



# Total Maximum Daily Loads for the Willamette Subbasins

## Technical Support Document Appendix A: Heat Source Model Report

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## 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                                       |
| 14211499               | Kelley Creek  | 45.4768  | -122.498  | USGS                                       |
| 28729-ORDEQ            | Johnson Creek at Revenue Road                         | 45.4617  | -122.337  | DEQ  |

| Monitoring Location ID | Monitoring Location Name                             | Latitude | Longitude | Source |
|------------------------|--|----------|-----------|--------|
| 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 72 <sup>nd</sup> 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         |
| 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         |

| Monitoring Location ID | Monitoring Location Name         | Latitude | Longitude | Source      |
|------------------------|----------------------------------|----------|-----------|-------------|
| 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    |
| 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 1 <sup>st</sup> 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    |

| Monitoring Location ID | Monitoring Location Name   | Latitude | Longitude | Source |
|------------------------|--|----------|-----------|--------|
| 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    |
| 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    |

| Monitoring Location ID | Monitoring Location Name | Latitude | Longitude | Source |
|------------------------|--------------------------|----------|-----------|--------|
| 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    |
| 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 122 <sup>nd</sup> (Portland)                  | 45.4737  | -122.536  | 7/30/2002 | 2.08/0.06      |
| 11326-ORDEQ            | Johnson Creek at Pleasant View / 190 <sup>th</sup> 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 327 <sup>th</sup> Avenue                      | 45.4605  | -122.326  | 7/29/2002 | 0.42/0.01      |

| Monitoring Location ID | Monitoring Location Name                             | Latitude | Longitude | Date      | Flow (cfs/cms) |
|------------------------|--|----------|-----------|-----------|----------------|
| 28729-ORDEQ            | Johnson Creek at Revenue Road                        | 45.4617  | -122.337  | 7/29/2002 | 1.01/0.03      |
| 28732-ORDEQ            | Johnson Creek at SE 72 <sup>nd</sup> 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      |

| Monitoring Location ID | Monitoring Location Name  | Latitude | Longitude | Date      | Flow (cfs/cms) |
|------------------------|---|----------|-----------|-----------|----------------|
| 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      |
| 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 | Longitude | 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            | Latitude | Longitude | 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 | Longitude | 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     |

| Monitoring Location ID | Monitoring Location Name                                      | Latitude | Longitude | Date      | Flow (cfs/cms) |
|------------------------|---|----------|-----------|-----------|----------------|
| 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     |
| 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     |

| Monitoring Location ID | Monitoring Location Name                             | Latitude | Longitude | Date      | Flow (cfs/cms) |
|------------------------|--|----------|-----------|-----------|----------------|
| 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        |
| 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   |

| Monitoring Location ID | Monitoring Location Name     | Latitude | Longitude | Source |
|------------------------|------------------------------|----------|-----------|--------|
| 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       |

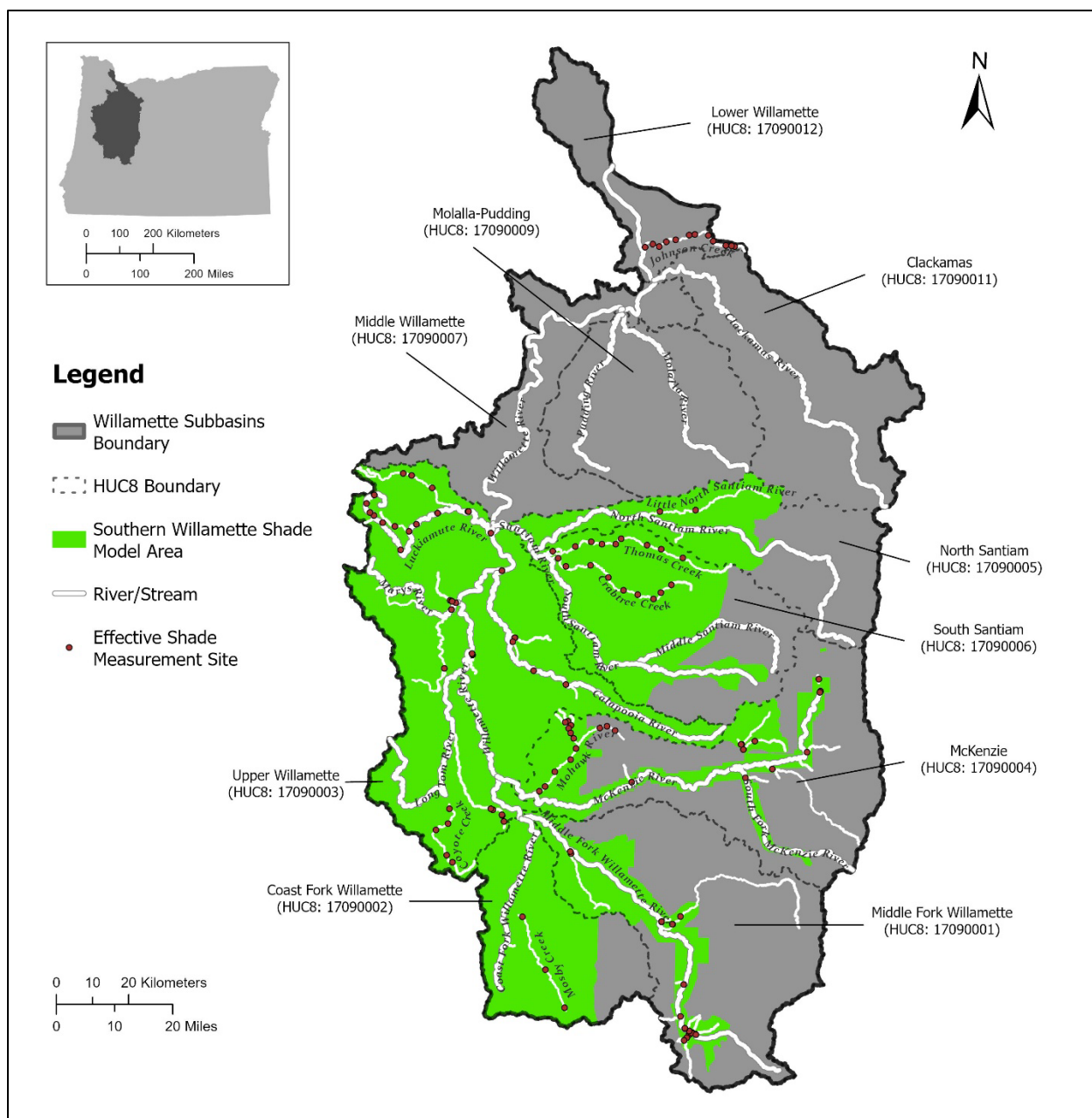
\*Date model was run.

### 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    |

| Monitoring Location Name                          | Latitude | Longitude | Effective Shade (%) | Source |
|---|----------|-----------|---------------------|--------|
| 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    |

| Monitoring Location Name  | Latitude | Longitude | Effective Shade (%) | Source |
|---|----------|-----------|---------------------|--------|
| 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    |
| 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 at <https://www.oregongeology.org/lidar>. 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**.

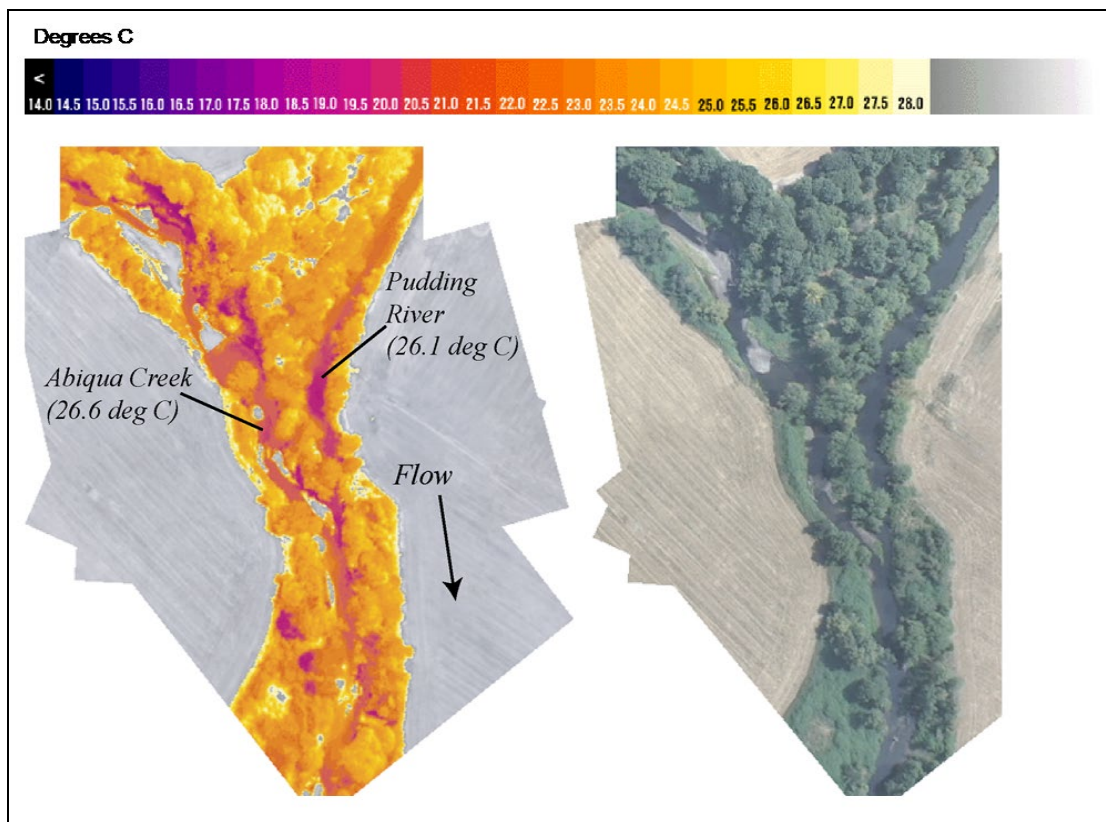


Figure 2-2: TIR/color video image pair showing Pudding River and Abiqua Creek temperatures on August 11, 2004.

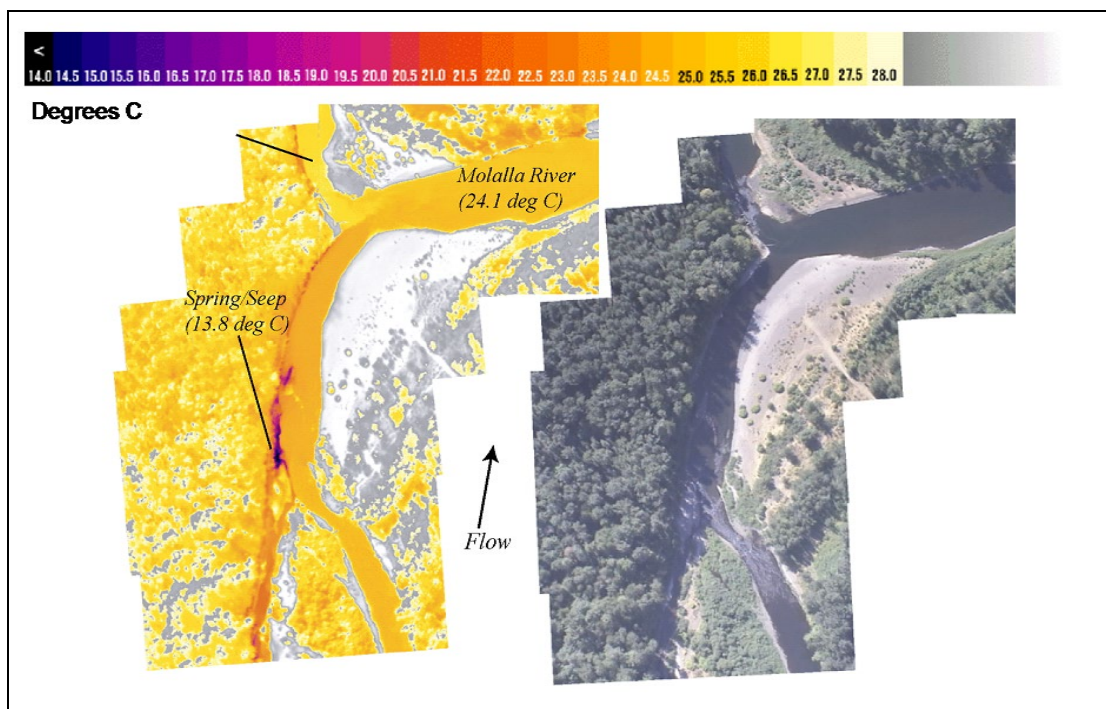


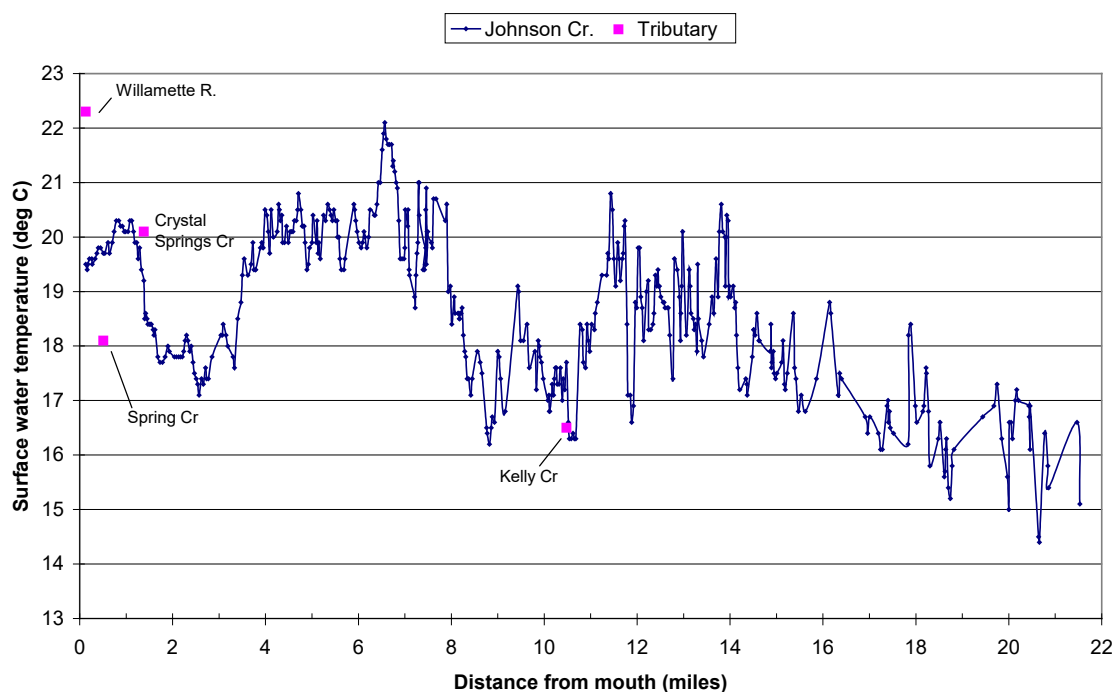
Figure 2-3: TIR/color video image pair showing the location of a spring or seep near the confluence of the Molalla and Pudding Rivers, July 26, 2004.

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

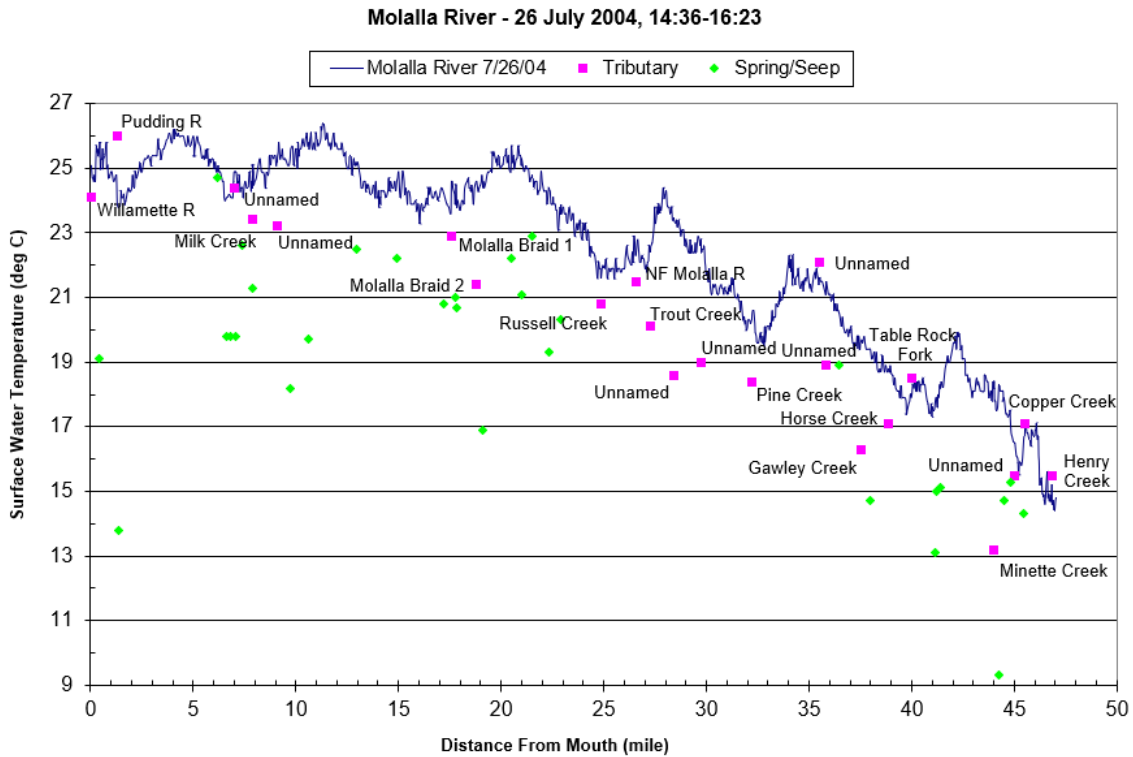
| <b>Stream</b>                                       | <b>Survey Extent</b>  | <b>Survey Date</b> | <b>Time</b> | <b>Survey Distance (mi)</b> |
|---|---|--------------------|-------------|-----------------------------|
| Johnson Creek                                       | Mouth to headwaters   | 7/31/2002          | 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                         |

| Stream                    | Survey Extent                     | Survey Date | Time        | Survey Distance (mi) |
|---------------------------|-----------------------------------|-------------|-------------|----------------------|
| 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                  |
| 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                 |

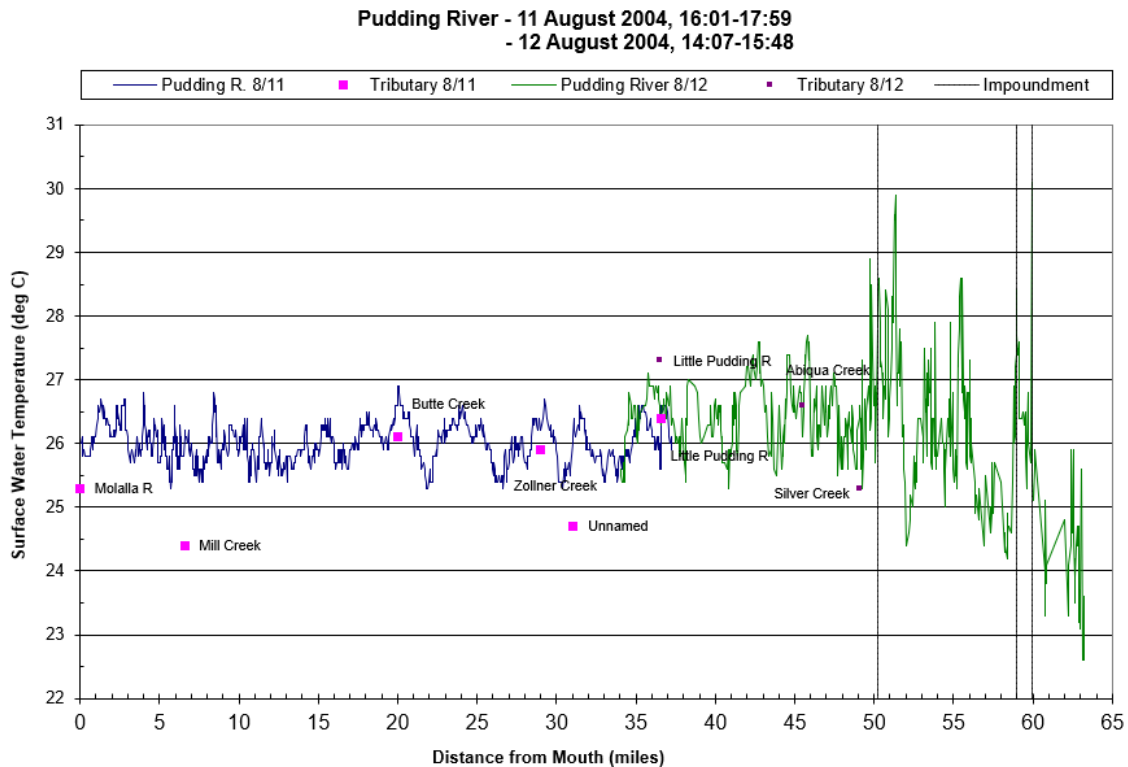
**Johnson Creek - 31 July 2002, 13:32-14:35**



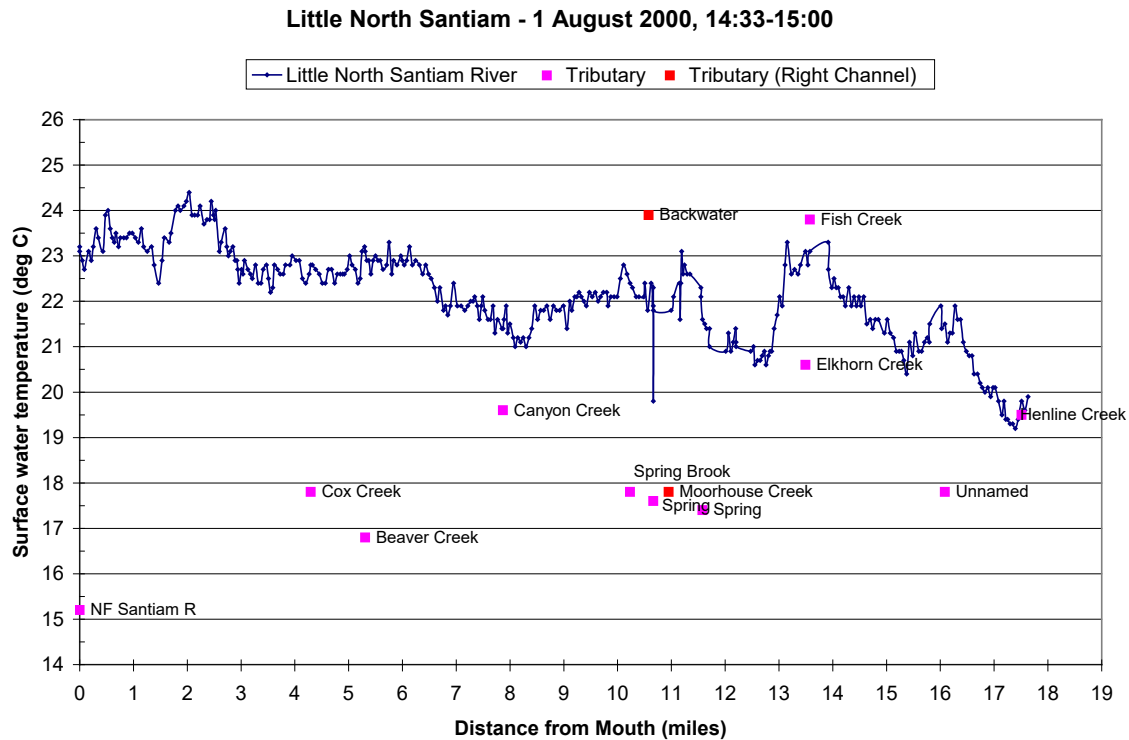
**Figure 2-4: TIR temperatures for Johnson Creek in the Lower Willamette Subbasin.**



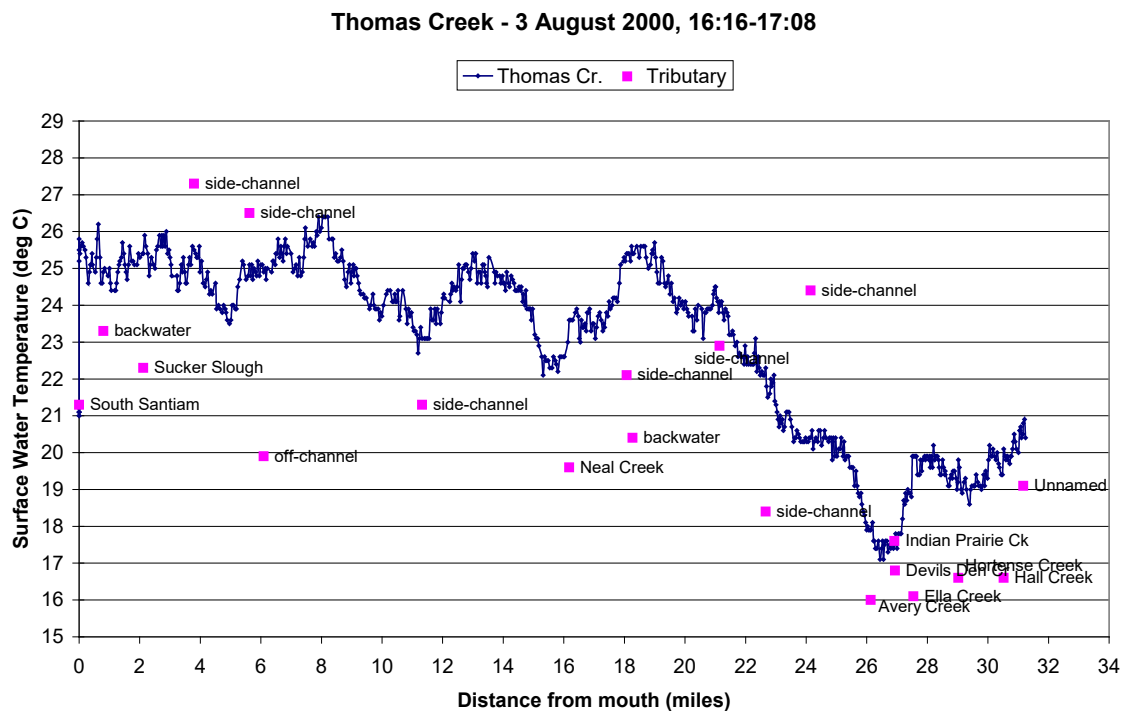
**Figure 2-5: TIR temperatures for the Molalla River in the Molalla-Pudding Subbasin.**



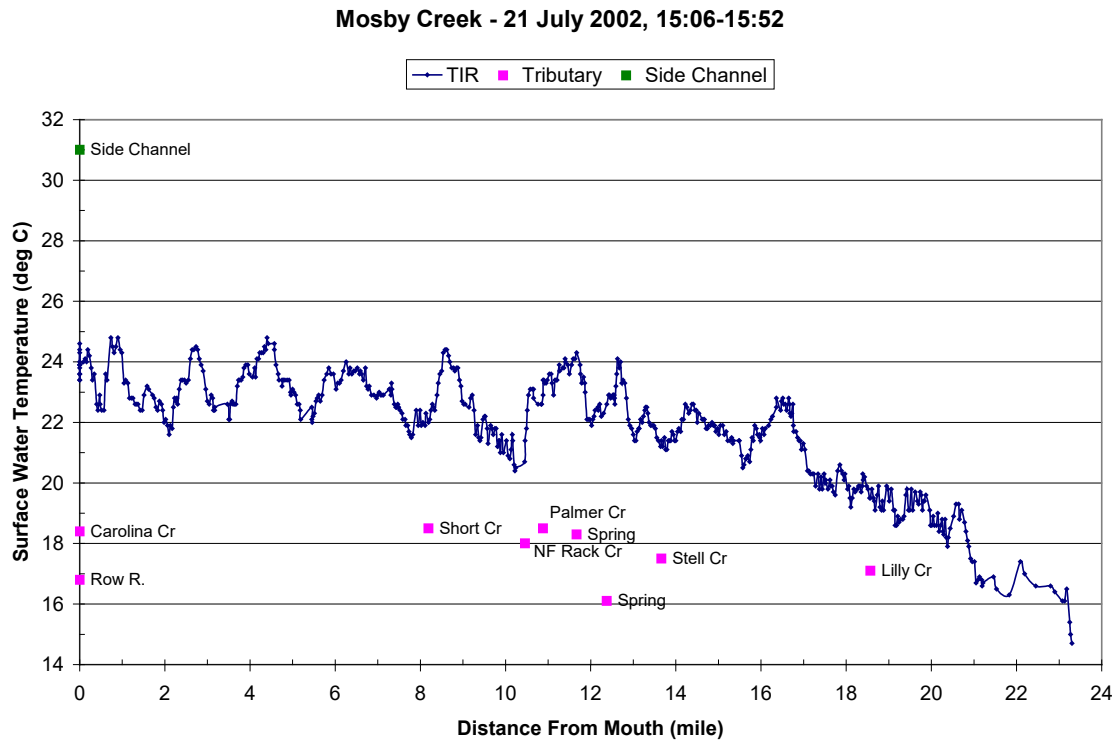
**Figure 2-6: TIR temperatures for the Pudding River in the Molalla-Pudding Subbasin.**



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



**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

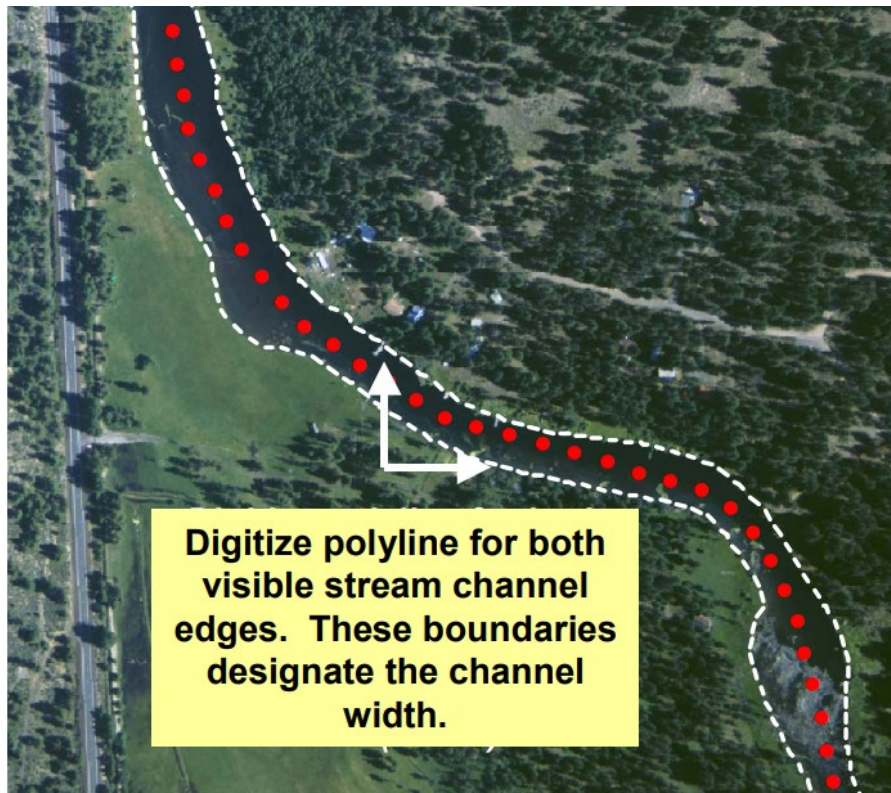
### 2.3.1 Stream position and channel width

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) and hillshade rasters derived from high resolution LiDAR ground elevation data (**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.

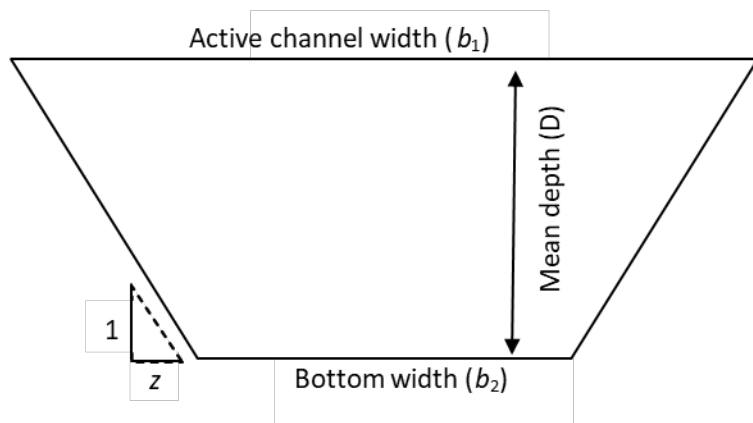
Step 3. The stream flowline was segmented into reaches no greater than 100m, with a node separating each reach (**Figure 2-10**). These nodes determine the location and flow path for modeling. Stream segmentation was completed using a python script called TTools.



**Figure 2-10: Example of digitized channel, flowline, and stream nodes.**

### **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.**

$$b_2 = b_1 - 2 \cdot z \cdot D \quad \text{Equation 2-1}$$

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 Molalla River, Pudding River, 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.

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

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.

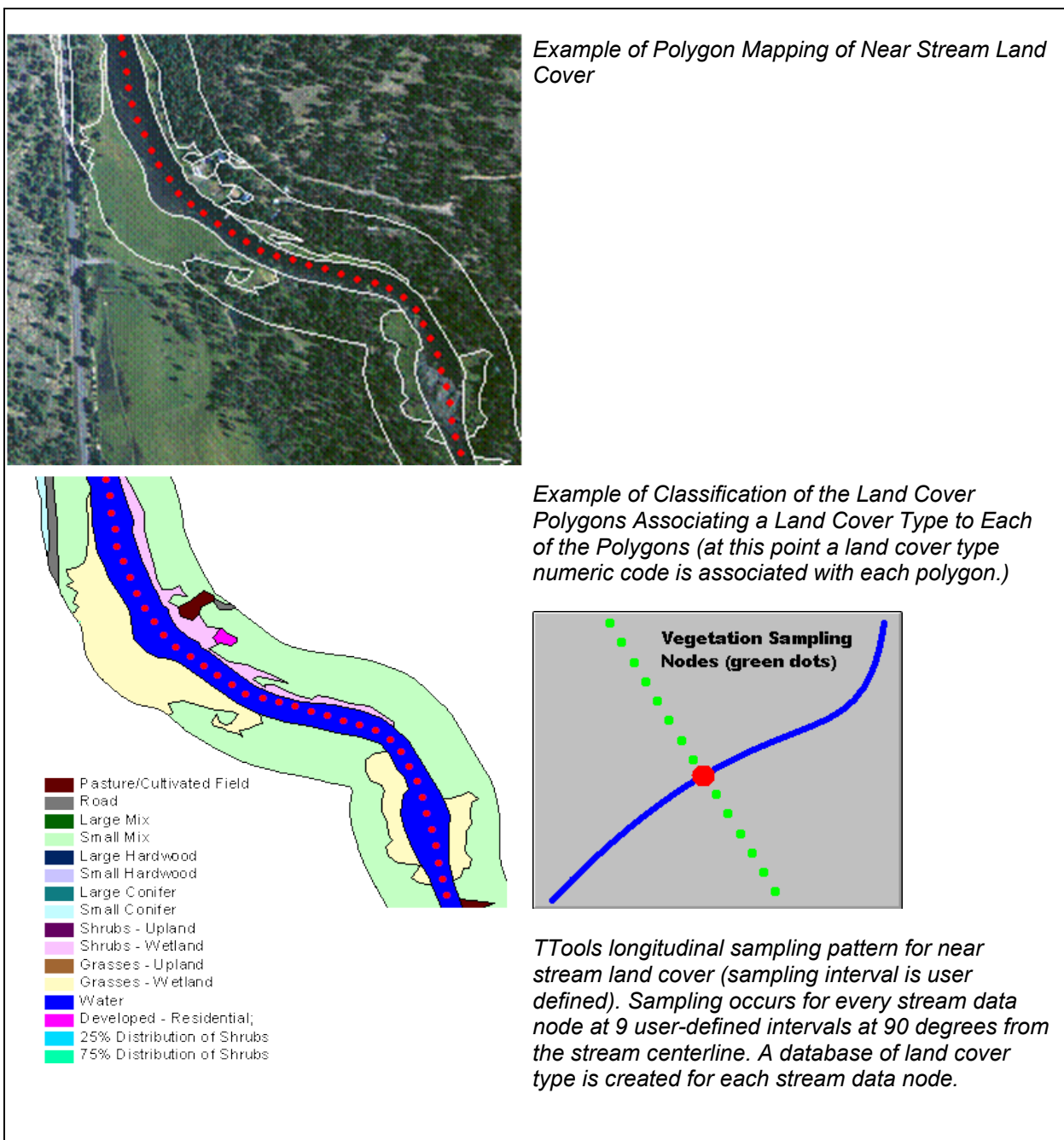
$d$  = Horizontal distance (meters) from the stream node to the topographic feature.

### 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 (ODFW, 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.



**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           |

| ODFW<br>Landcover<br>Code | PNWERC<br>Landcover<br>Code | DEQ<br>Landcover<br>Code | Landcover Type  | Height<br>(ft) | Density<br>(%) |
|---------------------------|-----------------------------|--------------------------|---|----------------|----------------|
| N/A                       | N/A                         | 401                      | Barren - Forest Road  | 0              | 0              |
| N/A                       | N/A                         | 402                      | Barren - Railroad   | 0              | 0              |
| 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<br>Trees, Nursery Stock | 10             | 75             |
| 2.4                       | N/A                         | 28                       | Orchards, Vineyards, Berries, Christmas<br>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             |
| 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             |

| ODFW Landcover Code | PNWERC Landcover Code | DEQ Landcover Code | Landcover Type             | Height (ft) | Density (%) |
|---------------------|-----------------------|--------------------|----------------------------|-------------|-------------|
| 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<br><br>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 |

| Method                   | Possible Parameters   | Description  |
|--------------------------|---|--|
|                          |   | 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. |
| 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 the following relationship:

$$T_{\text{mix}} = \frac{(Q_{\text{up}} \cdot T_{\text{up}}) + (Q_{\text{in}} \cdot T_{\text{in}})}{(Q_{\text{mix}})} = \frac{(Q_{\text{up}} \cdot T_{\text{up}}) + (Q_{\text{in}} \cdot T_{\text{in}})}{(Q_{\text{up}} + Q_{\text{in}})}$$

where,

$Q_{\text{up}}$ : Stream flow rate upstream from mass transfer process

$Q_{\text{in}}$ : Inflow volume or flow rate

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

$T_{\text{up}}$ : Stream temperature directly upstream from mass transfer process

$T_{\text{in}}$ : Temperature of inflow

$T_{\text{mix}}$ : Resulting stream temperature from mass transfer process assuming complete mix

All water temperatures (i.e.,  $T_{\text{up}}$ ,  $T_{\text{in}}$  and  $T_{\text{mix}}$ ) 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-

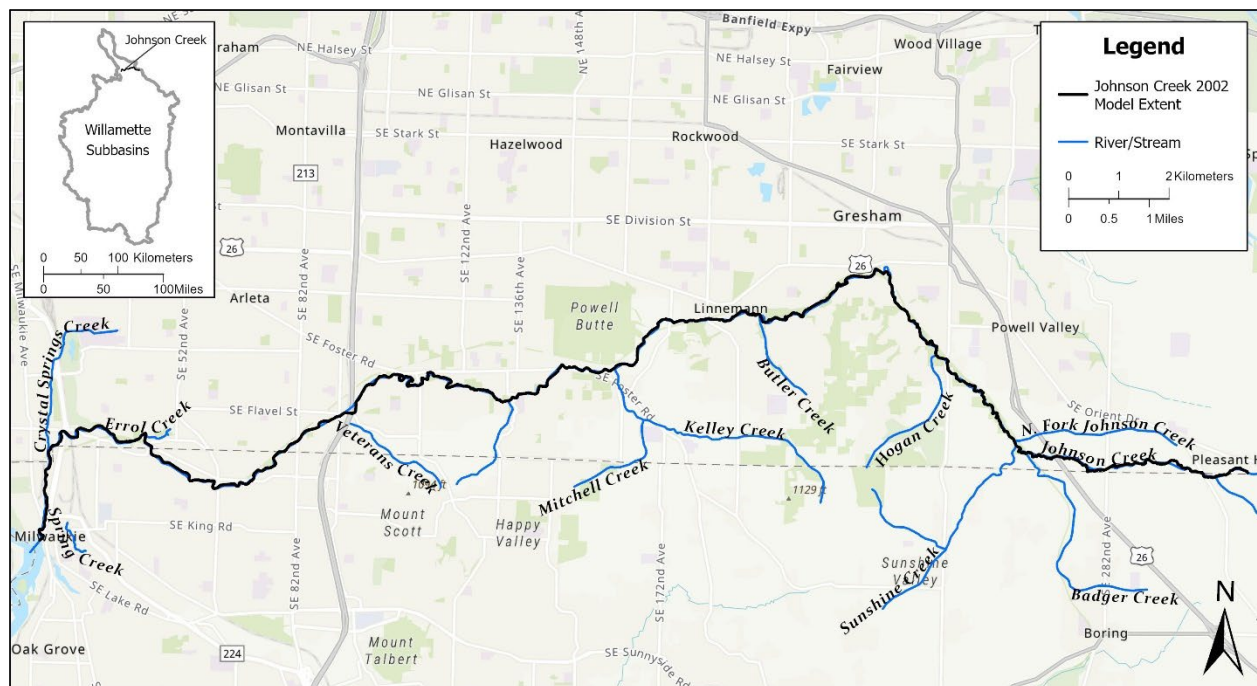
stream vegetation has the capacity to block incidental solar radiation on the surface of the modeled waterbody. Three vegetation inputs incorporated into the model calibration process are the vegetation density, overhang, and height. Field measurements offer a general understanding of vegetation characteristics 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

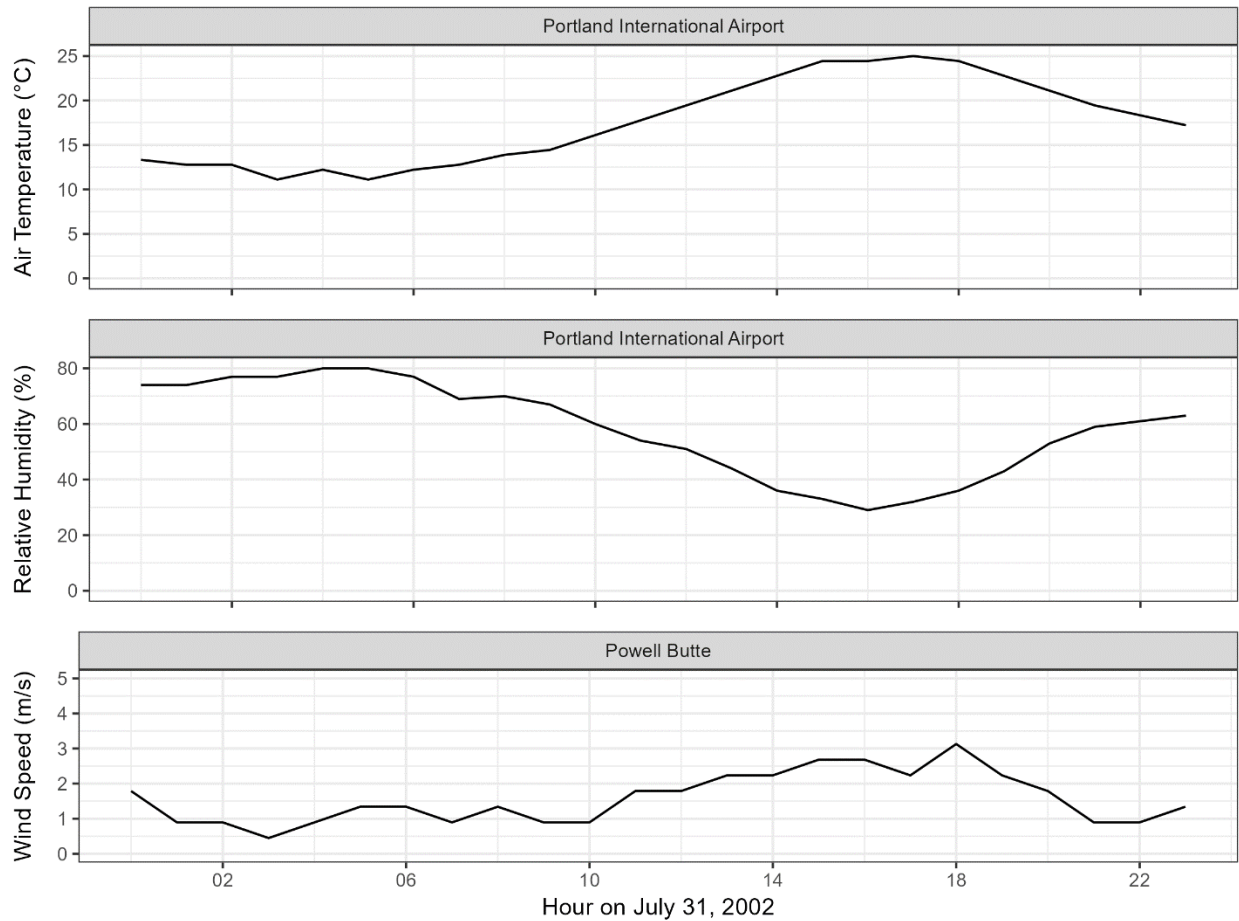
The model used air temperature, relative humidity, and wind speed from various sites (**Table 3-1**). Multiplicative wind sheltering coefficients were applied to the wind speed for calibration (**Table 3-2**). The meteorological observations are presented in **Figure 3-2**.

**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.**

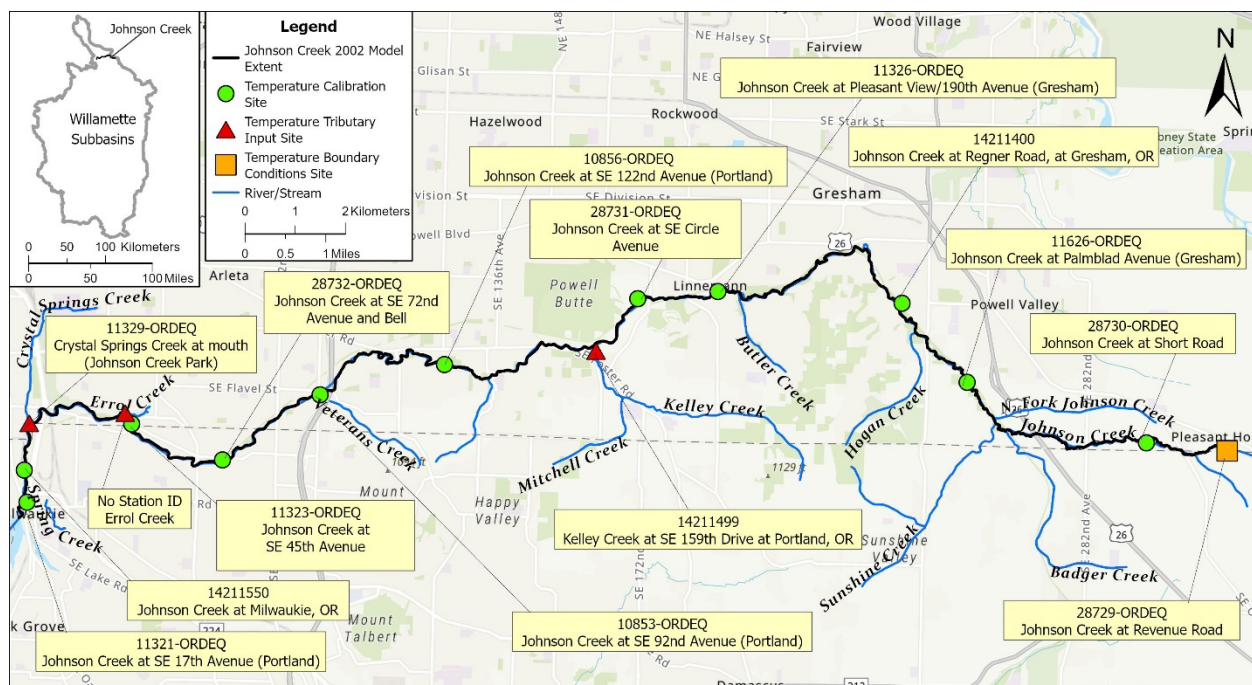
| Model Location Name                           | Model Location (km) | Wind Sheltering Coefficient |
|---|---------------------|-----------------------------|
| Johnson Creek at Revenue Road                 | 37.552              | 0.07                        |
| Johnson Creek at Short Road                   | 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.

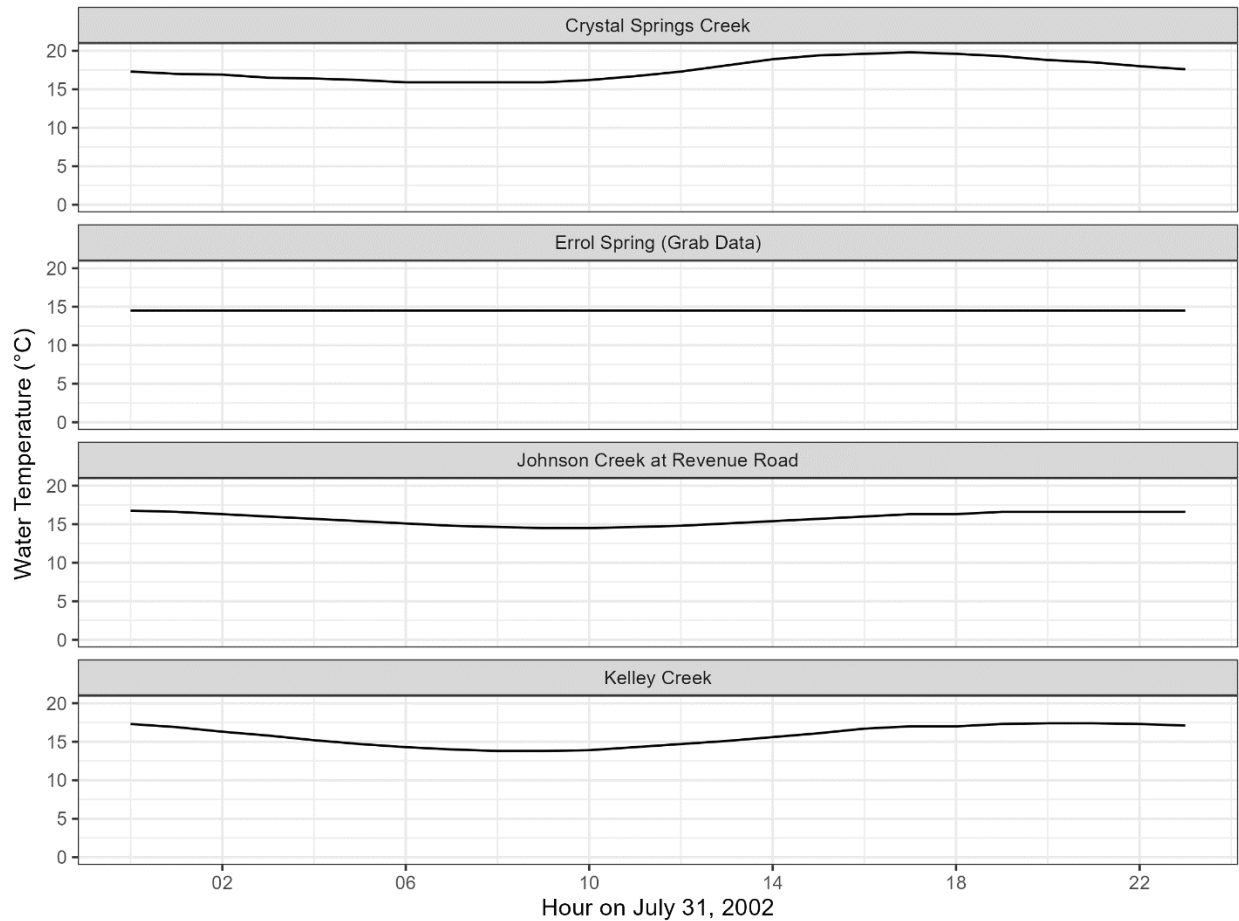


**Figure 3-3: Temperature monitoring locations used for Johnson Creek model setup and calibration.**

**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.**

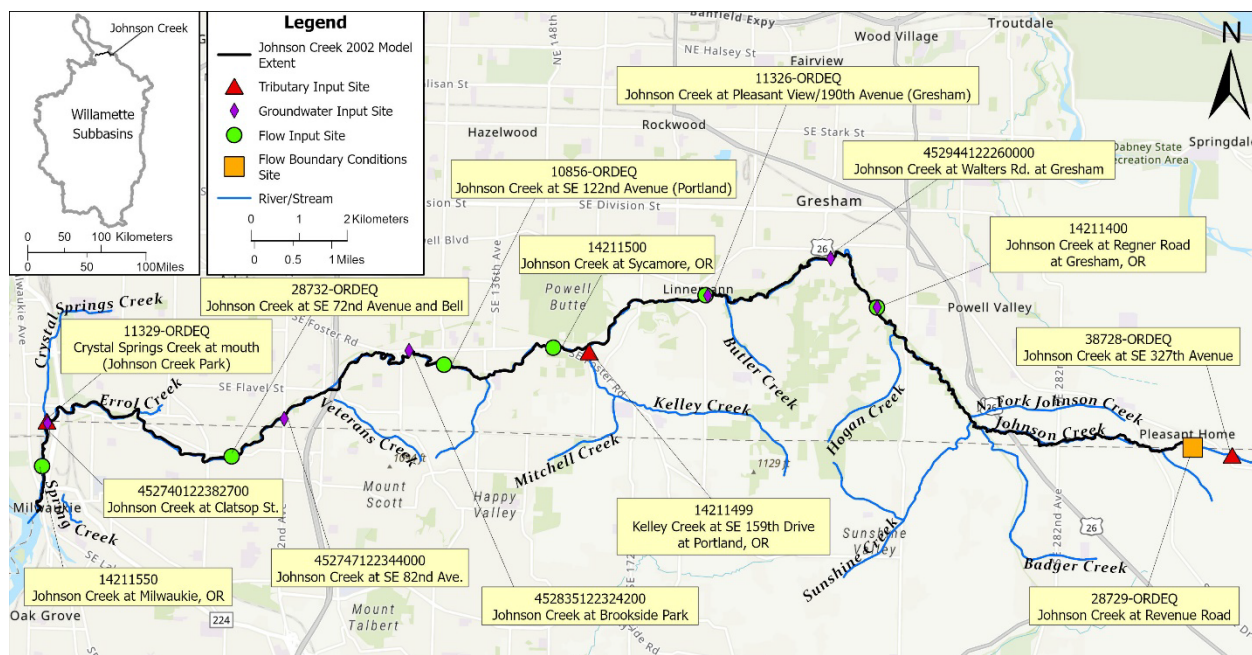
| Model Location Name                                 | Model Location (km) | Input Type         | Data Source                              |
|---|---------------------|--------------------|--|
| Johnson Creek at Revenue Road                       | 37.552              | Boundary Condition | 28729-ORDEQ                              |
| 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.

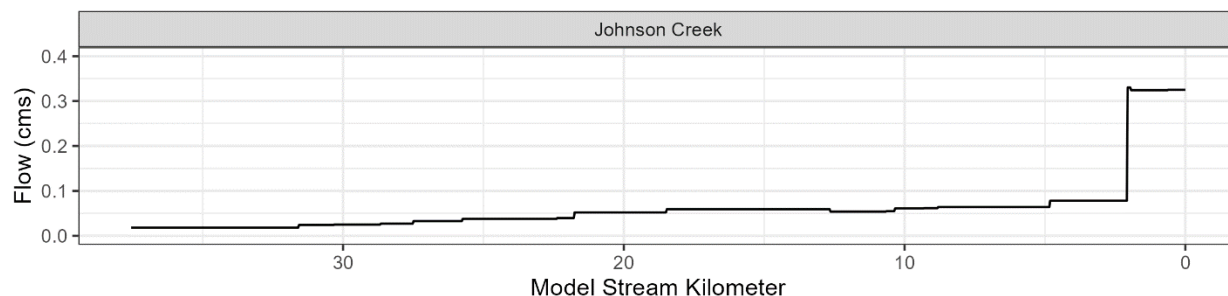
**Table 3-4: Boundary condition and tributary flow inputs to the Johnson Creek model.**

| 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 190 <sup>th</sup> Ave. | 21.752              | Estimated from USGS Seepage Investigation. |
| Johnson Creek at Brookside Park            | 12.64               | Estimated from USGS Seepage Investigation. |

| Model Location Name                       | Model Location (km) | Note                                       |
|---|---------------------|--|
| Johnson Creek at SE 82 <sup>nd</sup> Ave. | 9.296               | Estimated from USGS Seepage Investigation. |
| Johnson Creek at Clatsop St.              | 1.933               | Estimated from USGS Seepage Investigation. |



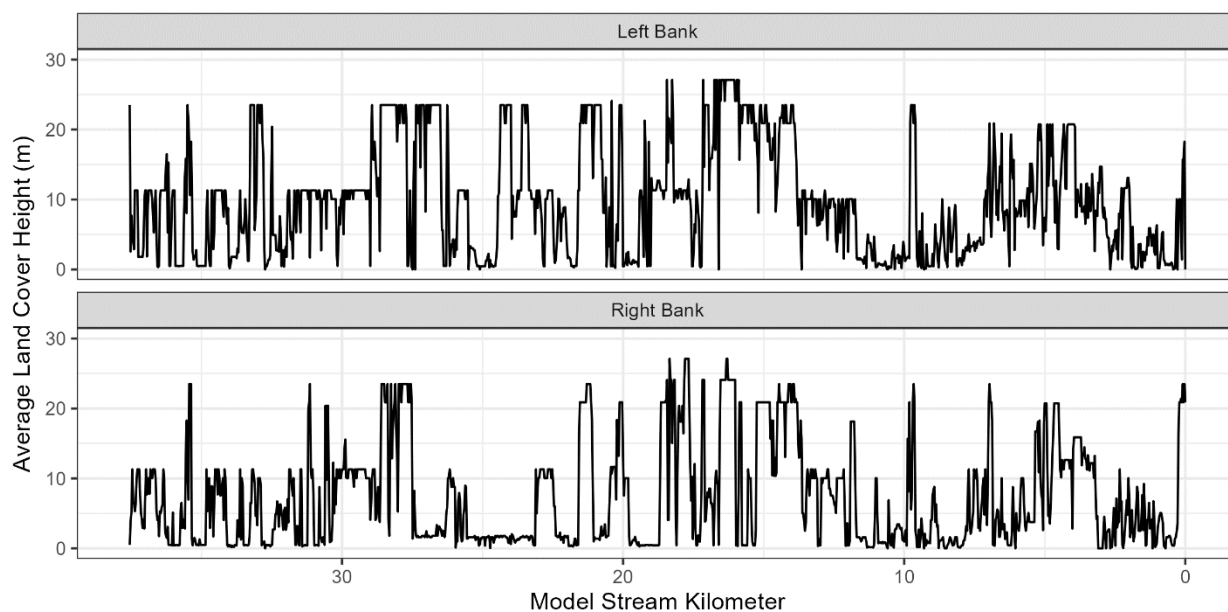
**Figure 3-6: Johnson Creek longitudinal flow model setup.**

### 3.1.7 Point source inputs

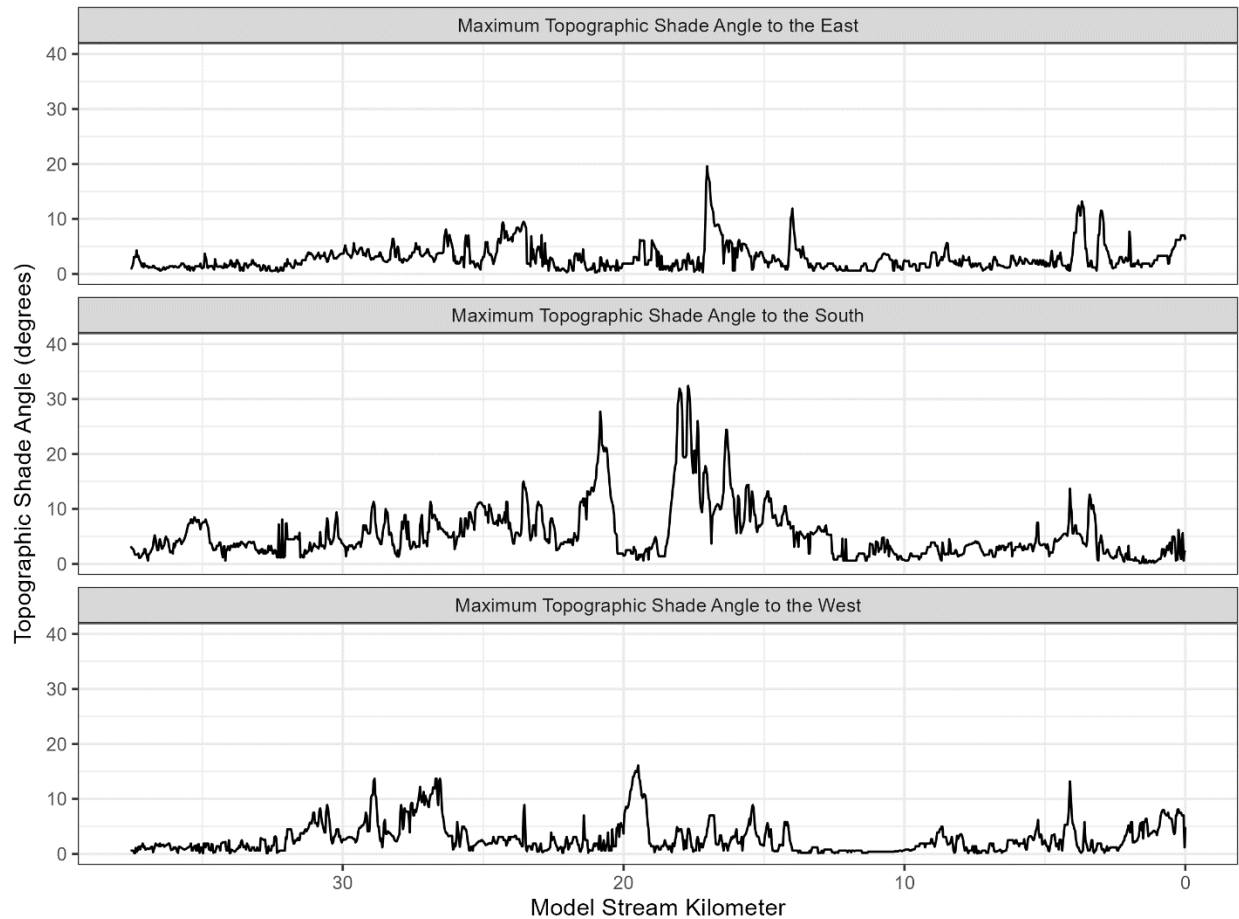
There are no point sources discharging within the model extent.

### 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**.



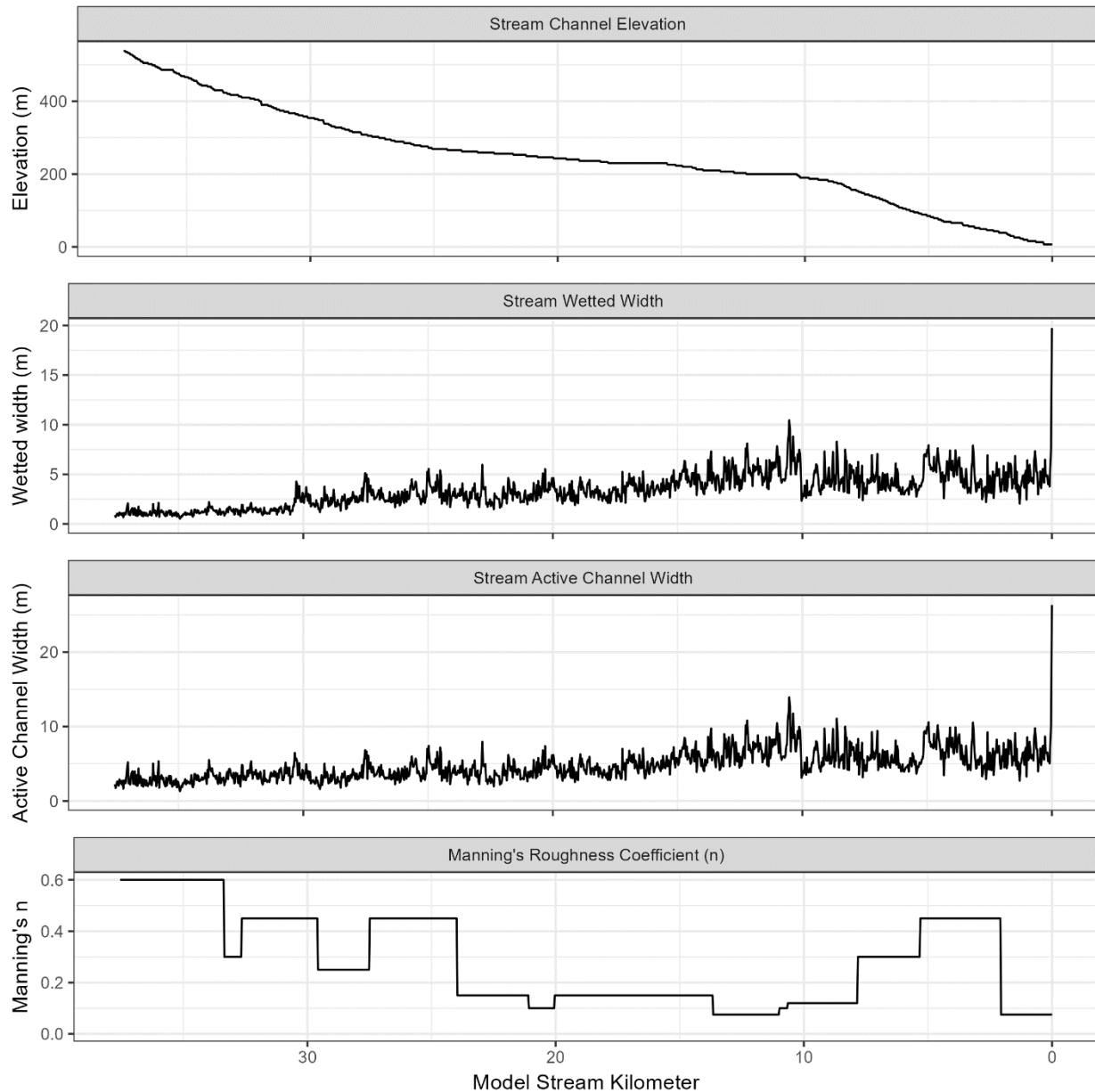
**Figure 3-7: Average land cover height inputs to the Johnson Creek model.**



**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

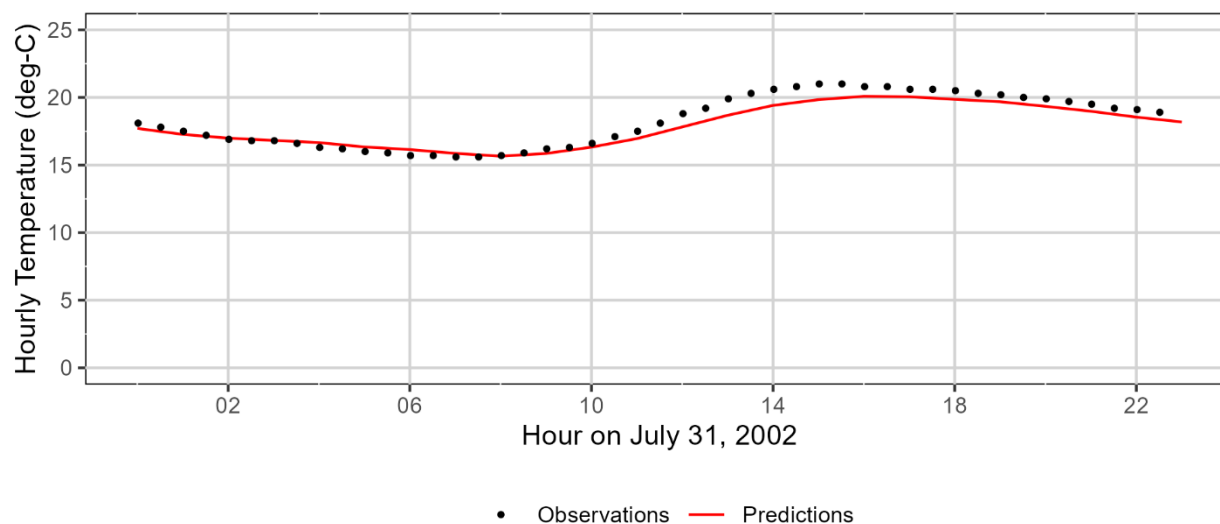
#### 3.1.10.1 Temperature

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.**

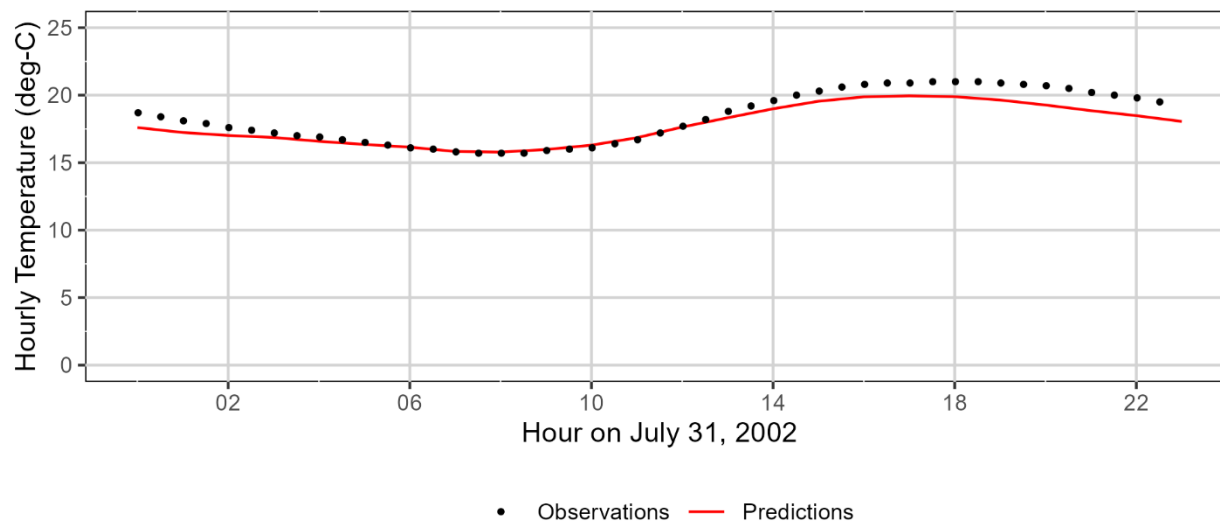
| Monitoring Location  | Model KM     | Temperature Statistics | ME    | MAE  | RMSE | NSE   | n   |
|--|--------------|------------------------|-------|------|------|-------|-----|
| All Stations   |              | Daily Maximum          | 0.67  | 1.03 | 1.07 | NA    | 11  |
| All Stations   |              | 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 |

11321-ORDEQ: Johnson Creek at SE 17th Avenue (Portland)  
Model Kilometer 0.4



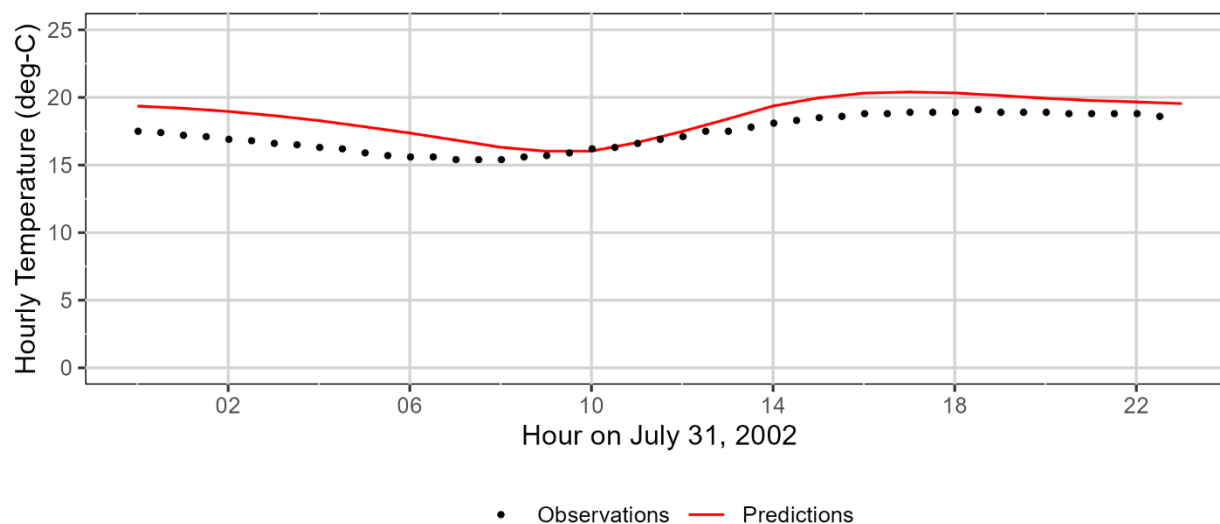
**Figure 3-10: Johnson Creek measured and model-predicted hourly temperatures at monitoring station 11321-ORDEQ.**

14211550: Johnson Creek at Milwaukie Gage  
Model Kilometer 1.1



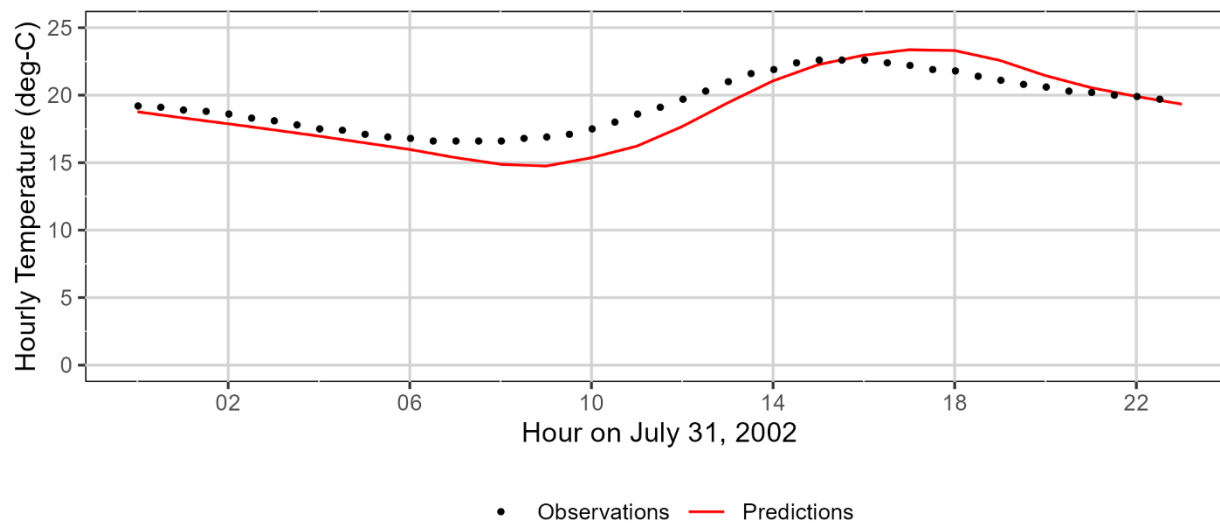
**Figure 3-11: Johnson Creek measured and model-predicted hourly temperatures at monitoring station 14211550.**

11323-ORDEQ: Johnson Creek at SE 45th Avenue (Portland)  
Model Kilometer 5.1



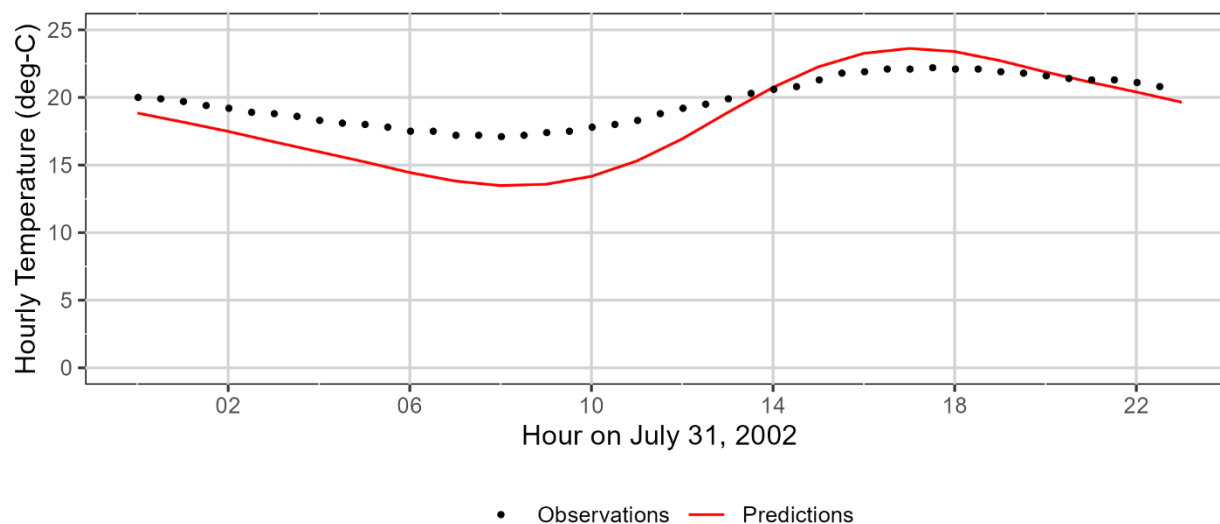
**Figure 3-12: Johnson Creek measured and model-predicted hourly temperatures at monitoring station 11323-ORDEQ.**

28732-ORDEQ: Johnson Creek at SE 72nd Avenue and Bell  
Model Kilometer 7.6



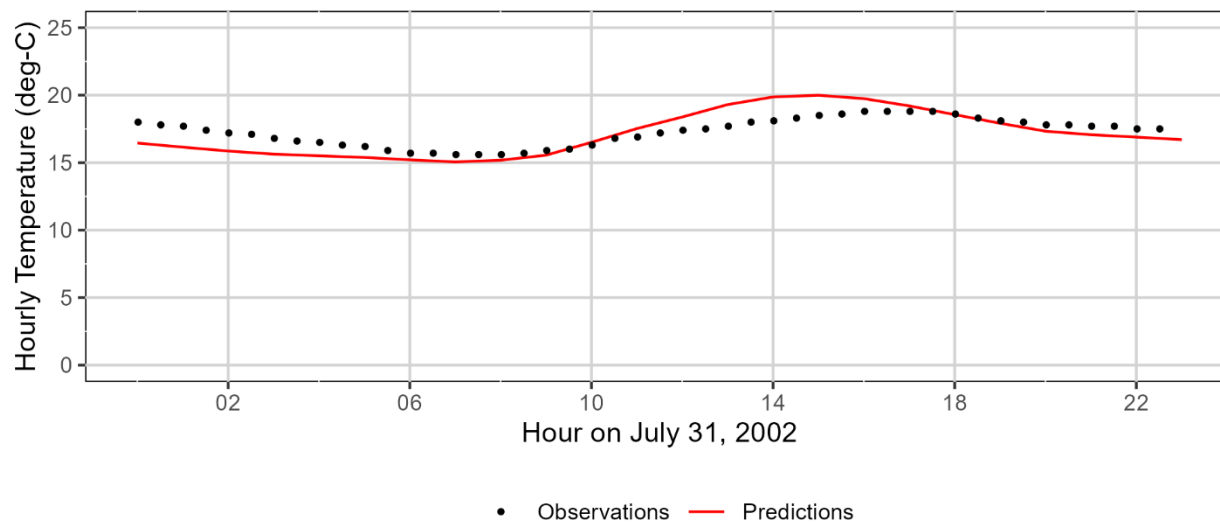
**Figure 3-13: Johnson Creek measured and model-predicted hourly temperatures at monitoring station 28732-ORDEQ.**

10853-ORDEQ: Johnson Creek at SE 92nd Avenue (Portland)  
Model Kilometer 10.3



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

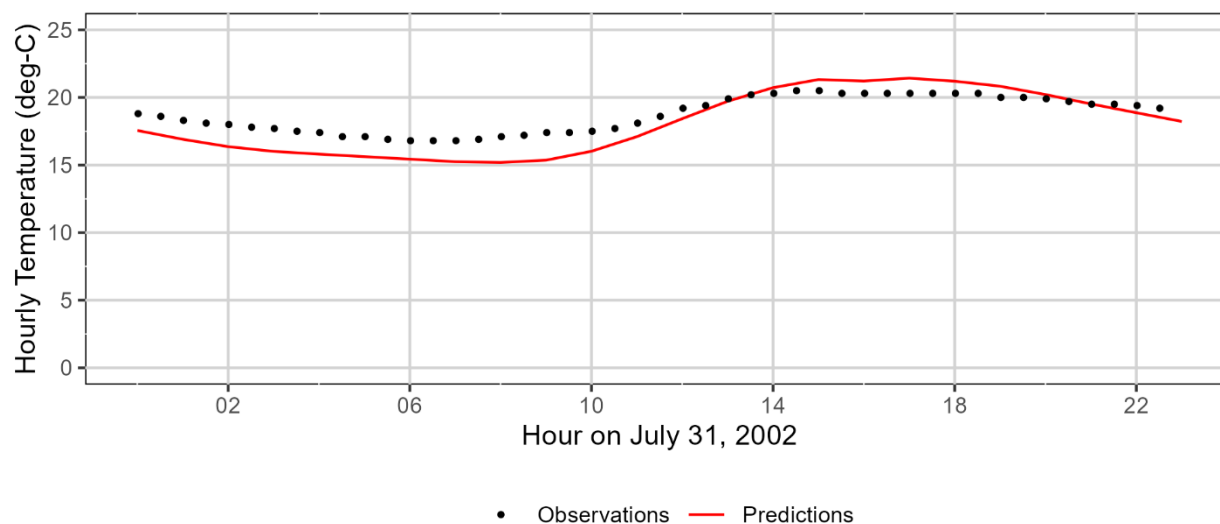
10856-ORDEQ: Johnson Creek at SE 122nd Avenue (Portland)  
Model Kilometer 14.7



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

28731-ORDEQ: Johnson Creek at SE Circle Avenue

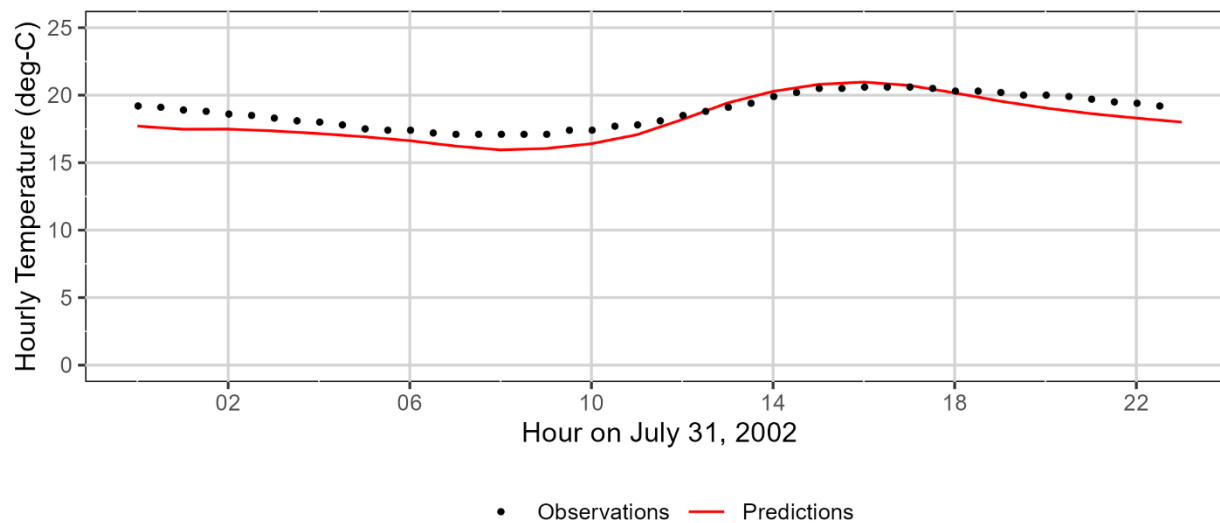
Model Kilometer 20



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

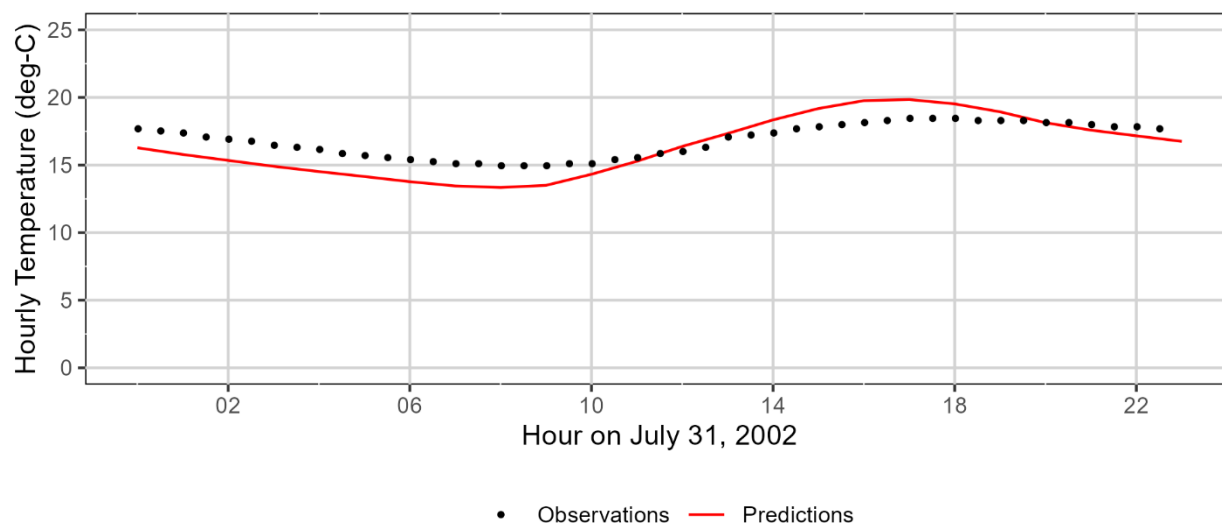
11326-ORDEQ: Johnson Creek at Pleasant View/190th Avenue (Gresham)

Model Kilometer 21.8



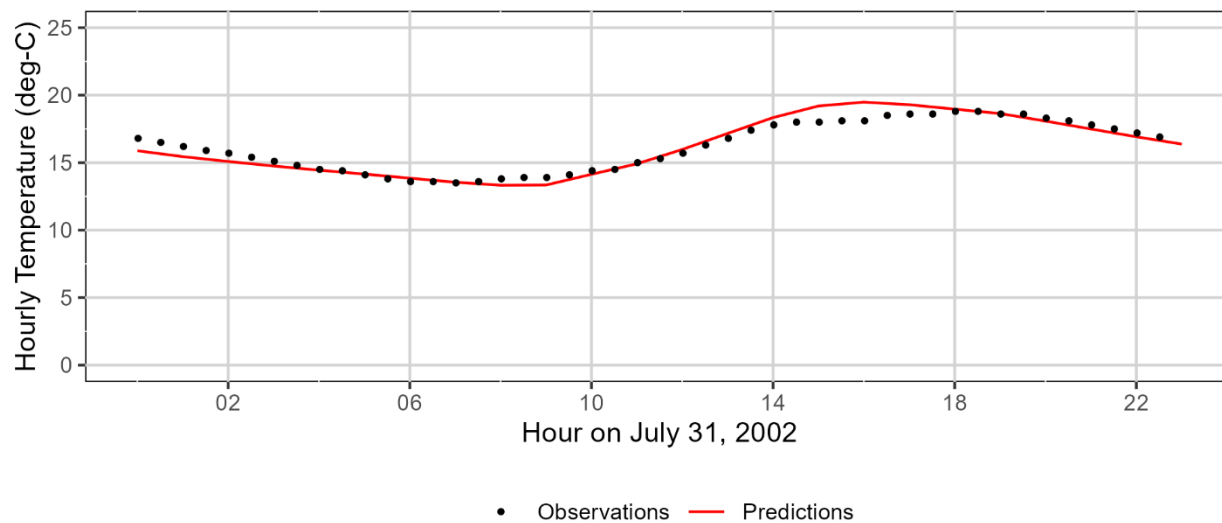
**Figure 3-17: Johnson Creek measured and model-predicted hourly temperatures at monitoring station 11326-ORDEQ.**

11327-ORDEQ: Johnson Creek at Regner Road (Gresham)  
Model Kilometer 27.5



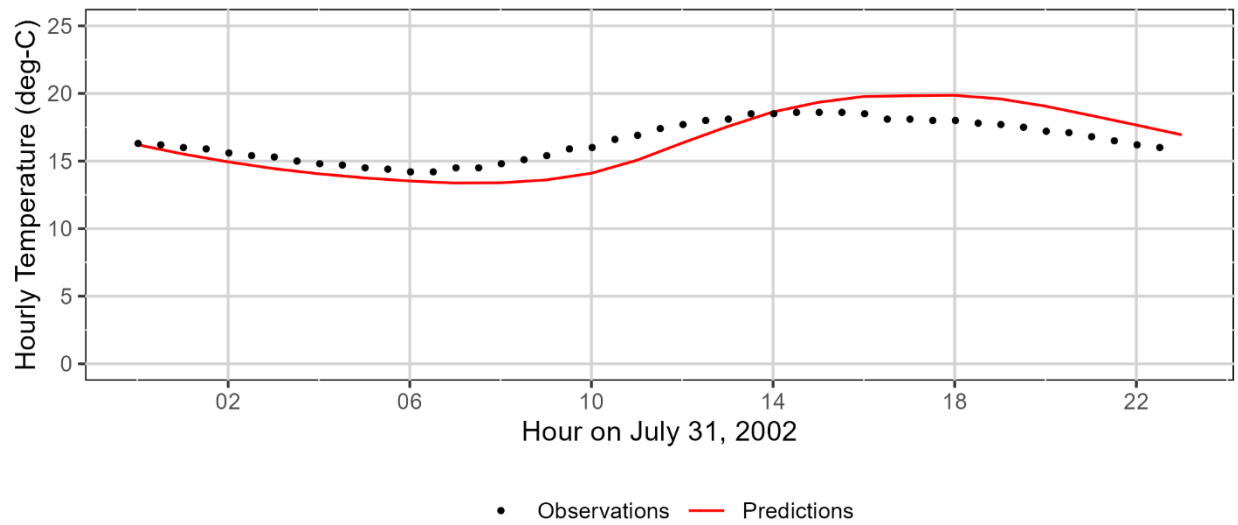
**Figure 3-18: Johnson Creek measured and model-predicted hourly temperatures at monitoring station 11327-ORDEQ.**

11626-ORDEQ: Johnson Creek at Palmbiad Avenue (Gresham)  
Model Kilometer 30.3

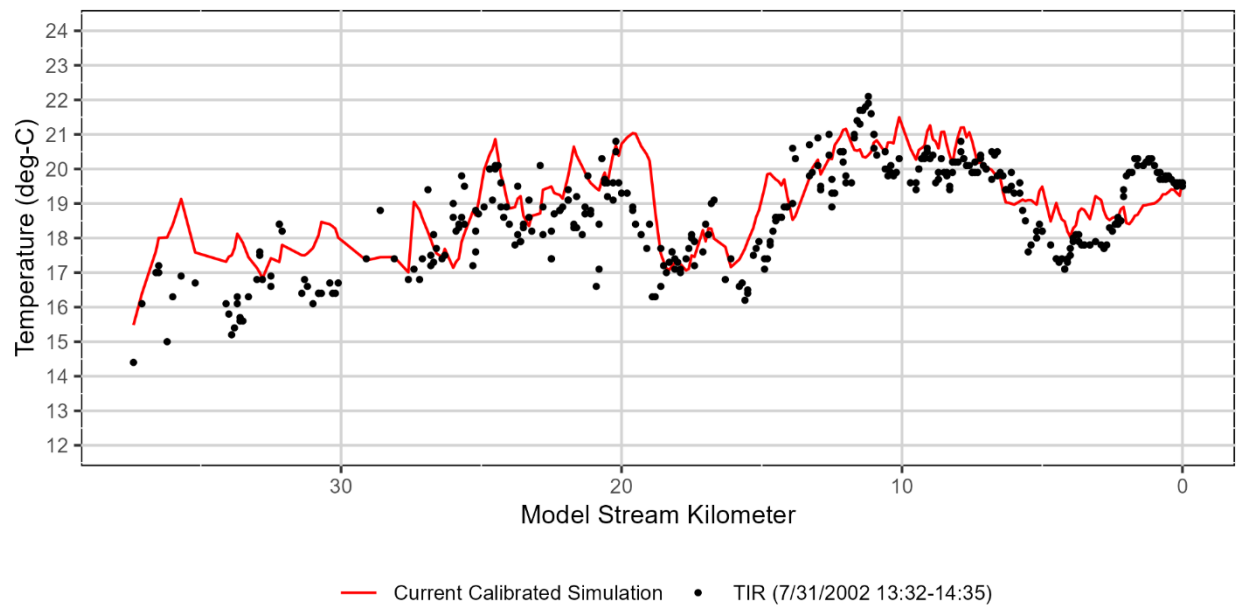


**Figure 3-19: Johnson Creek measured and model-predicted hourly temperatures at monitoring station 11626-ORDEQ.**

28730-ORDEQ: Johnson Creek at Short Road  
Model Kilometer 35.5



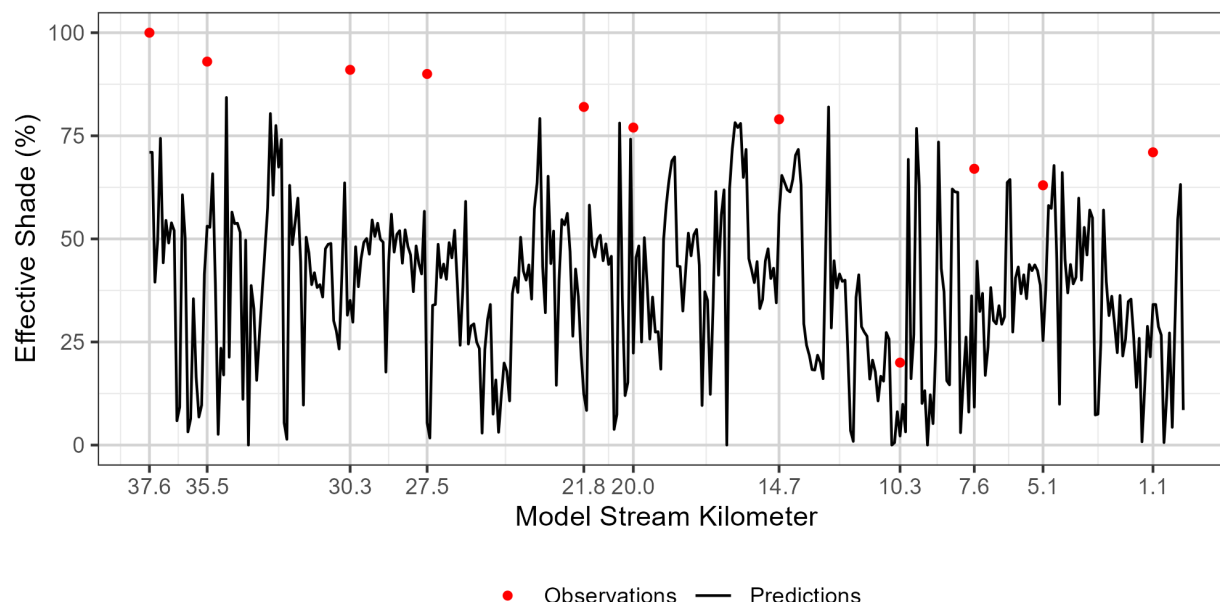
**Figure 3-20: Johnson Creek measured and model-predicted hourly temperatures at monitoring station 28730-ORDEQ.**



**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 <sup>2</sup> | ME    | MAE  | RMSE  |
|----|----------------|-------|------|-------|
| 11 | 0.34           | -46.1 | 46.1 | 50.04 |

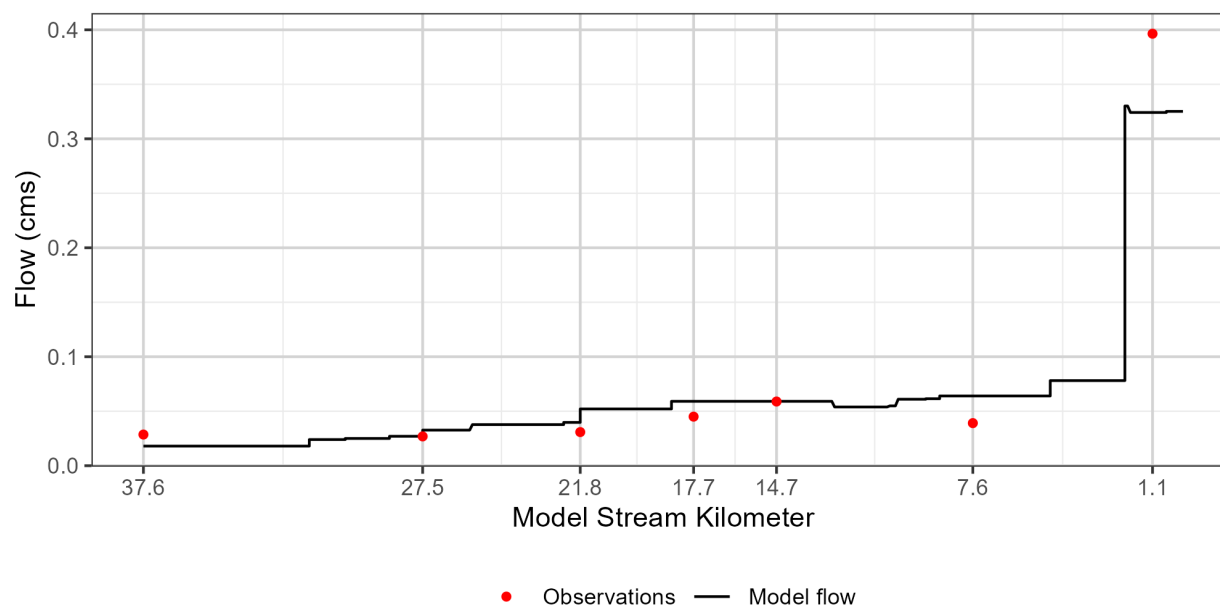
### 3.1.10.3 Flow

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 |

| Monitoring Location                                      | Model KM | Flow Statistics | Flow (cms) | Date      |
|--|----------|-----------------|------------|-----------|
| 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.**

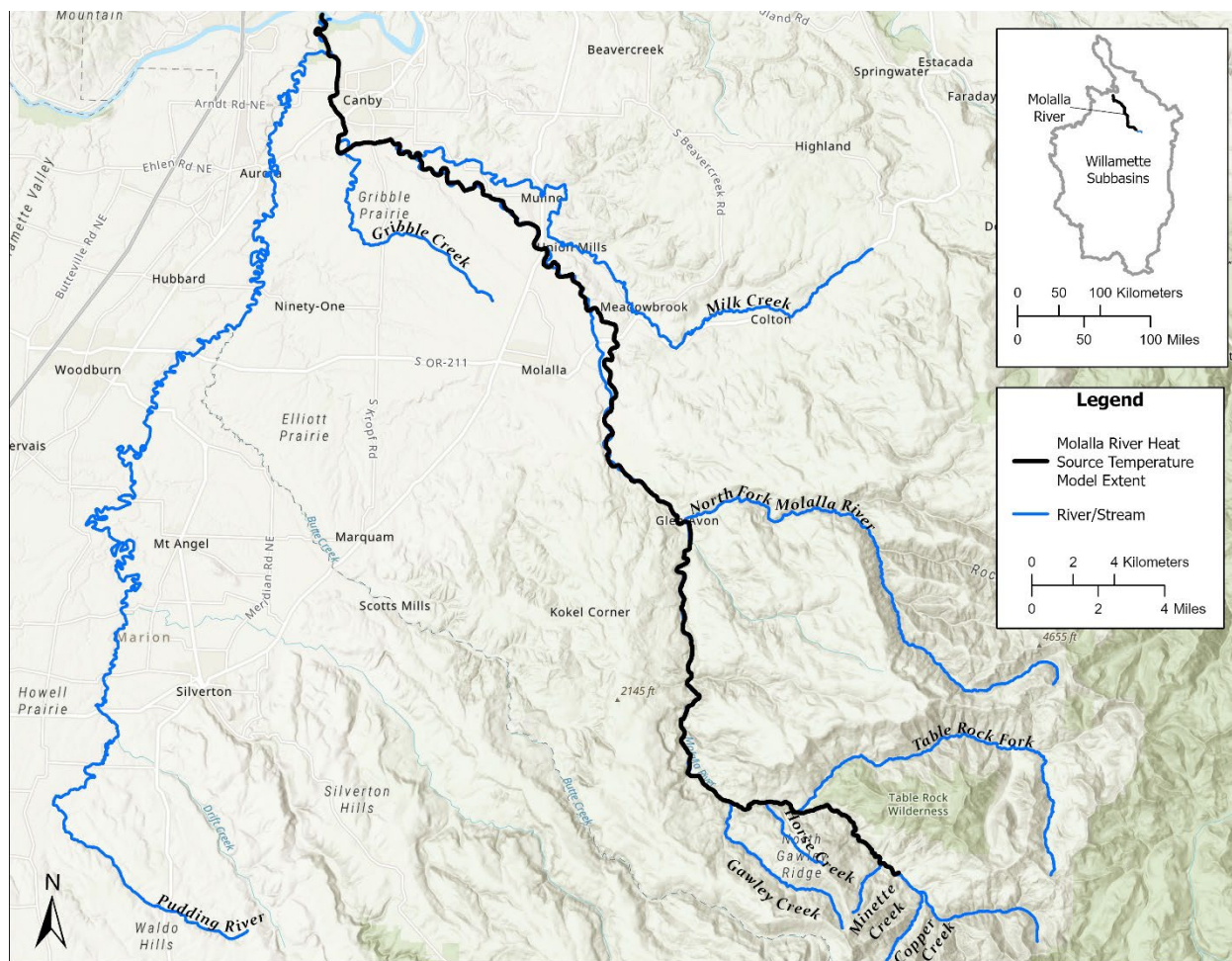
| N | R <sup>2</sup> | ME | MAE  | RMSE |
|---|----------------|----|------|------|
| 7 | 0.99           | 0  | 0.02 | 0.03 |

## 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.

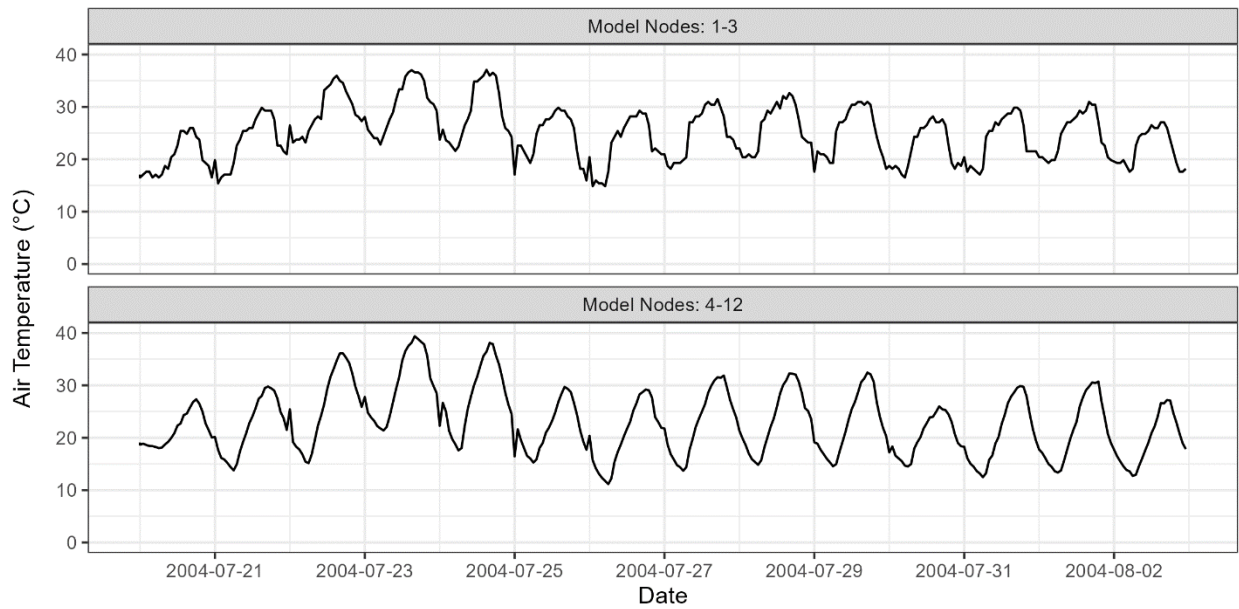
### 3.2.3 Time frame of simulation

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 (

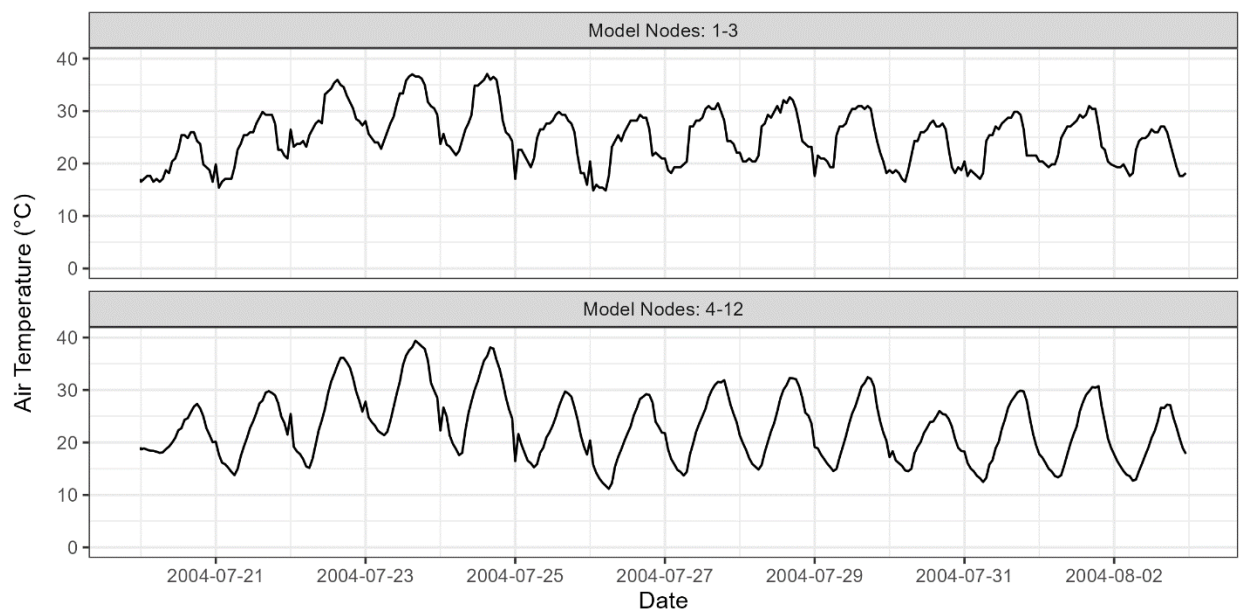
**Table 3-10**). Air temperature data were modified using the dry adiabatic lapse rate to adjust for differences in elevation between the measurement location and the model input location. Wind speeds were adjusted to improve the calibration and to represent difference in wind speed between the measurement 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**



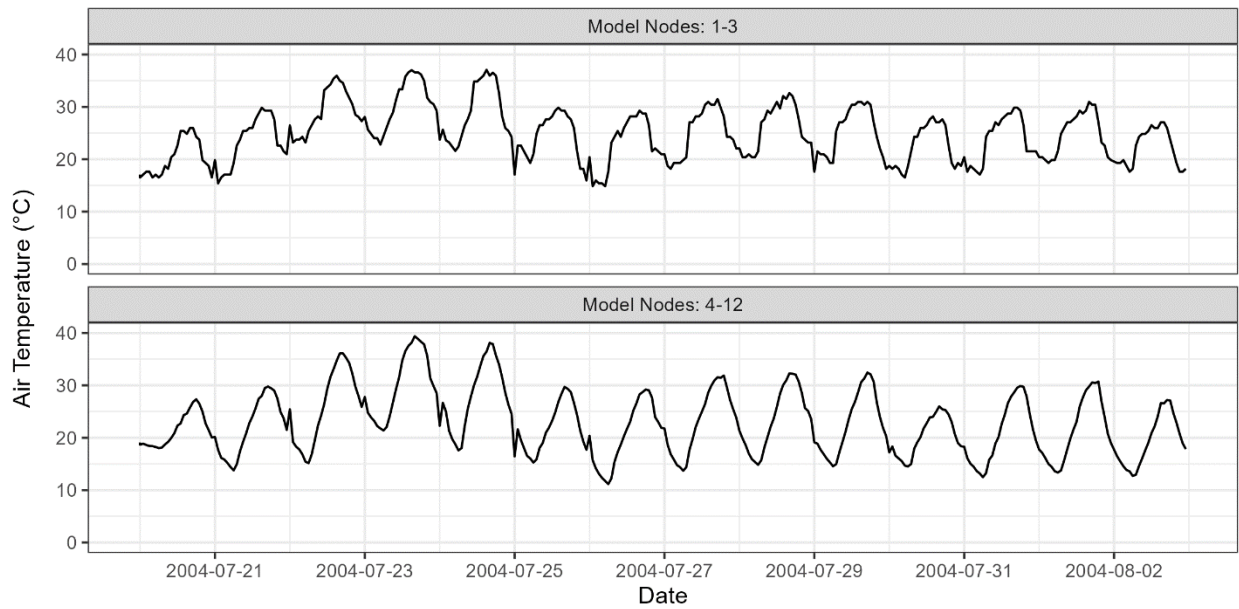
through **Figure 3-27**).

**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)                                   |

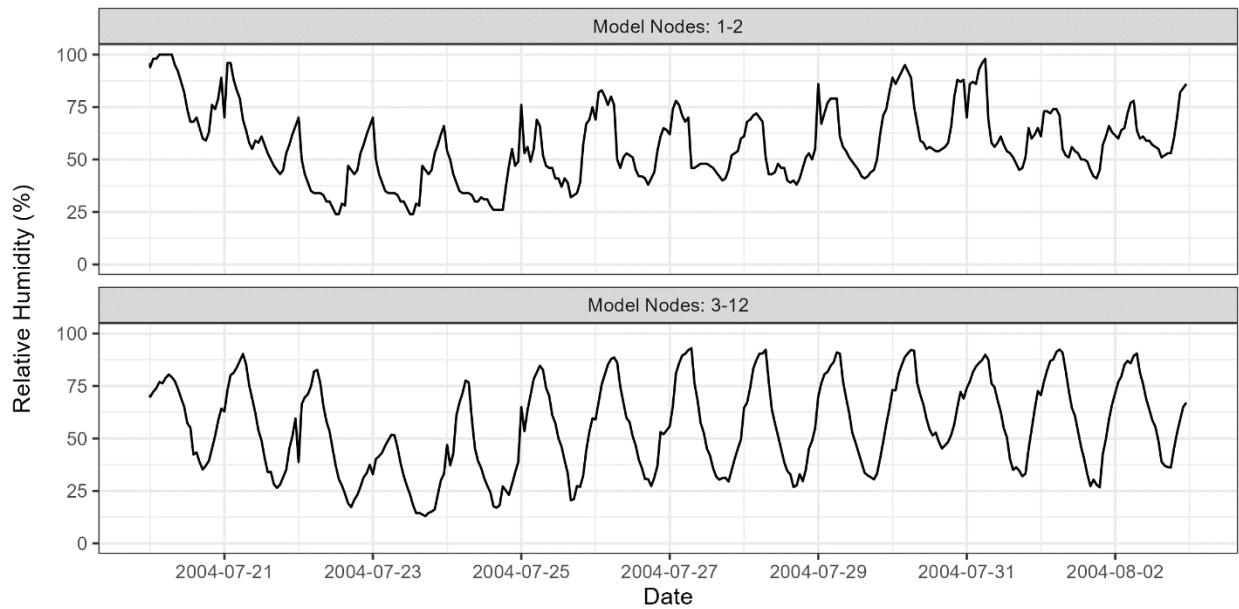


**(A)**

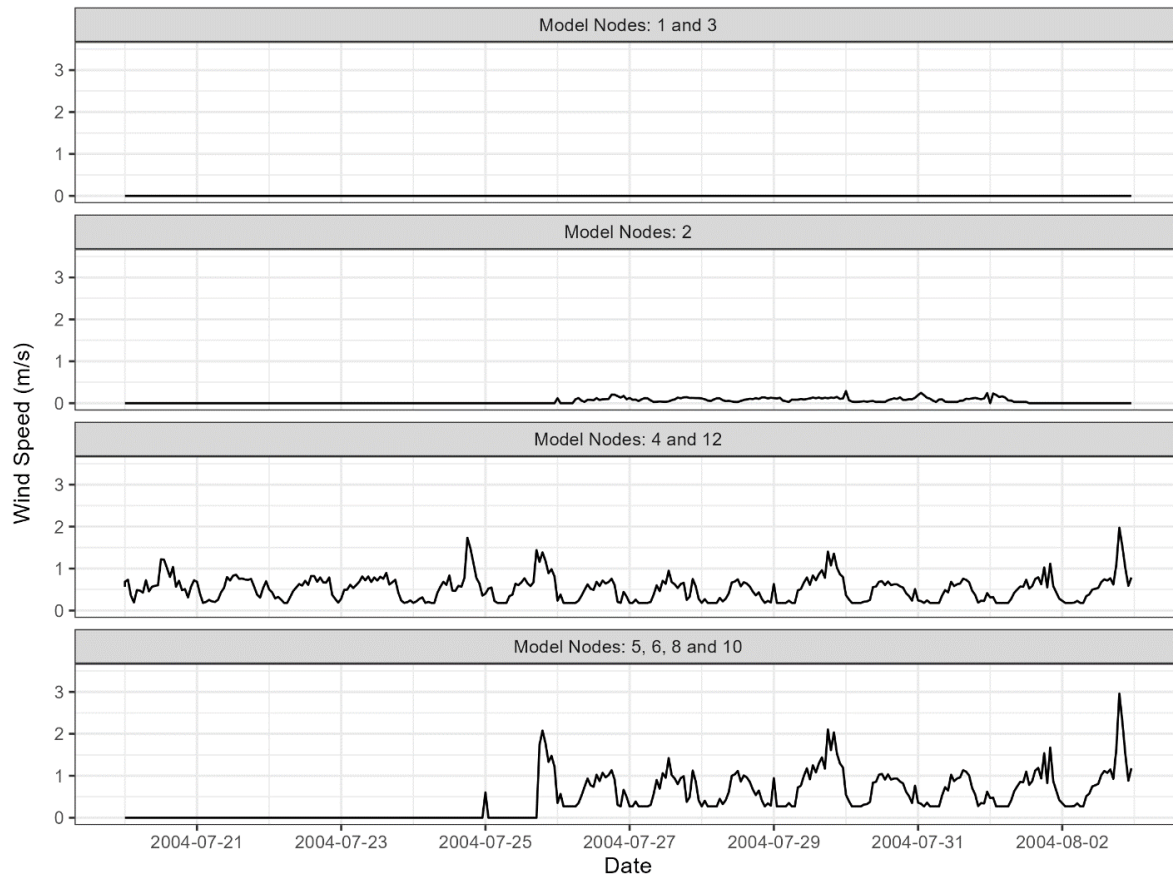


(B)

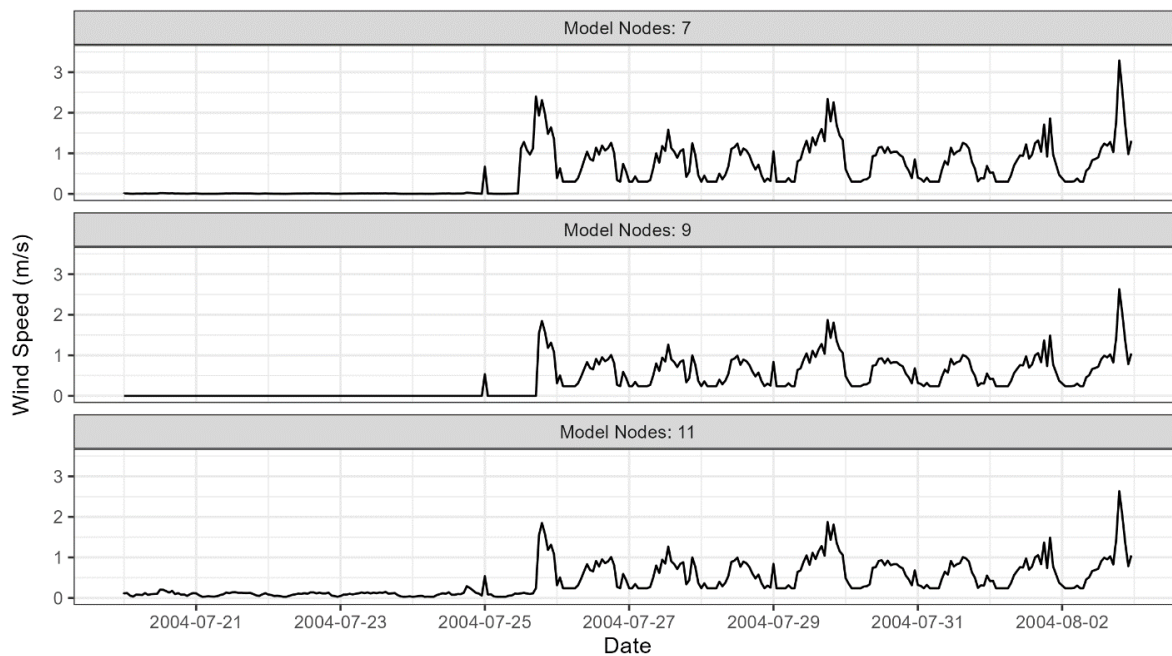
**Figure 3-25 (A) and (B): Air temperature inputs to the Molalla River model.**



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



(A)

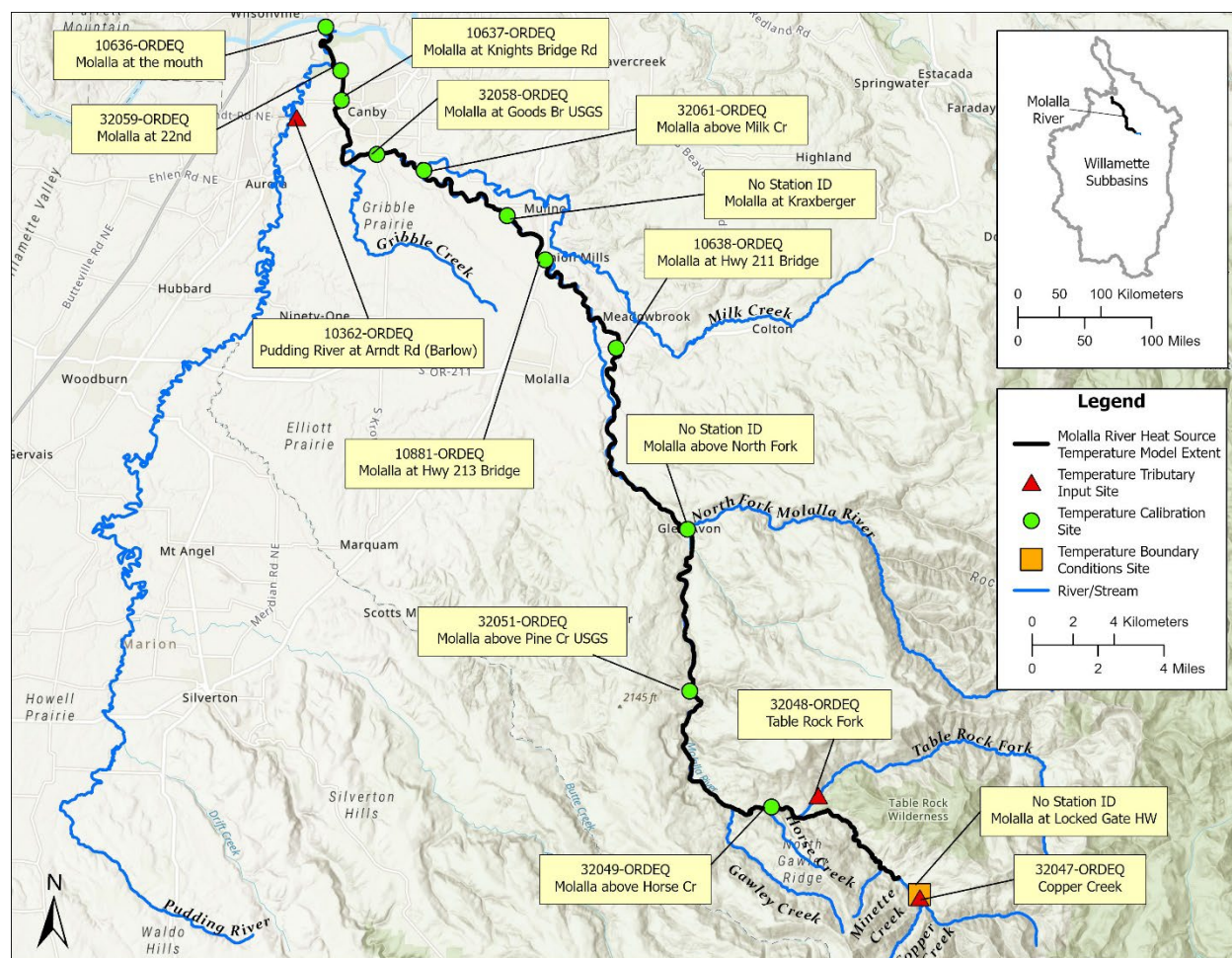


(B)

**Figure 3-27 (A) and (B): 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.**

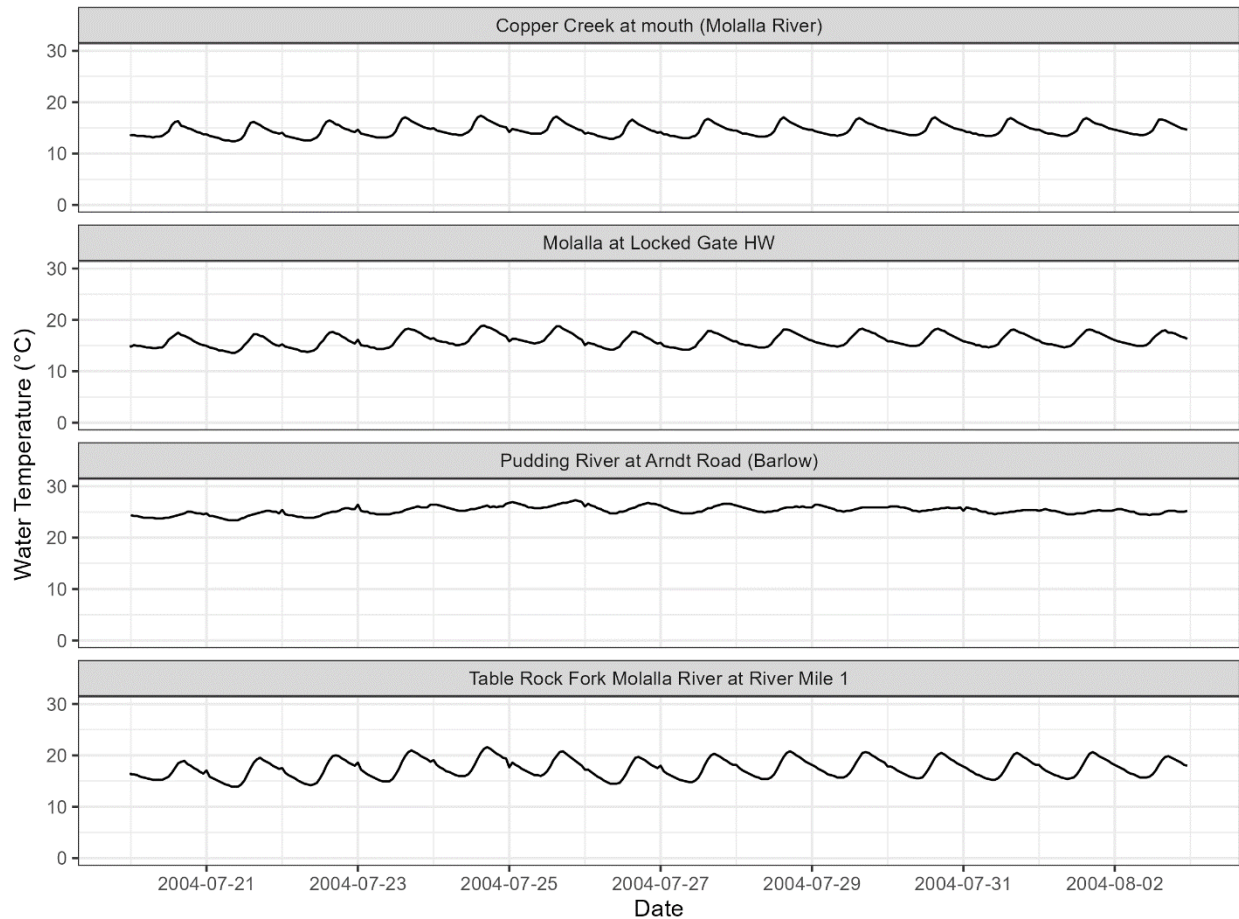
**Table 3-11** and **Figure 3-29** document the water temperature inputs to the model at the boundary condition (Molalla at Locked Gate HW) and tributaries where actually data were used in the model. Temperature monitors were lost from three locations (North Fork Molalla and Milk Creek at mouth, and 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         |

| Model Location Name                           | Model Location (kilometers) | Input Type | Data Source   |
|---|-----------------------------|------------|---|
| 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) |
| 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) |

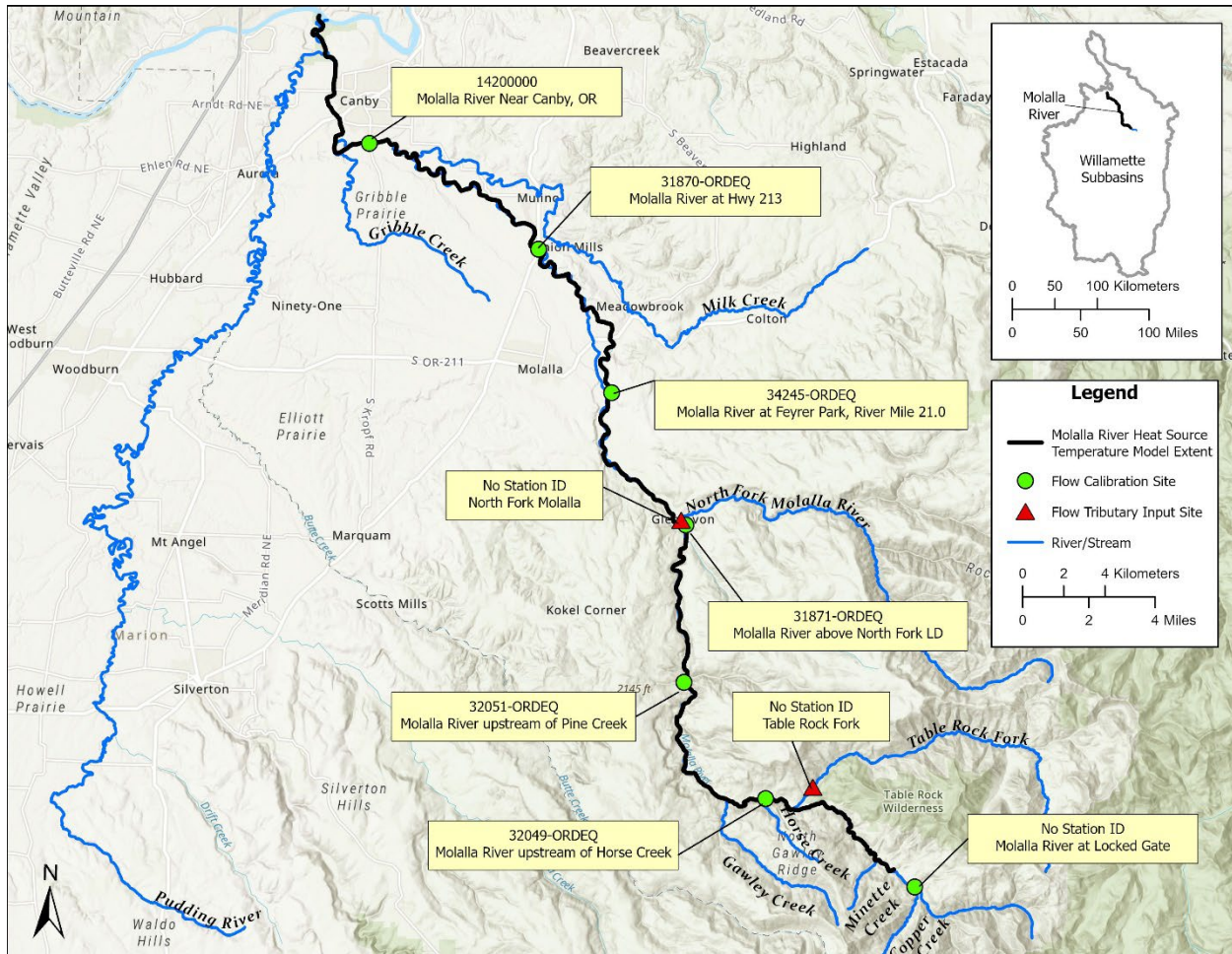
| Model Location Name                  | Model Location (kilometers) | Input Type | Data Source   |
|--------------------------------------|-----------------------------|------------|---|
| Spring at model kilometer 16.89      | 16.89                       | Tributary  | Derived from TIR. Constant temperature 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) |
| 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:

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

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         |
| 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

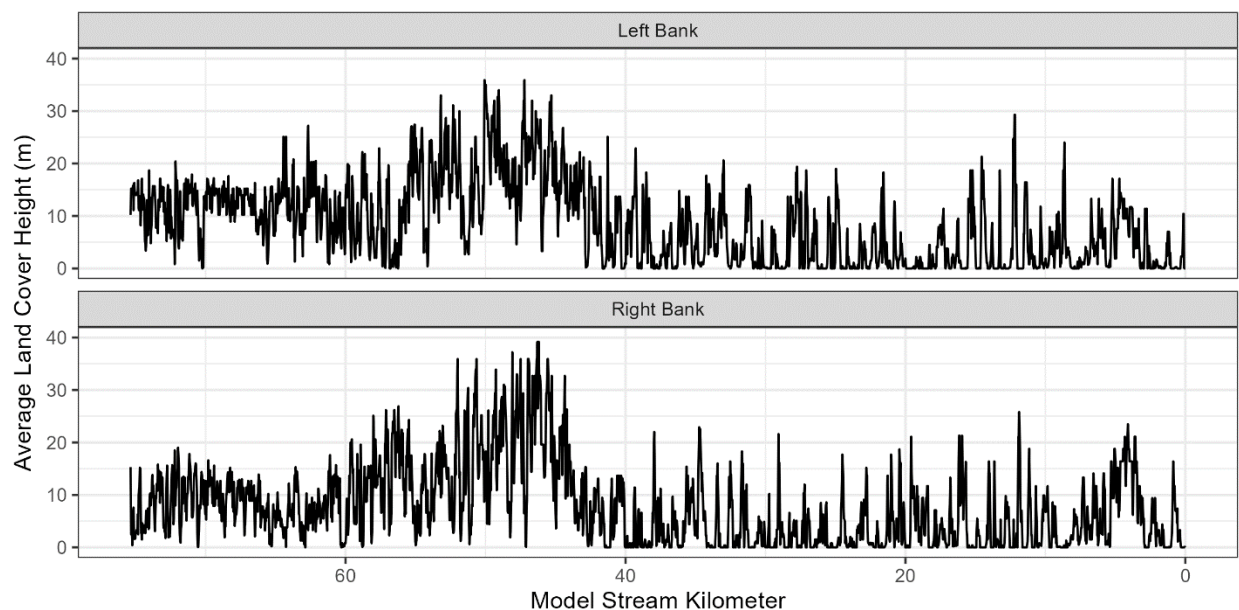
There are no point sources included in the calibrated model.

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.

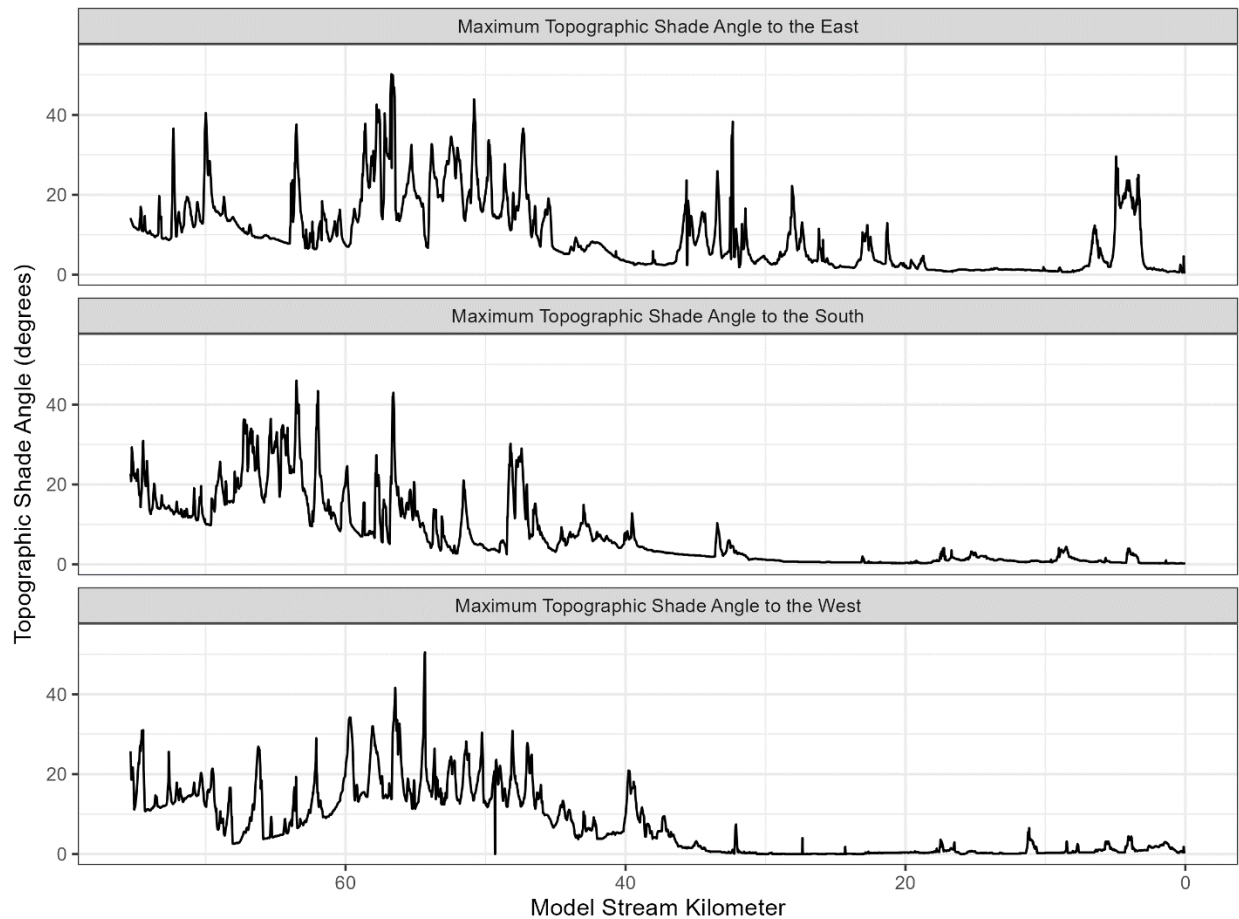
RSG Forest Products was also identified a potential discharge to Molalla River but was excluded because their discharge location is a settling pond that flows to a ditch, which then flows to farm ponds and terminates in a low, ponded area. There is no visible connection between the ditch and the mainstem 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**.



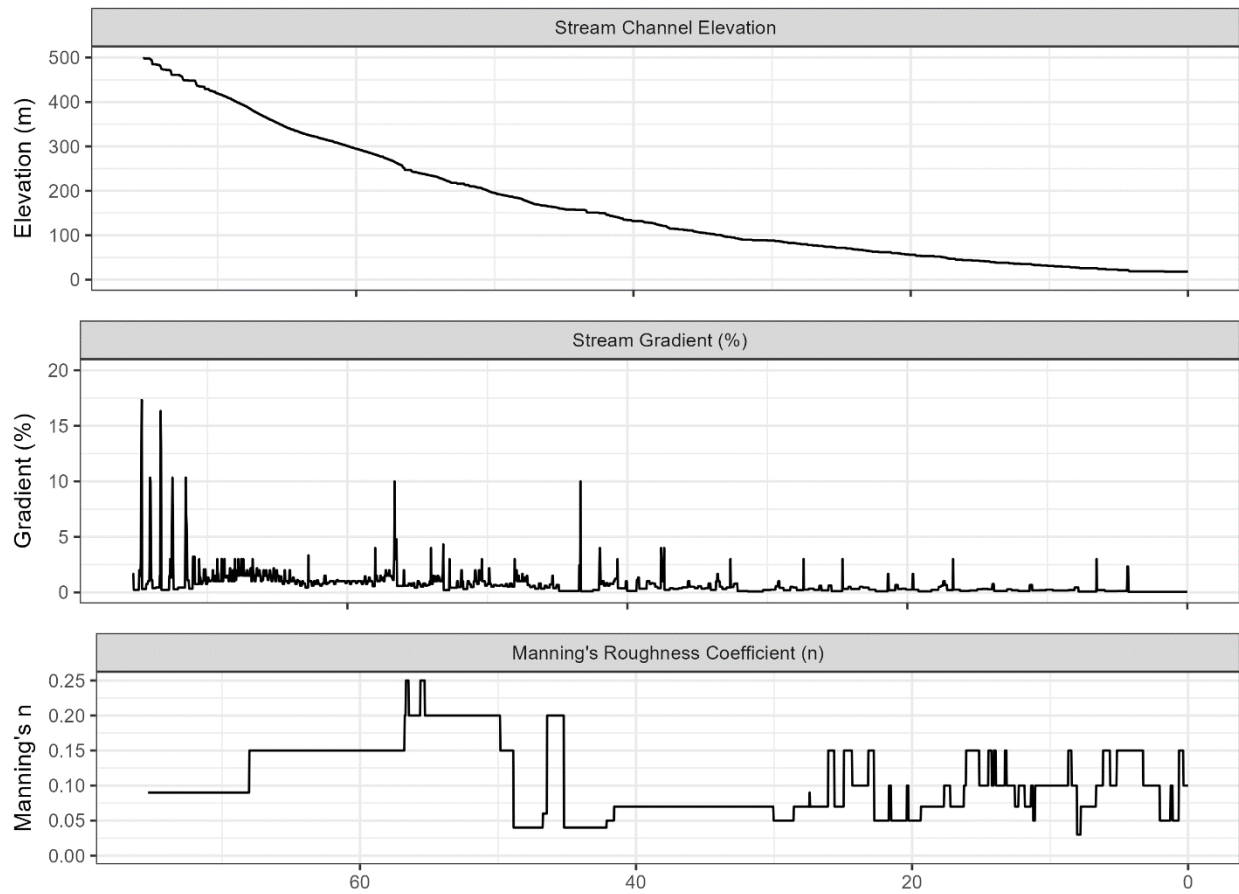
**Figure 3-31: Average land cover height inputs to the Molalla River model.**



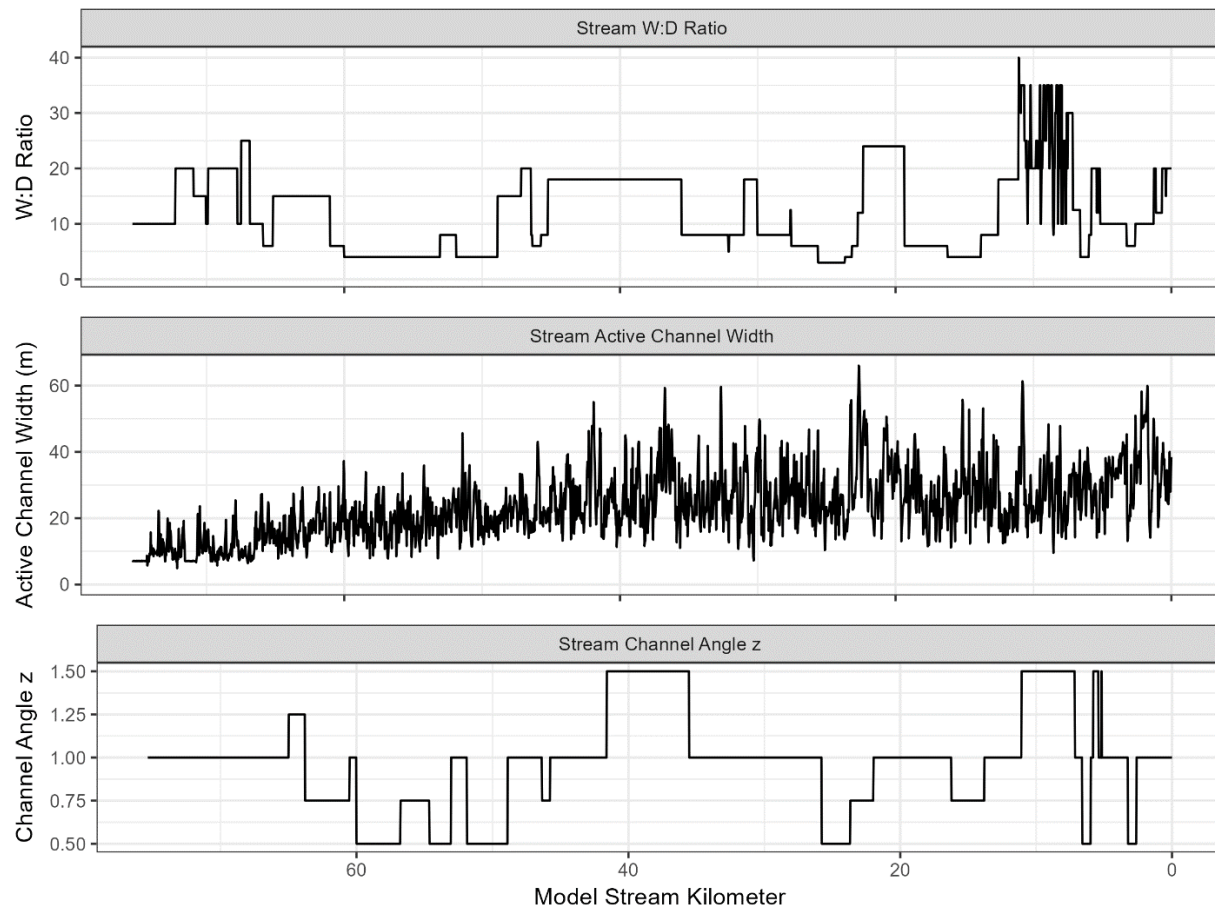
**Figure 3-32: Topographic shade angle inputs to the Molalla River model.**

### 3.2.9 Channel setup

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



(A)



(B)

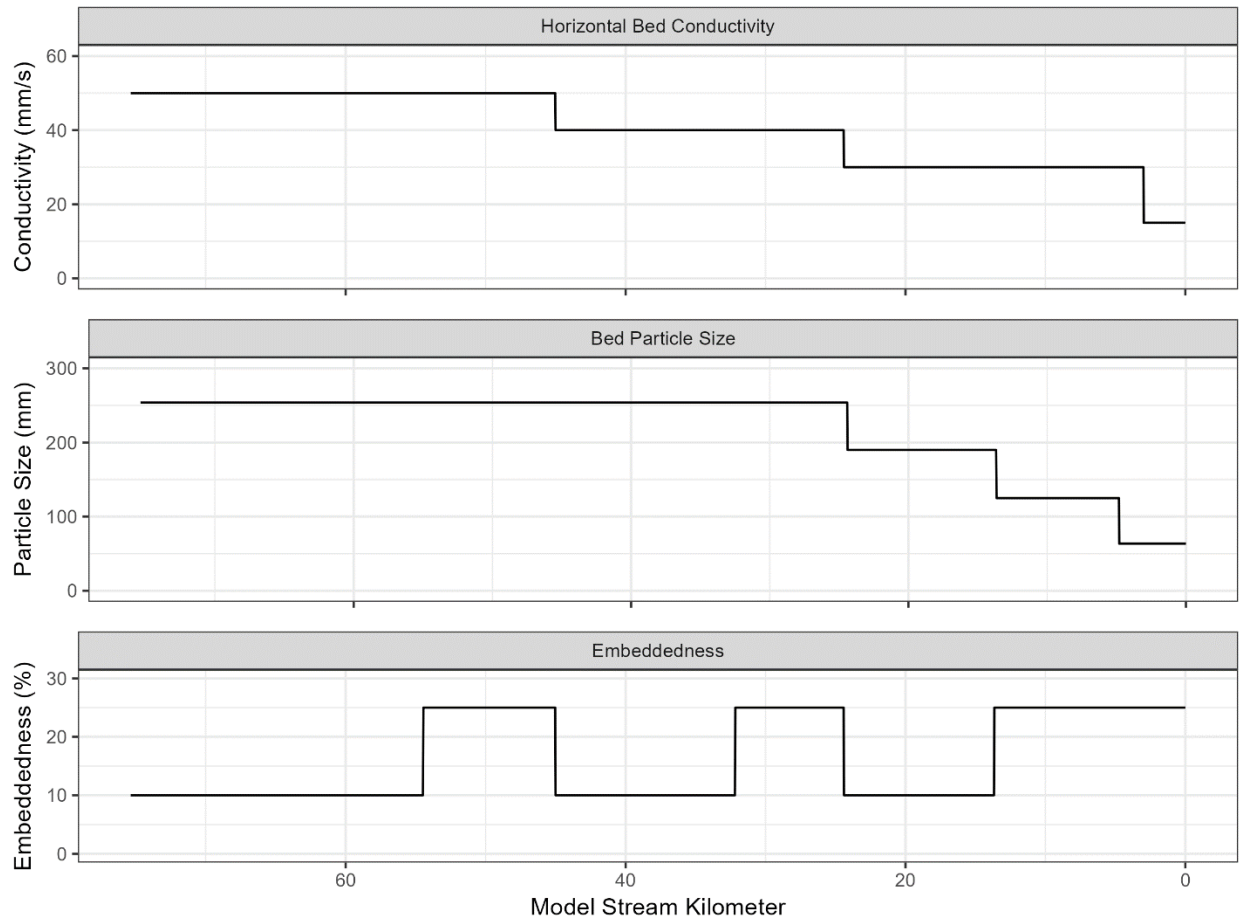
Figure 3-33 (A) and (B): Channel setup in the Molalla River model.

### 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 | $1.51 \times 10^{-9}$ |
| Wind Function, coefficient b | $1.60 \times 10^{-9}$ |



**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

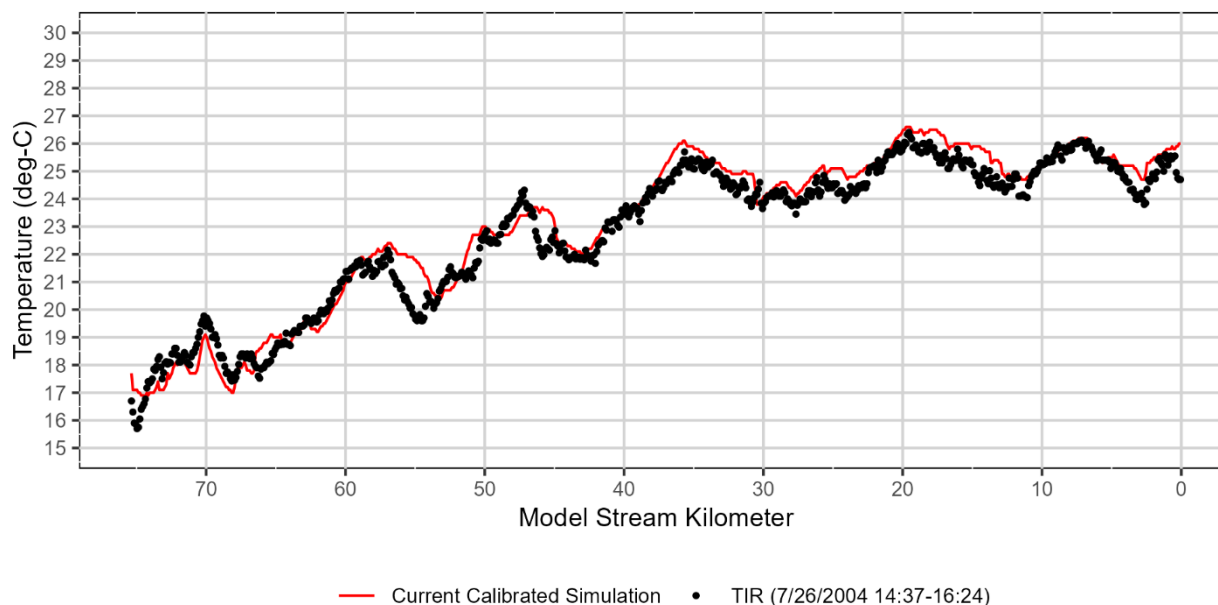
The temperature model was calibrated to the TIR data collected on July 26, 2004, as well as the continuous temperature data collected at several locations along the Molalla River throughout the modeled period. Simulations were performed for a total of 44 stream miles (76 km). Results for goodness of 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 1.0°C.

**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 |

| Monitoring Location  | Model KM | Temperature Statistics    | ME    | MAE  | RMSE | NSE   | n    |
|--|----------|---------------------------|-------|------|------|-------|------|
| 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  |
| 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  |

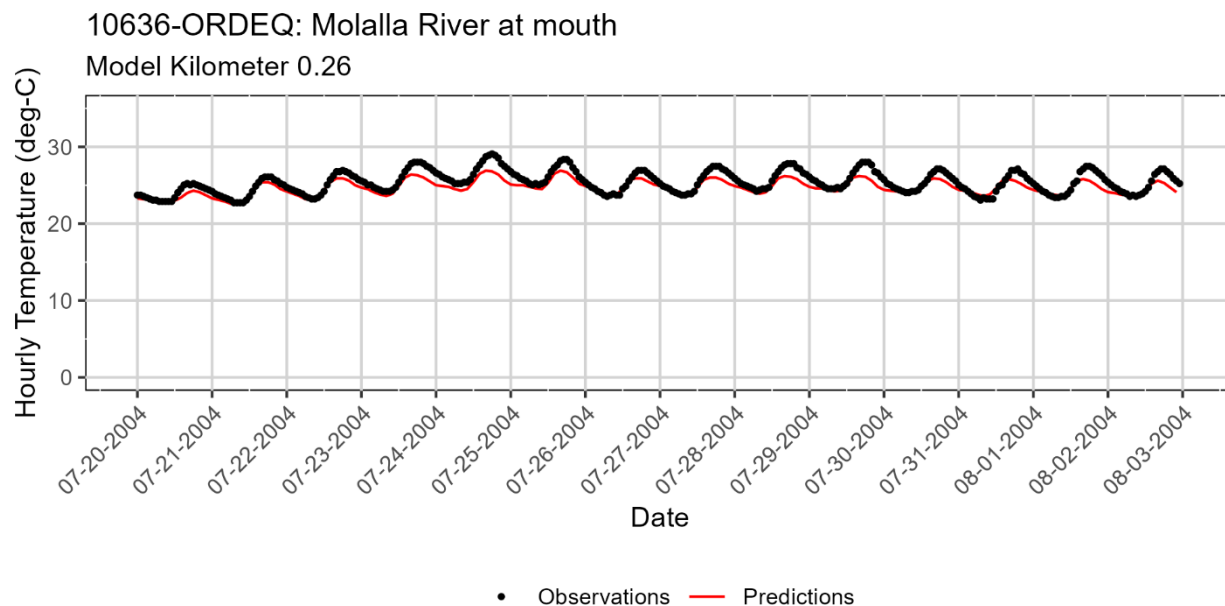
| Monitoring Location  | Model KM     | Temperature Statistics | ME    | MAE  | RMSE | NSE  | n   |
|--|--------------|------------------------|-------|------|------|------|-----|
| 32058-ORDEQ: Molalla River at Canby-Marquam Hwy (Goods Bridge) | 10.46        | Hourly                 | -0.99 | 1.04 | 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 |



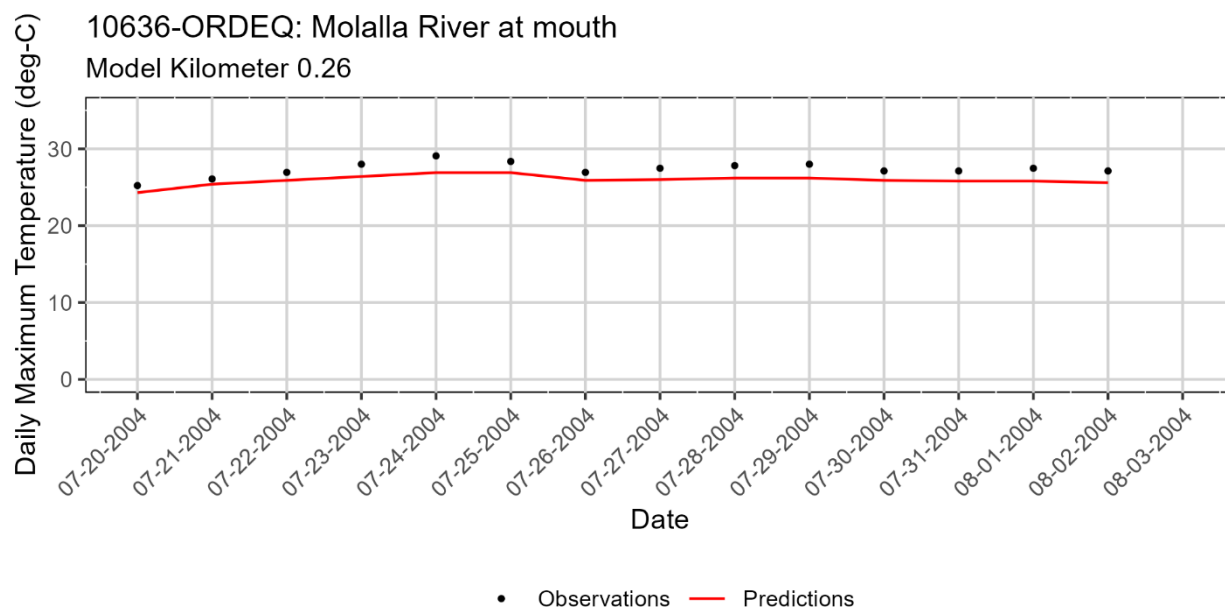
**Figure 3-35: Molalla River TIR and simulated current stream temperatures. Periodic temperature decreases may indicate the influence of cooler tributaries, Springs, seeps, and groundwater interaction.**

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

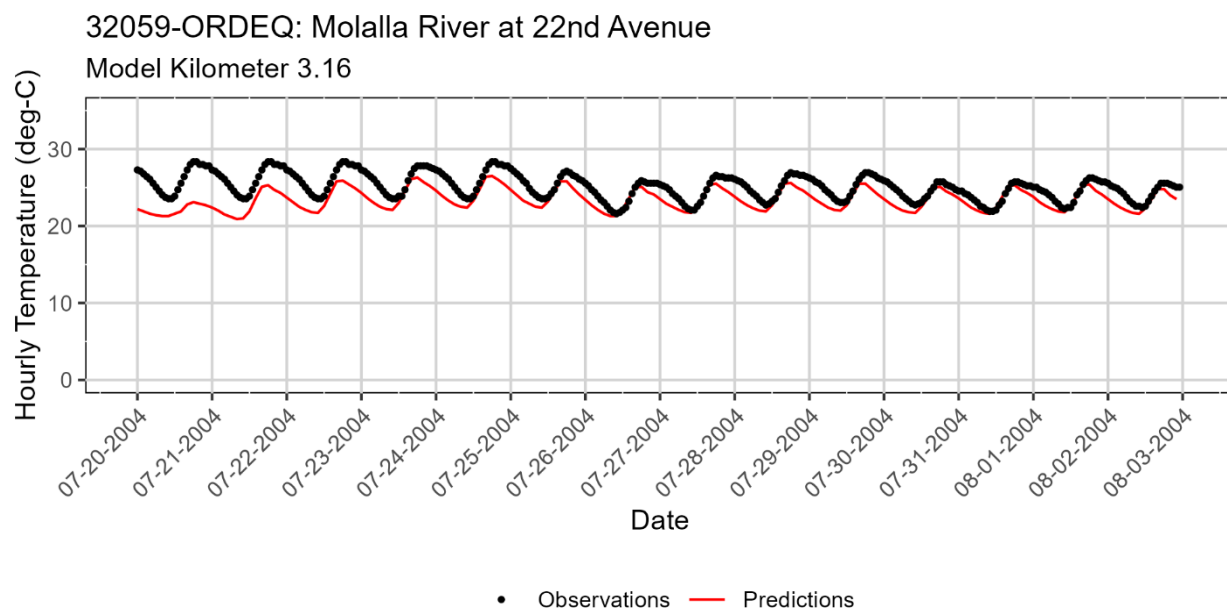
week of the model period (July 27 - August 2). In particular, maximum measured air temperatures on July 23, 24, and 25 were near or exceeding 38°C (100°F). Possibly, the model is not as sensitive to spikes in air temperature as is the stream itself. The wide stream conditions in the lower river may respond 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**.



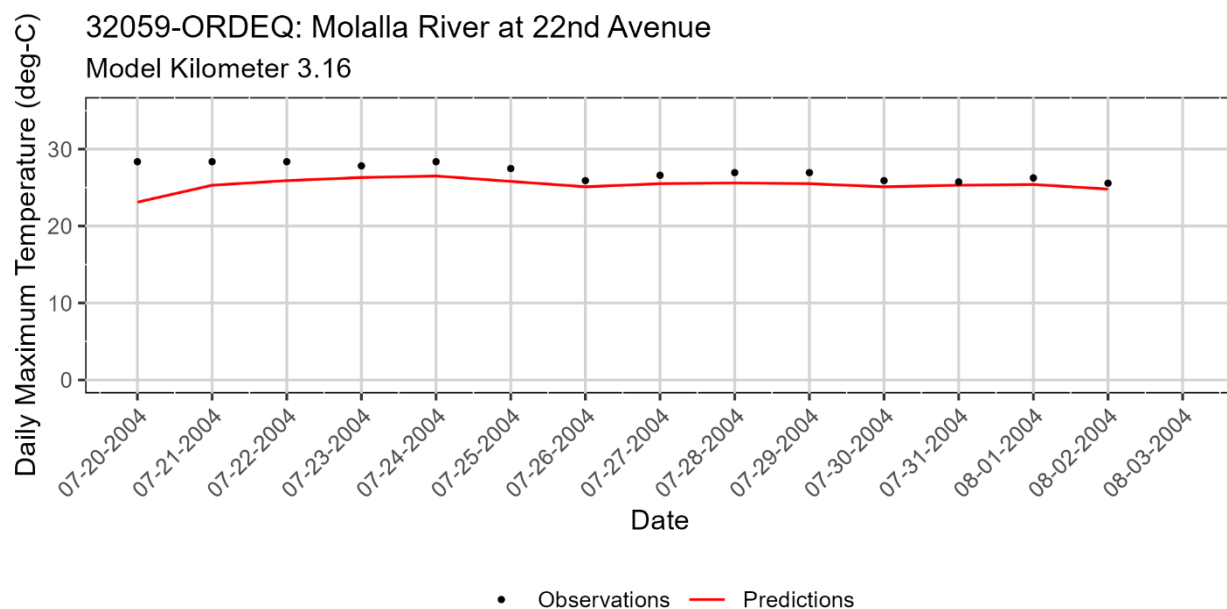
**Figure 3-36: Molalla River measured and model-predicted hourly temperatures at monitoring station 10636-ORDEQ.**



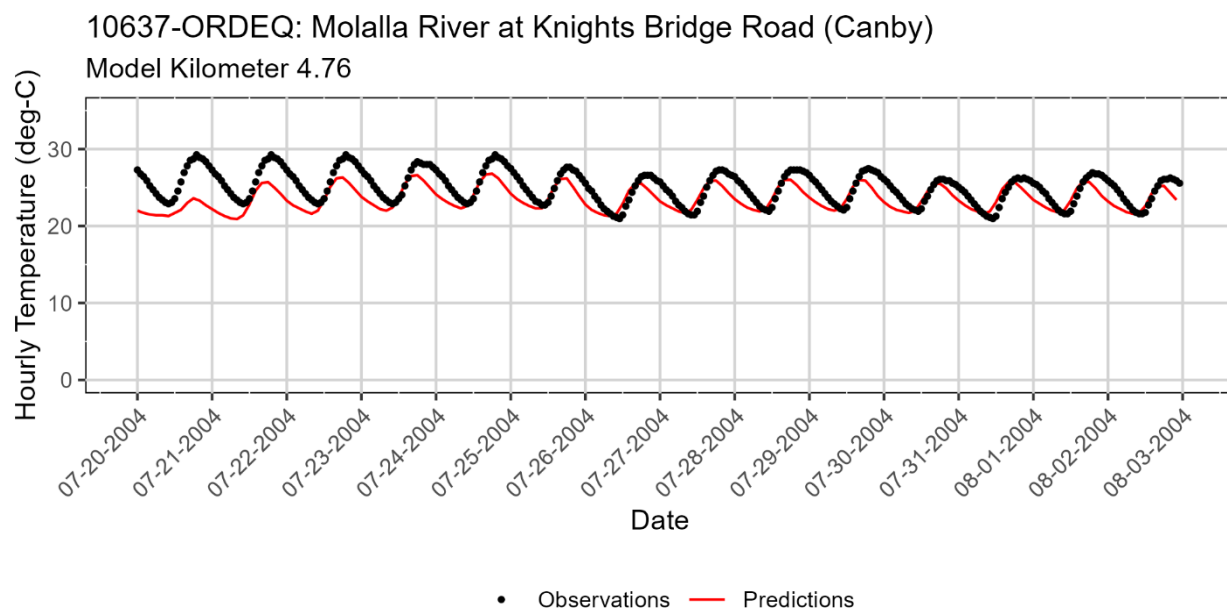
**Figure 3-37: Molalla River measured and model-predicted daily maximum temperatures at monitoring station 10636-ORDEQ.**



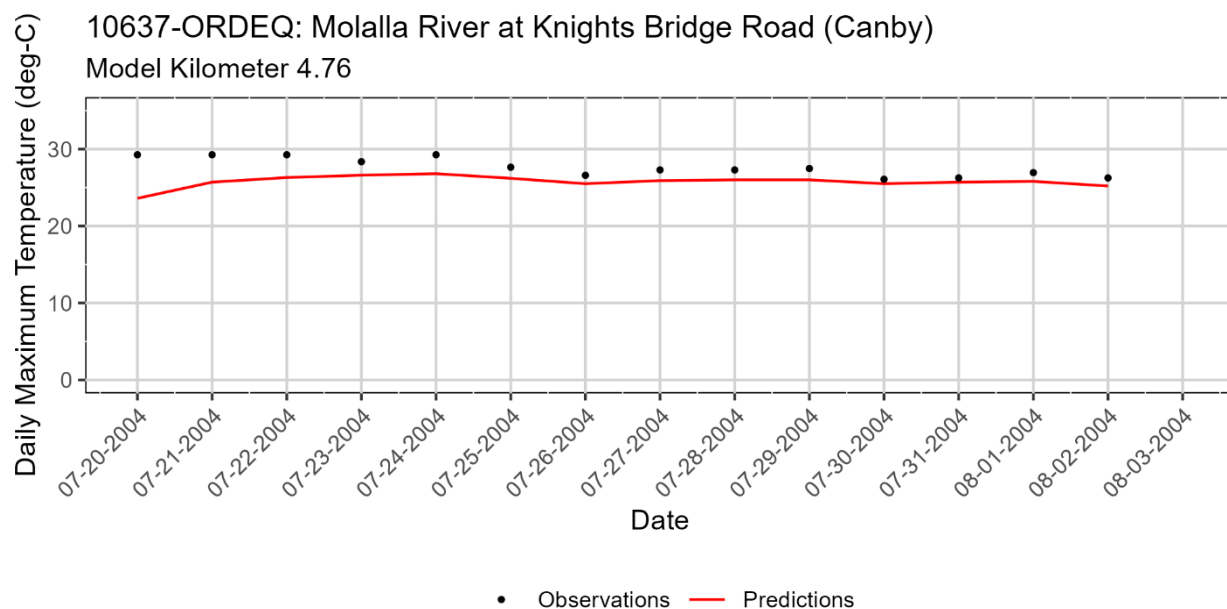
**Figure 3-38: Molalla River measured and model-predicted hourly temperatures at monitoring station 32059-ORDEQ.**



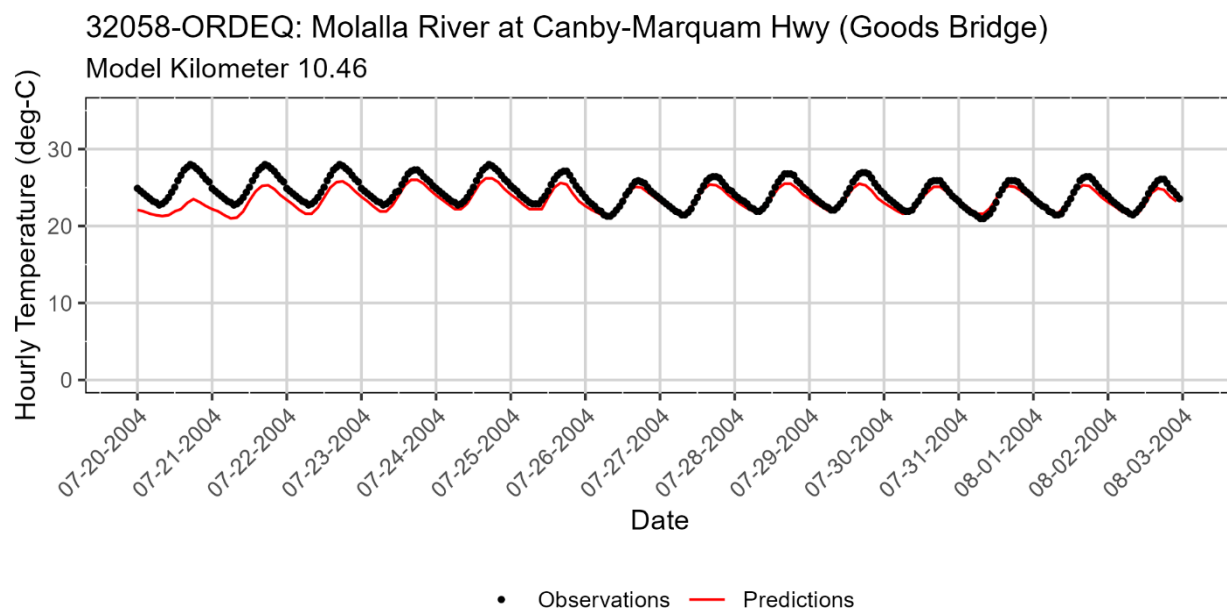
**Figure 3-39: Molalla River measured and model-predicted daily maximum temperatures at monitoring station 32059-ORDEQ.**



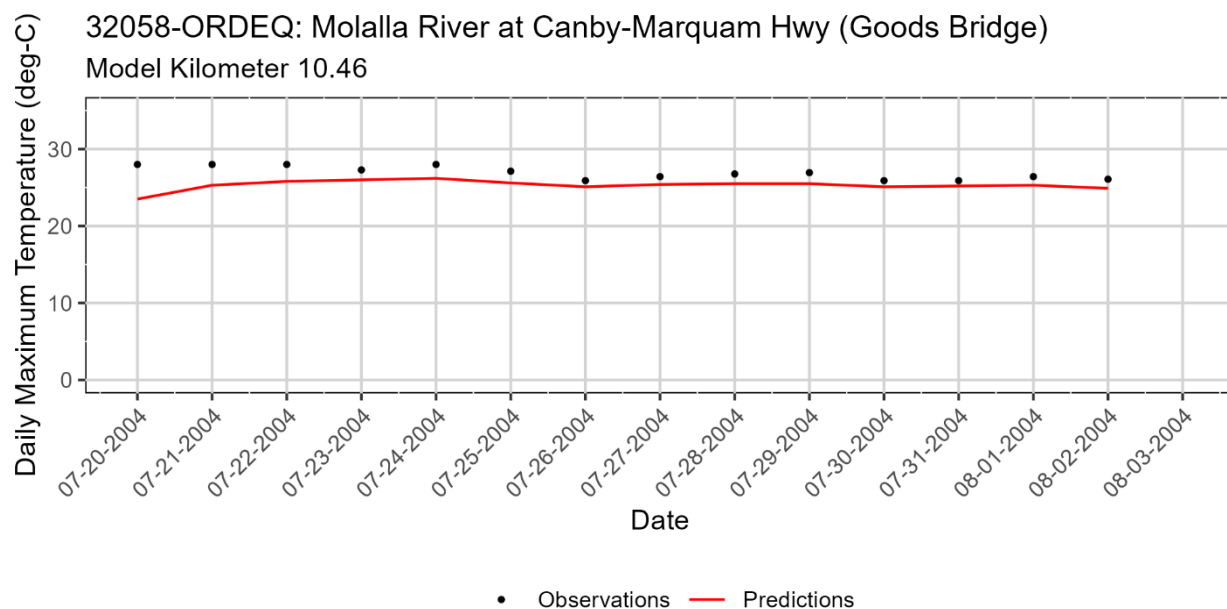
**Figure 3-40: Molalla River measured and model-predicted hourly temperatures at monitoring station 10637-ORDEQ.**



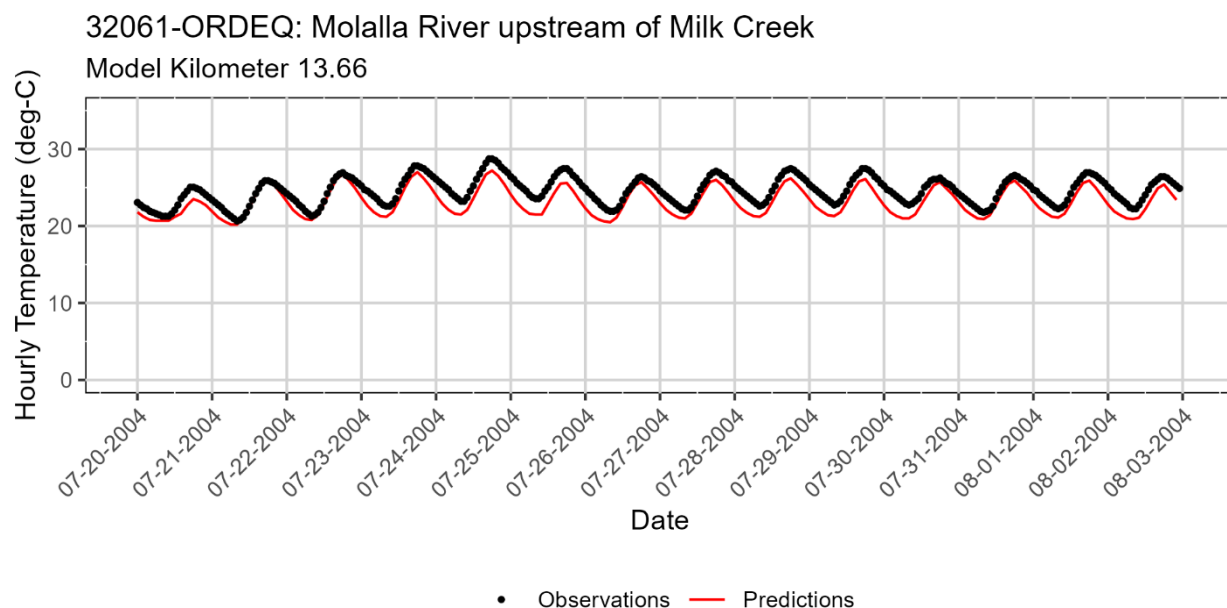
**Figure 3-41: Molalla River measured and model-predicted daily maximum temperatures at monitoring station 10637-ORDEQ.**



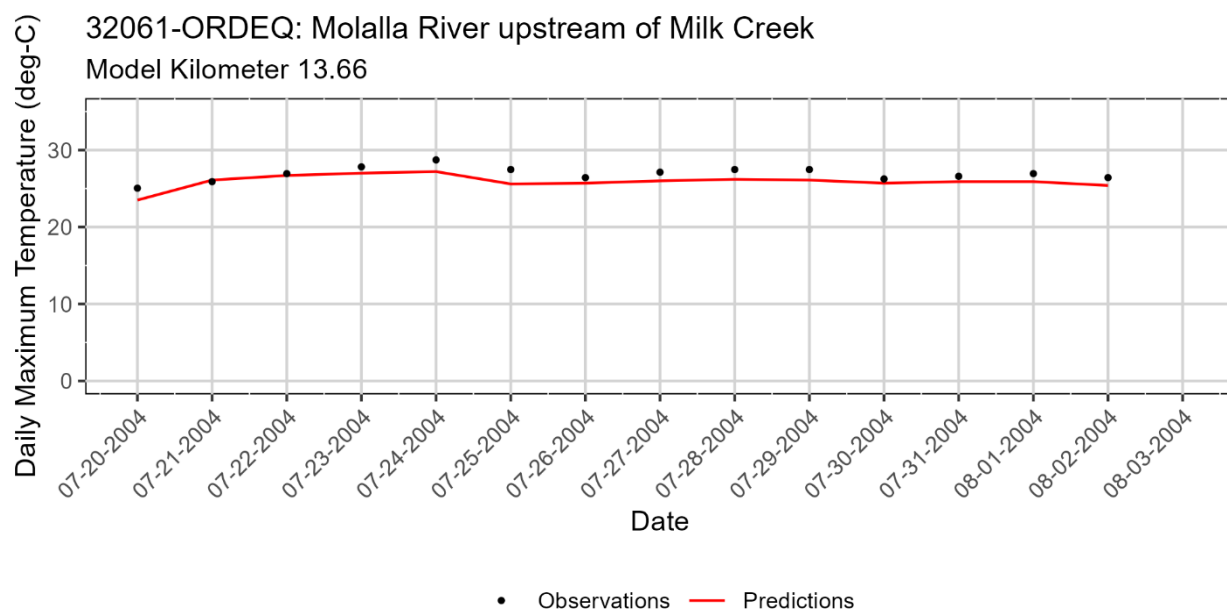
**Figure 3-42: Molalla River measured and model-predicted hourly temperatures at monitoring station 32058-ORDEQ.**



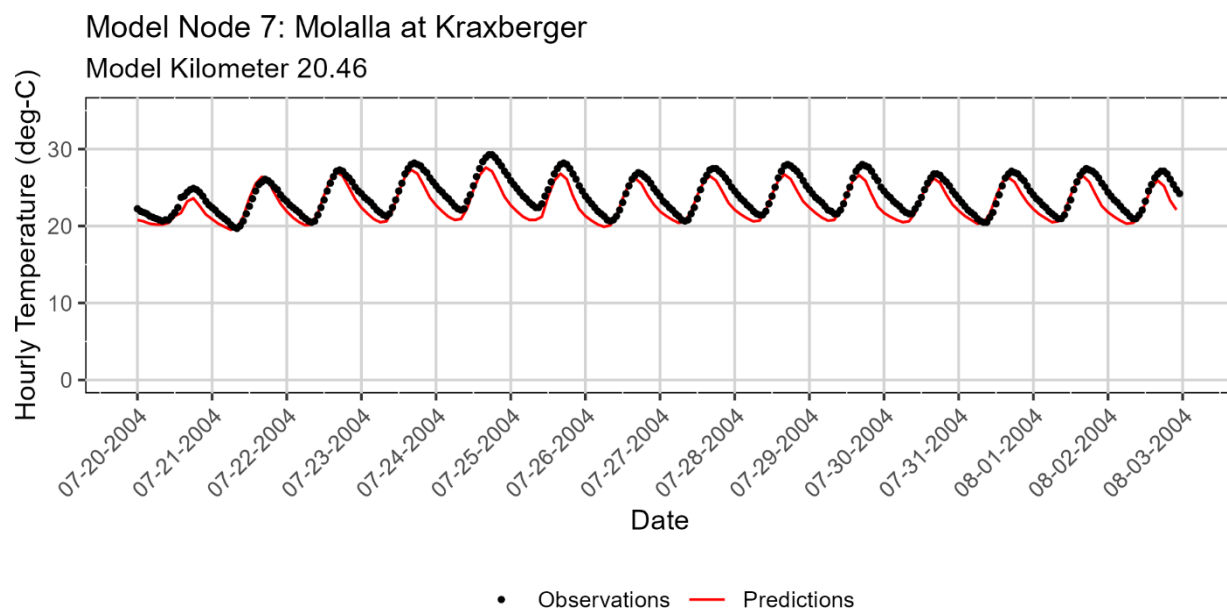
**Figure 3-43: Molalla River measured and model-predicted daily maximum temperatures at monitoring station 32058-ORDEQ.**



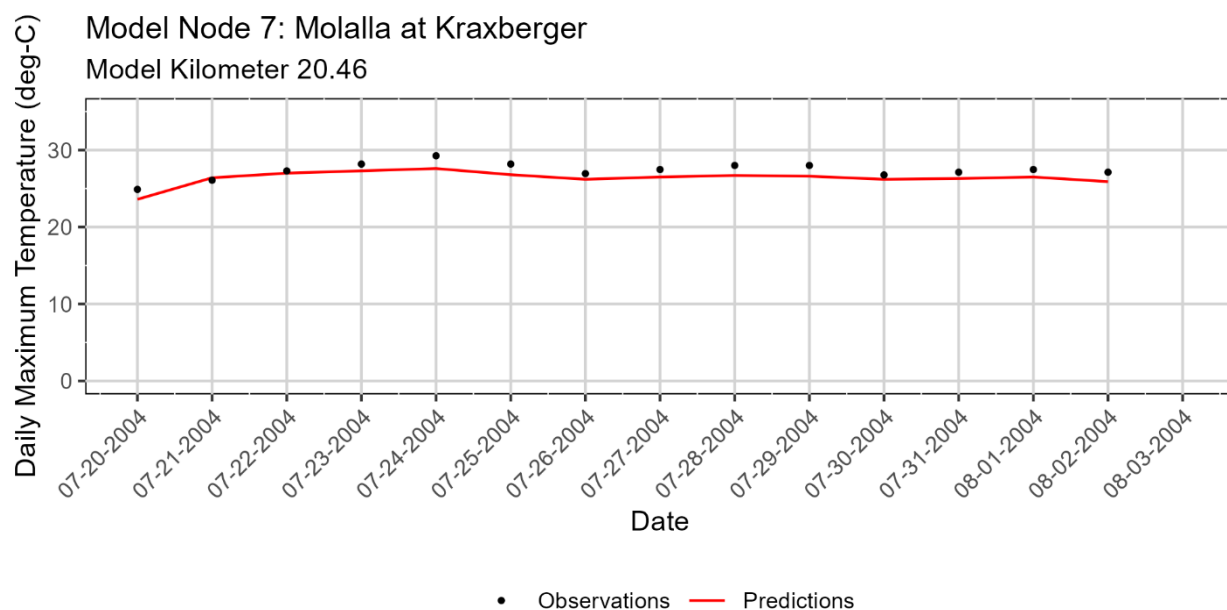
**Figure 3-44: Molalla River measured and model-predicted hourly temperatures at monitoring station 32061-ORDEQ.**



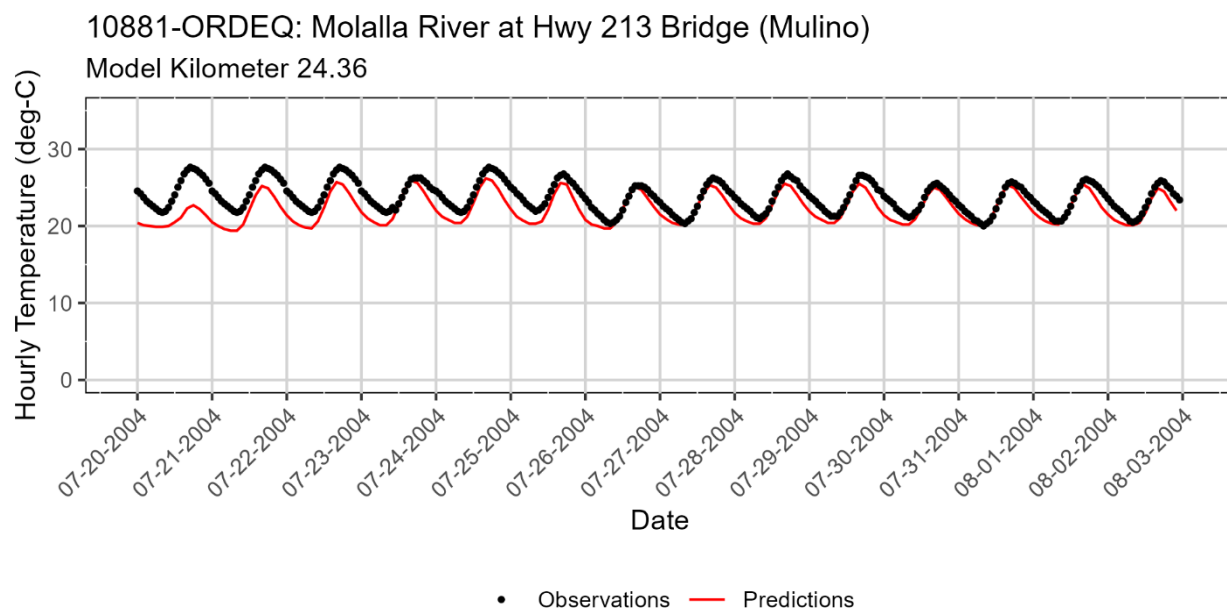
**Figure 3-45: Molalla River measured and model-predicted daily maximum temperatures at monitoring station 32061-ORDEQ.**



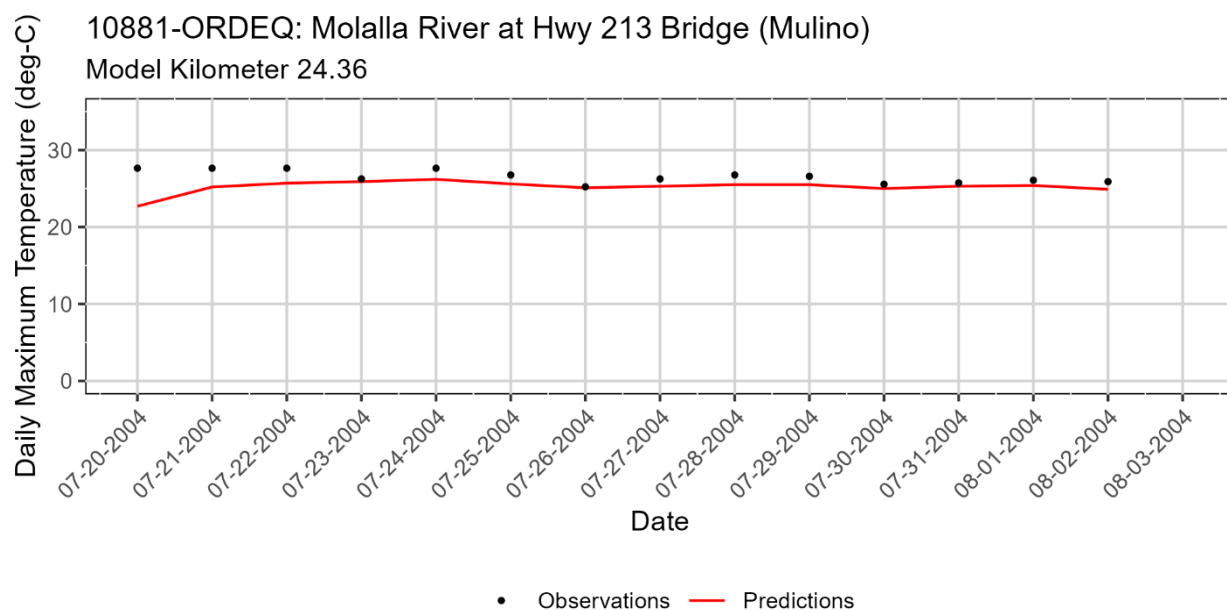
**Figure 3-46: Molalla River measured and model-predicted hourly temperatures at monitoring station Model Node 7.**



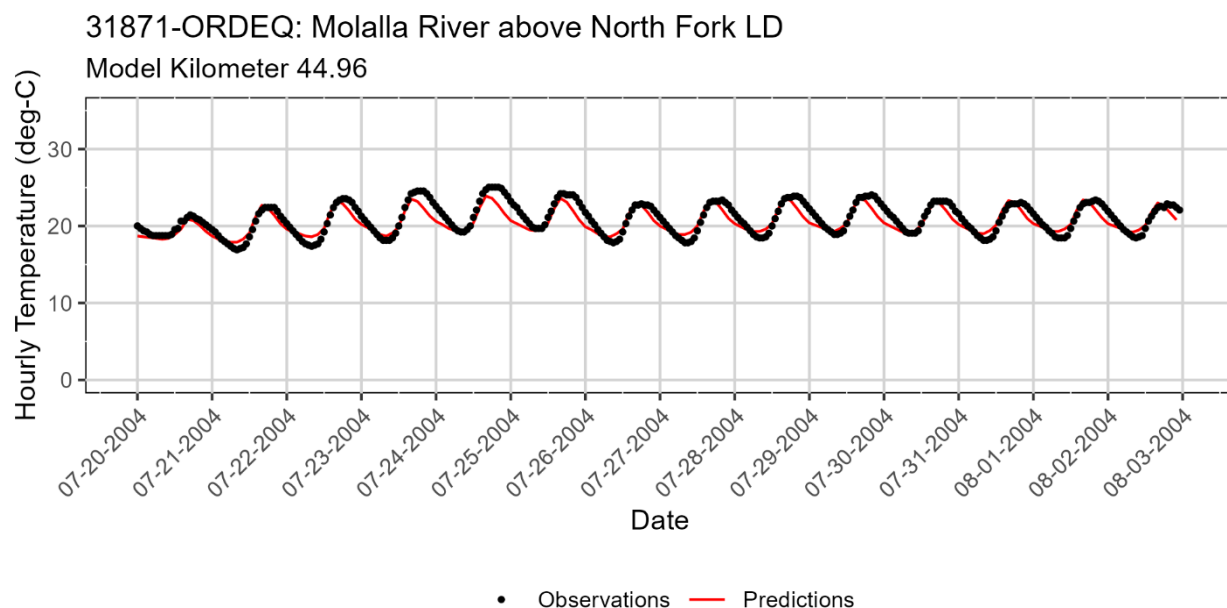
**Figure 3-47: Molalla River measured and model-predicted daily maximum temperatures at monitoring station Model Node 7.**



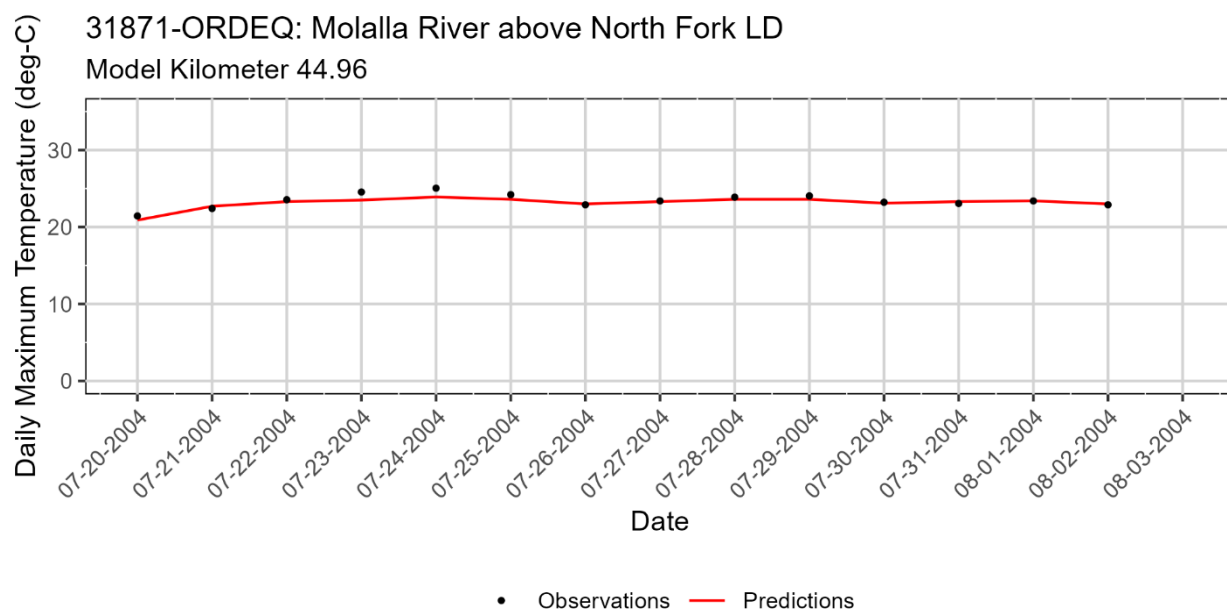
**Figure 3-48: Molalla River measured and model-predicted hourly temperatures at monitoring station 10881-ORDEQ.**



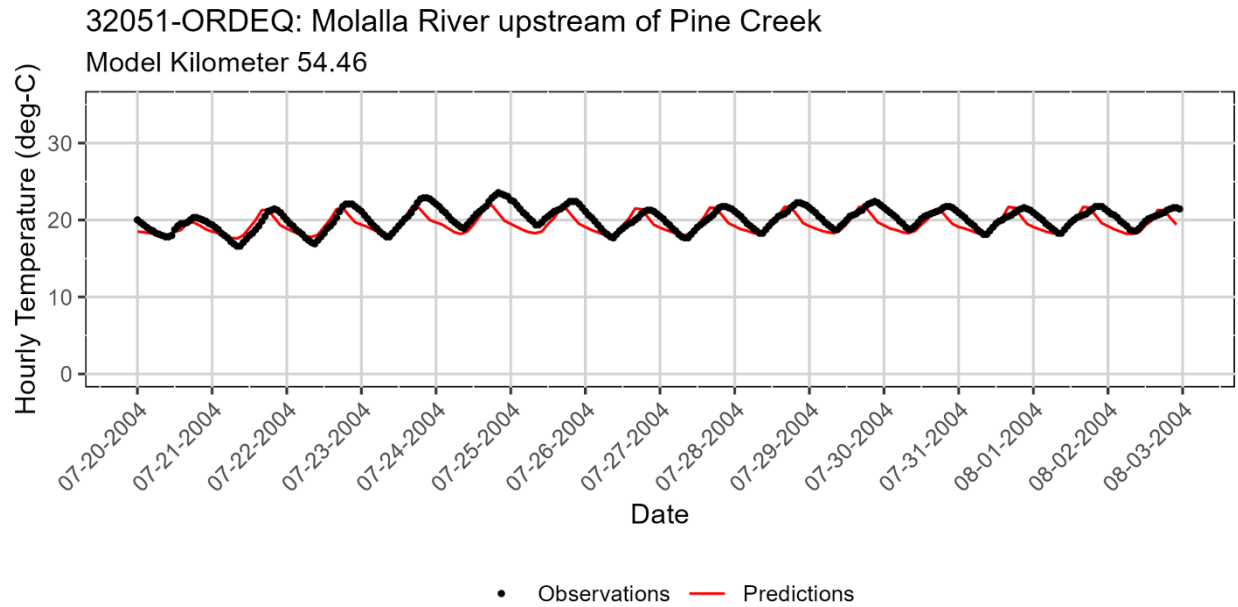
**Figure 3-49: Molalla River measured and model-predicted daily maximum temperatures at monitoring station 10881-ORDEQ.**



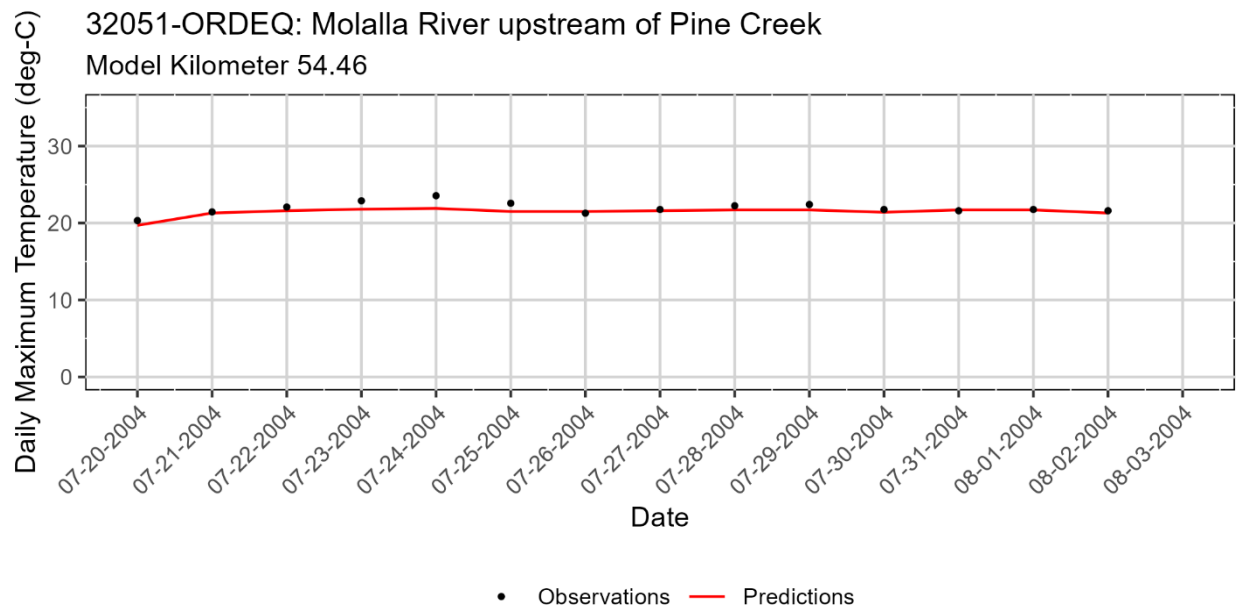
**Figure 3-50: Molalla River measured and model-predicted hourly temperatures at monitoring station 31871-ORDEQ.**



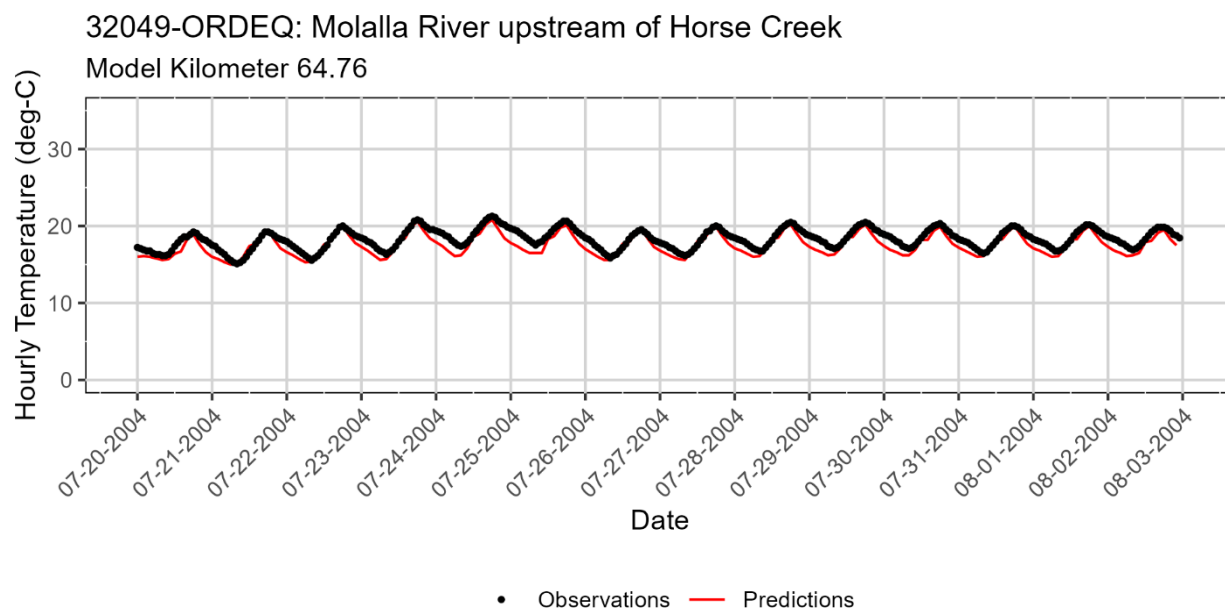
**Figure 3-51: Molalla River measured and model-predicted daily maximum temperatures at monitoring station 31871-ORDEQ.**



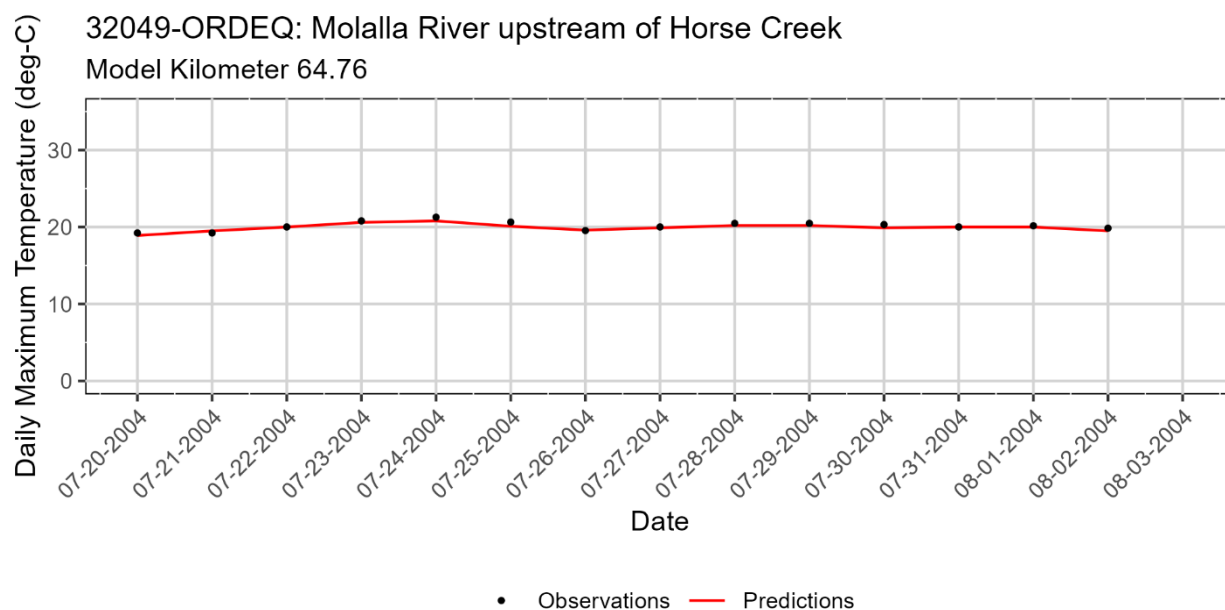
**Figure 3-52: Molalla River measured and model-predicted hourly temperatures at monitoring station 32051-ORDEQ.**



**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

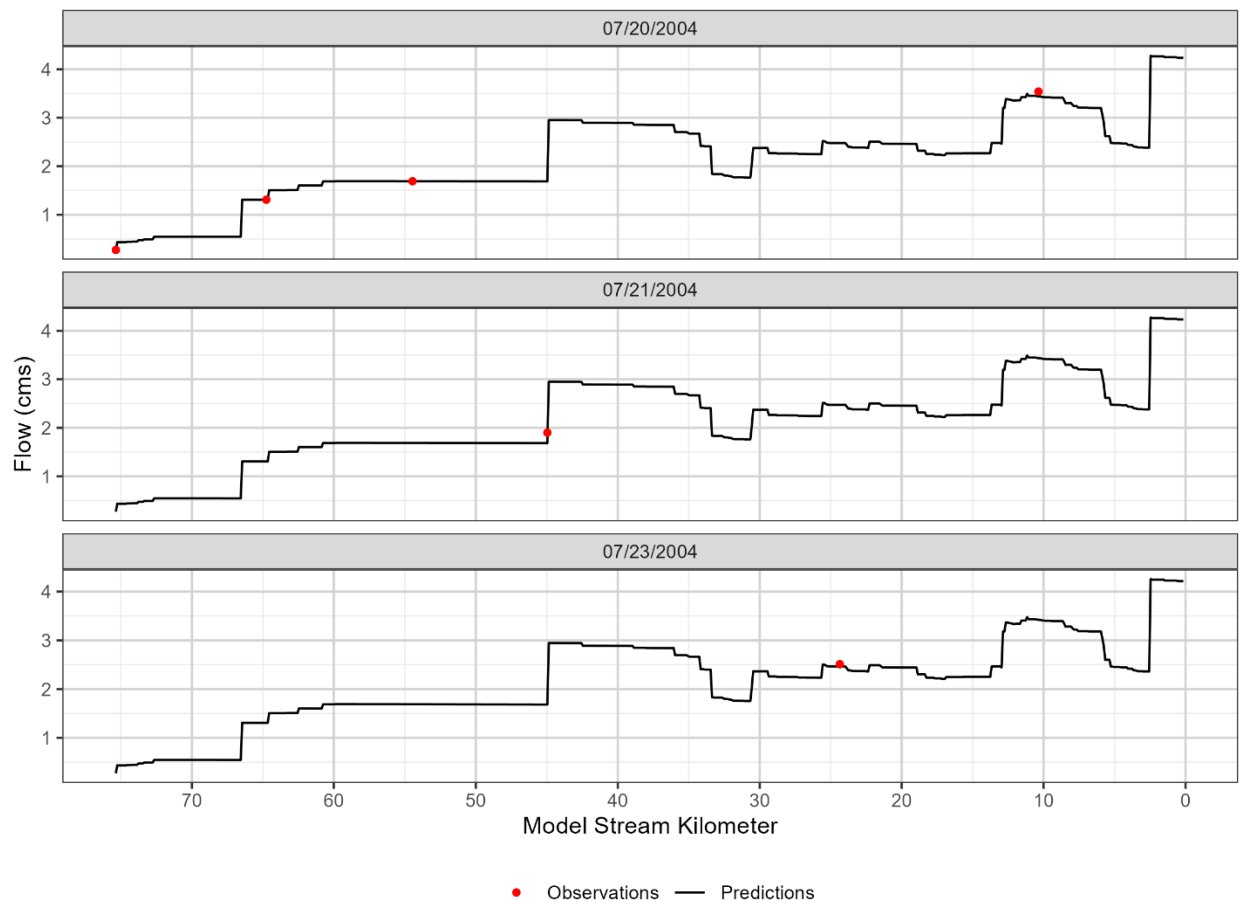
The Molalla River modeled longitudinal stream discharge based on measured flows, OWRD points of diversion (POD) data, and mass balance estimates are presented with measured discharge points in **Figure 3-56**. Stream discharge measurements were collected on July 20, 21 and 23, 2004, and these measurements 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 22<sup>nd</sup>, 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 <sup>2</sup> | ME    | MAE  | RMSE |
|---|----------------|-------|------|------|
| 6 | 0.99           | -0.06 | 0.06 | 0.1  |

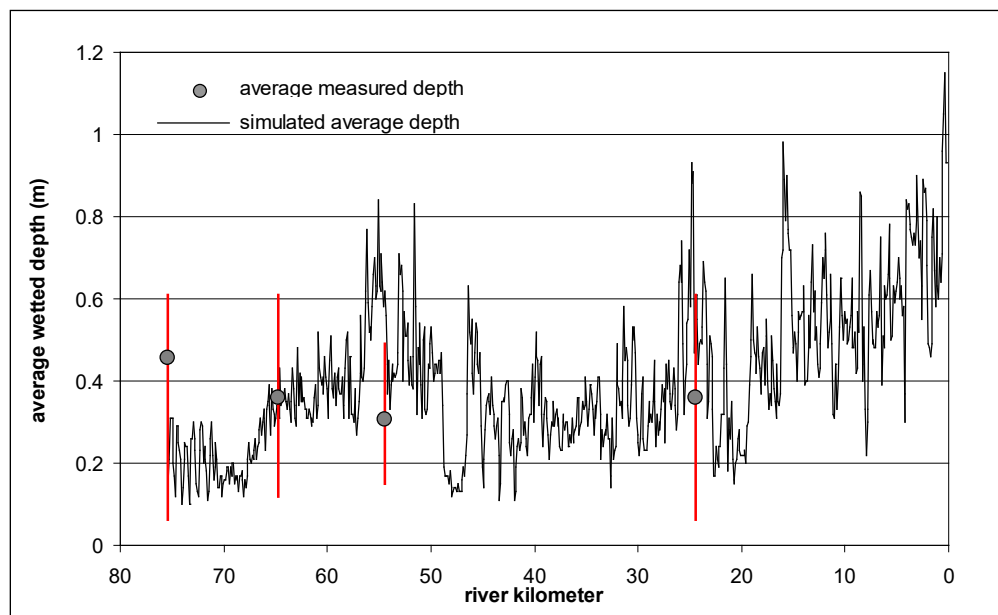
### 3.2.11.3 Channel

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.

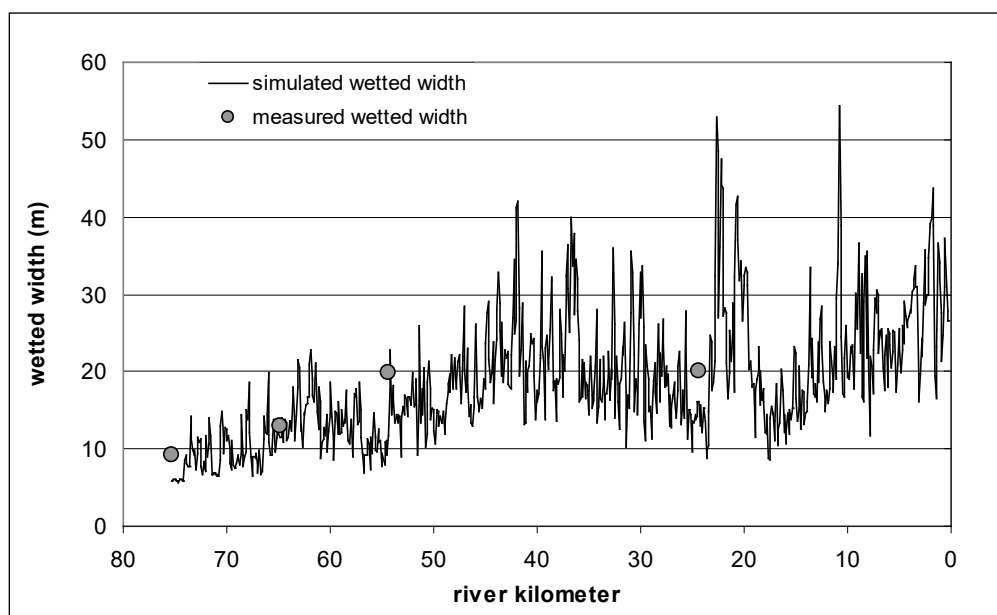
Results comparing channel widths derived from GIS and modeling to those measured in the field are presented in **Figure 3-58**. The wetted width measurements agree with the simulated measurements reasonably well.

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.

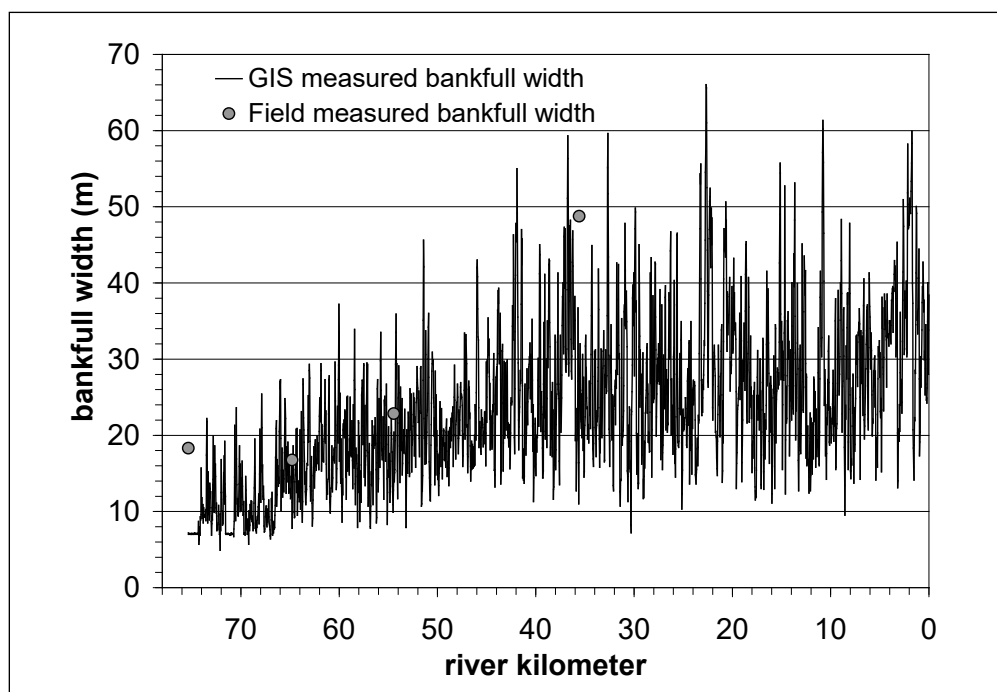
**Figure 3-60** illustrates a comparison of the GIS-measured bankfull width with the simulated wetted width. The wetted width is a model-calculated characteristic based on the channel shape and the amount of stream flow. One would expect the wetted width to be less than the bankfull width, but follow 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.**

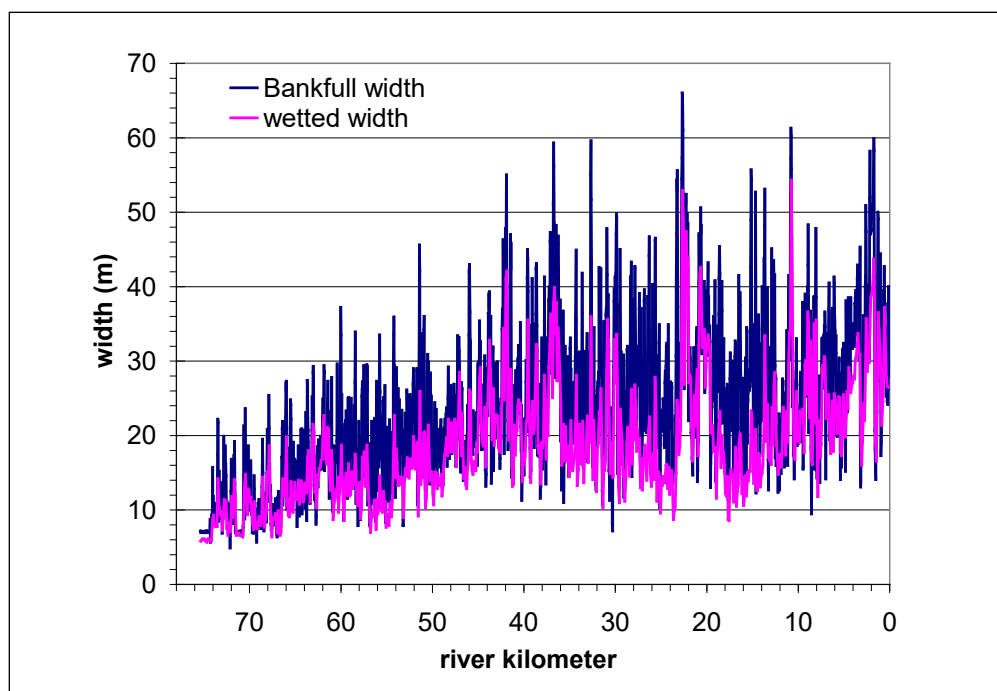


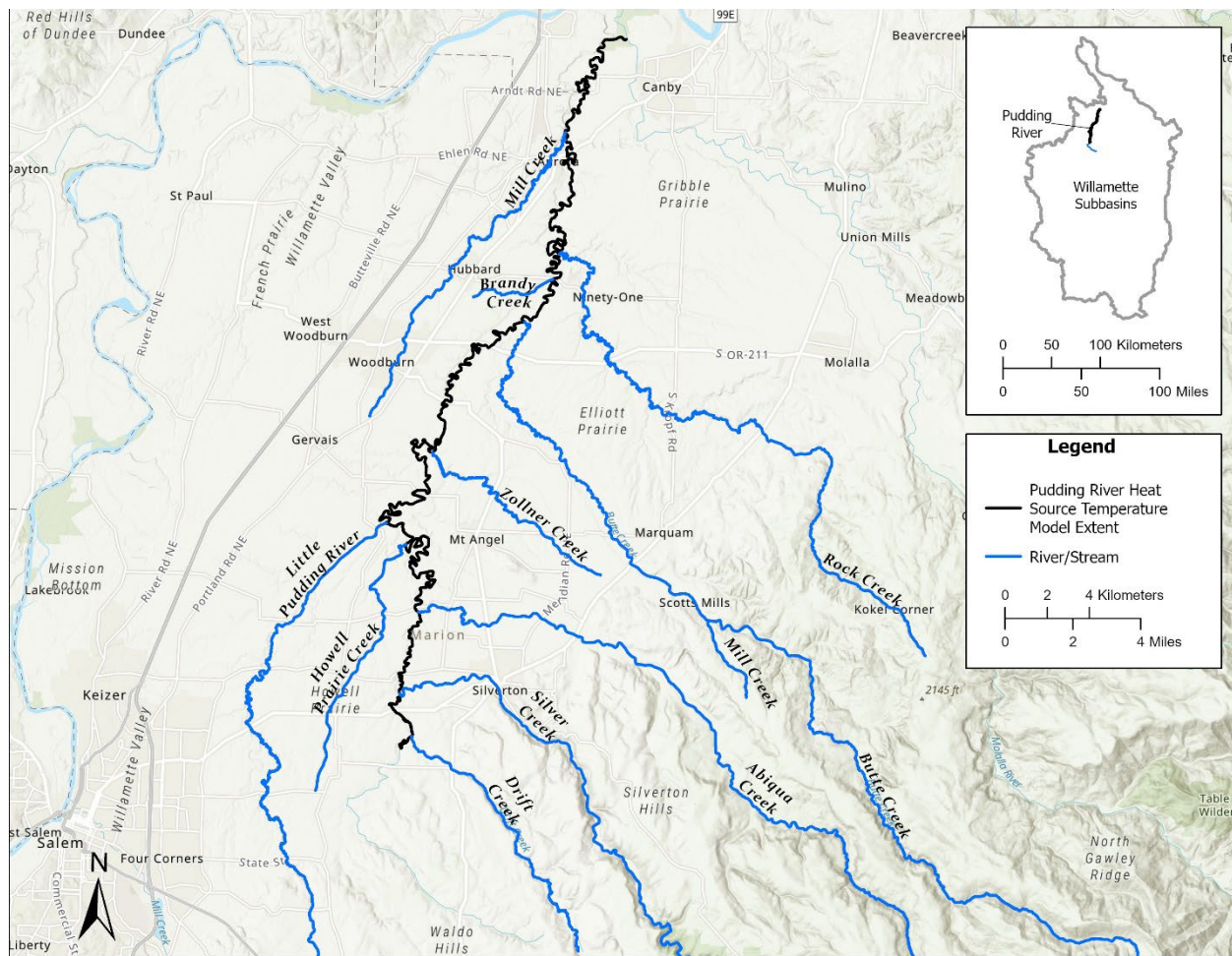
Figure 3-60: Comparison of bankfull width and simulated wetted width of the Molalla River.

## 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.

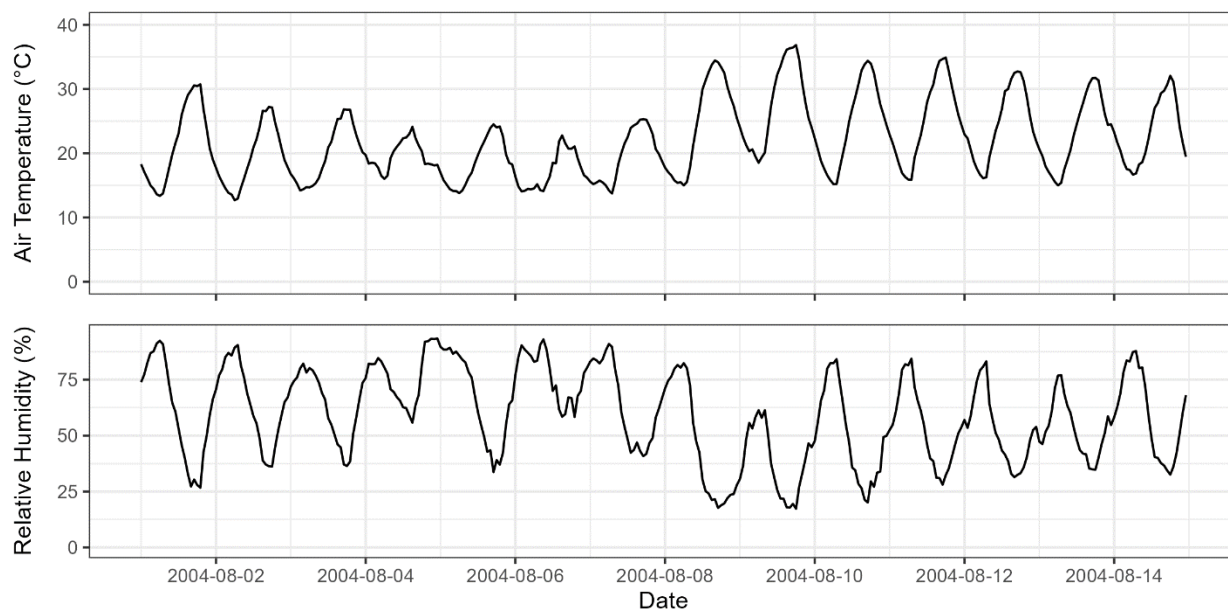
### 3.3.4 Meteorological inputs

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 |

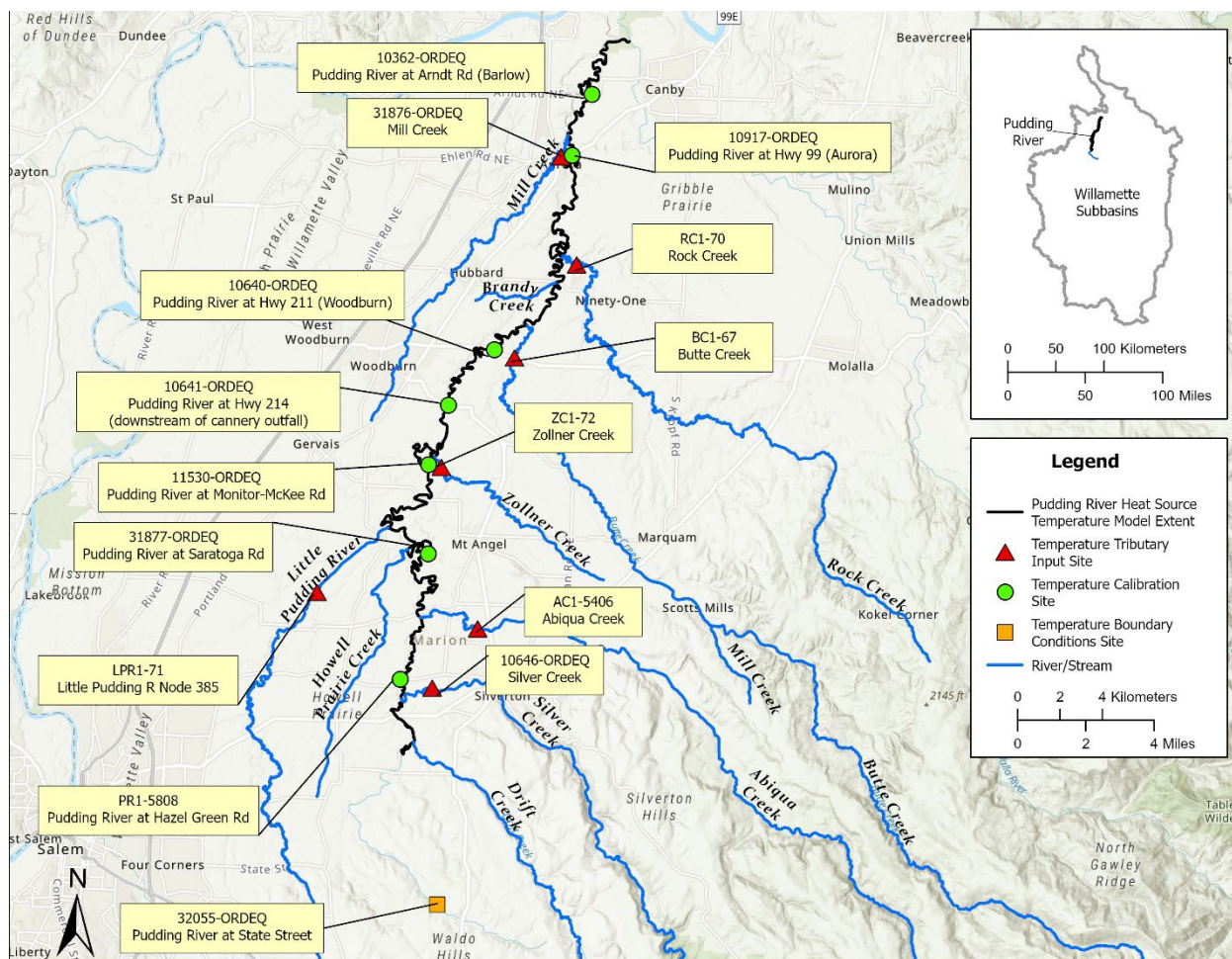
| Model Location Name         | Model Location (kilometers)             | Model Input | Data Source |
|-----------------------------|---|-------------|-------------|
| KUAO - Aurora State Airport | 7.7, 12.4, 36.2, 43.7, 51.7, 66.3, 79.6 | Cloudiness  | NWS         |



**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.**

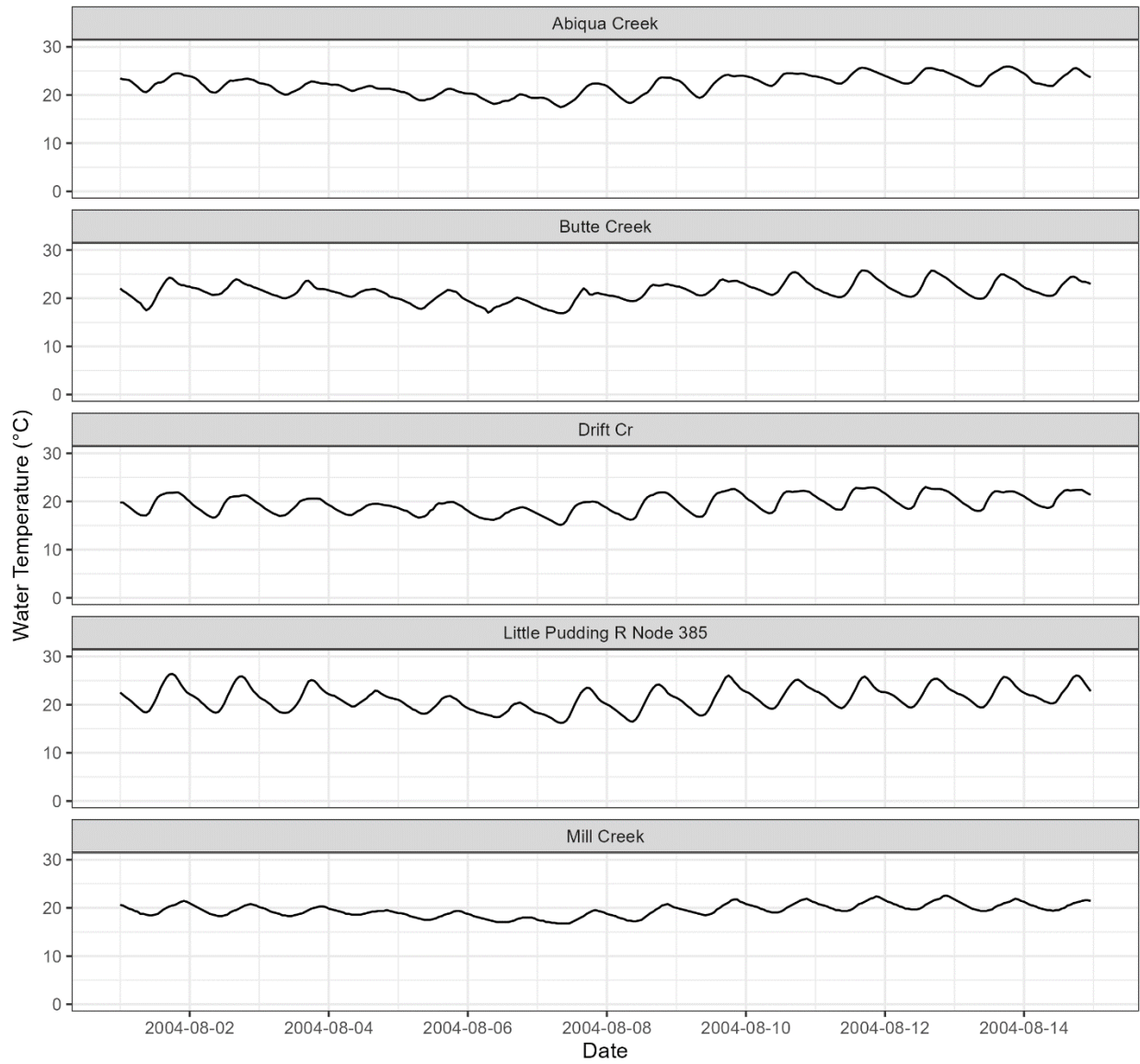
**Table 3-18** and **Figure 3-64** document the water temperature inputs to the model at the boundary condition (Pudding River at State Street) and tributaries.

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

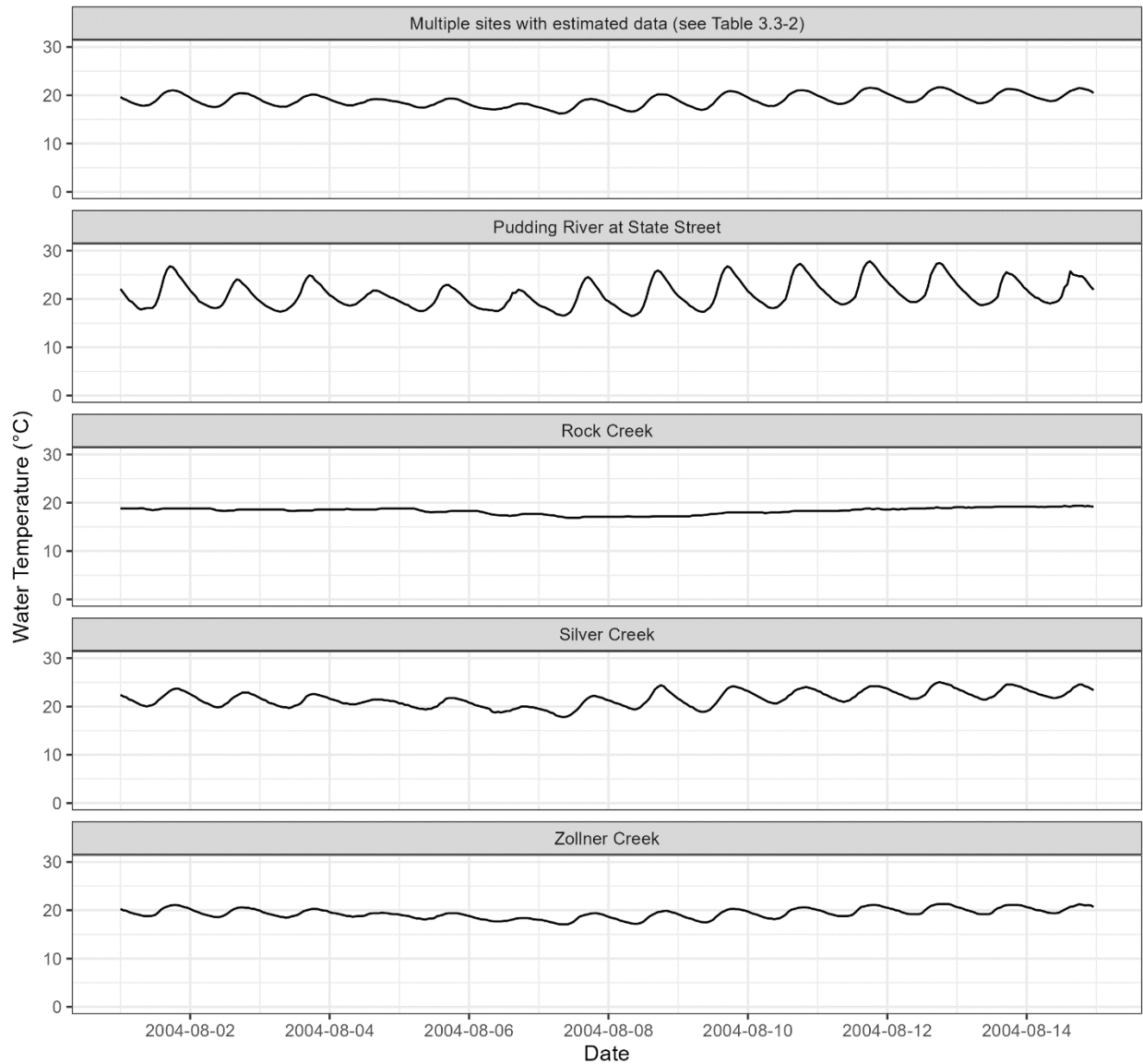
| Model Location Name  | Model Location (kilometers) | Input Type         | Data Source  |
|--|-----------------------------|--------------------|--|
| Pudding River at State Street  | 84.6                        | Boundary Condition | 32055-ORDEQ  |
| Drift Cr   | 84.5                        | Tributary          | 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*  |
| 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*  |

| Model Location Name   | Model Location (kilometers) | Input Type | Data Source            |
|---|-----------------------------|------------|------------------------|
| 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.



(A)

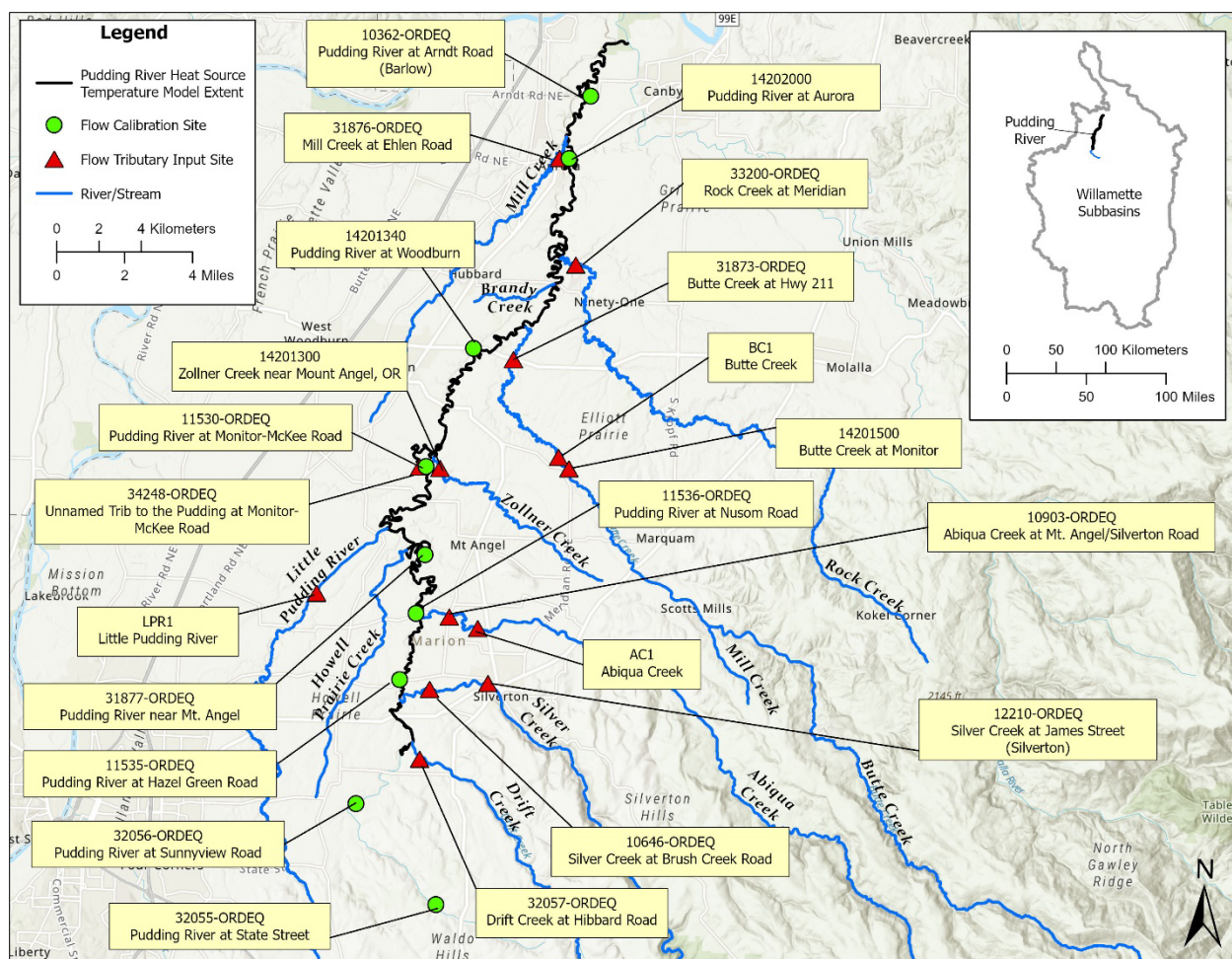


(B)

**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 | 1 <sup>st</sup> percentile (cfs) | 10 <sup>th</sup> 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<sup>2</sup>, 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<sup>2</sup>. 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<sup>2</sup>.

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<sup>2</sup> (**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<sup>2</sup> 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**.

$$Q_{R,Natural} = F_{cali} \left( \frac{Q_{R,AugMedian}}{Q_{R,LittleAbiquaCr,AugMedian}} \right) Q_{R,LittleAbiquaCr} \quad \text{Equation 3-2}$$

where,

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

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.

$$CU = F_{\%ofNormal} \times F_{\%ConsumedNormal} \times Q_{R, Natural, min} \quad \text{Equation 3-3}$$

where,

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

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.

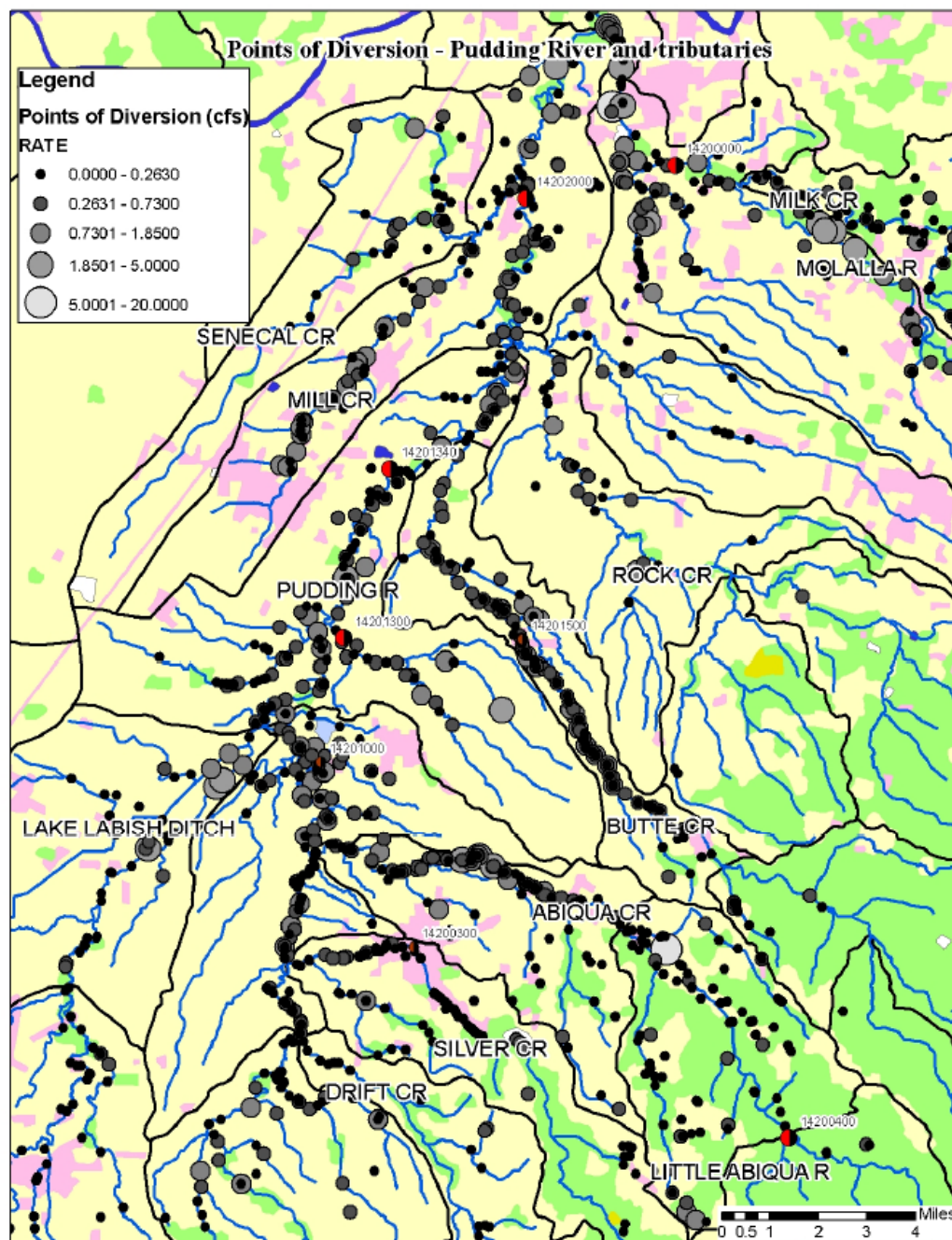
$$Q_{R, Tributary} = Q_{R, Natural} - CU \quad \text{Equation 3-4}$$

where,

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

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.

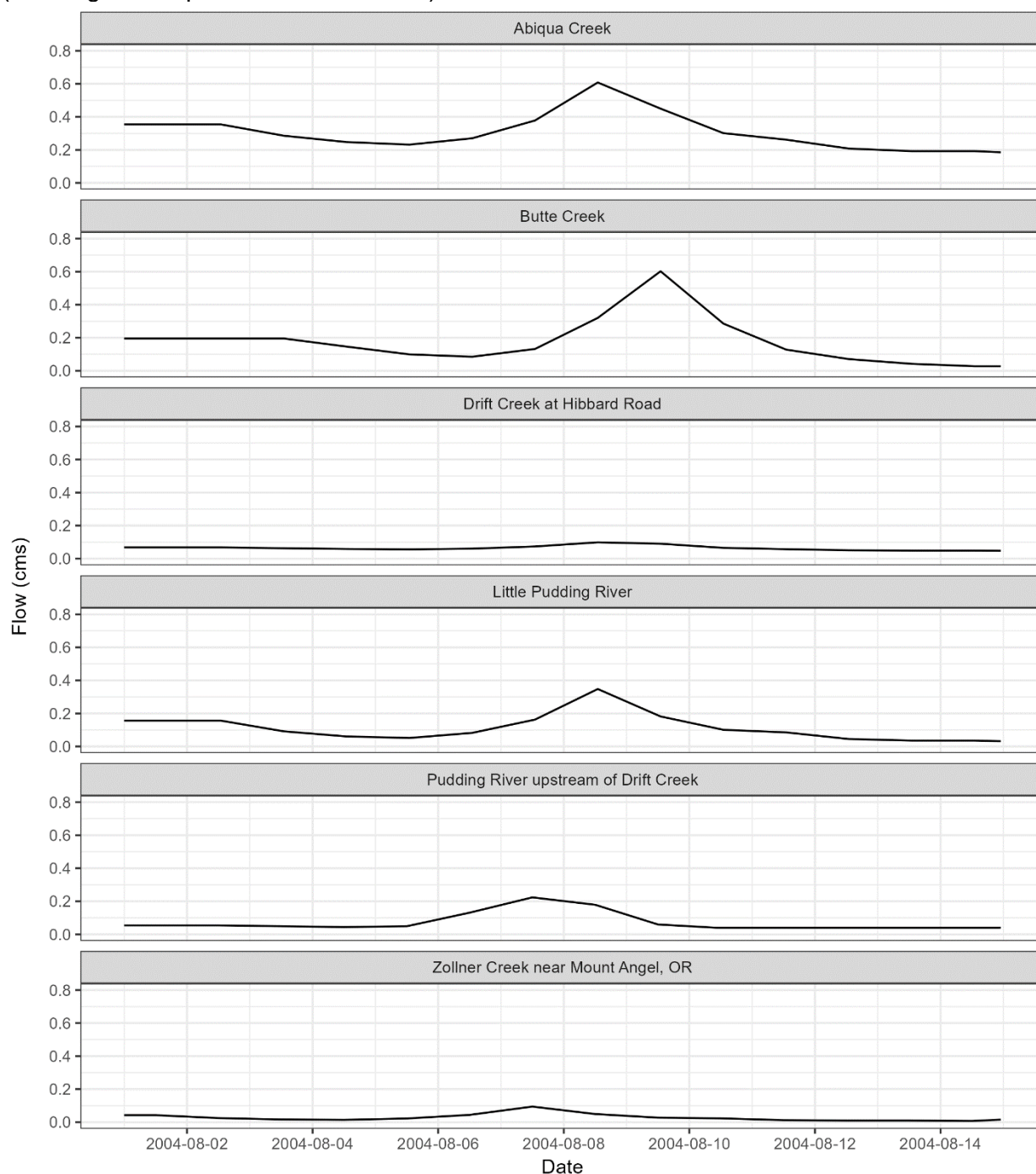
For Silver Creek, OWRD water availability reports indicate that the median August consumptive use is 6.31 cfs. Therefore, OWRD estimates that 51.5% of the estimated 14.1 cfs median August natural flow stream is consumed.

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 | Little Abiqua Creek flow rate | Natural Flow     | Estimated Consumptive Use | Net Flow           | Net Flow Shifted 1- day |
|-----------|---|-------------------------------|------------------|---------------------------|--------------------|-------------------------|
|           | F%ofNormal                                  | QR,LittleAbiquaCr (cfs)       | QR,Natural (cfs) | CU (cfs)                  | QR,Tributary (cfs) | 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                    |

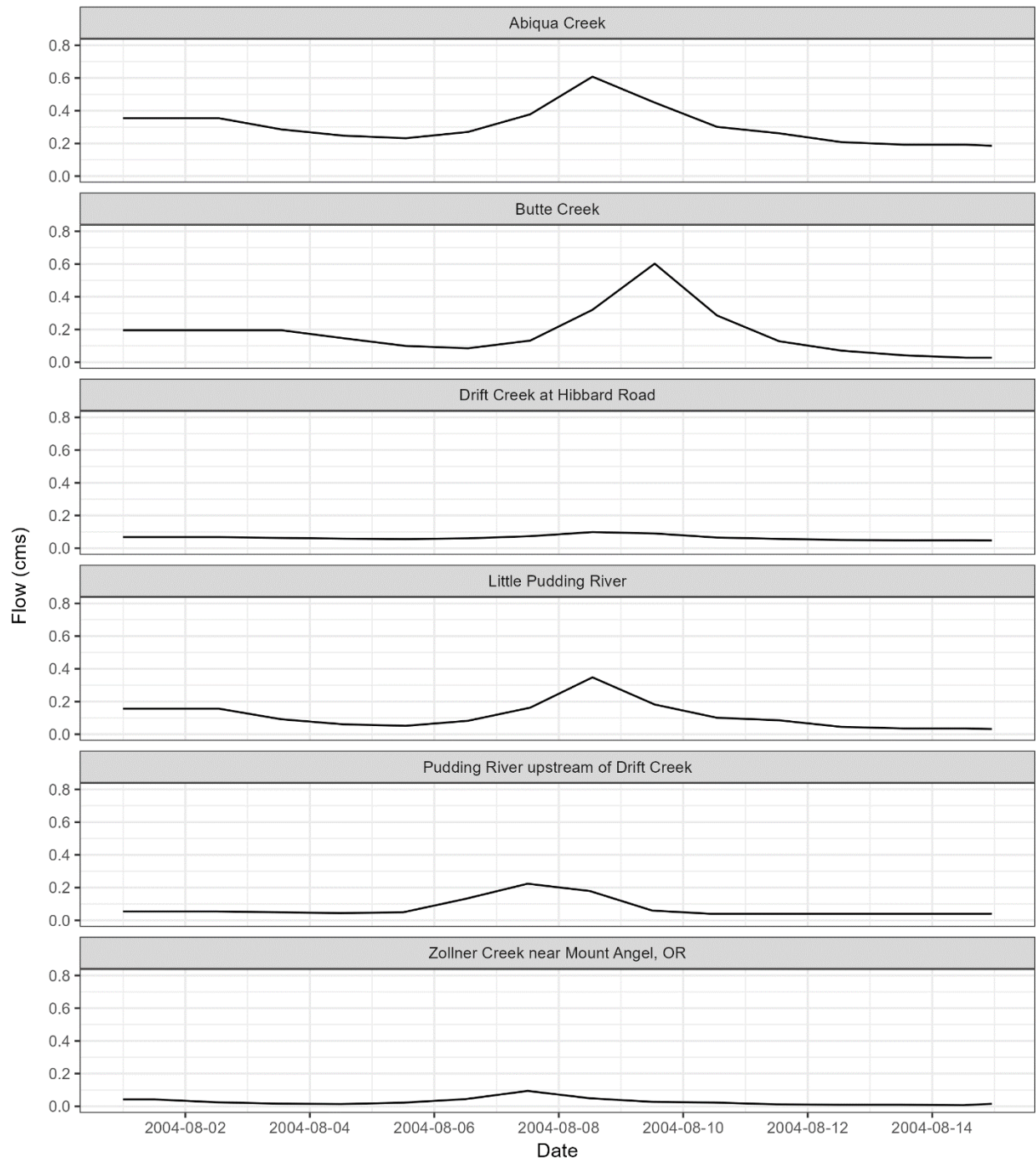
**Table 3-22** and **Figure 3-67** document the flow inputs to the model at the boundary condition (Pudding River upstream of Drift Creek) and tributaries.



**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) |

| Model Location Name   | Model Location (kilometers) | Input Type | Data Source        |
|---|-----------------------------|------------|--------------------|
| 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.**

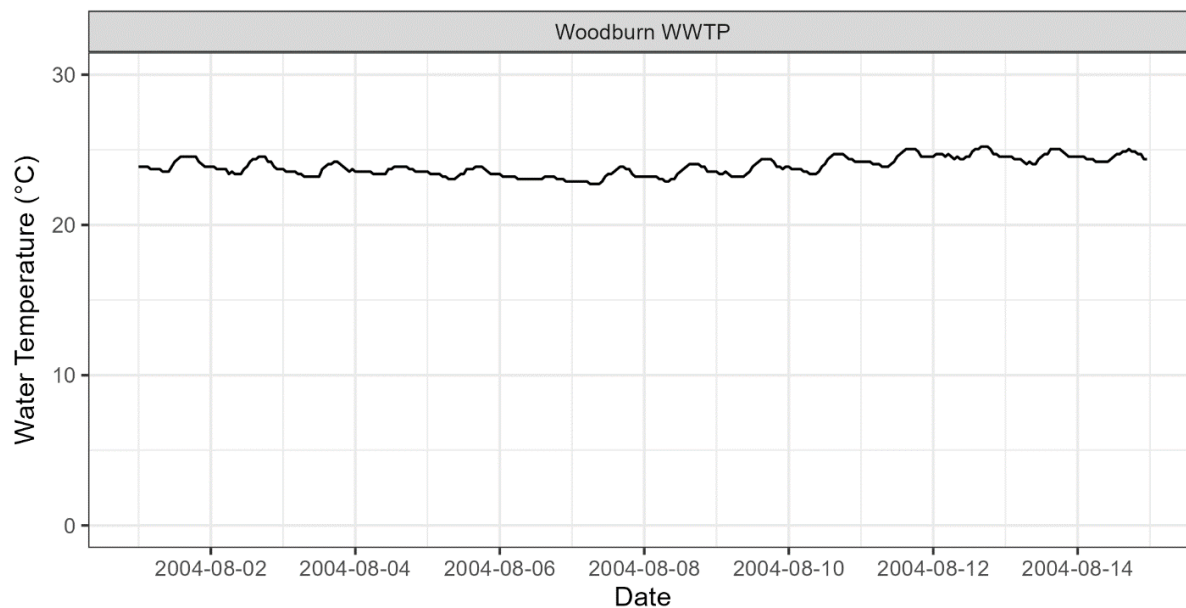
### 3.3.7 Point source inputs

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.

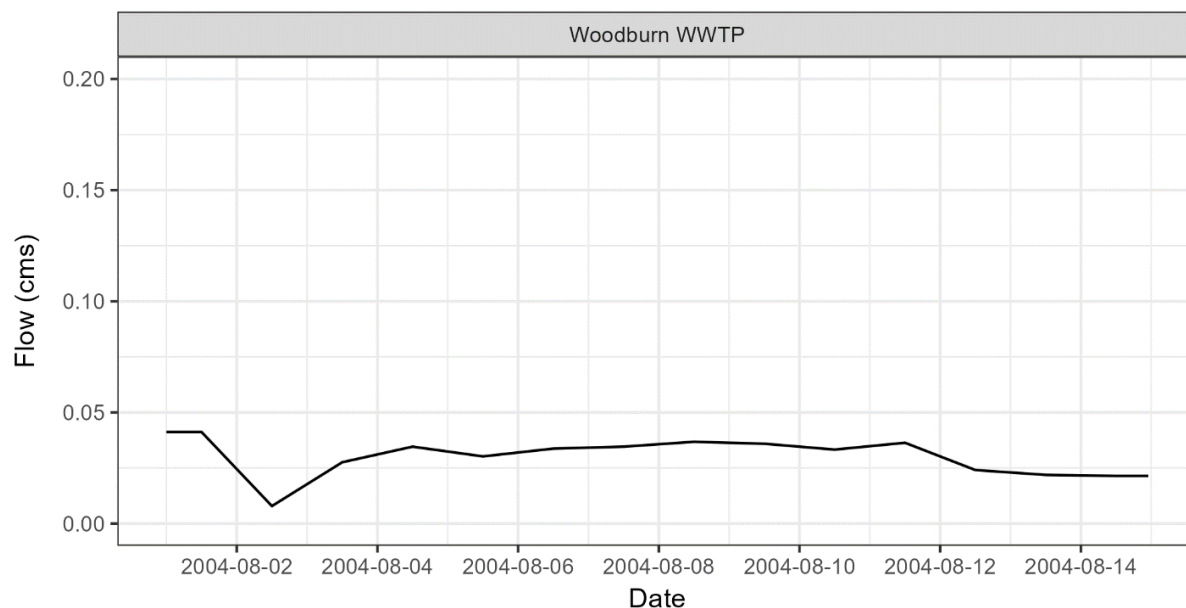
Discharge from the JLR, LLC facility (formerly known as Agripac/Bruce Pac) enters the Pudding River at river mile 27. The facility currently does not discharge in the summer months, but

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.

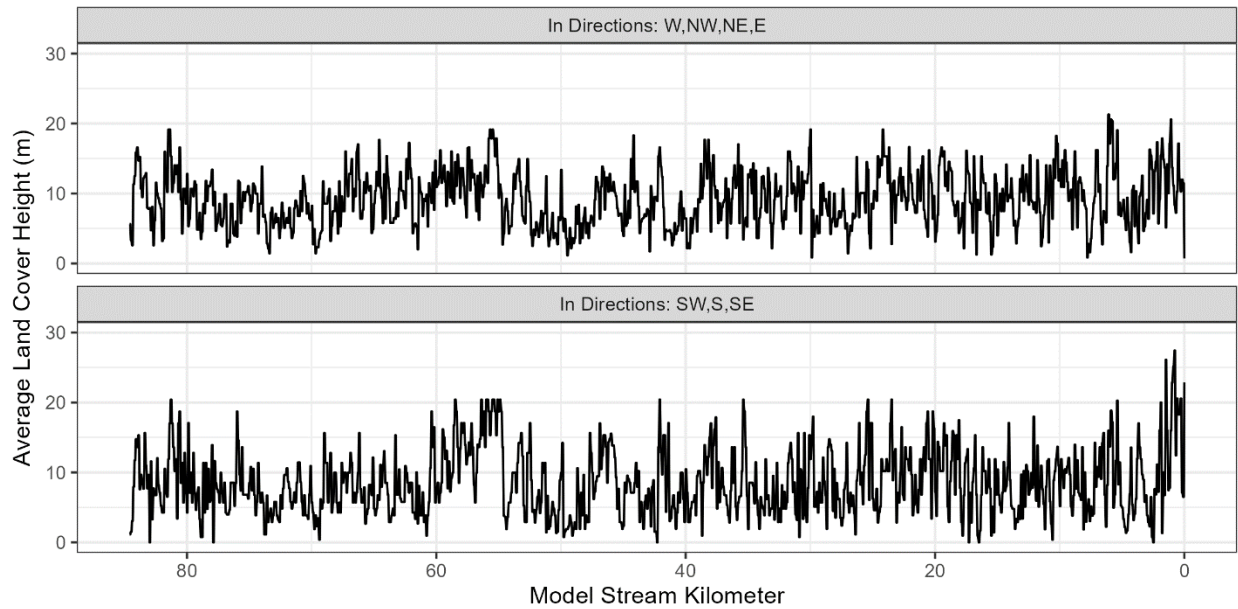
Columbia Helicopters was not included as a point source to the calibrated model because DEQ considers wastewater from this site to have no reasonable potential to increase stream temperature in the Pudding River. The contaminants of concern for this facility are oil and grease, pH, some metals and volatile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

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

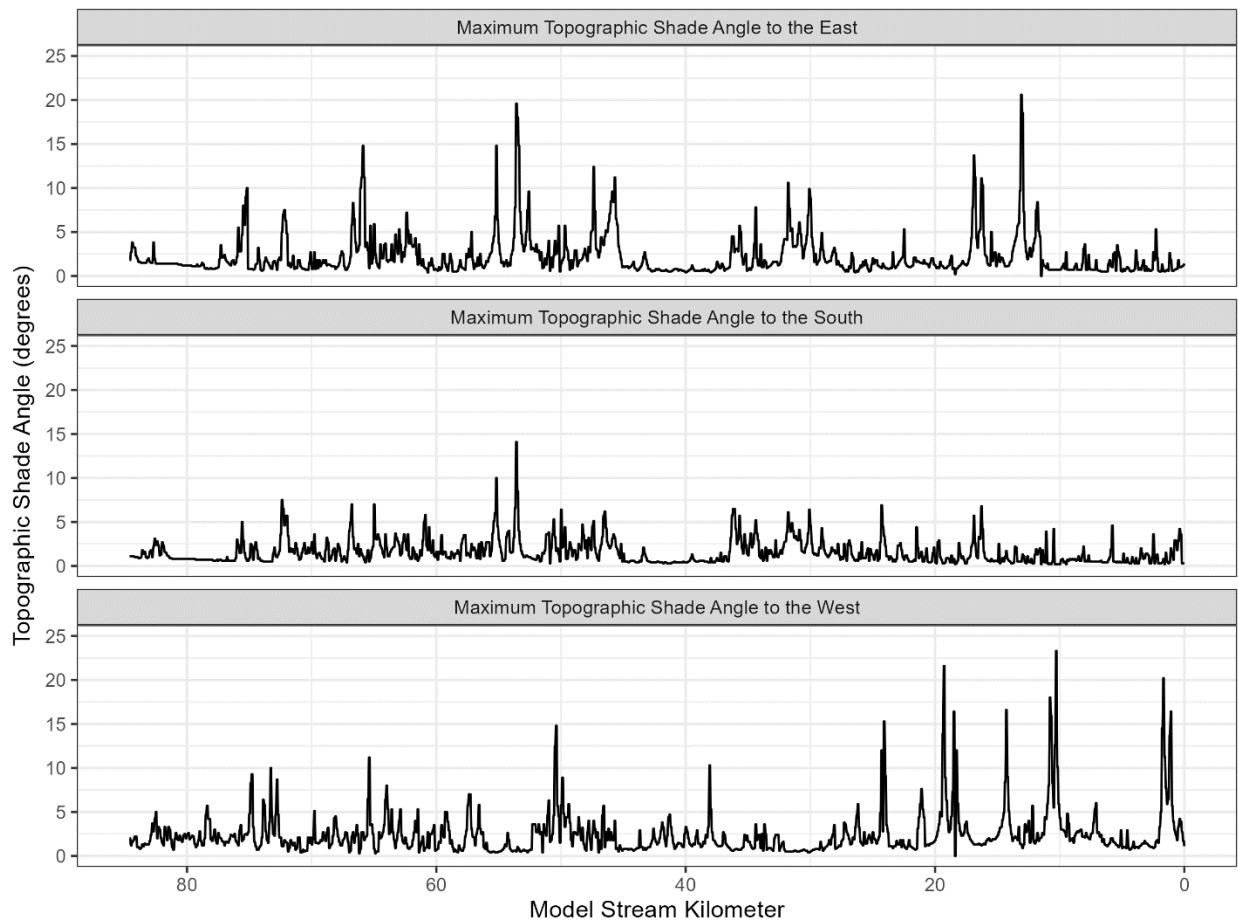
| <b>Facility Name<br/>(Facility Number)</b> | <b>Latitude/Longitude</b> | <b>Permit Type and Description</b>  | <b>Stream/River Mile</b>                                |
|--|---------------------------|---|---|
| Aurora STP (110020)                        | 45.2291/-122.753          | NPDES-DOM-Db: 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.

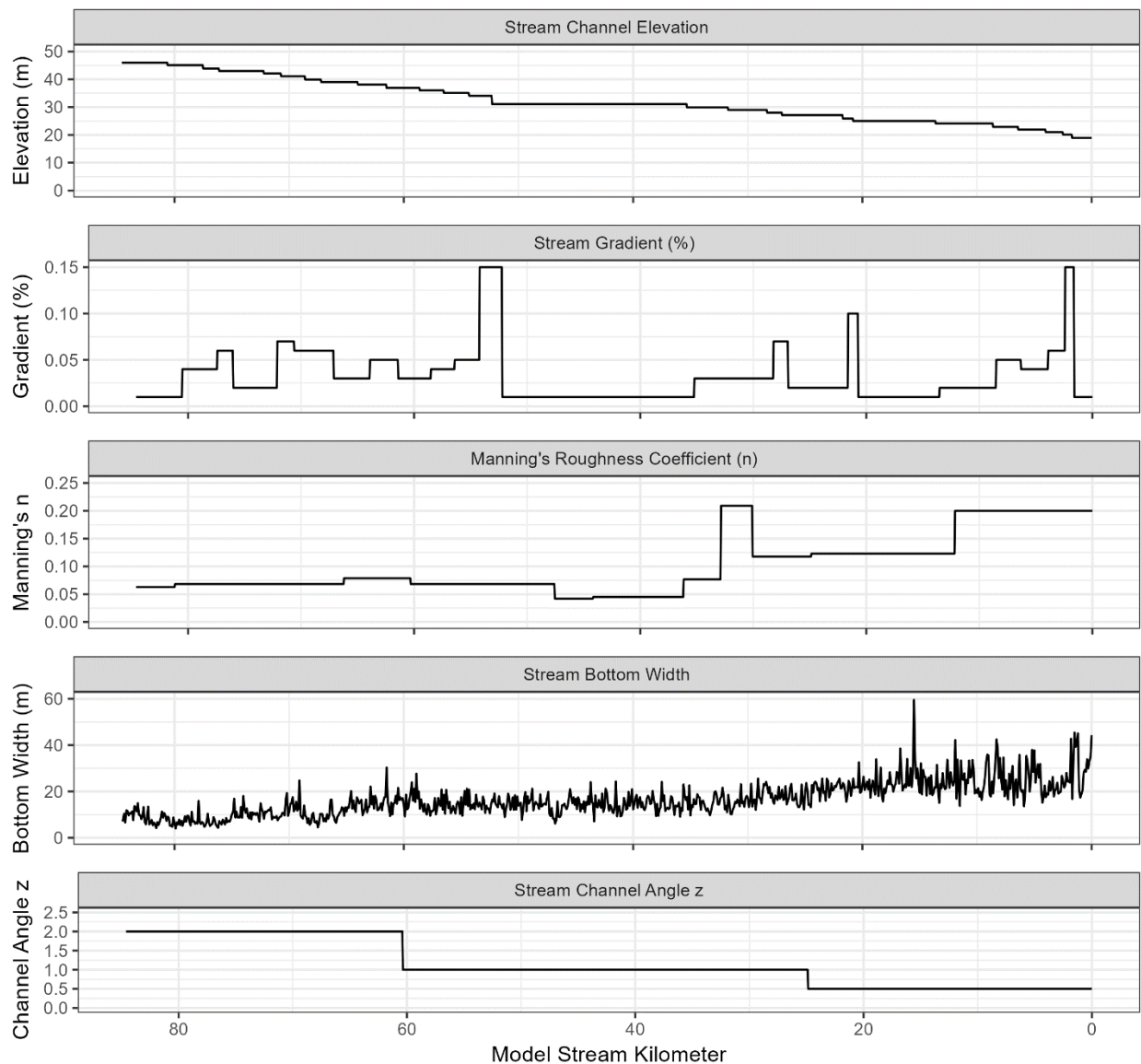


Figure 3-72: Channel setup in the Pudding River model.

### 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).

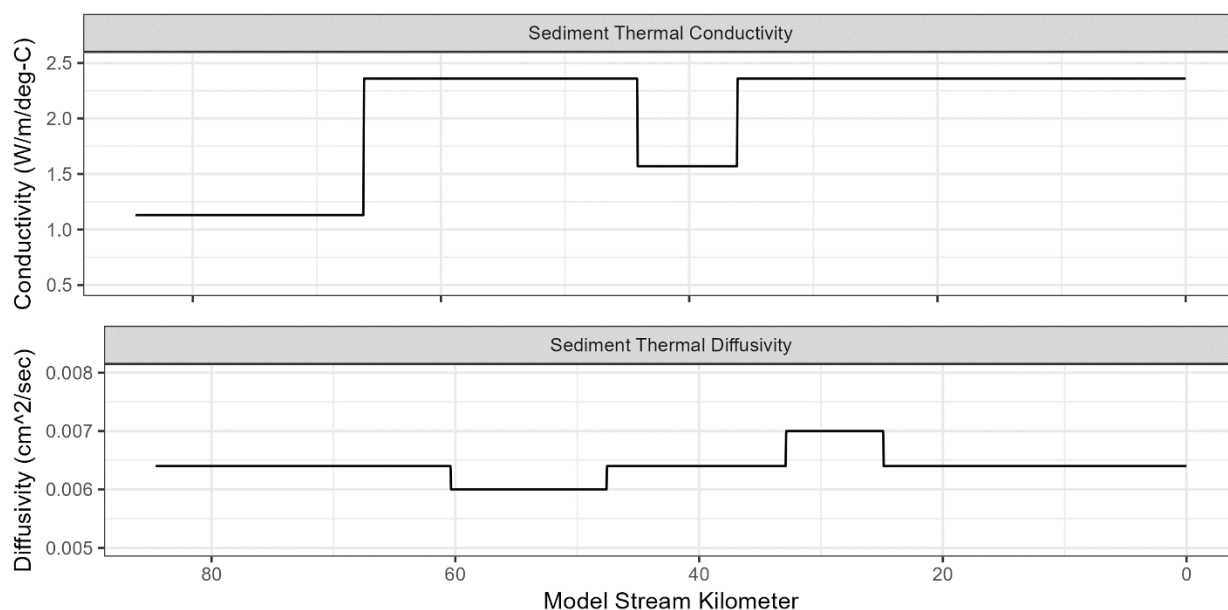
Sinokrot and Stefan (1993) and other researchers provided a summary of typical values for thermal conductivity and thermal diffusivity across various materials. The average thermal conductivity for many sediment materials is about 1.57 W/m/°C, while the average thermal

diffusivity for many different types of sediment material is about 0.0064 cm<sup>2</sup>/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<sup>2</sup>/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 x 10 <sup>-9</sup> |
| Wind Function, coefficient b            | 1.60 x 10 <sup>-9</sup> |
| Sediment / hyporheic zone thickness (m) | 0.1                     |
| Hyporheic Exchange                      | 0%                      |
| Porosity                                | 41%                     |



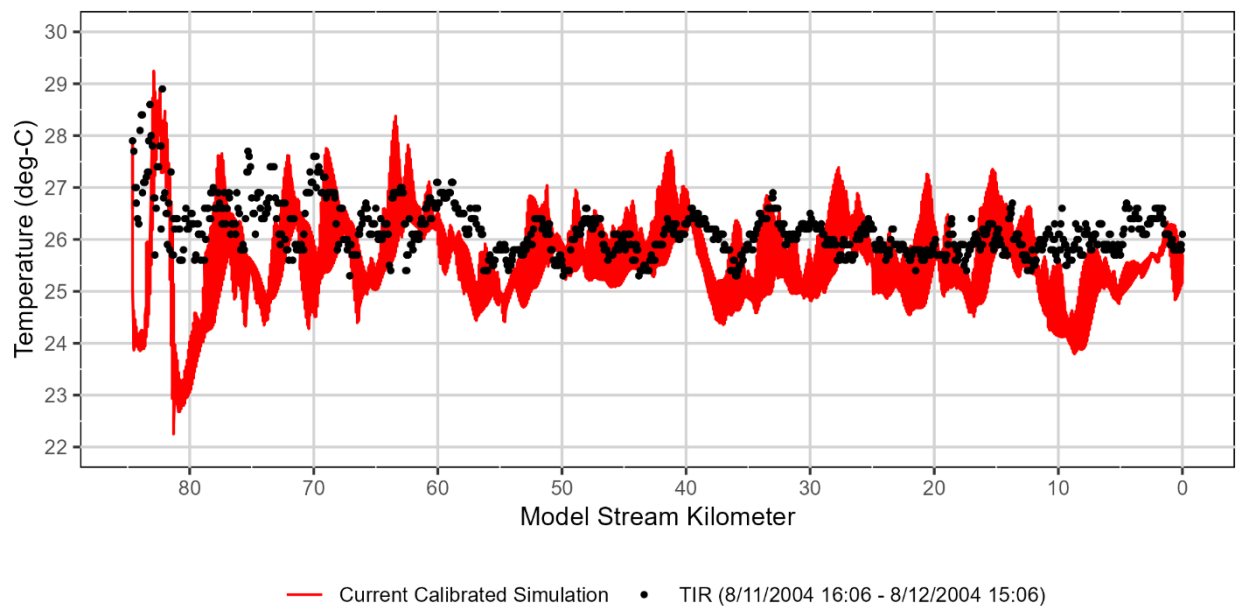
**Figure 3-73: The other model parameters used for channel setup in the Pudding River model.**

### 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.**

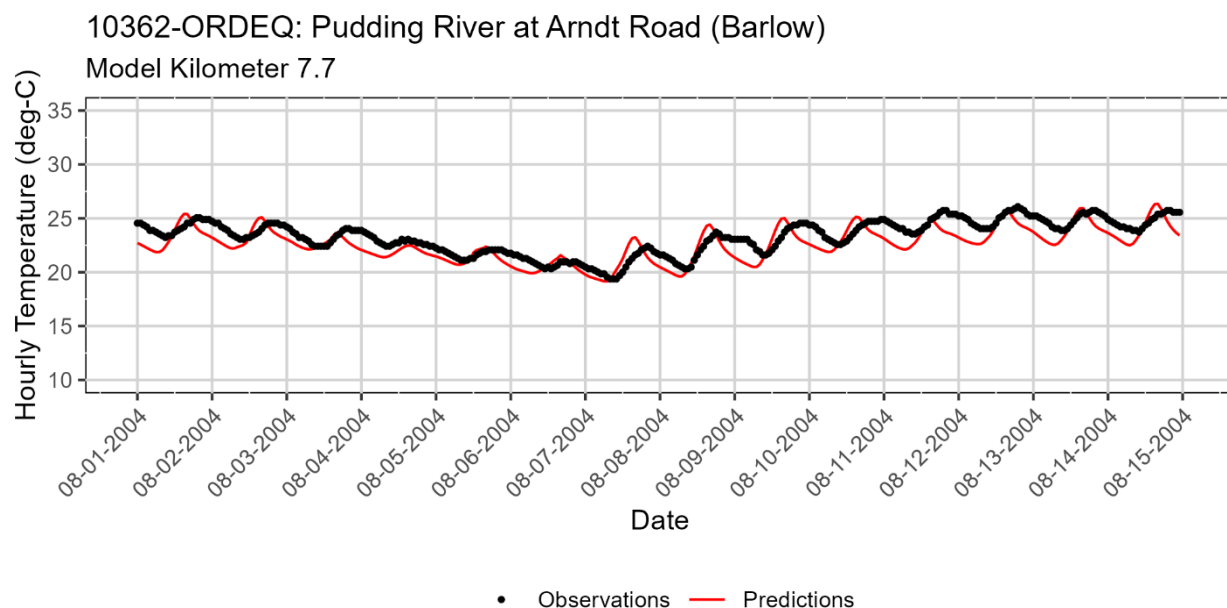
**Table 3-25: Pudding River hourly stream temperature goodness of fit statistics comparing field measured and model-predicted temperatures.**

| 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   |

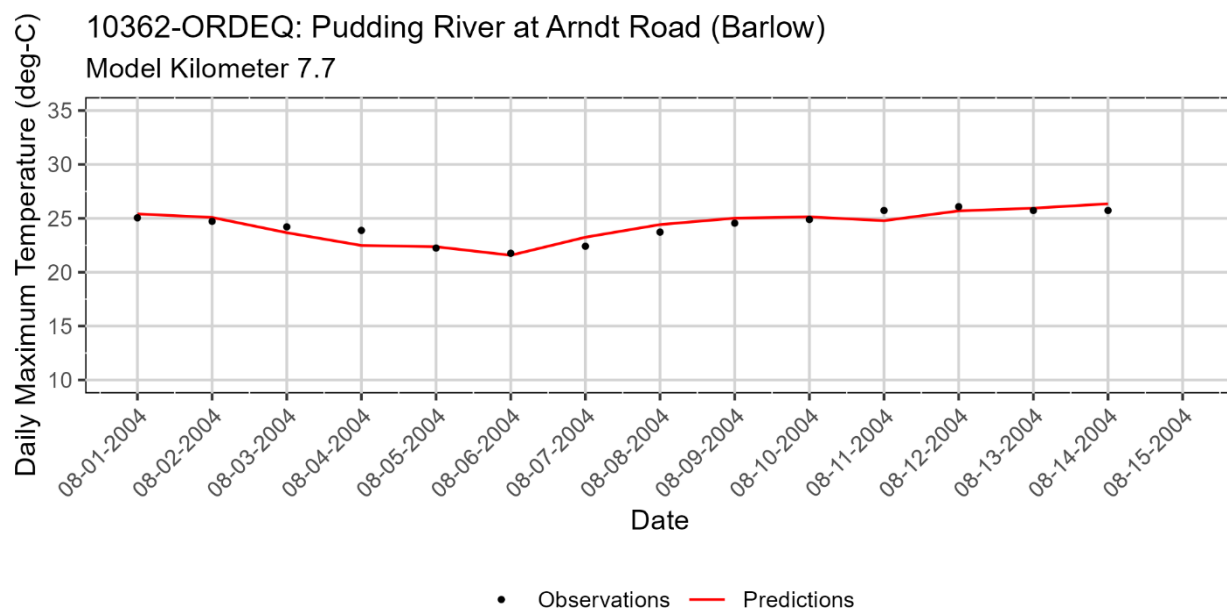
| Monitoring Location   | Model KM     | Temperature Statistics | ME    | MAE  | RMSE | NSE  | n   |
|---|--------------|------------------------|-------|------|------|------|-----|
| 10640-ORDEQ: Pudding River at Hwy 211 (Woodburn)                      | 36.2         | Daily Maximum          | -1.08 | 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**.

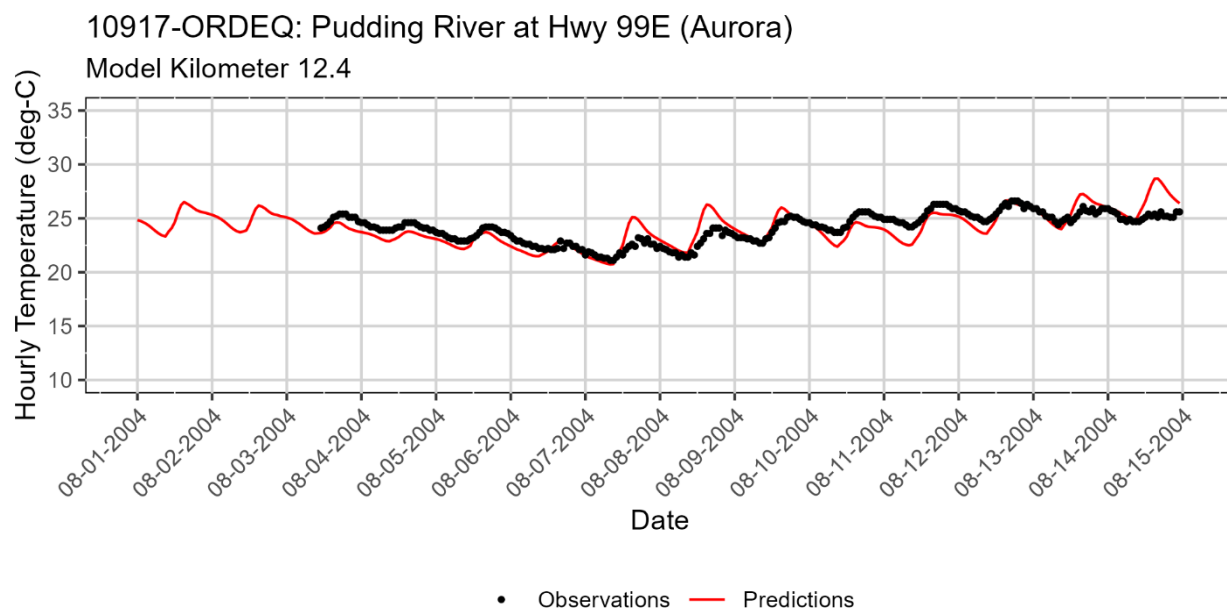
Comparisons of calculated hourly values to observed data are presented in **Figure 3-75** through **Figure 3-88**. Note that no data is available for Node 7 (Bernard Road, 11528-ORDEQ) since the thermistor failed at this location during the time period modeled. Note also that the thermistor for Node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



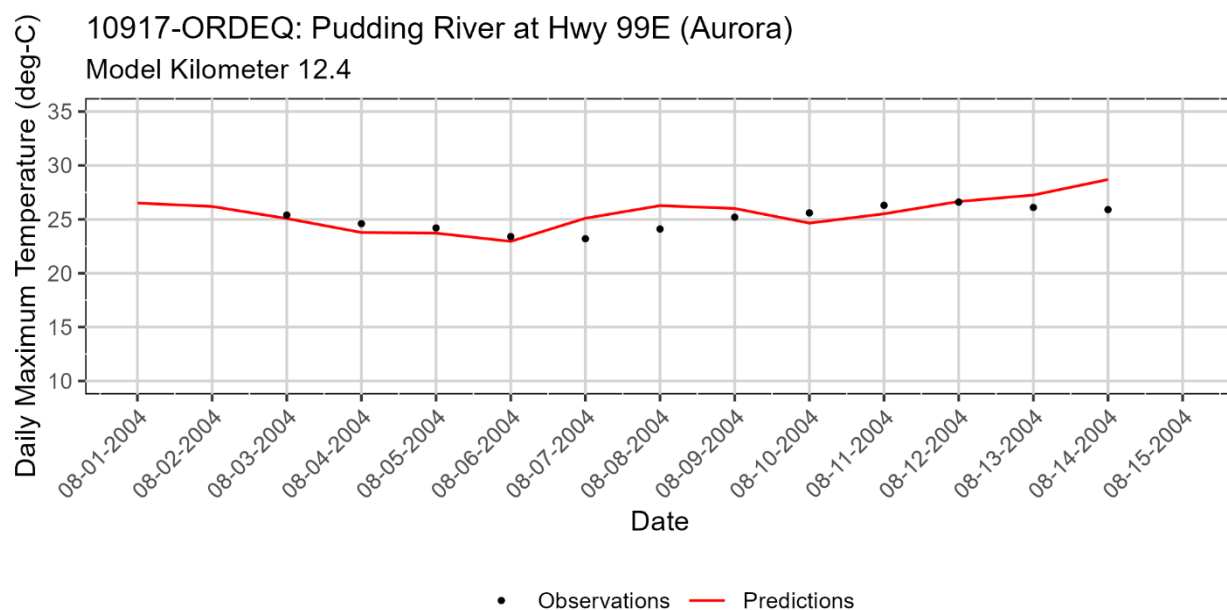
**Figure 3-75: Pudding River measured and model-predicted hourly stream temperatures at monitoring station 10362-ORDEQ.**



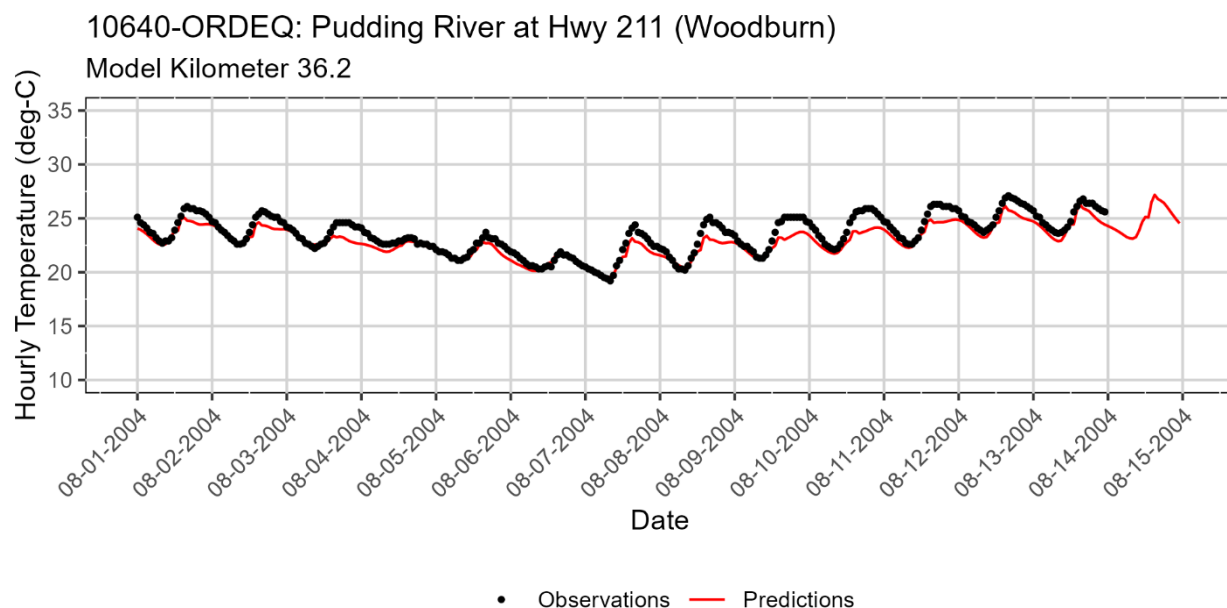
**Figure 3-76: Pudding River measured and model-predicted daily maximum stream temperatures at monitoring station 10362-ORDEQ.**



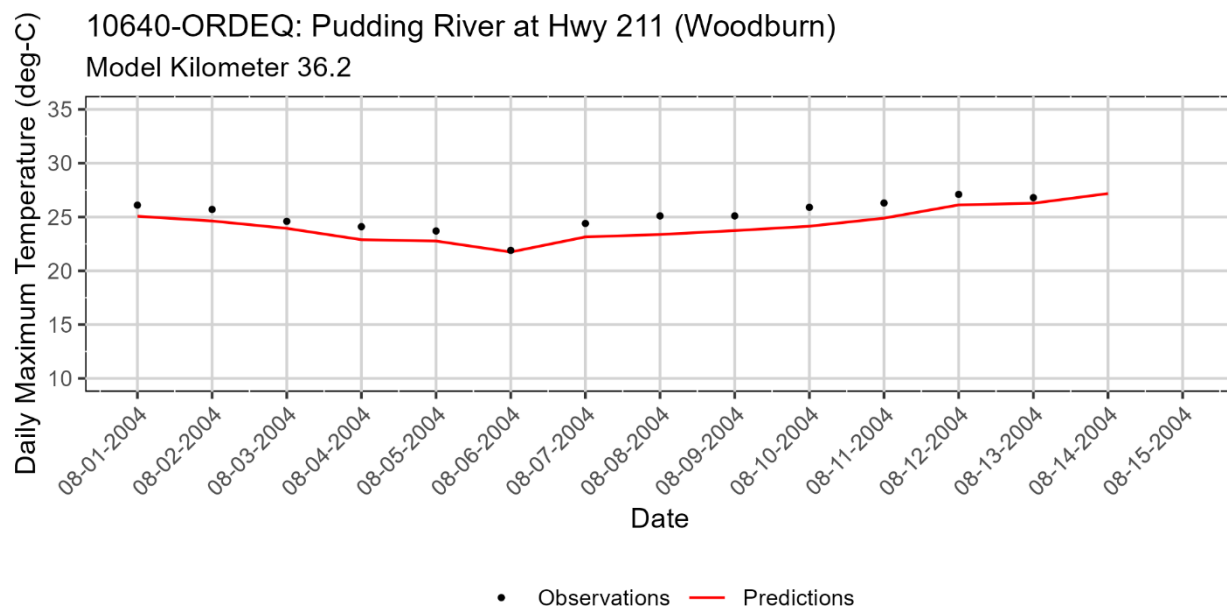
**Figure 3-77: Pudding River measured and model-predicted hourly stream temperatures at monitoring station 10917-ORDEQ.**



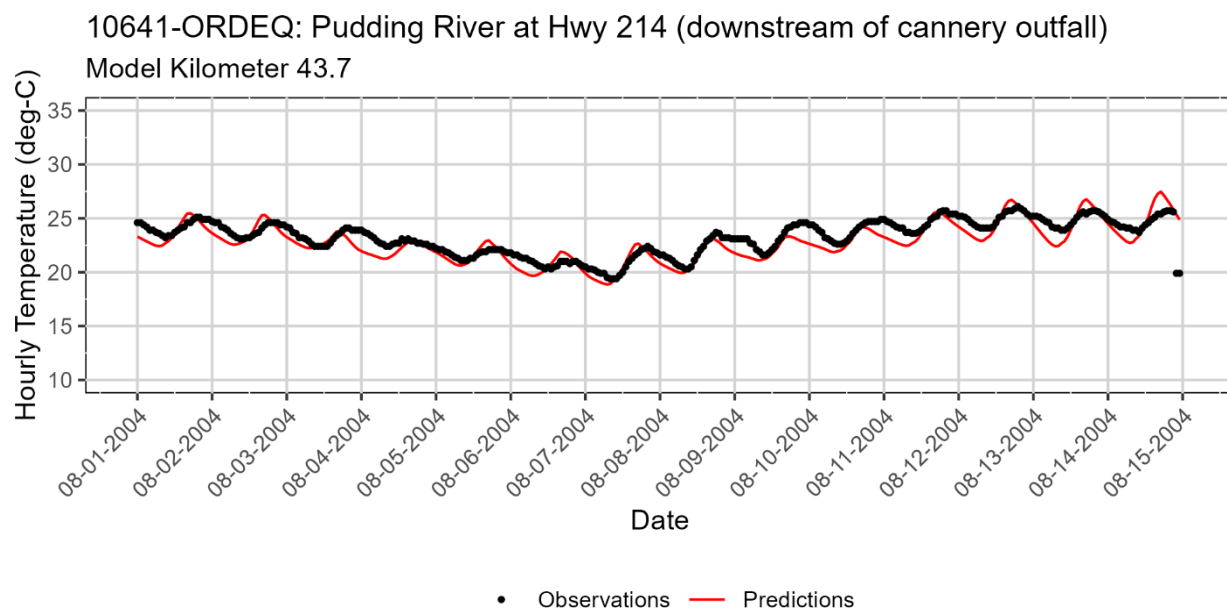
**Figure 3-78: Pudding River measured and model-predicted daily maximum stream temperatures at monitoring station 10917-ORDEQ.**



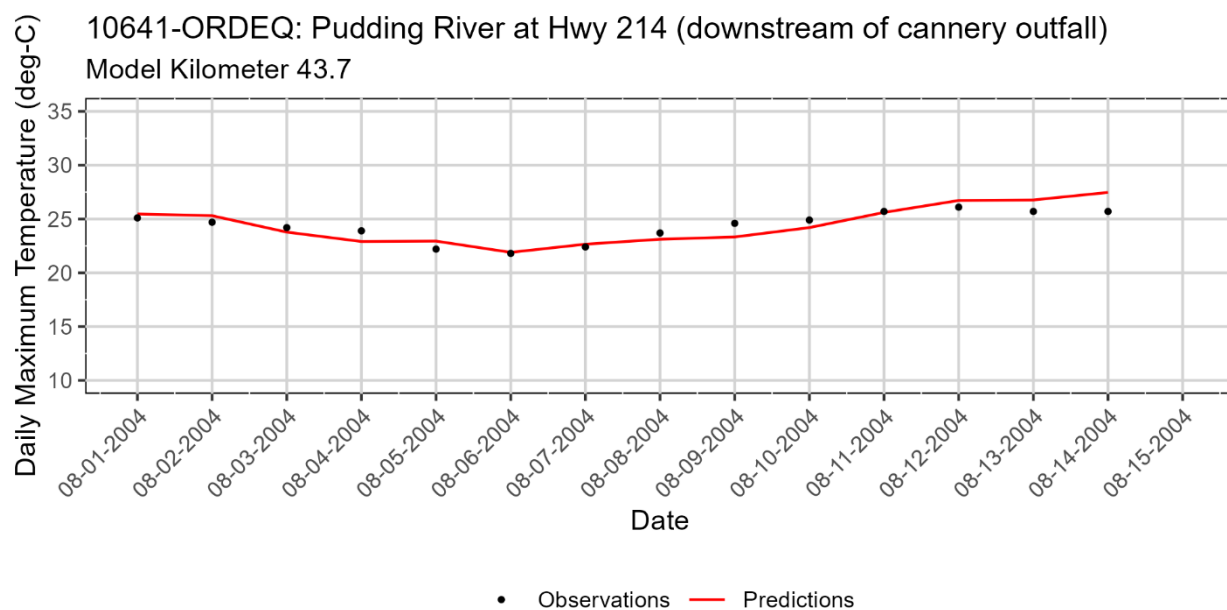
**Figure 3-79: Pudding River measured and model-predicted hourly stream temperatures at monitoring station 10640-ORDEQ.**



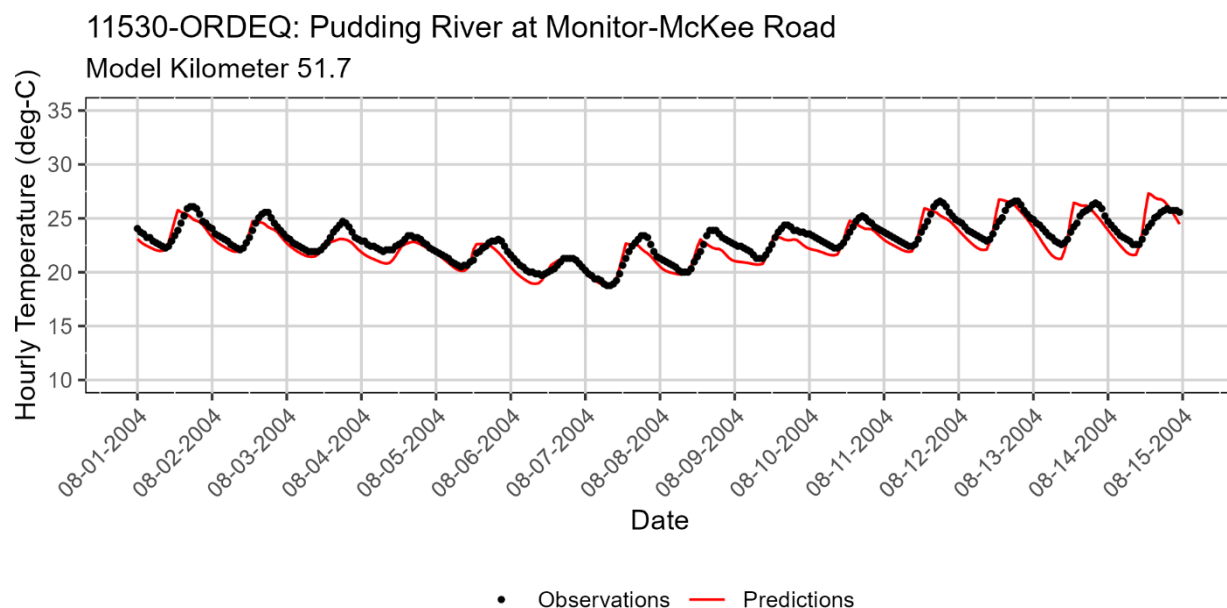
**Figure 3-80: Pudding River measured and model-predicted daily maximum stream temperatures at monitoring station 10640-ORDEQ.**



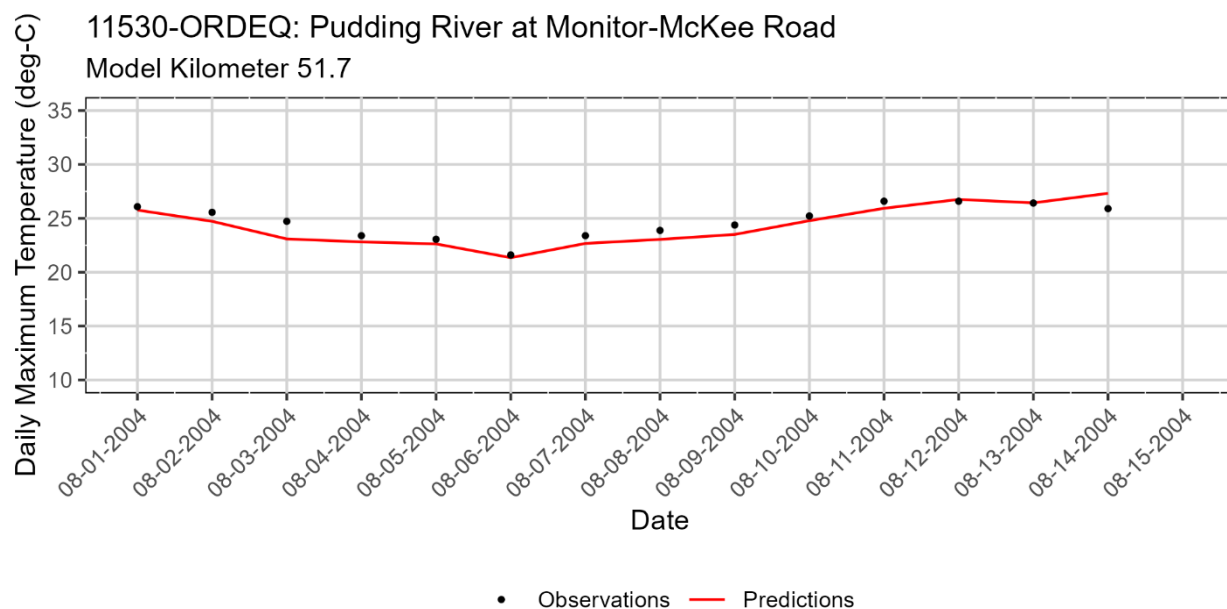
**Figure 3-81: Pudding River measured and model-predicted hourly stream temperatures at monitoring station 10641-ORDEQ.**



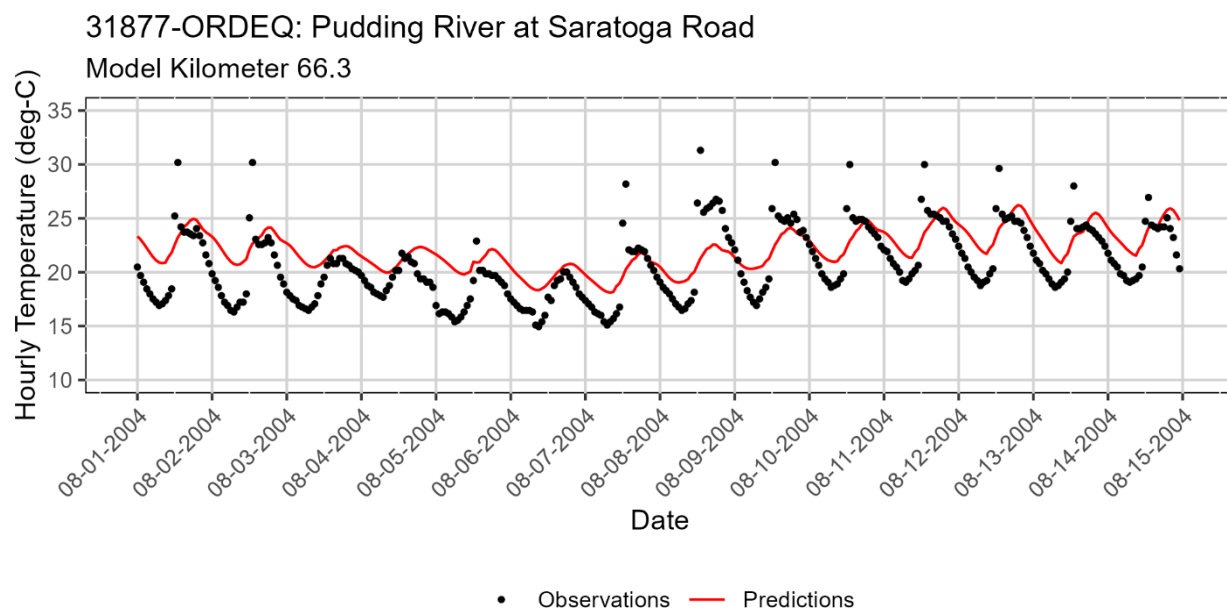
**Figure 3-82: Pudding River measured and model-predicted daily maximum stream temperatures at monitoring station 10641-ORDEQ.**



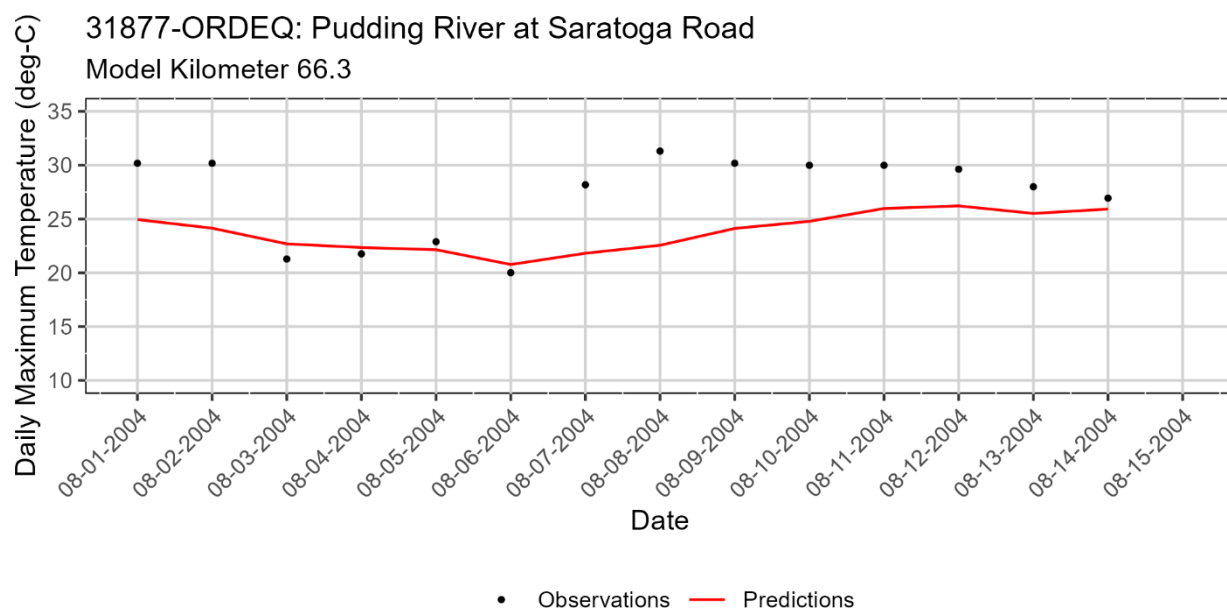
**Figure 3-83: Pudding River measured and model-predicted hourly stream temperatures at monitoring station 11530-ORDEQ.**



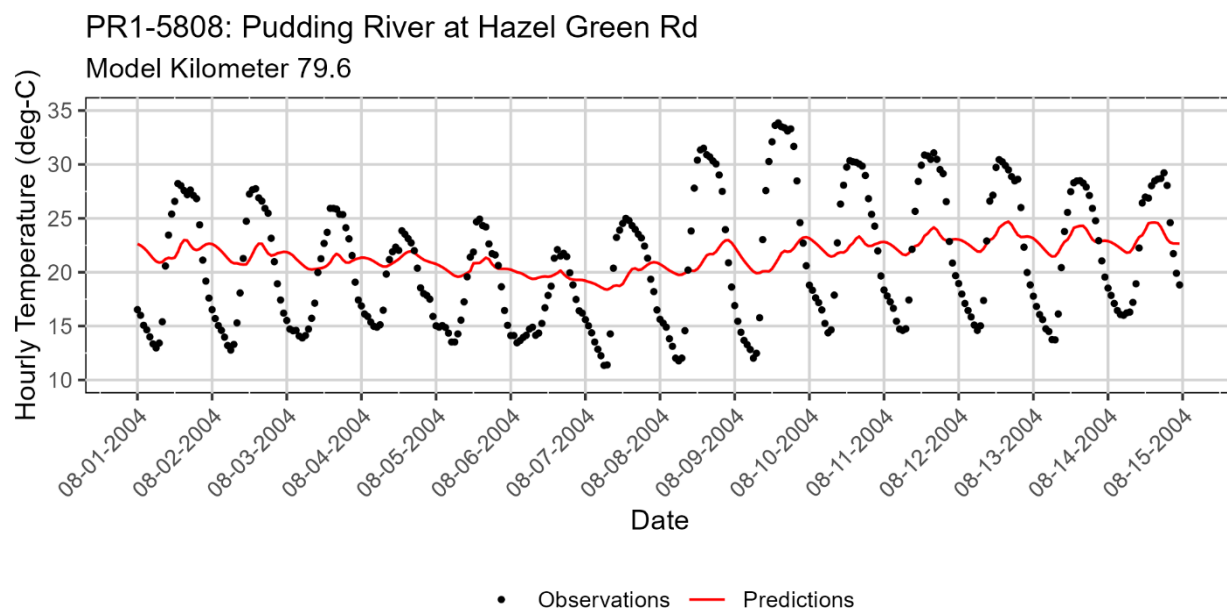
**Figure 3-84: Pudding River measured and model-predicted daily maximum stream temperatures at monitoring station 11530-ORDEQ.**



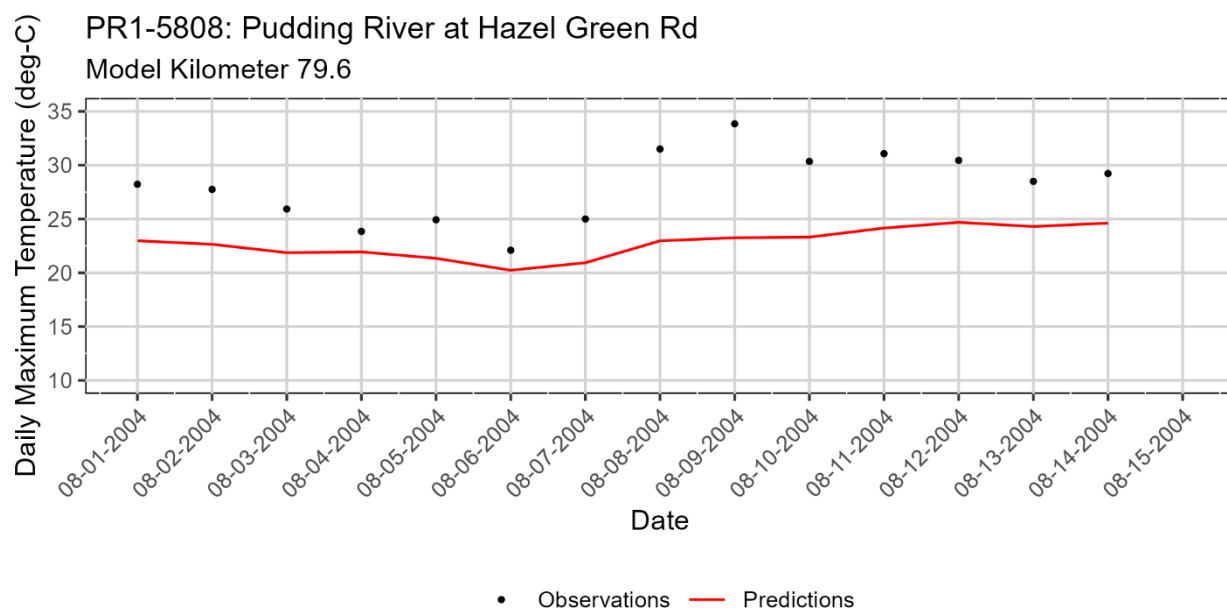
**Figure 3-85: Pudding River measured and model-predicted hourly stream temperatures at monitoring station 31877-ORDEQ.**



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



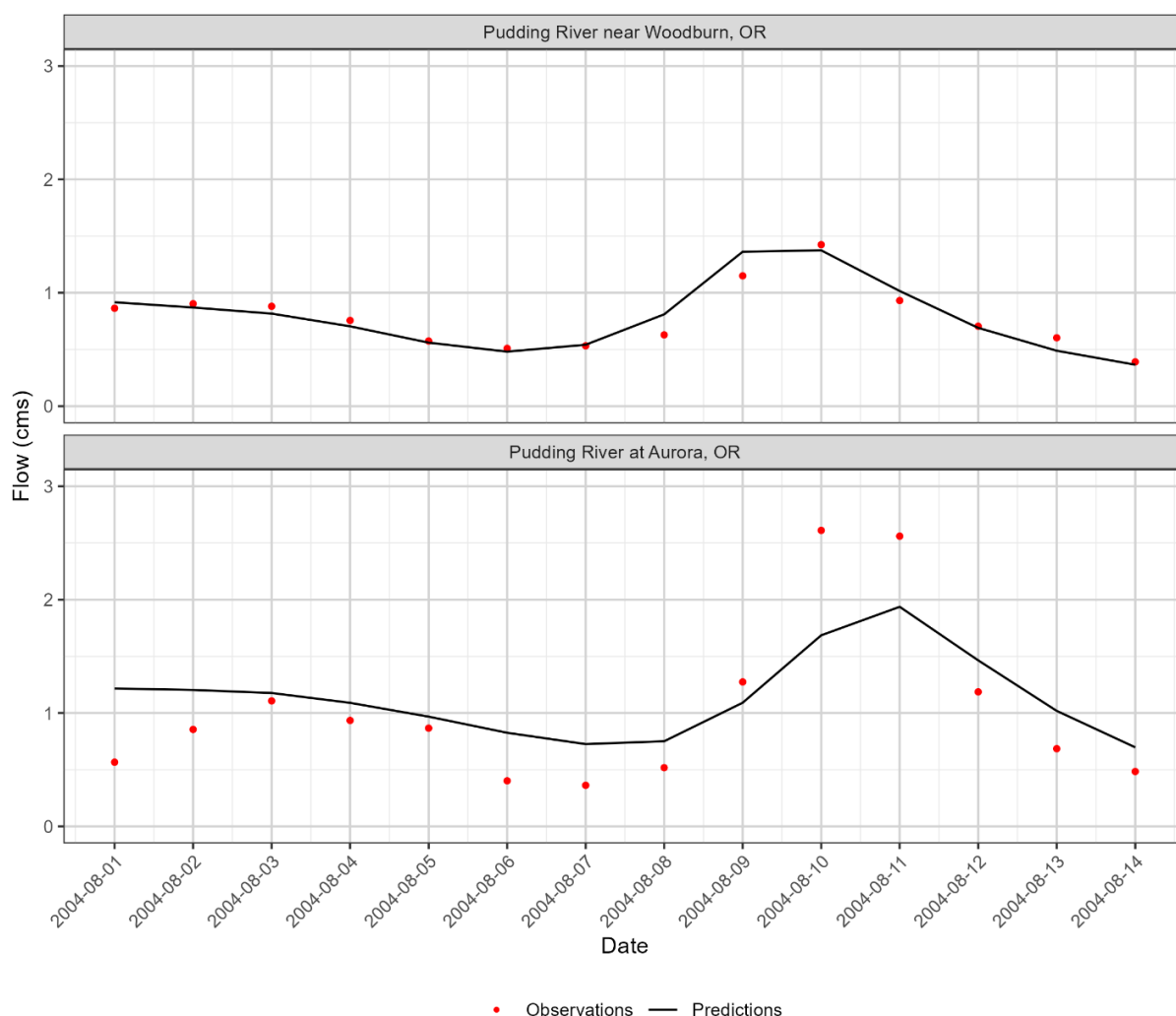
**Figure 3-87: Pudding River measured and model-predicted hourly stream temperatures at monitoring station PR1-5808.**



**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:

$$\text{Velocity} = aQ^b$$

$$\text{Depth} = cQ^d$$

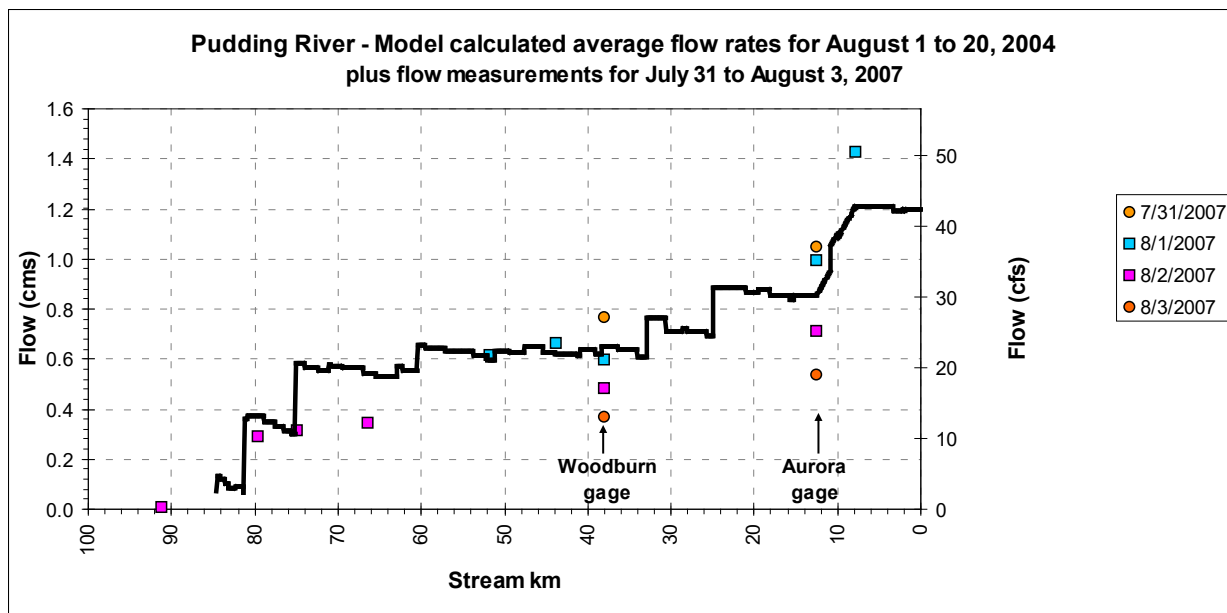
$$\text{Width} = eQ^e$$

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.

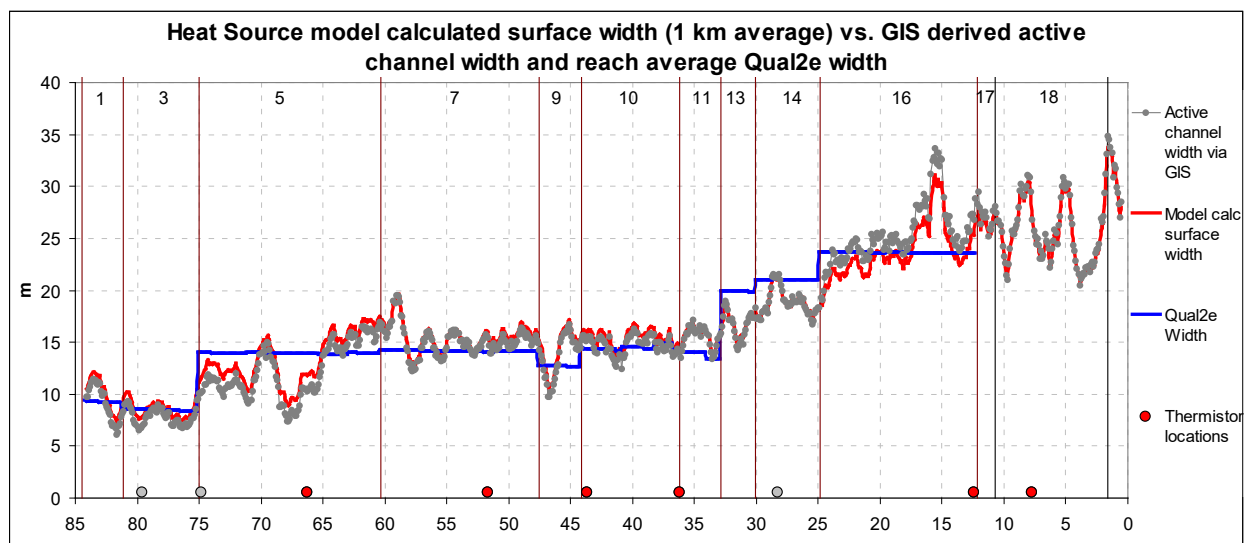
Average flow rates for August 1 to 20, as calculated by the model, are similar to flow conditions for which the QUAL2E model was calibrated. Average flow rates for this 20-day period are shown in **Figure 3-90**. As shown, these flow rates are slightly greater than the 7Q10 rates of 15 cfs at the Woodburn 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.**

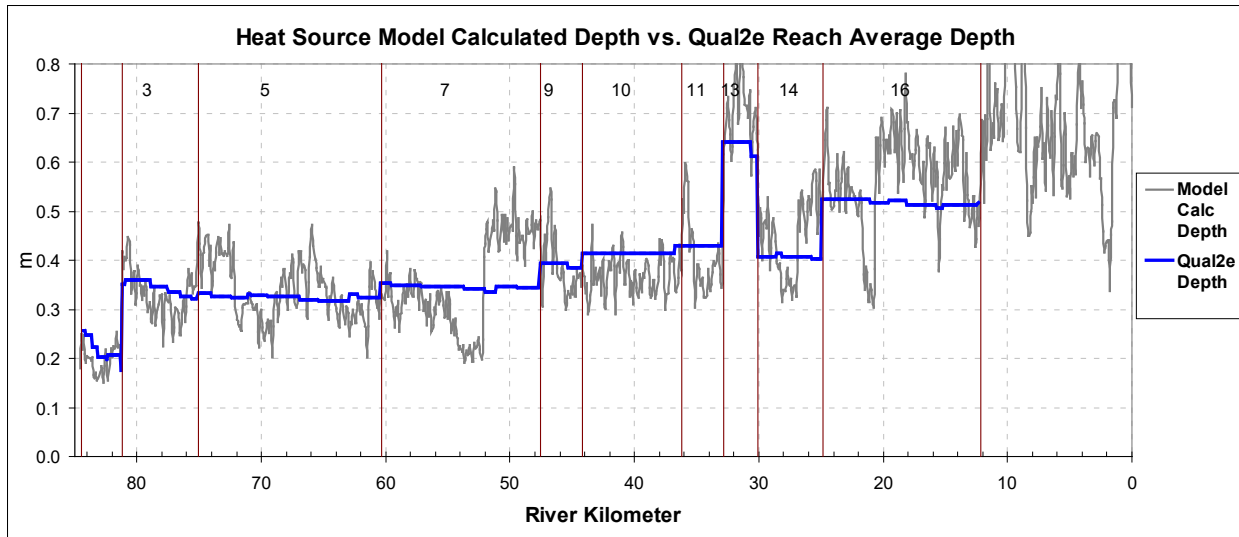


Figure 3-92: Pudding River model depth calibration.

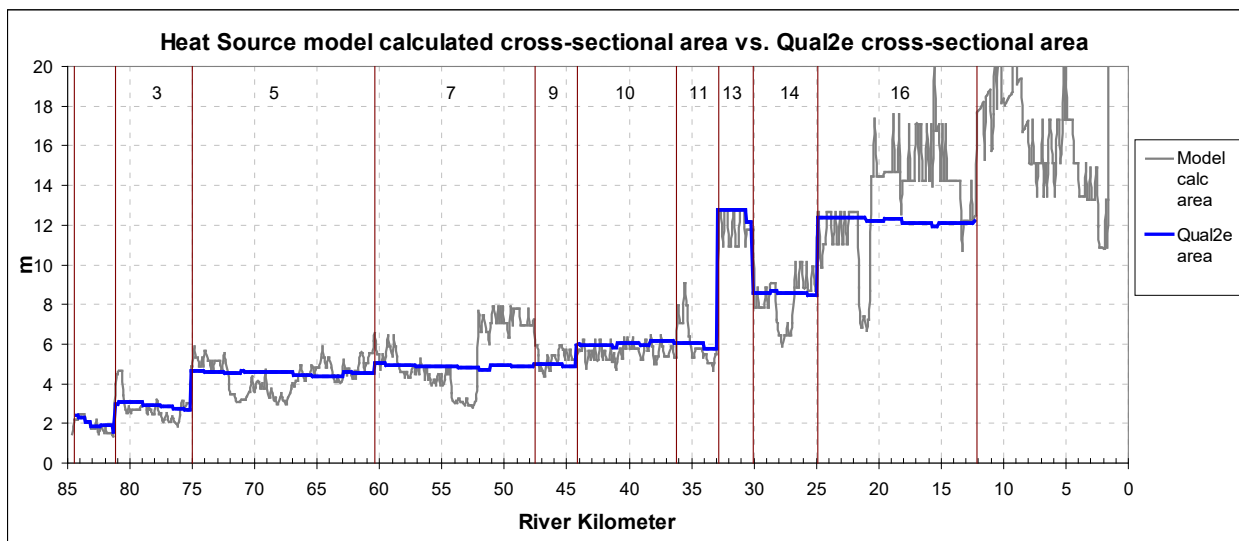


Figure 3-93: Pudding River model cross-sectional area calibration.

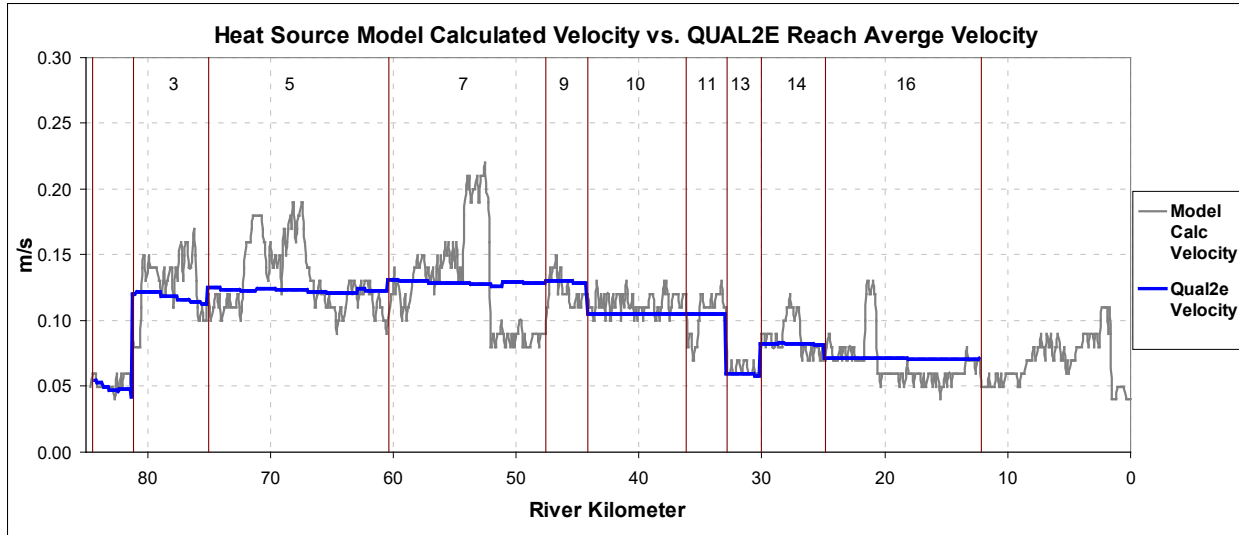


Figure 3-94: Pudding River model velocity calibration.

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).

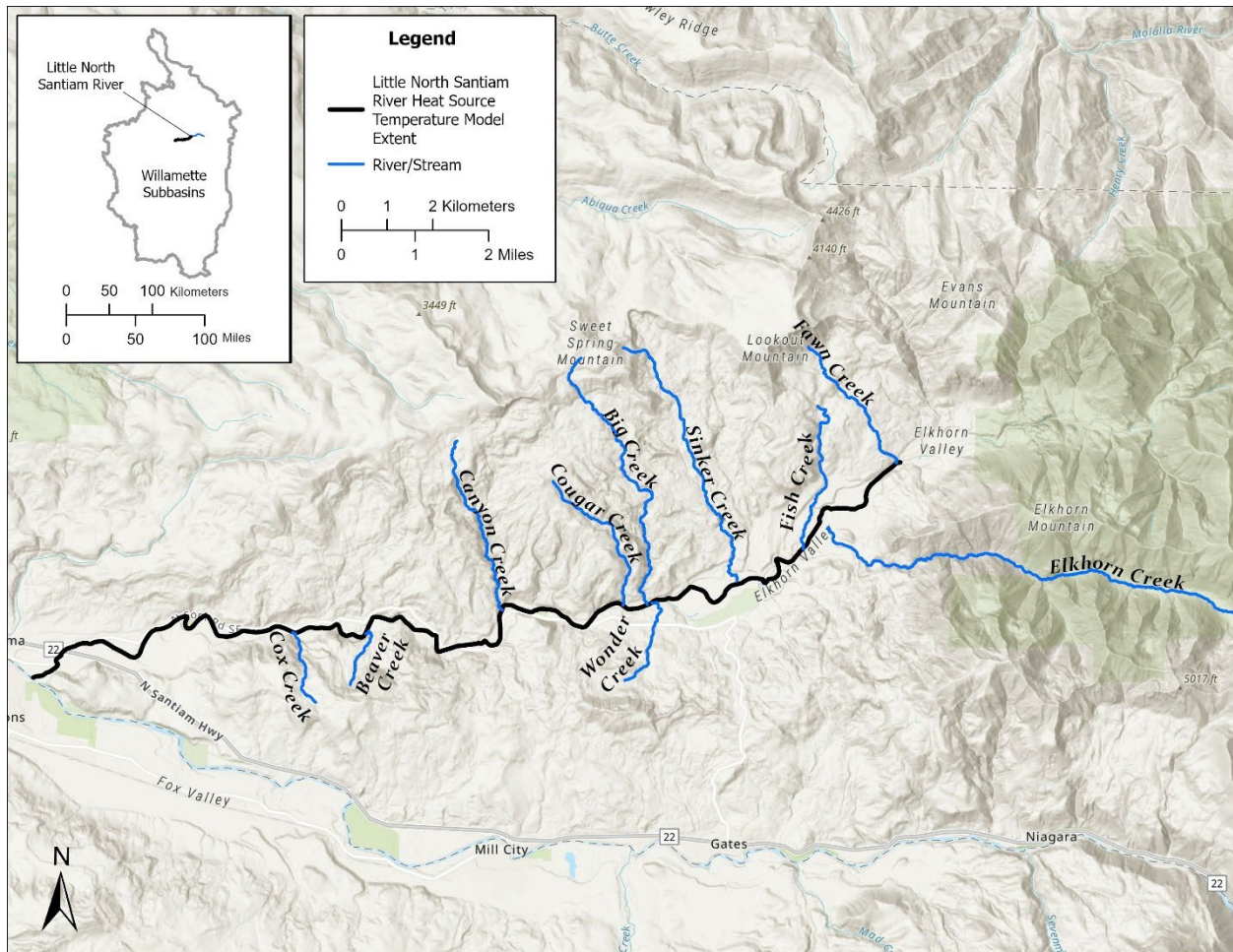


Figure 3-95: Little North Santiam temperature model extent.

### 3.4.2 Spatial and temporal resolution

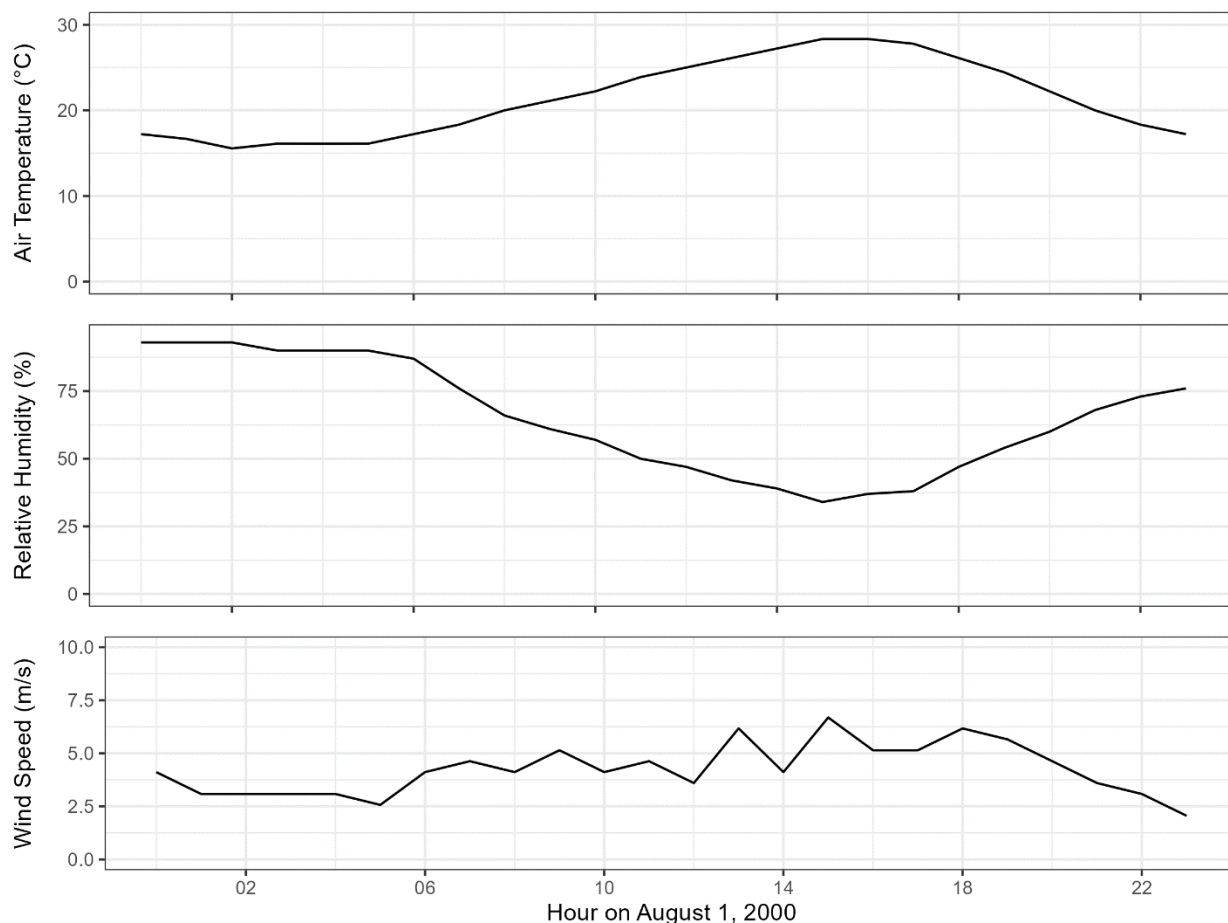
The model input spatial resolution ( $dx$ ) is 30 m. Outputs are generated every 100 m. The model time step ( $dt$ ) is 1 minute and outputs are generated every hour.

### 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.**

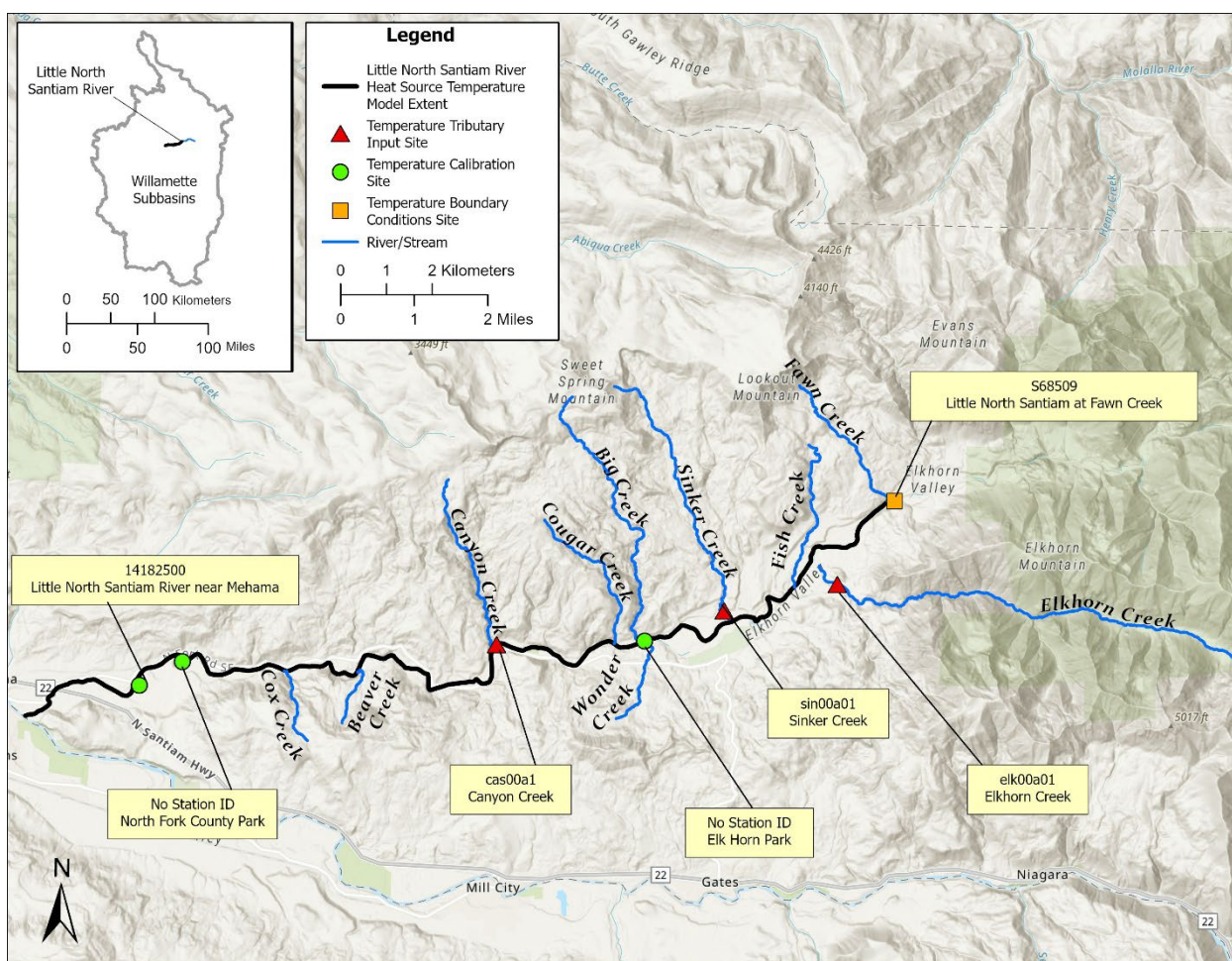
**Table 3-28: Wind-sheltering coefficient used in the Little North Santiam River model.**

| 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                       |

| Model Location Name  | Model Location (km) | Wind Sheltering Coefficient |
|--|---------------------|-----------------------------|
| 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.

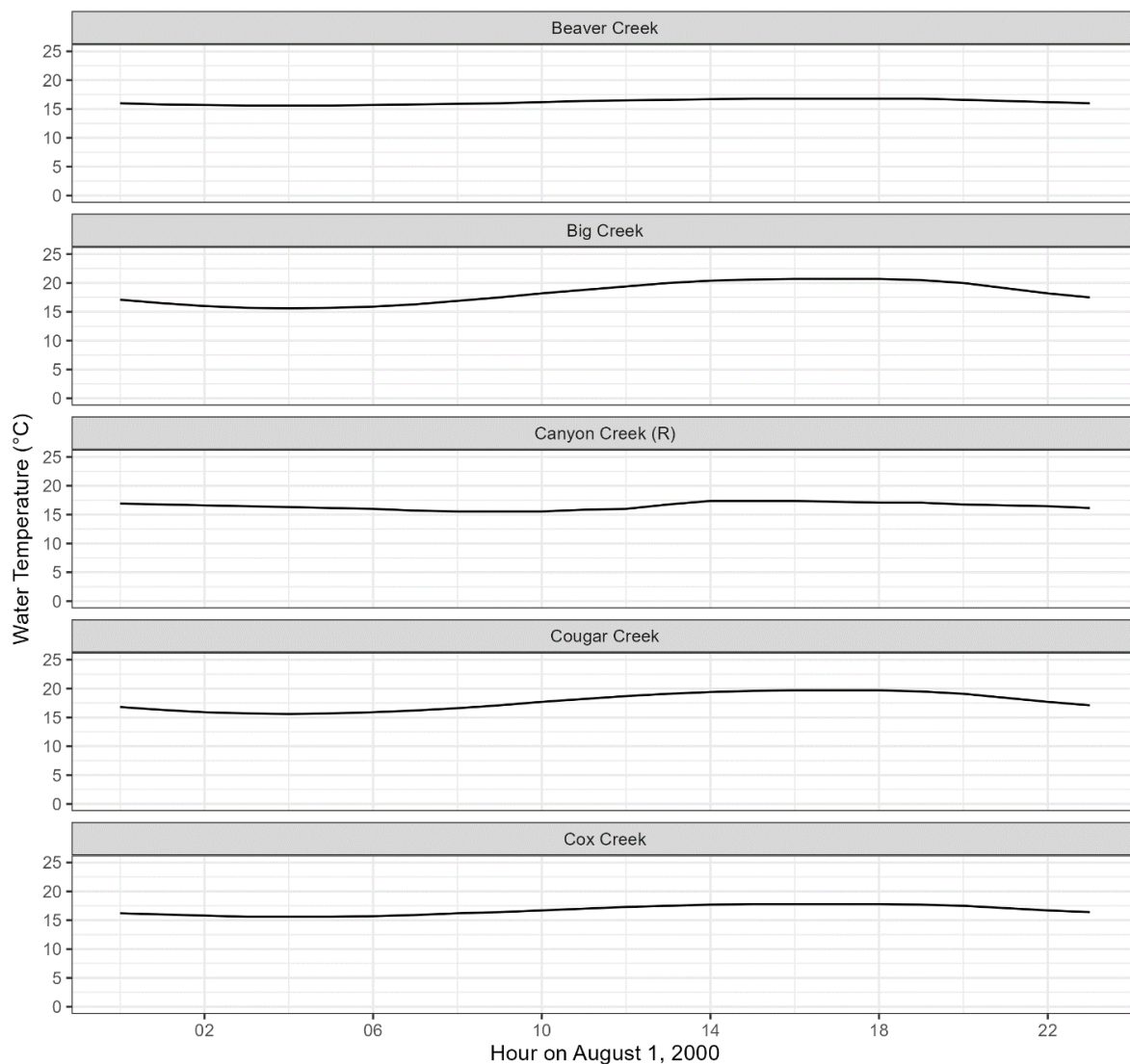


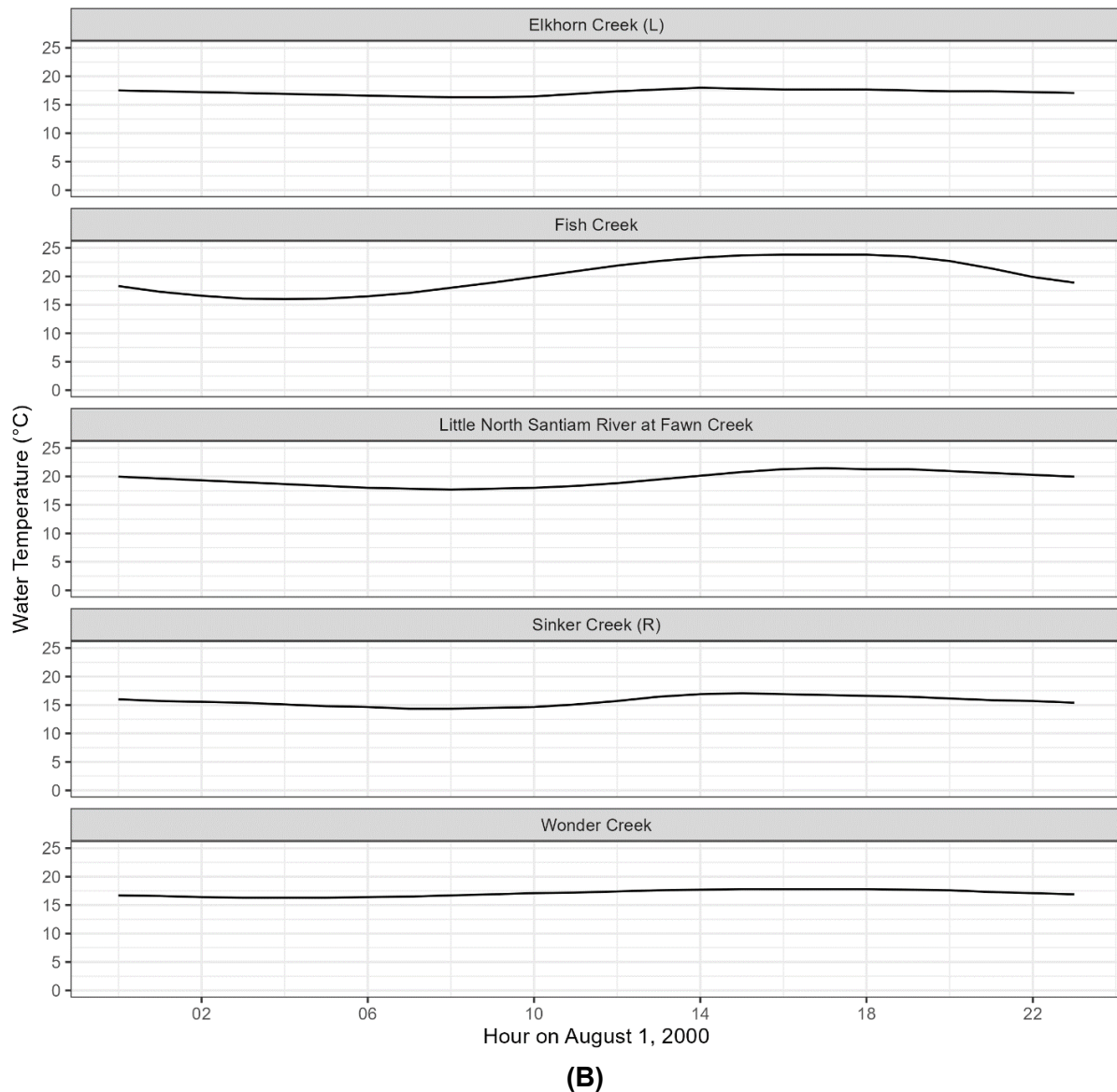
**Figure 3-97: Temperature monitoring locations used for the Little North Santiam River model setup and calibration.**

**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                                |

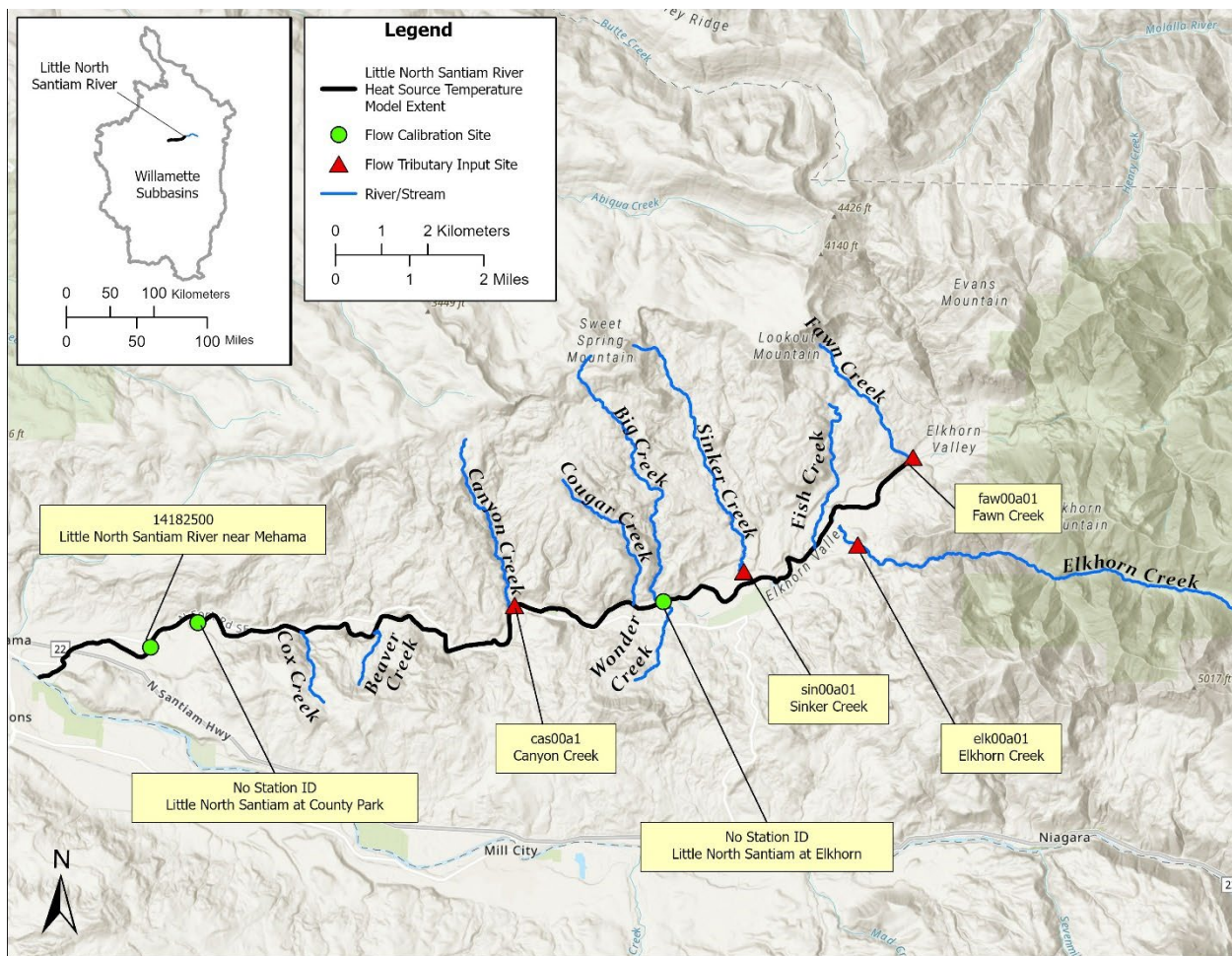




**Figure 3-98: (A) and (B) Boundary condition and tributary water temperature inputs to the Little North Santiam River model.**

### 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.



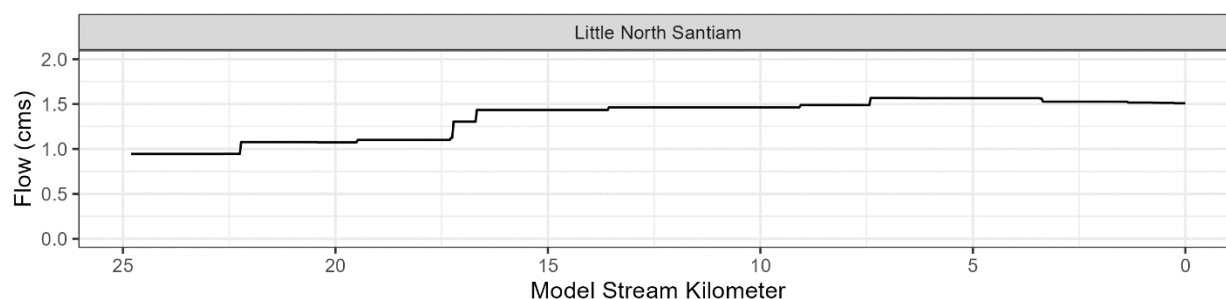
**Figure 3-99: Flow monitoring locations used for the Little North Santiam River model setup and calibration.**

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)  |
| Wonder Creek                       | 17.313              | 0.024           | Tributary          | Estimated using a flow mass balance based on TIR.                                 |

| Model Location Name | Model Location (km) | Flow Rate (cms) | Input Type | Data Source                                       |
|---------------------|---------------------|-----------------|------------|---|
| 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. |



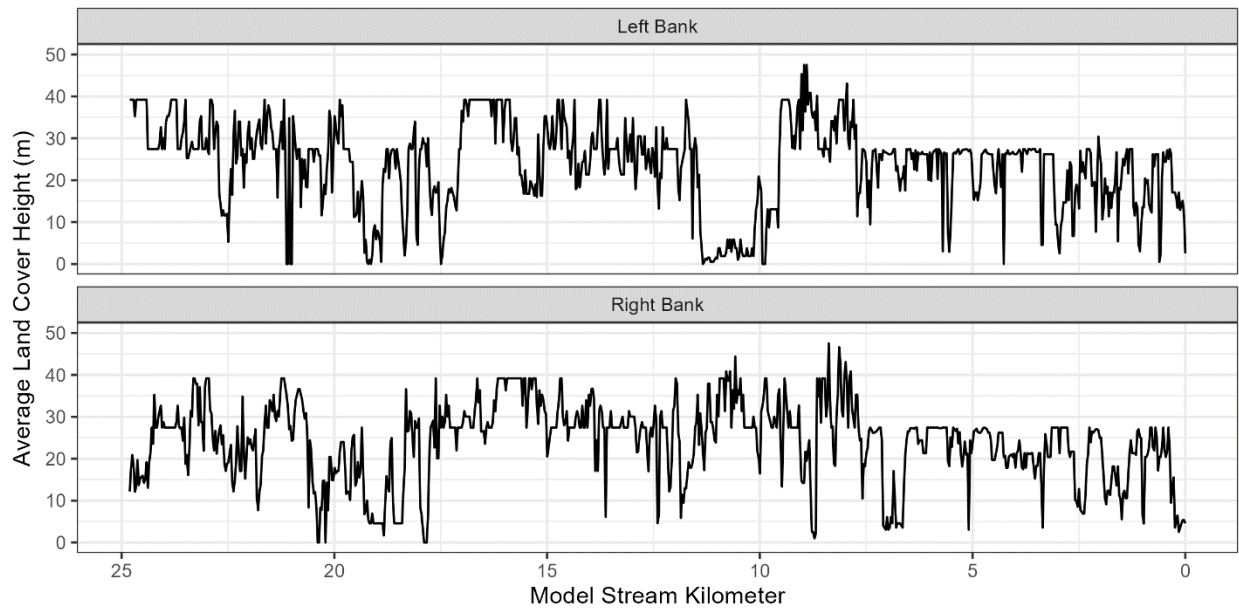
**Figure 3-100: Boundary condition and mainstem flow inputs to the Little North Santiam River model.**

### 3.4.7 Point source inputs

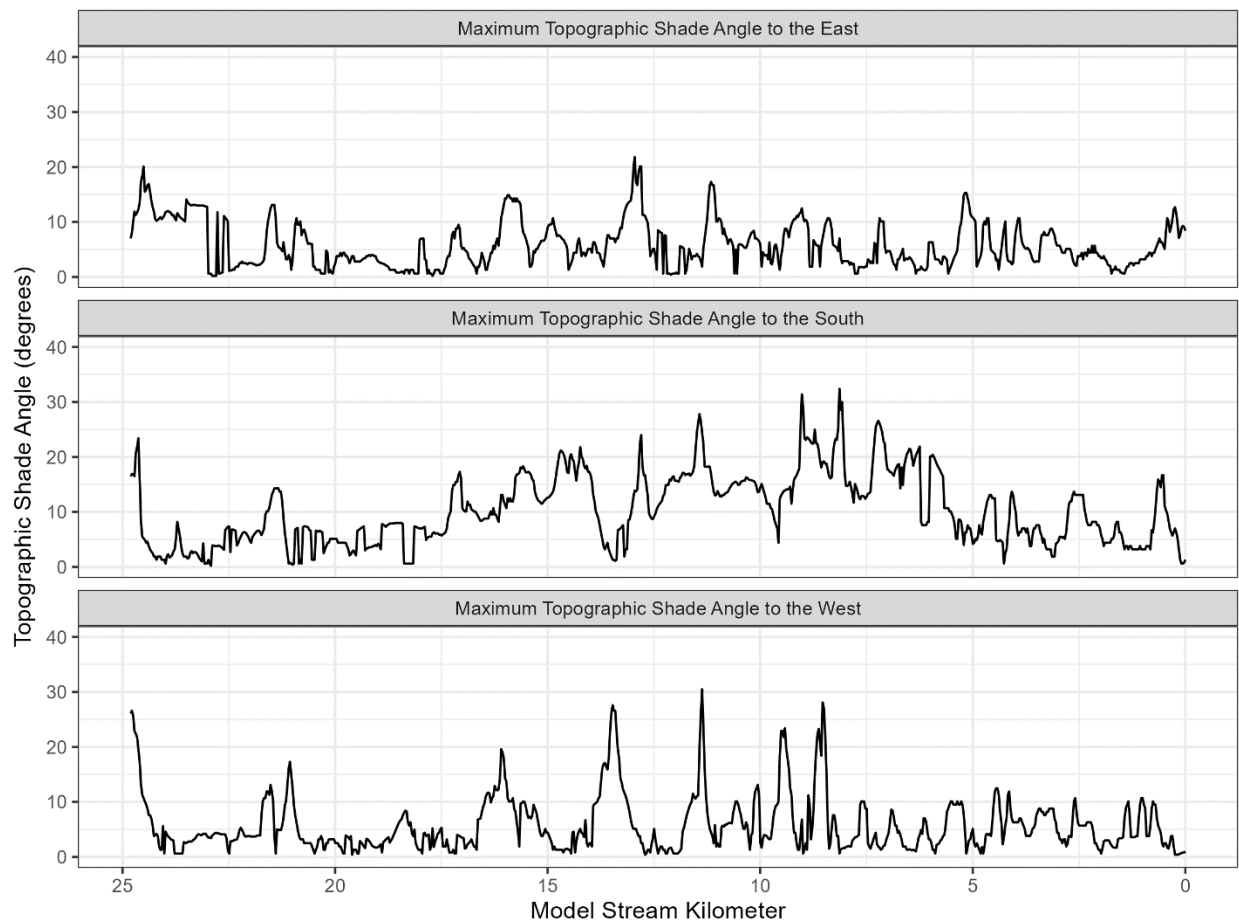
There are no point sources discharging within the model extent.

### 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.



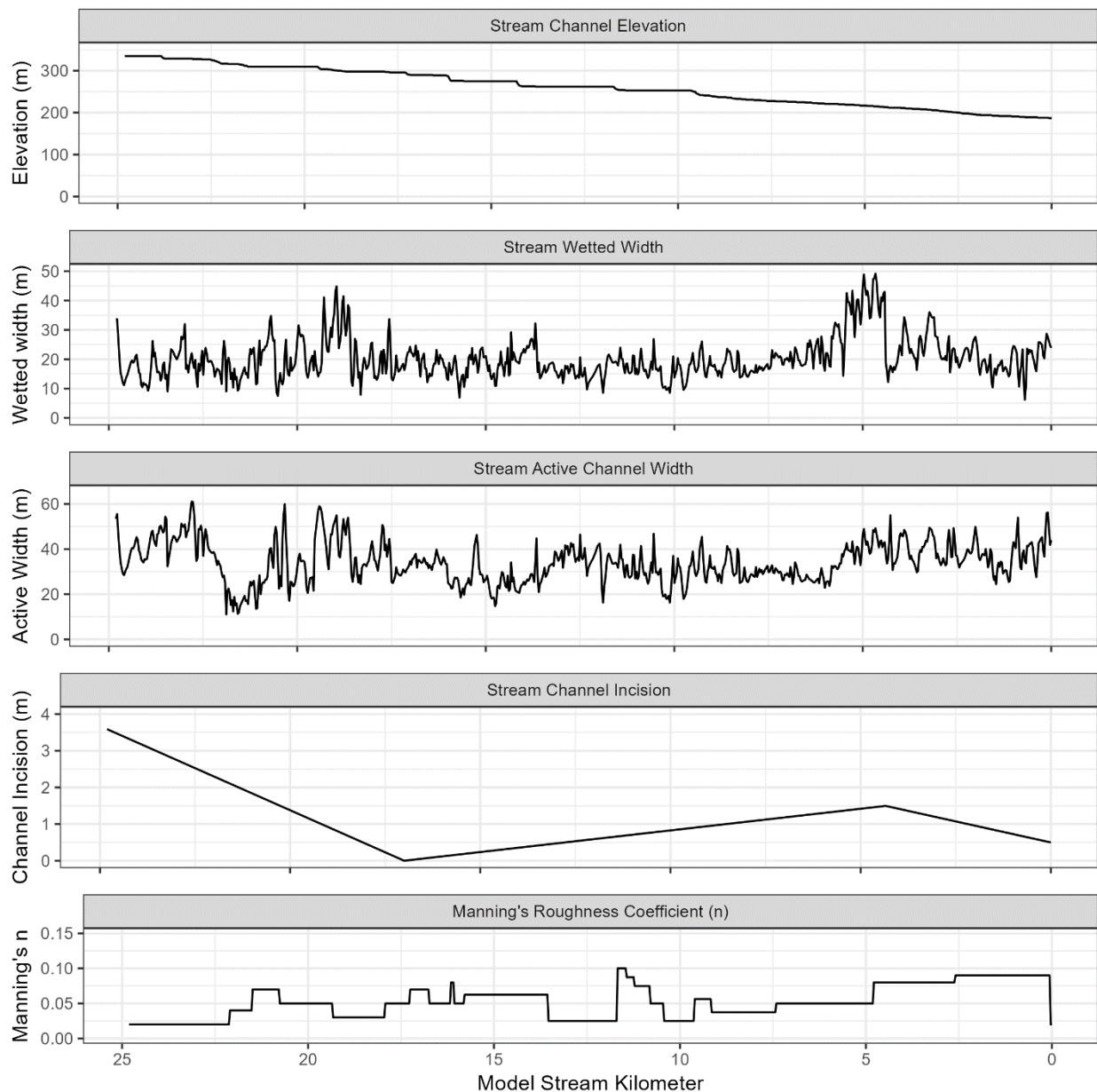
**Figure 3-101: Average land cover height inputs to the Little North Santiam River model.**



**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

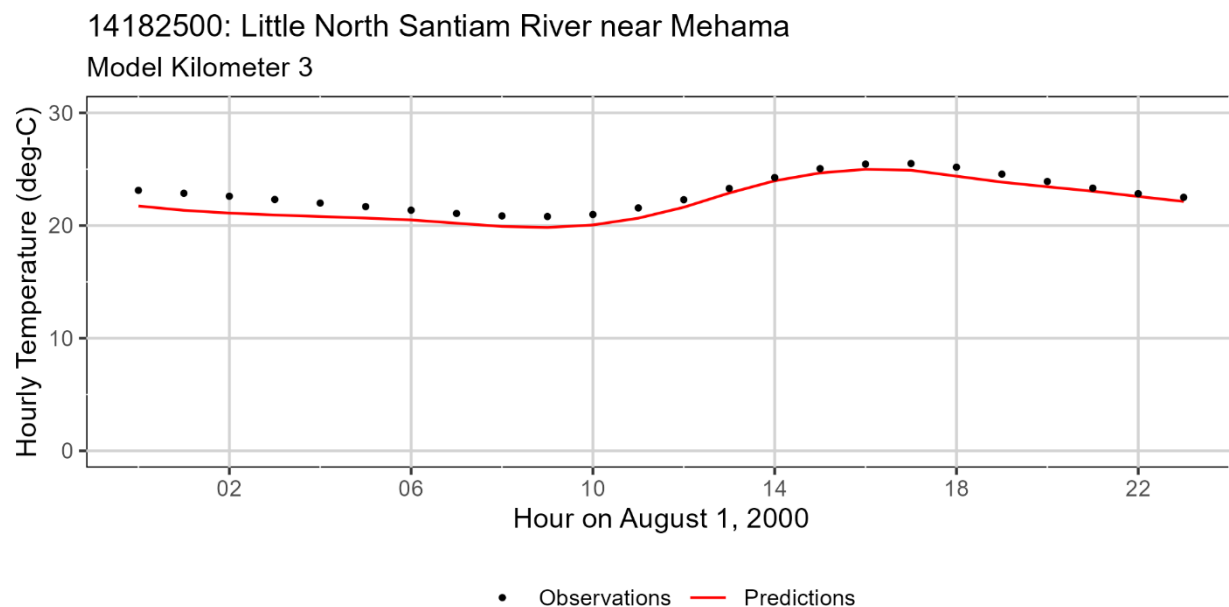
#### 3.4.10.1 Temperature

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

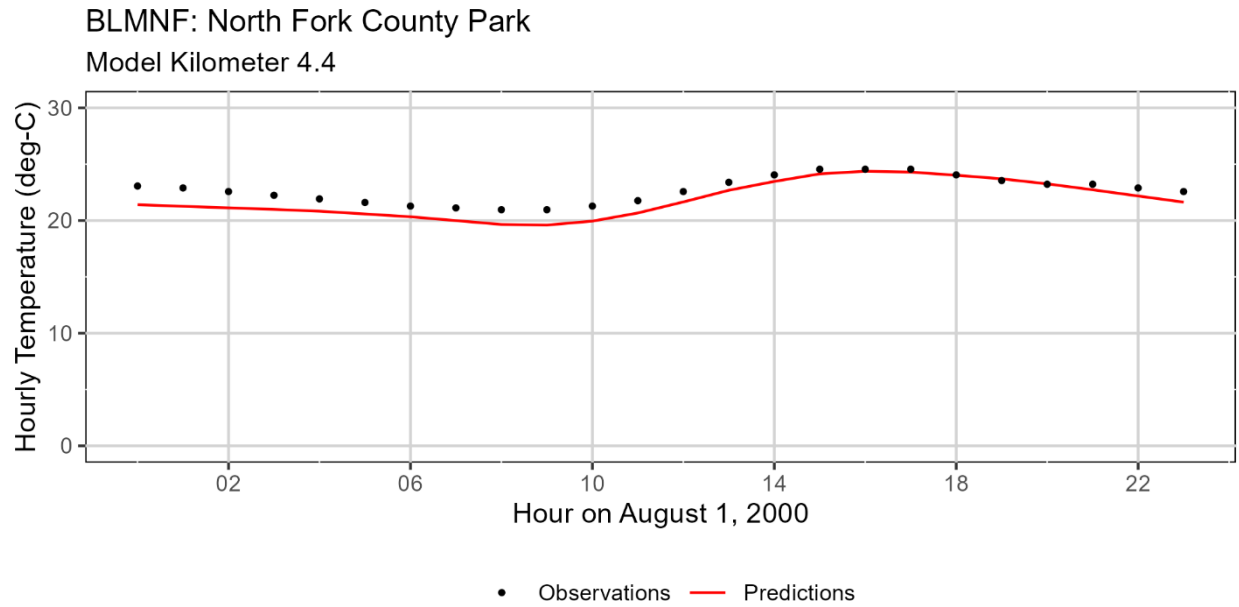
statistics comparing field observed and model-predicted temperatures are summarized in **Table 3-31**. Comparisons of model-calculated temperatures to continuous temperature data collected at monitoring locations where data was successfully retrieved is presented in **Figure 3-104** through **Figure 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.**

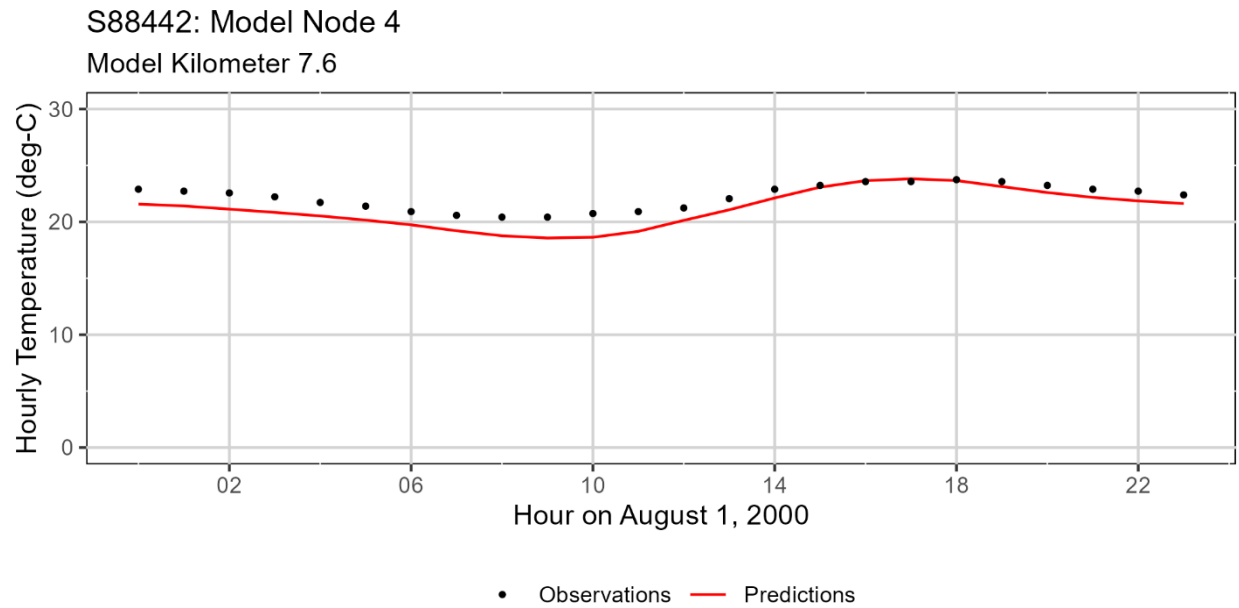
| Monitoring Location                              | Model KM     | Temperature Statistics | ME    | MAE  | RMSE | NSE   | n   |
|--|--------------|------------------------|-------|------|------|-------|-----|
| All Stations                                     |              | Daily Maximum          | 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 |



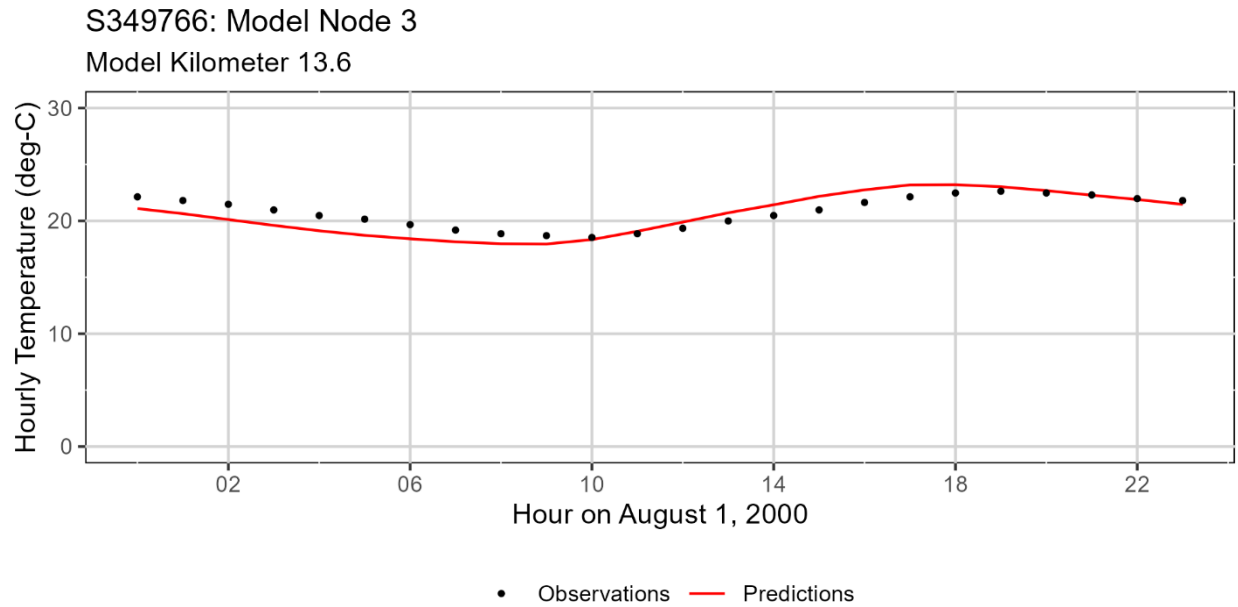
**Figure 3-104: Little North Santiam River measured and model-predicted hourly temperatures at monitoring station 14182500.**



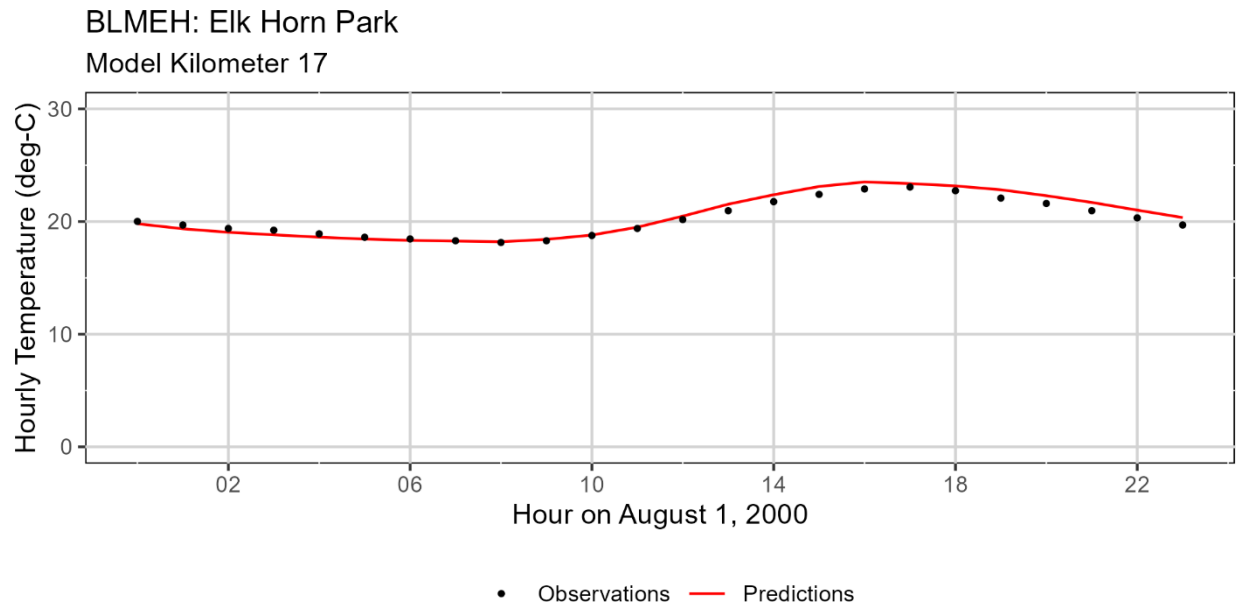
**Figure 3-105: Little North Santiam River measured and model-predicted hourly temperatures at monitoring station BLMNF.**



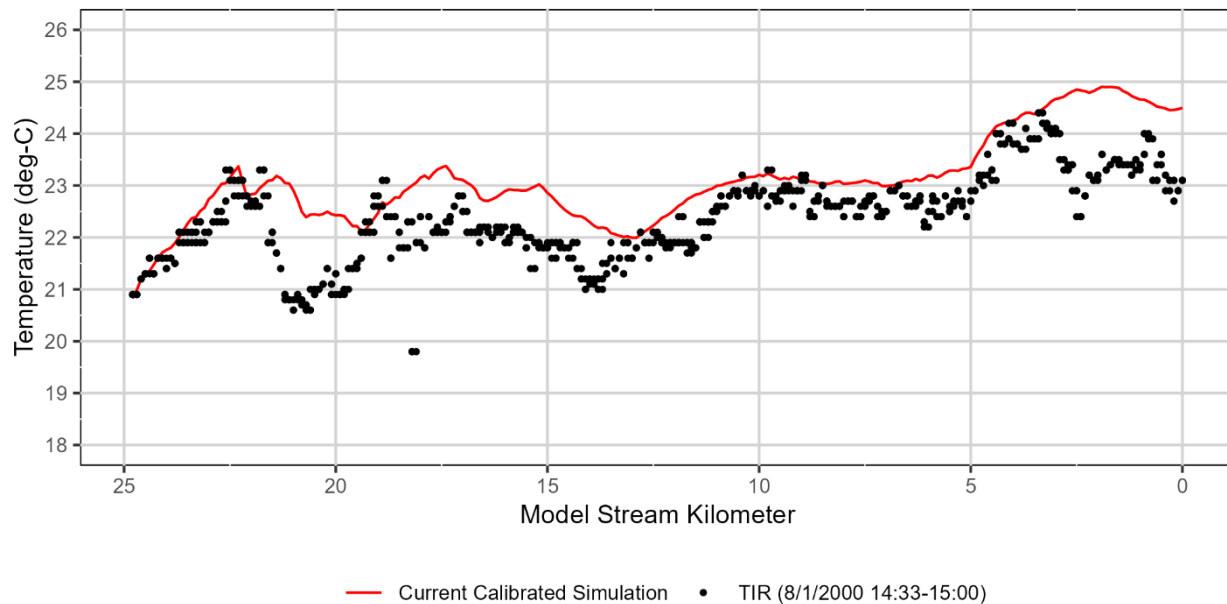
**Figure 3-106: Little North Santiam River measured and model-predicted hourly temperatures at monitoring station S88442.**



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



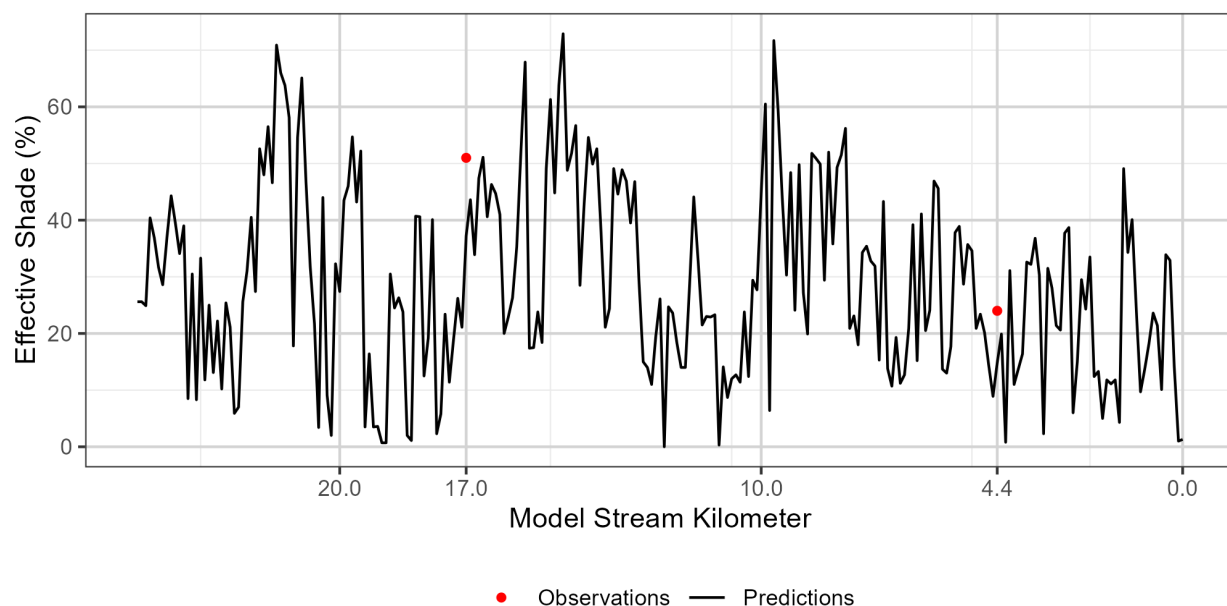
**Figure 3-108: Little North Santiam River measured and model-predicted hourly temperatures at monitoring station BLMEH.**



**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.**

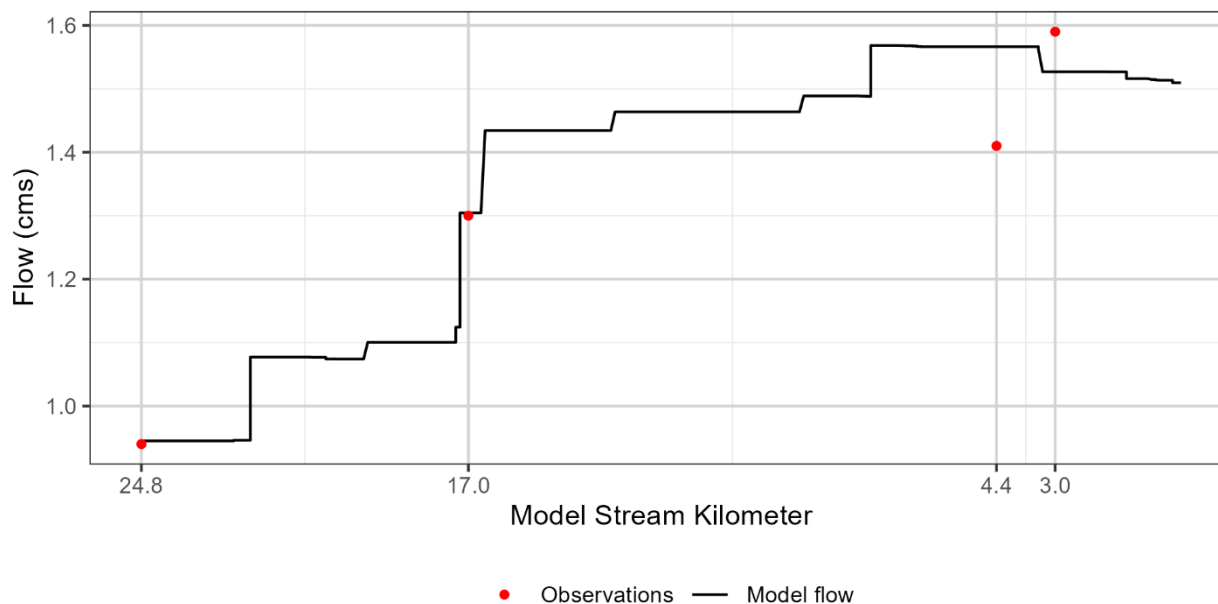
| N | R <sup>2</sup> | ME    | MAE  | RMSE  |
|---|----------------|-------|------|-------|
| 2 | 1.0            | -11.5 | 11.5 | 11.73 |

### 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 |



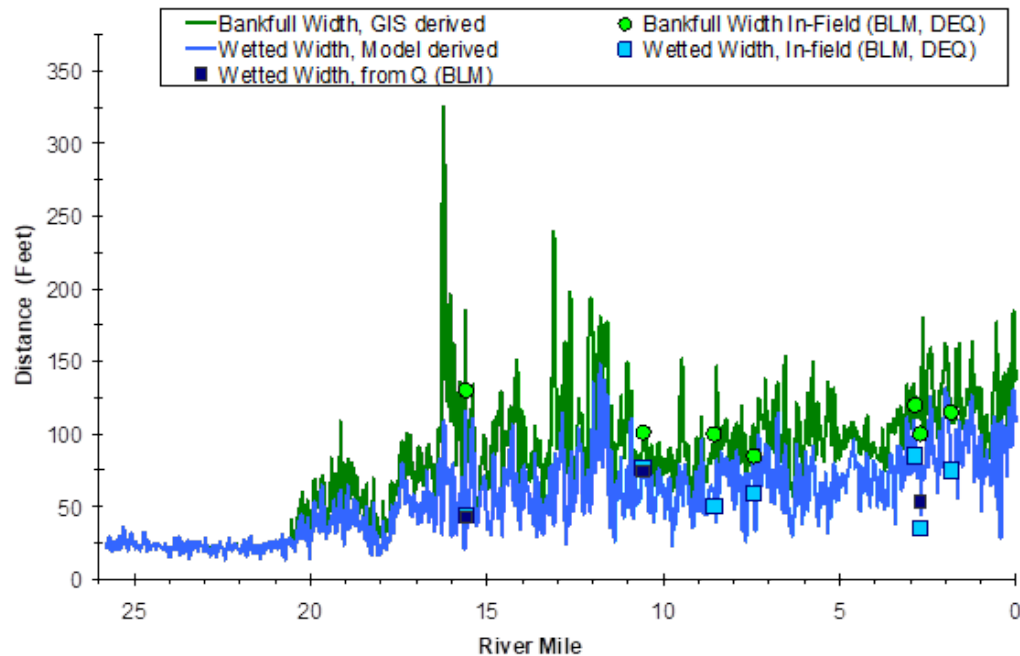
**Figure 3-111: Little North Santiam River field observed and model flow rates.**

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

| N | R <sup>2</sup> | 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**).

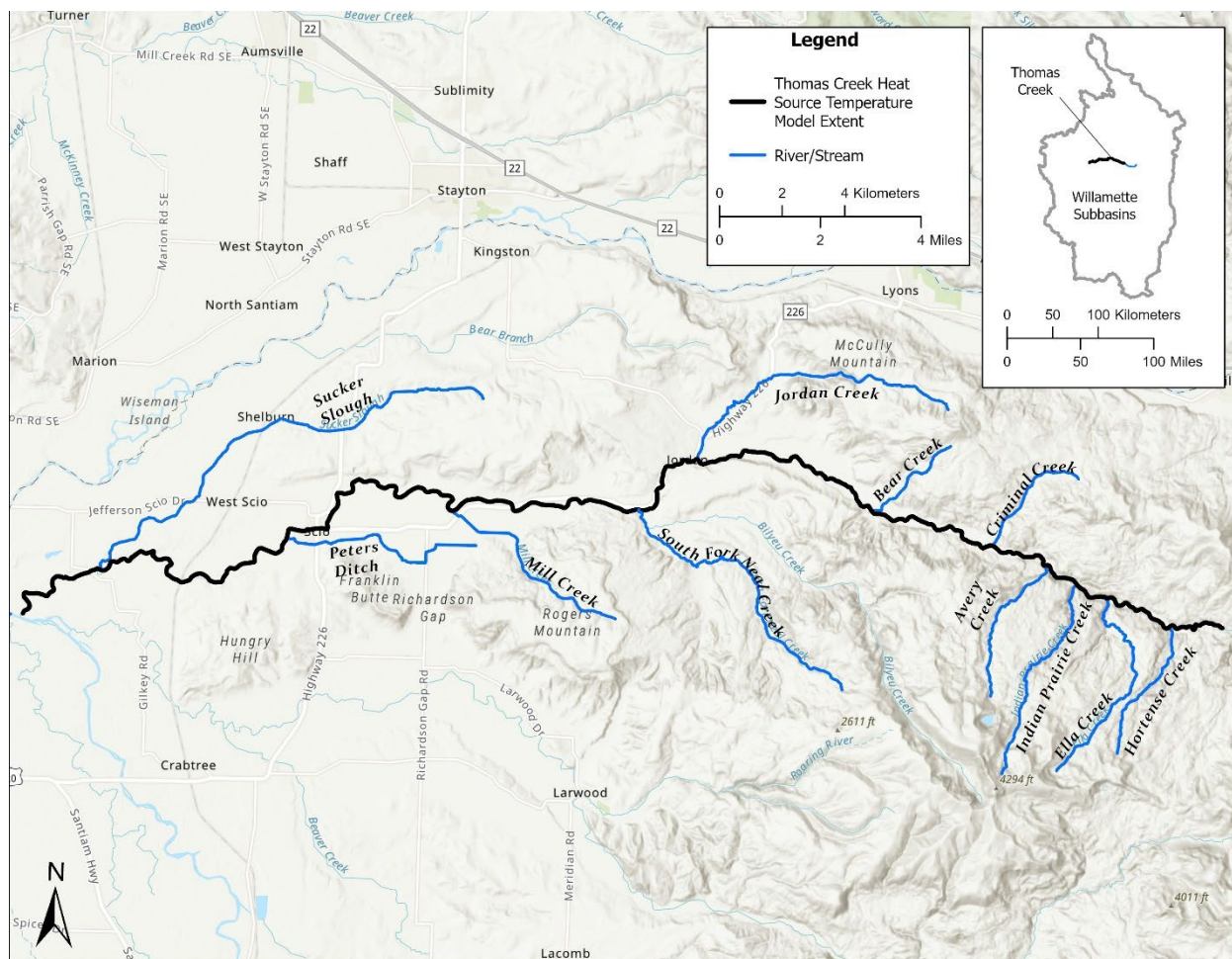


Figure 3-113: Thomas Creek temperature model extent.

### 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.

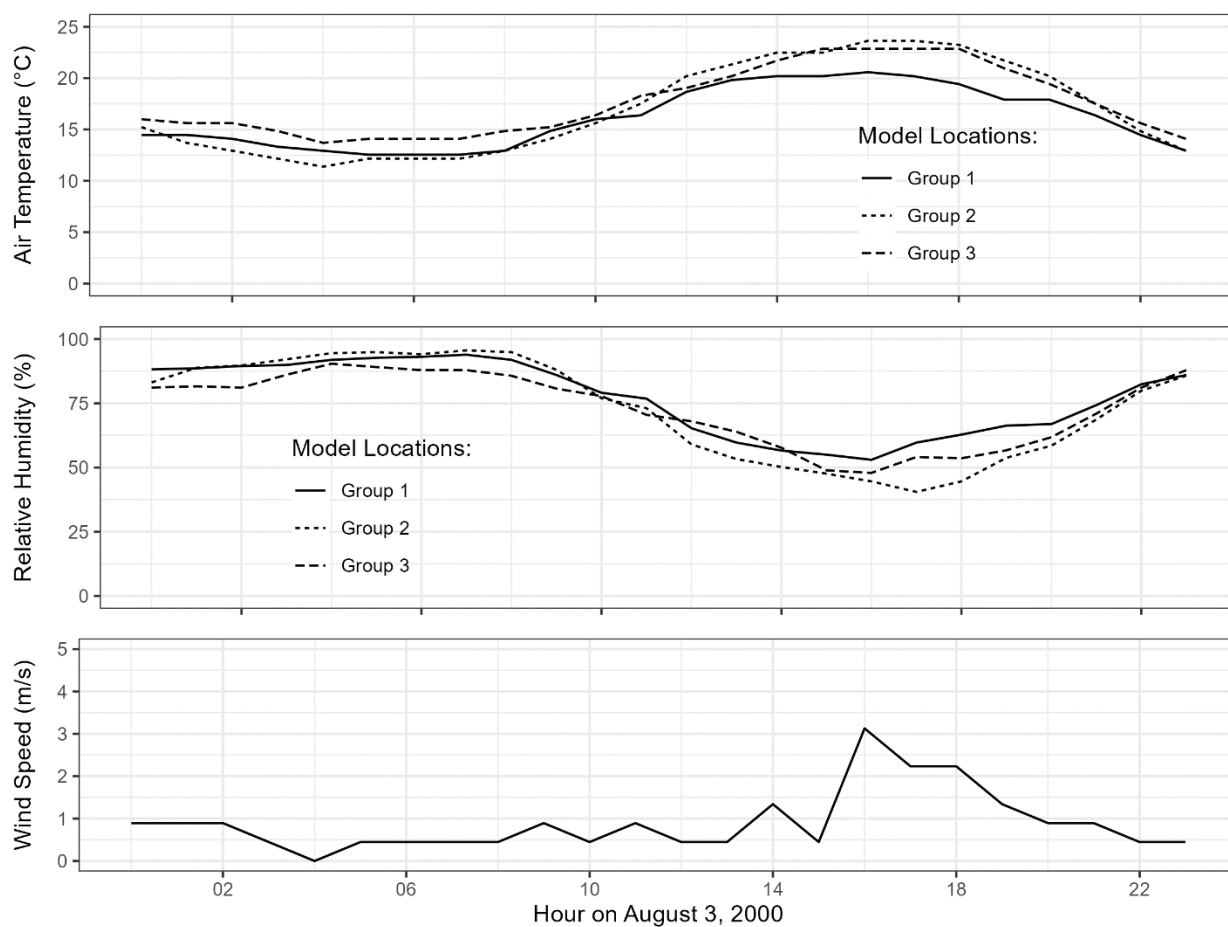
### 3.5.4 Meteorological inputs

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.**

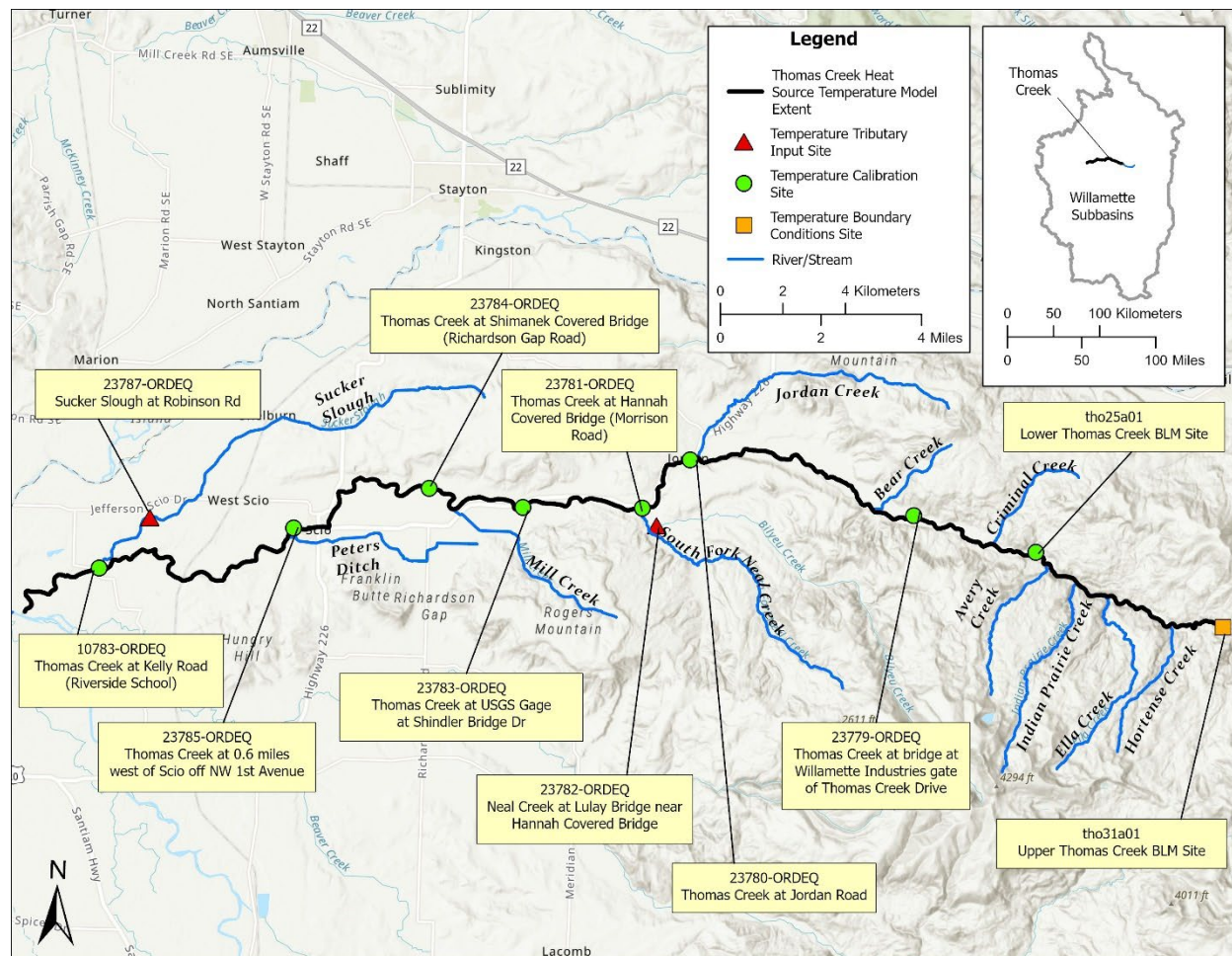
| Group   | Model Location (km) | Model Location Name                                  | Wind Sheltering Coefficient |
|---------|---------------------|--|-----------------------------|
| Group 1 | 50.871              | Upper Thomas Creek BLM Site                          | 0.04                        |
|         | 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.



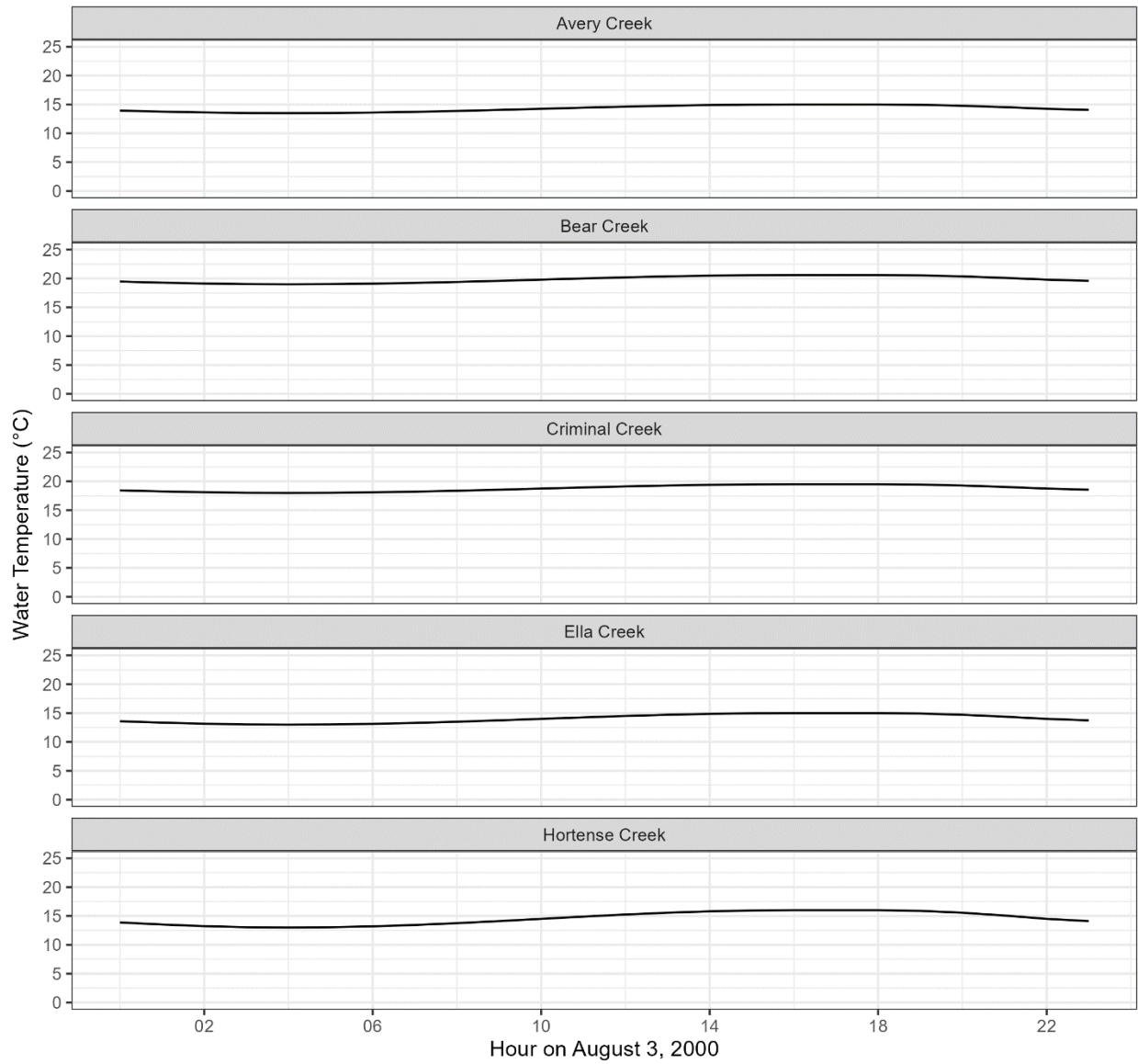
**Figure 3-115: Temperature monitoring locations used for the Thomas Creek model setup and calibration.**

**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.

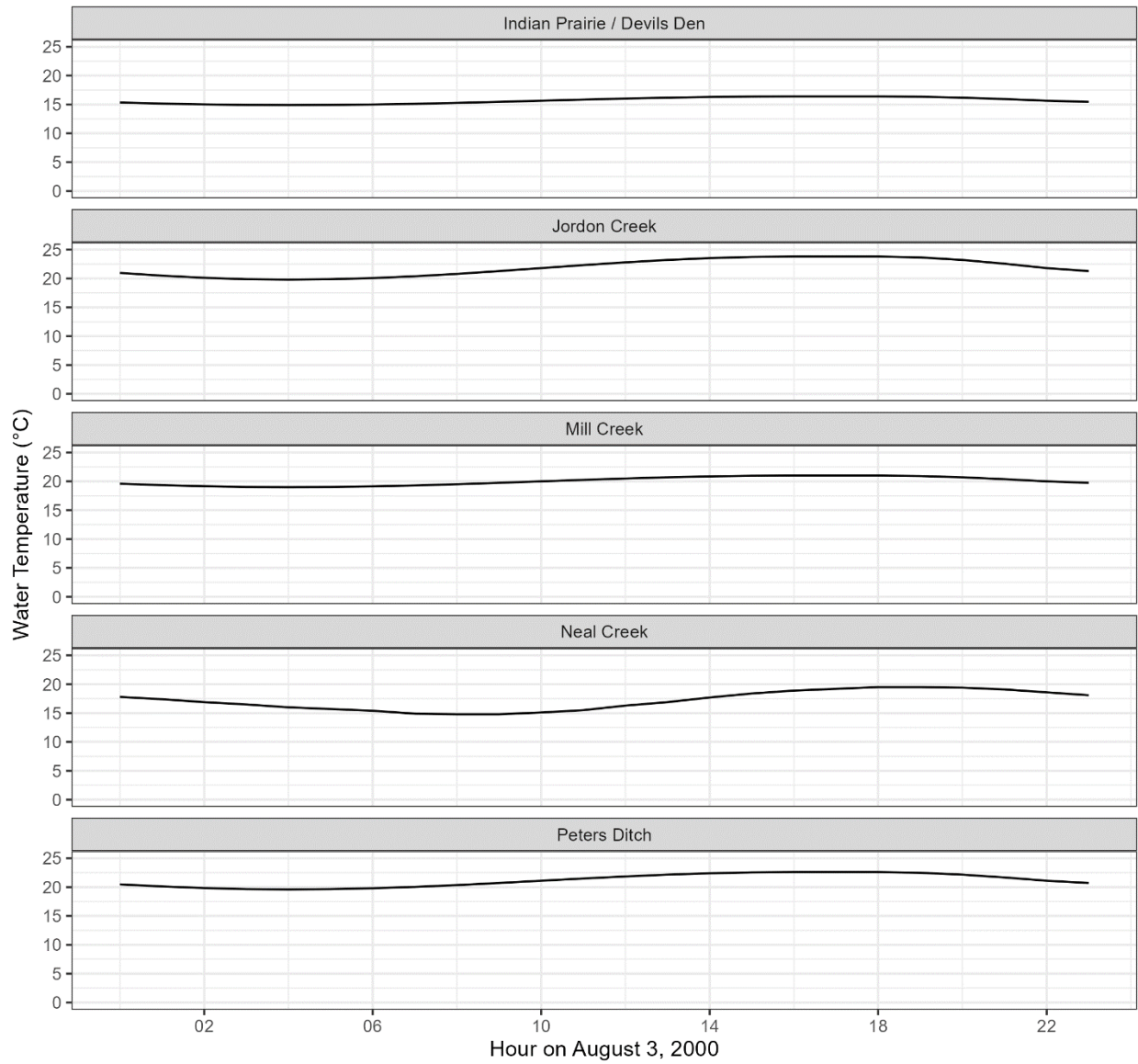
**Table 3-36: Boundary condition and tributary water temperature inputs to the Thomas Creek model.**

| 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                                 |

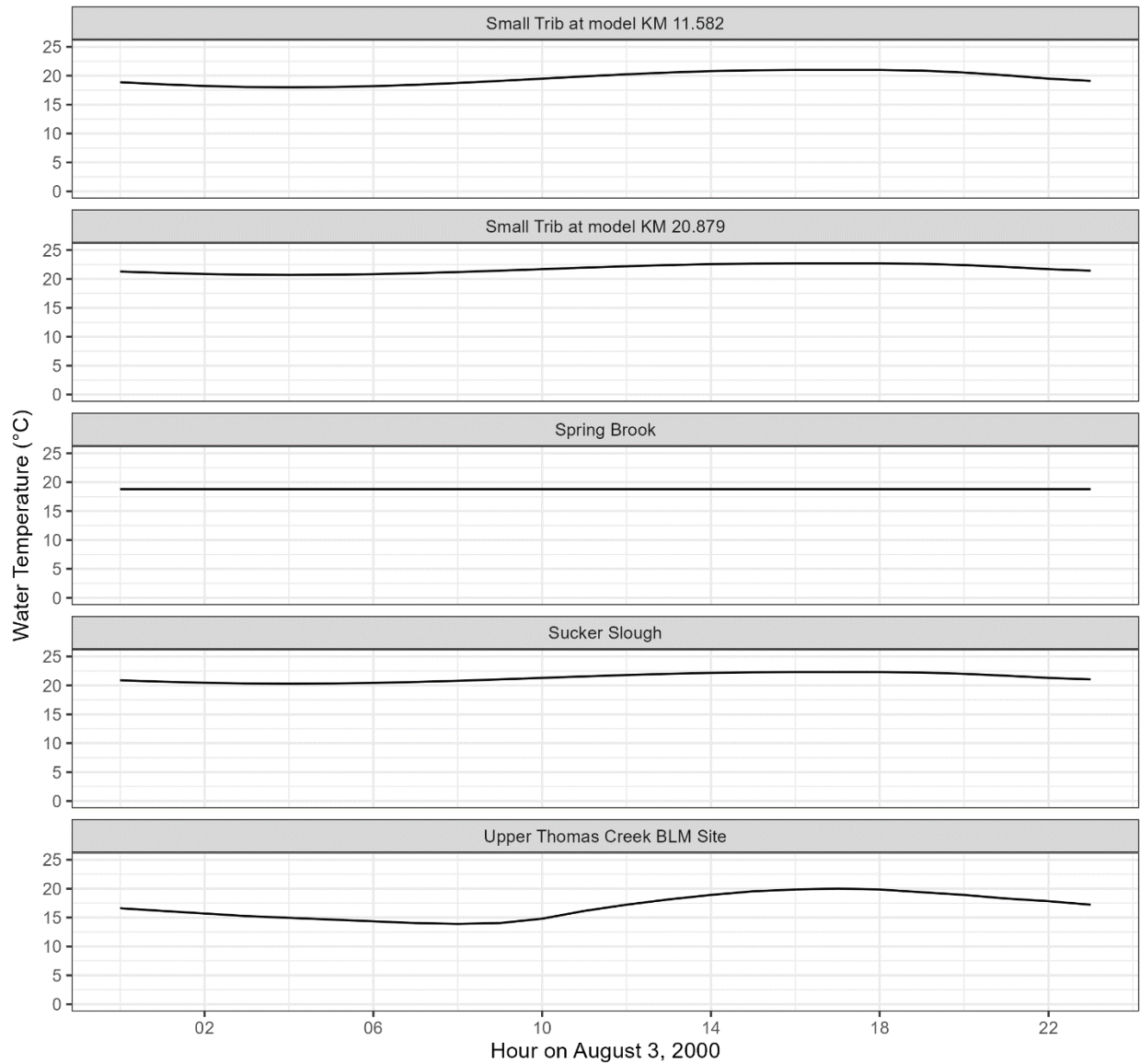
\* Constant temperature of 18.8°C.



(A)



(B)

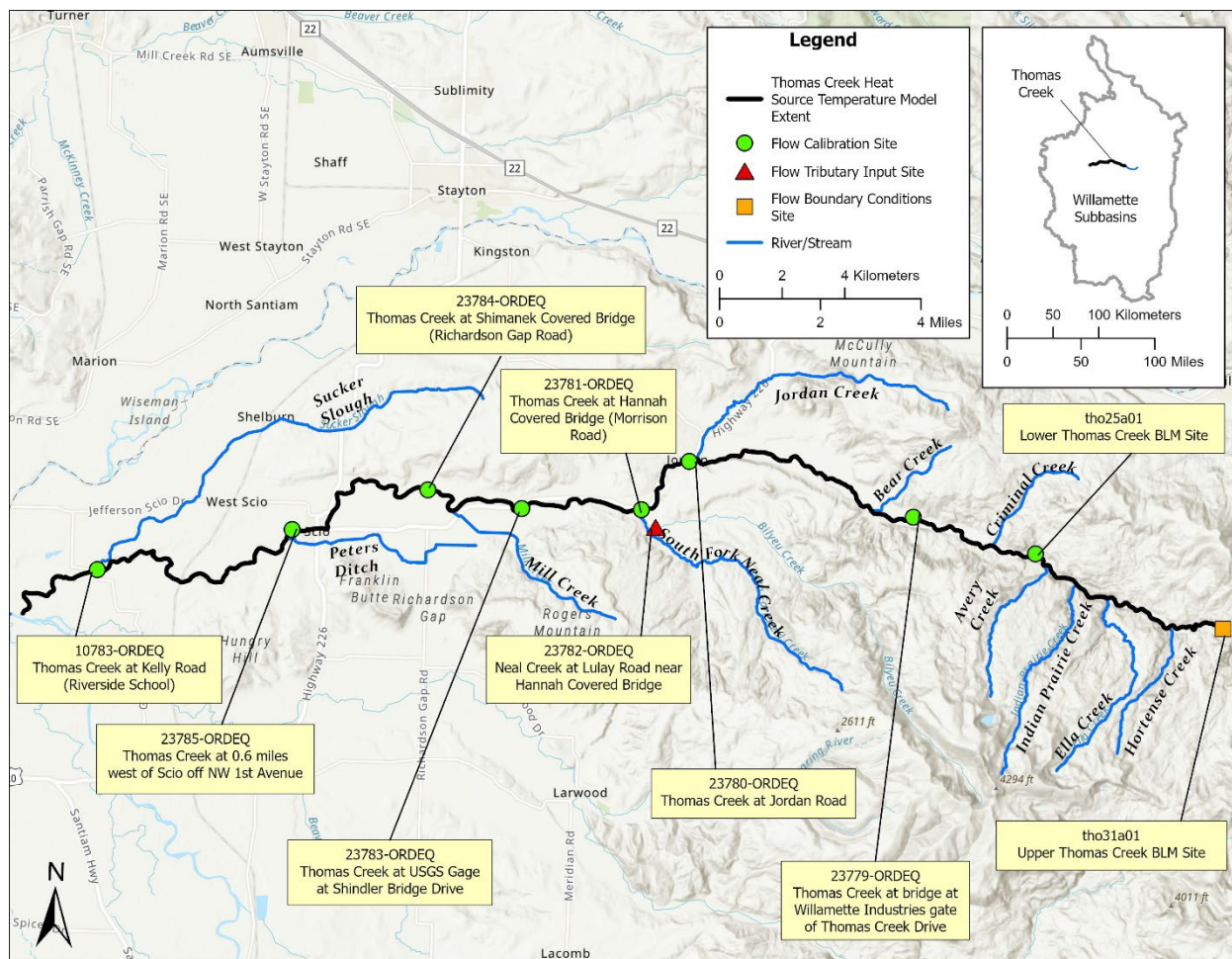


(C)

**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.



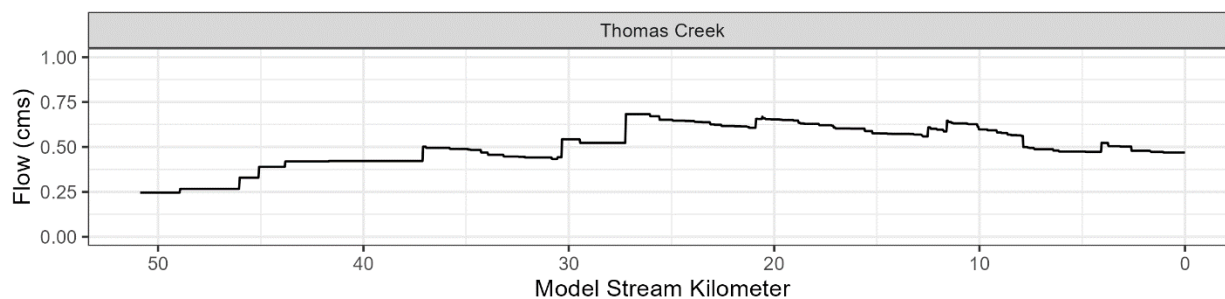
**Figure 3-117: Flow monitoring locations used for the Thomas Creek model setup and calibration.**

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 |
| Ella Creek                  | 46.055              | 0.063           | Tributary          | Estimated using a flow mass balance based on TIR |

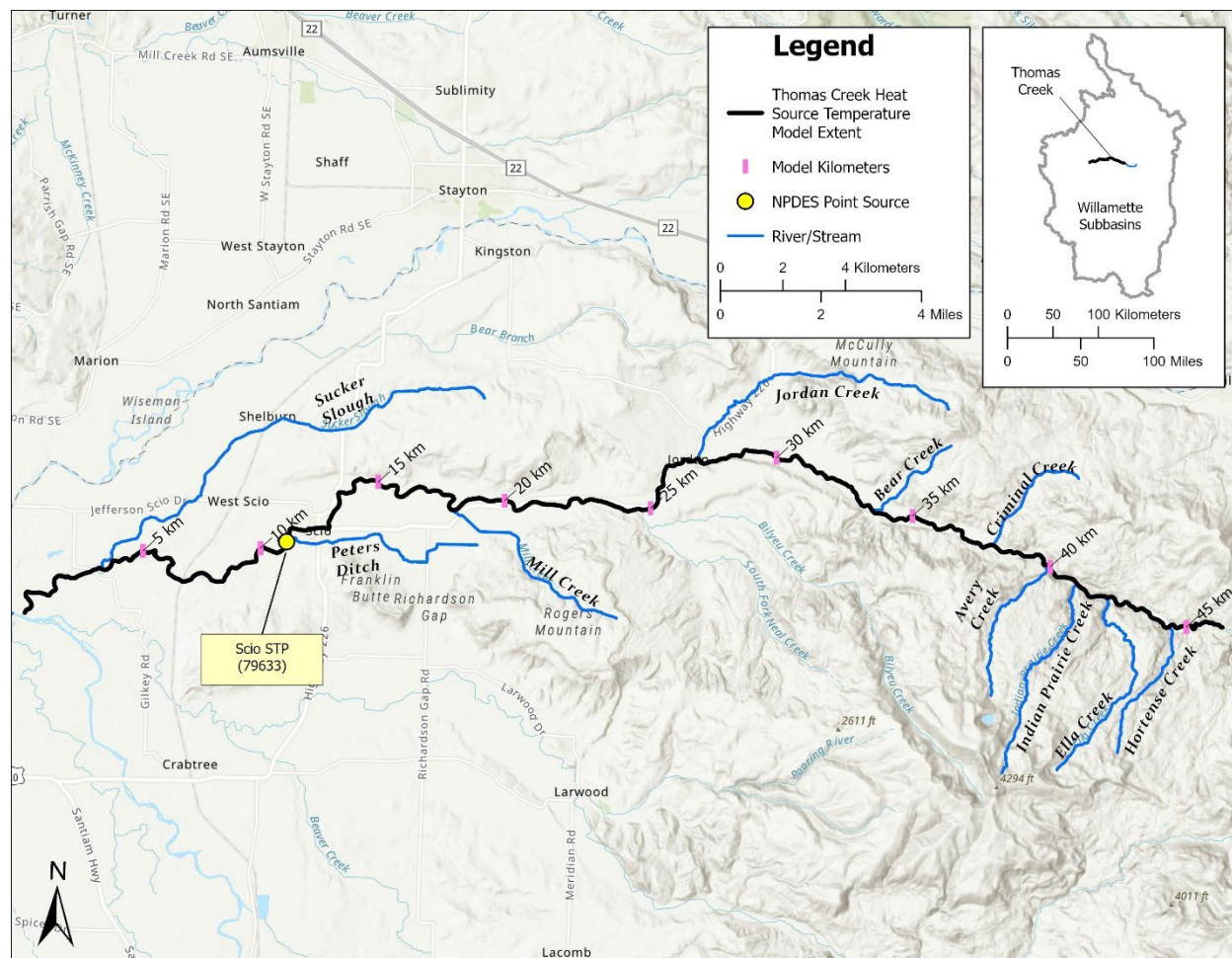
| Model Location Name                                   | Model Location (km) | Flow Rate (cms) | Input Type | Data Source                                      |
|---|---------------------|-----------------|------------|--|
| Indian Prairie / Devils Den                           | 45.11               | 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.



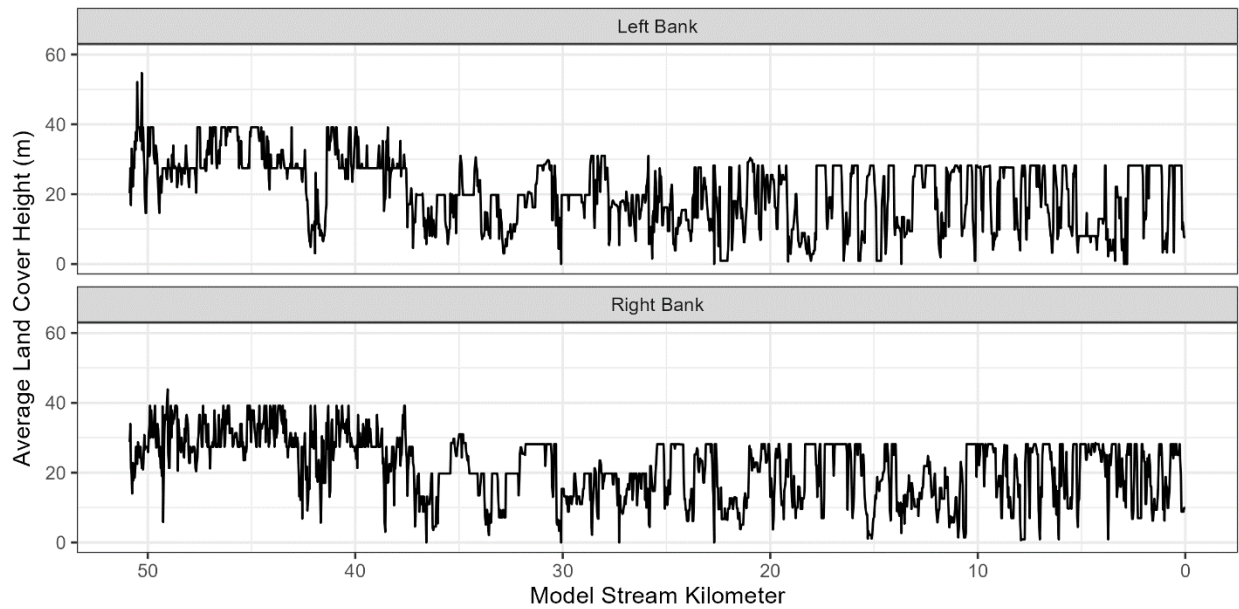
**Figure 3-119: Locations of permitted individual NPDES point sources near the Thomas River.**

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

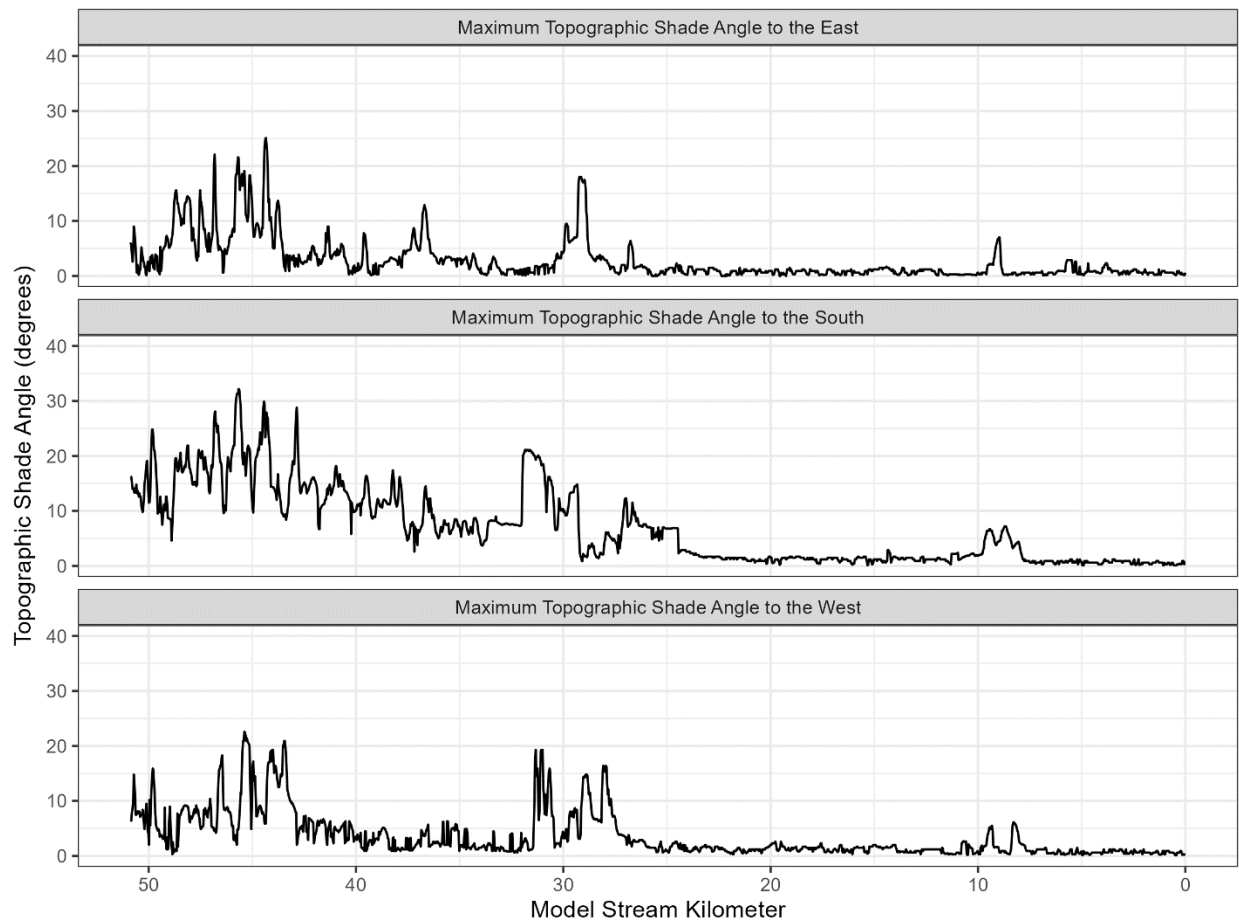
| Facility Name<br>(Facility Number) | Latitude/Longitude | Permit Type and Description                                     | Stream/River<br>Mile   |
|------------------------------------|--------------------|---|------------------------|
| Scio STP (79633)                   | 44.7001/-122.862   | NPDES-DOM-Db: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



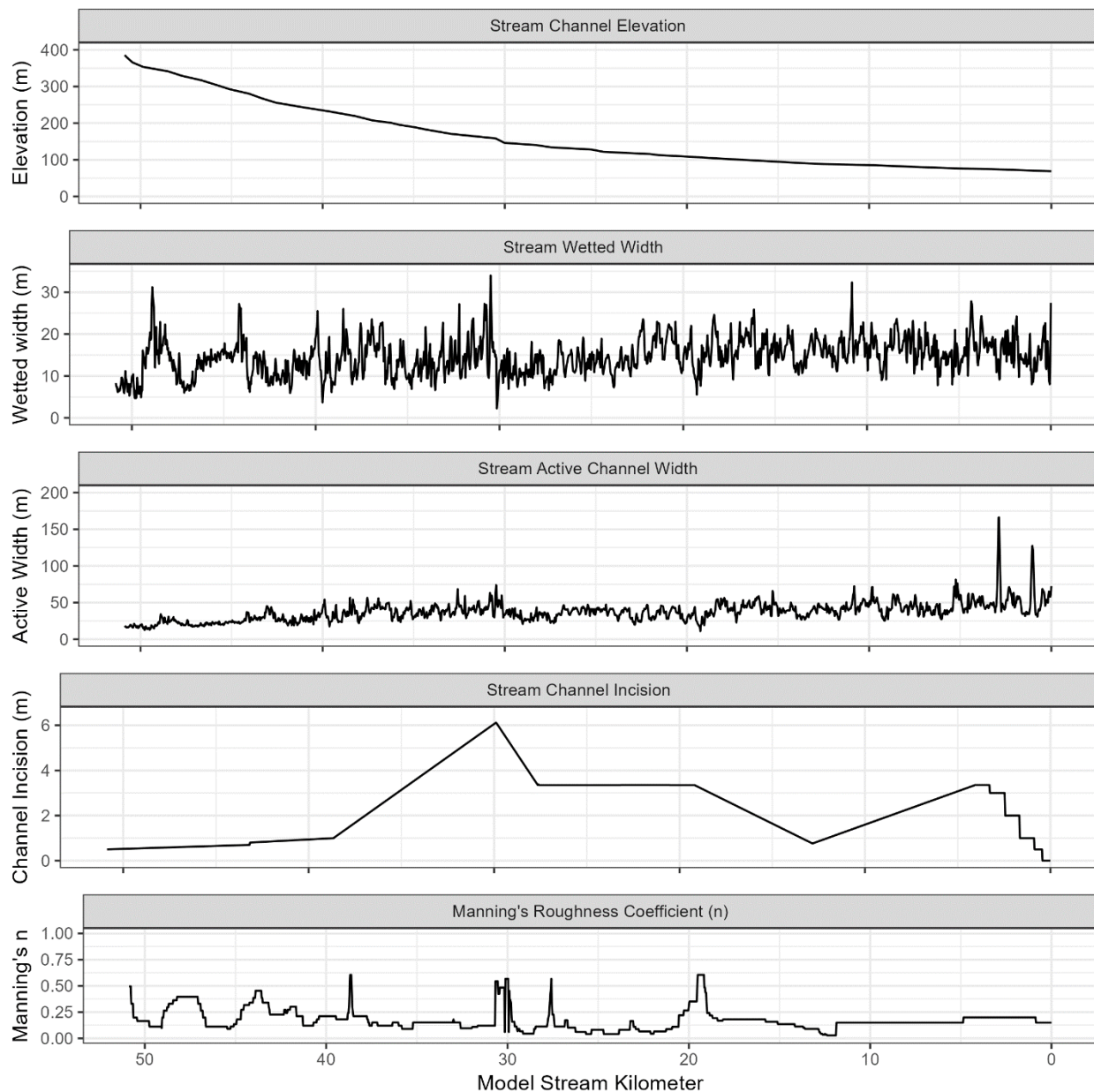
**Figure 3-120: Average land cover height inputs to the Thomas Creek model.**



**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

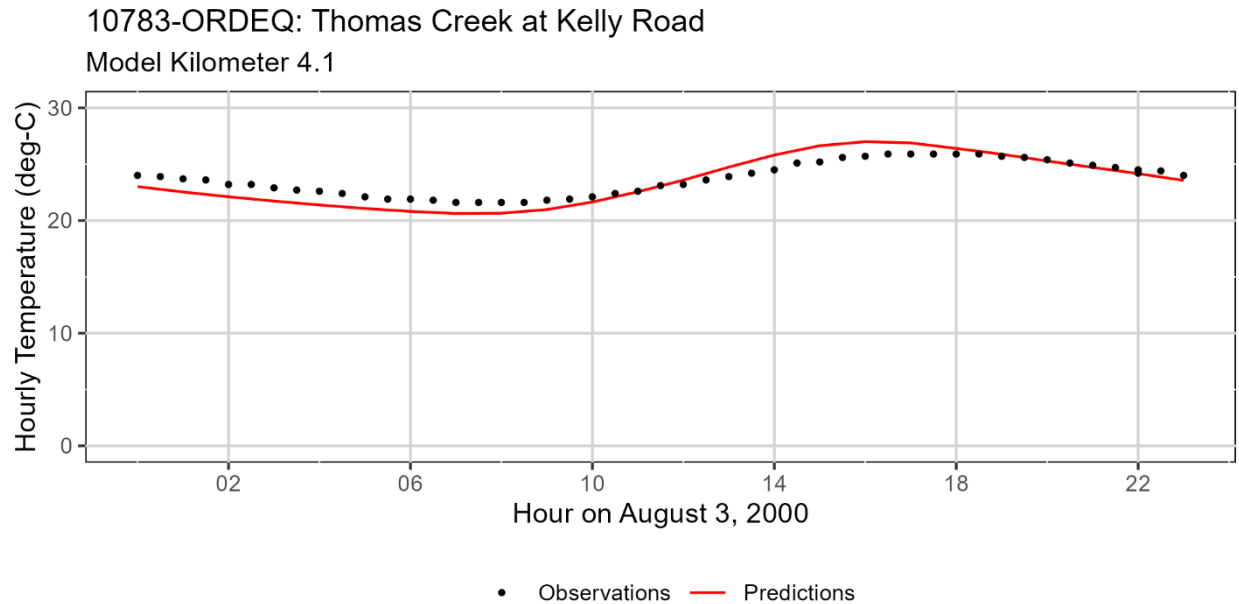
#### 3.5.10.1 Temperature

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

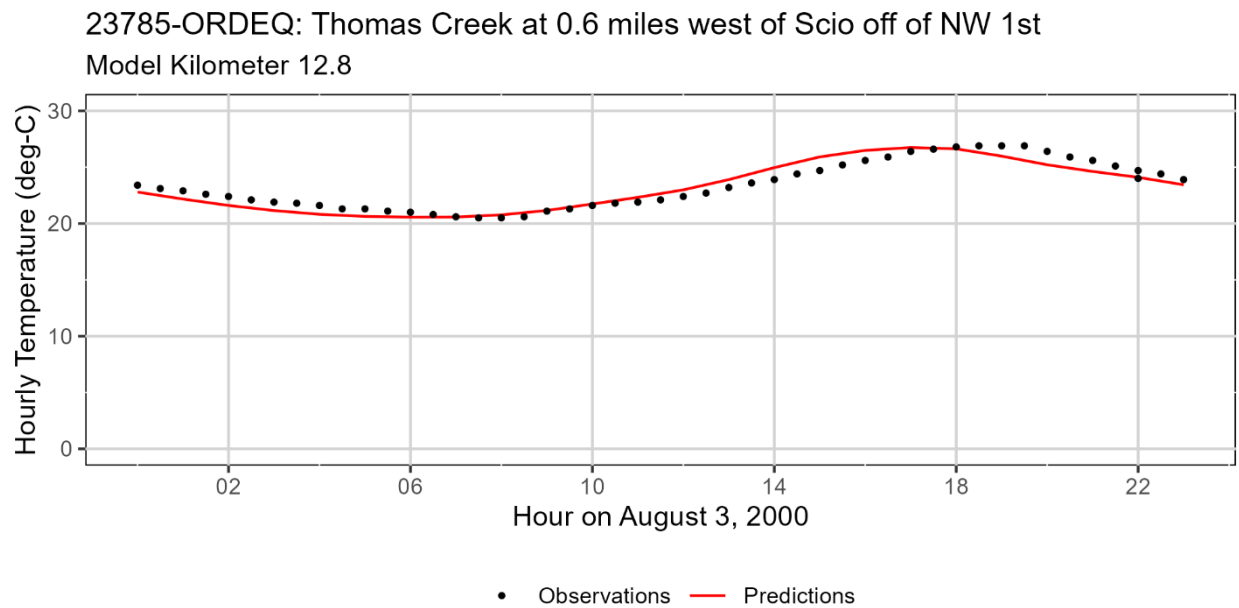
field observed and model-predicted temperatures are summarized in **Table 3-39**. Observed and model-predicted hourly temperatures were plotted for the monitoring stations (**Figure 3-123** through **Figure 3-130**). Modeling results comparing simulated current conditions for Johnson Creek to the TIR 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 |

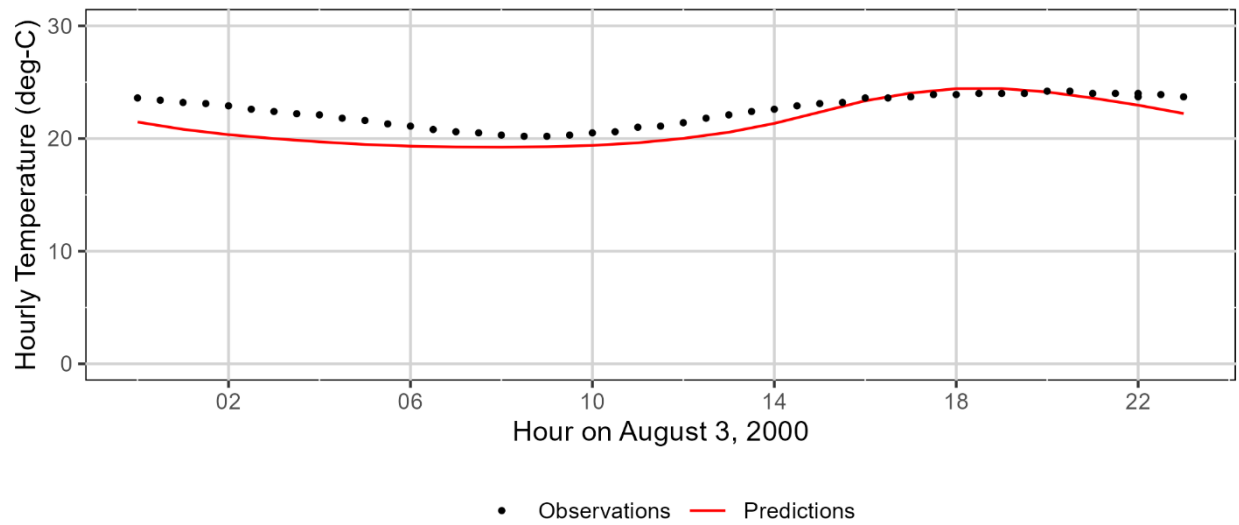


**Figure 3-123: Thomas Creek measured and model-predicted hourly temperatures at monitoring station 10783-ORDEQ.**



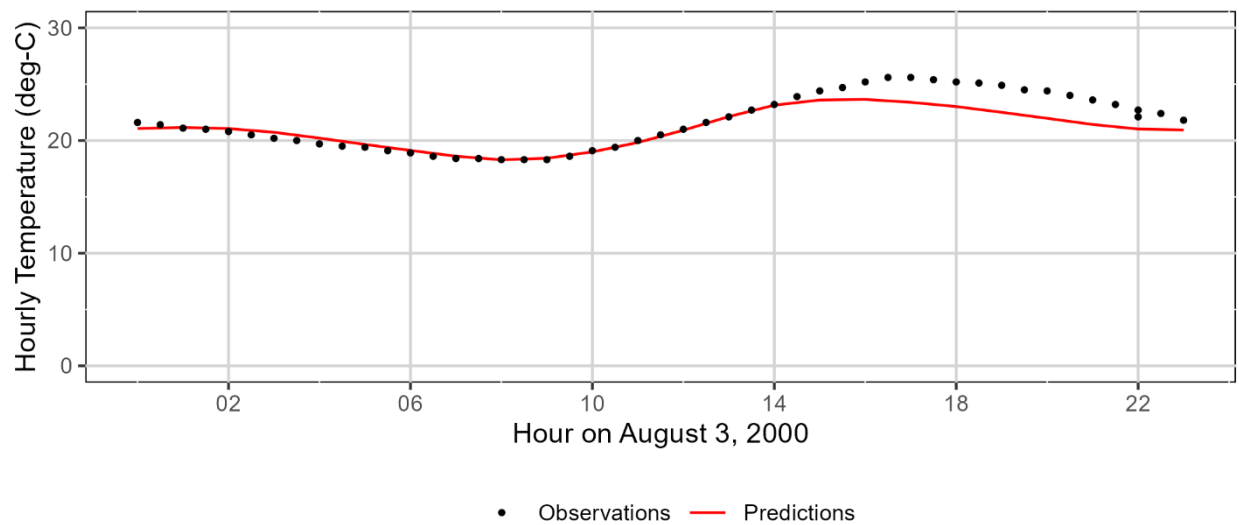
**Figure 3-124: Thomas Creek measured and model-predicted hourly temperatures at monitoring station 23785-ORDEQ.**

23784-ORDEQ: Thomas Creek at Shimanek Covered Bridge  
Model Kilometer 19.2



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

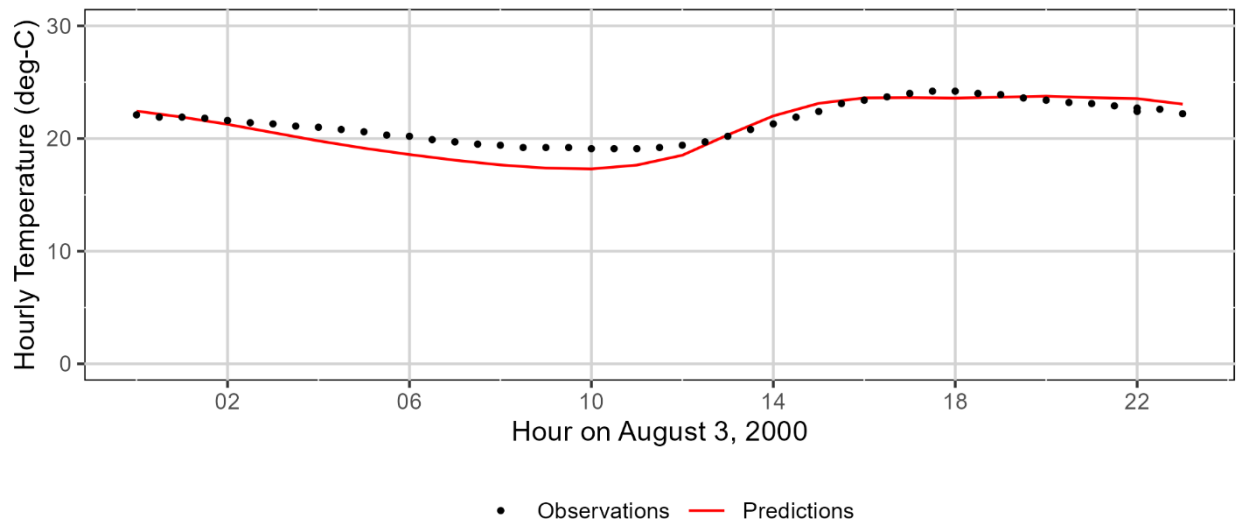
23783-ORDEQ: Thomas Creek at USGS Gauge at Shindler Bridge Dr  
Model Kilometer 23.2



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

### 23781-ORDEQ: Thomas Creek at Hannah Covered Bridge

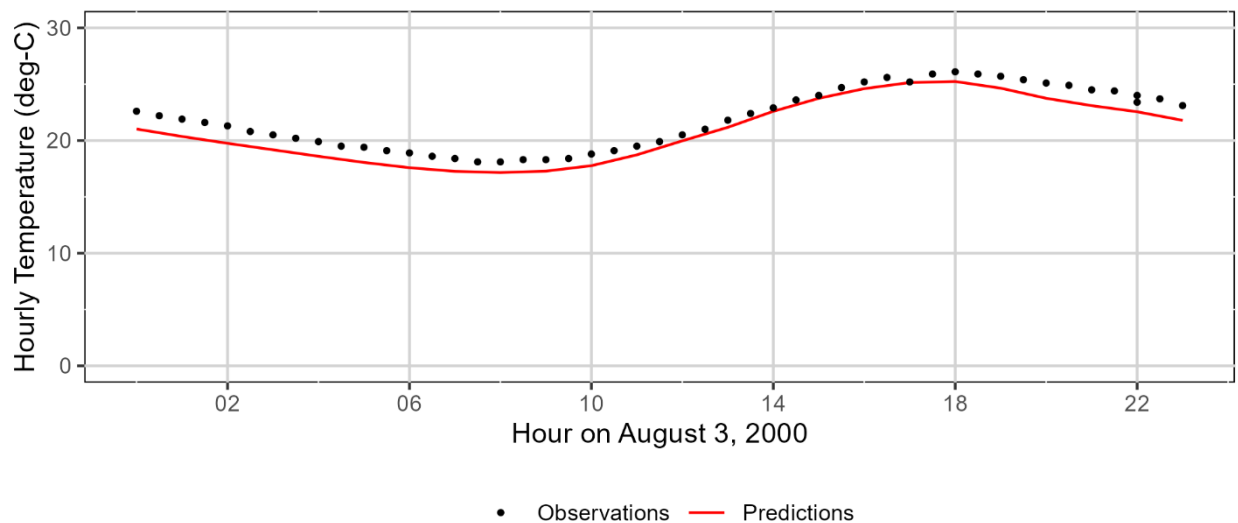
Model Kilometer 27.6



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

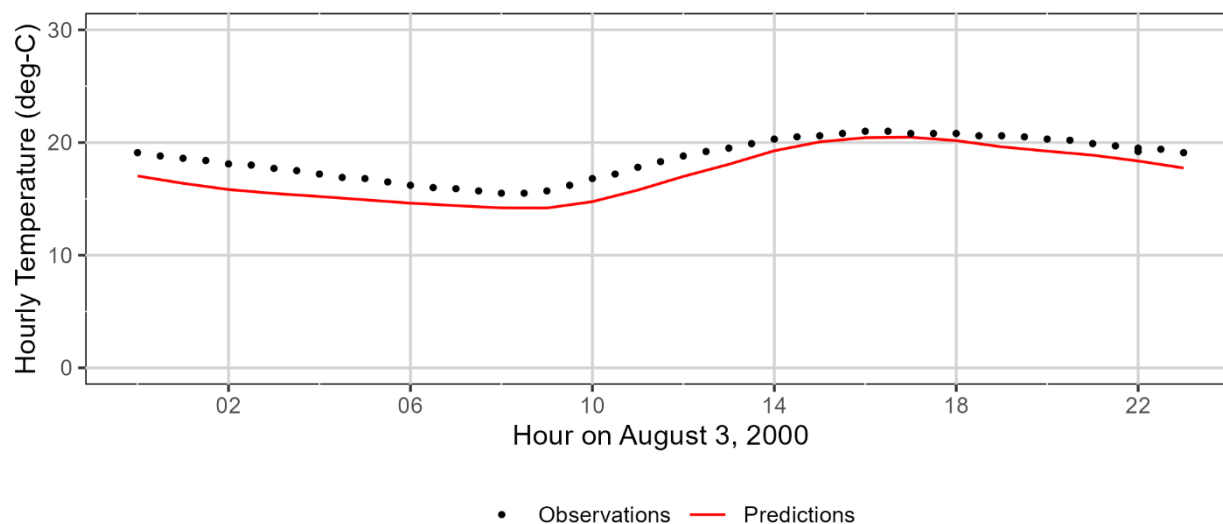
### 23780-ORDEQ: Downstream Jordon Creek

Model Kilometer 29.9



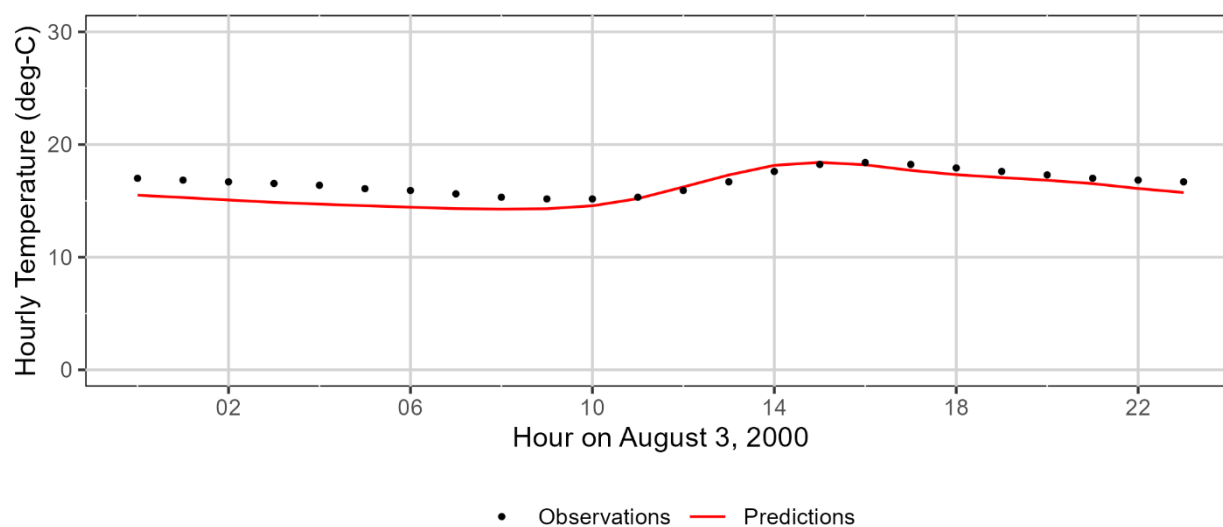
**Figure 3-128: Thomas Creek measured and model-predicted hourly temperatures at monitoring station 23780-ORDEQ.**

23779-ORDEQ: Thomas Creek at bridge at Willamette Industries Gate  
Model Kilometer 38.6

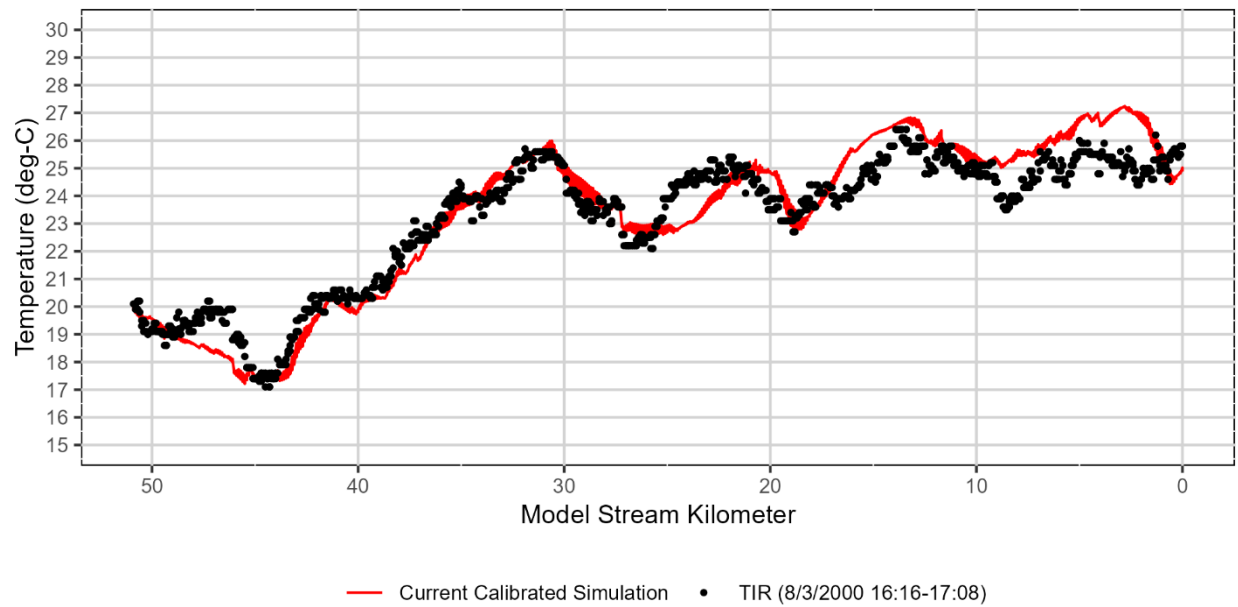


**Figure 3-129: Thomas Creek measured and model-predicted hourly temperatures at monitoring station 23779-ORDEQ.**

tho25a01: Lower Thomas Creek BLM Site  
Model Kilometer 43.2



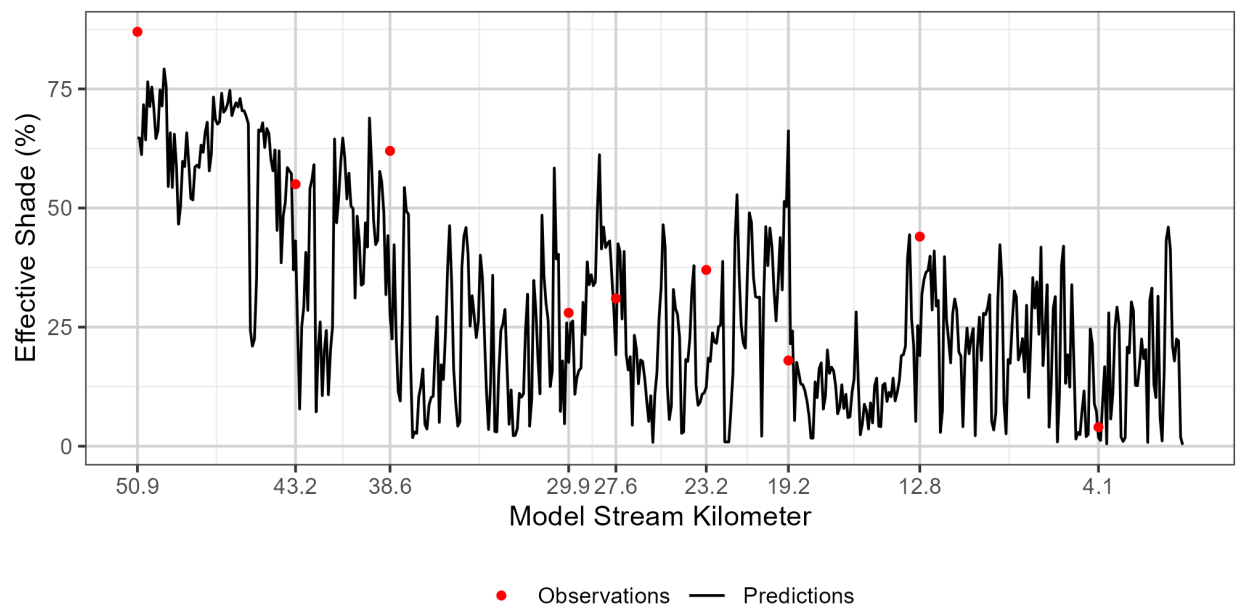
**Figure 3-130: Thomas Creek measured and model-predicted hourly temperatures at monitoring station tho25a01.**



**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.**

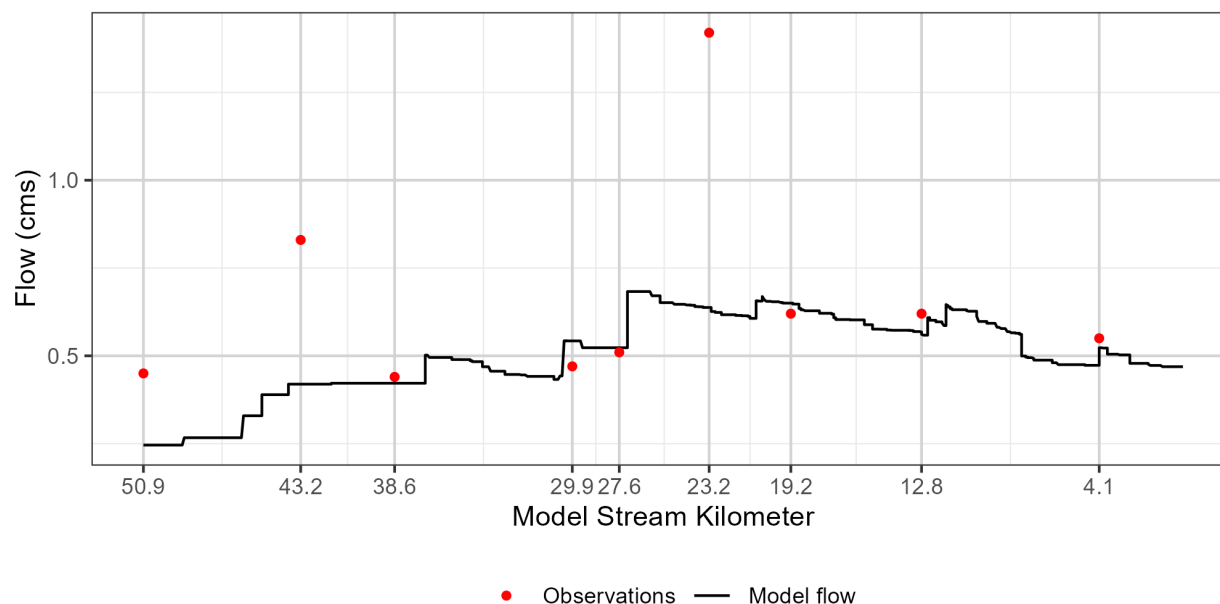
| N | R <sup>2</sup> | ME     | MAE   | RMSE  |
|---|----------------|--------|-------|-------|
| 9 | 0.24           | -10.48 | 21.19 | 24.99 |

### 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  |



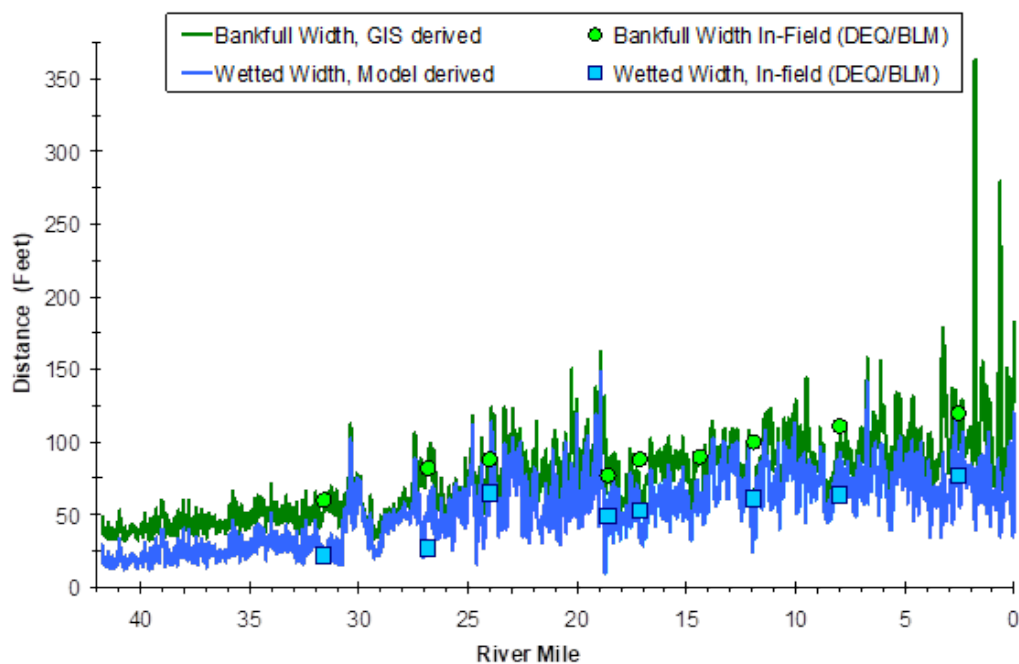
**Figure 3-133: Thomas Creek field observed and model flow rates.**

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

| N | R <sup>2</sup> | 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**).

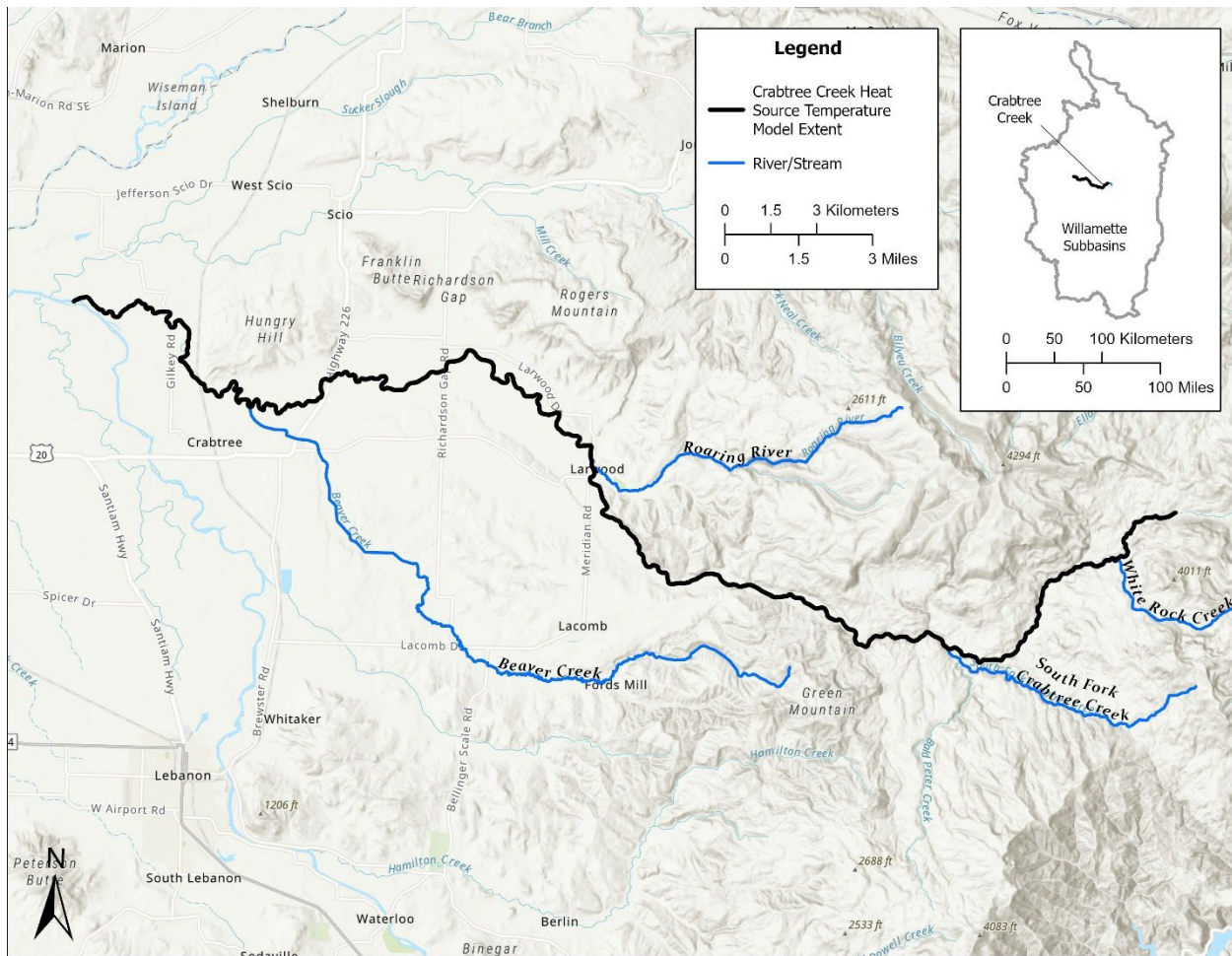


Figure 3-135: Crabtree Creek temperature model extent.

### 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

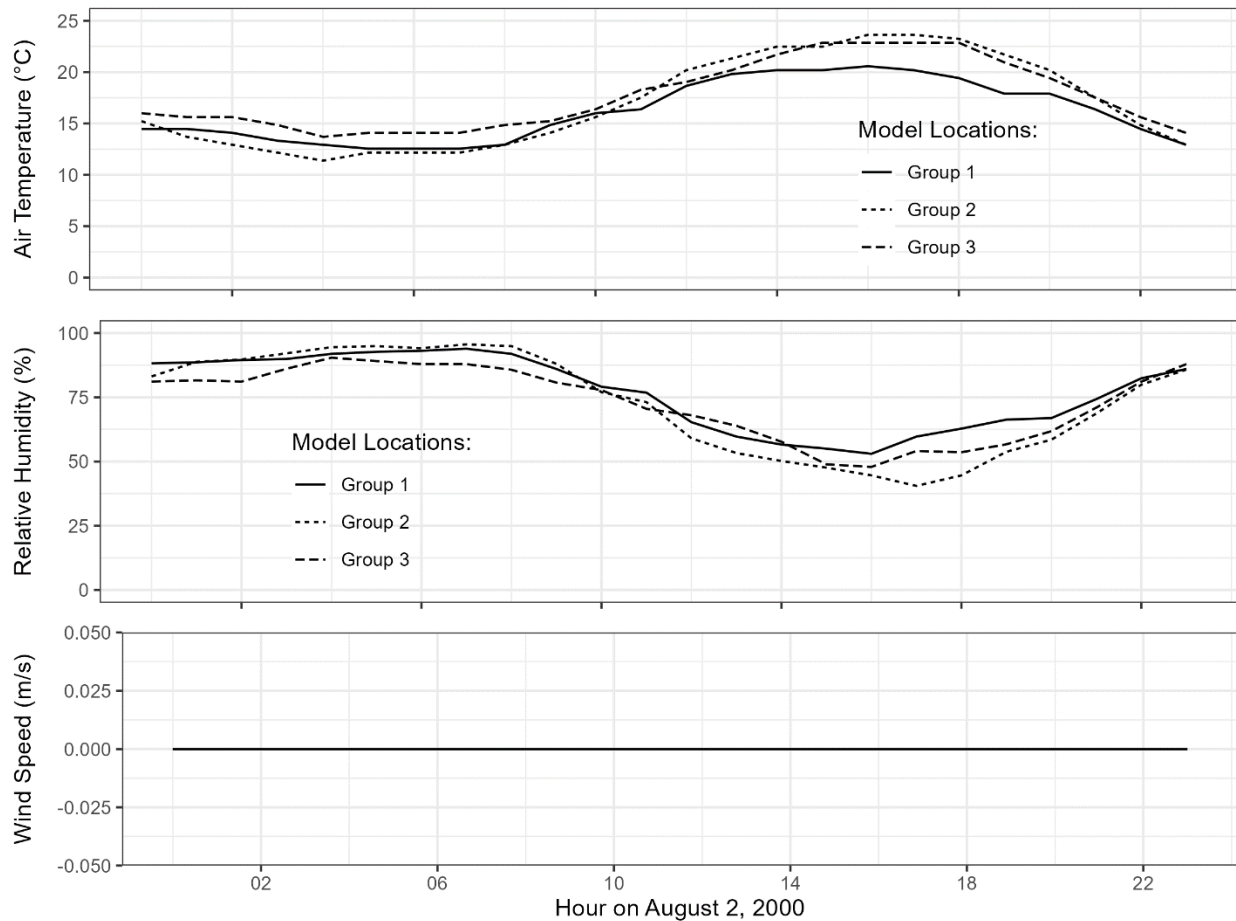
The model period is for a single day: August 02, 2000.

### 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.**

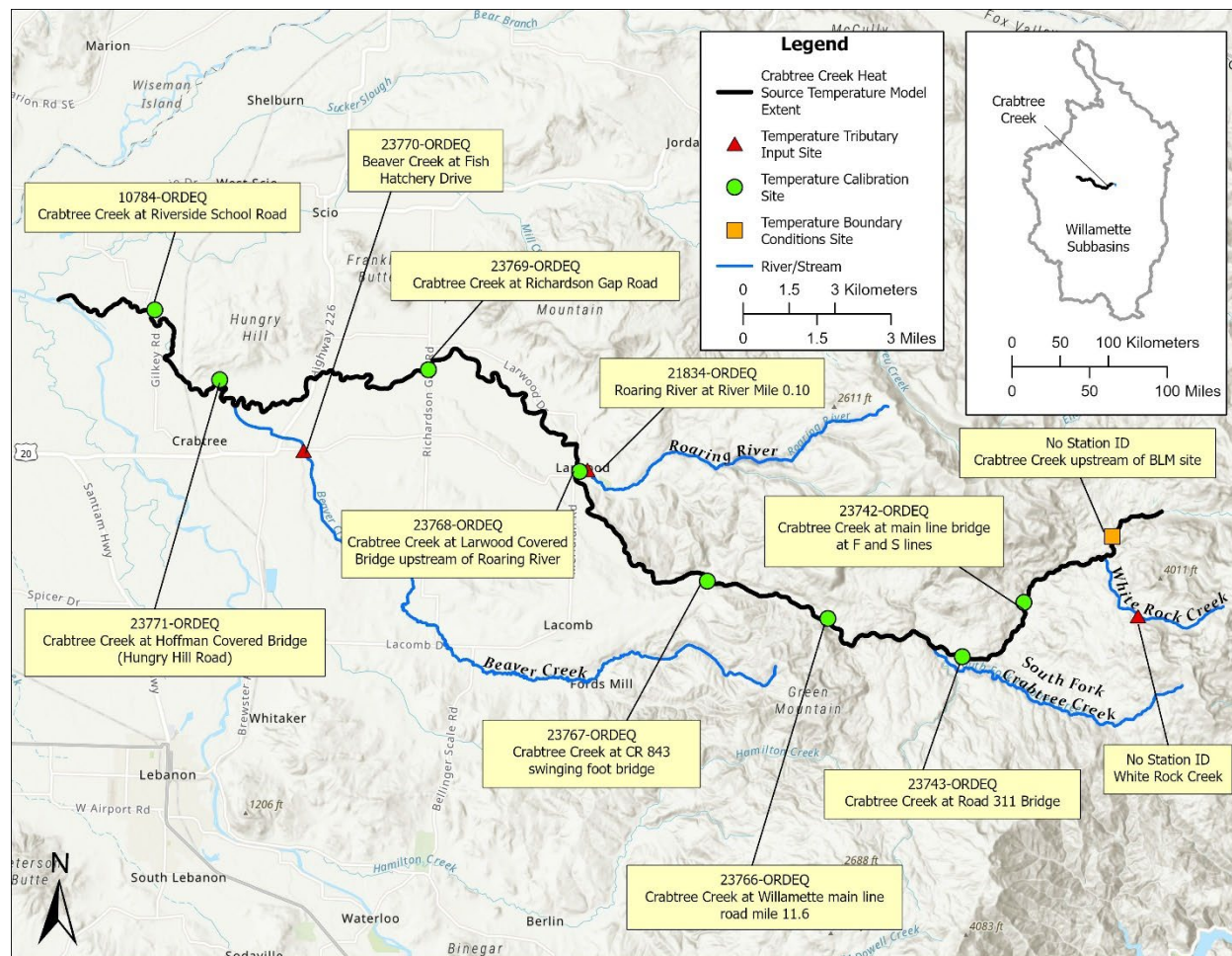
| Group   | Model Location  |
|---------|-----------------|
| Group 1 | Model KM 55.443 |
|         | Model KM 50.719 |
|         | Model KM 47.213 |
|         | Model KM 40.752 |
| Group 2 | Model KM 36.972 |
| Group 3 | Model KM 29.657 |
|         | Model KM 20.452 |
|         | Model KM 9.418  |
|         | 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.



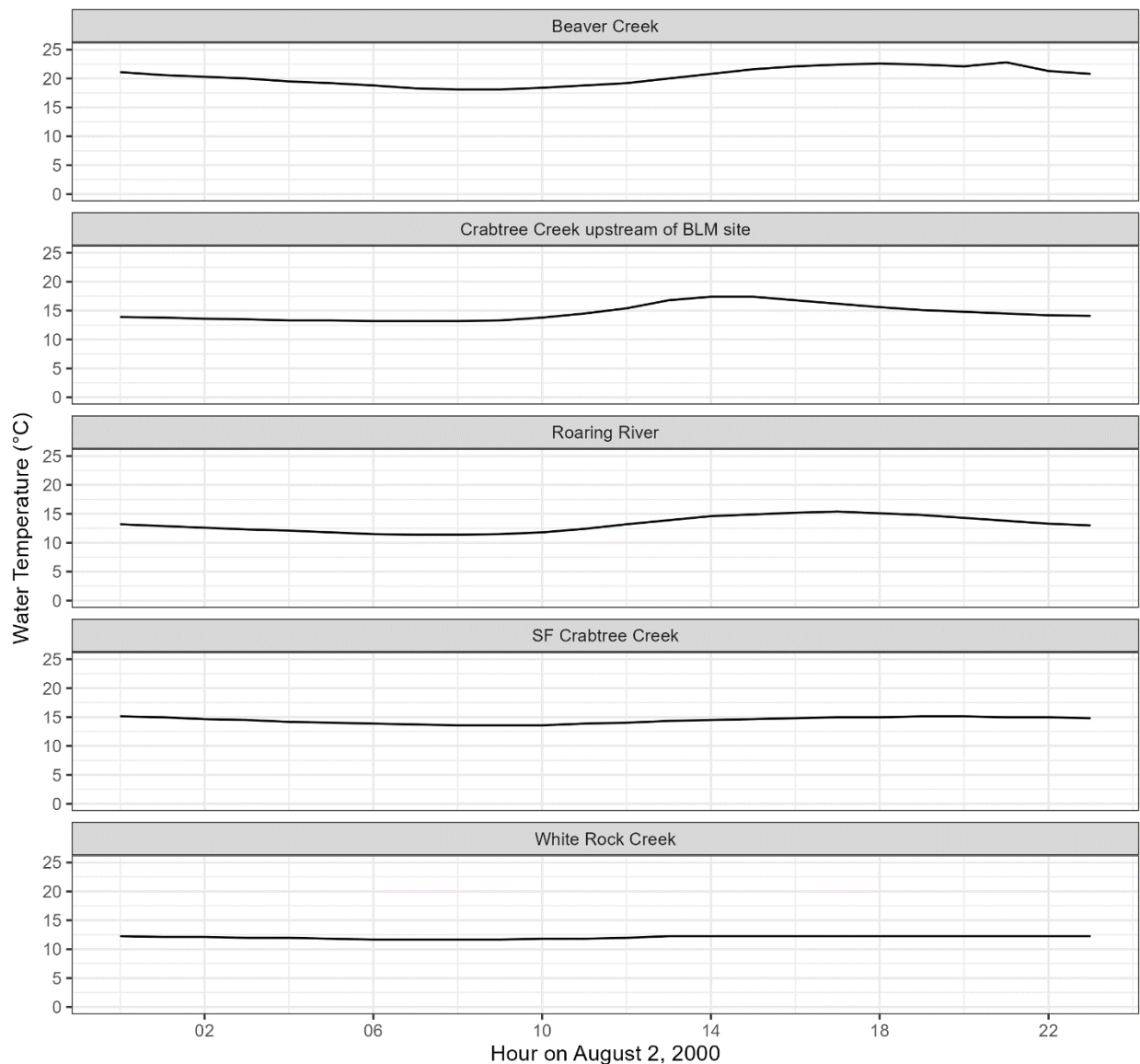
**Figure 3-137: Temperature monitoring locations used for the Crabtree Creek model setup and calibration.**

**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         |

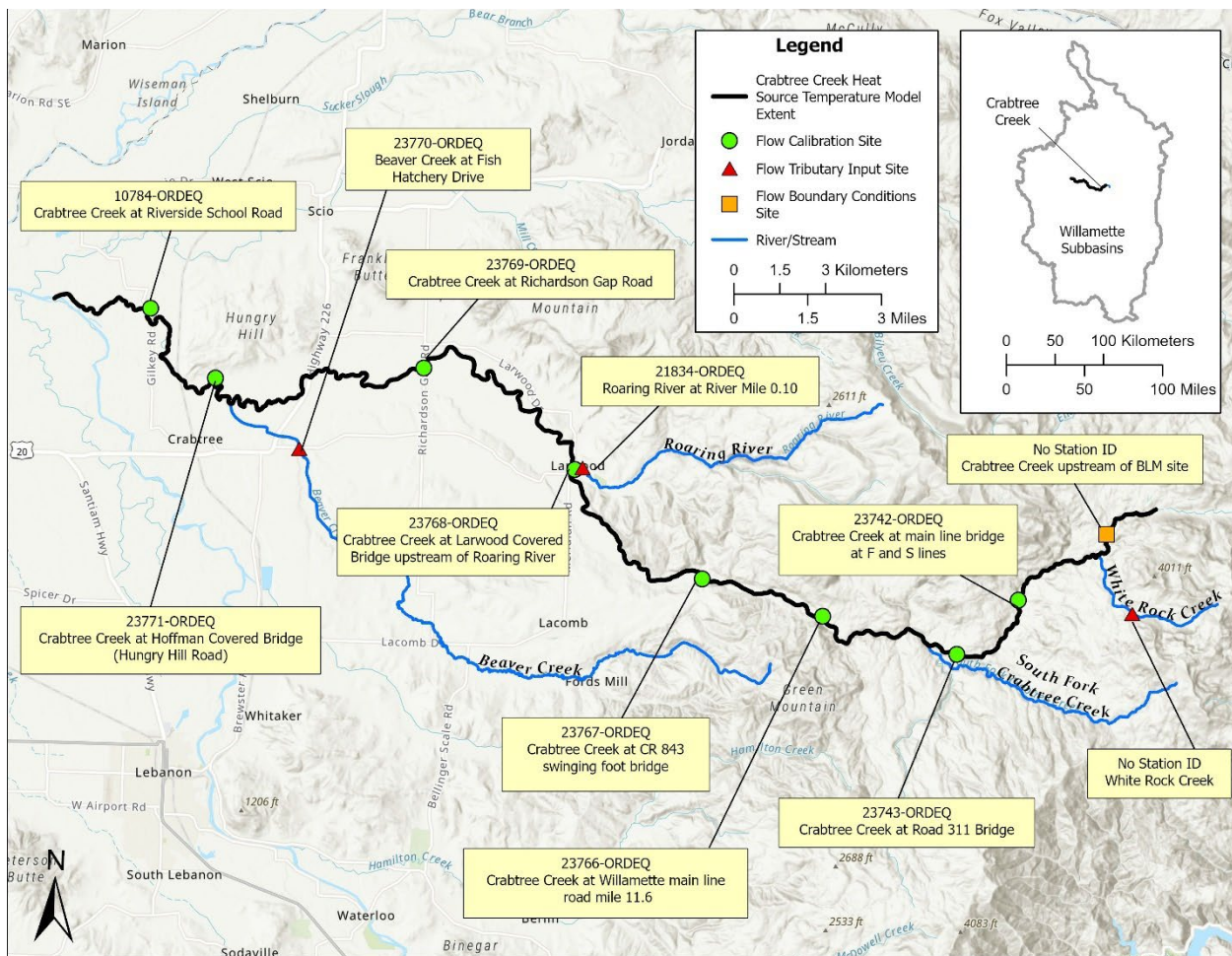
| Model Location Name | Model Location (km) | Input Type | Data Source |
|---------------------|---------------------|------------|-------------|
| White Rock Creek    | 11.125              | Tributary  | BLM         |



**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.

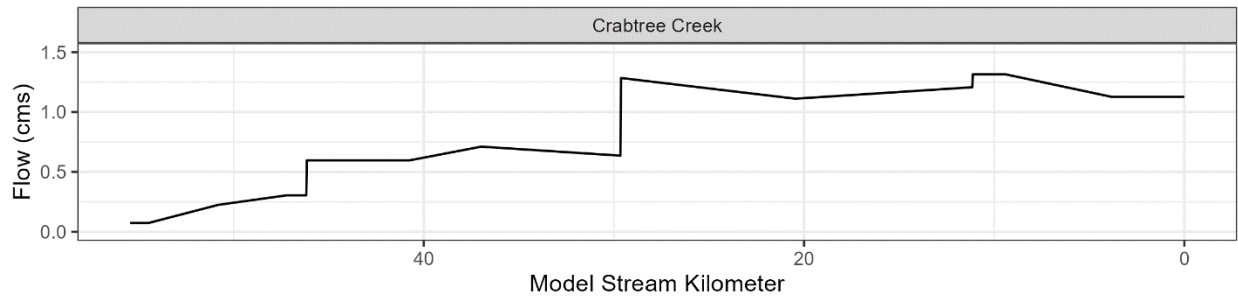


**Figure 3-139: Flow monitoring locations used for the Crabtree Creek model setup and calibration.**

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 |



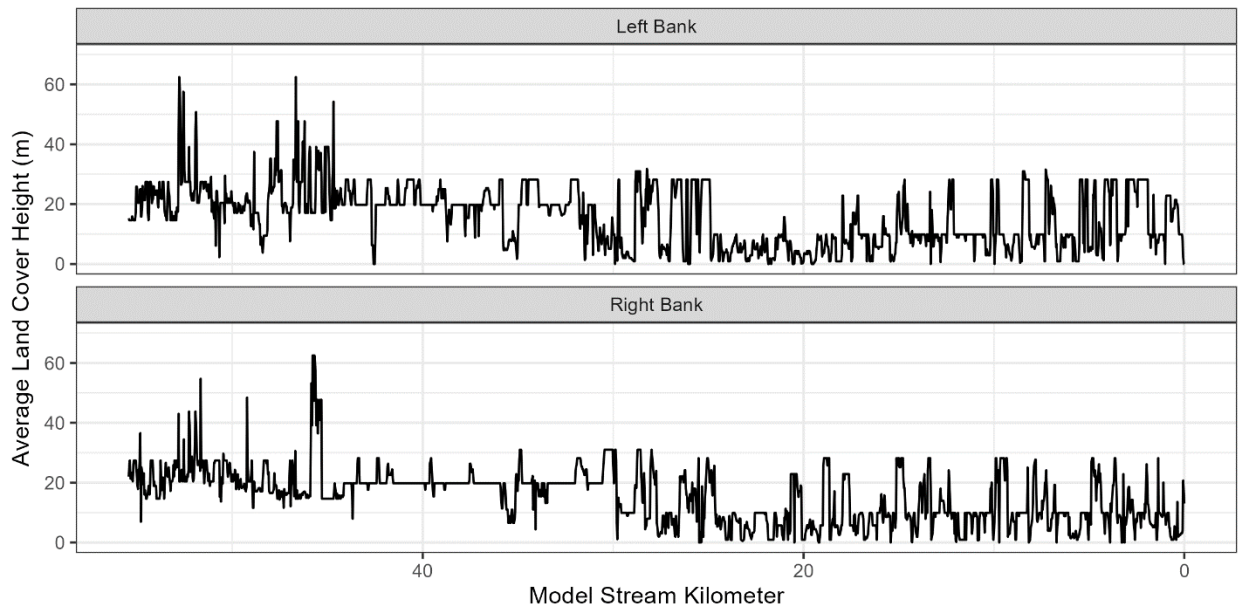
**Figure 3-140: Boundary condition and mainstem flow inputs to the Crabtree Creek model.**

### 3.6.7 Point source inputs

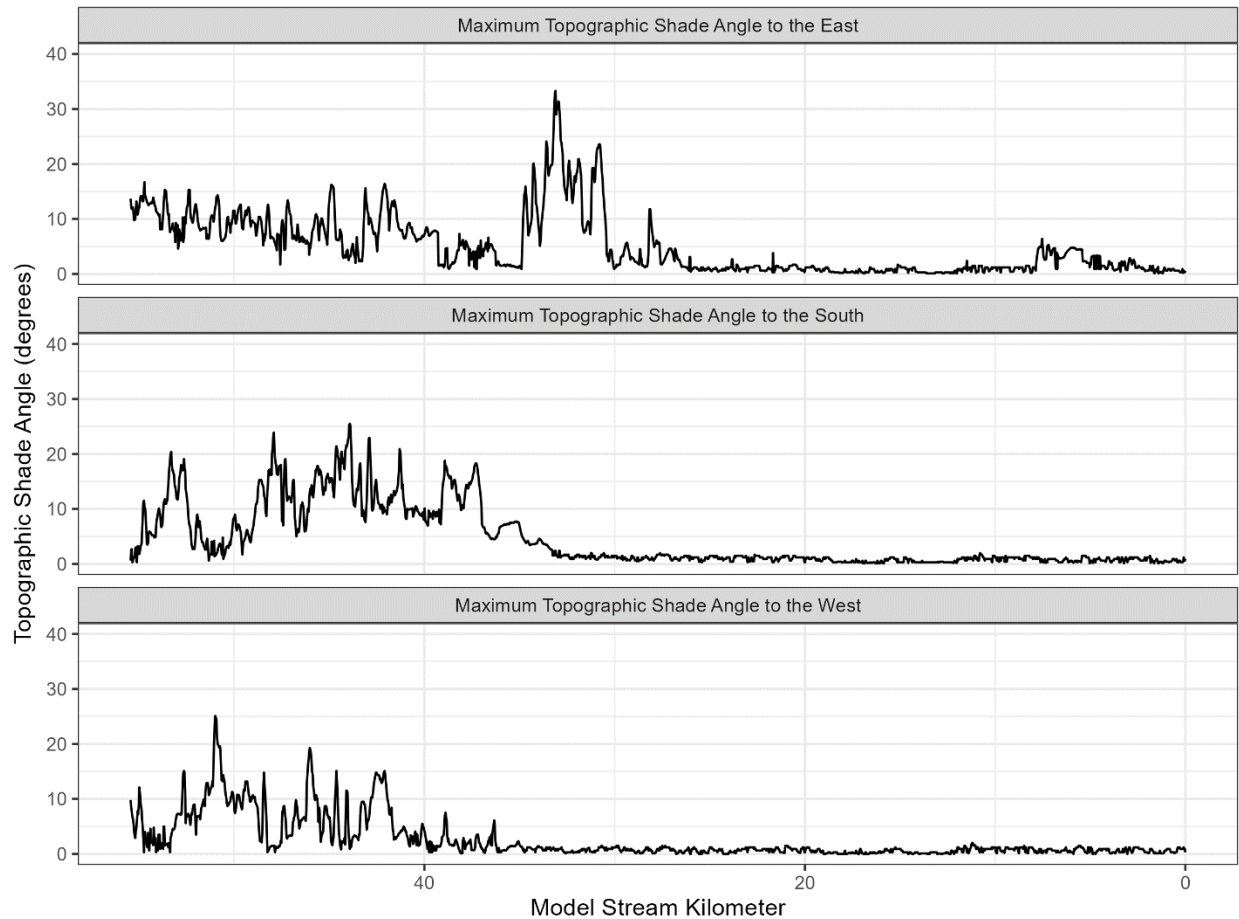
There are no point sources discharging within the model extent.

### 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.



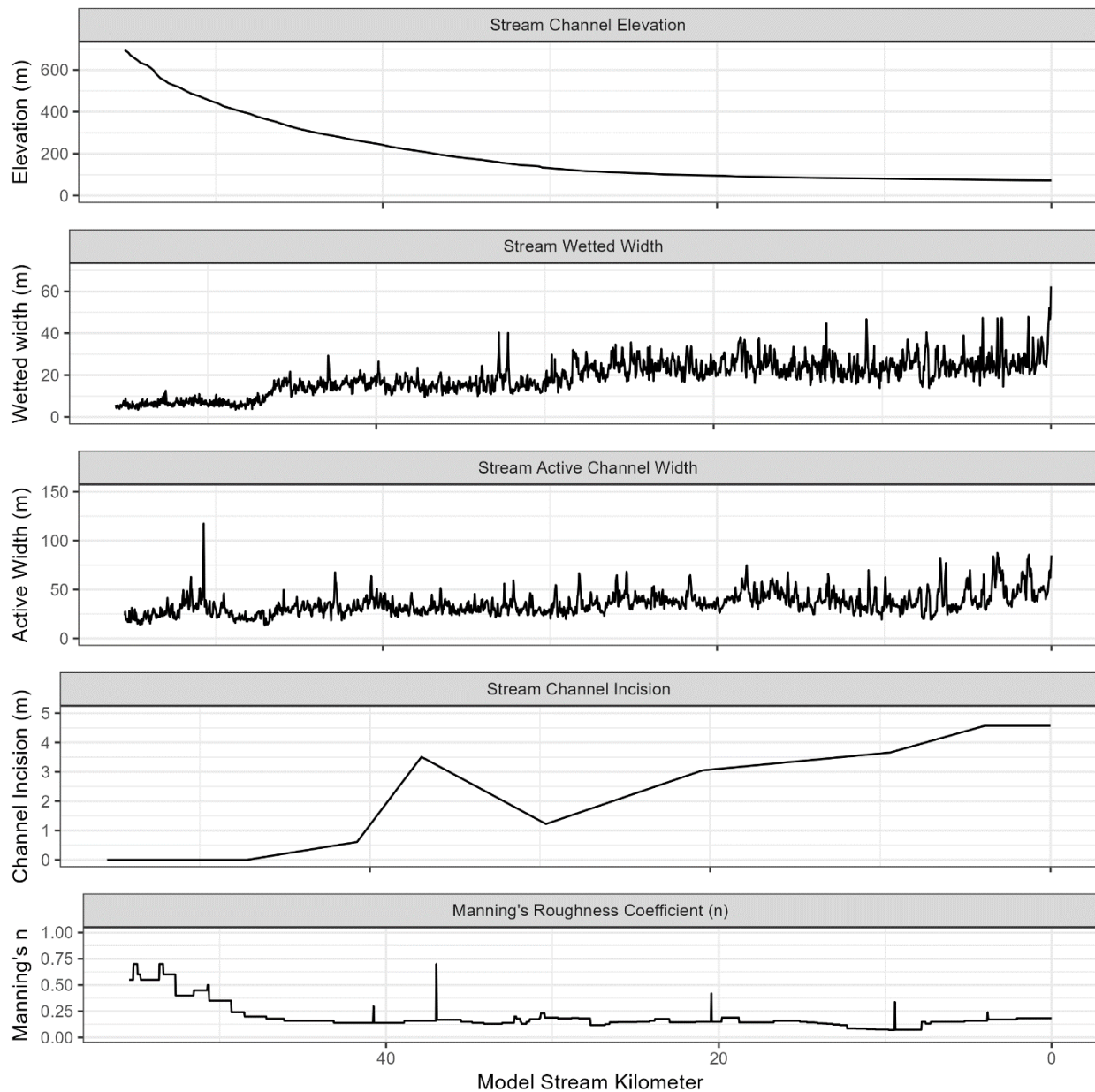
**Figure 3-141: Average land cover height inputs to the Crabtree Creek model.**



**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.**

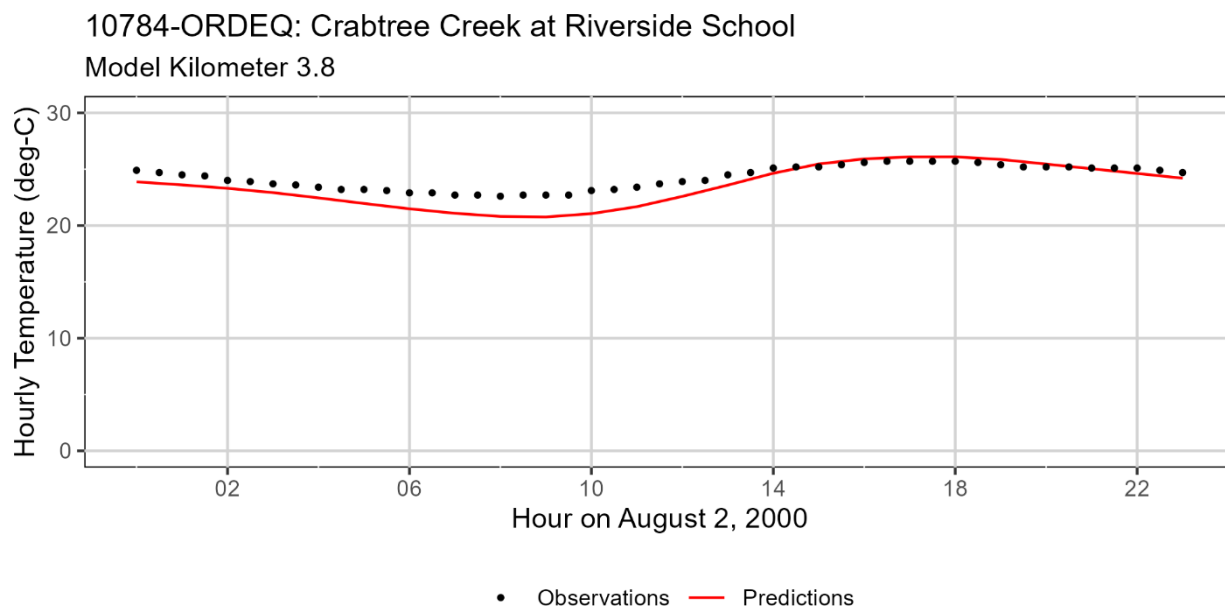
### 3.6.10 Calibration results

#### 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.**

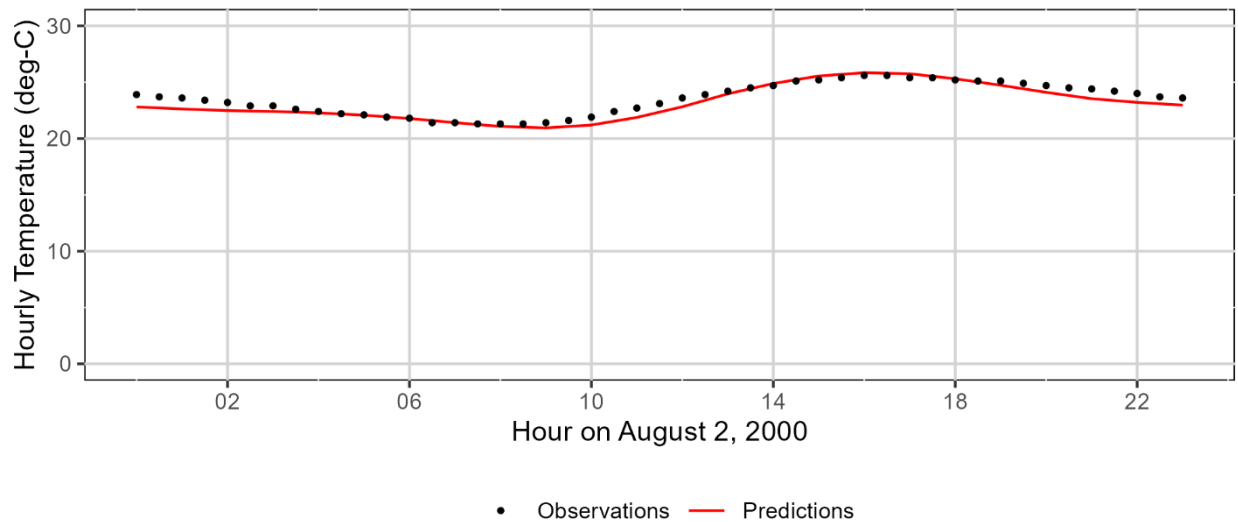
| Monitoring Location                                      | Model KM | Temperature Statistics | ME    | MAE  | RMSE | NSE   | n   |
|--|----------|------------------------|-------|------|------|-------|-----|
| All Stations   |          | Daily Maximum          | 0.73  | 0.75 | 0.88 | NA    | 8   |
| 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.**

23771-ORDEQ: Crabtree Creek at Hoffman Covered Bridge

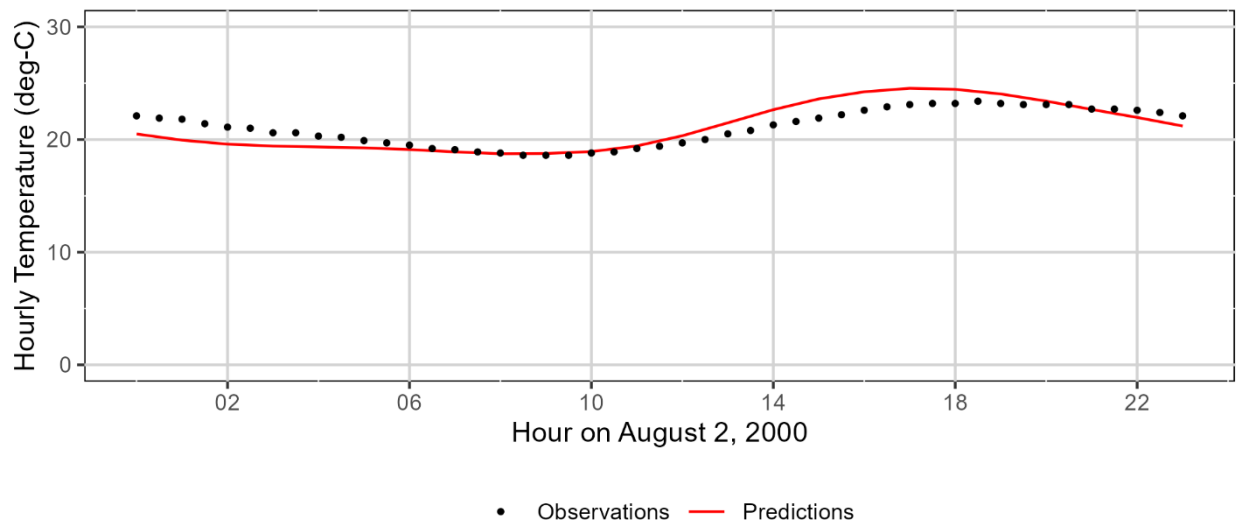
Model Kilometer 9.4



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

23769-ORDEQ: Crabtree Creek at Richardson Gap Road

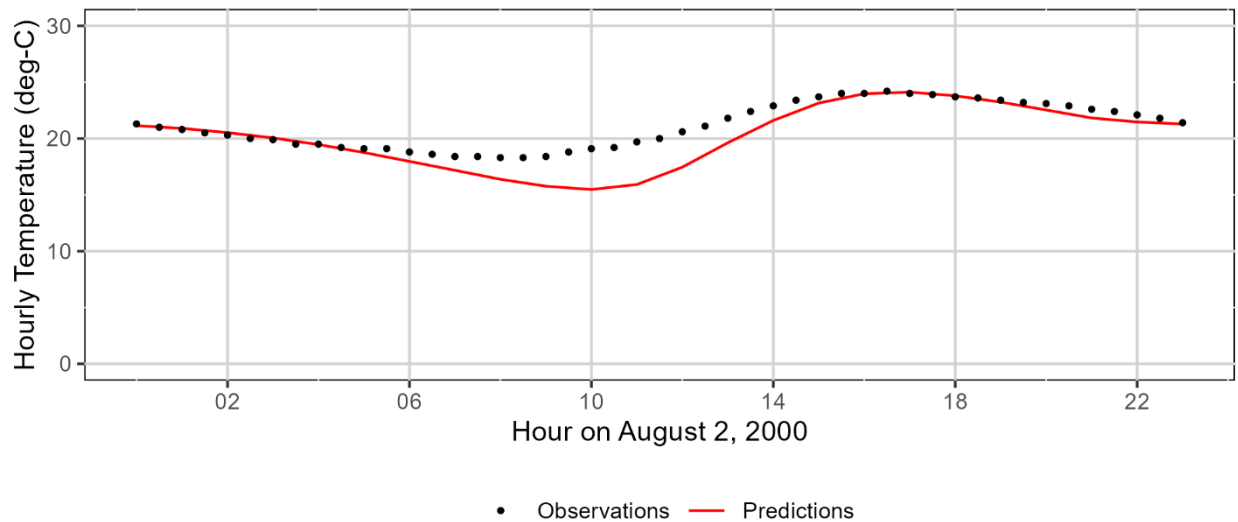
Model Kilometer 20.5



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

23768-ORDEQ: Crabtree Creek at Larwood Bridge

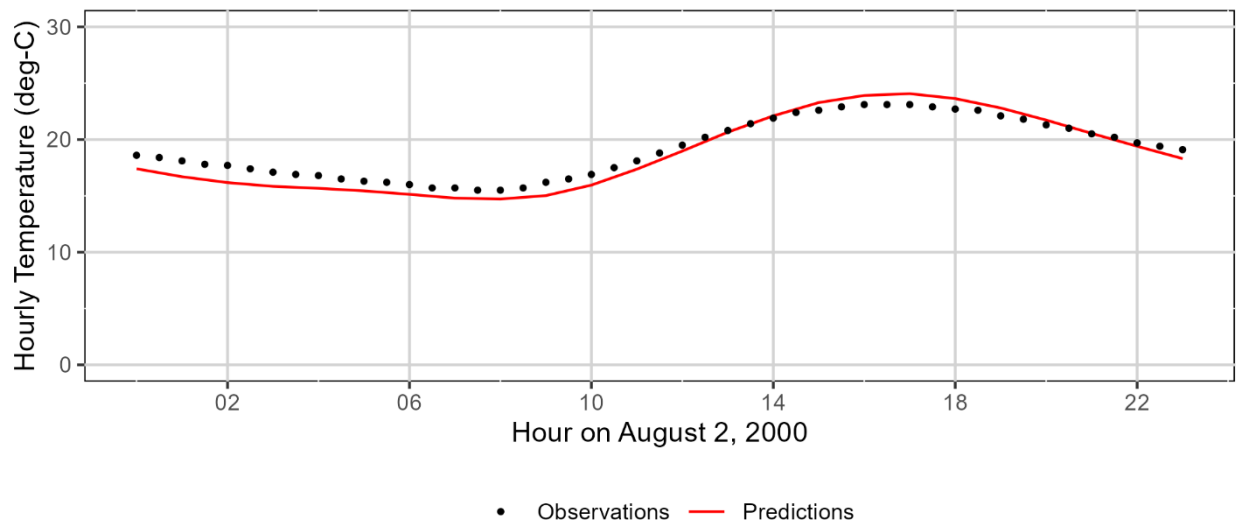
Model Kilometer 29.7



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

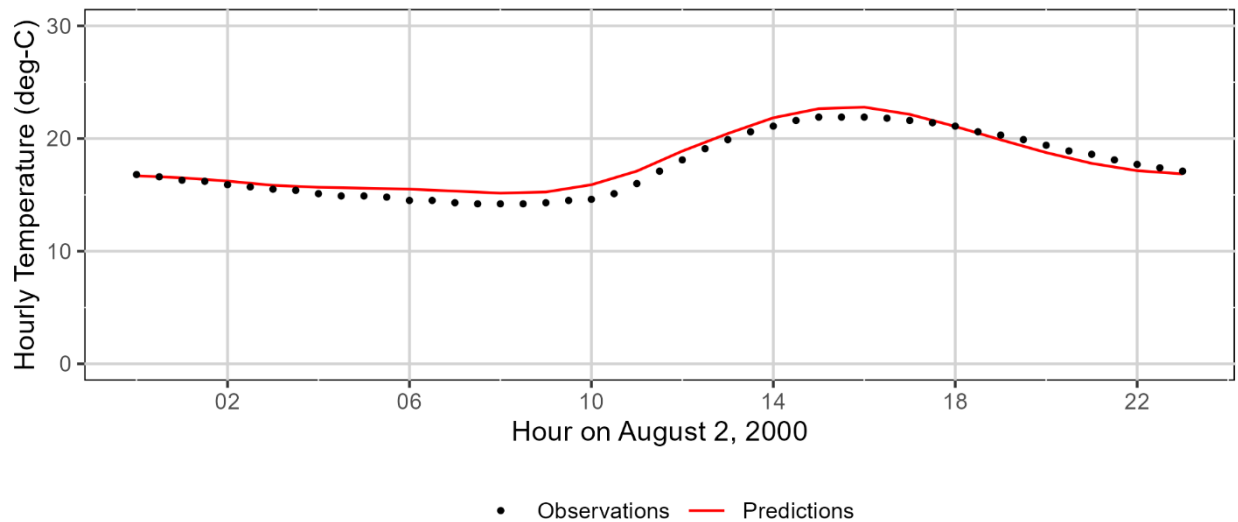
23767-ORDEQ: Crabtree Creek at swinging foot bridge

Model Kilometer 37



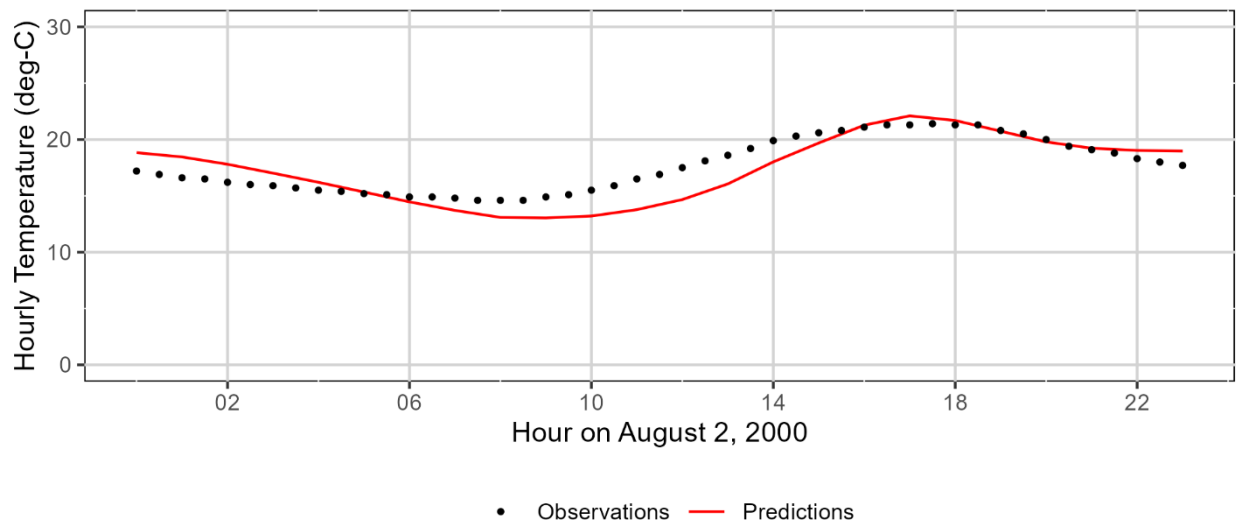
**Figure 3-148: Crabtree Creek measured and model-predicted hourly temperatures at monitoring station 23767-ORDEQ.**

23766-ORDEQ: Crabtree Creek at Willamette Main Line Road  
Model Kilometer 40.8



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

23743-ORDEQ: Crabtree Creek at Road 311 Bridge  
Model Kilometer 47.2

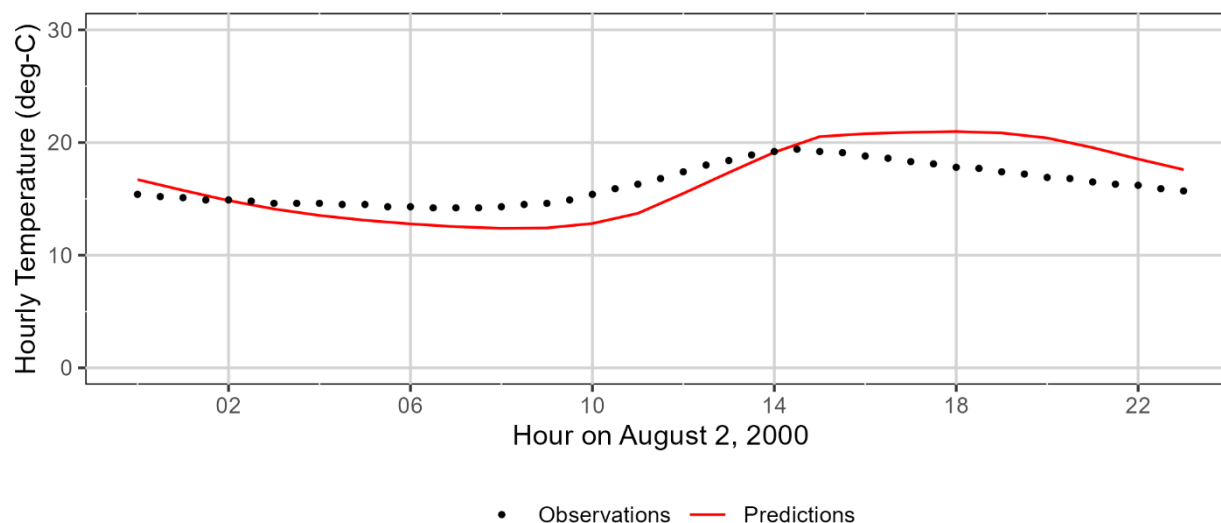


**Figure 3-150: Crabtree Creek measured and model-predicted hourly temperatures at monitoring station 23743-ORDEQ.**

Error! Reference source not found.

23742-ORDEQ: Crabtree Creek ar Main Line Bridge

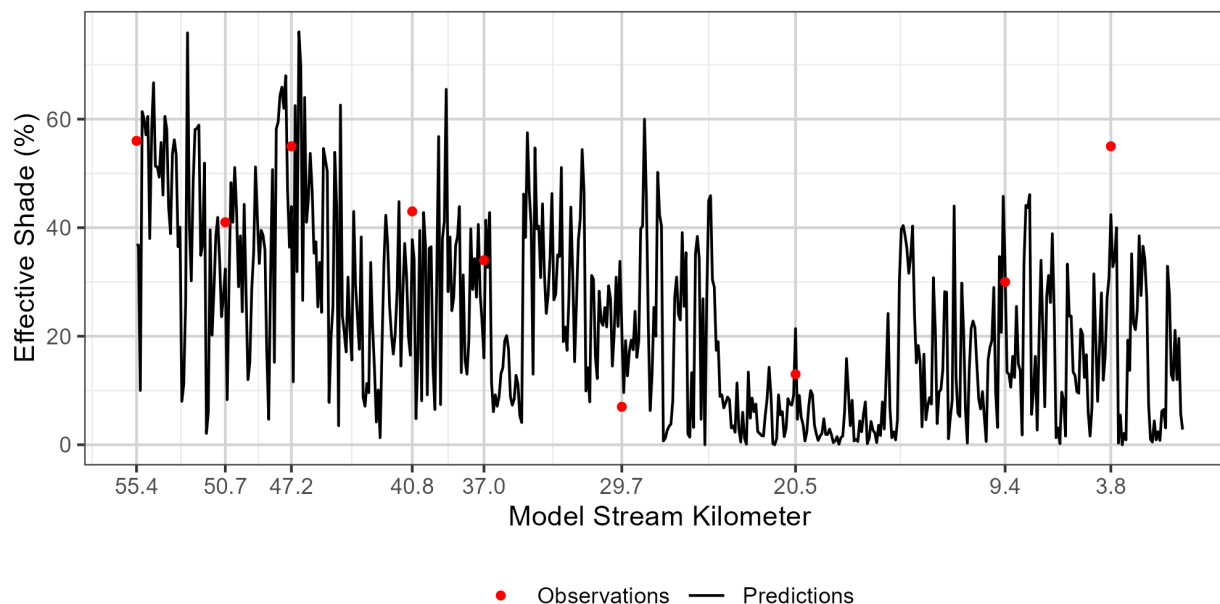
Model Kilometer 50.7



**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 <sup>2</sup> | ME    | MAE   | RMSE  |
|---|----------------|-------|-------|-------|
| 9 | 0.65           | -5.54 | 11.06 | 12.25 |

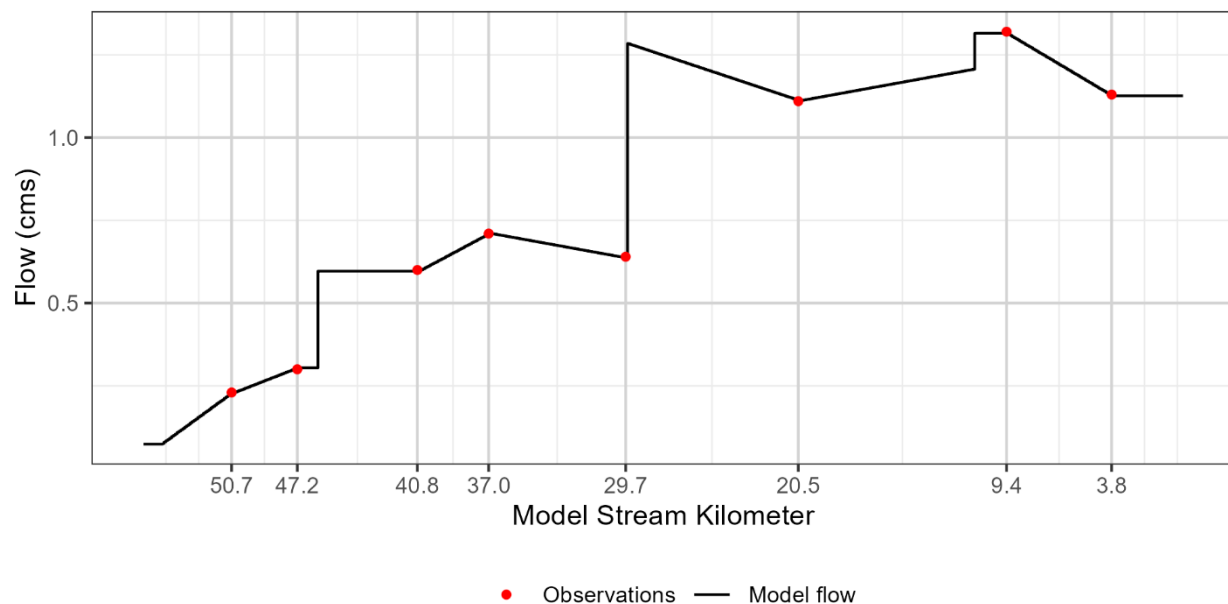
### 3.6.10.3 Flow

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 |

| Monitoring Location  | Model KM | Flow Statistics | Flow (cms) | Date      |
|--|----------|-----------------|------------|-----------|
| 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 |



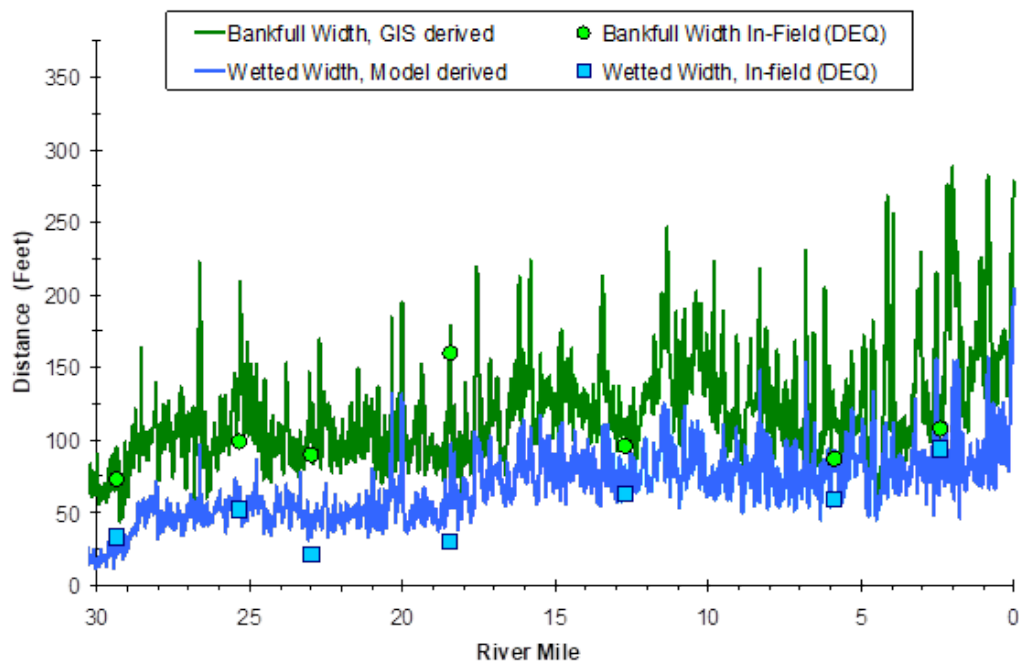
**Figure 3-153: Crabtree Creek field observed and model flow rates.**

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

| N | R <sup>2</sup> | 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.



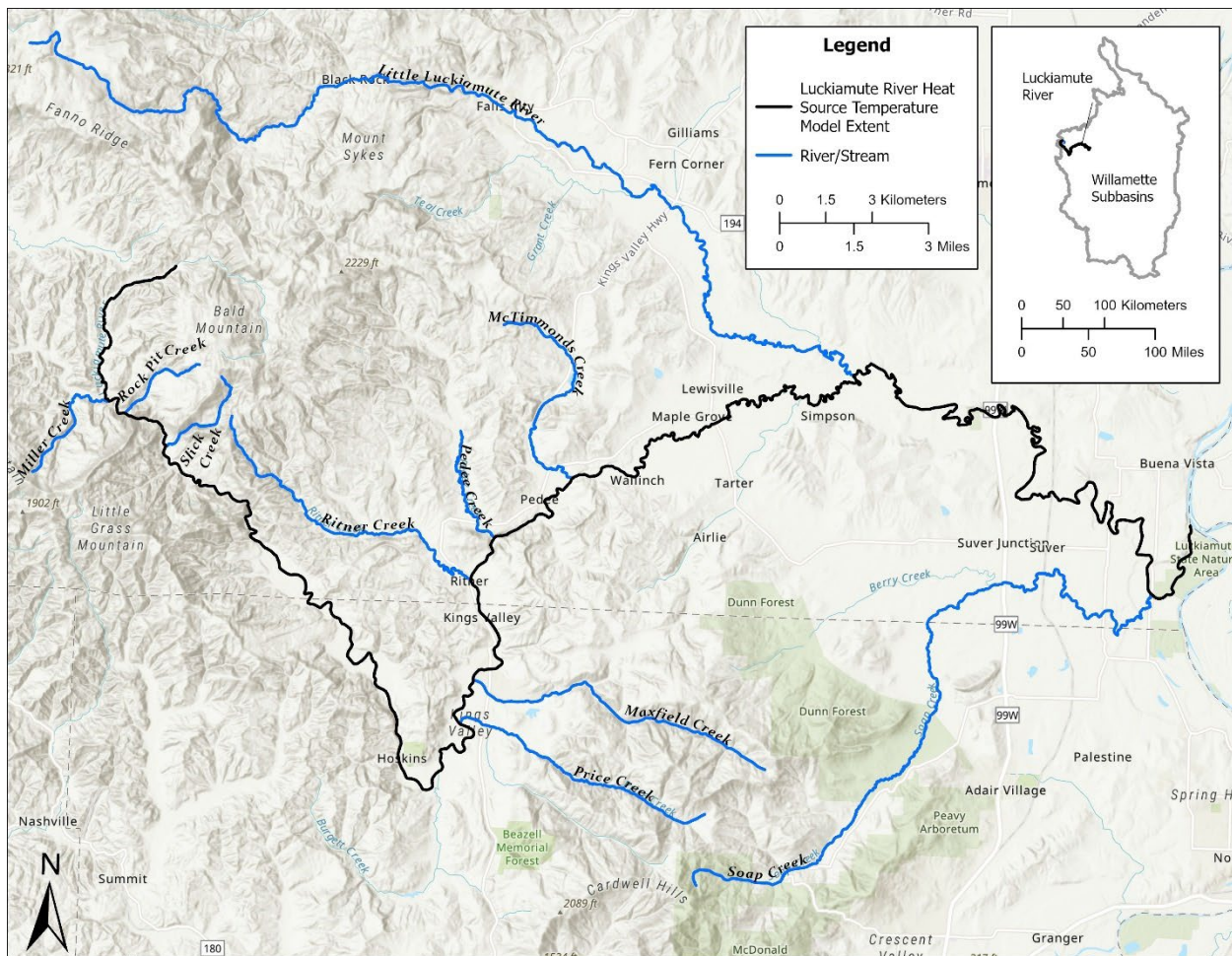
**Figure 3-154: Crabtree Creek field observed and derived bankfull and wetted width.**

## 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

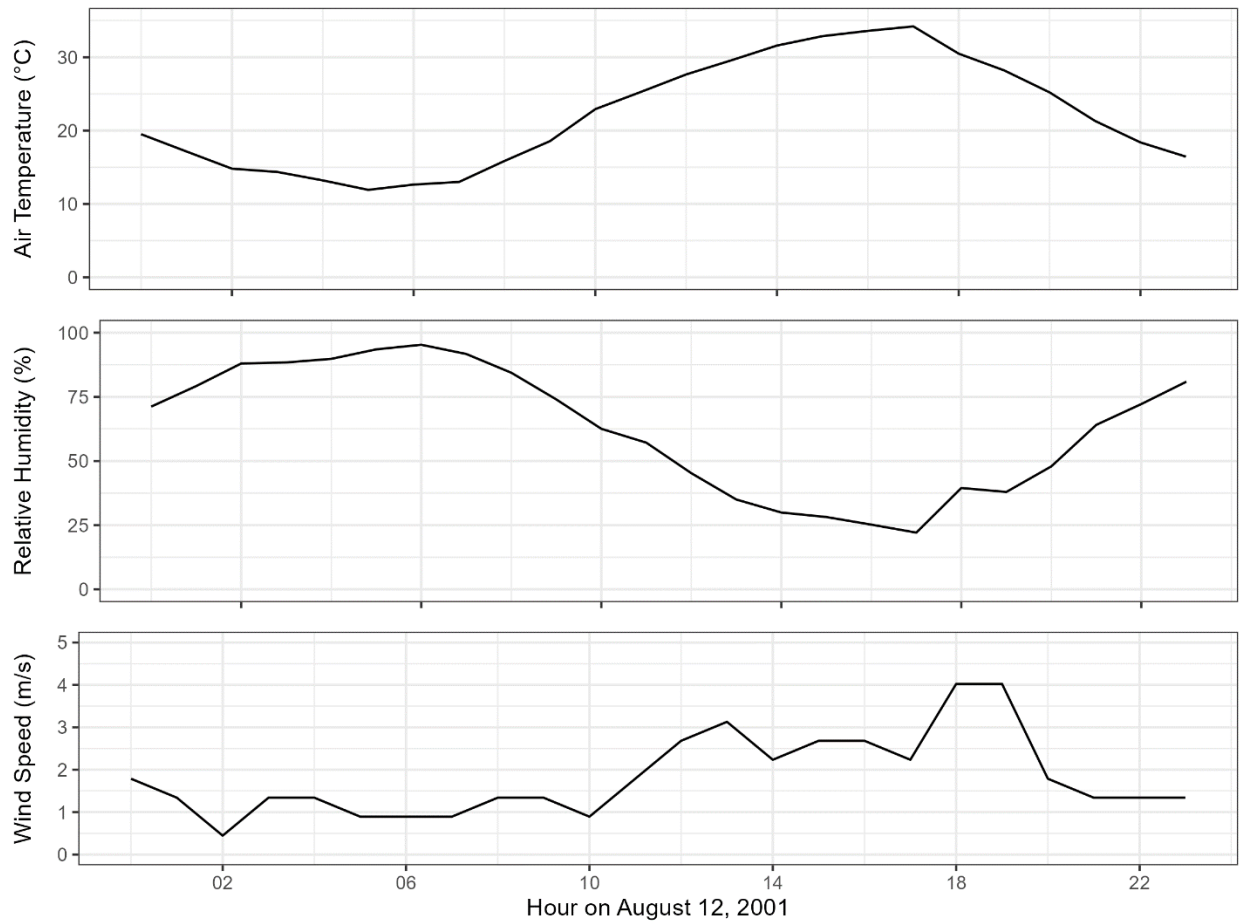
The model input spatial resolution (dx) is 30 m. Outputs are generated every 100 m. The model time step (dt) is 1 minute and outputs were generated every hour.

### 3.7.3 Time frame of simulation

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

### 3.7.4 Meteorological inputs

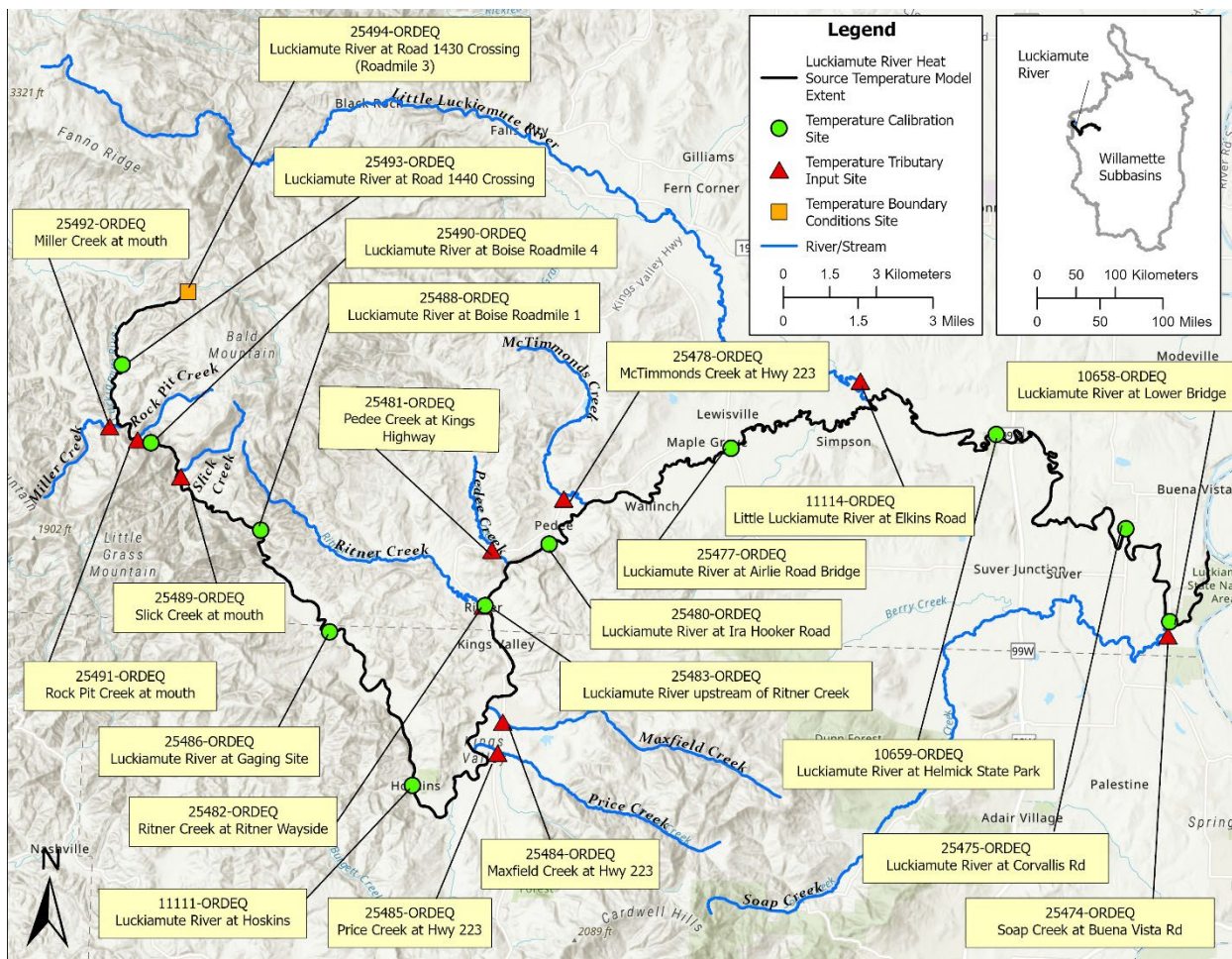
The model was set up using hourly air temperature, relative humidity, and wind speed measurements from the Corvallis AgriMet site (crvo) (**Figure 3-156**). Air temperature data were modified using the dry adiabatic lapse rate to adjust for differences in elevation between the measurement location and 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.



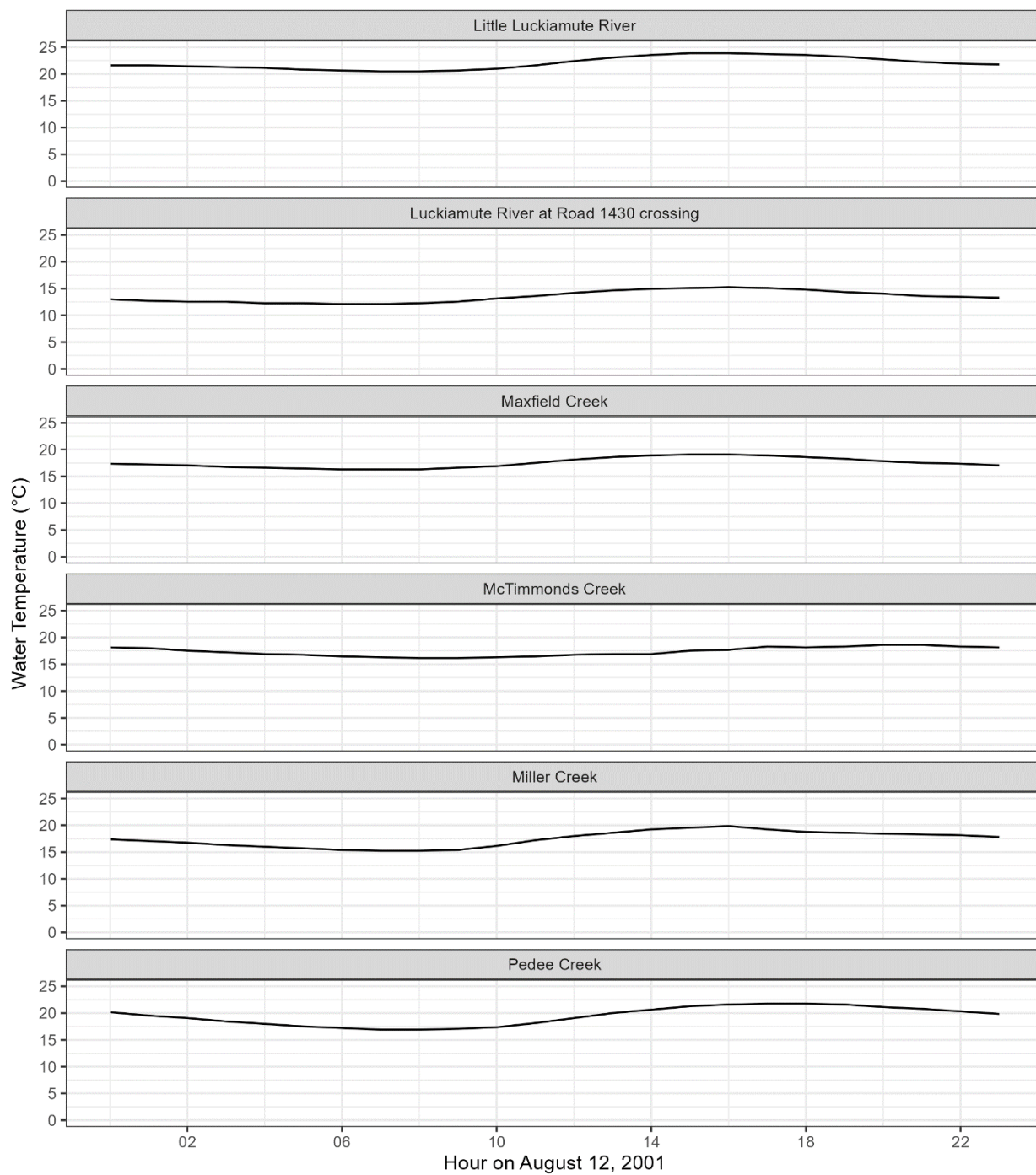
**Figure 3-157: Temperature monitoring locations used for the Luckiamute River model setup and calibration.**

**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.

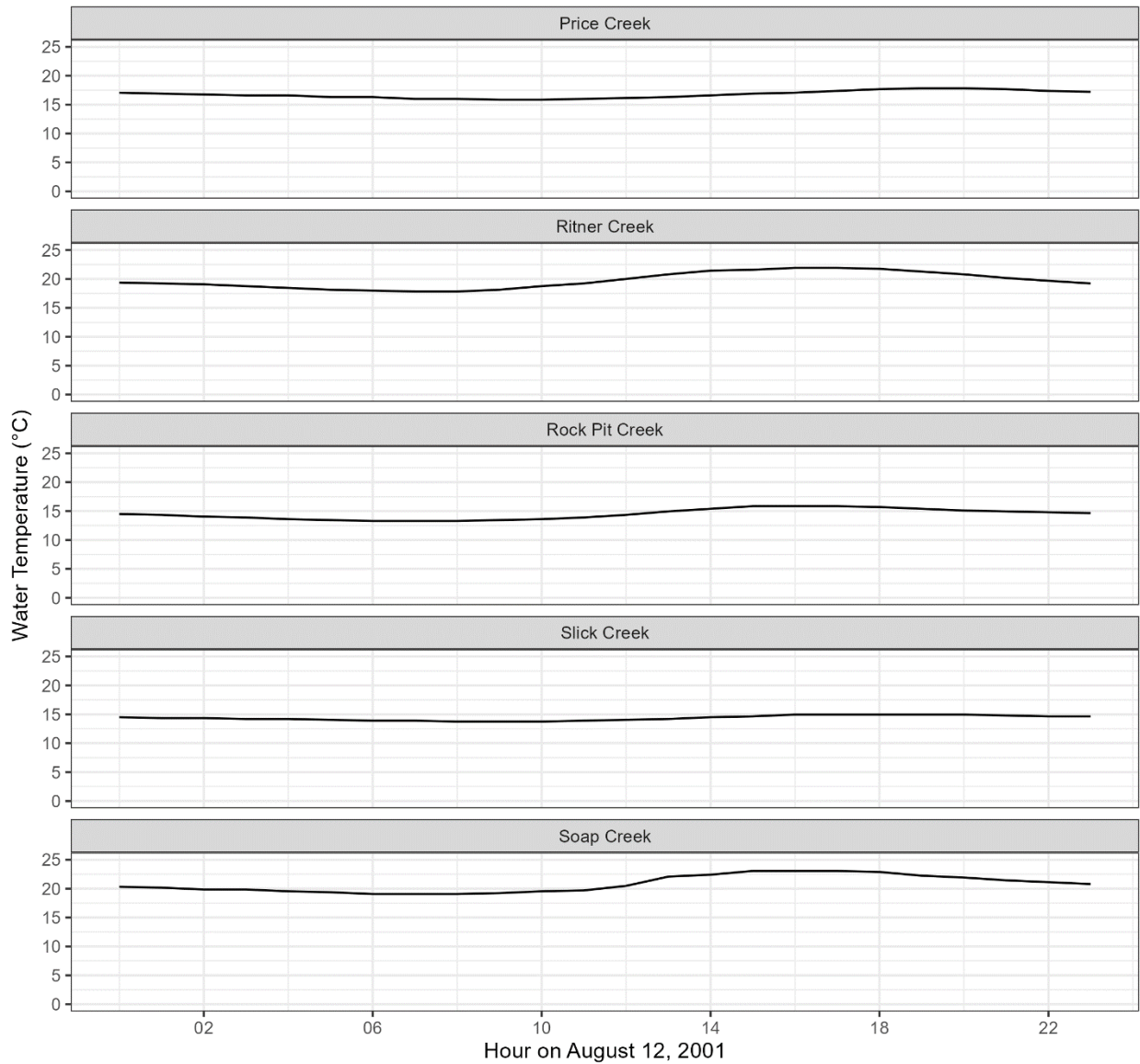
**Table 3-50: Boundary condition and tributary water temperature inputs to the Luckiamute River model.**

| 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 |

| Model Location Name | Model Location (km) | Input Type | Data Source |
|---------------------|---------------------|------------|-------------|
| Soap Creek          | 9.174               | Tributary  | 25474-ORDEQ |



(A)

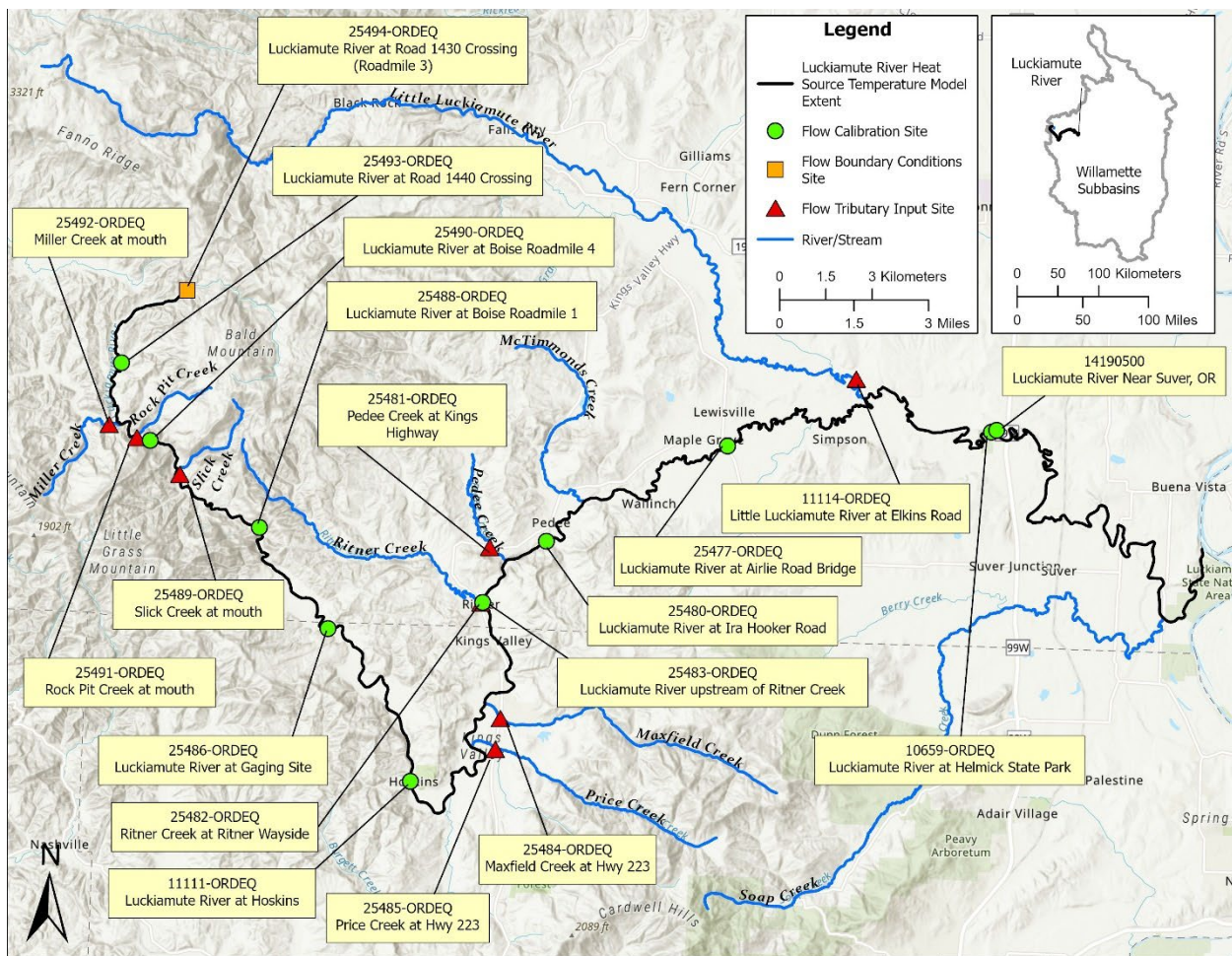


(B)

**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.



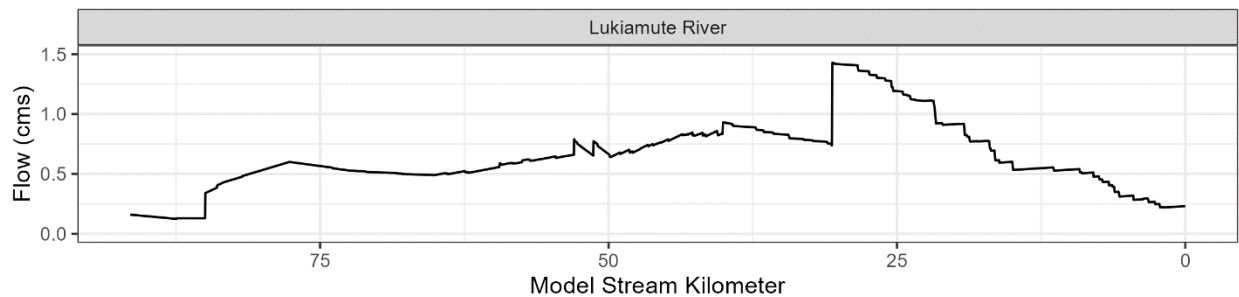
**Figure 3-159: Flow monitoring locations used for the Luckiamute River model setup and calibration.**

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 |

| Model Location Name                    | Model Location (km) | Flow Rate (cms) | Input Type | Data Source                                      |
|--|---------------------|-----------------|------------|--|
| 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 |



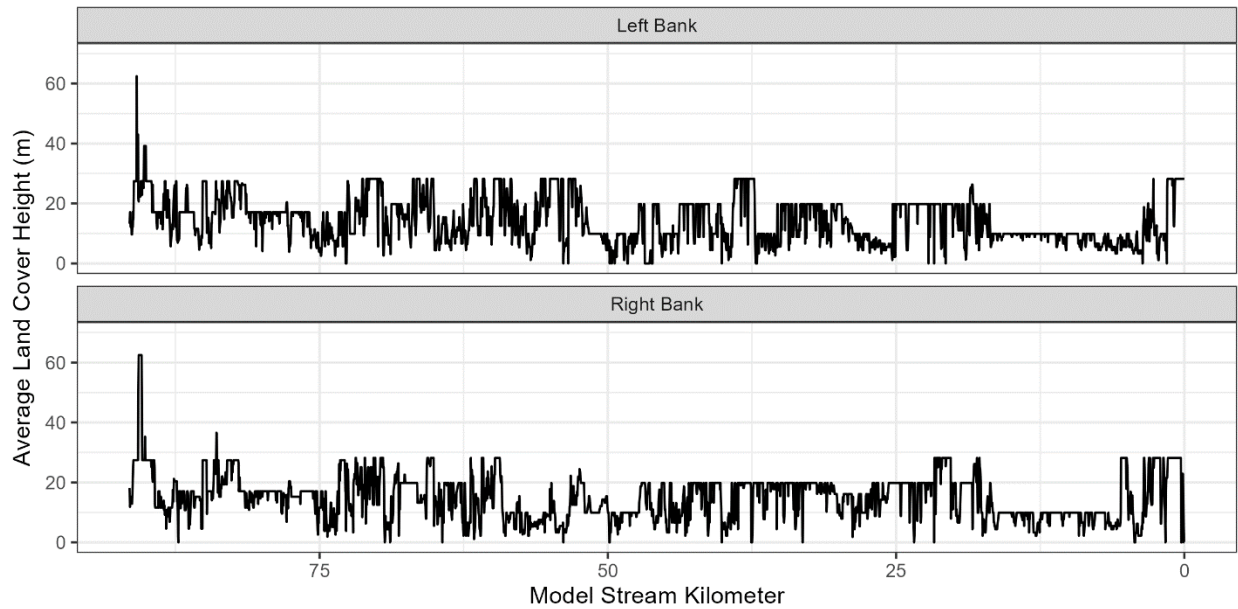
**Figure 3-160: Boundary condition and mainstem flow inputs to the Luckiamute River model.**

### 3.7.7 Point source inputs

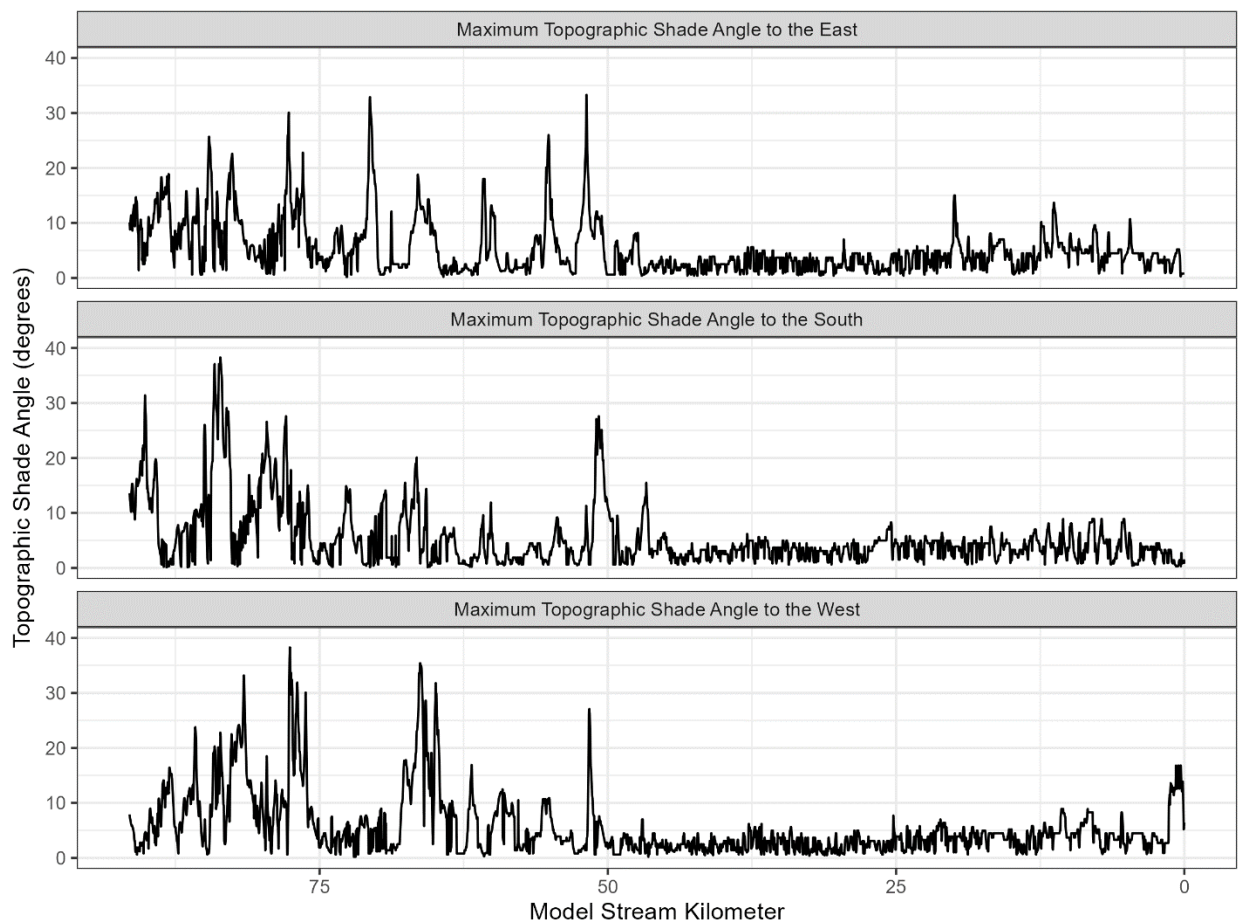
There are no point sources discharging within the model extent.

### 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.



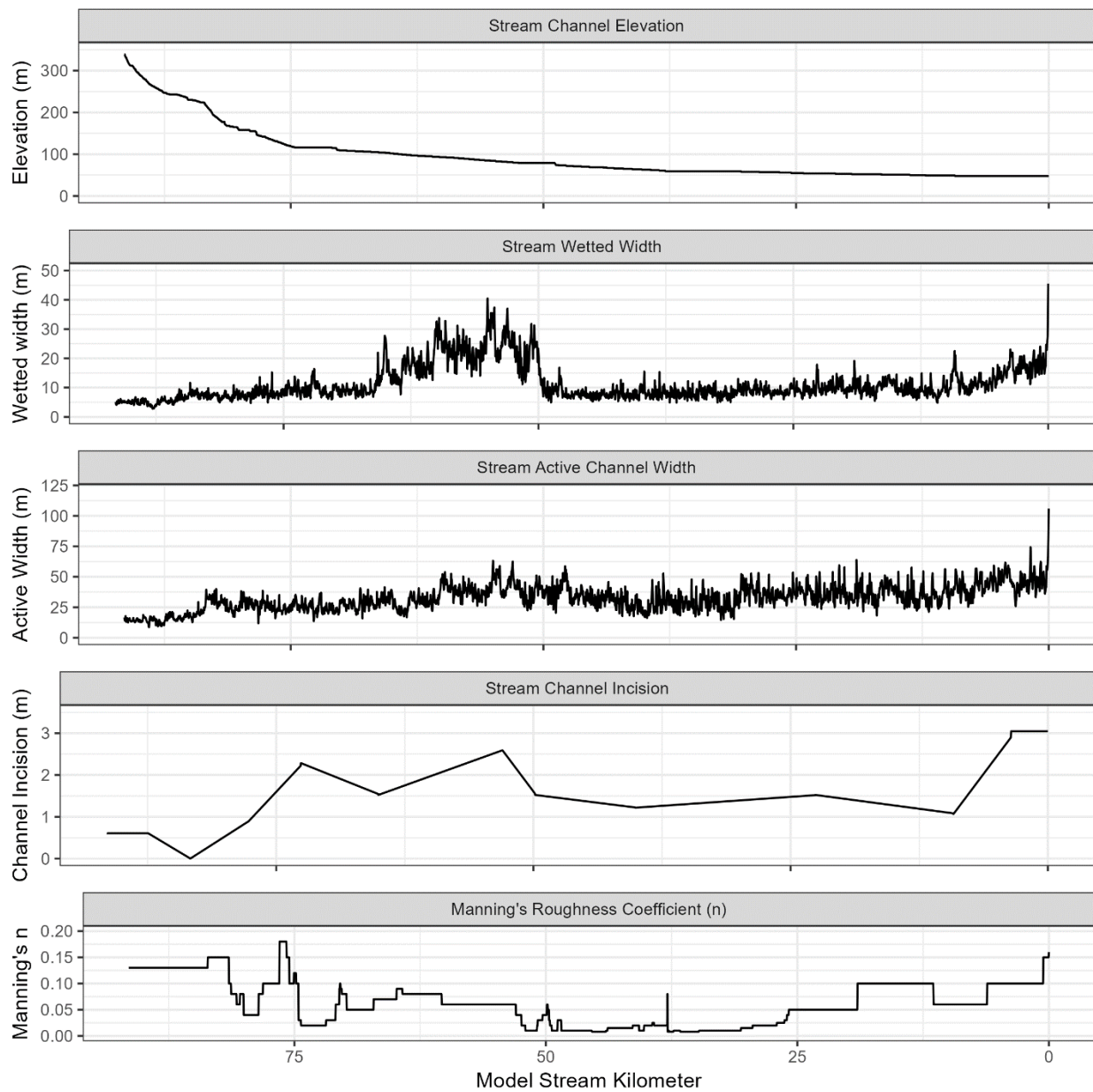
**Figure 3-161: Average land cover height inputs to the Luckiamute River model.**



**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.**

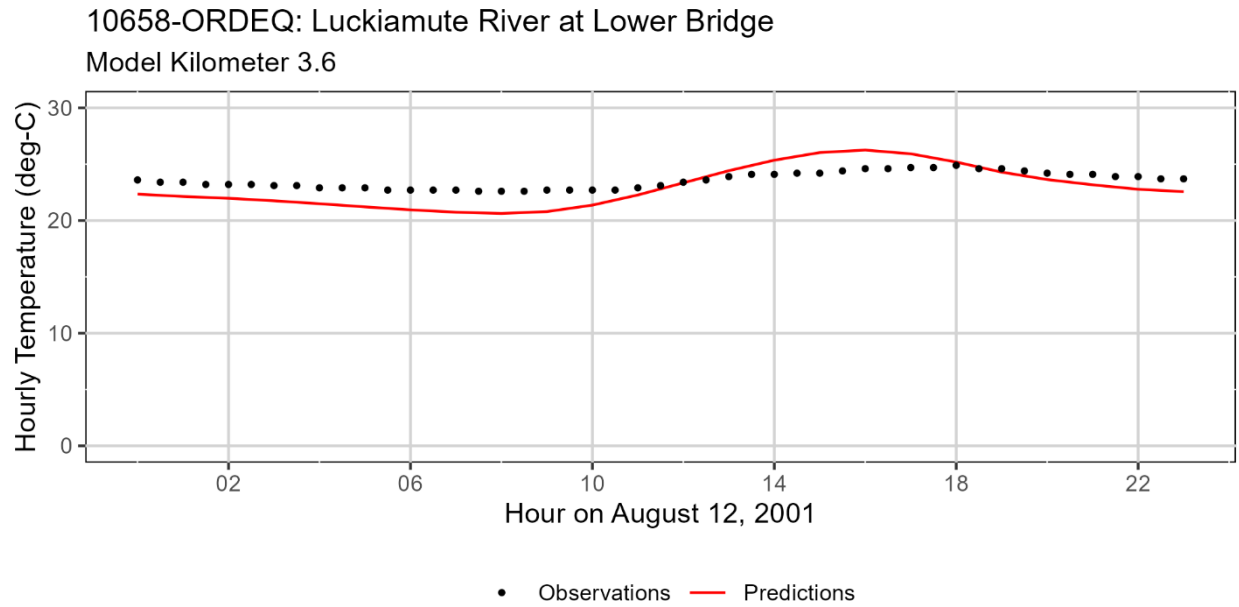
### 3.7.10 Calibration results

#### 3.7.10.1 Temperature

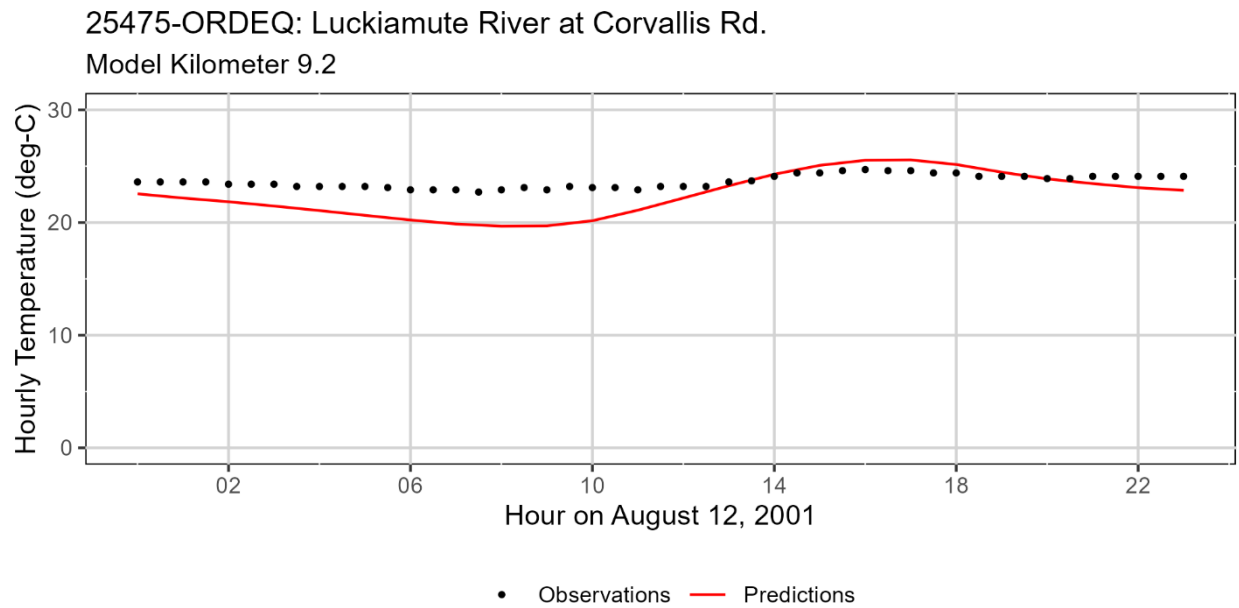
The model was calibrated to the continuous temperature data collected from several locations along Luckiamute Creek. Results for goodness of fit statistics comparing field observed and model-predicted temperatures are summarized in **Table 3-52**. Observed and model-predicted hourly temperatures were plotted for the monitoring stations (**Figure 3-164** through **Figure 3-174**).

**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  |

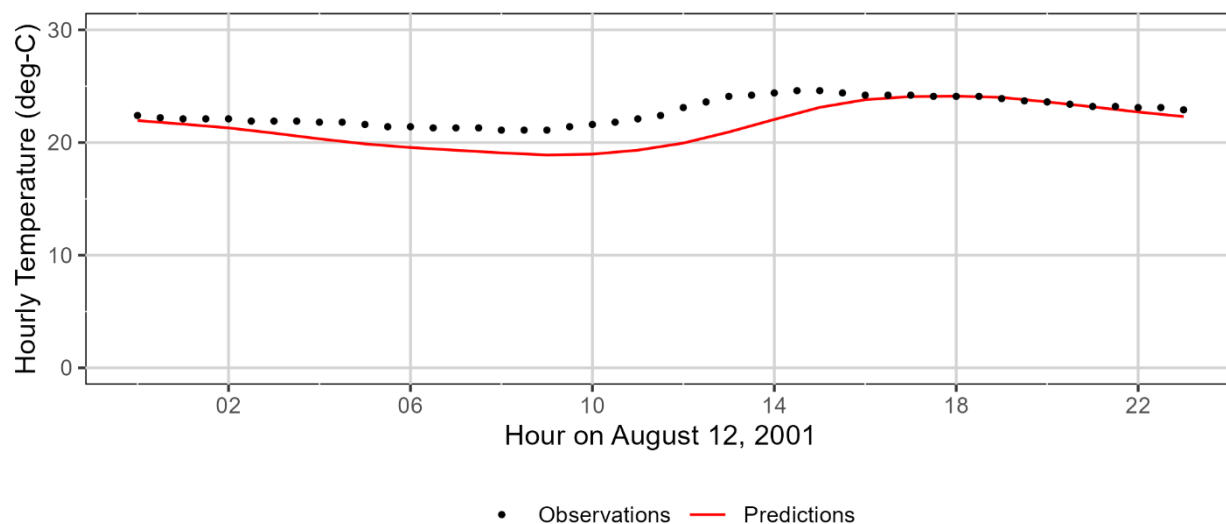


**Figure 3-164: Luckiamute River measured and model-predicted hourly temperatures at monitoring station 10658-ORDEQ.**



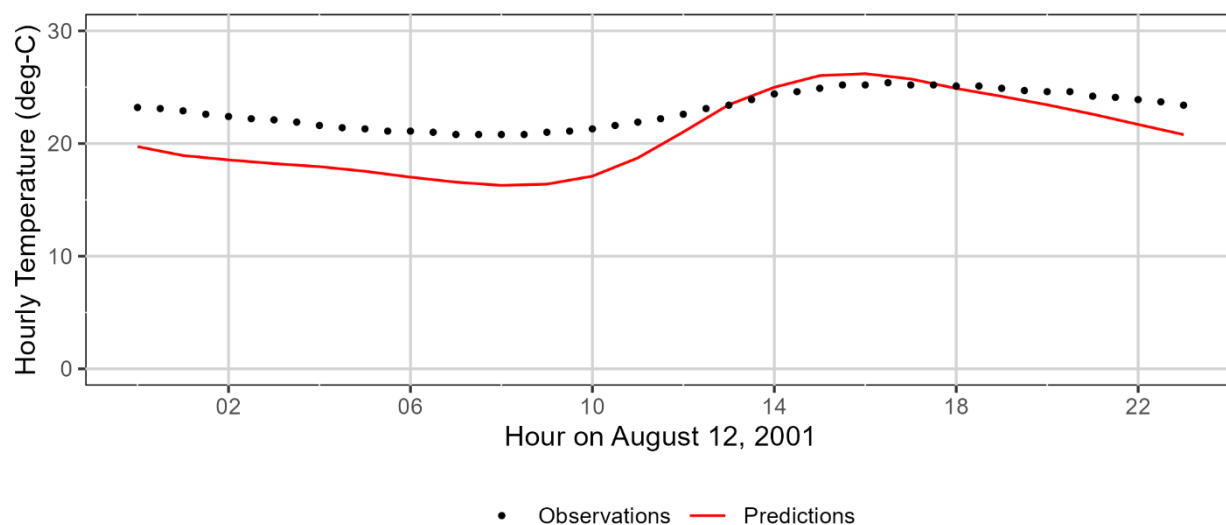
**Figure 3-165: Luckiamute River measured and model-predicted hourly temperatures at monitoring station 25475-ORDEQ.**

10659-ORDEQ: Luckiamute River at Helmick State Park  
Model Kilometer 22.6



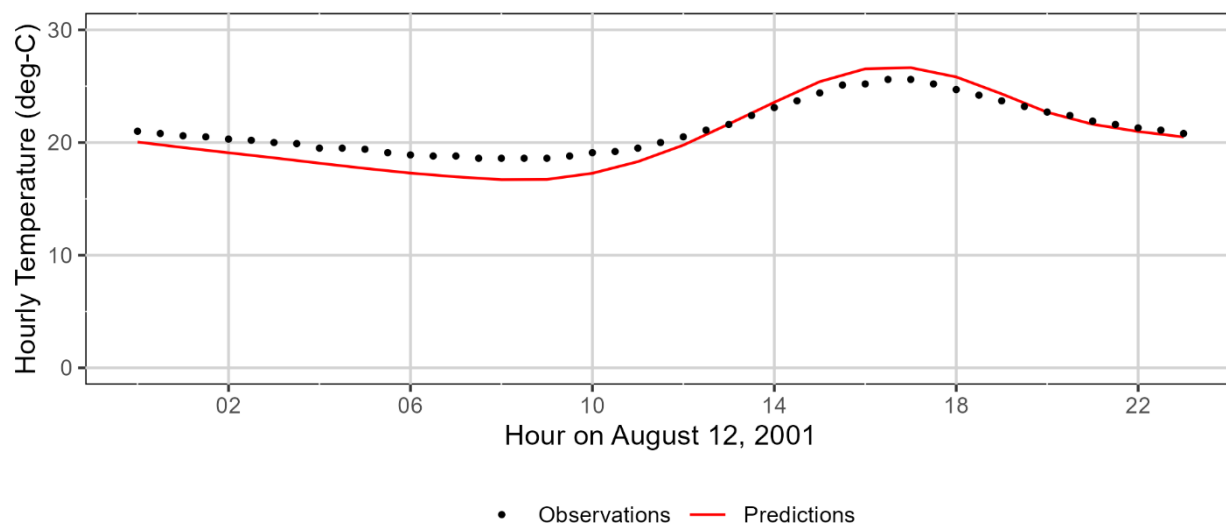
**Figure 3-166: Luckiamute River measured and model-predicted hourly temperatures at monitoring station 10659-ORDEQ.**

25477-ORDEQ: Luckiamute River at Airlie Rd. Bridge  
Model Kilometer 40.1



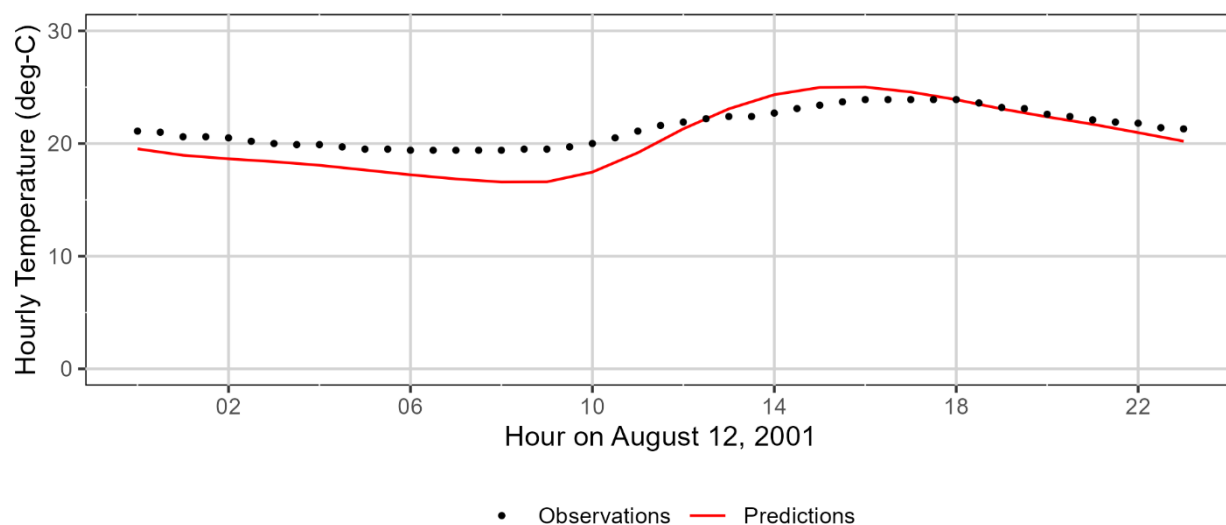
**Figure 3-167: Luckiamute River measured and model-predicted hourly temperatures at monitoring station 25477-ORDEQ.**

25480-ORDEQ: Luckiamute River at Ira Hooker Rd.  
Model Kilometer 49.8

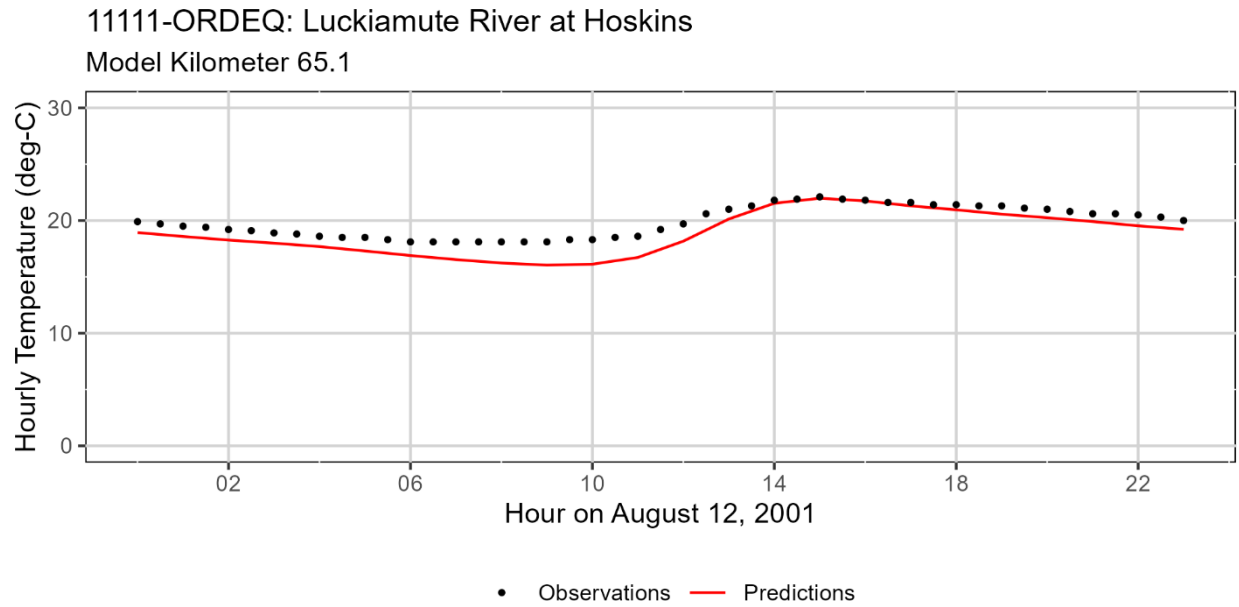


**Figure 3-168: Luckiamute River measured and model-predicted hourly temperatures at monitoring station 25480-ORDEQ.**

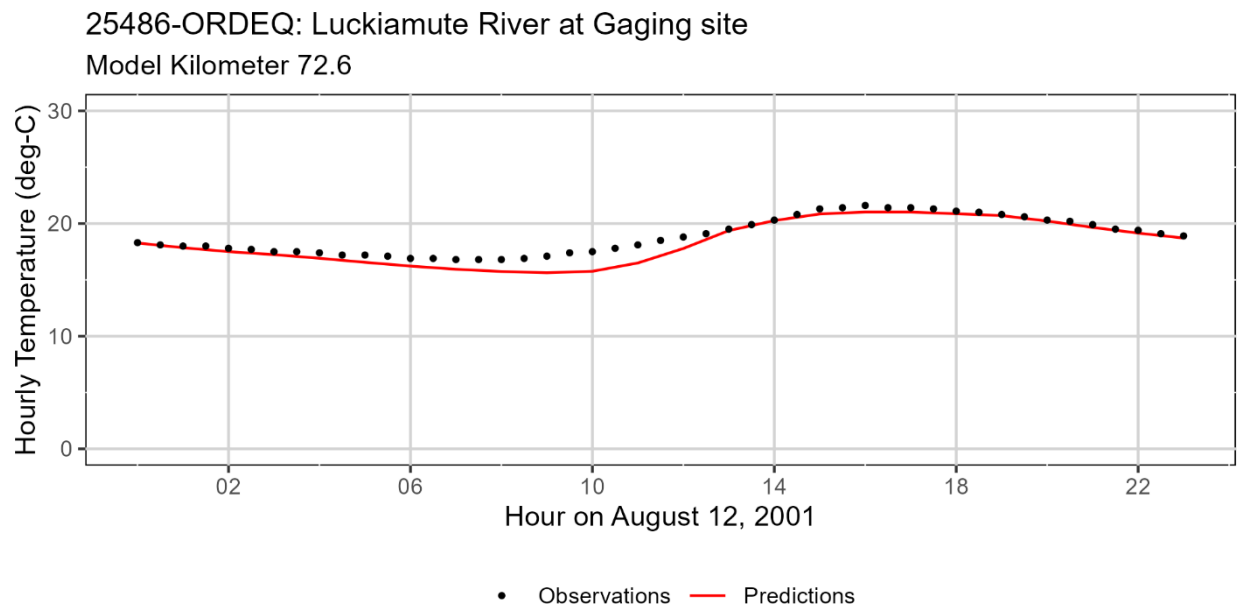
25483-ORDEQ: Luckiamute River just upstream Ritner Creek  
Model Kilometer 53



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

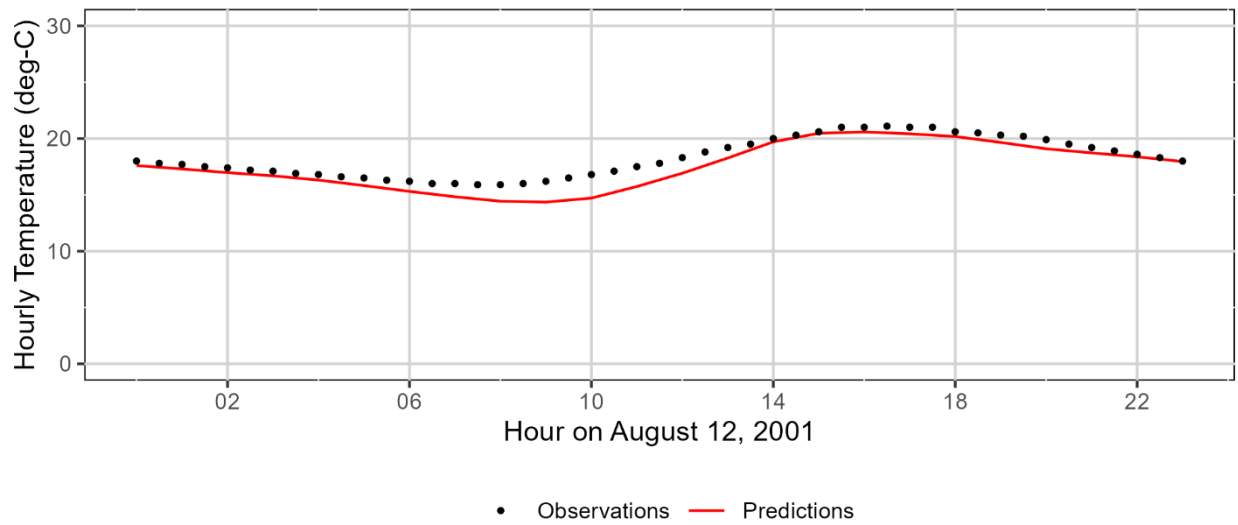


**Figure 3-170: Luckiamute River measured and model-predicted hourly temperatures at monitoring station 11111-ORDEQ.**



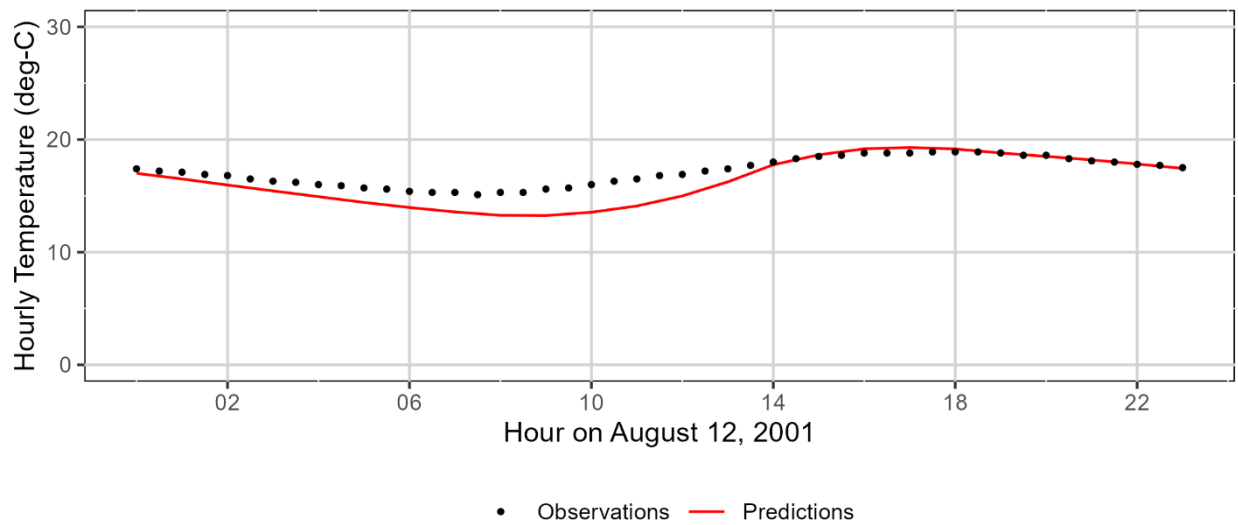
**Figure 3-171: Luckiamute River measured and model-predicted hourly temperatures at monitoring station 25486-ORDEQ.**

25488-ORDEQ: Luckiamute River at Boise Roadmile 1  
Model Kilometer 77.7



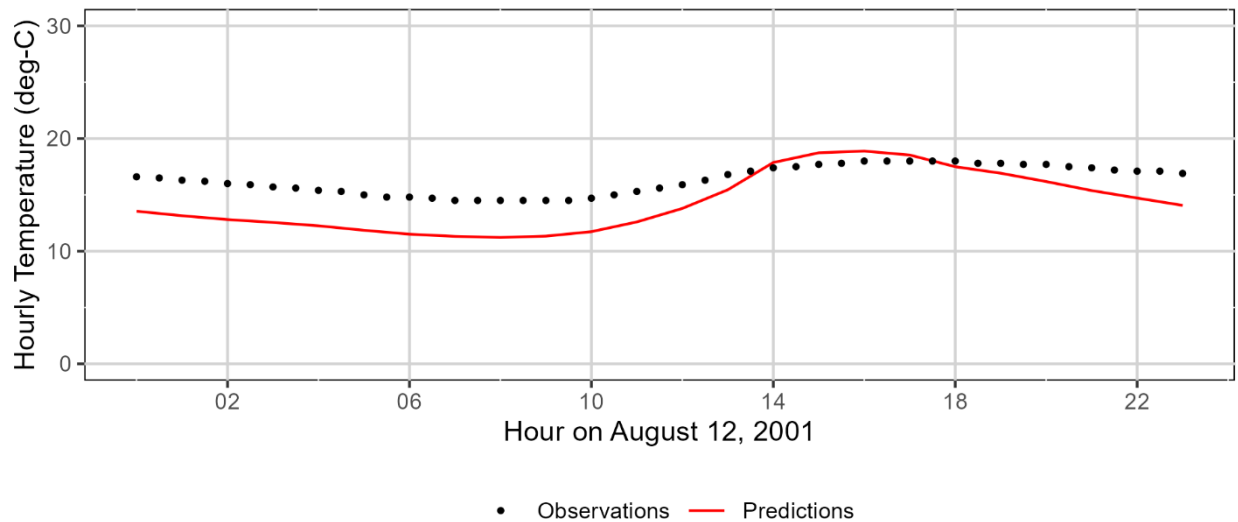
**Figure 3-172: Luckiamute River measured and model-predicted hourly temperatures at monitoring station 25488-ORDEQ.**

25490-ORDEQ: Luckiamute River at Boise Roadmile 4  
Model Kilometer 83.4



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

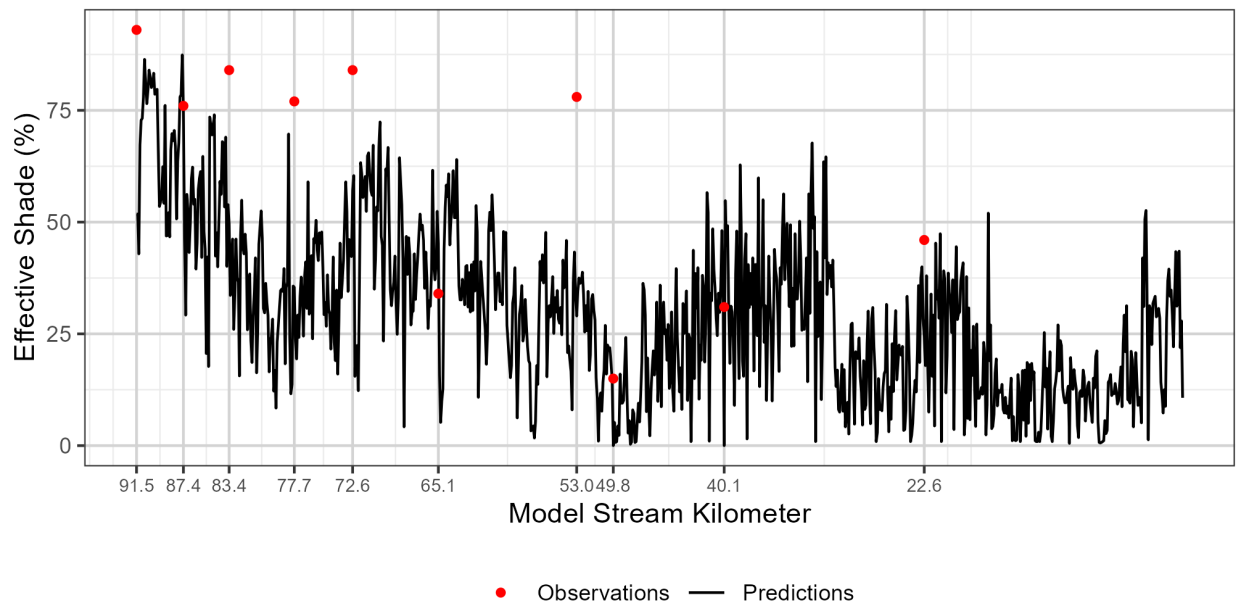
25493-ORDEQ: Luckiamute River at Road 1440 Crossing  
Model Kilometer 87.4



**Figure 3-174: 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 3-175**). 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 3-175: 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.**

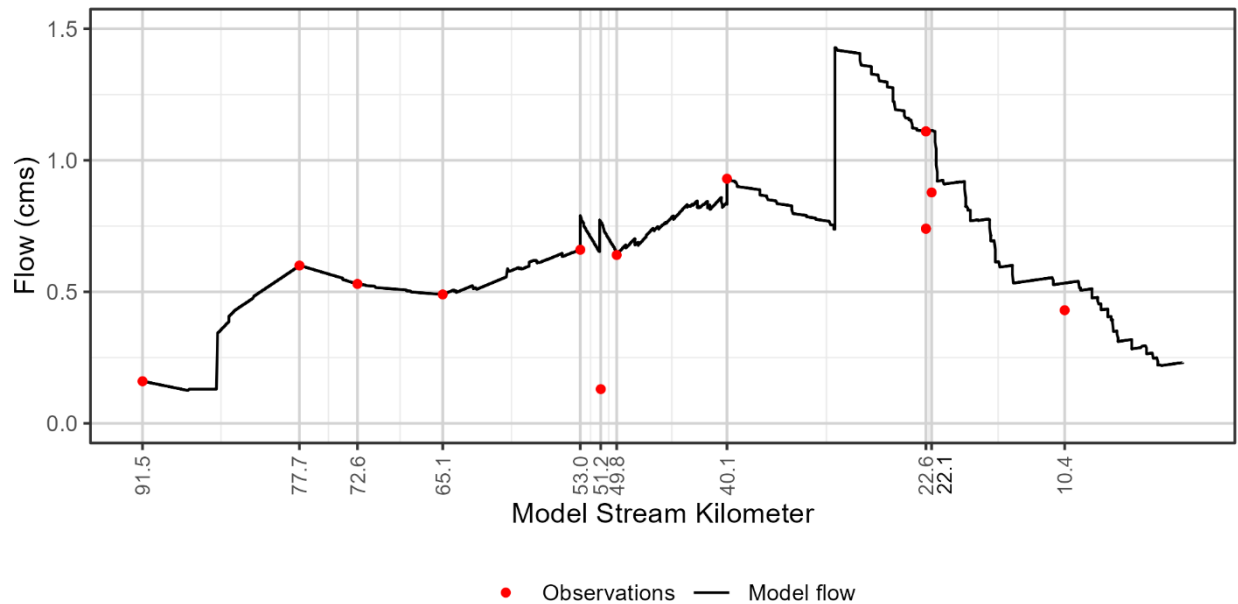
| N  | R <sup>2</sup> | ME     | MAE   | RMSE  |
|----|----------------|--------|-------|-------|
| 10 | 0.55           | -25.08 | 27.32 | 30.84 |

### 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 3-176**. 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 |



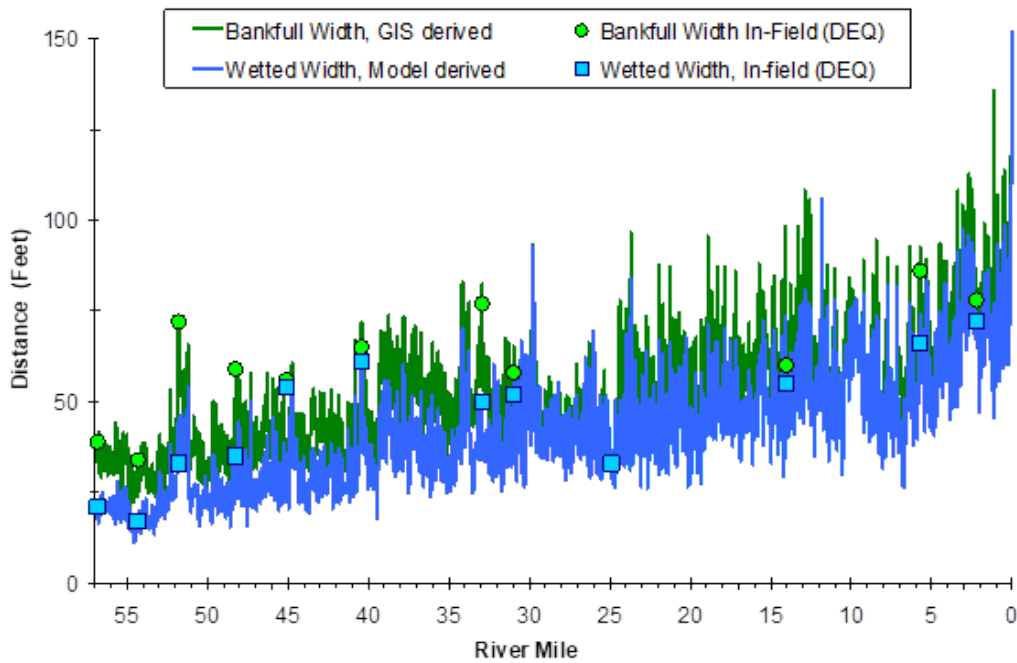
**Figure 3-176: Luckiamute River field observed and model flow rates.**

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

| N  | R <sup>2</sup> | 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 3-177**. Results shows channel widths only from streams modeled for temperature with Heat Source.



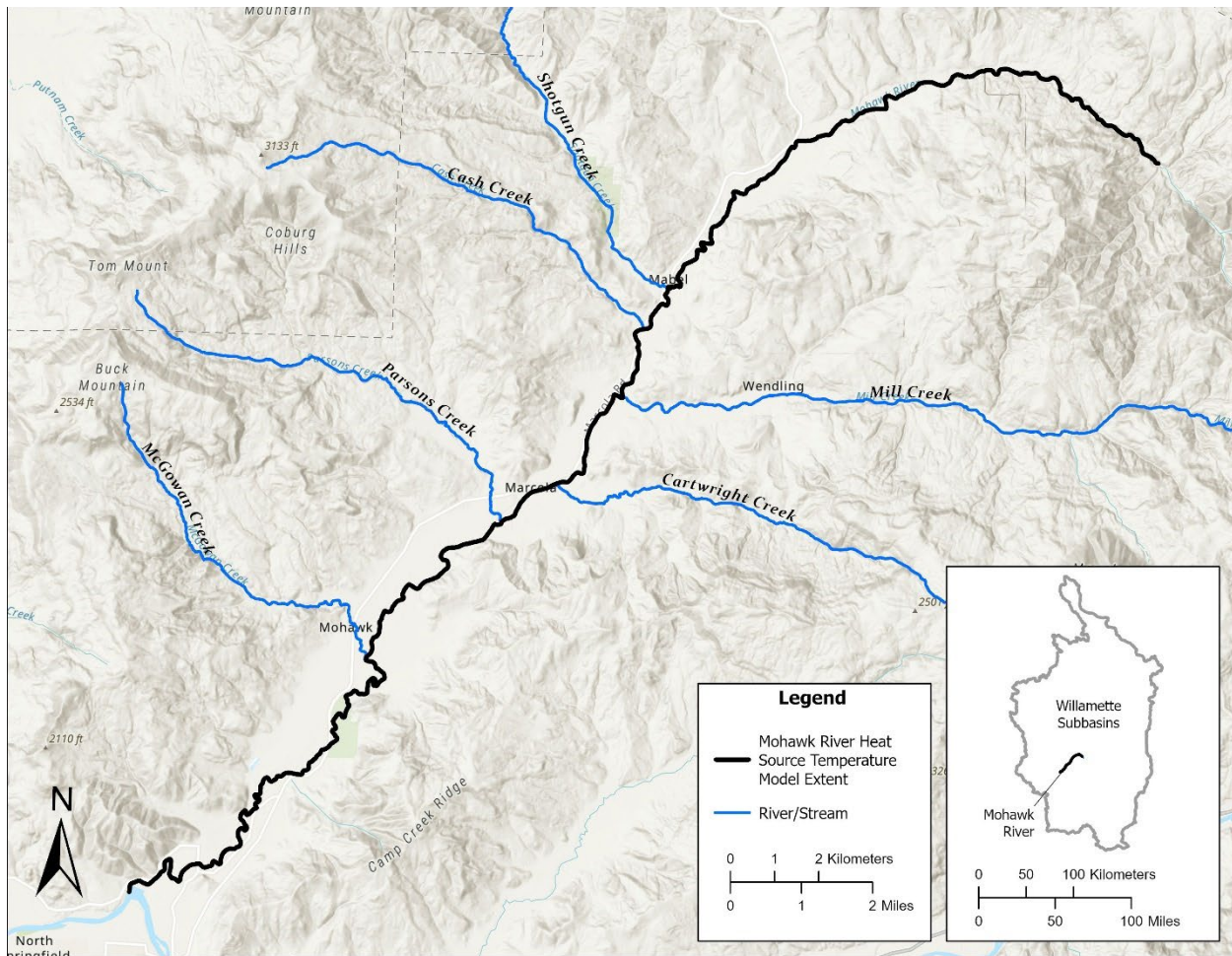
**Figure 3-177: Luckiamute River field observed and derived bankfull and wetted width.**

## 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 3-178**).



**Figure 3-178: 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

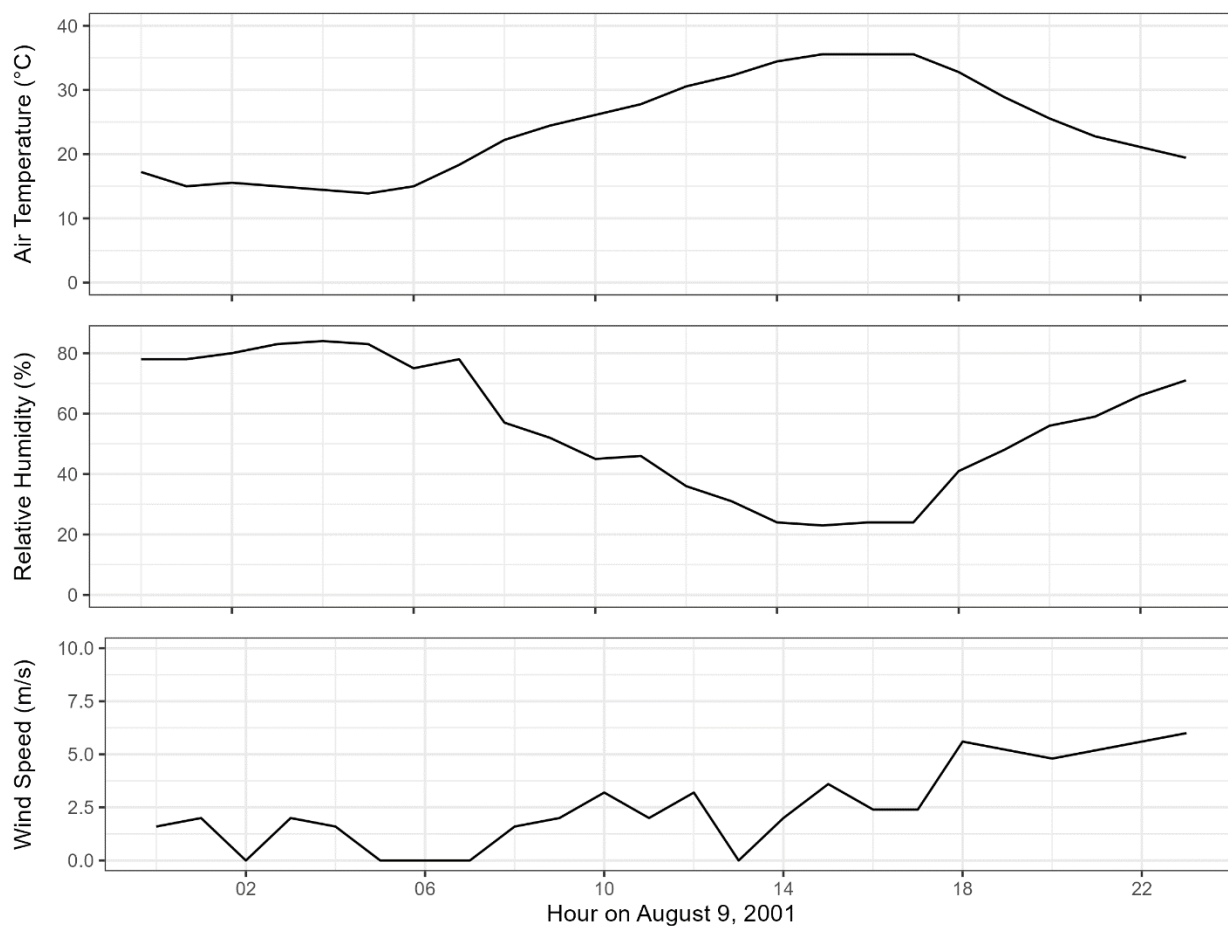
The model period is for a single day: August 09, 2001.

### 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 3-179**). 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.**

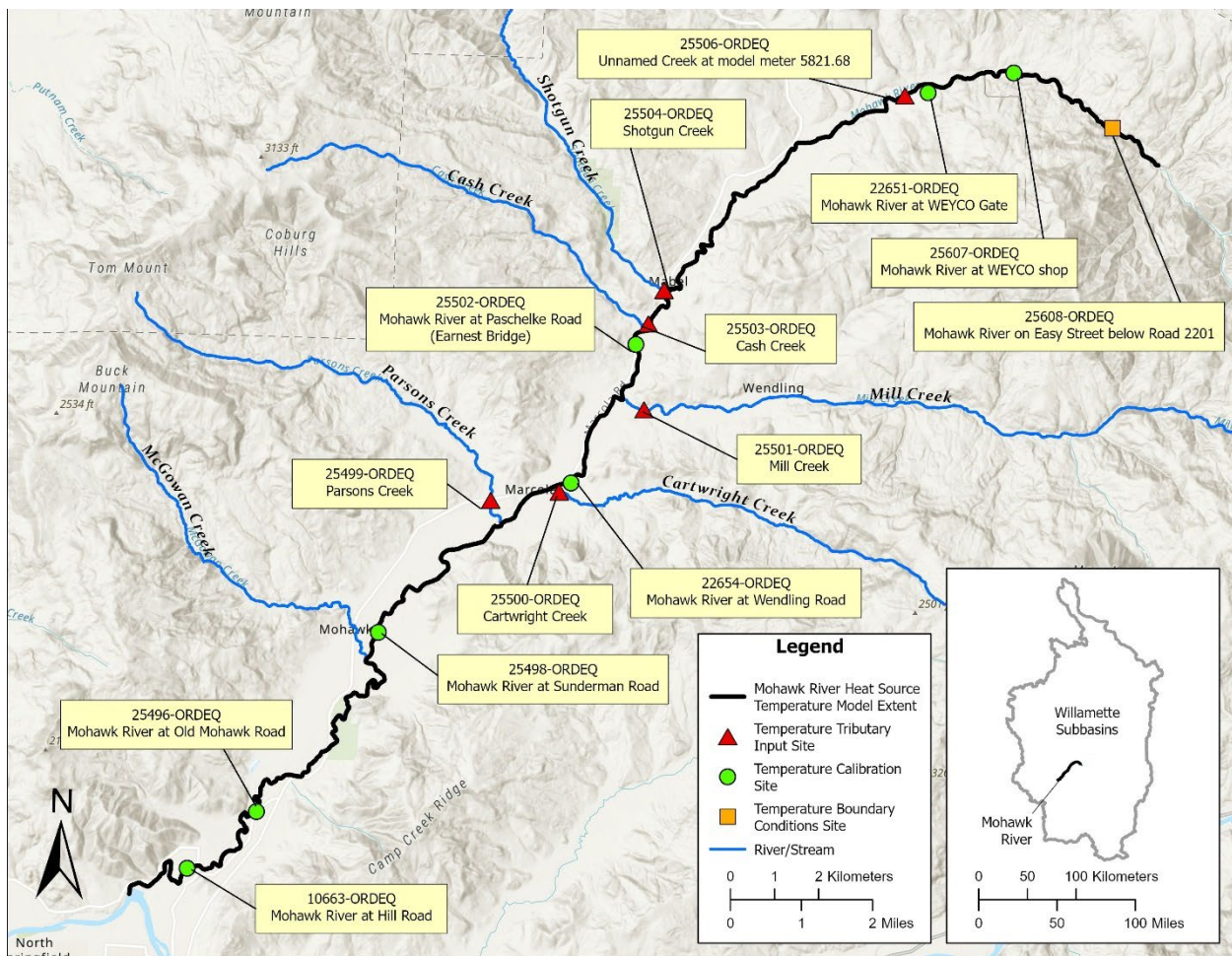
| Model Location Name             | Model Location (km) | Wind Sheltering Coefficient |
|---------------------------------|---------------------|-----------------------------|
| Mohawk River on East Street     | 39.807              | 0.25                        |
| Mohawk River at WEYCO shop      | 36.85               | 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 3-179: 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 3-180** shows the locations of the various stream temperature monitoring locations that were used for model setup or calibration.

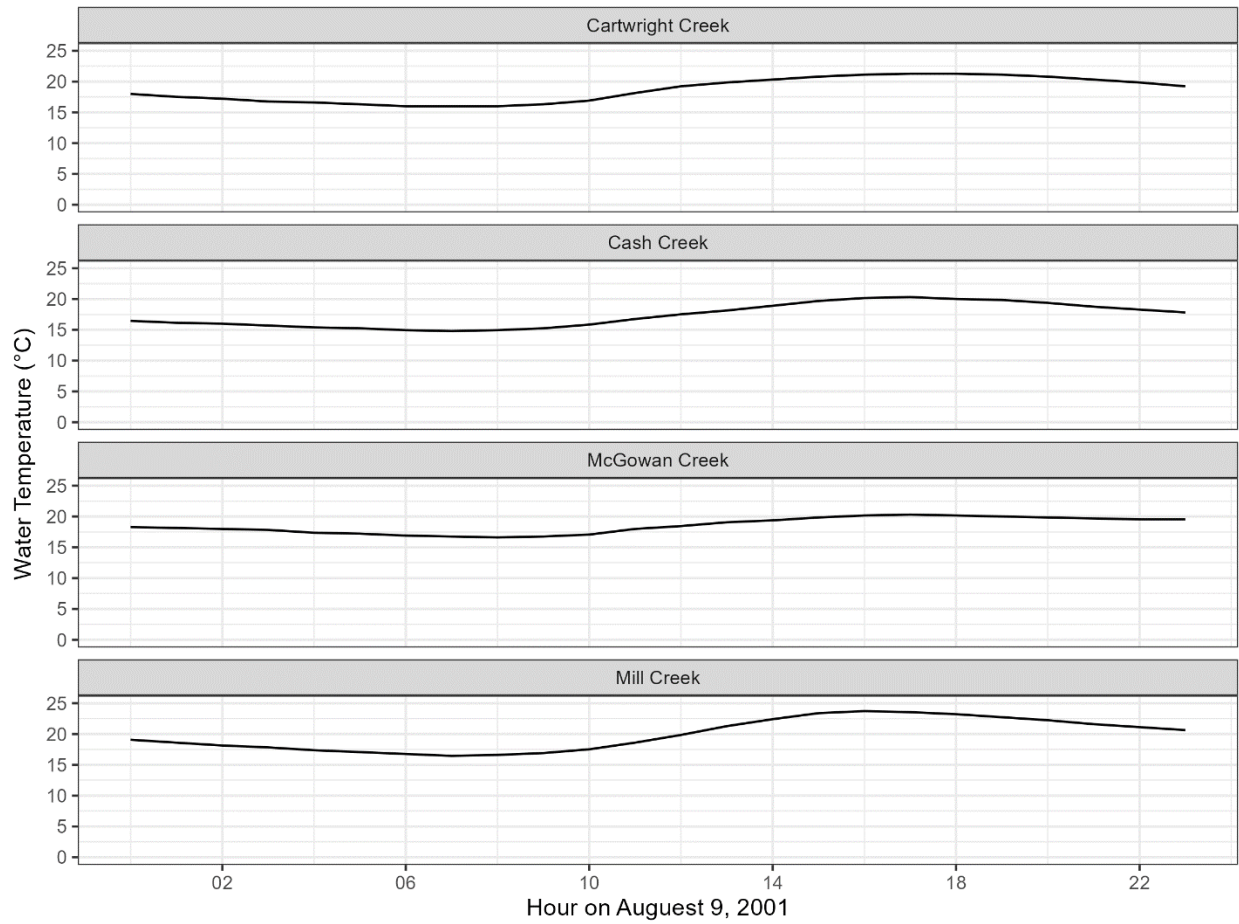


**Figure 3-180: Temperature monitoring locations used for the Mohawk River model setup and calibration.**

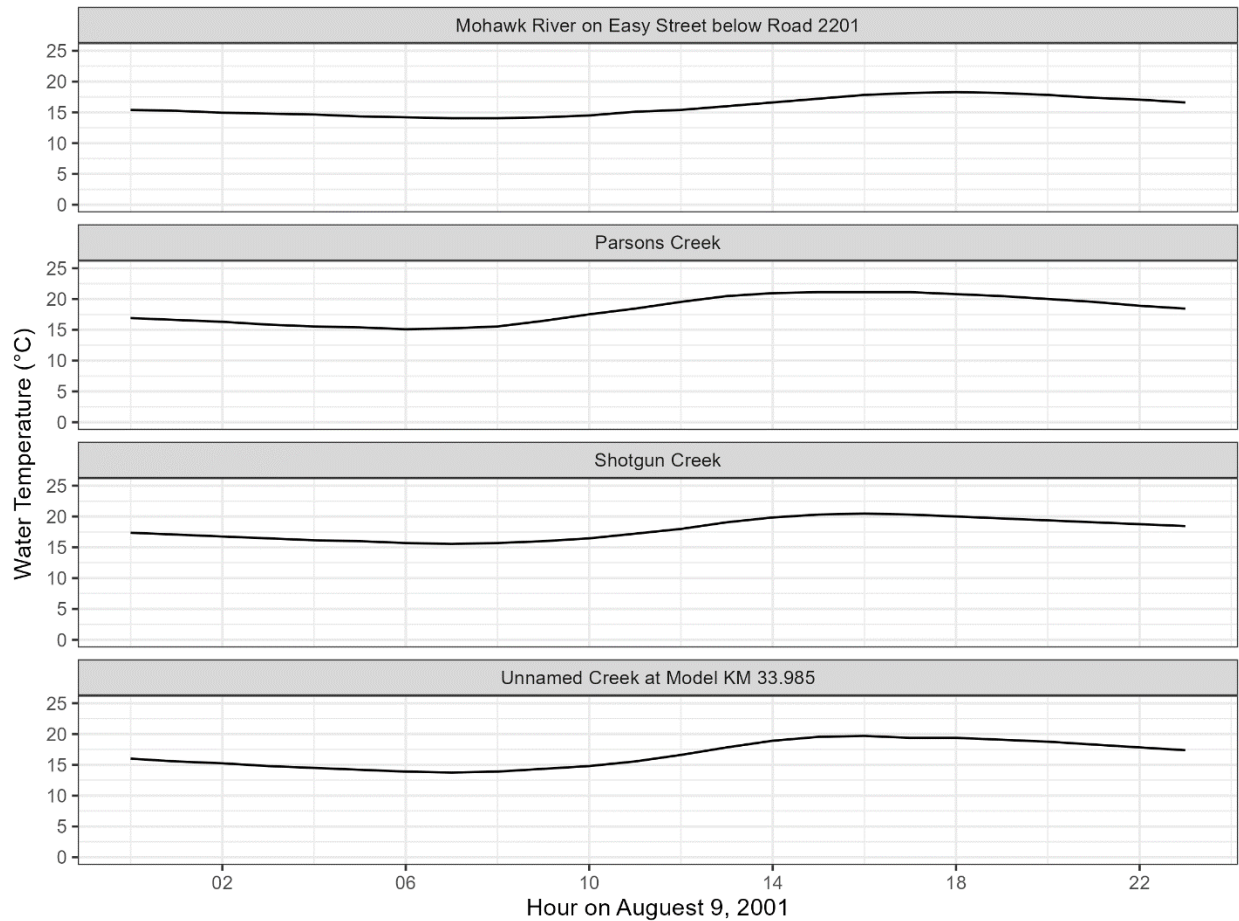
**Table 3-57** and **Figure 3-181** document the water temperature inputs to the model at the boundary condition (Mohawk River on Easy Street below Road 2201) and tributaries.

**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)

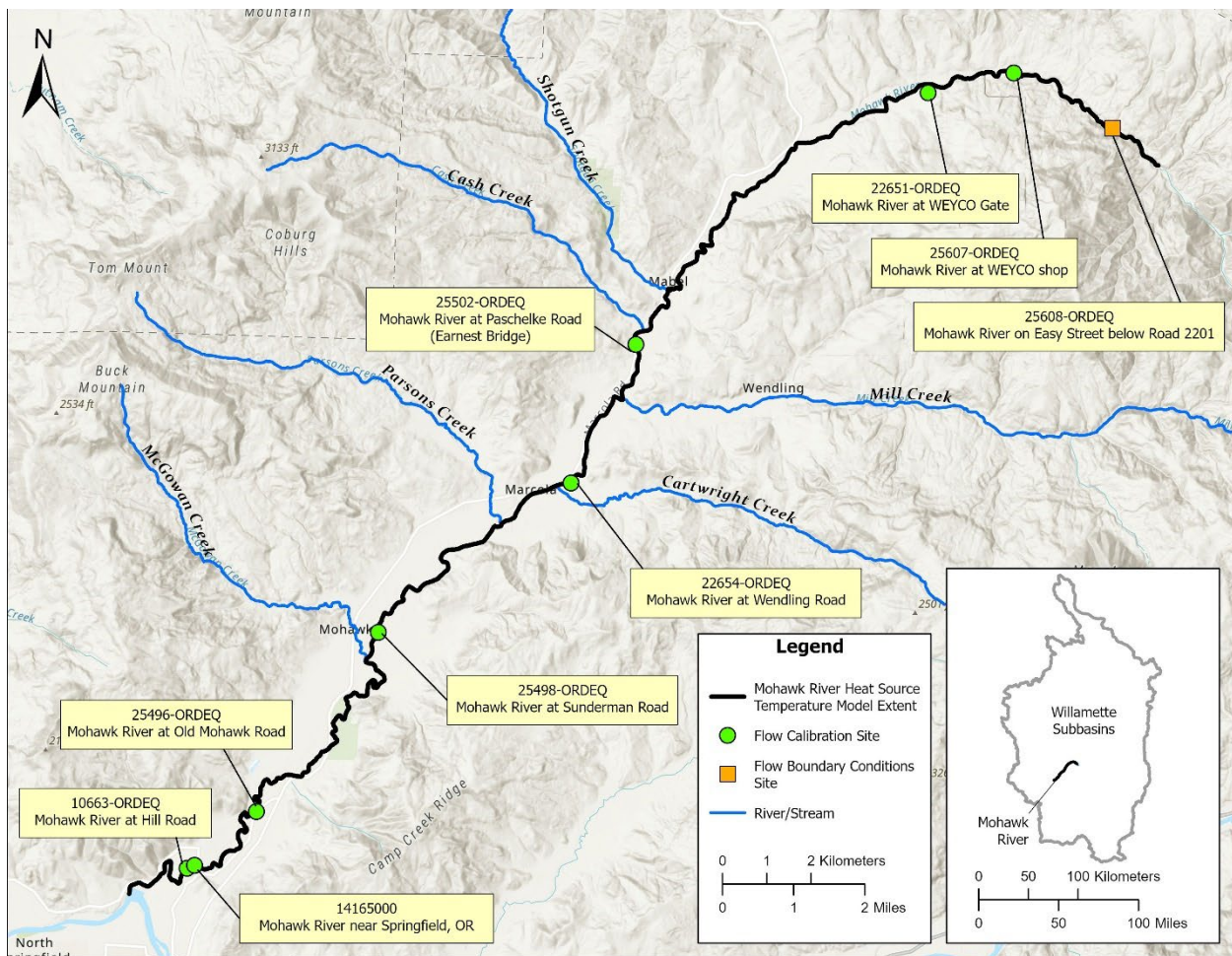


(B)

**Figure 3-181 (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 3-182** shows the locations of the various stream flow monitoring locations that were used for model setup or calibration.

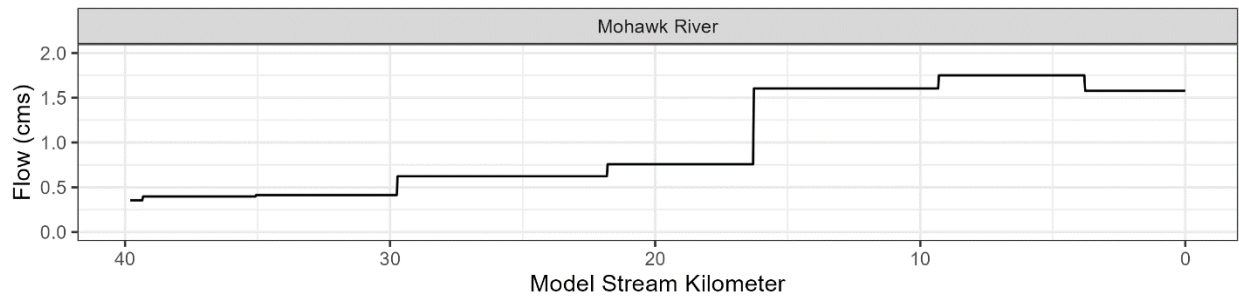


**Figure 3-182: Flow monitoring locations used for the Mohawk River model setup and calibration.**

The boundary condition and tributary flow inputs to the model is summarized in **Table 3-58**. **Figure 3-183** 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         |



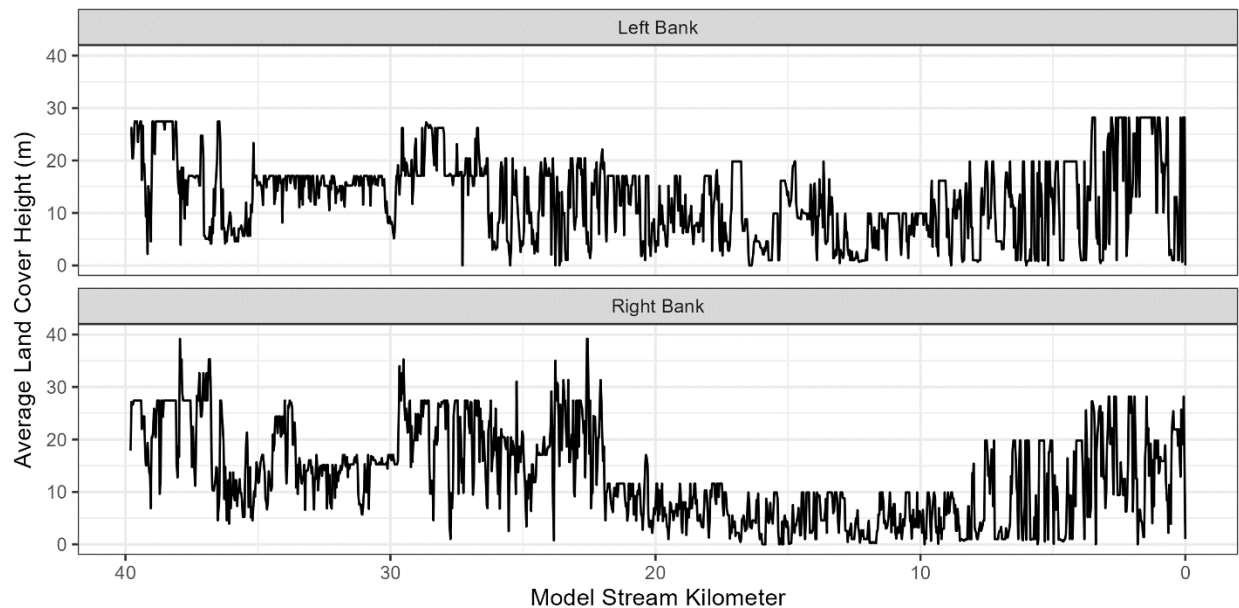
**Figure 3-183: Boundary condition and mainstem flow inputs to the Mohawk River model.**

### 3.8.7 Point source inputs

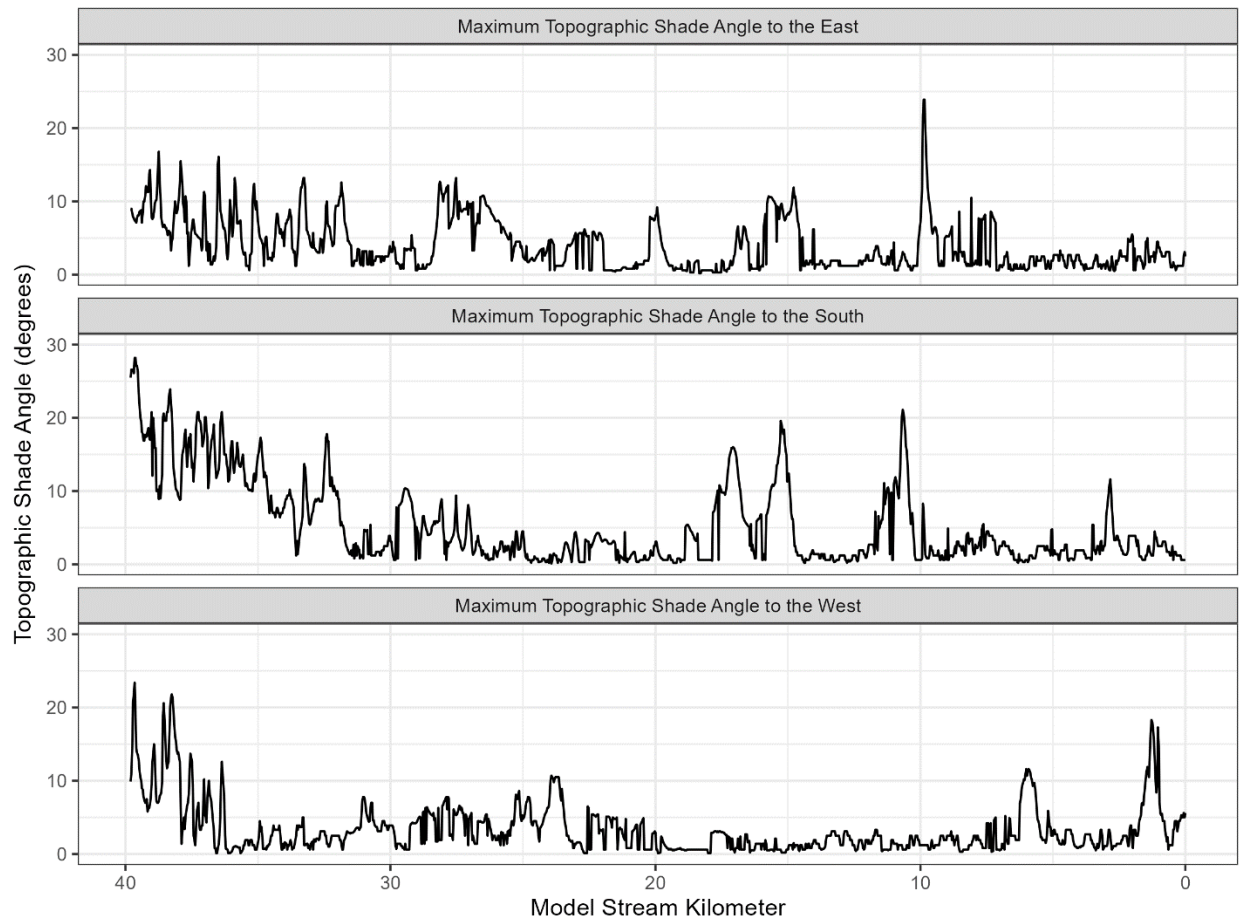
There are no point sources discharging within the model extent.

### 3.8.8 Landcover and topographic shade inputs

Average land cover height inputs and topographic shade angle inputs are shown in **Figure 3-184** and **Figure 3-185**, respectively.



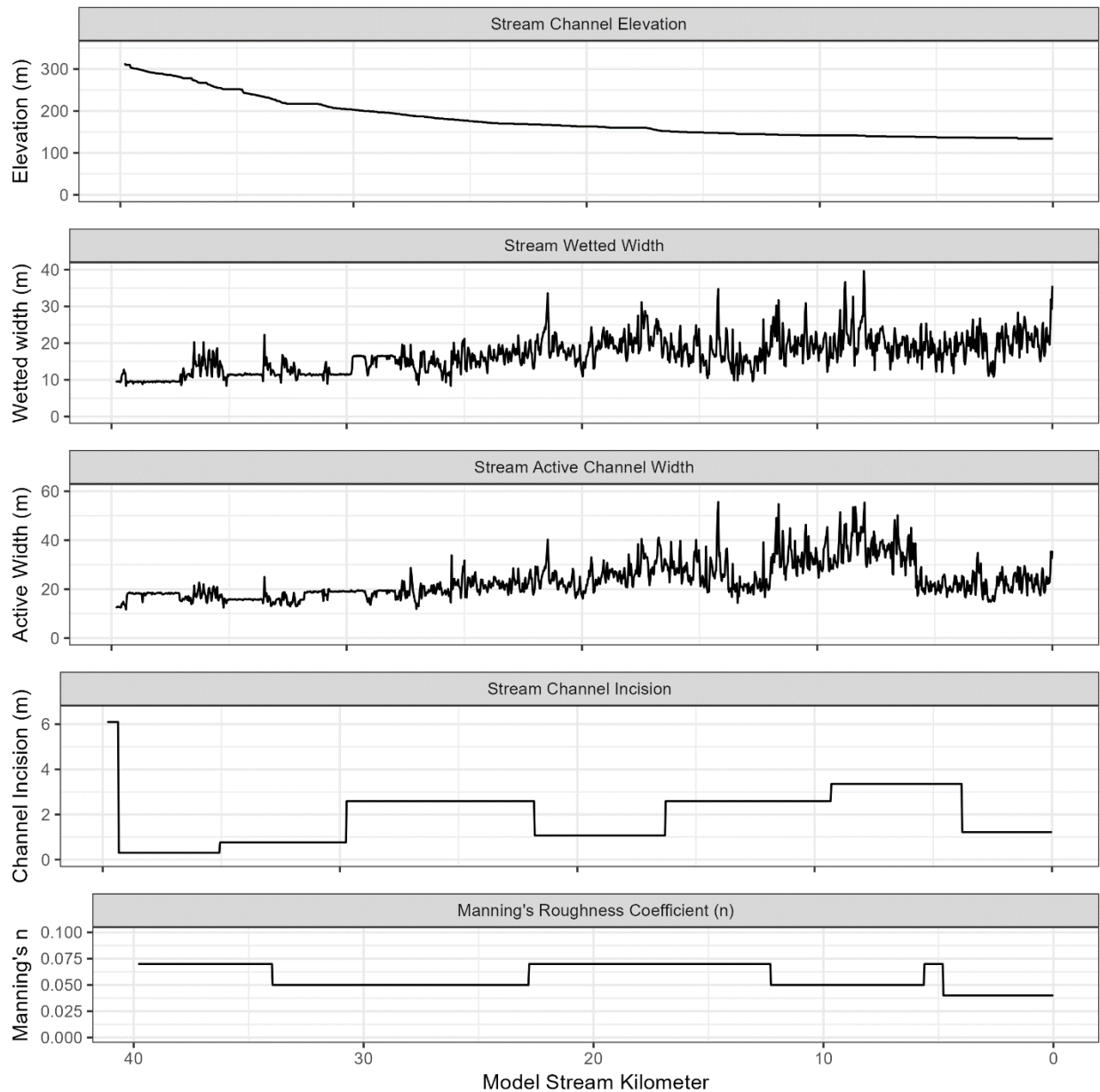
**Figure 3-184: Average land cover height inputs to the Mohawk River model.**



**Figure 3-185: Topographic shade angle inputs to the Mohawk River model.**

### 3.8.9 Channel setup

Channel setup for Mohawk River model is presented in **Figure 3-186**.



**Figure 3-186: Channel setup in the Mohawk River model.**

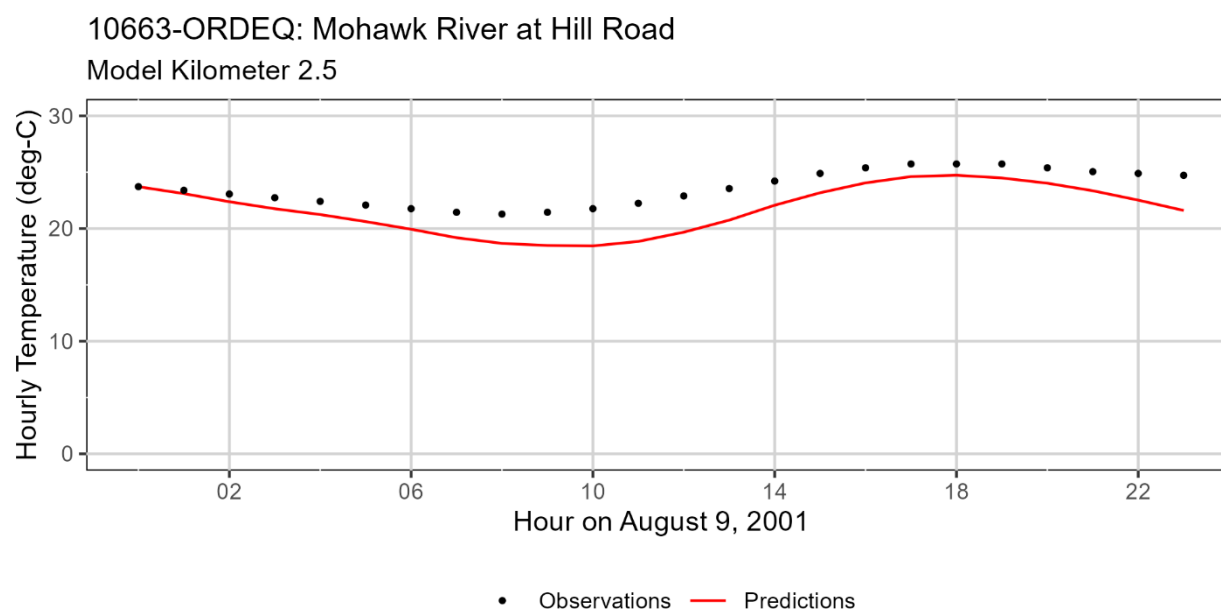
### 3.8.10 Calibration results

#### 3.8.10.1 Temperature

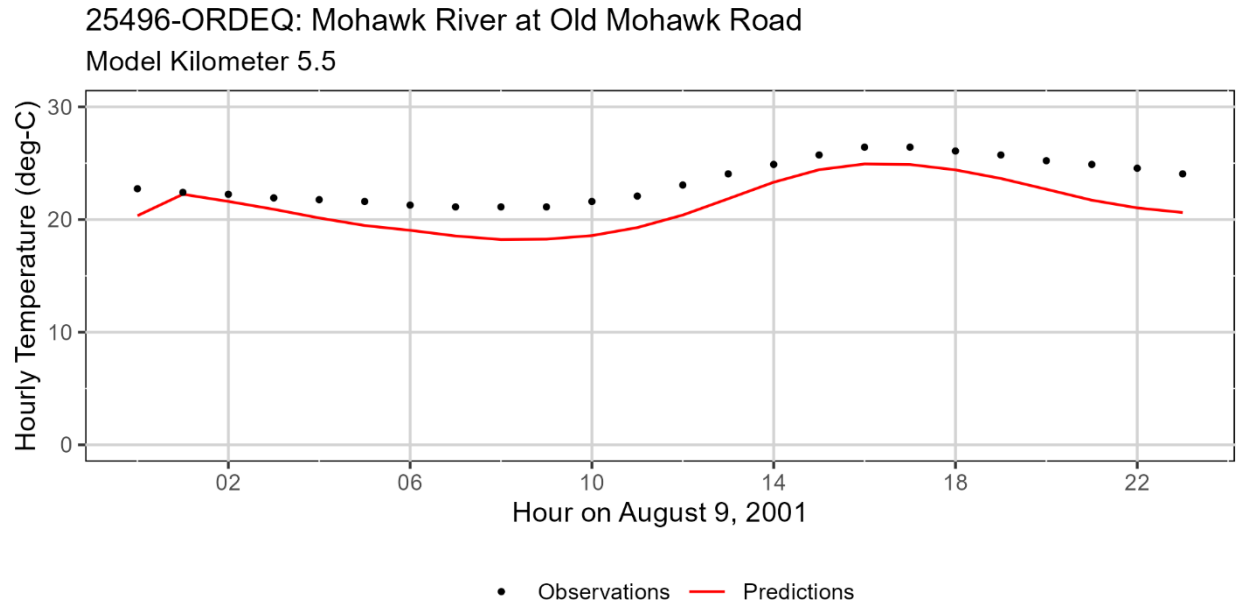
The model was calibrated to the continuous temperature data collected from several locations along the Mohawk River. Results for goodness of fit statistics comparing field observed and model-predicted temperatures are summarized in **Table 3-59**. Observed and model-predicted hourly temperatures were plotted for the monitoring stations (**Figure 3-187** through **Figure 3-193**).

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

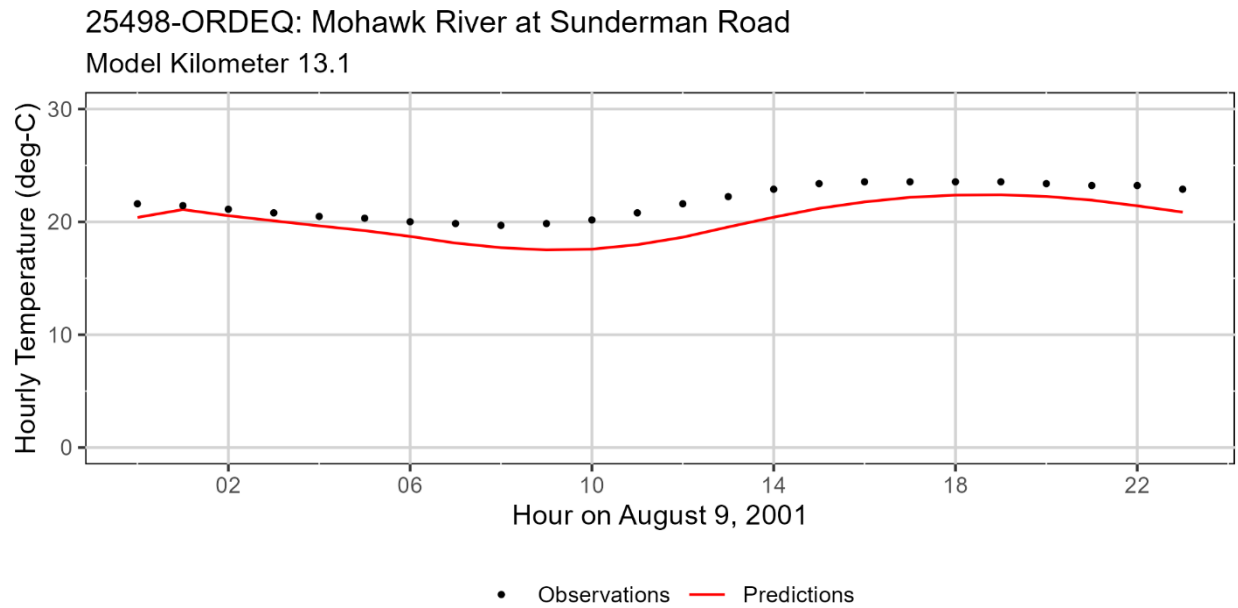
| Monitoring Location  | Model KM | Temperature Statistics | ME    | MAE  | RMSE | NSE   | n   |
|--|----------|------------------------|-------|------|------|-------|-----|
| All Stations   |          | Daily Maximum          | -0.85 | 0.85 | 0.98 | NA    | 7   |
| All Stations   |          | Hourly                 | -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  |



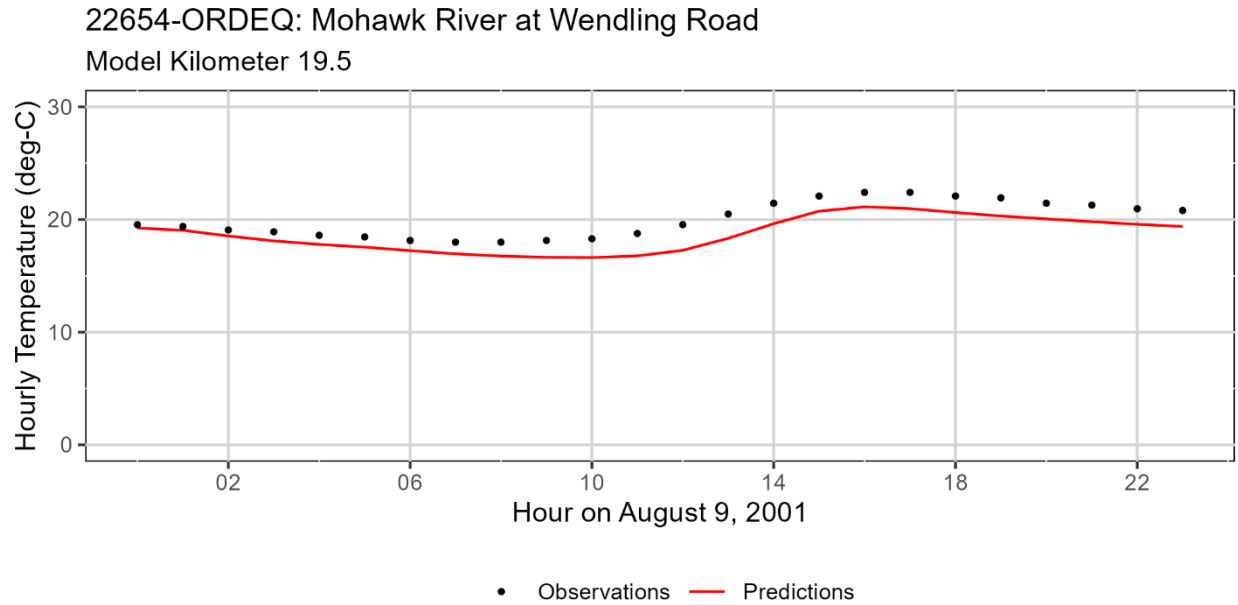
**Figure 3-187: Mohawk River measured and model-predicted hourly temperatures at monitoring station 10663-ORDEQ.**



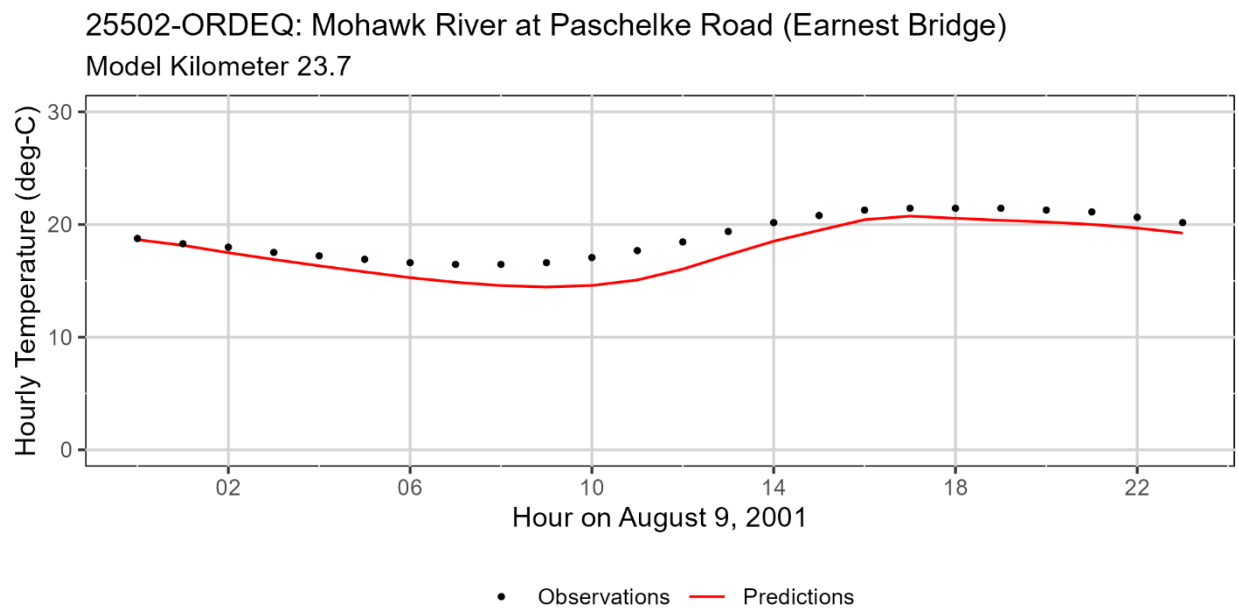
**Figure 3-188: Mohawk River measured and model-predicted hourly temperatures at monitoring station 25496-ORDEQ.**



**Figure 3-189: Mohawk River measured and model-predicted hourly temperatures at monitoring station 25498-ORDEQ.**



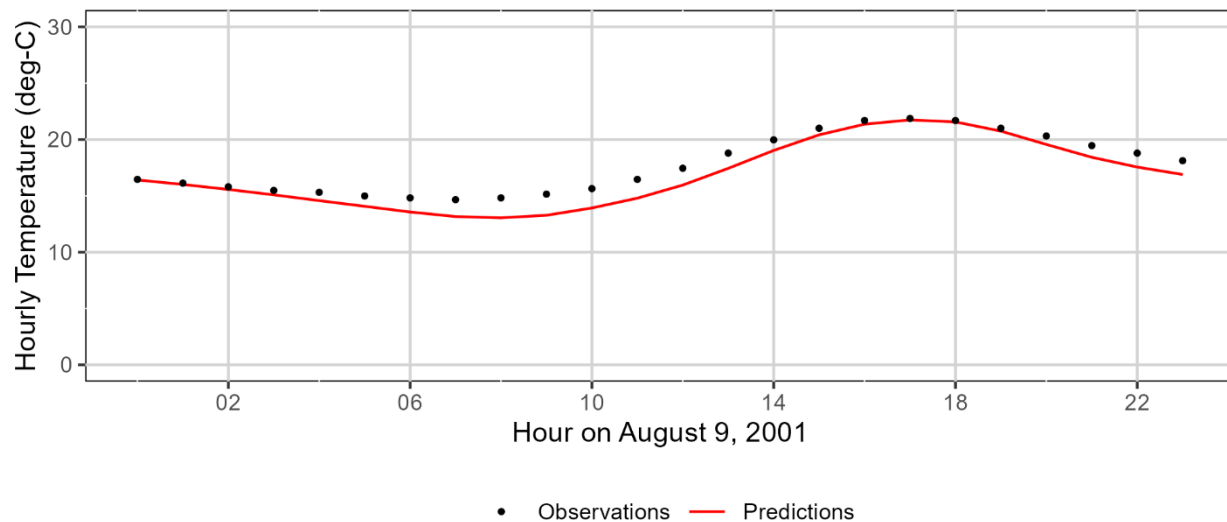
**Figure 3-190: Mohawk River measured and model-predicted hourly temperatures at monitoring station 22654-ORDEQ.**



**Figure 3-191: Mohawk River measured and model-predicted hourly temperatures at monitoring station 25502-ORDEQ.**

### 22651-ORDEQ: Mohawk River at Weyco Gate

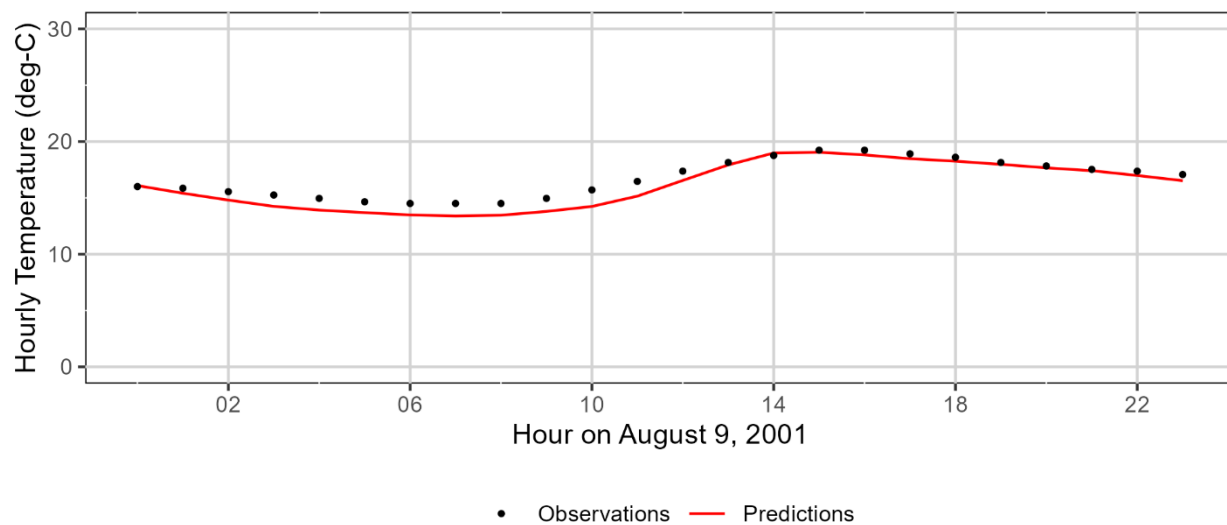
Model Kilometer 34.6



**Figure 3-192: Mohawk River measured and model-predicted hourly temperatures at monitoring station 22651-ORDEQ.**

### 25607-ORDEQ: Mohawk River at WEYCO Shop

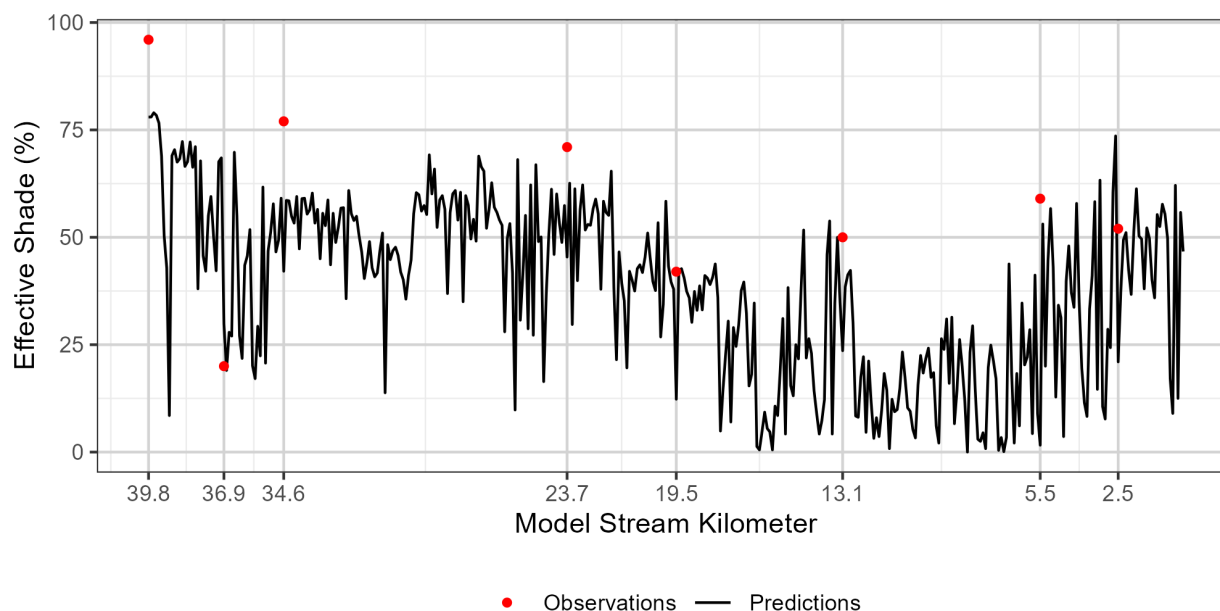
Model Kilometer 36.9



**Figure 3-193: 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 3-194**). 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 3-194: 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 <sup>2</sup> | ME     | MAE  | RMSE  |
|---|----------------|--------|------|-------|
| 8 | 0.46           | -26.65 | 29.1 | 31.88 |

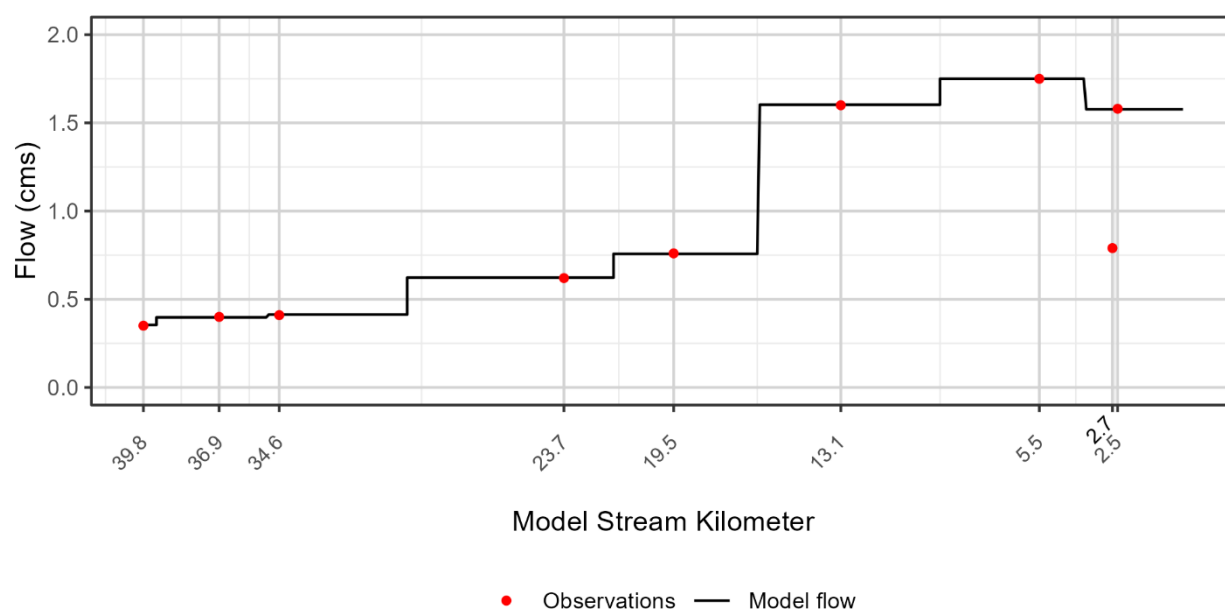
### 3.8.10.3 Flow

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 3-195**. 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 |

| Monitoring Location  | Model KM | Flow Statistics | Flow (cms) | Date     |
|--|----------|-----------------|------------|----------|
| 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 |



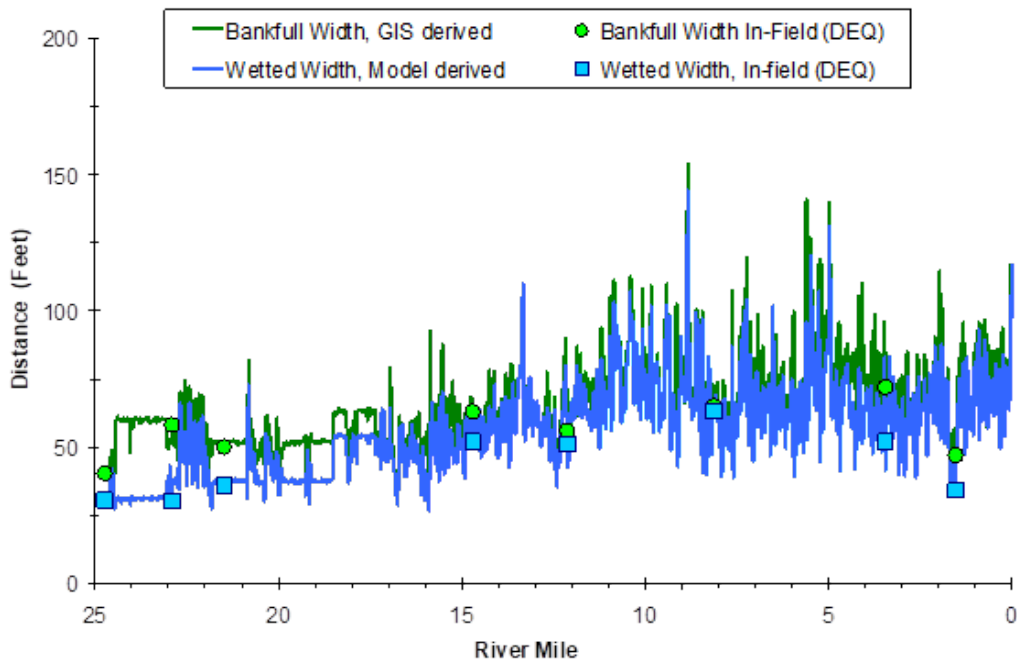
**Figure 3-195: Mohawk River field observed and model flow rates.**

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

| N | R <sup>2</sup> | 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 3-196**. Results shows channel widths only from streams modeled for temperature with Heat Source.



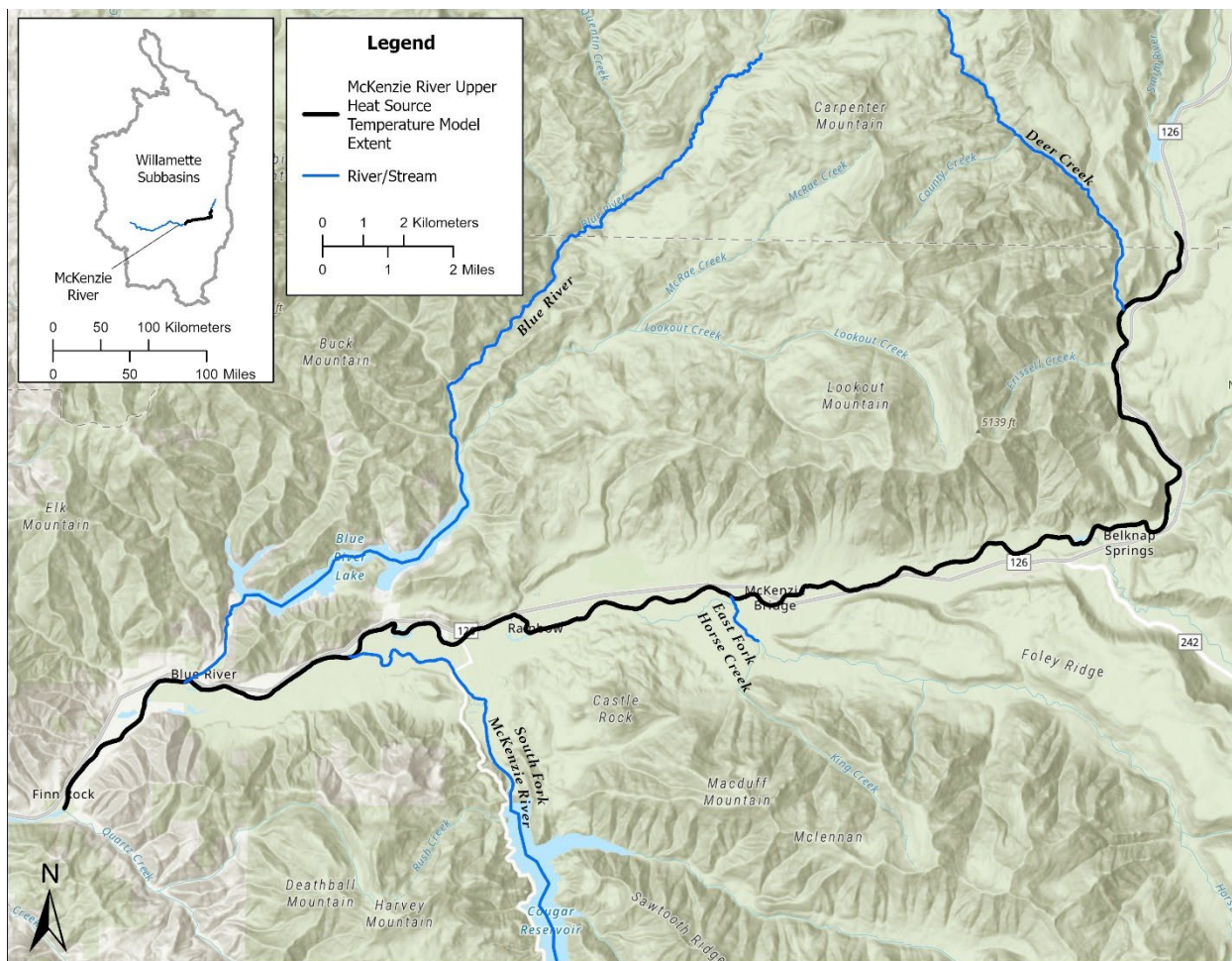
**Figure 3-196: Mohawk River field observed and derived bankfull and wetted width.**

## 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 3-197**).



**Figure 3-197: McKenzie River: Upper model extent.**

### 3.9.2 Spatial and temporal resolution

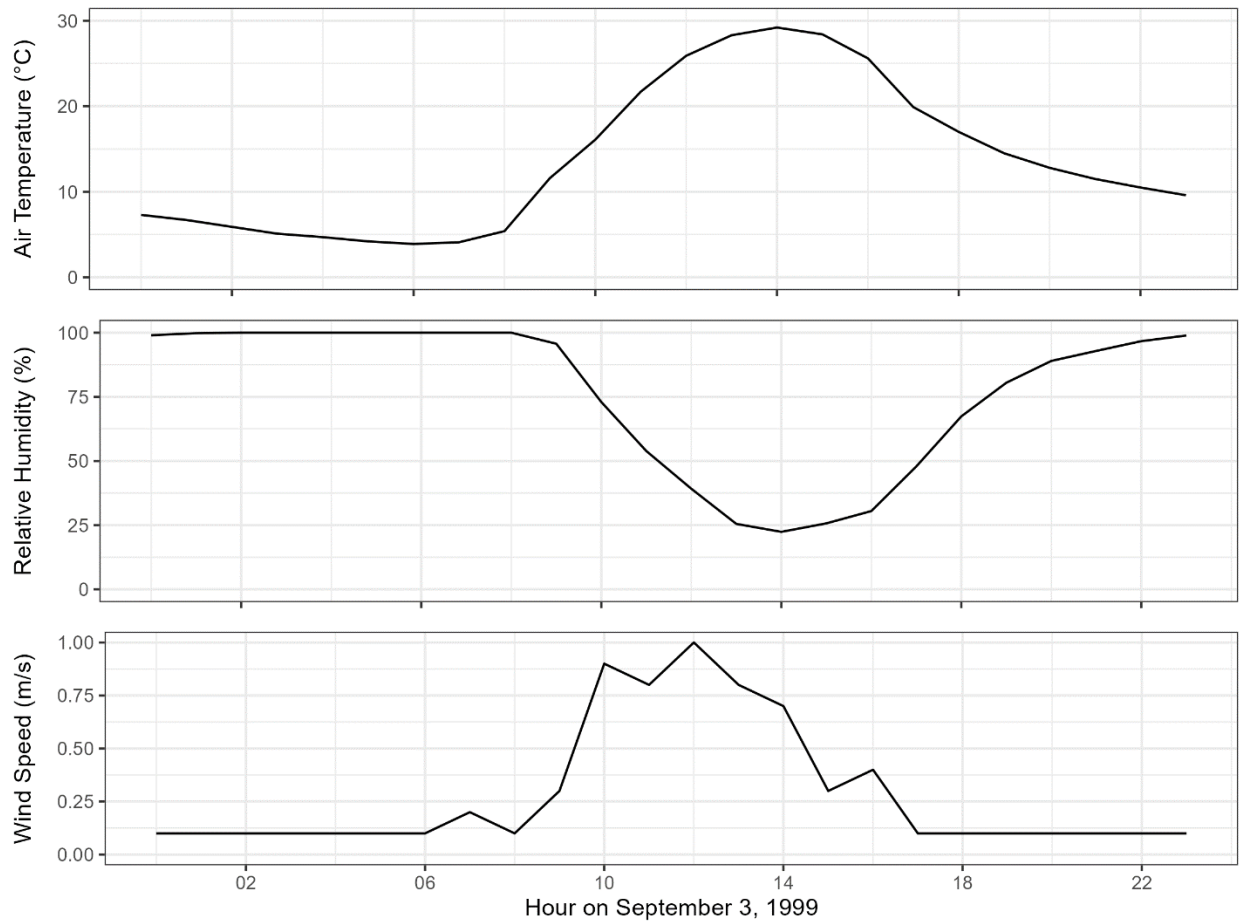
The model input spatial resolution ( $dx$ ) is 30 m. Outputs are generated every 100 m. The model time step ( $dt$ ) is 1 minute and outputs are generated every hour.

### 3.9.3 Time frame of simulation

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

### 3.9.4 Meteorological inputs

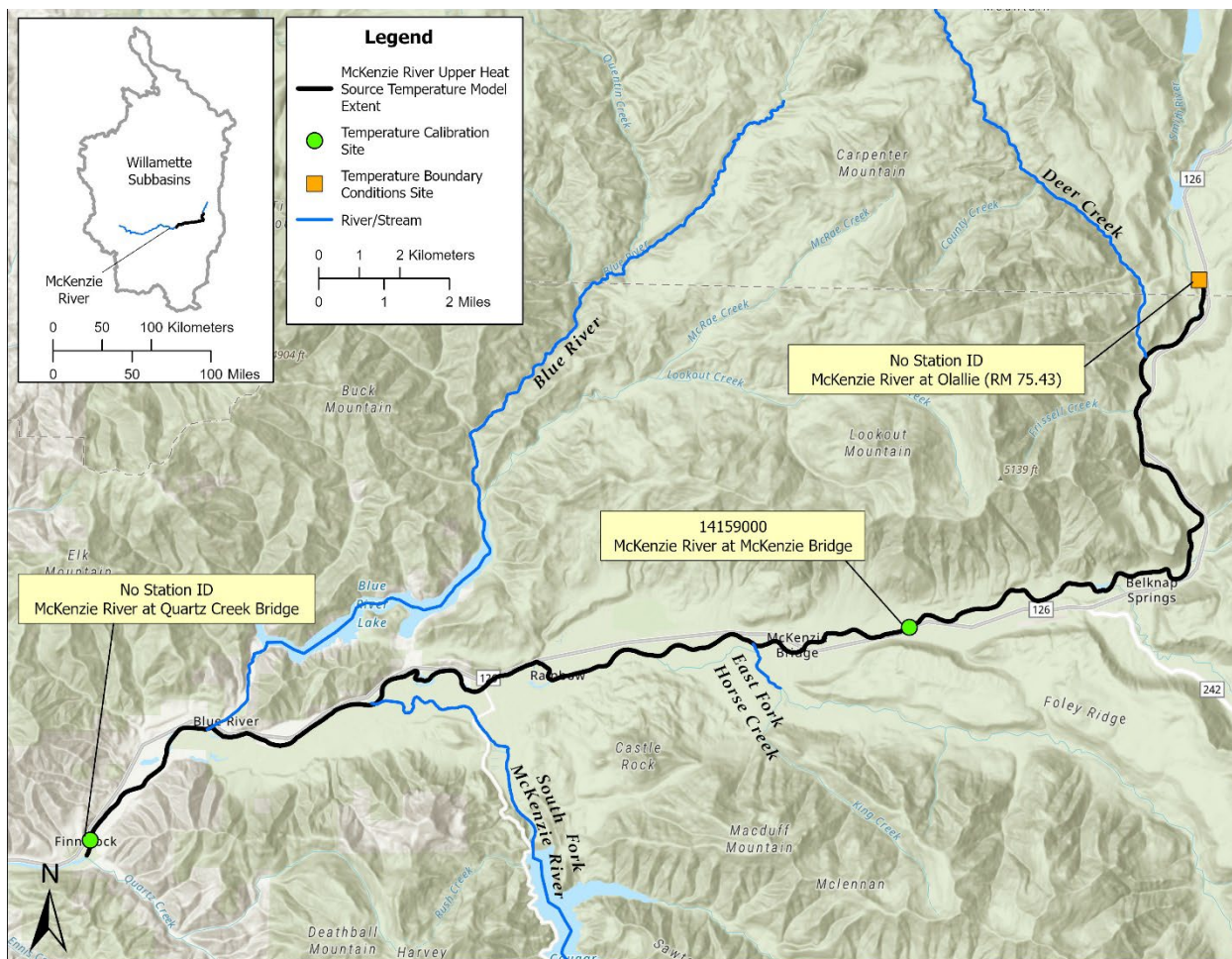
The model was set up using hourly air temperature, relative humidity, and wind speed measurements from a DEQ site at the H.J. Andrews Experimental Forest Meteorological Station (**Figure 3-198**). Air temperature data were modified using the dry adiabatic lapse rate to adjust for differences in elevation 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 3-198: 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 3-199** shows the locations of the various stream temperature monitoring locations that were used for model setup or calibration.



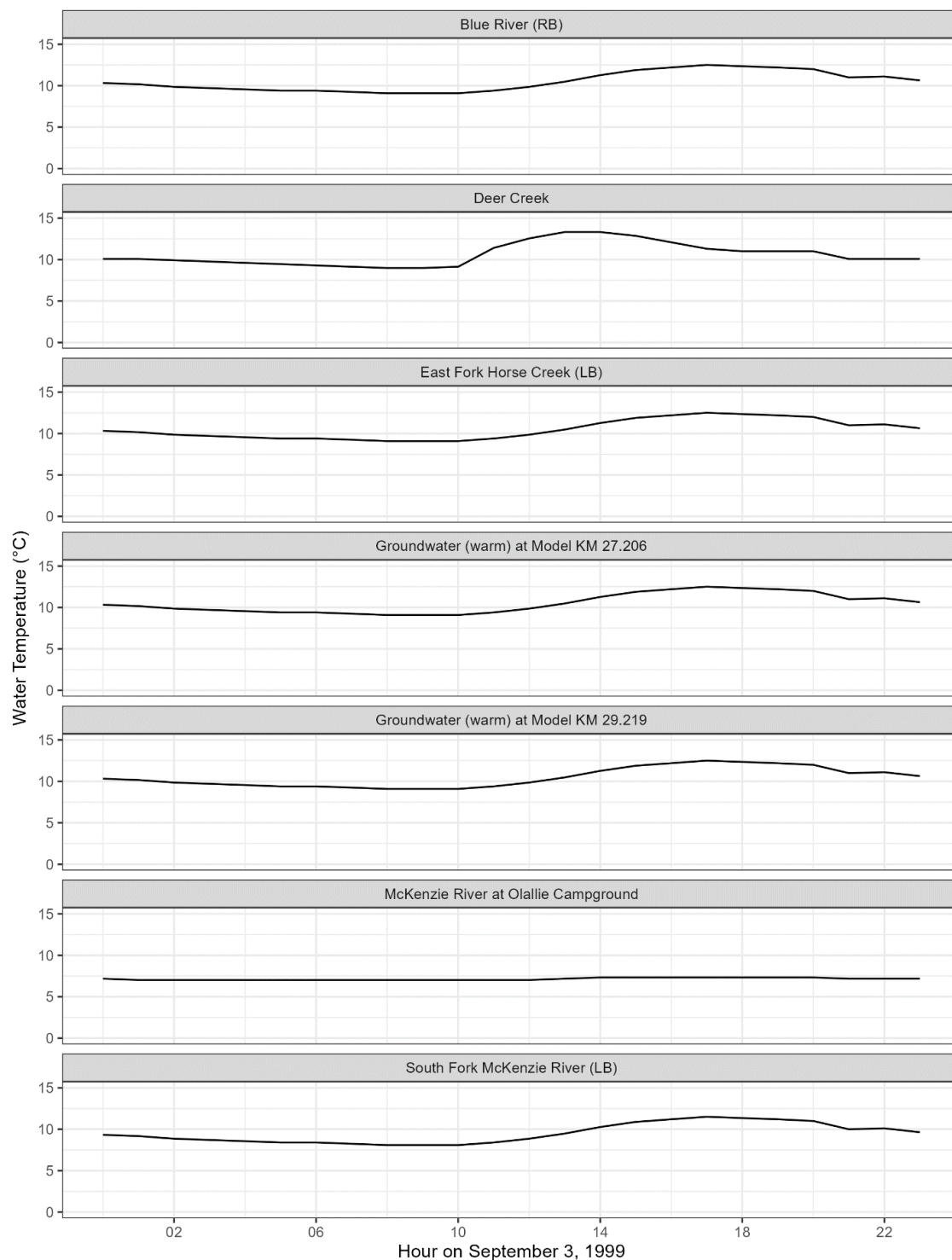
**Figure 3-199: Temperature monitoring locations used for the upper McKenzie River model setup and calibration.**

**Table 3-63** and **Figure 3-200** 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   |

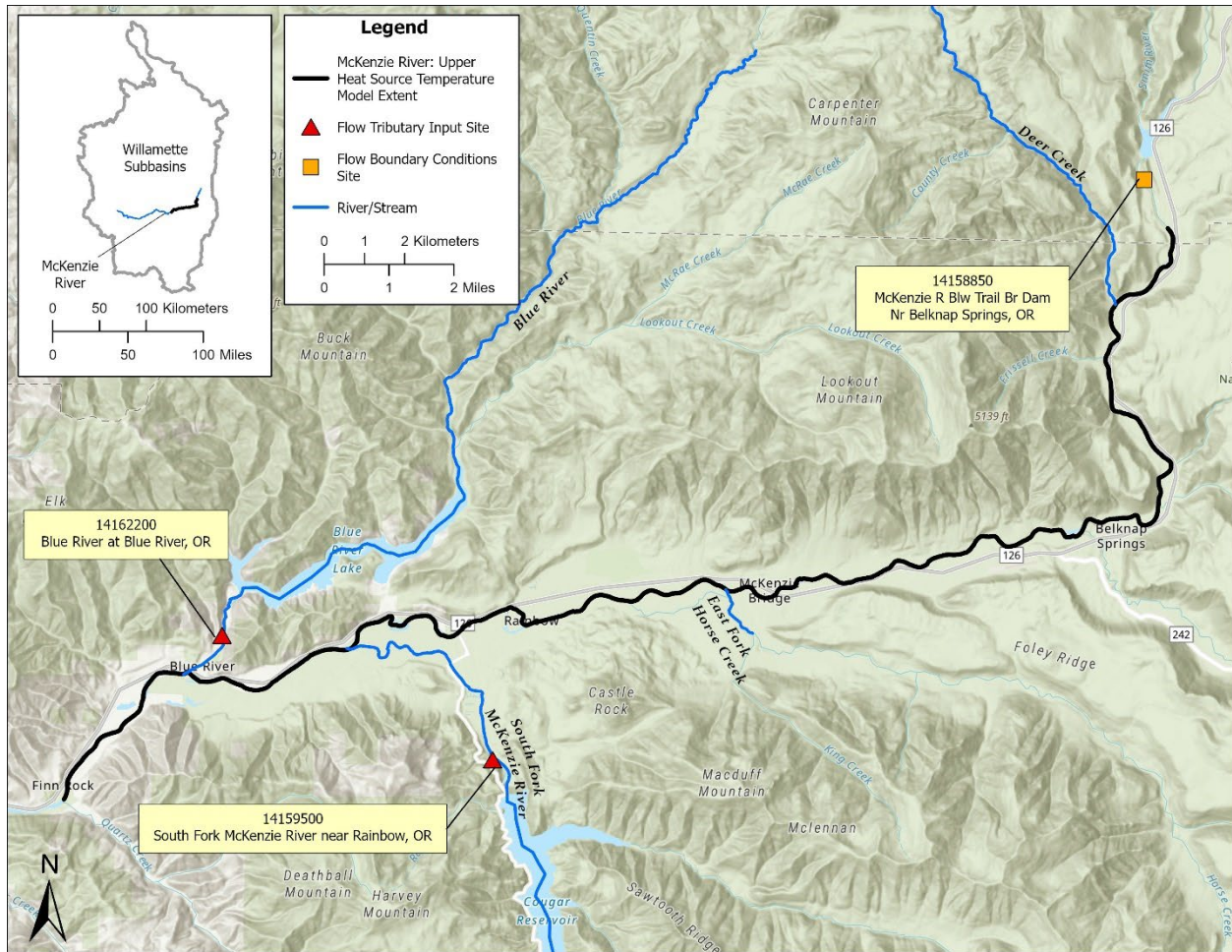
| Model Location Name | Model Location (km) | Input Type | Data Source   |
|---------------------|---------------------|------------|---|
| Blue River          | 4.362               | Tributary  | Estimated 1 degree warmer than South Fork McKenzie temp data. |



**Figure 3-200: 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 3-201** shows the locations of the various stream flow monitoring locations that were used for model setup or calibration.

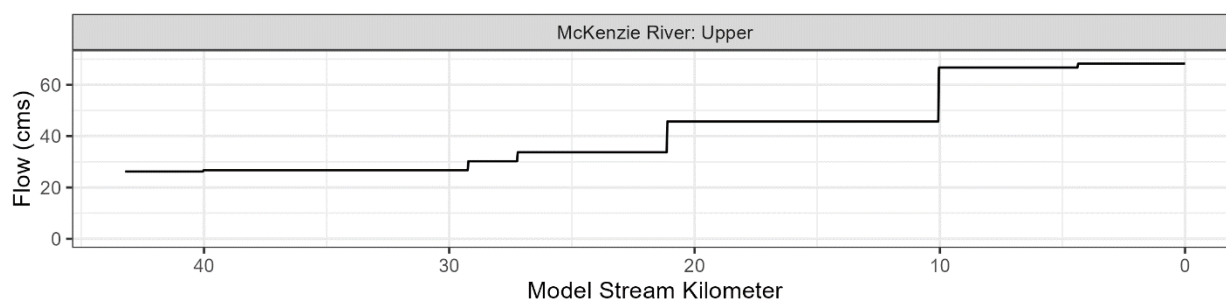


**Figure 3-201: Flow monitoring locations used for the upper McKenzie River model setup and calibration.**

The boundary condition and tributary flow inputs to the model is summarized in **Table 3-64**. **Figure 3-202** 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                               |

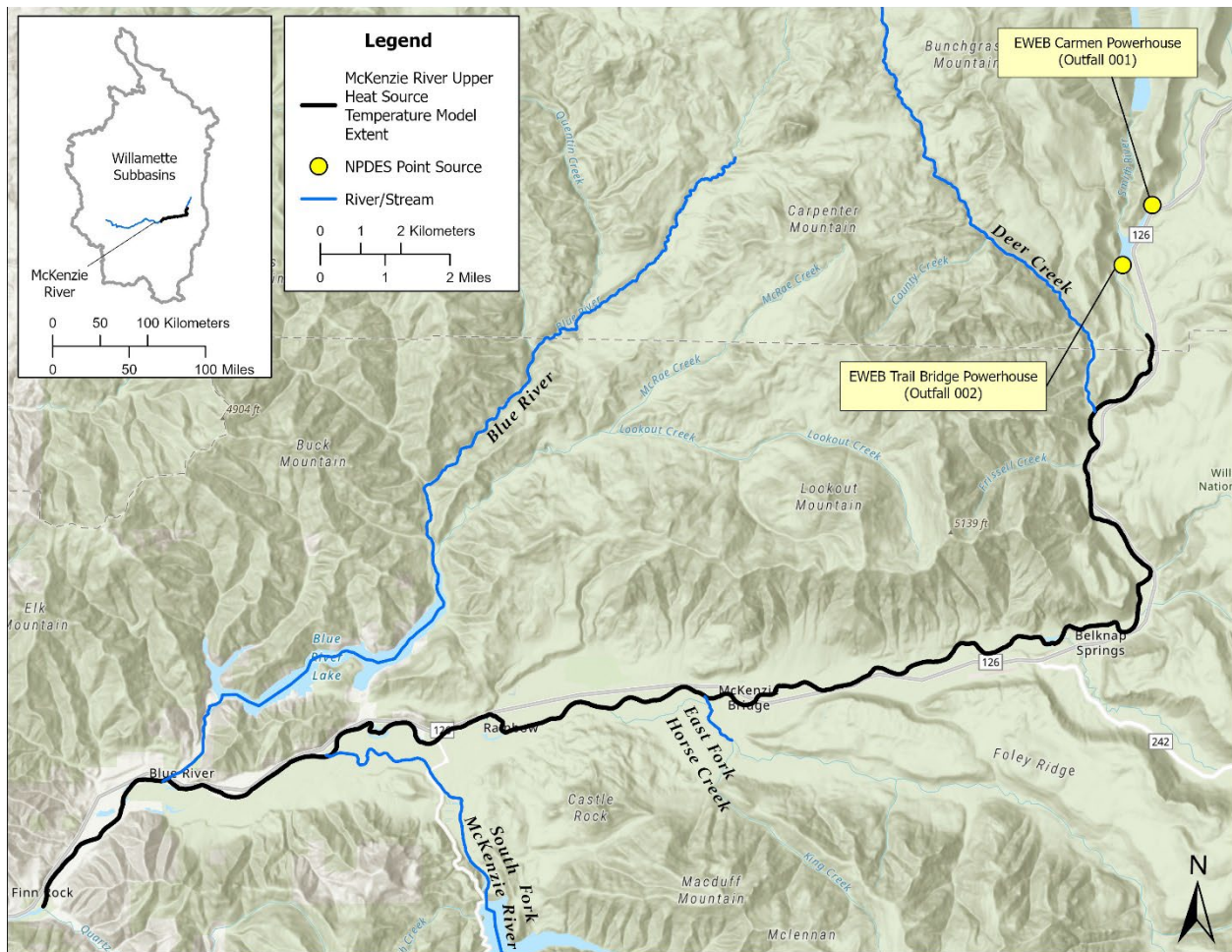


**Figure 3-202: Boundary condition and mainstem flow inputs to the upper McKenzie River model.**

### 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 3-203**). 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.

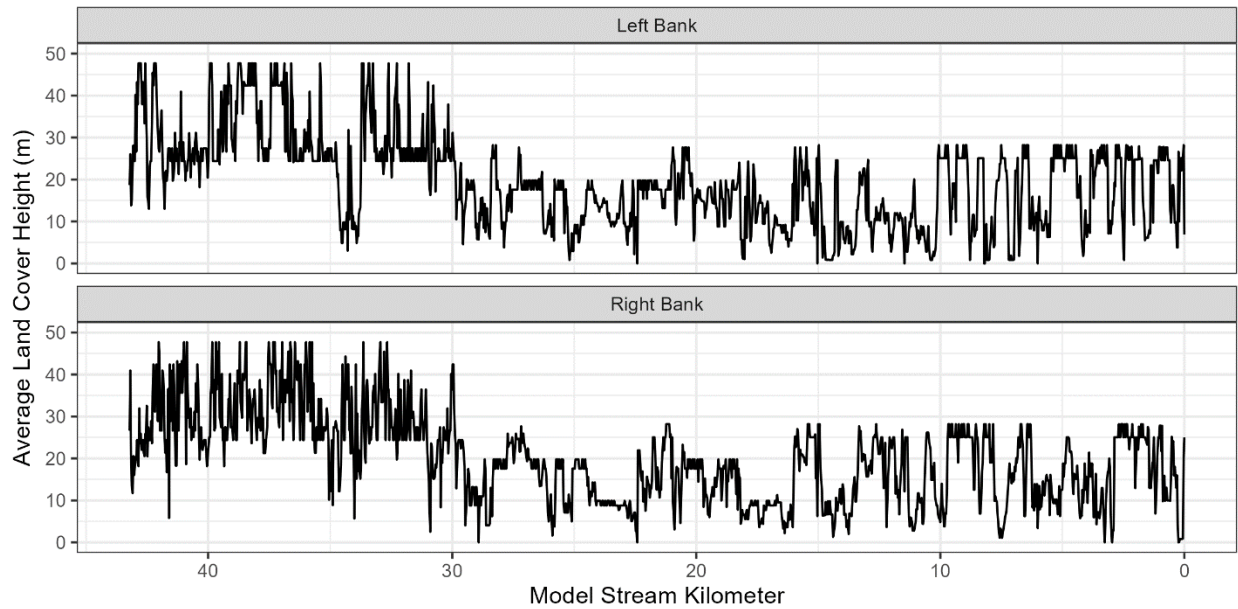
While the EWEB point source was not included in the calibrated model due to its location upstream of the model boundary condition, it was added as an input to the Wasteload Allocations model scenario. For this scenario, it was assumed that the discharge was located at the boundary condition (McKenzie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



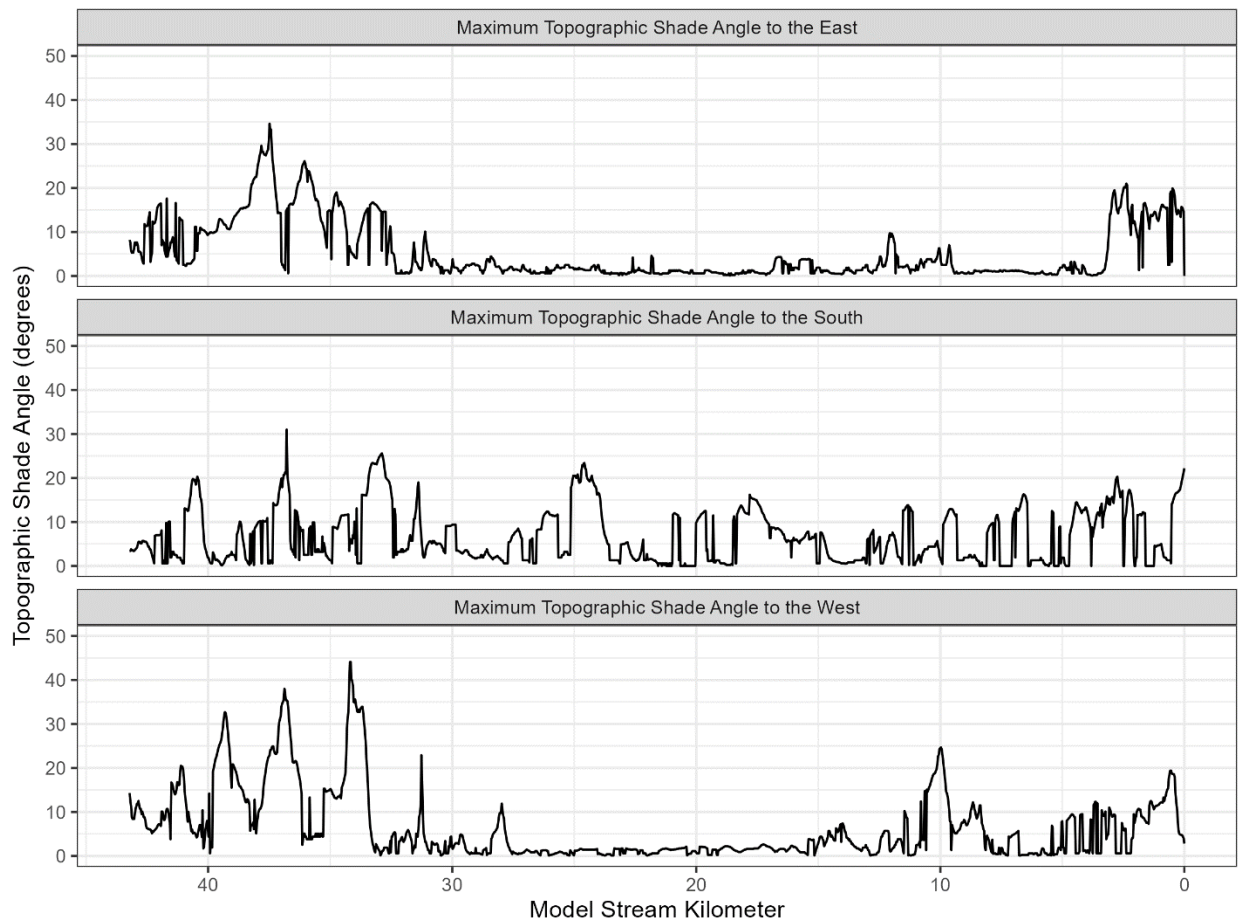
**Figure 3-203: Locations of permitted individual NPDES point sources upstream of the upper McKenzie River model extent.**

### 3.9.8 Landcover and topographic shade inputs

Average land cover height inputs and topographic shade angle inputs are shown in **Figure 3-204** and **Figure 3-205**, respectively.



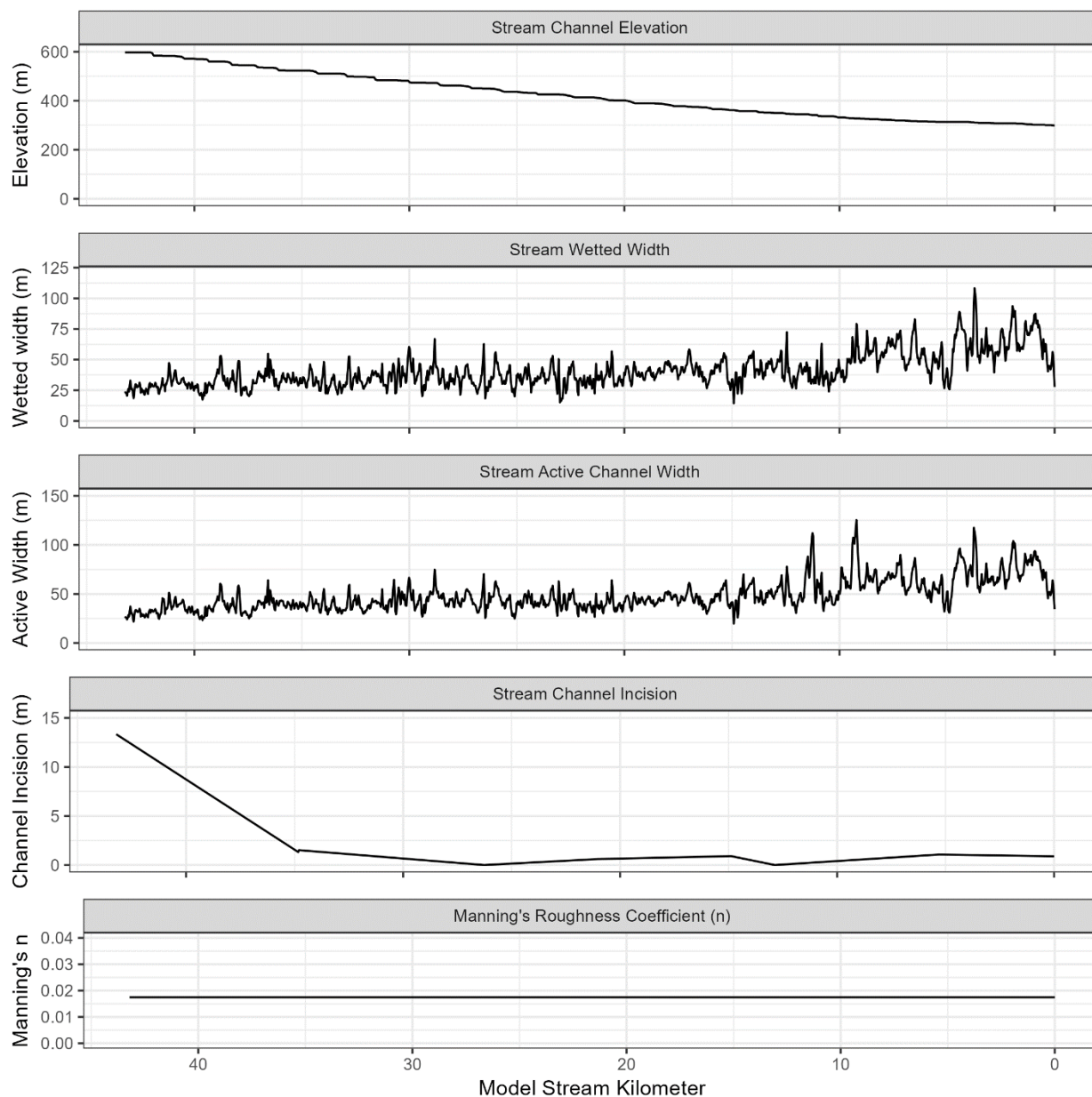
**Figure 3-204: Average land cover height inputs to the upper McKenzie River model.**



**Figure 3-205: 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 3-206**. 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 3-206: 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 3-207** through **Figure 3-209**). Modeling results comparing simulated current conditions for the upper McKenzie River to the TIR data are presented in **Figure 3-210**.

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).

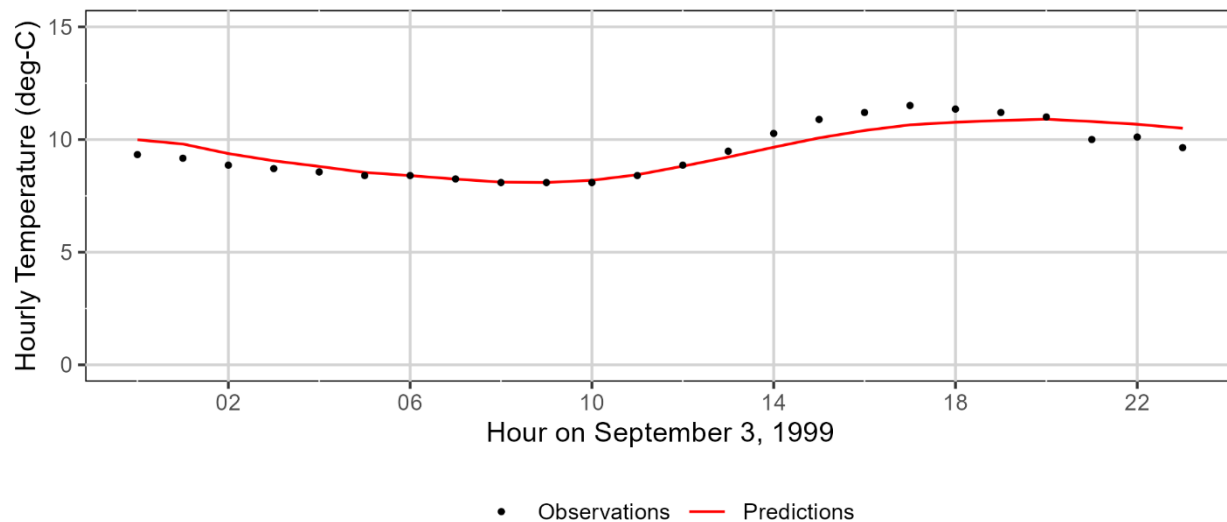
The majority of the flow for Horse Creek, which has three channels at the mouth, enters at the East Fork Horse River. The entire flow (from USFS flow meter measurements upstream) was input at that point in the McKenzie River.

**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 |

#### Model Node 4: McKenzie River at Quartz Creek Bridge

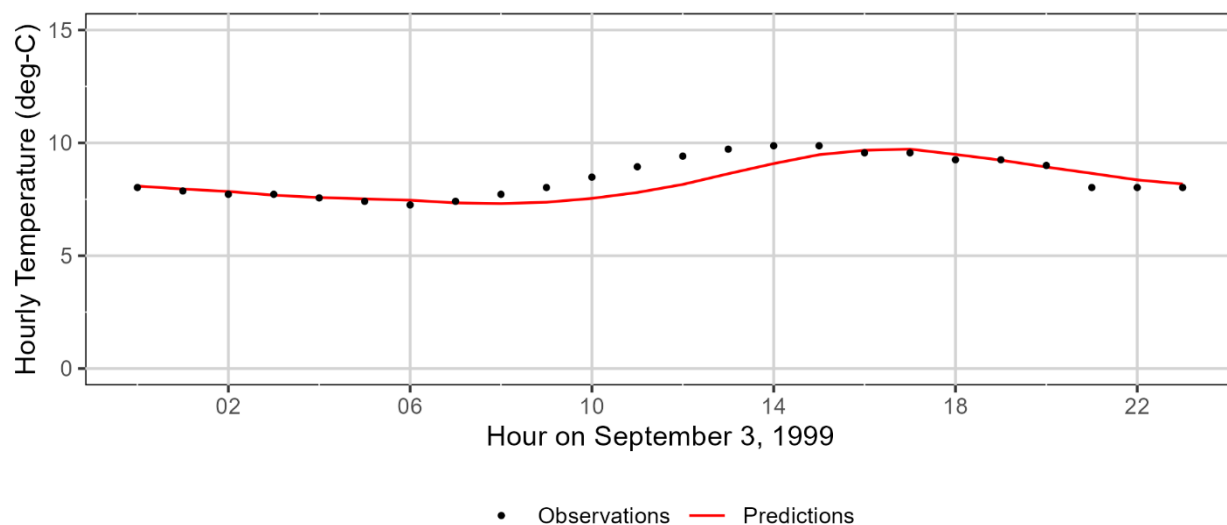
Model Kilometer 0.1



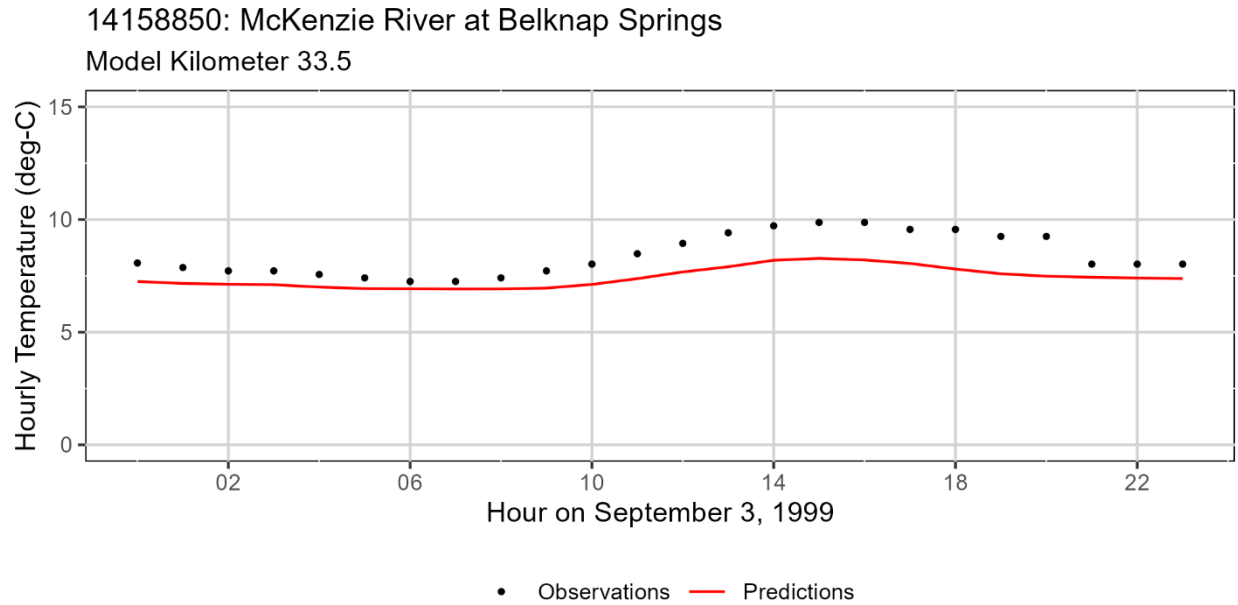
**Figure 3-207: Upper McKenzie River measured and model-predicted hourly temperatures at Model Node 4.**

#### 14159000: McKenzie River at McKenzie Bridge

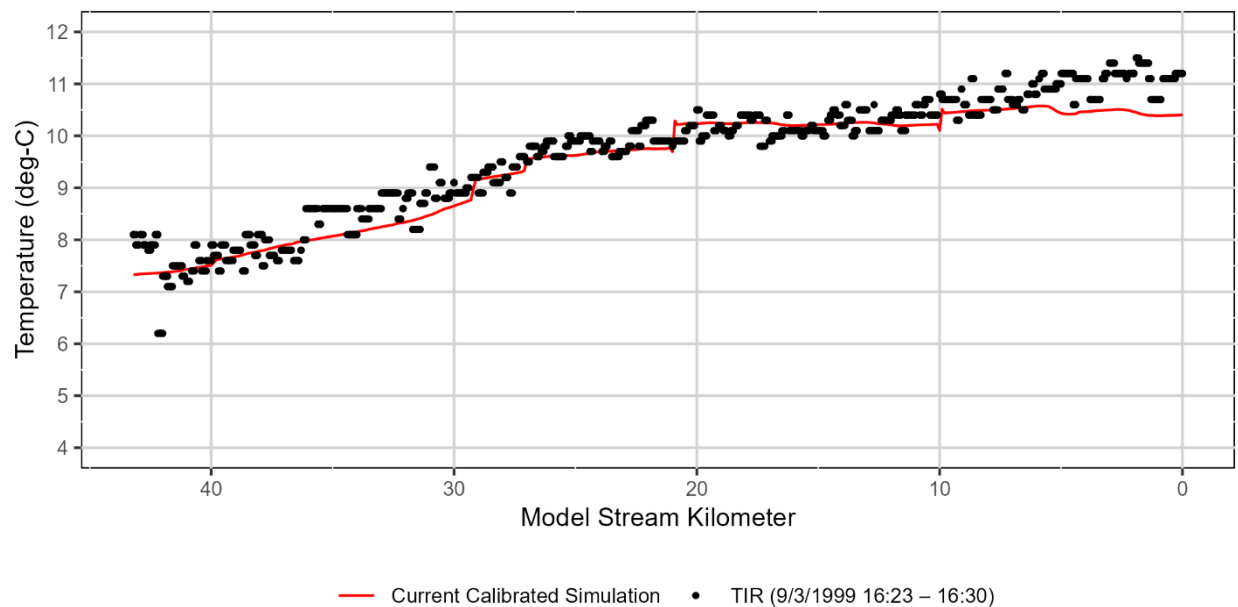
Model Kilometer 24.4



**Figure 3-208: Upper McKenzie River measured and model-predicted hourly temperatures at monitoring station 14159000.**



**Figure 3-209: Upper McKenzie River measured and model-predicted hourly temperatures at monitoring station 14158850.**



**Figure 3-210: 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 3-211**. Results shows channel widths only from streams modeled for temperature with Heat Source.

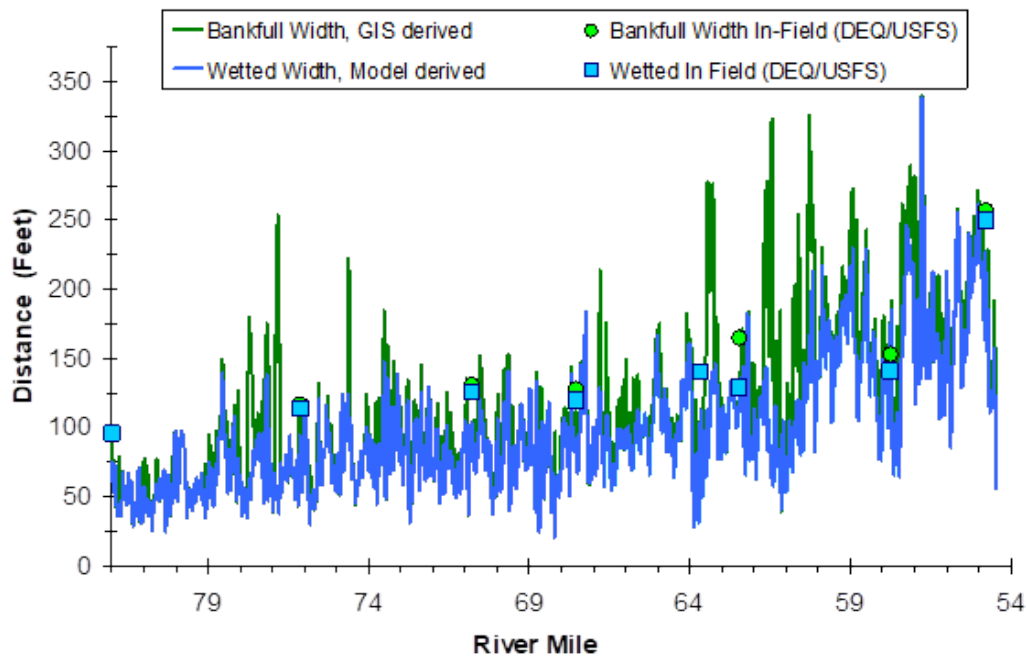


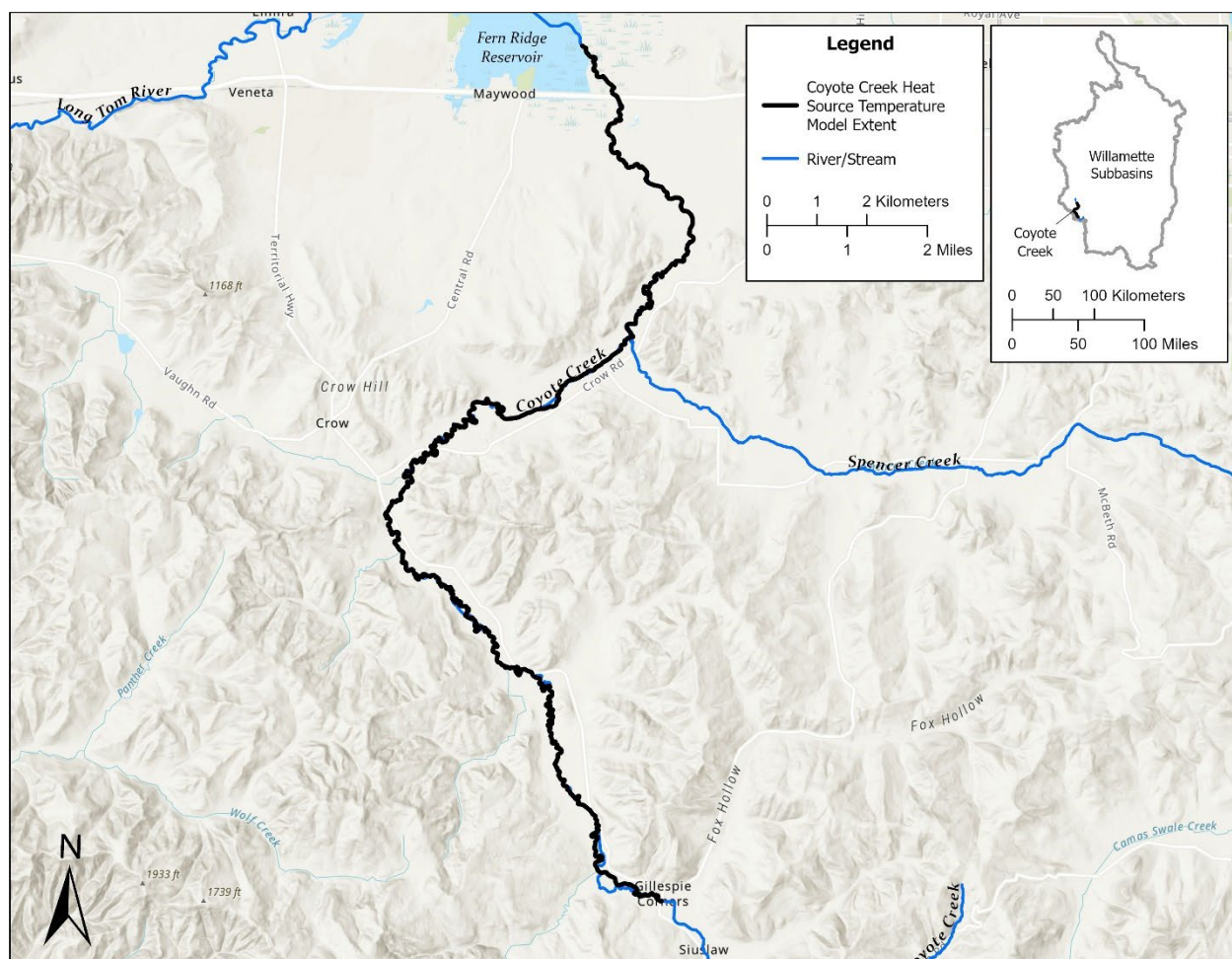
Figure 3-211: The upper McKenzie River field observed and derived bankfull and wetted width.

## 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 3-212**).



**Figure 3-212: Coyote Creek temperature model extent.**

### 3.10.2 Spatial and temporal resolution

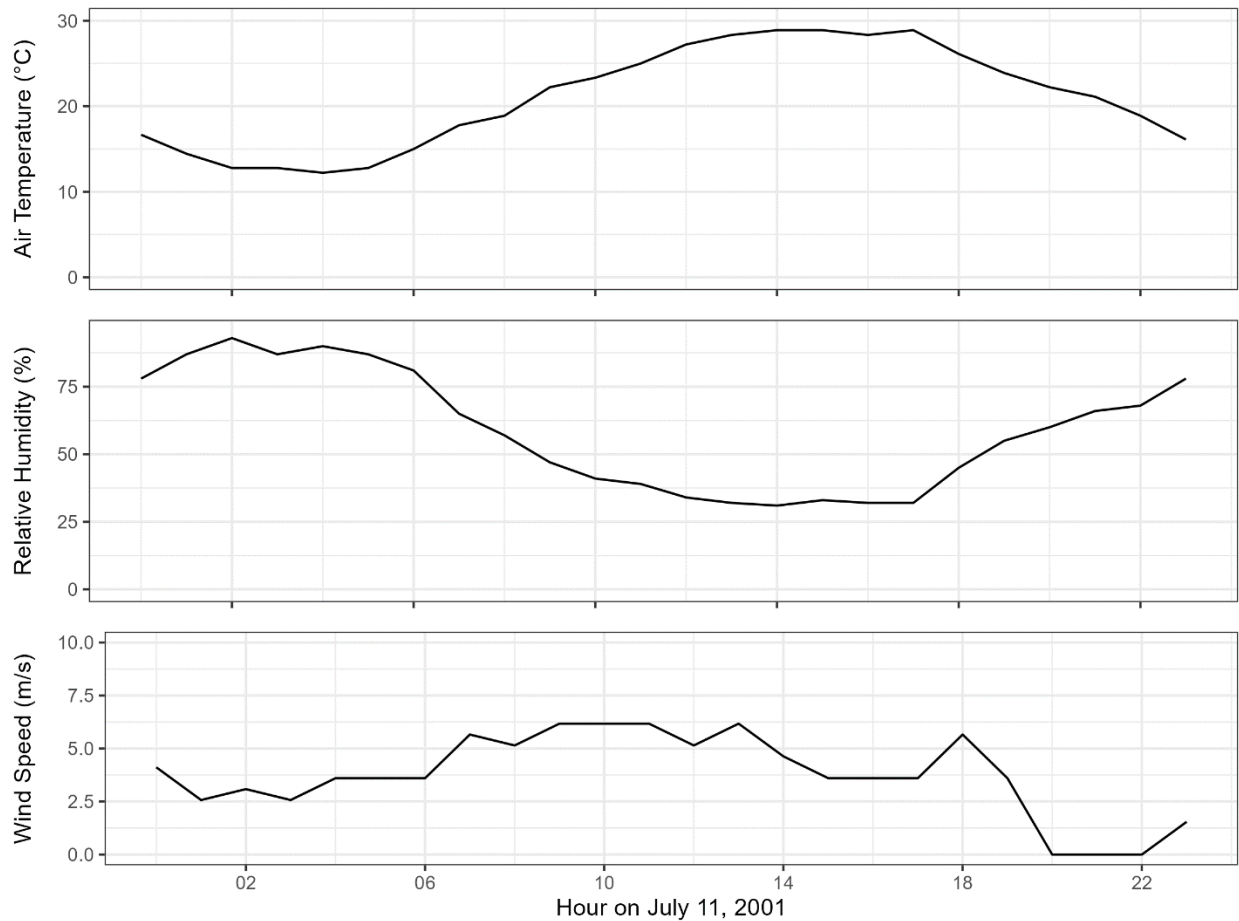
The model input spatial resolution ( $dx$ ) is 30 m. Outputs are generated every 100 m. The model time step ( $dt$ ) is 1 minute and outputs are generated every hour.

### 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 3-213**). 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**).



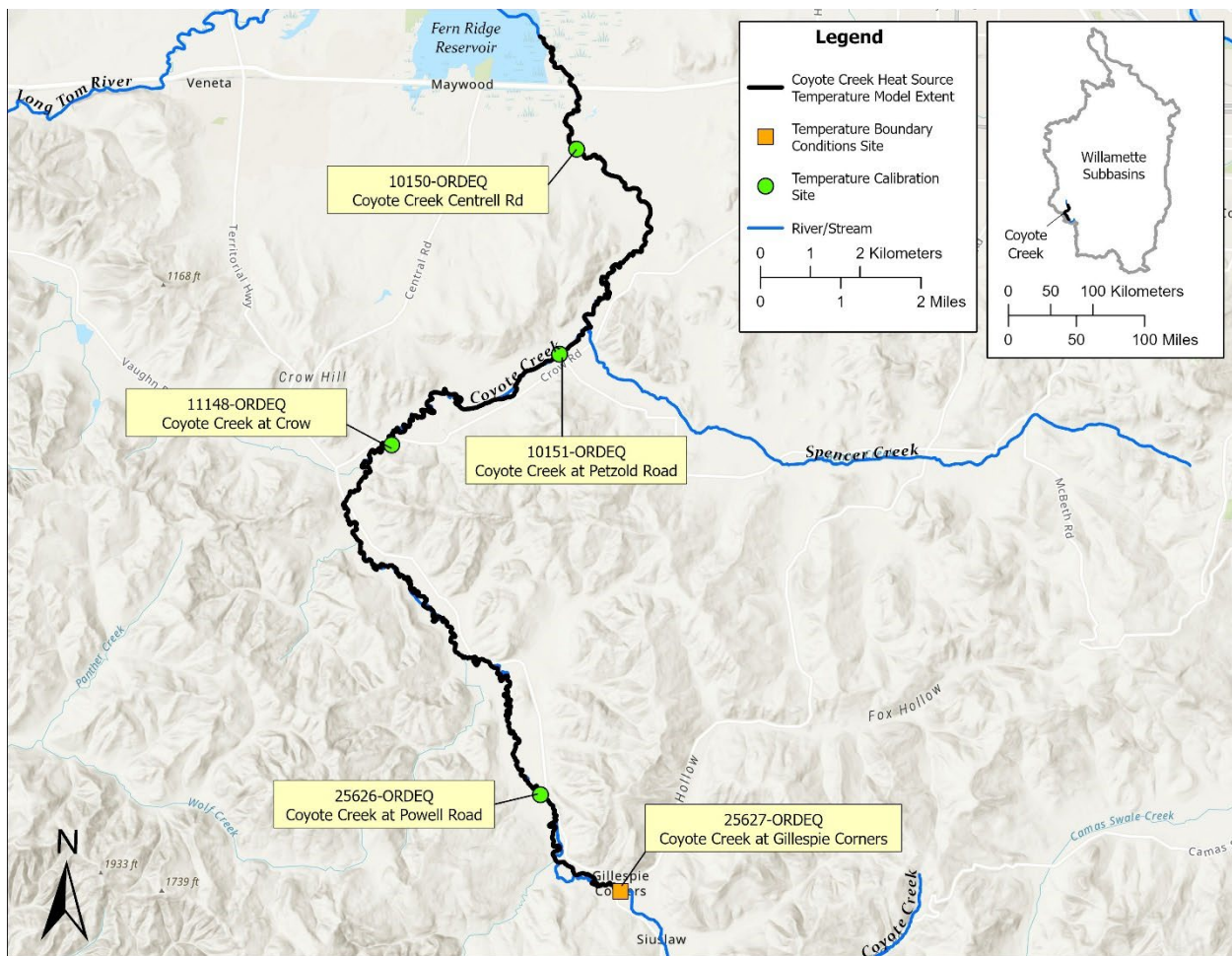
**Figure 3-213: Meteorological inputs to the Coyote Creek model.**

**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 3-214** shows the locations of the various stream temperature monitoring locations that were used for model setup or calibration.



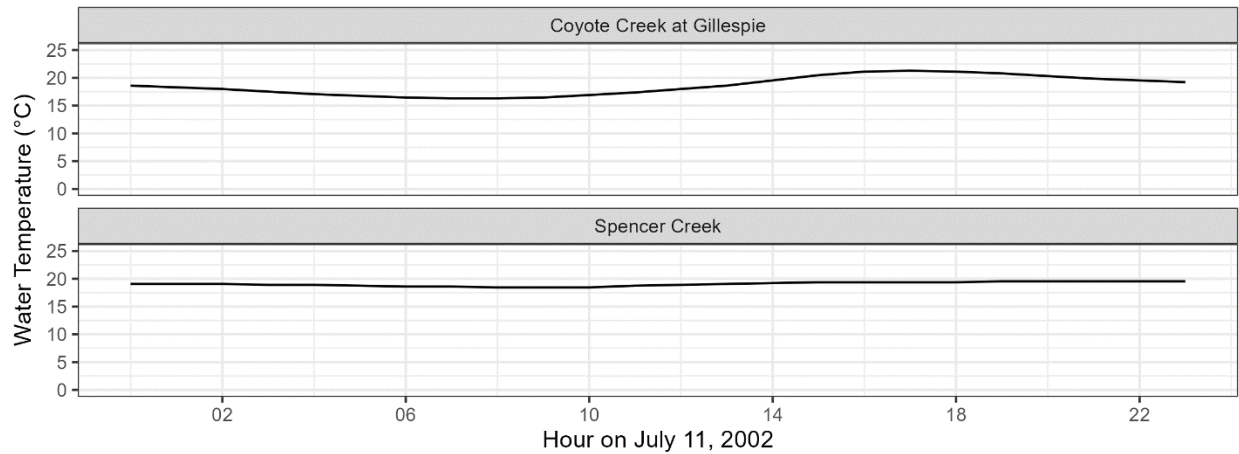
**Figure 3-214: Temperature monitoring locations used for the Coyote Creek model setup and calibration.**

**Table 3-67** and **Figure 3-215** 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*        |

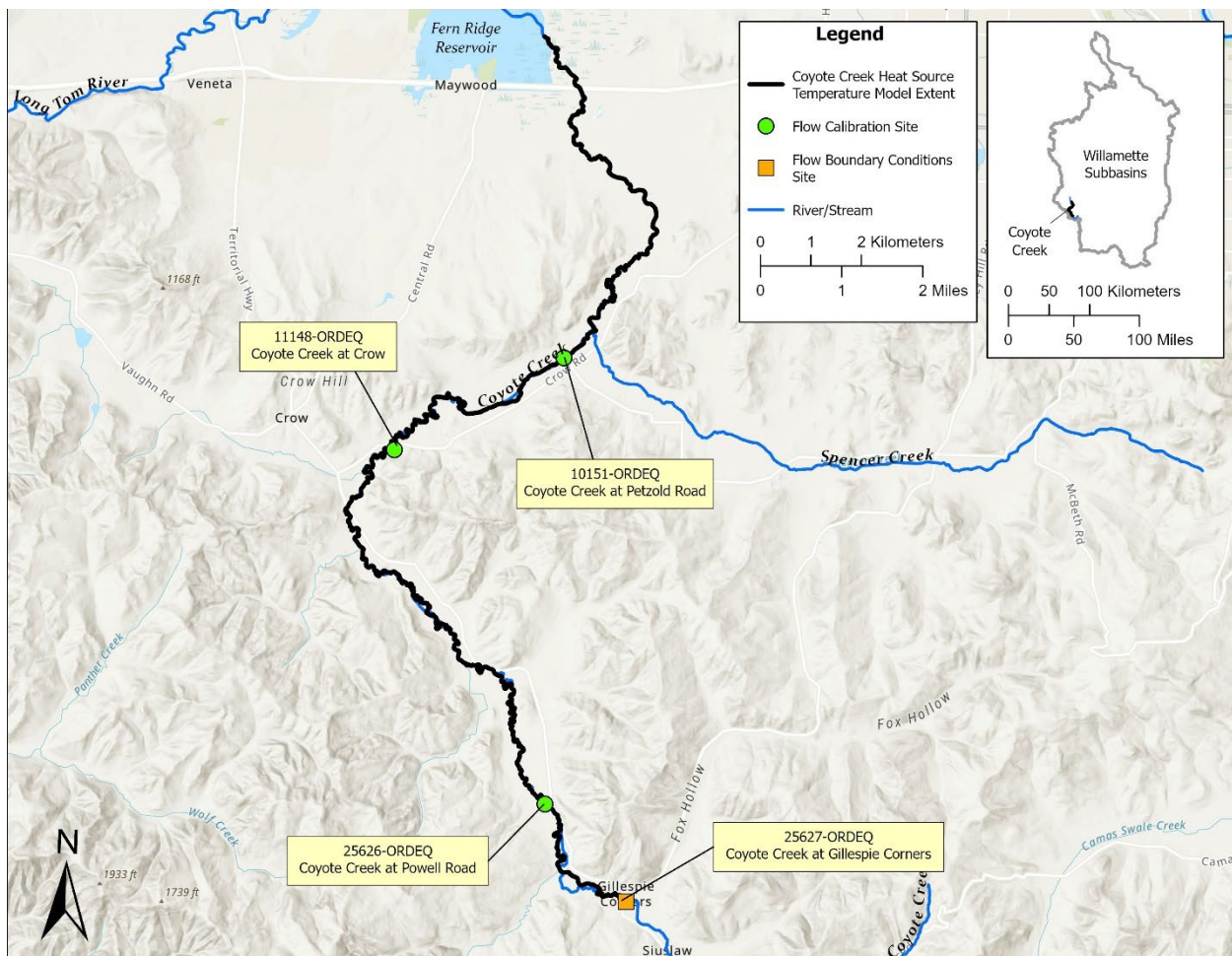
\* Data source unclear, assumed to be derived



**Figure 3-215: 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 3-216** shows the locations of the various stream flow monitoring locations that were used for model setup or calibration.



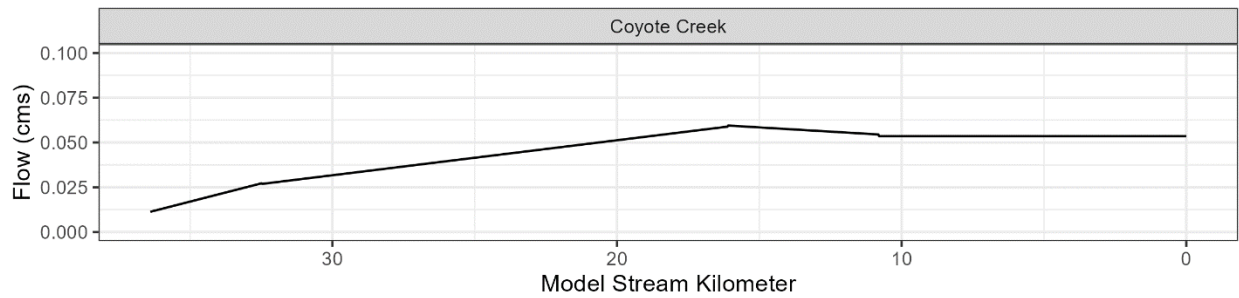
**Figure 3-216: Flow monitoring locations used for the Coyote Creek model setup and calibration.**

The boundary condition and tributary flow inputs to the model is summarized in **Table 3-68**. **Figure 3-217** 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.



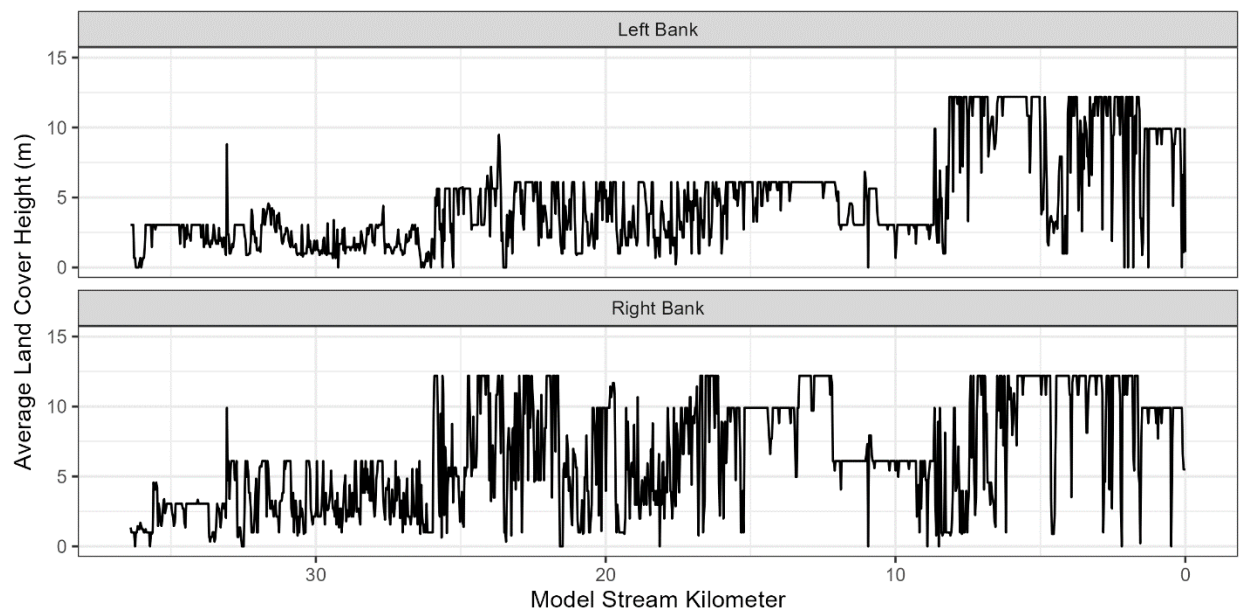
**Figure 3-217: Boundary condition and mainstem flow inputs to the Coyote Creek model.**

### 3.10.7 Point source inputs

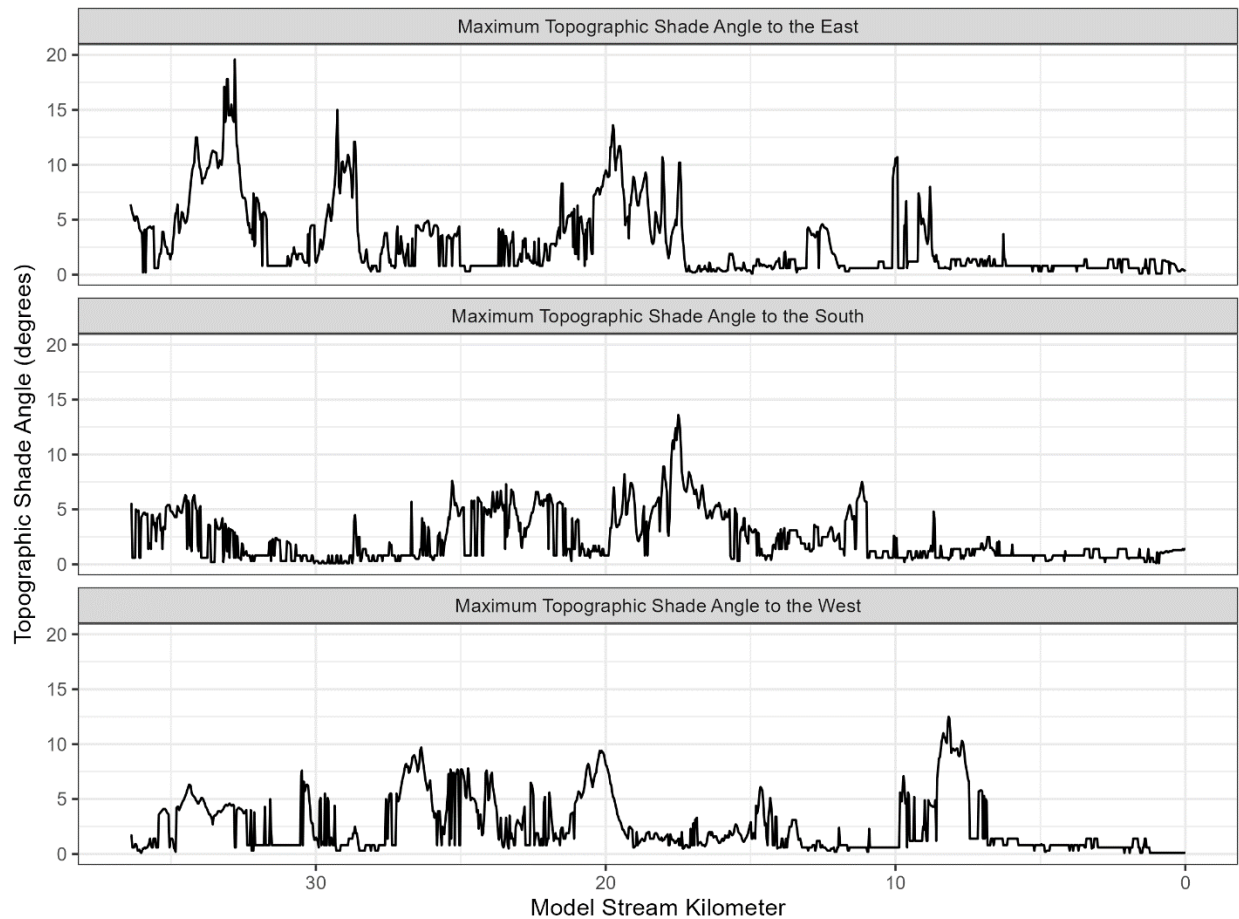
There are no point sources discharging within the model extent.

### 3.10.8 Landcover and topographic shade inputs

Average land cover height inputs and topographic shade angle inputs are shown in **Figure 3-218** and **Figure 3-219**, respectively.



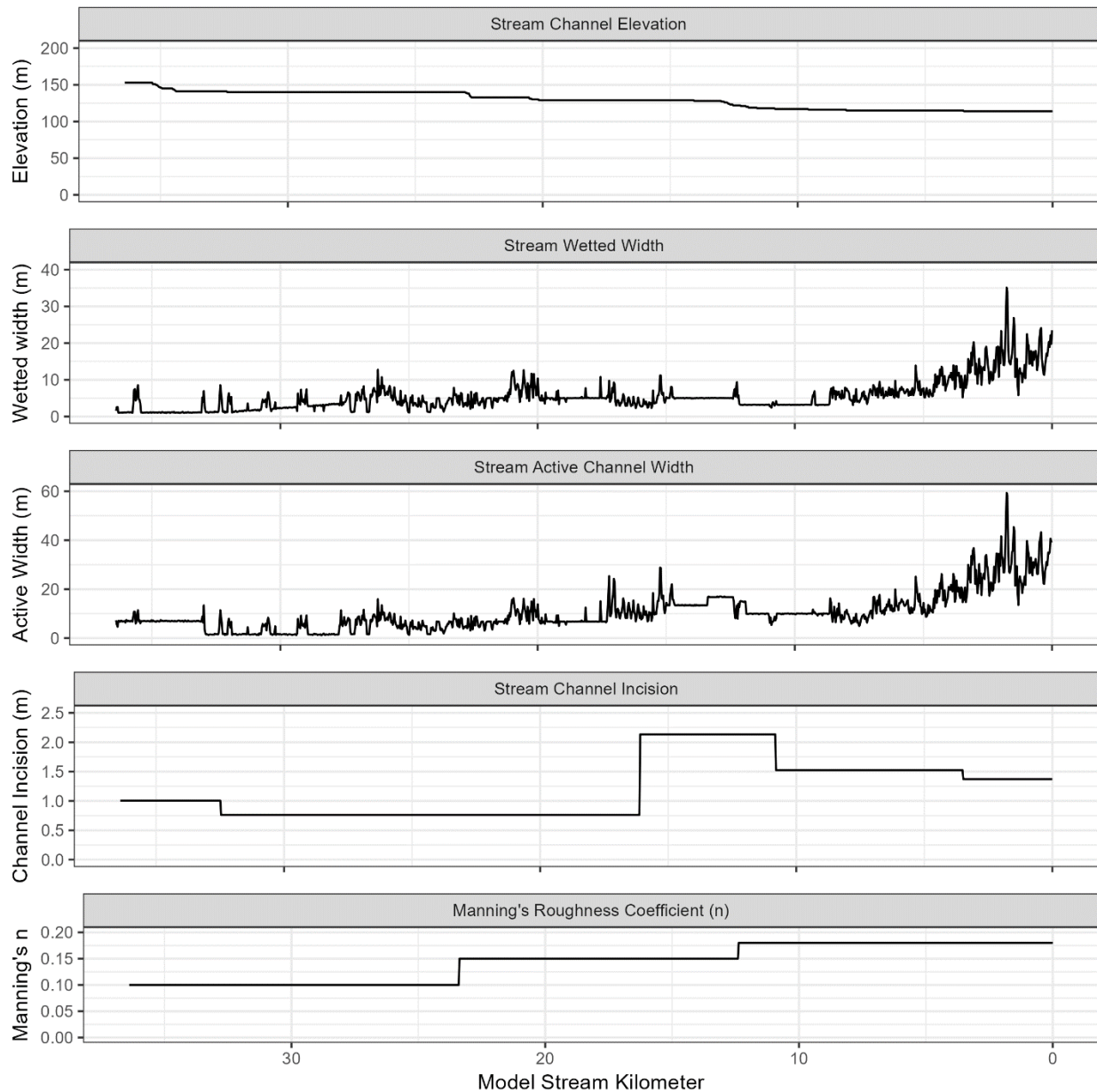
**Figure 3-218: Average land cover height inputs to the Coyote Creek model.**



**Figure 3-219: Topographic shade angle inputs to the Coyote Creek model.**

### 3.10.9 Channel setup

Channel setup for Coyote Creek model is presented in **Figure 3-220**.



**Figure 3-220: Channel setup in the Coyote Creek model.**

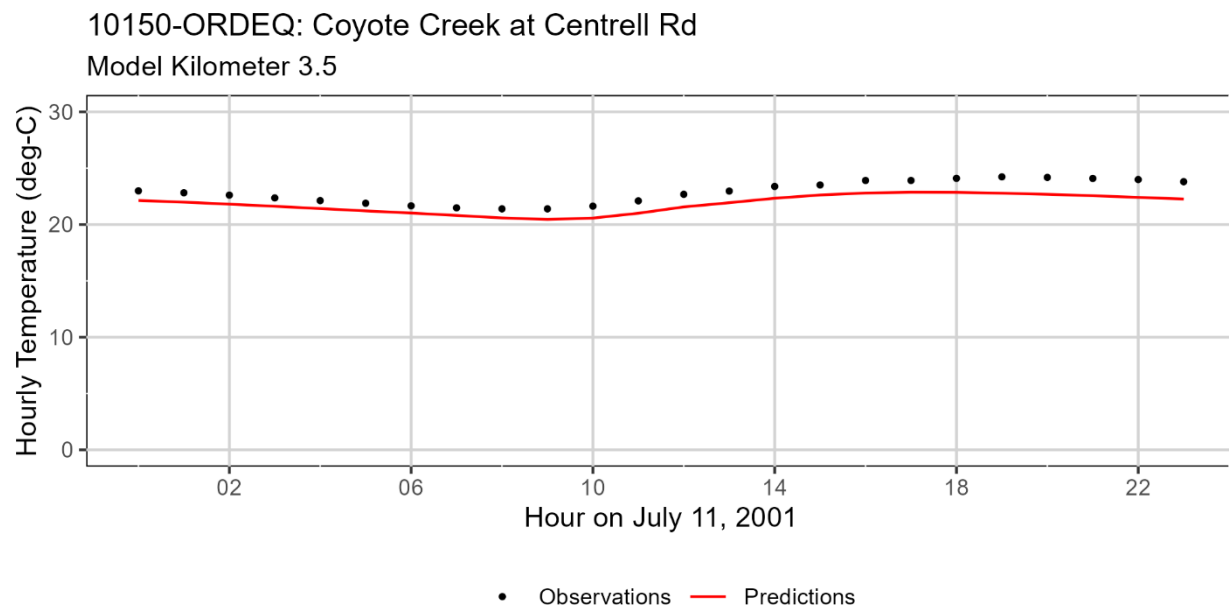
### 3.10.10 Calibration results

#### 3.10.10.1 Temperature

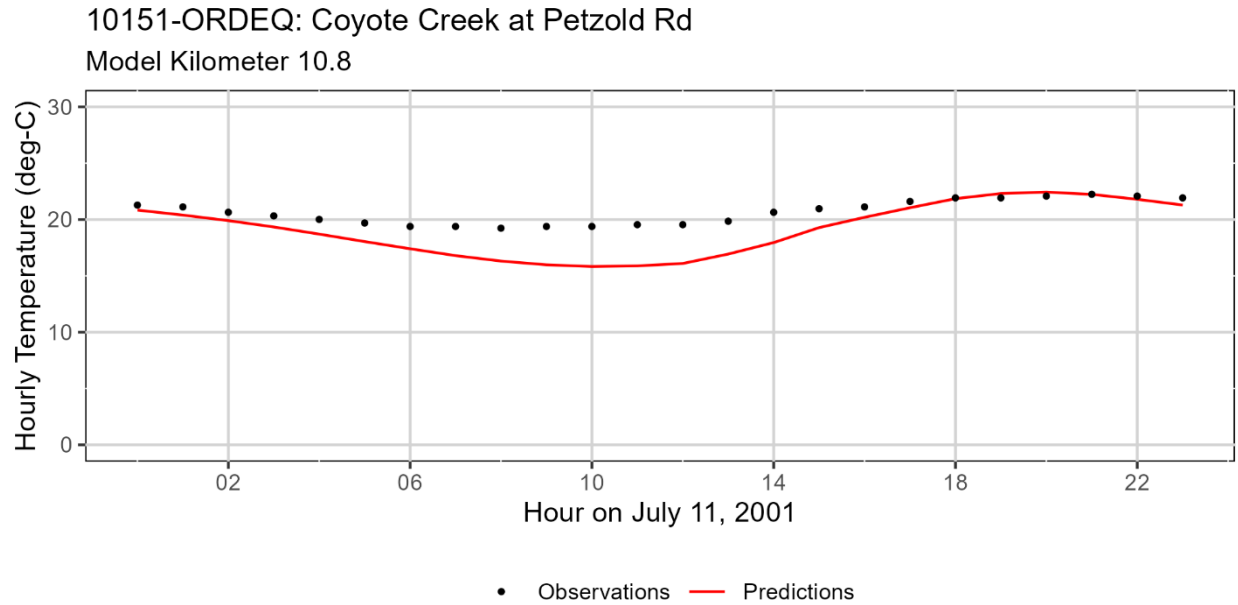
The model was calibrated to the continuous temperature data collected from several locations along Coyote Creek. Results for goodness of fit statistics comparing field observed and model-predicted temperatures are summarized in **Table 3-69**. Observed and model-predicted hourly temperatures were plotted for the monitoring stations (**Figure 3-221** through **Figure 3-224**).

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

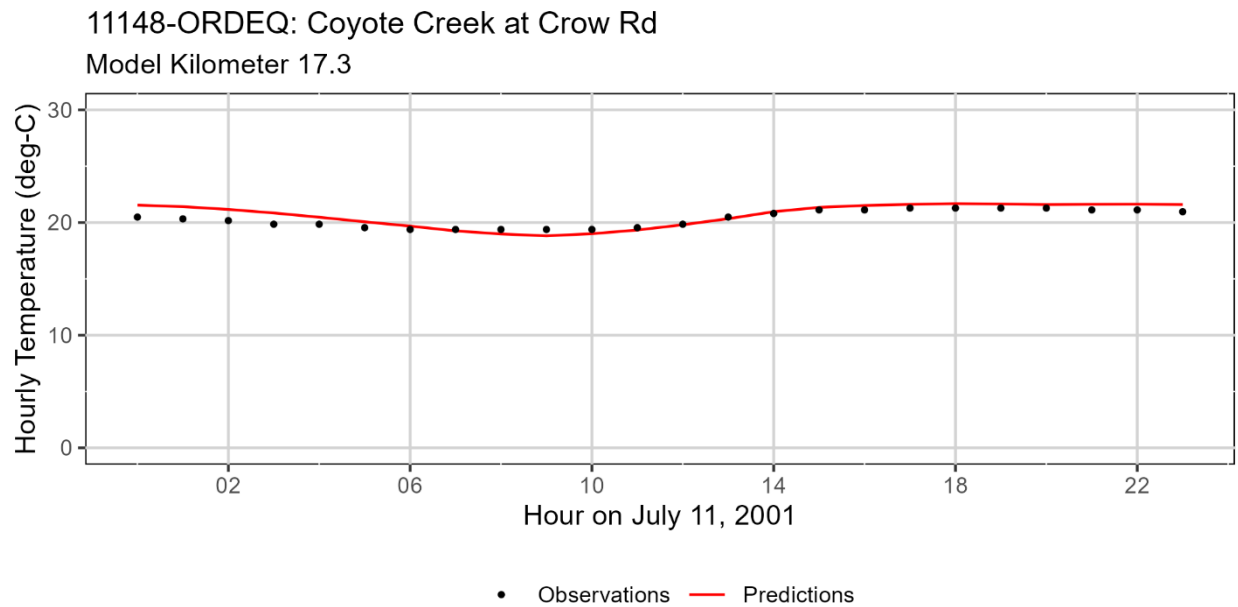
| Monitoring Location                      | Model KM | Temperature Statistics | ME    | MAE  | RMSE | NSE   | n  |
|--|----------|------------------------|-------|------|------|-------|----|
| All Stations                             |          | Daily Maximum          | -0.22 | 0.52 | 0.72 | NA    | 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 3-221: Coyote Creek measured and model-predicted hourly temperatures at monitoring station 10150-ORDEQ.**

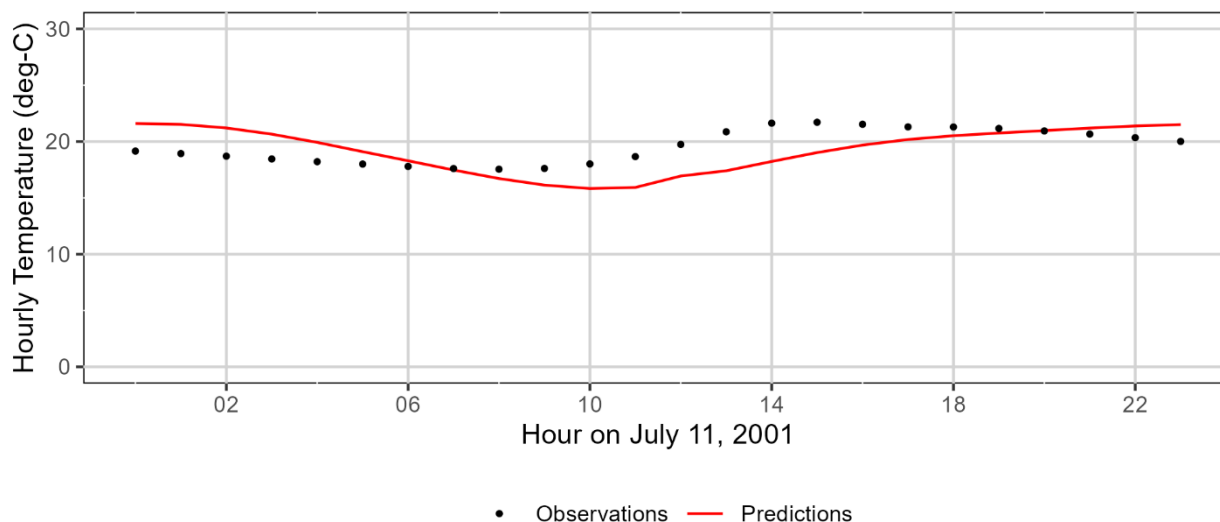


**Figure 3-222: Coyote Creek measured and model-predicted hourly temperatures at monitoring station 10151-ORDEQ.**



**Figure 3-223: Coyote Creek measured and model-predicted hourly temperatures at monitoring station 11148-ORDEQ.**

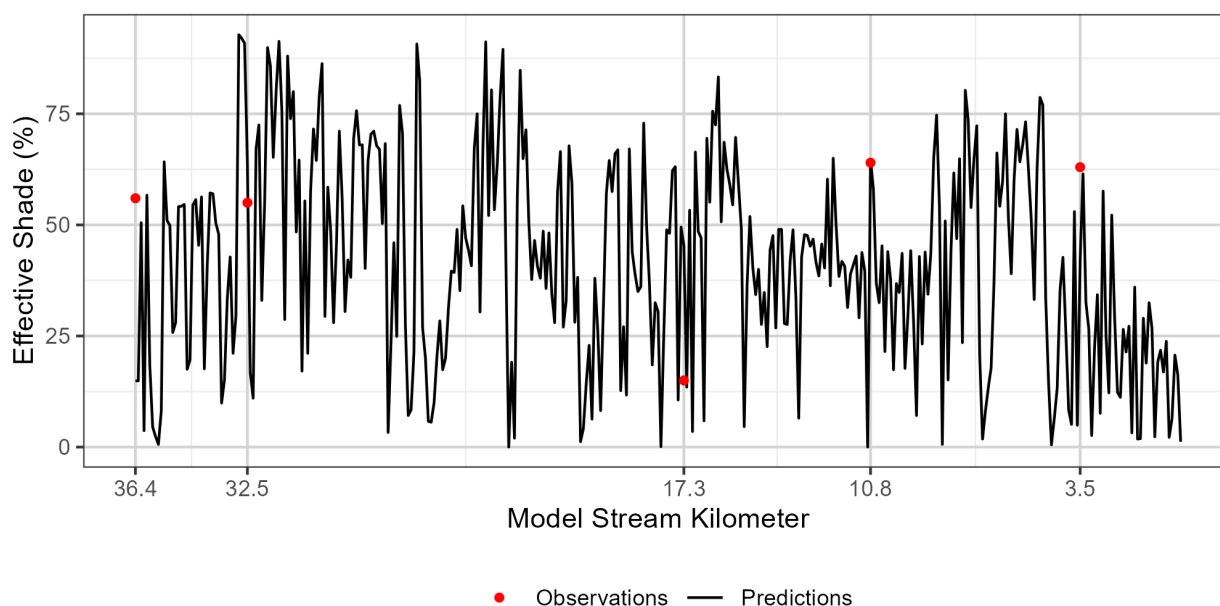
25626-ORDEQ: Coyote Creek at Powell Rd  
Model Kilometer 32.5



**Figure 3-224: 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 3-225**). 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 3-225: 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.**

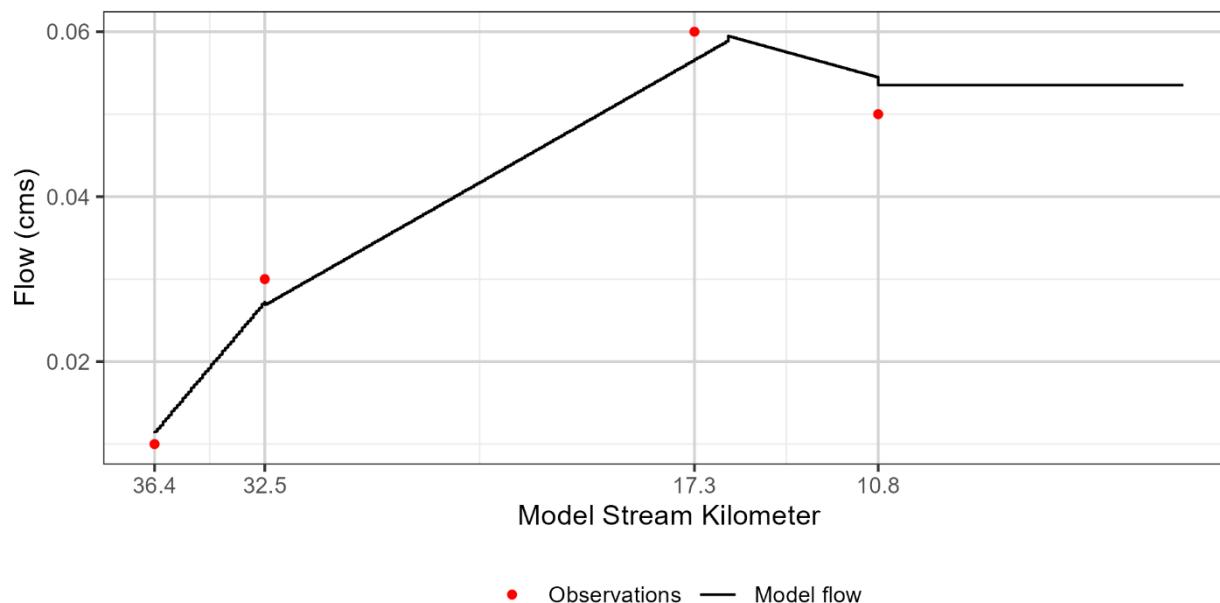
| N | R <sup>2</sup> | ME    | MAE   | RMSE  |
|---|----------------|-------|-------|-------|
| 5 | 0.01           | -4.48 | 20.32 | 24.97 |

### 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 3-226**. 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 |



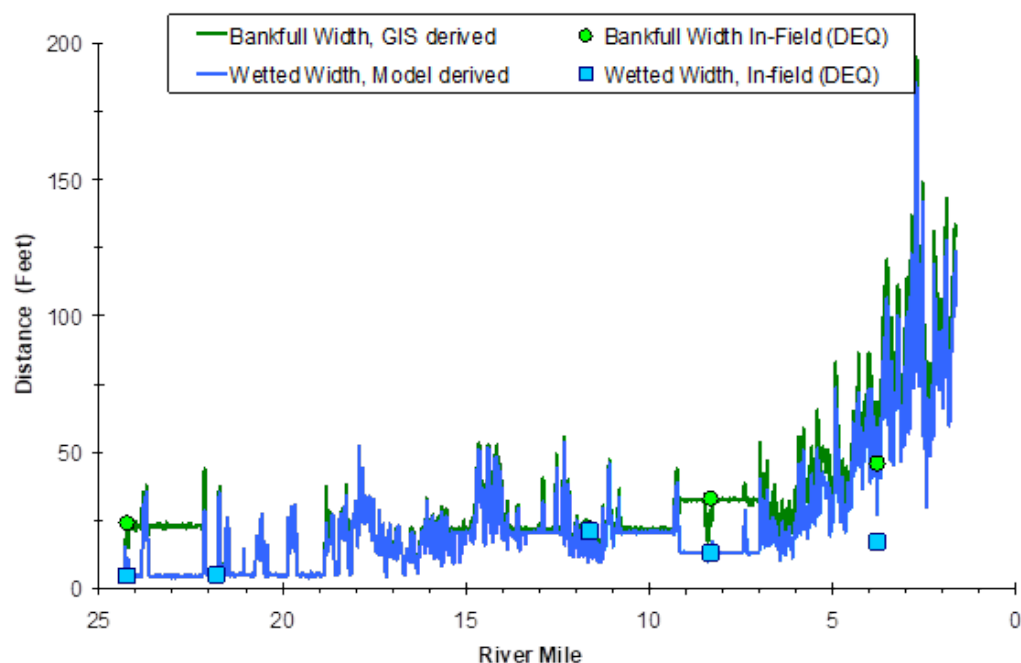
**Figure 3-226: Coyote Creek field observed and model flow rates.**

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

| N | R <sup>2</sup> | 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 3-227**. Results shows channel widths only from streams modeled for temperature with Heat Source.



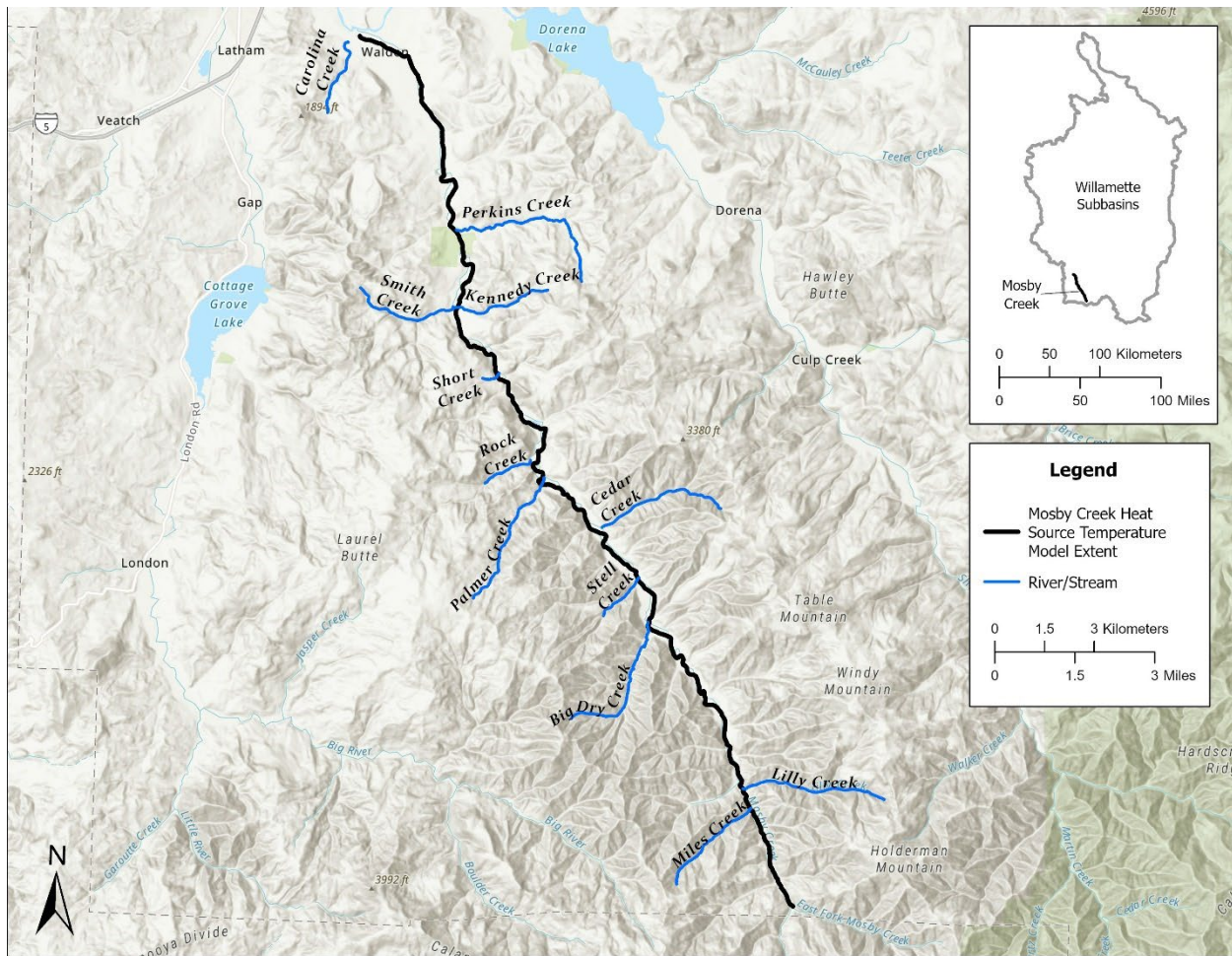
**Figure 3-227: Coyote Creek field observed and derived bankfull and wetted width.**

## 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 3-228**).



**Figure 3-228: Mosby Creek temperature model extent.**

### 3.11.2 Spatial and temporal resolution

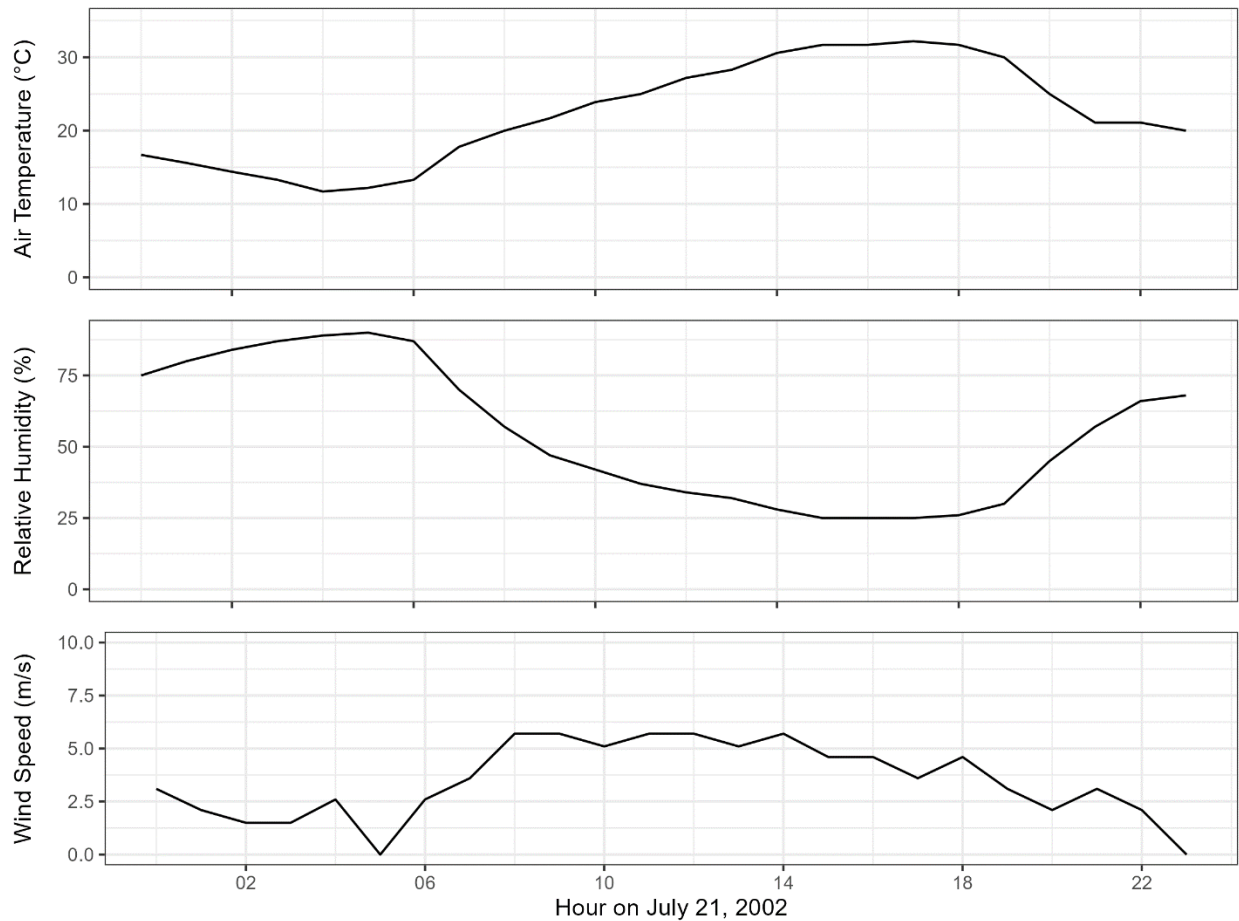
The model input spatial resolution ( $dx$ ) is 30 m. Outputs are generated every 100 m. The model time step ( $dt$ ) is 1 minute and outputs are generated every hour.

### 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 3-229**). 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.



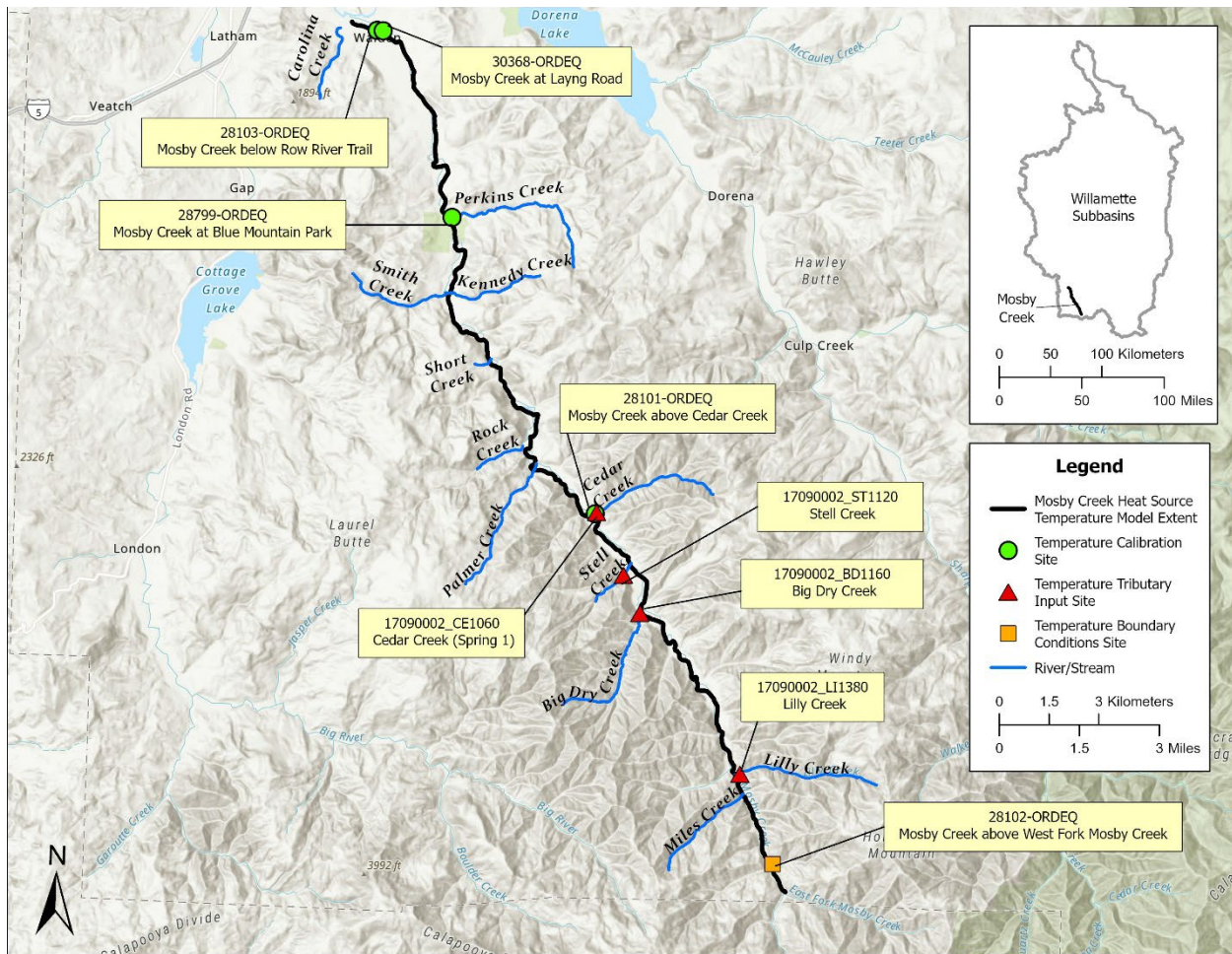
**Figure 3-229: Meteorological inputs to the Mosby Creek model.**

**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 3-230** shows the locations of the various stream temperature monitoring locations that were used for model setup or calibration.



**Figure 3-230: Temperature monitoring locations used for the Mosby Creek model setup and calibration.**

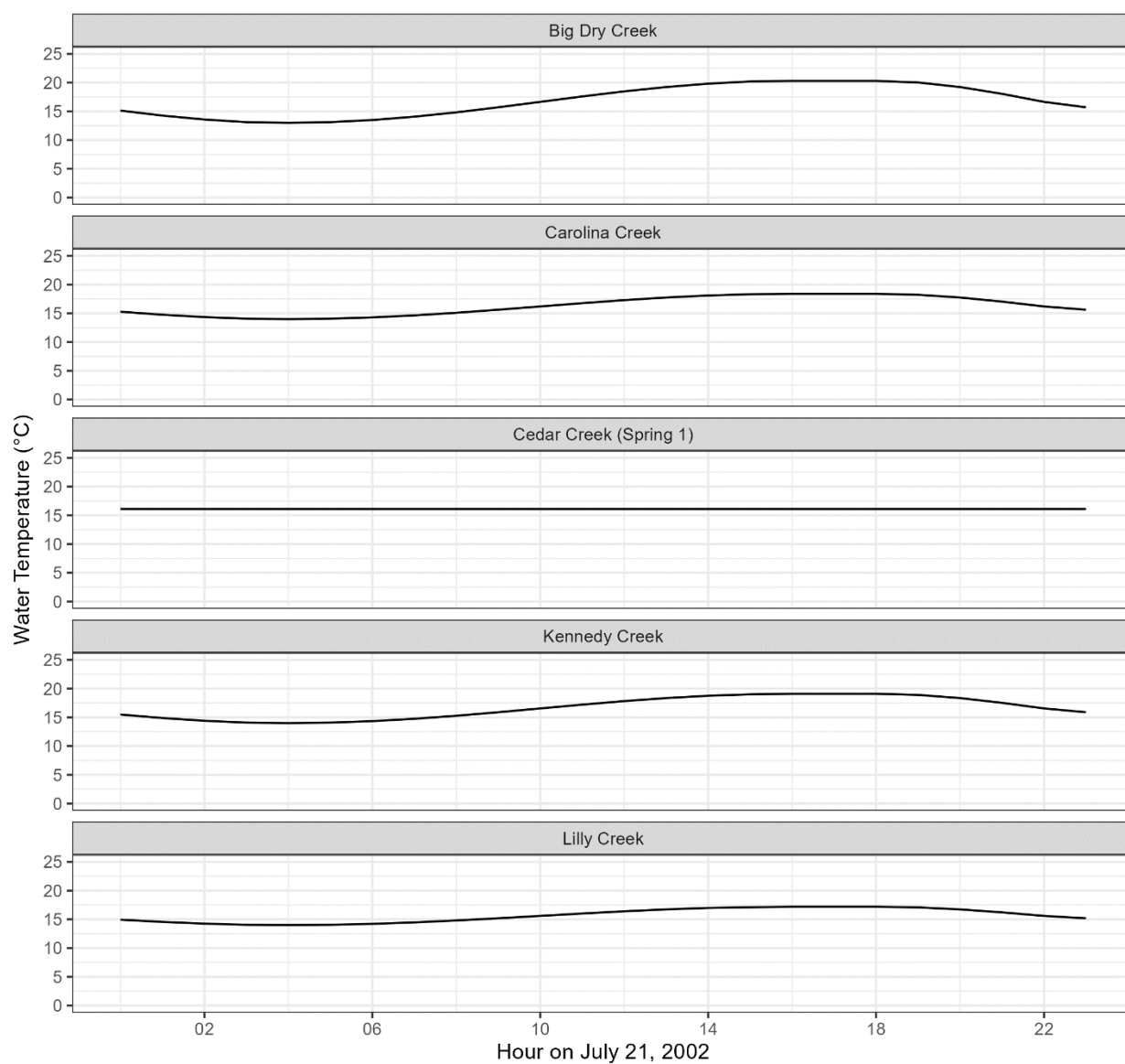
**Table 3-74** Table 3-74: Boundary condition and tributary water temperature inputs to the Mosby Creek model. and **Figure 3-231** document the water temperature inputs to the model at the boundary condition (Mosby Creek Above West Fork Mosby Creek) and tributaries. **Table 2-39** lists TIR Temperatures on Mosby Creek.

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

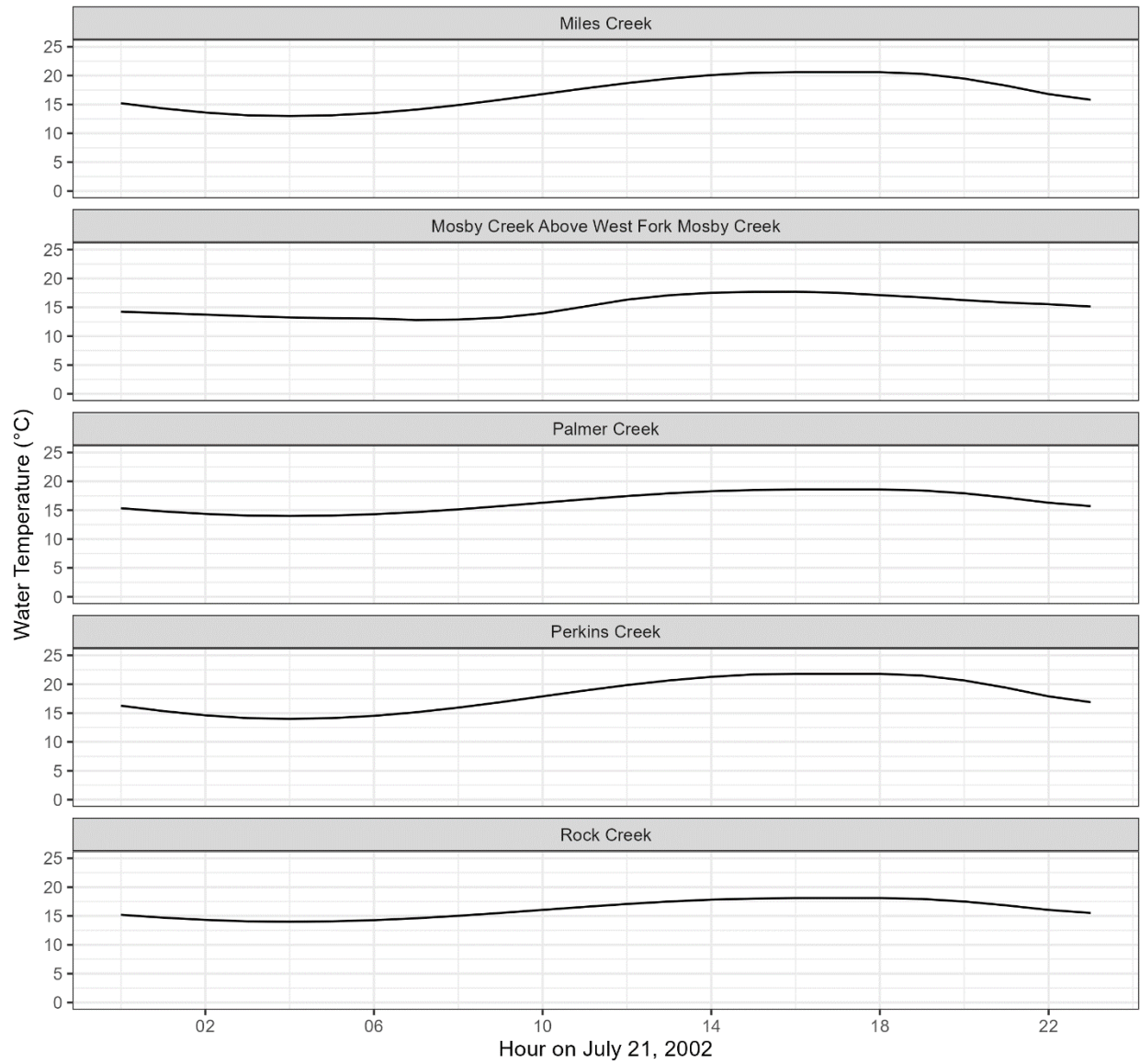
| Monitoring Location                     | Model KM | Flow Statistics    | Flow (cms)             |
|---|----------|--------------------|------------------------|
| Mosby Creek Above West Fork Mosby Creek | 34.595   | Boundary Condition | BLM                    |
| 28102-ORDEQ                             |          |                    |                        |
| 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                    |

| Monitoring Location | Model KM | Flow Statistics | Flow (cms)            |
|---------------------|----------|-----------------|-----------------------|
| 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                   |

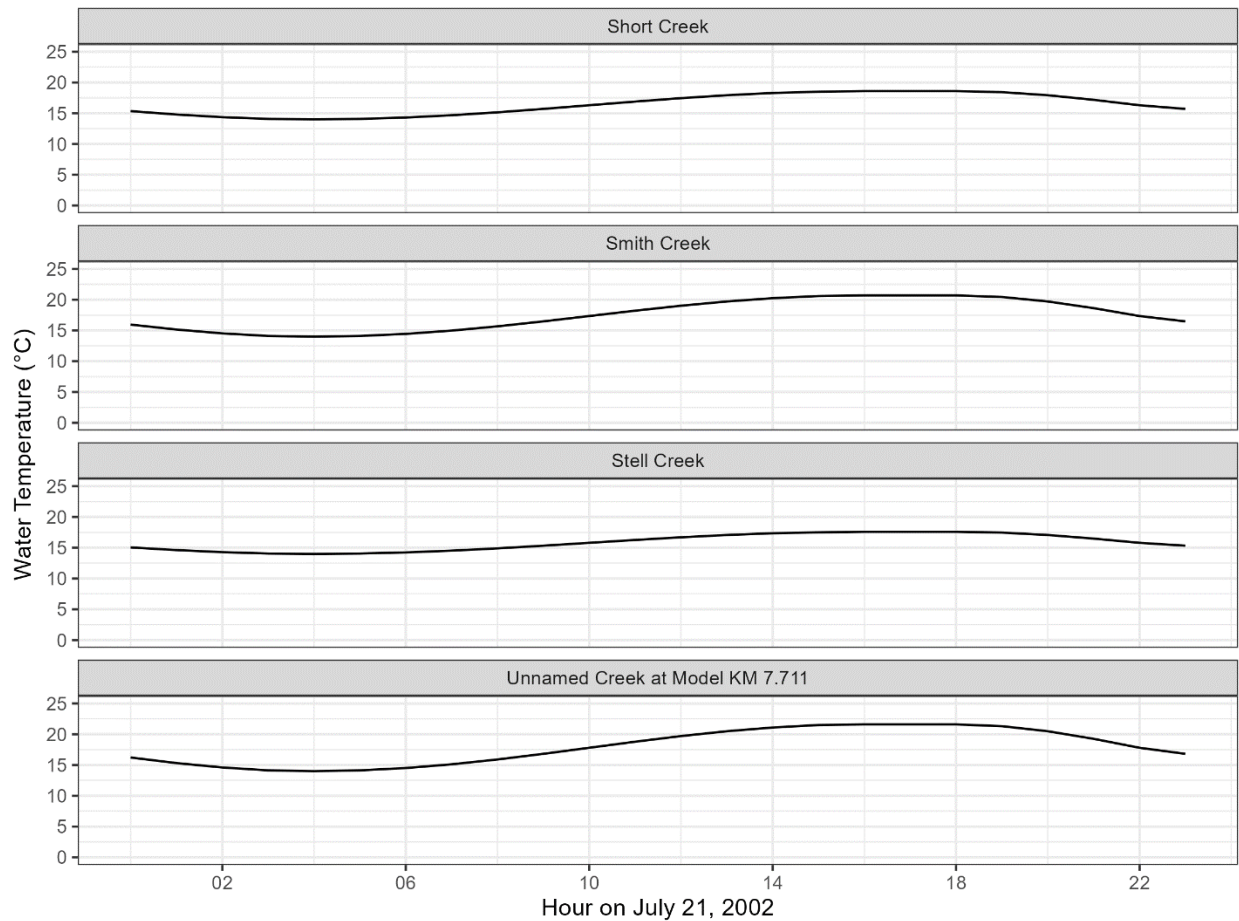
\* Constant temperature of 16.1.



(A)



(B)

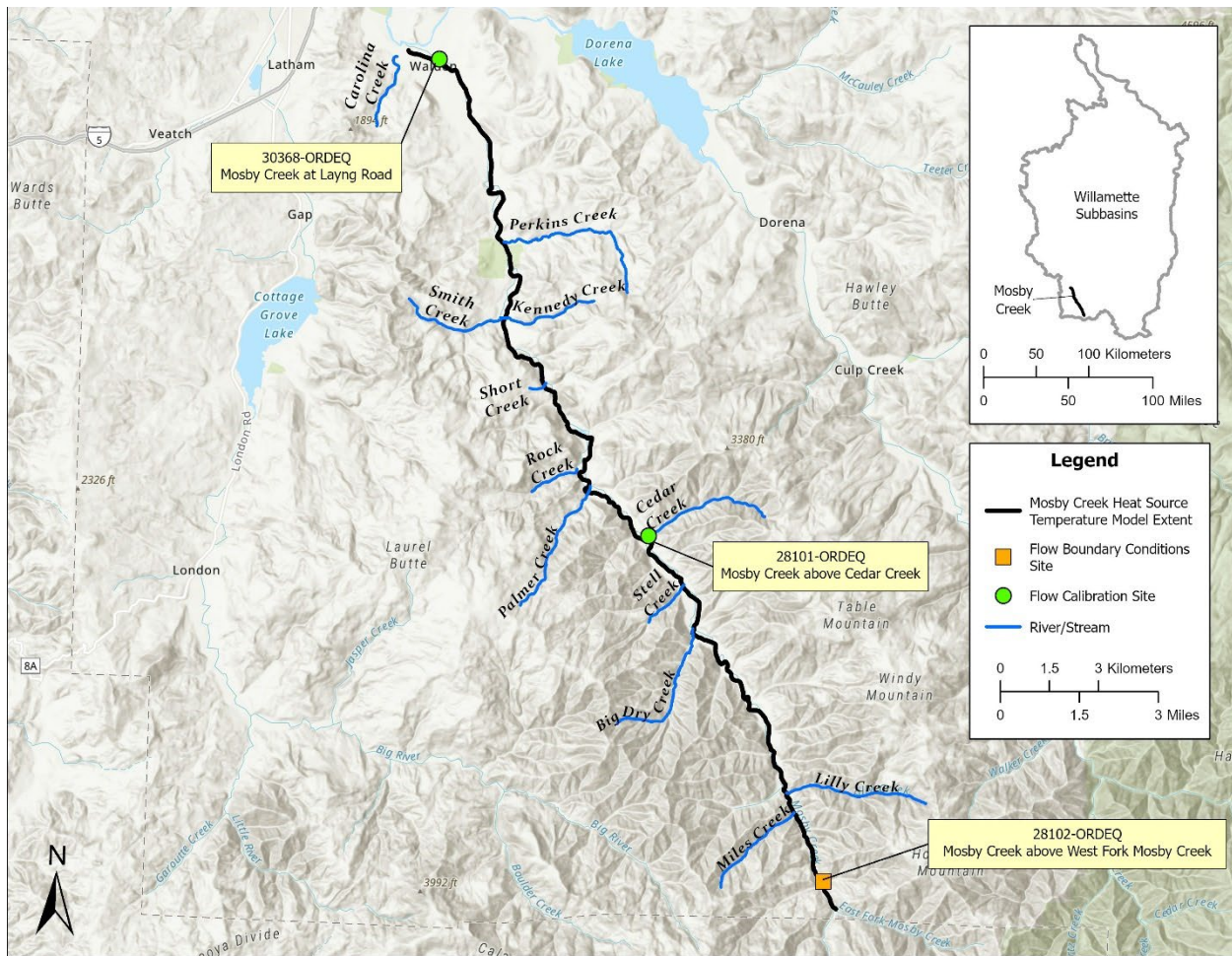


(C)

**Figure 3-231 (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 3-232** shows the locations of the various stream flow monitoring locations that were used for model setup or calibration.



**Figure 3-232: Flow monitoring locations used for the Mosby Creek model setup and calibration.**

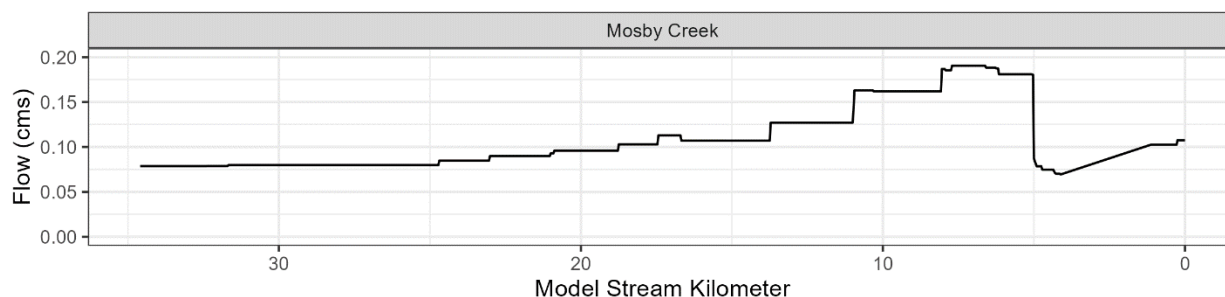
The boundary condition and tributary flow inputs to the model is summarized in **Table 3-75**. **Figure 3-233** documents mainstem model flow setup. The model flow was estimated between measured sites using a flow mass balance, which incorporated input from tributaries and demand from PODs. The total 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 |

| Model Location Name (Station ID) | Model Location (km) | Flow Rate (cms) | Input Type | Data Source                                      |
|----------------------------------|---------------------|-----------------|------------|--|
| 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.



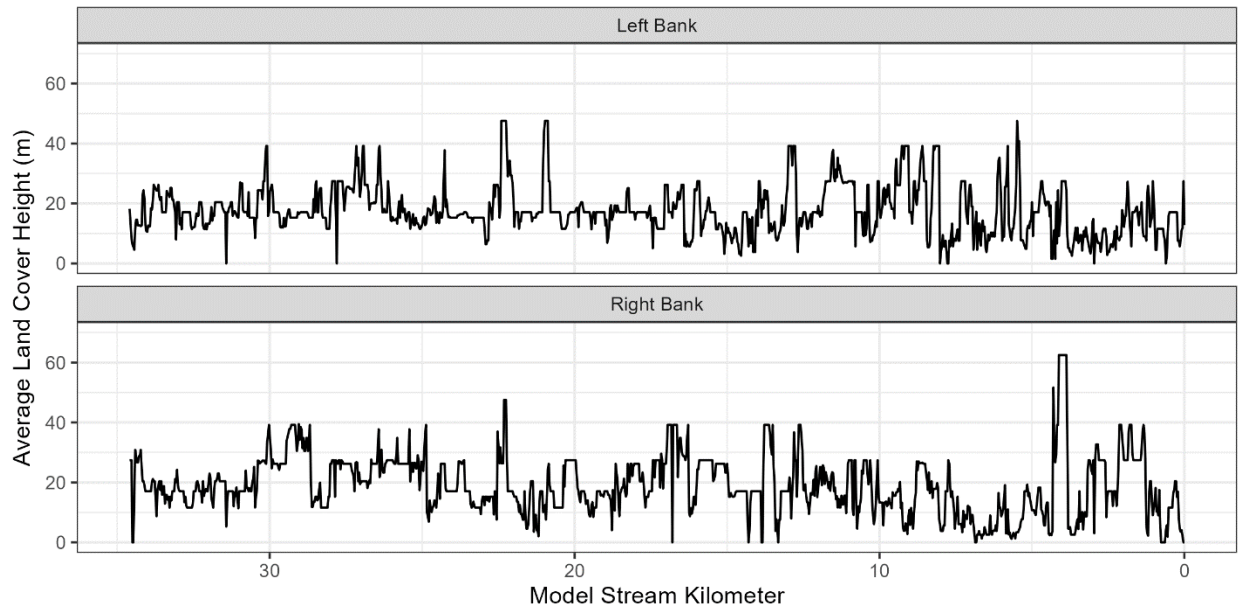
**Figure 3-233: Boundary condition and mainstem flow inputs to the Mosby Creek model.**

### 3.11.7 Point source inputs

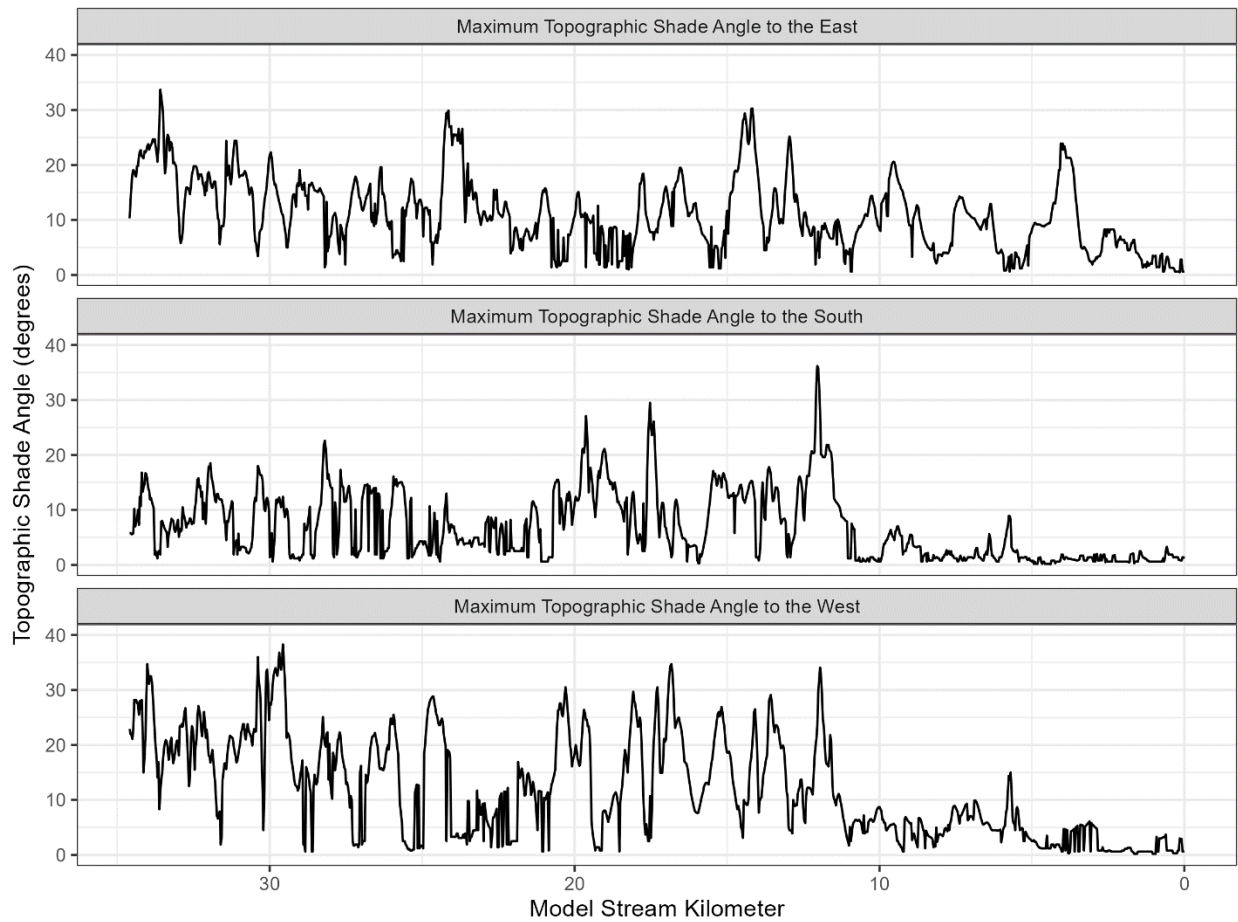
There are no point sources discharging within the model extent.

### 3.11.8 Landcover and topographic shade inputs

Average land cover height inputs and topographic shade angle inputs are shown in **Figure 3-234** and **Figure 3-235**, respectively.



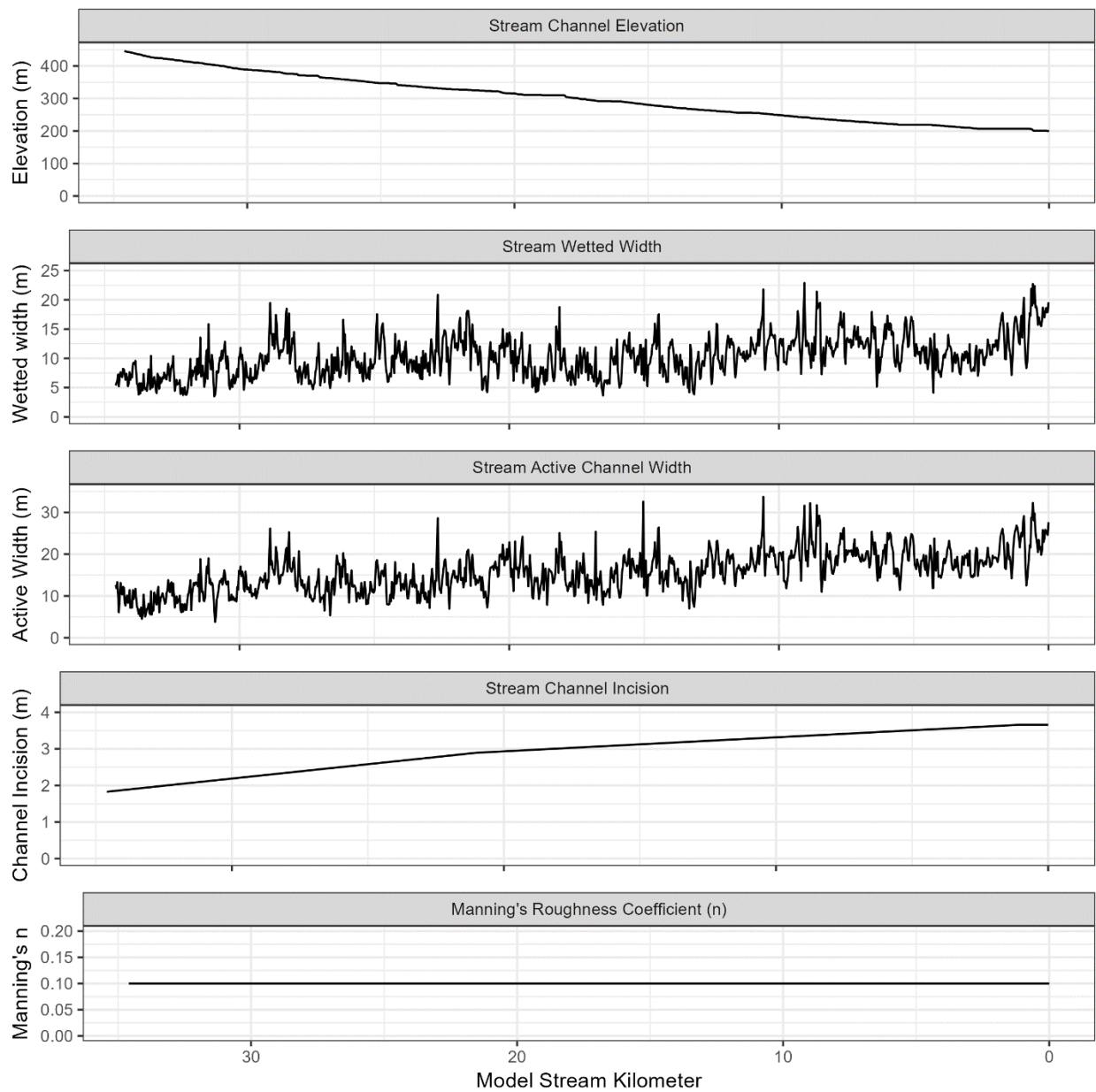
**Figure 3-234: Average land cover height inputs to the Mosby Creek model.**



**Figure 3-235: Topographic shade angle inputs to the Mosby Creek model.**

### 3.11.9 Channel setup

Channel setup for Mosby Creek model is presented in **Figure 3-236**.



**Figure 3-236: 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**.

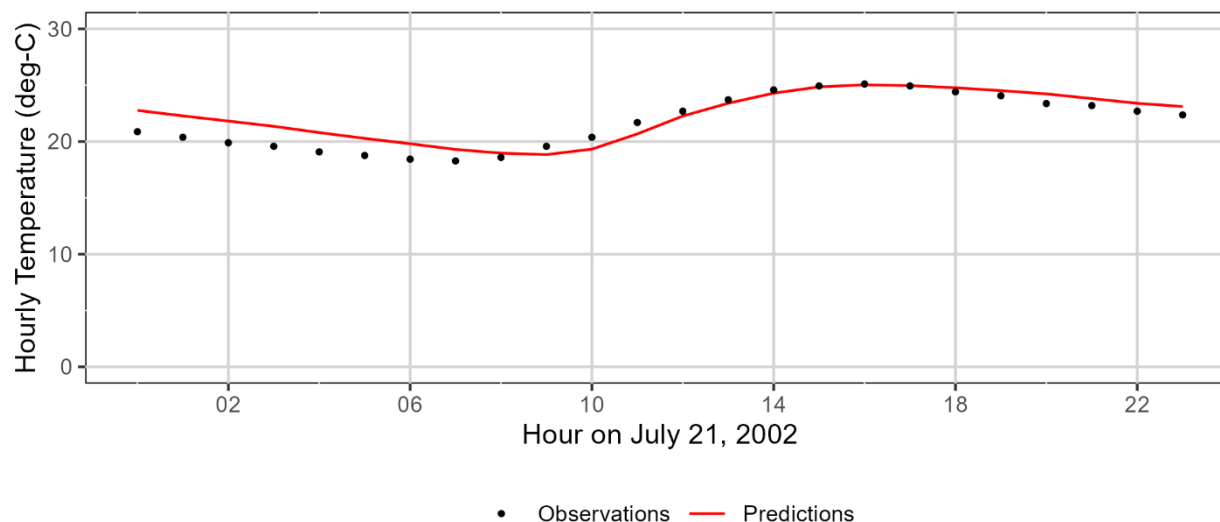
Reference source not found.. Observed and model-predicted hourly temperatures were plotted for the monitoring stations (**Figure 3-237** through **Figure 3-240**). Modeling results comparing simulated current conditions for Johnson Creek to the TIR data are presented in **Figure 3-241**.

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

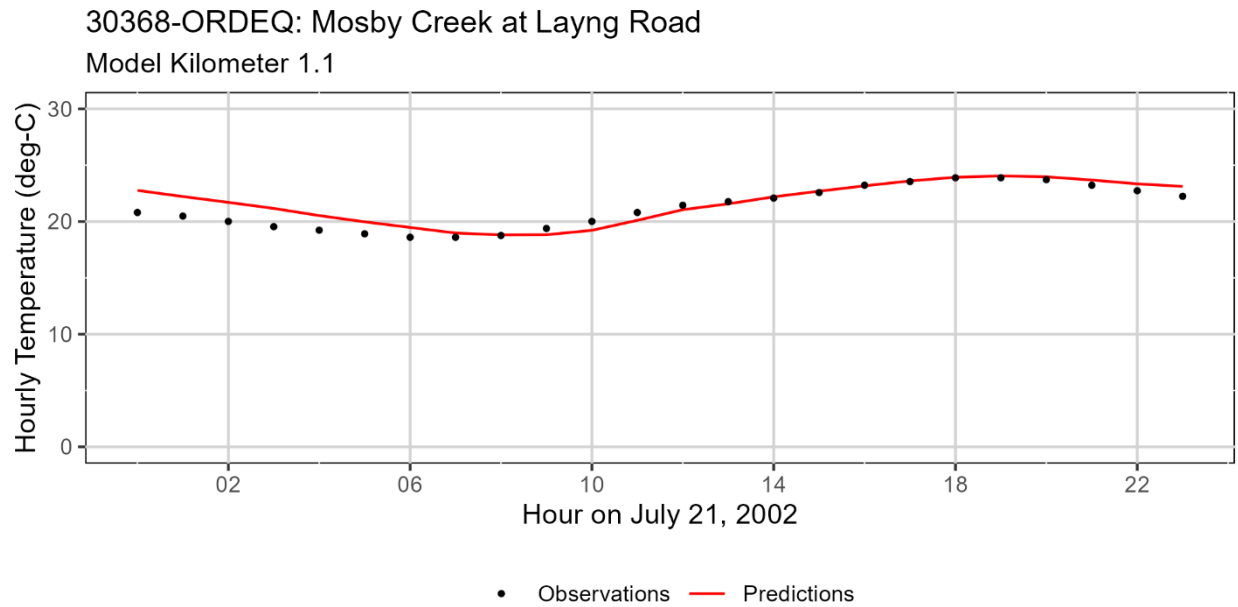
| Monitoring Location   | Model KM     | Temperature Statistics | ME    | MAE  | RMSE | NSE  | n   |
|---|--------------|------------------------|-------|------|------|------|-----|
| All Stations  |              | Daily Maximum          | -0.03 | 0.14 | 0.16 | NA   | 4   |
| All Stations  |              | 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 |

**28103-ORDEQ: Mosby Creek below Row River Trail**

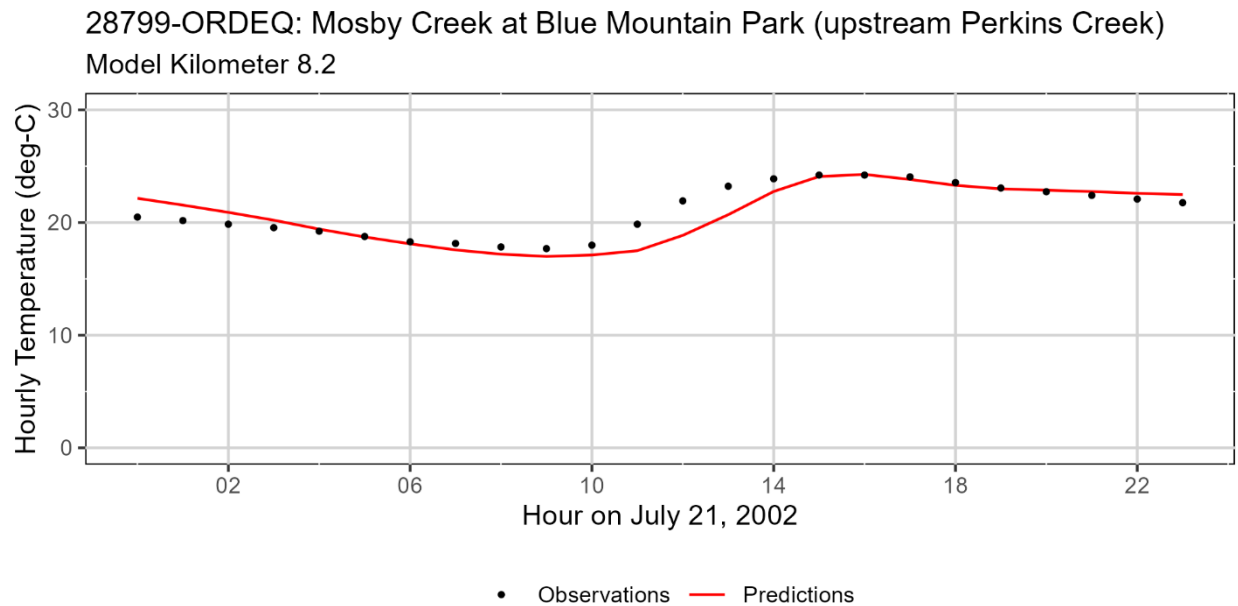
Model Kilometer 0.8



**Figure 3-237: Mosby Creek measured and model-predicted hourly temperatures at monitoring station 28103-ORDEQ.**



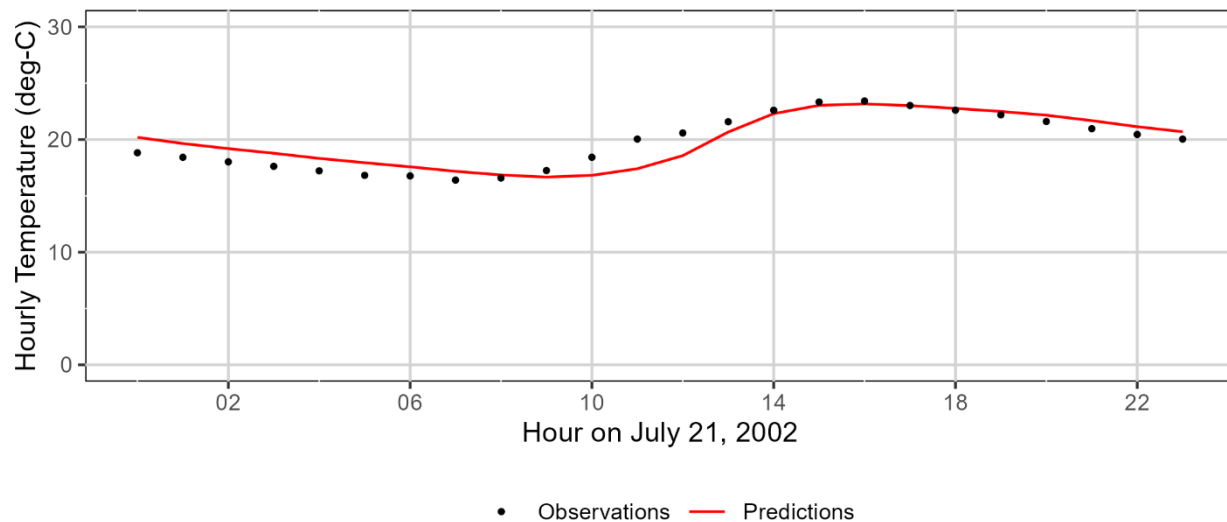
**Figure 3-238: Mosby Creek measured and model-predicted hourly temperatures at monitoring station 30368-ORDEQ.**



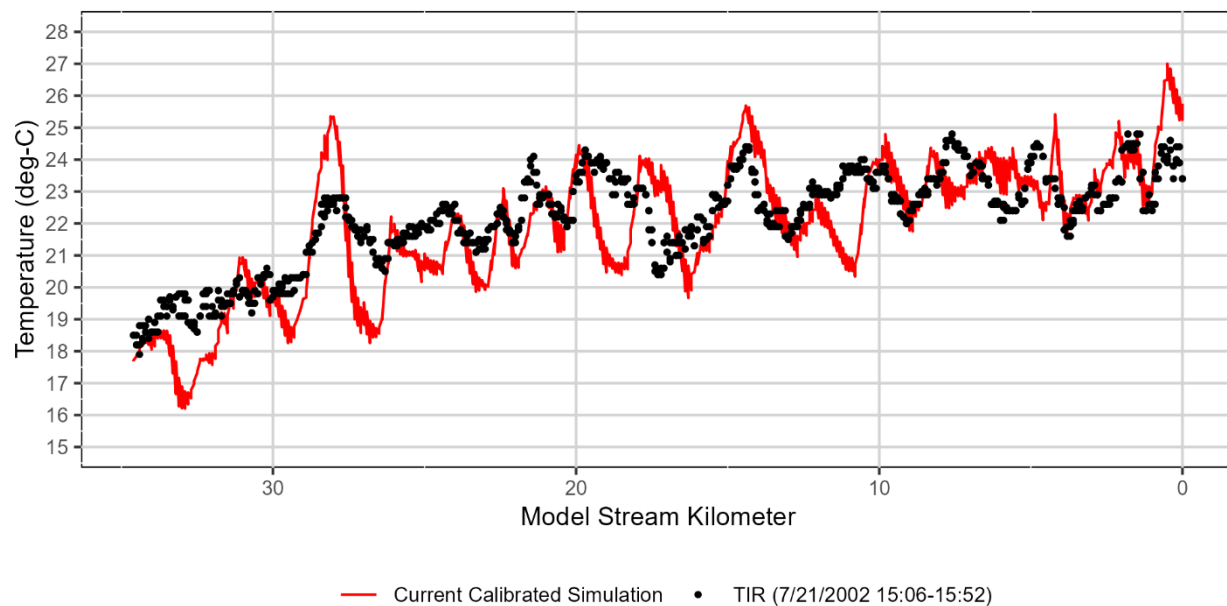
**Figure 3-239: Mosby Creek measured and model-predicted hourly temperatures at monitoring station 28799-ORDEQ.**

### 28101-ORDEQ: Mosby Creek Above Cedar Creek

Model Kilometer 21



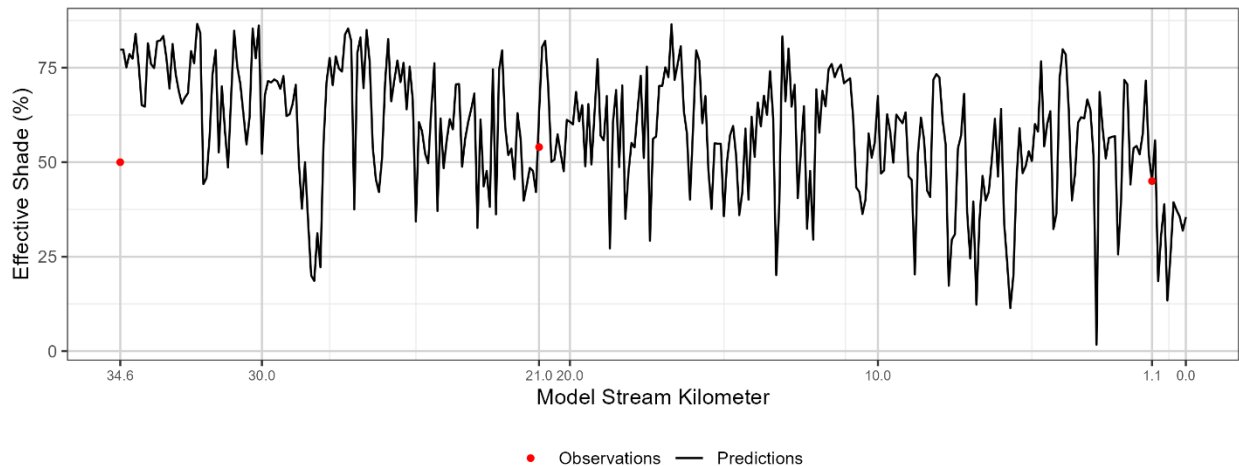
**Figure 3-240: Mosby Creek measured and model-predicted hourly temperatures at monitoring station 28101-ORDEQ.**



**Figure 3-241: 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 3-242**). 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 3-242: 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.**

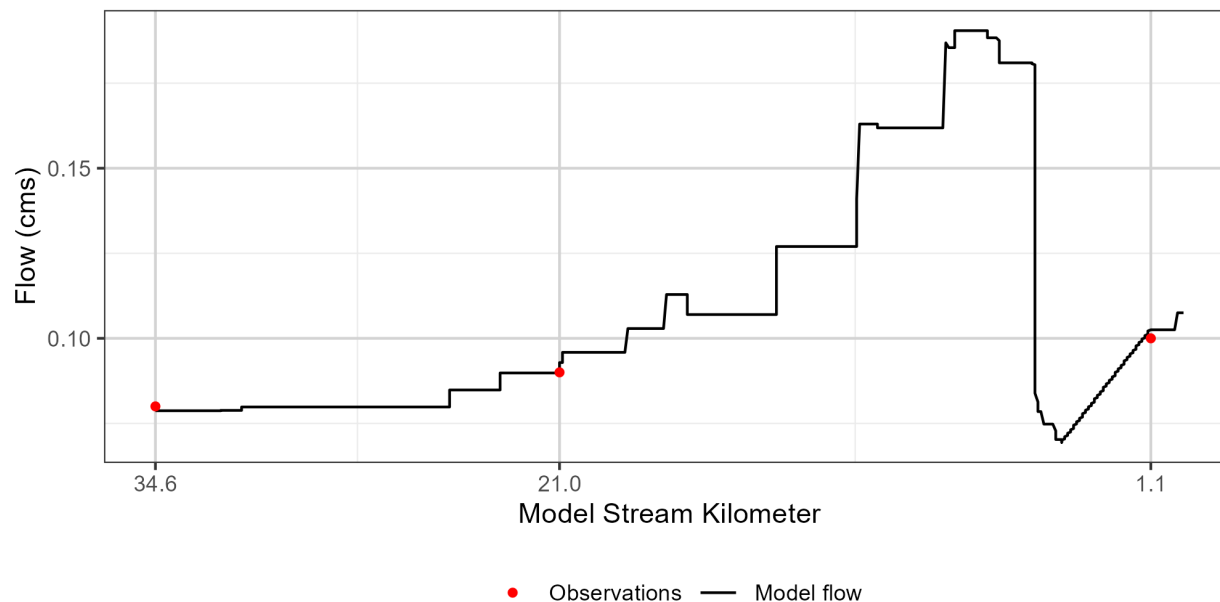
| N | R <sup>2</sup> | ME    | MAE | RMSE  |
|---|----------------|-------|-----|-------|
| 3 | 0.33           | 12.93 | 13  | 17.99 |

### 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 3-243**. 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 |



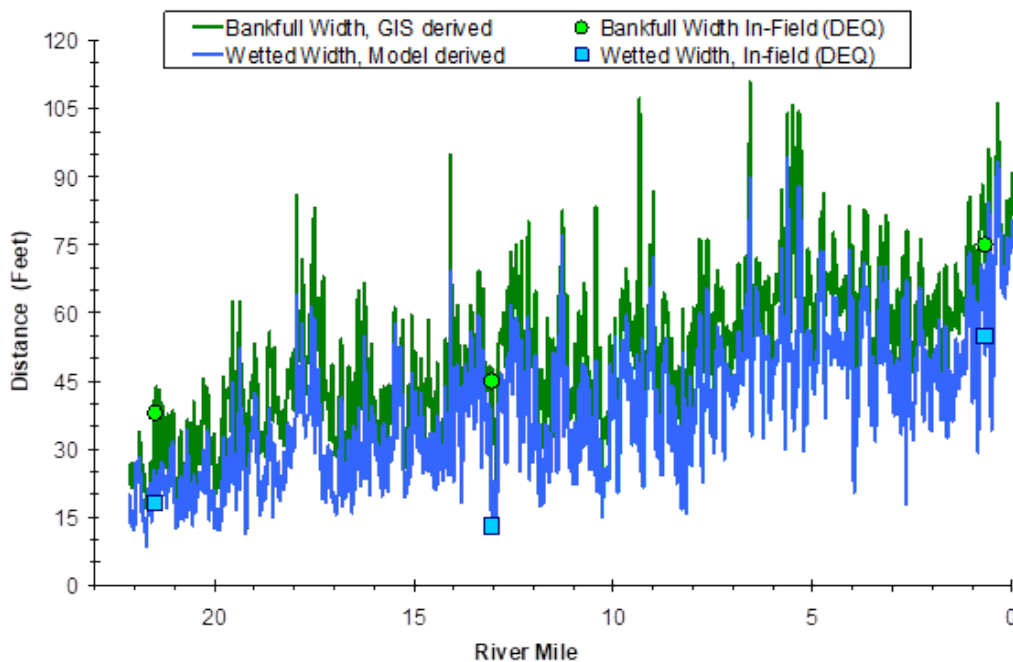
**Figure 3-243: Mosby Creek field observed and model flow rates.**

**Table 3-79: Mosby River goodness of fit statistics comparing field observed and model flow rates.**

| N | R <sup>2</sup> | 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 3-244**. Results shows channel widths only from streams modeled for temperature with Heat Source.



**Figure 3-244: 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.

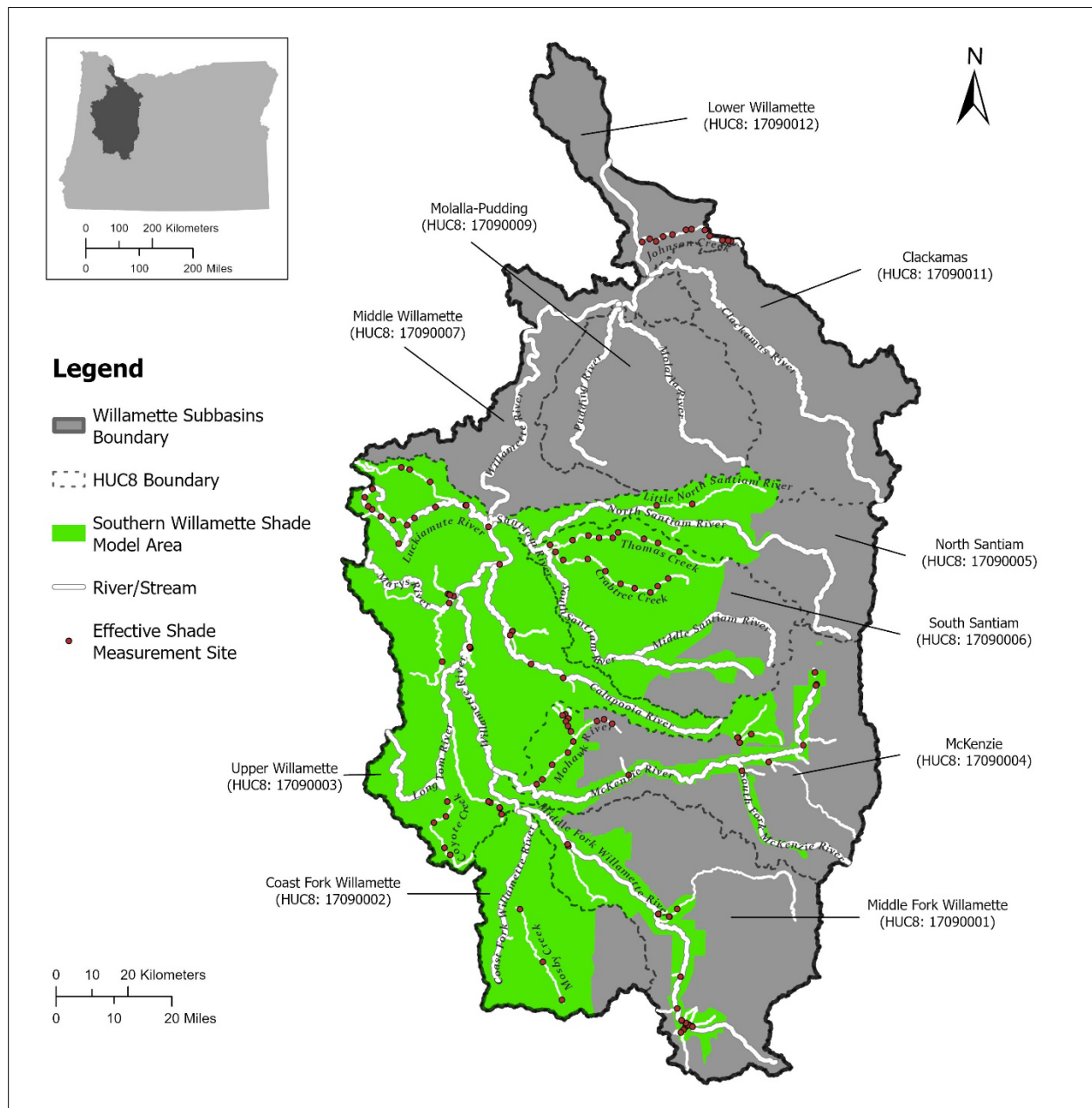
Several data sets used for model setup were derived using a GIS, associated spatial data, and a set of python-based scripting tools called TTools (Boyd and Kasper 2003). The scale and resolution of the derived data sets generally matched the resolution and accuracy of the input GIS data. The derived data sets include:

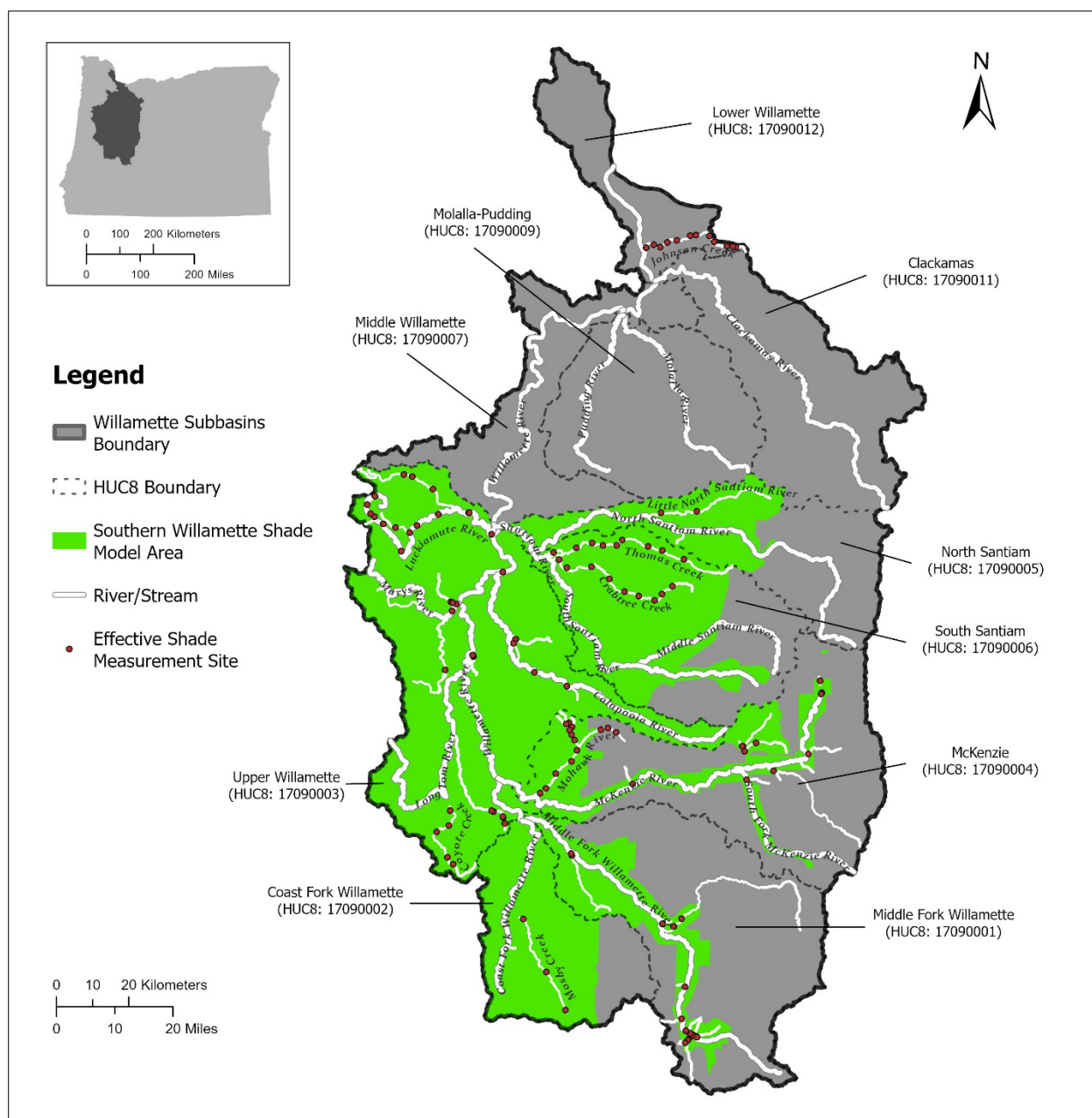
- Stream position
- Stream and ground elevation
- Topographic shade angles
- Land cover height

### 3.12.1 Model extent

Effective shade was modeled along all 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 3-245**.





**Figure 3-245: 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

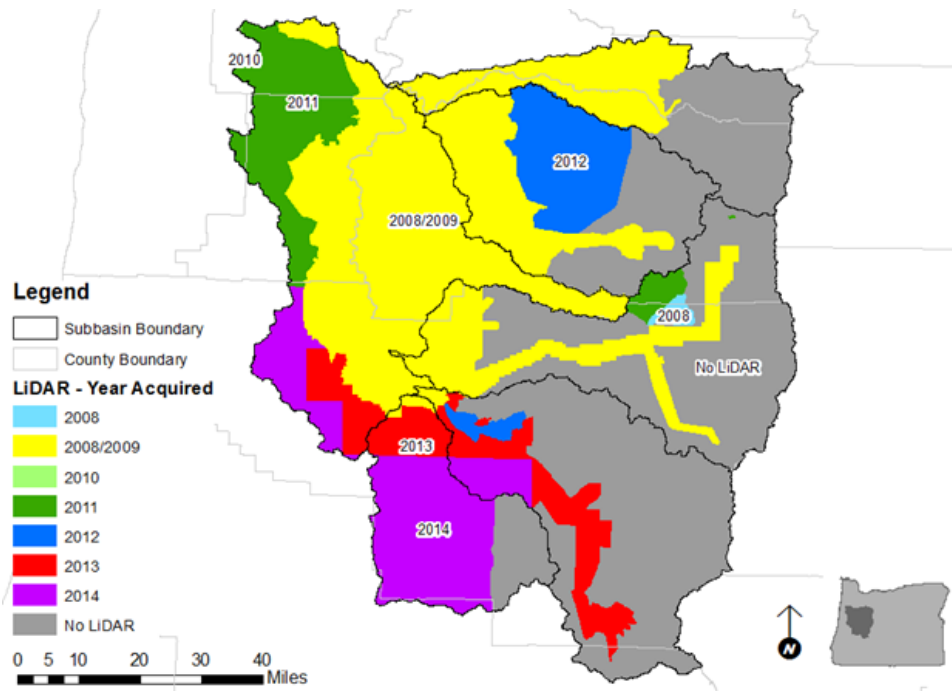
Multiple spatial GIS datasets were used to support model setup and configuration. **Table 3-80** identifies the GIS datasets used for the model setup and a brief summary of the application or derived data.

**Table 3-80: Spatial data used to support model setup and configuration.**

| Spatial Data   | Source  | Application  |
|--|---|--|
| LiDAR Bare Earth (DEM),<br>LiDAR Highest Hit (DSM)   | Watershed Sciences<br>2009, 2010, 2012a,<br>2012b;<br>WSI 2012a, 2012b, 2013,<br>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<br>Dataset high resolution v2.2 | USGS 2014   | Mapping stream position and location.  |
| National Wetland Inventory<br>(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 3-246** 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 3-246: 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.

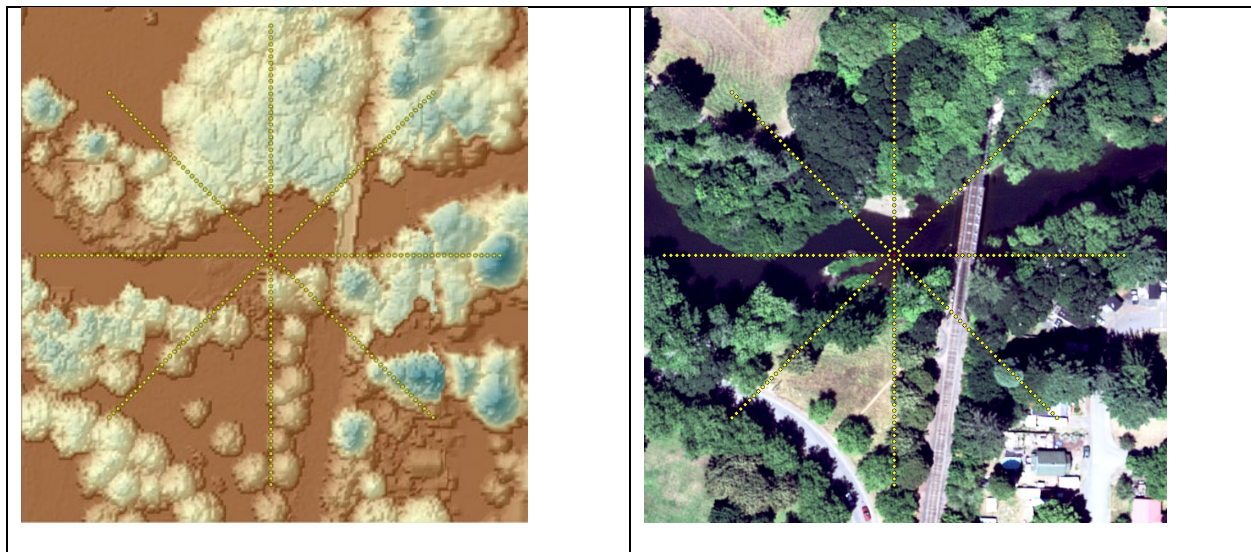
The stream flowlines in this version of NHD were primarily digitized from aerial photographs using a similar method that DEQ has used for other TMDLs, including the 2006 TMDL effort. In places where the stream is masked by forest cover, it is often hard to “see” the stream channel and this can result 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 3-247**). 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 3-247: 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.**

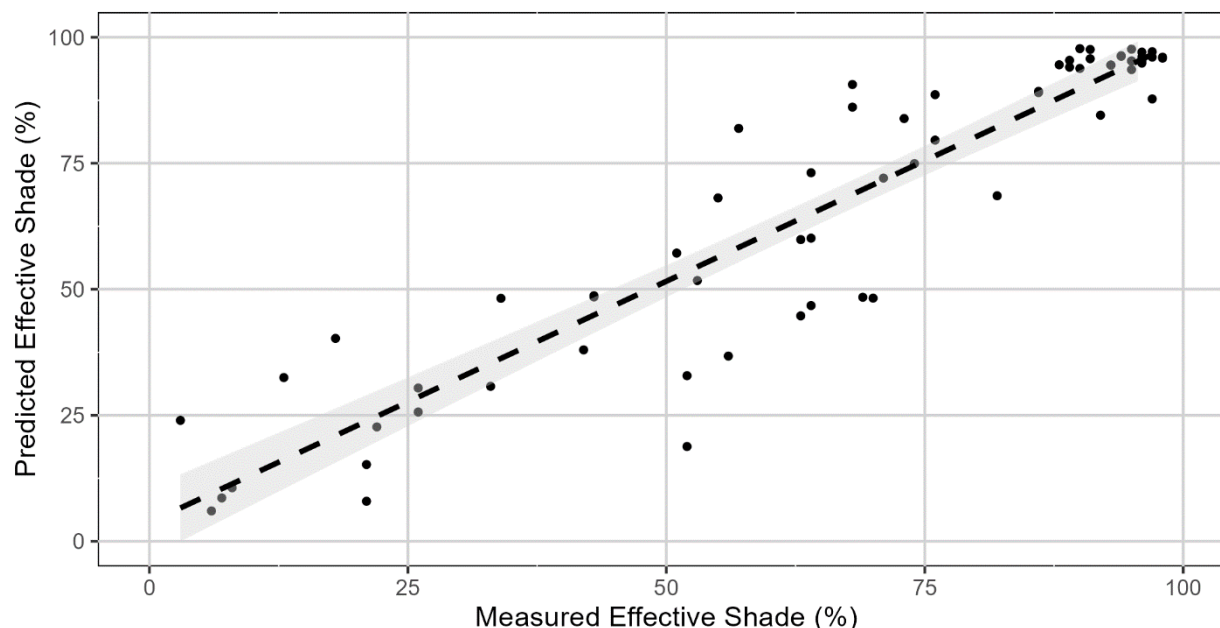
### 3.12.9 Calibration results

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 3-248**. Overall, these results were good and the bias is near zero.

**Table 3-81: Southern Willamette effective shade model goodness of fit statistics.**

| N  | R <sup>2</sup> | ME  | MAE | RMSE |
|----|----------------|-----|-----|------|
| 65 | 0.87           | 0.9 | 7.7 | 11   |



**Figure 3-248: 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 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.

### **3.14.1 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.

### **3.14.2 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.

### **3.14.3 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.

### **3.14.4 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.

### **3.14.5 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.

Effective shade curves were developed for the original Willamette Basin TMDL and WQMP (DEQ, 2006). Adjustments to the existing shade curve models are unlikely to occur as part of

this project. However, if it is determined that the models need to be updated DEQ will follow the procedures outlined in this QAPP.

### 3.14.6 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 3-82**.
- Effective shade lookup tables: Model input values to be used for the lookup tables are described in **Table 3-82**.

**Table 3-82: 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 7<sup>th</sup> 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 7<sup>th</sup> 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<sup>3</sup>/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<sup>3</sup>/s (4.75 cfs).

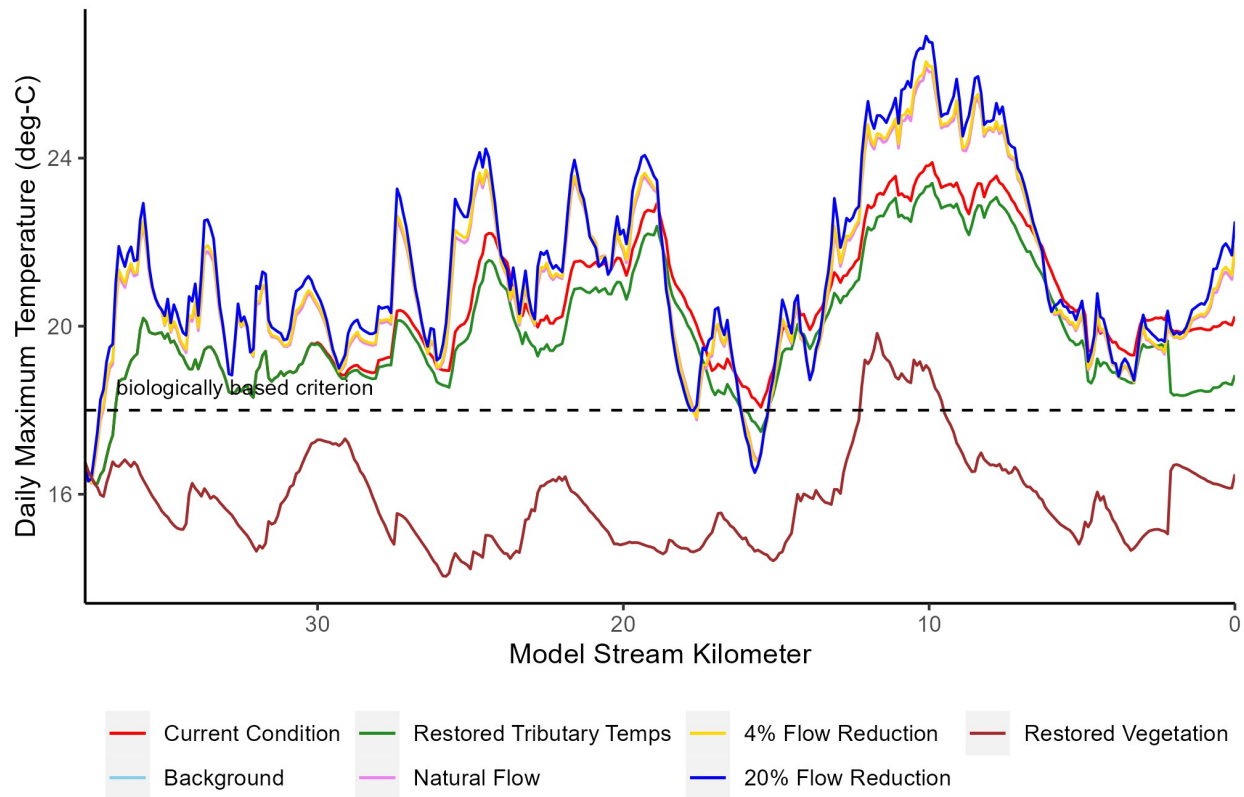
**Table 4-1: Johnson Creek model scenario descriptions.**

| 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  |

| Scenario Name | Description  |
|---------------|--|
|               | 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

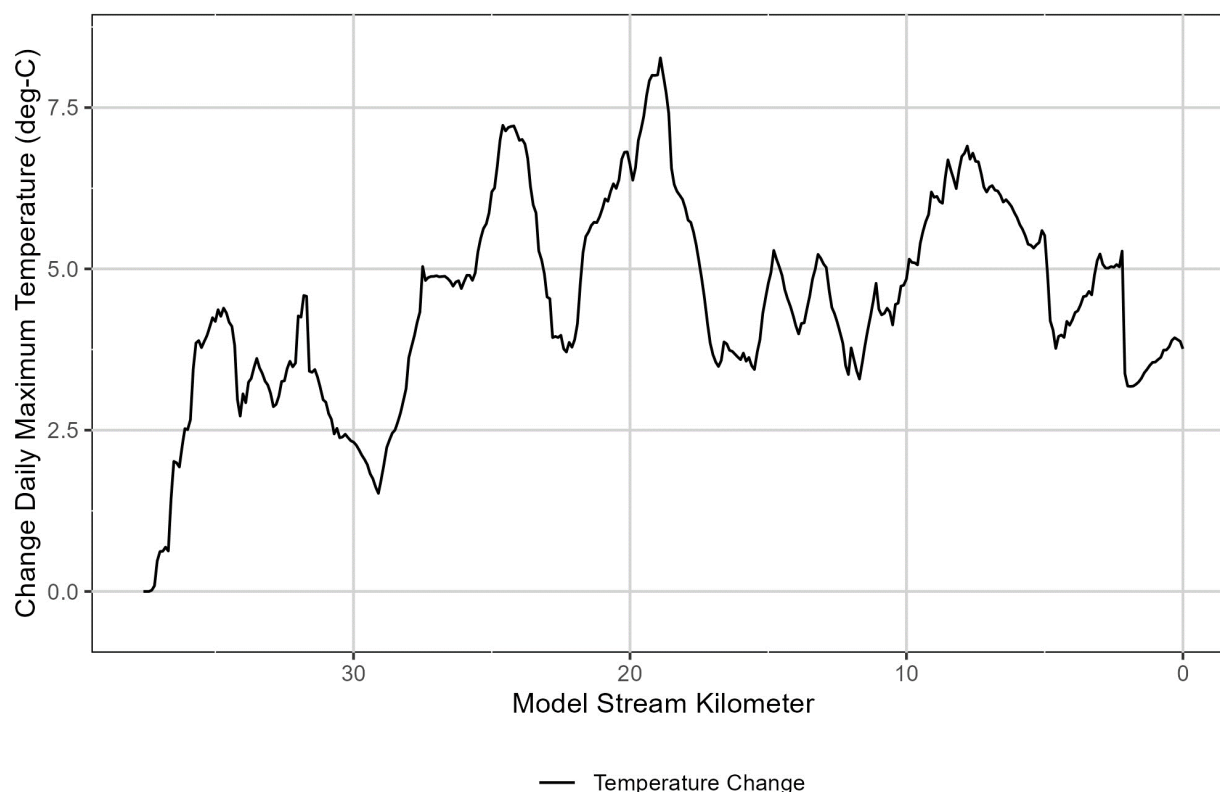
This section summarizes the temperature impacts of restored vegetation.

**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     |



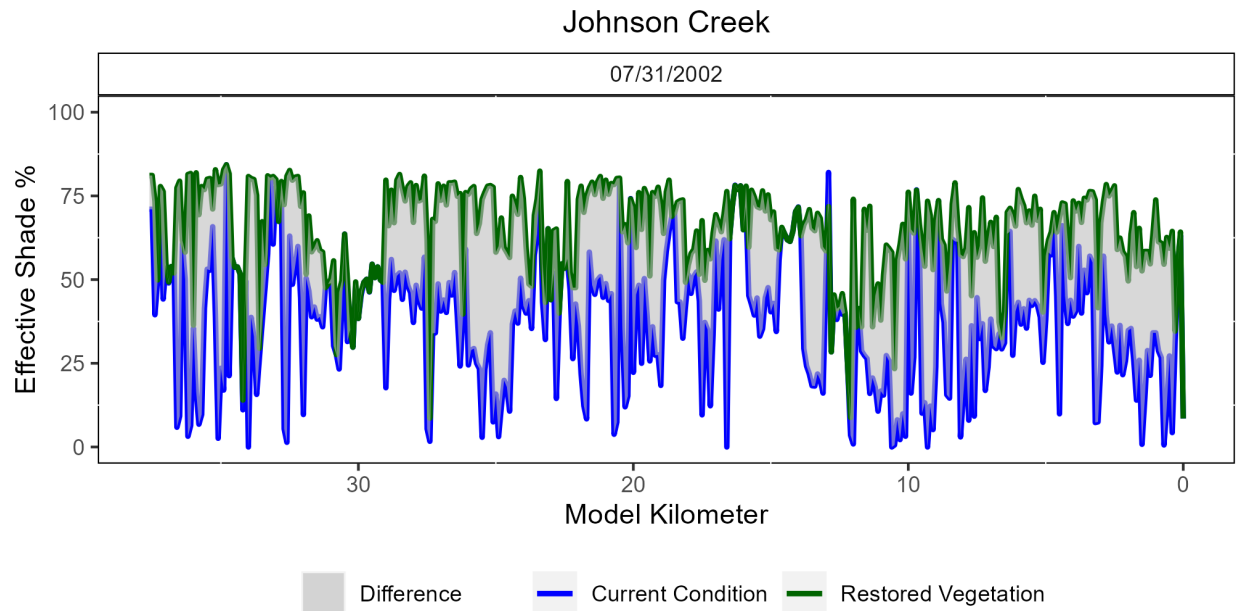
**Figure 4-2: Change in the daily maximum stream temperatures between the Current Condition and Restored Vegetation model scenarios for Johnson Creek over the entire model period.**

**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.

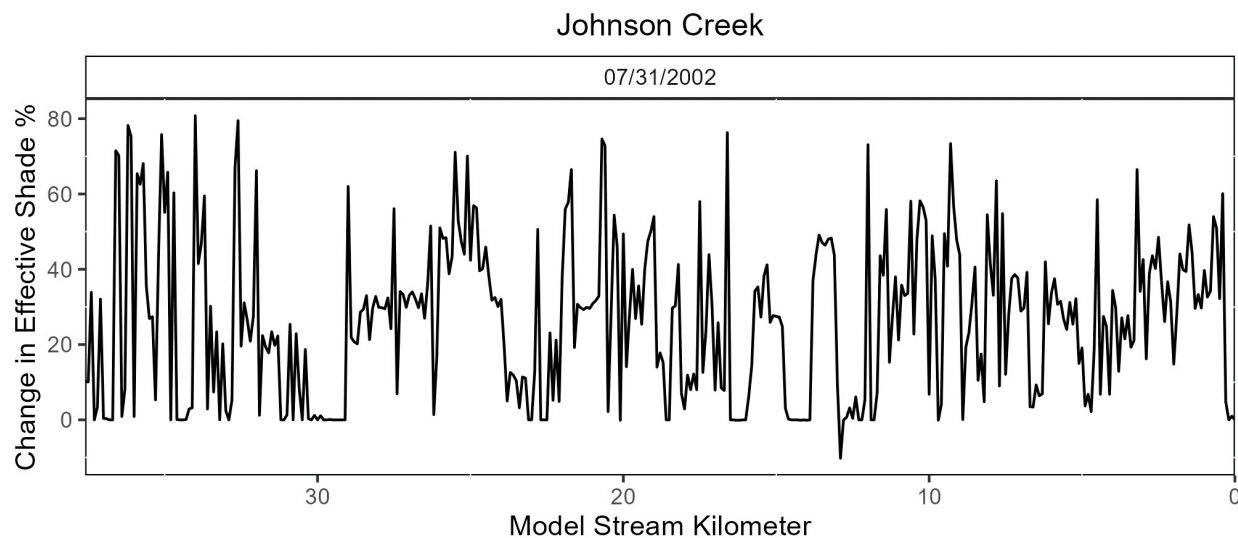
**Figure 4-3** and **Figure 4-4** compare effective shade predictions from the Current Condition and Restored Vegetation scenarios for Johnson Creek.

**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.

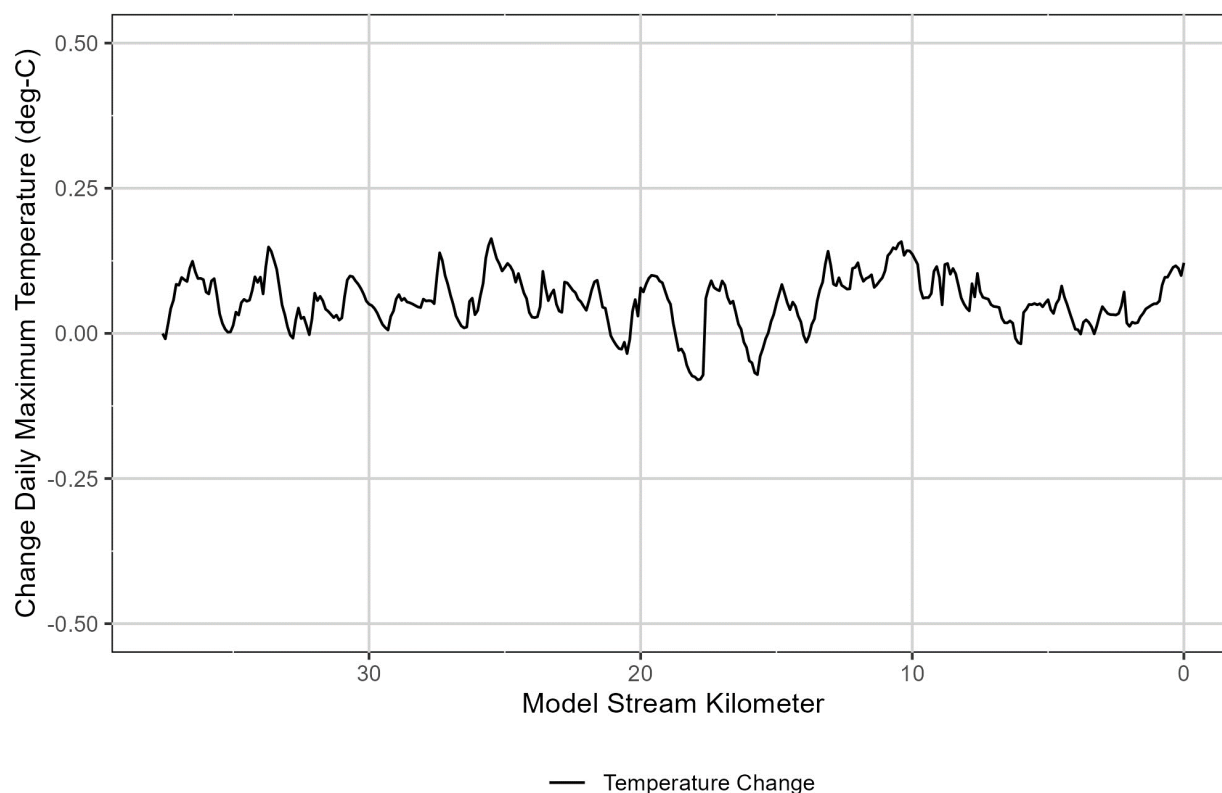
**Table 4-5** summarizes the daily maximum stream temperature change between the Restored Flow and HUA Attaining Flow scenarios for Johnson Creek. It shows the daily maximum temperature difference at the flow reference site (model km 1.2) is equal to 0.05°C.

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%.

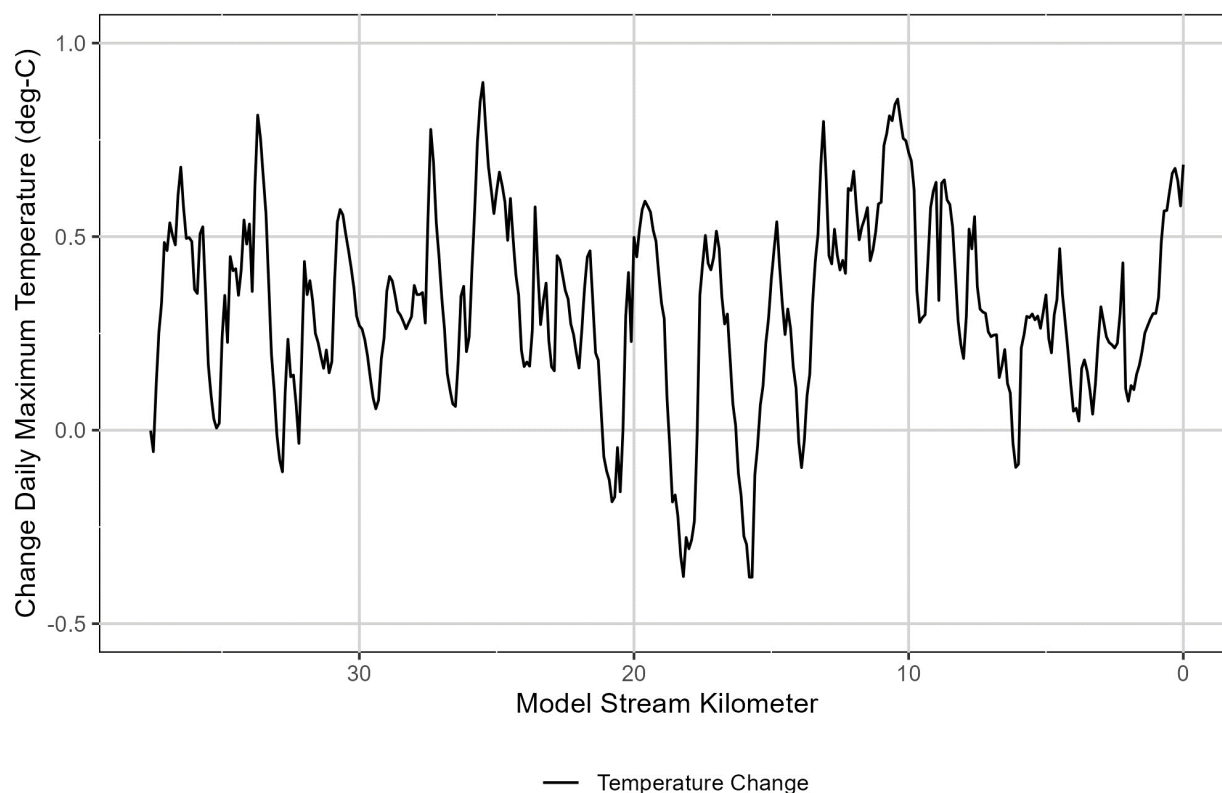
**Table 4-6** summarizes the daily maximum stream temperature change between the Restored Flow and 20% Stream Flow Reduction model scenarios for Johnson Creek. It shows the daily maximum temperature difference at the flow reference site (model km 1.2) is equal to 0.29°C.

**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

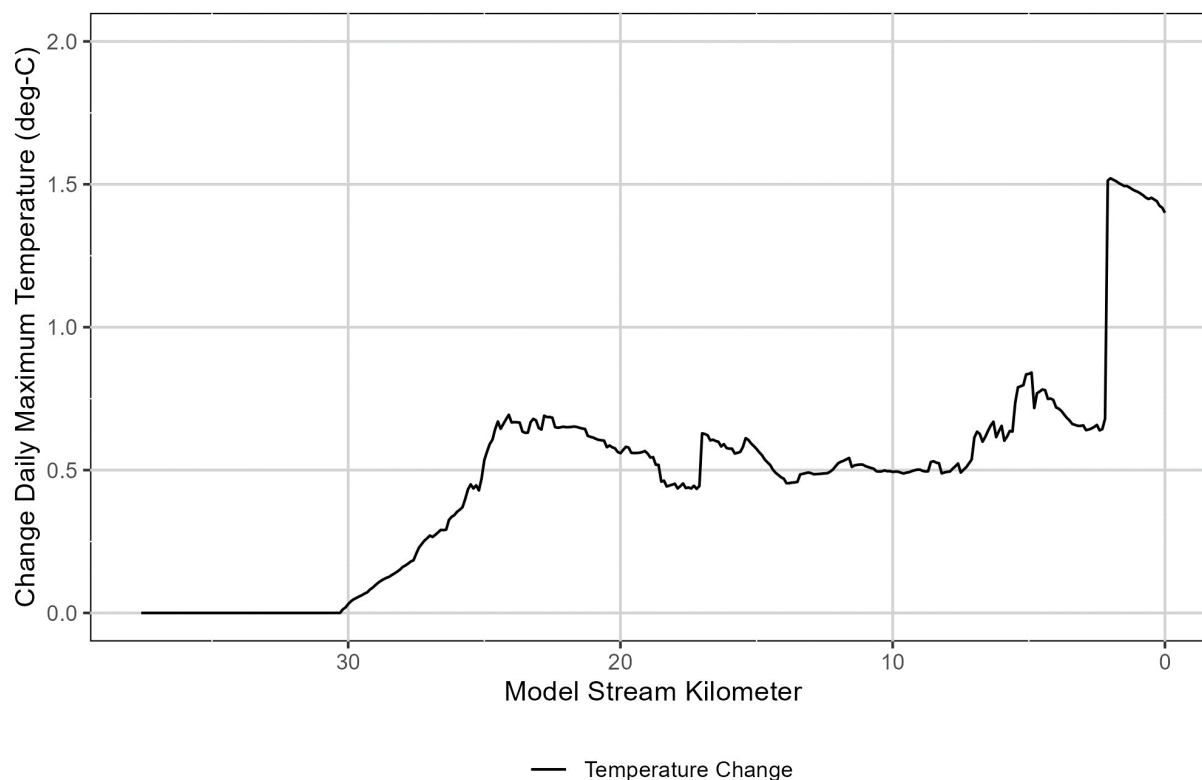
This section summarizes the temperature impacts of restored tributary temperatures.

**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.

Error! Reference source not found. 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

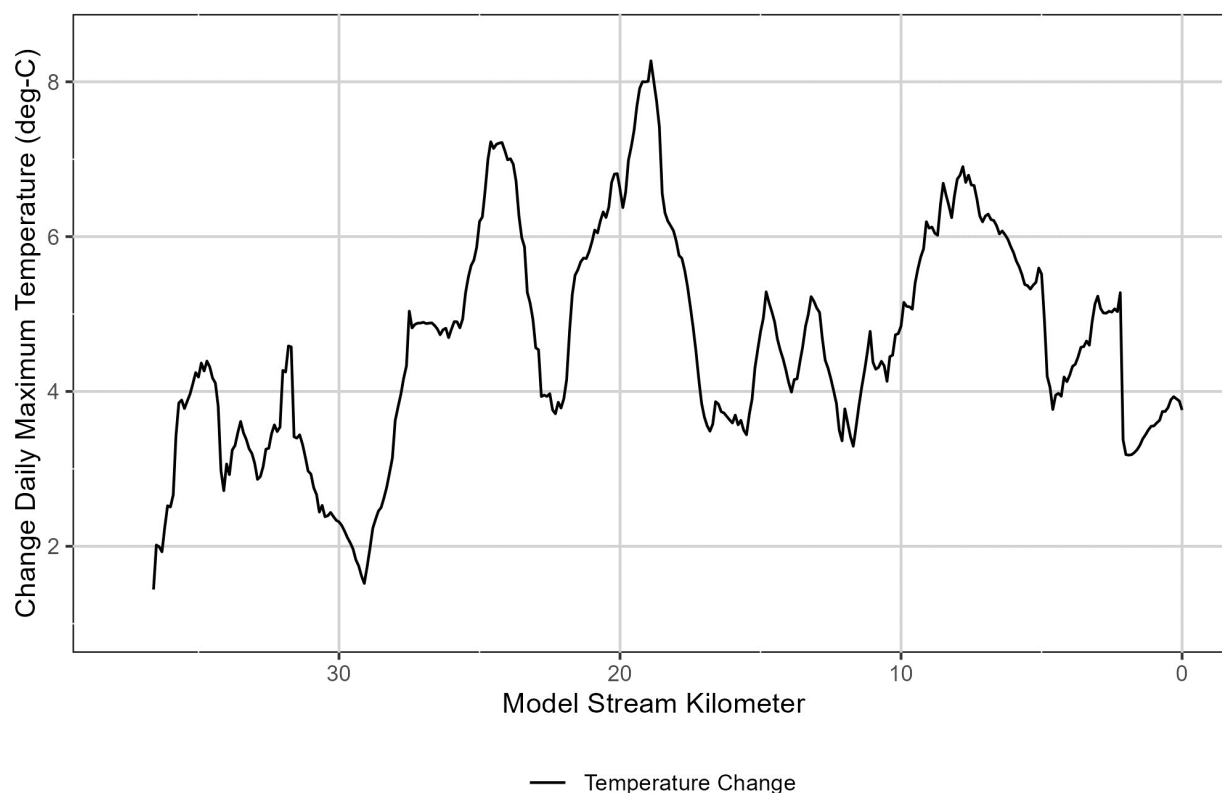
This section summarizes the temperature impacts of background conditions.

**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.

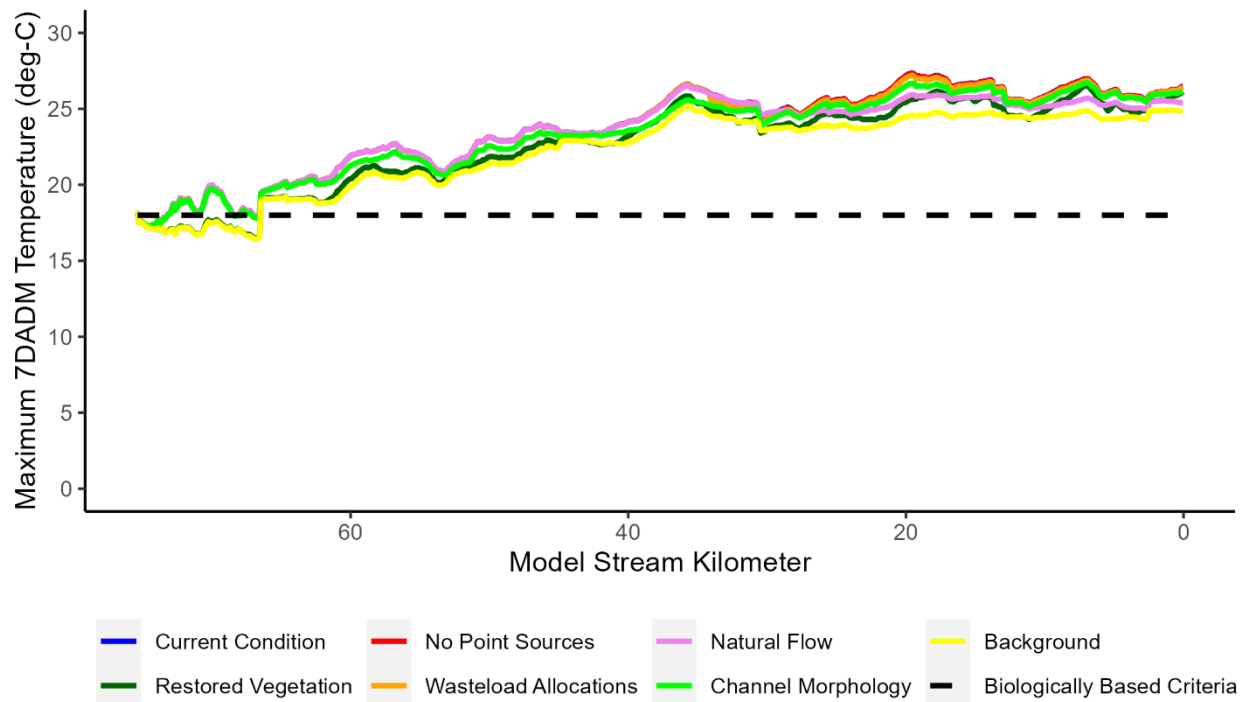
**Figure 4-10** shows current measured bankfull width compared with predicted potential bankfull width.

**Table 4-9: Molalla River model scenario descriptions.**

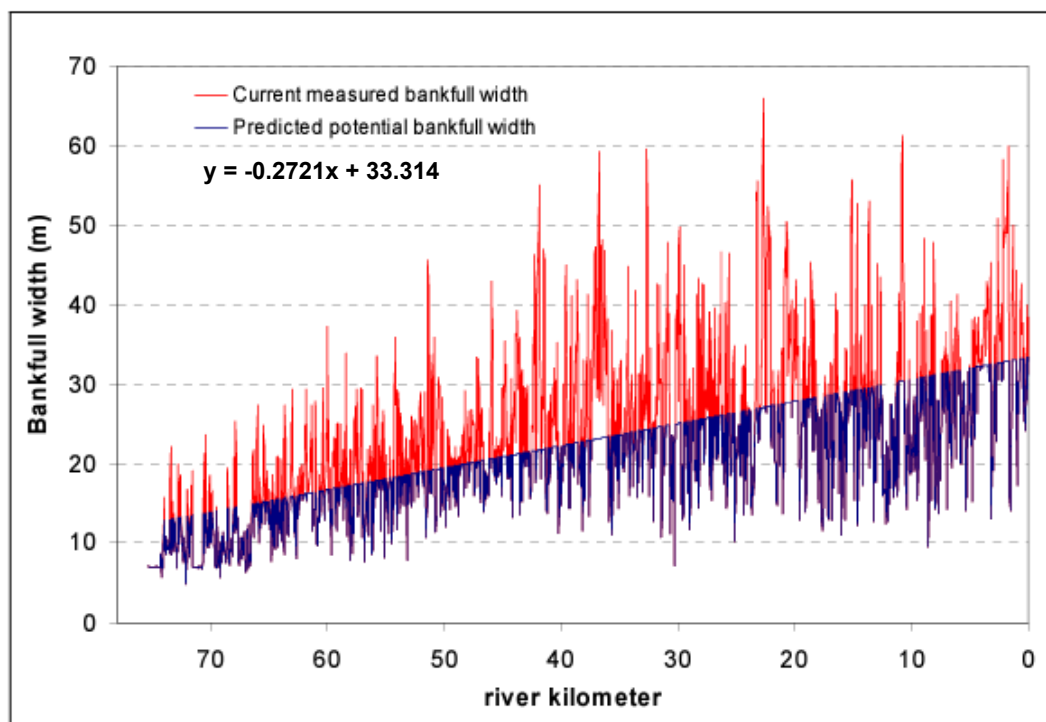
| Scenario Name              | Description  |
|----------------------------|--|
| Current Condition Scenario | The Molalla River Current Condition Scenario model has the following updates from the calibrated model created to support the original 2008 Molalla Pudding TMDL. Molalla STP was added to the 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.**



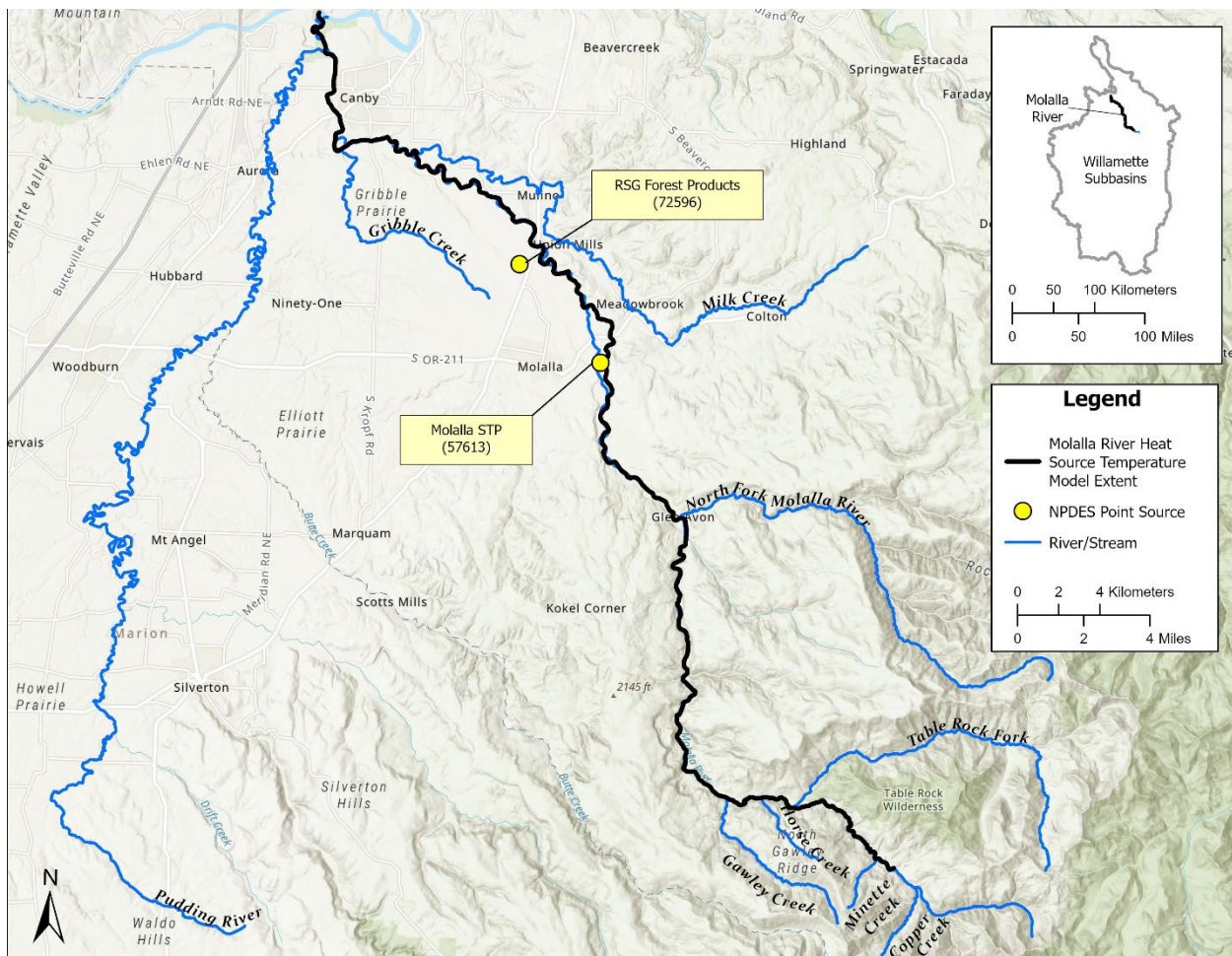
**Figure 4-10: GIS measured bankfull width compared with predicted bankfull width. A regression was performed of the moving median of bankfull width from headwaters to mouth. Modified bankfull width entered into the Heat Source model was the measured width, or the predicted width, the demarcating line 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

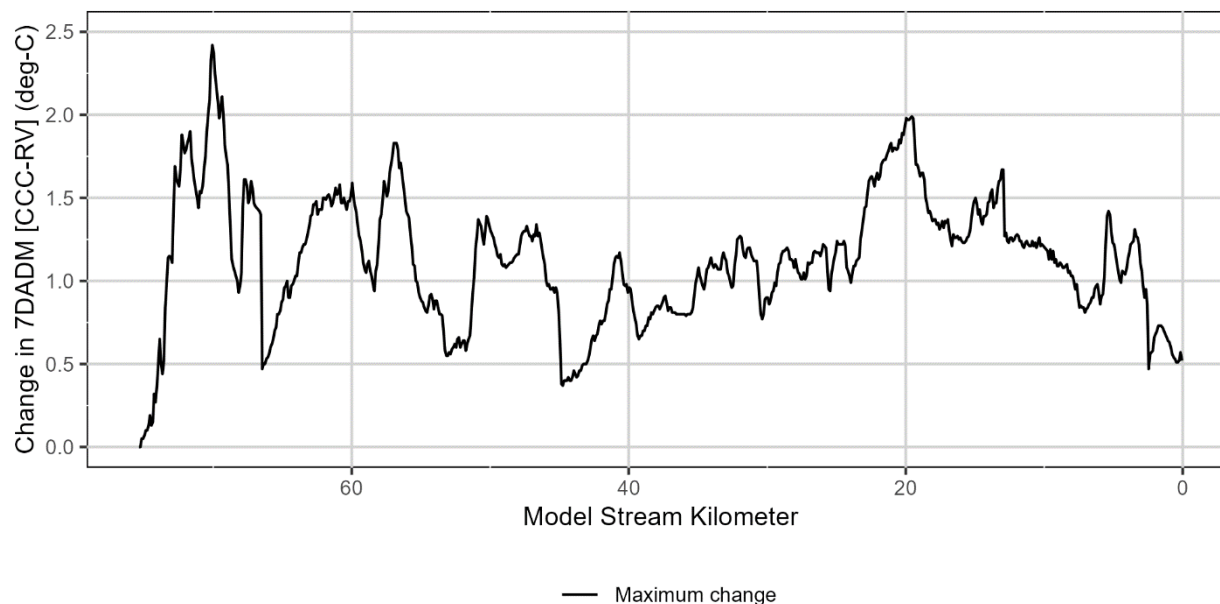
This section summarizes the temperature changes from restored vegetation.

**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     |



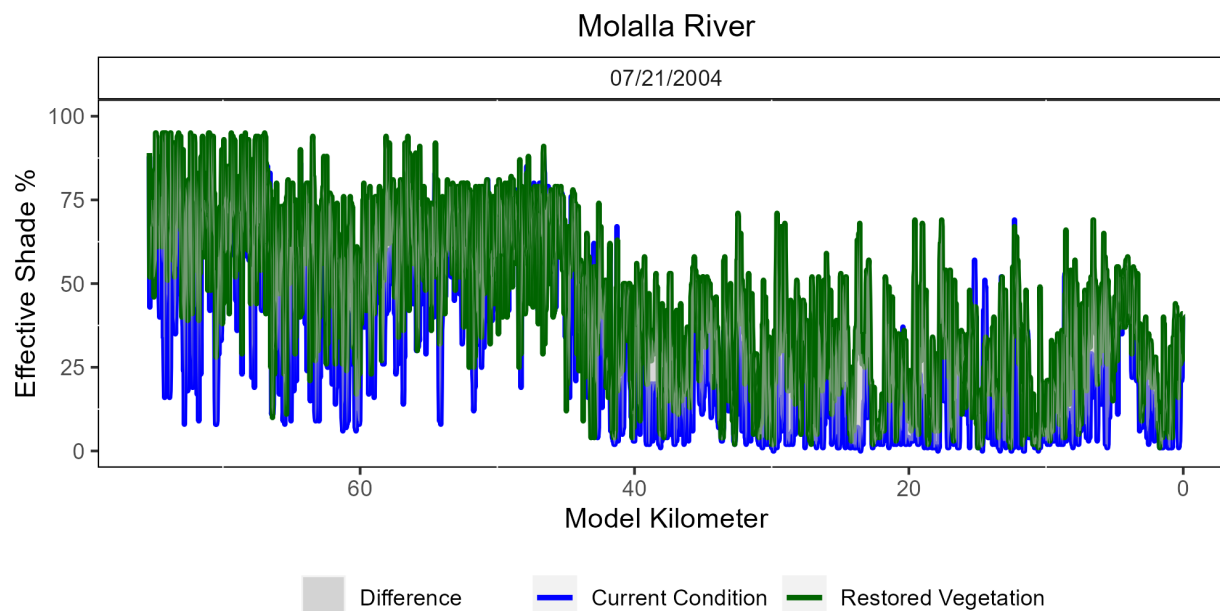
**Figure 4-12: Change in the maximum 7DADM stream temperatures between Current Condition and Restored Vegetation scenarios for the Molalla River over the entire model period.**

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.

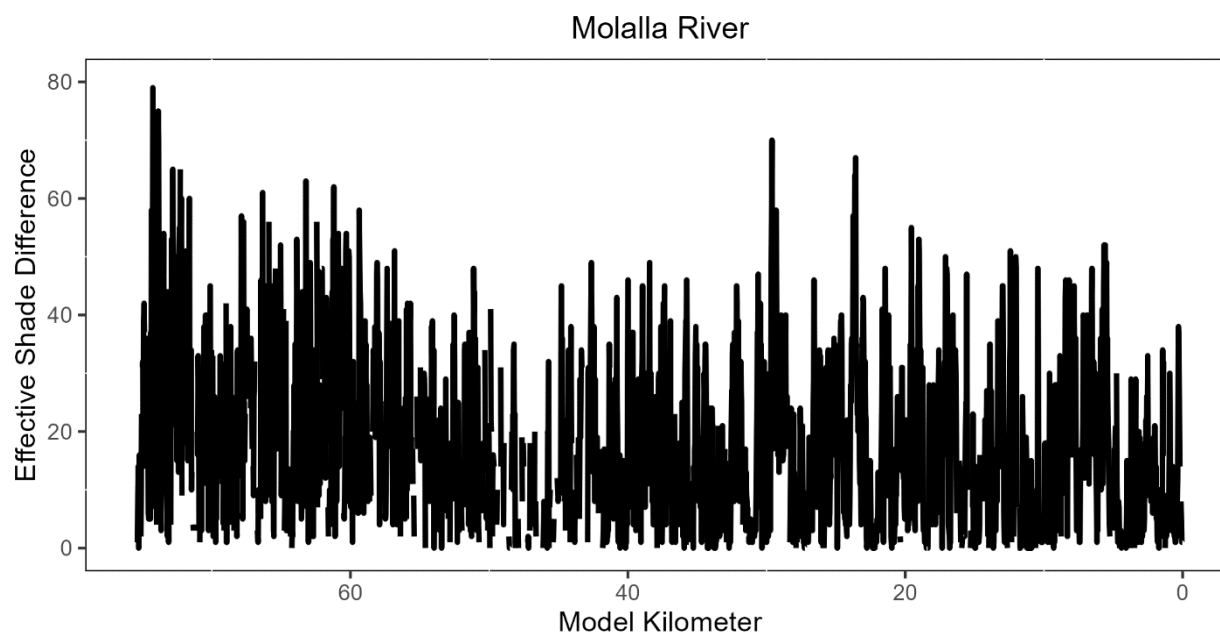
**Figure 4-13** and **Figure 4-14** compare effective shade predictions from the Current Condition and Restored Vegetation scenarios for the Molalla River.

**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.

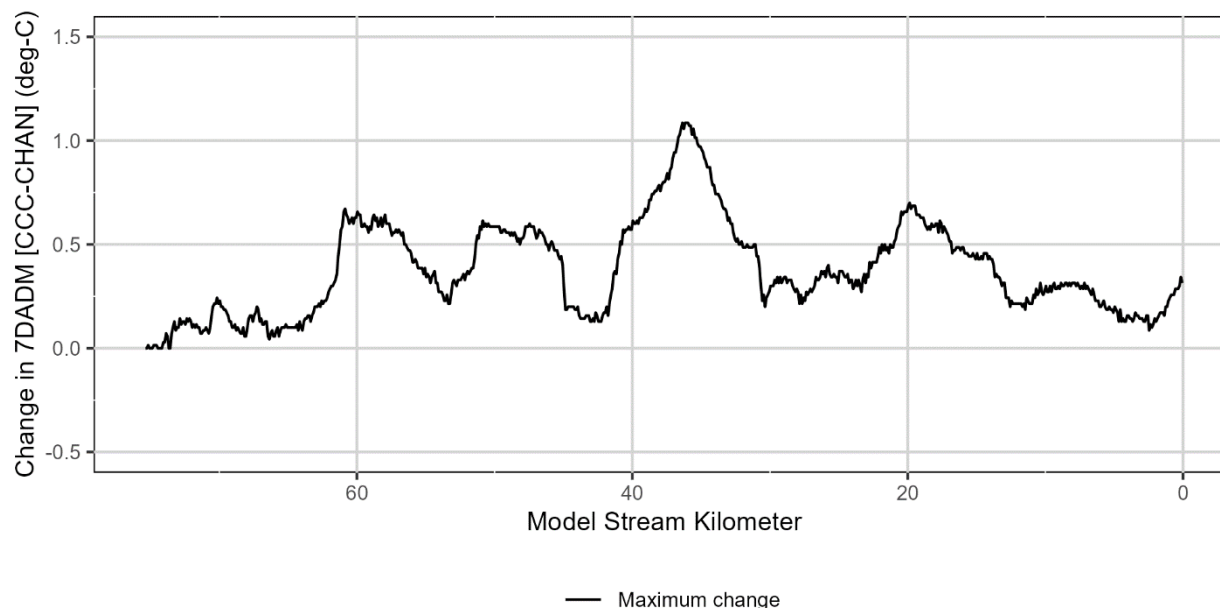
Natural bankfull width conditions were estimated using methodology from the Tillamook TMDL (DEQ, 2001). DEQ calculated the moving median of each 1000-foot section of the stream from headwaters to mouth and then performed a regression of those points with river mile. The resulting linear equation was 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.

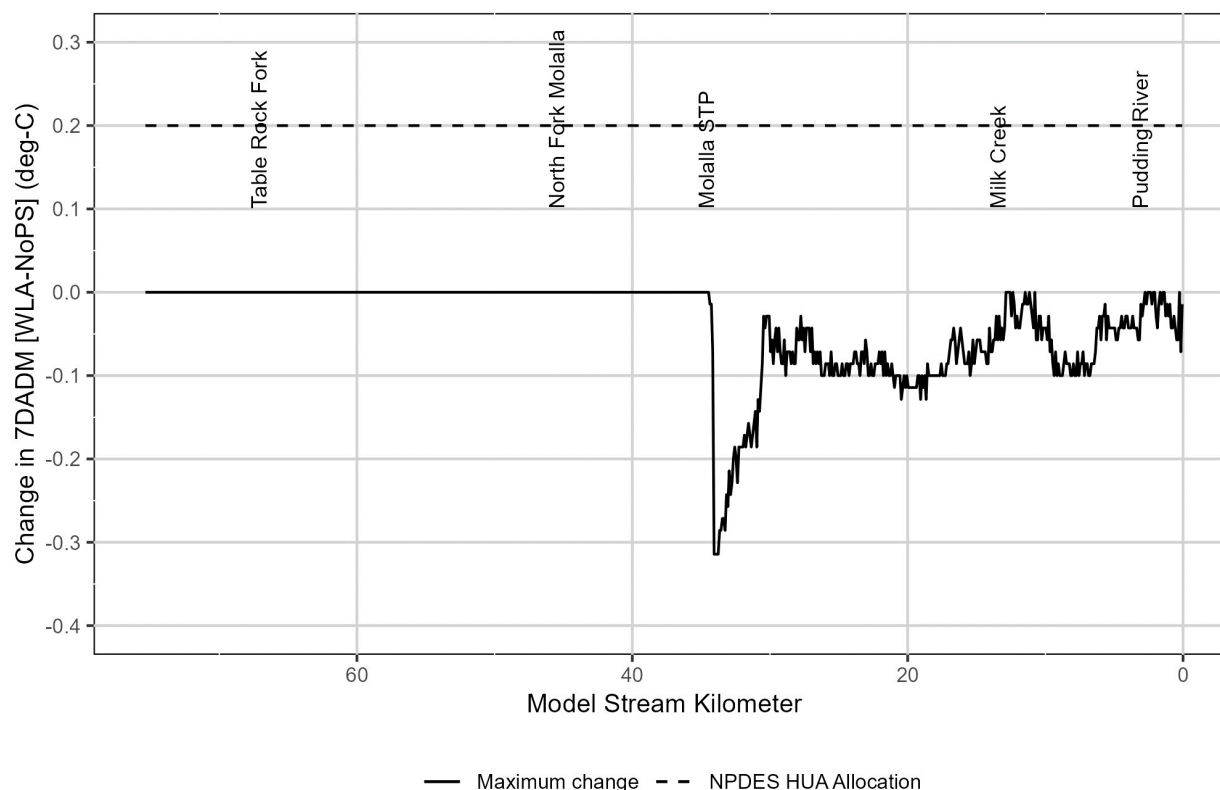
In the wasteload allocation scenario, water temperature and flow inputs from the Molalla STP were set to reflect their wasteload allocation. Wasteload allocations were calculated using equations described in the Willamette Subbasins TSD, Section 9.1 Wasteload allocation equation. For these calculations, 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.

Error! Reference source not found. 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.

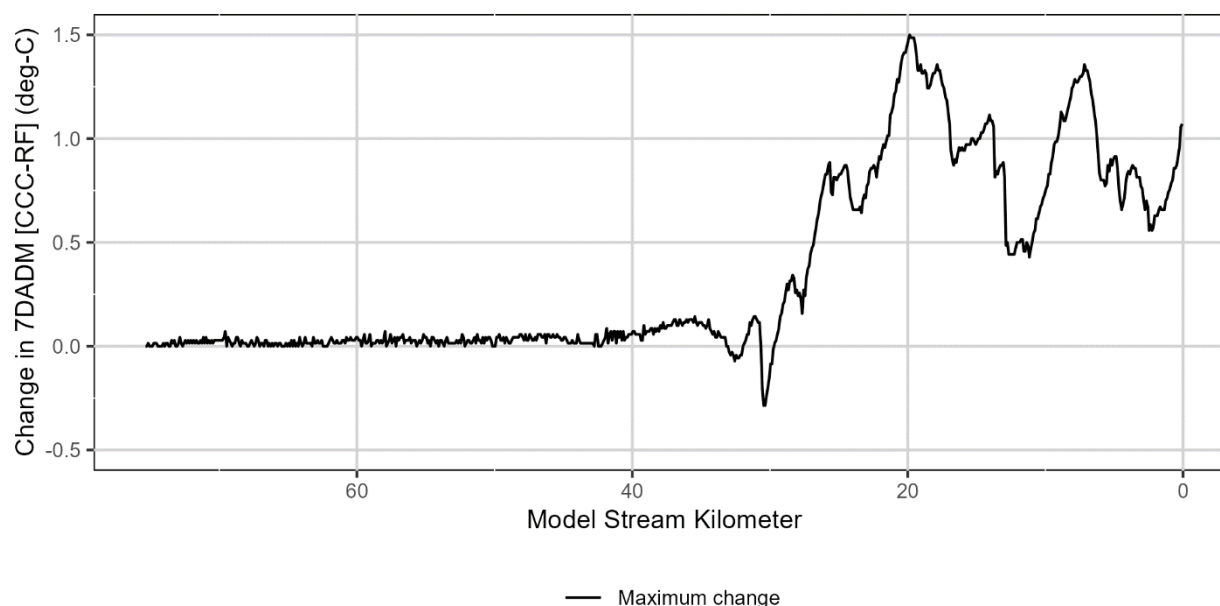
**Table 4-15** summarizes the maximum 7DADM stream temperature change between the Restored Flow and Current Condition scenarios for the Molalla River. It shows the 7DADM

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.

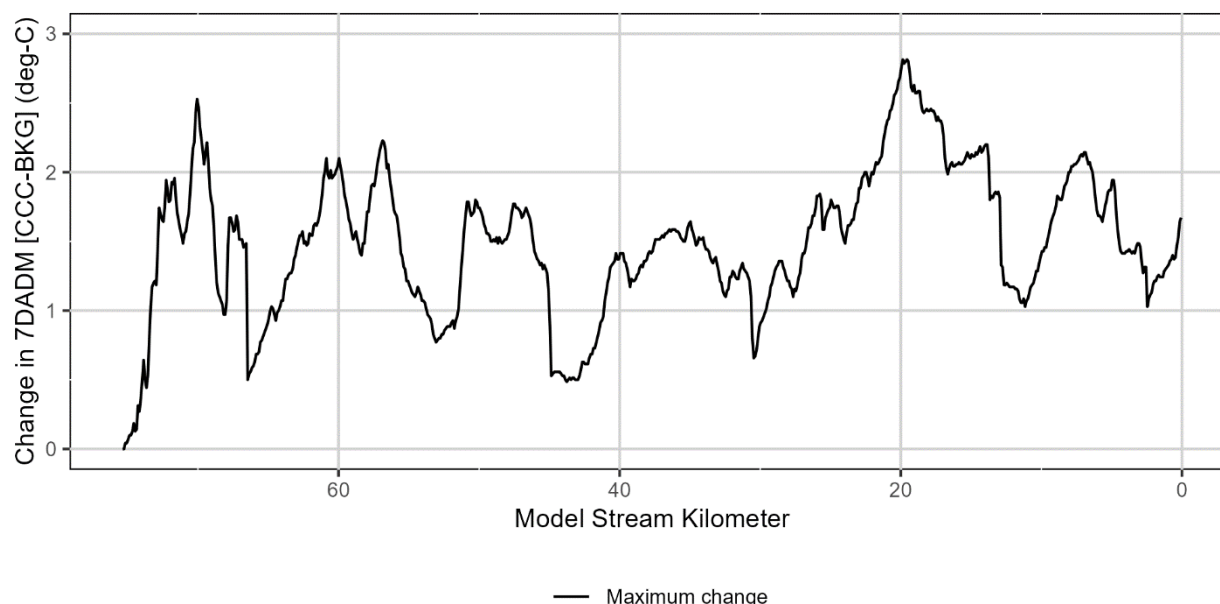
**Table 4-16** summarizes the maximum 7DADM stream temperature change between the Background and Current Condition scenarios as well as the Background and BBNC for the Molalla River. It shows the 7DADM temperature difference at the Background and Current Condition scenarios at the most downstream node (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.

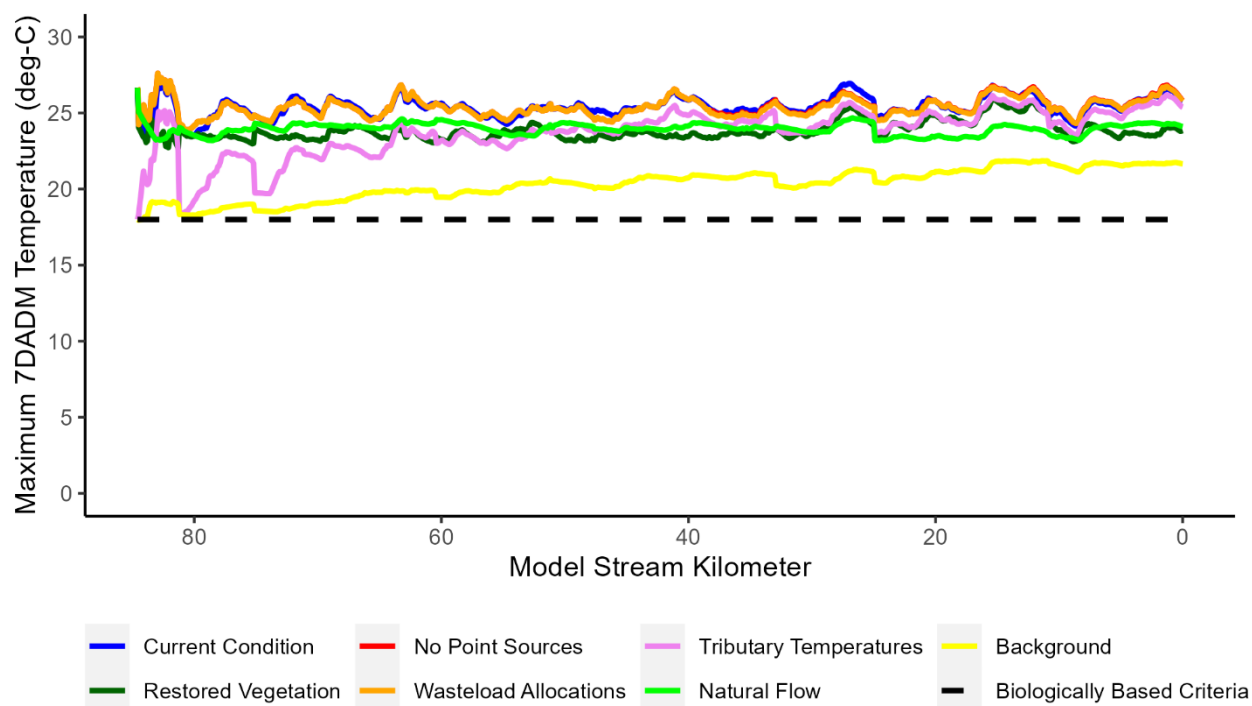
**Figure 4-19** shows the predicted maximum 7DADM for all Pudding River model scenarios.

**Table 4-17: Pudding River model scenario descriptions.**

| Scenario Name              | Description  |
|----------------------------|--|
| Current Condition Scenario | <p>The Pudding River Current Condition Scenario model has the following updates from the calibrated model created to support the original 2008 Molalla Pudding TMDL.</p> <ol style="list-style-type: none"> <li>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.</li> <li>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.</li> <li>3. Flow and temperature inputs for Woodburn WWTP were updated to reflect discharge conditions in August 2020 as reported on the DMRs.</li> </ol> |
| 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). <b>Figure 4-38 through Figure 4-46</b> 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           | <p>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.</p> <p><b>Figure 4-32</b> compares Pudding River flow for the Current Condition, Natural Flow and Consumptive Use model scenarios. See below for details regarding model scenario set up.</p>  |
| 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.

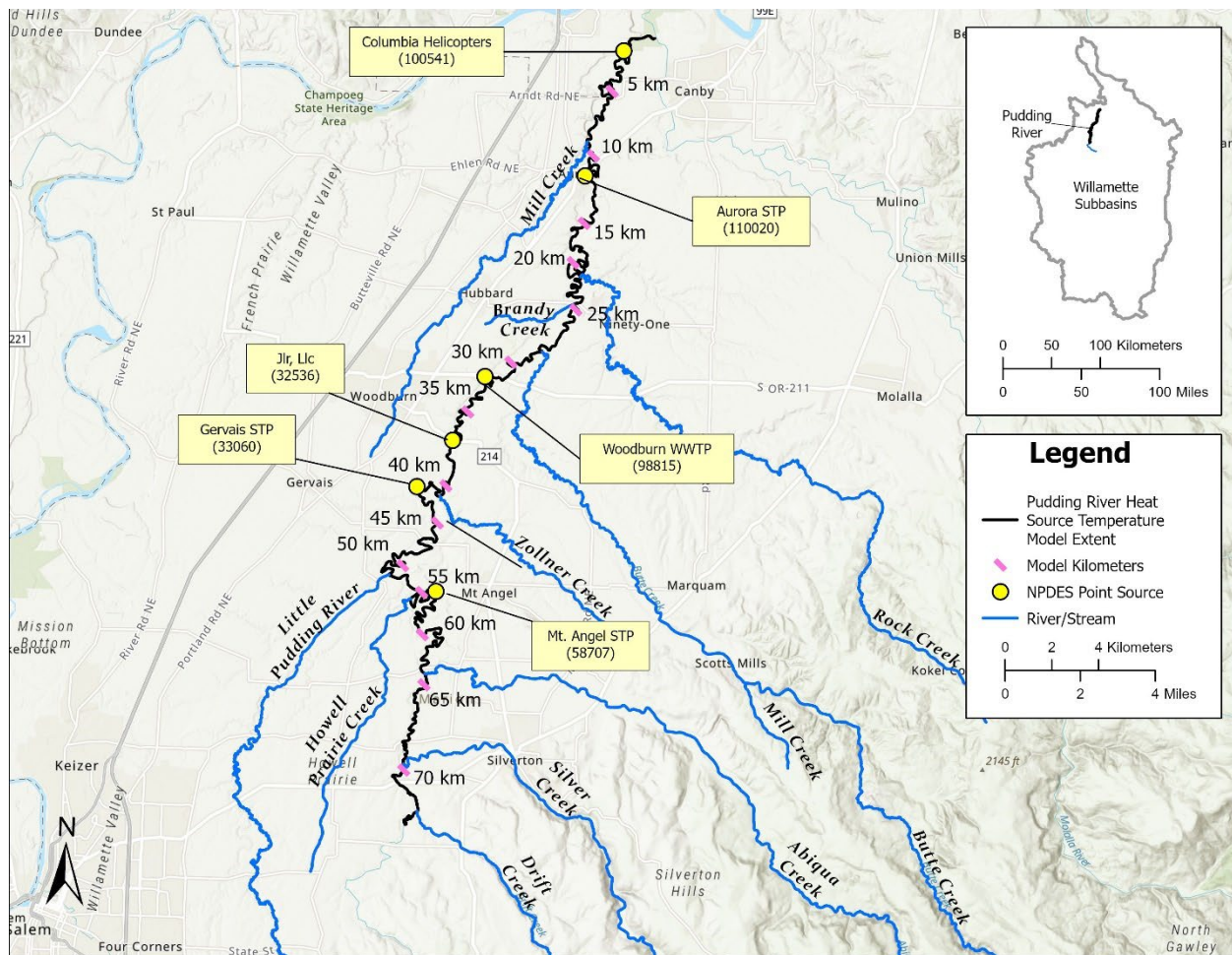
There are six permitted individual NPDES point sources along the model extent (**Figure 4-20**). Detail about each point source is summarized in **Table 3-23**.

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.

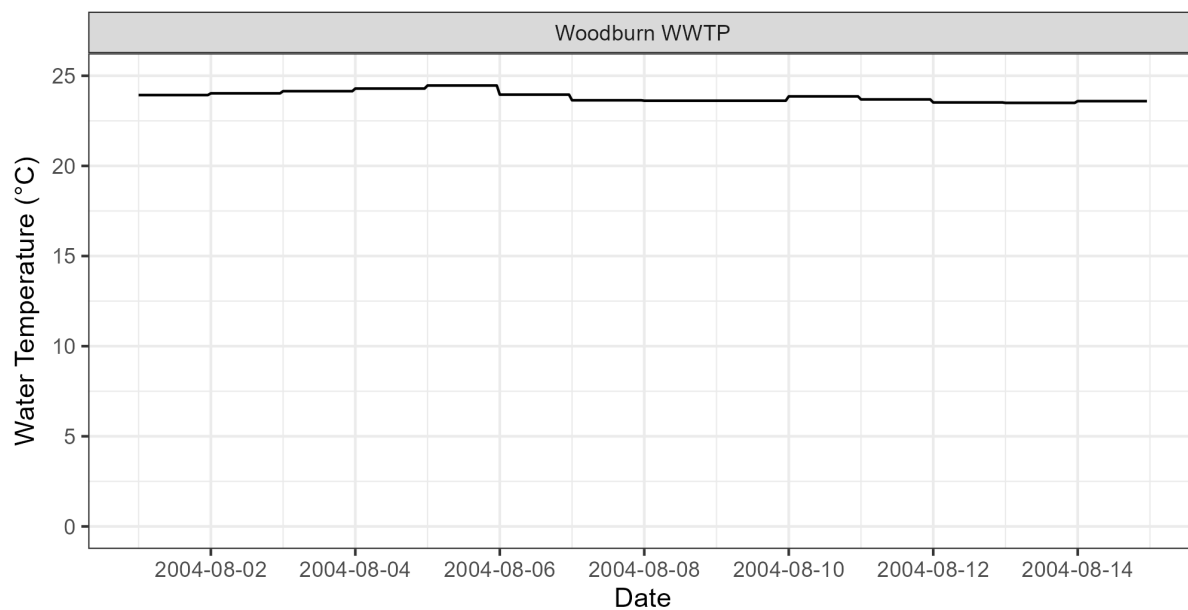
The JLR facility is allowed to discharge, but a review of DMRs from 2018 - 2020 showed that there have been no discharges in August during the model period. All discharges were land applied, therefore flow inputs to the model were set to zero. The 2004 calibrated model set JLR's discharge at 0.001 cms 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.

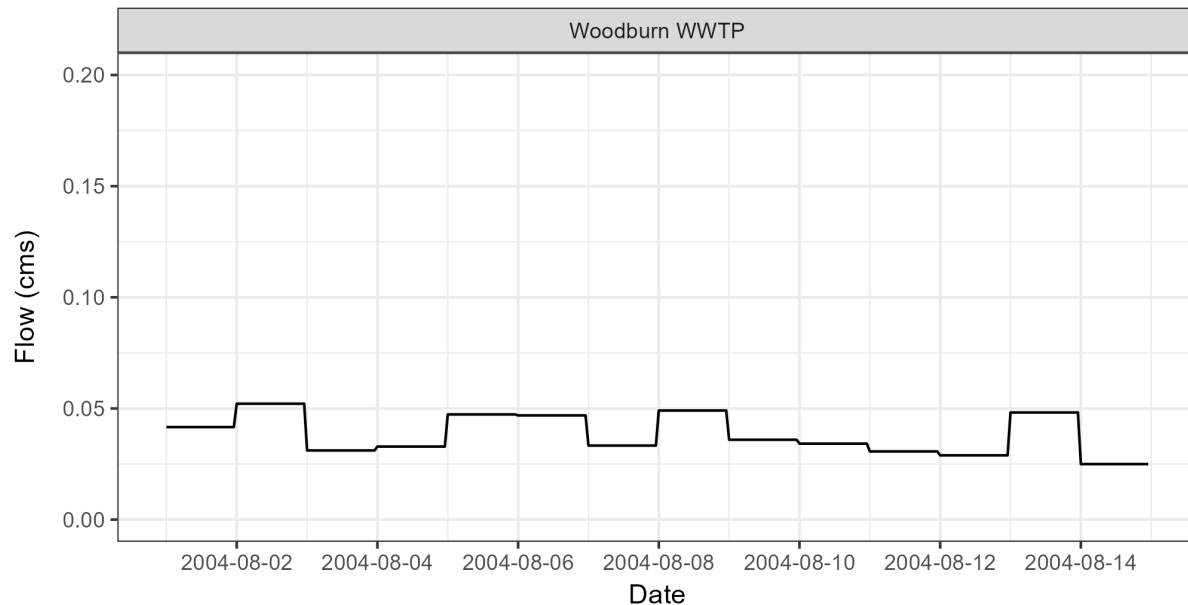
Columbia Helicopters is not included as point source to the model because DEQ considers wastewater from this site to have no reasonable potential to increase stream temperature in the Pudding River.



**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     |

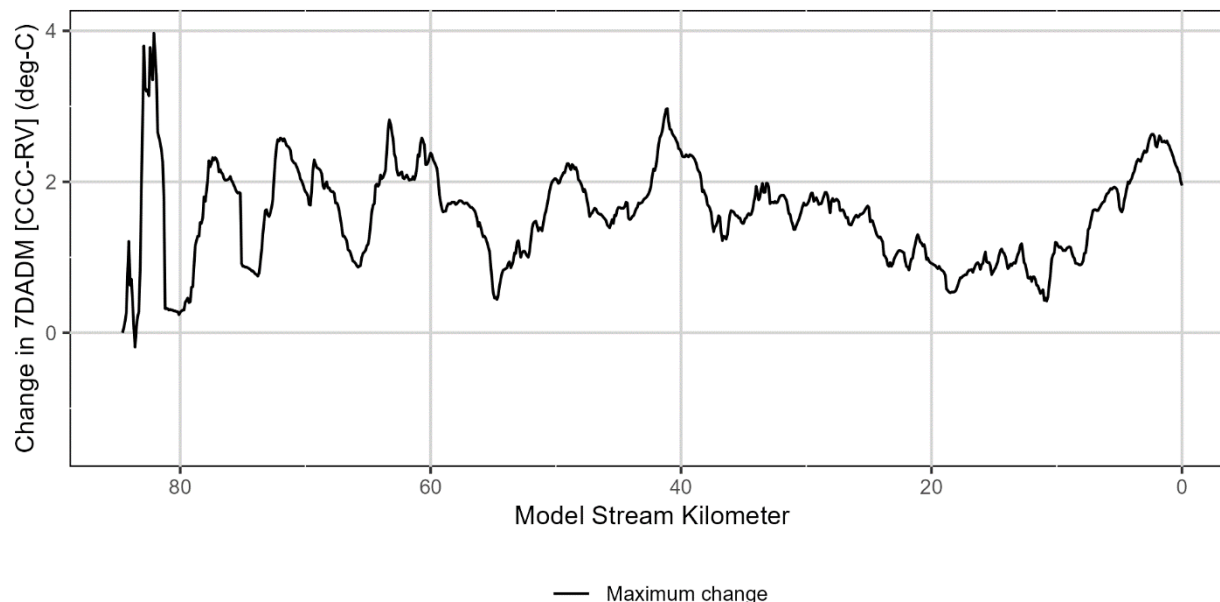
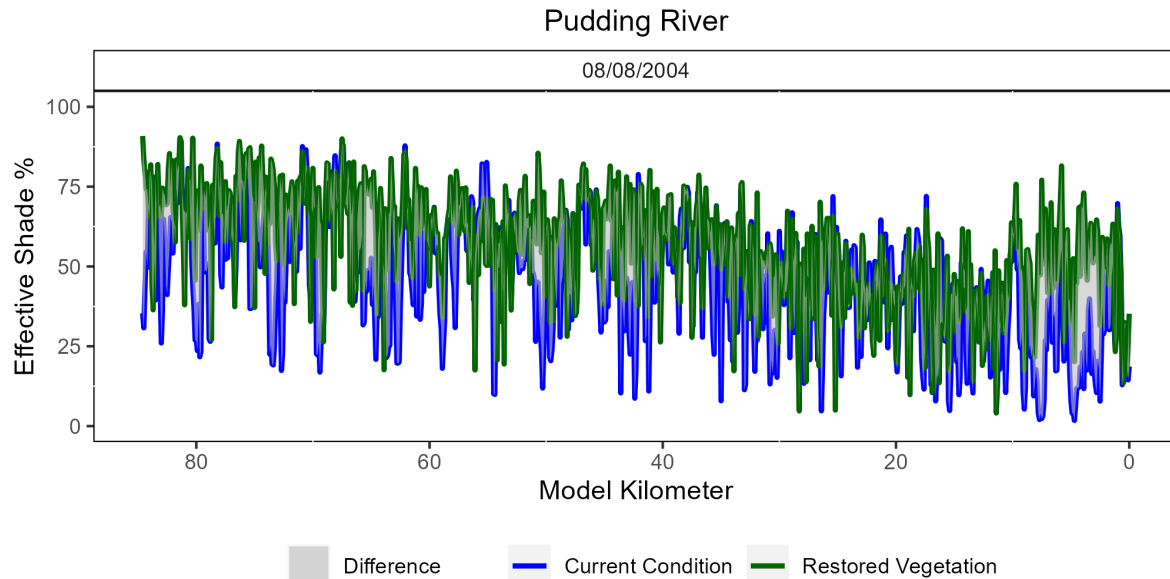


Figure 4-23: Change in the maximum 7DADM stream temperatures between Current Condition and Restored Vegetation scenarios for the Pudding River over the entire model period. Table 4-20 summarizes the mean effective shade for the Current Condition and Restored Vegetation scenarios for the Pudding River. The difference in mean effective shade between the scenarios is equal to 10.5 percentage points.

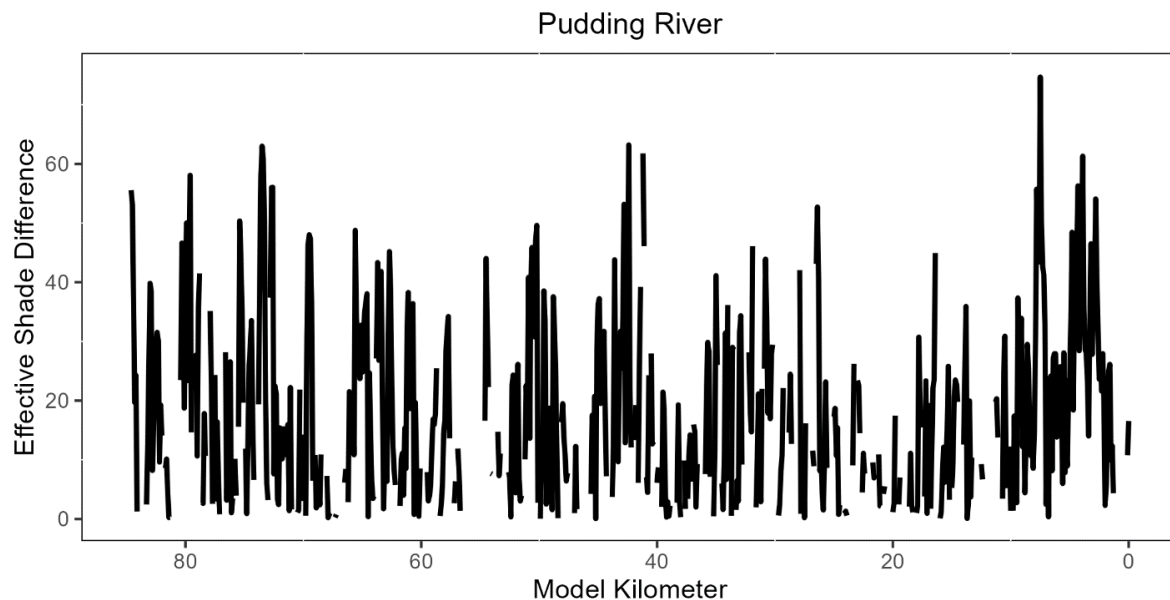
**Figure 4-24** and **Figure 4-25** compare effective shade predictions from the Current Condition and Restored Vegetation scenarios for the Pudding River.

**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

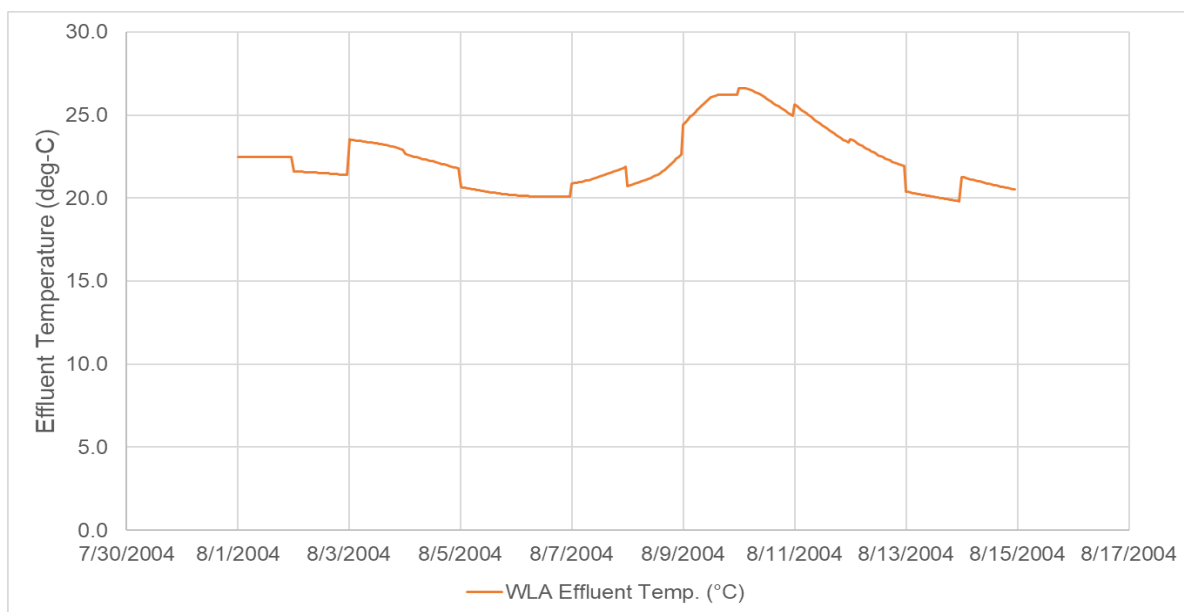
This section summarizes the temperature impacts of point sources discharging at their wasteload allocations. The impact of the wasteload allocations was determined by comparing the Wasteload Allocation scenario to the No Point Source scenario.

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.

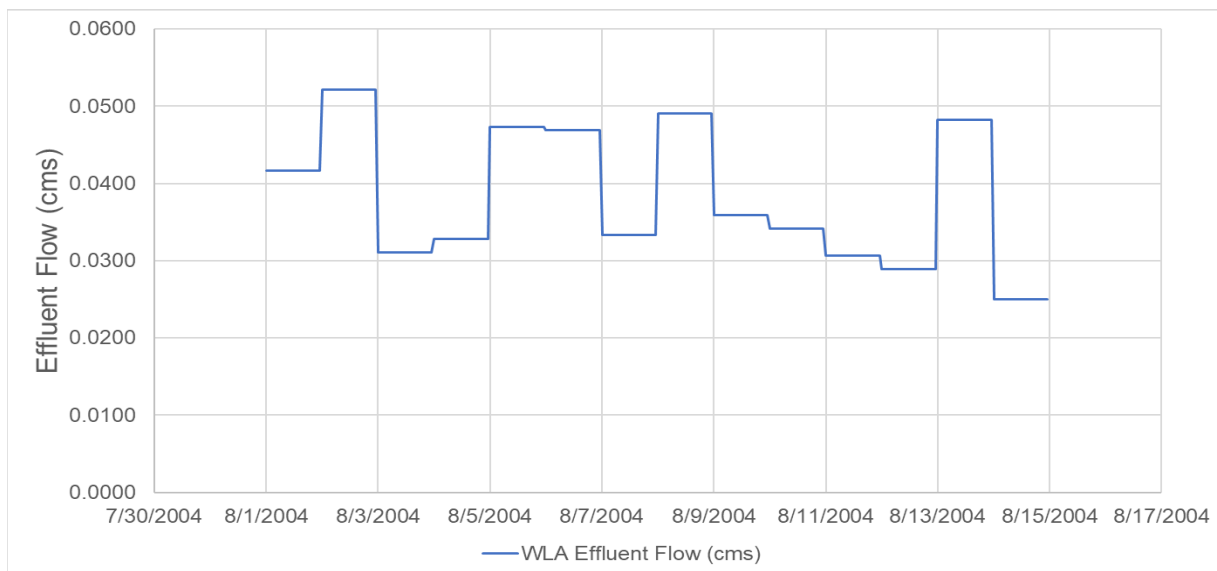
In the Wasteload Allocation scenario, effluent temperature and flow were equal to the wasteload allocations and calculated using equations described in the Willamette Subbasins TSD (Section 6.1.1 Wasteload allocation equation). Effluent flow inputs from individually permitted point source discharges 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. Error! Reference source not found. shows Woodburn WWTP daily maximum effluent temperatures that achieve the wasteload allocation. **Figure 4-27** shows Woodburn WWTP Wasteload Allocation effluent flow.

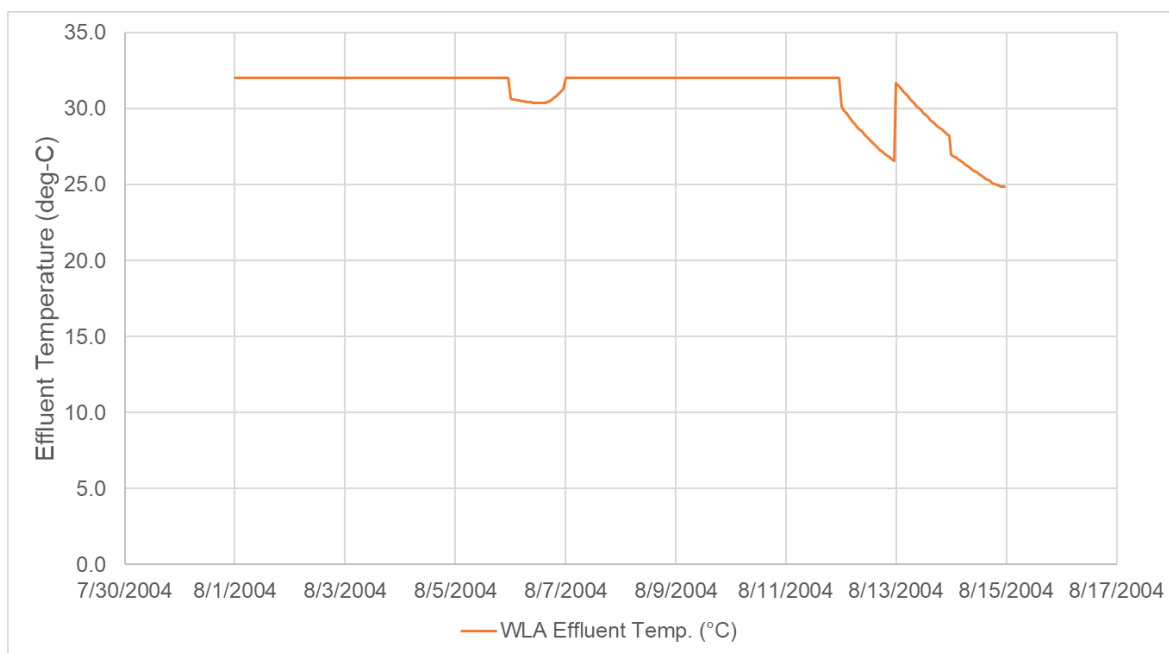
JLR does not discharge to the river during the summer. It is often land applied via outfall 004. For the allocation scenario, the discharge reported on the August 2022 DMR from outfall 004 was assumed to be the discharge to the Pudding River at outfall 001 (**Figure 4-28**). JLR's effluent temperature was updated to reflect their wasteload allocation (**Figure 4-29**). The portion of the HUA allocated to JLR was 0.01°C.



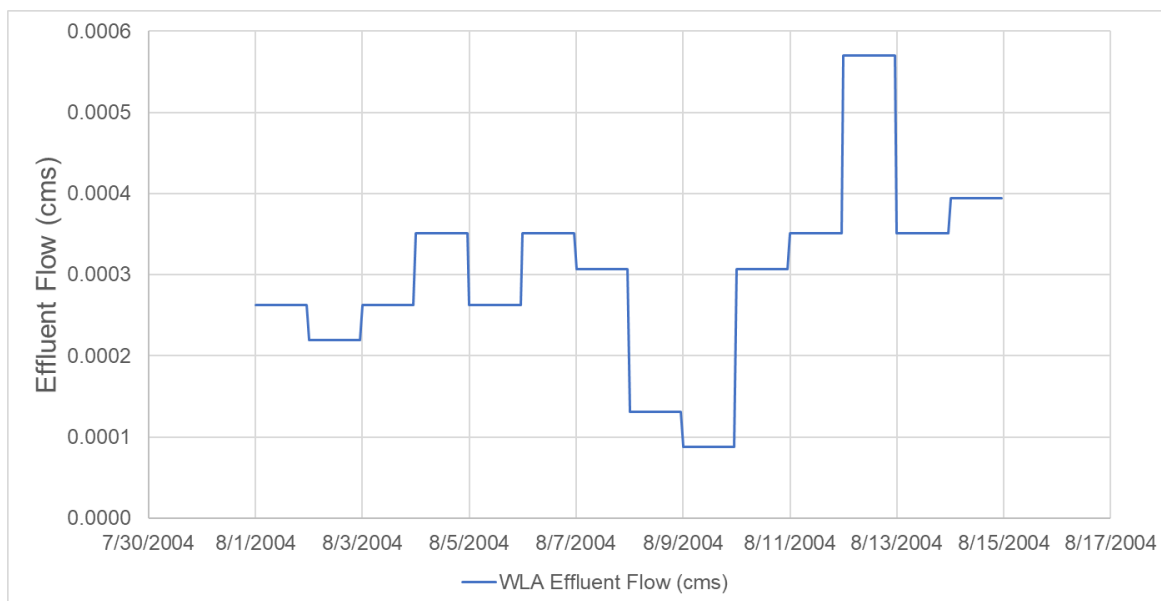
**Figure 4-26: Woodburn WWTP wasteload allocation model scenario effluent temperature (deg-C).**



**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.**

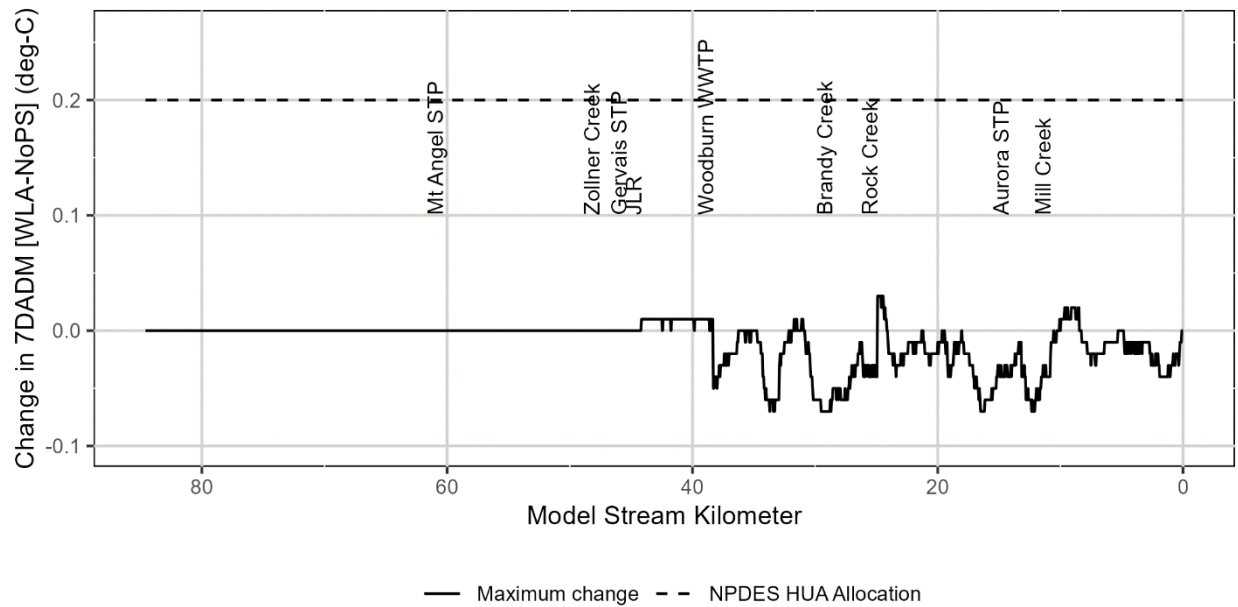
**Table 4-21** summarizes the 7DADM stream temperature change between the No Point Sources and Wasteload Allocations scenarios for the Pudding River. The results show that at the most downstream node (the outlet) the wasteload allocations do not impact 7DADM temperatures (0°C warming). At the POMI the 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

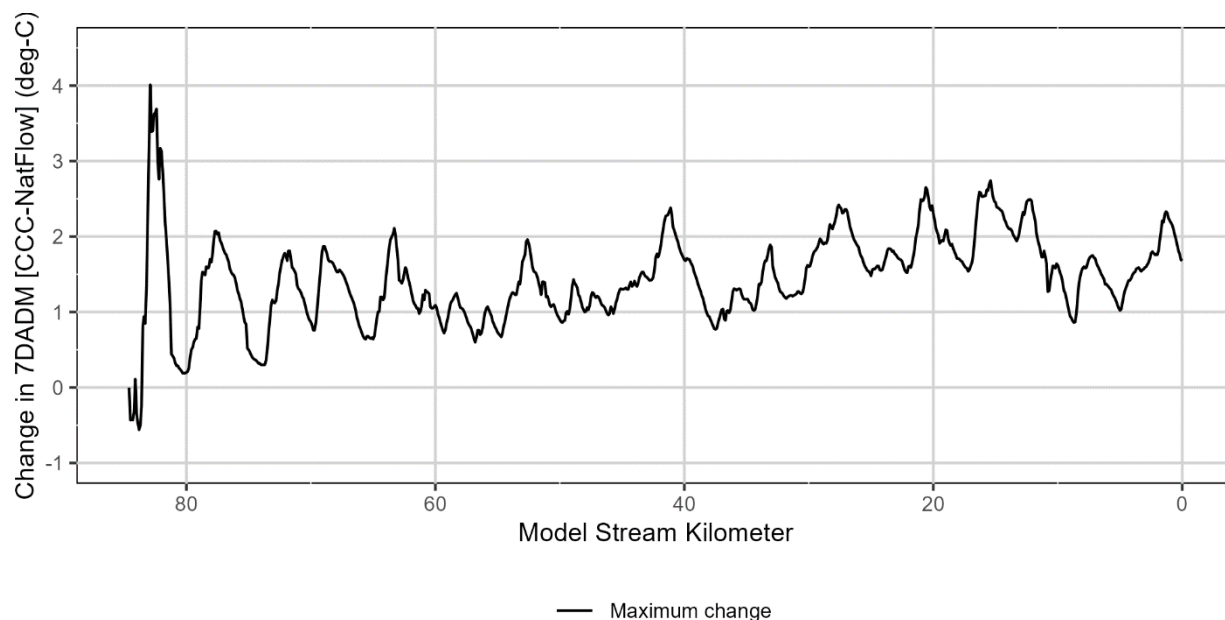
This section summarizes the temperature impacts of natural flow conditions.

**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.

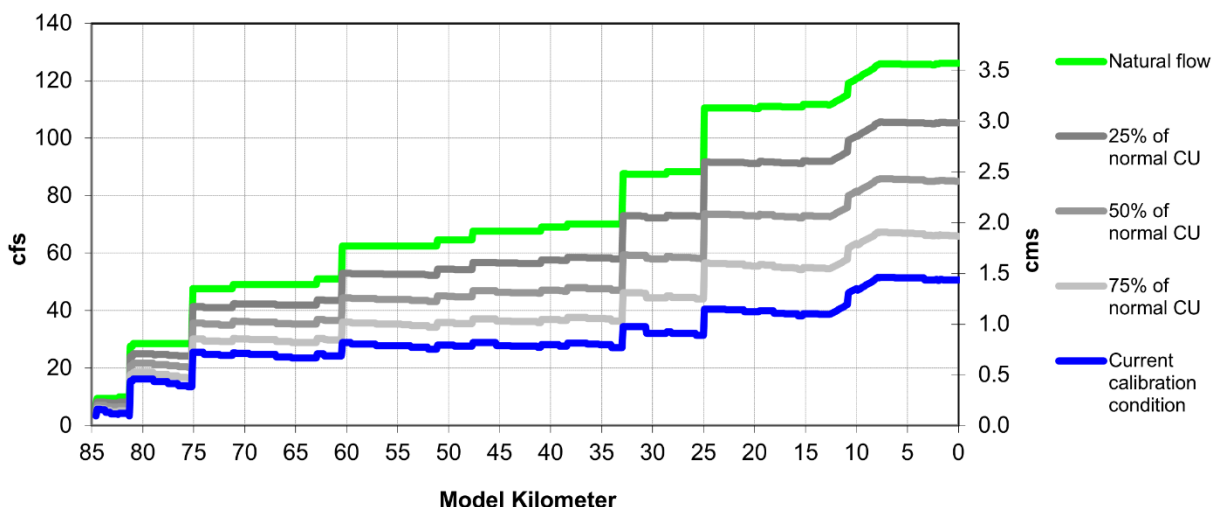
**Table 4-23: Inputs for Equation 3-2 for estimating daily natural flow at Pudding River model boundary condition and tributary flow input locations updated to create Natural Flow and Consumptive Use model scenarios.**

| Model Input Location   | Model KM | $Q_{R, AugMed}$<br>(cfs) | Drainage Area<br>(sq.mi) | $Q_{R, AugMed} /$<br>Drainage Area<br>(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                |

| Model Input Location  | Model KM | F%Consumed, Normal | QR,Natural,min |
|-----------------------|----------|--------------------|----------------|
| 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.**

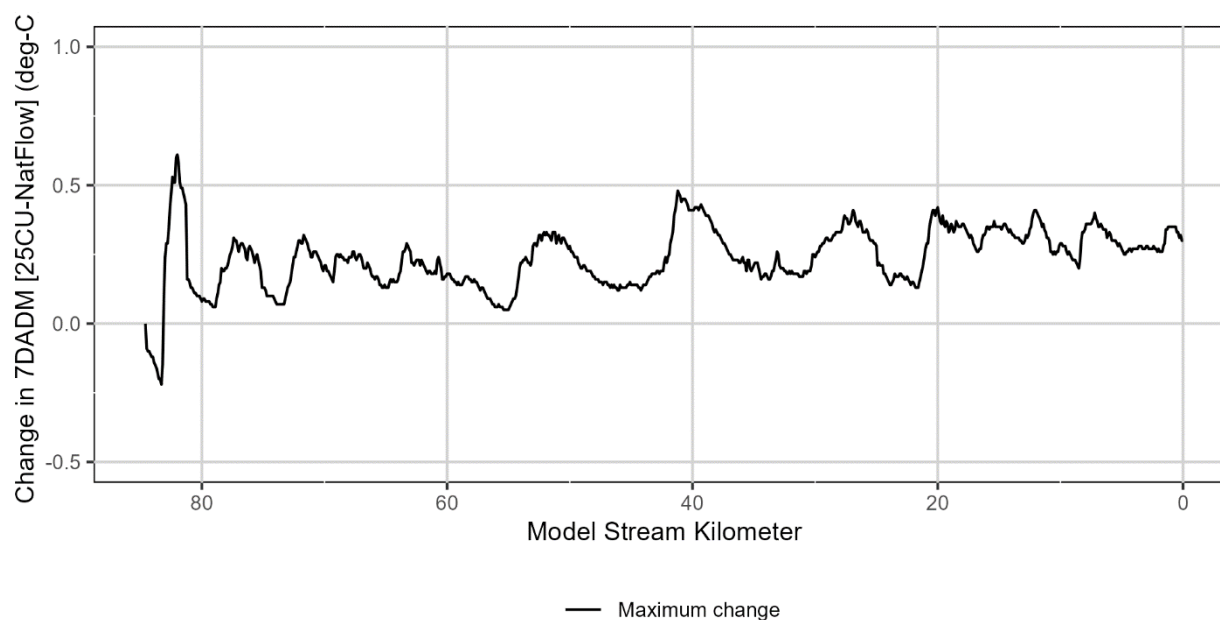
Natural flow was compared to several consumptive use reduction scenarios, including 25, 50, and 75 percent of typical August consumptive use. **Table 4-25** summarizes the maximum 7DADM stream temperature change between the Natural Flow and Consumptive Use scenarios for the Pudding River. A comparison 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.

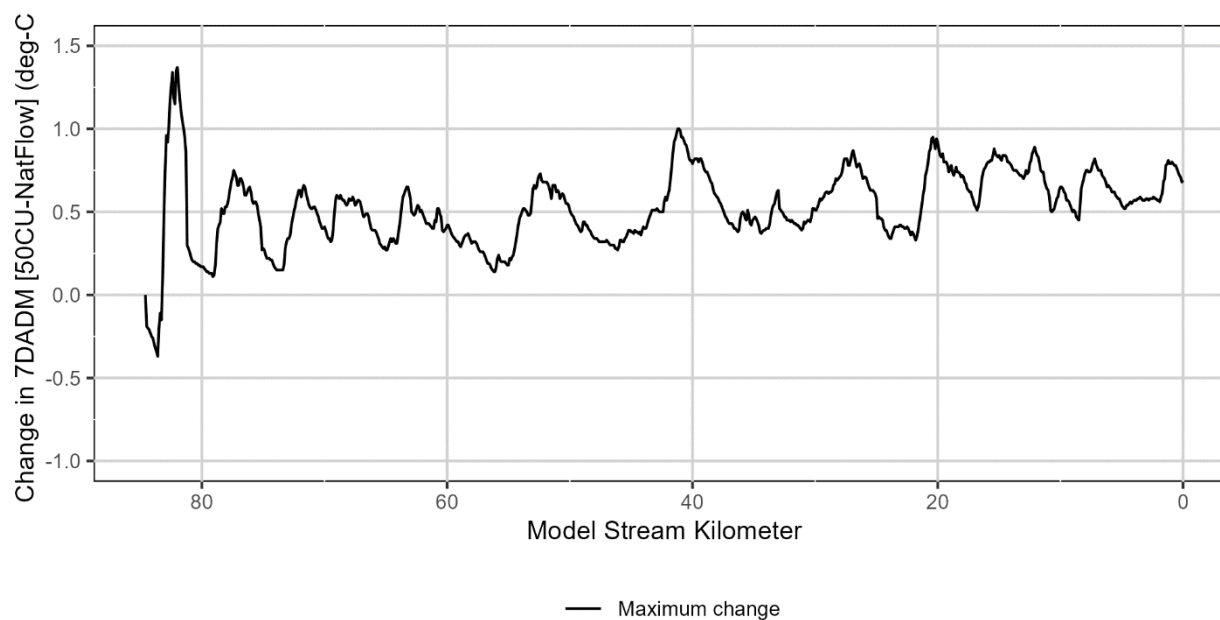
**Table 4-25: Summary of maximum 7DADM stream temperature change between Natural Flow and Consumptive Use model scenarios for the Pudding River over the entire model period.**

| 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 |

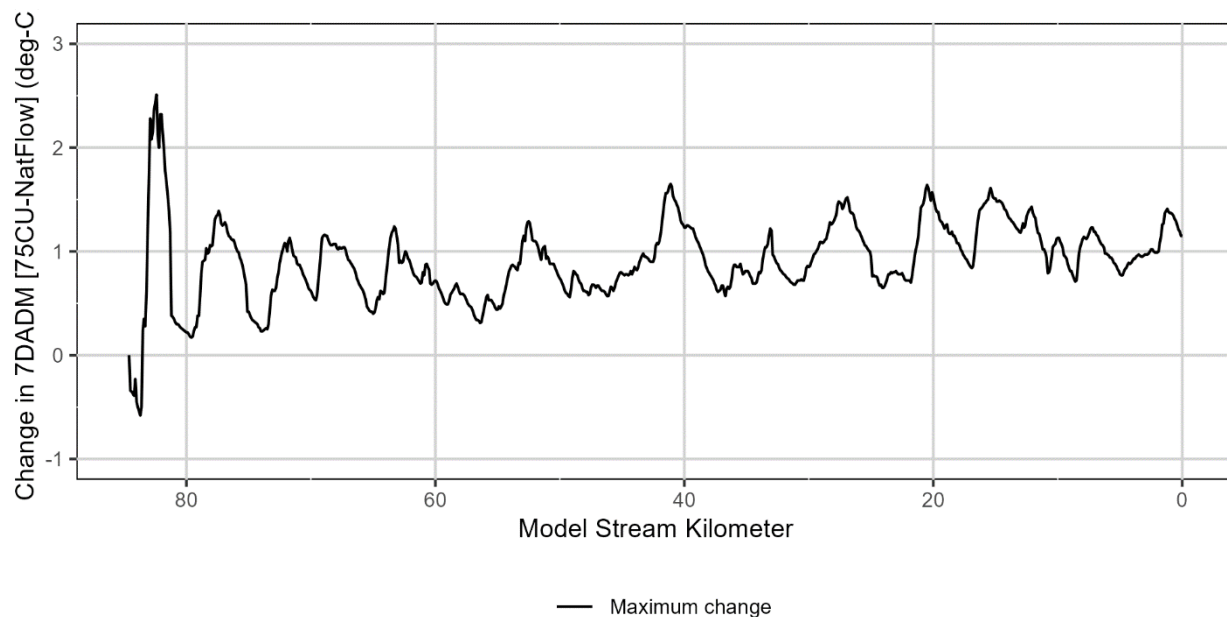
| Temperature Metric | Model KM | Scenario  | Stream Temperature (°C) | Location      |
|--------------------|----------|-----------|-------------------------|---------------|
| 7DADM              | 82.0     | 25CU - NF | 0.61                    | POMI          |
| 7DADM              | 0        | 25CU - NF | 0.3                     | outlet        |
| 7DADM              | 38.3     | 25CU - NF | 0.34                    | Woodburn Gage |



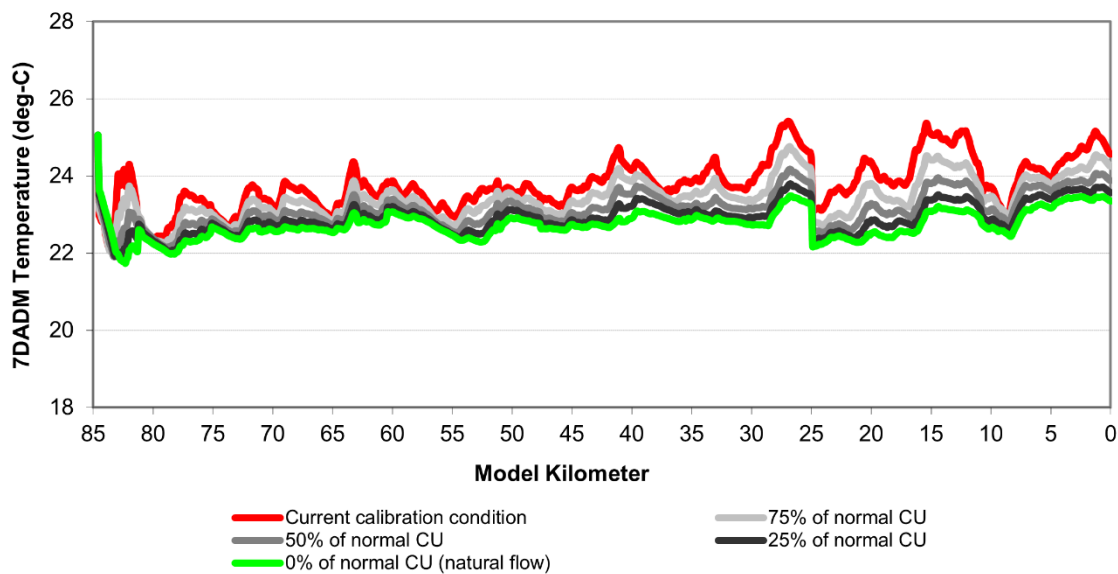
**Figure 4-33: 7DADM temperature difference between 25% of normal consumptive use and natural flow scenario for the Pudding River over the entire model period.**



**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

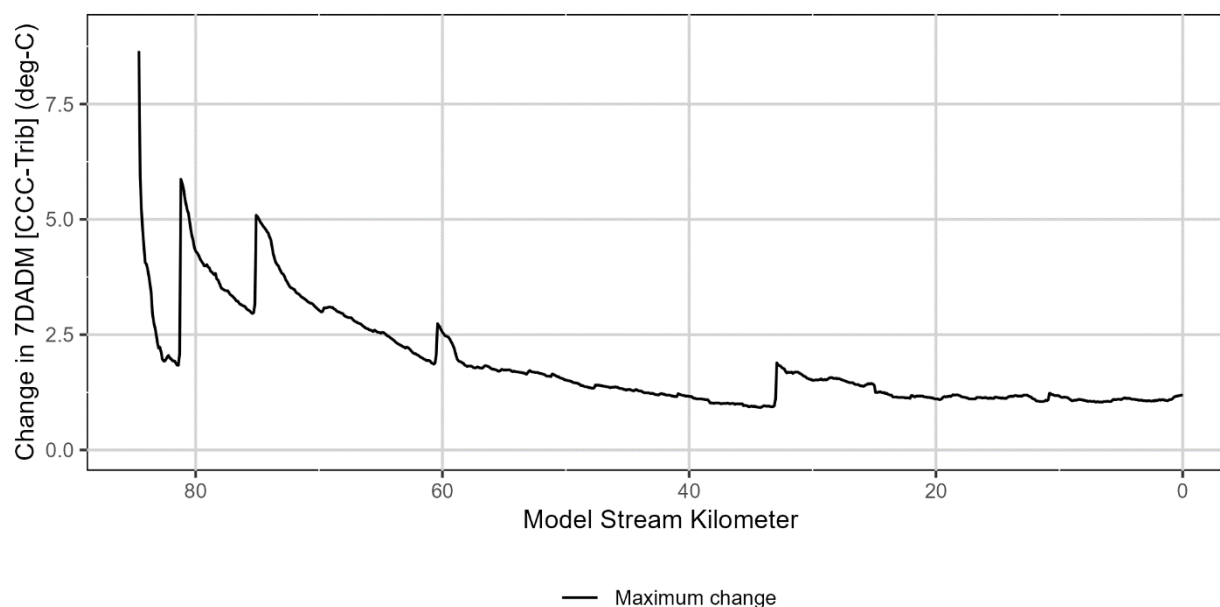
This section summarizes the temperature impacts of restored tributary temperatures.

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     |

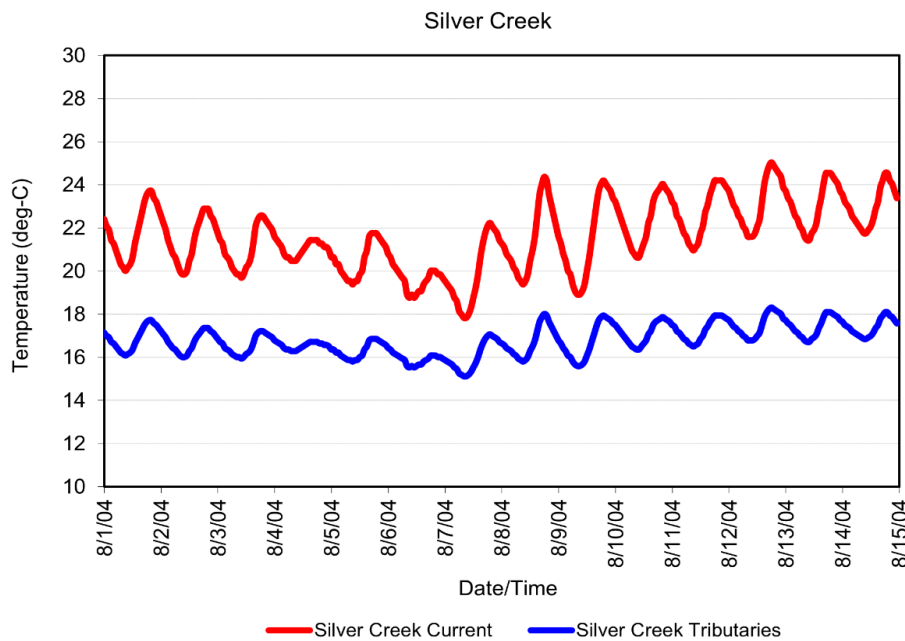


**Figure 4-37: Change in maximum 7DADM stream temperatures between the Current Condition and Tributary Temperatures scenarios for the Pudding River over the entire model period.**

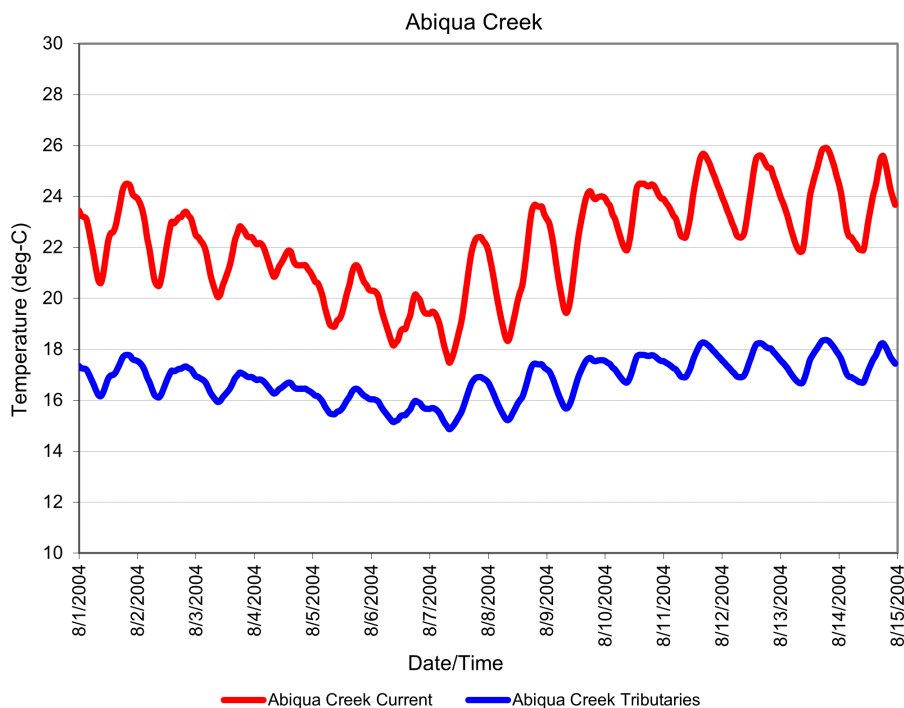
**Figure 4-38** through **Figure 4-46** show current and theoretical tributary temperatures that meet the biologically-based numeric criteria of 18°C for the Pudding River. Theoretical tributary temperatures were estimated using the following steps:

1. Calculate the rolling 24-hour average temperature for each hourly temperature input to the model.

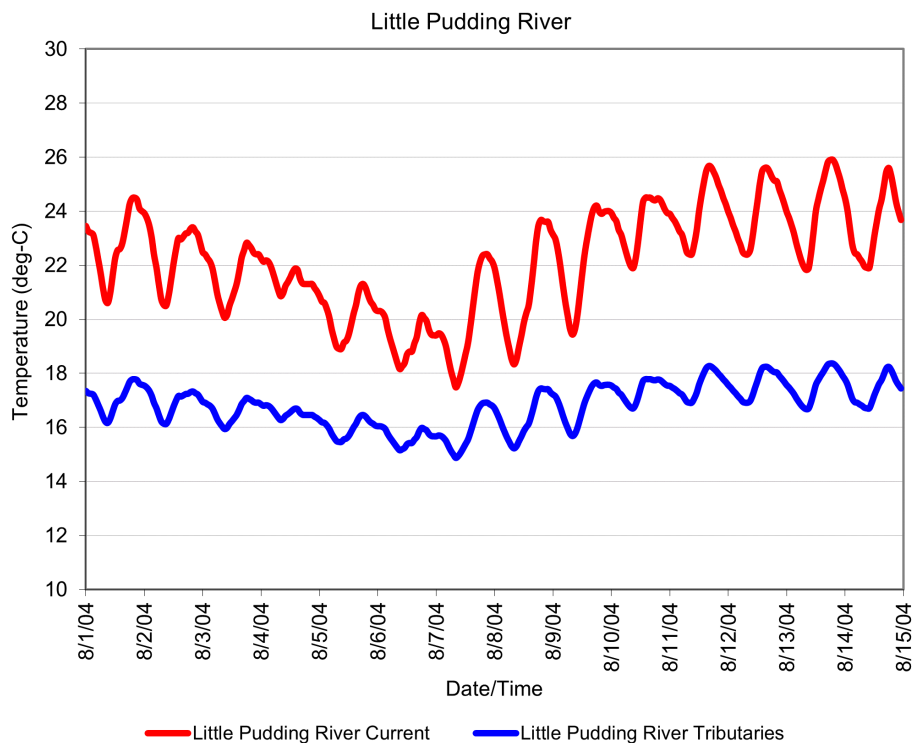
2. Subtract the rolling 24-hour average temperature from the associated hourly temperature input to calculate the difference between the two.
3. Reduce the difference between the rolling 24-hour average temperature and the hourly temperature input by 50%.
4. Add the 50% reduced difference between the 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.



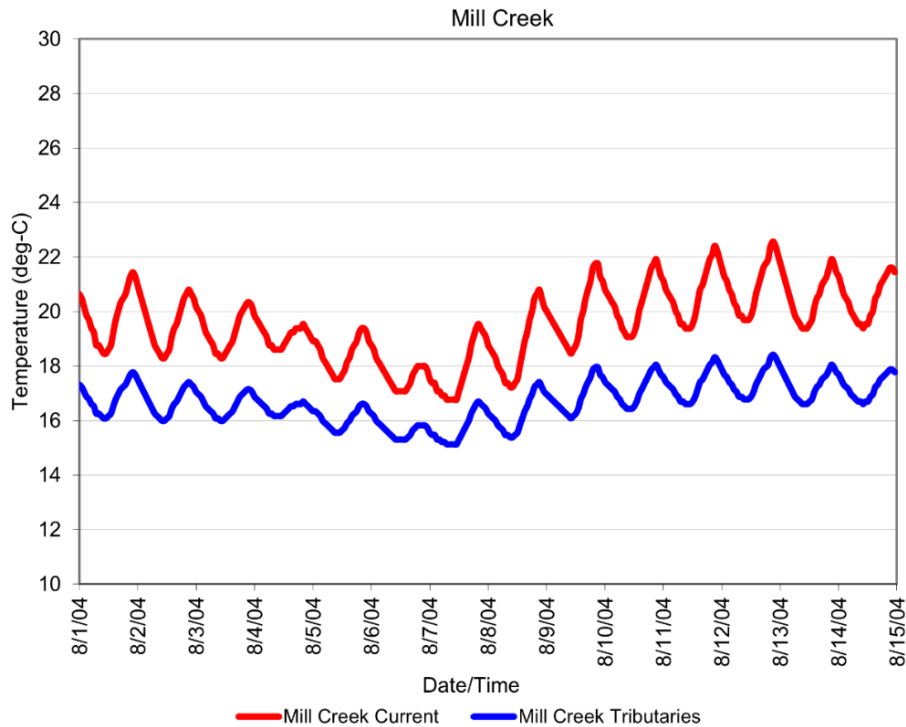
**Figure 4-38: Current temperatures for Silver Creek and theoretical tributary temperatures that meet the 18°C biological criterion.**



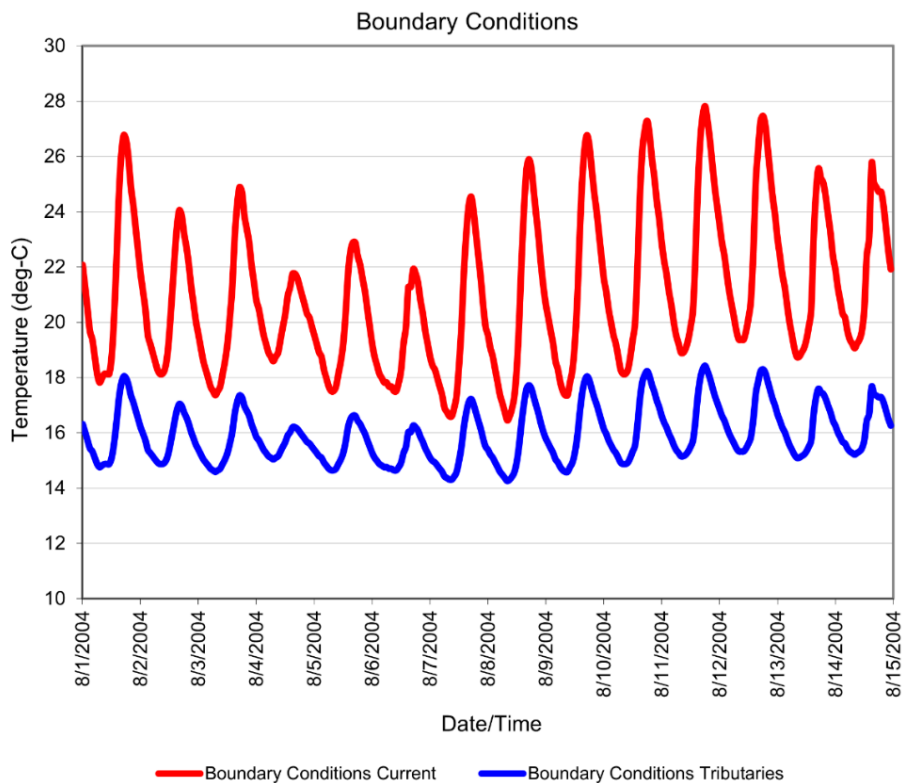
**Figure 4-39: Current temperatures for Abiqua Creek and theoretical tributary temperatures that meet the 18°C biological criterion.**



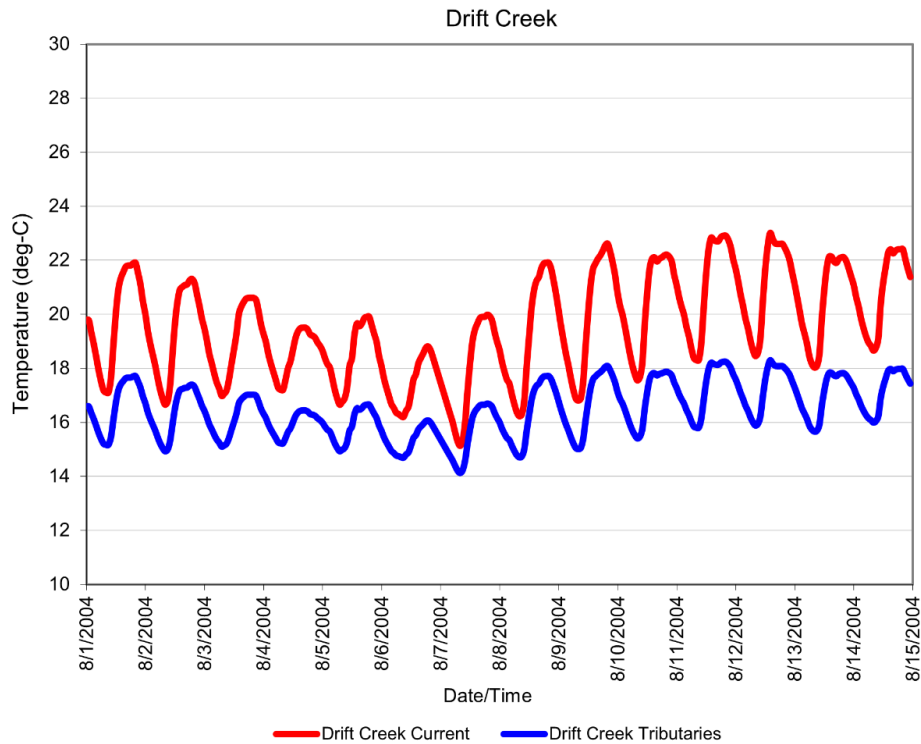
**Figure 4-40: Current temperatures for the Little Pudding River and theoretical tributary temperatures that meet the 18°C biological criterion.**



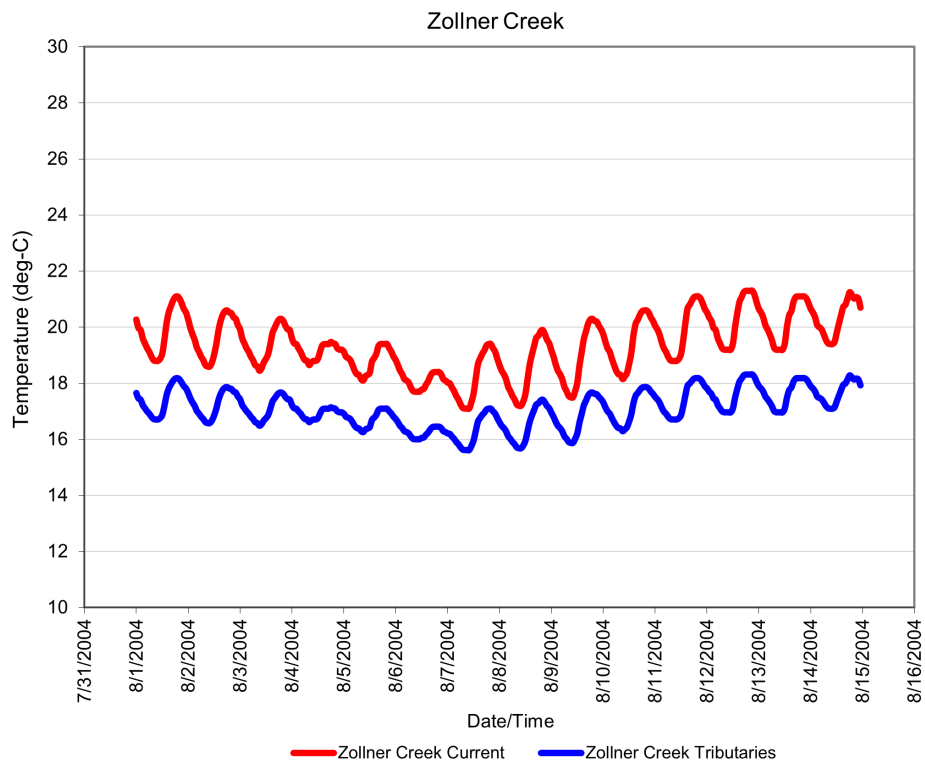
**Figure 4-41: Current temperatures for Mill Creek and theoretical tributary temperatures that meet the 18°C biological criterion.**



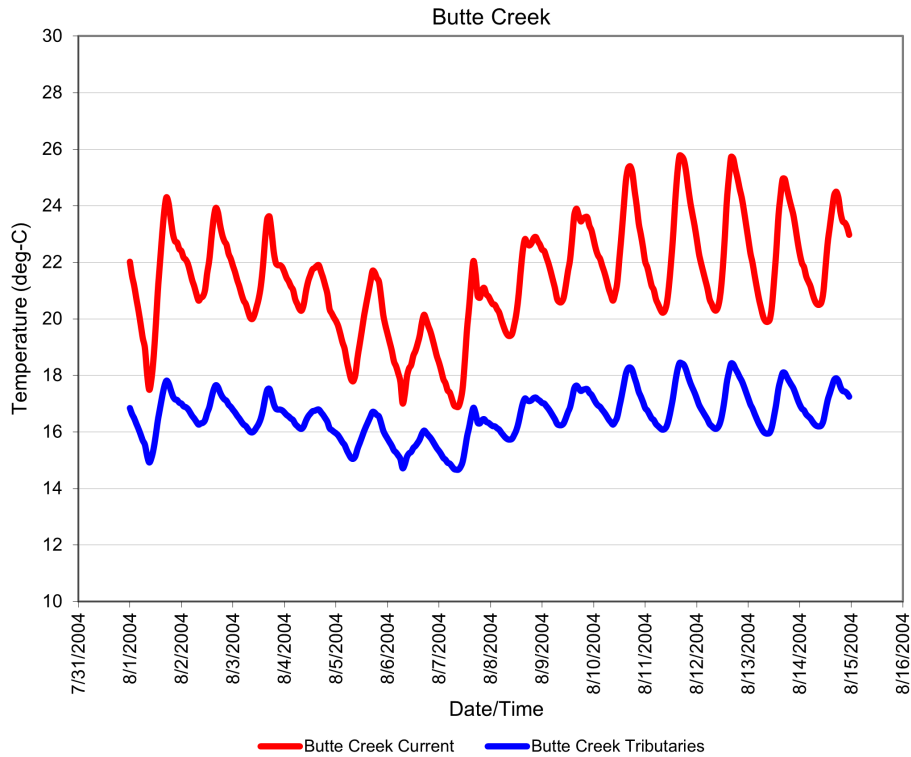
**Figure 4-42: Current temperatures for the Boundary Conditions and theoretical tributary temperatures that meet the 18°C biological criterion.**



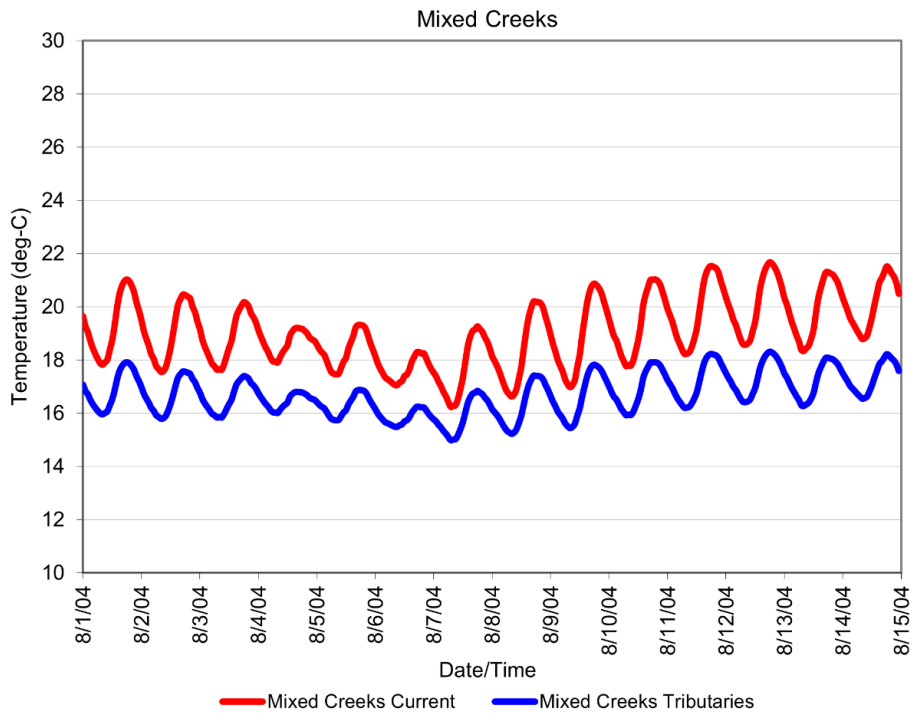
**Figure 4-43: Current temperatures for Drift Creek and theoretical tributary temperatures that meet the 18°C biological criterion.**



**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

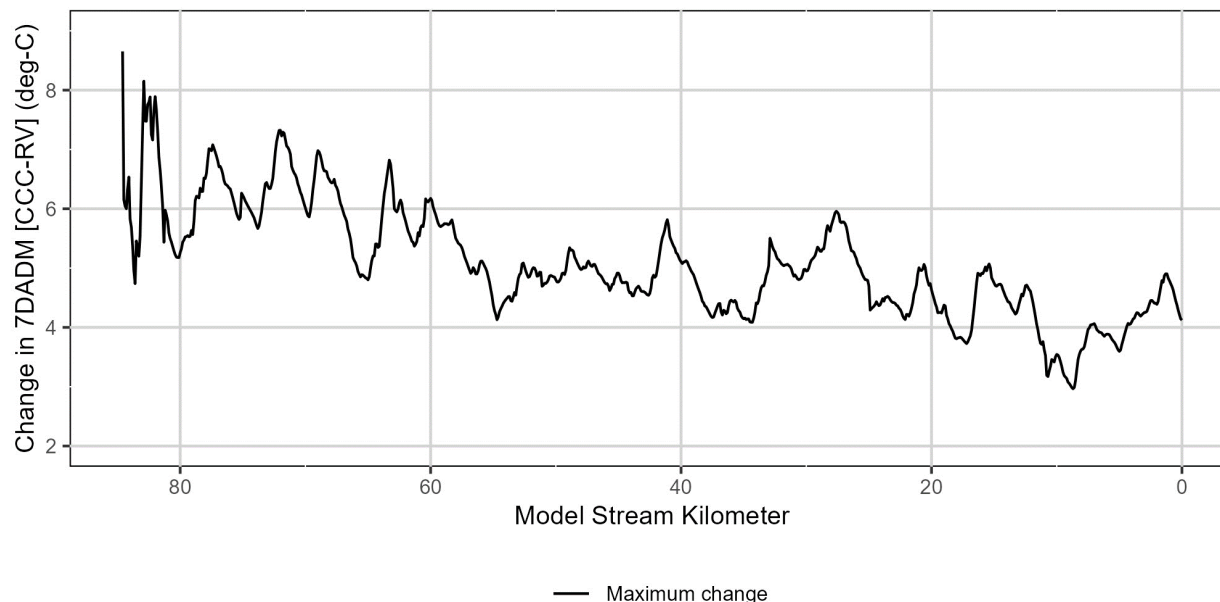
This section summarizes the temperature impacts of background conditions.

**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.

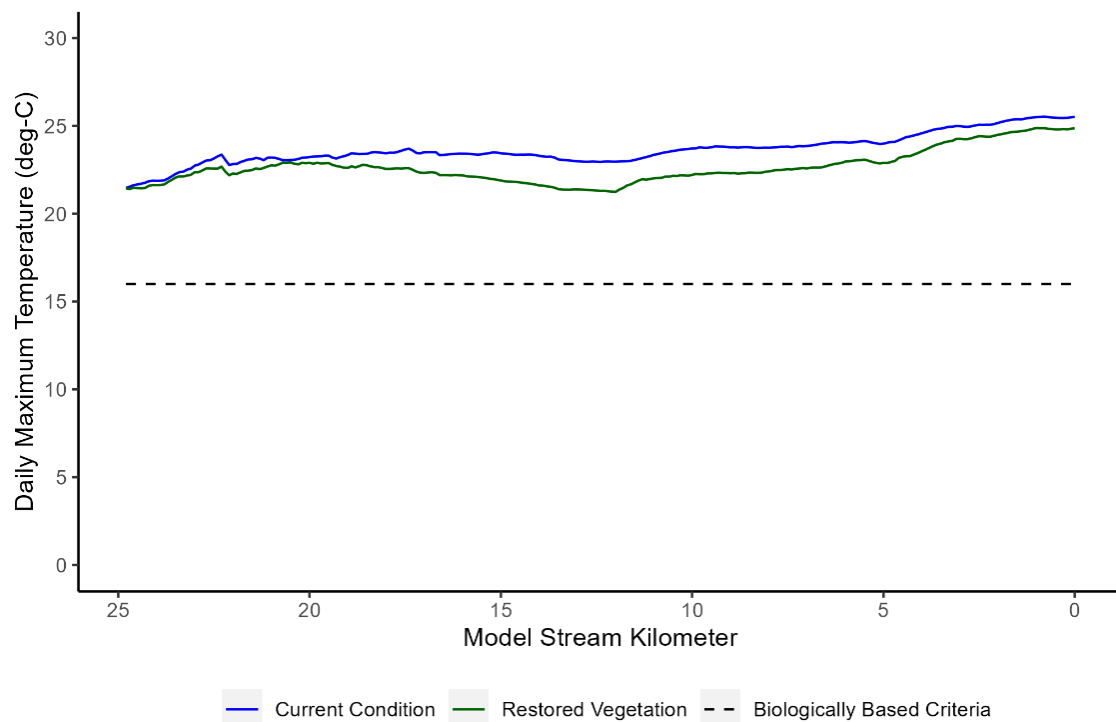
**Figure 4-48** shows the predicted daily maximum stream temperatures for the Current Condition and Restored Vegetation model scenarios for the Little North Santiam River.

**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.

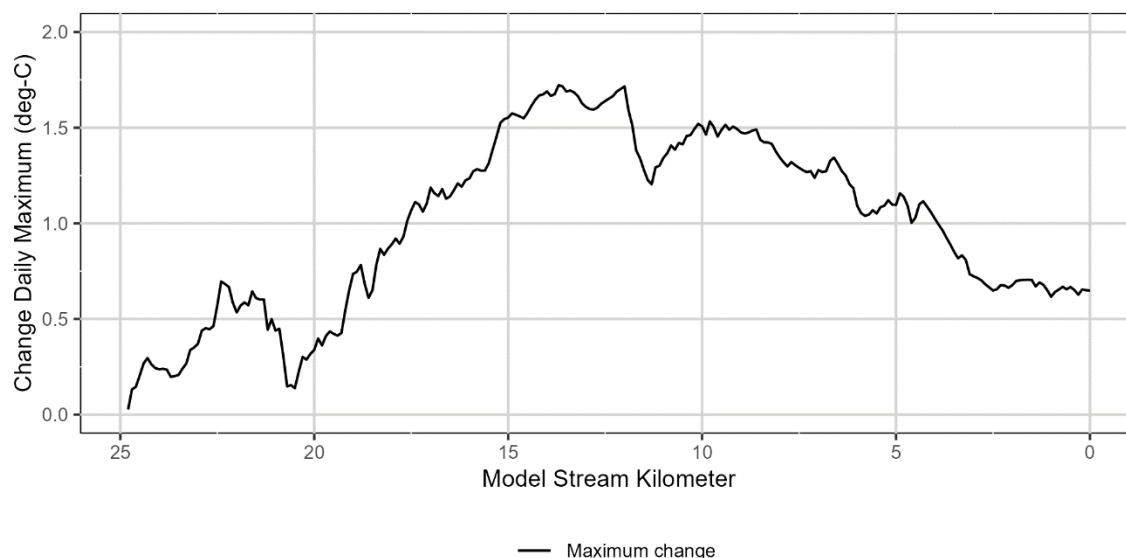
**Table 4-30** summarizes the daily maximum stream temperature change between the Current Condition and Restored Vegetation scenarios for the Little North Santiam River. It shows the daily maximum temperature difference at the most downstream node (the outlet) is equal to 0.65°C. In addition, the greatest 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     |



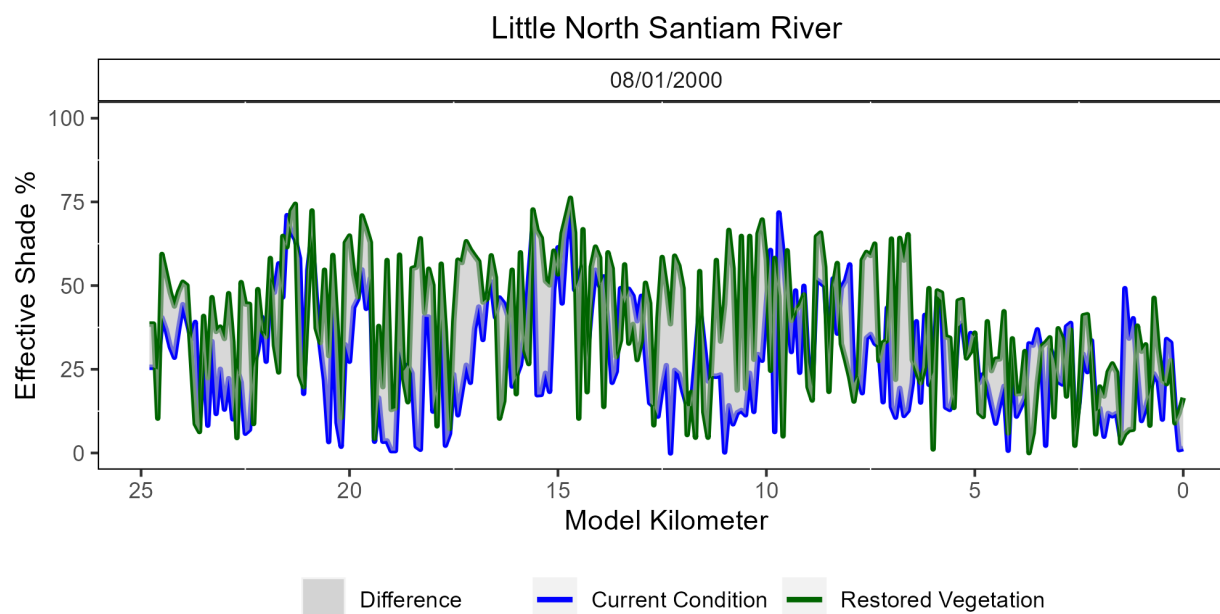
**Figure 4-49: Change in the daily maximum stream temperatures between the Current Condition and Restored Vegetation model scenarios for the Little North Santiam River over the entire model period.**

**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.

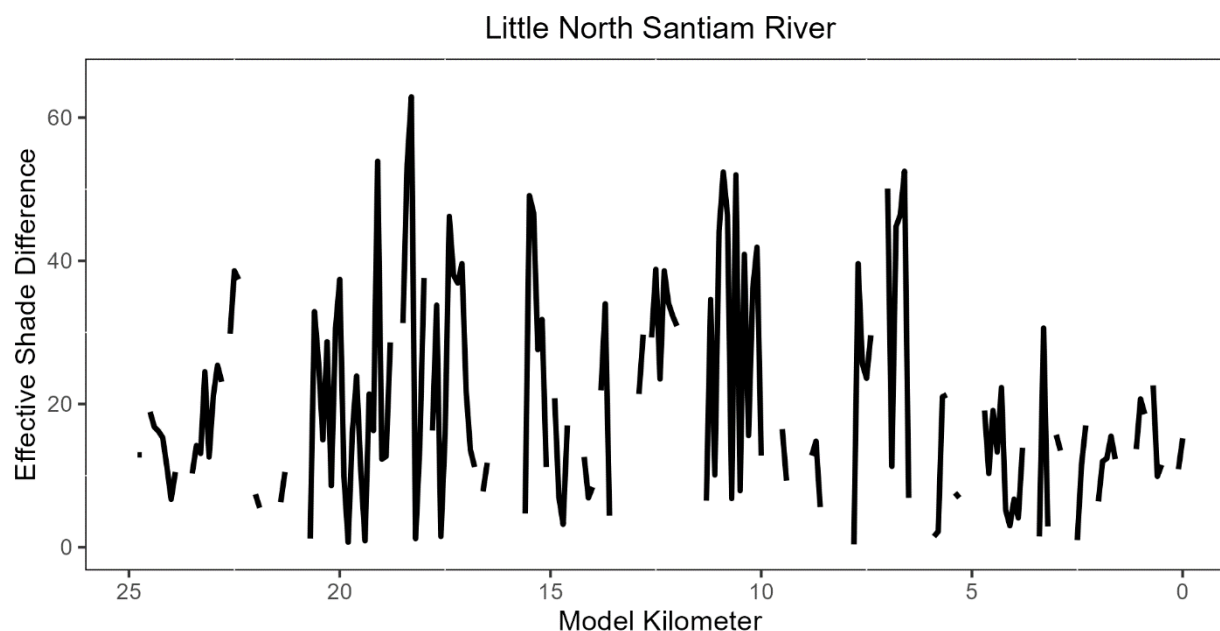
**Figure 4-50** and **Figure 4-51** compare effective shade predictions from the Current Condition and Restored Vegetation scenarios for the Little North Santiam River.

**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.

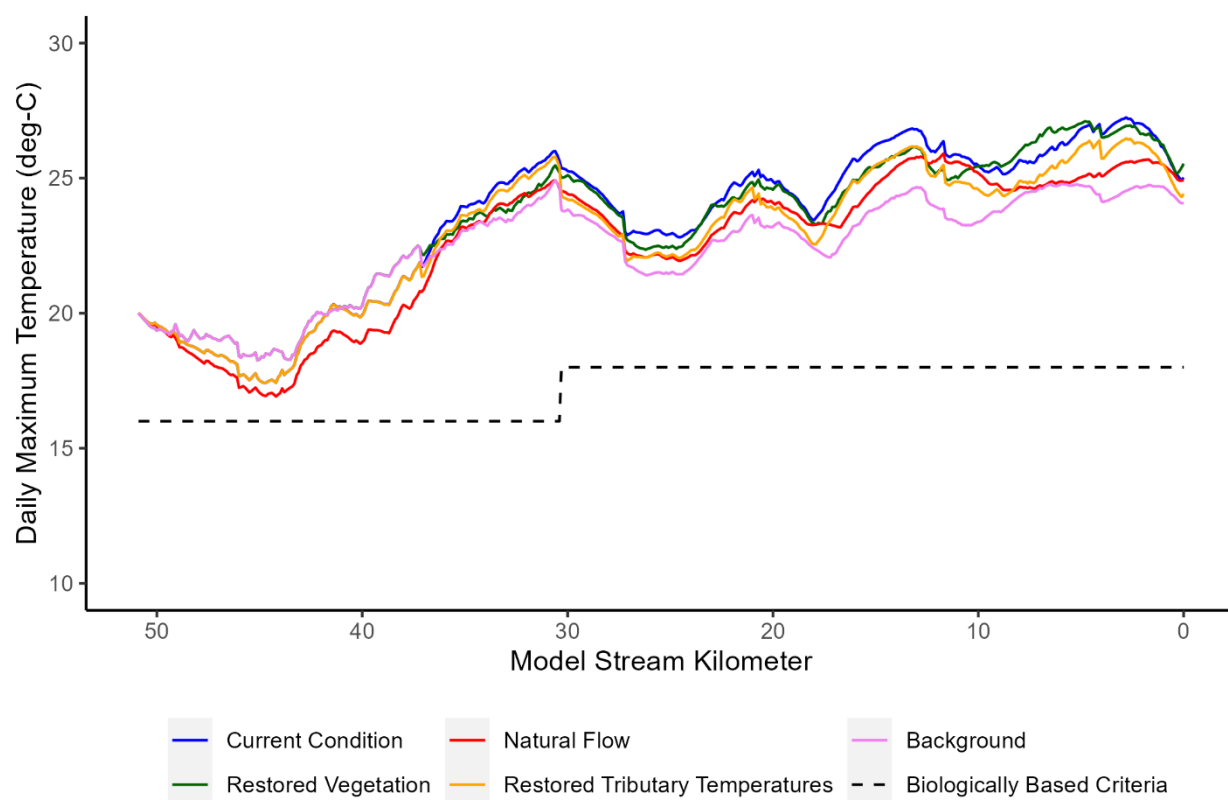
**Table 4-32: Thomas Creek model scenario descriptions.**

| 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 (16/18°C)   |

| Scenario Name | Description   |
|---------------|---|
| Background    | Restored Vegetation Land Cover (Vegetation) Conditions<br><br>Tributaries Maximum Biological Criteria (16/18°C)<br><br>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.

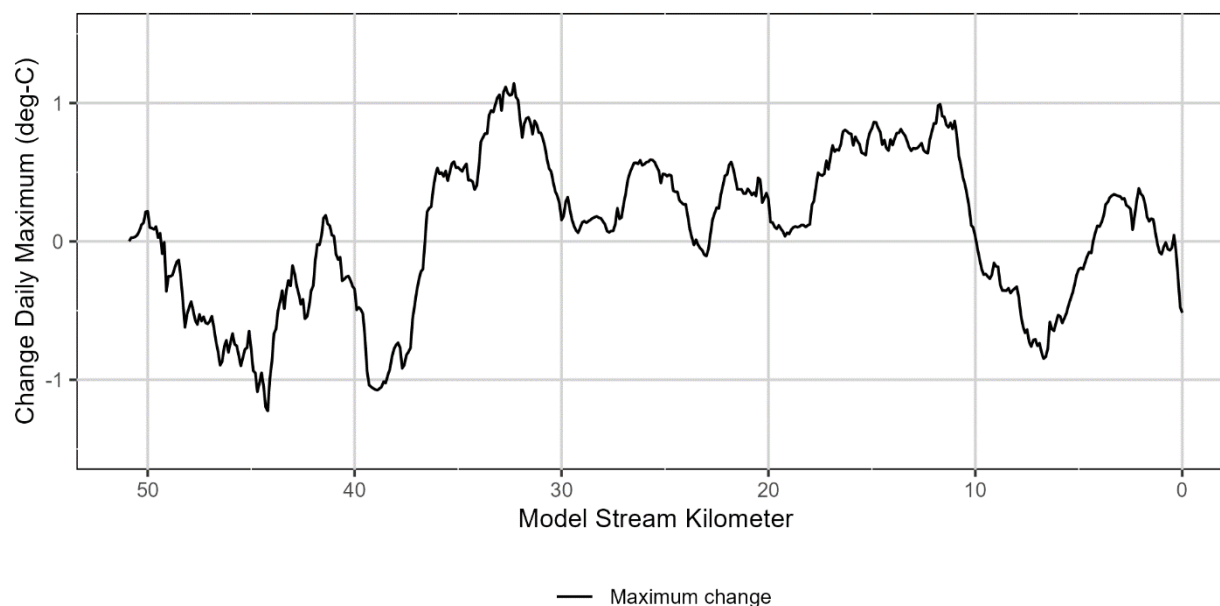
**Table 4-34** summarizes the maximum 7DADM stream temperature change between the Current Condition and Restored Vegetation scenarios for Thomas Creek. It shows the 7DADM temperature difference at the most downstream node (the outlet) is equal to  $-0.52^{\circ}\text{C}$ . This indicates that the Current 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  $1.14^{\circ}\text{C}$  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 ( $^{\circ}\text{C}$ ) | Location |
|--------------------|----------|----------|---|----------|
| Daily Maximum      | 0        | Change   | -0.52                                     | Outlet   |
| Daily Maximum      | 32.3     | Change   | 1.14                                      | POMI     |



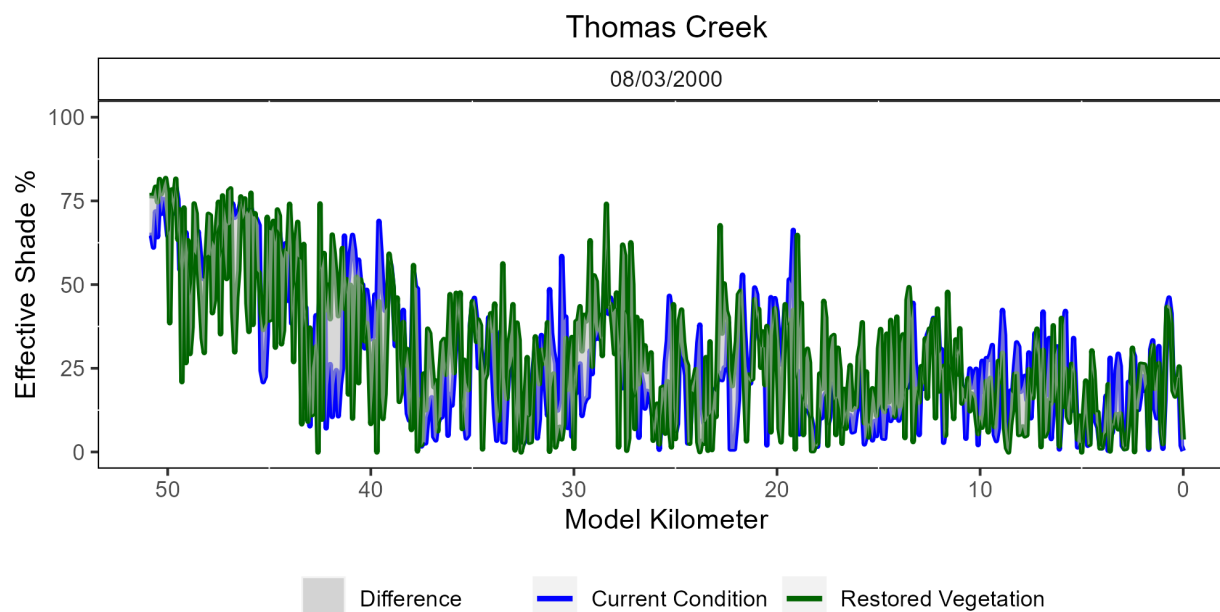
**Figure 4-53: Change in the daily maximum stream temperatures between the Current Condition and Restored Vegetation model scenarios for Thomas Creek over the entire model period.**

**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.

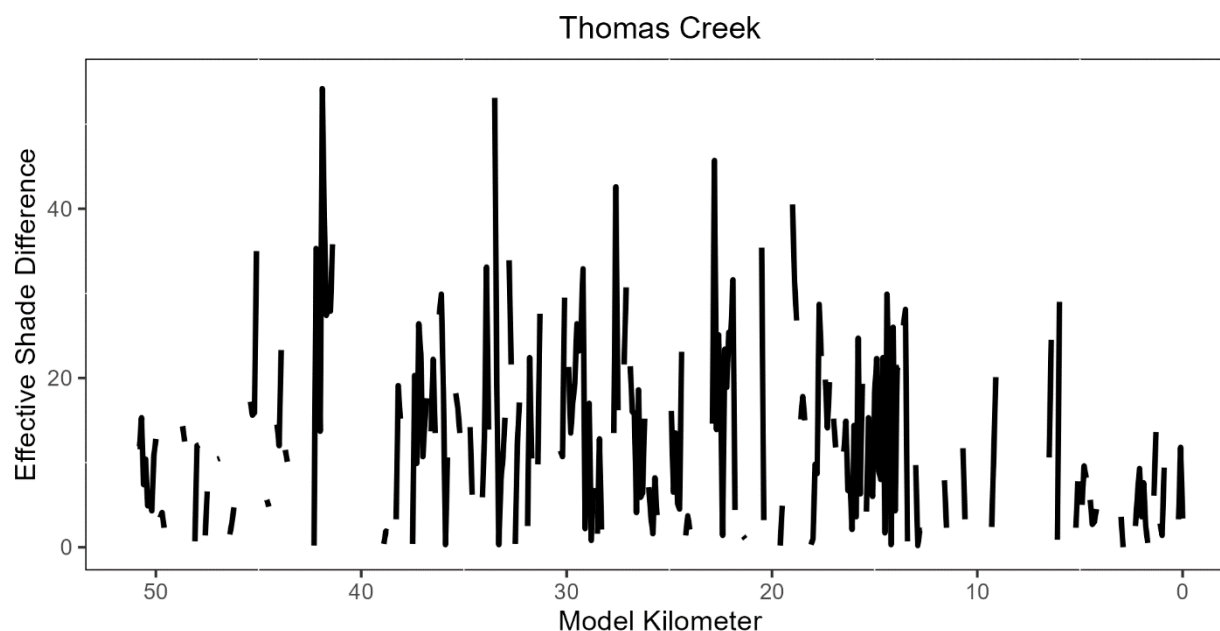
**Figure 4-54** and **Figure 4-55** compare effective shade predictions from the Current Condition and Restored Vegetation scenarios for Thomas Creek.

**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.**

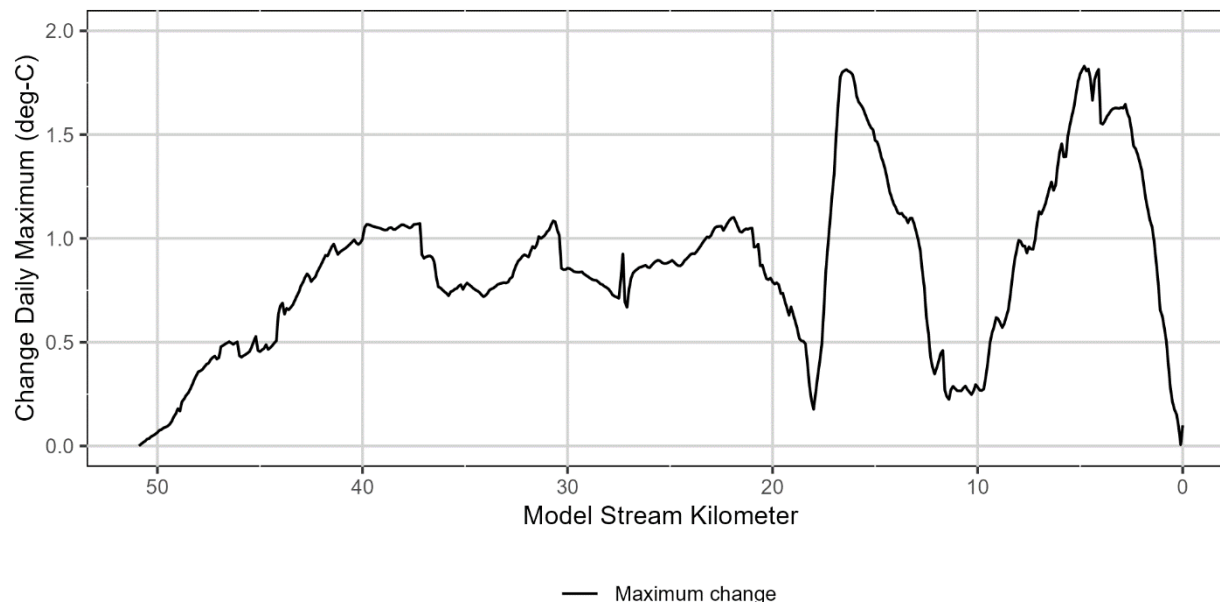
## 4.6.2 Natural Flow

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.**

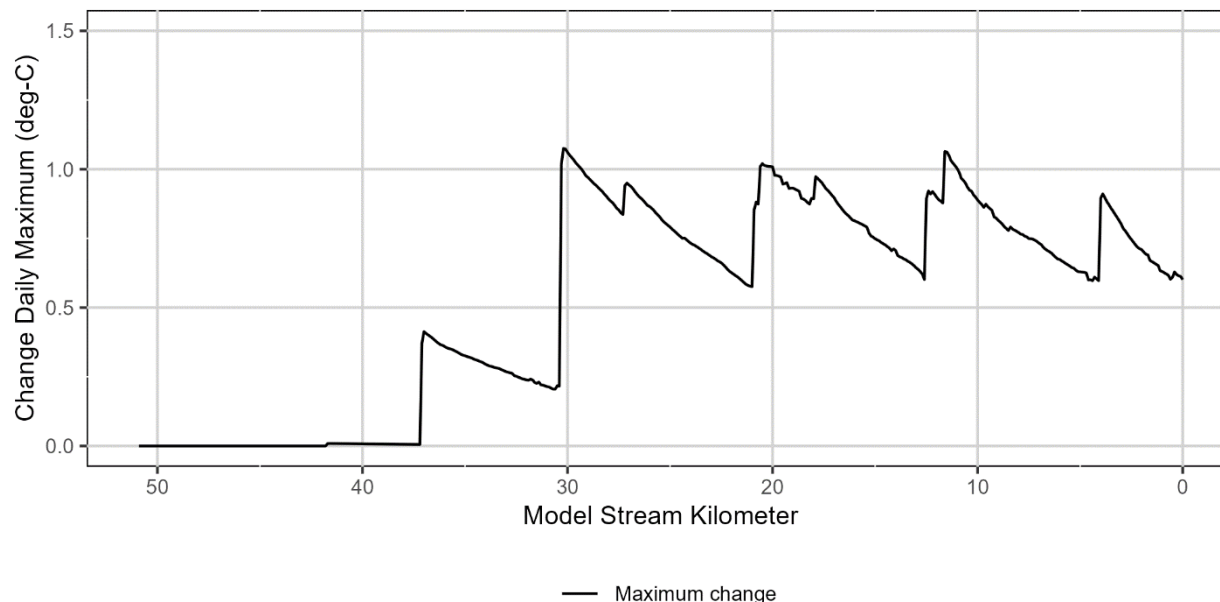
### 4.6.3 Tributary Temperatures

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

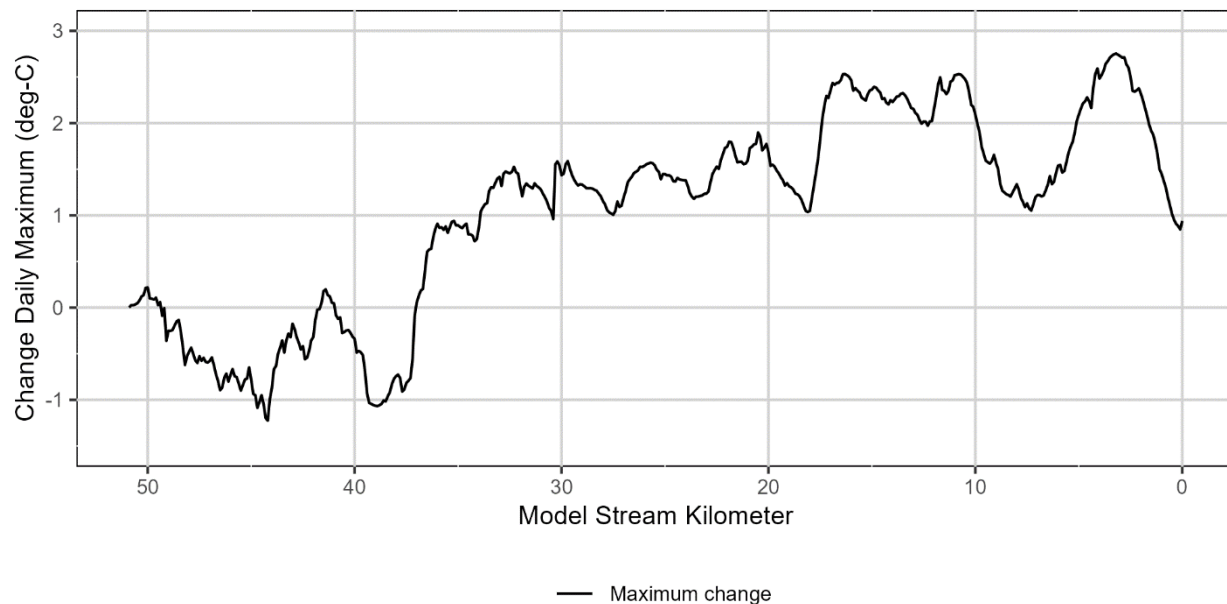
This section summarizes the temperature impacts of background conditions.

**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.

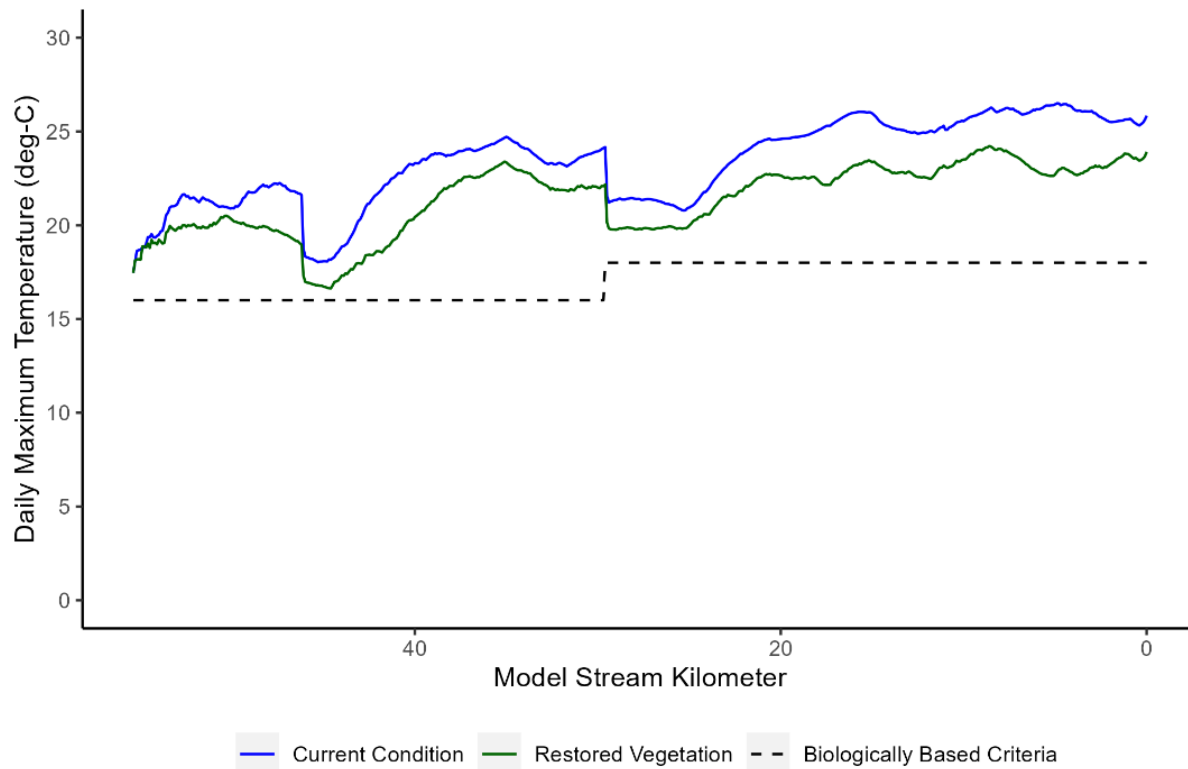
**Table 4-40** summarizes the daily maximum stream temperatures predicted at the mouth of Crabtree Creek for the Current Condition and Restored Vegetation model scenarios.

**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.

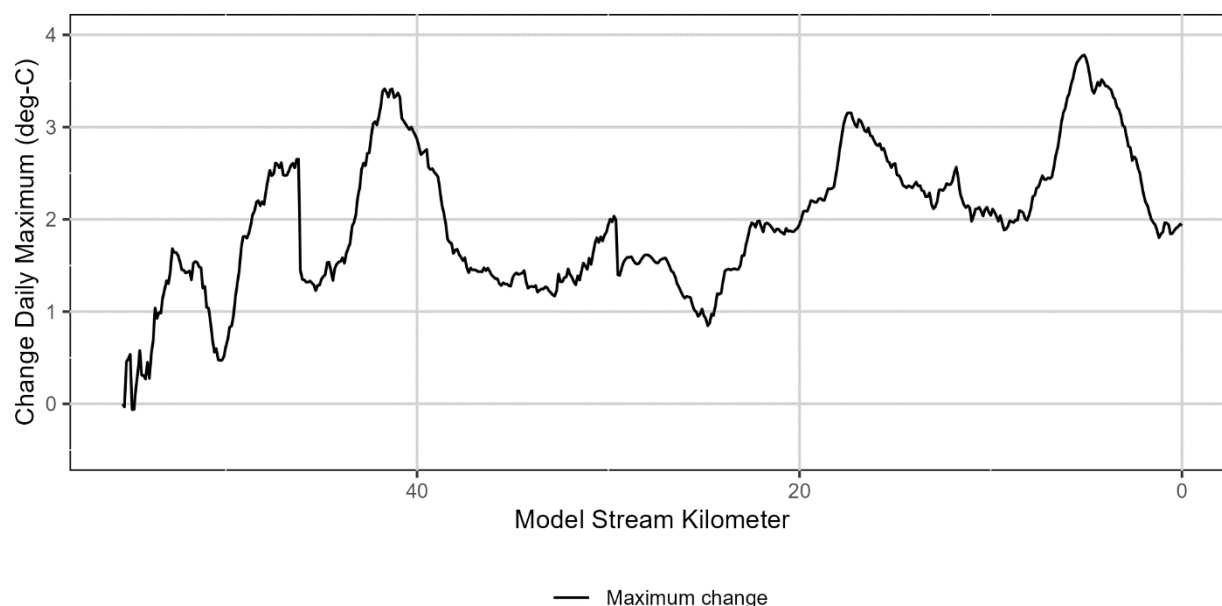
The Restored Vegetation scenario is our best estimate of background conditions given the available information. We did not evaluate restored channel morphology, tributary temperatures, or stream flows. Based on the Restored Vegetation scenario, the daily maximum temperature difference between background 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     |



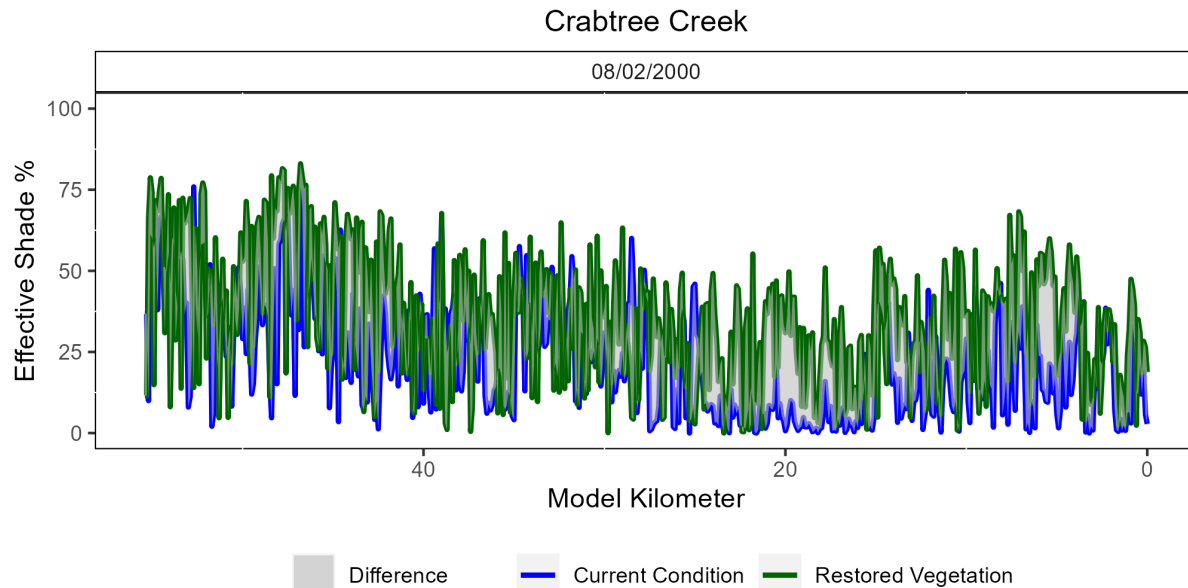
**Figure 4-60: Change in the daily maximum stream temperatures between the Current Condition and Restored Vegetation model scenarios for Crabtree Creek over the entire model period.**

**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.

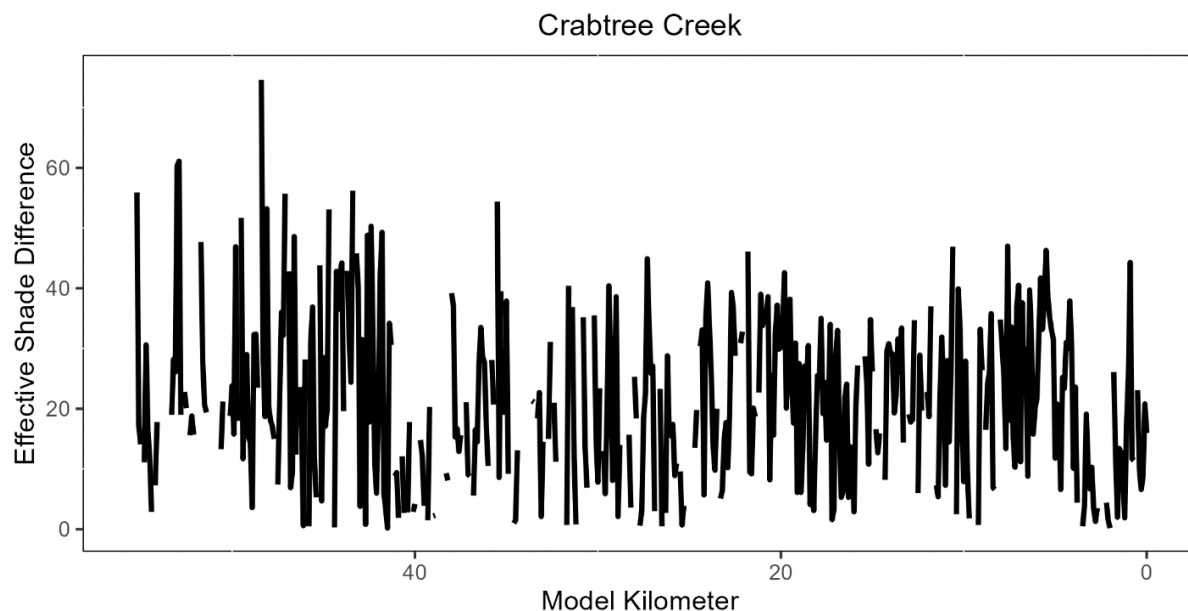
**Figure 4-61** and **Figure 4-62** compare effective shade predictions from the Current Condition and Restored Vegetation scenarios for Crabtree Creek.

**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.**

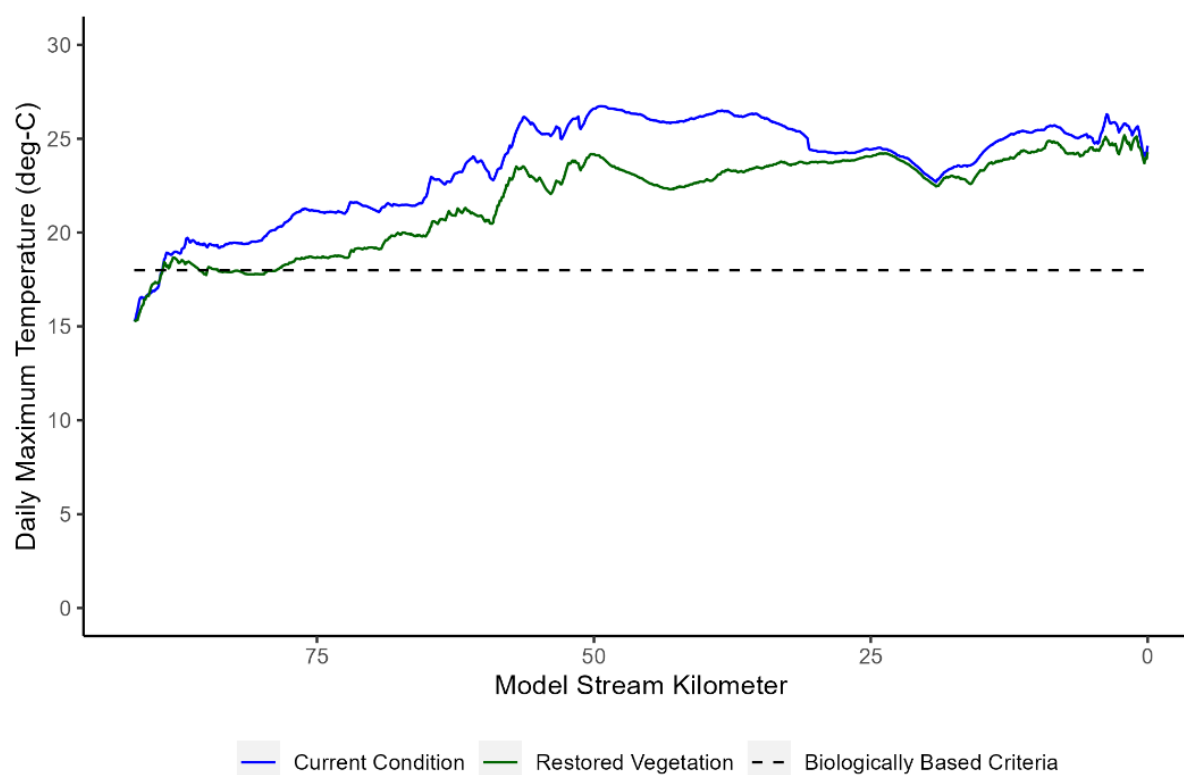
## 4.8 Luckiamute River

**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

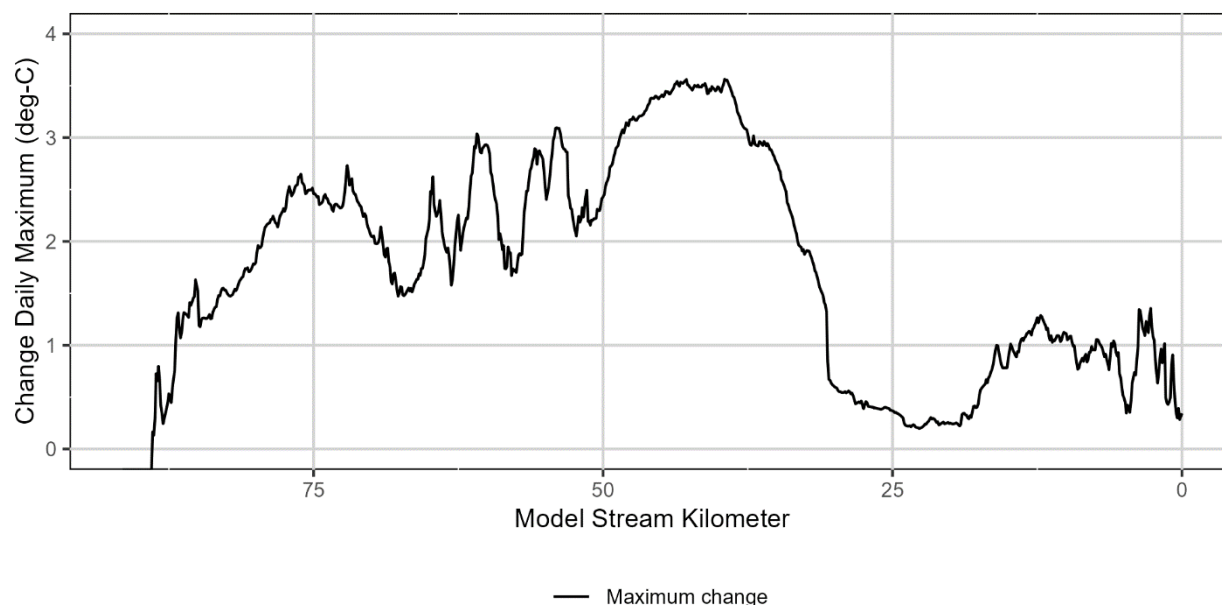
**Table 4-44** summarizes the daily maximum stream temperature change between the Current Condition and Restored Vegetation scenarios for the Luckiamute River. It shows the daily maximum temperature difference at the most downstream node (the outlet) is equal to 0.34°C. In addition, the greatest daily 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     |



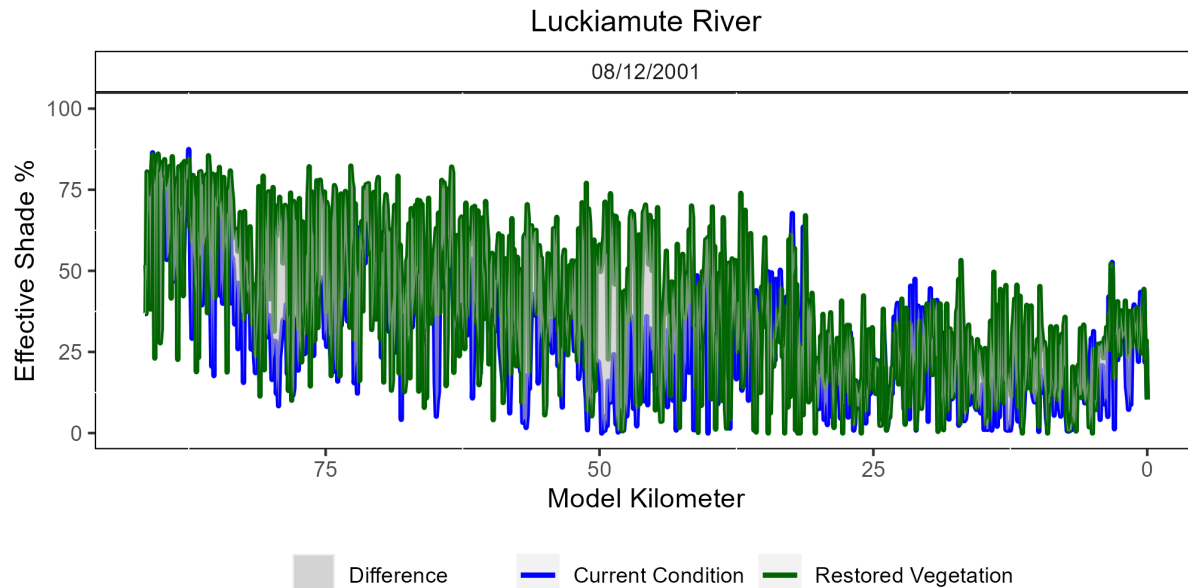
**Figure 4-64: Change in the daily maximum stream temperatures between the Current Condition and Restored Vegetation model scenarios for the Luckiamute River over the entire model period.**

**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.

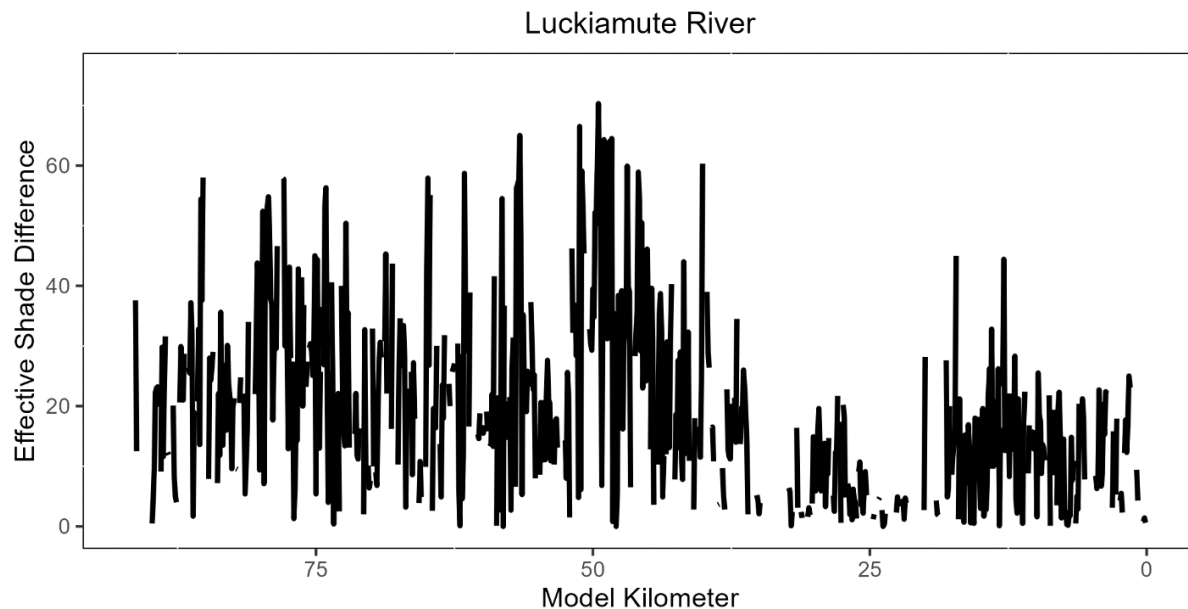
**Figure 4-65** and **Figure 4-66** compare effective shade predictions from the Current Condition and Restored Vegetation scenarios for the Luckiamute River.

**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.**

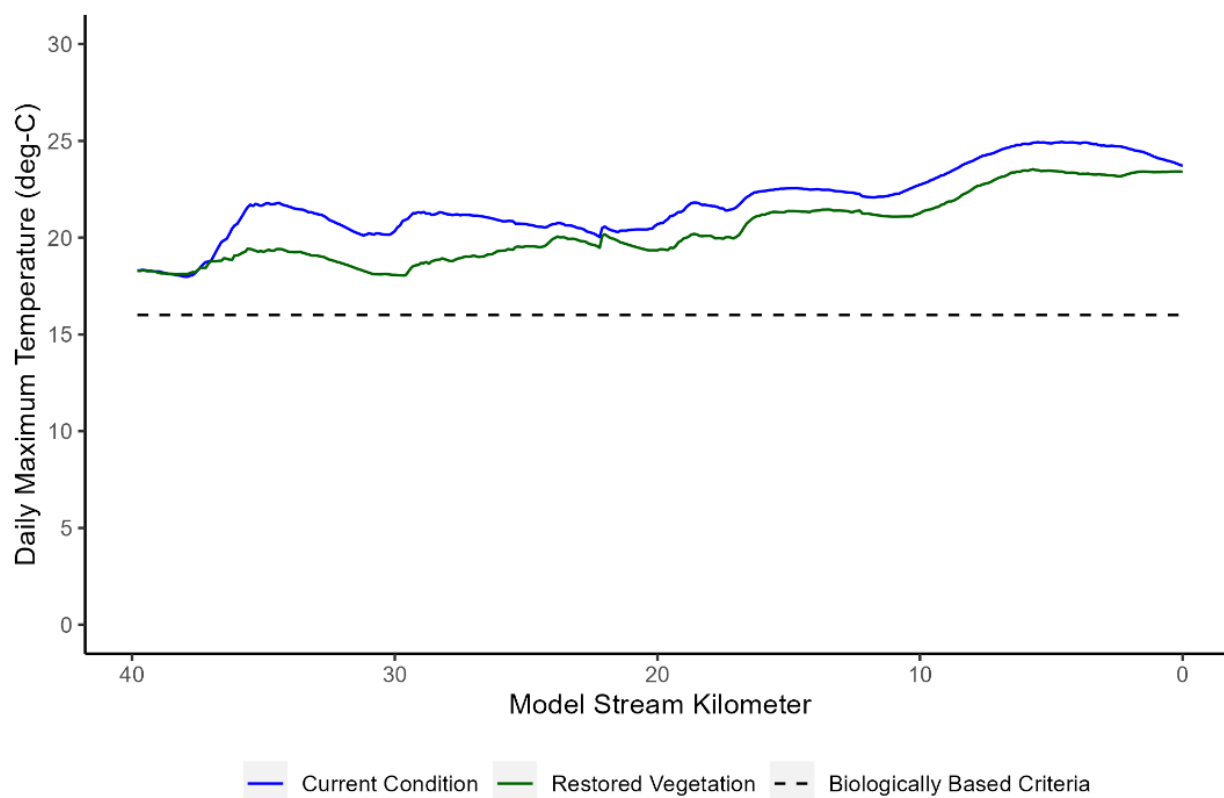
## 4.9 Mohawk River

**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.

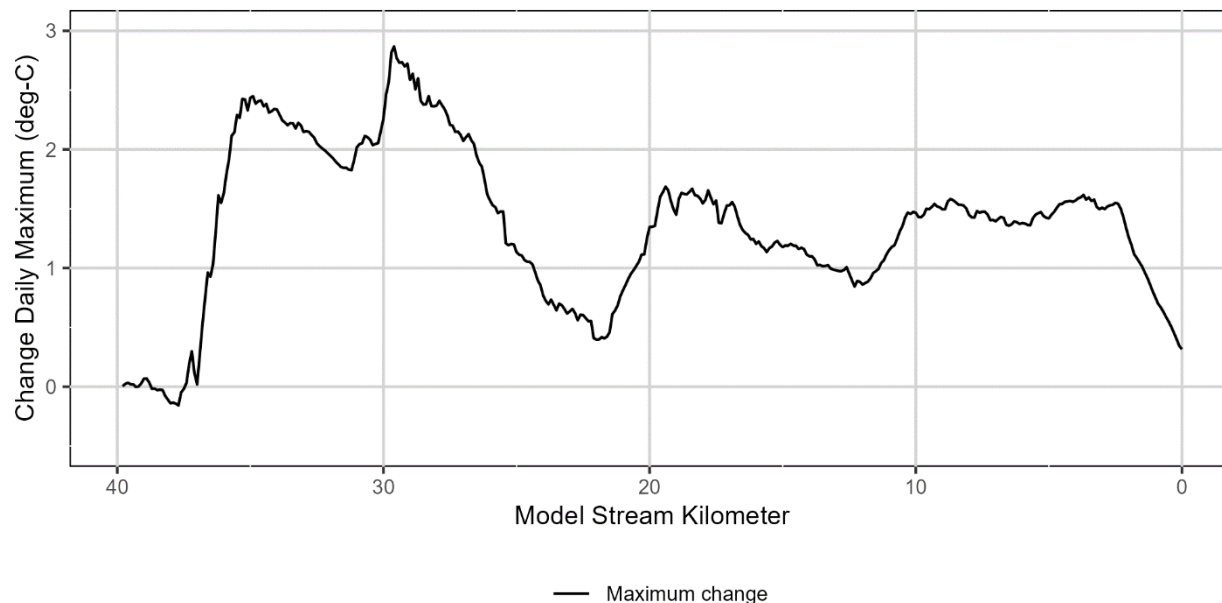
The Restored Vegetation scenario is our best estimate of background conditions given the available information. We did not evaluate restored channel morphology, tributary temperatures, or stream flows. Based on the Restored Vegetation scenario, the daily maximum temperature

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     |



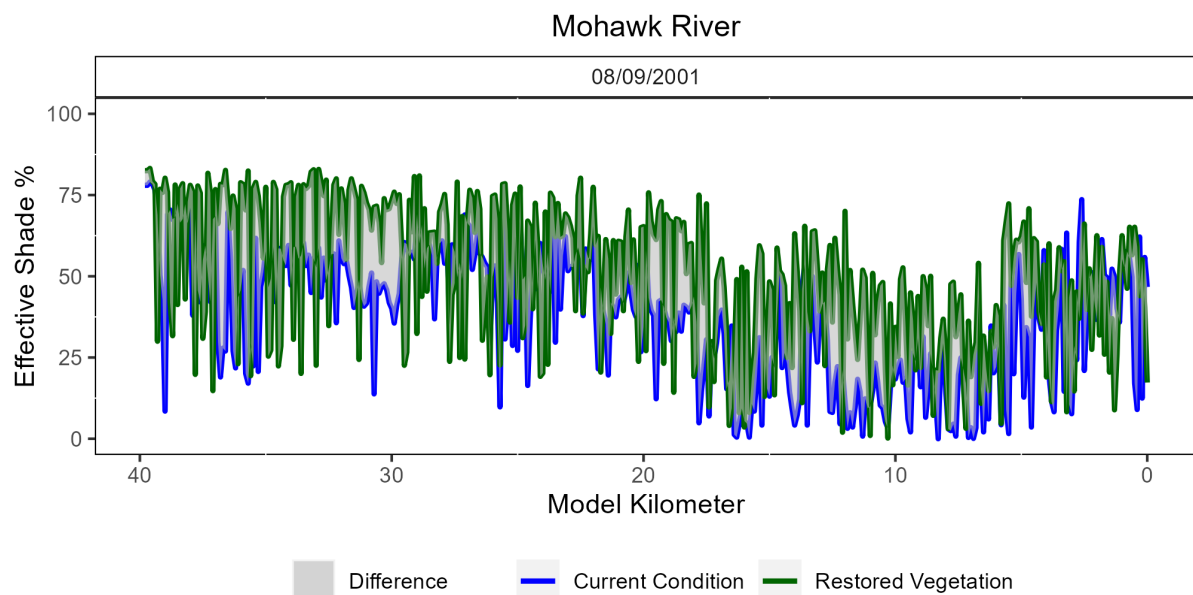
**Figure 4-68: Change in the daily maximum stream temperatures between the Current Condition and Restored Vegetation model scenarios for the Mohawk River over the entire model period.**

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.

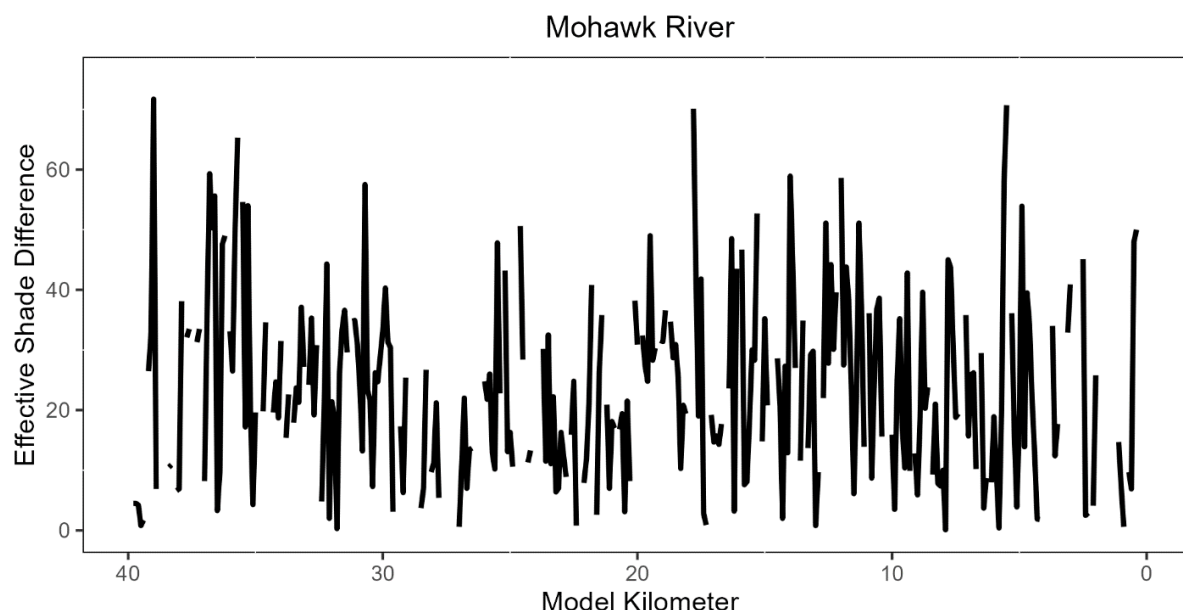
**Figure 4-69** and **Figure 4-70** compare effective shade predictions from the Current Condition and Restored Vegetation scenarios for the Mohawk River.

**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.

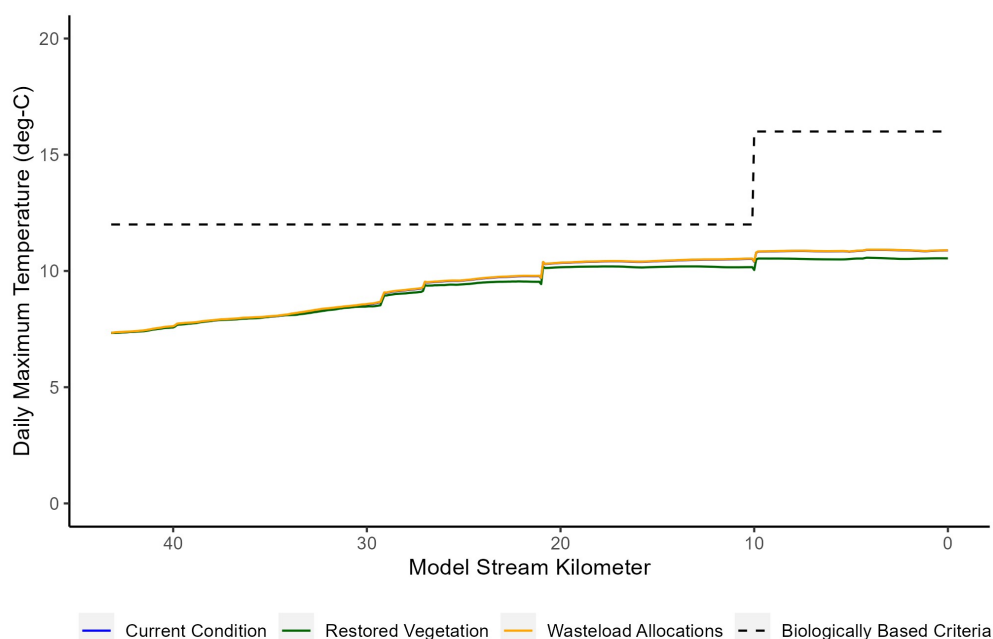
**Table 4-49: McKenzie River: Upper model scenario descriptions.**

| 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   |

| Temperature Metric        | Model KM | Scenario              | Stream Temperature (°C) | Location |
|---------------------------|----------|-----------------------|-------------------------|----------|
| 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.

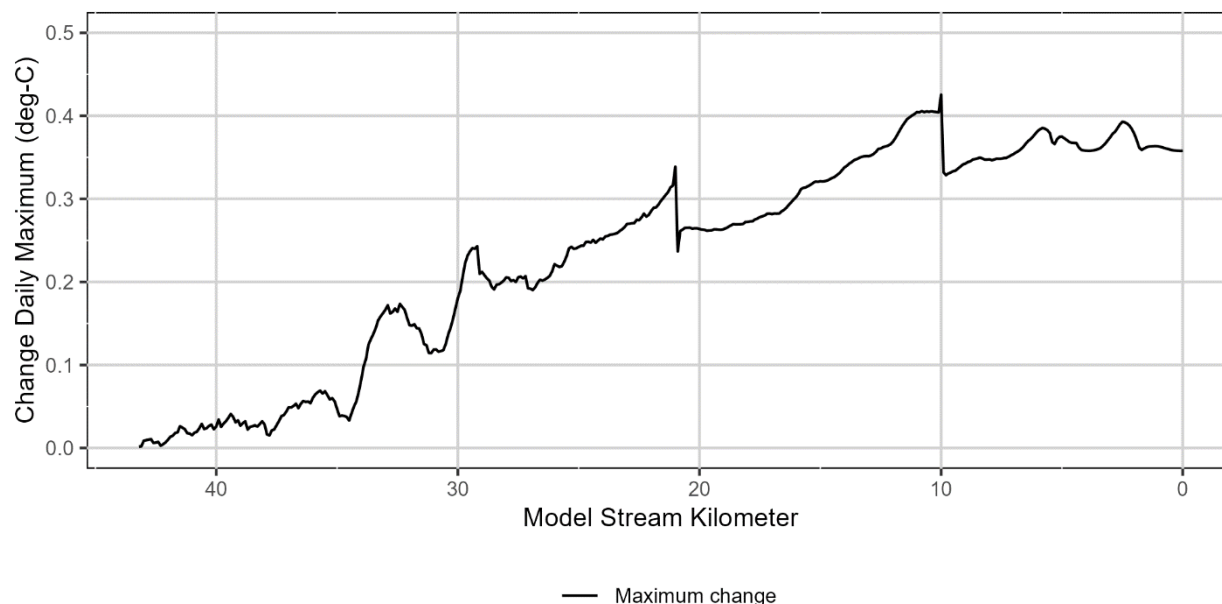
A comparison of the Current Condition and Restored Vegetation scenarios for the upper McKenzie River shows that the daily maximum stream temperatures do not exceed the biologically-based numeric criteria along the model reach. DEQ also evaluated maximum temperature differences between the two scenarios. 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     |



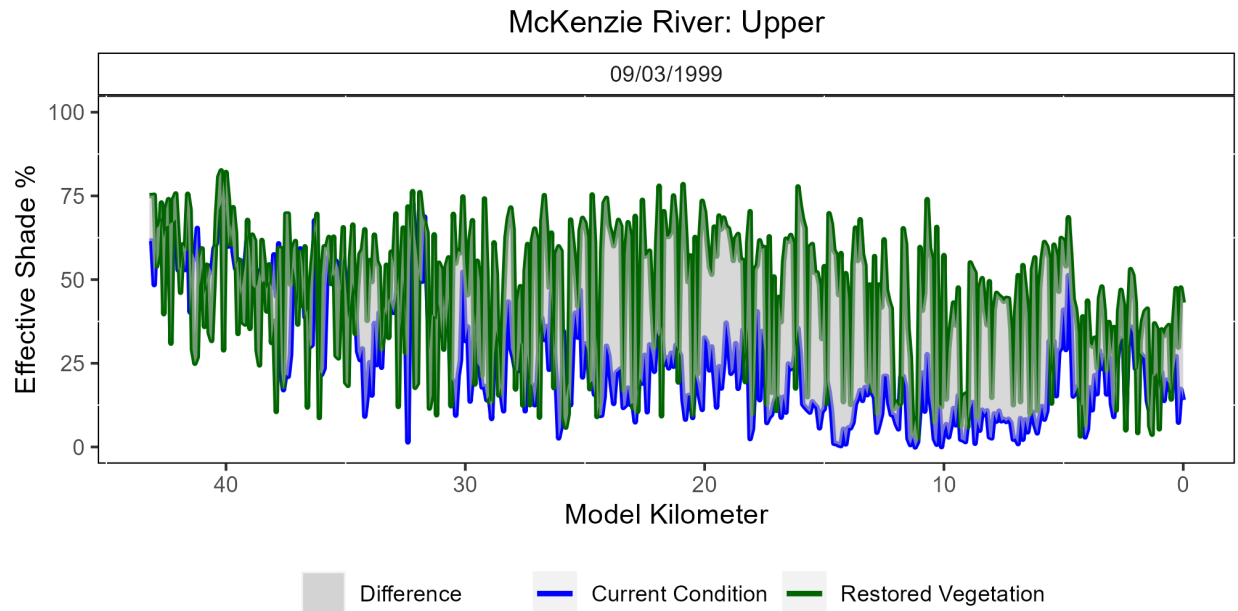
**Figure 4-72: Change in the daily maximum stream temperatures between the Current Condition and Restored Vegetation model scenarios for the upper McKenzie River over the entire model period.**

**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.

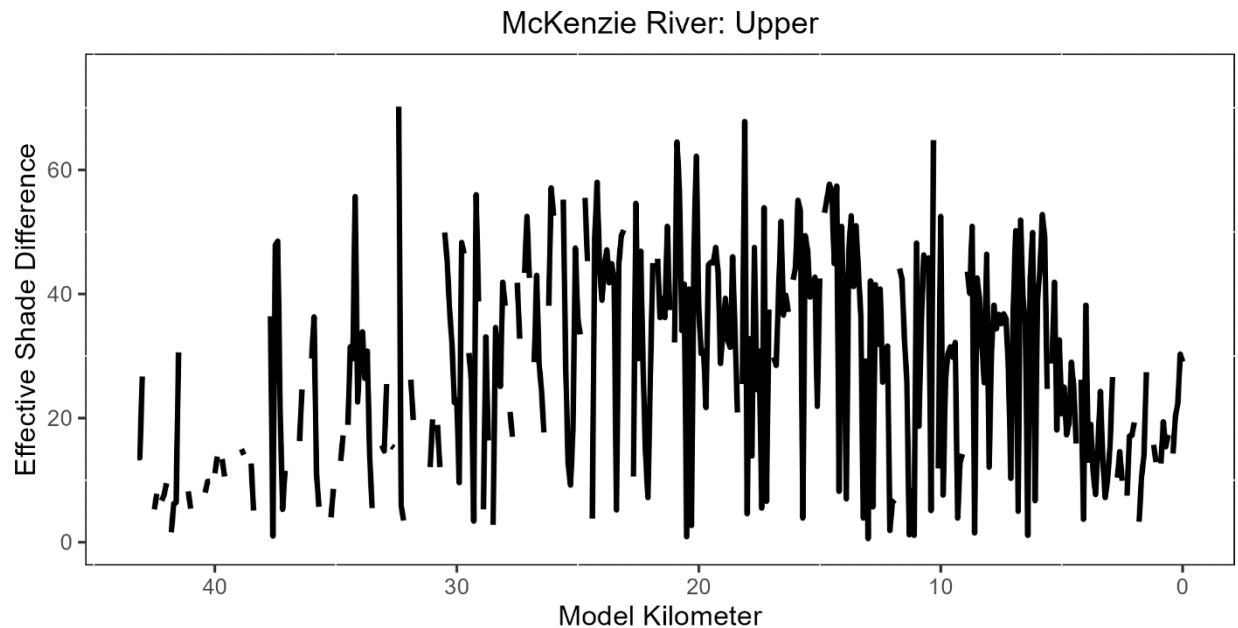
**Figure 4-73** and **Figure 4-74** compare effective shade predictions from the Current Condition and Restored Vegetation scenarios for the upper McKenzie River.

**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**.

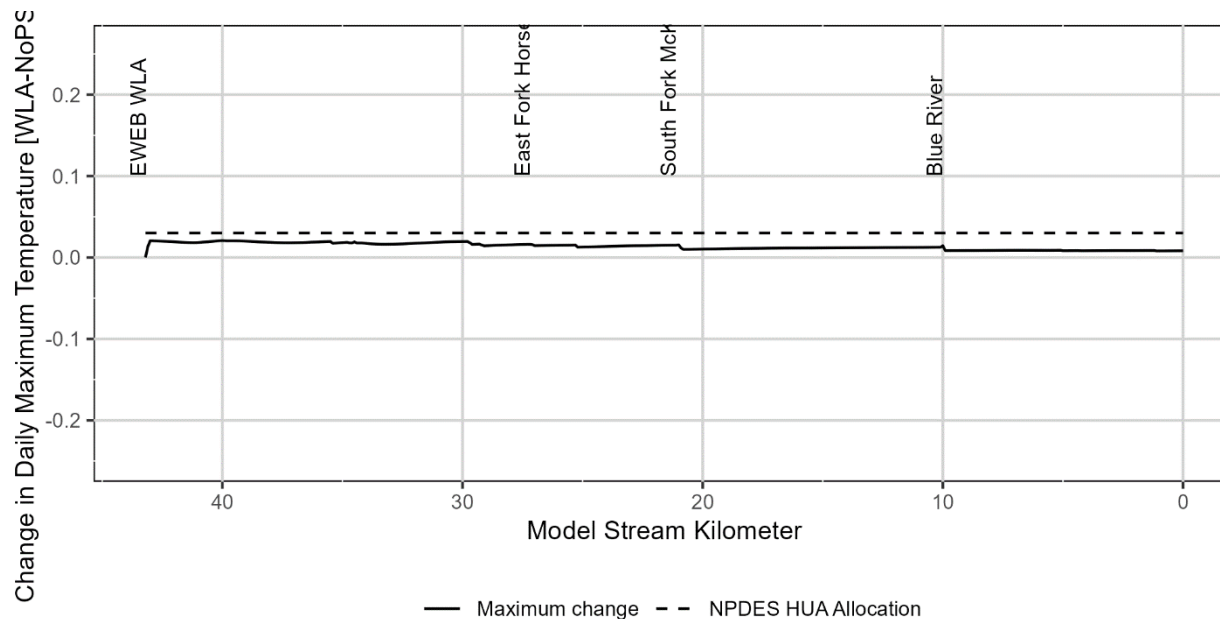
At the confluence of the McKenzie River and South Fork McKenzie River, the increase is equal to 0.015°C. This was the increase applied to the boundary condition in the McKenzie River CE-QUAL-W2 model evaluating waste load allocations on the lower McKenzie River (TSD Appendix K).

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.**

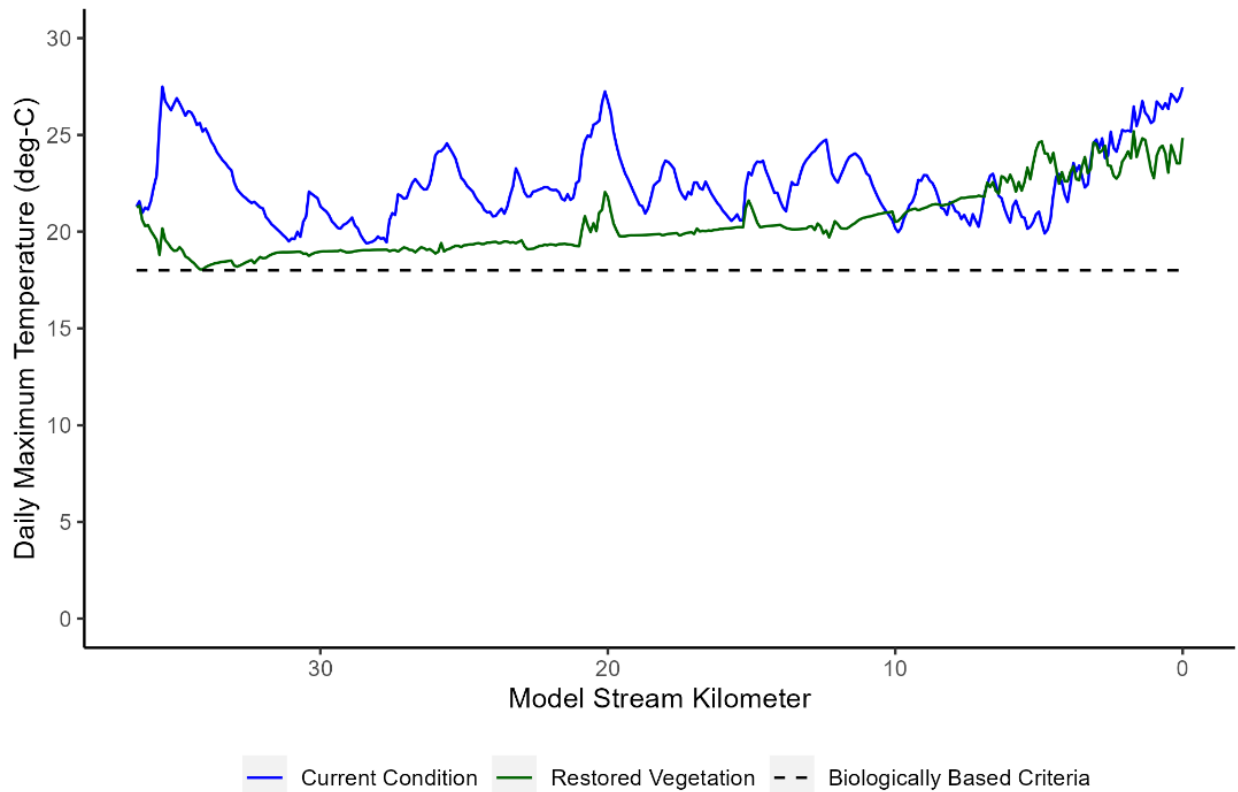
## 4.11 Coyote Creek

**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.

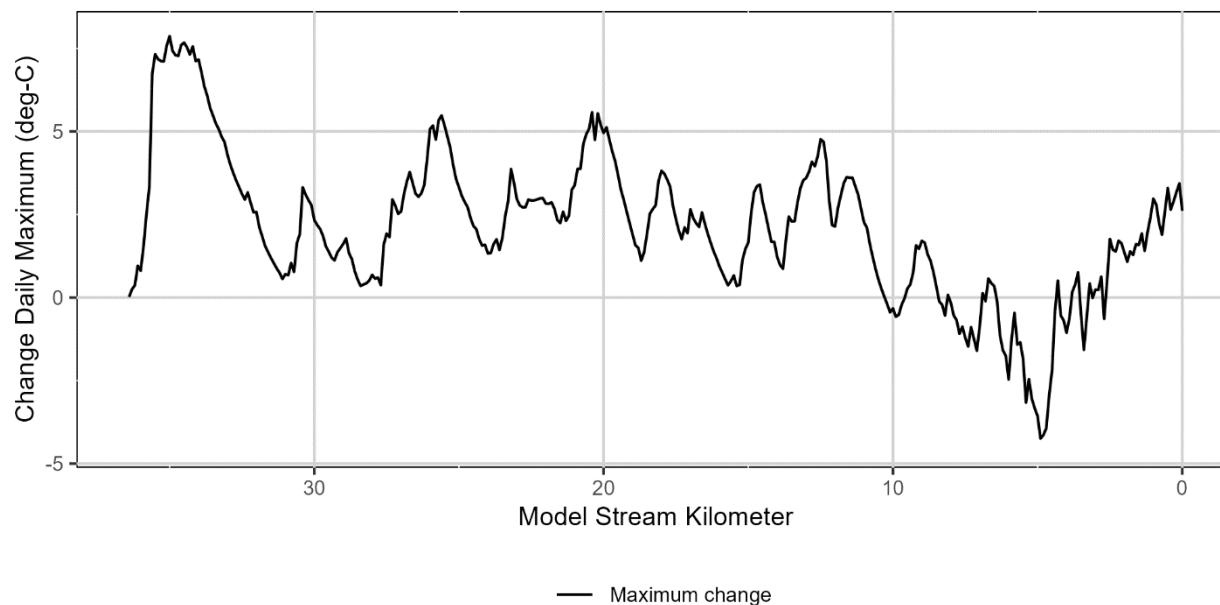
The Restored Vegetation scenario is our best estimate of background conditions given the available information. We did not evaluate restored channel morphology, tributary temperatures, or stream flows. Based on the Restored Vegetation scenario, the daily maximum temperature difference between background 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     |

| Temperature Metric | Model KM | Scenario    | Stream Temperature (°C) | Location |
|--------------------|----------|-------------|-------------------------|----------|
| Daily maximum      | 0        | Change_BBNC | 6.85                    | outlet   |
| Daily maximum      | 1.7      | Change_BBNC | 7.18                    | POMI     |



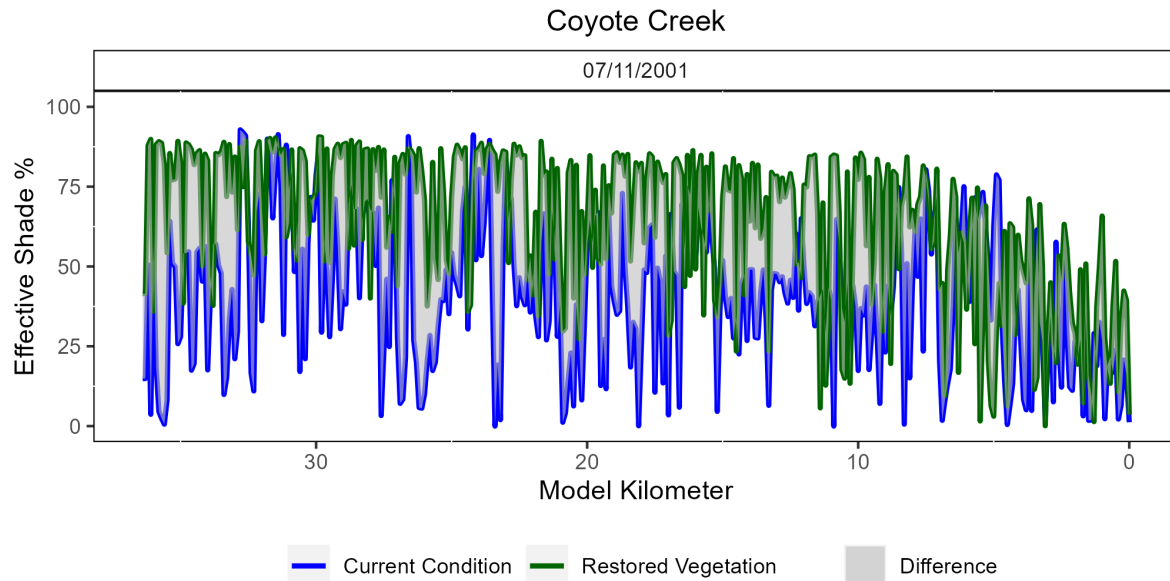
**Figure 4-77: Change in the daily maximum stream temperatures between the Current Condition and Restored Vegetation model scenarios for Coyote Creek over the entire model period.**

**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.

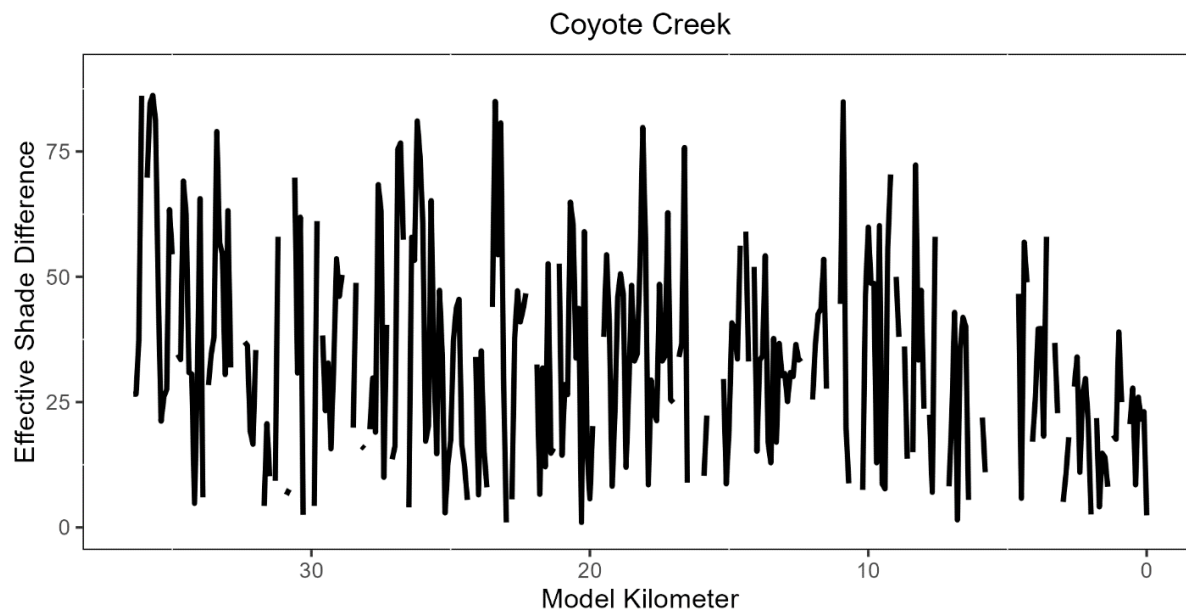
**Figure 4-78** and **Figure 4-79** compare effective shade predictions from the Current Condition and Restored Vegetation scenarios for Coyote Creek.

**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.**

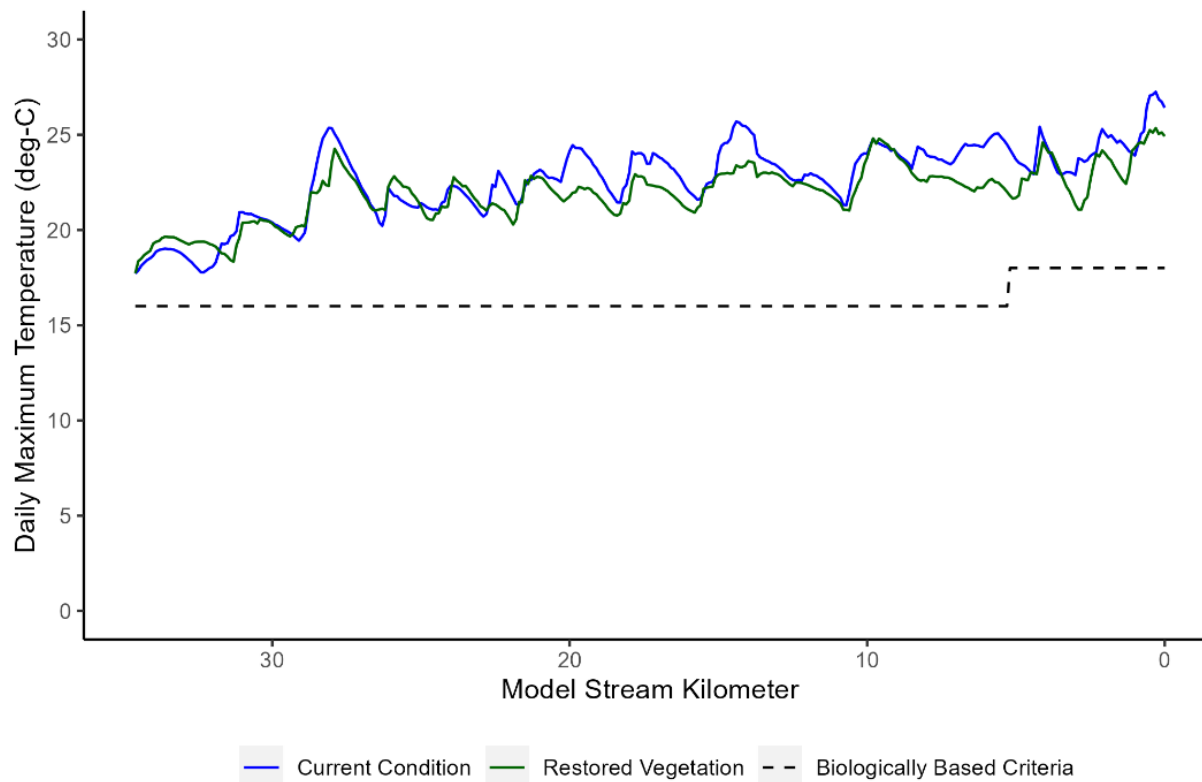
## 4.12 Mosby Creek

**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

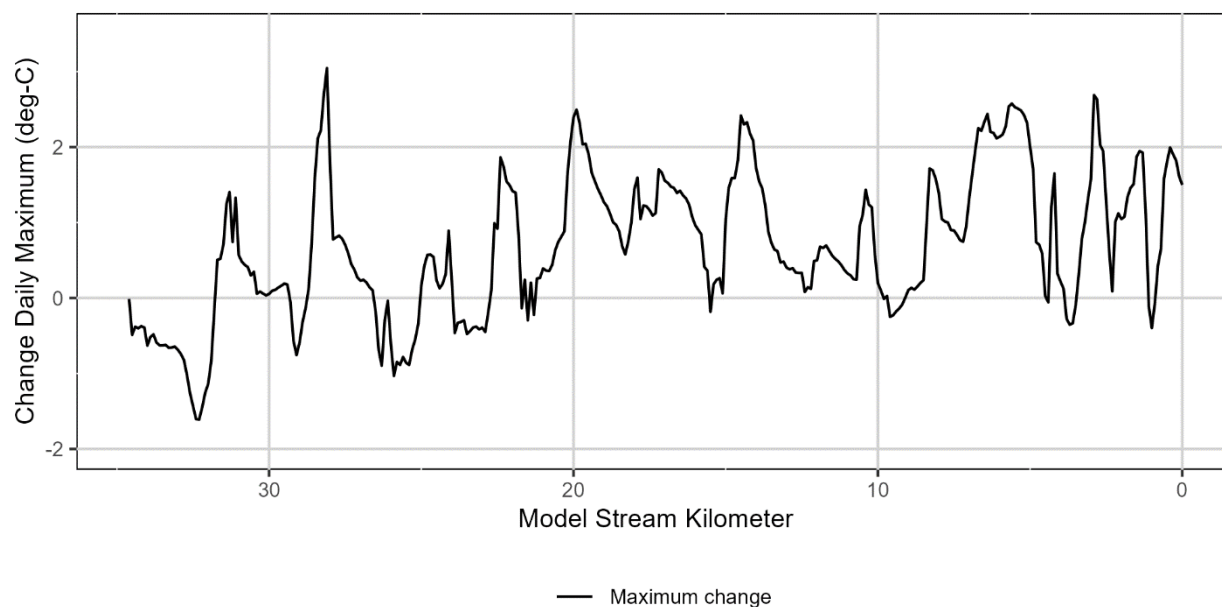
**Table 4-58** summarizes the daily maximum stream temperature change between the Current Condition and Restored Vegetation scenarios for Mosby Creek. It shows the daily maximum temperature difference at the most downstream node (the outlet) is equal to 1.5°C. In addition, the greatest daily maximum 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     |



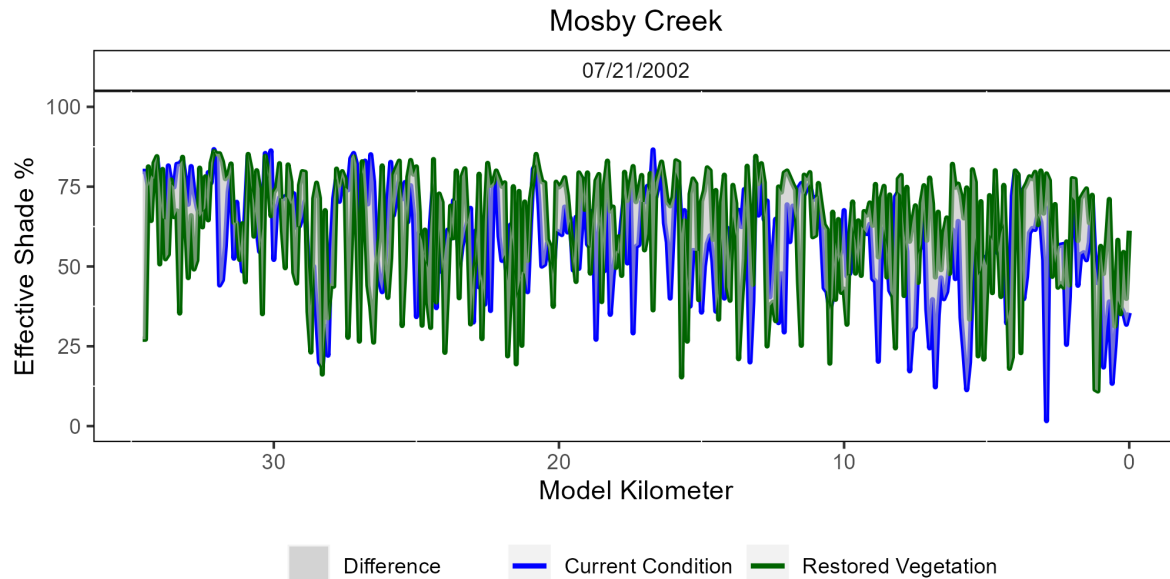
**Figure 4-81: Change in the daily maximum stream temperatures between the Current Condition and Restored Vegetation model scenarios for Mosby Creek over the entire model period.**

**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.

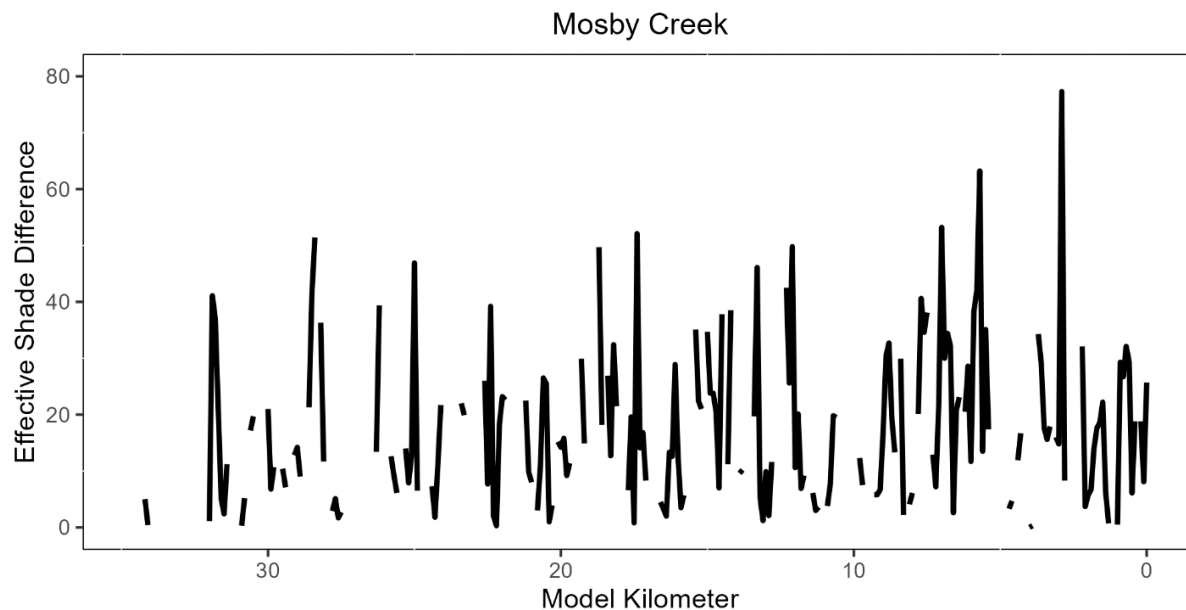
**Figure 4-82** and **Figure 4-83** compare effective shade predictions from the Current Condition and Restored Vegetation scenarios for Mosby Creek.

**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.

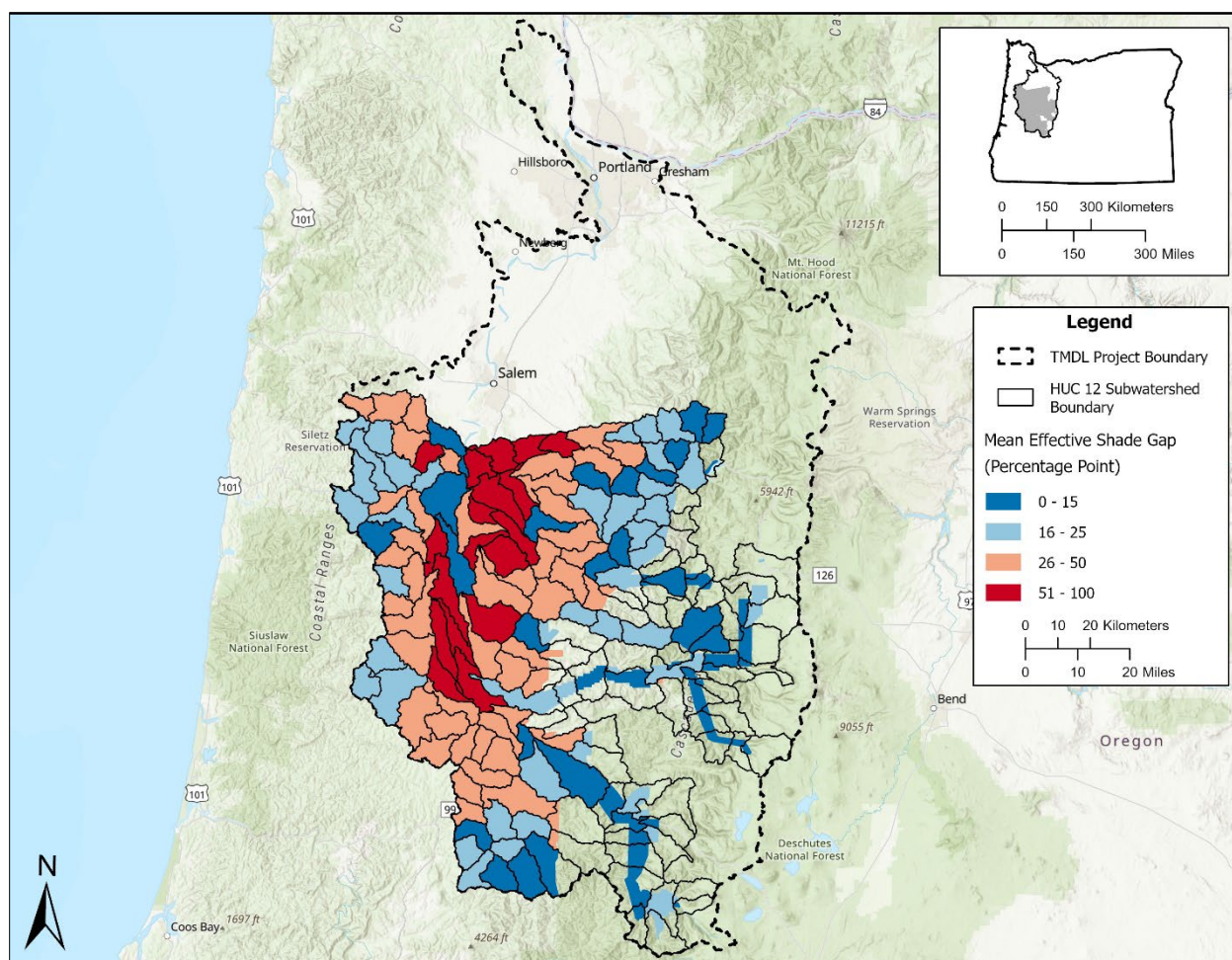
Results were summarized as the effective shade gap. The effective shade gap is the percentage point difference between the TMDL restored vegetation effective shade (TMDL surrogate measure target) and the current condition shade assessed from LiDAR. Larger numbers indicate greater lack of shade.

#### 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**.

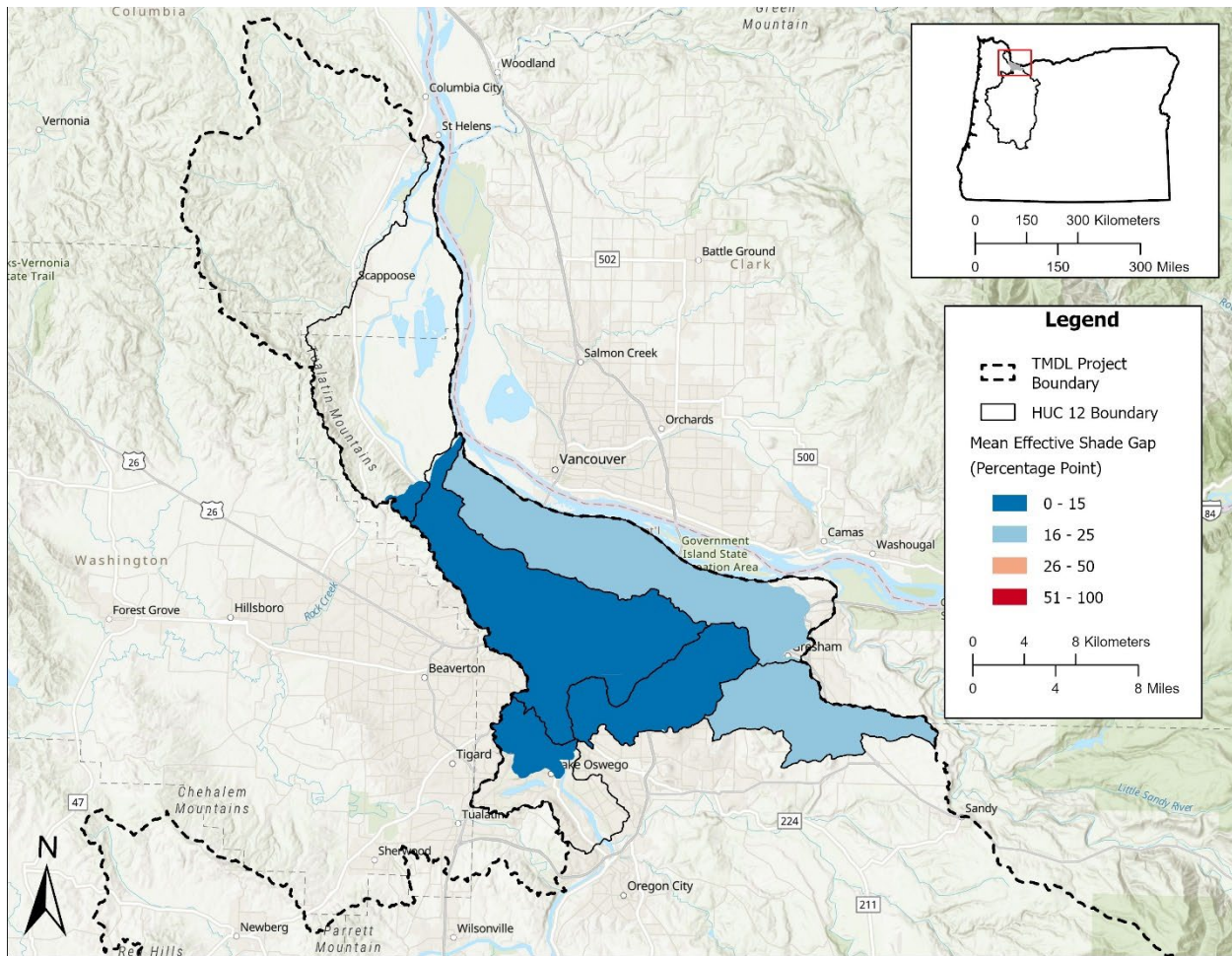
Results were also stratified by HUC8 subbasins, HUC10 watersheds, DMA, DEQ assessment unit ID, and by ODA's water quality management areas. These results are reported in more detail in TSD Appendix F.

**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.

## 5. References

- Bedient, P.B. and W.C. Huber. 1992. *Hydrology and Floodplain Analysis*. Reading, Massachusetts: Addison-Wesley Publishing Company.
- Bencala, K.E. and Walters, R.A. 1983. Simulation of solute transport in a mountain pool-and-riffle stream: A transient storage model. *Water Resources Research*. 19(3), 718-724.
- Brown, L.C. and Barnwell, T.O. 1987. The enhanced stream water quality models QUAL2E and QUAL2E-UNCAS: Documentation and user manual. U.S. Environmental Protection Agency, Environmental Research Laboratory, Athens, Georgia.
- DEQ (Oregon Department of Environmental Quality). 2001. "Tillamook Bay Watershed Total Maximum Daily Load (TMDL) Appendix A: Temperature Technical Analysis". Oregon Department of Environmental Quality. Portland, OR. chrome-extension://efaidnbmnnnibpcajpcgiclfefndmkaj/<https://www.oregon.gov/deq/FilterDocs/NCtillappxs.pdf>
- DEQ (Oregon Department of Environmental Quality). 2006. "Willamette Basin TMDL and WQMP." <https://www.oregon.gov/deq/wq/tmdls/Pages/TMDLs-Willamette-Basin.aspx>
- DEQ (Oregon Department of Environmental Quality). 2008. "Temperature water quality standard implementation—A DEQ internal management directive, Oregon". Oregon Department of Environmental Quality. Portland, OR. <https://www.oregon.gov/deq/Filtered%20Library/IMDTemperature.pdf>
- DEQ (Oregon Department of Environmental Quality). 2013a. "Data validation criteria for water quality parameters measured in the field. DEQ04-LAB-0003-QAG Version 5.0."
- DEQ (Oregon Department of Environmental Quality). 2013b. "Internal Management Directive – The Use of Significant Figures and Rounding Conventions in Water Quality Permitting. Water Quality Division, Surface Water Management Section, Headquarters. Portland, OR. <https://www.oregon.gov/deq/Filtered%20Library/SigFigsIMD.pdf>.
- DEQ (Oregon Department of Environmental Quality). 2021. "Quality Assurance Project Plan, Monitoring and assessment for Total Maximum Daily Loads". DEQ21-LAB-0013-QAPP Version 1.0.
- Dewitz, J., 2019. National Land Cover Database (NLCD) 2016 Products: U.S. Geological Survey data release, <https://doi.org/10.5066/P96HHBIE>.
- Dunne, T., and L. Leopold. 1978. *Water in environmental planning*. Freeman, New York.
- Federal Geographic Data Committee (FGDC). 2013. "Classification of wetlands and deepwater habitats of the United States". FGDC-STD-004-2013. Second Edition. Wetlands Subcommittee, Federal Geographic Data Committee and U.S. Fish and Wildlife Service, Washington, DC.
- Gianfagna, C.J. 2015. "Watershed area ratio accurately predicts daily streamflow in nested catchments in the Catskills, New York." *Journal of Hydrology*, 583-594.

Hart, D. R. 1995. Parameter estimation and stochastic interpretation of the transient storage model for solute transport in streams. *Water Resources Research*. 31(2), 323-328.

O'Connor, J.E., Sarna-Wojcick, A., Wozniak, K.C., Polette, D.J., Fleck, R.J., 2001. Origin, extent, and thickness of Quaternary geologic units in the Willamette Valley, Oregon; U.S. Geological Survey, Professional Paper 1620.

OAR (Oregon Administrative Rule) 340-041. Water Quality Standards: Beneficial Uses, Policies, and Criteria for Oregon.

ODFW (Oregon Department of Fish and Wildlife). 1998. "Willamette Valley land use / land cover map informational report". <https://digital.osl.state.or.us/islandora/object/osl:18785>.

OWEB (Oregon Watershed Enhancement Board). 1999. "Oregon Watershed Assessment Manual".

OWRD (Oregon Water Resources Department). 2002. Determining Surface Water Availability in Oregon. Open File Report SW 02-002. <http://www.oregon.gov/OWRD/SW/index.shtml>.

Pelletier, G.J., Chapra, C., Taob, H. 2006. QUAL2Kw – A framework for modeling water quality in streams and rivers using a genetic algorithm for calibration. *Environmental Modelling & Software*. 21(3), 419-425.

PNWERC/ISE (Pacific Northwest Ecosystem Research Consortium Institute for a Sustainable Environment). 1999. "Landuse and Landcover ca. 1990". Version 121599. <http://www.fsl.orst.edu/pnwerc/wrb/access.html>.

Ries III, K.G., J.K. Newson, M.J. Smith, J.D. Guthrie, P.A. Steeves, T.L. Haluska, K.R. Kolb, R.F. Thompson, R.D. Santoro, and H.W. Vraga. 2017. "StreamStats, version 4: U.S. Geological Survey Fact 2017–3046, 4 p." [Supersedes USGS Fact Sheet 2008–3067.] <https://doi.org/10.3133/fs20173046>

Risley, J. S. 2009. "Estimating flow-duration and low-flow frequency statistics for unregulated stream in Oregon." Reston, VA: U.S. Geological Survey.

Rosgen, D. 1996. Applied River Morphology. Wildland Hydrology. Pagosa Springs, Colorado.

Simonson, T.D., J. Lyons, and P.D. Kanehl. 1994. Quantifying fish habitat in streams: Transect spacing, sample size, and a proposed framework. *North American Journal of Fisheries Management* 14:607-615.

Sinokrot B.A. and Stefan H.G. 1993. Stream Temperature Dynamics: Measurements and Modeling. *Water Resources Research*. 29(7), 2299-2312.

SolarPathfinder. 2016. Instruction Manual For the SolarPathfinder Unit™. SolarPathfinder™. <https://www.solarpathfinder.com/manual>

USFWS (U.S. Fish & Wildlife Service). 2004. National Wetlands Inventory. <https://data.nal.usda.gov/dataset/national-wetlands-inventory>.

Watershed Sciences. 2001. "Remote Sensing Survey of the Santiam River Basin, Thermal Infrared and Color Videography. Prepared for Oregon Department of Environmental Quality."

Watershed Sciences. 2005. "Aerial Survey of Molalla, Pudding Rivers, OR, Thermal Infrared and Color Videography. Prepared for Oregon Department of Environmental Quality. April 11, 2005."

Watershed Sciences. 2009. LiDAR remote sensing data collection. Department of Geology and Mineral Industries. Willamette Valley Phase 1. Oregon.

Watershed Sciences. 2010. LiDAR remote sensing data collection. Department of Geology and Mineral Industries. Yambo study area.

Watershed Sciences. 2012a. LiDAR remote Sensing. Blue River, Oregon. Prepared for USDA Forest Service and the U.S. EPA Western Ecology Division. January 1, 2012.

Watershed Sciences. 2012b. LiDAR remote sensing data collection. Department of Geology and Mineral Industries. Fall Creek. March 28, 2012.

WSI. 2012a. LiDAR remote sensing data collection. Department of Geology and Mineral Industries. Central coast study area. July 31, 2012.

WSI. 2012b. OLC Green Peter LiDAR Report. December 20, 2012

WSI. 2013. OLC Clackamol LiDAR Report.

WSI. 2015. OLC Lane County: Delivery 7 LiDAR Report.