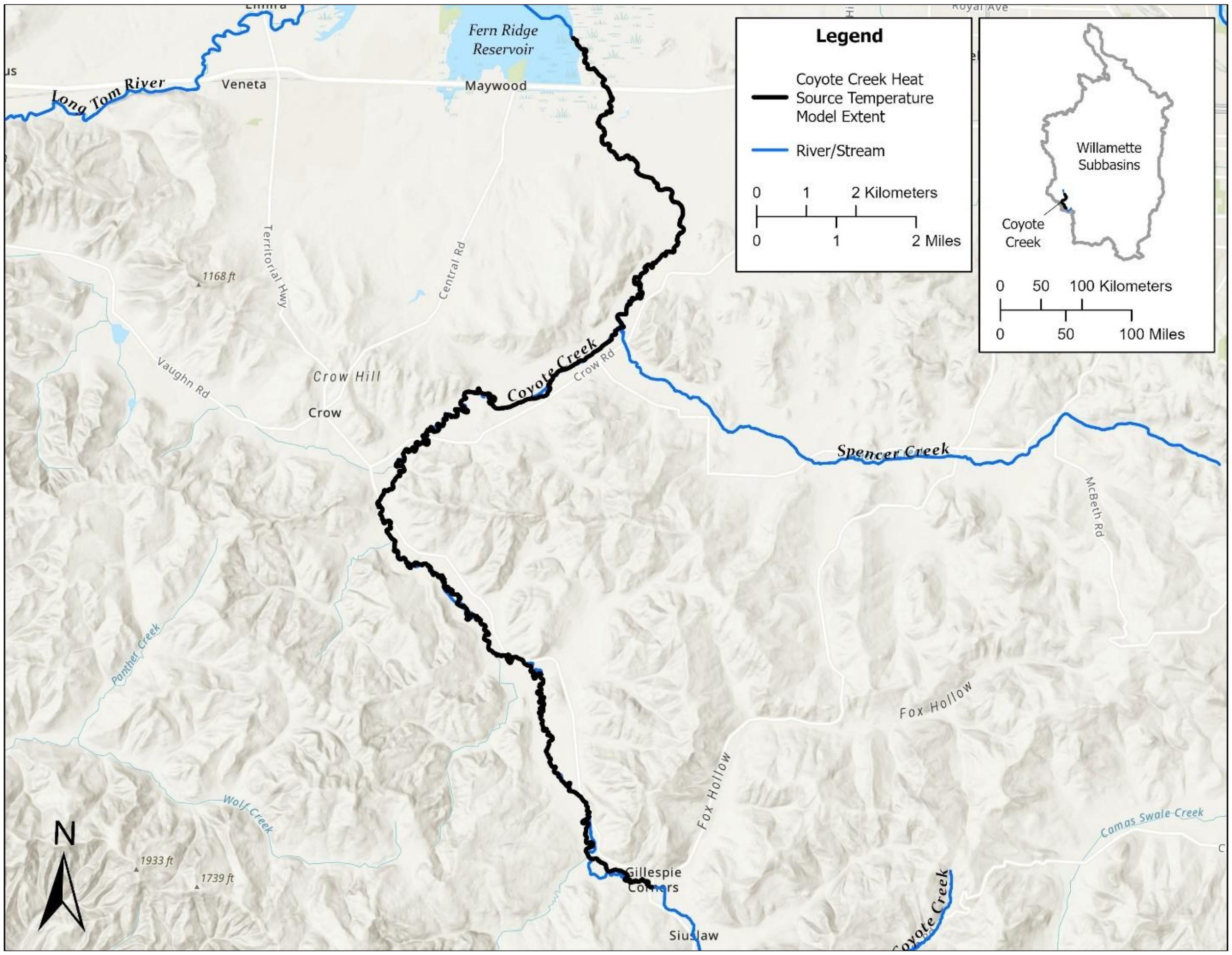


Figure 3-213: Coyote Creek temperature model extent.

3.10.2 Spatial and temporal resolution

The model input spatial resolution (*dx*) is 30 m. Outputs are generated every 100 m. The model time step (*dt*) is 1 minute and outputs are generated every hour.

3.10.3 Time frame of simulation

The model period is for a single day: July 11, 2001.

3.10.4 Meteorological inputs

The model was set up using hourly air temperature, relative humidity, and wind speed measurements from the NCDC site at the Eugene Airport (KEUG) (Figure 3-214). Air temperature data were modified using the dry adiabatic lapse rate to adjust for differences in elevation between the measurement location and the model input location. Wind speeds were adjusted to improve the calibration using wind-sheltering coefficients of 0.25 and 0.10 to represent differences in wind speed between the measurement location and above the stream within the riparian area (Table 3-66).

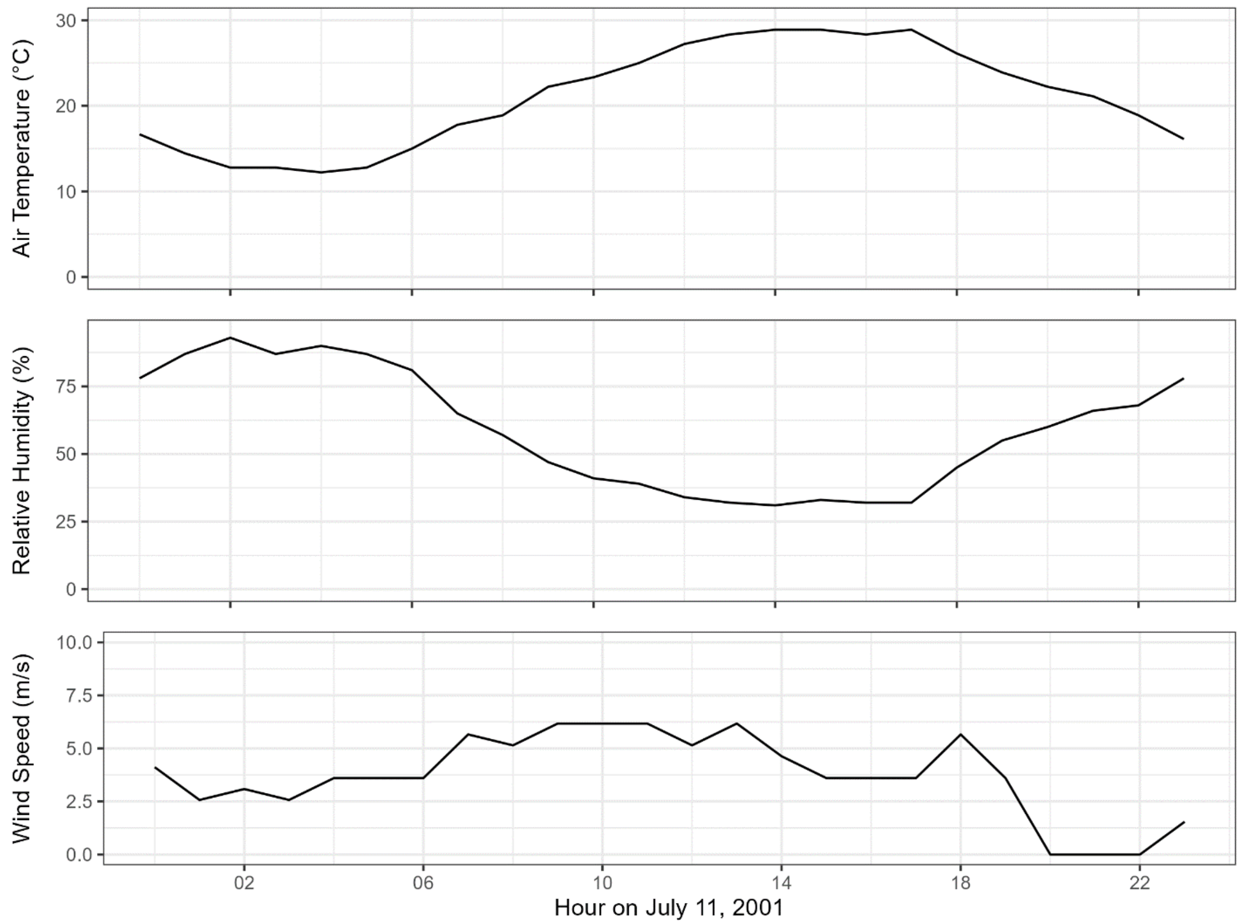


Figure 3-214: Meteorological inputs to the Coyote Creek model.

Table 3-66: Wind-sheltering coefficient used in the Coyote Creek model.

Model Location Name	Model Location (km)	Wind Sheltering Coefficient
Coyote Creek at Gillespie	36.393	0.25
Coyote Creek at Powell Rd	32.461	0.25
Coyote Creek Crow Rd	17.252	0.25
Coyote Creek Petzold Rd	10.79	0.1
Coyote Creek Centrell Rd	3.475	0.1

3.10.5 Temperature inputs

Hourly water temperature time series data were used to support tributary and boundary condition model setup. **Figure 3-215** shows the locations of the various stream temperature monitoring locations that were used for model setup or calibration.

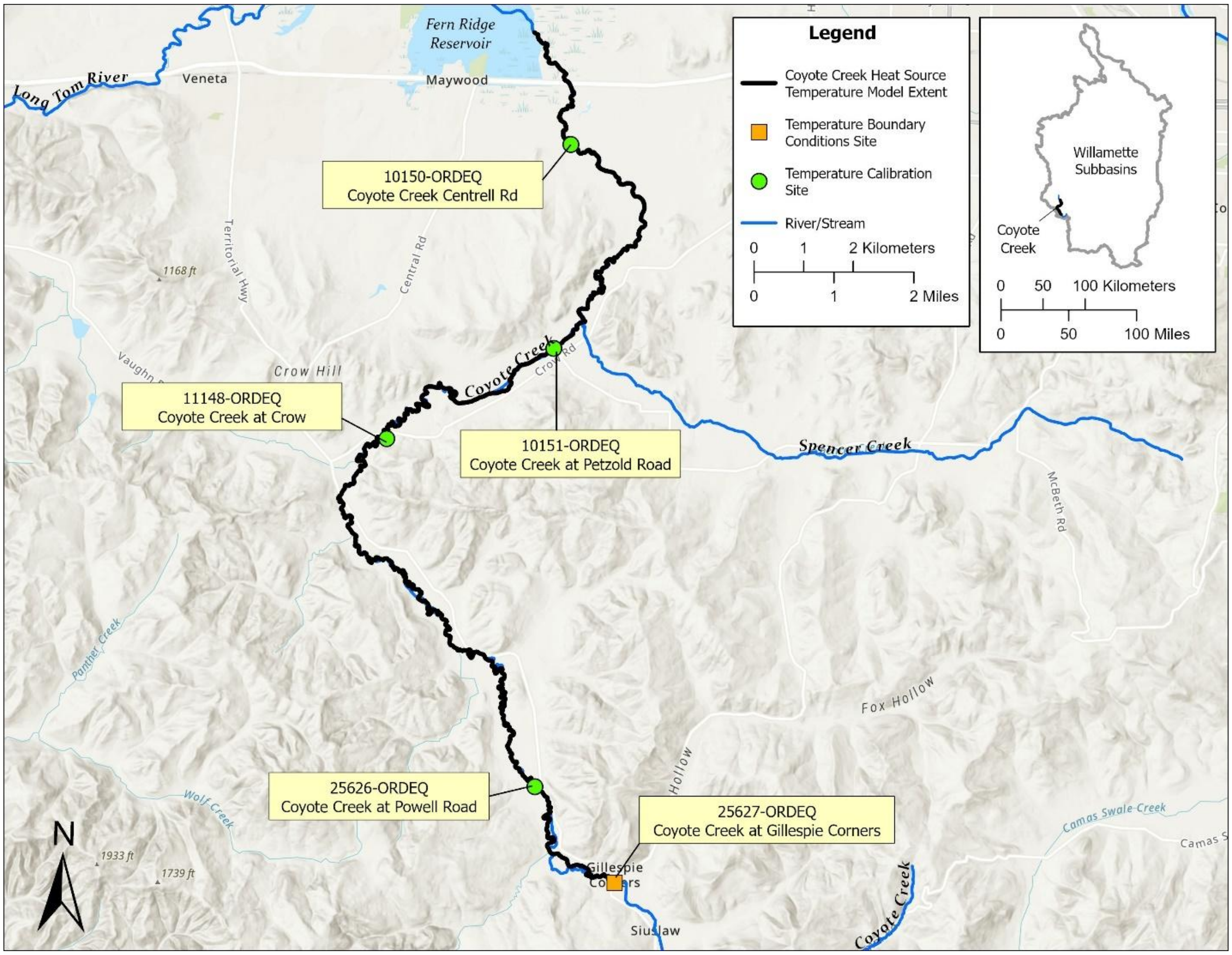


Figure 3-215: Temperature monitoring locations used for the Coyote Creek model setup and calibration.

Table 3-67 and **Figure 3-216** document the water temperature inputs to the model at the boundary condition (Coyote Creek at Gillespie Corners) and tributaries.

Table 3-67: Boundary condition and tributary water temperature inputs to the Coyote Creek model.

Model Location Name	Model Location (km)	Input Type	Data Source
Coyote Creek at Gillespie Corners	36.393	Boundary Condition	25627-ORDEQ
Spencer Creek	10.028	Tributary	DEQ*

* Data source unclear, assumed to be derived

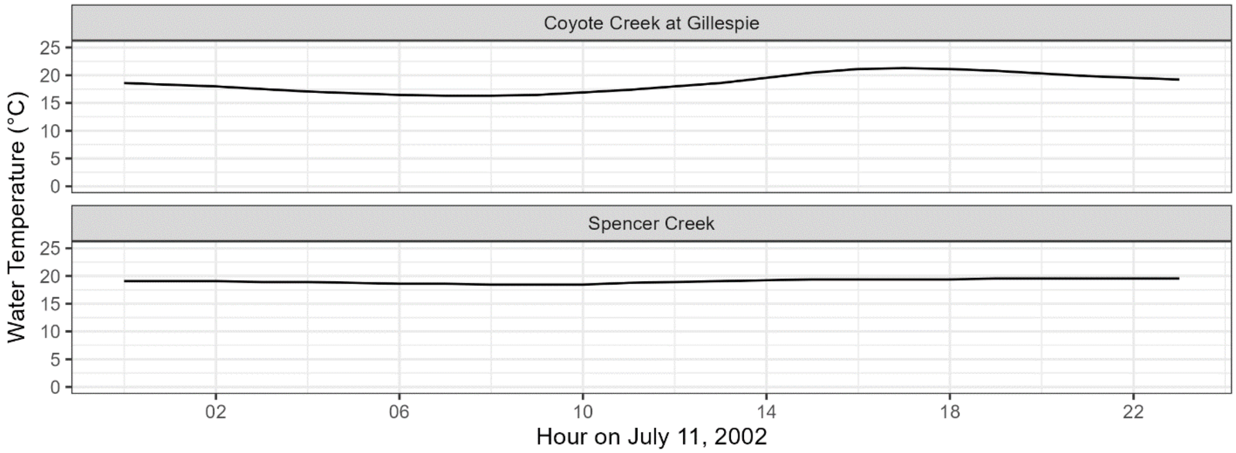


Figure 3-216: Boundary condition and tributary water temperature inputs to the Coyote Creek model.

3.10.6 Flow inputs

Hourly stream flow time series data were used to support tributary and boundary condition model setup. **Figure 3-217** shows the locations of the various stream flow monitoring locations that were used for model setup or calibration.

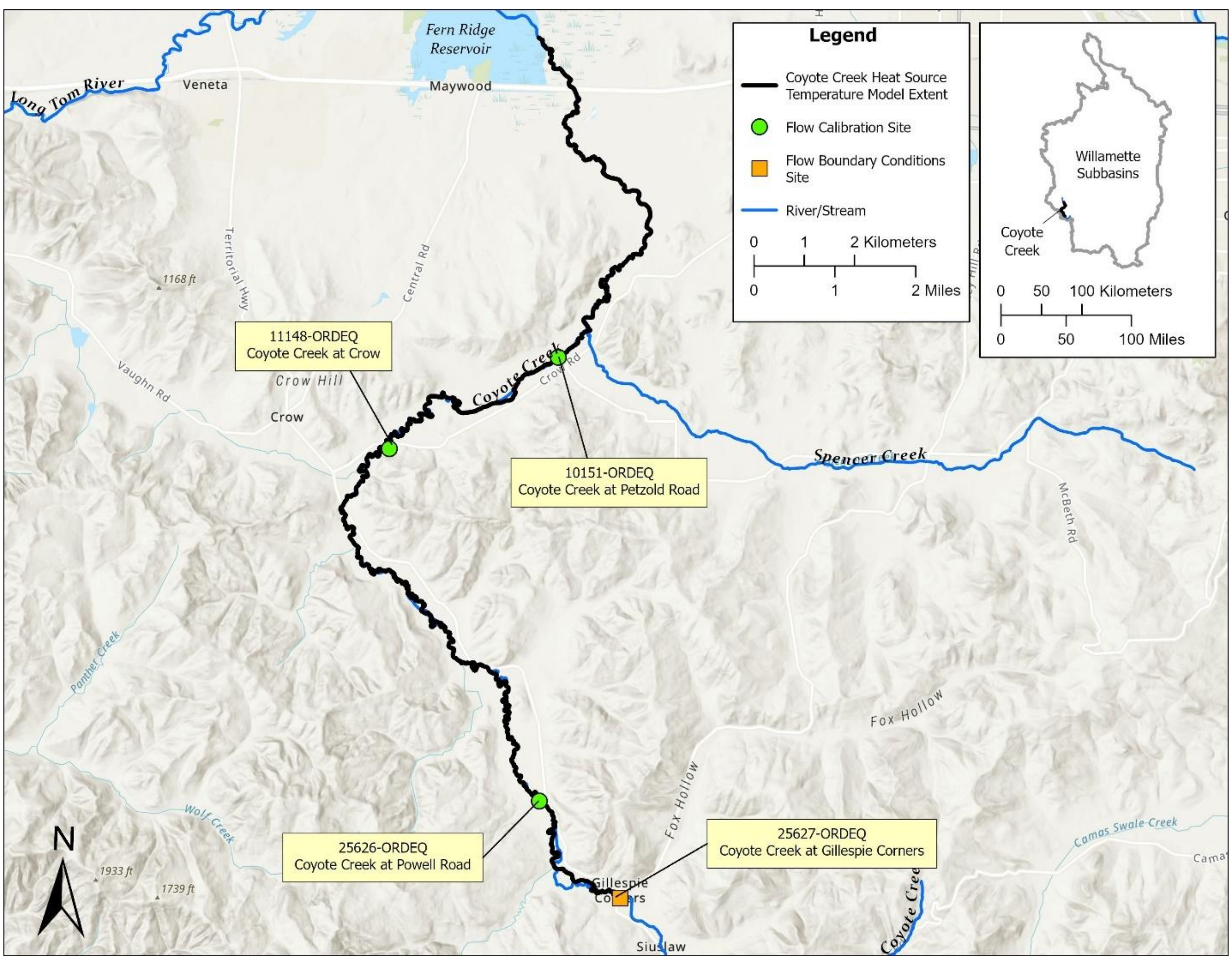


Figure 3-217: Flow monitoring locations used for the Coyote Creek model setup and calibration.

The boundary condition and tributary flow inputs to the model is summarized in Table 3-68. Figure 3-218 documents mainstem model flow setup. The model flow was estimated between measured sites using a flow balance.

Table 3-68: Boundary condition and tributary flow inputs to the Coyote Creek model.

Model Location Name	Model Location (km)	Flow Rate (cms)	Input Type	Data Source
Coyote Creek at Gillespie Corners	36.393	0.0113	Boundary Condition	25627-ORDEQ
Spencer Creek	10.028	0.020	Tributary	DEQ*

* Data source unclear, assumed to be derived.

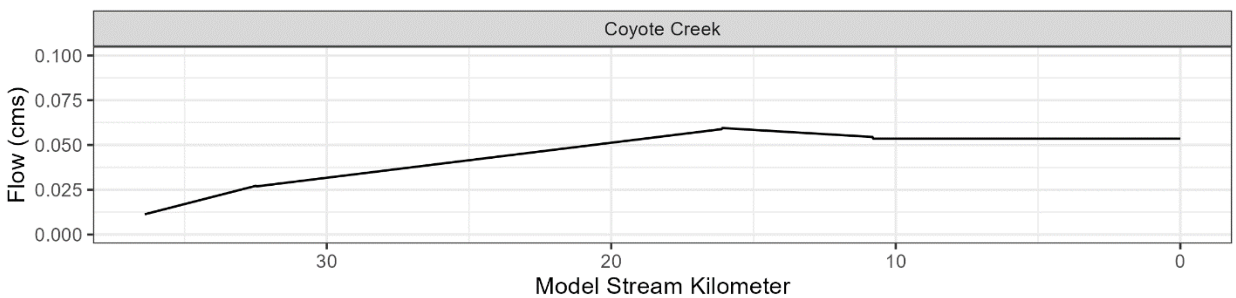


Figure 3-218: Boundary condition and mainstem flow inputs to the Coyote Creek model.

3.10.7 Point source inputs

There are no point sources discharging within the model extent.

3.10.8 Landcover and topographic shade inputs

Average land cover height inputs and topographic shade angle inputs are shown in Figure 3-219 and Figure 3-220, respectively.

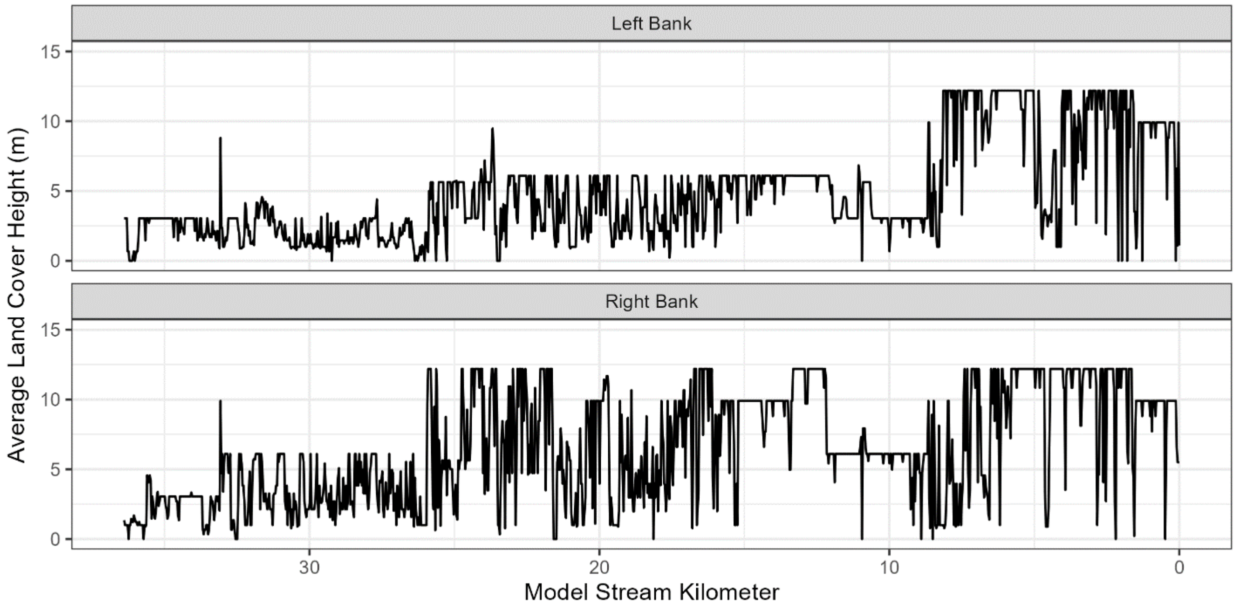


Figure 3-219: Average land cover height inputs to the Coyote Creek model.

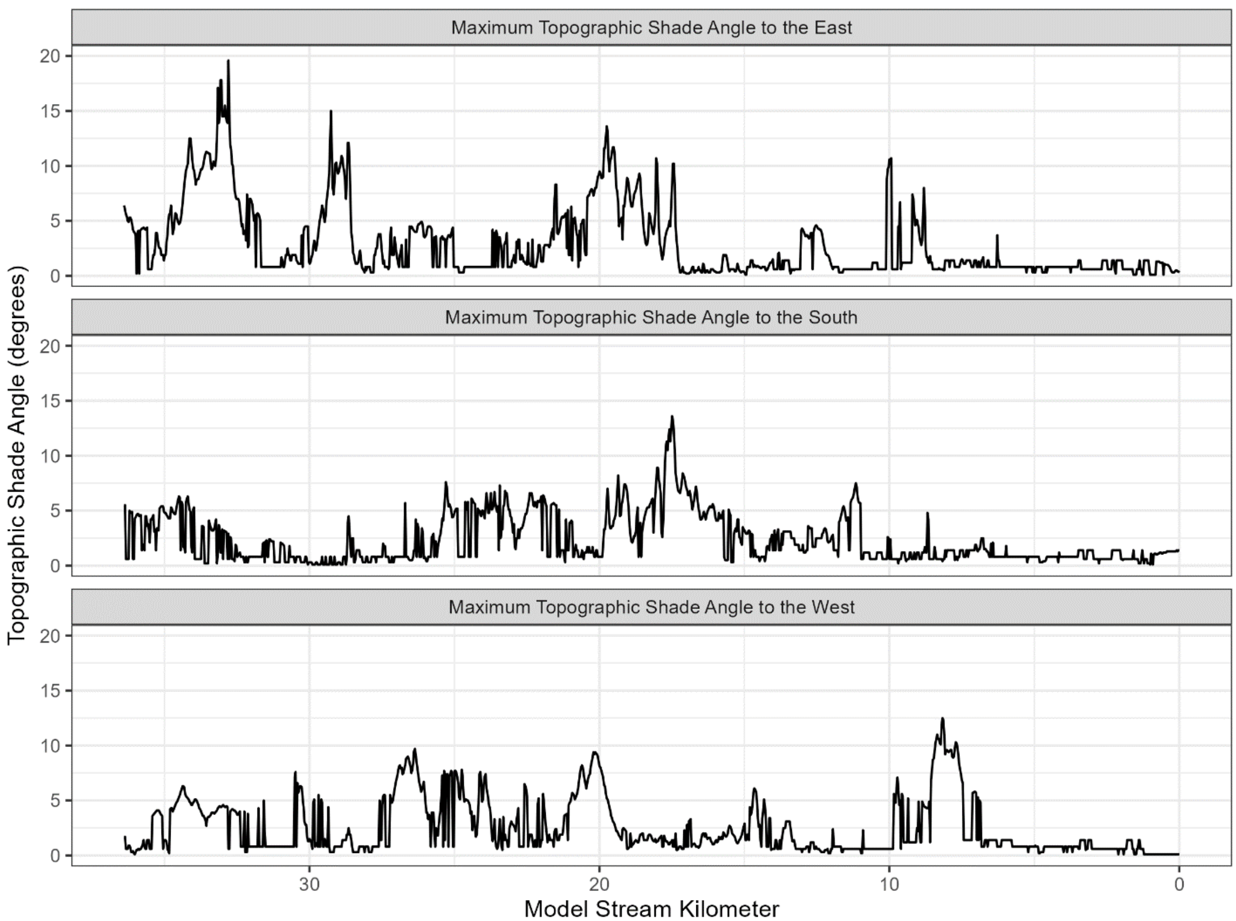


Figure 3-220: Topographic shade angle inputs to the Coyote Creek model.

3.10.9 Channel setup

Channel setup for Coyote Creek model is presented in **Figure 3-221**.

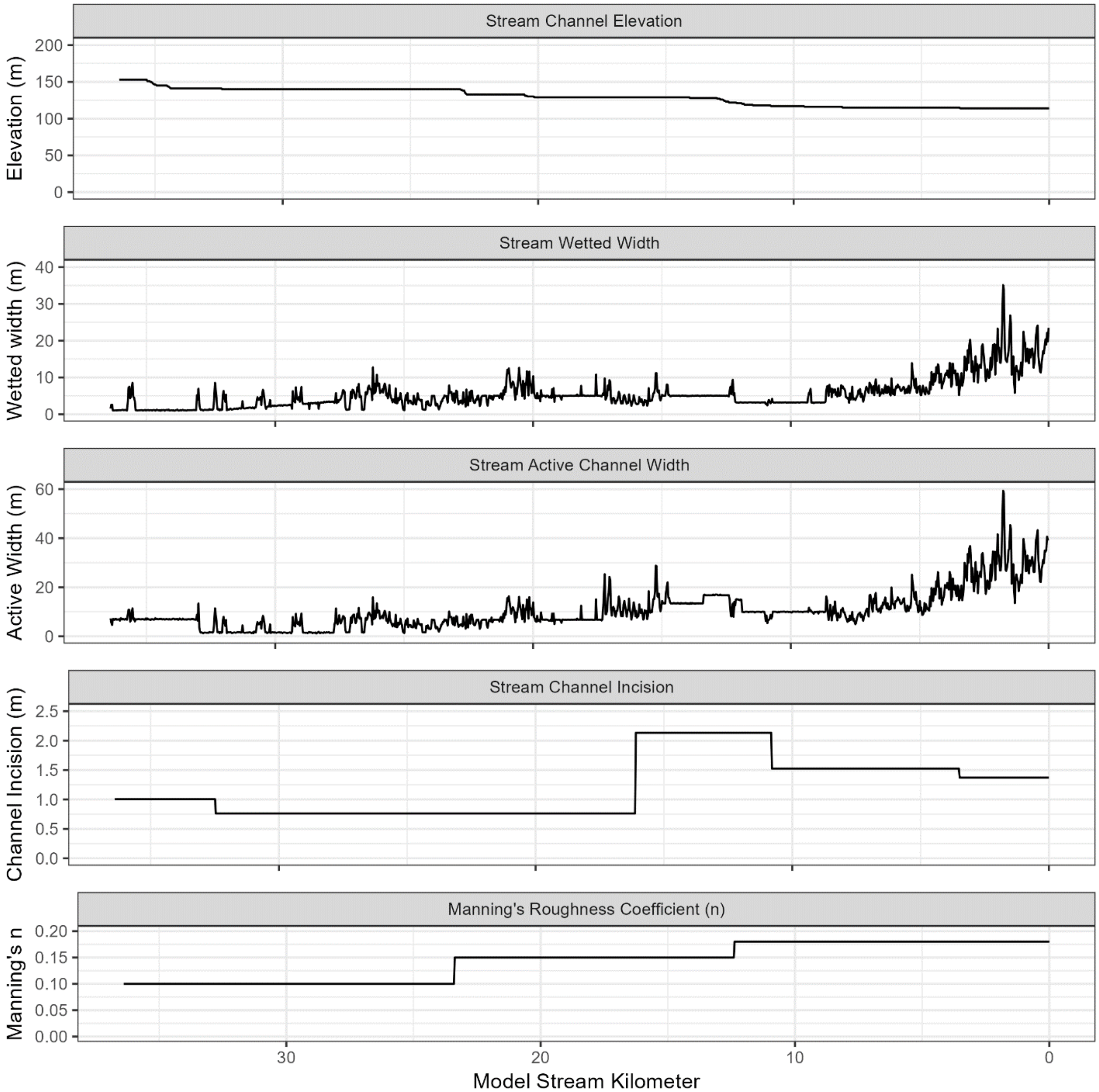


Figure 3-221: Channel setup in the Coyote Creek model.

3.10.10 Calibration results

3.10.10.1 Temperature

The model was calibrated to the continuous temperature data collected from several locations along Coyote Creek. Results for goodness of fit statistics comparing field observed and model-predicted temperatures are summarized in **Table 3-69**. Observed and model-predicted hourly temperatures were plotted for the monitoring stations (**Figure 3-222** through **Figure 3-225**).

Table 3-69: Coyote Creek water temperature goodness of fit statistics comparing field observed and model-predicted temperatures.

Monitoring Location	Model KM	Temperature Statistics	ME	MAE	RMSE	NSE	n
All Stations		Daily Maximum	-0.22	0.52	0.72	NA	4
All Stations		Hourly	-0.64	1.19	1.52	0.15	96
10150-ORDEQ: Coyote Creek at Centrell Rd	3.5	Hourly	-1.04	1.04	1.08	-0.2	24
10151-ORDEQ: Coyote Creek at Petzold Rd	10.8	Hourly	-1.52	1.58	2	-2.64	24
11148-ORDEQ: Coyote Creek at Crow Rd	17.3	Hourly	0.31	0.47	0.55	0.44	24
25626-ORDEQ: Coyote Creek at Powell Rd	32.5	Hourly	-0.32	1.67	1.95	-0.76	24

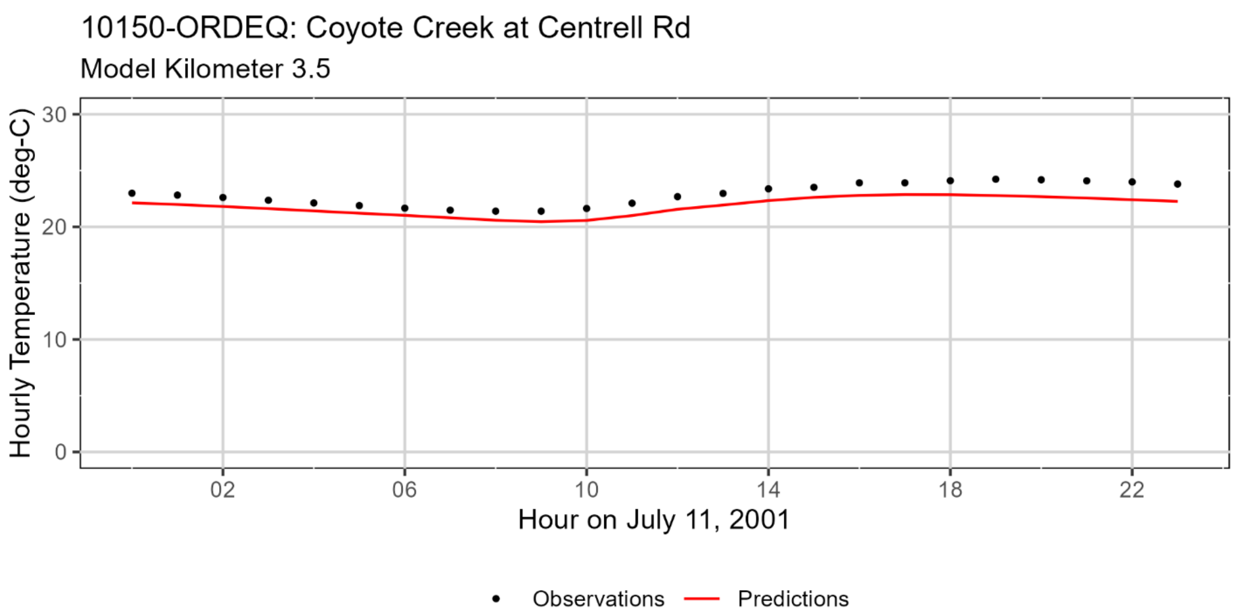


Figure 3-222: Coyote Creek measured and model-predicted hourly temperatures at monitoring station 10150-ORDEQ.

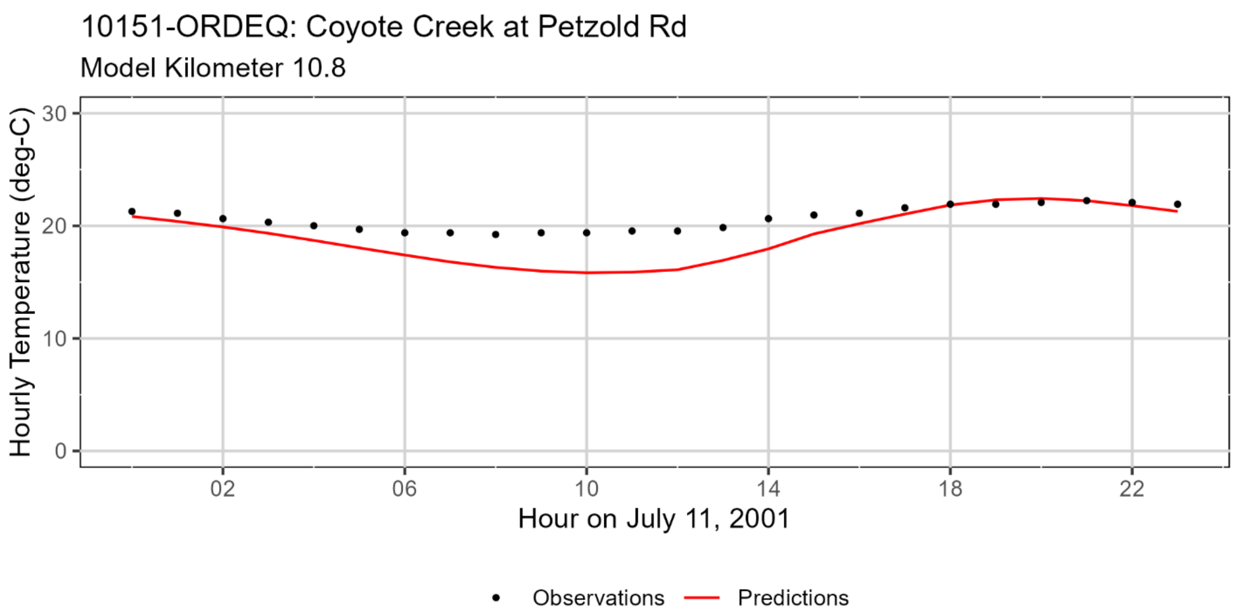


Figure 3-223: Coyote Creek measured and model-predicted hourly temperatures at monitoring station 10151-ORDEQ.

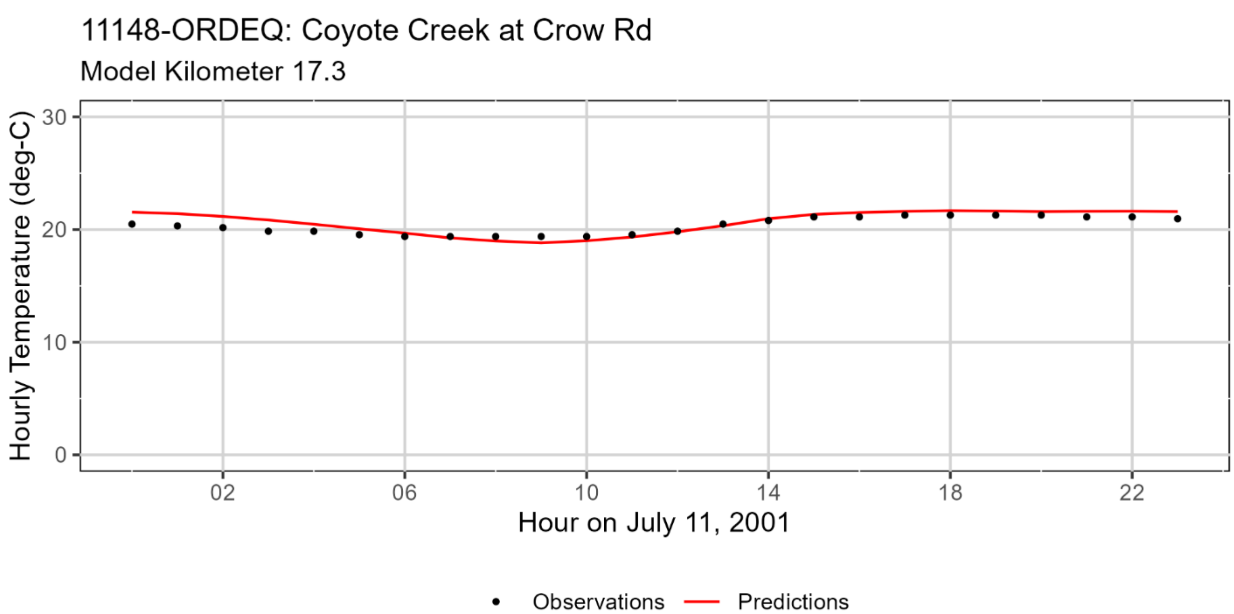


Figure 3-224: Coyote Creek measured and model-predicted hourly temperatures at monitoring station 11148-ORDEQ.

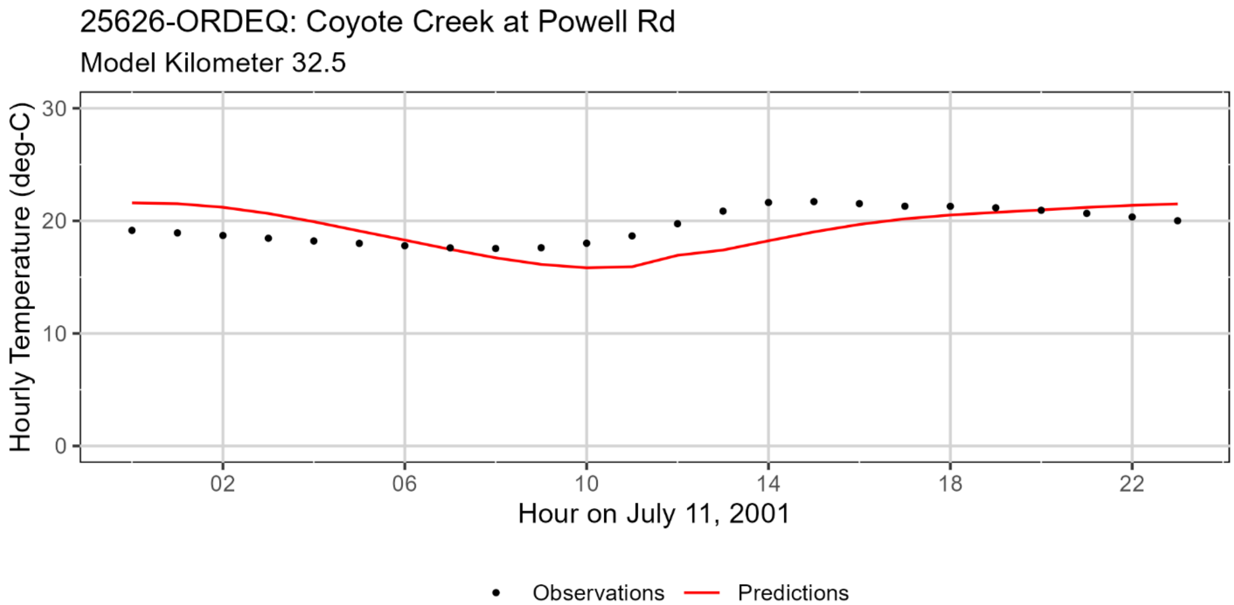


Figure 3-225: Coyote Creek measured and model-predicted hourly temperatures at monitoring station 25626-ORDEQ.

3.10.10.2 Effective Shade

Observed and model-predicted effective shade data were plotted along the Coyote Creek (**Figure 3-226**). The observed field data used for comparison is summarized in **Table 2-36**. Results for goodness of fit statistics comparing field observed and model-predicted temperatures are summarized in **Table 3-70**.

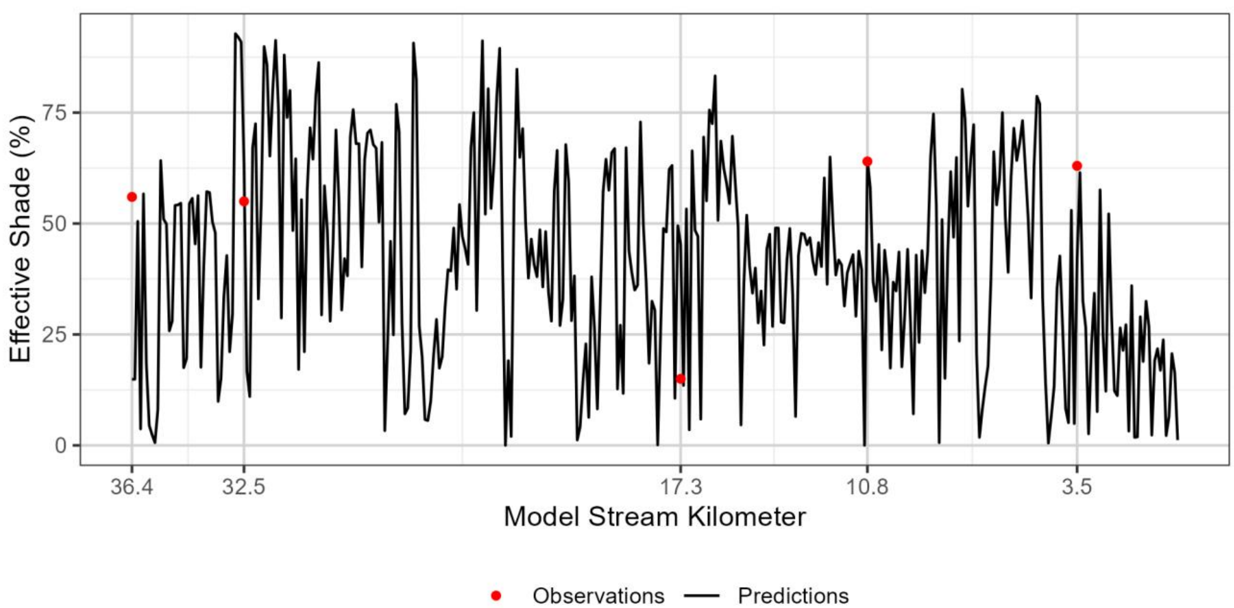


Figure 3-226: Coyote Creek field observed and model-predicted effective shade.

Table 3-70: Coyote Creek effective shade goodness of fit statistics comparing field observed and model values.

N	R^2	ME	MAE	RMSE
5	0.01	-4.48	20.32	24.97

3.10.10.3 Flow

A flow mass balance was completed to improve the calibration and match flows to the measured values. The observed flow used for comparison is summarized in **Table 3-71**, which is plotted with the model flow in **Figure 3-227**. Results for goodness of fit statistics comparing field observed flow and the model flow are summarized in **Table 3-72**.

Table 3-71: Coyote Creek stream flow rate measurements.

Monitoring Location	Model KM	Flow Statistics	Flow (cms)	Date
25627-ORDEQ: Coyote Creek at Gillespie Corners	36.4	Instantaneous	0.01	7/11/2001
25626-ORDEQ: Coyote Creek at Powell Road	32.5	Instantaneous	0.03	7/11/2001
11148-ORDEQ: Coyote Creek at Crow	17.3	Instantaneous	0.06	7/11/2001
10151-ORDEQ: Coyote Creek at Petzold Road	10.8	Instantaneous	0.05	7/11/2001

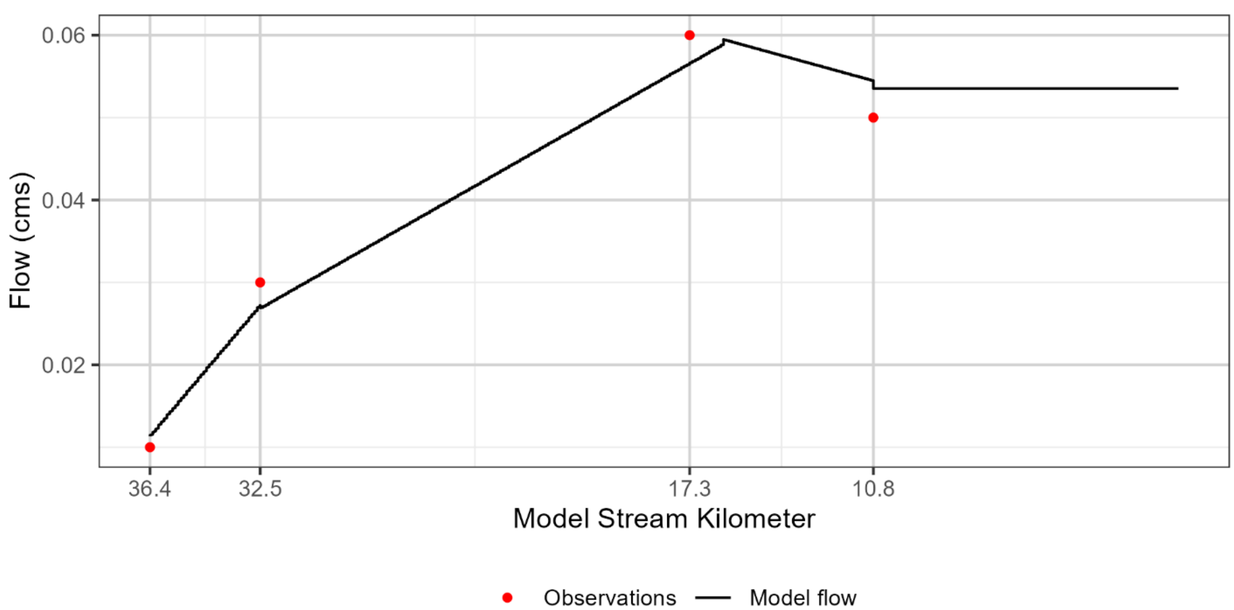


Figure 3-227: Coyote Creek field observed and model flow rates.

Table 3-72: Coyote River goodness of fit statistics comparing field observed and model flow rates.

N	R^2	ME	MAE	RMSE
4	0.98	0	0	0

3.10.10.4 Channel

Results comparing channels widths derived from GIS and modeling to those measured in the field are presented in **Figure 3-228**. Results shows channel widths only from streams modeled for temperature with Heat Source.

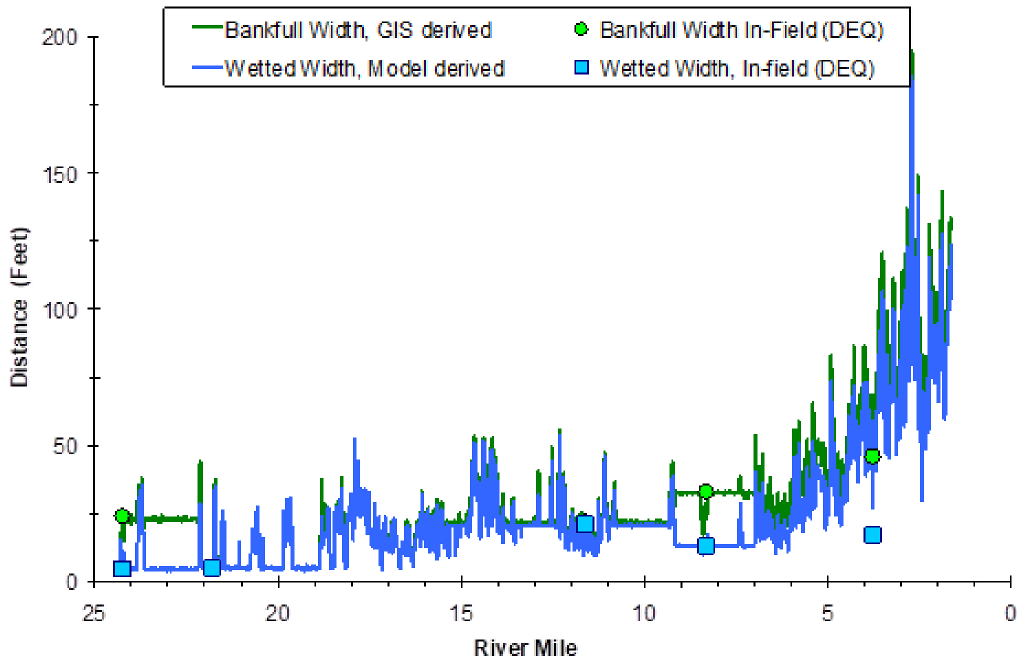


Figure 3-228: Coyote Creek field observed and derived bankfull and wetted width.

3.11 Mosby Creek

The Mosby Creek model is a temperature model developed using Heat Source 6.5.1. The model was developed by DEQ.

3.11.1 Model extent

The extent of the model domain is Mosby Creek from the confluence of the East and West Forks to the confluence with the Row River (**Figure 3-229**).

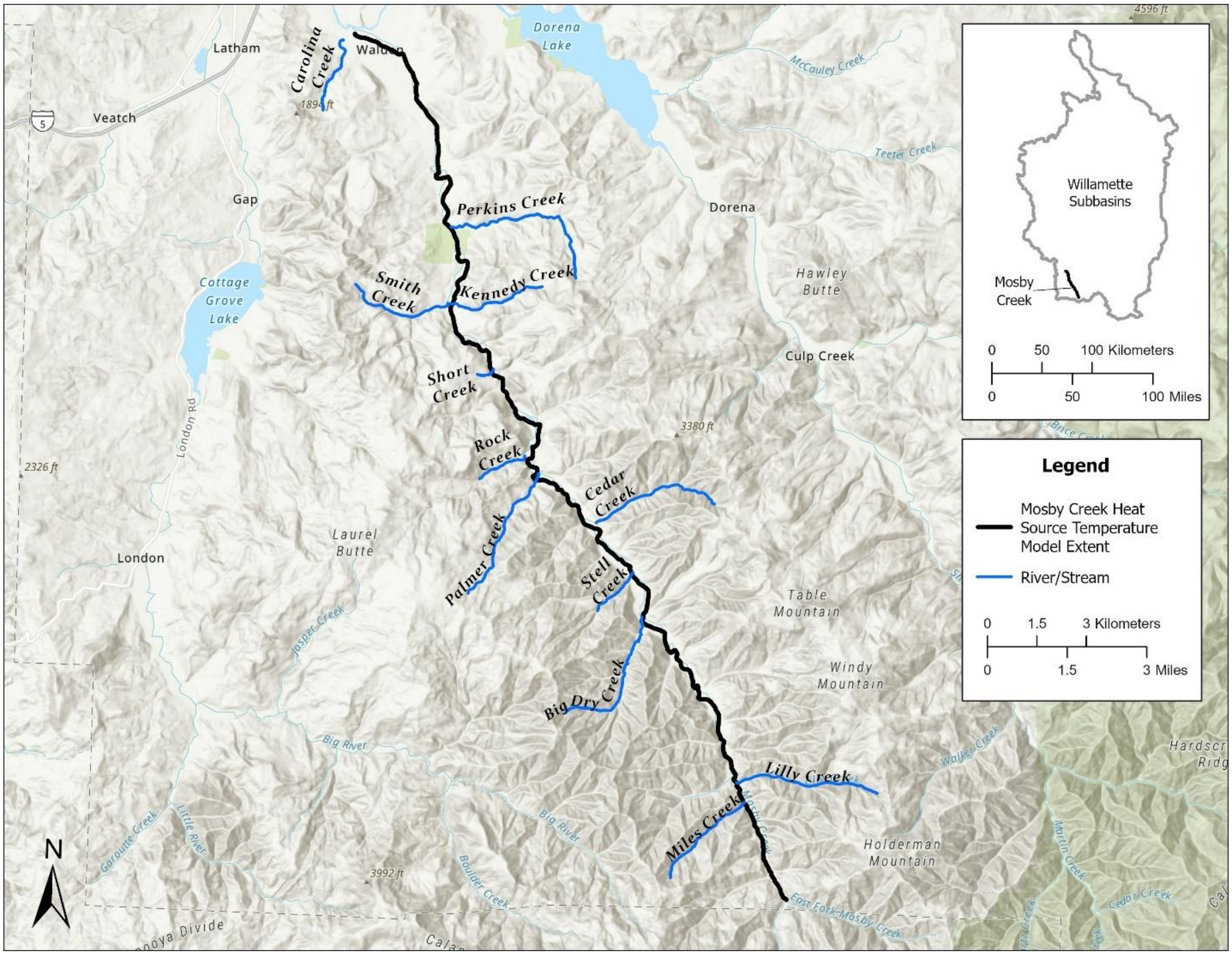


Figure 3-229: Mosby Creek temperature model extent.

3.11.2 Spatial and temporal resolution

The model input spatial resolution (*dx*) is 30 m. Outputs are generated every 100 m. The model time step (*dt*) is 1 minute and outputs are generated every hour.

3.11.3 Time frame of simulation

The model period is for a single day: July 21, 2002.

3.11.4 Meteorological inputs

The model was set up using hourly air temperature, relative humidity, and wind speed measurements from the NCDC site at the Eugene Airport (KEUG) (Figure 3-230). Air temperature data were modified using the dry adiabatic lapse rate to adjust for differences in elevation between the measurement location and the model input location (Table 3-73). Wind speeds were adjusted to improve the calibration using a wind-sheltering coefficient between 1 and 1.5 to represent differences in wind speed between the measurement location and above the stream within the riparian area.

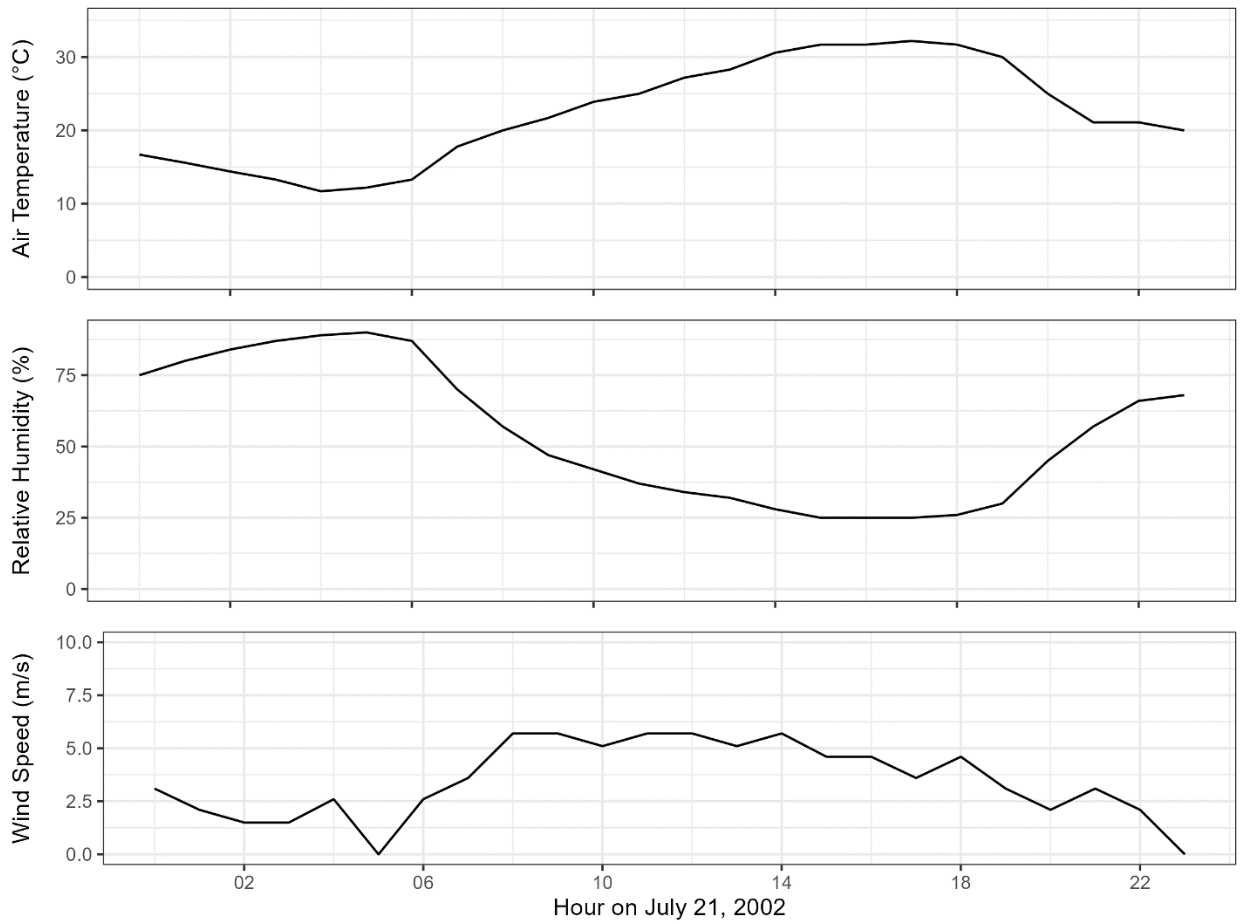


Figure 3-230: Meteorological inputs to the Mosby Creek model.

Table 3-73: Wind-sheltering coefficient used in the Mosby Creek model.

Model Location Name	Model Location (km)	Air Temperature Coefficient
Mosby Creek Above West Fork Mosby Creek	34.595	0.6
Mosby Creek Above Cedar Creek	21.001	0.65
Mosby Creek at Blue Mountain Park (upstream Perkins Creek)	8.23	0.65
Mosby Creek at Layng Road	1.097	0.7
Mosby Creek below Row River Trail	0.823	0.7

3.11.5 Temperature inputs

Hourly water temperature time series data were used to support tributary and boundary condition model setup. **Figure 3-231** shows the locations of the various stream temperature monitoring locations that were used for model setup or calibration.

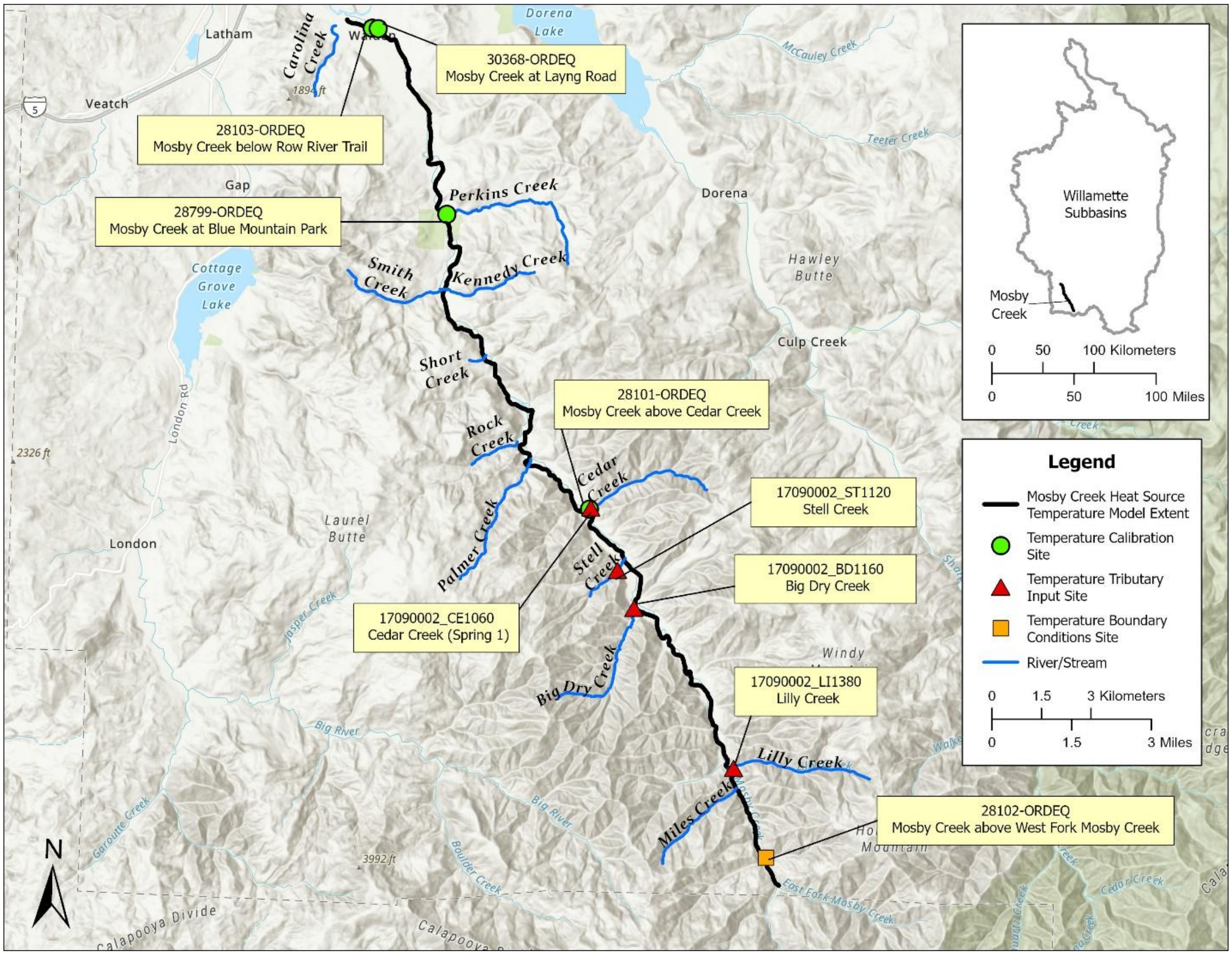


Figure 3-231: Temperature monitoring locations used for the Mosby Creek model setup and calibration.

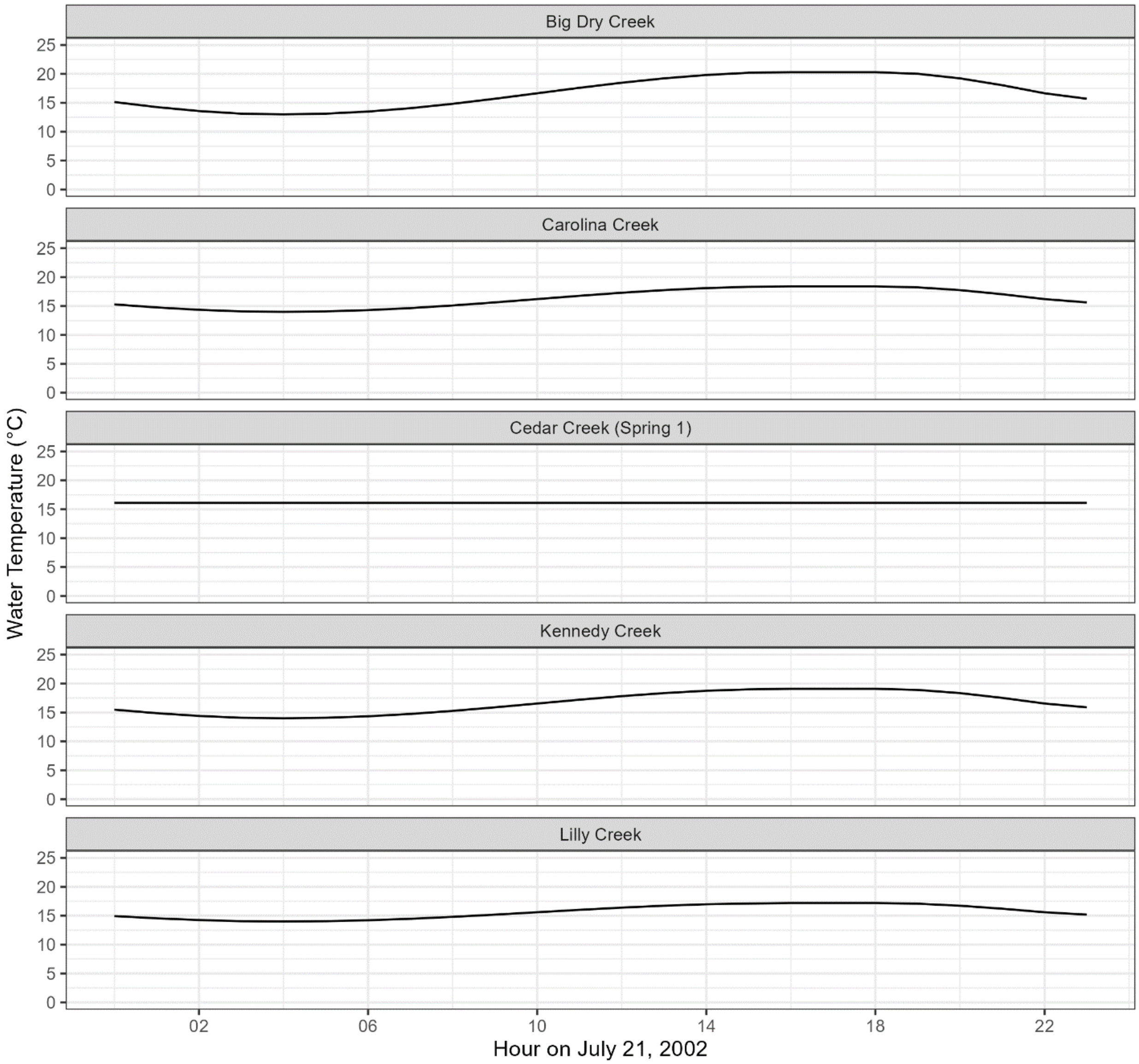
Table 3-74

Table 3-74: Boundary condition and tributary water temperature inputs to the Mosby Creek model. and Figure 3-232 document the water temperature inputs to the model at the boundary condition (Mosby Creek Above West Fork Mosby Creek) and tributaries. Table 2-39 lists TIR Temperatures on Mosby Creek.

Table 3-74: Boundary condition and tributary water temperature inputs to the Mosby Creek model.

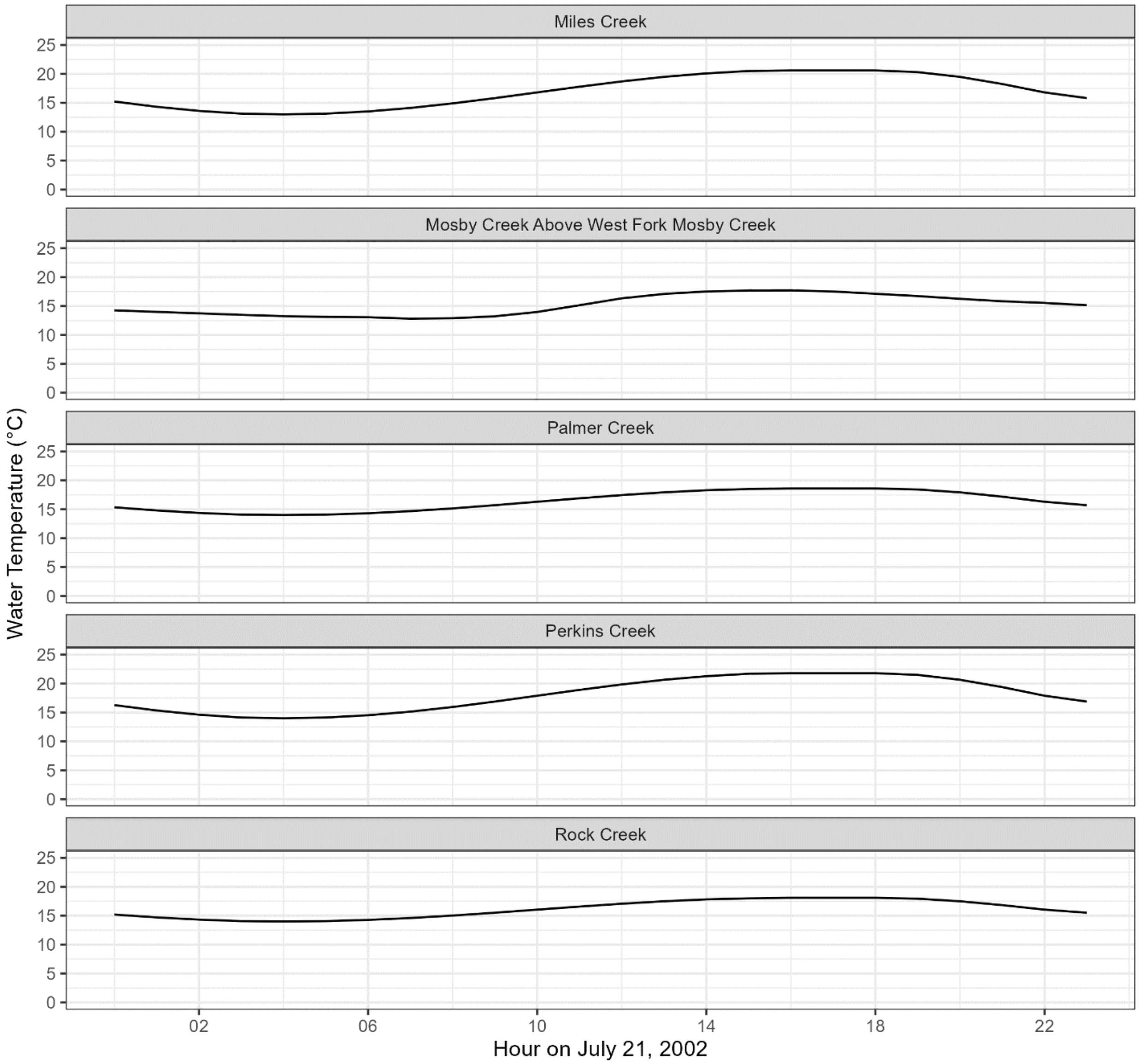
Monitoring Location	Model KM	Flow Statistics	Flow (cms)
Mosby Creek Above West Fork Mosby Creek	34.595	Boundary Condition	BLM
28102-ORDEQ			
Miles Creek	32.370	Tributary	DEQ
Lilly Creek	31.669	Tributary	BLM (17090002_LI1380)
Big Dry Creek	24.689	Tributary	BLM (17090002_BD1160)
Stell Creek	23.012	Tributary	BLM (17090002_ST1120)
Cedar Creek (Spring 1)	20.879	Tributary	BLM (17090002_CE1060)*
Palmer Creek	18.745	Tributary	DEQ
Rock Creek	17.435	Tributary	DEQ
Short Creek	13.716	Tributary	DEQ
Kennedy Creek	10.942	Tributary	DEQ
Smith Creek	10.973	Tributary	DEQ
Perkins Creek	8.047	Tributary	BLM (17090002_PE1235)
Unnamed Creek	7.711	Tributary	DEQ
Carolina Creek	0.244	Tributary	DEQ

* Constant temperature of 16.1.

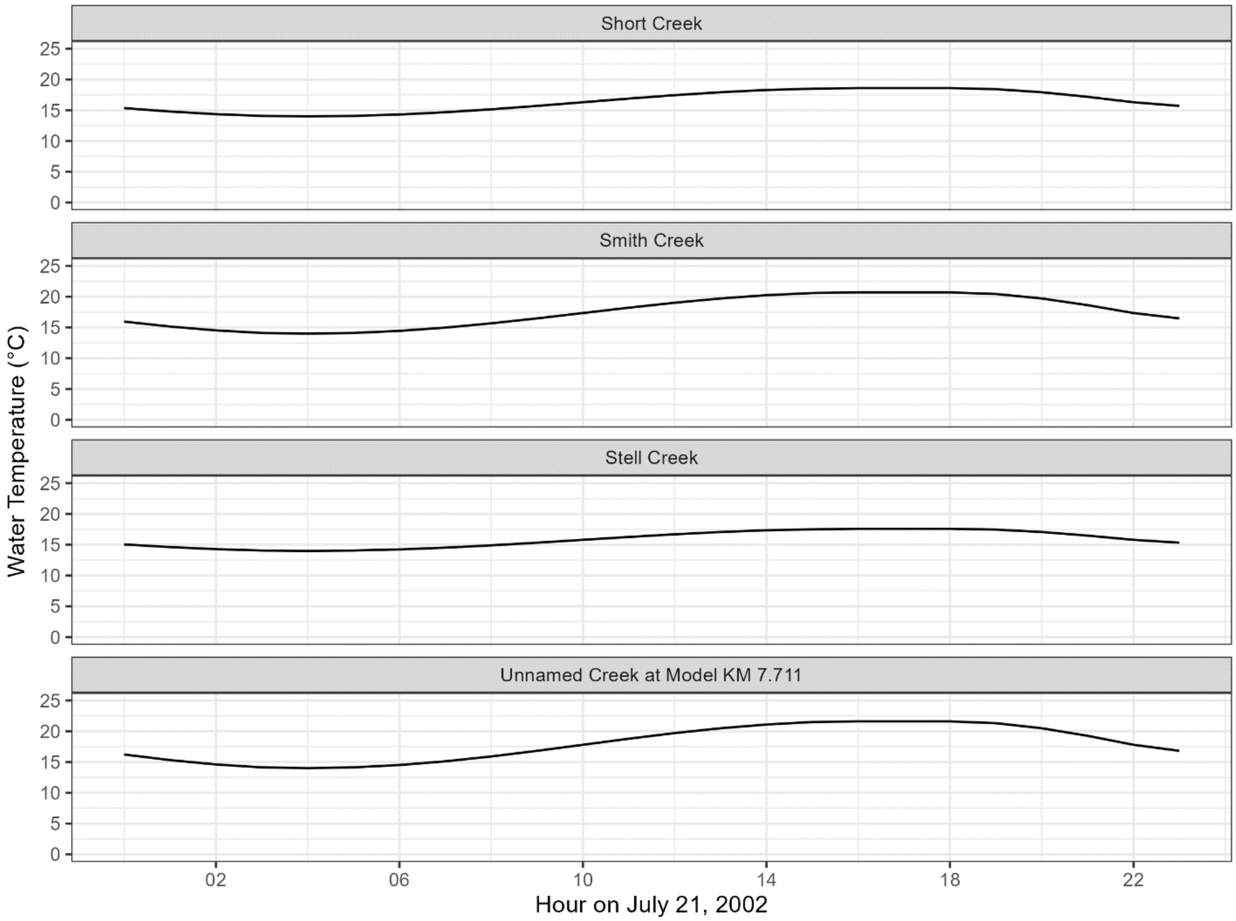


Big Dry Creek
Carolina Creek
Cedar Creek (Spring 1)
Kennedy Creek
Lilly Creek
Water Temperature (°C)
0
5
10
15
20
25
02
06
10
14
18
22
Hour on July 21, 2002

(A)


Miles Creek
Mosby Creek Above West Fork Mosby Creek
Palmer Creek
Perkins Creek
Rock Creek
Water Temperature (°C)
0
5
10
15
20
25
02
06
10
14
18
22
Hour on July 21, 2002

(B)



(C)

Figure 3-232 (A)-(C): Boundary condition and tributary water temperature inputs to the Mosby Creek model.

3.11.6 Flow inputs

Hourly stream flow time series data were used to support tributary and boundary condition model setup. **Figure 3-233** shows the locations of the various stream flow monitoring locations that were used for model setup or calibration.

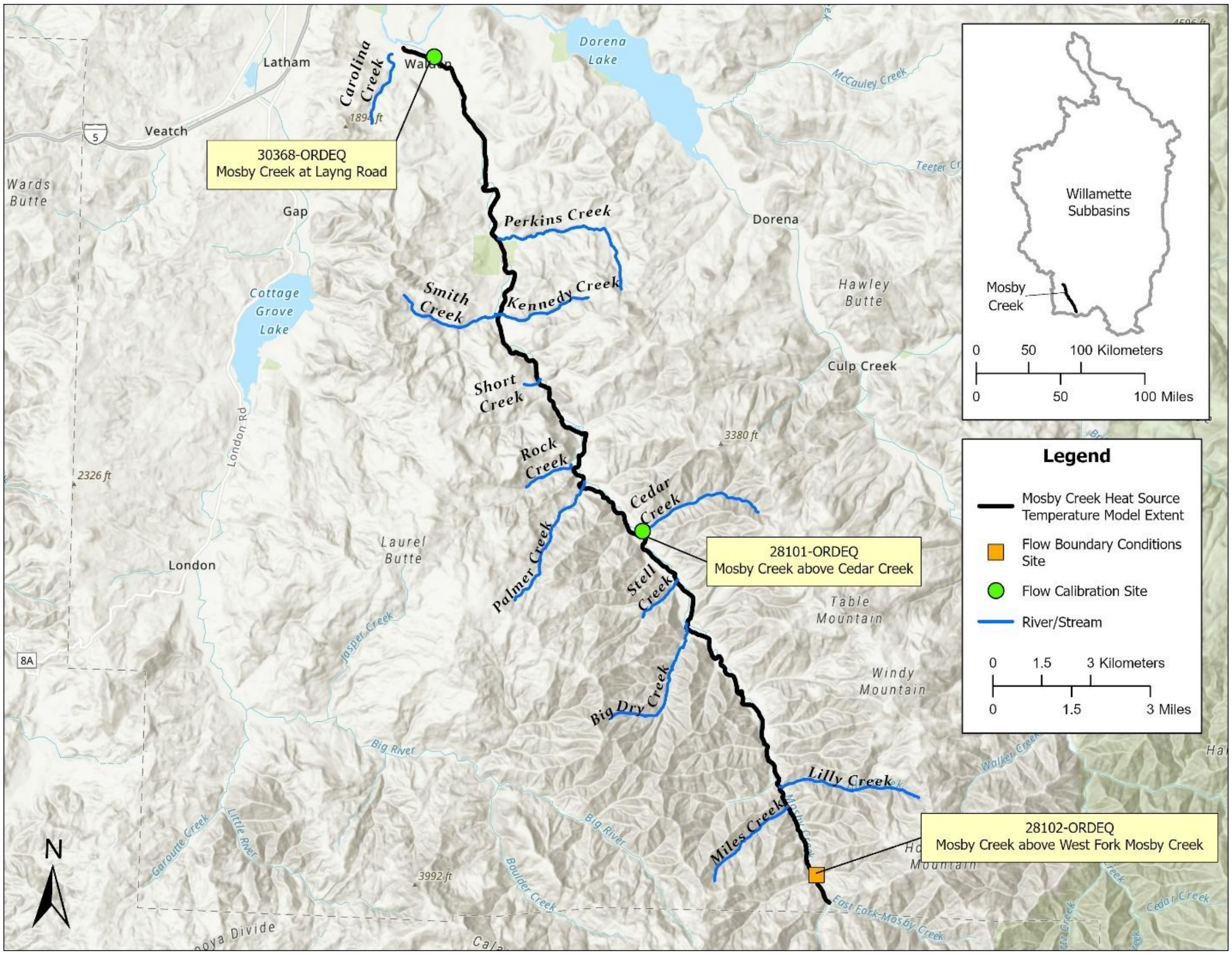


Figure 3-233: Flow monitoring locations used for the Mosby Creek model setup and calibration.

The boundary condition and tributary flow inputs to the model is summarized in

Table 3-75. **Figure 3-234** documents mainstem model flow setup. The model flow was estimated between measured sites using a flow mass balance, which incorporated input from tributaries and demand from PODs. The total water withdrawal volume at the PODs in the model flow amounted to 0.1295 cms.

Table 3-75: Boundary condition and tributary flow inputs to the Mosby Creek River model.

Model Location Name (Station ID)	Model Location (km)	Flow Rate (cms)	Input Type	Data Source
Mosby Creek Above West Fork Mosby Creek	34.595	0.0787	Boundary Condition	28102-ORDEQ
Miles Creek	32.370	0.000	Tributary	DEQ
Lilly Creek	31.669	0.001	Tributary	Estimated using a flow mass balance based on TIR
Big Dry Creek	24.689	0.005	Tributary	DEQ
Stell Creek	23.012	0.005	Tributary	DEQ
Cedar Creek (Spring 1)	20.879	0.003	Tributary	Estimated using a flow mass balance based on TIR
Palmer Creek	18.745	0.007	Tributary	Estimated using a flow mass balance based on TIR
Rock Creek	17.435	0.010	Tributary	Estimated using a flow mass balance based on TIR
Short Creek	13.716	0.020	Tributary	Estimated using a flow mass balance based on TIR
Kennedy Creek	10.942	0.014	Tributary	Estimated using a flow mass balance based on TIR
Smith Creek	10.973	0.022	Tributary	DEQ
Perkins Creek	8.047	0.025	Tributary	Estimated using a flow mass balance based on TIR
Unnamed Creek	7.711	0.005	Tributary	Estimated using a flow mass balance based on TIR
Carolina Creek	0.244	0.005	Tributary	Estimated using a flow mass balance based on TIR

Instantaneous flow measurements for Miles Creek (0.004 cfs), Big Dry Creek (0.18 cfs), Stell Creek (0.18 cfs), and Kennedy Creek (0.49 cfs) were used for the model setup but the original source of the data is unknown. As the exact flow measurement dates are also unknown, the model date of 7/21/2002 was assumed for these measurements.

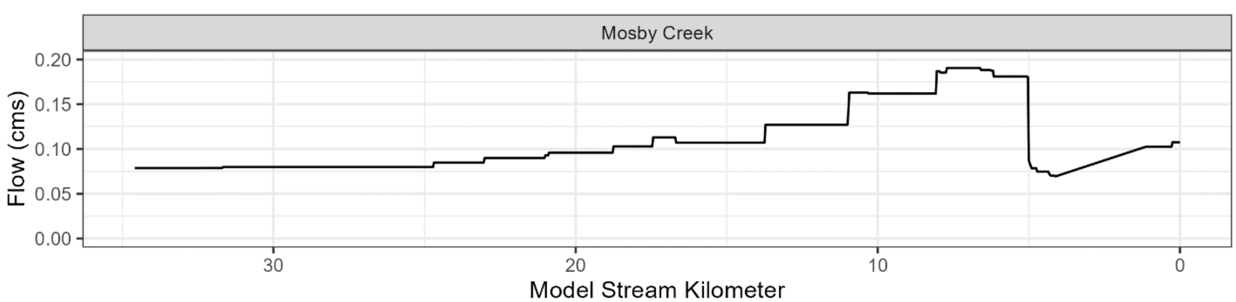


Figure 3-234: Boundary condition and mainstem flow inputs to the Mosby Creek model.

3.11.7 Point source inputs

There are no point sources discharging within the model extent.

3.11.8 Landcover and topographic shade inputs

Average land cover height inputs and topographic shade angle inputs are shown in Figure 3-235 and Figure 3-236, respectively.

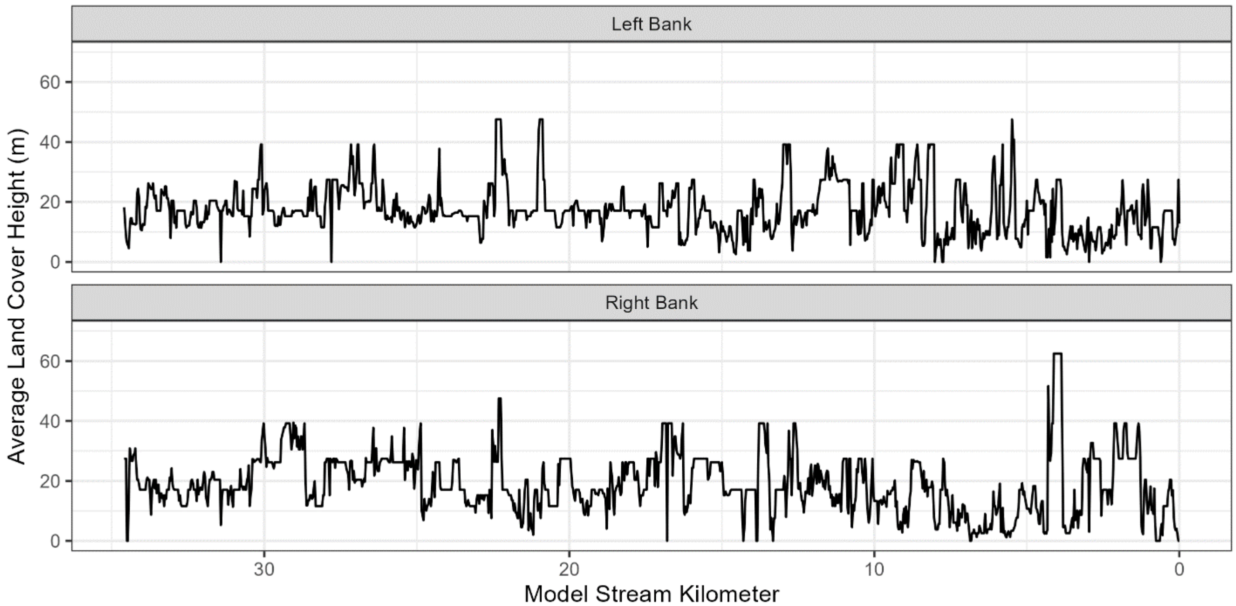


Figure 3-235: Average land cover height inputs to the Mosby Creek model.

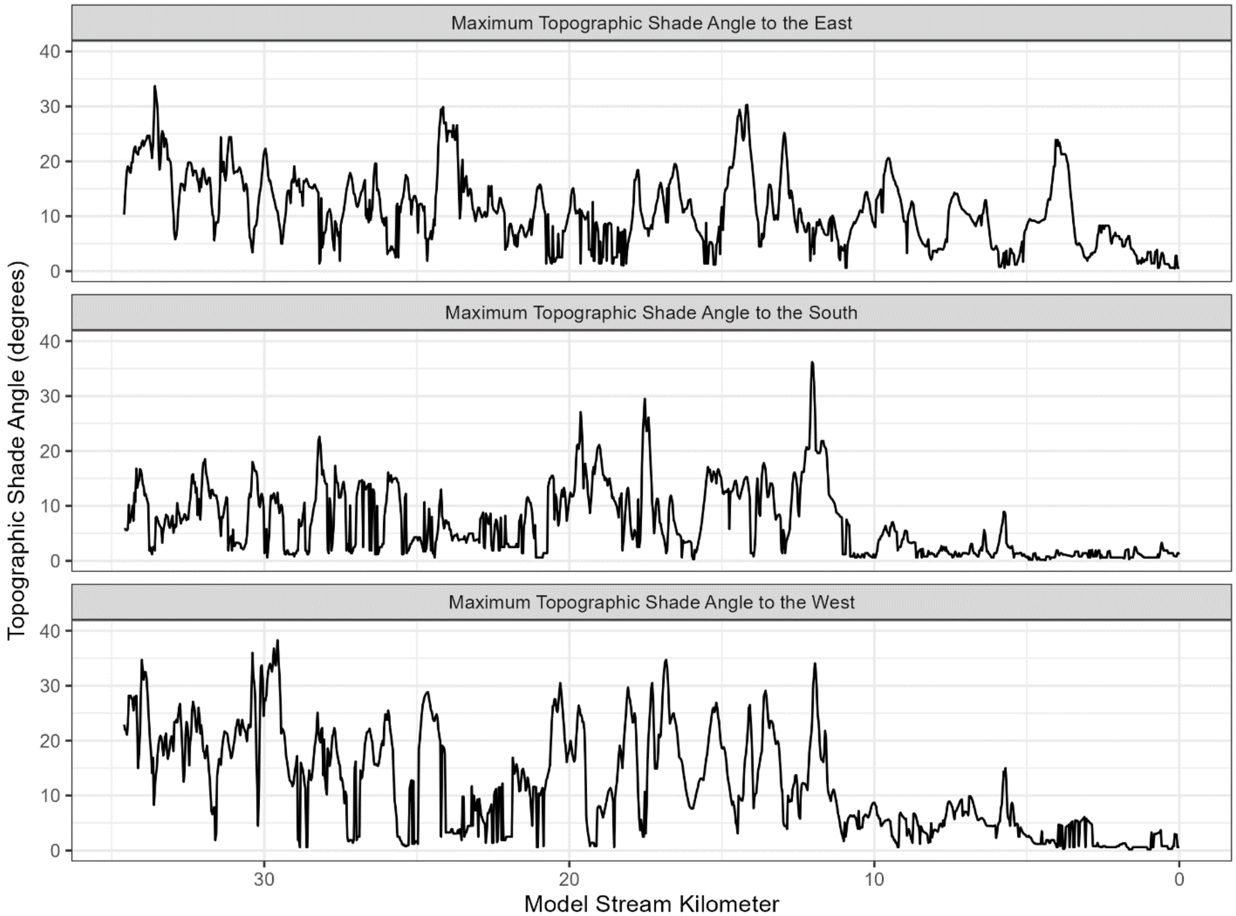


Figure 3-236: Topographic shade angle inputs to the Mosby Creek model.

3.11.9 Channel setup

Channel setup for Mosby Creek model is presented in Figure 3-237.

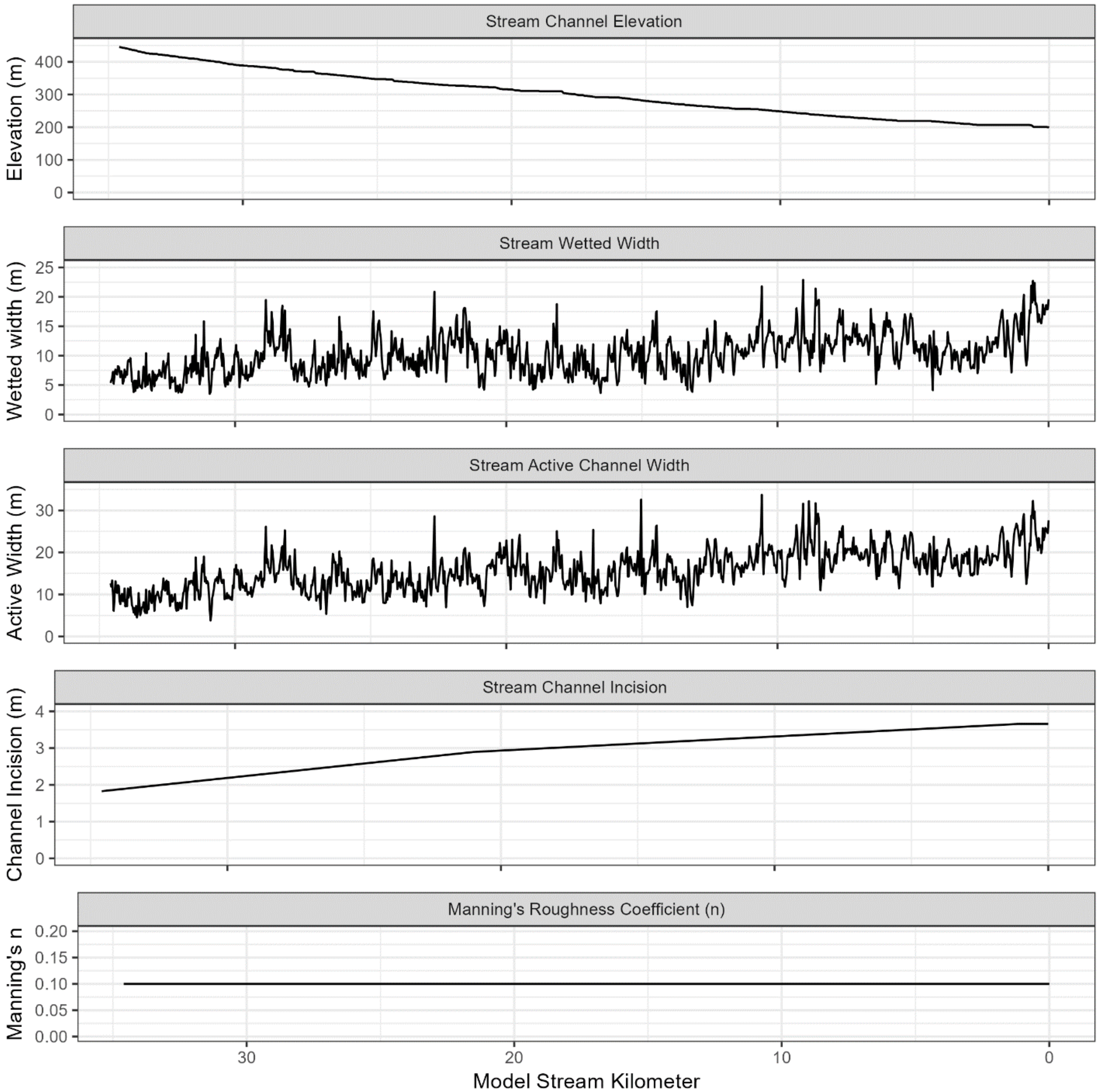


Figure 3-237: Channel setup in the Mosby Creek model.

3.11.10 Calibration results

3.11.10.1 Temperature

The model was calibrated to the continuous temperature data collected from several locations along Mosby Creek, as well as to the TIR data. Results for goodness of fit statistics comparing field observed and model-predicted temperatures are summarized in **Table 3-76**. Observed and model-predicted hourly temperatures were plotted for the monitoring stations (**Figure 3-238** through **Figure 3-241**). Modeling results comparing simulated current conditions for Johnson Creek to the TIR data are presented in **Figure 3-242**.

Table 3-76: Mosby Creek water temperature goodness of fit statistics comparing field observed and model-predicted temperatures.

Monitoring Location	Model KM	Temperature Statistics	ME	MAE	RMSE	NSE	n
All Stations		Daily Maximum	-0.03	0.14	0.16	NA	4
All Stations		Hourly	0.22	0.81	1.05	0.79	96
28103-ORDEQ: Mosby Creek below Row River Trail	0.8	Hourly	0.55	0.89	1.08	0.78	24
30368-ORDEQ: Mosby Creek at Layng Road	1.1	Hourly	0.44	0.67	0.89	0.76	24
28799-ORDEQ: Mosby Creek at Blue Mountain Park (upstream Perkins Creek)	8.2	Hourly	-0.25	0.81	1.15	0.74	24
28101-ORDEQ: Mosby Creek Above Cedar Creek	21	Hourly	0.14	0.86	1.06	0.8	24
Mosby Creek TIR	Model extent		-0.08	1.02	1.29	0.25	347

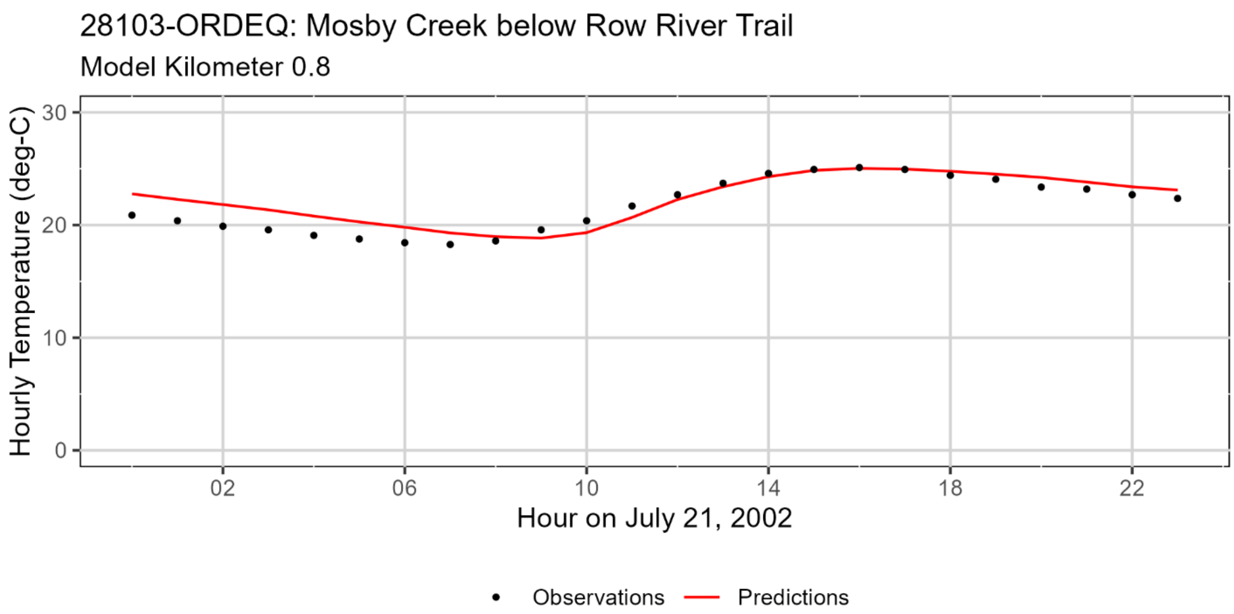


Figure 3-238: Mosby Creek measured and model-predicted hourly temperatures at monitoring station 28103-ORDEQ.

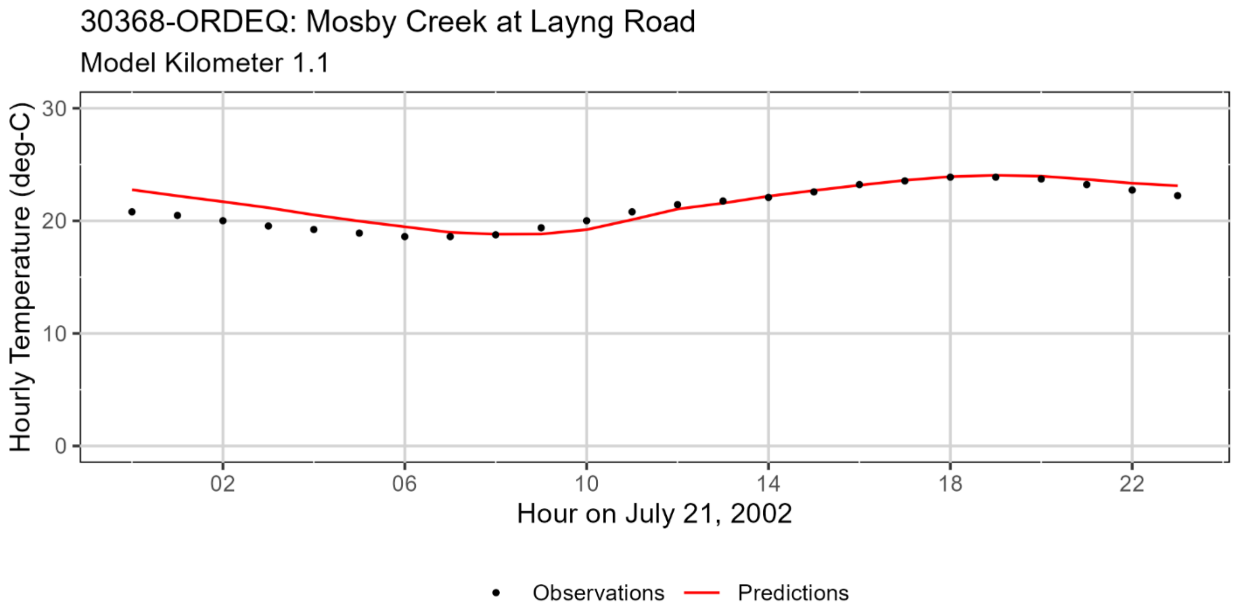


Figure 3-239: Mosby Creek measured and model-predicted hourly temperatures at monitoring station 30368-ORDEQ.

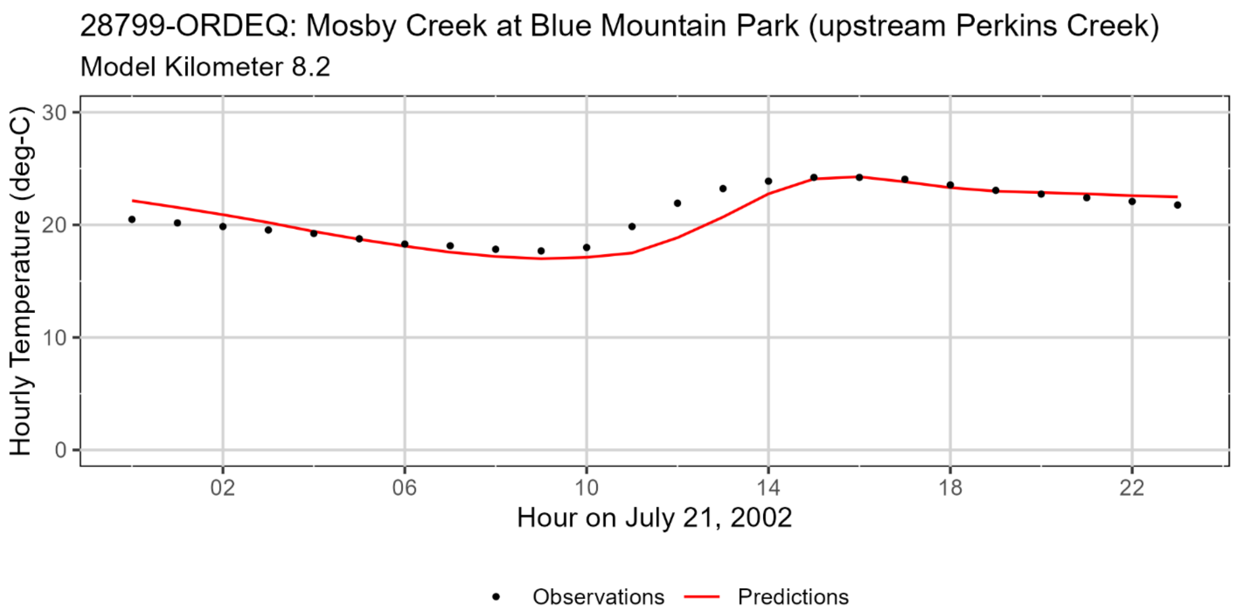


Figure 3-240: Mosby Creek measured and model-predicted hourly temperatures at monitoring station 28799-ORDEQ.

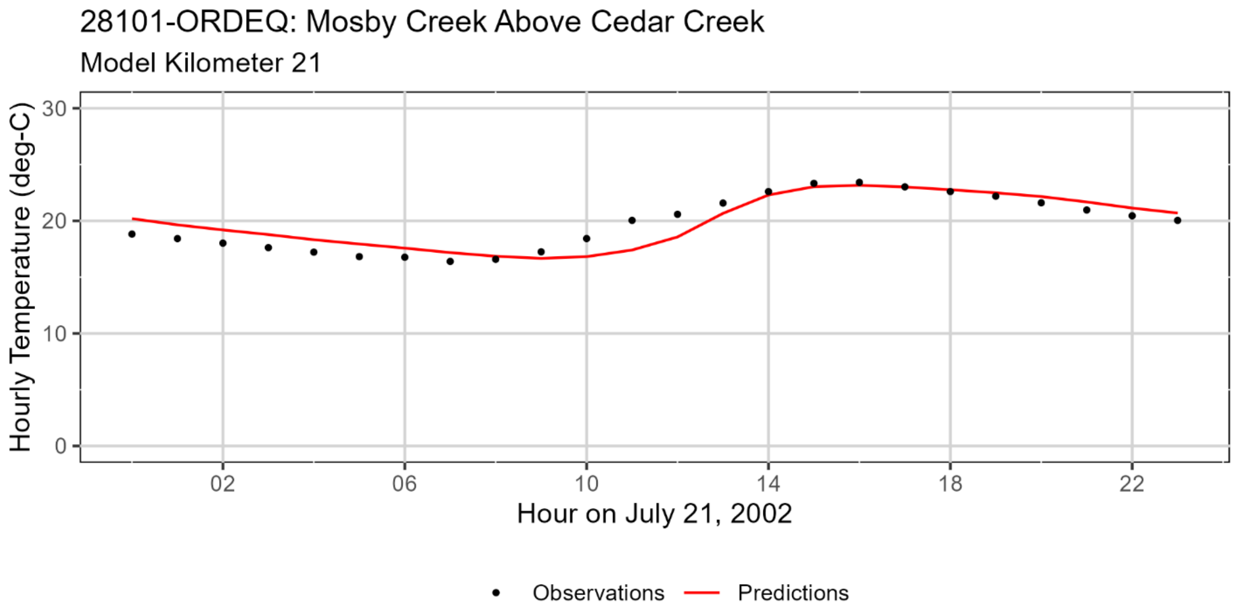


Figure 3-241: Mosby Creek measured and model-predicted hourly temperatures at monitoring station 28101-ORDEQ.

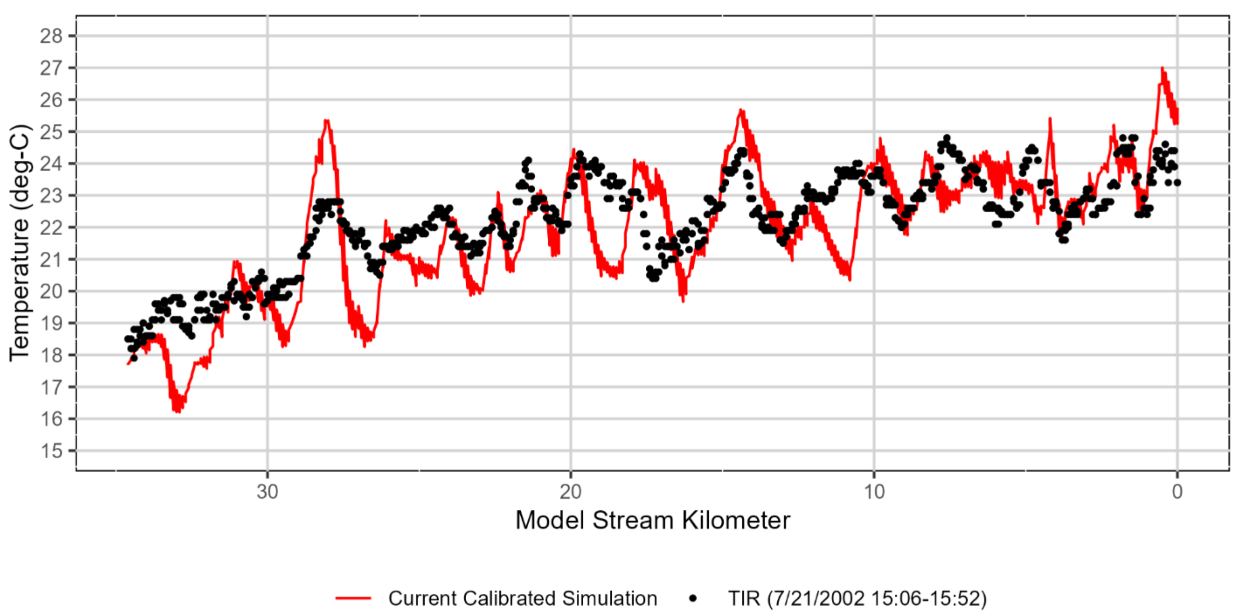


Figure 3-242: Mosby Creek TIR and simulated current stream temperatures.

3.11.10.2 Effective Shade

Observed and model-predicted effective shade data were plotted along Mosby Creek (**Figure 3-243**). The observed field data used for comparison is summarized in **Table 2-37**. Results for goodness of fit statistics comparing field observed and model-predicted temperatures are summarized in **Table 3-77**. Given the small sample size (n=3), it should take caution when drawing conclusions about the model's performance.

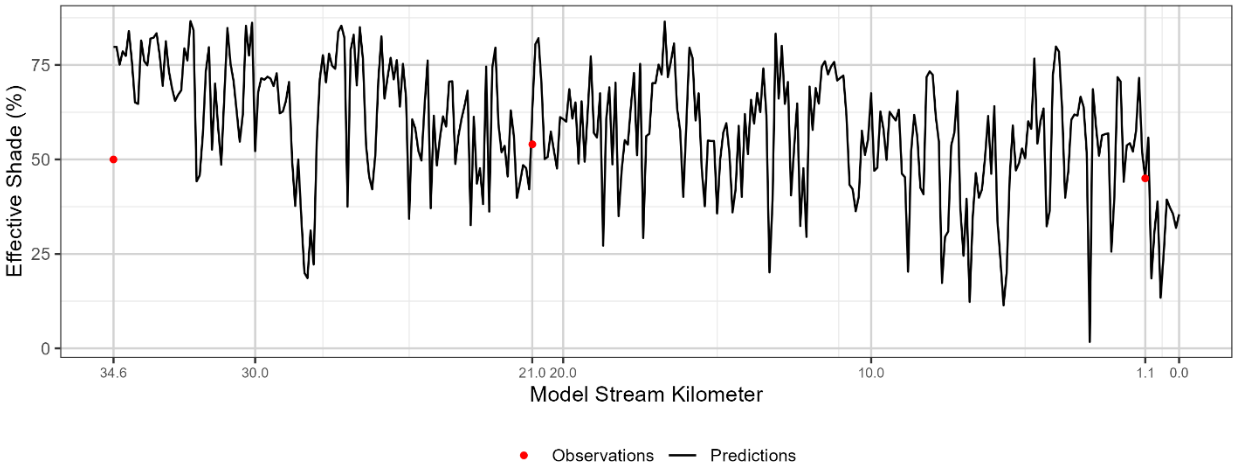


Figure 3-243: Mosby Creek field observed and model-predicted effective shade.

Table 3-77: Mosby Creek effective shade goodness of fit statistics comparing field observed and model values.

N	R^2	ME	MAE	RMSE
3	0.33	12.93	13	17.99

3.11.10.3 Flow

A flow mass balance was completed to improve the calibration and match flows to the measured values. The observed flow used for comparison is summarized in **Table 3-78**, which is plotted with the model flow in **Figure 3-244**. Results for goodness of fit statistics comparing field observed flow and the model flow are summarized in **Table 3-79**.

Table 3-78: Mosby Creek stream flow rate measurements.

Monitoring Location	Model KM	Flow Statistics	Flow (cms)	Date
28102-ORDEQ: Mosby Creek Above West Fork Mosby Creek	34.6	Instantaneous	0.08	7/21/2002
28101-ORDEQ: Mosby Creek Above Cedar Creek	21.0	Instantaneous	0.09	7/21/2002
30638-ORDEQ: Mosby Creek at Layng Road	1.1	Instantaneous	0.1	7/21/2002

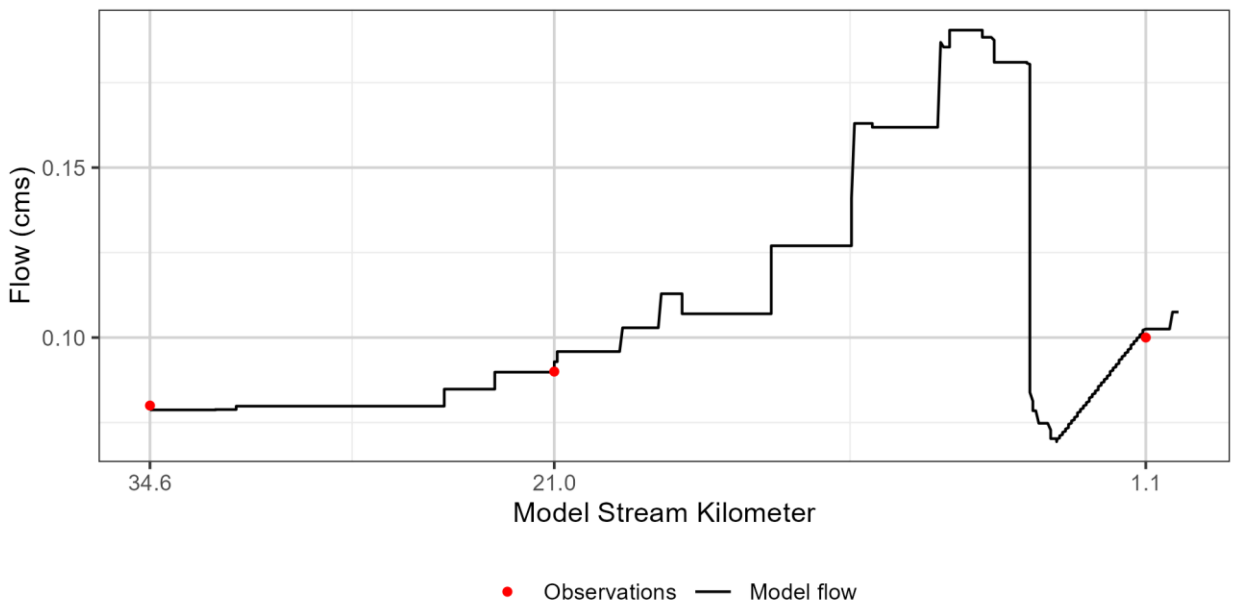


Figure 3-244: Mosby Creek field observed and model flow rates.

Table 3-79: Mosby River goodness of fit statistics comparing field observed and model flow rates.

N	R^2	ME	MAE	RMSE
3	0.99	0	0	0

3.11.10.4 Channel

Results comparing channels widths derived from GIS and modeling to those measured in the field are presented in **Figure 3-245**. Results shows channel widths only from streams modeled for temperature with Heat Source.

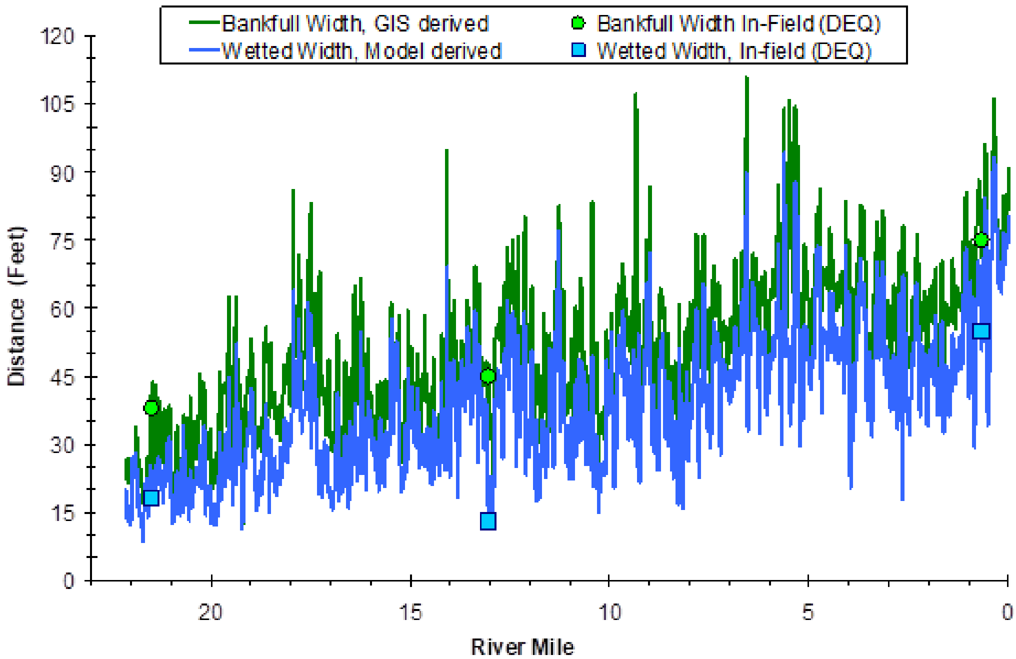


Figure 3-245: Mosby Creek field observed and derived bankfull and wetted width.

3.12 Southern Willamette shade

Between 2014 and 2018, DEQ developed a Heat Source version 9 shade model for streams in the southern portion of the Willamette Basin. The primary purpose of these models was to characterize the status of effective shade on project area streams and the gap between the current shade and the TMDL effective shade targets identified in the Willamette Basin TMDL (DEQ, 2006). Effective shade is a surrogate for solar radiation loading caused by the disturbance or removal of near stream vegetation. The model was developed and calibrated using high resolution LiDAR and 65 field-based effective shade measurements collected throughout the study area. Results were stratified by DMAs, HUC10 watersheds, and HUC12 subwatersheds.

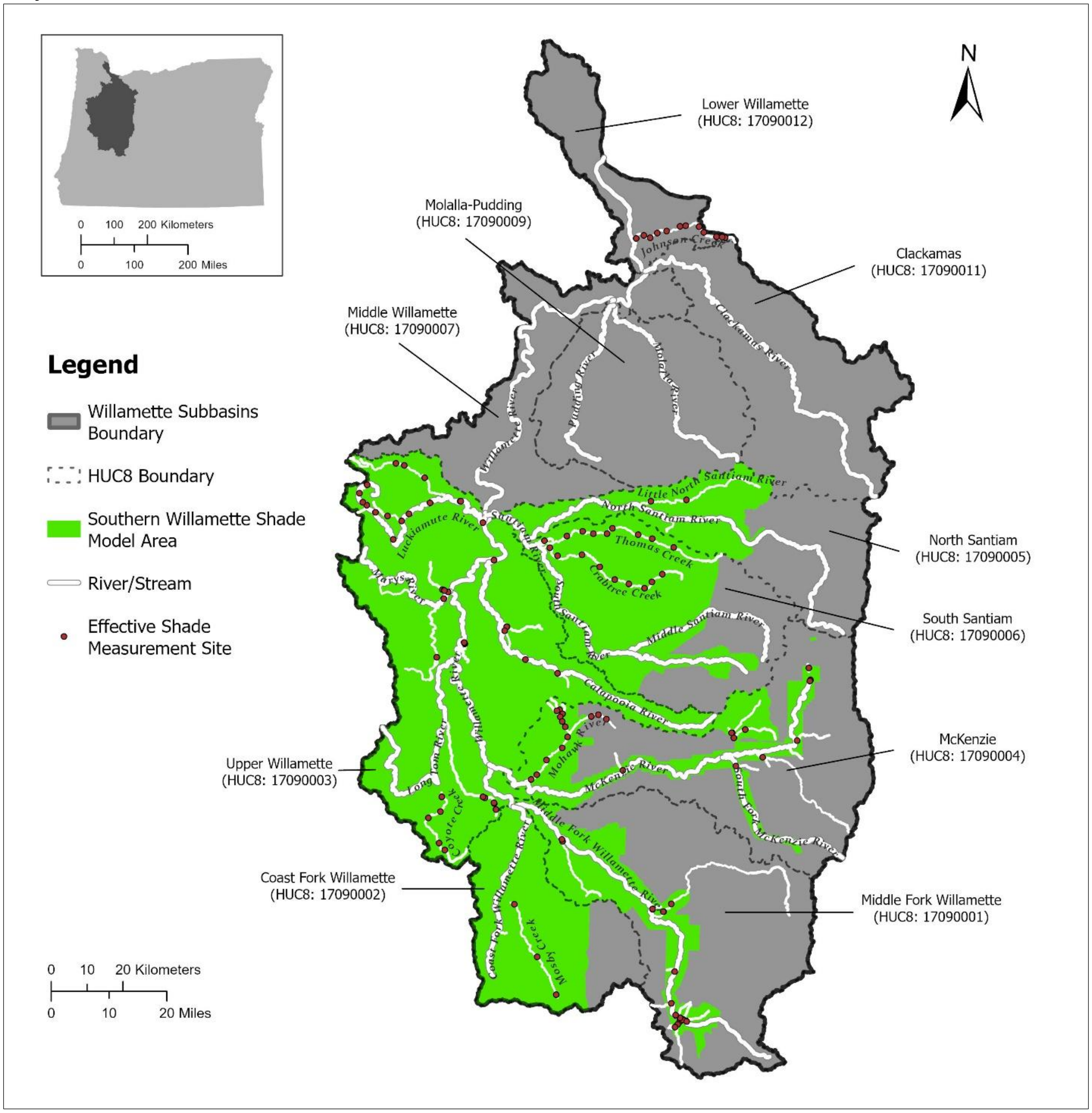
Several data sets used for model setup were derived using a GIS, associated spatial data, and a set of python-based scripting tools called TTools (Boyd and Kasper 2003). The scale and resolution of the derived data sets generally matched the resolution and accuracy of the input GIS data. The derived data sets include:

- Stream position
- Stream and ground elevation
- Topographic shade angles
- Land cover height

3.12.1 Model extent

Effective shade was modeled for streams mapped in the National Hydrography Dataset high resolution v2.2 database where LiDAR data was available in the Middle Fork Willamette

(17090001), Coast Fork Willamette (17090002), Upper Willamette (17090003), McKenzie (17090004), North Santiam (17090005), and South Santiam (17090006) Subbasins. These subbasins are all located in the southern half of the Willamette Basin (170900). The model area is shown in **Figure 3-246**. The model extent for the Southern Willamette excludes the Willamette River and major tributaries project area. Shade models for the Willamette River and major tributaries is discussed in Section 3.14.



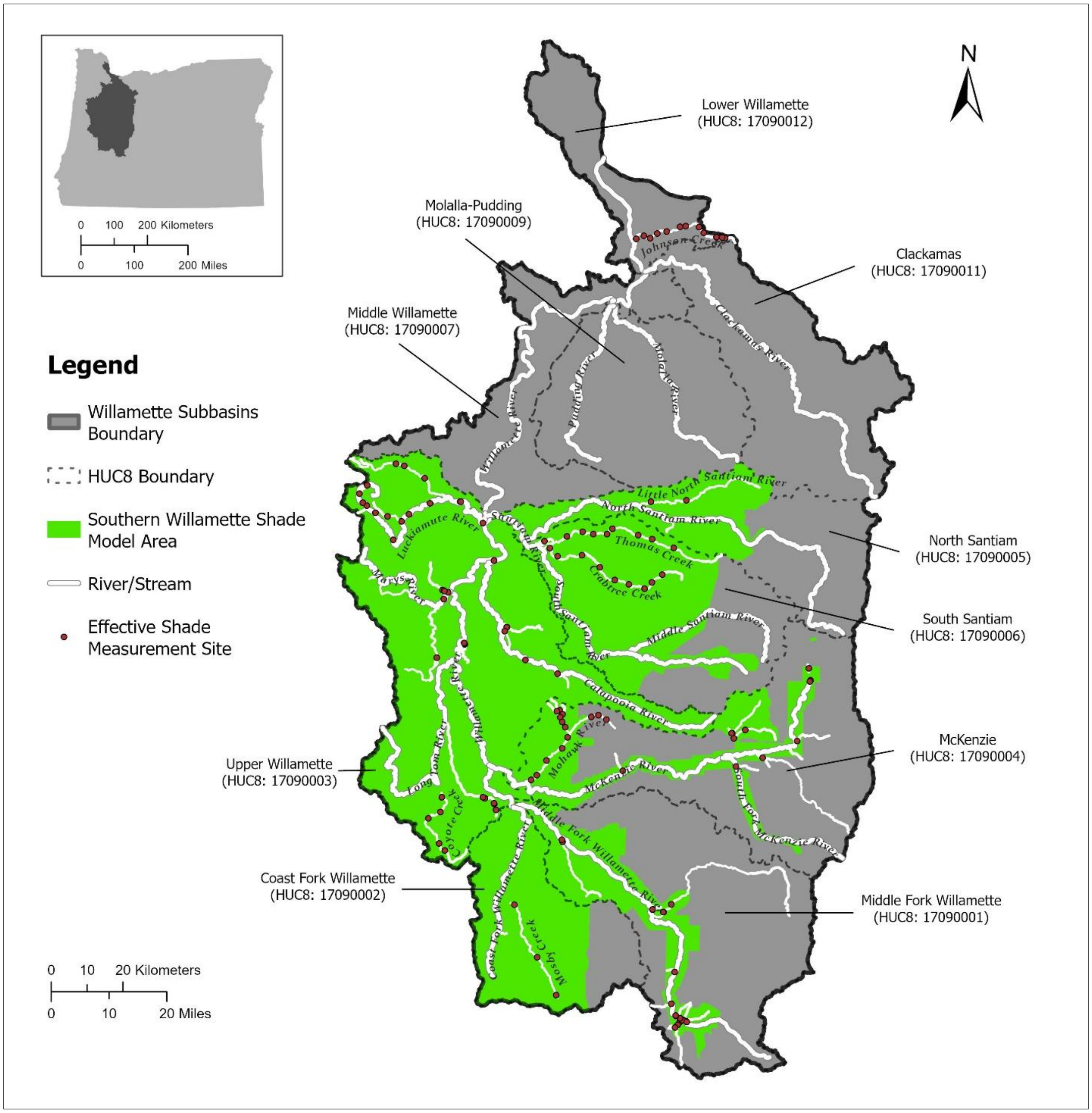


Figure 3-246: Effective shade and solar flux modeling area in the southern portion of the Willamette Basin (170900).

3.12.2 Spatial and temporal resolution

The model input spatial resolution (dx) is 200 m. Outputs were generated every 200 m. The model time step (dt) is 1 minute, and outputs are generated every hour. There is a total of 149500 nodes in the model.

3.12.3 Time frame of simulation

The model period is for a single day: August 15, 2014.

3.12.4 Meteorological inputs

The only meteorological input to the shade model is cloudiness. The model was set up to assume no cloud cover. This was done to isolate the solar radiation flux blocked by vegetation and topography only.

3.12.5 Spatial data

Multiple spatial GIS datasets were used to support model setup and configuration. **Table 3-80** identifies the GIS datasets used for the model setup and a brief summary of the application or derived data.

Table 3-80: Spatial data used to support model setup and configuration.

Spatial Data	Source	Application
LiDAR Bare Earth (DEM), LiDAR Highest Hit (DSM)	Watershed Sciences 2009, 2010, 2012a, 2012b; WSI 2012a, 2012b, 2013, and 2015	The LiDAR bare earth DEM is used to estimate topographic shading angles and land surface elevation. The difference between the bare earth DEM and highest hit DSM was used to derive vegetation canopy height.
National Hydrography Dataset high resolution v2.2	USGS 2014	Mapping stream position and location.
National Wetland Inventory (NWI)	USFWS 2004	The NWI was used to identify the location of open water and wetlands for development of the site potential vegetation model scenario.
Quaternary Geologic Units	O'Connor et al., 2001	The Quaternary geologic units were used to map and derive the appropriate site potential vegetation types identified in the Willamette Basin TMDL (DEQ, 2006).

As detailed in Section 2.2.2, LiDAR is a remote sensing method. The LiDAR bare earth DEM was used to estimate topographic shading angles and land surface elevation. The difference between the bare earth DEM and highest hit DSM was used to derive and characterize vegetation canopy height. All LiDAR datasets used in this study had a uniform three foot horizontal resolution.

The LiDAR datasets utilized in this study were collected between 2008 and 2014. The most recent LiDAR datasets were used at locations with overlapping LiDAR datasets collected in different years. **Figure 3-247** shows the location of existing LiDAR in the Southern Willamette Basin and the most recent year of acquisition at the time of the study.

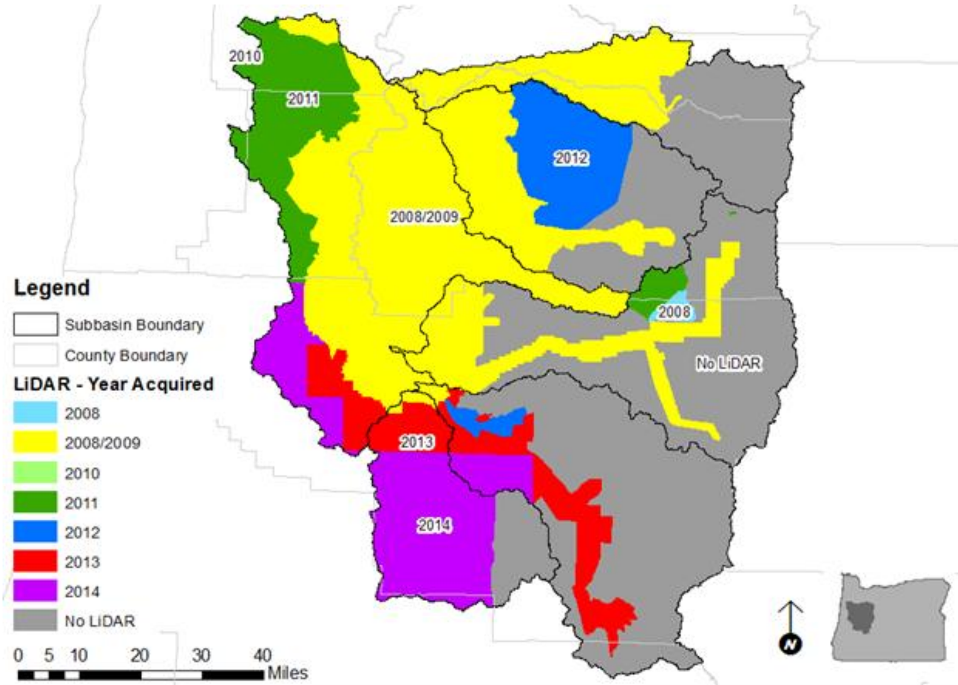


Figure 3-247: Location and year of LiDAR acquisition.

3.12.6 Stream Position

The stream position was determined using the National Hydrography Dataset high resolution v2.2 database. The NHD flowlines were segmented into 200 meter reaches with a node separating each 200-meter reach. These nodes determine the location for shade modeling. Stream segmentation was completed using a python script called TTools.

The stream flowlines in this version of NHD were primarily digitized from aerial photographs using a similar method that DEQ has used for other TMDLs, including the 2006 TMDL effort. In places where the stream is masked by forest cover, it is often hard to “see” the stream channel and this can result in the digitized line not always matching the true location of the stream. DEQ considered remapping the stream locations by modeling the flow path using the LiDAR bare earth DEMs. This approach has shown to improve accuracy. The limitation with this approach is that it requires significant effort to identify and correct the DEM in places where road culverts occur. Because of the large project area and number of road crossings, it was determined that remapping the stream locations required an effort and timeline that did not align with the project schedule or available resources. As a result, in forested areas where the stream is not visible, the position of the stream is less certain.

3.12.7 Stream Elevation

The elevation at each stream node was derived from three-foot resolution LiDAR bare earth elevation DEMs.

3.12.8 Canopy Height

A three-foot resolution land cover height raster was derived by subtracting the LiDAR bare earth elevation rasters from the LiDAR highest hit elevation rasters. The canopy height raster was used to characterize the vegetation and other land cover height along the stream. The characterization was completed using TTools. At each stream node, TTools samples the canopy height along a set of eight transects that form a star pattern around the node (**Figure 3-248**). The transects radiate around the node toward the northeast, east, southeast, south, southwest, west, northwest, and north. Along each transect the canopy height was sampled every five meters starting at the channel center out to 75 m. This sampling rate resulted in 120 samples per node.

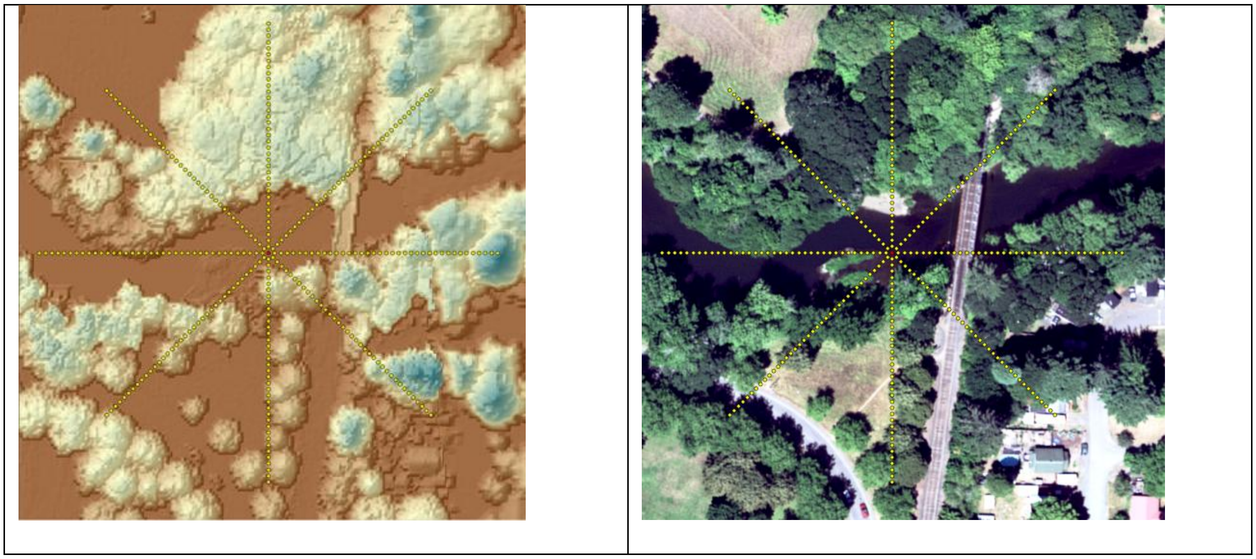


Figure 3-248: Example of the star pattern canopy height sampling at the MAR1 sample site. LiDAR derived height on the left and the same location as depicted in 2018 aerial imagery on the right. The stream node is depicted in red at the center.

3.12.9 Calibration results

The model was calibrated primarily by comparing the model effective shade predictions to the field measured effective shade values summarized in **Table 2-38**. To improve the calibration results global changes to the canopy cover parameter were made iteratively. Canopy cover was the only calibration parameter adjusted. The final calibrated canopy cover value was 0.80 (80%). Other potential calibration parameters (landcover height and landcover overhang) were determined directly from LiDAR and were not adjusted.

Goodness of fit statistics were calculated to compare the model-predicted shade results to the associated observed shade measurements. The statistics calculated include the coefficient of determination, mean error, mean absolute error, and root mean squared error. Results are presented in **Table 3-81**. A scatter plot of the measured and model-predicted results are shown in **Figure 3-249**. Overall, these results are considered good. The mean error is 0.9 percent effective shade points indicating the model does not have an under or over prediction bias relative to the field measured values.

Table 3-81: Southern Willamette effective shade model goodness of fit statistics.

N	R^2	ME	MAE	RMSE
65	0.87	0.9	7.7	11

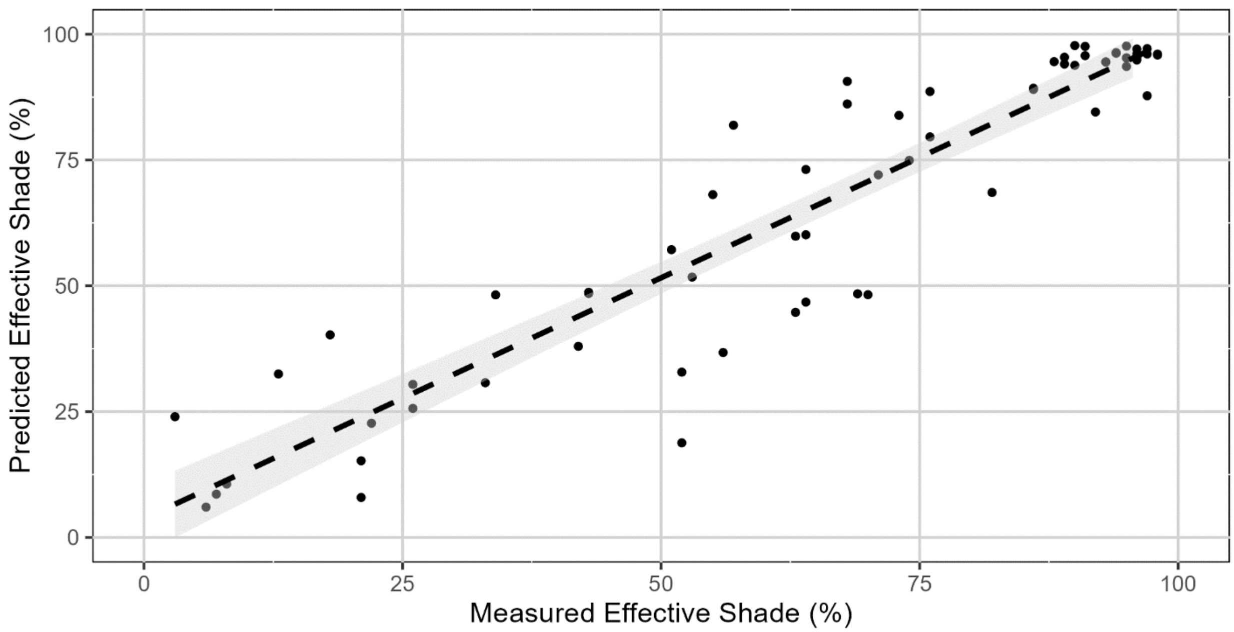


Figure 3-249: Southern Willamette measured and predicted effective shade. The dashed line is the best fit line, and the grey area represents the confidence interval.

3.13 Lower Willamette shade

The City of Portland developed Heat Source version 9 shade models for streams in the Lower Willamette Subbasins. The primary purpose of these models was to characterize the status of effective shade on project area streams and the gap between the current shade and the TMDL effective shade targets identified in the Willamette Basin TMDL (DEQ, 2006). See Technical Support Document (TSD) Appendix B for model set up and calibration details.

3.14 Willamette River and major tributaries

DEQ developed Heat Source version 6 shade models for all rivers included in the Willamette River and major tributaries project area. The modeled rivers include:

- Willamette River
- Clackamas River
- Coast Fork Willamette River
- Fall Creek
- Long Tom River
- Middle Fork Willamette River
- North Santiam River
- Row River
- Santiam River
- South Santiam River

The primary purpose of these models was to characterize the status of effective shade and the gap between the existing shade and the TMDL effective shade targets. The shade models were also used to derive the shade files for the CE-QUAL-W2 temperature models developed for the 2006 TMDL (Annear et al. 2004; Berger et al. 2004; Sullivan and Rounds 2004; ODEQ 2006) and the models used for the revised temperature TMDL (Stratton Garvin et al. 2022) and Technical Support Document (TSD) Appendix J – M.

Several data sets used for model setup were derived using a GIS, associated spatial data, and a set of python-based scripting tools called TTools (Boyd and Kasper 2003). The scale and resolution of the derived data sets generally matched the resolution and accuracy of the input GIS data. See Section 2.3 for details. The derived data sets include:

- Stream position
- Stream and ground elevation
- Topographic shade angles
- Land cover height

3.14.1 Model Extent

Effective shade was modeled for the river extents described in Table 3-82 and mapped in Figure 3-250 through Figure 3-259.

Table 3-82: Model domain extents for the Willamette River and major tributaries.

River	Model Extent
Willamette River	From Willamette Falls at approximately river mile 26.5 to the confluence of the Coast and Middle Forks of the Willamette River at approximately river mile 187 (**Figure 3-250**)
Clackamas River	From the confluence with the Willamette River upstream to River Mill Dam/Estacada Lake at approximately river mile 26 (**Figure 3-251**)
Coast Fork Willamette River	From the confluence with the Willamette River upstream to Cottage Grove Dam at approximately river mile 30 (**Figure 3-252**)
Fall Creek	From the confluence with the Middle Fork Willamette River upstream to Fall Creek Dam at approximately river mile 7 (**Figure 3-253**)
Long Tom River	From the confluence with the Willamette River upstream to Fern Ridge Dam at approximately river mile 26 (**Figure 3-254**)
Middle Fork Willamette River	From the confluence with the Willamette River upstream to Dexter Dam at approximately river mile 17 (**Figure 3-255**)
North Santiam River	From the confluence with the Santiam River upstream to Detroit Dam at approximately river mile 49 (**Figure 3-256**)
Row River	From the confluence with the Coast Fork Willamette River upstream to Dorena Dam at approximately river mile 7.5 (**Figure 3-257**)
Santiam River	From the confluence with the Willamette River upstream to the confluence of the North and South Santiam Rivers at approximately river mile 12 (**Figure 3-258**)
South Santiam River	From the confluence with the Santiam River upstream to Foster Dam at approximately river mile 38 (**Figure 3-259**)

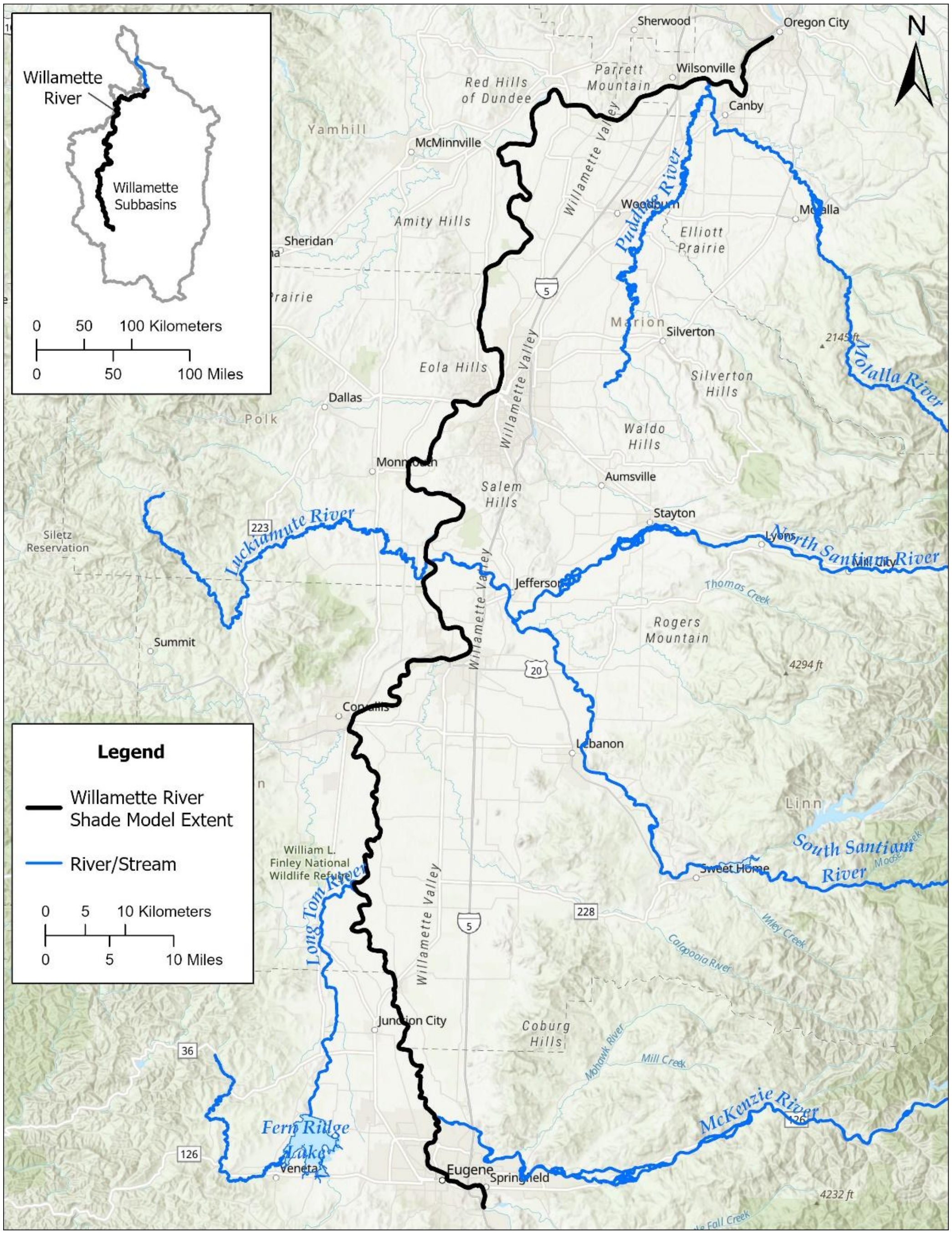


Figure 3-250: Willamette River effective shade model extent.

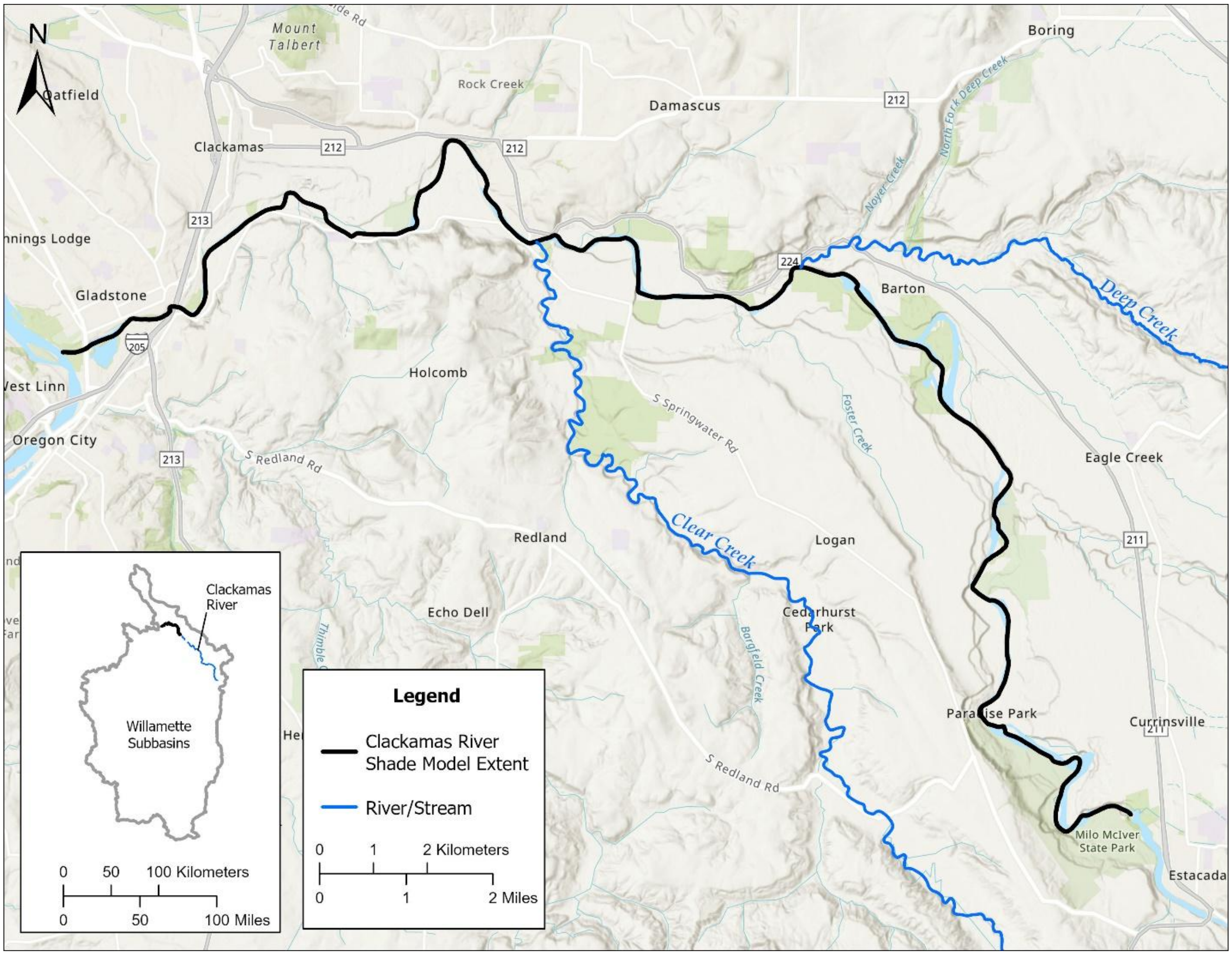


Figure 3-251: Clackamas River effective shade model extent.

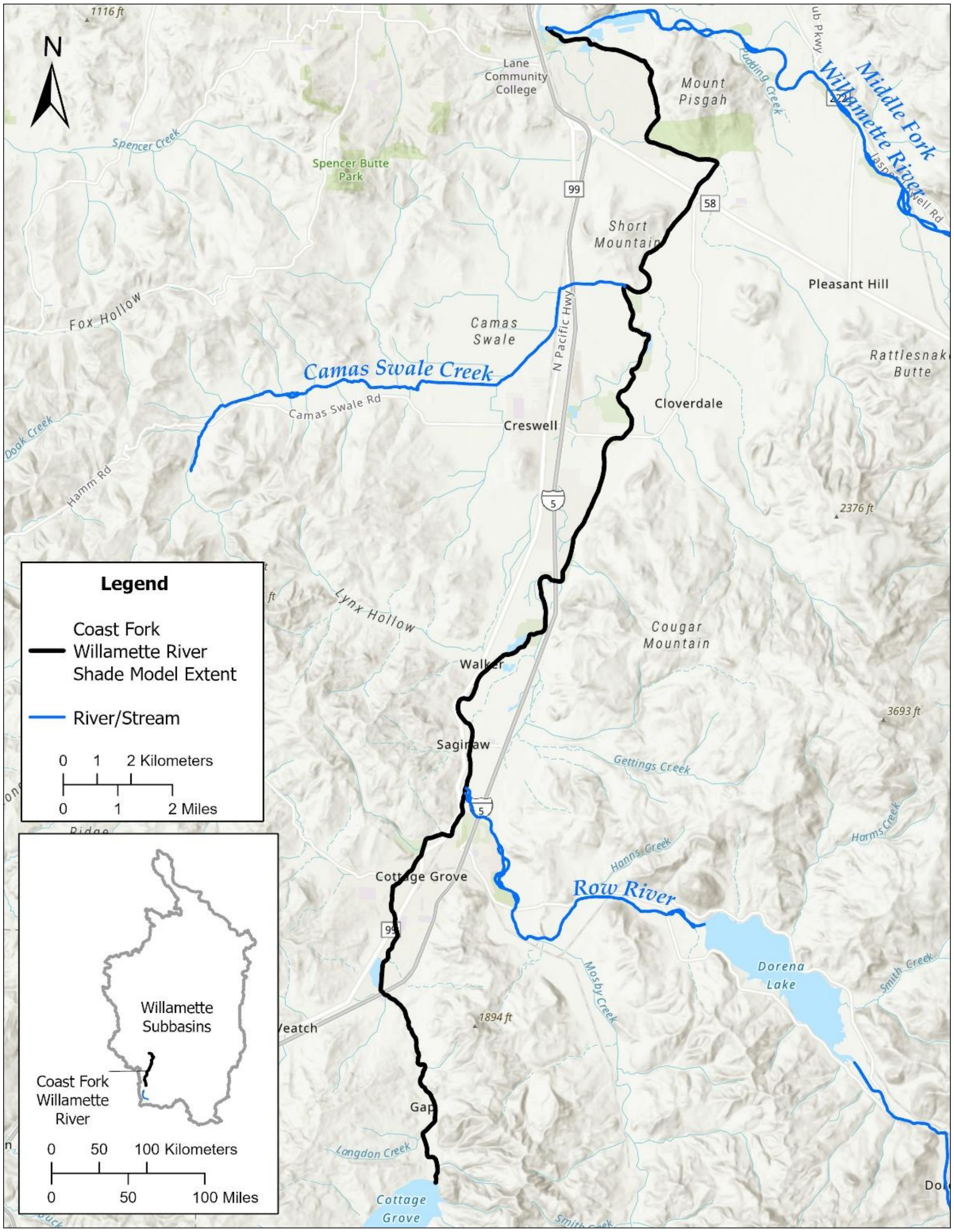


Figure 3-252: Coast Fork Willamette River effective shade model extent.

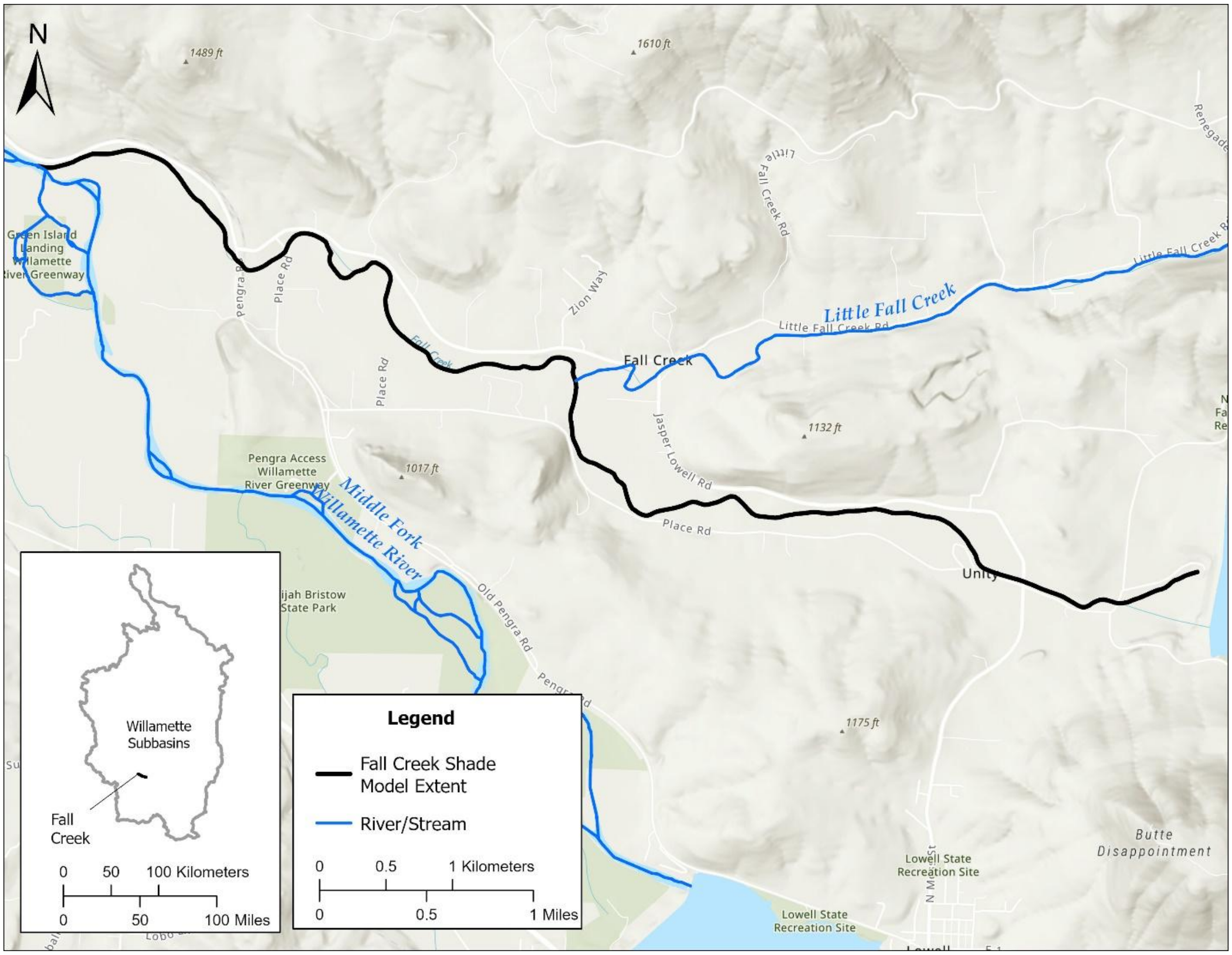


Figure 3-253: Fall Creek effective shade model extent.

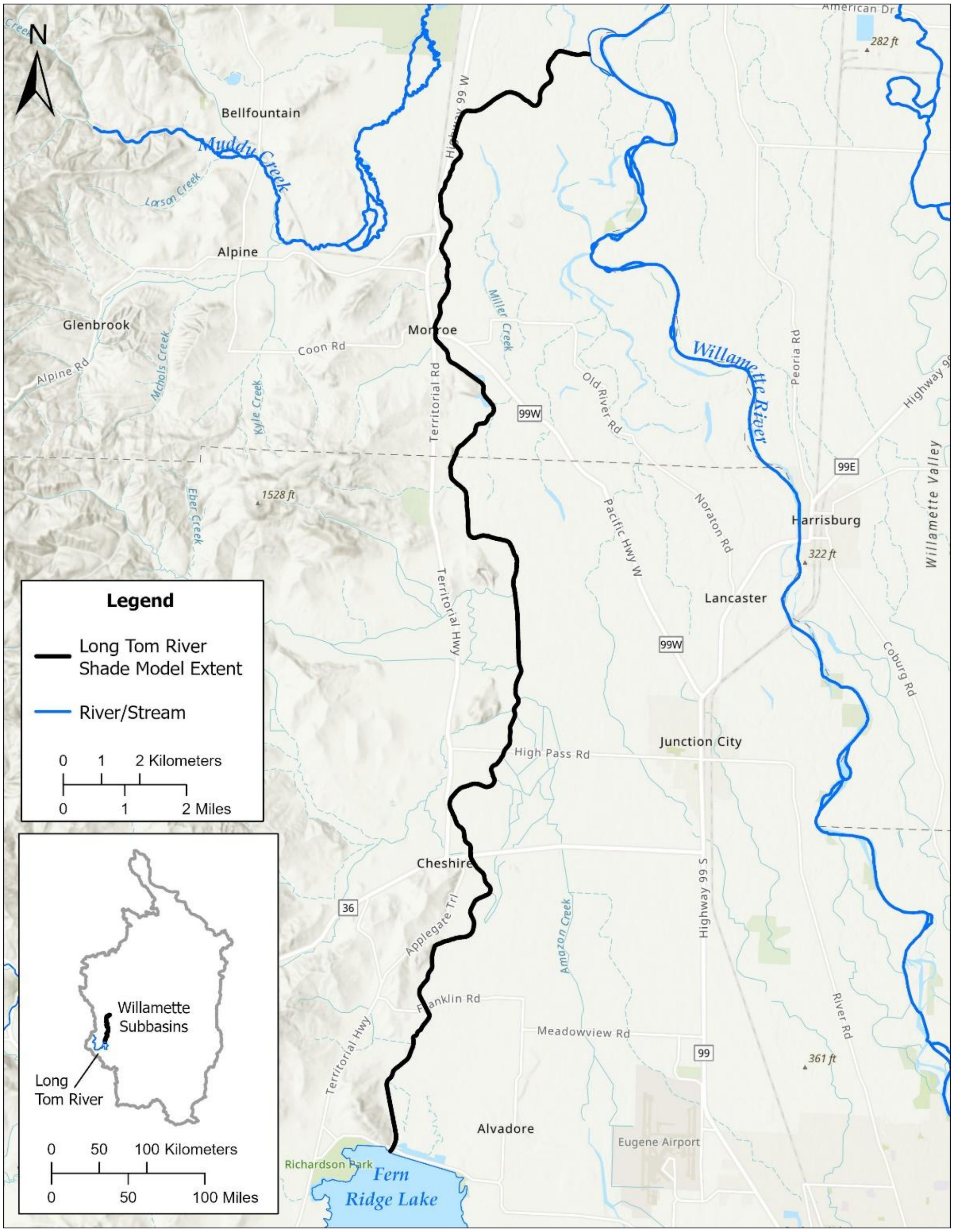


Figure 3-254: Long Tom River effective shade model extent.

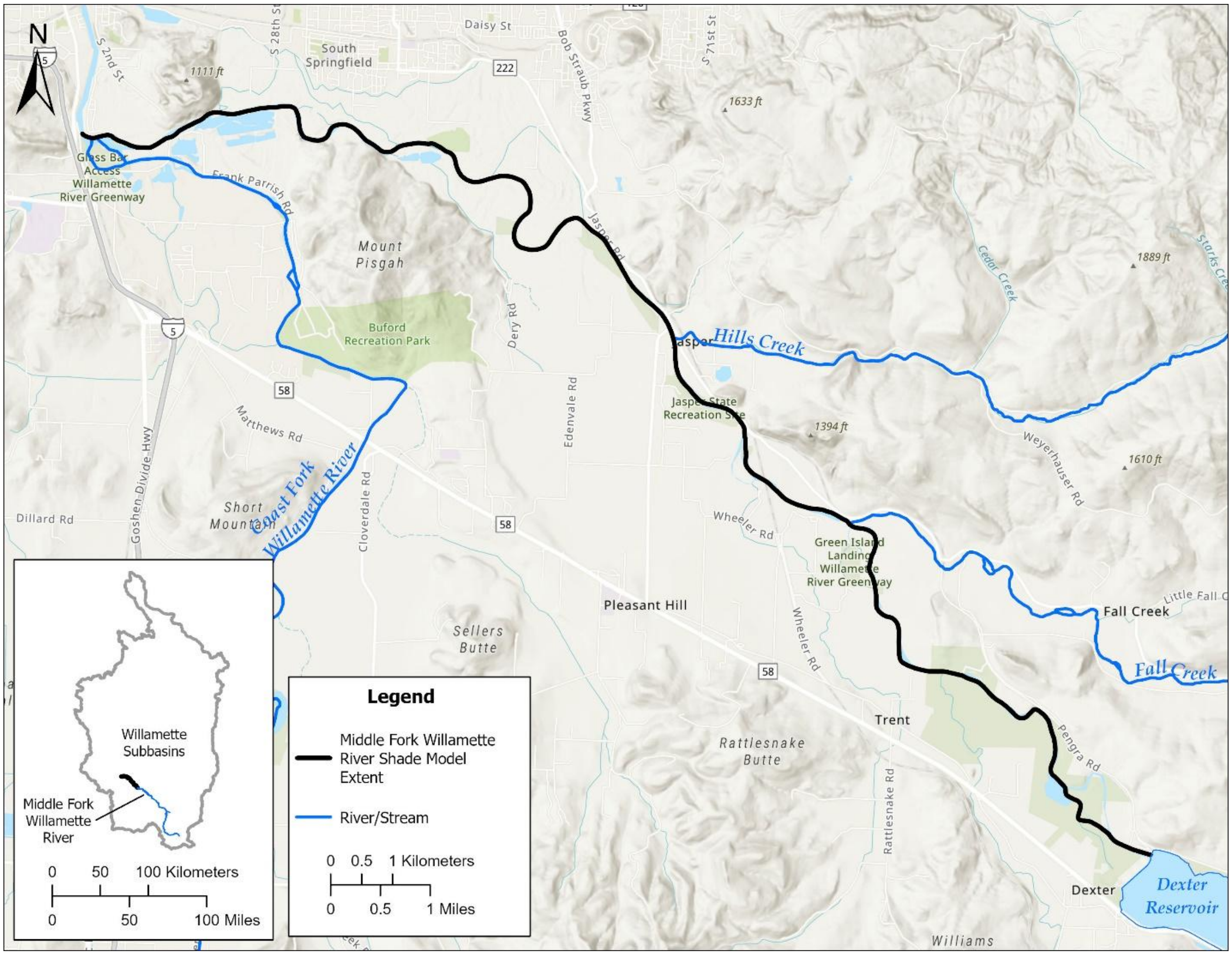


Figure 3-255: Middle Fork Willamette River effective shade model extent.

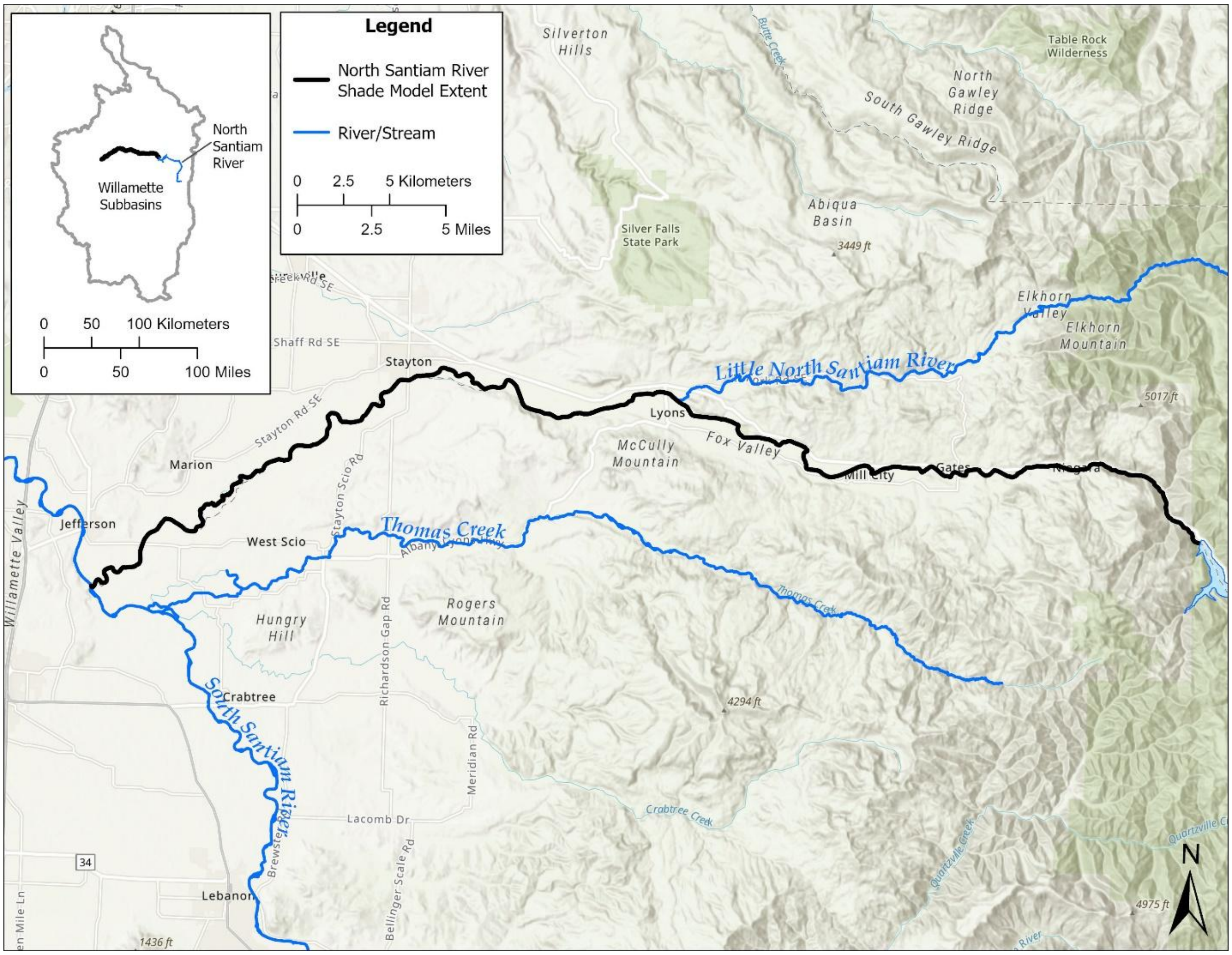


Figure 3-256: North Santiam River effective shade model extent.

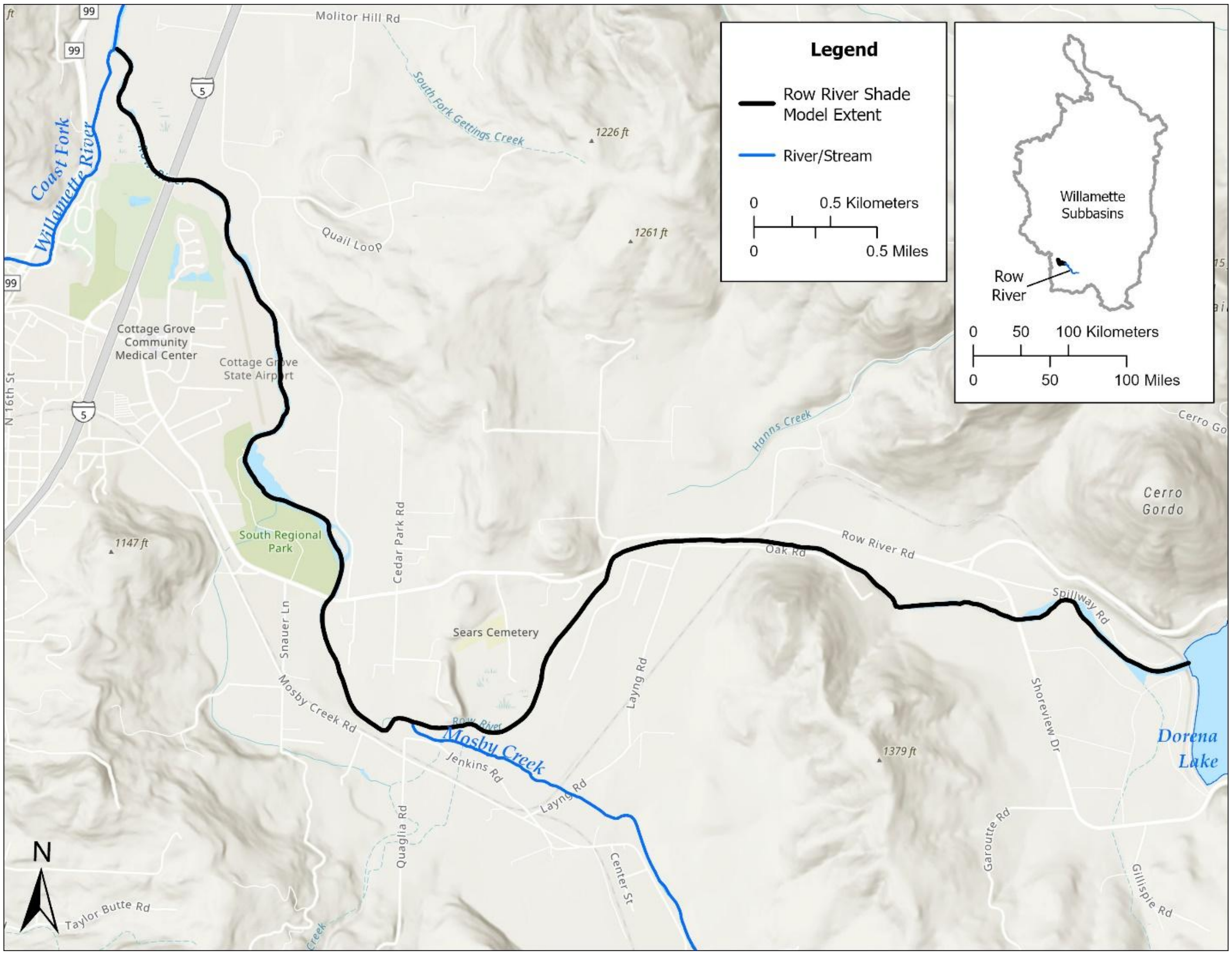


Figure 3-257: Row River effective shade model extent.

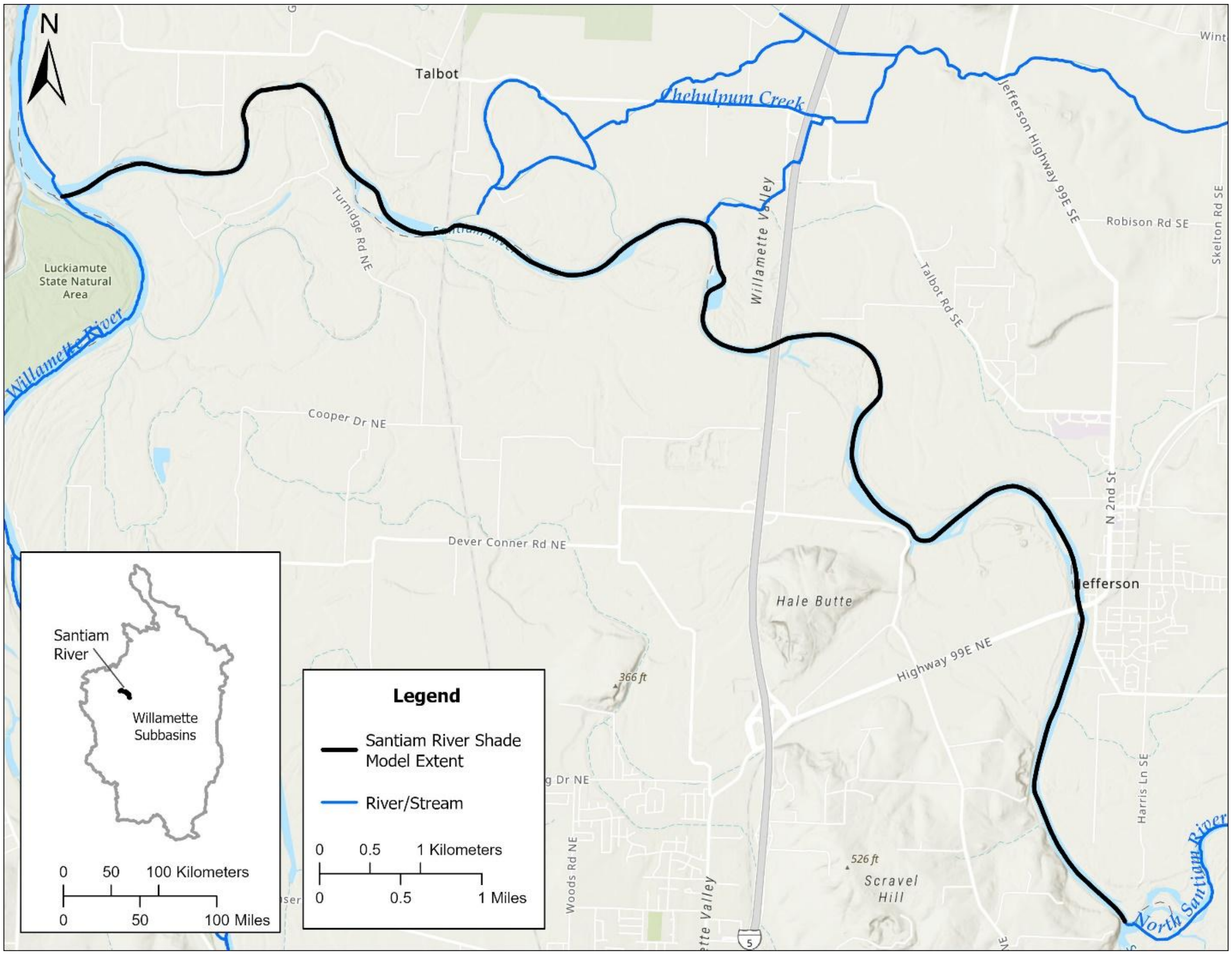


Figure 3-258: Santiam River effective shade model extent.

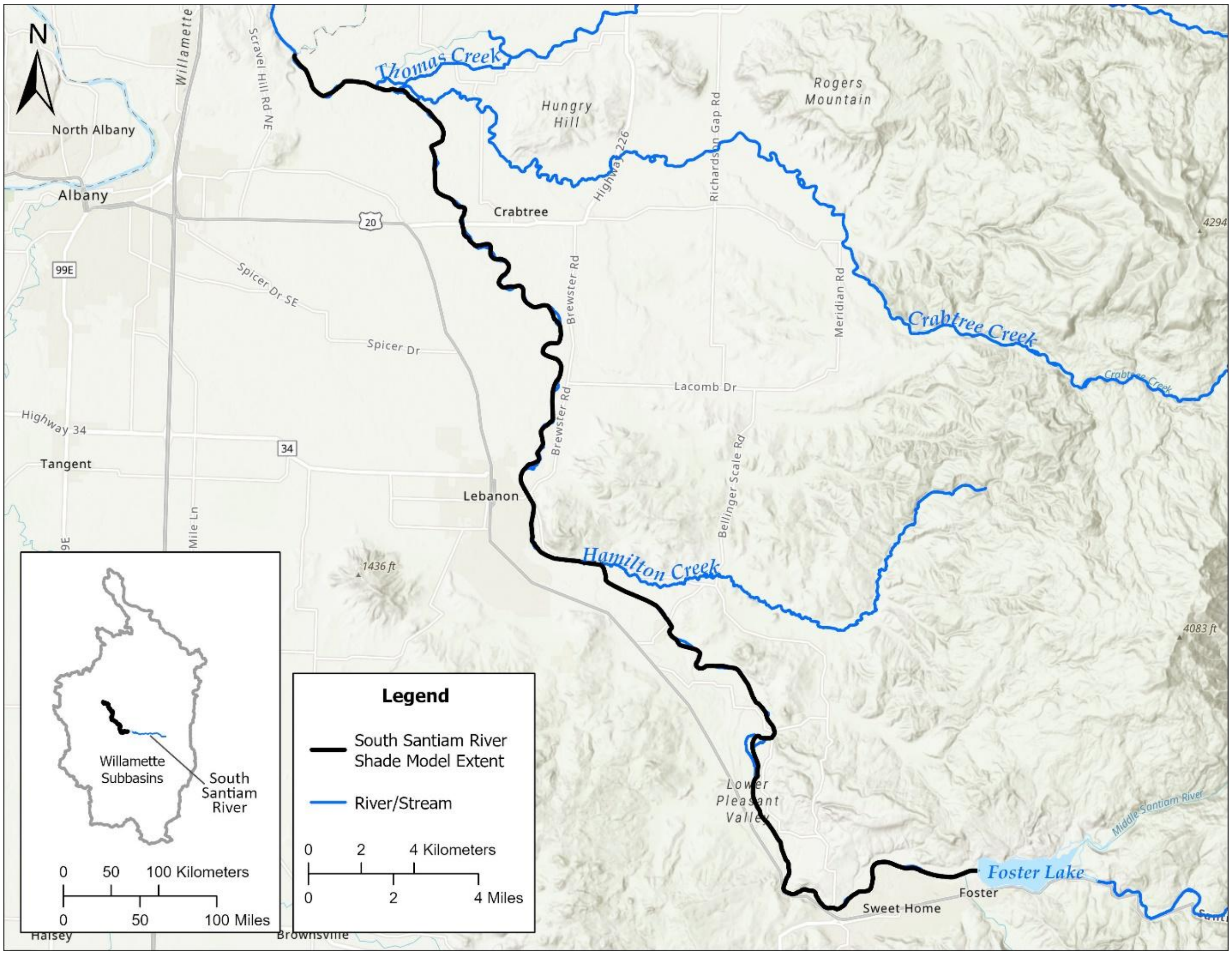


Figure 3-259: South Santiam River effective shade model extent.

3.14.2 Spatial and temporal resolution

The model input spatial resolution (dx) is 30.48 meters (100 feet). Outputs are generated every 30.48 meters (100 feet). The model time step (dt) is 10 minutes and solar flux outputs are generated every hour. Effective shade outputs are calculated daily.

3.14.3 Time frame of simulation

The model period is for a single day and varies by modeled extent:

- August 1, 2001: Willamette River, Clackamas River, Coast Fork Willamette River, Long Tom River, North Santiam River, Santiam River, South Santiam River
- July 1, 2002: Row River
- July 2, 2002: Middle Fork Willamette River
- July 3, 2002: Fall Creek

3.14.4 Meteorological inputs

Heat Source 6 shade models assume no cloud cover. This ensures the shade estimates are based on the solar radiation flux blocked by vegetation and topography only. Cloud cover is controlled in the CE-QUAL-W2 temperature model.

3.14.5 Landcover and topographic shade inputs

Average land cover height inputs and topographic shade angle inputs for the Willamette River and major tributary models are shown in **Figure 3-260** through **Figure 3-279**.

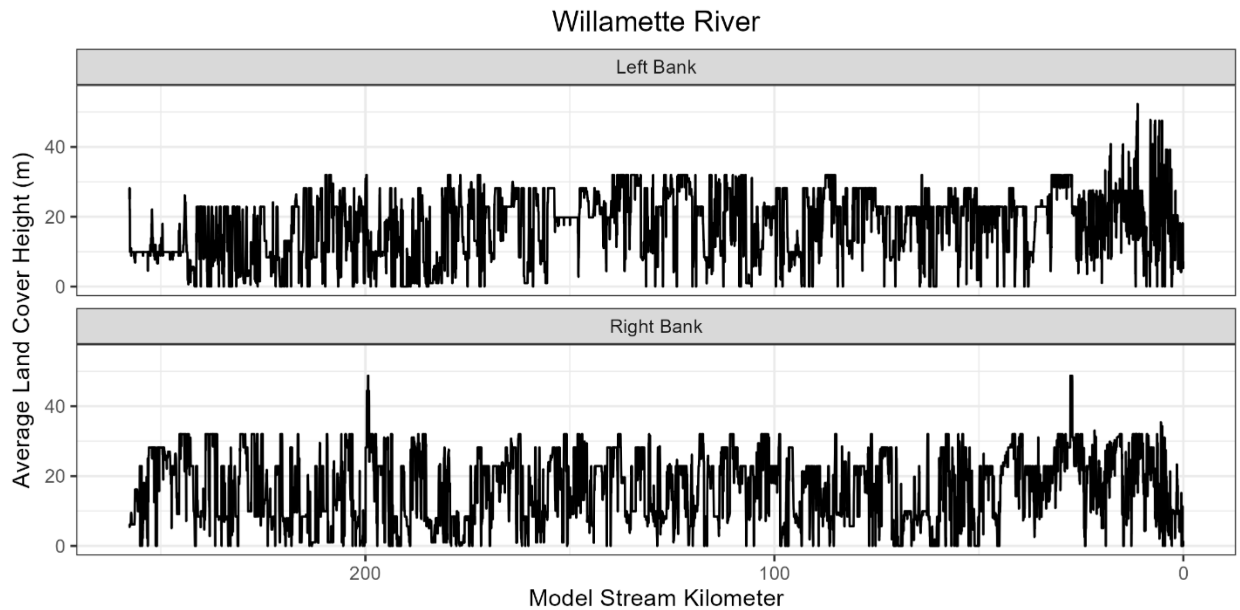


Figure 3-260: Average land cover height inputs to the Willamette River effective shade model.

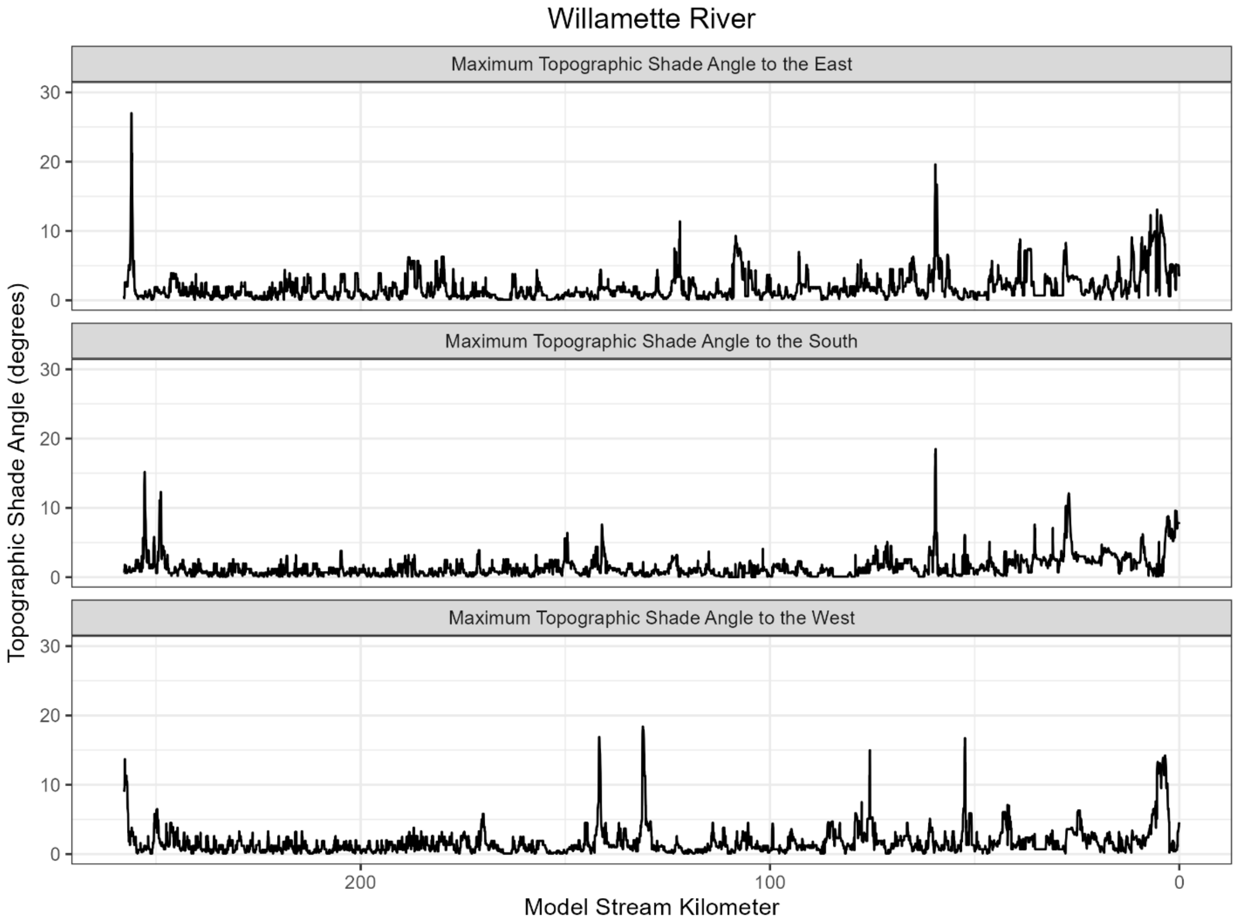


Figure 3-261: Topographic shade angle inputs to the Willamette River effective shade model.

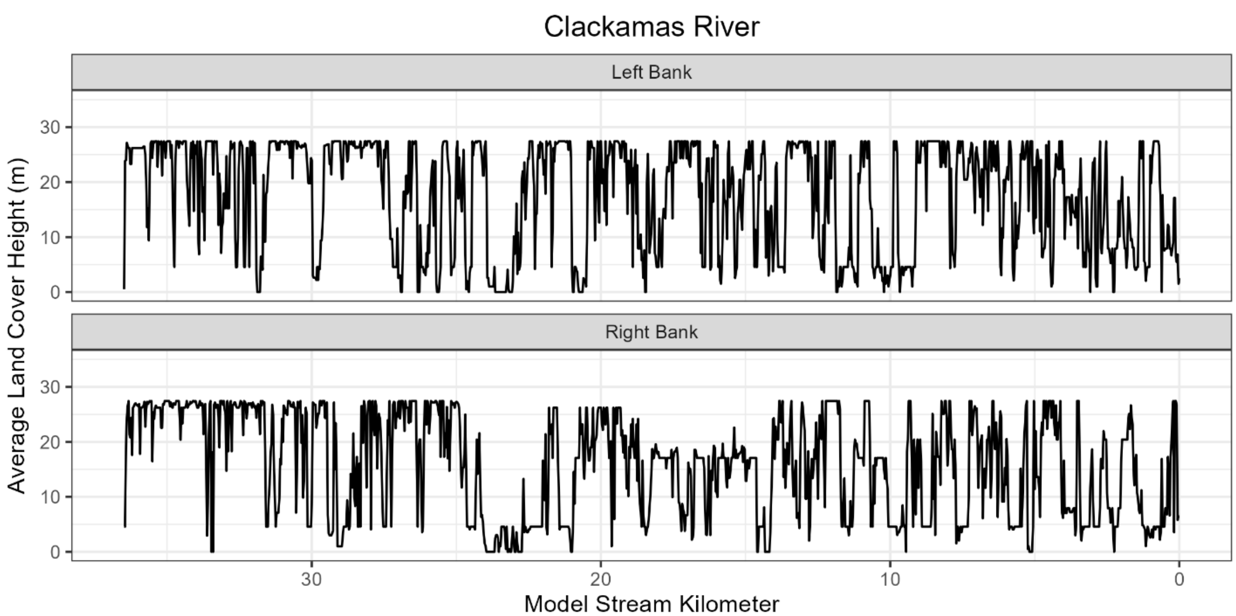


Figure 3-262: Average land cover height inputs to the Clackamas River effective shade model.

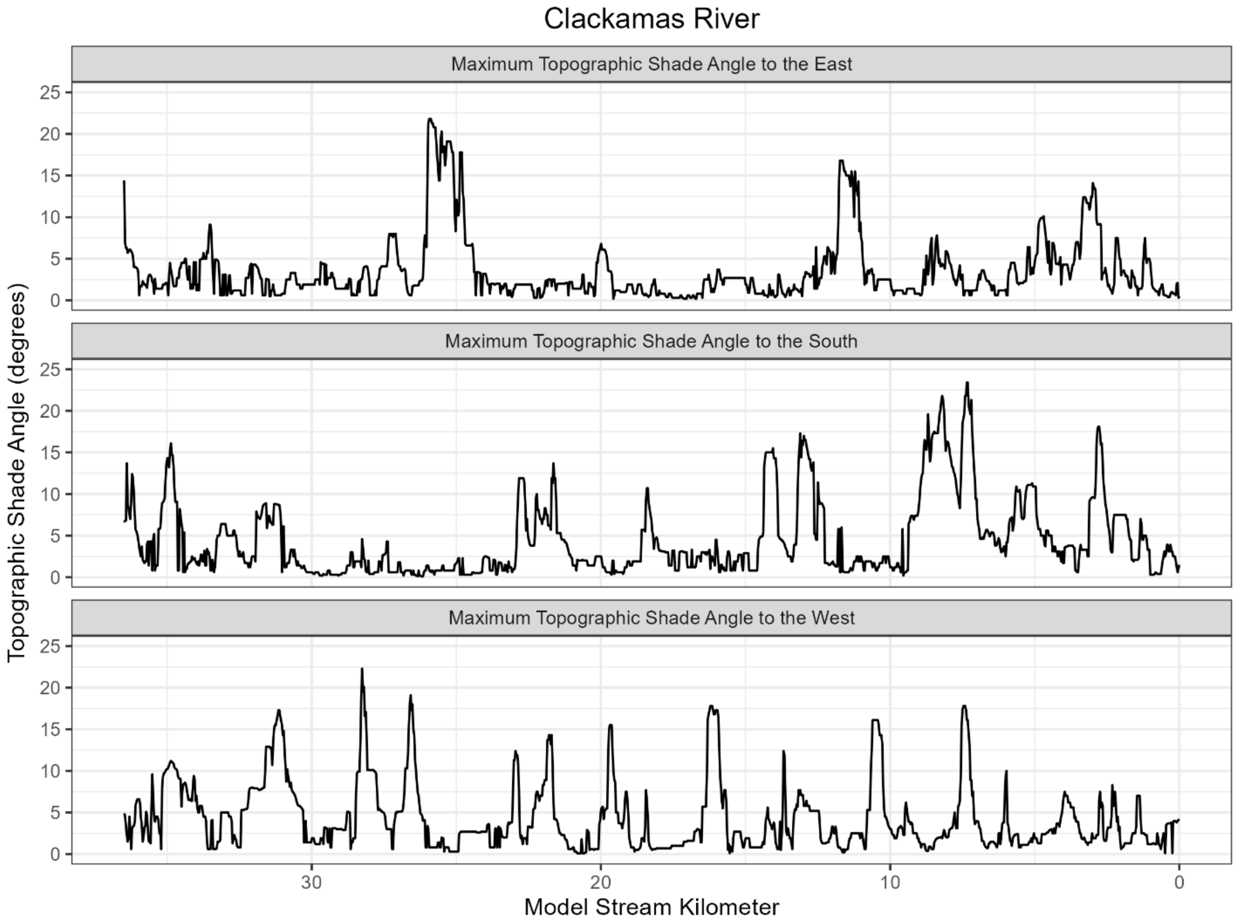


Figure 3-263: Topographic shade angle inputs to the Clackamas River effective shade model.

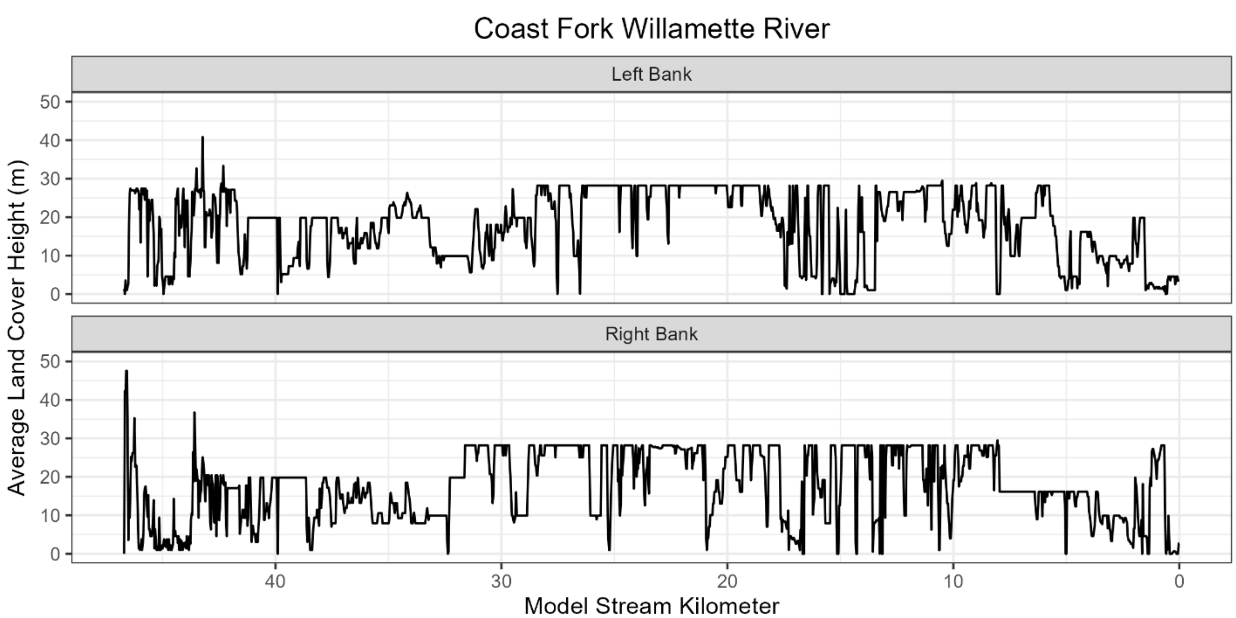


Figure 3-264: Average land cover height inputs to the Coast Fork Willamette River effective shade model.

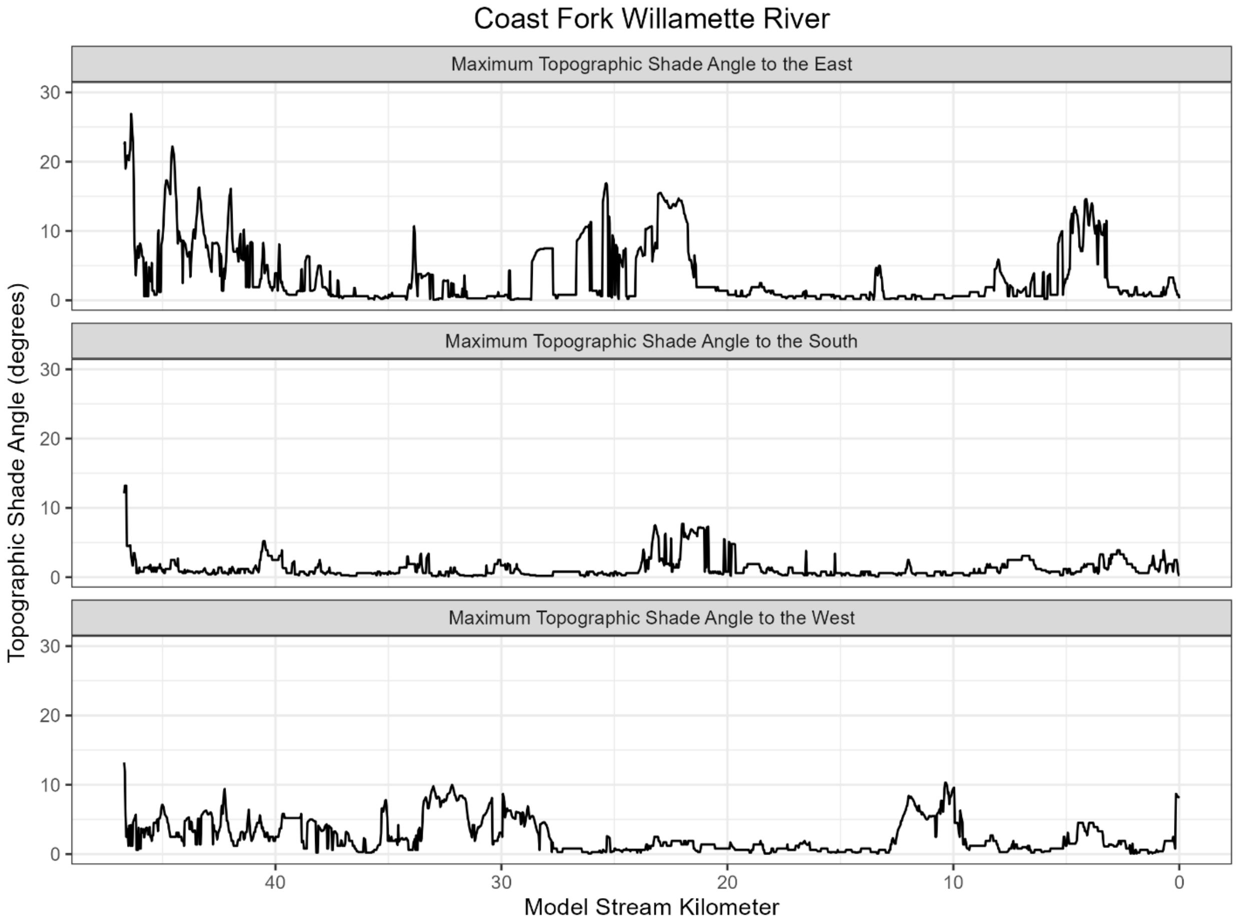


Figure 3-265: Topographic shade angle inputs to the Coast Fork Willamette River effective shade model.

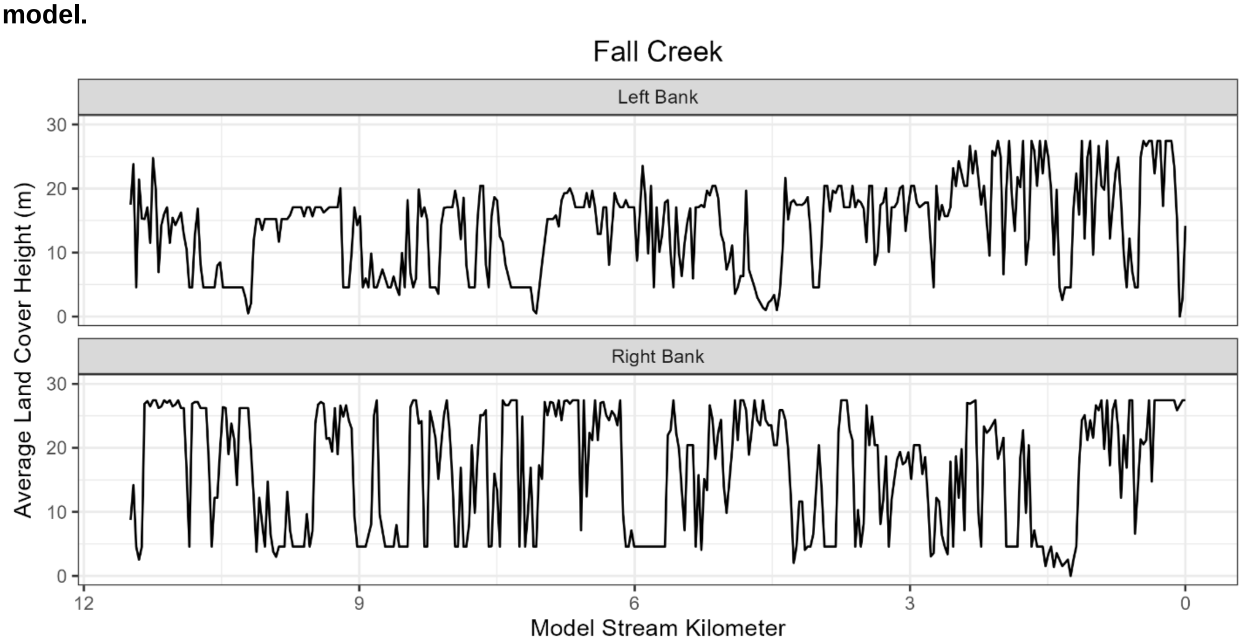


Figure 3-266: Average land cover height inputs to the Fall Creek effective shade model.

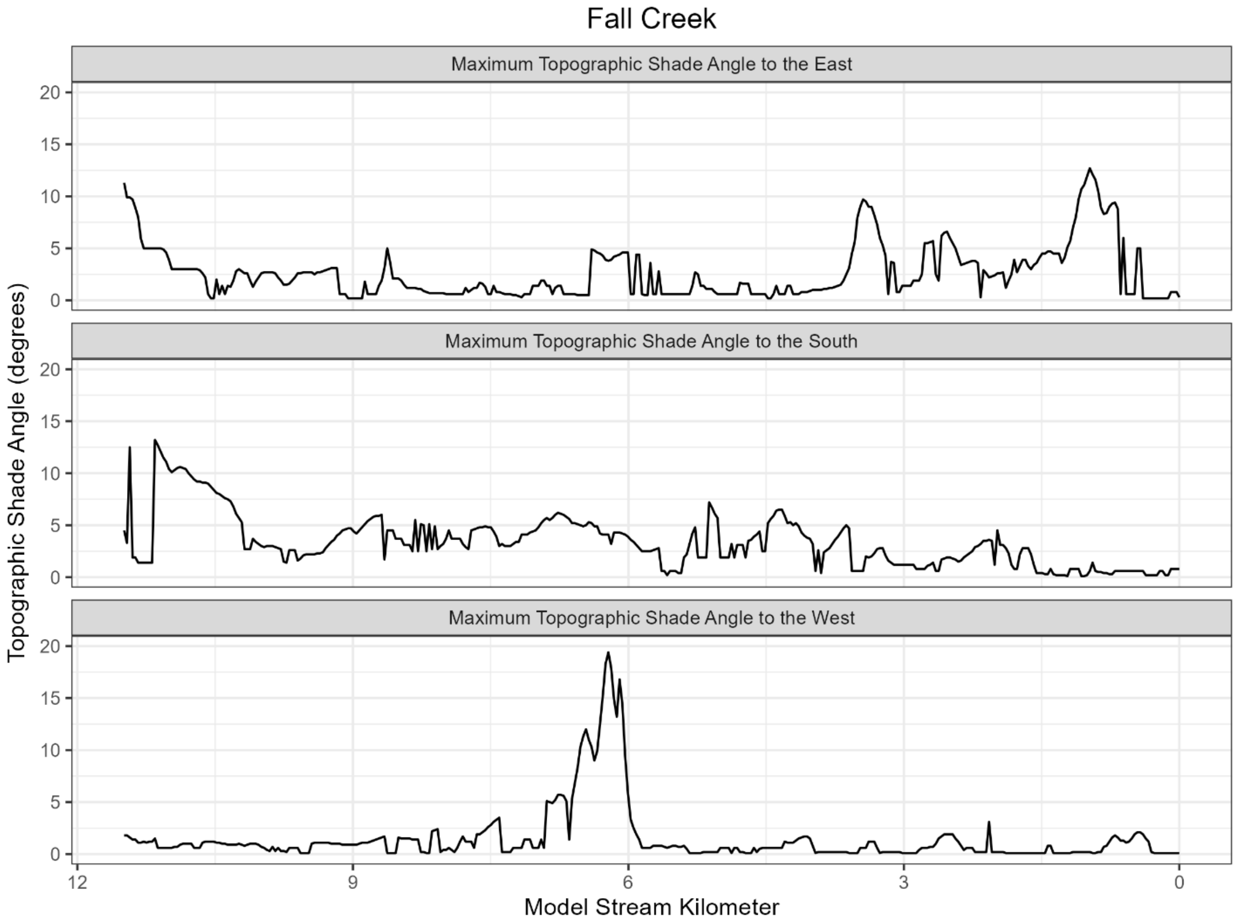


Figure 3-267: Topographic shade angle inputs to the Fall Creek effective shade model.

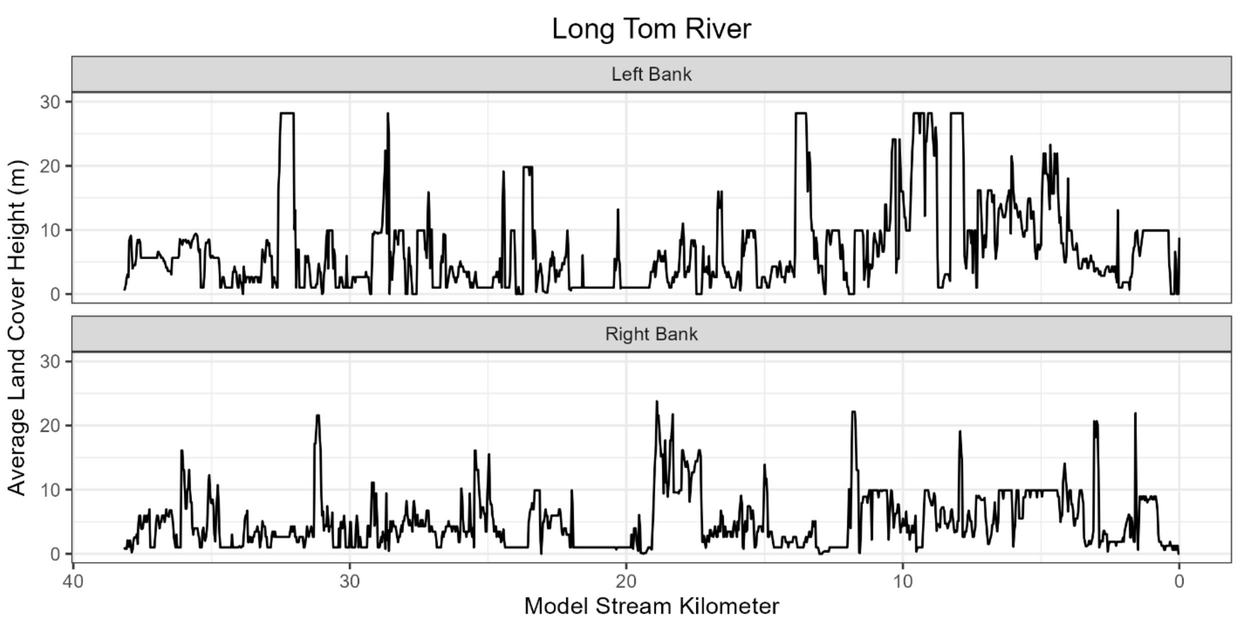


Figure 3-268: Average land cover height inputs to the Long Tom River effective shade model.

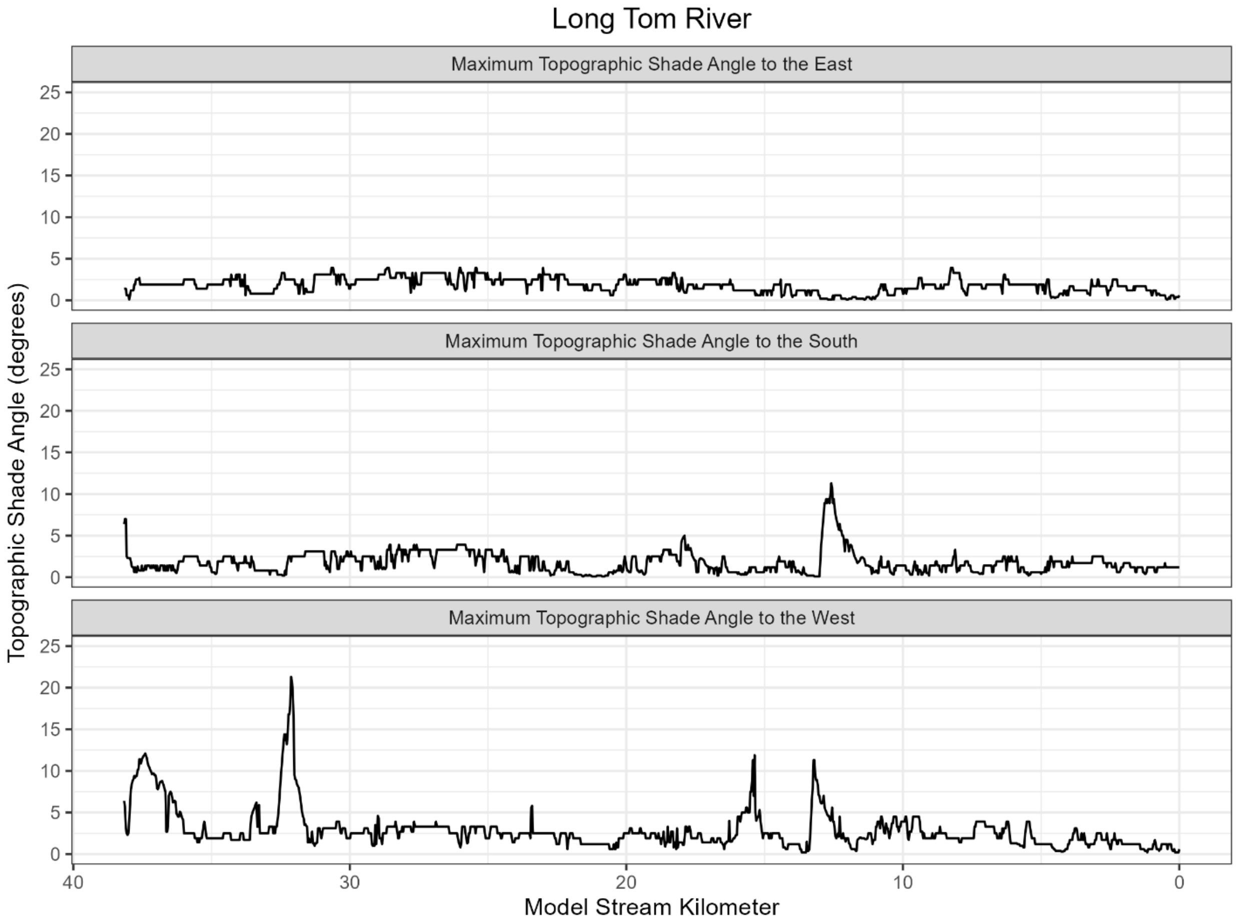


Figure 3-269: Topographic shade angle inputs to the Long Tom River effective shade model.

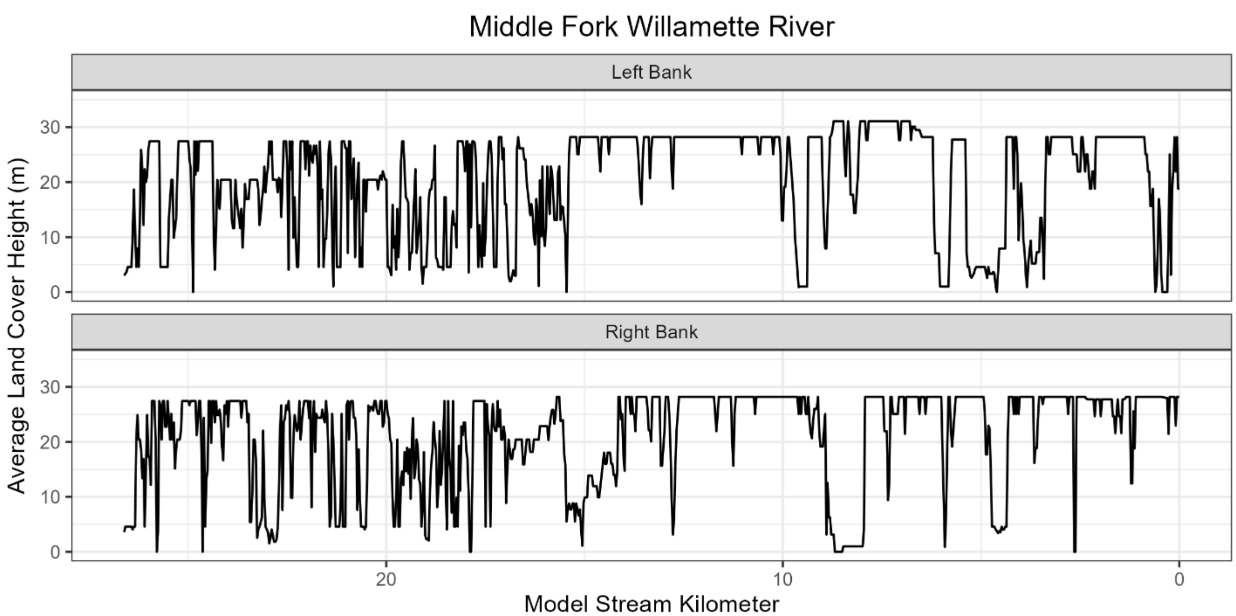


Figure 3-270: Average land cover height inputs to the Middle Fork Willamette River effective shade model.

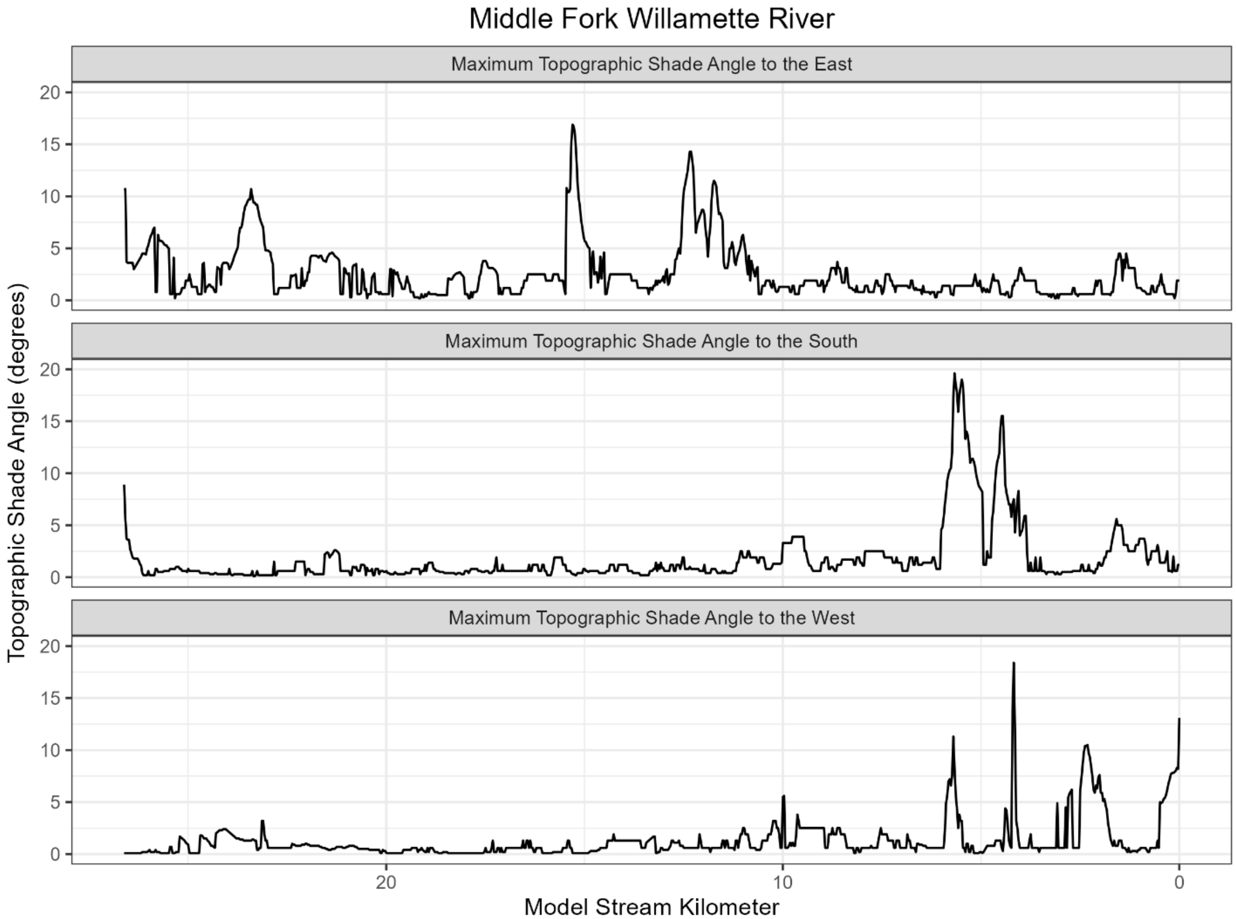


Figure 3-271: Topographic shade angle inputs to the Middle Fork Willamette River effective shade model.

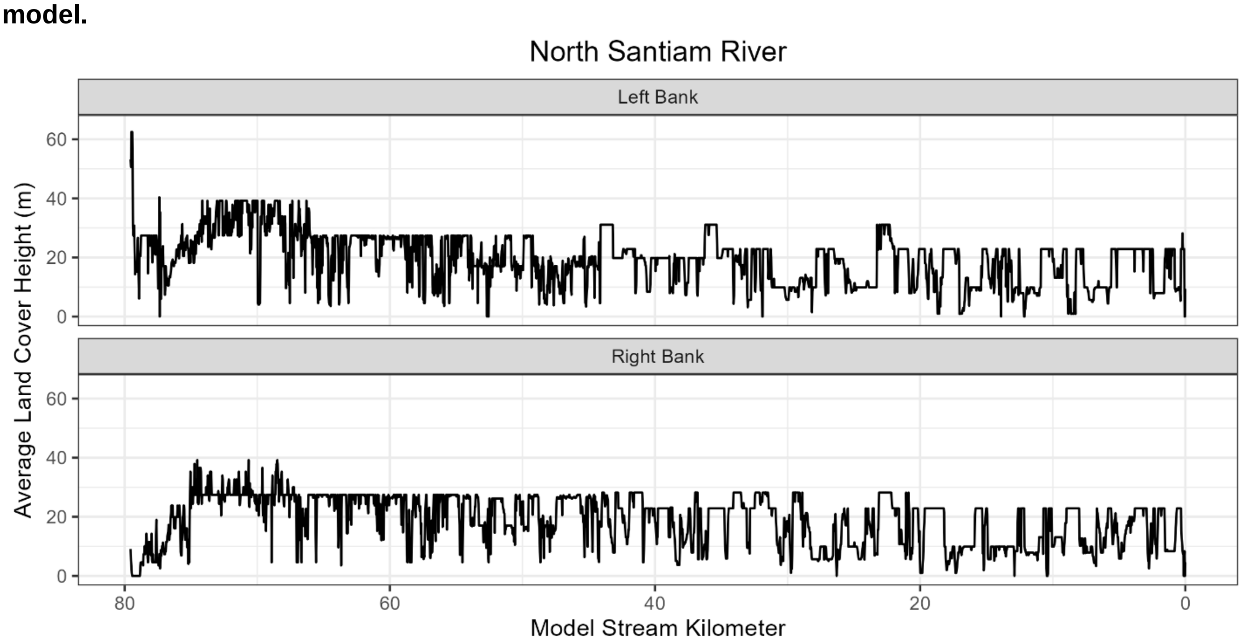


Figure 3-272: Average land cover height inputs to the North Santiam River effective shade model.

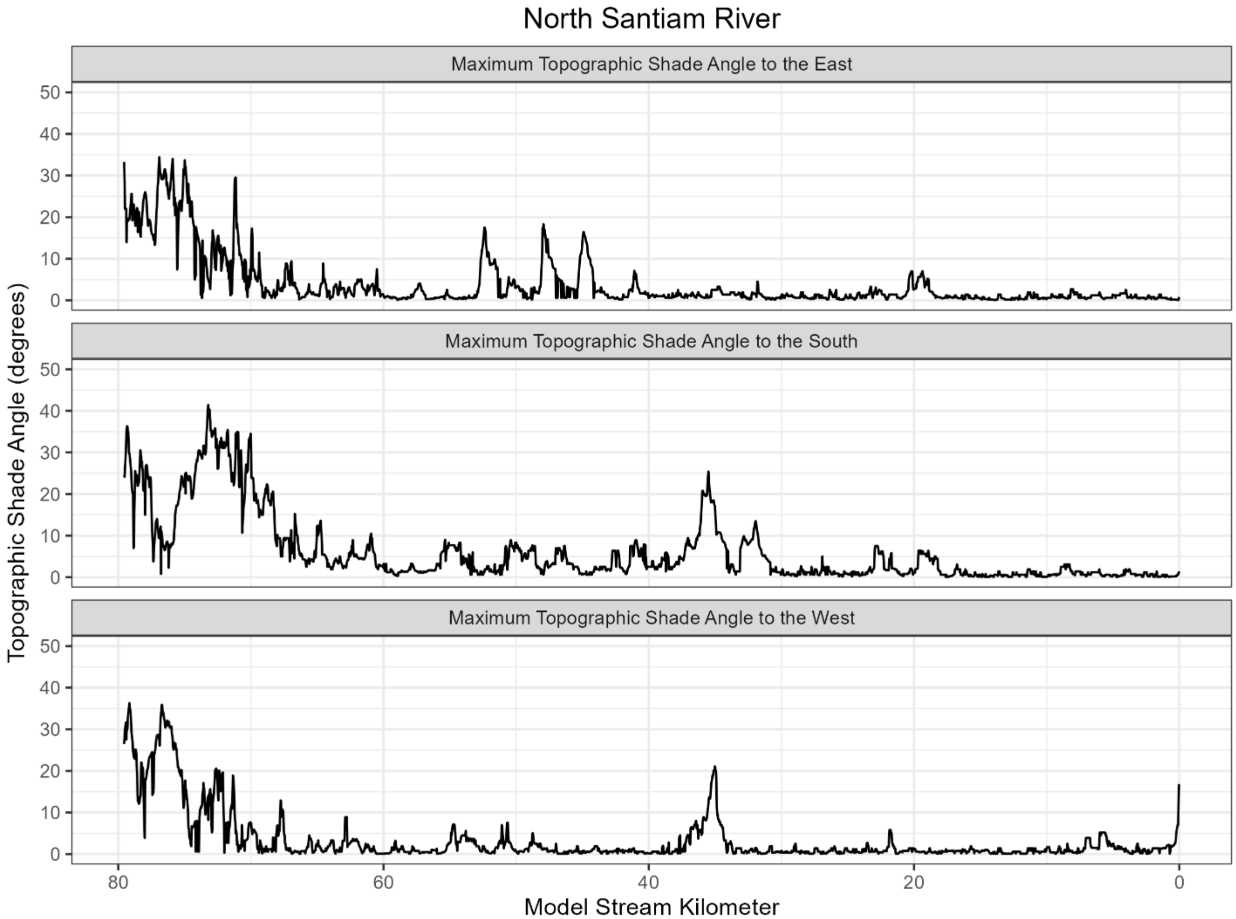


Figure 3-273: Topographic shade angle inputs to the North Santiam River effective shade model.

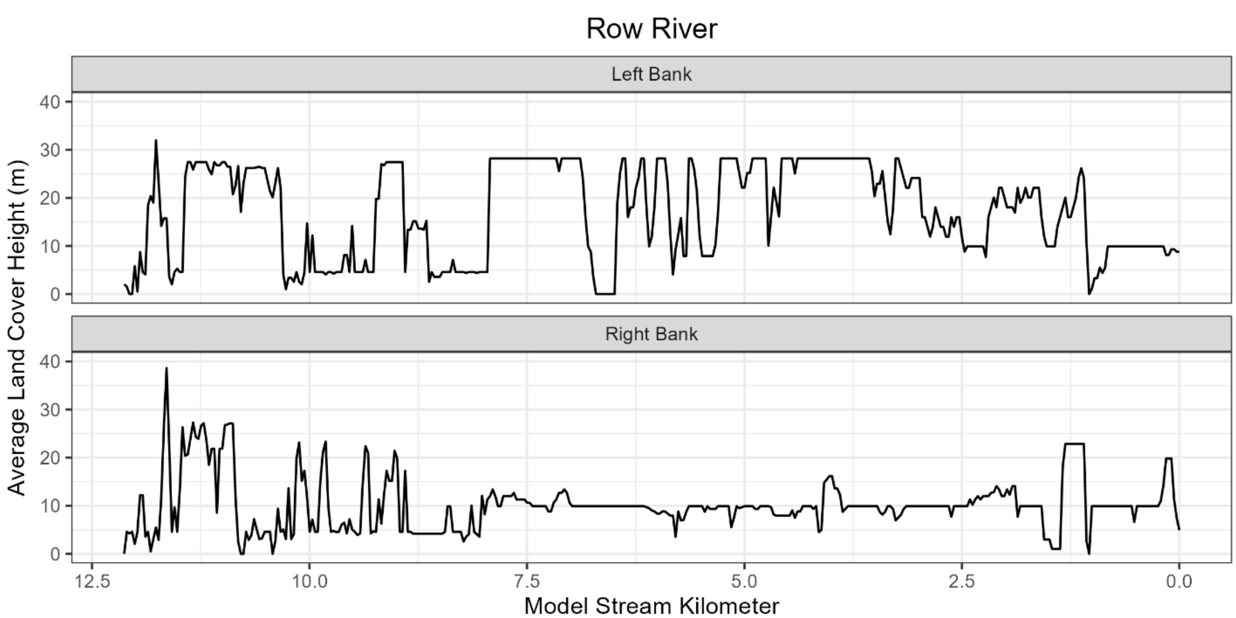


Figure 3-274: Average land cover height inputs to the Row River effective shade model.

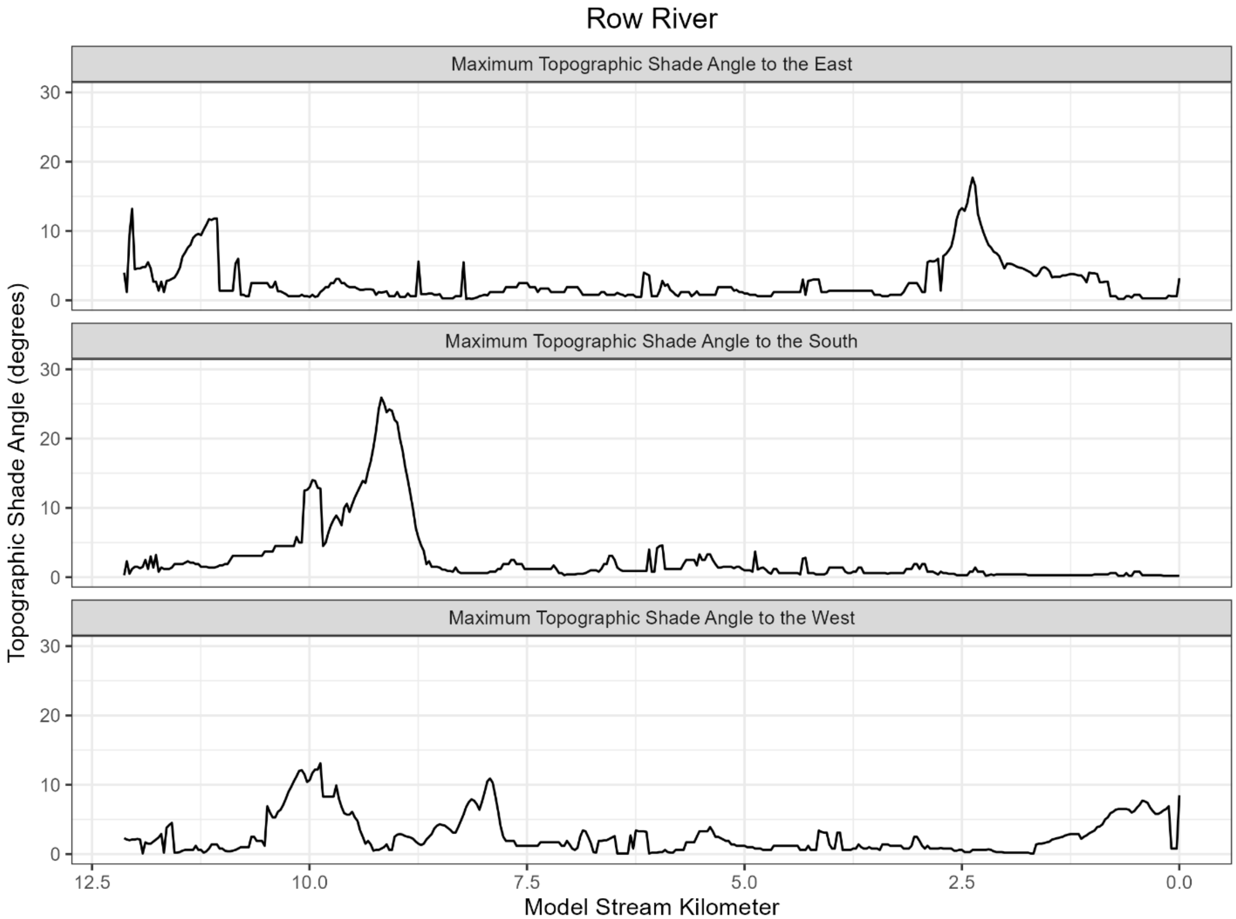


Figure 3-275: Topographic shade angle inputs to the Row River effective shade model.

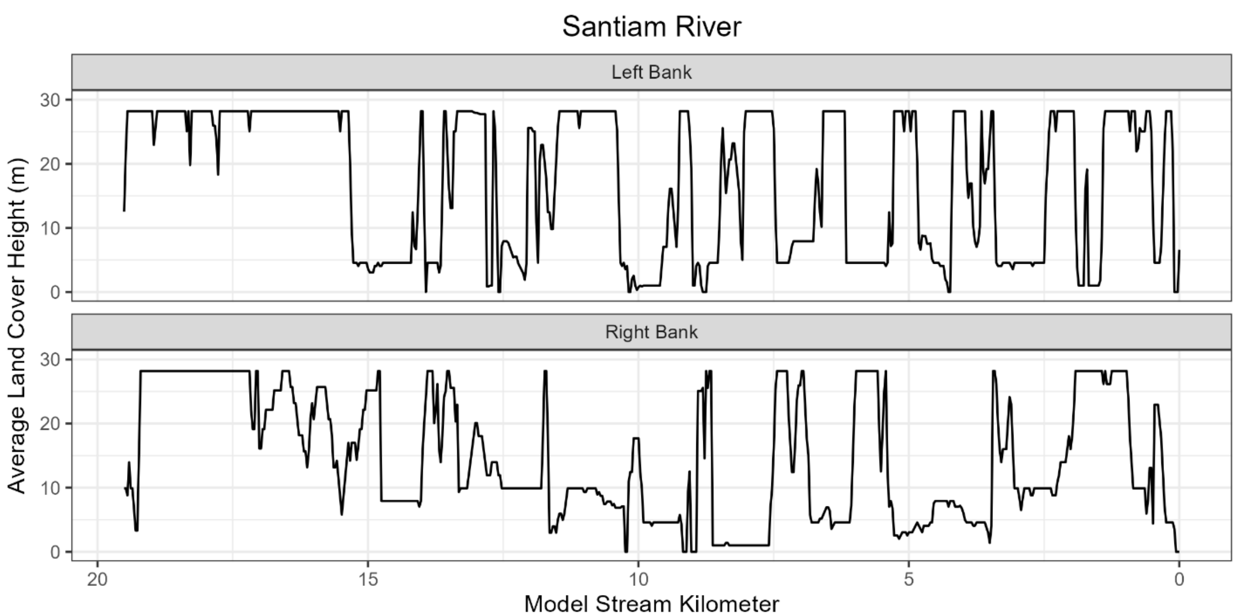


Figure 3-276: Average land cover height inputs to the Santiam River effective shade model.

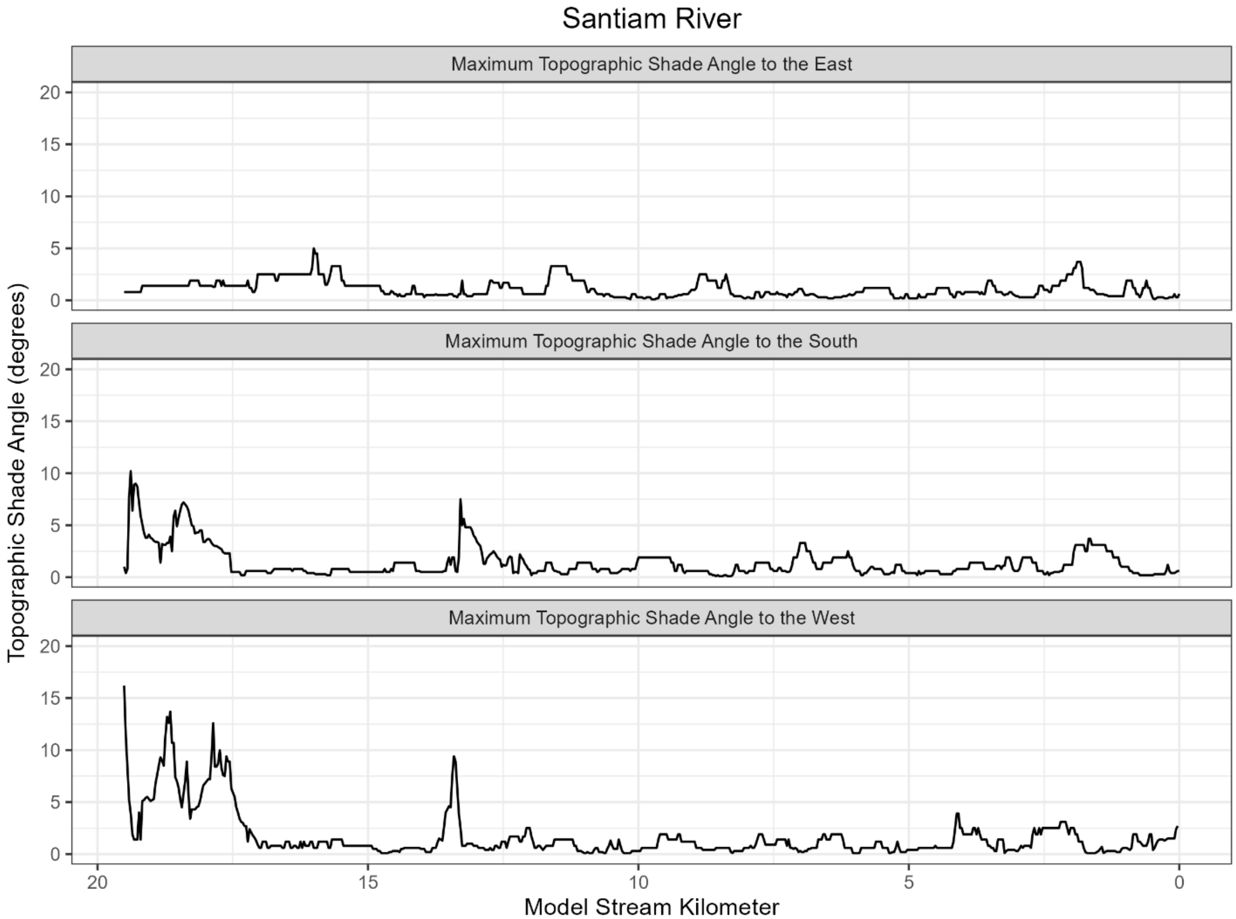


Figure 3-277: Topographic shade angle inputs to the Santiam River effective shade model.

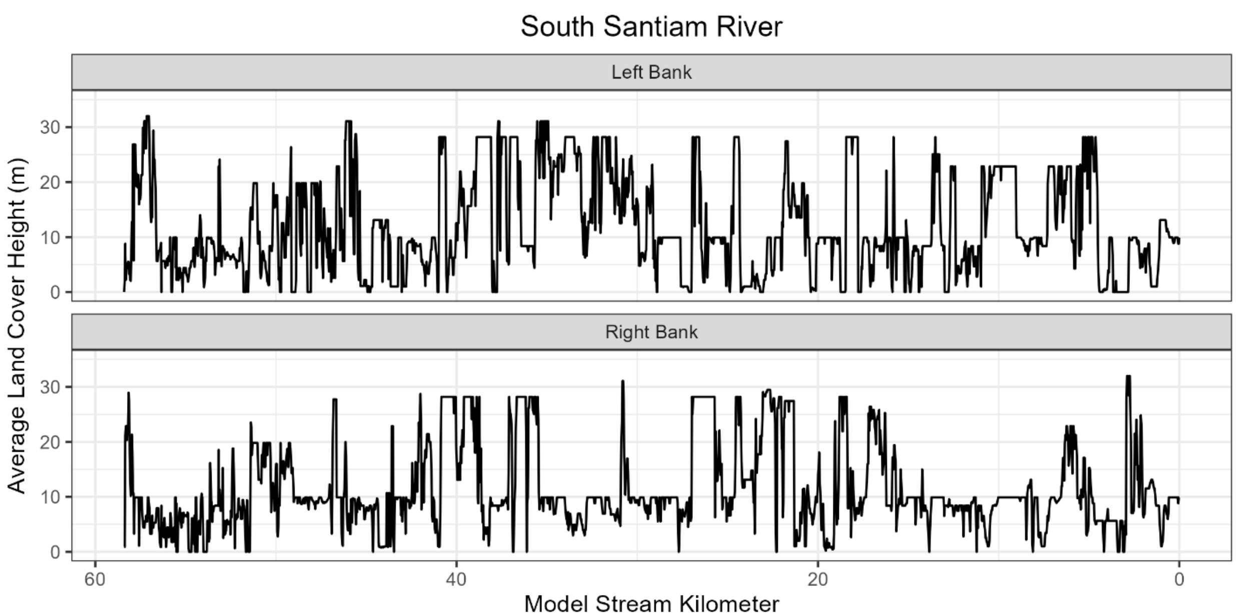


Figure 3-278: Average land cover height inputs to the South Santiam River effective shade model.

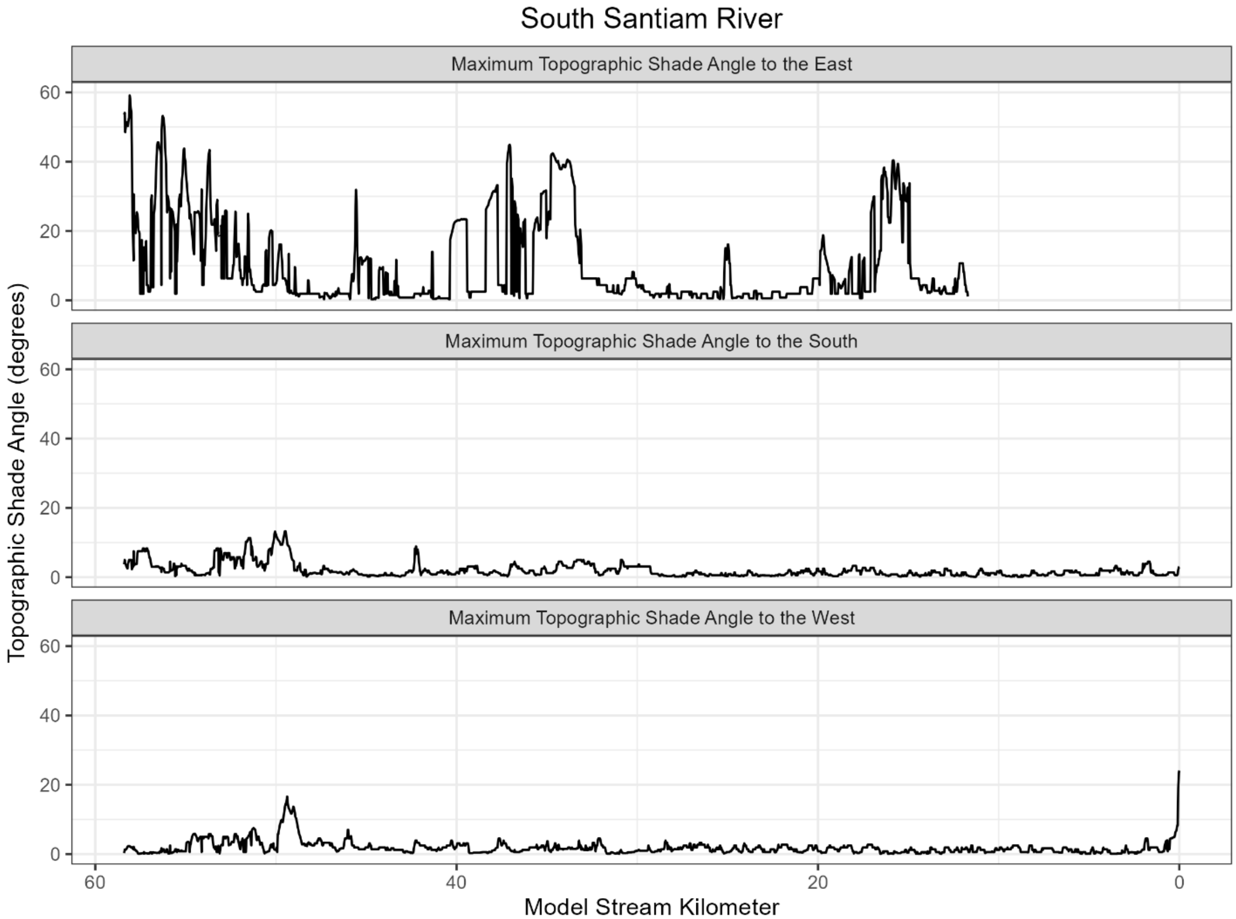


Figure 3-279: Topographic shade angle inputs to the South Santiam River effective shade model.

3.14.6 Channel setup

Channel setup for the Willamette River and major tributary models is shown in Figure 3-280 through Figure 3-289.

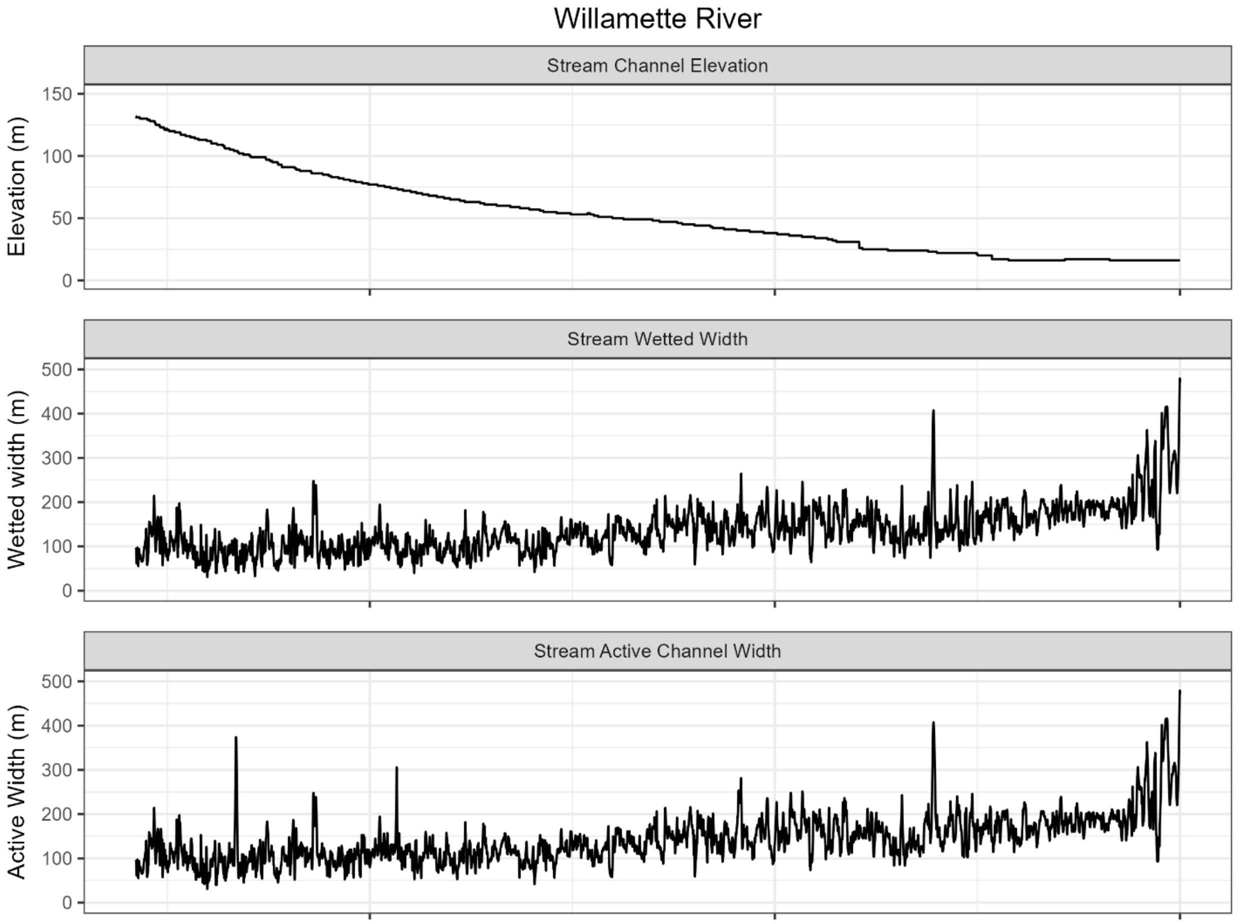


Figure 3-280: Channel setup in the Willamette River model.

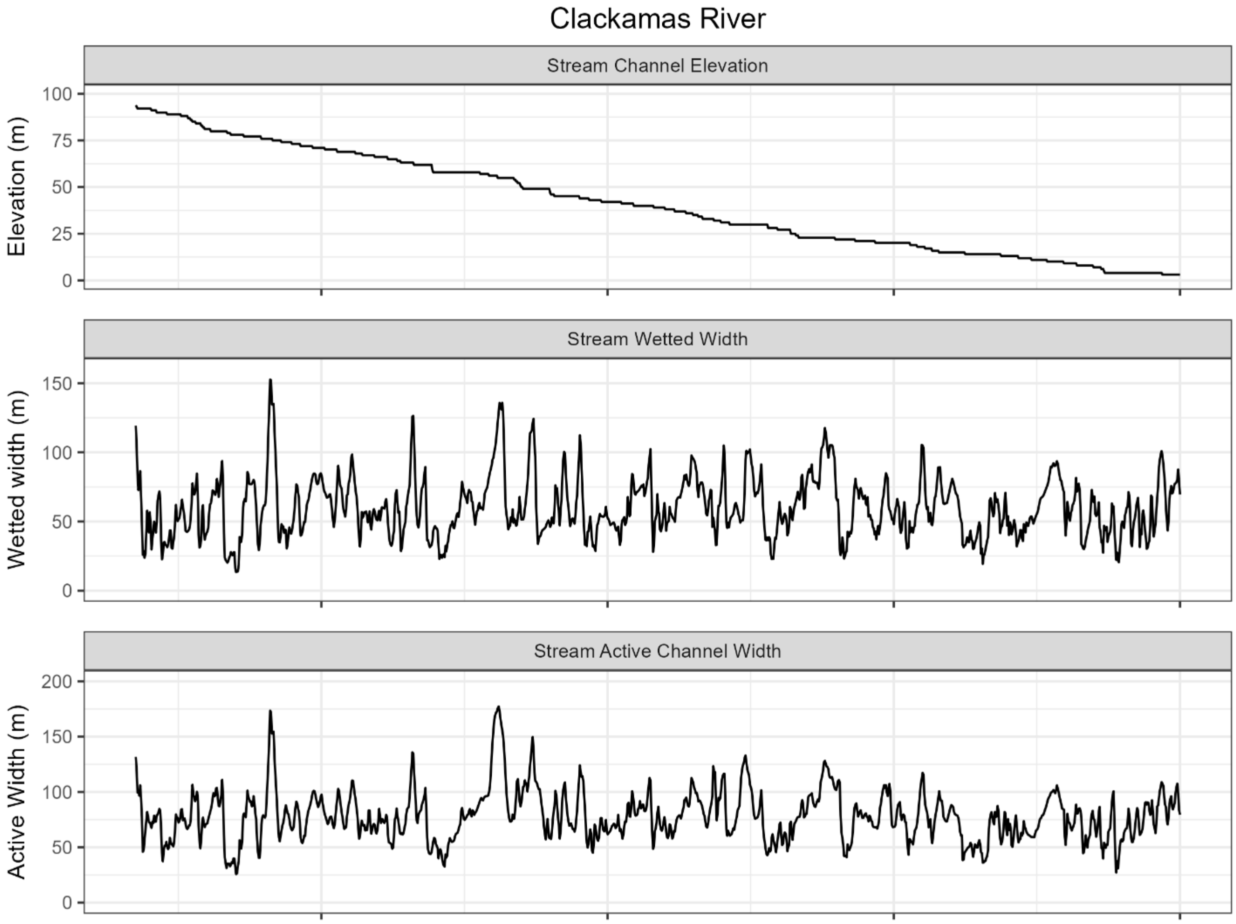


Figure 3-281: Channel setup in the Clackamas River model.

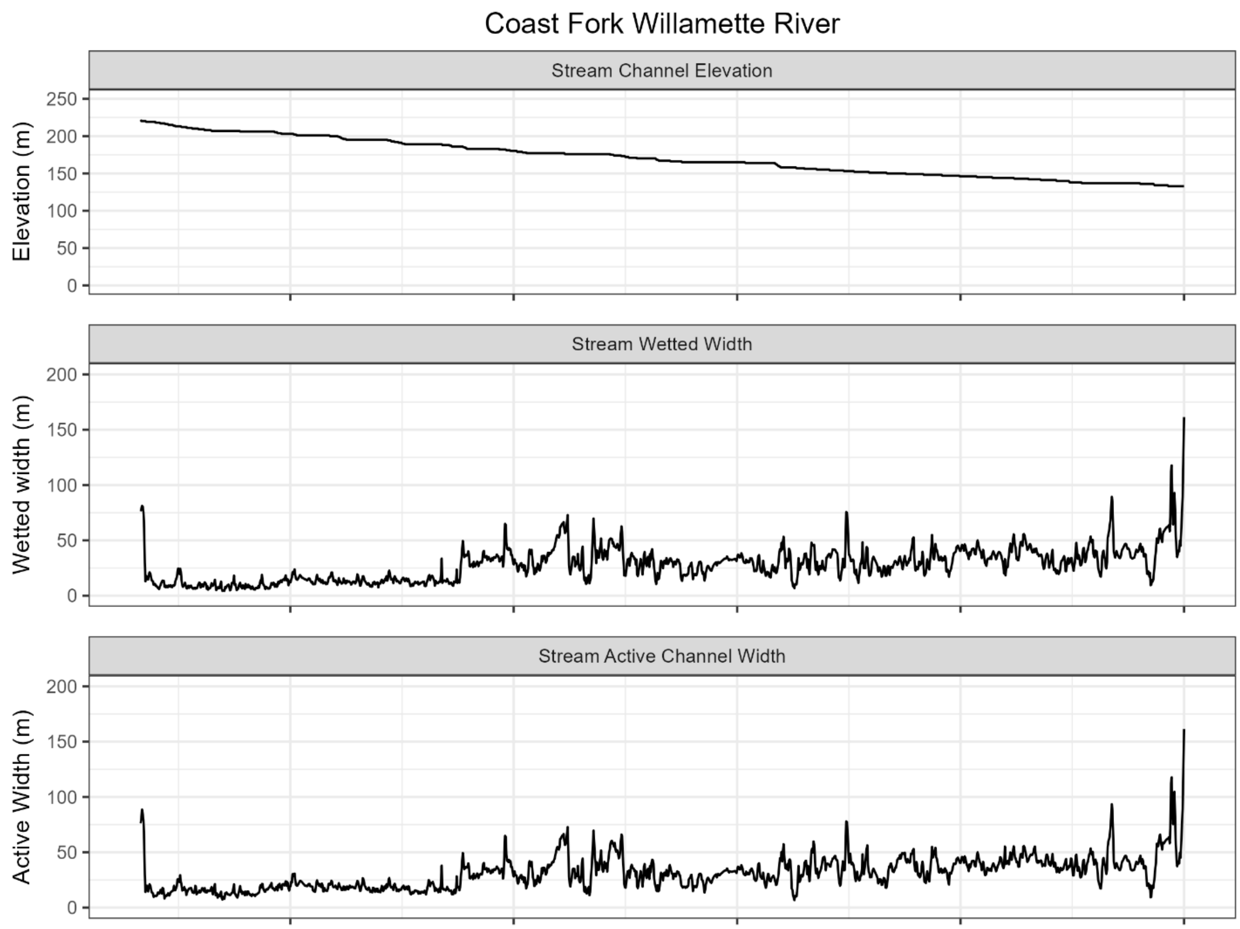


Figure 3-282: Channel setup in the Coast Fork Willamette River model.

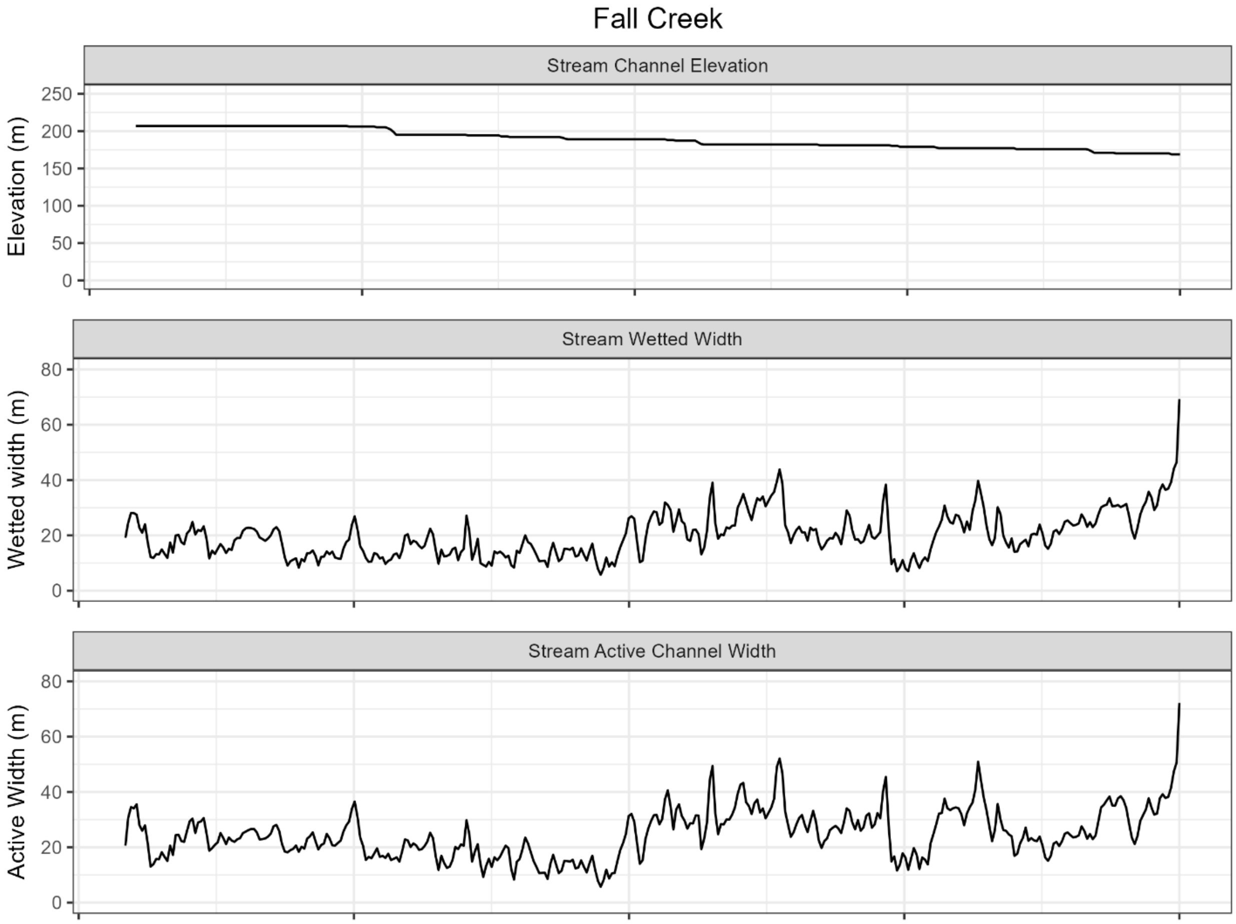


Figure 3-283: Channel setup in the Fall Creek model.

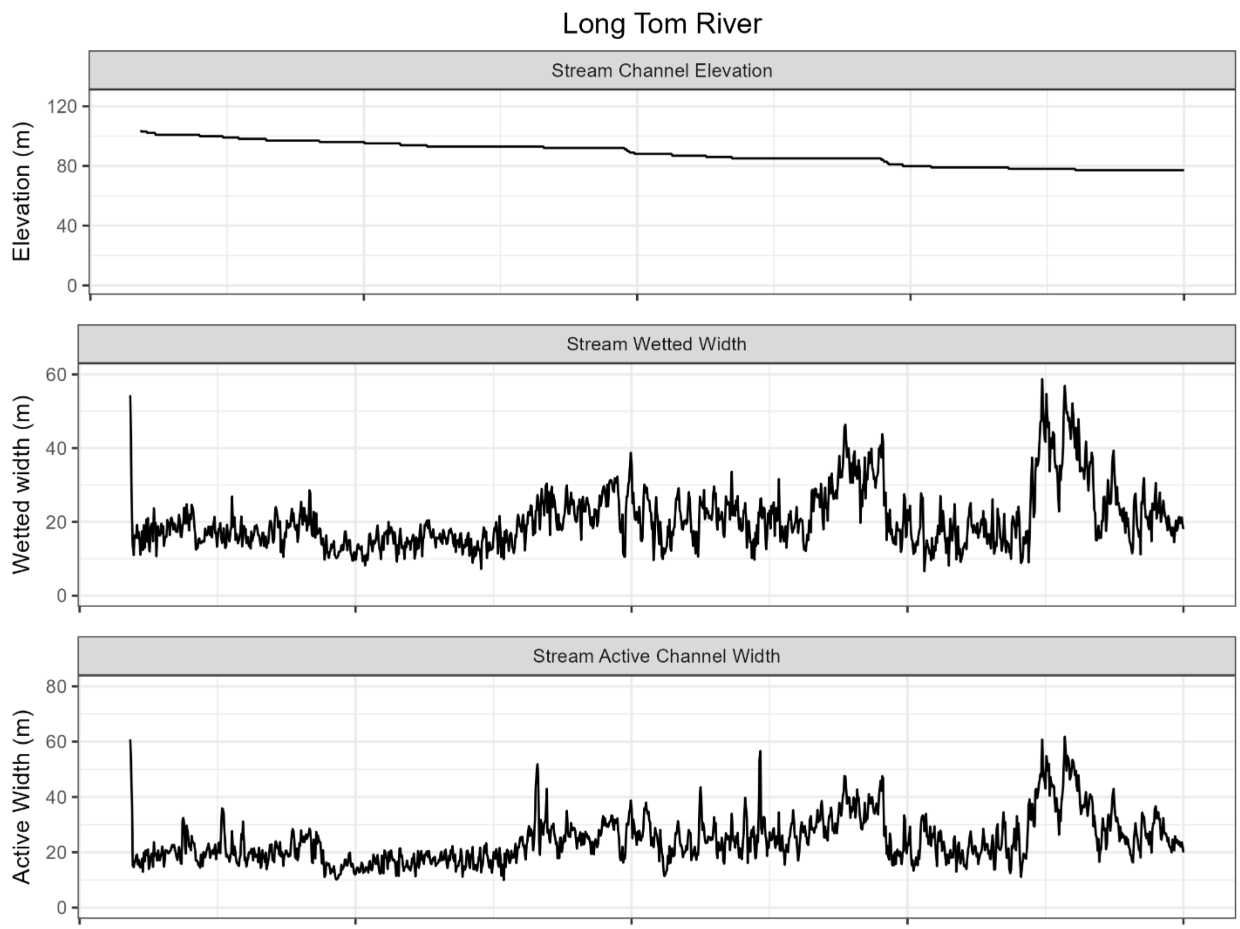


Figure 3-284: Channel setup in the Long Tom River model.

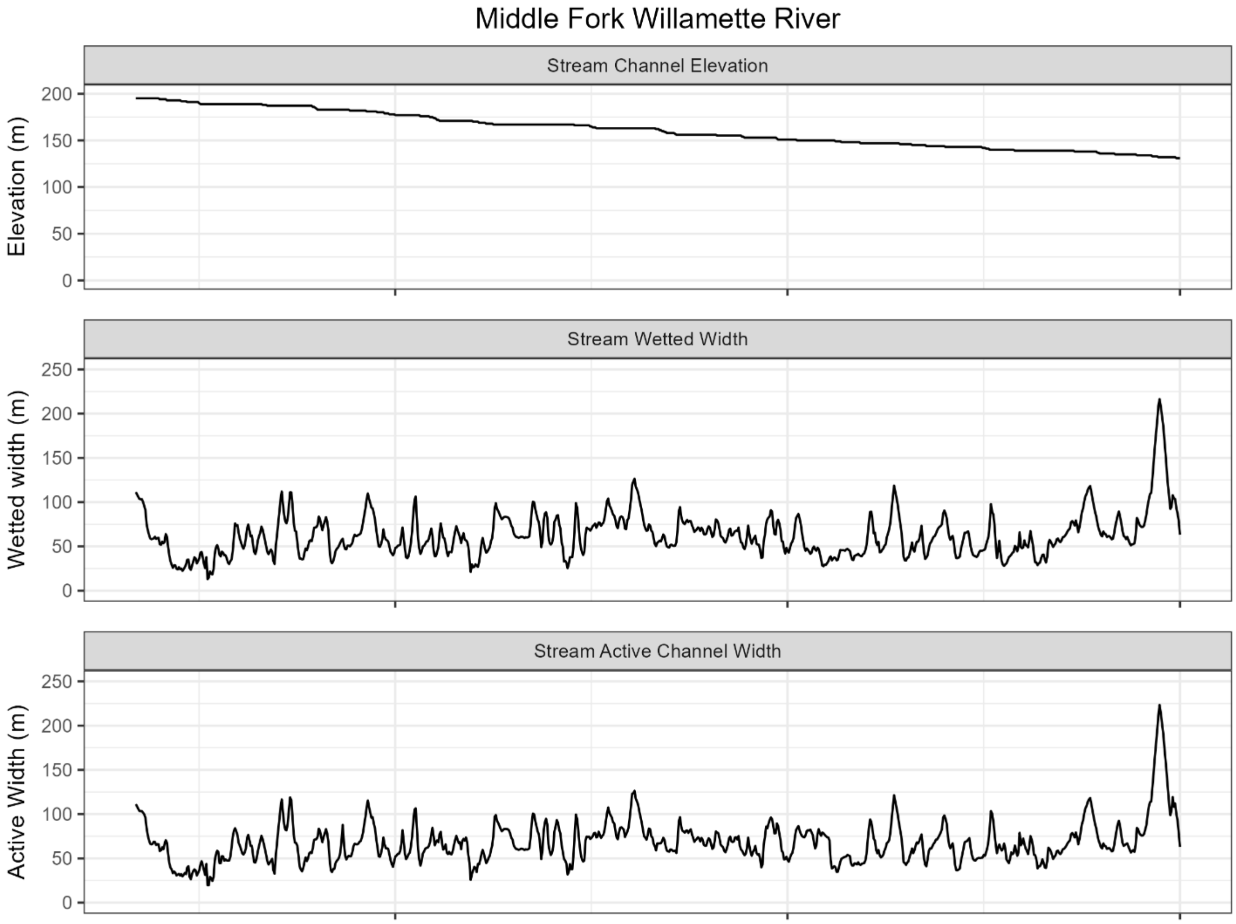


Figure 3-285: Channel setup in the Middle Fork Willamette River model.

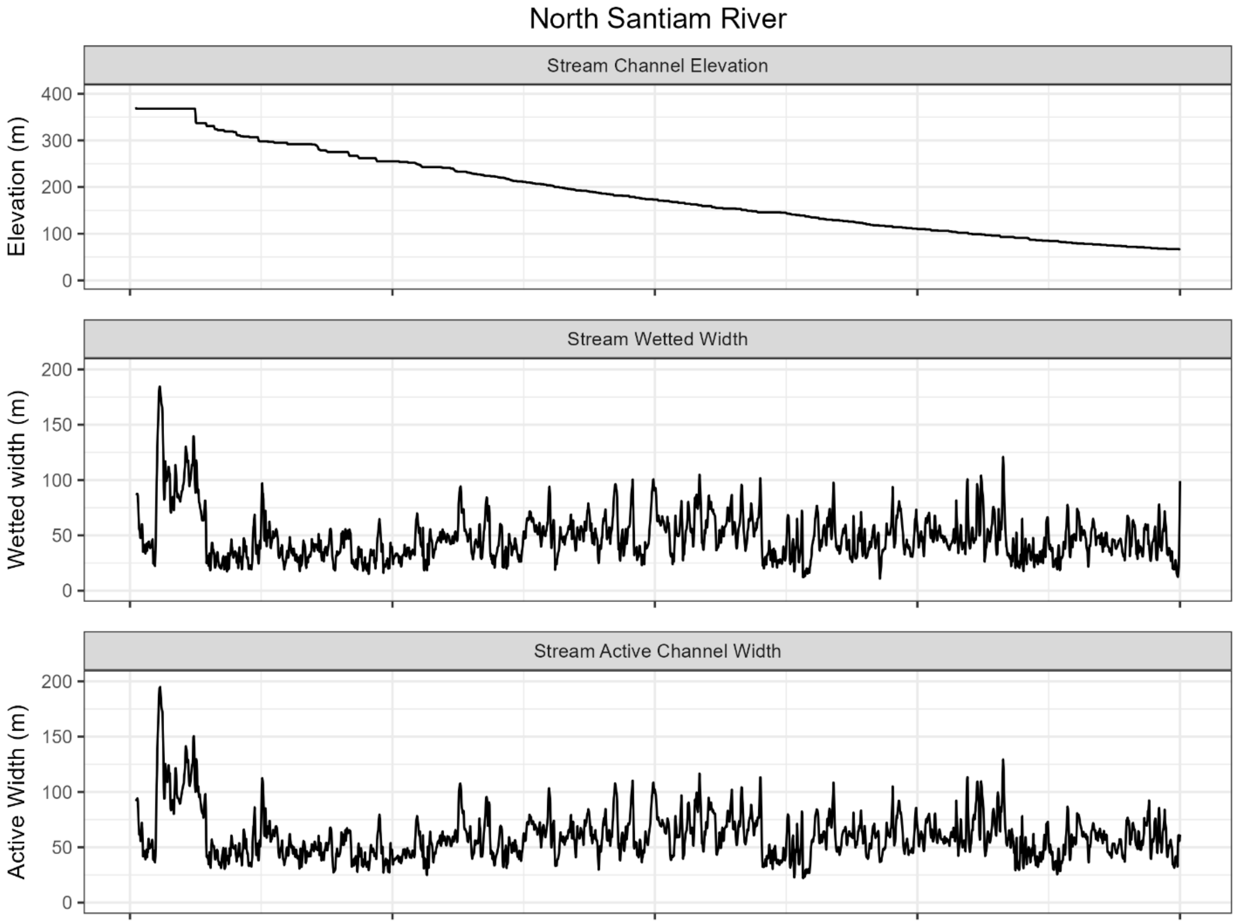


Figure 3-286: Channel setup in the North Santiam River model.

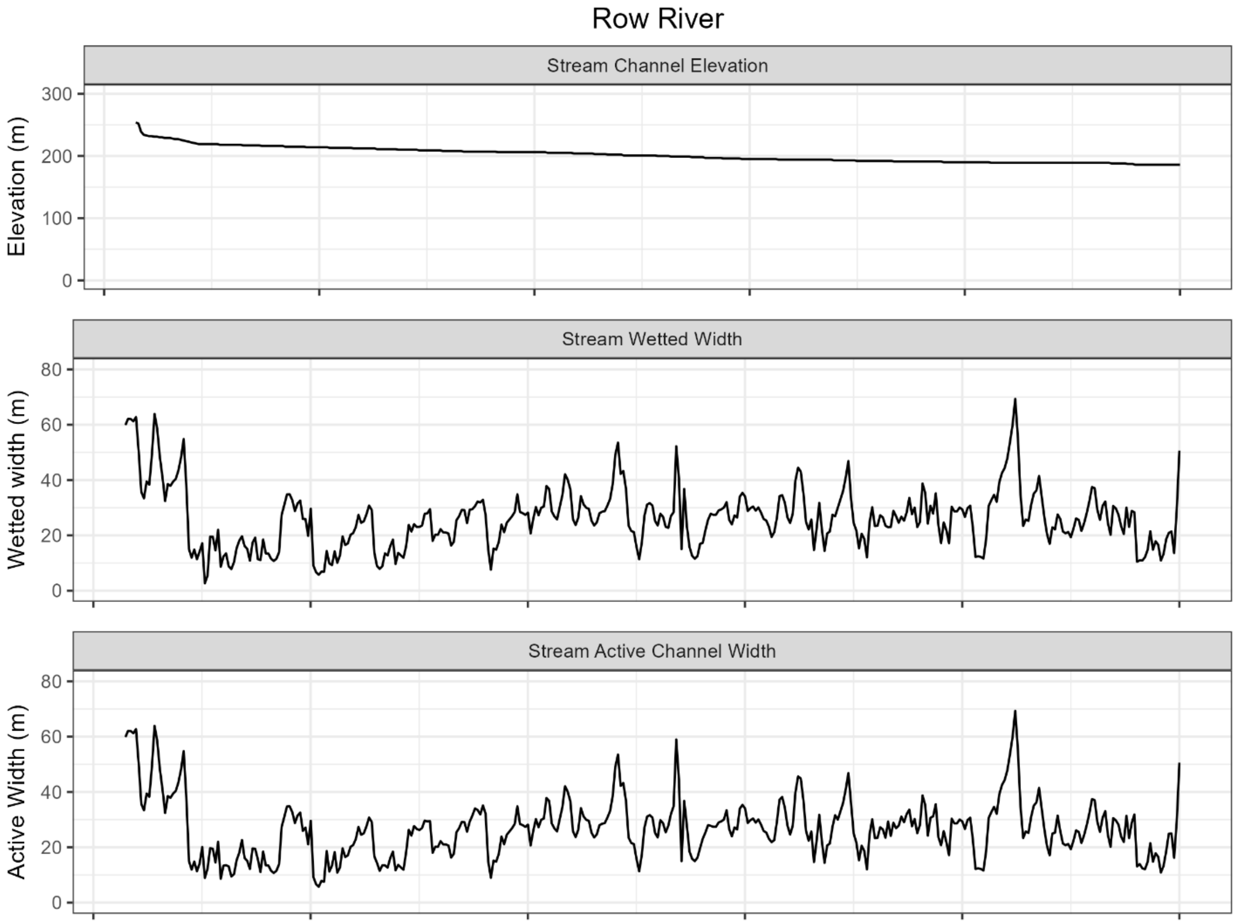


Figure 3-287: Channel setup in the Row River model.

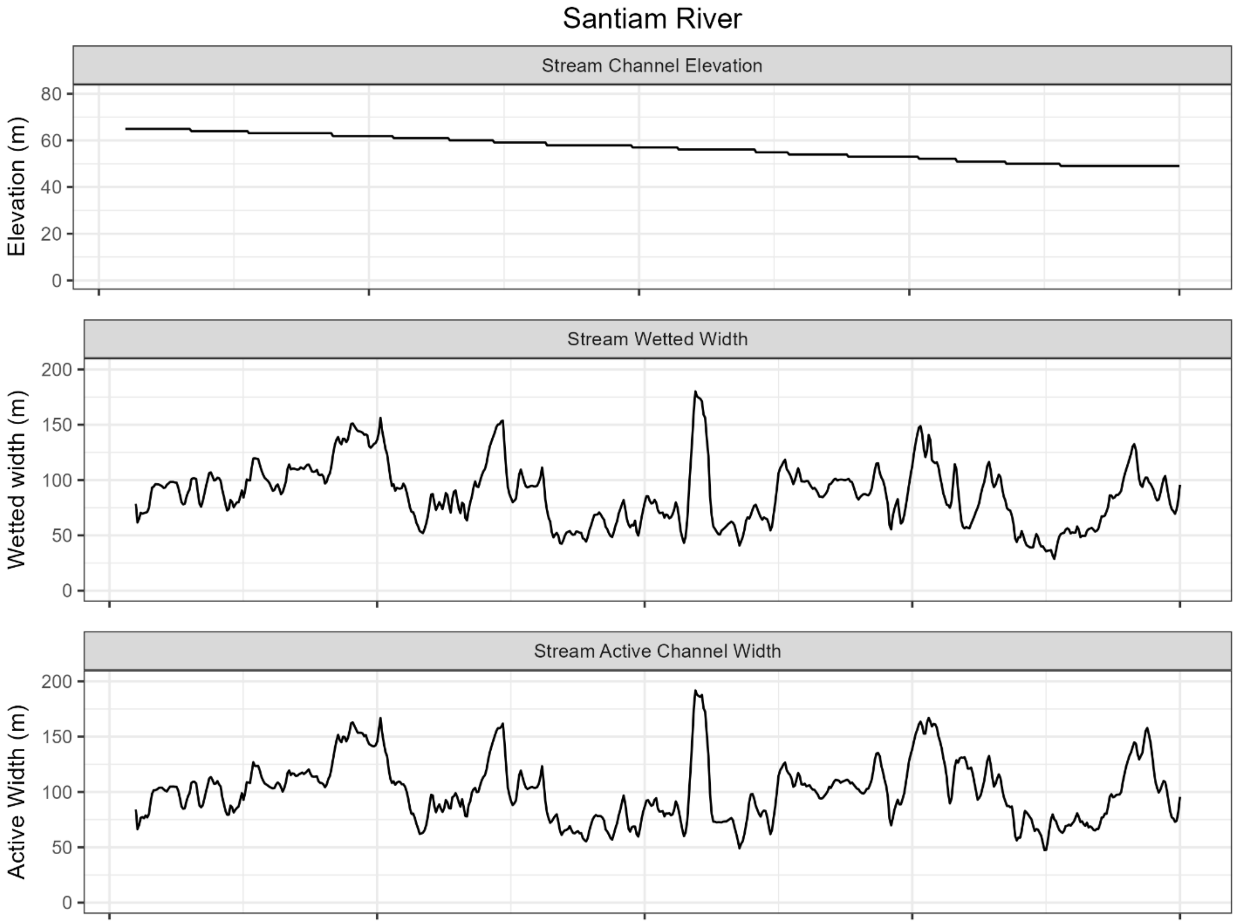


Figure 3-288: Channel setup in the Santiam River model.

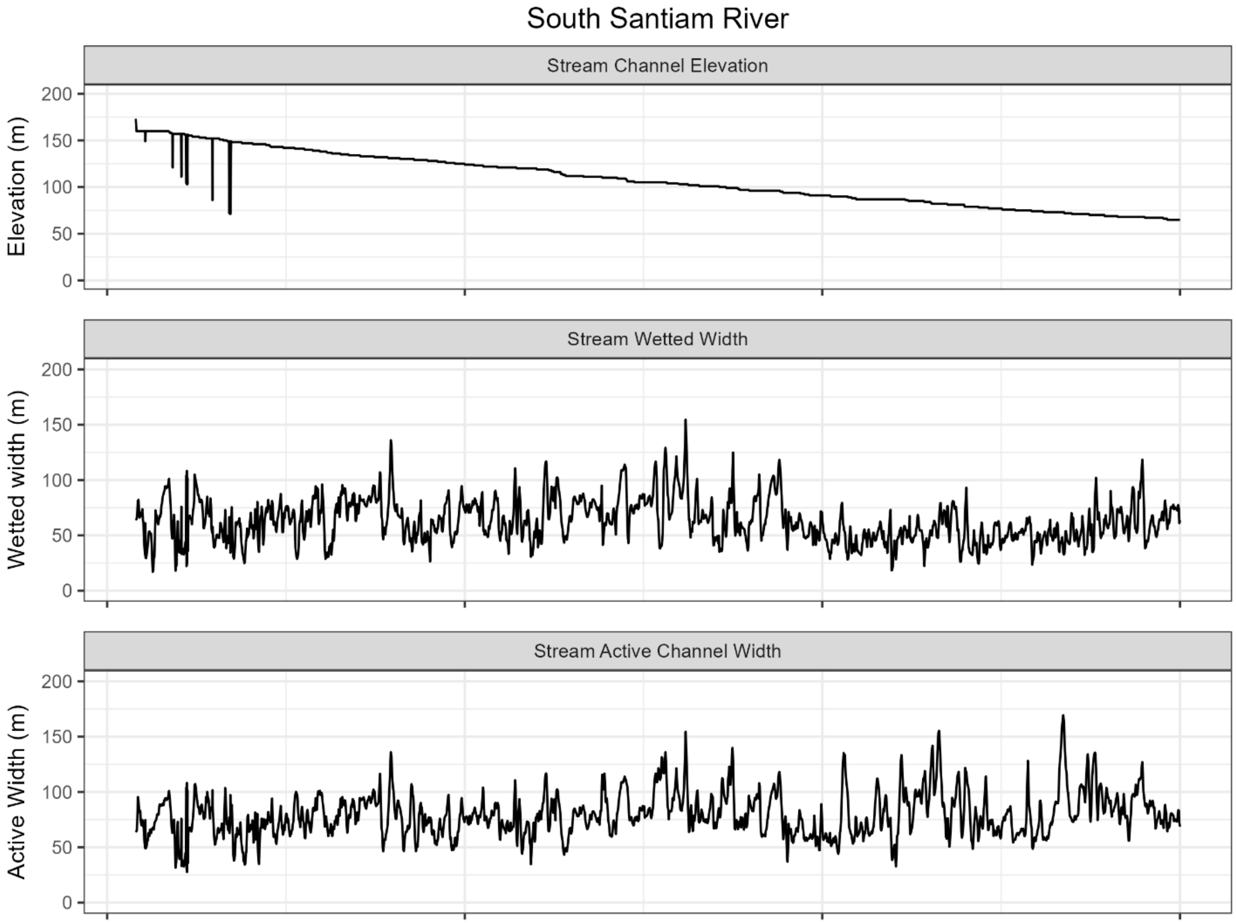


Figure 3-289: Channel setup in the South Santiam River model.

3.14.7 Results

Effective shade results are presented in the model scenarios, section 4.15.

3.15 Effective shade curves

Effective shade curves are plots that present the maximum possible effective shade as a function of natural near-stream vegetation type, active channel width, and stream aspect. Separate plots were produced for each natural vegetation type expected in the TMDL project area, i.e., conifer – high density, conifer – low density, upland grasses and wetlands, hardwood – high density, mixed conifer/hardwood – high density, and mixed conifer/hardwood – medium density. For each vegetation type, a plot was produced from a Heat Source version 6 shade model output that was parameterized with every combination of active channel width (in increments from 0.2-564 m) and stream aspect (i.e., N/S, NW/SE, E/W, or SE/NW). Channel width is plotted on the x-axis, effective shade is on the y-axis, and each line represents a different stream aspect. As channel width increases effective shade decreases. The plots are called effective shade curves because they resemble gentle downward sloping curves.

The effective shade curve approach can be used almost anywhere in the watershed to quantify background solar radiation loading and the effective shade necessary to eliminate temperature increases from anthropogenic near-stream vegetation removal or disturbance. It can also be used to develop lookup tables to quantify the effective shade resulting from other combinations of vegetation height, density, overhang, and buffer widths. These lookup tables provide convenience for TMDL readers to estimate effective shade for current conditions without using the model. Additionally, lookup tables can be used to reverse-lookup the required vegetation height, density, and/or buffer width to achieve a specific effective shade. The lookup tables and plots are provided in the main TMDL document.

3.15.1 Model extent

The model domain is not specific to any single waterbody but will be parameterized using a latitude and longitude located in the TMDL watershed to ensure that the modeled solar altitude and sun angles are appropriate for the area.

3.15.2 Spatial and temporal resolution

The model input spatial resolution (dx) is 30 m. Outputs are generated every 100 m. The spatial resolution is not very meaningful however, since each output distance step will represent a unique combination of the different modeled vegetation and channel conditions. The model time step (dt) is 1 minute and outputs are generated every hour.

3.15.3 Time frame of simulation

The model period is a single day in late July or early August. This time frame was chosen to characterize the solar loading when maximum stream temperatures are observed, the sun altitude angle is highest, and the period of solar exposure is longest.

3.15.4 Source characteristics

The effective shade curve approach can be used almost anywhere in the watershed to quantify the amount of background solar radiation loading and the effective shade necessary to eliminate temperature increases from anthropogenic disturbance or removal of near-stream vegetation.

The lookup tables can be used to estimate existing shade or current solar loading. Other potential sources of thermal loading and the temperature response will not be evaluated by this model.

3.15.5 Important Assumptions

Models used to develop effective shade curves assume no cloud cover and no topographic shade. The modeled terrain is flat so there is no difference in ground elevation between the stream and the adjacent vegetation buffer area. The vegetation density, vegetation height, vegetation overhang, and vegetation buffer width are assumed to be equal on both sides of the stream. The width of the active channel is assumed to be equal to the distance between near-stream vegetation on either side of the stream.

The effective shade curves were developed for the original Willamette Basin TMDL and WQMP (DEQ, 2006). No adjustments were made to these models for the updated TMDL.

3.15.6 Model inputs

There are two categories of models each with different sets of inputs:

- Effective shade curves: Model input values for vegetation height, vegetation density, vegetation overhang, and vegetation buffer width correspond to the restored streamside vegetation types expected in areas that are currently lacking streamside vegetation because of anthropogenic disturbance. The specific values will be determined during the TMDL process and will likely be the same or similar to the values presented in the Molalla-Pudding Subbasin TMDL and WQMP (DEQ, 2008) and Willamette Basin TMDL and WQMP (DEQ, 2006). The other model inputs are the same as what is described in **Table 3-83**.

- Effective shade lookup tables: Model input values to be used for the lookup tables are described in **Table 3-83**.

Table 3-83: Vegetation height, density, overhang, and horizontal distance buffer widths used to derive generalized effective shade curve targets for each mapping unit.

Mapping Unit	Height (m)	Height (ft)	Density (%)	Overhang (m)	Buffer Width (m)
Qff1	40.7	134	70	4.9	36.8
Qfc	37.7	124	64	4.5	36.8
Qalc	26.9	88	71	3.2	36.8
Qg1	21.6	71	64	2.6	36.8
Qau	22.6	74	69	2.7	36.8
Qalf	17.5	57	68	2.1	36.8
Qff2	21.5	71	66	2.6	36.8
Qbf	22.0	72	68	2.6	36.8
Tvc	27.8	91	65	3.3	36.8
Qtg	40.5	133	72	4.9	36.8
Tvw	35.1	115	65	4.2	36.8
Tcr	36.9	121	68	4.4	36.8
Tm	29.7	97	68	3.6	36.8
QTt	25.2	83	66	3.0	36.8
QTb	35.2	115	64	4.2	36.8
Qls	44.0	144	65	5.3	36.8
OW	1.9	6	74	0.2	36.8
Upland Forest	40.9	134	75	4.9	36.8
1d/1f - Coast Range - Volcanics and Willapa Hills	36.0	118.1	75	3.9	36.8
3a -Willamette Valley - Portland/Vancouver Basin	26.0	85.3	75	1.9	36.8
3c -Willamette Valley - Prairie Terraces	33.2	108.9	75	1.9	36.8
3d - Willamette Valley – Valley Foothills	31.0	101.7	75	1.9	36.8

4. Model scenarios results

4.1 Analysis and interpretation methods

4.1.1 Significant digits and rounding

The TMDL analysis and interpretation of all model and scenario results accounted for significant digits and rounding. To evaluate human use allowance (HUA) attainment, DEQ calculates and records values to the hundredths (0.01°C). Because DEQ assigns some source sector HUAs to the hundredths, attainment is tracked with equal precision. The TMDL analysis follows the rounding procedures outlined in a DEQ permit-related internal management directive (IMD) on rounding and significant digits (DEQ, 2013b). This IMD says that for “calculated values” (which includes model results), if the digit being dropped is a “5,” it is rounded up. For example, if an HUA allocation is set at 0.05°C and the model shows warming equal to 0.054°C, the value is rounded down to 0.05°C and the result is attainment. If the model shows warming equal to 0.055°C, the value is rounded up to 0.06°C and the result is non-attainment.

4.1.2 Calculating the 7-Day Average Daily Maximum temperature

For each scenario the 7DADM temperature was calculated using the hourly model output. The 7DADM was calculated using the procedure outlined in DEQ’s Temperature IMD (DEQ, 2008). As outlined in this IMD, the 7DADM temperature is calculated by (i) calculating the daily maximum for each day and each location, then (ii) calculating a 7-day rolling average of the daily maximums, the result for which lands on the 7th day and is considered the 7DADM for that day. Following transition to a new fish use designation (such as spawning), the first day that the 7DADM is reported occurs on the 7th day after the new fish use designation begins. For example, if spawning begins October 15, the first 7-day period would be October 15 to 21, with the first 7DADM temperature reported on October 21.

4.1.3 Comparing temperature between two scenarios

When comparing the hourly results from two model scenarios to determine the temperature change, the following steps were taken:

1. Calculate the 7DADM or daily maximum temperatures for scenario 1 at every model output location for every day of the model period.
2. Calculate the 7DADM or daily maximum temperatures for scenario 2 at every model output location for every day of the model period.
3. For allocation scenarios, the HUA is defined as the maximum allowable increase above the applicable biologically-based numeric criteria (BBNC). Thus, to determine the maximum temperature change in relation to HUAs, only days when the BBNC was exceeded were considered and thus days when 7DADM or daily maximum river temperatures did not exceed the BBNC were excluded. Note that the BBNC varied spatially and temporally and this was accounted for in the assessment.
4. Compute the difference between the 7DADM or daily maximum temperatures of scenario 1 and scenario 2 only for days that exceed the BBNC.

5. Round the differences to two decimals Celsius, based on the adopted rounding procedure discussed in Section 4.1.1.

The 7DADM is the preferred temperature metric for comparing two scenarios. If the model period or available data were less than 7 days, the daily maximum temperature metric was used instead. It was assumed that the daily maximum temperatures approximate 7DADM results.

4.2 Johnson Creek

Table 4-1 describes the different model scenarios used to simulate stream temperature and effective shade for Johnson Creek.

Table 4-2 summarizes the daily maximum stream temperatures predicted at the mouth of Johnson Creek for all model scenarios.

Figure 4-1 shows the predicted daily maximum stream temperatures for all model scenarios for Johnson Creek over the entire model period. Though they are plotted on the same figure, the three Restored Flow scenarios are not comparable to the other scenarios, as they are based on different flow regimes. Current Conditions, Restored Vegetation, Background, and Tributary Temperatures scenarios are based on observed Johnson Creek stream flow from July 31, 2002. The discharge at the mouth of Johnson Creek on this day was 0.32515 m^3/s (11.48 cfs), which is roughly equivalent to the 25% exceedance flow for August as estimated by the USGS StreamStats tool. The restored flow simulation scenarios are based on the 50% exceedance flow for August at the mouth of Johnson Creek, which is 0.134 m^3/s (4.75 cfs).

Table 4-1: Johnson Creek model scenario descriptions.

Scenario Name	Description
Current Condition	This is the calibrated model scenario that evaluates the stream temperature response to Johnson Creek conditions on July 31, 2002.
Restored Vegetation	This scenario evaluates the stream temperature response from setting near stream land cover to system potential vegetation conditions.
Restored Flow	This scenario evaluates the stream temperature response when the USGS StreamStats estimated August median flow is the assumed restored flow condition for the mainstem. Model boundary and tributary flows are set to achieve mainstem restored flows. This flow condition maintains all currently permitted water withdrawals as instream flow.
Restored Flow with 20% Flow Reduction	This scenario evaluates the stream temperature response when the mainstem flow is set to restored flows reduced by 20%. Model boundary and tributary flows are set to achieve mainstem restored flows reduced by 20%. This flow condition represents the consumptive use rate above which OWRD assumes water quality impacts due to water withdrawals.
Restored Flow with HUA Attaining (4%) Flow Reduction	This scenario evaluates the stream temperature response when the mainstem flow is set to restored flows reduced by the percent flow withdrawal that results in a 0.05°C water temperature increase at the flow reference site. In Johnson Creek, a 4% reduction of the mainstem restored flow conditions achieved HUA warming.
Tributary Temperatures	This scenario evaluates the stream temperature response when tributary temperature inputs were reduced to meet temperature standards. In Johnson Creek, Crystal Springs hourly tributary temperature inputs were reduced by 1.8°C. Crystal Springs was the only tributary altered because it was the only tributary with water temperatures that exceeded the standard of 18°C.
Background	This scenario evaluates the stream temperature response from background sources only. Background sources include all sources of pollution or pollutants not originating from human activities. Model inputs for land cover height, canopy density and overhang were modified to reflect restored conditions. Tributary temperature inputs were reduced to meet temperature standards. In Johnson Creek, Crystal Springs hourly tributary temperature inputs were reduced by 1.8°C.

Table 4-2: Summary of daily maximum stream temperature at the mouth of Johnson Creek for all model scenarios.

Temperature Metric	Model KM	Scenario	Stream Temperature (°C)	Location
Daily maximum temperature	0	Current Condition	20.24	outlet
Daily maximum temperature	0	Restored Vegetation	16.48	outlet
Daily maximum temperature	1.2	Restored Flow	20.21	Flow reference site
Daily maximum temperature	1.2	Restored Flow with HUA Attaining Flow Reduction	20.26	Flow reference site
Daily maximum temperature	1.2	Restored Flow with 20% Flow Reduction	20.50	Flow reference site
Daily maximum temperature	0	Tributary Temperatures	18.84	outlet
Daily maximum temperature	0	Background	16.48	outlet

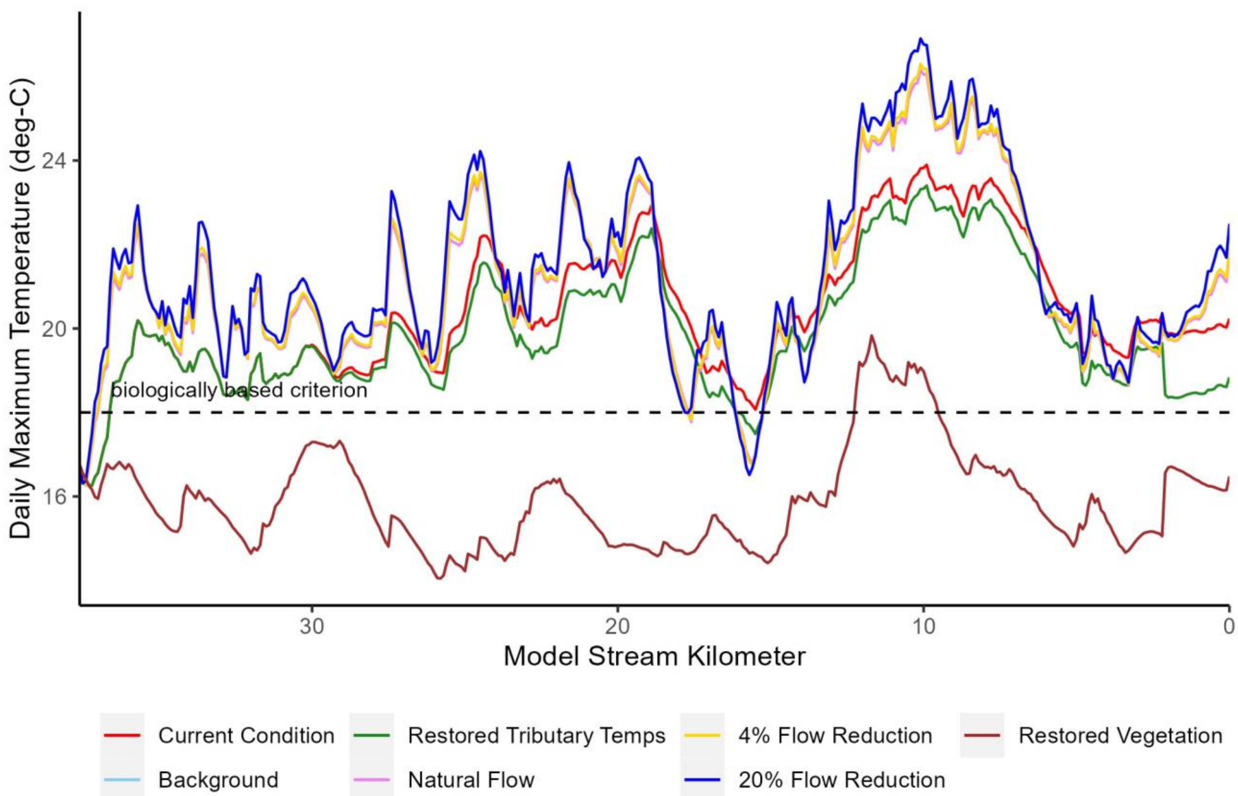


Figure 4-1: Daily maximum stream temperature for all model scenarios for Johnson Creek. The temperature profile of the Background scenario exactly matches the Restored Vegetation scenario and is therefore not visible on the plot.

4.2.1 Restored Vegetation

This section summarizes the temperature impacts of restored vegetation.

Table 4-3 summarizes the daily maximum stream temperature change between the Current Condition and Restored Vegetation scenarios for Johnson Creek. It shows the daily maximum temperature difference at the most downstream node (the outlet) is equal to 3.76°C. In addition, the greatest daily maximum temperature difference between the two scenarios (the point of maximum impact: POMI) is equal to 8.27°C and occurs at stream model km 18.9.

Figure 4-2 shows the change in the daily maximum stream temperatures between the Current Condition and Restored Vegetation model scenarios for Johnson Creek over the entire model period.

Table 4-3: Summary of daily maximum stream temperature change between Current Condition and Restored Vegetation model scenarios for Johnson Creek over the entire model period.

Temperature Metric	Model KM	Scenario	Stream Temperature (°C)	Location
Daily maximum temperature	0	Change	3.76	outlet
Daily maximum temperature	18.9	Change	8.27	POMI

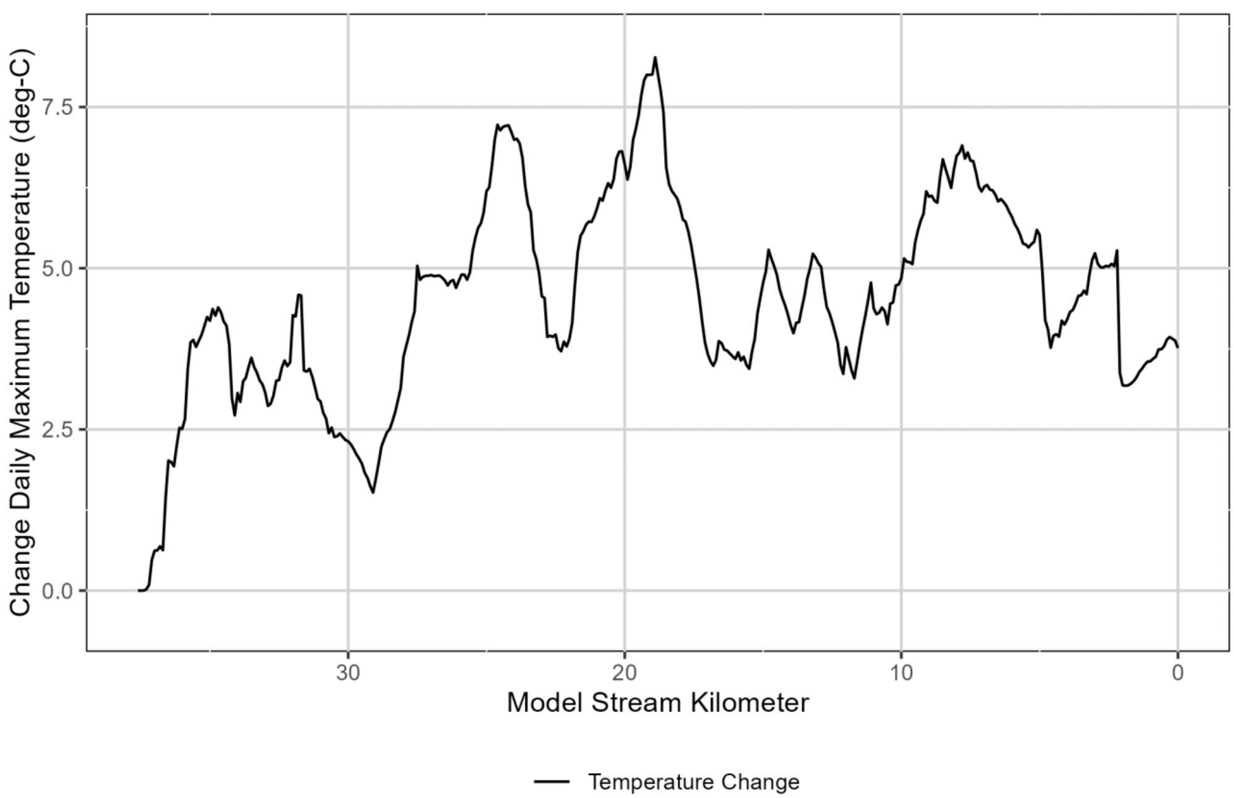


Figure 4-2: Change in the daily maximum stream temperatures between the Current Condition and Restored Vegetation model scenarios for Johnson Creek over the entire model period.

Table 4-4 summarizes the mean effective shade for the Current Condition and Restored Vegetation scenarios for Johnson Creek. The difference in mean effective shade between the scenarios is equal to 26.42 percentage points.

Figure 4-3 and **Figure 4-4** compare effective shade predictions from the Current Condition and Restored Vegetation scenarios for Johnson Creek.

Table 4-4: Summary of mean effective shade between the Current Condition and Restored Vegetation scenarios for Johnson Creek.

Scenario	Mean Effective Shade (%)
Current Condition	37.89
Restored Vegetation	64.31
Change	26.42

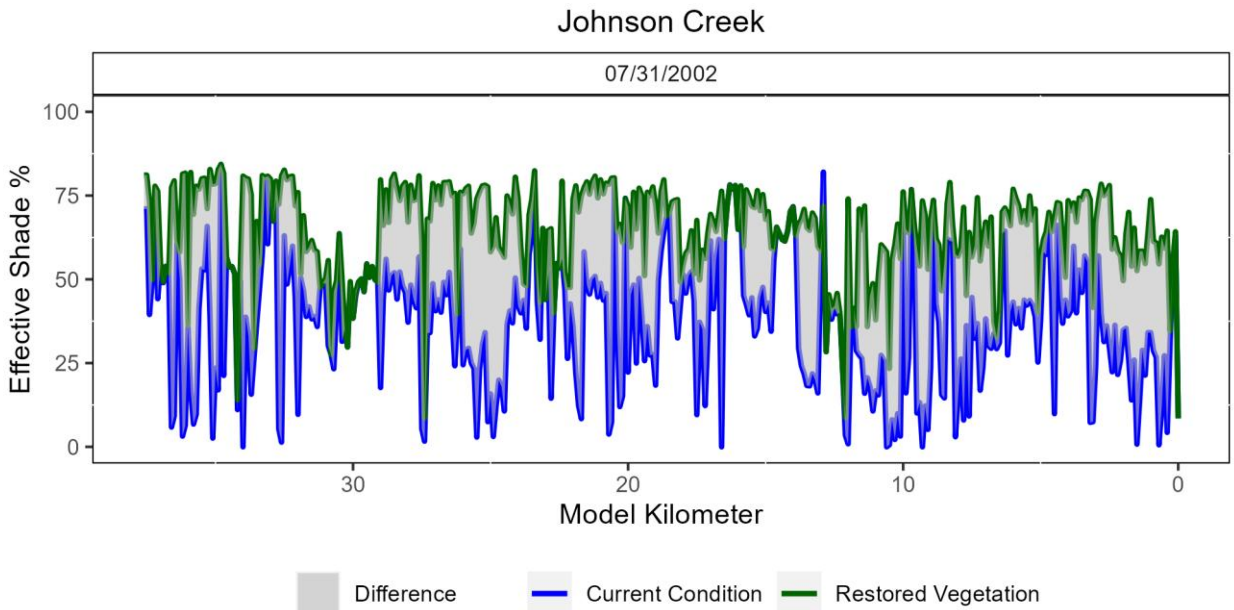


Figure 4-3: Comparison of effective shade from the Current Condition and Restored Vegetation scenarios for Johnson Creek.

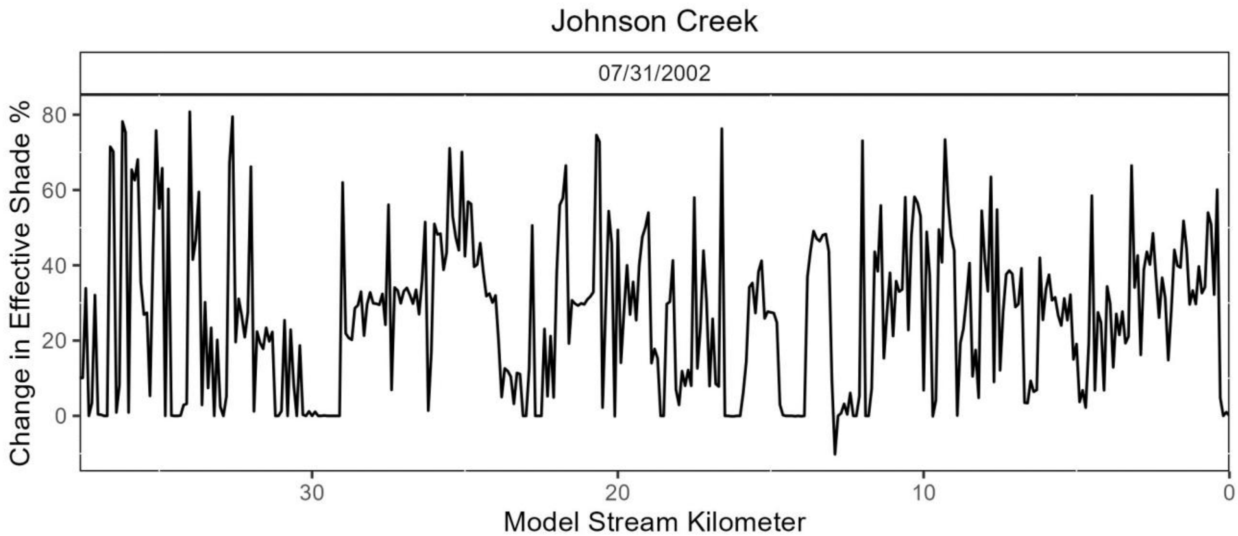


Figure 4-4: Percentage point difference between effective shade from the Current Condition and Restored Vegetation scenarios on 7/31/2002 for Johnson Creek. Missing values indicate that the shade difference is negative due to instances of higher effective shade in the Current Condition scenario versus the Restored Vegetation scenario.

4.2.2 Restored Flow with HUA Attaining Flow Reduction

This section summarizes the temperature impacts of HUA attaining stream flows.

Table 4-5 summarizes the daily maximum stream temperature change between the Restored Flow and HUA Attaining Flow scenarios for Johnson Creek. It shows the daily maximum temperature difference at the flow reference site (model km 1.2) is equal to 0.05°C.

The portion of the HUA that is allocated to water withdrawals (0.05°C) is attained at the flow reference site on Johnson Creek when the August maximum flow is reduced by 4%. The flow reference site is located at USGS gage 14211550 (Johnson Creek at Milwaukie, OR).

Figure 4-5 shows the change in the daily maximum stream temperatures between the Restored Flow and HUA Attaining Flow model scenarios for Johnson Creek over the entire model period.

Table 4-5: Summary of daily maximum stream temperature change between the Restored Flow and HUA Attaining Flow model scenarios for Johnson Creek over the entire model period.

Temperature Metric	Model KM	Scenario	Stream Temperature (°C)	Location
Daily maximum	1.2	Change	0.05	Flow reference site

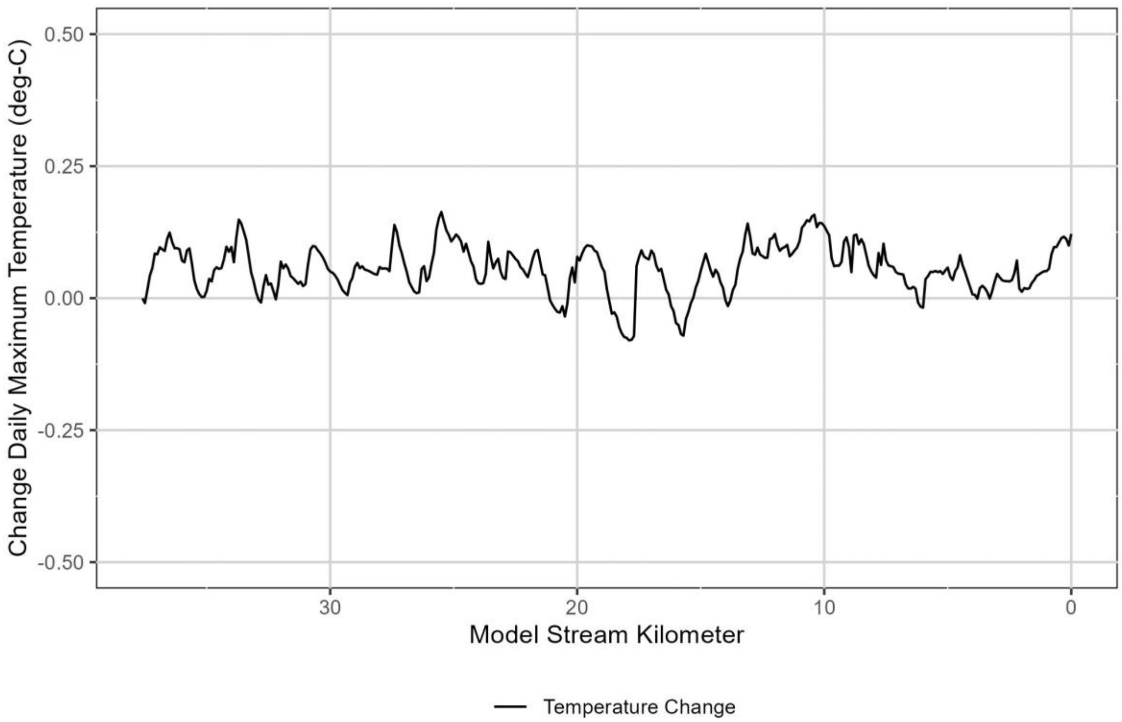


Figure 4-5: Change in the daily maximum stream temperatures between the Restored Flow and HUA Attaining Flow model scenarios for Johnson Creek over the entire model period.

4.2.3 Restored Flow with 20% Flow Reduction

This section summarizes the temperature impacts of reducing restored stream flow by 20%.

Table 4-6 summarizes the daily maximum stream temperature change between the Restored Flow and 20% Stream Flow Reduction model scenarios for Johnson Creek. It shows the daily maximum temperature difference at the flow reference site (model km 1.2) is equal to 0.29°C.

Figure 4-6 shows the change in the daily maximum stream temperatures between the Restored Flow and 20% Stream Flow Reduction model scenarios for Johnson Creek over the entire model period. The 20% reduced flow stream temperature is warmer than restored flow stream temperature at almost every point along the mainstem.

Table 4-6: Summary of daily maximum stream temperature change between the Restored Flow and 20% Reduction Flow model scenarios for Johnson Creek over the entire model period.

Temperature Metric	Model KM	Scenario	Stream Temperature (°C)	Location
Daily maximum	1.2	Change	0.29	Flow reference site

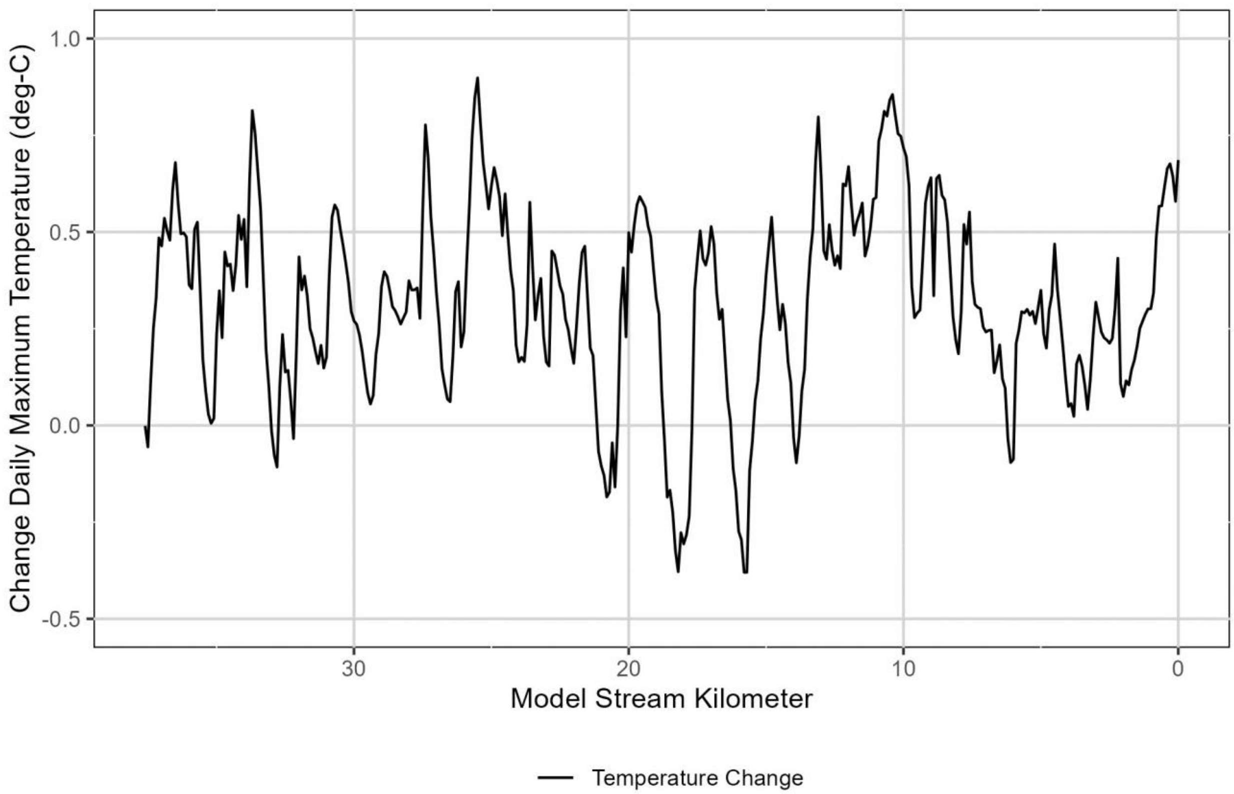


Figure 4-6: Change in the daily maximum stream temperatures between the Restored Flow and 20% Reduction Flow model scenarios for Johnson Creek over the entire model period.

4.2.4 Tributary Temperatures

This section summarizes the temperature impacts of restored tributary temperatures.

Table 4-7 summarizes the daily maximum stream temperature change between the Current Condition and Tributary Temperatures scenarios for Johnson Creek. It shows the daily maximum temperature difference at the most downstream node (the outlet) is equal to 1.40°C. In addition, the greatest daily maximum temperature difference between the two scenarios (POMI) is equal to 1.52°C and occurs at stream model km 2.

Figure 4-7 shows the change in the daily maximum stream temperatures between the Current Condition and Tributary Temperatures model scenarios for Johnson Creek over the entire model period. The restored Tributary Temperatures scenario was cooler than the Current Condition scenario at almost every point along the mainstem.

Table 4-7: Summary of daily maximum stream temperature change between Current Condition and Tributary Temperatures model scenarios for Johnson Creek over the entire model period.

Temperature Metric	Model KM	Scenario	Stream Temperature (°C)	Location
Daily maximum	0	Change	1.40	outlet
Daily maximum	2	Change	1.52	POMI

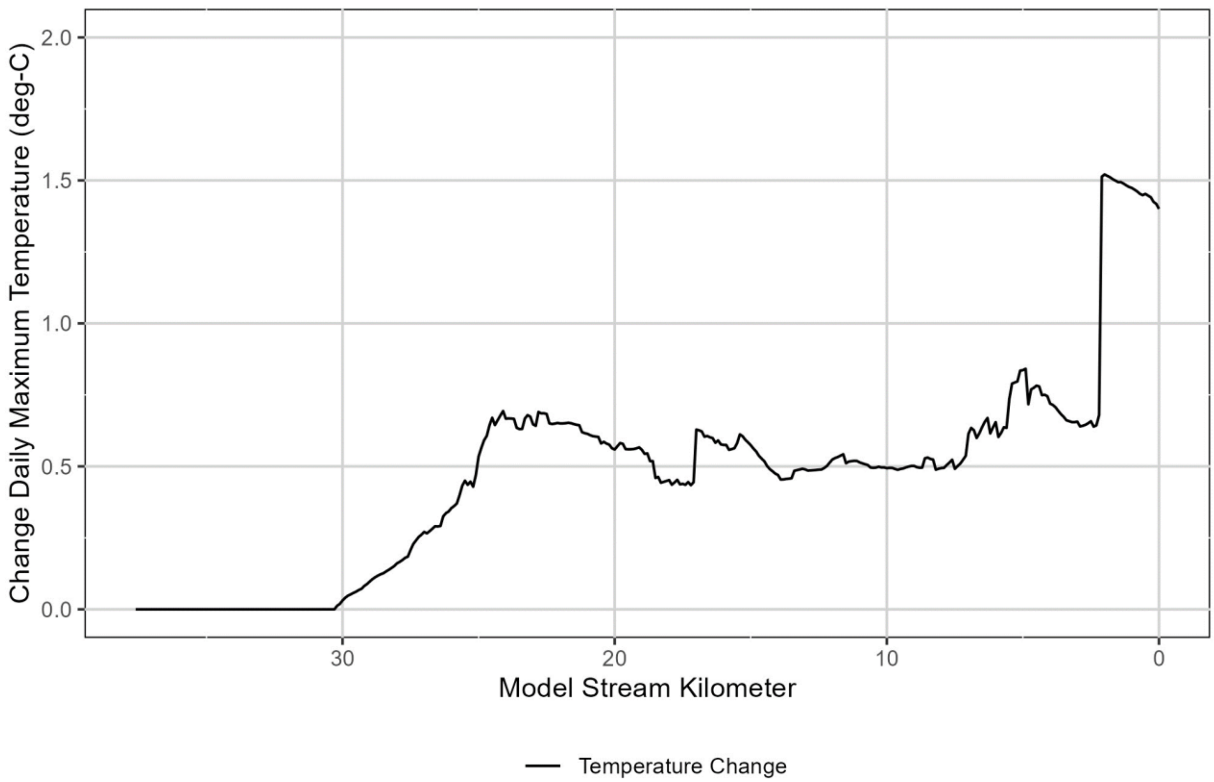


Figure 4-7: Change in the daily maximum stream temperatures between the Current Condition and Tributary Temperatures model scenarios for Johnson Creek over the entire model period.

4.2.5 Background

This section summarizes the temperature impacts of background conditions.

Figure 4-8 shows the change in the daily maximum stream temperatures between the Current Condition and Background model scenarios for Johnson Creek over the entire model period. Stream temperatures for the Current Condition scenario are warmer than stream temperatures for the Background scenario at every point along the mainstem.

Table 4-8 summarizes the daily maximum stream temperature change between the Current Condition and Background scenarios for Johnson Creek. It shows the daily maximum temperature difference at the most downstream node (the outlet) is equal to 3.76°C. In addition, the greatest daily maximum temperature difference between the two scenarios (the POMI) is equal to 8.27°C and occurs at stream model km 18.9.

Table 4-8: Summary of daily maximum stream temperature change between Current Condition and Background model scenarios for Johnson Creek over the entire model period.

Temperature Metric	Model KM	Scenario	Stream Temperature (°C)	Location
Daily maximum	0	Change	3.76	outlet
Daily maximum	18.9	Change	8.27	POMI
Daily maximum	0	Change_BBNC	-1.52	outlet
Daily maximum	11.7	Change_BBNC	1.83	POMI

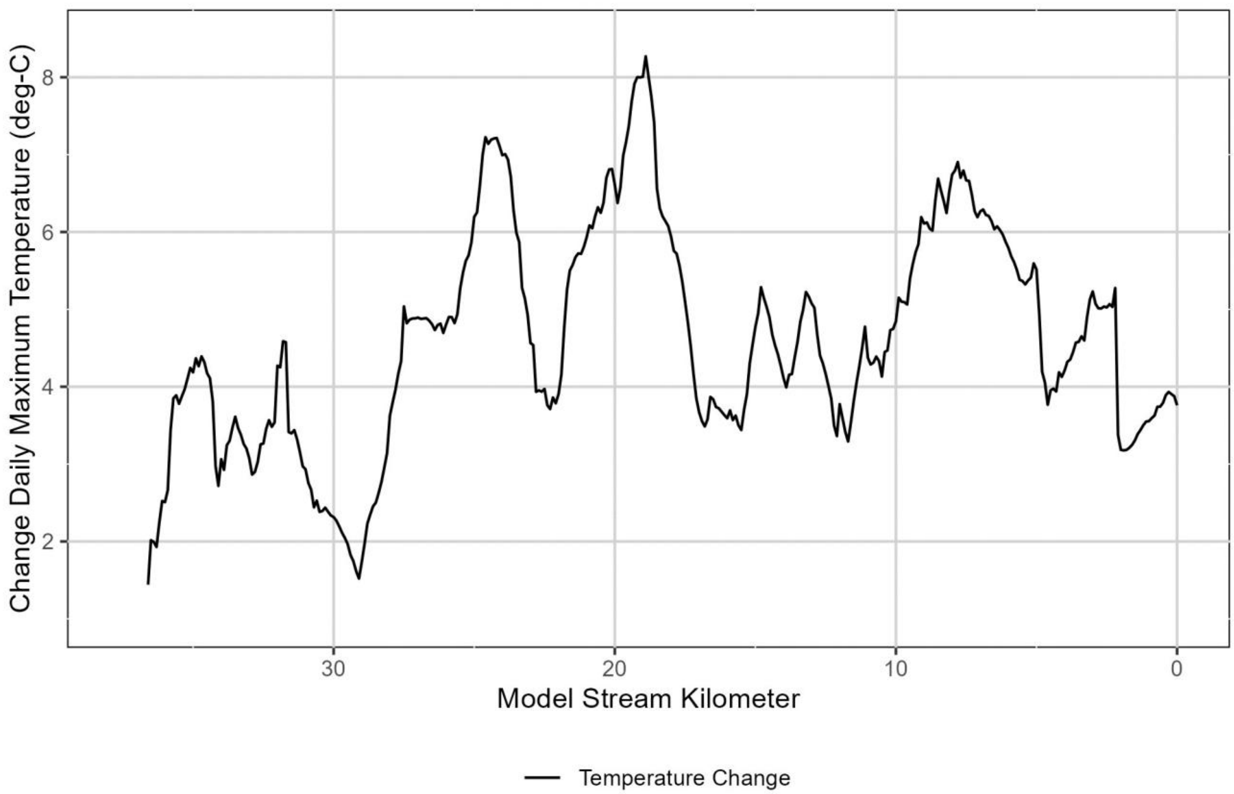


Figure 4-8: Change in the daily maximum stream temperatures between the Current Condition and Background model scenarios for Johnson Creek over the entire model period.

4.3 Molalla River

Table 4-9 describes the different model scenarios used to simulate stream temperature and effective shade for the Molalla River.

Table 4-10 summarizes the maximum 7DADM stream temperature predicted at the mouth of the Molalla River for all model scenarios over the entire model period.

Figure 4-9 shows the predicted maximum 7DADM for all Molalla River model scenarios.

Figure 4-10 shows current measured bankfull width compared with predicted potential bankfull width.

Table 4-9: Molalla River model scenario descriptions.

Scenario Name	Description
Current Condition Scenario	The Molalla River Current Condition Scenario model has the following updates from the calibrated model created to support the original 2008 Molalla Pudding TMDL. Molalla STP was added to the model as a point source discharge at model km 34.08. This discharge was moved from Bear Creek to the mainstem Molalla River in 2006. Discharge from the Molalla STP was set to zero because discharge is not permitted from May 1 – October 31.
No Point Sources	This scenario evaluates the stream temperature response from removing point source heat load. Discharge from Molalla STP was set to zero. This scenario is the same as the Current Condition scenario, because the Molalla STP is not permitted to discharge from May 1 – October 31.
Restored Flow	This scenario evaluates the stream temperature response from removing surface water withdrawals entirely. This scenario is only an approximation of natural flow because simulation only eliminates water withdrawals directly from the Molalla River, not groundwater or tributary withdrawals.
Channel Morphology	This scenario evaluates the stream temperature response from setting bankfull width to natural conditions.
Restored Vegetation	This scenario evaluates the stream temperature response from setting near stream land cover to system potential vegetation conditions. System potential vegetation is Upland Forest in the upper half of the watershed and Mixed Forest/Savannah/Prairie in the lower half of the watershed.
Wasteload Allocations	This scenario evaluates the stream temperature response from the TMDL wasteload allocations.
Background	This scenario evaluates the stream temperature response from removing point source heat load, removing surface water withdrawals, setting bankfull width to natural conditions, and setting near stream land cover to system potential vegetation conditions.

Table 4-10: Summary of maximum 7DADM stream temperature at the mouth of the Molalla River for all model scenarios over the entire model period.

Temperature Metric	Model KM	Scenario	Stream Temperature (°C)	Location
7DADM	0.06	Current Condition	26.47	outlet
7DADM	0.06	Restored Vegetation	26.13	outlet
7DADM	0.06	No Point Sources	26.47	outlet
7DADM	0.06	Wasteload Allocations	26.43	outlet
7DADM	0.06	Restored Flow	25.40	outlet
7DADM	0.06	Channel Morphology	26.16	outlet
7DADM	0.06	Background	24.81	outlet

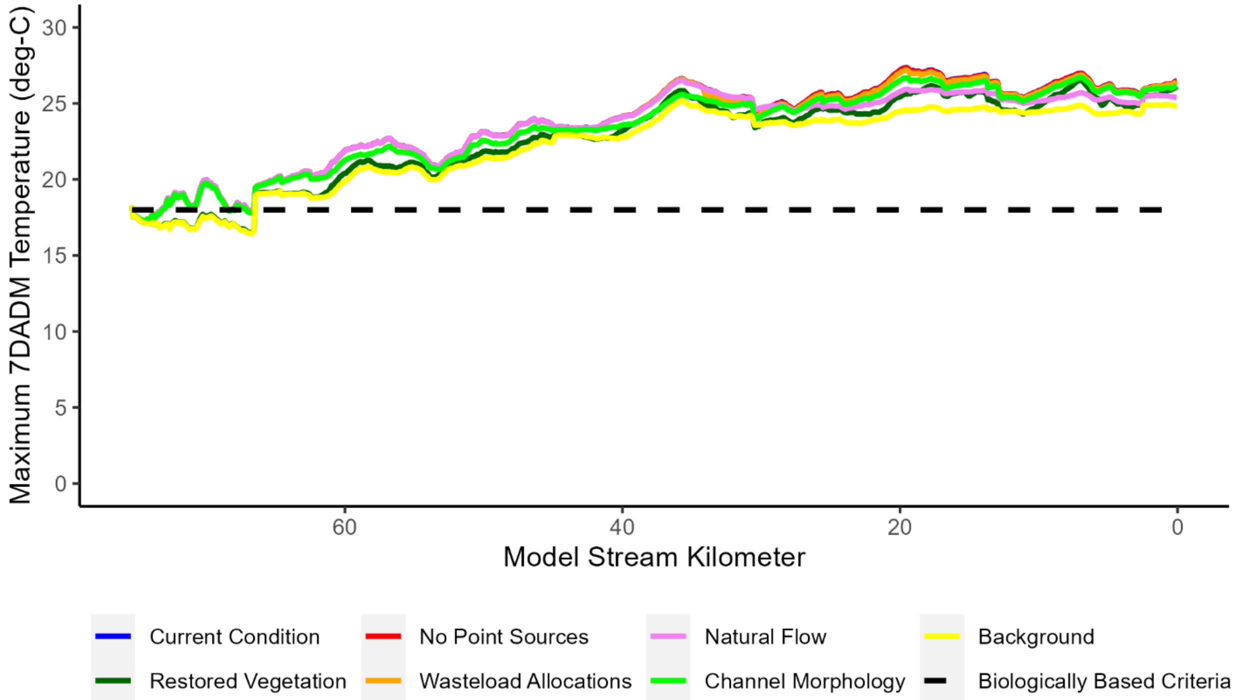


Figure 4-9: Maximum 7DADM stream temperature for all model scenarios for the Molalla River.

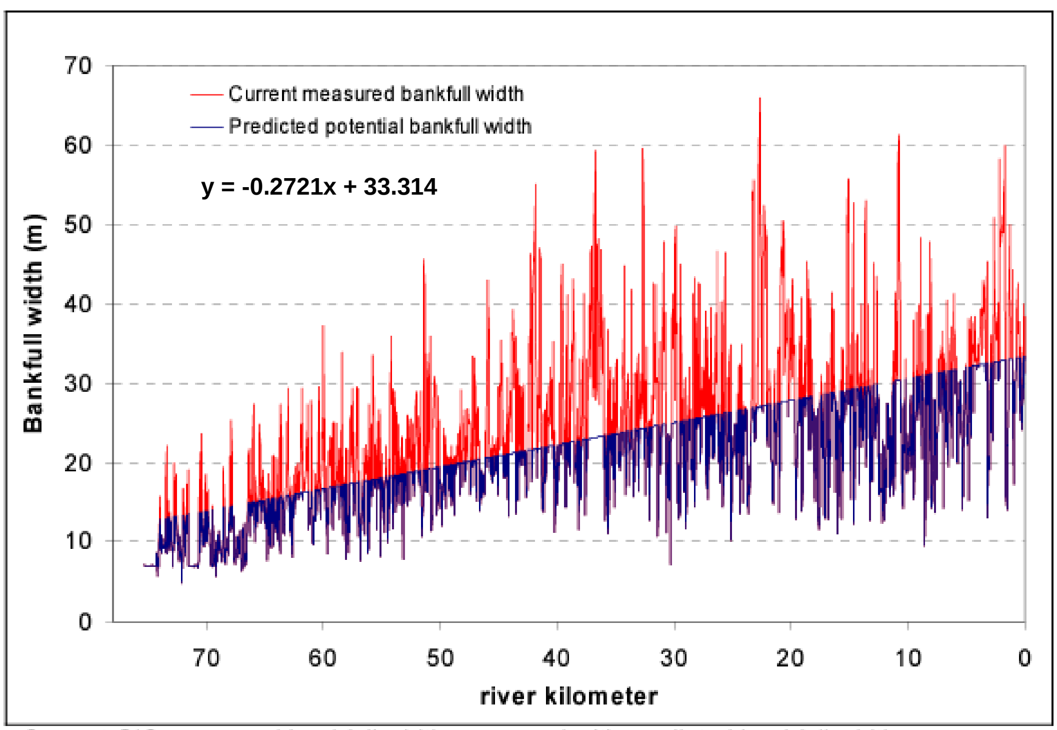


Figure 4-10: GIS measured bankfull width compared with predicted bankfull width. A regression was performed of the moving median of bankfull width from headwaters to mouth. Modified bankfull width entered into the Heat Source model was the measured width, or the predicted width, the demarcating line in this figure, whichever was less.

4.3.1 Current Condition Scenario

Molalla STP discharged to Bear Creek at the time the calibrated model was developed and therefore was not included as an input. The outfall was moved to the Molalla River in 2006 and the discharge to Bear Creek was abandoned in January 2007. A current condition scenario was considered for assessment of the discharge to the Molalla River but was not developed after review of DMR data.

The current NPDES permit for Molalla STP does not authorize discharge from May 1 – October 31. Although, based on a review of DMRs from 2016-2020, discharge did occur during this period in times of heavy rainfall and higher flows. There were no discharges to the Molalla River in July or August during the model period.

The discharge from RSG Forest Products was also considered but also excluded because their discharge location is a settling pond that flows to a ditch, which then flows to farm ponds and terminates in a low, ponded area. There is no visible connection between the ditch and the mainstem Molalla River. DEQ NPDES Permit Program staff do not believe there is a surface water connection between the RSG Forest Products discharge location and the mainstem Molalla River. The location of RSG Forest Products and the Molalla STP are shown in **Figure 4-11.**

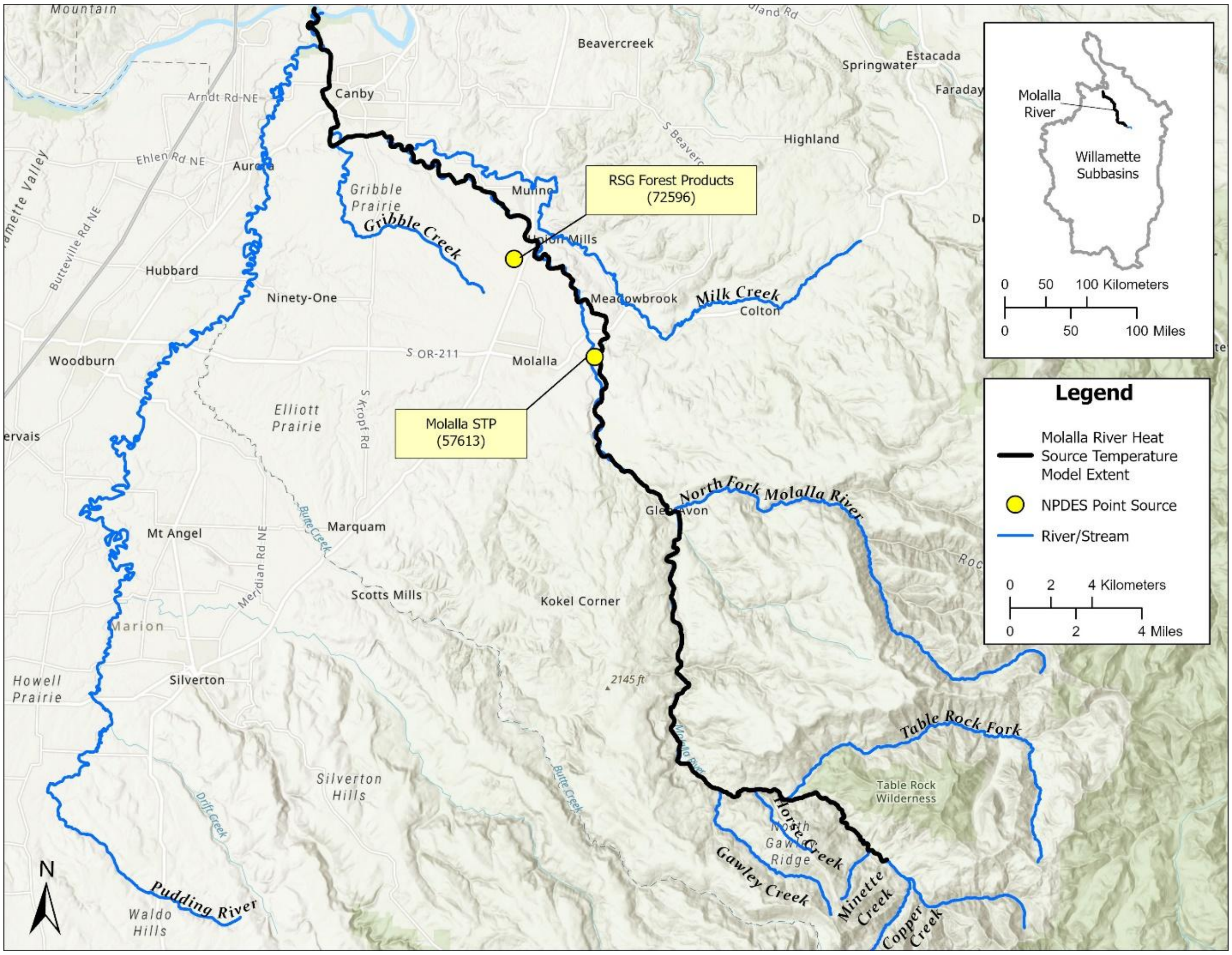


Figure 4-11: Locations of permitted individual NPDES point sources near the Molalla River.

4.3.2 Restored Vegetation

This section summarizes the temperature changes from restored vegetation.

Table 4-11 summarizes the maximum 7DADM stream temperature change between the Current Condition and Restored Vegetation scenarios for the Molalla River. It shows the 7DADM temperature difference at the most downstream node (the outlet) is equal to 0.52°C. In addition, the greatest 7DADM temperature difference between the two scenarios (the POMI) is equal to 2.42°C and occurs at stream model km 70.06.

Figure 4-12 shows the change in the maximum 7DADM stream temperatures between the Current Condition and Restored Vegetation model scenarios for the Molalla River over the entire model period.

Table 4-11: Summary of maximum 7DADM stream temperature change between Current Conditions and Restored Vegetation model scenarios for the Molalla River over the entire model period.

Temperature Metric	Model KM	Scenario	Stream Temperature (°C)	Location
7DADM	0.06	Change	0.52	outlet
7DADM	70.06	Change	2.42	POMI

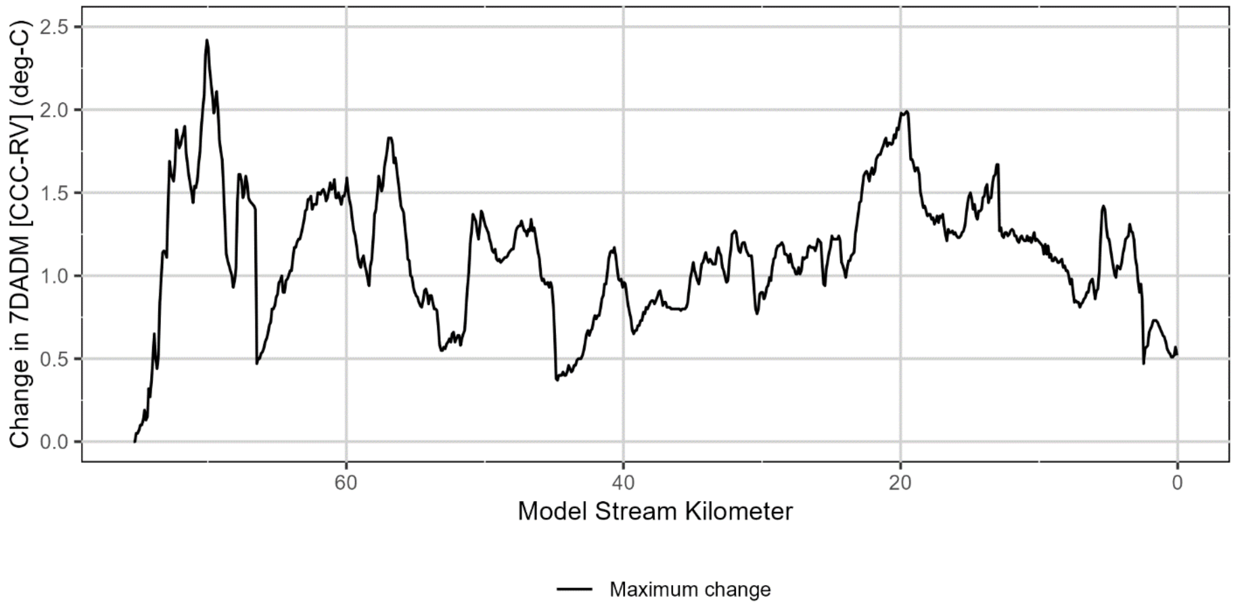


Figure 4-12: Change in the maximum 7DADM stream temperatures between Current Condition and Restored Vegetation scenarios for the Molalla River over the entire model period.

Table **4-12** summarizes the mean effective shade for the Current Condition and Restored Vegetation scenarios for the Molalla River. The difference in mean effective shade between the scenarios is equal to 14 percentage points.

Figure 4-13 and **Figure 4-14** compare effective shade predictions from the Current Condition and Restored Vegetation scenarios for the Molalla River.

Table 4-12: **Summary of mean effective shade between the Current Condition and Restored Vegetation scenarios for the Molalla River.**

Scenario	Mean Effective Shade (%)
Current Condition	30.82
Restored Vegetation	44.75
Difference	13.93

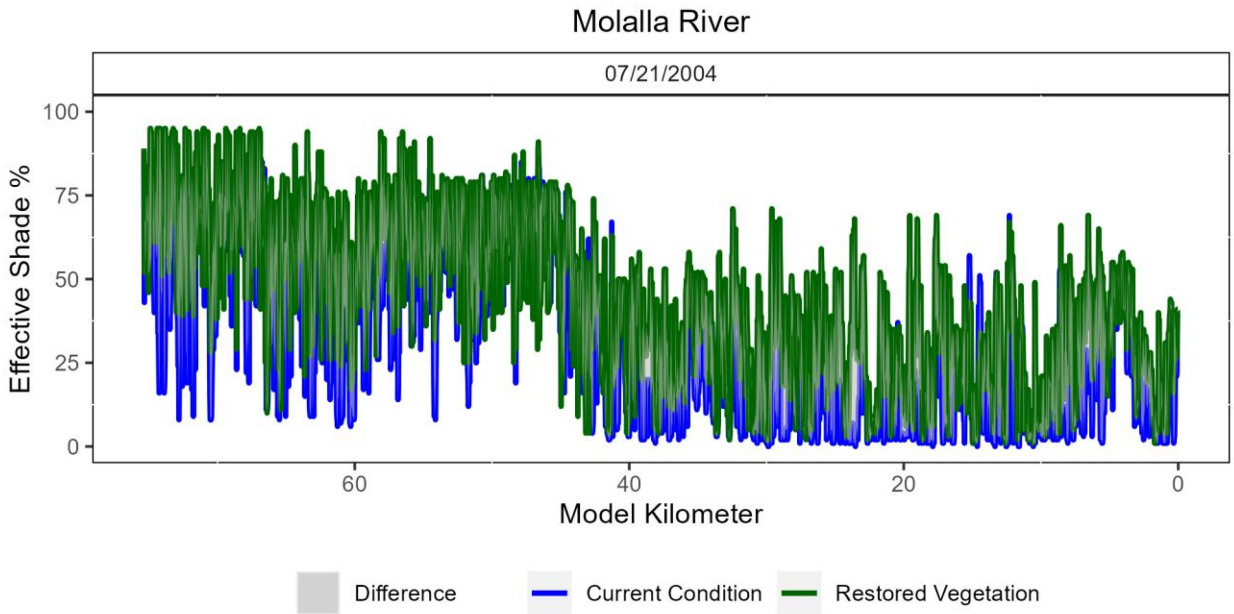


Figure 4-13: Comparison of effective shade from the Current Condition and Restored Vegetation scenarios for the Molalla River.

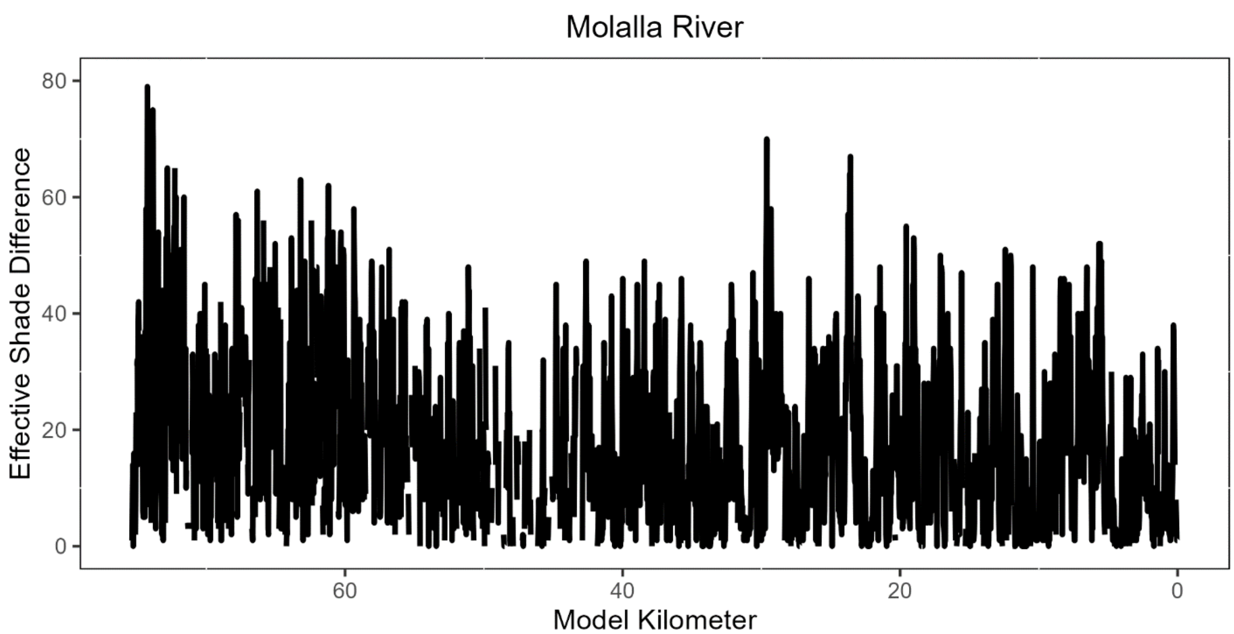


Figure 4-14: Percentage point difference between effective shade from the Current Condition and Restored Vegetation scenarios on 7/21/2004 for the Molalla River. Missing values indicate that the shade difference is negative due to instances of higher effective shade in the Current Condition scenario versus the Restored Vegetation scenario.

4.3.3 Channel Morphology

This section summarizes the temperature impacts of restored channel morphology.

Natural bankfull width conditions were estimated using methodology from the Tillamook TMDL (DEQ, 2001). DEQ calculated the moving median of each 1000-foot section of the stream from headwaters to mouth and then performed a regression of those points with river mile. The resulting linear equation was used to predict potential bankfull width (**Figure 4-10**). DEQ then ran the Heat Source model with either the measured bankfull width or the predicted potential bankfull width, whichever was less.

Table 4-13 summarizes the maximum 7DADM stream temperature change between the Channel Morphology and Current Condition scenarios for the Molalla River. It shows the 7DADM temperature difference at the most downstream node (the outlet) is equal to 0.31°C. In addition, the greatest daily maximum temperature difference between the two scenarios (the POMI) is equal to 1.09°C and occurs at stream model km 36.36.

Figure 4-15 shows the change in the maximum 7DADM stream temperatures between the Channel Morphology and Current Condition model scenarios for the Molalla River over the entire model period.

Table 4-13: Summary of maximum 7DADM stream temperature change between Channel Morphology and Current Condition model scenarios for the Molalla River over the entire model period.

Temperature Metric	Model KM	Scenario	Stream Temperature (°C)	Location
7DADM	0.06	Change	0.31	outlet
7DADM	36.36	Change	1.09	POMI

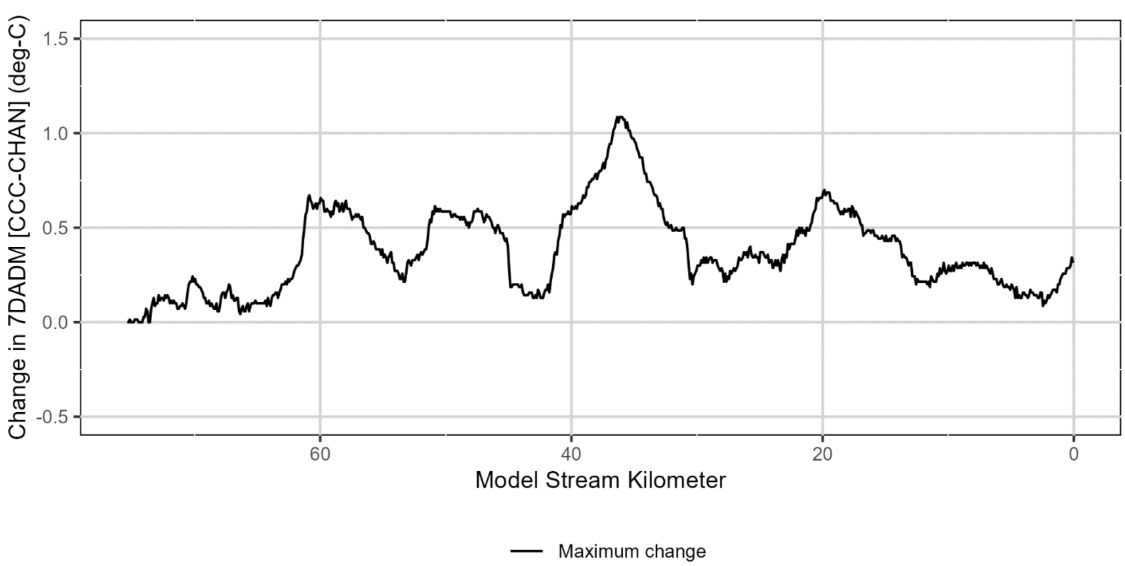


Figure 4-15: Change in maximum 7DADM stream temperatures between the Channel Morphology and Current Condition scenarios for the Molalla River over the entire model period.

4.3.4 Wasteload Allocations

This section summarizes the temperature impacts of point sources discharging at their wasteload allocations. The impact the waste load allocations was determined by comparing the Wasteload allocation scenario to the No Point Source scenario.

In the No Point Source scenario, discharge from Molalla STP was set to zero. This scenario is the same as the Calibrated model. Molalla STP discharged to Bear Creek at the time the calibrated model was developed and therefore was not included as an input.

In the wasteload allocation scenario, water temperature and flow inputs from the Molalla STP were set to reflect their wasteload allocation. Wasteload allocations were calculated using equations described in the Willamette Subbasins TSD, Section 9.1 Wasteload allocation equation. For these calculations, it was assumed that effluent temperature and flow were equal to the maximum recorded value between March and October from available DMR data, which was 20.4°C on 6/25/2017 and 0.0981 cms on 10/23/2017 respectively. The portion of the HUA allocated to Molalla STP was 0.10°C. The resulting WLA temperature and flow inputs to the Molalla River were 18.6°C and 0.0981 cms respectively.

Table 4-14 summarizes the 7DADM stream temperature change between the No Point Sources and Wasteload Allocations scenarios for the Molalla River. Results show that at the POMI the 7DADM temperature difference is equal to 0.00°C. At the most downstream model node (the outlet) the 7DADM temperature difference is equal to -0.04°C. The negative value means that the temperatures of the No Point Sources scenario were warmer than the temperatures in the Wasteload Allocations scenario. Because the wasteload allocations are based on an increase above the applicable temperature criteria, effluent temperatures are generally cooler than the ambient river temperatures in the Molalla River and thus there is a cumulative cooling impact.

Figure 4-16 displays the change in maximum 7DADM stream temperatures between the Wasteload Allocations and No Point Sources scenarios for the entire Molalla River model reach. The greatest change in temperature occurred at the Molalla STP (model km 34.08), where the 7DADM stream temperature was around 0.3°C cooler in the Wasteload Allocations scenario than in the No Point Sources scenario. The Molalla River was also cooler in the Wasteload Allocations scenario for most locations downstream of this point.

Table 4-14: Summary of maximum 7DADM stream temperature change between Wasteload Allocations and No Point Sources model scenarios for the Molalla River over the entire model period.

Temperature Metric	Model KM	Scenario	Stream Temperature (°C)	Location
7DADM	0.06	Change	-0.04	outlet
7DADM	34.08	Change	0	POMI

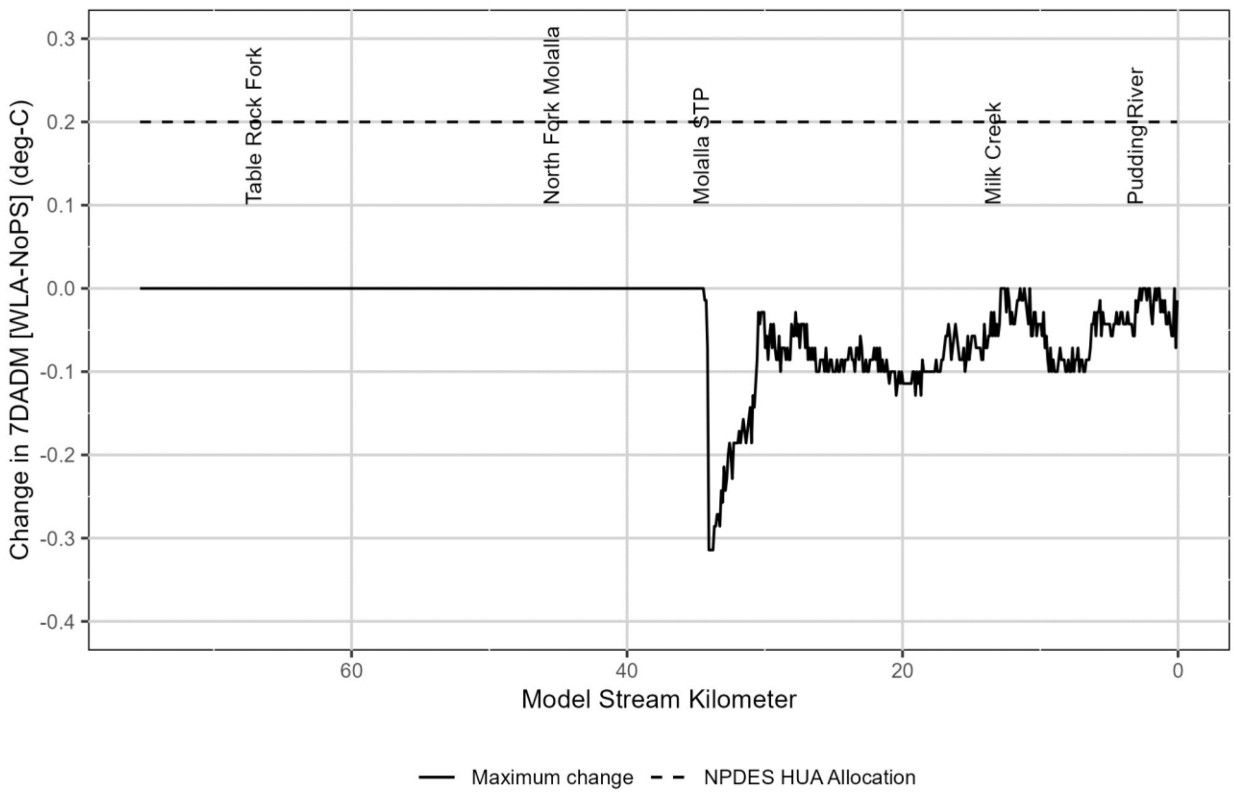


Figure 4-16: Change in maximum 7DADM stream temperatures between the Wasteload Allocations and No Point Sources scenarios for the Molalla River over the entire model period.

4.3.5 Restored Flow

This section summarizes the temperature impacts of restored stream flows.

Table 4-15 summarizes the maximum 7DADM stream temperature change between the Restored Flow and Current Condition scenarios for the Molalla River. It shows the 7DADM temperature difference at the most downstream node (the outlet) is equal to 1.07°C. In addition, the greatest daily maximum temperature difference between the two scenarios (the POMI) is equal to 1.50°C and occurs at stream model km 19.86.

Figure 4-17 shows the change in the maximum 7DADM stream temperatures between the Restored Flow and Current Condition model scenarios for the Molalla River over the entire model period.

Table 4-15: Summary of maximum 7DADM stream temperature change between Restored Flow and Current Condition model scenarios for the Molalla River over the entire model period.

Temperature Metric	Model KM	Scenario	Stream Temperature (°C)	Location
7DADM	0.06	Change	1.07	outlet
7DADM	19.86	Change	1.50	POMI

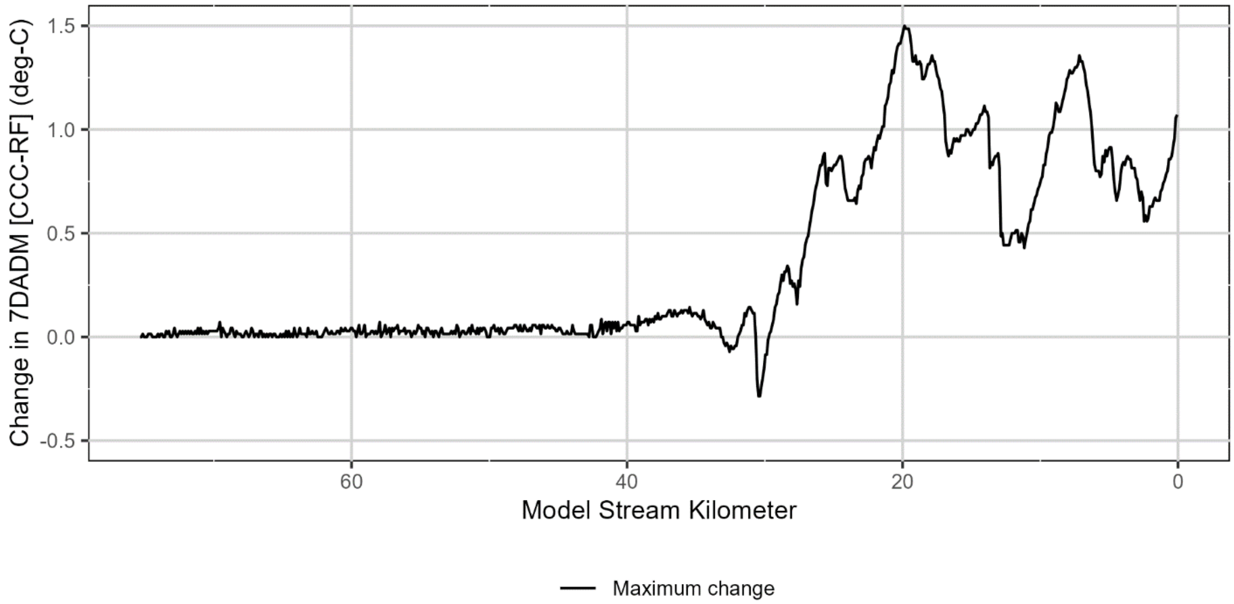


Figure 4-17: Change in maximum 7DADM stream temperatures between the Restored Flow and Current Condition scenarios for the Molalla River over the entire model period.

4.3.6 Background

This section summarizes the temperature impacts of background conditions.

Table 4-16 summarizes the maximum 7DADM stream temperature change between the Background and Current Condition scenarios as well as the Background and BBNC for the Molalla River. It shows the 7DADM temperature difference at the Background and Current Condition scenarios at the most downstream node (the outlet) is equal to 1.67°C; the difference between Background and the BBNC is 6.81°C. In addition, the greatest 7DADM temperature difference between the two scenarios (the POMI) is equal to 2.81°C and occurs at stream model km 19.86. The greatest 7DADM temperature difference between the Background scenario and the BBNC is equal to 9.16°C and occurs at stream model km 35.76.

Figure 4-18 shows the change in the maximum 7DADM stream temperatures between the Background and Current Condition model scenarios for the Molalla River over the entire model period.

Table 4-16: Summary of maximum 7DADM stream temperature change between Background and Current Condition model scenarios for the Molalla River over the entire model period.

Temperature Metric	Model KM	Scenario	Stream Temperature (°C)	Location
7DADM	0.06	Change	1.67	Outlet
7DADM	19.86	Change	2.81	POMI
7DADM	0.06	Change_BBNC	6.81	Outlet
7DADM	35.76	Change_BBNC	9.16	POMI

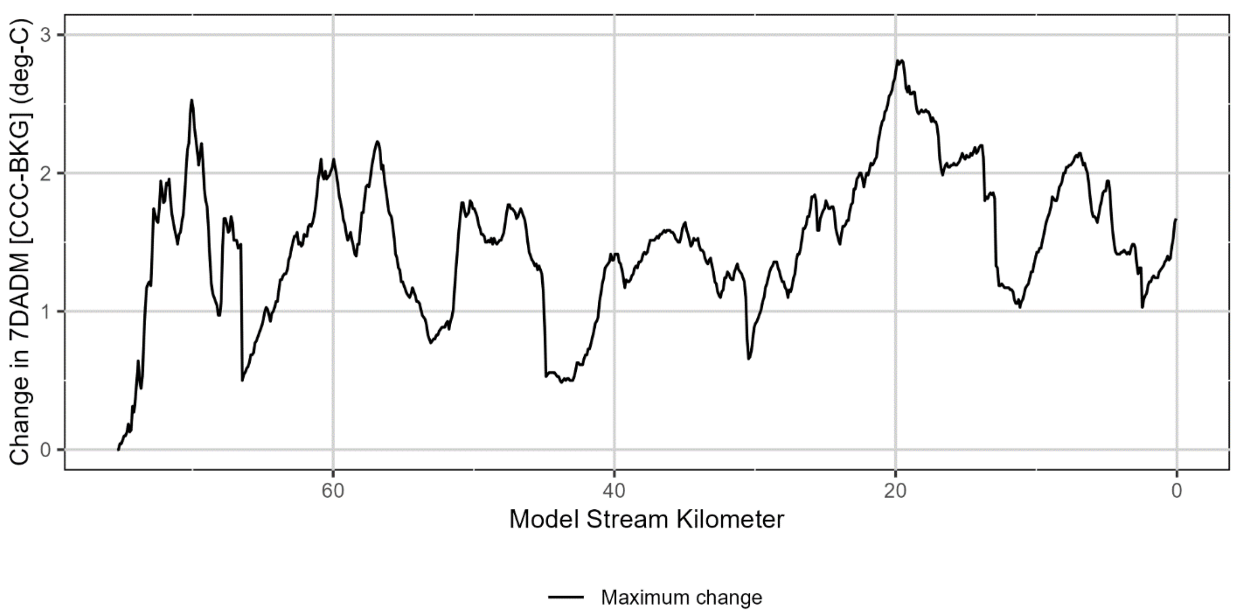


Figure 4-18: Change in maximum 7DADM stream temperatures between the Background and Current Condition scenarios for the Molalla River over the entire model period.

4.4 Pudding River

Table 4-17 describes the different model scenarios used to simulate stream temperature and effective shade for the Pudding River.

Table 4-18 summarizes the maximum 7DADM stream temperature predicted at the mouth of the Pudding River for all model scenarios over the entire model period.

Figure 4-19 shows the predicted maximum 7DADM for all Pudding River model scenarios.

Table 4-17: Pudding River model scenario descriptions.

Scenario Name	Description
Current Condition Scenario	The Pudding River Current Condition Scenario model has the following updates from the calibrated model created to support the original 2008 Molalla Pudding TMDL. 1. Point source discharges were added to the flow data sheet for Gervais STP, Aurora STP and Mt. Angel STP. Flow inputs at these facilities were set at zero since they are not permitted to discharge during the model period. 2. The NPDES permit for JLR authorizes discharge to the Pudding River but based on a review of the DMRs from 2018 - 2020 there were no discharges to the Pudding River during the model period. All discharge was land applied via outfall 004 and therefore flow inputs to the model were set at zero. 3. Flow and temperature inputs for Woodburn WWTP were updated to reflect discharge conditions in August 2020 as reported on the DMRs.
Restored Vegetation	This scenario evaluates the stream temperature response from setting near stream land cover to system potential vegetation conditions.
No Point Sources	This scenario evaluates the stream temperature response from removing point source heat load. Water temperature and flow inputs from individually permitted point source discharges within the model extent (JLR, Mt. Angel STP, Woodburn WWTP, Aurora STP and Gervais STP) were removed.
Wasteload Allocations	This scenario evaluates the stream temperature response from the TMDL wasteload allocations.
Tributary Temperatures	This scenario evaluates the stream temperature response when tributary temperature inputs were reduced to meet temperature standards at the confluence with the Pudding River (18°C). **Figure 4-38** through **Figure 4-46** demonstrate how hourly tributary temperature inputs were reduced.
Natural Flow	This scenario evaluates the stream temperature response from removing consumptive use withdrawals entirely.
Consumptive Uses	These scenarios evaluate the impact of consumptive use on river temperature. Three consumptive use scenarios were modeled, where consumptive uses were reduced to 25%, 50% and 75% of normal levels. **Figure 4-32 c**ompares Pudding River flow for the Current Condition, Natural Flow and Consumptive Use model scenarios. See below for details regarding model scenario set up.
Background	This scenario evaluates the stream temperature response from removing point source heat load, removing consumptive uses, reducing tributary temperatures to meet temperature standards, and setting near stream land cover to system potential vegetation conditions.

Table 4-18: Summary of maximum 7DADM stream temperature at the mouth of the Pudding River for all model scenarios over the entire model period.

Temperature Metric	Model KM	Scenario	Stream Temperature (°C)	Location
7DADM	0	Current Condition	25.79	outlet
7DADM	0	Restored Vegetation	23.84	outlet
7DADM	0	No Point Sources	25.8	outlet
7DADM	0	Wasteload Allocations	25.8	outlet
7DADM	0	Natural Flow	24.11	outlet
7DADM	0	25% Consumptive Use	24.41	outlet
7DADM	0	50% Consumptive Use	24.8	outlet
7DADM	0	75% Consumptive Use	25.26	outlet

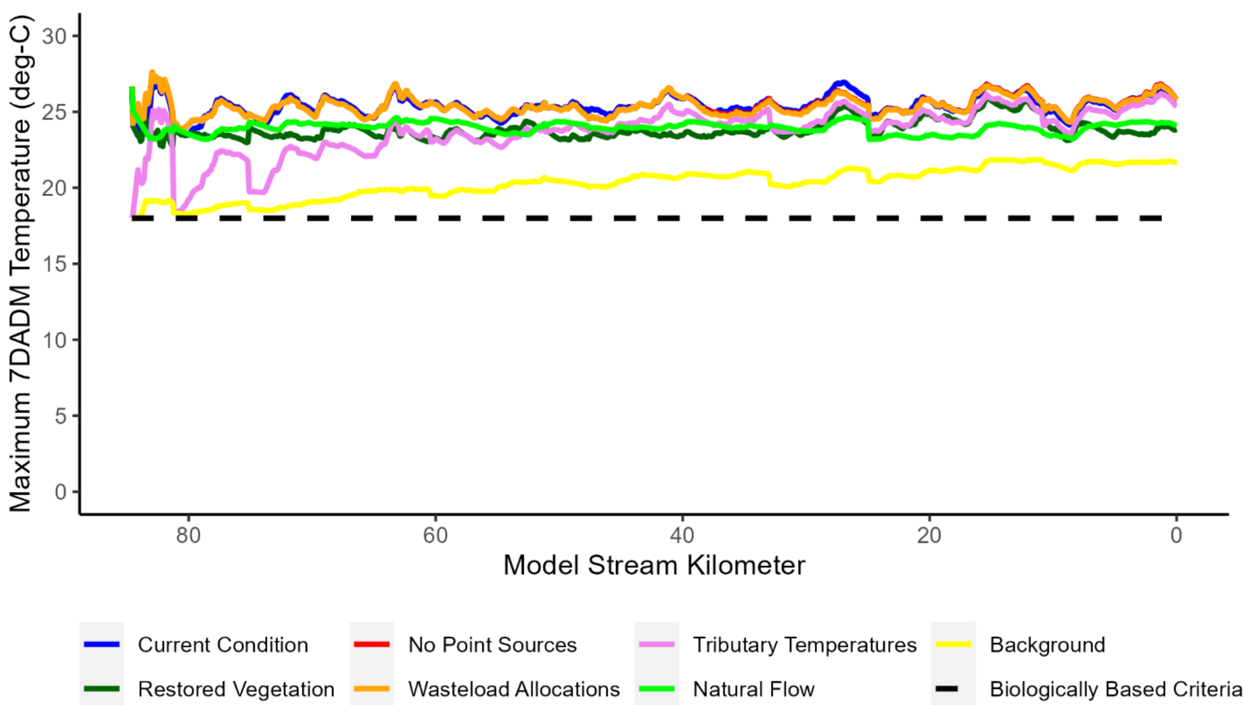


Figure 4-19: Maximum 7DADM stream temperature for all model scenarios for the Pudding River.

4.4.1 Current Condition Scenario

This scenario is the same as the calibrated model except for updates to reflect the current effluent discharge from JLR and Woodburn WWTP.

There are six permitted individual NPDES point sources along the model extent (**Figure 4-20**). Detail about each point source is summarized in **Table 3-23**.

Gervais STP, Aurora STP and Mt. Angel STP were included as point source inputs to the model, but flow inputs were set at zero since the facilities are not permitted to discharge during the model period.

The JLR facility is allowed to discharge, but a review of DMRs from 2018 - 2020 showed that there have been no discharges in August during the model period. All discharges were land applied, therefore flow inputs to the model were set to zero. The 2004 calibrated model set JLR's discharge at 0.001 cms and effluent temperatures at 18 degrees Celsius.

The Woodburn WWTP discharge was modified to reflect discharge conditions reported in the DMR for August 2020. The model effluent temperature and flow inputs are shown in **Figure 4-21** and **Figure 4-22**. Note the dates on the plot reflect the model year but the data is from 2020.

Columbia Helicopters is not included as point source to the model because DEQ considers wastewater from this site to have no reasonable potential to increase stream temperature in the Pudding River.

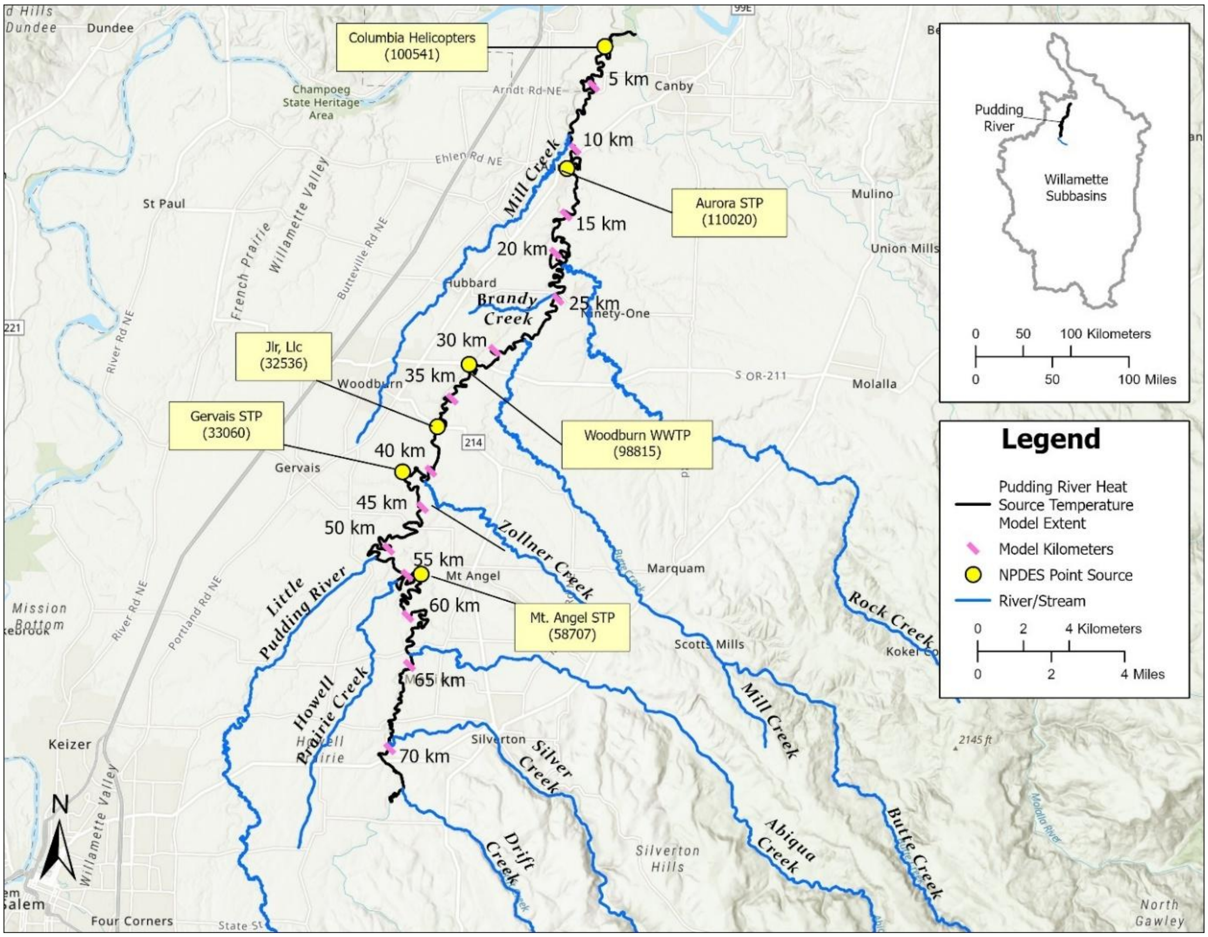


Figure 4-20: Locations of permitted individual NPDES point sources near the Pudding River.

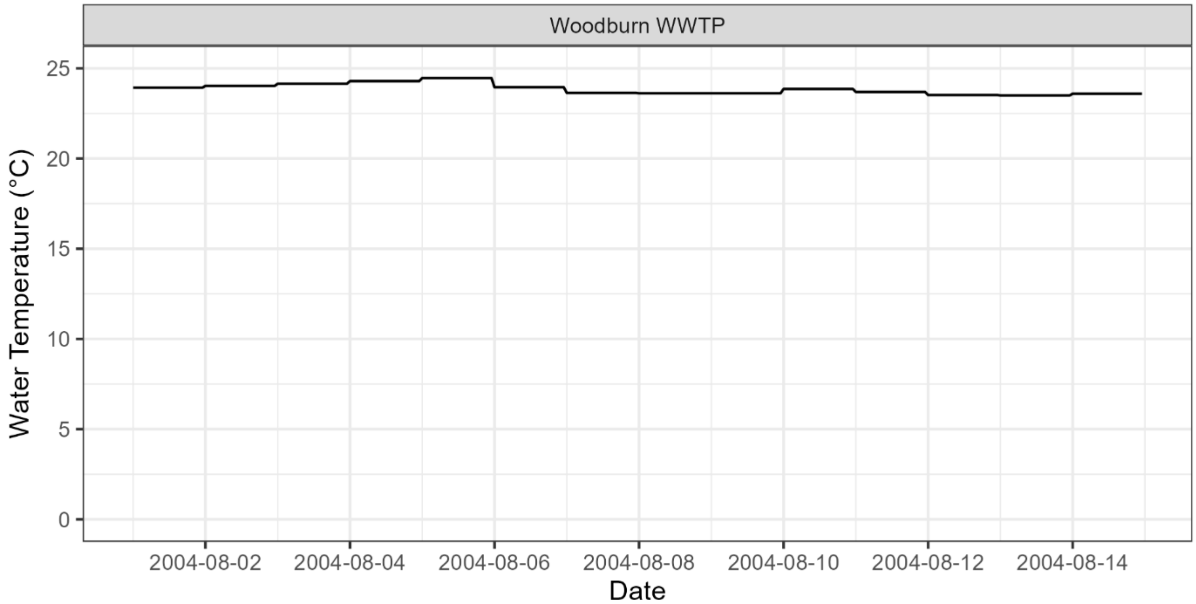


Figure 4-21: Pudding River current condition scenario model setup up for Woodburn WWTP effluent temperatures.

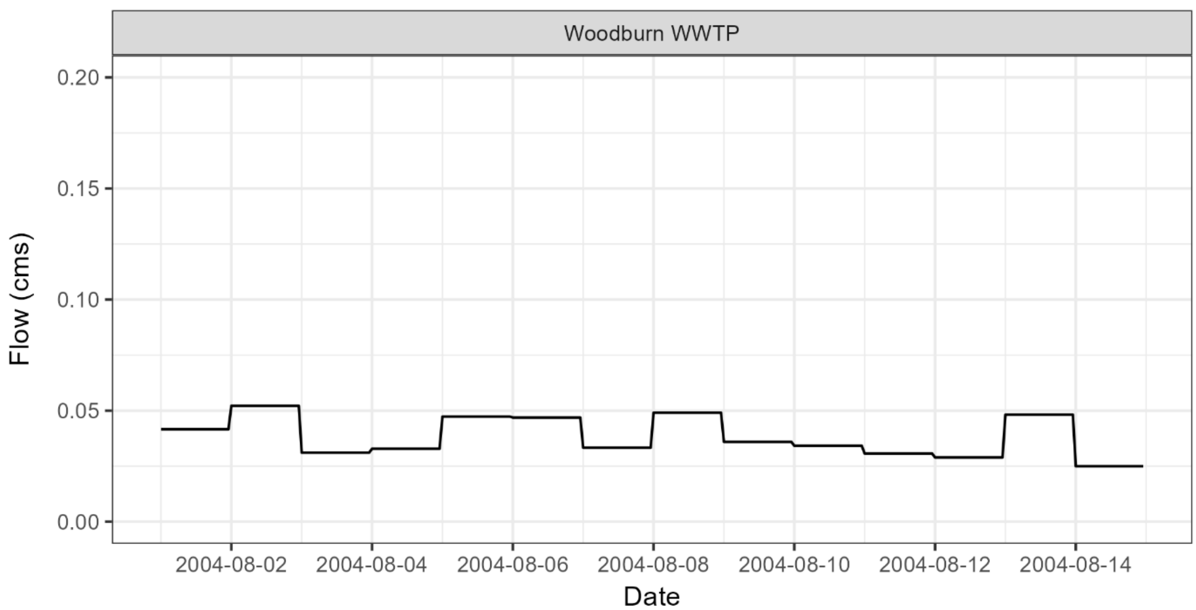


Figure 4-22: Pudding River current condition scenario model setup for Woodburn WWTP effluent flow rates.

4.4.2 Restored Vegetation

This section summarizes the temperature impacts of restored vegetation.

Table 4-19 summarizes the maximum 7DADM stream temperature change between the Current Condition and Restored Vegetation scenarios for the Pudding River. It shows the 7DADM temperature difference at the most downstream node (the outlet) is equal to 1.95°C. In addition, the greatest 7DADM temperature difference between the two scenarios (the POMI) is equal to 3.97°C and occurs at stream model km 82.1.

Figure 4-23 shows the change in the maximum 7DADM stream temperatures between the Current Condition and Restored Vegetation model scenarios for the Pudding River over the entire model period.

Table 4-19: Summary of maximum 7DADM stream temperature change between Restored Vegetation and Current Condition model scenarios for the Pudding River over the entire model period.

Temperature Metric	Model KM	Scenario	Stream Temperature (°C)	Location
7DADM Temperature	0	Change	1.95	outlet
7DADM Temperature	82.1	Change	3.97	POMI

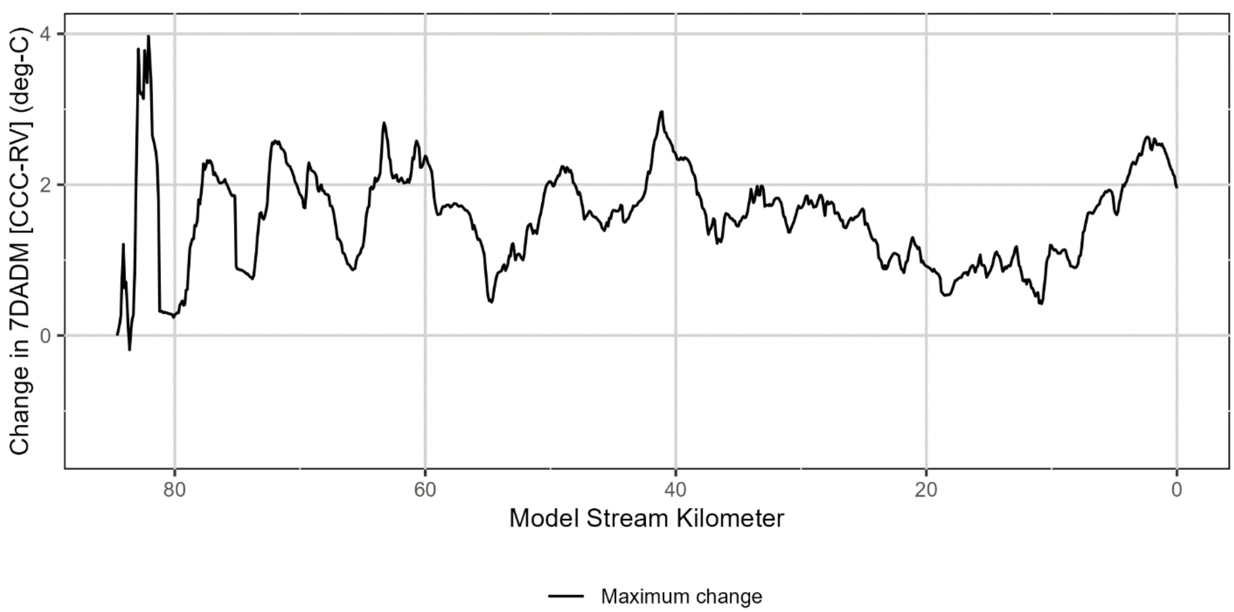


Figure 4-23: Change in the maximum 7DADM stream temperatures between Current Condition and Restored Vegetation scenarios for the Pudding River over the entire model period.

Table 4-20 summarizes the mean effective shade for the Current Condition and Restored Vegetation scenarios for the Pudding River. The difference in mean effective shade between the scenarios is equal to 10.5 percentage points.

Figure 4-24 and **Figure 4-25** compare effective shade predictions from the Current Condition and Restored Vegetation scenarios for the Pudding River.

Table 4-20: Summary of mean effective shade between the Current Condition and Restored Vegetation scenarios for the Pudding River.

Scenario	Mean Effective Shade (%)
Current Condition	46.2
Restored Vegetation	56.7
Change	10.5

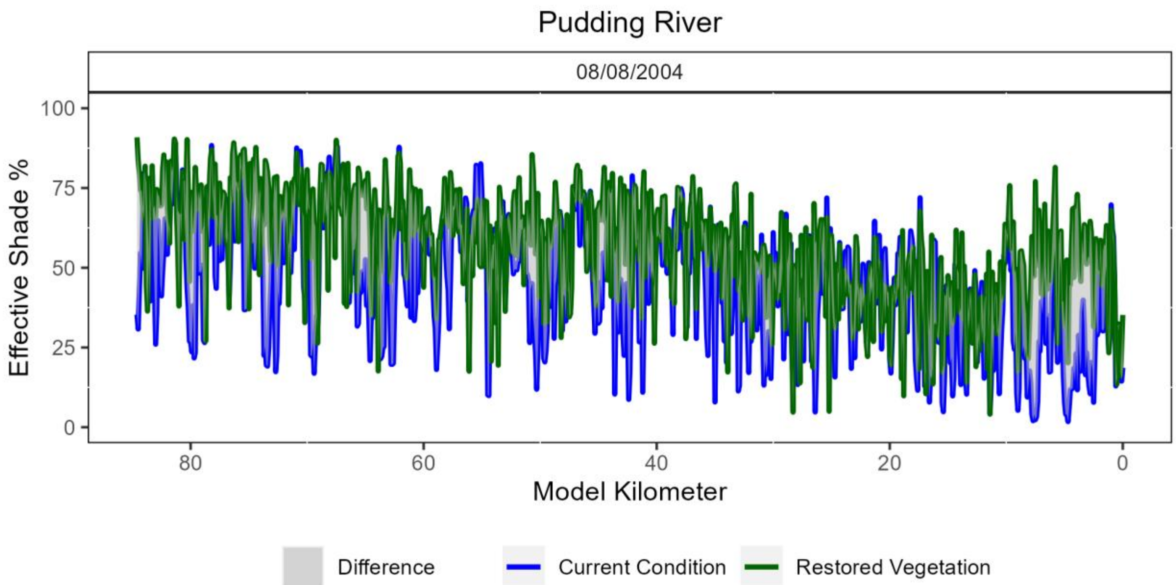


Figure 4-24: Comparison of effective shade from the Current Condition and Restored Vegetation scenarios for the Pudding River.

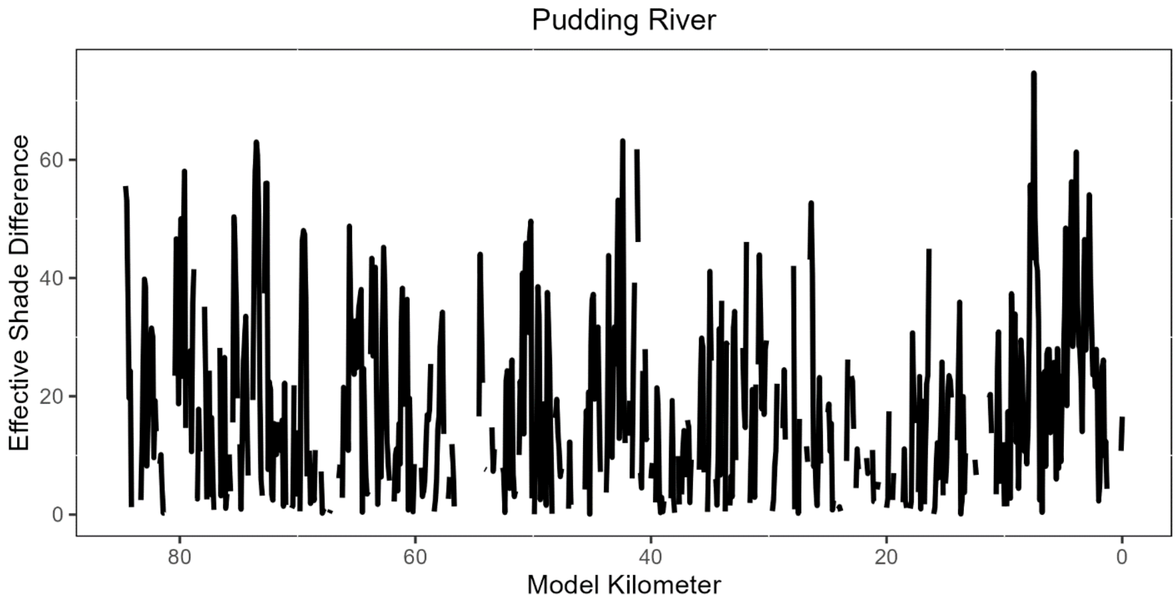


Figure 4-25: Percentage point difference between effective shade from the Current Condition and Restored Vegetation scenarios for the Pudding River. Missing values indicate that the shade difference is negative due to instances of higher effective shade in the current condition scenario versus the restored vegetation scenario.

4.4.3 Wasteload Allocations

This section summarizes the temperature impacts of point sources discharging at their wasteload allocations. The impact of the wasteload allocations was determined by comparing the Wasteload Allocation scenario to the No Point Source scenario.

In the No Point Source scenario, effluent temperature, and flow inputs from individually permitted point source discharges within the model extent (JLR, Mt. Angel STP, Woodburn WWTP, Aurora STP and Gervais STP) were removed.

In the Wasteload Allocation scenario, effluent temperature and flow were equal to the wasteload allocations and calculated using equations described in the Willamette Subbasins TSD (Section 6.1.1 Wasteload allocation equation). Effluent flow inputs from individually permitted point source discharges at Aurora STP, Gervais STP, and Mt Angel STP were set to zero since there is no discharge in the summer and their HUA is zero.

Woodburn WWTP effluent temperature was updated to reflect their wasteload allocation. For WLA calculations, it was assumed that effluent flow was equal to the maximum recorded values between March – October from available DMR data. The maximum effluent discharge occurred in August 2020. The portion of the HUA allocated to Woodburn WWTP is 0.20°C. **Figure 4-26** shows Woodburn WWTP daily maximum effluent temperatures that achieve the wasteload allocation. **Figure 4-27** shows Woodburn WWTP Wasteload Allocation effluent flow.

JLR does not discharge to the river during the summer. It is often land applied via outfall 004. For the allocation scenario, the discharge reported on the August 2022 DMR from outfall 004 was assumed to be the discharge to the Pudding River at outfall 001 (**Figure 4-28**). JLR's effluent temperature was updated to reflect their wasteload allocation (**Figure 4-29**). The portion of the HUA allocated to JLR was 0.01°C.

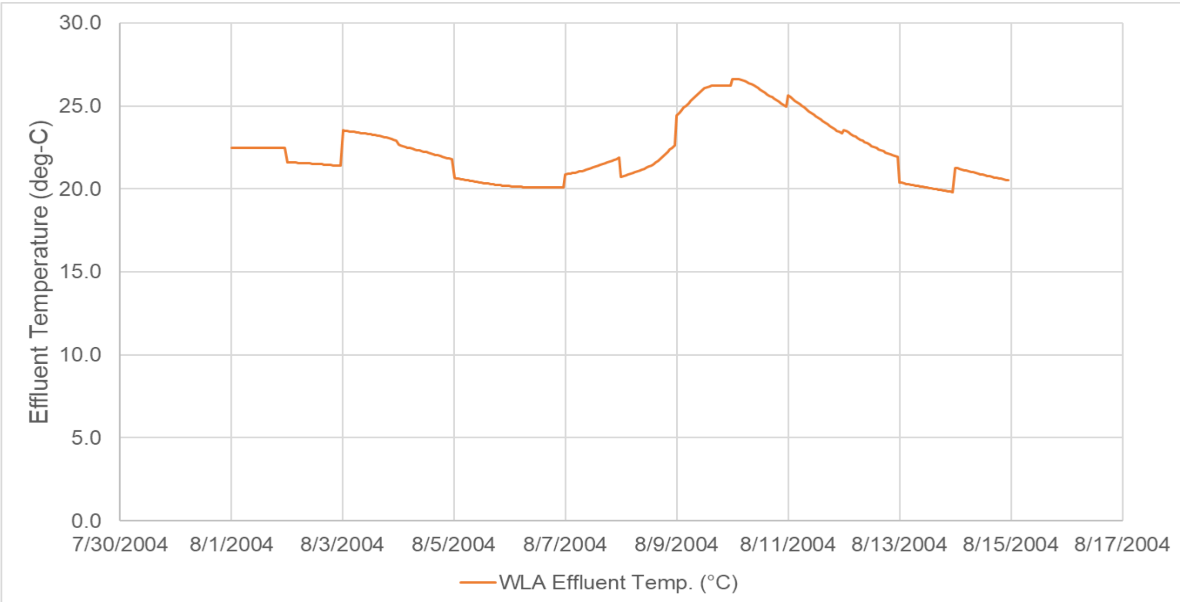


Figure 4-26: Woodburn WWTP wasteload allocation model scenario effluent temperature (deg-C).

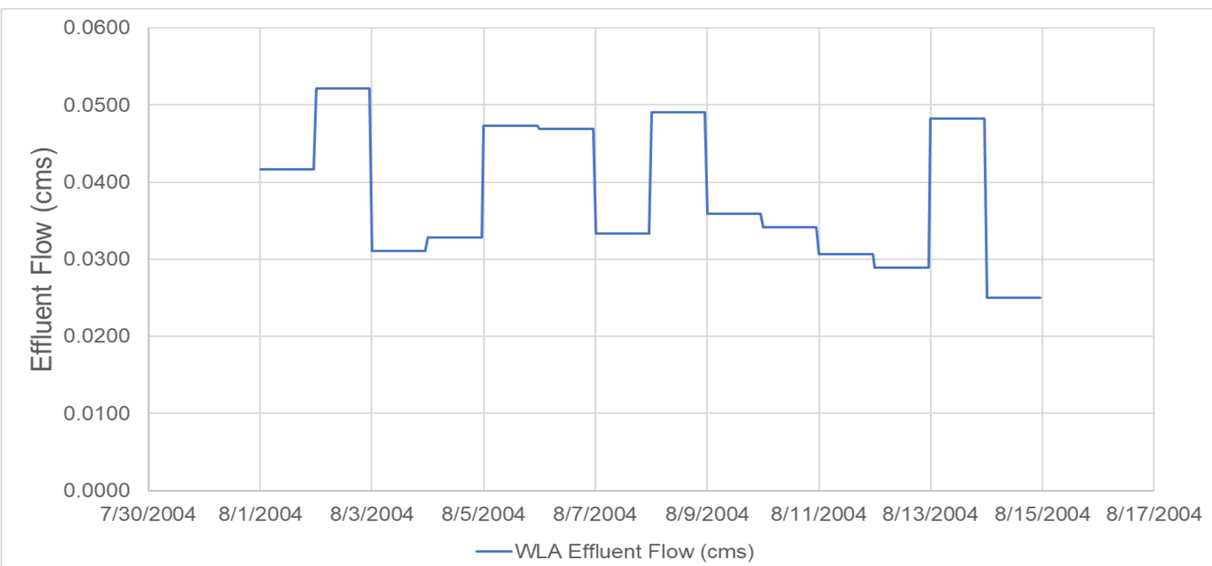


Figure 4-27: Woodburn WWTP wasteload allocation model scenario effluent flow (cms).

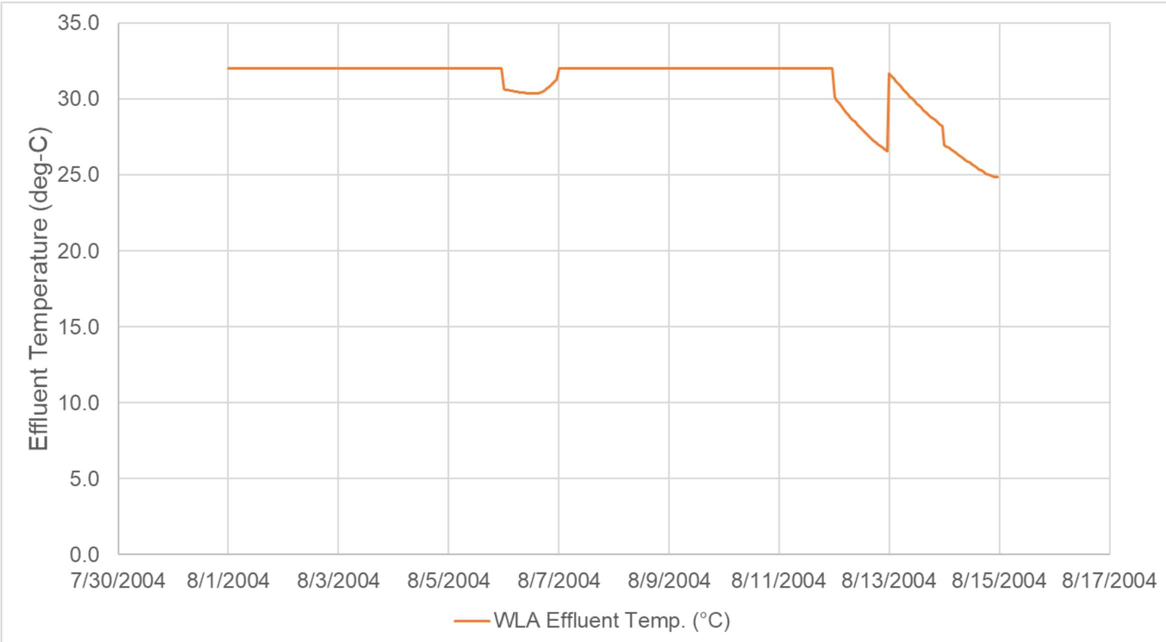


Figure 4-28: JLR wasteload allocation model scenario effluent temperature (deg-C).

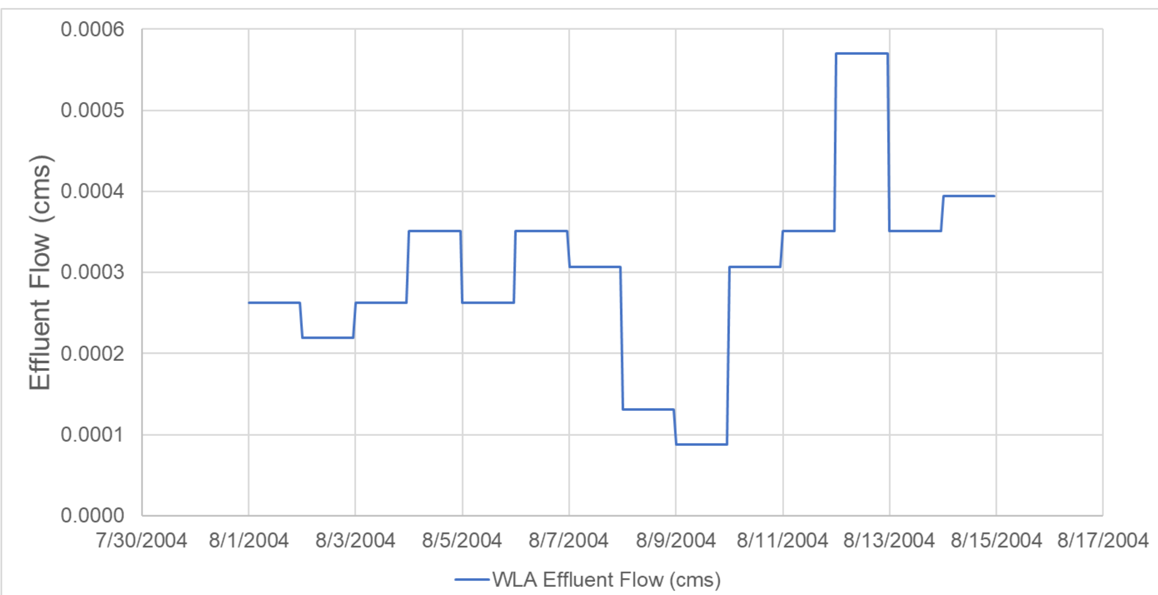


Figure 4-29: JLR wasteload allocation model scenario effluent flow (cms) based upon effluent flow at outfall 004.

Table 4-21 summarizes the 7DADM stream temperature change between the No Point Sources and Wasteload Allocations scenarios for the Pudding River. The results show that at the most downstream node (the outlet) the wasteload allocations do not impact 7DADM temperatures (0°C warming). At the POMI the 7DADM temperature difference is equal to 0.03°C.

Because the wasteload allocations are based on an increase above the applicable temperature criteria, effluent temperatures are often cooler than the ambient river temperatures resulting in small impacts relative to the allocated HUA.

Figure 4-30 displays the change in maximum 7DADM stream temperatures between the Wasteload Allocations and No Point Sources scenarios for the entire Pudding River model period. The greatest change in temperature occurred at Rock Creek (model km 24.9), where the 7DADM stream temperature was around 0.03°C warmer in the Wasteload Allocations scenario than in the No Point Sources scenario.

Table 4-21: Summary of maximum 7DADM stream temperature change between Wasteload Allocations and No Point Sources model scenarios for the Pudding River over the entire model period.

Temperature Metric	Model KM	Scenario	Stream Temperature (°C)	Location
7DADM	0	Change	0	outlet
7DADM	24.8	Change	0.03	POMI

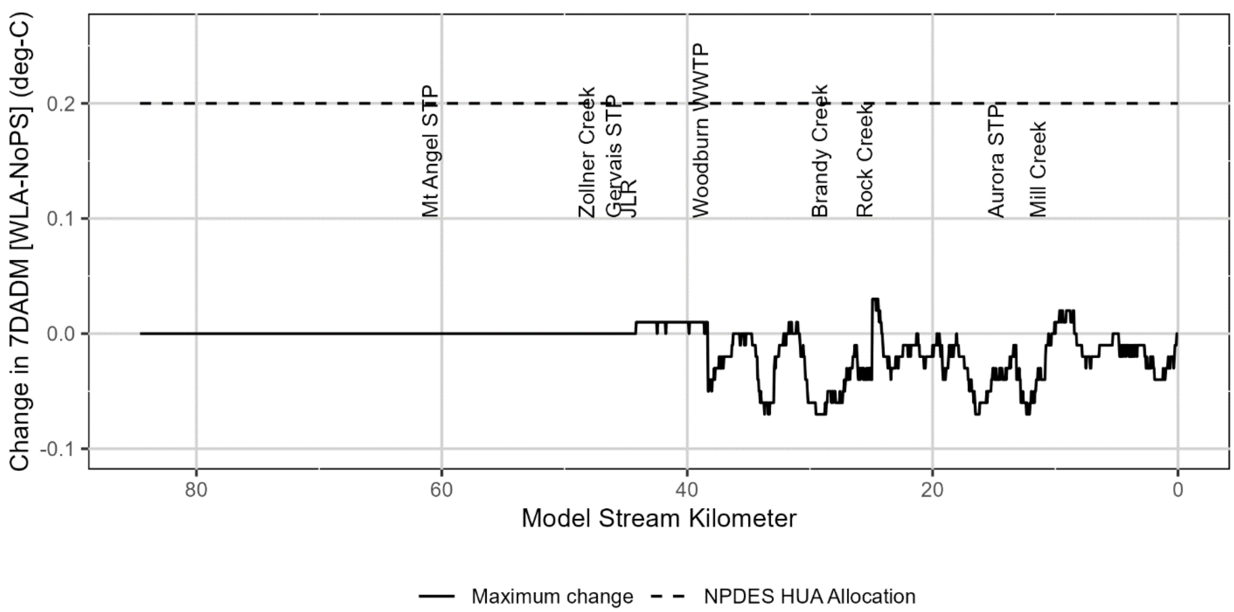


Figure 4-30: Change in maximum 7DADM stream temperatures between the Wasteload Allocations and No Point Sources scenarios for the Pudding River over the entire model period.

The impacts of the City of Woodburn WWTP effluent on daily maximum temperatures are generally small, the effluent is always significantly warmer than the river in the early morning and the daily average effluent temperatures are generally warmer than daily average river temperatures. Therefore, the effluent adds more heat to the river in the early morning than in the late afternoon. This results in greater increases in daily average temperatures than in daily maximum temperatures. While the effluent may reduce daily maximum temperatures at points downstream, it generally increases daily average temperatures and, therefore, reduces the capacity of the river to assimilate additional heat loads, such as anthropogenic solar radiation heat loads.

4.4.4 Natural Flow

This section summarizes the temperature impacts of natural flow conditions.

Table 4-22 summarizes the maximum 7DADM stream temperature change between the Current Condition and Natural Flow scenarios for the Pudding River. It shows the 7DADM temperature difference at the most downstream node (the outlet) is equal to 1.68°C. In addition, the greatest 7DADM temperature difference between the two scenarios (the POMI) is equal to 4.01°C and occurs at stream model km 82.9. The 7DADM temperature difference at the Woodburn Gage (model km 38.3) is equal to 1.04°C.

Figure 4-31 shows the change in the maximum 7DADM stream temperatures between the Current Condition and Natural Flow model scenarios for the Pudding River over the entire model period. The maximum change in 7DADM temperature is equal to 4.01°C and occurs at model km 82.9.

Table 4-22: Summary of maximum 7DADM stream temperature change between Natural Flow and Current Condition model scenarios for the Pudding River over the entire model period.

Temperature Metric	Model KM	Scenario	Stream Temperature (°C)	Location
7DADM	0	Change	1.68	outlet
7DADM	82.9	Change	4.01	POMI
7DADM	38.3	Change	1.04	Woodburn Gage

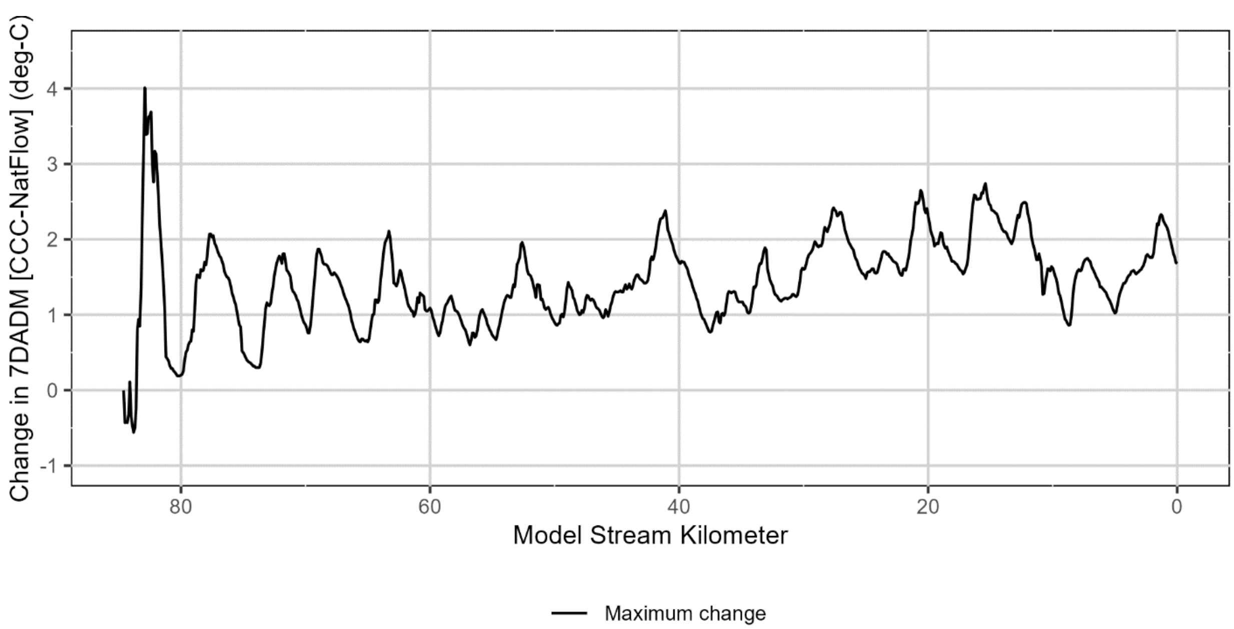


Figure 4-31: Change in maximum 7DADM stream temperatures between the Current Condition and Natural Flow scenarios for the Pudding River over the entire model period.

4.4.5 Natural Flow with Consumptive Uses

This section summarizes the temperature impacts of consumptive uses.

Five consumptive use scenarios were considered. These range from the current low flow calibration condition (CCC) scenario, in which consumptive use (CU) from the Pudding River and tributaries is set to the estimated CU for the two weeks modeled (August 1-14, 2004), on up to a natural flow scenario in which CU is set to zero. Except for one day that it rained, consumptive use for the current flow condition was set to 90 to 110% of the typical August consumptive use, as determined from OWRD data and model calibration on USGS gage data. For reduced consumptive use scenarios, consumptive use was reduced to maximums of 75%, 50%, 25%, and 0% of typical August consumptive use (**Figure 4-32**). The 0% of typical August consumptive use scenario is the natural flow scenario in which there is no CU from either the Pudding River or tributaries.

Table 4-23 summarizes inputs for **Equation 3-2** for estimating daily natural flow at Pudding River model boundary condition and tributary flow input locations updated to create Natural Flow and Consumptive Use model scenarios. **Table 4-24** summarizes inputs for **Equation 3-3** for estimating daily consumptive use at Pudding River model boundary condition and tributary flow input locations updated to create Natural Flow and Consumptive Use model scenarios.

Table 4-23: Inputs for Equation 3-2 for estimating daily natural flow at Pudding River model boundary condition and tributary flow input locations updated to create Natural Flow and Consumptive Use model scenarios.

Model Input Location	Model KM	$Q_{R, AugMed}$ (cfs)	Drainage Area (sq.mi)	$Q_{R, AugMed}$ / Drainage Area (cfs/sq.mi.)	F_{Cali}
Boundary Condition (Upper Pudding R / Howell Prairie (Headwater) abv Drift Cr)	84.6	5.29	34.09	0.155	1.1
Drift Creek	84.5	2.37	17.9	0.132	1.12
Lower Pudding R / Howell Prairie Catchment 1 (blw Drift Cr)	82.3	0.74	2.17	0.341	1.1
Silver Creek	81.2	14.10	53.2	0.265	1.12
Lower Pudding R / Howell Prairie Catchment 2 (Silver to Abiqua) Node 180	80.9	3.65	4.86	0.75	1.1
Abiqua Creek	75.1	15.10	78.1	0.193	1.125
Howell Prairie Creek	62.9	62.90	10.61	0.155	1.10
Little Pudding River	60.4	9.24	59.6	0.155	1.10
Unnamed Trib (Sacred Heart)	51.1	1.80	11.6	0.155	1.13
Zollner Creek	47.6	2.50	16.16	0.155	1.10
Unnamed Trib Node 580	40.9	1.22	7.87	0.155	1.00
Butte Creek	32.9	14.70	69.7	0.211	1.07
Brandy Creek	28.6	0.90	5.80	0.155	1.00
Rock Creek	24.9	18.06	85.61	0.211	1.10
Mill Creek	3.03	3.03	37	0.082	1.13

Table 4-24: Inputs for Equation 3-3 for estimating daily consumptive use at Pudding River model boundary condition and tributary flow input locations updated to create Natural Flow and Consumptive Use model scenarios.

Model Input Location	Model KM	$F_{\%Consumed,\ Normal}$	$Q_{R,Natural,min}$
Boundary Condition (Upper Pudding R / Howell Prairie (Headwater) abv Drift Cr)	84.6	95	4.51
Drift Creek	84.5	30	2.06
Lower Pudding R / Howell Prairie Catchment 1 (blw Drift Cr)	82.3	50	0.29
Silver Creek	81.2	51.5	12.26
Lower Pudding R / Howell Prairie Catchment 2 (Silver to Abiqua) Node 180	80.9	50	0.64
Abiqua Creek	75.1	61	13.19
Howell Prairie Creek	62.9	50	1.4
Little Pudding River	60.4	96.5	7.89
Unnamed Trib (Sacred Heart)	51.1	50	1.57
Zollner Creek	47.6	96.5	2.14
Unnamed Trib Node 580	40.9	50	0.95
Butte Creek	32.9	95	12.16
Brandy Creek	28.6	50	0.7
Rock Creek	24.9	98	15.43
Mill Creek	3.03	0	2.66

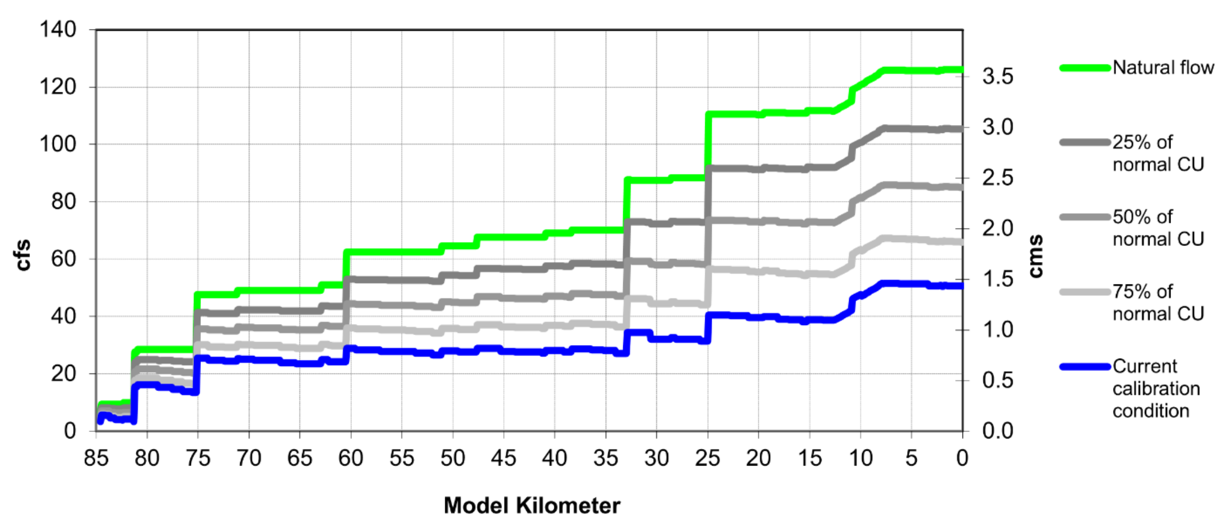


Figure 4-32: Median 7-day average stream flow rates for all Pudding River consumptive use model scenarios.

Natural flow was compared to several consumptive use reduction scenarios, including 25, 50, and 75 percent of typical August consumptive use. **Table 4-25** summarizes the maximum 7DADM stream temperature change between the Natural Flow and Consumptive Use scenarios for the Pudding River. A comparison of natural flow (with consumptive use set to zero) and the three consumptive use reductions shows maximum changes in 7DADM temperatures of 0.61°C for 25% of normal CU (**Figure 4-33**), 1.37°C for 50% of normal CU (**Figure 4-34**), and 2.51 for 75% of normal CU (**Figure 4-35**) at stream model km 82, 82, and 82.4, respectively.

Figure 4-36 shows the predicted maximum 7DADM for the Pudding River consumptive use model scenarios.

Table 4-25: Summary of maximum 7DADM stream temperature change between Natural Flow and Consumptive Use model scenarios for the Pudding River over the entire model period.

Temperature Metric	Model KM	Scenario	Stream Temperature (°C)	Location
7DADM	82.4	75CU - NF	2.51	POMI
7DADM	0	75CU - NF	1.15	outlet
7DADM	38.3	75CU - NF	0.87	Woodburn Gage
7DADM	82.0	50CU – NF	1.37	POMI
7DADM	0	50CU – NF	0.69	outlet
7DADM	38.3	50CU – NF	0.63	Woodburn Gage
7DADM	82.0	25CU - NF	0.61	POMI
7DADM	0	25CU - NF	0.3	outlet
7DADM	38.3	25CU - NF	0.34	Woodburn Gage

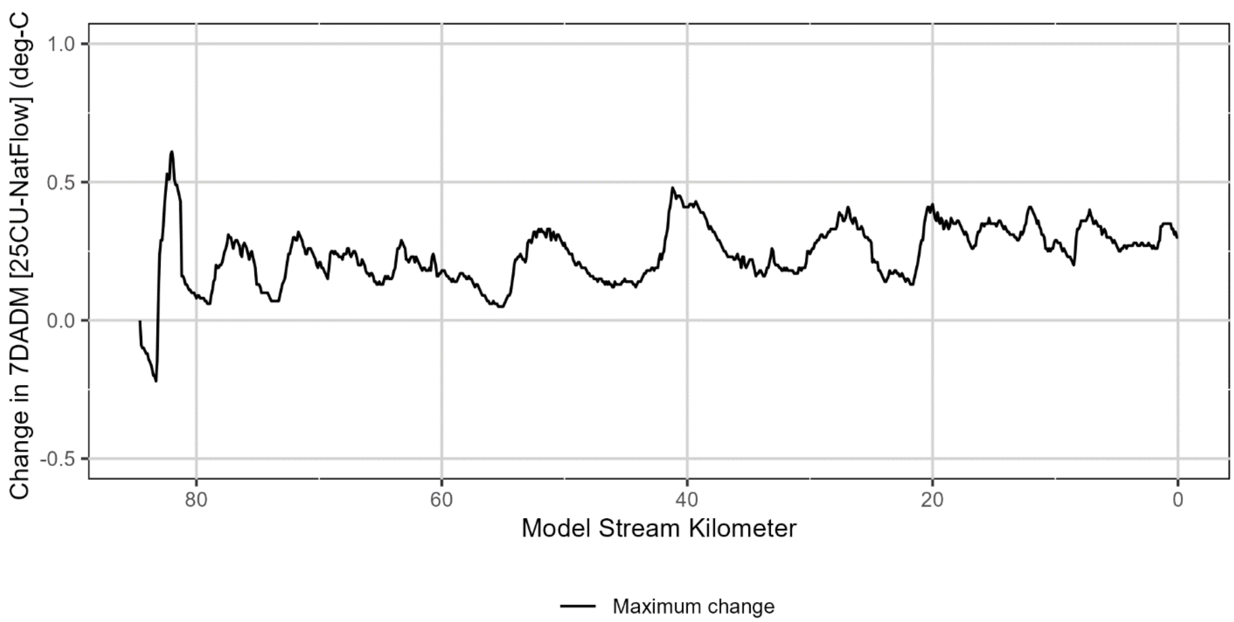


Figure 4-33: 7DADM temperature difference between 25% of normal consumptive use and natural flow scenario for the Pudding River over the entire model period.

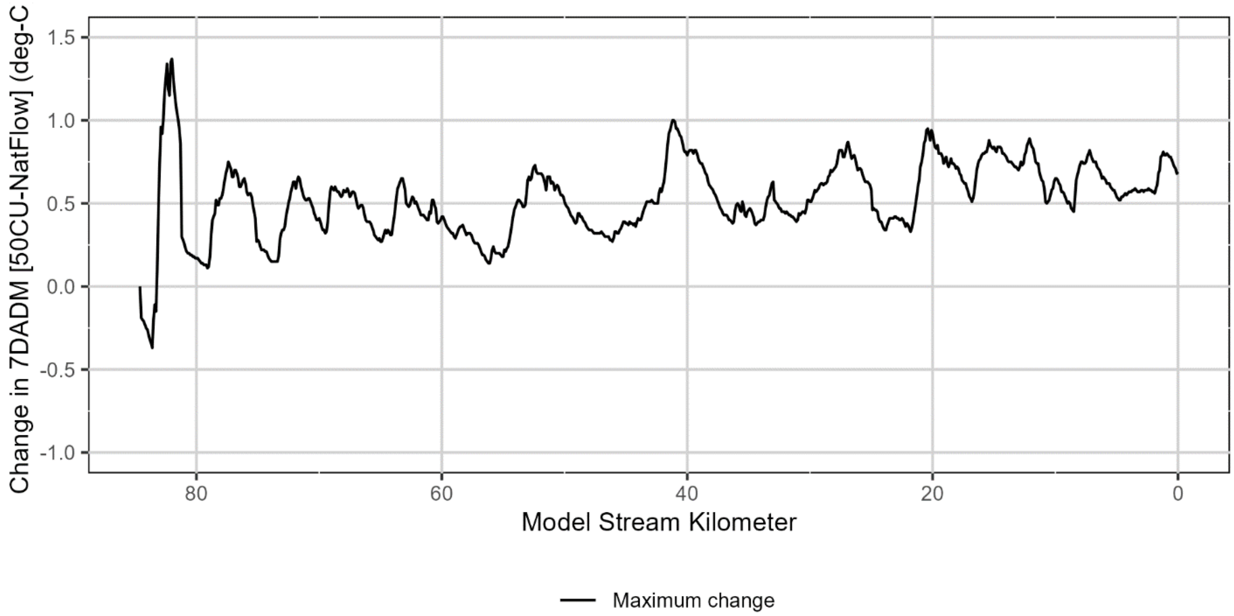


Figure 4-34: 7DADM temperature difference between 50% of normal consumptive use and natural flow scenarios for the Pudding River over the entire model period.

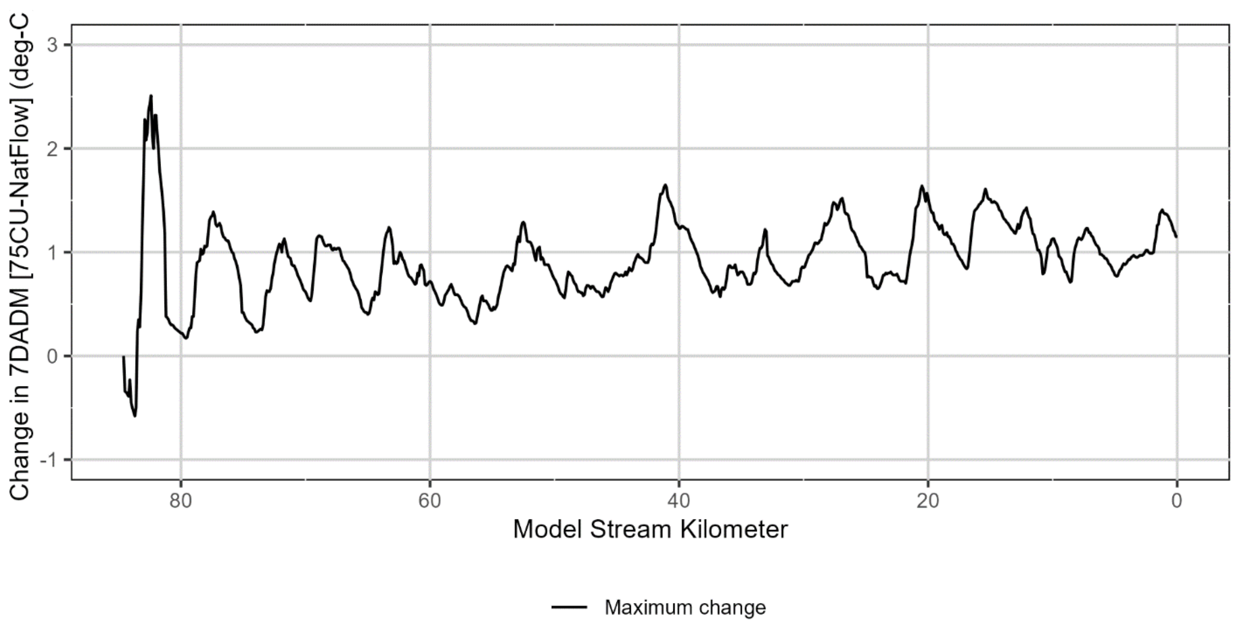


Figure 4-35: 7DADM temperature difference between 75% of normal consumptive use and natural flow scenarios for the Pudding River over the entire model period.

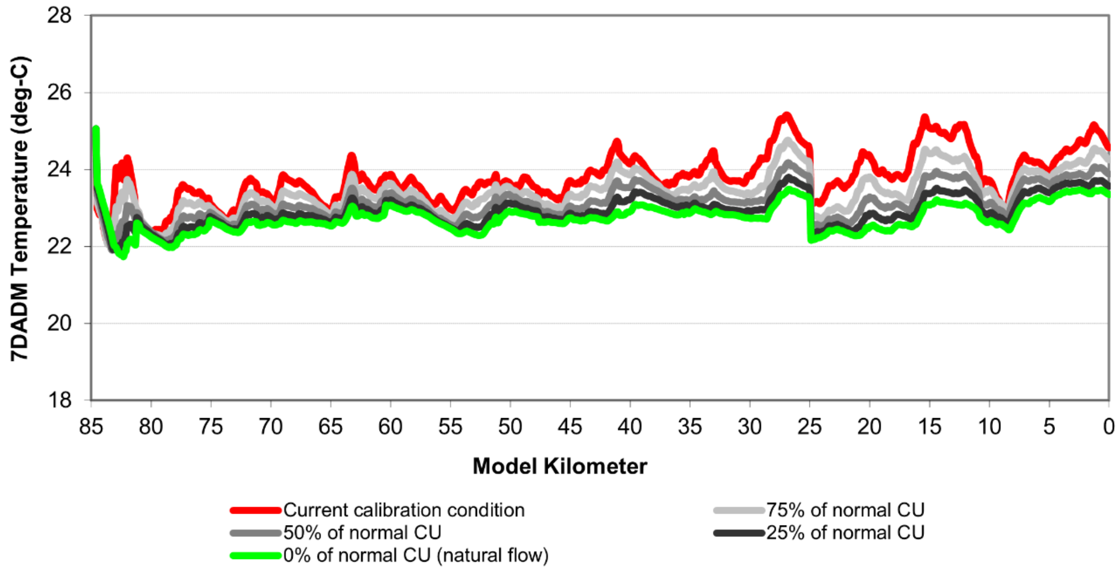


Figure 4-36: Maximum 7DADM stream temperature for all consumptive use model scenarios for the Pudding River.

4.4.6 Tributary Temperatures

This section summarizes the temperature impacts of restored tributary temperatures.

Reducing tributary temperatures enough to meet the 18°C temperature criteria at confluences with the Pudding River would result in Pudding River 7DADM temperatures that are 1.6°C less, on average, than current temperatures. In the vicinity of the Woodburn gage, the impact is 0.9°C.

Table 4-26 shows that the maximum change in maximum 7DADM stream temperature between the Tributary Temperature and Current Condition scenarios at the POMI and outlet. The largest 7DADM temperature reduction (8.65°C) occurs at the model boundary conditions (model km 84.6). This is much higher than the change in 7DADM temperature at the mouth of the Pudding River, which is equal to 1.19°C. These changes are also illustrated in Figure 4-37, which shows the change in maximum 7DADM stream temperatures between the two scenarios for the entire Pudding River model reach. The impacts are greatest at the boundary condition because temperatures there are warmer relative to the 18°C criterion. River temperatures got warmer moving downstream so the magnitude of the difference was reduced.

Table 4-26: Summary of maximum 7DADM stream temperature change between Tributary Temperatures and Current Condition model scenarios for the Pudding River over the entire model period.

Temperature Metric	Model KM	Scenario	Stream Temperature (°C)	Location
7DADM	0	Change	1.19	outlet
7DADM	84.6	Change	8.65	POMI

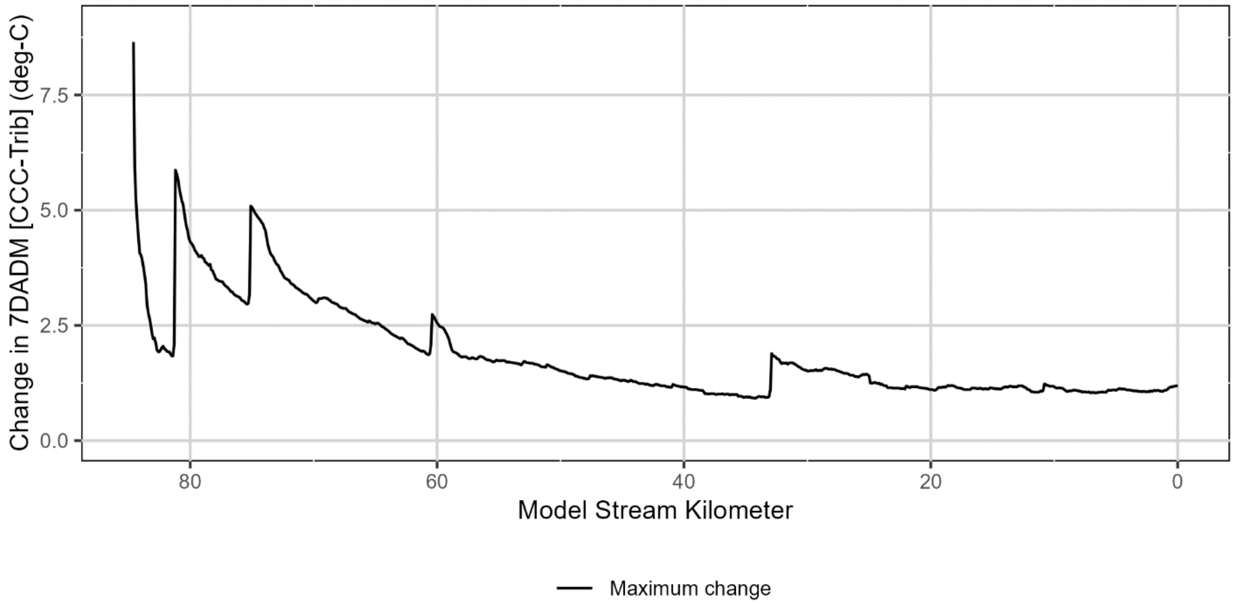


Figure 4-37: Change in maximum 7DADM stream temperatures between the Current Condition and Tributary Temperatures scenarios for the Pudding River over the entire model period.

Figure 4-38 through **Figure 4-46** show current and theoretical tributary temperatures that meet the biologically-based numeric criteria of 18°C for the Pudding River. Theoretical tributary temperatures were estimated using the following steps:

1. Calculate the rolling 24-hour average temperature for each hourly temperature input to the model.
2. Subtract the rolling 24-hour average temperature from the associated hourly temperature input to calculate the difference between the two.
3. Reduce the difference between the rolling 24-hour average temperature and the hourly temperature input by 50%.
4. Add the 50% reduced difference between the rolling 24-hour average temperature and the hourly temperature to the original hourly tributary temperature model inputs.
5. Calculate the 7DADM temperatures for the adjusted hourly tributary temperature model inputs.
6. Determine the maximum 7DADM temperature for the tributary over the model period.
7. Calculate the difference between the maximum 7DADM temperature and the applicable water quality temperature standard.
8. Determine the ratio by which the hourly temperature inputs to the model must be reduced to result in 7DADM temperatures that do not exceed the applicable water quality standard.
9. Adjust all hourly temperature inputs by the ratio determined in Step 8.

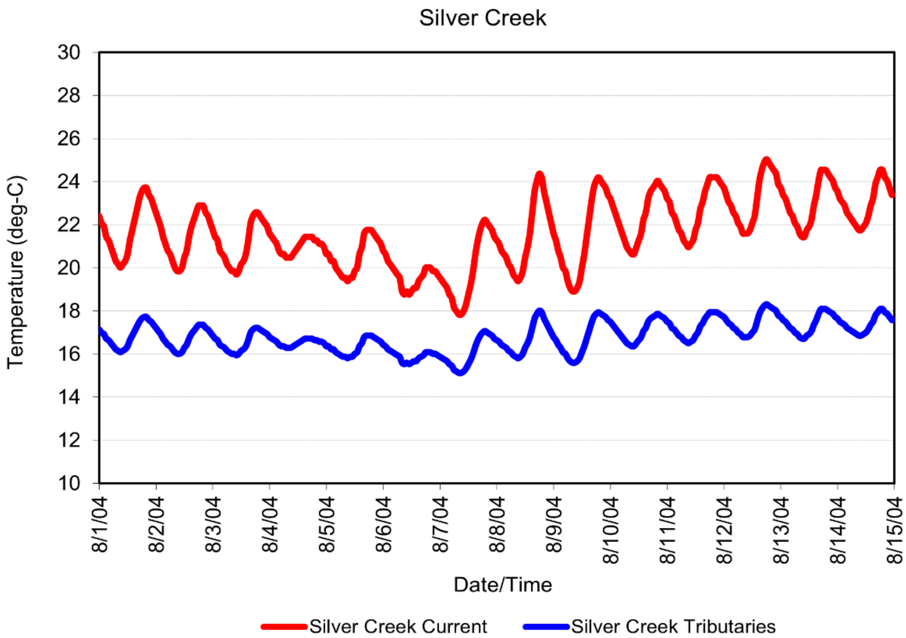


Figure 4-38: Current temperatures for Silver Creek and theoretical tributary temperatures that meet the 18°C biological criterion.

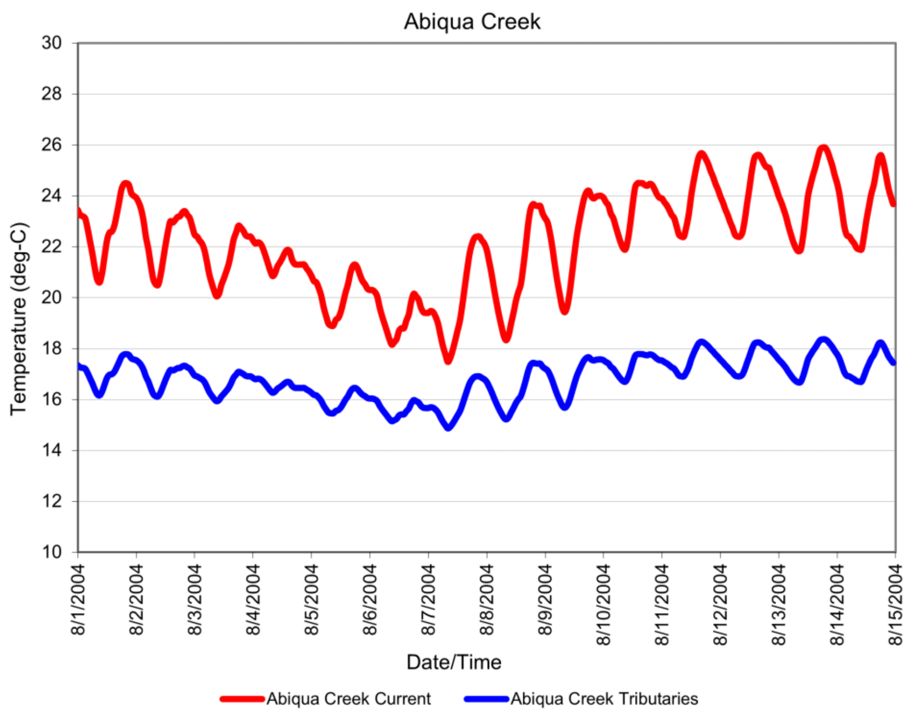


Figure 4-39: Current temperatures for Abiqua Creek and theoretical tributary temperatures that meet the 18°C biological criterion.

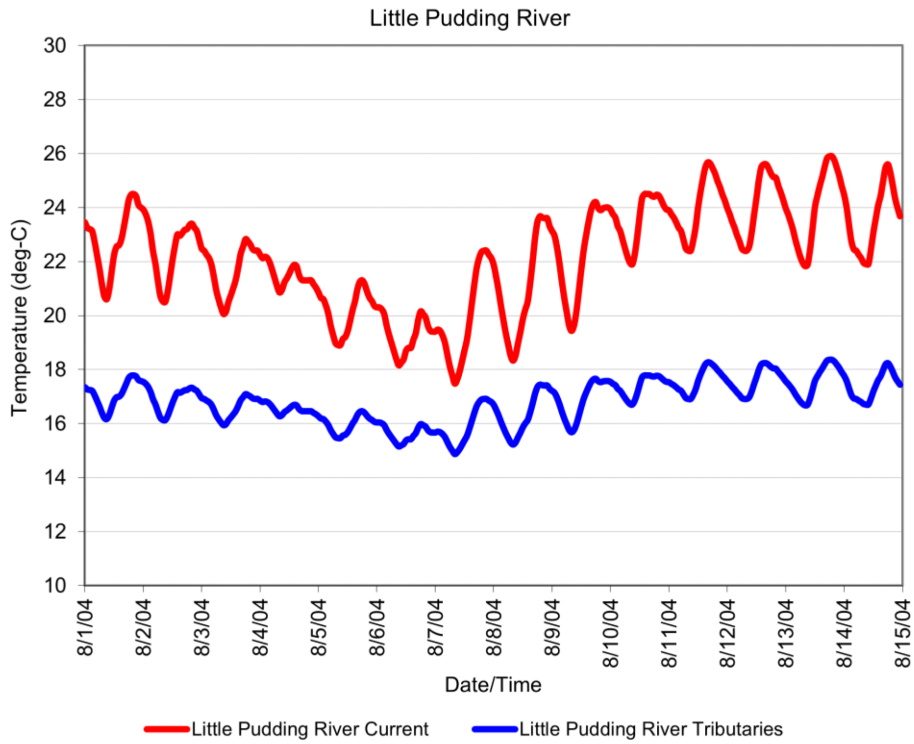


Figure 4-40: Current temperatures for the Little Pudding River and theoretical tributary temperatures that meet the 18°C biological criterion.

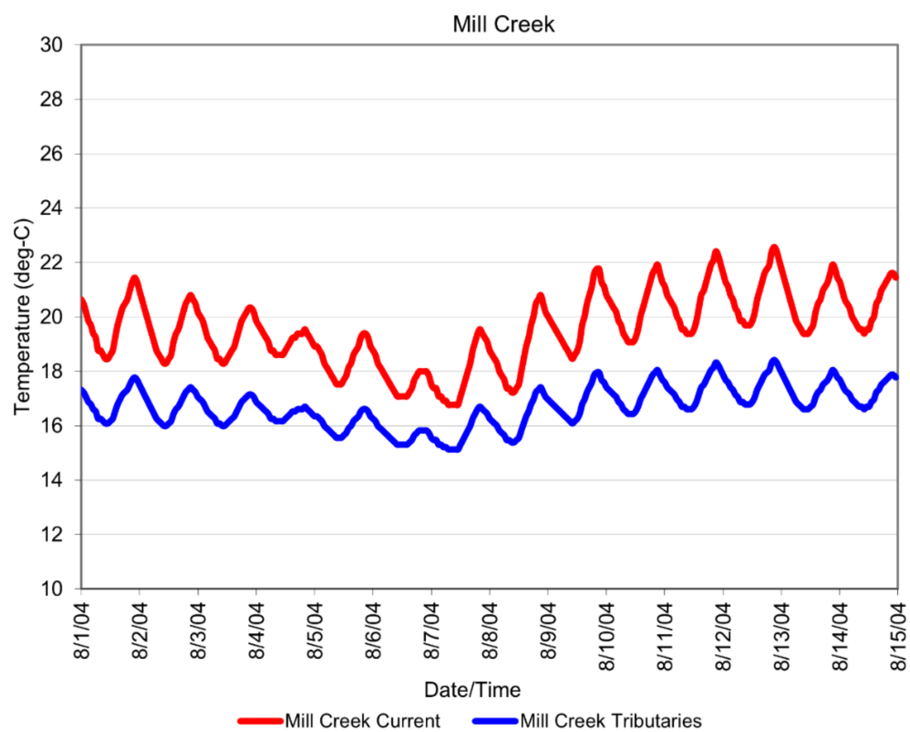


Figure 4-41: Current temperatures for Mill Creek and theoretical tributary temperatures that meet the 18°C biological criterion.

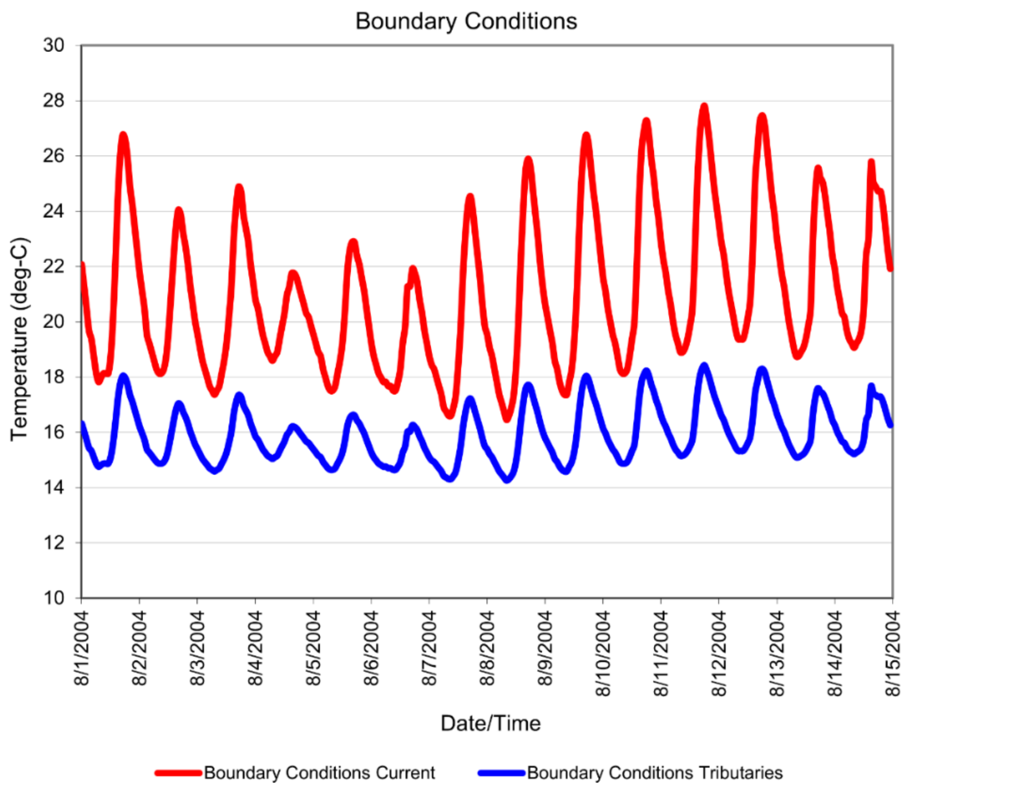


Figure 4-42: Current temperatures for the Boundary Conditions and theoretical tributary temperatures that meet the 18°C biological criterion.

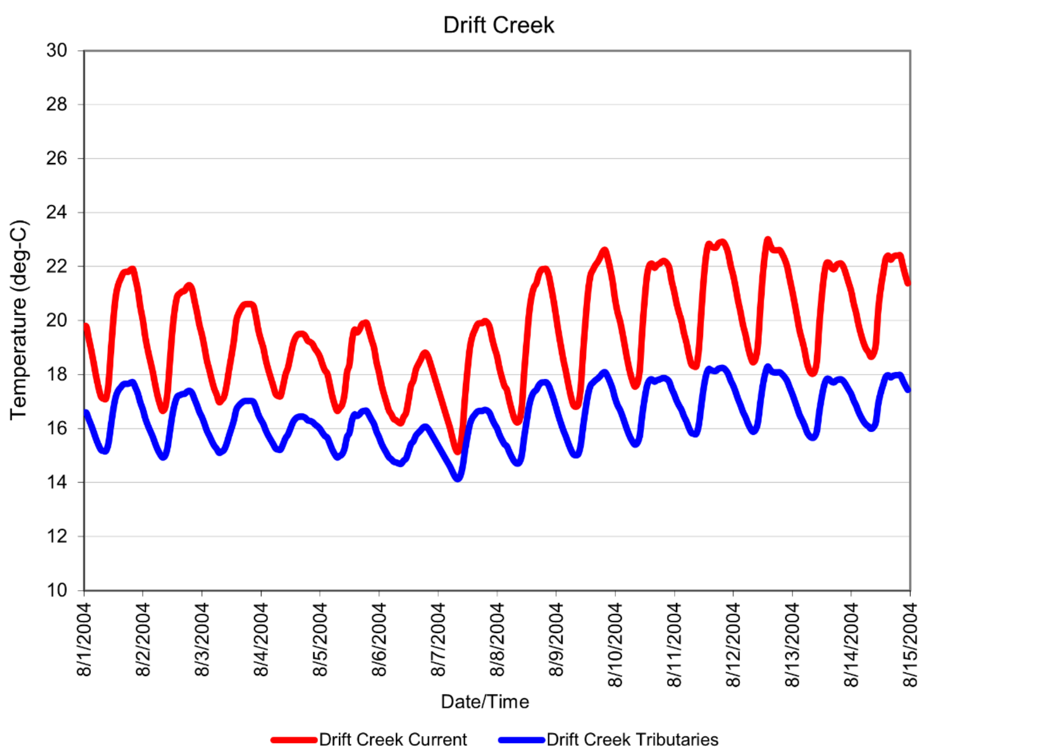


Figure 4-43: Current temperatures for Drift Creek and theoretical tributary temperatures that meet the 18°C biological criterion.

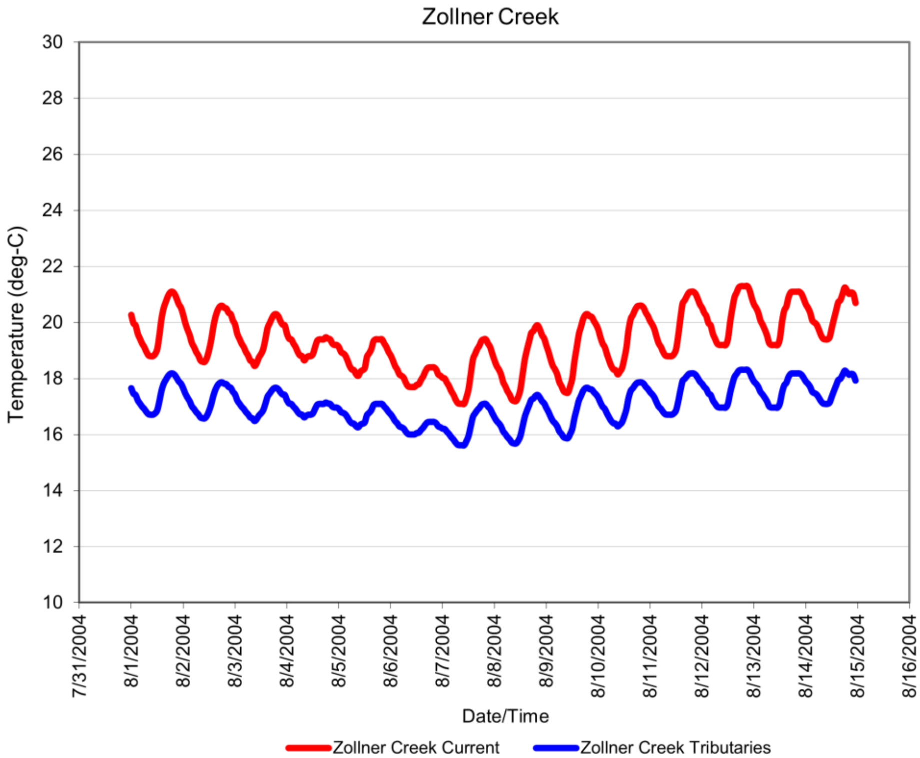


Figure 4-44: Current temperatures for Zollner Creek and theoretical tributary temperatures that meet the 18°C biological criterion.

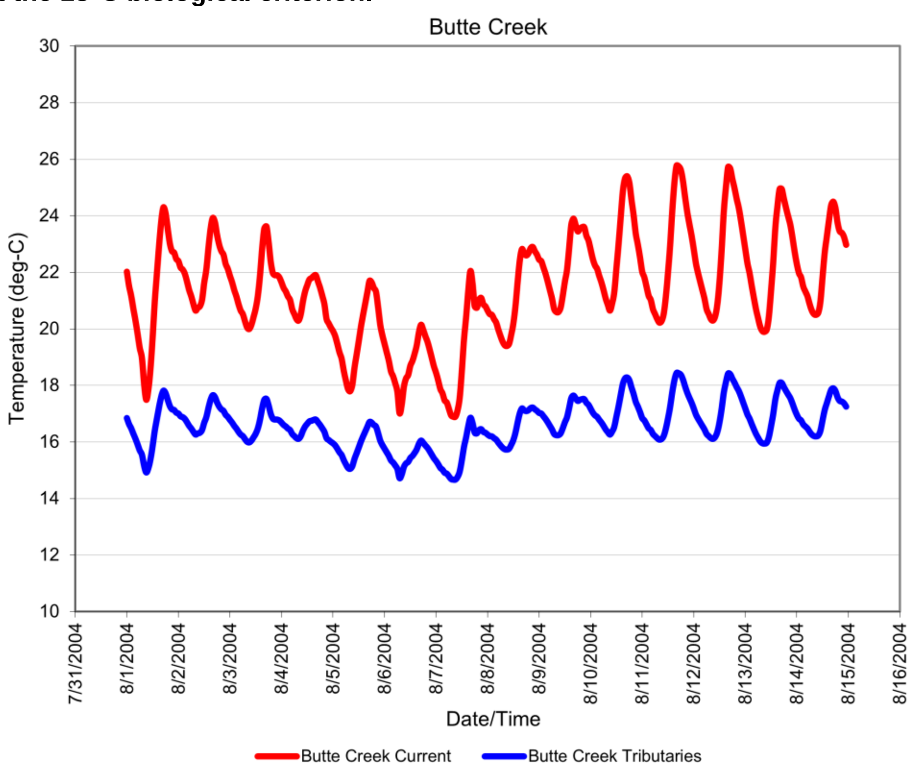


Figure 4-45: Current temperatures for Butte Creek and theoretical tributary temperatures that meet the 18°C biological criterion.

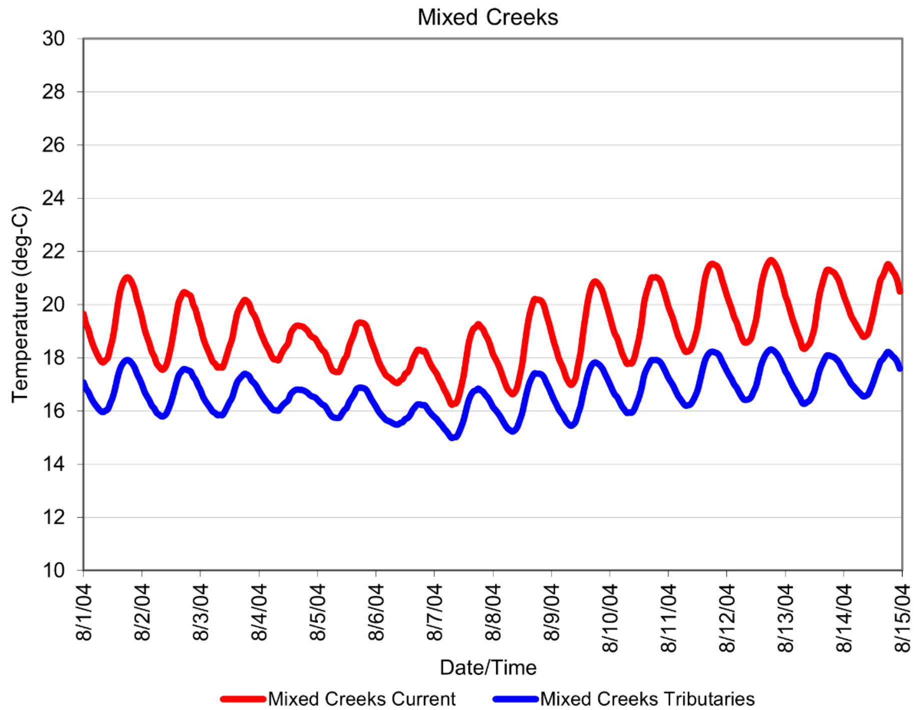


Figure 4-46: Current temperatures for mixed creeks (Mill Creek, Zollner Creek, Upper Pudding River, and groundwater) and theoretical tributary temperatures that meet the 18°C biological criterion.

4.4.7 Background

This section summarizes the temperature impacts of background conditions.

Table 4-27 summarizes the maximum 7DADM stream temperature change between the Background and Current Condition scenarios as well as the Background and BBNC for the Pudding River. It shows the 7DADM temperature difference between Current Condition at the most downstream node (the outlet) is equal to 4.12°C; the difference between Background and the BBNC is 3.66°C. The greatest 7DADM temperature difference between the Current Condition and Background scenarios (the POMI) is equal to 8.65°C and occurs at stream model km 84.6. The greatest 7DADM temperature difference between the Background scenario and the BBNC is equal to 3.86°C and occurs at stream model km 11.4.

Figure 4-47 shows the change in the maximum 7DADM stream temperatures between the Background and Current Condition model scenarios for the Molalla River over the entire model period.

Table 4-27: Summary of maximum 7DADM stream temperature change between Background and Current Condition model scenarios for the Pudding River over the entire model period.

Temperature Metric	Model KM	Scenario	Stream Temperature (°C)	Location
7DADM	0	Change	4.12	outlet
7DADM	84.6	Change	8.65	POMI
7DADM	0	Change_BBNC	3.66	outlet
7DADM	11.4	Change_BBNC	3.86	POMI

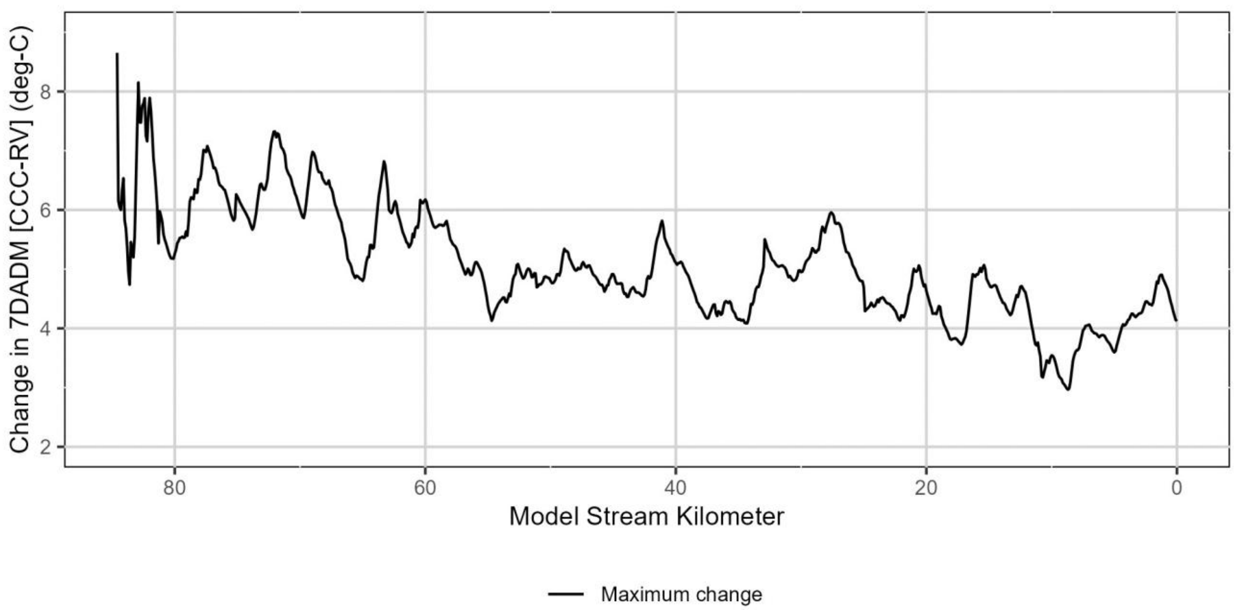


Figure 4-47: Change in maximum 7DADM stream temperatures between the Background and Current Condition scenarios for the Pudding River over the entire model period.

4.5 Little North Santiam River

Table 4-28 describes the different model scenarios used to simulate stream temperature and effective shade for the Little North Santiam River.

Table 4-29 summarizes the daily maximum stream temperatures predicted at the mouth of the Little North Santiam River for the Current Condition and Restored Vegetation model scenarios.

Figure 4-48 shows the predicted daily maximum stream temperatures for the Current Condition and Restored Vegetation model scenarios for the Little North Santiam River.

Table 4-28: Little North Santiam model scenario descriptions.

Scenario Name	Description
Current Condition	Stream temperature response to conditions on August 1, 2000
Restored Vegetation	This scenario evaluates the stream temperature response from setting near stream land cover to system potential vegetation conditions.

Table 4-29: Summary of daily maximum stream temperature at the mouth of the Little North Santiam River for the Current Condition and Restored Vegetation model scenarios.

Temperature Metric	Model KM	Scenario	Stream Temperature (°C)	Location
Daily maximum temperature	0	Current Condition	25.51	outlet
Daily maximum temperature	0	Restored Vegetation	24.86	outlet

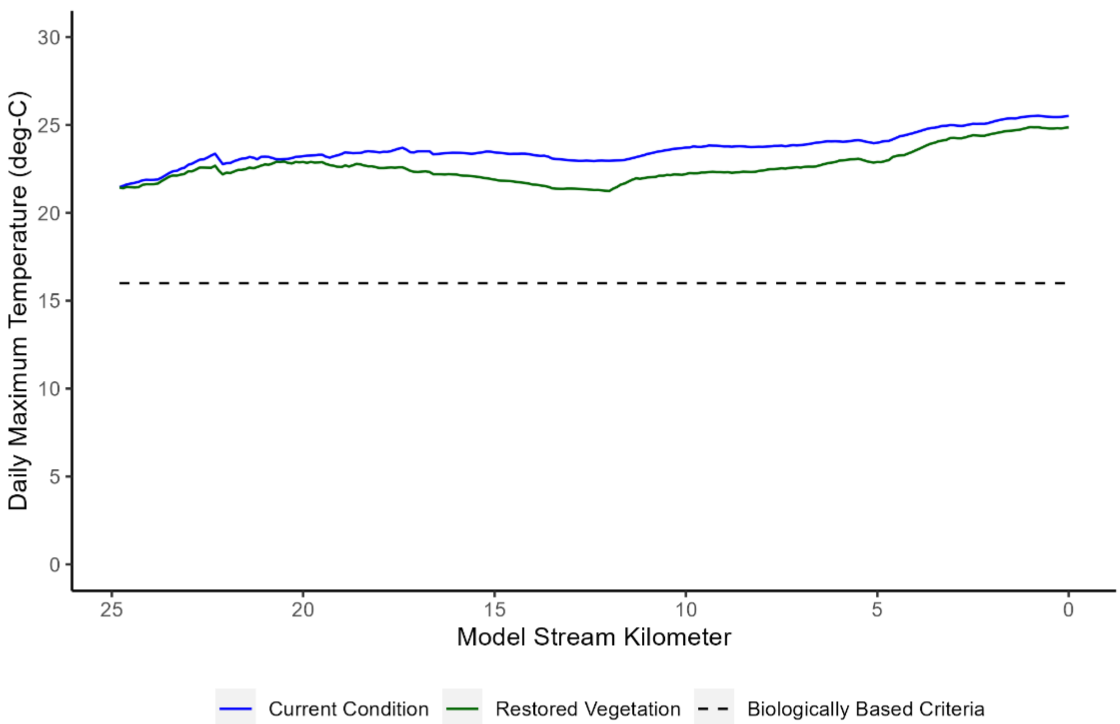


Figure 4-48: Daily maximum stream temperature for the Current Condition and Restored Vegetation model scenarios for the Little North Santiam River.

4.5.1 Restored Vegetation

This section summarizes the temperature impacts of restored vegetation.

Table 4-30 summarizes the daily maximum stream temperature change between the Current Condition and Restored Vegetation scenarios for the Little North Santiam River. It shows the daily maximum temperature difference at the most downstream node (the outlet) is equal to 0.65°C. In addition, the greatest daily maximum temperature difference between the two scenarios (the POMI) is equal to 1.72°C and occurs at stream model km 13.7.

The Restored Vegetation scenario is our best estimate of background conditions given the available information. We did not evaluate restored channel morphology, tributary temperatures, or stream flows. Based on the Restored Vegetation scenario, the daily maximum temperature difference between background conditions and the biologically based numeric criteria is 8.86°C at the outlet and 8.89°C at the POMI at stream model km 1.

Figure 4-49 shows the change in the daily maximum stream temperatures between the Current Condition and Restored Vegetation model scenarios for the Little North Santiam River.

Table 4-30: Summary of daily maximum stream temperature change between Current Condition and Restored Vegetation model scenarios for the Little North Santiam River over the entire model period.

Temperature Metric	Model KM	Scenario	Stream Temperature (°C)	Location
Daily maximum	0	Change	0.65	outlet
Daily maximum	13.7	Change	1.72	POMI
Daily maximum	0	Change_BBNC	8.86	outlet
Daily maximum	1	Change_BBNC	8.89	POMI

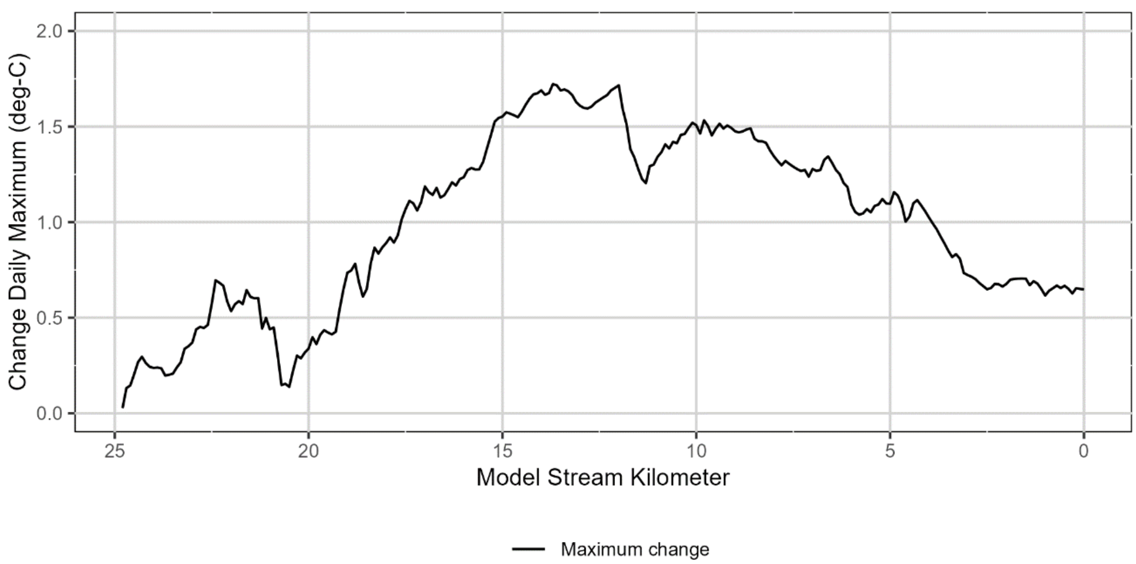


Figure 4-49: Change in the daily maximum stream temperatures between the Current Condition and Restored Vegetation model scenarios for the Little North Santiam River over the entire model period.

Table 4-31 summarizes the mean effective shade for the Current Condition and Restored Vegetation scenarios for the Little North Santiam River. The difference in mean effective shade between the scenarios is equal to 9.03 percentage points.

Figure 4-50 and Figure 4-51 compare effective shade predictions from the Current Condition and Restored Vegetation scenarios for the Little North Santiam River.

Table 4-31: Summary of mean effective shade between the Current Condition and Restored Vegetation scenarios for the Little North Santiam River.

Scenario	Mean Effective Shade (%)
Current Condition	28.98
Restored Vegetation	38.02
Change	9.03

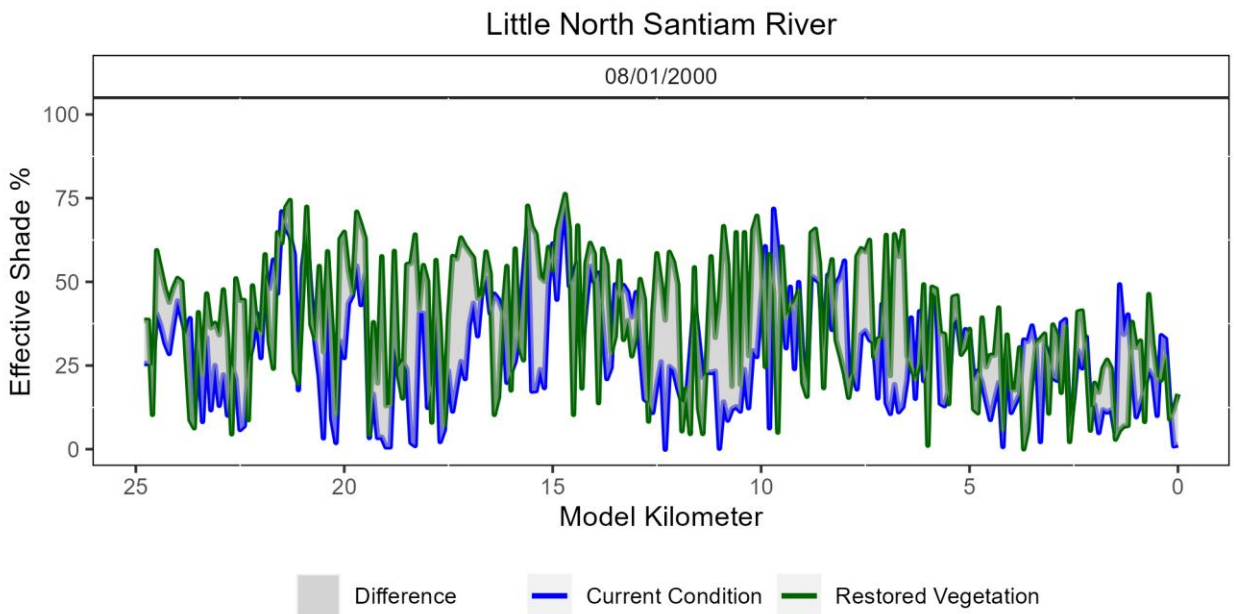


Figure 4-50: Comparison of effective shade from the Current Condition and Restored Vegetation scenarios for the Little North Santiam River.

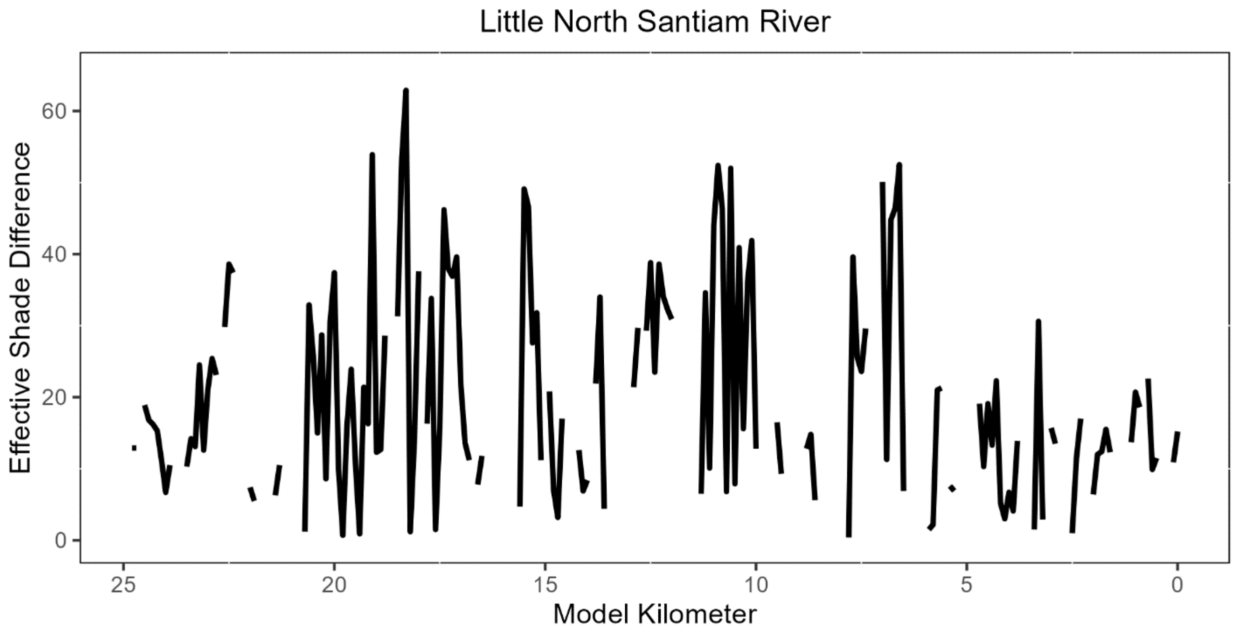


Figure 4-51: Percentage point difference between effective shade from the Current Condition and Restored Vegetation scenarios on 8/1/2000 for the Little North Santiam River. Missing values indicate that the shade difference is negative due to instances of higher effective shade in the Current Condition scenario versus the Restored Vegetation scenario.

4.6 Thomas Creek

Table 4-32 describes the different model scenarios used to simulate stream temperature and effective shade for Thomas Creek.

Table 4-33 summarizes the daily maximum stream temperatures predicted at the mouth of Thomas Creek for all model scenarios.

Figure 4-52 shows the daily maximum stream temperatures for all Thomas Creek model scenarios.

Table 4-32: Thomas Creek model scenario descriptions.

Scenario Name	Description
Current Condition	Stream temperature response to conditions on August 3, 2000.
Restored Vegetation	This scenario evaluates the stream temperature response from setting near stream land cover to system potential vegetation conditions.
Natural Flow	No water withdrawals. Other model inputs and parameters are the same as the current condition calibrated model.
Tributary Temperatures	Tributaries set at Maximum Biological Criteria (16/18ºC)
Background	Restored Vegetation Land Cover (Vegetation) Conditions Tributaries Maximum Biological Criteria (16/18ºC) No Water Withdrawals

Table 4-33: Summary of daily maximum stream temperature at the mouth of Thomas Creek for all model scenarios.

Temperature Metric	Model KM	Scenario	Stream Temperature (°C)	Location
Daily maximum temperature	0	Current Condition	25.02	Outlet
Daily maximum temperature	0	Restored Vegetation	25.54	Outlet
Daily maximum temperature	0	Natural Flow	24.92	Outlet
Daily maximum temperature	0	Tributary Temperatures	24.42	Outlet
Daily maximum temperature	0	Background	24.08	Outlet

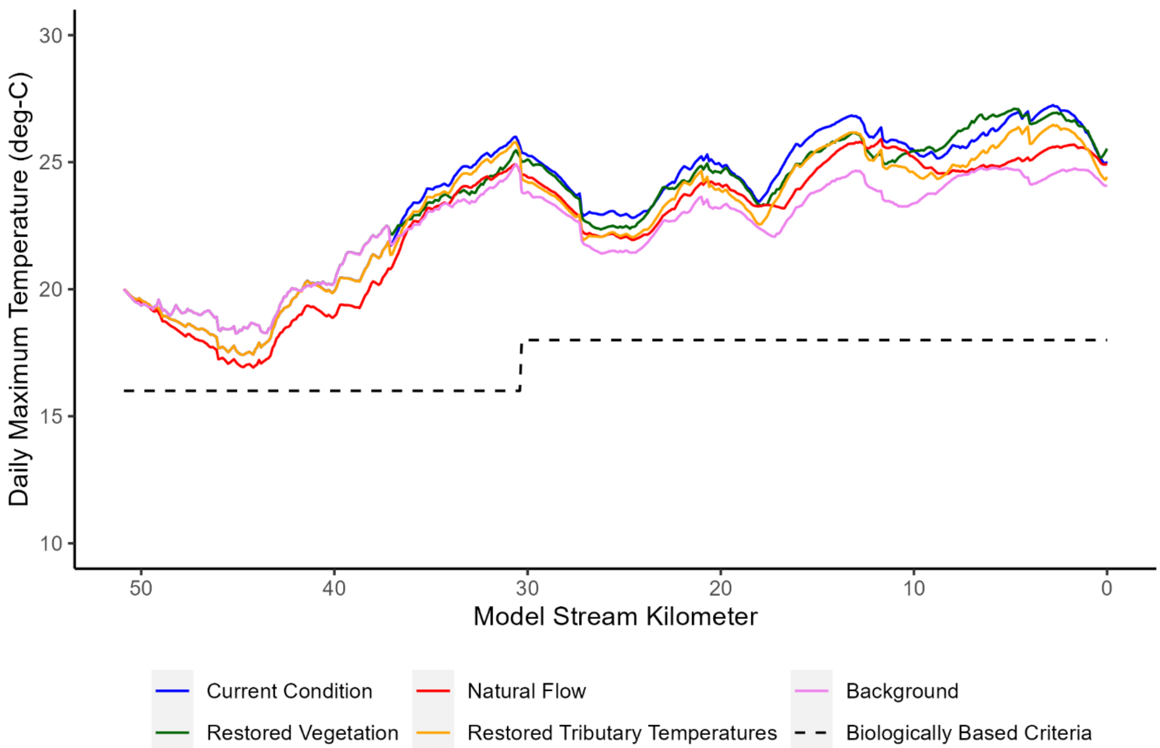


Figure 4-52: Daily maximum stream temperature for all model scenarios for Thomas Creek.

4.6.1 Restored Vegetation

This section summarizes the temperature impacts of restored vegetation.

Table 4-34 summarizes the maximum 7DADM stream temperature change between the Current Condition and Restored Vegetation scenarios for Thomas Creek. It shows the 7DADM temperature difference at the most downstream node (the outlet) is equal to -0.52°C. This indicates that the Current Condition scenario is cooler than the Restored Vegetation scenario at this point. In addition, the greatest 7DADM temperature difference between the two scenarios (the POMI) is equal to 1.14°C and occurs at stream model km 32.3.

Figure 4-53 shows the change in the daily maximum stream temperatures between the Current Condition and Restored Vegetation model scenarios for Thomas Creek over the entire model period.

The negative value of the temperature difference between the Current Condition and Restored Vegetation scenarios indicates that the Restored Vegetation scenario is characterized by a greater daily maximum temperature than the Current Condition scenario. Typically, restored vegetation provides greater percent effective shade values for a stream and thus lower daily maximum stream temperatures. However, in specific reaches of Thomas Creek, the Restored Vegetation scenario yields lower effective shade values than current conditions. This decrease in effective shade is due in part to the random distribution of natural disturbance included in the Restored Vegetation scenario.

Table 4-34: Summary of Daily Maximum stream temperature change between Restored Vegetation and Current Condition model scenarios for Thomas Creek.

Temperature Metric	Model KM	Scenario	Stream Temperature (°C)	Location
Daily Maximum	0	Change	-0.52	Outlet
Daily Maximum	32.3	Change	1.14	POMI

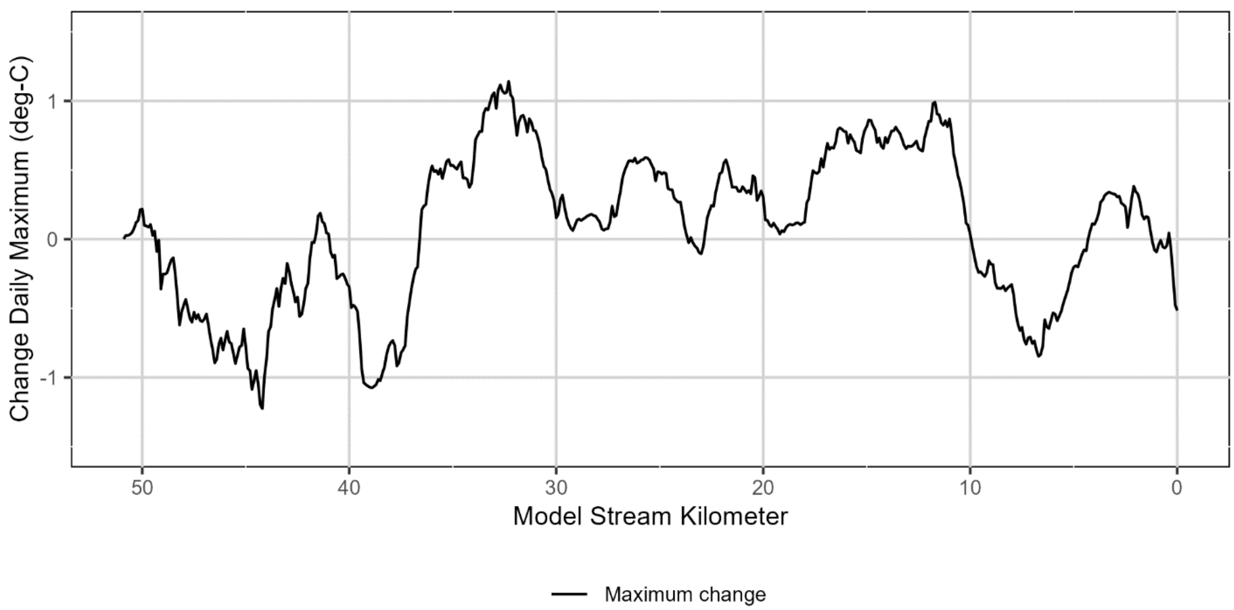


Figure 4-53: Change in the daily maximum stream temperatures between the Current Condition and Restored Vegetation model scenarios for Thomas Creek over the entire model period.

Table 4-35 summarizes the mean effective shade for the Current Condition and Restored Vegetation scenarios for Thomas Creek. The difference in mean effective shade between the scenarios is equal to 0.41 percentage points.

Figure 4-54 and Figure 4-55 compare effective shade predictions from the Current Condition and Restored Vegetation scenarios for Thomas Creek.

Table 4-35: Summary of mean effective shade between the Current Condition and Restored Vegetation scenarios for Thomas Creek.

Scenario	Mean Effective Shade (%)
Current Condition	28.88
Restored Vegetation	29.28
Change	0.41

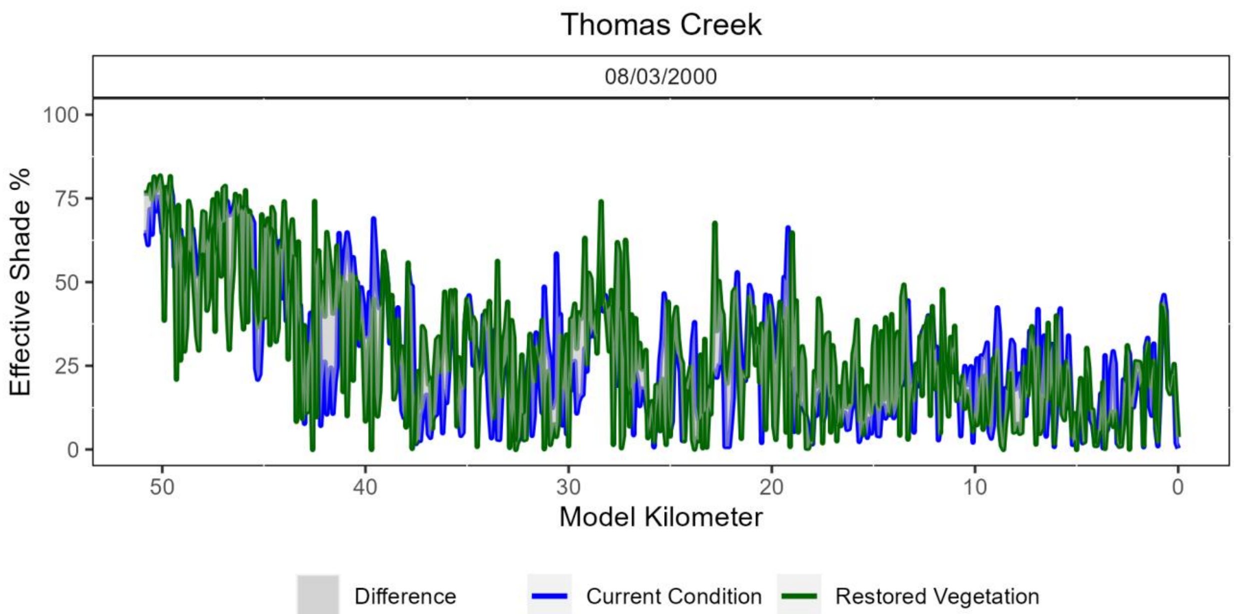


Figure 4-54: Comparison of effective shade from the Current Condition and Restored Vegetation scenarios for Thomas Creek.

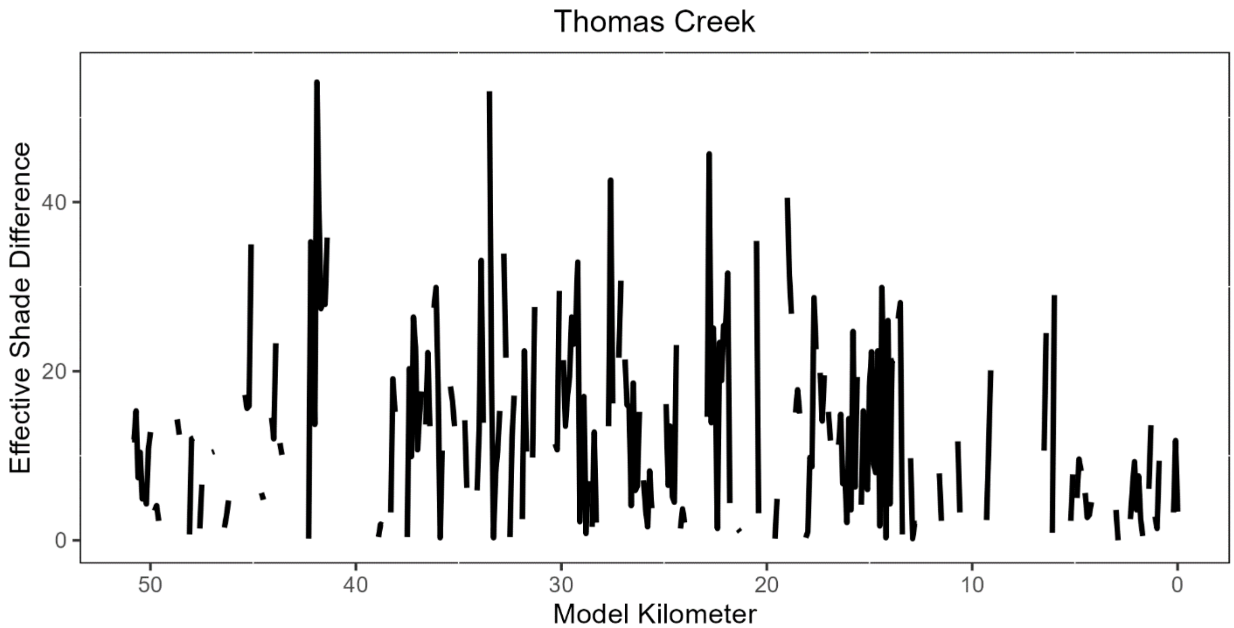


Figure 4-55: Percentage point difference between effective shade from the Current Condition and Restored Vegetation scenarios on 8/3/2000 for Thomas Creek. Missing values indicate that the shade difference is negative due to instances of higher effective shade in the Current Condition scenario versus the Restored Vegetation scenario.

4.6.2 Natural Flow

This section summarizes the temperature impacts of natural flow conditions.

A comparison of the Current Condition and Natural Flow scenarios for Thomas Creek shows that the daily maximum temperature difference at the outlet is equal to 0.10°C (**Table 4-36**). In addition, the POMI is equal to 1.83°C and occurs at stream model km 4.8 (**Table 4-36**). **Figure 4-56** shows the change in the daily maximum stream temperatures between the Current Condition and Natural Flow model scenarios for Thomas Creek over the entire model period

Table 4-36: Summary of Daily Maximum stream temperature change between Natural Flow and Current Condition model scenarios for Thomas Creek.

Temperature Metric	Model KM	Scenario	Stream Temperature (°C)	Location
Daily Maximum	0	Change	0.10	outlet
Daily Maximum	4.8	Change	1.83	POMI

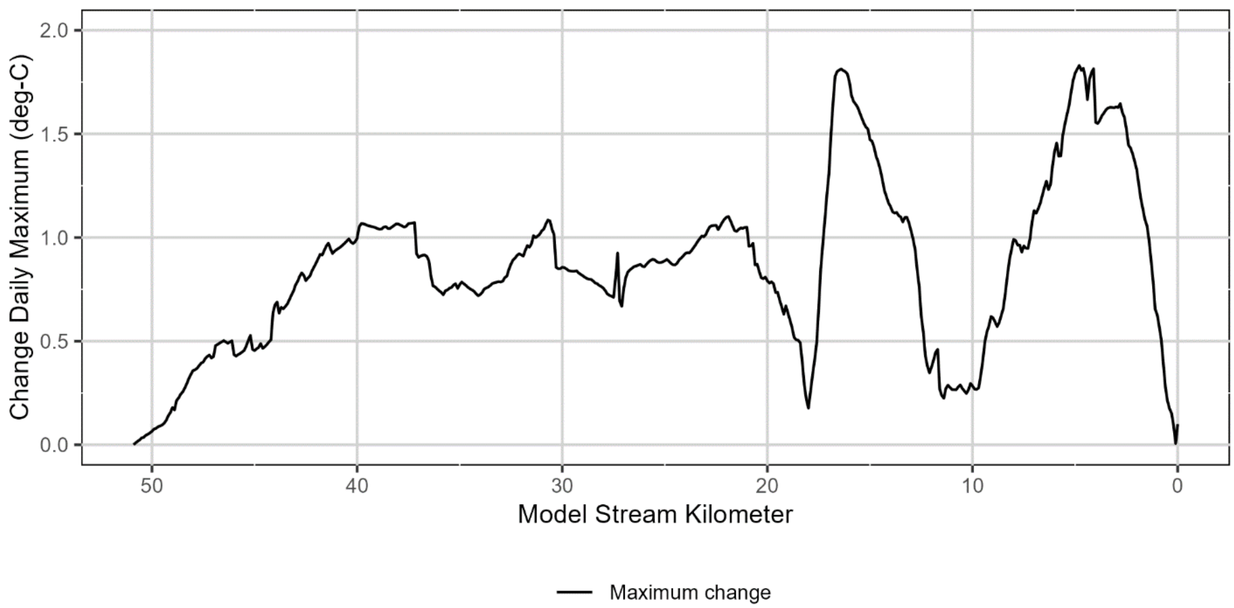


Figure 4-56: Change in the daily maximum stream temperatures between the Current Condition and Natural Flow model scenarios for Thomas Creek over the entire model period.

4.6.3 Tributary Temperatures

This section summarizes the temperature impacts of restored tributary temperatures.

A comparison of the Current Condition and Restored Tributary Temperatures scenarios for Thomas Creek shows that the daily maximum temperature difference at the outlet is equal to 0.60°C (**Table 4-37**). In addition, the POMI is equal to 1.08°C and occurs at stream model km 30.2 (**Table 4-37**). **Figure 4-57** shows the change in the daily maximum stream temperatures between the Current Condition and Restored Tributary Temperatures model scenarios for Thomas Creek over the entire model period.

Table 4-37: Summary of Daily Maximum stream temperature change between Tributary Temperatures plus Restored Vegetation and Current Condition model scenarios for Thomas Creek.

Temperature Metric	Model KM	Scenario	Stream Temperature (°C)	Location
Daily Maximum	0	Change	0.6	Outlet
Daily Maximum	30.2	Change	1.08	POMI

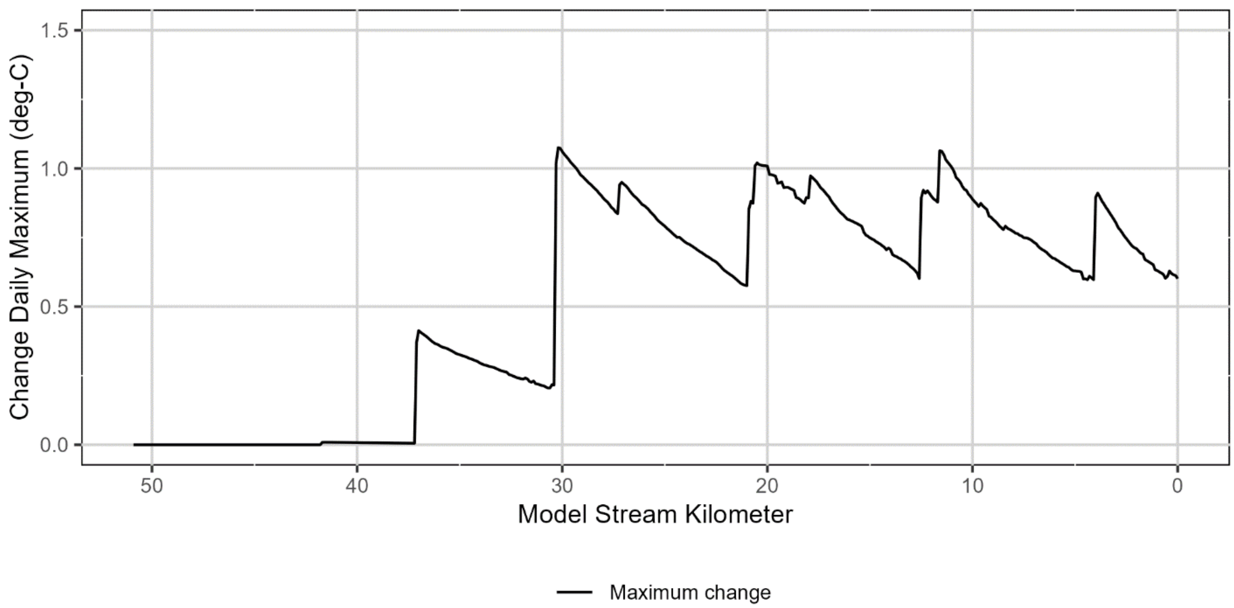


Figure 4-57: Change in the daily maximum stream temperatures between the Current Condition and Restored Tributary Temperatures model scenarios for Thomas Creek over the entire model period.

4.6.4 Background

This section summarizes the temperature impacts of background conditions.

Table 4-38 shows a comparison of the Current Condition and Background scenarios for Thomas Creek shows that the daily maximum temperature difference at the outlet is equal to 0.94°C. In addition, the POMI is equal to 2.75°C and occurs at stream model km 3.3. The daily maximum temperature difference between background conditions and the biologically based numeric criteria is 6.08°C at the outlet and 8.91°C at the POMI at stream model km 30.6.

Figure 4-58 shows the change in the daily maximum stream temperatures between the Current Condition and all model scenarios for Thomas Creek over the entire model period.

Table 4-38: Summary of Daily Maximum stream temperature change between the Background and Current Condition model scenarios for Thomas Creek.

Temperature Metric	Model KM	Scenario	Stream Temperature (°C)	Location
Daily maximum	0	Change	0.94	Outlet
Daily maximum	3.3	Change	2.75	POMI
Daily maximum	0	Change_BBNC	6.08	outlet
Daily maximum	30.6	Change_BBNC	8.91	POMI

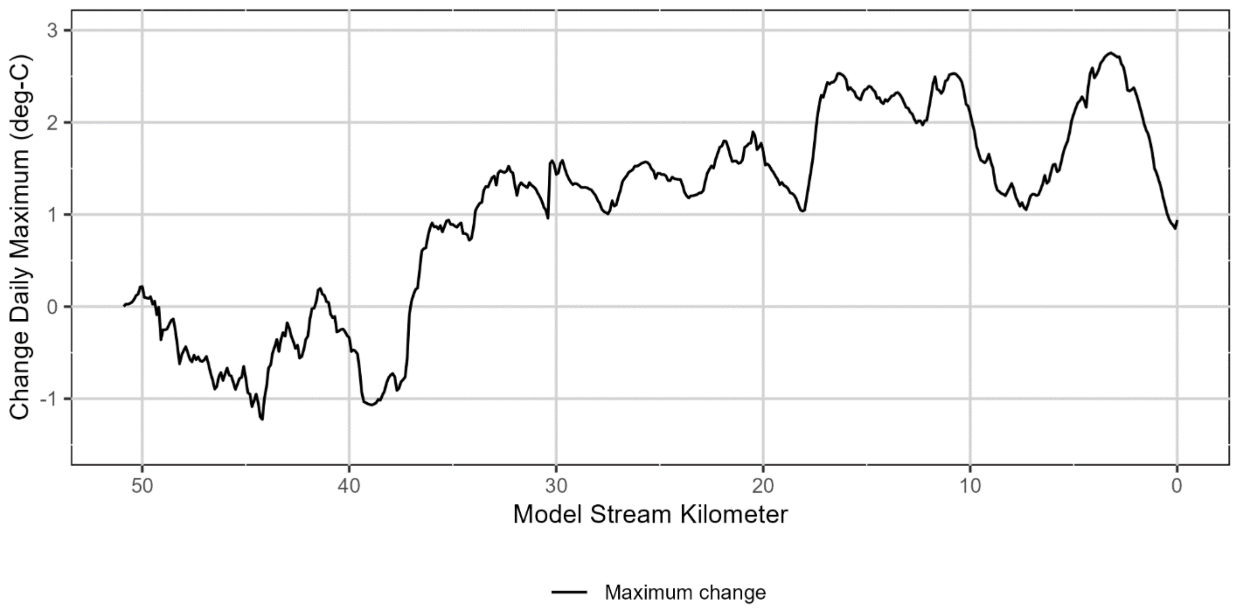


Figure 4-58: Change in the daily maximum stream temperatures between the Current Condition and Restored Tributary Temperatures model scenarios for Thomas Creek over the entire model period.

4.7 Crabtree Creek

Table 4-39 describes the different model scenarios used to simulate stream temperature and effective shade for Crabtree Creek.

Figure 4-59 shows the predicted daily maximum stream temperatures for the Current Condition and Restored Vegetation model scenarios for Crabtree Creek.

Table 4-40 summarizes the daily maximum stream temperatures predicted at the mouth of Crabtree Creek for the Current Condition and Restored Vegetation model scenarios.

Table 4-39: Crabtree Creek model scenario descriptions.

Scenario Name	Description
Current Condition	Stream temperature response to conditions on August 2, 2000.
Restored Vegetation	This scenario evaluates the stream temperature response from setting near stream land cover to system potential vegetation conditions.

Table 4-40: Summary of daily maximum stream temperature at the mouth of Crabtree Creek for all model scenarios.

Temperature Metric	Model KM	Scenario	Stream Temperature (°C)	Location
Daily maximum temperature	0	Current Condition	25.84	outlet
Daily maximum temperature	0	Restored Vegetation	23.91	outlet

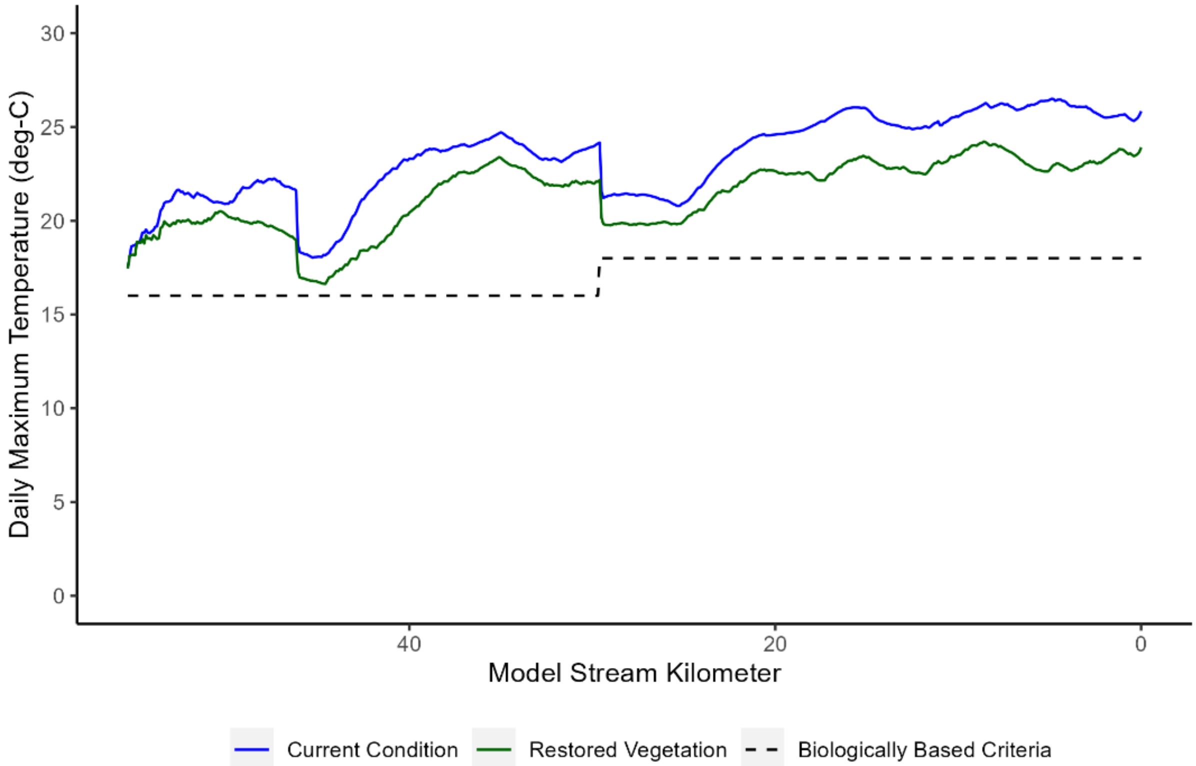


Figure 4-59: Daily maximum stream temperature for the Current Condition and Restored Vegetation model scenarios for Crabtree Creek.

4.7.1 Restored Vegetation

This section summarizes the temperature impacts of restored vegetation.

Table 4-41 summarizes the daily maximum stream temperature change between the Current Condition and Restored Vegetation scenarios for Crabtree Creek. It shows that the daily maximum temperature difference at the most downstream node (the outlet) is equal to 1.93°C. In addition, the greatest daily maximum temperature difference between the two scenarios (the POMI) is equal to 3.78°C and occurs at stream model km 5.2.

The Restored Vegetation scenario is our best estimate of background conditions given the available information. We did not evaluate restored channel morphology, tributary temperatures, or stream flows. Based on the Restored Vegetation scenario, the daily maximum temperature difference between background conditions and the biologically based numeric criteria is 5.91°C at the outlet and 7.39°C at the POMI at stream model km 35.1.

Similar to Thomas Creek, the Restored Vegetation scenario in specific reaches of Crabtree Creek yields lower effective shade values than current conditions. Again, this decrease in effective shade is due in part to the random distribution of natural disturbance included in the Restored Vegetation scenario.

Figure 4-60 shows the change in the daily maximum stream temperatures between the Current Condition and Restored Vegetation model scenarios for Crabtree Creek over the entire model period.

Table 4-41: Summary of daily maximum stream temperature change between Current Condition and Restored Vegetation model scenarios for Crabtree Creek over the entire model period.

Temperature Metric	Model KM	Scenario	Stream Temperature (°C)	Location
Daily maximum	0	Change	1.93	outlet
Daily maximum	5.2	Change	3.78	POMI
Daily maximum	0	Change_BBNC	5.91	outlet
Daily maximum	35.1	Change_BBNC	7.39	POMI

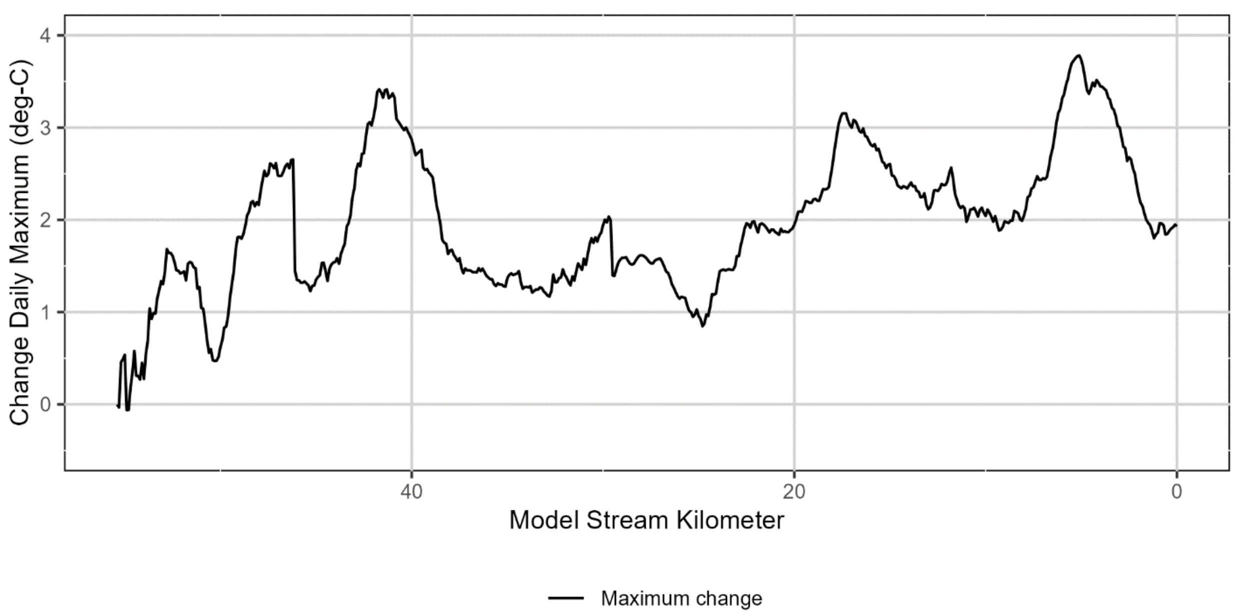


Figure 4-60: Change in the daily maximum stream temperatures between the Current Condition and Restored Vegetation model scenarios for Crabtree Creek over the entire model period.

Table 4-42 summarizes the mean effective shade for the Current Condition and Restored Vegetation scenarios for Crabtree Creek. The difference in mean effective shade between the scenarios is equal to 13.11 percentage points.

Figure 4-61 and **Figure 4-62** compare effective shade predictions from the Current Condition and Restored Vegetation scenarios for Crabtree Creek.

Table 4-42: Summary of mean effective shade between the Current Condition and Restored Vegetation scenarios for Crabtree Creek.

Scenario	Mean Effective Shade (%)
Current Condition	22.71
Restored Vegetation	35.82
Change	13.11

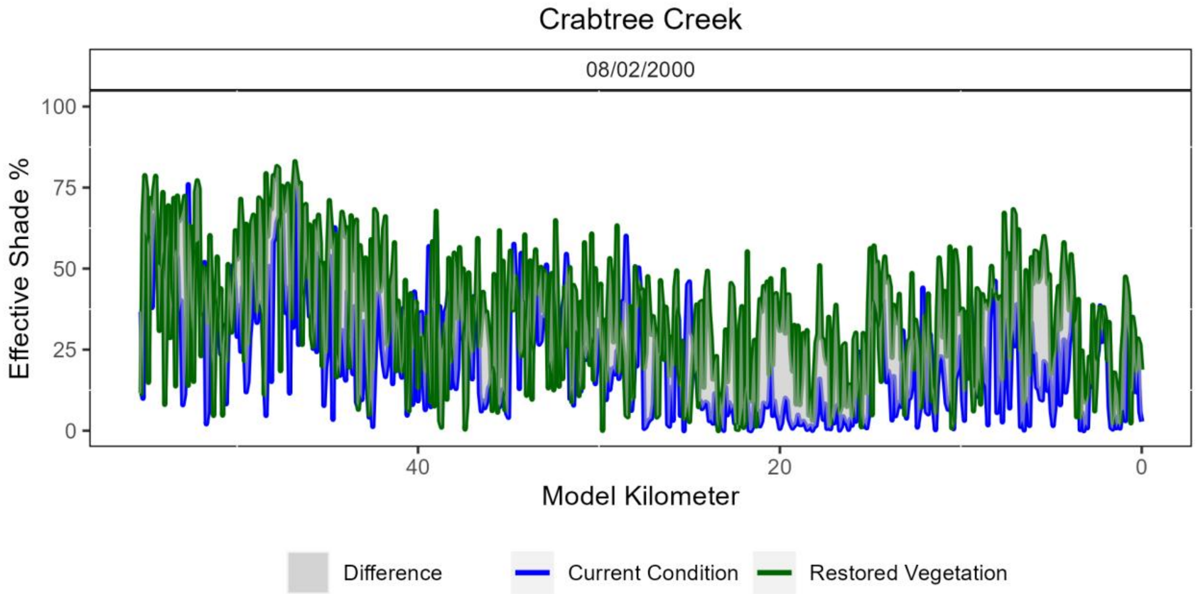


Figure 4-61: Comparison of effective shade from the Current Condition and Restored Vegetation scenarios for Crabtree Creek.

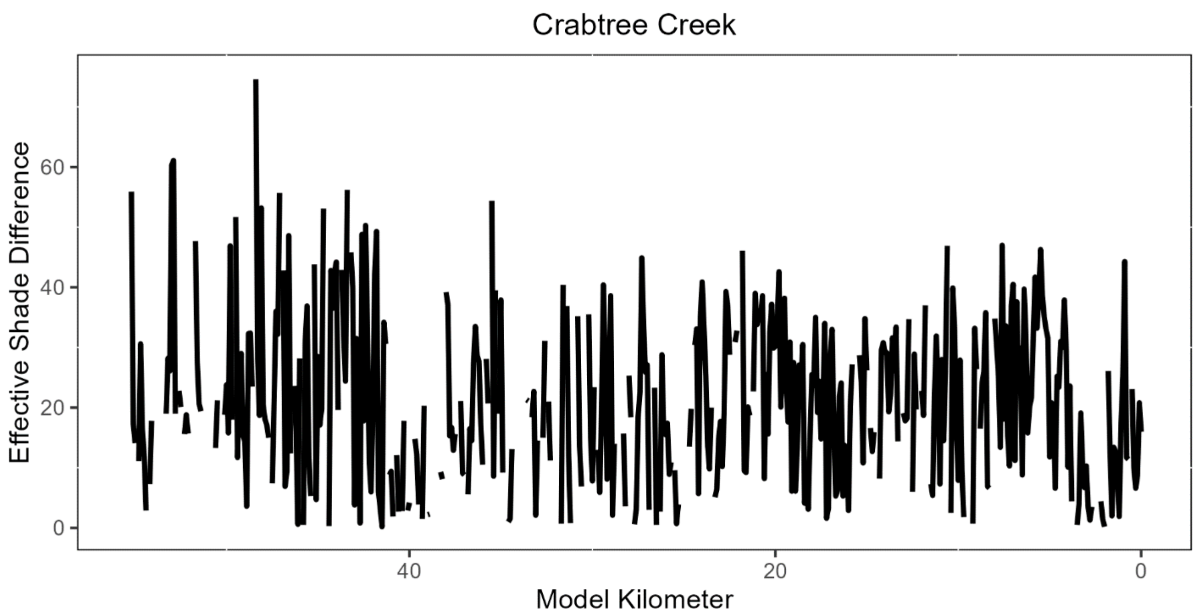


Figure 4-62: Percentage point difference between effective shade from the Current Condition and Restored Vegetation scenarios on 8/2/2000 for Crabtree Creek. Missing values indicate that the shade difference is negative due to instances of higher effective shade in the Current Condition scenario versus the Restored Vegetation scenario.

4.8 Luckiamute River

Table 4-43 describes the different model scenarios used to simulate stream temperature and effective shade for the Luckiamute River.

Figure 4-63 shows the predicted daily maximum stream temperatures for the Current Condition and Restored Vegetation model scenarios for the Luckiamute River.

Table 4-43: Luckiamute River model scenario descriptions.

Scenario Name	Description
Current Condition	Stream temperature response to conditions on August 12, 2001.
Restored Vegetation	This scenario evaluates the stream temperature response from setting near stream land cover to system potential vegetation conditions.

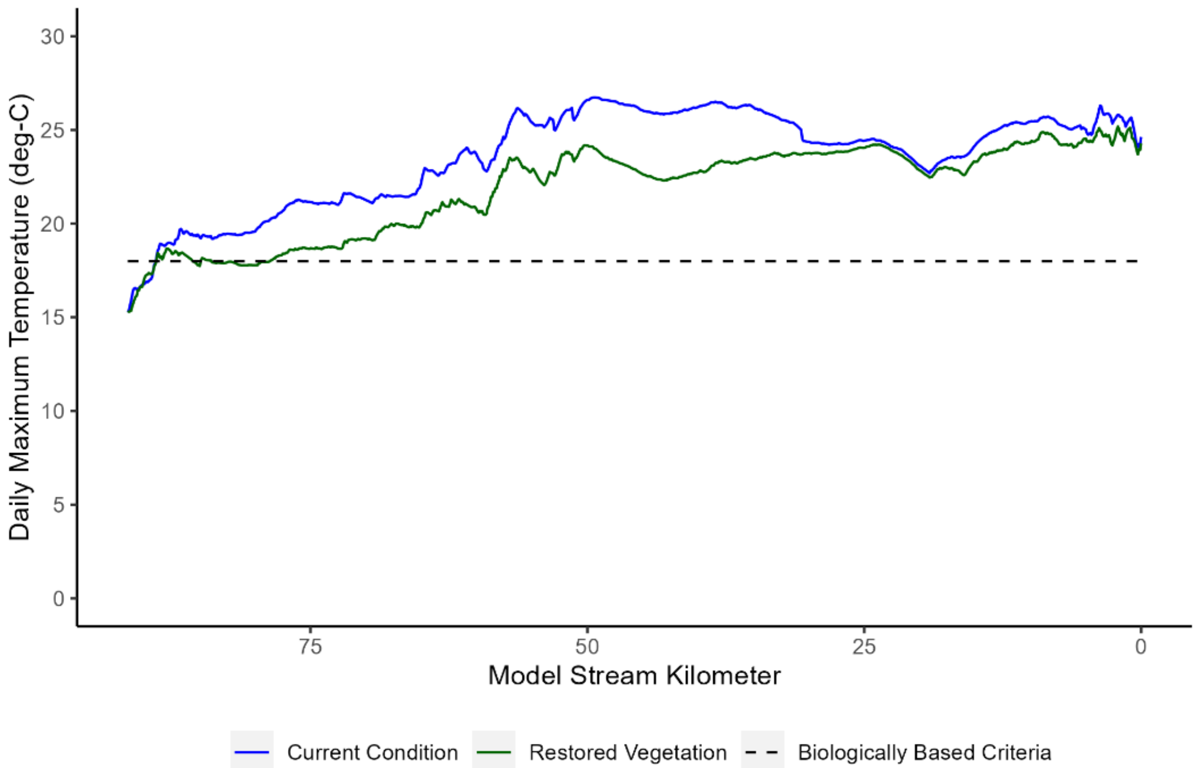


Figure 4-63: Daily maximum stream temperature for the Current Condition and Restored Vegetation model scenarios for the Luckiamute River.

4.8.1 Restored Vegetation

Table 4-44 summarizes the daily maximum stream temperature change between the Current Condition and Restored Vegetation scenarios for the Luckiamute River. It shows the daily maximum temperature difference at the most downstream node (the outlet) is equal to 0.34°C. In addition, the greatest daily maximum temperature difference between the two scenarios (the POMI) is equal to 3.56°C and occurs at stream model km 42.8.

The Restored Vegetation scenario is our best estimate of background conditions given the available information. We did not evaluate restored channel morphology, tributary temperatures, or stream flows. Based on the Restored Vegetation scenario, the daily maximum temperature difference between background conditions and the biologically based numeric criteria is 6.28°C at the outlet and 7.18°C at the POMI at stream model km 2.1.

Figure 4-64 shows the change in the daily maximum stream temperatures between the Current Condition and Restored Vegetation model scenarios for the Luckiamute River over the entire model period.

Table 4-44: Summary of daily maximum stream temperature change between Current Condition and Restored Vegetation model scenarios for the Luckiamute River over the entire model period.

Temperature Metric	Model KM	Scenario	Stream Temperature (°C)	Location
Daily maximum	0	Change	0.34	outlet
Daily maximum	42.8	Change	3.56	POMI
Daily maximum	0	Change_BBNC	6.28	outlet
Daily maximum	2.1	Change_BBNC	7.18	POMI

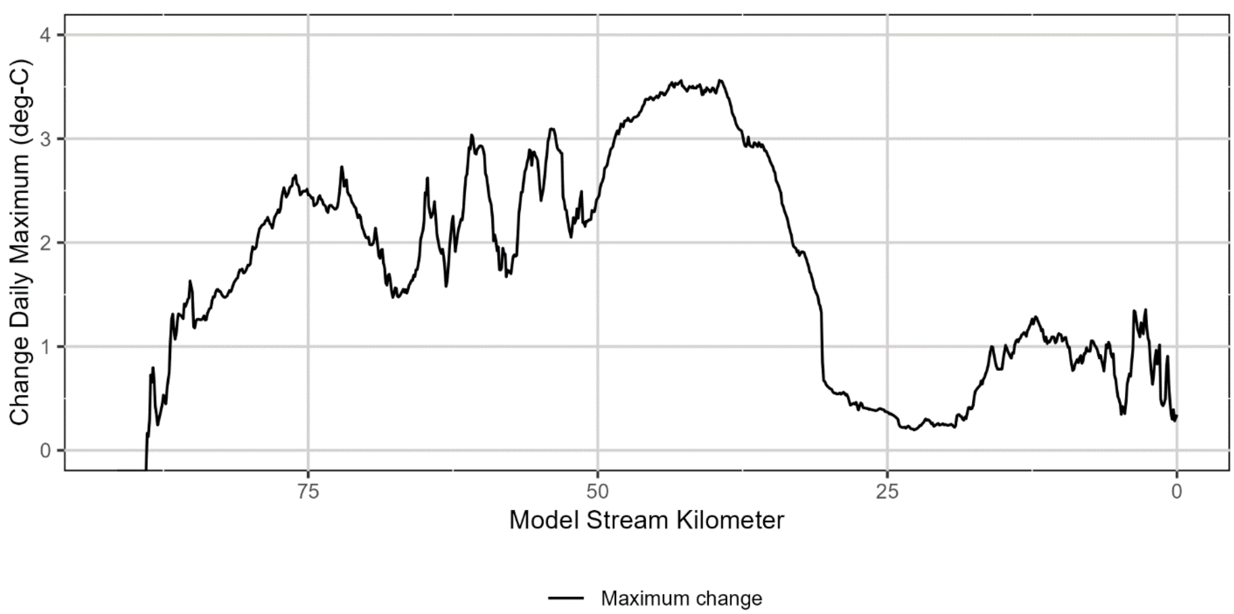


Figure 4-64: Change in the daily maximum stream temperatures between the Current Condition and Restored Vegetation model scenarios for the Luckiamute River over the entire model period.

Table 4-45 summarizes the mean effective shade for the Current Condition and Restored Vegetation scenarios for the Luckiamute River. The difference in mean effective shade between the scenarios is equal to 10.48 percentage points.

Figure 4-65 and Figure 4-66 compare effective shade predictions from the Current Condition and Restored Vegetation scenarios for the Luckiamute River.

Table 4-45: Summary of mean effective shade between the Current Condition and Restored Vegetation scenarios for the Luckiamute River.

Scenario	Mean Effective Shade (%)
Current Condition	29.70
Restored Vegetation	40.18
Change	10.48

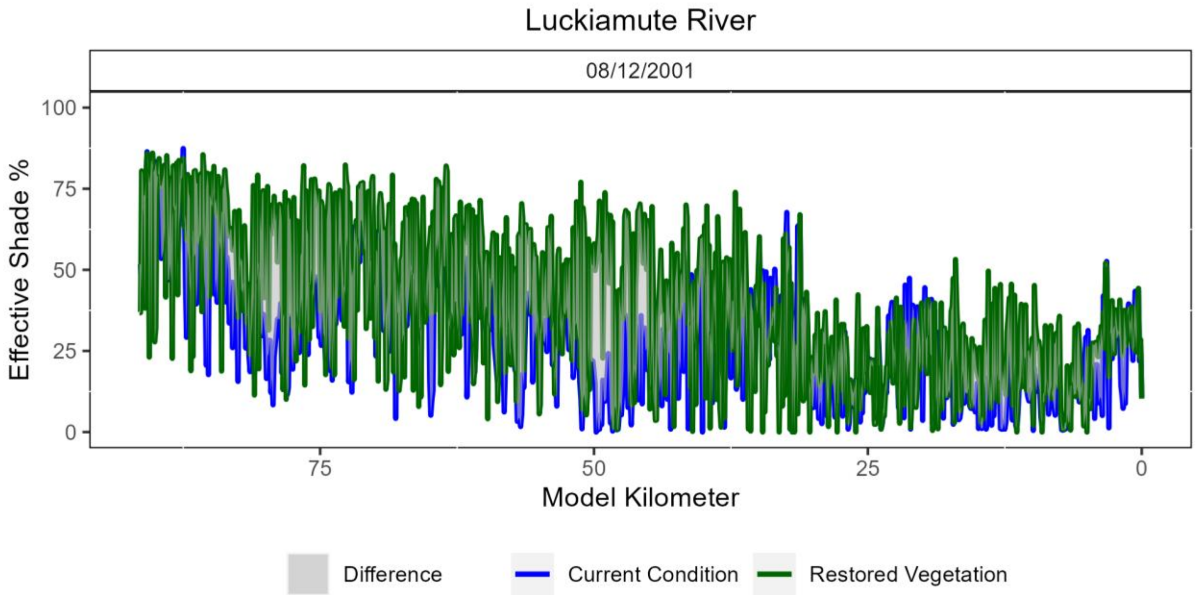


Figure 4-65: Comparison of effective shade from the Current Condition and Restored Vegetation scenarios for the Luckiamute River.

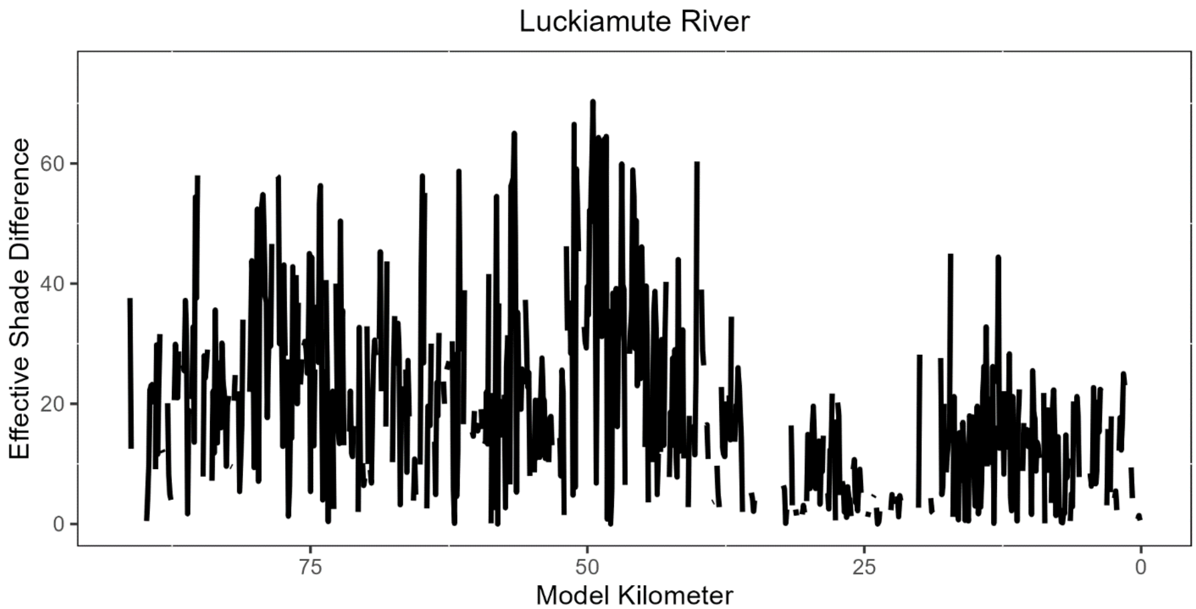


Figure 4-66: Percentage point difference between effective shade from the Current Condition and Restored Vegetation scenarios on 8/12/2001 for the Luckiamute River. Missing values indicate that

the shade difference is negative due to instances of higher effective shade in the Current Condition scenario versus the Restored Vegetation scenario.

4.9 Mohawk River

Table 4-46 describes the different model scenarios used to simulate stream temperature and effective shade for the Mohawk River.

Figure 4-67 shows the predicted daily maximum stream temperatures for the Current Condition and Restored Vegetation model scenarios for the Mohawk River.

Table 4-46: Mohawk River model scenario descriptions.

Scenario Name	Description
Current Condition	Stream temperature response to conditions on August 9, 2001.
Restored Vegetation	This scenario evaluates the stream temperature response from setting near stream land cover to system potential vegetation conditions.

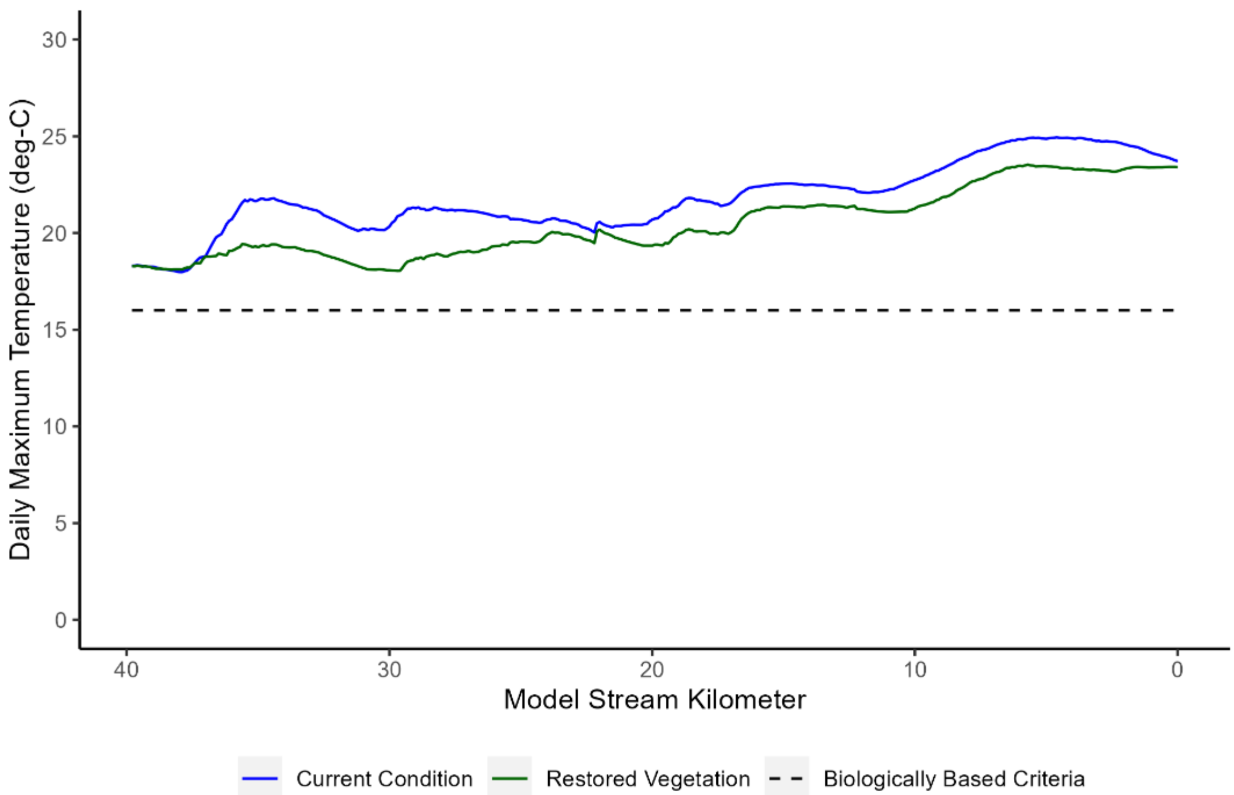


Figure 4-67: Daily maximum stream temperature for the Current Condition and Restored Vegetation model scenarios for the Mohawk River.

4.9.1 Restored Vegetation

Table 4-47 summarizes the daily maximum stream temperature change between the Current Condition and Restored Vegetation scenarios for the Mohawk River. It shows the daily maximum temperature difference at the most downstream node (the outlet) is equal to 0.32°C. In addition, the greatest daily maximum temperature difference between the two scenarios (the POMI) is equal to 2.87°C and occurs at stream model km 29.6.

The Restored Vegetation scenario is our best estimate of background conditions given the available information. We did not evaluate restored channel morphology, tributary temperatures, or stream flows. Based on the Restored Vegetation scenario, the daily maximum temperature difference between background conditions and the biologically based numeric criteria is 7.4°C at the outlet and 7.53°C at the POMI at stream model km 5.7.

Figure 4-68 shows the change in the daily maximum stream temperatures between the Current Condition and Restored Vegetation model scenarios for the Mohawk River over the entire model period.

Table 4-47: Summary of daily maximum stream temperature change between Current Condition and Restored Vegetation model scenarios for the Mohawk River over the entire model period.

Temperature Metric	Model KM	Scenario	Stream Temperature (°C)	Location
Daily maximum	0	Change	0.32	outlet
Daily maximum	29.6	Change	2.87	POMI
Daily maximum	0	Change_BBNC	7.4	outlet
Daily maximum	5.7	Change_BBNC	7.53	POMI

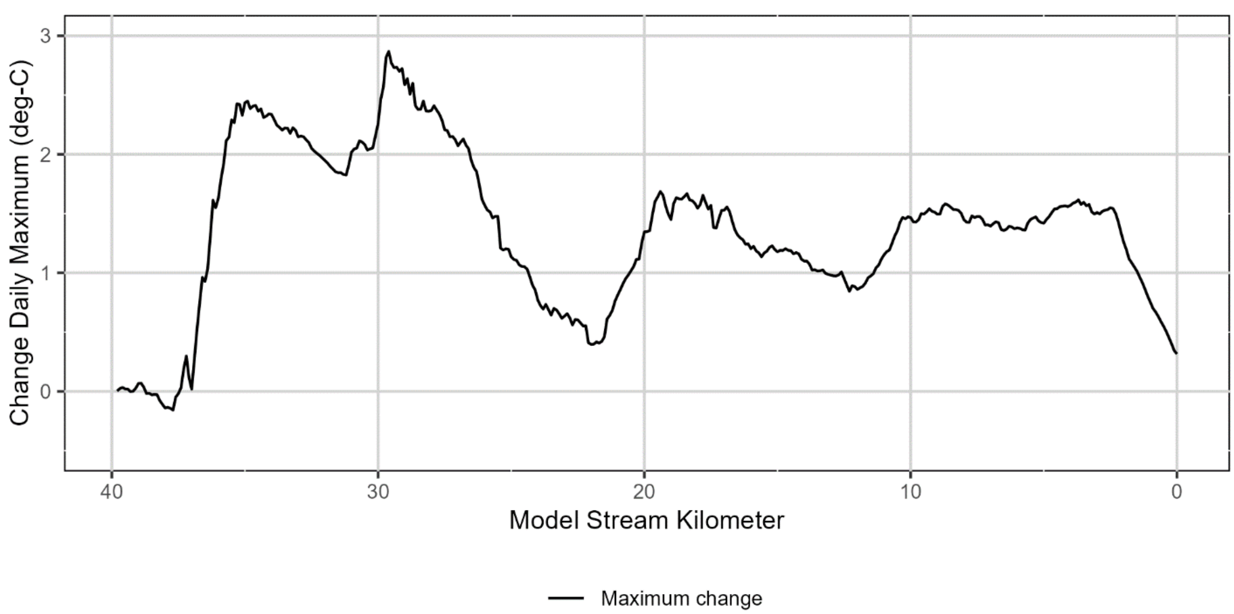


Figure 4-68: Change in the daily maximum stream temperatures between the Current Condition and Restored Vegetation model scenarios for the Mohawk River over the entire model period.

Table 4-48 summarizes the mean effective shade for the Current Condition and Restored Vegetation scenarios for the Mohawk River. The difference in mean effective shade between the scenarios is equal to 13.26 percentage points.

Figure 4-69 and Figure 4-70 compare effective shade predictions from the Current Condition and Restored Vegetation scenarios for the Mohawk River.

Table 4-48: Summary of mean effective shade between the Current Condition and Restored Vegetation scenarios for the Mohawk River.

Scenario	Mean Effective Shade (%)
Current Condition	37.92
Restored Vegetation	51.18
Change	13.26

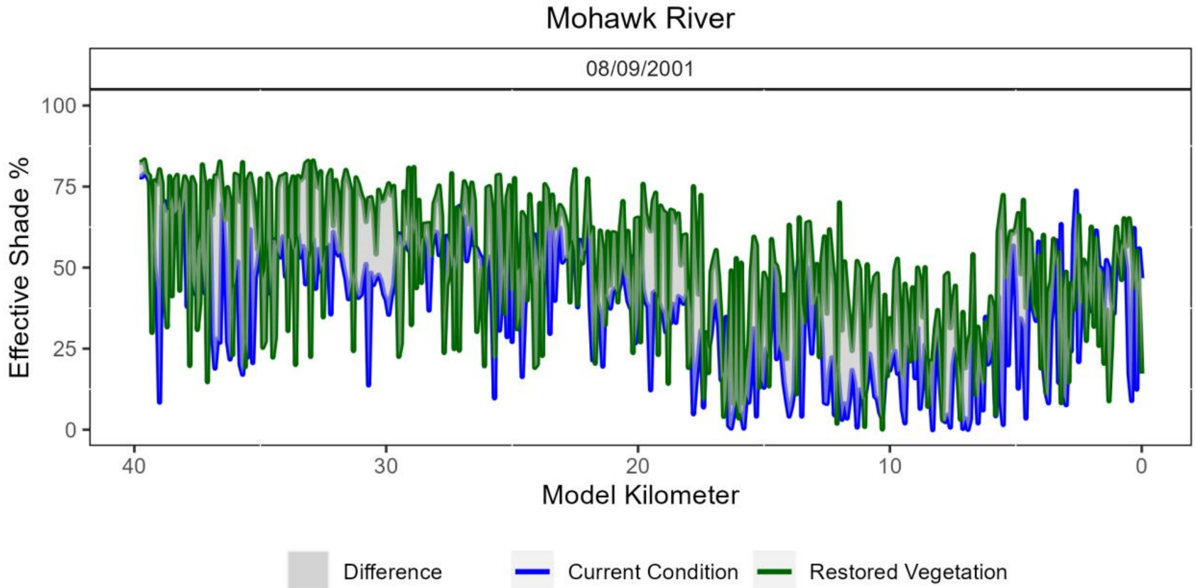


Figure 4-69: Comparison of effective shade from the Current Condition and Restored Vegetation scenarios for the Mohawk River.

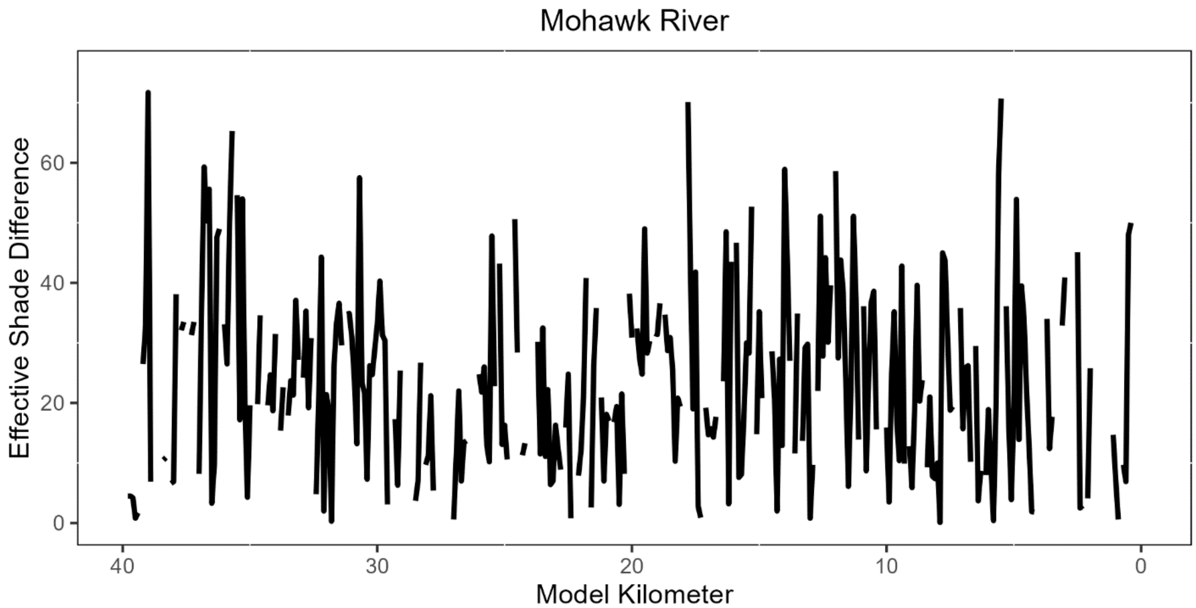


Figure 4-70: Percentage point difference between effective shade from the Current Condition and Restored Vegetation scenarios on 8/9/2001 for the Mohawk River. Missing values indicate that the shade difference is negative due to instances of higher effective shade in the Current Condition scenario versus the Restored Vegetation scenario.

4.10 McKenzie River: Upper

Table 4-49 describes the different model scenarios used to simulate stream temperature and effective shade for the upper McKenzie River.

Table 4-50 summarizes the daily maximum stream temperature predicted at the mouth of the upper McKenzie River for all model scenarios over the entire model period.

Figure 4-71 shows the predicted daily maximum stream temperatures for the Current Condition, Restored Vegetation and Wasteload Allocations model scenarios for the upper McKenzie River. Simulated daily maximum stream temperatures from all the scenarios are below the biologically-based criteria for the entire model reach.

Table 4-49: McKenzie River: Upper model scenario descriptions.

Scenario Name	Description
Current Condition	Stream temperature response to conditions on September 3, 1999.
Restored Vegetation	Stream temperature response to restored vegetation conditions.
Wasteload Allocations	This scenario evaluates the stream temperature response from the TMDL wasteload allocations for EWEB Carmen-Smith Outfall 002.

Table 4-50: Summary of daily maximum stream temperatures at the mouth of the upper McKenzie River for the Current Condition, Restored Vegetation and Wasteload Allocations model scenarios.

Temperature Metric	Model KM	Scenario	Stream Temperature (°C)	Location
Daily maximum temperature	0	Current Condition	10.9	outlet
Daily maximum temperature	0	Restored Vegetation	10.54	outlet
Daily maximum temperature	0	Wasteload Allocations	10.9	outlet

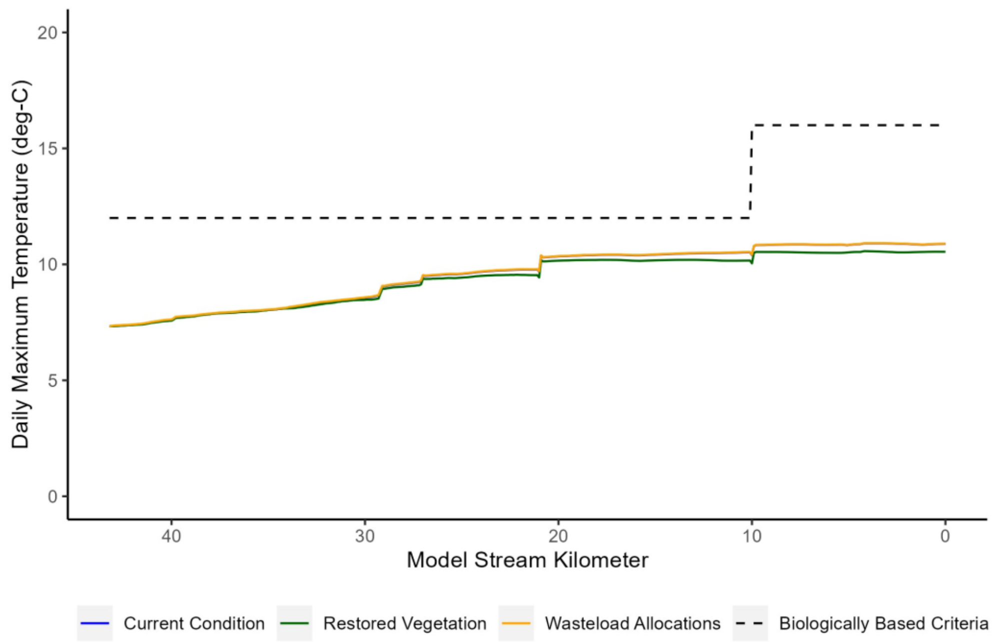


Figure 4-71: Daily maximum stream temperatures for all model scenarios for the upper McKenzie River.

4.10.1 Restored Vegetation

This section summarizes the temperature impacts of restored vegetation.

A comparison of the Current Condition and Restored Vegetation scenarios for the upper McKenzie River shows that the daily maximum stream temperatures do not exceed the biologically-based numeric criteria along the model reach. DEQ also evaluated maximum temperature differences between the two scenarios. In this case, the daily maximum temperature difference at the most downstream node (the outlet) is equal to 0.36°C. In addition, the greatest daily maximum temperature difference between the two scenarios (the POMI) is equal to 0.43°C and occurs at stream model km 10. These results are summarized in Table 4-51.

The Restored Vegetation scenario is our best estimate of background conditions given the available information. We did not evaluate restored channel morphology, tributary temperatures, or stream flows.

Figure 4-72 shows the change in the daily maximum stream temperatures between the Current Condition and Restored Vegetation model scenarios for the upper McKenzie River over the entire model period.

Table 4-51: Summary of daily maximum stream temperature change between the Current Condition and Restored Vegetation model scenarios for the upper McKenzie River.

Temperature Metric	Model KM	Scenario	Stream Temperature (°C)	Location
Daily maximum	0	Change (ambient)	0.36	outlet
Daily maximum	10	Change (ambient)	0.43	POMI

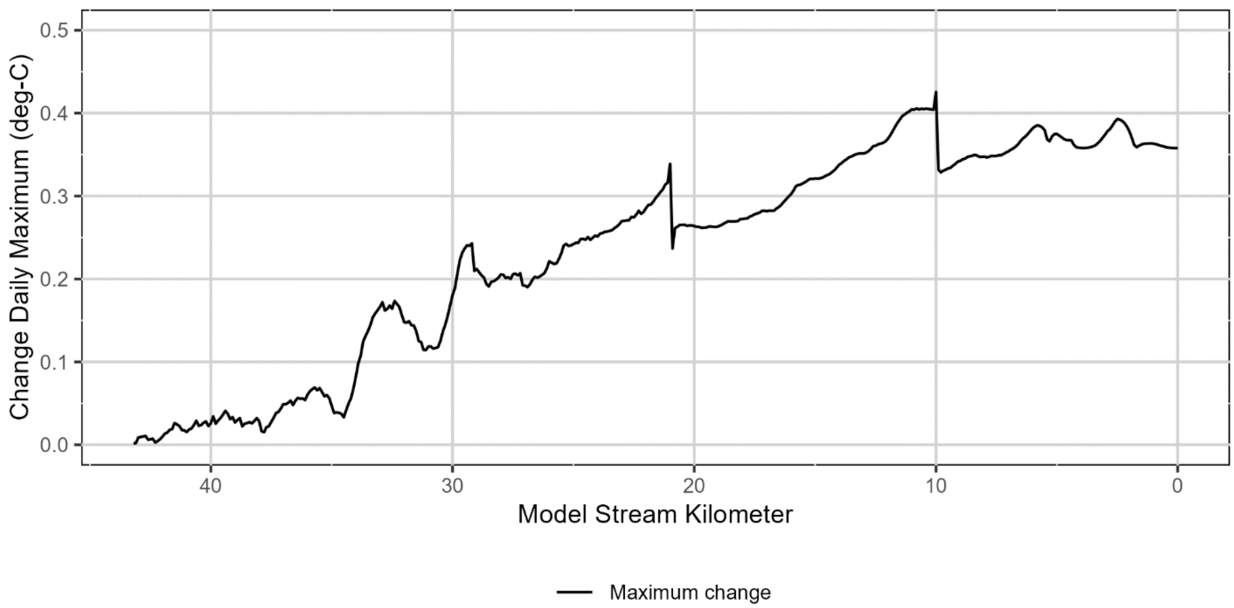


Figure 4-72: Change in the daily maximum stream temperatures between the Current Condition and Restored Vegetation model scenarios for the upper McKenzie River over the entire model period.

Table 4-52 summarizes the mean effective shade for the Current Condition and Restored Vegetation scenarios for the upper McKenzie River. The difference in mean effective shade between the scenarios is equal to 19.78 percentage points.

Figure 4-73 and Figure 4-74 compare effective shade predictions from the Current Condition and Restored Vegetation scenarios for the upper McKenzie River.

Table 4-52: Summary of mean effective shade between the Current Condition and Restored Vegetation scenarios for the upper McKenzie River.

Scenario	Mean Effective Shade (%)
Current Condition	26.70
Restored Vegetation	46.48
Change	19.78

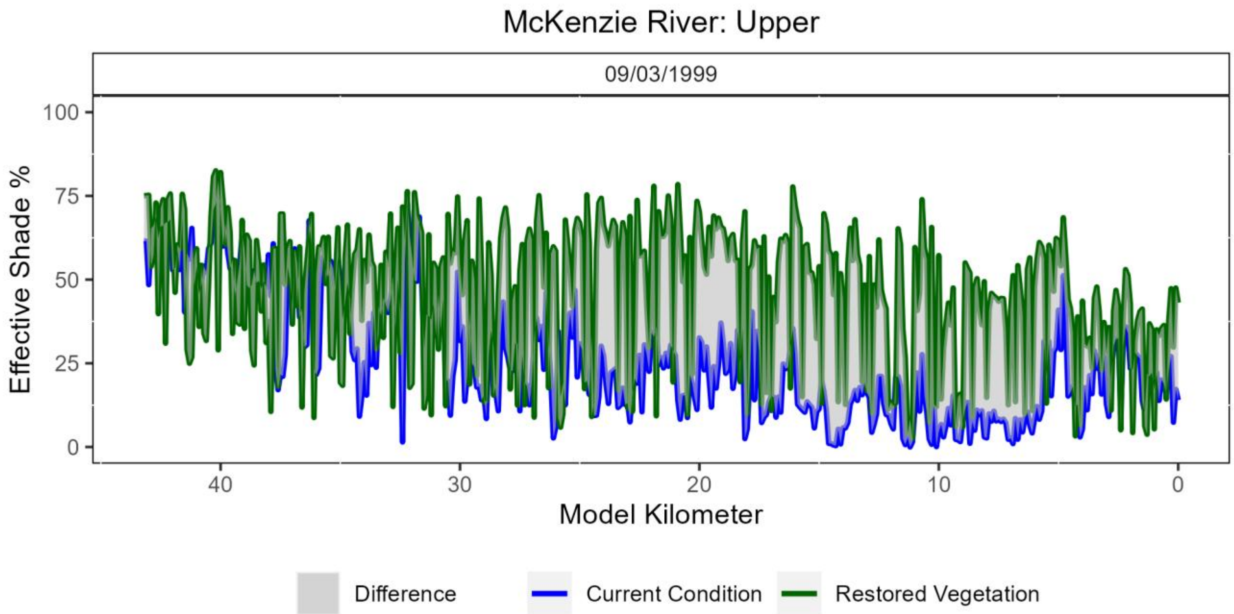


Figure 4-73: Comparison of effective shade from the Current Condition and Restored Vegetation scenarios for the upper McKenzie River.

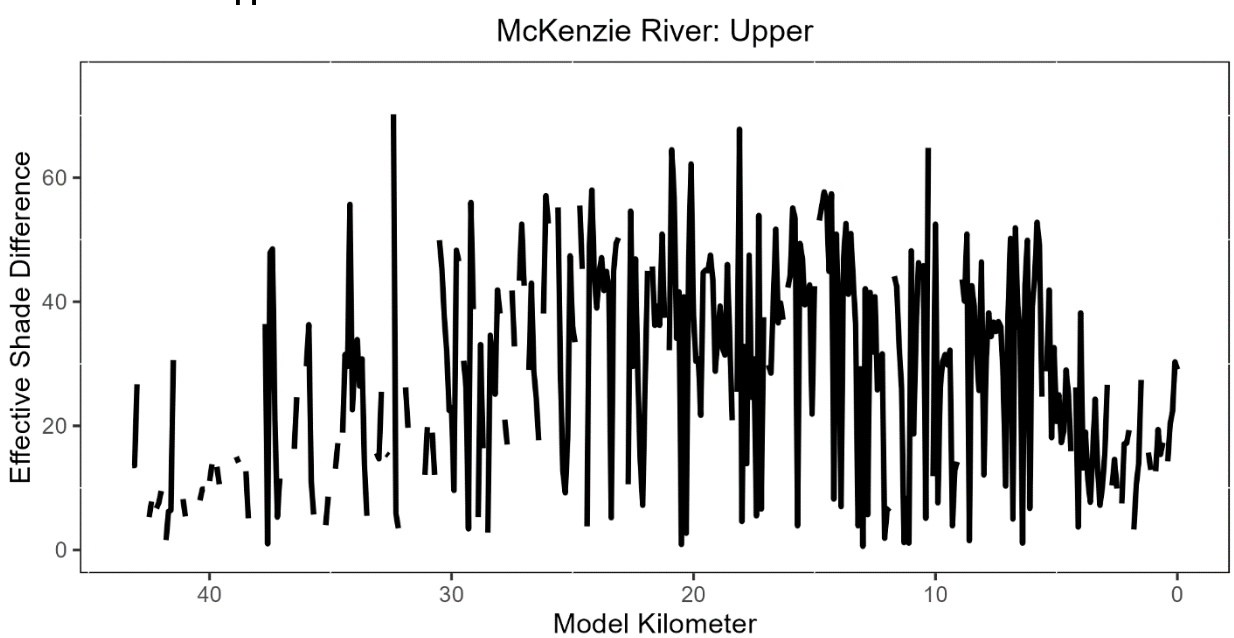


Figure 4-74: Percentage point difference between effective shade from the Current Condition and Restored Vegetation scenarios on 9/3/1999 for the upper McKenzie River. Missing values indicate that the shade difference is negative due to instances of higher effective shade in the Current Condition scenario versus the Restored Vegetation scenario.

4.10.2 Wasteload Allocations

This section summarizes the temperature impacts from the NPDES permitted discharge at EWEB's Trail Bridge Powerhouse (outfall 002) discharging at their wasteload allocation. This scenario does not evaluate the nonpoint source component of the reservoir operations. The trail bridge powerhouse is located just downstream of Trail Bridge Reservoir and approximately 1.2 miles upstream from the model boundary condition. The current condition model does include the powerhouse discharge directly as the impact of the discharge is incorporated into the flow and temperature at the boundary condition. The calibrated model was used as the baseline for comparison to the Wasteload allocation scenario. For the Wasteload allocation scenario, the boundary conditions were left unchanged and the NPDES discharge was input at the model boundary. This provided the means to compare how the discharge impacts downstream temperatures.

For WLA calculations, it was assumed that NPDES effluent flow was equal to the current permit limit at Outfall 002 (0.026 cms). The portion of the HUA allocated to EWEB was 0.03°C which is sufficient capacity to accommodate current effluent temperatures. Effluent temperatures were calculated using equations described in the Willamette Subbasins TSD (Section 6.1.1 Wasteload allocation equation).

At this location the Protecting Cold Water Criteria applies because water does not exceed the biologically-based numeric criteria year round. The Protecting Cold Water Criteria states that waters may not be warmed more than 0.3°C above the colder water ambient temperature (OAR 340-041-0028 (11)(a)). The wasteload allocation for EWEB was based on attaining this criterion by not increasing temperatures by more than 0.03°C as measured above ambient temperatures. The model results show the greatest daily maximum temperature increase is equal to 0.02°C and is located at stream model km 40.2. At the most downstream point in the model (model km 0.00 downstream of Blue River), the greatest daily maximum increase is equal to about 0.01°C (rounded from 0.008°C). These results are summarized in **Table 4-53**.

At the confluence of the McKenzie River and South Fork McKenzie River, the increase is equal to 0.015°C. This was the increase applied to the boundary condition in the McKenzie River CE-QUAL-W2 model evaluating waste load allocations on the lower McKenzie River (TSD Appendix K).

The Wasteload Allocation scenario also shows that the daily maximum stream temperatures do not exceed the biologically-based numeric criteria along the entire McKenzie model reach. **Figure 4-75** shows that the change between the Wasteload Allocations and Current Condition model scenarios.

The protecting cold water criterion also states that a point source that discharges into or above salmon & steelhead spawning waters that are colder than the spawning criterion, may not cause the water temperature in the spawning reach where the physical habitat for spawning exists during the time spawning through emergence use occurs, to increase more than specified amounts (OAR 340-041-0028 (11)(b)). This portion of the criterion could not be tested because the upper McKenzie River model does not simulate the spawning period. We expect this criterion to be addressed during the permitting process.

Table 4-53: Summary of daily maximum stream temperature change between the Current Condition and Wasteload Allocations model scenarios for the upper McKenzie River.

Temperature Metric	Model KM	Scenario	Stream Temperature (°C)	Location
Daily maximum temperature	40.2	Change (ambient)	0.02	POMI
Daily maximum temperature	0.0	Change (ambient)	0.01	McKenzie River downstream of Blue River

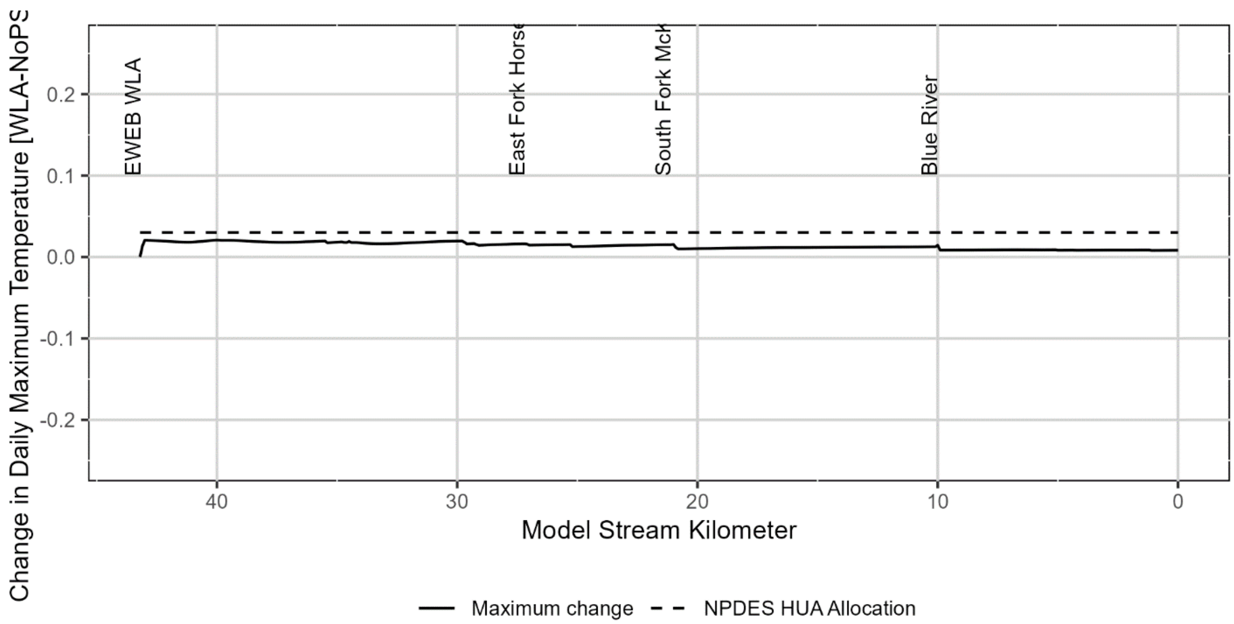


Figure 4-75: Change in daily maximum stream temperature between the Wasteload Allocations and Current Condition model scenarios for the upper McKenzie River.

4.11 Coyote Creek

Table 4-54 describes the different model scenarios used to simulate stream temperature and effective shade for Coyote Creek.

Figure 4-76 shows the predicted daily maximum stream temperatures for the Current Condition and Restored Vegetation model scenarios for Coyote Creek.

Table 4-54: Coyote Creek model scenario descriptions.

Scenario Name	Description
Current Condition	Stream temperature response to conditions on July 11, 2001.
Restored Vegetation	This scenario evaluates the stream temperature response from setting near stream land cover to system potential vegetation conditions.

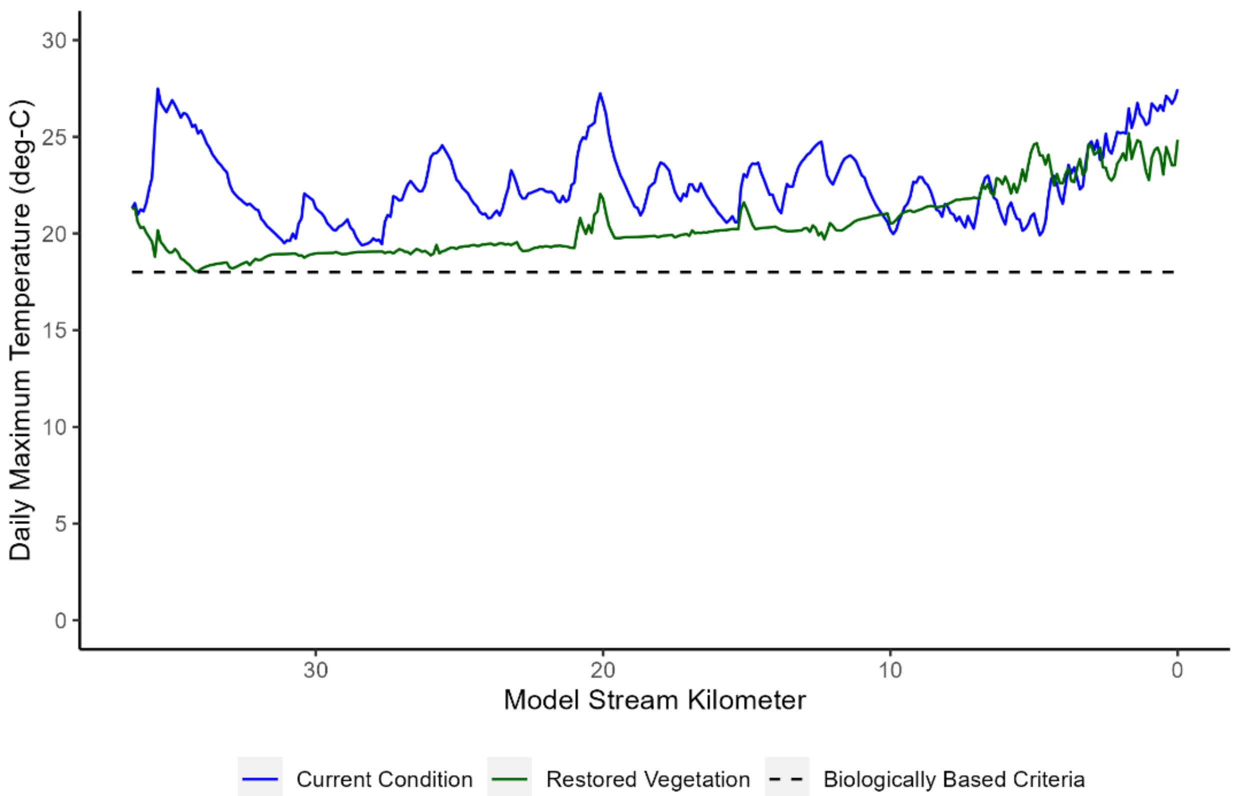


Figure 4-76: Daily maximum stream temperature for the Current Condition and Restored Vegetation model scenarios for Coyote Creek.

4.11.1 Restored Vegetation

Table 4-55 summarizes the daily maximum stream temperature change between the Current Condition and Restored Vegetation scenarios for Coyote Creek. It shows the daily maximum temperature difference at the most downstream node (the outlet) is equal to 2.61°C. In addition, the greatest daily maximum temperature difference between the two scenarios (the POMI) is equal to 7.87°C and occurs at stream model km 35.

The Restored Vegetation scenario is our best estimate of background conditions given the available information. We did not evaluate restored channel morphology, tributary temperatures, or stream flows. Based on the Restored Vegetation scenario, the daily maximum temperature difference between background conditions and the biologically based numeric criteria is 6.85°C at the outlet and 7.18°C at the POMI at stream model km 1.7.

Figure 4-77 shows the change in the daily maximum stream temperatures between the Current Condition and Restored Vegetation model scenarios for Coyote Creek over the entire model period.

Table 4-55: Summary of daily maximum stream temperature change between Current Condition and Restored Vegetation model scenarios for Coyote Creek over the entire model period.

Temperature Metric	Model KM	Scenario	Stream Temperature (°C)	Location
Daily maximum	0	Change	2.61	outlet
Daily maximum	35	Change	7.87	POMI
Daily maximum	0	Change_BBNC	6.85	outlet
Daily maximum	1.7	Change_BBNC	7.18	POMI

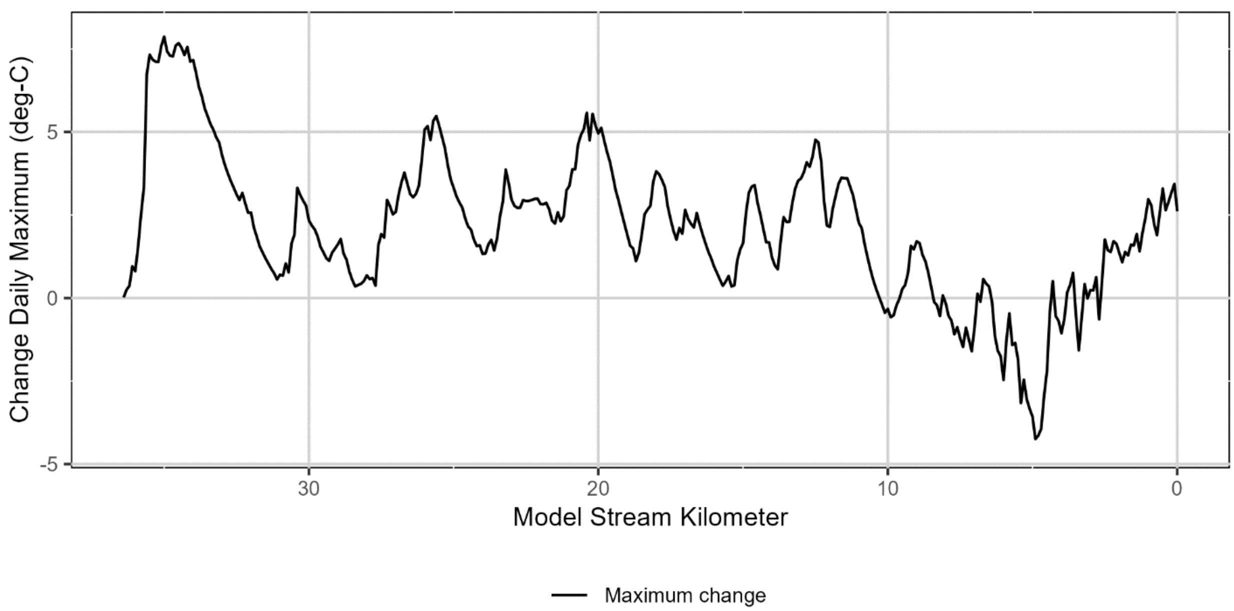


Figure 4-77: Change in the daily maximum stream temperatures between the Current Condition and Restored Vegetation model scenarios for Coyote Creek over the entire model period.

Table 4-56 summarizes the mean effective shade for the Current Condition and Restored Vegetation scenarios for Coyote Creek. The difference in mean effective shade between the scenarios is equal to 22.50 percentage points.

Figure 4-78 and Figure 4-79 compare effective shade predictions from the Current Condition and Restored Vegetation scenarios for Coyote Creek.

Table 4-56: Summary of mean effective shade between the Current Condition and Restored Vegetation scenarios for Coyote Creek.

Scenario	Mean Effective Shade (%)
Current Condition	41.56
Restored Vegetation	64.07
Change	22.50

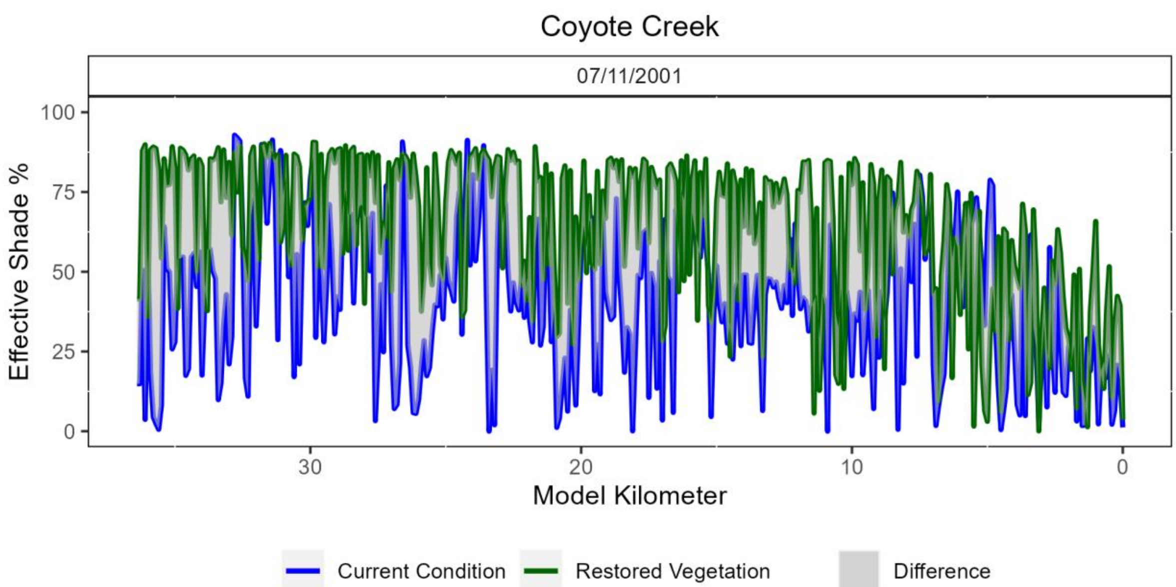


Figure 4-78: Comparison of effective shade from the Current Condition and Restored Vegetation scenarios for Coyote Creek.

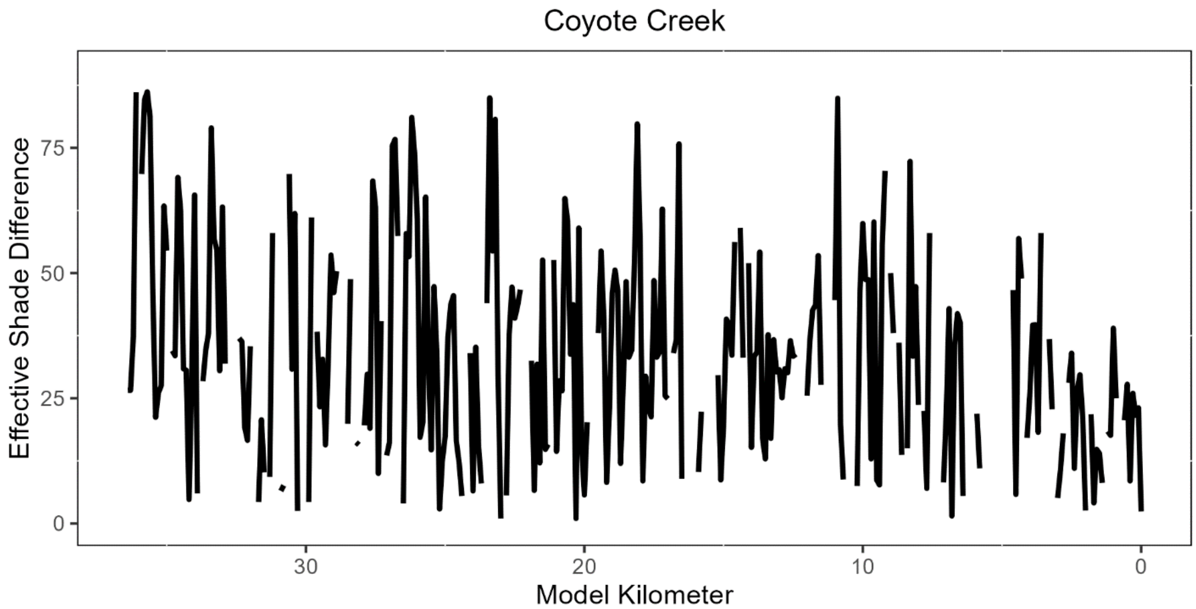


Figure 4-79: Percentage point difference between effective shade from the Current Condition and Restored Vegetation scenarios on 7/11/2001 for Coyote Creek. Missing values indicate that the shade difference is negative due to instances of higher effective shade in the Current Condition scenario versus the Restored Vegetation scenario.

4.12 Mosby Creek

Table 4-57 describes the different model scenarios used to simulate stream temperature and effective shade for Mosby Creek.

Figure 4-80 shows the predicted daily maximum stream temperatures for the Current Condition and Restored Vegetation model scenarios for Mosby Creek.

Table 4-57: Mosby Creek model scenario descriptions.

Scenario Name	Description
Current Condition	Stream temperature response to conditions on July 21, 2002.
Restored Vegetation	This scenario evaluates the stream temperature response from setting near stream land cover to system potential vegetation conditions.

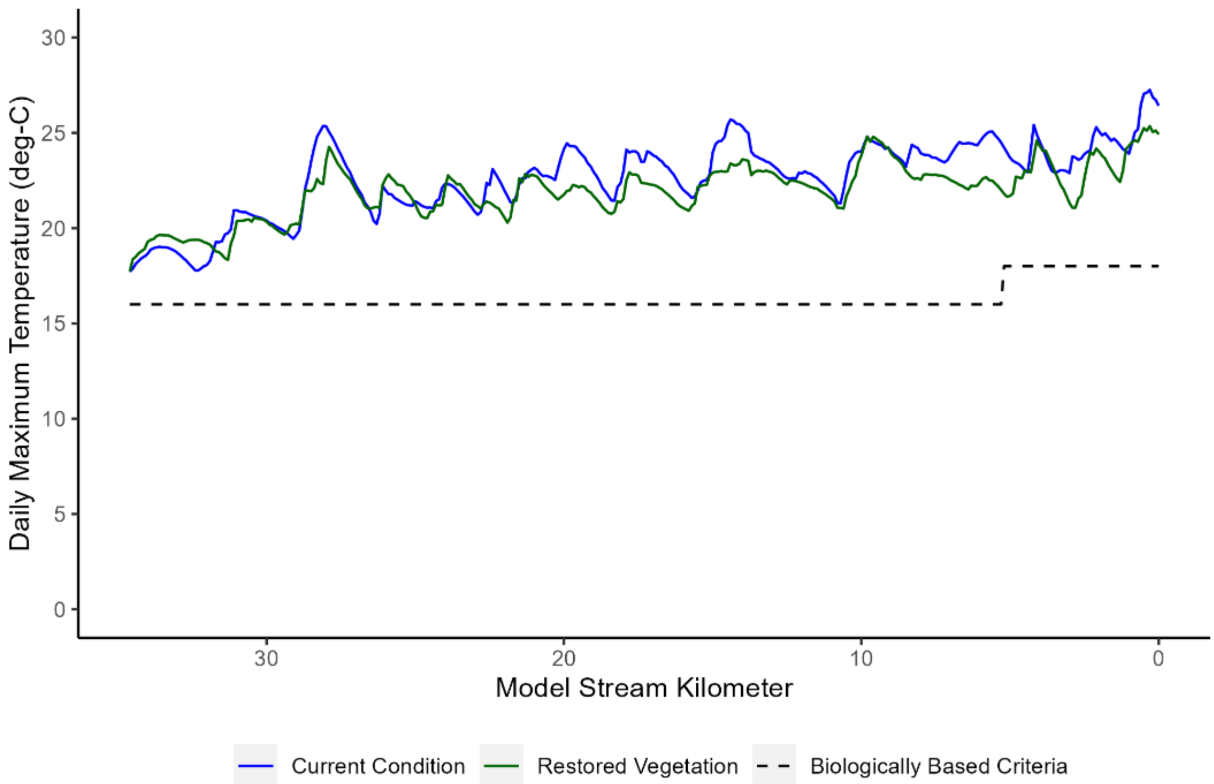


Figure 4-80: Daily maximum stream temperature for the Current Condition and Restored Vegetation model scenarios for Mosby Creek.

4.12.1 Restored Vegetation

Table 4-58 summarizes the daily maximum stream temperature change between the Current Condition and Restored Vegetation scenarios for Mosby Creek. It shows the daily maximum temperature difference at the most downstream node (the outlet) is equal to 1.5°C. In addition, the greatest daily maximum temperature difference between the two scenarios (the POMI) is equal to 3.05°C and occurs at stream model km 28.1.

The Restored Vegetation scenario is our best estimate of background conditions given the available information. We did not evaluate restored channel morphology, tributary temperatures, or stream flows. Based on the Restored Vegetation scenario, the daily maximum temperature difference between background conditions and the biologically based numeric criteria is 6.92°C at the outlet and 8.81°C at the POMI at stream model km 9.8.

Figure 4-81 shows the change in the daily maximum stream temperatures between the Current Condition and Restored Vegetation model scenarios for Mosby Creek over the entire model period.

Table 4-58: Summary of daily maximum stream temperature change between Current Condition and Restored Vegetation model scenarios for Mosby Creek over the entire model period.

Temperature Metric	Model KM	Scenario	Stream Temperature (°C)	Location
Daily maximum	0	Change	1.5	outlet
Daily maximum	28.1	Change	3.05	POMI
Daily maximum	0	Change_BBNC	6.92	outlet
Daily maximum	9.8	Change_BBNC	8.81	POMI

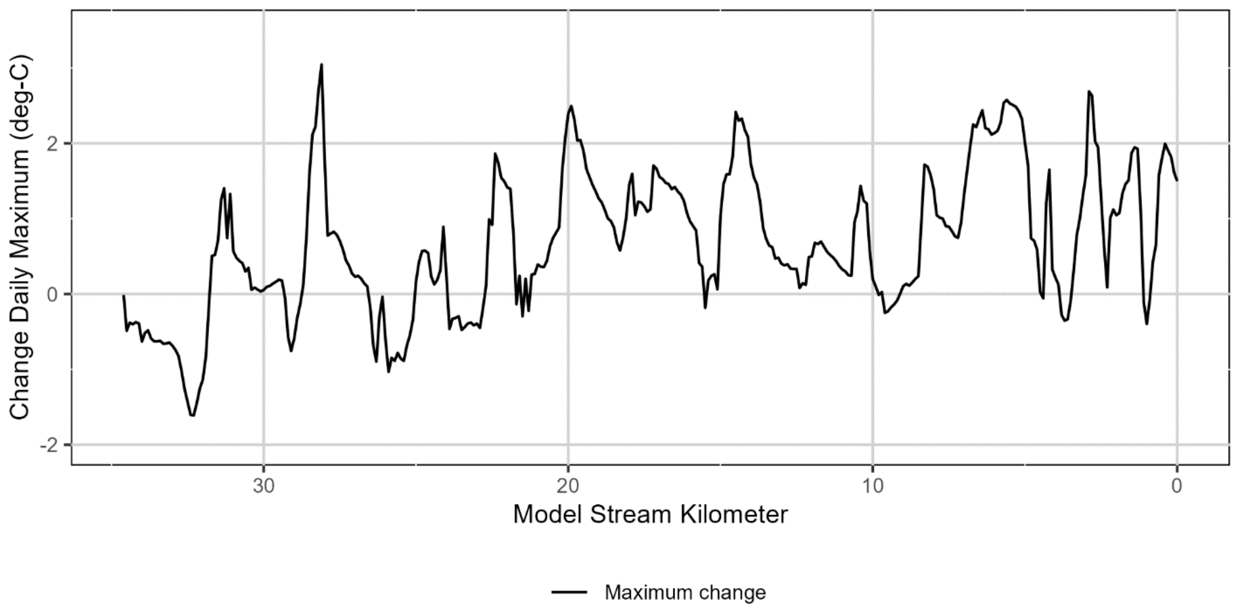


Figure 4-81: Change in the daily maximum stream temperatures between the Current Condition and Restored Vegetation model scenarios for Mosby Creek over the entire model period.

Table 4-59 summarizes the mean effective shade for the Current Condition and Restored Vegetation scenarios for Mosby Creek. The difference in mean effective shade between the scenarios is equal to 3.98 percentage points.

Figure 4-82 and Figure 4-83 compare effective shade predictions from the Current Condition and Restored Vegetation scenarios for Mosby Creek.

Table 4-59: Summary of mean effective shade between the Current Condition and Restored Vegetation scenarios for Mosby Creek.

Scenario	Mean Effective Shade (%)
Current Condition	58.08
Restored Vegetation	62.06
Change	3.98

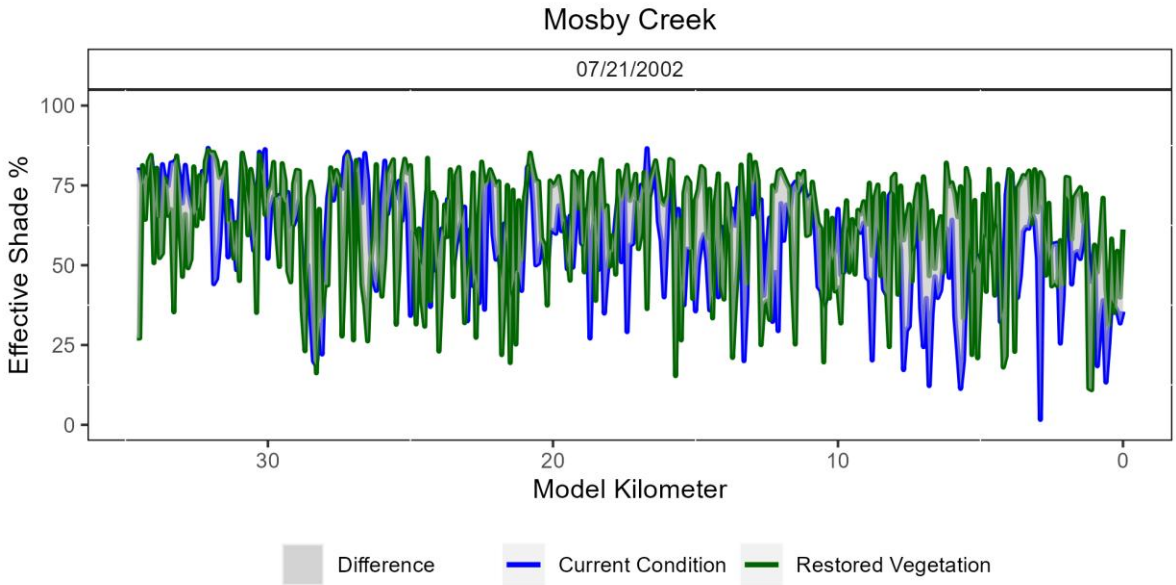


Figure 4-82: Comparison of effective shade from the Current Condition and Restored Vegetation scenarios for Mosby Creek.

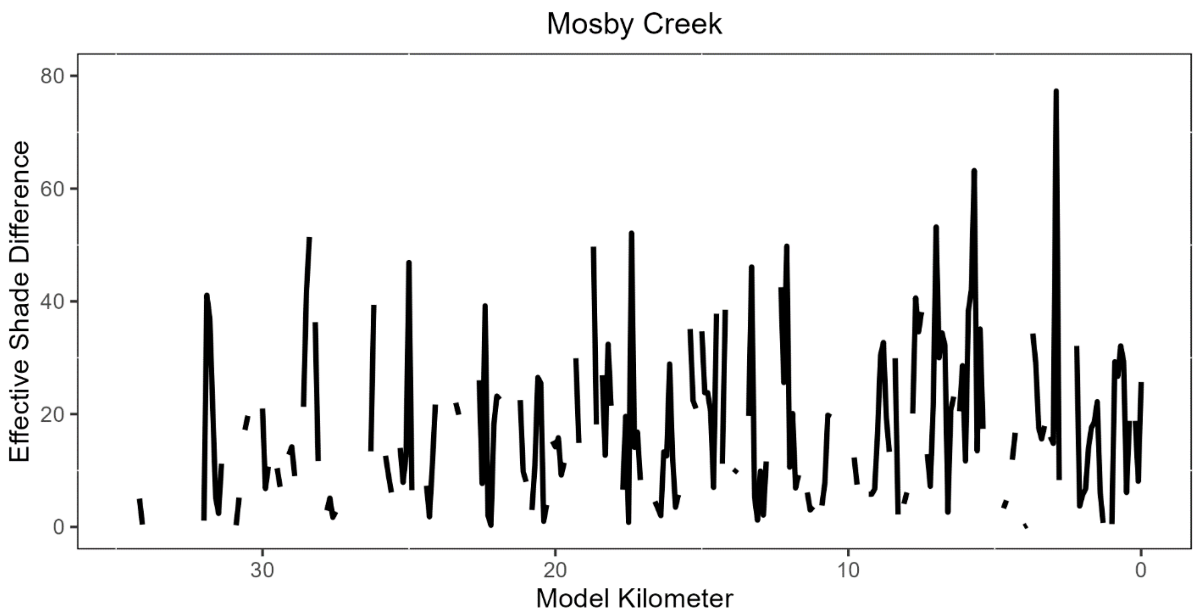


Figure 4-83: Percentage point difference between effective shade from the Current Condition and Restored Vegetation scenarios on 7/21/2002 for Mosby Creek. Missing values indicate that the shade difference is negative due to instances of higher effective shade in the Current Condition scenario versus the Restored Vegetation scenario.

4.13 Southern Willamette shade

Table 4-60 describes the different model scenarios used to simulate effective shade for the Southern Willamette.

Table 4-60: Southern Willamette shade model scenario descriptions.

Scenario Name	Description
Current Condition	Effective shade response to conditions on August 14, 2015.
Restored Vegetation	Near stream land cover assumed at site potential conditions. Site potential conditions explained in detail below and in TSD Appendix C.

A Restored Vegetation scenario was run using the Southern Willamette effective shade model. The Restored Vegetation scenario represents the effective shade under site potential vegetation conditions and is the primary basis for the TMDL solar load allocation and effective shade surrogate measure target. The site potential vegetation described in the TSD Appendix C is the type and mix of vegetation that is assumed to be restored in any given location and is the basis for the TMDL effective shade targets. The type, height, and density of site potential vegetation at any given location is primarily based upon on the Quaternary geologic mapping unit and the relative mix of forest, savanna, and prairie within that mapping unit.

In order to model the site potential effective shade targets across the project area, the appropriate type of site potential vegetation needed to be spatially mapped. To complete this task, python scripts were developed to process a raster layer of the Quaternary geologic geomorphic units and distribute forest, savanna, and prairie landcover types across the landscape following the process laid out in the TSD Appendix C. Two modifications to the approach needed to be made for the Southern Willamette project. Both modifications relate to the two land cover classes for water: open water and general water.

General water includes natural river channels, lakes, ponds, or wetland areas. Under the site potential vegetation scenario these features remained categorized as water. The 2006 effort mapped these areas using aerial photos and digitized them into a landcover feature class only for the streams that were modeled. The landcover class code used for general water was 3011. For this project, general water features needed to be mapped across the entire study area. The National Wetland Inventory (NWI) (USFWS, 2004) and the National Hydrography Dataset high resolution v2.2 databases contain extensive inventories of water features. These features were incorporated into the geomorphic raster. The assumption is that these spatial data features accurately capture most large river channels, lakes, ponds, or wetland areas that would be classified as “general water”.

The NWI’s classification system (FGDC, 2013) allowed the removal of most anthropogenic related water areas such as impounded reservoirs and gravel mining ponds. Waters classified as Lacustrine (L), Palustrine (P), Marine (M), or Estuarine (E) that are not forested (FO), scrub/shrub (SS), diked/impounded (h), a spoil (s), or excavated (x) were coded as general water. Forested and scrub/shrub classes were removed because they have emergent or overhanging vegetation. The NHD channel areas were used to map the riverine reaches because in some areas it was a little more accurate than NWI where the channel has migrated in recent years, mostly in portions of the Willamette River.

Open water (code 2000) are areas representing the ACOE reservoirs within the boundaries of the original geomorphic feature class and other anthropogenic related water areas that did not meet the criteria for general water. Under the classification rules for site potential vegetation these areas were treated as prairie or savanna vegetation types. In the upland forest zone impounded reservoirs were not mapped but were classified as upland forest (code 1900). The intent was that these site potential vegetation types would be present along the natural unimpounded channel (rather than present in the river channel). The reservoir areas were not modeled so no effort was made to map the location of the water channel in a natural (unimpounded) scenario.

Mapping the natural channel within impoundments requires additional analysis and attention and is beyond the scope of this project. Therefore, impounded lakes and reservoirs and areas classified as open waters in the geomorphic layer will be treated the same as general water (no change). Just as was done in other scenarios, stream nodes in these areas were removed from the analysis and excluded when calculating watershed effective shade.

Once the mapping of site potential vegetation was completed, the vegetation classification raster was resampled with TTools and input into the model. The effective shade results reflect the TMDL effective shade target for that location. Model results on streams outside of the Willamette Subbasins project area were removed and not included in the results summary.

Results were summarized as the effective shade gap. The effective shade gap is the percentage point difference between the TMDL restored vegetation effective shade (TMDL surrogate measure target) and the current condition shade assessed from LiDAR. Larger numbers indicate greater lack of shade.

4.13.1 Restored Vegetation

The mean shade gap over the entire study area is summarized in **Table 4-61**. The mean shade gap for each HUC12 subwatershed is presented in **Figure 4-84**. Results were also stratified by HUC8 subbasins, HUC10 watersheds, DMA, DEQ assessment unit ID, and by the Oregon Department of Agriculture (ODA)’s water quality management areas. These results are reported in more detail in TSD Appendix E.

Table 4-61: Southern Willamette effective shade results summarized as a mean over the entire model extent.

Mean Current Condition Effective Shade (%)	Mean Restored Vegetation Effective Shade (%)	Mean Effective Shade Gap (%)	Total Stream Kilometers Assessed	Stream Kilometers with 0%-15% Shade Gap	Stream Kilometers with 16%-25% Shade Gap	Stream Kilometers with 26%-50% Shade Gap	Stream Kilometers with 51%-100% Shade Gap
65	93	28	21,410.1	11,348.6	1627.8	2624.1	5809.6

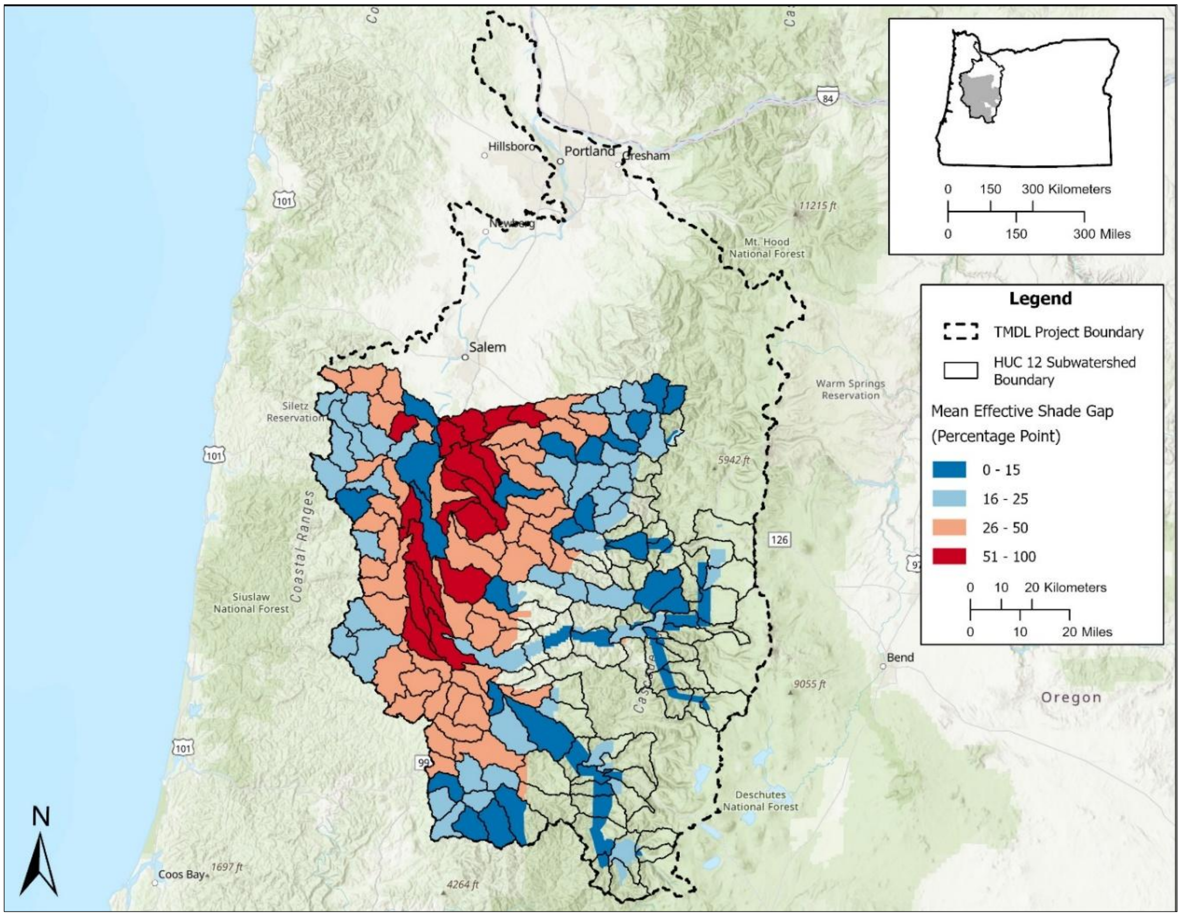


Figure 4-84: Mean effective shade gap for each HUC12 subwatershed within the Southern Willamette Shade model extent.

The results of the modeling summarized in TSD Appendix E indicate that agricultural areas regulated by ODA have the largest number of assessed stream nodes (2825.1 km out of 4790.6 total assessed kilometers) with mean shade gaps exceeding 50 percentage points. Private non-federal forestlands regulated by the Oregon Department of Forestry (ODF) have the second largest number of assessed stream nodes with shade gaps exceeding 50 percentage points (1966.7 km out of 8597.7 total assessed kilometers). The ODA and ODF also have the largest number of stream kilometers with large shade gaps relative to other DMAs.

In general, cities have fewer stream miles in their jurisdiction but have a higher proportion of shade gaps that exceed 50 percentage points. For example, all the stream nodes assessed in the cities of Halsey and Harrisburg (1.6 and 0.8 stream kilometers, respectively) have shade gaps greater than 50 percentage points.

On the opposite end of the spectrum, the federal forestlands managed by the Bureau of Land Management only have 2.6 percent of the assessed stream nodes (66.6 km out of 2569.5 total assessed kilometers) with shade gaps exceeding 50 percentage points. BLM had the fourth highest number of assessed stream nodes. Most of the federal forestlands managed by the USFS were not evaluated because of the lack of LiDAR.

The Muddy Creek-Willamette River Watershed (1709000306) had the largest number of assessed stream nodes (827 km out of 1397.9 total assessed kilometers), with effective shade gaps exceeding 50 percentage points.

4.14 Lower Willamette shade

Table 4-62 describes the different model scenarios used to simulate effective shade for the Lower Willamette. These models were developed by City of Portland Staff. See TSD Appendix B for detailed information regarding analysis and results.

Mean effective shade percentages for each of the modeled scenarios are summarized in **Table 4-63**. The mean shade gap for each HUC12 subwatershed is presented in **Figure 4-85**.

Results were also stratified by HUC8 subbasins, HUC10 watersheds, DMA, DEQ assessment unit ID, and by ODA's water quality management areas. These results are reported in more detail in TSD Appendix F.

Table 4-62: Lower Willamette shade model scenario descriptions.

Scenario Name	Description
Current Condition	Effective shade response to conditions in 2019.
Restored Vegetation	Near stream land cover assumed at site potential conditions. Site potential conditions explained in detail below, and in TSD Appendix B.
Protected Vegetation	Near stream land cover within areas protected by existing policies or regulations assumed at site potential conditions. Vegetation outside or protected areas is set to zero.
System Potential in Management Areas	Near stream land cover within areas protected by existing policies or regulations assumed at site potential conditions. Vegetation outside or protected areas is set to current condition.
Topography	Effective shade response to topography conditions with no vegetation. Represents existing topographic conditions in 2019.

Table 4-63: Lower Willamette effective shade results summarized as a mean over the entire model extent for all model scenarios.

Mean Current Condition Effective Shade (%)	Mean Protected Vegetation Effective Shade (%)	Mean Restored Vegetation Effective Shade (%)	Mean System Potential in Management Areas Effective Shade (%)	Mean Topography Effective Shade (%)
64	62	77	75	8

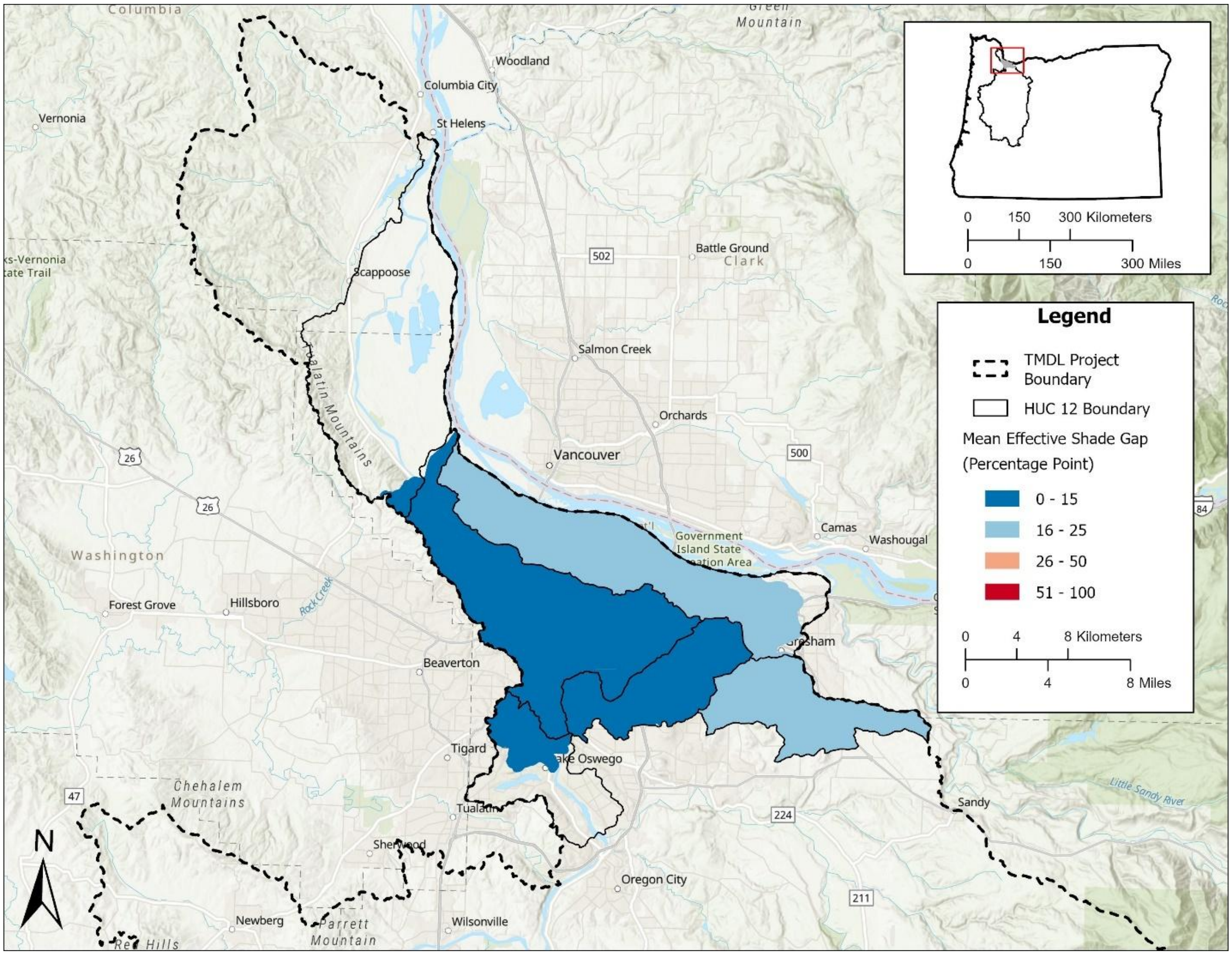


Figure 4-85: Mean effective shade gap between the Current Condition and Restored Vegetation model scenarios for each HUC12 subwatershed within the Lower Willamette shade model extent.

4.14.1 Restored Vegetation

The mean effective shade results over the entire study area for the Current Condition and Restored Vegetation scenarios are summarized in **Table 4-64**. The mean effective shade gap between Current Conditions and Restored Vegetation scenarios is 13 percentage points, with values ranging from 0% to 33%.

Table 4-64: Lower Willamette effective shade results summarized as a mean over the entire model extent for the Current Condition and Restored Vegetation scenarios.

Mean Current Condition Effective Shade (%)	Mean Restored Vegetation Effective Shade (%)	Mean Shade Gap (%)	Total Stream Kilometers Assessed	Stream Kilometers with 0%-15% Shade Gap	Stream Kilometers with 16%-25% Shade Gap	Stream Kilometers with 26%-50% Shade Gap	Stream Kilometers with 51%-100% Shade Gap
64	77	13	201.5	141.5	22.2	26	11.8

Mean effective shade results stratified by DMA, stream, assessment unit and watershed can be found in TSD Appendix F. In general, cities have relatively fewer stream kilometers assessed, but have a high proportion of shade gaps exceeding 50 percentage points. For example, the City of Fairview has the highest mean effective shade gap (33 percentage points) of all the DMAs in the model extent yet had only 0.1 total stream kilometers assessed. Clackamas County and ODA also had relatively large mean effective shade gaps (20 percentage points each) with 13.3 and 13.5 total stream kilometers assessed, respectively.

Of all the DMAs present in the model extent, the City of Portland had the largest number of stream kilometers with mean effective shade gaps exceeding 50 percentage points, followed by Clackamas County and ODA. At the HUC12 level, the Upper Johnson Creek subwatershed (170900120101) had the largest mean effective shade gap of 18 percentage points.

4.14.2 Protected Vegetation

The mean effective shade results over the entire study area for the Protected Vegetation and Restored Vegetation scenarios are summarized in **Table 4-65**. The mean effective shade gap between Protected Vegetation and Restored Vegetation scenarios is 15 percentage points, with values ranging from 0% to 78%.

Table 4-65: Lower Willamette effective shade results summarized as a mean over the entire model extent for the Restored Vegetation and Protected Vegetation scenarios.

Mean Protected Vegetation Effective Shade (%)	Mean Restored Vegetation Effective Shade (%)	Mean Shade Gap (%)	Total Stream Kilometers Assessed	Stream Kilometers with 0%-15% Shade Gap	Stream Kilometers with 16%-25% Shade Gap	Stream Kilometers with 26%-50% Shade Gap	Stream Kilometers with 51%-100% Shade Gap
62	77	15	201.5	137.8	21.5	25.1	17

Mean effective shade results stratified by DMA, stream, assessment unit and watershed can be found in TSD Appendix F. In general, a few DMAs experienced an increase in effective shade gaps when vegetation outside of protected areas was set to zero. The City of Fairview increased from a mean effective shade gap of 33 percentage points to a mean effective shade gap of 50 percentage points. In addition, roads went from a mean effective shade gap of 23 percentage points to a mean effective shade gap of 31 percentage points.

The City of Portland had the largest number of stream kilometers with effective shade gaps exceeding 50 percentage points, followed by ODA.

4.15 Willamette River and major tributaries

Table 4-66 describes the different model scenarios used to simulate effective shade in the Willamette River and major tributaries project area.

Table 4-66: Model scenario descriptions for the Willamette River and major tributaries.

Scenario Name	Description
Current Condition	Effective shade response to conditions on: • August 1, 2001 (Willamette River, Clackamas River, Coast Fork Willamette River, Long Tom River, North Santiam River, Santiam River, South Santiam River) • July 1, 2002 (Row River) • July 2, 2002 (Middle Fork Willamette River) • July 3, 2002 (Fall Creek)
Restored Vegetation	Near stream land cover assumed at site potential conditions. Site potential conditions explained in detail in TSD Appendix C.

4.15.1 Restored Vegetation

The restored vegetation scenario represents the effective shade under site potential vegetation conditions and is the primary basis for the TMDL solar load allocation and effective shade surrogate measure target. The type, height, and density of site potential vegetation at any given location is primarily based upon on the Quaternary geologic mapping unit and the relative mix of forest, savanna, and prairie within that mapping unit discussed in detail in TSD Appendix C.

Table 4-67 summarizes the current assessed effective shade, the TMDL effective shade targets, and the resulting shade gaps for each river in the Willamette River and major tributaries. Shade results were also combined with results from other rivers summarized by DMA (see TMDL Section 9.1.5.2).

Figure 4-86 through **Figure 4-105** compare effective shade predictions from the Current Condition and Restored Vegetation scenarios for the Willamette River and major tributaries.

Table 4-67: Site specific effective shade surrogate measure targets to meet nonpoint source load allocations for the Willamette River and major tributaries.

Model River	Total Kilometers Assessed	Assessed Mean Effective Shade (%)	TMDL Target Mean Effective Shade (%)	Mean Effective Shade Gap (%)
Clackamas River	36.5	13	37	24
Coast Fork Willamette River	46.7	35	54	19
Fall Creek	11.5	29	47	18
Long Tom River	38.2	25	57	32
Middle Fork Willamette River	26.6	16	26	10
North Santiam River	79.6	19	34	15
Row River	12.2	24	54	30
Santiam River	19.5	11	19	8
South Santiam River	58.4	7	21	14
Willamette River	257.8	11	20	9

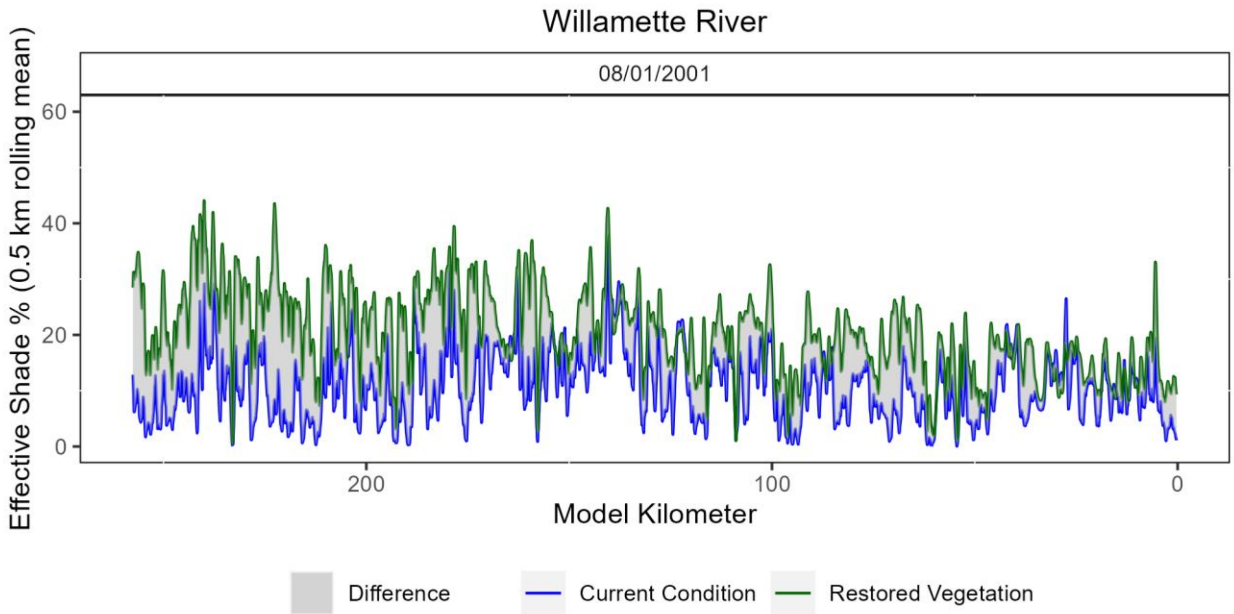


Figure 4-86: Comparison of half kilometer rolling mean effective shade from the Current Condition and Restored Vegetation scenarios for the Willamette River.

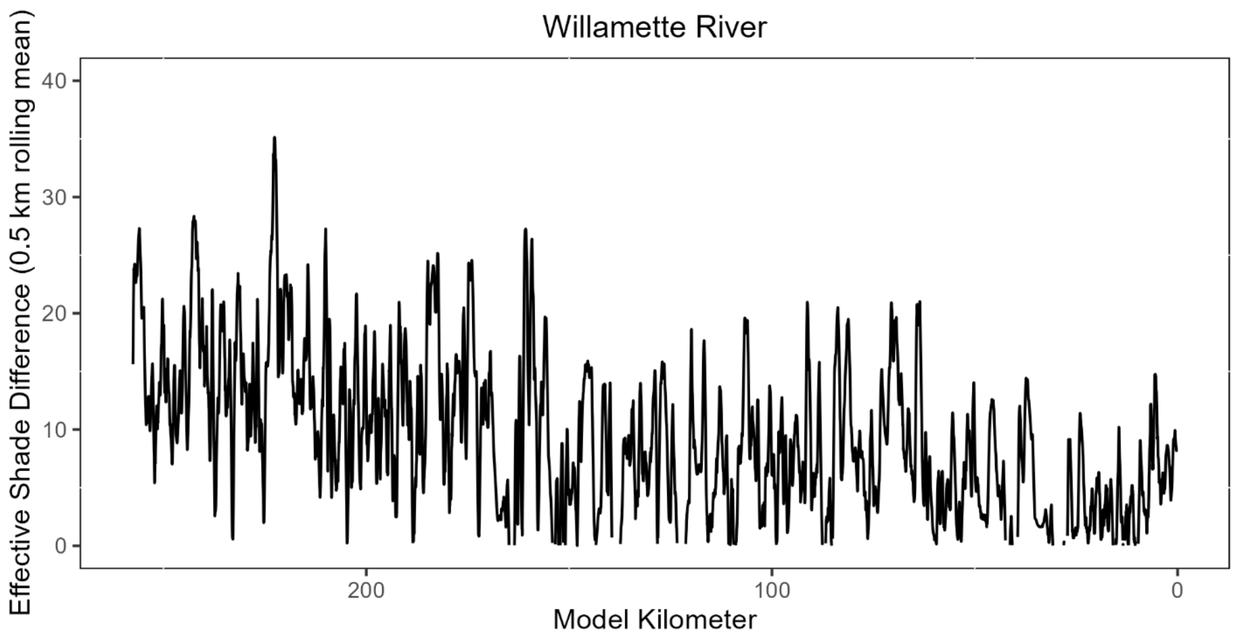


Figure 4-87: Percentage point difference between half kilometer rolling mean effective shade from the Current Condition and Restored Vegetation scenarios on 8/1/2001 for the Willamette River. Missing values indicate that the shade difference is negative due to instances of higher effective shade in the Current Condition scenario versus the Restored Vegetation scenario.

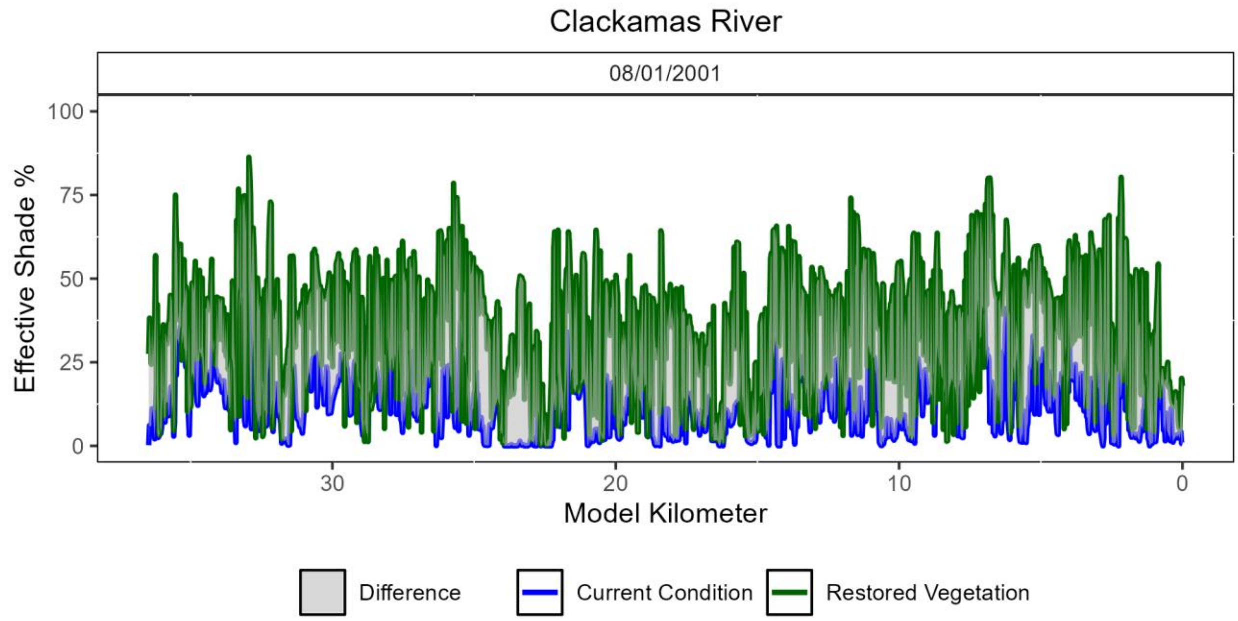


Figure 4-88: Comparison of effective shade from the Current Condition and Restored Vegetation scenarios for the Clackamas River.

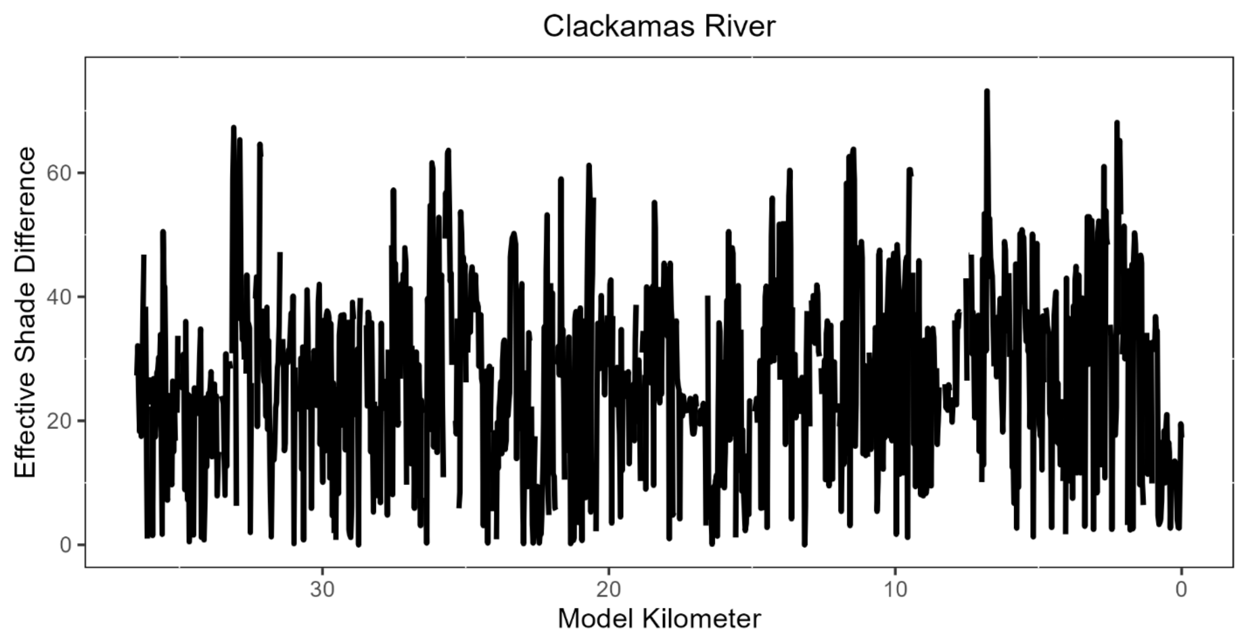


Figure 4-89: Percentage point difference between effective shade from the Current Condition and Restored Vegetation scenarios on 8/1/2001 for the Clackamas River. Missing values indicate that the shade difference is negative due to instances of higher effective shade in the Current Condition scenario versus the Restored Vegetation scenario.

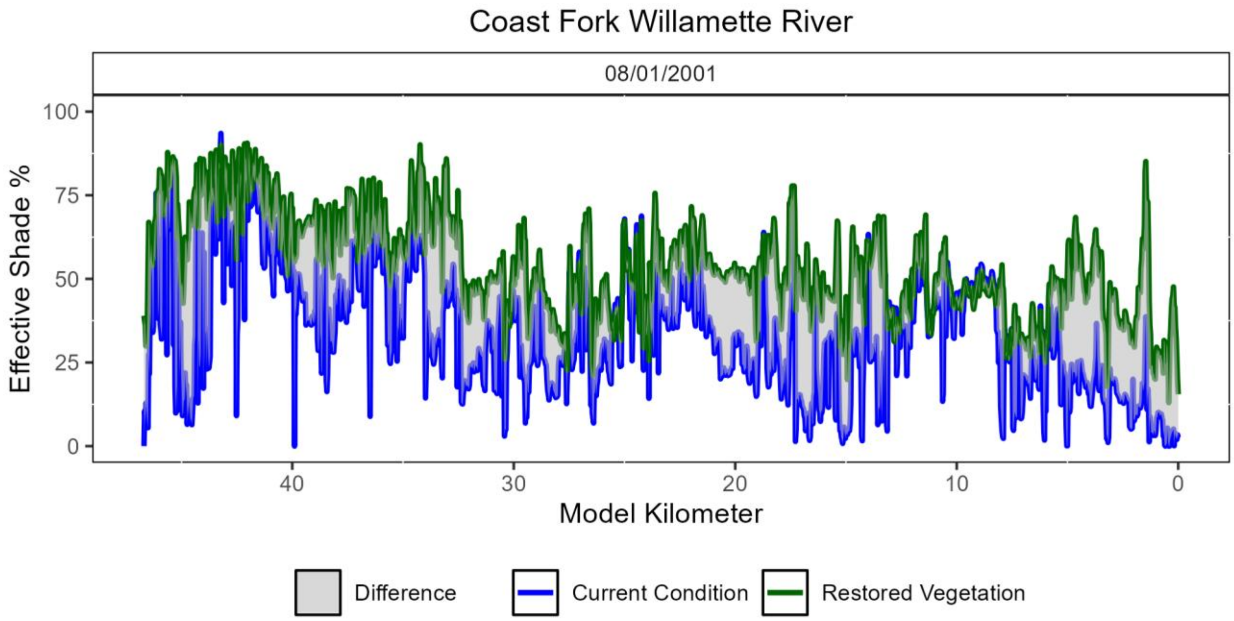


Figure 4-90: Comparison of effective shade from the Current Condition and Restored Vegetation scenarios for the Coast Fork Willamette River.

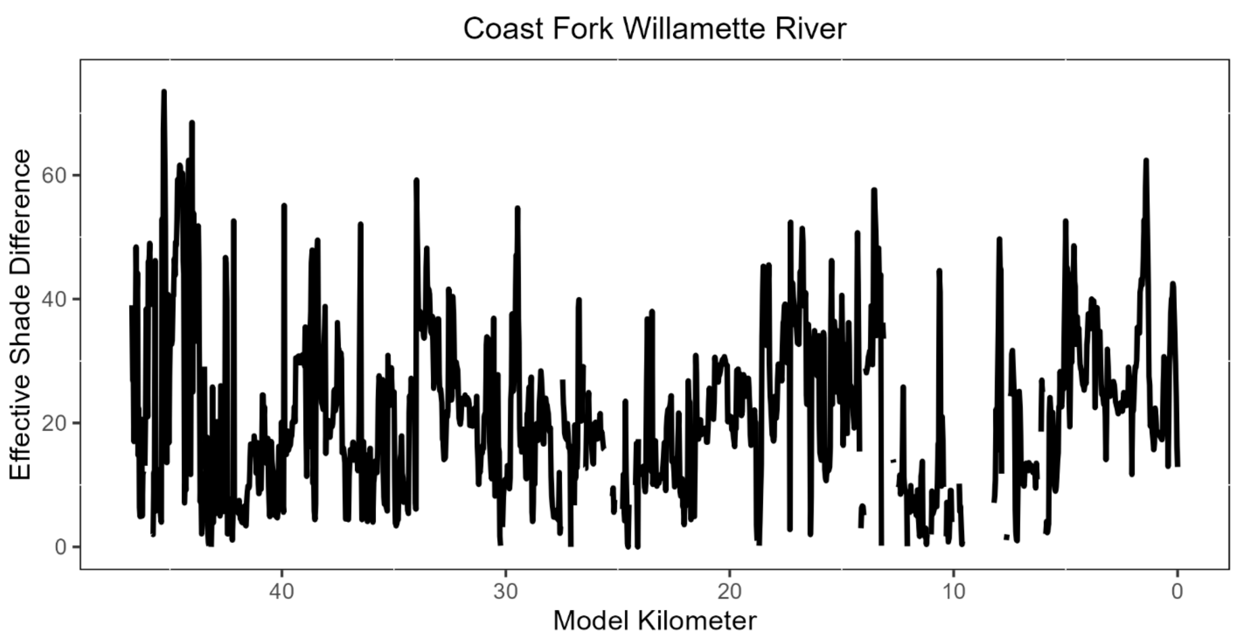


Figure 4-91: Percentage point difference between effective shade from the Current Condition and Restored Vegetation scenarios on 8/1/2001 for the Coast Fork Willamette River. Missing values indicate that the shade difference is negative due to instances of higher effective shade in the Current Condition scenario versus the Restored Vegetation scenario.

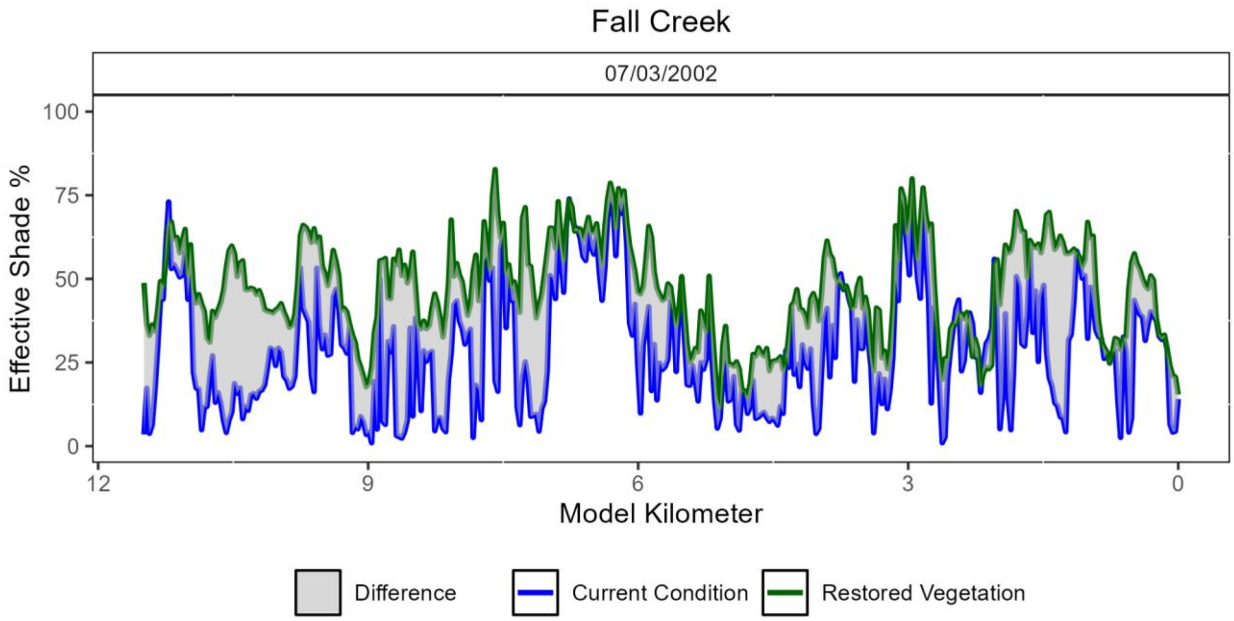


Figure 4-92: Comparison of effective shade from the Current Condition and Restored Vegetation scenarios for Fall Creek.

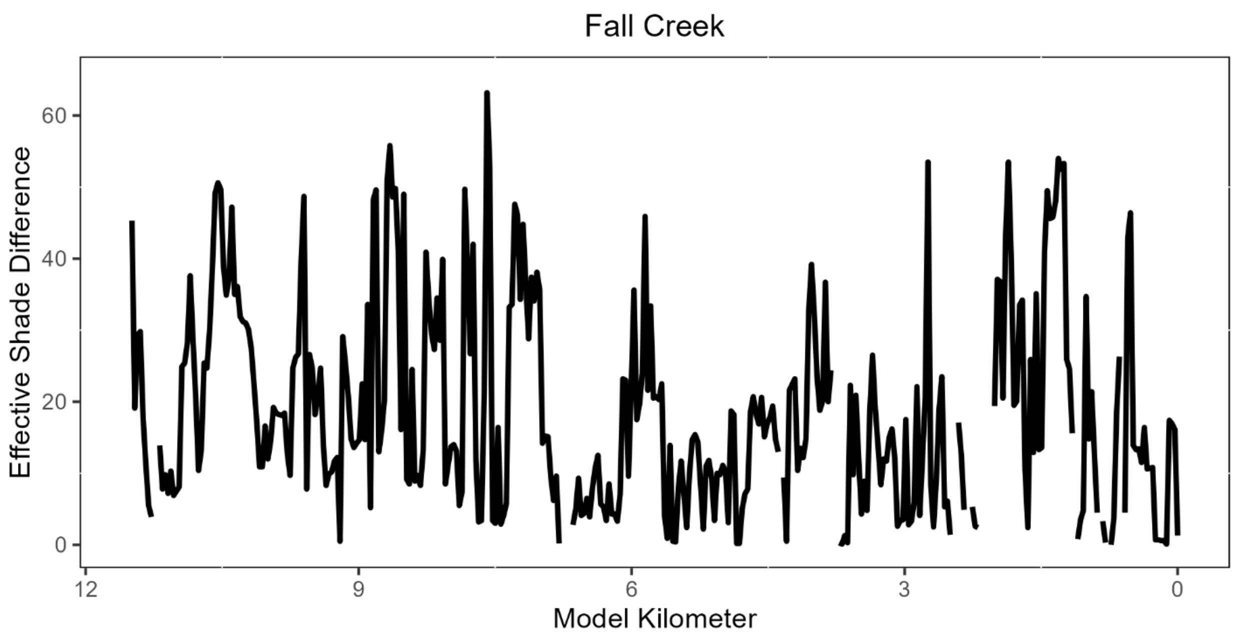


Figure 4-93: Percentage point difference between effective shade from the Current Condition and Restored Vegetation scenarios on 7/3/2002 for Fall Creek. Missing values indicate that the shade difference is negative due to instances of higher effective shade in the Current Condition scenario versus the Restored Vegetation scenario.

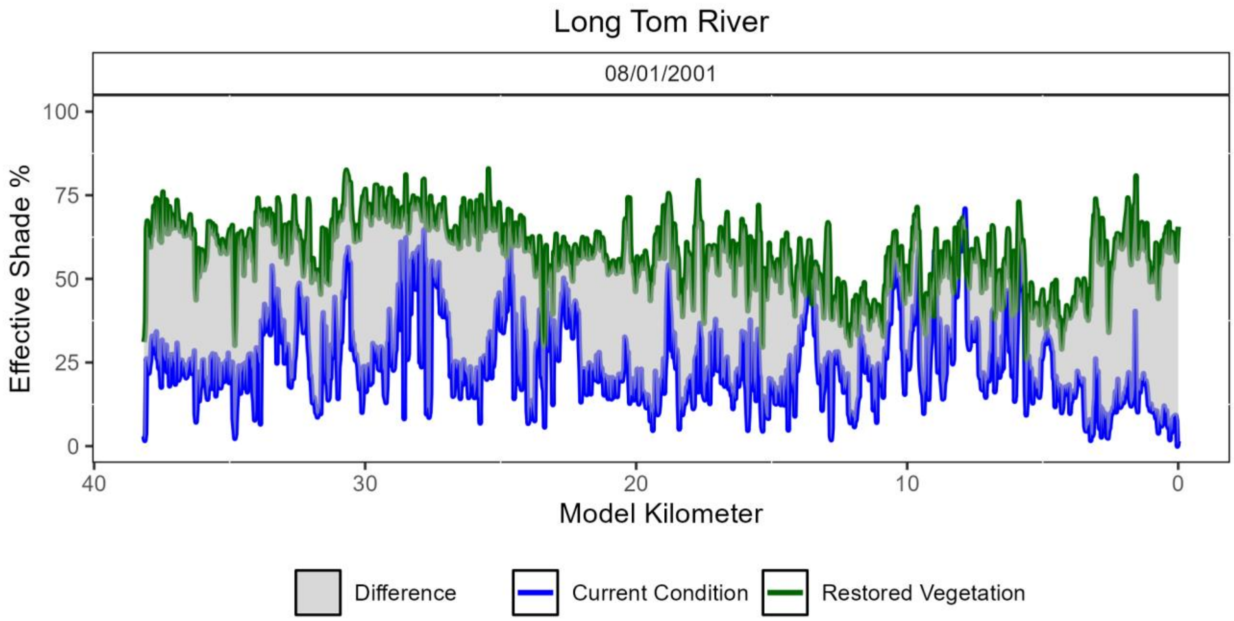


Figure 4-94: Comparison of effective shade from the Current Condition and Restored Vegetation scenarios for the Long Tom River.

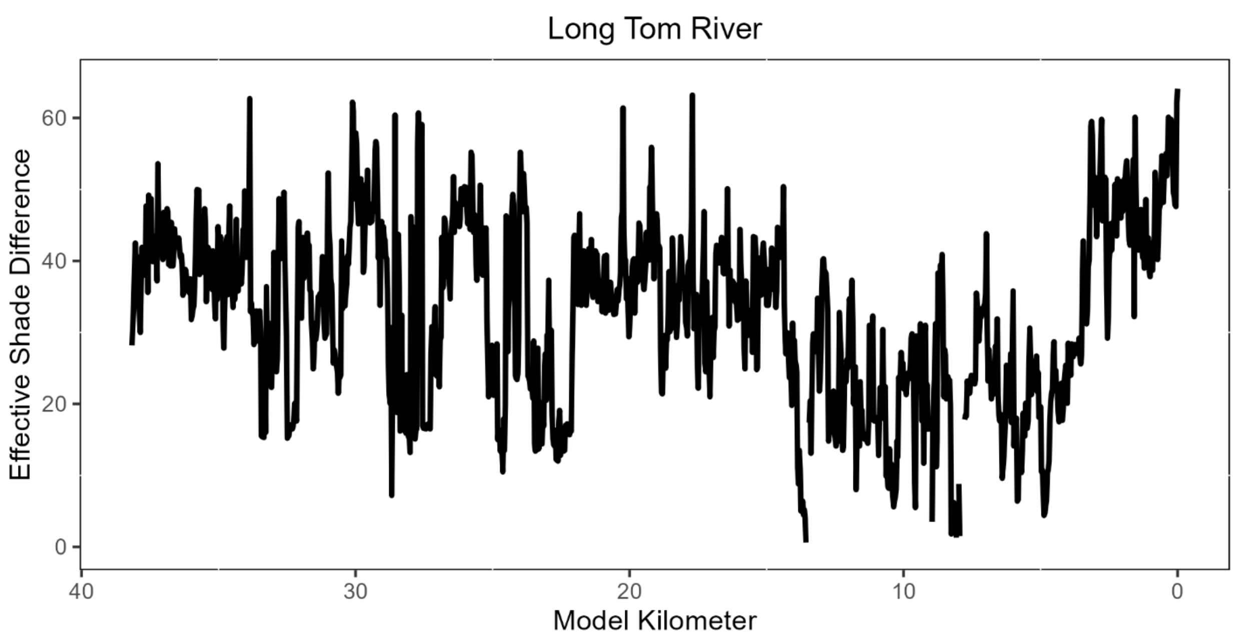


Figure 4-95: Percentage point difference between effective shade from the Current Condition and Restored Vegetation scenarios on 8/1/2001 for the Long Tom River. Missing values indicate that the shade difference is negative due to instances of higher effective shade in the Current Condition scenario versus the Restored Vegetation scenario.

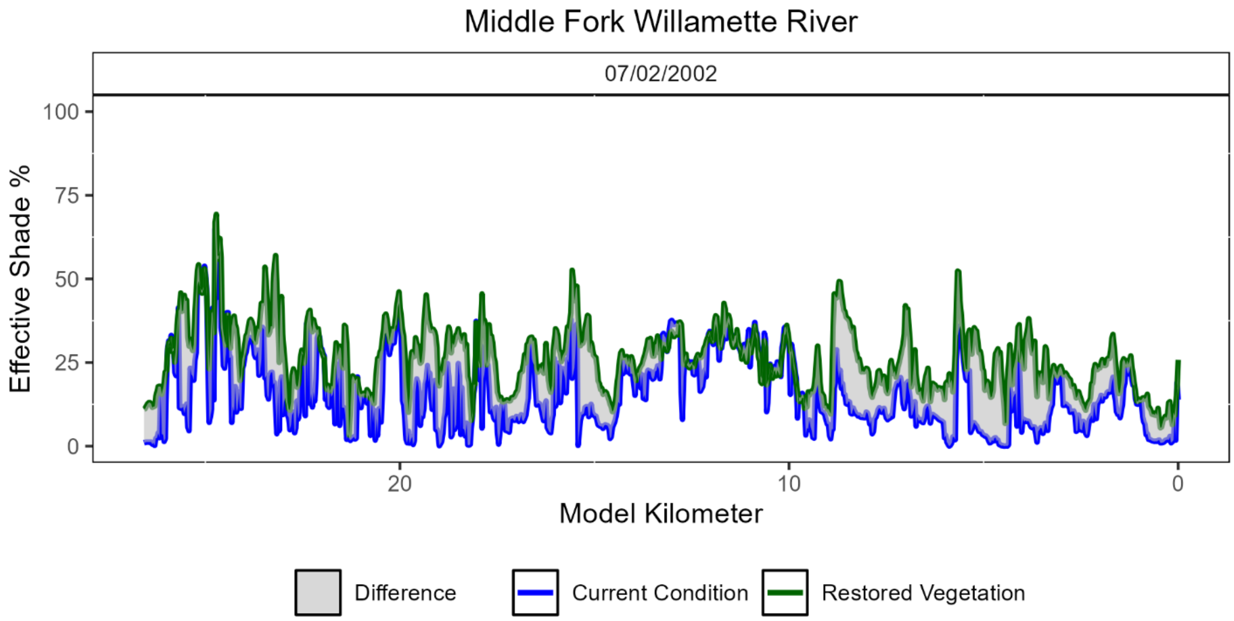


Figure 4-96: Comparison of effective shade from the Current Condition and Restored Vegetation scenarios for the Middle Fork Willamette River.

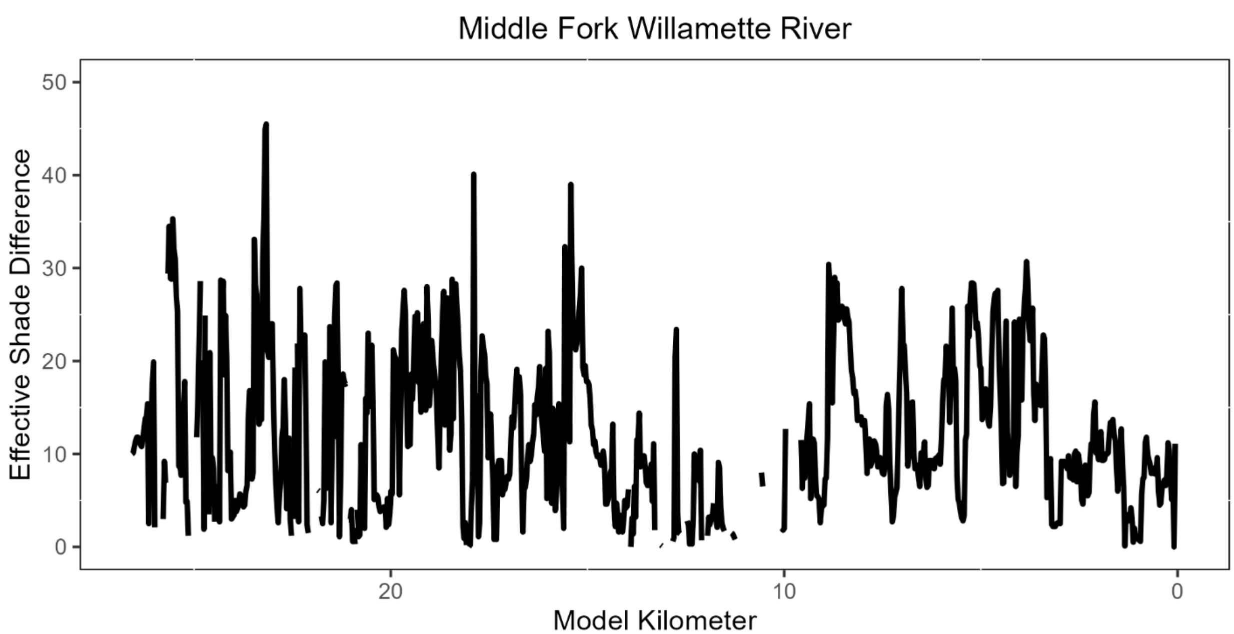


Figure 4-97: Percentage point difference between effective shade from the Current Condition and Restored Vegetation scenarios on 7/2/2002 for the Middle Fork Willamette River. Missing values indicate that the shade difference is negative due to instances of higher effective shade in the Current Condition scenario versus the Restored Vegetation scenario.

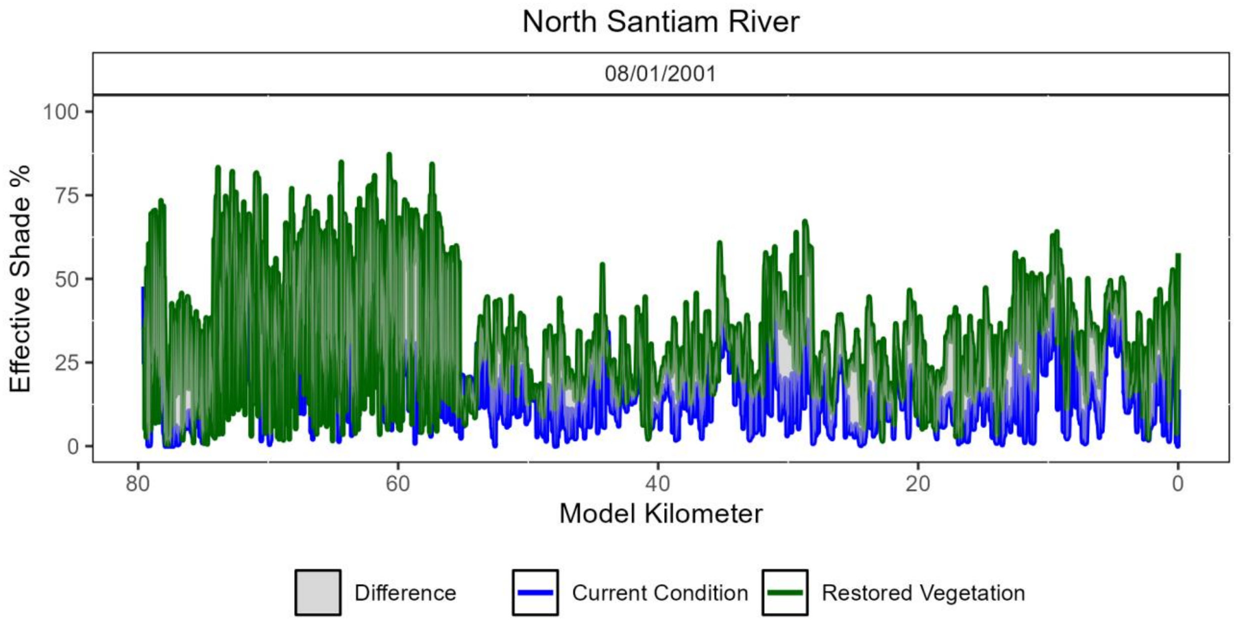


Figure 4-98: Comparison of effective shade from the Current Condition and Restored Vegetation scenarios for the North Santiam River.

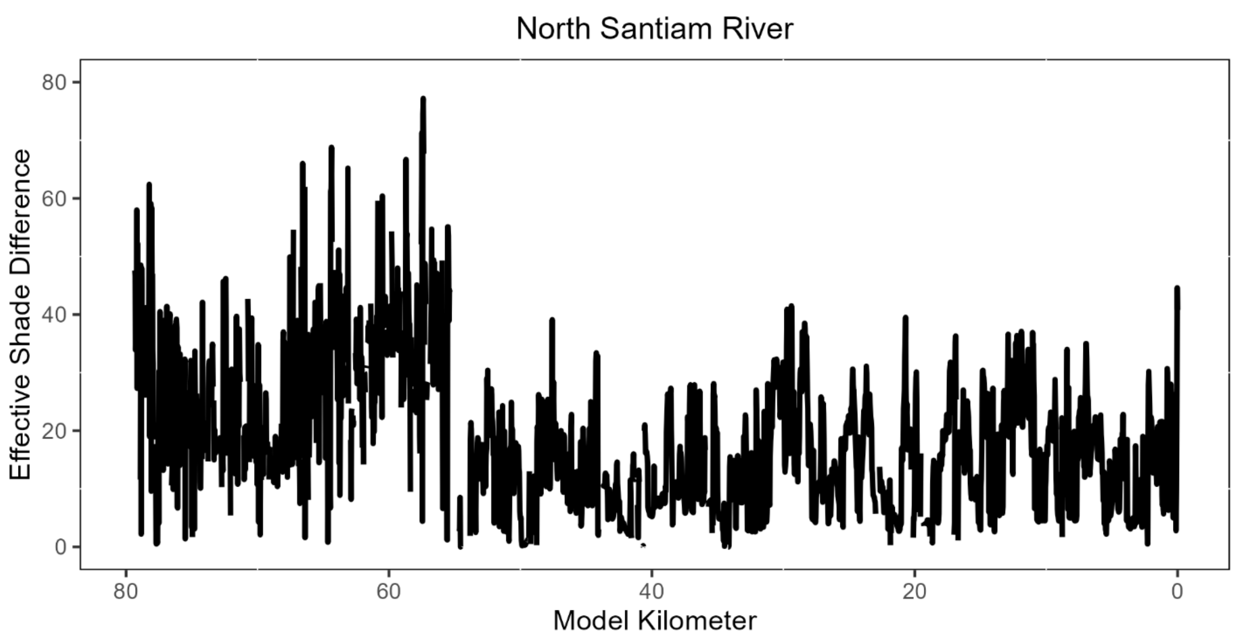


Figure 4-99: Percentage point difference between effective shade from the Current Condition and Restored Vegetation scenarios on 8/1/2001 for the North Santiam River. Missing values indicate that the shade difference is negative due to instances of higher effective shade in the Current Condition scenario versus the Restored Vegetation scenario.

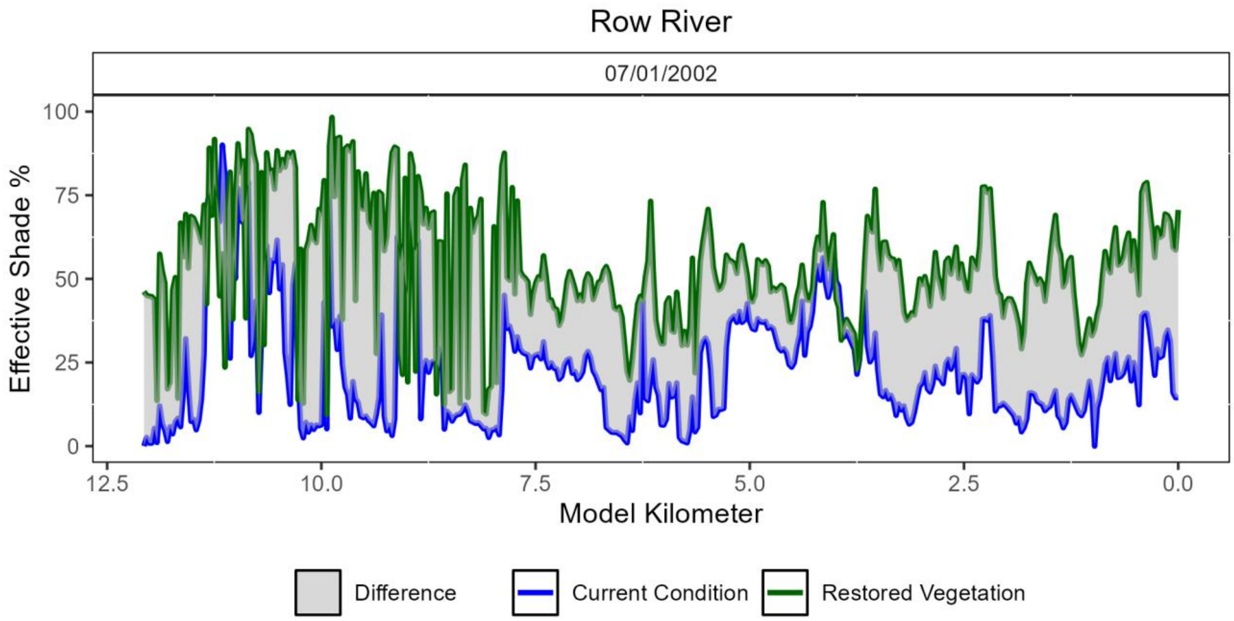


Figure 4-100: Comparison of effective shade from the Current Condition and Restored Vegetation scenarios for the Row River.

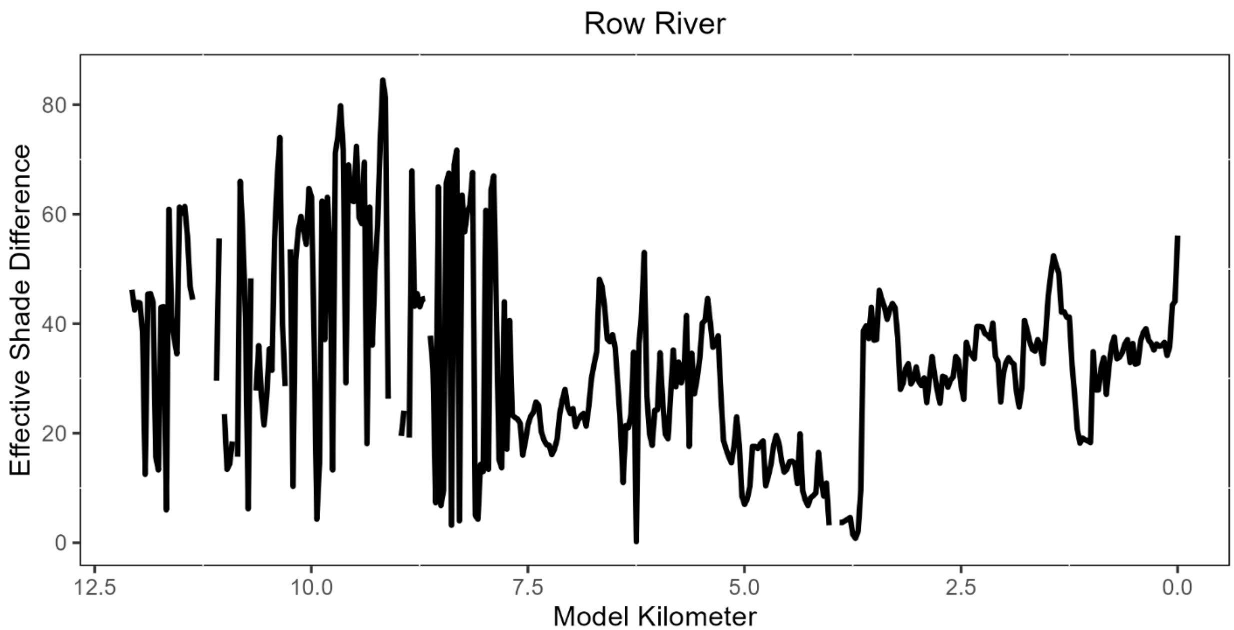


Figure 4-101: Percentage point difference between effective shade from the Current Condition and Restored Vegetation scenarios on 7/1/2002 for the Row River. Missing values indicate that the shade difference is negative due to instances of higher effective shade in the Current Condition scenario versus the Restored Vegetation scenario.

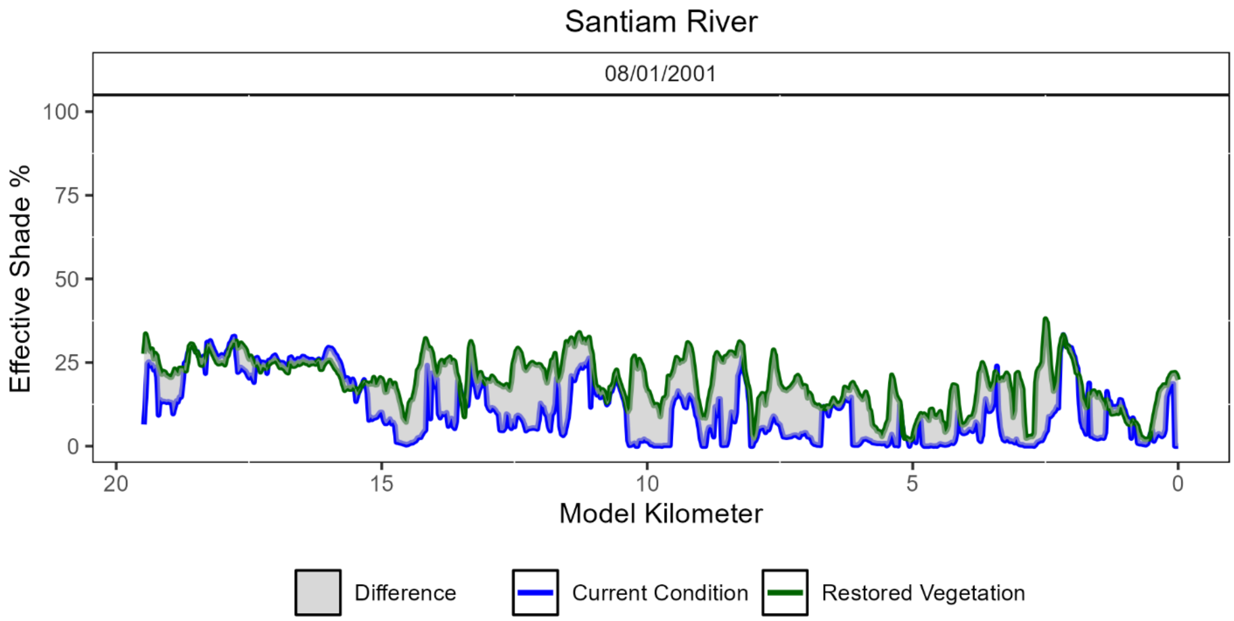


Figure 4-102: Comparison of effective shade from the Current Condition and Restored Vegetation scenarios for the Santiam River.

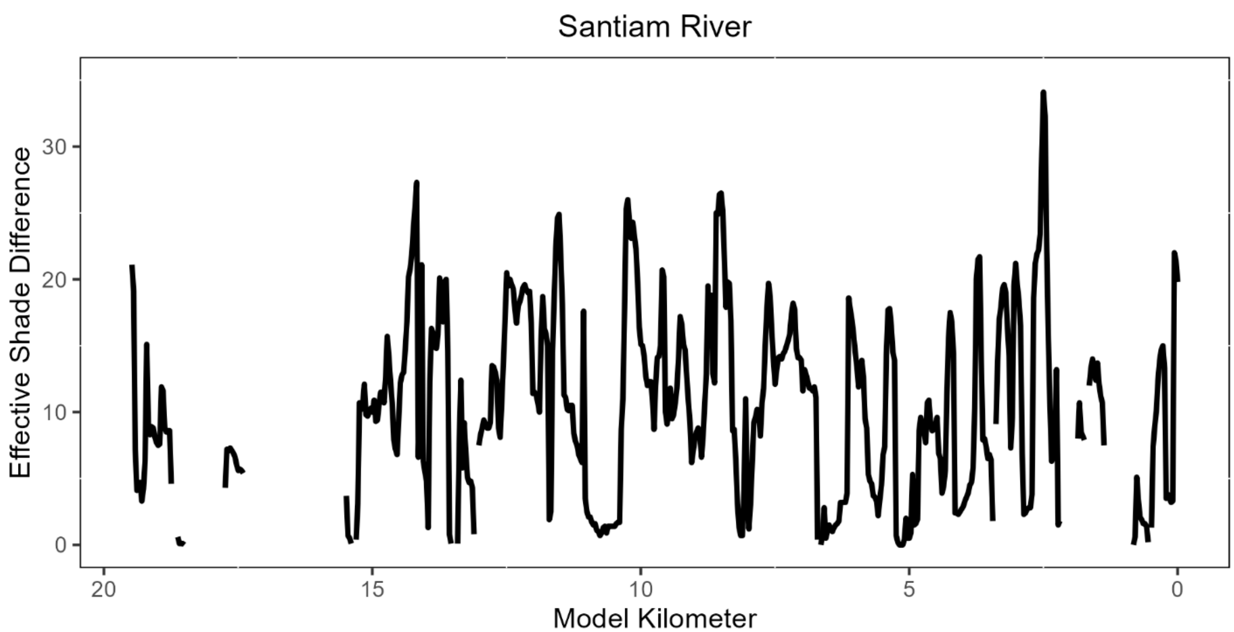


Figure 4-103: Percentage point difference between effective shade from the Current Condition and Restored Vegetation scenarios on 8/1/2001 for the Santiam River. Missing values indicate that the shade difference is negative due to instances of higher effective shade in the Current Condition scenario versus the Restored Vegetation scenario.

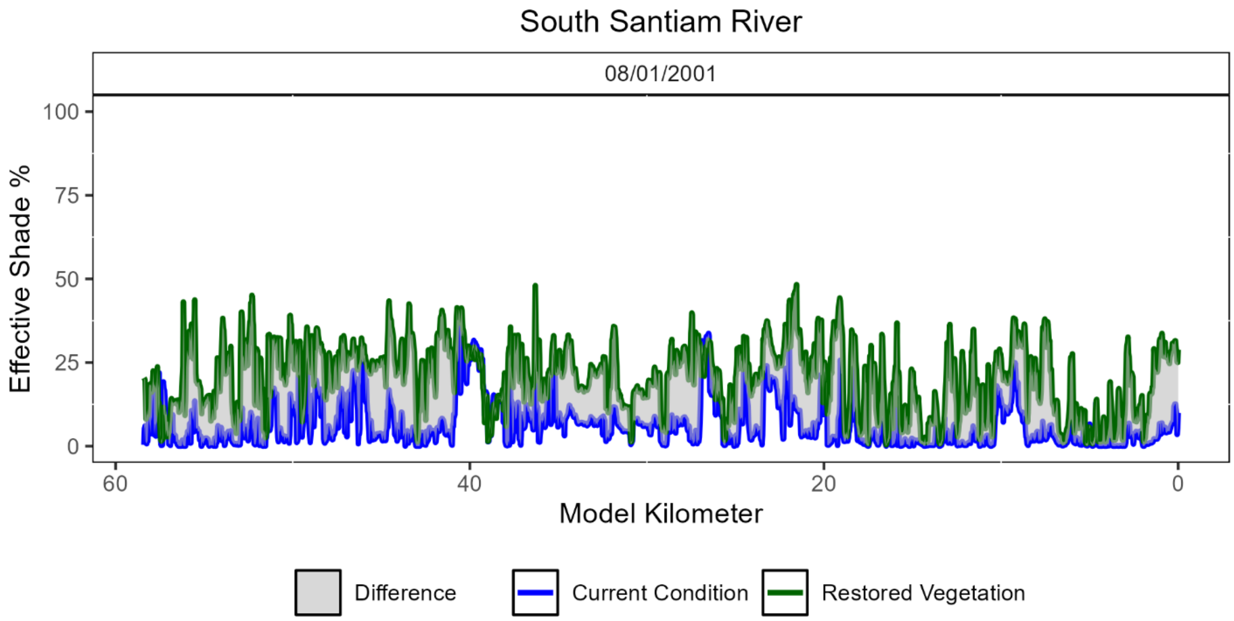


Figure 4-104: Comparison of effective shade from the Current Condition and Restored Vegetation scenarios for the South Santiam River.

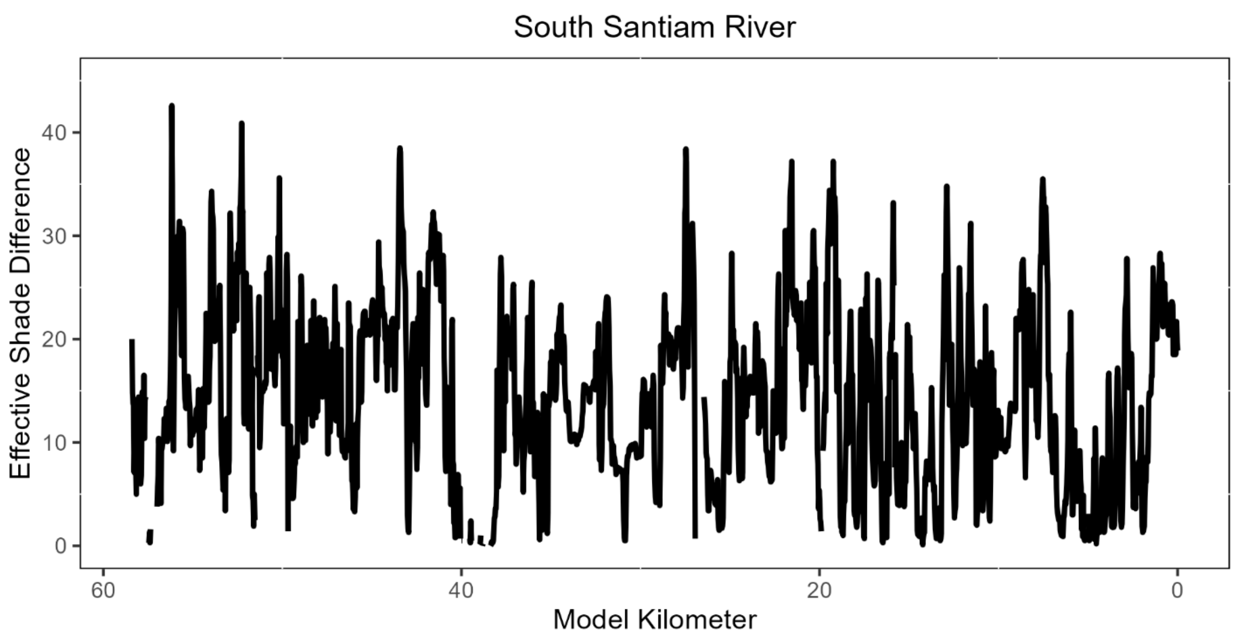


Figure 4-105: Percentage point difference between effective shade from the Current Condition and Restored Vegetation scenarios on 8/1/2001 for the South Santiam River. Missing values indicate that the shade difference is negative due to instances of higher effective shade in the Current Condition scenario versus the Restored Vegetation scenario.

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