Madison Sediment and Temperature TMDLs and Water Quality Improvement Plan

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ABBREVIATIONS AND ACRONYMS

Symbol or Unit of Measure	Definition
cfs	Cubic Feet per Second
ft	Feet
kcal/day	Kilocalories per Day
lbs/day	Pounds per Day
mm	Millimeters
^{o}C	Degrees Celsius
^{o}F	Degrees Fahrenheit
‘	Foot
>	Greater Than
<	Less Than
≥	Greater Than or Equal To
≤	Less Than or Equal To
%	Percent
~	Approximately

Abbreviation or Acronym	Definition
AL	Aquatic Life
ARM	Administrative Rules of Montana
AUM	Animal Unit Month
BANCS	Bank Assessment for Nonpoint Source Consequences of Sediment (model)
BLM	Bureau of Land Management (Federal)
BMP	Best Management Practice
CAAP	Concentrated Aquatic Animal Production
CD	Conservation District
CFR	Code of Federal Regulations
DEQ	Department of Environmental Quality (Montana)
DNRC	Department of Natural Resources & Conservation (Montana)
EPA	Environmental Protection Agency (U.S.)
EQIP	Environmental Quality Incentives Program
FWP	Fish, Wildlife & Parks (Montana)
GIS	Geographic Information System
HUC	Hydrologic Unit Code
IR	Integrated Report (Montana Water Quality)
LA	Load Allocation
MARS	Montana Aquatic Resources Services, Inc.
MBMG	Montana Bureau of Mines and Geology
MCA	Montana Code Annotated
MOS	Margin of Safety
MPDES	Montana Pollutant Discharge Elimination System
MWMT	Maximum Weekly Maximum Temperature
N/A	Not Applicable
NHD	National Hydrography Dataset

Abbreviation or Acronym	Definition
NM	Not Monitored
NRCS	Natural Resources Conservation Service (U.S. Dept. of Agriculture)
PIBO	Pacfish/Infish Biological Opinion
RM	River Mile
SMZ	Streamside Management Zone
STATSGO	State Soil Geographic Database
T	Temperature
TMDL	Total Maximum Daily Load
TPA	TMDL Planning Area (Madison)
UILT	Upper Incipient Lethal Temperature
USDA	United States Department of Agriculture
USFS	United States Forest Service
USGS	United States Geological Survey
W/D	Width to Depth Ratio
WEPP	Water Erosion Prediction Project (model)
WLA	Wasteload Allocation
WRP	Watershed Restoration Plan

HOW THIS DOCUMENT IS ORGANIZED AND WHAT IT CONTAINS

This document addresses all the required components of a TMDL and includes an implementation and monitoring strategy, as well as a strategy to address impairment causes other than sediment and temperature. The TMDL components are summarized within the main body of the document. Additional technical details are contained in the appendices.

This document is organized into three parts, in addition to a preceding document summary. Use the tables below to determine which part(s) to read to find the information most useful to you.

Document Part	Read for:
Part 1	Introductory information that provides the context for this document and defines the total maximum daily load (TMDL) process
Part 2	The TMDL components and how they are derived
Part 3	Information on ways to improve water quality in the Madison River watershed and information on developing a local water quality restoration plan

PART 1 – INTRODUCTORY INFORMATION

Part 1 Document Section	Section Contents
Section 1.0 Project Overview	Explains why DEQ writes TMDLs and provides a summary of what water quality impairments are addressed and a table of what TMDLs are included in this document
Section 2.0 Madison TMDL Planning Area Description	Describes the physical characteristics and social profile of the watershed
Section 3.0 Montana Water Quality Standards	Discusses the water quality standards that apply to the Madison River watershed and the TMDLs in this document
Section 4.0 Defining TMDLs and Their Components	Defines the components of TMDLs and how each is developed

PART 2 – TMDL COMPONENTS

Part 2 Document Section	Section Contents
Section 5.0 Sediment TMDL Components	Both pollutant sections include: (a) a discussion of the affected waterbodies and the pollutant's effect on designated beneficial uses, (b) the information sources and assessment methods used to evaluate stream health and pollutant source contributions, (c) water quality targets and existing water quality conditions, (d) the quantified pollutant loading from the identified sources, (e) the determined TMDL for each waterbody, (f) the allocations of the allowable pollutant load to the identified sources
Section 6.0 Temperature TMDL Components	

Part 2 Document Section	Section Contents
Section 7.0 Public Participation and Public Comments	Describes other agencies and stakeholder groups who were involved with the development of this document and the public participation process used to review the draft document. Addresses comments received during the public review period.

PART 3 – WATER QUALITY RECOMMENDATIONS

Part 3 Document Section	Section Contents
Glossary	Definitions of water quality terminology used in Part 3
Section 8.0 Non-Pollutant Impairments	Describes other problems that could potentially be contributing to water quality impairment and how the TMDLs in this document might address some of these concerns. This section also provides recommendations for combating these problems.
Section 9.0 Water Quality Improvement Plan	Discusses water quality restoration objectives and a strategy to meet the identified objectives and TMDLs.
Section 10.0 Monitoring for Effectiveness	Describes a water quality monitoring plan for evaluating the long-term effectiveness of the Madison TMDLs and any implemented restoration projects.

To supplement this TMDL document, succinct summaries of all streams monitored as part of the TMDL project were also compiled. The Madison Stream Summaries 2020 document can be found on DEQ's TMDL webpages and the Madison TMDL project wiki site (mtwaterqualityprojects.pbworks.com).

INDIVIDUAL STREAM SUMMARIES

To supplement the information provided in this total maximum daily load (TMDL) document, a summary of each stream monitored by DEQ during the Madison TMDL project between 2012 and 2014 is provided in the Madison Watershed Stream Summaries 2020 document found on DEQ's TMDL webpages (search "Montana DEQ TMDL" in your web browser) and on the Madison TMDL project wiki site at mtwaterqualityprojects.pbworks.com.

The stream summary document contains a summary for each impaired stream discussed in this TMDL document. A summary, map, and photos of each stream is provided in a succinct format to aid the reader in understanding the current condition of the stream and what types of restoration projects may be undertaken to improve water quality. Information for preparing a watershed restoration plan (further discussed in **Section 9.0** of this TMDL document) is also provided. Additional detail on the general water quality improvement recommendations provided within the stream summaries can be found in **Section 9.0** of this TMDL document.

TMDL DOCUMENT SUMMARY

This document presents a total maximum daily load (TMDL) and framework water quality improvement plan for 16 impaired tributaries to the Madison River (see **Figure 1-1**).

The Montana Department of Environmental Quality (DEQ) develops TMDLs and submits them to the U.S. Environmental Protection Agency (EPA) for approval. The Montana Water Quality Act requires DEQ to develop TMDLs for streams and lakes that do not meet, or are not expected to meet, Montana water quality standards. A TMDL is the maximum amount of a pollutant a waterbody can receive and still meet water quality standards. TMDLs provide an approach to improve water quality so that streams and lakes can support and maintain their state-designated beneficial uses.

The Madison TMDL Planning Area follows the Madison River from the Wyoming border, near West Yellowstone, to the river's mouth at the headwaters of the Missouri River near Three Forks, Montana. The planning area includes the watersheds of many tributary streams draining directly to the Madison River, but does not include the portion of the Madison River watershed within Yellowstone National Park. The TMDL planning area encompasses approximately 2,583 square miles (1,653,311 acres) in western Montana, and includes portions of Madison and Gallatin counties.

DEQ determined that a number of tributaries do not meet the applicable water quality standards. The scope of the TMDLs in this document address problems with sediment and temperature, and 16 TMDLs are included that address 17 pollutant impairments (**Table DS-1**). Although DEQ recognizes that there are other pollutant listings for the Madison TMDL planning area, this document addresses only those impairments identified in **Tables DS-1** and **1-1**. Future TMDL projects may require additional TMDLs for this TMDL planning area (**Table 1-2**).

Sediment
Sediment was identified as impairing aquatic life in Antelope, Bear, Blaine Spring, Cherry, Elk, Hot Springs, Moore, North Meadow, Red Canyon, Ruby, South Meadow, Watkins, and Wigwam creeks. Sediment is affecting designated uses in these streams by altering aquatic insect communities, reducing

fish spawning success, and increasing turbidity. Water quality restoration objectives for sediment were established on the basis of fine sediment levels in trout spawning areas and aquatic insect habitat, stream morphology and available instream habitat as it related to the effects of sediment, and the stability of streambanks. DEQ believes that once these water quality objectives are met, all water uses currently affected by sediment will be restored. DEQ's water quality assessment methods for sediment impairment are designed to evaluate the most sensitive use, thus ensuring protection of all designated uses. For streams in Western Montana, the most sensitive use assessed for sediment is aquatic life.

Sediment loads are quantified for unpaved roads and eroding streambanks for all tributaries with sediment TMDLs, as well as for upland hillslope erosion for Elk Creek. The most significant sources include streamside livestock grazing, removal of streamside vegetation, parallel road segments and undersized culverts, as well as natural sources. The Madison TMDL Planning Area sediment TMDLs indicate that reductions in sediment loads ranging from 7% to 38% will satisfy the water quality restoration objectives.

Recommended strategies for achieving the sediment reduction objectives are also presented in this plan. They include best management practices (BMPs) for building and maintaining roads, for riparian (streamside) livestock grazing, and for developing subdivisions. In addition, they include BMPs for expanding riparian buffer areas and using other land, soil, and water conservation practices that improve stream channel conditions and associated riparian vegetation.

Temperature

Temperature was identified as impairing aquatic life in Cherry, Elk, and Moore creeks. Aquatic life and fish depend upon cool water for survival. Increased stream temperatures are affecting designated uses in these streams by decreasing dissolved oxygen levels and increasing primary production via algal and bacterial growth that can lead to further decreases in dissolved oxygen. Additionally, higher instream temperatures make fish more prone to disease and may create lethal conditions for fish populations.

Water quality restoration objectives for temperature were established based on indicator parameters that influence temperature and can be linked to human causes. The indicator or target parameters include riparian (streamside) vegetation health and shading conditions and stream channel geometry/dimensions (with/depth ratio). Improved streamflow conditions, where applicable, will also help decrease stream temperatures. DEQ believes that once these water quality objectives are met, all water uses currently affected by temperature will be restored. DEQ's water quality assessment methods for temperature impairment are designed to evaluate the most sensitive use, thus ensuring protection of all designated uses. For streams in Western Montana, the most sensitive use assessed for temperature is aquatic life.

Destruction of riparian vegetation from livestock grazing, agricultural crop production, and urban development are the primary causes of temperature impairment in Cherry, Elk, and Moore creeks. The temperature TMDLs indicate that 14% to 26% reductions in temperature loads are necessary. General strategies for achieving the instream water temperature reduction goals are also presented in this plan and include BMPs for managing riparian areas.

Water Quality Improvement Measures

Implementation of most water quality improvement measures described in this plan is based on voluntary actions of watershed stakeholders. Ideally, local watershed groups and/or other watershed stakeholders will use this TMDL document, and associated information, as a tool to guide local water

quality improvement activities. Such activities can be documented within a watershed restoration plan consistent with DEQ and EPA recommendations.

A flexible approach to most nonpoint source TMDL implementation activities may be necessary as more knowledge is gained through implementation and future monitoring. This plan includes a monitoring strategy designed to track progress in meeting TMDL objectives and goals and to help refine the plan during its implementation.

Table DS-1. Impaired Waterbodies in the Madison TMDL Planning Area with TMDLs Contained in this Document

Waterbody (Assessment Unit)	Waterbody ID (Assessment Unit ID)	TMDL Prepared	Pollutant Group	Impaired Use
Antelope Creek, Headwaters to mouth (Cliff Lake)	MT41F004_140	Sediment	Sediment	Aquatic Life
Bear Creek, Headwaters to mouth (O'Dell Spring Creek)	MT41F004_021	Sediment	Sediment	Aquatic Life
Blaine Spring Creek, Headwaters to mouth (Madison River, T7S R1W S6)	MT41F004_010	Sediment	Sediment	Aquatic Life
Cherry Creek, Headwaters to mouth (Madison River)	MT41F002_010	Sediment	Sediment	Aquatic Life
		Temperature	Temperature	Aquatic Life
Elk Creek, Headwaters to mouth (Madison River)	MT41F002_020	Sediment	Sediment	Aquatic Life
		Temperature	Temperature	Aquatic Life
Hot Springs Creek, Headwaters to mouth (Madison River)	MT41F002_030	Sediment	Sediment	Aquatic Life
Moore Creek, Springs to mouth (Fletcher Channel), T5S R1W S15	MT41F004_130	Sediment	Sediment	Aquatic Life
		Temperature	Temperature	Aquatic Life
North Meadow Creek, Headwaters to mouth (Ennis Lake)	MT41F004_060	Sediment	Sediment	Aquatic Life
Red Canyon Creek, Headwaters to mouth (Hebgen Lake)	MT41F006_020	Sediment	Sediment	Aquatic Life
Ruby Creek, Headwaters to mouth (Madison River)	MT41F004_080	Sediment	Sediment	Aquatic Life
South Meadow Creek, Headwaters to mouth (Ennis Lake)	MT41F004_070	Sediment	Sediment	Aquatic Life
Watkins Creek, Headwaters to mouth (Hebgen Lake)	MT41F006_030	Sediment	Sediment	Aquatic Life

Table DS-1. Impaired Waterbodies in the Madison TMDL Planning Area with TMDLs Contained in this Document

Waterbody (Assessment Unit)	Waterbody ID (Assessment Unit ID)	TMDL Prepared	Pollutant Group	Impaired Use
Wigwam Creek, Headwaters to mouth (Madison River)	MT41F004_160	Sediment	Sediment	Aquatic Life

PART 1
INTRODUCTORY INFORMATION

1.0 PROJECT OVERVIEW

This document presents an analysis of water quality information and establishes total maximum daily loads (TMDLs) for sediment and temperature problems in the Madison TMDL Planning Area (TPA). This document also presents a general framework for resolving these problems. **Figure 1-1** below shows a map of the Madison River watershed. The Madison TMDL Planning Area, however, only encompasses the portion of the watershed within the state of Montana and excludes the portion within Yellowstone National Park.

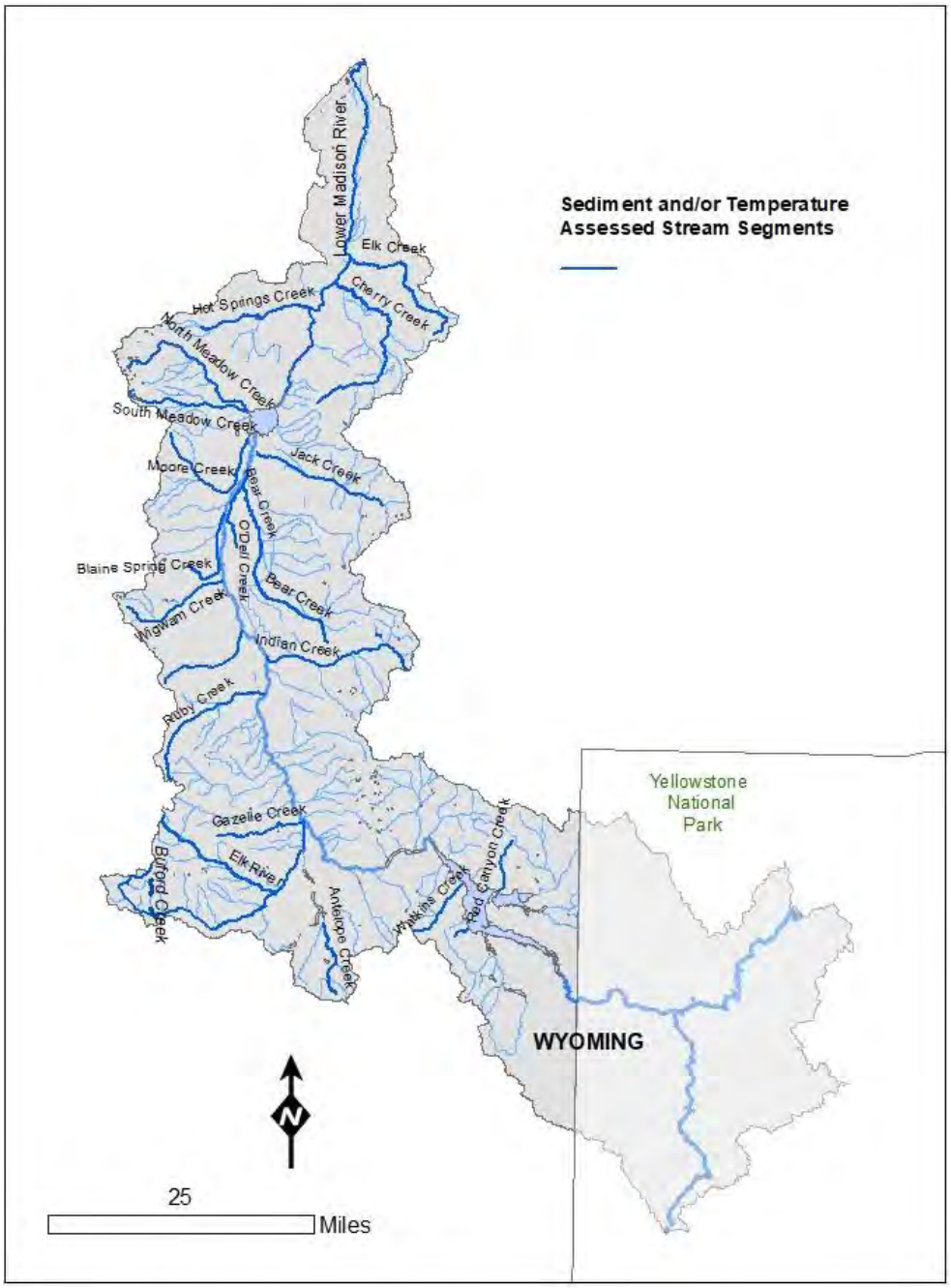


Figure 1-1. Location of the Madison River Watershed

1.1 Why We Write TMDLs

The Montana Department of Environmental Quality (DEQ) is charged with protection a clean and healthy environment. This includes actions that protect, maintain, and improve water quality, consistent with the Montana Water Quality Act and the federal Clean Water Act.

Montana's water quality designated use classification system includes the following:

- fish and aquatic life
- wildlife
- recreation
- agriculture
- industry
- drinking water

Each waterbody in Montana has a set of designated uses from the list above. Montana has established water quality standards to protect these uses, and a waterbody that does not meet one or more standards is called an impaired water. Each state must monitor their waters to track if they are supporting their designated uses, and every two years DEQ prepares a Water Quality Integrated Report (IR) which lists all impaired waterbodies and their identified impairment causes. Impairment causes fall within two main categories: pollutant and non-pollutant.

Montana's biennial IR identifies all the state's impaired waterbody segments. The 303(d) list portion of the IR includes all of those waterbody segments impaired by a pollutant. Both Montana state law (Section 75-5-701, Montana Code Annotated (MCA) of the Montana Water Quality Act) and section 303(d) of the federal Clean Water Act require the development of TMDLs for impaired waterbodies when water quality is impaired by a pollutant. TMDLs are not required for non-pollutant causes of impairment.

A TMDL is the maximum amount of a pollutant that a waterbody can receive and still meet water quality standards. **Section 4.0** provides more detail on TMDL development and the required TMDL components. In Montana, restoration strategies and monitoring recommendations are also incorporated in TMDL documents to help facilitate TMDL implementation (**Sections 9.0** and **10.0**).

Tables 1-1 and **1-2** identify all impaired waters for the Madison TMDL Planning Area from Montana's 2018 303(d) List, and include non-pollutant impairment causes included in Montana's "2018 Water Quality Integrated Report" (DEQ 2018). Both tables provide the current status of each impairment cause, identifying whether it has been addressed by TMDL development.

1.2 Water Quality Impairments and TMDLs Addressed by this Document

Table 1-1 below lists the impairment causes from the "2018 Water Quality Integrated Report" (DEQ 2018) that are addressed in this document (also see **Figure 1-1**). Each pollutant impairment falls within a TMDL pollutant category (i.e., sediment or temperature), and this document is organized by those categories.

TMDLs are completed for each waterbody – pollutant combination, and this document contains 16 TMDLs that address 17 pollutant impairments (**Table 1-1**). There are several non-pollutant types of impairment that are also addressed in this document. As noted above, TMDLs are not required for non-

pollutants, although in many situations the solution to one or more pollutant problems will be consistent with, or equivalent to, the solution for one or more non-pollutant problems. The overlap between the pollutant TMDLs and non-pollutant impairment causes is discussed in **Section 8.0**, Non-Pollutant Impairments. **Section 9.0**, Water Quality Improvement Plan, also provides some basic water quality solutions to address those non-pollutant causes not specifically addressed by TMDLs in this document.

Table 1-1. Water Quality Impairment Causes for the Madison TMDL Planning Area Addressed in This Document

Waterbody (Assessment Unit) [1]	Waterbody ID (Assessment Unit ID)	Impairment Cause	Pollutant Category	Impairment Cause Status
Antelope Creek, Headwaters to mouth (Cliff Lake)	MT41F004_140	Alteration in stream-side or littoral vegetative covers	Not Applicable; Non-Pollutant	Addressed by sediment TMDL
		Flow Regime Modification	Not Applicable; Non-Pollutant	Addressed in document (**Sections 8** and **9**); not linked to a TMDL
		Sedimentation-Siltation	Sediment	Sediment TMDL completed
Bear Creek, Headwaters to mouth (O'Dell Spring Creek)	MT41F004_021	Sedimentation-Siltation	Sediment	Sediment TMDL completed
Blaine Spring Creek, Headwaters to mouth (Madison River, T7S R1W S6)	MT41F004_010	Flow Regime Modification	Not Applicable; Non-Pollutant	Addressed in document (**Sections 8** and **9**); not linked to a TMDL
		Sedimentation-Siltation	Sediment	Sediment TMDL completed
Cherry Creek, Headwaters to mouth (Madison River)	MT41F002_010	Sedimentation-Siltation	Sediment	Sediment TMDL completed
		Temperature	Temperature	Temperature TMDL completed
Elk Creek, Headwaters to mouth (Madison River)	MT41F002_020	Alteration in stream-side or littoral vegetative covers	Not Applicable; Non-Pollutant	Addressed by sediment TMDL
		Sedimentation-Siltation	Sediment	Sediment TMDL completed
		Temperature	Temperature	Temperature TMDL completed
		Turbidity	Sediment	Addressed by sediment TMDL
Hot Springs Creek, Headwaters to mouth (Madison River)	MT41F002_030	Flow Regime Modification	Not Applicable; Non-Pollutant	Addressed in document (**Sections 8** and **9**); not linked to a TMDL
		Sedimentation-Siltation	Sediment	Sediment TMDL completed

Table 1-1. Water Quality Impairment Causes for the Madison TMDL Planning Area Addressed in This Document

Waterbody (Assessment Unit) [1]	Waterbody ID (Assessment Unit ID)	Impairment Cause	Pollutant Category	Impairment Cause Status
Indian Creek, Lee Metcalf Wilderness boundary to mouth (Madison River)	MT41F004_040	Alteration in stream-side or littoral vegetative covers	Not Applicable; Non-pollutant	Addressed in document (**Sections 8** and **9**); not linked to a TMDL
		Flow Regime Modification	Not Applicable; Non-pollutant	Addressed in document (**Sections 8** and **9**); not linked to a TMDL
Jack Creek, Headwaters to mouth (Madison River, T5S R1W S23)	MT41F004_050	Alteration in stream-side or littoral vegetative covers	Not Applicable; Non-pollutant	Addressed in document (**Sections 8** and **9**); not linked to a TMDL
		Flow Regime Modification	Not Applicable; Non-pollutant	Addressed in document (**Sections 8** and **9**); not linked to a TMDL
Moore Creek, Springs to mouth (Fletcher Channel), T5S R1W S15	MT41F004_130	Alteration in stream-side or littoral vegetative covers	Not Applicable; Non-pollutant	Addressed by sediment TMDL
		Sedimentation-Siltation	Sediment	Sediment TMDL completed
		Temperature	Temperature	Temperature TMDL completed
North Meadow Creek, Headwaters to mouth (Ennis Lake)	MT41F004_060	Flow Regime Modification	Not Applicable; Non-pollutant	Addressed in document (**Sections 8** and **9**); not linked to a TMDL
		Sedimentation-Siltation	Sediment	Sediment TMDL completed
O'Dell Spring Creek, Headwaters to mouth (Madison River)	MT41F004_020	Alteration in stream-side or littoral vegetative covers	Not Applicable; Non-Pollutant	Addressed in document (**Sections 8** and **9**); not linked to a TMDL
		Other anthropogenic substrate alterations	Not Applicable; Non-Pollutant	Addressed in document (**Sections 8** and **9**); not linked to a TMDL
		Physical substrate habitat alterations	Not Applicable; Non-Pollutant	Addressed in document (**Sections 8** and **9**); not linked to a TMDL

Table 1-1. Water Quality Impairment Causes for the Madison TMDL Planning Area Addressed in This Document

Waterbody (Assessment Unit) [1]	Waterbody ID (Assessment Unit ID)	Impairment Cause	Pollutant Category	Impairment Cause Status
Red Canyon Creek, Headwaters to mouth (Hebgen Lake)	MT41F006_020	Alteration in stream-side or littoral vegetative covers	Not Applicable; Non-pollutant	Addressed by sediment TMDL
		Flow Regime Modification	Not Applicable; Non-pollutant	Addressed in document (**Sections 8** and **9**); not linked to a TMDL
		Sedimentation-Siltation	Sediment	Sediment TMDL completed
Ruby Creek, Headwaters to mouth (Madison River)	MT41F004_080	Flow Regime Modification	Not Applicable; Non-Pollutant	Addressed in document (**Sections 8** and **9**); not linked to a TMDL
		Sedimentation-Siltation	Sediment	Sediment TMDL completed
South Meadow Creek, Headwaters to mouth (Ennis Lake)	MT41F004_070	Sedimentation-Siltation	Sediment	Sediment TMDL completed
Watkins Creek, Headwaters to mouth (Hebgen Lake)	MT41F006_030	Alteration in stream-side or littoral vegetative covers	Not Applicable; Non-pollutant	Addressed by sediment TMDL
		Flow Regime Modification	Not Applicable; Non-pollutant	Addressed in document (**Sections 8** and **9**); not linked to a TMDL
		Sedimentation-Siltation	Sediment	Sediment TMDL completed
Wigwam Creek, Headwaters to mouth (Madison River)	MT41F004_160	Sedimentation-Siltation	Sediment	Sediment TMDL completed
West Fork Madison River, Headwaters to mouth (Madison River)	MT41F004_100	Temperature	Temperature	Partially addressed in document (**Appendix H**)

[1] All waterbody segments within Montana's Water Quality Integrated Report are indexed to the National Hydrography Dataset (NHD)

1.3 Completed TMDLs and Future TMDL Development

Although DEQ recognizes that there are other pollutant listings for this TMDL planning area without completed TMDLs (**Table 1-2**), this document only addresses those identified in **Table 1-1** above. This is because DEQ sometimes develops TMDLs in a watershed at varying phases, with a focus on one or a couple of specific pollutant types. Nutrient, pathogen, and metal TMDLs were previously completed for the Madison TMDL planning area in 2019 for Elk, Hot Springs, Moore, O'Dell Spring, and South Meadow creeks (DEQ 2019).

Table 1-2. Water Quality Impairment Causes for the Madison TMDL Planning Area to be Addressed in a Future Project

Waterbody (Assessment Unit) [1]	Waterbody ID (Assessment Unit ID)	Impairment Cause	Pollutant Category
Blaine Spring Creek, Headwaters to mouth (Madison River, T7S R1W S6)	MT41F004_010	Arsenic	Metals
		Total Nitrogen	Nutrients
Buford Creek, Headwaters to confluence with West Fork Madison River	MT41F004_150	Arsenic	Metals
Elk Creek, Headwaters to mouth (Madison River)	MT41F002_020	Arsenic	Metals
Ennis Lake	MT41F005_030	Arsenic	Metals
		Flow Regime Modification	Not Applicable; Non-Pollutant
		Other anthropogenic substrate alterations	Not Applicable; Non-Pollutant
		Physical substrate habitat alterations	Not Applicable; Non-Pollutant
Madison River, Hebgen Dam to Quake Lake	MT41F001_030	Arsenic	Metals
Madison River, Quake Lake to Ennis Lake	MT41F001_020	Arsenic	Metals
Madison River, Madison Dam to mouth (Missouri River)	MT41F001_010	Alteration in stream-side or littoral vegetative covers	Not Applicable; Non-Pollutant
		Arsenic	Metals
		Sedimentation – Siltation	Sediment
		Temperature	Temperature
Moore Creek, Springs to mouth (Fletcher Channel), T5S R1W S15	MT41F004_130	Arsenic	Metals
O'Dell Spring Creek, Headwaters to mouth (Madison River)	MT41F004_020	Arsenic	Metals
West Fork Madison River, Headwaters to mouth (Madison River)	MT41F004_100	Temperature	Temperature

[1] All waterbody segments within Montana's Water Quality Integrated Report are indexed to the National Hydrography Dataset (NHD)

2.0 MADISON TMDL PLANNING AREA DESCRIPTION

This document section provides a general overview of the physical and social characteristics of the Madison TMDL Planning Area. Although certain information is current only through the 2016 to 2018 timeframe, the addition of more recently collected watershed description data would not affect overall TMDL development given the purpose of this section of the document.

2.1 PHYSICAL CHARACTERISTICS

The following information describes the physical characteristics of the Madison TMDL Planning Area, including topography, hydrology, climate, and geology.

2.1.1 Location

The Madison TMDL Planning Area follows the mainstem of the Madison River from the Wyoming border, near West Yellowstone, to the river's mouth at the headwaters of the Missouri River near Three Forks, Montana. The area includes the watersheds of many tributary streams draining directly to the Madison River. The planning area does not include the portion of the Madison River watershed within Yellowstone National Park. The TMDL planning area encompasses approximately 2,583 square miles (1,653,311 acres) in western Montana, and includes portions of Madison and Gallatin counties (**Figure 2-1**).

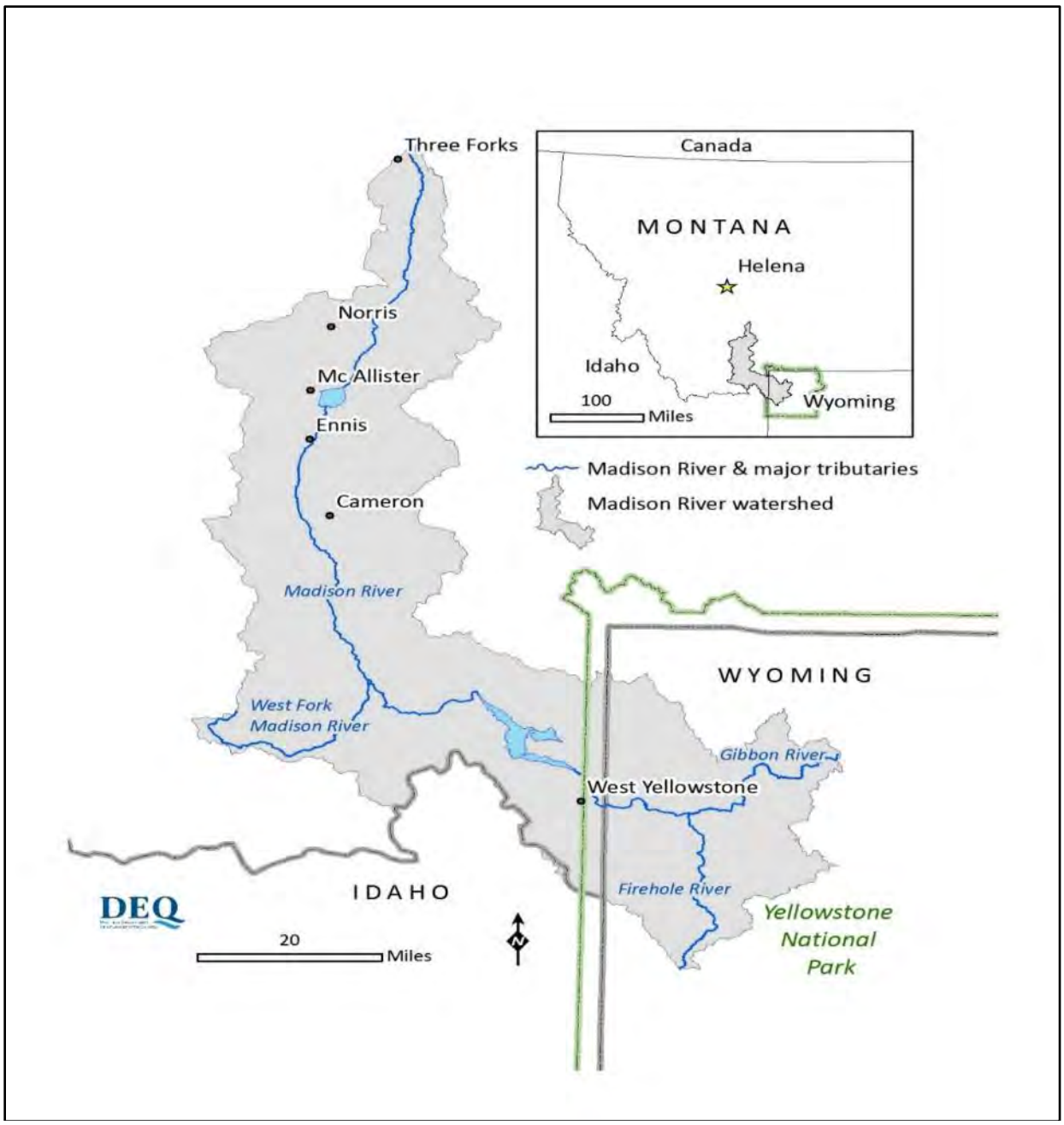


Figure 2-1. Location of the Madison TMDL Planning Area

2.1.2 Topography

The topography of the full Madison River watershed is mapped below in **Figure 2-2**. Elevation ranges from 11,316 feet (Hilgard Peak, north of Earthquake Lake) in the Madison Range on the east side of the Madison River, to 4,040 feet at the Madison River's mouth and confluence with the Jefferson River near Three Forks, Montana.

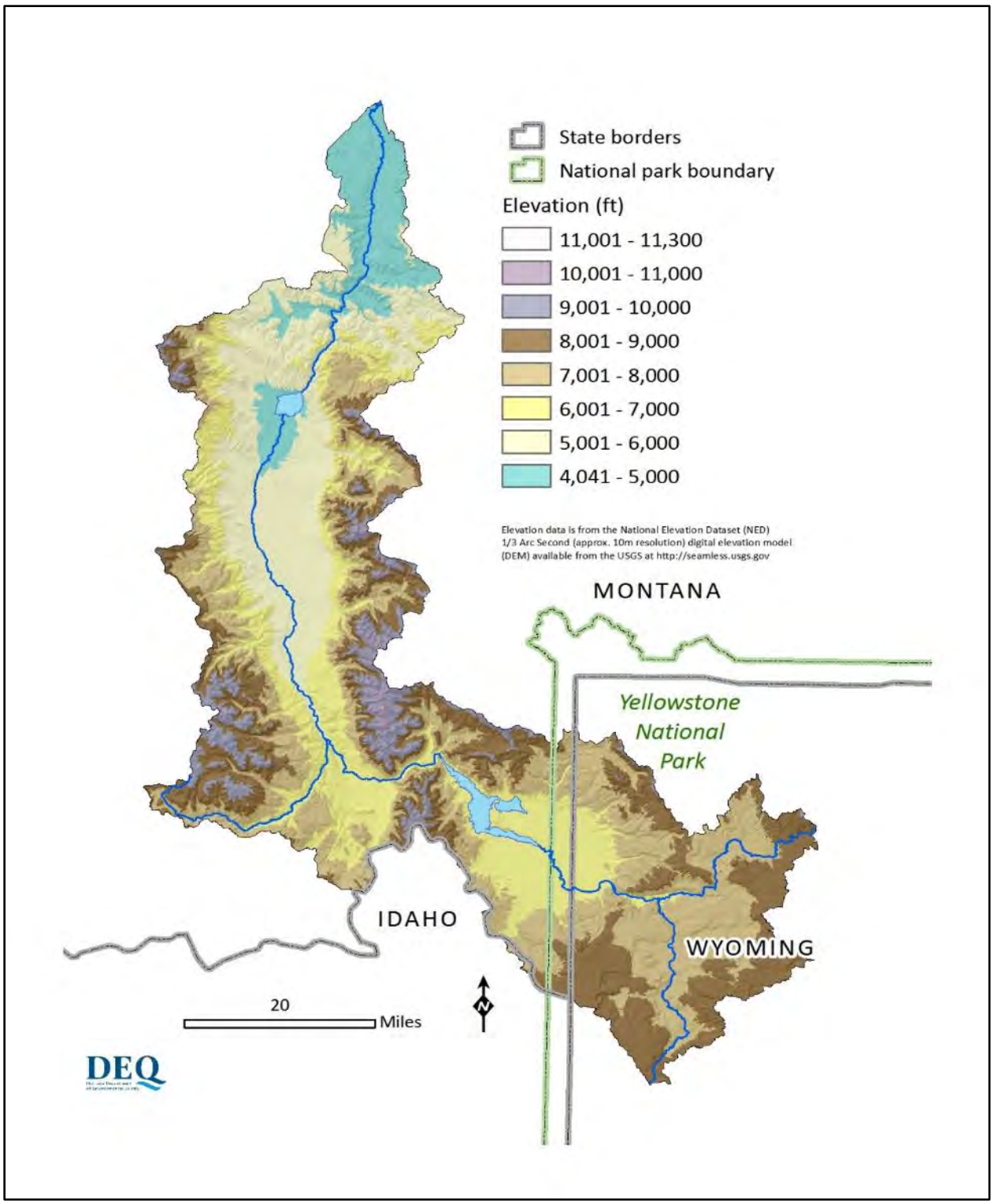


Figure 2-2. Topography of the Madison River Watershed

2.1.3 Climate

Due to the large area of the TMDL planning area, there is a measurable gradient in climate along its length. This is well illustrated by considering average precipitation and temperature. Average

precipitation along the Madison River corridor ranges from just over 24 inches per year near West Yellowstone to 11 inches per year at Three Forks, according to 30-year average precipitation data (http://prism.oregonstate.edu/explorer/). May and June are consistently the wettest months of the year, and winter precipitation is dominated by snowfall according to climate summaries of West Yellowstone and Ennis provided by the Western Regional Climate Center (http://www.wrcc.dri.edu/summary/Climsmnidwmt.html). Average annual precipitation of the TMDL planning area is mapped below in **Figure 2-3**. The map shows both Snow Telemetry (SNOTEL) and Climate monitoring stations in the planning area.

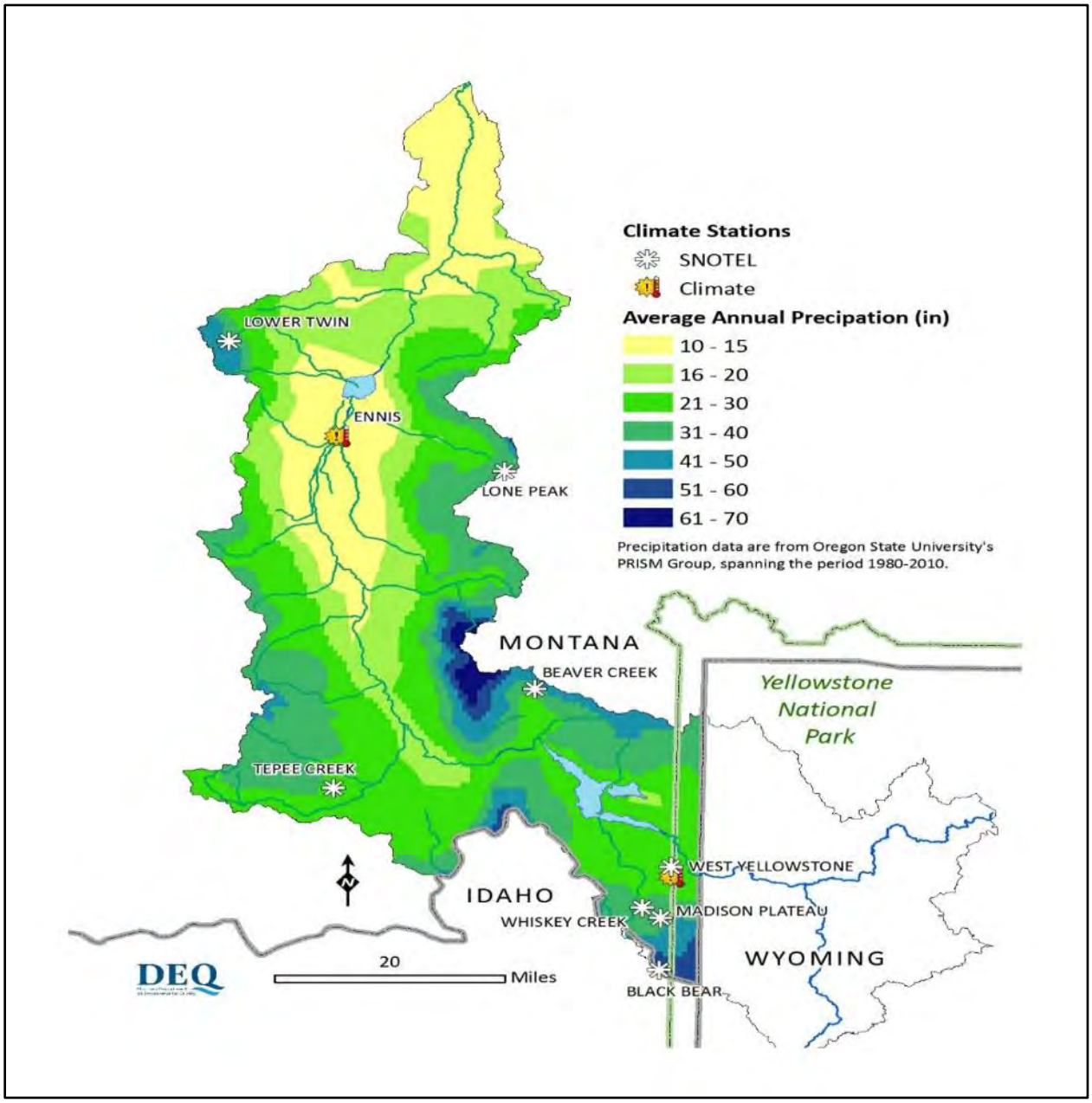


Figure 2-3. Average Annual Precipitation of the Madison TMDL Planning Area

The Madison Valley is a mid-elevation intermontane basin typified by cold winters and mild summers (Kendy and Tresch, 1996). Precipitation is greater and average temperatures are lower in the higher-elevation valley around Hebgen Lake and West Yellowstone. Average annual temperatures of the planning area are mapped below in **Figure 2-4**.

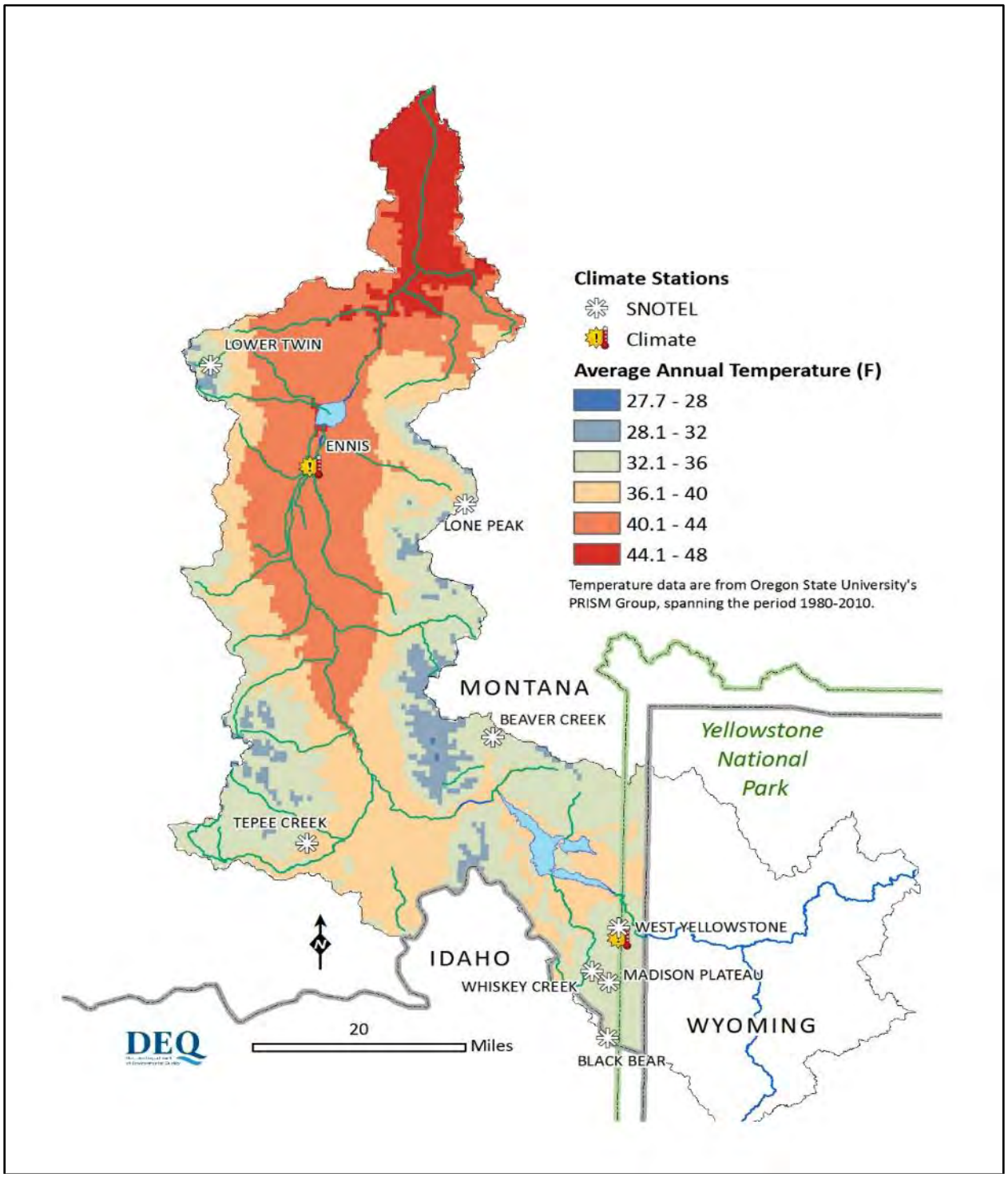


Figure 2-4. Average Annual Temperatures in the Madison TMDL Planning Area

2.1.4 Hydrology

The Madison River is one of the three forks forming the Missouri River, which begins at the confluence of the Madison and Jefferson rivers. The third fork, the Gallatin River, drains into the Missouri River a short distance below, at Three Forks, Montana. The Madison River begins at the confluence of the Firehole and Gibbon rivers in Yellowstone National Park in Wyoming. The drainage of the planning area is characterized by the mainstem of the Madison River and its tributary watersheds, mapped below in **Figure 2-5**. The Madison River is a 6th order stream at the outlet of Hebgen Dam, shown near the southern end of the planning area. The major tributaries tend to be 3rd and 4th order streams.

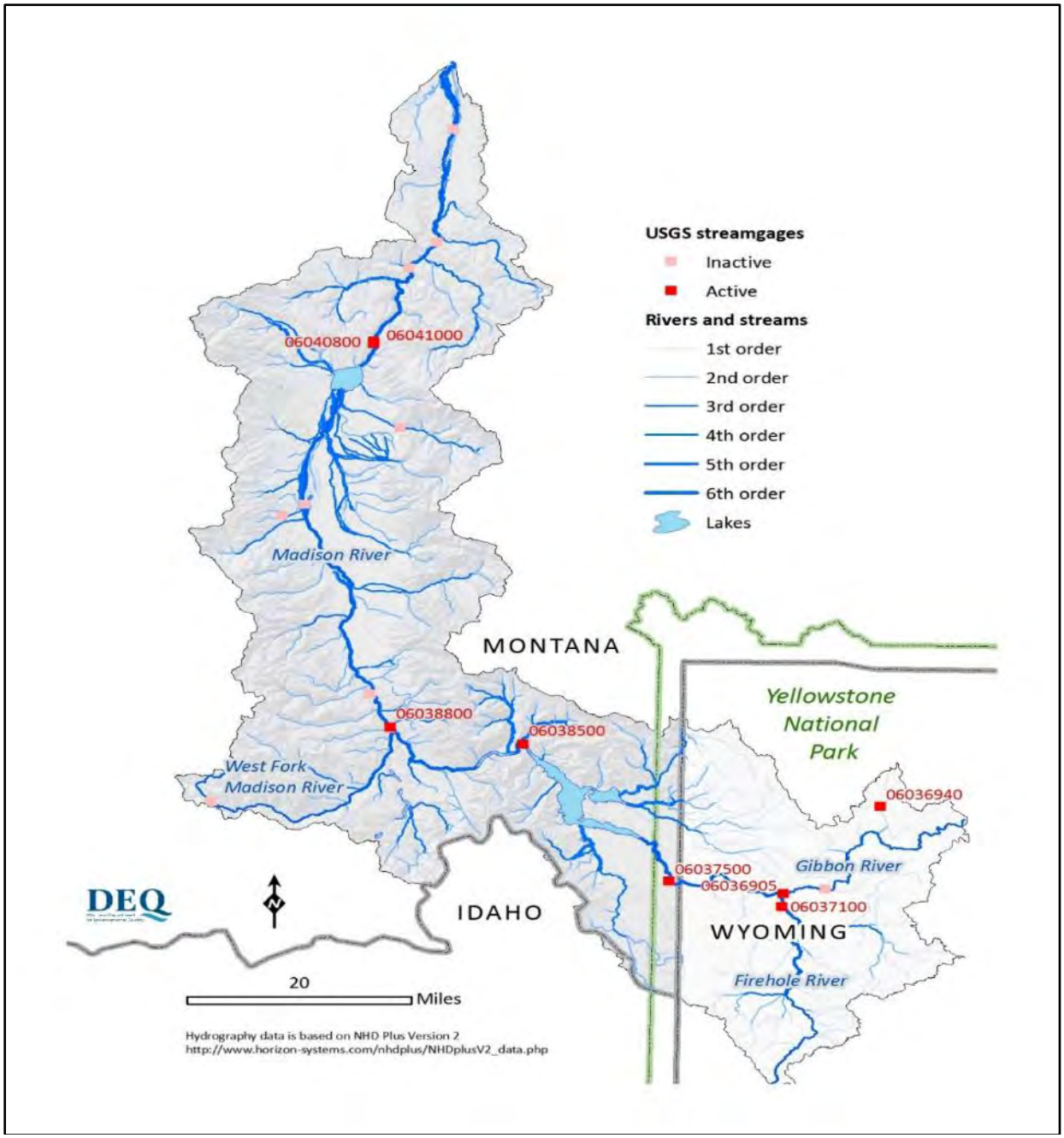


Figure 2-5. Hydrography of the Madison River Watershed

The tributary streams generally are not monitored by U.S. Geological Survey (USGS) gaging stations. Their streamflow generally follows a hydrograph typical for the region, highest in May and June. These are the months with the greatest amount of precipitation and snowmelt runoff. Streamflow begins to decline in late June or early July, reaching minimum flow levels in September when many streams go dry. Streamflow begins to rebound in October and November when fall storms supplement the base-flow levels.

2.1.5 Geology and Soils

The geology of the Madison River watershed is varied (**Figure 2-6**). Bedrock is dominated by Precambrian metamorphic rocks, with significant areas of Paleozoic and Mesozoic sedimentary rocks. Upstream of the planning area, in Wyoming, the watershed headwaters are underlain by mainly rhyolitic volcanic rocks of the Yellowstone caldera.

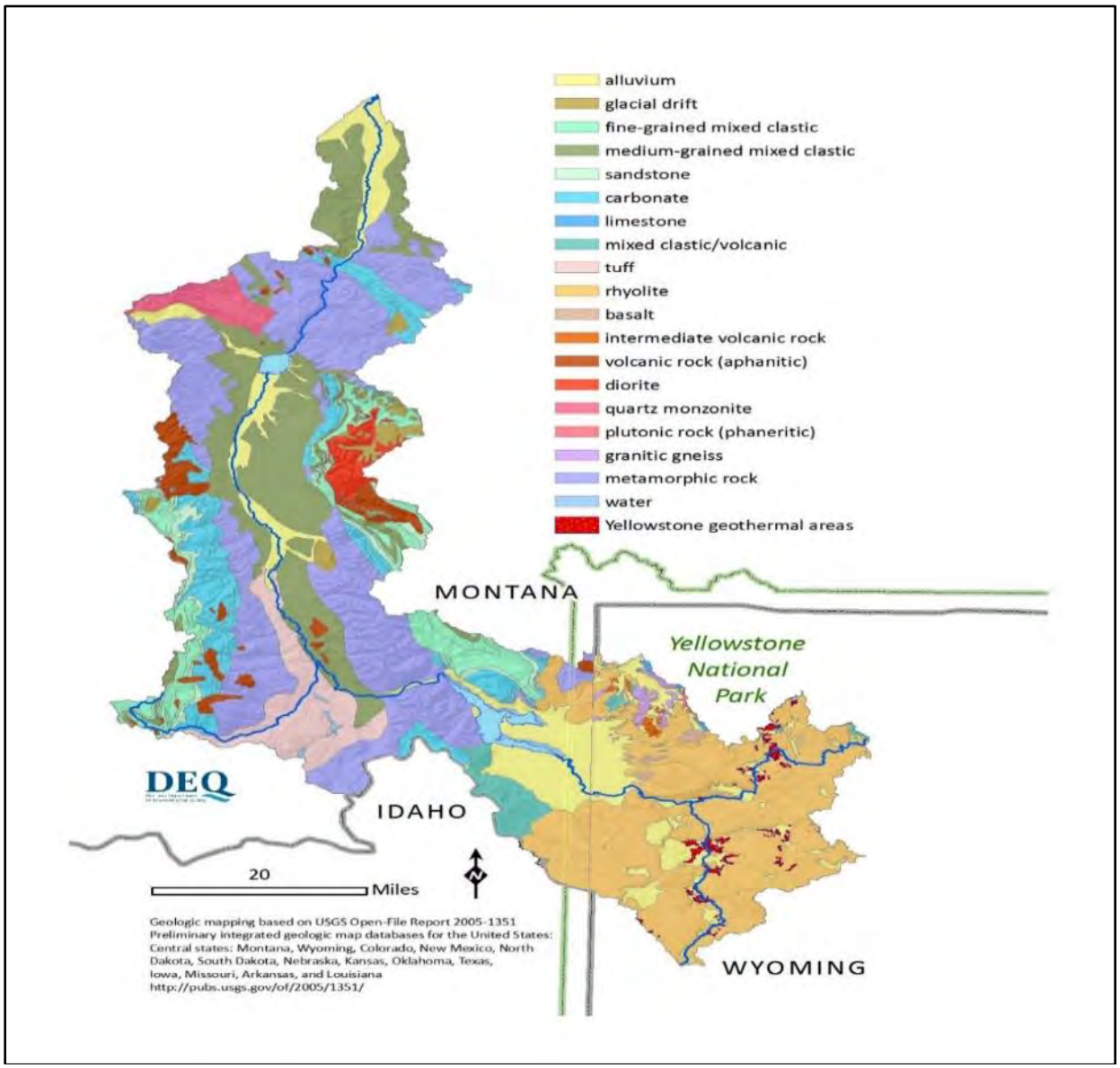


Figure 2-6. Generalized Geology of the Madison River Watershed

The USGS Water Resources Division (Schwartz and Alexander, 1995) created a dataset of hydrology-relevant soil attributes, based on the USDA Natural Resources Conservation Service (NRCS) State Soil Geographic (STATSGO) soil database. The STATSGO data are intended for small-scale (watershed or larger) mapping, and is too general to be used at scales larger than 1:250,000. It is important to realize, therefore, that each soil unit in the STATSGO data may include up to 21 soil components. Soil analysis at a larger scale should use NRCS SSURGO data.

Soil erodibility is based on the Universal Soil Loss Equation (USLE) K-factor (Wischmeier and Smith 1978). K-factor values range from 0 to 1, with a greater value corresponding to greater potential for erosion. Susceptibility to erosion is mapped below in **Figure 2-7**, with soil units assigned to the following ranges: low (0.0-0.2), moderate-low (0.2-0.29) and moderate-high (0.3-0.4). Values of > 0.4 are considered highly susceptible to erosion. Despite the steep and rugged topography, most of the planning area is mapped with soils rated as having low and moderate-low erodibility. Soils mapped with moderate-high erodibility are largely found along the margin of the Gravelly Range on the west side of the Madison River. No values greater than 0.34 are mapped in the planning area.

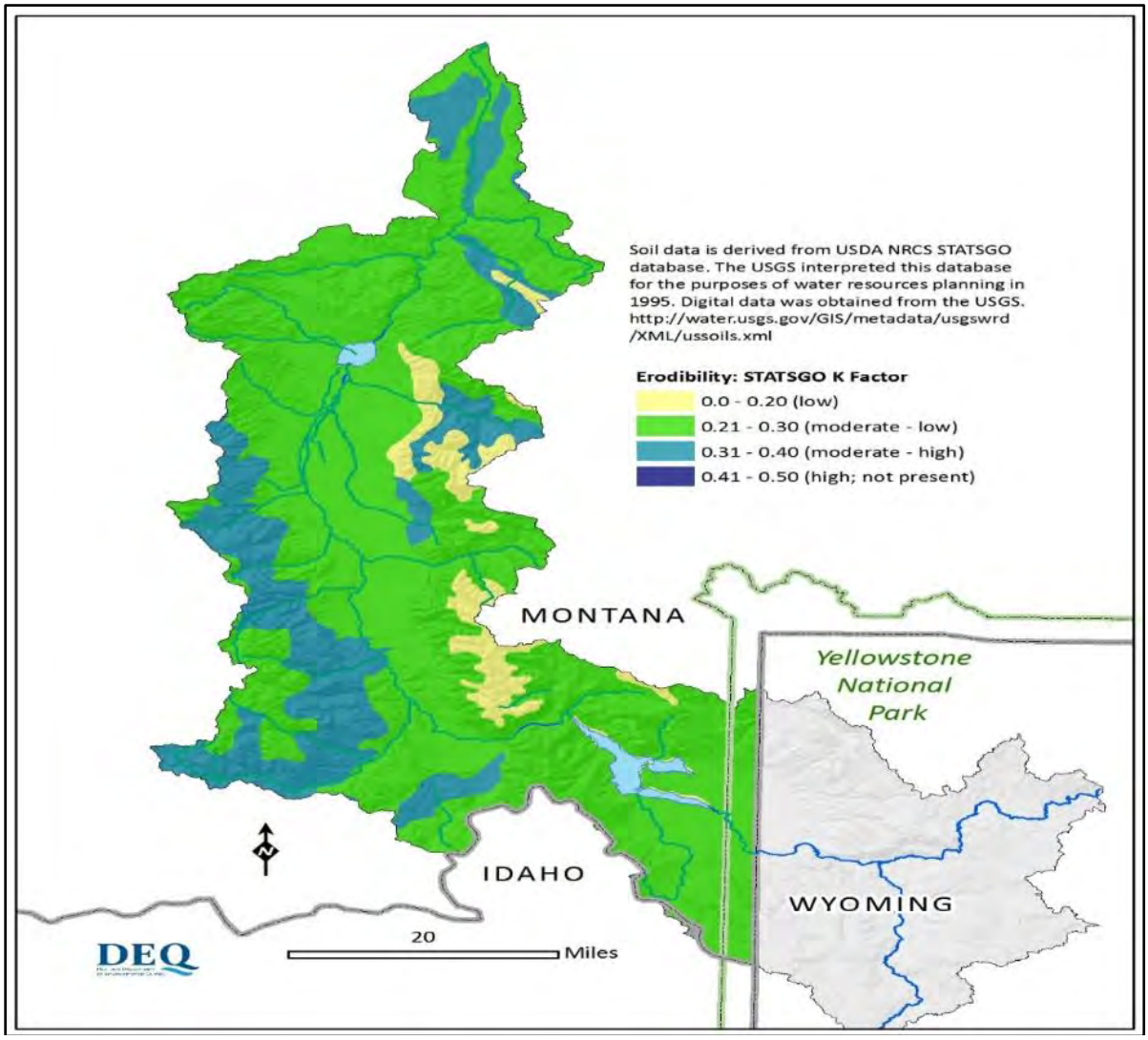


Figure 2-7. Soil Erodibility of the Madison TMDL Planning Area

2.2 Ecological Profile

This section describes the ecology of the Madison TMDL Planning Area, including the ecoregions mapped within it, land cover, fire history, and fish species of concern.

2.2.1 Ecoregions

The Madison TMDL planning area is located within the Middle Rockies Level III Ecoregion (Woods, et al., 2002). Twelve Level IV ecoregions are mapped within the full Madison River watershed, shown below in **Figure 2-8**. More detailed information about the ecoregions is available at: http://www.epa.gov/wed/pages/ecoregions/mt_eco.htm.

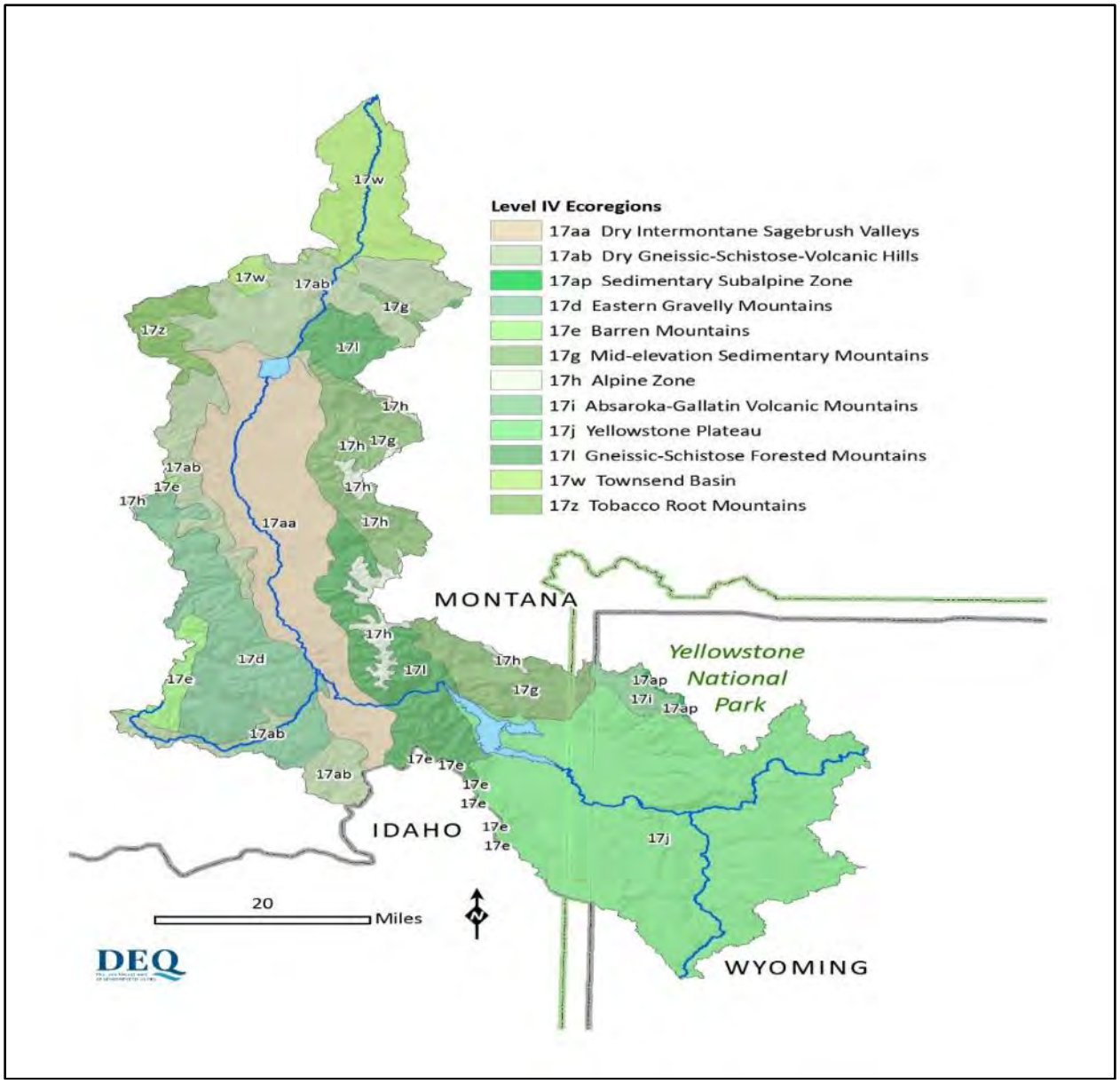


Figure 2-8. Level IV Ecoregions in the Madison River Watershed

2.2.2 Land Cover

Land cover is mapped below in **Figure 2-9**, based on the USGS 2013 National Land Cover Dataset, or NLCD (https://catalog.data.gov/dataset). As apparent in this figure, the planning area is dominated by evergreen forest in the uplands, and herbaceous and shrub/scrub cover in the lowlands. Development is largely limited to the larger communities of Ennis and West Yellowstone.

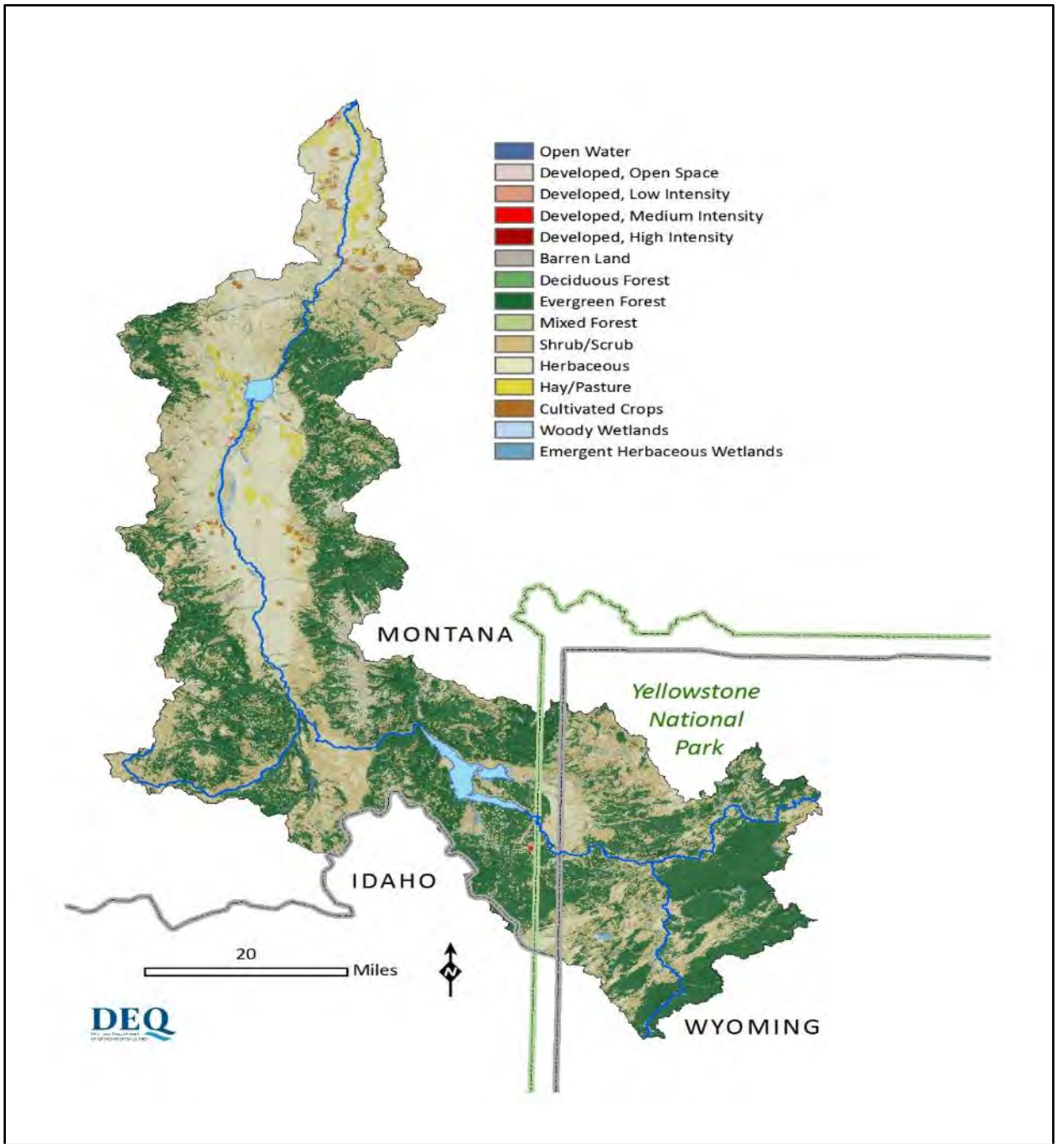


Figure 2-9. Land Cover in the Madison River Watershed

2.23 Fire History

Fire history from 1985 through 2013 is mapped below in **Figure 2-10**. Minor regions of the TMDL planning area have burned in more recent years. The largest fire of recent years was the Beartrap Fire of 2012, which burned approximately 15,000 acres.

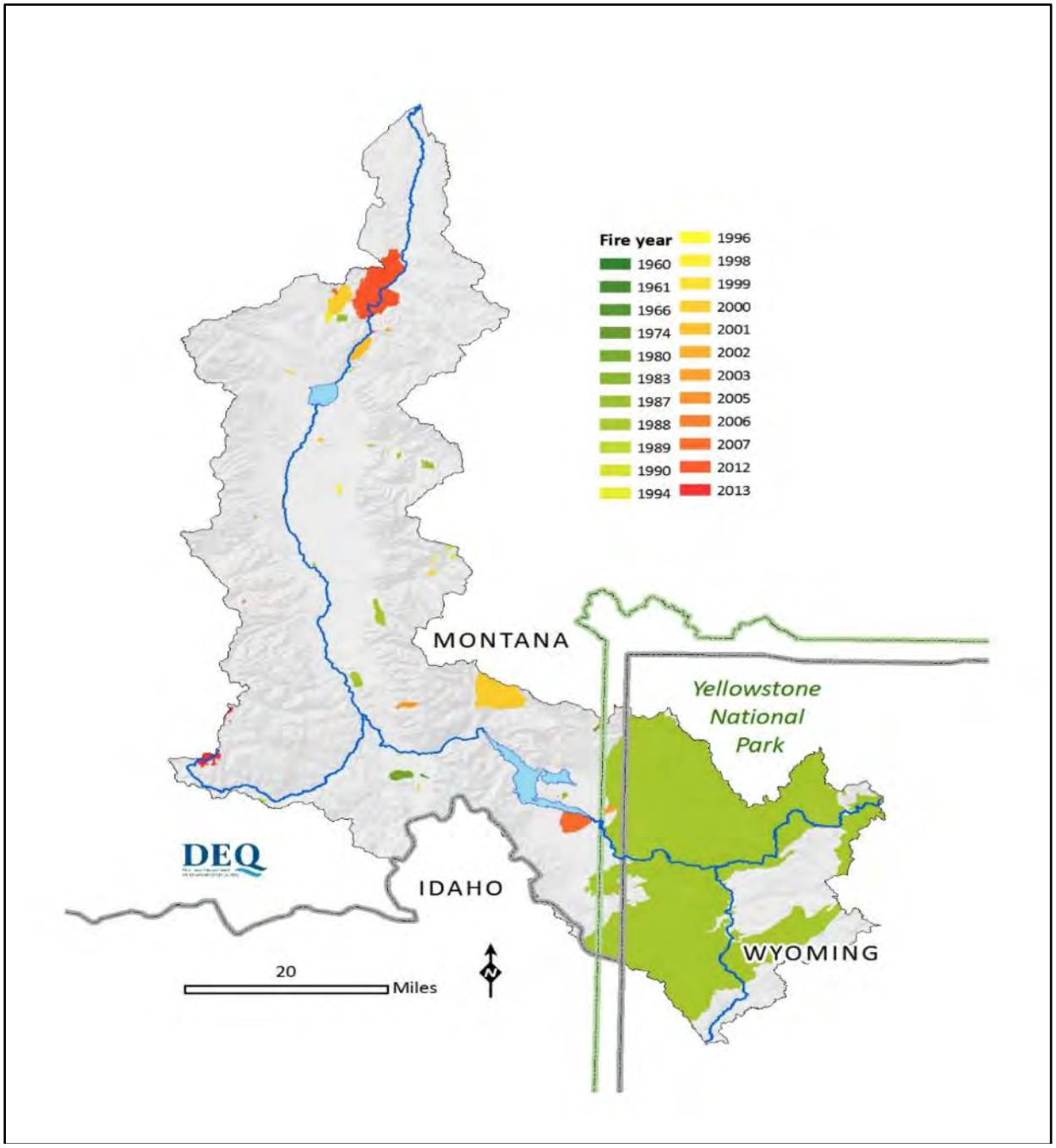


Figure 2-10. Fire History (1985-2013) of the Madison River Watershed

2.2.4 Fish Distribution

The planning area provides habitat for arctic grayling, yellowstone cutthroat trout, and westslope cutthroat trout, all Montana species of concern. Westslope cutthroat trout are found in tributary

streams, particularly in the higher reaches. Yellowstone cutthroat trout are mapped in larger streams as well as in the mainstem Madison River. Arctic grayling are mapped in the Madison River and North Meadow Creek. The mapped distribution of these species is shown below in **Figure 2-11**, based on data provided by Montana Fish, Wildlife & Parks (http://fwp.mt.gov/gis/maps/mFish/?zoomFeatures=%7BlayerName:%22STREAMS%22,features:[%7BLLID:%221123386455677%22%7D],fadeOutTimer:4%7D). In addition, the Madison River is a designated Blue Ribbon fishery.

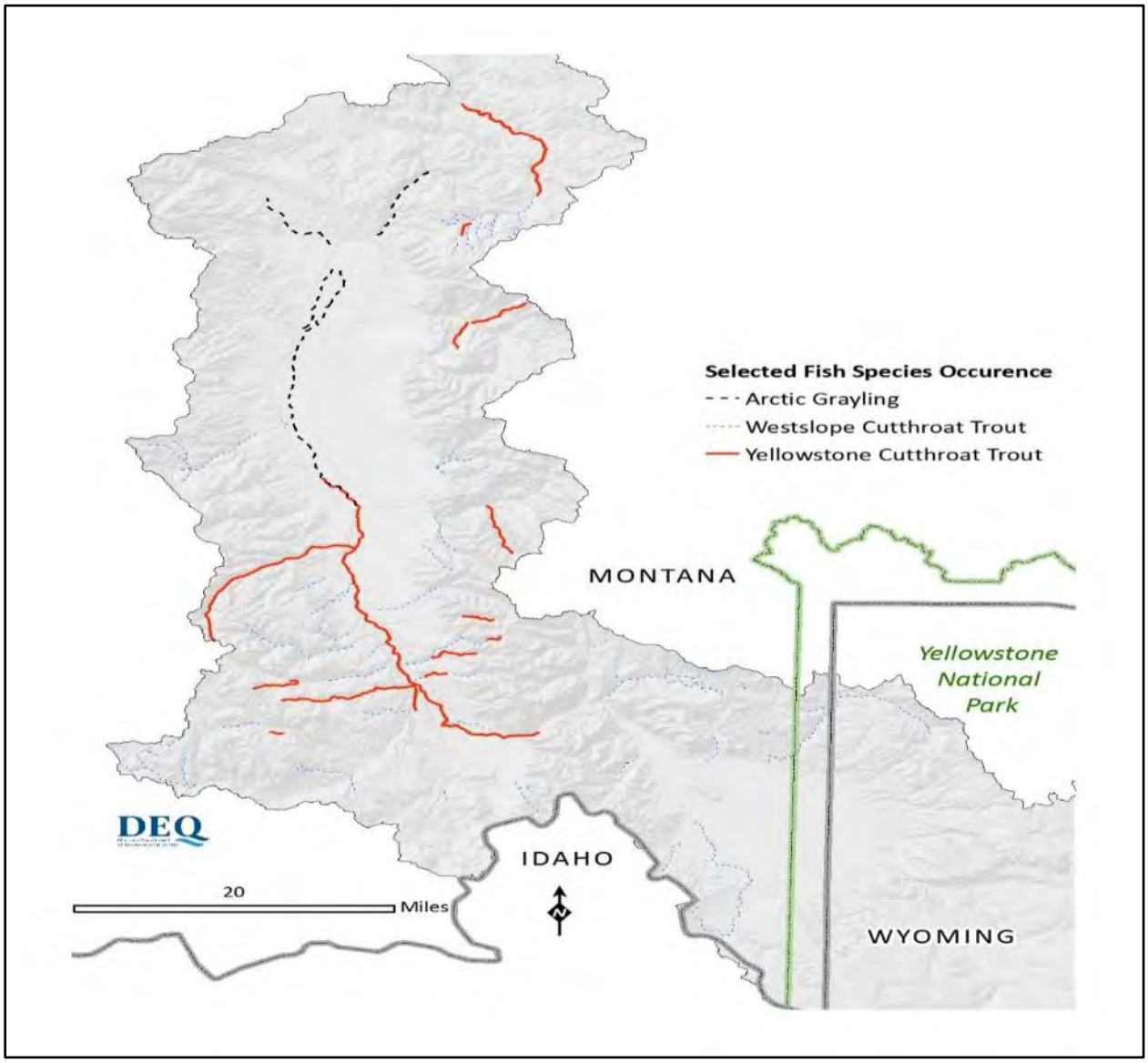


Figure 2-11. Arctic Grayling, Yellowstone Cutthroat Trout, and Westslope Cutthroat Trout Distribution in the Madison TMDL Planning Area

2.3 Social Profile

The following section describes the human geography of the planning area. This includes population distribution, land ownership, and land management.

2.3.1 Population Density

There are no census geometries that exactly correspond to the Madison TMDL planning area, but DEQ estimates the population at 2,544 people based on 2010 census GIS files. The population centers are Ennis (838 residents) and West Yellowstone (1,271 residents). Large areas of USFS land are uninhabited, although there are isolated inholdings. Population density is mapped below in **Figure 2-12**.

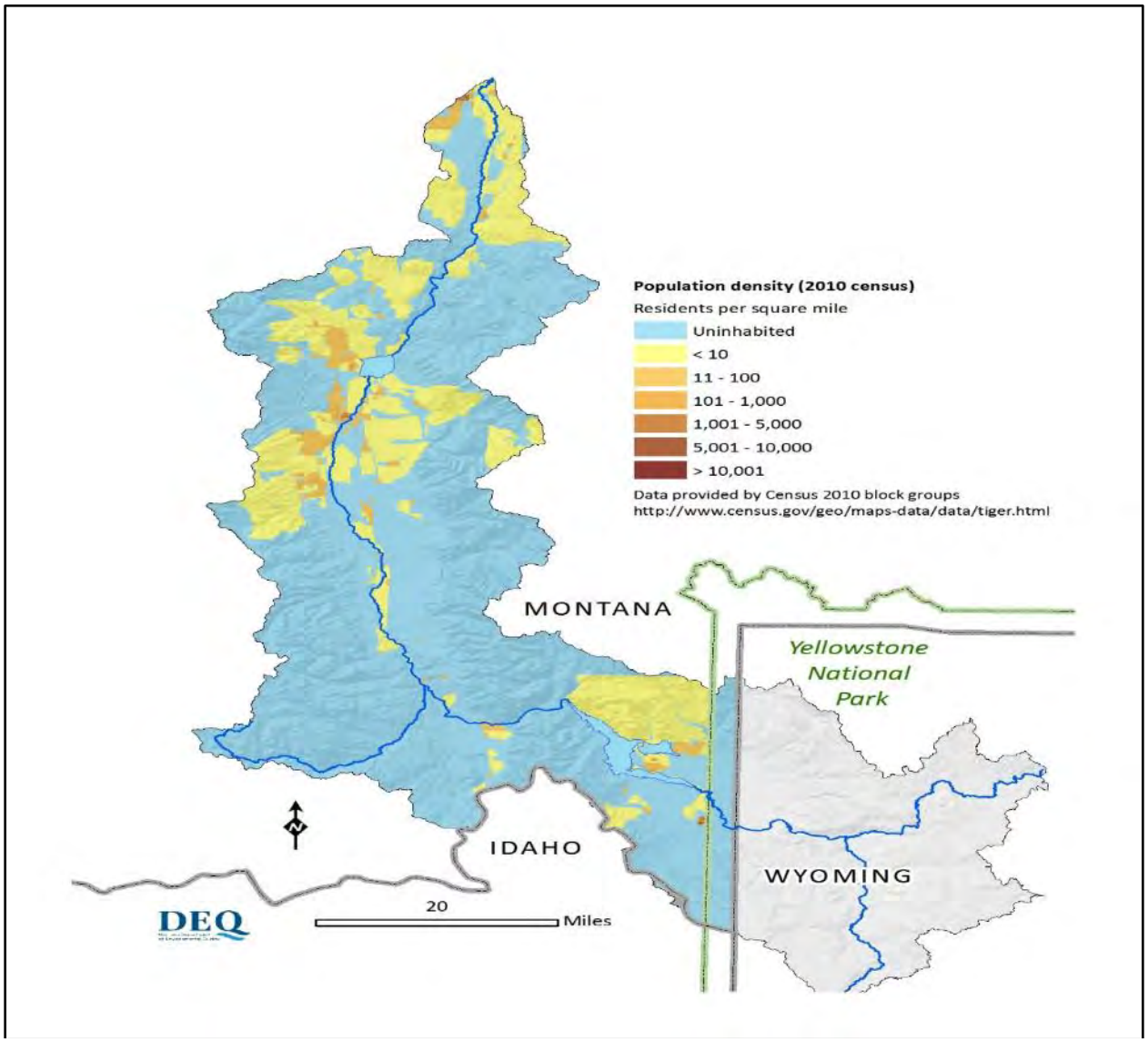


Figure 2-12. Population Density in the Madison TMDL Planning Area

2.3.2 Land Management

Federal lands managed by the U.S. Forest Service (USFS) dominate the planning area, and are found mostly in the upland areas (**Figure 2-13**). The U.S. Bureau of Land Management (BLM) oversees significant lands in the valley and foothills. Private lands dominate the river corridor and valley bottoms.

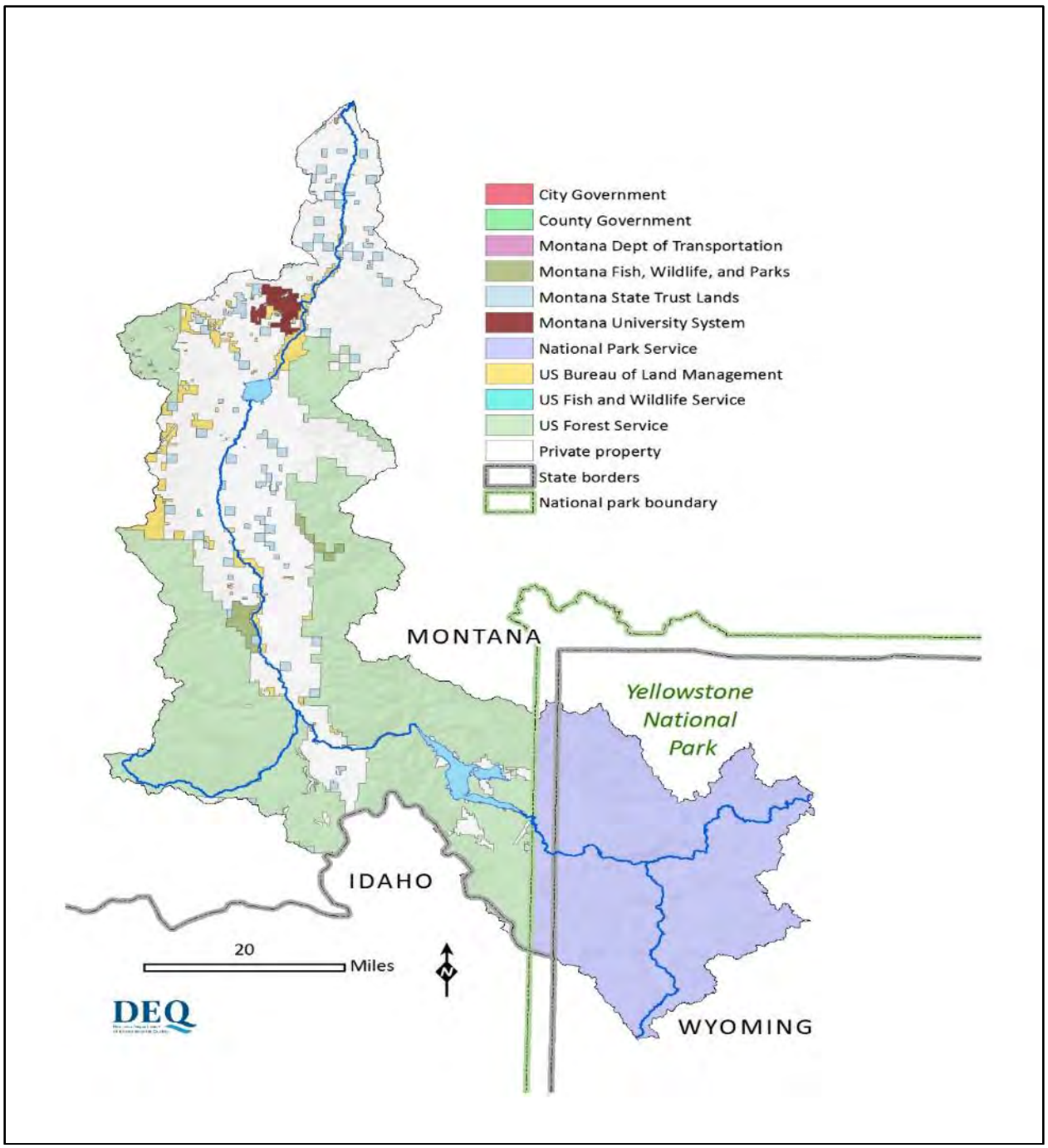


Figure 2-13. Land Management in the Madison River Watershed

2.2.3 Agricultural Land Use

Montana Department of Revenue assesses agricultural land for taxation; the resulting dataset is known as the Final Land Unit (FLU) classification. The agricultural uses were determined by Department of Revenue GIS specialists, and confirmed by maps sent to private landholders for verification. Agricultural uses as determined in the Final Land Unit classification are mapped below in **Figure 2-14**. The Final Land Use data are available at:
ftp://ftp.geoinfo.msl.mt.gov/Data/Spatial/NonMSDI/Geodatabases/revenue_flu.zip.

Grazing is common on both private lands and forested public lands. BLM and USFS grazing allotments are shown on the map, totaling 138 and 559 square miles, respectively. Private grazing operations are not specifically identified; however, much of the gray area on the map includes private land where grazing occurs. Grazing allotments and operations are further discussed in **Section 5.4.3**.

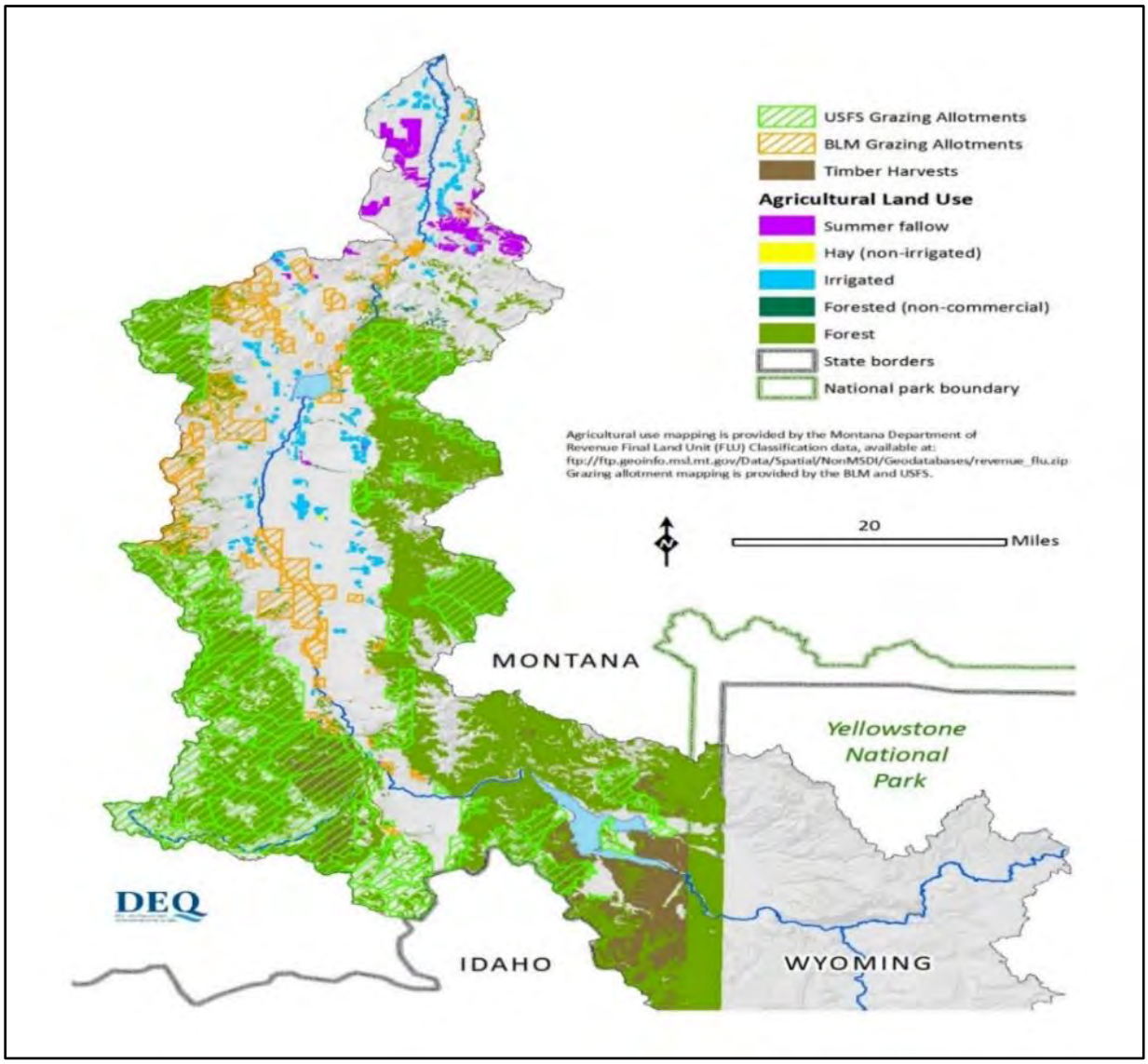


Figure 2-14. Agricultural Use and Grazing Allotments in the Madison River Watershed

2.3.4 Road Networks

The Madison TMDL Planning Area includes significant roadless areas, particularly around the Lee Metcalf Wilderness Area east of the Madison River in the Madison Range. There are extensive road networks both in the valley bottoms and in the timbered uplands. Some roads were constructed for timber harvesting, and may have been decommissioned. The planning area is too large to analyze the road network at this scale; however, **Figure 2-15** below provides a general idea of where the upland road networks are most extensive.

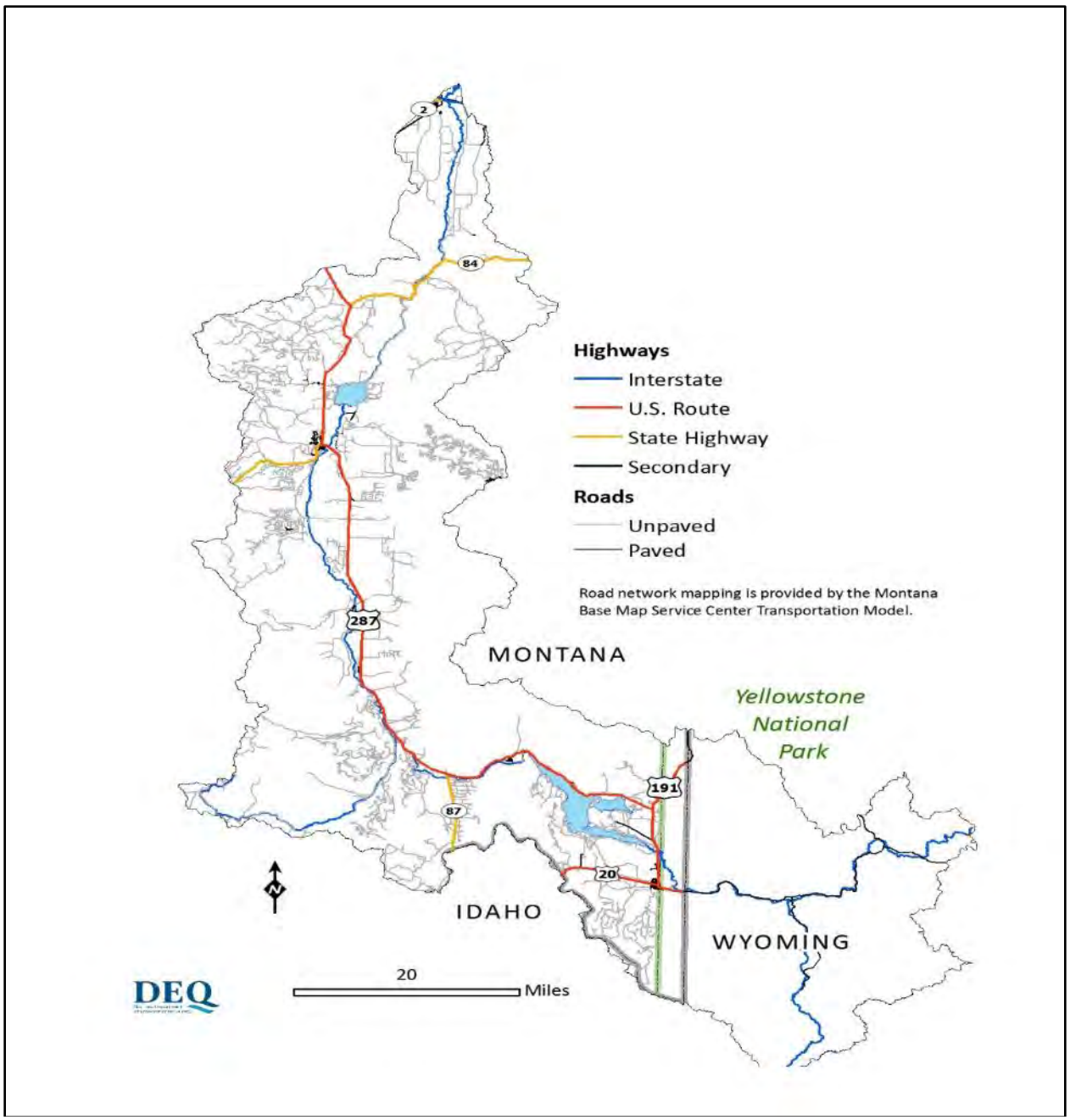


Figure 2-15. Road Network in the Madison TMDL Planning Area

2.3.5 Wastewater Discharges

Sources of pollution originating from a point source wastewater discharge are permitted and regulated through the Montana Pollutant Discharge Elimination System (MPDES) administered by Montana DEQ. The goal of the MPDES program is to control point source discharges of wastewater such that water quality in state surface water is protected. Levels of water quality that are required to maintain the various beneficial uses of state surface waters are set forth in the state's water quality standards. There are two types of discharge permits: general and individual.

A MPDES General Permit is a permit for wastewater discharges associated with common activities, such as concentrated animal feeding operations and storm water discharges from construction or industrial activity. Authorizations for General Permits are issued if a facility or activity falls within the guidelines of the existing permit. Individual MPDES Permits regulate wastewater discharges from point sources that do not fall under the guidelines for a General Permit. The individual permitting process is more rigorous, as individual permits address the specific conditions of the facility or activity needing authorization.

All point sources of wastewater discharge are required to obtain and comply with MPDES permits. The effluent limitations and other conditions for certain categories of wastewaters are required to be treated to federally-specified minimum levels based on available and achievable water treatment technologies. Additionally, effluent limits and permit conditions are established to protect beneficial uses and applicable water quality standards. Each MPDES permit issued is designed to protect the state surface water quality at the point of discharge. In addition, recognizing the dynamic nature of streams and the potential additive or cumulative effects of pollutants, MPDES permits also address stream reach or basin-wide pollution problems. If a TMDL has been developed for a waterbody, any wasteload allocations (WLAs) are incorporated into the applicable MPDES permits with discharges into that waterbody.

There are two MPDES permitted facilities that discharge to a waterbody in the Madison TMDL Planning Area: the Ennis National Fish Hatchery (permit number MTG13008) and the Ennis Wastewater Treatment Plant (permit number MT0030732). The permit for the Ennis National Fish Hatchery is a general permit for concentrated aquatic animal production. The permit for the Ennis Wastewater Treatment Plant is an individual MPDES permit for wastewater produced by the town of Ennis (**Table 2-1**). The Ennis National Fish Hatchery releases total suspended solids into Blaine Spring Creek, which is impaired for sediment. However, this load is organic and is not considered to be a contributor to the inorganic sediment load. Therefore, a wasteload allocation for the fish hatchery will not be included as part of the sediment TMDL for Blaine Spring Creek. The Ennis Wastewater Treatment Plant does not have water quality impairments addressed by a TMDL in this document.

Table 2-1. MPDES Permits in the Madison TMDL Planning Area

Facility Name	Permit Number	Permit Expiration Date	Receiving Waterbody
Ennis National Fish Hatchery	MTG13008	June 30, 2021	Blaine Spring Creek
Ennis Wastewater Treatment Plant	MT0030732	April 20, 2019 (Administratively Extended)	Madison River

3.0 MONTANA WATER QUALITY STANDARDS

The Montana Water Quality Act provides for the restoration and maintenance of the chemical, physical, and biological integrity of the state's surface waters so that they support all designated uses. Water quality standards are used to determine impairment, establish water quality targets, and to formulate the TMDLs and allocations.

Montana's water quality standards, and water quality standards in general, include three main parts:

1. Stream classifications and designated uses
2. Numeric and narrative water quality criteria designed to protect designated uses
3. Nondegradation provisions

Montana's water quality standards also incorporate prohibitions against water quality degradation as well as point source permitting and other water quality protection requirements.

Those water quality standards that apply to this document are reviewed briefly below. More detailed descriptions of Montana's water quality standards may be found in the Montana Water Quality Act (75-5-301,302 Montana Code Annotated (MCA)), Montana's Surface Water Quality Standards and Procedures (Administrative Rules of Montana (ARM) 17.30.601-670), and **Appendix A**, Regulatory Framework and Reference Condition Approach.

3.1 STREAM CLASSIFICATIONS AND DESIGNATED BENEFICIAL USES

Stream classification is the assignment (designation) of a single group of uses to a waterbody based on the potential of the waterbody to support those uses. Designated uses, or beneficial uses, are simple narrative descriptions of water quality expectations or water quality goals. Montana waters are classified for multiple uses. All streams and lakes within the Madison River TMDL Planning Area are classified as B-1 (ARM 17.30.623). In accordance with ARM 17.30.623, waters classified as B-1 are to be maintained suitable for:

- Culinary and food processing purposes after conventional treatment (Drinking Water)
- Bathing, swimming, and recreation (Primary Contact Recreation)
- Growth and propagation of salmonid fishes and associated aquatic life, waterfowl, and furbearers (Aquatic Life)
- Agricultural and industrial water supply

While a waterbody might not actually be used for a designated use (e.g., drinking water supply), its water quality still must be maintained suitable for that designated use. More detailed descriptions of Montana's surface water classifications and designated uses are provided in **Appendix A**. DEQ's water quality assessment methods are designed to evaluate the most sensitive uses for each pollutant group addressed within this document, thus ensuring protection of all designated uses (DEQ 2011). For streams in Western Montana, the most sensitive use assessed for sediment and temperature is aquatic life. DEQ determined that 13 waterbody segments in the Madison TMDL Planning Area do not meet the sediment and temperature water quality standards (**Table 3-1**).

Table 3-1. Impaired Waterbodies and Their Impaired Designated Uses in the Madison TMDL Planning Area

Waterbody (Assessment Unit)	Waterbody ID (Assessment Unit ID)	Impairment Cause[1]	Impaired Use[2]
Antelope Creek, Headwaters to mouth (Cliff Lake)	MT41F004_140	Sedimentation – Siltation	Aquatic Life
Bear Creek, Headwaters to mouth (O'Dell Spring Creek)	MT41F004_021	Sedimentation - Siltation	Aquatic Life
Blaine Spring Creek, Headwaters to mouth (Madison River, T7S R1W S6)	MT41F004_010	Sedimentation – Siltation	Aquatic Life
Cherry Creek, Headwaters to mouth (Madison River)	MT41F002_010	Sedimentation – Siltation	Aquatic Life
		Temperature	Aquatic Life
Elk Creek, Headwaters to mouth (Madison River)	MT41F002_020	Sedimentation – Siltation	Aquatic Life
		Temperature	Aquatic Life
		Turbidity	Aquatic Life
Hot Springs Creek, Headwaters to mouth (Madison River)	MT41F002_030	Sedimentation – Siltation	Aquatic Life
Moore Creek, Springs to mouth (Fletcher Channel), T5S R1W S15	MT41F004_130	Sedimentation – Siltation	Aquatic Life
		Temperature	Aquatic Life
North Meadow Creek, Headwaters to mouth (Ennis Lake)	MT41F004_060	Sedimentation – Siltation	Aquatic Life
Red Canyon Creek, Headwaters to mouth (Hebgen Lake)	MT41F006_020	Sedimentation – Siltation	Aquatic Life
Ruby Creek, Headwaters to mouth (Madison River)	MT41F004_080	Sedimentation – Siltation	Aquatic Life
South Meadow Creek, Headwaters to mouth (Ennis Lake)	MT41F004_070	Sedimentation – Siltation	Aquatic Life
Watkins Creek, Headwaters to mouth (Hebgen Lake)	MT41F006_030	Sedimentation – Siltation	Aquatic Life
Wigwam Creek, Headwaters to mouth (Madison River)	MT41F004_160	Sedimentation – Siltation	Aquatic Life

[1] Only includes those pollutant impairments addressed by TMDLs in this document
[2] A full summary of beneficial use support Information for each waterbody is contained at cwaic.mt.gov

It is important to note that waterbodies monitored by Montana DEQ are assigned an assessment unit (**Table 3-1**). Assessment units can be the full length of a stream, the full extent of a lake or reservoir, or they may be a portion of a lake or of a stream (a stream segment). Streams may be broken into individual segments, determined by a variety of factors such as stream length for very long streams, or lakes may be broken by ownership boundaries (tribal versus state, for example). Due to its length and

multiple dam impoundments, the Madison River, for example, has three assessment units / three stream segments (shown in **Table 1-2**).

3.2 Numeric and Narrative Water Quality Standards

Montana's water quality standards include numeric and narrative criteria that protect the designated uses described above. Numeric standards define the allowable concentrations, frequency, and duration of specific pollutants so as not to impair designated uses.

Numeric standards apply to pollutants that are known to have adverse effects on human health, aquatic life, or other beneficial uses of water (e.g., metals, nutrients, *E. coli*, organic chemicals, and other toxic constituents). Narrative standards are developed when there is insufficient information to develop numeric standards and/or the natural variability makes it impractical to develop numeric standards. Narrative standards describe the allowable or desired condition and are also designed to protect the designated beneficial uses. This condition is often defined as an allowable increase above "naturally occurring." DEQ often uses the naturally occurring condition, called a "reference condition," to help determine whether or not narrative standards are being met (see **Appendix A**). For sediment and temperature TMDL development in the Madison TMDL Planning Area, only narrative standards are applicable; they are summarized in **Appendix A**.

3.3 Nondegradation Provisions

Nondegradation is addressed via the Nondegradation Policy within Montana state statute (75-5-303, MCA) and via Montana's nondegradation rules (ARM 17.30.7). The Nondegradation Policy states that existing uses of state waters and the level of water quality necessary to protect those uses must be maintained and protected. Montana nondegradation rules apply to any new or increased point or nonpoint source resulting in a change of existing water quality occurring on or after April 29, 1993 (ARM 17.30.702).

4.0 DEFINING TMDLS AND THEIR COMPONENTS

A total maximum daily load (TMDL) is a tool for implementing water quality standards and is based on the relationship between pollutant sources and water quality conditions. More specifically, a TMDL is a calculation of the maximum amount of a pollutant that a waterbody can receive from all sources and still meet water quality standards. The ultimate goal of the TMDL is to identify an approach to achieve and maintain water quality standards.

Pollutant sources are generally defined as two categories: point sources and nonpoint sources. Point sources are often linked to community wastewater treatment or industrial facilities with discernible, confined and discrete conveyances, such as pipes or ditches from which pollutants are being, or may be, discharged to a waterbody. Some sources such as return flows from irrigated agriculture are not included in this definition. Pollutant loading sources that do not meet the definition of a point source are considered nonpoint sources. Nonpoint sources are associated with diffuse pollutant loading to a waterbody and are often linked to runoff from agricultural, urban, or forestry activities, as well as streambank erosion and groundwater seepage that can occur from these activities. Natural background loading and atmospheric deposition are both considered types of nonpoint sources.

As part of TMDL development, the allowable load is divided among all significant contributing point and nonpoint sources. For point sources, the allocated loads are called “wasteload allocations” (WLAs). For nonpoint sources, the allocated loads are called “load allocations” (LAs).

A TMDL is expressed by the equation: $TMDL = \Sigma WLA + \Sigma LA + MOS$, where:

ΣWLA is the sum of the wasteload allocation(s) (point sources)
ΣLA is the sum of the load allocation(s) (nonpoint sources)
MOS = margin of safety

TMDL development must include a margin of safety (MOS), which can be explicitly incorporated into the above equation as shown. Alternatively, the MOS can be implicit in the TMDL, meaning that the explicit MOS in the above equation is equal to zero and can therefore be removed from the above equation. A TMDL must also ensure that the waterbody will be able to meet and maintain water quality standards for all applicable seasonal variations (e.g., changes in pollutant loading during the year, or seasonal water quality standards).

Development of each TMDL has four major components:

- Determining water quality targets
- Quantifying pollutant sources
- Establishing the total allowable pollutant load
- Allocating the total allowable pollutant load to their sources

Although the way a TMDL is expressed can vary by pollutant, these four components are common to all TMDLs, regardless of pollutant. Each component is described in further detail in the following subsections.

Figure 4-1 illustrates how numerous sources contribute to the existing load and how the TMDL is defined. The existing load can be compared to the allowable load to determine the amount of pollutant reduction needed.

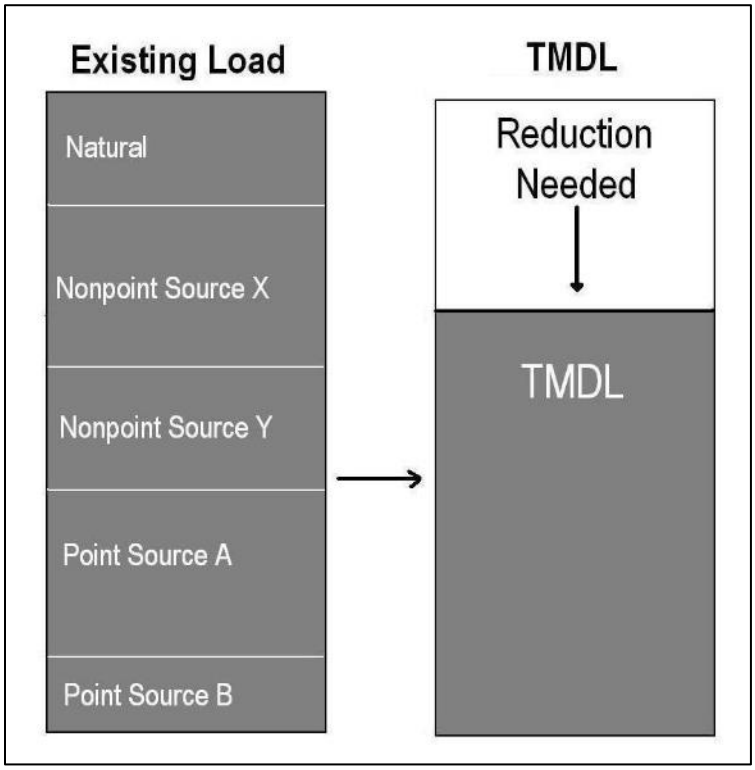


Figure 4-1: Schematic Example of TMDL Development

4.1 Developing Water Quality Targets

For each pollutant, TMDL water quality targets are applied to one or more parameters that link directly to the impaired beneficial use(s) and applicable water quality standard(s). For pollutants with established numeric water quality standards, the numeric value(s) are used as the TMDL targets. For pollutants with narrative water quality standard(s), the targets provide a translation of how the narrative standard(s) applies to the waterbody. Comparing existing stream conditions to target values allows for a better understanding of the extent and severity of the problem.

4.2 Quantifying Pollutant Sources

The goal of TMDL source assessment is to identify all significant pollutant loading sources, including natural background loading, and quantify them so that the relative pollutant contributions can be determined. Because the effects of pollutants on water quality can vary throughout the year, assessing pollutant sources includes an evaluation of the seasonal variability of the pollutant loading. The source assessment helps to define the extent of the problem by linking the pollutant load to specific sources in the watershed.

Source assessments are conducted on a watershed scale and can vary in level of detail resulting in reasonably accurate estimates or gross allotments, depending on the data availability and the

techniques used for predicting the loading (40 CFR 130.2(i)). Montana TMDL development often includes a combination of approaches, depending on the level of desired certainty for setting allocations and guiding implementation activities.

Nonpoint sources are quantified by source categories (e.g., eroding streambanks or unpaved roads) and/or by land uses (e.g., crop production or forestry). These source categories and land uses can be divided further by ownership, such as federal, state, or private. Alternatively, most, or all, nonpoint pollutant sources in a sub-watershed or source area can be combined for quantification and TMDL load allocation purposes.

Pollutant loading is typically quantified for each individual surface water point source permitted under the Montana Pollutant Discharge Elimination System (MPDES) program. Through MPDES permit requirements, point source dischargers provide discharge and other information that can be used for source assessment purposes. The allowable loading within each MPDES surface water permit condition must be consistent with the assumptions and requirements of the available WLA developed within the TMDL (40 CFR 122.44).

4.3 Establishing the Total Allowable Load

TMDL development requires a determination of the total allowable load over the appropriate time period necessary to comply with the applicable water quality standard(s). Per EPA requirements (40 CFR 130.2), "TMDLs can be expressed in terms of either mass per time, toxicity, or other appropriate measure." Where a stream is impaired by a pollutant for which numeric water quality criteria exist, the TMDL, or allowable load, is typically calculated as a function of streamflow and the numeric criteria. This results in a mass per unit time TMDL expression such as pounds per day. This same approach can be applied when a numeric target is developed to interpret a narrative standard.

Although a "TMDL" is specifically defined as a "daily load," determining a daily load may not be consistent with the applicable water quality standard(s), or may not be practical from a water quality management perspective. Therefore, the TMDL will ultimately be defined as the total allowable loading during a time period that is appropriate for applying the water quality standard(s) and which is consistent with established approaches to properly characterize, quantify, and manage pollutant sources in a given watershed. For example, sediment TMDLs may be expressed as an allowable annual load.

Some narrative standards, such as those for sediment, often have a suite of targets. In many of these situations it is difficult to link the desired target values to highly variable, and often episodic, instream loading conditions. In such cases the TMDL is often expressed as a percent reduction in total loading based on source quantification results and an evaluation of load reduction potential (**Figure 4-1**). The degree by which existing conditions exceed desired target values can also be used to justify a percent reduction value for a TMDL.

Even if the TMDL is preferably expressed using a time period other than daily, an allowable daily loading rate will also be calculated to meet specific requirements of the federal Clean Water Act. Where this occurs, TMDL implementation and the development of allocations will still be based on the preferred time period, as noted above.

4.4 Determining Pollutant Allocations

Once the allowable load (the TMDL) is determined, that total must be divided among the contributing sources so that the sum of the allocations is equal to the TMDL, consistent with the above TMDL equation. For sediment, the allocations are often determined by quantifying feasible and achievable load reductions through application of a variety of best management practices (BMPs) and other reasonable conservation practices. Where a TMDL is variable based on streamflow, nonpoint source load allocations are often variable based on this same receiving streamflow. On the other hand, point source wasteload allocations are often based on conservative streamflow and discharge conditions and/or can be variable based on the point source discharge flow and a discharge concentration limit. Where the TMDL is a function of streamflow, the TMDL and allocations are calculated for example high and low flow stream conditions.

Figure 4-2 illustrates how the TMDL is allocated to different sources using WLAs for point sources and load allocations (LA) for natural and nonpoint sources. Although some flexibility in allocations is possible, the sum of all allocations must meet the TMDL for all segments of the waterbody. **Figure 4-2** shows multiple point and nonpoint source allocations. In Montana, nonpoint source allocations are sometimes grouped into one composite allocation. This composite load allocation approach is applied in cases where data is limited, there is significant source assessment uncertainty, and/or DEQ has determined that the best approach is to provide stakeholders with flexibility in addressing sources, allowing them to choose where to focus on improved land management practices and other remediation or restoration efforts.

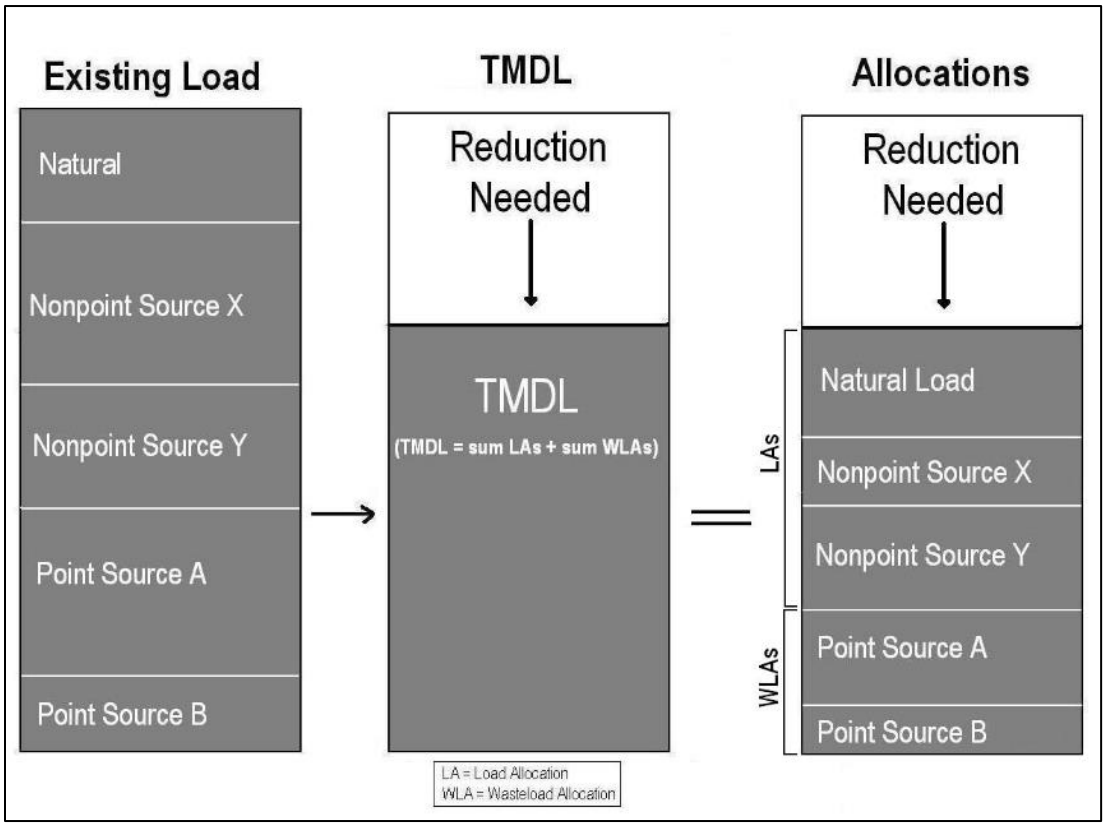


Figure 4.2: Schematic Diagram of a TMDL and its Allocations

4.5 IMPLEMENTING TMDL ALLOCATIONS

Montana law (Section 75-5-703, MCA of the Montana Water Quality Act) requires that wasteload allocations be incorporated into appropriate discharge permits, thereby providing a regulatory mechanism to achieve load reductions from point sources. Per federal regulation (40 CFR 122.44), the discharge permit effluent limits must be consistent with the assumptions and requirements of the available WLA developed within the TMDL.

Because of limited state and federal regulatory requirements, nonpoint source reductions linked to LAs are implemented primarily through voluntary measures, although there are some important nonpoint source regulatory requirements, such as Montana streamside management zone law and applicable septic system requirements.

This document contains several key components to assist stakeholders in implementing nonpoint source controls. **Section 9.0** provides a water quality improvement plan that discusses restoration strategies by pollutant group and source category, and provides recommended BMPs per source category (e.g., grazing, cropland, urban, etc.). **Section 9.7** discusses potential funding sources that stakeholders can use to implement best management practices (BMPs) for nonpoint sources. Other site-specific pollutant sources are discussed throughout the document, and can be used to target implementation activities. DEQ's Nonpoint Source Program helps to coordinate water quality improvement projects for nonpoint sources of pollution throughout the state and provides resources to stakeholders to assist in nonpoint source BMPs. Montana's Nonpoint Source Management Plan (DEQ 2017) further discusses nonpoint source implementation strategies at the state level.

DEQ uses an adaptive management approach to implementing TMDLs to ensure that water quality standards are met over time (outlined in **Section 10.0**). This includes a monitoring strategy and an implementation review that is required by Montana statute (Section 75-5-703, MCA of the Montana Water Quality Act). TMDLs may be refined as new data become available, land uses change, or as new sources are identified.

PART 2
TMDL COMPONENTS

5.0 SEDIMENT TMDL COMPONENTS

This portion of the document focuses on sediment as a cause of water quality impairment in the Madison Total Maximum Daily Load (TMDL) Planning Area (TPA). It describes: (1) how excess sediment impairs beneficial uses, (2) the affected stream segments, (3) the currently available data pertaining to sediment impairments in the planning area, (4) the sources of sediment, based on recent studies, and (5) the sediment TMDLs and their rationales.

5.1 EFFECTS OF EXCESS SEDIMENT ON BENEFICIAL USES

Sediment is a naturally occurring component of healthy and stable stream and lake ecosystems. Regular flooding allows sediment deposition to build floodplain soils and point bars, and it prevents excess scour of the stream channel (Knighton 1998). Riparian and wetland vegetation and natural instream barriers such as large woody debris, beaver dams, or overhanging vegetation help trap sediment and build channel and floodplain features. When these barriers are absent or excessive sediment enters the system from increased bank erosion or other sources, it may alter channel form and function and affect fish and other aquatic life by increasing turbidity and causing excess sediment to accumulate in critical aquatic habitat areas (Suttle et al. 2004, Sullivan et al. 2010)

Specifically, sediment may block light and cause a decline in plant and algal growth, and it may also interfere with fish and macroinvertebrate survival and reproduction. Fine sediment deposition reduces availability of suitable spawning habitat for salmonid fishes, such as trout, and can smother eggs or fry (Bowerman et al. 2014). Effects from excess sediment are not limited to suspended or fine sediment; an accumulation of larger sediment (e.g., cobbles) can fill pools, reduce the percentage of desirable particle sizes for fish spawning, and cause channel over-widening (which may lead to additional sediment loading and/or increased temperatures). This larger sediment can also reduce or eliminate flow in some stream reaches when it is deposited in excess within the channel, causing flow to go subsurface (May and Lee, 2004). Although fish and aquatic life are typically the most sensitive beneficial uses regarding sediment, excess sediment may also affect other uses. For example, high concentrations of suspended sediment in streams can cause water to appear murky and discolored, negatively impacting recreational use, and can increase filtration costs for water treatment facilities that provide safe drinking water.

5.2 SEDIMENT TMDL STREAM SEGMENTS

Based on the comparison of existing conditions to water quality targets, DEQ developed 13 sediment TMDLs in the Madison TPA (**Table 5-1**)**:** Antelope, Bear, Blaine Spring, Cherry, Elk, Hot Springs, Moore, North Meadow, Red Canyon, Ruby, South Meadow, Watkins, and Wigwam creeks (**Figure 5-1**). For a complete list of streams evaluated for sediment and details of the DEQ 2013-2014 sampling effort, see **Appendix B**. Habitat alterations are non-pollutant impairment causes commonly associated with sediment impairment. TMDLs are limited to pollutants, but implementation of land, soil, and water conservation practices to reduce pollutant loading will inherently address some non-pollutant impairments (further discussed in **Section 8.0**).

Table 5-1. Sediment TMDL Development Summary

Waterbody (Assessment Unit)	Assessment Unit ID
Antelope Creek	MT41F004_140
Bear Creek	MT41F004_021

Table 5-1. Sediment TMDL Development Summary

Waterbody (Assessment Unit)	Assessment Unit ID
Blaine Spring Creek	MT41F004_010
Cherry Creek	MT41F002_010
Elk Creek	MT41F002_020
Hot Springs Creek	MT41F002_030
Moore Creek	MT41F004_130
North Meadow Creek	MT41F004_060
Red Canyon Creek	MT41F006_020
Ruby Creek	MT41F004_080
South Meadow Creek	MT41F004_070
Watkins Creek	MT41F006_030
Wigwam Creek	MT41F004_160

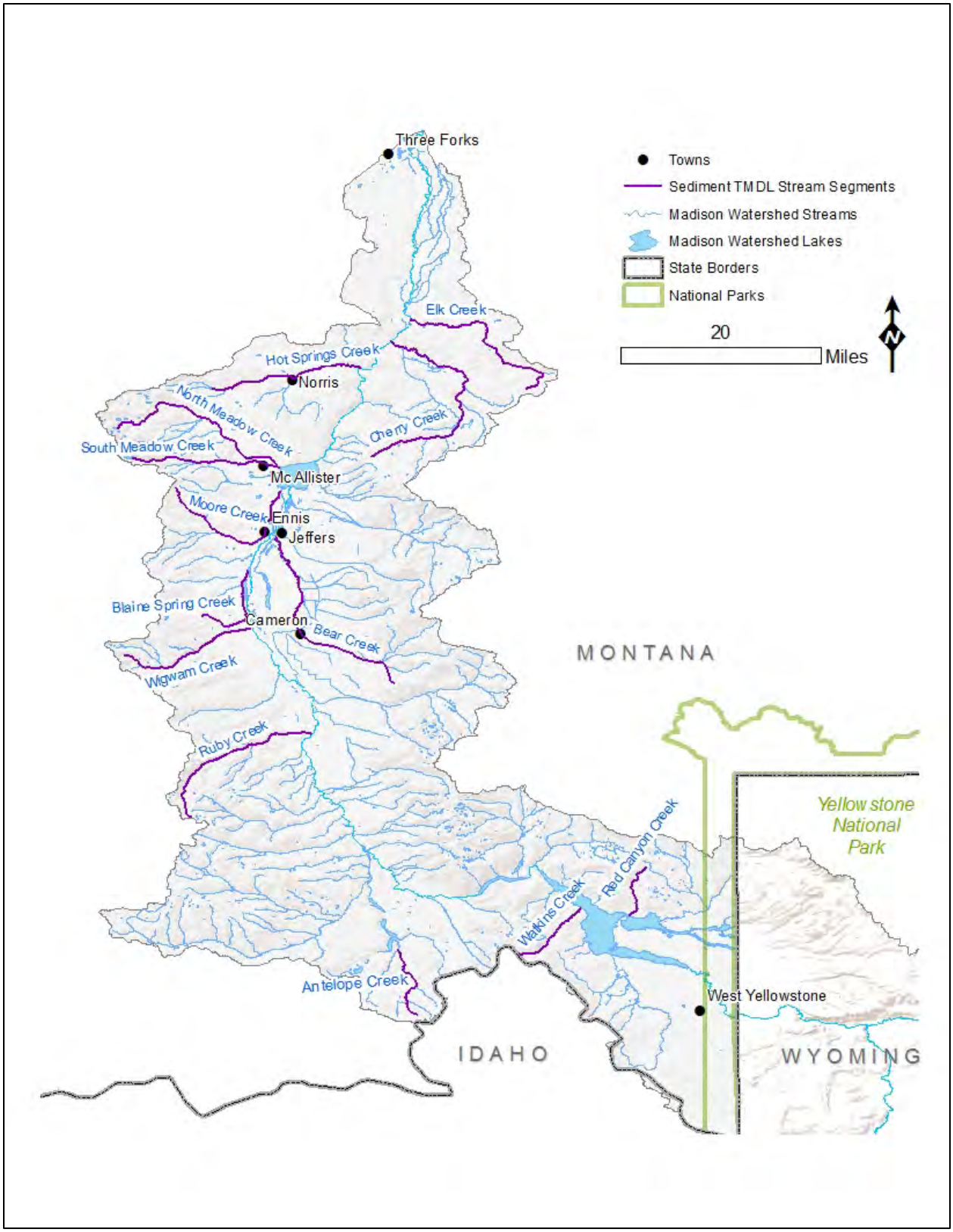


Figure 5-1. Sediment TMDL Stream Segments in the Madison TMDL Planning Area

5.3 Information Sources and Assessment Methods

Sediment TMDL development involves a review of available sediment and habitat data and field investigations to characterize overall stream health conditions and also quantify sources of sediment loading. DEQ compiled available sediment data and performed additional field investigations during 2013 and 2014. The data sources listed below were used to characterize water quality and/or develop TMDL targets. Summarized field data can be found in **Appendix B**.

- DEQ Assessment Files (cwaic.mt.gov)
- DEQ Sediment and Habitat Assessment Field Data (DEQ 2013, 2014)
- DEQ Bank Erosion Hazard Index and Greenline Field Data (DEQ 2015)
- DEQ Unpaved Road Sediment Assessment (DEQ 2014)
- U.S. Forest Service Pacfish/Infish Biological Opinion (PIBO) Program Data
- DEQ reference site data
- Other data and reports

5.4 Water Quality Targets and Target Development Rationale

The concept of water quality targets is presented in **Section 4.1**. This section provides the rationale for each sediment-related target parameter and discusses the basis of the target values. In developing targets, natural variation within and among streams must be considered. As discussed in more detail in **Appendix A**, DEQ uses the reference condition to gage natural variability and assess the effects of pollutants with narrative standards, such as sediment. The preferred approach to establishing the reference condition is using reference site data; however, modeling, professional judgment, and literature values may also be used. Although sediment water quality targets typically relate most directly to the aquatic life beneficial use, the targets are intended to protect all designated beneficial uses because they are based on the reference approach, which strives for the highest achievable quality condition.

The basis for each water quality target value varies depending on the availability of reference data. As discussed in **Appendix A**, there are several statistical approaches DEQ uses for target development. They include using percentiles of reference data or of the entire sample dataset, if reference data are limited. Although the basis for target values may differ by parameter, the goal is to define achievable sediment conditions that represent a translation of the narrative sediment standards.

5.4.1 Targets Summary

Consistent with EPA guidance for sediment TMDLs (U.S. Environmental Protection Agency, 1999), water quality targets for the Madison TMDL Planning Area include a suite of measurements of instream siltation, channel form, and habitat characteristics that contribute to loading, storage, and transport of sediment, or that demonstrate those effects. Water quality targets most closely linked to sediment accumulation or sediment-related effects to aquatic life habitat are given the most weight (i.e., fine sediment indices).

Sediment-related water quality targets for the Madison TPA are summarized in **Table 5-2** and described in detail in the sections that follow. These targets are based on reference site data discussed in **Section 5.4.2**. All statistical analyses were conducted on average values for each sample location and not on all site records, to avoid any single site or subset of sites having undue influence on the larger analysis.

For all water quality targets, future surveys should document stable (if meeting criterion) or improving trends. The exceedance of one or more target values does not necessarily equate to a determination that the information suggests impairment; the relative magnitude to which one or more targets are exceeded is taken into account, as well as the existing 303(d) listing status for sediment. The combination of target analysis, qualitative observations, and sound, scientific professional judgment is crucial when assessing stream condition. Site-specific conditions such as recent wildfires, changes in beaver activity, flow variability, or other natural long term or episodic events within a watershed may warrant the selection of unique indicator values that differ from those presented below, or alternate interpretation of the data relative to the sediment target values.

Target parameters and values are based on the current best available information but will be assessed during future TMDL reviews for their applicability and may be modified if new information provides a better understanding of reference conditions or if assessment metrics or field protocols are modified.

Table 5-2. Sediment targets for the Madison TMDL Planning Area

Parameter Type	Target Description	Criterion applicable to:	Target
Fine Sediment	Percentage of surface fine sediment < 6 mm in riffles via pebble count (site value) [(1)]	Channel slope ≤ 2% (excludes E channels)	≤ 19%
		Channel slope > 2%	≤ 16%
		Rosgen E channels	≤ 37%
	Percentage of surface fine sediment < 2mm in riffles via pebble count (site value) [(1)]	Channel slope ≤ 2% (excludes E channels)	≤ 17%
		Channel slope > 2%	≤ 12%
		Rosgen E channels	≤ 28%
	Percentage of fine surface sediment < 6mm in pool tails via grid toss (site average) [(1)]	Channel slope ≤ 2% (excludes E channels)	≤ 15%
		Channel slope > 2%	≤ 13%
		Rosgen E channels	≤ 31%
Channel Form and Stability	Bankfull width/depth ratio (site average) [(2)]	< 15 ft bankfull width	≤ 11
		15 ft - 30 ft bankfull width	≤ 24
		> 30 ft bankfull width	≤ 30
	Entrenchment ratio (site average)	Rosgen A stream type	≤ 1.6
		Rosgen B stream type	≥ 1.2
		Rosgen C and E stream types	≥ 2.0
Instream Habitat	Residual pool depth (site average) [(2)]	< 15’ bankfull width	≥ 0.7 ft
		15’-30’ bankfull width	≥ 0.9 ft
		> 30’ bankfull width	≥ 1.4 ft
	Pools/1000 ft [(2)]	< 15’ bankfull width	≥ 16
		15’-30’ bankfull width	≥ 4
		> 30’ bankfull width	≥ 3

[1] Primary indicator used to determine sediment impairment (Kusnierz et al., 2013)
[2] Primary indicator used to determine habitat impairment (Kusnierz et al., 2013)

5.4.2 Target Development Rationale

Targets were developed using a statistical approach consistent with **Appendix A**, and consistent with Montana's water quality standard for sediment as described in **Section 3.2** since targets must represent naturally occurring conditions. Literature values are usually taken into consideration during target development, however naturally occurring fine sediment conditions in the Madison trend higher than the low-end limits shown in the literature values below.

5.4.2.1 Percent Fine Sediment < 6mm and < 2mm in Riffles via Pebble Count

Bryce, et al. (2010) evaluated the effect of surface fine sediment (via reach transect pebble counts) on fish and macroinvertebrates and found that the minimum effect level for sediment < 2mm is 13% for fish and 10% for macroinvertebrates. Surface fine sediment measured in riffles by a modified Wolman pebble count (Wolman, 1954) describes the particle size distribution within riffles and is an indicator of aquatic habitat condition that can point to excessive sediment loading. Pebble counts by DEQ at reference sites and at stream assessment sites in the Madison TMDL Planning Area were conducted in four riffles per sampling site for a total of at least 400 particles.

The PIBO pebble count data are a composite of riffle and pool particles and are not directly relatable to DEQ methods. The PIBO method of collection typically results in a higher percentage of fines than a riffle pebble count. For this reason, the DEQ Middle Rockies reference dataset was used. Targets for fine sediment < 6mm and < 2mm are set at less than or equal to the 75th percentile of the DEQ Middle Rockies reference dataset for those parameters (**Tables 5-3** and **5-4**). Values are sorted by slope, as high gradient reaches are typically "transport" reaches, or those reaches where slope and velocity are conducive to the movement of sediment through a system, and low gradient reaches tend to deposit sediment on the stream bottom. As a result, it is expected that transport reaches will have less percent surface fines than low gradient reaches and thus targets are split into ≤ 2% and > 2% slope categories. Due to the low slope and high sinuosity of Rosgen E channels, fine sediment is readily stored, and they tend to have a higher percentage of fines than other channel types. Because of this inherent difference, Rosgen E channels were examined separately. As the DEQ reference dataset included only a single site that exhibited an E type channel (M01PRICC01), and the DEQ Madison TPA data for E channels consisted of sites with sediment sources and high fines values, the 10th percentile of the DEQ Madison TPA dataset and data from the single DEQ reference site was used to set the targets (**Tables 5-3** and **5-4**). Target values should be compared to the overall site value from the individual pebble counts.

Table 5-3. DEQ data summary for reference sites and Madison TPA assessment sites for percent fine sediment < 6 mm. Targets are shown in **bold**

Data Source	Sample Size	Minimum	Median	Maximum	Target
DEQ reference data – Channel Slope ≤ 2% (excludes E channels)	3	0.3	8.7	29.1	**19**[a]
DEQ reference data – Channel Slope > 2%	12	0.5	13.0	20.5	**16**[a]
DEQ reference data and DEQ Madison TPA data (E channels only)	7	20.8	51.3	95.8	**37**[b]

[a] 75th percentile of the dataset
[b] 10th percentile of the dataset

Table 5-4. DEQ data summary for reference sites and Madison TPA assessment sites for percent fine sediment < 2 mm. Targets are shown in **bold**

Data Source	Sample Size	Minimum	Median	Maximum	Target
DEQ reference data – Channel Slope ≤ 2% (excludes E channels)	3	0.3	7.4	27.1	**17**[a]
DEQ reference data – Channel Slope > 2%	12	0.5	11.1	18.5	**12**[a]
DEQ reference data and DEQ Madison TPA data (E channels only)	7	15.9	43.3	89.7	**28**[b]

[a] 75th percentile of the dataset
[b] 10th percentile of the dataset

5.4.2.2 Percent Fine Sediment < 6mm in Pool Tails via Grid Toss

Grid toss measurements in pool tails assess the level of fine sediment accumulation in macroinvertebrate habitat and potential fish spawning sites. Three tosses of a 49-point grid (Kramer, et al., 1993) were used to estimate the percent surface fine sediment < 6mm in in each pool tail in the Madison TPA. The percent fines < 6mm value in each pool tail were averaged to yield a site value. For the PIBO reference data, the value for each site was averaged across all site visits. The targets for percent fine sediment < 6mm in pool tails are set at less than or equal to the 75th percentile of the combined DEQ and PIBO Middle Rockies reference datasets for all streams except E channels (**Table 5-5**). Similar to the riffle fines targets, pool tail targets were split into ≤ 2% and > 2% slope categories. It should be noted that PIBO does not assign a Rosgen stream type to their sample sites, and the PIBO reference dataset may include some E channels. Due to an inherently high percentage of fines typical in Rosgen Type E channels, E channel values were examined separately. As with the percent fines in riffles, the 10th percentile of the DEQ Madison TPA and single reference site data was used to set the target for fine sediment in pool tails for E channels (**Table 5-5**). Target values should be compared to the site average value.

Table 5-5. Data summary for PIBO reference sites and Madison TPA assessment sites for percent fine sediment < 6mm via grid toss in pool tails. Targets are shown in **bold**

Data Source	Sample Size	Minimum	Median	Maximum	Target
DEQ and PIBO reference data – Channel Slope ≤ 2% (excludes E channels)	27	1.3	8.8	90.3	**15**[a]
DEQ and PIBO reference data – Channel Slope > 2%	30	0.5	6.5	95.8	**13**[a]
DEQ reference data and DEQ Madison TPA data (E channels only)	7	10.1	57.7	98.6	**31**[b]

[a] 75th percentile of the dataset
[b] 10th percentile of the dataset

5.4.2.3 Width/Depth Ratio

There is reference riffle width/depth ratio data for both the DEQ and PIBO datasets and the two were combined to develop the targets. Statistical analyses determined that bankfull width was the best way to categorize width/depth ratio, given that PIBO does not assign a Rosgen stream type. The target values for width/depth ratio are based on the 75th percentile of the combined DEQ and PIBO Middle Rockies reference datasets and are defined by bankfull width category (**Table 5-6**). Values greater than the target represent an over widening of the channel.

Table 5-6. Data summary for DEQ and PIBO Middle Rockies reference sites for width/depth ratios. Targets are shown in **bold**

Data Source	Sample Size	Minimum	Median	Maximum	Target
< 15 ft bankfull width	17	6.4	10.6	14.9	**11**
15 - 30 ft bankfull width	34	14.2	20.1	43.4	**24**
> 30 ft bankfull width	5	25.5	29.1	34.4	**30**

5.4.2.4 Entrenchment Ratio

The entrenchment ratio is an index value used to describe the degree of vertical containment of a river channel. It is measured as the width of the floodprone area at an elevation twice bankfull depth, divided by the bankfull width. Delineative criteria based on Rosgen stream type classification for entrenchment gives guidance of < 1.6 for A, F and G streams, 1.2-2.4 for B streams, and > 2.0 for C, E streams (Rosgen, 1996). These literature values will serve as the basis for the entrenchment ratio targets in the Madison TPA **(Table 5-7)**.

Table 5-7. Entrenchment targets for the Madison TMDL Planning Area

Rosgen Stream Type	Target Value
A	**≤ 1.6**
B	**≥ 1.2**
C, E	**≥ 2.0**

5.4.2.5 Instream Habitat Measures

For all instream habitat measures (i.e., residual pool depth and pool frequency), there is available reference data from DEQ and PIBO. All the instream habitat measures are important indicators of sediment input and movement as well as fish and aquatic life support, but they may be given less weight in the target evaluation if they do not seem to be directly related to sediment impacts. The use of instream habitat measures in evaluating or characterizing sediment impairment needs to be considered from the perspective of whether these measures are linked to fine, coarse, or total sediment loading.

Residual Pool Depth

The residual pool depth is the difference in the maximum depth of a pool and the pool crest depth, which is the depth at the downstream end of the pool before it becomes a riffle. The definition of pools for the PIBO protocol is similar to the definition used for DEQ site assessment data collection; both define a pool as having its maximum depth greater than or equal to 1.5 times the pool tail crest depth. However, the PIBO protocol only counts pools greater than half the wetted channel width whereas some DEQ pool data collected prior to 2013 was collected following the PIBO protocol and data collected during 2013 and 2014 counted all pools encountered. As a result, the DEQ dataset could

potentially have a greater pool frequency and more pools with a smaller residual pool depth. When comparing the two datasets, however, there is little difference in residual pool depth (**Table 5-8**). As a result, the two were combined to develop the residual pool depth target.

Table 5-8. Residual pool depth and pool count comparisons between the DEQ and PIBO reference datasets

Dataset	Residual Pool Depth 25th Percentile (feet)			Pools/1000 feet 25th Percentile		
	< 15 ft bankfull width	**15 - 30 ft bankfull width**	**> 30 ft bankfull width**	**< 15 ft bankfull width**	**15 - 30 ft bankfull width**	**> 30 ft bankfull width**
DEQ Reference	0.7	0.9	1.3	25.8	12.0	3.9
PIBO Reference	0.7	0.9	1.6	11.2	3.9	3.9

Because the targets for residual pool depth and pool frequency are minimum values (i.e., larger values represent a preferred condition), the targets were based on the 25th percentile of the combined DEQ and PIBO reference datasets (**Table 5-9**). Target comparisons should be based on the reach average residual pool depth value. Because residual pool depths may indicate if excess sediment is limiting pool habitat, this parameter will be particularly valuable for future trend analysis using the data collected in 2013 and 2014 as a baseline. Future monitoring should document an improving trend (i.e., deeper pools) at sites which fail to meet the target criteria.

Table 5-9. Data summary for DEQ and PIBO Middle Rockies reference sites for residual pool depth. Targets are shown in **bold**

Data Source	Sample Size	Minimum	Median	Maximum	Target
< 15 ft bankfull width	18	0.3	1.0	3.8	**0.7**
15 - 30 ft bankfull width	35	0	1.3	2.1	**0.9**
> 30 ft bankfull width	6	1.1	1.6	2.1	**1.4**

Pool Frequency

Pool frequency is the number of measured pools per site and scaled to frequency per 1,000 feet of stream reach. As mentioned in the previous section, methods for identification of pools between the DEQ and PIBO datasets differed because PIBO only counts pools greater than 1.5 times the wetted width. However, when all pools were counted regardless of size, the majority were greater than one half the wetted channel width. As a result, the two datasets were combined and the 25th percentile was used to develop the pool frequency targets (**Table 5-10**), A higher frequency value represents a preferred condition.

Table 5-10. Data summary for PIBO reference sites and Madison TPA assessment sites for pools/1,000 feet. Targets are shown in **bold**

Data Source	Sample Size	Minimum	Median	Maximum	Target
< 15 ft bankfull width	18	2.4	26.3	66.5	**16**

Table 5-10. Data summary for PIBO reference sites and Madison TPA assessment sites for pools/1,000 feet. Targets are shown in **bold**

Data Source	Sample Size	Minimum	Median	Maximum	Target
15 - 30 ft bankfull width	36	0	9.4	54.3	**4**
> 30 ft bankfull width	6	2.5	5.6	11.2	**3**

5.4.2.6 Periphyton

Periphyton are microscopic algae that attach or cling to plants and other objects in the stream. DEQ collects periphyton from rocks, sediment, and submerged branches in the summer or fall according to the Periphyton Standard Operating Procedure (DEQ 2011). Within periphyton samples, diatoms are single celled algae, that increase or decrease in response to stress. The diatom assemblage from periphyton samples was used in conjunction with habitat measures to support a listing of impairment. The probability of impairment increased as the presence of sediment increaser taxa increased. "Sediment increaser taxa" are those diatom taxa that have been found to increase with increasing likelihood of sediment impairment (Teply and Bahls 2007).

5.4.3 Existing Condition and Comparison to Water Quality Targets

This section presents summaries and evaluations of relevant water quality data for Madison TPA waterbodies assessed for sediment and found to be impaired. Summaries for streams investigated for sediment and habitat that were not determined to be impaired for sediment can be found in **Appendix B**. The weight-of-evidence approach using a suite of water quality targets, described in **Section 4.1**, has been applied to each waterbody evaluated. Data presented in this section comes primarily from sediment, habitat, BEHI (Bank Erosion Hazard Index), and greenline data collection performed by DEQ during summer 2013 and 2014. Results of the 2013 and 2014 data collection are supported by additional data in the DEQ Assessment Files, DEQ reference data, and PIBO managed site data (versus reference which was used for target development). However, this section is not intended to provide an exhaustive review of all available data.

5.4.3.1 Antelope Creek (MT41F004_140)

Antelope Creek (MT41F004_140) is listed for sedimentation-siltation on the 2018 303(d) List. This segment is also listed for alteration in streamside or littoral vegetative covers which is a non-pollutant listing that can often be linked to sediment impairment. The segment flows 9.48 miles from the headwaters to the mouth at Cliff Lake, through metamorphic and volcanic geology and a shrub/scrub landscape with smaller areas of evergreen forest. The channel goes dry as a result of diversions in the Antelope Basin. Groundwater returns restore flow in the lower portion above Cliff Lake.

Physical Condition and Sediment Sources

In 2014 DEQ collected sediment and habitat data from two sites on Antelope Creek: ALTP 04-02 and ALTP 10-01 (**Appendix B**; Figure B-1**).** ALTP 04-02 was the upstream site in this segment and was located in a grazed riparian setting (DEQ 2014; **Figure 5-2**). Vegetation consisted of about 44% sedges/rushes, 16% grasses/forbs, and 20% shrubs/trees (DEQ 2015). Grazing was apparent with disturbed bare ground and hummocking observed at 20% and 38% of the site, respectively. Most streambanks were unstable and consisted primarily of fine gravel (10-40%) and sand/clay (50-80%) with only about 10-20% being coarse gravel or larger sediment (DEQ 2015). About 88% of the site length had eroding banks with the majority being attributed to riparian grazing (84%) and the remainder being due to natural processes.

Sample diatom counts were evaluated to determine the probability of impairment for sediment using the sediment increaser taxa list for the Middle Rockies. One diatom sample collected at the site yielded a probability of 51.4% that the assemblage represented a stream impaired by sediment.

Figure 5-2. Evidence of cattle use including pugging, hoof shear, and eroding banks at ALTP 04-02

ALTP 10-1 was located about 5 miles downstream of ALTP 04-02, downstream of a dry reach of Antelope Creek that is grazed by cattle (DEQ 2014). The site was well vegetated with willows, sedges, and native forbs and grasses with about 91% of the vegetation being grasses/forbs and 7% being shrubs/trees (DEQ 2014, 2015). Although cattle were observed upstream of the site, they appeared to have been fenced out; 1% of the site was disturbed bare ground. Most of the land use impacts at this site (i.e., trails, lack of woody vegetation) appeared historical. Streambanks were generally stable and were composed primarily of fine gravel (0-45%) and sand/clay (45-85%) with about 5-30% being coarse gravel or larger sediment (DEQ 2015). About 11% of the site length had eroding banks with 96% being attributed to natural processes and the remainder to a livestock crossing. Nine linear feet of bank erosion within the site were the result of a cattle crossing.

Comparison to Water Quality Targets

The existing physical data in comparison with the targets for Antelope Creek are summarized in **Table 5-11**. All bolded cells are not meeting the target; depending on the target parameter, this may equate to being below or above the target value. For fine sediment, one site fails to meet the targets for riffle pebble count < 6 mm and < 2 mm. W/D ratio and residual pool depth each failed to meet the target values at one (different) site. These results indicate that while the channel appears stable, there potentially is excess fine sediment moving through the system.

Table 5-11. Existing sediment-related data for Antelope Creek relative to targets
Values that do not meet the target are in **bold** and shaded

Reach/ Site ID	Assessment Year	Mean BFW (ft)	Gradient (%)	Existing Stream Type	Riffle Pebble Count		Grid Toss	Channel Form		Instream Habitat	
					% <6mm	% <2mm	Pool % <6mm	W/D Ratio	Entrenchment Ratio	Residual Pool Depth (ft)	Pools / 1000 ft
ALTP 04-02	2014	11.9	1.2	C	**29**	**19**	13	**13.5**	7.5	0.8	32.4
ALTP 10-01	2014	18.1	0.7	C	19	15	4	19.7	2.2	**0.5**	19.2

Summary
Data collected by DEQ in 2014 (DEQ 2014, 2015) indicate that while the lower site appears to be managed appropriately, grazing in riparian areas contributes excess fine sediment to the segment and that restoration and implementation of best management practices will reduce sediment input from this source. The existing listings for Antelope Creek are supported based on current land management practices that are contributing human sources of sediment, the human-caused erosion observed, failure of both riffle targets at the upper site, the observed lack of woody vegetation at both sites, and the excessive bare ground and eroding banks at the upper site.

5.4.3.2 Bear Creek (MT41F004_021)

Bear Creek (MT41F004_021) is listed for sedimentation-siltation on the 2018 303(d) List. The segment impaired segment flows 27.3 miles from the headwaters to the mouth at O'Dell Spring Creek through sedimentary geology and a grass-dominated landscape with willows and sedges growing in riparian areas.

Physical Condition and Sediment Sources
In 2014 DEQ collected sediment and habitat data from two sites on Bear Creek: BEAR 09-03 and BEAR 10-01 (**Appendix B**; Figure B-2). BEAR 09-03 was the upstream site in this segment and was located in a grazed riparian setting (DEQ 2014). The site was vegetated with sedges and some willows with about 73% of the vegetation being sedges/rushes, 24% grasses/forbs, and 3% being shrubs/trees (DEQ 2014, 2015). Grazing was pervasive with hummocking observed at 100% of the site. Most streambanks were unstable but were lined with sedges and would stabilize given the time to recover. Banks were composed entirely of sand/clay (DEQ 2015). About 15% of the site length had eroding banks with 94% being attributed to riparian grazing and the remainder being due to natural processes. Sample diatom counts were evaluated to determine the probability of impairment for sediment using the sediment increaser taxa list for the Middle Rockies. One diatom sample collected at the site yielded a probability of 60.4% that the assemblage represented a stream impaired by sediment.

BEAR 10-01 was located about 2 miles downstream of BEAR 09-03 and was located in a reach that appears to have been heavily grazed in the past but was recovering (DEQ 2014). The site was vegetated with willows, sedges, cattails, and bulrush with about 72% of the vegetation being sedges/rushes, 23% grasses/forbs, and 5% being shrubs/trees (DEQ 2014, 2015). Non-native thistle and mustard species were present in upland areas. No disturbed bare ground was observed, but 38% of the site had

hummocking. (**Figure 5-3**). Most of the land use impacts at this site appeared to be either historical (i.e., lack of woody vegetation, eroding banks, hummocking) or from upstream grazing (i.e., high fine sediment). Streambanks were generally stable at the site and were composed primarily of fine gravel (0-20%) and sand/clay (75-100%) with only a small amount (0-15%) being coarse gravel or larger sediment (DEQ 2015). About 18% of the site length had eroding banks with about half (52%) being attributed to natural processes and the remainder being from riparian grazing. Many fish were observed at this site. Sample diatom counts were evaluated to determine the probability of impairment for sediment using the sediment increaser taxa list for the Middle Rockies. Based on this data, a 45.8% probability existed that the sample collected at BEAR 10-01 represented a site impaired by sediment. One diatom sample collected at the site yielded a probability of 45.8% that the assemblage represented a stream impaired by sediment.

Figure 5-3. An example of hummocking on Bear Creek

Comparison to Water Quality Targets

The existing physical data in comparison with the targets for Bear Creek are summarized in **Table 5-12**. All bolded cells are not meeting the target; depending on the target parameter, this may equate to being below or above the target value. For fine sediment, both sites fail to meet the targets for riffle pebble count < 6 mm and < 2 mm and pool tail fines. In addition, BEAR 09-03 fails to meet the targets for residual pool depth and pool frequency. These results indicate that while the channel form is meeting the targets, there is an excess amount of fine sediment and the sediment loading is likely having a negative impact on pool depth and frequency.

Table 5-12. Existing sediment-related data for Bear Creek relative to targets
Values that do not meet the target are in **bold** and shaded

Reach/ Site ID	Assessment Year	Mean BFW (ft)	Gradient (%)	Existing Stream Type	Riffle Pebble Count		Grid Toss	Channel Form		Instream Habitat	
					% <6mm	% <2mm	Pool % <6mm	W/D Ratio	Entrenchment Ratio	Residual Pool Depth (ft)	Pools / 1000 ft
BEAR 09-03	2014	14.9	0.5	E	**91**	**90**	**58**	10	2.5	**0.4**	**9.8**
BEAR 10-01	2014	20.8	0.2	C	**50**	**47**	**56**	18.2	2.2	1.1	5.8

Summary
Data collected by DEQ in 2014 (DEQ 2014, 2015) indicate that cattle grazing is contributing excess fine sediment to the segment and that restoration and implementation of best management practices will reduce sediment input from these sources. The sedimentation-siltation listing for Bear Creek is supported based on current land management practices that are contributing human sources of sediment, the human-caused erosion observed, and the failures of instream data to the targets.

5.4.3.3 Blaine Spring Creek (MT41F004_010)

Blaine Spring Creek (MT41F004_010) is listed for sedimentation-siltation on the 2018 303(d) List. The segment flows 4.95 miles from the headwaters to the mouth at the Madison River through sedimentary geology and a grass-dominated landscape with willows and sedges growing in riparian areas. Ennis National Fish Hatchery, operated by the U.S. Fish and Wildlife Service is located near the headwaters of Blaine Spring Creek.

Physical Condition and Sediment Sources
In 2014 DEQ collected sediment and habitat data from two sites on Blaine Spring Creek: BLNS 04-01 and BLNS 06-01 (**Appendix B**; Figure B-2**)**. BLNS 04-01 was the upstream site in this segment (DEQ 2014). Willows, juniper, gooseberry, sedges, and grass were observed at the site with vegetation consisting of about 3% sedges/rushes, 65% grasses/forbs, and 30% shrubs/trees (DEQ 2014, 2015). There was little evidence of grazing with disturbed bare ground observed at 2% of the site and no hummocking. Most streambanks appeared stable and consisted of 10-40% fine gravel, 20-70% sand/clay, and 15-80% coarse gravel or larger sediment (DEQ 2015). About 35% of the site length had eroding banks with 75% being attributed to natural processes, 24% to historical grazing, and the remainder being from diversion of stream energy via structures.

BLNS 06-01 was located about 2.5 miles downstream of BLNS 04-01 in an area fenced to exclude cattle from grazing (DEQ 2014). The site was well vegetated with willows, sedges, and grasses on high banks with about 17% of the vegetation being sedges/rushes, 78% grasses/forbs, and 5% being shrubs/trees (DEQ 2014, 2015; **Figure 5-4**). No disturbed bare ground was observed with 12% of the site having hummocking. Most of the land use impacts at this site appeared to be from past grazing. Streambanks were generally stable at the site and were composed primarily of sand/clay (50-90%) with a smaller amount of fine gravel (5-20%) and coarse gravel or larger sediment (0-30%) (DEQ 2015). About 63% of the site length had eroding banks with about 76% being attributed to natural processes and the

remainder being from riparian grazing. Sample diatom counts were evaluated to determine the probability of impairment for sediment using the sediment increaser taxa list for the Middle Rockies. One diatom sample collected at the site yielded a probability of 23.5% that the assemblage represented a stream impaired by sediment.

Figure 5-4. Riparian vegetation conditions at BLNS 06-01
Note the vegetation present to the waterline and lack of exposed banks

In addition to the DEQ data collection, the Madison Conservation District collected pebble counts from three sites on Blaine Spring Creek in July 2014; percent fines < 2 mm were 0%, 4%, and 25% (Madison Conservation District 2014).

Comparison to Water Quality Targets
The existing physical data in comparison with the targets for Blaine Spring Creek are summarized in **Table 5-13**. All bolded cells are not meeting the target; depending on the target parameter, this may equate to being below or above the target value. For fine sediment, the upper site fails to meet the targets for riffle pebble count < 6 mm and < 2 mm. With regards to the channel form and instream habitat variables, one site fails to meet the target for entrenchments while the other site fails to meet the target for residual pool depth. These results indicate that while the channel form and instream habitat are generally meeting the targets, there is an excess amount of fine sediment in the upper portion of Blaine Spring Creek.

Table 5-13. Existing sediment-related data for Blaine Spring Creek relative to targets
Values that do not meet the target are in **bold** and shaded

Reach/ Site ID	Assessment Year	Mean BFW (ft)	Gradient (%)	Existing Stream Type	Riffle Pebble Count		Grid Toss	Channel Form		Instream Habitat	
					% <6mm	% <2mm	Pool % <6mm	W/D Ratio	Entrenchment Ratio	Residual Pool Depth (ft)	Pools / 1000 ft
BLNS 04-01	2014	16.8	2.2	B	**25**	**19**	4	11.5	2.4	**0.7**	11.4
BLNS 06-01	2014	26.7	0.8	C	12	11	2	17.4	**1.6**	1.4	7.6

Summary
Data collected by DEQ in 2014 (DEQ 2014, 2015) indicate that while the lower site appears to be managed appropriately, historical grazing in riparian areas contributes excess fine sediment to the segment and that restoration and continued implementation of best management practices will reduce sediment input from these sources. The sedimentation-siltation listing for Blaine Spring Creek is supported based on current and past land management practices that are contributing human sources of sediment, human-caused erosion observed, and failure of both riffle targets at the upper site.

5.4.3.4 Cherry Creek (MT41F002_010)

Cherry Creek (MT41F002_010) is listed for sedimentation-siltation on the 2018 303(d) List. The segment flows 24 miles from the headwaters to the mouth at the Madison River through sedimentary geology and a shrub/scrub landscape with pockets of grasses and willows and sedges growing in the riparian areas. Cherry Creek was the location of a westslope cutthroat restoration project that re-established the species in 60 miles of the drainage (Wilkinson 2012).

Physical Condition and Sediment Sources
In 2014 DEQ collected sediment and habitat data from two sites on Cherry Creek: CHRR 18-02 and CHRR 20-01 (**Appendix B**; Figure B-2**)**. CHRR 18-02 was the upstream site in this segment and had evidence of channel restoration (rock placed on an outside meander, recently planted cottonwood and aspen; DEQ 2014). The site was well vegetated with rushes, grasses, and willows with about 9% of the vegetation being sedges/rushes, 89% grasses/forbs and 2% being shrubs/trees (DEQ 2014, 2015). No disturbed bare ground or hummocking was observed at the site. Streambanks were composed primarily of sand/clay (40-50%) and fine gravel (40%) with a lesser amount of coarse gravel or larger sediment (10-20%) (DEQ 2015). About 58% of the site length had eroding banks with 64% being attributed to natural processes and the remainder being historical (riparian grazing). A layer of sand within the banks made them easily eroded (**Figure 5-5**). Fine sediment was observed along the channel margins and within pools resulting in reduced pool volume. Sample diatom counts were evaluated to determine the probability of impairment for sediment using the sediment increaser taxa list for the Middle Rockies. One diatom sample collected at the site yielded a probability of 23.4% that the assemblage represented a stream impaired by sediment. Despite this low value, physical data from this site indicated impairment.

Figure 5-5. Eroding bank displaying a layer of easily eroded sand

CHRR 20-01 was located about 4 miles downstream of CHRR 18-02 within an area fenced to exclude livestock (DEQ 2014). This site had stable banks and was well vegetated with sedges, willows, and grass with about 18.5% of the vegetation being sedges/rushes, 80.5% grasses/forbs, and 1% being shrubs/trees (DEQ, 2014 2015). No disturbed bare ground or hummocking was observed at the site. Streambanks were composed of 20-40% sand/clay, 20-40% fine gravel, and 20% coarse gravel or larger sediment (DEQ 2015). About 62% of the site length had eroding banks with 80% being attributed to natural processes and the remainder being historical (riparian grazing). Some pools were storing sediment resulting in decreased depth. The channel was storing silt, likely from an upstream source. Many small fish were observed at the site suggesting that the creek is a spawning and rearing tributary for the lower Madison River. Sample diatom counts were evaluated to determine the probability of impairment for sediment using the sediment increaser taxa list for the Middle Rockies. One diatom sample collected at the site yielded a probability of 20.1% that the assemblage represented a stream impaired by sediment. However, despite this low value, the impairment listing is supported by the physical fine sediment data.

Comparison to Water Quality Targets

The existing physical data in comparison with the targets for Cherry Creek are summarized in **Table 5-14**. All bolded cells are not meeting the target; depending on the target parameter, this may equate to being below or above the target value. For fine sediment, both sites fail to meet the targets for riffle pebble count < 6 mm and < 2 mm and the upper site fails the target for pool tail fines. Entrenchment

ratio at the lower site is the only other target that is not met. These results indicate that while channel form and instream habitat targets are generally being met, there is an excess amount of fine sediment.

Table 5-14. Existing sediment-related data for Cherry Creek relative to targets
Values that do not meet the target are in **bold** and shaded

Reach/ Site ID	Assessment Year	Mean BFW (ft)	Gradient (%)	Existing Stream Type	Riffle Pebble Count		Grid Toss	Channel Form		Instream Habitat	
					% <6mm	% <2mm	Pool % <6mm	W/D Ratio	Entrenchment Ratio	Residual Pool Depth (ft)	Pools / 1000 ft
CHRR 18-02	2014	30.5	0.5	C	**48**	**41**	**43**	18.5	3.1	2.5	6.5
CHRR 20-01	2014	33.1	0.6	C	**24**	**21**	7	21.2	**1.6**	1.5	7.5

Summary
Restoration work on Cherry Creek has included replacing culverts with bridges and planting vegetation in riparian areas (Madison Conservation District 2015). Data collected by DEQ in 2014 (DEQ 2014, 2015) indicate that historical grazing practices are contributing excess fine sediment to the segment and that continued implementation of best management practices and additional restoration activities will reduce sediment input from these sources. The stream appears to be in recovery and it is likely that if the existing land management practices continue to be implemented, conditions will improve in Cherry Creek. The sedimentation-siltation listing for Cherry Creek is supported based on the historical load of fine sediment that remains within Cherry Creek, the existing loading caused by historical land use practices, and the failures of instream sediment targets.

5.4.3.5 Elk Creek (MT41F002_020)

Elk Creek (MT41F002_020) is listed for sedimentation-siltation on the 2018 303(d) List. In addition, this segment is listed for alteration in streamside or littoral vegetative covers which is a non-pollutant listing that can often be linked to sediment impairment. The segment flows 18.33 miles from the headwaters to the mouth at the Madison River through sedimentary geology and a grass-dominated landscape with willows and sedges growing in riparian areas. Beaver activity is present in the middle to lower portions of the creek. This segment is also listed for turbidity. Given that excess sediment is contributing to this turbidity, any actions to reduce sediment would also reduce turbidity. Therefore, turbidity is also addressed by the sediment TMDL.

Physical Condition and Sediment Sources
In 2010, DEQ collected sediment and habitat data from one site and in 2013 from four sites on Elk Creek: M06ELKC07, ELKC 05-01, ELKC 06-02, ELKC 11-01 (**Appendix B**; Figure B-2). Descriptive vegetation information was available for three of these sites and bank erosion data were available for two. ELKC 05-01 was the second to most upstream site in this segment and was located in a historically grazed riparian setting (DEQ 2014). The site was vegetated with sedge, willow, and alder with about 16% of the vegetation being sedges/rushes, 78% grasses/forbs, and 3% being shrubs/trees (DEQ 2014, 2015). Cheatgrass and Canada thistle were present in upland areas. Past cattle use was evident by the presence of the noxious weeds. About 3% of the site consisted of disturbed bare ground and no hummocking was

observed. Streambanks were composed entirely of sand/clay (DEQ 2015). About 74% of the site length had eroding banks with 90% being attributed to natural processes and the remainder being from riparian grazing. There was relatively little sediment loading coming from within the site. Sample diatom counts from site ELKC 05-01 were evaluated to determine the probability of impairment for sediment using the sediment increaser taxa list for the Middle Rockies. A diatom sampled collected at the site yielded a probability of 72.7% that the assemblage represented a stream impaired by sediment. An additional sample collected in close proximity upstream (at M06ELKC07) yielded a probability of 81.5%.

ELKC 06-02 was located about 4.3 miles downstream of ELKC 05-01 in a heavily grazed setting (DEQ 2014). The site was vegetated with native riparian shrubs and invasive weeds (DEQ 2014). Cattle use was evident with extensive pugging and streambank sloughing observed. Pugging occurs when the hooves of grazing livestock penetrate the soil surface during wet conditions causing damage to pasture plants as well as soil structure. Pasture plants can be torn and buried. A layer of silt was overlying most of the stream channel. Two diatom samples collected at the site yielded probabilities of 45.3% and 52.5% that the assemblage represented a stream impaired by sediment.

ELKC 11-01 was located about 6.5 miles downstream of ELKC 06-02 in a dry channel resulting from irrigation diversion (DEQ 2014). The site was vegetated with grasses, sedges, willow, alder, Canada thistle, and houndstongue with about 7% of the vegetation being sedges/rushes, 88% grasses/forbs and 5% being shrubs/trees (DEQ 2014, 2015). There were no clear indicators of grazing at the site with no disturbed bare ground or hummocking observed. Streambanks were composed primarily of sand/clay (80-100%) and fine gravel (5-18%) with a lesser amount of coarse gravel or larger sediment (0-2%) (DEQ 2015). About 48% of the site length had eroding banks with 50% being attributed to natural processes and the remainder being historical riparian grazing. A layer of fine sediment covered the substrate throughout the site.

Comparison to Water Quality Targets

The existing physical data in comparison with the targets for Elk Creek are summarized in **Table 5-15**. All bolded cells are not meeting the target; depending on the target parameter, this may equate to being below or above the target value. For fine sediment, all sites fail to meet the targets for riffle pebble count < 6 mm and < 2 mm and the target for pool tail fines. W/D ratio and entrenchment ratio each fail to meet their respective targets at one (different) site. Two sites fail to meet the target for residual pool depth. These results indicate that there is excessive fine sediment in Elk Creek. In addition, the failure of multiple channel form and instream habitat targets indicates that there are issues with habitat quality.

Table 5-15. Existing sediment-related data for Elk Creek relative to targets

Values that do not meet the target are in **bold** and shaded

Reach/ Site ID	Assessment Year	Mean BFW (ft)	Gradient (%)	Existing Stream Type	Riffle Pebble Count		Grid Toss	Channel Form		Instream Habitat	
					% <6mm	% <2mm	Pool % <6mm	W/D Ratio	Entrenchment Ratio	Residual Pool Depth (ft)	Pools / 1000 ft
MO6ELKC07 [1]	2013	7.5	2	E	**91**	**36**	**99**	9.4	2.5	**0.5**	52.7
ELKC 05-01	2013	5.6	1.3	E	**96**	**67**	**91**	7.9	8.1	**0.5**	30.8

Table 5-15. Existing sediment-related data for Elk Creek relative to targets
Values that do not meet the target are in **bold** and shaded

Reach/ Site ID	Assessment Year	Mean BFW (ft)	Gradient (%)	Existing Stream Type	Riffle Pebble Count		Grid Toss	Channel Form		Instream Habitat	
					% <6mm	% <2mm	Pool % <6mm	W/D Ratio	Entrenchment Ratio	Residual Pool Depth (ft)	Pools / 1000 ft
ELKC 06-02[2]	2010, 2013	13.6	1.7	C	**47**	**42**	**59**	**19.3**	3.0	0.9	26.1
ELKC 11-01	2013	7	1.7	C	**58**	**48**	-	9.0	**1.7**	-	18.9

[1]Located on the same stratified reach as ELKC 05-01
[2]Values are averages from one sampling event in 2010 and two in 2013 by different field crews

Summary and TMDL Development Determination
Data collected by DEQ in 2013 (DEQ 2013, 2015) indicate that riparian grazing (present and historical) is contributing excess fine sediment to the segment and that restoration and implementation of best management practices will reduce sediment input from these sources. The existing listings for Elk Creek are supported based on the current land management practices that are contributing human sources of sediment, the human-caused erosion observed, the failures of instream sediment targets, and the observed poor riparian conditions.

5.4.3.6 Hot Springs Creek (MT41F002_030)

Hot Springs Creek (MT41F002_030) is listed for sedimentation-siltation on the 2018 303(d) List. The segment flows 14 miles from the headwaters to the mouth at the Madison River through metamorphic, intrusive, and sedimentary geology and a grass and shrub/scrub landscape with pockets of evergreen forest and willows and sedges growing in the riparian areas.

Physical Condition and Sediment Sources
Sediment and habitat data were collected from Hot Springs Creek by DEQ at three sites in 2013: HOTS 05-01, HOTS 10-01, and HOTS 16-01 (**Appendix B**; Figure B-2). HOTS 05-01 was the upstream site in this segment, located in a grazed riparian setting (DEQ 2013). The site was vegetated with willow and alder with about 2% of the vegetation being sedges/rushes, 85% grasses/forbs, and 7% being shrubs/trees (DEQ 2013, 2015). Despite heaving grazing pressure in upland areas weeds were not observed. Disturbed bare ground and rock each made up 3% of the site with hummocking observed at 24% of the site. Streambanks overall appeared stable and were composed primarily of sand/clay (65-95%) with lesser amounts of fine gravel (5%) and coarse gravel or larger sediment (0-30%) (DEQ 2015). About 24% of the site length had eroding banks with 69% of this erosion being attributed to riparian grazing and the remainder being from natural processes. Sample diatom counts from site HOTS 05-01 were evaluated to determine the probability of impairment for sediment using the sediment increaser taxa list for the Middle Rockies. One diatom sample collected at the site yielded a probability of 85.8% that the assemblage represented a stream impaired by sediment.

HOTS 10-01 was located about 4.6 miles downstream of HOTS 05-01 in a setting that appears to have been heavily grazed in the past (DEQ 2013). The site was thickly vegetated with grasses, willow, and

alder with about 19% of the vegetation being sedges/rushes, 53% grasses/forbs, and 28% being shrubs/trees (DEQ 2013, 2015). Cattle use was evident with hummocking at 6% of the site; no disturbed bare ground or rock was observed. Streambanks were well-supported by grasses and shrubs and were composed primarily of sand/clay (80%) with lesser amounts of fine gravel (10%) and coarse gravel or larger sediment (10%) (DEQ 2015). About 21% of the site length had eroding banks with 57% being attributed to natural processes and the remainder being from riparian grazing.

HOTS 16-01 was located about 5.6 miles downstream of HOTS 10-01 in a site with vegetation consisting of about 40.5% sedges/rushes and 41.5% grasses/forbs (DEQ 2013, 2015). About 16% of the site was disturbed bare ground with rock comprising 2%; hummocking was not observed. Streambanks were composed primarily of sand/clay (40-100%) with lesser amounts of fine gravel (0-5%) and coarse gravel or larger sediment (0-60%) (DEQ 2015). About 28% of the site length had eroding banks with 46% being attributed to natural processes, about 39% being attributed to road crossings, and the remainder to historical sources (i.e., 2012 fire). One diatom sample collected at the site yielded a probability of 92.6% that the assemblage represented a stream impaired by sediment.

Evaluation of tributaries to Hot Springs Creek on grazing allotments by the BLM indicated that there are many sources of human-caused sediment loading and habitat disturbance in the watershed (BLM 2009). These sources included over widening of the stream, undersized culverts, mining waste, roads, and livestock-caused bank erosion. In addition, deep rooting vegetation and a middle age class of willows was absent while non-native and invasive plant species were present. Riparian conditions were judged to range from proper functioning condition to functioning at risk.

Comparison to Water Quality Targets

The existing physical data in comparison with the targets for Hot Springs Creek are summarized in **Table 5-16**. All bolded cells are not meeting the target; depending on the target parameter, this may equate to being below or above the target value. For fine sediment, all three sites fail to meet the targets for riffle pebble count < 6 mm and < 2 mm and pool tail grid toss. All three sites also fail to meet the residual pool depth target. W/D ratio and pool frequency each fail at one (different) site. These results indicate that there is excess fine sediment loading to Hot Springs Creek and habitat quality is poor.

Table 5-16. Existing sediment-related data for Hot Springs Creek relative to targets

Values that do not meet the target are in **bold** and shaded

Reach/ Site ID	Assessment Year	Mean BFW (ft)	Gradient (%)	Existing Stream Type	Riffle Pebble Count		Grid Toss	Channel Form		Instream Habitat	
					% <6mm	% <2mm	Pool % <6mm	W/D Ratio	Entrenchment Ratio	Residual Pool Depth (ft)	Pools / 1000 ft
HOTS 05-01	2013	4.8	3.3	B	**76**	**63**	**65**	8	5.9	**0.2**	37.3
HOTS 10-01	2013	4.8	1.0	C	**95**	**68**	**67**	**11.2**	3.4	**0.5**	21
HOTS 16-01	2013	11.0	1.5	E	**47**	**42**	**68**	8.3	7	**0.6**	**15.4**

Summary
Data collected by DEQ in 2013 (DEQ 2013, 2015) indicate that riparian grazing and roads are contributing excess fine sediment to the segment and that restoration and implementation of best management practices will reduce sediment input from these sources. The sedimentation-siltation listing for Hot Springs Creek is supported based on current land management practices that are contributing human sources of sediment, the human-caused erosion observed, and the failures of instream data to the targets.

5.4.3.7 Moore Creek (MT41F004_130)

Moore Creek (MT41F004_130) is listed for sedimentation-siltation on the 2018 303(d) List. In addition, this segment is listed for alteration in streamside or littoral vegetative covers which is a non-pollutant listing that can often be linked to sediment impairment. The segment flows 15.83 miles from springs in the headwaters to the mouth at Fletcher Channel of the Madison River through metamorphic and sedimentary geology and a landscape composed of shrub/scrub and evergreen in the headwaters, grasses and shrub/scrub in the middle portion of the watershed, and grasses, hay/pasture, and riparian vegetation near the mouth.

Physical Condition and Sediment Sources
In 2008, 18,500 feet of Moore Creek near the confluence with the Madison River were restored via rechanneling the stream and about 400 acres of wetlands were improved (Madison Conservation District 2015). Since 2010, the Madison Stream Team has performed monitoring within this section of Moore Creek. As of May 2015, there were plans to install ½ mile of fencing on Moore Creek to limit livestock access to the stream.

In 2014 DEQ collected sediment and habitat data from two sites on Moore Creek: MOOR 09-01 and MOOR 09-04 (**Appendix B**; Figure B-2). MOOR 09-01 was the upstream site in this segment and was located in an area that has not been grazed by cattle in more than 5 years (DEQ 2014). The site was vegetated with reed canary grass, willow, alder, cottonwood, and mint but also had Canada thistle, tansy, and houndstongue with about 9% of the vegetation being sedges/rushes, 64% grasses/forbs, and 27% being shrubs/trees (DEQ 2014, 2015). Disturbed bare ground and hummocking were not observed at the site. Streambanks appeared to be in good condition, have recovered from past disturbance, and were primarily composed of sand/clay (70-85%) with lesser amounts of fine gravel (10-20%) and coarse gravel or larger sediment (0-20%) (DEQ 2015). About 53% of the site length had eroding banks with 54% being attributed to natural processes and the remainder being historical riparian grazing. A periphyton sample from the site yielded a 95% probability of the site having excess fine sediment. A layer of silt is covering the predominantly gravel substrate and areas of sandy/silty deposition were present (DEQ 2014). The site appears to be in recovery. Sample diatom counts were evaluated to determine the probability of impairment for sediment using the sediment increaser taxa list for the Middle Rockies. One diatom sample collected at the site yielded a probability of 95% that the assemblage represented a stream impaired by sediment.

MOOR 09-04 was located about 3.8 miles downstream of MOOR 09-01 in an area that appears to have been heavily grazed in the past (DEQ 2014). The site was vegetated with reed canary grass, sedges, native grasses, and Canada thistle with about 53% of the vegetation being sedges/rushes and 47% being grasses/forbs (DEQ 2014, 2015). The riparian area upstream of the site appeared to be heavily grazed pasture. Disturbed bare ground and hummocking were not observed at the site. Streambanks were supported by thick growth of sedges and reed canary and were composed of 100% sand/clay (DEQ 2015). About 62% of the site length had eroding banks with 60% being attributed to natural processes

and the remainder being riparian grazing. Sample diatom counts were evaluated to determine the probability of impairment for sediment using the sediment increaser taxa list for the Middle Rockies. One diatom sample collected at the site yielded a probability of 42.3% that the assemblage represented a stream impaired by sediment.

In addition to the DEQ data collection, the Madison Conservation District collected pebble counts from three sites on Moore Creek in July 2014; percent fines < 2 mm were 18%, 45%, and 63% (Madison Conservation District 2014).

Comparison to Water Quality Targets

The existing physical data in comparison with the targets for Moore Creek are summarized in **Table 5-17**. All bolded cells are not meeting the target; depending on the target parameter, this may equate to being below or above the target value. For fine sediment, both sites fail to meet the targets for riffle pebble count < 6 mm and < 2 mm and pool tail fines. In addition, both sites fail the residual pool depth targets and the targets for entrenchment ratio and pool frequency are each failed at one (different) site. These results indicate that while the channel form is generally meeting the targets, there is an excess amount of fine sediment and the sediment loading is likely having a negative impact on pool depth and frequency.

Table 5-17. Existing sediment-related data for Moore Creek relative to targets

Values that do not meet the target are in **bold** and shaded

Reach/ Site ID	Assessment Year	Mean BFW (ft)	Gradient (%)	Existing Stream Type	Riffle Pebble Count		Grid Toss	Channel Form		Instream Habitat	
					% <6mm	% <2mm	Pool % <6mm	W/D Ratio	Entrenchment Ratio	Residual Pool Depth (ft)	Pools / 1000 ft
MOOR 09-01	2014	18.3	1.0	C	**58**	**50**	**51**	21.1	**1.8**	**0.5**	13.4
MOOR 09-04	2014	4.6	0.5	E	**51**	**45**	**45**	4.8	59.1	**0.6**	**6.5**

Summary

Data collected by DEQ in 2014 (DEQ 2014, 2015) indicate that historical and existing riparian grazing are contributing excess fine sediment to the segment and that restoration and implementation of best management practices will reduce sediment input from these sources. The existing listings for Moore Creek are supported based on current land management practices that are contributing human sources of sediment, the human-caused erosion observed, the failures of instream data to the targets, and the lack of willows and many noxious weeds present.

5.4.3.8 North Meadow Creek (MT41F004_060)

North Meadow Creek (MT41F004_060) is listed for sedimentation-siltation on the 2018 303(d) List. The segment flows 18.53 miles from the headwaters to the mouth at Ennis Lake through primarily sedimentary geology and a landscape composed of evergreen in the headwaters, evergreen, grasses, and shrub/scrub in the middle portion of the watershed, and grasses, hay/pasture, and riparian vegetation near the mouth.

Physical Condition and Sediment Sources

Sediment and habitat data were collected from North Meadow Creek at one site by PIBO in 2009 and 2014 and two sites by DEQ in 2014: 2699 (PIBO), NMDW 14-02, and NMDW 17-01 (**Appendix B**; Figure B-2). NMDW 14-02 was the upstream site visited by DEQ in this segment and located in a grazed riparian setting (DEQ 2014). The site was located within a pasture enclosure; grazing had occurred during the year of the visit and pugging was observed. Pugging occurs when the hooves of grazing livestock penetrate the soil surface during wet conditions causing damage to pasture plants as well as soil structure. Pasture plants can be torn and buried. Streambanks were eroding in areas throughout the site, typically in locations where willows were absent, and grazing had occurred up to the stream channel. The site was vegetated with sedges, grasses, and willow with about 31% of the vegetation being sedges/rushes, 39% grasses/forbs, and 25% being shrubs/tree cover (DEQ 2014, 2015). Disturbed bare ground and riprap each made up 4.5% and 0.5% of the site respectively; 4.4% of the site had hummocking. Banks were primarily composed of sand/clay (70-100%) with lesser amounts of fine gravel (0-10%), and coarse gravel or larger sediment (0-20%) (DEQ 2015). About 69% of the site length had eroding banks with 80% being attributed to riparian grazing and the remainder to natural processes. Sample diatom counts were evaluated to determine the probability of impairment for sediment using the sediment increaser taxa list for the Middle Rockies. One diatom sample collected at the site yielded a probability of 18.9% that the assemblage represented a stream impaired by sediment.

NMDW 17-01 was located about 5.2 miles downstream of NMDW 14-02. The site was well vegetated with willow, sedges, rushes, alder, cottonwood, and non-native grasses with about 3% of the vegetation being sedges/rushes, 93% grasses/forbs, and 4% being shrubs/trees (DEQ 2014, 2015). Disturbed bare ground and hummocking were not observed at the site. Streambanks appeared to be stable and were primarily composed of 20-90% sand/clay, 10-70% fine gravel, and 0-10% coarse gravel or larger sediment (DEQ 2015). About 48% of the site length had eroding banks with 69% being attributed to natural processes, 14% to historical channel manipulation, 12% to residential/urban development, and the remainder to a bridge where humans and animals access the stream. Sample diatom counts were evaluated to determine the probability of impairment for sediment using the sediment increaser taxa list for the Middle Rockies. One diatom sample collected at the site yielded a probability of 63% that the assemblage represented a stream impaired by sediment.

In addition to the DEQ data collection, the Madison Conservation District collected a pebble count from one site on North Meadow Creek in July 2014 near the mouth percent fines < 2 mm were 27% (Madison Conservation District 2014).

Comparison to Water Quality Targets

The existing physical data in comparison with the targets for North Meadow Creek are summarized in **Table 5-18**. All bolded cells are not meeting the target; depending on the target parameter, this may equate to being below or above the target value. For fine sediment, one DEQ site fails to meet the targets for riffle pebble count %< 6 mm and %< 2 mm. The other DEQ site failed to meet the target for riffle pebble count % < 6 mm. The PIBO site failed to meet the grid toss target of %< 6 mm. No other target failures were observed. These results indicate that while the channel form and instream habitat are meeting the targets, there is an excess amount of fine sediment in North Meadow Creek.

Table 5-18. Existing sediment-related data for North Meadow Creek relative to targets
Values that do not meet the target are in **bold** and shaded

Reach/ Site ID	Assessment Year	Mean BFW (ft)	Gradient (%)	Existing Stream Type	Riffle Pebble Count		Grid Toss	Channel Form		Instream Habitat	
					% <6mm	% <2mm	Pool % <6mm	W/D Ratio	Entrenchment Ratio	Residual Pool Depth (ft)	Pools / 1000 ft
2699 (PIBO)[1]	2009, 2014	27.9	0.45	*NC*	*NC*	*NC*	**25**	16.0	*NC*	1.8	10.6
NMDW 14-02	2014	18.9	1.6	C	**30**	**20**	7	16.3	2.4	1.1	13.2
NMDW 17-01	2014	18.5	0.8	C	**20**	17	14	11.3	2.3	1.2	8.9

[1] Values are averages from sampling events in 2009 and 2014
NC = not collected

Summary
Data collected by DEQ in 2014 (DEQ 2014, 2015) indicate that riparian grazing, historical channel manipulation, and development are contributing excess fine sediment to the segment and that restoration and implementation of best management practices will reduce sediment input from these sources. The sedimentation-siltation listing for North Meadow Creek is supported based on current land management practices that are contributing human sources of sediment, the human-caused erosion observed, and the failures of instream data to the targets.

5.4.3.9 Red Canyon Creek (MT41F006_020)

Red Canyon Creek (MT41F006_020) is listed for sedimentation-siltation on the 2018 303(d) List. In addition, this segment is listed for alteration in streamside or littoral vegetative covers which is a non-pollutant listing that can often be linked to sediment impairment. The segment flows 6.27 miles from the headwaters to the mouth at Hebgen Lake through primarily sedimentary geology and an evergreen-dominated landscape interspersed with shrub/scrub vegetation.

Physical Condition and Sediment Sources
Sediment and habitat data were collected from Red Canyon Creek at one site by PIBO in 2006 and 2011 and three sites by DEQ in 2013: 1929 (PIBO), RCYN 07-01, RCYN 08-01, RCYN 09-02 (**Appendix B**; Figure B-1**)**. RCYN 07-01 was the most upstream site visited by DEQ in this segment and was located upstream of the end of the forest service road (DEQ 2013). The site was vegetated with conifer, willow, grasses, and forbs with about 69% of the vegetation being grasses/forbs and 15% being shrubs/trees (DEQ 2013, 2015). Disturbed bare ground and rock each made up 9.5% and 6.5% of the site respectively; no hummocking was observed. Undercut streambanks were common with banks being primarily composed of sand/clay (40-90%) with lesser amounts of fine gravel (5-20%) and coarse gravel or larger sediment (5-40%) (DEQ 2015). About 21% of the site length had eroding banks with 92% being attributed to natural processes, with 5% to transportation, and the remainder to grazing (pack horses). Sample diatom counts were evaluated to determine the probability of impairment for sediment using the sediment increaser taxa list for the Middle Rockies. One diatom sample collected at the site yielded a probability of 41.1% that the assemblage represented a stream impaired by sediment.

RCYN 08-01 was located about 1.1 miles downstream of RCYN 07-01 in a similar setting. The site was vegetated primarily with conifer with about 33.5% of the vegetation being grasses/forbs and 64.5% being shrubs/trees (DEQ 2013, 2015). Disturbed bare ground and rock each made up 1% of the site; no hummocking was observed. Eroding streambanks were common and were primarily composed of sand/clay (55-98%) with lesser amounts of fine gravel (0-25%) and coarse gravel or larger sediment (2-30%) (DEQ 2015). About 55% of the site length had eroding banks with 80% being attributed to natural processes, 15% to transportation/roads, and the remainder to dispersed camping. One diatom sample collected at the site yielded a probability of 26.5% that the assemblage represented a stream impaired by sediment.

RCYN 09-02 was located about 1.6 miles downstream of RCYN 08-01 in an area that appears to have been historically been grazed by cattle as evident by slumping and the presence of invasive plant species (DEQ 2013). The riparian vegetation community was in recovery with Canada thistle and brome species present with about 72% of the vegetation being grasses/forbs and 28% being shrubs/trees (DEQ 2013, 2015). Disturbed bare ground and hummocking were not observed at the site. Bank sloughing was identified, and streambanks were composed of 100% sand/clay (DEQ 2015). About 60% of the site length had eroding banks with about 50% being attributed to historical grazing with 43% being natural processes, 6.5% existing riparian grazing, and the remainder to transportation. A layer of silt is covering the predominantly cobble substrate (DEQ 2013).

Comparison to Water Quality Targets

The existing physical data in comparison with the targets for Red Canyon Creek are summarized in **Table 5-19**. All bolded cells are not meeting the target; depending on the target parameter, this may equate to being below or above the target value. For fine sediment, three sites fail to meet the targets for riffle pebble count < 6 mm and < 2 mm. In addition, the pool tail fines and residual pool depth targets each fail to be achieved at one site. W/D ratio fails to meet the target at all four sites and pool frequency fails at two sites. These results indicate that there is an excess amount of fine sediment in Red Canyon Creek and that both channel form and instream habitat are degraded.

Table 5-19. Existing sediment-related data for Red Canyon Creek relative to targets

Values that do not meet the target are in **bold** and shaded

Reach/ Site ID	Assessment Year	Mean BFW (ft)	Gradient (%)	Existing Stream Type	Riffle Pebble Count		Grid Toss	Channel Form		Instream Habitat	
					% <6mm	% <2mm	Pool % <6mm	W/D Ratio	Entrenchment Ratio	Residual Pool Depth (ft)	Pools / 1000 ft
1929 (PIBO)[1]	2006, 2011	12.0	2.75	*NC*	*NC*	*NC*	13.5	**16.2**	*NC*	0.9	**13.5**
RCYN 07-01	2013	12.0	4.7	B	**17**	**14**	7	**15.2**	1.9	0.7	30.8
RCYN 08-01	2013	11.1	2.6	B	**25**	**25**	8	**12.6**	1.4	0.7	**9.6**
RCYN 09-02	2013	9.0	1.8	C	**91**	**90**	**96**	**13.1**	3.5	**0.6**	23.4

[1] Values are averages from sampling events in 2006 and 2011; NC = not collected

Summary
Data collected by DEQ in 2013 (DEQ 2013, 2015) indicate that existing and historical grazing, the road along the creek, and dispersed camping are contributing excess fine sediment to the segment and that restoration and implementation of best management practices will reduce sediment input from these sources. The existing listings for Red Canyon Creek are supported based on current land management practices that are contributing human sources of sediment, the human-caused erosion observed, the failures of instream data to the targets, and the poor riparian vegetation condition at the lower site.

5.4.3.10 Ruby Creek (MT41F004_080)

Ruby Creek (MT41F004_080) is listed for sedimentation-siltation on the 2018 303(d) List. The segment flows 15.91 miles from the headwaters to the mouth at the Madison River primarily through sedimentary (with some metamorphic and volcanic) geology and an evergreen landscape with shrub/scrub and grasses in the headwaters and near the mouth. A westslope cutthroat trout restoration project involving removal of non-native trout and the introduction of westslope cutthroat eggs, has been ongoing on Ruby Creek since 2012 (FWP 2015).

Physical Condition and Sediment Sources
A portion of Ruby Creek is located within the BLM Bar Seven Grazing Allotment (BLM 2009). A report by the BLM (BLM 2009) indicates that the uplands adjacent to Ruby Creek are functioning at risk due in part to the existing livestock management and a revision of the terms and conditions for livestock grazing is recommended. With regards to riparian areas, livestock use has led to a change in riparian vegetation and streambank erosion (BLM 2009).

In October 2015, about 75 feet of channel was relocated and restored on Ruby Creek (see FWP 2014 for plan details) to address a seven-foot-tall eroding bank and prevent an historical building from falling into the creek. Before and after photos of the project site are shown in **Figures 5-6** and **5-7**, respectively.

Figure 5-6. Ruby Creek at the McAtee Homestead cabin prior to restoration in October 2015 (FWP photo by Pat Clancey)

Figure 5-7. Ruby Creek at the McAtee Homestead cabin after restoration in October 2015 (FWP photo by Pat Clancey)

Sediment and habitat data were collected from Ruby Creek at one site by PIBO in 2008 and 2013 and two sites by DEQ in 2013: 2663 (PIBO), RUBY 17-01, RUBY 18-02 (**Appendix B**; Figure B-1**)**. RUBY 17-01 was the most upstream site visited by DEQ in this segment and was in a lightly grazed riparian setting (DEQ 2013). The understory was vegetated with willow and water birch. About 42.5% of the groundcover vegetation was grasses/forbs (DEQ 2013, 2015). Undisturbed bare ground made up 16% of the groundcover, and disturbed bare ground made up 41.5% of the ground cover. No hummocking was observed. Streambanks were primarily composed of sand/clay (40-100%) with lesser amounts of fine gravel (0-10%), and coarse gravel or larger sediment (0-50%) (DEQ 2015). About 43% of the site length had eroding banks with 76% being attributed to riparian grazing, with 22% to natural processes, and the remainder to an old road/trail. Sample diatom counts were evaluated to determine the probability of impairment for sediment using the sediment increaser taxa list for the Middle Rockies. One diatom sample collected at the site yielded a probability of 40% that the assemblage represented a stream impaired by sediment.

RUBY 18-02 was located about 2 miles downstream of RUBY 17-01 near the confluence the Madison River. Vegetation at the site consisted of about 1% sedges/rushes, 78.5% grass/forbs, and 16% shrubs/trees (DEQ 2013, 2015). Disturbed bare ground made up 4.5% of the site; no hummocking was observed. Streambanks were primarily composed of sand/clay (50-100%) with lesser amounts of fine gravel (0-15%), and coarse gravel or larger sediment (0-35%) (DEQ 2015). About 31% of the site length

had eroding banks with 78% being attributed to natural processes and the remainder to historical riparian grazing. The probability that the diatom assemblage represented a stream impaired by sediment was 38.6%, which is a moderate value. This information, combined with the physical data, supports an impairment listing.

Comparison to Water Quality Targets

The existing physical data in comparison with the targets for Ruby Creek are summarized in **Table 5-20**. All bolded cells are not meeting the target; depending on the target parameter, this may equate to being below or above the target value. For fine sediment, both DEQ sites fail to meet the targets for riffle pebble count < 6 mm and < 2 mm. These results indicate that although the channel form and habitat quality in Ruby Creek appear healthy, there is an excess amount of fine sediment.

Table 5-20. Existing sediment-related data for Ruby Creek relative to targets

Values that do not meet the target are in **bold**

Reach/ Site ID	Assessment Year	Mean BFW (ft)	Gradient (%)	Existing Stream Type	Riffle Pebble Count		Grid Toss	Channel Form		Instream Habitat	
					% <6mm	% <2mm	Pool % <6mm	W/D Ratio	Entrenchment Ratio	Residual Pool Depth (ft)	Pools / 1000 ft
2663 (PIBO)[1]	2008, 2013	25.5	2.3	*NM*	*NM*	*NM*	3.5	23.2	*NM*	1.2	11.4
RUBY 17-01	2013	16.2	2.8	C	**17**	**15**	8	14.5	3.1	1.3	12.8
RUBY 18-02	2013	9.9	1.6	B	**24**	**23**	7	9.7	1.9	1.3	17.3

[1] Values are averages from sampling events in 2008 and 2013

Summary

Data collected by DEQ in 2013 (DEQ 2013, 2015) indicate that existing and historical grazing and an old road are contributing excess fine sediment to the segment and that continued restoration and implementation of best management practices will reduce sediment input from these sources. The sedimentation-siltation listing for Ruby Creek is supported based on current land management practices that are contributing human sources of sediment, the human-caused erosion observed, and the failures of instream data to the fine sediment targets.

5.4.3.11 South Meadow Creek (MT41F004_070)

South Meadow Creek (MT41F004_070) is listed for sedimentation-siltation on the 2018 303(d) List. The segment flows 12.98 miles from the headwaters to the mouth at the Ennis Lake through metamorphic and sedimentary geology and a landscape composed of evergreen in the headwaters, grasses and shrub/scrub in the middle portion of the watershed, and grasses, hay/pasture, and riparian vegetation near the mouth.

A 0.5 mile segment impacted by grazing was fenced in 2010 (Madison Conservation District 2015). Since this project was implemented, riparian vegetation has improved in the fenced section. In addition, in

2015, a second restoration project was successfully undertaken to relocate a straightened section of the stream channel and restore sinuosity.

Physical Condition and Sediment Sources

Sediment and habitat data were collected from South Meadow Creek at two sites by DEQ in 2014: SMDW 18-01 and SMDW 19-01 (**Appendix B**; Figure B-2**)**. SMDW 18-01 was the upstream site in this segment and was located in a grazed riparian setting (DEQ 2014). The site was vegetated with grasses, sedges, water birch, and willow with about 16.5% of the vegetation being sedges/rushes, 53% grasses/forbs, and 22.5% being shrubs/trees (DEQ 2013, 2015). Disturbed bare ground made up 8% of the site; hummocking was present on 31% of the site. Streambanks generally appeared to be stable and were primarily composed of sand/clay (60-95%) with lesser amounts of fine gravel (5-40%), and coarse gravel or larger sediment (0-15%) (DEQ 2015). About 16% of the site length had eroding banks with 68% being attributed to riparian grazing and the remainder to natural processes.

SMDW 19-01 was located about 1.9 miles downstream of SMDW 18-01 in a dewatered reach that is fenced to exclude livestock (DEQ 2014). Vegetation at the site consisted of about 6% sedges/rushes, 89% grasses/forbs, and 1% shrub/tree (DEQ 2013, 2015). Disturbed bare ground made up 4% of the site; no hummocking was observed. Bank sloughing was observed, and streambanks were primarily composed of sand/clay (50-100%) with lesser amounts of fine gravel (0-20%), and coarse gravel or larger sediment (0-30%) (DEQ 2015). About 98% of the site length had eroding banks with 80% being attributed to riparian grazing and the remainder to natural processes. A periphyton sample from the site yielded a 29.1% probability of the site having excess fine sediment.

In addition to the DEQ data collection, the Madison Conservation District collected pebble counts from three sites on South Meadow Creek in July 2014; percent fines < 2 mm were 6%, 10%, and 14% (Madison Conservation District 2014).

Comparison to Water Quality Targets

The existing physical data in comparison with the targets for South Meadow Creek are summarized in **Table 5-21**. All bolded cells are not meeting the target; depending on the target parameter, this may equate to being below or above the target value. For fine sediment, both DEQ sites fail to meet the targets for riffle pebble count < 6 mm and < 2 mm and the upper site fails to meet the target for pool tail fines. There were no target failures for any of the channel form and instream habitat variables. These results indicate that although the channel form and habitat quality in South Meadow Creek appears healthy, there is an excess amount of fine sediment.

Table 5-21. Existing sediment-related data for South Meadow Creek relative to targets
Values that do not meet the target are in **bold**

Reach/ Site ID	Assessment Year	Mean BFW (ft)	Gradient (%)	Existing Stream Type	Riffle Pebble Count		Grid Toss	Channel Form		Instream Habitat	
					% <6mm	% <2mm	Pool % <6mm	W/D Ratio	Entrenchment Ratio	Residual Pool Depth (ft)	Pools / 1000 ft
SMDW 18-01	2014	19.0	1.5	C	**38**	**32**	**21**	17.4	5.8	1.1	10.7
SMDW 19-01	2014	7.4	1.0	C	**25**	**23**	13	7.7	2.4	0.7	30.8

Summary
Data collected by DEQ in 2014 (DEQ 2014, 2015) indicate that riparian grazing is contributing excess fine sediment to the segment and that continued restoration and implementation of best management practices will reduce sediment input from these sources. The sedimentation-siltation listing for South Meadow Creek is supported based on current land management practices that are contributing human sources of sediment, the human-caused erosion observed, and the failures of instream data to the fine sediment targets.

5.4.3.12 Watkins Creek (MT41F006_030)

Watkins Creek (MT41F006_030) is listed for sedimentation-siltation on the 2018 303(d) List. In addition, this segment is listed for alteration in streamside or littoral vegetative covers which is a non-pollutant listing that can often be linked to sediment impairment. The segment flows 7.08 miles from the headwaters to the mouth at Hebgen Lake through metamorphic and sedimentary geology and an evergreen-dominated landscape with shrub/scrub and grasses at the mouth.

Physical Condition and Sediment Sources
Sediment and habitat data were collected from Watkins Creek at two sites by DEQ in 2013: WATK 12-01 and WATK 14-01 (**Appendix B**; Figure B-1**)**. WATK 12-01 was the upstream site in this segment and was located in a grazed riparian setting (DEQ 2013). Cattle use was evident by extensive pugging along the banks. Pugging occurs when the hooves of grazing livestock penetrate the soil surface during wet conditions causing damage to pasture plants as well as soil structure. Pasture plants can be torn and buried. The site was vegetated with willow, sedges, and conifer with 0.5% of the vegetation being sedges/rushes, 30% grasses/forbs, and 25.5% being shrubs/trees (DEQ 2013, 2015). Disturbed bare ground and rock made up 42% and 2% of the site respectively; hummocking was not observed. Streambanks generally appeared to be stable and were primarily composed of sand/clay (50-100%) with lesser amounts of fine gravel (0-10%) and coarse gravel or larger sediment (0-40%) (DEQ 2015). About 47% of the site length had eroding banks with 64% being attributed to riparian grazing, 24% to natural processes, and the remainder to logs that had been place in the creek for habitat. Sample diatom counts were evaluated to determine the probability of impairment for sediment using the sediment increaser taxa list for the Middle Rockies. One diatom sample collected at the site yielded a probability of 13.5% that the assemblage represented a stream impaired by sediment.

WATK 14-01 was located about 1.8 miles downstream of WATK 12-01, near the mouth. The site was vegetated with willow and grass with about 30.5% of the vegetation being grasses/forbs and 19.5% being shrubs/trees (DEQ 2013, 2015). Large wood appeared to have been added to the stream. Disturbed bare ground and hummocking were not observed at the site. Streambanks were primarily composed of sand/clay (70-100%) with lesser amounts of fine gravel (0-10%) and coarse gravel or larger sediment (0-30%) (DEQ 2015). About 30% of the site length had eroding banks with 100% being attributed to natural processes. One diatom sample collected at the site yielded a probability of 11.8% that the assemblage represented a stream impaired by sediment.

A portion of Watkins Creek is located within the Watkins Creek Grazing Allotment (USFS, 2011). The USFS allotment report (USFS, 2011) states that there is some bank cutting from cattle in the lower part of Watkins Creek but that the creek is in proper functioning condition; there is concern that cattle grazing could affect the channel form of Watkins Creek because of the sensitive soils adjacent to the channel. High fine sediment was observed within Watkins Creek including in areas upstream of the allotment and it was hypothesized that this sediment is predominantly natural (USFS, 2011). Restoration activities in the watershed include culvert removal and replacement to improve fish passage, installation of a fish barrier to preserve a westslope cutthroat population, and the addition of large woody debris (USFS, 2011). In 2012, the private landowner at the mouth of Watkins Creek signed a 10-year water rights lease with the Montana Department of Natural Resources for 5.5 cfs to maintain flow in the creek (Trout Unlimited, 2012).

Comparison to Water Quality Targets

The existing physical data in comparison with the targets for Watkins Creek are summarized in **Table 5-22**. All bolded cells are not meeting the target; depending on the target parameter, this may equate to being below or above the target value. For fine sediment, both DEQ sites fail to meet the targets for riffle pebble count < 2 mm and pool tail fines. The lower site fails to meet the target for riffle pebble count < 6 mm. The only other target failure was for W/D ratio at the upper site. These results indicate that although the channel form and habitat quality in Watkins Creek generally appear healthy, there is an excess amount of fine sediment.

Table 5-22. Existing sediment-related data for Watkins Creek relative to targets

Values that do not meet the target are in **bold** and shaded

Reach/ Site ID	Assessment Year	Mean BFW (ft)	Gradient (%)	Existing Stream Type	Riffle Pebble Count		Grid Toss	Channel Form		Instream Habitat	
					% <6mm	% <2mm	Pool % <6mm	W/D Ratio	Entrenchment Ratio	Residual Pool Depth (ft)	Pools / 1000 ft
WATK 12-01	2013	27.7	3.1	B	16	**13**	**17**	**26.3**	6.8	1.6	6.7
WATK 14-01	2013	6.3	2.0	B	**51**	**41**	**16**	7.4	3.2	0.8	20.6

Summary

Data collected by DEQ in 2013 (DEQ 2013, 2015) indicate that cattle grazing is contributing excess fine sediment to the segment and that continued restoration activities and implementation of best management practices will reduce sediment input from these sources. The existing listings for Watkins

Creek are supported based on current land management practices that are contributing human sources of sediment, the human-caused erosion observed, the failures of instream data to the fine sediment targets, and the extensive amount of disturbed bare ground at the upper site.

5.4.2.13 Wigwam Creek (MT41F004_160)

Wigwam Creek (MT41F004_160) is listed for sedimentation-siltation on the 2018 303(d) List. The segment flows 11.9 miles from the headwaters to the mouth at the Madison River through sedimentary geology and a shrub/scrub and evergreen forest-dominated landscape in the upper watershed and a grass-dominated landscape with willows and sedges growing in riparian areas in the lower watershed.

Physical Condition and Sediment Sources

A portion of Wigwam Creek is located within the BLM North Morgan Grazing Allotment (BLM 2009). A report by the BLM (BLM 2009) indicates that the uplands adjacent to Wigwam Creek are functioning at risk due in part to the existing livestock management and a revision of the terms and conditions for livestock grazing is recommended.

Restoration work in the Wigwam Creek watershed includes the construction of an exclosure and a hardened crossing on Wigwam Creek in 2010 and erecting two miles of exclusion fencing on a tributary of Wigwam Creek in 2012 (Madison River Foundation 2015). This work was performed by the Madison River Foundation and USFS.

Sediment and habitat data were collected from Wigwam Creek at two sites by DEQ in 2013 (WGWM 08-01, and WGWM 18-01 (**Appendix B**; Figure B-2**)**. WGWM 08-01 was the upstream site in this segment and was located in a restored reach (DEQ 2013). The site was vegetated with sedges, willow, grasses, and forbs with about 74% of the vegetation being sedges/rushes and 25% being shrubs/trees (DEQ 2013, 2015). Rock made up 1% of the site and no hummocking was observed. Livestock are excluded (with fence) from the site. Streambanks were primarily composed of sand/clay (85-100%) with lesser amounts of fine gravel (0-5%) and coarse gravel or larger sediment (0-10%) (DEQ 2015). About 13% of the site length had eroding banks with 60% being attributed to natural processes and the remainder to historical grazing. Trout were observed at the site. Sample diatom counts were evaluated to determine the probability of impairment for sediment using the sediment increaser taxa list for the Middle Rockies. One diatom sample collected at the site yielded a probability of 40% that the assemblage represented a stream impaired by sediment.

WGWM 18-01 was located about 8.4 miles downstream of WGWM 08-01 in a grazed riparian setting. The site was vegetated with cottonwoods and weeds with about 5% of the vegetation being sedges/rushes, 77% grasses/forbs, and 14% being shrubs/trees (DEQ 2013, 2015). Disturbed bare ground made up 4% of the site with hummocking covering 27%. Streambanks were primarily composed of sand/clay (85-100%) with lesser amounts of fine gravel (0-10%), and coarse gravel or larger sediment (0-10%) (DEQ 2015). About 20% of the site length had eroding banks with 90% being attributed to riparian grazing and the remainder to natural processes. Sample diatom counts were evaluated to determine the probability of impairment for sediment using the sediment increaser taxa list for the Middle Rockies. One diatom sample collected at the site yielded a probability of 56% that the assemblage represented a stream impaired by sediment.

Comparison to Water Quality Targets

The existing physical data in comparison with the targets for Wigwam Creek are summarized in **Table 5-23**. All bolded cells are not meeting the target; depending on the target parameter, this may equate to

being below or above the target value. For fine sediment, both DEQ sites fail to meet the targets for riffle pebble count < 6mm and < 2 mm and pool tail fines. The only other target failure was for W/D ratio at the lower site. These results indicate that there is an excess amount of fine sediment in Wigwam Creek.

Table 5-23. Existing sediment-related data for Wigwam Creek relative to targets
Values that do not meet the target are in **bold** and shaded

Reach/ Site ID	Assessment Year	Mean BFW (ft)	Gradient (%)	Existing Stream Type	Riffle Pebble Count		Grid Toss	Channel Form		Instream Habitat	
					% <6mm	% <2mm	Pool % <6mm	W/D Ratio	Entrenchment Ratio	Residual Pool Depth (ft)	Pools / 1000 ft
WGWM 08-01	2013	8.1	1.8	C	**33**	**25**	**32**	7.5	5.5	0.8	28.8
WGWM 18-01	2013	17.2	3.6	B	**30**	**25**	**23**	23.1	1.5	**0.6**	11.1

Summary
Data collected by DEQ in 2013 (DEQ 2013, 2015) indicate that riparian grazing is contributing excess fine sediment to the segment and that continued restoration activities and implementation of best management practices will reduce sediment input from these sources. The sedimentation-siltation listing for Wigwam Creek is supported based on current land management practices that are contributing human sources of sediment, the human-caused erosion observed, and the failures of instream data to the targets.

5.5 Source Assessment and Quantification

This section summarizes the assessment approach, current sediment load estimates, and the determination of the allowable load for each source category. DEQ determines the allowable load by estimating the obtainable load reduction once all reasonable land, soil, and water conservation practices have been implemented. The reduction forms the basis of the allocations and TMDLs provided in **Section 5.7** This section focuses on three potentially significant sediment source categories and associated controllable human loading for each of these sediment source categories:

- Streambank erosion
- Upland erosion and riparian health
- Unpaved roads

EPA's guidance for developing sediment TMDLs provides the basic procedure for assessing sources, which includes inventorying all sediment sources to the waterbody. In addition, the guidance suggests using one or more methods to determine the relative magnitude of loading, focusing on the primary and controllable sources (U.S. Environmental Protection Agency, 1999b). Federal regulations allow that loading determinations "may range from reasonably accurate estimates to gross allotments, depending on the availability of data and appropriate techniques for predicting the loading" (Water quality planning and management, 40 CFR 130.2(G), 2012).

For each impaired waterbody segment, sediment loads from each source category are estimated according to field surveys, load extrapolation, and limited hillslope modeling techniques (described below). The results include a mix of sediment sizes. Bank erosion involves both fine and coarse sediment loading to the receiving water. Conversely, loading from roads and upland erosion is predominately of fine sediment. The complete methods and results for source assessments for streambank erosion, roads, and upland erosion are found in **Appendices C**, **D**, and **E**, respectively.

5.5.1 Eroding Streambank Sediment Assessment

In the absence of human activities, streambank erosion is typically dominated by small and/or slowly eroding streambanks. Human disturbances to riparian vegetation and health and stream hydrology may result in greater lengths of eroding banks and accelerate the erosion rate. This commonly occurs when streambanks change from being well vegetated to being largely, or entirely, unvegetated with vertical banks. Causes of streambank erosion include the following:

- transportation
- riparian grazing
- cropping
- mining
- silviculture
- irrigation-related shifts in stream energy
- other (e.g. historical or legacy sources)
- natural processes

DEQ assessed streambank erosion for all 13 waterbodies impaired for sediment in the Madison TPA. The streambank erosion assessment involved several procedures. First, impaired segments of streams were stratified into reaches with similar gradient, confinement, and stream size using an aerial assessment performed in GIS (DEQ 2015b). As part of the aerial assessment, the percent of the reach within the 100-foot buffer that was in “natural” riparian quality, with little evidence of grazing or other anthropogenic disturbance was also estimated via aerial photography (DEQ 2015b). Streambank erosion data was then collected in the field at 42 monitoring sites in 2013 and 2014.

For each eroding streambank at each sampled site, channel cross section measurements were collected to estimate the erosive force (i.e., near bank stress) (Rosgen, 1996), and measurements of the bank height, bankfull height, root depth, root density, bank angle, and surface protection were collected as indicators of each streambank’s susceptibility to erosion (i.e., bank erosion hazard index or BEHI). A combination of the BEHI score and near bank stress were used to estimate the depth of sediment eroded per year (i.e., retreat rate) using the Bank Erosion for Nonpoint Sources of Sediment (BANCS) model method as described in Appendix C. This depth was multiplied by the height and length of the bank to obtain an estimate of the total volume eroded for each sampled bank. This was summed across the sampled site to obtain an estimate of total loading for the site, then adjusted to standardize to a 1,000 foot length (**Appendix C**). For each bank the cause of erosion (due to natural factors, roads, riparian grazing, residential/urban land use, historic land use, and other) was also estimated, and the loading estimates were weighted by these values to determine how each land use contributed to loading amounts (**Appendix C**)

Sediment loads from field assessed monitoring sites were then extrapolated to the unassessed stream reaches and segments in each impaired subwatershed to estimate a loading for the entire subwatershed. All reaches in the Madison TPA are in the Middle Rockies Ecoregion. Gradient, stream

order, and estimated percent of riparian zone in natural vegetation (based on aerial photos) were used to extrapolate the amount of bank erosion to unassessed streams (**Table 5-24**). The role of riparian vegetation was based on the finding that low and mid gradient sites with > 70% of the riparian zone intact had significantly lower rates of streambank erosion than sites with ≤ 70% riparian vegetation intact.

Table 5-24. Average loading from sampled reaches used to estimate loading in unsampled reaches

Sampled Reaches			**Assigned to**	**Unsampled Reaches**		
Gradient	**Order**	**Condition (based on aerial photos)**		**Gradient**	**Order**	**Condition (based on aerial photos)**
0-2%	Non 1st	High (> 70%) of riparian zone in natural condition	--->	0-2%	Non 1st	High (> 70%) of riparian zone in natural condition
0-2%	Non 1st	Low (≤ 70%)of riparian zone in natural condition	--->	0-2%	Non 1st	Low (≤ 70%)of riparian zone in natural condition
>2-4%	Non 1st	High (> 70%) of riparian zone in natural condition	--->	>2-4%	Non 1st	High (> 70%) of riparian zone in natural condition
>2-4%	Non 1st	Low (≤ 70%)of riparian zone in natural condition	--->	>2-4%	Non 1st	Low (≤ 70%)of riparian zone in natural condition
>4-10%	Non 1st	All land uses	--->	>4-10%	Non 1st	All land uses
> 10%	Non 1st	All land uses	--->	> 10%	Non 1st	All land uses
Any	1st	All land uses	--->	Any	1st	All land uses

The assumptions used during the assessment of eroding streambanks are provided below:

- The condition of streambanks at monitored sites sampled during 2013 and 2014 is representative of current conditions within the larger Madison TPA.
- The average annual load at sampled reaches are applicable to reaches in the Madison TPA within the same gradient, order and condition category (**Table 5-24**).
- The annual streambank retreat rates used to develop the sediment loading numbers were based on Rosgen BEHI studies in the Lamar Valley of Yellowstone National Park (Rosgen, 2001). The Madison TPA primarily has similar geology including weakly lithified sedimentary geology, with broad areas of volcaniclastic tuff in the upper Madison River and West Fork valleys (Kellogg et al. 2007). Therefore, we assume the retreat rates from Rosgen 2001 can be applied to the Madison TPA.

Substantial human-caused sources of streambank erosion contribute to the sediment loads in the Madison TPA. Based on the visual assessment of contributing factors immediately adjacent to eroding streambanks, riparian grazing and the past history of land use activities (usually grazing) contributed large amounts (approximately 19% each) of the sediment load from bank erosion (**Table 5-25**). However, natural sources were the biggest cause of erosion.

Table 5-25. Estimated sources of bank erosion at sampled sites

Source	Sediment Load (Tons/Year)	Sediment Load (Percent)
Natural	655.1	51.1
Roads	52.9	4.1
Riparian Grazing	252.7	19.7
Other	72.5	5.7
Residential/Urban	2.3	0.2
Historic	246.5	19.2
Total	**1282.1**	**100**

The extrapolation procedure outlined in **Appendix C** allowed for estimation of total loading from bank erosion within each impaired subwatershed. Streambank erosion loads range from 652 tons per year in the Watkins Creek subwatershed to 7481 tons per year in the Cherry Creek subwatershed (**Table 5-26**).

Table 5-26. Estimated bank erosion load by subwatershed from highest to lowest

Subwatershed	Estimated Load (Tons/Yr)	Estimated Load (Tons/Stream Mile/Yr)
Cherry Creek	7481	319.4
Bear Creek	6990	272.5
Elk Creek	4840	277.0
Hot Springs Creek	3884	227.8
Moore Creek	3523	226.1
North Meadow Creek	3277	179.5
Blaine Spring Creek	2508	278.1
Antelope Creek	2115	227.7
Ruby Creek	2073	138.0
South Meadow Creek	2032	171.7
Wigwam Creek	1269	111.8
Red Canyon Creek	1015	170.0
Watkins Creek	652	96.6

5.5.2 Unpaved Road Sediment Assessment

DEQ conducted a sediment source assessment on the unpaved road network in the Madison TMDL Planning Area (**Appendix D**). DEQ staff used ArcGIS software to locate each unpaved crossing (e.g., bridges, culverts, fords) and stream-adjacent stretch of road (called “parallel road segment”) that could contribute sediment to streams in the Madison TPA. A total of 554 unpaved road crossings and 130 miles of unpaved parallel road segments were identified within the sediment-impaired watersheds of the Madison TPA.

A total of 25 randomly selected crossings and 16 parallel road segments were sampled in summer 2014. Road parameters evaluated at the field sites included those needed to estimate sediment loading. The estimate of loading was conducted using the WEPP: Road forest road erosion prediction model (http://forest.moscowfsl.wsu.edu/fswepp/). WEPP: Road is an interface to the Water Erosion Prediction Project (WEPP) model (Flanagan and Livingston, 1995), developed by the USDA Forest Service and other agencies, and is used to predict runoff, erosion, and sediment delivery from forest roads. The model predicts sediment yields based on the specific soil, climate, ground cover, and topographic conditions collected in the field. In the WEPP analysis, detailed weather information for Norris, MT Ranger Station was used for cross-sections and parallel road segments < 6300 feet in elevation. For cross-sections and parallel road segments > 6,300 feet, a custom climate was implemented to represent higher locations in the watershed based on PRISM climate data.

Data collected at sampled sites was used to estimate sediment loads at unsampled crossings and parallel road segments based on average estimated loading values within different ownership and elevation categories, including: 1) public, high (> 6,300 feet) elevation; 2) public, low (≤ 6,300 feet) elevation; and 3) private, low (≤ 6,300 feet) elevation. The contribution from private, high elevation crossings and parallel road segments was not estimated due to their extremely low prevalence within the impaired watersheds of Madison TPA.

A simple breakdown of the modeled loads shows which subwatersheds have significant sediment contributions attributable to unpaved roads (**Figure 5-8** and **Table 5-27**). It also shows in which subwatersheds unpaved roads have a negligible contribution to the overall sediment load. In general, the subwatersheds with the highest number of unpaved road crossings and parallel road segments are predicted to have the greatest sediment contributions from roads. Some of the highest estimated contributions are from Bear Creek, Hot Springs Creek, and North Meadow Creek. The subwatersheds with the smallest contributions include Watkins and Antelope, due to the small size of these subwatersheds and the low number of crossings and parallel road segments.

Loading per stream mile may be used to more accurately assess the potential impact of roads on aquatic biota because it indicates a higher intensity of roads and more potential deposition to the stream bed. The two subwatersheds with notably higher loading per stream mile are South Meadow and Red Canyon. Antelope and Watkins have the lowest estimated sediment contributions per stream mile (**Table 5-27**).

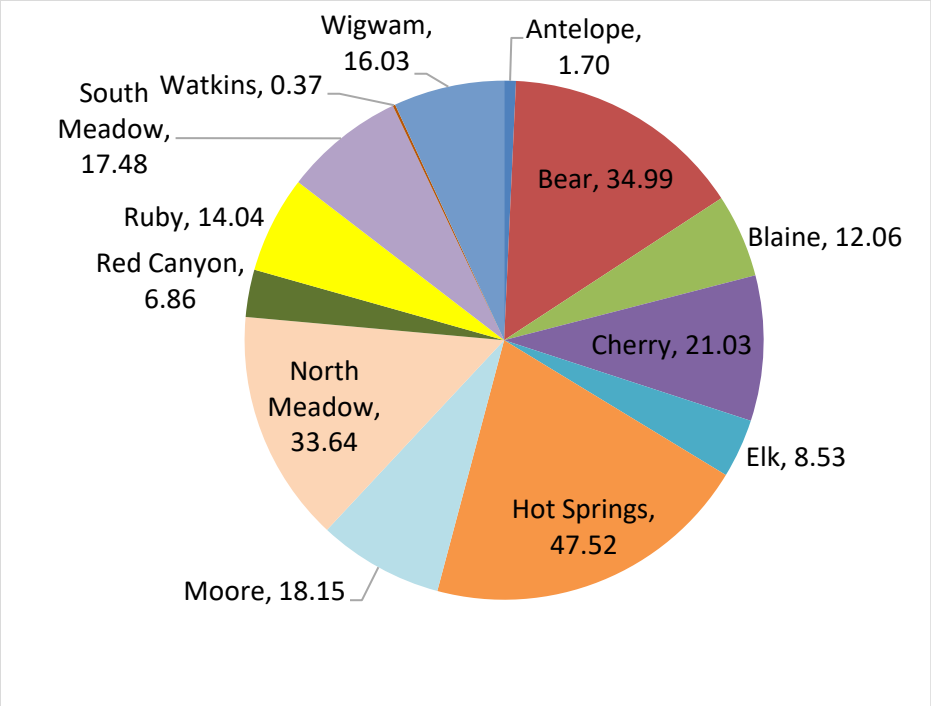


Figure 5-8. Estimated percent sediment contribution by subwatershed from unpaved road crossings and parallel road segments

Table 5-27. Loading estimates per subwatershed, ranked by decreasing load per stream mile

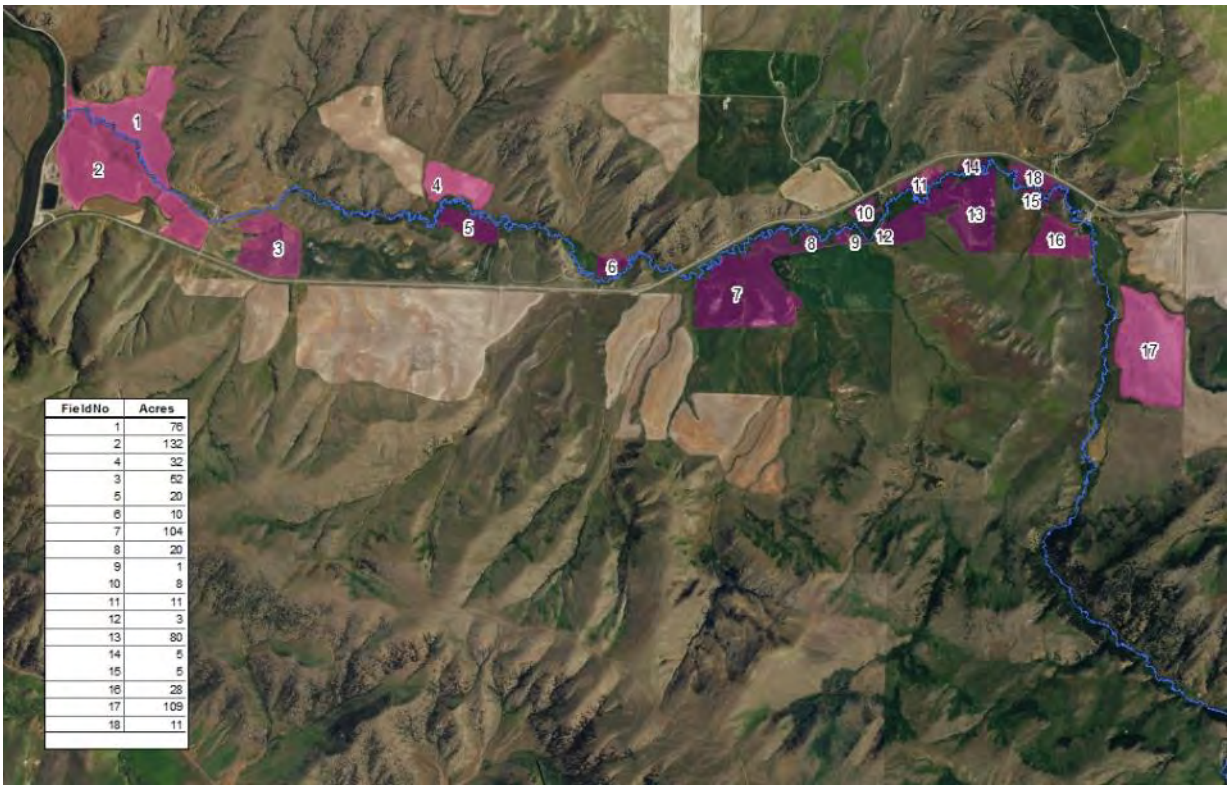
Subwatershed	No. Crossings	No. Parallel Road Miles	Stream Crossings (Tons/Yr)	Parallel Segments (Tons/Yr)	Total Loading (Tons/Yr)	(Tons/Mile/Yr)
South Meadow	39	8.92	7.46	10.02	17.48	0.46
Red Canyon	15	4.82	4.30	2.56	6.86	0.41
Blaine	33	8.02	4.25	7.81	12.06	0.34
Hot Springs	96	22.41	9.25	38.27	47.52	0.30
Ruby	9	5.98	0.34	13.70	14.04	0.29
Moore	30	11.74	4.13	14.02	18.15	0.28
North Meadow	87	18.17	14.25	19.39	33.64	0.25
Wigwam	66	8.22	7.43	8.60	16.03	0.15
Bear	84	24.20	10.06	24.93	34.99	0.12
Cherry	66	13.24	9.10	11.93	21.03	0.11
Elk	19	4.84	2.39	6.14	8.53	0.09
Antelope	7	0.08	1.63	0.07	1.70	0.05
Watkins	3	0.27	0.15	0.22	0.37	0.02

5.5.3 Upland Sediment Assessment

In general, DEQ does not consider transport of upland sediment to be a significant source of stream sediment in the Madison TPA. This conclusion is based upon a planning area-wide survey of land uses and riparian buffer conditions during the three-year field work process. Upland areas were found to have reasonable land, soil and water conservation practices. This is supported by the general

appearance of upslope grazing lands and overall application of Montana forest management practices in silvicultural areas. Localized areas of bare ground near streams were observed, but this is generally incorporated into the bank erosion assessment. A review of aerial photos for all watersheds with sediment TMDLs only identified tilled fields in the near stream areas of Elk Creek as potentially having a significant contribution of fine sediment to the streams. Therefore, the upland sediment assessment scope was limited to agricultural lands in the Elk Creek drainage.

DEQ conducted an analysis of upland sediment for Elk Creek, identifying numerous near stream agricultural fields may have a significant sediment contribution to the stream (**Figure 5-9**). Many of the agricultural fields have areas within 50-100 feet of the stream that have poor cover and little to no riparian buffer or buffer strips to filter sediment contribution to the stream. Collectively, these areas of ground disturbance have the potential to be significant sediment sources if proper BMPs are not implemented and maintained.



FieldNo	Acres
1	76
2	132
4	32
3	52
5	20
6	10
7	104
8	20
9	1
10	8
11	11
12	3
13	80
14	5
15	5
16	28
17	109
18	11

Figure 5-9. Fields along Elk Creek identified as having an elevated sediment contribution to the stream

To analyze the contribution of sediment from these fields to Elk Creek, hillslope erosion was estimated for fields in the Elk Creek watershed within 100 feet of Elk C reek using upland erosion rates estimated for cultivated fields in the Boulder-Elkhorn watershed, which is in the same ecoregion. Fields 10 and 17 were removed from the analysis because additional GIS measurements showed that they were already > 100 feet from the stream (and therefore had high sediment filtering ability). Riparian health was assessed for each field to estimate the percent reduction the existing buffer provides in sediment delivery to the stream (**Table 5-28**). The estimated reduction in sediment due to the width of the buffer was extrapolated based on the sediment filtering ability of buffer strips of a given width according to the literature (Wegner 1999, Knutson and Naef 1997). By multiplying the field acres by the estimated

loading rate for fields without BMPs (0.037 tons/acre/year), and then subtracting the amount retained by the buffer, the existing load was estimated (**Table 5-28**; **Appendix E**):

Existing Field Load= (Acres * Field Erosion Rate: 0.037) - (Acres*Field Erosion Rate: 0.037*Existing Buffer Efficiency)

Table 5-28. Estimated load delivered by agricultural fields to the stream based on existing field conditions and buffer quality

Field No	Acres	Existing Field Load (Tons/Year)	Existing Buffer Efficiency (Proportion Entering Stream)	Existing load Delivered to Stream (Tons/Year) = Existing Field Load * Proportion Entering Stream
1	76	2.81	Poor (0.70)	1.97
2	132	4.88	Poor (0.70)	3.42
3	52	1.92	Poor (0.70)	1.35
4	32	1.18	Moderate-Fair (0.60)	0.71
5	20	0.74	Moderate-Fair (0.60)	0.44
6	10	0.37	Moderate-Fair (0.60)	0.22
7	104	3.85	Moderate-Fair (0.60)	2.31
8	20	0.74	Moderate-Fair (0.60)	0.44
9	1	0.04	Moderate-Fair (0.60)	0.02
10	> 100 Foot Buffer Already Present			
11	11	0.41	Moderate-Fair (0.60)	0.24
12	3	0.11	Fair (0.50)	0.06
13	80	2.96	Moderate-Good (0.40)	1.18
14	5	0.19	Moderate-Fair (0.60)	0.11
15	5	0.19	Fair (0.50)	0.09
16	28	1.04	Poor (0.70)	0.73
17	> 100 Foot Buffer Already Present			
18	11	0.41	Fair (0.50)	0.20
Total	590	21.83		13.50

5.5.4 Source Assessment Summary

Based on field observations, all assessed source categories represent controllable loads within the Madison TMDL Planning Area. Because each source category has different seasonal loading rates, the relative percentage of the total load from each source category may vary by season. The intention of the source assessments is to broadly evaluate source effects (e.g., bank erosion, upland erosion, roads). Results for each source assessment category provide an adequate tool to focus water quality restoration activities in the Madison TPA. They indicate the relative contribution of sediment to different subwatersheds for each source category and the potential for percent loading reductions with the implementation of improved management practices.

5.6 Determining the Total Allowable Sediment Load

The percent-reduction allocations are based on the BMP scenarios for each major source type (e.g., streambank erosion, upland erosion, and roads). These BMP scenarios are discussed within this section

and within associated appendices, and reflect reasonable reductions as determined from literature, agency and industry documentation of BMP effectiveness, and/or field assessments. Sediment loading reductions can be achieved through a combination of BMPs, and the most appropriate BMPs will vary. Sediment loading was evaluated at the watershed scale and associated sediment reductions are also applied at the watershed scale.

5.6.1 Streambank Erosion

Streambank erosion is closely linked to the health of the riparian zone because vegetation provides the roots and soil structure to hold the streambank soil in place. Therefore, BMPs that involve restoring vegetation to the riparian zone will typically result in reduced streambank loading. These include improvements in grazing management, road maintenance or relocation, and general reductions in intensity of human activities within the riparian zone.

Based on aerial photo analysis, sampled sites in subwatersheds of the Madison TPA that were unimpaired for sediment had a greater percentage of the riparian zone in natural conditions (meaning not heavily influenced by grazing, transportation, or other human activities) than sites in unimpaired subwatersheds. It was assumed that these sampled sites had more BMPs already occurring in the riparian zone. Across both unimpaired and unimpaired subwatersheds, amounts of estimated streambank erosion were also substantially lower at sites with >70% of the riparian zone in natural conditions. This information was used to estimate reductions in streambank erosion loading rates with BMPs.

The average sediment loading rates from reaches in good (> 70% natural) riparian condition were used as the BMP loading rate in unsampled reaches of stream with similar geomorphic characteristics that were in poor ≤70% riparian condition (**Table 5-29**). The exception was mid-high gradient and first order streams, which had too few sampled sites for such an estimate. Loading at mid-gradient streams was estimated by determining the new loading rate if bank erosion was reduced at the reaches with the highest erosion. High gradient and first order streams were found to have good riparian conditions and comparatively little contribution of sediment. Therefore, the loading rate for these reaches went unchanged in the BMP scenario (**Table 5-29**). The loading in reaches already estimated to have good riparian condition also went unchanged in the BMP scenario. Loading was summed across all reaches in a subwatershed to obtain the total loading from bank erosion if BMPs were implemented (**Appendix C**).

Table 5-29. Conditions used to estimate BMP loads at unsampled reaches

Gradient	Order	Riparian Condition	BMP Action	Pre-BMP Load (Tons/Yr/1000 Ft)	Post-BMP Load (Tons/Yr/1000 Ft)
0-2%	Non 1st	High, > 70% Riparian Zone in Natural Condition	NONE	43.5	43.5
0-2%	Non 1st	Low, ≤ 70% Riparian Zone in	Change to average at reaches with	59.8	43.5

Table 5-29. Conditions used to estimate BMP loads at unsampled reaches

Gradient	Order	Riparian Condition	BMP Action	Pre-BMP Load (Tons/Yr/1000 Ft)	Post-BMP Load (Tons/Yr/1000 Ft)
		Natural Condition	riparian zone in high condition		
>2-4%	Non 1st	High, > 70% Riparian Zone in Natural Condition	NONE	27.0	27.0
>2-4%	Non 1st	Low, ≤ 70% Riparian Zone in Natural Condition	Change to average at reaches with riparian zone in high condition	38.1	27.0
>4-10%	Non 1st	Any	Average at sampled reaches after changing bank erosion from extreme to very high, very high to high, and from high to moderate	14.0	11.3
> 10%	Non 1st	Any	NONE	12.5	12.5
Any	1st	Any	NONE	20.7	20.7

However, while this method is considered adequate to provide a good approximation of changes in sediment loading due to potential BMPs, it should not be seen as a substitute for on-the-ground reconnaissance. Further, BMPs may still be needed in portions of reaches estimated to have high riparian condition because not all issues can be observed from aerial photography.

The annual sediment loads, and the methods used to estimate loads, are based on aerial photography, best professional judgment, and limited on-the-ground access to stream reaches. DEQ recognizes that local land owners and managers are often in a better position to identify the causes of bank erosion and adopt practices to reduce bank erosion wherever practical.

Depending on the subwatershed, DEQ estimates that implementing riparian best management practices (BMPs) could decrease the level of human-caused streambank erosion by up to 38% (**Table 5-30**).

Appendix C contains additional information about the streambank erosion source assessment and associated load estimates for the 303(d) listed streams in the Madison TMDL Planning Area.

Table 5-30. Estimated reduction in sediment loads with BMPs implemented

Subbasin	Existing Load (Tons/Yr)	BMP Load Estimated Load (Tons/Yr)	% Reduction
Antelope Creek	2115.4	1612.9	23.8%
Bear Creek	6990.27	5059.4	27.6%
Blaine Spring Creek	2507.6	1545.2	38.4%
Cherry Creek	7481.4	5835.0	22.0%
Elk Creek	4839.5	3346.0	30.9%
Hot Springs Creek	3884.3	2801.1	27.9%
Moore Creek	3522.5	2199.4	37.6%
North Meadow Creek	3277.4	2508.3	23.5%
Red Canyon Creek	1014.7	701.2	30.9%
Ruby Creek	2072.7	1914.2	7.6%
South Meadow Creek	2032.2	1378.1	32.2%
Watkins Creek	652.2	459.2	29.6%
Wigwam Creek	1269.3	1044.2	17.7%
Total	**41659.5**	**30404.3**	**27.0%**

5.6.2 Unpaved Roads

A total of 25 randomly selected crossings and 16 parallel road segments were sampled in summer 2014. Road parameters evaluated at the field sites included those needed to estimate sediment loading. The estimate of loading was conducted using the WEPP: Road forest road erosion prediction model as described in **Section 5.5.2**. As an estimate of the amount of loading once BMPs were implemented, the contributing length in the model was shortened to 200 feet for crossings and 500 feet for parallel road segmentse. This represented the type of reduction that could be achieved through actions suggested in Montana's Nonpoint Source Management Plan (DEQ 2017) such as constructing waterbars, rolling dips, and insloping roads along steep banks.

Adjusted WEPP loads were used to estimate sediment loads at unsampled crossings and parallel road segments based on average BMP-adjusted estimated loading values within different ownership and elevation categories, including: 1) public, high (> 6,300 feet) elevation; 2) public, low (≤ 6,300 feet) elevation; and 3) private, low (≤ 6,300 feet) elevation (**Appendix D**). Based on these estimates, an average 46% reduction in sediment from crossings and similar 46% reduction in sediment from unpaved roads is potentially achievable across the Madison TMDL Planning Area by implementing standard road BMPs (**Table 5-31**).

Table 5-31. WEPP: Road Model Results by Subwatershed given the BMP Scenario

Subwatershed	Crossings (Tons/Yr)	Crossings-BMPs (Tons/Yr)	% Reduction-Crossings	Parallel Road Segments (Tons/Yr)	Parallel Road Segments BMPs (Tons/Yr)	% Reduction-Parallel Road Segments
Antelope	1.63	0.38	77%	0.07	0.04	46%
Bear	10.06	6.76	33%	24.93	12.72	49%
Blaine	4.25	2.89	32%	7.81	3.87	50%
Cherry	9.10	5.71	37%	11.93	5.85	51%
Elk	2.39	1.61	33%	6.14	3.26	47%

Table 5-31. WEPP: Road Model Results by Subwatershed given the BMP Scenario

Subwatershed	Crossings (Tons/Yr)	Crossings-BMPs (Tons/Yr)	% Reduction-Crossings	Parallel Road Segments (Tons/Yr)	Parallel Road Segments BMPs (Tons/Yr)	% Reduction-Parallel Road Segments
Hot Springs	9.25	5.80	37%	38.27	21.62	44%
Moore	4.13	2.04	51%	14.02	7.60	46%
North Meadow	14.25	7.23	49%	19.39	10.06	48%
Red Canyon	4.30	0.90	79%	2.56	1.39	46%
Ruby	0.34	0.15	55%	13.70	8.08	41%
South Meadow	7.46	2.85	62%	10.02	5.36	47%
Watkins	0.15	0.02	88%	0.22	0.12	46%
Wigwam	7.43	4.09	34%	8.60	4.59	47%
Total	**74.7**	**40.43**	**46%**	**157.7**	**84.6**	**46%**

5.6.3 Upland Sediment

DEQ conducted an analysis of upland sediment for the Elk Creek watershed, as numerous near stream agricultural fields were identified through on the ground and aerial photo observation to have a potentially significant sediment contribution to the stream. Many of the fields have areas within 50-100 feet of the stream that have poor cover and little to no riparian buffer to filter sediment contribution to the stream. Collectively, these areas of ground disturbance have the potential to be significant sediment sources if proper BMPs are not implemented and maintained.

DEQ estimated potential reductions in upland sediment loading to Elk Creek given three scenarios: 1) implementing upland BMPs by increasing groundcover crops, 2) implementing riparian BMPs by increasing vegetation in the 100-foot buffer of the creek, and 3) both implementing upland and riparian BMPs. A hypothetical 20% increase in groundcover was used as an estimate of the outcome of implementing Upland BMPs. A potential load after implementing riparian BMP's was estimated by decreasing the sediment passing through the buffer by 20% with a total reduction no greater than 75%, which is the value considered attainable once reasonable BMPs have been put in place (**Table 5-32**; **Appendix E**).

Table 5-32. Elk Creek existing sediment loading, management scenarios, and reduction estimates

Field No	Acres	Existing Load Delivered to Stream (Tons/Yr)	Upland BMP Only (Tons/Yr)	% Change from Existing Load	Buffer BMP Only (Tons/Yr)	% Change from Existing Load	Upland and Buffer BMPs (Tons/Yr)	% Change from Existing Load
1	76	1.97	1.01	49%	1.41	29%	0.72	63%
2	132	3.42	1.76	49%	2.44	29%	1.25	63%
3	52	1.35	0.69	49%	0.96	29%	0.49	63%
4	32	0.71	0.36	49%	0.47	33%	0.24	66%
5	20	0.44	0.23	49%	0.3	33%	0.15	66%
6	10	0.22	0.11	49%	0.15	33%	0.08	66%

Table 5-32. Elk Creek existing sediment loading, management scenarios, and reduction estimates

Field No	Acres	Existing Load Delivered to Stream (Tons/Yr)	Upland BMP Only (Tons/Yr)	% Change from Existing Load	Buffer BMP Only (Tons/Yr)	% Change from Existing Load	Upland and Buffer BMPs (Tons/Yr)	% Change from Existing Load
7	104	2.31	1.19	49%	1.54	33%	0.79	66%
8	20	0.44	0.23	49%	0.3	33%	0.15	66%
9	1	0.02	0.01	49%	0.01	33%	0.01	66%
10	>100 Foot Buffer Already Present							
11	11	0.24	0.13	49%	0.16	33%	0.08	66%
12	3	0.06	0.03	49%	0.03	40%	0.02	69%
13	80	1.18	0.61	49%	0.89	25%	0.46	61%
14	5	0.11	0.06	49%	0.07	33%	0.04	66%
15	5	0.09	0.05	49%	0.06	40%	0.03	69%
16	28	0.73	0.37	49%	0.52	29%	0.27	63%
17	>100 Foot Buffer Already Present							
18	11	0.2	0.1	49%	0.12	40%	0.06	69%
Total	**590**	**13.5**	**6.93**	**49%**	**9.43**	**30%**	**4.84**	**64%**

5.7 SEDIMENT TMDLS AND ALLOCATIONS

The allowable loads described above are determined by modeling reasonable load reduction conditions for each source category. These allowable loads provide the load allocations to each sediment source. Conceptually, the sediment TMDL is the sum of the load allocations. This differs from DEQ's approach for other pollutants (e.g., metals or nutrients) where the TMDL is calculated first and then apportioned amongst contributing sources. The difference between the existing and allowable loads equals the excess amount of sediment causing impaired conditions for each stream. Eliminating this excess load for each source category within an impaired stream's watershed would equate to meeting all load allocations and represents a best path forward toward meeting sediment target conditions at all locations within the stream.

The total allowable sediment load is the sum of the load allocations to: bank erosion (natural and human caused), road sediment, and upland sediment runoff (significant areas where BMPs are obviously lacking).

Although all the sediment loads are presented in units of tons per year, direct comparison of sediment loads between sources is problematic and unpractical. This is because the loading estimates are produced by separate and unrelated models: BEHI, WEPP: Road and USLE. Therefore, the most important consideration is the relative percent reductions between subwatersheds. Percent reduction provides a useful and relatable description of the magnitude of the problem, the degree to which it can be mitigated, and a way to prioritize mitigation efforts and resources.

Sediment load allocations and TMDLs for each stream are provided below in **Tables 5-33** through **5-45** and estimated daily loads can be found in **Appendix F**.

5.7.1 Antelope Creek (MT41F004_140)

Sediment issues in the Antelope Creek subwatershed are predominantly due to eroding banks. There are few road crossings in the watershed. Moderate reductions in bank erosion are needed to achieve target conditions (**Table 5-33**).

Table 5-33. Antelope Creek sediment source assessment, allocations, and TMDL

Sediment Sources	Existing Load (Tons/Year)	Reduced Load (Tons/Year)	Load Allocation (Percent Reduction)
Unpaved Roads	1.7	0.4	76.5%
Eroding Banks	2115	1613	23.7%
Total	**2117**	**1613**	**23.8%**

5.7.2 Bear Creek (MT41F004_021)

Sediment issues in the Bear Creek subwatershed arise from both the unpaved road network and eroding banks, with the highest loads being from eroding banks. Moderate reductions are needed to achieve target conditions (**Table 5-34**).

Table 5-34. Bear Creek Sediment Source Assessment, Allocations, and TMDL

Sediment Sources	Existing Load (Tons/Year)	Reduced Load (Tons/Year)	Load Allocation (Percent Reduction)
Unpaved Roads	35	19	45.7%
Eroding Banks	6990	5059	27.6%
Total	**7025**	**5079**	**27.7%**

5.7.3 Blaine Spring Creek (MT41F004_010)

Sediment issues in the Blaine Spring Creek subwatershed arise from both the unpaved road network and eroding banks, with the highest loads being from eroding banks. Moderate-high reductions are needed to achieve target conditions (**Table 5-35**).

Table 5-35. Blaine Spring Creek sediment source assessment, allocations, and TMDL

Sediment Sources	Existing Load (Tons/Year)	Reduced Load (Tons/Year)	Load Allocation (Percent Reduction)
Unpaved Roads	12	7	41.7%
Eroding Banks	2508	1545	38.4%
Total	**2520**	**1552**	**38.4%**

5.7.4 Cherry Creek (MT41F002_010)

Sediment issues in the Cherry Creek subwatershed arise from both the unpaved road network and eroding banks, with the highest loads being from eroding banks. Moderate reductions are needed in order to achieve target conditions (**Table 5-36**).

Table 5-36. Cherry Creek sediment source assessment, allocations, and TMDL

Sediment Sources	Existing Load (Tons/Year)	Reduced Load (Tons/Year)	Load Allocation (Percent Reduction)
Unpaved Roads	21	11.5	45.2%
Eroding Banks	7481	5835	22.0%

Table 5-36. Cherry Creek sediment source assessment, allocations, and TMDL

Sediment Sources	Existing Load (Tons/Year)	Reduced Load (Tons/Year)	Load Allocation (Percent Reduction)
Total	**7502**	**5847**	**22.1%**

5.7.5 Elk Creek (MT41F002_020)

Sediment issues in the Elk Creek subwatershed arise from the unpaved road network, upland erosion from near stream crop production, and eroding banks. Eroding banks need the most significant reductions in order to achieve target conditions (**Table 5-37**). Moderate-high reductions are needed to achieve target conditions.

Table 5-37. Elk Creek sediment source assessment, allocations, and TMDL

Sediment Sources	Existing Load (Tons/Year)	Reduced Load (Tons/Year)	Load Allocation (Percent Reduction)
Unpaved Roads	9	5	44.4%
Eroding Banks	4840	3346	30.9%
Upland Erosion	14	9	35.7%
Total	**4863**	**3360**	**30.9%**

totals are rounded

5.7.6 Hot Springs Creek (MT41F002_030)

Sediment issues in the Hot Springs Creek subwatershed arise from both the unpaved road network and eroding banks, with the highest loads being from eroding banks. Moderate reductions are needed to achieve target conditions (**Table 5-38**).

Table 5-38. Hot Springs Creek sediment source assessment, allocations, and TMDL

Sediment Sources	Existing Load (Tons/year)	Reduced Load (tons/year)	Load Allocation (Percent Reduction)
Unpaved Roads	47.5	27	43.2%
Eroding Banks	3884	2801	27.9%
Total	**3932**	**2828**	**28.1%**

5.7.7 Moore Creek (MT41F004_130)

Sediment issues in the Moore Creek subwatershed arise from both the unpaved road network and eroding banks, with the highest loads being from eroding banks. Moderate-high reductions are needed in order to achieve target conditions (**Table 5-39**).

Table 5-39. Moore Creek sediment source assessment, allocations, and TMDL

Sediment Sources	Existing Load (Tons/Year)	Reduced Load (Tons/Year)	Load Allocation (Percent Reduction)
Unpaved Roads	18	10	44.4%
Eroding Banks	3523	2199	37.6%
Total	**3541**	**2209**	**37.6%**

5.7.8 North Meadow Creek (MT41F004_060)

Sediment issues in the North Meadow Creek subwatershed arise from both the unpaved road network and eroding banks, with the highest loads being from eroding banks. Moderate reductions are needed in order to achieve target conditions (**Table 5-40**).

Table 5-40. North Meadow Creek sediment source assessment, allocations, and TMDL

Sediment Sources	Existing Load (Tons/Year)	Reduced Load (Tons/Year)	Load Allocation (Percent Reduction)
Unpaved Roads	34	17	50.0%
Eroding Banks	3277	2508	23.5%
Total	**3311**	**2525**	**23.7%**

5.7.9 Red Canyon Creek (MT41F006_020)

The Red Canyon Creek subwatershed has few unpaved road crossings or parallel road segments; sediment issues are mostly due to eroding banks. Moderate-high reductions are needed to achieve target conditions (**Table 5-41**).

Table 5-41. Red Canyon sediment source assessment, allocations, and TMDL

Sediment Sources	Existing Load (Tons/year)	Reduced Load (Tons/Year)	Load Allocation (Percent Reduction)
Unpaved Roads	7	2	71.4%
Eroding Banks	1015	701	30.9%
Total	**1022**	**703**	**31.2%**

5.7.10 Ruby Creek (MT41F004_080)

The Ruby Creek subwatershed has few unpaved road crossings or parallel road segments; sediment issues are mostly due to eroding banks. Relatively low reductions in sediment loading are needed to achieve target conditions (**Table 5-42**).

Table 5-42. Ruby Creek sediment source assessment, allocations, and TMDL

Sediment Sources	Existing Load (Tons/year)	Reduced Load (Tons/Year)	Load Allocation (Percent Reduction)
Unpaved Roads	14	8	42.9%
Eroding Banks	2073	1914	7.7%
Total	**2087**	**1922**	**7.9%**

5.7.11 South Meadow Creek (MT41F004_070)

Sediment issues in the South Meadow Creek subwatershed arise from both the unpaved road network and eroding banks, but most erosion is from eroding banks. Moderate-high reductions are needed in order to achieve target conditions (**Table 5-43**).

Table 5-43. South Meadow Creek sediment source assessment, allocations, and TMDL

Sediment Sources	Existing Load (Tons/year)	Reduced Load (Tons/Year)	Load Allocation (Percent Reduction)
Unpaved Roads	17	8	52.9%
Eroding Banks	2032	1378	32.2%

Table 5-43. South Meadow Creek sediment source assessment, allocations, and TMDL

Sediment Sources	Existing Load (Tons/year)	Reduced Load (Tons/Year)	Load Allocation (Percent Reduction)
Total	**2049**	**1386**	**32.4%**

5.7.12 Watkins Creek (MT41F006_030)

The Watkins Creek subwatershed has few unpaved road crossings; sediment issues are mostly due to eroding banks. Moderate reductions in sediment loading are needed to achieve target conditions (**Table 5-44**).

Table 5-44. Watkins Creek sediment source assessment, allocations, and TMDL

Sediment Sources	Existing Load (Tons/year)	Reduced Load (Tons/Year)	Load Allocation (Percent Reduction)
Unpaved Roads	0.40	0.15	62.5%
Eroding Banks	652	459	29.6%
Total	**652.5**	**459**	**29.6%**

5.7.13 Wigwam Creek (MT41F004_160)

The Wigwam Creek subwatershed has few unpaved road crossings; sediment issues are mostly due to eroding banks. Relatively low reductions in sediment loading are needed to achieve target conditions (**Table 5-45**).

Table 5-45. Wigwam Creek sediment source Assessment, allocations, and TMDL

Sediment Sources	Existing Load (Tons/Year)	Reduced Load (Tons/Year)	Load Allocation (Percent Reduction)
Unpaved Roads	16	9	43.8%
Eroding Banks	1270	1044	17.8%
Total	**1286**	**1053**	**18.1%**

It is important to recognize that the first critical step toward meeting the sediment allocations involves applying and/or maintaining the land management practices or BMPs that will reduce sediment loading. Once these actions have been completed at a given location, the landowner or land manager will have taken action consistent with the intent of the sediment allocation for that location. For many nonpoint source activities, it can take several years to achieve the full load reduction at the location of concern, even though full BMP implementation is in effect. For example, it may take several years for riparian areas to fully recover after implementing grazing BMPs or allowing re-growth in areas of historical riparian harvest. It is also important to apply proper BMPs and other water quality protection practices for all new or changing land management activities to limit any potential increased sediment loading. For a description of potential BMP practices, refer to **Section 9.0** and Montana DEQ's Nonpoint Source Management Plan (DEQ 2017).

5.8 Seasonality and Margin of Safety

Seasonality and margin of safety are both required elements of TMDL development. This section describes how seasonality and margin of safety were applied during development of the Madison TPA sediment TMDLs.

5.8.1 Seasonality

All TMDL documents must consider the seasonal applicability of water quality standards as well as the seasonal variability of pollutant loads to a stream. Seasonality was addressed in several ways:

- The applicable narrative water quality standards (**Appendix A**) are not seasonally dependent, although low flow conditions provide the best ability to measure harm to use based on the selected target parameters. The low flow or base flow condition represents the most practical time period for assessing substrate and habitat conditions, and also represents a time period when high fine sediment in riffles or pool tails will likely influence fish and aquatic life. Therefore, meeting targets during this time frame represents an adequate approach for determining standards attainment.
- The substrate and habitat target parameters within each stream are measured during summer or autumn low flow conditions consistent with the time of year when reference stream measurements are conducted. This time period also represents an opportunity to assess effects of the annual snow runoff and early spring rains, which is the typical time frame for sediment loading to occur.
- The DEQ sampling protocol for macroinvertebrates identifies a specific time period for collecting samples based on macroinvertebrate life cycles. This time period coincides with the low flow or base flow condition.
- All assessment modeling approaches are standard approaches that specifically incorporate the yearly hydrologic cycle specific to the Madison TPA. The resulting loads are expressed as average yearly loading rates to fully assess loading throughout the year.
- Allocations are based on average yearly loading and the preferred TMDL expression is as an average yearly load reduction, consistent with the assessment methods.

5.8.2 Margin of Safety

Natural systems are inherently complex. Any approach used to quantify or define the relationship between pollutant loading rates and the resultant water quality impacts, no matter how rigorous, will include some level of uncertainty or error. To compensate for this uncertainty and ensure water quality standards are attained, a margin of safety is required as a component of each TMDL. The MOS may be applied implicitly by using conservative assumptions in the TMDL development process or explicitly by setting aside a portion of the allowable loading (U.S. Environmental Protection Agency, 1999). This plan incorporates an implicit MOS in a variety of ways:

- By using multiple targets to assess a broad range of physical and biological parameters known to illustrate the effects of sediment in streams and rivers. These targets serve as indicators of potential impairment from sediment and also help signal recovery, and eventual standards attainment, after TMDL implementation. Conservative assumptions were used during development of these targets.
- By developing TMDLs for streams that were close to meeting all target values. This approach addresses some of the uncertainty associated with sampling variability and site representativeness and recognizes that capabilities to reduce sediments exist throughout the watershed.
- Sediment impairment is typically identified based on excess fine sediment but the targets and TMDLs address both coarse and fine sediment delivery.
- By properly incorporating seasonality into target development, source assessments, and TMDL allocations.

- By using an adaptive management approach to evaluate target attainment and allow for refinement of load allocation, targets, modeling assumptions, and restoration strategies to further reduce uncertainties associated with TMDL development (discussed below in **Section 5.9**).
- By using naturally occurring sediment loads as described in ARM 17.30.602(17) to establish the TMDLs and allocations based on reasonably achievable load reductions for each source category.

5.9 TMDL Development Uncertainties and Adaptive Management

A degree of uncertainty is inherent in any study of watershed processes. While uncertainties are an undeniable fact of TMDL development, mitigation and reduction of uncertainty through adaptive management is a key component of TMDL implementation. The process of adaptive management is predicated on the premise that sediment assessment methods, TMDLs, allocations and their supporting analyses are not static, but are processes that can be subject to periodic modification or adjustment as new information and relationships are better understood. Within the Madison TPA, adaptive management for sediment TMDLs relies on continued monitoring of water quality and stream habitat conditions, continued assessment of impacts from human activities and natural conditions, and continued assessment of how aquatic life and coldwater fish respond to changes in water quality and stream habitat conditions.

As further monitoring and assessment is conducted, uncertainties with present assumptions and consideration may be mitigated via periodic revision or review of the assessment that occurred for this document. As noted in **Section 5.8.2**, adaptive management represents an important component of the implicit margin of safety. This document provides a framework to satisfy the MOS by including sections focused on TMDL implementation, monitoring and adaptive management (**Sections 9.0** and **10.0**). Furthermore, state law (ARM 75-5-703), requires monitoring to gage progress toward meeting water quality standards and satisfying TMDL requirements. These TMDL implementation evaluations represent an important component of adaptive management in Montana.

Perhaps the most significant uncertainties within this document involve the accuracy and representativeness of 1) field data and target development and 2) the accuracy and representativeness of the source assessments and associated load reductions. These uncertainties and approaches used to reduce uncertainty are discussed in following subsections.

5.9.1 Sediment and Habitat Data Collection and Target Development

Some of the uncertainties regarding accuracy and representativeness of the data and information used to characterize existing water quality conditions and develop water quality targets are discussed below.

Data Collection

The stream sampling approach used to characterize water quality is described within **Appendix B**. To control sampling variability and improve accuracy, the sampling was done by trained environmental professionals using a standard DEQ procedure developed for the purpose of sediment TMDL development (Montana Department of Environmental Quality, 2012). This procedure defines specific methods for each parameter, including sampling location and frequency to ensure proper representation and applicability of results. Prior to any sampling, a sampling and analysis plan was developed to ensure that all activity was consistent with applicable quality control and quality assurance

requirements. Site selection was a major component of the sampling and analysis plan, and was based on a stratification process described in **Appendix B**. The stratification work ensured that each stream included one or more sample sites representing a location where excess sediment loading or altered stream habitat could affect fish or aquatic life.

Even with the applied quality controls, a level of uncertainty regarding overall accuracy of collected data will exist. There is uncertainty regarding whether or not the appropriate sites were assessed and whether or not an adequate number of sites were evaluated for each stream. Also, there is the uncertainty of the representativeness of collecting data from one sampling season. These uncertainties are difficult to quantify and even more difficult to eliminate given resource limitations and occasional stream access problems.

Target Development

DEQ evaluated several data sets to ensure that the most representative information and statistic were used to develop each target parameter, consistent with the reference approach framework outlined in **Section 5.4.2**. Using reference data is the preferred approach for target setting; however, some uncertainty is introduced because of differing protocols between the available reference data and recent sample data for the project area. These differences were acknowledged within the target development discussion and taken into consideration during target setting. For each target parameter, DEQ stratified the Madison sample results and target data into similar categories, such as stream width or Rosgen stream type, to ensure that the target exceedance evaluations were based on appropriate comparisons.

The established targets are meant to apply under median conditions of natural background and natural disturbance. DEQ recognizes that under some natural conditions, such as a large fire or flood event, it may be impossible to satisfy one or more of the targets until the stream and/or watershed recovers from the natural event. Under these conditions the goal is to ensure that management activities do not significantly delay achievement of targets as compared to the time for natural recovery to occur.

Also, human activity should not significantly increase the magnitude of water quality effects from natural events. For example, extreme flood events can cause a naturally high level of sediment loading that could be further increased by a large number of road crossing or culvert failures.

Because sediment target values are based on data percentiles, DEQ recognizes that it may be impossible to meet all targets for some streams even under normal levels of disturbance. On the other hand, some target values may underestimate the potential of a given stream, and it may be appropriate to apply more protective targets upon further evaluation during adaptive management. It is important to recognize that the adaptive management approach provides flexibility to refine targets as necessary to ensure resource protection and to adapt to new information concerning target achievability. This approach is consistent with the continuous improvement activities DEQ has pursued toward interpreting and applying the narrative sediment standards.

5.9.2 Source Assessments and Load Reduction Analyses

Each assessment method introduces uncertainties regarding the accuracy and representativeness of the sediment load estimates and percent load reduction analyses. For each source assessment, assumptions must be made to evaluate sediment loading and potential reductions at the watershed scale, and because of these uncertainties, conclusions may not be representative of existing conditions and

achievable reductions at all locations within the watershed. Uncertainties are discussed independently for the three major source categories of bank erosion, upland erosion, and unpaved road crossings.

Bank Erosion

The load quantification approach for bank erosion is based on a standard methodology (BANCS model) as defined within **Appendix C**. Field data collection was by trained environmental professionals per a standard DEQ procedure (Montana Department of Environmental Quality, 2012). Prior to any sampling, a sampling and analysis plan was developed to ensure that all activity was consistent with applicable quality control and quality assurance requirements. Site selection was a major component of the sampling and analysis plan, and was based on a stratification process described in **Appendix C**. The results were then extrapolated across the Madison sub-watersheds as defined in **Appendix C** to provide an estimate of the relative bank erosion loading from various streams and associated stream reaches.

Notwithstanding the above quality controls, there is uncertainty regarding the bank retreat rates, which directly influence loading rates. Even with the increased bank erosion sites, stratifying and assessing each unique reach type was not practical, therefore adding to uncertainty associated with the load extrapolation results. Also, the complexity of the BANCS methodology can introduce error and uncertainty, although this is somewhat limited by the averaging component of the measured variables.

There is additional uncertainty regarding the amount of bank erosion linked to human activities and the specific human sources, as well as the ability to reduce the human related bank erosion levels. This is further complicated by historical human disturbances in the watershed, which could still be influencing proper channel shape, pattern and profile and thus contributing to increased bank erosion loading that may appear natural. Even if difficult to quantify, the linkages between human activity such as riparian clearing and bank erosion, are well established and these linkages clearly exist at different locations throughout the Madison watershed. Evaluating bank erosion levels, particularly where best management practices have been applied along streams, is an important part of adaptive management that can help define the level of human-caused bank erosion as well as the relative impact that bank erosion has on water quality throughout the Madison watershed.

Roads

As described in **Appendix D**, the road crossings sediment load was estimated via a standardized simple yearly model developed by the U.S. Forest Service. This model relies on a few basic input parameters that are easily measured in the field, as well as inclusion of precipitation data from local weather stations. Roughly 10% of the total population of unpaved road crossings in the watershed were evaluated in the field. The results from these sites were extrapolated to the whole population of roads. The potential to reduce sediment loads from unpaved roads through the application of BMPs was assessed by reducing the existing length to the potential BMP length based on the field measured values. This approach introduces uncertainty based on how well the sites and associated BMPs represent the whole population. Although the exact percent reduction will vary by road, the analysis clearly shows the potential for sediment loading reduction by applying standard road BMPs in places where they are lacking or can be improved. The percent reductions resulting from this analysis are comparable to most road sediment reduction evaluations from other DEQ completed TMDLs.

Upland Erosion

A USLE model from the Boulder-Elkhorn TMDL assessment (which has similar ecoregions and land practices) was used to determine upland erosion loads from cultivated fields in the Elk Creek watershed, as discussed in **Appendix E**. As with any model, there will be uncertainty in the model input parameters

including uncertainties regarding land use, land cover and assumptions regarding existing levels of BMP application.

The upland erosion assessment for Elk Creek integrates sediment delivery based on riparian health. The potential to reduce sediment loading was based on land cover improvements to reduce the generation of eroded sediment particles in combination with riparian improvements. The uncertainty regarding existing erosion prevention BMPs and ability to reduce erosion with additional BMPs represents a level of uncertainty. Even with these uncertainties, the ability to reduce upland sediment erosion and delivery to nearby waterbodies is well documented in literature and the reduction values used for estimating load reductions and setting allocations are based on literature values coupled with specific assessment results for Elk Creek.

Application of Source Assessment Results

Model results should not be applied as absolute accurate sediment loading values within each watershed or for each source category because of the uncertainties discussed above. Because of the un-calibrated nature of the source assessment work, the relative percentage of the total load from each source category does not necessarily indicate its importance as a loading source. Instead, the intention is to separately evaluate source impacts within each assessment category (e.g., bank erosion, upland erosion, roads) and use the modeling and assessment results from each source category to evaluate reduction potentials based on different BMP scenarios. The process of adaptive management can help sort out the relative importance of the different source categories through time.

6.0 TEMPERATURE TMDL COMPONENTS

This portion of the document focuses on temperature as a cause of water quality impairment in the Madison TMDL Planning Area (TPA). It describes: (1) effects of elevated water temperature on beneficial uses, (2) the affected stream segments, (3) the currently available data pertaining to temperature impairments in the planning area, (4) the sources of elevated temperature based on recent studies, and (5) the temperature TMDLs and their rationales.

6.1 EFFECTS OF EXCESS TEMPERATURE ON BENEFICIAL USES

Human influences that reduce stream shade, increase stream channel width, add heated water, or decrease the capacity of the stream to buffer incoming solar radiation all increase stream temperatures. Warmer temperatures can negatively affect aquatic life and fish that depend upon cool water for survival. Increased water temperature reduces dissolved oxygen and causes increased primary production via algal (Robarts and Zohary 1987) and bacterial (Kaplan and Bott 1989) growth that can exacerbate nutrient-related problems and lead to further reductions in dissolved oxygen. In addition, higher instream temperatures make fish more prone to disease (Tops et al. 2006; Roth 1972). Coldwater fish species are more stressed in warmer water temperatures as these conditions increase metabolism and reduce the amount of available oxygen in the water. Coldwater fish and other aquatic species may feed less frequently and use more energy to survive in thermal conditions above their tolerance range, sometimes creating lethal conditions for a percentage of the fish population. Elevated temperatures can also boost the ability of non-native fish to outcompete native fish if the latter are less able to adapt to warmer water conditions (Bear et al. 2007).

Because different fish species have varying optimal temperature ranges for survival and some are more sensitive than others to elevated stream temperatures, it is important to identify the fish species within each stream segment of concern. To help put sampling data into perspective and understand how elevated stream temperatures may affect aquatic life, information on fish species of concern presence in the Madison TPA is described below.

The fish species of concern that historically occupied the Madison TPA are Westslope cutthroat trout and Arctic grayling. Montana Fish Wildlife and Parks data in the MFISH database (http://fwp.mt.gov/fishing/mFish/) indicate that Westslope cutthroat trout still occupy drainages within the TPA. Special temperature considerations are warranted for this species because of its status as species of concern and its requirement for coldwater habitat. Research by Bear et al. (2007) found that Westslope cutthroat trout maximum growth occurs around 56.5°F with an optimum growth range (based on 95% confidence intervals) from 50.5 – 62.6°F. Rainbow trout were found to have a similar optimum growth temperature; however, rainbow trout were predicted to grow better over a wider range of temperatures than Westslope cutthroat trout, with growth being significantly better at temperatures below 44.2° F and above 69.4°F, possibly allowing for increased competition with Westslope cutthroat trout in lower-elevation (warmer) streams. The upper incipient lethal temperature (UILT) is the temperature considered to be survivable by 50% of a population over a specified time period. The sensitivity of Westslope cutthroat trout to temperature has also been illustrated by the higher UILT values compared to rainbow trout. Bear et al. (2007) found the 60-day UILT for Westslope cutthroat trout to be 67.3°F and the 7-day UILT to be 75.4°F. In contrast they observed that rainbow trout had a 60-day UILT of 75.7°F and a 7-day UILT of 78.8°F. The lethal temperature dose in a 24 hour

period for 10% of the population was found to be 73.0°F for Westslope cutthroat trout (Liknes et al. 1988).

Although Arctic grayling were nearly entirely extirpated from the drainage, re-introduction efforts have resulted in successful reproduction in Moore Creek. The 7-day UUILT for Arctic grayling is 77.0°F (Lohr et al. 1996), which is higher than that of Westslope cutthroat trout. Given the lower tolerance of Westslope cutthroat trout the temperature requirements noted above for Westslope cutthroat trout. were used in determining severity of temperature impairment and were used during source assessment, in addition to shade data, to highlight areas where Montana's temperature standard is likely being exceeded and the severity of those exceedances.

A lack of shade and an over-widened channel can also result in lower winter temperatures due to increased heat exchange (Hewlett and Fortson 1982; Poole and Berman 2001). These lower winter temperatures can lead to the formation of anchor and frazil ice, which can harm aquatic life by causing changes in movement patterns (Brown 1999; Jakober et al. 1998), reducing available habitat, and inducing physiological stress (Brown et al. 1993). Addressing the issues associated with increased summer maximum temperatures will also address these potential winter problems. Assessing thermal effects upon a beneficial use is an important initial consideration when interpreting Montana's water quality standard and subsequently developing temperature TMDLs.

6.2 Stream Segments of Concern

The temperature impaired stream segments of concern for which TMDLs were developed in the Madison TPA are listed in **Table 6-1**. **Figure 6-1** shows the location of these three temperature impaired stream segments in the Madison TPA. Summaries of stream segments that were assessed with no TMDL written at this time are found in **Appendix H**.

Table 6-1. Temperature Impaired Streams in the Madison TMDL Planning Area

Waterbody (Assessment Unit)	Assessment Unit ID
Cherry Creek – headwaters to mouth (Madison River)	MT41F002_010
Elk Creek – headwaters to mouth (Madison River)	MT41F002_020
Moore Creek – springs to mouth (Fletcher Channel), T5S R1W S15	MT41F004_130

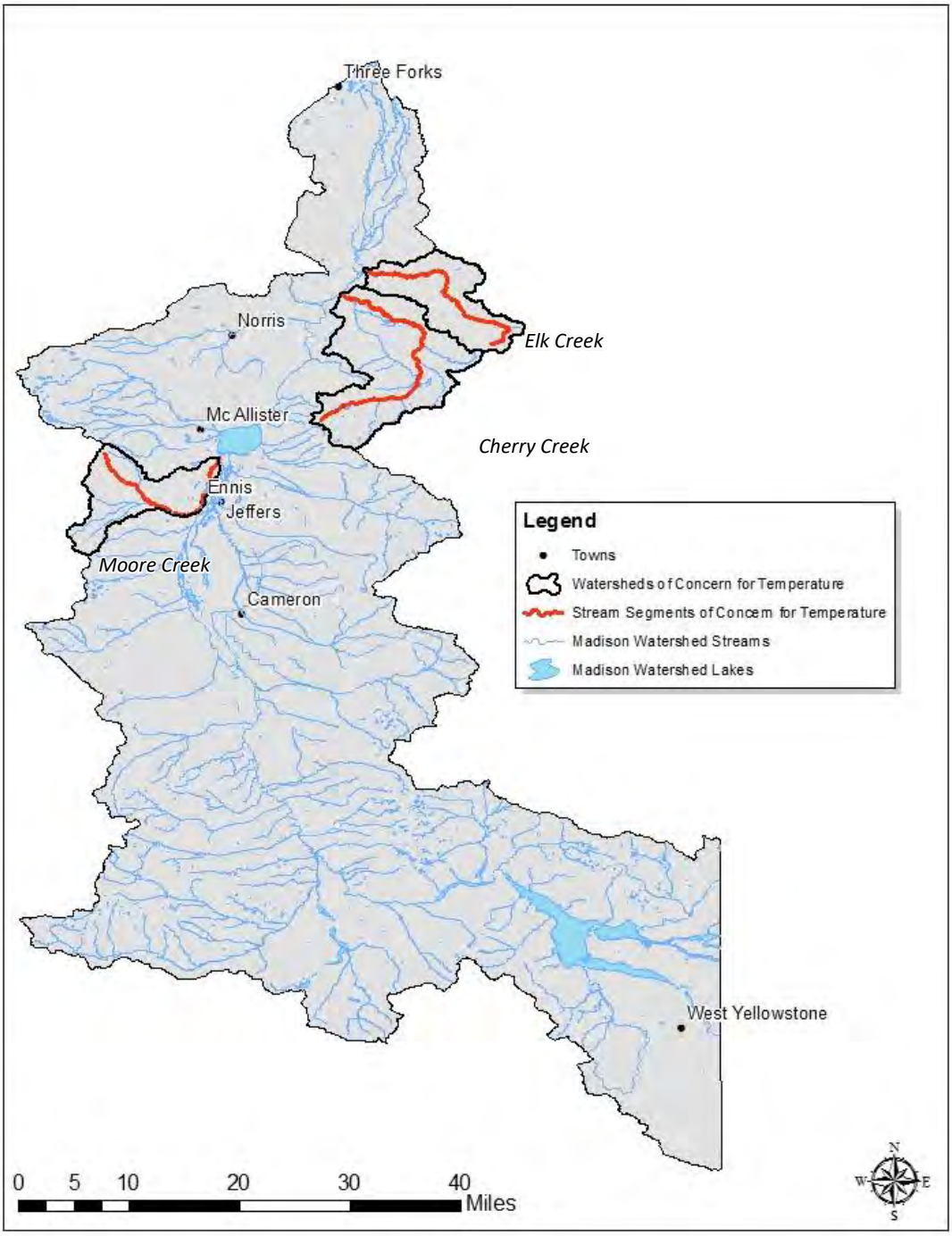


Figure 6-1. Map of the Temperature Impaired Streams in the Madison TMDL Planning Area

6.3 INFORMATION SOURCES

The information sources used to develop the TMDL components include data used to determine impairments (see **Section 3.0**) and data obtained during the TMDL development process. The data collected by DEQ, its contractors, other agencies or organizations, and volunteer monitoring groups, was catalogued within DEQ's centralized water quality database and DEQ collected data can also be found in

Appendix G of this document. Data and information used for impairment determination, source assessment, and TMDL development consisted of:

- Water temperature and streamflow data collected by DEQ, Montana Fish, Wildlife, and Parks (FWP), Northwestern Energy (formerly PPL Montana), and the Madison Stream Team
- Stream channel morphology, vegetation, and shade data collected by DEQ
- Fisheries inventories conducted by FWP
- Streamflow data collected by the USGS
- Grazing management plans developed by the Bureau of Land Management (BLM) and the US Forest Service (USFS)
- Cropland data collected by the US Department of Agriculture (USDA)
- Aerial photography and Geographic Information System (GIS) data and analysis
- Literature reviews

DEQ's methods for temperature TMDL development included a combination of characterizing water temperatures throughout the summer, and collecting vegetation, channel width, shade, and streamflow data, which were used to model shade using the Shade Tool (Washington State Department of Ecology 2008). Sample locations were generally such that they provided a comprehensive upstream to downstream view of stream temperature. The location of sample collection also allowed for analysis of potential source impacts (e.g., shade, irrigation influence, point sources). All data used in TMDL development were collected during June – September, the time of year when fish are likely to be the most stressed by thermal conditions.

The data used for the analyses in this document can be obtained from the Montana Department of Environmental Quality's Water Quality Division. Other water quality data from the watershed are publicly available through the Environmental Protection Agency's (EPA) Water Quality Portal and DEQ's EQuIS water quality database.

6.3.1 Temperature Monitoring

Temperature monitoring was conducted in 2013 on Cherry Creek, Elk Creek, and Moore Creek, between June and September. The study examined stream temperatures during the period when streamflow tends to be the lowest and water temperatures the warmest, and thus when negative effects to the aquatic life beneficial use are likely most pronounced. Temperature monitoring consisted of placing temperature data loggers at multiple sites within the watershed. Temperature monitoring sites were selected to bracket stream reaches with similar hydrology, riparian vegetation type, valley type, stream aspect, and channel width. Temperature data are summarized within **Section 6.4.2** of this document and **Appendix G**.

6.3.2 Streamflow

Streamflow measurements were collected at multiple locations on each of the stream segments of concern for temperature. Streamflow data used in the model included data collected by DEQ on Cherry Creek, Elk Creek, and Moore Creek in 2013, and by the Madison Stream Team on Moore Creek in 2013 (Madison Stream Team 2013, **Appendix G**).

6.3.3 Riparian Shading

Characterization of riparian shade was based on a combination of field data and aerial imagery analysis. Riparian shading was quantified using GIS tools and aerial imagery analysis to input variables into the Shade Tool (**Appendix I**), which is a model developed by the Washington Department of Ecology that

calculates the percent effective shade and solar flux along a stream (Washington State Department of Ecology 2008). Field data were collected by DEQ to input into the Shade Tool, and Solar Pathfinder measured shade data were collected at multiple sites along each stream to verify and calibrate the Shade Tool outputs (**Appendix G**).

6.3.4 Channel Geometry

Although not a direct measure of thermal effect on the stream, channel geometry can influence the rate of thermal loading. Wide, shallow streams transfer heat energy faster than narrow, deep streams. Therefore, channel geometry can be used to identify areas that may be destabilized, and may be more prone to rapid thermal loading, particularly in locations where shading is minimal. Channel geometry measurements were obtained during field outings be Montana DEQ, including those selected during sediment surveys, shade surveys, and when measuring discharge as described in **Appendix G**.

6.4 WATER QUALITY TARGETS

Water quality targets are measurable indicators used to evaluate attainment of water quality standards, and are discussed in further detail in **Section 4.0**. The following section describes 1) the framework for interpreting Montana's temperature standard; 2) the selection of indicator parameters used as targets for TMDL development and how target values were developed; and 3) a summary of the temperature target values for Madison TPA temperature streams of concern.

6.4.1 Temperature Targets and Target Values

Montana's water quality standard for temperature is narrative in that it specifies a maximum allowable increase above the naturally occurring temperature to protect fish and aquatic life. For waters classified as B-1, which includes all stream segments of concern for temperature in the Madison TPA, the maximum allowable increase over the naturally occurring temperature is 1°F when the naturally occurring temperature is less than 66°F. Within the naturally occurring temperature range of 66 – 66.5°F, the allowable increase cannot exceed 67°F. If the naturally occurring temperature is greater than 66.5°F the maximum allowable increase is 0.5°F [Administrative Rules of Montana (ARM) 17.30.623(e)]. To further understand this standard, **Figure 6-2** is a graphic displaying the Montana temperature standard for B-1 classified waterbodies.

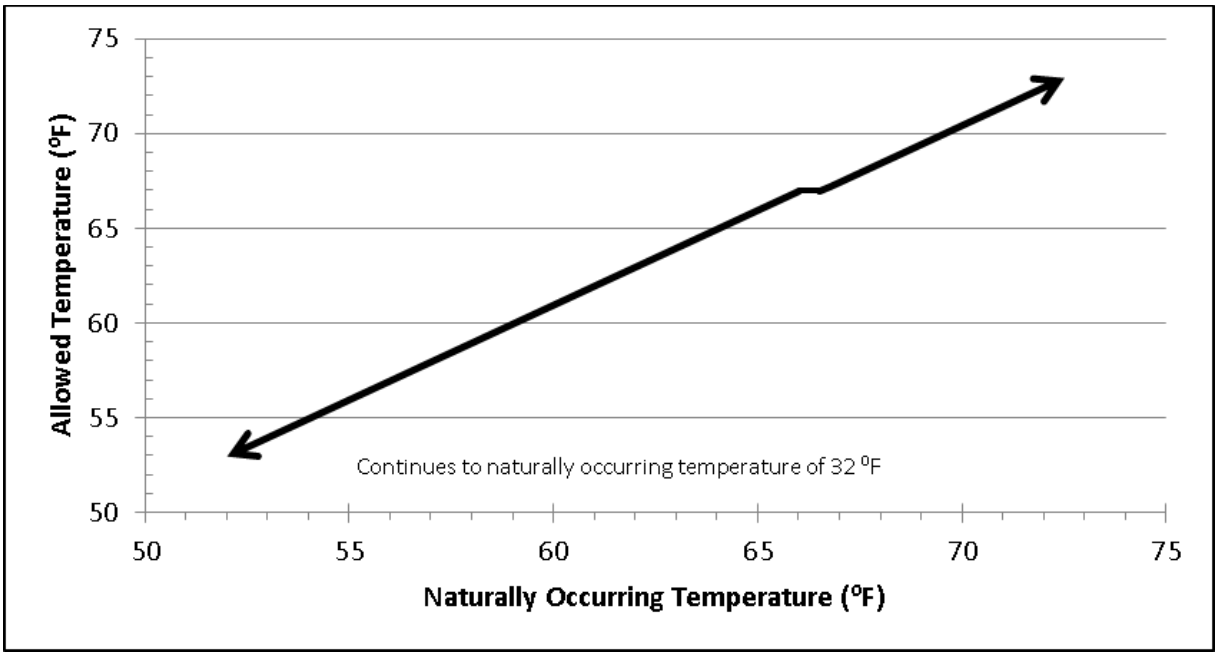


Figure 6-2. Montana's Temperature Standard for B-1 Classified Waterbodies

Under Montana water quality law, naturally occurring temperatures incorporate natural sources and human sources that are applying all reasonable land, soil, and water conservation practices. Naturally occurring temperatures can be estimated for a given set of conditions using modeling approaches, but because water temperature changes daily and seasonally, no single temperature value can be identified to represent standards attainment. Therefore, in addition to evaluating whether it is likely that the allowable temperature change is being exceeded, a suite of temperature TMDL targets were developed to translate the narrative temperature standard into measurable parameters that collectively represent attainment of applicable water quality standards at all times. The goal is to set the target values at levels that occur under naturally occurring conditions but are conservatively selected to incorporate an implicit margin of safety that helps account for uncertainty and natural variability.

Because naturally occurring temperatures can significantly vary throughout the summer, as well as from year to year, the quantified temperature targets include those indicator parameters that influence temperature and can be linked to human causes. These indicator or target parameters include riparian health/shade and channel geometry. Improved streamflow conditions, where applicable, will also help decrease stream temperatures. Values are developed for each target parameter and are set at levels that result in attainment of Montana's temperature standard under all seasonal and yearly variability. The goal is to set the target values at levels that would contribute to naturally occurring temperature conditions, while ensuring that any variability from naturally occurring conditions is less than that allowed by the standard. The target values presented are protective of the use most sensitive to elevated temperatures, aquatic life; as such, the targets are protective of all designated uses for the applicable waterbody segments.

For the stream segments of concern in the Madison TPA, the Shade Tool (Washington State Department of Ecology 2008) was the primary means of examining the difference between existing shade and potential shade conditions for a given stream and determining the likelihood that water temperatures are excessively warm as a result of insufficient shade. The Shade Tool estimates effective shade at a particular point based on topography, vegetation height and density, stream channel width, and time of

year. Existing shade was modeled based on aerial photography and vegetation currently existing, while potential shade was determined based on shade curves for the expected vegetation community (**Appendix I**). These shade curves were developed by the EPA and Idaho DEQ, and serve as a reference condition for an expected vegetative community (Shumar and de Varona 2009).

Although the primary temperature target is the allowable human-caused temperature change (i.e., 0.5 – 1.0°F, depending on the naturally occurring temperature), it is expected that this target can be achieved by meeting the riparian shade targets and channel geometry (bankfull width/depth) targets for each stream of concern. Improvements in instream flow conditions are beneficial in helping to meet the temperature target, and a 15% increase in streamflow is recommended as a starting point. Any voluntary water savings and subsequent in-stream flow augmentation must be done in a way that protects water rights. The temperature and temperature-influencing targets are described in more detail below.

6.4.1.1 Allowable Human-Caused Temperature Change

The target for allowable human-caused temperature change for streams in the Madison TPA links directly to Montana's temperature standard for B-1 streams [ARM 17.30.623(e)] (**Section 6.4.1**). Naturally occurring temperatures incorporate natural sources, yet also include human sources that are applying all reasonable land, soil, and water conservation practices.

6.4.1.2 Riparian Health/Shade

Increased shading from riparian vegetation reduces sunlight hitting the stream, thus reducing heat load to the stream. Riparian vegetation also reduces near-stream wind speed and traps air against the water surface, which reduces heat exchange with the atmosphere. In addition, lack of established riparian areas can lead to bank instability, which could result in over-widened streams. Human influences affecting riparian canopy cover in the Madison TPA watersheds include present and historical agricultural activities, timber harvest, and residential development.

DEQ uses a reference approach to define naturally occurring conditions for riparian health. DEQ defines "reference" as the condition of a waterbody capable of supporting its present and future beneficial uses when all reasonable land, soil, and water conservation practices have been applied. In other words, the reference condition reflects a waterbody's greatest potential for water quality given past and current land-use activities. The riparian shade targets for the Madison TPA stream segments of concern are based on vegetation effective shade curves developed by the EPA and Idaho DEQ, which represent potential reference conditions for the respective streams based on stream orientation (aspect), bankfull width, and plant species (Shumar and de Varona 2009). The detailed shade targets for each stream can be found in **Section 6.4.2.**

Improvement in riparian health needs significant time before changes are visible. DEQ does not expect these targets to be met in the short-term; however, changes in land management practices and a commitment to those practices would need to be implemented to start meeting goals for temperature in the Madison TPA. DEQ recognizes that for any given stream segment, target values may be lower or higher than the actual potential depending on the presence of roads and road crossings and the vegetation that can be established. An adaptive management approach should be used in concert with the effective shade target values to ensure that the true potential effective shade is realized for each stream segment.

6.4.1.3 Channel Width/Depth Ratio

The width/depth ratio is a dimensionless value representing a fundamental aspect of channel morphology, and provides a measure of channel stability. As the width/depth ratio increases, streams become wider and shallower, and susceptible to an increase in thermal loading to the stream. A narrower channel with a lower width-to-depth ratio results in a smaller contact area with warm afternoon air and is slower to absorb heat (Poole and Berman 2001). A narrower channel also increases the effectiveness of shading produced by the riparian canopy. Width/depth ratios were calculated for each DEQ assessment reach based on four riffle cross section measurements. This parallels the method used by the US Forest Service for the PacFish/InFish Biological Opinion Monitoring Program (PIBO) for width/depth from 2001-2008. From 2009-2014 the PIBO width/depth average was calculated from 10 channel cross-sections in riffle and pool features.

There is reference riffle width/depth ratio data for both the DEQ and PIBO datasets and the two were combined to develop the targets. Statistical analyses determined that bankfull width was the best correlation for width/depth ratio given that PIBO does not assign a Rosgen stream type. The target values for width/depth ratio are based on the 75th percentile of the combined DEQ and PIBO Middle Rockies level IV ecoregion reference datasets and are defined by bankfull width category (**Table 6-2**). This upper limit provides a target that prevents over widening of the channel with an accompanying decrease in mean depth.

Table 6-2. Data Summary for DEQ and PIBO Middle Rockies Reference sites for Width/Depth Ratios

Data Source	Sample Size	Minimum	Median	Maximum	Target (75th percentile)
< 15 ft bankfull width	17	6.4	10.6	14.9	11
15 - 30 ft bankfull width	34	14.2	20.1	43.4	24
> 30 ft bankfull width	5	25.5	29.1	34.4	30

The target is not intended to be specific to every given point on the stream; the intent rather, is to maintain width/depth ratios in their current condition throughout each segment. If specific locations have the potential to become narrower, improved vegetation in riparian areas will generally lead to gradual improvements in these width/depth ratios over time. If deemed appropriate, active restoration techniques could be used to give the stream channel an appropriate width and depth at these locations.

6.4.1.4 Instream Discharge (Streamflow Conditions)

Larger volumes of water take longer to heat up during the day; therefore, the volumetric heat capacity of a stream is reduced if water volumes are reduced. Reductions in water withdrawals resulting from voluntary reductions in water withdrawals, in-stream water leases and reservations, or improvements in water diversion, delivery, or application infrastructure, can lead to an increase in streamflow, and ultimately lower water temperatures for the stream. Per Montana's water quality law, TMDL development cannot be construed to divest, impair, or diminish any water right recognized pursuant to Title 85 (Montana Code Annotated Section 75-5-705). As a result, any voluntary water savings and subsequent in-stream flow augmentation must be done in a way that protects water rights, and water users are encouraged to work with the United States Department of Agriculture Natural Resource Conservation Service (NRCS), the Montana Department of Natural Resources and Conservation (DNRC), their local conservation district, and other state, federal, or local land management agencies to review their irrigation systems, practices, and the variables that may affect overall water use efficiencies (Negri

and Brooks 1990; NRCS NEH 652). A target increase in stream flow of 15% is a good starting point, which may result in a decrease in daily maximum temperatures.

In-stream water leases or reservations are a way that a water right holder can reduce their water withdrawals from a stream, while still maintaining the ownership of their water right. The State of Montana has a statutory water leasing program to provide water for fish in streams. A water user that wishes to reduce irrigation water withdrawals to improve in-stream flows has three options (1) convert all or part of a consumptive-use water right to an in-stream use by seeking a change in purpose and place of use without the use of a lease; (2) lease a water right to Montana Department of Fish Wildlife and Parks; or (3) lease a water right to a private entity such as Trout Unlimited (Bradshaw ND).

Improving irrigation water application efficiencies is a potential tool to divert less water and leave more water in the stream; however, improvements in application efficiencies do not themselves equate to less water use and must be accompanied by reduced water withdrawals to achieve the goal of increased streamflow. Irrigation water application efficiencies for flood irrigation on average are 35% efficient, while high pressure sprinkler applications (hand lines and wheel lines) on average are 65% efficient, and low pressure center pivot or linear sprinklers on average are 80% efficient (NRCS NEH 652). Higher application efficiencies result in greater application uniformity, higher crop yield, and less water losses due to runoff or deep percolation. To achieve an in-stream water savings through irrigation system upgrades, the producer will likely have to sacrifice some of the increase in crop yield gained by upgrading the irrigation system, which may not be economically feasible to the producer.

Improving the efficiencies of existing irrigation diversions and delivery ditches is another potential tool that could possibly lead to additional increases in instream flow due to reduced water withdrawals. Each diversion and delivery ditch is unique, and this study did not attempt to characterize each piece of irrigation infrastructure in the watershed. Unlined delivery ditches typically have low efficiencies for getting water from the point of diversion to the point of use, and therefore more water must be diverted to obtain the desired amount of water at the point of use. Lining delivery ditches with a more impermeable material to reduce loss due to percolation or using pipe will improve water delivery efficiencies and could potentially allow the water user to leave more water in the stream during the irrigation season.

6.4.1.5 Target Values Summary

The allowable human-caused temperature change is the primary target that must be achieved to meet the standard. Alternatively, compliance with the temperature standard can be attained by meeting all temperature-influencing targets for shade (**Table 6-3**). In this approach, if all reasonable land, soil, and water conservation practices are installed or practiced, state standards are met.

Table 6-3. Temperature Targets for the Madison TPA

Temperature Target Parameter	Target Value
Allowable human caused temperature change	If the naturally occurring temperature is less than 66°F, the maximum allowable increase is 1°F. Within the naturally occurring temperature range of 66–66.5^{o}F, the allowable increase cannot exceed 67°F. If the naturally occurring temperature is greater than 66.5^{o}F, the maximum allowable increase is 0.5^{o}F.

Table 6-3. Temperature Targets for the Madison TPA

Temperature Target Parameter	Target Value
Riparian health/shade	A riparian buffer producing effective shade representative of the potential vegetative community for each respective Level IV Ecoregion. Waterbody and location specific shade targets can be found in **Section 6.4.2**.
Bankfull width/depth ratio[1]	< 15 ft bankfull width - Target: a width/depth ratio of ≤ 11
	15 ft - 30 ft bankfull width - Target: a width/depth ratio of ≤ 24
	> 30 ft bankfull width - Target: a width/depth ratio of ≤ 30
Instream discharge	15% water savings from improved irrigation delivery and application efficiencies (any voluntary water savings and subsequent in stream flow augmentation must be done in a way that protects water rights)

[1] Bankfull width/depth ratio targets are equal to the target values set for sediment impaired streams in **Section 5.0**

6.4.2 Existing Conditions and Comparison to Targets

DEQ evaluated temperature target attainment by comparing existing effective shade with riparian health/shade targets in **Table 6-3**. For each waterbody segment, a comparison of existing data with targets is presented.

6.4.2.1 Cherry Creek

Cherry Creek flows from its headwaters in the Madison Range to its mouth at the Madison River, below Ennis Lake. A summary of the existing temperature-related water quality conditions and a comparison of those conditions to water quality targets are presented in this section.

Water Temperature

In 2013 DEQ collected water temperature at 30-minute intervals and shade-related data from three sites on Cherry Creek (Sites 2A, 2B, and 2C, **Appendix G**) (**Table 6-4** and **Figure 6-3**). Sites CHRR 18-02 and CHRR 20-01 in **Figure 6-3** were sites where only channel geometry measurements were collected, but are shown for reference because the width of the stream affects heating at the water surface and was used in Qual-2k model development described below. A maximum temperature (T_{max}) of 77.9°F was recorded at Site 2A near the mouth, with 34 days exceeding 73°F, which is the 24-hour lethal temperature dose for 10% of the population of Westslope cutthroat trout. The warmest 7-day period in 2013, or the Maximum Weekly Maximum Temperature (MWMT) was 76.3°F, which also exceeded the 7-day Upper Incipient Lethal Temperature (UILT) of 75.4°F for Westslope cutthroat trout. The UILT is the temperature at which 50% of Westslope cutthroat die after 7 days of exposure.

Table 6-4. Temperature Data Summary for Cherry Creek in 2013

Stream	Site[1]	Maximum Temperature (T_{max})	7-day Average Daily Maximum (MWMT)	Number of Days With Water Temperatures Exceeding 73°F
Cherry Creek	2A	77.9°F	76.3°F	34
Cherry Creek	2B	66.4°F	65.2°F	0
Cherry Creek	2C	66.3°F	65.3°F	0

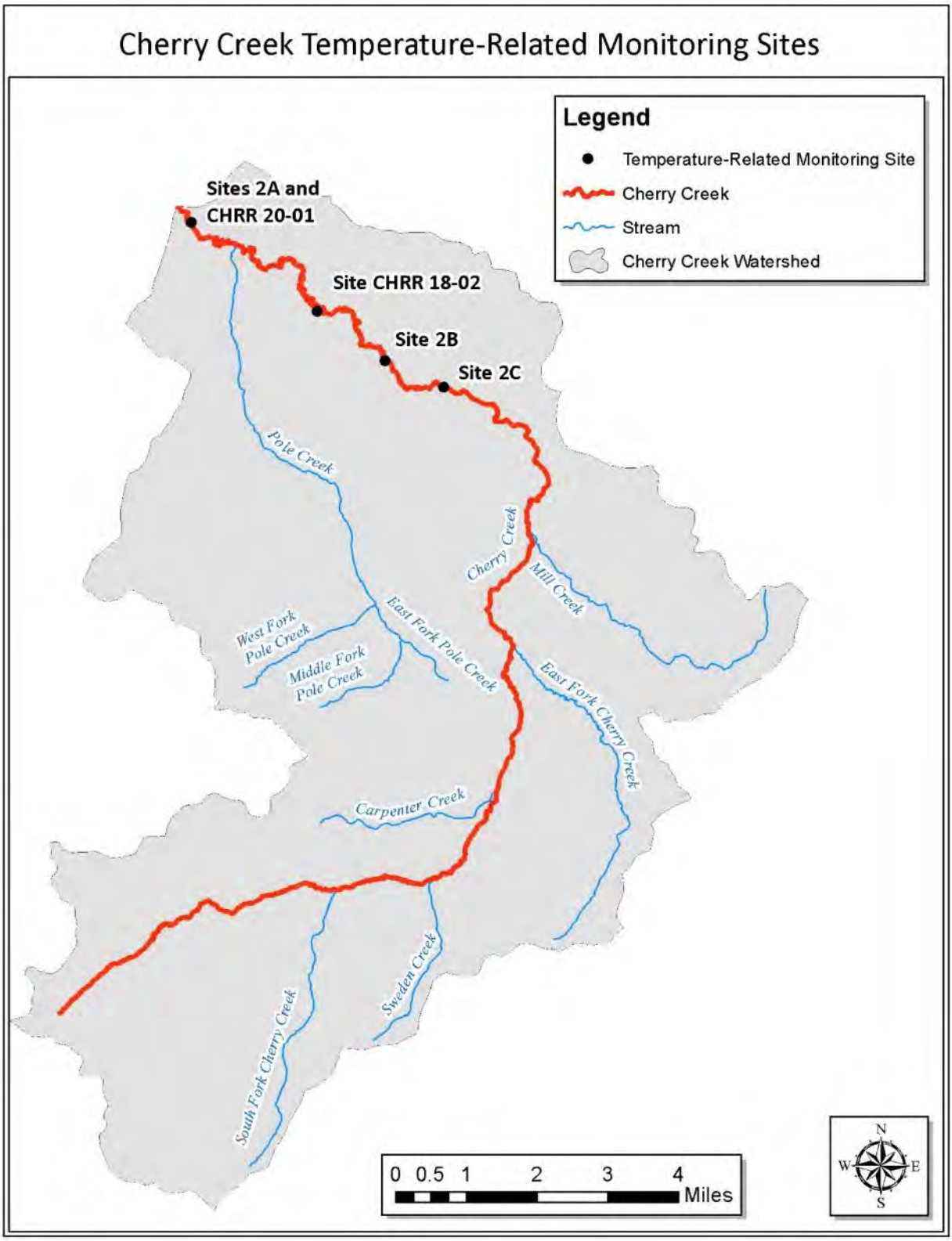


Figure 6-3. Map of Temperature-Related Monitoring Sites on Cherry Creek

Figure 6-4 shows the water temperature data for Cherry Creek near the mouth (Site 2A). This data shows that there were several exceedances of the 24-hour lethal dose threshold for 10% of the population of Westslope cutthroat trout in July, August, and September. The MWMT threshold was also exceeded in July and September, indicating that water temperature is potentially harming the Westslope cutthroat trout population in Cherry Creek.

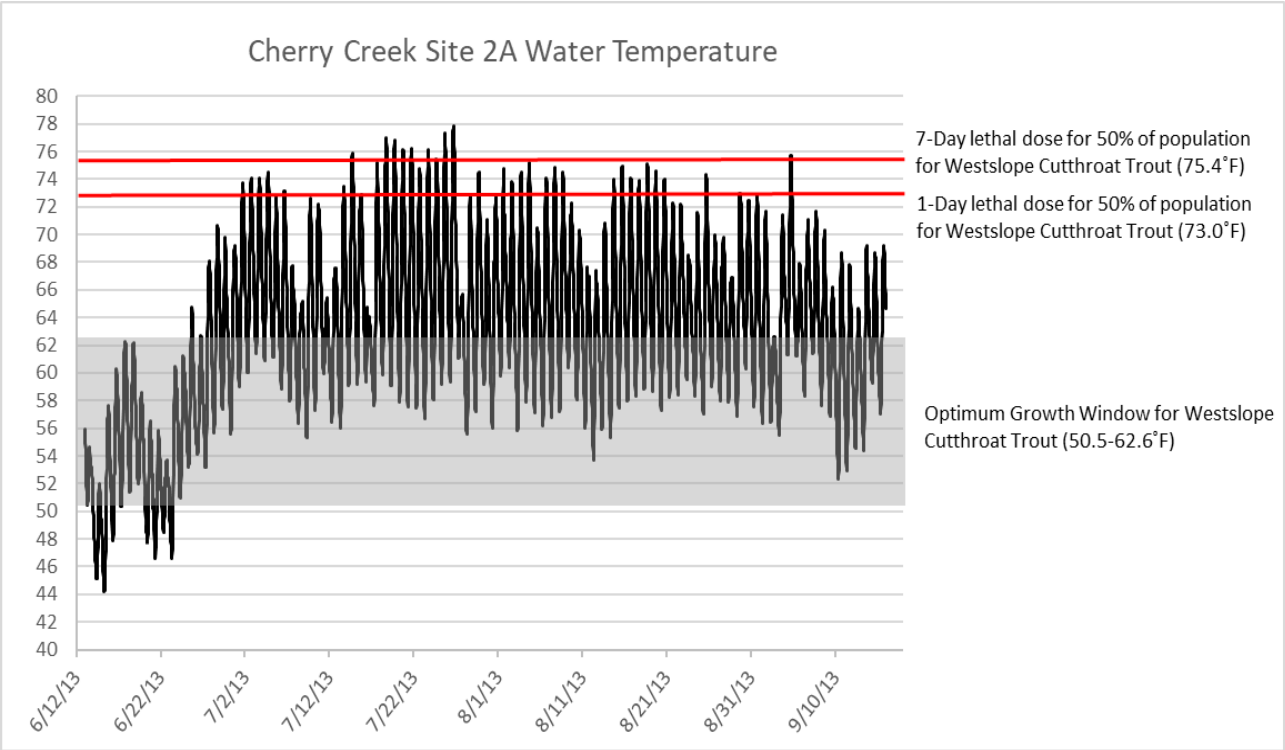


Figure 6-4. Water Temperature Data for Cherry Creek near the Mouth (Site 2A)

Riparian Health/Shade

Shade-related data, including Solar Pathfinder data (**Appendix G**) were collected at sites 2A, 2B, and 2C, and used in conjunction with aerial photography to model the existing effective shade using the Shade Tool (Washington State Department of Ecology 2007). Shade targets were developed based on level IV ecoregion and the expected riparian vegetation community for that ecoregion (**Appendix I**). That vegetation community was then compared to shade curves developed for the near-by Targhee National Forest for reference riparian vegetation conditions (Shumar and de Varona 2009). **Figure 6-5** compares the existing effective shade to its respective shade targets, while **Figure 6-6** plots the difference between the existing effective shade and the shade targets. The plots are displayed in an upstream (left) to downstream (right) orientation to easily correlate targets and existing shade to location on the stream. Positive numbers in **Figure 6-6** indicate that the existing effective shade exceeds the shade targets, while negative numbers indicate areas where existing effective shade is deficient. A section near the headwaters of Cherry Creek was excluded from this analysis because it had been burned by a forest fire and was showing a significant shade deficit when compared to shade targets. Since this was a naturally occurring event, it was excluded from the dataset as to not skew the data. As shown in **Figure 6-6**, the lower portion of Cherry Creek (downstream of Site 2B) has deficient shade in comparison to shade targets, which is ultimately contributing to the high-water temperatures collected near the mouth at Site 2A.

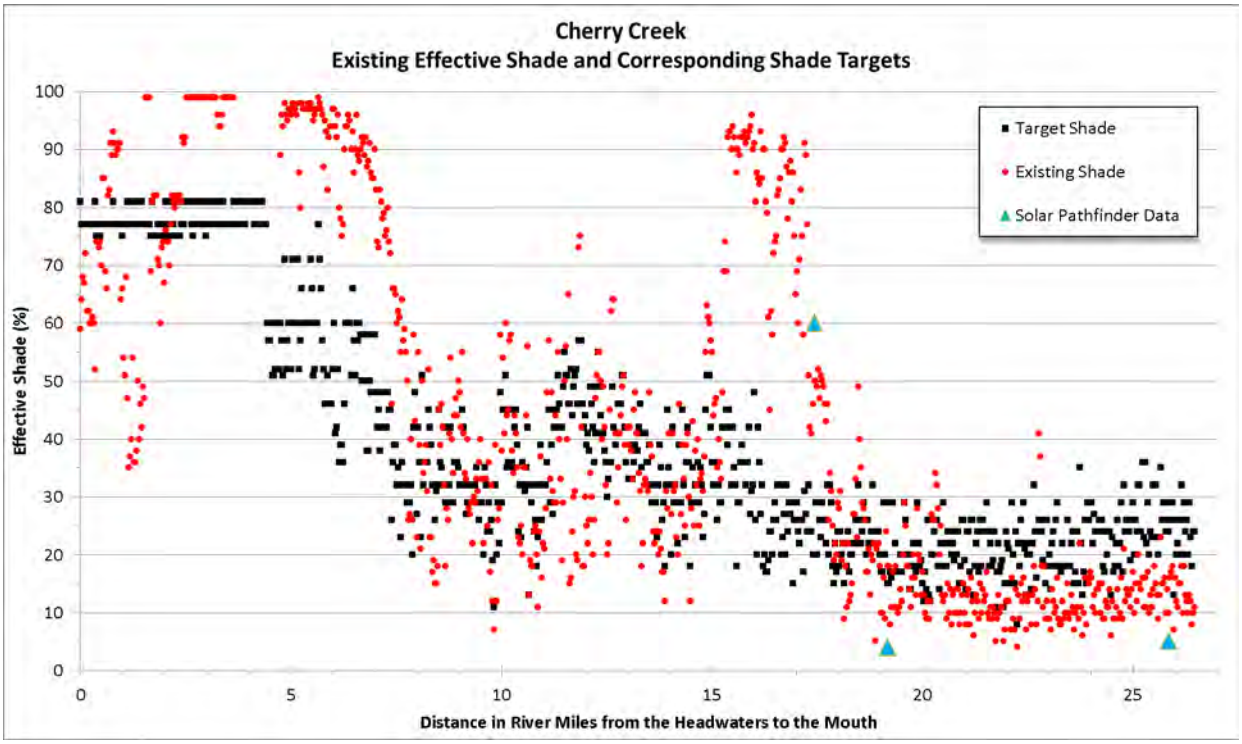


Figure 6-5. Existing Effective Shade and Corresponding Shade Targets for Cherry Creek

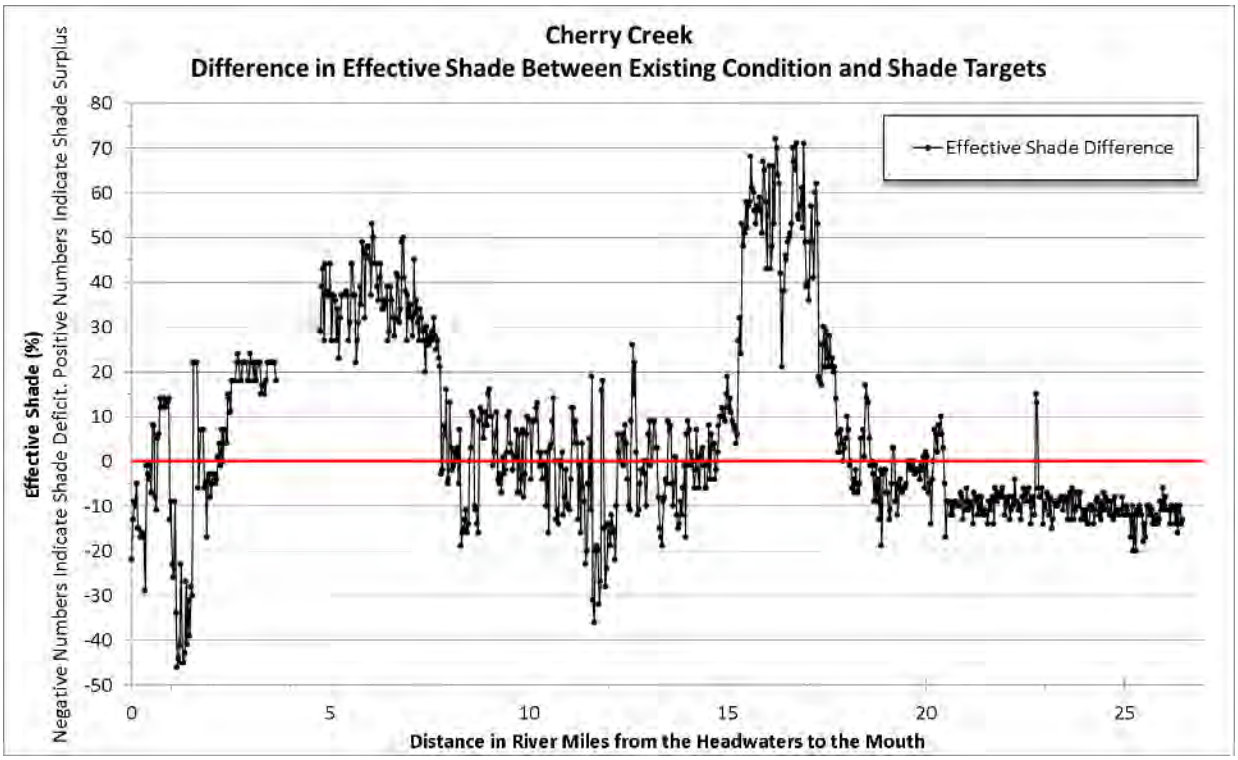


Figure 6-6. Difference in Effective Shade between Existing Condition and Shade Targets for Cherry Creek

Channel Width/Depth Ratio

Channel width/depth ratio was measured at two sites along Cherry Creek as a part of the data collection effort to assess sediment impairment (**Section 5.0**). Data collected by DEQ in 2014 indicate that Cherry Creek is meeting the width/depth ratio targets at the two monitoring sites (**Table 6-5**). Although this data was collected in two discrete locations, the locations of the monitoring sites were chosen because they are assumed to be representative of Cherry Creek as a whole. It is possible that the width/depth ratio may be exceeding targets in areas along Cherry Creek, especially in areas where land management practices are poor, but areas that have good land management practices in place should not be negatively affecting the width/depth ratio of Cherry Creek. The stream appears to be in recovery from past poor land use practices and it is likely that if the existing land management practices continue to be implemented, conditions will improve in Cherry Creek.

Table 6-5. Cherry Creek Calculated Width/Depth Ratios in Comparison to Width/Depth Ratio Targets

Reach/Site ID	Year Data Collected	Mean BFW (ft)	W/D Ratio Target	W/D Ratio
CHRR 18-02	2014	30.5	≤ 30	18.5
CHRR 20-01	2014	33.1	≤ 30	21.2

Instream Discharge (Streamflow Conditions)

As of February 4, 2020, a total of six entities held water rights on Cherry Creek and its tributaries. Historically, the lower 4.5 miles of Cherry Creek was severely dewatered during the summer irrigation season; in response to this dewatering, Montana FWP obtained a water right for an instream flow reservation of 15 cfs for the purpose of providing spawning and rearing habitats to trout and whitefish residing in the Madison River, to maintain the existing resident trout populations, and to help protect the habitat of those wildlife species which depend on the stream and its associated riparian zone for food, water, and shelter.

Qual2k Temperature Simulation and Implications for Fish Populations

Water temperature, flow, channel characteristics, and riparian shade data were incorporated into a QUAL2K water quality model to characterize existing temperature conditions and evaluate the effects of increases in shade and streamflow for Cherry Creek (Chapra et al 2012). The model was developed for the warmest water temperature day occurring during temperature logger deployment during summer 2013, which occurred on 7/26/2013.

The portion of stream modeled during this analysis extended from the mouth of Cherry Creek to approximately 9 miles upstream, which occurs near site 3C (**Figure 6-3**). Within the model, water temperatures were predicted largely based on climate data from the Western Climate Center (https://wrcc.dri.edu/) Ennis Montana weather station. Estimates of riparian shade along the length of the study section were estimated using the Shade Tool (**Section 6.4.2.1**). Headwater temperature conditions were estimated using hourly temperature loggers deployed at monitoring sites in **Figure 6-3**. Channel characteristics were based on field measurements taken by Montana DEQ during discharge measurements and sediment surveys. Detailed boundary conditions and parameter used in the model can be found in **Appendix J**. The model is considered adequate for evaluating the potential impacts of increasing shade and stream flow on water temperature. However, it may not be suitable for all purposes.

The performance of the model was evaluated by comparing modeled temperatures at temperature loggers to actual temperatures collected on 7/26/2013 using the absolute relative error method, as

described in **Appendix J**. Despite limited field data, the modeled maximum temperatures approximated measured maximum temperatures with an error rate of 1.9% (representing the average percent difference between modeled and actual conditions) (**Appendix J**; Table J-1).

Based on measured and modeled conditions, actual maximum temperatures became suitable for Westslope cutthroat trout at approximately 3.5 miles upstream from the mouth. Although temperature was not collected above Site 2C, temperatures continued to decrease with distance upstream indicating that the entire section upstream of the modeled section was likely suitable for Westslope cutthroat trout during the day of 7/26/2013 (**Appendix J**; Figure J-1)

The potential management scenarios modeled as part of this exercise include an 15% increased flow scenario, an increased shade scenario to represent achievable shade increases as a result of riparian restoration, and a scenario that included both actions (15% increased flow and increased shade). The increased shade scenario was developed using predictions of natural vegetation for ecoregion IV and shade curves for the near-by Targhee National Forest for reference riparian vegetation conditions (Shumar and de Varona 2009; **Section 6.5.2.1** and **Appendix J)**. Results indicated that the increased flow scenario decreased modeled maximum temperatures by an average of 1.1˚C at the most downstream site, while the increased shade scenario decreased modeled maximum temperatures by 1.5˚C. The combined scenario decreased modeled maximum temperatures by 1.9˚C (**Appendix J**; Figure J-4)

None of the scenarios resulted in a substantial increase in potential stream miles inhabited by Westslope cutthroat trout (The combined scenario resulted in only a ~ 0.5 mile potential increase in usable habitat) although an increase in shade had the most impact. However, given that the modeling represented the warmest day of the year, increased shade could increase the habitable portion of Cherry Creek by a greater amount other parts of the summer with less warm temperatures. Westslope cutthroat trout on Cherry Creek reside primarily above a waterfall located approximately 8 miles upstream from the mouth that provides a barrier from non-native fish (Shepard et al. 2020), but some of the Westslope cutthroat residing in upper Cherry Creek have migrated to lower Cherry Creek and the Madison River (Yablonski 2014). Decreasing temperatures in this lower section could prove beneficial to Westslope cutthroat trout, although further research would be done to fully understand the impact of increased shade on temperature as well as potential impacts to the Westslope cutthroat trout population.

6.4.2.2 Elk Creek

Elk Creek flows from its headwaters in the Madison Range to its mouth at the Madison River, below Ennis Lake. Elk Creek was listed as impaired by temperature in the 2016 Integrated Report based on recent data collected and the comparison of that data to the water quality targets outlined in **Table 6-3**. A summary of the existing temperature-related water quality conditions and a comparison of those conditions to water quality targets are presented in this section.

Water Temperature

In 2013 DEQ collected water temperature at 30-minute intervals and shade-related data from four sites on Elk Creek (Sites 1A, 1B, 1C, and 1D, **Appendix G**) (**Table 6-6** and **Figure 6-7**). Sites ELKC11-01, ELKC05-01, ELKC06-02 and M06ELKC07 in **Figure 6-7** were sites where only channel geometry measurements were collected. They are shown for reference because the width of the stream affects heating at the water surface and was used in Qual-2k model development described below. A maximum temperature (T_{max}) of 84.7°F was recorded at Site 1A near the mouth, with 9 days exceeding 73°F, which is the 24-hour lethal temperature dose for 10% of the population of Westslope cutthroat trout. Site 1A went dry

on June 18th due to irrigation diversions, but all sites had multiple days exceeding 73°F. The warmest 7-day period in 2013, or the Maximum Weekly Maximum Temperature (MWMT) was 78.3°F at Site 1B, and the MWMT at all sites exceeded the 7-day UILT of 75.4°F for Westslope cutthroat trout.

Table 6-6. Temperature Data Summary for Elk Creek in 2013

Stream	Site[1]	Maximum Temperature (T_{max})	7-day Average Daily Maximum (MWMT)	Number of Days With Water Temperatures Exceeding 73°F
Elk Creek	1A	84.7°F	75.8°F	9
Elk Creek	1B	80.6°F	78.3°F	16
Elk Creek	1C	77.7°F	75.7°F	15
Elk Creek	1D	77.8°F	76.0°F	12

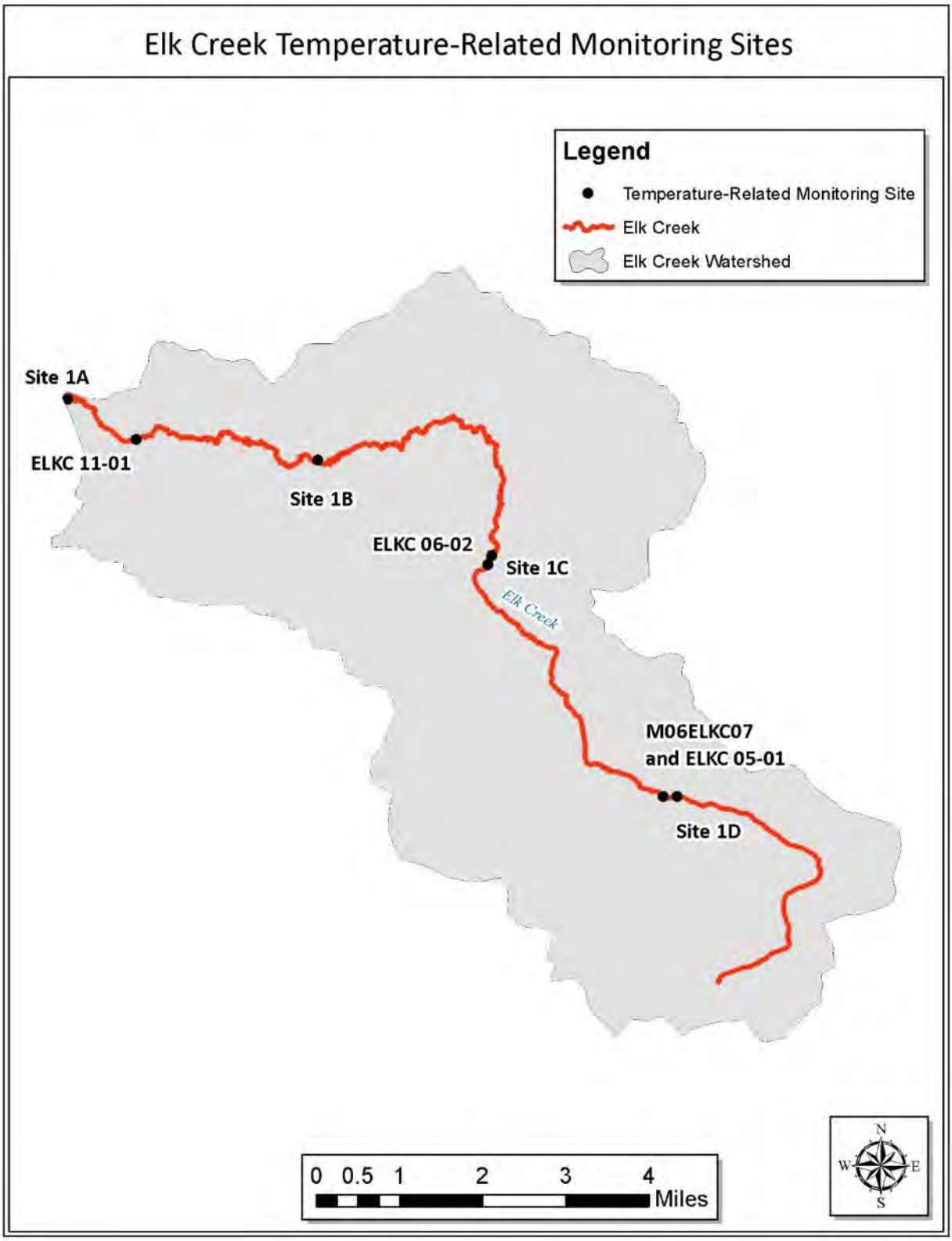


Figure 6-7. Map of Temperature-Related Monitoring Sites on Elk Creek

Figure 6-8 shows the water temperature data for Elk Creek Site 1B. This data shows that there were several exceedances of the 24-hour lethal dose threshold for 10% of the population of Westslope cutthroat trout in June and July. The MWMT threshold was also exceeded in June and July.

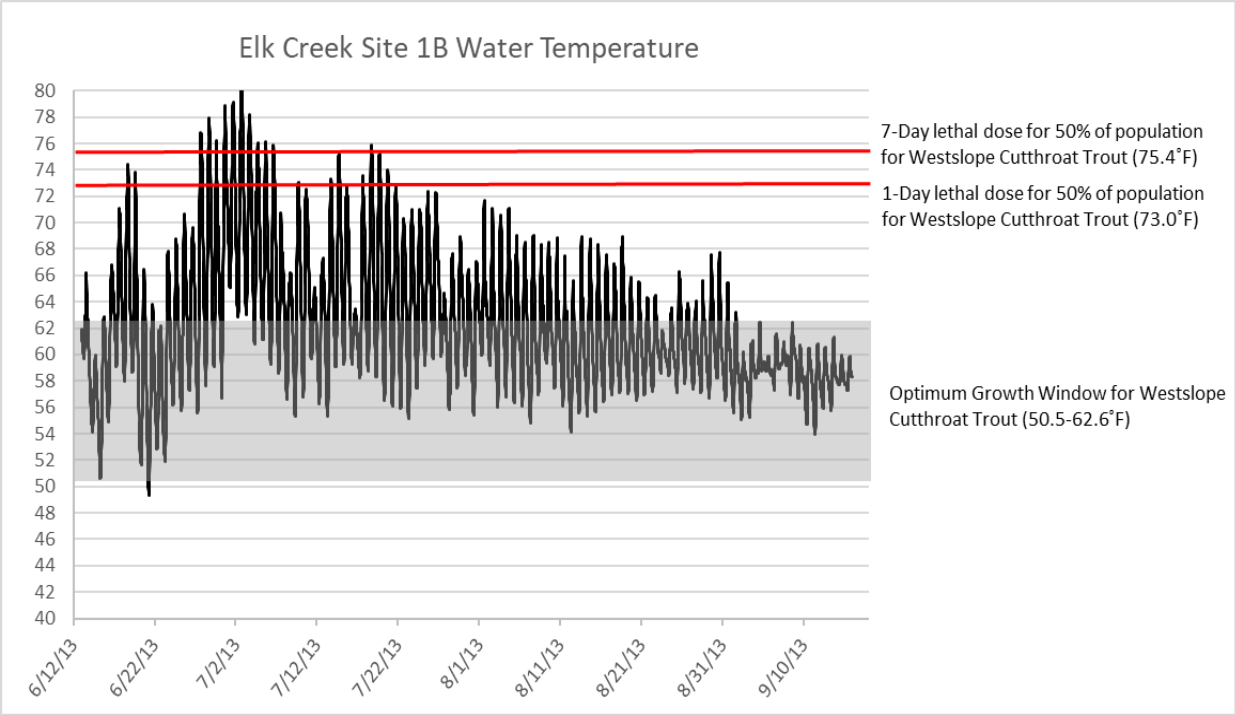


Figure 6-8. Water temperature data for Elk Creek Site 1B

Riparian Health/Shade

Shade-related data, including Solar Pathfinder data (**Appendix G**) were collected at sites 1A, 1B, 1C, and 1D, and used in conjunction with aerial photography to model the existing effective shade using the Shade Tool (Washington State Department of Ecology 2008). Shade targets were developed based on level IV ecoregion and the expected riparian vegetation community for that ecoregion (**Appendix I**). That vegetation community was then compared to shade curves developed for the near-by Targhee National Forest for reference riparian vegetation conditions (Shumar and de Varona 2009). **Figure 6-9** compares the existing effective shade to its respective shade targets, while **Figure 6-10** plots the difference between the existing effective shade and the shade targets. The plots are displayed in an upstream (left) to downstream (right) orientation to easily correlate targets and existing shade to location on the stream. Positive numbers in **Figure 6-10** indicate that the existing effective shade exceeds the shade targets, while negative numbers indicate areas where existing effective shade is deficient. As shown in **Figure 6-10**, Elk Creek has deficient shade in comparison to shade targets throughout much of the stream, which is ultimately contributing to the high water temperatures collected at all monitoring sites.

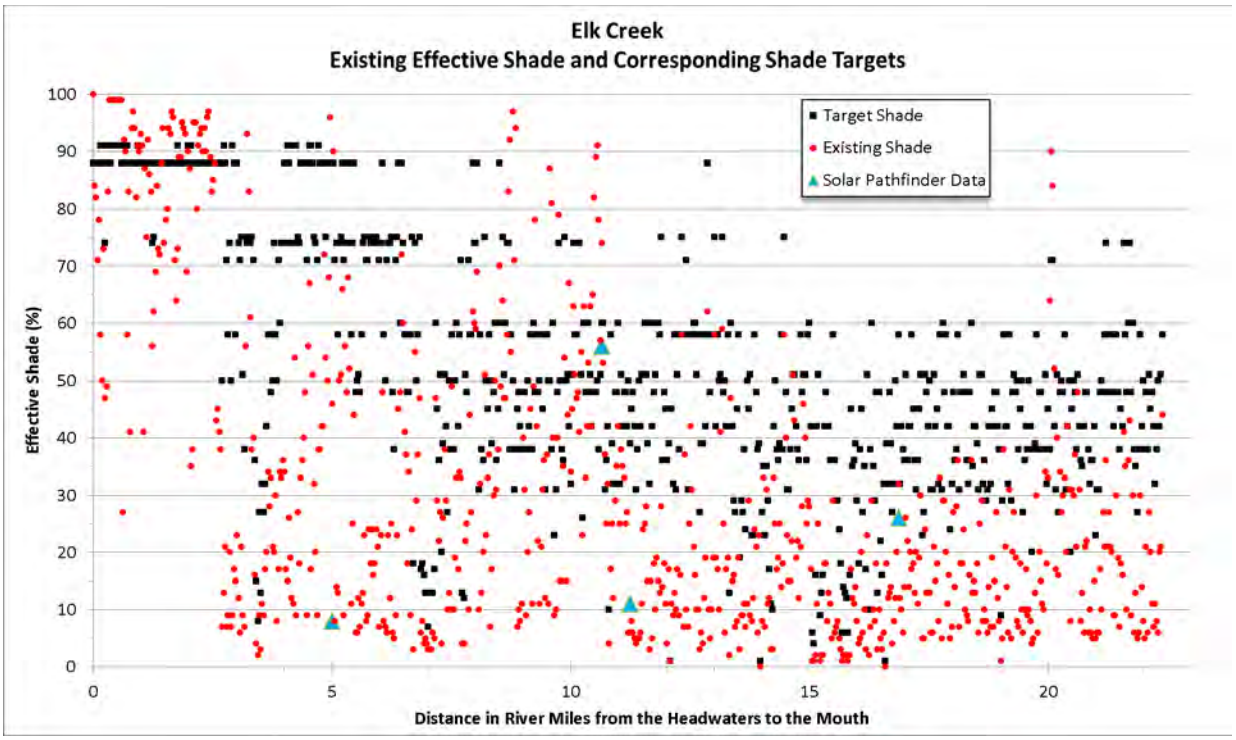


Figure 6-9. Existing Effective Shade and Corresponding Shade Targets for Elk Creek

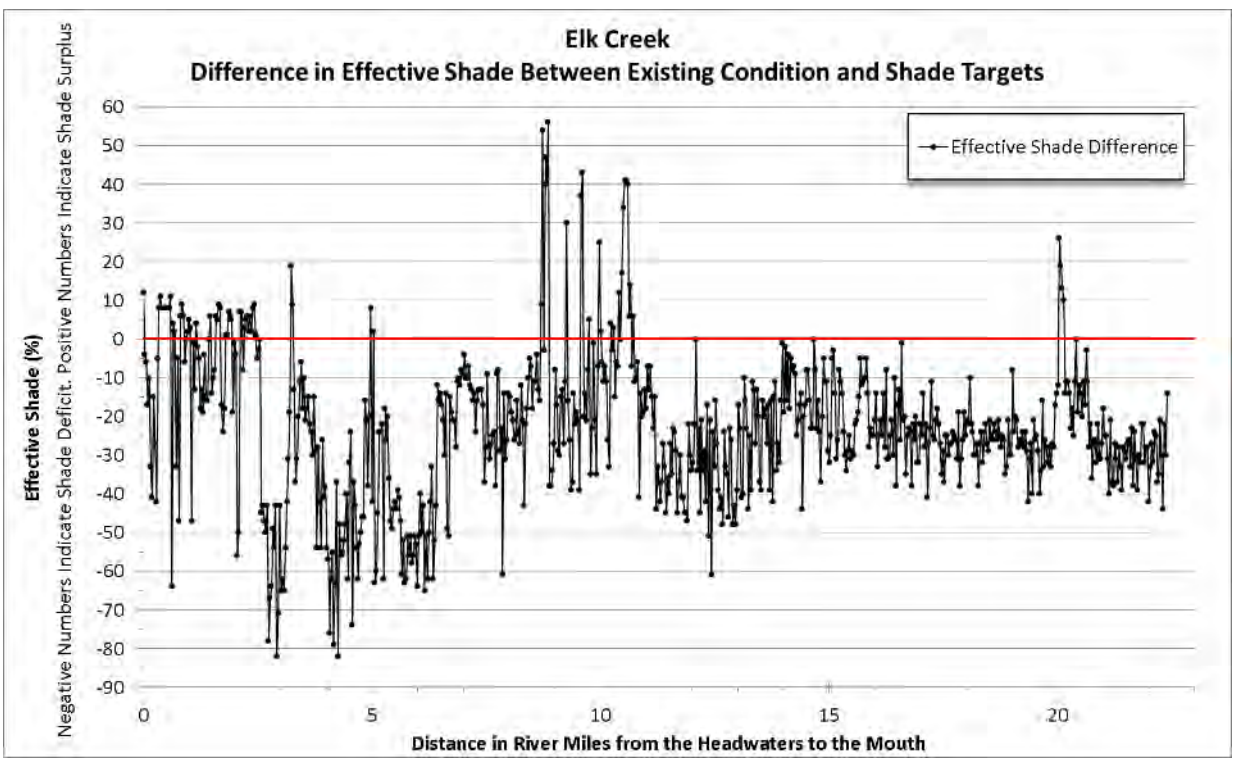


Figure 6-10. Difference in Effective Shade between Existing Condition and Shade Targets for Elk Creek

Channel Width/Depth Ratio

Channel width/depth ratio was measured at four sites along Elk Creek as a part of the data collection effort to assess sediment impairment (**Section 5.0**). Data collected by DEQ in 2010 and 2013 indicate that Elk Creek is meeting the width/depth ratio targets at three of the four monitoring sites (**Table 6-7**). It was noted in **Section 5.4.3.5** that historical and current beaver activity in addition to livestock grazing in the middle portion of Elk Creek may be affecting the width/depth ratio at site ELKC 06-02. Although this data was collected in four discrete locations, the locations of the monitoring sites were chosen because they are assumed to be representative of Elk Creek as a whole. It is possible that the width/depth ratio may be exceeding targets in more areas along Elk Creek, especially in areas where land management practices are poor, but areas that have good land management practices in place should not be negatively affecting the width/depth ratio of Elk Creek.

Table 6-7. Elk Creek Calculated Width/Depth Ratios in Comparison to Width/Depth Ratio Targets

Reach/Site ID	Year Data Collected	Mean BFW (ft)	W/D Ratio Target	W/D Ratio
M06ELKC07	2013	7.5	≤ 11	9.4
ELKC 05-01	2013	5.6	≤ 11	7.9
ELKC 06-02[1]	2010, 2013	13.6	≤ 11	19.3
ELKC 11-01	2013	7.0	≤ 11	9.0

[1]Values are averages from one sampling event in 2010 and two in 2013

Instream Discharge (Streamflow Conditions)

As of February 2, 2020, there were at least 10 entities that held water rights on Elk Creek and its tributaries. During the irrigation season in 2013, the monitoring site at the mouth (Site 1A) went dry by June 18th. Based on the in-stream temperature data collected at that site, it appears that instream discharge is having a significant effect on water temperatures in Elk Creek. The high water temperature and lack of instream flow in Elk Creek may be preventing fish from the Madison River from migrating up Elk Creek to spawn.

Qual2k Temperature Simulation and Implications for Fish Populations

Water temperature, flow, channel characteristics, and riparian shade data were incorporated into a QUAL2K water quality model to characterize existing temperature conditions and evaluate the effects of increases in shade and streamflow for Elk Creek (Chapra et al 2012). The model was developed for the warmest temperature day occurring during temperature logger deployment during summer 2013, which occurred on 7/3/2013.

The stream section modeled for this analysis included the section from the mouth of Elk Creek to 18.6 miles upstream (which is near site 1-D on **Figure 6-7**). Within the model, water temperatures were predicted largely based on climate data from the Western Climate Center (https://wrcc.dri.edu/) Ennis Montana weather station. Estimates of riparian shade along the length of the study section were estimated using the Shade Tool (**Section 6.4.2.2**) in ArcGIS. Headwater temperature conditions were estimated using hourly temperature loggers deployed at monitoring sites in **Figure 6-7**. Channel characteristics were based on field measurements taken by Montana DEQ during discharge measurements and sediment surveys. Detailed boundary conditions and parameter used in the model can be found in **Appendix J**. The model is considered adequate for evaluating the potential impacts of increasing shade and stream flow on water temperature. However, it may not be suitable for all purposes.

The performance of the model was evaluated by comparing modeled temperatures at temperature loggers to actual temperatures collected on 7/3/2013 using the absolute relative error method, as described in **Appendix J**. Despite limited field data, the modeled maximum temperatures approximated measured maximum temperatures with an error rate of 2.4% (representing the average percent difference between modeled and actual conditions) (**Appendix J**; Table J-2).

Existing data indicates that the entire modeled section of Elk Creek is currently not suitable for Westslope cutthroat trout or Arctic grayling due to high temperatures (**Appendix J**; Figure J-5) Elk Creek does not currently contain either species (Mike Duncan FWP, personal communication January 24, 2020), but a basin-wide initiative has focused on introducing these species throughout the Madison drainage (Clancy and Lohrenz 2015).

The potential management scenarios modeled as part of this exercise included an 15% increased flow scenario, an increased shade scenario to represent likely shade as a result of riparian restoration, and a scenario that included a combination of actions (15% increased flow, increased shade, and decreased wetted with on sections predicted to not meet the width: depth criteria). The increased shade scenario was developed using predictions of natural vegetation for ecoregion IV and shade curves for the near-by Targhee National Forest for reference riparian vegetation conditions (Shumar and de Varona 2009; **Section 6.4.2.2** and **Appendix I**). Results indicate that the increased flow scenario decreased maximum temperatures at the most downstream site by 0.48˚C, the increased shade scenario decreased temperatures by 4.7˚C, and the combination scenario of increased shade and flow and decreased wetted width decreased temperatures by 5.0˚C (**Appendix J**; Figure J-5 to J-8).

The increased shade scenario showed a decrease in the maximum temperature below the 7-Day Lethal Temperature for 50% of the population at the most upstream section of the modeled portion above mile 13). The combination scenario did not greatly reduce temperatures below values estimated for increased shade alone. Because the decrease of temperature below lethal limits would primarily occur only in the very upstream portion of the creek, this would not leave much stream length suitable for Westslope cutthroat or Arctic grayling if they were present. Nonetheless, Elk Creek would be suitable for these sensitive fish species during other time periods of the summer, and efforts to increase shade could increase the amount of thermal refuge available for other species. Although a 15% increase in instream flow had a minimal impact on temperature according to our models, any increase in stream flow would also be beneficial given that water withdrawals may contribute to complete dewatering of Elk Creek.

6.4.2.3 Moore Creek

Moore Creek flows from its headwaters in the Tobacco Root Mountains to its mouth at the Fletcher Channel, a side channel of the Madison River, which flows into Ennis Lake. Moore Creek was listed as impaired by temperature in the 2016 Integrated Report based on recent data collected and the comparison of that data to the water quality targets outlined in **Table 6-3**. A summary of the existing temperature-related water quality conditions and a comparison of those conditions to water quality targets are presented in this section.

Water Temperature

In 2013 DEQ collected water temperature at 30-minute intervals and shade-related data from four sites on Moore Creek (Sites 4A, 4D, 4E, and 4F, **Appendix G**) (**Table 6-7** and **Figure 6-11**). Sites 09-01 and 09-04 in **Figure 6-11** were sites where only channel geometry measurements were collected. They are shown for reference because the width of the stream affects heating at the water surface and was used

in Qual-2k model development described below. A maximum temperature (T_{max}) of 78.0°F was recorded at Site 4A near the mouth, with 15 days exceeding 73°F which is the 24 hour lethal temperature dose for 10% of the population of Westslope cutthroat trout. The warmest 7-day period in 2013 or the Maximum Weekly Maximum Temperature (MWMT) was 77.0°F at Site 4A, and the MWMT at Site 4A exceeded the 7-day UILT of 75.4°F for Westslope cutthroat trout, and just met the 7-day UILT for Arctic grayling (77.0°F), which is a species of concern that has been re-introduced to Moore Creek.

Table 6-7. Temperature Data Summary for Moore Creek in 2013

Stream	Site[1]	Maximum Temperature (T_{max})	7-day Average Daily Maximum (MWMT)	Number of Days With Water Temperatures Exceeding 73°F
Moore Creek	4A	78.0°F	77.0°F	15
Moore Creek	4D	72.1°F	70.9°F	0
Moore Creek	4E	65.7°F	64.9°F	0
Moore Creek	4F	70.0°F	68.9°F	0

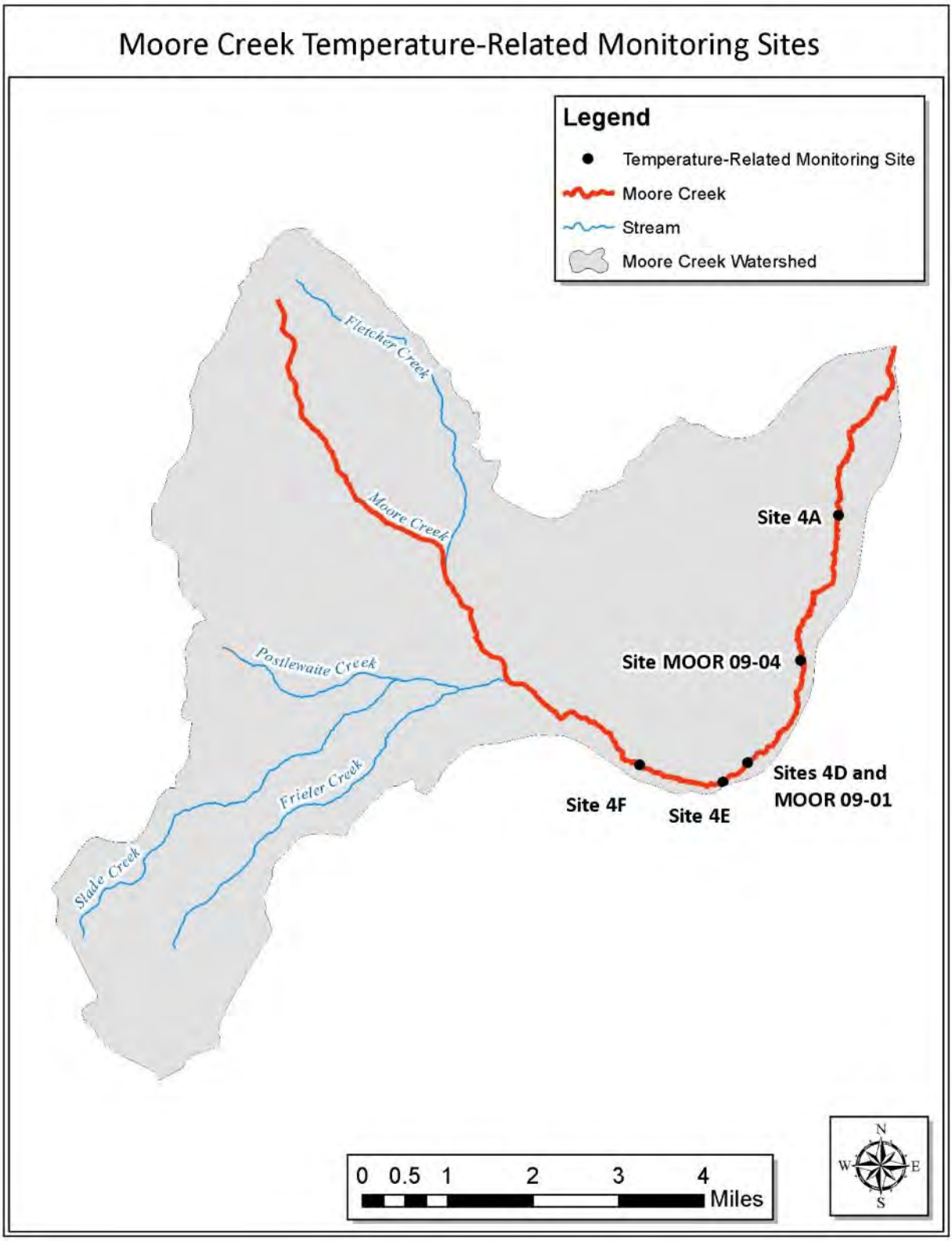


Figure 6-11. Map of Temperature-Related Monitoring Sites on Moore Creek

Figure 6-12 shows the water temperature data for Moore Creek Site 4A. This data shows that there were several exceedances of the 24-hour lethal dose threshold for 10% of the population of Westslope cutthroat trout in June and July. The MWMT threshold was also exceeded in June and July.

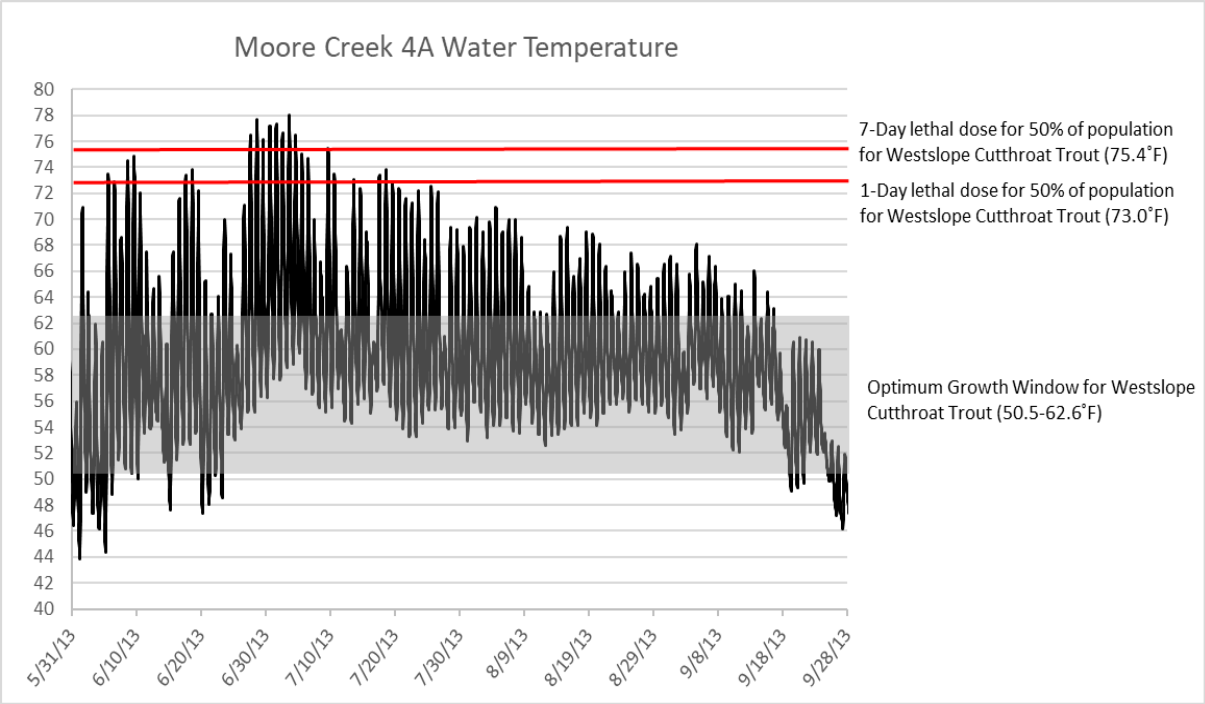


Figure 6-12. Water temperature data for Moore Creek Site 4A

Riparian Health/Shade

Shade-related data, including Solar Pathfinder data (**Appendix G)** were collected at sites 4A, 4D, 4E, and 4F, and used in conjunction with aerial photography to model the existing effective shade using the Shade Tool (Washington State Department of Ecology 2007). Shade targets were developed based on level IV ecoregion and the expected riparian vegetation community for that ecoregion (**Appendix I**). That vegetation community was then compared to shade curves developed for the near-by Targhee National Forest for reference riparian vegetation conditions (Shumar and de Varona 2009). **Figure 6-13** compares the existing effective shade to their respective shade targets, while **Figure 6-14** plots the difference between the existing effective shade and the shade targets. The plots are displayed in an upstream (left) to downstream (right) orientation to easily correlate targets and existing shade to location on the stream. Positive numbers in **Figure 6-14** indicate that the existing effective shade exceeds the shade targets, while negative numbers indicate areas where existing effective shade is deficient. As shown in **Figure 6-14**, the lower portion of Moore Creek (downstream of the Town of Ennis) has deficient shade in comparison to shade targets, which is ultimately contributing to the high water temperatures collected near the mouth at Site 4A.

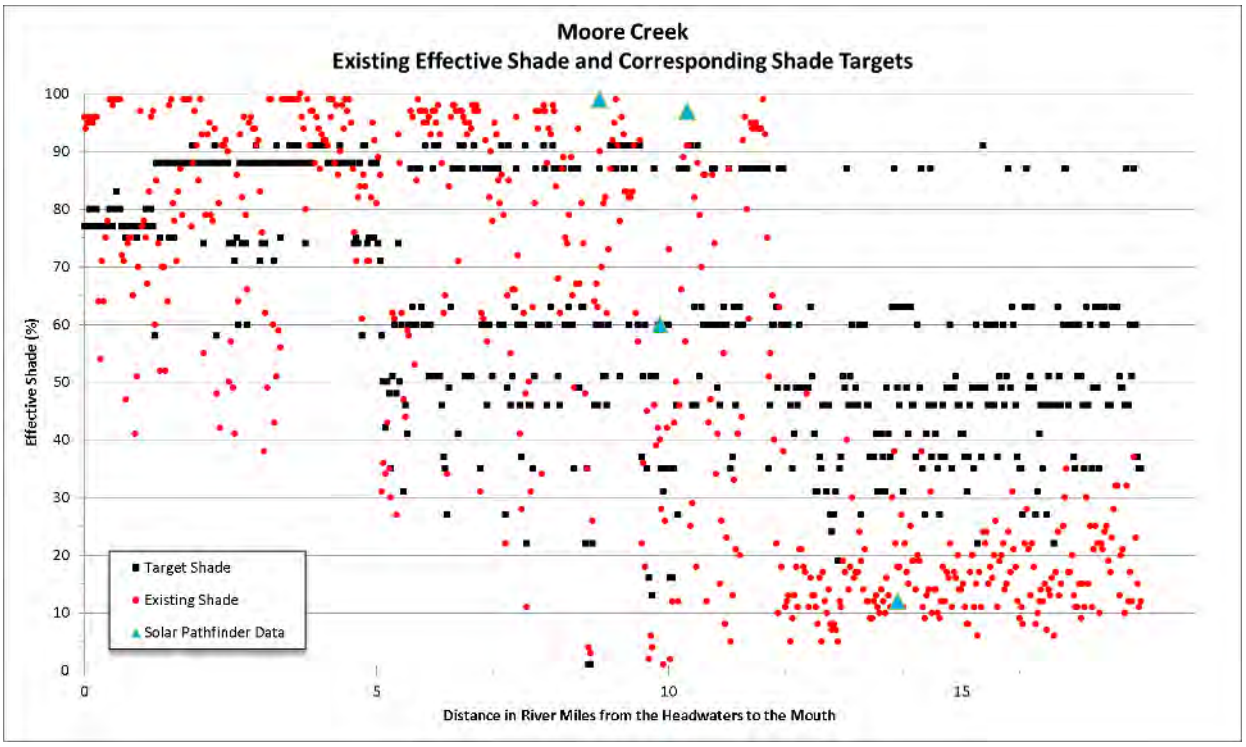


Figure 6-13. Existing Effective Shade and Corresponding Shade Targets for Moore Creek

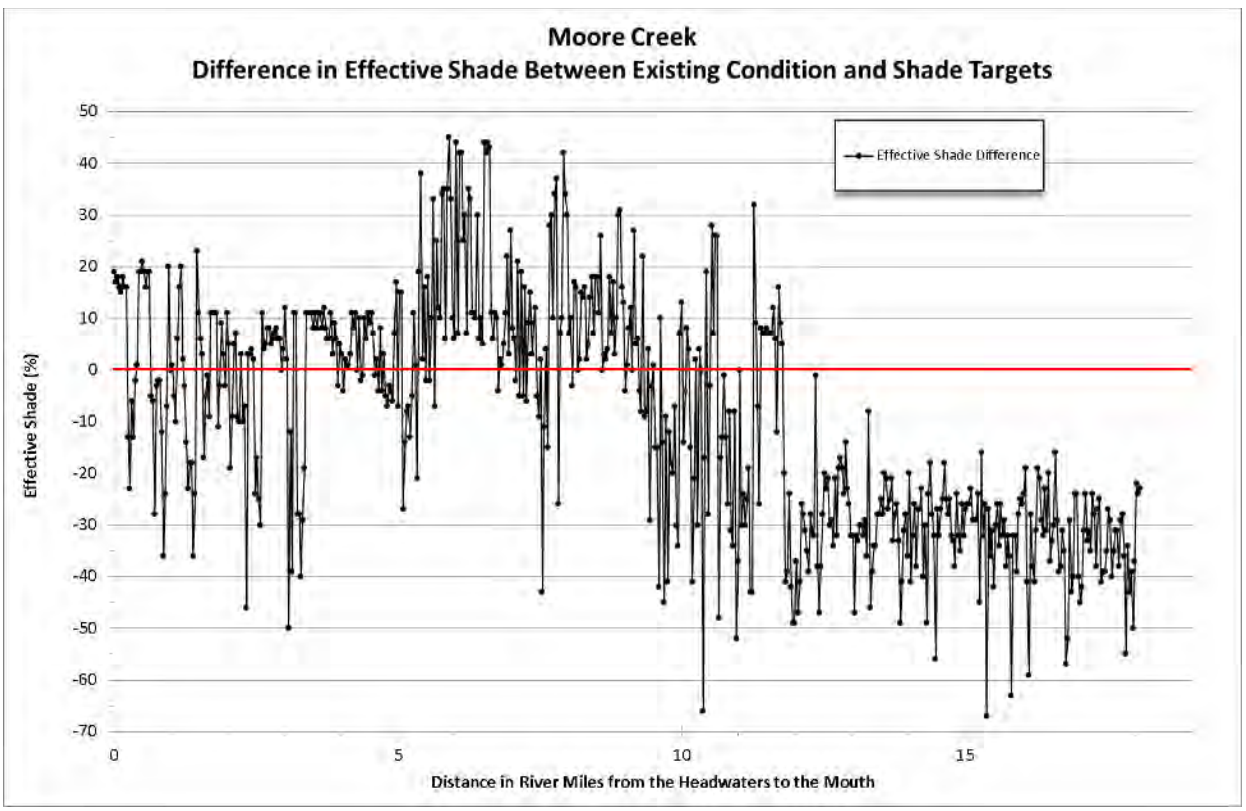


Figure 6-14. Difference in Effective Shade between Existing Condition and Shade Targets for Moore Creek

Channel Width/Depth Ratio

Channel width/depth ratio was measured at two sites along Moore Creek as a part of the data collection effort to assess sediment impairment (**Section 5.0**). Data collected by DEQ in 2014 indicate that Moore Creek is meeting the width/depth ratio targets at both of the monitoring sites (**Table 6-8**). Although this data was collected in two discrete locations, the locations of the monitoring sites were chosen because they are assumed to be representative of Moore Creek as a whole. It is possible that the width/depth ratio may be exceeding targets in areas along Moore Creek, especially in areas where land management practices are poor, but areas that have good land management practices in place should not be negatively affecting the width/depth ratio of Moore Creek.

Table 6-8. Moore Creek Calculated Width/Depth Ratios in Comparison to Width/Depth Ratio Targets

Reach/Site ID	Year Data Collected	Mean BFW (ft)	W/D Ratio Target	W/D Ratio
MOOR 09-01	2014	18.3	≤ 24	21.1
MOOR 09-04	2014	4.6	≤ 11	4.8

Instream Discharge (Streamflow Conditions)

As of February 4, 2020, a total of 10 entities held water rights on Moore Creek and its tributaries. In addition to these diversions, there is a small reservoir (Hacker Dam) located upstream of the town of Ennis. Moore Creek is a relatively small stream; therefore, any irrigation withdrawals could potentially have a significant impact on streamflow. Montana FWP holds a water right for an instream flow reservation of 1.4 cfs for the purpose of maintaining the resident trout population in Moore Creek; protecting important spawning habitat for the arctic grayling population that inhabits Ennis Lake and the channels of the Madison River below the town of Ennis; and to help protect the habitat of those wildlife species which depend upon the stream and its associated riparian zone for food, water, and shelter (Montana Department of Fish Wildlife and Parks 1989).

Qual2k Temperature Simulation and Implications for Fish Populations

Water temperature, flow, channel characteristics, and riparian shade data were incorporated into a QUAL2K water quality model to characterize existing temperature conditions and evaluate the effects of increases in shade and streamflow for Moore Creek (Chapra et al 2012). The model was developed for the warmest temperature day occurring during temperature logger deployment during summer 2013, which occurred on 7/3/2013.

The stream section modeled for this analysis included the section from the mouth of Moore Creek to approximately 12 miles upstream, which is near site 4-F on **Figure 6-11**. Within the model, water temperatures were predicted largely based on climate data from the Western Climate Center (https://wrcc.dri.edu/) Ennis Montana weather station. Estimates of riparian shade along the length of the study section were estimated using the Shade Tool (**Section 6.4.2.3**) in ArcGIS. Headwater temperature conditions were estimated using hourly temperature loggers deployed at monitoring sites in **Figure 6-11**. Channel characteristics were based on field measurements taken by Montana DEQ during discharge measurements and sediment surveys. Detailed boundary conditions and parameter used in the model can be found in **Appendix J**. The model is considered adequate for evaluating the potential impacts of increasing shade and stream flow on water temperature. However, it may not be suitable for all purposes.

The performance of the model was evaluated by comparing modeled temperatures at temperature loggers to actual temperatures collected on 7/3/2013 using the absolute relative error method, as described in **Appendix J**. Despite limited field data, the modeled maximum temperatures approximated measured maximum temperatures with an error rate of 2.7% (representing the average percent difference between modeled and actual conditions).

Existing data indicates that, during the hottest day of the year, Moore Creek becomes suitable for sensitive Westslope cutthroat trout and Arctic grayling starting at approximately 3 miles upstream from the mouth (**Appendix J**, Figure J-9). While Moore Creek does not currently contain Westslope cutthroat trout, this sensitive species is being introduced in the Madison drainage as part of recent efforts. Arctic grayling was introduced to Moore Creek in 2015 as part of a re-introduction initiative (Clancy and Lohrenz 2015).).

The potential management scenarios modeled as part of this exercise included an 15% increased flow scenario, an increased shade scenario to represent likely shade as a result of riparian restoration, and a scenario that included a combination of actions (15% increased flow, increased shade) The increased shade scenario was developed using predictions of natural vegetation for ecoregion IV and shade curves for the near-by Targhee National Forest for reference riparian vegetation conditions (Shumar and de Varona 2009; **Section 6.4.2.3** and **Appendix I**).

Results indicate that the increased flow scenario decreased modeled maximum temperatures at the most downstream site by 0.48˚C, the increased shade scenario decreased modeled maximum temperature by 2.1˚C, and the combination scenario decreased modeled maximum temperature by 2.4˚C (**Appendix J**, Table J-3). While an increase in shade had a bigger impact on stream temperatures, the combined scenario could decrease the temperature near the mouth to be at or just slightly above the 24-hour Lethal temperature for 10% of the population for Westslope cutthroat trout, and would potentially increase the overall length of stream available to these species during the warmest times by up to 3 miles (**Appendix J**; Figure J-9 to Figure J-12).

6.4.3 Summary of Madison TPA Stream Shade Conditions

Effective stream shade plays a crucial role in the temperature regime of a stream. To determine where Cherry Creek, Elk Creek, and Moore Creek are in relation to adequate stream shade, an effective stream shade net balance was calculated based on the magnitude of shade surplus or shade deficit at each 50-meter point along the length of the stream, using the data presented in **Figures 6-6, 6-10,** and **6-14**. These data were plotted in box plots for each stream, showing how close each stream is to meeting its shade targets (**Figure 6-15**). Box plots depict the smallest observation (sample minimum), 25th percentile, median, 75th percentile, and the largest observation (sample maximum). If the median value (dark line in the middle of the box) is above zero, then the stream has adequate shade in more places than it has deficient shade. If the median value is below zero, then the stream has deficient shade in more places than it has adequate shade. The magnitude above or below this line represents the amount of the shade deficit or surplus, which makes it easier to compare different streams. For example, Cherry Creek is much closer to meeting its shade targets than Elk Creek.

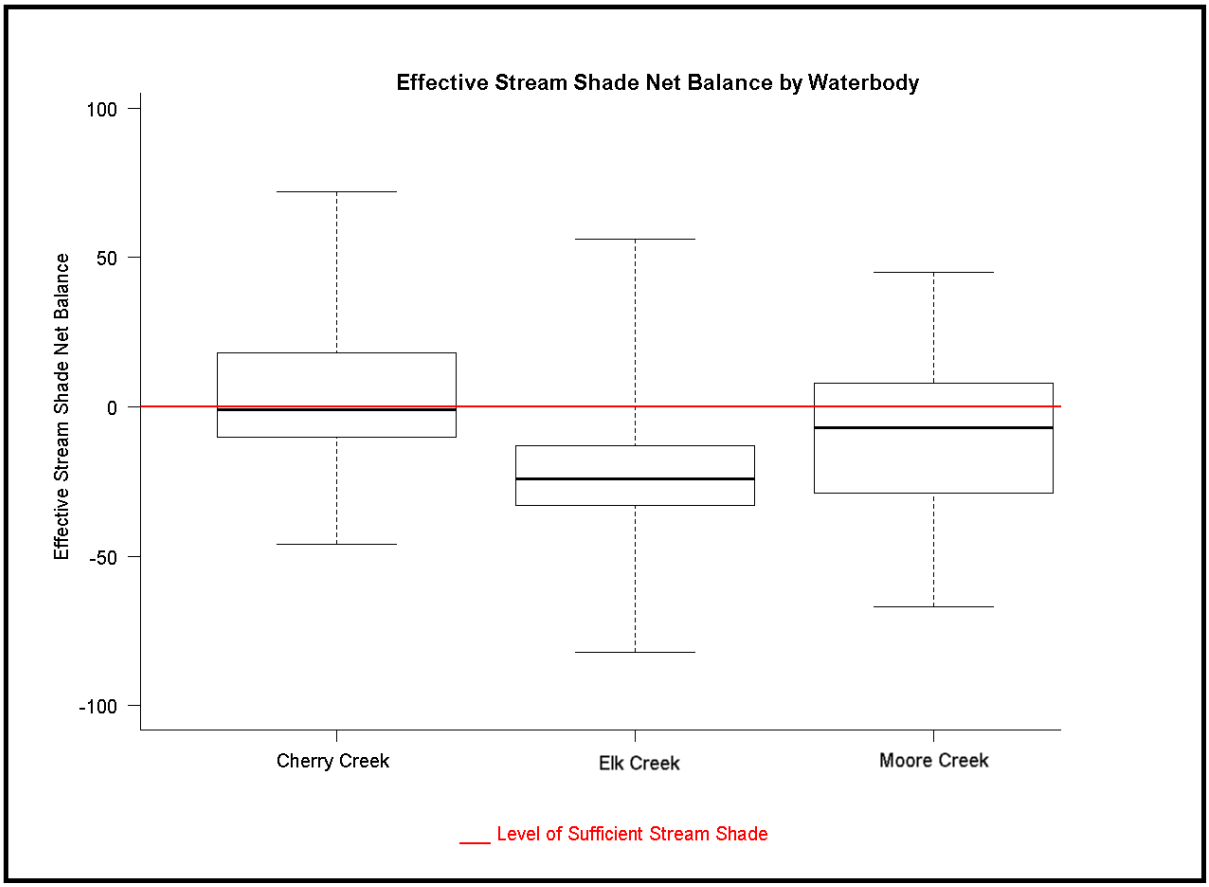


Figure 6-15. Box plot showing the effective stream shade net balance for Cherry Creek, Elk Creek, and Moore Creek

6.5 Total Maximum Daily Loads (TMDLs)

This section summarizes the approach used for TMDL development, and then presents the TMDLs, allocations, and estimated reductions necessary to meet water quality targets for the three temperature impaired streams. **Table 6-9** shows the temperature TMDLs developed in the Madison TPA.

Table 6-9. Temperature TMDLs developed in the Madison TMDL Planning Area

Stream Segment	Assessment Unit ID
Cherry Creek – headwaters to mouth (Madison River)	MT41F002_010
Elk Creek – headwaters to mouth (Madison River)	MT41F002_020
Moore Creek – springs to mouth (Fletcher Channel), T5S R1W S15	MT41F004_130

Stream temperatures are continuously variable and dependent on multiple factors such as climate, riparian shade, and streamflow. However, temperature TMDLs for these streams are based on solar loading to a stream at an achievable condition in which the stream is meeting its targets for riparian shade. Daytime solar radiation is often the most significant temperature source and increased riparian vegetation (shade) can intercept solar radiation (Beschta, 1997). Nonetheless, even under ideal conditions, a stream might not be meeting its target at every single point along its length due to

localized disturbances or other environmental factors and therefore, in evaluating targets it is important to look at overall shade health for a stream or specific reach.

While meeting shade targets is the ultimate method for determining if a stream is meeting its temperature TMDL, a daily load can be calculated by quantifying the amount of solar flux reaching the stream on the warmest day of the year, while under target shade conditions (**Equation 6-1**).

Equation 6-1: TMDL = (X) (Y) (20.4)

TMDL = Total maximum daily load in kcal/day
X = daily watts/ft^2 of solar flux to the stream surface for the stream reach under target shade conditions
Y = water surface area of stream reach in ft^2 (wetted width x length)
20.4 = conversion factor from watts to kcal/day

6.6 Source Assessment

This section provides the approach used for source assessment, which characterizes the type, magnitude, and distribution of sources contributing to temperature loading and establishes the approach used to develop TMDLs and allocations to specific source categories for each. Source characterization and assessment to determine the major sources in each of the temperature impaired watersheds was conducted by using monitoring data collected from the Madison TPA from 2009-2014, which represents the most recent data for determining existing conditions, and by using aerial photos, Geographic Information System (GIS) analysis, field work, and literature reviews. Assessment of existing temperature sources is needed to understand Load Allocations (LAs), and load reductions for different source categories. Source characterization links temperature sources, temperature loading to streams, and water quality response, and supports the formulation of the allocation portion of the TMDL.

Watersheds with temperature issues primarily consist of agricultural land uses (dryland and irrigated cropland, pasture, and rangeland), silviculture (timber harvest and forest roads), and residential development. These nonpoint sources may include a variety of discrete and diffuse pollutant inputs that have differing pathways to a waterbody. Ideally, monitoring efforts are conducted in a way that helps with the identification of these pathways. There are no permitted point source discharges to streams with temperature TMDLs developed in the Madison.

6.6.1 Description of Temperature Sources

The following sections give a general overview of temperature sources. More detailed source descriptions are included for each specific stream in **Sections 6.6.2** through **6.6.4.**

6.6.1.1 Point Source Discharges

There are no point sources with an active Montana Pollutant Discharge Elimination System (MPDES) permit in the Cherry Creek, Elk Creek, or Moore Creek watersheds

6.6.1.2 Agriculture

Agricultural sources of temperature can result from land use practices that remove riparian vegetation by cultivation or livestock grazing and practices that alter streamflow by the use of surface water diversions. Temperature contributions from specific agricultural activities are described below.

Irrigated and Dryland Cropping

Cropping in the watersheds of temperature impaired waterbodies in the Madison TPA is relatively minimal (**Figures 6-16,6-18**, and **6-20**). Cropland in these watersheds is predominately irrigated production of alfalfa hay and pasture/hay, with smaller acreages of irrigated and dryland cultivated cropland. Irrigated lands are usually in continuous production and have annual soil disturbance. Dryland cropping may have fallow periods of 16 to 22 months, depending on site characteristics and landowner management. Cropland may contribute temperature loading to streams when it encroaches on the riparian area, reducing the amount of shade producing woody vegetation, or by altering streamflow by irrigation withdrawals and irrigation return drains. Water withdrawals reduce the volume of water in a stream, which decreases the buffering capacity that stream has to handle solar radiation. Irrigation return flows are generally warmer in temperature than water that remains in the stream due to exposure to solar radiation in ditches and canals, which do not typically have shade producing woody vegetation on the banks.

Livestock Grazing

Grazing on rangeland and in pastures is common in the Madison TPA (**Figures 6-16,6-18**, and **6-20**). Cattle are allowed to roam and are generally not concentrated along the valley bottoms during the growing season when many pasture systems are hayed. Horses may also be allowed to roam and graze, though they have been mostly observed on small acreage lots that are fenced. Pastures are managed for hay production during the summer and for grazing during the fall through spring. Hay pastures are thickly vegetated in the summer; less so in the fall through spring. The winter grazing period is typically long (October–May), and trampling and feeding further reduce biomass when it is already low. Rangeland is typically grazed during the summer in the watershed. Rangeland differs from pasture in that rangeland has much less biomass.

Although no livestock grazing data were collected for private or state managed lands, grazing allotment data were collected from the BLM and USFS on the federally managed lands and were compiled per impaired waterbody watershed as total Animal Unit Months (AUM) per drainage. An assumption was made that livestock management on private and state lands is similar to the federally managed lands. The BLM does not make an annual “count” of the livestock that graze on BLM-managed lands because the actual number of livestock grazing on public lands on any single day varies throughout the year and livestock are often moved from one grazing allotment to another. Instead, the BLM compiles information on the number of AUMs used each year, which takes into account both the number of livestock and the amount of time they spend on public lands (U.S. Department of Interior, Bureau of Land Management 2017a).

Total AUMs were determined only for allotments that have some areas draining to an impaired waterbody. These numbers constitute the existing permits for grazing leases on public lands within grazing allotments and represent a maximum number of AUMs possible at any one time. AUMs are reported for public lands within each allotment. However, since allotment boundaries differ from the watershed boundaries, a distinction is made between grazing on public land within the entire allotment and on public land within the allotment that also lies within the sub-watershed boundary. This compilation is for coarse source assessment purposes only. Some attempt was made to obtain grazing reports of USFS allotments to verify grazing practices for Moore Creek and Cherry Creek, and this information is presented in the Agriculture portion of the source assessment.

6.6.1.3 Silviculture

A significant portion of the Madison TPA is on forested lands administered by the US Forest Service (USFS) specifically the Beaverhead-Deerlodge and Gallatin National Forests, and lands administered by the Bureau of Land Management (BLM). Silviculture practices inevitably cause some measure of downstream effects that may or may not be significant over time. Changes in land cover will alter the rate at which water evapotranspires and thus the water balance; in that the distribution of water between base flow and runoff will change. Disturbances of the ground surface will also disrupt the hydrological cycle. The combination of these changes can alter water yield, peak flows, and water quality (Jacobson, 2004). In addition to changes in the hydrologic cycle, removal of riparian vegetation can result in decreased effective shade to the stream. The Montana Streamside Management Zone (SMZ) law, passed in 1991, prohibits timber harvest within 50 feet or 100 feet of a stream or lake depending on stream class and slope. Adjacent wetlands to the stream are also included within this protected zone, but a 50-foot buffer around the wetland is not required (MCA, 2017). If silvicultural activities follow the requirements of the SMZ law, there should not be a significant change in effective shade to the stream resulting from these activities.

An assessment of timber harvest operations for the Cherry Creek, Elk Creek, and Moore Creek watersheds was made based on harvest data collected by the US Forest Service from 1820 to present, and by using the Montana Spatial Data Infrastructure (MSDI) geospatial land cover data layer. These data were used to better understand recent operations by scale and location in comparison with available water quality data. Based on this data, there has been no significant timber harvest in any of these watersheds. Therefore, silviculture is not classified as a major source contributing to temperature impairment in these watersheds.

6.6.1.4 Residential Development

Residential development in a watershed can contribute to temperature through encroachment on riparian areas by buildings, streets, and residential lawns. This encroachment reduces the amount of shade producing woody vegetation and can limit the extent for future riparian vegetation expansion. Residential development in the Madison watershed is concentrated around the Ennis area and Moore Creek. Cherry Creek and Elk Creek watersheds have relatively low levels of residential development.

6.6.1.5 Natural Background

Natural sources contributing to increased stream temperatures including riparian grazing and browsing by wildlife, geology that limits riparian expansion, thermal springs, and the effects of natural events such as flooding, fire, and beetle kill were accounted for in target development and represent the reference condition to which existing condition data were compared to.

6.6.2 Cherry Creek Source Assessment

Factors contributing to elevated stream temperatures in Cherry Creek come from several nonpoint sources (i.e., diffuse sources that cannot easily be pinpointed) which are shown in **Figure 6-16**. There are no permitted point sources in the Cherry Creek watershed. DEQ identified the following source categories that contribute to elevated stream temperatures in the Cherry Creek watershed:

- Agriculture (irrigated cropping and livestock grazing)
- Natural background

Since stream shade is one of the primary temperature-influencing targets, areas lacking sufficient shade can be identified through the source assessment process as areas likely contributing to temperature

impairment. **Figure 6-17** is a map displaying the difference between target shade and existing shade for each data point in the analysis. This map can be used to identify areas where stream shade conditions can likely be improved, thus improving in-stream temperature conditions.

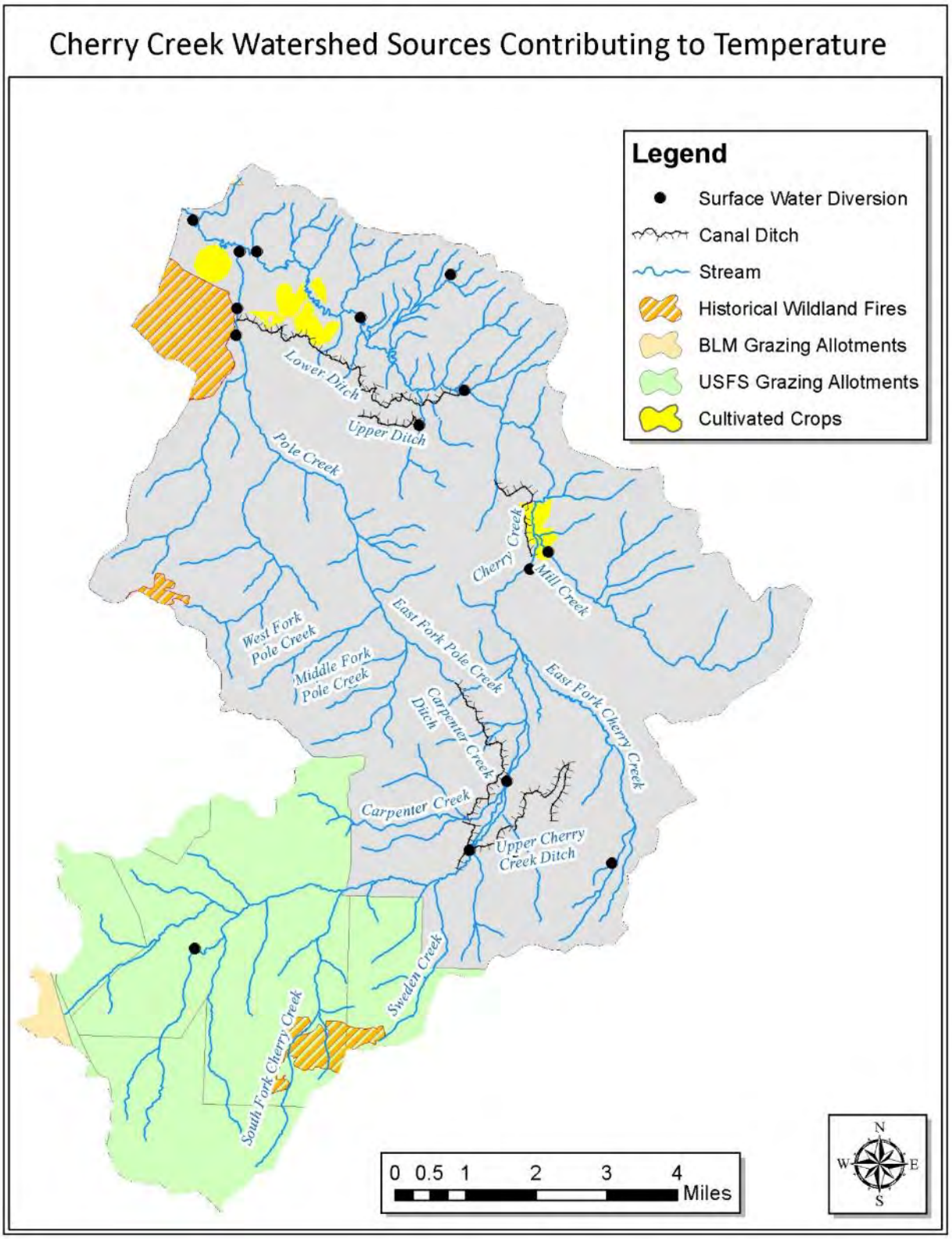


Figure 6-16. Map showing potential sources contributing to temperature impairment in Cherry Creek

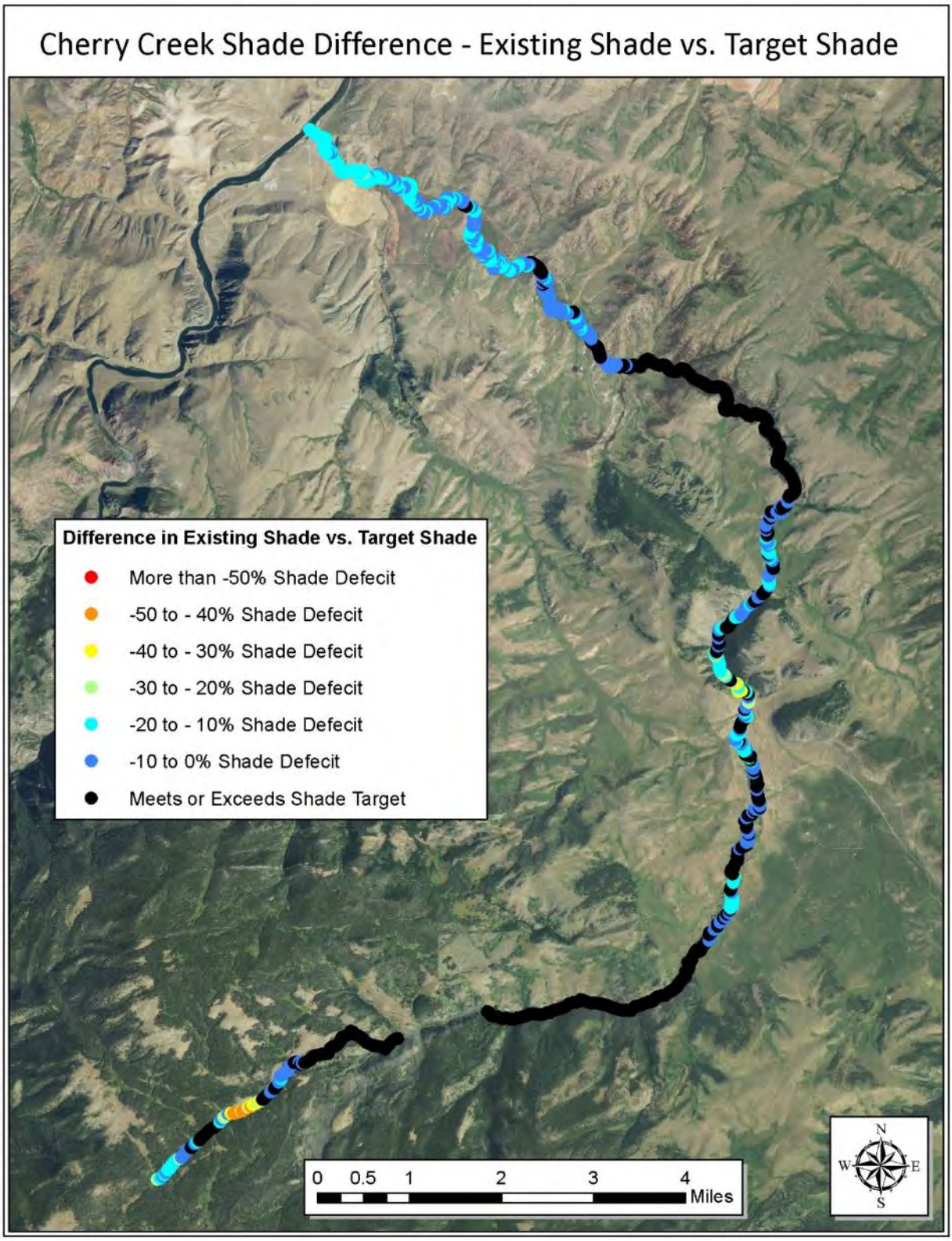


Figure 6-17. Map of Difference in Effective Shade between Existing Condition and Shade Targets for Cherry Creek

6.6.2.1 Agriculture

There are several possible ways that agriculture can contribute to stream temperatures as described in **Section 6.6.1.2** above. **Figure 6-16** shows the location of agricultural land and surface water diversions in the Cherry Creek watershed.

Irrigated Cropping

Cropland in the Cherry Creek watershed is primarily hay and pasture land, most of which is irrigated (U.S. Department of Agriculture, Montana Agricultural Statistics 2016) Several surface water diversion ditches shown in **Figure 6-16** are used to supply these irrigated hay fields and pastures. Areas downstream of these surface water diversions are generally lacking sufficient stream shade (**Figure 6-17**), indicating that agriculture is likely a significant factor in these areas not meeting shade targets. Hay fields encroaching in riparian areas and livestock grazing in riparian pastures can reduce the effectiveness of the existing shade-producing vegetation and prevent new shade producing vegetation from recolonizing in these riparian areas.

Livestock Grazing

Grazing on rangeland and pastures is common in the Cherry Creek watershed and occurs in a manner as described in **Section 6.6.1.2**. Private land grazing occurs throughout the watershed, and in areas where livestock have direct access to the stream, they can potentially be contributing to a lack of effective stream shade by grazing and browsing riparian vegetation. In addition to private land grazing, there are several public land grazing allotments in the Cherry Creek watershed (**Figure 6-16**). The Red Knob allotment is the only U. S. Forest Service allotment that Cherry Creek flows through. Prior to 2003, this allotment was part of three allotments (Red Knob South, Red Knob North, and Cherry Creek) (U. S. Forest Service 2010), with the Cherry Creek and Red Knob South areas closed to grazing. In 2010, these three allotments were combined into the Red Knob North allotments and new riparian grazing standards were adopted. Extensive efforts were undertaken by the USFS to add riparian exclosures to improve riparian vegetation in the Red Knob North section. An implementation monitoring review in 2010 reported that extensive improvements were made in riparian vegetation growth since the exclosures were added. USFS also reported that all riparian grazing standards were met for Red Knob pastures in 2010, which had not occurred previously. However, some trespass grazing occurred as cattle were able step over the wire stands. As of the 2010 report, the USFS was working to improve these exclosures (U. S. Forest Service 2010).

6.6.2.2 Natural Background

Natural sources contributing to stream temperatures including riparian grazing and browsing by wildlife, geology that limits riparian expansion, thermal springs, and the effects of natural events such as flooding, fire, and beetle kill were accounted for in target development and represent the reference condition to which existing condition data were compared to. Riparian grazing and browsing by wildlife occurs in the watershed, but since much of the watershed is grazed by livestock, it was not possible to differentiate wildlife impacts from domestic livestock impacts. Several wildland fires have historically occurred in the Cherry Creek watershed and are shown in **Figure 6-16**, while **Table 6-10** shows the details of these fires. One area of upper Cherry Creek which experienced a conifer die-off appears to have either been burned by an unidentified wildland fire or had tree loss through disease. This area was excluded from the shade analysis because the die-off was caused by natural factors and it is expected that this area will return to mature shade producing vegetation on its own.

Table 6-10. Wildland Fires in the Cherry Creek Watershed

Fire Name	Acres Burned[1]	Year
Bear Trap 2	15372	2012
Bear Trap	148	2002
Cherry Creek	544	Not Reported

[1]Acres burned includes total acres for the fire which may include areas outside of the watershed

6.6.3 Elk Creek Source Assessment

Factors contributing to elevated stream temperatures in Elk Creek come from several nonpoint sources (i.e., diffuse sources that cannot easily be pinpointed) which are shown in **Figure 6-18**. There are no permitted point sources in the Elk Creek watershed. DEQ identified the following source categories that contribute to elevated stream temperatures in the Elk Creek watershed:

- Agriculture (irrigated and dryland cropping and livestock grazing)
- Natural background

Since stream shade is one of the primary temperature-influencing targets, areas lacking sufficient shade can be identified through the source assessment process as areas likely contributing to temperature impairment. **Figure 6-19** is a map displaying the difference between target shade and existing shade for each data point in the analysis. This map can be used to identify areas where stream shade conditions can likely be improved, thus improving in-stream temperature conditions.

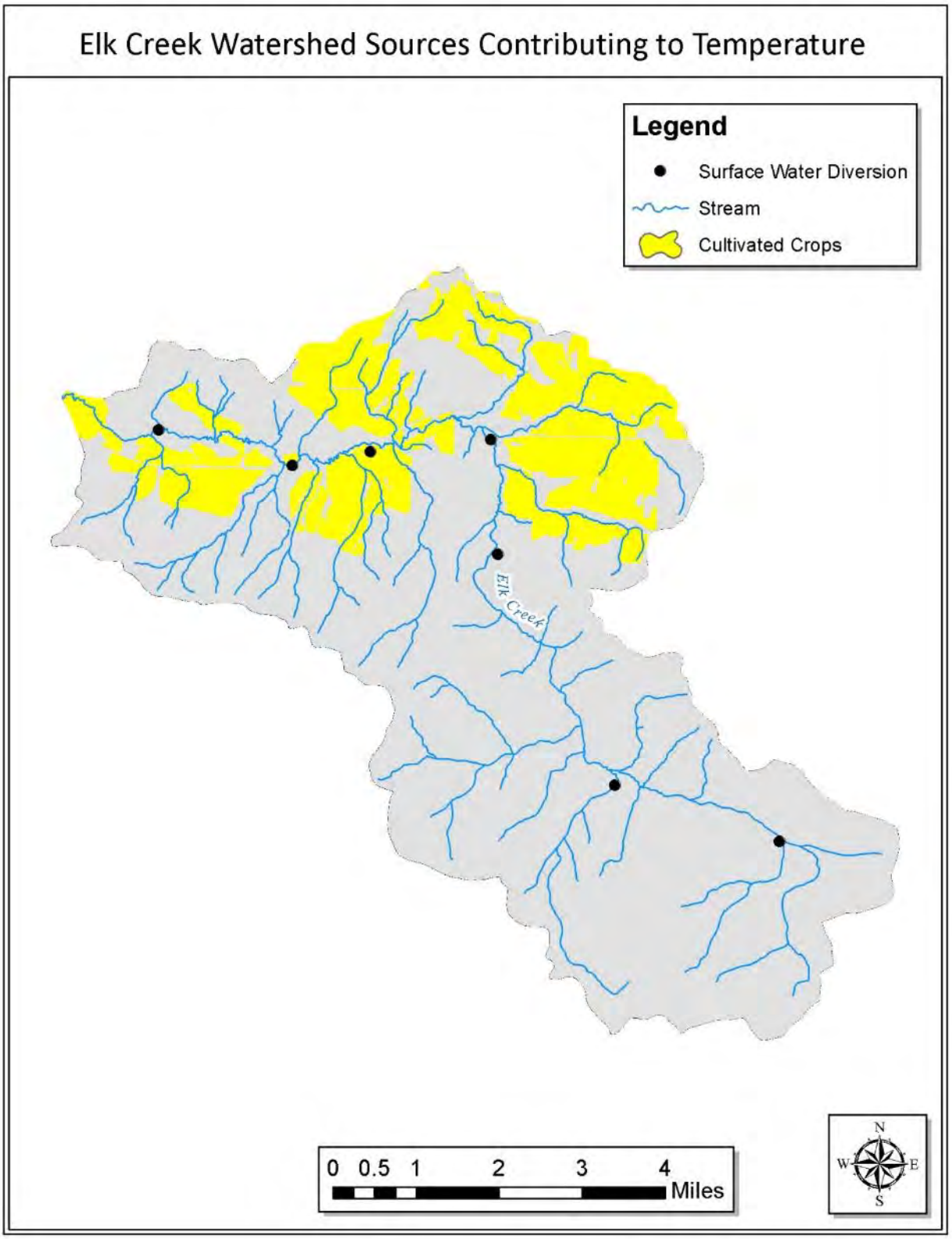


Figure 6-18. Map showing potential sources contributing to temperature impairment in Elk Creek

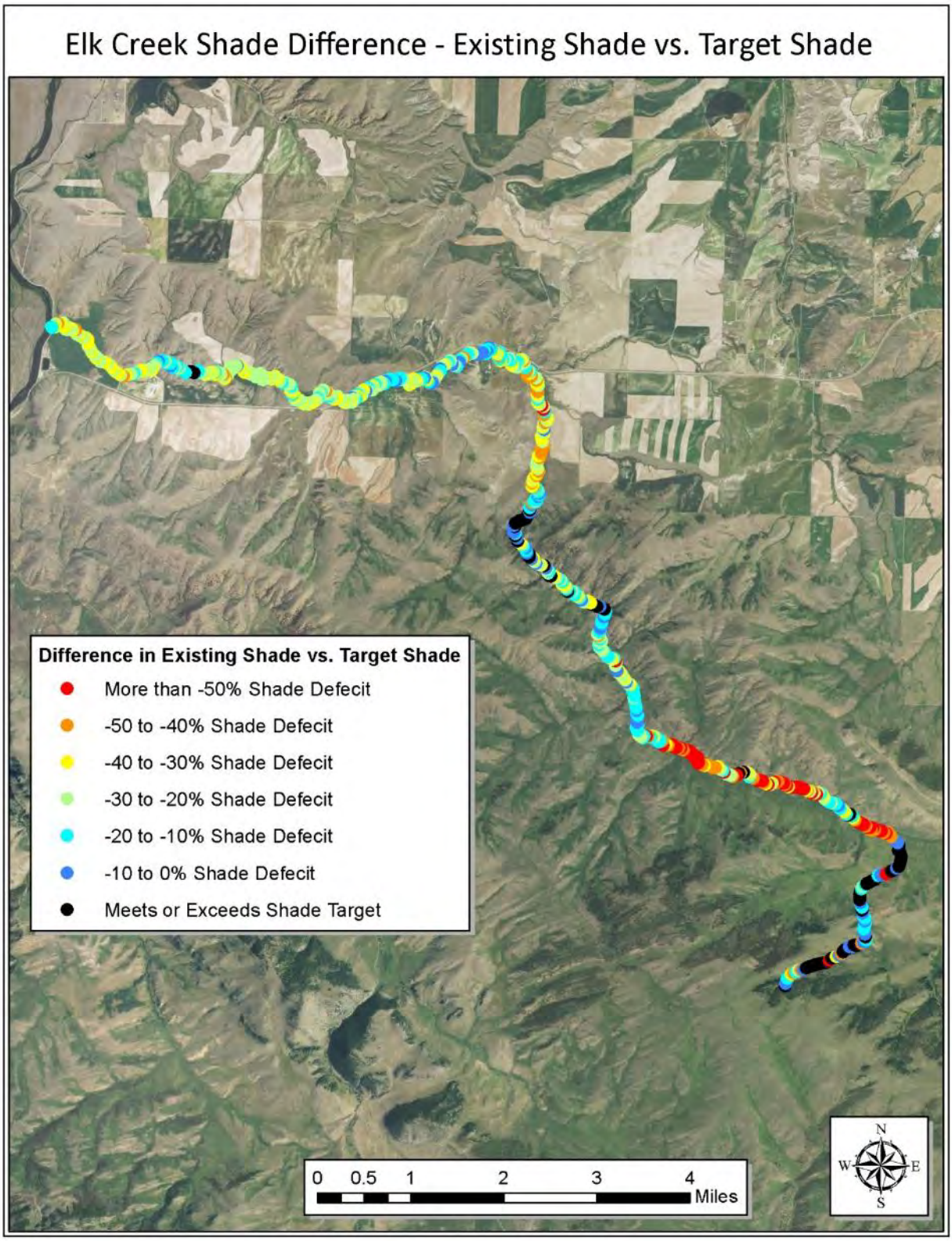


Figure 6-19. Map of Difference in Effective Shade Between Existing Condition and Shade Targets for Elk Creek

6.6.3.1 Agriculture

There are several possible ways that agriculture can contribute to stream temperatures as described in **Section 6.6.1.2** above. **Figure 6-18** shows the location of agricultural land and surface water diversions in the Elk Creek watershed.

Irrigated and Dryland Cropping

Cropland in the Elk Creek watershed is primarily dryland small grains production (specifically wheat and barley) and irrigated and dryland hay and pasture land (grass and alfalfa) (U.S. Department of Agriculture, Montana Agricultural Statistics 2016). Dryland cropping may have fallow periods, depending on site characteristics and landowner management. Several surface water diversions, shown in **Figure 6-18**, are used to supply these irrigated hay fields and pastures in the lower part of the watershed. Areas downstream of these surface water diversions are generally lacking sufficient stream shade (**Figure 6-19**), indicating that agriculture is likely a significant factor in these areas not meeting shade targets. Hay fields encroaching in riparian areas and livestock grazing in riparian pastures can reduce the effectiveness of the existing shade-producing vegetation and prevent new shade producing vegetation from recolonizing in these riparian areas.

Livestock Grazing

Grazing on rangeland and pastures is common in the Elk Creek watershed and occurs in a manner as described in **Section 6.6.1.2**. Private land grazing occurs throughout the watershed, and in areas where livestock have direct access to the stream, they can potentially be contributing to a lack of effective stream shade by grazing and browsing riparian vegetation. There were no public land grazing allotments identified in the Elk Creek watershed. Portions of the headwater areas of Elk Creek had some of the most significant shade deficits, suggesting that livestock grazing in this these areas may be contributing to the lack of shade.

6.6.3.2 Natural Background

Natural sources contributing to stream temperatures including riparian grazing and browsing by wildlife, geology that limits riparian expansion, thermal springs, and the effects of natural events such as flooding, fire, and beetle kill were accounted for in target development and represent the reference condition to which existing condition data were compared to. Riparian grazing and browsing by wildlife occurs in the watershed, but since much of the watershed is grazed by livestock, it was not possible to differentiate wildlife impacts from domestic livestock impacts. There have not been any significant wildland fires in the Elk Creek watershed, so wildland fire is not expected to be a significant source causing increased instream water temperatures.

6.6.4 Moore Creek Source Assessment

Factors contributing to elevated stream temperatures in Moore Creek come from several nonpoint sources (i.e., diffuse sources that cannot easily be pinpointed) which are shown in **Figure 6-20**. There are no permitted point sources in the Moore Creek watershed. Ennis Hot Springs LLP previously held an MPDES permit to discharge unaltered groundwater to Moore Creek, but this permit (MT0028843) expired on September 30, 2016, and the facility has chosen to not renew the permit. Since the facility discharges unaltered groundwater, it is not required to have a permit to discharge; therefore, the facility may continue to discharge to Moore Creek without needing a permit.

DEQ identified the following source categories that contribute to elevated stream temperatures in the Moore Creek watershed:

- Agriculture (irrigated cropping and livestock grazing)
- Thermal springs
- Residential development
- Natural background

Since stream shade is one of the primary temperature-influencing targets, areas lacking sufficient shade can be identified through the source assessment process as areas likely contributing to temperature impairment. **Figure 6-21** is a map displaying the difference between target shade and existing shade for each data point in the analysis. This map can be used to identify areas where stream shade conditions can likely be improved, thus improving in-stream temperature conditions.

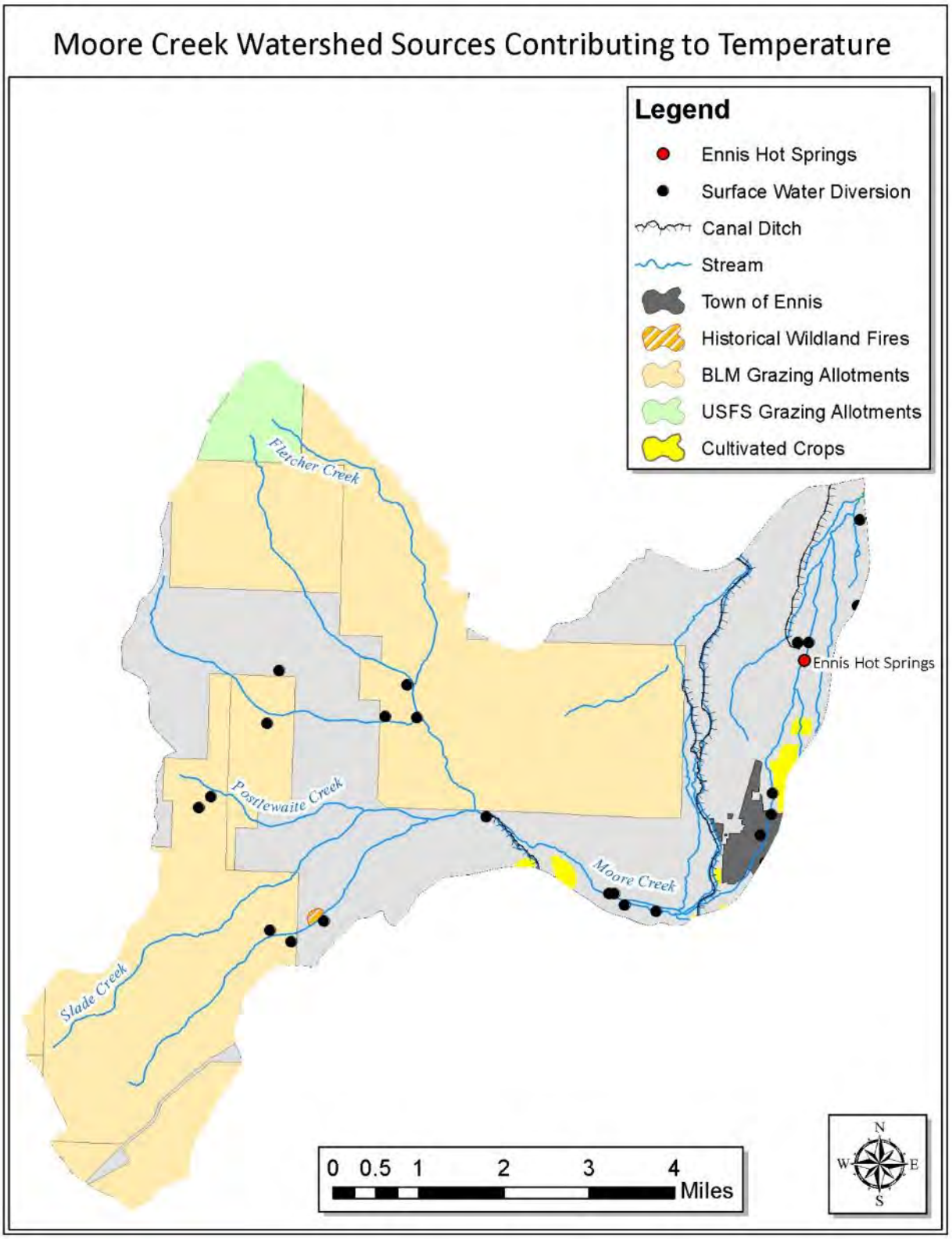


Figure 6-20. Map showing potential sources contributing to temperature impairment in Moore Creek

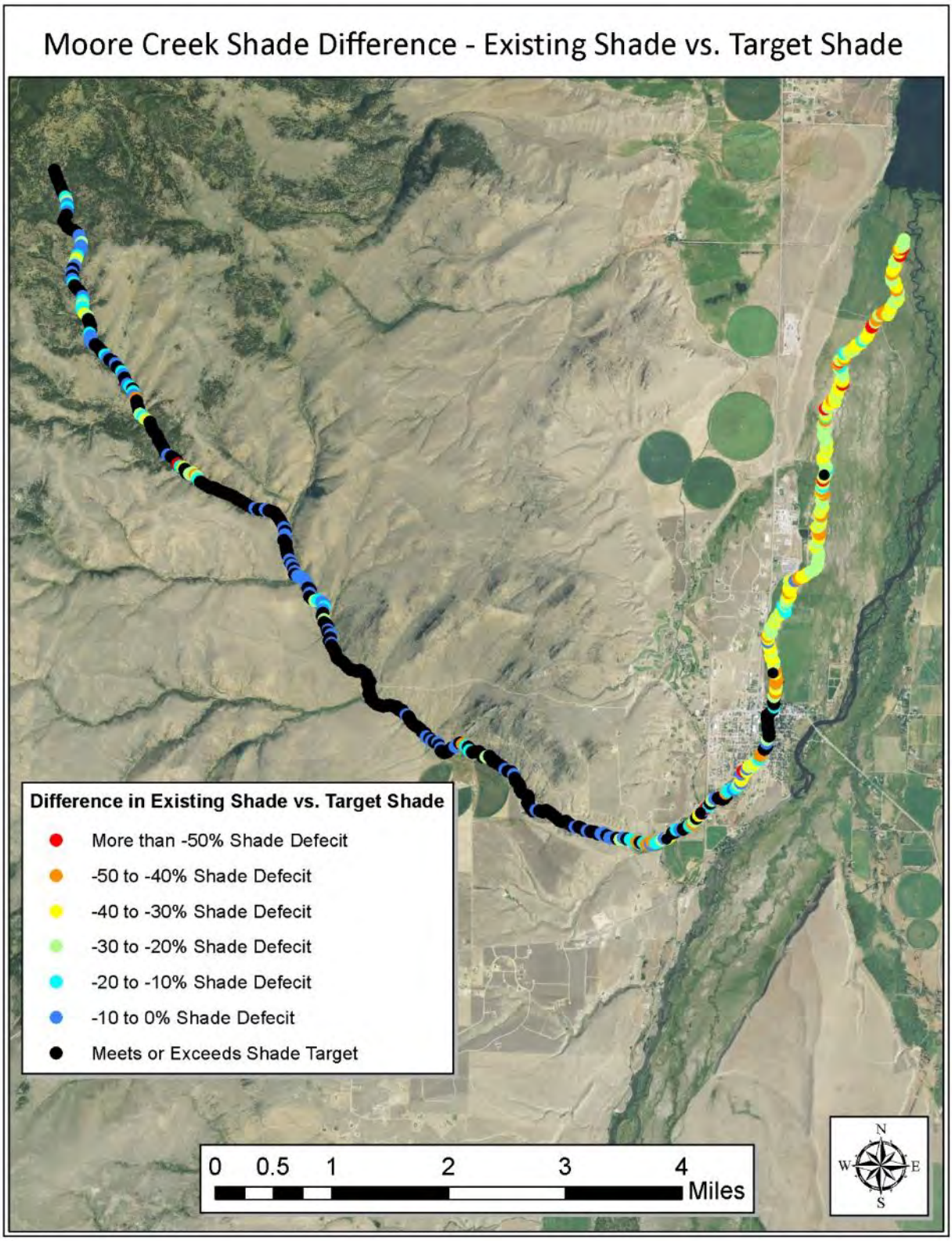


Figure 6-21. Map of Difference in Effective Shade Between Existing Condition and Shade Targets for Moore Creek

6.6.4.1 Agriculture

There are several possible ways that agriculture can contribute to stream temperatures as described in **Section 6.6.1.2** above. **Figure 6-20** shows the location of agricultural land and surface water diversions in the Moore Creek watershed.

Irrigated Cropping

Cropland in the Moore Creek watershed is primarily hay and pasture land with some small grains production, most of which is irrigated (U.S. Department of Agriculture and Montana Department of Agriculture 2016). Several surface water diversion ditches shown in **Figure 6-20** are used to supply these irrigated hay fields and pastures. Hay and pasture land in the Moore Creek valley bottom is irrigated using a combination of sprinkler, sub-irrigation and flood irrigation. Irrigated lands are supplied with water being diverted from Moore Creek in multiple locations and the Madison River via the West Madison Canal. Upstream of the town of Ennis, the West Madison Canal crosses Moore Creek. Further investigation indicated that this is a bypass structure, with check-boards to control the amount of any discharge from the canal into Moore Creek, with Moore Creek passing underneath the canal. It was discovered that some water from the West Madison Canal was mixing with Moore Creek via a headgate upstream of the intersection and some minor leakage through the check boards; see **Figure 6-22**. There was no temperature monitoring at this location, so the influence of the West Madison Canal on Moore Creek stream temperatures is unknown at this time, but is likely variable based on the amount of water being released through the check-boards. Upstream of the Town of Ennis, there is a small reservoir, Hacker Dam, which could be leading to increased water temperatures in Moore Creek due to a larger percentage of water surface area being exposed to solar radiation. DEQ collected continuous water temperature data below Hacker Dam, but was not able to collect water temperature upstream of the impoundment to quantify the impacts that this impoundment may have on the water temperatures in Moore Creek.

Dryland cropping, if present, may have fallow periods, depending on site characteristics and landowner management. Agricultural fields encroaching in riparian areas and livestock grazing in riparian pastures can reduce the effectiveness of the existing shade-producing vegetation and prevent new shade producing vegetation from recolonizing in these riparian areas.

Figure 6-22. Photo showing West Madison Canal crossing Moore Creek and mixing through leaky check-boards in the center of the photo. Headgate releases water into Moore Creek to the left of photo (off photo).

Livestock Grazing

Grazing on rangeland and pastures is common in the Moore Creek watershed and occurs in a manner as described in **Section 6.6.1.2**. Private land grazing occurs throughout the watershed, and in areas where livestock have direct access to the stream, they can potentially be contributing to a lack of effective stream shade by grazing and browsing riparian vegetation. Livestock grazing downstream of the town of Ennis is likely a significant contributor to the lack of shade producing woody vegetation in that area, but recent land management changes have been made, such as off-stream watering tanks and riparian fencing, which should allow the riparian vegetation to eventually return to a state where it is providing sufficient stream shade.

In addition to private land grazing, there are seven public land grazing allotments in the Moore Creek watershed, six on BLM managed lands and one on USFS managed lands (**Figure 6-20**). Moore Creek flows through three of these allotments, the South Meadow (USFS), Granite-Moore (BLM), and Fletcher-Moore (BLM). The BLM managed grazing allotments in the Moore Creek watershed fall within the 2007 South Tobacco Roots Watershed Assessment report. According to the report, in 2007 the Granite-Moore and Fletcher-Moore allotments were not meeting the standards for riparian wetlands and bio-diversity due to conifer encroachment, forest health (insects and/or disease), excessive fuel loads, and streambank impacts from livestock grazing. It was determined that livestock management was a

significant factor in these standards not being met (U.S. Department of the Interior, Bureau of Land Management 2007). However, a new report using dated collected in 2012 indicated that the Granite-Moore allotment was meeting all health standards as a result of pastures being rested for five consecutive years (U.S. Department of the Interior, Bureau of Land Management 2017b). The Fletcher-Moore allotment also met health standards in 2012. A large part of the Fletcher-Moore allotment has been sold, and management of the remaining portion in BLM land was changed in 2012 to include a grazing rotation that reduces livestock during sensitive time periods, but has fewer years of rest (every 4th year versus every other year). The allotment is expected to continue to meet standards with this new rotation method.

The Allotment Management Plan for the USFS managed South Meadow Creek allotment indicates that this allotment is currently meeting USFS standards and no major changes have occurred since the plan was last updated in 1996 (U.S. Department of Agriculture, Forest Service 1997; Suzuki 2015).

It is likely that livestock grazing in the upper portions of the Moore Creek watershed is contributing to the lack of sufficient stream shade in those areas of Moore Creek as shown in **Figure 6-21**. There are however, portions of these allotments that are meeting shade targets, and the current levels of effective stream shade on these allotments are similar to the amount of effective stream shade found on nearby private lands.

6.6.4.2 Thermal Springs

Ennis Hot Springs is a developed thermal spring located downstream of Ennis, and flows into Moore Creek after passing through a cooling pond. Quarterly water temperature data exists on the spring from 2011-2015, and based on this data, the spring has minimal impact on the water temperature of Moore Creek, with a maximum measured increase of 0.1°F (**Table 6-11**). Other non-developed thermal springs may be located in this area, and are covered under the natural background source category.

Table 6-11. Quarterly temperature monitoring results for the Ennis Hot Springs discharge

Monitoring Period	Spring Discharge (cfs)	Spring Temperature After Cooling Pond (°F)	Upstream Temperature (°F)	Downstream Temperature (°F)	Net Change in Temperature (°F)
4th Quarter 2011	0.08	55.2	48.9	49	0.1
1st Quarter 2012	0.08	48.1	44.6	44.6	0
2nd Quarter 2012	0.08	65.3	54.9	54.9	0
3rd Quarter 2012	0.08	61.5	53.1	53.2	0.1
4th Quarter 2012	0.08	38.4	33.8	33.9	0.1
1st Quarter 2013	0.08	51.8	46.3	46.3	0
2nd Quarter 2013	0.08	68.8	58.6	58.7	0.1
3rd Quarter 2013	0.08	68.6	57.4	57.5	0.1
4th Quarter 2013	0.08	43.1	38.3	38.3	0
1st Quarter 2014	0.08	40.6	36.3	36.4	0.1
2nd Quarter 2014	0.08	61.5	55.2	55.2	0
3rd Quarter 2014	0.08	71.2	62.3	62.3	0
4th Quarter 2014	0.08	39.6	35.2	35.3	0.1
1st Quarter 2015	0.08	43.7	41.7	41.7	0
2nd Quarter 2015	0.08	64.8	53.4	53.5	0.1

6.6.4.3 Residential Development

Residential development in the Moore Creek watershed occurs in and around the Town of Ennis. Residential lawns can often encroach on riparian areas and the removal of woody vegetation in favor of grasses is common. In parts where the shade producing overstory remains intact, the effective shade is high, while in areas where the vegetation has been removed, the effective shade is quite low. Effective stream shade in these areas can be improved by maintaining existing shade producing woody vegetation and planting new shade producing woody vegetation (where possible). Homeowner and small acreage owner education and outreach can be a useful tool in achieving this.

6.6.4.4 Natural Background

Natural sources contributing to stream temperatures including riparian grazing and browsing by wildlife, geology that limits riparian expansion, thermal springs, and the effects of natural events such as flooding, fire, and beetle kill were accounted for in target development and represent the reference condition to which existing condition data were compared to. Riparian grazing and browsing by wildlife occurs in the watershed. There has been one small documented wildland fire in the Moore Creek watershed, the Bobcat fire, which burned 15 acres on Frieler Creek in 1999. Due to the size and age of this fire, it is not anticipated that there are any current stream temperature impacts from this fire.

6.7 APPROACH TO TMDL ALLOCATIONS

As discussed in **Section 4.0**, the temperature TMDLs for applicable impaired waterbodies consist of the sum of load allocations (LAs) to individual sources and source categories (**Table 6-12**). There are no point sources in the Cherry Creek, Elk Creek, or Moore Creek watersheds, therefore the entire allowable load is allocated to natural and human-caused nonpoint sources of temperature and will be presented as a composite load allocation ($LA_{composite}$). Since the TMDL is based on a reference stream shade condition, improvements in effective stream shade can be made regardless of the source (human-caused or natural) to achieve the goals of the TMDL. Because the TMDLs for each stream consist of a composite load allocation to natural background and human-caused nonpoint sources with no wasteload allocations, the TMDL equals $LA_{composite}$ (**Equation 6-2**). An implicit margin of safety (MOS) is applied such that the MOS in the TMDL equation is equal to zero as discussed in **Section 4.0**.

Table 6-12. Temperature Source Categories and Descriptions for the Madison TPA

Source Category	Source Descriptions
Natural Background	• local geology • naturally occurring thermal springs • wild animal grazing and browsing of riparian vegetation • effects from natural events such as fire, beetle kill, drought, etc.
Human-Caused Nonpoint Sources	• agriculture • silviculture • residential development • human-influenced thermal springs

Equation 6-2: TMDL = $LA_{composite}$ = (X) (Y) (20.4)

TMDL = Total maximum daily load in kcal/day

$LA_{composite}$ = Load allocation to natural background and human-caused nonpoint sources in kcal/day

X = daily watts/ft^2 of solar flux to the stream surface for the stream reach under target shade conditions
Y = water surface area of stream reach in ft^2 (wetted width x length)
20.4 = conversion factor from watts to kcal/day

6.7.1 Total Existing Load

To estimate a total existing load for the purpose of estimating a required load reduction, **Equation 6-3** will be used. **Equation 6-3** uses similar calculations as used for the TMDL, but uses the daily watts/m^2 of solar flux under existing shade conditions instead of target shade conditions.

Equation 6-3: Total existing load = (X) (Y) (20.4)

Total existing load = Total existing load in kcal/day
X = daily watts/ft^2 of solar flux to the stream surface for the stream reach under existing shade conditions
Y = water surface area of stream reach in ft^2 (wetted width x length)
20.4 = conversion factor from watts to kcal/day

6.7.2 Load Reductions

Loads greater than the TMDL require load reductions to meet the TMDL. Existing effective shade in excess of shade targets decreases the existing solar load at a particular point, while deficit shade increases the existing solar load at that point. In areas where existing effective shade is in excess of shade targets, a load reduction is not required to meet the TMDL. Equation 6-3 and **Equation 6-4** were used to calculate temperature load reductions for stream segments in the Madison TPA:

Equation 6-4: % Load Reduction = (1 - (TMDL/Total Existing Load)) *100

*TMDL = Total maximum daily load in kcal/day (**Equation 6-1**)*
*Total Existing Load = calculated total existing load in kcal/day (**Equation 6-3**)*

Stream sections with high wetted widths have larger surface are and greater potential for solar load. Therefore, data permitting, wetted widths were decreased to reflect wetted widths that could be achieved through restoration or re-vegetation efforts. Using aerial photograph, wetted width was estimated for each stream segment based on aerial photography and adjusted to reflect wetted widths that would occur if width: depth target ratios were not exceeded. For sections with estimated wetted widths greater than the accepted range, the wetted width was reduced to reflect target conditions as part of the solar load reduction scenario.

Although a 15% increase in flow is also recommended as a target to improve temperatures, this target was not addressed in the load reduction scenario. A sensitivity performed to determine relative effects of increases in shade versus 15% flow augmentation on temperature targets illustrated the potential effects of such an increase in flow (see **Sections 6.4.2.1, 6.4.2.2**, and **6.4.2.3**)

6.8 TMDLS AND ALLOCATIONS BY STREAM

The below sections establish TMDLs and composite LAs to identified sources. These sections additionally provide temperature loading estimates to temperature-impaired stream segments, and estimate reductions necessary to meet water quality targets for the following streams:

- Cherry Creek
- Elk Creek
- Moore Creek

The total existing loads, as discussed above in **Section 6.7.1**, are used to estimate load reductions by comparing them to the allowable (TMDL) load and computing a required percent reduction to meet the TMDL. The temperature TMDLs for Cherry Creek, Elk Creek, and Moore Creek represent a condition on these streams in which all reasonable land, soil, and water conservation practices are in place. This condition can be measured by using temperature-influencing factors such as effective shade and channel width/depth ratio as surrogates for stream temperature conditions. Meeting targets for effective shade and channel width/depth ratio, and applying all reasonable land, soil, and water conservation practices will equate to meeting the TMDL.

Each stream was divided into segments based on land cover and land use for purposes of identifying general areas where effective stream shade is sufficient and areas where stream shade can be improved. To calculate a load reduction by using stream shade as a surrogate, the difference between percent target shade and percent existing shade was averaged for each segment. This equates to meeting the shade targets for that segment, therefore when all segments of a stream are meeting shade targets, it is assumed that all reasonable land, soil, and water conservation practices are in place and that stream is meeting the TMDL.

6.8.1 Cherry Creek TMDL and Allocations

This section describes the temperature TMDL for Cherry Creek.

6.8.1.1 Cherry Creek Temperature TMDL, Allocations, and Current Loading

The TMDL for temperature is based on **Equation 6-1** and the TMDL allocations are based on **Equation 6-2.** The value of the temperature TMDL is a function of the water surface area exposed to solar flux, and the modeled solar energy load in kilocalories (kcal) per day.

To estimate the reduction in solar load needed to meet the TMDL, the solar load was adjusted for the amount of shade that would be present during natural conditions under the shade surrogate model. Field data indicated that Cherry Creek met width:depth targets at the subset of sites sampled (**Table 6-5**). Because too few estimates of width: depth ratio were made in the field to estimate width: depth ratios at unsampled sites, adjustments for wetted width were not included in the load reduction scenario. In cases where human activities have increased wetted widths beyond expected natural conditions, riparian restoration or revegetation efforts could be implemented to reduce wetted widths and resulting solar load.

The following is the Cherry Creek temperature TMDL for the mouth of Cherry Creek at river mile 26.5 (RM 26.5).

TMDL at the mouth (RM 26.5) = (32.8 ft) (164 ft) (530 Watts/ft^2) (20.4 Kilocalories/Watt) = 58,159,910 Kilocalories/day

The total existing load at the mouth (RM 26.5) is based on **Equation 6-3**, and is calculated as follows:

Total existing load at the mouth (RM 26.5) = (32.8 ft) (164 ft) (613 Watts/ft^2) (20.4 Kilocalories/Watt) = 67,267,971 Kilocalories/day

Results for each stream segment can be found in **Appendix I**. The TMDL and total existing load presented in the equations above and in the table below (**Table 6-13**) are an expression of the modeled existing load and the TMDL at the mouth of Cherry Creek (RM 26.5). Since the TMDL and total existing load are based on stream surface area, target shade, and existing shade at that particular point in the stream, this number is dynamic in relation to location on the stream, and therefore the TMDL presented in **Table 6-13** is applicable only to that particular location on the stream. To provide a better picture of the overall stream temperature (shade) conditions in Cherry Creek, the shade surrogate TMDL presented in **Table 6-13** should be used for TMDL implementation purposes. **Figure 6-23** contains a map displaying the location of the breakouts for each segment identified in the shade surrogate TMDL

Table 6-13. Cherry Creek temperature TMDL at the mouth (RM 26.5) and shade surrogate TMDL

Temperature TMDL at the Mouth of Cherry Creek (RM 26.5)			
TMDL	*Total Maximum Daily Load in kcal/day*	*Existing Load in kcal/day*	*Load Reduction Needed to Meet the TMDL (%)*
	58,159,910	67,267,971	14%
Allocations • $LA_{composite}$	*Load Allocation in kcal/day*	*Existing Load in kcal/day*	*Load Reduction Needed to Meet the Allocation (%)*
	58,159,910	67,267,971	14%

Shade Surrogate TMDL for Cherry Creek			
Stream Segment[1]	*Average Target Effective Shade (%) (TMDL)*	*Average Existing Effective Shade (%)*	*Effective Shade Increase Needed to Meet TMDL (%)*
Headwaters (RM 0) to RM 7	70%	76%	0% - Meets Shade Targets
RM 7 to RM 11.5	35%	47%	0% - Meets Shade Targets
RM 11.5 to RM 13.2	44%	41%	3%
RM 13.2 to RM 14.8	33%	37%	0% - Meets Shade Targets
RM 14.8 to RM 17.7	30%	65%	0% - Meets Shade Targets
RM 17.7 to Mouth (RM 26.5)	22%	16%	6%

[1]Stream segments are divided by land cover and land use and are displayed by river mile (RM)

The source assessment of the Cherry Creek watershed indicates that agriculture is the most likely source of temperature in Cherry Creek; load reductions should focus on limiting and controlling temperature loading from those sources. Meeting LAs for Cherry Creek may be achieved through a variety of water quality planning and implementation actions which are identified in **Section 9.0**.

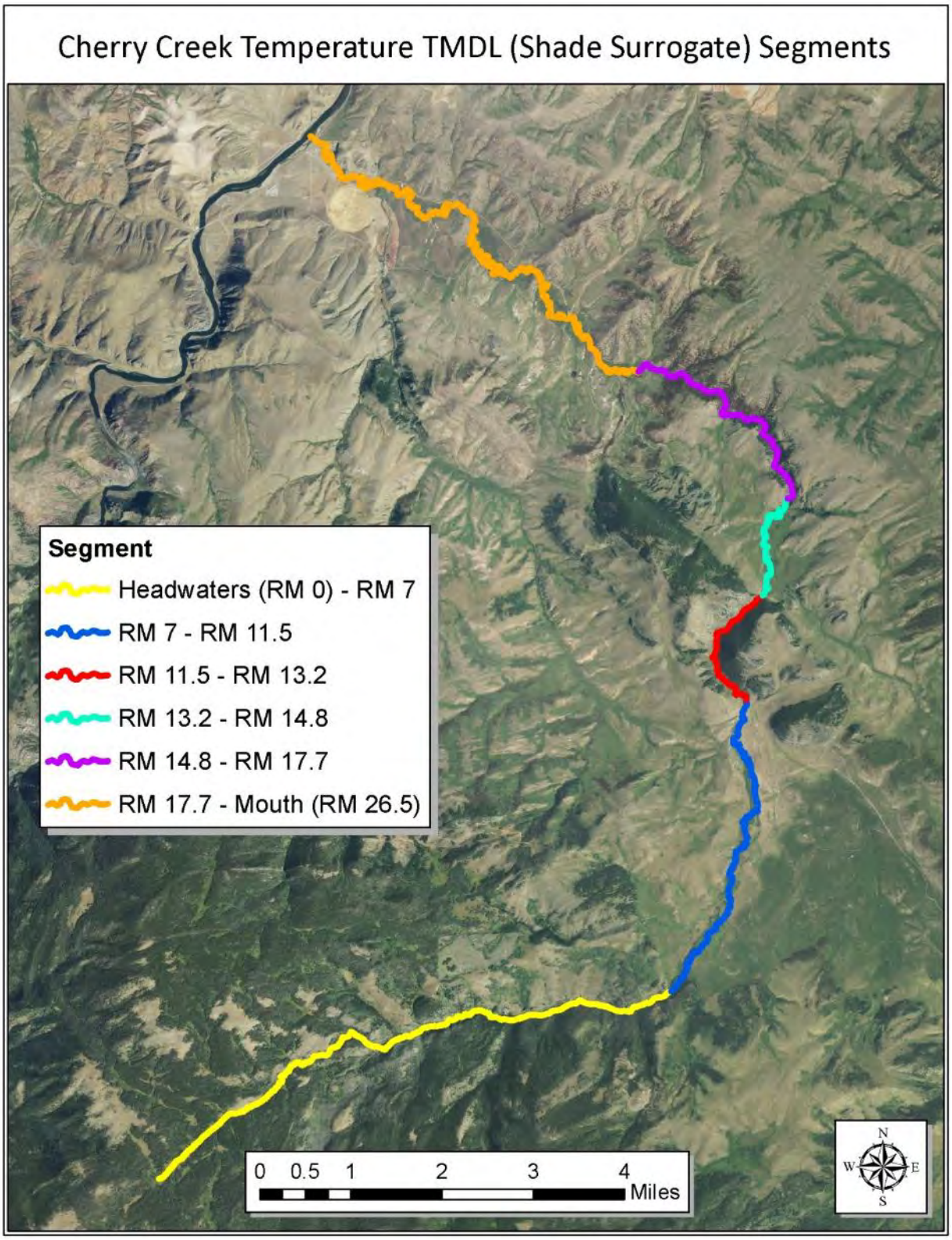


Figure 6-23. Map displaying the location of the stream segment breakouts by river mile (RM) for the shade surrogate TMDL for Cherry Creek

6.8.2 Elk Creek TMDL and Allocations

This section describes the temperature TMDL for Elk Creek.

6.8.2.1 Elk Creek Temperature TMDL, Allocations, and Current Loading

The TMDL for temperature is based on **Equation 6-1** and the TMDL allocations are based on **Equation 6-2**. The value of the temperature TMDL is a function of the water surface area exposed to solar flux, and the modeled solar energy load in kilocalories (kcal) per day.

The solar load was adjusted for the amount of shade that would be present under the shade model. Adjustments were also made to the wetted width portion of equation 6-1 for sites estimated to not meet width: depth targets. Based on field data, sites not meeting width: depth targets typically had a wetted width of >8 feet. Therefore, based on aerial photos, any stream sections with wetted widths > 8.5 feet were given the value of 8.5 feet for the solar energy load calculation under the solar load reduction scenario. Riparian restoration or revegetation efforts could be implemented to reduce wetted widths in these sections.

The following is the Elk Creek temperature TMDL for the mouth of Elk Creek at river mile 22.4 (RM 22.4).

TMDL at the mouth (RM 22.4) = (417 Watts/ft^2) (164ft) (9.84 ft) (20.4 Kilocalories/Watt) = 10,304,180 Kilocalories/day

The total existing load at the mouth (RM 22.4) is based on **Equation 6-3**, and is calculated as follows:

Total existing load at the mouth (RM 22.4) = (313 Watts/ft^2) (164 ft) (9.84 ft) (20.4 Kilocalories/Watt) = 13,727,934 Kilocalories/day

Results for each stream segment can be found in **Appendix I**. The TMDL and total existing load presented in the equations above and in the table below (**Table 6-14**) are an expression of the modeled existing load and the TMDL at the mouth of Elk Creek (RM 22.4). Since the TMDL and total existing load are based on stream surface area, target shade, and existing shade at that particular point in the stream, this number is dynamic in relation to location on the stream, and therefore the TMDL presented in **Table 6-14** is applicable only to that particular location on the stream. To provide a better picture of the overall stream temperature (shade) conditions in Elk Creek, the shade surrogate TMDL presented in **Table 6-14** should be used for TMDL implementation purposes. **Figure 6-24** contains a map displaying the location of the breakouts for each segment identified in the shade surrogate TMDL.

Table 6-14. Elk Creek temperature TMDL at the mouth (RM 22.4) and shade surrogate TMDL

Temperature TMDL at the Mouth of Elk Creek (RM 22.4)			
TMDL	*Total Maximum Daily Load in kcal/day*	*Existing Load in kcal/day*	*Load Reduction Needed to Meet the TMDL (%)*
	13,727,934	**10,304,180**	25%
Allocations • $LA_{composite}$	*Load Allocation in kcal/day*	*Existing Load in kcal/day*	*Load Reduction Needed to Meet the Allocation (%)*
	13,727,934	**10,304,180**	25%

Shade Surrogate TMDL for Elk Creek			
Stream Segment[1]	*Average Target Effective Shade (%) (TMDL)*	*Average Existing Effective Shade (%)*	*Effective Shade Increase Needed to Meet TMDL (%)*
Headwaters (RM 0) to RM 2.5	88%	82%	6%
RM 2.5 to RM 8.3	63%	28%	35%
RM 8.3 to RM 11	50%	43%	7%
RM 11 to Mouth (RM 22.4)	42%	17%	25%

[1]Stream segments are divided by land cover and land use and are displayed by river mile (RM)

The source assessment of the Elk Creek watershed indicates that agriculture is the most likely source of temperature in Elk Creek; load reductions should focus on limiting and controlling temperature loading from those sources. Meeting LAs for Elk Creek may be achieved through a variety of water quality planning and implementation actions which are identified in **Section 9.0**.

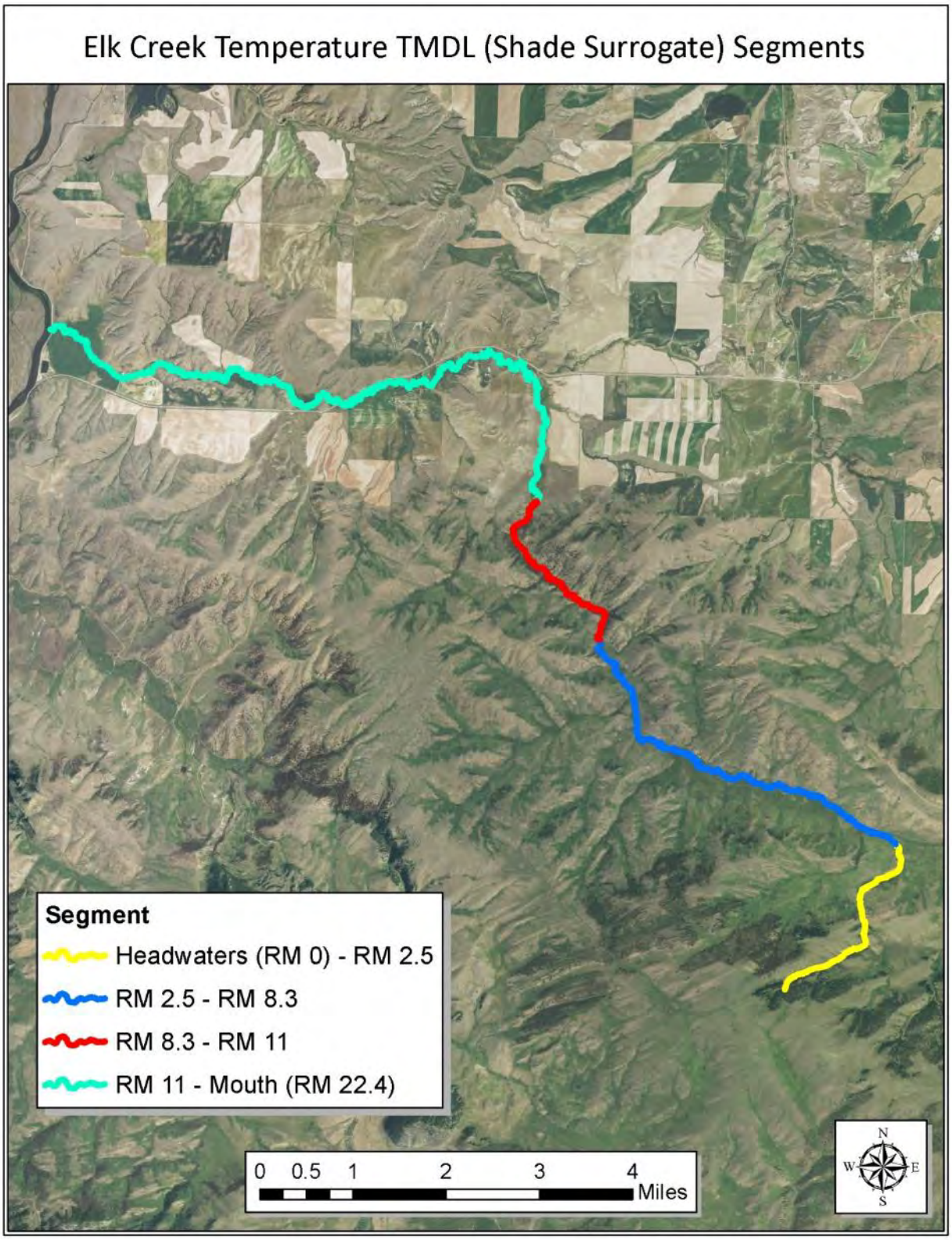


Figure 6-24. Map displaying the location of the stream segment breakouts by river mile (RM) for the shade surrogate TMDL for Elk Creek

6.8.3 Moore Creek TMDL and Allocations

This section describes the temperature TMDL for Moore Creek.

6.8.3.1 Moore Creek Temperature TMDL, Allocations, and Current Loading

The TMDL for temperature is based on **Equation 6-1** and the TMDL allocations are based on **Equation 6-2**. The value of the temperature TMDL is a function of the water surface area exposed to solar flux, and the modeled solar energy load in kilocalories (kcal) per day. The following is the Moore Creek temperature TMDL for the mouth of Moore Creek at river mile 18.1 (RM 18.1).

The solar load was adjusted for the amount of shade that would be present under the shade model. Based on sampled sections and aerial photography, all sections were predicted to meet width: depth targets, and wetted widths were therefore not adjusted in the solar load TMDL calculation. However, it is possible that sections with high wetted widths are present in Moore Creek, and this could be determined through further field reconnaissance. Riparian restoration or revegetation efforts could be implemented to reduce wetted widths in sections that have high wetted widths due to land use activities.

TMDL at the mouth (RM 18.1) = (9.84 ft) (164 ft) (483.7 Watts/ft^2) (20.4 Kilocalories/Watt) = 15,923,745 Kilocalories/day

The total existing load at the mouth (RM 18.1) is based on **Equation 6-3**, and is calculated as follows:

Total existing load at the mouth (RM 18.1) = (9.84 ft) (164 ft) (654.8 Watts/ft^2)(20.4 Kilocalories/Watt) = 21,556,476 Kilocalories/day

The TMDL and total existing load presented in the equations above and in the table below (**Table 6-15**) are an expression of the modeled existing load and the TMDL at the mouth of Moore Creek (RM 18.1). Since the TMDL and total existing load are based on stream surface area, target shade, and existing shade at that particular point in the stream, this number is dynamic in relation to location on the stream, and therefore the TMDL presented in **Table 6-15** is applicable only to that particular location on the stream. To provide a better picture of the overall stream temperature (shade) conditions in Moore Creek, the shade surrogate TMDL presented in **Table 6-15** should be used for TMDL implementation purposes. **Figure 6-25** contains a map displaying the location of the breakouts for each segment identified in the shade surrogate TMDL. In addition, the load reduction targets for each segment can be found in **Appendix I**.

Table 6-15. Moore Creek temperature TMDL at the mouth (RM 18.1) and shade surrogate TMDL

Temperature TMDL at the Mouth of Moore Creek (RM 18.1)			
TMDL	*Total Maximum Daily Load in kcal/day*	*Existing Load in kcal/day*	*Load Reduction Needed to Meet the TMDL (%)*
	15,923,745	21,556,476	26%
Allocations • $LA_{composite}$	*Load Allocation in kcal/day*	*Existing Load in kcal/day*	*Load Reduction Needed to Meet the Allocation (%)*
	15,923,745	21,556,476	26%

Shade Surrogate TMDL for Moore Creek			
Stream Segment[1]	*Average Target Effective Shade (%) (TMDL)*	*Average Existing Effective Shade (%)*	*Effective Shade Increase Needed to Meet TMDL (%)*
Headwaters (RM 0) to RM 4.2	83%	82%	1%
RM 4.2 to RM 10.4	65%	71%	0% - Meets Shade Targets
RM 10.4 to RM 11.8	67%	59%	8%
RM 11.8 to Mouth (RM 18.1)	49%	17%	32%

[1]Stream segments are divided by land cover and land use and are displayed by river mile (RM)

The source assessment of the Moore Creek watershed indicates that agriculture and residential development are the most likely sources of temperature in Moore Creek; load reductions should focus on limiting and controlling temperature loading from those sources. Meeting LAs for Moore Creek may be achieved through a variety of water quality planning and implementation actions which are identified in **Section 9.0**.

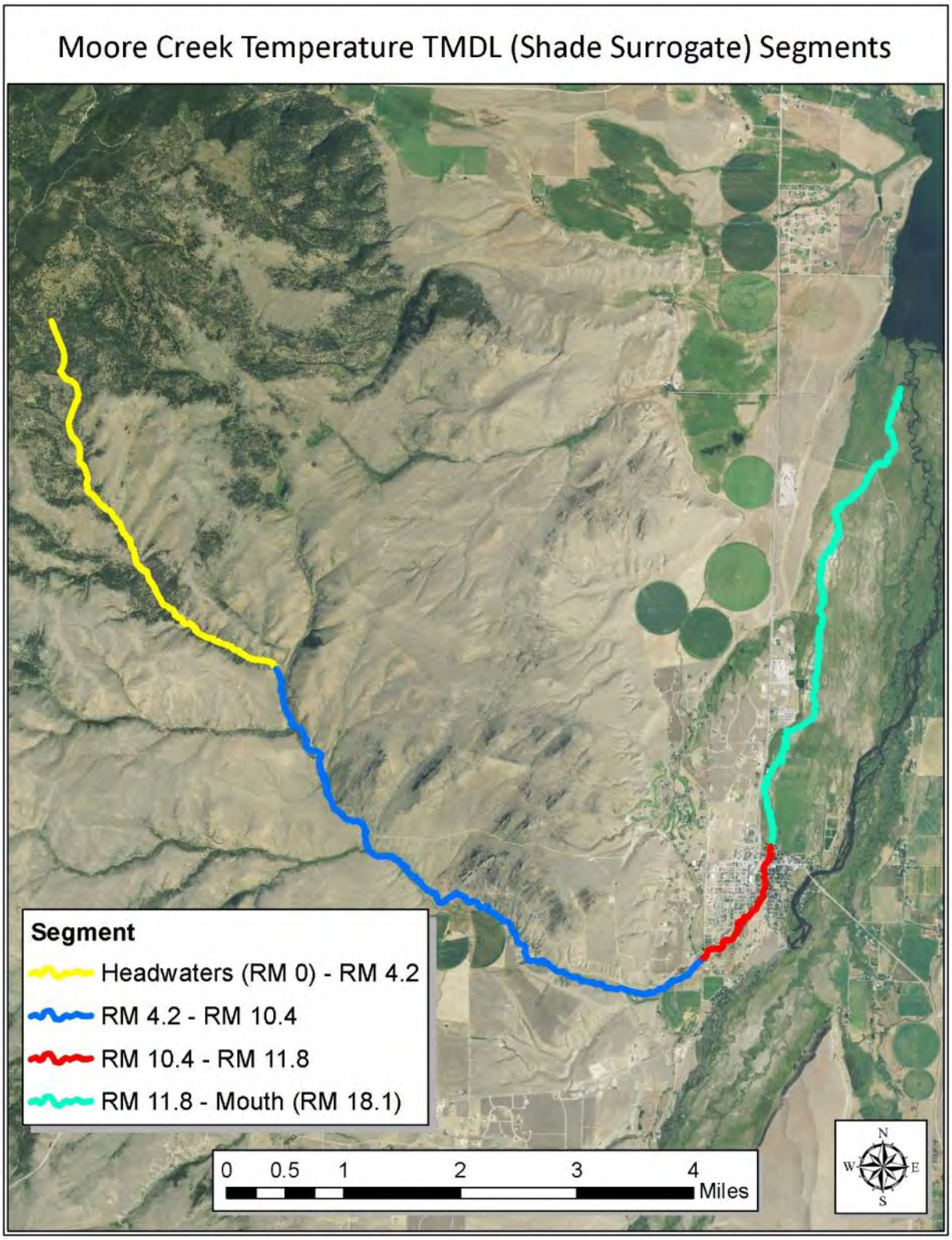


Figure 6-25. Map displaying the location of the stream segment breakouts by river mile (RM) for the shade surrogate TMDL for Moore Creek

6.8.4 Summary of Madison TPA Temperature Load Reduction Requirements

The shade surrogate temperature TMDLs developed for streams in the Madison TPA, the existing effective shade, and the percent effective shade increase needed to meet these TMDLs are summarized below in **Table 6-16**.

Table 6-16. Summary of the Madison TPA shade surrogate Temperature TMDLs, and Percent Effective Shade Increase Needed to Meet Each TMDL

Waterbody Name	Stream Segment	Average Target Effective Shade (%) (TMDL)	Average Existing Effective Shade (%)	Effective Shade Increase Needed to Meet TMDL (%)[1]
Cherry Creek	Headwaters (RM 0) to RM 7	70%	76%	0% - Meets Shade Targets
	RM 7 to RM 11.5	35%	47%	0% - Meets Shade Targets
	RM 11.5 to RM 13.2	44%	41%	**3%**
	RM 13.2 to RM 14.8	33%	37%	0% - Meets Shade Targets
	RM 14.8 to RM 17.7	30%	65%	0% - Meets Shade Targets
	RM 17.7 to Mouth (RM 26.5)	22%	16%	**6%**
Elk Creek	Headwaters (RM 0) to RM 2.5	88%	82%	**6%**
	RM 2.5 to RM 8.3	63%	28%	**35%**
	RM 8.3 to RM 11	50%	43%	**7%**
	RM 11 to Mouth (RM 22.4)	42%	17%	**25%**
Moore Creek	Headwaters (RM 0) to RM 4.2	83%	82%	**1%**
	RM 4.2 to RM 10.4	65%	71%	0% - Meets Shade Targets
	RM 10.4 to RM 11.8	67%	59%	**8%**
	RM 11.8 to Mouth (RM 18.1)	49%	17%	**32%**

[1]Bolded values indicate temperature reductions (shade increases) are needed to meet the TMDL

6.9 SEASONALITY AND MARGIN OF SAFETY

TMDL documents must consider the seasonal variability, or seasonality, on water quality impairment conditions, maximum allowable pollutant loads in a stream (TMDLs), Wasteload Allocations (WLAs) (if applicable) and Load Allocations (LAs). TMDL development must also incorporate a margin of safety (MOS) to account for uncertainties between pollutant sources and the quality of the receiving waterbody, and to ensure (to the degree practicable) that the TMDL components and requirements are sufficiently protective of water quality and beneficial uses. This section describes seasonality and MOS in the Madison TPA temperature TMDL development process.

6.9.1 Seasonality

Addressing seasonal variations is an important and required component of TMDL development and throughout this plan, seasonality is an integral consideration. Specific examples of how seasonality has been addressed within this document include:

- Temperature monitoring occurred during the summer period, which is the warmest time of the year and when temperature-related impacts to aquatic life are most likely to occur

- Shade model development was based on the day in which water temperatures reached their maximum, based on water temperature data collected (See **Appendix G**)
- Temperature targets, the TMDLs, and the allocations apply year-round, but exceedances are most likely to occur during the summer period.
- Physical factors such as riparian vegetation and channel width/depth ratio targets, once met, will not likely change seasonally and will contribute year-round benefits to temperature loading

6.9.2 Margin of Safety

A margin of safety (MOS) is a required component of TMDL development. The MOS accounts for the uncertainty about the pollutant loads and the quality of the receiving water and is intended to protect beneficial uses in the face of this uncertainty. The MOS may be applied implicitly by using conservative assumptions in the TMDL development process or explicitly by setting aside a portion of the allowable loading (U.S. Environmental Protection Agency, 1999). This plan addresses MOS implicitly in a variety of ways:

- Riparian areas are an excellent indicator of overall health of a stream. By using shade as a surrogate for temperature, for a waterbody to meet its target shade, all reasonable land, soil, and water conservation practices must be in place to sustain the health of that riparian area. When good land management is in place, it is unlikely that riparian health will worsen unless management practices change.
- Shade model development was based on the day in which water temperatures reached their maximum, therefore if shade requirements are met for that most critical day, they would also be met for all other days in which water temperatures are cooler.
- Seasonality (discussed above) and variability in temperature loading is considered in target development, monitoring design, and source assessment.
- An adaptive management approach (discussed below) is recommended to evaluate target attainment and allow for refinement of load allocations, assumptions, and restoration strategies to further reduce uncertainties associated with TMDL development over time.

6.10 Uncertainty and Adaptive Management

Uncertainties in the accuracy of field data, temperature targets, source assessments, loading calculations, and other considerations are inherent when assessing and evaluating environmental variables for TMDL development. Therefore, mitigation and reduction of uncertainties through adaptive management approaches is a key component of ongoing TMDL implementation and evaluation. The process of adaptive management is predicated on the premise that TMDL targets, allocations, and the analyses supporting them are not static, but are processes subject to modification and adjustment as new information and relationships are understood. Uncertainty is inherent in both the water quality-based and model-based methods of assessing temperature sources and needed reductions. The main sources of uncertainty are summarized below.

6.10.1 Water Quality Conditions

It was assumed that sampling data for each waterbody segment are representative of conditions in each segment. Future monitoring **would help** reduce the uncertainty regarding data representativeness, improve the understanding of the effectiveness of Best Management Practice (BMP) implementation, and increase the understanding of the load reductions needed to meet the TMDLs.

Uncertainties may arise in aerial photo interpretation of vegetation, and reference condition selection for each stream. Aerial photos provide a point in time snapshot of an area, and interpretation is dependent on what year and season the photos were taken. These can be verified by on the ground data collection, and if there are discrepancies between the aerial photo-interpretation and the data collected, the variables in the Shade Tool can be adjusted to reflect the actual condition. Each stream analyzed as a part of this study had multiple field verification sites to assist with ground-truthing aerial assessments.

6.10.2 Source Assessment

Source characterization and assessment to determine the major sources in each of the temperature impaired waterbodies was conducted by using monitoring data collected from the Madison TPA from 2009-2014, which represents the most recent data for determining existing conditions, and by using aerial photos, Geographic Information System (GIS) analysis, field work, and literature reviews. Uncertainties in source assessment can occur by using data that does not reflect the current condition of the waterbody, the misinterpretation of aerial photos, using outdated GIS data, and using field data that may not be representative of the overall condition of the waterbody.

Water quality monitoring data used for source assessment includes the time period from 2009-2014. Sources of pollutants or the level of contribution from those sources may have changed since data collection, and therefore there is some uncertainty that the data used is reflective of the current conditions of a particular waterbody. An assumption was made that the data used are representative of current conditions. Data collected on a waterbody accurately characterizes that particular site, but there is some uncertainty as to whether or not that site is representative of the overall waterbody conditions. To address this, monitoring site locations were selected to generate the most representative samples.

When using aerial photography and GIS data, uncertainty may occur through the misinterpretation of aerial photos and using GIS data that may either be inaccurate or outdated. To reduce uncertainty, multiple years of aerial photos were analyzed and only GIS data containing complete metadata and generated from reliable sources were used for source assessment.

6.10.3 Loading Estimates

Loading estimates are based on currently available data, and are only representative of the pollutant load at the time of data analysis. It is important to recognize that pollutant loads are not static and can therefore be different than the loads reported in this document. This brings some uncertainty into load reductions, as achieving the load reductions stated in this document may or may not result in meeting in-stream water quality targets based on current conditions. To account for this, shade was used as a surrogate for temperature, and therefore, meeting the shade targets for a stream will equate to meeting the temperature TMDL at any given solar load. Adaptive management can address uncertainties related to loading estimates through the re-evaluation of water quality conditions as BMPs are installed, land uses change, or pollutant sources and their contribution levels change.

7.0 PUBLIC PARTICIPATION AND PUBLIC COMMENTS

Stakeholder and public involvement is a component of total maximum daily load (TMDL) planning required by Montana state law which directs the Department of Environmental Quality (DEQ) to consult with a watershed advisory group and local conservation districts during the TMDL development process. Technical advisors, stakeholders, state and federal agencies, interest groups, and the public were solicited to participate in differing capacities throughout the TMDL development process for this project in the Madison TMDL Planning Area.

7.1 PARTICIPANTS AND THEIR ROLES

Throughout completion of the sediment and temperature TMDLs in this document, DEQ worked to keep stakeholders apprised of project status and solicited input from a TMDL watershed advisory group. A description of the participants and their roles in the development of the TMDLs in this document is contained below.

Montana Department of Environmental Quality
The Montana Water Quality Act (75-5-703, Montana Code Annotated (MCA)) directs DEQ to develop all necessary TMDLs. DEQ provided resources toward completion of these TMDLs in terms of staff, funding, internal planning, data collection, technical assessments, document development, and stakeholder communication and coordination. DEQ has worked with other state and federal agencies to gather data and conduct technical assessments.

United States Environmental Protection Agency
EPA is the federal agency responsible for administering and coordinating requirements of the Clean Water Act. Section 303(d) of the Clean Water Act directs states to develop TMDLs (see **Section 1.1**), and EPA has developed guidance and programs to assist states in that regard. EPA has provided funding and technical assistance to Montana's overall TMDL program and is responsible for reviewing and evaluating TMDLs to see that they meet all federal requirements.

Local Conservation Districts
DEQ consulted with the Madison and Gallatin conservation districts during development of the TMDLs in this document, which included opportunities to provide comment during the various stages of TMDL development and an opportunity for participation in the watershed advisory group described below.

Madison TMDL Planning Area Watershed Advisory Group
The Madison TMDL Planning Area TMDL Watershed Advisory Group consisted of selected resource professionals who possess a familiarity with water quality issues and processes in the Madison River watershed, and representatives of applicable interest groups. All members were solicited to participate and work with DEQ in an advisory capacity per Montana state law. DEQ requested participation from the interest groups defined in 75-5-704 MCA and included local city and county representatives; livestock-oriented and farming-oriented agriculture representatives; conservation groups; watershed groups; hydroelectric industry representatives; state and federal land management agencies; and representatives of fishing, recreation, and tourism interests. The advisory group also included additional state and federal agency professionals, local action groups, and stakeholders with an interest in maintaining and improving water quality and riparian resources.

Advisory group involvement was voluntary, and the level of involvement was at the discretion of the individual members. Members had the opportunity to attend meetings organized by DEQ for soliciting feedback on project planning. Communication with advisory group members was conducted through a series of group meetings, video calls, and e-mails. Draft documents, project status updates, and meeting agendas and presentations were made available both via e-mail and through DEQ's wiki for water quality planning projects (http://mtwaterqualityprojects.pbworks.com/). Opportunities for review and comment were provided for participants at varying stages of TMDL development, including a two-week review and comment period for a draft version of this TMDL document prior to the public comment period. Member's comments were incorporated into this version of the document. The draft TMDLs were also presented to and discussed with the group at a virtual meeting in June 2020.

7.2 Response to Public Comments

Upon completion of a draft TMDL document, DEQ issues a press release and enters into a public comment period. During this timeframe, the draft TMDL document is made available for general public comment; DEQ then addresses and responds to all formal public comments.

The public comment period for this document was initiated on July 22, 2020 and closed on August 20, 2020. A virtual public informational meeting was held August 05, 2020 at 5:00 p.m. via Zoom. At the meeting, DEQ provided an overview of the TMDL document, answered questions, and solicited input and comment on the document. The public comment period and public meeting were announced in a July 22, 2020 press release from DEQ which was published on DEQ's website and was distributed to multiple media outlets across Montana. A public notice advertising the public comment period and public meeting was published in the following newspapers: Bozeman Daily Chronicle, The Madisonian, Lone Peak Lookout. Additionally, the announcement was distributed to the project's TMDL watershed advisory group, the Statewide TMDL Advisory Group, and other additional contacts via e-mail.

One formal, written comment was received and is summarized below, along with DEQ's response to this comment. DEQ evaluates comments and related information to ensure no critical information was excluded from the document. The original comment submission is in the TMDL project files at DEQ and may be reviewed upon request.

Comment: Were Jack and Grayling creeks evaluated for inclusion in the lists of sediment and temperature impaired streams? Jack Creek experiences significant sediment inputs from adjacent roads upstream of the Madison Valley as well as degraded habitat from overgrazing and a poor riparian zone in much of the stream near the Madison River. I am surprised it did not meet the sediment thresholds to be included in this document. The habitat in Grayling Creek is generally in better condition than Jack Creek, but habitat alterations near Hebgen Reservoir have decreased habitat quality to some extent.

> **Response:** Several methods were used to identify waterbodies in the Madison TMDL Planning Area to be monitored for sediment and/or temperature parameters. Waterbodies previously listed by DEQ for sediment, habitat, and temperature impairments were identified first, which included Jack Creek. Additional waterbodies were selected based on recommendations from Montana Fish, Wildlife & Parks fisheries biologists, the U.S. Forest Service, and the Madison Conservation District. Unimpaired, major tributaries to the Madison River were also included. Grayling Creek was not identified for inclusion; however, two sites were monitored for sediment on Jack Creek. Section B3.5 in **Appendix B** presents the monitoring results, provides a comparison to water quality targets, and a summary of the TMDL development determination.

Using the data collected in 2014, a water quality beneficial use support assessment determined Jack Creek was not impaired for sediment, and therefore, a sediment TMDL was not written for Jack Creek. Jack Creek is, however, listed as impaired for "alteration in stream-side or littoral vegetative covers" and "flow regime modification," which are further described in **Section 8.0**. Water quality improvement measures that address these two impairments will also address excess sediment inputs to Jack Creek.

PART 3
WATER QUALITY IMPROVEMENT RECOMMENDATIONS

GLOSSARY OF WATER QUALITY TERMINOLOGY

Term	Definition or Description
Anthropogenic	Human-caused, or human-influenced. Water quality pollution originating from human activity.
Aquatic Life	Fish and aquatic bugs (macroinvertebrates)
Beneficial Use(s)	Beneficial uses, or designated uses, are simply the ways that we use water, and are the uses of water that we protect with water quality standards. They may include support of drinking water, recreation, fish and aquatic life, agricultural uses, and industrial uses. All surface waters in Montana are classified with, or assigned, a group of beneficial uses they must support, based on the potential of the waterbody to support those uses.
Best Management Practice (BMP)	Appropriate management practices designed and implemented for a specific purpose and include management methods as well as actual physical structures. In the case of water quality, BMPs are practices designed to protect or improve the physical, chemical, or biological characteristics of surface water and groundwater resources.
Buffer	Also referred to as a “riparian buffer” or “buffer strip.” In the context of this document, a buffer is a strip of vegetation that filters pollutants from entering the water. It can also be defined as the distance between a waterbody and the adjacent uplands, which includes the riparian area/zone.
Floodplain	Floodplains are the areas adjacent to streams, and sometimes to lakes and reservoirs, which are subject to periodic flooding. Often, they are defined by whether they would be inundated during a flood with a given probability of occurrence, such as a 100-year flood, which has a 1% chance of happening in any given year.
Habitat, Instream or Aquatic	Fish habitat within a waterbody (stream channel, lake, or reservoir).
Habitat, Streamside or Riparian	Wildlife habitat adjacent to a waterbody (stream channel, lake, or reservoir) and within the riparian zone.
Hummocking	Formation of grass mounds in a knob-like shape due to livestock access to soft ground in the riparian area or in a wetland. The mounds of grass or wetland vegetation are typically surrounded by bare soil.
Impaired	An unhealthy water or waterbody for which water quality data shows that the waterbody is failing to achieve compliance with applicable water quality standards and is not fully supporting one or more of its designated beneficial uses. DEQ maintains a list of impaired waters.
Nonpoint Source Pollution	Polluted runoff that comes from a variety of land-use activities. Common nonpoint source pollutants include sediment (dirt), nutrients (nitrogen and phosphorus), water temperature changes, metals, pesticides, pathogens, and salinity (salt). Nonpoint source pollution is the largest contributor of water quality problems in Montana, when compared to point sources of pollution in the state.

Term	Definition or Description
Non-Pollutant	Non-pollutants are human-induced alterations in the health of a water and have a harmful effect on any living thing that drinks or uses or lives in the water. For example, a human-induced alteration is the removal of streamside vegetation that results in the alteration of aquatic and wildlife habitat in and along the stream, which may subsequently increase stream temperatures and negatively affect the shape of the stream channel.
Point Source Pollution	Water pollution that requires a permit, usually from a single, traceable location. Note that agricultural stormwater discharges and return flows from irrigated agriculture are considered nonpoint sources and do not require a permit.
Pollutant	A pollutant is any substance that is introduced into a water, naturally or by human activities, that adversely affects the water quality. Common water pollutants include nutrients (nitrogen and phosphorus), sediment (dirt), pathogens, temperature, and metals (e.g., aluminum, arsenic, cadmium, copper, iron, lead, nickel, mercury, zinc).
Residual Pool Depth	A pool is defined as a depression in the streambed that is concave in profile. The "residual" pool is identified by visualizing the shape of the pool and evaluating where standing water would remain if all the flowing water were drained from the stream. The residual pool is defined as the portion of the pool that is deeper than the riffle crest forming the downstream end of the pool, and is calculated by subtracting the maximum depth at the riffle crest from the maximum pool depth.
Riparian	Riparian areas are typically vegetated zones along a waterbody and are usually transitional areas between the waterbody and upland habitat. Riparian areas have one or both of the following characteristics: • Distinctly different vegetative species than adjacent areas • Species similar to adjacent areas but exhibiting more vigorous or robust growth forms
Stakeholder	A person or entity with a direct interest in, or concern with, this project, usually local to the Madison River watershed.
Stormwater	Snowmelt and rainfall that does not infiltrate into the ground and runs off the land; also referred to as runoff or overland flow.
Total Maximum Daily Load (TMDL)	The maximum amount of a pollutant that a stream or waterbody can receive and still meet water quality standards. Think of it as a pollution diet or pollution budget. **Section 4.0** in Part 1 of this document further defines a TMDL and the TMDL development process.
Upland	Land outside of the riparian zone, usually higher than, or elevated above, the riparian.

Term	Definition or Description
Waterbody	A water; a stream, creek, river, lake, or reservoir. Also referred to as an assessment unit for water quality impairment assessments/determinations, which can be the full length, or partial segment of the length or area, of a waterbody.
Watershed	A geographic area drained by a river or stream; also referred to as a drainage basin, which is any area of land where precipitation collects and drains into a common outlet, such as into a river, bay, or other body of water.
Wetland	Wetlands are transitional lands between terrestrial and aquatic systems where the water table is usually at or near the surface, or the land is covered by shallow water. Wetlands are typically defined as those areas that are inundated or saturated by surface water or groundwater at a frequency and duration sufficient to support, and under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soils.
Width/Depth Ratio	A number calculated by dividing the width of a stream channel by the depth of the stream channel, which is measured along what is called a cross-section or transect.

8.0 NON-POLLUTANT IMPAIRMENTS

This section discusses non-pollutant impairments in the Madison TMDL Planning Area (TPA). This section is included for informational purposes to help with development of overall watershed management goals and objectives and prioritization of restoration projects in the Madison TPA.

8.1 NON-POLLUTANT IMPAIRMENTS

A waterbody may be on Montana's list of impaired waters, but does not require a TMDL if it is not impaired for a pollutant, such as sediment, temperature, a nutrient, or metal. Non-pollutant causes of impairment such as "alteration in stream-side or littoral vegetative covers" do not require a TMDL. Non-pollutant causes of impairment are often associated with a pollutant cause of impairment; however, in some cases, non-pollutant impairments are causing a deleterious effect on beneficial uses without a clearly defined quantitative measurement or direct linkage to a pollutant.

The Montana Department of Environmental Quality (DEQ) recognizes that non-pollutant impairments can limit a waterbody's ability to fully support all beneficial uses and these impairment causes are important to consider when improving water quality conditions in both individual streams, and the Madison TMDL Planning Area as a whole. **Table 8-1** shows the non-pollutant impairments for waterbodies in the Madison TPA on Montana's 2018 list of impaired waters. They are summarized in this section to increase awareness of the non-pollutant impairment definitions and typical sources, and should be considered during planning of watershed-scale restoration efforts.

It is important to note that water quality issues are not limited to waterbodies that have identified pollutant and non-pollutant impairments. In some cases, streams have not yet been reviewed through DEQ's water quality assessment process and do not appear on Montana's list of impaired waters even though they may not be fully supporting all their beneficial uses.

Table 8-1. Waterbody Segments with Non-Pollutant Impairments in the 2018 Water Quality Integrated Report

Waterbody (Assessment Unit)	Waterbody ID (Assessment Unit ID)	Impairment Cause	Addressed by a TMDL in This Document
Antelope Creek, Headwaters to mouth (Cliff Lake)	MT41F004_140	Alteration in stream-side or littoral vegetative covers	Yes (sediment TMDL)
		Flow Regime Modification	No
Blaine Spring Creek, Headwaters to mouth (Madison River, T7S R1W S6)	MT41F004_010	Flow Regime Modification	No
Elk Creek, Headwaters to mouth (Madison River)	MT41F002_020	Alteration in stream-side or littoral vegetative covers	Yes (sediment and temperature TMDLs)
Hot Springs Creek, Headwaters to mouth (Madison River)	MT41F002_030	Flow Regime Modification	No
Indian Creek, Lee Metcalf Wilderness boundary to mouth (Madison River)	MT41F004_040	Alteration in stream-side or littoral vegetative covers	No
		Flow Regime Modification	No

Table 8-1. Waterbody Segments with Non-Pollutant Impairments in the 2018 Water Quality Integrated Report

Waterbody (Assessment Unit)	Waterbody ID (Assessment Unit ID)	Impairment Cause	Addressed by a TMDL in This Document
Jack Creek, Headwaters to mouth (Madison River, T5S R1W S23)	MT41F004_050	Alteration in stream-side or littoral vegetative covers	No
		Flow Regime Modification	No
Moore Creek, Springs to mouth (Fletcher Channel), T5S R1W S15	MT41F004_130	Alteration in stream-side or littoral vegetative covers	Yes (sediment and temperature TMDLs)
North Meadow Creek, Headwaters to mouth (Ennis Lake)	MT41F004_060	Flow Regime Modification	No
O'Dell Spring Creek, Headwaters to mouth (Madison River)	MT41F004_020	Alteration in stream-side or littoral vegetative covers	No
		Other anthropogenic substrate alterations	No
		Physical substrate habitat alterations	No
Red Canyon Creek, Headwaters to mouth (Hebgen Lake)	MT41F006_020	Alteration in stream-side or littoral vegetative covers	Yes (sediment TMDL)
		Flow Regime Modification	No
Ruby Creek, Headwaters to mouth (Madison River)	MT41F004_080	Flow Regime Modification	No
Watkins Creek, Headwaters to mouth (Hebgen Lake)	MT41F006_030	Alteration in stream-side or littoral vegetative covers	Yes (sediment TMDL)
		Flow Regime Modification	No

8.2 Non-Pollutant Impairment Cause Descriptions

Non-pollutants are often used as a probable cause of impairment when available data at the time of a water quality assessment do not provide a direct, quantifiable linkage to a specific pollutant. In some cases, the pollutant and non-pollutant categories are linked and appear together in the list of impairment causes for a waterbody; however, a non-pollutant impairment cause may appear independently of a pollutant cause. The following discussion provides some rationale for the application of the identified non-pollutant causes to a waterbody, and thereby provides additional insight into possible factors in need of additional investigation and potential restoration.

Alteration in Stream-side or Littoral Vegetative Covers

"Alteration in stream-side or littoral vegetative covers" refers to circumstances where practices along the stream channel have altered or removed riparian vegetation and subsequently affected channel geomorphology and/or stream temperature. Such instances may be riparian vegetation removal for a road or utility corridor, or overgrazing by livestock along the stream. As a result of altering the streamside vegetation, destabilized banks from loss of vegetative root mass could lead to over-widened stream channel conditions, elevated sediment and/or nutrient loads, and the resultant lack of canopy cover can lead to increased water temperatures.

Physical Substrate Habitat Alterations and Other Anthropogenic Substrate Alterations
"Physical substrate habitat alterations" generally describe cases where the stream channel has been physically altered or manipulated, such as straightening of the channel or human-influenced channel downcutting, resulting in a reduction of morphological complexity and loss of habitat (riffles and pools) for fish and aquatic life. For example, this may occur when a stream channel has been straightened to accommodate roads, agricultural fields, or placer mine operations. "Other anthropogenic substrate alterations" (human-caused modifications) may include channel alterations due to new infrastructure such as highways, roads, and bridges; and construction of dams or impoundments.

Flow Regime Modification
Flow modification refers to a change in the flow characteristics of a waterbody relative to natural conditions. An impairment listing caused by flow regime modification could be associated with changes in runoff and streamflow due to activities such as urban development, road construction, and timber harvest. Changes in runoff are commonly linked to elevated peak flows, which can also cause excess sedimentation by increasing streambank erosion and channel scour. Road crossings, particularly where culverts are undersized or inadequately maintained, can also alter flows by causing water to back-up upstream of the culvert.

Streams can also be listed as impaired for flow regime modification when irrigation withdrawal management leads to base flows that are too low to support the beneficial uses designated for that system. This could result in dry channels or extreme low flow conditions unsupportive of fish and aquatic life. Low flow conditions absorb thermal radiation more readily and increase stream temperatures, which in turn creates dissolved oxygen conditions too low to support some species of fish.

It should be noted that while Montana law requires monitoring and assessment to identify impaired waterbodies (75-5-702, Montana Code Annotated (MCA)) and to subsequently develop TMDLs for these waterbodies (75-5-703, MCA), the law also states that these requirements may not be construed to divest, impair, or diminish any legally-recognized water right (75-5-705, MCA). The identification of flow regime modification as a probable cause of impairment, related to probable sources of agriculture and irrigated crop production, should not be construed to divest, impair, or diminish a water right. Instead, it should be considered an opportunity to characterize the impacts of flow alterations, and pursue solutions that can result in improved streamflows during critical periods, while at the same time ensuring no harm to water rights. These same considerations apply to flow-related targets applied to temperature TMDLs in this document. It is up to local users, agencies, and entities to voluntarily improve instream flows through water and land management, which may include irrigation efficiency improvements and/or instream water leases that result in reduced amounts of water diverted from streams.

8.3 Monitoring and Best Management Practices for Non-Pollutant Affected Streams

Table 8-1 above indicates whether the non-pollutant impairment causes are addressed by a sediment and/or temperature TMDL in this document. It is likely that meeting the sediment and temperature TMDL targets (**Sections 5.4** and **6.4**) will also equate to addressing the habitat and flow regime modification impairment conditions in the streams listed in the table above. For streams with habitat alteration or flow regime modification impairments that do not have a sediment or temperature TMDL,

meeting the sediment targets applied to streams of similar size will likely equate to addressing the habitat impairment condition for each stream.

Streams with non-pollutant impairments should be considered when developing watershed management goals and plans and when prioritizing restoration projects. Additional sediment and/or temperature information should be collected where data is insufficient for pollutant impairment determinations and the linkage between probable cause, non-pollutant listing, and effects to the beneficial uses is not well defined. The monitoring and restoration strategies that follow in **Sections 9.0** and **10.0** are presented to address both pollutant and non-pollutant issues for streams in the Madison TMDL Planning Area with TMDLs in this document, and they are equally applicable to streams listed for the above non-pollutant impairment causes. The strategies also apply to the entire Madison River watershed.

9.0 WATER QUALITY IMPROVEMENT PLAN

There are many approaches to implementing a total maximum daily load (TMDL) and improving water quality, often with the majority of approaches linked to voluntary measures by landowners (including homeowners), particularly those located along an impaired stream or a tributary to an impaired stream. Landowners may independently choose to implement conservation measures (i.e., best management practices (BMPs)) with or without technical assistance offered by a variety of agency and other professionals (see **Section 9.2**), and with or without financial assistance offered via many available water quality improvement programs (see **Section 9.7**).

Equally important toward improving water quality is the continuation and maintenance of those land management activities that may already be incorporating conservation practices or other approaches toward limiting sediment loading and increases in water temperature, as well as limiting instream and streamside habitat alterations. **Section 9.5** discusses applicable BMPs.

While certain land uses and human activities are identified as sources and causes of water quality impairment, this document does not advocate for the removal of land and water uses to achieve the water quality restoration objectives discussed in this document. Changes to current and future land management practices that will improve and maintain water quality are instead the intended goal.

In addition to the information provided in this section, a document of stream summaries was compiled to provide a succinct description of each stream monitored for this TMDL project. These summaries include a general description of prominent sources of pollution to the stream and general recommendations to combat these problems. A location map showing monitoring locations is also provided for each stream. The stream summaries can be found on Montana DEQ's TMDL webpage, alongside this TMDL document.

9.1 PURPOSE OF THIS WATER QUALITY IMPROVEMENT PLAN AND SUPPORT IT PROVIDES FOR WATERSHED RESTORATION PLAN DEVELOPMENT

This section provides an overall strategy and specific on-the-ground measures designed to restore water quality beneficial uses and attain water quality standards in the Madison TMDL Planning Area. This strategy includes general measures for reducing loading from identified nonpoint sources of pollutants (i.e., pollution that originates from a diffuse area, such as an agricultural field or an unpaved road adjacent to a stream).

To help promote and achieve water quality improvements linked to a TMDL document, the Montana Department of Environmental Quality (DEQ) endorses and provides technical support toward a collaborative watershed approach that involves development of what is called a "watershed restoration plan" (WRP). While this document section does not serve as a watershed restoration plan, it should assist local stakeholders in developing a WRP, which is a locally-developed plan providing more specific restoration goals for the Madison TMDL Planning Area, and the WRP may encompass broader goals than the water quality improvement information outlined in this document. The intent of a WRP for the Madison is to serve as a locally organized "road map" for watershed activities, prioritizing types of projects, sequences of projects, and funding sources towards achieving local watershed goals. Within the WRP, local stakeholders identify and prioritize streams, tasks, resources, and schedules for applying

best management practices. A WRP is intended to be a living document that can be revised based on new information related to restoration effectiveness, monitoring results, and stakeholder priorities.

The U.S. Environmental Protection Agency's nine minimum elements for a WRP are summarized here:

1. Identification of the causes and sources of pollutants
2. Estimated load reductions expected, based on implemented management measures
3. Description of needed nonpoint source management measures
4. Estimate of the amounts of technical and financial assistance needed
5. An information/education component
6. Schedule for implementing the nonpoint source management measures
7. Description of interim, measurable milestones
8. Set of criteria that can be used to determine whether loading reductions are being achieved over time
9. A monitoring component to evaluate effectiveness of the implementation efforts over time

The 2020 Madison Stream Summaries document (found on DEQ's TMDL website with this TMDL document) succinctly aids with elements 1, 2, and 8 for waterbodies that received a sediment and/or temperature TMDL in this document. This document section (**Section 9.0**) can assist with element 3 for all waterbodies prioritized within the WRP, and **Section 10.0** can provide technical assistance for element 9. DEQ TMDL and nonpoint source pollution program staff can provide technical assistance for development of all nine of the required elements, including assistance with sources of funding (**Section 9.7**); staff contacts and WRP planning assistance documents can be found on the DEQ website at http://deq.mt.gov.

9.2 Role of DEQ, Other Agencies, and Stakeholders

DEQ does not implement TMDL pollutant-reduction projects for nonpoint source activities, but may provide technical and financial assistance for stakeholders interested in improving their water quality. Successful implementation of TMDL pollutant-reduction projects requires collaboration among private landowners, land management agencies, and other stakeholders. DEQ will work with participants to use the TMDLs as a basis for developing locally-driven WRPs, administer funding specifically to help support water quality improvement and pollution prevention projects, and help identify other sources of funding.

Because most nonpoint source reductions rely on voluntary measures, it is important that local landowners, watershed organizations, and resource managers work collaboratively with local and state agencies to achieve water quality restoration goals and to meet TMDL targets and load reductions. In addition to DEQ, specific stakeholders and agencies that will likely be vital to restoration efforts for streams discussed in this document include:

- Madison Conservation District
- Gallatin Conservation District
- U.S. Environmental Protection Agency (EPA)
- U.S. Forest Service (USFS)
- Natural Resources and Conservation Service (NRCS)
- U.S. Fish & Wildlife Service (USFWS)
- Montana Department of Natural Resources and Conservation (DNRC)
- Montana Fish, Wildlife and Parks (FWP)

- Montana Department of Transportation
- Montana Bureau of Mines and Geology
- Northwestern Energy
- Trout Unlimited: Madison-Gallatin Chapter
- Local City and County Representatives
- Gallatin Local Water Quality District
- Madison Valley Ranchlands Group
- Jack Creek Preserve Foundation

Other organizations and non-profits that may provide assistance through technical expertise, funding, educational outreach, or other means include:

- Montana Water Center (at Montana State University)
- University of Montana Watershed Health Clinic
- Montana Aquatic Resources Services
- Montana State University Extension Water Quality Program

9.3 Water Quality Restoration Objective

The water quality restoration objective for the Madison TMDL Planning Area is to reduce pollutant loads, as identified throughout this document, to meet the water quality standards and TMDL targets for full recovery of beneficial uses for all impaired streams. Meeting the TMDLs provided in this document, as well as in the 2019 nutrient, pathogen, and metals TMDL document (DEQ 2019), will achieve this objective for all identified pollutant-impaired streams. Based on the assessment provided in both TMDL documents, the TMDLs can be achieved through proper implementation of best management practices and using the appropriate technology to treat wastewater (both private and municipal). However, this section focuses on BMPs for nonpoint sources.

9.4 Restoration Approaches by Pollutant

TMDLs were completed for 13 waterbody segments for sediment and three waterbody segments for temperature. Other streams in the planning area may be in need of restoration or pollutant reduction, but insufficient information about them precludes TMDL development at this time. The following sub-sections describe some generalized recommendations for implementing projects to achieve the TMDLs. Details specific to each stream, and therefore which of the following strategies may be most appropriate, are found within **Sections 5.0** and **6.0** and the 2020 Madison Stream Summaries document found on DEQ's TMDL website.

Many of the BMPs discussed involve what is often referred to as soft, or passive, approaches. These include situations where impacts along a stream are often reduced due to changes in grazing management and nature is allowed to 'run her course' over time via establishment of healthy riparian vegetation and other conditions that improve water quality and overall stream function. These are often the most practical and least expensive approaches, although full recovery can take years. In some situations, it can be advantageous to take a more aggressive or active approach which can be as simple as planting willows along the stream to help hold banks together, versus waiting for willows to naturally repopulate. In more extreme cases, particularly where channel form and function have been significantly altered and passive approaches could take decades, an active approach could involve

reconfiguring a whole reach of a stream along with creation of stream meander patterns and planting of willows or other appropriate riparian vegetation.

9.4.1 Sediment Restoration Approach

The goal of the sediment restoration strategy is to limit the availability, transport, and delivery of excess sediment by a combination of minimizing sediment delivery, reducing the rate of runoff, and intercepting sediment transport. Monitoring data used to develop targets and determine impairments are described in **Section 5.0** and in **Appendix B**, Sediment and Habitat Data Collection Methods. Sediment restoration activities on impaired stream segments will help reduce the amount of fine sediment, reduce width/depth ratio, increase residual pool depths, increase pool frequency, increase riparian understory shrub cover, reduce impacts of human-caused sediment sources, and restore appropriate macroinvertebrate assemblages. These are indicators of successful restoration activities targeted toward sediment reduction and need to be considered together and within the context of stream potential in comparison to appropriate reference sites. For example, pool frequency tends to decline as stream size increases; therefore, indicators for these parameters will vary. General targets for these indicators are summarized in **Table 5-2**.

Streamside riparian and wetland vegetation restoration and long-term management are crucial to achieving the sediment TMDLs. Native streamside riparian and wetland vegetation provides root mass, which hold streambanks together. Suitable root mass density ultimately slows bank erosion. Riparian and wetland vegetation filter pollutants from upland runoff. Therefore, improving riparian and wetland vegetation will decrease streambank erosion by improving streambank stability and will also reduce pollutant delivery from upland sources. Suspended sediment is also deposited more effectively in healthy riparian zones and wetland areas during flooding because water velocities slow in these areas enough for excess sediment to settle out. Restoration recommendations involve the promotion of riparian and wetland recovery through improved grazing and land management (including the timing and duration of grazing, the development of multi-pasture systems that include riparian pastures, and the development of off-site watering areas), application of timber harvest best management practices, floodplain and streambank stabilization, revegetation efforts, and instream channel and habitat restoration where necessary. Appropriate BMPs will differ by location and are recommended to be included and prioritized as part of a comprehensive watershed scale plan (e.g., a WRP).

In areas where stormwater is accelerating sediment loading to streams, the sediment restoration strategy will be achieved by BMPs that promote infiltration of runoff and lessen its volume and the timing of delivery to surface water. Smart growth and low impact development are two closely related planning strategies that help reduce stormwater volume, slow its transport to surface waterbodies, and improve groundwater recharge.

Although unpaved roads may be a small source of sediment at the watershed scale, sediment derived from roads may cause significant localized impact in some stream reaches. Restoration approaches for unpaved roads near streams primarily include measures that divert water to ditches before it enters the stream. The diverted water should be routed through natural healthy vegetation, which will act as filter zones for the sediment laden runoff before it enters streams. In addition, routine maintenance of unpaved roads (particularly near stream crossings) and proper sizing and maintenance of culverts, regardless of road use status, are crucial components to limiting sediment production from roads.

9.4.2 Temperature Restoration Approach

The goal of the temperature restoration approach is to reduce water temperatures where possible to be consistent with naturally occurring conditions. The most significant mechanism for reducing water temperature in Cherry Creek, Elk Creek, and Moore Creek is increasing riparian shade. Secondarily, recovery of over widened stream channels to a more natural morphology and increasing instream flow during summer months may also aid in reducing temperatures.

Increase in shade can be accomplished through the restoration and protection of shade-providing vegetation within the riparian corridor. This type of vegetation can also have the added benefit of serving as a stabilizing component to streambanks to reduce bank erosion, slow lateral river migration, and buffer pollutants from upland sources from entering the stream. In some cases, this can be achieved by limiting the frequency and duration of livestock access to the riparian corridor, or through other grazing-related BMPs such as installing water gaps or off-site watering. Other areas may require planting, active bank restoration, and protection from browse to establish vegetation.

Specific targets for instream summer flow are provided for Cherry, Elk, and Moore creeks in **Sections 6.4.1.4** and **6.4.1.5**. If increases in instream summer flows are possible, they can be achieved through a thorough investigation of water use practices and water conveyance infrastructure, and a willingness and ability of local water users to keep more water in the stream. This TMDL document cannot, nor is it intended to, prescribe limitations on individual water rights owners and users. However, it is understood that increased summer instream flows could improve summer water temperatures, and in addition, improve quality and connectivity among instream features used by aquatic life. Local water users should work collectively and with local, state, and federal resource management professionals to review water use options and available assistance programs.

Recovery of stream channel morphology in most cases will occur slowly over time and follow the improvement of riparian condition, stabilization of streambanks, and reduction in overall sediment load. For smaller streams, there may be discrete locations or portions of reaches that demand a more rapid intervention through physical restoration, but size, scale, and cost of restoration in most cases are limiting factors to applying a constructed remedy.

The above approaches give only the broadest description of activities to help reduce water temperatures. The temperature assessments described in **Section 6.0** looked at possible scenarios based on limited information at the watershed scale. Those scenarios showed that improvements in stream temperatures can primarily be made by improvements to riparian shade, but site-specific analysis and detailed review of current land management and water use practices was not included in the assessment. Therefore, it is not suggested that every operator and water user in the Madison River watershed need to change their practices to reduce stream temperatures; there may be some who currently manage their land and water use consistent with all reasonable land, soil, and water conservation practices, and there may be others for whom changing their practices at this stage is not a viable option due to economic or other constraints. Nevertheless, it is strongly encouraged that resource managers and land owners continue to work to identify all potential areas of improvement and develop projects and practices to reduce stream temperatures in Cherry, Elk, and Moore creeks and the West Fork Madison River.

9.4.3 Non-Pollutant Restoration Approach

Although TMDL development is not required for non-pollutant causes of impairment, they are frequently linked to pollutants, and addressing non-pollutant causes is an important component of TMDL implementation. Non-pollutant impairment causes within the Madison TMDL Planning Area include alteration in streamside or littoral vegetative covers, physical substrate habitat alterations, other anthropogenic substrate alterations, and flow regime modification, and are described in **Section 8.0**. Typically, habitat impairments are addressed during implementation of associated pollutant TMDLs. Although flow modifications have the most direct link with temperature, adequate flow is also critical for downstream sediment transport and improving the assimilative capacity of streams for sediment and nutrient inputs. Therefore, if restoration goals within the Madison TMDL Planning Area are not also addressing non-pollutant impairments, additional non-pollutant related BMP implementation should be considered.

9.5 Restoration Approaches by Source

General management recommendations are outlined below for the major sources of human-caused pollutant loads in the Madison TMDL Planning Area: agricultural sources, riparian and wetland vegetation removal, forestry and timber harvest, and roads. Applying and maintaining BMPs is the core of the nonpoint source pollutant reduction strategy, but are only part of a watershed restoration strategy. Restoration activities may also address other current pollution-causing uses and management practices. In some cases, efforts beyond implementing new BMPs may be required to address key pollutant sources. In these cases, BMPs are usually identified as a first effort and further monitoring and evaluation of activities and outcomes, as part of an adaptive management approach, will be used to determine if further restoration approaches are necessary to achieve water quality standards. Monitoring is an important part of the restoration process, and monitoring recommendations are outlined in **Section 10.0**.

The information provided in the 2020 Madison Stream Summaries document found on DEQ's TMDL website with this TMDL document, should be used to help determine restoration priorities and which restoration approaches below should be applied for each stream. In recognition that noxious weeds are a problem throughout Montana and may be associated with any of the following source categories, noxious weed control should be actively pursued whenever BMPs are being implemented.

9.5.1 Agriculture Sources

Reduction of pollutants from upland agricultural sources can be accomplished by limiting the amount of erodible soil, reducing the rate of runoff, and intercepting eroding soil and runoff before it enters a waterbody. The main BMP recommendations for the Madison TMDL Planning Area are riparian buffers, wetland restoration, and vegetated filter strips, where appropriate. These methods reduce the rate of runoff, promote infiltration of the soil (instead of delivering runoff directly to the stream), and intercept pollutants. Filter strips and buffers are even more effective for reducing upland agricultural-related sediment when used in conjunction with BMPs that reduce the availability of erodible soil such as conservation tillage, crop rotation, and strip-cropping. Additional BMP information, design standards and effectiveness, and details on the suggested BMPs can be obtained from your local USDA Agricultural Service Center and in Montana's Nonpoint Source Management Plan (DEQ 2017).

An additional benefit of reducing sediment input to the stream is a decrease in sediment-bound nutrients. Reductions in sediment loads may help address some nutrient-related problems. Nutrient

management considers the amount, source, placement, form, and timing of plant nutrients and soil amendments. Conservation plans should include the following information (NRCS Conservation Practice Standard 590 and 590-1, Nutrient Management (United States Department of Agriculture, Natural Resources Conservation Service, 2019):

- Field maps and soil maps
- Planned crop rotation or sequence
- Results of soil, water, plant, and organic materials sample analysis
- Realistic expected yields
- Sources of all nutrients to be applied
- A detailed nutrient budget
- Nutrient rates, form, timing, and application method to meet crop demands and soil quality concerns
- Location of environmentally sensitive areas, including streams, wetlands, springs, or other locations that deliver surface runoff to groundwater or surface water
- Guidelines for operation and maintenance

9.5.1.1 Grazing

Grazing has the potential to increase sediment and nutrient loads, as well as stream temperatures (by altering channel width and riparian vegetation), but these effects can be mitigated with appropriate management. Development of riparian grazing management plans should be a goal for any landowner who operates livestock and does not currently have such plans. Private land owners may be assisted by state, county, federal, and local conservation groups to establish and implement appropriate grazing management plans. Note that riparian grazing management does not necessarily eliminate all grazing in riparian corridors. In some areas however, a more limited management strategy may be necessary for a period of time in order to accelerate reestablishment of a riparian community with the most desirable species composition and structure.

Every livestock grazing operation should have a grazing management plan. The NRCS Prescribed Grazing Conservation Practice Standard (Code 528) recommends the plan include the following elements (Natural Resource Conservation Service, 2010):

- A map of the operation showing fields, riparian and wetland areas, winter feeding areas, water sources, animal shelters, etc.
- The number and type of livestock
- Realistic estimates of forage needs and forage availability
- The size and productivity of each grazing unit (pasture/field/allotment)
- The duration and time of grazing
- Practices that will prevent overgrazing and allow for appropriate regrowth
- Practices that will protect riparian and wetland areas and associated water quality
- Procedures for monitoring forage use on an ongoing basis
- Development plan for off-site watering areas

Reducing grazing pressure in riparian and wetland areas and improving forage stand health are the two keys to preventing nonpoint source pollution from grazing. Grazing operations should use some or all of the following practices:

- Minimizing or preventing livestock grazing in riparian and wetland areas
- Providing off-stream watering facilities or using low-impact water gaps to prevent ‘loafing’ in wet areas

- Managing riparian pastures separately from upland pastures
- Installing salt licks, feeding stations, and shelter fences in areas that prevent 'loafing' in riparian areas and help distribute animals
- Replanting trodden down banks and riparian and wetland areas with native vegetation (this should always be coupled with a reduction in grazing pressure)
- Rotational grazing or intensive pasture management that takes season, frequency, and duration into consideration

The following resources provide guidance to help prevent pollution and maximize productivity from grazing operations:

- USDA, Natural Resources Conservation Service
  The office serving Madison County is the Sheridan Service Center (find your local USDA Agricultural Service Center listed in your phone directory or at www.nrcs.usda.gov)
- Montana State University Extension Service (www.musextension.org)
- DEQ Watershed Protection Section, Nonpoint Source Program: Nonpoint Source Management Plan (http://deq.mt.gov/Water/SurfaceWater/npspollution)

The key strategy of the recommended grazing BMPs is to develop and maintain healthy riparian and wetland vegetation and minimize disturbance of the streambank and channel. The primary recommended BMPs for the Madison TMDL Planning Area are limiting livestock access to streams and stabilizing the stream at access points, providing off-site watering sources when and where appropriate, planting native stabilizing vegetation along streambanks, and establishing and maintaining riparian buffers. Although bank revegetation is a preferred BMP, in some instances bank stabilization may be necessary prior to planting vegetation.

9.5.1.2 Animal Feeding Operations

Animal feeding operations (AFOs) can pose a number of risks to water quality and public health if the animal manure and wastewater they generate contaminates nearby waters. To minimize water quality and public health concerns from AFOs and land applications of animal waste, the USDA and EPA released the Unified National Strategy for AFOs in 1999 (USDA and U.S. EPA, 1999). This strategy encouraged owners of AFOs of any size of number of animals to voluntarily develop and implement site-specific Comprehensive Nutrient Management Plans (CNMPs). A CNMP is a written document detailing manure storage and handling systems, surface runoff control measures, mortality management, chemical handling, manure application rates, schedules to meet crop nutrient needs, land management practices, and other options for manure disposal.

An AFO that meets certain specified criteria is referred to as a Concentrated Animal Feeding Operation (CAFO), and may be required to obtain a Montana Pollution Discharge Elimination System (MPDES) permit as a point source. Montana's AFO compliance strategy is based on federal law and has voluntary, as well as, regulatory components. If voluntary efforts can eliminate discharges to state waters, in some cases no direct regulation is necessary through a permit.

Operators of AFOs may take advantage of effective, low cost practices to reduce potential runoff to state waters. In addition to water quality benefits, these practices may help increase property values and operation productivity. Properly installed vegetative filter strips, in conjunction with other practices to reduce wasteloads and runoff volume, are very effective at trapping and detaining sediment and reducing transport of nutrients and pathogens to surface waters, with removal rates approaching 90

percent (USDA, NRCS 2005). Other options may include clean water diversions, roof gutters, berms, sediment traps, fencing, structures for temporary manure storage, shaping, and grading. Animal health and productivity also benefit when clean, alternative water sources are installed to prevent contamination of surface water.

Opportunities for financial and technical assistance (including comprehensive nutrient management plan development) in achieving voluntary AFO and CAFO compliance are available from conservation districts, NRCS field offices, or the Montana DEQ Watershed Protection Section. Further information may be obtained from the DEQ website at: http://deq.mt.gov/Water/permits.

Montana's nonpoint source pollution control strategies for addressing AFOs are summarized in the bullets below:

- Work with producers to prevent nonpoint source pollution from AFOs
- Promote use of State Revolving Fund for implementing AFO BMPs
- Collaborate with Montana State University (MSU) Extension Service, NRCS, and agriculture organizations in providing resources and training in whole farm planning to farmers, ranchers, conservation districts, watershed groups and other resource agencies
- Encourage inspectors to refer farmers and ranchers with potential nonpoint source discharges to DEQ watershed protection staff for assistance with locating funding sources and grant opportunities for BMPs that meet their needs (this is in addition to funds available through NRCS and the Farm Bill)
- Develop early intervention of education and outreach programs for small farms and ranches that have potential to discharge nonpoint source pollutants from animal management activities. This includes assistance from the DEQ Permitting Division, as well as external entities such as DNRC, local watershed groups, conservation districts, and MSU Extension.

9.5.1.3 Water Management and Irrigation

Flow modification and dewatering are commonly considered water quantity rather than water quality issues. However, changes to streamflow can have a profound effect on the ability of a stream to attenuate pollutants, especially nutrients, metals, and heat. Flow reduction may increase water temperature, allow pollutants to accumulate in stream channels, reduce available habitat for fish and other aquatic life, and may cause the channel to respond by changing in size, morphology, meander pattern, rate of migration, bed elevation, bed material composition, floodplain morphology, and streamside vegetation if flood flows are reduced (Andrews and Nankervis, 1995; Schmidt and Potyondy, 2004). Implementation strategies recognize the need for specific flow regimes, and may suggest flow-related improvements as a means to achieve full support of beneficial uses. However, local coordination and planning are especially important for flow management because Montana state law indicates that legally obtained water rights cannot be divested, impaired, or diminished by Montana's water quality law (75-5-705, Montana Code Annotated).

Irrigation management is a critical component of attaining both coldwater fishery conservation and TMDL goals. Understanding irrigation water, groundwater, and surface water interactions is an important part of understanding how irrigation practices will affect streamflow during specific seasons. Improvements should focus on how to reduce the amount of stream water diverted during July and August, while still maintaining healthy crops or forage. It may also be desirable to investigate irrigation practices earlier in the year that promote groundwater return during July and August, and September.

Some irrigation practices in western Montana are based on flood irrigation methods. Occasionally head gates and ditches leak, which can decrease the amount of water in diversion flows. The following recommended activities could potentially result in notable water savings:

- Install upgraded head gates for more exact control of diversion flow and to minimize leakage when not in operation
- Develop more efficient means to supply water to livestock
- Determine necessary diversion flows and timeframes that would reduce over watering and improve forage quality and production
- Where appropriate, redesign or reconfigure irrigation systems
- Upgrade ditches (including possible lining, if appropriate) to increase ditch conveyance efficiency

Some water from spring and early summer flood irrigation likely returns as cool groundwater to the streams during the heat of the summer. These critical areas could be identified so that they can be preserved as flood irrigation areas. Other irrigated areas which do not contribute to summer groundwater returns to the river should be identified as areas where year-round irrigation efficiencies could be more beneficial than seasonal management practices. Winter baseflow should also be considered during these investigations.

9.5.1.4 Small Acreages

Throughout Montana, the number of small acreages is growing rapidly, and many small acreage owners own horses or cattle. Animals grazing on small acreages can lead to overgrazing and a shortage of grass cover, leaving the soil subject to erosion and runoff to surface waters. General BMP recommendations for small acreage lots with animals include creating drylots, developing a rotational grazing system, and maintaining healthy riparian buffers. Small acreage owners should collaborate with MSU Extension Service, NRCS, conservation districts and agriculture organizations to develop management plans for their lots. Further information may be obtained from the Montana Nonpoint Source Management Plan (DEQ, 2017) or the MSU extension website at: http://animalrangeextension.montana.edu/range/small-acreages.html

9.5.1.5 Cropland

The primary strategy of the recommended cropland BMPs is to reduce sediment inputs. The major factors involved in decreasing sediment loads are reducing the amount of erodible soil, reducing the rate of runoff, and intercepting eroding soil before it enters waterbodies. The main BMP recommendations for the Madison TMDL Planning Area are vegetated filter strips and riparian buffers. Both methods reduce the rate of runoff, promote infiltration of the soil (instead of delivering runoff directly to the stream), and intercept sediment. Effectiveness is typically about 70% for the filter strips (Arora 1996) and 50% for the buffers (Liu 2008). Filter strips and buffers are most effective when used in conjunction with agricultural BMPs that reduce the availability of erodible soil such as conservation tillage, crop rotation, strip cropping, and precision farming. Filter strips along streams should be composed of natural vegetative communities. Additional BMPs and details on the suggested BMPs can be obtained from NRCS and in Appendix A of Montana's Nonpoint Source Management Plan (DEQ 2017).

9.5.2 Riparian Areas, Wetlands, and Floodplains

Healthy and functioning riparian areas, wetlands, and floodplains are critical for wildlife habitat, groundwater recharge, reducing the severity of floods and upland and streambank erosion, and filtering

pollutants from runoff. The performance of these functions is dependent on the connectivity of riparian areas, wetlands, and floodplains to both the stream channel and upland areas. Human activities affecting the quality of these transitional habitats or their connectivity can alter their performance and greatly affect the transport of water, sediments, and contaminants (e.g., channelization, increased stream power, bank erosion, and habitat loss or degradation). Therefore, restoring, maintaining, and protecting riparian areas, wetlands, and floodplains within the watershed should be a priority of TMDL implementation in the Madison TMDL Planning Area.

Reduction of riparian and wetland vegetative cover by various land management activities is a principal cause of water quality and habitat degradation in watersheds throughout Montana. Although implementation and maintenance of passive BMPs that allow riparian and wetland vegetation to recover at natural rates is typically the most cost-effective approach, active restoration (e.g., plantings) may be necessary in some instances. The primary advantage of riparian and wetland plantings is that installation can be accomplished with minimum impact to the stream channel, existing vegetation, and private property. Weed management should also be a dynamic component of managing riparian areas.

Factors influencing the appropriate riparian and wetland restoration would include severity of degradation, site-potential for various species, and availability of local sources for native transplant materials. In general, riparian and wetland plantings would promote establishment of functioning stands of native species. The following recommended restoration measures would allow for stabilization of the soil, decrease sediment delivery to the stream, and increase absorption of nutrients from overland runoff:

- Harvesting and transplanting locally available sod mats with an existing dense root mass provides immediate promotion of bank stability and filtering nutrients and sediments
- Seeding with native graminoids (grasses and sedges) and forbs is a low-cost activity at locations where lower bank shear stresses would be unlikely to cause erosion
- Transplanting mature native shrubs, particularly willows (*Salix* sp.), provides rapid restoration of instream habitat and water quality through overhead cover and stream shading, as well as uptake of nutrients
- Willow sprigging expedites vegetative recovery, but involves harvest of dormant willow stakes from local sources

Note: Before transplanting *Salix* from one location to another it is important to determine the exact species so that we do not propagate the spread of non-native species. There are several non-native willow species that are similar to our native species and commonly present in Montana watersheds.

In addition to the benefits described above, it should be noted that in some cases, wetlands act as areas of shallow subsurface groundwater recharge and/or storage areas. The captured water via wetlands is then generally discharged to the stream later in the season and contributes to the maintenance of base flows and stream temperatures. Restoring ditched or drained wetlands can have a substantial effect on the quantity, temperature, and timing of water returning to a stream, as well as the pollutant filtering capacity that improved riparian and wetlands provide. Planning guides and informational publications related to wetlands and native plant species in Montana can be found on DEQ's Wetlands Conservation website at: http://deq.mt.gov/water/surfacewater/wetlands.

9.5.3 Bank Hardening/Riprap/Revetment and Floodplain Development

The use of riprap or other "hard" approaches is not recommended and is not consistent with water quality protection or implementation of this plan. Although it may be necessary in some instances, these

"hard" approaches generally redirect channel energy and exacerbate erosion in other places. Bank armoring should be limited to areas with a demonstrated infrastructure threat. Where deemed necessary, apply bioengineered bank treatments to induce vegetative reinforcement of the upper bank, reduce stream scouring energy, and provide shading and cover habitat. Limit threats to infrastructure by reducing floodplain development through local land use planning initiatives.

As discussed above, passive riparian restoration is preferable, but in areas where stream channels are unnaturally unstable or streambanks are eroding excessively, additional active restoration approaches, such as channel design, woody debris and log vanes, bank sloping, seeding, and shrub planting may be desired to speed up the rate of recovery. Bank stabilization using natural channel design techniques can provide both bank stability and aquatic habitat potential. The primary recommended structures include natural or "natural-like" structures, such as large woody debris jams. These natural arrays can be constructed to emulate historical debris assemblages that were introduced to the channel by the adjacent cottonwood-dominated riparian community types. When used together, woody debris jams and straight log vanes can benefit the stream and fishery by improving bank stability, reducing bank erosion rates, adding protection to fillslopes and/or embankments, reducing near-bank shear stress, and enhancing aquatic habitat and lateral channel margin complexity.

Initiatives to protect riparian areas and floodplains will help protect property, increase channel stability, and buffer waterbodies from pollutants. However, in areas with a much smaller buffer or where historical vegetation removal and development have shifted the riparian vegetation community and limited its functionality, a tiered approach for restoring stream channels and adjacent riparian vegetation should be considered that prioritizes areas for restoration based on the existing condition and potential for improvement. In non-conifer dominated areas, the restoration goals should focus on restoring natural shrub cover on streambanks.

DEQ encourages the consideration of adopting local zoning or regulations that protect the functions of floodplains and riparian and wetland areas where future growth may occur. Requirements for protecting native vegetation riparian buffers can be an effective mechanism for maintaining or improving stream health. Local outreach activities to inform new residential property owners of the effects of riparian degradation may also prevent such activities from occurring, including providing information on: appropriate fertilizer application rates to lawns and gardens, regular septic system maintenance, preserving existing riparian vegetation, native vegetation for landscaping, maintaining a buffer to protect riparian and wetland areas, and practices to reduce the amount of stormwater originating from developed property. Montana's Nonpoint Source Management Plan contains suggested BMPs to address the effects of residential and urban development, and also contains an appendix of setback regulations that have been adopted by various cities and counties in Montana (DEQ 2017).

9.5.4 Beaver Populations

Historic heavy trapping of beavers throughout Montana has likely had an effect on sediment yields in watersheds in the western areas of the state. Before the removal of beavers, many streams had a series of catchments that moderated flow, with smaller un-incised multiple channels and frequent flooding. Now some of these streams have incised channels and are no longer connected to the floodplain. This results in more bank erosion because high flows scour streambanks to a greater extent instead of flowing onto the floodplain. Beaver ponds capture and store sediment and can result in large reductions in total suspended solids (TSS) concentrations below a beaver impoundment in comparison to TSS concentrations above the beaver impoundment (Bason, 2004). Management of streams should include

consideration of beaver habitat in appropriate areas currently lacking the beaver complexes that can trap sediment, reduce peak flows, and increase summer low flows. Allowing for existing and even increased beaver habitat is considered consistent with the sediment TMDL water quality goals.

9.5.5 Unpaved Roads

Unpaved roads contribute sediment (as well as nutrients and other pollutants) to streams in the Madison TMDL Planning Area. The road sediment reductions in this document represent a gross estimation of the sediment load that will remain once appropriate road BMPs are applied and maintained at all locations, assuming no current BMPs are in place. In general, a road with associated BMPs assumes contributing road treads, cutslopes, and fillslopes were reduced to 200 feet from each side of a crossing and 500 feet from each parallel road segment. This distance is selected as an example to illustrate the potential for sediment reduction through BMP application and is not a formal goal at every crossing. For example, many roads may easily allow for a smaller contributing length, while others may not be able to meet a 200-foot goal.

Achieving this reduction in sediment loading from roads may occur through a variety of methods at the discretion of local land managers and restoration specialists. Road BMPs can be found on the Montana DEQ or DNRC websites and within Montana's Nonpoint Source Management Plan (DEQ 217). Examples include:

- Providing adequate ditch relief up-grade of stream crossings
- Constructing waterbars, where appropriate, and up-grade of stream crossings
- Instead of cross pipes, using rolling dips on downhill grades with an embankment on one side to direct flow to the ditch. When installing rolling dips, ensure proper fillslope stability and sediment filtration between the road and nearby streams.
- Insloping roads along steep banks with the use of cross slopes and cross culverts
- Outsloping low traffic roads on gently sloping terrain with the use of a cross slope
- Using ditch turnouts and vegetative filter strips to decrease water velocity and sediment carrying capacity in ditches
- For maintenance, grade materials to the center of the road and avoid removing the toe of the cutslope
- Preventing disturbance to vulnerable slopes
- Using topography to filter sediments; flat, vegetated areas are more effective sediment filters
- Where possible, limit road access during wet periods when drainage features could be damaged
- Limit new road stream crossings and the length of near-stream parallel segments to the extent practicable

9.5.5.1 Culverts and Fish Passage

Undersized and improperly installed and maintained culverts can be a substantial source of sediment to streams, and a barrier to fish and other aquatic organisms. There are many factors associated with culvert failure and it is difficult to estimate the true at-risk load. The allocation strategy for culverts is that, regardless of road use status, there should be no loading from culverts as a result of being undersized, improperly installed, or inadequately maintained. It is recommended that culverts be assessed so that a priority list may be developed for culvert replacement. As culverts fail, they should be replaced by culverts that pass a 100 year flood on fish-bearing streams and at least 25 year events on non-fish bearing streams. Some road crossings may not pose a feasible situation for upgrades to these sizes because of road bed configuration; in those circumstances, the largest size culvert feasible should be used. If funding is available, culverts should be prioritized and replaced prior to failure.

Another consideration for culvert upgrades should be fish and aquatic organism passage. Each culvert that is deemed a fish barrier should be assessed individually to determine if it functions as an invasive species and/or native species barrier. These two functions should be weighed against each other to determine if each culvert acting as a fish passage barrier should be mitigated. Montana Fish, Wildlife & Parks can aid in determining if a fish passage barrier should be mitigated, and, if so, can aid in culvert design.

9.5.5.2 Traction Sand

Severe winter weather and mountainous roads in the Madison TMDL Planning Area will require the continued use of relatively large quantities of traction sand. Nevertheless, closer evaluation of and adjustments to existing practices should be done to reduce traction sand loading to streams to the extent practicable. The necessary BMPs may vary throughout the watershed and particularly between state and private roads but may include the following:

- Use a snow blower to directionally place snow and traction sand on cut/fillslopes away from sensitive environments
- Increase the use of chemical deicers and decrease the use of road sand, as long as doing so does not create a safety hazard or cause undue degradation to vegetation and water quality
- Improve maintenance records to better estimate the use of road sand and chemicals, as well as to estimate the amount of sand recovered in sensitive areas
- Continue to fund Montana Department of Transportation research projects that will identify the best designs and procedures for minimizing road sand impacts to adjacent bodies of water and incorporate those findings into additional BMPs
- Street sweeping and sand reclamation
- Identify areas where the buffer could be improved, or structural control measures may be needed
- Improved maintenance of existing BMPs
- Increase availability of traction sand BMP training to both permanent and seasonal MDT employees, as well as private contractors

9.5.6 Forestry and Timber Harvest

Currently, active timber harvest is not significantly affecting sediment the Madison TMDL Planning Area and no load allocations were allocated directly to timber harvests. Timber harvesting will likely continue in the future within the Beaverhead-Deer Lodge National Forest, and on private land. Therefore, future timber harvest activities should be conducted by all landowners according to Forestry BMPs for Montana (Montana State University Extension Service, 2001) and the Montana Streamside Management Zone (SMZ) Law (77-5-301 through 307, Montana Code Annotated). The Montana Forestry BMPs cover timber harvesting, site preparation, and road building including culvert design, harvest design, other harvesting activities, slash treatment and site preparation, winter logging, and hazardous substances. While the SMZ Law is intended to guide commercial timber harvesting activities in streamside areas (i.e., within 50 feet of a waterbody), the riparian protection principles behind the law should be applied to numerous land management activities (e.g., timber harvest for personal use, agriculture, development). Prior to harvesting on private land, landowners or operators are required to notify the Montana Department of Natural Resources and Conservation. DNRC is responsible for assisting landowners with BMPs and monitoring their effectiveness. The Montana Logging Association and DNRC offer regular Forestry BMP training sessions for private landowners.

In addition to the BMPs identified above, effects that timber harvest may have on yearly streamflow levels, such as peak flow, should be considered. Timber harvest plans should evaluate the potential for cumulative effects on water yield and peak flow increases and implement BMPs to reduce sediment and nutrients loading. Finally, noxious weed control should be actively pursued in all harvest areas.

9.6 Nonpoint Source Pollution Education

Because most nonpoint source pollution (NPS) is generated by individuals, a key factor in reducing NPS pollution is increasing public awareness through education. Local watershed groups can provide educational opportunities to both students and adults through water quality workshops and informational meetings. Continued education is key to an ongoing understanding of water quality issues in the Madison TMDL Planning Area, and to the support for implementation and restorative activities.

9.7 Potential Funding Sources

Prioritization and funding of restoration or water quality improvement projects is integral to maintaining restoration activities and monitoring project successes and failures. Several government agencies and also a few non-governmental organizations fund or can provide assistance with watershed or water quality improvement projects or wetlands restoration projects. Below is a brief summary of potential funding sources and organizations to assist with TMDL implementation. Note that some programs or funding sources summarized below may be discontinued in the future, and new sources of funding could possibly become available. Be sure to inquire with these agencies and organizations for the most current information.

In addition to the information presented below, numerous other funding opportunities exist for addressing nonpoint source pollution. Additional information regarding funding opportunities from state agencies is contained in Montana's Nonpoint Source Management Plan (DEQ 2017) and information regarding additional funding opportunities can be found at https://www.epa.gov/nps/funding-resources-watershed-protection-and-restoration.

Section 319 Nonpoint Source Grant Program

DEQ issues a call for proposals every year to award federal Section 319 grant funds administered under the federal Clean Water Act. The primary goal of the 319 program is to restore water quality in waterbodies whose beneficial uses are impaired by nonpoint source pollution and whose water quality does not meet state standards. 319 funds are distributed competitively to support the most effective and highest priority projects. To receive funding, projects must directly implement a DEQ-accepted watershed restoration plan (**Section 9.2**) and funds may only be used for planning and implementing restoration projects. The recommended range for 319 funds per project proposal is $50,000 to $300,000. All funding has a 40% cost share requirement, and projects must be administered through a governmental entity such as a conservation district or county, or a nonprofit organization. For information about past grant awards and how to apply, please visit: http://deq.mt.gov/Water/SurfaceWater/319Projects.

Future Fisheries Improvement Program

The Future Fisheries grant program is administered by FWP and offers funding for projects that focus on habitat restoration to benefit wild and native fish. Anyone ranging from a landowner or community-based group to a state or local agency is eligible to apply. Applications are reviewed annually in December and June. Projects that may be applicable to the Madison TMDL Planning Area include

restoring streambanks, improving fish passage, and restoring/protecting spawning habitats. For additional information about the program and how to apply, please visit http://fwp.mt.gov/fishAndWildlife/habitat/fish/futureFisheries/.

Renewable Resource Project Planning Grants
The DNRC administers watershed grants to pay for contracted costs associated with the development of a watershed assessment. Grant are available for a maximum of $75,000 per project. Eligible applicants include conservation districts and irrigation districts, among many others. For additional information about the program and how to apply, please visit: http://dnrc.mt.gov/grants-and-loans.

Environmental Quality Incentives Program
The Environmental Quality Incentives Program (EQIP) is administered by NRCS and offers financial (i.e., incentive payments and cost-share grants) and technical assistance to farmers and ranchers to help plan and implement conservation practices that improve soil, water, air and other natural resources on their land. The program is based on the concept of balancing agricultural production and forest management with environmental quality, and is also used to help producers meet environmental regulations. EQIP offers contracts with a minimum length of one year after project implementation to a maximum of 10 years. Each county receives an annual EQIP allocation and applications are accepted continually during the year; payments may not exceed $300,000 within a six-year period. For additional information about the program and how to apply, please visit http://www.nrcs.usda.gov/wps/portal/nrcs/main/national/programs/financial/eqip/.

Montana Partners for Fish and Wildlife
Montana Partners for Fish and Wildlife is a program under the U.S. Fish & Wildlife Service that assists private landowners to restore wetlands and riparian habitat by offering technical and financial assistance. For additional information about the program and to find your local contact for the Madison River watershed, please visit: http://www.fws.gov/mountain-prairie/pfw/montana/.

Wetland Reserve Easements
The NRCS provides technical and financial assistance to private landowners and Indian tribes to restore, enhance, and protect wetlands through permanent easements, 30-year easements, or term easements. Land eligible for these easements includes farmed or converted wetland that can be successfully and cost-effectively restored. For additional information about the program and how to apply, please visit http://www.nrcs.usda.gov/wps/portal/nrcs/detail/national/programs/easements/acep/.

Montana Wetland Council
The Montana Wetland Council is an active network of diverse interests that works cooperatively to conserve and restore Montana's wetland and riparian ecosystems. Please visit their website to find dates and locations of upcoming meetings, wetland program contacts, and additional information on potential grants and funding opportunities: http://deq.mt.gov/water/surfacewater/wetlands.

Montana Natural Heritage Program
The Montana Natural Heritage Program is a valuable resource for restoration and implementation information, including maps. Wetlands and riparian areas are one of the 14 themes in the Montana Spatial Data Infrastructure. The Montana Wetland and Riparian Mapping Center (found at: http://mtnhp.org/nwi/) is creating a statewide digital wetland and riparian layer as a resource for management, planning, and restoration efforts.

Montana Aquatic Resources Services, Inc.
Montana Aquatic Resources Services, Inc. (MARS) is a nonprofit organization focused on restoring and protecting Montana's rivers, streams and wetlands. MARS identifies and implements stream, lake, and wetland restoration projects, collaborating with private landowners, local watershed groups and conservation districts, state and federal agencies, and tribes. For additional information about the program, please visit http://montanaaquaticresources.org/.

10.0 MONITORING FOR EFFECTIVENESS

The monitoring strategies discussed in this section are an important component of watershed restoration, and a requirement of total maximum daily load (TMDL) implementation under the Montana Water Quality Act (75-5-703(7), Montana Code Annotated (MCA)), and the foundation of the adaptive management approach discussed below. Water quality targets and allocations presented in this document are based on available data at the time of analysis. The scale of the watershed analysis, coupled with constraints on time and resources, often result in necessary compromises that include estimations, extrapolation, and a level of uncertainty in TMDLs. The margin of safety (**Section 4.4**) is put in place to reflect some of this uncertainty, but other issues only become apparent when restoration strategies are underway. Having a monitoring strategy in place allows for feedback on the effectiveness of restoration activities, the amount of reduction of instream pollutants (whether TMDL targets are being met), if all significant sources have been identified, and whether attainment of TMDL targets is feasible. Data from long-term monitoring programs also provide technical justifications to modify restoration strategies, targets, or allocations where appropriate.

The monitoring strategy presented in this section provides a starting point for the development of more detailed planning efforts regarding monitoring needs; it does not assign monitoring responsibility. Monitoring recommendations provided are intended to assist local land managers, stakeholder groups, and federal and state agencies in developing appropriate monitoring plans to meet the water quality improvement goals outlined in this document. Funding for future monitoring is uncertain and can vary with economic and political changes. Prioritizing monitoring activities depends on funding opportunities and stakeholder priorities for restoration. Once restoration measures have been implemented for a waterbody with an approved TMDL and given time to take effect, the Department of Environmental Quality (DEQ) will conduct a formal evaluation of the waterbody's impairment status and whether TMDL targets and water quality standards are being met. Based on this evaluation, DEQ will make recommendations on the next steps to take toward meeting water quality goals (**Section 10.2**).

The objectives for future monitoring in the Madison TMDL Planning Area include: 1) tracking and monitoring restoration activities and evaluating the effectiveness of individual and cumulative restoration activities, 2) baseline and impairment status monitoring to assess attainment of water quality targets and identify long-term trends in water quality, and 3) refining the source assessments. Each of these objectives is discussed below.

10.1 ADAPTIVE MANAGEMENT AND UNCERTAINTY

Adaptive management as discussed throughout this document is a systematic approach for improving resource management by learning from management outcomes, and allows for flexible decision making. There is an inherent amount of uncertainty involved in the TMDL process, including: establishing water quality targets for sediment and temperature, calculating existing pollutant loads and necessary load allocations, and determining effects of BMP implementation. Use of an adaptive management approach based on continued monitoring of project implementation helps manage resource commitments as well as achieve success in meeting the water quality standards and supporting all water quality beneficial uses. This approach further allows for adjustments to restoration goals, TMDLs, and/or allocations, as necessary.

The analysis presented in this document assumes that the load reductions proposed for each of the listed streams will enable the streams to meet target conditions and that meeting target conditions will ensure full support of all beneficial uses (and attainment of water quality standards). Much of the monitoring proposed in this section of the document is intended to validate this assumption. If it looks like greater reductions in loading or improved performance is necessary to meet targets, then updated TMDL(s) and/or allocations will be developed based on achievable reductions via application of reasonable land, soil, and water conservations practices. Additionally, as new stressors are added to the watershed and additional data are collected, new water quality targets may need to be developed or existing targets/allocations may need to be modified.

10.2 Effectiveness Monitoring for Restoration Activities

As restoration activities are implemented, watershed-scale monitoring may be valuable in determining if restoration activities are improving water quality, instream flow, and aquatic habitat and communities. It is important to remember that degradation of aquatic resources happens over many decades and that restoration is often also a long-term process. An efficiently executed long-term monitoring effort is an essential component to any restoration effort.

Due to the natural high variability in water quality conditions, trends in water quality are difficult to define and even more difficult to relate directly to restoration or other changes in management. Improvements in water quality or aquatic habitat from restoration activities will most likely be evident in fine sediment deposition and channel substrate embeddedness, changes in channel cumulative width/depths, improvements in streambank stability and riparian habitat, increases in instream flow, and changes in communities and distribution of fish and other bio-indicators. Specific monitoring methods, priorities, and locations will depend heavily on the type of restoration projects implemented, landscape or other natural setting, the land use influences specific to potential monitoring sites, and budget and time constraints.

As restoration activities begin throughout the watershed, monitoring should be conducted prior to and after project implementation to help evaluate the effectiveness of specific practices or projects. Monitoring activities should be selected such that they directly investigate those subjects and pollutants that the project is intended to effect, and when possible, linked to targets and allocations in the TMDL.

For sediment, which has no numeric standard, and temperature, which was evaluated using a Qual2k water quality modeling approach, loading reductions and BMP effectiveness may be estimated using the approaches used within this document. However, tracking BMP implementation, maintenance, and project-related measurements will likely be most practical for sediment and temperature. For instance, for road improvements, it is not anticipated that post-project sediment loads will be measured. Instead, documentation of the BMP, reduced contributing length, and before and after photos documenting the presence and effectiveness of the BMP will be most appropriate. For installation of riparian fencing, photo point monitoring (before and after photo documentation) of riparian vegetation and streambank conditions, and a measurement such as “greenline” that documents the percentage of bare ground and shrub cover, may be most appropriate.

Evaluating instream parameters used for sediment targets will be one of the tools used to gauge the success of implementation when DEQ conducts a formal assessment, but may not be practical for most projects since the sediment effects within a stream represent cumulative effects from many watershed scale activities and because there is typically a lag time between project implementation and instream

improvements (Meals et al., 2010). DEQ TMDL and nonpoint source staff can help local stakeholders determine the most practical and effective monitoring techniques.

If sufficient implementation progress is made within a watershed, DEQ will conduct a TMDL Implementation Evaluation. During this process, DEQ compiles recent data, conducts monitoring (if necessary), may compare data to water quality targets, summarizes BMP implementation that has occurred since TMDL development, and evaluates data to determine if the TMDL is being achieved or if conditions are trending one way or another. If conditions indicate the TMDL is being achieved, the waterbody will be recommended for reassessment and may be removed from the list of impaired waters if assessment results show that water quality standards are being met. If conditions indicate the TMDL is not being achieved, according to Montana State Law (75-5-703(9), MCA), the evaluation must determine if:

- The implementation of a new or improved phase of voluntary reasonable land, soil, and water conservation practices is necessary,
- Water quality is improving, but more time is needed for compliance with water quality standards, or
- Revisions to the TMDL are necessary to achieve applicable water quality standards.

10.3 Baseline and Impairment Status Monitoring

In addition to effectiveness monitoring, watershed scale monitoring should be conducted to expand knowledge of existing conditions and to provide data that can be used during the TMDL implementation evaluation. Infrequent sampling events at a small number of sampling sites may provide some indication of overall water quality and habitat condition, however regularly scheduled sampling at consistent locations, under a variety of seasonal conditions is the best way to assess overall stream health and monitor change.

Although DEQ is the lead agency for conducting impairment status monitoring, other agencies or entities may collect and provide compatible data. Wherever possible, it is recommended that the type of data and methodologies used to collect and analyze the information be consistent with DEQ methodology to allow for comparison to TMDL targets and track progress toward meeting TMDL goals. The information in this section provides general guidance for future impairment status monitoring.

10.3.1 Sediment Monitoring and Data Collection Methodology

Each of the sediment streams of interest for this TMDL project was stratified into unique reaches based on physical characteristics and anthropogenic (human) influence. The sites assessed in the field represent only a percentage of the total number of stratified reaches. Sampling additional monitoring locations could provide additional data to assess existing conditions, and provide more specific information on a per stream basis as well as the TMDL planning area as a whole.

Sediment and habitat assessment protocols consistent with DEQ field methodologies, and that serve as the basis for sediment targets and assessment within this TMDL document, should be implemented whenever possible. Current protocols are identified within Standard Operating Procedure for Sediment Beneficial Use Assessment Monitoring: Wadeable Streams in Mountainous and Transitional Ecoregions (Makarowski, 2020). It is acknowledged that various agencies and entities have differing objectives, as well as time and resources available to achieve those objectives. However, when possible, it is

recommended that at a minimum the following parameters be collected to allow for comparison to TMDL targets:

- Riffle Cross Section, using Rosgen methodology
- Riffle Pebble Count, using Wolman Pebble Count methodology
- Residual Pool Depth Measurements
- Greenline Assessment, using NRCS methodology

Prior to conducting this type of monitoring, DEQ TMDL and nonpoint source staff should also be contacted to discuss appropriate monitoring techniques and methods.

Additional monitoring information will undoubtedly be useful and assist DEQ with TMDL effectiveness monitoring and impairment status evaluations in the future. Examples of additional useful information may include total suspended solids; identifying percentage of eroding streambanks, human sediment sources, and areas with a high background sediment load; macroinvertebrate studies; McNeil core sediment samples; and fish population surveys and redd counts.

An important part of impairment determination and adaptive management is determining when a stream has fully recovered from past management practices, and where recovery is still occurring from historical improvements in management but recent BMPs were not applied. Particularly within the Beaverhead-Deerlodge National Forest, ongoing PIBO monitoring can provide critical insight into the extent of recovery from past practices via comparisons between reference and managed sites.

10.3.2 Temperature Monitoring and Data Collection Methodology

For temperature investigation in the Madison TMDL Planning Area, data loggers were deployed throughout Cherry, Elk, and Moore creeks and the West Fork Madison River, and shade sampling was distributed spatially along each waterbody to best delineate shade condition. If additional water temperature data is collected, data loggers should be deployed at the same locations through the years to accurately represent the site-specific conditions over time, and recorded temperatures should at a minimum represent the hottest part of the summer when aquatic life is most sensitive to warmer temperatures. Data loggers should be deployed in the same manner at each location and during each sampling event, and follow a consistent process for calibration and installation. Any modeling that is used should refer to previous modeling efforts (such as the QUAL2K analysis used in this document) for consistency in model development to ensure comparability. In addition, flow measurements should also be conducted using consistent locations and method.

10.4 Source Assessment Refinement

In the Madison TMDL Planning Area, the identification of sources was conducted largely through watershed field tours, aerial assessment, the incorporation of GIS information, available data and literature review, with limited field verification and on-the-ground analysis. In many cases, assumptions were made based on overall planning area conditions and extrapolated throughout the watershed. As a result, the level of detail often does not provide specific areas by which to focus restoration efforts, only broad source categories to reduce sediment loads from each of the discussed subwatersheds. Strategies for strengthening sediment and temperature source assessments are outlined below.

Sediment

- Field surveys of unpaved roads and road crossings to identify specific contributing road crossings, their associated loads, and prioritize those road segments/crossings of most concern

- Review of land use practices specific to subwatersheds of concern to determine where the greatest potential for improvement and likelihood of sediment reduction can occur for the identified major land use categories
- More thorough examinations of bank erosion conditions and investigation of related contributing factors for each subwatershed of concern through site visits and subwatershed scale bank assessments. Additionally, the development of bank erosion retreat rates specific to the Madison TMDL Planning Area would provide a more accurate quantification of sediment loading from bank erosion. Bank retreat rates can be determined by installing bank pins at different positions on the streambank at several transects across a range of landscapes and stability ratings. Bank erosion is documented after high flows and throughout the year for several years to capture retreat rates under a range of flow conditions.

Temperature

- Assessment of irrigation network in Cherry, Elk Creek, and Moore Creeks, other streams in the watershed impacted by irrigation water use, to better understand irrigation efficiency and needs
- Temperature and flow monitoring in additional streams of the Madison TMDL Planning Area not covered by this TMDL
- Continued monitoring of flow and temperature with future changes in climate and water use
- Field surveys to better identify riparian area conditions and potential for improvement throughout the streams covered by this TMDL, as well as those not included
- Investigation of groundwater influence on instream temperatures, and relationships between groundwater availability and water use in the valley
- Assessment of water use in the Madison TMDL Planning Area and potential for improvements in water use that would result in increased instream flows
- Continued monitoring of arctic grayling and westslope cutthroat trout distributions in the Madison TMDL Planning Area in relation to temperature and flow
- Flow measurements at all temperature data locations at the time of data collection

10.5 Watershed Wide Analysis

Recommendations for monitoring in the Madison TMDL Planning Area should not be confined to only those streams addressed within this document. The water quality targets presented herein are applicable to all streams in the watershed, and the absence of a stream from the state's list of impaired waters does not necessarily imply a stream that fully supports all beneficial uses. Furthermore, as conditions change over time and land management evolves, consistent data collection methods throughout the watershed will allow resource professionals to identify problems as they occur, and to track improvements over time.

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APPENDIX A - REGULATORY FRAMEWORK AND REFERENCE CONDITION APPROACH

This appendix presents details about applicable Montana Water Quality Standards and the general and statistical methods used for development of reference conditions.

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A1.0 TMDL DEVELOPMENT REQUIREMENTS

The Montana Water Quality Act (WQA) (Section 75-5-703, Montana Code Annotated (MCA)) and Section 303(d) of the federal Clean Water Act require development of TMDLs for impaired waterbodies that do not meet Montana water quality standards. Although waterbodies can become impaired from pollution (e.g., low flow alterations and habitat degradation) and pollutants (e.g., nutrients, sediment, metals, pathogens, and temperature), the Clean Water Act and Montana state law (75-5-703, MCA) require TMDL development only for impaired waters with pollutant causes. Section 303(d) also requires states to submit a list of impaired waterbodies to the U.S. Environmental Protection Agency (EPA) every two years. Prior to 2004, EPA and DEQ referred to this list simply as the 303(d) list.

Since 2004, EPA has requested that states combine the 303(d) list with the 305(b) report containing an assessment of Montana's water quality and its water quality programs. EPA refers to this new combined 303(d)/305(b) report as the Integrated Water Quality Report (DEQ 2018). The 303(d) list also includes identification of the probable cause(s) of the water quality impairment (e.g., pollutants such as metals, nutrients, sediment, pathogens, or temperature), and the suspected source(s) of the pollutants of concern (e.g., various land use activities). State law (75-5-702, MCA) identifies that a sufficient credible data methodology for determining the impairment status of each waterbody is used for consistency. The impairment status determination methodology is identified in DEQ's Water Quality Assessment Process and Methods (Montana Department of Environmental Quality, 2011).

Under Montana state law, an "impaired waterbody" is defined as a waterbody or stream segment for which sufficient credible data show that the waterbody or stream segment is failing to achieve compliance with applicable water quality standards (Section 75-5-103(11), MCA of the Montana Water Quality Act). A "threatened waterbody" is defined as a waterbody or stream segment for which sufficient credible data and calculated increases in loads show that the waterbody or stream segment is fully supporting its designated uses, but threatened for a particular designated use because of either: (a) proposed sources that are not subject to pollution prevention or control actions required by a discharge permit; the nondegradation provisions; or reasonable land, soil, and water conservation practices or (b) documented adverse pollution trends (Section 75-5-103(31), MCA of the Montana Water Quality Act). State law and Section 303(d) of the Clean Water Act require states to develop all necessary TMDLs for impaired or threatened waterbodies. None of the waterbodies being addressed within the scope of this document are listed as threatened.

A TMDL is a pollutant budget for a waterbody identifying the maximum amount of the pollutant that a waterbody can assimilate without causing applicable water quality standards to be exceeded (not met). TMDLs are often expressed in terms of an amount, or load, of a particular pollutant (expressed in units of mass per time such as pounds per day). TMDLs must account for loads/impacts from point and nonpoint sources in addition to natural background sources and must incorporate a margin of safety and consider influences of seasonality on analysis and compliance with water quality standards. **Section 4.0** of the main document provides a description of the components of a TMDL.

To satisfy the federal Clean Water Act and Montana state law, TMDLs are developed for each waterbody-pollutant combination identified on Montana's 303(d) list of impaired or threatened waters, and are often presented within the context of a water quality restoration or protection plan. State law (75-5-703(8), MCA) also directs Montana DEQ to "…support a voluntary program of reasonable land, soil, and water conservation practices to achieve compliance with water quality standards for nonpoint

source activities for waterbodies that are subject to a TMDL…" This is an important directive that is reflected in the overall TMDL development and implementation strategy within this plan. It is important to note that water quality protection measures are not considered voluntary where such measures are already a requirement under existing federal, state, or local regulations.

A2.0 APPLICABLE WATER QUALITY STANDARDS

Water quality standards include the uses designated for a waterbody, the legally enforceable standards that ensure that the uses are supported, and a nondegradation policy that protects the high quality of a waterbody. The ultimate goal of this TMDL document, once implemented, is to ensure that all designated beneficial uses are fully supported and all water quality standards are met. Water quality standards form the basis for the targets described in **Sections 5.0** and **6.0**. Pollutants addressed in this water quality improvement plan include sediment and temperature. This section provides a summary of the applicable water quality standards for these pollutants.

A2.1 CLASSIFICATION AND BENEFICIAL USES

Classification is the assignment (designation) of a single or group of uses to a waterbody based on the potential of the waterbody to support those uses. Designated uses, or beneficial uses, are simple narrative descriptions of water quality expectations or water quality goals. There are a variety of "uses" of state waters including growth and propagation of fish and associated aquatic life, drinking water, agriculture, industrial supply, and recreation, and wildlife. The Montana WQA directs the Board of Environmental Review (BER) (i.e., the state) to establish a classification system for all waters of the state that includes their present (when the Act was originally written) and future most beneficial uses (Administrative Rules of Montana (ARM) 17.30.607-616) and to adopt standards to protect those uses (ARM 17.30.620-670).

Montana, unlike many other states, uses a watershed-based classification system, with some specific exceptions. As a result, all waters of the state are classified and have designated uses and supporting standards. All classifications have multiple uses and in only one case (A-Closed) is a specific use (drinking water) given preference over the other designated uses. Some waters may not actually be used for a specific designated use, for example as a public drinking water supply; however, the quality of that waterbody must be maintained suitable for that designated use. When natural conditions limit or preclude a designated use, permitted point source discharges or nonpoint source activities or pollutant discharges must not make the natural conditions worse.

Modification of classifications or standards that would lower a water's classification or a standard (e.g., B-1 to a B-3), or removal of a designated use because of natural conditions, can only occur if the water was originally misclassified. All such modifications must be approved by the BER, and are undertaken via a Use Attainability Analysis (UAA) that must meet EPA requirements (40 CFR 131.10(g), (h) and (j)). The UAA and findings presented to the BER during rulemaking must prove that the modification is correct and all existing uses are supported. An existing use cannot be removed or made less stringent.

Descriptions of Montana's surface water classifications and designated beneficial uses are presented in **Table A2-1**. In 2003, Montana added four classes: D, E, F, and G. These classes include ephemeral streams (E-1 and E-2), ditches (D-1 and D-2), seasonal or semi-permanent lakes and ponds (E-3, E-4, E-5)

and waters with low or sporadic flow (F-1). All waterbodies within the Madison TMDL Planning Area are classified as B-1.

Table A2-1. Montana Surface Water Classifications and Designated Beneficial Uses

Classification	Designated Uses
A-CLOSED	Waters classified A-Closed are to be maintained suitable for drinking, culinary and food processing purposes after simple disinfection.
A-1	Waters classified A-1 are to be maintained suitable for drinking, culinary and food processing purposes after conventional treatment for removal of naturally present impurities.
B-1	Waters classified B-1 are to be maintained suitable for drinking, culinary and food processing purposes after conventional treatment; bathing, swimming and recreation; growth and propagation of salmonid fishes and associated aquatic life, waterfowl and furbearers; and agricultural and industrial water supply.
B-2	Waters classified B-2 are to be maintained suitable for drinking, culinary and food processing purposes after conventional treatment; bathing, swimming and recreation; growth and marginal propagation of salmonid fishes and associated aquatic life, waterfowl and furbearers; and agricultural and industrial water supply.
B-3	Waters classified B-3 are to be maintained suitable for drinking, culinary and food processing purposes after conventional treatment; bathing, swimming and recreation; growth and propagation of non-salmonid fishes and associated aquatic life, waterfowl and furbearers; and agricultural and industrial water supply.
C-1	Waters classified C-1 are to be maintained suitable for bathing, swimming and recreation; growth and propagation of salmonid fishes and associated aquatic life, waterfowl and furbearers; and agricultural and industrial water supply.
C-2	Waters classified C-2 are to be maintained suitable for bathing, swimming and recreation; growth and marginal propagation of salmonid fishes and associated aquatic life, waterfowl and furbearers; and agricultural and industrial water supply.
C-3	Waters classified C-3 are to be maintained suitable for bathing, swimming and recreation; growth and propagation of non-salmonid fishes and associated aquatic life, waterfowl and furbearers. The quality of these waters is naturally marginal for drinking, culinary and food processing purposes, agriculture and industrial water supply.
I	The goal of the State of Montana is to have these waters fully support the following uses: drinking, culinary and food processing purposes after conventional treatment; bathing, swimming and recreation; growth and propagation of fishes and associated aquatic life, waterfowl and furbearers; and agricultural and industrial water supply.
D-1	Waters classified D-1 are to be maintained suitable for agricultural purposes and secondary contact recreation.
D-2	Waters classified D-2 are to be maintained suitable for agricultural purposes and secondary contact recreation. Because of conditions resulting from low flow regulations, maintenance of the ditch, or geomorphologic and riparian habitat conditions, quality is marginally suitable for aquatic life.
E-1	Waters classified E-1 are to be maintained suitable for agricultural purposes, secondary contact recreation, and wildlife.
E-2	Waters classified E-2 are to be maintained suitable for agricultural purposes, secondary contact recreation, and wildlife. Because of habitat, low flow, hydro-geomorphic, and other physical conditions, waters are marginally suitable for aquatic life.
E-3	Waters classified E-3 are to be maintained suitable for agricultural purposes, secondary contact recreation, and wildlife.
E-4	Waters classified E-4 are to be maintained suitable for aquatic life, agricultural purposes, secondary contact recreation, and wildlife.

Table A2-1. Montana Surface Water Classifications and Designated Beneficial Uses

Classification	Designated Uses
E-5	Waters classified E-5 are to be maintained suitable for agricultural purposes, secondary contact recreation, saline-tolerant aquatic life, and wildlife.
F-1	Waters classified F-1 are to be maintained suitable for secondary contact recreation, wildlife, and aquatic life, not including fish.
G-1	Waters classified G-1 are to be maintained suitable for watering wildlife and livestock; aquatic life, not including fish; secondary contact recreation; marginally suitable for irrigation after treatment or with mitigation measures.

A2.2 STANDARDS

In addition to the use classifications described above, Montana's water quality standards include numeric and narrative criteria, as well as a nondegradation policy.

Numeric Standards

Numeric surface water quality standards have been developed for many parameters to protect human health and aquatic life. These standards are in the Department Circular DEQ-7 (Montana Department of Environmental Quality, 2019) and Circular DEQ-12A (DEQ 2014). The numeric human health standards have been developed for parameters determined to be toxic, carcinogenic, or harmful, and have been established at levels to be protective of long-term (i.e., lifelong) exposures, as well as through direct contact such as swimming.

The numeric aquatic life standards in Circular DEQ-7 include chronic and acute values that are based on extensive laboratory studies including a wide variety of potentially affected species, a variety of life stages, and durations of exposure. Chronic aquatic life standards are protective of long-term exposure to a parameter. The protection afforded by the chronic standards includes detrimental effects to reproduction, early life stage survival, and growth rates. In most cases the chronic standard is more stringent than the corresponding acute standard. Acute aquatic life standards are protective of short-term exposures to a parameter and are not to be exceeded.

High quality waters are afforded an additional level of protection by the nondegradation rules (ARM 17.30.701 et. seq.,) and in statute (75-5-303, MCA). Changes in water quality must be "non-significant", or an authorization to degrade must be granted by DEQ. However, under no circumstance may standards be exceeded. It is important to note that waters that meet, or are of better quality than a standard, are high quality for that parameter, and nondegradation policies apply to new or increased discharges to that the waterbody.

Narrative Standards

Narrative standards have been developed for substances or conditions for which sufficient information does not exist to develop specific numeric standards. The term "Narrative Standards" commonly refers to the General Prohibitions in ARM 17.30.637 and other descriptive portions of the surface water quality standards. The General Prohibitions are also called the "free from" standards; that is, the surface waters of the state must be free from substances attributable to discharges, including thermal pollution, that impair the beneficial uses of a waterbody. Uses may be impaired by toxic or harmful conditions (from one or a combination of parameters) or conditions that produce undesirable aquatic life. Undesirable aquatic life includes bacteria, fungi, and algae.

The sediment and temperature standards applicable to the list of pollutants addressed in the Madison TMDL Planning Area TMDLs are summarized below. In addition to the standards below, the beneficial-use support standard for B-1 streams, as defined above, can apply to other conditions, often linked to pollution, limiting aquatic life. These other conditions can include effects from dewatering/flow modifications and effects from habitat modifications.

A2.2.1 Sediment Standards

Sediment (i.e., coarse and fine bed sediment) and suspended sediment are addressed via the narrative criteria identified in **Table A2-2**. The relevant narrative criteria do not allow for harmful or other undesirable conditions related to increases above naturally occurring levels or from discharges to state surface waters. This is interpreted to mean that water quality goals should strive toward a condition in which any increases in sediment above naturally occurring levels are not harmful, detrimental, or injurious to beneficial uses (see definitions in **Table A2-2**).

Table A-2. Applicable Rules for Sediment Related Pollutants

Rule(s)	Standard or Definition
17.30.622(3), 623(2), 624(2), 627(2)	No person may violate the following specific water quality standards for waters classified [A-1, B-1, B-2, C-2]:
17.30.622(3)(f) [A-1], 17.30.623(2)(f) [B-1], 17.30.624(2)(f) [B-2], 17.30.627(2)(f) [C-2]	No increases are allowed above naturally occurring concentrations of sediment or suspended sediment (except a permitted in 75-5-318, MCA), settleable solids, oils, or floating solids, which will or are likely to create a nuisance or render the waters harmful, detrimental, or injurious to public health, recreation, safety, welfare, livestock, wild animals, birds, fish, or other wildlife.
17.30.622(3)(d) [A-1 classification]	No increase above naturally occurring turbidity or suspended sediment is allowed except at permitted in 75-5-318, MCA. Note: 75-5-318, MCA allows for short term variances linked to construction activities, etc.
17.30.623(2)(d) [B-1 classification]	The maximum allowable increase above naturally occurring turbidity is five nephelometric turbidity units except at permitted in 75-5-318, MCA. Note: 75-5-318, MCA allows for short term variances linked to construction activities, etc.
17.30.624(2)(e) [B-2], 17.30.627(2)(d) [C-2]	The maximum allowable increase above naturally occurring turbidity is 10 nephelometric turbidity units except as permitted in 75-5-318, MCA.
17.30.637(1) (a & d) [applies to all streams discussed in this document]	State surface waters must be free from substances attributable to municipal, industrial, agricultural practices or other discharges that will: (a) settle to form objectionable sludge deposits or emulsions beneath the surface of the water or upon adjoining shorelines; … and (d) create concentrations or combinations of materials that are toxic or harmful to human, animal, plant, or aquatic life.
17.30.602	DEFINITIONS
	"Sediment" means solid material settled from suspension in a liquid; mineral or organic solid material that is being transported or has been moved from its site of origin by air, water, or ice and has come to rest on the earth's surface, either above or below sea level; or inorganic or organic particles originating from weathering, chemical precipitation, or biological activity.
	"Naturally occurring" means conditions or material present from runoff or percolation over which man has no control or from developed land where all reasonable land, soil, and water conservation practices have been applied. Conditions resulting from the reasonable operations of dams in existence as of July 1, 1971, are natural.

Table A-2. Applicable Rules for Sediment Related Pollutants

Rule(s)	Standard or Definition
	"Reasonable land, soil, and water conservation practices" means methods, measures, or practices that protect present and reasonably anticipated beneficial uses. These practices include but are not limited to structural and nonstructural controls and operation and maintenance procedures. Appropriate practices may be applied before, during, or after pollution-producing activities.

A2.2.2 Temperature Standards

Montana's temperature standards were originally developed to address situations associated with point source discharges, making them somewhat awkward to apply when dealing with primarily nonpoint source issues. In practical terms, the temperature standards address a maximum allowable increase above "naturally occurring" temperatures to protect the existing temperature regime for fish and aquatic life. Additionally, Montana's temperature standards address the maximum allowable decrease or rate at which cooling temperature changes (below naturally occurring) can occur to avoid fish and aquatic life temperature shock.

For waters classified as B-1 (ARM 17.30.623(e)), B-2 (ARM 17.30.624(e)), and C-2 (ARM 17.30.627(e)): A 1° F maximum increase above naturally occurring water temperature is allowed within the range 32° F to 66° F; within the naturally occurring range of 66° F to 66.5^{o} F, no discharge is allowed which will cause the water temperature to exceed 67° F; and where the naturally occurring water temperature is 66.5^{o} F or greater, the maximum allowable increase in water temperature is 0.5^{o} F. A 2° F per-hour maximum decrease below naturally occurring water temperature is above 55° F. A 2° F maximum decrease below naturally occurring water temperature is allowed within the range of 55° F to 32° F.

A3.0 Reference Conditions

A3.1 Reference Conditions as Defined in DEQ's Standard Operating Procedure for Water Quality Assessment

DEQ uses the reference condition to evaluate compliance with many of the narrative water quality standards (Montana Department of Environmental Quality, 2011). The term "reference condition" is defined as the condition of a waterbody capable of supporting its present and future beneficial uses when all reasonable land, soil, and water conservation practices have been applied. In other words, reference condition reflects a waterbody's greatest potential for water quality, given historic land use activities.

DEQ applies the reference condition approach for making beneficial use-support determinations for certain pollutants (such as sediment) that have specific narrative standards. All classes of waters are subject to the provision that there can be no increase above naturally occurring concentrations of sediment and settleable solids, oils, or floating solids sufficient to create a nuisance or render the water harmful, detrimental, or injurious. These levels depend on site-specific factors, so the reference conditions approach is used.

Also, Montana water quality standards do not contain specific provisions addressing detrimental modifications of habitat or flow. However, these factors are known to adversely affect beneficial uses

under certain conditions or combination of conditions. The reference conditions approach is used to determine if beneficial uses are supported when flow or habitat modifications are present.

Waterbodies used to determine reference condition are not necessarily pristine or perfectly suited to giving the best possible support to all possible beneficial uses. Reference condition also does not reflect an effort to turn the clock back to conditions that may have existed before human settlement, but is intended to accommodate natural variations in biological communities, water chemistry, etc. due to climate, bedrock, soils, hydrology, and other natural physiochemical differences. The intention is to differentiate between natural conditions and widespread or significant alterations of biology, chemistry, or hydrogeomorphology due to human activity. Therefore, reference conditions should reflect minimum impacts from human activities. It attempts to identify the potential condition that could be attained (given historical land use) by the application of reasonable land, soil, and water conservation practices. DEQ realizes that pre-settlement water quality conditions usually are not attainable.

Comparison of conditions in a waterbody to reference waterbody conditions must be made during similar season and/or hydrologic conditions for both waters. For example, the total suspended solids (TSS) of a stream at base flow during the summer should not be compared to the TSS of reference condition that would occur during a runoff event in the spring. In addition, a comparison should not be made to the lowest or highest TSS values of a reference site, which represent the outer boundaries of reference conditions.

The following methods may be used to determine reference conditions:

Primary Approach

- Comparing conditions in a waterbody to baseline data from minimally impaired waterbodies that are in a nearby watershed or in the same region having similar geology, hydrology, morphology, and/or riparian habitat
- Evaluating historical data relating to condition of the waterbody in the past
- Comparing conditions in a waterbody to conditions in another portion of the same waterbody, such as an unimpaired segment of the same stream

Secondary Approach

- Reviewing literature (e.g., a review of studies of fish populations, etc. that were conducted on similar waterbodies that are least impaired)
- Seeking expert opinion (e.g., expert opinion from a regional fisheries biologist who has a good understanding of the waterbody's fisheries health or potential)
- Applying quantitative modeling (e.g., applying sediment transport models to determine how much sediment is entering a stream based on land use information, etc.)

DEQ uses the primary approach for determining reference condition if adequate regional reference data are available and uses the secondary approach to estimate reference condition when there is no regional data. DEQ often uses more than one approach to determine reference condition, especially when regional reference condition data are sparse or nonexistent.

A3.2 Use of Statistics for Developing Reference Values or Ranges

Reference value development must consider natural variability as well as variability that can occur as part of field measurement techniques. Statistical approaches are commonly used to help incorporate

variability. One statistical approach is to compare stream conditions to the mean (average) value of a reference data set to see if the stream condition compares favorably to this value or falls within the range of one standard deviation around the reference mean. The use of these statistical values assumes a normal distribution; whereas, water resources data tend to have a non-normal distribution (Helsel and Hirsch, 1995). For this reason, another approach is to compare stream conditions to the median value of a reference data set to see if the stream condition compares favorably to this value or falls within the range defined by the 25th and 75th percentiles of the reference data. This is a more realistic approach than using one standard deviation since water quality data often include observations considerably higher or lower than most of the data. Very high and low observations can have a misleading impact on the statistical summaries if a normal distribution is incorrectly assumed, whereas statistics based on non-normal distributions are far less influenced by such observations.

Figure A3-1 is an example boxplot-type presentation of the median, 25th and 75th percentiles, and minimum and maximum values of a reference data set. In this example, the reference stream results are stratified by two different stream types. Typical stratifications for reference stream data may include Rosgen stream types, stream size ranges, or geology. If the parameter being measured is one where low values are undesirable and can cause harm to aquatic life, then measured values in the potentially impaired stream that fall below the 25th percentile of reference data are not desirable and can be used to indicate impairment. If the parameter being measured is one where high values are undesirable, then measured values above the 75th percentile can be used to indicate impairment.

The use of a non-parametric statistical distribution for interpreting narrative water quality standards or developing numeric criteria is consistent with EPA guidance for determining nutrient criteria (Buck et al., 2000). Furthermore, the selection of the applicable 25th or 75th percentile values from a reference data set is consistent with ongoing DEQ guidance development for interpreting narrative water quality standards where it is determined that there is “good” confidence in the quality of the reference sites and resulting information (Suplee, 2004). If it is determined that there is only a “fair” confidence in the quality of the reference sites, then the 50th percentile or median value should be used, and if it is determined that there is “very high” confidence, then the 90th percentile of the reference data set should be used. Most reference data sets available for water quality restoration planning and related TMDL development, particularly those dealing with sediment and habitat alterations, would tend to be “fair” to “good” quality. This is primarily due to the limited number of available reference sites/data points available after applying all potentially applicable stratifications on the data, inherent variations in monitoring results among field crews, the potential for variations in field methodologies, and natural yearly variations in stream systems often not accounted for in the data set.

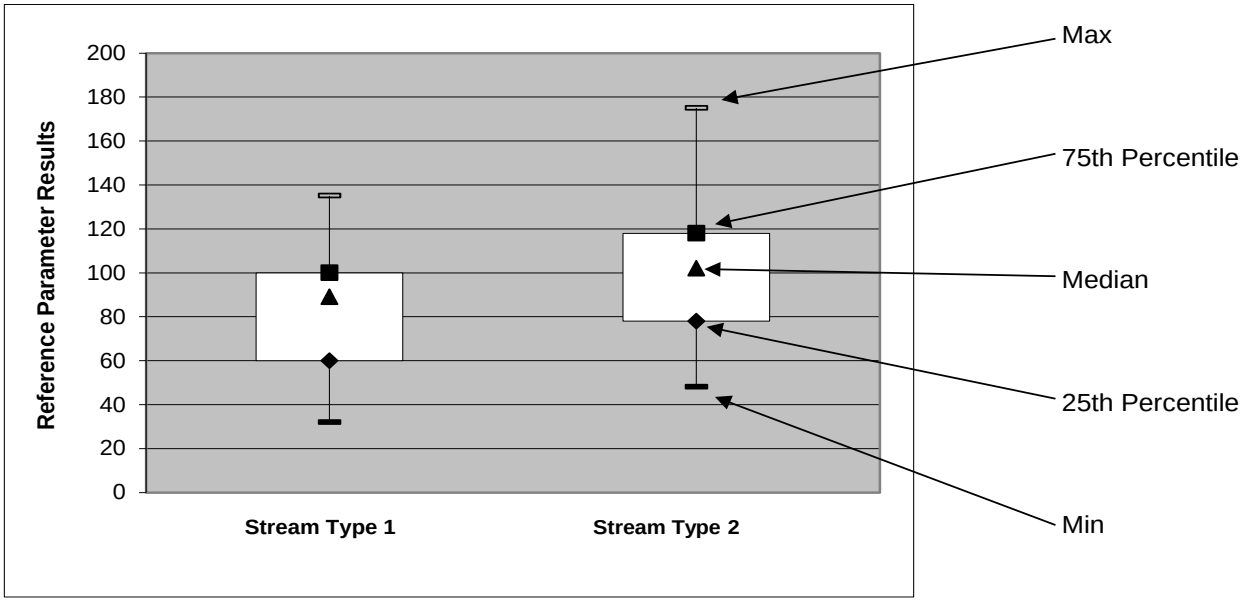

Figure A3-1. Boxplot Example for Reference Data

The above 25th – 75th percentile statistical approach has several considerations:

1. It is a simple approach that is easy to apply and understand.
2. About 25% of all streams would naturally fall into the impairment range. Thus, it should not be applied unless there is some linkage to human activities that could lead to the observed conditions. Where applied, it must be noted that the stream's potential may prevent it from achieving the reference range as part of an adaptive management plan.
3. About 25% of all streams would naturally have a greater water quality potential than the minimum water quality bar represented by the 25th to 75th percentile range. This may represent a condition where the stream's potential has been significantly underestimated. Adaptive management can also account for these considerations.
4. Obtaining reference data that represents a naturally occurring condition can be difficult, particularly for larger waterbodies with multiple land uses within the drainage. This is because all reasonable land, soil, and water conservation practices may not be in place in many larger waterbodies across the region. Even if these practices are in place, the proposed reference stream may not have fully recovered from past activities, such as riparian harvest, where reasonable land, soil, and water conservation practices were not applied.
5. A stream should not be considered impaired unless there is a relationship between the parameter of concern and the beneficial use such that not meeting the reference range is likely to cause harm or other negative impacts to the beneficial use as described by the water quality standards in **Table B2-2**. In other words, if not meeting the reference range is not expected to negatively impact aquatic life, coldwater fish, or other beneficial uses, then an impairment determination should not be made based on the particular parameter being evaluated. Relationships that show an impact to the beneficial use can be used to justify impairment based on the above statistical approach.

As identified in (2) and (3) above, there are two types of errors that can occur due to this or similar statistical approaches where a reference range or reference value is developed: (1) A stream could be considered impaired even though the naturally occurring condition for that stream parameter does not

meet the desired reference range or (2) a stream could be considered not impaired for the parameter(s) of concern because the results for a given parameter fall just within the reference range, whereas the naturally occurring condition for that stream parameter represents much higher water quality and beneficial uses could still be negatively impacted. The implications of making either of these errors can be used to modify the above approach, although the approach used will need to be protective of water quality to be consistent with DEQ guidance and water quality standards (Suplee, 2004). Either way, adaptive management is applied to this water quality plan and associated TMDL development to help address the above considerations.

Where the data does suggest a normal distribution, or reference data is presented in a way that precludes use of non-normal statistics, the above approach can be modified to include the mean plus or minus one standard deviation to provide a similar reference range with all of the same considerations defined above.

Options When Regional Reference Data is Limited or Does Not Exist

In some cases, there is very limited reference data and applying a statistical approach like above is not possible. Under these conditions, the limited information can be used to develop a reference value or range, with the need to note the greater level of uncertainty and perhaps a greater level of future monitoring as part of the adaptive management approach. These conditions can also lead to more reliance on secondary type approaches for reference development.

Another approach would be to develop statistics for a given parameter from all streams within a watershed or region of interest (Buck et al., 2000). The boxplot distribution of all the data for a given parameter can still be used to help determine potential target values knowing that most or all of the streams being evaluated are either impaired or otherwise have a reasonable probability of having significant water quality impacts. Under these conditions you would still use the median and the 25th or 75th percentiles as potential target values, but you would use the 25th and 75th percentiles in a way that is opposite from how you use the results from a regional reference distribution. This is because you are assuming that, for the parameter being evaluated, as many as 50% to 75% of the results from the whole data distribution represent questionable water quality. **Figure A3-2** is an example statistical distribution of an entire dataset where lower values represent better water quality (and reference data are limited).

In **Figure A3-2**, the median and 25th percentiles of all data represent potential target values versus the median and 75th percentiles discussed above for regional reference distribution. Whether you use the median, the 25th percentile, or both should be based on an assessment of how impacted all the measured streams are in the watershed. Additional consideration of target achievability is important when using this approach. Also, there may be a need to also rely on secondary reference development methods to modify how you apply the target and/or to modify the final target value(s). Your certainty regarding indications of impairment may be lower using this approach, and you may need to rely more on adaptive management as part of TMDL implementation.

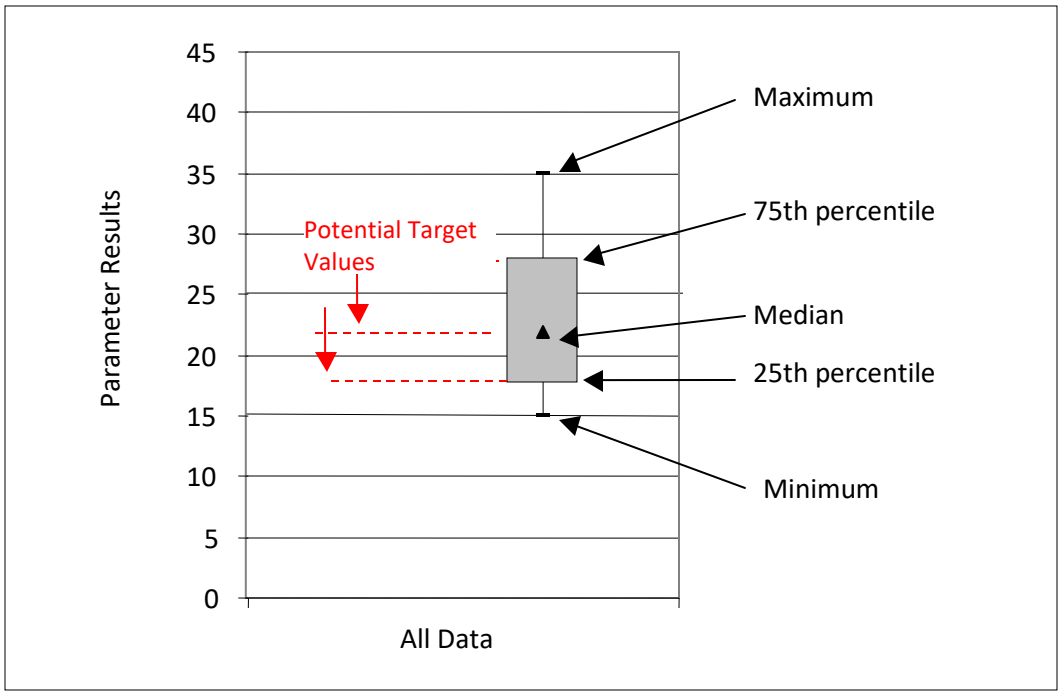

Figure B3-2. Boxplot example for the use of all data to set targets

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APPENDIX B - SEDIMENT DATA COLLECTION METHODS AND SUMMARIES OF MONITORED WATERBODIES WITH NO TMDL WRITTEN

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B1.0 INTRODUCTION

This appendix summarizes sediment and habitat data collected and analyzed for the stream segments evaluated in the Madison TPA. Twenty-one stream segments in the Madison TPA were evaluated for sediment impairments based on existing impairment listings, reconnaissance, and input from local stakeholders (**Table B-1 and Figure B-1**). Of the twenty-one, thirteen were found to be impaired and TMDLs were written (see **Section 5.4.3** in the main TMDL document for summary information on these thirteen stream segments). Seven stream segments were found not impaired by sediment and are summarized within this Appendix; along with the lower Madison River where the impairment remains but did not have a TMDL written. Several of the twenty-one stream segments, including some of the streams with no sediment impairment, have a habitat alteration, which is a non-pollutant impairment commonly associated with sediment impairment (**Table B-1**). TMDLs are limited to pollutants, but implementation of land, soil, and water conservation practices to reduce pollutant loading will inherently address some non-pollutant impairments. Such approaches are highlighted in Montana DEQ's Nonpoint Source Management Plan (DEQ 2017)

Table B-1. Stream Segments Evaluated for Sediment Impairment

Stream Segment	Segment (Assessment Unit) ID	Sediment TMDL Developed
Antelope Creek	MT41F004_140	Yes*
Bear Creek	MT41F004_021	Yes
Blaine Spring Creek	MT41F004_010	Yes
Buford Creek	MT41F004_150	No
Cherry Creek	MT41F002_010	Yes
Elk Creek	MT41F002_020	Yes*
Elk River	MT41F004_110	No
Gazelle Creek	MT41F004_120	No
Hot Springs Creek	MT41F002_030	Yes*
Indian Creek	MT41F004_040	No*
Jack Creek	MT41F004_050	No*
Lower Madison River	MT41F001_010	No*
Moore Creek	MT41F004_130	Yes*
North Meadow Creek	MT41F004_060	Yes*
O'Dell Spring Creek	MT41F004_020	No*
Red Canyon Creek	MT41F006_020	Yes*
Ruby Creek	MT41F004_080	Yes*
South Meadow Creek	MT41F004_070	Yes
Watkins Creek	MT41F006_030	Yes*
West Fork Madison River	MT41F004_100	No
Wigwam Creek	MT41F004_160	Yes

*Non-pollutant listing(s) associated with sediment impairment on 2018 303(d) List

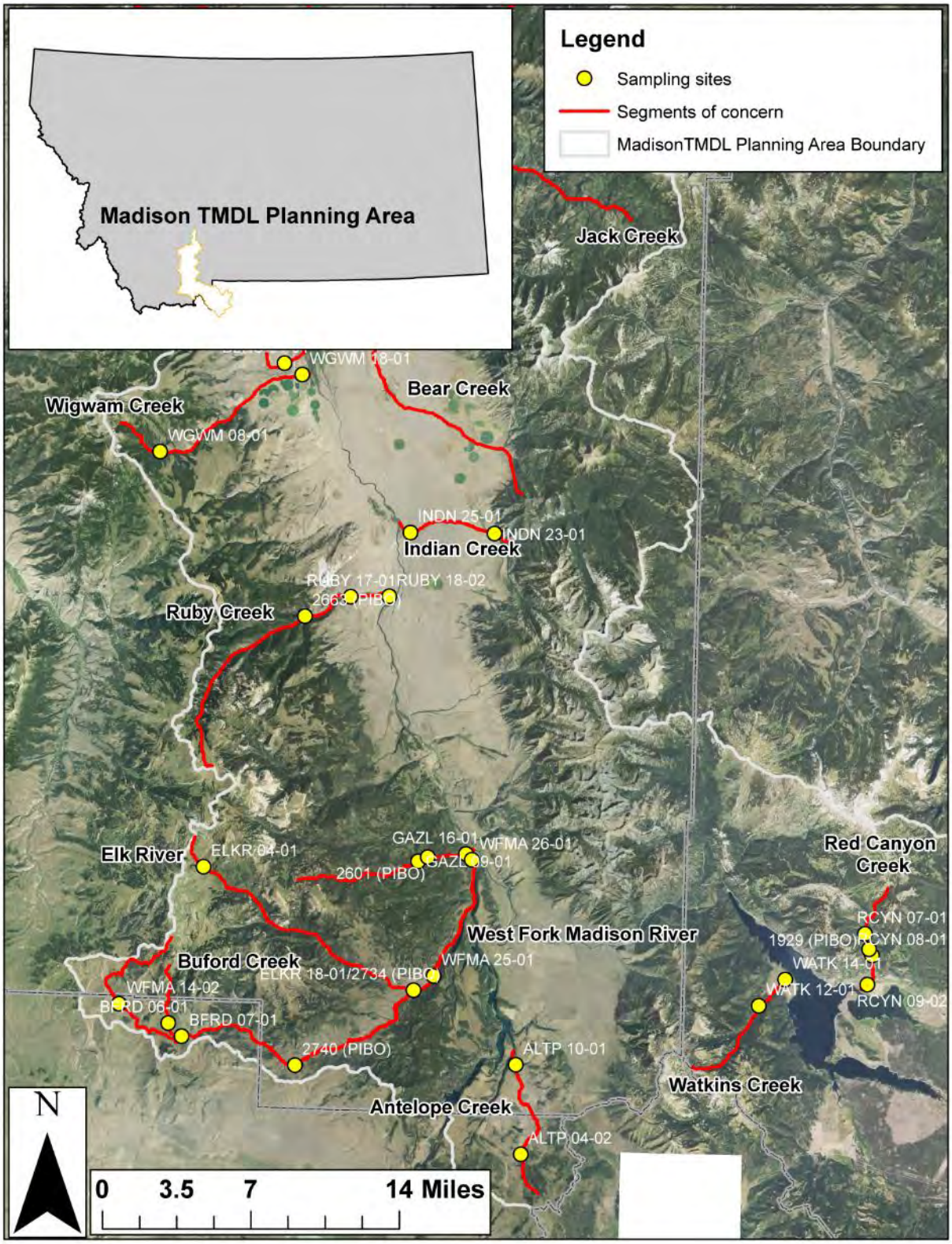

Figure B-1. Stream segments upstream of Indian Creek evaluated in this document and sampling sites on these segments

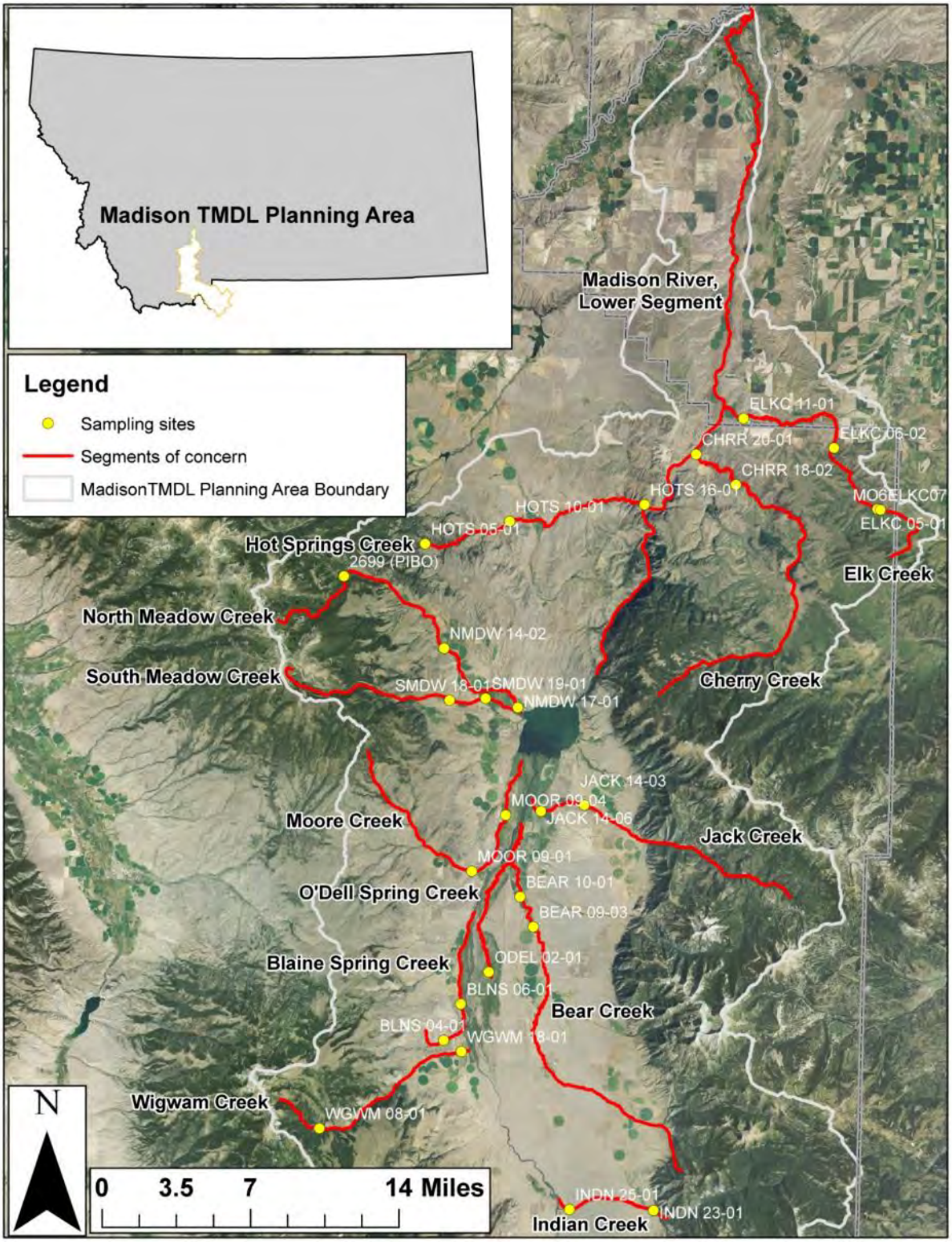

Figure B-2. Stream segments downstream of Indian Creek evaluated in this document and sampling sites on these segments

B2.0 DEQ SEDIMENT AND HABITAT ASSESSMENT

To aid in TMDL development, the DEQ performed field measurements of channel morphology, riparian and instream habitat parameters, and bank erosion during the summers of 2013 and 2014 from 43 sites within 20 of the 21 segments of concern (the Madison River downstream of Ennis Lake was not sampled by DEQ; **Figures B-1** and **B-2**).

B2.1 Aerial Assessment Reach Stratification

Prior to field data collection, DEQ completed a stream stratification process on stream segments in the Madison TPA. The stratification methodology can be found in *Sediment – Habitat Reach Stratification and Riparian Assessment Procedure* (DEQ, 2015b). The reason for this stratification is that the inherent differences in landscape controls between stream reaches often prevents a direct comparison from being made between the physical attributes of one stream reach to another. By initially stratifying waterbody segments into stream reaches having similar landscape controls, it is possible to make broad comparisons between similar reaches with regards to observed versus expected channel morphology. Likewise, when land use is used as an additional stratification category (e.g. grazed vs. non-grazed sub-reaches), sediment and habitat parameters for impaired stream reaches can be more readily compared to reference reaches that meet the same geomorphic stratification criteria.

B2.1.1 Stream Reaches

Waterbody segments are delineated by a water use class designated by the State of Montana, e.g. A-1, B-3, C-3 (Administrative Rules of Montana Title 17 Chapter 30, Sub-Chapter 6). Although a waterbody segment is the smallest unit for which an impairment determination is made, the stratification approach described in this document initially stratifies individual waterbody segments into discrete assessment reaches that are delineated by landscape controls including Ecoregion, Strahler stream order, valley gradient, and valley confinement. These attributes represent main factors influencing stream morphology, which in turn influence sediment transport and deposition. Relevant geographic data layers were acquired from the U.S. Geological Survey (USGS), the U.S. Environmental Protection Agency (USEPA) and the Montana State National Resource Information System (NRIS) database.

Once stream reaches have been stratified, reaches are further divided based on the surrounding vegetation and land-use characteristics as observed in the color aerial imagery using GIS. The result is a series of stream reaches and sub-reaches delineated by landscape and land-use factors. Stream reaches with similar landscape factors can then be compared based on the character of surrounding land-use practices.

For ease of labeling, each listed stream in the assessment was assigned an abbreviation based on the stream name. These labels were used in the individual stream reach classification. **Table B-2** shows the abbreviations developed for each waterbody.

Table B-2. Waterbody naming key

Waterbody	Label Abbreviation
Antelope Creek	ALTP
Bear Creek	BEAR
Blaine Spring Creek	BLNS
Buford Creek	BFRD
Cherry Creek	CHRR
Elk Creek	ELKC
Elk River	ELKR
Gazelle Creek	GAZL
Hot Springs Creek	HOTS
Indian Creek	INDN
Jack Creek	JACK
Moore Creek	MOOR
North Meadow Creek	NMDW
O'Dell Spring Creek	ODEL
Red Canyon Creek	RCYN
Ruby Creek	RUBY
South Meadow Creek	SMDW
Watkins Creek	WATK
West Fork Madison River	WFMA
Wigwam Creek	WGWM

B2.1.2 Reach Types

For the purposes of this report, a "reach type" is defined as a unique combination of Ecoregion, valley gradient, Strahler stream order, and valley confinement, and is designated using the following naming convention based on the reach type identifiers:

Level III Ecoregion – Valley Gradient – Strahler Stream Order – Confinement

The Madison TPA exists within the Middle Rockies Level III Ecoregion (Ecoregion 17). There are eleven Level IV Ecoregions within the Madison TPA: Absaroka-Gallatin Volcanic Mountains (17i), Alpine Zone (17h), Barren Mountains (17e), Dry Gneissic-Schistose-Volcanic Hills (17ab), Dry Intermontane Sagebrush Valleys (17aa), Eastern Gravelly Mountains (17d), Gneissic-Schistose Forested Mountains (17l), Mid-elevation Sedimentary Mountains (17g), Tobacco Root Mountains (17z), Townsend Basin (17w), Yellowstone Plateau (17j).

Reach type combinations for the Madison TPA are provided in **Table B-3**, and following the initial primary reach stratification, representative reaches were chosen by DEQ for monitoring sites.

Table B-3. Stratified reach types within the Madison TPA.

Level III Ecoregion	Valley Gradient	Strahler Stream Order	Confine-ment	Reach Type	Total Number of Reaches	Number of Monitoring Sites
Middle Rockies	<2%	1	U	MR-0-1-U	1	-
		2	C	MR-0-2-C	7	1
			U	MR-0-2-U	13	1
		3	C	MR-0-3-C	3	1
			U	MR-0-3-U	68	10
		4	C	MR-0-4-C	2	1
			U	MR-0-4-U	25	5
		5	U	MR-0-5-U	1	-
		6	C	MR-0-6-C	5	-
			U	MR-0-6-U	17	-
	2-4%	1	U	MR-2-1-U	11	1
		2	C	MR-2-2-C	17	-
			U	MR-2-2-U	32	4
		3	C	MR-2-3-C	21	1
			U	MR-2-3-U	47	10
		4	C	MR-2-4-C	1	-
			U	MR-2-4-U	8	1
		6	C	MR-2-6-C	1	-
			U	MR-2-6-U	2	-
	4-10%	1	C	MR-4-1-C	21	-
			U	MR-4-1-U	49	2
		2	C	MR-4-2-C	16	-
			U	MR-4-2-U	45	3
		3	C	MR-4-3-C	18	-
			U	MR-4-3-U	14	-
		4	C	MR-4-4-C	5	-
			U	MR-4-4-U	2	-
	>10%	1	C	MR-10-1-C	16	-
			U	MR-10-1-U	34	-
		2	C	MR-10-2-C	11	1
			U	MR-10-2-U	7	-
		3	C	MR-10-3-C	4	-
			U	MR-10-3-U	2	-
Totals:					**526**	**42**

Table B-4 shows the assessed water bodies and monitored reaches included within each reach type. A map of monitoring site locations is provided in **Figures B-1** and **B-2**, above.

Table B-4. Monitoring sites in assessed reach types.

Reach Type	waterbody	Monitoring Sites
MR-0-2-C	West Fork Madison River	WFMA 14-02
MR-0-2-U	O'Dell Spring Creek	ODEL 02-01
MR-0-3-C	Indian Creek	INDN 25-01
MR-0-3-U	Cherry Creek, Elk Creek, Hot Springs Creek, Jack Creek, Moore Creek, South Meadow Creek	CHRR 18-02, CHRR 20-01, ELKC 05-01, ELKC 11-01, HOTS 10-01, JACK 14-03, JACK 14-06, MOOR 09-01, MOOR 09-04, SMDW 19-01
MR-0-4-C	West Fork Madison River	WFMA 25-01
MR-0-4-U	Bear Creek, Blaine Spring Creek, North Meadow Creek, West Fork Madison River	BEAR 09-03, BEAR 10-01, BLNS 06-01, NMDW 17-01, WFMA 26-01
MR-2-1-U	Buford Creek	BFRD 07-01
MR-2-2-U	Antelope Creek, Elk River, Red Canyon Creek	ALTP 04-02, ELKR 04-01, RCYN 08-01, RCYN 09-02
MR-2-3-C	Ruby Creek	RUBY 17-01
MR-2-3-U	Blaine Spring Creek, Elk Creek, Elk River, Indian Creek, North Meadow Creek, Ruby Creek, South Meadow Creek, Watkins Creek, Wigwam Creek	BLNS 04-01, ELKC 06-02, ELKR 18-01, INDN 23-01 NMDW 14-02, RUBY 18-02, SMDW 18-01, WATK 12-01, WATK 14-01, WGWM 18-01
MR-2-4-U	Hot Springs Creek	HOTS 16-01
MR-4-1-U	Buford Creek, Hot Springs Creek	BFRD 06-01, HOTS 05-01
MR-4-2-U	Gazelle Creek, Red Canyon Creek, Wigwam Creek	GAZL 16-01, RCYN 07-01, WGWM 08-01
MR-10-2-C	Gazelle Creek	GAZL 09-01

B2.2 Field Work

Substrate character and stream habitat conditions were evaluated by performing a stream channel assessment in tributaries listed in **Table B-2**. Longitudinal surveys including pebble counts, grid toss, cross sections, pool data collection, riparian greenline surveys, and eroding streambank measurements were performed at each of the selected monitoring sites during the summers of 2013 and 2014; following methods presented in *The Montana Department of Environmental Quality Sediment Assessment Method: Considerations, Physical and Biological Parameters, and Decision Making* (Kusnierz et al., 2013) and *Field Methodology for Sediment and Habitat Source Assessment* (DEQ, 2012) .

Field assessment reaches were selected in relatively low-gradient portions of the listed streams to facilitate the evaluation of sediment loading impacts. The monitoring locations were chosen to represent various reach characteristics, land-use categories, and human-caused influences, but their representativeness relative to other reaches of the same slope, order, confinement and ecoregion, as well as ease of access, were also considered. There was a preference toward sampling those reaches where human influences would most likely lead to impairment conditions, since it is a primary goal of sediment TMDL development to further characterize sediment impairment conditions. Thus, it is not a random sampling design intended to sample stream reaches representing all potential impairment and non-impairment conditions. Instead, it is a targeted sampling design that aims to assess a representative

subset of reach types, while ensuring that reaches within each 303(d) listed waterbody with potential sediment impairment conditions are incorporated into the overall evaluation.

B2.2.1 Sediment and Habitat field Methods

Sediment and habitat assessments were performed at 43 field monitoring sites, which were selected based on the aerial assessment in GIS and on-the-ground reconnaissance using the factors discussed above. Sediment and habitat data was collected along all stream segments cited in **Table B-2**. Sediment and habitat data was collected within fifteen reach types (**Table B-3**). Field monitoring sites were assessed progressing in an upstream direction and the length of the monitoring site was based on the bankfull channel width.

After a minimum site length was determined, DEQ identified pools, riffles, and pool-forming woody debris; mapped the site; and set up an "EMAP" reach for collecting biological samples. The crew then performed channel form and instream sediment and habitat measurements:

Biological Measurements (EMAP)
- Periphyton samples

Channel Form and Stability Measurements
- Field Determination of Bankfull
- Channel Cross-sections
  - Bankfull Width
  - Channel Bed Morphology
  - Width/Depth Ratio
  - Floodprone Width
  - Entrenchment Ratio
- Water Surface Slope

Fine Sediment Measurements
- Sitewide Riffle Pebble Count
- Pool Tail Grid Toss

In-stream Habitat Measurements
- Residual Pool Depth

General Site Information
- Notes
- GPS Coordinates
- Photographs

An in-depth description of the methods are available in *The Montana Department of Environmental Quality Sediment Assessment Method: Considerations, Physical and Biological Parameters, and Decision Making* (Kusnierz et al., 2013).

B2.2.2 Bank Erosion and Greenline Field Methods

A separate field crew set up sites to perform greenline and bank erosion assessments, typically downstream from the in-stream assessment crew or in the same location as the in-stream crew when the in-stream crew had completed their monitoring. The bank data is used to estimate loading to streams from bank erosion, as well as give an indication of the causes of bank erosion and composition of sediment entering the streams. The greenline data helps establish the composition and condition of riparian vegetation along the streams and provides location information of healthy and degraded areas,

and from where sources of riparian degradation are coming. More details regarding the greenline and bank erosion methodologies can be found in *Field Methodology for Sediment and Habitat Source Assessment* (DEQ, 2012). The data collected is below:

Riparian Health Measurements

- Riparian Greenline Assessment

Bank Erosion

- Field Determination of Bankfull
- Bank Erosion Hazard Measurements
- Near Bank Stress
- Source Information

General Site Information

- Notes
- GPS Coordinates
- Photographs
- Slope

B2.3 Other Information Sources

As indicated in **Section 5.3** of this document, DEQ compiled available sediment data and performed additional field investigations during 2013 and 2014 to characterize sediment conditions for TMDL development purposes. Other data sources listed below were also used to help characterize water quality and/or develop TMDL targets.

- DEQ Assessment Files (cwaic.mt.gov)
- US Forest Service Pacfish/Infish Biological Opinion (PIBO) Program Data
- DEQ reference site data
- Data and reports

B2.3.1 DEQ Assessment Files

The DEQ assessment files contain information used to make sediment impairment determinations. The assessment files include a summary of physical, biological, and habitat data collected and/or compiled by DEQ. The files also include information on sediment water quality characterization and potentially significant sources of sediment, as well as information on non-pollutant impairment determinations and associated rationales. This information is available at cwaic.mt.gov.

B2.3.2 US Forest Service PIBO Program Data

The US Forest Service PACFISH/INFISH Biological Opinion Effectiveness (PIBO) monitoring program annually collects sediment and habitat data from watersheds throughout the northwestern United States. Data collected from “reference” sites (minimally impacted by human activities) was used to develop the targets described in **Section 5.4**. The protocols for collection of this data are found in Archer et al. (2012) and are analogous to those used by DEQ when collecting sediment and habitat data.

B2.3.3 DEQ Reference Site Data

Data collected by DEQ at reference sites was used in conjunction with PIBO data to develop water quality targets. DEQ reference sites are located in watersheds with minimal human impacts (Suplee et al. 2005). The protocols for data collected from DEQ reference sites are found in Kusnierz et al. (2013).

B2.3.4 Data and Reports

Several other documents that provided historical context to sediment sources, described the sensitivity of watersheds to disturbance, provide information about current conditions or sources, and described restoration work that has taken place were also used to help evaluate conditions within the stream segments of concern. These documents were written by state and federal agencies, the Madison Conservation District, and non-profit and private entities.

B3.0 SUMMARIES FOR WATERBODIES WITH NO TMDL WRITTEN

B3.1 Buford Creek MT41F004_150

Buford Creek (MT41F004_150) is not listed for any sediment- or habitat-related issues on the 2018 303(d) List. The segment flows 4.36 miles from the headwaters to the confluence with the West Fork Madison River through sedimentary geology and a shrub/scrub landscape with pockets of evergreen forest and willows growing in the wider riparian areas.

Physical Condition and Sediment Sources

In 2014 DEQ collected sediment and habitat data from two sites on Buford Creek (BFRD 06-01, BFRD 07-01; **Figure B-3**). BFRD 06-01 was the upstream site in this segment and had no sign of human impacts (DEQ 2014). The site was well vegetated with willows, sedges, and native grasses and forbs with about 50% of the vegetation being grass/forbs, and 45.5% being shrub/tree; 4.5% of the ground cover was rock (DEQ 2014, 2015; **Figure B-3**). No disturbed bare ground or hummocking was observed at the site. Streambanks were stable at the site and were composed of sand/clay (10-100%) and fine gravel (0-90%) (DEQ 2015). About 34% of the site length had eroding banks with all being attributed to natural processes. A periphyton sample from the site yielded a 55% probability of the site having excess fine sediment.

Figure B-3. Healthy riparian vegetation conditions at BFRD 06-01

BFRD 07-01 was located about 1.1 miles downstream of BFRD 06-01 near the confluence with the West Fork Madison River and had little evidence of human impacts other than a trail/road ford (DEQ 2014). The site was vegetated with sedges, native grasses and forbs, and some willows with about 83% of the vegetation being wetland species, 16% grass/forbs and 1% being shrub/tree (DEQ 2014, 2015). No disturbed bare ground or hummocking was observed at the site. Streambanks were stable at the site and were composed primarily of sand/clay (90-100%) with some fine gravel (0-10%) (DEQ 2015). About 42% of the site length had eroding banks with 88% being attributed to natural processes and the remainder being riparian grazing. A periphyton sample from the site yielded a 38.1% probability of the site having excess fine sediment.

Comparison to Water Quality Targets

The existing physical data in comparison with the targets for Buford Creek are summarized in **Table B-5**. All bolded cells are not meeting the target; depending on the target parameter, this may equate to being below or above the target value. For fine sediment, both sites fail to meet the target for riffle pebble count < 6 mm. With regards to the channel form and instream habitat variables, one site fails to meet the target for residual pool depth. These results indicate that the creek is generally meeting targets.

Table B-5. Existing sediment-related data for Buford Creek relative to targets
Values that do not meet the target are in bold and shaded

Reach/ Site ID	Assessment Year	Mean BFW (ft)	Gradient (%)	Existing Stream Type	Riffle Pebble Count		Grid Toss	Channel Form		Instream Habitat	
					% <6mm	% <2mm	Pool % <6mm	W/D Ratio	Entrenchment Ratio	Residual Pool Depth (ft)	Pools / 1000 ft
BFRD 06-01	2014	*NM (<15)*	1.7	B	**25**	17	8	*NM*	*NM*	0.7	19.8
BFRD 07-01	2014	4.2	0.7	E	**21**	16	10	3.8	10.2	**0.4**	25

Summary and TMDL Development Determination
Data collected by DEQ in 2014 (DEQ 2014, 2015) indicate that while riparian grazing is a potential source contributing some fine sediment to the segment, the predominant source is natural processes. The physical data indicate that fine sediment targets are generally being met. The lack of sediment- and habitat-related listings is supported based on current land management practices in place, the general lack of human-caused erosion observed, the apparent improvement in conditions since the last DEQ evaluation, and the few instream target failures; a TMDL will not be written.

B3.2 Elk River MT41F004_110

Elk River (MT41F004_110) is not listed for any sediment- or habitat-related issues on the 2018 303(d) List. The segment flows 15.59 miles from the headwaters to the mouth at the West Fork Madison River through sedimentary, intrusive, and volcanic geology and an evergreen landscape interspersed with shrub/scrub vegetation.

Physical Condition and Sediment Sources
Sediment and habitat data were collected from the Elk River by PIBO at one site in 2009 and 2014 and by DEQ at one site in 2013 and another in 2014 (ELKR 04-01, ELKR 18-01/2734 (PIBO)); **Figure B-1**). ELKR 04-01 was the upstream site sampled by DEQ in this segment. Vegetation at the site consisted of willow, sedges, grass, and forbs with about 52% of the vegetation being wetland species, 1% grass/forbs, and 36% being shrub/tree (DEQ 2014, 2015; **Figure B-4**). Disturbed ground and rock comprised about 6% and 5% of the site respectively with no hummocking observed. Streambanks were composed primarily of sand/clay (60-70%) with lesser amounts of fine gravel (10-20%) and coarse gravel or larger sediment (20-30%) (DEQ 2015). About 25% of the site length had eroding banks with 100% being attributed to natural processes. A periphyton sample from the site yielded a 55.7% probability of the site having excess fine sediment.

Figure B-4. Willow growth within the riparian zone at ELKR 04-01

ELKR 18-01 was located about 12.5 miles downstream of ELKR 04-01 near the confluence with the West Fork Madison River within an upland area that was lightly grazed (DEQ 2013). Vegetation and bank erosion data was collected just upstream of ELKR 18-01 at a site named ELKR 17-01. Vegetation at this location consisted of about 15% of the vegetation being wetland species, 39.5% grass/forbs, and 22% being shrub/tree (DEQ 2015). Disturbed bare ground was present at 0.5% of the site with rock comprising 23%; no hummocking was observed. Streambanks were composed primarily of sand/clay (50-70%) with lesser amounts of fine gravel (10%) and coarse gravel or larger sediment (20-40%) (DEQ 2015). About 25% of the site length had eroding banks with half being attributed to natural processes and the other half being riparian grazing. A periphyton sample from ELKR 18-01 yielded a 45.6% probability of the site having excess fine sediment.

Comparison to Water Quality Targets

The existing physical data in comparison with the targets for the Elk River are summarized in **Table B-6**. All bolded cells are not meeting the target; depending on the target parameter, this may equate to being below or above the target value. For fine sediment, both sites fail to meet the targets for riffle pebble count < 6 mm and < 2 mm. The target for < 6 mm is exceeded by three percentage points at both sites and the target for < 2 mm is exceeded by one percentage point at one site and three at the other. The only other variable that fails to meet its respective target is residual pool depth at the upper site. These results indicate that there may be excessive fine sediment in the Elk River; however, both riffle fines targets are exceeded by a small margin and the pool tail fines at both sites are very low.

Table B-6. Existing sediment-related data for Elk River relative to targets
Values that do not meet the target are in bold and shaded

Reach/ Site ID	Assessment Year	Mean BFW (ft)	Gradient (%)	Existing Stream Type	Riffle Pebble Count		Grid Toss	Channel Form		Instream Habitat	
					% <6mm	% <2mm	Pool % <6mm	W/D Ratio	Entrenchment Ratio	Residual Pool Depth (ft)	Pools / 1000 ft
ELKR 04-01	2014	10.1	1	C	**21**	**20**	4	11	2.3	**0.6**	20.2
ELKR 18-01, 2734 (PIBO)	2009 2013 2014	26.8	1.8	C	**21**	**18**	5	15.0	6.6	1.3	8.5

[1]PIBO site 2734 is co-located with ELKR 18-01, values are averages from sampling events in 2009, 2013, and 2014

Summary and TMDL Development Determination
Data collected by DEQ in 2013 and 2014 (DEQ 2013, 2014, 2015) indicate that most of the erosion observed on the Elk River was attributed to natural processes and that continued implementation of best management practices will maintain the existing sediment loading to the Elk River. The lack of sediment- and habitat-related listings is supported based on the current land management practices that are limiting sediment sources, the apparent improvement in conditions since the 2003 DEQ evaluation, the minimal human-caused erosion observed, and the borderline failures of instream sediment ; a TMDL will not be written.

B3.3 Gazelle Creek MT41F004_120

Gazelle Creek (MT41F004_120) is not listed for any sediment- or habitat-related issues on the 2018 303(d) List. The segment flows 9.65 miles from the headwaters to the mouth at the West Fork Madison River through metamorphic and volcanic geology and an evergreen landscape interspersed with shrub/scrub vegetation.

Physical Condition and Sediment Sources
Sediment and habitat data were collected from Gazelle Creek by PIBO at one site in 2008 and 2013 and by DEQ at two sites in 2014 (2601 (PIBO), GAZL 09-01, GAZL 16-01; **Figure B-1**). GAZL 09-01 was the upstream site in this segment and was located in a lightly grazed setting (DEQ 2014). The site was well vegetated with currant, conifer, sedge, thimbleberry, willow, and dogwood with about 31% of the vegetation being wetland species, 36% grass/forbs and 18% being shrub/tree (DEQ 2014, 2015; **Figure B-5**). Large woody debris was prevalent within the site and limited cattle access to riparian areas. Rock covered about 15% of the site and there was hummocking within 1%; no disturbed bare ground was observed. Streambanks were composed entirely of sand/clay (DEQ 2015). About 90% of the site length had eroding banks with 90% being attributed to natural processes and the remainder being riparian grazing. A periphyton sample from the site yielded a 42.9% probability of the site having excess fine sediment.

Figure B-5. Vegetation and large woody debris at GAZL 09-01

GAZL 16-01 was located about 2.6 miles downstream of GAZL 09-01 near the confluence with the West Fork Madison River. The site was well vegetation with conifer, grasses, forbs, willow, and dogwood with about 28% of the vegetation being wetland species, 9% grass/forbs and 26% being shrub/tree (DEQ 2014, 2015). There was limited cattle access to riparian areas though livestock paths were observed along the channel. Rock covered about 31% of the site and there was hummocking within 2%; 6% was disturbed bare ground. Streambanks were composed primarily of sand/clay (70%) with lesser amounts of fine gravel (10%) and coarse gravel or larger sediment (20%) (DEQ 2015). About 27% of the site length had eroding banks with 100% being attributed to natural processes. A periphyton sample from the site yielded a 27.9% probability of the site having excess fine sediment.

Comparison to Water Quality Targets

The existing physical data in comparison with the targets for Gazelle Creek are summarized in **Table B-7**. All bolded cells are not meeting the target; depending on the target parameter, this may equate to being below or above the target value. For fine sediment, both DEQ sites meet the targets for riffle pebble count < 6 mm and < 2 mm and pool tail grid toss. The target for pool tail grid toss is exceeded at the PIBO site. The only other failure is for W/D ratio at a single site. These results indicate that while there may be some localized deposits of fine sediment (i.e., PIBO site) in general, fine sediment loading, channel form, and instream habitat quality appear to be appropriate for the creek.

Table B-7. Existing sediment-related data for Gazelle Creek relative to targets
Values that do not meet the target are in bold and shaded

Reach/ Site ID	Assessment Year	Mean BFW (ft)	Gradient (%)	Existing Stream Type	Riffle Pebble Count		Grid Toss	Channel Form		Instream Habitat	
					% <6mm	% <2mm	Pool % <6mm	W/D Ratio	Entrenchment Ratio	Residual Pool Depth (ft)	Pools / 1000 ft
2601 (PIBO)[1]	2008, 2013	18.6	0.2	*NM*	*NM*	*NM*	**34**	13.6	*NM*	1.65	22.2
GAZL 09-01	2014	14.9	2.3	B	10	6	9	**11.3**	2.1	0.9	54.6
GAZL 16-01	2014	16.5	3.4	B	6	4	5	16.7	1.8	1	25.0

[1]Values are averages from sampling events in 2008 and 2013; PIBO site 2601 is located on stratified reach GAZL 11-01 downstream of GAZL 09-01

Summary and TMDL Development Determination
Data collected by DEQ in 2014 (DEQ 2014, 2015) indicate that natural processes dominate the sediment source load, there is limited potential loading from riparian grazing, and that continued implementation of best management practices will maintain the existing sediment loading to Gazelle Creek. The lack of sediment- and habitat-related listings is supported based on the current land management practices that are limiting sediment sources, the apparent improvement in conditions since the 2003 evaluation, the limited human-caused erosion observed, and the healthy riparian vegetation conditions observed at the sampling sites; a TMDL will not be written.

B3.4 Indian Creek MT41F004_040

Indian Creek (MT41F004_040) is listed for alteration in stream-side or littoral vegetative covers on the 2018 303(d) List. The segment flows 6.34 miles from the Lee Metcalf Wilderness to the mouth at the Madison River through sedimentary geology and a grass and shrub/scrub landscape with pockets of evergreen forest.

Physical Condition and Sediment Sources
INDN 25-01 was located about 4.5 miles downstream of INDN 23-01 in a lightly grazed setting (DEQ 2015). The site was vegetated with cottonwood, conifer, alder, dogwood, cedar, and grass with about 3% of the vegetation being wetland species, 28.5% grass/forbs and 44% being shrub/tree (DEQ 2014, 2015). Disturbed bare ground and rock each made up 2.5% and 14% of the site respectively with hummocking observed at less than 1% of the site. Streambanks were well armored and were composed of 40% sand/silt, 20% fine gravel, and 40% coarse gravel or larger sediment (DEQ 2015). About 7% of the site length had eroding banks with 74% being attributed to natural processes, 16% to historical riparian grazing, and the remainder being from an old bridge. A periphyton sample from the site yielded a 14.7% probability of the site having excess fine sediment.

Comparison to Water Quality Targets
The existing physical data in comparison with the targets for Indian Creek are summarized in **Table B-8**. All bolded cells are not meeting the target; depending on the target parameter, this may equate to being below or above the target value. For fine sediment, both sites meet the targets for riffle pebble count < 6 mm and < 2 mm and pool tail grid toss. The only target failure is for residual pool depth at one

site. These results indicate that fine sediment loading, channel form, and instream habitat quality appear to be appropriate for the creek.

Table B-8. Existing sediment-related data for Indian Creek relative to targets
Values that do not meet the target are in bold and shaded

Reach/ Site ID	Assessment Year	Mean BFW (ft)	Gradient (%)	Existing Stream Type	Riffle Pebble Count		Grid Toss	Channel Form		Instream Habitat	
					% <6mm	% <2mm	Pool % <6mm	W/D Ratio	Entrenchment Ratio	Residual Pool Depth (ft)	Pools / 1000 ft
INDN 23-01	2014	37.8	2.0	B	9	7	0	20.5	1.4	1.9	20.3
INDN 25-01	2014	36.0	2.1	B	7	3	1	22.7	1.7	**1.0**	16.6

Summary and TMDL Development Determination
Data collected by DEQ in 2014 (DEQ 2014, 2015) indicate that there are limited potential sources (historical grazing, an old bridge) contributing excess fine sediment to the segment and that continued implementation of best management practices will maintain the existing sediment loading to Indian Creek. The lack of a sedimentation-siltation listing for Indian Creek is supported based on the current land management practices that are limiting sediment sources and the lack of human-caused erosion observed. The alteration in stream-side or littoral vegetative covers listing is supported by site visits indicating that the riparian community is not meeting potential. Because “alteration in stream-side or littoral vegetative covers” is a non-pollutant listing and there is no listing for sedimentation-siltation, a TMDL will not be written for Indian Creek.

B3.5 Jack Creek MT41F004_050

Jack Creek (MT41F004_050) is listed for alteration in stream-side or littoral vegetative covers on the 2018 303(d) List. The segment flows 15.18 miles from the headwaters to the mouth at the Madison River primarily through sedimentary geology and a shrub/scrub and evergreen-dominated landscape in the headwaters with a grass-dominated landscape with willows and sedges growing in riparian areas near the mouth.

Physical Condition and Sediment Sources
The Jack Creek watershed has been the focus of a monitoring project since 2006 (Madison Conservation District 2014). The goals of the project include collecting baseline water quality data, identifying changes in water quality, and providing opportunities for the public (youth and adults) to learn about and participate in water quality data collection. The effects of development in the Jack Creek watershed on water quality are a concern and the Jack Creek monitoring projects has the potential to evaluate such impacts.

In addition to regular sampling, Jack Creek has been the location of restoration work. In 2003 about 880 feet of new channel was constructed on Jack Creek and 50 acres of wetlands were created adjacent to the creek (Madison Conservation District 2015). Two streambank restoration projects also took place in 2016, involving the use of willow soil lifts to replace hard bank structures (Madison Conservation District 2015).

Sediment and habitat data were collected from Jack Creek at two sites by DEQ in 2014 (JACK 14-03, JACK 14-06; **Figure B-2**). JACK 14-03 was the upstream site in this segment and was located in a non-grazed riparian setting (except for at water gaps) (DEQ 2015). The site was vegetated with cottonwood, alder, willow, and reed canary grass with about 12.5% of the vegetation being wetland species, 77% grass/forbs, and 9% being shrub/tree (DEQ 2014, 2015). Disturbed bare ground and rock each made up 0.5% and 1% of the site respectively; no hummocking was observed. Streambanks were eroding in locations where vegetation was lacking and were primarily composed of sand/clay (60-80%) with lesser amounts of fine gravel (10-20%), and coarse gravel or larger sediment (10-30%) (DEQ 2015). About 51% of the site length had eroding banks with 81% being attributed to historical grazing and channel manipulation and the remainder to natural processes. A periphyton sample from the site yielded a 24.9% probability of the site having excess fine sediment.

JACK 14-06 was located about 2.3 miles downstream of JACK 14-03 and has had recent restoration work including adding channel meanders and planting willows, cottonwoods, and aspen (DEQ 2014,2015). The site was vegetated with cottonwood, aspen, willow, reed canary grass and other grasses with about 78% of the vegetation being grass/forbs and 11.5 being shrub/tree (DEQ 2014, 2015). Disturbed bare ground and rock each made up 2.5% and 0.5% of the site respectively; no hummocking was observed. Streambanks had riprap in places and were composed of primarily sand/clay (65-80%) with lesser amounts of fine gravel (10%), and coarse gravel or larger sediment (10-30%) (DEQ 2015). About 47% of the site length had eroding banks with about 57% being attributed to natural processes, 35% being attributed to existing historical channelization, and the remainder being due to roads. A periphyton sample from the site yielded a 27.3% probability of the site having excess fine sediment.

In addition to the DEQ data collection, the Madison Conservation District collected pebble counts from four sites on Jack Creek in July, 2014; percent fines < 2 mm were 10%, 14%, 14%, and 18% (Madison Conservation District 2014).

Comparison to Water Quality Targets

The existing physical data in comparison with the targets for Jack Creek are summarized in **Table B-9.** All bolded cells are not meeting the target; depending on the target parameter, this may equate to being below or above the target value. For fine sediment, both DEQ sites meet the targets for riffle pebble count < 6 mm and < 2 mm and pool tail grid toss. One site fails to meet the targets for channel form; both of these failures are considered borderline because the site is within 1.3 feet of being in the next class for the W/D target and the entrenchment ratio is only one unit less than the target. These results indicate that fine sediment loading, channel form, and instream habitat quality appear to be appropriate for the creek.

Table B-9. Existing sediment-related data for Jack Creek relative to targets

Values that do not meet the target are in bold and shaded

Reach/ Site ID	Assessment Year	Mean BFW (ft)	Gradient (%)	Existing Stream Type	Riffle Pebble Count		Grid Toss	Channel Form		Instream Habitat	
					% <6mm	% <2mm	Pool % <6mm	W/D Ratio	Entrenchment Ratio	Residual Pool Depth (ft)	Pools / 1000 ft
JACK 14-03	2014	30.4	0.3	C	11	8	4	27.3	2.8	2.0	11.3
JACK 14-06	2014	28.7	0.2	C	16	13	4	**26.9**	**1.9**	2.4	9.7

Summary and TMDL Development Determination

Data collected by DEQ in 2014 (DEQ 2014, 2015) indicate that there are limited potential sources (historical grazing and channel manipulation) contributing fine sediment to the segment and that continued restoration and implementation of best management practices and additional restoration will maintain and potentially reduce the existing sediment loading to Jack Creek. The lack of a sedimentation-siltation listing for Jack Creek is supported based on the current land management practices that are limiting sediment sources, the apparent improvement in conditions since the 2000 DEQ evaluation, and the limited human-caused erosion observed. The alteration in stream-side or littoral vegetative covers listing is supported by site visits indicating that a lack of vegetation is resulting in some bank erosion. Because "alteration in stream-side or littoral vegetative covers" is a non-pollutant listing and there is no listing for sedimentation-siltation, a TMDL will not be written for Jack Creek. With the current developed state of the watershed, continuing to seize opportunities for stream restoration projects will be an important component of maintaining a properly functioning Jack Creek. And with anticipated further development in the watershed, implementation of management practices throughout the watershed will be important for maintaining the sediment loading in Jack Creek at a healthy level.

B3.6 Madison River, lower segment MT41F001_010

The Madison River, lower segment (MT41F001_010), is listed for sedimentation-siltation on the 2018 303(d) List. In addition, this segment is listed for alteration in stream-side or littoral vegetative covers which is a non-pollutant listing that can often be linked to sediment impairment. The segment flows 41.31 miles from Madison Dam to the mouth at the Missouri River through sedimentary geology and a landscape consisting of grass-dominated landscape with willows and sedges growing in riparian areas.

Physical Condition and Sediment Sources

The previous DEQ assessment file indicated that there was moderate impairment from impacts to riparian vegetation and sedimentation, found by comparing aerial photos from 1990 to 1950. The files indicated these impacts could be mitigated by release of flushing flows from Hebgen Dam. Sources were listed as Dam Construction (Other than Upstream Flood Control Projects), Dam or Impoundment, Impacts from Abandoned Mine Lands (Inactive), and Agriculture.

DEQ did not conduct sediment fieldwork on this segment in 2013 or 2014 due to the size of the river and in light of the 2013 report authorized by Pacific Power and Light (PPL) on flushing flow needs in the river as part of their FERC license renewal (PPL Montana, 2013). The lower segment of the Madison River is wide and shallow, with fines found in depositional areas. The PPL document reports that data collection of various sediment parameters started in 1994 and have occurred with fair regularity in the years since. In June 1996, there was a large flushing flow event from natural events that resulted in a three-day period averaged flow from Madison Dam (at Ennis) of ~7,600 cfs. This flushing event resulted in a significant reduction in the percentage of fines at the two monitoring locations in the lower river (Norris Bridge and Greycliff FAS). Attempting to recreate the 1996 event and its results, PPL released flushing flows from Hebgen Dam in 2006, 2008, and 2010. Given the operational constraints of the FERC license, which includes a maximum flow limit of 3,500 cfs at Kirby Ranch to limit erosion from the outlet of Quake Lake, PPL is unable to release enough flow to the mainstem to fully recreate the June 1996 event. Reservoir modeling by the consultant determined the upward limit of a PPL-generated flushing flow to be ~5,400 cfs. The PPL study also determined that fine sediment is trapped by Ennis Lake and the upper reach is not a significant source of fines to the Lower Madison. Ultimately, sampling has determined that while the PPL-generated flushing flows are providing some benefits to the Lower

Madison River, flushing flows are not enough to transport the fines out of the reach, and may also contribute to excess stream bank erosion.

Summary and TMDL Development Determination
Developing a sediment TMDL for the Lower Madison River requires a complex modeling effort due to the presence of Hebgen Dam and Madison Dam. A sediment TMDL for the Lower Madison River was not developed as part of this TMDL document.

B3.7 O'Dell Spring Creek MT41F004_020

O'Dell Spring Creek (MT41F004_020) is listed for other anthropogenic substrate alterations, physical substrate habitat alterations, and alteration in stream-side or littoral vegetative covers on the 2018 303(d) List. These are non-pollutant listing that can often be linked to sediment impairment. The segment flows 13.19 miles from the headwaters to the mouth at the Madison River through sedimentary geology and a landscape consisting of interspersed grasses, shrub/scrub, and wetlands.

Physical Condition and Sediment Sources
The DEQ assessment file indicates that channelization and eroding banks and channel widening as a result of cattle trampling were observed on O'Dell Spring Creek. A range of riparian vegetative conditions were observed from there being no vegetation to willows present. Some areas of the stream were heavily grazed while others had fencing and little grazing pressure. Up to 50% of the stream bottom was covered by silt.

Since 2005 restoration work on O'Dell Creek has involved the filling of ditches, creation of wetlands, planting vegetation, and reconstruction of at least nine miles of channel (Madison Conservation District 2015).

Sediment and habitat data were collected from O'Dell Spring Creek at one site by DEQ in 2014 (ODEL 02-01; **Figure B-2**). The site was located in an area within a recent restoration project and had no evidence of grazing (DEQ 2014). The site was vegetated with sedges and grasses and had some cottonwood plantings with about 64% of the vegetation being wetland species and 36% grass/forbs (DEQ 2014, 2015). Disturbed bare ground and hummocking were not observed at the site. Banks were composed of 100% sand/clay (DEQ 2015). About 59% of the site length had eroding banks with 80% being attributed to natural processes and the remainder to recent restoration work. A periphyton sample from the site yielded a 40.1% probability of the site having excess fine sediment.

In addition to the DEQ data collection, the Madison Conservation District collected pebble counts from two sites on O'Dell Spring Creek in July, 2014; percent fines < 2 mm were 38% and 59% (Madison Conservation District 2014).

Comparison to Water Quality Targets
The existing physical data in comparison with the targets for O'Dell Spring Creek are summarized in **Table B-10**. All bolded cells are not meeting the target; depending on the target parameter, this may equate to being below or above the target value. Although the existing stream type for the sampled site is a Rosgen C, it is believed that the W/D ration has been increased because of human impacts and the potential and expected channel type given the opportunity to recover is a Rosgen E. The only target failure at the sampled site was for riffle pebble count < 2 mm. These results indicate that sediment

loading, channel form (except with regards to the potential Rosgen E channel type), and instream habitat appear to be appropriate for the site.

Table B-10. Existing sediment-related data for O'Dell Spring Creek relative to targets
Values that do not meet the target are in bold and shaded; values were compared to the targets for a Rosgen E channel type

Reach/ Site ID	Assessment Year	Mean BFW (ft)	Gradient (%)	Existing Stream Type	Riffle Pebble Count		Grid Toss	Channel Form		Instream Habitat	
					% <6mm	% <2mm	Pool % <6mm	W/D Ratio	Entrenchment Ratio	Residual Pool Depth (ft)	Pools / 1000 ft
ODEL 02-01	2014	33.3	0.5	C	33	**33**	12	19.6	9.6	2.5	6.0

Summary and TMDL Development Determination
Data collected by DEQ in 2014 (DEQ 2014, 2015) indicate that predominantly natural processes are contributing fine sediment to the segment and that continued restoration and implementation of best management practices will reduce sediment input from any historical sources. Most targets were met and it appears that conditions in O'Dell Spring Creek have improved since the last DEQ evaluation. In addition, insufficient information was collected to fully evaluate this creek. Therefore, a TMDL will not be written.

B3.8 West Fork Madison River MT41F004_100

West Fork Madison River (MT41F004_100) is not listed for any sediment- or habitat-related issues on the 2018 303(d) List. The segment flows 39.41 miles from the headwaters to the mouth at the Madison River through predominantly volcanic geology with sedimentary geology in the headwaters and a shrub/scrub-dominated landscape with pockets of conifers.

Physical Condition and Sediment Sources
Restoration activities were initiated on the West Fork Madison River in 2014. This work involved installing riparian fencing, installing hardened crossings, and closing unauthorized off highway vehicle trails in the National Forest (Madison Conservation District 2015).

Sediment and habitat data were collected from the West Fork Madison River at one site by PIBO in 2009 and 2014, one site by DEQ in 2013 and two sites by DEQ in 2014 (2740 (PIBO), WFMA 14-02, WFMA 25-01, WFMA 26-01; **Figure B-1**). WFMA 14-02 was the most upstream site visited by DEQ in this segment and was located in an area that was heavily grazed in the past; cattle are now excluded from the riparian area (DEQ 2015). The site had a healthy riparian vegetation community that consisted of willow, sedges, and forbs with about 34% of the vegetation being wetland species, 4% grass/forbs, and 50% being shrub/tree (DEQ 2014, 2015; **Figure B-6**). Disturbed bare ground and rock each made up 4% and 8% of the site respectively; hummocking covered about 10% of the site. Streambanks were primarily composed of sand/clay (50-80%) with lesser amounts of fine gravel (5-10%) and coarse gravel or larger sediment (15-40%) (DEQ 2015). About 20% of the site length had eroding banks with 62% being attributed to natural processes and the remainder to riparian grazing.

Figure B-6. Riparian conditions at WFMA 14-02

WFMA 25-01 was located about 19.5 miles downstream of WFMA 14-02, downstream of the confluence with the Elk River. The site was vegetated with willow, conifer, grasses, and forbs with about 3.5% of the vegetation being grass/forbs and 64% being shrub/tree (DEQ 2014, 2015, **Figures B-6** and **B-7**). Disturbed bare ground and rock made up 17.5% and 15% of the site respectively; no hummocking was observed. About 1000 feet of riparian fencing was recently installed downstream of the site (DEQ 2015). Streambanks were primarily composed of sand/clay (80%) with lesser amounts of fine gravel (10%), and coarse gravel or larger sediment (10%) (DEQ 2015; **Figure B-7**). About 12% of the site length had eroding banks with 98% being attributed to riparian grazing and the remainder to natural processes (**Figure B-8** and **Figure B-9**). A periphyton sample from the site yielded a 47% probability of the site having excess fine sediment.

Figure B-7. Relatively healthy riparian conditions at WFMA 25-01

Figure B-8. Grazed riparian conditions at WFMA 25-01

Figure B-9. Eroding streambank at WFMA 25-01

WFMA 26-01 was located about 6.3 miles downstream of WFMA 25-01 in a lightly grazed area upstream of the confluence with Gazelle Creek (DEQ 2013). The site had a healthy riparian vegetation community consisting of conifer, willow, rushes, tall grasses, and forbs with about 6.5% of the vegetation being wetland species, 67% grass/forbs, and 14% being shrub/tree (DEQ 2013, 2015). Disturbed bare ground and rock made up 8.5% and 4% of the site respectively; no hummocking was observed. Streambanks were composed primarily of sand/clay (75-100%) with lesser amounts of fine gravel (0-15%), and coarse gravel or larger sediment (0-10%) (DEQ 2015). About 40% of the site length had eroding banks with about 65% being attributed to natural processes and the remainder to historical timber harvest. A periphyton sample from the site yielded a 35% probability of the site having excess fine sediment.

In addition to the DEQ data collection, the Madison Conservation District collected pebble counts from three sites on the West Fork Madison River in July, 2014; percent fines < 2 mm were 5%, 10%, and 18% (Madison Conservation District 2014).

Comparison to Water Quality Targets

The existing physical data in comparison with the targets for West Fork Madison River are summarized in **Table B-11**. All bolded cells are not meeting the target; depending on the target parameter, this may equate to being below or above the target value. For fine sediment, none of the sites failed to meet targets. The upper DEQ site fails the targets for W/D ratio and pool frequency and the middle DEQ site fails the targets for entrenchment ratio and residual pool depth. These results indicate that sediment

loading is appropriate and that although the channel form and habitat quality in the West Fork Madison River fails to meet some targets, it overall appears healthy.

Table B-11. Existing sediment-related data for West Fork Madison River relative to targets
Values that do not meet the target are in bold and shaded

Reach/ Site ID	Assessment Year	Mean BFW (ft)	Gradient (%)	Existing Stream Type	Riffle Pebble Count		Grid Toss	Channel Form		Instream Habitat	
					% <6mm	% <2mm	Pool % <6mm	W/D Ratio	Entrenchment Ratio	Residual Pool Depth (ft)	Pools / 1000 ft
2740 (PIBO)[1]	2009, 2014	23.7	0.5	*NM*	*NM*	*NM*	14	12.8	*NM*	1.9	12.2
WFMA 14-02	2014	12.6	1.1	C	13	13	1	**13.9**	3.0	1.4	**12.3**
WFMA 25-01	2014	53.5	1.3	C	7	6	8	32.4	**1.5**	**1.0**	3.8
WFMA 26-01	2013	43.5	0.8	C	16	12	3	28.1	5.7	1.5	6.5

[1] Values are averages from sampling events in 2009 and 2014

Summary and TMDL Development Determination

Data collected by DEQ in 2013 and 2014 (DEQ 2013, 2014, 2015) indicate that there are limited potential sources (riparian grazing, historical timber harvest) contributing excess fine sediment to the segment and that continued implementation of best management practices will maintain or improve the existing sediment loading to the West Fork Madison River. The lack of sediment- and habitat-related listings is supported based on the current land management practices that are limiting sediment sources, the apparent improvement in conditions since the last evaluation, and the limited human-caused erosion observed; a TMDL will not be written.

B4.0 REFERENCES

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APPENDIX C - BANK EROSION ASSESSMENT, MADISON TMDL PLANNING AREA

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C1.0 INTRODUCTION

This appendix presents an assessment of sediment loading due to streambank erosion in the Madison TMDL Planning Area (TPA) located in Madison and Gallatin counties. Sediment loads due to streambank erosion were estimated based on field data collected at 42 monitoring sites in summer 2014.

The streambank erosion assessment involved several procedures. First, streams were stratified into similar reaches using an aerial assessment performed in GIS. Streambank erosion data was then collected in the field at selected monitoring sites, and sediment loads were estimated based on field surveys of streambanks. Sediment loads from field assessed monitoring sites were then extrapolated to the unassessed stream reaches and segments in each impaired watershed to estimate a loading for the watershed. Finally, the potential for reducing human influenced streambank erosion was evaluated by decreasing the level of loading to be similar to that at unimpaired reaches, or by estimating the load if erosion at high-eroding banks was reduced. Detailed methods describing each procedure, as well as results, are provided in the following sections.

C2.0 DATA COLLECTION

C2.1 AERIAL ASSESSMENT REACH STRATIFICATION

Prior to field data collection, an aerial assessment of streams in the Madison River TPA was conducted using GIS. Data layers were used to stratify streams into distinct reaches based on landscape and land-use factors following techniques described in *Watershed Stratification Methodology for TMDL Sediment and Habitat Investigations* (Montana Department of Environmental Quality, 2008).

The reach stratification process was completed for the mainstem segments of the following sediment-listed streams in the Madison TPA: Antelope Creek, Bear Creek, Blaine Spring Creek, Cherry Creek, Elk Creek, Hot Springs Creek, Moore Creek, North Meadow Creek, Red Canyon Creek, Ruby Creek, South Meadow Creek, Watkins Creek, and Wigwam Creek. It was also completed for stream segments in the following non-listed streams: Elk River, Gazelle Creek, Hot Springs Creek, Indian Creek, Jack Creek, No Man Creek, O'Dell Spring Creek, West Fork Madison River.

The aerial assessment reach stratification process involved dividing each stream into distinct reaches based on four watershed characteristics. A reach type is defined as a unique combination of EPA Ecoregion, valley gradient, Strahler stream order, and valley confinement, and is designated using the following naming convention based on the reach type identifiers provided in **Table C-1**:

Level III Ecoregion – Valley Gradient – Strahler Stream Order – Confinement

Table C-1. Reach Type Identifiers

Watershed Characteristic	Stratification Category	Reach Type Identifier
Level III Ecoregion	Northern Rockies	NR
	Canadian Rockies	CR
Valley Gradient	0-2%	0
	2-4%	2
	4-10%	4
	> 10%	10

Table C-1. Reach Type Identifiers

Watershed Characteristic	Stratification Category	Reach Type Identifier
Strahler Stream Order	first order	1
	second order	2
	third order	3
	fourth order	4
	fifth order	5
Confinement	confined	C
	unconfined	U

For example, a reach identified as NR-0-3-U is in the Northern Rockies Level III Ecoregion, has a valley gradient of 0-2%, is a 3rd order stream, and is within an unconfined valley.

Streambank erosion data was collected at 42 example monitoring sites at which reach surveys were conducted which were 500, 1000, or 2000 feet long based on bankfull width of the stream: the larger the bankfull width, the longer the monitored reach. In this assessment, a sampled reach was referred to as a ”site”. These monitoring sites included the 28 sites located within impaired watersheds, as well as 14 located in unimpaired watersheds. **Table C-2** describes the distribution of sampled sites across different reach types. The sites sampled for the bank erosion assessment (**Table C-3**) were the same sites sampled to determine if stream segments were meeting sediment targets, as described in **Appendix B**.

Table C-2. Stratified reach types within the Madison TPA, and the number of monitoring sites within each type

Level III Ecoregion	Valley Gradient	Strahler Stream Order	Confine-ment	Reach Type	Total Number of Reaches	Number of Monitoring Sites/Reaches
Middle Rockies	<2%	1	U	MR-0-1-U	1	-
		2	C	MR-0-2-C	7	1
			U	MR-0-2-U	13	1
		3	C	MR-0-3-C	3	1
			U	MR-0-3-U	68	10
		4	C	MR-0-4-C	2	1
			U	MR-0-4-U	25	5
		5	U	MR-0-5-U	1	-
		6	C	MR-0-6-C	5	-
			U	MR-0-6-U	17	-
	2-4%	1	U	MR-2-1-U	11	1
		2	C	MR-2-2-C	17	-
			U	MR-2-2-U	32	4
		3	C	MR-2-3-C	21	1
			U	MR-2-3-U	47	10
		4	C	MR-2-4-C	1	-
			U	MR-2-4-U	8	1
		6	C	MR-2-6-C	1	-
			U	MR-2-6-U	2	-
	4-10%	1	C	MR-4-1-C	21	-
			U	MR-4-1-U	49	2
		2	C	MR-4-2-C	16	-
			U	MR-4-2-U	45	3

Table C-2. Stratified reach types within the Madison TPA, and the number of monitoring sites within each type

Level III Ecoregion	Valley Gradient	Strahler Stream Order	Confine-ment	Reach Type	Total Number of Reaches	Number of Monitoring Sites/Reaches
		3	C	MR-4-3-C	18	-
			U	MR-4-3-U	14	-
		4	C	MR-4-4-C	5	-
			U	MR-4-4-U	2	-
	>10%	1	C	MR-10-1-C	16	-
			U	MR-10-1-U	34	-
		2	C	MR-10-2-C	11	1
			U	MR-10-2-U	7	-
		3	C	MR-10-3-C	4	-
			U	MR-10-3-U	2	-
Totals:					**526**	**42**

C2.2 FIELD SURVEYS

Field data collection utilized the approach described the in *Longitudinal Field Methods for the Assessment of TMDL Sediment and Habitat Impairments* (Montana Department of Environmental Quality, 2007).

At each eroding bank, Bank Erosion Hazard Index (BEHI) measurements were performed and the Near Bank Stress (NBS) was estimated or determined based on field measurements (Rosgen,2001). Bank erosion severity was rated from “very low” to “extreme” based on the BEHI score, which was determined by the following six parameters: bank height, bankfull height, root depth, root density, bank angle, and surface protection. Near Bank Stress was rated from “very low” to “extreme” depending on the shape of the channel at the toe of the bank and the force of the water (i.e. “stream power”) along the bank.

In addition, the source or underlying cause of streambank erosion was evaluated based on current or observed human disturbances within the riparian corridor adjacent to each bank, as well as historical land-use practices in the surrounding landscape. The following near-stream source categories were used: transportation (roads), grazing, cropland, mining, logging, irrigation, natural, and “other”. Naturally eroding streambanks were considered those with no observed or known historic human impacts in the riparian zone, while the “other” category was chosen when streambank erosion resulted from a source not specifically identified in the list. If multiple sources were observed, then a percent of the total was estimated for each source at each bank.

Table C-3. Monitoring sites assessed in each watershed by reach type

Reach Type	waterbody	Monitoring Sites
MR-0-2-C	West Fork Madison River	WFMA 14-02
MR-0-2-U	O’Dell Spring Creek	ODEL 02-01
MR-0-3-C	Indian Creek	INDN 25-01
MR-0-3-U	Cherry Creek, Elk Creek, Hot Springs Creek, Jack Creek, Moore Creek, South Meadow Creek	CHRR 18-02, CHRR 20-01, ELKC 05-01, ELKC 11-01, HOTS 10-01, JACK 14-03, JACK 14-06, MOOR 09-01, MOOR 09-04, SMDW 19-01
MR-0-4-C	West Fork Madison River	WFMA 25-01

Table C-3. Monitoring sites assessed in each watershed by reach type

Reach Type	waterbody	Monitoring Sites
MR-0-4-U	Bear Creek, Blaine Spring Creek, North Meadow Creek, West Fork Madison River	BEAR 09-03, BEAR 10-01, BLNS 06-01, NMDW 17-01, WFMA 26-01
MR-2-1-U	Buford Creek	BFRD 07-01
MR-2-2-U	Antelope Creek, Elk River, Red Canyon Creek	ALTP 04-02, ELKR 04-01, RCYN 08-01, RCYN 09-02
MR-2-3-C	Ruby Creek	RUBY 17-01
MR-2-3-U	Blaine Spring Creek, Elk Creek, Elk River, Indian Creek, North Meadow Creek, Ruby Creek, South Meadow Creek, Watkins Creek, Wigwam Creek	BLNS 04-01, ELKC 06-02, ELKR 18-01, INDN 23-01 NMDW 14-02, RUBY 18-02, SMDW 18-01, WATK 12-01, WATK 14-01, WGWM 18-01
MR-2-4-U	Hot Springs Creek	HOTS 16-01
MR-4-1-U	Buford Creek, Hot Springs Creek	BFRD 06-01, HOTS 05-01
MR-4-2-U	Gazelle Creek, Red Canyon Creek, Wigwam Creek	GAZL 16-01, RCYN 07-01, WGWM 08-01
MR-10-2-C	Gazelle Creek	GAZL 09-01

C3.0 SAMPLED REACHES-SEDIMENT LOAD CALCULATIONS

For each eroding streambank, the average annual sediment load was estimated based on the BANCS model, which incorporates the BEHI score and near bank stress (Rosgen, 2001; Rosgen, 2006). Annual retreat rates were estimated based on those measured from the Lamar River in Yellowstone National Park (Rosgen, 2001) (**Table C-4**).

Table C-4. Streambank erosion retreat rates (ft/year) from Lamar River, YNP were applied

BEHI	Near Bank Stress					
	very low	low	moderate	high	very high	extreme
very Low	0.002	0.004	0.009	0.021	0.050	0.12
low	0.02	0.04	0.10	0.24	0.57	1.37
moderate	0.10	0.17	0.28	0.47	0.79	1.33
high - very high	0.37	0.53	0.76	1.09	1.57	2.26
extreme	0.98	1.21	1.49	1.83	2.25	2.76

The annual sediment load in cubic feet was then calculated from the field data (annual retreat rate x mean bank height x bank length), converted into cubic yards, and finally converted into tons per year based on the bulk density of streambank material. The bulk density of streambank material was assumed to average 1.3 tons/cubic yard (USDI 1998). This process resulted in a sediment load from each eroding bank expressed in tons/year. The sum of loading across all banks gave a loading estimate for the site/reach. To standardize across the reaches, the sum of all loading at the site was multiplied by the necessary value to obtain the amount of sediment loading in a 1,000-foot reach. For instance, if only 500 feet were sampled, the value was multiplied by two.

To obtain an estimate of amount of natural bank erosion, at a bank, the total bank erosion was multiplied by the proportion of the surrounding riparian zone without obvious current or historical human impacts. This was summed across the reach to obtain an estimate of natural bank erosion for the reach.

Below are equations used to estimate total bank erosion and natural bank erosion rates:

$$Total\ Bank\ Erosion - Bank\ \left(\frac{Tons}{Yr}\right) = \frac{Length\ Eroding\ Bank\ (ft) * Retreat\left(\frac{ft}{yr}\right) * Bank\ Height\ (ft)}{27\ \frac{cubic\ yards}{cubic\ feet}} * 1.3\frac{Tons}{Cubic\ Yard}$$

$$Natural\ Bank\ Erosion\ \left(\frac{Tons}{Yr}\right) = Total\ Bank\ Erosion\ \left(\frac{Tons}{Yr}\right) * Proportion\ in\ Natural\ Conditions$$

Estimated bank erosion loading rates varied widely from two tons/year/1000 feet to 143 tons/year/1000 feet (**Table C-5**).

Table C-5. Estimated bank erosion loading rates by monitoring site

Stream	Site/Reach ID	Reach Type	Length of Eroding Banks (Feet)	Monitoring Site Length (Feet)	Eroding Bank (% of Reach)	% Natural Erosion	Sediment Load (Tons/Year)	Load per 1000 feet (Tons/Year)
Antelope Creek	ATLP04-02a	MR-2-2-U	883	500	88%	33	26	52
	ATLP10-10a	MR-4-3-C	229	1000	11%	95	17	17
Bear Creek	BEAR09-03a	MR-0-4-U	151	500	15%	8	6	12
	BEAR10-01a	MR-0-4-U	176	500	18%	55	7	14
Buford Creek	BFRD06-01a	MR-4-1-U	64	110	29%	100	3	27
	BFRD07-01a	MR-2-1-U	420	500	42%	88	14	28
Blaine Spring Creek	BLNS04-01a	MR-2-3-U	350	500	35%	62	18	36
	BLNS06-01a	MR-0-4-U	1267	1000	63%	75	68	68
Cherry Creek	CHRR18-02a	MR-0-3-U	1167	1000	58%	48	143	143
	CHRR20-01a	MR-0-3-U	1245	1000	62%	80	56	56
Elk Creek	ELKC 05-01a	MR-0-3-U	742	500	74%	91	32	64
	ELKC 11-01a	MR-0-3-U	481	500	48%	50	36	72
Elk River	ELKR04-01a	MR-2-2-U	251	500	25%	100	20	40
	ELKR18-01a	MR-2-3-U	503	1000	25%	30	17	17
Gazelle Creek	GAZL09-01a	MR-10-2-C	322	400	40%	90	5	13
	GAZL16-01a	MR-4-2-U	267	500	27%	100	3	6

Table C-5. Estimated bank erosion loading rates by monitoring site

Stream	Site/Reach ID	Reach Type	Length of Eroding Banks (Feet)	Monitoring Site Length (Feet)	Eroding Bank (% of Reach)	% Natural Erosion	Sediment Load (Tons/Year)	Load per 1000 feet (Tons/Year)
Hot Springs Creek	HOTS05-01a	MR-4-1-U	238	500	24%	7	3	6
	HOTS10-01a	MR-0-3-U	212	500	21%	52	20	40
	HOTS16-01a	MR-2-4-U	561	1000	28%	43	40	40
Indian Creek	INDN23-01a	MR-2-3-U	233	700	17%	100	9	13
	INDN25-01a	MR-0-3-C	136	1000	7%	37	2	2
Jack Creek	JACK14-03a	MR-0-3-U	1016	1000	51%	14	95	95
	JACK14-06a	MR-0-3-U	935	1000	47%	40	51	51
Moore Creek	MOOR09-01a	MR-0-3-U	531	500	53%	47	21	42
	MOOR09-04a	MR-0-3-U	618	500	62%	60	30	60
North Meadow Creek	NMDW14-02a	MR-2-3-U	1108	800	69%	20	23	29
	NMDW17-01a	MR-0-4-U	480	500	48%	65	21	42
O'Dell Spring Creek	ODEL02-01a	MR-0-2-U	1178	1000	59%	80	24	24
Red Canyon Creek	RCYN07-01a	MR-4-2-U	419	1000	21%	90	23	23
	RCYN08-01a	MR-2-2-U	1097	1000	55%	71	70	70
	RCYN09-02a	MR-2-2-U	599	500	60%	42	39	78
Ruby Creek	RUBY17-01a	MR-2-3-C	869	1000	43%	22	57	57
	RUBY18-02a	MR-2-3-U	613	1000	31%	77	16	16
South Meadow Creek	SMDW18-01a	MR-2-3-U	318	1000	16%	25	18	18
	SMDW19-01a	MR-0-3-U	982	500	98%	20	34	68
Watkins Creek	WATK12-01a	MR-2-3-U	792	1000	40%	30	28	28
	WATK14-01a	MR-2-3-U	304	500	30%	100	9	18
West Fork Madison	WFMA14-02a	MR-0-2-C	195	500	20%	53	33	66
	WFMA25-01a	MR-0-4-C	242	1000	12%	30	34	34

Table C-5. Estimated bank erosion loading rates by monitoring site

Stream	Site/Reach ID	Reach Type	Length of Eroding Banks (Feet)	Monitoring Site Length (Feet)	Eroding Bank (% of Reach)	% Natural Erosion	Sediment Load (Tons/Year)	Load per 1000 feet (Tons/Year)
	WFMA26-01a	MR-0-4-U	805	1000	40%	58	91	91
Wigwam Creek	WGWM08-01a	MR-4-2-C	130	500	13%	10	6	12
	WGWM18-01a	MR-2-3-U	403	1000	20%	54	14	14

Based on the riparian assessment, the biggest cause of bank erosion was natural sources, followed by grazing-related activities, and historic sources (**Table C-6** and **C-7**). Historic sources refer to grazing or other activities that occurred in the past, but the banks are still recovering. At most reaches, road impacts and residential activities were estimated to contribute low amounts of bank erosion (**Table C-7**).

Table C-6. Estimated sediment load from banks by source at sampled reaches

Stream	Reach ID	Reach Type	Reach Sediment Load (Tons/Yr)	Road Load		Grazing Load		Natural Load		Residential %		Other %		Historic %	
				%	Tons/Yr	%	Tons/Yr	%	Tons/Yr	%	Tons/Yr	%	Tons/Yr	%	Tons/Yr
Antelope Creek	ATLP04-02a	MR-2-2-U	25.7	0%	0.0	67%	17.2	33%	8.5	0%	0.0	0%	0.0	0%	0.0
	ATLP10-01a	MR-4-3-C	16.8	0%	0.0	5%	0.9	95%	15.9	0%	0.0	0%	0.0	0%	0.0
Bear Creek	BEAR09-03a	MR-0-4-U	6.1	0%	0.0	92%	5.6	8%	0.5	0%	0.0	0%	0.0	0%	0.0
	BEAR10-01a	MR-0-4-U	7.2	0%	0.0	45%	3.3	55%	4.0	0%	0.0	0%	0.0	0%	0.0
Buford Creek	BFRD06-01a	MR-4-1-U	3.1	0%	0.0	0%	0.0	100 %	3.1	0%	0.0	0%	0.0	0%	0.0
	BFRD07-01a	MR-2-1-U	13.9	0%	0.0	12%	1.7	88%	12.2	0%	0.0	0%	0.0	0%	0.0
Blaine Spring Creek	BLNS04-01a	MR-2-3-U	18.4	0%	0.0	0%	0.0	62%	11.5	0%	0.0	17%	3.1	21%	3.8
	BLNS06-01a	MR-0-4-U	68.0	0%	0.0	25%	17.1	75%	50.9	0%	0.0	0%	0.0	0%	0.0
Cherry Creek	CHRR18-02a	MR-0-3-U	142.5	0%	0.0	0%	0.0	48%	68.7	0%	0.0	0%	0.0	52%	73.8
Cherry Creek	CHRR20-01a	MR-0-3-U	56.0	0%	0.0	0%	0.0	80%	44.8	0%	0.0	0%	0.0	20%	11.2
Elk Creek	ELKC 05-01a	MR-0-3-U	31.5	0%	0.0	9%	2.9	91%	28.6	0%	0.0	0%	0.0	0%	0.0
Elk Creek	ELKC 11-01a	MR-0-3-U	36.4	0%	0.0	0%	0.0	50%	18.2	0%	0.0	0%	0.0	50%	18.2
Elk River	ELKR04-01a	MR-2-2-U	20.2	0%	0.0	0%	0.0	100 %	20.2	0%	0.0	0%	0.0	0%	0.0
Elk River	ELKR18-01a	MR-2-3-U	17.1	0%	0.0	70%	11.9	30%	5.2	0%	0.0	0%	0.0	0%	0.0
Gazelle Creek	GAZL09-01a	MR-10-2-C	5.0	0%	0.0	10%	0.5	90%	4.5	0%	0.0	0%	0.0	0%	0.0
Gazelle Creek	GAZL16-01a	MR-4-2-U	3.4	0%	0.0	0%	0.0	100 %	3.4	0%	0.0	0%	0.0	0%	0.0
Hot Springs Creek	HOTS05-01a	MR-4-1-U	3.2	0%	0.0	93%	3.0	7%	0.2	0%	0.0	0%	0.0	0%	0.0

Table C-6. Estimated sediment load from banks by source at sampled reaches

Stream	Reach ID	Reach Type	Reach Sediment Load (Tons/Yr)	Road Load		Grazing Load		Natural Load		Residential %		Other %		Historic %	
				%	Tons/Yr	%	Tons/Yr	%	Tons/Yr	%	Tons/Yr	%	Tons/Yr	%	Tons/Yr
Hot Springs Creek	HOTS10-01a	MR-0-3-U	20.3	0%	0.0	6%	1.3	52%	10.7	0%	0.0	0%	0.0	41%	8.4
Hot Springs Creek	HOTS16-01a	MR-2-4-U	40.2	48 %	19.3	0%	0.0	43%	17.4	0%	0.0	0%	0.0	9%	3.5
Indian Creek	INDN23-01a	MR-2-3-U	8.6	0%	0.0	0%	0.0	100 %	8.6	0%	0.0	0%	0.0	0%	0.0
Indian Creek	INDN25-01a	MR-0-4-C	2.2	0%	0.0	0%	0.0	37%	0.8	0%	0.0	54%	1.2	9%	0.2
Jack Creek	JACK14-03a	MR-0-3-U	94.6	0%	0.0	0%	0.0	14%	12.8	0%	0.0	35%	33.3	51%	48.5
Jack Creek	JACK14-06a	MR-0-3-U	50.5	19 %	9.5	0%	0.0	40%	20.3	0%	0.0	32%	16.0	0%	0.0
Moore Creek	MOOR09-01a	MR-0-3-U	20.9	0%	0.0	0%	0.0	47%	9.8	0%	0.0	0%	0.0	53%	11.0
Moore Creek	MOOR09-04a	MR-0-3-U	29.7	0%	0.0	40%	11.9	60%	17.8	0%	0.0	0%	0.0	0%	0.0
North Meadow Creek	NMDW14-02a	MR-2-3-U	23.0	0%	0.0	80%	18.4	20%	4.6	0%	0.0	0%	0.0	0%	0.0
North Meadow Creek	NMDW17-01a	MR-0-4-U	21.1	0%	0.0	0%	0.0	65%	13.6	11%	2.3	5%	1.2	19%	4.0
O'Dell Creek	ODEL02-01a	MR-0-2-U	43.8	0%	0.0	0%	0.0	80%	35.1	0%	0.0	20%	8.8	0%	0.0
Red Canyon Creek	RCYN07-01a	MR-4-2-U	22.9	7%	1.6	3%	0.7	90%	20.5	0%	0.0	0%	0.0	0%	0.0
Red Canyon Creek	RCYN08-01a	MR-2-2-U	70.4	22 %	15.4	0%	0.0	71%	50.0	0%	0.0	7%	5.0	0%	0.0
Red Canyon Creek	RCYN09-02a	MR-2-2-U	39.4	0%	0.0	8%	3.0	42%	16.7	0%	0.0	0%	0.0	50%	19.7
Ruby Creek	RUBY17-01a	MR-2-3-C	57.2	0%	0.0	76%	43.5	22%	12.4	0%	0.0	2%	1.2	0%	0.0
Ruby Creek	RUBY18-02a	MR-2-3-U	15.8	0%	0.0	0%	0.0	77%	12.2	0%	0.0	0%	0.0	23%	3.6
South Meadow Creek	SMDW18-01a	MR-2-3-U	17.9	0%	0.0	75%	13.4	25%	4.5	0%	0.0	0%	0.0	0%	0.0

Table C-6. Estimated sediment load from banks by source at sampled reaches

Stream	Reach ID	Reach Type	Reach Sediment Load (Tons/Yr)	Road Load		Grazing Load		Natural Load		Residential %		Other %		Historic %	
				%	Tons/Yr	%	Tons/Yr	%	Tons/Yr	%	Tons/Yr	%	Tons/Yr	%	Tons/Yr
South Meadow Creek	SMDW19-01a	MR-0-3-U	34.0	0%	0.0	80%	27.2	20%	6.8	0%	0.0	0%	0.0	0%	0.0
Watkins Creek	WATK12-01a	MR-2-3-U	28.2	0%	0.0	53%	14.8	30%	8.4	0%	0.0	18%	5.0	0%	0.0
Watkins Creek	WATK14-01a	MR-2-3-U	8.8	0%	0.0	0%	0.0	100 %	8.8	0%	0.0	0%	0.0	0%	0.0
West Fork Madison River	WFMA14-02a	MR-0-2-C	33.4	0%	0.0	47%	15.5	53%	17.9	0%	0.0	0%	0.0	0%	0.0
West Fork Madison River	WFMA25-01a	MR-0-4-C	33.7	21 %	7.0	78%	26.3	1%	0.4	0%	0.0	0%	0.0	0%	0.0
West Fork Madison River	WFMA26-01a	MR-0-4-U	90.5	0%	0.0	0%	0.0	58%	52.8	0%	0.0	0%	0.0	42%	37.7
Wigwam Creek	WGWM08-01a	MR-4-2-C	6.1	0%	0.0	0%	0.0	54%	3.3	0%	0.0	0%	0.0	46%	2.8
Wigwam Creek	WGWM18-01a	MR-2-3-U	14.0	0%	0.0	90%	12.6	10%	1.4	0%	0.0	0%	0.0	0%	0.0

Table C-7. Summary of erosion sources at sampled reaches

Source	Sediment Load (Tons/Year)	Sediment Load (Percent)
Natural	655.1	51.1
Roads	52.9	4.1
Riparian Grazing	252.7	19.7
Other	72.5	5.7
Residential/Urban	2.3	0.2
Historic	246.5	19.2
Total	**1282.1**	**100**

C4.0 SEDIMENT LOAD EXTRAPOLATION

Sediment load extrapolations were performed for monitoring sites, stream reaches, and stream segments, which are defined as follows:

Monitoring Site/Reach *- A 500, 1,000, or 2,000 foot section of a stream reach where field monitoring was conducted (as in Table C-3)*

Stream Reach *-Subdivision of the stream segment based on Ecoregion, stream order, gradient and confinement as evaluated in GIS*

Stream Segment *-A group of stream reaches within the same sub drainage (e.g., "Antelope Creek"). The total loading from each impaired segment was determined by summing the loading for all reaches in the segment. Several non-impaired segments were also evaluated.*

Average annual sediment loads from monitoring reaches were extrapolated to the unsampled stream reaches based on similar reach type characteristics and land use (**Table C-8**). Although a large number of reach types were estimated to be present in the Madison TPA, for extrapolation these were grouped together into broad types that were expected to have similar loading. Gradient, order, and land use characteristics were estimated for field reaches using field surveys, and for unsampled reaches based on aerial photography and Digital Elevation Models according to the aerial assessment procedure.

C4.1 REACH TYPE SEDIMENT LOADS

Based on an exploratory analysis, sampled sites found to have >70% of the riparian zone in natural vegetation based on aerial surveys also had lower loading rates This information was used to estimate average loading in unsampled reaches based on land use information from aerial surveys (**Table C-8**). First order and high gradient streams had the lowest loading estimates. However, fewer sampled reaches were found in these categories and they represented a lower proportion of the total reaches present. Therefore, for these reaches, the average across all sites was used.

Table C-8. Average reach loading rates assigned to unsampled reaches

Description	% of Riparian Zone in Natural Vegetation	Reach ID	Reach Type	Average Reach Type Load Per 1000 Feet (Tons/Year)	Average Reach Type Sediment Load per 1000 Feet (Tons/Year)
Low gradient streams (0-2% gradient), non first-order	≤70%	JACK14-03a	MR-0-3-U	94.6	59.8
		SMDW19-01a	MR-0-3-U	68.0	
		JACK14-06a	MR-0-3-U	50.5	
		MOOR09-01a	MR-0-3-U	41.7	
		CHRR18-02a	MR-0-3-U	142.5	
		ELKC 11-01a	MR-0-3-U	72.8	
		HOTS10-01a	MR-0-3-U	40.7	
		MOOR09-04a	MR-0-3-U	59.3	
		WFMA25-01a	MR-0-4-C	33.7	
		BEAR09-03a	MR-0-4-U	12.3	
		NMDW17-01a	MR-0-4-U	42.3	
		CHRR20-01a	MR-0-3-U	55.9	
		ELKC 05-01a	MR-0-3-U	63.1	
Low gradient streams (0-2% gradient), non first-order	>70%	WFMA14-02a	MR-0-2-C	66.8	43.5
		INDN25-01a	MR-0-4-C	2.2	
		BEAR10-01a	MR-0-4-U	14.4	
		WFMA26-01a	MR-0-4-U	90.5	
		ODEL02-01a	MR-0-2-U	43.8	
		BLNS06-01a	MR-0-4-U	67.9	
		ODEL02-01a	MR-0-2-U	24.3	
Mid gradient streams (2-4% gradient), non first-order	≤ 70%	RCYN09-02a	MR-2-2-U	78.8	38.1
		RCYN08-01a	MR-2-2-U	70.4	
		RUBY17-01a	MR-2-3-C	57.2	
		WGWM18-01a	MR-2-3-U	14.0	
		NMDW14-02a	MR-2-3-U	28.8	
		SMDW18-01a	MR-2-3-U	17.9	
		ELKR18-01a	MR-2-3-U	17.1	
		BLNS04-01a	MR-2-3-U	36.9	
		HOTS16-01a	MR-2-4-U	40.2	
		ELKR04-01a	MR-2-2-U	40.3	
		WATK14-01a	MR-2-3-U	17.6	
Mid gradient streams (2-4% gradient), non first-order	>70%	ATLP04-02a	MR-2-2-U	51.4	27.0
		WATK12-01a	MR-2-3-U	28.2	
		INDN23-01a	MR-2-3-U	12.4	
		RUBY18-02a	MR-2-3-U	15.9	
High gradient streams (4-10%), non first-order	0-100%	GAZL16-01a	MR-4-2-U	6.9	14.0
		RCYN07-01a	MR-4-2-U	22.9	
		WGWM08-01a	MR-4-2-C	12.3	

Table C-8. Average reach loading rates assigned to unsampled reaches

Description	% of Riparian Zone in Natural Vegetation	Reach ID	Reach Type	Average Reach Type Load Per 1000 Feet (Tons/Year)	Average Reach Type Sediment Load per 1000 Feet (Tons/Year)
very high gradient streams (>10%)	0-100%	GAZL09-01a	MR-10-2-C	12.4	12.4
first Order Streams	0-100%	BFRD07-01a	MR-2-1-U	27.8	20.7
		HOTS05-01a	MR-4-1-U	6.4	
		BFRD06-01a	MR-4-1-U	27.8	

C4.2 SEGMENT SEDIMENT LOADS

Stream segment sediment loads were estimated for all Madison River TPA stream segments impaired for sediment per Montana's 2020 Integrated Report, including Antelope Creek, Bear Creek, Blaine Spring Creek, Cherry Creek, Elk Creek, Hot Springs Creek, Moore Creek, North Meadow Creek, Red Canyon Creek, Ruby Creek, South Meadow Creek, Watkins Creek, and Wigwam Creek. It was also completed for stream segments in the following non-listed streams: Elk River, Gazelle Creek, Hot Springs Creek, Indian Creek, Jack Creek, No Man Creek, O'Dell Spring Creek, West Fork Madison River.

Total stream segment loads calculated by summing the cumulative sediment load of all reaches within each segment as illustrated in the following tables.

C4.2.1 Antelope Creek Sediment Loads

A total of 14 reaches were delineated for the Antelope Creek drainage (**Table C-9**). A large number of these were low gradient reaches with a riparian zone with ≤70% in natural vegetation, which were assigned a higher loading rate than streams in > 70% natural vegetation. First order streams also comprised a large number of the stream reaches and were assigned a loading rate of 20.7 tons/yr/1000 ft.

Table C-9. Estimated annual sediment loads for Antelope Creek

Stream	Reach ID	Reach Type	Length (feet)	Strahler Order	Grad-ient Class	% Natural Veg	Load Per 1000 Feet (Tons/Yr/1000 Feet)			Total Load (Tons/Year)
							Extrapolated	Field Assessed	Estimated*	
Antelope Creek	ATLP 05-01	MR-0-2-U	860	2	0	50	59.8	NA	59.8	51.4
Antelope Creek	ATLP 05-02	MR-0-2-U	1005	2	0	50	59.8	NA	59.8	60.1
Antelope Creek	ATLP 09-01	MR-0-3-C	1588	3	0	80	43.5	NA	43.5	69.1
Antelope Creek	ATLP 06-01	MR-0-3-U	11874	3	0	45	59.8	NA	59.8	710.1
Antelope Creek	ATLP 07-01	MR-0-3-U	3862	3	0	30	59.8	NA	59.8	230.9

Table C-9. Estimated annual sediment loads for Antelope Creek

Stream	Reach ID	Reach Type	Length (feet)	Strahler Order	Grad-ient Class	% Natural Veg	Load Per 1000 Feet (Tons/Yr/1000 Feet)			Total Load (Tons/Year)
							Extrapolated	Field Assessed	Estimated*	
Antelope Creek	ATLP 08-01	MR-0-3-U	5451	3	0	30	59.8	NA	59.8	325.9
Antelope Creek	ATLP 02-01	MR-10-1-C	650	1	10	90	20.7	NA	20.7	13.5
Antelope Creek	ATLP 01-01	MR-10-1-U	1837	1	10	90	20.7	NA	20.7	38.0
Antelope Creek	ATLP 01-02	MR-10-1-U	2137	1	10	90	20.7	NA	20.7	44.2
Antelope Creek	ATLP 04-01	MR-2-2-U	2445	2	2	90	27	NA	27.0	66.0
Antelope Creek	ATLP 04-02	MR-2-2-U	3039	2	2	75	27	51.37	51.4	156.1
Antelope Creek	ATLP 04-03	MR-2-2-U	4316	2	2	40	38.1	NA	38.1	164.4
Antelope Creek	ATLP 03-01	MR-4-1-C	4526	1	4	90	20.7	NA	20.7	93.7
Antelope Creek	ATLP 10-01	MR-4-3-C	5467	3	4	90	14	16.81	16.8	91.9
										Total: 2115.4 Tons/Yr

* If reach was sampled, actual field loading value was used; otherwise extrapolated value was used

C4.2.2 Bear Creek Sediment Loads

A total of 18 reaches were delineated for the Bear Creek drainage (**Table C-10**). While several of these were high gradient or first order streams, most were low gradient, higher orders streams with low percentage of the riparian zone in natural vegetation. Thus, they had a high extrapolated sediment loading rate of 59.8 tons/yr/1,000 ft.

Table C-10. Estimated annual sediment loads for Bear Creek

Stream	Reach ID	Reach Type	Length (feet)	Strahler Order	Grad -ient Class	% Natural Veg	Load Per 1000 Feet (Tons/Yr/1000 Feet)			Total Load (Tons/Year)
							Extrapol-ated	Field Assessed	Estimated *	
Bear Creek	BEAR 03-01	MR-4-1-U	747	1	4	80	20.7	NA	20.7	15.5
Bear Creek	BEAR 04-01	MR-4-2-U	964	2	4	70	14	NA	14.0	13.5
Bear Creek	BEAR 05-01	MR-4-3-U	1877	3	4	80	14	NA	14.0	26.3
Bear Creek	BEAR 06-01	MR-2-3-U	1684	3	2	50	38.1	NA	38.1	64.2
Bear Creek	BEAR 07-01	MR-2-3-U	19297	3	2	10	38.1	NA	38.1	735.2
Bear Creek	BEAR 08-01	MR-0-3-U	7990	3	0	30	59.8	NA	59.8	477.8
Bear Creek	BEAR 08-02	MR-0-3-U	3409	3	0	30	59.8	NA	59.8	203.9
Bear Creek	BEAR 08-03	MR-0-3-U	7940	3	0	20	59.8	NA	59.8	474.8
Bear Creek	BEAR 08-04	MR-0-3-U	19877	3	0	20	59.8	NA	59.8	1188.7
Bear Creek	BEAR 08-05	MR-0-3-U	16750	3	0	10	59.8	NA	59.8	1001.6
Bear Creek	BEAR 09-01	MR-0-4-U	5395	4	0	10	59.8	NA	59.8	322.6

Table C-10. Estimated annual sediment loads for Bear Creek

Stream	Reach ID	Reach Type	Length (feet)	Strahler Order	Grad -ient Class	% Natural Veg	Load Per 1000 Feet (Tons/Yr/1000 Feet)			Total Load (Tons/Year)
							Extrapol-ated	Field Assessed	Estimated *	
Bear Creek	BEAR 09-02	MR-0-4-U	12901	4	0	10	59.8	NA	59.8	771.5
Bear Creek	BEAR 09-03	MR-0-4-U	5751	4	0	10	59.8	12.26	12.3	70.5
Bear Creek	BEAR 09-04	MR-0-4-U	9297	4	0	20	59.8	NA	59.8	555.9
Bear Creek	BEAR 10-01	MR-0-4-U	4867	4	0	80	43.5	14.40	14.4	70.1
Bear Creek	BEAR 11-01	MR-0-4-U	5577	4	0	30	59.8	NA	59.8	333.5
Bear Creek	BEAR 11-02	MR-0-4-U	4619	4	0	30	59.8	NA	59.8	276.2
Bear Creek	BEAR 11-03	MR-0-4-U	6497	4	0	70	59.8	NA	59.8	388.5
										Total: 6990.27 Tons/Yr

* If reach was sampled, actual field loading value was used; otherwise extrapolated value was used.

C4.2.3 Buford Creek Sediment Loads

A total of seven reaches were delineated in the Buford Creek drainage (**Table C-11**). Most of these were first order unsampled reaches with an estimated loading rate of 20.7 tons/year/1000 feet.

Table C-11. Estimated sediment loads for Buford Creek

Stream	Reach ID	Reach Type	Length (feet)	Strahler Order	Grad-ient Class	% Natural Veg	Load Per 1000 Feet (Tons/Yr/1000 Feet)			Total Load (Tons/Year)
							Extrapolated	Field Assessed	Estimated *	
Buford Creek	BFRD 02-01	MR-4-1-U	1307	1	4	80	20.7	NA	20.7	27.1
Buford Creek	BFRD 03-01	MR-10-1-U	2974	1	10	80	20.7	NA	20.7	61.6
Buford Creek	BFRD 04-01	MR-4-1-C	1751	1	4	80	20.7	NA	20.7	36.3
Buford Creek	BFRD 05-01	MR-4-1-U	1017	1	4	80	20.7	NA	20.7	21.0
Buford Creek	BFRD 05-02	MR-4-1-U	3214	1	4	80	20.7	NA	20.7	66.5
Buford Creek	BFRD 06-01	MR-4-1-U	7490	1	4	80	20.7	27.82	27.8	208.4
Buford Creek	BFRD 06-02	MR-2-1-U	4327	1	2	50	20.7	6.40	6.4	27.7
										Total: 448.5 Tons/Yr

* If reach was sampled, actual field loading value was used; otherwise extrapolated value was used.

C4.2.4 Blaine Creek Sediment Loads

A total of seven reaches were delineated for Blaine Spring Creek drainage (**Table C-12**). These were primarily low and mid gradient reaches with ≤ 70% natural vegetation and relatively high estimated loading rates.

Table C-12. Estimated sediment loads for Blaine Spring Creek

Stream	Reach ID	Reach Type	Length (feet)	Strahler Order	Grad-ient Class	% Natural Veg	Load Per 1000 Feet (Tons/Yr/1000 Feet)			Total Load (Tons/Year)
							Extrapolated	Field Assessed	Estimated*	
Blaine Spring Creek	BLNS 02-01	MR-4-1-U	5160	1	4	30	20.7	NA	20.7	106.8
Blaine Spring Creek	BLNS 03-01	MR-2-2-U	1266	2	2	40	38.1	NA	38.1	48.2
Blaine Spring Creek	BLNS 03-02	MR-2-2-U	3110	2	2	30	38.1	NA	38.1	118.5
Blaine Spring Creek	BLNS 04-01	MR-2-3-U	7589	3	2	40	38.1	36.87	36.9	279.8
Blaine Spring Creek	BLNS 05-01	MR-2-4-U	1774	4	2	40	38.1	NA	38.1	67.6
Blaine Spring Creek	BLNS 06-01	MR-0-4-U	20829	4	0	70	59.8	67.95	68.0	1415.3
Blaine Spring Creek	BLNS 07-01	MR-0-4-U	7883	4	0	70	59.8	NA	59.8	471.4
										Total: 2507.6 Tons/Yr

* If reach was sampled, actual field loading value was used; otherwise extrapolated value was used.

C4.2.5 Cherry Creek Sediment Loads

A total of 28 reaches were delineated for the Cherry Creek drainage (**Table C-13**). These spanned many reach types and land uses, with many of the first order and high-gradient reaches having a high percentage of the riparian zone in natural vegetation. However, the lower gradient reaches tended to have a low percentage of the riparian zone in natural vegetation and therefore a higher estimated loading rate.

Table C-13. Estimated sediment loads for Cherry Creek

Stream	Reach ID	Reach Type	Length (feet)	Strahler Order	Gradient Class	% Natural Veg	Load Per 1000 Feet (Tons/Yr/1000 Feet)			Total Load (Tons/Year)
							Extrapolated	Field Assessed	Estimated*	
Cherry Creek	CHRR 02-01	MR-4-1-U	2138	1	4	100	20.7	NA	20.7	44.3
Cherry Creek	CHRR 03-01	MR-2-1-U	7611	1	2	100	20.7	NA	20.7	157.6
Cherry Creek	CHRR 04-01	MR-4-1-C	2240	1	4	100	20.7	NA	20.7	46.4
Cherry Creek	CHRR 05-01	MR-10-2-C	2292	2	10	100	12.5	NA	12.5	28.6
Cherry Creek	CHRR 06-01	MR-4-3-U	1372	3	4	75	14	NA	14.0	19.2
Cherry Creek	CHRR 06-02	MR-4-3-U	2223	3	4	30	14	NA	14.0	31.1
Cherry Creek	CHRR 07-01	MR-4-3-C	2803	3	4	30	14	NA	14.0	39.2
Cherry Creek	CHRR 07-02	MR-4-3-C	2388	3	4	100	14	NA	14.0	33.4
Cherry Creek	CHRR 08-01	MR-2-3-C	9295	3	2	100	27	NA	27.0	251.0
Cherry Creek	CHRR 09-01	MR-2-3-U	2265	3	2	80	27	NA	27.0	61.2
Cherry Creek	CHRR 10-01	MR-2-3-U	1975	3	2	70	38.1	NA	38.1	75.3
Cherry Creek	CHRR 10-02	MR-2-3-U	3583	3	2	50	38.1	NA	38.1	136.5
Cherry Creek	CHRR 10-03	MR-2-3-U	1422	3	2	60	38.1	NA	38.1	54.2

Table C-13. Estimated sediment loads for Cherry Creek

Stream	Reach ID	Reach Type	Length (feet)	Strahler Order	Gradient Class	% Natural Veg	Load Per 1000 Feet (Tons/Yr/1000 Feet)			Total Load (Tons/Year)
							Extrapolated	Field Assessed	Estimated*	
Cherry Creek	CHRR 11-01	MR-0-3-U	7748	3	0	50	59.8	NA	59.8	463.3
Cherry Creek	CHRR 11-02	MR-0-3-U	2988	3	0	60	59.8	NA	59.8	178.7
Cherry Creek	CHRR 12-01	MR-0-3-U	694	3	0	50	59.8	NA	59.8	41.5
Cherry Creek	CHRR 13-01	MR-0-3-U	5644	3	0	40	59.8	NA	59.8	337.5
Cherry Creek	CHRR 13-02	MR-0-3-U	2819	3	0	30	59.8	NA	59.8	168.6
Cherry Creek	CHRR 13-03	MR-0-3-U	1441	3	0	40	59.8	NA	59.8	86.2
Cherry Creek	CHRR 14-01	MR-0-3-U	5099	3	0	60	59.8	NA	59.8	304.9
Cherry Creek	CHRR 15-01	MR-4-3-C	1986	3	4	60	14	NA	14.0	27.8
Cherry Creek	CHRR 15-02	MR-4-3-C	9395	3	4	80	14	NA	14.0	131.5
Cherry Creek	CHRR 16-01	MR-10-3-C	2118	3	10	80	12.5	NA	12.5	26.5
Cherry Creek	CHRR 17-01	MR-4-3-U	2330	3	4	60	14	NA	14.0	32.6
Cherry Creek	CHRR 17-02	MR-4-3-U	1663	3	4	80	14	NA	14.0	23.3
Cherry Creek	CHRR 18-01	MR-0-3-U	29334	3	0	60	59.8	142.54	142.5	4181.4
Cherry Creek	CHRR 19-01	MR-0-3-U	1617	3	0	70	59.8	NA	59.8	96.7
Cherry Creek	CHRR 20-01	MR-0-3-U	7206	3	0	40	59.8	55.92	55.9	403.0
										Total: 7481.4 Tons/Year

* If reach was sampled, actual field loading value was used; otherwise extrapolated value was used.

C4.2.6 Elk Creek Sediment Loads

A total of 14 reaches were delineated for the Elk Creek drainage (**Table C-14**). These consisted of a variety or reach types, most with a relatively low percentage (≤70%) of the riparian zone in natural vegetation and a high estimated loading rate from bank erosion.

Table C-14. Estimated sediment loads for Elk Creek

Stream	Reach ID	Reach Type	Length (feet)	Strahler Order	Grad-ient Class	% Natural Veg	Load Per 1000 Feet (Tons/Yr/1000 Feet)			Total Load (Tons/Year)
							Extrapolated	Field Assessed*	Estimated	
Elk Creek	ELKC 02-01	MR-4-2-C	2975	2	4	60	14	NA	14.0	41.6
Elk Creek	ELKC 03-01	MR-4-2-U	6411	2	4	50	14	NA	14.0	89.8
Elk Creek	ELKC 04-01	MR-2-3-U	2589	3	2	55	38.1	NA	38.1	98.7
Elk Creek	ELKC 04-02	MR-2-3-U	2329	3	2	70	38.1	NA	38.1	88.7
Elk Creek	ELKC 05-01	MR-0-3-U	11967	3	0	50	59.8	63.09	63.1	755.1
Elk Creek	ELKC 06-01	MR-2-3-U	4398	3	2	60	38.1	NA	38.1	167.6

Table C-14. Estimated sediment loads for Elk Creek

Stream	Reach ID	Reach Type	Length (feet)	Strahler Order	Grad-ient Class	% Natural Veg	Load Per 1000 Feet (Tons/Yr/1000 Feet)			Total Load (Tons/Year)
							Extrapolated	Field Assessed*	Estimated	
Elk Creek	ELKC 06-02	MR-2-3-U	10198	3	2	70	38.1	NA	38.1	388.6
Elk Creek	ELKC 06-03	MR-2-3-U	2546	3	2	50	38.1	NA	38.1	97.0
Elk Creek	ELKC 07-01	MR-0-3-U	17603	3	0	20	59.8	NA	59.8	1052.7
Elk Creek	ELKC 08-01	MR-0-3-U	1535	3	0	30	59.8	NA	59.8	91.8
Elk Creek	ELKC 09-01	MR-0-3-U	6360	3	0	15	59.8	NA	59.8	380.3
Elk Creek	ELKC 10-01	MR-0-3-U	2167	3	0	40	59.8	NA	59.8	129.6
Elk Creek	ELKC 11-01	MR-0-3-U	14851	3	0	30	59.8	72.75	72.8	1080.4
Elk Creek	ELKC 11-02	MR-0-3-U	6319	3	0	0	59.8	NA	59.8	377.9
										Total: 4839.5 Tons/Yr

* If reach was sampled, actual field loading value was used; otherwise extrapolated value was used.

C4.2.7 Elk River Sediment Loads

A total of three 23 reaches were delineated along the Elk River mainstem (**Table C-15**). Many of these reaches had > 70% of vegetation in natural condition and a low estimated bank erosion loading rate.

Table C-15. Estimated sediment loads for Elk River

Stream	Reach ID	Reach Type	Length (feet)	Strahler Order	Grad-ient Class	% Natural Veg	Load Per 1000 Feet (Tons/Yr/1000 Feet)			Total Load (Tons/Year)
							Extrapolated	Field Assessed	Estimated*	
Elk River	ELKR 02-01	MR-4-1-U	1155	1	4	80	20.7	NA	20.7	23.9
Elk River	ELKR 02-02	MR-4-1-U	1898	1	4	60	20.7	NA	20.7	39.3
Elk River	ELKR 03-01	MR-2-1-U	3664	1	2	70	20.7	NA	20.7	75.9
Elk River	ELKR 04-01	MR-2-2-U	5292	2	2	60	38.1	40.30	40.3	213.3
Elk River	ELKR 05-01	MR-4-2-U	1043	2	4	70	14	NA	14.0	14.6
Elk River	ELKR 05-02	MR-4-2-U	1579	2	4	70	14	NA	14.0	22.1
Elk River	ELKR 06-01	MR-10-2-C	731	2	10	70	12.5	NA	12.5	9.1
Elk River	ELKR 07-01	MR-10-2-C	1136	2	10	70	12.5	NA	12.5	14.2
Elk River	ELKR 08-01	MR-4-2-U	1226	2	4	70	14	NA	14.0	17.2
Elk River	ELKR 09-01	MR-4-2-C	4627	2	4	80	14	NA	14.0	64.8
Elk River	ELKR 10-01	MR-2-2-C	2306	2	2	80	27	NA	27.0	62.3
Elk River	ELKR 10-02	MR-2-2-C	1503	2	2	80	27	NA	27.0	40.6
Elk River	ELKR 11-01	MR-0-2-U	4198	2	0	80	43.5	NA	43.5	182.6

Table C-15. Estimated sediment loads for Elk River

Stream	Reach ID	Reach Type	Length (feet)	Strahler Order	Grad-ient Class	% Natural Veg	Load Per 1000 Feet (Tons/Yr/1000 Feet)			Total Load (Tons/Year)
							Extrapolated	Field Assessed	Estimated*	
Elk River	ELKR 11-02	MR-0-2-U	3778	2	0	90	43.5	NA	43.5	164.3
Elk River	ELKR 12-01	MR-2-2-C	3406	2	2	90	27	NA	27.0	92.0
Elk River	ELKR 13-01	MR-4-2-C	4139	2	4	90	14	NA	14.0	57.9
Elk River	ELKR 14-01	MR-2-2-U	4079	2	2	90	27	NA	27.0	110.1
Elk River	ELKR 15-01	MR-2-3-U	3143	3	2	90	27	NA	27.0	84.9
Elk River	ELKR 16-01	MR-2-3-U	9612	3	2	90	27	NA	27.0	259.5
Elk River	ELKR 16-02	MR-2-3-U	8354	3	2	80	27	NA	27.0	225.6
Elk River	ELKR 17-01	MR-2-3-U	6291	3	2	80	27	NA	27.0	169.8
Elk River	ELKR 17-02	MR-2-3-U	4423	3	2	60	38.1	NA	38.1	168.5
Elk River	ELKR 18-01	MR-2-3-U	2706	3	2	40	38.1	17.10	17.1	46.3
* If reach was sampled, actual field loading value was used; otherwise extrapolated value was used.										**Total: 2158.8 Tons/Yr**

C4.2.8 Gazelle Creek Sediment Loads

A total of 15 reaches were sampled in the Gazelle Creek drainage (**Table C-16**). These were comprised primarily of higher gradient and first order streams with > 70% of the riparian zone in natural condition. The mid-gradient streams present in the drainage had low estimated loading from bank erosion, also due to the riparian zone being in > 70% natural vegetation.

Table C-16. Estimated sediment loads for Gazelle Creek

Stream	Reach ID	Reach Type	Length (feet)	Strahler Order	Grad-ient Class	% Natural Veg	Load Per 1000 Feet (Tons/Yr/1000 Feet)			Total Load (Tons/Year)
							Extrapolated	Field Assessed	Estimated *	
Gazelle Creek	GAZL 02-01	MR-4-1-C	2568	1	4	90	20.7	NA	20.7	53.2
Gazelle Creek	GAZL 03-01	MR-4-2-C	2154	2	4	90	14	NA	14.0	30.2
Gazelle Creek	GAZL 04-01	MR-4-2-U	7008	2	4	90	14	NA	14.0	98.1
Gazelle Creek	GAZL 05-01	MR-10-2-C	841	2	10	90	12.5	NA	12.5	10.5
Gazelle Creek	GAZL 06-01	MR-4-2-U	3362	2	4	90	14	NA	14.0	47.1
Gazelle Creek	GAZL 07-01	MR-2-2-C	3002	2	2	90	21.6	NA	21.6	64.8
Gazelle Creek	GAZL 08-01	MR-4-2-U	3540	2	4	90	14	NA	14.0	49.6
Gazelle Creek	GAZL 09-01	MR-10-2-C	1458	2	10	90	12.5	12.52	12.5	18.3
Gazelle Creek	GAZL 10-01	MR-4-2-U	1636	2	4	90	14	NA	14.0	22.9

Table C-16. Estimated sediment loads for Gazelle Creek

Stream	Reach ID	Reach Type	Length (feet)	Strahler Order	Grad-ient Class	% Natural Veg	Load Per 1000 Feet (Tons/Yr/1000 Feet)			Total Load (Tons/Year)
							Extrapolated	Field Assessed	Estimated *	
Gazelle Creek	GAZL 11-01	MR-2-2-U	3450	2	2	90	21.6	NA	21.6	74.5
Gazelle Creek	GAZL 12-01	MR-10-2-U	1271	2	10	90	12.5	NA	12.5	15.9
Gazelle Creek	GAZL 13-01	MR-4-2-U	1453	2	4	90	14	NA	14.0	20.3
Gazelle Creek	GAZL 14-01	MR-2-2-C	2666	2	2	90	21.6	NA	21.6	57.6
Gazelle Creek	GAZL 15-01	MR-4-2-C	3426	2	4	90	14	NA	14.0	48.0
Gazelle Creek	GAZL 16-01	MR-4-2-U	2731	2	4	90	14	6.88	6.9	18.8
										Total: 678.9 tons/year

* If reach was sampled, actual field loading value was used; otherwise extrapolated value was used.

C4.2.9 Hot Springs Creek Sediment Loads

A total of 20 reaches were delineated in the Hot Spring Creek drainage (**Table C-17**). The first order streams had a high percentage of the riparian zone in natural conditions. However, the more prevalent low-gradient stream reaches typically had 0 percent of the riparian zone in natural conditions resulting in a high estimated amount of loading from bank erosion.

Table C-17. Estimated sediment loads for Hot Springs Creek

Stream	Reach ID	Reach Type	Length (feet)	Strahler Order	Grad-ient Class	% Natural Veg	Load Per 1000 Feet (Tons/Yr/1000 Feet)			Total Load (Tons/Year)
							Extrapolated	Field Assessed	Estimated*	
Mid Frk Hot Springs Creek	HOTS 02-01	MR-10-1-C	4473	1	10	90	20.7	NA	20.7	92.6
Mid Frk Hot Springs Creek	HOTS 02-02	MR-10-1-C	1332	1	10	90	20.7	NA	20.7	27.6
Mid Frk Hot Springs Creek	HOTS 03-01	MR-4-1-C	6223	1	4	80	20.7	NA	20.7	128.8
Mid Frk Hot Springs Creek	HOTS 04-01	MR-4-1-U	1813	1	4	40	20.7	NA	20.7	37.5
Mid Frk Hot Springs Creek	HOTS 05-01	MR-4-1-U	2489	1	4	80	20.7	6.40	6.4	15.9
Hot Springs Creek	HOTS 06-01	MR-4-2-C	1742	2	4	90	14	NA	14.0	24.4
Hot Springs Creek	HOTS 07-01	MR-2-2-C	3832	2	2	90	27	NA	27.0	103.5
Hot Springs Creek	HOTS 08-01	MR-2-3-C	4208	3	2	90	27	NA	27.0	113.6
Hot Springs Creek	HOTS 08-02	MR-2-3-C	4728	3	2	60	38.1	NA	38.1	180.1
Hot Springs Creek	HOTS 09-01	MR-0-3-U	4034	3	0	80	43.5	NA	43.5	175.5
Hot Springs Creek	HOTS 10-01	MR-0-3-U	11469	3	0	50	59.8	40.66	40.7	466.4

Table C-17. Estimated sediment loads for Hot Springs Creek

Stream	Reach ID	Reach Type	Length (feet)	Strahler Order	Grad-ient Class	% Natural Veg	Load Per 1000 Feet (Tons/Yr/1000 Feet)			Total Load (Tons/Year)
							Extrapolated	Field Assessed	Estimated*	
Hot Springs Creek	HOTS 10-02	MR-0-3-U	1756	3	0	0	59.8	NA	59.8	105.0
Hot Springs Creek	HOTS 11-01	MR-0-3-U	2011	3	0	0	59.8	NA	59.8	120.2
Hot Springs Creek	HOTS 12-01	MR-0-3-U	2381	3	0	0	59.8	NA	59.8	142.4
Hot Springs Creek	HOTS 13-01	MR-0-4-U	4575	4	0	10	59.8	NA	59.8	273.6
Hot Springs Creek	HOTS 13-02	MR-0-4-U	3085	4	0	0	59.8	NA	59.8	184.5
Hot Springs Creek	HOTS 14-01	MR-0-4-U	5228	4	0	0	59.8	NA	59.8	312.6
Hot Springs Creek	HOTS 15-01	MR-0-4-U	6748	4	0	0	59.8	NA	59.8	403.5
Hot Springs Creek	HOTS 15-02	MR-0-4-U	13061	4	0	0	59.8	NA	59.8	781.1
Hot Springs Creek	HOTS 16-01	MR-2-4-U	4860	4	2	0	38.1	40.23	40.2	195.5
										Total: 3884.3 Tons/Yr

* If reach was sampled, actual field loading value was used; otherwise extrapolated value was used.

C4.2.10 Indian Creek Sediment Loads

A total of 29 reaches were delineated in the Indian Creek drainage (**Table C-18**), spanning a wide range of reach types and levels of riparian health. In general, estimated bank loading rates were relatively low due to the large percentage of reaches having riparian zone vegetation estimated to be in > 70% natural conditions.

Table C-18. Estimated sediment loads in Indian Creek

Stream	Reach ID	Reach Type	Length (feet)	Strahler Order	Grad-ient Class	% Natural Veg	Load Per 1000 Feet (Tons/Yr/1000 Feet)			Total Load (Tons/Year)
							Extrapolated	Field Assessed	Estimated*	
Indian Creek	INDN 02-01	MR-4-1-U	1644	1	4	0	20.7	NA	20.7	34.0
Indian Creek	INDN 03-01	MR-4-1-C	386	1	4	0	20.7	NA	20.7	8.0
Indian Creek	INDN 04-01	MR-4-1-U	1068	1	4	60	20.7	NA	20.7	22.1
Indian Creek	INDN 05-01	MR-4-1-C	1531	1	4	50	20.7	NA	20.7	31.7
Indian Creek	INDN 06-01	MR-4-1-U	784	1	4	40	20.7	NA	20.7	16.2
Indian Creek	INDN 07-01	MR-4-2-U	439	2	4	40	14	NA	14.0	6.1
Indian Creek	INDN 08-01	MR-4-2-C	1300	2	4	100	14	NA	14.0	18.2
Indian Creek	INDN 09-01	MR-2-2-C	1660	2	2	100	21.6	NA	21.6	35.8
Indian Creek	INDN 10-01	MR-2-2-U	1556	2	2	100	21.6	NA	21.6	33.6
Indian Creek	INDN 10-02	MR-2-2-U	3160	2	2	100	21.6	NA	21.6	68.3
Indian Creek	INDN 10-03	MR-2-2-U	858	2	2	100	21.6	NA	21.6	18.5

Table C-18. Estimated sediment loads in Indian Creek

Stream	Reach ID	Reach Type	Length (feet)	Strahler Order	Grad-ient Class	% Natural Veg	Load Per 1000 Feet (Tons/Yr/1000 Feet)			Total Load (Tons/Year)
							Extrapolated	Field Assessed	Estimated*	
Indian Creek	INDN 11-01	MR-4-2-U	3279	2	4	100	14	NA	14.0	45.9
Indian Creek	INDN 12-01	MR-2-2-U	3458	2	2	100	21.6	NA	21.6	74.7
Indian Creek	INDN 13-01	MR-4-3-U	872	3	4	100	20.7	NA	20.7	34.0
Indian Creek	INDN 14-01	MR-4-3-C	1678	3	4	100	20.7	NA	20.7	8.0
Indian Creek	INDN 15-01	MR-2-3-C	9699	3	2	100	20.7	NA	20.7	22.1
Indian Creek	INDN 16-01	MR-4-3-C	3417	3	4	100	20.7	NA	20.7	31.7
Indian Creek	INDN 16-02	MR-4-3-C	1880	3	4	100	20.7	NA	20.7	16.2
Indian Creek	INDN 17-01	MR-10-3-C	2548	3	10	100	14	NA	14.0	6.1
Indian Creek	INDN 18-01	MR-2-3-U	8749	3	2	100	14	NA	14.0	18.2
Indian Creek	INDN 19-01	MR-2-3-C	3646	3	2	100	27	NA	27.0	44.8
Indian Creek	INDN 20-01	MR-4-3-C	2550	3	4	100	27	NA	27.0	42.0
Indian Creek	INDN 21-01	MR-2-3-C	4532	3	2	100	27	NA	27.0	85.3
Indian Creek	INDN 22-01	MR-2-3-C	1805	3	2	80	27	NA	27.0	23.2
Indian Creek	INDN 23-01	MR-2-3-U	5822	3	2	80	14	NA	14.0	45.9
Indian Creek	INDN 24-01	MR-2-3-C	17858	3	2	20	27	NA	27.0	93.4
Indian Creek	INDN 25-01	MR-0-3-C	3010	3	0	20	14	NA	14.0	12.2
Indian Creek	INDN 26-01	MR-0-3-U	1497	3	0	20	14	NA	14.0	23.5
Indian Creek	INDN 26-02	MR-0-3-U	2451	3	0	20	27	NA	27.0	261.9
										Total: 2410.5 Tons/Yr

* If reach was sampled, actual field loading value was used; otherwise extrapolated value was used.

C4.2.11 Jack Creek Sediment Loads

A total of 24 reaches were delineated in Jack Creek drainage. These spanned the entire range of reach types and amount of natural vegetation. However, most reaches had ≤ 70% of the riparian zone in natural vegetation and had high estimated loading from stream banks (**Table C-19**). Field surveys and aerial photography indicated a large amount of the bank erosion may be from historical sources, such as past grazing.

Table C-19. Estimated sediment loads in Jack Creek

Stream	Reach ID	Reach Type	Length (feet)	Strahler Order	Grad-ient Class	% Natural Veg	Load Per 1000 Feet (Tons/Yr/1000 Feet)			Total Load (Tons/Year)
							Extrapolated	Field Assessed	Estimated*	
Jack Creek	JACK 02-01	MR-2-3-C	3222	3	2	100	21.6	NA	21.6	69.6
Jack Creek	JACK 03-01	MR-4-3-C	2554	3	4	100	14	NA	14.0	35.7
Jack Creek	JACK 04-01	MR-2-3-C	1101	3	2	20	27	NA	27.0	87.0
Jack Creek	JACK 05-01	MR-2-3-U	657	3	2	10	14	NA	14.0	35.7
Jack Creek	JACK 05-02	MR-2-3-U	1784	3	2	0	38.1	NA	38.1	41.9
Jack Creek	JACK 06-01	MR-0-3-U	3708	3	0	0	38.1	NA	38.1	25.0
Jack Creek	JACK 06-02	MR-0-3-U	509	3	0	0	38.1	NA	38.1	68.0
Jack Creek	JACK 07-01	MR-2-3-C	7596	3	2	100	59.8	NA	59.8	221.8
Jack Creek	JACK 08-01	MR-4-3-C	4657	3	4	100	59.8	NA	59.8	30.4
Jack Creek	JACK 09-01	MR-2-3-U	1447	3	2	100	27	NA	27.0	205.1
Jack Creek	JACK 10-01	MR-2-3-U	4734	3	2	30	14	NA	14.0	65.2
Jack Creek	JACK 11-01	MR-2-3-U	1098	3	2	20	27	NA	27.0	39.1
Jack Creek	JACK 11-02	MR-2-3-U	1727	3	2	10	38.1	NA	38.1	180.4
Jack Creek	JACK 11-03	MR-2-3-U	2022	3	2	10	38.1	NA	38.1	41.8
Jack Creek	JACK 12-01	MR-2-3-C	7004	3	2	20	38.1	NA	38.1	65.8
Jack Creek	JACK 13-01	MR-2-3-U	5576	3	2	40	38.1	NA	38.1	77.0
Jack Creek	JACK 13-02	MR-2-3-U	6246	3	2	40	38.1	NA	38.1	266.9
Jack Creek	JACK 14-01	MR-0-3-U	4477	3	0	30	38.1	NA	38.1	212.4
Jack Creek	JACK 14-02	MR-0-3-U	2053	3	0	0	38.1	NA	38.1	238.0
Jack Creek	JACK 14-03	MR-0-3-U	2651	3	0	10	59.8	NA	59.8	267.7
Jack Creek	JACK 14-04	MR-0-3-U	2461	3	0	0	59.8	NA	59.8	122.8
Jack Creek	JACK 14-05	MR-0-3-U	3126	3	0	0	59.8	94.55	94.6	250.6
Jack Creek	JACK 14-06	MR-0-3-U	6809	3	0	40	59.8	NA	59.8	147.2
Jack Creek	JACK 14-07	MR-0-3-U	4243	3	0	0	59.8	NA	59.8	186.9
										Total: 3474.5 Tons/Yr

* If reach was sampled, actual field loading value was used; otherwise extrapolated value was used.

C4.2.12 Moore Creek Sediment Loads

A total of 13 reaches were delineated in Moore Creek (Table C-20). These spanned a range of stream types but generally had high estimated loading from bank erosion due to a large amount of low and mid gradient reaches, and a low percentage of natural vegetation present in the riparian zone.

Table C-20. Estimated sediment loads in Moore Creek

Stream	Reach ID	Reach Type	Length (feet)	Strahler Order	Grad-ient Class	% Natural Veg	Load Per 1000 Feet (Tons/Yr/1000 Feet)			Total Load (Tons/Year)
							Extrapolated	Field Assessed	Estimated*	
Moore Creek	MOOR 01-02	MR-10-1-U	1377	1	10	100	20.7	NA	20.7	28.5
Moore Creek	MOOR 02-01	MR-4-1-C	3496	1	4	20	20.7	NA	20.7	72.4
Moore Creek	MOOR 03-01	MR-4-1-C	13631	1	4	10	20.7	NA	20.7	282.2
Moore Creek	MOOR 04-01	MR-2-1-U	2602	1	2	80	20.7	NA	20.7	53.9
Moore Creek	MOOR 05-01	MR-2-2-C	4019	2	2	60	38.1	NA	38.1	153.1
Moore Creek	MOOR 06-01	MR-2-2-U	4734	2	2	30	38.1	NA	38.1	180.4
Moore Creek	MOOR 07-01	MR-2-3-U	4303	3	2	20	38.1	NA	38.1	163.9
Moore Creek	MOOR 07-02	MR-2-3-U	3032	3	2	20	38.1	NA	38.1	115.5
Moore Creek	MOOR 08-01	MR-2-3-C	2844	3	2	30	38.1	NA	38.1	108.3
Moore Creek	MOOR 09-01	MR-0-3-U	8420	3	0	10	59.8	41.71	41.7	351.2
Moore Creek	MOOR 09-02	MR-0-3-U	6884	3	0	10	59.8	NA	59.8	411.7
Moore Creek	MOOR 09-03	MR-0-3-U	7980	3	0	0	59.8	NA	59.8	477.2
Moore Creek	MOOR 09-04	MR-0-3-U	18947	3	0	0	59.8	59.34	59.3	1124.3
										Total: 3522.5 Tons/Yr

* If reach was sampled, actual field loading value was used; otherwise extrapolated value was used.

C4.2.13 North Meadow Creek Sediment Loads

A total of 28 stream reaches were delineated in North Meadow Creek drainage (**Table C-21**). Whereas the first order streams had mostly natural vegetation in the riparian zone, the lower gradient reaches exhibited very little riparian vegetation in natural conditions, resulting in high estimated loading rates from bank erosion.

Table C-21. Estimated sediment loads in North Meadow Creek

Stream	Reach ID	Reach Type	Length (feet)	Strahler Order	Grad-ient Class	% Natural Veg	Load Per 1000 Feet (Tons/Yr/1000 Feet)			Total Load (Tons/Year)
							Extrapolated	Field Assessed	Estimated*	
N Meadow Creek	NMDW 01-02	MR-10-1-U	736	1	10	100	20.7	NA	20.7	15.2
N Meadow Creek	NMDW 02-01	MR-4-1-U	3061	1	4	100	20.7	NA	20.7	63.4
N Meadow Creek	NMDW 02-02	MR-4-1-U	3390	1	4	100	20.7	NA	20.7	70.2
N Meadow Creek	NMDW 03-01	MR-10-1-U	2179	1	10	80	20.7	NA	20.7	45.1

Table C-21. Estimated sediment loads in North Meadow Creek

Stream	Reach ID	Reach Type	Length (feet)	Strahler Order	Grad-ient Class	% Natural Veg	Load Per 1000 Feet (Tons/Yr/1000 Feet)			Total Load (Tons/Year)
							Extrapolated	Field Assessed	Estimated*	
N Meadow Creek	NMDW 04-01	MR-2-1-U	1701	1	2	90	20.7	NA	20.7	35.2
N Meadow Creek	NMDW 04-02	MR-2-1-U	272	1	2	100	20.7	NA	20.7	5.6
N Meadow Creek	NMDW 04-03	MR-2-1-U	673	1	2	50	20.7	NA	20.7	13.9
N Meadow Creek	NMDW 04-04	MR-2-1-U	742	1	2	60	20.7	NA	20.7	15.4
N Meadow Creek	NMDW 05-01	MR-4-1-U	2035	1	4	10	20.7	NA	20.7	42.1
N Meadow Creek	NMDW 06-01	MR-4-2-U	6097	2	4	10	14	NA	14.0	85.4
N Meadow Creek	NMDW 06-02	MR-4-2-U	2985	2	4	10	14	NA	14.0	41.8
N Meadow Creek	NMDW 07-01	MR-2-2-U	1100	2	2	20	38.1	NA	38.1	41.9
N Meadow Creek	NMDW 07-02	MR-2-2-U	692	2	2	20	38.1	NA	38.1	26.3
N Meadow Creek	NMDW 07-03	MR-2-2-U	1440	2	2	20	38.1	NA	38.1	54.9
N Meadow Creek	NMDW 08-01	MR-4-3-U	1774	3	4	0	14	NA	14.0	24.8
N Meadow Creek	NMDW 08-02	MR-4-3-U	2104	3	4	0	14	NA	14.0	29.5
N Meadow Creek	NMDW 08-03	MR-4-3-U	1193	3	4	20	14	NA	14.0	16.7
N Meadow Creek	NMDW 09-01	MR-2-3-U	1030	3	2	20	38.1	NA	38.1	39.3
N Meadow Creek	NMDW 09-02	MR-2-3-U	1771	3	2	30	38.1	NA	38.1	67.5
N Meadow Creek	NMDW 10-01	MR-4-3-U	3203	3	4	20	14	NA	14.0	44.8
N Meadow Creek	NMDW 11-01	MR-10-3-U	1720	3	10	50	12.5	NA	12.5	21.5
N Meadow Creek	NMDW 12-01	MR-4-3-U	1372	3	4	50	14	NA	14.0	19.2
N Meadow Creek	NMDW 13-01	MR-2-3-U	4862	3	2	30	38.1	NA	38.1	185.3

Table C-21. Estimated sediment loads in North Meadow Creek

Stream	Reach ID	Reach Type	Length (feet)	Strahler Order	Grad-ient Class	% Natural Veg	Load Per 1000 Feet (Tons/Yr/1000 Feet)			Total Load (Tons/Year)
							Extrapolated	Field Assessed	Estimated*	
N Meadow Creek	NMDW 14-01	MR-2-3-U	11842	3	2	80	27	NA	27.0	319.7
N Meadow Creek	NMDW 14-02	MR-2-3-U	5572	3	2	20	38.1	28.79	28.8	160.4
N Meadow Creek	NMDW 15-01	MR-0-3-U	8100	3	0	30	59.8	NA	59.8	484.4
N Meadow Creek	NMDW 16-01	MR-0-3-U	14900	3	0	0	59.8	NA	59.8	891.0
N Meadow Creek	NMDW 17-01	MR-0-4-U	9861	4	0	0	59.8	42.28	42.3	416.9
										Total: 3277.4 Tons/Yr

* If reach was sampled, actual field loading value was used; otherwise extrapolated value was used.

C4.2.14 No Man Creek Sediment Loads

A total of 15 stream reaches were delineated in No Man Creek drainage (**Table C-22**). This drainage was comprised largely of first order and high gradient stream reaches, which were estimated to have low estimated bank erosion.

Table C-22. Estimated sediment loads in No Man Creek

Stream	Reach ID	Reach Type	Length (feet)	Strahler Order	Grad-ient Class	% Natural Veg	Load Per 1000 Feet (Tons/Yr/1000 Feet)			Total Load (Tons/Year)
							Extrapolated	Field Assessed	Estimated*	
No Man Creek	NOMN 02-01	MR-10-1-C	2027	1	10	100	20.7	NA	20.7	42.0
No Man Creek	NOMN 03-01	MR-10-1-U	1719	1	10	100	20.7	NA	20.7	35.6
No Man Creek	NOMN 04-01	MR-4-1-U	1229	1	4	100	20.7	NA	20.7	25.4
No Man Creek	NOMN 05-01	MR-4-1-U	419	1	4	100	20.7	NA	20.7	8.7
No Man Creek	NOMN 05-02	MR-4-1-U	617	1	4	100	20.7	NA	20.7	12.8
No Man Creek	NOMN 06-01	MR-10-1-C	2438	1	10	100	20.7	NA	20.7	50.5
No Man Creek	NOMN 07-01	MR-10-1-U	2815	1	10	100	20.7	NA	20.7	58.3
No Man Creek	NOMN 08-01	MR-10-2-U	1576	2	10	100	12.5	NA	12.5	19.7
No Man Creek	NOMN 09-01	MR-4-2-C	3328	2	4	100	14	NA	14.0	46.6
No Man Creek	NOMN 10-01	MR-4-2-U	4857	2	4	100	14	NA	14.0	68.0
No Man Creek	NOMN 11-01	MR-10-2-C	7599	2	10	100	12.5	NA	12.5	95.0
No Man Creek	NOMN 12-01	MR-4-2-U	678	2	4	100	14	NA	14.0	9.5
No Man Creek	NOMN 13-01	MR-4-2-U	1013	2	4	100	14	NA	14.0	14.2

Table C-22. Estimated sediment loads in No Man Creek

Stream	Reach ID	Reach Type	Length (feet)	Strahler Order	Grad-ient Class	% Natural Veg	Load Per 1000 Feet (Tons/Yr/1000 Feet)			Total Load (Tons/Year)
							Extrapolated	Field Assessed	Estimated*	
No Man Creek	NOMN 14-01	MR-4-2-C	872	2	4	100	14	NA	14.0	12.2
No Man Creek	NOMN 15-01	MR-4-2-U	1077	2	4	90	14	NA	14.0	15.1
* If reach was sampled, actual field loading value was used; otherwise extrapolated value was used.										**513.4 Tons/Yr**

C4.2.15 O'Dell Spring Creek Sediment Loads

A total of 8 reaches were delineated in O'Dell Spring Creek drainage (**Table C-23**). The riparian zone in this drainage was generally > 70% in natural conditions, which resulted in low stream bank erosion estimates for the primarily low-gradient stream reaches present.

Table C-23. Estimated sediment loads in O'Dell Spring Creek

Stream	Reach ID	Reach Type	Length (feet)	Strahler Order	Grad-ient Class	% Natural Veg	Load Per 1000 Feet (Tons/Yr/1000 Feet)			Total Load (Tons/Year)
							Extrapolated	Field Assessed	Estimated*	
O'Dell Spring Creek	ODEL 02-01	MR-0-2-U	5540	2	0	70	59.8	24.30	24.3	134.6
O'Dell Spring Creek	ODEL 03-01	MR-0-3-U	2459	3	0	80	43.5	NA	43.5	106.9
O'Dell Spring Creek	ODEL 03-02	MR-0-3-U	11235	3	0	80	43.5	NA	43.5	488.7
O'Dell Spring Creek	ODEL 03-03	MR-0-3-U	11238	3	0	80	43.5	NA	43.5	488.9
O'Dell Spring Creek	ODEL 03-04	MR-0-3-U	7742	3	0	60	59.8	NA	59.8	463.0
O'Dell Spring Creek	ODEL 04-01	MR-0-4-U	3219	4	0	70	59.8	NA	59.8	192.5
O'Dell Spring Creek	ODEL 04-02	MR-0-4-U	3769	4	0	40	59.8	NA	59.8	225.4
O'Dell Spring Creek	ODEL 04-03	MR-0-4-U	8865	4	0	40	59.8	NA	59.8	530.1
* If reach was sampled, actual field loading value was used; otherwise extrapolated value was used.										**Total: 2630.1 Tons/Yr**

C4.2.16 Red Canyon Sediment Loads

A total of 10 reaches were delineated in Red Canyon Creek drainage which varied in riparian condition. The first order reaches had an estimate 100 percentage of the banks in natural vegetation, but the mid-gradient reaches had only 0-40% of the riparian zone in natural vegetation conditions. Bank loading estimates were high for these mid-gradient reaches (**Table C-24**).

Table C-24. Estimated sediment loads in Red Canyon Creek

Stream	Reach ID	Reach Type	Length (feet)	Strahler Order	Grad-ient Class	% Natural Veg	Load Per 1000 Feet (Tons/Yr/1000 Feet)			Total Load (Tons/Year)
							Extrapolated	Field Assessed	Estimated *	
Red Canyon Creek	RCYN 02-01	MR-10-1-U	3154	1	10	100	20.7	NA	20.7	65.3
Red Canyon Creek	RCYN 03-01	MR-4-1-U	2628	1	4	100	20.7	NA	20.7	54.4

Table C-24. Estimated sediment loads in Red Canyon Creek

Stream	Reach ID	Reach Type	Length (feet)	Strahler Order	Grad-ient Class	% Natural Veg	Load Per 1000 Feet (Tons/Yr/1000 Feet)			Total Load (Tons/Year)
							Extrapolated	Field Assessed	Estimated *	
Red Canyon Creek	RCYN 04-01	MR-4-1-C	1962	1	4	100	20.7	NA	20.7	40.6
Red Canyon Creek	RCYN 05-01	MR-10-1-C	567	1	10	100	20.7	NA	20.7	11.7
Red Canyon Creek	RCYN 06-01	MR-10-2-C	883	2	10	100	12.5	NA	12.5	11.0
Red Canyon Creek	RCYN 07-01	MR-4-2-U	8281	2	4	40	14	22.87	22.9	189.4
Red Canyon Creek	RCYN 08-01	MR-2-2-U	1894	2	2	40	38.1	70.40	70.4	133.3
Red Canyon Creek	RCYN 08-02	MR-2-2-U	1868	2	2	40	38.1	NA	38.1	71.2
Red Canyon Creek	RCYN 09-01	MR-2-2-U	8475	2	2	0	38.1	NA	38.1	322.9
Red Canyon Creek	RCYN 09-02	MR-2-2-U	1799	2	2	0	38.1	78.81	78.8	141.8
* If reach was sampled, actual field loading value was used; otherwise extrapolated value was used.										**1040.7 Tons/Yr**

C4.2.17 Ruby Creek Sediment Loads

A total of 19 reaches were delineated in Ruby Creek drainage (**Table C-25**). Many of these had a large percentage of the riparian zone in natural condition. The exception was some of the mid-gradient reaches near the mouth, which had a much poorer riparian condition and higher amounts of estimated loading from bank erosion.

Table C-25. Estimated sediment loads in Ruby Creek

Stream	Reach ID	Reach Type	Length (feet)	Strahler Order	Grad-ient Class	% Natural Veg	Load Per 1000 Feet (Tons/Yr/1000 Feet)			Total Load (Tons/Year)
							Extrapolated	Field Assessed	Estimated *	
Ruby Creek	RUBY 02-01	MR-4-1-C	4338	1	4	100	20.7	NA	20.7	89.8
Ruby Creek	RUBY 03-01	MR-4-1-C	815	1	4	80	20.7	NA	20.7	16.9
Ruby Creek	RUBY 04-01	MR-10-1-C	2201	1	10	90	20.7	NA	20.7	45.6
Ruby Creek	RUBY 05-01	MR-4-1-C	1993	1	4	90	20.7	NA	20.7	41.3
Ruby Creek	RUBY 06-01	MR-10-1-C	4359	1	10	100	20.7	NA	20.7	90.2
Ruby Creek	RUBY 07-01	MR-4-1-C	1007	1	4	90	20.7	NA	20.7	20.8
Ruby Creek	RUBY 07-02	MR-4-1-C	706	1	4	90	20.7	NA	20.7	14.6
Ruby Creek	RUBY 08-01	MR-10-1-C	3398	1	10	100	20.7	NA	20.7	70.3
Ruby Creek	RUBY 08-02	MR-4-1-C	8734	1	4	100	20.7	NA	20.7	180.8
Ruby Creek	RUBY 09-01	MR-4-1-U	3160	1	4	100	20.7	NA	20.7	65.4
Ruby Creek	RUBY 10-01	MR-2-1-C	4108	1	2	100	20.7	NA	20.7	85.0
Ruby Creek	RUBY 11-01	MR-2-2-U	2801	2	2	100	27	NA	27.0	75.6
Ruby Creek	RUBY 12-01	MR-2-2-C	13789	2	2	100	27	NA	27.0	372.3

Table C-25. Estimated sediment loads in Ruby Creek

Stream	Reach ID	Reach Type	Length (feet)	Strahler Order	Grad-ient Class	% Natural Veg	Load Per 1000 Feet (Tons/Yr/1000 Feet)			Total Load (Tons/Year)
							Extrapolated	Field Assessed	Estimated *	
Ruby Creek	RUBY 13-01	MR-2-3-C	4568	3	2	100	27	NA	27.0	123.3
Ruby Creek	RUBY 14-01	MR-2-3-C	9585	3	2	90	27	NA	27.0	258.8
Ruby Creek	RUBY 15-01	MR-2-3-C	4591	3	2	80	27	NA	27.0	123.9
Ruby Creek	RUBY 15-02	MR-2-3-U	4180	3	2	20	38.1	NA	38.1	159.3
Ruby Creek	RUBY 16-01	MR-2-3-C	2425	3	2	30	38.1	NA	38.1	92.4
Ruby Creek	RUBY 17-01	MR-2-3-U	2552	3	2	40	38.1	57.32	57.3	146.3
										Total: 2072.7 Tons/Yr

* If reach was sampled, actual field loading value was used; otherwise extrapolated value was used.

C4.2.18 South Meadow Creek Sediment Loads

A total of 20 reaches were delineated in South Meadow Creek drainage (**Table C-26**). A considerable number of these reaches were in first order streams with low estimated amounts of loading from bank erosion. However, the lower gradient, larger streams near the mouth were estimated to contribute high sediment loads from banks due to the riparian zone having little natural vegetation.

Table C-26. Estimated sediment loads in South Meadow Creek

Stream	Reach ID	Reach Type	Length (feet)	Strahler Order	Grad-ient Class	% Natural Veg	Load Per 1000 Feet (Tons/Yr/1000 Feet)			Total Load (Tons/Year)
							Extrapolated	Field Assessed	Estimated*	
S Meadow Creek	SMDW 02-01	MR-4-1-U	624	1	4	100	20.7	NA	20.7	12.9
S Meadow Creek	SMDW 03-01	MR-10-1-U	1586	1	10	100	20.7	NA	20.7	32.8
S Meadow Creek	SMDW 04-01	MR-10-1-U	814	1	10	100	20.7	NA	20.7	16.9
S Meadow Creek	SMDW 05-01	MR-10-1-U	2777	1	10	90	20.7	NA	20.7	57.5
S Meadow Creek	SMDW 06-01	MR-4-1-U	2866	1	4	95	20.7	NA	20.7	59.3
S Meadow Creek	SMDW 07-01	MR-10-1-U	2252	1	10	95	20.7	NA	20.7	46.6
S Meadow Creek	SMDW 08-01	MR-4-1-U	1445	1	4	90	20.7	NA	20.7	29.9
S Meadow Creek	SMDW 09-01	MR-10-1-U	1430	1	10	80	20.7	NA	20.7	29.6
S Meadow Creek	SMDW 10-01	MR-4-1-C	1115	1	4	80	20.7	NA	20.7	23.1
S Meadow Creek	SMDW 11-01	MR-10-1-U	3651	1	10	80	20.7	NA	20.7	75.6
S Meadow Creek	SMDW 12-01	MR-4-1-U	3689	1	4	65	20.7	NA	20.7	76.4
S Meadow Creek	SMDW 13-01	MR-10-1-U	1556	1	10	80	20.7	NA	20.7	32.2
S Meadow Creek	SMDW 14-01	MR-4-1-U	1149	1	4	80	20.7	NA	20.7	23.8
S Meadow Creek	SMDW 15-01	MR-10-1-U	1360	1	10	70	20.7	NA	20.7	28.1

Table C-26. Estimated sediment loads in South Meadow Creek

Stream	Reach ID	Reach Type	Length (feet)	Strahler Order	Grad-ient Class	% Natural Veg	Load Per 1000 Feet (Tons/Yr/1000 Feet)			Total Load (Tons/Year)
							Extrapolated	Field Assessed	Estimated*	
S Meadow Creek	SMDW 16-01	MR-4-1-U	1937	1	4	70	20.7	NA	20.7	40.1
S Meadow Creek	SMDW 17-01	MR-4-2-U	6030	2	4	20	14	NA	14.0	84.4
S Meadow Creek	SMDW 17-02	MR-4-2-U	5772	2	4	60	14	NA	14.0	80.8
S Meadow Creek	SMDW 18-01	MR-2-3-U	4156	3	2	60	38.1	17.87	17.9	74.3
S Meadow Creek	SMDW 19-01	MR-0-3-U	14059	3	0	20	59.8	68.02	68.0	956.3
S Meadow Creek	SMDW 19-02	MR-0-3-U	4207	3	0	50	59.8	NA	59.8	251.6
										Total: 2032.2 Tons/Yr

* If reach was sampled, actual field loading value was used; otherwise extrapolated value was used.

C4.2.19 Watkins Creek Sediment Loads

A total of 13 reaches were delineated in the Watkins Creek drainage. These were estimated to have low loading from bank erosion due to higher gradients and > 70% natural vegetation in most reaches (Table **C-27**).

Table C-27. Estimated sediment loads in Watkins Creek

Stream	Reach ID	Reach Type	Length (feet)	Strahler Order	Grad-ient Class	% Natural Veg	Load Per 1000 Feet (Tons/Yr/1000 Feet)			Total Load (Tons/Year)
							Extrapolated	Field Assessed	Estimated *	
Watkins Creek	WATK 02-01	MR-10-1-U	634	1	10	100	20.7	NA	20.7	13.1
Watkins Creek	WATK 03-01	MR-4-1-C	1141	1	4	100	20.7	NA	20.7	23.6
Watkins Creek	WATK 04-01	MR-10-1-C	1835	1	10	90	20.7	NA	20.7	38.0
Watkins Creek	WATK 05-01	MR-10-2-C	675	2	10	90	12.5	NA	12.5	8.4
Watkins Creek	WATK 06-01	MR-10-2-U	2207	2	10	100	12.5	NA	12.5	27.6
Watkins Creek	WATK 07-01	MR-4-2-U	4322	2	4	80	14	NA	14.0	60.5
Watkins Creek	WATK 08-01	MR-10-2-C	2280	2	10	100	12.5	NA	12.5	28.5
Watkins Creek	WATK 09-01	MR-4-2-U	2005	2	4	100	14	NA	14.0	28.1
Watkins Creek	WATK 10-01	MR-2-3-U	2274	3	2	80	27	NA	27.0	61.4
Watkins Creek	WATK 11-01	MR-4-3-U	2467	3	4	80	14	NA	14.0	34.5
Watkins Creek	WATK 12-01	MR-2-3-U	5867	3	2	80	27	28.20	28.2	165.5
Watkins Creek	WATK 13-01	MR-4-3-U	3336	3	4	80	14	NA	14.0	46.7
Watkins Creek	WATK 14-01	MR-2-3-U	6593	3	2	30	38.1	17.64	17.6	116.3
										Total: 652.2 Tons/Yr

* If reach was sampled, actual field loading value was used; otherwise extrapolated value was used.

C4.2.20 West Fork Madison River Sediment Loads

A total of 30 reaches were delineated in the West Fork Madison River drainage. The loading estimate from bank erosion was low for most reaches, given that the riparian zone was generally >70% in natural vegetation (**Table C-28**).

Table C-28. Estimated sediment loads in West Fork Madison River

Stream	Reach ID	Reach Type	Length (feet)	Strahler Order	Grad-ient Class	% Natural Veg	Load Per 1000 Feet (Tons/Yr/1000 Feet)			Total Load (Tons/Year)
							Extrapolated	Field Assessed	Estimated*	
WFk Madison River	WFMA 02-01	MR-4-1-C	4578	1	4	90	20.7	NA	20.7	94.8
WFk Madison River	WFMA 03-01	MR-10-1-C	881	1	10	90	20.7	NA	20.7	18.2
WFk Madison River	WFMA 04-01	MR-4-1-U	4505	1	4	80	20.7	NA	20.7	93.3
WFk Madison River	WFMA 05-01	MR-10-1-C	959	1	10	90	20.7	NA	20.7	19.9
WFk Madison River	WFMA 05-02	MR-10-1-C	529	1	10	90	20.7	NA	20.7	11.0
WFk Madison River	WFMA 06-01	MR-4-1-U	4350	1	4	90	20.7	NA	20.7	90.0
WFk Madison River	WFMA 07-01	MR-2-1-U	2359	1	2	90	20.7	NA	20.7	48.8
WFk Madison River	WFMA 08-01	MR-2-2-C	1734	2	2	90	27	NA	27.0	46.8
WFk Madison River	WFMA 09-01	MR-2-2-C	4875	2	2	80	27	NA	27.0	131.6
WFk Madison River	WFMA 10-01	MR-0-2-C	4732	2	0	85	43.5	NA	43.5	205.9
WFk Madison River	WFMA 11-01	MR-0-2-U	8697	2	0	80	43.5	NA	43.5	378.3
WFk Madison River	WFMA 12-01	MR-0-2-C	6540	2	0	85	43.5	NA	43.5	284.5
WFk Madison River	WFMA 13-01	MR-0-2-U	9241	2	0	80	43.5	NA	43.5	402.0
WFk Madison River	WFMA 14-01	MR-0-2-C	1416	2	0	90	43.5	NA	43.5	61.6
WFk Madison River	WFMA 14-02	MR-0-2-C	5964	2	0	90	43.5	66.79	66.8	398.3
WFk Madison River	WFMA 15-01	MR-2-2-C	4965	2	2	90	27	NA	27.0	134.1
WFk Madison River	WFMA 16-01	MR-0-2-C	8258	2	0	90	43.5	NA	43.5	359.2
WFk Madison River	WFMA 16-02	MR-0-2-C	5996	2	0	90	43.5	NA	43.5	260.8
WFk Madison River	WFMA 17-01	MR-2-2-C	1322	2	2	90	27	NA	27.0	35.7
WFk Madison River	WFMA 18-01	MR-2-2-C	2610	2	2	90	27	NA	27.0	70.5
WFk Madison River	WFMA 18-02	MR-2-2-C	2027	2	2	90	27	NA	27.0	54.7
WFk Madison River	WFMA 19-01	MR-0-2-C	28305	2	0	90	43.5	NA	43.5	1231.3
WFk Madison River	WFMA 20-01	MR-0-3-U	21993	3	0	80	43.5	NA	43.5	956.7
WFk Madison River	WFMA 21-01	MR-0-3-U	1716	3	0	80	43.5	NA	43.5	74.6
WFk Madison River	WFMA 22-01	MR-0-3-U	11756	3	0	80	43.5	NA	43.5	511.4

Table C-28. Estimated sediment loads in West Fork Madison River

Stream	Reach ID	Reach Type	Length (feet)	Strahler Order	Grad-ient Class	% Natural Veg	Load Per 1000 Feet (Tons/Yr/1000 Feet)			Total Load (Tons/Year)
							Extrapolated	Field Assessed	Estimated*	
WFk Madison River	WFMA 23-01	MR-0-3-U	2827	3	0	80	43.5	NA	43.5	123.0
WFk Madison River	WFMA 24-01	MR-0-3-C	3898	3	0	80	43.5	NA	43.5	169.6
WFk Madison River	WFMA 25-01	MR-0-4-C	19803	4	0	70	59.8	NA	59.8	1184.2
WFk Madison River	WFMA 25-02	MR-0-4-C	23371	4	0	60	59.8	33.66	33.7	786.6
WFk Madison River	WFMA 26-01	MR-0-4-C	6470	4	0	80	43.5	90.53	90.5	585.7
										Total: 8822.9 Tons/Yr

* If reach was sampled, actual field loading value was used; otherwise extrapolated value was used.

C4.2.21 Wigwam Creek Sediment Loads

A total of 19 reaches were delineated in the Wigwam Creek drainage. The majority of Wigwam Creek drainage was estimated to have low sediment loads from bank erosion, being comprised of small streams with relatively high gradients. In addition, the riparian zone along Wigwam Creek was primarily in > 70% natural vegetation. The exception was near the mouth of Wigwam Creek, which was estimated to have high loads from bank erosion due to low gradients and a lack of natural vegetation in the riparian zone (**Table C-29**).

Table C-29. Estimated sediment loads in Wigwam Creek

Stream	Reach ID	Reach Type	Length (feet)	Strahler Order	Grad-ient Class	% Natural Veg	Load Per 1000 Feet (Tons/Yr/1000 Feet)			Total Load (Tons/Year)
							Extrapolated	Field Assessed	Estimated*	
Wigwam Creek	WGWM 02-01	MR-4-1-C	2841	1	4	90	20.7	NA	20.7	58.8
Wigwam Creek	WGWM 03-01	MR-10-1-U	998	1	10	90	20.7	NA	20.7	20.7
Wigwam Creek	WGWM 04-01	MR-4-1-C	2454	1	4	80	20.7	NA	20.7	50.8
Wigwam Creek	WGWM 05-01	MR-10-1-C	1128	1	10	80	20.7	NA	20.7	23.4
Wigwam Creek	WGWM 06-01	MR-10-2-C	835	2	10	90	12.5	NA	12.5	10.4
Wigwam Creek	WGWM 07-01	MR-10-2-C	915	2	10	90	12.5	NA	12.5	11.4
Wigwam Creek	WGWM 08-01	MR-4-2-C	7135	2	4	70	14	12.28	12.3	87.6
Wigwam Creek	WGWM 09-01	MR-2-3-C	3722	3	2	80	27	NA	27.0	100.5
Wigwam Creek	WGWM 10-01	MR-4-3-C	7972	3	4	90	14	NA	14.0	111.6
Wigwam Creek	WGWM 11-01	MR-2-3-C	4159	3	2	90	27	NA	27.0	112.3
Wigwam Creek	WGWM 12-01	MR-4-3-C	2005	3	4	90	14	NA	14.0	28.1
Wigwam Creek	WGWM 13-01	MR-10-3-C	837	3	10	90	12.5	NA	12.5	10.5
Wigwam Creek	WGWM 14-01	MR-4-3-C	2256	3	4	90	14	NA	14.0	31.6
Wigwam Creek	WGWM 14-02	MR-4-3-C	2197	3	4	80	14	NA	14.0	30.8

Table C-29. Estimated sediment loads in Wigwam Creek

Stream	Reach ID	Reach Type	Length (feet)	Strahler Order	Grad-ient Class	% Natural Veg	Load Per 1000 Feet (Tons/Yr/1000 Feet)			Total Load (Tons/Year)
							Extrapolated	Field Assessed	Estimated*	
Wigwam Creek	WGWM 15-01	MR-2-3-C	3542	3	2	40	38.1	NA	38.1	135.0
Wigwam Creek	WGWM 15-02	MR-2-3-C	1005	3	2	0	38.1	NA	38.1	38.3
Wigwam Creek	WGWM 16-01	MR-2-3-C	2466	3	2	10	38.1	NA	38.1	94.0
Wigwam Creek	WGWM 17-01	MR-2-3-C	5188	3	2	70	38.1	NA	38.1	197.7
Wigwam Creek	WGWM 18-01	MR-2-3-C	8290	3	2	10	38.1	13.99	14.0	116.0
										Total: 1269.3 Tons/Yr

* If reach was sampled, actual field loading value was used; otherwise extrapolated value was used.

C4.3 BMP SEDIMENT LOADS

For low and mid gradient streams (0-2% and >2%-4%) in low riparian condition (≤70% natural conditions), the sediment load if BMPs were implemented was estimated as the average of low and mid gradient streams with high riparian condition (Table C-30). For low and mid gradient reaches with already high riparian condition, no change was made in the estimated load. Because too few >4-10% gradient were sampled, a different method was used. To estimate BMP loads in these reaches, the BEHI score at individual banks within sampled reaches was changed from extreme to very high, very high to high, and high to moderate, and then the loading was estimated by taking the average of these reduced values. This new average was applied to estimate the BMP load at unsampled mid-gradient reaches. No different BMP load was estimated for very high (4-10%) gradient and first order unsampled reaches. These reaches tended to have riparian zones in high condition. Also, they comprised a low percentage of reaches in most watersheds.

The drainages with the highest estimated percent reduction in sediment load due to BMP's (>30%) include Blaine Spring Creek, Elk Creek, Moore Creek, Red Canyon Creek, and South Meadow Creek (**Tables C-30** and **C-31**). However, this is an estimate based on our aerial assessment of the riparian zone and may vary due to already-implemented BMPs are other local conditions.

Table C-30. Stream characteristics used to estimate BMP Loads at unsampled reaches

Gradient	Order	Riparian Condition	BMP Action	Pre-BMP Load (Tons/Yr/1000 Ft)	Post-BMP Load (Tons/Yr/1000 Ft)
0-2%	Non 1st	High, > 70% Riparian Zone in Natural Condition	NONE	43.5	43.5
0-2%	Non 1st	Low, ≤ 70% Riparian Zone in Natural Condition	Change to average at reaches with riparian zone in high condition	59.8	43.5
>2-4%	Non 1st	High, > 70% Riparian Zone in Natural Condition	NONE	27.0	27.0
>2-4%	Non 1st	Low, ≤ 70% Riparian Zone in Natural Condition	Change to average at reaches with riparian zone in high condition	38.1	27.0

Table C-30. Stream characteristics used to estimate BMP Loads at unsampled reaches

Gradient	Order	Riparian Condition	BMP Action	Pre-BMP Load (Tons/Yr/1000 Ft)	Post-BMP Load (Tons/Yr/1000 Ft)
>4-10%	Non 1st	Any	Average at sampled reaches after changing bank erosion from extreme to very high, very high to high, and from high to moderate	14.0	11.3
> 10%	Non 1st	Any	NONE	12.5	12.5
Any	1st	Any	NONE	20.7	20.7

Table C-31. Estimated reduction in sediment loads with BMP's

Watershed	Estimated Load (Tons/Yr)	BMP Load Estimated Load (Tons/Yr)	% Reduction
Antelope Creek*	2115.4	1612.9	23.8
Bear Creek*	6990.27	5059.4	27.6
Buford Creek	448.5	448.5	0.0
Blaine Spring Creek*	2507.6	1545.2	38.4
Cherry Creek*	7481.4	5835.0	22.0
Elk Creek*	4839.5	3346.0	30.9
Elk River	2158.8	2009.4	6.9
Gazelle Creek	678.9	617.9	9.0
Hot Springs Creek	3884.3	2801.1	27.9
Indian Creek	2410.5	2103.9	12.7
Jack Creek	3474.5	2499.9	28.1
Moore Creek*	3522.5	2199.4	37.6
North Meadow Creek*	3277.4	2508.3	23.5
No Man Creek	513.4	481.5	6.2
O'Dell Spring Creek	2630.1	2169.1	17.5
Red Canyon Creek*	1014.7	701.2	30.9
Ruby Creek*	2072.7	1914.2	7.6
South Meadow Creek*	2032.2	1378.1	32.2
Watkins Creek*	652.2	459.2	29.6
West Fork Madison River	8822.9	7516.7	14.8
Wigwam Creek*	1269.3	1044.2	17.7

*considered impaired for sediment

C5.0 REFERENCES

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APPENDIX D- ROAD SEDIMENT ASSESSMENT, MADISON TMDL PLANNING AREA

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D1.0 INTRODUCTION

This appendix presents a sediment assessment of the unpaved road network within the Madison River TMDL Planning Area (TPA). Through a combination of GIS analysis, field assessment, and computer modeling, estimated sediment loads were developed for road crossing and parallel road segments in the impaired watersheds within the Madison TPA. Potential future conditions were also estimated after the application of sediment reducing Best Management Practices (BMPs).

D2.0 DATA COLLECTION

D2.1 SPATIAL ANALYSIS

Unpaved roads were identified in the impaired watersheds using a combination of aerial imagery and attribute information within the TIGER Roads Layer. Unpaved road crossings were identified as locations where the resulting unpaved roads layer intersected the National Hydrography Dataset (NHD) stream layer. Parallel road segments were identified by placing a 150-foot buffer around the NHD stream layer, and selecting sections of the unpaved roads layer that intersected this buffer. A total of 554 unpaved gravel road crossings and 130 miles of gravel unpaved parallel road segments were identified within the sediment-impaired watersheds of the Madison TPA.

D2.2 FIELD DATA COLLECTION

A total of 25 gravel unpaved crossings and 16 gravel parallel road segments totaling 4 miles were selected as representative and evaluated in the field in 2015 (**Tables D-1** & **D-2**). In cases where the original crossing or segment could not be sampled due to access issues or was found to be unpaved, a crossing or parallel road segment in the field with the closest spatial proximity was substituted, and identified with an “A” following the name. If a road crossed the stream twice at the same approximate location, then both segments of the crossing were sampled. The following information was collected at road crossings and parallel road segments: soil type, percent rock, road surface, road design, traffic level, and road topographic values (road grade, road length, road width, fill grade, fill length, buffer grade, and buffer length).

Table D-1. Locations of sampled cross sections in the Madison TPA

Watershed	Cross-section	Latitude	Longitude
Red Canyon	X-1A	44.834	-111.201
Red Canyon	X-2A	44.836	-111.203
Watkins	X-2	44.836	-111.203
Red Canyon	X-3	44.831	-111.200
Watkins	X-4	44.799	-111.286
Watkins	X-5	44.806	-111.279
Red Canyon	X-13	45.060	-111.668
Bear	X-16A	45.168	-111.596
North Meadow	X-21	45.525	-111.835
North Meadow	X-25	45.514	-111.822
Bear	X-26A	45.162	-111.591

Table D-1. Locations of sampled cross sections in the Madison TPA

Watershed	Cross-section	Latitude	Longitude
South Meadow	X-26	45.471	-111.878
South Meadow	X-27A	45.468	-111.871
South Meadow	X-28A	45.449	-111.854
South Meadow	X-29	45.451	-111.854
North Meadow	X-33A	45.514	111.800
Wigwam	X-35 A	45.208	-111.761
North Meadow	X-38	45.233	-111.734
Blaine Spring	X-39A	45.210	-111.810
Blaine Spring	X-40	45.209	-111.802
Moore	X-46A	45.346	-111.730
Hot Springs	X-51A	45.565	-111.754
Hot Springs	X-52	45.587	-111.648
Hot Springs	X-53	45.573	-111.710
Red Canyon	X-RC extra	44.825	-111.197

Table D-2. Locations of sampled parallel road segments in the Madison TPA

Watershed	Road Name	Site ID	Upstream Latitude	Upstream Longitude	Downstream Latitude	Downstream Longitude
Red Canyon	USFS Rd 681	P-1A	44.824	-111.197	44.823	-111.197
Red Canyon	USFS Rd 681	P-2A	44.823	-111.197	44.821	-111.197
Red Canyon	USFS Rd 681	P-3A	44.834	-111.201		
Ruby		P-11	45.059	-111.712		
Ruby		P-12	45.060	111.715	45.060	-111.714
Ruby		P-13A	45.060	-111.716	45.060	-111.717
Bear	Bear Creek Rd E	P-16	45.163	-111.566	45.163	-111.569
Bear		P-17	45.156	-111.555	45.156	-111.555
South Meadow	Natl Forest Develop Road 1221 Rd	P-39A	45.450	-111.852	45.449	-111.849
Hot Springs	Bradley Creek Rd	P-40	45.53	-111.675	45.529	-111.675
North Meadow	N Meadow Creek Rd	P-41	45.474	-111.773	45.473	-111.773
North Meadow	N Meadow Creek Rd	P-42	45.469	111.773	45.468	111.773
North Meadow	N Meadow Creek Rd	P-48A	45.530	-111.849	45.529	-111.845
Hot Springs	Sterling Rd	P-49	45.573	-111.709	45.573	-111.708
Hot Springs	Bradley Creek Rd	P-55A			45.565	-111.653
Moore	Moore's Creek Rd	P-MC-extra			45.333	-111.748

D3.0 SEDIMENT LOADING EXTRAPOLATION

D3.1 SAMPLED CROSS-SECTION

The WEPP model (Flanagan and Livingston 1995) produced an estimate of sediment leaving the cross-section given the crossing characteristics and resulting contributing length. To estimate the sediment reduction at sampled cross sections if BMP's were implemented, the original field data was used in the WEPP model, but the length of road contributing sediment was shortened to 200 feet (**Table D-5**).

Table D-5. Estimated sediment leaving each sampled crossings, before and after BMPS

Watershed	XS ID	Contributing Length (ft)	Contributing Length-BMP's (ft)	Sediment Leaving Buffer (Tons/Yr)	Sediment Leaving Buffer After BMP's (Tons/Yr)
Red Canyon	X-1A	909	200	0.020	0.001
Red Canyon	X-2	22	200	0.004	0.004
Red Canyon	X-2A	243	200	0.011	0.005
Red Canyon	X-2A (2)	756	200	0.073	0.006
Red Canyon	X-3	78	200	0.025	0.025
Red Canyon	X-3	694	200	1.754	0.309
Watkins	X-4	853	200	0.059	0.007
South Meadow	X-5	11	200	0.001	0.001
Ruby	X-13	153	200	0.035	0.035
Bear	X-16A	350	200	0.611	0.349
North Meadow	X-21	77	200	0.000	0.000
North Meadow	X-25	260	200	0.332	0.226
North Meadow	X-25 (2)	226	200	0.270	0.226
South Meadow	X-26	507	200	0.074	0.014
South Meadow	X 26 (2)	109	200	0.016	0.016
Bear	x-26A	362	200	0.343	0.243
South Meadow	X-27A	235	200	0.077	0.064
South Meadow	X-28A	203	200	0.023	0.023
South Meadow	X-29	730	200	0.006	0.000
South Meadow	X-29 (2)	1000	200	0.013	0.000
North Meadow	X-33A	35	200	0.024	0.024
Wigwam	X-35 A	205	200	0.030	0.029
Wigwam	X-35 A (2)	277	200	0.108	0.070
North Meadow	X-38	35	200	0.006	0.006
Blaine	X-39A	93	200	0.007	0.007
Blaine	X-40	385	200	0.020	0.011
Moore	X-46A	678	200	0.012	0.004
Hot Springs	X-51A	635	200	0.013	0.004
Hot Springs	X-52	690	200	0.139	0.040
Hot Springs	X-53	188	200	0.028	0.028
Red Canyon	X-RC extra	449	200	0.497	0.151

D3.2 Sampled Parallel Road Segments

The WEPP model produced an estimate of sediment leaving the parallel road segment given the current length. To estimate the sediment reduction at sampled parallel road segments if BMP's were implemented, the original field data was used in the WEPP model, but the length of the parallel road segment contributing sediment was shortened to 500 feet (**Table D-6**).

Table D-6. Estimated sediment leaving each sampled parallel road segment, before and after BMPs

Watershed	PS ID	Road Length (ft)	Contributing Length-BMP's (ft)	Sediment Leaving Buffer (Tons/Yr)	Sediment Leaving Buffer After BMP's (Tons/Yr)
Bear	P-16	824	500	0.110	0.040
Bear	X 16A	350	500	0.611	0.611
Bear	P-17	381	500	0.015	0.015
Hot Springs	P-40	562	500	1.116	1.002
Hot Springs	P-49	179	500	0.097	0.097
Hot Springs	P-55A	1000	500	0.746	0.389
Moore	P-MC Extra	363	500	0.013	0.013
North Meadow	P-41	1000	500	1.111	0.622
North Meadow	P-42	160	500	0.020	0.020
North Meadow	P-48A	154	500	0.002	0.002
Red Canyon	P-1A	130	500	0.044	0.044
Red Canyon	P-1A (2)	443	500	0.203	0.203
Red Canyon	P-2A	914	500	0.062	0.034
Red Canyon	P-3A	883	500	0.802	0.443
Ruby	P-11	75	500	0.005	0.005
Ruby	P-11 (2)	119	500	0.008	0.008
Ruby	P-12	361	500	0.231	0.231
Ruby	P-13A	188	500	0.037	0.037
South Meadow	P-39 A	796	500	0.799	0.436

D3.3 Watershed Level: Cross-Sections

For watersheds with > 20% of crossings sampled (Red Canyon, Watkins), the total sediment yield at crossings (sampled + unsampled) was determined by multiplying the total number of crossings estimated using GIS by the average yield per crossing at sampled cross-sections in that watershed (**Table D-7**). For the other watersheds, the sediment yield was estimated by weighing by ownership and elevation category according to the following method. First, the average sediment yield per crossing was determined for the following categories of crossings: Public, high elevation (>6300 feet); public, low elevation (≤ 6300 feet); private, low elevation (≤ 6300 feet) (**Table D-8**). Then the number of crossings in each category was multiplied by the average sediment yield for that type of crossings. For both methods, the private, high elevation crossings were excluded from the analysis due to low prevalence

and a lack of data. Results from all categories were summed to obtain a total estimate of sediment yield in the watershed from crossings. A similar method was used to determine yields once BMP's were implemented (**Table D-9**).

Table D-7. Summary of estimated sediment loads leaving sampled crossings, by watershed

Watershed	No. Gravel Crossings	No. Crossings Evaluated	Total Sediment at Crossings-Field (Tons/Year)	Average Sediment Per Crossing-Field (Tons/Year)	Total Sediment at Crossings - BMP Field (Tons/Year)	Average Sediment Per Crossing-BMP (Tons/Year)
Bear	84	2	0.80	0.40	0.29	0.15
Blaine	33	2	0.02	0.01	0.02	0.01
Hot Springs	96	3	0.15	0.05	0.06	0.02
Moore	30	1	0.01	0.01	0.00	0.00
North Meadow	87	3	0.52	0.17	0.40	0.13
Red Canyon	15	6	1.99	0.33	0.42	0.07
Ruby	9	1	0.03	0.03	0.03	0.03
South Meadow	39	5	0.18	0.04	0.10	0.02
Watkins	3	1	0.05	0.05	0.01	0.01
Wigwam	66	1	0.12	0.12	0.08	0.08
Antelope	7	0	NA	NA	NA	NA
Elk	19	0	NA	NA	NA	NA
Cherry	66	0	NA	NA	NA	NA

Table D-8. Summary of sediment loads leaving sampled crossings by ownership and elevation category

Ownership/Elevation Category	No. Crossings	Total Sediment by Category (Tons/Year)	Total Sediment By Category with BMP's (Tons/Year)	Average Sediment Per Crossing (Tons/Year)	Average Sediment Per Crossing-BMP's (Tons/Year)
Public, high elevation	8	2.18	0.50	0.272	0.063
Public, low elevation	5	0.19	0.09	0.038	0.017
Private, high elevation	0	NA	0.00	NA	NA
Private, low elevation	11	1.49	1.02	0.136	0.093

Table D-9. Estimated sediment loads from crossings in each subwatershed

Watershed	No. Gravel Crossings	No. Public, Low	No. Private, Low	No. Public, High	No. Private, High	Method Used	Total Sediment (Tons/Yr)	Total Sediment (Tons/Yr) with BMP's	% Reduction
Antelope	7	0	0	6	1	own/elev	1.63	0.38	77
Bear	84	11	71	0	4	own/elev	10.06	6.76	33
Blaine	33	1	31	0	1	own/elev	4.25	2.89	32
Cherry	66	0	59	4	4	own/elev	9.10	5.71	37
Elk	19	2	17	0	0	own/elev	2.39	1.61	33
Hot Springs	96	43	54	1	0	own/elev	9.25	5.80	37
Moore	30	5	17	6	2	own/elev	4.13	2.04	51
North Meadow	87	3	64	20	1	own/elev	14.25	7.23	49
Red Canyon	15	0	0	13	2	watershed	4.30	0.90	79
Ruby	9	9	0	0	0	own/elev	0.34	0.15	55
South Meadow	39	3	18	18	1	own/elev	7.46	2.85	62
Watkins	3	0	0	3	0	watershed	0.15	0.02	88
Wigwam	66	13	37	7	10	own/elev	7.43	4.09	45

D3.4 WATERSHED LEVEL: PARALLEL ROAD SEGMENTS

The sediment yield at sampled parallel road segments was estimated by weighing by ownership and elevation category according to the following method. First, the average sediment yield (tons/mile/yr) was estimated for each ownership/elevation category based on sampled parallel road segments across the Madison TPA: Public, high elevation (>6300 feet); public, low elevation (≤ 6300 feet); private, low elevation (≤ 6300 feet) (**Table D-10**). To estimate the sediment yield per mile from parallel road segments for each watershed, the number of miles in each category was multiplied by the average sediment yield per mile in that category. Results from all categories were summed to obtain a total estimate of sediment yield from parallel road segments in the watershed (**Table D-11**).

Table D-10. Summary of sediment leaving the buffer at parallel road segments by ownership and elevation category, using results from the WEPP modeling approach

	No. Parallel Segments Sampled	Length of Parallel Road Segments Sampled-miles	Total Sediment By Category (Tons/Year)	Total Sediment By Category with BMP's (Tons/Year)	Average Sediment Per Mile (Tons/Year)	Average Sediment Per Mile with BMP's
Public, high elevation	3	1.33	1.111	0.723	0.835	0.544
Public, low elevation	8	1.05	2.959	2.124	2.818	2.023
Private, high elevation	0	0	NA	NA	NA	NA
Private, low elevation	5	1.45	1.352	0.792	0.932	0.546

Table D-11. Estimated sediment entering streams from parallel road segments by subwatershed

	Public Low (miles)	Private Low (miles)	Public High (miles)	Private High (miles)	Public Low (Tons)	Private Low (Tons)	Public High (Tons)	Private High (Tons)	Public Low (tons BMP)	Private Low (Tons BMP)	Public High (Tons BMP)	Private High (Tons BMP)	Total(Tons/Yr)	Total (Tons/Yr -BMP's)	% Reduction
Antelope	0.00	0.00	0.08	0.00	0.00	0.00	0.07	NA	0.00	0.00	0.04	NA	0.07	0.04	45.78
Bear	1.72	21.33	0.22	0.92	4.86	19.89	0.19	NA	2.90	9.71	0.10	NA	24.93	12.72	49.00
Blaine	0.20	7.79	0.00	0.04	0.55	7.26	0.00	NA	0.33	3.54	0.00	NA	7.81	3.87	50.40
Cherry	0.00	12.26	0.60	0.38	0.00	11.43	0.50	NA	0.00	5.58	0.27	NA	11.93	5.85	50.95
Elk	0.86	3.98	0.00	0.00	2.42	3.71	0.00	NA	1.45	1.81	0.00	NA	6.14	3.26	46.84
Hot Springs	9.28	11.81	1.32	0.00	26.16	11.01	1.10	NA	15.65	5.38	0.60	NA	38.27	21.62	43.51
Moore	2.16	6.72	2.01	0.86	6.07	6.27	1.68	NA	3.63	3.06	0.91	NA	14.02	7.60	45.77
North Meadow	1.46	13.56	3.14	0.00	4.13	12.65	2.62	NA	2.47	6.17	1.42	NA	19.39	10.06	48.11
Red Canyon	0.00	0.00	3.07	1.76	0.00	0.00	2.56	NA	0.00	0.00	1.39	NA	2.56	1.39	45.78
Ruby	4.36	0.71	0.92	0.00	12.27	0.66	0.77	NA	7.34	0.32	0.42	NA	13.70	8.08	41.03
South Meadow	1.10	4.92	2.78	0.11	3.11	4.58	2.33	NA	1.86	2.24	1.26	NA	10.02	5.36	46.51
Watkins	0.00	0.00	0.27	0.01	0.00	0.00	0.22	NA	0.00	0.00	0.12	NA	0.22	0.12	45.78
Wigwam	1.10	4.79	1.21	1.11	3.11	4.47	1.01	NA	1.86	2.18	0.55	NA	8.60	4.59	46.56

D4.0 REFERENCES

Flanagan, D. C. and S. J. Livingston. 1995. USDA-Water Erosion Prediction Project User Summary. NSERL Report No. 11, National Soil Erosion Research Lab, USDA, West Lafayette IN, 139 pp.

APPENDIX E - UPLAND SEDIMENT ASSESSMENT FOR ELK CREEK

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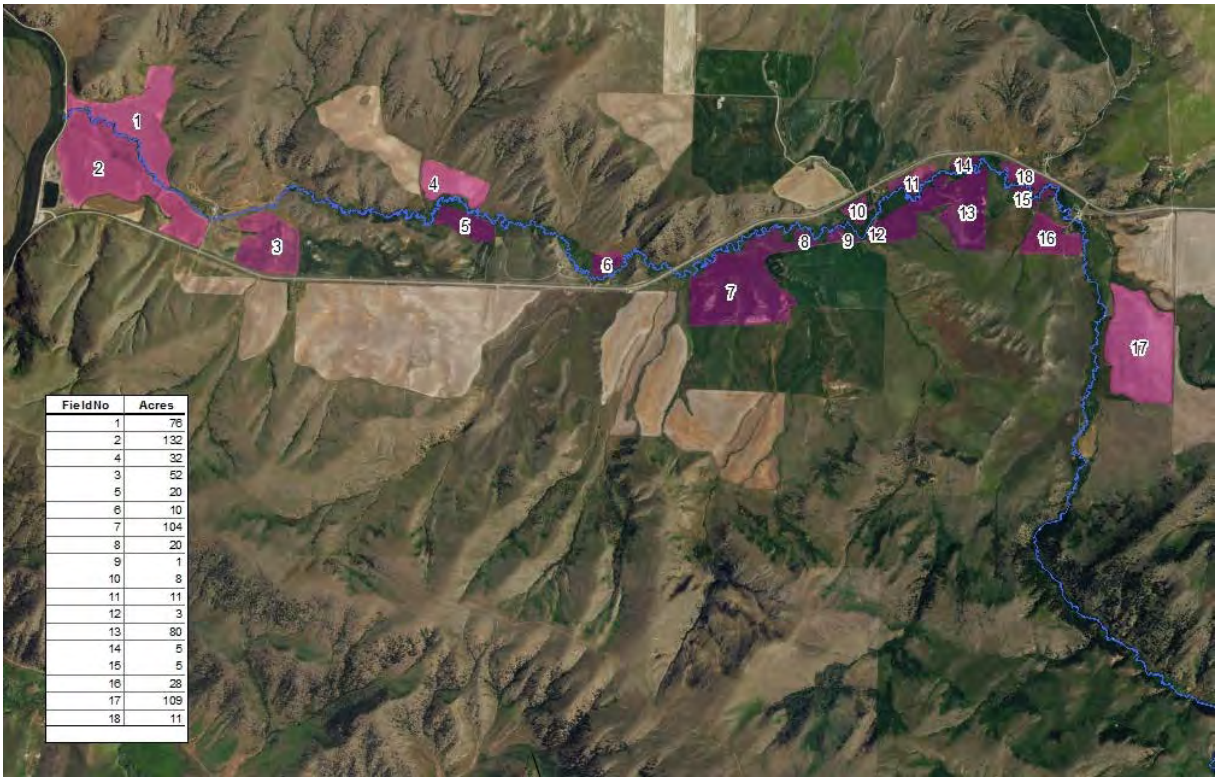
E1.0 AERIAL ASSESSMENT

DEQ conducted an analysis of upland sediment for the Elk Creek watershed, as numerous near stream agricultural fields were identified through on the ground and aerial photo observation to have a potentially significant sediment contribution to the stream (**Figures E-1 to E-5**). Many of the fields have areas within 50-100 feet of the stream that have poor cover and little to no riparian buffer to filter sediment contribution to the stream. Collectively, these areas of ground disturbance have the potential to be significant sediment sources if proper BMPs are not implemented and maintained.



FieldNo	Acres
1	76
2	132
4	32
3	52
5	20
6	10
7	104
8	20
9	1
10	8
11	11
12	3
13	80
14	5
15	5
16	28
17	109
18	11

Figure E-1. Fields along Elk Creek identified as having an elevated sediment contribution to the stream.

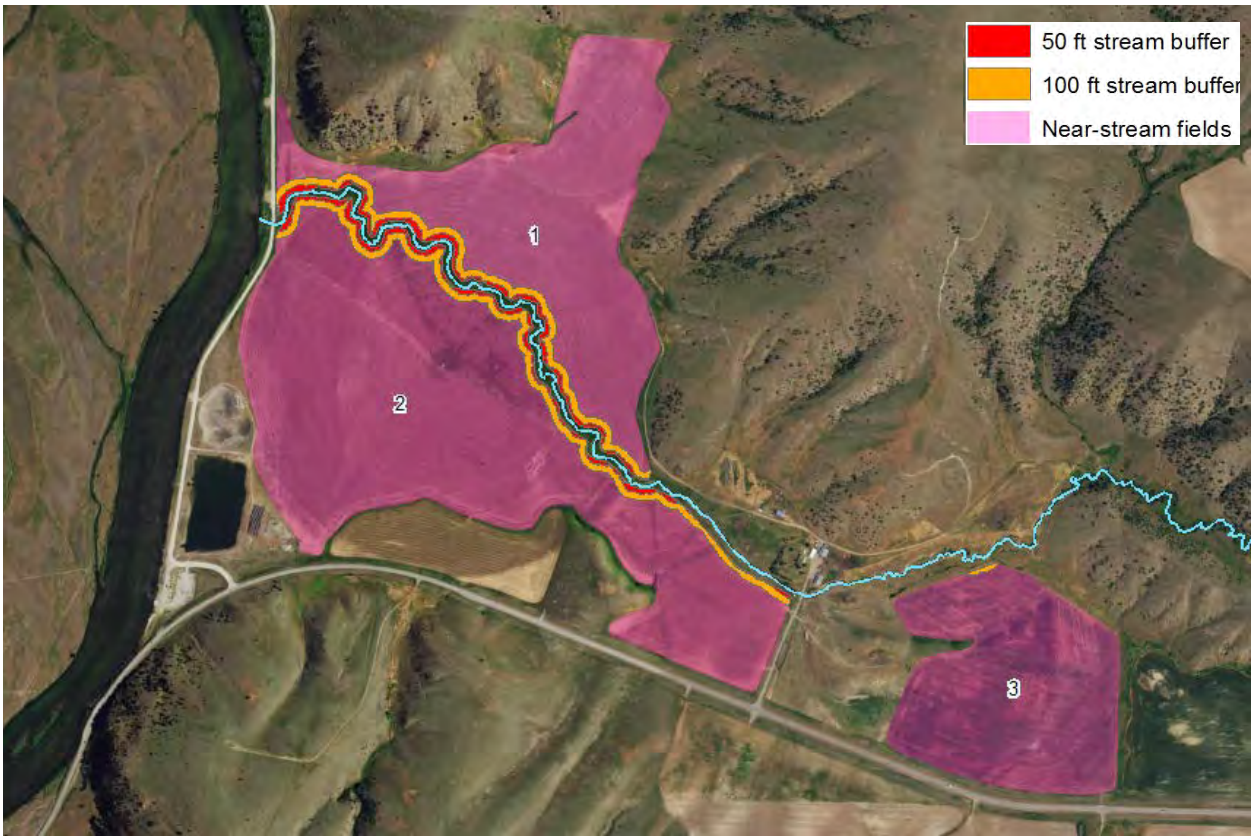


Figure E-2. Elk Creek fields 1-3, with 50 and 100-foot buffers

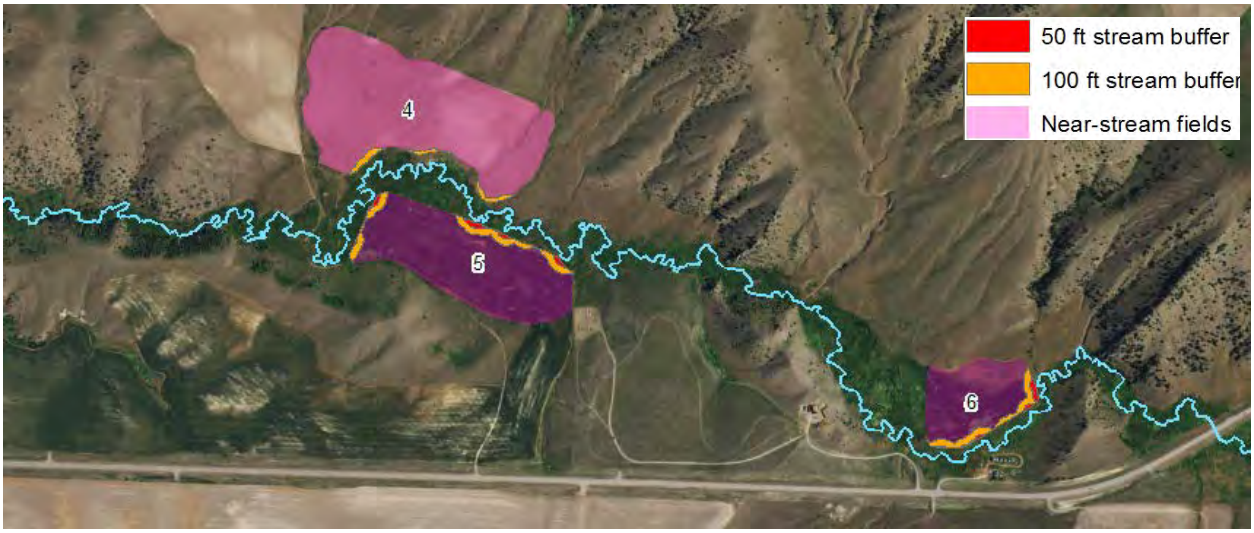


Figure E-3. Elk Creek fields 4-6, with 50 and 100-foot buffers

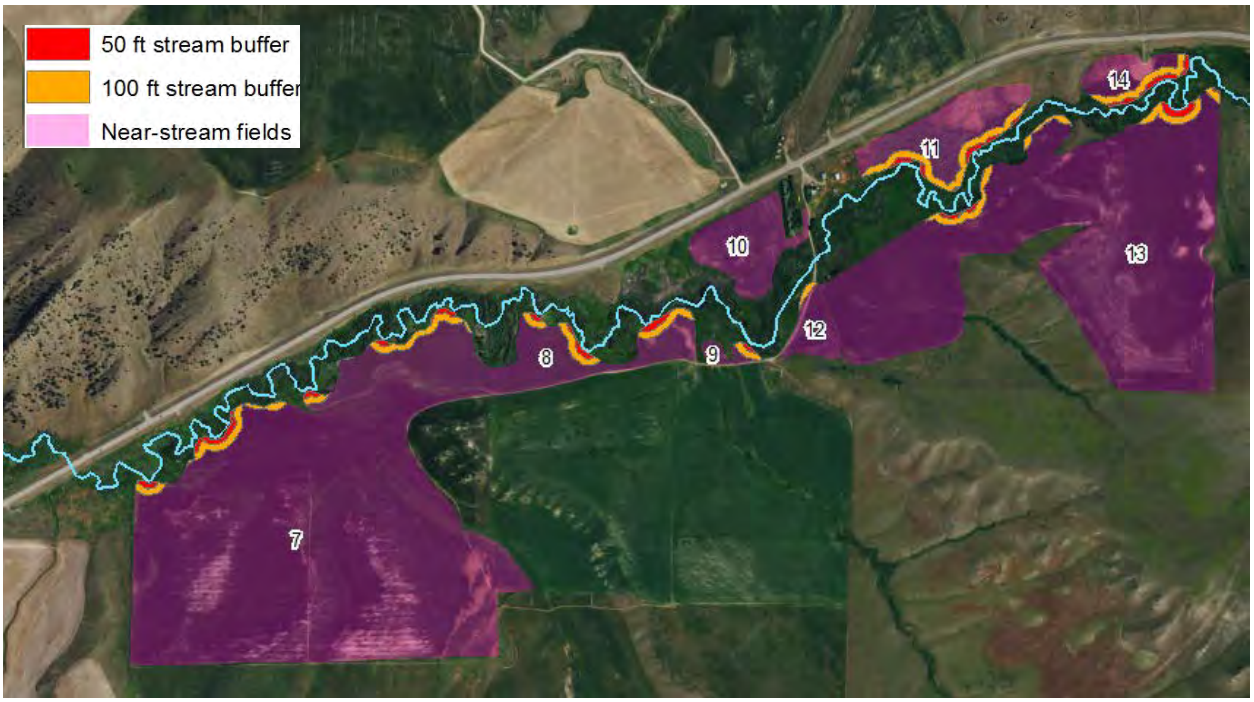


Figure E-4. Elk Creek fields 7-14, with 50 and 100-foot buffers

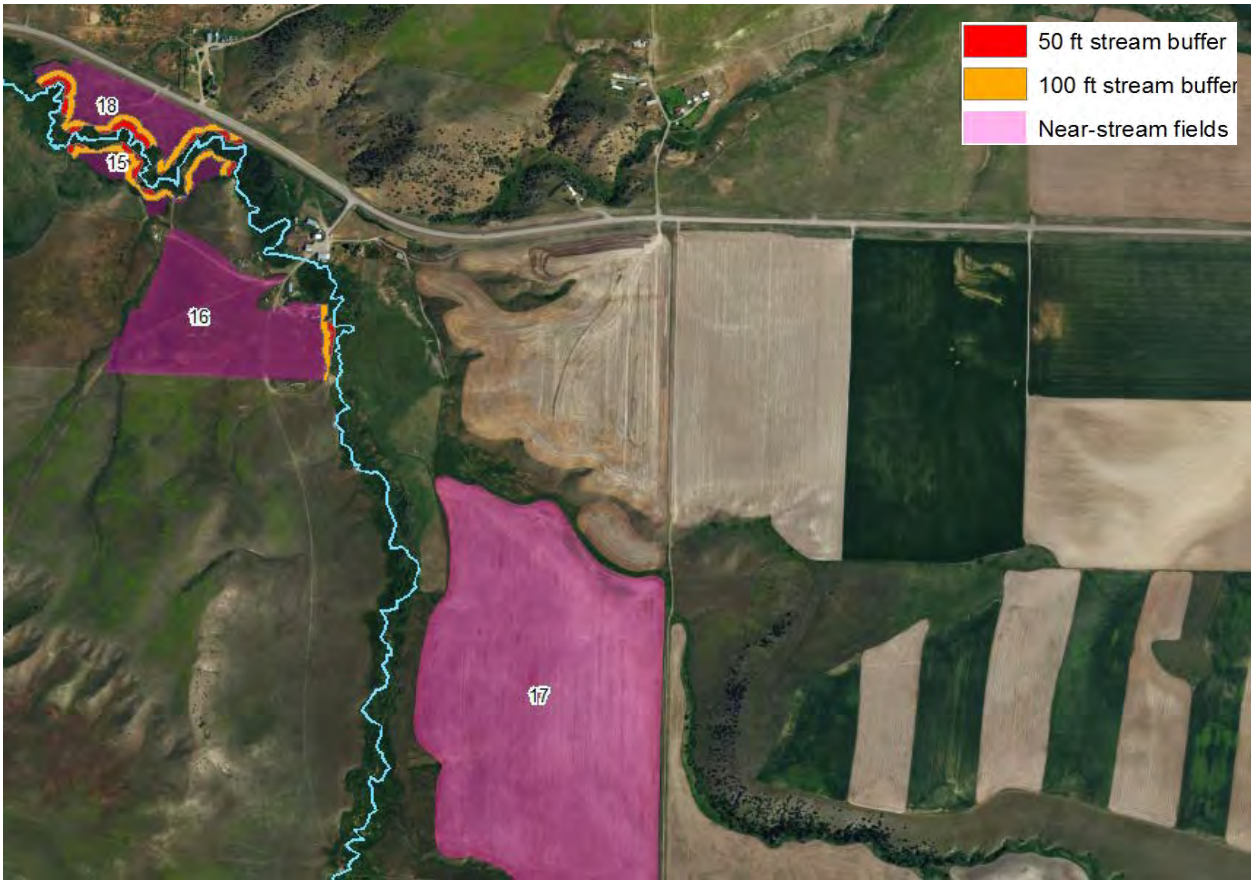


Figure E-5. Elk Creek fields 15-18, with 50 and 100-foot buffers

E2.0 SEDIMENT CONTRIBUTION FROM CULTIVATED FIELDS

To analyze the contribution of sediment from these fields to the stream, hillslope erosion was estimated using loading rates estimated for cultivated fields in the Boulder-Elkhorn watershed. The majority of cultivated fields in the Boulder-Elkhorn USLE assessment area reside in the same ecoregion as the near-stream agricultural fields in the Elk Creek watershed (Ecoregion IV – Townsend Basin) (**Figure E-6**).

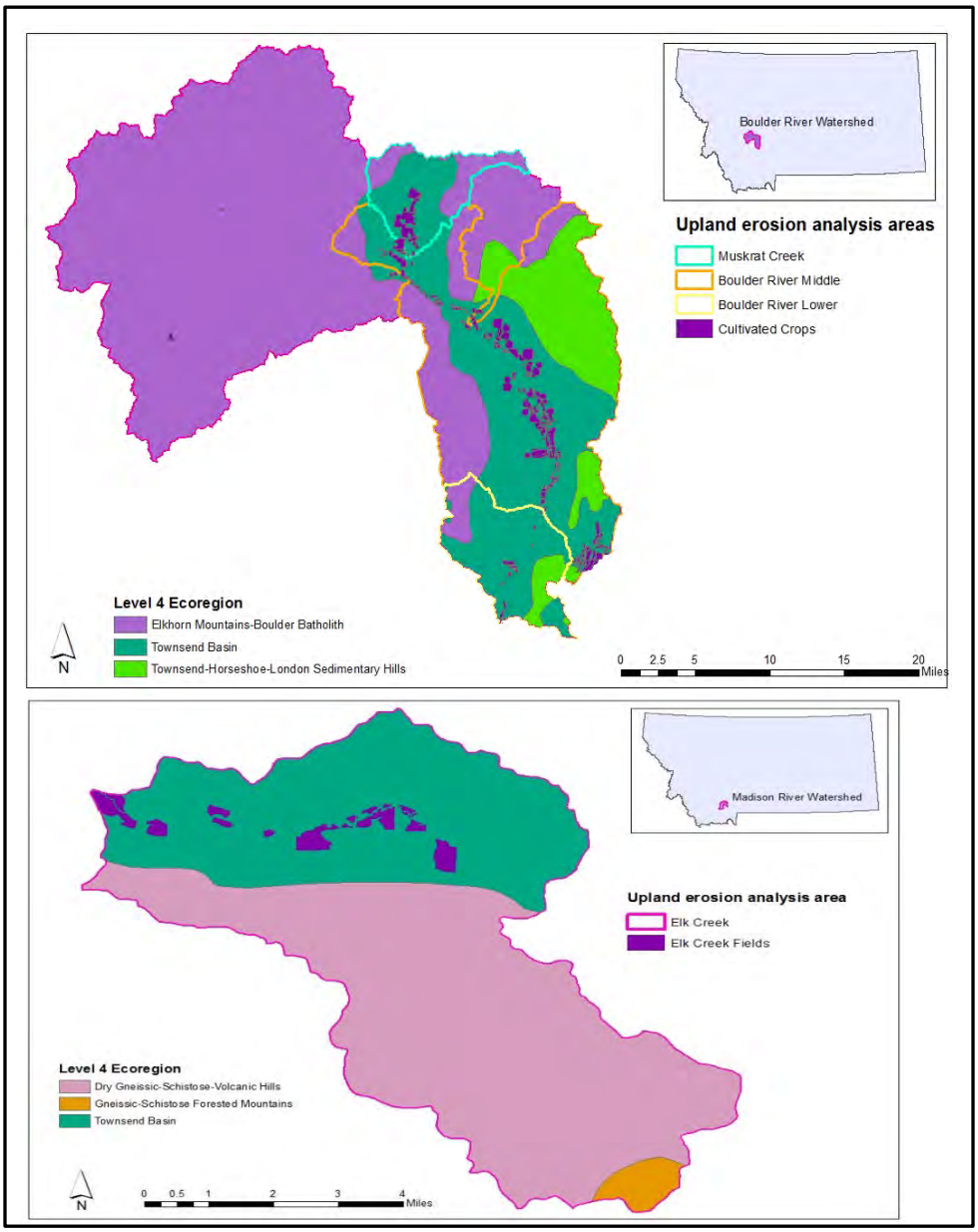


Figure E-6. Ecoregion comparison of Boulder valley agricultural area and Elk Creek near-stream fields.

The Boulder-Elkhorn assessment used the Universal Soil Loss Equation (USLE) to estimate existing sediment loads from cultivated fields and sediment loads from cultivated fields after the application of upland best management practices (a 20% increase in ground cover over existing conditions). In order to

predict how much of these existing and BMP sediment loads from cultivated fields made it to the stream, existing and potential conditions of the 100 foot riparian buffer were taken into account. To learn more about how erosion from cultivated fields was calculated in the Boulder-Elkhorn watershed, refer to Attachment 2 of the *Boulder-Elkhorn Sediment, Nutrients and Temperature TMDLs and Water Quality Improvement Plans, September 2013* document.

Erosion rates calculated for cultivated fields in the Muskrat Creek, Boulder River Middle, and Boulder River Lower subwatersheds were averaged (**Table E-1**) and this average was used for fields in the Elk Creek watershed to estimate sediment loading rates before and after BMP's.

Table E-1. Estimated field sediment loads and erosion rates for cultivated fields in the Muskrat Creek, Middle Boulder River, and Lower Boulder River watersheds.

Boulder-Elkhorn Subwatersheds		**Cultivated Fields - Existing Sediment Loads and Erosion Rates**		**Cultivated Fields - BMP Sediment Loads and Erosion Rates**	
	Area (acres)	Tons/year	Avg. tons/acre/year	Tons/year	Avg. tons/acre/year
Muskrat Creek	225	7.7	0.034	3.8	0.017
Boulder River Middle	1,001.90	31.6	0.032	15.8	0.016
Boulder River Lower	10.7	0.5	0.047	0.25	0.023
Avg. erosion rate			**0.037**		**0.019**

E3.0 RIPARIAN HEALTH ASSESSMENT

Well-vegetated riparian buffers have been shown to act as filters that remove sediment from overland flow. Because of this ability, the influence of riparian corridors on water quality is proportionately much greater than the relatively small area in the landscape they occupy. In general, the effectiveness of vegetated riparian buffers is proportional to their width and overall health. Thus, information regarding riparian zone health can be used to refine estimates of sediment delivery to streams from upstream sources.

A literature review (Wengner 1999, Knutson and Naef 1997) indicated that a 100 foot wide, well-vegetated riparian buffer zone can be expected to filter 75-90% of incoming sediment from reaching its stream channel. Accordingly, this analysis conservatively assumes that a sediment reduction efficiency of 75% represents the performance of a 100 foot wide, high quality (good) vegetated riparian buffer on Elk Creek. Conversely, this analysis conservatively assumes that a 100 foot wide riparian zone without vegetation cover would only filter 10% of incoming sediment from reaching its stream. An approximately equal apportionment of the remaining range in sediment reduction efficiency between the 'poor', 'moderately fair, 'fair', and 'moderately good' riparian assessment categories results in the riparian health/sediment delivery relationship shown in **Figure E-7**.

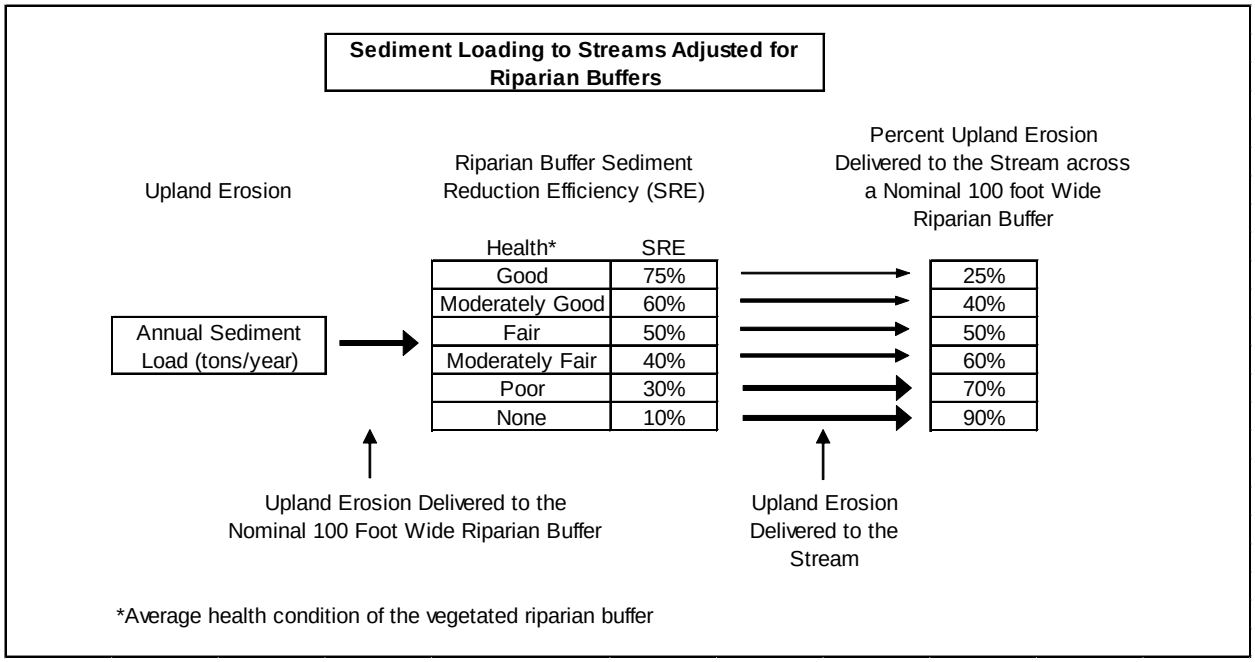


Figure E-7. USLE upland sediment load delivery adjusted for riparian buffer capacity

These load adjustments, based on the condition of the 100 foot buffer, were applied to the existing sediment load from near-stream fields in order to get a total existing load delivered to the stream (**Table E-2**). A potential load after implementing riparian BMP's was estimated by increasing the buffer efficiency by 20% with a total proportion entering the stream no less than 25% which is the value considered attainable once reasonable BMP's have been put in place (**Table E-3**).

Table E-2 Estimated load delivered by agricultural fields to the stream based on existing field conditions and buffer quality

Field No	Acres	Existing Field Load (Tons/Year)	Existing Buffer Efficiency (Proportion Entering Stream)	Existing Load Delivered to Stream (Tons/Year) = Existing Field Load * Proportion Entering Stream
1	76	2.81	Poor (0.70)	1.97
2	132	4.88	Poor (0.70)	3.42
3	52	1.92	Poor (0.70)	1.35
4	32	1.18	Moderate-Fair (0.60)	0.71
5	20	0.74	Moderate-Fair (0.60)	0.44
6	10	0.37	Moderate-Fair (0.60)	0.22
7	104	3.85	Moderate-Fair (0.60)	2.31
8	20	0.74	Moderate-Fair (0.60)	0.44
9	1	0.04	Moderate-Fair (0.60)	0.02
10	>100 Foot Buffer Already Present			
11	11	0.41	Moderate-Fair (0.60)	0.24
12	3	0.11	Fair (0.50)	0.06
13	80	2.96	Moderate-Good (0.40)	1.18

Table E-2 Estimated load delivered by agricultural fields to the stream based on existing field conditions and buffer quality

Field No	Acres	Existing Field Load (Tons/Year)	Existing Buffer Efficiency (Proportion Entering Stream)	Existing Load Delivered to Stream (Tons/Year) = Existing Field Load * Proportion Entering Stream
14	5	0.19	Moderate-Fair (0.60)	0.11
15	5	0.19	Fair (0.50)	0.09
16	28	1.04	Poor (0.70)	0.73
17	>100 Foot Buffer Already Present			
18	11	0.41	Fair (0.50)	0.20
Total	590	21.83		13.50

Table E-3. Potential changes in buffer quality of agricultural fields in the Elk Creek Watershed after implementing BMPs.

FieldNo	Existing Buffer Quality Proportion Entering Stream	Potential Buffer Proportion Entering Stream
1	Poor (0.70)	Fair (0.50)
2	Poor (0.70)	Fair (0.50)
3	Poor (0.70)	Fair (0.50)
4	Moderate-Fair (0.60)	Moderate-Good (0.40)
5	Moderate-Fair (0.60)	Moderate-Good (0.40)
6	Moderate-Fair (0.60)	Moderate-Good (0.40)
7	Moderate-Fair (0.60)	Moderate-Good (0.40)
8	Moderate-Fair (0.60)	Moderate-Good (0.40)
9	Moderate-Fair (0.60)	Moderate-Good (0.40)
11	Moderate-Fair (0.60)	Moderate-Good (0.40)
12	Fair (0.50)	Good (0.30)
13	Moderate-Good (0.40)	Good (0.25)
14	Moderate-Fair (0.60)	Moderate-Good (0.40)
15	Fair (0.50)	Good (0.30)
16	Poor (0.70)	Fair (0.50)
18	Fair (0.50)	Good (0.30)

E4.0 Management Scenarios and Sediment Load Reductions

To determine the potential reduction in sediment entering streams after implementing BMP's, the following equations were applied, using estimated erosion rates from Tables E-1 and E-3.

Scenario 1:
BMP Field Load (Existing Buffer) = Acres * Average Erosion Rate (with BMPs) * Upland Erosion Rate (with Existing Buffer Quality)

Scenario 2:
Existing Field Load (BMP Buffer)=Acres * Average Erosion Rate (without BMPs) * Upland Erosion Rate (with Potential BMP Buffer Quality)

Scenario 3: BMP Field Load (BMP Buffer)
Acres * Average Erosion Rate (with BMP's) * Upland Erosion Rate (with Potential BMP Buffer Quality)

The following table (**Table E-4**) provides an estimate of existing sediment loading from agricultural fields and estimates of potential sediment loading reductions that could be achieved through the three scenarios.

Table E-4. Estimated reduction in sediment in the Elk Creek watershed with 3 BMP scenarios.

							Scenario 1		Scenario 2		Scenario 3	
FieldNo	**Acres**	**Existing Field Load in Tons/year**	**Potential BMP Field Load**	**Existing Buffer quality (Erosion Rate)**	**Potential buffer Quality (Erosion Rate)**	**Existing Load Delivered to Stream (Tons/Yr)**	**Upland BMP Only (Tons/Yr)**	**% Change from Existing Load**	**Buffer BMP Only**	**% Change from Existing Load**	**Upland and Buffer BMP (Tons /Yr)**	**% Change from Existing Load**
1	76	2.81	1.44	Poor (0.70)	Fair (0.50)	1.97	1.01	49%	1.41	29%	0.72	63%
2	132	4.88	2.51	Poor (0.70)	Fair (0.50)	3.42	1.76	49%	2.44	29%	1.25	63%
3	52	1.92	0.99	Poor (0.70)	Fair (0.50)	1.35	0.69	49%	0.96	29%	0.49	63%
4	32	1.18	0.61	Moderate-Fair (0.60)	Moderate-Good (0.40)	0.71	0.36	49%	0.47	33%	0.24	66%
5	20	0.74	0.38	Moderate-Fair (0.60)	Moderate-Good (0.40)	0.44	0.23	49%	0.30	33%	0.15	66%
6	10	0.37	0.19	Moderate-Fair (0.60)	Moderate-Good (0.40)	0.22	0.11	49%	0.15	33%	0.08	66%
7	104	3.85	1.98	Moderate-Fair (0.60)	Moderate-Good (0.40)	2.31	1.19	49%	1.54	33%	0.79	66%
8	20	0.74	0.38	Moderate-Fair (0.60)	Moderate-Good (0.40)	0.44	0.23	49%	0.30	33%	0.15	66%
9	1	0.04	0.02	Moderate-Fair (0.60)	Moderate-Good (0.40)	0.02	0.01	49%	0.01	33%	0.01	66%
11	11	0.41	0.21	Moderate-Fair (0.60)	Moderate-Good (0.40)	0.24	0.13	49%	0.16	33%	0.08	66%
12	3	0.11	0.06	Fair (0.50)	Good (0.30)	0.06	0.03	49%	0.03	40%	0.02	69%
13	80	2.96	1.52	Moderate-Good (0.40)	Good (0.25)	1.18	0.61	49%	0.89	25%	0.46	61%
14	5	0.19	0.10	Moderate-Fair (0.60)	Moderate-Good (0.40)	0.11	0.06	49%	0.07	33%	0.04	66%
15	5	0.19	0.10	Fair (0.50)	Good (0.30)	0.09	0.05	49%	0.06	40%	0.03	69%
16	28	1.04	0.53	Poor (0.70)	Fair (0.50)	0.73	0.37	49%	0.52	29%	0.27	63%

Table E-4. Estimated reduction in sediment in the Elk Creek watershed with 3 BMP scenarios.

							Scenario 1		Scenario 2		Scenario 3	
FieldNo	**Acres**	**Existing Field Load in Tons/year**	**Potential BMP Field Load**	**Existing Buffer quality (Erosion Rate)**	**Potential buffer Quality (Erosion Rate)**	**Existing Load Delivered to Stream (Tons/Yr)**	**Upland BMP Only (Tons/Yr)**	**% Change from Existing Load**	**Buffer BMP Only**	**% Change from Existing Load**	**Upland and Buffer BMP (Tons /Yr)**	**% Change from Existing Load**
18	11	0.41	0.21	Fair (0.50)	Good (0.30)	0.20	0.10	49%	0.12	40%	0.06	69%
Total	**590**	**21.83**	**11.21**			**13.50**	**6.93**	**49%**	**9.43**	**30%**	**4.84**	**64%**

E5.0 REFERENCES

Knutson, K. L. and V. L. Naef. 1997. Management recommendations for Washington's priority habitats: riparian. Washington Department of Fish and Wildlife, Olympia, WA. 181 pp.

DEQ (Montana Department of Environmental Quality). 2012. Final Boulder-Elkhorn Metals TMDLs and Framework Water Quality Improvement Plan. Helena, MT: Montana Dept. of Environmental Quality.

Wenger, S. 1999. A review of the scientific literature on riparian buffer width, extent and vegetation. Office of Public Service and Outreach, Institute of Ecology, University of Georgia, Athens, GA.

APPENDIX F - SEDIMENT TOTAL MAXIMUM DAILY LOAD ESTIMATES

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F1.0 INTRODUCTION

The approaches used to estimate sediment loading from bank erosion, roads, and upland sources each use a modeling framework that estimates annual loads (BEHI, WEPP, and USLE respectively; **Appendices C-E**). The preferred approach for calculating daily sediment loads is to use a nearby water quality gage with a long-term dataset for flow and suspended sediment, and to distribute the annual loads estimated from these other methods over the course of a year based on the discharge-total suspended sediment relationship.

The only current stream gauges in the Madison TPA are on the Madison River, which is largely affected by a series of impoundments. Further, the impaired subwatersheds are much smaller in area than the Madison River gauge at West Yellowstone, which is above most of these impoundments. Therefore, an approach was used whereby the daily discharge near the mouth of Jack Creek was estimated using a relationship between the West Yellowstone Gauge (06037500) and a now discontinued gauge on Jack Creek (06040300) during the time period when both gauges were operational: 1983-1984 (**Figure F-1**). A stream flow-total suspended sediment relationship was developed using flow and total suspended solids data collected for Cherry and Jack Creek by Montana DEQ in multiple seasons during 1976-1977; this relationship was similar for both creeks (**Figure F-2**). This allowed for a prediction of the proportion of annual sediment load leaving Jack Creek as total suspended solids on any given day according to the calculations described in the following section.

This daily proportion was multiplied by the annual load estimated for each watershed estimated from the source assessment in the Madison TPA to obtain a daily load. It was assumed that the relationship between flow and seasonal changes in suspended solids has not changed from the 1976-1977 timeframe, even though the total suspended sediment load itself may have changed. In addition, in order to estimate Total Maximum Daily Loads, it was assumed that the effects of discharge on the proportion of the sediment load are relatively the same across the subwatersheds.

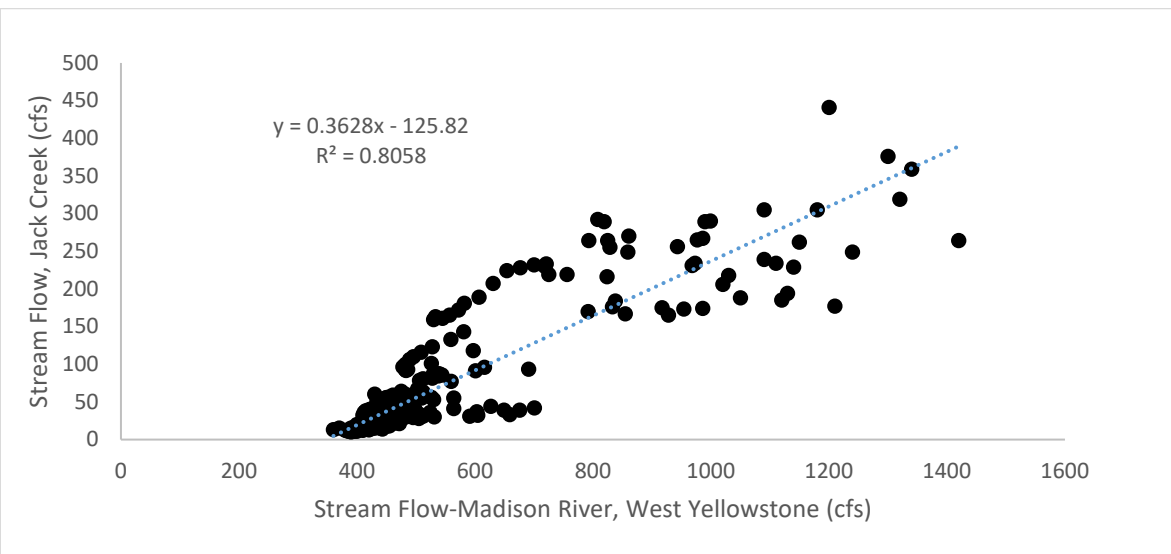

Figure F-1. Relationship between daily mean stream flow at Madison River, West Yellowstone Gauge and Jack Creek gauge (1983-1984)

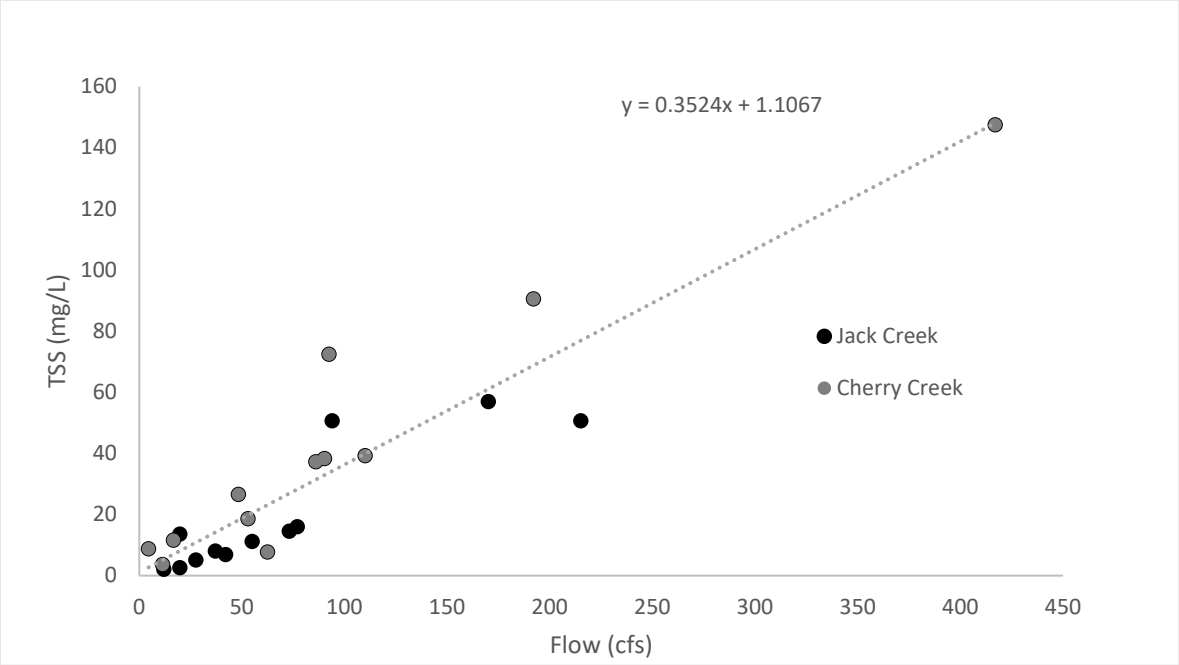

Figure F-2. Relationship between measured stream flow at Cherry Creek and Jack Creek and TSS during field surveys by Montana DEQ in 1976 and 1977

F2.0 CALCULATIONS

1. Estimate Jack Creek Daily Mean Flow (using relationship from 1983-1984 data (Figure F-1) and average daily streamflow statistics for West Yellowstone gauge):

   Daily Mean Stream Flow-Jack Creek (cfs) = 0.3628 * (Daily Average Mean Stream Flow at West Yellowstone River (cfs))-125.82

2. Estimate Daily TSS concentration of Jack Creek using discharge-TSS relationship from 1976-1977 data (Figure F-2):

   TSS Jack Creek (mg/L) =0.3524 * Streamflow (cfs) + 1.11

3. Estimate Daily TSS Load of Jack Creek by multiplying result of step 1 (Daily Mean Stream Flow) by result of step 2 for each day (Estimate daily TSS concentration), and converting to tons per day:

   Daily TSS Load (Jack Creek) (tons) = (Daily Mean Stream Flow (cfs) * 28.32 L/cfs * 86400 s/day) * TSS concentration Jack Creek (mg/L) * 1 ton/100000000 mg

4. Divide the total TSS load estimated for each day by the sum of the TSS load across all days to obtain daily load proportion for Jack Creek:

   Daily Load Proportion (Jack Creek) = Daily TSS Load (Tons)/Annual TSS Load (Tons)

5. To determine daily loads for another subwatershed, multiply the estimated combined load from roads, upland sources, and bank erosion by the daily proportion estimated for Jack Creek, assuming the relative proportions are similar:
6.

Daily Load =Annual $\text{Load}_{\text{Roads+Bank Erosion + Upland}}$ (Tons) * Daily Load Proportion

Table F-1. Historical data collected at Jack Creek was used to estimate the proportion of sediment load for each day of the year for a typical subwatershed in the Madison TPA

Day of Year	Flow *Madison River* cfs	Estimated Flow *Jack Creek* cfs	Estimated TSS *Jack Creek* (mg/L)	Daily Water Volume *Jack Creek* (Liters per Day)	Daily Sediment Load *Jack Creek* (mg per Day)	Daily Sediment Load *Jack Creek* (Tons per Day)	Daily Load Proportion *Jack Creek* (Proportion of Annual)
1/1	408	22.2024	8.9	54325898	485175130	0.5	0.00024
1/2	408	22.2024	8.9	54325898	485175130	0.5	0.00024
1/3	414	24.3792	9.7	59652197	578502833	0.6	0.00029
1/4	405	21.114	8.5	51662749	441575648	0.4	0.00022
1/5	406	21.4768	8.7	52550465	455881818	0.5	0.00023
1/6	405	21.114	8.5	51662749	441575648	0.4	0.00022
1/7	407	21.8396	8.8	53438182	470414979	0.5	0.00023
1/8	410	22.928	9.2	56101331	515376403	0.5	0.00026
1/9	406	21.4768	8.7	52550465	455881818	0.5	0.00023
1/10	404	20.7512	8.4	50775032	427496468	0.4	0.00021
1/11	403	20.3884	8.3	49887316	413644279	0.4	0.00021
1/12	398	18.5744	7.7	45448733	347788187	0.3	0.00017
1/13	399	18.9372	7.8	46336450	360505424	0.4	0.00018
1/14	401	19.6628	8.0	48111883	386620871	0.4	0.00019
1/15	403	20.3884	8.3	49887316	413644279	0.4	0.00021
1/16	402	20.0256	8.2	48999599	400019079	0.4	0.00020
1/17	402	20.0256	8.2	48999599	400019079	0.4	0.00020
1/18	401	19.6628	8.0	48111883	386620871	0.4	0.00019
1/19	401	19.6628	8.0	48111883	386620871	0.4	0.00019
1/20	401	19.6628	8.0	48111883	386620871	0.4	0.00019
1/21	401	19.6628	8.0	48111883	386620871	0.4	0.00019
1/22	401	19.6628	8.0	48111883	386620871	0.4	0.00019
1/23	402	20.0256	8.2	48999599	400019079	0.4	0.00020
1/24	401	19.6628	8.0	48111883	386620871	0.4	0.00019
1/25	402	20.0256	8.2	48999599	400019079	0.4	0.00020
1/26	400	19.3	7.9	47224166	373449652	0.4	0.00019
1/27	399	18.9372	7.8	46336450	360505424	0.4	0.00018
1/28	400	19.3	7.9	47224166	373449652	0.4	0.00019
1/29	397	18.2116	7.5	44561017	335297940	0.3	0.00017
1/30	397	18.2116	7.5	44561017	335297940	0.3	0.00017

Table F-1. Historical data collected at Jack Creek was used to estimate the proportion of sediment load for each day of the year for a typical subwatershed in the Madison TPA

Day of Year	Flow *Madison River* cfs	Estimated Flow *Jack Creek* cfs	Estimated TSS *Jack Creek* (mg/L)	Daily Water Volume *Jack Creek* (Liters per Day)	Daily Sediment Load *Jack Creek* (mg per Day)	Daily Sediment Load *Jack Creek* (Tons per Day)	Daily Load Proportion *Jack Creek* (Proportion of Annual)
1/31	397	18.2116	7.5	44561017	335297940	0.3	0.00017
2/1	398	18.5744	7.7	45448733	347788187	0.3	0.00017
2/2	397	18.2116	7.5	44561017	335297940	0.3	0.00017
2/3	398	18.5744	7.7	45448733	347788187	0.3	0.00017
2/4	399	18.9372	7.8	46336450	360505424	0.4	0.00018
2/5	400	19.3	7.9	47224166	373449652	0.4	0.00019
2/6	399	18.9372	7.8	46336450	360505424	0.4	0.00018
2/7	398	18.5744	7.7	45448733	347788187	0.3	0.00017
2/8	397	18.2116	7.5	44561017	335297940	0.3	0.00017
2/9	397	18.2116	7.5	44561017	335297940	0.3	0.00017
2/10	399	18.9372	7.8	46336450	360505424	0.4	0.00018
2/11	398	18.5744	7.7	45448733	347788187	0.3	0.00017
2/12	399	18.9372	7.8	46336450	360505424	0.4	0.00018
2/13	399	18.9372	7.8	46336450	360505424	0.4	0.00018
2/14	398	18.5744	7.7	45448733	347788187	0.3	0.00017
2/15	398	18.5744	7.7	45448733	347788187	0.3	0.00017
2/16	397	18.2116	7.5	44561017	335297940	0.3	0.00017
2/17	397	18.2116	7.5	44561017	335297940	0.3	0.00017
2/18	398	18.5744	7.7	45448733	347788187	0.3	0.00017
2/19	397	18.2116	7.5	44561017	335297940	0.3	0.00017
2/20	397	18.2116	7.5	44561017	335297940	0.3	0.00017
2/21	398	18.5744	7.7	45448733	347788187	0.3	0.00017
2/22	398	18.5744	7.7	45448733	347788187	0.3	0.00017
2/23	398	18.5744	7.7	45448733	347788187	0.3	0.00017
2/24	397	18.2116	7.5	44561017	335297940	0.3	0.00017
2/25	398	18.5744	7.7	45448733	347788187	0.3	0.00017
2/26	397	18.2116	7.5	44561017	335297940	0.3	0.00017
2/27	397	18.2116	7.5	44561017	335297940	0.3	0.00017
2/28	397	18.2116	7.5	44561017	335297940	0.3	0.00017
2/29	395	17.486	7.3	42785584	310998416	0.3	0.00015
3/1	396	17.8488	7.4	43673301	323034683	0.3	0.00016
3/2	397	18.2116	7.5	44561017	335297940	0.3	0.00017
3/3	398	18.5744	7.7	45448733	347788187	0.3	0.00017
3/4	398	18.5744	7.7	45448733	347788187	0.3	0.00017

Table F-1. Historical data collected at Jack Creek was used to estimate the proportion of sediment load for each day of the year for a typical subwatershed in the Madison TPA

Day of Year	Flow *Madison River* cfs	Estimated Flow *Jack Creek* cfs	Estimated TSS *Jack Creek* (mg/L)	Daily Water Volume *Jack Creek* (Liters per Day)	Daily Sediment Load *Jack Creek* (mg per Day)	Daily Sediment Load *Jack Creek* (Tons per Day)	Daily Load Proportion *Jack Creek* (Proportion of Annual)
3/5	398	18.5744	7.7	45448733	347788187	0.3	0.00017
3/6	398	18.5744	7.7	45448733	347788187	0.3	0.00017
3/7	398	18.5744	7.7	45448733	347788187	0.3	0.00017
3/8	400	19.3	7.9	47224166	373449652	0.4	0.00019
3/9	400	19.3	7.9	47224166	373449652	0.4	0.00019
3/10	402	20.0256	8.2	48999599	400019079	0.4	0.00020
3/11	406	21.4768	8.7	52550465	455881818	0.5	0.00023
3/12	404	20.7512	8.4	50775032	427496468	0.4	0.00021
3/13	402	20.0256	8.2	48999599	400019079	0.4	0.00020
3/14	404	20.7512	8.4	50775032	427496468	0.4	0.00021
3/15	404	20.7512	8.4	50775032	427496468	0.4	0.00021
3/16	405	21.114	8.5	51662749	441575648	0.4	0.00022
3/17	408	22.2024	8.9	54325898	485175130	0.5	0.00024
3/18	407	21.8396	8.8	53438182	470414979	0.5	0.00023
3/19	406	21.4768	8.7	52550465	455881818	0.5	0.00023
3/20	408	22.2024	8.9	54325898	485175130	0.5	0.00024
3/21	410	22.928	9.2	56101331	515376403	0.5	0.00026
3/22	412	23.6536	9.4	57876764	546485637	0.5	0.00027
3/23	414	24.3792	9.7	59652197	578502833	0.6	0.00029
3/24	413	24.0164	9.6	58764480	562380740	0.6	0.00028
3/25	413	24.0164	9.6	58764480	562380740	0.6	0.00028
3/26	414	24.3792	9.7	59652197	578502833	0.6	0.00029
3/27	414	24.3792	9.7	59652197	578502833	0.6	0.00029
3/28	416	25.1048	10.0	61427630	611427991	0.6	0.00030
3/29	418	25.8304	10.2	63203063	645261110	0.6	0.00032
3/30	417	25.4676	10.1	62315346	628231055	0.6	0.00031
3/31	420	26.556	10.5	64978495	680002191	0.7	0.00034
4/1	424	28.0072	11.0	68529361	752208236	0.8	0.00037
4/2	428	29.4584	11.5	72080227	828046128	0.8	0.00041
4/3	430	30.184	11.7	73855660	867327016	0.9	0.00043
4/4	433	31.2724	12.1	76518809	927950776	0.9	0.00046
4/5	438	33.0864	12.8	80957392	1033530183	1.0	0.00052
4/6	443	34.9004	13.4	85395974	1144784350	1.1	0.00057
4/7	444	35.2632	13.5	86283690	1167716155	1.2	0.00058

Table F-1. Historical data collected at Jack Creek was used to estimate the proportion of sediment load for each day of the year for a typical subwatershed in the Madison TPA

Day of Year	Flow *Madison River* cfs	Estimated Flow *Jack Creek* cfs	Estimated TSS *Jack Creek* (mg/L)	Daily Water Volume *Jack Creek* (Liters per Day)	Daily Sediment Load *Jack Creek* (mg per Day)	Daily Sediment Load *Jack Creek* (Tons per Day)	Daily Load Proportion *Jack Creek* (Proportion of Annual)
4/8	449	37.0772	14.2	90722273	1285780033	1.3	0.00064
4/9	450	37.44	14.3	91609989	1310073780	1.3	0.00065
4/10	449	37.0772	14.2	90722273	1285780033	1.3	0.00064
4/11	452	38.1656	14.6	93385422	1359342244	1.4	0.00068
4/12	459	40.7052	15.5	99599437	1538932067	1.5	0.00077
4/13	465	42.882	16.2	104925736	1701718826	1.7	0.00085
4/14	476	46.8728	17.6	114690617	2021384817	2.0	0.00101
4/15	482	49.0496	18.4	120016916	2207324594	2.2	0.00110
4/16	487	50.8636	19.0	124455498	2368516643	2.4	0.00118
4/17	497	54.4916	20.3	133332662	2707925021	2.7	0.00135
4/18	508	58.4824	21.7	143097543	3107491624	3.1	0.00155
4/19	516	61.3848	22.7	150199275	3415336786	3.4	0.00170
4/20	523	63.9244	23.6	156413290	3696618297	3.7	0.00184
4/21	534	67.9152	25.0	166178171	4161104148	4.2	0.00207
4/22	543	71.1804	26.2	174167619	4561567159	4.6	0.00227
4/23	559	76.9852	28.2	188371083	5318899477	5.3	0.00265
4/24	558	76.6224	28.1	187483366	5269863780	5.3	0.00263
4/25	560	77.348	28.4	189258799	5368162166	5.4	0.00268
4/26	568	80.2504	29.4	196360531	5770435324	5.8	0.00288
4/27	569	80.6132	29.5	197248247	5821740925	5.8	0.00290
4/28	578	83.8784	30.7	205237695	6293705905	6.3	0.00314
4/29	587	87.1436	31.8	213227143	6784057106	6.8	0.00338
4/30	589	87.8692	32.1	215002576	6895520933	6.9	0.00344
5/1	603	92.9484	33.9	227430607	7701190648	7.7	0.00384
5/2	608	94.7624	34.5	231869189	7999711875	8.0	0.00399
5/3	622	99.8416	36.3	244297219	8865761030	8.9	0.00442
5/4	645	108.186	39.2	264714698	10385140475	10.4	0.00518
5/5	663	114.7164	41.5	280693594	11657979490	11.7	0.00581
5/6	681	121.2468	43.8	296672490	13004363386	13.0	0.00648
5/7	706	130.3168	47.0	318865401	14996348346	15.0	0.00747
5/8	723	136.4844	49.2	333956581	16431933684	16.4	0.00819
5/9	746	144.8288	52.1	354374060	18478611772	18.5	0.00921
5/10	765	151.722	54.6	371240672	20259915004	20.3	0.01010
5/11	773	154.6244	55.6	378342404	21034452378	21.0	0.01048

Table F-1. Historical data collected at Jack Creek was used to estimate the proportion of sediment load for each day of the year for a typical subwatershed in the Madison TPA

Day of Year	Flow *Madison River* cfs	Estimated Flow *Jack Creek* cfs	Estimated TSS *Jack Creek* (mg/L)	Daily Water Volume *Jack Creek* (Liters per Day)	Daily Sediment Load *Jack Creek* (mg per Day)	Daily Sediment Load *Jack Creek* (Tons per Day)	Daily Load Proportion *Jack Creek* (Proportion of Annual)
5/12	787	159.7036	57.4	390770434	22424849301	22.4	0.01117
5/13	806	166.5968	59.8	407637047	24382978036	24.4	0.01215
5/14	816	170.2248	61.1	416514211	25446485712	25.4	0.01268
5/15	838	178.2064	63.9	436043973	27866103211	27.9	0.01389
5/16	878	192.7184	69.0	471552632	32546875820	32.5	0.01622
5/17	912	205.0536	73.4	501734991	36811086430	36.8	0.01834
5/18	924	209.4072	74.9	512387589	38378751283	38.4	0.01912
5/19	932	212.3096	75.9	519489320	39442020415	39.4	0.01965
5/20	945	217.026	77.6	531029634	41200816941	41.2	0.02053
5/21	961	222.8308	79.6	545233097	43418151356	43.4	0.02164
5/22	970	226.096	80.8	553222545	44690938381	44.7	0.02227
5/23	970	226.096	80.8	553222545	44690938381	44.7	0.02227
5/24	978	228.9984	81.8	560324277	45837739972	45.8	0.02284
5/25	977	228.6356	81.7	559436561	45693595307	45.7	0.02277
5/26	975	227.91	81.4	557661128	45405986948	45.4	0.02263
5/27	976	228.2728	81.6	558548844	45549677632	45.5	0.02270
5/28	981	230.0868	82.2	562987426	46271535909	46.3	0.02306
5/29	991	233.7148	83.5	571864591	47732276743	47.7	0.02379
5/30	977	228.6356	81.7	559436561	45693595307	45.7	0.02277
5/31	961	222.8308	79.6	545233097	43418151356	43.4	0.02164
6/1	953	219.9284	78.6	538131366	42302220457	42.3	0.02108
6/2	953	219.9284	78.6	538131366	42302220457	42.3	0.02108
6/3	939	214.8492	76.8	525703335	40384297901	40.4	0.02012
6/4	930	211.584	75.7	517713887	39174841190	39.2	0.01952
6/5	923	209.0444	74.8	511499872	38246864098	38.2	0.01906
6/6	924	209.4072	74.9	512387589	38378751283	38.4	0.01912
6/7	922	208.6816	74.6	510612156	38115203904	38.1	0.01899
6/8	923	209.0444	74.8	511499872	38246864098	38.2	0.01906
6/9	916	206.5048	73.9	505285857	37330009535	37.3	0.01860
6/10	906	202.8768	72.6	496408692	36039511484	36.0	0.01796
6/11	879	193.0812	69.1	472440348	32668548438	32.7	0.01628
6/12	847	181.4716	65.1	444033422	28887611890	28.9	0.01440
6/13	832	176.0296	63.1	430717675	27195311991	27.2	0.01355
6/14	818	170.9504	61.3	418289644	25661911132	25.7	0.01279

Table F-1. Historical data collected at Jack Creek was used to estimate the proportion of sediment load for each day of the year for a typical subwatershed in the Madison TPA

Day of Year	Flow *Madison River* cfs	Estimated Flow *Jack Creek* cfs	Estimated TSS *Jack Creek* (mg/L)	Daily Water Volume *Jack Creek* (Liters per Day)	Daily Sediment Load *Jack Creek* (mg per Day)	Daily Sediment Load *Jack Creek* (Tons per Day)	Daily Load Proportion *Jack Creek* (Proportion of Annual)
6/15	810	168.048	60.3	411187913	24805657222	24.8	0.01236
6/16	809	167.6852	60.2	410300196	24699646940	24.7	0.01231
6/17	790	160.792	57.8	393433584	22728579754	22.7	0.01133
6/18	767	152.4476	54.8	373016105	20452187405	20.5	0.01019
6/19	749	145.9172	52.5	357037209	18754422408	18.8	0.00935
6/20	729	138.6612	50.0	339282880	16954273197	17.0	0.00845
6/21	714	133.2192	48.1	325967133	15663746263	15.7	0.00781
6/22	700	128.14	46.3	313539103	14505333504	14.5	0.00723
6/23	685	122.698	44.3	300223356	13313547384	13.3	0.00663
6/24	670	117.256	42.4	286907609	12172834098	12.2	0.00607
6/25	657	112.5396	40.8	275367295	11225528165	11.2	0.00559
6/26	646	108.5488	39.4	265602414	10453924336	10.5	0.00521
6/27	639	106.0092	38.5	259388399	9977204111	10.0	0.00497
6/28	624	100.5672	36.5	246072652	8993114184	9.0	0.00448
6/29	602	92.5856	33.7	226542890	7642167374	7.6	0.00381
6/30	589	87.8692	32.1	215002576	6895520933	6.9	0.00344
7/1	583	85.6924	31.3	209676278	6563853335	6.6	0.00327
7/2	570	80.976	29.6	198135964	5873273517	5.9	0.00293
7/3	564	78.7992	28.9	192809665	5567482822	5.6	0.00277
7/4	551	74.0828	27.2	181269351	4932969626	4.9	0.00246
7/5	541	70.4548	25.9	172392186	4470986446	4.5	0.00223
7/6	537	69.0036	25.4	168841321	4292548905	4.3	0.00214
7/7	525	64.65	23.9	158188723	3779027356	3.8	0.00188
7/8	519	62.4732	23.1	152862424	3534524063	3.5	0.00176
7/9	512	59.9336	22.2	146648409	3259598282	3.3	0.00162
7/10	509	58.8452	21.8	143985260	3145177803	3.1	0.00157
7/11	506	57.7568	21.5	141322111	3032800237	3.0	0.00151
7/12	500	55.58	20.7	135995812	2814173846	2.8	0.00140
7/13	495	53.766	20.1	131557230	2638227422	2.6	0.00131
7/14	485	50.138	18.8	122680065	2303358852	2.3	0.00115
7/15	479	47.9612	18.0	117353766	2113333249	2.1	0.00105
7/16	473	45.7844	17.2	112027468	1931479298	1.9	0.00096
7/17	469	44.3332	16.7	108476602	1814783139	1.8	0.00090
7/18	465	42.882	16.2	104925736	1701718826	1.7	0.00085

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Day of Year	Flow *Madison River* cfs	Estimated Flow *Jack Creek* cfs	Estimated TSS *Jack Creek* (mg/L)	Daily Water Volume *Jack Creek* (Liters per Day)	Daily Sediment Load *Jack Creek* (mg per Day)	Daily Sediment Load *Jack Creek* (Tons per Day)	Daily Load Proportion *Jack Creek* (Proportion of Annual)
7/19	460	41.068	15.6	100487154	1565495718	1.6	0.00078
7/20	460	41.068	15.6	100487154	1565495718	1.6	0.00078
7/21	462	41.7936	15.8	102262587	1619303990	1.6	0.00081
7/22	461	41.4308	15.7	101374870	1592286359	1.6	0.00079
7/23	460	41.068	15.6	100487154	1565495718	1.6	0.00078
7/24	458	40.3424	15.3	98711721	1512595407	1.5	0.00075
7/25	457	39.9796	15.2	97824004	1486485737	1.5	0.00074
7/26	454	38.8912	14.8	95160855	1409518670	1.4	0.00070
7/27	451	37.8028	14.4	92497706	1334594517	1.3	0.00067
7/28	450	37.44	14.3	91609989	1310073780	1.3	0.00065
7/29	452	38.1656	14.6	93385422	1359342244	1.4	0.00068
7/30	456	39.6168	15.1	96936288	1460603058	1.5	0.00073
7/31	450	37.44	14.3	91609989	1310073780	1.3	0.00065
8/1	448	36.7144	14.0	89834556	1261713276	1.3	0.00063
8/2	444	35.2632	13.5	86283690	1167716155	1.2	0.00058
8/3	442	34.5376	13.3	84508257	1122079536	1.1	0.00056
8/4	442	34.5376	13.3	84508257	1122079536	1.1	0.00056
8/5	441	34.1748	13.1	83620541	1099601712	1.1	0.00055
8/6	438	33.0864	12.8	80957392	1033530183	1.0	0.00052
8/7	432	30.9096	12.0	75631093	907515866	0.9	0.00045
8/8	431	30.5468	11.9	74743376	887307946	0.9	0.00044
8/9	430	30.184	11.7	73855660	867327016	0.9	0.00043
8/10	431	30.5468	11.9	74743376	887307946	0.9	0.00044
8/11	431	30.5468	11.9	74743376	887307946	0.9	0.00044
8/12	427	29.0956	11.4	71192511	808746169	0.8	0.00040
8/13	427	29.0956	11.4	71192511	808746169	0.8	0.00040
8/14	425	28.37	11.1	69417078	770827224	0.8	0.00038
8/15	424	28.0072	11.0	68529361	752208236	0.8	0.00037
8/16	424	28.0072	11.0	68529361	752208236	0.8	0.00037
8/17	423	27.6444	10.8	67641645	733816239	0.7	0.00037
8/18	421	26.9188	10.6	65866212	697713216	0.7	0.00035
8/19	424	28.0072	11.0	68529361	752208236	0.8	0.00037
8/20	428	29.4584	11.5	72080227	828046128	0.8	0.00041
8/21	426	28.7328	11.2	70304794	789673201	0.8	0.00039

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8/22	426	28.7328	11.2	70304794	789673201	0.8	0.00039
8/23	422	27.2816	10.7	66753928	715651233	0.7	0.00036
8/24	422	27.2816	10.7	66753928	715651233	0.7	0.00036
8/25	419	26.1932	10.3	64090779	662518155	0.7	0.00033
8/26	419	26.1932	10.3	64090779	662518155	0.7	0.00033
8/27	417	25.4676	10.1	62315346	628231055	0.6	0.00031
8/28	416	25.1048	10.0	61427630	611427991	0.6	0.00030
8/29	417	25.4676	10.1	62315346	628231055	0.6	0.00031
8/30	419	26.1932	10.3	64090779	662518155	0.7	0.00033
8/31	421	26.9188	10.6	65866212	697713216	0.7	0.00035
9/1	419	26.1932	10.3	64090779	662518155	0.7	0.00033
9/2	419	26.1932	10.3	64090779	662518155	0.7	0.00033
9/3	419	26.1932	10.3	64090779	662518155	0.7	0.00033
9/4	416	25.1048	10.0	61427630	611427991	0.6	0.00030
9/5	417	25.4676	10.1	62315346	628231055	0.6	0.00031
9/6	421	26.9188	10.6	65866212	697713216	0.7	0.00035
9/7	422	27.2816	10.7	66753928	715651233	0.7	0.00036
9/8	417	25.4676	10.1	62315346	628231055	0.6	0.00031
9/9	423	27.6444	10.8	67641645	733816239	0.7	0.00037
9/10	425	28.37	11.1	69417078	770827224	0.8	0.00038
9/11	420	26.556	10.5	64978495	680002191	0.7	0.00034
9/12	421	26.9188	10.6	65866212	697713216	0.7	0.00035
9/13	420	26.556	10.5	64978495	680002191	0.7	0.00034
9/14	419	26.1932	10.3	64090779	662518155	0.7	0.00033
9/15	421	26.9188	10.6	65866212	697713216	0.7	0.00035
9/16	418	25.8304	10.2	63203063	645261110	0.6	0.00032
9/17	418	25.8304	10.2	63203063	645261110	0.6	0.00032
9/18	422	27.2816	10.7	66753928	715651233	0.7	0.00036
9/19	427	29.0956	11.4	71192511	808746169	0.8	0.00040
9/20	430	30.184	11.7	73855660	867327016	0.9	0.00043
9/21	430	30.184	11.7	73855660	867327016	0.9	0.00043
9/22	429	29.8212	11.6	72967944	847573077	0.8	0.00042
9/23	425	28.37	11.1	69417078	770827224	0.8	0.00038
9/24	426	28.7328	11.2	70304794	789673201	0.8	0.00039

Table F-1. Historical data collected at Jack Creek was used to estimate the proportion of sediment load for each day of the year for a typical subwatershed in the Madison TPA

Day of Year	Flow *Madison River* cfs	Estimated Flow *Jack Creek* cfs	Estimated TSS *Jack Creek* (mg/L)	Daily Water Volume *Jack Creek* (Liters per Day)	Daily Sediment Load *Jack Creek* (mg per Day)	Daily Sediment Load *Jack Creek* (Tons per Day)	Daily Load Proportion *Jack Creek* (Proportion of Annual)
9/25	424	28.0072	11.0	68529361	752208236	0.8	0.00037
9/26	422	27.2816	10.7	66753928	715651233	0.7	0.00036
9/27	423	27.6444	10.8	67641645	733816239	0.7	0.00037
9/28	428	29.4584	11.5	72080227	828046128	0.8	0.00041
9/29	425	28.37	11.1	69417078	770827224	0.8	0.00038
9/30	428	29.4584	11.5	72080227	828046128	0.8	0.00041
10/1	428	29.4584	11.5	72080227	828046128	0.8	0.00041
10/2	430	30.184	11.7	73855660	867327016	0.9	0.00043
10/3	433	31.2724	12.1	76518809	927950776	0.9	0.00046
10/4	428	29.4584	11.5	72080227	828046128	0.8	0.00041
10/5	429	29.8212	11.6	72967944	847573077	0.8	0.00042
10/6	433	31.2724	12.1	76518809	927950776	0.9	0.00046
10/7	436	32.3608	12.5	79181959	990617449	1.0	0.00049
10/8	434	31.6352	12.3	77406526	948612677	0.9	0.00047
10/9	430	30.184	11.7	73855660	867327016	0.9	0.00043
10/10	432	30.9096	12.0	75631093	907515866	0.9	0.00045
10/11	435	31.998	12.4	78294242	969501568	1.0	0.00048
10/12	433	31.2724	12.1	76518809	927950776	0.9	0.00046
10/13	430	30.184	11.7	73855660	867327016	0.9	0.00043
10/14	428	29.4584	11.5	72080227	828046128	0.8	0.00041
10/15	433	31.2724	12.1	76518809	927950776	0.9	0.00046
10/16	437	32.7236	12.6	80069675	1011960321	1.0	0.00050
10/17	431	30.5468	11.9	74743376	887307946	0.9	0.00044
10/18	429	29.8212	11.6	72967944	847573077	0.8	0.00042
10/19	428	29.4584	11.5	72080227	828046128	0.8	0.00041
10/20	431	30.5468	11.9	74743376	887307946	0.9	0.00044
10/21	427	29.0956	11.4	71192511	808746169	0.8	0.00040
10/22	428	29.4584	11.5	72080227	828046128	0.8	0.00041
10/23	431	30.5468	11.9	74743376	887307946	0.9	0.00044
10/24	430	30.184	11.7	73855660	867327016	0.9	0.00043
10/25	429	29.8212	11.6	72967944	847573077	0.8	0.00042
10/26	429	29.8212	11.6	72967944	847573077	0.8	0.00042
10/27	430	30.184	11.7	73855660	867327016	0.9	0.00043
10/28	431	30.5468	11.9	74743376	887307946	0.9	0.00044

Table F-1. Historical data collected at Jack Creek was used to estimate the proportion of sediment load for each day of the year for a typical subwatershed in the Madison TPA

Day of Year	Flow *Madison River* cfs	Estimated Flow *Jack Creek* cfs	Estimated TSS *Jack Creek* (mg/L)	Daily Water Volume *Jack Creek* (Liters per Day)	Daily Sediment Load *Jack Creek* (mg per Day)	Daily Sediment Load *Jack Creek* (Tons per Day)	Daily Load Proportion *Jack Creek* (Proportion of Annual)
10/29	431	30.5468	11.9	74743376	887307946	0.9	0.00044
10/30	428	29.4584	11.5	72080227	828046128	0.8	0.00041
10/31	432	30.9096	12.0	75631093	907515866	0.9	0.00045
11/1	427	29.0956	11.4	71192511	808746169	0.8	0.00040
11/2	424	28.0072	11.0	68529361	752208236	0.8	0.00037
11/3	426	28.7328	11.2	70304794	789673201	0.8	0.00039
11/4	427	29.0956	11.4	71192511	808746169	0.8	0.00040
11/5	427	29.0956	11.4	71192511	808746169	0.8	0.00040
11/6	425	28.37	11.1	69417078	770827224	0.8	0.00038
11/7	426	28.7328	11.2	70304794	789673201	0.8	0.00039
11/8	424	28.0072	11.0	68529361	752208236	0.8	0.00037
11/9	426	28.7328	11.2	70304794	789673201	0.8	0.00039
11/10	429	29.8212	11.6	72967944	847573077	0.8	0.00042
11/11	425	28.37	11.1	69417078	770827224	0.8	0.00038
11/12	422	27.2816	10.7	66753928	715651233	0.7	0.00036
11/13	424	28.0072	11.0	68529361	752208236	0.8	0.00037
11/14	422	27.2816	10.7	66753928	715651233	0.7	0.00036
11/15	422	27.2816	10.7	66753928	715651233	0.7	0.00036
11/16	421	26.9188	10.6	65866212	697713216	0.7	0.00035
11/17	419	26.1932	10.3	64090779	662518155	0.7	0.00033
11/18	419	26.1932	10.3	64090779	662518155	0.7	0.00033
11/19	420	26.556	10.5	64978495	680002191	0.7	0.00034
11/20	421	26.9188	10.6	65866212	697713216	0.7	0.00035
11/21	422	27.2816	10.7	66753928	715651233	0.7	0.00036
11/22	419	26.1932	10.3	64090779	662518155	0.7	0.00033
11/23	418	25.8304	10.2	63203063	645261110	0.6	0.00032
11/24	418	25.8304	10.2	63203063	645261110	0.6	0.00032
11/25	419	26.1932	10.3	64090779	662518155	0.7	0.00033
11/26	417	25.4676	10.1	62315346	628231055	0.6	0.00031
11/27	418	25.8304	10.2	63203063	645261110	0.6	0.00032
11/28	419	26.1932	10.3	64090779	662518155	0.7	0.00033
11/29	415	24.742	9.8	60539913	594851917	0.6	0.00030
11/30	416	25.1048	10.0	61427630	611427991	0.6	0.00030
12/1	417	25.4676	10.1	62315346	628231055	0.6	0.00031

Table F-1. Historical data collected at Jack Creek was used to estimate the proportion of sediment load for each day of the year for a typical subwatershed in the Madison TPA

Day of Year	Flow *Madison River* cfs	Estimated Flow *Jack Creek* cfs	Estimated TSS *Jack Creek* (mg/L)	Daily Water Volume *Jack Creek* (Liters per Day)	Daily Sediment Load *Jack Creek* (mg per Day)	Daily Sediment Load *Jack Creek* (Tons per Day)	Daily Load Proportion *Jack Creek* (Proportion of Annual)
12/2	419	26.1932	10.3	64090779	662518155	0.7	0.00033
12/3	420	26.556	10.5	64978495	680002191	0.7	0.00034
12/4	417	25.4676	10.1	62315346	628231055	0.6	0.00031
12/5	415	24.742	9.8	60539913	594851917	0.6	0.00030
12/6	415	24.742	9.8	60539913	594851917	0.6	0.00030
12/7	416	25.1048	10.0	61427630	611427991	0.6	0.00030
12/8	414	24.3792	9.7	59652197	578502833	0.6	0.00029
12/9	414	24.3792	9.7	59652197	578502833	0.6	0.00029
12/10	415	24.742	9.8	60539913	594851917	0.6	0.00030
12/11	414	24.3792	9.7	59652197	578502833	0.6	0.00029
12/12	414	24.3792	9.7	59652197	578502833	0.6	0.00029
12/13	416	25.1048	10.0	61427630	611427991	0.6	0.00030
12/14	414	24.3792	9.7	59652197	578502833	0.6	0.00029
12/15	413	24.0164	9.6	58764480	562380740	0.6	0.00028
12/16	412	23.6536	9.4	57876764	546485637	0.5	0.00027
12/17	411	23.2908	9.3	56989047	530817525	0.5	0.00026
12/18	409	22.5652	9.1	55213614	500162271	0.5	0.00025
12/19	411	23.2908	9.3	56989047	530817525	0.5	0.00026
12/20	409	22.5652	9.1	55213614	500162271	0.5	0.00025
12/21	409	22.5652	9.1	55213614	500162271	0.5	0.00025
12/22	411	23.2908	9.3	56989047	530817525	0.5	0.00026
12/23	415	24.742	9.8	60539913	594851917	0.6	0.00030
12/24	413	24.0164	9.6	58764480	562380740	0.6	0.00028
12/25	412	23.6536	9.4	57876764	546485637	0.5	0.00027
12/26	409	22.5652	9.1	55213614	500162271	0.5	0.00025
12/27	408	22.2024	8.9	54325898	485175130	0.5	0.00024
12/28	411	23.2908	9.3	56989047	530817525	0.5	0.00026
12/29	411	23.2908	9.3	56989047	530817525	0.5	0.00026
12/30	410	22.928	9.2	56101331	515376403	0.5	0.00026
12/31	409	22.5652	9.1	55213614	500162271	0.5	0.00025

F3.0 SEDIMENT TOTAL MAXIMUM DAILY LOADS

To estimate total maximum daily loads, the daily load proportion was multiplied by the current estimated annual load for each subwatershed after implementing BMPs as described in Section 5.7 of the main TMDL document.

Table F-2. Estimated Total Maximum Daily Load for sediment impaired watersheds in Madison TPA (in Tons)

Day	Antelope	Bear	Blaine Spring	Cherry	Elk	Hot Springs	Moore Creek	North Meadow	Red Canyon	Ruby	South Meadow	Watkins	Wigwam
1/1	0.4	1.2	0.4	1.4	0.8	0.7	0.5	0.6	0.2	0.5	0.3	0.1	0.3
1/2	0.4	1.2	0.4	1.4	0.8	0.7	0.5	0.6	0.2	0.5	0.3	0.1	0.3
1/3	0.5	1.5	0.4	1.7	1.0	0.8	0.6	0.7	0.2	0.6	0.4	0.1	0.3
1/4	0.4	1.1	0.3	1.3	0.7	0.6	0.5	0.6	0.2	0.4	0.3	0.1	0.2
1/5	0.4	1.2	0.4	1.3	0.8	0.6	0.5	0.6	0.2	0.4	0.3	0.1	0.2
1/6	0.4	1.1	0.3	1.3	0.7	0.6	0.5	0.6	0.2	0.4	0.3	0.1	0.2
1/7	0.4	1.2	0.4	1.4	0.8	0.7	0.5	0.6	0.2	0.5	0.3	0.1	0.2
1/8	0.4	1.3	0.4	1.5	0.9	0.7	0.6	0.6	0.2	0.5	0.4	0.1	0.3
1/9	0.4	1.2	0.4	1.3	0.8	0.6	0.5	0.6	0.2	0.4	0.3	0.1	0.2
1/10	0.3	1.1	0.3	1.2	0.7	0.6	0.5	0.5	0.1	0.4	0.3	0.1	0.2
1/11	0.3	1.0	0.3	1.2	0.7	0.6	0.5	0.5	0.1	0.4	0.3	0.1	0.2
1/12	0.3	0.9	0.3	1.0	0.6	0.5	0.4	0.4	0.1	0.3	0.2	0.1	0.2
1/13	0.3	0.9	0.3	1.1	0.6	0.5	0.4	0.5	0.1	0.3	0.2	0.1	0.2
1/14	0.3	1.0	0.3	1.1	0.6	0.5	0.4	0.5	0.1	0.4	0.3	0.1	0.2
1/15	0.3	1.0	0.3	1.2	0.7	0.6	0.5	0.5	0.1	0.4	0.3	0.1	0.2
1/16	0.3	1.0	0.3	1.2	0.7	0.6	0.4	0.5	0.1	0.4	0.3	0.1	0.2
1/17	0.3	1.0	0.3	1.2	0.7	0.6	0.4	0.5	0.1	0.4	0.3	0.1	0.2
1/18	0.3	1.0	0.3	1.1	0.6	0.5	0.4	0.5	0.1	0.4	0.3	0.1	0.2
1/19	0.3	1.0	0.3	1.1	0.6	0.5	0.4	0.5	0.1	0.4	0.3	0.1	0.2
1/20	0.3	1.0	0.3	1.1	0.6	0.5	0.4	0.5	0.1	0.4	0.3	0.1	0.2
1/21	0.3	1.0	0.3	1.1	0.6	0.5	0.4	0.5	0.1	0.4	0.3	0.1	0.2
1/22	0.3	1.0	0.3	1.1	0.6	0.5	0.4	0.5	0.1	0.4	0.3	0.1	0.2
1/23	0.3	1.0	0.3	1.2	0.7	0.6	0.4	0.5	0.1	0.4	0.3	0.1	0.2
1/24	0.3	1.0	0.3	1.1	0.6	0.5	0.4	0.5	0.1	0.4	0.3	0.1	0.2
1/25	0.3	1.0	0.3	1.2	0.7	0.6	0.4	0.5	0.1	0.4	0.3	0.1	0.2
1/26	0.3	0.9	0.3	1.1	0.6	0.5	0.4	0.5	0.1	0.4	0.3	0.1	0.2
1/27	0.3	0.9	0.3	1.1	0.6	0.5	0.4	0.5	0.1	0.3	0.2	0.1	0.2
1/28	0.3	0.9	0.3	1.1	0.6	0.5	0.4	0.5	0.1	0.4	0.3	0.1	0.2
1/29	0.3	0.8	0.3	1.0	0.6	0.5	0.4	0.4	0.1	0.3	0.2	0.1	0.2
1/30	0.3	0.8	0.3	1.0	0.6	0.5	0.4	0.4	0.1	0.3	0.2	0.1	0.2
1/31	0.3	0.8	0.3	1.0	0.6	0.5	0.4	0.4	0.1	0.3	0.2	0.1	0.2
2/1	0.3	0.9	0.3	1.0	0.6	0.5	0.4	0.4	0.1	0.3	0.2	0.1	0.2

Table F-2. Estimated Total Maximum Daily Load for sediment impaired watersheds in Madison TPA (in Tons)

Day	Antelope	Bear	Blaine Spring	Cherry	Elk	Hot Springs	Moore Creek	North Meadow	Red Canyon	Ruby	South Meadow	Watkins	Wigwam
2/2	0.3	0.8	0.3	1.0	0.6	0.5	0.4	0.4	0.1	0.3	0.2	0.1	0.2
2/3	0.3	0.9	0.3	1.0	0.6	0.5	0.4	0.4	0.1	0.3	0.2	0.1	0.2
2/4	0.3	0.9	0.3	1.1	0.6	0.5	0.4	0.5	0.1	0.3	0.2	0.1	0.2
2/5	0.3	0.9	0.3	1.1	0.6	0.5	0.4	0.5	0.1	0.4	0.3	0.1	0.2
2/6	0.3	0.9	0.3	1.1	0.6	0.5	0.4	0.5	0.1	0.3	0.2	0.1	0.2
2/7	0.3	0.9	0.3	1.0	0.6	0.5	0.4	0.4	0.1	0.3	0.2	0.1	0.2
2/8	0.3	0.8	0.3	1.0	0.6	0.5	0.4	0.4	0.1	0.3	0.2	0.1	0.2
2/9	0.3	0.8	0.3	1.0	0.6	0.5	0.4	0.4	0.1	0.3	0.2	0.1	0.2
2/10	0.3	0.9	0.3	1.1	0.6	0.5	0.4	0.5	0.1	0.3	0.2	0.1	0.2
2/11	0.3	0.9	0.3	1.0	0.6	0.5	0.4	0.4	0.1	0.3	0.2	0.1	0.2
2/12	0.3	0.9	0.3	1.1	0.6	0.5	0.4	0.5	0.1	0.3	0.2	0.1	0.2
2/13	0.3	0.9	0.3	1.1	0.6	0.5	0.4	0.5	0.1	0.3	0.2	0.1	0.2
2/14	0.3	0.9	0.3	1.0	0.6	0.5	0.4	0.4	0.1	0.3	0.2	0.1	0.2
2/15	0.3	0.9	0.3	1.0	0.6	0.5	0.4	0.4	0.1	0.3	0.2	0.1	0.2
2/16	0.3	0.8	0.3	1.0	0.6	0.5	0.4	0.4	0.1	0.3	0.2	0.1	0.2
2/17	0.3	0.8	0.3	1.0	0.6	0.5	0.4	0.4	0.1	0.3	0.2	0.1	0.2
2/18	0.3	0.9	0.3	1.0	0.6	0.5	0.4	0.4	0.1	0.3	0.2	0.1	0.2
2/19	0.3	0.8	0.3	1.0	0.6	0.5	0.4	0.4	0.1	0.3	0.2	0.1	0.2
2/20	0.3	0.8	0.3	1.0	0.6	0.5	0.4	0.4	0.1	0.3	0.2	0.1	0.2
2/21	0.3	0.9	0.3	1.0	0.6	0.5	0.4	0.4	0.1	0.3	0.2	0.1	0.2
2/22	0.3	0.9	0.3	1.0	0.6	0.5	0.4	0.4	0.1	0.3	0.2	0.1	0.2
2/23	0.3	0.9	0.3	1.0	0.6	0.5	0.4	0.4	0.1	0.3	0.2	0.1	0.2
2/24	0.3	0.8	0.3	1.0	0.6	0.5	0.4	0.4	0.1	0.3	0.2	0.1	0.2
2/25	0.3	0.9	0.3	1.0	0.6	0.5	0.4	0.4	0.1	0.3	0.2	0.1	0.2
2/26	0.3	0.8	0.3	1.0	0.6	0.5	0.4	0.4	0.1	0.3	0.2	0.1	0.2
2/27	0.3	0.8	0.3	1.0	0.6	0.5	0.4	0.4	0.1	0.3	0.2	0.1	0.2
2/28	0.3	0.8	0.3	1.0	0.6	0.5	0.4	0.4	0.1	0.3	0.2	0.1	0.2
2/29	0.3	0.8	0.2	0.9	0.5	0.4	0.3	0.4	0.1	0.3	0.2	0.1	0.2
3/1	0.3	0.8	0.2	0.9	0.5	0.5	0.4	0.4	0.1	0.3	0.2	0.1	0.2
3/2	0.3	0.8	0.3	1.0	0.6	0.5	0.4	0.4	0.1	0.3	0.2	0.1	0.2
3/3	0.3	0.9	0.3	1.0	0.6	0.5	0.4	0.4	0.1	0.3	0.2	0.1	0.2
3/4	0.3	0.9	0.3	1.0	0.6	0.5	0.4	0.4	0.1	0.3	0.2	0.1	0.2
3/5	0.3	0.9	0.3	1.0	0.6	0.5	0.4	0.4	0.1	0.3	0.2	0.1	0.2
3/6	0.3	0.9	0.3	1.0	0.6	0.5	0.4	0.4	0.1	0.3	0.2	0.1	0.2
3/7	0.3	0.9	0.3	1.0	0.6	0.5	0.4	0.4	0.1	0.3	0.2	0.1	0.2
3/8	0.3	0.9	0.3	1.1	0.6	0.5	0.4	0.5	0.1	0.4	0.3	0.1	0.2
3/9	0.3	0.9	0.3	1.1	0.6	0.5	0.4	0.5	0.1	0.4	0.3	0.1	0.2
3/10	0.3	1.0	0.3	1.2	0.7	0.6	0.4	0.5	0.1	0.4	0.3	0.1	0.2

Table F-2. Estimated Total Maximum Daily Load for sediment impaired watersheds in Madison TPA (in Tons)

Day	Antelope	Bear	Blaine Spring	Cherry	Elk	Hot Springs	Moore Creek	North Meadow	Red Canyon	Ruby	South Meadow	Watkins	Wigwam
3/11	0.4	1.2	0.4	1.3	0.8	0.6	0.5	0.6	0.2	0.4	0.3	0.1	0.2
3/12	0.3	1.1	0.3	1.2	0.7	0.6	0.5	0.5	0.1	0.4	0.3	0.1	0.2
3/13	0.3	1.0	0.3	1.2	0.7	0.6	0.4	0.5	0.1	0.4	0.3	0.1	0.2
3/14	0.3	1.1	0.3	1.2	0.7	0.6	0.5	0.5	0.1	0.4	0.3	0.1	0.2
3/15	0.3	1.1	0.3	1.2	0.7	0.6	0.5	0.5	0.1	0.4	0.3	0.1	0.2
3/16	0.4	1.1	0.3	1.3	0.7	0.6	0.5	0.6	0.2	0.4	0.3	0.1	0.2
3/17	0.4	1.2	0.4	1.4	0.8	0.7	0.5	0.6	0.2	0.5	0.3	0.1	0.3
3/18	0.4	1.2	0.4	1.4	0.8	0.7	0.5	0.6	0.2	0.5	0.3	0.1	0.2
3/19	0.4	1.2	0.4	1.3	0.8	0.6	0.5	0.6	0.2	0.4	0.3	0.1	0.2
3/20	0.4	1.2	0.4	1.4	0.8	0.7	0.5	0.6	0.2	0.5	0.3	0.1	0.3
3/21	0.4	1.3	0.4	1.5	0.9	0.7	0.6	0.6	0.2	0.5	0.4	0.1	0.3
3/22	0.4	1.4	0.4	1.6	0.9	0.8	0.6	0.7	0.2	0.5	0.4	0.1	0.3
3/23	0.5	1.5	0.4	1.7	1.0	0.8	0.6	0.7	0.2	0.6	0.4	0.1	0.3
3/24	0.5	1.4	0.4	1.6	0.9	0.8	0.6	0.7	0.2	0.5	0.4	0.1	0.3
3/25	0.5	1.4	0.4	1.6	0.9	0.8	0.6	0.7	0.2	0.5	0.4	0.1	0.3
3/26	0.5	1.5	0.4	1.7	1.0	0.8	0.6	0.7	0.2	0.6	0.4	0.1	0.3
3/27	0.5	1.5	0.4	1.7	1.0	0.8	0.6	0.7	0.2	0.6	0.4	0.1	0.3
3/28	0.5	1.5	0.5	1.8	1.0	0.9	0.7	0.8	0.2	0.6	0.4	0.1	0.3
3/29	0.5	1.6	0.5	1.9	1.1	0.9	0.7	0.8	0.2	0.6	0.4	0.1	0.3
3/30	0.5	1.6	0.5	1.8	1.1	0.9	0.7	0.8	0.2	0.6	0.4	0.1	0.3
3/31	0.5	1.7	0.5	2.0	1.1	1.0	0.7	0.9	0.2	0.7	0.5	0.2	0.4
4/1	0.6	1.9	0.6	2.2	1.3	1.1	0.8	0.9	0.3	0.7	0.5	0.2	0.4
4/2	0.7	2.1	0.6	2.4	1.4	1.2	0.9	1.0	0.3	0.8	0.6	0.2	0.4
4/3	0.7	2.2	0.7	2.5	1.5	1.2	1.0	1.1	0.3	0.8	0.6	0.2	0.5
4/4	0.7	2.3	0.7	2.7	1.6	1.3	1.0	1.2	0.3	0.9	0.6	0.2	0.5
4/5	0.8	2.6	0.8	3.0	1.7	1.5	1.1	1.3	0.4	1.0	0.7	0.2	0.5
4/6	0.9	2.9	0.9	3.3	1.9	1.6	1.3	1.4	0.4	1.1	0.8	0.3	0.6
4/7	0.9	3.0	0.9	3.4	2.0	1.6	1.3	1.5	0.4	1.1	0.8	0.3	0.6
4/8	1.0	3.3	1.0	3.7	2.2	1.8	1.4	1.6	0.5	1.2	0.9	0.3	0.7
4/9	1.1	3.3	1.0	3.8	2.2	1.8	1.4	1.6	0.5	1.3	0.9	0.3	0.7
4/10	1.0	3.3	1.0	3.7	2.2	1.8	1.4	1.6	0.5	1.2	0.9	0.3	0.7
4/11	1.1	3.4	1.1	4.0	2.3	1.9	1.5	1.7	0.5	1.3	0.9	0.3	0.7
4/12	1.2	3.9	1.2	4.5	2.6	2.2	1.7	1.9	0.5	1.5	1.1	0.4	0.8
4/13	1.4	4.3	1.3	5.0	2.9	2.4	1.9	2.1	0.6	1.6	1.2	0.4	0.9
4/14	1.6	5.1	1.6	5.9	3.4	2.9	2.2	2.5	0.7	1.9	1.4	0.5	1.1
4/15	1.8	5.6	1.7	6.4	3.7	3.1	2.4	2.8	0.8	2.1	1.5	0.5	1.2
4/16	1.9	6.0	1.8	6.9	4.0	3.3	2.6	3.0	0.8	2.3	1.6	0.5	1.2
4/17	2.2	6.9	2.1	7.9	4.5	3.8	3.0	3.4	0.9	2.6	1.9	0.6	1.4

Table F-2. Estimated Total Maximum Daily Load for sediment impaired watersheds in Madison TPA (in Tons)

Day	Antelope	Bear	Blaine Spring	Cherry	Elk	Hot Springs	Moore Creek	North Meadow	Red Canyon	Ruby	South Meadow	Watkins	Wigwam
4/18	2.5	7.9	2.4	9.1	5.2	4.4	3.4	3.9	1.1	3.0	2.1	0.7	1.6
4/19	2.7	8.6	2.6	10.0	5.7	4.8	3.8	4.3	1.2	3.3	2.4	0.8	1.8
4/20	3.0	9.4	2.9	10.8	6.2	5.2	4.1	4.7	1.3	3.5	2.6	0.8	1.9
4/21	3.3	10.5	3.2	12.1	7.0	5.9	4.6	5.2	1.5	4.0	2.9	1.0	2.2
4/22	3.7	11.5	3.5	13.3	7.6	6.4	5.0	5.7	1.6	4.4	3.2	1.0	2.4
4/23	4.3	13.5	4.1	15.5	8.9	7.5	5.9	6.7	1.9	5.1	3.7	1.2	2.8
4/24	4.2	13.3	4.1	15.4	8.8	7.4	5.8	6.6	1.8	5.0	3.6	1.2	2.8
4/25	4.3	13.6	4.2	15.6	9.0	7.6	5.9	6.8	1.9	5.1	3.7	1.2	2.8
4/26	4.6	14.6	4.5	16.8	9.7	8.1	6.4	7.3	2.0	5.5	4.0	1.3	3.0
4/27	4.7	14.7	4.5	17.0	9.8	8.2	6.4	7.3	2.0	5.6	4.0	1.3	3.1
4/28	5.1	15.9	4.9	18.3	10.5	8.9	6.9	7.9	2.2	6.0	4.4	1.4	3.3
4/29	5.5	17.2	5.3	19.8	11.4	9.6	7.5	8.5	2.4	6.5	4.7	1.6	3.6
4/30	5.5	17.5	5.3	20.1	11.5	9.7	7.6	8.7	2.4	6.6	4.8	1.6	3.6
5/1	6.2	19.5	6.0	22.4	12.9	10.9	8.5	9.7	2.7	7.4	5.3	1.8	4.0
5/2	6.4	20.3	6.2	23.3	13.4	11.3	8.8	10.1	2.8	7.7	5.5	1.8	4.2
5/3	7.1	22.4	6.9	25.8	14.8	12.5	9.8	11.2	3.1	8.5	6.1	2.0	4.7
5/4	8.4	26.3	8.0	30.3	17.4	14.6	11.4	13.1	3.6	9.9	7.2	2.4	5.5
5/5	9.4	29.5	9.0	34.0	19.5	16.4	12.8	14.7	4.1	11.2	8.1	2.7	6.1
5/6	10.5	32.9	10.1	37.9	21.8	18.3	14.3	16.4	4.6	12.5	9.0	3.0	6.8
5/7	12.1	38.0	11.6	43.7	25.1	21.1	16.5	18.9	5.3	14.4	10.4	3.4	7.9
5/8	13.2	41.6	12.7	47.9	27.5	23.2	18.1	20.7	5.8	15.7	11.4	3.8	8.6
5/9	14.9	46.8	14.3	53.8	30.9	26.1	20.3	23.3	6.5	17.7	12.8	4.2	9.7
5/10	16.3	51.3	15.7	59.0	33.9	28.6	22.3	25.5	7.1	19.4	14.0	4.6	10.6
5/11	16.9	53.2	16.3	61.3	35.2	29.7	23.2	26.5	7.4	20.1	14.5	4.8	11.0
5/12	18.0	56.8	17.4	65.3	37.6	31.6	24.7	28.2	7.9	21.5	15.5	5.1	11.8

Table F-2. Estimated Total Maximum Daily Load for sediment impaired watersheds in Madison TPA (in Tons)

Day	Antelope	Bear	Blaine Spring	Cherry	Elk	Hot Springs	Moore Creek	North Meadow	Red Canyon	Ruby	South Meadow	Watkins	Wigwam
5/13	19.6	61.7	18.9	71.1	40.8	34.4	26.8	30.7	8.6	23.4	16.9	5.6	12.8
5/14	20.5	64.4	19.7	74.2	42.6	35.9	28.0	32.0	8.9	24.4	17.6	5.8	13.4
5/15	22.4	70.5	21.6	81.2	46.7	39.3	30.7	35.1	9.8	26.7	19.3	6.4	14.6
5/16	26.2	82.4	25.2	94.8	54.5	45.9	35.8	41.0	11.4	31.2	22.5	7.4	17.1
5/17	29.6	93.2	28.5	107.3	61.7	51.9	40.5	46.4	12.9	35.3	25.4	8.4	19.3
5/18	30.9	97.2	29.7	111.8	64.3	54.1	42.2	48.3	13.5	36.8	26.5	8.8	20.2
5/19	31.7	99.8	30.5	114.9	66.1	55.6	43.4	49.7	13.8	37.8	27.3	9.0	20.7
5/20	33.1	104.3	31.9	120.1	69.0	58.1	45.4	51.9	14.5	39.5	28.5	9.4	21.6
5/21	34.9	109.9	33.6	126.5	72.7	61.2	47.8	54.7	15.2	41.6	30.0	9.9	22.8
5/22	35.9	113.1	34.6	130.2	74.9	63.0	49.2	56.3	15.7	42.8	30.9	10.2	23.5
5/23	35.9	113.1	34.6	130.2	74.9	63.0	49.2	56.3	15.7	42.8	30.9	10.2	23.5
5/24	36.9	116.0	35.5	133.6	76.8	64.6	50.5	57.7	16.1	43.9	31.7	10.5	24.1
5/25	36.8	115.7	35.4	133.2	76.5	64.4	50.3	57.5	16.0	43.8	31.6	10.5	24.0
5/26	36.5	114.9	35.1	132.3	76.0	64.0	50.0	57.2	15.9	43.5	31.4	10.4	23.8
5/27	36.6	115.3	35.3	132.7	76.3	64.2	50.1	57.4	16.0	43.6	31.5	10.4	23.9
5/28	37.2	117.1	35.8	134.8	77.5	65.3	50.9	58.3	16.2	44.3	32.0	10.6	24.3
5/29	38.4	120.8	36.9	139.1	79.9	67.3	52.5	60.1	16.7	45.7	33.0	10.9	25.1
5/30	36.8	115.7	35.4	133.2	76.5	64.4	50.3	57.5	16.0	43.8	31.6	10.5	24.0
5/31	34.9	109.9	33.6	126.5	72.7	61.2	47.8	54.7	15.2	41.6	30.0	9.9	22.8
6/1	34.0	107.1	32.7	123.3	70.8	59.7	46.6	53.3	14.8	40.5	29.2	9.7	22.2

Table F-2. Estimated Total Maximum Daily Load for sediment impaired watersheds in Madison TPA (in Tons)

Day	Antelope	Bear	Blaine Spring	Cherry	Elk	Hot Springs	Moore Creek	North Meadow	Red Canyon	Ruby	South Meadow	Watkins	Wigwam
6/2	34.0	107.1	32.7	123.3	70.8	59.7	46.6	53.3	14.8	40.5	29.2	9.7	22.2
6/3	32.5	102.2	31.3	117.7	67.6	57.0	44.5	50.9	14.2	38.7	27.9	9.2	21.2
6/4	31.5	99.2	30.3	114.2	65.6	55.2	43.1	49.3	13.7	37.5	27.1	9.0	20.6
6/5	30.8	96.8	29.6	111.5	64.1	53.9	42.1	48.2	13.4	36.6	26.4	8.7	20.1
6/6	30.9	97.2	29.7	111.8	64.3	54.1	42.2	48.3	13.5	36.8	26.5	8.8	20.2
6/7	30.7	96.5	29.5	111.1	63.8	53.8	42.0	48.0	13.4	36.5	26.3	8.7	20.0
6/8	30.8	96.8	29.6	111.5	64.1	53.9	42.1	48.2	13.4	36.6	26.4	8.7	20.1
6/9	30.0	94.5	28.9	108.8	62.5	52.6	41.1	47.0	13.1	35.8	25.8	8.5	19.6
6/10	29.0	91.2	27.9	105.0	60.4	50.8	39.7	45.4	12.6	34.5	24.9	8.2	18.9
6/11	26.3	82.7	25.3	95.2	54.7	46.1	36.0	41.1	11.5	31.3	22.6	7.5	17.2
6/12	23.2	73.1	22.4	84.2	48.4	40.7	31.8	36.4	10.1	27.7	20.0	6.6	15.2
6/13	21.9	68.8	21.0	79.3	45.5	38.4	29.9	34.2	9.5	26.0	18.8	6.2	14.3
6/14	20.6	65.0	19.9	74.8	43.0	36.2	28.2	32.3	9.0	24.6	17.7	5.9	13.5
6/15	20.0	62.8	19.2	72.3	41.5	35.0	27.3	31.2	8.7	23.8	17.1	5.7	13.0
6/16	19.9	62.5	19.1	72.0	41.4	34.8	27.2	31.1	8.7	23.7	17.1	5.6	13.0
6/17	18.3	57.5	17.6	66.2	38.1	32.1	25.0	28.6	8.0	21.8	15.7	5.2	11.9
6/18	16.4	51.8	15.8	59.6	34.3	28.8	22.5	25.8	7.2	19.6	14.1	4.7	10.7
6/19	15.1	47.5	14.5	54.7	31.4	26.4	20.6	23.6	6.6	18.0	13.0	4.3	9.9
6/20	13.6	42.9	13.1	49.4	28.4	23.9	18.7	21.3	5.9	16.2	11.7	3.9	8.9
6/21	12.6	39.7	12.1	45.6	26.2	22.1	17.2	19.7	5.5	15.0	10.8	3.6	8.2

Table F-2. Estimated Total Maximum Daily Load for sediment impaired watersheds in Madison TPA (in Tons)

Day	Antelope	Bear	Blaine Spring	Cherry	Elk	Hot Springs	Moore Creek	North Meadow	Red Canyon	Ruby	South Meadow	Watkins	Wigwam
6/22	11.7	36.7	11.2	42.3	24.3	20.5	16.0	18.3	5.1	13.9	10.0	3.3	7.6
6/23	10.7	33.7	10.3	38.8	22.3	18.8	14.7	16.8	4.7	12.8	9.2	3.0	7.0
6/24	9.8	30.8	9.4	35.5	20.4	17.2	13.4	15.3	4.3	11.7	8.4	2.8	6.4
6/25	9.0	28.4	8.7	32.7	18.8	15.8	12.4	14.1	3.9	10.8	7.8	2.6	5.9
6/26	8.4	26.5	8.1	30.5	17.5	14.7	11.5	13.2	3.7	10.0	7.2	2.4	5.5
6/27	8.0	25.3	7.7	29.1	16.7	14.1	11.0	12.6	3.5	9.6	6.9	2.3	5.2
6/28	7.2	22.8	7.0	26.2	15.1	12.7	9.9	11.3	3.2	8.6	6.2	2.1	4.7
6/29	6.1	19.3	5.9	22.3	12.8	10.8	8.4	9.6	2.7	7.3	5.3	1.7	4.0
6/30	5.5	17.5	5.3	20.1	11.5	9.7	7.6	8.7	2.4	6.6	4.8	1.6	3.6
7/1	5.3	16.6	5.1	19.1	11.0	9.3	7.2	8.3	2.3	6.3	4.5	1.5	3.4
7/2	4.7	14.9	4.5	17.1	9.8	8.3	6.5	7.4	2.1	5.6	4.1	1.3	3.1
7/3	4.5	14.1	4.3	16.2	9.3	7.9	6.1	7.0	2.0	5.3	3.8	1.3	2.9
7/4	4.0	12.5	3.8	14.4	8.3	7.0	5.4	6.2	1.7	4.7	3.4	1.1	2.6
7/5	3.6	11.3	3.5	13.0	7.5	6.3	4.9	5.6	1.6	4.3	3.1	1.0	2.3
7/6	3.5	10.9	3.3	12.5	7.2	6.1	4.7	5.4	1.5	4.1	3.0	1.0	2.3
7/7	3.0	9.6	2.9	11.0	6.3	5.3	4.2	4.8	1.3	3.6	2.6	0.9	2.0
7/8	2.8	8.9	2.7	10.3	5.9	5.0	3.9	4.5	1.2	3.4	2.4	0.8	1.9
7/9	2.6	8.3	2.5	9.5	5.5	4.6	3.6	4.1	1.1	3.1	2.3	0.7	1.7
7/10	2.5	8.0	2.4	9.2	5.3	4.4	3.5	4.0	1.1	3.0	2.2	0.7	1.7
7/11	2.4	7.7	2.3	8.8	5.1	4.3	3.3	3.8	1.1	2.9	2.1	0.7	1.6
7/12	2.3	7.1	2.2	8.2	4.7	4.0	3.1	3.5	1.0	2.7	1.9	0.6	1.5
7/13	2.1	6.7	2.0	7.7	4.4	3.7	2.9	3.3	0.9	2.5	1.8	0.6	1.4
7/14	1.9	5.8	1.8	6.7	3.9	3.2	2.5	2.9	0.8	2.2	1.6	0.5	1.2
7/15	1.7	5.3	1.6	6.2	3.5	3.0	2.3	2.7	0.7	2.0	1.5	0.5	1.1
7/16	1.6	4.9	1.5	5.6	3.2	2.7	2.1	2.4	0.7	1.8	1.3	0.4	1.0
7/17	1.5	4.6	1.4	5.3	3.0	2.6	2.0	2.3	0.6	1.7	1.3	0.4	1.0
7/18	1.4	4.3	1.3	5.0	2.9	2.4	1.9	2.1	0.6	1.6	1.2	0.4	0.9
7/19	1.3	4.0	1.2	4.6	2.6	2.2	1.7	2.0	0.5	1.5	1.1	0.4	0.8
7/20	1.3	4.0	1.2	4.6	2.6	2.2	1.7	2.0	0.5	1.5	1.1	0.4	0.8

Table F-2. Estimated Total Maximum Daily Load for sediment impaired watersheds in Madison TPA (in Tons)

Day	Antelope	Bear	Blaine Spring	Cherry	Elk	Hot Springs	Moore Creek	North Meadow	Red Canyon	Ruby	South Meadow	Watkins	Wigwam
7/21	1.3	4.1	1.3	4.7	2.7	2.3	1.8	2.0	0.6	1.6	1.1	0.4	0.9
7/22	1.3	4.0	1.2	4.6	2.7	2.2	1.8	2.0	0.6	1.5	1.1	0.4	0.8
7/23	1.3	4.0	1.2	4.6	2.6	2.2	1.7	2.0	0.5	1.5	1.1	0.4	0.8
7/24	1.2	3.8	1.2	4.4	2.5	2.1	1.7	1.9	0.5	1.4	1.0	0.3	0.8
7/25	1.2	3.8	1.2	4.3	2.5	2.1	1.6	1.9	0.5	1.4	1.0	0.3	0.8
7/26	1.1	3.6	1.1	4.1	2.4	2.0	1.6	1.8	0.5	1.3	1.0	0.3	0.7
7/27	1.1	3.4	1.0	3.9	2.2	1.9	1.5	1.7	0.5	1.3	0.9	0.3	0.7
7/28	1.1	3.3	1.0	3.8	2.2	1.8	1.4	1.6	0.5	1.3	0.9	0.3	0.7
7/29	1.1	3.4	1.1	4.0	2.3	1.9	1.5	1.7	0.5	1.3	0.9	0.3	0.7
7/30	1.2	3.7	1.1	4.3	2.4	2.1	1.6	1.8	0.5	1.4	1.0	0.3	0.8
7/31	1.1	3.3	1.0	3.8	2.2	1.8	1.4	1.6	0.5	1.3	0.9	0.3	0.7
8/1	1.0	3.2	1.0	3.7	2.1	1.8	1.4	1.6	0.4	1.2	0.9	0.3	0.7
8/2	0.9	3.0	0.9	3.4	2.0	1.6	1.3	1.5	0.4	1.1	0.8	0.3	0.6
8/3	0.9	2.8	0.9	3.3	1.9	1.6	1.2	1.4	0.4	1.1	0.8	0.3	0.6
8/4	0.9	2.8	0.9	3.3	1.9	1.6	1.2	1.4	0.4	1.1	0.8	0.3	0.6
8/5	0.9	2.8	0.9	3.2	1.8	1.6	1.2	1.4	0.4	1.1	0.8	0.3	0.6
8/6	0.8	2.6	0.8	3.0	1.7	1.5	1.1	1.3	0.4	1.0	0.7	0.2	0.5
8/7	0.7	2.3	0.7	2.6	1.5	1.3	1.0	1.1	0.3	0.9	0.6	0.2	0.5
8/8	0.7	2.2	0.7	2.6	1.5	1.3	1.0	1.1	0.3	0.8	0.6	0.2	0.5
8/9	0.7	2.2	0.7	2.5	1.5	1.2	1.0	1.1	0.3	0.8	0.6	0.2	0.5
8/10	0.7	2.2	0.7	2.6	1.5	1.3	1.0	1.1	0.3	0.8	0.6	0.2	0.5
8/11	0.7	2.2	0.7	2.6	1.5	1.3	1.0	1.1	0.3	0.8	0.6	0.2	0.5
8/12	0.7	2.0	0.6	2.4	1.4	1.1	0.9	1.0	0.3	0.8	0.6	0.2	0.4
8/13	0.7	2.0	0.6	2.4	1.4	1.1	0.9	1.0	0.3	0.8	0.6	0.2	0.4
8/14	0.6	2.0	0.6	2.2	1.3	1.1	0.8	1.0	0.3	0.7	0.5	0.2	0.4
8/15	0.6	1.9	0.6	2.2	1.3	1.1	0.8	0.9	0.3	0.7	0.5	0.2	0.4
8/16	0.6	1.9	0.6	2.2	1.3	1.1	0.8	0.9	0.3	0.7	0.5	0.2	0.4
8/17	0.6	1.9	0.6	2.1	1.2	1.0	0.8	0.9	0.3	0.7	0.5	0.2	0.4
8/18	0.6	1.8	0.5	2.0	1.2	1.0	0.8	0.9	0.2	0.7	0.5	0.2	0.4
8/19	0.6	1.9	0.6	2.2	1.3	1.1	0.8	0.9	0.3	0.7	0.5	0.2	0.4
8/20	0.7	2.1	0.6	2.4	1.4	1.2	0.9	1.0	0.3	0.8	0.6	0.2	0.4
8/21	0.6	2.0	0.6	2.3	1.3	1.1	0.9	1.0	0.3	0.8	0.5	0.2	0.4
8/22	0.6	2.0	0.6	2.3	1.3	1.1	0.9	1.0	0.3	0.8	0.5	0.2	0.4
8/23	0.6	1.8	0.6	2.1	1.2	1.0	0.8	0.9	0.3	0.7	0.5	0.2	0.4
8/24	0.6	1.8	0.6	2.1	1.2	1.0	0.8	0.9	0.3	0.7	0.5	0.2	0.4
8/25	0.5	1.7	0.5	1.9	1.1	0.9	0.7	0.8	0.2	0.6	0.5	0.2	0.3
8/26	0.5	1.7	0.5	1.9	1.1	0.9	0.7	0.8	0.2	0.6	0.5	0.2	0.3
8/27	0.5	1.6	0.5	1.8	1.1	0.9	0.7	0.8	0.2	0.6	0.4	0.1	0.3

Table F-2. Estimated Total Maximum Daily Load for sediment impaired watersheds in Madison TPA (in Tons)

Day	Antelope	Bear	Blaine Spring	Cherry	Elk	Hot Springs	Moore Creek	North Meadow	Red Canyon	Ruby	South Meadow	Watkins	Wigwam
8/28	0.5	1.5	0.5	1.8	1.0	0.9	0.7	0.8	0.2	0.6	0.4	0.1	0.3
8/29	0.5	1.6	0.5	1.8	1.1	0.9	0.7	0.8	0.2	0.6	0.4	0.1	0.3
8/30	0.5	1.7	0.5	1.9	1.1	0.9	0.7	0.8	0.2	0.6	0.5	0.2	0.3
8/31	0.6	1.8	0.5	2.0	1.2	1.0	0.8	0.9	0.2	0.7	0.5	0.2	0.4
9/1	0.5	1.7	0.5	1.9	1.1	0.9	0.7	0.8	0.2	0.6	0.5	0.2	0.3
9/2	0.5	1.7	0.5	1.9	1.1	0.9	0.7	0.8	0.2	0.6	0.5	0.2	0.3
9/3	0.5	1.7	0.5	1.9	1.1	0.9	0.7	0.8	0.2	0.6	0.5	0.2	0.3
9/4	0.5	1.5	0.5	1.8	1.0	0.9	0.7	0.8	0.2	0.6	0.4	0.1	0.3
9/5	0.5	1.6	0.5	1.8	1.1	0.9	0.7	0.8	0.2	0.6	0.4	0.1	0.3
9/6	0.6	1.8	0.5	2.0	1.2	1.0	0.8	0.9	0.2	0.7	0.5	0.2	0.4
9/7	0.6	1.8	0.6	2.1	1.2	1.0	0.8	0.9	0.3	0.7	0.5	0.2	0.4
9/8	0.5	1.6	0.5	1.8	1.1	0.9	0.7	0.8	0.2	0.6	0.4	0.1	0.3
9/9	0.6	1.9	0.6	2.1	1.2	1.0	0.8	0.9	0.3	0.7	0.5	0.2	0.4
9/10	0.6	2.0	0.6	2.2	1.3	1.1	0.8	1.0	0.3	0.7	0.5	0.2	0.4
9/11	0.5	1.7	0.5	2.0	1.1	1.0	0.7	0.9	0.2	0.7	0.5	0.2	0.4
9/12	0.6	1.8	0.5	2.0	1.2	1.0	0.8	0.9	0.2	0.7	0.5	0.2	0.4
9/13	0.5	1.7	0.5	2.0	1.1	1.0	0.7	0.9	0.2	0.7	0.5	0.2	0.4
9/14	0.5	1.7	0.5	1.9	1.1	0.9	0.7	0.8	0.2	0.6	0.5	0.2	0.3
9/15	0.6	1.8	0.5	2.0	1.2	1.0	0.8	0.9	0.2	0.7	0.5	0.2	0.4
9/16	0.5	1.6	0.5	1.9	1.1	0.9	0.7	0.8	0.2	0.6	0.4	0.1	0.3
9/17	0.5	1.6	0.5	1.9	1.1	0.9	0.7	0.8	0.2	0.6	0.4	0.1	0.3
9/18	0.6	1.8	0.6	2.1	1.2	1.0	0.8	0.9	0.3	0.7	0.5	0.2	0.4
9/19	0.7	2.0	0.6	2.4	1.4	1.1	0.9	1.0	0.3	0.8	0.6	0.2	0.4
9/20	0.7	2.2	0.7	2.5	1.5	1.2	1.0	1.1	0.3	0.8	0.6	0.2	0.5
9/21	0.7	2.2	0.7	2.5	1.5	1.2	1.0	1.1	0.3	0.8	0.6	0.2	0.5
9/22	0.7	2.1	0.7	2.5	1.4	1.2	0.9	1.1	0.3	0.8	0.6	0.2	0.4
9/23	0.6	2.0	0.6	2.2	1.3	1.1	0.8	1.0	0.3	0.7	0.5	0.2	0.4
9/24	0.6	2.0	0.6	2.3	1.3	1.1	0.9	1.0	0.3	0.8	0.5	0.2	0.4
9/25	0.6	1.9	0.6	2.2	1.3	1.1	0.8	0.9	0.3	0.7	0.5	0.2	0.4
9/26	0.6	1.8	0.6	2.1	1.2	1.0	0.8	0.9	0.3	0.7	0.5	0.2	0.4
9/27	0.6	1.9	0.6	2.1	1.2	1.0	0.8	0.9	0.3	0.7	0.5	0.2	0.4
9/28	0.7	2.1	0.6	2.4	1.4	1.2	0.9	1.0	0.3	0.8	0.6	0.2	0.4
9/29	0.6	2.0	0.6	2.2	1.3	1.1	0.8	1.0	0.3	0.7	0.5	0.2	0.4
9/30	0.7	2.1	0.6	2.4	1.4	1.2	0.9	1.0	0.3	0.8	0.6	0.2	0.4
10/1	0.7	2.1	0.6	2.4	1.4	1.2	0.9	1.0	0.3	0.8	0.6	0.2	0.4
10/2	0.7	2.2	0.7	2.5	1.5	1.2	1.0	1.1	0.3	0.8	0.6	0.2	0.5
10/3	0.7	2.3	0.7	2.7	1.6	1.3	1.0	1.2	0.3	0.9	0.6	0.2	0.5
10/4	0.7	2.1	0.6	2.4	1.4	1.2	0.9	1.0	0.3	0.8	0.6	0.2	0.4

Table F-2. Estimated Total Maximum Daily Load for sediment impaired watersheds in Madison TPA (in Tons)

Day	Antelope	Bear	Blaine Spring	Cherry	Elk	Hot Springs	Moore Creek	North Meadow	Red Canyon	Ruby	South Meadow	Watkins	Wigwam
10/5	0.7	2.1	0.7	2.5	1.4	1.2	0.9	1.1	0.3	0.8	0.6	0.2	0.4
10/6	0.7	2.3	0.7	2.7	1.6	1.3	1.0	1.2	0.3	0.9	0.6	0.2	0.5
10/7	0.8	2.5	0.8	2.9	1.7	1.4	1.1	1.2	0.3	0.9	0.7	0.2	0.5
10/8	0.8	2.4	0.7	2.8	1.6	1.3	1.0	1.2	0.3	0.9	0.7	0.2	0.5
10/9	0.7	2.2	0.7	2.5	1.5	1.2	1.0	1.1	0.3	0.8	0.6	0.2	0.5
10/10	0.7	2.3	0.7	2.6	1.5	1.3	1.0	1.1	0.3	0.9	0.6	0.2	0.5
10/11	0.8	2.5	0.8	2.8	1.6	1.4	1.1	1.2	0.3	0.9	0.7	0.2	0.5
10/12	0.7	2.3	0.7	2.7	1.6	1.3	1.0	1.2	0.3	0.9	0.6	0.2	0.5
10/13	0.7	2.2	0.7	2.5	1.5	1.2	1.0	1.1	0.3	0.8	0.6	0.2	0.5
10/14	0.7	2.1	0.6	2.4	1.4	1.2	0.9	1.0	0.3	0.8	0.6	0.2	0.4
10/15	0.7	2.3	0.7	2.7	1.6	1.3	1.0	1.2	0.3	0.9	0.6	0.2	0.5
10/16	0.8	2.6	0.8	2.9	1.7	1.4	1.1	1.3	0.4	1.0	0.7	0.2	0.5
10/17	0.7	2.2	0.7	2.6	1.5	1.3	1.0	1.1	0.3	0.8	0.6	0.2	0.5
10/18	0.7	2.1	0.7	2.5	1.4	1.2	0.9	1.1	0.3	0.8	0.6	0.2	0.4
10/19	0.7	2.1	0.6	2.4	1.4	1.2	0.9	1.0	0.3	0.8	0.6	0.2	0.4
10/20	0.7	2.2	0.7	2.6	1.5	1.3	1.0	1.1	0.3	0.8	0.6	0.2	0.5
10/21	0.7	2.0	0.6	2.4	1.4	1.1	0.9	1.0	0.3	0.8	0.6	0.2	0.4
10/22	0.7	2.1	0.6	2.4	1.4	1.2	0.9	1.0	0.3	0.8	0.6	0.2	0.4
10/23	0.7	2.2	0.7	2.6	1.5	1.3	1.0	1.1	0.3	0.8	0.6	0.2	0.5
10/24	0.7	2.2	0.7	2.5	1.5	1.2	1.0	1.1	0.3	0.8	0.6	0.2	0.5
10/25	0.7	2.1	0.7	2.5	1.4	1.2	0.9	1.1	0.3	0.8	0.6	0.2	0.4
10/26	0.7	2.1	0.7	2.5	1.4	1.2	0.9	1.1	0.3	0.8	0.6	0.2	0.4
10/27	0.7	2.2	0.7	2.5	1.5	1.2	1.0	1.1	0.3	0.8	0.6	0.2	0.5
10/28	0.7	2.2	0.7	2.6	1.5	1.3	1.0	1.1	0.3	0.8	0.6	0.2	0.5
10/29	0.7	2.2	0.7	2.6	1.5	1.3	1.0	1.1	0.3	0.8	0.6	0.2	0.5
10/30	0.7	2.1	0.6	2.4	1.4	1.2	0.9	1.0	0.3	0.8	0.6	0.2	0.4
10/31	0.7	2.3	0.7	2.6	1.5	1.3	1.0	1.1	0.3	0.9	0.6	0.2	0.5
11/1	0.7	2.0	0.6	2.4	1.4	1.1	0.9	1.0	0.3	0.8	0.6	0.2	0.4
11/2	0.6	1.9	0.6	2.2	1.3	1.1	0.8	0.9	0.3	0.7	0.5	0.2	0.4
11/3	0.6	2.0	0.6	2.3	1.3	1.1	0.9	1.0	0.3	0.8	0.5	0.2	0.4
11/4	0.7	2.0	0.6	2.4	1.4	1.1	0.9	1.0	0.3	0.8	0.6	0.2	0.4
11/5	0.7	2.0	0.6	2.4	1.4	1.1	0.9	1.0	0.3	0.8	0.6	0.2	0.4
11/6	0.6	2.0	0.6	2.2	1.3	1.1	0.8	1.0	0.3	0.7	0.5	0.2	0.4
11/7	0.6	2.0	0.6	2.3	1.3	1.1	0.9	1.0	0.3	0.8	0.5	0.2	0.4
11/8	0.6	1.9	0.6	2.2	1.3	1.1	0.8	0.9	0.3	0.7	0.5	0.2	0.4
11/9	0.6	2.0	0.6	2.3	1.3	1.1	0.9	1.0	0.3	0.8	0.5	0.2	0.4
11/10	0.7	2.1	0.7	2.5	1.4	1.2	0.9	1.1	0.3	0.8	0.6	0.2	0.4
11/11	0.6	2.0	0.6	2.2	1.3	1.1	0.8	1.0	0.3	0.7	0.5	0.2	0.4

Table F-2. Estimated Total Maximum Daily Load for sediment impaired watersheds in Madison TPA (in Tons)

Day	Antelope	Bear	Blaine Spring	Cherry	Elk	Hot Springs	Moore Creek	North Meadow	Red Canyon	Ruby	South Meadow	Watkins	Wigwam
11/12	0.6	1.8	0.6	2.1	1.2	1.0	0.8	0.9	0.3	0.7	0.5	0.2	0.4
11/13	0.6	1.9	0.6	2.2	1.3	1.1	0.8	0.9	0.3	0.7	0.5	0.2	0.4
11/14	0.6	1.8	0.6	2.1	1.2	1.0	0.8	0.9	0.3	0.7	0.5	0.2	0.4
11/15	0.6	1.8	0.6	2.1	1.2	1.0	0.8	0.9	0.3	0.7	0.5	0.2	0.4
11/16	0.6	1.8	0.5	2.0	1.2	1.0	0.8	0.9	0.2	0.7	0.5	0.2	0.4
11/17	0.5	1.7	0.5	1.9	1.1	0.9	0.7	0.8	0.2	0.6	0.5	0.2	0.3
11/18	0.5	1.7	0.5	1.9	1.1	0.9	0.7	0.8	0.2	0.6	0.5	0.2	0.3
11/19	0.5	1.7	0.5	2.0	1.1	1.0	0.7	0.9	0.2	0.7	0.5	0.2	0.4
11/20	0.6	1.8	0.5	2.0	1.2	1.0	0.8	0.9	0.2	0.7	0.5	0.2	0.4
11/21	0.6	1.8	0.6	2.1	1.2	1.0	0.8	0.9	0.3	0.7	0.5	0.2	0.4
11/22	0.5	1.7	0.5	1.9	1.1	0.9	0.7	0.8	0.2	0.6	0.5	0.2	0.3
11/23	0.5	1.6	0.5	1.9	1.1	0.9	0.7	0.8	0.2	0.6	0.4	0.1	0.3
11/24	0.5	1.6	0.5	1.9	1.1	0.9	0.7	0.8	0.2	0.6	0.4	0.1	0.3
11/25	0.5	1.7	0.5	1.9	1.1	0.9	0.7	0.8	0.2	0.6	0.5	0.2	0.3
11/26	0.5	1.6	0.5	1.8	1.1	0.9	0.7	0.8	0.2	0.6	0.4	0.1	0.3
11/27	0.5	1.6	0.5	1.9	1.1	0.9	0.7	0.8	0.2	0.6	0.4	0.1	0.3
11/28	0.5	1.7	0.5	1.9	1.1	0.9	0.7	0.8	0.2	0.6	0.5	0.2	0.3
11/29	0.5	1.5	0.5	1.7	1.0	0.8	0.7	0.7	0.2	0.6	0.4	0.1	0.3
11/30	0.5	1.5	0.5	1.8	1.0	0.9	0.7	0.8	0.2	0.6	0.4	0.1	0.3
12/1	0.5	1.6	0.5	1.8	1.1	0.9	0.7	0.8	0.2	0.6	0.4	0.1	0.3
12/2	0.5	1.7	0.5	1.9	1.1	0.9	0.7	0.8	0.2	0.6	0.5	0.2	0.3
12/3	0.5	1.7	0.5	2.0	1.1	1.0	0.7	0.9	0.2	0.7	0.5	0.2	0.4
12/4	0.5	1.6	0.5	1.8	1.1	0.9	0.7	0.8	0.2	0.6	0.4	0.1	0.3
12/5	0.5	1.5	0.5	1.7	1.0	0.8	0.7	0.7	0.2	0.6	0.4	0.1	0.3
12/6	0.5	1.5	0.5	1.7	1.0	0.8	0.7	0.7	0.2	0.6	0.4	0.1	0.3
12/7	0.5	1.5	0.5	1.8	1.0	0.9	0.7	0.8	0.2	0.6	0.4	0.1	0.3
12/8	0.5	1.5	0.4	1.7	1.0	0.8	0.6	0.7	0.2	0.6	0.4	0.1	0.3
12/9	0.5	1.5	0.4	1.7	1.0	0.8	0.6	0.7	0.2	0.6	0.4	0.1	0.3
12/10	0.5	1.5	0.5	1.7	1.0	0.8	0.7	0.7	0.2	0.6	0.4	0.1	0.3
12/11	0.5	1.5	0.4	1.7	1.0	0.8	0.6	0.7	0.2	0.6	0.4	0.1	0.3
12/12	0.5	1.5	0.4	1.7	1.0	0.8	0.6	0.7	0.2	0.6	0.4	0.1	0.3
12/13	0.5	1.5	0.5	1.8	1.0	0.9	0.7	0.8	0.2	0.6	0.4	0.1	0.3
12/14	0.5	1.5	0.4	1.7	1.0	0.8	0.6	0.7	0.2	0.6	0.4	0.1	0.3
12/15	0.5	1.4	0.4	1.6	0.9	0.8	0.6	0.7	0.2	0.5	0.4	0.1	0.3
12/16	0.4	1.4	0.4	1.6	0.9	0.8	0.6	0.7	0.2	0.5	0.4	0.1	0.3
12/17	0.4	1.3	0.4	1.5	0.9	0.7	0.6	0.7	0.2	0.5	0.4	0.1	0.3
12/18	0.4	1.3	0.4	1.5	0.8	0.7	0.6	0.6	0.2	0.5	0.3	0.1	0.3
12/19	0.4	1.3	0.4	1.5	0.9	0.7	0.6	0.7	0.2	0.5	0.4	0.1	0.3

Table F-2. Estimated Total Maximum Daily Load for sediment impaired watersheds in Madison TPA (in Tons)

Day	Antelope	Bear	Blaine Spring	Cherry	Elk	Hot Springs	Moore Creek	North Meadow	Red Canyon	Ruby	South Meadow	Watkins	Wigwam
12/20	0.4	1.3	0.4	1.5	0.8	0.7	0.6	0.6	0.2	0.5	0.3	0.1	0.3
12/21	0.4	1.3	0.4	1.5	0.8	0.7	0.6	0.6	0.2	0.5	0.3	0.1	0.3
12/22	0.4	1.3	0.4	1.5	0.9	0.7	0.6	0.7	0.2	0.5	0.4	0.1	0.3
12/23	0.5	1.5	0.5	1.7	1.0	0.8	0.7	0.7	0.2	0.6	0.4	0.1	0.3
12/24	0.5	1.4	0.4	1.6	0.9	0.8	0.6	0.7	0.2	0.5	0.4	0.1	0.3
12/25	0.4	1.4	0.4	1.6	0.9	0.8	0.6	0.7	0.2	0.5	0.4	0.1	0.3
12/26	0.4	1.3	0.4	1.5	0.8	0.7	0.6	0.6	0.2	0.5	0.3	0.1	0.3
12/27	0.4	1.2	0.4	1.4	0.8	0.7	0.5	0.6	0.2	0.5	0.3	0.1	0.3
12/28	0.4	1.3	0.4	1.5	0.9	0.7	0.6	0.7	0.2	0.5	0.4	0.1	0.3
12/29	0.4	1.3	0.4	1.5	0.9	0.7	0.6	0.7	0.2	0.5	0.4	0.1	0.3
12/30	0.4	1.3	0.4	1.5	0.9	0.7	0.6	0.6	0.2	0.5	0.4	0.1	0.3
12/31	0.4	1.3	0.4	1.5	0.8	0.7	0.6	0.6	0.2	0.5	0.3	0.1	0.3

APPENDIX G – MADISON TEMPERATURE STUDY DATA COLLECTION

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G1.0 PROJECT BACKGROUND

The Montana Department of Environmental Quality (DEQ) performed a temperature study in 2013 to 2014 for several stream segments of concern based on temperature impairment listings at the time of the DEQ investigation, input from stakeholders in the Madison watershed, and DEQ observations in the field (**Table G-1** and **Figure G-1**).

Table G-1. Stream Segments of Concern for Temperature TMDL development in the Madison TPA

Stream Segment (Assessment Unit)	Assessment Unit ID	Temperature related impairment identified in the 2018 Integrated Report
Cherry Creek – headwaters to mouth (Madison River)	MT41F002_010	Temperature[1]
Elk Creek – headwaters to mouth (Madison River)	MT41F002_020	Temperature[1]
Jack Creek - headwaters to mouth (Madison River, T5S R1W S23)	MT41F004_050	None
Madison River – Madison Dam to mouth (Missouri River)	MT41F001_010	Temperature[2]
Moore Creek – springs to mouth (Fletcher Channel), T5S R1W S15	MT41F004_130	Temperature[1]
West Fork Madison River – headwaters to mouth (Madison River)	MT41F004_100	Temperature[2]

[1] Temperature TMDL written
[2] No temperature TMDL written in this document

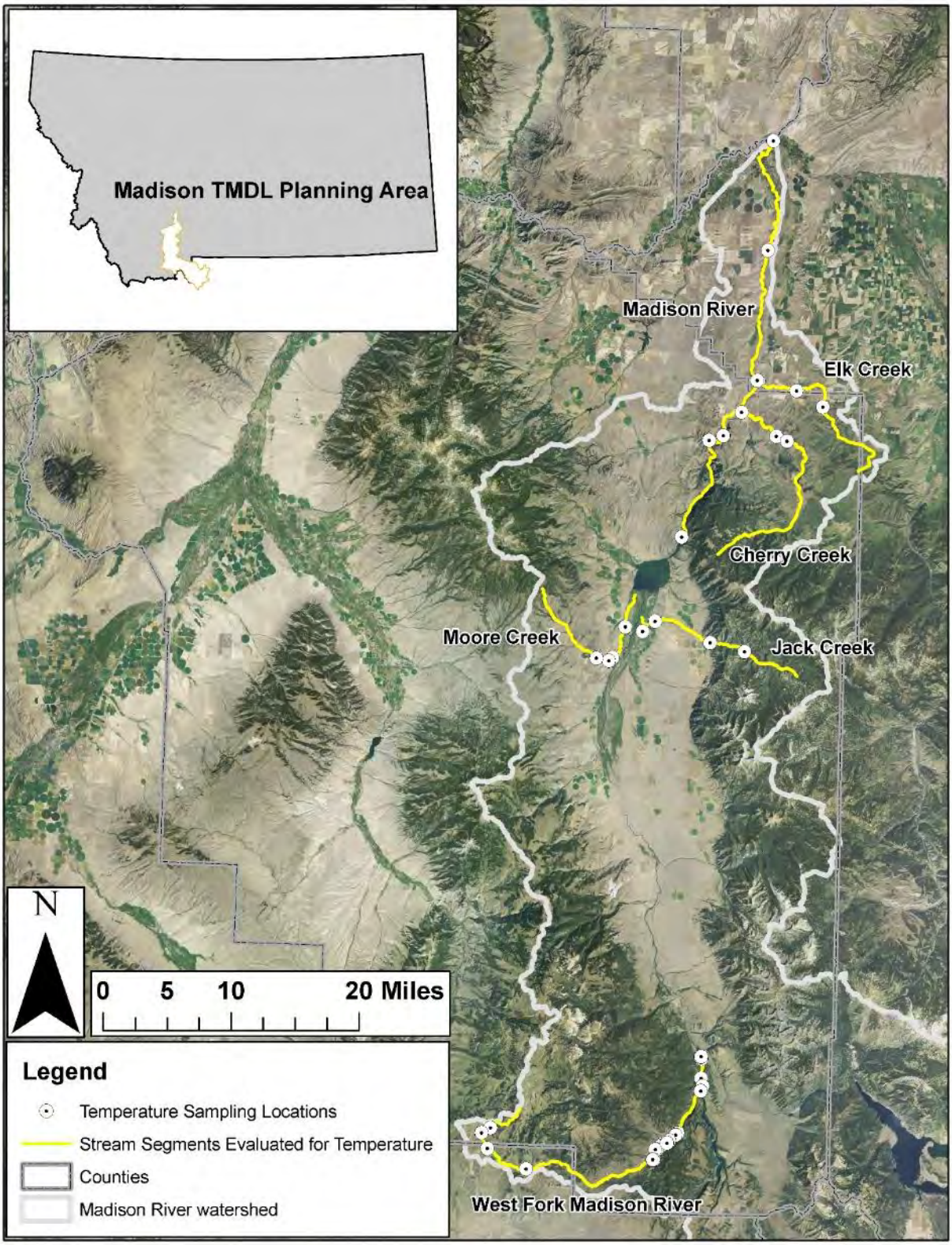

Figure G-1. Map of the Stream Segments Evaluated for Temperature in the Madison TPA

G2.0 DEQ MONITORING

Water temperature and shade data were collected by DEQ on Elk, Cherry, Jack, and Moore Creeks and on the West Fork Madison River in 2013. Additional data was collected in 2014 on the West Fork Madison and the lower Madison Rivers. A complete list of 2013 and 2014 DEQ temperature study sites can be found in **Section G.4.1** of this document. Streamflow data was collected by DEQ as part of the chemistry effort in 2012-2014. Channel geometry data was collected on the study streams in 2013-2014 as part of the sediment monitoring effort. Information regarding the lower segment of the Madison River was also provided by FWP and Northwestern Energy (formerly PPL Montana).

G2.1 TEMPERATURE MONITORING

Temperature monitoring was conducted by DEQ in 2013 and 2014 between June and September. The study examined stream temperatures during the period when streamflow tends to be the lowest and water temperatures the warmest, and thus when negative effects to the aquatic life beneficial use are likely most pronounced. Temperature monitoring consisted of placing temperature data loggers at multiple sites on each stream. Temperature monitoring sites were selected to bracket stream reaches with similar hydrology, riparian vegetation type, valley type, stream aspect, and channel width. Temperature data are summarized within **Section G.4.2** of this Appendix. For complete continuous temperature data, visit The National Water Quality Monitoring Council – Water Quality Portal - https://www.waterqualitydata.us/. FWP temperature monitoring data for the Madison River can be obtained by contacting DEQ's Monitoring and Assessment Section and site locations and a maximum temperature summary are found in **Section G.4.2.4** of this appendix.

G2.2 STREAMFLOW

Streamflow measurements were collected at multiple locations on each of the stream segments of concern for temperature by DEQ as part of chemistry sampling in 2012-2014.

G2.3 RIPARIAN SHADING

Characterization of riparian shade was based on a combination of field data collected at each site by DEQ in 2013 and aerial imagery analysis. Riparian shading was quantified using GIS tools and aerial imagery analysis to input variables into the Shade Tool, which is a model developed by the Washington Department of Ecology that calculates the percent effective shade and solar flux along a stream (Washington State Department of Ecology 2007). Field data were collected by DEQ to input into the Shade Tool, and Solar Pathfinder measured shade data were collected at multiple sites along each stream to verify and calibrate the Shade Tool outputs (See **Appendix F** for Shade Tool).

G2.4 CHANNEL GEOMETRY

Although not a direct measure of thermal effect on the stream, channel geometry can influence the rate of thermal loading. Wide, shallow streams transfer heat energy faster than narrow, deep streams. Therefore, channel geometry can be used to identify areas that may be destabilized, and may be more prone to rapid thermal loading, particularly in locations where shading is minimal. Channel geometry measurements were collected by DEQ in 2013 and 2014 as part of the sediment assessment for Elk, Cherry, Jack, and Moore Creeks and on the West Fork Madison River and can be found in **Sections**

6.4.2.1, 6.4.2.2, and **6.4.2.3** of this main TMDL document. Channel geometry was not collected by DEQ on the Madison River below Madison Dam.

G3.0 Data Compilation for Stream Segments of Concern – Site List, Temperature Data, Solar Pathfinder Data, and Riparian Vegetation Summary

G3.1 DEQ Temperature Monitoring Site List

Table G-2. Madison Temperature Study Sites

Site Number	Waterbody Name	Latitude	Longitude	2013	2014
1A	Elk Creek	45.6544	-111.5188	X	
1B	Elk Creek	45.6442	-111.4568	X	
1C	Elk Creek	45.6267	-111.4139	X	
1D	Elk Creek	45.5871	-111.3657	X	
2A	Cherry Creek	45.6184	-111.5448	X	
2B	Cherry Creek	45.5921	-111.4875	X	
2C	Cherry Creek	45.5870	-111.4702	X	
3A	Jack Creek	45.3672	-111.6948	X	
3X	Jack Creek	45.3789	-111.6750	X	
3D	Jack Creek	45.3565	-111.5859	X	
3F	Jack Creek	45.3472	-111.5299	X	
4A	Moore Creek	45.3719	-111.7227	X	
4D	Moore Creek	45.3363	-111.7420	X	
4E	Moore Creek	45.3329	-111.7478	X	
4F	Moore Creek	45.3354	-111.7679	X	
5A	West Fork Madison River	44.8872	-111.5833	X	X
5B	West Fork Madison River	44.8853	-111.5821	X	
5C	West Fork Madison River	44.8632	-111.5816	X	X
5D	West Fork Madison River	44.8490	-111.5813	X	X
5E	West Fork Madison River	44.8007	-111.6167	X	
5F	West Fork Madison River	44.7986	-111.6195	X	
5G	West Fork Madison River	44.7917	-111.6295	X	X
5H	West Fork Madison River	44.7888	-111.6331	X	X
5I	West Fork Madison River	44.7875	-111.6402	X	
5J	West Fork Madison River	44.7854	-111.6428	X	
5K	West Fork Madison River	44.7812	-111.6490	X	
5L	West Fork Madison River	44.7812	-111.6513	X	
5M	West Fork Madison River	44.7698	-111.6532	X	X
5N	West Fork Madison River	44.7697	-111.6556	X	X
5P	West Fork Madison River	44.7770	-111.9185		X

Table G-2. Madison Temperature Study Sites

Site Number	Waterbody Name	Latitude	Longitude	2013	2014
5Y	West Fork Madison River	44.8002	-111.9148		X
5X	West Fork Madison River	44.7944	-111.9287		X
7A	Elk River (West Fork Madison River project)	44.7898	-111.6333	X	X
8A	Freezeout Creek (West Fork Madison River project)	44.7983	-111.6198	X	
9A	Gazelle Creek (West Fork Madison River project)	44.8871	-111.5835	X	
12A	Lake Creek	44.8544	-111.5789		X
10A	Teepee Creek (West Fork Madison River project)	44.7698	-111.6550	X	X
6B	Madison River - Cobblestone	45.8023	-111.5089		X
6A	Madison River - Headwaters State Park	45.9264	-111.5044		X
6D	Madison River - Norris Rd.	45.5912	-111.5733		X
6C	Madison River -Black's Ford	45.6549	-111.5209		X
6E	Madison River-Beartrap Mouth	45.5856	-111.5958		X
6F	Madison River-Madison Dam	45.4752	-111.6357		X

Monitoring activities included continuous temperature loggers, instantaneous temperature data, and site notes at all stream segments of concern and their selected tributaries (Gazelle Creek, Teepee Creek, Lake Creek, Freezeout Creek, and the Elk River). Stream segments of concern additionally included channel morphology, photos, and shade data collection (Elk Creek, Cherry Creek, Jack Creek, Moore Creek, West Fork Madison River, and Mainstem Madison River sites).

G3.2 Temperature, Flow, Solar Pathfinder, and Riparian Vegetation Summary

Temperature, flow, solar pathfinder, and riparian vegetation data are summarized for the main study streams: Cherry, Elk, Jack, and Moore Creeks and the West Fork Madison and Lower Madison Rivers. For complete continuous temperature data, visit The National Water Quality Monitoring Council – Water Quality Portal - https://www.waterqualitydata.us/

G3.2.1 Cherry Creek

The following describe site location and maximum temperatures for 3 sites on Cherry Creek (**Table G-3 and Figures G-2** to **G-6**). Flow data are summarized in **Table G-4** and solar pathfinder data is summarized in **Table G-5**. Riparian vegetation summaries are found at the end of this appendix in **Table G-20**.

Table G-3. Cherry Creek DEQ Temperature Study Sites and Maximum Temperatures

Site	Site Description	River Mile	Tmax (°F)	MWAT/7-Day Avg Daily Max (°F)	Warmest Day of 7-Day Max
2A	Near the mouth	0.4	77.9	76.3	7/26/13
2B	At the bridge, above riparian restoration project	5.9	66.4	65.2	8/18/13
2C	Below Cowboy Canyon	7.1	66.3	65.3	7/3/13

Figure G-2. Cherry Creek DEQ Temperature Study Sites

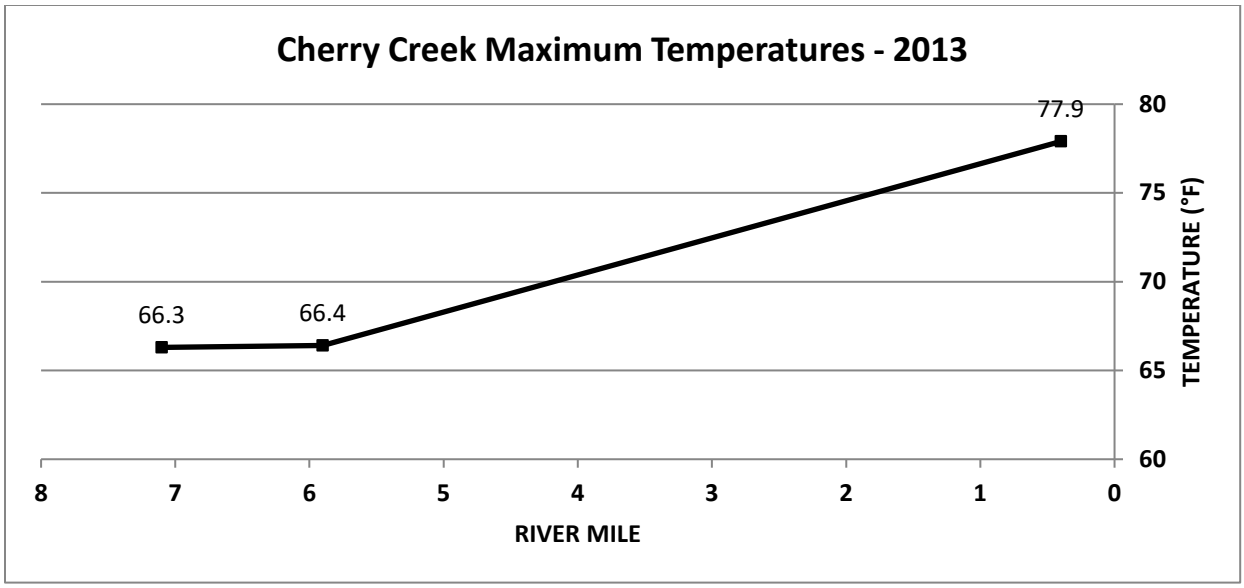

Figure G-3. Maximum temperature profile for three sites on Cherry Creek

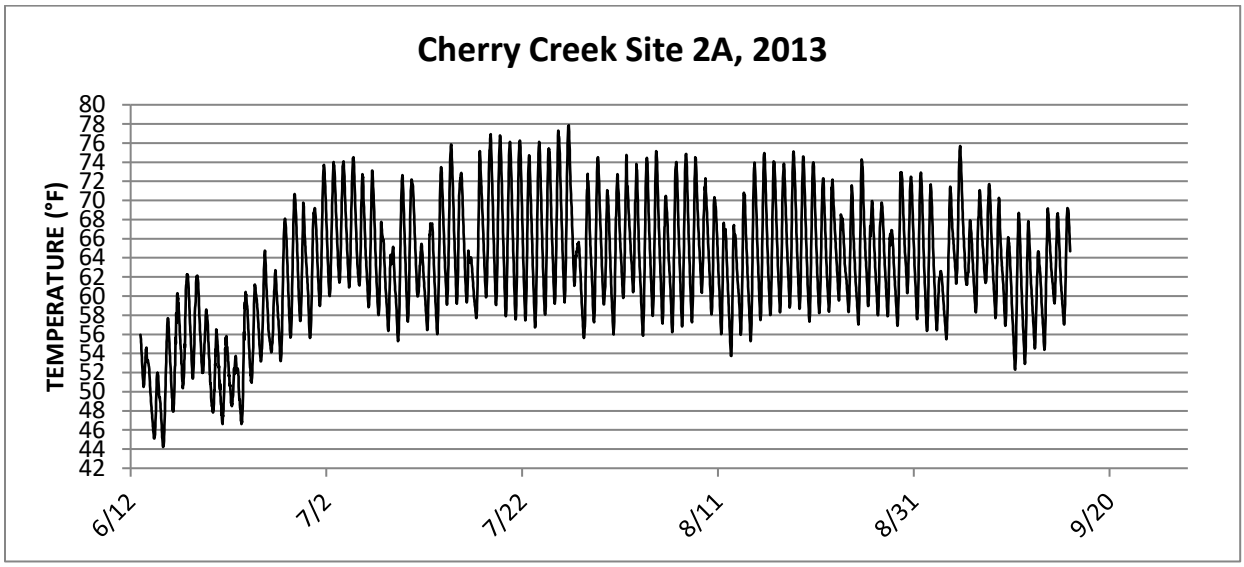

Figure G-4. Cherry Creek 2A Continuous Temperature 6/13/13 through 9/15/13

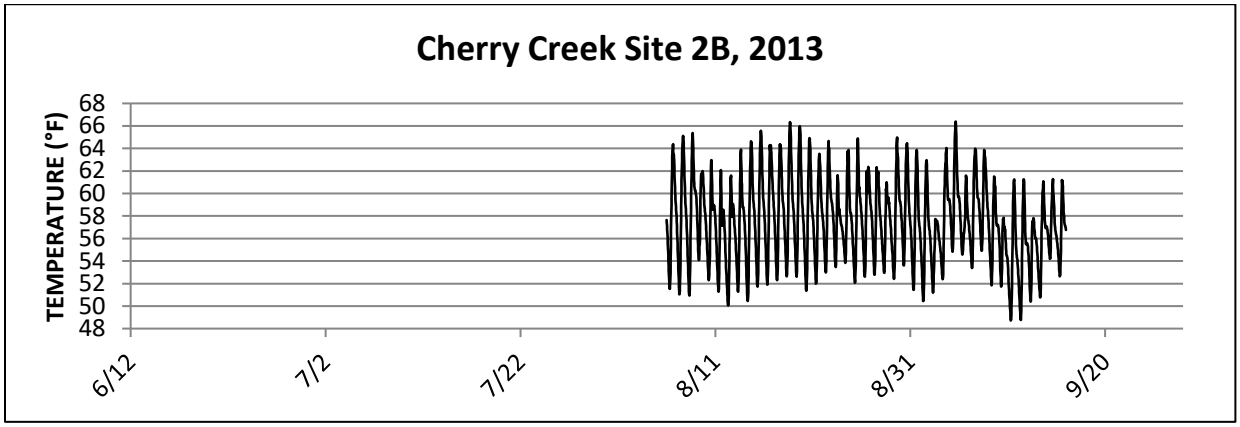

Figure G-5. Cherry Creek 2B Continuous Temperature 8/06/13 through 9/15/13

On 6/14, a high flow event swept the datalogger and brick anchor up onto riprap beneath the bridge where it was deployed. It remained dry until August 6, when discovered, and was then placed back in the channel

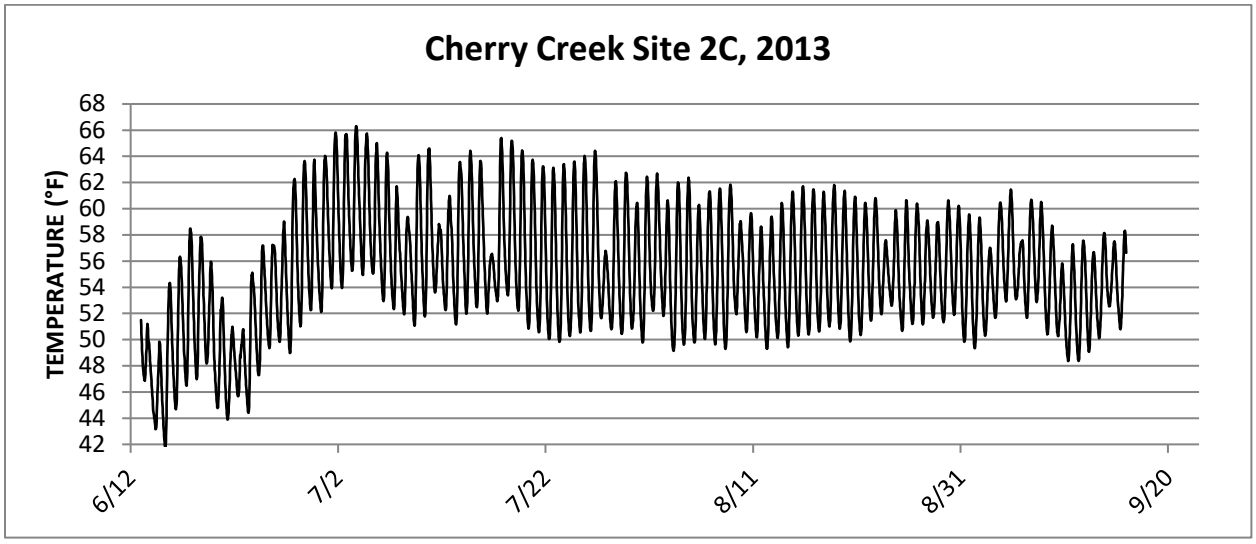

Figure G-6. Cherry Creek 2C Continuous Temperature 8/06/13 through 9/15/13

Table G-4. Cherry Creek DEQ Flow Measurements 2013

Date	Stream	STORET Site ID	Total Discharge (ft3/s)
8/6/2013	Cherry Creek	MDEQ_WQ_WQX-M06CHRYC01	14.59
8/5/2013	Cherry Creek	MDEQ_WQ_WQX-M06CHRYC02	18.05
8/5/2013	Cherry Creek	MDEQ_WQ_WQX-M06CHRYC03	17.4

Table G-5. Cherry Creek DEQ Solar Pathfinder Data 2013

Date	Stream Name	Transect Number	Solar Pathfinder Photo #s at 25%, 50%, 75% Wetted Width	Percent Shade at 25 % Wetted width	Percent Shade at 50 % Wetted width	Percent Shade at 75 % Wetted width
8/5/2013	Cherry Creek	2C-1	0536, 0537, 0538	83	69	65
8/5/2013	Cherry Creek	2B-1	0542, 0543, 0544	3	8	16
8/6/2013	Cherry Creek	2A-1	0565, 0566, 0567	6	3	2

Cherry Creek DEQ Riparian Vegetation Summary
See **Table G-20** at the end of this Appendix.

G3.2.2 Elk Creek

The following describe site location and maximum temperatures for 4 sites on Elk Creek (**Table G-6 and Figures G-7 to G12**). Flow data are summarized in **Table G-7** and solar pathfinder data is summarized in **Table G-8.** Riparian vegetation summaries are found at the end of this appendix in **Table G-20**.

Table G-6. Elk Creek Temperature Study Sites and Maximum Temperatures

Site	Site Description	River Mile	Tmax (°F)	7-Day Avg Daily Max (°F)	Warmest Day of 7-Day Max
1A	Near the mouth	0.2	84.7	75.8	6/26/13 (went dry)
1B	Upstream of an irrigated crop field and a different valley type than the site located u/s	3.9	80.6	78.3	7/2/13
1C	Located in a narrow valley dominated by conifer trees. It is u/s of pasture land and a wider valley type.	8.5	77.7	75.7	7/3/13
1D	Site is near the headwaters	12.8	77.8	76.0	7/3/13

Figure G-7. Elk Creek DEQ Temperature Study Sites

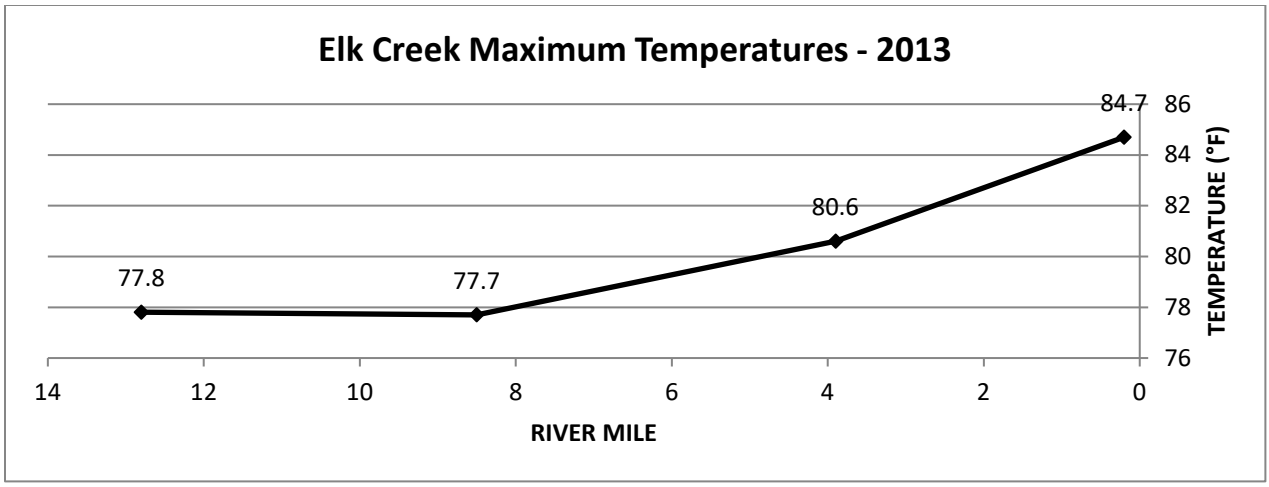

Figure G-8. Maximum temperature profile for four sites on Elk Creek

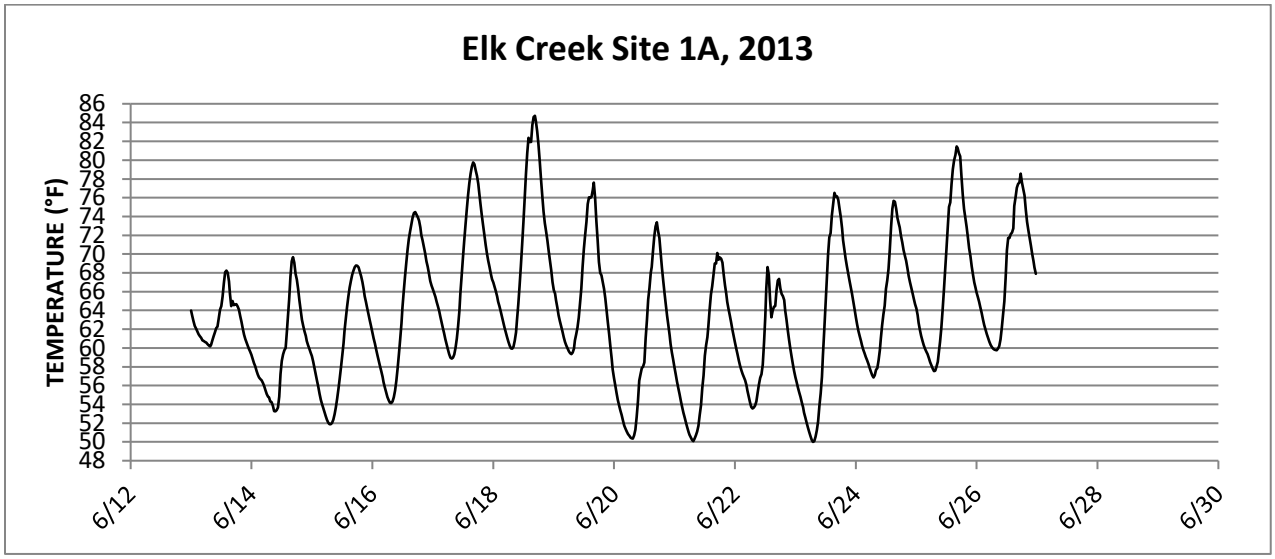

Figure G-9. Elk Creek 1A Continuous Temperature 6/13/13 through 6/26/13

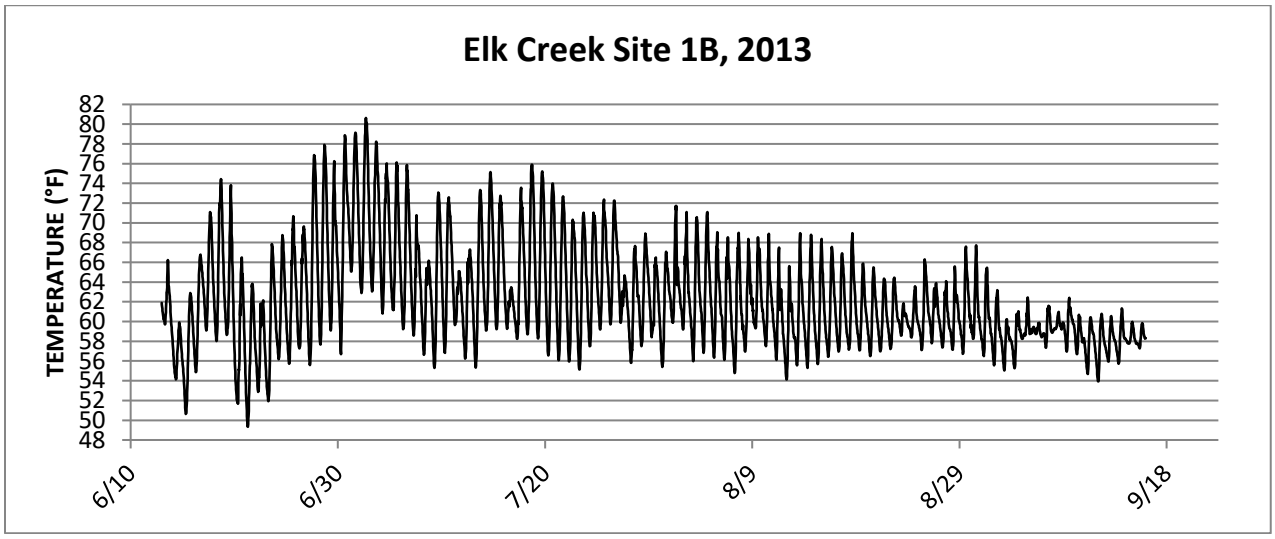

Figure G-10. Elk Creek 1B Continuous Temperature 6/13/13 through 9/15/13

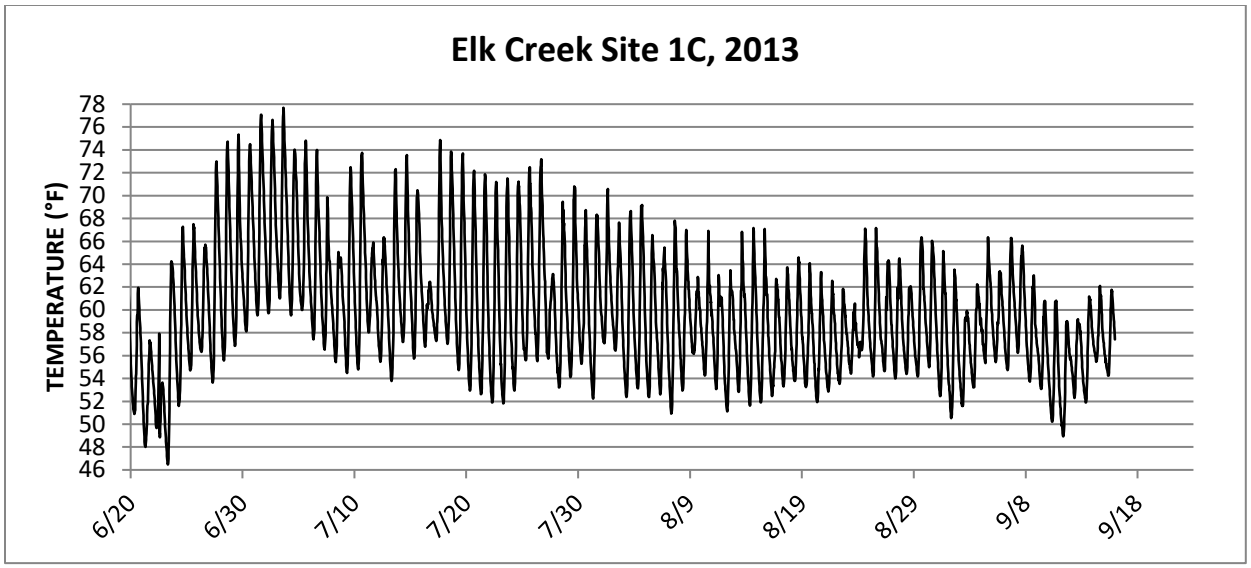

Figure G-11. Elk Creek 1C Continuous Temperature 6/13/13 through 9/15/13

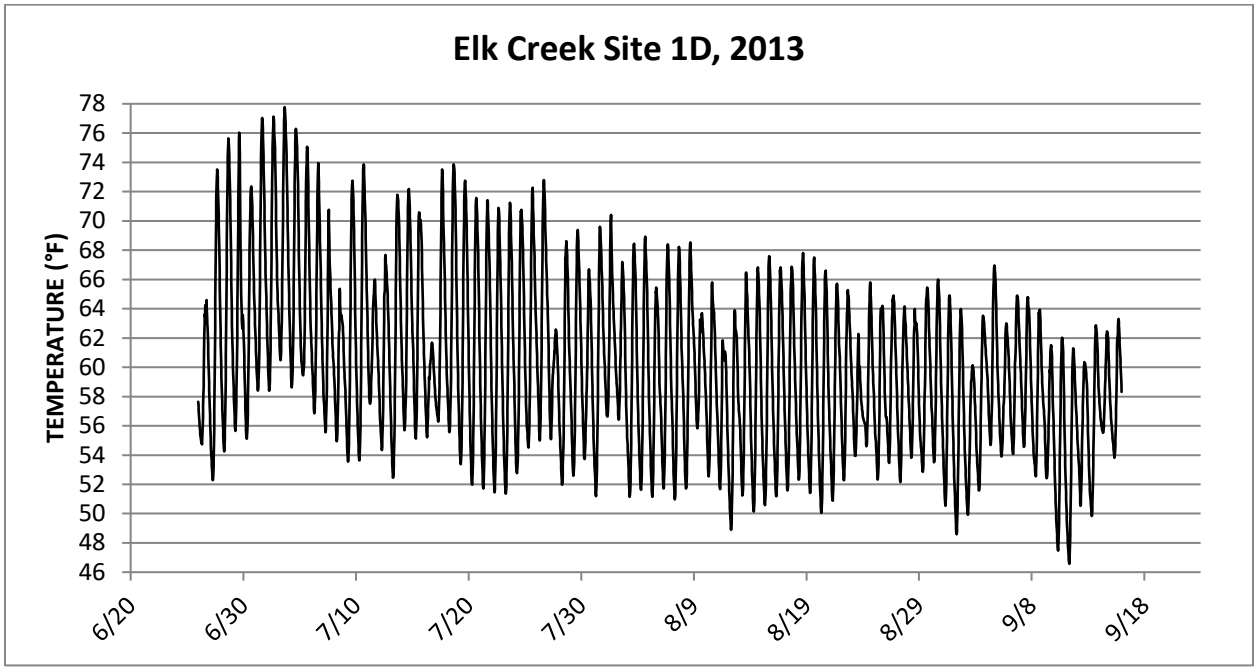

Figure G-12. Elk Creek 1D Continuous Temperature 6/26/13 through 9/15/13

Table G-7. Elk Creek DEQ Flow Measurements 2013

Date	Stream	Site ID	Total Discharge (ft^3/s)
6/19/2012	Elk Creek	MDEQ_WQ_WQX-M06ELKC03	2.03
7/25/2012	Elk Creek	MDEQ_WQ_WQX-M06ELKC03	0.46
8/28/2012	Elk Creek	MDEQ_WQ_WQX-M06ELKC03	0.11
6/19/2012	Elk Creek	MDEQ_WQ_WQX-M06ELKC04	2.97
7/25/2012	Elk Creek	MDEQ_WQ_WQX-M06ELKC04	0.47
8/28/2012	Elk Creek	MDEQ_WQ_WQX-M06ELKC04	0.05
8/6/2013	Elk Creek	MDEQ_WQ_WQX-M06ELKC02	0.14
9/16/2013	Elk Creek	MDEQ_WQ_WQX-M06ELKC02	0.23
6/12/2013	Elk Creek	MDEQ_WQ_WQX-M06ELKC03	2.71

Table G-7. Elk Creek DEQ Flow Measurements 2013

Date	Stream	Site ID	Total Discharge (ft^3/s)
8/2/2013	Elk Creek	MDEQ_WQ_WQX-M06ELKC03	0.05
8/15/2013	Elk Creek	MDEQ_WQ_WQX-M06ELKC03	0.05
9/16/2013	Elk Creek	MDEQ_WQ_WQX-M06ELKC03	0.001
8/2/2013	Elk Creek	MDEQ_WQ_WQX-M06ELKC04	0
8/5/2013	Elk Creek	MDEQ_WQ_WQX-M06ELKC05	0.11
9/16/2013	Elk Creek	MDEQ_WQ_WQX-M06ELKC05	0.21
8/23/2013	Elk Creek	MDEQ_WQ_WQX-M06ELKC06	0

Table G-8. Elk Creek Solar Pathfinder Data 2013

Date	Stream Name	Transect Number	Solar Pathfinder Photo #s at 25%, 50%, 75% Wetted Width	Percent Shade at 25 % Wetted width	Percent Shade at 50 % Wetted width	Percent Shade at 75 % Wetted width
8/2/2013	Elk Creek	1A	No measurement taken			
8/2/2013	Elk Creek	1B-1	0516, 0517, 0518	23	9	21
8/6/2013	Elk Creek	1C-1	0545, 0546, 0547	75	72	74
8/6/2013	Elk Creek	1C-2	0559, 0560, 0561	5	5	21
8/5/2013	Elk Creek	1D-1	0525, 0526, 0527	25	33	6

Elk Creek DEQ Riparian Vegetation Summary
See **Table G-20** at the end of this Appendix.

G3.2.3 Jack Creek

The following describe site location and maximum temperatures for 4 sites on Jack Creek (**Table G-9 and Figures G-13 to G-18**). Flow data are summarized in **Table G-10** and solar pathfinder data is summarized in **Table G-11.** Riparian vegetation summaries are found at the end of this appendix in **Table G-20**.

Table G-9. Jack Creek Temperature Study Sites and Maximum Temperatures

Site	Site Description	River Mile	Tmax (°F)	7-Day Avg Daily Max (°F)	Warmest Day of 7-Day Max
Jack Creek-3A	Near the mouth, at Jeffers Road	0.5	57.50	55.2	7/2/2013
Jack Creek 3X	At bridge on Jack Creek Road	1.5	72.00	70.5	8/19/2013
Jack Creek-3D	At gage station	6.5	63.10	61.8	7/17/2013
Jack Creek-3F	At CG, u/s of Aspen Cr.	9.7	59.80	58.9	7/18/2013

Figure G-13. Jack Creek DEQ Temperature Study Sites

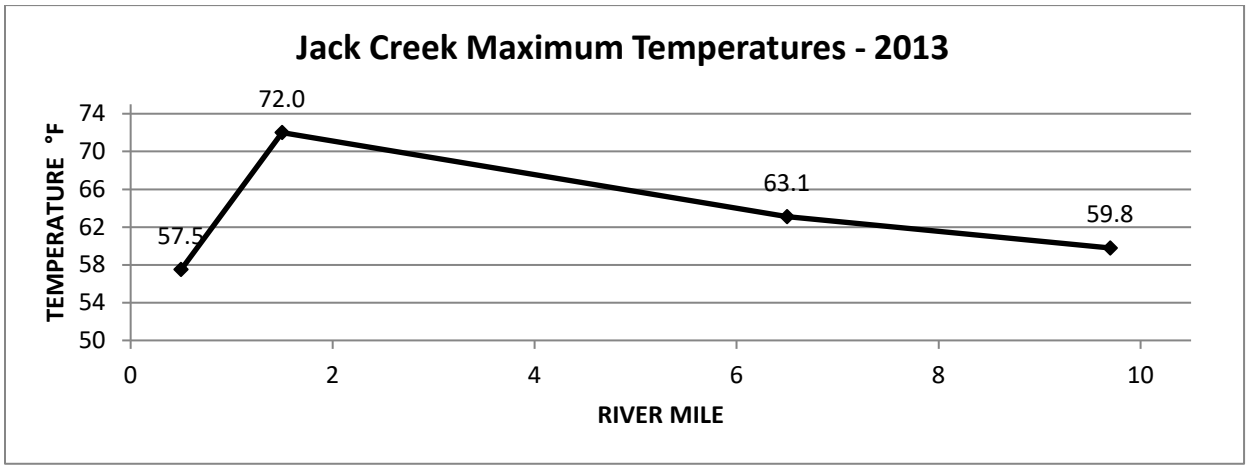

Figure G-14. Maximum temperature profile for four sites on Jack Creek

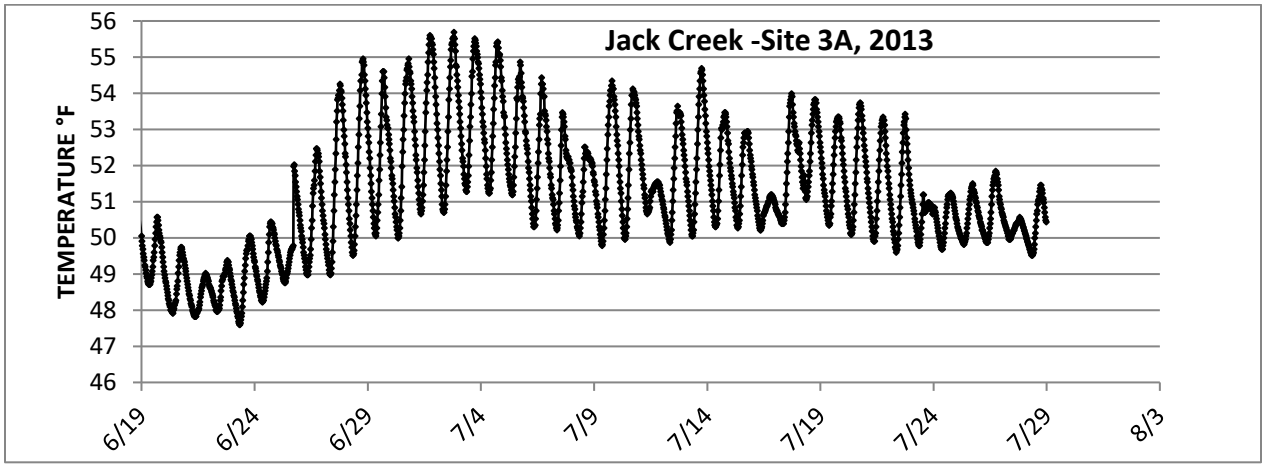

Figure G-15. Jack Creek 3A Continuous Temperature 6/12/13 through 7/28/13

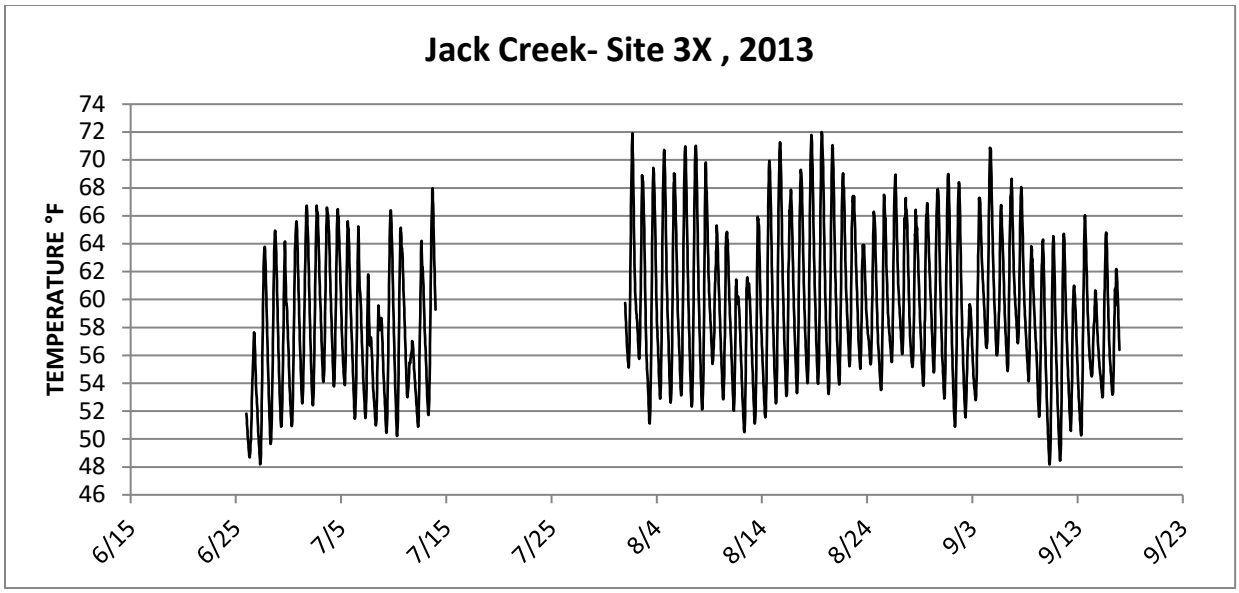

Figure G-16. Jack Creek 3X Continuous Temperature 6/26/13-7/13/13 and 8/1/13-9/16/13

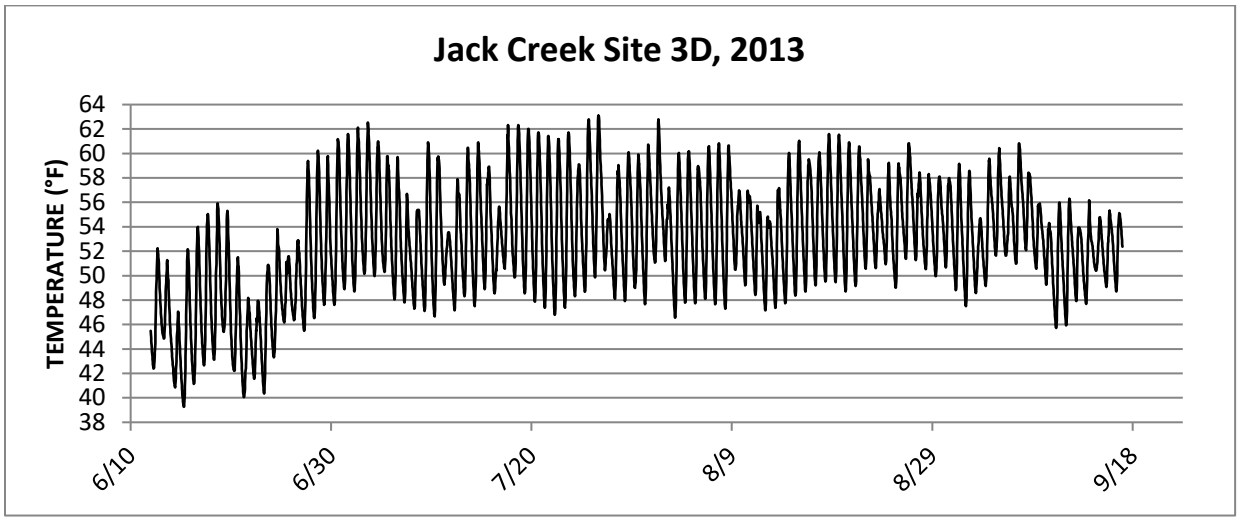

Figure G-17. Jack Creek 3D Continuous Temperature 6/12/13 through 9/16/13

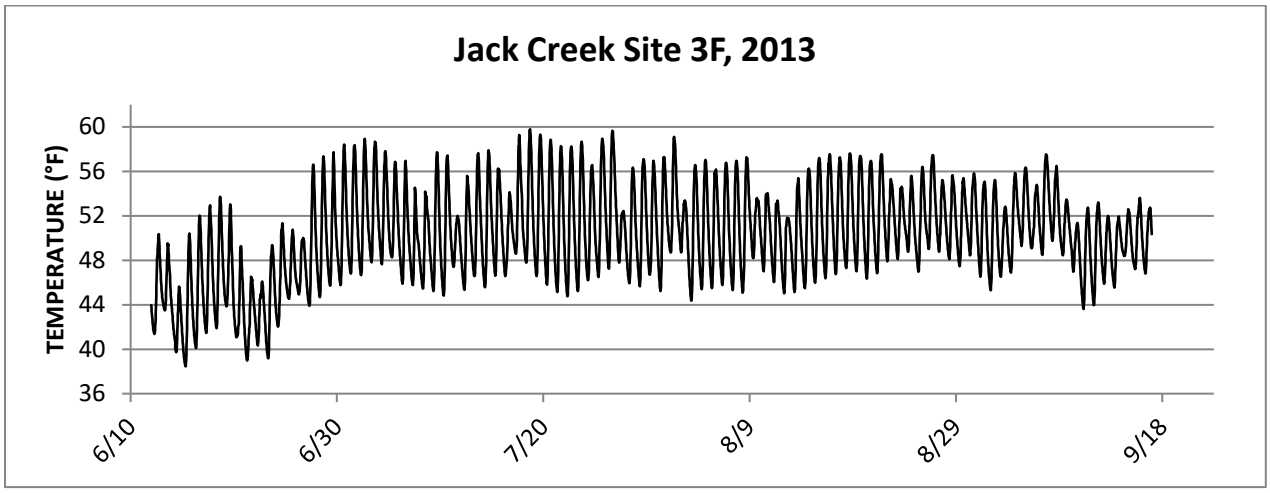

Figure G-18. Jack Creek 3F Continuous Temperature 6/12/13 through 9/16/13

Table G-10. Jack Creek DEQ Flow Measurements 2012 and 2013

Date	Stream	Site ID	Total Discharge (ft3/s)
7/29/2013	Jack Creek	MDEQ_WQ_WQX-M06JACKC01	30.98
8/1/2013	Jack Creek	MDEQ_WQ_WQX-M06JACKC03	8.51
8/1/2013	Jack Creek	MDEQ_WQ_WQX-M06JACKC04	14
8/21/2012	Jack Creek	MDEQ_WQ_WQX-M06JACKC01	27.16
8/22/2012	Jack Creek	MDEQ_WQ_WQX-M06JACKC02	10.51

Table G-11. Jack Creek Solar Pathfinder Data 2013

Date	Stream Name	Transect Number	Solar Pathfinder Photo #s at 25%, 50%, 75% Wetted Width	Percent Shade at 25 % Wetted width	Percent Shade at 50 % Wetted width	Percent Shade at 75 % Wetted width
7/29/2013	Jack Creek	3D-1	0421, 0422, 0423	90	45	46
7/29/2013	Jack Creek	3F-1	0412, 0413, 0414	15	19	57
7/29/2013	Jack Creek	3F-2	0418, 0419, 0420	71	67	53
8/1/2013	Jack Creek	3X-1	0468, 0469, 0470	47	54	37
8/1/2013	Jack Creek	3A-1	0476, 0477, 0478	13	12	13

Jack Creek DEQ Riparian Vegetation Summary
See **Table G-20** at the end of this Appendix.

G3.2.4 Madison River

The following describe FWP water temperature monitoring locations for 15 sites, from upstream of Hebgen Reservoir to the Mouth of the Madison River at Headwaters State Park (**Table G-12** and **Figure G-19**) and seasonal maximum temperature longitudinal profiles for Madison River FWP monitored sites from 2008-2013 (**Figure G-20**). DEQ shade monitoring locations and solar pathfinder data are summarized in **Figure G-21** and **Table G-13**.

Table G-12. FWP temperature monitoring site locations

Site	Approx. river mile	Latitude	Longitude
Hebgen Inlet	125.6	44.71602	-111.1024
Hebgen discharge	109	44.8649	-111.3377
Quake inlet	107	44.85318	-111.3531
Quake outlet	101.4	44.82975	-111.4236
Kirby	89.8	44.88888	-111.5799
Wall Ck Bridge	81.4	44.97582	-111.6469
McAtee	72.2	45.09721	-111.6624
Ennis Bridge	50.6	45.34794	-111.7224
Ennis Res Inlet	43.9	45.41301	-111.6942
Ennis Dam	40.3	45.46977	-111.6381
Beartrap Mouth	30.6	45.58558	-111.5958
Norris	28.2	45.59121	-111.5733
Black's Ford	23.7	45.6549	-111.5209
Cobblestone	11.4	45.80234	-111.5089
Headwaters State Park	0.1	45.92639	111.5044

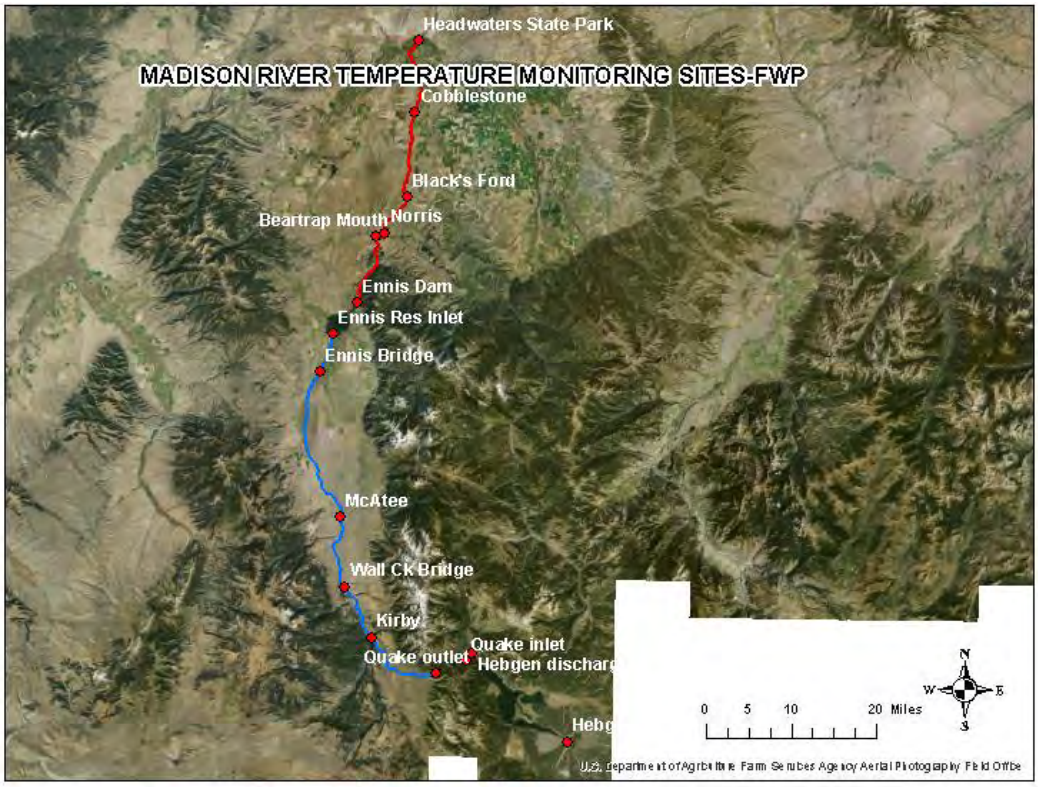

Figure G-19. FWP temperature monitoring site locations

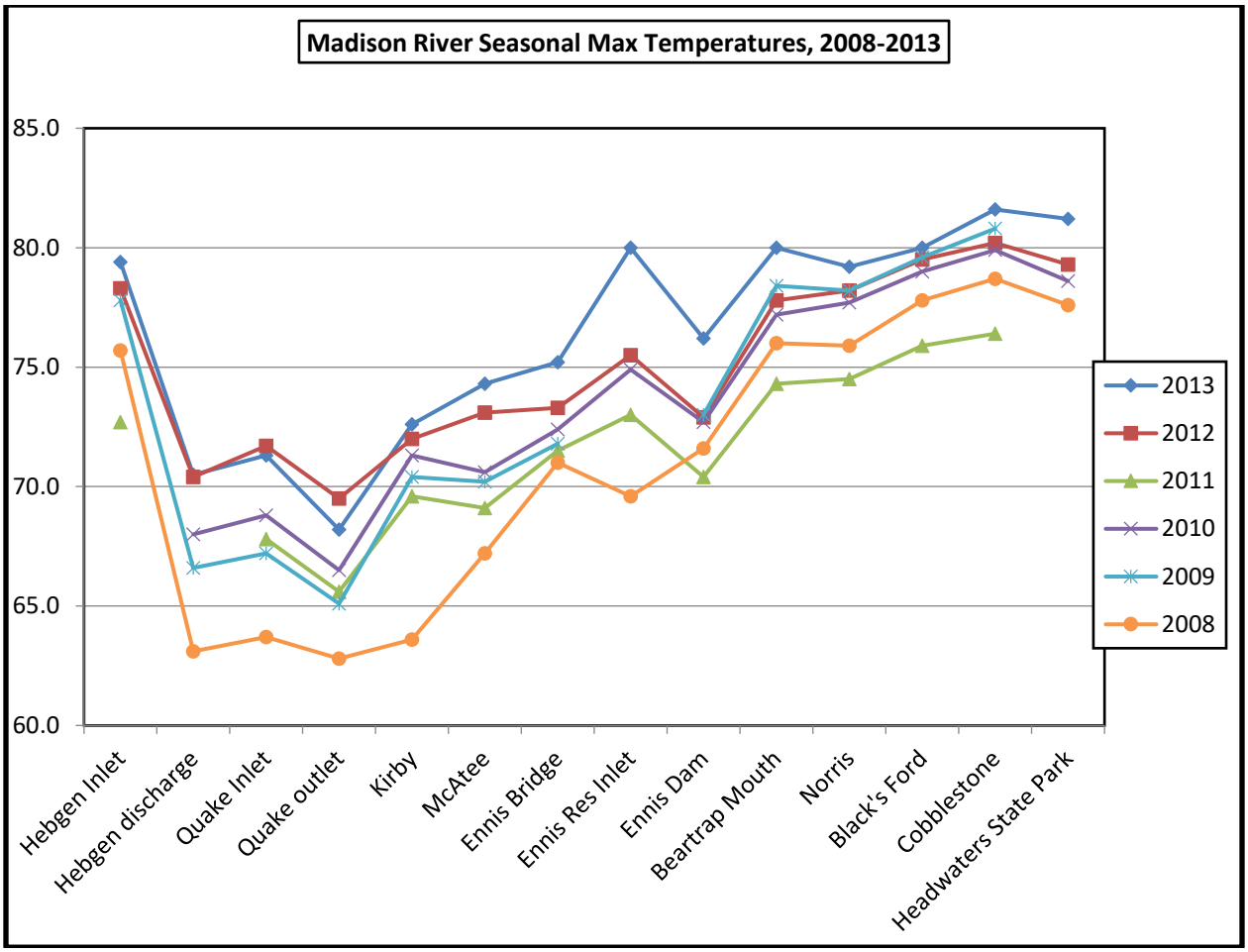

Figure G-20. Seasonal maximum temperature longitudinal profiles of the Madison River for 2008-2013 (FWP data)

Table G-13. Madison River Solar Pathfinder Data 2014

Date	Stream Name	Transect Number	Solar Pathfinder Photo #s at 25%, 50%, 75% Wetted Width	Percent Shade at 25 % Wetted width	Percent Shade at 50 % Wetted width	Percent Shade at 75 % Wetted width
7/22/2014	Madison River	6F	0942	22 (at L bank)	34 (at right bank)	
7/22/2014	Madison River	6E	0932	4 (at L bank)	46 (at right bank)	
7/22/2014	Madison River	6D	0928, 0919	7 (at L bank)	78 (at right bank)	
7/22/2014	Madison River	6C	0913	no data	5 (at right bank)	
7/22/2014	Madison River	6B	0904, 0905, 0909	2 (at L bank)	0 (at right bank)	
7/22/2014	Madison River	6A	0900, 0893	0 (at L bank)	2 (at right bank)	

Figure G-21. DEQ shade monitoring locations on the Madison River

G3.2.5 Moore Creek

The following describe site location and maximum temperatures for 4 sites on Moore Creek (**Table G-14 and Figures G-22 to G-27**). Flow data are summarized in **Table G-15** and solar pathfinder data is summarized in **Table G-16**. Riparian vegetation summaries are found at the end of this appendix in **Table G-20**.

Table G-14. Moore Creek Temperature Study Sites and Maximum Temperatures

Site ID	Site Description	River Mile	Tmax (°F)	7-Day Avg Daily Max/MWMT (°F)	Warmest Day of 7-Day Max
4A	Southern boundary of Valley Garden property	5.0	78.0	77.0	7/3/2013
4D	On Willow Ranch	7.9	72.1	70.9	7/3/2013
4E	Upstream of Madison Canal	8.3	65.7	64.9	7/3/2013
4F	Downstream of Maloney Pond	9.3	70.0	68.9	7/1/2013

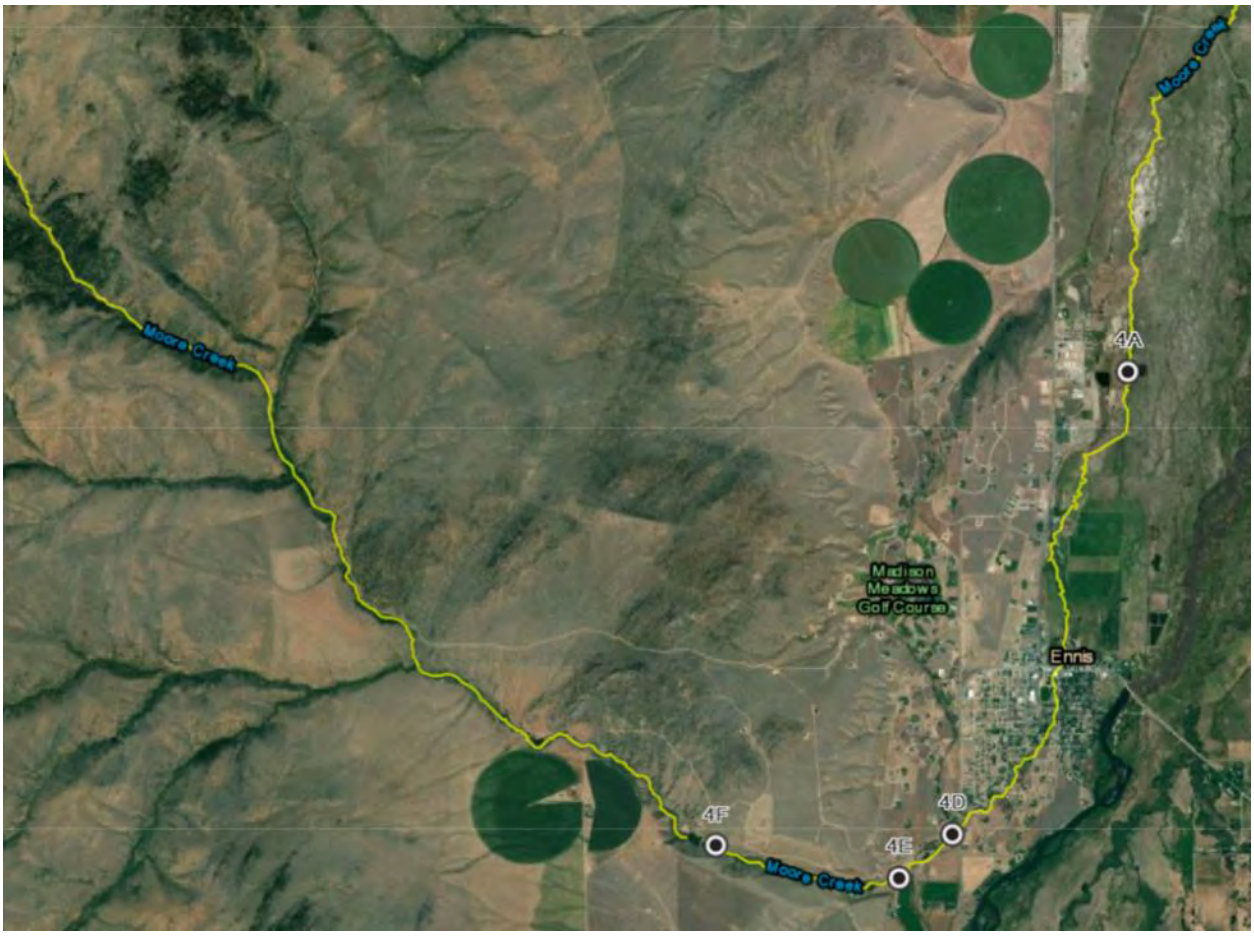

Figure G-22. Moore Creek DEQ Temperature Study Sites

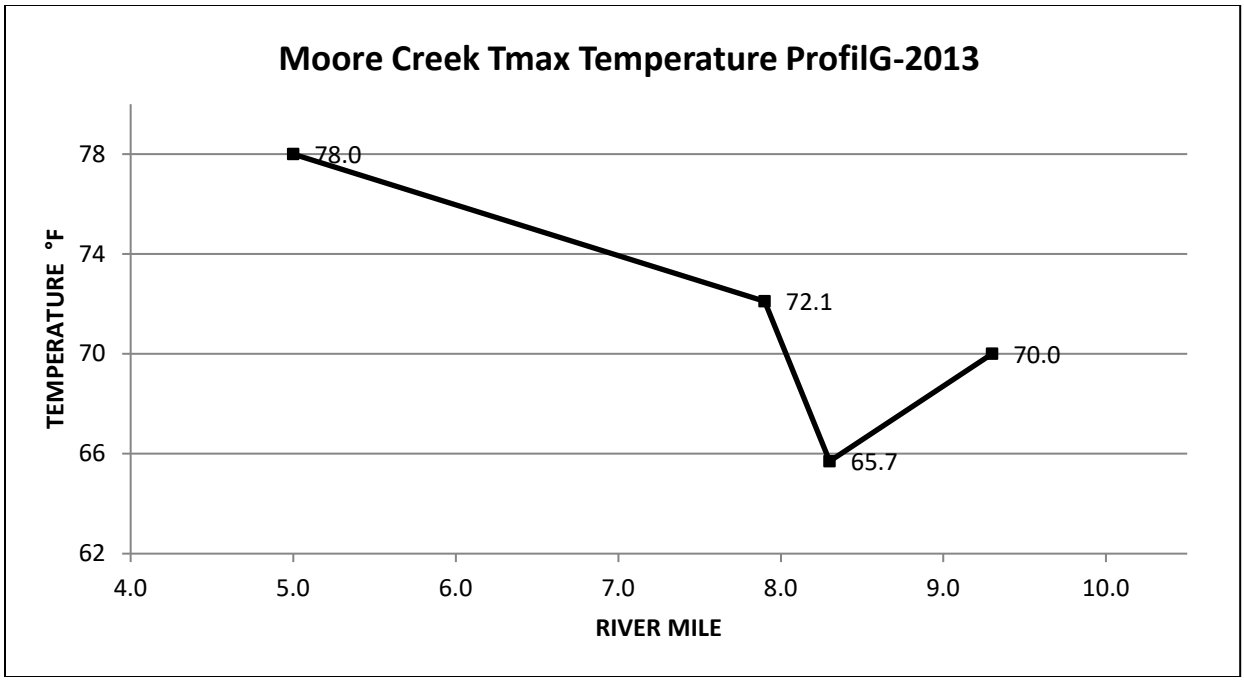

Figure G-23. Maximum temperature profile for four sites on Moore Creek

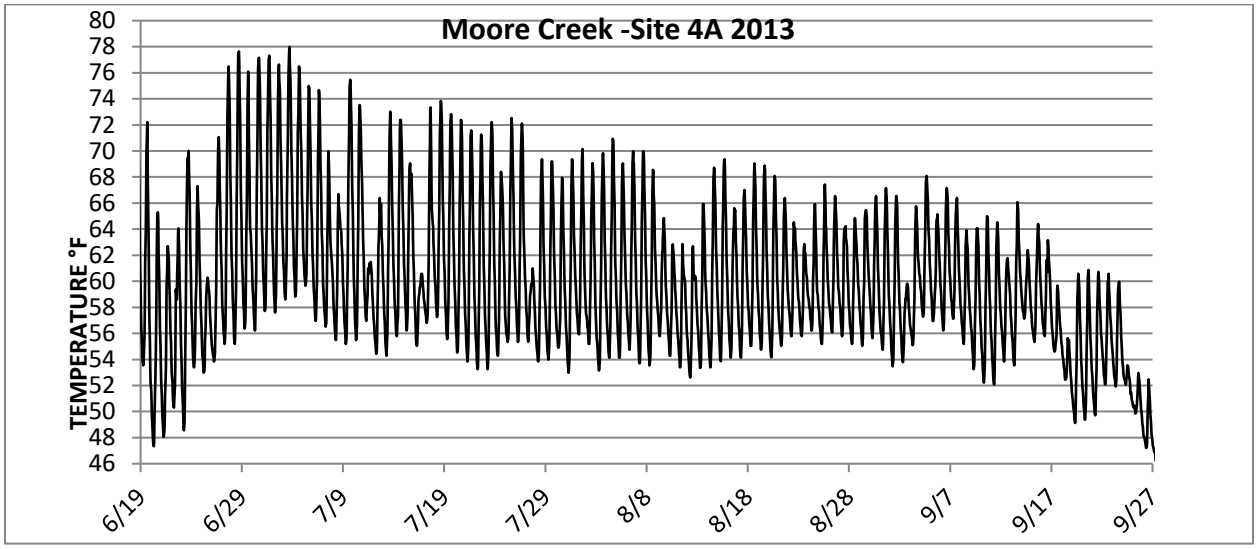

Figure G-24. Moore Creek 4A Continuous Temperature 6/19/13 through 9/27/13

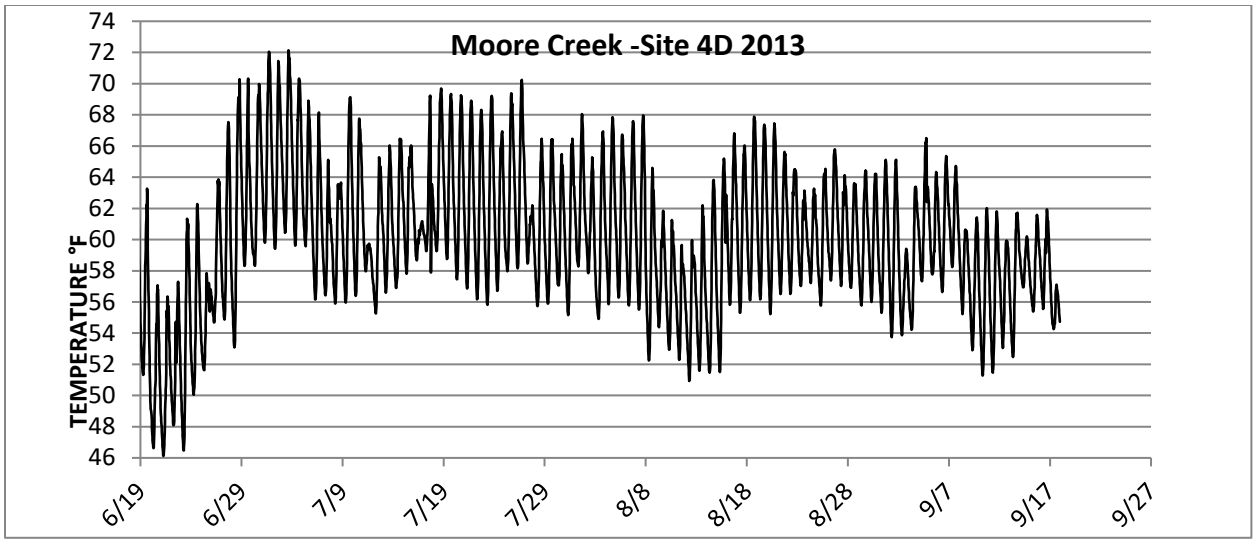

Figure G-25. Moore Creek 4D Continuous Temperature 6/12/13 through 9/17/13

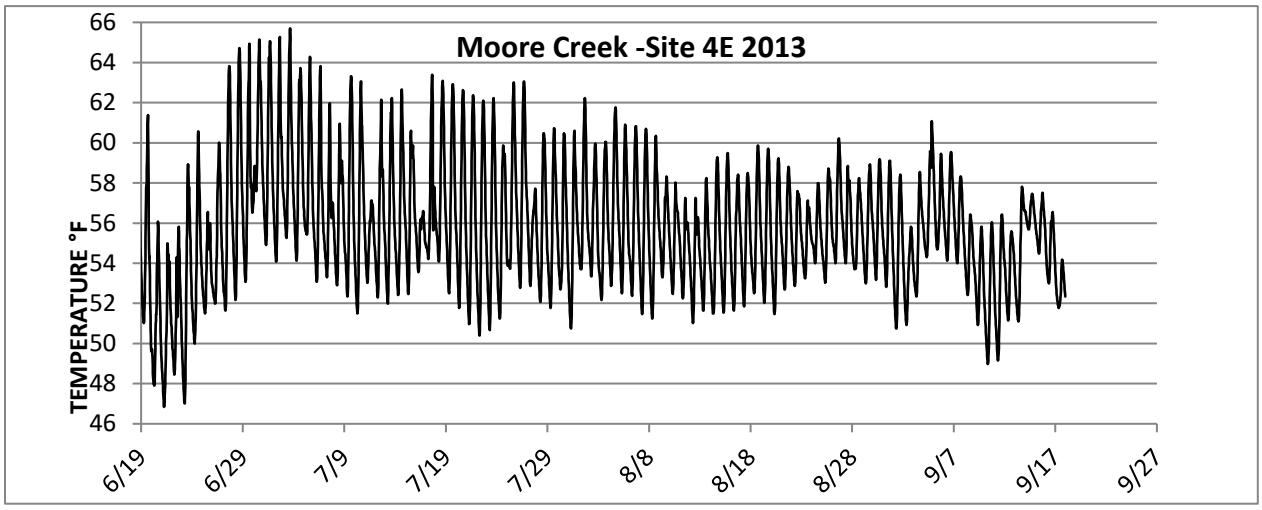

Figure G-26. Moore Creek 4E Continuous Temperature 6/12/13 through 9/17/13

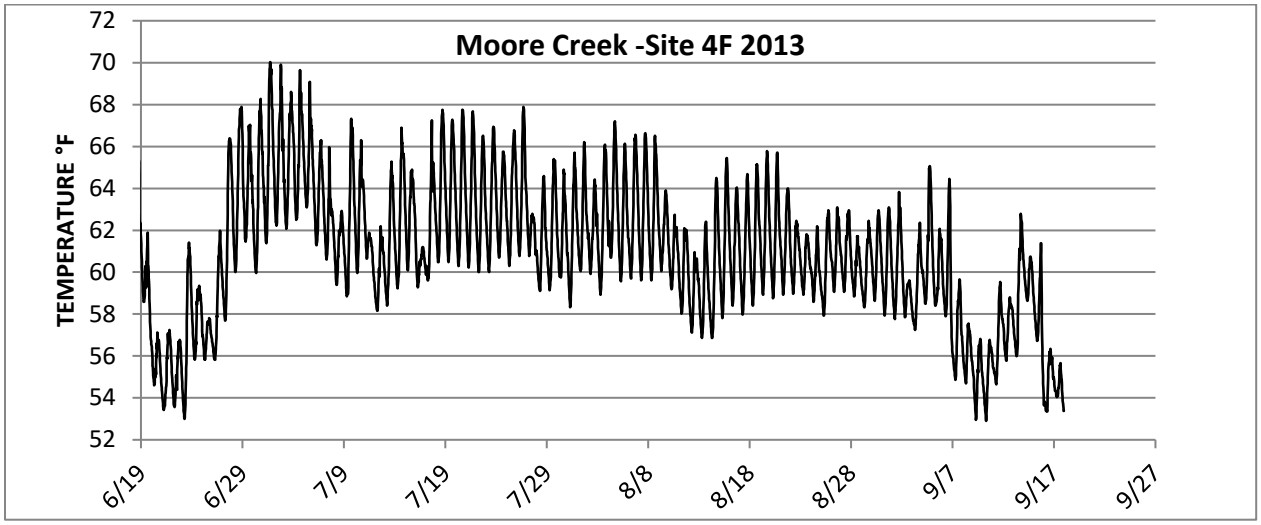

Figure G-27. Moore Creek 4F Continuous Temperature 6/12/13 through 9/17/13

Table G-15. Moore Creek DEQ Flow Measurements 2012-2014

Date	Stream	Site ID	Total Discharge (ft3/s)
8/1/2013	Moore Creek	MDEQ_WQ_WQX-M06MOREC01	0.26
8/1/2013	Moore Creek	MDEQ_WQ_WQX-M06MOREC02	1.15
8/1/2013	Moore Creek	MDEQ_WQ_WQX-M06MOREC03	0.58
8/1/2013	Moore Creek	MDEQ_WQ_WQX-M06MOREC06	0.52
6/20/2012	Moore Creek	MDEQ_WQ_WQX-M06MOREC01	0.72
7/20/2012	Moore Creek	MDEQ_WQ_WQX-M06MOREC01	2.06
8/22/2012	Moore Creek	MDEQ_WQ_WQX-M06MOREC01	0.38
6/20/2012	Moore Creek	MDEQ_WQ_WQX-M06MOREC02	1.18
7/19/2012	Moore Creek	MDEQ_WQ_WQX-M06MOREC02	0.9
8/22/2012	Moore Creek	MDEQ_WQ_WQX-M06MOREC02	0.84
6/20/2012	Moore Creek	MDEQ_WQ_WQX-M06MOREC03	0.84
7/19/2012	Moore Creek	MDEQ_WQ_WQX-M06MOREC03	0.85
8/22/2012	Moore Creek	MDEQ_WQ_WQX-M06MOREC03	0.77
7/20/2012	Moore Creek	MDEQ_WQ_WQX-M06MOREC05	1.78
9/5/2014	Moore Creek	MDEQ_WQ_WQX-M06MOREC07	2.5
9/5/2014	Moore Creek	MDEQ_WQ_WQX-M06MOREC08	2.89

Table G-16. Moore Creek Solar Pathfinder Data 2013

Date	Stream Name	Transect Number	Solar Pathfinder Photo #s at 25%, 50%, 75% Wetted Width	Percent Shade at 25 % Wetted width	Percent Shade at 50 % Wetted width	Percent Shade at 75 % Wetted width
8/1/2013	Moore Creek	4A-1	0484, 0485, 0486	27	26	29
8/1/2013	Moore Creek	4D-1	0493, 0494, 0495	95	90	89
8/1/2013	Moore Creek	4G-1	0500, 0501, 0502	61	71	89
8/1/2013	Moore Creek	4F-1	0506, 0507, 0508	100	100	100

Moore Creek DEQ Riparian Vegetation Summary
See **Table G-20** at the end of this Appendix.

G3.2.6 West Fork Madison River

The following describe site location and seasonal maximum temperatures for 16 sites on the West Fork Madison River and 5 sites on tributaries to the West Fork Madison River (**Table G-17 and Figures G-28 to G-59**). Flow data is summarized in **Table G-18** and solar pathfinder data is summarized in **Tables G-19.** Riparian vegetation summaries are found at the end of this appendix in **Table G-20.**

Table G-17. West Fork Madison River Temperature Study Sites and Maximum Temperatures

Site Number	Waterbody Name	Site Description	2013 Seasonal Maximum Temperature (°F)	2014 Seasonal Maximum Temperature (°F)
5A	West Fork Madison River	near mouth and serves as the d/s bracket for a trib, Gazelle Cr.	71.6	68.72

Table G-17. West Fork Madison River Temperature Study Sites and Maximum Temperatures

Site Number	Waterbody Name	Site Description	2013 Seasonal Maximum Temperature (°F)	2014 Seasonal Maximum Temperature (°F)
5B	West Fork Madison River	above the mouth of Gazelle Creek	72.68	
5C	West Fork Madison River	d/s of the mouth of Lake Cr. Reference riparian condition	72.14	69.44
5D	West Fork Madison River	u/s of the mouth of Lake Cr.	73.04	
5E	West Fork Madison River	Similar channel type, veg, and shade to site 5D, 5 miles u/s of 5D	69.8	
5F	West Fork Madison River	u/s of the mouth of Freezeout Creek	69.8	
5G	West Fork Madison River	d/s of the mouth of Elk River, a major trib; serves to help bracket the effects of the tributary. A shift from willow-dominated riparian veg to conifers and willows and alders occurs from here to the mouth	69.26	66.2
5H	West Fork Madison River	u/s of the mouth of Elk River, and is the lower extent of a Rosgen E/C channel type, with high sinuosity and willow/sedge-dominated riparian vegetation	77.9	
5I	West Fork Madison River	d/s of large warm spring	80.96	
5J	West Fork Madison River	u/s of large warm spring, beaver complex u/s of site	77	
5K	West Fork Madison River	near u/s extent of beaver colonies, u/s of cold spring, d/s of grazed pasture	75.38	
5L	West Fork Madison River	d/s of a small warm trib, in a beaver complex, 1.5mile d/s of site 5M, site tests the extent of the influence of the cold trib located u/s of site 5M	74.48	
5M	West Fork Madison River	d/s of Teepee Creek; serves to help bracket the effects of the trib. A geologic nick point here results in cobble channel material and conifers near the riparian area	73.94	73.04
5N	West Fork Madison River	u/s of Teepee Creek, a major trib to the West Fork Madison R., and is d/s of Meridian Cr.	79.52	77
5P	West Fork Madison River	100'downstream Anderson Cr. (7/23/14). Air Temp monitoring site here also. (7/23/14)		68.14
5X	West Fork Madison River	about 1- 1/4 mile d/s of Fox Cr.		70.34

Table G-17. West Fork Madison River Temperature Study Sites and Maximum Temperatures

Site Number	Waterbody Name	Site Description	2013 Seasonal Maximum Temperature (°F)	2014 Seasonal Maximum Temperature (°F)
7A	Elk River	Significant cold water trib to the West Fork Madison R results in an approximate six-fold increase to West Fork flows during baseflow conditions	66.56	63.5
8A	Freezeout Creek	Trib to West Fork Madison	71.6	
9A	Gazelle Creek	Trib to West Fork Madison	66.2	
12A	Lake Creek	Significant trib to the West Fork Madison R		71.06
10A	Teepee Creek	Significant cool water trib to the West Fork Madison R	67.82	

Figure G-28. All West Fork Madison River and Tributary Sites

Figure G-29. Upper West Fork Madison River and Tributary Sites

Figure G-30. Middle West Fork Madison River and Tributary Sites

Figure G-31. Downstream West Fork Madison River and Tributary Sites

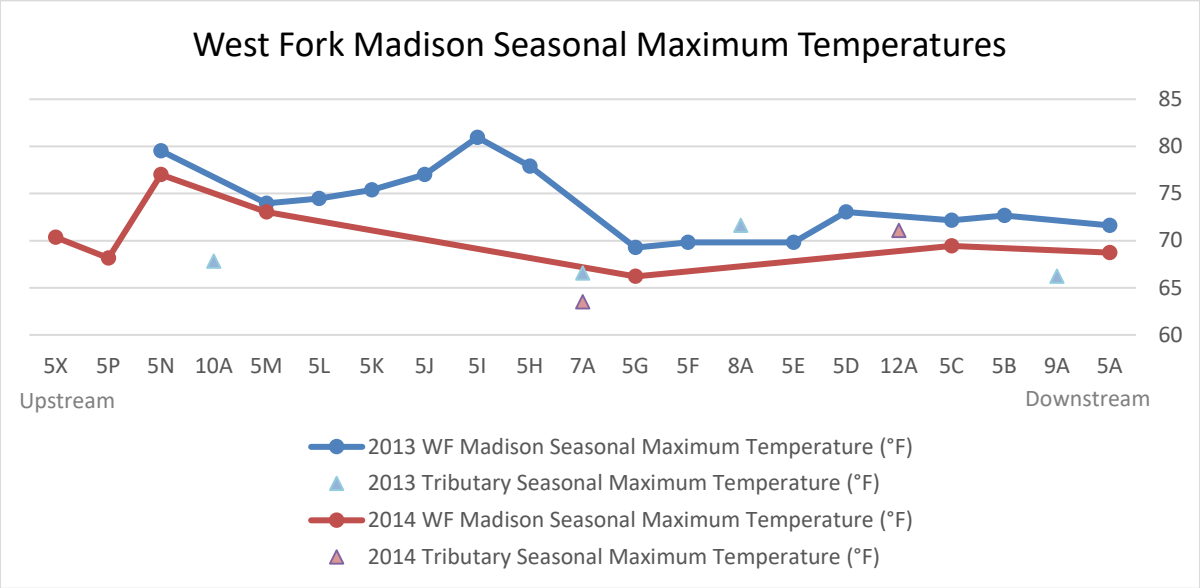

Figure G-32. West Fork Madison River Temperature Study Sites and Maximum Temperatures

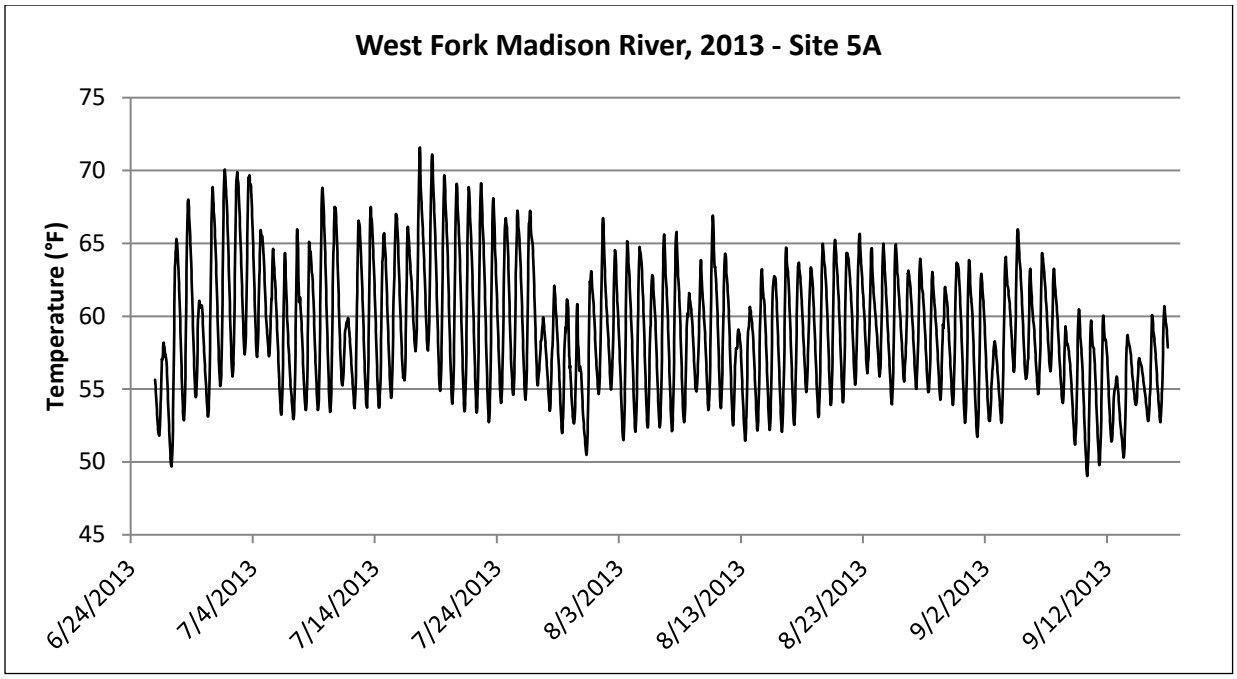

Figure G-33. WF Madison River 5A Continuous Temperature 6/26/13 through 9/16/13

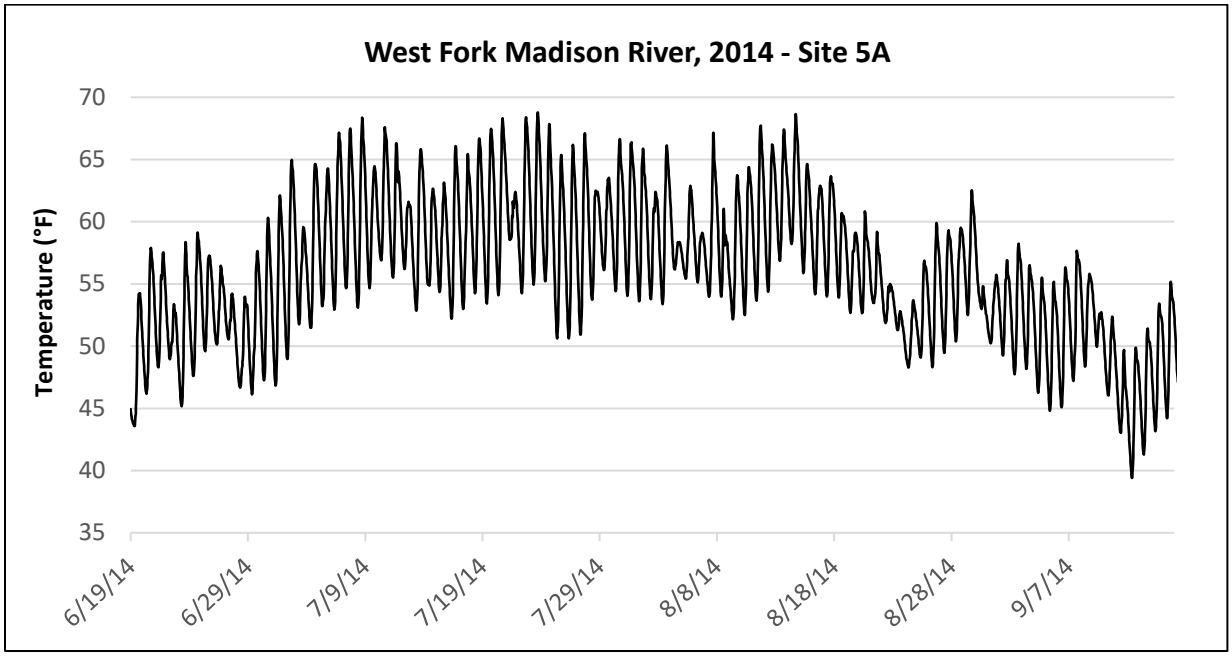

Figure G-34. WF Madison River 5A Continuous Temperature 6/19/14 through 9/16/14

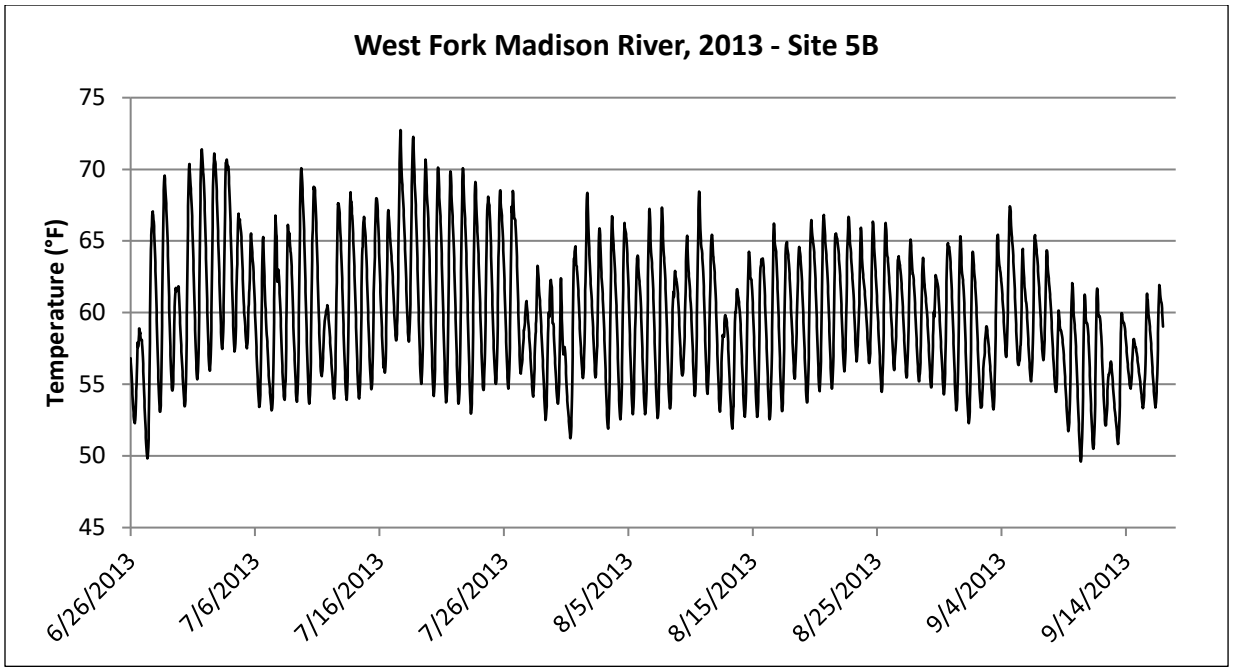

Figure G-35. WF Madison River 5B Continuous Temperature 6/26/13 through 9/16/13

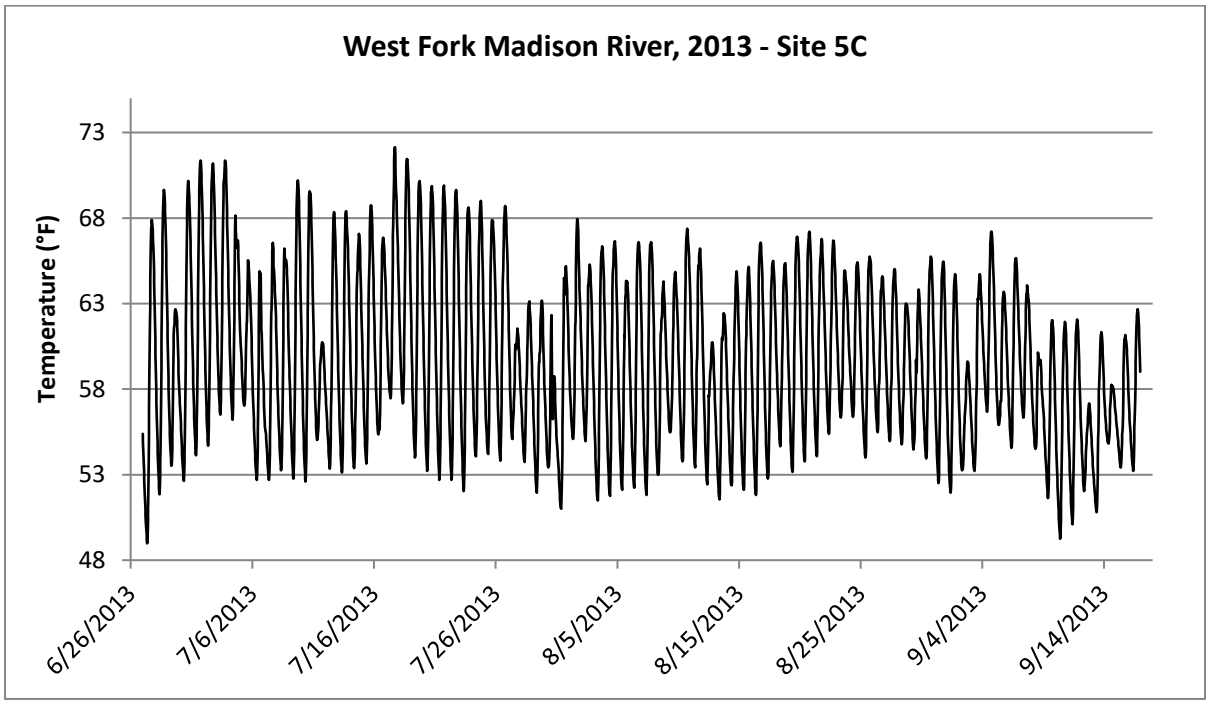

Figure G-36. WF Madison River 5C Continuous Temperature 6/27/13 through 9/16/13

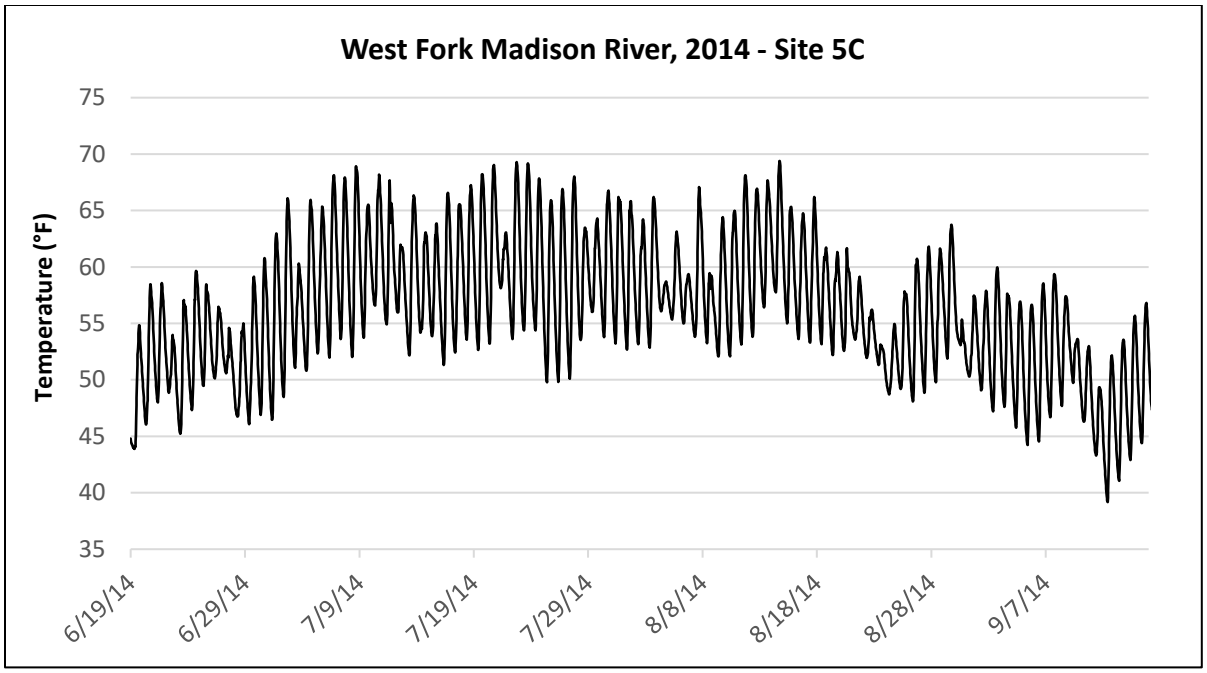

Figure G-37. WF Madison River 5C Continuous Temperature 6/19/14 through 9/16/14

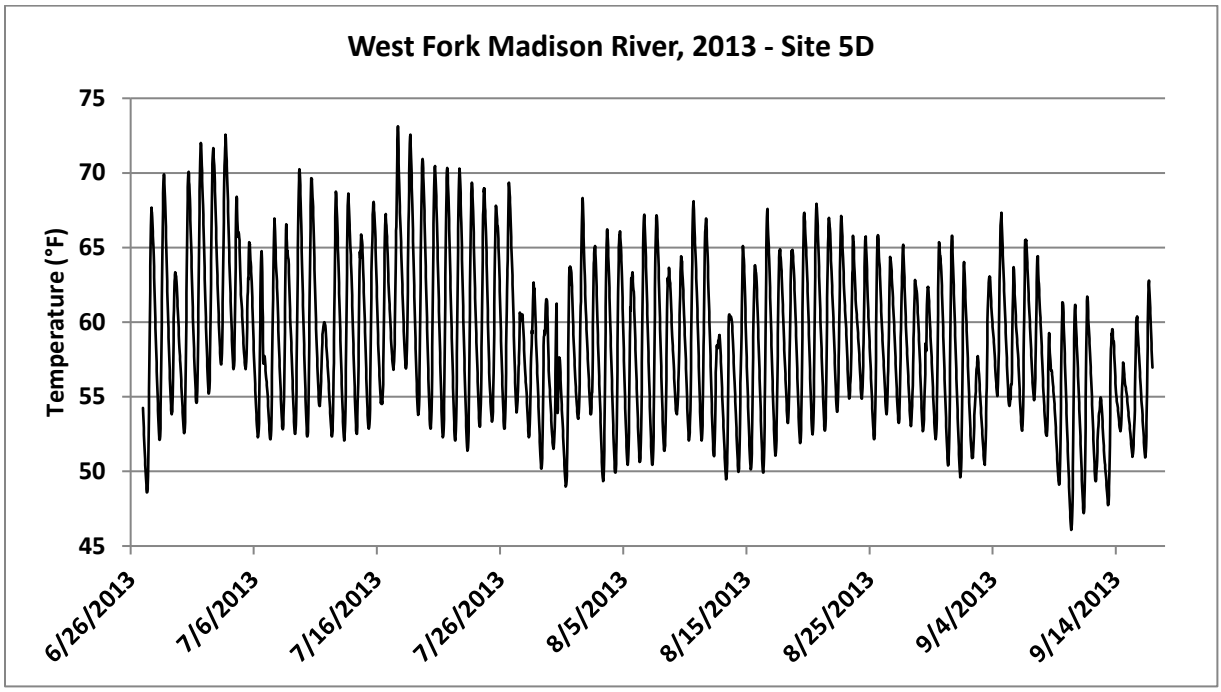

Figure G-38. WF Madison River 5D Continuous Temperature 6/27/13 through 9/16/13

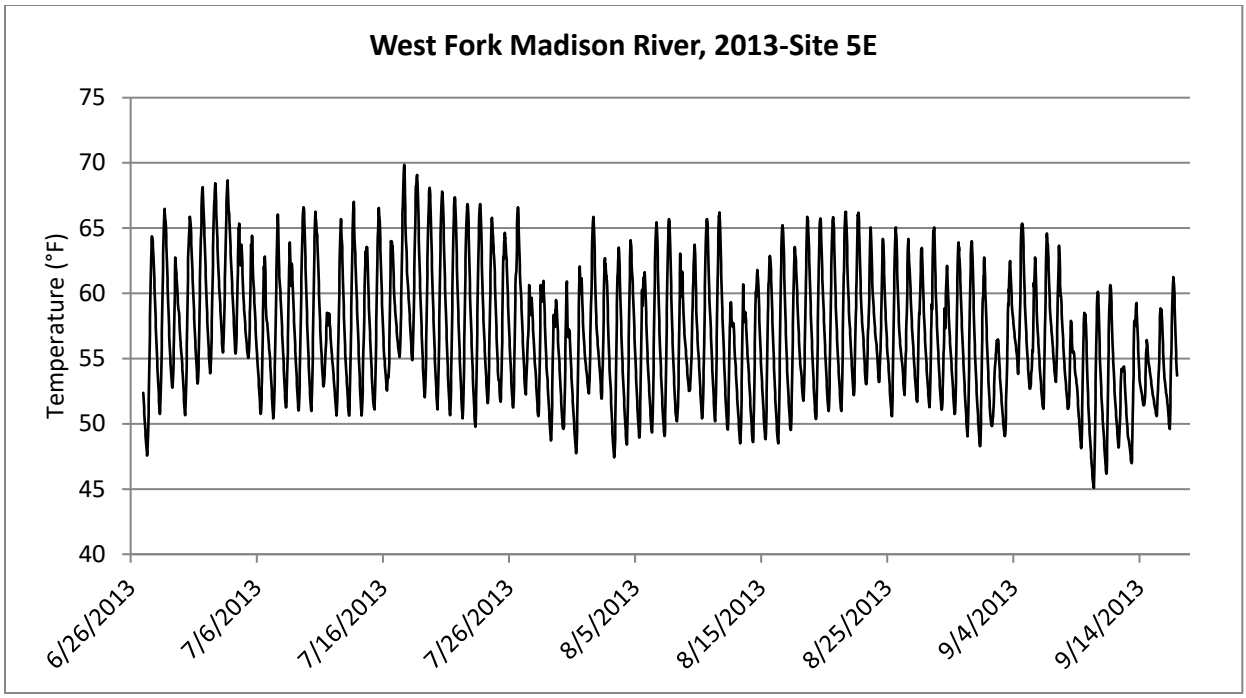

Figure G-39. WF Madison River 5E Continuous Temperature 6/27/13 through 9/16/13

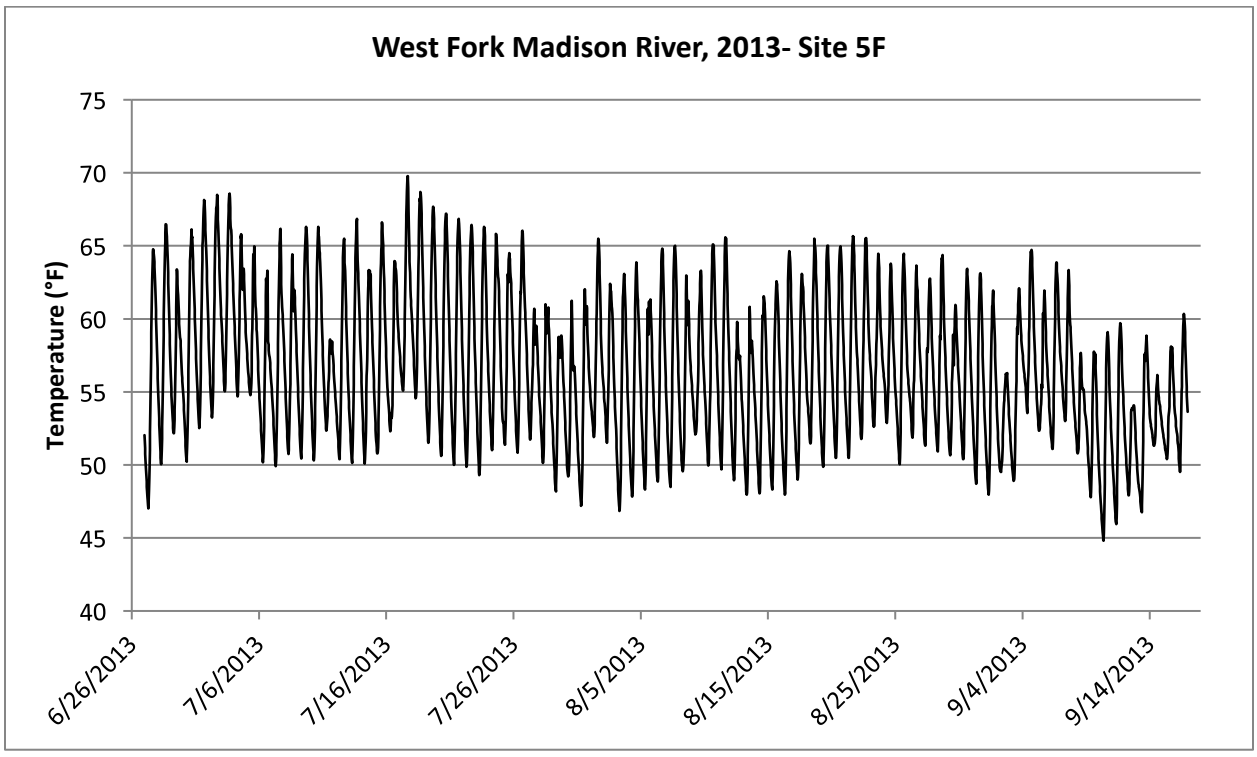

Figure G-40. WF Madison River 5F Continuous Temperature 6/27/13 through 9/16/13

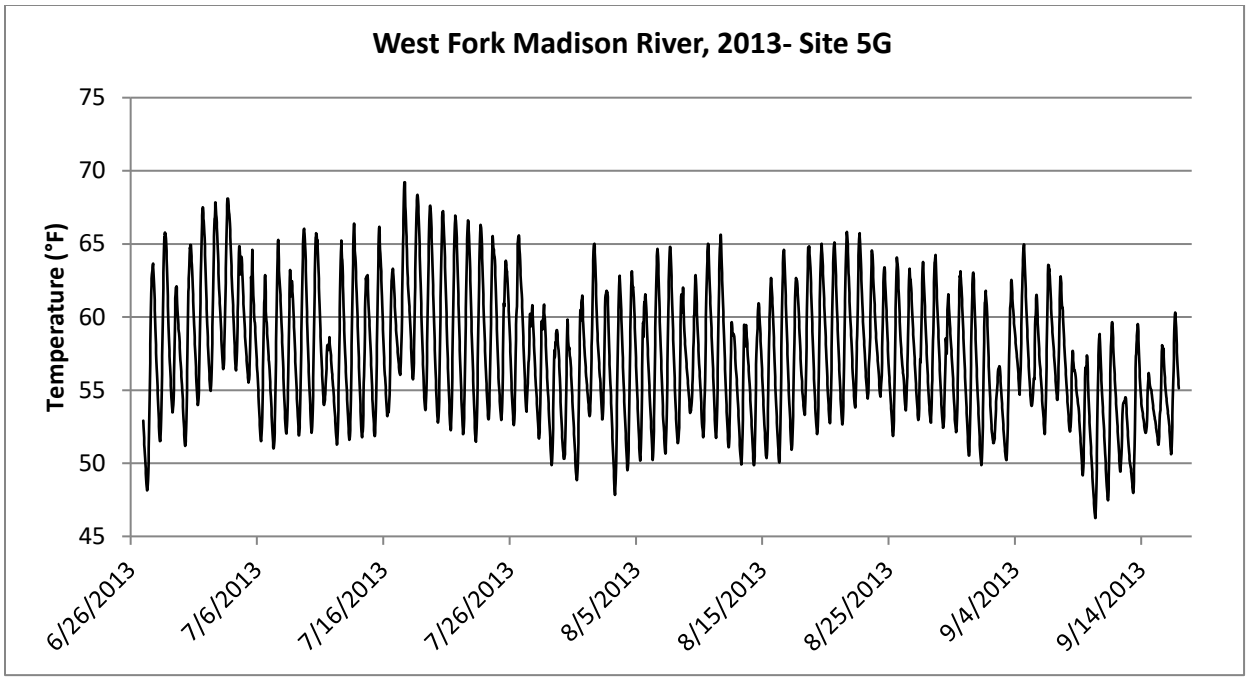

Figure G-41. WF Madison River 5G Continuous Temperature 6/27/13 through 9/16/13

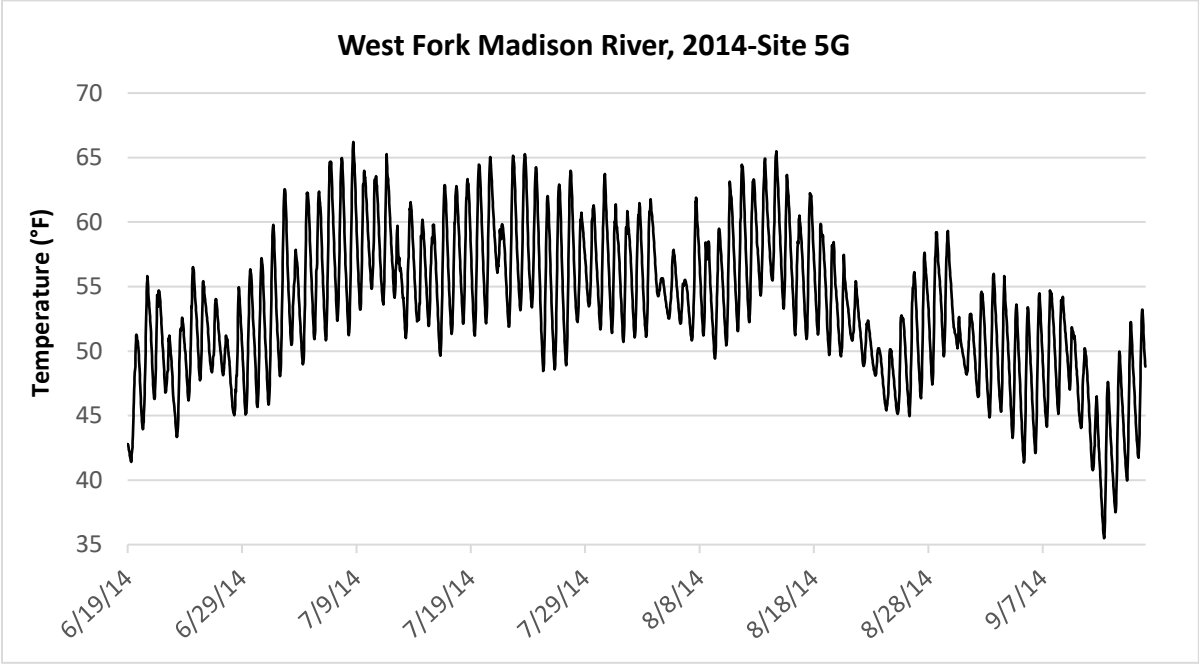

Figure G-42. WF Madison River 5G Continuous Temperature 6/19/14 through 9/15/14

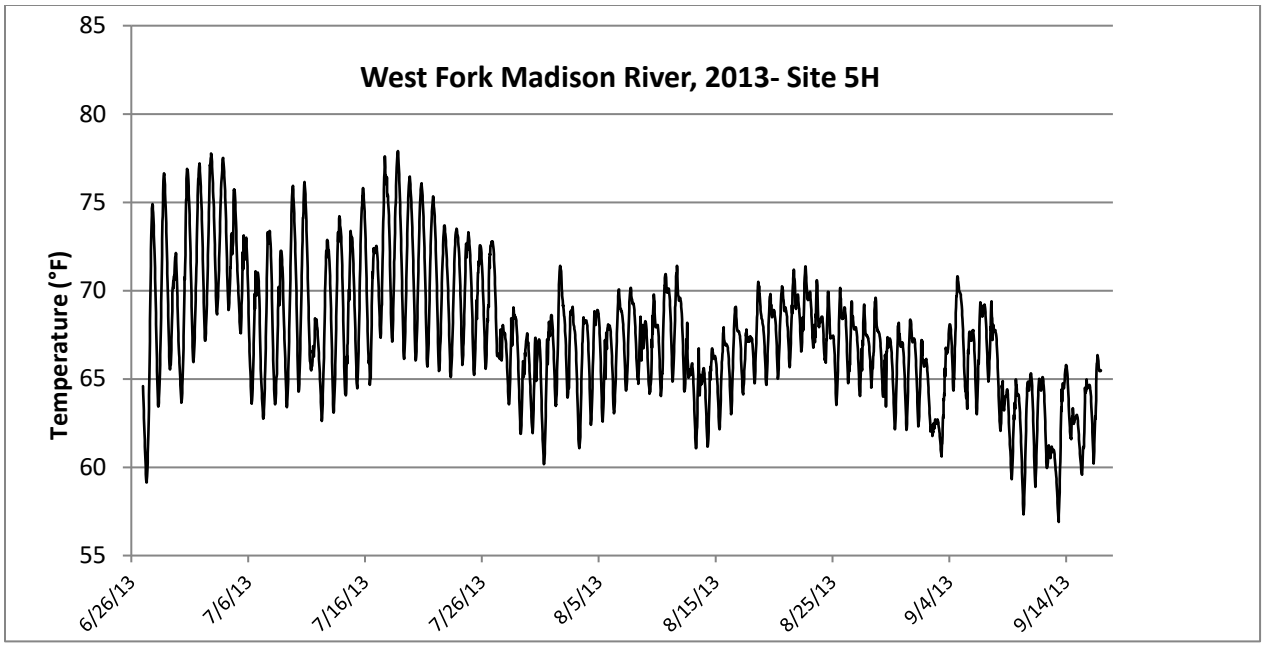

Figure G-43. WF Madison River 5H Continuous Temperature 6/27/13 through 9/16/13

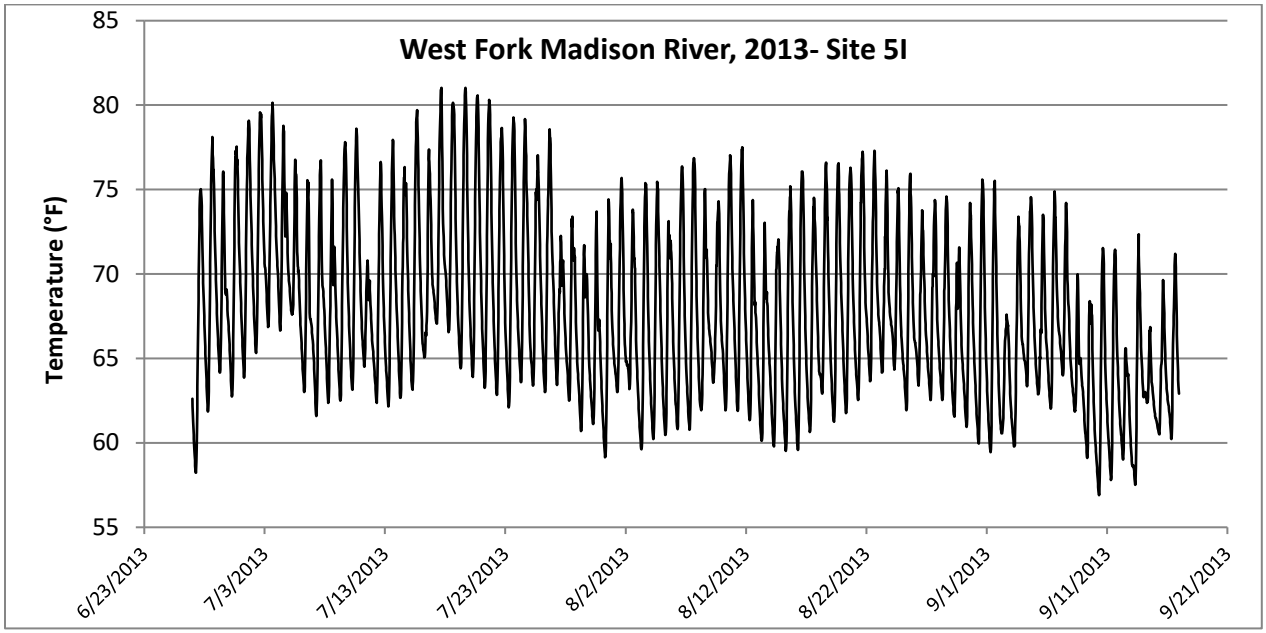

Figure G-44. WF Madison River 5I Continuous Temperature 6/27/13 through 9/16/13

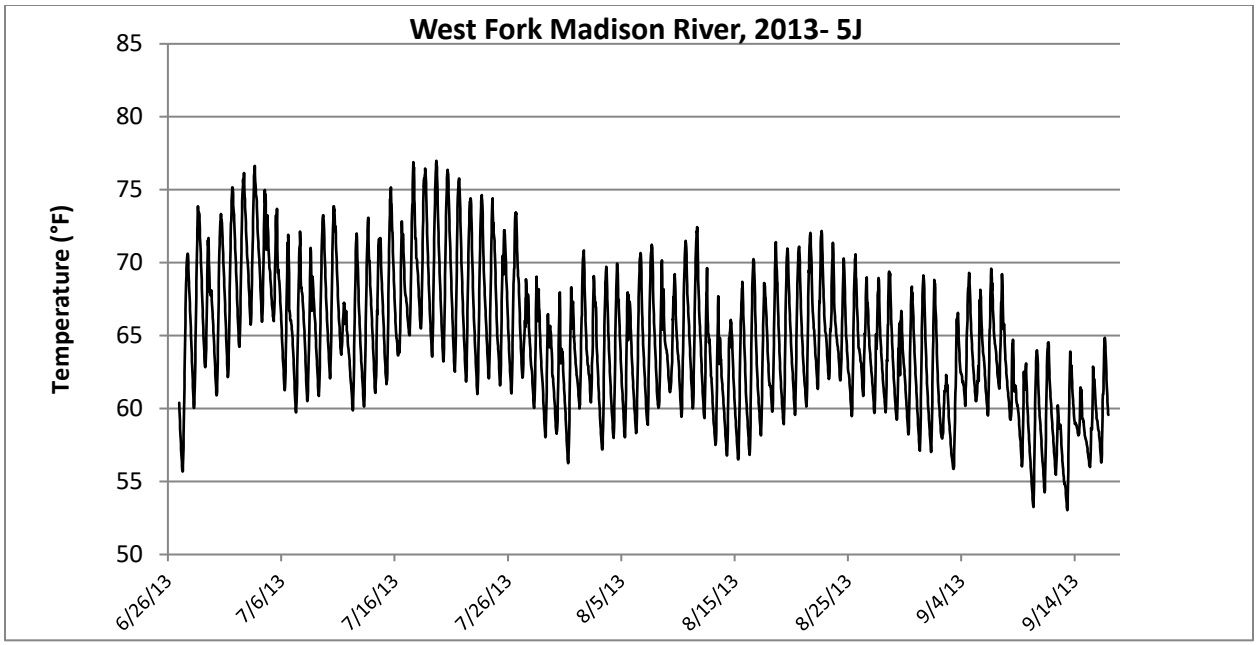

Figure G-45. WF Madison River 5J Continuous Temperature 6/27/13 through 9/16/13

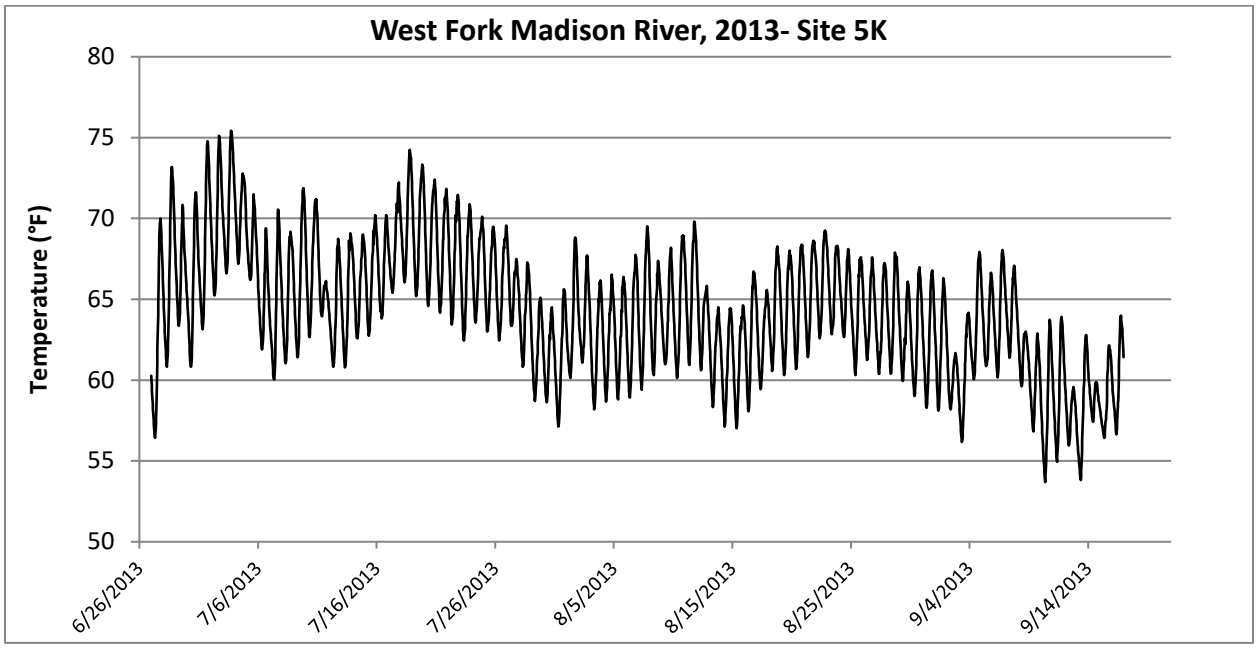

Figure G-46. WF Madison River 5K Continuous Temperature 6/27/13 through 9/16/13

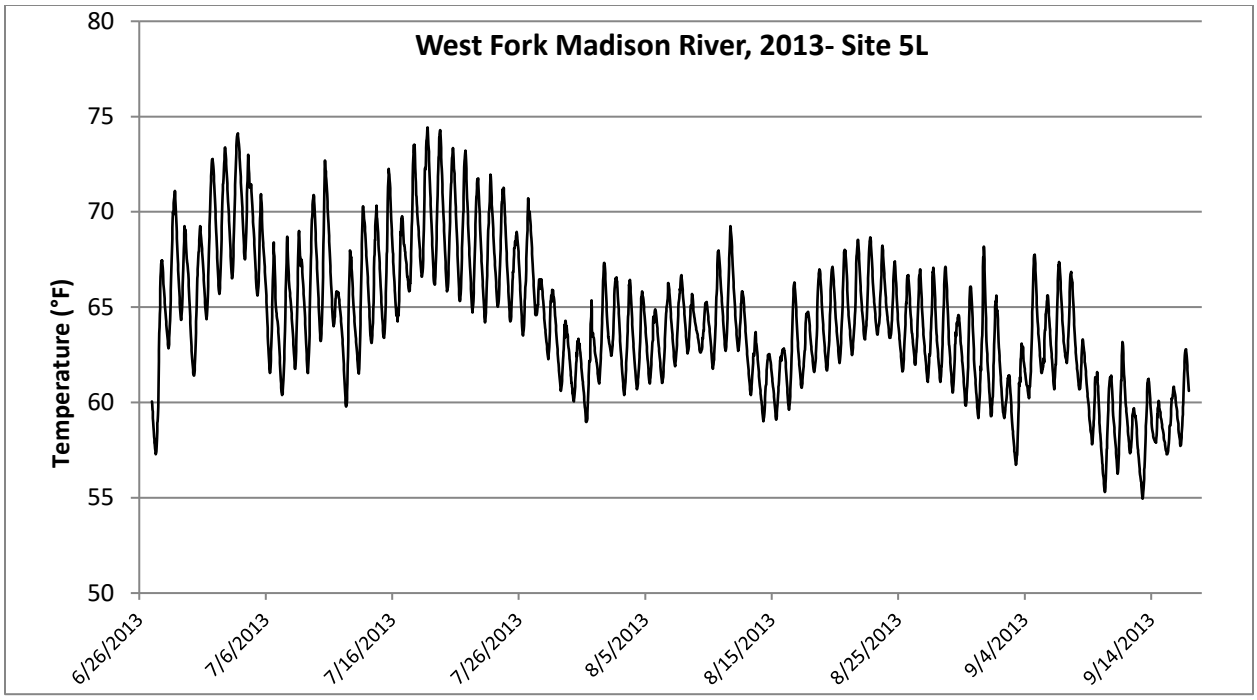

Figure G-47. WF Madison River 5L Continuous Temperature 6/27/13 through 9/16/13

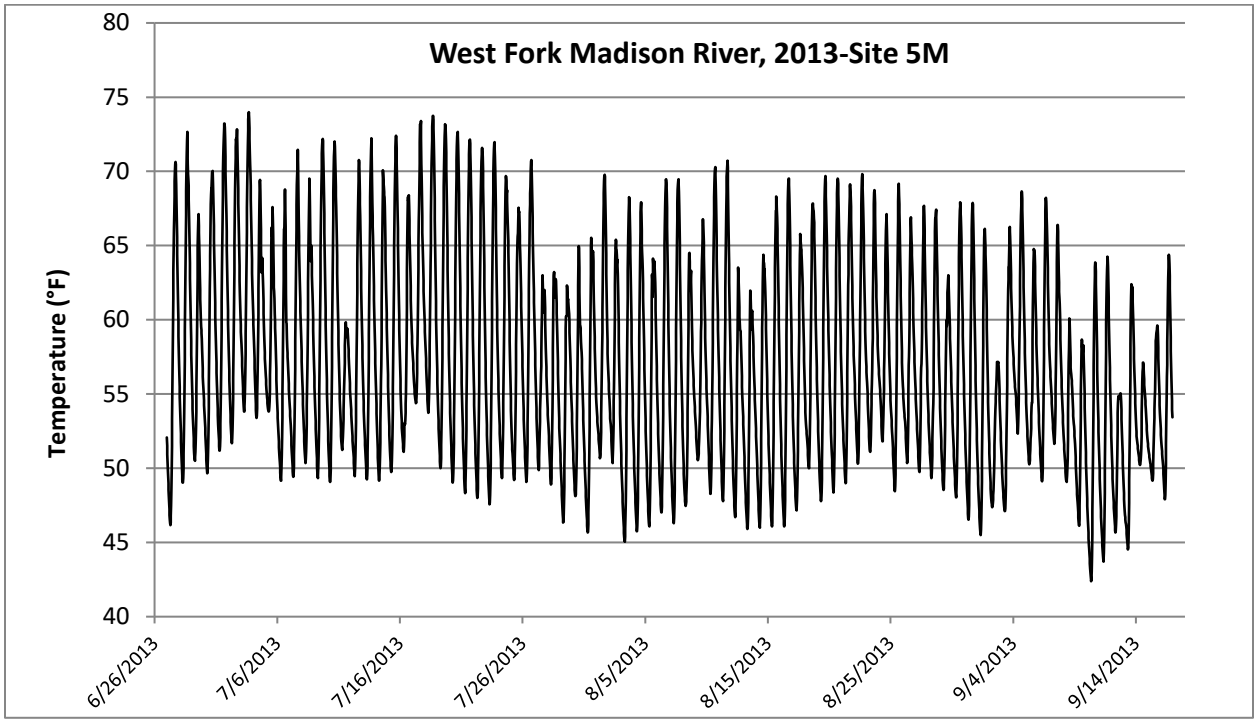

Figure G-48. WF Madison River 5M Continuous Temperature 6/27/13 through 9/16/13

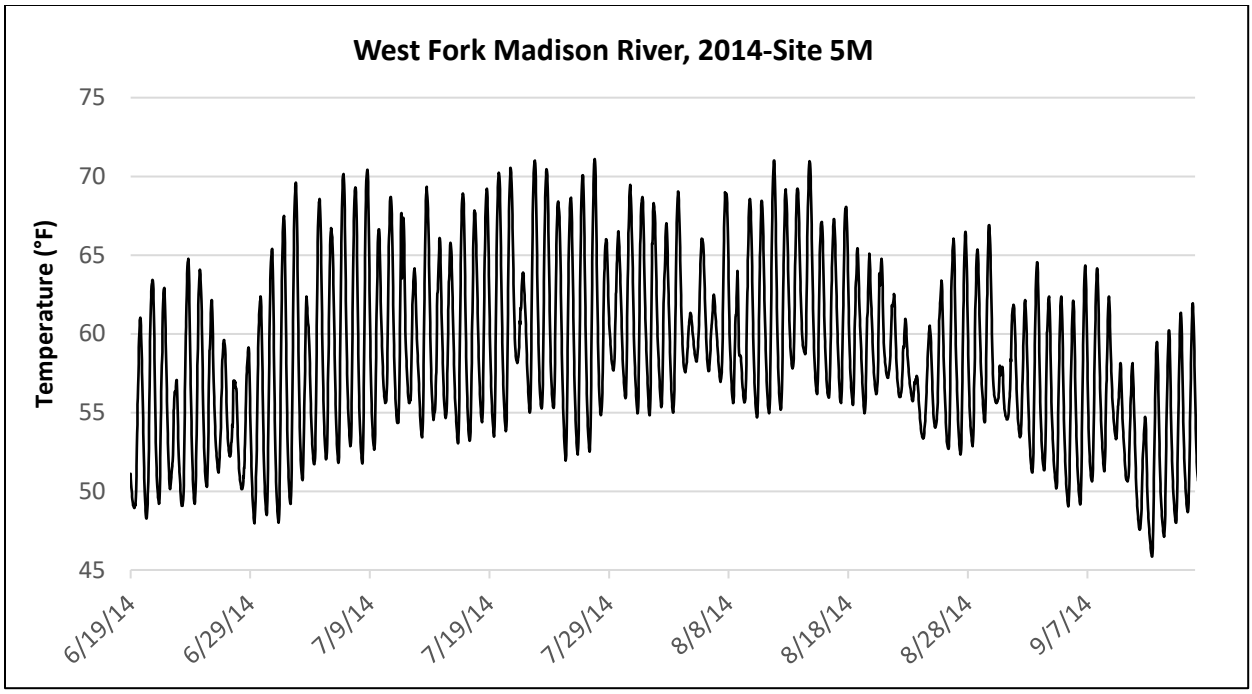

Figure G-49. WF Madison River 5M Continuous Temperature 6/19/14 through 9/16/14

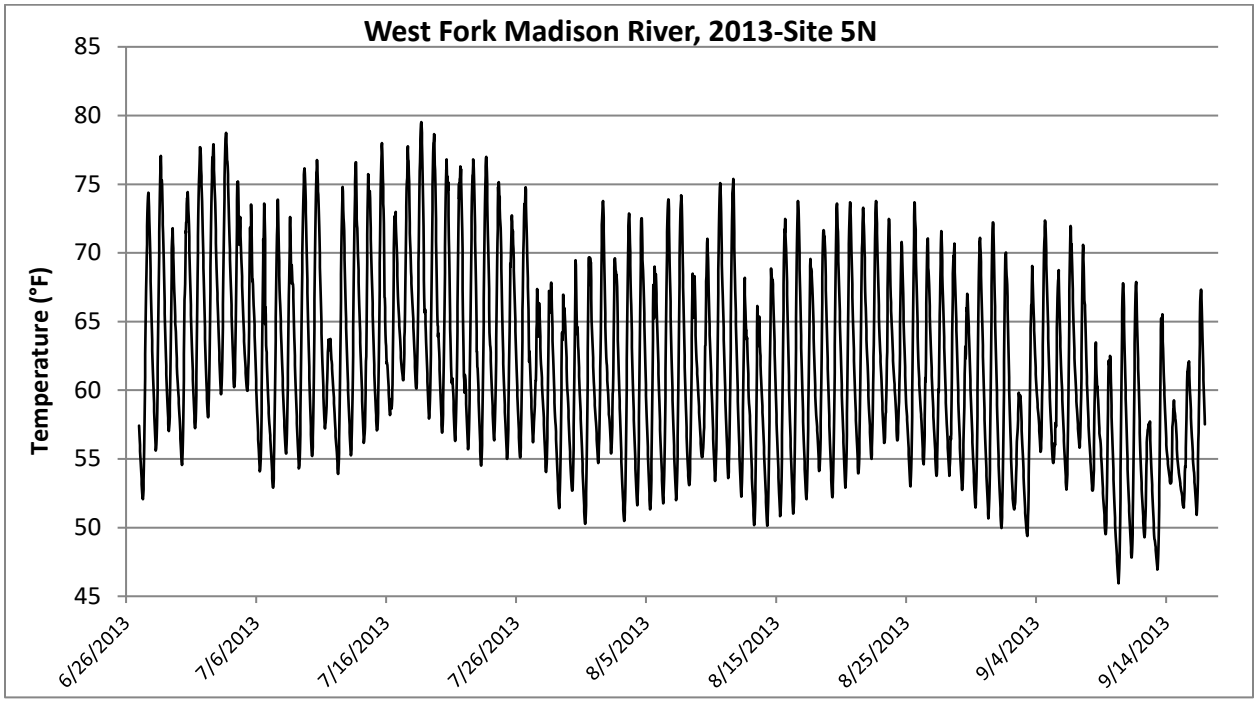

Figure G-50. WF Madison River 5N Continuous Temperature 6/27/13 through 9/16/13

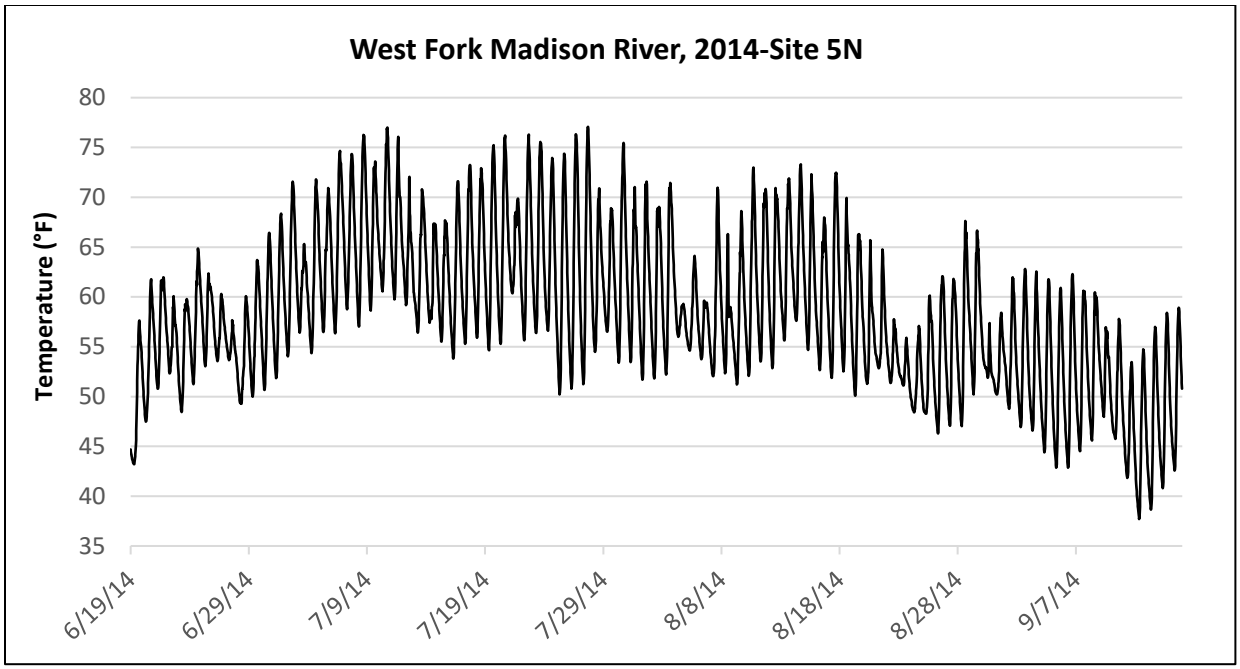

Figure G-51. WF Madison River 5N Continuous Temperature 6/19/14 through 9/15/14

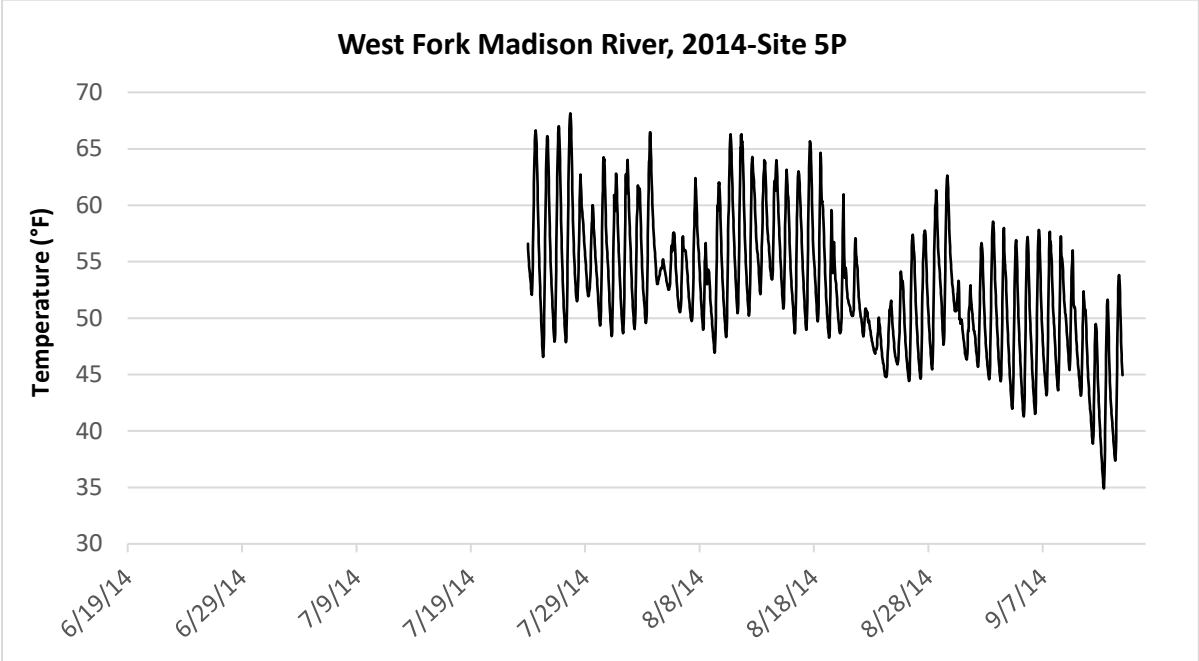

Figure G-52. WF Madison River 5P Continuous Temperature 7/24/14 through 9/14/14

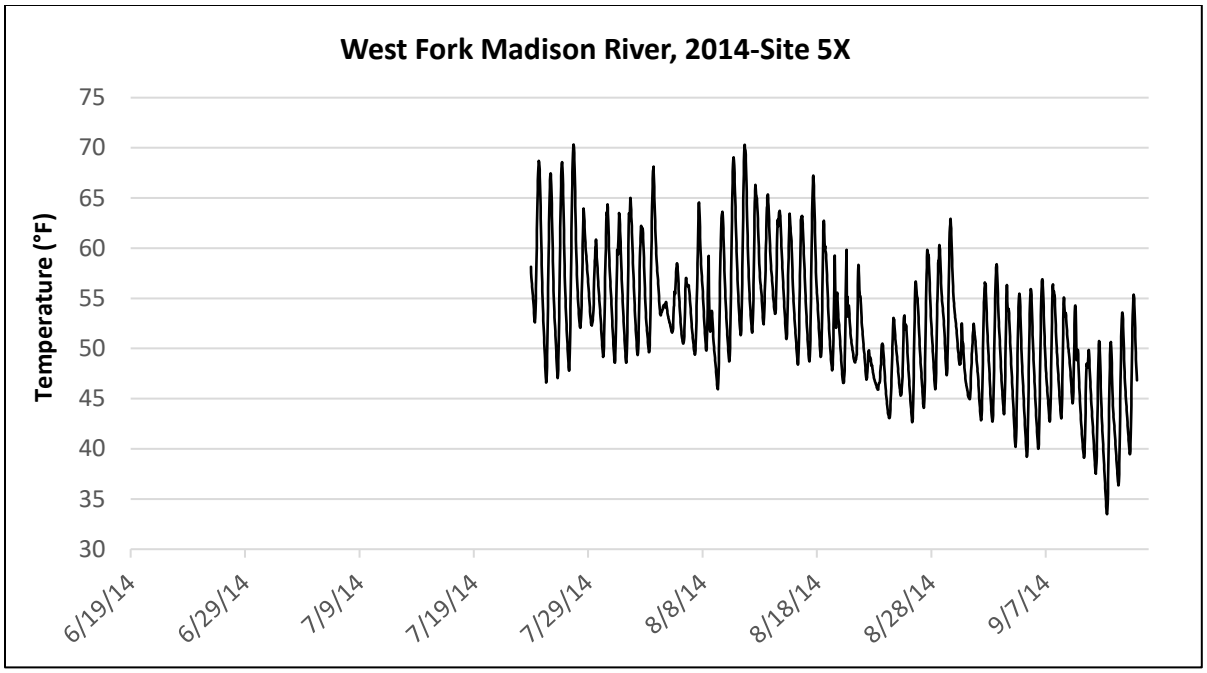

Figure G-53. WF Madison River 5X Continuous Temperature 7/24/14 through 9/14/14

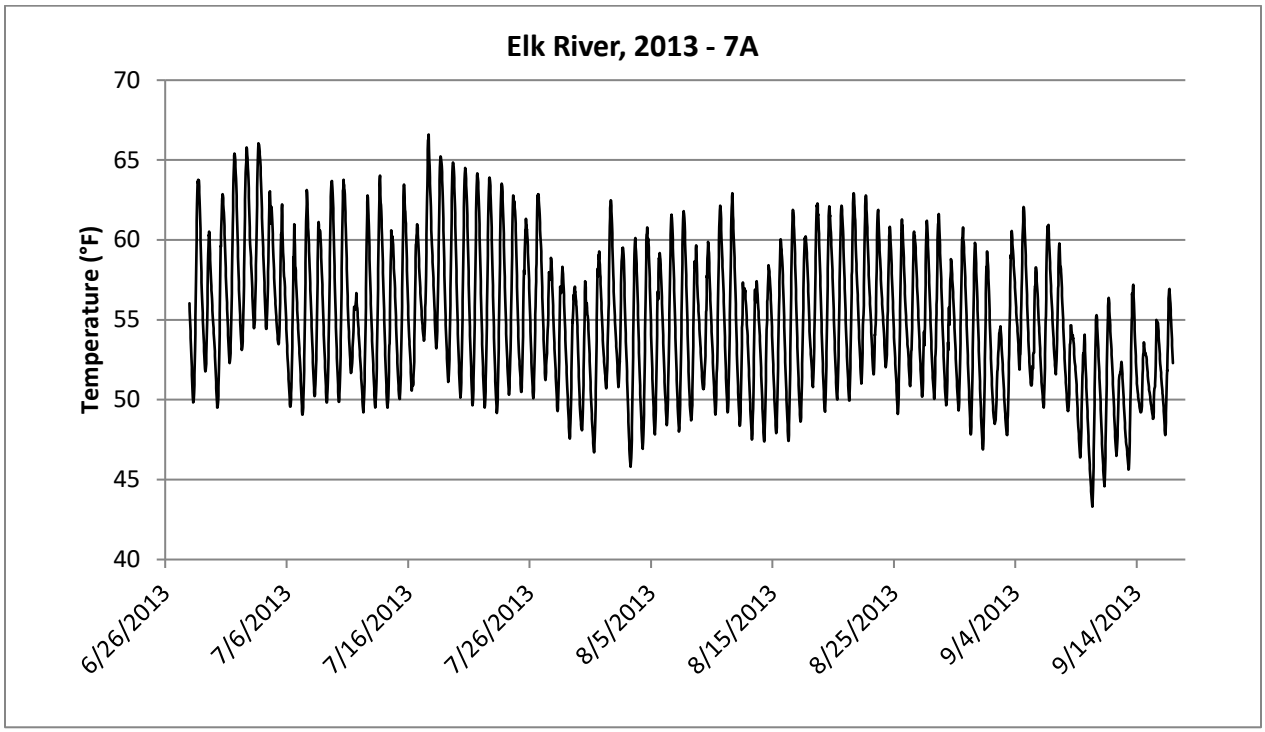

Figure G-54. Elk River 7A Continuous Temperature 6/28/13 through 9/16/13

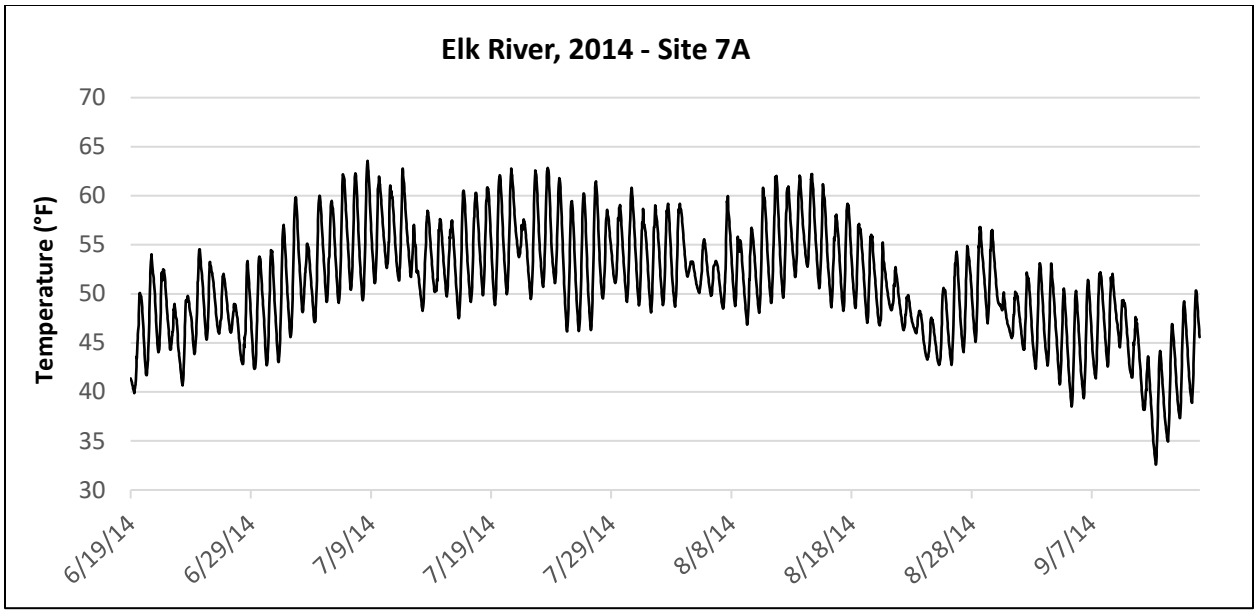

Figure G-55. Elk River 7A Continuous Temperature 6/19/14 through 9/15/14

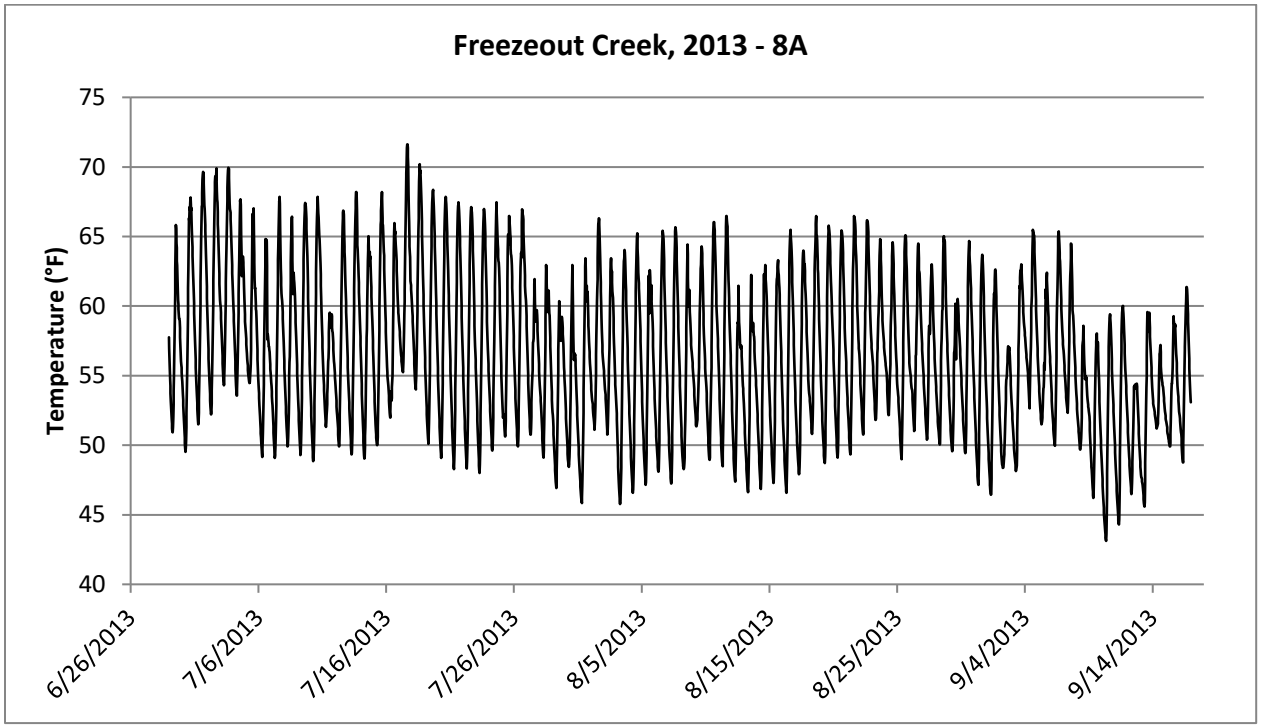

Figure G-56. Freezeout Creek 8A Continuous Temperature 6/29/13 through 9/16/13

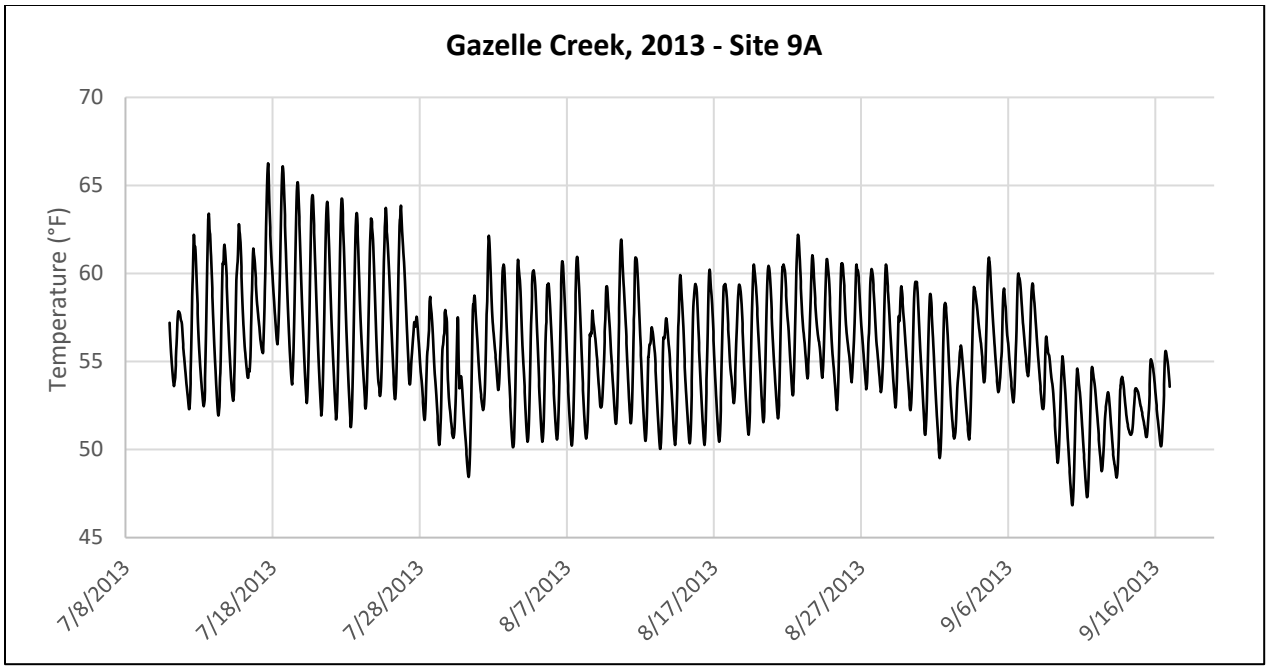

Figure G-57. Gazelle Creek 9A Continuous Temperature 7/11/13 through 9/16/13

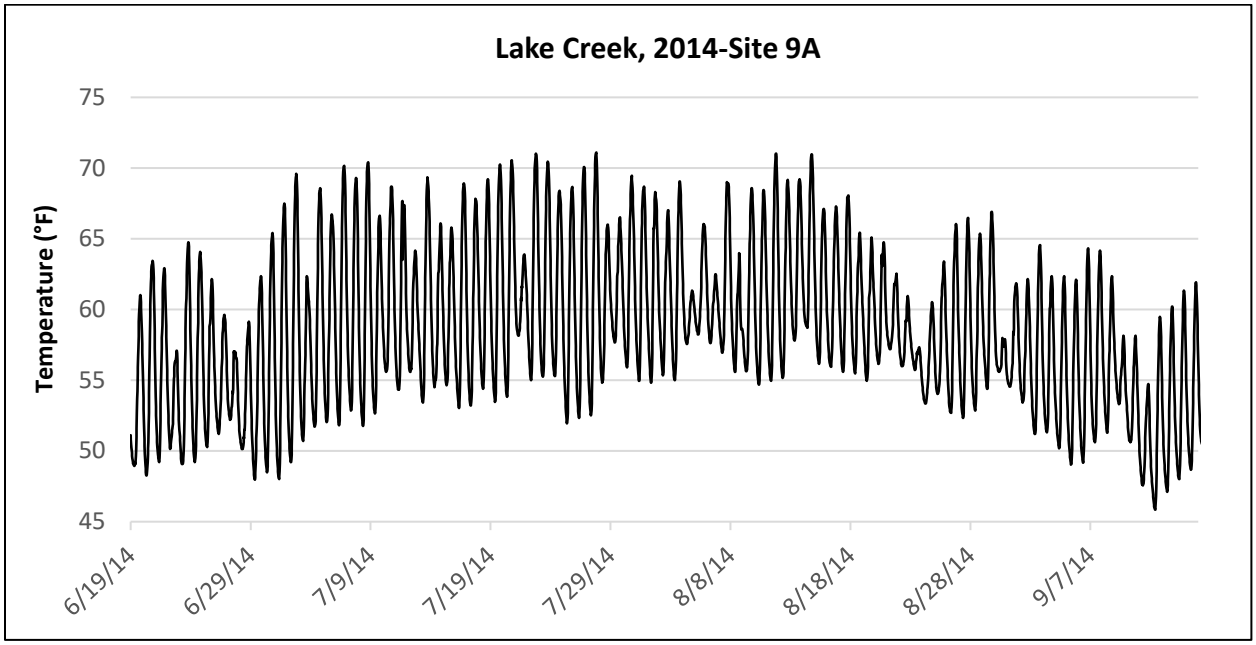

Figure G-58. Lake Creek 9A Continuous Temperature 6/19/13 through 9/16/13

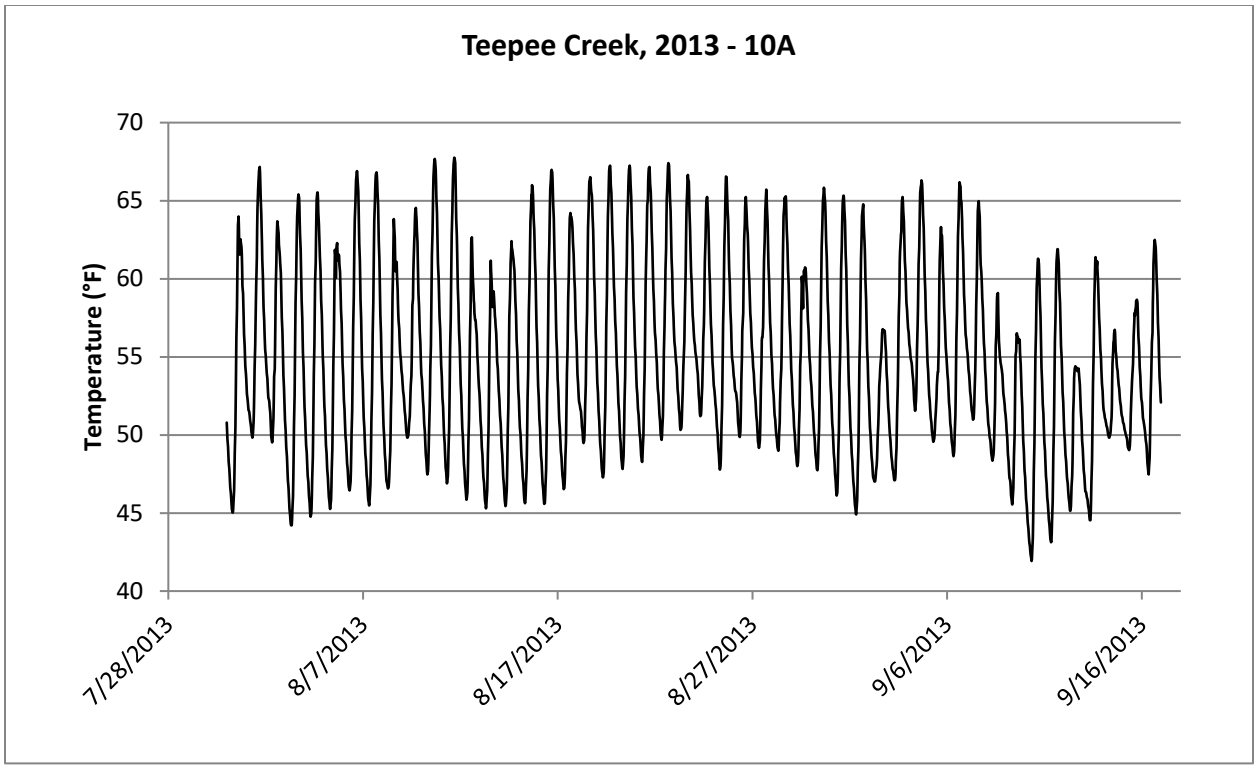

Figure G-59. Teepee Creek 10A Continuous Temperature 7/31/13 through 9/16/13

Table G-18. West Fork Madison River and Tributary DEQ Flow Measurements 2012 through 2014

Date	Stream	Site ID	Total Discharge (ft3/s)
7/9/2013	Elk River	MDEQ_WQ_WQX-M06ELKR01	25.71
6/12/2012	Elk River	MDEQ_WQ_WQX-M06ELKR03	87.56
7/23/2012	Elk River	MDEQ_WQ_WQX-M06ELKR03	26.32
8/25/2012	Elk River	MDEQ_WQ_WQX-M06ELKR03	15.78
6/12/2013	Elk River	MDEQ_WQ_WQX-M06ELKR03	220.18
6/27/2013	Elk River	MDEQ_WQ_WQX-M06ELKR03	40
7/8/2013	Elk River	MDEQ_WQ_WQX-M06ELKR03	24.06
8/13/2013	Elk River	MDEQ_WQ_WQX-M06ELKR03	13.15
9/16/2013	Elk River	MDEQ_WQ_WQX-M06ELKR03	12.82
7/30/2014	Elk River	MDEQ_WQ_WQX-M06ELKR03	21.95
9/16/2014	Elk River	MDEQ_WQ_WQX-M06ELKR03	16.09
6/27/2013	Freezeout Creek	MDEQ_WQ_WQX-M06FZOTC01	3.5
7/10/2013	Gazelle Creek	MDEQ_WQ_WQX-M06GAZLC03	7
7/23/2014	Gazelle Creek	MDEQ_WQ_WQX-M06GAZLC04	3
9/17/2014	Gazelle Creek	MDEQ_WQ_WQX-M06GAZLC04	4.6
6/18/2014	Lake Creek	MDEQ_WQ_WQX-M06LAKEC01	29
7/28/2014	Lake Creek	MDEQ_WQ_WQX-M06LAKEC01	19.2
9/17/2014	Lake Creek	MDEQ_WQ_WQX-M06LAKEC01	18.66
6/12/2012	West Fork Madison River	MDEQ_WQ_WQX-M06MDWFR01	316.49
7/26/2012	West Fork Madison River	MDEQ_WQ_WQX-M06MDWFR01	64.6
8/23/2012	West Fork Madison River	MDEQ_WQ_WQX-M06MDWFR01	52.03
7/10/2013	West Fork Madison River	MDEQ_WQ_WQX-M06MDWFR01	62.22

Table G-18. West Fork Madison River and Tributary DEQ Flow Measurements 2012 through 2014

Date	Stream	Site ID	Total Discharge (ft3/s)
7/28/2014	West Fork Madison River	MDEQ_WQ_WQX-M06MDWFR01	61.91
9/17/2014	West Fork Madison River	MDEQ_WQ_WQX-M06MDWFR01	53.74
6/12/2012	West Fork Madison River	MDEQ_WQ_WQX-M06MDWFR02	370.74
7/26/2012	West Fork Madison River	MDEQ_WQ_WQX-M06MDWFR02	31.3
8/26/2012	West Fork Madison River	MDEQ_WQ_WQX-M06MDWFR02	28.35
7/11/2013	West Fork Madison River	MDEQ_WQ_WQX-M06MDWFR02	37.04
8/13/2013	West Fork Madison River	MDEQ_WQ_WQX-M06MDWFR02	23.84
9/16/2013	West Fork Madison River	MDEQ_WQ_WQX-M06MDWFR02	17.03
7/28/2014	West Fork Madison River	MDEQ_WQ_WQX-M06MDWFR02	42.28
9/17/2014	West Fork Madison River	MDEQ_WQ_WQX-M06MDWFR02	29.28
6/12/2012	West Fork Madison River	MDEQ_WQ_WQX-M06MDWFR03	316.67
7/23/2012	West Fork Madison River	MDEQ_WQ_WQX-M06MDWFR03	33.05
8/23/2012	West Fork Madison River	MDEQ_WQ_WQX-M06MDWFR03	24.4
7/11/2013	West Fork Madison River	MDEQ_WQ_WQX-M06MDWFR03	35.9
8/13/2013	West Fork Madison River	MDEQ_WQ_WQX-M06MDWFR03	23.62
9/16/2013	West Fork Madison River	MDEQ_WQ_WQX-M06MDWFR03	18.57
7/31/2012	West Fork Madison River	MDEQ_WQ_WQX-M06MDWFR04	0
9/16/2013	West Fork Madison River	MDEQ_WQ_WQX-M06MDWFR05	45.71
7/11/2013	West Fork Madison River	MDEQ_WQ_WQX-M06MDWFR06	58.67
7/11/2013	West Fork Madison River	MDEQ_WQ_WQX-M06MDWFR07	58.91
7/28/2014	West Fork Madison River	MDEQ_WQ_WQX-M06MDWFR07	55.22
9/17/2014	West Fork Madison River	MDEQ_WQ_WQX-M06MDWFR07	50.58
7/12/2013	West Fork Madison River	MDEQ_WQ_WQX-M06MDWFR08	38.66
7/12/2013	West Fork Madison River	MDEQ_WQ_WQX-M06MDWFR09	33.68
9/16/2014	West Fork Madison River	MDEQ_WQ_WQX-M06MDWFR09	21.14
7/12/2013	West Fork Madison River	MDEQ_WQ_WQX-M06MDWFR10	5.51
7/30/2014	West Fork Madison River	MDEQ_WQ_WQX-M06MDWFR10	4.49
9/16/2014	West Fork Madison River	MDEQ_WQ_WQX-M06MDWFR10	5.13
7/31/2013	West Fork Madison River	MDEQ_WQ_WQX-M06MDWFR11	6.7
7/30/2013	West Fork Madison River	MDEQ_WQ_WQX-M06MDWFR12	6.7
7/30/2013	West Fork Madison River	MDEQ_WQ_WQX-M06MDWFR15	5.1
9/16/2014	West Fork Madison River	MDEQ_WQ_WQX-M06MDWFR15	4.17
6/26/2013	West Fork Madison River	MDEQ_WQ_WQX-M06MDWFR16	6
7/30/2013	West Fork Madison River	MDEQ_WQ_WQX-M06MDWFR16	3.26
9/16/2014	West Fork Madison River	MDEQ_WQ_WQX-M06MDWFR16	1.26
7/23/2014	West Fork Madison River	MDEQ_WQ_WQX-M06MDWFR17	0.25
7/23/2014	West Fork Madison River	MDEQ_WQ_WQX-M06MDWFR18	0.5
9/15/2014	West Fork Madison River	MDEQ_WQ_WQX-M06MDWFR18	0.93
9/15/2014	West Fork Madison River	MDEQ_WQ_WQX-M06MDWFR19	1.58
7/30/2013	Tepee Creek	MDEQ_WQ_WQX-M06TEPEC01	3.3
9/16/2014	Tepee Creek	MDEQ_WQ_WQX-M06TEPEC01	2.01

Table G-19. West Fork Madison River Solar Pathfinder Data 2013 and 2014

Date	Stream Name	Transect Number	Solar Pathfinder Photo #s at 25%, 50%, 75% Wetted Width	Percent Shade at 25 % Wetted width	Percent Shade at 50 % Wetted width	Percent Shade at 75 % Wetted width
7/10/2013	WF Madison	5A-1	0064, 0065, 0066	2	4	10
7/11/2013	WF Madison	5B-1	0107, 0108, 0109	8	11	15
7/11/2013	WF Madison	5C-1	0089, 0090, 0091	35	37	43
7/11/2013	WF Madison	5C-2	0098, 0099, 0100	49	47	56
7/11/2013	WF Madison	5D-1	0071, 0072, 0073	11	26	50
7/11/2013	WF Madison	5D-2	0080, 0081, 0082	8	11	8
7/11/2013	WF Madison	5G-1	0122, 0123, 0124	36	42	55
7/12/2013	WF Madison	5F-1	0131, 0132, 0134	57	59	61
7/12/2013	WF Madison	5G-1	0135, 0136, 0137	59	54	62
7/12/2013	WF Madison	5H-1	0144, 0145, 0146	17	10	11
7/30/2013	WF Madison	5I-1	0454, 0455, 0456	4	4	24
7/31/2013	WF Madison	5J-1	0460, 0461, 0462	7	8	18
7/30/2013	WF Madison	5K-1	NonG-not wadeable			
7/30/2013	WF Madison	5M-1	0442, 0443, 0444	10	10	8
7/30/2013	WF Madison	5N-1	0432, 0433, 0434	4	1	1
7/23/2014	WF Madison	5P	0963, 0964, 0965	64	29	29
7/23/2014	WF Madison	5X	0954, 0955, 0956	21	14	3
7/23/2014	WF Madison	5Y	No data			

West Fork Madison River DEQ Riparian Vegetation Summary

See **Table G-20** at the end of this Appendix.

Table G-20. DEQ Riparian Vegetation Summary

Stream Name	Date	Transect Number	Reach Aspect °	Transect Aspect °	Bankfull Width	Existing Veg. Type	Potential Veg. Type	Shade Can. Topo	Shade Canopy Trees	Shade Canopy Shrubs	Shade Canopy Ground	Wetted Width	NSDZ	NSDZ Left to	Topographic Altitude ° W S E	Vegetation Height (ft)	Vegetation Crown (ft)	Vegetation Offset (ft)	Vegetation Density (densiometer %)	Vegetation Overhang (ft)	Bank Height (ft)	Bank Angle ° (opposite 120° is acute not obtuse)	Photos
Cherry Creek	8/5/2013	2C-1	80	60	40	cottonwood (CTWD), conifer (CNF), red osier dogwood (ROD), mountain maple	cottonwood, conifer, red osier dogwood, mountain maple	none	CNF/CTWD	ROD	none	29.5	40	23	L 4 30 18 R 5 18 15	L 70 80 CTWD CNF R 54 79 CTWD CNF	L 19 18 CTWD CNF R 19 20 CTWD CNF	L 10 R 8	L 58 94 CTWD CNF R 58 94 CTWD CNF	L 4 R 4	L 5 R 5	L 120 R 140	0533-0538
Cherry Creek	8/5/2013	2B-1	310	310	21.5	willow (W), sedge	willow, sedge	none	W	none	none	18.3	30	18	L 2 7 12 R 3 8 22	L 7 W R 7 W	L 8 W R 8 W	L 1 R 1	L 89 W R 77 W	L 1 R 3	L 3.5 R 4	L 150 R 90	0539-0544
Cherry Creek	8/6/2013	2A-1	140	120	26.5	young willow, grass (G), sedge (S)	cottonwood, willow (W), sedge (S)	banks	none	none	none	23	23	12	L 2 2 R 9 5 17	L 2 1 W G/S R 3 1 W G/S	L 0 W R 0 W	L 1 R 1	L 80 W/S/G R 83 W/S/G	L 1 R 0	L 5 R 4	L 100 R 130	0565-0572
Elk Creek	8/2/2013	1B-1	300	35	8.3	willow (W), juniper (J), snowberry (SB), sedge (S)	willow (W), juniper (J), snowberry (SB), sedge (S)	none	W/J	SB	S/G	8.3	12	11	L 17 8 8 R 9 5 10	L 5 R 12 W/J	L 3 W R 12	L 5-15 R 1	L 82 74 WS R 87 88 WJ	L 4 R 6	L 5 R 3	L 110 R 110	0516-0524
Elk Creek	8/5/2013	1D-1	50	60	5.8	willow (W), sedge (S)	willow (W), sedge (S)	none	W	none	S	2.5	5.9	3	L 2 12 5 R 2 12 5	L 8 W R 8 W	L 6 R 6	L 5 R 5	L 94 88 WS R 94 82 WS	L 1.5 R 1.5	L 2 R 2	L 80 R 80	0525-0530
Elk Creek	8/6/2013	1C-1	45	50	9	cottonwood (CTWD), conifer (CNF), willows (W), alders (A)	cottonwood (CTWD), conifer (CNF), willows (W), alders (A)	none	CTWD/CNF/A	none	none	5	14	8	L 16 79 23 R 14 22 23	L 45 28 CTWD CNF R 70 18 CTWD/CNF A	L 14 R 20 16 CTWD/CNF A	L 18 R 18	L 76 94 82 CTWD CNF A R 94 88 94 CTWD CNF A	L 4 R 1	L 2 R 2	L 130 R 90	0545-0553

Stream Name	Date	Transect Number	Reach Aspect °	Transect Aspect °	Bankfull Width	Existing Veg. Type	Potential Veg. Type	Shade Can. Topo	Shade Canopy Trees	Shade Canopy Shrubs	Shade Canopy Ground	Wetted Width	NSDZ	NSDZ Left to	Topographic Altitude ° W S E	Vegetation Height (ft)	Vegetation Crown (ft)	Vegetation Offset (ft)	Vegetation Density (densiometer %)	Vegetation Overhang (ft)	Bank Height (ft)	Bank Angle ° (opposite 120° is acute not obtuse)	Photos
Elk Creek	8/6/2013	1C-2	350	340	8	sedge (S), willow, alders (A), aspens (AP)	grass (G), sedge (S)	yes	A	none	S	4	20	14	L 8 8 9 R 10 10 11	L 118 S/G 18 AP A R 1 G/S	L 14 R no trees on RB	L 30 R none	L 88 A 88 AP 19 G/S R 0.3 G/S	L 1 R 0	L 4 R 5	L 110 R 150,110	0559-0564
Jack Creek	8/1/2013	3X-1	20	0	17	cottonwood (CTWD), willow (W)	cottonwood (CTWD), willow (W)	none	CTWD/ CNF/ SB	none	none	12.5	23	14	L 10 2 8 R 19 2 6	L 505 CTWD W R 504 CTWD W	L 22 CTWD R 30 CTWD	L 15 R 2	L 82 CTWD 85 SB 76 W R 76 W - very few	L 12 R 8	L 1.8 R 4	L 150 R 130	0468-0473
Jack Creek	7/29/2013	3F-1	100	95	35.8	cottonwood (CTWD), conifer (CNF), willows (W), alders (A)	cottonwood (CTWD), conifer (CNF), willows (W), alders (A)	none	CNF	none	none	32	36	18	L 25 24 14 R 23 23 10	L 110 CNF 18 A 15 W R 102 CNF 21 A 60 CTWD	L 20 CNF 12 A 8 W R 20 CNF 12 A 18 CTWD	L 15 R 12	L 98 CNF 82 A 98 W R 98 CNF 95 CTWD 84 A	L 3 R 3	L 1.5 R 1	L 140 R 150	0406 - 0414
Jack Creek	7/29/2013	3F-2	100	90	33	conifer (CNF), alder (A), red osier dogwood (ROD)	conifer (CNF), alder (A), red osier dogwood (ROD)	yes	CNF, A, ROD	wild rose	grass /forb	30	34	18	L 14 22 14 R 8 21 11	L 80 CNF 14 A R 18 A	L 18 CNF 10 A 6 ROD R 14 A 8 ROD	L 10 R 1	L 97 CNF 96 A 100 ROD R 97 A 98 ROD	L R 5	L 1 R 2	L 120 R 135	0415-0420
Jack Creek	7/29/2013	3D-1	35	30	29	cottonwood (CTWD), conifer (CNF), alder (A)	cottonwood (CTWD), conifer (CNF), alder (A)	steep hill	CNF, A, ROD	yes	grass /rush	19.7	29	15	L 8 37 20 R 10 35 10	L 60 CNF/CTWD R 63 CTWD 40 CNF 14 A	L 20 CTWD 24 CNF R 20 CTWD 16 A 6 CNF	L 2-35 R 2-25	L 84 CTWD 100 CNF 100 A R 90 CTWD 96 CNF 94 A	L 1 R 0	L 8 R 5	L 105 R 110	0421-0428
Jack Creek	8/1/2013	3A-1	145	95	22.5	willow (W), grass (G), birch (B)	willow (W), grass (G), sedge (S)	none	W, birch	none	none	17.5	24.5	13.5	L 3 18 4	L 18 W	L 9	L 8	L 62 W (small) 84 W 85 B	L 0	L 3.5	L 100	0476-0483

Stream Name	Date	Transect Number	Reach Aspect °	Transect Aspect °	Bankfull Width	Existing Veg. Type	Potential Veg. Type	Shade Can. Topo	Shade Canopy Trees	Shade Canopy Shrubs	Shade Canopy Ground	Wetted Width	NSDZ	NSDZ Left to	Topographic Altitude ° W S E	Vegetation Height (ft)	Vegetation Crown (ft)	Vegetation Offset (ft)	Vegetation Density (densiometer %)	Vegetation Overhang (ft)	Bank Height (ft)	Bank Angle ° (opposite 120° is acute not obtuse)	Photos
															R 10 13 5	R 23 22 W B	R 16	R 6	R 94 88 W B	R 2	R 3	R 90	
Madison River	7/22/2014	6A-1	320	320	180	willow (W), grass (G), cottonwood (CTWD)	willow (W), Grass (G), cottonwood (CTWD), sedge, rush	none	yes	none	none	148	0	0	L 30 25 1 R 31 2	L 12 W R 40	L 8 R 35	L 30 R 90	L 88 R 82 46 CTWD G	L 0.5 R 0	L 3 R 5.5	L 30 R 35	0894-0899
Madison River	7/22/2014	6B-1	20	20	330	willow (W), cottonwood (CTWD)	willow (W), cottonwood (CTWD)	yes	yes	none	none	126	45	45	L 50 45 5 R 34 7 5	L 2 R 24	L 1 R 18	L 4 R 210	L 12 R 81 37 W/CTWD NSDZ W	L 0 R 0	L 51 R 5	L 15 R 1	0901-0908
Madison River	7/22/2014	6C-1	345	345	332	willow (W), grass (G), sedge (S)	willow (W), grass (G), sedge (S)	yes	yes	yes	none	330	0	0	L - - - R 9 8 10	L - - R 5	L - R 3	L - R 1	L - R 78	L - R 1	L - R 1.5	L - R 90	0910-0915
Madison River	7/22/2014	6D-1	260	260	288	reed canary grass (RCG), juniper (J)	juniper (J), willow (W)	yes	none	yes	none	278	0	0	L 15 28 13 R 15 38 14	L 3 R 7	L - R 8	L 3 R 0	L 6 G R 93 RCG	L 0 R 2	L 5 R 3.5	L 35 R 30	0916-0918 0925-0927
Madison River	7/22/2014	6G-1	280	280	200	willow (W), grass (G)	willow (W), grass (G)	yes	none	yes	none	194	0	0	L 10 11 5 R 15 11 6	L 5 R 4.5	L 4 R 2	L 0 R 0	L 76 W R 88 W	L 0.5 R 2	L 2 R 2.5	L 20 R 15	0920 - 0922 0928-0931
Madison River	7/22/2014	6F-1	200	200	196	grass (G), red osier dogwood (ROD), juniper (J), rush (R), nightshade	willow (W), alder (A), grass, (G), rush (R)	yes	yes	none	none	186	0	-	L 30 12 32 R 28 10 50	L 75 R 50	L 22 R 18	L 25 R 50	L 56 R 80	L 1 R 0	L 2.5 R 6	L 30 R 30	0933-0935 0939-0941
Moore Creek	8/1/2013	4A-1	150	140	7	grass (G), Russian olive (RO)	willow (W), sedge (S)	stream bank	none	none	grass	6	6	3	L 18 40 30 R 18 30 40	L 2 R 2	L - dense G R - dense G	L 0 R 0	L 88 G R 87 G	L 1.5 R 1.5	L 1 R 1	L 90 R 90	0484-0492

Stream Name	Date	Transect Number	Reach Aspect °	Transect Aspect °	Bankfull Width	Existing Veg. Type	Potential Veg. Type	Shade Can. Topo	Shade Canopy Trees	Shade Canopy Shrubs	Shade Canopy Ground	Wetted Width	NSDZ	NSDZ Left to	Topographic Altitude ° W	S	E	Vegetation Height (ft)		Vegetation Crown (ft)		Vegetation Offset (ft)	Vegetation Density (densiometer %)		Vegetation Overhang (ft)	Bank Height (ft)	Bank Angle ° (opposite 120° is acute not obtuse)	Photos
Moore Creek	8/1/2013	4D-1	10	10	7	willow (W), grass (G)	willow (W), sedge (S)	none	yes	none	none	4.5	7	3.5	L 11 R 10	3 2	2 2	L 64 R 64	W W	L 60 R 60		L 2 R 2	L 100 R 100		L 25 R 25	L 0.7 R 0.7	L 150 R 150	0493-0499
Moore Creek	8/1/2013	4G-1	130	120	10.7	alder (A), willow (W), sedge (S)	alder (A), willow (W), sedge (S)	none	A/W	none	G	7.5	12	7.5	L 8 R 10	10 7	8 10	L 20 R 20	W/A W/A	L 16 R 16		L 2 R 3	L 9974 R 9368	W/A G/S W/A G/S	L 12 R 12	L 6 R 5	L 95 R 110	0500-0505
Moore Creek	8/1/2013	4F-1	80	60	9.7	water birch (B), alder (A), conifer (CNF), sedge (S)	water birch (B), alder (A), conifer (CNF), sedge (S)	yes	yes	none	none	6	9.7	6.5	L 8 R 10	13 12	12 12	L 18 R 18 35	B/A B/A CNF	L 16 R 16	B/A A/CNF	L 0 R 8	L 9971 R 9988	A S/G A CNF	L 8 R 8	L 2 R 1.5	L 100 R 150	0506-0511
West Fork Madison River	7/10/2013	5A-1	40	100	50	willow (W), conifer (CNF)	willow (W), conifer (CNF)	none	CNF	none	none	34	52	34	L 12 R 10	10 3	13 12	L 75 R 60		L 24 R 36		L 10 R 60	L 9785 R 9381	CNF W CNF W	L 8 R 0	L 1.8 R 0.2	L 300 R 5	0064-0066 0069-0070
West Fork Madison River	7/11/2013	5D-1	70	85	56	willow (W), conifer (CNF)	willow (W), conifer (CNF)	none	CNF	none	none	50	56	25	L 8 R 12	15 18	23 24	L 72 R 78	CNF CNF	L 14 R 16	CNF CNF	L 5 R 7	L 9472 R 97	CNF W CNF	L 12 R 12	L 1.7 R 1.2	L 70 R 120	0071-0079
West Fork Madison River	7/11/2013	5D-2	70	50	48	willow (W), conifer (CNF)	willow (W), conifer (CNF)	east	south, west	none	none	42	48	24	L 12 R 13	6 10	23 23	L 588 R 566	CNF W CNF W	L 164 R 184	CNF W CNF W	L 102 R 51	L 8685 R 9390	CNF W CNF W	L 4 R 1	L 0.5 R 2	L 190 R 200	0080-0088
West Fork Madison River	7/11/2013	5C-1	150	110	34	willow (W), conifer (CNF)	willow (W), conifer (CNF)	none	CNF	none	none	25.5	42.5	36	L 22 R 20	6 26	32 35	L 78 R 68		L 20 R 18		L 50 R 10	L 8659 R 81	CNF W CNF	L 0 R 1	L 1 R 5	L 160 R 50	0089-0097
West Fork Madison River	7/11/2013	5C-2	150	140	57	conifer (CNF)	conifer (CNF)	right hill	CNF	none	none	45	57	28.5	L 17 R 17	12 5	37 40	L 60 R 65		L 20 R 16		L 8 R 5	L 8659 R 81	CNF W CNF	L 5 R 5	L 3 R 2	L 80 R 150	0098-0106
West Fork Madison River	7/11/2013	5B-1	320	360	32	conifer (CNF), alder (A), willow (W)	conifer (CNF), alder (A), willow (W)	none	yes	none	none	27	64	80	L 45 R 8	8 7	10 15	L 4015 R 604	CNF W CNF W	L 12 R 163	CNF W	L 81 R 351	L 8493 R 9282	CNF W CNF W	L 6 R 0	L 1.8 R 1.8	L 70 R 150	0107-0115

Stream Name	Date	Transect Number	Reach Aspect °	Transect Aspect °	Bankfull Width	Existing Veg. Type	Potential Veg. Type	Shade Can. Topo	Shade Canopy Trees	Shade Canopy Shrubs	Shade Canopy Ground	Wetted Width	NSDZ	NSDZ Left to	Topographic Altitude ° W S E	Vegetation Height (ft)	Vegetation Crown (ft)	Vegetation Offset (ft)	Vegetation Density (densiometer %)	Vegetation Overhang (ft)	Bank Height (ft)	Bank Angle ° (opposite 120° is acute not obtuse)	Photos
West Fork Madison River	7/11/2013	5G-1	330	350	53.5	willow (W), conifer (CNF)	willow (W), conifer (CNF)	none	W/CNF	none	none	41	54	27	L 13 4 26 R 12 7 27	L 43 R 55	L 16 R 16	L 2 R 10	L 9984 CNF W R 9793 CNF W	L 8 R 1	L 2 R 1.8	L 90 R 170	0116-0124
West Fork Madison River	7/12/2013	5F-1	340	350	37.5	willow (W), conifer (CNF)	willow (W), conifer (CNF)	none	CNF	none	none	30.5	37.5	18.8	L 18 2 20 R 14 10 22	L 40 R 55	L 16 R 18	L 1 R 1	L 9797 CNF W R 100 93 CNF W	L 5 R 8	L 2 R 2	L 155 R 140	0125-0134
West Fork Madison River	7/12/2013	5G-1	330	340	36.5	willow (W), conifer (CNF)	willow (W), conifer (CNF)	none	CNF	none	none	34.8	36.5	18.2	L 11 16 28 R 9 17 35	L 57 R -	L 12 R -	L 4 R -	L 94 R 98	L 0 R 6	L 1.5 R 2	L 100 R 140	0137-0141
West Fork Madison River	7/12/2013	5H-1	40	340	16.7	willow (W), sedge (S)	willow (W), sedge (S)	none	W	none	none	15.5	16.7	8.3	L 12 18 15 R 6 18 15	L 9 R 9	L 9 R 9	L 2 R 1	L 9667 W S R 7897 W S	L 1-4 R 0-2	L 0.5 R 0.5	L 90 R 90	0144-0152
West Fork Madison River	7/30/2013	5N-1	60	70	21.7	willow (W), sedge (S)	willow (W), sedge (S)	none	yes	S	none	16	22.5	11.5	L 8 9 10 R 9 7 11	L 5 W R 6 W	L 4 W R 4 W	L 1 R 0	L 8557 W S R 8378 W S	L 1.5 R 1.5	L 2.5 R 1.5	L 110 R 150	0432-0437
West Fork Madison River	7/30/2013	5M-1	40	40	20	conifer (CNF), willow (W), sedge (S)	conifer (CNF), willow (W), sedge (S)	none	CNF/W	S	none	16.5	20	10.5	L 8 14 16 R 7 16 11	L 5 W R 968 CNF W	L 3 W R 5 W	L 1 R 505	L 9349 W S R 9893 CNF W	L - R 2	L 3.2 R 1.2	L 115 R 150	0442-0444
West Fork Madison River	7/30/2013	5K-1	60	80	48	willow (W), sedge (S)	willow (W), sedge (S)	none	W	S	none	46	48	24	L 8 5 10 R - - -	L 6 R 8	L 4 R 4	L 1 R 1	L 98 R 98	L 2 R 2	L 3.5 R 2	L 110 R 100	0449-0453
West Fork Madison River	7/30/2013	5I-1	65	60	22.5	willow (W), sedge (S)	willow (W), sedge (S)	none	W	none	none	22.5	22.5	11.3	L 10 9 13 R 10 10 11	L 7 R 7	L 6 R 4	L 0 R 0	L 88 R 94	L 3 R 3	L 1 R 1.5	L 100 R 80	0454-0459
West Fork Madison River	7/31/2013	5J-1	150	115	30	conifer (CNF), willow (W), sedge (S)	conifer (CNF), willow (W), sedge (S)	none	W/CNF	none	none	23	30	18.5	L 13 10 16 R 12 13 15	L 8 W R 862 W CNF	L 6 W R 618 W CNF	L 3 R 260	L 9574 W S R 9985 W CNF S	L 0 R 4	L 1 R 2	L 140 R 85	0460-0467

Stream Name	Date	Transect Number	Reach Aspect °	Transect Aspect °	Bankfull Width	Existing Veg. Type	Potential Veg. Type	Shade Can. Topo	Shade Canopy Trees	Shade Canopy Shrubs	Shade Canopy Ground	Wetted Width	NSDZ	NSDZ Left to	Topographic Altitude ° W S E	Vegetation Height (ft)	Vegetation Crown (ft)	Vegetation Offset (ft)	Vegetation Density (densiometer %)	Vegetation Overhang (ft)	Bank Height (ft)	Bank Angle ° (opposite 120° is acute not obtuse)	Photos
West Fork Madison River	7/23/2013	5X-1	40	60	7	willow (W), sedge (S), rush (R)	willow (W), sedge (S), rush (R)	yes	none	yes	none	7	0	0	L 2 16 7 R 5 10 9	L 5 W R 5 W	L 4 R 4	L 1 R 1	L 60 R 65	L 1.5 R 1.5	L 1 R 1.5	L 80 R 80	0951-0956
West Fork Madison River	7/23/2013	5P-1	280	270	11.5	willow (W), sedge (S), grass (G)	willow (W), sedge (S), grass (G)	yes	none	yes	none	10	0	0	L 11 8 8 R 11 8 6	L 6 W R 5 W	L 7 R 6	L 2 R 0	L 69 R 68	L 1 R 2	L 1.2 R 2	L 30 R 90	0960-0965

G4.0 REFERENCES

Washington State Department of Ecology. 2007. Shade (shade_ver31b02.xls in shade.zip) in Models for Total Maximum Daily Load Studies at http://www.ecy.wa.gov/programs/eap/models.html. Downloaded January, 24, 2017.

APPENDIX H – TEMPERATURE CONDITIONS FOR LOWER MADISON RIVER AND WEST FORK MADISON RIVER

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H1.0 INTRODUCTION

Cherry Creek, Elk Creek, and Moore Creek were found to be temperature impaired through the Madison TMDL Planning Area temperature study, and TMDLs were written for those streams, details of which can be found in Section 6.0 of the main TMDL document. Jack Creek was not identified prior to this study as having a temperature impairment but was evaluated based on field reconnaissance and stakeholder concern. Data collected during this effort indicates Jack Creek is not impaired for temperature and no TMDL was written and a summary of the Jack Creek data is not included in this appendix. This appendix details stream conditions in the Madison River below Madison Dam (Assessment Unit MT41F001_010) and the West Fork Madison River (Assessment Unit MT41F004_100), both of which currently remain listed for temperature impairment in Montana's 2018 Water Quality Integrated Report (DEQ, 2018).

H2.0 MADISON RIVER (MADISON DAM TO MOUTH) TEMPERATURE CONDITIONS

The Madison River downstream of Ennis Lake (Madison Dam), also referred to as the lower Madison River, has a hydrologic regime that is modified by the presence of two major reservoirs, Hebgen Lake and Ennis Lake (Madison Reservoir). The Madison River flows from its headwaters in Yellowstone National Park into Hebgen Lake, which is located just outside of the Yellowstone National Park boundary. Hebgen Lake was created in 1914 with the construction of Hebgen Dam, and is used to control streamflow for the downstream Madison River system. From Hebgen Lake, the river has a short free-flowing stretch before it enters Quake Lake, a lake that was formed in 1959 by an earthquake-induced landslide. Downstream of Quake Lake, the Madison River flows approximately 59 miles to Ennis Lake. Ennis Lake is a shallow reservoir that was created by Madison Dam in 1906, and is normally operated as a run of the river dam. Because Madison Dam is operated as run of the river, the outflow from Madison Dam is regulated by upstream flow and dam operations at Hebgen Dam. Downstream of Madison Dam, the Madison River travels approximately 41.3 miles to the mouth, which forms the headwaters of the Missouri River. The lower Madison River is listed as impaired by temperature in the 2018 Integrated Report.

Riparian Health/Shade

The lower Madison River, like many other large river systems, has a wide channel where shade produced by riparian vegetation may not have a significant cooling effect on the entire width of the stream. Downstream of Madison Dam, the Madison River flows through a large canyon which provides significant topographical shade to the stream. Because the stream is contained in this confined canyon, the existing riparian vegetation is likely at or near its potential.

Dam Operations

Northwestern Energy (FERC licensee), formerly PPL Montana and Montana Power Company, currently operates Hebgen Dam for water storage and Madison Dam for hydropower generation. As a part of Northwestern Energy's Federal Energy Regulatory Commission (FERC) licensing and Clean Water Act §401 certification through DEQ for these facilities, Northwestern Energy monitors the effects on water quality that these facilities may have. In 1989, the FERC licensee installed multiple long-term air and water temperature monitoring stations, and river time-of-travel and fisheries studies were conducted along the lower Madison River. The FERC licensee also developed a Madison thermal statistical model

that used data collected each half-hour at these stations between 1989 and 1995. The model described the thermal character of the lower Madison River by river mile with and without the influence of Madison Dam. Thermal model data showed that the lower Madison River with or without the influence of Madison Dam and Reservoir would produce summer thermal conditions much higher than optimal for resident trout (Jourdonnais 2004).

Madison statistical model results showed that Madison Reservoir (Ennis Lake), during the hot, dry summer of 1988, increased mean river temperature by 2.5°F in the lower Madison River at Black's Ford and increased maximum river temperature by 5.7°F, compared to a theoretical reservoir absence condition. In cooler, wetter summers (e.g. 1993) Madison Reservoir raised maximum lower Madison River temperature by only 2.3°F and raised mean temperatures by 1.9°F, compared to reservoir absence. Hence, the Madison thermal model statistically quantified thermal effects of Madison Reservoir on lower river temperatures for the first time and provided definitive guidance on the scope of thermal impacts and potential for mitigative solutions (Jourdonnais 2004).

In 1993 and 1994, the FERC licensee, in consultation with resource agencies and the public, investigated the feasibility of 14 thermal alternatives to reduce water temperature in the lower Madison River. The selected alternative involved cooling the lower Madison River by pulsing river flows during the heat of the day, effectively reducing peak water temperatures. Pulse flows are based on the well-known principle that a greater mass of water has a greater resistance to heating than a smaller mass of water given the same thermal input. Hence, the lower Madison River at higher flow volumes (1,400 cfs to 2,100 cfs) are expected to warm more slowly and reach lower maximum temperatures on a given hot summer day compared to minimum (1,100 cfs) baseflow rates. Pulse flow releases from Madison Dam, ramped at 200 cfs per hour to protect fisheries resources, are timed so that the increased flow reaches the downstream target area near Black's Ford during peak water temperature hours in late afternoon. Between flow pulses, the lower river is ramped to baseflow at night. Lower river pulsed flows are drafted from Madison Reservoir, which refills on the baseflow cycle. Upper Madison River flows from Hebgen Dam are slightly increased (though ramped slowly and stabilized) to backfill Madison Reservoir during extended pulsing events. Minimal flow changes in the upper Madison River are important both to protect important riverine aquatic resources and angling success and to minimize water level fluctuations in Hebgen Reservoir to protect recreation and biological resources there (Jourdonnais 2004).

To further improve the thermal program, the FERC licensee, resource agencies, and HARZA developed a state-of-the-art pulse flow Decision Support System (DSS) Plan for the lower Madison River using the data, technologies, and models employed during the licensing period since 1989 (Jourdonnais 2004). The goal of the DSS is to maintain maximum daily water temperature in the Madison River at or below 80°F to protect brown and rainbow trout. The DSS monitors air and water temperature, weather forecasts, and employs pulse flows from Madison Dam whenever lower Madison River temperatures are predicted to exceed 80°F at Sloan Meteorological Station. The Madison River DSS has operated every summer from 2001 through present. Daily data are publicly available online at http://www.madisondss.com.

Discussion

The lower Madison River is a large river system that has its hydrologic and thermal regimes modified by the presence of two large reservoirs upstream, Hebgen Lake and Ennis Lake (Madison Reservoir). Due to the wide channel width of the Madison River, improvements in riparian vegetation, where possible, will likely have minimal influence on effective stream shade and water temperatures. Dam operations

however, play a significant role in water temperatures of the lower Madison River. Programs have been implemented by the FERC licensee of these dams (currently Northwestern Energy), to mitigate any negative effects of water temperature increases that these reservoirs may cause. Successful implementation of the pulse flow program maintains water temperatures of below 80°F in the lower Madison River to prevent fish kills.

Developing a sediment TMDL for the Lower Madison River requires a complex modeling effort due to the presence of Hebgen Dam and Madison Dam. A sediment TMDL for the Lower Madison River was not developed as part of this document.

H3.0 West Fork Madison River Temperature Conditions

The West Fork Madison River flows from its headwaters in the Gravelly Range to its mouth at the Madison River south of Cameron, Montana. The West Fork Madison River is listed as impaired by temperature in the 2018 Integrated Report.

In the West Fork Madison River watershed, riparian health/shade, channel width/depth ratio, and instream discharge are the three main variables that contribute to human-caused sources of stream temperature. Each of these variables in relation to the West Fork Madison River is described below.

Riparian Health/Shade
Shade-related data, including Solar Pathfinder data were collected at 17 sites and used in conjunction with aerial photography to model the existing effective shade using the Shade Tool (Washington State Department of Ecology 2007). Shade targets were developed based on level IV ecoregion and the expected riparian vegetation community for that ecoregion. That vegetation community was then compared to shade curves developed for the near-by Targhee National Forest for reference riparian vegetation conditions (Shumar and de Varona 2009). **Figure H-1** compares the existing effective shade to its respective shade targets, while **Figure H-2** plots the difference between the existing effective shade and the shade targets. The plots are displayed in an upstream (left) to downstream (right) orientation to easily correlate targets and existing shade to location on the stream. Positive numbers in **Figure H-2** indicate that the existing effective shade exceeds the shade targets, while negative numbers indicate areas where existing effective shade is deficient. The West Fork Madison River generally meets shade targets throughout most of the length of the stream. Portions of the upper West Fork Madison River are naturally intermittent, which may be leading to the lack of shade in those areas, but overall, the riparian shade conditions are meeting or exceeding target shade (**Figure H-2**) (conversation with USFS Range Manager, Ennis Office, Kevin Suzuki on June 26, 2014).

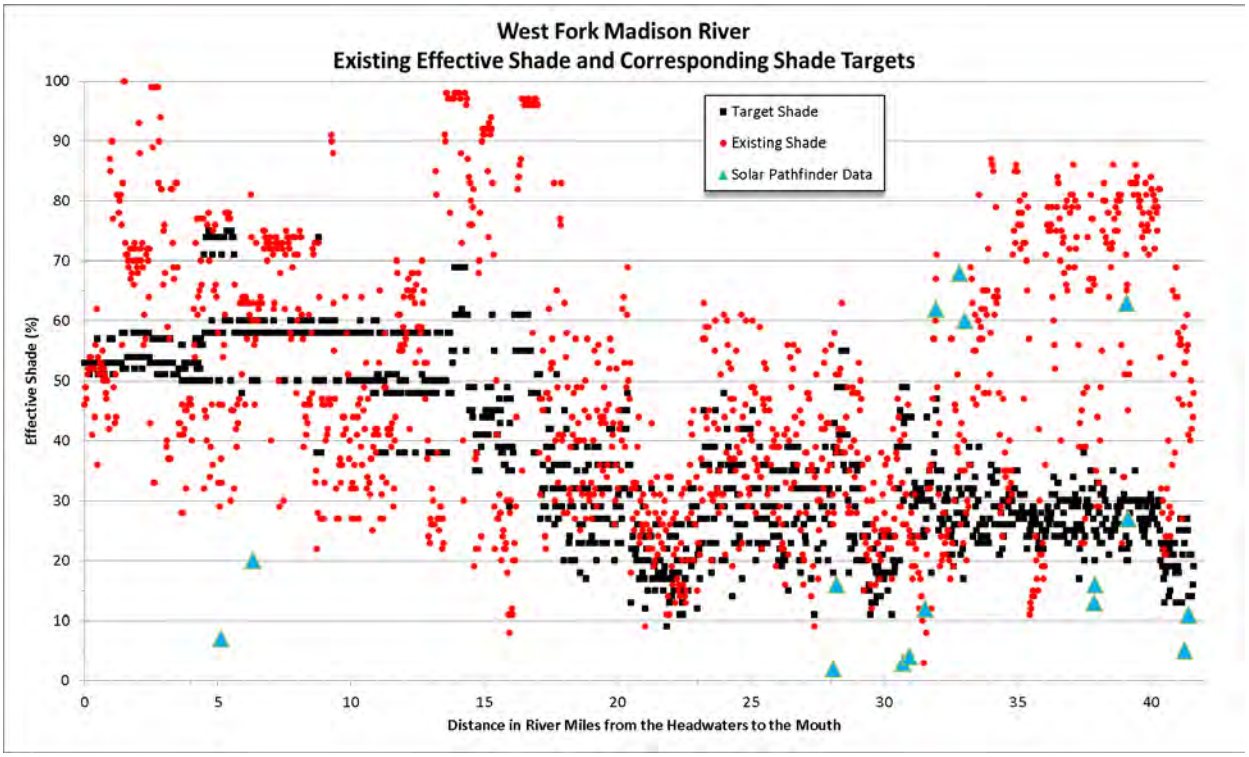

Figure H-1. Existing Effective Shade and Corresponding Shade Targets for the West Fork Madison River

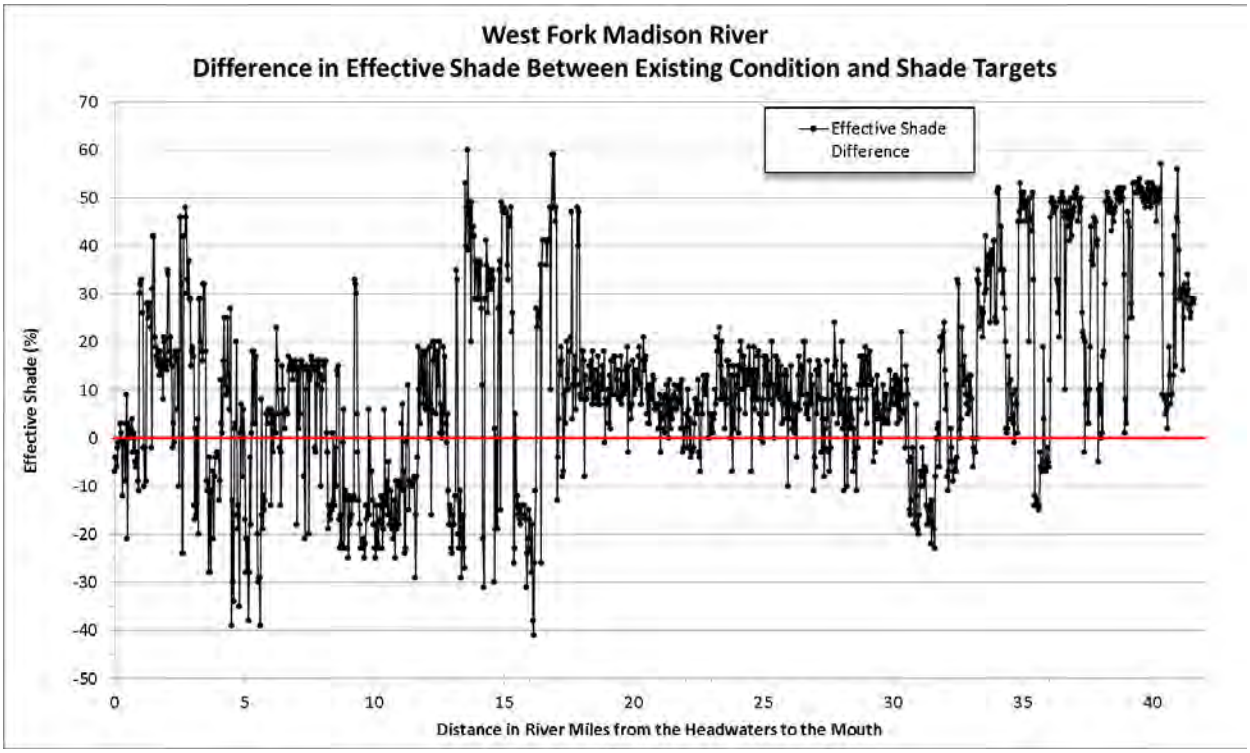

Figure H-2. Difference in Effective Shade between Existing Condition and Shade Targets for the West Fork Madison River

Channel Width/Depth Ratio

Channel width/depth ratio was measured at four sites along the West Fork Madison River as a part of the data collection effort to assess sediment impairment (**Section 5.0**). Data collected by DEQ in 2014 and the USFS in 2009 indicate that the West Fork Madison River is meeting the width/depth ratio targets at two of the four monitoring sites (**Table H-1**). Although this data was collected in four discrete locations, the locations of the monitoring sites were chosen because they are assumed to be representative of the West Fork Madison River as a whole. It is possible that the width/depth ratio may be exceeding targets in areas along the West Fork Madison River, especially in areas where land management practices are poor, but areas that have good land use management practices in place should not be negatively affecting the width/depth ratio of the West Fork Madison River.

Table H-1. West Fork Madison River Calculated Width/Depth Ratios in Comparison to Width/Depth Ratio Targets

Reach/Site ID	Year Data Collected	Mean BFW (ft)	W/D Ratio Target	W/D Ratio
2740 (PIBO)[1]	2009, 2014	23.7	≤ 24	12.8
WFMA 14-02	2014	12.6	≤ 11	13.9
WFMA 25-01	2014	53.5	≤ 30	32.4
WFMA 26-01	2013	43.5	≤ 30	28.1

[1] Values are averages from sampling events in 2009 and 2014

Although the West Fork Madison River fails to meet the width/depth ratio targets in two areas, it overall appears healthy. Data collected by DEQ in 2013 and 2014 indicate that there are limited potential human-caused sources contributing to channel instability, and that continued implementation of best management practices will maintain or improve the existing channel condition of the West Fork Madison River.

Instream Discharge (Streamflow Conditions)

There are no active water diversions on the West Fork Madison River. The Staudemeyer Canal, which previously diverted water from the upper West Fork Madison River to Metzel Creek in the Red Rock River watershed, is no longer in use and has not been in operation for over 30 years (conversation with USFS Range Manager, Ennis Office, Kevin Suzuki on June 26, 2014).

Discussion

There are relatively few current human-caused sources of temperature, and because of this, any elevated stream temperatures that may occur in the West Fork Madison River are likely due to historical human-caused sources that have since been removed and are now in recovery, and natural sources such as intermittent flow, thermal springs, wildland fire, and riparian grazing and browsing by wildlife. The comparison of recently collected data to the water quality targets outlined above indicate the river is at or near meeting targets and no TMDL was written at this time.

H4.0 REFERENCES

DEQ (Montana Department of Environmental Quality). 2018. Montana Final 2018 Water Quality Integrated Report. Helena, MT: Montana Dept. of Environmental Quality.

Jourdonnais, J. June 21, 2004. A Winning Combination. Water Power and Dam Construction.

Suzuki, K. Personal Communication. June 25, 2014.

APPENDIX I – SHADE TARGETS AND TARGET DEVELOPMENT DATA FOR TEMPERATURE TMDLS IN THE MADISON TMDL PLANNING AREA

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I1.0 INTRODUCTION

This appendix contains the shade targets and the data used to develop those targets for Cherry Creek, Elk Creek, and Moore Creek. Shade and solar loading were modeled using ArcGIS and the Shade Tool (Washington State Department of Ecology 2007).

I2.0 SHADE TARGETS

I2.1 CHERRY CREEK

Table I-1 contains the Shade Tool model results for Cherry Creek, the data that was used for the temperature targets (shade surrogate TMDL), the modeled existing solar load, and the percent load reduction needed to meet the temperature TMDL. Vegetation-specific shade curves developed by the EPA and Idaho DEQ were used for shade target development (Shumar and de Varona 2009). Each level IV ecoregion was assigned a shade curve to represent the potential riparian vegetative community for that ecoregion. The level IV ecoregions represented in the Cherry Creek shade model are 17l - Gneissic-Schistone Forested Mountains, 17ab - Dry Gneissic-Schistone-Volcanic Hills, 17g - Mid-Elevation Sedimentary Mountains, and 17w - Townsend Basin. The shade curves selected for these ecoregions are shown in **Figure I-1** through **Figure I-6**.

Table I-1. Cherry Creek Shade-Related Data, TMDLs, Existing Solar Loading, and the Percent Increase in Shade Needed to Meet the TMDLs

Longitudinal Distance (m)	River Mile (RM)	Aspect	Wetted Width (ft)-GIS	General Direction	Ecoregion	Target Shade (%)	Existing Shade (%)	Shade Difference (%)	Daily Solar Flux with Existing Shade (watts/ft^2)	Daily Solar Flux with Potential Shade (watts/ft^2)	Existing Load (kcal/day)	Potential Load (kcal/day)	Percent Reduction Needed to Meet TMDL
42600	0	74.74526	6.56	E/W	17l	81	59	-22	284	131	6232986.624	2875074.82	53.66%
42550	0.03106855	57.26489	6.56	NE/SW	17l	77	64	-13	249	159	5464836.864	3489594.62	36.11%
42500	0.0621371	33.69031	6.56	NE/SW	17l	77	68	-9	222	160	4872264.192	3511541.76	28.12%
42450	0.09320565	54.46249	6.56	NE/SW	17l	77	69	-8	217	161	4762528.512	3533488.9	25.81%
42400	0.1242742	30.96403	6.56	NE/SW	17l	77	74	-3	180	159	3950484.48	3489594.62	11.54%
42350	0.15534275	40.23632	6.56	NE/SW	17l	77	62	-15	264	160	5794043.904	3511541.76	39.47%
42300	0.1864113	40.60078	6.56	NE/SW	17l	77	62	-15	265	160	5815991.04	3511541.76	39.47%
42250	0.21747985	54.46249	6.56	NE/SW	17l	77	60	-17	277	160	6079356.672	3511541.76	42.50%
42200	0.2485484	55.00769	6.56	NE/SW	17l	77	60	-17	278	160	6101303.808	3511541.76	42.50%
42150	0.27961695	41.18631	6.56	NE/SW	17l	77	62	-15	266	161	5837938.176	3533488.9	39.47%
42100	0.3106855	53.97236	6.56	NE/SW	17l	77	60	-17	277	159	6079356.672	3489594.62	42.50%
42050	0.34175405	79.8449	6.56	E/W	17l	81	53	-28	328	133	7198660.608	2918969.09	59.57%
42000	0.3728226	21.80184	6.56	N/S	17l	75	76	1	171	178	3752960.256	3906590.21	0.00%
41950	0.40389115	26.56505	6.56	NE/SW	17l	77	75	-2	173	159	3796854.528	3489594.62	8.00%
41900	0.4349597	32.47145	6.56	NE/SW	17l	77	74	-3	180	159	3950484.48	3489594.62	11.54%
41850	0.46602825	20.55605	6.56	N/S	17l	75	76	1	170	177	3731013.12	3884643.07	0.00%
41800	0.4970968	43.1655	6.56	NE/SW	17l	77	72	-5	196	161	4301638.656	3533488.9	17.86%
41750	0.52816535	63.43495	6.56	NE/SW	17l	77	87	10	93	164	2041083.648	3599330.3	0.00%
41700	0.5592339	60.64238	6.56	NE/SW	17l	77	87	10	88	156	1931347.968	3423753.22	0.00%
41650	0.59030245	47.48958	6.56	NE/SW	17l	77	71	-6	204	161	4477215.744	3533488.9	20.69%
41600	0.621371	59.0357	6.56	NE/SW	17l	77	67	-10	228	159	5003947.008	3489594.62	30.30%
41550	0.65243955	32.47145	6.56	NE/SW	17l	77	80	3	140	161	3072599.04	3533488.9	0.00%

Table I-1. Cherry Creek Shade-Related Data, TMDLs, Existing Solar Loading, and the Percent Increase in Shade Needed to Meet the TMDLs

Longitudinal Distance (m)	River Mile (RM)	Aspect	Wetted Width (ft)-GIS	General Direction	Ecoregion	Target Shade (%)	Existing Shade (%)	Shade Difference (%)	Daily Solar Flux with Existing Shade (watts/ft^2)	Daily Solar Flux with Potential Shade (watts/ft^2)	Existing Load (kcal/day)	Potential Load (kcal/day)	Percent Reduction Needed to Meet TMDL
41500	0.6835081	30.46559	6.56	NE/SW	17l	77	81	4	136	165	2984810.496	3621277.44	0.00%
41450	0.71457665	57.52895	6.56	NE/SW	17l	77	89	12	76	160	1667982.336	3511541.76	0.00%
41400	0.7456452	52.43118	6.56	NE/SW	17l	77	88	11	84	161	1843559.424	3533488.9	0.00%
41350	0.77671375	71.5649	6.56	E/W	17l	81	91	10	60	126	1316828.16	2765339.14	0.00%
41300	0.8077823	59.42074	6.56	NE/SW	17l	77	90	13	73	168	1602140.928	3687118.85	0.00%
41250	0.83885085	41.98752	6.56	NE/SW	17l	77	87	10	89	157	1953295.104	3445700.35	0.00%
41200	0.8699194	50.19448	6.56	NE/SW	17l	77	88	11	83	159	1821612.288	3489594.62	0.00%
41150	0.90098795	50.19448	6.56	NE/SW	17l	77	88	11	83	159	1821612.288	3489594.62	0.00%
41100	0.9320565	57.52855	6.56	NE/SW	17l	77	89	12	76	159	1667982.336	3489594.62	0.00%
41050	0.96312505	45	6.56	NE/SW	17l	77	61	-16	273	161	5991568.128	3533488.9	41.03%
41000	0.9941936	21.03767	6.56	N/S	17l	75	65	-10	248	177	5442889.728	3884643.07	28.57%
40950	1.02526215	54.4622	6.56	NE/SW	17l	77	55	-22	315	161	6913347.84	3533488.9	48.89%
40900	1.0563307	65.55583	6.56	NE/SW	17l	77	49	-28	356	160	7813180.416	3511541.76	54.90%
40850	1.08739925	61.3893	6.56	NE/SW	17l	77	60	-17	277	159	6079356.672	3489594.62	42.50%
40800	1.1184678	104.0364	6.56	E/W	17l	81	40	-41	415	132	9108061.44	2897021.95	68.33%
40750	1.14953635	89.23966	6.56	E/W	17l	81	36	-45	445	132	9766475.52	2897021.95	70.31%
40700	1.1806049	79.69505	6.56	E/W	17l	81	38	-43	434	133	9525057.024	2918969.09	69.35%
40650	1.21167345	69.6978	6.56	E/W	17l	81	41	-40	415	134	9108061.44	2940916.22	67.80%
40600	1.242742	32.20848	6.56	NE/SW	17l	77	54	-23	317	159	6957242.112	3489594.62	50.00%
40550	1.27381055	81.8699	6.56	E/W	17l	81	37	-44	439	132	9634792.704	2897021.95	69.84%
40500	1.3048791	82.4053	6.56	E/W	17l	81	37	-44	439	133	9634792.704	2918969.09	69.84%
40450	1.33594765	75.96376	6.56	E/W	17l	81	39	-42	425	132	9327532.8	2897021.95	68.85%

Table I-1. Cherry Creek Shade-Related Data, TMDLs, Existing Solar Loading, and the Percent Increase in Shade Needed to Meet the TMDLs

Longitudinal Distance (m)	River Mile (RM)	Aspect	Wetted Width (ft)-GIS	General Direction	Ecoregion	Target Shade (%)	Existing Shade (%)	Shade Difference (%)	Daily Solar Flux with Existing Shade (watts/ft^2)	Daily Solar Flux with Potential Shade (watts/ft^2)	Existing Load (kcal/day)	Potential Load (kcal/day)	Percent Reduction Needed to Meet TMDL
40400	1.3670162	129.2897	6.56	NW/SE	17l	77	51	-26	344	162	7549814.784	3555436.03	53.06%
40350	1.39808475	71.56484	6.56	E/W	17l	81	41	-40	412	133	9042220.032	2918969.09	67.80%
40300	1.4291533	60.25512	6.56	NE/SW	17l	77	47	-30	370	160	8120440.32	3511541.76	56.60%
40250	1.46022185	111.8011	6.56	E/W	17l	81	43	-38	398	133	8734960.128	2918969.09	66.67%
40200	1.4912904	52.12511	6.56	NE/SW	17l	77	50	-27	348	160	7637603.328	3511541.76	54.00%
40150	1.52235895	57.52895	6.56	NE/SW	17l	77	48	-29	361	160	7922916.096	3511541.76	55.77%
40100	1.5534275	45	6.56	NE/SW	17l	77	97	20	24	185	526731.264	4060220.16	0.00%
40050	1.58449605	32.00517	6.56	NE/SW	17l	77	97	20	23	175	504784.128	3840748.8	0.00%
40000	1.6155646	26.56487	6.56	NE/SW	17l	77	97	20	23	174	504784.128	3818801.66	0.00%
39950	1.64663315	24.44417	6.56	NE/SW	17l	77	97	20	24	187	526731.264	4104114.43	0.00%
39900	1.6777017	0	6.56	N/S	17l	75	71	-4	201	173	4411374.336	3796854.53	13.79%
39850	1.70877025	75.96357	6.56	E/W	17l	81	86	5	95	129	2084977.92	2831180.54	0.00%
39800	1.7398388	12.52895	6.56	N/S	17l	75	85	10	102	170	2238607.872	3731013.12	0.00%
39750	1.77090735	15.94563	6.56	N/S	17l	75	85	10	102	170	2238607.872	3731013.12	0.00%
39700	1.8019759	16.69942	6.56	N/S	17l	75	85	10	102	169	2238607.872	3709065.98	0.00%
39650	1.83304445	35.53768	6.56	NE/SW	17l	77	74	-3	182	161	3994378.752	3533488.9	11.54%
39600	1.864113	8.130227	6.56	N/S	17l	75	72	-3	196	175	4301638.656	3840748.8	10.71%
39550	1.89518155	314.9994	6.56	NW/SE	17l	77	62	-15	263	159	5772096.768	3489594.62	39.47%
39500	1.9262501	50.19443	6.56	NE/SW	17l	77	76	-1	171	163	3752960.256	3577383.17	4.17%
39450	1.95731865	120.9643	6.56	NW/SE	17l	77	77	0	161	161	3533488.896	3533488.9	0.00%
39400	1.9883872	345.9643	6.56	N/S	17l	75	69	-6	213	172	4674739.968	3774907.39	19.35%
39350	2.01945575	90	6.56	E/W	17l	81	83	2	120	134	2633656.32	2940916.22	0.00%

Table I-1. Cherry Creek Shade-Related Data, TMDLs, Existing Solar Loading, and the Percent Increase in Shade Needed to Meet the TMDLs

Longitudinal Distance (m)	River Mile (RM)	Aspect	Wetted Width (ft)-GIS	General Direction	Ecoregion	Target Shade (%)	Existing Shade (%)	Shade Difference (%)	Daily Solar Flux with Existing Shade (watts/ft^2)	Daily Solar Flux with Potential Shade (watts/ft^2)	Existing Load (kcal/day)	Potential Load (kcal/day)	Percent Reduction Needed to Meet TMDL
39300	2.0505243	56.31005	6.56	NE/SW	17l	77	77	0	162	162	3555436.032	3555436.03	0.00%
39250	2.08159285	60.25474	6.56	NE/SW	17l	77	77	0	159	159	3489594.624	3489594.62	0.00%
39200	2.1126614	17.10286	6.56	N/S	17l	75	73	-2	191	177	4191902.976	3884643.07	7.41%
39150	2.14372995	75.96363	6.56	E/W	17l	81	81	0	133	133	2918969.088	2918969.09	0.00%
39100	2.1747985	74.74526	6.56	E/W	17l	81	86	5	95	129	2084977.92	2831180.54	0.00%
39050	2.20586705	123.6901	6.56	NW/SE	17l	77	85	8	104	159	2282502.144	3489594.62	0.00%
39000	2.2369356	94.08565	6.56	E/W	17l	81	87	6	89	131	1953295.104	2875074.82	0.00%
38950	2.26800415	168.6898	6.56	N/S	17l	75	85	10	102	171	2238607.872	3752960.26	0.00%
38900	2.2990727	102.9947	6.56	E/W	17l	81	86	5	94	128	2063030.784	2809233.41	0.00%
38850	2.33014125	0	6.56	N/S	17l	75	85	10	102	170	2238607.872	3731013.12	0.00%
38800	2.3612098	352.8749	6.56	N/S	17l	75	85	10	102	170	2238607.872	3731013.12	0.00%
38750	2.39227835	45	6.56	NE/SW	17l	77	85	8	105	161	2304449.28	3533488.9	0.00%
38700	2.4233469	39.80552	6.56	NE/SW	17l	77	92	15	57	164	1250986.752	3599330.3	0.00%
38650	2.45441545	32.73511	6.56	NE/SW	17l	77	92	15	59	169	1294881.024	3709065.98	0.00%
38600	2.485484	82.87532	6.56	E/W	17l	81	91	10	66	140	1448510.976	3072599.04	0.00%
38550	2.51655255	79.69505	6.56	E/W	17l	81	97	16	19	122	416995.584	2677550.59	0.00%
38500	2.5476211	77.90506	6.56	E/W	17l	81	97	16	18	112	395048.448	2458079.23	0.00%
38450	2.57868965	93.17952	6.56	E/W	17l	81	97	16	20	127	438942.72	2787286.27	0.00%
38400	2.6097582	94.76368	6.56	E/W	17l	81	97	16	20	125	438942.72	2743392	0.00%
38350	2.64082675	43.02505	6.56	NE/SW	17l	77	97	20	21	159	460889.856	3489594.62	0.00%
38300	2.6718953	17.52566	6.56	N/S	17l	75	97	22	22	184	482836.992	4038273.02	0.00%
38250	2.70296385	23.96246	6.56	NE/SW	17l	77	97	20	22	172	482836.992	3774907.39	0.00%

Table I-1. Cherry Creek Shade-Related Data, TMDLs, Existing Solar Loading, and the Percent Increase in Shade Needed to Meet the TMDLs

Longitudinal Distance (m)	River Mile (RM)	Aspect	Wetted Width (ft)-GIS	General Direction	Ecoregion	Target Shade (%)	Existing Shade (%)	Shade Difference (%)	Daily Solar Flux with Existing Shade (watts/ft^2)	Daily Solar Flux with Potential Shade (watts/ft^2)	Existing Load (kcal/day)	Potential Load (kcal/day)	Percent Reduction Needed to Meet TMDL
38200	2.7340324	85.23657	6.56	E/W	17l	81	97	16	19	120	416995.584	2633656.32	0.00%
38150	2.76510095	74.745	6.56	E/W	17l	81	98	17	17	165	373101.312	3621277.44	0.00%
38100	2.7961695	29.35762	6.56	NE/SW	17l	77	97	20	23	179	504784.128	3928537.34	0.00%
38050	2.82723805	40.60126	6.56	NE/SW	17l	77	97	20	22	165	482836.992	3621277.44	0.00%
38000	2.8583066	24.22772	6.56	NE/SW	17l	77	97	20	23	175	504784.128	3840748.8	0.00%
37950	2.88937515	27.75881	6.56	NE/SW	17l	77	97	20	24	181	526731.264	3972431.62	0.00%
37900	2.9204437	81.87005	6.56	E/W	17l	81	97	16	19	122	416995.584	2677550.59	0.00%
37850	2.95151225	73.61031	6.56	E/W	17l	81	97	16	19	123	416995.584	2699497.73	0.00%
37800	2.9825808	12.09442	6.56	N/S	17l	75	97	22	23	188	504784.128	4126061.57	0.00%
37750	3.01364935	63.4347	6.56	NE/SW	17l	77	97	20	20	155	438942.72	3401806.08	0.00%
37700	3.0447179	122.0054	6.56	NW/SE	17l	77	97	20	22	166	482836.992	3643224.58	0.00%
37650	3.07578645	111.8016	6.56	E/W	17l	81	97	16	21	132	460889.856	2897021.95	0.00%
37600	3.106855	134.9996	6.56	NW/SE	17l	77	97	20	21	160	460889.856	3511541.76	0.00%
37550	3.13792355	104.0361	6.56	E/W	17l	81	97	16	19	122	416995.584	2677550.59	0.00%
37500	3.1689921	122.7356	6.56	NW/SE	17l	77	97	20	22	165	482836.992	3621277.44	0.00%
37450	3.20006065	149.0361	6.56	NW/SE	17l	77	97	20	22	168	482836.992	3687118.85	0.00%
37400	3.2311292	124.6951	6.56	NW/SE	17l	77	97	20	20	153	438942.72	3357911.81	0.00%
37350	3.26219775	103.4958	6.56	E/W	17l	81	96	15	29	139	636466.944	3050651.9	0.00%
37300	3.2932663	120.2563	6.56	NW/SE	17l	77	95	18	36	167	790096.896	3665171.71	0.00%
37250	3.32433485	120.9638	6.56	NW/SE	17l	77	95	18	37	171	812044.032	3752960.26	0.00%
37200	3.3554034	107.1029	6.56	E/W	17l	81	96	15	29	138	636466.944	3028704.77	0.00%
37150	3.38647195	108.4347	6.56	E/W	17l	81	97	16	20	126	438942.72	2765339.14	0.00%

Table I-1. Cherry Creek Shade-Related Data, TMDLs, Existing Solar Loading, and the Percent Increase in Shade Needed to Meet the TMDLs

Longitudinal Distance (m)	River Mile (RM)	Aspect	Wetted Width (ft)-GIS	General Direction	Ecoregion	Target Shade (%)	Existing Shade (%)	Shade Difference (%)	Daily Solar Flux with Existing Shade (watts/ft^2)	Daily Solar Flux with Potential Shade (watts/ft^2)	Existing Load (kcal/day)	Potential Load (kcal/day)	Percent Reduction Needed to Meet TMDL
37100	3.4175405	130.2363	6.56	NW/SE	17l	77	97	20	23	176	504784.128	3862695.94	0.00%
37050	3.44860905	63.43513	6.56	NE/SW	17l	77	97	20	20	156	438942.72	3423753.22	0.00%
37000	3.4796776	47.12089	6.56	NE/SW	17l	77	97	20	21	160	460889.856	3511541.76	0.00%
36950	3.51074615	43.02505	6.56	NE/SW	17l	77	97	20	21	161	460889.856	3533488.9	0.00%
36900	3.5418147	36.25377	6.56	NE/SW	17l	77	97	20	23	173	504784.128	3796854.53	0.00%
36850	3.57288325	53.74604	6.56	NE/SW	17l	77	97	20	23	174	504784.128	3818801.66	0.00%
36800	3.6039518	64.53643	6.56	NE/SW	17l	77	97	20	22	171	482836.992	3752960.26	0.00%
36750	3.63502035	72.64622	6.56	E/W	17l	81	97	16	20	129	438942.72	2831180.54	0.00%
36700	3.6660889	53.97273	6.56	NE/SW	17l	77	59	-18	286	160	6276880.896	3511541.76	43.90%
36650	3.69715745	84.80555	6.56	E/W	17l	81	39	-42	423	132	9283638.528	2897021.95	68.85%
36600	3.728226	51.34027	6.56	NE/SW	17l	77	58	-19	290	159	6364669.44	3489594.62	45.24%
36550	3.75929455	113.1984	6.56	NW/SE	17l	77	40	-37	419	161	9195849.984	3533488.9	61.67%
36500	3.7903631	71.5649	6.56	E/W	17l	81	40	-41	415	131	9108061.44	2875074.82	68.33%
36450	3.82143165	42.51042	6.56	NE/SW	17l	77	48	-29	361	160	7922916.096	3511541.76	55.77%
36400	3.8525002	70.34643	6.56	E/W	17l	81	38	-43	432	133	9481162.752	2918969.09	69.35%
36350	3.88356875	69.44404	6.56	E/W	17l	81	39	-42	428	133	9393374.208	2918969.09	68.85%
36300	3.9146373	24.77532	6.56	NE/SW	17l	77	51	-26	343	161	7527867.648	3533488.9	53.06%
36250	3.94570585	69.4437	6.56	E/W	17l	81	39	-42	428	133	9393374.208	2918969.09	68.85%
36200	3.9767744	69.67671	6.56	E/W	17l	81	38	-43	430	132	9437268.48	2897021.95	69.35%
36150	4.00784295	69.1456	6.56	E/W	17l	81	49	-32	358	133	7857074.688	2918969.09	62.75%
36100	4.0389115	90	6.56	E/W	17l	81	40	-41	420	133	9217797.12	2918969.09	68.33%
36050	4.06998005	74.35762	6.56	E/W	17l	81	45	-36	386	133	8471594.496	2918969.09	65.45%

Table I-1. Cherry Creek Shade-Related Data, TMDLs, Existing Solar Loading, and the Percent Increase in Shade Needed to Meet the TMDLs

Longitudinal Distance (m)	River Mile (RM)	Aspect	Wetted Width (ft)-GIS	General Direction	Ecoregion	Target Shade (%)	Existing Shade (%)	Shade Difference (%)	Daily Solar Flux with Existing Shade (watts/ft^2)	Daily Solar Flux with Potential Shade (watts/ft^2)	Existing Load (kcal/day)	Potential Load (kcal/day)	Percent Reduction Needed to Meet TMDL
36000	4.1010486	82.87492	6.56	E/W	17l	81	41	-40	412	133	9042220.032	2918969.09	67.80%
35950	4.13211715	65.7724	6.56	NE/SW	17l	77	51	-26	339	159	7440079.104	3489594.62	53.06%
35900	4.1631857	90	6.56	E/W	17l	81	33	-48	470	133	10315153.92	2918969.09	71.64%
35850	4.19425425	86.42364	6.56	E/W	17l	81	33	-48	468	133	10271259.65	2918969.09	71.64%
35800	4.2253228	39.80552	6.56	NE/SW	17l	77	49	-28	356	161	7813180.416	3533488.9	54.90%
35750	4.25639135	28.07234	6.56	NE/SW	17l	77	51	-26	341	160	7483973.376	3511541.76	53.06%
35700	4.2874599	113.9619	6.56	NW/SE	17l	77	41	-36	411	160	9020272.896	3511541.76	61.02%
35650	4.31852845	83.65977	6.56	E/W	17l	81	33	-48	466	132	10227365.38	2897021.95	71.64%
35600	4.349597	34.50844	6.56	NE/SW	17l	77	50	-27	349	161	7659550.464	3533488.9	54.00%
35550	4.38066555	50.71065	6.56	NE/SW	17l	77	46	-31	376	160	8252123.136	3511541.76	57.41%
35500	4.4117341	120.9636	6.56	NW/SE	17l	77	43	-34	396	160	8691065.856	3511541.76	59.65%
35450	4.44280265	81.86977	13.12	E/W	17l	60	18	-42	570	278	25019735.04	12202607.6	51.22%
35400	4.4738712	25.30825	13.12	NE/SW	17l	57	32	-25	473	299	20761990.66	13124387.3	36.76%
35350	4.50493975	131.9875	13.12	NW/SE	17l	57	27	-30	508	300	22298290.18	13168281.6	41.10%
35300	4.5360083	79.3802	13.12	E/W	17l	60	18	-42	570	278	25019735.04	12202607.6	51.22%
35250	4.56707685	60.25507	16.4	NE/SW	17l	51	18	-33	569	340	31219800.96	18655065.6	40.24%
35200	4.5981454	45	16.4	NE/SW	17l	51	22	-29	541	340	29683501.44	18655065.6	37.18%
35150	4.62921395	87.87888	16.4	E/W	17l	52	15	-37	591	334	32426893.44	18325858.6	43.53%
35100	4.6602825	90	16.4	E/W	17l	52	17	-35	579	335	31768479.36	18380726.4	42.17%
35050	4.69135105	93.57636	13.12	E/W	17l	60	17	-43	580	280	25458677.76	12290396.2	51.81%
35000	4.7224196	109.9833	16.4	E/W	17l	52	22	-30	543	334	29793237.12	18325858.6	38.46%
34950	4.75348815	99.46241	13.12	E/W	17l	60	85	25	103	275	4521110.016	12070924.8	0.00%

Table I-1. Cherry Creek Shade-Related Data, TMDLs, Existing Solar Loading, and the Percent Increase in Shade Needed to Meet the TMDLs

Longitudinal Distance (m)	River Mile (RM)	Aspect	Wetted Width (ft)-GIS	General Direction	Ecoregion	Target Shade (%)	Existing Shade (%)	Shade Difference (%)	Daily Solar Flux with Existing Shade (watts/ft^2)	Daily Solar Flux with Potential Shade (watts/ft^2)	Existing Load (kcal/day)	Potential Load (kcal/day)	Percent Reduction Needed to Meet TMDL
34900	4.7845567	119.0544	13.12	NW/SE	17l	57	90	33	68	291	2984810.496	12773233.2	0.00%
34850	4.81562525	132.5104	16.4	NW/SE	17l	51	88	37	82	336	4499162.88	18435594.2	0.00%
34800	4.8466938	90	9.84	E/W	17l	71	95	24	32	187	1053462.528	6156171.65	0.00%
34750	4.87776235	102.9943	16.4	E/W	17l	52	91	39	61	327	3346938.24	17941783.7	0.00%
34700	4.9088309	125.2175	13.12	NW/SE	17l	57	90	33	73	314	3204281.856	13782801.4	0.00%
34650	4.93989945	107.7446	13.12	E/W	17l	60	94	34	44	294	1931347.968	12904916	0.00%
34600	4.970968	73.61036	13.12	E/W	17l	60	94	34	41	270	1799665.152	11851453.4	0.00%
34550	5.00203655	106.9274	16.4	E/W	17l	52	89	37	75	326	4115088	17886915.8	0.00%
34500	5.0331051	105.9455	9.84	E/W	17l	71	96	25	31	227	1020541.824	7472999.81	0.00%
34450	5.06417365	87.69259	13.12	E/W	17l	60	94	34	39	259	1711876.608	11368616.4	0.00%
34400	5.0952422	85.60126	13.12	E/W	17l	60	94	34	41	272	1799665.152	11939242	0.00%
34350	5.12631075	75.46565	13.12	E/W	17l	60	92	32	58	288	2545867.776	12641550.3	0.00%
34300	5.1573793	94.08565	9.84	E/W	17l	71	95	24	32	188	1053462.528	6189092.35	0.00%
34250	5.18844785	85.91435	16.4	E/W	17l	52	81	29	130	328	7132819.2	17996651.5	0.00%
34200	5.2195164	57.99444	13.12	NE/SW	17l	57	77	20	159	297	6979189.248	13036598.8	0.00%
34150	5.25058495	64.53678	9.84	NE/SW	17l	66	95	29	35	239	1152224.64	7868048.26	0.00%
34100	5.2816535	78.11152	13.12	E/W	17l	60	94	34	39	262	1711876.608	11500299.3	0.00%
34050	5.31272205	94.63534	13.12	E/W	17l	60	94	34	40	267	1755770.88	11719770.6	0.00%
34000	5.3437906	91.36394	13.12	E/W	17l	60	94	34	43	289	1887453.696	12685444.6	0.00%
33950	5.37485915	79.11461	13.12	E/W	17l	60	94	34	45	300	1975242.24	13168281.6	0.00%
33900	5.4059277	92.20262	13.12	E/W	17l	60	95	35	37	292	1624088.064	12817127.4	0.00%
33850	5.43699625	76.42967	13.12	E/W	17l	60	94	34	39	262	1711876.608	11500299.3	0.00%

Table I-1. Cherry Creek Shade-Related Data, TMDLs, Existing Solar Loading, and the Percent Increase in Shade Needed to Meet the TMDLs

Longitudinal Distance (m)	River Mile (RM)	Aspect	Wetted Width (ft)-GIS	General Direction	Ecoregion	Target Shade (%)	Existing Shade (%)	Shade Difference (%)	Daily Solar Flux with Existing Shade (watts/ft^2)	Daily Solar Flux with Potential Shade (watts/ft^2)	Existing Load (kcal/day)	Potential Load (kcal/day)	Percent Reduction Needed to Meet TMDL
33800	5.4680648	73.73989	9.84	E/W	17l	71	95	24	36	207	1185145.344	6814585.73	0.00%
33750	5.49913335	63.43495	9.84	NE/SW	17l	66	94	28	40	226	1316828.16	7440079.1	0.00%
33700	5.5302019	48.17985	16.4	NE/SW	17l	51	89	38	75	333	4115088	18270990.7	0.00%
33650	5.56127045	74.93161	16.4	E/W	17l	52	90	38	72	345	3950484.48	18929404.8	0.00%
33600	5.592339	75.37925	13.12	E/W	17l	60	92	32	52	262	2282502.144	11500299.3	0.00%
33550	5.62340755	85.81504	13.12	E/W	17l	60	94	34	39	260	1711876.608	11412510.7	0.00%
33500	5.6544761	50.90618	6.56	NE/SW	17l	77	96	19	25	141	548678.4	3094546.18	0.00%
33450	5.68554465	70.71013	9.84	E/W	17l	71	95	24	36	209	1185145.344	6880427.14	0.00%
33400	5.7166132	50.90618	9.84	NE/SW	17l	66	93	27	48	235	1580193.792	7736365.44	0.00%
33350	5.74768175	63.43506	13.12	NE/SW	17l	57	91	34	66	314	2897021.952	13782801.4	0.00%
33300	5.7787503	73.73966	16.4	E/W	17l	52	81	29	133	337	7297422.72	18490462.1	0.00%
33250	5.80981885	85.03048	19.68	E/W	17l	46	86	40	101	388	6649982.208	25546466.3	0.00%
33200	5.8408874	45	19.68	NE/SW	17l	46	83	37	121	385	7966810.368	25348942.1	0.00%
33150	5.87195595	53.12998	16.4	NE/SW	17l	51	76	25	169	346	9272664.96	18984272.6	0.00%
33100	5.9030245	145.4914	19.68	NW/SE	17l	46	81	35	133	379	8756907.264	24953893.6	0.00%
33050	5.93409305	104.0363	19.68	E/W	17l	46	82	36	128	385	8427700.224	25348942.1	0.00%
33000	5.9651616	101.31	19.68	E/W	17l	46	81	35	131	373	8625224.448	24558845.2	0.00%
32950	5.99623015	90	16.4	E/W	17l	52	93	41	47	323	2578788.48	17722312.3	0.00%
32900	6.0272987	90	13.12	E/W	17l	60	94	34	43	283	1887453.696	12422079	0.00%
32850	6.05836725	76.60737	22.96	E/W	17l	41	82	41	126	412	9678686.976	31647770.1	0.00%
32800	6.0894358	115.0167	22.96	NW/SE	17l	42	79	37	146	403	11214986.5	30956435.3	0.00%
32750	6.12050435	100.3044	16.4	E/W	17l	52	88	36	85	339	4663766.4	18600197.8	0.00%

Table I-1. Cherry Creek Shade-Related Data, TMDLs, Existing Solar Loading, and the Percent Increase in Shade Needed to Meet the TMDLs

Longitudinal Distance (m)	River Mile (RM)	Aspect	Wetted Width (ft)-GIS	General Direction	Ecoregion	Target Shade (%)	Existing Shade (%)	Shade Difference (%)	Daily Solar Flux with Existing Shade (watts/ft^2)	Daily Solar Flux with Potential Shade (watts/ft^2)	Existing Load (kcal/day)	Potential Load (kcal/day)	Percent Reduction Needed to Meet TMDL
32700	6.1515729	105.9453	26.24	E/W	17l	36	65	29	248	453	21771558.91	39768210.4	0.00%
32650	6.18264145	66.37066	26.24	NE/SW	17l	39	63	24	257	424	22561655.81	37222342.7	0.00%
32600	6.21371	130.2363	26.24	NW/SE	17l	39	63	24	260	429	22825021.44	37661285.4	0.00%
32550	6.24477855	117.646	29.52	NW/SE	17l	36	61	25	271	444	26764532.35	43850377.7	0.00%
32500	6.2758471	112.9321	19.68	NW/SE	17l	46	80	34	136	368	8954431.488	24229638.1	0.00%
32450	6.30691565	108.9246	13.12	E/W	17l	60	93	33	49	281	2150819.328	12334290.4	0.00%
32400	6.3379842	103.3924	13.12	E/W	17l	60	92	32	55	275	2414184.96	12070924.8	0.00%
32350	6.36905275	92.04543	13.12	E/W	17l	60	93	33	49	282	2150819.328	12378184.7	0.00%
32300	6.4001213	83.65973	13.12	E/W	17l	60	91	31	60	265	2633656.32	11631982.1	0.00%
32250	6.43118985	117.7586	16.4	NW/SE	17l	51	84	33	113	345	6200065.92	18929404.8	0.00%
32200	6.4622584	57.99455	9.84	NE/SW	17l	66	91	25	64	243	2106925.056	7999731.07	0.00%
32150	6.49332695	24.62355	13.12	NE/SW	17l	57	83	26	117	297	5135629.824	13036598.8	0.00%
32100	6.5243955	51.34024	16.4	NE/SW	17l	51	85	34	107	349	5870858.88	19148876.2	0.00%
32050	6.55546405	109.1789	13.12	E/W	17l	60	91	31	60	266	2633656.32	11675876.4	0.00%
32000	6.5865326	59.53441	13.12	NE/SW	17l	57	87	30	92	303	4038273.024	13299964.4	0.00%
31950	6.61760115	70.70986	13.12	E/W	17l	60	87	27	90	278	3950484.48	12202607.6	0.00%
31900	6.6486697	64.53667	9.84	NE/SW	17ab	58	89	31	74	283	2436132.096	9316559.23	0.00%
31850	6.67973825	85.23632	9.84	E/W	17ab	50	92	42	58	363	1909400.832	11950215.6	0.00%
31800	6.7108068	73.81087	9.84	E/W	17ab	50	90	40	67	334	2205687.168	10995515.1	0.00%
31750	6.74187535	50.71065	9.84	NE/SW	17ab	58	87	29	88	283	2897021.952	9316559.23	0.00%
31700	6.7729439	29.05449	9.84	NE/SW	17ab	58	90	32	69	291	2271528.576	9579924.86	0.00%
31650	6.80401245	70.01696	13.12	E/W	17ab	38	86	48	97	429	4257744.384	18830642.7	0.00%

Table I-1. Cherry Creek Shade-Related Data, TMDLs, Existing Solar Loading, and the Percent Increase in Shade Needed to Meet the TMDLs

Longitudinal Distance (m)	River Mile (RM)	Aspect	Wetted Width (ft)-GIS	General Direction	Ecoregion	Target Shade (%)	Existing Shade (%)	Shade Difference (%)	Daily Solar Flux with Existing Shade (watts/ft^2)	Daily Solar Flux with Potential Shade (watts/ft^2)	Existing Load (kcal/day)	Potential Load (kcal/day)	Percent Reduction Needed to Meet TMDL
31600	6.835081	70.71013	13.12	E/W	17ab	38	88	50	86	445	3774907.392	19532951	0.00%
31550	6.86614955	83.15717	9.84	E/W	17ab	50	90	40	68	338	2238607.872	11127198	0.00%
31500	6.8972181	61.18918	13.12	NE/SW	17ab	48	85	37	107	372	4696687.104	16328669.2	0.00%
31450	6.92828665	45	9.84	NE/SW	17ab	58	88	30	86	303	2831180.544	9974973.31	0.00%
31400	6.9593552	64.05764	13.12	NE/SW	17ab	48	87	39	93	371	4082167.296	16284774.9	0.00%
31350	6.99042375	66.80144	9.84	NE/SW	17ab	58	91	33	64	298	2106925.056	9810369.79	0.00%
31300	7.0214923	46.97474	13.12	NE/SW	17ab	48	86	38	97	361	4257744.384	15845832.2	0.00%
31250	7.05256085	47.72634	16.4	NE/SW	17ab	42	78	36	154	406	8449647.36	22276343	0.00%
31200	7.0836294	10.00804	16.4	N/S	17ab	45	80	35	142	390	7791233.28	21398457.6	0.00%
31150	7.11469795	69.94974	13.12	E/W	17ab	38	85	47	108	445	4740581.376	19532951	0.00%
31100	7.1457665	26.5649	13.12	NE/SW	17ab	48	85	37	106	366	4652792.832	16065303.6	0.00%
31050	7.17683505	66.80162	16.4	NE/SW	17ab	42	80	38	141	410	7736365.44	22495814.4	0.00%
31000	7.2079036	42.27366	13.12	NE/SW	17ab	48	82	34	122	353	5355101.184	15494678	0.00%
30950	7.23897215	332.1027	13.12	NW/SE	17ab	48	84	36	111	360	4872264.192	15801937.9	0.00%
30900	7.2700407	25.20141	16.4	NE/SW	17ab	42	81	39	134	410	7352290.56	22495814.4	0.00%
30850	7.30110925	60.25507	13.12	NE/SW	17ab	48	82	34	125	362	5486784	15889726.5	0.00%
30800	7.3321778	8.746234	16.4	N/S	17ab	45	81	36	134	388	7352290.56	21288721.9	0.00%
30750	7.36324635	345.9636	16.4	N/S	17ab	45	87	42	94	398	5157576.96	21837400.3	0.00%
30700	7.3943149	35.73609	29.52	NE/SW	17ab	26	59	33	288	519	28443488.26	51257536.1	0.00%
30650	7.42538345	66.37048	19.68	NE/SW	17ab	36	81	45	130	438	8559383.04	28838536.7	0.00%
30600	7.456452	5.19448	19.68	N/S	17ab	39	80	41	136	415	8954431.488	27324184.3	0.00%
30550	7.48752055	0	19.68	N/S	17ab	39	80	41	142	432	9349479.936	28443488.3	0.00%

Table I-1. Cherry Creek Shade-Related Data, TMDLs, Existing Solar Loading, and the Percent Increase in Shade Needed to Meet the TMDLs

Longitudinal Distance (m)	River Mile (RM)	Aspect	Wetted Width (ft)-GIS	General Direction	Ecoregion	Target Shade (%)	Existing Shade (%)	Shade Difference (%)	Daily Solar Flux with Existing Shade (watts/ft^2)	Daily Solar Flux with Potential Shade (watts/ft^2)	Existing Load (kcal/day)	Potential Load (kcal/day)	Percent Reduction Needed to Meet TMDL
30500	7.5185891	33.68995	22.96	NE/SW	17ab	32	74	42	180	470	13826695.68	36103038.7	0.00%
30450	7.54965765	18.4347	22.96	N/S	17ab	35	76	41	166	449	12751286.02	34489924.2	0.00%
30400	7.5807262	41.6335	22.96	NE/SW	17ab	32	75	43	172	468	13212175.87	35949408.8	0.00%
30350	7.61179475	90	22.96	E/W	17ab	23	70	47	211	541	16207959.94	41556902	0.00%
30300	7.6428633	29.74474	19.68	NE/SW	17ab	36	79	43	148	451	9744528.384	29694475	0.00%
30250	7.67393185	21.03767	26.24	N/S	17ab	32	71	39	199	467	17469920.26	40997250	0.00%
30200	7.7050004	47.72634	22.96	NE/SW	17ab	32	74	42	183	478	14057140.61	36717558.5	0.00%
30150	7.73606895	9.462378	26.24	N/S	17ab	32	69	37	219	479	19225691.14	42050712.6	0.00%
30100	7.7671375	52.12511	26.24	NE/SW	17ab	29	64	35	252	497	22122713.09	43630906.4	0.00%
30050	7.79820605	32.47105	26.24	NE/SW	17ab	29	31	2	483	497	42401866.75	43630906.4	0.00%
30000	7.8292746	5.710347	29.52	N/S	17ab	29	33	4	471	499	46516954.75	49282293.9	0.00%
29950	7.86034315	330.6424	22.96	NW/SE	17ab	32	51	19	342	474	26270721.79	36410298.6	0.00%
29900	7.8914117	76.60765	26.24	E/W	17ab	20	35	15	452	556	39680421.89	48810430.5	0.00%
29850	7.92248025	33.69016	16.4	NE/SW	17ab	42	68	26	224	406	12290396.16	22276343	0.00%
29800	7.9535488	54.4622	13.12	NE/SW	17ab	48	46	-2	378	364	16592034.82	15977515	3.70%
29750	7.98461735	77.90515	19.68	E/W	17ab	27	25	-2	525	511	34566739.2	33644959.5	2.67%
29700	8.0156859	334.9833	16.4	NW/SE	17ab	42	64	22	251	405	13771827.84	22221475.2	0.00%
29650	8.04675445	28.07251	19.68	NE/SW	17ab	36	45	9	386	449	25414783.49	29562792.2	0.00%
29600	8.077823	77.47138	22.96	E/W	17ab	23	23	0	540	540	41480087.04	41480087	0.00%
29550	8.10889155	15.94551	13.12	N/S	17ab	51	56	5	305	339	13387752.96	14880158.2	0.00%
29500	8.1399601	40.60126	22.96	NE/SW	17ab	32	39	7	425	474	32646364.8	36410298.6	0.00%
29450	8.17102865	37.8751	19.68	NE/SW	17ab	36	41	5	409	444	26929135.87	29233585.2	0.00%

Table I-1. Cherry Creek Shade-Related Data, TMDLs, Existing Solar Loading, and the Percent Increase in Shade Needed to Meet the TMDLs

Longitudinal Distance (m)	River Mile (RM)	Aspect	Wetted Width (ft)-GIS	General Direction	Ecoregion	Target Shade (%)	Existing Shade (%)	Shade Difference (%)	Daily Solar Flux with Existing Shade (watts/ft^2)	Daily Solar Flux with Potential Shade (watts/ft^2)	Existing Load (kcal/day)	Potential Load (kcal/day)	Percent Reduction Needed to Meet TMDL
29400	8.2020972	31.60737	19.68	NE/SW	17ab	36	45	9	386	449	25414783.49	29562792.2	0.00%
29350	8.23316575	57.26489	19.68	NE/SW	17ab	36	34	-2	461	447	30352889.09	29431109.4	3.03%
29300	8.2642343	355.9148	16.4	N/S	17ab	45	60	15	281	386	15417863.04	21178986.2	0.00%
29250	8.29530285	41.18631	16.4	NE/SW	17ab	42	24	-18	532	406	29189690.88	22276343	23.68%
29200	8.3263714	351.2538	19.68	N/S	17ab	39	24	-15	533	427	35093470.46	28114281.2	19.74%
29150	8.35743995	306.2056	22.96	NW/SE	17ab	32	17	-15	579	474	44475871.1	36410298.6	18.07%
29100	8.3885085	26.56484	22.96	NE/SW	17ab	32	20	-12	561	477	43093201.54	36640743.6	15.00%
29050	8.41957705	345.0685	32.8	N/S	17ab	26	15	-11	592	515	64963522.56	56513875.2	12.94%
29000	8.4506456	276.3402	16.4	E/W	17ab	31	15	-16	592	481	32481761.28	26391431	18.82%
28950	8.48171415	0	26.24	N/S	17ab	32	19	-13	567	476	49776104.45	41787346.9	16.05%
28900	8.5127827	352.4057	16.4	N/S	17ab	45	49	4	354	382	19423215.36	20959514.9	0.00%
28850	8.54385125	337.38	19.68	NW/SE	17ab	36	45	9	381	444	25085576.45	29233585.2	0.00%
28800	8.5749198	0	22.96	N/S	17ab	35	56	21	309	457	23735827.58	35104444	0.00%
28750	8.60598835	30.25666	22.96	NE/SW	17ab	32	53	21	327	473	25118497.15	36333483.6	0.00%
28700	8.6370569	38.65973	16.4	NE/SW	17ab	42	36	-6	446	404	24471056.64	22166607.4	9.37%
28650	8.66812545	3.81413	29.52	N/S	17ab	29	18	-11	571	494	56393165.95	48788483.3	13.41%
28600	8.699194	30.25666	16.4	NE/SW	17ab	42	28	-14	500	403	27433920	22111739.5	19.44%
28550	8.73026255	236.3101	16.4	NE/SW	17ab	42	30	-12	490	406	26885241.6	22276343	17.14%
28500	8.7613311	329.036	22.96	NW/SE	17ab	32	52	20	334	473	25656201.98	36333483.6	0.00%
28450	8.79239965	35.97277	16.4	NE/SW	17ab	42	63	21	257	403	14101034.88	22111739.5	0.00%
28400	8.8234682	7.125064	29.52	N/S	17ab	29	50	21	350	497	34566739.2	49084769.7	0.00%
28350	8.85453675	41.18587	26.24	NE/SW	17ab	29	46	17	380	500	33359646.72	43894272	0.00%

Table I-1. Cherry Creek Shade-Related Data, TMDLs, Existing Solar Loading, and the Percent Increase in Shade Needed to Meet the TMDLs

Longitudinal Distance (m)	River Mile (RM)	Aspect	Wetted Width (ft)-GIS	General Direction	Ecoregion	Target Shade (%)	Existing Shade (%)	Shade Difference (%)	Daily Solar Flux with Existing Shade (watts/ft^2)	Daily Solar Flux with Potential Shade (watts/ft^2)	Existing Load (kcal/day)	Potential Load (kcal/day)	Percent Reduction Needed to Meet TMDL
28300	8.8856053	326.3095	19.68	NW/SE	17ab	36	55	19	315	449	20740043.52	29562792.2	0.00%
28250	8.91667385	37.56852	19.68	NE/SW	17ab	36	58	22	295	450	19423215.36	29628633.6	0.00%
28200	8.9477424	37.56852	19.68	NE/SW	17ab	36	55	19	312	443	20542519.3	29167743.7	0.00%
28150	8.97881095	354.2893	22.96	N/S	17ab	35	62	27	265	453	20355968.64	34797184.1	0.00%
28100	9.0098795	11.82185	26.24	N/S	17ab	32	55	23	312	472	27390025.73	41436192.8	0.00%
28050	9.04094805	0	26.24	N/S	17ab	32	52	20	338	479	29672527.87	42050712.6	0.00%
28000	9.0720166	13.2406	16.4	N/S	17ab	45	64	19	251	384	13771827.84	21069250.6	0.00%
27950	9.10308515	64.79889	16.4	NE/SW	17ab	42	55	13	313	403	17173633.92	22111739.5	0.00%
27900	9.1341537	60.25526	22.96	NE/SW	17ab	32	47	15	372	477	28575171.07	36640743.6	0.00%
27850	9.16522225	96.34027	19.68	E/W	17ab	27	44	17	390	509	25678149.12	33513276.7	0.00%
27800	9.1962908	337.38	26.24	NW/SE	17ab	29	51	22	342	495	30023682.05	43455329.3	0.00%
27750	9.22735935	0	26.24	N/S	17ab	32	34	2	462	476	40558307.33	41787346.9	0.00%
27700	9.2584279	33.69039	22.96	NE/SW	17ab	32	31	-1	480	473	36871188.48	36333483.6	1.45%
27650	9.28949645	0	26.24	N/S	17ab	32	34	2	459	473	40294941.7	41523981.3	0.00%
27600	9.320565	36.87027	26.24	NE/SW	17ab	29	27	-2	512	498	44947734.53	43718694.9	2.74%
27550	9.35163355	319.3992	26.24	NW/SE	17ab	29	38	9	431	494	37836862.46	43367540.7	0.00%
27500	9.3827021	18.4351	26.24	N/S	17ab	32	34	2	462	476	40558307.33	41787346.9	0.00%
27450	9.41377065	355.6013	22.96	N/S	17ab	35	39	4	426	454	32723179.78	34873999.1	0.00%
27400	9.4448392	339.4437	29.52	N/S	17ab	29	38	9	432	495	42665232.38	48887245.4	0.00%
27350	9.47590775	39.80557	29.52	NE/SW	17ab	26	45	19	381	512	37628364.67	50566201.3	0.00%
27300	9.5069763	23.96275	26.24	NE/SW	17ab	29	51	22	343	496	30111470.59	43543117.8	0.00%
27250	9.53804485	303.6898	26.24	NW/SE	17ab	29	45	16	381	492	33447435.26	43191963.6	0.00%

Table I-1. Cherry Creek Shade-Related Data, TMDLs, Existing Solar Loading, and the Percent Increase in Shade Needed to Meet the TMDLs

Longitudinal Distance (m)	River Mile (RM)	Aspect	Wetted Width (ft)-GIS	General Direction	Ecoregion	Target Shade (%)	Existing Shade (%)	Shade Difference (%)	Daily Solar Flux with Existing Shade (watts/ft^2)	Daily Solar Flux with Potential Shade (watts/ft^2)	Existing Load (kcal/day)	Potential Load (kcal/day)	Percent Reduction Needed to Meet TMDL
27200	9.5691134	94.39874	26.24	E/W	17ab	20	29	9	495	558	43455329.28	48986007.6	0.00%
27150	9.60018195	12.09485	22.96	N/S	17ab	35	39	4	425	453	32646364.8	34797184.1	0.00%
27100	9.6312505	30.96403	22.96	NE/SW	17ab	32	40	8	420	476	32262289.92	36563928.6	0.00%
27050	9.66231905	116.5648	32.8	NW/SE	17ab	24	35	11	456	533	50039470.08	58489117.4	0.00%
27000	9.6933876	354.8055	29.52	N/S	17ab	29	46	17	373	491	36838267.78	48492197	0.00%
26950	9.72445615	47.72662	32.8	NE/SW	17ab	24	21	-3	553	532	60683831.04	58379381.8	3.80%
26900	9.7555247	30.25628	29.52	NE/SW	17ab	26	43	17	400	519	39504844.8	51257536.1	0.00%
26850	9.78659325	57.99427	42.64	NE/SW	17ab	19	15	-4	591	564	84309922.94	80458200.6	4.71%
26800	9.8176618	95.71059	49.2	E/W	17ab	11	9	-2	632	618	104029424.6	101724975	2.20%
26750	9.84873035	349.9919	26.24	N/S	17ab	32	49	17	354	472	31077144.58	41436192.8	0.00%
26700	9.8797989	30.96363	39.36	NE/SW	17ab	20	13	-7	604	555	79536420.86	73083962.9	8.05%
26650	9.91086745	12.09494	29.52	N/S	17ab	29	31	2	480	494	47405813.76	48788483.3	0.00%
26600	9.941936	326.3101	36.08	NW/SE	17ab	22	38	16	430	541	51904976.64	65303703.2	0.00%
26550	9.97300455	26.56484	13.12	NE/SW	17ab	48	66	18	238	365	10446836.74	16021409.3	0.00%
26500	10.0040731	333.4352	26.24	NW/SE	17ab	29	49	20	357	497	31340510.21	43630906.4	0.00%
26450	10.0351417	355.6013	16.4	N/S	17ab	45	63	18	257	383	14101034.88	21014382.7	0.00%
26400	10.0662102	21.03783	16.4	N/S	17ab	45	47	2	371	385	20355968.64	21124118.4	0.00%
26350	10.0972788	4.085648	13.12	N/S	17ab	51	67	16	227	337	9963999.744	14792369.7	0.00%
26300	10.1283473	6.709879	22.96	N/S	17ab	35	54	19	320	452	24580792.32	34720369.2	0.00%
26250	10.1594159	317.7263	19.68	NW/SE	17ab	36	57	21	303	451	19949946.62	29694475	0.00%
26200	10.1904844	19.98279	16.4	N/S	17ab	45	65	20	243	382	13332885.12	20959514.9	0.00%
26150	10.221553	349.6952	16.4	N/S	17ab	45	66	21	239	387	13113413.76	21233854.1	0.00%

Table I-1. Cherry Creek Shade-Related Data, TMDLs, Existing Solar Loading, and the Percent Increase in Shade Needed to Meet the TMDLs

Longitudinal Distance (m)	River Mile (RM)	Aspect	Wetted Width (ft)-GIS	General Direction	Ecoregion	Target Shade (%)	Existing Shade (%)	Shade Difference (%)	Daily Solar Flux with Existing Shade (watts/ft^2)	Daily Solar Flux with Potential Shade (watts/ft^2)	Existing Load (kcal/day)	Potential Load (kcal/day)	Percent Reduction Needed to Meet TMDL
26100	10.2526215	296.5647	19.68	NW/SE	17ab	36	51	15	340	444	22386078.72	29233585.2	0.00%
26050	10.2836901	18.43526	22.96	N/S	17ab	35	41	6	413	455	31724585.09	34950814.1	0.00%
26000	10.3147586	332.1027	16.4	NW/SE	17ab	42	50	8	348	404	19094008.32	22166607.4	0.00%
25950	10.3458272	5.19448	16.4	N/S	17ab	45	46	1	377	384	20685175.68	21069250.6	0.00%
25900	10.3768957	0	19.68	N/S	17ab	39	41	2	413	427	27192501.5	28114281.2	0.00%
25850	10.4079643	299.0549	32.8	NW/SE	17ab	24	31	7	484	533	53112069.12	58489117.4	0.00%
25800	10.4390328	50.19504	22.96	NE/SW	17ab	32	26	-6	514	472	39482897.66	36256668.7	8.11%
25750	10.4701014	283.7982	22.96	E/W	17ab	23	33	10	467	537	35872593.79	41249642.1	0.00%
25700	10.5011699	37.87489	19.68	NE/SW	17ab	36	21	-15	551	446	36278615.81	29365268	18.99%
25650	10.5322385	331.3893	22.96	NW/SE	17ab	32	42	10	406	476	31186880.26	36563928.6	0.00%
25600	10.563307	270	16.4	E/W	17ab	31	47	16	370	481	20301100.8	26391431	0.00%
25550	10.5943756	0	22.96	N/S	17ab	35	54	19	322	455	24734422.27	34950814.1	0.00%
25500	10.6254441	24.77532	16.4	NE/SW	17ab	42	64	22	249	401	13662092.16	22002003.8	0.00%
25450	10.6565127	281.3101	42.64	E/W	17ab	13	18	5	573	608	81742108.03	86735081.5	0.00%
25400	10.6875812	325.0081	22.96	NW/SE	17ab	32	19	-13	562	472	43170016.51	36256668.7	16.05%
25350	10.7186498	0	29.52	N/S	17ab	29	19	-10	568	498	56096879.62	49183531.8	12.35%
25300	10.7497183	318.0128	22.96	NW/SE	17ab	32	18	-14	571	474	43861351.3	36410298.6	17.07%
25250	10.7807869	336.0373	32.8	NW/SE	17ab	24	31	7	483	532	53002333.44	58379381.8	0.00%
25200	10.8118554	347.471	32.8	N/S	17ab	26	31	5	482	517	52892597.76	56733346.6	0.00%
25150	10.842924	253.3006	29.52	E/W	17ab	18	27	9	512	575	50566201.34	56788214.4	0.00%
25100	10.8739925	279.4624	22.96	E/W	17ab	23	12	-11	617	540	47394840.19	41480087	12.50%
25050	10.9050611	45	22.96	NE/SW	17ab	32	27	-5	507	472	38945192.83	36256668.7	6.85%

Table I-1. Cherry Creek Shade-Related Data, TMDLs, Existing Solar Loading, and the Percent Increase in Shade Needed to Meet the TMDLs

Longitudinal Distance (m)	River Mile (RM)	Aspect	Wetted Width (ft)-GIS	General Direction	Ecoregion	Target Shade (%)	Existing Shade (%)	Shade Difference (%)	Daily Solar Flux with Existing Shade (watts/ft^2)	Daily Solar Flux with Potential Shade (watts/ft^2)	Existing Load (kcal/day)	Potential Load (kcal/day)	Percent Reduction Needed to Meet TMDL
25000	10.9361296	347.0053	19.68	N/S	17ab	39	43	4	400	428	26336563.2	28180122.6	0.00%
24950	10.9671982	116.5646	29.52	NW/SE	17ab	26	19	-7	564	516	55701831.17	50961249.8	8.64%
24900	10.9982667	56.31041	22.96	NE/SW	17ab	32	26	-6	517	475	39713342.59	36487113.6	8.11%
24850	11.0293353	28.30058	22.96	NE/SW	17ab	32	22	-10	546	476	41940976.9	36563928.6	12.82%
24800	11.0604038	342.8971	26.24	N/S	17ab	32	33	1	468	475	41085038.59	41699558.4	0.00%
24750	11.0914724	23.19875	19.68	NE/SW	17ab	36	58	22	293	446	19291532.54	29365268	0.00%
24700	11.1225409	3.814102	16.4	N/S	17ab	45	65	20	246	387	13497488.64	21233854.1	0.00%
24650	11.1536095	55.0084	26.24	NE/SW	17ab	29	45	16	384	496	33710800.9	43543117.8	0.00%
24600	11.184678	15.94522	19.68	N/S	17ab	39	58	19	296	430	19489056.77	28311805.4	0.00%
24550	11.2157466	87.74298	19.68	E/W	17ab	27	41	14	408	505	26863294.46	33249911	0.00%
24500	11.2468151	296.0721	16.4	NW/SE	17ab	42	29	-13	497	406	27269316.48	22276343	18.31%
24450	11.2778837	341.5652	16.4	N/S	17ab	45	50	5	351	386	19258611.84	21178986.2	0.00%
24400	11.3089522	12.99427	16.4	N/S	17ab	45	30	-15	492	386	26994977.28	21178986.2	21.43%
24350	11.3400208	0	13.12	N/S	17ab	51	61	10	270	339	11851453.44	14880158.2	0.00%
24300	11.3710893	29.0549	19.68	NE/SW	17g	46	45	-1	382	375	25151417.86	24690528	1.82%
24250	11.4021579	34.69505	22.96	NE/SW	17g	42	38	-4	435	407	33414514.56	31263695.2	6.45%
24200	11.4332264	45	22.96	NE/SW	17g	42	19	-23	565	404	43400461.44	31033250.3	28.40%
24150	11.464295	348.69	16.4	N/S	17g	49	30	-19	490	357	26885241.6	19587818.9	27.14%
24100	11.4953635	19.98279	13.12	N/S	17g	55	55	0	311	311	13651118.59	13651118.6	0.00%
24050	11.5264321	335.5558	16.4	NW/SE	17g	51	65	14	248	347	13607224.32	19039140.5	0.00%
24000	11.5575006	310.6012	16.4	NW/SE	17g	51	44	-7	392	343	21508193.28	18819669.1	12.50%
23950	11.5885692	293.1986	19.68	NW/SE	17g	46	80	34	137	369	9020272.896	24295479.6	0.00%

Table I-1. Cherry Creek Shade-Related Data, TMDLs, Existing Solar Loading, and the Percent Increase in Shade Needed to Meet the TMDLs

Longitudinal Distance (m)	River Mile (RM)	Aspect	Wetted Width (ft)-GIS	General Direction	Ecoregion	Target Shade (%)	Existing Shade (%)	Shade Difference (%)	Daily Solar Flux with Existing Shade (watts/ft^2)	Daily Solar Flux with Potential Shade (watts/ft^2)	Existing Load (kcal/day)	Potential Load (kcal/day)	Percent Reduction Needed to Meet TMDL
23900	11.6196377	256.7594	19.68	E/W	17g	46	16	-30	588	378	38714747.9	24888052.2	35.71%
23850	11.6507063	270	16.4	E/W	17g	52	16	-36	583	333	31987950.72	18270990.7	42.86%
23800	11.6817748	0	19.68	N/S	17g	44	25	-19	523	391	34435056.38	25743990.5	25.33%
23750	11.7128434	0	16.4	N/S	17g	49	31	-18	484	357	26556034.56	19587818.9	26.09%
23700	11.7439119	327.2649	16.4	NW/SE	17g	51	31	-20	482	342	26446298.88	18764801.3	28.99%
23650	11.7749805	281.8884	16.4	E/W	17g	52	20	-32	558	335	30616254.72	18380726.4	40.00%
23600	11.806049	303.6902	19.68	NW/SE	17g	46	20	-26	561	379	36937029.89	24953893.6	32.50%
23550	11.8371176	335.5563	13.12	NW/SE	17g	57	87	30	92	304	4038273.024	13343858.7	0.00%
23500	11.8681861	311.1857	13.12	NW/SE	17g	57	89	32	79	310	3467647.488	13607224.3	0.00%
23450	11.8992547	312.7094	13.12	NW/SE	17g	57	47	-10	373	303	16372563.46	13299964.4	18.87%
23400	11.9303232	296.5648	19.68	NW/SE	17g	46	18	-28	572	376	37661285.38	24756369.4	34.15%
23350	11.9613918	300.9636	22.96	NW/SE	17g	42	19	-23	566	405	43477276.42	31110065.3	28.40%
23300	11.9924603	21.03767	19.68	N/S	17g	44	30	-14	485	388	31933082.88	25546466.3	20.00%
23250	12.0235289	315	26.24	NW/SE	17g	39	26	-13	519	428	45562254.34	37573496.8	17.57%
23200	12.0545974	17.10286	22.96	N/S	17g	41	22	-19	541	409	41556902.02	31417325.2	24.36%
23150	12.085666	353.2901	26.24	N/S	17g	38	24	-14	529	431	46440139.78	37836862.5	18.42%
23100	12.1167345	349.2156	16.4	N/S	17g	49	32	-17	471	353	25842752.64	19368347.5	25.00%
23050	12.1478031	330.6421	19.68	NW/SE	17g	46	29	-17	495	376	32591496.96	24756369.4	23.94%
23000	12.1788716	297.7584	22.96	NW/SE	17g	42	21	-21	554	407	42555496.7	31263695.2	26.58%
22950	12.2099402	70.55985	26.24	E/W	17g	36	28	-8	504	448	44245426.18	39329267.7	11.11%
22900	12.2410087	0	22.96	N/S	17g	41	52	11	337	414	25886646.91	31801400.1	0.00%
22850	12.2720773	10.0081	16.4	N/S	17g	49	55	6	315	357	17283369.6	19587818.9	0.00%

Table I-1. Cherry Creek Shade-Related Data, TMDLs, Existing Solar Loading, and the Percent Increase in Shade Needed to Meet the TMDLs

Longitudinal Distance (m)	River Mile (RM)	Aspect	Wetted Width (ft)-GIS	General Direction	Ecoregion	Target Shade (%)	Existing Shade (%)	Shade Difference (%)	Daily Solar Flux with Existing Shade (watts/ft^2)	Daily Solar Flux with Potential Shade (watts/ft^2)	Existing Load (kcal/day)	Potential Load (kcal/day)	Percent Reduction Needed to Meet TMDL
22800	12.3031458	20.8543	13.12	N/S	17g	55	59	4	289	317	12685444.61	13914484.2	0.00%
22750	12.3342144	0	16.4	N/S	17g	49	60	11	276	352	15143523.84	19313479.7	0.00%
22700	12.3652829	0	19.68	N/S	17g	44	56	12	306	390	20147470.85	25678149.1	0.00%
22650	12.3963515	19.44015	22.96	N/S	17g	41	45	4	386	414	29650580.74	31801400.1	0.00%
22600	12.42742	9.865636	22.96	N/S	17g	41	52	11	337	414	25886646.91	31801400.1	0.00%
22550	12.4584886	345.0685	26.24	N/S	17g	38	48	10	360	429	31603875.84	37661285.4	0.00%
22500	12.4895571	32.00528	29.52	NE/SW	17g	36	36	0	444	444	43850377.73	43850377.7	0.00%
22450	12.5206257	72.55282	32.8	E/W	17g	30	21	-9	552	489	60574095.36	53660747.5	11.39%
22400	12.5516942	87.51042	29.52	E/W	17g	33	22	-11	541	465	53430302.59	45924382.1	14.10%
22350	12.5827628	73.49566	26.24	E/W	17g	36	31	-5	479	445	42050712.58	39065902.1	7.25%
22300	12.6138313	33.69	29.52	NE/SW	17g	36	54	18	318	442	31406351.62	43652853.5	0.00%
22250	12.6448999	14.74372	16.4	N/S	17g	49	61	12	270	354	14814316.8	19423215.4	0.00%
22200	12.6759684	31.75918	22.96	NE/SW	17g	42	58	16	296	409	22737232.9	31417325.2	0.00%
22150	12.707037	28.61048	26.24	NE/SW	17g	39	45	6	385	427	33798589.44	37485708.3	0.00%
22100	12.7381055	81.02759	22.96	E/W	17g	41	38	-3	435	413	33414514.56	31724585.1	4.84%
22050	12.7691741	79.28678	19.68	E/W	17g	46	41	-5	411	376	27060818.69	24756369.4	8.47%
22000	12.8002426	48.36649	19.68	NE/SW	17g	46	48	2	363	377	23900431.1	24822210.8	0.00%
21950	12.8313112	31.72773	19.68	NE/SW	17g	46	47	1	367	374	24163796.74	24624686.6	0.00%
21900	12.8623797	25.55985	16.4	NE/SW	17g	51	52	1	335	342	18380726.4	18764801.3	0.00%
21850	12.8934483	46.39734	16.4	NE/SW	17g	51	52	1	332	339	18216122.88	18600197.8	0.00%
21800	12.9245168	57.26478	22.96	NE/SW	17g	42	44	2	392	406	30111470.59	31186880.3	0.00%
21750	12.9555854	64.79889	29.52	NE/SW	17g	36	33	-3	466	445	46023144.19	43949139.8	4.48%

Table I-1. Cherry Creek Shade-Related Data, TMDLs, Existing Solar Loading, and the Percent Increase in Shade Needed to Meet the TMDLs

Longitudinal Distance (m)	River Mile (RM)	Aspect	Wetted Width (ft)-GIS	General Direction	Ecoregion	Target Shade (%)	Existing Shade (%)	Shade Difference (%)	Daily Solar Flux with Existing Shade (watts/ft^2)	Daily Solar Flux with Potential Shade (watts/ft^2)	Existing Load (kcal/day)	Potential Load (kcal/day)	Percent Reduction Needed to Meet TMDL
21700	12.9866539	59.62085	22.96	NE/SW	17g	42	45	3	383	404	29420135.81	31033250.3	0.00%
21650	13.0177225	60.52408	32.8	NE/SW	17g	33	37	4	441	469	48393434.88	51466033.9	0.00%
21600	13.048791	47.86258	32.8	NE/SW	17g	33	39	6	423	465	46418192.64	51027091.2	0.00%
21550	13.0798596	43.36341	26.24	NE/SW	17g	39	40	1	420	427	36871188.48	37485708.3	0.00%
21500	13.1109281	51.84283	32.8	NE/SW	17g	33	35	2	454	468	49819998.72	51356298.2	0.00%
21450	13.1419967	59.53441	29.52	NE/SW	17g	36	50	14	347	445	34270452.86	43949139.8	0.00%
21400	13.1730652	47.92006	26.24	NE/SW	17g	39	51	12	341	424	29935893.5	37222342.7	0.00%
21350	13.2041338	10.30495	26.24	N/S	17g	38	52	14	336	434	29496950.78	38100228.1	0.00%
21300	13.2352023	348.6899	26.24	N/S	17g	38	51	13	341	432	29935893.5	37924651	0.00%
21250	13.2662709	57.99472	22.96	NE/SW	17g	42	47	5	368	403	28267911.17	30956435.3	0.00%
21200	13.2973394	296.5648	19.68	NW/SE	17g	46	42	-4	405	377	26665770.24	24822210.8	6.90%
21150	13.328408	5.440388	29.52	N/S	17g	35	18	-17	569	451	56195641.73	44541712.5	20.73%
21100	13.3594765	0	22.96	N/S	17g	41	23	-18	540	414	41480087.04	31801400.1	23.38%
21050	13.3905451	9.462448	22.96	N/S	17g	41	37	-4	438	410	33644959.49	31494140.2	6.35%
21000	13.4216136	0	22.96	N/S	17g	41	38	-3	429	408	32953624.7	31340510.2	4.84%
20950	13.4526822	134.9996	29.52	NW/SE	17g	36	44	8	393	449	38813510.02	44344188.3	0.00%
20900	13.4837507	37.56852	29.52	NE/SW	17g	36	42	6	403	444	39801131.14	43850377.7	0.00%
20850	13.5148193	12.26489	19.68	N/S	17ab	39	58	19	292	424	19225691.14	27916757	0.00%
20800	13.5458878	341.5648	26.24	N/S	17ab	32	49	17	353	470	30989356.03	41260615.7	0.00%
20750	13.5769564	347.4714	29.52	N/S	17ab	29	48	19	363	496	35850646.66	48986007.6	0.00%
20700	13.6080249	324.4625	26.24	NW/SE	17ab	29	29	0	497	497	43630906.37	43630906.4	0.00%
20650	13.6390935	309.8055	22.96	NW/SE	17ab	32	26	-6	514	472	39482897.66	36256668.7	8.11%

Table I-1. Cherry Creek Shade-Related Data, TMDLs, Existing Solar Loading, and the Percent Increase in Shade Needed to Meet the TMDLs

Longitudinal Distance (m)	River Mile (RM)	Aspect	Wetted Width (ft)-GIS	General Direction	Ecoregion	Target Shade (%)	Existing Shade (%)	Shade Difference (%)	Daily Solar Flux with Existing Shade (watts/ft^2)	Daily Solar Flux with Potential Shade (watts/ft^2)	Existing Load (kcal/day)	Potential Load (kcal/day)	Percent Reduction Needed to Meet TMDL
20600	13.670162	323.9727	26.24	NW/SE	17ab	29	28	-1	501	494	43982060.54	43367540.7	1.39%
20550	13.7012306	90	22.96	E/W	17ab	23	32	9	472	534	36256668.67	41019197.2	0.00%
20500	13.7322991	297.7584	22.96	NW/SE	17ab	32	23	-9	535	473	41096012.16	36333483.6	11.69%
20450	13.7633677	356.6335	19.68	N/S	17ab	39	25	-14	527	428	34698422.02	28180122.6	18.67%
20400	13.7944362	0	22.96	N/S	17ab	35	22	-13	545	454	41864161.92	34873999.1	16.67%
20350	13.8255048	25.20141	29.52	NE/SW	17ab	26	17	-9	579	516	57183262.85	50961249.8	10.84%
20300	13.8565733	0	29.52	N/S	17ab	29	18	-11	573	496	56590690.18	48986007.6	13.41%
20250	13.8876419	277.1251	29.52	E/W	17ab	18	14	-4	600	572	59257267.2	56491928.1	4.65%
20200	13.9187104	0	26.24	N/S	17ab	32	37	5	442	478	38802536.45	41962924	0.00%
20150	13.949779	17.52576	16.4	N/S	17ab	45	29	-16	498	386	27324184.32	21178986.2	22.54%
20100	13.9808475	19.65371	22.96	N/S	17ab	35	52	17	336	456	25809831.94	35027629.1	0.00%
20050	14.0119161	42.87865	22.96	NE/SW	17ab	32	52	20	332	470	25502572.03	36103038.7	0.00%
20000	14.0429846	250.0167	26.24	E/W	17ab	20	37	17	441	561	38714747.9	49249373.2	0.00%
19950	14.0740532	32.47145	16.4	NE/SW	17ab	42	48	6	364	406	19971893.76	22276343	0.00%
19900	14.1051217	300.964	26.24	NW/SE	17ab	29	43	14	396	493	34764263.42	43279752.2	0.00%
19850	14.1361903	17.10286	26.24	N/S	17ab	32	38	6	433	475	38012439.55	41699558.4	0.00%
19800	14.1672588	39.28951	26.24	NE/SW	17ab	29	27	-2	507	493	44508791.81	43279752.2	2.74%
19750	14.1983274	30.96367	36.08	NE/SW	17ab	22	24	2	530	544	63975901.44	65665830.9	0.00%
19700	14.2293959	14.93113	19.68	N/S	17ab	39	56	17	305	423	20081629.44	27850915.6	0.00%
19650	14.2604645	336.8014	26.24	NW/SE	17ab	29	32	3	477	498	41875135.49	43718694.9	0.00%
19600	14.291533	355.6013	16.4	N/S	17ab	45	44	-1	390	383	21398457.6	21014382.7	1.79%
19550	14.3226016	49.39871	22.96	NE/SW	17ab	32	42	10	407	477	31263695.23	36640743.6	0.00%

Table I-1. Cherry Creek Shade-Related Data, TMDLs, Existing Solar Loading, and the Percent Increase in Shade Needed to Meet the TMDLs

Longitudinal Distance (m)	River Mile (RM)	Aspect	Wetted Width (ft)-GIS	General Direction	Ecoregion	Target Shade (%)	Existing Shade (%)	Shade Difference (%)	Daily Solar Flux with Existing Shade (watts/ft^2)	Daily Solar Flux with Potential Shade (watts/ft^2)	Existing Load (kcal/day)	Potential Load (kcal/day)	Percent Reduction Needed to Meet TMDL
19500	14.3536701	90	22.96	E/W	17ab	23	34	11	460	536	35334888.96	41172827.1	0.00%
19450	14.3847387	52.43148	19.68	NE/SW	17ab	36	52	16	338	451	22254395.9	29694475	0.00%
19400	14.4158072	203.1989	16.4	NE/SW	17ab	42	47	5	367	401	20136497.28	22002003.8	0.00%
19350	14.4468758	39.80557	19.68	NE/SW	17ab	36	34	-2	460	446	30287047.68	29365268	3.03%
19300	14.4779443	83.65973	29.52	E/W	17ab	18	14	-4	598	570	59059742.98	56294403.8	4.65%
19250	14.5090129	320.1945	26.24	NW/SE	17ab	29	36	7	447	496	39241479.17	43543117.8	0.00%
19200	14.5400814	0	22.96	N/S	17ab	35	54	19	323	457	24811237.25	35104444	0.00%
19150	14.57115	26.5653	26.24	NE/SW	17ab	29	33	4	470	498	41260615.68	43718694.9	0.00%
19100	14.6022185	174.8055	26.24	N/S	17ab	32	49	17	357	477	31340510.21	41875135.5	0.00%
19050	14.6332871	52.12511	26.24	NE/SW	17ab	29	44	15	391	496	34325320.7	43543117.8	0.00%
19000	14.6643556	57.52895	19.68	NE/SW	17ab	36	53	17	329	448	21661823.23	29496950.8	0.00%
18950	14.6954242	32.47105	26.24	NE/SW	17ab	29	33	4	470	498	41260615.68	43718694.9	0.00%
18900	14.7264927	0	22.96	N/S	17ab	35	38	3	429	450	32953624.7	34566739.2	0.00%
18850	14.7575613	28.81069	22.96	NE/SW	17ab	32	41	9	408	471	31340510.21	36179853.7	0.00%
18800	14.7886298	68.19838	22.96	E/W	17ab	23	40	17	421	540	32339104.9	41480087	0.00%
18750	14.8196984	68.19864	19.68	E/W	17ab	27	46	19	377	509	24822210.82	33513276.7	0.00%
18700	14.8507669	18.43516	16.4	N/S	17ab	45	56	11	308	385	16899294.72	21124118.4	0.00%
18650	14.8818355	0	13.12	N/S	17ab	51	63	12	256	339	11236933.63	14880158.2	0.00%
18600	14.912904	342.6459	13.12	N/S	17ab	51	61	10	271	340	11895347.71	14924052.5	0.00%
18550	14.9439726	356.8202	13.12	N/S	17ab	51	60	9	276	338	12114819.07	14836263.9	0.00%
18500	14.9750411	337.38	16.4	NW/SE	17ab	42	57	15	302	408	16570087.68	22386078.7	0.00%
18450	15.0061097	331.1136	19.68	NW/SE	17ab	36	55	19	315	448	20740043.52	29496950.8	0.00%

Table I-1. Cherry Creek Shade-Related Data, TMDLs, Existing Solar Loading, and the Percent Increase in Shade Needed to Meet the TMDLs

Longitudinal Distance (m)	River Mile (RM)	Aspect	Wetted Width (ft)-GIS	General Direction	Ecoregion	Target Shade (%)	Existing Shade (%)	Shade Difference (%)	Daily Solar Flux with Existing Shade (watts/ft^2)	Daily Solar Flux with Potential Shade (watts/ft^2)	Existing Load (kcal/day)	Potential Load (kcal/day)	Percent Reduction Needed to Meet TMDL
18400	15.0371782	328.3925	22.96	NW/SE	17ab	32	44	12	388	472	29804210.69	36256668.7	0.00%
18350	15.0682468	331.2603	22.96	NW/SE	17ab	32	46	14	377	475	28959245.95	36487113.6	0.00%
18300	15.0993153	327.3807	19.68	NW/SE	17ab	36	47	11	373	450	24558845.18	29628633.6	0.00%
18250	15.1303839	305.8378	29.52	NW/SE	17ab	26	34	8	457	513	45134285.18	50664963.5	0.00%
18200	15.1614524	316.8478	22.96	NW/SE	17ab	32	40	8	419	475	32185474.94	36487113.6	0.00%
18150	15.192521	308.6598	26.24	NW/SE	17ab	29	36	7	448	497	39329267.71	43630906.4	0.00%
18100	15.2235895	300.9638	26.24	NW/SE	17ab	29	33	4	470	498	41260615.68	43718694.9	0.00%
18050	15.2546581	332.1029	16.4	NW/SE	17ab	42	47	5	369	404	20246232.96	22166607.4	0.00%
18000	15.2857266	25.20097	16.4	NE/SW	17ab	42	65	23	242	401	13278017.28	22002003.8	0.00%
17950	15.3167952	28.81069	16.4	NE/SW	17ab	42	71	29	200	400	10973568	21947136	0.00%
17900	15.3478637	354.5599	16.4	N/S	17ab	45	66	21	234	379	12839074.56	20794911.4	0.00%
17850	15.3789323	15.9452	19.68	N/S	17ab	39	85	46	105	428	6913347.84	28180122.6	0.00%
17800	15.4100008	9.462154	16.4	N/S	17ab	45	87	42	93	395	5102709.12	21672796.8	0.00%
17750	15.4410694	320.7107	16.4	NW/SE	17ab	42	84	42	114	414	6254933.76	22715285.8	0.00%
17700	15.4721379	308.1572	22.96	NW/SE	17ab	32	80	48	141	478	10830911.62	36717558.5	0.00%
17650	15.5032065	309.094	16.4	NW/SE	17ab	42	88	46	86	414	4718634.24	22715285.8	0.00%
17600	15.534275	0	22.96	N/S	17ab	35	83	48	117	448	8987352.192	34413109.2	0.00%
17550	15.5653436	343.6104	26.24	N/S	17ab	32	80	48	140	475	12290396.16	41699558.4	0.00%
17500	15.5964121	291.8016	29.52	E/W	17ab	18	69	51	213	564	21036329.86	55701831.2	0.00%
17450	15.6274807	295.201	26.24	NW/SE	17ab	29	78	49	154	498	13519435.78	43718694.9	0.00%
17400	15.6585492	307.5685	26.24	NW/SE	17ab	29	78	49	153	494	13431647.23	43367540.7	0.00%
17350	15.6896178	313.2643	19.68	NW/SE	17ab	36	84	48	114	457	7505920.512	30089523.5	0.00%

Table I-1. Cherry Creek Shade-Related Data, TMDLs, Existing Solar Loading, and the Percent Increase in Shade Needed to Meet the TMDLs

Longitudinal Distance (m)	River Mile (RM)	Aspect	Wetted Width (ft)-GIS	General Direction	Ecoregion	Target Shade (%)	Existing Shade (%)	Shade Difference (%)	Daily Solar Flux with Existing Shade (watts/ft^2)	Daily Solar Flux with Potential Shade (watts/ft^2)	Existing Load (kcal/day)	Potential Load (kcal/day)	Percent Reduction Needed to Meet TMDL
17300	15.7206863	6.009074	19.68	N/S	17ab	39	83	44	122	438	8032651.776	28838536.7	0.00%
17250	15.7517549	44.99979	19.68	NE/SW	17ab	36	84	48	114	456	7505920.512	30023682	0.00%
17200	15.7828234	23.19855	19.68	NE/SW	17ab	36	86	50	101	460	6649982.208	30287047.7	0.00%
17150	15.813892	331.9277	22.96	NW/SE	17ab	32	83	51	119	476	9140982.144	36563928.6	0.00%
17100	15.8449605	318.8141	19.68	NW/SE	17ab	36	83	47	121	456	7966810.368	30023682	0.00%
17050	15.8760291	306.8698	16.4	NW/SE	17ab	42	85	43	101	392	5541651.84	21508193.3	0.00%
17000	15.9070976	280.6194	19.68	E/W	17ab	27	83	56	121	519	7966810.368	34171690.8	0.00%
16950	15.9381662	266.9872	16.4	E/W	17ab	31	92	61	55	474	3017731.2	26007356.2	0.00%
16900	15.9692347	293.9627	22.96	NW/SE	17ab	32	75	43	175	477	13442620.8	36640743.6	0.00%
16850	16.0003033	243.4349	13.12	NE/SW	17ab	48	87	39	88	351	3862695.936	15406889.5	0.00%
16800	16.0313718	241.699	29.52	NE/SW	17ab	26	70	44	208	514	20542519.3	50763725.6	0.00%
16750	16.0624404	290.5562	26.24	E/W	17ab	20	71	51	200	552	17557708.8	48459276.3	0.00%
16700	16.0935089	317.4896	16.4	NW/SE	17ab	42	80	38	136	395	7462026.24	21672796.8	0.00%
16650	16.1245775	316.6368	19.68	NW/SE	17ab	36	77	41	162	451	10666308.1	29694475	0.00%
16600	16.155646	271.975	19.68	E/W	17ab	27	85	58	106	516	6979189.248	33974166.5	0.00%
16550	16.1867146	241.3893	22.96	NE/SW	17ab	32	78	46	155	478	11906321.28	36717558.5	0.00%
16500	16.2177831	273.0128	29.52	E/W	17ab	18	75	57	176	577	17382131.71	56985738.6	0.00%
16450	16.2488517	266.9875	26.24	E/W	17ab	20	71	51	200	550	17557708.8	48283699.2	0.00%
16400	16.2799202	268.2643	32.8	E/W	17ab	17	59	42	285	577	31274668.8	63317487.4	0.00%
16350	16.3109888	272.8624	32.8	E/W	17ab	17	57	40	298	575	32701232.64	63098016	0.00%
16300	16.3420573	324.4624	42.64	NW/SE	17ab	19	48	29	360	560	51356298.24	79887575	0.00%
16250	16.3731259	25.01705	32.8	NE/SW	17ab	24	45	21	387	534	42467708.16	58598853.1	0.00%

Table I-1. Cherry Creek Shade-Related Data, TMDLs, Existing Solar Loading, and the Percent Increase in Shade Needed to Meet the TMDLs

Longitudinal Distance (m)	River Mile (RM)	Aspect	Wetted Width (ft)-GIS	General Direction	Ecoregion	Target Shade (%)	Existing Shade (%)	Shade Difference (%)	Daily Solar Flux with Existing Shade (watts/ft^2)	Daily Solar Flux with Potential Shade (watts/ft^2)	Existing Load (kcal/day)	Potential Load (kcal/day)	Percent Reduction Needed to Meet TMDL
16200	16.4041944	14.03637	36.08	N/S	17ab	24	54	30	319	528	38506250.11	63734482.9	0.00%
16150	16.435263	35.21728	39.36	NE/SW	17ab	20	54	34	320	556	42138501.12	73215645.7	0.00%
16100	16.4663315	4.617029	32.8	N/S	17ab	26	66	40	235	512	25787884.8	56184668.2	0.00%
16050	16.4974001	349.6951	29.52	N/S	17ab	29	69	40	215	492	21233854.08	48590959.1	0.00%
16000	16.5284686	325.0079	29.52	NW/SE	17ab	26	68	42	223	515	22023950.98	50862487.7	0.00%
15950	16.5595372	319.3985	22.96	NW/SE	17ab	32	78	46	154	476	11829506.3	36563928.6	0.00%
15900	16.5906057	320.7107	22.96	NW/SE	17ab	32	77	45	160	474	12290396.16	36410298.6	0.00%
15850	16.6216743	308.6597	22.96	NW/SE	17ab	32	77	45	163	483	12520841.09	37101633.4	0.00%
15800	16.6527428	279.8659	26.24	E/W	17ab	20	72	52	198	565	17382131.71	49600527.4	0.00%
15750	16.6838114	254.0547	22.96	E/W	17ab	23	77	54	158	528	12136766.21	40558307.3	0.00%
15700	16.7148799	258.2319	19.68	E/W	17ab	27	83	56	119	509	7835127.552	33513276.7	0.00%
15650	16.7459485	270	26.24	E/W	17ab	20	75	55	172	550	15099629.57	48283699.2	0.00%
15600	16.777017	294.2277	22.96	NW/SE	17ab	32	79	47	147	476	11291801.47	36563928.6	0.00%
15550	16.8080856	309.8055	32.8	NW/SE	17ab	24	70	46	208	527	22825021.44	57830703.4	0.00%
15500	16.8391541	295.71	26.24	NW/SE	17ab	29	72	43	192	488	16855400.45	42840809.5	0.00%
15450	16.8702227	289.0934	19.68	E/W	17ab	27	79	52	145	504	9547004.16	33184069.6	0.00%
15400	16.9012912	294.7749	26.24	NW/SE	17ab	29	67	38	229	493	20103576.58	43279752.2	0.00%
15350	16.9323598	277.5947	36.08	E/W	17ab	15	66	51	234	585	28245964.03	70614910.1	0.00%
15300	16.9634283	309.2893	29.52	NW/SE	17ab	26	66	40	239	520	23604144.77	51356298.2	0.00%
15250	16.9944969	352.8749	32.8	N/S	17ab	26	58	32	291	513	31933082.88	56294403.8	0.00%
15200	17.0255654	320.7107	26.24	NW/SE	17ab	29	66	37	235	491	20630307.84	43104175.1	0.00%
15150	17.056634	305.5376	32.8	NW/SE	17ab	24	56	32	304	525	33359646.72	57611232	0.00%

Table I-1. Cherry Creek Shade-Related Data, TMDLs, Existing Solar Loading, and the Percent Increase in Shade Needed to Meet the TMDLs

Longitudinal Distance (m)	River Mile (RM)	Aspect	Wetted Width (ft)-GIS	General Direction	Ecoregion	Target Shade (%)	Existing Shade (%)	Shade Difference (%)	Daily Solar Flux with Existing Shade (watts/ft^2)	Daily Solar Flux with Potential Shade (watts/ft^2)	Existing Load (kcal/day)	Potential Load (kcal/day)	Percent Reduction Needed to Meet TMDL
15100	17.0877025	340.346	39.36	N/S	17ab	22	61	39	275	550	36212774.4	72425548.8	0.00%
15050	17.1187711	293.1986	29.52	NW/SE	17ab	26	68	42	226	522	22320237.31	51553822.5	0.00%
15000	17.1498396	231.8428	29.52	NE/SW	17ab	26	61	35	269	511	26567008.13	50467439.2	0.00%
14950	17.1809082	231.009	49.2	NE/SW	17ab	17	44	27	389	577	64030769.28	94976231	0.00%
14900	17.2119767	277.1251	16.4	E/W	17ab	31	86	55	101	497	5541651.84	27269316.5	0.00%
14850	17.2430453	257.471	19.68	E/W	17ab	27	77	50	157	499	10337101.06	32854862.6	0.00%
14800	17.2741138	294.4439	32.8	NW/SE	17ab	24	61	37	269	525	29518897.92	57611232	0.00%
14750	17.3051824	327.0948	22.96	NW/SE	17ab	32	51	19	342	474	26270721.79	36410298.6	0.00%
14700	17.3362509	352.5771	36.08	N/S	17ab	24	42	18	406	532	49007954.69	64217319.9	0.00%
14650	17.3673195	302.0055	32.8	NW/SE	17ab	24	41	17	409	526	44881893.12	57720967.7	0.00%
14600	17.398388	254.3576	26.24	E/W	17ab	20	46	26	377	559	33096281.09	49073796.1	0.00%
14550	17.4294566	274.3987	26.24	E/W	17ab	20	48	28	360	554	31603875.84	48634853.4	0.00%
14500	17.4605251	293.1986	26.24	NW/SE	17ab	29	50	21	348	494	30550413.31	43367540.7	0.00%
14450	17.4915937	288.4349	26.24	E/W	17ab	20	49	29	359	563	31516087.3	49424950.3	0.00%
14400	17.5226622	300.3792	26.24	NW/SE	17ab	29	53	24	330	499	28970219.52	43806483.5	0.00%
14350	17.5537308	323.1299	29.52	NW/SE	17ab	26	47	21	372	519	36739505.66	51257536.1	0.00%
14300	17.5847993	267.5107	22.96	E/W	17ab	23	50	27	350	539	26885241.6	41403272.1	0.00%
14250	17.6158679	222.2737	26.24	NE/SW	17ab	29	51	22	343	497	30111470.59	43630906.4	0.00%
14200	17.6469364	205.3462	29.52	NE/SW	17ab	26	49	23	353	513	34863025.54	50664963.5	0.00%
14150	17.678005	217.8753	29.52	NE/SW	17ab	26	46	20	377	516	37233316.22	50961249.8	0.00%
14100	17.7090735	217.8749	36.08	NE/SW	17ab	22	43	21	397	543	47921571.46	65545121.7	0.00%
14050	17.7401421	329.0362	22.96	NW/SE	17ab	32	53	21	328	475	25195312.13	36487113.6	0.00%

Table I-1. Cherry Creek Shade-Related Data, TMDLs, Existing Solar Loading, and the Percent Increase in Shade Needed to Meet the TMDLs

Longitudinal Distance (m)	River Mile (RM)	Aspect	Wetted Width (ft)-GIS	General Direction	Ecoregion	Target Shade (%)	Existing Shade (%)	Shade Difference (%)	Daily Solar Flux with Existing Shade (watts/ft^2)	Daily Solar Flux with Potential Shade (watts/ft^2)	Existing Load (kcal/day)	Potential Load (kcal/day)	Percent Reduction Needed to Meet TMDL
14000	17.7712106	243.4346	39.36	NE/SW	17ab	20	32	12	477	561	62812703.23	73874059.8	0.00%
13950	17.8022792	237.2649	22.96	NE/SW	17ab	32	47	15	370	475	28421541.12	36487113.6	0.00%
13900	17.8333477	240.2553	26.24	NE/SW	17ab	29	43	14	395	492	34676474.88	43191963.6	0.00%
13850	17.8644163	249.7749	29.52	E/W	17ab	18	34	16	459	570	45331809.41	56294403.8	0.00%
13800	17.8954848	287.3539	36.08	E/W	17ab	15	27	12	511	595	61682425.73	71822002.6	0.00%
13750	17.9265534	296.5648	36.08	NW/SE	17ab	22	31	9	480	542	57940439.04	65424412.4	0.00%
13700	17.9576219	267.2737	32.8	E/W	17ab	17	27	10	508	578	55745725.44	63427223	0.00%
13650	17.9886905	201.8016	36.08	N/S	17ab	24	39	15	428	533	51663558.14	64338029.2	0.00%
13600	18.019759	318.3661	45.92	NW/SE	17ab	18	32	14	474	572	72820597.25	87876332.5	0.00%
13550	18.0508276	0	36.08	N/S	17ab	24	41	17	410	528	49490791.68	63734482.9	0.00%
13500	18.0818961	245.2247	39.36	NE/SW	17ab	20	28	8	504	560	66368139.26	73742377	0.00%
13450	18.1129647	239.7437	36.08	NE/SW	17ab	22	31	9	480	543	57940439.04	65545121.7	0.00%
13400	18.1440332	270	36.08	E/W	17ab	15	11	-4	618	590	74598315.26	71218456.3	4.49%
13350	18.1751018	221.6339	36.08	NE/SW	17ab	22	22	0	543	543	65545121.66	65545121.7	0.00%
13300	18.2061703	298.3006	45.92	NW/SE	17ab	18	14	-4	599	571	92024341.25	87722702.6	4.65%
13250	18.2372389	3.576359	36.08	N/S	17ab	24	27	3	507	528	61199588.74	63734482.9	0.00%
13200	18.2683074	291.0377	32.8	E/W	17ab	17	15	-2	593	579	65073258.24	63536958.7	2.35%
13150	18.299376	302.7351	39.36	NW/SE	17ab	20	16	-4	585	558	77034447.36	73479011.3	4.76%
13100	18.3304445	310.2366	39.36	NW/SE	17ab	20	19	-1	565	558	74400791.04	73479011.3	1.23%
13050	18.3615131	347.9055	39.36	N/S	17ab	22	31	9	482	544	63471117.31	71635451.9	0.00%
13000	18.3925816	340.0167	39.36	N/S	17ab	22	31	9	479	541	63076068.86	71240403.5	0.00%
12950	18.4236502	6.709519	32.8	N/S	17ab	26	39	13	429	520	47076606.72	57062553.6	0.00%

Table I-1. Cherry Creek Shade-Related Data, TMDLs, Existing Solar Loading, and the Percent Increase in Shade Needed to Meet the TMDLs

Longitudinal Distance (m)	River Mile (RM)	Aspect	Wetted Width (ft)-GIS	General Direction	Ecoregion	Target Shade (%)	Existing Shade (%)	Shade Difference (%)	Daily Solar Flux with Existing Shade (watts/ft^2)	Daily Solar Flux with Potential Shade (watts/ft^2)	Existing Load (kcal/day)	Potential Load (kcal/day)	Percent Reduction Needed to Meet TMDL
12900	18.4547187	293.1988	36.08	NW/SE	17ab	22	23	1	540	547	65182993.92	66027958.7	0.00%
12850	18.4857873	326.3097	22.96	NW/SE	17ab	32	49	17	358	477	27499761.41	36640743.6	0.00%
12800	18.5168558	315	29.52	NW/SE	17ab	26	40	14	419	517	41381324.93	51060011.9	0.00%
12750	18.5479244	292.6196	36.08	NW/SE	17ab	22	35	13	457	548	55164126.34	66148667.9	0.00%
12700	18.5789929	338.1984	36.08	N/S	17ab	24	29	5	496	531	59871787.01	64096610.7	0.00%
12650	18.6100615	344.4757	29.52	N/S	17ab	29	28	-1	502	495	49578580.22	48887245.4	1.39%
12600	18.64113	346.7597	32.8	N/S	17ab	26	31	5	485	520	53221804.8	57062553.6	0.00%
12550	18.6721986	323.7462	39.36	NW/SE	17ab	20	21	1	549	556	72293865.98	73215645.7	0.00%
12500	18.7032671	300.9633	29.52	NW/SE	17ab	26	20	-6	558	516	55109258.5	50961249.8	7.50%
12450	18.7343357	204.4442	36.08	NE/SW	17ab	22	26	4	517	545	62406681.22	65786540.2	0.00%
12400	18.7654042	295.0171	36.08	NW/SE	17ab	22	16	-6	588	546	70977037.82	65907249.4	7.14%
12350	18.7964728	337.6199	36.08	N/S	17ab	24	24	0	528	528	63734482.94	63734482.9	0.00%
12300	18.8275413	298.301	22.96	NW/SE	17ab	32	22	-10	545	475	41864161.92	36487113.6	12.82%
12250	18.8586099	0	36.08	N/S	17ab	24	27	3	507	528	61199588.74	63734482.9	0.00%
12200	18.8896784	318.8141	32.8	NW/SE	17ab	24	7	-17	651	532	71437927.68	58379381.8	18.28%
12150	18.920747	324.4619	32.8	NW/SE	17ab	24	25	1	523	530	57391760.64	58159910.4	0.00%
12100	18.9518155	48.3665	32.8	NE/SW	17ab	24	29	5	495	529	54319161.6	58050174.7	0.00%
12050	18.9828841	16.38964	45.92	N/S	17ab	20	23	3	535	556	82192024.32	85418253.3	0.00%
12000	19.0139526	270	32.8	E/W	17ab	17	12	-5	613	578	67267971.84	63427223	5.68%
11950	19.0450212	289.9833	32.8	E/W	17ab	17	10	-7	626	577	68694535.68	63317487.4	7.78%
11900	19.0760897	34.9919	26.24	NE/SW	17ab	29	17	-12	581	497	51005144.06	43630906.4	14.46%
11850	19.1071583	302.471	39.36	NW/SE	17ab	20	10	-10	630	560	82960174.08	73742377	11.11%

Table I-1. Cherry Creek Shade-Related Data, TMDLs, Existing Solar Loading, and the Percent Increase in Shade Needed to Meet the TMDLs

Longitudinal Distance (m)	River Mile (RM)	Aspect	Wetted Width (ft)-GIS	General Direction	Ecoregion	Target Shade (%)	Existing Shade (%)	Shade Difference (%)	Daily Solar Flux with Existing Shade (watts/ft^2)	Daily Solar Flux with Potential Shade (watts/ft^2)	Existing Load (kcal/day)	Potential Load (kcal/day)	Percent Reduction Needed to Meet TMDL
11800	19.1382268	19.98329	29.52	N/S	17ab	29	29	0	493	493	48689721.22	48689721.2	0.00%
11750	19.1692954	263.991	36.08	E/W	17ab	15	25	10	524	594	63251645.95	71701293.3	0.00%
11700	19.2003639	260.5376	36.08	E/W	17ab	15	25	10	522	591	63010227.46	71339165.6	0.00%
11650	19.2314325	281.31	32.8	E/W	17ab	17	8	-9	644	581	70669777.92	63756430.1	9.78%
11600	19.262501	305.8378	52.48	NW/SE	17ab	16	14	-2	601	587	105521829.9	103063751	2.33%
11550	19.2935696	294.7753	26.24	NW/SE	17ab	29	20	-9	555	493	48722641.92	43279752.2	11.25%
11500	19.3246381	281.31	32.8	E/W	17ab	17	13	-4	605	577	66390086.4	63317487.4	4.60%
11450	19.3557067	116.5648	36.08	NW/SE	17ab	22	24	2	529	543	63855192.19	65545121.7	0.00%
11400	19.3867752	265.2363	32.8	E/W	17ab	17	13	-4	606	578	66499822.08	63427223	4.60%
11350	19.4178438	270	32.8	E/W	17ab	17	12	-5	611	576	67048500.48	63207751.7	5.68%
11300	19.4489123	281.3096	32.8	E/W	17ab	17	13	-4	606	578	66499822.08	63427223	4.60%
11250	19.4799809	309.8055	39.36	NW/SE	17ab	20	18	-2	573	559	75454253.57	73610694.1	2.44%
11200	19.5110494	252.8976	32.8	E/W	17ab	17	14	-3	599	578	65731672.32	63427223	3.49%
11150	19.542118	27.67013	39.36	NE/SW	17ab	20	26	6	515	557	67816650.24	73347328.5	0.00%
11100	19.5731865	38.66011	26.24	NE/SW	17ab	29	37	8	441	497	38714747.9	43630906.4	0.00%
11050	19.6042551	355.6013	32.8	N/S	17ab	26	30	4	488	516	53551011.84	56623610.9	0.00%
11000	19.6353236	327.5292	39.36	NW/SE	17ab	20	22	2	542	556	71372086.27	73215645.7	0.00%
10950	19.6663922	331.39	39.36	NW/SE	17ab	20	23	3	538	559	70845355.01	73610694.1	0.00%
10900	19.6974607	96.34027	39.36	E/W	17ab	14	19	5	562	596	74005742.59	78482958.3	0.00%
10850	19.7285293	250.0167	39.36	E/W	17ab	14	13	-1	605	598	79668103.68	78746324	1.15%
10800	19.7595978	333.4351	45.92	NW/SE	17ab	18	20	2	557	571	85571883.26	87722702.6	0.00%
10750	19.7906664	353.9912	39.36	N/S	17ab	22	25	3	523	544	68870112.77	71635451.9	0.00%

Table I-1. Cherry Creek Shade-Related Data, TMDLs, Existing Solar Loading, and the Percent Increase in Shade Needed to Meet the TMDLs

Longitudinal Distance (m)	River Mile (RM)	Aspect	Wetted Width (ft)-GIS	General Direction	Ecoregion	Target Shade (%)	Existing Shade (%)	Shade Difference (%)	Daily Solar Flux with Existing Shade (watts/ft^2)	Daily Solar Flux with Potential Shade (watts/ft^2)	Existing Load (kcal/day)	Potential Load (kcal/day)	Percent Reduction Needed to Meet TMDL
10700	19.8217349	345.9636	49.2	N/S	17ab	18	20	2	556	570	91519557.12	93824006.4	0.00%
10650	19.8528035	249.4437	32.8	E/W	17ab	17	15	-2	591	577	64853786.88	63317487.4	2.35%
10600	19.883872	12.09494	29.52	N/S	17ab	29	34	5	458	493	45233047.3	48689721.2	0.00%
10550	19.9149406	336.8011	36.08	NW/SE	17ab	22	24	2	527	541	63613773.7	65303703.2	0.00%
10500	19.9460091	24.44417	45.92	NE/SW	17ab	18	24	6	529	570	81270244.61	87569072.6	0.00%
10450	19.9770777	310.6013	42.64	NW/SE	17ab	19	17	-2	580	566	82740702.72	80743513.3	2.41%
10400	20.0081462	84.80552	36.08	E/W	17ab	15	22	7	544	593	65665830.91	71580584.1	0.00%
10350	20.0392148	108.4352	45.92	E/W	17ab	12	18	6	570	611	87569072.64	93867900.7	0.00%
10300	20.0702833	29.05408	49.2	NE/SW	17ab	17	10	-7	626	578	103041803.5	95140834.6	7.78%
10250	20.1013519	278.7462	39.36	E/W	17ab	14	9	-5	631	597	83091856.9	78614641.2	5.49%
10200	20.1324204	299.6576	29.52	NW/SE	17ab	26	12	-14	612	515	60442412.54	50862487.7	15.91%
10150	20.163489	288.4352	42.64	E/W	17ab	13	9	-4	633	605	90301491.07	86307112.3	4.40%
10100	20.1945575	285.9456	45.92	E/W	17ab	12	12	0	614	614	94328790.53	94328790.5	0.00%
10050	20.2256261	4.398742	45.92	N/S	17ab	20	27	7	512	561	78658535.42	86186403.1	0.00%
10000	20.2566946	292.6196	39.36	NW/SE	17ab	20	26	6	517	559	68080015.87	73610694.1	0.00%
9950	20.2877632	28.6107	32.8	NE/SW	17ab	24	27	3	512	533	56184668.16	58489117.4	0.00%
9900	20.3188317	300.9636	29.52	NW/SE	17ab	26	34	8	459	515	45331809.41	50862487.7	0.00%
9850	20.3499003	325.0077	29.52	NW/SE	17ab	26	32	6	475	517	46912003.2	51060011.9	0.00%
9800	20.3809688	291.0377	29.52	E/W	17ab	18	28	10	501	571	49479818.11	56393166	0.00%
9750	20.4120374	273.3665	39.36	E/W	17ab	14	20	6	557	599	73347328.51	78878006.8	0.00%
9700	20.4431059	246.8011	36.08	NE/SW	17ab	22	25	3	524	545	63251645.95	65786540.2	0.00%
9650	20.4741745	201.8011	49.2	N/S	17ab	18	13	-5	604	569	99420526.08	93659402.9	5.75%

Table I-1. Cherry Creek Shade-Related Data, TMDLs, Existing Solar Loading, and the Percent Increase in Shade Needed to Meet the TMDLs

Longitudinal Distance (m)	River Mile (RM)	Aspect	Wetted Width (ft)-GIS	General Direction	Ecoregion	Target Shade (%)	Existing Shade (%)	Shade Difference (%)	Daily Solar Flux with Existing Shade (watts/ft^2)	Daily Solar Flux with Potential Shade (watts/ft^2)	Existing Load (kcal/day)	Potential Load (kcal/day)	Percent Reduction Needed to Meet TMDL
9600	20.505243	294.4437	26.24	NW/SE	17ab	29	13	-16	608	496	53375434.75	43543117.8	18.39%
9550	20.5363116	334.9829	36.08	NW/SE	17ab	22	14	-8	602	546	72666967.3	65907249.4	9.30%
9500	20.5673801	270	29.52	E/W	17ab	18	9	-9	631	569	62318892.67	56195641.7	9.89%
9450	20.5984487	185.656	36.08	N/S	17ab	24	15	-9	592	529	71459874.82	63855192.2	10.59%
9400	20.6295172	247.0421	36.08	NE/SW	17ab	22	10	-12	629	545	75926116.99	65786540.2	13.33%
9350	20.6605858	190.3049	36.08	N/S	17ab	24	14	-10	599	529	72304839.55	63855192.2	11.63%
9300	20.6916543	293.1986	39.36	NW/SE	17ab	20	8	-12	640	557	84277002.24	73347328.5	13.04%
9250	20.7227229	206.5648	36.08	NE/SW	17ab	22	14	-8	601	545	72546258.05	65786540.2	9.30%
9200	20.7537914	214.9919	42.64	NE/SW	17ab	19	11	-8	622	567	88732270.85	80886169.7	8.99%
9150	20.78486	351.2542	36.08	N/S	17ab	24	14	-10	599	529	72304839.55	63855192.2	11.63%
9100	20.8159285	270	26.24	E/W	17ab	20	10	-10	629	559	55218994.18	49073796.1	11.11%
9050	20.8469971	8.745767	36.08	N/S	17ab	24	14	-10	601	531	72546258.05	64096610.7	11.63%
9000	20.8780656	258.6905	36.08	E/W	17ab	15	8	-7	641	592	77374627.97	71459874.8	7.61%
8950	20.9091342	260.5381	29.52	E/W	17ab	18	10	-8	629	573	62121368.45	56590690.2	8.89%
8900	20.9402027	50.19453	29.52	NE/SW	17ab	26	14	-12	602	518	59454791.42	51158774	13.95%
8850	20.9712713	349.0895	32.8	N/S	17ab	26	16	-10	589	519	64634315.52	56952817.9	11.90%
8800	21.0023398	318.0128	42.64	NW/SE	17ab	19	10	-9	626	564	89302896.38	80458200.6	10.00%
8750	21.0334084	285.9448	39.36	E/W	17ab	14	8	-6	643	601	84672050.69	79141372.4	6.52%
8700	21.0644769	135	32.8	NW/SE	17ab	24	14	-10	603	533	66170615.04	58489117.4	11.63%
8650	21.0955455	194.0364	36.08	N/S	17ab	24	14	-10	600	530	72425548.8	63975901.4	11.63%
8600	21.126614	270	32.8	E/W	17ab	17	9	-8	637	581	69901628.16	63756430.1	8.79%
8550	21.1576826	167.471	32.8	N/S	17ab	26	16	-10	583	514	63975901.44	56404139.5	11.90%

Table I-1. Cherry Creek Shade-Related Data, TMDLs, Existing Solar Loading, and the Percent Increase in Shade Needed to Meet the TMDLs

Longitudinal Distance (m)	River Mile (RM)	Aspect	Wetted Width (ft)-GIS	General Direction	Ecoregion	Target Shade (%)	Existing Shade (%)	Shade Difference (%)	Daily Solar Flux with Existing Shade (watts/ft^2)	Daily Solar Flux with Potential Shade (watts/ft^2)	Existing Load (kcal/day)	Potential Load (kcal/day)	Percent Reduction Needed to Meet TMDL
8500	21.1887511	243.4347	29.52	NE/SW	17ab	26	12	-14	614	516	60639936.77	50961249.8	15.91%
8450	21.2198197	300.4424	32.8	NW/SE	17ab	13	6	-7	655	606	136566053.8	126349662	7.45%
8400	21.2508882	26.5653	32.8	NE/SW	17ab	18	11	-7	624	575	95865090.05	88337222.4	7.87%
8350	21.2819568	11.31005	39.36	N/S	17ab	22	14	-8	603	546	79404738.05	71898817.5	9.30%
8300	21.3130253	50.19453	32.8	NE/SW	17ab	24	13	-11	608	531	66719293.44	58269646.1	12.64%
8250	21.3440939	248.4487	32.8	E/W	17ab	17	10	-7	631	582	69243214.08	63866165.8	7.78%
8200	21.3751624	26.5653	29.52	NE/SW	17ab	26	16	-10	588	518	58072121.86	51158774	11.90%
8150	21.406231	277.1251	29.52	E/W	17ab	18	10	-8	629	573	62121368.45	56590690.2	8.89%
8100	21.4372995	199.9833	32.8	N/S	17ab	26	15	-11	594	517	65182993.92	56733346.6	12.94%
8050	21.4683681	229.3988	32.8	NE/SW	17ab	24	12	-12	611	528	67048500.48	57940439	13.64%
8000	21.4994366	311.9869	32.8	NW/SE	17ab	24	13	-11	608	531	66719293.44	58269646.1	12.64%
7950	21.5305052	11.31005	29.52	N/S	17ab	29	17	-12	579	495	57183262.85	48887245.4	14.46%
7900	21.5615737	246.3705	32.8	NE/SW	17ab	24	10	-14	627	530	68804271.36	58159910.4	15.56%
7850	21.5926423	274.7637	29.52	E/W	17ab	18	10	-8	630	574	62220130.56	56689452.3	8.89%
7800	21.6237108	52.43118	36.08	NE/SW	17ab	22	11	-11	618	541	74598315.26	65303703.2	12.36%
7750	21.6547794	90	29.52	E/W	17ab	18	10	-8	630	574	62220130.56	56689452.3	8.89%
7700	21.6858479	33.68997	42.64	NE/SW	17ab	19	11	-8	618	563	88161645.31	80315544.2	8.99%
7650	21.7169165	296.5654	32.8	NW/SE	17ab	24	10	-14	624	527	68475064.32	57830703.4	15.56%
7600	21.747985	261.8703	52.48	E/W	17ab	11	6	-5	659	624	115705301	109560103	5.32%
7550	21.7790536	286.6994	32.8	E/W	17ab	17	9	-8	634	579	69572421.12	63536958.7	8.79%
7500	21.8101221	175.9144	39.36	N/S	17ab	22	13	-9	605	543	79668103.68	71503769.1	10.34%
7450	21.8411907	0	52.48	N/S	17ab	17	10	-7	627	578	110086834.2	101483557	7.78%

Table I-1. Cherry Creek Shade-Related Data, TMDLs, Existing Solar Loading, and the Percent Increase in Shade Needed to Meet the TMDLs

Longitudinal Distance (m)	River Mile (RM)	Aspect	Wetted Width (ft)-GIS	General Direction	Ecoregion	Target Shade (%)	Existing Shade (%)	Shade Difference (%)	Daily Solar Flux with Existing Shade (watts/ft^2)	Daily Solar Flux with Potential Shade (watts/ft^2)	Existing Load (kcal/day)	Potential Load (kcal/day)	Percent Reduction Needed to Meet TMDL
7400	21.8722592	0	49.2	N/S	17ab	18	11	-7	621	573	102218785.9	94317817	7.87%
7350	21.9033278	23.62919	42.64	NE/SW	17ab	19	12	-7	616	567	87876332.54	80886169.7	7.95%
7300	21.9343963	267.4769	49.2	E/W	17ab	11	6	-5	659	624	108473719.7	102712596	5.32%
7250	21.9654649	270	36.08	E/W	17ab	15	8	-7	645	596	77857464.96	71942711.8	7.61%
7200	21.9965334	315.3186	32.8	NW/SE	17ab	24	12	-12	610	527	66938764.8	57830703.4	13.64%
7150	22.027602	320.7107	36.08	NW/SE	17ab	22	12	-10	611	542	73753350.53	65424412.4	11.36%
7100	22.0586705	0	42.64	N/S	17ab	21	12	-9	613	550	87448363.39	78461011.2	10.23%
7050	22.0897391	98.1301	36.08	E/W	17ab	15	8	-7	644	595	77736755.71	71822002.6	7.61%
7000	22.1208076	345.9636	29.52	N/S	17ab	29	17	-12	580	496	57282024.96	48986007.6	14.46%
6950	22.1518762	241.39	39.36	NE/SW	17ab	20	9	-11	632	556	83223539.71	73215645.7	12.09%
6900	22.1829447	270	36.08	E/W	17ab	15	7	-8	646	591	77978174.21	71339165.6	8.60%
6850	22.2140133	4.398742	36.08	N/S	17ab	24	14	-10	600	530	72425548.8	63975901.4	11.63%
6800	22.2450818	75.96357	68.88	E/W	17ab	8	4	-4	666	639	153476322	147254309	4.17%
6750	22.2761504	8.746234	39.36	N/S	17ab	22	14	-8	603	547	79404738.05	72030500.4	9.30%
6700	22.3072189	270	29.52	E/W	17ab	18	10	-8	631	575	62318892.67	56788214.4	8.89%
6650	22.3382875	348.69	32.8	N/S	17ab	26	16	-10	587	517	64414844.16	56733346.6	11.90%
6600	22.369356	52.12468	36.08	NE/SW	17ab	22	12	-10	612	542	73874059.78	65424412.4	11.36%
6550	22.4004246	19.98329	29.52	N/S	17ab	29	16	-13	584	494	57677073.41	48788483.3	15.48%
6500	22.4314931	4.763685	42.64	N/S	17ab	21	13	-8	607	551	86592425.09	78603667.6	9.20%
6450	22.4625617	99.46249	42.64	E/W	17ab	13	7	-6	648	606	92441336.83	86449768.7	6.45%
6400	22.4936302	321.3399	39.36	NW/SE	17ab	20	12	-8	613	558	80721566.21	73479011.3	9.09%
6350	22.5246988	333.4352	36.08	NW/SE	17ab	22	14	-8	601	545	72546258.05	65786540.2	9.30%

Table I-1. Cherry Creek Shade-Related Data, TMDLs, Existing Solar Loading, and the Percent Increase in Shade Needed to Meet the TMDLs

Longitudinal Distance (m)	River Mile (RM)	Aspect	Wetted Width (ft)-GIS	General Direction	Ecoregion	Target Shade (%)	Existing Shade (%)	Shade Difference (%)	Daily Solar Flux with Existing Shade (watts/ft^2)	Daily Solar Flux with Potential Shade (watts/ft^2)	Existing Load (kcal/day)	Potential Load (kcal/day)	Percent Reduction Needed to Meet TMDL
6300	22.5557673	29.98035	39.36	NE/SW	17ab	20	13	-7	605	556	79668103.68	73215645.7	8.05%
6250	22.5868359	39.80552	59.04	NE/SW	17ab	14	9	-5	638	603	126020454.9	119107107	5.49%
6200	22.6179044	317.7263	36.08	NW/SE	17ab	22	13	-9	607	544	73270513.54	65665830.9	10.34%
6150	22.648973	347.471	26.24	N/S	17ab	32	19	-13	567	476	49776104.45	41787346.9	16.05%
6100	22.6800415	311.9875	32.8	NW/SE	17ab	24	14	-10	600	530	65841408	58159910.4	11.63%
6050	22.7111101	312.2737	52.48	NW/SE	17ab	16	8	-8	638	583	112018182.1	102361442	8.70%
6000	22.7421786	228.3665	32.8	NE/SW	17ab	24	13	-11	610	533	66938764.8	58489117.4	12.64%
5950	22.7732472	304.9919	29.52	NW/SE	17ab	26	41	15	411	515	40591228.03	50862487.7	0.00%
5900	22.8043157	296.5648	32.8	NW/SE	17ab	24	38	14	436	534	47844756.48	58598853.1	0.00%
5850	22.8353843	0	36.08	N/S	17ab	24	18	-6	572	530	69045689.86	63975901.4	7.32%
5800	22.8664528	310.2363	42.64	NW/SE	17ab	19	11	-8	619	564	88304301.7	80458200.6	8.99%
5750	22.8975214	327.9943	29.52	NW/SE	17ab	26	19	-7	567	518	55998117.5	51158774	8.64%
5700	22.9285899	284.9315	36.08	E/W	17ab	15	9	-6	631	590	76167535.49	71218456.3	6.59%
5650	22.9596585	241.6988	29.52	NE/SW	17ab	26	12	-14	614	517	60639936.77	51060011.9	15.91%
5600	22.990727	264.5599	29.52	E/W	17ab	18	10	-8	630	574	62220130.56	56689452.3	8.89%
5550	23.0217956	301.6074	39.36	NW/SE	17ab	20	9	-11	634	557	83486905.34	73347328.5	12.09%
5500	23.0528641	270	39.36	E/W	17ab	14	7	-7	650	601	85593830.4	79141372.4	7.53%
5450	23.0839327	206.5648	36.08	NE/SW	17ab	22	14	-8	600	544	72425548.8	65665830.9	9.30%
5400	23.1150012	225	32.8	NE/SW	17ab	24	13	-11	610	533	66938764.8	58489117.4	12.64%
5350	23.1460698	80.5381	29.52	E/W	17ab	18	10	-8	628	572	62022606.34	56491928.1	8.89%
5300	23.1771383	66.03725	29.52	NE/SW	17ab	26	11	-15	620	515	61232509.44	50862487.7	16.85%
5250	23.2082069	225.0004	26.24	NE/SW	17ab	29	16	-13	583	492	51180721.15	43191963.6	15.48%

Table I-1. Cherry Creek Shade-Related Data, TMDLs, Existing Solar Loading, and the Percent Increase in Shade Needed to Meet the TMDLs

Longitudinal Distance (m)	River Mile (RM)	Aspect	Wetted Width (ft)-GIS	General Direction	Ecoregion	Target Shade (%)	Existing Shade (%)	Shade Difference (%)	Daily Solar Flux with Existing Shade (watts/ft^2)	Daily Solar Flux with Potential Shade (watts/ft^2)	Existing Load (kcal/day)	Potential Load (kcal/day)	Percent Reduction Needed to Meet TMDL
5200	23.2392754	261.0273	29.52	E/W	17ab	18	9	-9	632	570	62417654.78	56294403.8	9.89%
5150	23.270344	126.027	45.92	NW/SE	17ab	18	8	-10	638	569	98015909.38	87415442.7	10.87%
5100	23.3014125	270	32.8	E/W	17ab	17	8	-9	638	576	70011363.84	63207751.7	9.78%
5050	23.3324811	343.3006	39.36	N/S	17ab	22	13	-9	609	546	80194834.94	71898817.5	10.34%
5000	23.3635496	266.4236	29.52	E/W	17ab	18	10	-8	630	574	62220130.56	56689452.3	8.89%
4950	23.3946182	255.9636	29.52	E/W	17ab	18	10	-8	627	571	61923844.22	56393166	8.89%
4900	23.4256867	327.9948	45.92	NW/SE	17ab	18	11	-7	624	575	95865090.05	88337222.4	7.87%
4850	23.4567553	170.5376	32.8	N/S	17ab	26	16	-10	588	518	64524579.84	56843082.2	11.90%
4800	23.4878238	270	29.52	E/W	17ab	18	9	-9	633	571	62516416.9	56393166	9.89%
4750	23.5188924	259.6951	29.52	E/W	17ab	18	10	-8	627	572	61923844.22	56491928.1	8.89%
4700	23.5499609	206.5654	36.08	NE/SW	17ab	22	14	-8	601	545	72546258.05	65786540.2	9.30%
4650	23.5810295	241.6988	32.8	NE/SW	17ab	24	11	-13	620	529	68036121.6	58050174.7	14.61%
4600	23.612098	275.7107	36.08	E/W	17ab	15	8	-7	644	595	77736755.71	71822002.6	7.61%
4550	23.6431666	335.5558	49.2	NW/SE	17ab	17	10	-7	625	577	102877200	94976231	7.78%
4500	23.6742351	300.964	32.8	NW/SE	17ab	24	11	-13	621	530	68145857.28	58159910.4	14.61%
4450	23.7053037	287.3542	36.08	E/W	17ab	15	9	-6	636	594	76771081.73	71701293.3	6.59%
4400	23.7363722	338.9627	22.96	N/S	17ab	35	22	-13	544	453	41787346.94	34797184.1	16.67%
4350	23.7674408	49.39922	36.08	NE/SW	17ab	22	11	-11	619	543	74719024.51	65545121.7	12.36%
4300	23.7985093	285.9456	42.64	E/W	17ab	13	6	-7	656	607	93582587.9	86592425.1	7.45%
4250	23.8295779	290.5563	32.8	E/W	17ab	17	10	-7	626	577	68694535.68	63317487.4	7.78%
4200	23.8606464	355.6017	32.8	N/S	17ab	26	16	-10	584	515	64085637.12	56513875.2	11.90%
4150	23.891715	253.3006	36.08	E/W	17ab	15	8	-7	640	591	77253918.72	71339165.6	7.61%

Table I-1. Cherry Creek Shade-Related Data, TMDLs, Existing Solar Loading, and the Percent Increase in Shade Needed to Meet the TMDLs

Longitudinal Distance (m)	River Mile (RM)	Aspect	Wetted Width (ft)-GIS	General Direction	Ecoregion	Target Shade (%)	Existing Shade (%)	Shade Difference (%)	Daily Solar Flux with Existing Shade (watts/ft^2)	Daily Solar Flux with Potential Shade (watts/ft^2)	Existing Load (kcal/day)	Potential Load (kcal/day)	Percent Reduction Needed to Meet TMDL
4100	23.9227835	344.7447	29.52	N/S	17ab	29	16	-13	583	493	57578311.3	48689721.2	15.48%
4050	23.9538521	318.8141	29.52	NW/SE	17ab	26	15	-11	590	513	58269646.08	50664963.5	12.94%
4000	23.9849206	15.25474	29.52	N/S	17ab	29	17	-12	579	495	57183262.85	48887245.4	14.46%
3950	24.0159892	345.0684	29.52	N/S	17ab	29	17	-12	580	496	57282024.96	48986007.6	14.46%
3900	24.0470577	55.0081	36.08	NE/SW	17ab	22	11	-11	621	545	74960443.01	65786540.2	12.36%
3850	24.0781263	84.28935	19.68	E/W	17ab	27	14	-13	603	512	39702369.02	33710800.9	15.12%
3800	24.1091948	298.6107	32.8	NW/SE	17ab	24	11	-13	623	532	68365328.64	58379381.8	14.61%
3750	24.1402634	0	36.08	N/S	17ab	24	14	-10	599	529	72304839.55	63855192.2	11.63%
3700	24.1713319	213.6894	32.8	NE/SW	17ab	24	15	-9	594	531	65182993.92	58269646.1	10.59%
3650	24.2024005	20.55562	32.8	N/S	17ab	26	16	-10	587	517	64414844.16	56733346.6	11.90%
3600	24.233469	247.38	32.8	NE/SW	17ab	24	10	-14	629	531	69023742.72	58269646.1	15.56%
3550	24.2645376	180	32.8	N/S	17ab	26	16	-10	588	518	64524579.84	56843082.2	11.90%
3500	24.2956061	270	29.52	E/W	17ab	18	9	-9	633	571	62516416.9	56393166	9.89%
3450	24.3266747	255.9636	32.8	E/W	17ab	17	9	-8	632	576	69352949.76	63207751.7	8.79%
3400	24.3577432	228.0128	32.8	NE/SW	17ab	24	12	-12	613	530	67267971.84	58159910.4	13.64%
3350	24.3888118	322.1251	39.36	NW/SE	17ab	20	11	-9	619	557	81511663.1	73347328.5	10.11%
3300	24.4198803	308.6597	32.8	NW/SE	17ab	24	12	-12	614	530	67377707.52	58159910.4	13.64%
3250	24.4509489	0	36.08	N/S	17ab	24	15	-9	592	529	71459874.82	63855192.2	10.59%
3200	24.4820174	286.6994	42.64	E/W	17ab	13	7	-6	648	606	92441336.83	86449768.7	6.45%
3150	24.513086	290.5563	22.96	E/W	17w	23	14	-9	603	540	46319430.53	41480087	10.47%
3100	24.5441545	288.4346	32.8	E/W	17w	17	10	-7	630	581	69133478.4	63756430.1	7.78%
3050	24.5752231	279.4624	29.52	E/W	17w	18	10	-8	628	572	62022606.34	56491928.1	8.89%

Table I-1. Cherry Creek Shade-Related Data, TMDLs, Existing Solar Loading, and the Percent Increase in Shade Needed to Meet the TMDLs

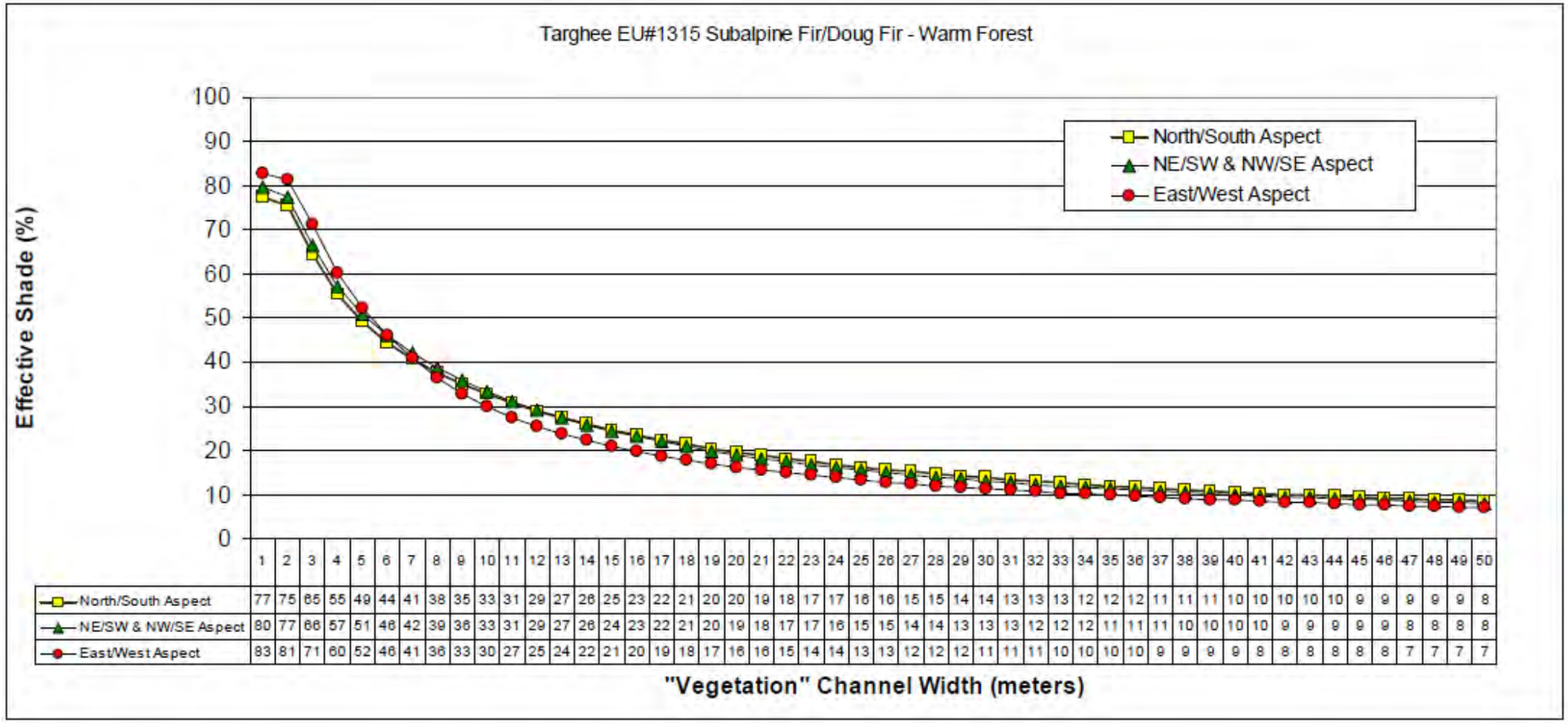
Longitudinal Distance (m)	River Mile (RM)	Aspect	Wetted Width (ft)-GIS	General Direction	Ecoregion	Target Shade (%)	Existing Shade (%)	Shade Difference (%)	Daily Solar Flux with Existing Shade (watts/ft^2)	Daily Solar Flux with Potential Shade (watts/ft^2)	Existing Load (kcal/day)	Potential Load (kcal/day)	Percent Reduction Needed to Meet TMDL
3000	24.6062916	315	36.08	NW/SE	17w	22	12	-10	614	544	74115478.27	65665830.9	11.36%
2950	24.6373602	321.3403	29.52	NW/SE	17w	26	16	-10	588	518	58072121.86	51158774	11.90%
2900	24.6684287	270	29.52	E/W	17w	18	9	-9	631	569	62318892.67	56195641.7	9.89%
2850	24.6994973	306.8694	36.08	NW/SE	17w	22	11	-11	621	544	74960443.01	65665830.9	12.36%
2800	24.7305658	0	29.52	N/S	17w	29	17	-12	576	493	56886976.51	48689721.2	14.46%
2750	24.7616344	248.9623	32.8	E/W	17w	17	10	-7	625	576	68584800	63207751.7	7.78%
2700	24.7927029	202.62	22.96	NE/SW	17w	32	23	-9	538	475	41326457.09	36487113.6	11.69%
2650	24.8237715	225	32.8	NE/SW	17w	24	13	-11	608	531	66719293.44	58269646.1	12.64%
2600	24.85484	324.4625	29.52	NW/SE	17w	26	16	-10	588	518	58072121.86	51158774	11.90%
2550	24.8859086	318.8141	32.8	NW/SE	17w	24	14	-10	599	530	65731672.32	58159910.4	11.63%
2500	24.9169771	173.6597	36.08	N/S	17w	24	15	-9	594	531	71701293.31	64096610.7	10.59%
2450	24.9480457	203.1982	42.64	NE/SW	17w	19	13	-6	610	568	87020394.24	81028826.1	6.90%
2400	24.9791142	159.4437	32.8	N/S	17w	26	16	-10	586	516	64305108.48	56623610.9	11.90%
2350	25.0101828	163.3012	29.52	N/S	17w	29	18	-11	572	495	56491928.06	48887245.4	13.41%
2300	25.0412513	237.529	39.36	NE/SW	17w	20	10	-10	625	555	82301760	73083962.9	11.11%
2250	25.0723199	318.3665	29.52	NW/SE	17w	26	16	-10	587	517	57973359.74	51060011.9	11.90%
2200	25.1033884	40.60078	32.8	NE/SW	17w	24	13	-11	605	528	66390086.4	57940439	12.64%
2150	25.134457	209.7453	22.96	NE/SW	17w	32	21	-11	552	475	42401866.75	36487113.6	13.92%
2100	25.1655255	298.0723	22.96	NW/SE	17w	32	16	-16	585	474	44936760.96	36410298.6	19.05%
2050	25.1965941	33.69039	32.8	NE/SW	17w	24	15	-9	593	530	65073258.24	58159910.4	10.59%
2000	25.2276626	63.43516	19.68	NE/SW	17w	36	18	-18	574	448	37792968.19	29496950.8	21.95%
1950	25.2587312	73.30058	22.96	E/W	17w	23	13	-10	610	540	46857135.36	41480087	11.49%

Table I-1. Cherry Creek Shade-Related Data, TMDLs, Existing Solar Loading, and the Percent Increase in Shade Needed to Meet the TMDLs

Longitudinal Distance (m)	River Mile (RM)	Aspect	Wetted Width (ft)-GIS	General Direction	Ecoregion	Target Shade (%)	Existing Shade (%)	Shade Difference (%)	Daily Solar Flux with Existing Shade (watts/ft^2)	Daily Solar Flux with Potential Shade (watts/ft^2)	Existing Load (kcal/day)	Potential Load (kcal/day)	Percent Reduction Needed to Meet TMDL
1900	25.2897997	296.5647	19.68	NW/SE	17w	36	16	-20	584	445	38451382.27	29299426.6	23.81%
1850	25.3208683	309.805	36.08	NW/SE	17w	22	11	-11	619	543	74719024.51	65545121.7	12.36%
1800	25.3519368	180	29.52	N/S	17w	29	18	-11	570	494	56294403.84	48788483.3	13.41%
1750	25.3830054	260.5376	26.24	E/W	17w	20	11	-9	620	558	54428897.28	48986007.6	10.11%
1700	25.4140739	331.699	32.8	NW/SE	17w	24	15	-9	593	530	65073258.24	58159910.4	10.59%
1650	25.4451425	270	22.96	E/W	17w	23	12	-11	614	537	47164395.26	41249642.1	12.50%
1600	25.476211	296.5652	22.96	NW/SE	17w	32	15	-17	590	472	45320835.84	36256668.7	20.00%
1550	25.5072796	213.6905	22.96	NE/SW	17w	32	20	-12	560	476	43016386.56	36563928.6	15.00%
1500	25.5383481	230.1945	22.96	NE/SW	17w	32	17	-15	580	475	44552686.08	36487113.6	18.07%
1450	25.5694167	290.5556	22.96	E/W	17w	23	15	-8	595	539	45704910.72	41403272.1	9.41%
1400	25.6004852	270	26.24	E/W	17w	20	10	-10	626	556	54955628.54	48810430.5	11.11%
1350	25.6315538	251.5649	22.96	E/W	17w	23	14	-9	600	538	46088985.6	41326457.1	10.47%
1300	25.6626223	348.6907	22.96	N/S	17w	35	23	-12	534	450	41019197.18	34566739.2	15.58%
1250	25.6936909	340.0172	32.8	N/S	17w	26	16	-10	588	518	64524579.84	56843082.2	11.90%
1200	25.7247594	311.1859	26.24	NW/SE	17w	29	17	-12	582	498	51092932.61	43718694.9	14.46%
1150	25.755828	338.1984	29.52	N/S	17w	29	18	-11	575	498	56788214.4	49183531.8	13.41%
1100	25.7868965	293.9619	32.8	NW/SE	17w	24	10	-14	625	527	68584800	57830703.4	15.56%
1050	25.8179651	303.6896	29.52	NW/SE	17w	26	15	-11	591	514	58368408.19	50763725.6	12.94%
1000	25.8490336	296.5653	32.8	NW/SE	17w	24	11	-13	618	528	67816650.24	57940439	14.61%
950	25.8801022	45	26.24	NE/SW	17w	29	17	-12	579	495	50829566.98	43455329.3	14.46%
900	25.9111707	331.3893	29.52	NW/SE	17w	26	19	-7	567	518	55998117.5	51158774	8.64%
850	25.9422393	354.2893	29.52	N/S	17w	29	20	-9	557	494	55010496.38	48788483.3	11.25%

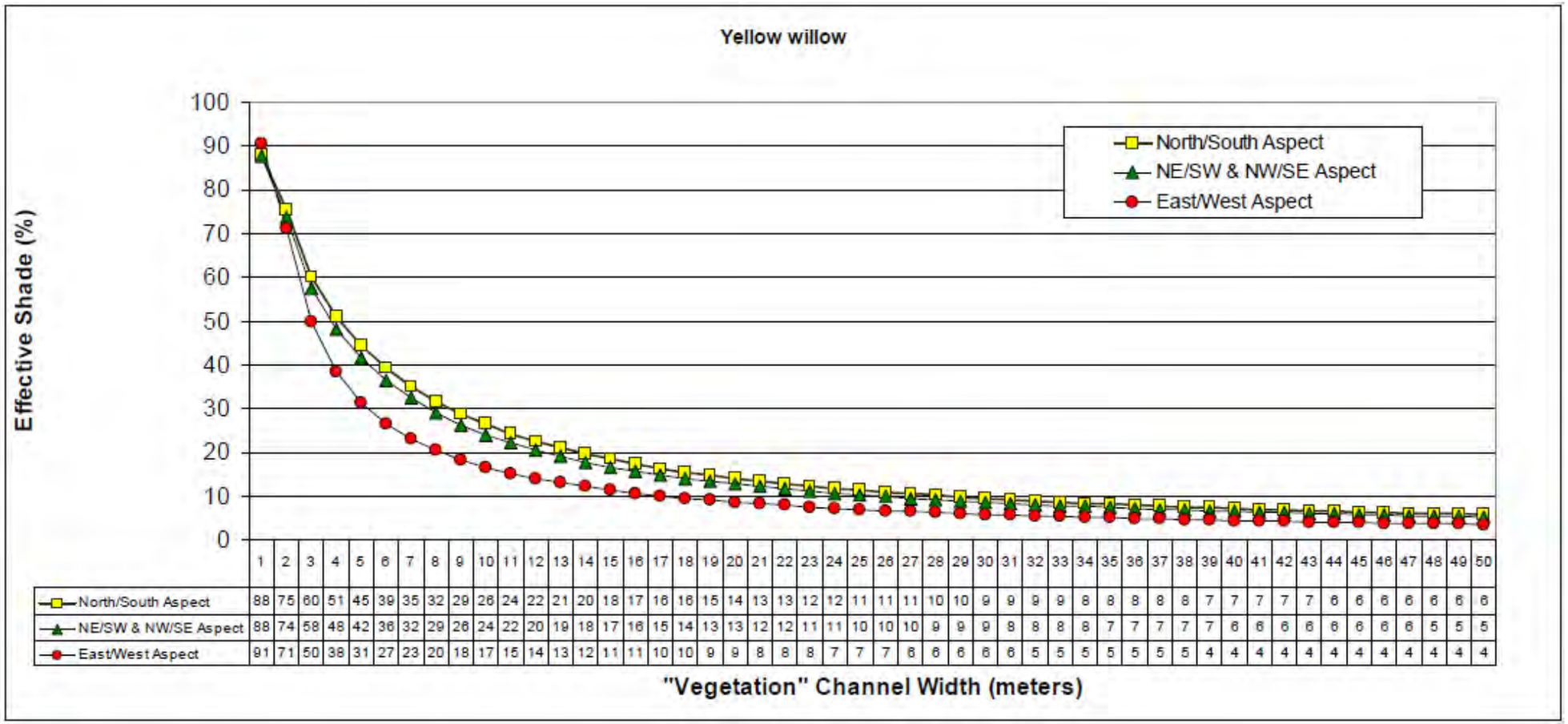
Table I-1. Cherry Creek Shade-Related Data, TMDLs, Existing Solar Loading, and the Percent Increase in Shade Needed to Meet the TMDLs

Longitudinal Distance (m)	River Mile (RM)	Aspect	Wetted Width (ft)-GIS	General Direction	Ecoregion	Target Shade (%)	Existing Shade (%)	Shade Difference (%)	Daily Solar Flux with Existing Shade (watts/ft^2)	Daily Solar Flux with Potential Shade (watts/ft^2)	Existing Load (kcal/day)	Potential Load (kcal/day)	Percent Reduction Needed to Meet TMDL
800	25.9733078	270	42.64	E/W	17w	13	7	-6	646	605	92156024.06	86307112.3	6.45%
750	26.0043764	180	32.8	N/S	17w	26	18	-8	574	518	62988280.32	56843082.2	9.76%
700	26.0354449	149.0364	39.36	NW/SE	17w	20	14	-6	603	561	79404738.05	73874059.8	6.98%
650	26.0665135	305.5376	36.08	NW/SE	17w	22	12	-10	616	546	74356896.77	65907249.4	11.36%
600	26.097582	348.69	32.8	N/S	17w	26	16	-10	585	515	64195372.8	56513875.2	11.90%
550	26.1286506	0	32.8	N/S	17w	26	17	-9	582	519	63866165.76	56952817.9	10.84%
500	26.1597191	0	26.24	N/S	17w	32	20	-12	560	476	49161584.64	41787346.9	15.00%
450	26.1907877	78.68995	26.24	E/W	17w	20	11	-9	624	561	54780051.46	49249373.2	10.11%
400	26.2218562	333.4349	26.24	NW/SE	17w	29	18	-11	571	495	50127258.62	43455329.3	13.41%
350	26.2529248	313.3576	32.8	NW/SE	17w	24	13	-11	607	530	66609557.76	58159910.4	12.64%
300	26.2839933	303.6899	29.52	NW/SE	17w	26	13	-13	610	519	60244888.32	51257536.1	14.94%
250	26.3150619	270	26.24	E/W	17w	20	11	-9	623	560	54692262.91	49161584.6	10.11%
200	26.3461304	299.7453	26.24	NW/SE	17w	29	14	-15	603	498	52936492.03	43718694.9	17.44%
150	26.377199	281.3101	22.96	E/W	17w	23	13	-10	609	539	46780320.38	41403272.1	11.49%
100	26.4082675	309.8055	45.92	NW/SE	17w	18	10	-8	630	574	96786869.76	88183592.4	8.89%
50	26.4393361	309.2897	32.8	NW/SE	17w	24	11	-13	621	531	68145857.28	58269646.1	14.61%
0	26.4704046	315	32.8	NW/SE	17w	24	12	-12	613	530	67267971.84	58159910.4	13.64%



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
North/South Aspect	77	75	65	55	49	44	41	38	35	33	31	29	27	26	25	23	22	21	20	20	19	18	17	17	16	16	15	15	14	14	13	13	13	12	12	12	11	11	11	10	10	10	10	10	9	9	9	9	9	8
NE/SW & NW/SE Aspect	80	77	66	57	51	46	42	39	36	33	31	29	27	26	24	23	22	21	20	19	18	17	17	16	15	15	14	14	13	13	13	12	12	12	11	11	11	10	10	10	10	9	9	9	9	9	8	8	8	8
East/West Aspect	83	81	71	60	52	46	41	36	33	30	27	25	24	22	21	20	19	18	17	16	16	15	14	14	13	13	12	12	12	11	11	11	10	10	10	10	9	9	9	9	8	8	8	8	8	8	7	7	7	7

Figure I-1. Shade Curve Selected for Cherry Creek to Represent the Target Shade Conditions for Ecoregions 17l and 17g



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
North/South Aspect	88	75	60	51	45	39	35	32	29	26	24	22	21	20	18	17	16	16	15	14	13	13	12	12	11	11	11	10	10	9	9	9	9	8	8	8	8	8	7	7	7	7	7	6	6	6	6	6	6	6
NE/SW & NW/SE Aspect	88	74	58	48	42	36	32	29	26	24	22	20	19	18	17	16	15	14	13	13	12	12	11	11	10	10	10	9	9	9	8	8	8	8	7	7	7	7	7	6	6	6	6	6	6	6	6	5	5	5
East/West Aspect	91	71	50	38	31	27	23	20	18	17	15	14	13	12	11	11	10	10	9	9	8	8	8	7	7	7	6	6	6	6	6	5	5	5	5	5	5	5	4	4	4	4	4	4	4	4	4	4	4	4

Figure I-2. Shade Curve Selected for Cherry Creek to Represent the Target Shade Conditions for Ecoregions 17ab and 17w

I2.2 ELK CREEK

Table I-2 contains the Shade Tool model results for Elk Creek, the data that was used for the temperature targets (shade surrogate TMDL), the modeled existing solar load, and the percent load reduction needed to meet the temperature TMDL. Vegetation-specific shade curves developed by the EPA and Idaho DEQ were used for shade target development (Shumar and de Varona 2009). Each level IV ecoregion was assigned a shade curve to represent the potential riparian vegetative community for that ecoregion. The level IV ecoregions represented in the Elk Creek shade model are 17ab - Dry Gneissic-Schistone-Volcanic Hills and 17w - Townsend Basin. The shade curve selected for these ecoregions is shown in **Figures I-3**.

Table I-2. Elk Creek Shade-Related Data, TMDLs, Existing Solar Loading, and the Percent Increase in Shade Needed to Meet the TMDLs

Longitudinal Distance (m)	River Mile (RM)	Aspect	Wetted Width (ft)-GIS	Wetted Width (ft) TMDL	General Direction	Ecoregion	Target Shade (%)	Existing Shade (%)	Shade Difference (%)	Daily Solar Flux with Existing Shade (watts/ft2)	Daily Solar Flux with Potential Shade (watts/ft2)	Existing Load (kcal/day)	Potential Load (kcal/day)	Percent Reduction to Meet TMDL
0	0.00	1.55	3.28	3.28	N/S	17ab	88	100	12	0	0	0	33436	0%
50	0.03	42.20	3.28	3.28	NE/SW	17ab	88	84	-4	118	89	1297205	973265	25%
100	0.06	358.27	3.28	3.28	N/S	17ab	88	82	-6	137	92	1505890	1004300	33%
150	0.09	45.00	3.28	3.28	NE/SW	17ab	88	71	-17	214	89	2347072	971563	59%
200	0.12	49.72	3.28	3.28	NE/SW	17ab	88	78	-10	162	88	1775669	968907	45%
250	0.16	80.20	3.28	3.28	E/W	17ab	91	58	-33	310	66	3402635	729407	79%
300	0.19	106.09	3.28	3.28	E/W	17ab	91	50	-41	370	67	4058665	730831	82%
350	0.22	37.51	3.28	3.28	NE/SW	17ab	88	73	-15	202	90	2214560	984615	56%
400	0.25	66.25	6.56	6.56	NE/SW	17ab	74	47	-27	398	195	8730449	4284454	51%
450	0.28	107.10	3.28	3.28	E/W	17ab	91	49	-42	381	67	4182324	738332	82%
500	0.31	26.98	3.28	3.28	NE/SW	17ab	88	83	-5	129	91	1411055	996409	29%
550	0.34	69.18	3.28	3.28	E/W	17ab	91	99	8	8	70	85743	771973	0%
600	0.37	51.01	3.28	3.28	NE/SW	17ab	88	99	11	7	82	75228	903075	0%
650	0.40	68.66	3.28	3.28	E/W	17ab	91	99	8	5	46	55561	500235	0%
700	0.43	70.87	3.28	3.28	E/W	17ab	91	99	8	6	56	67747	609948	0%
750	0.47	74.62	3.28	3.28	E/W	17ab	91	99	8	7	66	80076	720954	0%
800	0.50	77.23	3.28	3.28	E/W	17ab	91	99	8	6	54	65952	593786	0%

Table I-2. Elk Creek Shade-Related Data, TMDLs, Existing Solar Loading, and the Percent Increase in Shade Needed to Meet the TMDLs

Longitudinal Distance (m)	River Mile (RM)	Aspect	Wetted Width (ft)-GIS	Wetted Width (ft) TMDL	General Direction	Ecoregion	Target Shade (%)	Existing Shade (%)	Shade Difference (%)	Daily Solar Flux with Existing Shade (watts/ft2)	Daily Solar Flux with Potential Shade (watts/ft2)	Existing Load (kcal/day)	Potential Load (kcal/day)	Percent Reduction to Meet TMDL
850	0.53	75.50	3.28	3.28	E/W	17ab	91	99	8	8	72	87225	785315	0%
900	0.56	77.57	3.28	3.28	E/W	17ab	91	99	8	7	61	74271	668692	0%
950	0.59	54.74	3.28	3.28	NE/SW	17ab	88	99	11	5	65	59689	716540	0%
1000	0.62	73.75	3.28	3.28	E/W	17ab	91	27	-64	546	67	5991657	738972	88%
1050	0.65	35.61	3.28	3.28	NE/SW	17ab	88	92	4	59	88	643026	964897	0%
1100	0.68	64.12	3.28	3.28	NE/SW	17ab	88	90	2	76	91	836199	1003812	0%
1150	0.71	69.81	3.28	3.28	E/W	17ab	91	58	-33	311	67	3408285	730618	79%
1200	0.75	43.60	3.28	3.28	NE/SW	17ab	88	83	-5	127	90	1398614	987624	29%
1250	0.78	50.53	3.28	3.28	NE/SW	17ab	88	41	-47	438	89	4807365	978133	80%
1300	0.81	47.50	3.28	3.28	NE/SW	17ab	88	94	6	42	84	463370	927085	0%
1350	0.84	29.67	3.28	3.28	NE/SW	17ab	88	97	9	20	78	214530	858440	0%
1400	0.87	60.72	3.28	3.28	NE/SW	17ab	88	94	6	46	93	508412	1017203	0%
1450	0.90	55.03	3.28	3.28	NE/SW	17ab	88	82	-6	133	89	1462937	975654	33%
1500	0.93	86.94	3.28	3.28	E/W	17ab	91	91	0	68	68	750920	751199	0%
1550	0.96	49.64	3.28	3.28	NE/SW	17ab	88	90	2	71	86	781771	938473	0%
1600	0.99	51.40	3.28	3.28	NE/SW	17ab	88	93	5	49	84	535184	917799	0%
1650	1.03	66.30	3.28	3.28	NE/SW	17ab	88	91	3	66	89	729411	972910	0%
1700	1.06	63.71	3.28	3.28	NE/SW	17ab	88	41	-47	443	90	4861893	989227	80%
1750	1.09	60.29	3.28	3.28	NE/SW	17ab	88	87	-1	101	93	1102933	1018471	8%
1800	1.12	25.02	3.28	3.28	NE/SW	17ab	88	75	-13	183	88	2005704	963096	52%
1850	1.15	344.49	3.28	3.28	N/S	17ab	88	92	4	60	90	659990	990353	0%
1900	1.18	340.32	3.28	3.28	N/S	17ab	88	86	-2	103	88	1130132	969044	14%
1950	1.21	351.27	3.28	3.28	N/S	17ab	88	83	-5	129	91	1416058	999942	29%
2000	1.24	40.19	6.56	6.56	NE/SW	17ab	74	56	-18	329	194	7214619	4264769	41%

Table I-2. Elk Creek Shade-Related Data, TMDLs, Existing Solar Loading, and the Percent Increase in Shade Needed to Meet the TMDLs

Longitudinal Distance (m)	River Mile (RM)	Aspect	Wetted Width (ft)-GIS	Wetted Width (ft) TMDL	General Direction	Ecoregion	Target Shade (%)	Existing Shade (%)	Shade Difference (%)	Daily Solar Flux with Existing Shade (watts/ft2)	Daily Solar Flux with Potential Shade (watts/ft2)	Existing Load (kcal/day)	Potential Load (kcal/day)	Percent Reduction to Meet TMDL
2050	1.27	359.59	6.56	6.56	N/S	17ab	75	62	-13	283	186	6203608	4082838	34%
2100	1.30	19.09	3.28	3.28	N/S	17ab	88	69	-19	234	91	2567491	994237	61%
2150	1.34	358.43	3.28	3.28	N/S	17ab	88	84	-4	122	91	1334489	1001239	25%
2200	1.37	337.64	3.28	3.28	N/S	17ab	88	73	-15	205	91	2244353	997861	56%
2250	1.40	332.20	3.28	3.28	NE/SW	17ab	88	72	-16	211	90	2312767	991554	57%
2300	1.43	346.98	3.28	3.28	N/S	17ab	88	88	0	86	86	943230	943581	0%
2350	1.46	346.41	3.28	3.28	N/S	17ab	88	94	6	42	84	461667	923677	0%
2400	1.49	337.49	3.28	3.28	NE/SW	17ab	88	74	-14	197	91	2163104	998727	54%
2450	1.52	16.45	3.28	3.28	N/S	17ab	88	78	-10	162	88	1774805	968435	45%
2500	1.55	326.09	3.28	3.28	NE/SW	17ab	88	80	-8	150	90	1648263	989326	40%
2550	1.58	356.81	3.28	3.28	N/S	17ab	88	94	6	45	91	498775	997922	0%
2600	1.62	353.20	3.28	3.28	N/S	17ab	88	93	5	53	92	586465	1005743	0%
2650	1.65	3.29	3.28	3.28	N/S	17ab	88	97	9	26	104	285399	1142021	0%
2700	1.68	6.44	3.28	3.28	N/S	17ab	88	96	8	30	89	325872	977980	0%
2750	1.71	19.94	3.28	3.28	N/S	17ab	88	71	-17	216	89	2371863	981826	59%
2800	1.74	67.26	3.28	3.28	NE/SW	17ab	88	64	-24	265	88	2906704	969261	67%
2850	1.77	95.71	3.28	3.28	E/W	17ab	91	73	-18	199	66	2183314	728042	67%
2900	1.80	57.53	3.28	3.28	NE/SW	17ab	88	89	1	79	87	870810	950327	0%
2950	1.83	63.08	3.28	3.28	NE/SW	17ab	88	89	1	84	92	925536	1010051	0%
3000	1.86	65.06	3.28	3.28	NE/SW	17ab	88	95	7	34	82	373214	896047	0%
3050	1.90	67.34	3.28	3.28	NE/SW	17ab	88	94	6	46	92	502726	1005826	0%
3100	1.93	12.43	3.28	3.28	N/S	17ab	88	93	5	51	88	561982	963755	0%
3150	1.96	62.29	3.28	3.28	NE/SW	17ab	88	69	-19	235	91	2573347	996504	61%
3200	1.99	76.22	3.28	3.28	E/W	17ab	91	90	-1	75	67	821540	739661	10%

Table I-2. Elk Creek Shade-Related Data, TMDLs, Existing Solar Loading, and the Percent Increase in Shade Needed to Meet the TMDLs

Longitudinal Distance (m)	River Mile (RM)	Aspect	Wetted Width (ft)-GIS	Wetted Width (ft) TMDL	General Direction	Ecoregion	Target Shade (%)	Existing Shade (%)	Shade Difference (%)	Daily Solar Flux with Existing Shade (watts/ft2)	Daily Solar Flux with Potential Shade (watts/ft2)	Existing Load (kcal/day)	Potential Load (kcal/day)	Percent Reduction to Meet TMDL
3250	2.02	76.42	3.28	3.28	E/W	17ab	91	87	-4	96	66	1050647	727641	31%
3300	2.05	75.26	3.28	3.28	E/W	17ab	91	35	-56	481	67	5280750	731453	86%
3350	2.08	66.60	3.28	3.28	NE/SW	17ab	88	38	-50	462	89	5071804	982004	81%
3400	2.11	64.33	3.28	3.28	NE/SW	17ab	88	95	7	36	86	392773	943005	0%
3450	2.14	64.83	3.28	3.28	NE/SW	17ab	88	95	7	41	98	445924	1070617	0%
3500	2.17	57.77	3.28	3.28	NE/SW	17ab	88	80	-8	147	88	1611282	967128	40%
3550	2.21	32.12	3.28	3.28	NE/SW	17ab	88	91	3	65	87	716247	955352	0%
3600	2.24	17.82	3.28	3.28	N/S	17ab	88	93	5	55	94	600497	1029807	0%
3650	2.27	359.59	3.28	3.28	N/S	17ab	88	94	6	43	86	470291	940932	0%
3700	2.30	13.95	3.28	3.28	N/S	17ab	88	90	2	76	91	830797	997327	0%
3750	2.33	344.26	3.28	3.28	N/S	17ab	88	94	6	42	85	465732	931810	0%
3800	2.36	319.70	3.28	3.28	NE/SW	17ab	88	90	2	73	88	805329	966754	0%
3850	2.39	353.00	3.28	3.28	N/S	17ab	88	96	8	28	83	303213	909977	0%
3900	2.42	314.27	3.28	3.28	NE/SW	17ab	88	97	9	20	78	214383	857852	0%
3950	2.45	350.48	3.28	3.28	N/S	17ab	88	89	1	85	93	931418	1016470	0%
4000	2.49	311.45	3.28	3.28	NE/SW	17ab	88	83	-5	127	90	1394412	984657	29%
4050	2.52	322.31	3.28	3.28	NE/SW	17ab	88	85	-3	114	91	1254287	1003803	20%
4100	2.55	300.10	3.28	3.28	NE/SW	17ab	88	88	0	92	92	1009524	1009900	0%
4150	2.58	304.35	3.28	3.28	NE/SW	17ab	88	43	-45	424	89	4657816	980957	79%
4200	2.61	350.69	3.28	3.28	N/S	17ab	88	45	-43	409	89	4490187	980041	78%
4250	2.64	217.37	3.28	3.28	NE/SW	17ab	88	41	-47	438	89	4809308	978528	80%
4300	2.67	293.81	3.28	3.28	NE/SW	17ab	88	38	-50	462	89	5069132	981487	81%
4350	2.70	261.07	9.84	9.84	E/W	17ab	50	7	-43	691	372	22759057	12240601	46%
4400	2.73	280.92	3.28	3.28	E/W	17ab	91	13	-78	645	67	7079125	732596	90%

Table I-2. Elk Creek Shade-Related Data, TMDLs, Existing Solar Loading, and the Percent Increase in Shade Needed to Meet the TMDLs

Longitudinal Distance (m)	River Mile (RM)	Aspect	Wetted Width (ft)-GIS	Wetted Width (ft) TMDL	General Direction	Ecoregion	Target Shade (%)	Existing Shade (%)	Shade Difference (%)	Daily Solar Flux with Existing Shade (watts/ft2)	Daily Solar Flux with Potential Shade (watts/ft2)	Existing Load (kcal/day)	Potential Load (kcal/day)	Percent Reduction to Meet TMDL
4450	2.77	307.87	3.28	3.28	NE/SW	17ab	88	21	-67	591	90	6488859	986016	85%
4500	2.80	285.26	6.56	6.56	E/W	17ab	71	7	-64	692	216	15194331	4739778	69%
4550	2.83	298.37	9.84	9.84	NE/SW	17ab	58	9	-49	679	313	22345521	10317151	54%
4600	2.86	227.12	6.56	6.56	NE/SW	17ab	74	20	-54	598	194	13125921	4267510	67%
4650	2.89	290.17	9.84	9.84	E/W	17ab	50	7	-43	695	374	22878398	12304787	46%
4700	2.92	278.97	3.28	3.28	E/W	17ab	91	9	-82	679	67	7452246	737309	90%
4750	2.95	293.43	3.28	3.28	NE/SW	17ab	88	17	-71	621	90	6815050	985675	86%
4800	2.98	335.54	9.84	9.84	NE/SW	17ab	58	15	-43	630	311	20742679	10253134	51%
4850	3.01	301.40	3.28	3.28	NE/SW	17ab	88	23	-65	578	90	6337417	988017	84%
4900	3.04	301.64	6.56	6.56	NE/SW	17ab	74	12	-62	659	195	14459993	4273859	70%
4950	3.08	276.65	6.56	6.56	E/W	17ab	71	6	-65	698	215	15324163	4729425	69%
5000	3.11	6.12	6.56	6.56	N/S	17ab	75	21	-54	588	186	12906819	4085955	68%
5050	3.14	341.29	13.12	13.12	N/S	17ab	51	9	-42	675	364	29630928	15961046	46%
5100	3.17	282.77	13.12	13.12	E/W	17ab	38	7	-31	696	464	30551225	20375055	33%
5150	3.20	18.08	6.56	6.56	N/S	17ab	75	56	-19	329	187	7216429	4101768	43%
5200	3.23	295.48	6.56	6.56	NE/SW	17ab	74	93	19	54	202	1192579	4431226	0%
5250	3.26	233.13	6.56	6.56	NE/SW	17ab	74	83	9	126	193	2767977	4234950	0%
5300	3.29	335.91	6.56	6.56	NE/SW	17ab	74	61	-13	290	193	6353786	4237432	33%
5350	3.32	352.36	6.56	6.56	N/S	17ab	75	38	-37	460	186	10103723	4075597	60%
5400	3.36	252.35	6.56	6.56	E/W	17ab	71	40	-31	444	215	9754518	4716436	52%
5450	3.39	302.15	19.68	15.00	NE/SW	17ab	36	16	-20	628	478	41323042	24006042	42%
5500	3.42	312.66	19.68	15.00	NE/SW	17ab	15	4	-11	713	632	46968154	31708724	32%
5550	3.45	299.22	19.68	15.00	NE/SW	17ab	8	2	-6	734	689	48314668	34583451	28%
5600	3.48	288.44	19.68	15.00	E/W	17ab	27	9	-18	681	546	44828721	27419870	39%

Table I-2. Elk Creek Shade-Related Data, TMDLs, Existing Solar Loading, and the Percent Increase in Shade Needed to Meet the TMDLs

Longitudinal Distance (m)	River Mile (RM)	Aspect	Wetted Width (ft)-GIS	Wetted Width (ft) TMDL	General Direction	Ecoregion	Target Shade (%)	Existing Shade (%)	Shade Difference (%)	Daily Solar Flux with Existing Shade (watts/ft2)	Daily Solar Flux with Potential Shade (watts/ft2)	Existing Load (kcal/day)	Potential Load (kcal/day)	Percent Reduction to Meet TMDL
5650	3.51	311.42	19.68	15.00	NE/SW	17ab	13	3	-10	720	646	47425885	32433256	32%
5700	3.54	302.84	20.00	15.00	NE/SW	17ab	32	11	-21	664	508	44456549	25484571	43%
5750	3.57	277.12	19.68	15.00	E/W	17ab	27	9	-18	680	545	44755703	27375208	39%
5800	3.60	309.01	20.00	15.00	NE/SW	17ab	32	17	-15	622	510	41600767	25571420	39%
5850	3.64	312.08	16.40	15.00	NE/SW	17ab	42	20	-22	595	431	32621452	21639644	34%
5900	3.67	294.60	9.84	9.84	NE/SW	17ab	58	34	-24	489	312	16111345	10256486	36%
5950	3.70	34.38	9.84	9.84	NE/SW	17ab	58	28	-30	536	313	17645930	10297286	42%
6000	3.73	224.28	13.12	13.12	NE/SW	17ab	48	33	-15	498	387	21855611	16968870	22%
6050	3.76	287.20	9.84	9.84	E/W	17ab	50	21	-29	591	374	19465496	12324514	37%
6100	3.79	206.15	6.56	6.56	NE/SW	17ab	74	20	-54	594	193	13041718	4240134	67%
6150	3.82	333.90	9.84	9.84	NE/SW	17ab	58	30	-28	523	314	17214083	10332289	40%
6200	3.85	272.25	9.84	9.84	E/W	17ab	50	8	-42	684	372	22503191	12234541	46%
6250	3.88	270.74	6.56	6.56	E/W	17ab	71	17	-54	617	216	13546497	4734873	65%
6300	3.91	15.21	9.84	9.84	N/S	17ab	60	34	-26	491	298	16171952	9804826	39%
6350	3.95	331.66	6.56	6.56	NE/SW	17ab	74	33	-41	502	195	11016334	4276585	61%
6400	3.98	205.77	6.56	6.56	NE/SW	17ab	74	36	-38	478	194	10486470	4261712	59%
6450	4.01	303.69	3.28	3.28	NE/SW	17ab	88	34	-54	490	89	5374682	977578	82%
6500	4.04	240.93	6.56	6.56	NE/SW	17ab	74	17	-57	617	193	13538663	4242604	69%
6550	4.07	248.43	3.28	3.28	E/W	17ab	91	15	-76	636	67	6976565	738970	89%
6600	4.10	224.09	3.28	3.28	NE/SW	17ab	88	26	-62	550	89	6034535	978937	84%
6650	4.13	139.64	6.56	6.56	NE/SW	17ab	74	19	-55	605	194	13275839	4262965	68%
6700	4.16	284.04	3.28	3.28	E/W	17ab	91	12	-79	655	67	7184513	735053	90%
6750	4.19	237.48	6.56	6.56	NE/SW	17ab	74	11	-63	662	193	14528849	4245961	71%
6800	4.23	258.23	3.28	3.28	E/W	17ab	91	54	-37	345	68	3786933	741197	80%

Table I-2. Elk Creek Shade-Related Data, TMDLs, Existing Solar Loading, and the Percent Increase in Shade Needed to Meet the TMDLs

Longitudinal Distance (m)	River Mile (RM)	Aspect	Wetted Width (ft)-GIS	Wetted Width (ft) TMDL	General Direction	Ecoregion	Target Shade (%)	Existing Shade (%)	Shade Difference (%)	Daily Solar Flux with Existing Shade (watts/ft2)	Daily Solar Flux with Potential Shade (watts/ft2)	Existing Load (kcal/day)	Potential Load (kcal/day)	Percent Reduction to Meet TMDL
6850	4.26	278.23	3.28	3.28	E/W	17ab	91	9	-82	677	67	7433847	735489	90%
6900	4.29	2.77	6.56	6.56	N/S	17ab	75	27	-48	546	187	11988808	4107283	66%
6950	4.32	225.94	6.56	6.56	NE/SW	17ab	74	18	-56	609	193	13374397	4242239	68%
7000	4.35	17.65	3.28	3.28	N/S	17ab	88	33	-55	502	90	5506489	986604	82%
7050	4.38	303.71	3.28	3.28	NE/SW	17ab	88	36	-52	481	90	5275676	989557	81%
7100	4.41	206.89	3.28	3.28	NE/SW	17ab	88	40	-48	449	90	4925512	985469	80%
7150	4.44	334.54	3.28	3.28	NE/SW	17ab	88	48	-40	388	89	4252358	981678	77%
7200	4.47	247.71	6.56	6.56	E/W	17ab	71	9	-62	679	216	14898760	4749722	68%
7250	4.50	225.00	3.28	3.28	NE/SW	17ab	88	56	-32	329	90	3608638	984540	73%
7300	4.54	284.44	3.28	3.28	E/W	17ab	91	67	-24	249	68	2736818	746683	73%
7350	4.57	288.03	3.28	3.28	E/W	17ab	91	17	-74	616	67	6759413	733221	89%
7400	4.60	352.87	3.28	3.28	N/S	17ab	88	51	-37	368	90	4040478	989873	76%
7450	4.63	337.72	6.56	6.56	N/S	17ab	75	32	-43	510	188	11192674	4116483	63%
7500	4.66	312.35	6.56	6.56	NE/SW	17ab	74	20	-54	599	195	13149146	4275061	67%
7550	4.69	247.66	6.56	6.56	E/W	17ab	71	9	-62	678	216	14879287	4743514	68%
7600	4.72	283.50	3.28	3.28	E/W	17ab	91	38	-53	463	67	5083506	738203	85%
7650	4.75	238.76	3.28	3.28	NE/SW	17ab	88	38	-50	462	90	5072596	982158	81%
7700	4.78	337.70	3.28	3.28	N/S	17ab	88	42	-46	433	90	4746528	982405	79%
7750	4.82	204.44	3.28	3.28	NE/SW	17ab	88	42	-46	434	90	4762650	985742	79%
7800	4.85	20.09	3.28	3.28	N/S	17ab	88	72	-16	209	90	2296931	984765	57%
7850	4.88	355.54	6.56	6.56	N/S	17ab	75	54	-21	344	187	7547252	4103292	46%
7900	4.91	237.14	3.28	3.28	NE/SW	17ab	88	50	-38	371	89	4070059	977177	76%
7950	4.94	311.19	3.28	3.28	NE/SW	17ab	88	68	-20	241	90	2639501	990181	62%
8000	4.97	293.96	3.28	3.28	NE/SW	17ab	88	96	8	30	90	330273	991189	0%

Table I-2. Elk Creek Shade-Related Data, TMDLs, Existing Solar Loading, and the Percent Increase in Shade Needed to Meet the TMDLs

Longitudinal Distance (m)	River Mile (RM)	Aspect	Wetted Width (ft)-GIS	Wetted Width (ft) TMDL	General Direction	Ecoregion	Target Shade (%)	Existing Shade (%)	Shade Difference (%)	Daily Solar Flux with Existing Shade (watts/ft2)	Daily Solar Flux with Potential Shade (watts/ft2)	Existing Load (kcal/day)	Potential Load (kcal/day)	Percent Reduction to Meet TMDL
8050	5.00	239.65	3.28	3.28	NE/SW	17ab	88	46	-42	400	89	4389102	975719	78%
8100	5.03	195.46	3.28	3.28	N/S	17ab	88	90	2	75	90	818348	982383	0%
8150	5.06	270.00	6.56	6.56	E/W	17ab	71	8	-63	684	216	15020059	4736344	68%
8200	5.10	245.07	6.56	6.56	NE/SW	17ab	74	14	-60	644	195	14142059	4277096	70%
8250	5.13	325.56	9.84	9.84	NE/SW	17ab	58	13	-45	647	313	21314385	10293528	52%
8300	5.16	298.65	6.56	6.56	NE/SW	17ab	74	50	-24	376	195	8245126	4289059	48%
8350	5.19	340.71	6.56	6.56	N/S	17ab	75	51	-24	362	185	7941112	4053094	49%
8400	5.22	331.46	3.28	3.28	NE/SW	17ab	88	66	-22	253	89	2772291	978819	65%
8450	5.25	265.95	6.56	6.56	E/W	17ab	71	9	-62	675	215	14814367	4722817	68%
8500	5.28	323.13	6.56	6.56	NE/SW	17ab	74	56	-18	328	194	7205518	4259389	41%
8550	5.31	306.77	6.56	6.56	NE/SW	17ab	74	48	-26	388	194	8510173	4256668	50%
8600	5.34	33.39	3.28	3.28	NE/SW	17ab	88	68	-20	240	90	2637011	989247	62%
8650	5.37	193.65	3.28	3.28	N/S	17ab	88	52	-36	355	89	3897507	974739	75%
8700	5.41	222.51	9.84	9.84	NE/SW	17ab	58	11	-47	667	315	21947968	10361318	53%
8750	5.44	235.56	6.56	6.56	NE/SW	17ab	74	25	-49	562	195	12339525	4279292	65%
8800	5.47	353.05	3.28	3.28	N/S	17ab	88	44	-44	421	90	4614869	989268	79%
8850	5.50	302.99	13.12	13.12	NE/SW	17ab	48	6	-42	701	388	30767605	17026705	45%
8900	5.53	265.64	9.84	9.84	E/W	17ab	50	6	-44	701	373	23075874	12278964	47%
8950	5.56	193.61	13.12	13.12	N/S	17ab	51	12	-39	657	366	28837331	16063120	44%
9000	5.59	312.97	13.12	13.12	NE/SW	17ab	48	7	-41	693	388	30432257	17022211	44%
9050	5.62	316.03	9.84	9.84	NE/SW	17ab	58	11	-47	665	314	21877733	10328161	53%
9100	5.65	293.54	6.56	6.56	NE/SW	17ab	74	13	-61	646	193	14178681	4238882	70%
9150	5.69	358.81	6.56	6.56	N/S	17ab	75	23	-52	575	187	12625442	4100693	68%
9200	5.72	71.57	6.56	6.56	E/W	17ab	71	8	-63	683	215	14981470	4724175	68%

Table I-2. Elk Creek Shade-Related Data, TMDLs, Existing Solar Loading, and the Percent Increase in Shade Needed to Meet the TMDLs

Longitudinal Distance (m)	River Mile (RM)	Aspect	Wetted Width (ft)-GIS	Wetted Width (ft) TMDL	General Direction	Ecoregion	Target Shade (%)	Existing Shade (%)	Shade Difference (%)	Daily Solar Flux with Existing Shade (watts/ft2)	Daily Solar Flux with Potential Shade (watts/ft2)	Existing Load (kcal/day)	Potential Load (kcal/day)	Percent Reduction to Meet TMDL
9250	5.75	282.23	6.56	6.56	E/W	17ab	71	9	-62	675	215	14819470	4724444	68%
9300	5.78	201.37	6.56	6.56	N/S	17ab	75	24	-51	570	188	12507679	4115898	67%
9350	5.81	43.45	6.56	6.56	NE/SW	17ab	74	18	-56	612	194	13438150	4262461	68%
9400	5.84	17.61	6.56	6.56	N/S	17ab	75	24	-51	570	187	12498917	4113014	67%
9450	5.87	237.26	6.56	6.56	NE/SW	17ab	74	16	-58	625	194	13724106	4249517	69%
9500	5.90	317.66	6.56	6.56	NE/SW	17ab	74	18	-56	612	194	13438851	4262683	68%
9550	5.93	6.54	6.56	6.56	N/S	17ab	75	24	-51	564	186	12384238	4075277	67%
9600	5.97	319.40	6.56	6.56	NE/SW	17ab	74	21	-53	591	195	12971565	4270710	67%
9650	6.00	274.69	6.56	6.56	E/W	17ab	71	7	-64	694	216	15220750	4748020	69%
9700	6.03	331.53	6.56	6.56	NE/SW	17ab	74	23	-51	577	195	12665827	4278362	66%
9750	6.06	295.20	3.28	3.28	NE/SW	17ab	88	48	-40	389	90	4266923	985040	77%
9800	6.09	298.93	9.84	9.84	NE/SW	17ab	58	8	-50	685	313	22554299	10300356	54%
9850	6.12	248.70	9.84	9.84	E/W	17ab	50	7	-43	692	372	22772579	12247873	46%
9900	6.15	268.69	6.56	6.56	E/W	17ab	71	6	-65	700	216	15359216	4740243	69%
9950	6.18	333.44	6.56	6.56	NE/SW	17ab	74	23	-51	577	195	12656500	4275212	66%
10000	6.21	302.15	6.56	6.56	NE/SW	17ab	74	12	-62	657	194	14409461	4258923	70%
10050	6.24	193.24	6.56	6.56	N/S	17ab	75	25	-50	556	186	12212972	4072504	67%
10100	6.28	295.59	13.12	13.12	NE/SW	17ab	48	6	-42	704	389	30886688	17092605	45%
10150	6.31	284.17	13.12	13.12	E/W	17ab	38	5	-33	709	463	31118159	20316243	35%
10200	6.34	289.03	6.56	6.56	E/W	17ab	71	9	-62	676	215	14828599	4727354	68%
10250	6.37	1.55	6.56	6.56	N/S	17ab	75	23	-52	575	187	12622525	4099746	68%
10300	6.40	347.73	3.28	3.28	N/S	17ab	88	45	-43	408	89	4481848	978221	78%
10350	6.43	198.43	9.84	9.84	N/S	17ab	60	48	-12	386	297	12722920	9790500	23%
10400	6.46	172.40	3.28	3.28	N/S	17ab	88	72	-16	206	89	2265905	971463	57%

Table I-2. Elk Creek Shade-Related Data, TMDLs, Existing Solar Loading, and the Percent Increase in Shade Needed to Meet the TMDLs

Longitudinal Distance (m)	River Mile (RM)	Aspect	Wetted Width (ft)-GIS	Wetted Width (ft) TMDL	General Direction	Ecoregion	Target Shade (%)	Existing Shade (%)	Shade Difference (%)	Daily Solar Flux with Existing Shade (watts/ft2)	Daily Solar Flux with Potential Shade (watts/ft2)	Existing Load (kcal/day)	Potential Load (kcal/day)	Percent Reduction to Meet TMDL
10450	6.49	319.27	6.56	6.56	NE/SW	17ab	74	60	-14	295	192	6473396	4209272	35%
10500	6.52	303.98	9.84	9.84	NE/SW	17ab	58	41	-17	440	313	14479008	10310922	29%
10550	6.56	315.00	9.84	9.84	NE/SW	17ab	58	37	-21	468	312	15405450	10274118	33%
10600	6.59	298.07	13.12	13.12	NE/SW	17ab	48	18	-30	614	390	26961169	17103683	37%
10650	6.62	311.91	13.12	13.12	NE/SW	17ab	48	34	-14	495	390	21721987	17120655	21%
10700	6.65	305.22	9.84	9.84	NE/SW	17ab	58	9	-49	678	313	22306400	10299089	54%
10750	6.68	201.80	6.56	6.56	N/S	17ab	75	24	-51	564	186	12372232	4071326	67%
10800	6.71	265.91	20.00	15.00	E/W	17ab	18	3	-15	722	610	48277834	30620521	37%
10850	6.74	237.61	6.56	6.56	NE/SW	17ab	74	55	-19	333	192	7308882	4224479	42%
10900	6.77	290.14	9.84	9.84	E/W	17ab	50	29	-21	528	372	17395024	12254571	30%
10950	6.80	303.49	9.84	9.84	NE/SW	17ab	58	37	-21	467	311	15363054	10245843	33%
11000	6.84	9.71	6.56	6.56	N/S	17ab	75	47	-28	393	186	8630274	4072397	53%
11050	6.87	266.93	6.56	6.56	E/W	17ab	17	6	-11	704	622	15454946	13651461	12%
11100	6.90	345.34	6.56	6.56	N/S	17ab	18	8	-10	688	614	15102055	13465531	11%
11150	6.93	4.09	6.56	6.56	N/S	17ab	16	4	-12	713	624	15652710	13701212	12%
11200	6.96	9.43	6.56	6.56	N/S	17ab	13	5	-8	710	651	15591915	14284220	8%
11250	6.99	334.84	6.56	6.56	NE/SW	17ab	13	4	-9	718	651	15749517	14278306	9%
11300	7.02	71.57	6.56	6.56	E/W	17ab	7	3	-4	721	692	15833176	15185905	4%
11350	7.05	353.89	6.56	6.56	N/S	17ab	13	3	-10	724	650	15893513	14260306	10%
11400	7.08	324.49	6.56	6.56	NE/SW	17ab	13	3	-10	721	647	15815435	14190251	10%
11450	7.11	6.52	6.56	6.56	N/S	17ab	13	6	-7	700	648	15358827	14220369	7%
11500	7.15	305.67	6.56	6.56	NE/SW	17ab	17	5	-12	709	620	15565125	13604059	13%
11550	7.18	353.59	9.84	9.84	N/S	17ab	60	47	-13	393	297	12930583	9762558	25%
11600	7.21	353.52	16.40	15.00	N/S	17ab	45	29	-16	526	407	28846651	20446010	29%

Table I-2. Elk Creek Shade-Related Data, TMDLs, Existing Solar Loading, and the Percent Increase in Shade Needed to Meet the TMDLs

Longitudinal Distance (m)	River Mile (RM)	Aspect	Wetted Width (ft)-GIS	Wetted Width (ft) TMDL	General Direction	Ecoregion	Target Shade (%)	Existing Shade (%)	Shade Difference (%)	Daily Solar Flux with Existing Shade (watts/ft2)	Daily Solar Flux with Potential Shade (watts/ft2)	Existing Load (kcal/day)	Potential Load (kcal/day)	Percent Reduction to Meet TMDL
11650	7.24	26.74	19.68	15.00	NE/SW	17ab	36	22	-14	583	479	38401381	24024801	37%
11700	7.27	18.44	13.12	13.12	N/S	17ab	51	27	-24	544	365	23867109	16026344	33%
11750	7.30	289.84	20.00	15.00	E/W	17ab	20	4	-16	713	595	47734279	29845015	37%
11800	7.33	0.00	19.68	15.00	N/S	17ab	39	26	-13	552	455	36322002	22829451	37%
11850	7.36	356.24	13.12	13.12	N/S	17ab	51	38	-13	459	363	20134606	15918749	21%
11900	7.39	27.00	16.40	15.00	NE/SW	17ab	42	29	-13	531	434	29113386	21760616	25%
11950	7.43	72.32	19.68	15.00	E/W	17ab	27	10	-17	670	543	44089212	27267183	38%
12000	7.46	290.04	9.84	9.84	E/W	17ab	50	13	-37	645	371	21237360	12209917	43%
12050	7.49	272.25	13.12	13.12	E/W	17ab	38	10	-28	673	464	29555606	20368098	31%
12100	7.52	334.44	9.84	9.84	NE/SW	17ab	58	49	-9	381	314	12543149	10333492	18%
12150	7.55	276.58	13.12	13.12	E/W	17ab	38	10	-28	673	464	29549647	20363991	31%
12200	7.58	266.08	9.84	9.84	E/W	17ab	50	19	-31	604	373	19887145	12280579	38%
12250	7.61	7.06	9.84	9.84	N/S	17ab	60	33	-27	501	299	16487305	9846826	40%
12300	7.64	307.46	16.40	15.00	NE/SW	17ab	42	17	-25	622	435	34115865	21812986	36%
12350	7.67	36.51	9.84	9.84	NE/SW	17ab	58	34	-24	490	312	16146663	10278969	36%
12400	7.71	261.66	6.56	6.56	E/W	17ab	71	33	-38	501	217	10990486	4758844	57%
12450	7.74	313.05	6.56	6.56	NE/SW	17ab	13	4	-9	716	649	15711428	14243775	9%
12500	7.77	2.64	6.56	6.56	N/S	17ab	12	4	-8	715	656	15692421	14390067	8%
12550	7.80	6.82	13.12	13.12	N/S	17ab	51	22	-29	580	364	25456559	15997886	37%
12600	7.83	26.47	13.12	13.12	NE/SW	17ab	48	25	-23	556	385	24383611	16912255	31%
12650	7.86	252.35	6.56	6.56	E/W	17ab	71	10	-61	669	216	14682494	4732785	68%
12700	7.89	317.12	9.84	9.84	NE/SW	17ab	58	44	-14	421	316	13858901	10398040	25%
12750	7.92	329.09	9.84	9.84	NE/SW	17ab	58	27	-31	546	314	17972397	10344127	42%
12800	7.95	295.92	3.28	3.28	NE/SW	17ab	88	62	-26	286	90	3135373	990486	68%

Table I-2. Elk Creek Shade-Related Data, TMDLs, Existing Solar Loading, and the Percent Increase in Shade Needed to Meet the TMDLs

Longitudinal Distance (m)	River Mile (RM)	Aspect	Wetted Width (ft)-GIS	Wetted Width (ft) TMDL	General Direction	Ecoregion	Target Shade (%)	Existing Shade (%)	Shade Difference (%)	Daily Solar Flux with Existing Shade (watts/ft2)	Daily Solar Flux with Potential Shade (watts/ft2)	Existing Load (kcal/day)	Potential Load (kcal/day)	Percent Reduction to Meet TMDL
12850	7.98	304.48	6.56	6.56	NE/SW	17ab	74	60	-14	298	194	6537441	4250916	35%
12900	8.02	324.50	6.56	6.56	NE/SW	17ab	74	59	-15	305	194	6697279	4248634	37%
12950	8.05	332.87	3.28	3.28	NE/SW	17ab	88	69	-19	231	90	2539183	983275	61%
13000	8.08	254.35	16.40	15.00	E/W	17ab	31	10	-21	672	515	36877177	25868609	30%
13050	8.11	306.54	9.84	9.84	NE/SW	17ab	58	32	-26	505	312	16632809	10277024	38%
13100	8.14	286.24	13.12	13.12	E/W	17ab	38	13	-25	651	464	28554221	20356550	29%
13150	8.17	41.67	19.68	15.00	NE/SW	17ab	36	20	-16	598	478	39352078	24004090	39%
13200	8.20	19.43	6.56	6.56	N/S	17ab	75	51	-24	368	188	8080157	4124062	49%
13250	8.23	68.96	9.84	9.84	E/W	17ab	50	23	-27	576	374	18957414	12314585	35%
13300	8.26	355.16	16.40	15.00	N/S	17ab	45	33	-12	502	412	27524926	20673922	25%
13350	8.30	50.91	9.84	9.84	NE/SW	17ab	58	37	-21	469	313	15447054	10301864	33%
13400	8.33	266.35	9.84	9.84	E/W	17ab	50	7	-43	695	374	22890555	12311325	46%
13450	8.36	351.67	19.68	15.00	N/S	17ab	39	17	-22	616	453	40577167	22738460	44%
13500	8.39	50.23	13.12	13.12	NE/SW	17ab	48	30	-18	522	388	22895259	17014230	26%
13550	8.42	354.81	9.84	9.84	N/S	17ab	60	50	-10	370	296	12167248	9737417	20%
13600	8.45	26.57	19.68	15.00	NE/SW	17ab	36	31	-5	518	480	34089623	24109081	29%
13650	8.48	345.11	16.40	15.00	N/S	17ab	45	38	-7	460	408	25242784	20488826	19%
13700	8.51	2.73	3.28	3.28	N/S	17ab	88	70	-18	221	88	2421843	969097	60%
13750	8.54	339.73	9.84	9.84	N/S	17ab	60	49	-11	377	296	12401198	9730046	22%
13800	8.57	12.01	6.56	6.56	N/S	17ab	75	64	-11	269	187	5907494	4103951	31%
13850	8.61	18.43	13.12	13.12	N/S	17ab	51	47	-4	392	363	17207023	15914294	8%
13900	8.64	13.06	9.84	9.84	N/S	17ab	60	47	-13	394	297	12958044	9783292	25%
13950	8.67	319.07	6.56	6.56	NE/SW	17ab	74	58	-16	311	193	6830648	4230068	38%
14000	8.70	331.47	6.56	6.56	NE/SW	17ab	74	83	9	128	195	2798396	4281491	0%

Table I-2. Elk Creek Shade-Related Data, TMDLs, Existing Solar Loading, and the Percent Increase in Shade Needed to Meet the TMDLs

Longitudinal Distance (m)	River Mile (RM)	Aspect	Wetted Width (ft)-GIS	Wetted Width (ft) TMDL	General Direction	Ecoregion	Target Shade (%)	Existing Shade (%)	Shade Difference (%)	Daily Solar Flux with Existing Shade (watts/ft2)	Daily Solar Flux with Potential Shade (watts/ft2)	Existing Load (kcal/day)	Potential Load (kcal/day)	Percent Reduction to Meet TMDL
14050	8.73	276.87	13.12	13.12	E/W	17ab	38	92	54	59	460	2606749	20209816	0%
14100	8.76	323.00	9.84	9.84	NE/SW	17ab	58	55	-3	333	311	10970176	10242637	7%
14150	8.79	280.20	9.84	9.84	E/W	17ab	50	97	47	21	356	703127	11723135	0%
14200	8.82	283.31	16.40	15.00	E/W	17ab	31	71	40	214	510	11751237	25582531	0%
14250	8.85	271.31	13.12	13.12	E/W	17ab	38	94	56	48	494	2098170	21689151	0%
14300	8.89	344.55	16.40	15.00	N/S	17ab	45	7	-38	691	409	37891216	20503458	46%
14350	8.92	318.01	13.12	13.12	NE/SW	17ab	48	10	-38	674	390	29603151	17110401	42%
14400	8.95	206.91	16.40	15.00	NE/SW	17ab	42	8	-34	686	432	37622156	21701646	42%
14450	8.98	288.66	13.12	13.12	E/W	17ab	38	11	-27	661	460	29005002	20213243	30%
14500	9.01	329.96	13.12	13.12	NE/SW	17ab	48	40	-8	446	387	19572321	16968984	13%
14550	9.04	306.87	13.12	13.12	NE/SW	17ab	48	31	-17	516	389	22628134	17059426	25%
14600	9.07	266.53	13.12	13.12	E/W	17ab	38	9	-29	678	462	29764367	20286558	32%
14650	9.10	281.31	9.84	9.84	E/W	17ab	50	20	-30	600	375	19738341	12341049	37%
14700	9.13	25.71	16.40	15.00	NE/SW	17ab	42	27	-15	547	434	29985341	21798317	27%
14750	9.17	337.43	9.84	9.84	NE/SW	17ab	58	45	-13	407	311	13398847	10235650	24%
14800	9.20	253.01	13.12	13.12	E/W	17ab	38	11	-27	661	460	28998642	20208811	30%
14850	9.23	349.22	9.84	9.84	N/S	17ab	60	49	-11	384	301	12625866	9906322	22%
14900	9.26	295.32	13.12	13.12	NE/SW	17ab	48	78	30	167	395	7341846	17359904	0%
14950	9.29	317.44	9.84	9.84	NE/SW	17ab	58	42	-16	431	312	14193612	10281953	28%
15000	9.32	321.68	13.12	13.12	NE/SW	17ab	48	22	-26	581	387	25498882	17005574	33%
15050	9.35	265.53	9.84	9.84	E/W	17ab	50	11	-39	665	374	21894268	12304723	44%
15100	9.38	66.22	9.84	9.84	NE/SW	17ab	58	21	-37	590	314	19434558	10336138	47%
15150	9.41	6.34	16.40	15.00	N/S	17ab	45	31	-14	514	410	28216092	20578764	27%
15200	9.44	300.80	9.84	9.84	NE/SW	17ab	58	36	-22	480	315	15818369	10384664	34%

Table I-2. Elk Creek Shade-Related Data, TMDLs, Existing Solar Loading, and the Percent Increase in Shade Needed to Meet the TMDLs

Longitudinal Distance (m)	River Mile (RM)	Aspect	Wetted Width (ft)-GIS	Wetted Width (ft) TMDL	General Direction	Ecoregion	Target Shade (%)	Existing Shade (%)	Shade Difference (%)	Daily Solar Flux with Existing Shade (watts/ft2)	Daily Solar Flux with Potential Shade (watts/ft2)	Existing Load (kcal/day)	Potential Load (kcal/day)	Percent Reduction to Meet TMDL
15250	9.48	250.13	16.40	15.00	E/W	17ab	31	12	-19	656	514	35982038	25814339	28%
15300	9.51	305.54	9.84	9.84	NE/SW	17ab	58	37	-21	468	312	15398692	10269611	33%
15350	9.54	276.86	9.84	9.84	E/W	17ab	50	11	-39	667	375	21948893	12335423	44%
15400	9.57	267.87	9.84	9.84	E/W	17ab	50	87	37	97	374	3195760	12295954	0%
15450	9.60	280.12	13.12	13.12	E/W	17ab	38	81	43	140	456	6129596	20009275	0%
15500	9.63	347.88	9.84	9.84	N/S	17ab	60	40	-20	446	298	14693993	9799637	33%
15550	9.66	274.09	20.00	15.00	E/W	17ab	23	9	-14	682	577	45601211	28949988	37%
15600	9.69	257.77	16.40	15.00	E/W	17ab	31	10	-21	669	513	36685206	25733945	30%
15650	9.72	320.06	13.12	13.12	NE/SW	17ab	48	40	-8	449	389	19691227	17072074	13%
15700	9.76	323.86	6.56	6.56	NE/SW	17ab	74	79	5	156	193	3413044	4227244	0%
15750	9.79	283.91	9.84	9.84	E/W	17ab	50	15	-35	637	375	20957953	12332791	41%
15800	9.82	289.07	13.12	13.12	E/W	17ab	38	15	-23	637	465	27966950	20407006	27%
15850	9.85	311.66	19.68	15.00	NE/SW	17ab	36	35	-1	487	480	32065536	24073138	25%
15900	9.88	347.20	6.56	6.56	N/S	17ab	75	54	-21	340	185	7451952	4051479	46%
15950	9.91	283.15	9.84	9.84	E/W	17ab	50	15	-35	635	374	20919092	12309923	41%
16000	9.94	349.89	13.12	13.12	N/S	17ab	51	44	-7	419	367	18399573	16105611	12%
16050	9.97	311.71	16.40	15.00	NE/SW	17ab	42	67	25	245	430	13429536	21596526	0%
16100	10.00	323.34	20.00	15.00	NE/SW	17ab	32	34	2	494	509	33053595	25550909	23%
16150	10.04	0.40	13.12	13.12	N/S	17ab	51	45	-6	412	367	18092013	16124330	11%
16200	10.07	331.26	6.56	6.56	NE/SW	17ab	74	63	-11	278	195	6096616	4285701	30%
16250	10.10	335.81	9.84	9.84	NE/SW	17ab	58	51	-7	363	311	11939867	10237976	14%
16300	10.13	335.63	9.84	9.84	NE/SW	17ab	58	47	-11	396	314	13026785	10326950	21%
16350	10.16	300.96	6.56	6.56	NE/SW	17ab	74	48	-26	387	194	8504287	4253724	50%
16400	10.19	293.08	6.56	6.56	NE/SW	17ab	74	41	-33	443	195	9727482	4288281	56%

Table I-2. Elk Creek Shade-Related Data, TMDLs, Existing Solar Loading, and the Percent Increase in Shade Needed to Meet the TMDLs

Longitudinal Distance (m)	River Mile (RM)	Aspect	Wetted Width (ft)-GIS	Wetted Width (ft) TMDL	General Direction	Ecoregion	Target Shade (%)	Existing Shade (%)	Shade Difference (%)	Daily Solar Flux with Existing Shade (watts/ft2)	Daily Solar Flux with Potential Shade (watts/ft2)	Existing Load (kcal/day)	Potential Load (kcal/day)	Percent Reduction to Meet TMDL
16450	10.22	338.93	13.12	13.12	N/S	17ab	51	55	4	334	364	14656710	15965461	0%
16500	10.25	298.41	20.00	15.00	NE/SW	17ab	26	23	-3	572	550	38257965	27585798	28%
16550	10.28	347.68	9.84	9.84	N/S	17ab	60	63	3	277	300	9125478	9869049	0%
16600	10.31	42.08	13.12	13.12	NE/SW	17ab	48	33	-15	501	389	21975685	17062096	22%
16650	10.35	325.20	13.12	13.12	NE/SW	17ab	48	42	-6	429	385	18850302	16906554	10%
16700	10.38	15.62	9.84	9.84	N/S	17ab	60	53	-7	348	296	11447065	9745805	15%
16750	10.41	5.42	13.12	13.12	N/S	17ab	51	63	12	278	368	12207658	16172909	0%
16800	10.44	52.52	16.40	15.00	NE/SW	17ab	42	42	0	429	430	23558650	21555556	9%
16850	10.47	40.09	13.12	13.12	NE/SW	17ab	48	65	17	258	384	11342014	16857257	0%
16900	10.50	56.38	13.12	13.12	NE/SW	17ab	48	82	34	133	384	5827663	16841729	0%
16950	10.53	47.91	13.12	13.12	NE/SW	17ab	48	89	41	80	380	3530726	16696910	0%
17000	10.56	77.03	9.84	9.84	E/W	17ab	50	91	41	65	361	2136814	11875601	0%
17050	10.59	69.88	13.12	13.12	E/W	17ab	38	78	40	165	465	7235778	20399319	0%
17100	10.63	8.97	13.12	13.12	N/S	17ab	51	57	6	322	367	14115747	16091366	0%
17150	10.66	20.70	9.84	9.84	N/S	17ab	60	74	14	191	293	6277580	9661406	0%
17200	10.69	341.81	9.84	9.84	N/S	17ab	60	53	-7	349	297	11476961	9771257	15%
17250	10.72	290.83	16.40	15.00	E/W	17ab	31	37	6	470	515	25790130	25844665	0%
17300	10.75	330.34	19.68	15.00	NE/SW	17ab	36	25	-11	561	479	36910107	24015498	35%
17350	10.78	118.75	16.40	15.00	NE/SW	17ab	42	32	-10	509	435	27944062	21808081	22%
17400	10.81	93.13	13.12	13.12	E/W	17ab	10	4	-6	715	670	31377512	29427353	6%
17450	10.84	307.87	9.84	9.84	NE/SW	17ab	58	17	-41	616	312	20285787	10268913	49%
17500	10.87	162.01	19.68	15.00	N/S	17ab	39	25	-14	558	454	36763739	22799001	38%
17550	10.91	51.01	20.00	15.00	NE/SW	17ab	32	12	-20	659	509	44077764	25554564	42%
17600	10.94	42.31	13.12	13.12	NE/SW	17ab	48	29	-19	531	389	23316558	17083264	27%

Table I-2. Elk Creek Shade-Related Data, TMDLs, Existing Solar Loading, and the Percent Increase in Shade Needed to Meet the TMDLs

Longitudinal Distance (m)	River Mile (RM)	Aspect	Wetted Width (ft)-GIS	Wetted Width (ft) TMDL	General Direction	Ecoregion	Target Shade (%)	Existing Shade (%)	Shade Difference (%)	Daily Solar Flux with Existing Shade (watts/ft2)	Daily Solar Flux with Potential Shade (watts/ft2)	Existing Load (kcal/day)	Potential Load (kcal/day)	Percent Reduction to Meet TMDL
17650	10.97	53.13	13.12	13.12	NE/SW	17ab	48	35	-13	483	387	21220357	16982596	20%
17700	11.00	340.11	9.84	9.84	N/S	17ab	60	42	-18	432	298	14219823	9810420	31%
17750	11.03	33.69	20.00	15.00	NE/SW	17ab	32	25	-7	556	504	37190590	25299002	32%
17800	11.06	11.20	13.12	13.12	N/S	17ab	51	38	-13	465	368	20403494	16131337	21%
17850	11.09	29.59	16.40	15.00	NE/SW	17ab	42	35	-7	481	429	26385720	21542317	18%
17900	11.12	316.11	13.12	13.12	NE/SW	17ab	48	33	-15	497	386	21796970	16923340	22%
17950	11.15	241.03	13.12	13.12	NE/SW	17ab	48	25	-23	562	390	24658525	17102933	31%
18000	11.18	45.13	16.40	15.00	NE/SW	17ab	42	27	-15	548	436	30064350	21855754	27%
18050	11.22	287.49	9.84	9.84	E/W	17ab	50	6	-44	698	372	22990296	12233427	47%
18100	11.25	8.60	19.68	15.00	N/S	17ab	39	6	-33	704	457	46354409	22936155	51%
18150	11.28	340.37	16.40	15.00	N/S	17ab	45	8	-37	685	410	37569717	20550463	45%
18200	11.31	303.99	13.12	13.12	NE/SW	17ab	48	6	-42	699	387	30667512	16971314	45%
18250	11.34	56.31	16.40	15.00	NE/SW	17w	42	5	-37	706	431	38722287	21630881	44%
18300	11.37	87.28	16.40	15.00	E/W	17w	31	4	-27	718	516	39391992	25905658	34%
18350	11.40	87.14	13.12	13.12	E/W	17w	38	5	-33	712	465	31247784	20400872	35%
18400	11.43	88.65	9.84	9.84	E/W	17w	50	5	-45	707	372	23268411	12251084	47%
18450	11.46	45.17	16.40	15.00	NE/SW	17w	42	6	-36	704	435	38627443	21807452	44%
18500	11.50	19.70	13.12	13.12	N/S	17w	51	11	-40	664	366	29154772	16057471	45%
18550	11.53	352.87	13.12	13.12	N/S	17w	51	24	-27	565	364	24787922	15987628	36%
18600	11.56	341.76	9.84	9.84	N/S	17w	60	25	-35	560	299	18451149	9844271	47%
18650	11.59	18.89	13.12	13.12	N/S	17w	51	28	-23	537	366	23588906	16059529	32%
18700	11.62	346.51	19.68	15.00	N/S	17w	39	15	-24	631	453	41577035	22750556	45%
18750	11.65	57.79	20.00	15.00	NE/SW	17w	32	3	-29	726	509	48572897	25547821	47%
18800	11.68	10.30	9.84	9.84	N/S	17w	60	15	-45	634	299	20878699	9828923	53%

Table I-2. Elk Creek Shade-Related Data, TMDLs, Existing Solar Loading, and the Percent Increase in Shade Needed to Meet the TMDLs

Longitudinal Distance (m)	River Mile (RM)	Aspect	Wetted Width (ft)-GIS	Wetted Width (ft) TMDL	General Direction	Ecoregion	Target Shade (%)	Existing Shade (%)	Shade Difference (%)	Daily Solar Flux with Existing Shade (watts/ft2)	Daily Solar Flux with Potential Shade (watts/ft2)	Existing Load (kcal/day)	Potential Load (kcal/day)	Percent Reduction to Meet TMDL
18850	11.71	53.19	16.40	15.00	NE/SW	17w	42	5	-37	711	434	38997352	21784537	44%
18900	11.74	322.40	13.12	13.12	NE/SW	17w	48	18	-30	610	387	26762816	16977851	37%
18950	11.77	11.03	13.12	13.12	N/S	17w	51	10	-41	667	364	29296744	15956379	46%
19000	11.81	355.12	9.84	9.84	N/S	17w	60	19	-41	605	299	19915431	9838437	51%
19050	11.84	347.73	9.84	9.84	N/S	17w	60	15	-45	636	300	20951695	9863287	53%
19100	11.87	36.23	9.84	9.84	NE/SW	17w	58	13	-45	651	314	21423551	10346249	52%
19150	11.90	342.84	6.56	6.56	N/S	17w	75	28	-47	536	186	11768340	4087748	65%
19200	11.93	33.95	19.68	15.00	NE/SW	17w	36	14	-22	640	477	42159650	23922474	43%
19250	11.96	328.71	13.12	13.12	NE/SW	17w	48	18	-30	608	386	26705292	16941359	37%
19300	11.99	10.22	16.40	15.00	N/S	17w	45	11	-34	663	410	36382750	20572025	43%
19350	12.02	62.45	19.68	15.00	NE/SW	17w	36	4	-32	717	478	47185432	23985251	49%
19400	12.05	11.17	19.68	15.00	N/S	17w	39	17	-22	617	454	40641816	22774687	44%
19450	12.09	274.29	16.40	15.00	E/W	17w	1	1	0	738	738	40496977	37053688	9%
19500	12.12	10.77	16.40	15.00	N/S	17w	45	11	-34	663	410	36374833	20567548	43%
19550	12.15	49.76	20.00	15.00	NE/SW	17w	32	9	-23	676	505	45245219	25366637	44%
19600	12.18	39.33	9.84	9.84	NE/SW	17w	58	13	-45	651	314	21422459	10345721	52%
19650	12.21	79.30	16.40	15.00	E/W	17w	31	10	-21	671	514	36791844	25808749	30%
19700	12.24	347.52	13.12	13.12	N/S	17w	51	17	-34	617	365	27098855	16004066	41%
19750	12.27	256.46	13.12	13.12	E/W	17w	38	9	-29	676	461	29674860	20225553	32%
19800	12.30	22.98	9.84	9.84	NE/SW	17w	58	16	-42	624	312	20530812	10269222	50%
19850	12.33	358.80	6.56	6.56	N/S	17w	75	58	-17	313	187	6874280	4093354	40%
19900	12.37	292.77	9.84	9.84	NE/SW	17w	58	7	-51	694	314	22855904	10325858	55%
19950	12.40	33.55	9.84	9.84	NE/SW	17w	58	37	-21	473	315	15555337	10374080	33%
20000	12.43	277.77	6.56	6.56	E/W	17w	71	10	-61	674	217	14782364	4764977	68%

Table I-2. Elk Creek Shade-Related Data, TMDLs, Existing Solar Loading, and the Percent Increase in Shade Needed to Meet the TMDLs

Longitudinal Distance (m)	River Mile (RM)	Aspect	Wetted Width (ft)-GIS	Wetted Width (ft) TMDL	General Direction	Ecoregion	Target Shade (%)	Existing Shade (%)	Shade Difference (%)	Daily Solar Flux with Existing Shade (watts/ft2)	Daily Solar Flux with Potential Shade (watts/ft2)	Existing Load (kcal/day)	Potential Load (kcal/day)	Percent Reduction to Meet TMDL
20050	12.46	273.81	16.40	15.00	E/W	17w	31	7	-24	693	514	38033793	25819309	32%
20100	12.49	327.45	9.84	9.84	NE/SW	17w	58	25	-33	560	314	18448197	10334831	44%
20150	12.52	328.59	9.84	9.84	NE/SW	17w	58	42	-16	435	315	14312112	10367796	28%
20200	12.55	45.76	9.84	9.84	NE/SW	17w	58	31	-27	514	313	16916748	10300979	39%
20250	12.58	343.04	9.84	9.84	N/S	17w	60	21	-39	590	299	19419009	9836065	49%
20300	12.61	352.75	9.84	9.84	N/S	17w	60	16	-44	628	299	20661042	9842249	52%
20350	12.64	343.30	13.12	13.12	N/S	17w	51	10	-41	671	365	29442638	16035840	46%
20400	12.68	38.51	9.84	9.84	NE/SW	17w	58	10	-48	668	312	21979020	10260689	53%
20450	12.71	279.97	19.68	15.00	E/W	17w	27	3	-24	726	546	47786278	27420913	43%
20500	12.74	349.62	19.68	15.00	N/S	17w	39	6	-33	703	457	46305664	22912036	51%
20550	12.77	13.48	19.68	15.00	N/S	17w	39	4	-35	717	456	47219513	22877454	52%
20600	12.80	27.57	9.84	9.84	NE/SW	17w	58	12	-46	653	312	21483617	10257356	52%
20650	12.83	307.22	16.40	15.00	NE/SW	17w	42	19	-23	607	435	33290693	21810953	34%
20700	12.86	297.53	3.28	3.28	NE/SW	17w	88	62	-26	284	90	3121095	985975	68%
20750	12.89	229.99	9.84	9.84	NE/SW	17w	58	10	-48	669	312	22025964	10282604	53%
20800	12.92	295.87	13.12	13.12	NE/SW	17w	48	5	-43	705	386	30926832	16934664	45%
20850	12.96	306.33	9.84	9.84	NE/SW	17w	58	10	-48	674	315	22195694	10361841	53%
20900	12.99	51.71	9.84	9.84	NE/SW	17w	58	19	-39	606	314	19947772	10347134	48%
20950	13.02	21.34	6.56	6.56	N/S	17w	75	58	-17	316	188	6927510	4125051	40%
21000	13.05	234.19	16.40	15.00	NE/SW	17w	42	19	-23	603	432	33104455	21688936	34%
21050	13.08	300.47	9.84	9.84	NE/SW	17w	58	17	-41	619	313	20363897	10308453	49%
21100	13.11	93.63	9.84	9.84	E/W	17w	50	10	-40	669	372	22013647	12234350	44%
21150	13.14	341.30	13.12	13.12	N/S	17w	51	41	-10	441	367	19365582	16089259	17%
21200	13.17	2.53	6.56	6.56	N/S	17w	75	59	-16	307	187	6735083	4108285	39%

Table I-2. Elk Creek Shade-Related Data, TMDLs, Existing Solar Loading, and the Percent Increase in Shade Needed to Meet the TMDLs

Longitudinal Distance (m)	River Mile (RM)	Aspect	Wetted Width (ft)-GIS	Wetted Width (ft) TMDL	General Direction	Ecoregion	Target Shade (%)	Existing Shade (%)	Shade Difference (%)	Daily Solar Flux with Existing Shade (watts/ft2)	Daily Solar Flux with Potential Shade (watts/ft2)	Existing Load (kcal/day)	Potential Load (kcal/day)	Percent Reduction to Meet TMDL
21250	13.20	26.57	13.12	13.12	NE/SW	17w	48	25	-23	562	390	24664373	17106989	31%
21300	13.24	272.86	9.84	9.84	E/W	17w	50	6	-44	702	374	23123665	12304394	47%
21350	13.27	330.69	16.40	15.00	NE/SW	17w	42	17	-25	619	432	33943536	21702802	36%
21400	13.30	227.32	9.84	9.84	NE/SW	17w	58	19	-39	605	314	19925495	10335579	48%
21450	13.33	216.25	9.84	9.84	NE/SW	17w	13	2	-11	731	649	24064091	21370961	11%
21500	13.36	158.11	9.84	9.84	N/S	17w	60	47	-13	395	298	13002510	9816863	25%
21550	13.39	220.60	16.40	15.00	NE/SW	17w	42	15	-27	635	433	34817340	21737695	38%
21600	13.42	334.28	20.00	15.00	NE/SW	17w	29	16	-13	624	527	41735237	26466995	37%
21650	13.45	259.33	19.68	15.00	E/W	17w	27	7	-20	693	544	45628689	27308981	40%
21700	13.48	0.38	16.40	15.00	N/S	17w	45	8	-37	688	412	37768326	20659101	45%
21750	13.51	319.24	9.84	9.84	NE/SW	17w	58	19	-39	606	314	19937223	10341662	48%
21800	13.55	301.08	6.56	6.56	NE/SW	17w	19	3	-16	725	606	15922338	13300916	16%
21850	13.58	333.08	20.00	15.00	NE/SW	17w	29	9	-20	675	527	45163439	26437881	41%
21900	13.61	284.66	19.68	15.00	E/W	17w	27	9	-18	678	544	44636695	27302416	39%
21950	13.64	274.78	13.12	13.12	E/W	17w	38	11	-27	666	464	29236813	20374790	30%
22000	13.67	229.69	13.12	13.12	NE/SW	17w	24	7	-17	691	565	30334786	24798933	18%
22050	13.70	273.53	9.84	9.84	E/W	17w	50	11	-39	662	372	21783202	12242303	44%
22100	13.73	8.13	16.40	15.00	N/S	17w	45	29	-16	530	411	29065657	20601237	29%
22150	13.76	339.59	13.12	13.12	N/S	17w	51	9	-42	679	366	29785725	16044429	46%
22200	13.79	281.91	20.00	15.00	E/W	17w	23	8	-15	683	572	45680547	28685134	37%
22250	13.83	290.25	20.00	15.00	E/W	17w	23	12	-11	654	573	43775645	28738447	34%
22300	13.86	231.82	9.84	9.84	NE/SW	17w	58	24	-34	568	314	18685686	10330139	45%
22350	13.89	322.43	13.12	13.12	NE/SW	17w	48	21	-27	591	389	25932942	17076130	34%
22400	13.92	286.41	13.12	13.12	E/W	17w	38	6	-32	699	461	30690996	20250523	34%

Table I-2. Elk Creek Shade-Related Data, TMDLs, Existing Solar Loading, and the Percent Increase in Shade Needed to Meet the TMDLs

Longitudinal Distance (m)	River Mile (RM)	Aspect	Wetted Width (ft)-GIS	Wetted Width (ft) TMDL	General Direction	Ecoregion	Target Shade (%)	Existing Shade (%)	Shade Difference (%)	Daily Solar Flux with Existing Shade (watts/ft2)	Daily Solar Flux with Potential Shade (watts/ft2)	Existing Load (kcal/day)	Potential Load (kcal/day)	Percent Reduction to Meet TMDL
22450	13.95	348.69	19.68	15.00	N/S	17w	39	23	-16	571	453	37603774	22714236	40%
22500	13.98	311.04	16.40	15.00	NE/SW	17w	1	0	-1	743	736	40748353	36910853	9%
22550	14.01	263.07	19.68	15.00	E/W	17w	27	8	-19	688	546	45288459	27399975	39%
22600	14.04	172.30	20.00	15.00	N/S	17w	35	33	-2	497	482	33224690	24183668	27%
22650	14.07	270.99	20.00	15.00	E/W	17w	23	7	-16	690	571	46142892	28663899	38%
22700	14.11	22.27	20.00	15.00	N/S	17w	35	31	-4	514	484	34370346	24292424	29%
22750	14.14	232.78	20.00	15.00	NE/SW	17w	29	11	-18	660	527	44151998	26426606	40%
22800	14.17	207.46	20.00	15.00	NE/SW	17w	17	12	-5	658	621	44018601	31149734	29%
22850	14.20	274.23	20.00	15.00	E/W	17w	11	3	-8	724	665	48468452	33365689	31%
22900	14.23	264.60	16.40	15.00	E/W	17w	10	3	-7	727	675	39873277	33850223	15%
22950	14.26	227.15	16.40	15.00	NE/SW	17w	42	33	-9	499	432	27392668	21696833	21%
23000	14.29	281.71	9.84	9.84	E/W	17w	50	25	-25	561	374	18457404	12309510	33%
23050	14.32	279.28	13.12	13.12	E/W	17w	38	17	-21	622	465	27321410	20416351	25%
23100	14.35	231.21	19.68	15.00	NE/SW	17w	36	19	-17	603	477	39720357	23929613	40%
23150	14.38	199.77	19.68	15.00	N/S	17w	39	25	-14	556	452	36599137	22696924	38%
23200	14.42	295.05	9.84	9.84	NE/SW	17w	58	14	-44	639	312	21037663	10278027	51%
23250	14.45	253.51	13.12	13.12	E/W	17w	38	18	-20	609	461	26736267	20222741	24%
23300	14.48	172.96	6.56	6.56	N/S	17w	75	58	-17	315	188	6918350	4119596	40%
23350	14.51	224.06	13.12	13.12	NE/SW	17w	48	40	-8	450	390	19753110	17125726	13%
23400	14.54	290.67	16.40	15.00	E/W	17w	31	23	-8	571	512	31319345	25679104	18%
23450	14.57	259.45	16.40	15.00	E/W	17w	31	15	-16	630	512	34573743	25679431	26%
23500	14.60	291.55	13.12	13.12	E/W	17w	38	15	-23	636	464	27909796	20365302	27%
23550	14.63	181.97	16.40	15.00	N/S	17w	45	22	-23	580	409	31823510	20531704	35%
23600	14.66	341.76	13.12	13.12	N/S	17w	51	51	0	368	368	16150085	16156088	0%

Table I-2. Elk Creek Shade-Related Data, TMDLs, Existing Solar Loading, and the Percent Increase in Shade Needed to Meet the TMDLs

Longitudinal Distance (m)	River Mile (RM)	Aspect	Wetted Width (ft)-GIS	Wetted Width (ft) TMDL	General Direction	Ecoregion	Target Shade (%)	Existing Shade (%)	Shade Difference (%)	Daily Solar Flux with Existing Shade (watts/ft2)	Daily Solar Flux with Potential Shade (watts/ft2)	Existing Load (kcal/day)	Potential Load (kcal/day)	Percent Reduction to Meet TMDL
23650	14.70	339.39	13.12	13.12	N/S	17w	51	43	-8	424	365	18621907	16014257	14%
23700	14.73	243.44	16.40	15.00	NE/SW	17w	42	19	-23	607	435	33305044	21820355	34%
23750	14.76	250.58	13.12	13.12	E/W	17w	38	22	-16	584	464	25624698	20375921	20%
23800	14.79	223.55	19.68	15.00	NE/SW	17w	36	12	-24	657	478	43266166	23992378	45%
23850	14.82	305.61	9.84	9.84	NE/SW	17w	58	21	-37	586	312	19293718	10261233	47%
23900	14.85	221.26	13.12	13.12	NE/SW	17w	48	28	-20	534	386	23447609	16940680	28%
23950	14.88	190.90	13.12	13.12	N/S	17w	51	46	-5	402	365	17652965	16024386	9%
24000	14.91	166.84	13.12	13.12	N/S	17w	51	40	-11	444	363	19483646	15917559	18%
24050	14.94	213.69	19.68	15.00	NE/SW	17w	36	25	-11	561	479	36961836	24049156	35%
24100	14.98	219.61	9.84	9.84	NE/SW	17w	58	29	-29	532	315	17501027	10356569	41%
24150	15.01	202.35	9.84	9.84	N/S	17w	60	28	-32	536	298	17646301	9807145	44%
24200	15.04	210.83	16.40	15.00	NE/SW	17w	42	17	-25	619	433	33986317	21730155	36%
24250	15.07	196.09	16.40	15.00	N/S	17w	6	1	-5	740	702	40577478	35252226	13%
24300	15.10	290.95	16.40	15.00	E/W	17w	4	1	-3	740	718	40604959	36026656	11%
24350	15.13	307.38	16.40	15.00	NE/SW	17w	16	2	-14	727	623	39896810	31289614	22%
24400	15.16	307.50	16.40	15.00	NE/SW	17w	42	11	-31	661	431	36278335	21631875	40%
24450	15.19	345.82	13.12	13.12	N/S	17w	51	25	-26	556	363	24399108	15946677	35%
24500	15.22	143.23	13.12	13.12	NE/SW	17w	9	1	-8	735	676	32258981	29663218	8%
24550	15.25	284.04	13.12	13.12	E/W	17w	13	2	-11	727	646	31905631	28334916	11%
24600	15.29	228.79	13.12	13.12	NE/SW	17w	16	2	-14	728	624	31934421	27382536	14%
24650	15.32	216.96	16.40	15.00	NE/SW	17w	42	18	-24	611	433	33547635	21711252	35%
24700	15.35	317.40	13.12	13.12	NE/SW	17w	48	18	-30	611	388	26839833	17026709	37%
24750	15.38	237.01	16.40	15.00	NE/SW	17w	42	8	-34	686	433	37661651	21724428	42%
24800	15.41	222.09	16.40	15.00	NE/SW	17w	42	13	-29	648	432	35575723	21700578	39%

Table I-2. Elk Creek Shade-Related Data, TMDLs, Existing Solar Loading, and the Percent Increase in Shade Needed to Meet the TMDLs

Longitudinal Distance (m)	River Mile (RM)	Aspect	Wetted Width (ft)-GIS	Wetted Width (ft) TMDL	General Direction	Ecoregion	Target Shade (%)	Existing Shade (%)	Shade Difference (%)	Daily Solar Flux with Existing Shade (watts/ft2)	Daily Solar Flux with Potential Shade (watts/ft2)	Existing Load (kcal/day)	Potential Load (kcal/day)	Percent Reduction to Meet TMDL
24850	15.44	220.76	19.68	15.00	NE/SW	17w	36	11	-25	666	479	43819061	24025953	45%
24900	15.47	295.71	19.68	15.00	NE/SW	17w	36	5	-31	705	475	46443714	23856729	49%
24950	15.50	331.11	9.84	9.84	NE/SW	17w	58	29	-29	530	313	17436262	10318243	41%
25000	15.53	296.12	19.68	15.00	NE/SW	17w	36	6	-30	703	479	46301767	24036834	48%
25050	15.57	219.53	20.00	15.00	NE/SW	17w	29	7	-22	690	527	46186516	26455336	43%
25100	15.60	343.02	20.00	15.00	N/S	17w	29	8	-21	684	528	45756728	26494038	42%
25150	15.63	244.64	20.00	15.00	NE/SW	17w	24	5	-19	710	568	47511699	28517617	40%
25200	15.66	226.20	20.00	15.00	NE/SW	17w	18	3	-15	724	612	48432948	30718903	37%
25250	15.69	280.52	20.00	15.00	E/W	17w	6	1	-5	736	699	49254347	35088105	29%
25300	15.72	296.52	20.00	15.00	NE/SW	17w	14	2	-12	729	640	48769144	32109992	34%
25350	15.75	256.94	20.00	15.00	E/W	17w	13	2	-11	727	646	48667785	32415852	33%
25400	15.78	243.53	20.00	15.00	NE/SW	17w	12	2	-10	731	657	48945306	32975419	33%
25450	15.81	184.85	20.00	15.00	N/S	17w	6	1	-5	740	702	49487339	35254085	29%
25500	15.84	243.78	20.00	15.00	NE/SW	17w	16	2	-14	727	624	48656511	31290814	36%
25550	15.88	339.97	16.40	15.00	N/S	17w	45	17	-28	617	409	33877505	20540208	39%
25600	15.91	183.66	20.00	15.00	N/S	17w	35	12	-23	654	483	43772548	24258011	45%
25650	15.94	214.53	19.68	15.00	NE/SW	17w	36	11	-25	660	475	43474572	23837070	45%
25700	15.97	165.11	19.68	15.00	N/S	17w	39	14	-25	645	457	42439260	22952329	46%
25750	16.00	10.82	20.00	15.00	N/S	17w	29	8	-21	689	532	46126618	26708212	42%
25800	16.03	180.33	20.00	15.00	N/S	17w	18	4	-14	717	613	47974275	30744945	36%
25850	16.06	278.06	13.12	13.12	E/W	17w	38	5	-33	708	462	31090438	20298144	35%
25900	16.09	166.16	16.40	15.00	N/S	17w	45	20	-25	597	411	32769888	20613726	37%
25950	16.12	260.13	19.68	15.00	E/W	17w	27	6	-21	703	546	46275396	27401399	41%
26000	16.16	342.00	20.00	15.00	N/S	17w	35	10	-25	669	484	44782681	24266303	46%

Table I-2. Elk Creek Shade-Related Data, TMDLs, Existing Solar Loading, and the Percent Increase in Shade Needed to Meet the TMDLs

Longitudinal Distance (m)	River Mile (RM)	Aspect	Wetted Width (ft)-GIS	Wetted Width (ft) TMDL	General Direction	Ecoregion	Target Shade (%)	Existing Shade (%)	Shade Difference (%)	Daily Solar Flux with Existing Shade (watts/ft2)	Daily Solar Flux with Potential Shade (watts/ft2)	Existing Load (kcal/day)	Potential Load (kcal/day)	Percent Reduction to Meet TMDL
26050	16.19	237.33	16.40	15.00	NE/SW	17w	17	3	-14	721	617	39567560	30978077	22%
26100	16.22	173.77	13.12	13.12	N/S	17w	51	23	-28	571	364	25075075	15962798	36%
26150	16.25	337.07	16.40	15.00	NE/SW	17w	10	2	-8	733	674	40228902	33803638	16%
26200	16.28	247.65	13.12	13.12	E/W	17w	38	7	-31	695	463	30488509	20333229	33%
26250	16.31	176.05	9.84	9.84	N/S	17w	60	29	-31	530	299	17437759	9827741	44%
26300	16.34	158.63	20.00	15.00	N/S	17w	35	10	-25	669	484	44782600	24266259	46%
26350	16.37	207.48	20.00	15.00	NE/SW	17w	29	8	-21	683	527	45695704	26458704	42%
26400	16.40	310.49	13.12	13.12	NE/SW	17w	48	18	-30	615	390	26982170	17117005	37%
26450	16.44	266.04	16.40	15.00	E/W	17w	13	3	-10	727	652	39873468	32722039	18%
26500	16.47	244.92	13.12	13.12	NE/SW	17w	48	10	-38	672	389	29514727	17059293	42%
26550	16.50	198.65	16.40	15.00	N/S	17w	22	5	-17	710	583	38948433	29259697	25%
26600	16.53	12.19	20.00	15.00	N/S	17w	16	3	-13	724	627	48422740	31461512	35%
26650	16.56	230.96	20.00	15.00	NE/SW	17w	32	6	-26	700	507	46845730	25425749	46%
26700	16.59	224.15	19.68	15.00	NE/SW	17w	1	0	-1	742	735	48866291	36886899	25%
26750	16.62	162.44	19.68	15.00	N/S	17w	39	18	-21	615	457	40470779	22955414	43%
26800	16.65	210.40	20.00	15.00	NE/SW	17w	32	12	-20	654	505	43737565	25357330	42%
26850	16.68	300.93	13.12	13.12	NE/SW	17w	48	13	-35	648	388	28462719	17018524	40%
26900	16.71	191.63	19.68	15.00	N/S	17w	39	14	-25	639	453	42059898	22747160	46%
26950	16.75	255.34	19.68	15.00	E/W	17w	27	4	-23	713	542	46922374	27205655	42%
27000	16.78	48.58	20.00	15.00	NE/SW	17w	32	8	-24	689	509	46083053	25555537	45%
27050	16.81	251.11	9.84	9.84	E/W	17w	50	12	-38	658	374	21665325	12314420	43%
27100	16.84	332.66	16.40	15.00	NE/SW	17w	42	20	-22	600	435	32926347	21841899	34%
27150	16.87	320.63	9.84	9.84	NE/SW	17w	58	32	-26	503	311	16573692	10240498	38%
27200	16.90	222.06	20.00	15.00	NE/SW	17w	32	12	-20	659	509	44096388	25565361	42%

Table I-2. Elk Creek Shade-Related Data, TMDLs, Existing Solar Loading, and the Percent Increase in Shade Needed to Meet the TMDLs

Longitudinal Distance (m)	River Mile (RM)	Aspect	Wetted Width (ft)-GIS	Wetted Width (ft) TMDL	General Direction	Ecoregion	Target Shade (%)	Existing Shade (%)	Shade Difference (%)	Daily Solar Flux with Existing Shade (watts/ft2)	Daily Solar Flux with Potential Shade (watts/ft2)	Existing Load (kcal/day)	Potential Load (kcal/day)	Percent Reduction to Meet TMDL
27250	16.93	234.09	16.40	15.00	NE/SW	17w	42	10	-32	669	431	36703502	21642221	41%
27300	16.96	287.65	13.12	13.12	E/W	17w	38	6	-32	699	461	30663773	20232561	34%
27350	16.99	24.73	19.68	15.00	NE/SW	17w	36	14	-22	641	477	42207084	23949390	43%
27400	17.03	184.72	13.12	13.12	N/S	17w	51	26	-25	554	367	24306026	16100514	34%
27450	17.06	333.08	19.68	15.00	NE/SW	17w	36	22	-14	584	480	38479459	24073648	37%
27500	17.09	35.42	16.40	15.00	NE/SW	17w	42	14	-28	644	435	35343859	21809833	38%
27550	17.12	336.92	16.40	15.00	NE/SW	17w	42	20	-22	595	431	32640951	21652579	34%
27600	17.15	298.45	9.84	9.84	NE/SW	17w	58	17	-41	620	314	20423889	10338822	49%
27650	17.18	163.64	16.40	15.00	N/S	17w	45	18	-27	610	410	33495078	20556003	39%
27700	17.21	211.83	19.68	15.00	NE/SW	17w	36	13	-23	646	475	42526957	23853527	44%
27750	17.24	292.25	16.40	15.00	E/W	17w	31	20	-11	596	514	32680095	25789994	21%
27800	17.27	318.55	19.68	15.00	NE/SW	17w	36	11	-25	665	478	43774330	24001427	45%
27850	17.31	177.68	16.40	15.00	N/S	17w	45	19	-26	603	410	33110924	20571114	38%
27900	17.34	182.18	13.12	13.12	N/S	17w	51	30	-21	525	368	23064361	16151055	30%
27950	17.37	278.49	20.00	15.00	E/W	17w	23	5	-18	705	571	47151155	28673595	39%
28000	17.40	260.12	19.68	15.00	E/W	17w	27	5	-22	705	542	46448037	27214114	41%
28050	17.43	190.17	13.12	13.12	N/S	17w	51	24	-27	568	366	24912858	16068208	36%
28100	17.46	298.74	13.12	13.12	NE/SW	17w	48	13	-35	649	388	28491281	17035602	40%
28150	17.49	231.68	16.40	15.00	NE/SW	17w	42	13	-29	649	433	35615036	21724559	39%
28200	17.52	262.33	9.84	9.84	E/W	17w	50	13	-37	649	373	21370325	12286362	43%
28250	17.55	277.77	16.40	15.00	E/W	17w	31	6	-25	698	512	38281432	25710957	33%
28300	17.58	285.70	16.40	15.00	E/W	17w	31	6	-25	700	514	38425140	25807476	33%
28350	17.62	337.50	13.12	13.12	N/S	17w	51	21	-30	591	367	25934246	16091778	38%
28400	17.65	207.55	16.40	15.00	NE/SW	17w	42	15	-27	636	434	34918904	21801105	38%

Table I-2. Elk Creek Shade-Related Data, TMDLs, Existing Solar Loading, and the Percent Increase in Shade Needed to Meet the TMDLs

Longitudinal Distance (m)	River Mile (RM)	Aspect	Wetted Width (ft)-GIS	Wetted Width (ft) TMDL	General Direction	Ecoregion	Target Shade (%)	Existing Shade (%)	Shade Difference (%)	Daily Solar Flux with Existing Shade (watts/ft2)	Daily Solar Flux with Potential Shade (watts/ft2)	Existing Load (kcal/day)	Potential Load (kcal/day)	Percent Reduction to Meet TMDL
28450	17.68	9.06	16.40	15.00	N/S	17w	45	18	-27	610	409	33444837	20525169	39%
28500	17.71	225.71	20.00	15.00	NE/SW	17w	32	8	-24	689	510	46125238	25578931	45%
28550	17.74	313.81	9.84	9.84	NE/SW	17w	58	33	-25	496	311	16328458	10239555	37%
28600	17.77	254.36	16.40	15.00	E/W	17w	31	5	-26	708	514	38837323	25809739	34%
28650	17.80	346.45	9.84	9.84	N/S	17w	60	29	-31	526	296	17304381	9752571	44%
28700	17.83	301.89	13.12	13.12	NE/SW	17w	48	29	-19	532	389	23330181	17093245	27%
28750	17.86	309.36	9.84	9.84	NE/SW	17w	58	20	-38	597	314	19666932	10328978	47%
28800	17.90	56.08	16.40	15.00	NE/SW	17w	42	11	-31	666	434	36558287	21798803	40%
28850	17.93	319.56	16.40	15.00	NE/SW	17w	42	16	-26	630	435	34555404	21830994	37%
28900	17.96	316.68	19.68	15.00	NE/SW	17w	24	5	-19	710	568	46722508	28499925	39%
28950	17.99	41.31	20.00	15.00	NE/SW	17w	32	7	-25	694	507	46414350	25462493	45%
29000	18.02	322.29	13.12	13.12	NE/SW	17w	48	27	-21	546	389	23983413	17090426	29%
29050	18.05	293.28	19.68	15.00	NE/SW	17w	36	14	-22	640	477	42163010	23924381	43%
29100	18.08	282.43	13.12	13.12	E/W	17w	38	28	-10	540	465	23712362	20426569	14%
29150	18.11	29.05	9.84	9.84	NE/SW	17w	58	36	-22	480	315	15810446	10379462	34%
29200	18.14	284.04	16.40	15.00	E/W	17w	31	7	-24	690	512	37865035	25704747	32%
29250	18.18	306.07	13.12	13.12	NE/SW	17w	48	18	-30	615	390	26992730	17123704	37%
29300	18.21	305.73	13.12	13.12	NE/SW	17w	48	18	-30	613	389	26926310	17081568	37%
29350	18.24	181.10	13.12	13.12	N/S	17w	51	24	-27	564	364	24760850	15970167	36%
29400	18.27	246.59	13.12	13.12	NE/SW	17w	48	10	-38	670	387	29403651	16995092	42%
29450	18.30	229.53	19.68	15.00	NE/SW	17w	36	9	-27	681	479	44865890	24059270	46%
29500	18.33	229.59	20.00	15.00	NE/SW	17w	32	8	-24	686	507	45878025	25441838	45%
29550	18.36	307.35	13.12	13.12	NE/SW	17w	48	16	-32	628	389	27577135	17077906	38%
29600	18.39	174.24	9.84	9.84	N/S	17w	60	36	-24	474	296	15593729	9749704	37%

Table I-2. Elk Creek Shade-Related Data, TMDLs, Existing Solar Loading, and the Percent Increase in Shade Needed to Meet the TMDLs

Longitudinal Distance (m)	River Mile (RM)	Aspect	Wetted Width (ft)-GIS	Wetted Width (ft) TMDL	General Direction	Ecoregion	Target Shade (%)	Existing Shade (%)	Shade Difference (%)	Daily Solar Flux with Existing Shade (watts/ft2)	Daily Solar Flux with Potential Shade (watts/ft2)	Existing Load (kcal/day)	Potential Load (kcal/day)	Percent Reduction to Meet TMDL
29650	18.42	179.36	20.00	15.00	N/S	17w	35	13	-22	649	485	43434270	24347216	44%
29700	18.45	318.69	16.40	15.00	NE/SW	17w	42	15	-27	635	433	34842063	21753130	38%
29750	18.49	46.71	16.40	15.00	NE/SW	17w	42	13	-29	647	431	35494406	21650976	39%
29800	18.52	358.68	19.68	15.00	N/S	17w	39	18	-21	611	455	40230595	22819179	43%
29850	18.55	282.76	16.40	15.00	E/W	17w	31	6	-25	700	514	38430657	25811181	33%
29900	18.58	183.91	13.12	13.12	N/S	17w	51	25	-26	558	365	24508462	16018148	35%
29950	18.61	181.97	13.12	13.12	N/S	17w	51	29	-22	530	366	23277547	16070758	31%
30000	18.64	312.15	20.00	15.00	NE/SW	17w	32	8	-24	683	505	45730947	25360275	45%
30050	18.67	313.52	19.68	15.00	NE/SW	17w	36	10	-26	671	477	44181994	23955782	46%
30100	18.70	213.89	20.00	15.00	NE/SW	17w	29	8	-21	685	529	45805933	26522529	42%
30150	18.73	263.94	16.40	15.00	E/W	17w	31	6	-25	697	512	38261949	25697872	33%
30200	18.77	40.91	16.40	15.00	NE/SW	17w	42	14	-28	638	431	35029544	21615877	38%
30250	18.80	226.61	20.00	15.00	NE/SW	17w	32	7	-25	690	504	46146408	25315502	45%
30300	18.83	176.35	16.40	15.00	N/S	17w	45	19	-26	606	412	33239270	20650852	38%
30350	18.86	297.74	16.40	15.00	NE/SW	17w	42	7	-35	691	431	37904565	21629446	43%
30400	18.89	306.59	13.12	13.12	NE/SW	17w	48	15	-33	633	387	27783629	17003363	39%
30450	18.92	330.88	13.12	13.12	NE/SW	17w	48	27	-21	545	388	23914342	17041207	29%
30500	18.95	310.38	16.40	15.00	NE/SW	17w	42	12	-30	653	430	35819922	21601245	40%
30550	18.98	280.22	13.12	13.12	E/W	17w	38	8	-30	689	464	30233935	20382617	33%
30600	19.01	192.17	16.40	15.00	N/S	17w	9	1	-8	737	678	40461794	34029860	16%
30650	19.05	305.54	20.00	15.00	NE/SW	17w	29	5	-24	710	531	47497545	26633521	44%
30700	19.08	322.59	9.84	9.84	NE/SW	17w	58	38	-20	460	312	15148084	10265420	32%
30750	19.11	335.63	16.40	15.00	NE/SW	17w	42	21	-21	589	433	32321491	21712064	33%
30800	19.14	231.67	16.40	15.00	NE/SW	17w	42	14	-28	643	434	35264280	21760726	38%

Table I-2. Elk Creek Shade-Related Data, TMDLs, Existing Solar Loading, and the Percent Increase in Shade Needed to Meet the TMDLs

Longitudinal Distance (m)	River Mile (RM)	Aspect	Wetted Width (ft)-GIS	Wetted Width (ft) TMDL	General Direction	Ecoregion	Target Shade (%)	Existing Shade (%)	Shade Difference (%)	Daily Solar Flux with Existing Shade (watts/ft2)	Daily Solar Flux with Potential Shade (watts/ft2)	Existing Load (kcal/day)	Potential Load (kcal/day)	Percent Reduction to Meet TMDL
30850	19.17	127.01	20.00	15.00	NE/SW	17w	32	6	-26	700	507	46836223	25420589	46%
30900	19.20	231.24	9.84	9.84	NE/SW	17w	58	31	-27	516	314	16978699	10338702	39%
30950	19.23	237.93	20.00	15.00	NE/SW	17w	29	5	-24	709	530	47413492	26586390	44%
31000	19.26	225.78	13.12	13.12	NE/SW	17w	48	20	-28	595	387	26129519	16990501	35%
31050	19.29	178.54	13.12	13.12	N/S	17w	51	27	-24	547	367	24009521	16121971	33%
31100	19.32	220.84	13.12	13.12	NE/SW	17w	48	19	-29	603	387	26480726	17006292	36%
31150	19.36	264.88	9.84	9.84	E/W	17w	50	8	-42	689	375	22676675	12328861	46%
31200	19.39	284.86	13.12	13.12	E/W	17w	38	7	-31	694	463	30447851	20306114	33%
31250	19.42	11.15	16.40	15.00	N/S	17w	45	18	-27	608	408	33355442	20470307	39%
31300	19.45	281.78	9.84	9.84	E/W	17w	50	10	-40	672	373	22108593	12287118	44%
31350	19.48	254.35	19.68	15.00	E/W	17w	27	6	-21	702	545	46229577	27374268	41%
31400	19.51	38.37	19.68	15.00	NE/SW	17w	36	10	-26	673	479	44304267	24022080	46%
31450	19.54	215.66	16.40	15.00	NE/SW	17w	42	17	-25	620	433	34014362	21748087	36%
31500	19.57	248.34	13.12	13.12	E/W	17w	38	9	-29	680	463	29827597	20329654	32%
31550	19.60	252.68	9.84	9.84	E/W	17w	50	10	-40	668	371	21976737	12213837	44%
31600	19.64	298.66	16.40	15.00	NE/SW	17w	42	8	-34	687	433	37709100	21751798	42%
31650	19.67	64.34	13.12	13.12	NE/SW	17w	20	4	-16	712	594	31265953	26064647	17%
31700	19.70	272.11	13.12	13.12	E/W	17w	38	5	-33	706	461	30977589	20224468	35%
31750	19.73	185.61	19.68	15.00	N/S	17w	39	13	-26	646	453	42540984	22742893	47%
31800	19.76	315.00	9.84	9.84	NE/SW	17w	58	30	-28	520	312	17110480	10270104	40%
31850	19.79	260.62	13.12	13.12	E/W	17w	38	6	-32	702	463	30813566	20331397	34%
31900	19.82	230.71	13.12	13.12	NE/SW	17w	48	20	-28	597	388	26217255	17047551	35%
31950	19.85	304.34	13.12	13.12	NE/SW	17w	48	15	-33	637	390	27953718	17107455	39%
32000	19.88	291.94	13.12	13.12	E/W	17w	38	11	-27	663	462	29083553	20267984	30%

Table I-2. Elk Creek Shade-Related Data, TMDLs, Existing Solar Loading, and the Percent Increase in Shade Needed to Meet the TMDLs

Longitudinal Distance (m)	River Mile (RM)	Aspect	Wetted Width (ft)-GIS	Wetted Width (ft) TMDL	General Direction	Ecoregion	Target Shade (%)	Existing Shade (%)	Shade Difference (%)	Daily Solar Flux with Existing Shade (watts/ft2)	Daily Solar Flux with Potential Shade (watts/ft2)	Existing Load (kcal/day)	Potential Load (kcal/day)	Percent Reduction to Meet TMDL
32050	19.91	289.63	13.12	13.12	E/W	17w	38	10	-28	674	465	29605854	20402726	31%
32100	19.95	345.96	13.12	13.12	N/S	17w	51	34	-17	488	363	21440336	15923743	26%
32150	19.98	246.56	20.00	15.00	NE/SW	17w	32	18	-14	612	508	40983460	25499188	38%
32200	20.01	188.81	16.40	15.00	N/S	17w	45	33	-12	502	412	27528245	20676415	25%
32250	20.04	275.76	13.12	13.12	E/W	17w	38	64	26	265	457	11647927	20067776	0%
32300	20.07	291.21	6.56	6.56	E/W	17w	71	90	19	77	225	1700564	4933468	0%
32350	20.10	258.44	6.56	6.56	E/W	17w	71	84	13	119	215	2605384	4724014	0%
32400	20.13	239.27	16.40	15.00	NE/SW	17w	42	52	10	355	429	19462877	21518035	0%
32450	20.16	269.41	16.40	15.00	E/W	17w	31	17	-14	618	514	33906395	25790600	24%
32500	20.19	350.91	13.12	13.12	N/S	17w	51	40	-11	450	368	19749689	16134909	18%
32550	20.23	292.07	19.68	15.00	E/W	17w	27	16	-11	623	542	41049385	27200558	34%
32600	20.26	217.30	13.12	13.12	NE/SW	17w	48	34	-14	490	386	21513526	16956352	21%
32650	20.29	263.34	9.84	9.84	E/W	17w	50	27	-23	546	374	17983586	12322104	31%
32700	20.32	309.62	13.12	13.12	NE/SW	17w	48	30	-18	521	387	22880881	17003545	26%
32750	20.35	301.28	9.84	9.84	NE/SW	17w	58	33	-25	498	312	16403078	10286349	37%
32800	20.38	275.41	16.40	15.00	E/W	17w	31	20	-11	595	513	32622580	25744605	21%
32850	20.41	333.96	16.40	15.00	NE/SW	17w	42	42	0	432	433	23723035	21705964	9%
32900	20.44	106.61	9.84	9.84	E/W	17w	50	31	-19	516	374	16994222	12319232	28%
32950	20.47	271.66	20.00	15.00	E/W	17w	20	8	-12	686	597	45925057	29962258	35%
33000	20.51	352.46	16.40	15.00	N/S	17w	45	31	-14	512	409	28116402	20506058	27%
33050	20.54	255.62	9.84	9.84	E/W	17w	50	30	-20	524	374	17243745	12321539	29%
33100	20.57	318.83	13.12	13.12	NE/SW	17w	48	37	-11	468	386	20526793	16949048	17%
33150	20.60	272.32	13.12	13.12	E/W	17w	38	21	-17	586	460	25719387	20192339	21%
33200	20.63	172.96	13.12	13.12	N/S	17w	51	48	-3	389	367	17093075	16112924	6%

Table I-2. Elk Creek Shade-Related Data, TMDLs, Existing Solar Loading, and the Percent Increase in Shade Needed to Meet the TMDLs

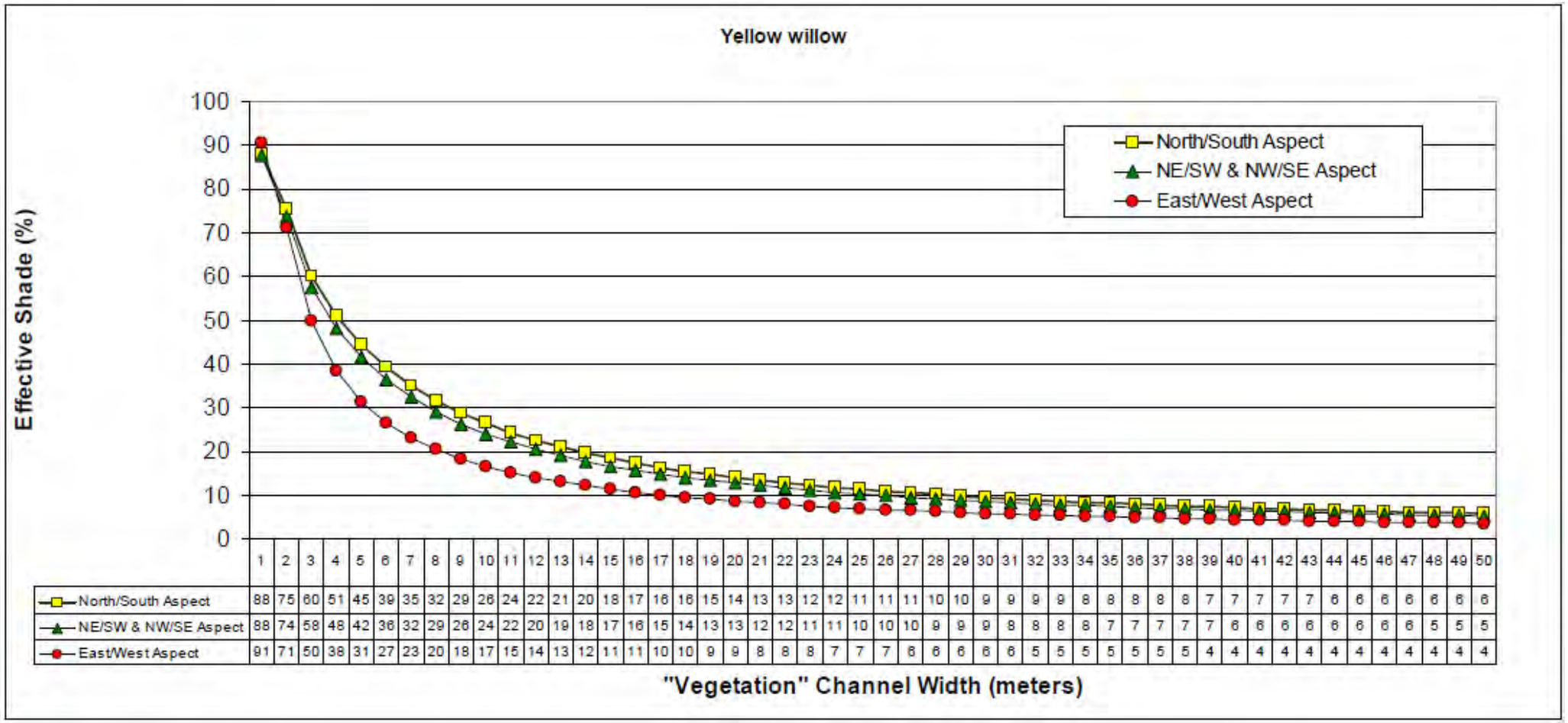
Longitudinal Distance (m)	River Mile (RM)	Aspect	Wetted Width (ft)-GIS	Wetted Width (ft) TMDL	General Direction	Ecoregion	Target Shade (%)	Existing Shade (%)	Shade Difference (%)	Daily Solar Flux with Existing Shade (watts/ft2)	Daily Solar Flux with Potential Shade (watts/ft2)	Existing Load (kcal/day)	Potential Load (kcal/day)	Percent Reduction to Meet TMDL
33250	20.66	234.97	16.40	15.00	NE/SW	17w	42	31	-11	512	431	28116747	21624835	23%
33300	20.69	235.06	19.68	15.00	NE/SW	17w	36	8	-28	688	479	45321665	24039509	47%
33350	20.72	188.22	20.00	15.00	N/S	17w	35	13	-22	647	483	43283557	24262734	44%
33400	20.75	293.31	16.40	15.00	NE/SW	17w	42	6	-36	699	431	38334057	21641819	44%
33450	20.78	318.50	13.12	13.12	NE/SW	17w	48	21	-27	593	390	26010193	17126998	34%
33500	20.82	222.98	13.12	13.12	NE/SW	17w	48	22	-26	581	388	25518168	17018436	33%
33550	20.85	265.91	13.12	13.12	E/W	17w	38	6	-32	702	463	30815309	20332547	34%
33600	20.88	14.41	20.00	15.00	N/S	17w	32	10	-22	668	505	44719156	25350275	43%
33650	20.91	247.40	19.68	15.00	NE/SW	17w	36	6	-30	704	480	46362994	24068619	48%
33700	20.94	244.24	19.68	15.00	NE/SW	17w	36	5	-31	707	477	46559039	23915968	49%
33750	20.97	216.43	16.40	15.00	NE/SW	17w	42	15	-27	631	431	34634945	21623819	38%
33800	21.00	249.89	20.00	15.00	E/W	17w	23	5	-18	709	574	47408401	28830031	39%
33850	21.03	254.23	16.40	15.00	E/W	17w	31	6	-25	700	514	38385246	25780682	33%
33900	21.06	279.92	16.40	15.00	E/W	17w	31	6	-25	702	515	38495383	25854653	33%
33950	21.10	227.86	13.12	13.12	NE/SW	17w	48	17	-31	620	389	27220717	17060283	37%
34000	21.13	280.52	9.84	9.84	E/W	17w	50	10	-40	674	375	22201326	12338655	44%
34050	21.16	299.39	13.12	13.12	NE/SW	17w	48	27	-21	548	390	24049647	17137624	29%
34100	21.19	301.88	9.84	9.84	NE/SW	17w	58	21	-37	590	314	19427612	10332443	47%
34150	21.22	303.69	6.56	6.56	NE/SW	17w	74	36	-38	475	193	10414737	4232560	59%
34200	21.25	316.85	13.12	13.12	NE/SW	17w	48	21	-27	587	386	25745901	16952969	34%
34250	21.28	325.35	9.84	9.84	NE/SW	17w	58	27	-31	545	314	17938175	10324431	42%
34300	21.31	313.39	9.84	9.84	NE/SW	17w	58	21	-37	591	314	19464418	10352019	47%
34350	21.34	314.54	13.12	13.12	NE/SW	17w	48	20	-28	593	386	26038959	16931615	35%
34400	21.38	307.08	16.40	15.00	NE/SW	17w	42	9	-33	678	432	37190049	21688134	42%

Table I-2. Elk Creek Shade-Related Data, TMDLs, Existing Solar Loading, and the Percent Increase in Shade Needed to Meet the TMDLs

Longitudinal Distance (m)	River Mile (RM)	Aspect	Wetted Width (ft)-GIS	Wetted Width (ft) TMDL	General Direction	Ecoregion	Target Shade (%)	Existing Shade (%)	Shade Difference (%)	Daily Solar Flux with Existing Shade (watts/ft2)	Daily Solar Flux with Potential Shade (watts/ft2)	Existing Load (kcal/day)	Potential Load (kcal/day)	Percent Reduction to Meet TMDL
34450	21.41	245.32	13.12	13.12	NE/SW	17w	48	9	-39	676	386	29667207	16958992	43%
34500	21.44	335.97	9.84	9.84	NE/SW	17w	58	30	-28	521	313	17165319	10303020	40%
34550	21.47	329.40	13.12	13.12	NE/SW	17w	48	19	-29	605	388	26540776	17044857	36%
34600	21.50	280.42	13.12	13.12	E/W	17w	38	7	-31	695	463	30489754	20334059	33%
34650	21.53	11.77	16.40	15.00	N/S	17w	45	18	-27	611	410	33498153	20557890	39%
34700	21.56	315.00	16.40	15.00	NE/SW	17w	42	16	-26	627	433	34398285	21731731	37%
34750	21.59	335.45	6.56	6.56	NE/SW	17w	74	41	-33	443	195	9713532	4282131	56%
34800	21.62	336.44	9.84	9.84	NE/SW	17w	58	35	-23	483	312	15899002	10277020	35%
34850	21.65	300.90	13.12	13.12	NE/SW	17w	48	10	-38	669	387	29383208	16983276	42%
34900	21.69	13.17	9.84	9.84	N/S	17w	60	36	-24	475	297	15621224	9766895	37%
34950	21.72	312.04	6.56	6.56	NE/SW	17w	74	43	-31	425	194	9320360	4252973	54%
35000	21.75	62.33	13.12	13.12	NE/SW	17w	48	9	-39	679	388	29821011	17046912	43%
35050	21.78	359.75	9.84	9.84	N/S	17w	60	30	-30	522	298	17173528	9817093	43%
35100	21.81	284.24	13.12	13.12	E/W	17w	38	6	-32	703	464	30867162	20366761	34%
35150	21.84	345.65	20.00	15.00	N/S	17w	35	13	-22	646	482	43194659	24212901	44%
35200	21.87	283.63	19.68	15.00	E/W	17w	27	5	-22	705	542	46428289	27202544	41%
35250	21.90	266.72	13.12	13.12	E/W	17w	38	6	-32	701	462	30748505	20288468	34%
35300	21.93	322.42	9.84	9.84	NE/SW	17w	58	30	-28	523	314	17204614	10326606	40%
35350	21.97	35.82	16.40	15.00	NE/SW	17w	42	14	-28	642	433	35249463	21751584	38%
35400	22.00	274.49	9.84	9.84	E/W	17w	50	8	-42	688	374	22650351	12314549	46%
35450	22.03	270.60	13.12	13.12	E/W	17w	38	5	-33	708	462	31073949	20287379	35%
35500	22.06	328.45	13.12	13.12	NE/SW	17w	48	21	-27	587	387	25766334	16966423	34%
35550	22.09	270.96	13.12	13.12	E/W	17w	38	6	-32	700	462	30738932	20282152	34%
35600	22.12	189.66	13.12	13.12	N/S	17w	51	27	-24	545	366	23932826	16070471	33%

Table I-2. Elk Creek Shade-Related Data, TMDLs, Existing Solar Loading, and the Percent Increase in Shade Needed to Meet the TMDLs

Longitudinal Distance (m)	River Mile (RM)	Aspect	Wetted Width (ft)-GIS	Wetted Width (ft) TMDL	General Direction	Ecoregion	Target Shade (%)	Existing Shade (%)	Shade Difference (%)	Daily Solar Flux with Existing Shade (watts/ft2)	Daily Solar Flux with Potential Shade (watts/ft2)	Existing Load (kcal/day)	Potential Load (kcal/day)	Percent Reduction to Meet TMDL
35650	22.15	341.15	16.40	15.00	N/S	17w	45	20	-25	594	409	32613637	20515437	37%
35700	22.18	299.93	13.12	13.12	NE/SW	17w	48	11	-37	665	389	29205529	17070248	42%
35750	22.21	65.17	16.40	15.00	NE/SW	17w	42	7	-35	691	431	37903041	21628576	43%
35800	22.25	212.51	20.00	15.00	NE/SW	17w	32	11	-21	667	510	44627659	25582659	43%
35850	22.28	288.23	13.12	13.12	E/W	17w	38	8	-30	690	465	30268641	20406015	33%
35900	22.31	276.28	9.84	9.84	E/W	17w	50	6	-44	700	372	23031692	12255454	47%
35950	22.34	207.13	16.40	15.00	NE/SW	17w	42	20	-22	598	434	32801019	21758762	34%
36000	22.37	190.25	13.12	13.12	N/S	17w	51	21	-30	587	365	25787340	16000625	38%
36050	22.40	294.17	9.84	9.84	NE/SW	17w	58	44	-14	417	313	13727934	10304180	25%



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
North/South Aspect	88	75	60	51	45	39	35	32	29	26	24	22	21	20	18	17	16	16	15	14	13	13	12	12	11	11	11	10	10	9	9	9	9	8	8	8	8	8	7	7	7	7	7	6	6	6	6	6	6	6
NE/SW & NW/SE Aspect	88	74	58	48	42	36	32	29	26	24	22	20	19	18	17	16	15	14	13	13	12	12	11	11	10	10	10	9	9	9	8	8	8	8	7	7	7	7	7	6	6	6	6	6	6	6	6	5	5	5
East/West Aspect	91	71	50	38	31	27	23	20	18	17	15	14	13	12	11	11	10	10	9	9	8	8	8	7	7	7	6	6	6	6	6	5	5	5	5	5	5	5	4	4	4	4	4	4	4	4	4	4	4	4

Figure I-3. Shade Curve Selected for Elk Creek to Represent the Target Shade Conditions for Ecoregions 17ab and 17w.

I2.3 MOORE CREEK

Table I-3 contains the Shade Tool model results for Moore Creek, the data that was used for temperature targets (shade surrogate TMDL), the modeled existing solar load, and the percent load reduction needed to meet the temperature TMDL. Vegetation-specific shade curves developed by the EPA and Idaho DEQ were used for shade target development (Shumar and de Varona 2009). Each level IV ecoregion was assigned a shade curve to represent the potential riparian vegetative community for that ecoregion. The level IV ecoregions represented in the Moore's Creek shade model are 17z - Tobacco Root Mountains, 17ab - Dry Gneissic-Schistone-Volcanic Hills, 17aa - Dry Intermontane Sagebrush Valleys. The shade curves selected for these ecoregions are shown in **Figures I-4, I-5 and I-6**.

Table I-3. Moore's Creek Shade-Related Data, TMDLs, Existing Solar Loading, and the Percent Increase in Shade Needed to Meet the TMDLs

Longitudinal Distance (m)	River Mile (RM)	Aspect	Wetted Width (ft)-GIS	General Direction	Ecoregion	Target Shade (%)	Existing Shade (%)	Shade Difference (%)	Daily Solar Flux with Existing Shade (watts/ft2)	Daily Solar Flux with Potential Shade (watts/ft2)	Existing Load (kcal/day)	Potential Load (kcal/day)	Percent Reduction Needed to Meet TMDL
0	0	158.8556	3.28	N/S	17z	77	96	19	33.06834	190.1429	362877.64	2086546.44	0%
50	0.031069	159.8559	3.28	N/S	17z	77	94	17	43.38792	166.3204	476120.30	1825127.80	0%
100	0.062137	159.8195	3.28	N/S	17z	77	95	18	37.67391	173.3	413417.18	1901719.03	0%
150	0.093206	156.7403	3.28	NE/SW	17z	80	96	16	33.05908	165.2954	362776.04	1813880.20	0%
200	0.124274	156.7433	3.28	NE/SW	17z	80	95	15	35.58331	142.3333	390475.92	1561903.70	0%
250	0.155343	164.1749	3.28	N/S	17z	77	95	18	38.21708	175.7986	419377.76	1929137.71	0%
300	0.186411	154.0696	3.28	NE/SW	17z	80	96	16	28.87863	144.3931	316901.56	1584507.78	0%
350	0.21748	153.9405	3.28	NE/SW	17z	80	96	16	27.11792	135.5896	297580.39	1487901.94	0%
400	0.248548	159.4557	3.28	N/S	17z	77	64	-13	265.3131	169.5056	2911430.97	1860080.90	36%
450	0.279617	163.4306	3.28	N/S	17z	77	54	-23	346.3215	173.1608	3800382.91	1900191.45	50%
500	0.310686	171.1793	3.28	N/S	17z	77	71	-6	220.1271	174.5836	2415579.97	1915804.81	21%
550	0.341754	175.9918	3.28	N/S	17z	77	64	-13	265.1861	169.4245	2910037.66	1859190.73	36%
600	0.372823	188.7285	3.28	N/S	17z	77	75	-2	187.5757	172.5696	2058374.58	1893704.61	8%

Table I-3. Moore's Creek Shade-Related Data, TMDLs, Existing Solar Loading, and the Percent Increase in Shade Needed to Meet the TMDLs

Longitudinal Distance (m)	River Mile (RM)	Aspect	Wetted Width (ft)-GIS	General Direction	Ecoregion	Target Shade (%)	Existing Shade (%)	Shade Difference (%)	Daily Solar Flux with Existing Shade (watts/ft2)	Daily Solar Flux with Potential Shade (watts/ft2)	Existing Load (kcal/day)	Potential Load (kcal/day)	Percent Reduction Needed to Meet TMDL
650	0.403891	200.1403	3.28	N/S	17z	77	78	1	163.603	171.0395	1795308.86	1876913.81	0%
700	0.43496	207.7464	3.28	NE/SW	17z	80	99	19	7.197937	143.9587	78987.05	1579740.95	0%
750	0.466028	153.4351	3.28	NE/SW	17z	80	99	19	8.546155	170.9231	93781.81	1875636.29	0%
800	0.497097	138.3541	6.56	NE/SW	17z	77	98	21	11.74233	135.0367	257710.41	2963669.70	0%
850	0.528165	135.8352	3.28	NE/SW	17z	80	99	19	8.815119	176.3024	96733.30	1934666.09	0%
900	0.559234	109.2899	3.28	E/W	17z	83	99	16	6.361266	108.1415	69805.79	1186698.35	0%
950	0.590302	140.6571	3.28	NE/SW	17z	80	99	19	10.00822	200.1643	109825.83	2196516.67	0%
1000	0.621371	127.3836	3.28	NE/SW	17z	80	99	19	7.891412	157.8282	86596.95	1731939.00	0%
1050	0.65244	158.4132	3.28	N/S	17z	77	72	-5	209.8862	172.4065	2303200.04	1891914.32	18%
1100	0.683508	172.4056	3.28	N/S	17z	77	71	-6	219.9767	174.4643	2413929.69	1914495.96	21%
1150	0.714577	161.857	6.56	N/S	17z	75	47	-28	397.7006	187.5946	8728390.09	4117165.14	53%
1200	0.745645	188.1147	3.28	N/S	17z	77	74	-3	194.0712	171.6784	2129653.95	1883924.65	12%
1250	0.776714	184.981	3.28	N/S	17z	77	75	-2	190.0145	174.8134	2085137.28	1918326.30	8%
1300	0.807782	193.5861	3.28	N/S	17z	77	75	-2	185.9202	171.0466	2040207.75	1876991.13	8%
1350	0.838851	183.6083	3.28	N/S	17z	77	65	-12	260.2083	170.994	2855413.46	1876414.56	34%
1400	0.869919	203.8861	6.56	NE/SW	17z	77	41	-36	439.3342	171.2659	9642127.77	3758795.57	61%
1450	0.900988	202.2669	6.56	N/S	17z	75	51	-24	366.698	187.0908	8047970.53	4106107.42	49%
1500	0.932057	182.6155	3.28	N/S	17z	77	70	-7	224.8826	172.41	2467764.01	1891952.40	23%
1550	0.963125	196.55	3.28	N/S	17z	77	97	20	25.01475	191.7798	274501.09	2104508.34	0%
1600	0.994194	184.3986	3.28	N/S	17z	77	77	0	169.2557	169.2557	1857339.33	1857339.33	0%
1650	1.025262	169.4523	3.28	N/S	17z	77	78	1	162.6673	170.0613	1785040.65	1866178.86	0%

Table I-3. Moore's Creek Shade-Related Data, TMDLs, Existing Solar Loading, and the Percent Increase in Shade Needed to Meet the TMDLs

Longitudinal Distance (m)	River Mile (RM)	Aspect	Wetted Width (ft)-GIS	General Direction	Ecoregion	Target Shade (%)	Existing Shade (%)	Shade Difference (%)	Daily Solar Flux with Existing Shade (watts/ft2)	Daily Solar Flux with Potential Shade (watts/ft2)	Existing Load (kcal/day)	Potential Load (kcal/day)	Percent Reduction Needed to Meet TMDL
1700	1.056331	140.4921	3.28	NE/SW	17z	80	75	-5	189.3254	151.4603	2077574.99	1662059.99	20%
1750	1.087399	181.5906	3.28	N/S	17z	77	67	-10	244.5995	170.4784	2684128.90	1870756.50	30%
1800	1.118468	151.0108	6.56	NE/SW	17z	77	83	6	128.3865	173.6994	2817715.87	3812203.82	0%
1850	1.149536	156.5522	3.28	NE/SW	17z	80	96	16	27.20424	136.0212	298527.57	1492637.84	0%
1900	1.180605	158.3983	3.28	N/S	17z	77	97	20	23.09164	177.0359	253397.70	1942715.68	0%
1950	1.211673	141.0718	9.84	NE/SW	17ab	58	60	2	301.4068	316.4771	9922523.09	10418649.25	0%
2000	1.242742	175.6278	3.28	N/S	17ab	88	85	-3	111.2339	88.98715	1220633.16	976506.53	20%
2050	1.273811	162.2775	3.28	N/S	17ab	88	74	-14	197.325	91.07309	2165359.64	999396.76	54%
2100	1.304879	197.7929	6.56	N/S	17ab	75	52	-23	356.4989	185.6765	7824128.78	4075067.07	48%
2150	1.335948	185.4691	3.28	N/S	17ab	88	70	-18	224.374	89.74961	2462183.71	984873.49	60%
2200	1.367016	164.0125	3.28	N/S	17ab	88	70	-18	221.1623	88.46491	2426939.28	970775.71	60%
2250	1.398085	119.4156	3.28	NE/SW	17ab	88	52	-36	355.8384	88.95959	3904816.33	976204.08	75%
2300	1.429153	135.3198	3.28	NE/SW	17ab	88	64	-24	266.3323	88.77743	2922615.54	974205.18	67%
2350	1.460222	165.2778	6.56	N/S	17ab	75	98	23	14.96821	187.1027	328509.42	4106367.70	0%
2400	1.49129	184.5046	3.28	N/S	17ab	88	99	11	10.23488	122.8185	112313.13	1347757.58	0%
2450	1.522359	167.7259	6.56	N/S	17ab	75	81	6	138.8244	182.6637	3046798.47	4008945.35	0%
2500	1.553428	191.0933	6.56	N/S	17ab	75	78	3	160.8716	182.8086	3530670.41	4012125.46	0%
2550	1.584496	184.7635	3.28	N/S	17ab	88	71	-17	214.1308	88.60585	2349778.85	972322.28	59%
2600	1.615565	144.2011	3.28	NE/SW	17ab	88	83	-5	128.3852	90.62482	1408843.23	994477.58	29%
2650	1.646633	159.444	3.28	N/S	17ab	88	87	-1	95.35087	88.01619	1046339.25	965851.61	8%
2700	1.677702	136.4172	3.28	NE/SW	17ab	88	79	-9	153.5534	87.74479	1685028.45	962873.40	43%

Table I-3. Moore's Creek Shade-Related Data, TMDLs, Existing Solar Loading, and the Percent Increase in Shade Needed to Meet the TMDLs

Longitudinal Distance (m)	River Mile (RM)	Aspect	Wetted Width (ft)-GIS	General Direction	Ecoregion	Target Shade (%)	Existing Shade (%)	Shade Difference (%)	Daily Solar Flux with Existing Shade (watts/ft2)	Daily Solar Flux with Potential Shade (watts/ft2)	Existing Load (kcal/day)	Potential Load (kcal/day)	Percent Reduction Needed to Meet TMDL
2750	1.70877	143.5556	3.28	NE/SW	17ab	88	99	11	7.538569	90.46283	82725.00	992700.04	0%
2800	1.739839	135.341	3.28	NE/SW	17ab	88	99	11	5.319033	63.8284	58368.78	700425.31	0%
2850	1.770907	135.4304	3.28	NE/SW	17ab	88	99	11	5.396489	64.75787	59218.74	710624.90	0%
2900	1.801976	166.6492	3.28	N/S	17ab	88	99	11	7.006519	84.07823	76886.51	922638.12	0%
2950	1.833044	125.4657	3.28	NE/SW	17ab	88	77	-11	168.1866	87.74952	1845606.80	962925.29	48%
3000	1.864113	90.48555	3.28	E/W	17ab	91	88	-3	90.36728	67.77546	991651.49	743738.62	25%
3050	1.895182	113.6944	0	NE/SW	17ab	88	97	9	19.00444	76.01775	0.00	0.00	0%
3100	1.92625	134.6043	3.28	NE/SW	17ab	88	91	3	66.0774	88.1032	725104.84	966806.45	0%
3150	1.957319	148.48	3.28	NE/SW	17ab	88	85	-3	115.4627	92.37019	1267038.26	1013630.61	20%
3200	1.988387	151.187	3.28	NE/SW	17ab	88	99	11	5.69649	68.35787	62510.82	750129.78	0%
3250	2.019456	142.2142	3.28	NE/SW	17ab	88	93	5	51.55065	88.37254	565694.55	969762.09	0%
3300	2.050524	132.646	6.56	NE/SW	17ab	74	55	-19	335.875	194.0611	7371494.62	4259085.78	42%
3350	2.081593	141.6226	3.28	NE/SW	17ab	88	79	-9	156.6518	89.51534	1719029.70	982302.69	43%
3400	2.112661	176.5191	3.28	N/S	17ab	88	93	5	53.50668	91.72574	587159.22	1006558.66	0%
3450	2.14373	172.0502	3.28	N/S	17ab	88	95	7	39.19143	94.05944	430069.85	1032167.63	0%
3500	2.174799	129.8212	3.28	NE/SW	17ab	88	79	-9	155.8896	89.07979	1710665.45	977523.12	43%
3550	2.205867	144.7911	3.28	NE/SW	17ab	88	78	-10	161.8497	88.28168	1776069.17	968765.00	45%
3600	2.236936	88.21741	3.28	E/W	17ab	91	94	3	47.90014	71.85021	525635.48	788453.22	0%
3650	2.268004	219.0943	9.84	NE/SW	17ab	58	48	-10	389.9516	314.9609	12837480.94	10368734.60	19%
3700	2.299073	179.5585	3.28	N/S	17ab	88	81	-7	143.1821	90.43079	1571218.36	992348.44	37%
3750	2.330141	121.2503	3.28	NE/SW	17ab	88	42	-46	429.3437	88.82973	4711432.47	974779.13	79%

Table I-3. Moore's Creek Shade-Related Data, TMDLs, Existing Solar Loading, and the Percent Increase in Shade Needed to Meet the TMDLs

Longitudinal Distance (m)	River Mile (RM)	Aspect	Wetted Width (ft)-GIS	General Direction	Ecoregion	Target Shade (%)	Existing Shade (%)	Shade Difference (%)	Daily Solar Flux with Existing Shade (watts/ft2)	Daily Solar Flux with Potential Shade (watts/ft2)	Existing Load (kcal/day)	Potential Load (kcal/day)	Percent Reduction Needed to Meet TMDL
3800	2.36121	160.3297	3.28	N/S	17ab	88	91	3	64.9465	86.59534	712694.85	950259.80	0%
3850	2.392278	198.866	3.28	N/S	17ab	88	91	3	68.76346	91.68462	754580.53	1006107.37	0%
3900	2.423347	131.8928	3.28	NE/SW	17ab	88	92	4	59.41615	89.12422	652007.16	978010.73	0%
3950	2.454415	192.4394	3.28	N/S	17ab	88	90	2	76.23829	91.48595	836606.08	1003927.30	0%
4000	2.485484	142.8041	6.56	NE/SW	17ab	74	50	-24	376.0597	195.5511	8253433.84	4291785.60	48%
4050	2.516553	150.5928	6.56	NE/SW	17ab	74	57	-17	317.977	192.2651	6978683.54	4219669.12	40%
4100	2.547621	120.585	6.56	NE/SW	17ab	74	49	-25	377.3992	192.3996	8282832.50	4222620.49	49%
4150	2.57869	98.97263	6.56	E/W	17ab	71	41	-30	437.5418	215.0629	9602788.84	4720014.86	51%
4200	2.609758	161.3721	6.56	N/S	17ab	75	86	11	104.966	187.4393	2303703.08	4113755.50	0%
4250	2.640827	172.5308	9.84	N/S	17ab	60	64	4	268.9909	298.8788	8855369.93	9839299.93	0%
4300	2.671895	171.3939	3.28	N/S	17ab	88	93	5	53.80141	92.23098	590393.38	1012102.94	0%
4350	2.702964	140.0215	6.56	NE/SW	17ab	74	82	8	136.8966	197.7395	3004487.33	4339815.03	0%
4400	2.734032	167.3589	3.28	N/S	17ab	88	96	8	32.53343	97.60028	357007.78	1071023.33	0%
4450	2.765101	155.3915	6.56	NE/SW	17ab	74	79	5	156.3451	193.5702	3431327.66	4248310.43	0%
4500	2.79617	164.3726	9.84	N/S	17ab	60	66	6	256.2115	301.4253	8434664.06	9923134.19	0%
4550	2.827238	150.2024	3.28	NE/SW	17ab	88	95	7	38.25526	91.81262	419796.67	1007512.01	0%
4600	2.858307	151.2782	3.28	NE/SW	17ab	88	96	8	32.7902	98.37059	359825.47	1079476.41	0%
4650	2.889375	151.5044	3.28	NE/SW	17ab	88	94	6	41.4932	82.98641	455328.49	910656.98	0%
4700	2.920444	143.5995	3.28	NE/SW	17ab	88	94	6	45.42789	90.85578	498506.05	997012.09	0%
4750	2.951512	102.9946	3.28	E/W	17ab	91	91	0	64.88802	64.88802	712053.07	712053.07	0%
4800	2.982581	125.5695	3.28	NE/SW	17ab	88	92	4	59.18909	88.78363	649515.47	974273.21	0%

Table I-3. Moore's Creek Shade-Related Data, TMDLs, Existing Solar Loading, and the Percent Increase in Shade Needed to Meet the TMDLs

Longitudinal Distance (m)	River Mile (RM)	Aspect	Wetted Width (ft)-GIS	General Direction	Ecoregion	Target Shade (%)	Existing Shade (%)	Shade Difference (%)	Daily Solar Flux with Existing Shade (watts/ft2)	Daily Solar Flux with Potential Shade (watts/ft2)	Existing Load (kcal/day)	Potential Load (kcal/day)	Percent Reduction Needed to Meet TMDL
4850	3.013649	108.7431	6.56	E/W	17ab	71	83	12	129.7555	221.3477	2847762.49	4857947.79	0%
4900	3.044718	153.8638	6.56	NE/SW	17ab	74	76	2	178.9128	193.8222	3926623.73	4253842.37	0%
4950	3.075786	170.7189	3.28	N/S	17ab	88	38	-50	460.9036	89.20716	5057757.44	978920.79	81%
5000	3.106855	128.0849	6.56	NE/SW	17ab	74	62	-12	282.453	193.2573	6199033.91	4241444.25	32%
5050	3.137924	58.49573	3.28	NE/SW	17ab	88	49	-39	377.3662	88.79205	4141053.84	974365.61	76%
5100	3.168992	154.8265	3.28	NE/SW	17ab	88	99	11	9.078605	108.9433	99624.69	1195496.32	0%
5150	3.200061	127.157	3.28	NE/SW	17ab	88	99	11	6.64477	79.73724	72916.83	875002.02	0%
5200	3.231129	57.50019	3.28	NE/SW	17ab	88	60	-28	302.1004	90.63012	3315119.15	994535.75	70%
5250	3.262198	90	6.56	E/W	17ab	71	43	-28	426.1715	216.8241	9353244.03	4758668.01	49%
5300	3.293266	73.77533	3.28	E/W	17ab	91	51	-40	362.6084	66.60154	3979107.63	730856.50	82%
5350	3.324335	163.3651	3.28	N/S	17ab	88	59	-29	302.6202	88.57177	3320823.38	971948.31	71%
5400	3.355403	197.9954	6.56	N/S	17ab	75	56	-19	332.1228	188.7061	7289143.54	4141558.83	43%
5450	3.386472	157.2401	3.28	NE/SW	17ab	88	99	11	4.308594	51.70313	47280.65	567367.81	0%
5500	3.417541	119.1612	3.28	NE/SW	17ab	88	99	11	4.26513	51.18156	46803.69	561644.33	0%
5550	3.448609	119.1144	3.28	NE/SW	17ab	88	99	11	4.994375	59.93249	54806.11	657673.30	0%
5600	3.479678	119.0803	3.28	NE/SW	17ab	88	99	11	5.743476	68.92172	63026.43	756317.15	0%
5650	3.510746	89.60486	3.28	E/W	17ab	91	99	8	6.144508	55.30057	67427.18	606844.62	0%
5700	3.541815	197.643	3.28	N/S	17ab	88	99	11	8.207975	98.4957	90070.77	1080849.21	0%
5750	3.572883	111.2995	3.28	E/W	17ab	91	99	8	5.382307	48.44076	59063.11	531568.01	0%
5800	3.603952	158.5144	3.28	N/S	17ab	88	99	11	6.712308	80.54769	73657.97	883895.59	0%
5850	3.63502	116.1982	0	NE/SW	17ab	88	99	11	4.915395	58.98474	0.00	0.00	0%

Table I-3. Moore's Creek Shade-Related Data, TMDLs, Existing Solar Loading, and the Percent Increase in Shade Needed to Meet the TMDLs

Longitudinal Distance (m)	River Mile (RM)	Aspect	Wetted Width (ft)-GIS	General Direction	Ecoregion	Target Shade (%)	Existing Shade (%)	Shade Difference (%)	Daily Solar Flux with Existing Shade (watts/ft2)	Daily Solar Flux with Potential Shade (watts/ft2)	Existing Load (kcal/day)	Potential Load (kcal/day)	Percent Reduction Needed to Meet TMDL
5900	3.666089	99.51692	0	E/W	17ab	91	99	8	4.66137	41.95233	0.00	0.00	0%
5950	3.697157	114.9772	0	NE/SW	17ab	88	100	12	2.975981	#DIV/0!	0.00	0.00	0%
6000	3.728226	139.4846	0	NE/SW	17ab	88	96	8	30.2635	90.79049	0.00	0.00	0%
6050	3.759295	122.3669	3.28	NE/SW	17ab	88	94	6	47.21102	94.42204	518073.33	1036146.67	0%
6100	3.790363	65.34423	6.56	NE/SW	17ab	74	80	6	150.5542	195.7204	3304232.46	4295502.19	0%
6150	3.821432	137.9802	0	NE/SW	17ab	88	99	11	5.266356	63.19628	0.00	0.00	0%
6200	3.8525	138.8412	3.28	NE/SW	17ab	88	91	3	67.22117	89.62823	737656.07	983541.43	0%
6250	3.883569	121.0329	3.28	NE/SW	17ab	88	97	9	22.26055	89.0422	244277.65	977110.62	0%
6300	3.914637	110.1285	3.28	E/W	17ab	91	97	6	22.34274	67.02822	245179.57	735538.70	0%
6350	3.945706	109.0412	3.28	E/W	17ab	91	88	-3	92.2808	69.2106	1012649.59	759487.19	25%
6400	3.976774	92.34527	3.28	E/W	17ab	91	96	5	32.16731	72.37644	352990.14	794227.83	0%
6450	4.007843	103.8348	3.28	E/W	17ab	91	94	3	46.6474	69.9711	511888.45	767832.67	0%
6500	4.038912	77.21426	3.28	E/W	17ab	91	87	-4	97.69728	67.63658	1072087.73	742214.58	31%
6550	4.06998	105.9609	3.28	E/W	17ab	91	93	2	50.00489	64.292	548732.06	705512.65	0%
6600	4.101049	99.68177	3.28	E/W	17ab	91	92	1	62.90666	70.77	690310.55	776599.37	0%
6650	4.132117	84.19335	3.28	E/W	17ab	91	92	1	62.1926	69.96667	682474.72	767784.06	0%
6700	4.163186	133.2675	3.28	NE/SW	17ab	88	91	3	69.79836	93.06448	765937.02	1021249.36	0%
6750	4.194254	155.6126	0	NE/SW	17ab	88	99	11	9.606474	115.2777	0.00	0.00	0%
6800	4.225323	146.5182	3.28	NE/SW	17ab	88	96	8	33.05405	99.16214	362720.81	1088162.44	0%
6850	4.256391	179.9359	0	N/S	17ab	88	99	11	9.680222	116.1627	0.00	0.00	0%
6900	4.28746	153.0743	3.28	NE/SW	17ab	88	88	0	90.71148	90.71148	995428.56	995428.56	0%

Table I-3. Moore's Creek Shade-Related Data, TMDLs, Existing Solar Loading, and the Percent Increase in Shade Needed to Meet the TMDLs

Longitudinal Distance (m)	River Mile (RM)	Aspect	Wetted Width (ft)-GIS	General Direction	Ecoregion	Target Shade (%)	Existing Shade (%)	Shade Difference (%)	Daily Solar Flux with Existing Shade (watts/ft2)	Daily Solar Flux with Potential Shade (watts/ft2)	Existing Load (kcal/day)	Potential Load (kcal/day)	Percent Reduction Needed to Meet TMDL
6950	4.318528	194.5705	0	N/S	17ab	88	98	10	13.77132	82.62794	0.00	0.00	0%
7000	4.349597	182.3366	3.28	N/S	17ab	88	86	-2	102.0081	87.43548	1119392.36	959479.17	14%
7050	4.380666	256.464	3.28	E/W	17ab	91	90	-1	76.44999	68.80499	838929.19	755036.27	10%
7100	4.411734	145.9342	3.28	NE/SW	17ab	88	98	10	16.92715	101.5629	185751.20	1114507.21	0%
7150	4.442803	145.222	3.28	NE/SW	17ab	88	94	6	47.02724	94.05449	516056.66	1032113.32	0%
7200	4.473871	185.3185	0	N/S	17ab	88	99	11	4.137442	49.6493	0.00	0.00	0%
7250	4.50494	169.8972	3.28	N/S	17ab	88	97	9	21.26265	85.0506	233327.13	933308.53	0%
7300	4.536008	173.7146	0	N/S	17ab	88	99	11	5.883703	70.60443	0.00	0.00	0%
7350	4.567077	213.048	3.28	NE/SW	17ab	88	95	7	38.7217	92.93208	424915.23	1019796.55	0%
7400	4.598145	175.8976	3.28	N/S	17ab	88	87	-1	97.35022	89.86175	1068279.31	986103.98	8%
7450	4.629214	141.2746	6.56	NE/SW	17ab	74	76	2	182.1314	197.309	3997262.38	4330367.58	0%
7500	4.660283	196.4214	6.56	N/S	17ab	75	71	-4	215.3926	185.6833	4727250.32	4075215.80	14%
7550	4.691351	148.5818	6.56	NE/SW	17ab	74	82	8	136.0939	196.5801	2986871.99	4314370.66	0%
7600	4.72242	217.6083	3.28	NE/SW	17ab	88	84	-4	117.3277	87.99577	1287503.49	965627.61	25%
7650	4.753488	134.5657	9.84	NE/SW	17ab	58	61	3	289.0075	311.2389	9514331.03	10246202.65	0%
7700	4.784557	108.3083	3.28	E/W	17ab	91	86	-5	104.0573	66.89401	1141880.38	734065.96	36%
7750	4.815625	89.84726	3.28	E/W	17ab	91	84	-7	121.2873	68.22411	1330954.49	748661.90	44%
7800	4.846694	139.7232	6.56	NE/SW	17ab	74	71	-3	212.872	190.8507	4671930.13	4188627.01	10%
7850	4.877762	159.7184	6.56	N/S	17ab	75	71	-4	214.698	185.0845	4712007.21	4062075.18	14%
7900	4.908831	176.0091	3.28	N/S	17ab	88	82	-6	137.3492	91.56615	1507211.10	1004807.40	33%
7950	4.939899	199.6534	3.28	N/S	17ab	88	95	7	35.75711	85.81705	392383.03	941719.28	0%

Table I-3. Moore's Creek Shade-Related Data, TMDLs, Existing Solar Loading, and the Percent Increase in Shade Needed to Meet the TMDLs

Longitudinal Distance (m)	River Mile (RM)	Aspect	Wetted Width (ft)-GIS	General Direction	Ecoregion	Target Shade (%)	Existing Shade (%)	Shade Difference (%)	Daily Solar Flux with Existing Shade (watts/ft2)	Daily Solar Flux with Potential Shade (watts/ft2)	Existing Load (kcal/day)	Potential Load (kcal/day)	Percent Reduction Needed to Meet TMDL
8000	4.970968	158.5518	6.56	N/S	17ab	75	92	17	58.95988	184.2496	1294000.57	4043751.78	0%
8050	5.002037	198.1528	3.28	N/S	17ab	88	81	-7	142.5946	90.05977	1564771.96	988277.03	37%
8100	5.033105	151.3894	6.56	NE/SW	17ab	74	89	15	81.62199	192.9247	1791368.81	4234144.46	0%
8150	5.064174	95.19441	6.56	E/W	17ab	71	86	15	103.8355	215.0879	2278892.56	4720563.16	0%
8200	5.095242	116.2548	9.84	NE/SW	17ab	58	31	-27	511.4091	311.2925	16835946.60	10247967.50	39%
8250	5.126311	76.55204	9.84	E/W	17ab	50	36	-14	477.7538	373.2451	15727990.31	12287492.43	22%
8300	5.157379	150.0368	16.4	NE/SW	17ab	42	34	-8	489.3351	430.0217	26848759.01	23594363.97	12%
8350	5.188448	106.6991	9.84	E/W	17ab	50	43	-7	422.6723	370.7652	13914669.34	12205850.30	12%
8400	5.219516	218.5653	13.12	NE/SW	17ab	48	35	-13	488.0256	390.4205	21421527.34	17137221.88	20%
8450	5.250585	201.714	22.96	N/S	17ab	35	30	-5	519.4534	482.3496	39901800.14	37051671.56	7%
8500	5.281654	164.6637	13.12	N/S	17ab	51	62	11	285.6728	368.3675	12539398.25	16169224.05	0%
8550	5.312722	178.3159	9.84	N/S	17ab	60	61	1	290.2228	297.6644	9554337.28	9799320.29	0%
8600	5.343791	142.8531	13.12	NE/SW	17ab	48	27	-21	541.9463	386.044	23788339.16	16945118.31	29%
8650	5.374859	154.4858	6.56	NE/SW	17ab	74	93	19	53.90509	200.2189	1183062.29	4394231.36	0%
8700	5.405928	73.44322	9.84	E/W	17ab	50	88	38	88.69603	369.5668	2919935.62	12166398.43	0%
8750	5.436996	303.3416	6.56	NE/SW	17aa	60	62	2	286.22	301.2842	6281709.40	6612325.69	0%
8800	5.468065	150.8195	16.4	NE/SW	17aa	31	47	16	393.5419	512.3471	21592796.36	28111376.40	0%
8850	5.499133	233.6428	9.84	NE/SW	17aa	46	44	-2	420.0975	405.094	13829906.21	13335980.99	4%
8900	5.530202	169.3155	13.12	N/S	17aa	41	59	18	309.361	445.1781	13579177.22	19540767.21	0%
8950	5.56127	130.9144	6.56	NE/SW	17aa	60	58	-2	311.7772	296.9306	6842616.15	6516777.29	5%
9000	5.592339	191.4062	3.28	N/S	17aa	87	97	10	21.43516	92.88571	235220.23	1019287.68	0%

Table I-3. Moore's Creek Shade-Related Data, TMDLs, Existing Solar Loading, and the Percent Increase in Shade Needed to Meet the TMDLs

Longitudinal Distance (m)	River Mile (RM)	Aspect	Wetted Width (ft)-GIS	General Direction	Ecoregion	Target Shade (%)	Existing Shade (%)	Shade Difference (%)	Daily Solar Flux with Existing Shade (watts/ft2)	Daily Solar Flux with Potential Shade (watts/ft2)	Existing Load (kcal/day)	Potential Load (kcal/day)	Percent Reduction Needed to Meet TMDL
9050	5.623408	184.303	6.56	N/S	17aa	63	96	33	27.06007	250.3056	593890.93	5493491.13	0%
9100	5.654476	122.3073	6.56	NE/SW	17aa	60	53	-7	353.0046	300.4294	7747439.15	6593565.23	15%
9150	5.685545	121.5955	6.56	NE/SW	17aa	60	85	25	113.6243	302.9981	2493727.90	6649941.08	0%
9200	5.716613	160.0428	3.28	N/S	17aa	87	99	12	10.58972	137.6664	116207.02	1510691.30	0%
9250	5.747682	160.6864	3.28	N/S	17aa	87	97	10	19.05157	82.55682	209063.74	905942.88	0%
9300	5.77875	159.2275	6.56	N/S	17aa	63	97	34	23.94753	295.3529	525579.68	6482149.34	0%
9350	5.809819	144.8658	6.56	NE/SW	17aa	60	95	35	40.80211	326.4169	895489.46	7163915.68	0%
9400	5.840887	109.6342	3.28	E/W	17aa	91	97	6	23.27942	69.83827	255458.33	766375.00	0%
9450	5.871956	142.3793	6.56	NE/SW	17aa	60	95	35	38.52247	308.1797	845457.82	6763662.56	0%
9500	5.903025	108.2557	6.56	E/W	17aa	51	96	45	28.06675	343.8177	615984.83	7545814.16	0%
9550	5.934093	140.556	6.56	NE/SW	17aa	60	93	33	53.95942	308.3396	1184254.83	6767170.48	0%
9600	5.965162	117.7497	3.28	NE/SW	17aa	87	97	10	22.81659	98.87187	250379.36	1084977.21	0%
9650	5.99623	95.9951	3.28	E/W	17aa	91	97	6	24.68878	74.06635	270924.05	812772.14	0%
9700	6.027299	91.90915	6.56	E/W	17aa	51	95	44	36.10505	353.8295	792402.38	7765543.34	0%
9750	6.058367	80.01817	3.28	E/W	17aa	91	98	7	15.2064	68.42878	166868.42	750907.88	0%
9800	6.089436	71.90951	6.56	E/W	17aa	51	93	42	54.36002	380.5201	1193046.72	8351327.07	0%
9850	6.120504	132.0183	9.84	NE/SW	17aa	46	88	42	90.96711	409.352	2994701.30	13476155.85	0%
9900	6.151573	140.7743	13.12	NE/SW	17aa	37	62	25	279.9598	464.1439	12288633.36	20373260.57	0%
9950	6.182641	166.5838	16.4	N/S	17aa	35	65	30	259.2689	481.4994	14225525.63	26418833.31	0%
10000	6.21371	210.5102	19.68	NE/SW	17aa	27	34	7	491.522	543.6532	32362503.07	35794889.76	0%
10050	6.244779	177.8184	9.84	N/S	17aa	49	84	35	116.3998	371.0243	3831962.29	12214379.81	0%

Table I-3. Moore's Creek Shade-Related Data, TMDLs, Existing Solar Loading, and the Percent Increase in Shade Needed to Meet the TMDLs

Longitudinal Distance (m)	River Mile (RM)	Aspect	Wetted Width (ft)-GIS	General Direction	Ecoregion	Target Shade (%)	Existing Shade (%)	Shade Difference (%)	Daily Solar Flux with Existing Shade (watts/ft2)	Daily Solar Flux with Potential Shade (watts/ft2)	Existing Load (kcal/day)	Potential Load (kcal/day)	Percent Reduction Needed to Meet TMDL
10100	6.275847	158.6002	6.56	N/S	17aa	63	96	33	31.6212	292.4961	693994.68	6419450.83	0%
10150	6.306916	186.3816	3.28	N/S	17aa	87	98	11	11.68539	75.95503	128230.41	833497.68	0%
10200	6.337984	137.816	3.28	NE/SW	17aa	87	98	11	15.58947	101.3316	171072.11	1111968.72	0%
10250	6.369053	145.4995	3.28	NE/SW	17aa	87	97	10	23.51872	101.9145	258084.29	1118365.24	0%
10300	6.400121	157.7094	13.12	N/S	17aa	41	71	30	219.9922	447.5704	9656398.28	19645775.81	0%
10350	6.43119	108.7814	3.28	E/W	17aa	91	97	6	20.30281	60.90842	222794.24	668382.72	0%
10400	6.462258	114.8705	3.28	NE/SW	17aa	87	97	10	25.25616	109.4434	277150.19	1200984.18	0%
10450	6.493327	104.8683	3.28	E/W	17aa	91	96	5	26.42758	59.46206	290004.86	652510.94	0%
10500	6.524396	89.74191	6.56	E/W	17aa	51	95	44	34.25055	335.6554	751701.40	7366673.72	0%
10550	6.555464	73.1482	6.56	E/W	17aa	51	93	42	52.22216	365.5551	1146126.78	8022887.43	0%
10600	6.586533	76.26373	6.56	E/W	17aa	51	95	44	38.31449	375.482	840893.22	8240753.59	0%
10650	6.617601	90	6.56	E/W	17aa	51	94	43	45.45016	371.1763	997500.86	8146257.00	0%
10700	6.64867	138.2095	3.28	NE/SW	17aa	87	98	11	12.7356	82.78143	139755.02	908407.62	0%
10750	6.679738	94.4031	3.28	E/W	17aa	91	97	6	20.89407	62.68222	229282.53	687847.58	0%
10800	6.710807	186.9112	3.28	N/S	17aa	87	98	11	17.31292	112.534	189984.50	1234899.28	0%
10850	6.741875	134.0906	3.28	NE/SW	17aa	87	97	10	23.58459	102.1999	258807.14	1121497.61	0%
10900	6.772944	84.86318	9.84	E/W	17aa	35	31	-4	515.7367	485.8389	16978415.57	15994159.59	6%
10950	6.804012	42.06433	6.56	NE/SW	17aa	60	62	2	280.7402	295.516	6161444.22	6485730.76	0%
11000	6.835081	243.4349	6.56	NE/SW	17aa	60	61	1	294.6218	302.1762	6466104.53	6631902.08	0%
11050	6.86615	141.6411	3.28	NE/SW	17aa	87	92	5	63.11657	102.5644	692614.02	1125497.78	0%
11100	6.897218	130.6418	9.84	NE/SW	17aa	46	57	11	321.315	403.5119	10577917.61	13283896.54	0%

Table I-3. Moore's Creek Shade-Related Data, TMDLs, Existing Solar Loading, and the Percent Increase in Shade Needed to Meet the TMDLs

Longitudinal Distance (m)	River Mile (RM)	Aspect	Wetted Width (ft)-GIS	General Direction	Ecoregion	Target Shade (%)	Existing Shade (%)	Shade Difference (%)	Daily Solar Flux with Existing Shade (watts/ft2)	Daily Solar Flux with Potential Shade (watts/ft2)	Existing Load (kcal/day)	Potential Load (kcal/day)	Percent Reduction Needed to Meet TMDL
11150	6.928287	135.5162	6.56	NE/SW	17aa	60	82	22	137.2522	305.0048	3012292.08	6693982.40	0%
11200	6.959355	53.50596	3.28	NE/SW	17aa	87	90	3	74.70936	97.12217	819828.23	1065776.70	0%
11250	6.990424	107.8562	6.56	E/W	17aa	51	78	27	163.6801	364.5601	3592308.60	8001050.96	0%
11300	7.021492	113.98	3.28	NE/SW	17aa	87	95	8	33.95153	88.27397	372569.41	968680.46	0%
11350	7.052561	155.5925	3.28	NE/SW	17aa	87	93	6	50.53367	93.84824	554534.66	1029850.08	0%
11400	7.083629	130.6792	3.28	NE/SW	17aa	87	85	-2	109.814	95.17211	1205051.04	1044377.57	13%
11450	7.114698	148.465	6.56	NE/SW	17aa	60	81	21	143.2032	301.4803	3142899.07	6616629.61	0%
11500	7.145767	95.02285	3.28	E/W	17aa	91	86	-5	106.3847	68.39017	1167419.78	750484.14	36%
11550	7.176835	144.1248	6.56	NE/SW	17aa	60	79	19	157.9685	300.8925	3466957.12	6603727.86	0%
11600	7.207904	86.42398	13.12	E/W	17aa	27	22	-5	584.389	546.9281	25651328.20	24007012.29	6%
11650	7.238972	184.4424	9.84	N/S	17aa	49	65	16	258.254	376.313	8501903.19	12388487.50	0%
11700	7.270041	106.0075	3.28	E/W	17aa	91	85	-6	113.0549	67.83296	1240616.05	744369.63	40%
11750	7.301109	145.7351	9.84	NE/SW	17aa	46	55	9	337.3802	404.8562	11106793.32	13328151.98	0%
11800	7.332178	78.33104	6.56	E/W	17aa	51	66	15	257.4354	371.0098	5649969.09	8142602.51	0%
11850	7.363246	20.57065	6.56	N/S	17aa	63	66	3	255.8616	278.4376	5615429.30	6110908.36	0%
11900	7.394315	23.34772	3.28	NE/SW	17aa	87	96	9	33.44803	108.7061	367044.23	1192893.74	0%
11950	7.425383	41.92845	6.56	NE/SW	17aa	60	72	12	206.3372	294.7674	4528510.62	6469300.88	0%
12000	7.456452	33.68953	9.84	NE/SW	17aa	46	41	-5	442.1669	404.6952	14556447.09	13322849.88	8%
12050	7.487521	48.24707	13.12	NE/SW	17aa	37	28	-9	537.1043	469.9663	23575803.07	20628827.69	13%
12100	7.518589	115.3205	6.56	NE/SW	17aa	60	62	2	284.5119	299.4862	6244221.24	6572864.46	0%
12150	7.549658	94.81429	3.28	E/W	17aa	91	48	-43	388.493	67.23917	4263153.90	737853.56	83%

Table I-3. Moore's Creek Shade-Related Data, TMDLs, Existing Solar Loading, and the Percent Increase in Shade Needed to Meet the TMDLs

Longitudinal Distance (m)	River Mile (RM)	Aspect	Wetted Width (ft)-GIS	General Direction	Ecoregion	Target Shade (%)	Existing Shade (%)	Shade Difference (%)	Daily Solar Flux with Existing Shade (watts/ft2)	Daily Solar Flux with Potential Shade (watts/ft2)	Existing Load (kcal/day)	Potential Load (kcal/day)	Percent Reduction Needed to Meet TMDL
12200	7.580726	111.0968	16.4	E/W	17aa	22	11	-11	663.6358	581.6134	36412264.60	31911872.34	12%
12250	7.611795	136.3123	9.84	NE/SW	17aa	46	50	4	372.9359	402.7708	12277313.80	13259498.90	0%
12300	7.642863	126.7032	9.84	NE/SW	17aa	46	31	-15	513.5562	401.9136	16906631.75	13231277.03	22%
12350	7.673932	98.1488	9.84	E/W	17aa	35	63	28	277.8062	488.0379	9145576.13	16066552.66	0%
12400	7.705	74.0546	6.56	E/W	17aa	51	81	30	144.8905	373.665	3179931.40	8200875.72	0%
12450	7.736069	124.3923	3.28	NE/SW	17aa	87	97	10	22.59368	97.90596	247933.31	1074377.67	0%
12500	7.767138	132.969	6.56	NE/SW	17aa	60	94	34	46.91106	312.7404	1029563.51	6863756.72	0%
12550	7.798206	120.2036	6.56	NE/SW	17aa	60	97	37	25.95954	346.1272	569737.55	7596500.60	0%
12600	7.829275	115.7688	6.56	NE/SW	17aa	60	34	-26	491.6556	297.9731	10790431.28	6539655.32	39%
12650	7.860343	76.53444	3.28	E/W	17aa	91	98	7	15.26037	68.67166	167460.68	753573.08	0%
12700	7.891412	202.1098	3.28	N/S	17aa	87	97	10	23.15156	100.3234	254055.20	1100905.88	0%
12750	7.92248	136.0227	9.84	NE/SW	17aa	46	88	42	90.25062	406.1278	2971114.08	13370013.37	0%
12800	7.953549	125.3479	6.56	NE/SW	17aa	60	94	34	41.98403	279.8936	921429.28	6142861.85	0%
12850	7.984617	170.9415	6.56	N/S	17aa	63	93	30	51.28631	271.0848	1125587.56	5949534.23	0%
12900	8.015686	95.46766	3.28	E/W	17aa	91	98	7	13.341	60.0345	146398.37	658792.67	0%
12950	8.046754	115.2891	3.28	NE/SW	17aa	87	97	10	22.99635	99.65085	252352.02	1093525.42	0%
13000	8.077823	162.0218	3.28	N/S	17aa	87	84	-3	115.9883	94.24046	1272805.05	1034154.10	19%
13050	8.108892	91.84789	6.56	E/W	17aa	51	68	17	239.4009	366.5826	5254163.66	8045438.10	0%
13100	8.13996	123.793	9.84	NE/SW	17aa	46	62	16	281.4606	399.9703	9265879.71	13167302.75	0%
13150	8.171029	152.5132	3.28	NE/SW	17aa	87	87	0	99.4662	99.4662	1091499.10	1091499.10	0%
13200	8.202097	162.3844	3.28	N/S	17aa	87	89	2	79.94309	94.47819	877260.90	1036762.88	0%

Table I-3. Moore's Creek Shade-Related Data, TMDLs, Existing Solar Loading, and the Percent Increase in Shade Needed to Meet the TMDLs

Longitudinal Distance (m)	River Mile (RM)	Aspect	Wetted Width (ft)-GIS	General Direction	Ecoregion	Target Shade (%)	Existing Shade (%)	Shade Difference (%)	Daily Solar Flux with Existing Shade (watts/ft2)	Daily Solar Flux with Potential Shade (watts/ft2)	Existing Load (kcal/day)	Potential Load (kcal/day)	Percent Reduction Needed to Meet TMDL
13250	8.233166	151.327	6.56	NE/SW	17aa	60	75	15	187.2874	299.6599	4110422.56	6576676.10	0%
13300	8.264234	130.3147	6.56	NE/SW	17aa	60	74	14	193.3835	297.5131	4244214.41	6529560.63	0%
13350	8.295303	170.1586	6.56	N/S	17aa	63	79	16	154.7029	272.5718	3395285.86	5982170.33	0%
13400	8.326371	168.2624	3.28	N/S	17aa	87	89	2	79.40143	93.83805	871316.94	1029738.20	0%
13450	8.35744	117.0028	6.56	NE/SW	17aa	60	65	5	260.1962	297.367	5710560.69	6526355.07	0%
13500	8.388509	108.5892	9.84	E/W	17aa	35	49	14	377.7564	481.4542	12436006.24	15849811.88	0%
13550	8.419577	157.7903	9.84	N/S	17aa	49	67	18	243.7125	376.6466	8023186.35	12399469.81	0%
13600	8.450646	180.5847	3.28	N/S	17aa	87	94	7	47.3263	102.5403	519338.35	1125233.09	0%
13650	8.481714	171.1041	9.84	N/S	17aa	49	67	18	246.6692	381.2161	8120525.29	12549902.72	0%
13700	8.512783	164.9816	6.56	N/S	17aa	63	81	18	145.4035	283.1542	3191190.93	6214424.43	0%
13750	8.543851	191.3099	6.56	N/S	17aa	63	74	11	194.4206	276.6755	4266975.30	6072234.09	0%
13800	8.57492	100.1657	16.4	E/W	17aa	22	48	26	389.349	584.0235	21362738.25	32044107.38	0%
13850	8.605988	69.00715	9.84	E/W	17aa	35	35	0	486.6445	486.6445	16020678.36	16020678.36	0%
13900	8.637057	109.5815	16.4	E/W	17aa	0	4	4	713.3935	743.1182	39142359.08	40773290.70	0%
13950	8.668125	78.8072	16.4	E/W	17aa	0	3	3	721.5832	743.9003	39591714.03	40816200.04	0%
14000	8.699194	83.92804	16.4	E/W	17aa	22	26	4	554.1889	584.1451	30407149.98	32050779.71	0%
14050	8.730263	148.2915	9.84	NE/SW	17aa	46	64	18	267.0719	400.6078	8792193.75	13188290.62	0%
14100	8.761331	138.6119	6.56	NE/SW	17aa	60	67	7	246.3529	298.6096	5406740.55	6553624.91	0%
14150	8.7924	143.5491	9.84	NE/SW	17aa	46	63	17	274.7198	400.9424	9043968.45	13199305.31	0%
14200	8.823468	141.4958	3.28	NE/SW	17aa	87	90	3	76.43665	99.36764	838782.73	1090417.56	0%
14250	8.854537	132.6524	6.56	NE/SW	17aa	60	70	10	224.3606	299.1474	4924071.73	6565428.98	0%

Table I-3. Moore's Creek Shade-Related Data, TMDLs, Existing Solar Loading, and the Percent Increase in Shade Needed to Meet the TMDLs

Longitudinal Distance (m)	River Mile (RM)	Aspect	Wetted Width (ft)-GIS	General Direction	Ecoregion	Target Shade (%)	Existing Shade (%)	Shade Difference (%)	Daily Solar Flux with Existing Shade (watts/ft2)	Daily Solar Flux with Potential Shade (watts/ft2)	Existing Load (kcal/day)	Potential Load (kcal/day)	Percent Reduction Needed to Meet TMDL
14300	8.885605	104.6764	6.56	E/W	17aa	51	81	30	141.4345	364.752	3104081.37	8005262.47	0%
14350	8.916674	81.60707	6.56	E/W	17aa	51	82	31	133.9407	364.6164	2939615.16	8002285.70	0%
14400	8.947742	132.7559	9.84	NE/SW	17aa	46	62	16	287.08	407.9558	9450876.95	13430193.55	0%
14450	8.978811	129.7394	6.56	NE/SW	17aa	60	73	13	201.5508	298.5937	4423461.85	6553276.82	0%
14500	9.00988	99.14164	3.28	E/W	17aa	91	87	-4	94.17834	65.20039	1033472.44	715480.92	31%
14550	9.040948	80.97546	3.28	E/W	17aa	91	92	1	63.07186	70.95585	692123.38	778638.80	0%
14600	9.072017	145.424	3.28	NE/SW	17aa	87	95	8	33.59821	87.35536	368692.29	958599.95	0%
14650	9.103085	145.6084	0	NE/SW	17aa	87	99	12	5.046409	65.60331	0.00	0.00	0%
14700	9.134154	106.1684	3.28	E/W	17aa	91	91	0	67.57118	67.57118	741496.98	741496.98	0%
14750	9.165222	100.4642	6.56	E/W	17aa	51	78	27	162.4708	361.8669	3565769.47	7941941.08	0%
14800	9.196291	107.8785	3.28	E/W	17aa	91	96	5	31.74448	71.42509	348350.25	783788.05	0%
14850	9.227359	136.3552	3.28	NE/SW	17aa	87	93	6	53.95318	100.1988	592058.88	1099537.92	0%
14900	9.258428	58.21266	3.28	NE/SW	17aa	87	83	-4	129.4253	98.97228	1420257.19	1086079.03	24%
14950	9.289496	111.8015	3.28	E/W	17aa	91	83	-8	129.9736	68.80958	1426274.60	755086.55	47%
15000	9.320565	134.549	6.56	NE/SW	17aa	60	82	22	133.2863	296.1918	2925253.04	6500562.31	0%
15050	9.351634	92.15753	3.28	E/W	17aa	91	82	-9	134.2933	67.14667	1473677.04	736838.52	50%
15100	9.382702	108.2394	3.28	E/W	17aa	91	83	-8	128.5352	68.04804	1410489.59	746729.78	47%
15150	9.413771	129.3228	3.28	NE/SW	17aa	87	91	4	64.95029	93.81708	712736.38	1029508.10	0%
15200	9.444839	82.23477	3.28	E/W	17aa	91	62	-29	281.4	66.64737	3087962.13	731359.45	76%
15250	9.475908	65.82132	6.56	NE/SW	17aa	60	57	-3	319.3665	297.0851	7009179.74	6520167.20	7%
15300	9.506976	111.2179	3.28	E/W	17aa	91	92	1	60.89636	68.5084	668250.31	751781.59	0%

Table I-3. Moore's Creek Shade-Related Data, TMDLs, Existing Solar Loading, and the Percent Increase in Shade Needed to Meet the TMDLs

Longitudinal Distance (m)	River Mile (RM)	Aspect	Wetted Width (ft)-GIS	General Direction	Ecoregion	Target Shade (%)	Existing Shade (%)	Shade Difference (%)	Daily Solar Flux with Existing Shade (watts/ft2)	Daily Solar Flux with Potential Shade (watts/ft2)	Existing Load (kcal/day)	Potential Load (kcal/day)	Percent Reduction Needed to Meet TMDL
15350	9.538045	120.5789	13.12	NE/SW	17aa	37	22	-15	583.4868	471.2778	25611726.65	20686394.60	19%
15400	9.569113	104.5814	6.56	E/W	17aa	51	36	-15	475.2545	363.8667	10430474.54	7985832.07	23%
15450	9.600182	119.6499	6.56	NE/SW	17aa	60	18	-42	615.6224	300.3036	13511147.76	6590803.78	51%
15500	9.631251	79.46082	9.84	E/W	17aa	35	45	10	412.2327	487.1841	13570990.89	16038443.78	0%
15550	9.662319	97.24015	22.96	E/W	17aa	16	2	-14	728.5409	624.4636	55962848.54	47968155.89	14%
15600	9.693388	97.35238	6.56	E/W	17aa	51	6	-45	702.0914	365.9838	15408895.88	8032296.79	48%
15650	9.724456	88.40886	26.24	E/W	17aa	13	4	-9	713.1025	646.2491	62602226.27	56733267.56	9%
15700	9.755525	114.444	3.28	NE/SW	17aa	87	46	-41	405.5989	97.64418	4450867.09	1071505.04	76%
15750	9.786593	79.76531	6.56	E/W	17aa	51	39	-12	455.267	365.7062	9991805.86	8026204.70	20%
15800	9.817662	43.3866	6.56	NE/SW	17aa	60	42	-18	435.8257	300.5694	9565125.46	6596638.25	31%
15850	9.84873	56.09367	6.56	NE/SW	17aa	60	40	-20	444.4559	296.304	9754534.65	6503023.10	33%
15900	9.879799	107.9036	9.84	E/W	17aa	35	28	-7	539.8947	487.4049	17773712.92	16045713.05	10%
15950	9.910867	63.61044	16.4	NE/SW	17aa	31	1	-30	740.5364	516.1314	40631632.15	28319016.34	30%
16000	9.941936	52.89606	6.56	NE/SW	17aa	60	26	-34	550.6524	297.65	12085243.93	6532564.29	46%
16050	9.973005	73.81087	9.84	E/W	17aa	35	42	7	435.977	488.5949	14352670.48	16084889.33	0%
16100	10.00407	43.45184	6.56	NE/SW	17aa	60	73	13	202.7901	300.4297	4450661.23	6593572.19	0%
16150	10.03514	84.9079	22.96	E/W	17aa	16	2	-14	734.5561	629.6195	56424911.95	48364210.24	14%
16200	10.06621	80.10611	22.96	E/W	17aa	16	12	-4	653.7835	624.066	50220362.26	47937618.51	5%
16250	10.09728	95.35583	9.84	E/W	17aa	35	43	8	423.525	482.9671	13942739.94	15899615.72	0%
16300	10.12835	46.30215	9.84	NE/SW	17aa	46	50	4	369.8161	399.4014	12174607.77	13148576.39	0%
16350	10.15942	91.36414	13.12	E/W	17aa	27	12	-15	656.1423	544.2999	28800889.20	23891646.72	17%

Table I-3. Moore's Creek Shade-Related Data, TMDLs, Existing Solar Loading, and the Percent Increase in Shade Needed to Meet the TMDLs

Longitudinal Distance (m)	River Mile (RM)	Aspect	Wetted Width (ft)-GIS	General Direction	Ecoregion	Target Shade (%)	Existing Shade (%)	Shade Difference (%)	Daily Solar Flux with Existing Shade (watts/ft2)	Daily Solar Flux with Potential Shade (watts/ft2)	Existing Load (kcal/day)	Potential Load (kcal/day)	Percent Reduction Needed to Meet TMDL
16400	10.19048	34.96064	3.28	NE/SW	17aa	87	46	-41	400.5593	96.43095	4395564.84	1058191.54	76%
16450	10.22155	34.75265	3.28	NE/SW	17aa	87	66	-21	252.4206	96.51377	2769954.88	1059100.40	62%
16500	10.25262	39.54253	3.28	NE/SW	17aa	87	89	2	79.282	93.6969	870006.37	1028189.34	0%
16550	10.28369	45.47466	3.28	NE/SW	17aa	87	57	-30	318.8658	96.40127	3499095.04	1057865.94	70%
16600	10.31476	45.26992	3.28	NE/SW	17aa	87	91	4	67.12399	96.95688	736589.70	1063962.90	0%
16650	10.34583	72.44026	3.28	E/W	17aa	91	91	0	68.53908	68.53908	752118.24	752118.24	0%
16700	10.3769	72.60487	3.28	E/W	17aa	91	25	-66	556.6445	66.79733	6108375.76	733005.09	88%
16750	10.40796	38.15643	9.84	NE/SW	17aa	46	29	-17	526.9794	400.8012	17348532.87	13194658.80	24%
16800	10.43903	18.70926	6.56	N/S	17aa	63	82	19	134.3434	276.1504	2948453.56	6060710.09	0%
16850	10.4701	61.62076	9.84	NE/SW	17aa	46	18	-28	611.8453	402.9225	20142378.80	13264493.35	34%
16900	10.50117	95.55297	3.28	E/W	17aa	91	88	-3	91.61076	68.70807	1005296.95	753972.71	25%
16950	10.53224	79.1405	6.56	E/W	17aa	51	79	28	157.3808	367.2219	3454058.01	8059468.68	0%
17000	10.56331	169.0889	6.56	N/S	17aa	63	70	7	220.9781	272.5396	4849835.48	5981463.76	0%
17050	10.59438	67.17266	6.56	NE/SW	17aa	60	86	26	104.0389	297.2539	2283355.19	6523871.96	0%
17100	10.62544	32.90484	6.56	NE/SW	17aa	60	86	26	101.6268	290.3622	2230416.65	6372619.01	0%
17150	10.65651	315.0897	6.56	NE/SW	17aa	60	12	-48	655.755	298.0705	14391944.75	6541793.07	55%
17200	10.68758	41.10115	6.56	NE/SW	17aa	60	43	-17	425.8582	298.8479	9346368.34	6558854.97	30%
17250	10.71865	129.5597	6.56	NE/SW	17aa	60	47	-13	399.2031	301.2854	8761364.95	6612350.90	25%
17300	10.74972	55.61966	3.28	NE/SW	17aa	87	86	-1	106.3587	98.76168	1167134.77	1083768.00	7%
17350	10.78079	37.24672	3.28	NE/SW	17aa	87	74	-13	191.9225	95.96124	2106074.31	1053037.16	50%
17400	10.81186	34.22309	6.56	NE/SW	17aa	60	34	-26	491.5667	297.9192	10788482.18	6538474.05	39%

Table I-3. Moore's Creek Shade-Related Data, TMDLs, Existing Solar Loading, and the Percent Increase in Shade Needed to Meet the TMDLs

Longitudinal Distance (m)	River Mile (RM)	Aspect	Wetted Width (ft)-GIS	General Direction	Ecoregion	Target Shade (%)	Existing Shade (%)	Shade Difference (%)	Daily Solar Flux with Existing Shade (watts/ft2)	Daily Solar Flux with Potential Shade (watts/ft2)	Existing Load (kcal/day)	Potential Load (kcal/day)	Percent Reduction Needed to Meet TMDL
17450	10.84292	356.3322	9.84	N/S	17aa	49	41	-8	438.523	379.0623	14436485.98	12478996.35	14%
17500	10.87399	66.54098	9.84	NE/SW	17aa	46	15	-31	637.6241	405.0788	20991033.95	13335480.39	36%
17550	10.90506	36.09828	6.56	NE/SW	17aa	60	26	-34	549.1265	296.8252	12051755.07	6514462.20	46%
17600	10.93613	345.1143	6.56	N/S	17aa	63	55	-8	333.8577	274.5052	7327219.99	6024603.11	18%
17650	10.9672	65.09564	6.56	NE/SW	17aa	60	8	-52	688.0649	299.1587	15101053.89	6565675.61	57%
17700	10.99827	124.6952	6.56	NE/SW	17aa	60	23	-37	574.8039	298.5994	12615298.55	6553401.84	48%
17750	11.02934	29.14855	3.28	NE/SW	17aa	87	87	0	93.73933	93.73933	1028654.91	1028654.91	0%
17800	11.0604	99.05757	9.84	E/W	17aa	35	5	-30	712.1977	487.2932	23446051.05	16042034.93	32%
17850	11.09147	51.18856	13.12	NE/SW	17aa	37	13	-24	652.9806	472.8481	28662109.92	20755320.98	28%
17900	11.12254	22.38047	6.56	N/S	17aa	63	33	-30	498.9622	275.5463	10950790.44	6047451.44	45%
17950	11.15361	28.61062	9.84	NE/SW	17aa	46	21	-25	592.6708	405.1167	19511139.06	13336727.96	32%
18000	11.18468	64.02142	6.56	NE/SW	17aa	60	41	-19	441.5116	299.3299	9689914.07	6569433.27	32%
18050	11.21575	14.80417	6.56	N/S	17aa	63	20	-43	597.0823	276.1506	13104246.01	6060713.78	54%
18100	11.24682	34.48741	3.28	NE/SW	17aa	87	44	-43	418.8222	97.22659	4595974.10	1066922.56	77%
18150	11.27788	31.67501	6.56	NE/SW	17aa	60	92	32	58.16792	290.8396	1276619.20	6383095.98	0%
18200	11.30895	17.38687	3.28	N/S	17aa	87	96	9	30.92771	100.515	339387.30	1103008.72	0%
18250	11.34002	3.098777	0	N/S	17aa	87	80	-7	148.9111	96.79221	0.00	0.00	0%
18300	11.37109	28.88473	3.28	NE/SW	17aa	87	61	-26	288.2542	96.08472	3163176.66	1054392.22	67%
18350	11.40216	4.783988	3.28	N/S	17aa	87	95	8	38.47799	100.0428	422240.87	1097826.25	0%
18400	11.43323	346.1713	3.28	N/S	17aa	87	94	7	41.62144	90.17978	456735.68	989593.98	0%
18450	11.46429	350.7333	3.28	N/S	17aa	87	94	7	42.60464	92.31006	467524.96	1012970.75	0%

Table I-3. Moore's Creek Shade-Related Data, TMDLs, Existing Solar Loading, and the Percent Increase in Shade Needed to Meet the TMDLs

Longitudinal Distance (m)	River Mile (RM)	Aspect	Wetted Width (ft)-GIS	General Direction	Ecoregion	Target Shade (%)	Existing Shade (%)	Shade Difference (%)	Daily Solar Flux with Existing Shade (watts/ft2)	Daily Solar Flux with Potential Shade (watts/ft2)	Existing Load (kcal/day)	Potential Load (kcal/day)	Percent Reduction Needed to Meet TMDL
18500	11.49536	20.54671	3.28	N/S	17aa	87	95	8	40.14381	104.3739	440520.82	1145354.14	0%
18550	11.52643	331.0736	3.28	NE/SW	17aa	87	94	7	45.90432	99.45936	503734.20	1091424.09	0%
18600	11.5575	4.332227	3.28	N/S	17aa	87	94	7	43.34938	93.92366	475697.40	1030677.71	0%
18650	11.58857	4.361549	3.28	N/S	17aa	87	94	7	41.77251	90.50711	458393.52	993185.97	0%
18700	11.61964	43.22853	3.28	NE/SW	17aa	87	99	12	6.166941	80.17023	67673.34	879753.47	0%
18750	11.65071	42.77855	3.28	NE/SW	17aa	87	93	6	55.15788	102.4361	605278.71	1124089.04	0%
18800	11.68177	47.58949	3.28	NE/SW	17aa	87	75	-12	184.4698	95.92428	2024291.55	1052631.61	48%
18850	11.71284	264.3592	9.84	E/W	17aa	35	51	16	367.9973	488.1597	12114730.79	16070561.25	0%
18900	11.74391	62.52499	9.84	NE/SW	17aa	46	55	9	339.1341	406.9609	11164533.51	13397440.21	0%
18950	11.77498	42.78534	6.56	NE/SW	17aa	60	65	5	259.1944	296.2222	5688574.34	6501227.82	0%
19000	11.80605	49.57353	6.56	NE/SW	17aa	60	40	-20	445.3982	296.9321	9775215.31	6516810.21	33%
19050	11.83712	15.27764	6.56	N/S	17aa	63	22	-41	583.2825	276.6853	12801379.90	6072449.44	53%
19100	11.86819	13.7812	9.84	N/S	17aa	49	10	-39	674.4585	382.1931	22203647.66	12582067.01	43%
19150	11.89925	12.72393	3.28	N/S	17aa	87	63	-24	273.0936	95.95179	2996810.78	1052933.52	65%
19200	11.93032	321.3405	6.56	NE/SW	17aa	60	18	-42	609.7792	297.4533	13382907.04	6528247.34	51%
19250	11.96139	26.75487	3.28	NE/SW	17aa	87	38	-49	463.0326	97.08748	5081119.77	1065396.08	79%
19300	11.99246	323.2311	6.56	NE/SW	17aa	60	11	-49	663.9819	298.4188	14572500.14	6549438.26	55%
19350	12.02353	14.52251	9.84	N/S	17aa	49	12	-37	655.6022	379.9513	21582884.98	12508262.89	42%
19400	12.0546	324.1883	6.56	NE/SW	17aa	60	13	-47	649.8001	298.7587	14261251.37	6556897.18	54%
19450	12.08567	305.819	9.84	NE/SW	17aa	46	5	-41	706.5625	401.625	23260535.46	13221778.05	43%
19500	12.11673	77.17542	9.84	E/W	17aa	35	9	-26	678.4686	484.6204	22335662.57	15954044.69	29%

Table I-3. Moore's Creek Shade-Related Data, TMDLs, Existing Solar Loading, and the Percent Increase in Shade Needed to Meet the TMDLs

Longitudinal Distance (m)	River Mile (RM)	Aspect	Wetted Width (ft)-GIS	General Direction	Ecoregion	Target Shade (%)	Existing Shade (%)	Shade Difference (%)	Daily Solar Flux with Existing Shade (watts/ft2)	Daily Solar Flux with Potential Shade (watts/ft2)	Existing Load (kcal/day)	Potential Load (kcal/day)	Percent Reduction Needed to Meet TMDL
19550	12.1478	15.03034	13.12	N/S	17aa	41	13	-28	650.9936	441.4784	28574888.70	19378372.80	32%
19600	12.17887	348.1499	9.84	N/S	17aa	49	18	-31	612.6016	381.0083	20167276.03	12543061.92	38%
19650	12.20994	293.6626	9.84	NE/SW	17aa	46	11	-35	666.1279	404.1675	21929398.11	13305477.50	39%
19700	12.24101	28.96763	6.56	NE/SW	17aa	60	21	-39	588.7507	298.1016	12921392.64	6542477.29	49%
19750	12.27208	10.40763	9.84	N/S	17aa	49	21	-28	592.3551	382.4065	19500746.98	12589089.82	35%
19800	12.30315	338.583	9.84	N/S	17aa	49	18	-31	611.3409	380.2242	20125771.67	12517248.23	38%
19850	12.33421	8.00468	9.84	N/S	17aa	49	17	-32	621.5369	381.9082	20461430.71	12572686.34	39%
19900	12.36528	358.3902	9.84	N/S	17aa	49	48	-1	384.556	377.1607	12659854.75	12416396.01	2%
19950	12.39635	348.8709	9.84	N/S	17aa	49	11	-38	662.6217	379.7046	21813973.22	12500141.96	43%
20000	12.42742	356.7431	6.56	N/S	17aa	63	16	-47	627.3642	276.339	13768847.68	6064849.57	56%
20050	12.45849	97.40635	6.56	E/W	17aa	51	13	-38	651.3561	366.8558	14295401.89	8051433.25	44%
20100	12.48956	337.8889	13.12	N/S	17aa	41	13	-28	646.6472	438.5308	28384107.26	19248992.28	32%
20150	12.52063	330.6651	16.4	NE/SW	17aa	31	11	-20	664.8478	515.4438	36478764.08	28281289.00	22%
20200	12.55169	60.09406	16.4	NE/SW	17aa	31	8	-23	688.2459	516.1844	37762566.72	28321925.04	25%
20250	12.58276	28.07249	13.12	NE/SW	17aa	37	16	-21	627.9042	470.9281	27561396.07	20671047.05	25%
20300	12.61383	347.7509	16.4	N/S	17aa	35	5	-30	705.6452	482.8099	38717230.48	26490736.64	32%
20350	12.6449	35.05943	9.84	NE/SW	17aa	46	17	-29	618.063	402.1133	20347068.69	13237851.92	35%
20400	12.67597	57.44195	9.84	NE/SW	17aa	46	12	-34	653.7013	401.1349	21520308.05	13205643.58	39%
20450	12.70704	358.8427	19.68	N/S	17aa	31	10	-21	674.6388	517.2231	44419171.56	34054698.19	23%
20500	12.73811	134.2468	9.84	NE/SW	17aa	46	14	-32	638.8543	401.1411	21031533.97	13205846.91	37%
20550	12.76917	72.8106	13.12	E/W	17aa	27	8	-19	688.8559	546.5922	30236827.25	23992265.10	21%

Table I-3. Moore's Creek Shade-Related Data, TMDLs, Existing Solar Loading, and the Percent Increase in Shade Needed to Meet the TMDLs

Longitudinal Distance (m)	River Mile (RM)	Aspect	Wetted Width (ft)-GIS	General Direction	Ecoregion	Target Shade (%)	Existing Shade (%)	Shade Difference (%)	Daily Solar Flux with Existing Shade (watts/ft2)	Daily Solar Flux with Potential Shade (watts/ft2)	Existing Load (kcal/day)	Potential Load (kcal/day)	Percent Reduction Needed to Meet TMDL
20600	12.80024	349.5308	22.96	N/S	17aa	24	7	-17	696.1364	568.8857	53473701.91	43698939.19	18%
20650	12.83131	39.80557	19.68	NE/SW	17aa	27	8	-19	684.5242	543.1551	45070039.59	35762096.63	21%
20700	12.86238	53.72378	16.4	NE/SW	17aa	31	7	-24	690.5099	512.3138	37886784.89	28109550.08	26%
20750	12.89345	284.3227	19.68	E/W	17aa	19	5	-14	709.2694	604.7455	46699297.56	39817295.81	15%
20800	12.92452	357.553	16.4	N/S	17aa	35	12	-23	659.0272	486.7814	36159397.79	26708646.09	26%
20850	12.95559	50.40728	13.12	NE/SW	17aa	37	11	-26	660.9094	467.8348	29010137.76	20535266.05	29%
20900	12.98665	74.53878	6.56	E/W	17aa	51	19	-32	607.7782	367.6683	13338990.40	8069265.80	40%
20950	13.01772	352.4667	9.84	N/S	17aa	49	17	-32	622.6474	382.5906	20497990.97	12595151.08	39%
21000	13.04879	36.02737	3.28	NE/SW	17aa	87	40	-47	450.5184	97.61232	4943794.54	1071155.48	78%
21050	13.07986	44.43273	9.84	NE/SW	17aa	46	14	-32	642.8025	403.6202	21161511.04	13287460.42	37%
21100	13.11093	257.074	6.56	E/W	17aa	51	18	-33	612.9938	366.3011	13453457.44	8039261.15	40%
21150	13.142	42.76883	6.56	NE/SW	17aa	60	30	-30	524.0134	299.4363	11500594.41	6571768.24	43%
21200	13.17307	24.96279	9.84	NE/SW	17aa	46	16	-30	627.7088	403.5271	20664615.88	13284395.93	36%
21250	13.20413	347.5741	9.84	N/S	17aa	49	17	-32	616.3476	378.7196	20290596.74	12467716.07	39%
21300	13.2352	311.4412	9.84	NE/SW	17aa	46	17	-29	620.0971	403.4367	20414033.81	13281419.59	35%
21350	13.26627	156.1613	6.56	NE/SW	17aa	60	24	-36	570.9969	300.5247	12531746.36	6595655.98	47%
21400	13.29734	67.89726	13.12	E/W	17aa	27	19	-8	607.0877	547.1284	26647672.40	24015803.52	10%
21450	13.32841	64.71752	6.56	NE/SW	17aa	60	14	-46	644.0621	299.5638	14135318.33	6574566.66	53%
21500	13.35948	63.85823	6.56	NE/SW	17aa	60	21	-39	589.1612	298.3095	12930400.75	6547038.35	49%
21550	13.39055	65.76112	9.84	NE/SW	17aa	46	12	-34	655.6978	402.36	21586033.92	13245975.36	39%
21600	13.42161	57.13313	9.84	NE/SW	17aa	46	12	-34	658.4293	404.0362	21675956.74	13301155.27	39%

Table I-3. Moore's Creek Shade-Related Data, TMDLs, Existing Solar Loading, and the Percent Increase in Shade Needed to Meet the TMDLs

Longitudinal Distance (m)	River Mile (RM)	Aspect	Wetted Width (ft)-GIS	General Direction	Ecoregion	Target Shade (%)	Existing Shade (%)	Shade Difference (%)	Daily Solar Flux with Existing Shade (watts/ft2)	Daily Solar Flux with Potential Shade (watts/ft2)	Existing Load (kcal/day)	Potential Load (kcal/day)	Percent Reduction Needed to Meet TMDL
21650	13.45268	60.06514	13.12	NE/SW	17aa	37	9	-28	677.6201	469.1216	29743642.41	20591752.43	31%
21700	13.48375	58.83481	13.12	NE/SW	17aa	37	9	-28	677.3887	468.9614	29733482.66	20584718.77	31%
21750	13.51482	34.343	13.12	NE/SW	17aa	37	12	-25	660.0124	472.5088	28970762.11	20740431.96	28%
21800	13.54589	17.10265	13.12	N/S	17aa	41	13	-28	648.4044	439.7225	28461240.28	19301300.88	32%
21850	13.57696	37.45046	16.4	NE/SW	17aa	31	11	-20	666.809	516.9643	36586368.62	28364712.75	22%
21900	13.60802	326.6114	16.4	NE/SW	17aa	31	10	-21	672.1031	515.2791	36876847.60	28272249.83	23%
21950	13.63909	0.734805	13.12	N/S	17aa	41	14	-27	638.2888	437.8958	28017220.02	19221116.06	31%
22000	13.67016	321.1464	13.12	NE/SW	17aa	37	12	-25	654.1606	468.3195	28713903.07	20556544.24	28%
22050	13.70123	12.99452	19.68	N/S	17aa	31	10	-21	672.9005	515.8904	44304717.70	33966950.24	23%
22100	13.7323	345.6602	9.84	N/S	17aa	49	16	-33	625.3632	379.6848	20587396.68	12499490.84	39%
22150	13.76337	356.1861	13.12	N/S	17aa	41	13	-28	650.0807	440.8594	28534821.10	19351200.51	32%
22200	13.79444	321.5819	13.12	NE/SW	17aa	37	11	-26	661.3465	468.1441	29029321.60	20548845.63	29%
22250	13.8255	2.033365	6.56	N/S	17aa	63	30	-33	520.2724	275.0011	11418489.57	6035487.35	47%
22300	13.85657	355.1563	3.28	N/S	17aa	87	38	-49	465.3423	97.57177	5106465.26	1070710.46	79%
22350	13.88764	345.1599	6.56	N/S	17aa	63	22	-41	579.3735	274.831	12715588.95	6031753.73	53%
22400	13.91871	17.28173	9.84	N/S	17aa	49	18	-31	612.2737	380.8043	20156479.77	12536347.18	38%
22450	13.94978	30.36788	9.84	NE/SW	17aa	46	18	-28	610.4651	402.0136	20096942.25	13234571.73	34%
22500	13.98085	354.7091	6.56	N/S	17aa	63	27	-36	546.9228	277.2074	12003388.71	6083909.35	49%
22550	14.01192	26.28881	16.4	NE/SW	17aa	31	11	-20	665.3338	515.8206	36505427.58	28301960.71	22%
22600	14.04298	18.43451	6.56	N/S	17aa	63	22	-41	581.3788	275.7822	12759598.96	6052630.28	53%
22650	14.07405	19.98356	9.84	N/S	17aa	49	17	-32	617.6649	379.5291	20333964.60	12494363.79	39%

Table I-3. Moore's Creek Shade-Related Data, TMDLs, Existing Solar Loading, and the Percent Increase in Shade Needed to Meet the TMDLs

Longitudinal Distance (m)	River Mile (RM)	Aspect	Wetted Width (ft)-GIS	General Direction	Ecoregion	Target Shade (%)	Existing Shade (%)	Shade Difference (%)	Daily Solar Flux with Existing Shade (watts/ft2)	Daily Solar Flux with Potential Shade (watts/ft2)	Existing Load (kcal/day)	Potential Load (kcal/day)	Percent Reduction Needed to Meet TMDL
22700	14.10512	357.6146	13.12	N/S	17aa	41	15	-26	635.5465	441.144	27896849.78	19363695.73	31%
22750	14.13619	354.719	6.56	N/S	17aa	63	25	-38	562.6033	277.551	12347531.12	6091448.69	51%
22800	14.16726	322.4314	9.84	NE/SW	17aa	46	19	-27	606.7844	404.5229	19975769.70	13317179.80	33%
22850	14.19833	335.8976	9.84	NE/SW	17aa	46	19	-27	606.7617	404.5078	19975022.83	13316681.88	33%
22900	14.2294	32.8277	13.12	NE/SW	17aa	37	14	-23	645.4624	472.8388	28332104.22	20754913.56	27%
22950	14.26046	303.1299	6.56	NE/SW	17aa	60	20	-40	595.7261	297.863	13074481.57	6537240.78	50%
23000	14.29153	339.9442	9.84	N/S	17aa	49	19	-30	600.9815	378.3957	19784733.08	12457054.16	37%
23050	14.3226	9.089907	3.28	N/S	17aa	87	38	-49	464.6029	97.41673	5098351.11	1069009.10	79%
23100	14.35367	101.0701	9.84	E/W	17aa	35	11	-24	663.7188	484.7384	21850088.64	15957929.91	27%
23150	14.38474	325.0081	19.68	NE/SW	17aa	27	9	-18	679.0254	544.7126	44707985.31	35864647.56	20%
23200	14.41581	343.8865	13.12	N/S	17aa	41	13	-28	648.5458	439.8184	28467446.07	19305509.41	32%
23250	14.44688	33.8868	9.84	NE/SW	17aa	46	14	-32	640.2736	402.0322	21078256.67	13235184.42	37%
23300	14.47794	242.241	3.28	NE/SW	17aa	87	31	-56	516.9082	97.3885	5672327.21	1068699.33	81%
23350	14.50901	55.34267	13.12	NE/SW	17aa	37	10	-27	671.1914	469.834	29461457.74	20623020.42	30%
23400	14.54008	328.4381	9.84	NE/SW	17aa	46	14	-32	638.5826	400.9705	21022588.41	13200229.93	37%
23450	14.57115	12.09476	13.12	N/S	17aa	41	14	-27	645.4007	442.7749	28329391.82	19435280.43	31%
23500	14.60222	96.44092	9.84	E/W	17aa	35	10	-25	673.108	486.1336	22159189.29	16003858.93	28%
23550	14.63329	72.04421	13.12	E/W	17aa	27	9	-18	680.4272	545.8372	29866856.36	23959126.53	20%
23600	14.66436	318.0128	13.12	NE/SW	17aa	37	12	-25	659.3086	472.0051	28939873.19	20718318.31	28%
23650	14.69542	335.2607	9.84	NE/SW	17aa	46	18	-28	610.5688	402.0819	20100356.35	13236820.04	34%
23700	14.72649	312.5102	13.12	NE/SW	17aa	37	12	-25	657.6059	470.786	28865132.24	20664810.58	28%

Table I-3. Moore's Creek Shade-Related Data, TMDLs, Existing Solar Loading, and the Percent Increase in Shade Needed to Meet the TMDLs

Longitudinal Distance (m)	River Mile (RM)	Aspect	Wetted Width (ft)-GIS	General Direction	Ecoregion	Target Shade (%)	Existing Shade (%)	Shade Difference (%)	Daily Solar Flux with Existing Shade (watts/ft2)	Daily Solar Flux with Potential Shade (watts/ft2)	Existing Load (kcal/day)	Potential Load (kcal/day)	Percent Reduction Needed to Meet TMDL
23750	14.75756	13.32446	9.84	N/S	17aa	49	17	-32	621.8768	382.1171	20472622.91	12579563.48	39%
23800	14.78863	20.25063	9.84	N/S	17aa	49	16	-33	627.8822	381.2142	20670324.50	12549839.88	39%
23850	14.8197	135.6585	6.56	NE/SW	17aa	60	22	-38	584.2086	299.5941	12821705.03	6575233.35	49%
23900	14.85077	71.27421	9.84	E/W	17aa	35	11	-24	667.3639	487.4006	21970089.39	16045570.91	27%
23950	14.88184	345.204	9.84	N/S	17aa	49	17	-32	616.879	379.0461	20308091.76	12478466.02	39%
24000	14.9129	265.2923	6.56	E/W	17aa	51	16	-35	625.1198	364.6532	13719588.59	8003093.34	42%
24050	14.94397	26.46339	9.84	NE/SW	17aa	46	20	-26	596.0165	402.3111	19621283.16	13244366.13	33%
24100	14.97504	306.2978	9.84	NE/SW	17aa	46	14	-32	639.4354	401.506	21050664.07	13217858.83	37%
24150	15.00611	340.2406	13.12	N/S	17aa	41	14	-27	638.7485	438.2112	28037402.54	19234962.21	31%
24200	15.03718	6.086858	13.12	N/S	17aa	41	15	-26	633.2123	439.5238	27794393.02	19292578.68	31%
24250	15.06825	320.3559	13.12	NE/SW	17aa	37	11	-26	663.4258	469.616	29120592.47	20613453.10	29%
24300	15.09932	50.33264	16.4	NE/SW	17aa	31	8	-23	685.9821	514.4866	37638358.58	28228768.94	25%
24350	15.13038	294.3053	13.12	NE/SW	17aa	37	8	-29	683.3055	467.9157	29993197.66	20538820.13	32%
24400	15.16145	327.5837	9.84	NE/SW	17aa	46	17	-29	618.0451	402.1016	20346478.35	13237467.84	35%
24450	15.19252	1.00477	9.84	N/S	17aa	49	20	-29	597.373	380.8253	19665939.07	12537036.16	36%
24500	15.22359	354.4274	16.4	N/S	17aa	35	11	-24	666.4765	486.7525	36568124.95	26707057.55	27%
24550	15.25466	59.30007	6.56	NE/SW	17aa	60	15	-45	633.5327	298.133	13904227.40	6543165.83	53%
24600	15.28573	74.34551	16.4	E/W	17aa	22	6	-16	699.907	580.7739	38402386.93	31865810.43	17%
24650	15.3168	338.1994	9.84	N/S	17aa	49	17	-32	622.7292	382.6408	20500684.31	12596806.02	39%
24700	15.34786	44.27534	13.12	NE/SW	17aa	37	11	-26	662.7559	469.1418	29091189.45	20592639.72	29%
24750	15.37893	68.38992	3.28	E/W	17aa	91	24	-67	570.6346	67.57515	6261897.22	741540.46	88%

Table I-3. Moore's Creek Shade-Related Data, TMDLs, Existing Solar Loading, and the Percent Increase in Shade Needed to Meet the TMDLs

Longitudinal Distance (m)	River Mile (RM)	Aspect	Wetted Width (ft)-GIS	General Direction	Ecoregion	Target Shade (%)	Existing Shade (%)	Shade Difference (%)	Daily Solar Flux with Existing Shade (watts/ft2)	Daily Solar Flux with Potential Shade (watts/ft2)	Existing Load (kcal/day)	Potential Load (kcal/day)	Percent Reduction Needed to Meet TMDL
24800	15.41	0.56259	9.84	N/S	17aa	49	22	-27	583.1236	381.2731	19196839.98	12551779.99	35%
24850	15.44107	31.42957	6.56	NE/SW	17aa	60	24	-36	564.9393	297.3365	12398799.81	6525684.11	47%
24900	15.47214	145.3048	9.84	NE/SW	17aa	46	15	-31	631.878	401.4284	20801867.37	13215303.97	36%
24950	15.50321	123.851	6.56	NE/SW	17aa	60	18	-42	613.7547	299.3925	13470156.83	6570808.21	51%
25000	15.53428	54.78241	9.84	NE/SW	17aa	46	16	-30	630.6465	405.4156	20761325.99	13346566.71	36%
25050	15.56534	29.90808	9.84	NE/SW	17aa	46	20	-26	599.981	404.9872	19751796.70	13332462.77	33%
25100	15.59641	48.53229	6.56	NE/SW	17aa	60	26	-34	552.925	298.8784	12135119.08	6559523.83	46%
25150	15.62748	122.6806	13.12	NE/SW	17aa	37	11	-26	665.7012	471.2267	29220470.30	20684153.14	29%
25200	15.65855	71.14776	6.56	E/W	17aa	51	19	-32	607.621	367.5732	13335540.11	8067178.58	40%
25250	15.68962	13.13305	9.84	N/S	17aa	49	20	-29	598.5487	381.5748	19704642.99	12561709.91	36%
25300	15.72069	25.76883	6.56	NE/SW	17aa	60	22	-38	578.727	296.7831	12701401.08	6513539.01	49%
25350	15.75175	58.46539	9.84	NE/SW	17aa	46	14	-32	642.5892	403.4863	21154490.04	13283051.89	37%
25400	15.78282	76.38623	6.56	E/W	17aa	51	15	-36	632.1065	364.3908	13872927.12	7997334.46	42%
25450	15.81389	302.9321	3.28	NE/SW	17aa	87	24	-63	565.1791	96.67537	6202031.36	1060873.79	83%
25500	15.84496	344.8327	9.84	N/S	17aa	49	17	-32	618.3045	379.9221	20355020.88	12507301.98	39%
25550	15.87603	358.5798	6.56	N/S	17aa	63	31	-32	514.2246	275.7436	11285756.49	6051782.46	46%
25600	15.9071	332.2853	6.56	NE/SW	17aa	60	21	-39	591.7058	299.5979	12986247.02	6575314.95	49%
25650	15.93817	41.06981	9.84	NE/SW	17aa	46	18	-28	611.0649	402.4086	20116685.83	13247573.60	34%
25700	15.96923	320.0134	13.12	NE/SW	17aa	37	12	-25	658.1037	471.1424	28886981.49	20680452.66	28%
25750	16.0003	276.5192	9.84	E/W	17aa	35	9	-26	677.4	483.8571	22300484.63	15928917.59	29%
25800	16.03137	78.69066	9.84	E/W	17aa	35	11	-24	667.0452	487.1678	21959596.08	16037907.25	27%

Table I-3. Moore's Creek Shade-Related Data, TMDLs, Existing Solar Loading, and the Percent Increase in Shade Needed to Meet the TMDLs

Longitudinal Distance (m)	River Mile (RM)	Aspect	Wetted Width (ft)-GIS	General Direction	Ecoregion	Target Shade (%)	Existing Shade (%)	Shade Difference (%)	Daily Solar Flux with Existing Shade (watts/ft2)	Daily Solar Flux with Potential Shade (watts/ft2)	Existing Load (kcal/day)	Potential Load (kcal/day)	Percent Reduction Needed to Meet TMDL
25850	16.06244	286.6991	13.12	E/W	17aa	27	8	-19	688.2655	546.1237	30210915.06	23971704.34	21%
25900	16.09351	340.4972	6.56	N/S	17aa	63	22	-41	583.4021	276.742	12804005.59	6073694.96	53%
25950	16.12458	302.7346	3.28	NE/SW	17aa	87	28	-59	539.1498	97.3465	5916397.44	1068238.43	82%
26000	16.15565	163.78	9.84	N/S	17aa	49	21	-28	587.7991	379.4652	19350760.07	12492262.83	35%
26050	16.18671	84.09736	6.56	E/W	17aa	51	13	-38	652.5771	367.5434	14322198.47	8066525.58	44%
26100	16.21778	345.7001	6.56	N/S	17aa	63	22	-41	579.8358	275.0503	12725735.27	6036566.73	53%
26150	16.24885	349.9202	9.84	N/S	17aa	49	18	-31	612.9016	381.1949	20177151.10	12549203.73	38%
26200	16.27992	74.05417	13.12	E/W	17aa	27	8	-19	690.2491	547.6977	30297982.57	24040790.52	21%
26250	16.31099	18.79942	19.68	N/S	17aa	31	10	-21	673.9975	516.7314	44376944.18	34022323.87	23%
26300	16.34206	7.21398	13.12	N/S	17aa	41	12	-29	660.4412	442.7958	28989586.23	19436199.86	33%
26350	16.37313	127.9418	9.84	NE/SW	17aa	46	14	-32	644.6416	404.775	21222055.51	13325476.71	37%
26400	16.40419	70.34599	9.84	E/W	17aa	35	12	-23	659.5236	487.1481	21711980.14	16037258.06	26%
26450	16.43526	25.4081	9.84	NE/SW	17aa	46	15	-31	634.5221	403.1081	20888913.18	13270603.66	36%
26500	16.46633	270	13.12	E/W	17aa	27	7	-20	692.2391	543.3705	30385330.34	23850850.69	22%
26550	16.4974	266.5664	6.56	E/W	17aa	51	14	-37	640.6684	365.032	14060836.76	8011406.99	43%
26600	16.52847	64.93241	9.84	NE/SW	17aa	46	13	-33	647.4184	401.8459	21313469.86	13229050.26	38%
26650	16.55954	23.19868	9.84	NE/SW	17aa	46	16	-30	629.2582	404.5231	20715622.18	13317185.69	36%
26700	16.59061	93.86496	16.4	E/W	17aa	22	6	-16	702.4732	582.9033	38543189.17	31982646.34	17%
26750	16.62167	33.23881	9.84	NE/SW	17aa	46	17	-29	622.9801	405.3124	20508943.35	13343167.96	35%
26800	16.65274	9.560942	6.56	N/S	17aa	63	24	-39	570.2557	277.6245	12515478.84	6093062.06	51%
26850	16.68381	99.29331	6.56	E/W	17aa	51	13	-38	651.4373	366.9015	14297184.08	8052437.01	44%

Table I-3. Moore's Creek Shade-Related Data, TMDLs, Existing Solar Loading, and the Percent Increase in Shade Needed to Meet the TMDLs

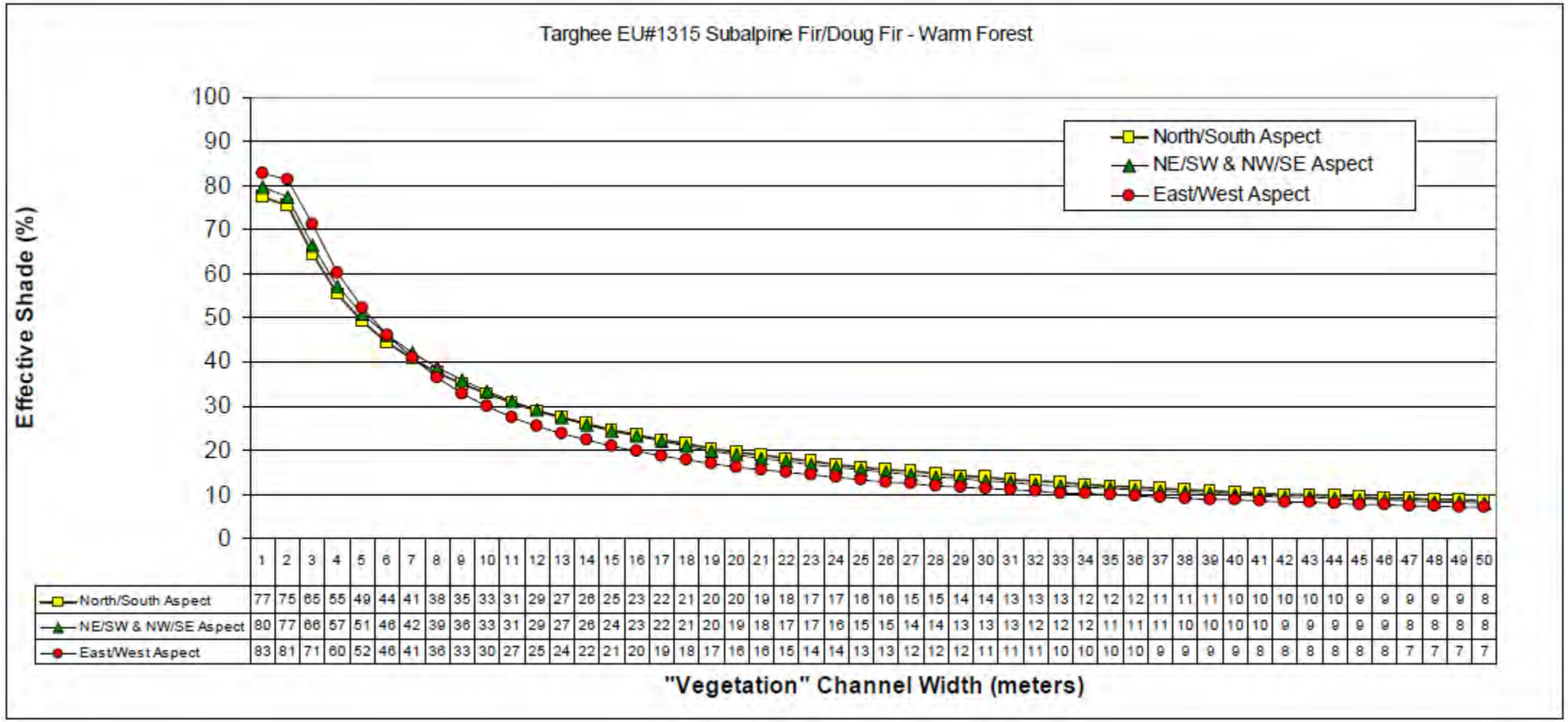
Longitudinal Distance (m)	River Mile (RM)	Aspect	Wetted Width (ft)-GIS	General Direction	Ecoregion	Target Shade (%)	Existing Shade (%)	Shade Difference (%)	Daily Solar Flux with Existing Shade (watts/ft2)	Daily Solar Flux with Potential Shade (watts/ft2)	Existing Load (kcal/day)	Potential Load (kcal/day)	Percent Reduction Needed to Meet TMDL
26900	16.71488	48.81477	9.84	NE/SW	17aa	46	15	-31	631.0643	400.9114	20775080.69	13198286.55	36%
26950	16.74595	23.68209	6.56	NE/SW	17aa	60	25	-35	556.565	296.8347	12215007.82	6514670.83	47%
27000	16.77702	37.99873	3.28	NE/SW	17aa	87	30	-57	519.9458	96.56136	5705660.69	1059622.70	81%
27050	16.80809	7.529343	3.28	N/S	17aa	87	35	-52	482.7872	96.55744	5297897.93	1059579.59	80%
27100	16.83915	29.24883	9.84	NE/SW	17aa	46	17	-29	617.4331	401.7035	20326333.16	13224361.33	35%
27150	16.87022	129.5086	6.56	NE/SW	17aa	60	17	-43	617.6278	297.6519	13555161.17	6532607.79	52%
27200	16.90129	320.3322	6.56	NE/SW	17aa	60	20	-40	600.2819	300.141	13174469.30	6587234.65	50%
27250	16.93236	142.7652	13.12	NE/SW	17aa	37	13	-24	648.4756	469.5858	28464364.83	20612126.26	28%
27300	16.96343	81.43911	9.84	E/W	17aa	35	11	-24	666.7289	486.9368	21949183.26	16030302.38	27%
27350	16.9945	79.31529	6.56	E/W	17aa	51	11	-40	661.7731	364.347	14524025.31	7996373.49	45%
27400	17.02557	65.69475	6.56	NE/SW	17aa	60	15	-45	638.1389	300.3007	14005321.22	6590739.40	53%
27450	17.05663	70.16672	6.56	E/W	17aa	51	9	-42	678.1217	365.1425	14882829.73	8013831.39	46%
27500	17.0877	49.08553	9.84	NE/SW	17aa	46	15	-31	634.9857	403.4027	20904174.83	13280299.30	36%
27550	17.11877	73.39059	9.84	E/W	17aa	35	11	-24	663.4046	484.509	21839747.83	15950377.63	27%
27600	17.14984	343.2176	6.56	N/S	17aa	63	30	-33	525.577	277.805	11534910.08	6097023.90	47%
27650	17.18091	133.3151	9.84	NE/SW	17aa	46	15	-31	633.2779	402.3177	20847954.00	13244582.54	36%
27700	17.21198	331.5573	6.56	NE/SW	17aa	60	25	-35	562.5256	300.0137	12345826.92	6584441.02	47%
27750	17.24305	102.8357	9.84	E/W	17aa	35	11	-24	661.4598	483.0886	21775721.34	15903616.71	27%
27800	17.27411	357.7101	9.84	N/S	17aa	49	21	-28	586.4984	378.6256	19307940.60	12464619.88	35%
27850	17.30518	348.8867	6.56	N/S	17aa	63	25	-38	559.3222	275.9323	12275521.09	6055923.74	51%
27900	17.33625	0	9.84	N/S	17aa	49	22	-27	585.4223	382.7761	19272513.02	12601258.51	35%

Table I-3. Moore's Creek Shade-Related Data, TMDLs, Existing Solar Loading, and the Percent Increase in Shade Needed to Meet the TMDLs

Longitudinal Distance (m)	River Mile (RM)	Aspect	Wetted Width (ft)-GIS	General Direction	Ecoregion	Target Shade (%)	Existing Shade (%)	Shade Difference (%)	Daily Solar Flux with Existing Shade (watts/ft2)	Daily Solar Flux with Potential Shade (watts/ft2)	Existing Load (kcal/day)	Potential Load (kcal/day)	Percent Reduction Needed to Meet TMDL
27950	17.36732	256.3725	9.84	E/W	17aa	35	10	-25	668.8436	483.0537	22018800.80	15902467.24	28%
28000	17.39839	343.8553	6.56	N/S	17aa	63	22	-41	582.0813	276.1155	12775017.84	6059944.36	53%
28050	17.42946	34.43875	6.56	NE/SW	17aa	60	21	-39	589.2869	298.3731	12933160.28	6548435.59	49%
28100	17.46053	352.5687	6.56	N/S	17aa	63	24	-39	568.3174	276.6808	12472938.23	6072351.51	51%
28150	17.49159	336.4309	6.56	NE/SW	17aa	60	25	-35	559.1177	298.1961	12271033.14	6544551.01	47%
28200	17.52266	336.9486	9.84	NE/SW	17aa	46	19	-27	608.2322	405.4882	20023433.41	13348955.61	33%
28250	17.55373	36.42058	9.84	NE/SW	17aa	46	17	-29	616.5698	401.1418	20297910.42	13205869.43	35%
28300	17.5848	1.432646	6.56	N/S	17aa	63	23	-40	578.027	277.7532	12686036.86	6095887.84	52%
28350	17.61587	4.236718	6.56	N/S	17aa	63	28	-35	540.6146	277.8158	11864942.44	6097262.09	49%
28400	17.64694	357.3162	6.56	N/S	17aa	63	32	-31	504.5372	274.5276	11073147.39	6025094.90	46%
28450	17.678	340.9417	6.56	N/S	17aa	63	32	-31	505.4233	275.0098	11092594.76	6035676.56	46%
28500	17.70907	75.56371	6.56	E/W	17aa	51	13	-38	648.3527	365.1641	14229483.97	8014307.06	44%
28550	17.74014	7.125016	9.84	N/S	17aa	49	20	-29	595.982	379.9385	19620146.50	12507843.39	36%
28600	17.77121	17.89965	9.84	N/S	17aa	49	21	-28	591.2394	381.6862	19464016.90	12565378.00	35%
28650	17.80228	113.7495	9.84	NE/SW	17aa	46	10	-36	670.9996	402.5997	22089778.12	13253866.87	40%
28700	17.83335	332.6575	3.28	NE/SW	17aa	87	32	-55	507.0223	96.93073	5563843.25	1063675.92	81%
28750	17.86442	309.6676	9.84	NE/SW	17aa	46	12	-34	654.848	401.8385	21558055.69	13228806.90	39%
28800	17.89548	310.7325	6.56	NE/SW	17aa	60	17	-43	617.179	297.4357	13545311.15	6527860.79	52%
28850	17.92655	104.9333	6.56	E/W	17aa	51	12	-39	654.4244	364.3954	14362742.01	7997435.89	44%
28900	17.95762	8.74538	3.28	N/S	17aa	87	37	-50	471.9105	97.37835	5178541.51	1068587.93	79%
28950	17.98869	32.47179	6.56	NE/SW	17aa	60	23	-37	577.6424	300.074	12677596.23	6585764.28	48%

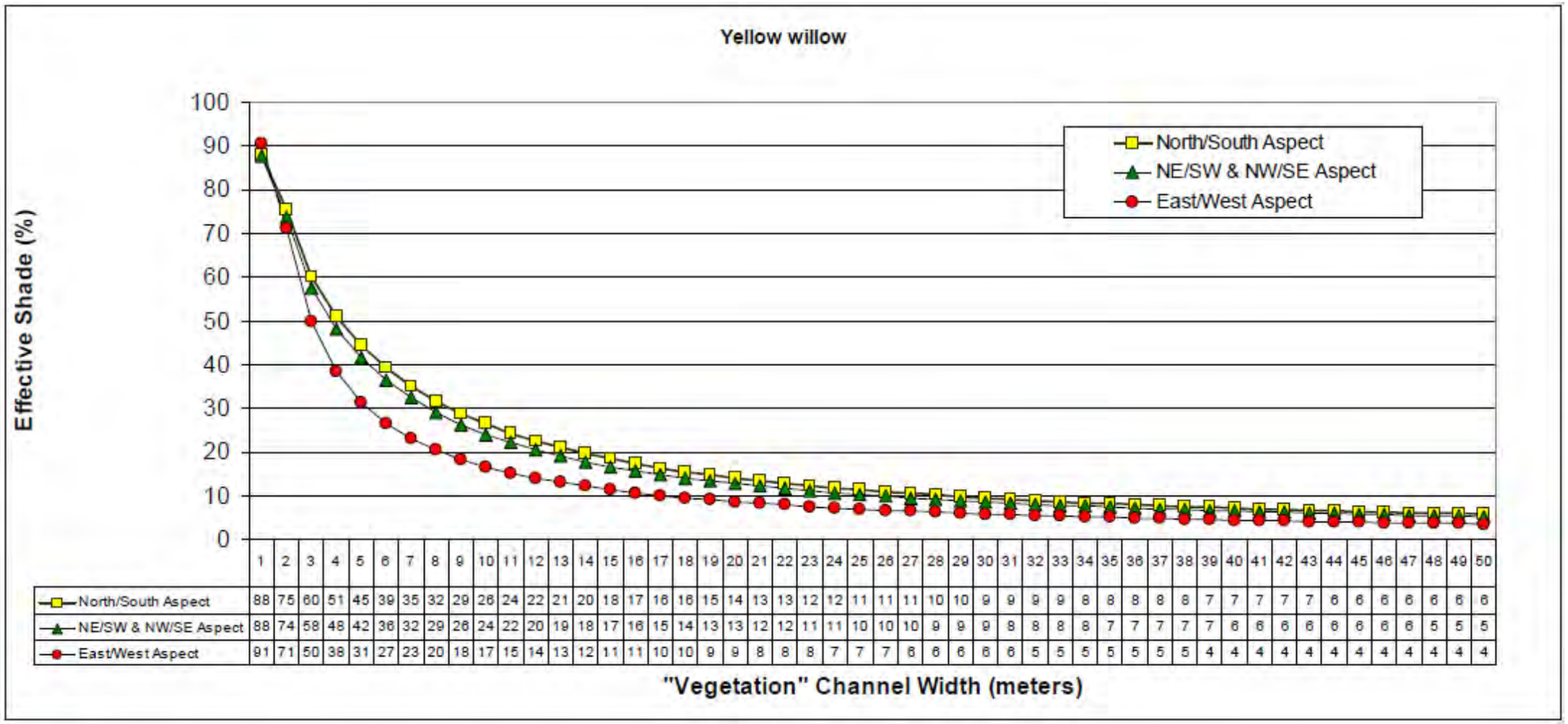
Table I-3. Moore's Creek Shade-Related Data, TMDLs, Existing Solar Loading, and the Percent Increase in Shade Needed to Meet the TMDLs

Longitudinal Distance (m)	River Mile (RM)	Aspect	Wetted Width (ft)-GIS	General Direction	Ecoregion	Target Shade (%)	Existing Shade (%)	Shade Difference (%)	Daily Solar Flux with Existing Shade (watts/ft2)	Daily Solar Flux with Potential Shade (watts/ft2)	Existing Load (kcal/day)	Potential Load (kcal/day)	Percent Reduction Needed to Meet TMDL
29000	18.01976	25.769	13.12	NE/SW	17aa	37	15	-22	637.7657	472.6969	27994260.83	20748687.44	26%
29050	18.05083	339.9626	16.4	N/S	17aa	35	11	-24	667.2174	487.2936	36608777.26	26736747.44	27%
29100	18.0819	73.78476	9.84	E/W	17aa	35	12	-23	654.8	483.7	21556476.98	15923744.52	26%



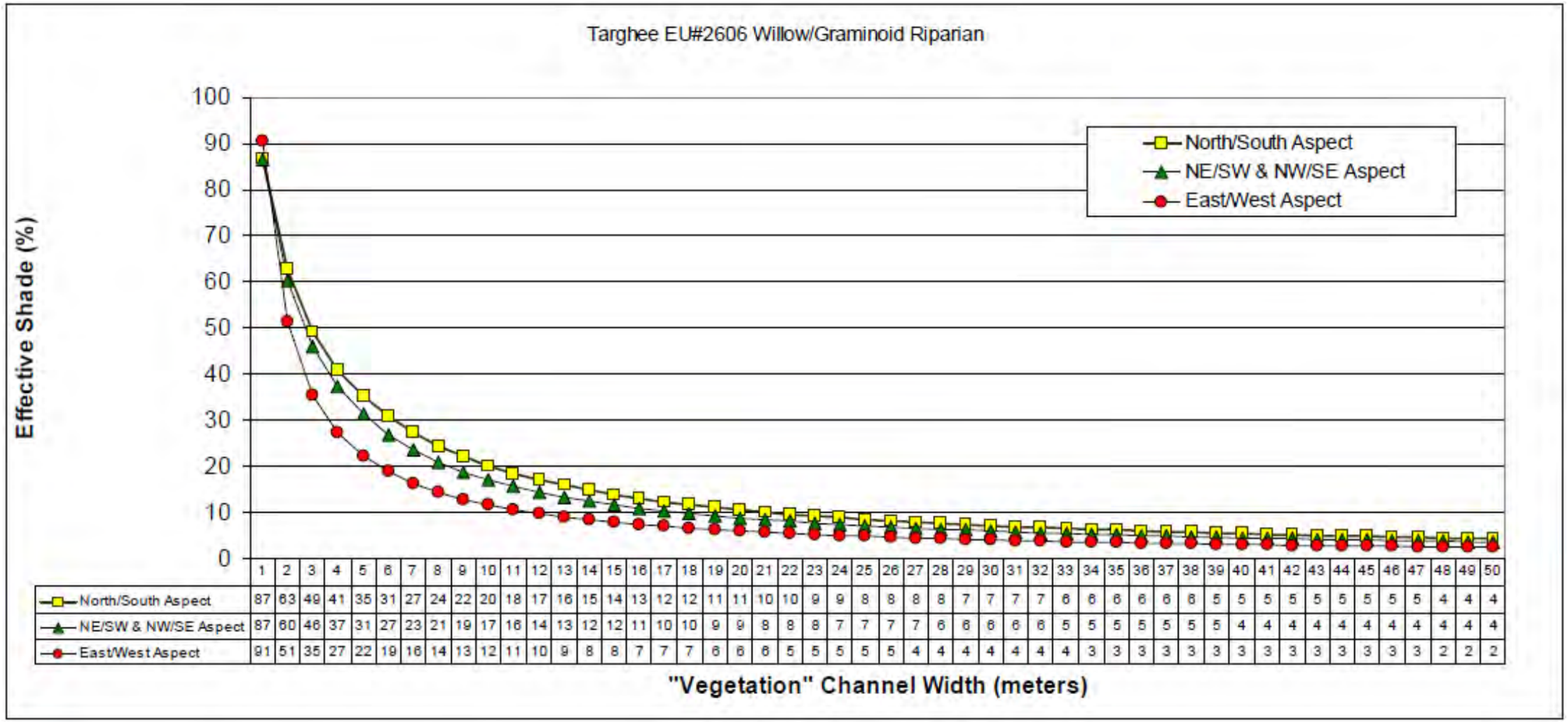
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
North/South Aspect	77	75	65	55	49	44	41	38	35	33	31	29	27	26	25	23	22	21	20	20	19	18	17	17	16	16	15	15	14	14	13	13	13	12	12	12	11	11	11	10	10	10	10	10	9	9	9	9	9	8
NE/SW & NW/SE Aspect	80	77	66	57	51	46	42	39	36	33	31	29	27	26	24	23	22	21	20	19	18	17	17	16	15	15	14	14	13	13	13	12	12	12	11	11	11	10	10	10	10	9	9	9	9	9	8	8	8	8
East/West Aspect	83	81	71	60	52	46	41	36	33	30	27	25	24	22	21	20	19	18	17	16	16	15	14	14	13	13	12	12	12	11	11	11	10	10	10	10	9	9	9	9	8	8	8	8	8	8	7	7	7	7

Figure I-4. Shade Curve Selected for Moore's Creek to Represent the Target Shade Conditions for Ecoregion 17z.



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
North/South Aspect	88	75	60	51	45	39	35	32	29	26	24	22	21	20	18	17	16	16	15	14	13	13	12	12	11	11	11	10	10	9	9	9	9	8	8	8	8	8	7	7	7	7	7	6	6	6	6	6	6	6
NE/SW & NW/SE Aspect	88	74	58	48	42	36	32	29	26	24	22	20	19	18	17	16	15	14	13	13	12	12	11	11	10	10	10	9	9	9	8	8	8	8	7	7	7	7	7	6	6	6	6	6	6	6	6	5	5	5
East/West Aspect	91	71	50	38	31	27	23	20	18	17	15	14	13	12	11	11	10	10	9	9	8	8	8	7	7	7	6	6	6	6	6	5	5	5	5	5	5	5	4	4	4	4	4	4	4	4	4	4	4	4

Figure I-5. Shade Curve Selected for Moore's Creek to Represent the Target Shade Conditions for Ecoregion 17ab.



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
North/South Aspect	87	63	49	41	35	31	27	24	22	20	18	17	16	15	14	13	12	12	11	11	10	10	9	9	8	8	8	8	7	7	7	7	6	6	6	6	6	6	5	5	5	5	5	5	5	5	5	4	4	4
NE/SW & NW/SE Aspect	87	60	46	37	31	27	23	21	19	17	16	14	13	12	12	11	10	10	9	9	8	8	8	7	7	7	7	6	6	6	6	6	5	5	5	5	5	5	5	4	4	4	4	4	4	4	4	4	4	4
East/West Aspect	91	51	35	27	22	19	16	14	13	12	11	10	9	8	8	7	7	7	6	6	6	5	5	5	5	5	4	4	4	4	4	4	4	3	3	3	3	3	3	3	3	3	3	3	3	3	3	2	2	2

Figure I-6. Shade Curve Selected for Moore's Creek to Represent the Target Shade Conditions for Ecoregion 17aa.

I3.0 REFERENCES

Shumar, M. and J. de Varona. 2009. The Potential Natural Vegetation (PNV) Temperature Total Maximum Daily Load (TMDL) Procedures Manual. Boise, ID: Idaho Department of Environmental Quality, State Technical Services Office.

Washington State Department of Ecology. 2007. Shade (shade_ver31b02.xls in shade.zip) in Models for Total Maximum Daily Load Studies at http://www.ecy.wa.gov/programs/eap/models.html. Downloaded January, 24, 2017.

APPENDIX J - QUAL2K TEMPERATURE ANALYSIS, DESCRIPTION, AND CONSTRAINING PARAMETERS

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J1.0 APPROACH

The QUAL2K modeling approach was used to determine the effects of shade and streamflow conditions on temperatures within Cherry, Moore, and Elk Creeks. QUAL2K incorporates measured air temperature, riparian shading, stream flow, and channel characteristics to predict stream temperatures. Minimum, maximum temperatures were modeled along a longitudinal gradient of each creek for the hottest temperature day during summer 2013. After temperatures were predicted accurately using measured conditions, the effects of changes in temperature with streamflow and shade modifications were evaluated by increasing these to target conditions.

QUAL2K is a one-dimensional river and stream water quality model that assumes the channel is well-mixed vertically and laterally. The QUAL2K model uses steady state hydraulics that simulates non-uniform steady flow. Since hydraulic and flow data was not collected specifically for the modeling of temperature, data collected for each creek by Montana DEQ for other purposes was used in the QUAL2K model. Whenever possible, data was used from a similar timeframe as the day when the temperature was modeled. However, in several cases, the only available data was collected at a different timeframe than the day that was modeled. Differences in modeled and actual temperatures may be partly due to discrepancies in dates between available data.

Model performance was determined using the average absolute relative error, which was the average of the percent difference between temperatures measured in the field and those modeled at the same locations.

Detailed data and parameters used in these models are located at the end of this appendix.

J2.0 DATA METHODS AND LIMITATIONS

The following describe the methods used to determine bounding parameters and conditions for the QUAL2K modeling. The datasets are provided at the end of this appendix.

J2.1 SHADE

Aerial photography with ArcGIS was used to estimate existing effective shade along length of the creek the using the Shade Tool (Washington State Department of Ecology 2007) (**Appendix G**) and validated using percent shade data collected in the field at the stream temperatures sites using a solar pathfinder.

J2.2 STREAM FLOW

Most of the streamflow data used in modeling was collected in the field by Montana DEQ. For Cherry Creek, temperature data was collected on 7/26/2013, while flow data used in modeling was collected on 8/5/2013. For Moore Creek, stream flow collected near the headwater site was not available from Montana DEQ near the date of the warmest temperature (7/3/2013). Therefore, stream flow data collected from Madison Stream Team on 7/3/2013 for their annual report was used in modeling (Madison Stream Team 2013). For Elk Creek, stream flow not available near the time of the highest temperature (7/3/2013) and stream flow collected on 6/12/13 was used in modeling.

Specific permitted irrigation withdrawals were not incorporated into the model. However, when possible, a water abstraction was used to represent the decrease in flow due to water use along the length of the River. For Cherry Creek, flow data from multiple sites on 8/5/2013 was used to estimate water withdrawals. Since Montana DEQ did not have adequate data available for Moore Creek near the date of highest temperature (7/3/2013), the relative changes in water use for the date of 8/1/2003 was applied to the flow measured by Madison Stream Team. For Elk Creek, not enough data was available to determine relative changes in water consumption along the creek. Therefore, no abstractions were included in the model.

J2.3 Hydraulic Characteristics

Wetted stream width and stream slope was estimated based on field measurements made by Montana DEQ during stream discharge estimates or habitat surveys. Manning's n was derived from these measurements using the Manning's Equation. When possible, flow and instream measurements taken near the time of the modelled temperature (i.e., the highest temperature day) were applied. Manning's n values were greater than would be expected during high flow conditions but were in the range of those typically observed at lower and mid flows (Chapra et al. 2012). The specific dates of each measurement used in the QUAL2k model are detailed at the tables at the end of this appendix.

J2.4 Climate

Climate data for the modeled days were obtained from the Western Climate Center (https://wrcc.dri.edu/), Ennis Montana Site, including hourly air temperature and dew point temperature. Cloud cover was set at 5% and wind speed was set at 4 mph, which are typical values present on warm temperature days in Montana.

J2.5 Water Temperature

Hourly water temperature data was collected using HOBO temperature loggers deployed at temperature monitoring sites in summer 2013 as described in **Appendix G**. Hourly data from the uppermost temperature monitoring site was used as a bounding condition. Minimum, mean, and maximum data from each site on this date was used to evaluate performance of the baseline model.

J2.6 Light and Heat Parameters

QUAL2K default light and heat parameters were used in the models. The exceptions were the Ryan-Stolzenbach solar parameter, which was increased from 0.80 to 0.85, and the thermal thickness parameter, which was increased from 10 cm to 15 cm. Increases in these values improved performance, and were similar to changes employed during other temperature modeling efforts previously done for creeks in western Montana by Montana DEQ.

J3.0 Modeled Target Scenarios

The potential management scenarios modeled as part of this exercise reflected targets recommended by DEQ, including a 15% increased flow scenario, an increased shade scenario to represent likely shade as a result of riparian restoration, and a scenario that included a combination of actions (15 % increased

flow and increased shade). In addition, for Elk Creek, a reduced width scenario was modeled given that a habitat sampling site (near temperature site 1C) was not meeting target width/depth conditions.

The resulting temperatures were predicted along the longitudinal gradient of each creek. Graphs were used to compare these temperatures with the 7-Day Lethal Temperature for 50% of the population of Cutthroat Trout, and the 24-hour Lethal Temperature for 10% of the Population of Cutthroat Trout. This comparison was made given the importance of this area for Westslope Cutthroat Trout, which is the most sensitive fish species present in the creeks of interest.

J4.0 RESULTS

J4.1 VALIDATION

Modeled temperatures closely approximated actual temperatures for most temperature loggers (**Tables J-1, J-2,** and **J-3**) The absolute percent error was calculated for the maximum temperature value at each logger location using the formula:

Absolute Percent Error = | (Modeled-Actual)/Actual | 100)*

This was averaged across temperature loggers. The average absolute percent error between modeled and actual maximum temperatures for Cherry, Elk, and Moore Creeks was 1.9%, 2.4%, and 2.7%, respectively.

Table J-1 Difference Between Actual and Modeled Temperatures for Cherry Creek, 7/26/2013

Logger ID	Distance (miles)	Temperature Measure	Actual ˚C	Modeled ˚C
2A	13.5	minimum	11.28	12.89
2A	13.5	average	16.11	15.36
2A	13.5	maximum	18.01	17.76
2B	11.6	minimum	12.41	14.08
2B	11.6	average	15.78	16.41
2B	11.6	maximum	19.18	19.32
2C	1	minimum	15.17	16.88
2C	1	average	20.34	20.06
2C	1	maximum	25.47	24.76

Table J-2 Difference Between Actual and Modeled Temperatures for Elk Creek, 7/3/2013

Logger ID	Distance (miles)	Temperature Measure	Actual ˚C	Modeled ˚C
1B	8.4	minimum	15.8	16.7
1B	8.4	average	20.3	20.6
1B	8.4	maximum	25.4	26.0
1C	7.2	minimum	16.1	17.0
1C	7.2	average	20.1	21.1
1C	7.2	maximum	25.3	25.9
1D	0.6	minimum	18.8	17.4
1D	0.6	average	25.0	23.0
1D	0.6	maximum	30.8	29.9

Table J-3. Difference Between Actual and Modeled Temperatures for Moore Creek,7/3/2013

Logger ID	Distance (miles)	Temperature Measure	Actual ˚C	Modeled ˚C
4A	10.5	minimum	16.7	16.63
4A	10.5	average	18.5	18.25
4A	10.5	maximum	20.3	20.11
4D	7.8	minimum	15.7	16.23
4D	7.8	average	18.9	18.43
4D	7.8	maximum	22.29	20.87
4F	1.8	minimum	14.78	15.75
4F	1.8	average	19.7	19.95
4F	1.8	maximum	25.5	25.24

J4.2 Scenario Outputs

J4.2.1 Cherry Creek

Results indicated that the increased flow scenario decreased modeled maximum temperatures by an average of 1.1˚C at the most downstream site, while the increased shade scenario decreased modeled maximum temperatures by 1.5˚ C. The combined scenario decreased modeled maximum temperatures by 1.9 ˚C (**Figure J-1** to **J-4**)

None of the scenarios resulted in a substantial increase in potential stream miles inhabited by Westslope cutthroat trout (The combined scenario resulted in only a ~ 0.5 mile potential increase in usable habitat) although an increase in shade had the most impact. However, given that the modeling represented the warmest day of the year, increased shade could increase the habitable portion of Cherry Creek by a greater amount other parts of the summer with less warm temperatures.

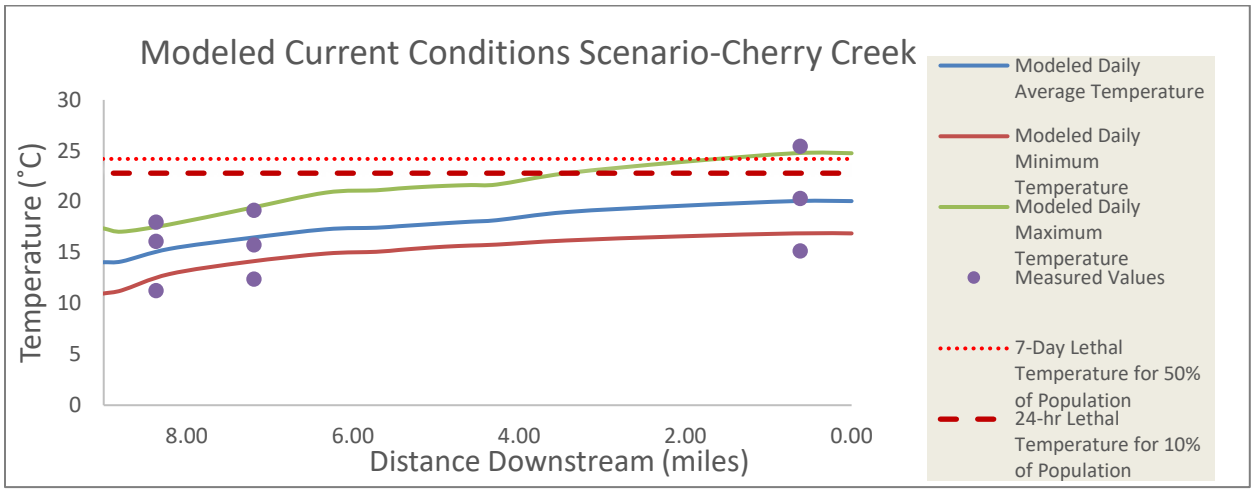

Figure J-1. Model Scenario for Cherry Creek-Current Conditions

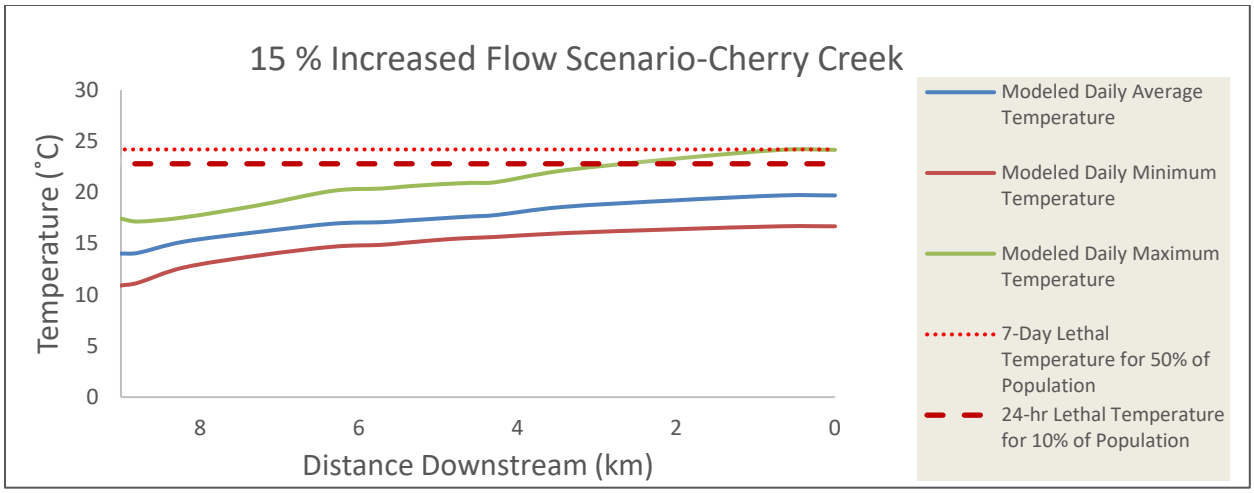

Figure J-2. Model Scenario for Cherry Creek-Increased Flow Conditions

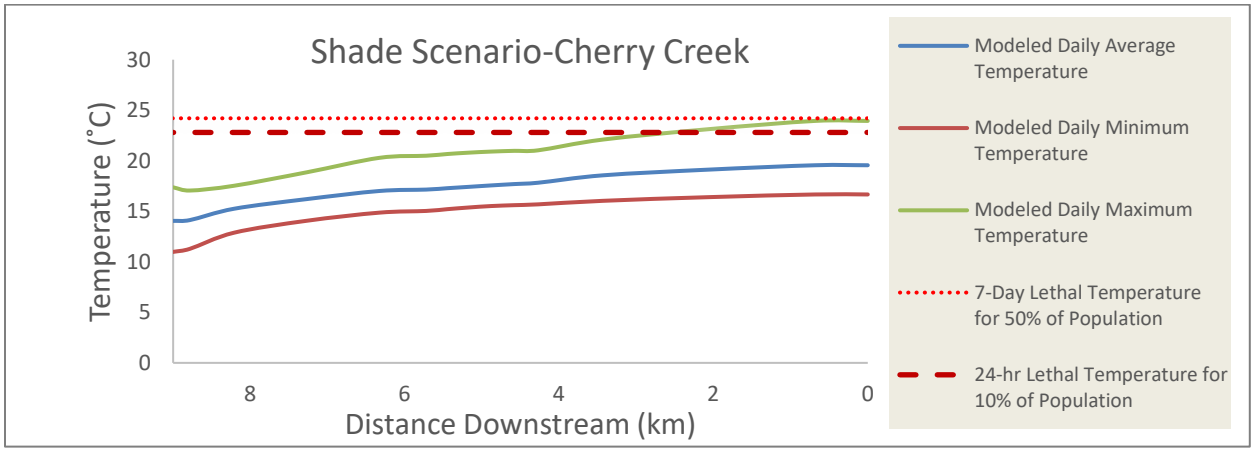

Figure J-3. Model Scenario for Cherry Creek-Increased Shade Conditions

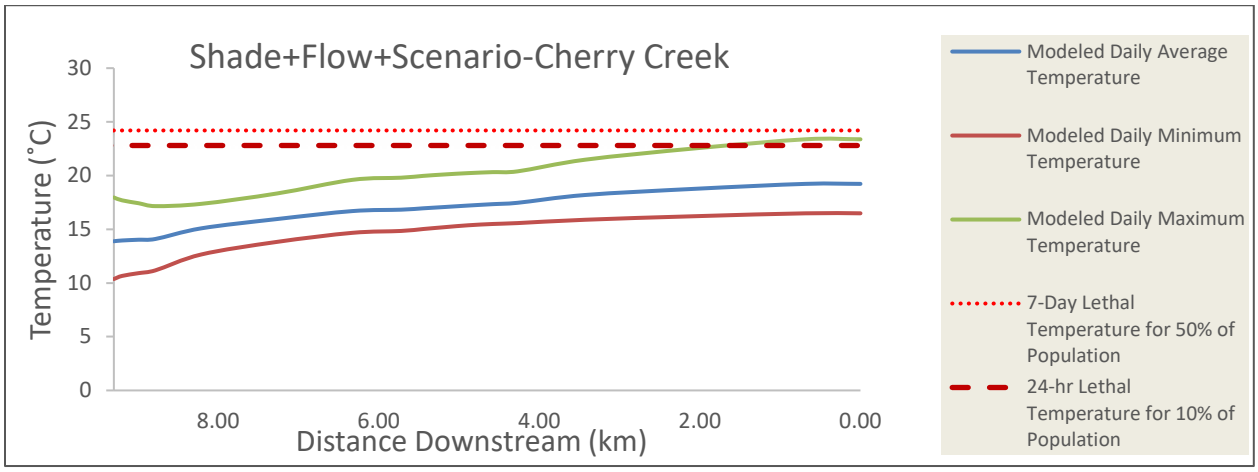

Figure J-4. Model Scenario for Cherry Creek-Increased Shade & Flow Conditions

J4.2.2 Elk Creek

Results indicate that the increased flow scenario decreased maximum temperatures at the most downstream site by 1.1 ˚C, the increased shade scenario decreased temperatures by 4.7 ˚C, and the combination scenario of increased shade and flow and decreased wetted width decreased temperatures by 5.0˚C. (**Figure J-5** to **Figure J-8**)

The increased shade scenario showed a decrease in the maximum temperature below the 7-Day Lethal Temperature for 50% of the population at the most upstream section of the modeled portion (above mile 13). The combination scenario (flow + shade+ width) did not greatly reduce temperatures below values estimated for increased shade alone.

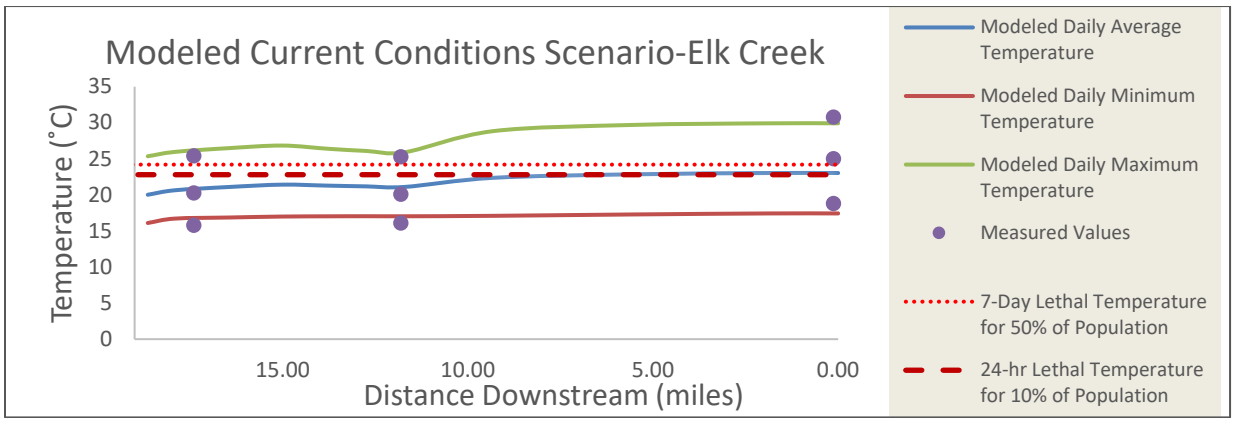

Figure J-5. Model Scenario for Elk Creek-Current Conditions

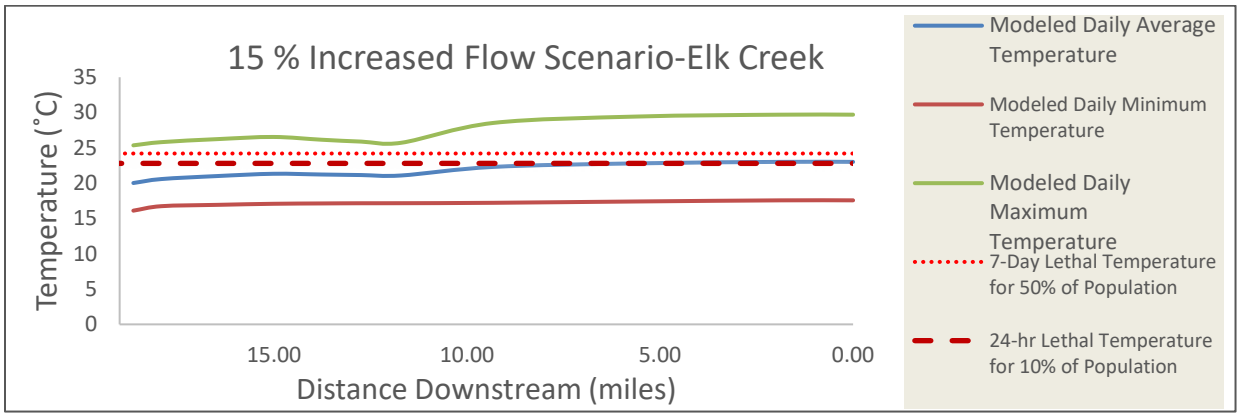

Figure J-6. Model Scenario for Elk Creek-Increased Flow Conditions

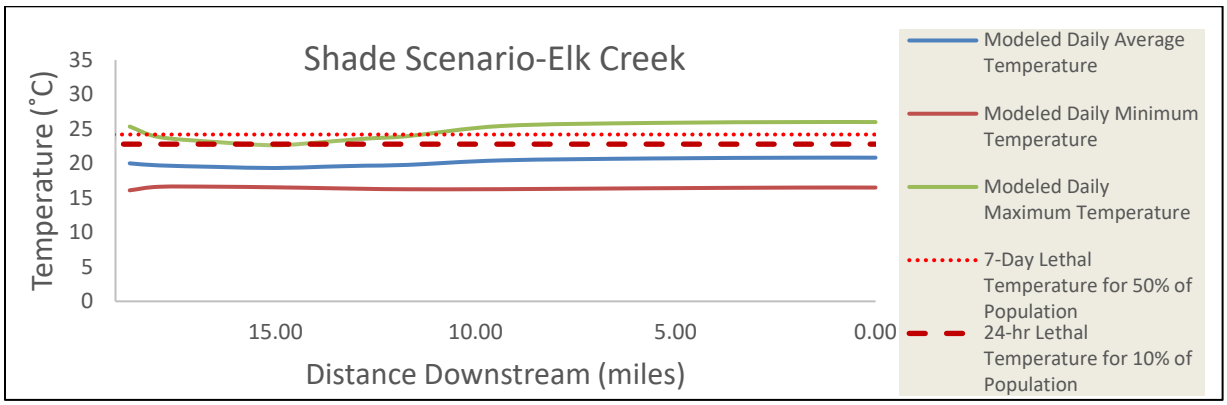

Figure J-7. Model Scenario for Elk Creek-Increased Shade Conditions

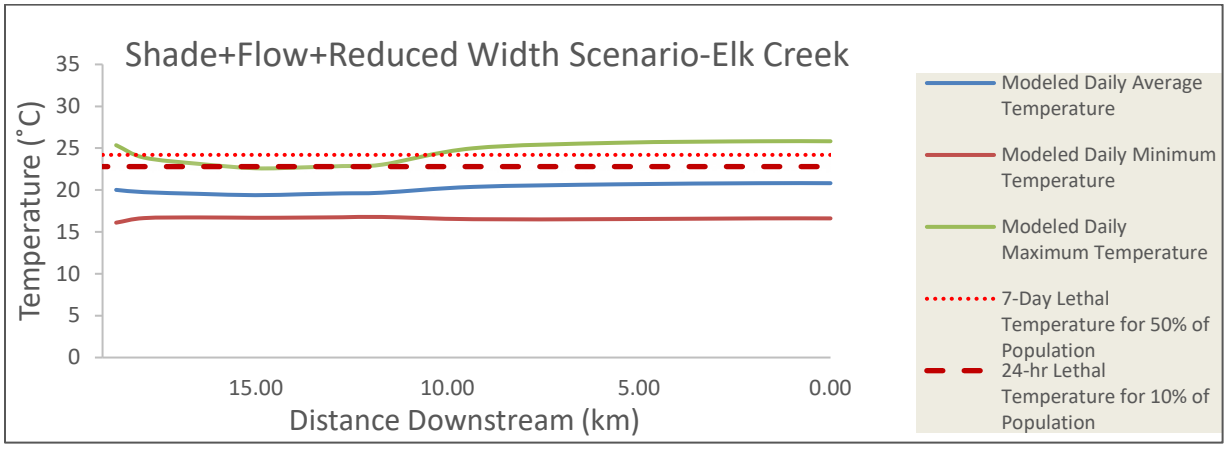

Figure J-8. Model Scenario for Elk Creek-Increased Shade and Flow Conditions

J4.2.3 Moore Creek

Results indicate that the increased flow scenario decreased modeled maximum temperatures at the most downstream site by 0.48˚C, the increased shade scenario decreased modeled maximum temperature by 2.1 ˚C, and the combination scenario decreased modeled maximum temperature by 2.4˚C.

While an increase in shade had a bigger impact on stream temperatures, the combined scenario could decrease the temperature near the mouth to be at or just slightly above the 24-hour Lethal temperature for 10% of the population for Westslope cutthroat trout, and would potentially increase the overall length of stream available to these species during the warmest times by up to 3 miles (**Figure J-9** to **Figure J-12**)

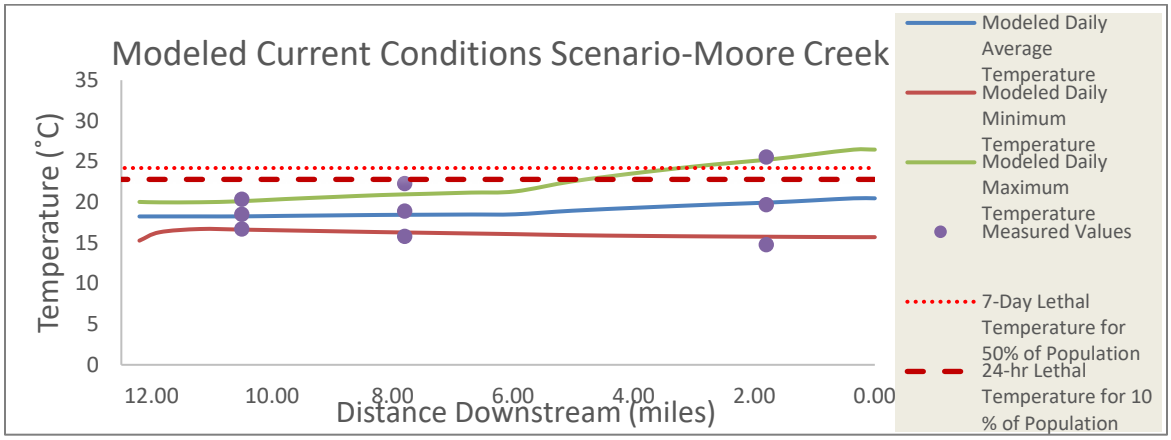

Figure J-9. Model Scenario for Moore Creek-Current Conditions

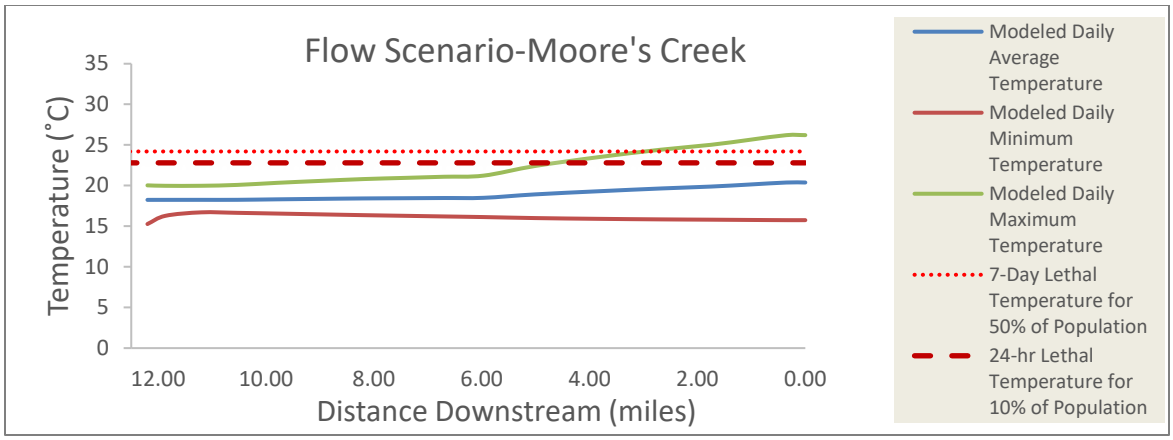

Figure J-10. Model Scenario for Moore Creek-Increased Flow Conditions

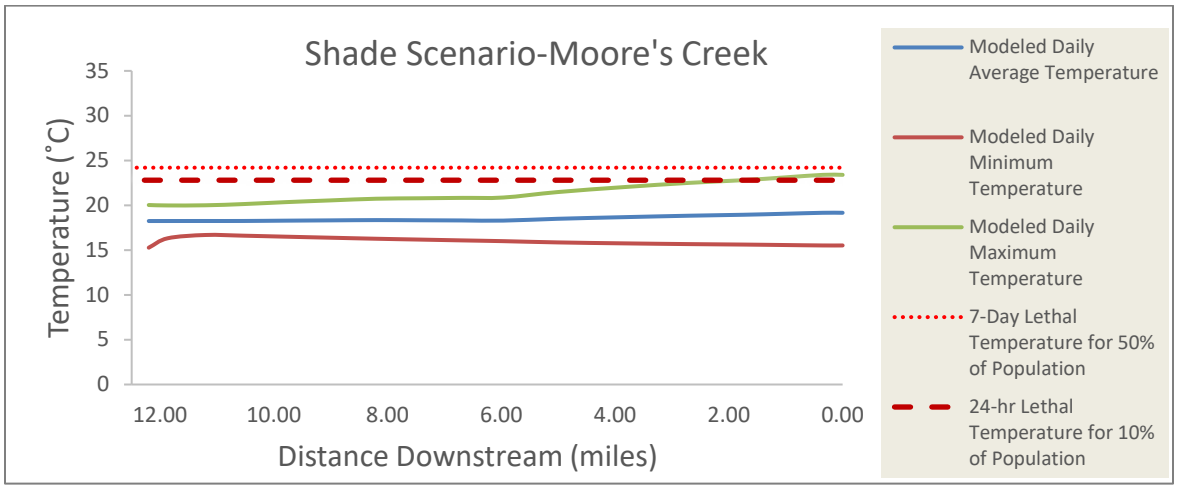

Figure J-11. Model Scenario for Moore Creek-Increased Shade Conditions

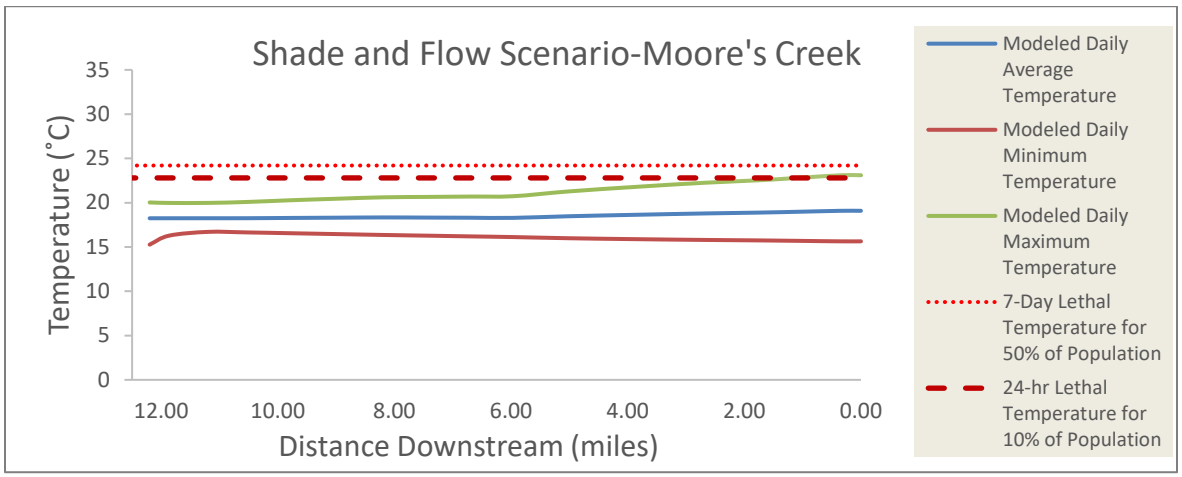

Figure J-12. Model Scenario for Moore Creek-Increased Shade Conditions

J5.0 PARAMETERS

J5.1 CHERRY CREEK

The following tables describe parameters used in the Cherry Creek model, including headwater bounding conditions (**Table J-4**) reach characteristics (**Table J-5**), and hourly climate and shade Conditions (**Table J-6**)

Table J-4 Headwater characteristics for Cherry Creek

Measurement	Original Scenario	Flow Scenario	Data Source
Flow (m^3/s)	0.5	0.58	DEQ: 8/5/2013, site 2C
Flow Abstraction (m^3/s) (3 km-0 km)	0.07	0.07	DEQ 8/5/2013 sites 2A,2B,2C
Elevation (m)	1383	1383	Estimated from ArcGIS; Site 2A
Slope	0.015	0.015	estimated from photos 8/5/2013, site 2C
Manning's n	0.18	0.18	Derived from manning's Equation
Bottom Width (m)	9	9	DEQ: 8/5/2013, site 2C

Table J-5. Reach Characteristics for Cherry Creek

Upstream Distance (km)	Down stream Distance (km)	Longitude	Latitude	Slope	Bottom Width (m)	Manning's n	Data Sources
15	14	45.5870	111.4702	0.015	8.9	0.18	Bot Width=DEQ: 8/5/2013, Site2C; slope=DEQ: stream photos, Site 2C
14	9.5	45.5968	111.4953	0.015	8.9	0.18	Bot Width=DEQ: 8/5/2013, Site2C; slope=DEQ: stream photos, Site 2C
9.5	8.1	45.5950	111.4893	0.005	5.6	0.18	Bot Width=DEQ: 8/5/2013, Site2B; slope=DEQ:8/5/2014, SITE CHRR18-02
8.1	6.6	45.5916	111.4863	0.005	5.6	0.18	Bot Width=DEQ: 8/5/2013, Site2B; slope=DEQ:8/5/2014, SITE CHRR18-02
6.6	0	45.6184	111.5497	0.006	9	0.09	Bot Width=DEQ: 8/5/2013, Site2A; slope=DEQ:8/5/2014, SITE CHRR20-01

Table J-6 Cherry Creek Hourly Climate and Shade Data 7/26/2013

Parameter	*12:00 AM*	*1:00 AM*	*2:00 AM*	*3:00 AM*	*4:00 AM*	*5:00 AM*	*6:00 AM*	*7:00 AM*	*8:00 AM*
Cloud Cover (%)	5	5	5	5	5	5	5	5	5
Wind Speed (m/s)	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
Dew Point (˚C)	17.8	22.2	21.1	15.6	25.0	26.1	13.3	10.0	5.6
Headwater Temperature (˚C),7/26/2013	14.6	13.8	13.1	12.4	11.7	11.0	10.8	10.5	10.4
Air Temperature (˚C)	13.3	12.2	11.7	9.4	12.2	15.6	18.9	22.8	25.6
Shade (15.0-14.0):Original	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	65%	65%	65%
Shade (14.0-9.5):Original	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	16%	16%	16%
Shade (9.5-0.0):Original	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	16%	16%	16%
Shade (15.0-14.0):Shade Model	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	65%	65%	65%
Shade (14.0-9.5):Shade Model	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	22%	22%	22%
Shade (9.5-0):Shade Model	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	22%	22%	22%

Table J-6 Cherry Creek Hourly Climate and Shade Data 7/26/2013

Parameter	9:00 AM	10:00 AM	11:00 AM	12:00 PM	1:00 PM	2:00 PM	3:00 PM	4:00 PM	5:00 PM
Cloud Cover (%)	5	5	5	5	5	5	5	5	5
Wind Speed (m/s)	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
Dew Point (˚C)	2.8	-0.6	-6.1	-11.1	-11.1	-12.2	-12.2	-12.8	-10.6
Headwater Temperature (˚C),7/26/2013	10.4	10.6	11.1	11.9	12.4	14.1	15.7	16.9	17.7
Air Temperature (˚C)	28.9	31.1	33.3	32.8	33.9	33.9	33.3	30.6	28.3
Shade (15.0-14.0):Original	65%	65%	65%	65%	65%	65%	65%	65%	65%
Shade (14.0-9.5):Original	16%	16%	16%	16%	16%	16%	16%	16%	16%
Shade (9.5-0.0):Original	16%	16%	16%	16%	16%	16%	16%	16%	16%
Shade (15.0-14.0):Shade Model	65%	65%	65%	65%	65%	65%	65%	65%	65%
Shade (14.0-9.5):Shade Model	22%	22%	22%	22%	22%	22%	22%	22%	22%
Shade (9.5-0):Shade Model	22%	22%	22%	22%	22%	22%	22%	22%	22%

Parameter	6:00 PM	7:00 PM	8:00 PM	9:00 PM	10:00 PM	11:00 PM
Cloud Cover (%)	5	5	5	5	5	5
Wind Speed (m/s)	4.0	4.0	4.0	4.0	4.0	4.0
Dew Point (˚C)	-9.4	-8.3	-7.8	-7.8	-4.4	-1.1
Headwater Temperature (˚C),7/26/2013	18.0	18.0	17.8	17.4	16.8	16.2
Air Temperature (˚C)	27.8	26.7	26.7	23.3	21.1	20.0
Shade (15.0-14.0):Original	65%	65%	65%	100.0%	100.0%	100.0%
Shade (14.0-9.5):Original	16%	16%	16%	100.0%	100.0%	100.0%
Shade (9.5-0.0):Original	16%	16%	16%	100.0%	100.0%	100.0%
Shade (15.0-14.0):Shade Model	65%	65%	65%	100.0%	100.0%	100.0%
Shade (14.0-9.5):Shade Model	22%	22%	22%	100.0%	100.0%	100.0%
Shade (9.5-0):Shade Model	22%	22%	22%	100.0%	100.0%	100.0%

J5.2 ELK CREEK

The following tables describe parameters used in the Elk Creek model, including headwater bounding conditions (**Table J-7**) reach characteristics (**Table J-8**), and hourly climate and shade Conditions (**Table J-9**)

Table J-7. Headwater characteristics for Elk Creek

Measurement	Original Scenario	Flow Scenario	Flow and Width Scenario	Data Source
Flow (m^3/s)	0.076	0.087	0.087	DEQ: 6/12/2013, Site 1B
Elevation (m)	1577	1577	1577	Estimated from ArcGIS, site 1B
Slope	0.02	0.02	0.02	DEQ: 08/19/2013, site M06ELK07
Manning's n	0.12	0.12	0.12	Derived from manning's Equation
Bottom Width (m)	2.22	2.22	2.22	DEQ 6:/12/2013, site 1B

Table J-8. Reach characteristics for Elk Creek

Upstream Distance (km)	Down stream Distance (km)	Latitude	Longitude	Slope	Bottom Width (m)	Manning' s n	Data Sources
30	23	45.6056	111.3968	0.020	2.2	0.14	Bot Width=DEQ: 6/12/2013, Site 1B; slope=DEQ: 08/23/2013, Site ELK 11-01
23	18	45.6279	111.4137	0.017	1.9/1.6[1]	0.13	Bot Width=DEQ: 8/15/2013, site 1C; slope=DEQ: 08/19/2013, site ELKC 06-02
18	0	45.6539	111.5208	0.017	1.5	0.13	Wet Width=DEQ: 8/15/2013, site 1D; slope=DEQ: 2013, site MO6ELKC07

[1] The second value after the / was used in the reduced width scenario.

Table J-9 Elk Creek Hourly Climate and Shade Data 7/3/2013

	12:00 AM	*1:00 AM*	*2:00 AM*	*3:00 AM*	*4:00 AM*	*5:00 AM*	*6:00 AM*	*7:00 AM*	*8:00 AM*
Cloud Cover (%)	5	5	5	5	5	5	5	5	5
Wind Speed (m/s)	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
Dew Point (˚C)	10.6	10.0	9.4	8.3	10.0	12.2	10.6	11.7	12.2
Headwater Temperature (˚C)	19.4	18.8	18.4	17.9	17.5	17.0	16.6	16.2	16.1
Air Temperature (˚C)	20.0	20.0	18.3	18.3	17.8	17.8	21.7	24.4	25.6
Shade (30-23): Original	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	28%	28%	28%
Shade (23-18): Original	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	43%	43%	43%
Shade (18-0): Original	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	17%	17%	17%
Shade (30-23): Shade Model	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	63%	63%	63%
Shade (23-18): Shade Model	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	50%	50%	50%
Shade (18-0): Shade Model	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	42%	42%	42%

	9:00 AM	*10:00 AM*	*11:00 AM*	*12:00 PM*	*1:00 PM*	*2:00 PM*	*3:00 PM*	*4:00 PM*	*5:00 PM*
Cloud Cover (%)	5	5	5	5	5	5	5	5	5
Wind Speed (m/s)	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
Dew Point (˚C)	13.3	9.4	7.2	6.7	7.8	6.1	7.8	8.9	11.7
Headwater Temperature (˚C)	16.4	16.9	17.8	19.6	21.7	23.7	24.9	25.4	24.6
Air Temperature (˚C)	28.9	31.7	32.2	32.8	33.9	32.8	32.2	31.7	30.0
Shade (30-23): Original	28%	28%	28%	28%	28%	28%	28%	28%	28%
Shade (23-18): Original	43%	43%	43%	43%	43%	43%	43%	43%	43%
Shade (18-0): Original	17%	17%	17%	17%	17%	17%	17%	17%	17%
Shade (30-23): Shade Model	63%	63%	63%	63%	63%	63%	63%	63%	63%
Shade (23-18): Shade Model	50%	50%	50%	50%	50%	50%	50%	50%	50%
Shade (18-0): Shade Model	42%	42%	42%	42%	42%	42%	42%	42%	42%

Table J-9 Elk Creek Hourly Climate and Shade Data 7/3/2013

	6:00 PM	*7:00 PM*	*8:00 PM*	*9:00 PM*	*10:00 PM*	*11:00 PM*
Cloud Cover (%)	5	5	5	5	5	5
Wind Speed (m/s)	4.0	4.0	4.0	4.0	4.0	4.0
Dew Point (˚C)	13.3	11.1	11.1	11.7	10.6	11.1
Headwater Temperature (˚C)	23.8	23.2	22.5	21.6	20.6	19.8
Air Temperature (˚C)	28.3	25.6	22.2	22.2	19.4	18.3
Shade (30-23): Original	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Shade (23-18): Original	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Shade (18-0): Original	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Shade (30-23): Shade Model	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Shade (23-18): Shade Model	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Shade (18-0): Shade Model	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

J5.3 MOORE CREEK

The following tables describe parameters used in the Moore Creek model, including headwater bounding conditions (**Table J-10**) reach characteristics (**Table J-11**), and hourly climate and shade Conditions (**Table J-12**)

Table H.-10. Headwater characteristics for Moore Creek

Measurement	Original Scenario	Flow Scenario	Data Source
Flow (m^3/s)	0.16	0.18	Stream Team, 2013 Report
Elevation (m)	1500	1500	ArcGIS site 4A
Slope	0.01	0.01	DEQ: 09/04/2014, site MOOR 09-01
Manning's n	0.03	0.03	Derived from Manning's Equation
Bottom Width (m)	1.6	1.6	DEQ 08/1/2003, site 4F

Table H-11. Reach Characteristics for Moore Creek

Upstream Distance (km)	Downstream Distance (km)	Latitude	Longitude	Slope	Bottom Width (m)	Manning's n	Data Sources
12.2	10.2	45.3369	111.7411	0.010	1.8	0.06	Bot Width=DEQ: 08/01/2013, site 4F; slope: =DEQ: 09/04/2014, site MOOR 09-01
10.2	7.8	45.3369	111.7411	0.010	1.8	0.06	Bot Width=DEQ:08/01/2013, Site 4F; slope: =DEQ: 09/04/2014, site MOOR 09-01
7.8	5.6	45.3519	111.7295	0.010	1.6	0.05	Bot Width=DEQ: 08/01/2013, site 4D; slope: =DEQ: 09/04/2014, site MOOR 09-01
5.6	2.1	45.4084	111.7092	0.005	2.1	0.05	Bot Width=DEQ: 08/01/2013, site 4A; slope: =DEQ: 09/02/2014, site MOOR 09-02

Table H-11. Reach Characteristics for Moore Creek

Upstream Distance (km)	Downstream Distance (km)	Latitude	Longitude	Slope	Bottom Width (m)	Manning's n	Data Sources
2.1	9	45.4084	111.7092	0.005	2.1	0.05	Bot Width=DEQ: 08/01/2013, site 4A; slope: =DEQ: 09/02/2014, site MOOR 09-02

Table J-12. Moore Creek Hourly Climate and Shade Data 7/3/2013

	12:00 AM	*1:00 AM*	*2:00 AM*	*3:00 AM*	*4:00 AM*	*5:00 AM*	*6:00 AM*	*7:00 AM*	*8:00 AM*
Cloud Cover (%)	5	5	5	5	5	5	5	5	5
Wind Speed (m/s)	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
Dew Point (˚C), 7/3/2013	10.6	10.6	10.0	9.4	8.3	10.0	12.2	10.6	11.7
Headwater Temperature (˚C),7/3/2013	19.0	18.7	17.9	17.8	17.6	17.2	17.0	16.8	16.7
Air Temperature (˚C)	20.0	20.0	20.0	18.3	18.3	17.8	17.8	21.7	24.4
Shade (12.2-10.2): Original	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %	67%	67%	67%
Shade (10.2-7.8): Original	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %	57%	57%	57%
Shade (7.8-5.6): Original	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %	60%	60%	60%
Shade (5.6-2.1): Original	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %	19%	19%	19%
Shade (2.1-0.0): Original	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %	16%	16%	16%
Shade (12.2-10.2): Shade Model	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %	67%	67%	67%
Shade (10.2-7.8): Shade Model	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %	62%	62%	62%
Shade (7.8-5.6): Shade Model	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %	70%	70%	70%
Shade (5.6-2.1): Shade Model	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %	47%	47%	47%
Shade (2.1-0.0): Shade Model	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %	47%	47%	47%

	9:00 AM	*10:00 AM*	*11:00 AM*	*12:00 PM*	*1:00 PM*	*2:00 PM*	*3:00 PM*	*4:00 PM*	*5:00 PM*
Cloud Cover (%)	5	5	5	5	5	5	5	5	5
Wind Speed (m/s)	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
Dew Point (˚C)	12.2	13.3	9.4	7.2	6.7	7.8	6.1	7.8	8.9
Headwater Temperature (˚C),7/3/2013	16.8	17.1	17.5	17.8	18.3	18.8	19.4	19.7	19.6
Air Temperature (˚C)	25.6	28.9	31.7	32.2	32.8	33.9	32.8	32.2	31.7
Shade (12.2-10.2): Original	67%	67%	67%	67%	67%	67%	67%	67%	67%
Shade (10.2-7.8): Original	57%	57%	57%	57%	57%	57%	57%	57%	57%
Shade (7.8-5.6): Original	60%	60%	60%	60%	60%	60%	60%	60%	60%
Shade (5.6-2.1): Original	19%	19%	19%	19%	19%	19%	19%	19%	19%
Shade (2.1-0.0): Original	16%	16%	16%	16%	16%	16%	16%	16%	16%
Shade (12.2-10.2): Shade Model	67%	67%	67%	67%	67%	67%	67%	67%	67%
Shade (10.2-7.8): Shade Model	62%	62%	62%	62%	62%	62%	62%	62%	62%

Table J-12. Moore Creek Hourly Climate and Shade Data 7/3/2013

	12:00 AM	*1:00 AM*	*2:00 AM*	*3:00 AM*	*4:00 AM*	*5:00 AM*	*6:00 AM*	*7:00 AM*	*8:00 AM*
Shade (7.8-5.6): Shade Model	70%	70%	70%	70%	70%	70%	70%	70%	70%
Shade (5.6-2.1): Shade Model	47%	47%	47%	47%	47%	47%	47%	47%	47%
Shade (2.1-0.0): Shade Model	47%	47%	47%	47%	47%	47%	47%	47%	47%

	6:00 PM	*7:00 PM*	*8:00 PM*	*9:00 PM*	*10:00 PM*	*11:00 PM*
Cloud Cover (%)	5	5	5	5	5	5
Wind Speed (m/s)	4.0	4.0	4.0	4.0	4.0	4.0
Dew Point (˚C)	11.7	13.3	11.1	11.1	11.7	10.6
Headwater Temperature (˚C),7/3/2013	20.0	20.0	19.8	15.3	19.7	19.4
Air Temperature (˚C)	30.0	28.3	25.6	22.2	22.2	19.4
Shade (12.2-10.2): Original	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %
Shade (10.2-7.8): Original	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %
Shade (7.8-5.6): Original	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %
Shade (5.6-2.1): Original	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %
Shade (2.1-0.0): Original	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %
Shade (12.2-10.2): Shade Model	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %
Shade (10.2-7.8): Shade Model	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %
Shade (7.8-5.6): Shade Model	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %
Shade (5.6-2.1): Shade Model	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %
Shade (2.1-0.0): Shade Model	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %

J6.0 LIGHT AND HEAT PARAMETERS, ALL MODELS

Default light and heater parameters were used in all models, except that the Ryan Stolzenbach solar parameter was increased from 0.80 to 0.85 and the sediment thermal thickness was increased from 10 cm to 15 cm (**Table J-13**)

Table J-13 Heat and Light Parameters Used in Models (Copied from Qual2k)

Parameter	Value	Units
Photosynthetically Available Radiation	**0.47**	
Background light extinction	**0.2**	***/m***
Linear chlorophyll light extinction	**0.0088**	***1/m-(ugA/L)***
Nonlinear chlorophyll light extinction	**0.054**	***1/m-(ugA/L)2/3***
ISS light extinction	**0.052**	***1/m-(mgD/L)***
Detritus light extinction	**0.174**	***1/m-(mgD/L)***

Table J-13 Heat and Light Parameters Used in Models (Copied from Qual2k)

Parameter	Value	Units
Solar shortwave radiation model		
atmospheric turbidity coefficient (2=clear, 5=smoggy, default=2)	**2**	
Ryan-Stolzenbach solar parameter **atmospheric transmission coefficient (0.70-0.91, default 0.8)**	**0.85**	
Downwelling atmospheric longwave IR radiation		
atmospheric longwave emissivity model	**Brutsaert**	
Evaporation and air convection/conduction		
wind speed function for evaporation and air convection/conduction	**Adams 2**	
Sediment heat parameters		
Sediment thermal thickness	**15**	***cm***
Sediment thermal diffusivity	**0.0118**	***cm^2/s***
Sediment density	**2.2**	***g/cm^3***
Water density	**1**	***g/cm^3***
Sediment heat capacity	**0.4**	***cal/(g °C)***
Water heat capacity	**1**	***cal/(g °C)***
Sediment diagenesis model		
Compute SOD and nutrient fluxes	**Yes**	

J7.0 REFERENCES

Chapra, S.C., Pelletier, G.J. and Tao, H. 2012. QUAL2K: A Modeling Framework for Simulating River and Stream Water Quality, Version 2.12: Documentation and Users Manual. Civil and Environmental Engineering Dept., Tufts University, Medford, MA, Steven.Chapra@tufts.edu.

Washington State Department of Ecology. 2007. Shade (shade_ver31b02.xls in shade.zip) in Models for Total Maximum Daily Load Studies at http://www.ecy.wa.gov/programs/eap/models.html. Downloaded January, 24, 2017.