Appendix A.

Factors Potentially Influencing Stream Temperature in Nemote Creek

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A-1. Introduction

Stream temperature regimes are influenced by processes that are external to the stream as well as processes that occur within the stream and its associated riparian zone (Poole et. al., 2001). Examples of factors external to the stream that can affect in-stream water temperatures include: topographic shade, land use/land cover (e.g., vegetation and the shading it provides, impervious surfaces), solar angle, meteorological conditions (e.g., precipitation, air temperature, cloud cover, relative humidity), groundwater exchange and temperature, and tributary inflow temperatures and volumes. The shape of the channel can also affect the temperature—wide shallow channels are more easily heated and cooled than deep, narrow channels. The amount of water in the stream is another factor influencing stream temperature regimes. Streams that carry large amounts of water resist heating and cooling, whereas temperature in small streams (or reduced flows) can be changed more easily.

The following factors that may have an influence on stream temperatures in Nemote Creek are discussed below:

- Local/regional climate
- Land ownership
- Land use
- Riparian vegetation
- Shade
- Hydrology
- Point sources

A-2. Climate

The nearest weather station to the Nemote Creek watershed is located 14 miles to the northwest in the city of Superior, Montana (National Weather Service station 24159). Average annual precipitation is 16.1 inches with a relatively even distribution throughout the year (**Error! Reference source not found.**). Average maximum temperatures occur in July and August and are 87.0 ºF and 85.9ºF, respectively (**Figure A-2**). It should be noted that the weather station is located at an elevation of 2,700 feet above MSL, compared to Nemote Creek that ranges in elevation from approximately 2,750 to 6,375 feet above MSL.

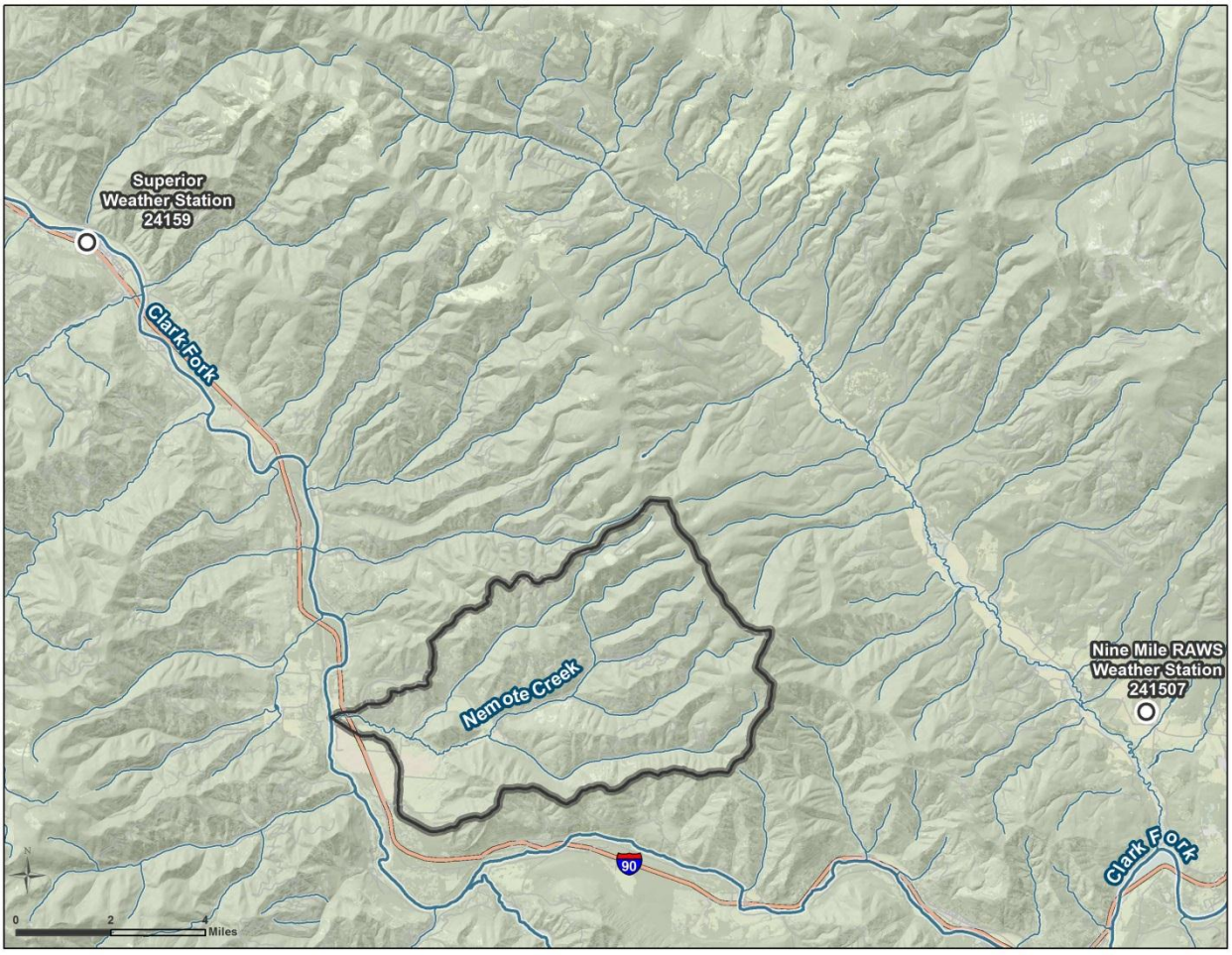
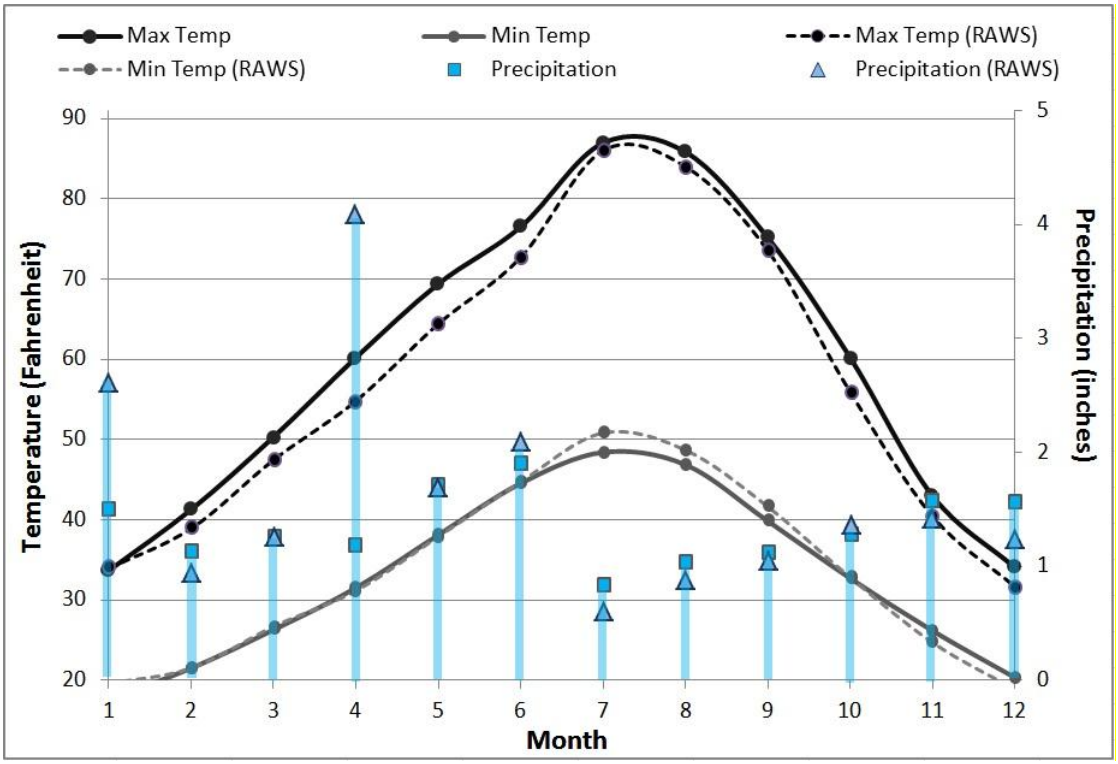


Figure A-1. Nemote Creek watershed.



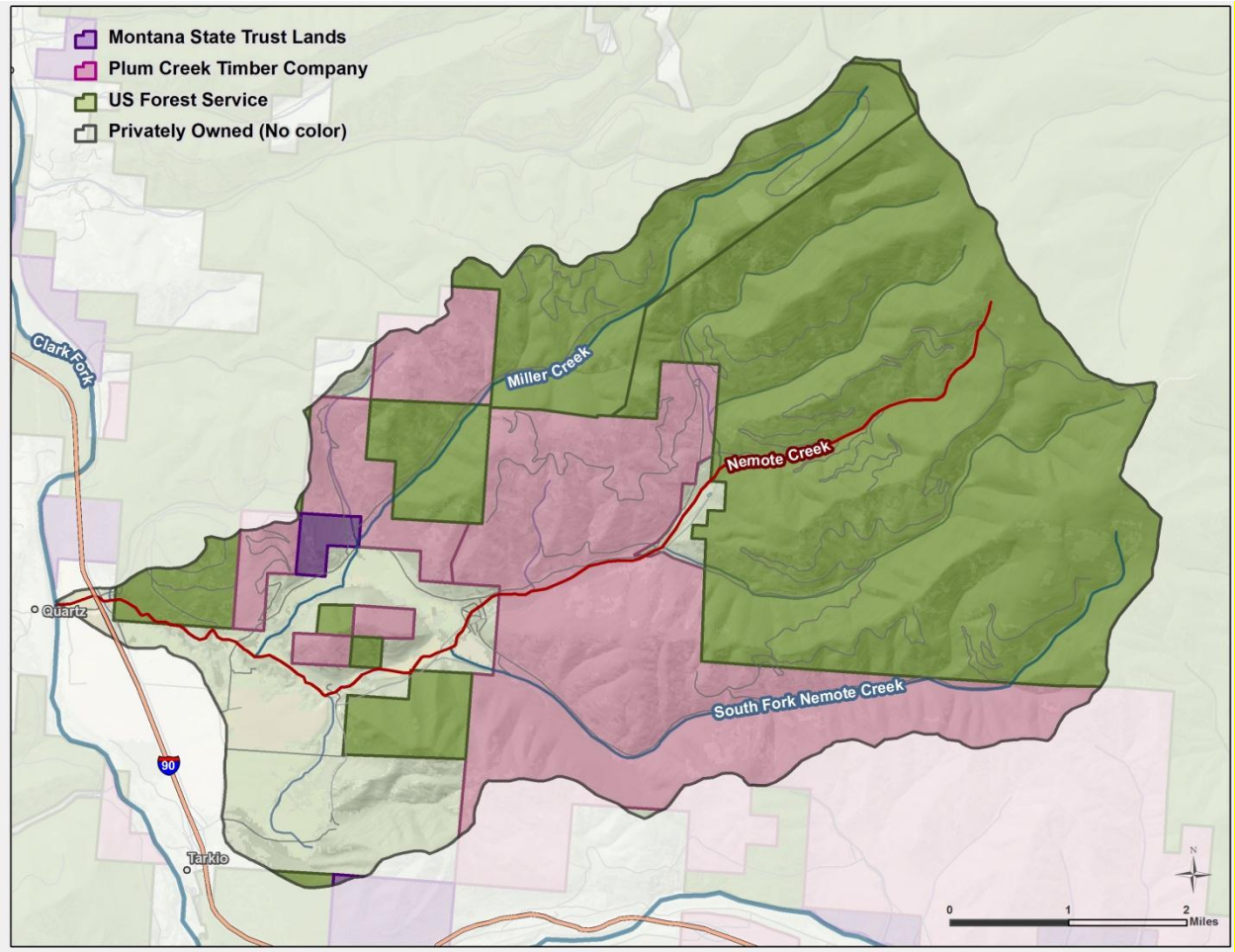
Sources: GHCN-D Monthly Summaries from 1914 to 2013 at NWS station 24159, in Superior, Montana (NCDC 2013) and RAWS Monthly Summary Time Series from 2000 to 2013 at NWS station 241507 in Nine-Mile, Montana (WRCC 2013).

Figure A-2. Monthly average temperatures and precipitation at Superior and Nine-Mile, Montana.

A Remote Automatic Weather Station (RAWS) is located 9 miles away in Nine-Mile, Montana (National Weather Service station ID 241507) at 3,300 feet above mean sea level (MSL). The available data only date back to 2000, but the station records weather data hourly whereas station 24159 only records weather data daily. Thus, Nine-Mile RAWS hourly temperature data were used to develop the QUAL2K inputs. The Nine-Mile RAWS data are also summarized in **Sources:** GHCN-D Monthly Summaries from 1914 to 2013 at NWS station 24159, in Superior, Montana (NCDC 2013) and RAWS Monthly Summary Time Series from 2000 to 2013 at NWS station 241507 in Nine-Mile, Montana (WRCC 2013).
Figure A-2**.**

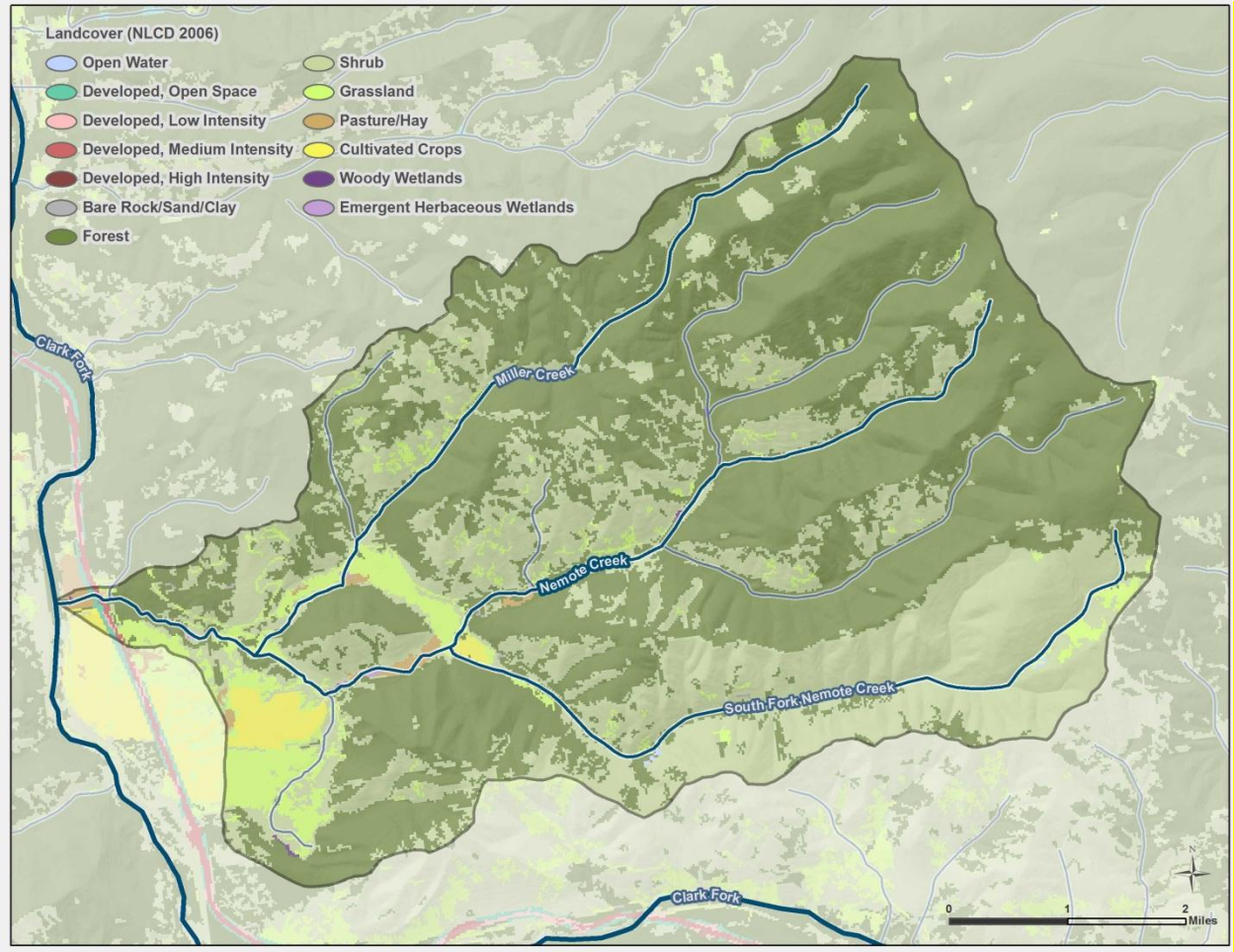
A-3. Land Ownership and Land Use

Private ownership accounts for 14 percent of the land ownership in the the Nemote Creek watershed, primarily located in the southern, downstream areas. The Plum Creek Timber Company manages 30 percent of the area, the U.S. Forest Service manages another 56 percent, and the remainder is owned by the state in trust lands (**Figure A-3**). The landscape is predominantly forested, with patches of mature forest interspersed with selective harvests and clearcuts at various stages of regrowth, though some agriculture and light development occur in the valleys (**Figure A-4** and **Source of** *aerial imagery:* 2011 NAIP (Montana NRIS 2012)
Note: The inset map show an area of timber harvest.
Figure A-5).



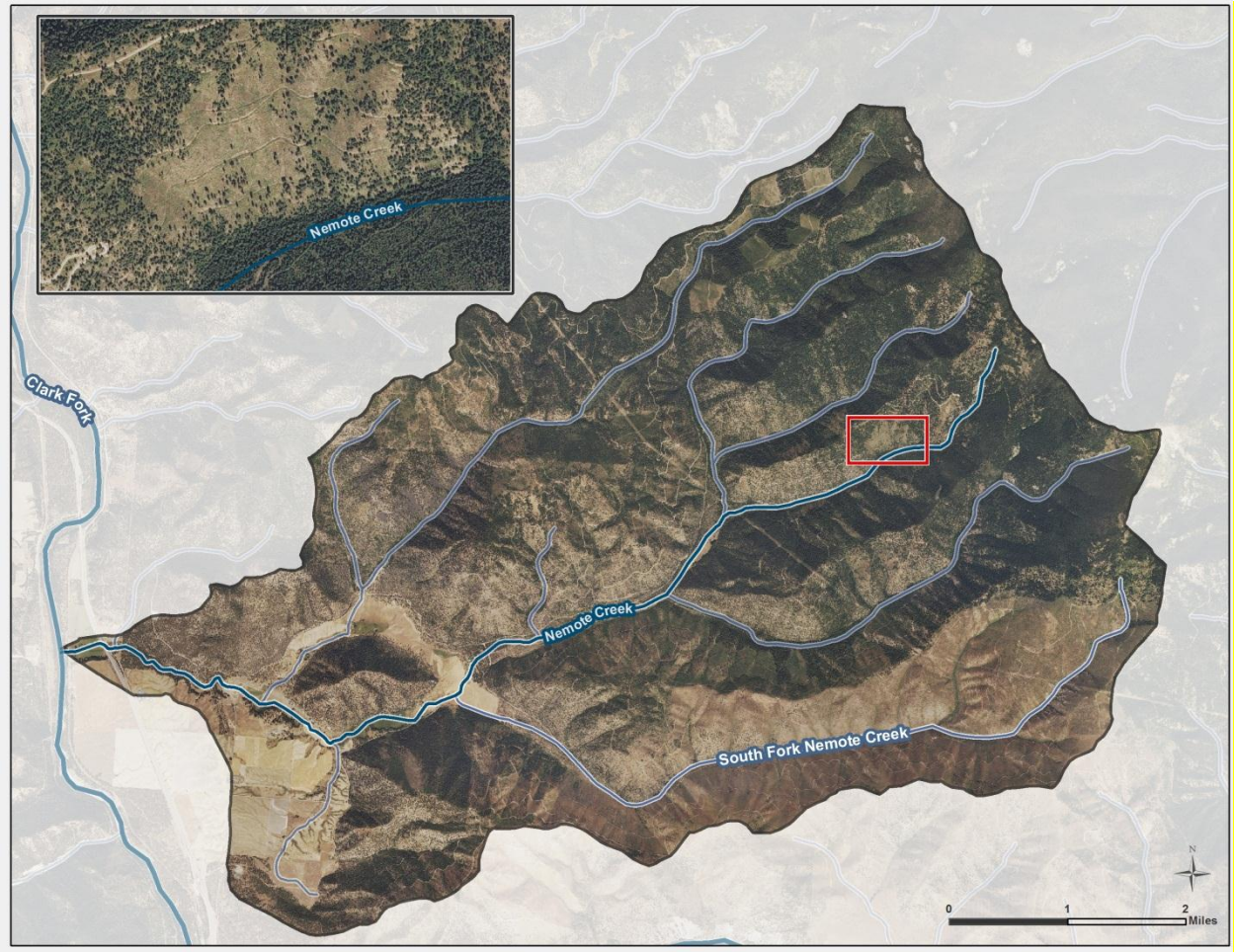
Source of land ownership: NRIS 2012.

Figure A-3. Land ownership in the Nemote Creek watershed.



Source of land cover: 2006 National Land Cover Dataset (Multi-Resolution Land Characteristics Consortium 2006).

Figure A-4. Land cover in the Nemote Creek watershed.



Source of aerial imagery: 2011 NAIP (Montana NRIS 2012)
Note: The inset map show an area of timber harvest.

Figure A-5. Aerial imagery of the Nemote Creek watershed.

A-4. Existing Riparian Vegetation

Vegetation communities were visually characterized based on aerial imagery (GoogleEarth™ 2013). Observed vegetative communities within 150 feet of the stream centerline were classified as trees, shrubs, or herbaceous. Bare ground, buildings, and roads were also identified. Trees were further divided into the following classes based on percent canopy cover derived from the 2006 NLCD (**Figure A-6**):

- High density (75 to 100 percent cover)
- Medium density (51 to 74 percent cover)
- Low density (25 to 50 percent cover)
- Sparse density (less than 24 percent cover)

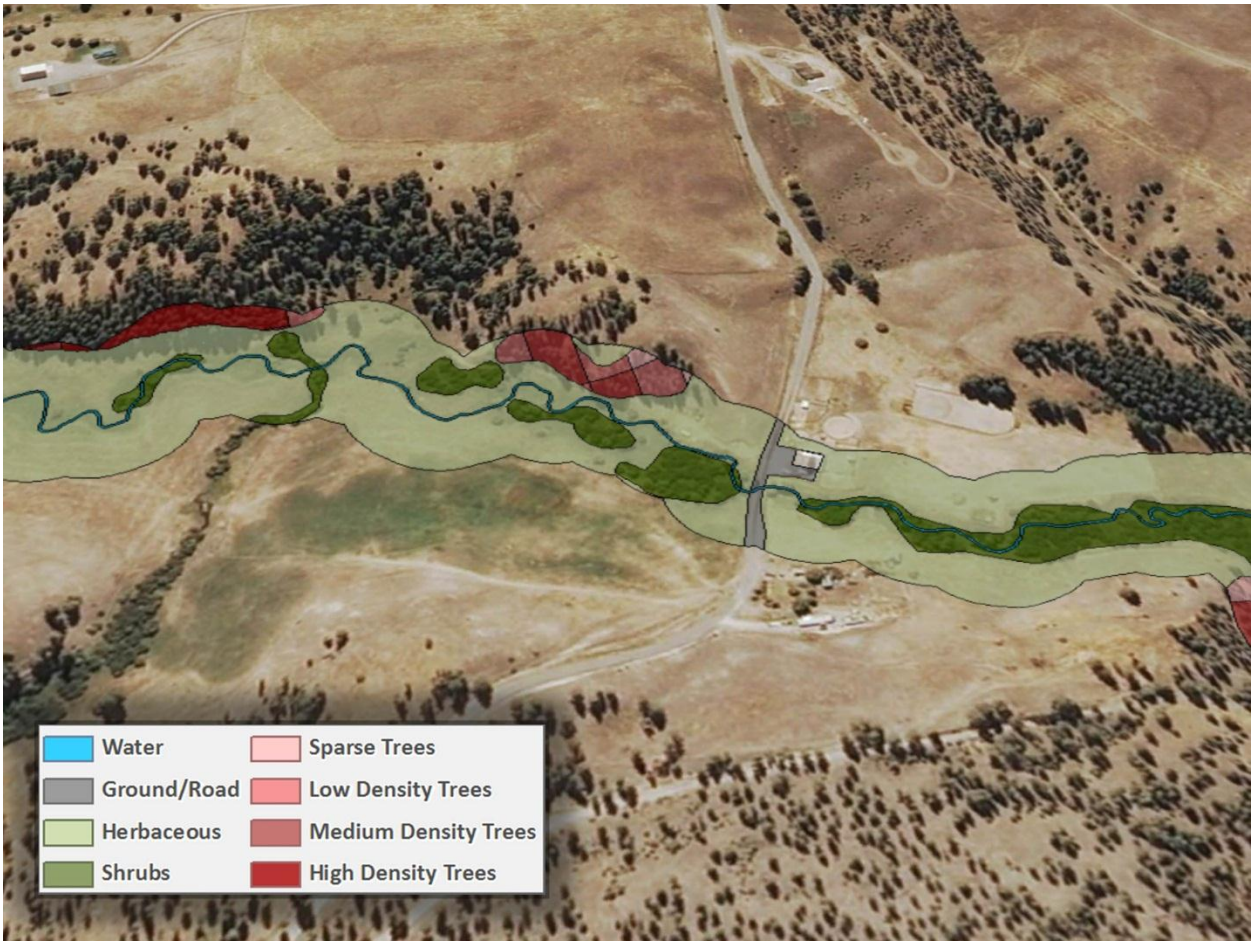


Figure A-6. Vegetation mapping example for Nemote Creek.

Herbaceous vegetation and medium density trees are the most common cover types along Nemote Creek, followed by high and low density trees (**Table A-1**). Roads and buildings compose only a small percentage of the riparian area.

Table A-1. Land cover types in the Nemote Creek riparian zone

Land cover type	Area (acres)	Relative area (percent)
Buildings	0.6	0.2%
Herbaceous	152.8	39.4%
Roads	8.0	2.1%
Shrub	21.6	5.6%
Sparse trees	19.4	5.0%
Low density trees	27.2	7.0%
Medium density trees	85.8	22.1%
High density trees	72.6	18.7%

A-5. Shade

Shade is one of several factors that control in-stream water temperatures. Shade is defined as the fraction of potential solar radiation that is blocked by topography and vegetation.

A-5.1. *Measured Shade*

EPA (i.e., Atkins) collected shade characterization data on September 15, 2011, at six monitoring locations along Nemote Creek using a Solar Pathfinder™ (**Figure A-7**). Hourly shade estimates based on the Solar Pathfinder™ measurements are presented in **Attachment A**. The data are summarized in **Table A-2**.

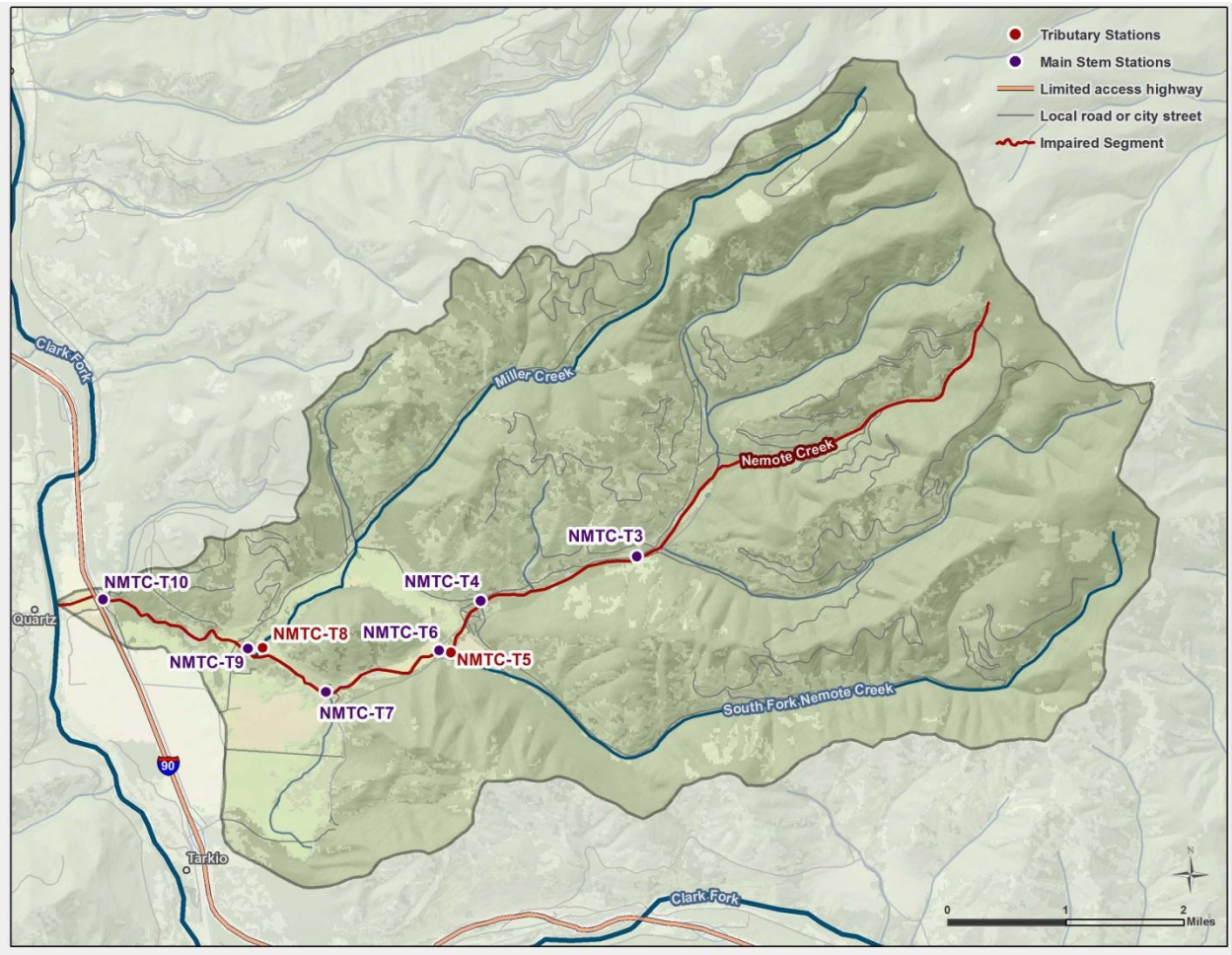


Figure A-7. EPA flow, shade, and continuous temperature monitoring locations.

Table A-2. Average shade per reach from Solar Pathfinder™ measurements

Site ID	Average daily shade (averaged across daylight hours)
NMTC-T3	82%
NMTC-T4	76%
NMTC-T6	13%
NMTC-T7	17%
NMTC-T9	49%
NMTC-T10	53%

Note: Sites are listed as headwaters to mouth from top to bottom.

A-5.2. *Shade Modeling*

An analysis of aerial imagery and site reconnaissance showed that shading along Nemote Creek was highly variable. Therefore, shade was also evaluated using the spreadsheet Shadev3.0.xls. Shade version 3.0 is a riparian vegetation and topography model that computes the hourly effective shade for a single day (Washing State Department of Ecology 2008). Shade is an Excel/Visual Basic for Applications program. The model uses the latitude and longitude, day of year, aspect and gradient (the direction and slope of the stream), solar path, buffer width, canopy cover, and vegetation height to compute hourly, dawn-to-dusk shade. The model input variables include channel orientation, wetted width, bankfull width, channel incision, topography, and canopy cover. Bankfull width in the shade calculations is defined as the near-stream disturbance zone (NSDZ), which is the distance between the edge of the first vegetation zone on the left and right bank.

Available Data

The application of the Shade Model to Nemote Creek relied upon field data collected during a 2011 field study, as well as a 2012 field study in Wolf and Fortine creeks, and the interpretation of these data (**Attachment B**). The results of the study included: tree/shrub height, overhang, wetted channel width, and bankfull width.

GIS Pre-Processing

TTools version 3.0 is an ArcView extension to translate spatial data into Shade Model inputs (Oregon Department of Environmental Quality 2001). TTools was used to estimate the following values: elevation, aspect, gradient, distance from the stream center to the left bank, and topographic shade. Elevation was calculated using a 10 meter (33 foot) digital elevation model (DEM) and a stream centerline file digitized from aerial imagery in GoogleEarth™. Aspect was calculated to the nearest degree using TTools with the stream centerline file.

Although the field study report provided an estimate of the wetted width, an assessment along the entire stream was obtained by digitizing both the right and left banks from aerial imagery in GoogleEarth™. TTools then calculates wetted width based on the distance between the stream centerline and the left and right banks. Topographic shade was calculated using TTools with the stream centerline file and a DEM.

Riparian Input

The Shade Model requires the description of riparian vegetation: a unique vegetation code, height, density, and overhang (OH). The results in the field study report and the above described vegetation mapping were used to develop a riparian description table (**Table A-3**). Vegetation descriptions used the average value for tree/shrub height and overhang from field observation.

Table A-3. Vegetation input values for the Shade Model

Attribute	Value	Basis
Trees		
Height	23 meters (75 feet)	In the absence of site-specific data, this value was based on work conducted in Wolf and Fortine creeks.
Density	Variable	2001 NLCD.
Overhang	2.3 meters (7.5 feet)	Estimated as 10% of height (Stuart 2012).
Shrubs		
Height	4.0 meters (13 feet)	In the absence of site-specific data, this value was based on work conducted in Wolf and Fortine creeks.
Density	90%	Ocular estimate based on aerial imagery.
Overhang	1.0 meter (3.3 feet)	Estimated as 25% of height (Shumar and de Varona 2009)
Herbaceous		
Height	0.5 meter (1.6 feet)	Estimated
Density	100%	Estimated
Overhang	0 meters	Estimated

Shade Input

The Shade Model inputs are riparian zones, reach length, channel incision, elevation, aspect, wetted width, near-stream disturbance zone width, distance from the bank to the center of the stream, and topographic shade. Input for the riparian zone is presented above in **Table A-3**. The Shade Model requires reach lengths be an equal interval. The reaches in the field study report were not at an equal interval and were very widely spaced. A uniform reach length interval of 15 meters (49 feet) was used. The remaining variables were computed as part of the GIS pre-processing described above.

Shade Model Results

The current longitudinal effective shade profile generated from the Shade Model and the Solar Pathfinder™ measurements are presented in **Figure A-8**.

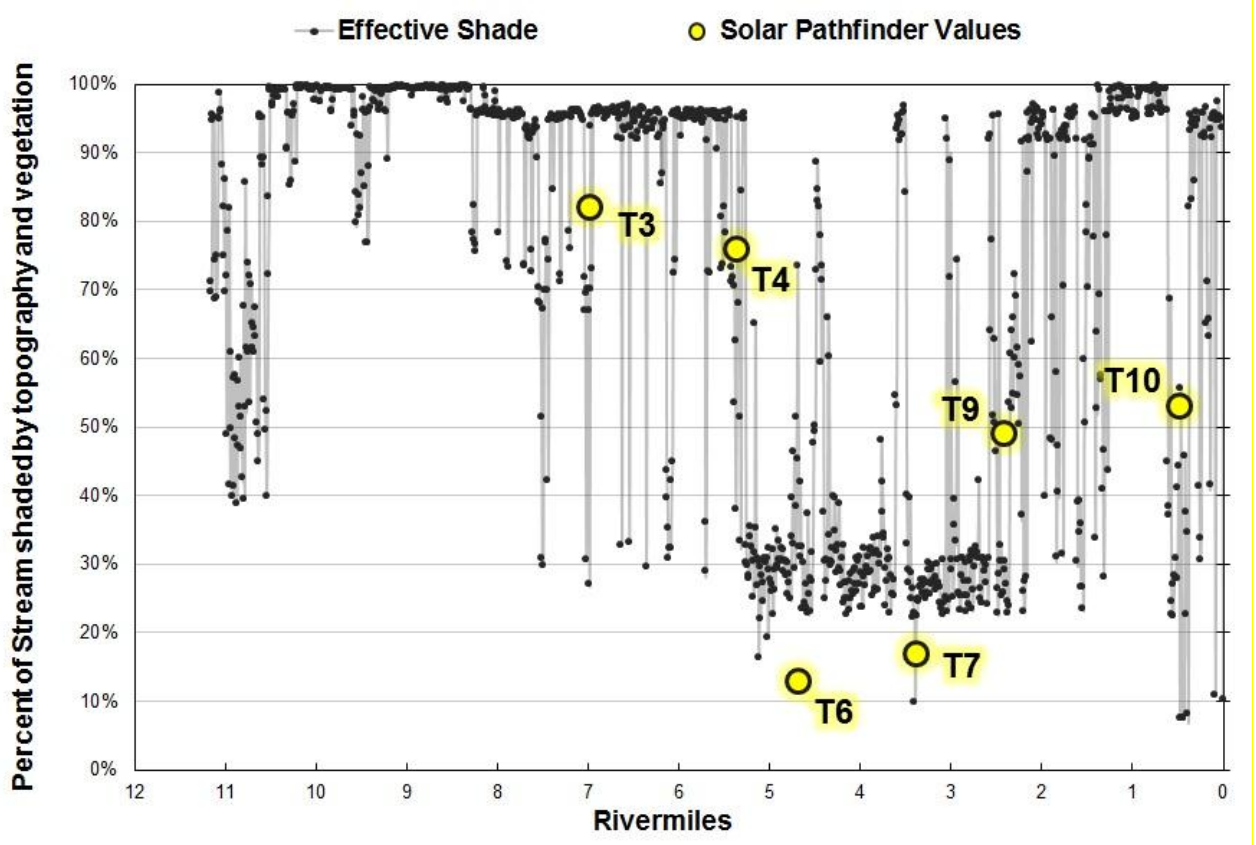


Figure A-8. Longitudinal estimates of observed and simulated effective shade along Nemote Creek.

The goodness of fit for the Shade Model was summarized using the mean error (ME), average absolute mean error (AME), and root mean square error (RMSE) as a measure of the deviation of model-predicted shade values from the measured values. These model performance measures were calculated as follows:

$$ME = \frac{1}{N}\sum_{n=1}^{n} P_n - O_n$$

$$AME = \frac{1}{N}\sum_{n=1}^{n} |P_n - O_n|$$

$$RMSE = \sqrt{\frac{1}{N}\sum_{n=1}^{n} (P_n - O_n)^2}$$

where

P = model predicted values
O = observed values
n = number of samples

Model error statistics are provided in **Table A-4** and suggest a good fit between observed and predicted average effective shade values. The average absolute mean error is 8 percent. (i.e., the average error from the Shade Model output and Solar Pathfinder™ measurements was 8 percent daily average shade; see **Table A-4**).

Table A-4. Shade model error statistics

Error Statistic	Formula	Result	Units
Mean Error (ME)	$(1/N)*\Sigma(P_n-O_n)$	-3%	percent of percent shade
Average Absolute Mean Error (AME)	$(1/N)*\Sigma\lvert(P_n-O_n)\rvert$	7%	percent shade
Root Mean Square Error (RMSE)	$[(1/N)*\Sigma(P_n-O_n)^2]^{1/2}$	9%	percent of percent shade

A-6. Stream Temperature

In 2011, Atkins collected continuous temperature data at six locations in Nemote Creek (sites NMTC-T3, NMTC-T4, NMTC-T6, NMTC-T7, NMTC-T9, and NMTC-T10) and at two tributary locations (NMTC-T5 and NMTC-T8). Data loggers recorded temperatures every one-half hour for approximately three months between July 12-13 and September 14-15. Instantaneous temperatures were also monitored by Atkins and DEQ (**Table A-5** and **Table A-6**).

Table A-5. Atkins instantaneous water temperature measurements (°F), summer 2011

Date	NMTC-T3	NMTC-T4	NMTC-T5[a]	NMTC-T6	NMTC-T7	NMTC-T8[b]	NMTC-T9	NMTC-T10
September 15, 2011	48.7	48.0	--[c]	--[c]	56.8	55.0	51.8	50.5

Notes
a. Site is on South Fork Nemote Creek, a tributary to Nemote Creek.
b. Site is on Miller Creek, a tributary to Nemote Creek.
c. Stream channel was dry.

Table A-6. DEQ instantaneous temperature measurements in support of other water quality studies

Date	C04NEMOC01	C04NEMOC10	C04NEMOC09	C04NEMOC04	C04NEMOC08	C04NEMOC07	C04NEMOC06	C04NEMOC05
August 8, 2011	51.8	54.9	57.2	48.0	64.4	56.7	53.1	51.6
September 6-7, 2011	47.7	48.7	47.5	44.6	--	59.5	54.5	50.0

A-7. Hydrology

No active U.S. Geological Survey continuously recording gages are located on Nemote Creek. The closest such gage is gage 12353650, located 11 miles away on the Clark Fork River near Superior, MT. The closest continuously recording gage on a small stream similar to Nemote Creek is gage 12413875, located 30 miles away on the St. Joe River[1]. EPA (i.e., Atkins) collected instantaneous flow measurements in 2011, during temperature data logger deployment and retrieval (**Table A-7** and **Table A-8; Attachment C**). Flow data were collected by DEQ in support of other water quality studies in 2011 (**Table A-8**). Locations of the flow measurements are shown in **Figure A-9**.

Table A-7: EPA instantaneous flow measurements (cfs) on Nemote Creek in support of modeling

Date	NMTC-T3	NMTC-T4	NMTC-T5[a]	NMTC-T6	NMTC-T7	NMTC-T8[b]	NMTC-T9	NMTC-T10
July 12-13, 2011	5.83	7.38	1.53	4.09	10.73	2.03	11.87	12.63
September 14-15, 2011	0.19	0.93	0	0	1.91	0.54	2.49	1.62

Notes
a. Site is located on South Fork Nemote Creek, a tributary to Nemote Creek.
b. Site is located on Miller Creek, a tributary to Nemote Creek.

Table A-8: DEQ instantaneous flow measurements (cfs) in support of other water quality studies

Date	C04NEMOC01	C04NEMOC10	C04NEMOC09	C04NEMOC04	C04NEMOC08	C04NEMOC07	C04NEMOC06	C04NEMOC05
August 8, 2011	0.92	0.44	0.69	3.39	0.75	5.22	6.16	4.18
September 6-7, 2011	0.67	0.28	0.5	1.98	0	1.85	2.32	1.4

[1] Gage 12413875 on the St. Joe River at Red Ives Ranger Station drains 120 square miles.

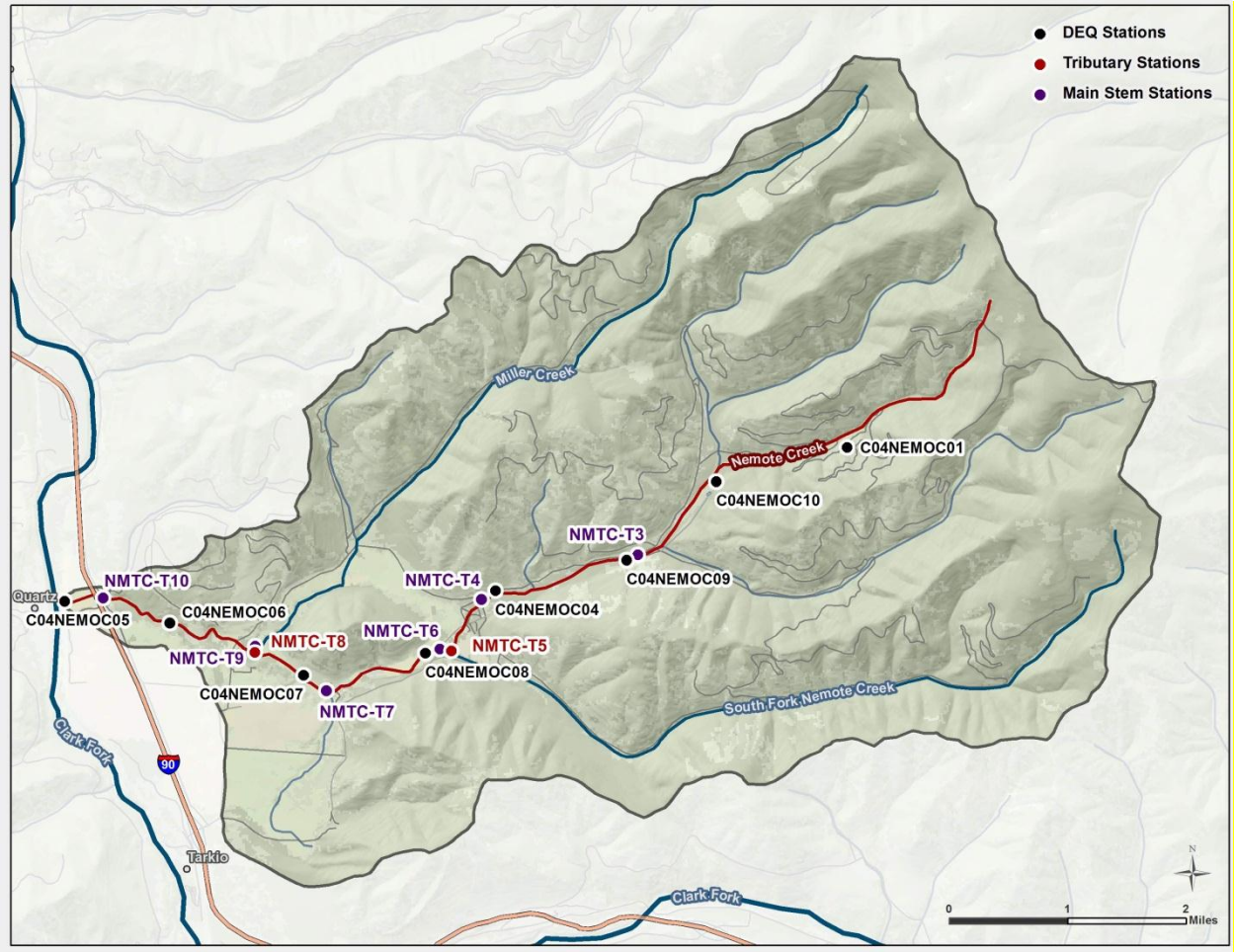
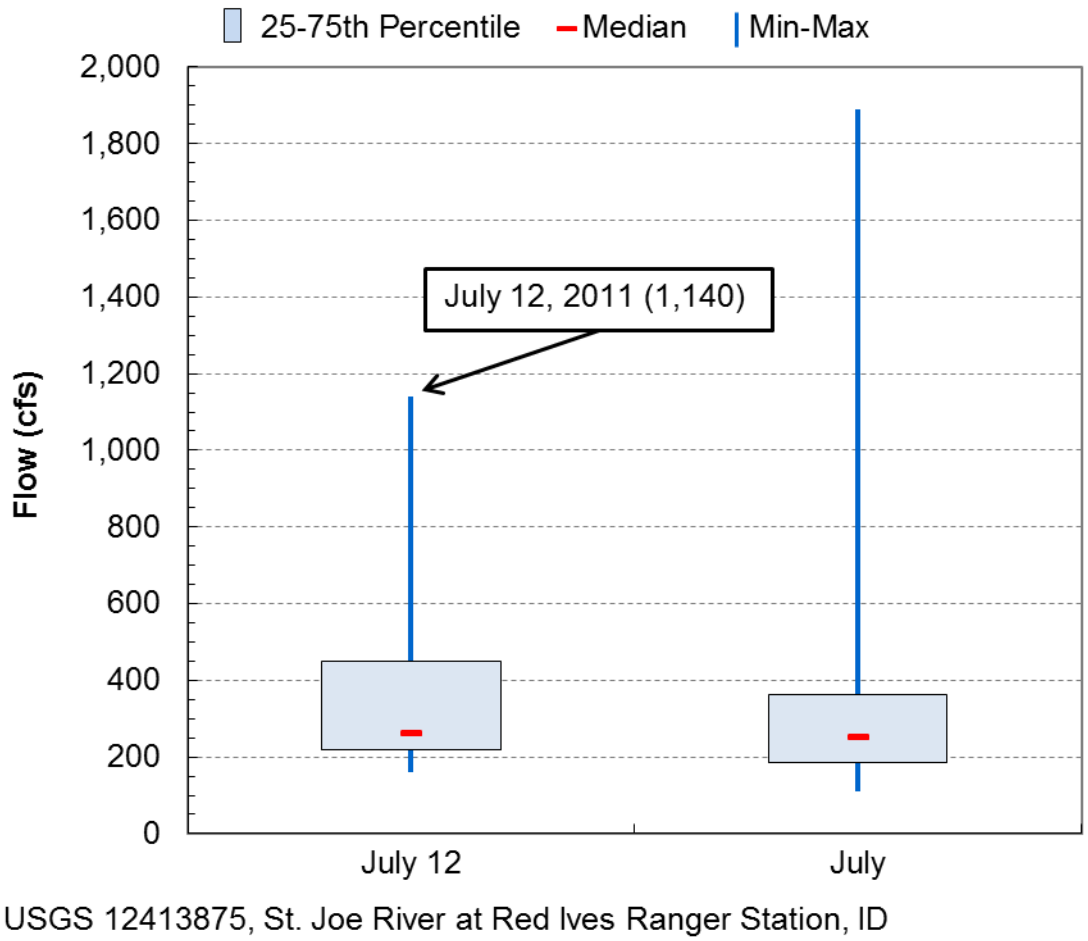


Figure A-9. Flow monitoring locations in the Nemote Creek watershed.

All available data were used to evaluate the water balance in Nemote Creek and to develop a pre-modeling understanding of the hydrology. However, the 2011 data (primarily the July data) will be relied upon for model inputs and hydrologic calibration. It should be noted that, compared to the historic period of record at the nearest continuous recording USGS gage on a waterbody of similar size to Nemote Creek (i.e., USGS 12353650, St. Joe River at Red Ives Ranger Station), flows on July 12, 2011 were at the maximum of 16 years of records (**Figure A-10**).

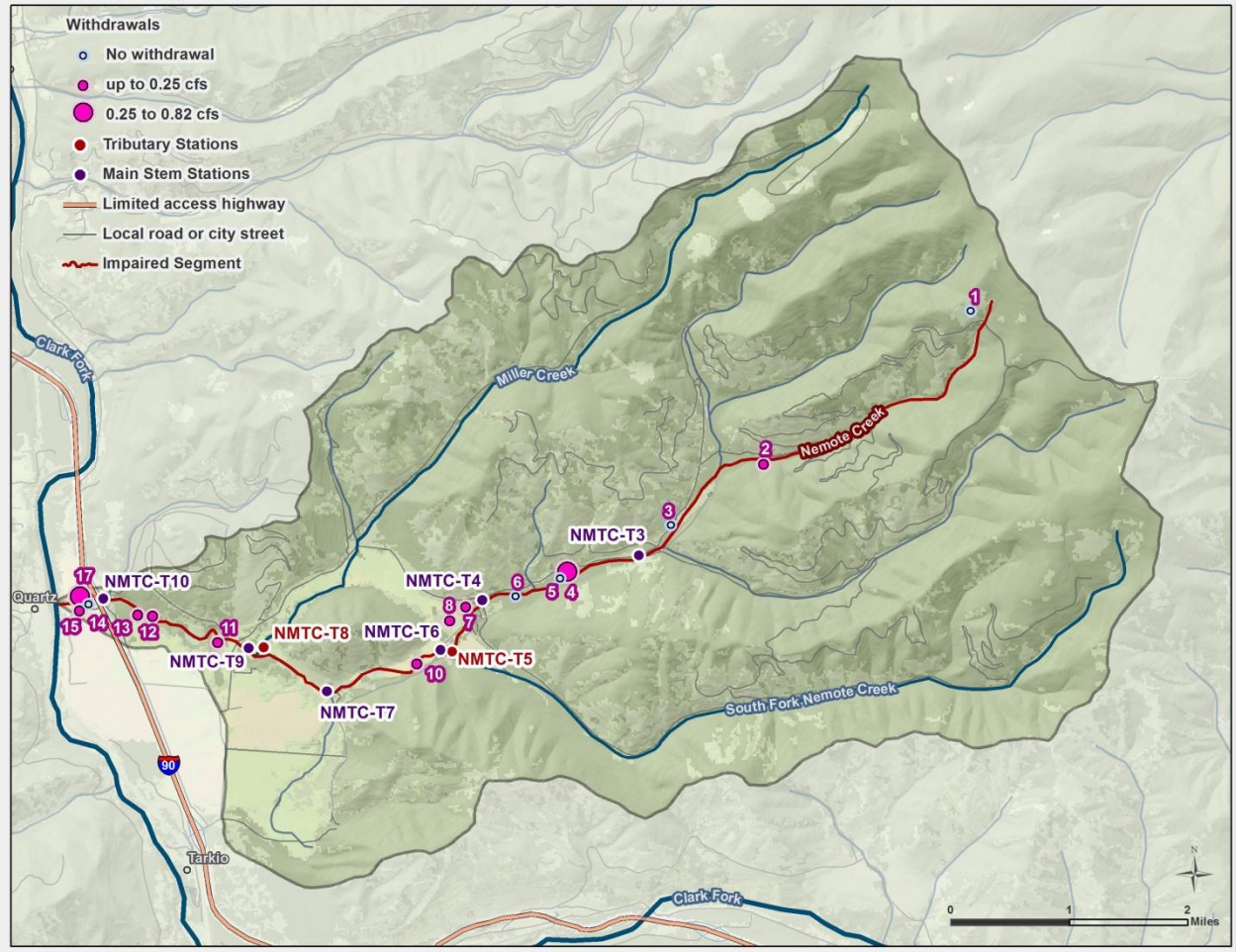


Note: "July" represents the daily average flow for the month of July per year (i.e., the average of 31 daily average flows)

Figure A-10. Flow analysis with USGS gage 12413875 (St. Joe River at Red Ives Ranger Station).

A-8. Flow Modification

Based on review of aerial photographs and online water rights data (ftp://nris.mt.gov/dnrc), there are 16 active surface diversions from Nemote Creek that support various uses (**Figure A-11**). "Points of diversion" and "places of use" spatial data were obtained from the Montana Natural Resource Information System (NRIS 2012). A total of 107 "places of use" were found, which represent individual water usage allotments, such as a total annual volume required for a specific acreage of land. These "places of use" corresponded to 22 "points of diversion", which represent individual water right permit numbers associated with the physical stream diversions. These "points of diversion" further correspond to 16 distinct locations along Nemote Creek. (**Figure A-11** and **Table A-9**).



Source of "points of diversion" data: NRIS 2012.

Figure A-11. Surface diversions in the Nemote Creek watershed.

Table A-9. Points of diversion from Nemote Creek

Map ID	Purpose	Irrigation type	Means of Diversion [a]	Est. daily flow rate (cfs)[b]	
				July	Sept
1	Stock		L	0.00	0.00
2	Irrigation	Sprinkler/Furrow	P/HDP	0.09	0.04
3	Stock		L	0.00	0.00
4	Multiple Domestic		Flowing	0.27	0.13
5	Stock		L	0.00	0.00
6	Stock		L	0.00	0.00
7	Irrigation	Flood	HDP/FD	0.15	0.07
8	Irrigation	Flood	HDP/FD	0.15	0.07
9	Irrigation	Flood	HDP/FD	0.15	0.07
10	Irrigation	Flood	HDP/FD	0.15	0.07
11	Irrigation	Sprinkler	Pump	0.05	0.03
12	Irrigation	Sprinkler/Flood	P/HDP	0.22	0.10
13	Irrigation	Sprinkler/Flood	P/HDP	0.22	0.10
15	Irrigation		Pump	0.06	0.03
16	Stock		L	0.00	0.00
17	Irrigation		Pump	0.82	0.39
Total Withdrawal				***2.33***	***1.10***

Source: NRIS 2012
Notes
a. L = Livestock Direct From Source, P/H D P = Pump/Headgate with Ditch or Pipeline, H D P/F D = Headgate with Ditch or Pipeline/Flood and Dike.

A-9. Point Sources

There are no permitted point sources within the Nemote Creek watershed. There is one abandoned mine, named Highbar Placer, near the mouth (MBMG 2006).

A-10. References

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